

HyperTransport™ I/O Link Specification

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Revision History

REVISION	CHANGE	SECTION	DATE
1.03	Initial release	All	10/10/01
1.04	Fixed errata and made clarifications	All	5/30/02
	Fully defined open-drain signal behavior	2, 17, 22.5	
	Document Isochronous VC limitations	4.4.3, 4.4.4, 7.5.4.10, D.1	
	Allow RMW with count other than 1 or 3	4.4.5	
	Relaxed response UnitID for rejected packets	4.9.3	
	Updated upstream configuration requirements	4.9.4, F	
	Swapped Interrupt and Address chapters (5 and 9)	5, 9	
	Added new x86 reserved address range	5	
	Tighten Config and I/O space access requirements	5, B	
	Highlighted required registers	7.3-7.5	
	Expanded description of Address registers	7.3.5, 7.4.6	
	ISA and VGA enable bits required and documented	7.4.9.3	
	Require a revision ID in every function	7.5	
	Extend HyperTransport Capability Type field to 5 bits	7.5.3.1, 7.7.1	
	Documented behavior of multiple nonprefetchable memory range register extensions	7.5.13	
	Added Isochronous, NonCoherent, and Compat bits to Address Remapping Block	7.7	
	Created Revision ID Capability	7.8	
	Documented reset data corruption case	10.1	
	Documented behavior when all UnitIDs are consumed	12.3	
	Combined Appendices B and C	B	
	Relaxed PCI ordering, added HyperTransport to PCI command mapping	B.2	
	Added PCI-X ordering rules and command mapping	B.4	
	Added Deadlock Appendix C	C	
	Document legacy interrupt boot requirements	F.1	
	Document legacy PIC multiple ExtInt requirements	F.1.3	
	Document delay from STOP_GRANT to LDTSTOP#	F.2	
	Document A20M ordering requirements	F.2.1.1	
Updated LDTREQ# requirements	F.2.4		
Updated differential signal input edge rate requirements	22.10		

REVISION	CHANGE	SECTION	DATE
1.05	Added 64-bit addressing	3.2.1, 5, 7.3.5, 7.4.6, 7.5.4.13, 7.5.8, 7.5.10.5, 10.1.6	11/22/02
	Changed Coherent bit from Ignored to Reserved and set	3.2.1.5, 4.4.1	
	Added Data Error to Responses and Posted Writes, Changed Error and NXA bits in Responses to Error0/1	4.4.1, 4.5, 7.3, 7.4, 10.2.1, B.2.2, B.4.2	
	Added Isoc bit to Flush and Fence	4.4.3, 4.4.4, D.1	
	Added UnitID Clumping	4.2, 4.5, 4.6, 4.9, 6.4, 7.5.10, 7.10, 12.3	
	Various clarifications	3.2.1, 4.7, 4.9, 5, 6.1, 7.1, 8.3, 12.2, B.2.2, B.4.2, C.1.2	
	Require peer-to-peer reflection of Atomic RMW	4.4.5	
	Added Extended Configuration Space and Device Messaging	4.4.1, 4.9, 5, 7.1, 7.2, 7.5.15, 7.11, 13, B.4.2, F	
	Restricted ordering within the chain	6, 6.1	
	Added Interrupt Disable and Status bits	7.3.1.6, 7.3.2.1	
	Removed VGA Palette Snoop	7.4.1	
	Added Upstream Configuration Enable bit	7.5.10.9	
	Added 64-bit Address Remapping	7.8	
	Added INTA/B/C/D Virtual Wires	8.1, 8.4	
	Added No Snoop to HyperTransport-to-PCI-X Mapping	B.4.2	
	Added Message Signaled Interrupt Mapping	B.5	
	Added x86 Thermal Management Messages	F.2.1	
	Relaxed x86 SMI and SMIACK Requirements	F.2.5	
	Added Switch Appendix	7.5.3.1, I	
	Combined First Two Electrical Chapters	17	

REVISION	CHANGE	SECTION	DATE
1.10	Incorporated All 1.05c Errata	3.2.3, 4.4.1, 4.4.5, 4.8.1, 4.9.5.2, 5, 6, 6.1, 6.2, 7.3.1.4, 7.3.2.3, 7.3.2.8, 7.4.1, 7.4.9, 7.5.3.1, 7.5.4, 7.5.5, 7.5.6, 7.5.7, 7.5.8.3, 7.5.10.6, 7.5.12, 7.5.13, 7.5.14, 7.10.2, 7.12, 8.1, 8.3, 8.5, 9.1, 10.1.1, 0, 10.1.6, 10.2.2, 10.2.4, 12.2, B.2.2, B.4.2, B.5, F.1.1, F.2.1, I.3.3.5, J, 22.7	8/25/03
	Added Retry Mode	2, 3.1, 4.8, 7.5.3.1, 7.5.4.9, 7.15, 0, 10.3, H	
	Added New Virtual Channel Sets	3.2.1, 4.4.1, 4.5, 4.7, 4.8.2, 4.9.7, 6.1, 7.5.3.1, 7.14, 10.1.6	
	Added DirectRoute Peer-to-Peer Routing	4.1, 4.2, 4.9, 6, 7.5.3.1, 7.5.3.2.4, 7.13	
	Added Streaming Packets	14	
	Added End-to-End Flow Control	K	
	Various Editorial and Typographical Corrections	All	
2.00	Added PCI Express Ordering Rules and Command Mappings	B.6	2/9/04
	Added 2, 2.4, and 2.8GT/s Electricals	7.5.7, 17, 21, 22, 23, 24, M, O	
	Added Fixed MSI Mapping Capability	7.12	
	Added Translation Permitted bit for PCI-X and Express Message interoperability.	13, B.4.2	
	Errata	7.12, 8.4, B.2.2, B.4.2, C.1.2	
	Relaxed Host and Bridge ordering requirements	6.1	
	Relaxed End of Chain bit requirements	7.5.4.7	
	Various Editorial and Typographical Corrections	4.7.1, 4.7.10, 4.8.2, 6, 7.5.4.7, 7.14	
2.00a	Removed unnecessary 1us delay from LDTSTOP disconnect in retry mode	10.3.12	7/8/04
	Clarified per-packet CRC polarity and usage	0	
	Clarified scope of Interrupt Disable bit	7.3.1.6	
	Clarified INTx chain host state requirements	8.4	
	Clarified Bridge Bit and UnitID in DirectRoute	4.2, 4.9, 7.13.1.6	
	Clarified SYNC detection in Retry Mode	10.3.5	
	Clarified LDTSTOP sequence in Retry Mode	0	
	Corrected nonvectored interrupt addressing	F.1.1	
Clarified replay ordering/buffer issues in Retry Mode	10.3.4, 10.3.7		

REVISION	CHANGE	SECTION	DATE
2.00b	Remove Interrupt Capability requirement	7.6, 9	4/27/05
	Clarify Disconnect NOP insertion for LDTSTOP	8.3	
	Allow protocol error logging in Retry Mode	10.3.3, 10.3.5	
	Clarify stomped packet behavior in Retry Mode	10.3.3, 10.3.5	
	Clarify RxNextPktToAck behavior	10.3.4	
	Restrict control packet insertion	10.3.5	
	Allow new packets during history structure replay	10.3.7	
	Clarify transmitter disconnect and reconnect behavior in Retry Mode	10.3.12	
	Fix chain bit in PCI-X and PCI-Express Mappings	B.4.2, B.6.2	
	Clarify Unsupported Request and Completer Abort mapping and No Snoop bit handling in PCI-Express	B.6.2	
	Correct Data Error handling in PCI-Express	B.6.2	
	Fix formatting and typographical errors	3.2.1.5, 7.12, 10.1.6, 13, F.2	
	2.00c	Clarify SYNC packet recognition requirements	
Correct typo		4.9.7.3	
Clarify usage of Link Frequency register		7.5.7	
Purge usage of HT abbreviation		7.1, I.2.1	
Clarify timing of link width/frequency changes		8.3	
Allow noncoherent <u>oncoherent</u> traffic while host is in C3		8.5, F.2.4	
Correct inconsistency in control packet insertion		10.3.3	

REVISION	CHANGE	SECTION	DATE
3.00	Incorporate known 2.00 errata and merge 3.0 proposed protocol and electrical changes	All	12/23/05
	SourceID enable bit, feature bit, and packet extension	3.2.1.3, 7.5.4, 7.5.10.7, 7.5.15	3/10/06
	Retry Mode required at Gen3 frequencies	4.8.1, 4.8.2, 7.15	
	Correct required size of fairness window register	4.9.5.2	
	InitComplete holds state across LDTSTOP	7.5.4.6	
	Clarify reserved behavior/modes for Ganged, AC, 8b10b, ScrEn, LSSel, DeempEn, RetryEn	7.5.4.11, 7.15.2.1, 7.16.4, 7.16.5.8	
	Clarify retry counter behavior	7.15.4, 10.3.10	
	Added Function-Level Extension Capability and Function-Level Reset Extension	7.17	
	Clarify LDTSTOP reassertion requirement	8.3	
	Allow CTL[1] to be undefined in Gen1 protocol	12.2.1	
	ILM and BIST test modes	15	
	Add more detail to hot plug methods	16	
	Clarify NPW data error handling in PCI* bridges	B.6.2	
	Clarify async reference clock sources for Gen3	31	
	Editorial cleanup	3.2.1, 4.2, 6.1, 10.3.5, 12.3.4, J	
	More editorial cleanup	7.5.4.6, 8.3, 12.3.13, 12.3.17, 15.1	
	Clarify UnitID Clumping Enable Software Requirements	7.10.2	
	Add chipset-controlled power management extensions	7.18, 8.2, 8.6, F.2.1	
	Clarify minimum LDTSTOP# assertion times	2.1, 8.3, 12.3.19	
	Require Enumeration Scratchpad in devices that support unganging	7.5.11, 0, 12.3.4	
	Correct Gen3 CRC calculation	0	
	Added appendix with table of 8b10b encodings	L	
	Allow HW to report InitComplete=0 during BIST/ILM	7.5.4.6	
	Clarify RxRetries behavior	10.3.7	3/28/06
	Editorial cleanup	2.1.4, 7.16.7, 18.3	
	Editorial cleanup, copyrights, headers, front matter		
	Clarify EndOfChain and TXOff Gen1/3 behavior	7.5.4.7, 7.5.4.8	4/21/06
Create LS3 Capability bit and expand LS2En to LSSel	2.1.2, 7.5.4.11, 7.16.2, 7.16.4		
Clarify use of LaneSel in BIST	7.16.4.10		
Correct order of fields in CDLR config register	7.18.3		
Clarify INTx virtual wire handling	8.4		

REVISION	CHANGE	SECTION	DATE
	Allow CDLC, CDLD, CDLW, and CDLF in Gen1	7.18.2, 8.6.1, 8.6.9	
	Allow CILR to not refresh lanes above program width	8.6.8	
	Clarify flow control handling for stomped packets	10.3.3	
	Limit Gen1 initialization time and clarify async clocking mode behavior	12.2.1, 12.3.13	
	Clarify PHY OFF behavior	12.3.2, 12.3.9	
	Clarify RX DLL behavior	12.3.7, 12.3.19, 12.3.20	
3.00a	Add split In/Out control of InLnSt and LSSel	7.16.2, 7.16.2.5, 7.16.3.2	9/7/06
	Allow flexibility in full training times with FullT0Time field	7.16.3.2, 7.16.3, 7.16.3.7, 7.16.3.8, 7.16.3.11, 7.16.3.12, 7.16.3.13, 7.16.3.17, 7.16.3.19	
	Remove Tmr1 timeout following resets	12.3.11	
	Editorial Cleanup	Revision history, 3.2.1.3, 3.2.1.5, 7.5, 7.5.4.11, 7.5.8, 7.5.8.1, 7.16.2.4, 7.16.3.3, 7.16.4.6, 9.1, 10.1.4, 10.2.4, 10.3.6, 10.3.3, 10.3.8, 11.1, 12.3.2, 12.3.3, 12.3.4, 12.3.9, F.2.1, 26.6, 29.1	
	Finish removing open-drain usage of sideband signals in Gen3 systems	2, 2.5, 2.6, 4.1.2, 12.2, F	
	Clarify CTL behavior	3, 10.1.4	
	NOP reserved bit behavior	4.8.1	
	Clarify behavior of reserved memory spaces	5, F1, F.2.1	
	Clarify SourceID behavior	7.5.4.1	
	Clarify behavior of TXOff and EOC bits for Gen3	7.5.4.7, 7.5.4.8, 7.5.7, 12.2, 12.3.5.2, 12.3.8, 12.3.16	
	Clarify scope of InLnSt	7.5.4.11	
	Clarify short retry attempts	7.15.2, 17.15.2.7, 7.16.4.5, 10.3.8, 12.3.2	
	Add implementation flexibility to Tmr0	7.16.3.1	
	Add vendor-defined virtual wire messages	8.2, 8.7	
	Clarify INT_PENDING behavior	8.5	
	Reinsert P-state change msgs missing from 3.0 rel	F.2.1	
	Clarify async mode requirements for Gen3	11.1	
	Remove compensation column	12.3.3	
	Clarify DLL locking requirements	12.3.3, 12.3.19, 12.3.20	
	Relax implementation requirements for LDTSTOP assertion during training	12.3.18	
Clarify RX FIFO sizing for Gen3	12.3.13		
Clarify RX phase recovery requirements	12.3.19		

REVISION	CHANGE	SECTION	DATE
	Clarify Cold Reset requirements for unganging, hotplug, and AC options	12.3.5, 12.3.5.1, 12.3.5.2	
	Clarify Gen1 behavior with InLnSt=10b	7.16.3.2	
	Clarify Inactive lane timer behavior	8.6.8, 12.3.19	
	Allow Inactive lane alignment flexibility	12.3.7	
	Clarify LDTREQ# usage	8.5, F.2.4	
	Add per-packet CRC implementation note	0	
	Correct electrical parameter definitions	22.2.3, 22.8.2, 26.6, 27.5, 28.5, 29.2	
	Add LS1 Clock Division to Link Training register	7.16.4	
	Clarify CTL errors as protocol errors	10.1.4	
	Clarify LDTSTOP# assertion in Retry Disconnect	12.3.17	
	Add LS0 to LSSel	7.16.4.6	
	Make CDLRint encoding implementation-specific	7.18.3.1	
	Clarify TX behavior when RX saw Training 3 fail after TX advanced to Operational	12.3.13	
	Allow Command Packet Insertion at Gen1 frequencies	3.1.2.1, 7.16.2.3, 0	10/13/06
	Add Translated Address and Translation Request bits to SourceID packet; Flesh out SourceID format and move it and address extension out of 4.4; Add new packet descriptions in appendix B	3.2.1.3, 4.4, 5	
	Clarify behavior exiting warm reset or LDTSTOP when EOC=1 and TXOff=0	7.5.4.7, 7.5.4.8	
	Clarify LSSel register fields apply to software width, CLMC LSSel applies to CDLW width	7.16.4, 8.6.7	
	Extended P-state change message and added C-states	F.2.1	
	Clarify behavior exiting <i>Disconnected</i> when transmitter is ready before receiver	12.3.19	
	Clarify behavior of inactive lanes around LDTSTOP	12.3.6, 12.3.13	
	Require warm reset signaling in <i>Disconnected</i> for Gen1 links to simplify high LDTSTOP# skew	2.1.2, 7.5.4.11, 7.16.4.6	

REVISION	CHANGE	SECTION	DATE	
	More editorial cleanup	1.1, 2, 4.3, 7, 7.5.4.4, 7.5.11, 7.5.12, 7.5.13, 7.5.14, 7.5.15, 7.16.3.2, 7.16.4.17, 7.18.3.2, 8.6.7, 8.6.8, 10.1.1, 10.3.3, 10.3.8, 12.2, 12.3.2, 12.3.4, 12.3.11, 12.3.13, 12.6, 15.1, B.6.3.2, 26.6, 28.5, 29.2		
	Clarify CTL[1] sampled in <i>DC Detect Phase 1</i>	12.3.4.1	10/17/06	
	Document <i>Refresh</i> state for CILR	12.3.6, 12.3.7		
	Gen1 LDTSTOP to RESET delay is for narrowest half of the link	2.1.1	10/19/06	
	CDLW width must not exceed software width	8.6.7		
	Clarify flow control zeroing at retry	10.3.6		
	Correct link state diagram figure	12.3		
	No exception to CILR for PHY OFF	12.3.7		
	Completion Count encoding of 0 means 8 completions	B.7.4		
	Allow AC-coupled 32-bit links	3.1.2		11/22/06
	Allow /16 and /64 ratios for LS1D	7.16.4.17		
	Require retry for most protocol errors in Gen3	10.1.4		
	Limit AC Detect observation to provide margin	12.3.5		
	Clarify sync flood entry requirements	12.3.16		
	Clarify LS1D TXCLK requirements	12.3.19		
	Clarify LDTSTOP skew requirement for BIST	15		
	Clarify Isoc requirement for SMI and STPCLK	F.2.5		
	More Editorial Cleanup	2.1.3, 7.5.4.4, 0, 12.3.2, 12.3.4, 12.3.5, J		
3.0b	Clarify skew and documentation requirements	2.1	5/1/07	
	Clarify running disparity, add new checking recommendations	2.3		
	Clarify SrcTag details	3.2.1		
	Clarify flow control of Address/Source ID extensions	3.2.1.3, 4.8		
	Add flow control example for Gen3 devices	4.8		
	Clean up description of host ordering requirements	6.1, 6.2		
	Define missing DL2 field and correct RX Margin field	7.16.5, 7.16.6.4		
	Clarify RxNextPktToAck ordering w.r.t. flow control	10.3.4		
	Clarify CTL[1] state in warm reset for ganged links	12.2, 12.3.8		

REVISION	CHANGE	SECTION	DATE
	Correct Gen1 PWROK=0 PHY state	12.3.2	
	Add requirements for ganged-only AC-coupled 16b detect	12.3.4, 12.3.6, 26.6	
	Correct requirement for BIST device RX deskew	12.3.13	
	Clarify LinkFail behavior when CfiEn is clear	12.3.16	
	Clarify reconnection sequence is for both retry and LDTSTOP	12.3.17, 12.3.19	
	Add notes about DLL lock to BIST and ILM	15.1, 15.2	
	Correct typo in AT field of translation request and clarify other fields in response	B.7.1, B.7.2	
	Clarify lane skew requirements	26.6, 27.5, 28.5	
	Correct typo "RXOFFTRM" to "RXOFF"	28.3.3	
	Reserved FD_F94x_xxxx range for x86 extension	5	5/24/07
	Reserved SysMgtCmd 17Xh for CDLF extension	8.6.11	
	Changed requirements for ganged-only AC-coupled 16b detect	12.3.4, 12.3.6	
	Clarify and strengthen margining requirements	7.16.5, 7.16.6, 30	6/2/07
	Add 8b10b error checking recommendation	2.3	
	Clarify inactive lane state description in link width out register	7.5.5.7	6/15/07
	Strengthen TX margin requirement	30.1	
	Clarify async vs. "arbitrary async" clocking	11.1	
	Update jEye reference	27.2	
	Clean up unnecessary use of past and future tense	All	
3.0c	Correct notation in scrambler LFSR figure and text	2.2	9/6/07
	Clean up incorrect occurrences of "fatal interrupt"	7.15.2, 10.2.3, 10.2.4, 10.3.10, I.3.2, I.3.3.3	
	Clarify LSSel for Gen1	7.16.4.6	
	Remove conflicting CDLF note	8.6.9.1	
	Clarify error deferral until CRC in retry mode	10.1.4, 10.1.5, 10.1.6, 10.1.8	
	Correct AC detect requirements	12.3.5	
	Correct DLL/CDR LDTSTOP disconnect entry	12.3.18	
	Allow optimal implementation of LS0, InLnSt==10b	12.3.19	
	Editorial Cleanup	7.16.5, 12.3.19, 23, 24, 26.4.5, F.1, N, O	
	Added reminder that V_{RX-CM-AC} applies to DC mode	28.5	9/14/07

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Preface

This Document

The *HyperTransport™ I/O Link Specification* defines and describes the input/output link protocol and electrical interface for the HyperTransport™ link. The document is divided into two principal parts: Protocol and Electrical. The protocol part includes information on HyperTransport signals, packets, commands, interrupts, configuration accesses, address map, error handling, clocking, and initialization. The electrical part includes information on I/O power supply, AC and DC characteristics, transfer timing, and phase recovery timing.

It is intended for system designers, circuit designers, sales and marketing engineers, and other technology professionals. This document serves as the primary reference for the HyperTransport protocol.

Organization

The document is divided into two sections, each with appendices.

Section 1 – Protocol

Section 2 – Electrical Interface.

Section 1 – Protocol

1 Overview

This document describes the HyperTransport™ I/O link. HyperTransport technology, formerly code-named Lightning Data Transport (LDT), is a packet-based link implemented on two unidirectional sets of signals. The link is packet-based, nominally point-to-point, and connects exactly two devices. Devices can have multiple HyperTransport links, allowing the construction of larger HyperTransport fabrics.

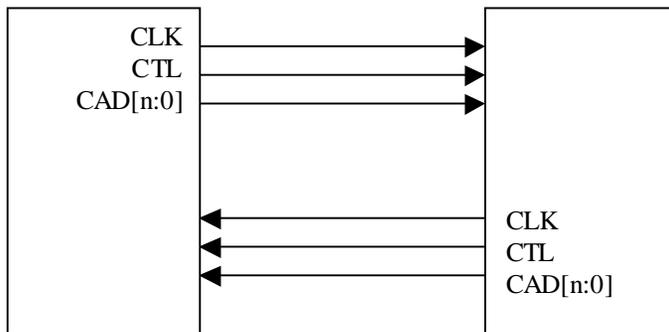


Figure 1. HyperTransport™ I/O Link

HyperTransport technology is used as an I/O channel, connecting chains of HyperTransport I/O devices and bridges to a host system. The interface from the host to the HyperTransport chain(s) is called the host bridge.

1.1 Terminology

For reference, the following terms are used in the HyperTransport protocol:

- *AC-Coupled*—A link where each device has its own ground reference and the transmitter and receiver are connected through capacitors
- *ATE*—Automated Test Equipment, typically used in a production test environment
- *BIST*—Built-In Self-Test
- *Bit-time/Unit Interval (UI)*—Half of a clock period in duration. Two data bits are transmitted on each signal per cycle.
- *Bridge*—A device that bridges between a logical primary bus (connecting it to the host) and one or more logical secondary buses. It contains a bridge register set to control mapping of transactions between the two buses.
- *Byte*—Eight bits.
- *Cave*—A device that implements a single primary link interface.
- *CDLC*—Centralized dynamic link configuration
- *CDLD*—Centralized dynamic link disconnection
- *CDLF*—Centralized dynamic link frequency
- *CDLR*—Centralized dynamic link refresh
- *CDLW*—Centralized dynamic link width
- *Chain*—A set of HyperTransport devices connected in a straight-line daisy-chain topology with each device connecting to at most two others. Devices with two link interfaces have no logical bridging function between the two interfaces; the entire chain operates as a single logical bus.
- *CILR*—Centralized inactive lane refresh

- *CLMC*—Centralized link management controller
- *Coherent*—A link in which memory coherency is maintained between devices or request that requires coherence checking against other requests
- *Cold Reset*—An assertion of RESET# in which PWROK deasserts
- *CRC*—Cyclic Redundancy Check
- *CSR*—Configuration Space Register
- *DC-Coupled*—A link where both devices share a single ground reference and are directly connected
- *Differentially Driven*—The high (_H) and low (_L) sides of a signal are driven to opposite voltage levels
- *DLL*—Delay Locked Loop, typically used to track received link clock
- *Doubleword (DW)*—Four bytes.
- *Downstream*—Away from the chain host
- *Fabric*—A HyperTransport I/O *fabric* is implemented as one or more daisy chains of HyperTransport devices, with a bridge to the host system at one end.
- *Function*—See Unit
- *Ganged*—Two (or more) sublinks that are connected between the same two devices and operate as one link
- *Gen1 Device*—A device compliant with revision 2.00 or earlier of this specification
- *Gen1 Frequency*—1.0GHz or less
- *Gen1 System*—A system composed of one or more Gen1 devices
- *Gen3 Device*—A device compliant with revision 3.00 or later of this specification that implements the Gen3 capability block
- *Gen3 Frequency*—1.2GHz or more
- *Gen3 System*—A system composed of only Gen3 devices
- *Host*—A host can contain multiple bridges, each supporting either a single HyperTransport chain or a tree of HyperTransport chains.
- *Host bridge*—The interface from the host to the HyperTransport chain.
- *I/O stream*—A collection of transactions that can be treated independently in the fabric with respect to ordering rules. A given I/O stream always originates from the same node and terminates at the same destination.
- *ILM*—Internal Loopback Mode
- *LMAF*—Link management action field
- *LMM*—Link management mode
- *Node*—A physical entity that connects to one end of a HyperTransport link.
- *Noncoherent*—A link in which memory coherency is not required between devices or request that does not require coherence checking against other requests
- *Packet*—A series of bit-times that forms the basis of communication between two nodes.
- *PIC*—Programmable Interrupt Controller
- *PLL*—Phase Locked Loop, typically used to generate transmit link clock
- *Quadword (QW)*—Eight bytes.

- *Slave*—A tunnel or cave, implementing HyperTransport link(s) as its primary interface, not implementing the Host bridge functionality.
- *SMC*—System Management Controller
- *Source*—The node that initiates a transaction.
- *Sublink*—A portion of a link with independent clocking and control allowing it to be split from the rest of the link, consisting of 8 CAD signals, one CTL signal, and one CLK signal
- *Target*—The node that ultimately services the transaction on behalf of the source. Note that there may be intermediary nodes between the source and the target.
- *Transaction*—A sequence of packets that are exchanged between two or more nodes in the system and that result in a transfer of information.
- *Tunnel*—A device that implements two link interfaces and is capable of forwarding traffic between other devices within a chain.
- *Undefined*—Operations or behaviors that are described as undefined in this specification may result in any outcome from no change in the state of the system to creating an environment in which the system no longer continues to operate. Note that a cold reset of the HyperTransport fabric may not be sufficient to restore deterministic operation since the effects of an undefined action may propagate beyond the HyperTransport fabric.
- *Unganged*—Two (or more) sublinks that operate independently
- *Unit or function*—A logical entity within a node that can act as a source or destination of transactions. Functions are useful for describing the transaction ordering rules of the HyperTransport protocol.
- *Upstream*—Towards the chain host
- *VC*—Virtual Channel
- *Warm Reset*—An assertion of RESET# in which PWROK stays asserted

1.2 HyperTransport™ Technology in x86 Platforms

This specification is written as a generic reference suitable for implementation with all CPU architectures. However, because of the legacy infrastructure associated with x86 platforms, some additional features must be supported in those platforms. These additional requirements are specified in Appendix F.

2 Signaling

The HyperTransport™ signals listed in Table 1 constitute a single unidirectional connection between two nodes. A full link requires a connection in each direction. However, the connections need not be the same width in each direction.

Table 1. Link Signals

Signal	Width	Description
CAD	2, 4, 8, 16, or 32	Command, Addresses, and Data (CAD). Carries HyperTransport™ requests, responses, addresses and data. CAD width can be different in each direction.
CTL	1, 2, or 4	Differentiates control and data. Each byte of CAD has a CTL signal in Gen3 protocol. One CTL signal is used for an entire link in Gen1 protocol.
CLK	1, 2, or 4	Clocks for the CAD and CTL signals. Each byte of CAD and its respective CTL signal has a separate clock signal.

HyperTransport links wider than 8 bits are built by ganging multiple 8-bit links in parallel to form either 16- or 32-bit links.

In addition to the link signals, all HyperTransport devices require the reset/initialization input pins listed in Table 2.

Table 2. Reset/Initialization Signals

Signal	Width	Description
PWROK	1	Power and clocks are stable.
RESET#	1	Reset the HyperTransport™ chain.

All devices in a given HyperTransport chain receive the same PWROK and RESET# signals. HyperTransport devices must sample PWROK and RESET# as inputs, and Gen1 devices in some systems may optionally drive these signals low as open-drain outputs. Pullup resistors and appropriate buffering must be provided by the system. These signals control the power-up and reset sequence for their HyperTransport links, and may or may not also control the power-up and reset sequence for other logic within the device—this is device-specific. See Section 2.1.5 for a description of these signals in the context of systems with multiple HyperTransport chains. See Chapter 12 for information on reset sequencing.

HyperTransport devices deployed in x86 or other systems requiring power management include the signals listed in Table 3, which are used during the sequencing of system activities such as power-

savings state transitions. LDTREQ# is open-drain wired-OR, allowing multiple sources to request link reconnection, and requiring pullup resistors. In Gen3 systems, LDTSTOP# may only be driven by a single device for a chain.

Table 3. Power Management Signals

Signal	Width	Description
LDTSTOP#	1	Enables and disables links during system state transitions.
LDTREQ#	1	Indicates link is active or requested by a device.

PWROK, RESET#, LDTSTOP#, and LDTREQ# typically have long transition times, and therefore require hysteresis and/or debounce logic in the input path for correct operation.

2.1 Sideband Signal Timing

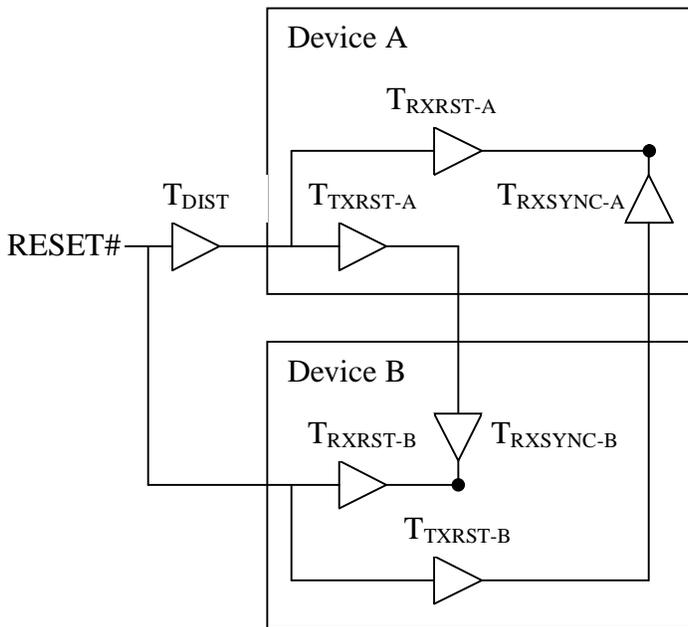
PWROK deassertion and RESET# assertion have priority over LDTSTOP# assertion. LDTSTOP# must be deasserted before RESET# is deasserted. See Section 12.2 for more details about reset and initialization.

To ensure proper operation of the protocol, the specification places limits on observed skew of the sideband signals between two linked devices in a system.

- For the purposes of this specification, skew is defined to include the difference in delay between connected devices including both signal distribution and receive synchronization within devices.
- HyperTransport devices must document their synchronization delays as shown in Figure 2 so that system designers can ensure signal distribution skew meets the system requirements.

Table 4. Maximum Signal Skews (ns)

Signal	Gen1 Skew	Gen3 Skew
PWROK	1000	
RESET#	1000	200
LDTSTOP#	400	100
LDTREQ#	1000	



T_{RXRST} – The delay from assertion of RESET# at the device pin to when inputs are ignored at an internal state commit point. $< T_{RXSYNC}$ recommended.

T_{TXRST} – The delay from assertion of RESET# at the device pin to when output pins change in response.

T_{RXSYNC} – The delay from input pins changing to when they reach an internal state commit point.

T_{DIST} – The difference in delay from the source of RESET# assertion to each device pin. T_{DIST} must be less than $T_{RXSYNC-A} + T_{TXRST-B} - T_{RXRST-A}$ OR $T_{RXSYNC-B} + T_{TXRST-A} - T_{RXRST-B}$

Figure 2. RESET# Signal Distribution Timing

2.1.1 RESET# Skew Exceptions

- The RESET# skew specification may be exceeded with Gen3 protocol, up to a maximum of 100us of skew, if LDTSTOP# is asserted at least 200ns before each RESET# assertion and deasserted at least 1us before RESET# deasserts. With Gen1 protocol, LDTSTOP# would have to assert at least 580 bit-times before RESET# assertion (1160 for a 4-bit link, 2320 for a 2-bit link; in the case of asymmetric link widths, the smaller side determines the time required).
- An unlimited amount of RESET# skew can be tolerated if software sets LinkTrain[HotPlugEn] and supports hot-add of devices that see RESET# deassertion too late to perform normal link initialization.

2.1.2 LDTSTOP# Skew Exceptions

- The LDTSTOP# skew specification may be exceeded, up to a maximum of 500us of skew, if software configures:
 - LinkTrain[RxLSSel and TxLSSel] to LS0 or LS1
 - GlibLinkTrain[T0Time] to a time long enough to retrain the phase recovery mechanism on both sides of the link (for Gen3 frequencies)
 - Link Control[LSEn]=0

- An unlimited amount of LDTSTOP# skew can be tolerated at Gen3 frequencies if software additionally sets LinkTrain[HotPlugEn], or at Gen1 frequencies if LinkControl[LSEn]=0.

2.1.3 PWROK Skew Exception

- Up to 200us of PWROK skew can be tolerated by Gen3 devices.
- An unlimited amount of PWROK skew can be tolerated if software and/or a service processor supports hot-add of devices that see PWROK assertion too late to perform normal link initialization.

2.1.4 LDTSTOP# Assertion Time

Once LDTSTOP# is asserted, it must remain asserted for at least 1 us after both sides of the link have seen it asserted.

Additionally, when LDTSTOP# is asserted to change to or between Gen3 frequencies, it must remain asserted for up to 100us after both sides of the link have seen it asserted. See Section 12.3.19 for more details.

2.1.5 PWROK and RESET# Requirements

All devices on a HyperTransport I/O chain are expected to share a single logical PWROK/RESET# signal pair. Due to the potential for devices sampling these signals on different clocks, copies of the signals coming from different drivers, slow edges being sensed at different times, or receivers having different thresholds, these signals cannot necessarily be observed to transition simultaneously at all devices. The system must guarantee that all devices see PWROK and RESET# pulses overlap and that the duration of the overlap meets the minimum requirements given in Section 12.2. These signals are inputs to each device on the chain and may be driven by one or more devices on the chain in Gen1 systems only. These signals control the powerup and reset sequence for each link interface in the chain and may optionally control the powerup and reset sequence for other logic inside any device along the chain.

A HyperTransport-to-HyperTransport bridge device must have dedicated PWROK/RESET# pin pairs for its primary chain and for each secondary chain. The bridge must be able to drive PWROK/RESET# on its secondary chain. In addition, the bridge must pass the assertion and deassertion of PWROK/RESET# from its primary chain to its secondary chain. A bridge does not pass the assertion and deassertion of PWROK/RESET# from its secondary chain to its primary chain. A bridge is required to provide appropriate error responses to any outstanding nonposted requests when the secondary bus reset is asserted, as described in Section 10.1.7.

2.1.6 PWROK and RESET# Host Implementations

In the case of a host with a single HyperTransport chain, the host's reset signal can be independent of the HyperTransport link's PWROK/RESET# signals. This allows software running on the host to reset the HyperTransport chain without requiring the host to be reset (see Section 7.4.9.7). In such an implementation, the host bridge must be able to both drive and sample PWROK and RESET#. In

addition, the host bridge must pass the assertion and deassertion of host reset (or PWROK) to RESET# (or PWROK). Other implementations are possible—for example, host reset and HyperTransport reset functions may be tied to a single host reset pin.

In the case of a host with multiple host bridges, there can be independent PWROK/RESET# signal pairs for each chain connected to the host. As in the previous case, each of these PWROK/RESET# signals can be independent of host reset. Other implementations are possible—for example, host reset and all HyperTransport reset functions may be tied to a single host reset pin.

Proper sequencing of the PWROK and RESET#, as described in Section 12.2, must be assured, even if the host’s own PWROK and reset signals do not follow these sequencing rules.

Devices used in x86 systems have specific mandatory PWROK and RESET# requirements, described in Appendix F.

2.2 Gen3 Scrambling

The scrambling pattern used in Gen3 protocol is produced by a 23 bit linear feedback shift register (LFSR) of polynomial $x^{23} + x^{18} + 1$.

To minimize EMI and crosstalk, different CTL and CAD lanes use different scrambling patterns derived from a single LFSR by XORing two different taps for each pattern, as shown in Figure 3. For clarity, only the tap for CTL is shown but there are taps for all lanes.

The scrambler LFSR is initialized after each reset or disconnect (either LDTSTOP or Retry) with all 1’s and is frozen until the end of *Training 3*. The first bit-time sent in *Operational* is the first bit-time of the first NOP packet and the first bit-time scrambling is used. See Section 12.3 for more details about Gen3 initialization and training.

The periodic CRC timeslot is scrambled to allow simple transmitter implementations.

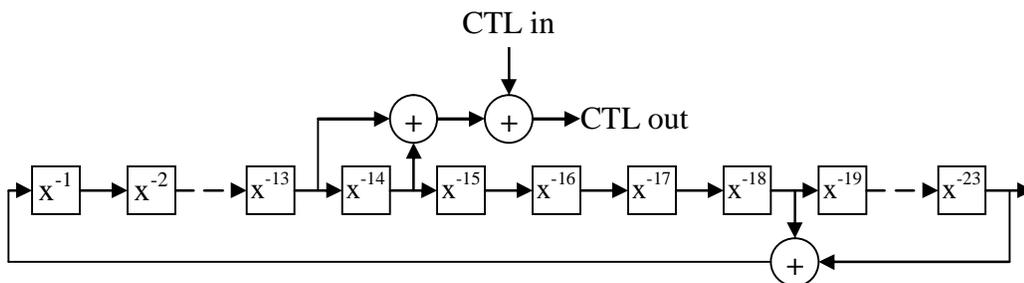


Figure 3. Scrambler Diagram

The LFSR taps used to generate the scramble pattern for each lane are shown in Table 5. Each sublink operates an independent scrambler, even when in a ganged link. Many implementations are expected to process more than one bit-time at once, so the taps for the current bit-time (0) are shown first, followed by rows for each successive bit-time. The LFSR must shift by the number of bit-times processed in one clock, so taps x^{-1} through x^{-7} are avoided in the selection of taps.

Table 5. Scrambling Taps

Lane	CAD0	CAD1	CAD2	CAD3	CLK	CAD4	CAD5	CAD6	CAD7	CTL
Scramble 0	$X^{-13} \wedge X^{-18}$	$X^{-10} \wedge X^{-17}$	$X^{-12} \wedge X^{-16}$	$X^{-8} \wedge X^{-16}$	none	$X^{-9} \wedge X^{-15}$	$X^{-9} \wedge X^{-18}$	$X^{-11} \wedge X^{-13}$	$X^{-11} \wedge X^{-14}$	$X^{-13} \wedge X^{-14}$
1	$X^{-12} \wedge X^{-17}$	$X^{-9} \wedge X^{-16}$	$X^{-11} \wedge X^{-15}$	$X^{-7} \wedge X^{-15}$		$X^{-8} \wedge X^{-14}$	$X^{-8} \wedge X^{-17}$	$X^{-10} \wedge X^{-12}$	$X^{-10} \wedge X^{-13}$	$X^{-12} \wedge X^{-13}$
2	$X^{-11} \wedge X^{-16}$	$X^{-8} \wedge X^{-15}$	$X^{-10} \wedge X^{-14}$	$X^{-6} \wedge X^{-14}$		$X^{-7} \wedge X^{-13}$	$X^{-7} \wedge X^{-16}$	$X^{-9} \wedge X^{-11}$	$X^{-9} \wedge X^{-12}$	$X^{-11} \wedge X^{-12}$
3	$X^{-10} \wedge X^{-15}$	$X^{-7} \wedge X^{-14}$	$X^{-9} \wedge X^{-13}$	$X^{-5} \wedge X^{-13}$		$X^{-6} \wedge X^{-12}$	$X^{-6} \wedge X^{-15}$	$X^{-8} \wedge X^{-10}$	$X^{-8} \wedge X^{-11}$	$X^{-10} \wedge X^{-11}$
4	$X^{-9} \wedge X^{-14}$	$X^{-6} \wedge X^{-13}$	$X^{-8} \wedge X^{-12}$	$X^{-4} \wedge X^{-12}$		$X^{-5} \wedge X^{-11}$	$X^{-5} \wedge X^{-14}$	$X^{-7} \wedge X^{-9}$	$X^{-7} \wedge X^{-10}$	$X^{-9} \wedge X^{-10}$
5	$X^{-8} \wedge X^{-13}$	$X^{-5} \wedge X^{-12}$	$X^{-7} \wedge X^{-11}$	$X^{-3} \wedge X^{-11}$		$X^{-4} \wedge X^{-10}$	$X^{-4} \wedge X^{-13}$	$X^{-6} \wedge X^{-8}$	$X^{-6} \wedge X^{-9}$	$X^{-8} \wedge X^{-9}$
6	$X^{-7} \wedge X^{-12}$	$X^{-4} \wedge X^{-11}$	$X^{-6} \wedge X^{-10}$	$X^{-2} \wedge X^{-10}$		$X^{-3} \wedge X^{-9}$	$X^{-3} \wedge X^{-12}$	$X^{-5} \wedge X^{-7}$	$X^{-5} \wedge X^{-8}$	$X^{-7} \wedge X^{-8}$
7	$X^{-6} \wedge X^{-11}$	$X^{-3} \wedge X^{-10}$	$X^{-5} \wedge X^{-9}$	$X^{-1} \wedge X^{-9}$		$X^{-2} \wedge X^{-8}$	$X^{-2} \wedge X^{-11}$	$X^{-4} \wedge X^{-6}$	$X^{-4} \wedge X^{-7}$	$X^{-6} \wedge X^{-7}$

2.3 Gen3 8b10b Encoding for AC-Coupled Operation

During normal 8b10b operation, each lane (except CLK) is independently passed through an 8b10b encoder 8 bits at a time, separately from other lanes. The first 5 bits (LSb first) select the first 6 bit subblock of the encoding (from the set D0 through D31) and the last 3 bits select the remaining 4 bit subblock (from the set 0 through 7).

In addition to the set of data encodings, 8b10b defines special symbols (K codes) which are only used during training in HyperTransport links. Receipt of a K code during *Operational* may be treated as a disparity error resulting in a retry.

Each 10-bit symbol has two versions. Both versions may have 5 1's (neutral disparity) or one version may have 4 1's (negative disparity) while the other has 6 1's (positive disparity). The encoder tracks the disparity of each symbol and combines it with the running disparity from previous symbols to decide which version to use for the next symbol to move running disparity towards zero. HyperTransport links always assume a negative 1 running disparity at the entry to *Operational*. Note that the running disparity can never be 0, since it can only increase or decrease by 2 bits.

The tables of 8b10b encodings are in Appendix L.

Receivers can increase the speed and accuracy of error detection by implementing individual disparity checks on the 6 bit and 4 bit subblocks that make up each 10 bit symbol. The rules for these checks are:

- Each subblock must have -2, 0, or +2 disparity
- The polarity of nonzero subblocks must alternate
- A D7.x subblock must use the 111000b variant for negative running disparity, 000111b for positive
- A x.3 4b subblock must use the 1100b variant for negative running disparity, 0011b for positive

2.4 Gen3 Order of Operations

Figure 4 illustrates the order in which the scrambling and 8b10b encoding operations are applied in the transmitter for 64 bits of data. For clarity, the 8b10b encoder path is only shown for CAD5, but there is an encoder for each lane. In the receiver, 8b10b decode is applied before descrambling.

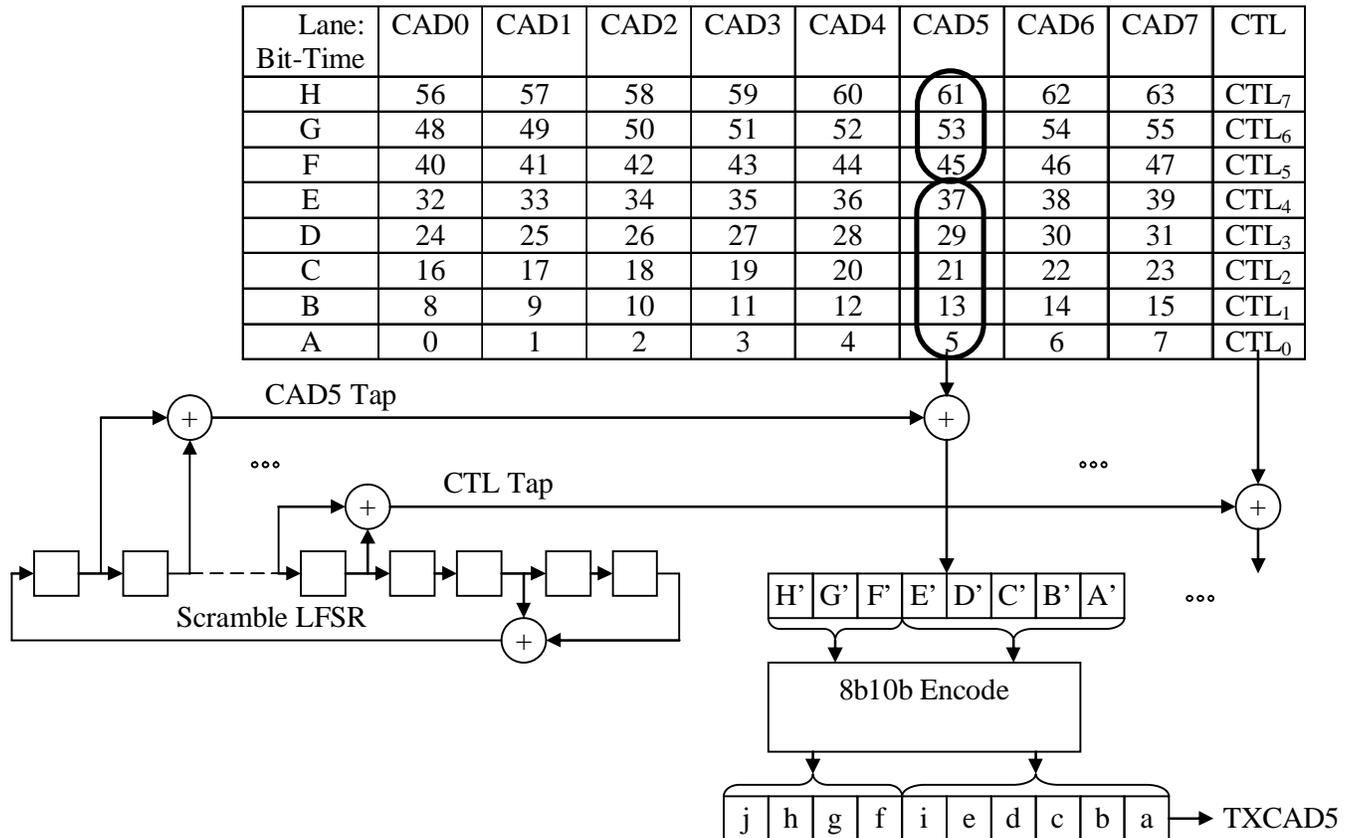


Figure 4. Gen3 Transmitter Order of Operations

3 Packet Definition

This chapter describes the packet definition for the HyperTransport™ link. HyperTransport technology supports link widths of 2, 4, 8, 16, and 32 bits. All tables later in this chapter assume an 8-bit wide link.

The packet structure for 16- and 32-bit links can be derived from the 8-bit link packet structure by combining the fields within adjacent bit-times. Some examples include:

$$BT_{16}[15:0] = BT_{28}[7:0] \ || \ BT_{18}[7:0]$$

$$BT_{32}[31:0] = BT_{48}[7:0] \ || \ BT_{38}[7:0] \ || \ BT_{28}[7:0] \ || \ BT_{18}[7:0]$$

where BTN_m represents the Nth bit-time within a packet for a link of width m and “||” represents concatenation.

Since all packets are multiples of four bytes long, packet boundaries always fall on bit-time boundaries.

The packet structure for 2- and 4-bit links can be derived from the 8-bit link packet structure by splitting the 8-bit link bit-times into adjacent bit-times. Some examples:

$$\begin{aligned} BT_{12}[1:0] &= BT_{18}[1:0] \\ BT_{22}[1:0] &= BT_{18}[3:2] \\ BT_{32}[1:0] &= BT_{18}[5:4] \\ BT_{42}[1:0] &= BT_{18}[7:6] \end{aligned}$$

$$\begin{aligned} BT_{14}[3:0] &= BT_{18}[3:0] \\ BT_{24}[3:0] &= BT_{18}[7:4] \end{aligned}$$

The above description also applies in a similar way to the CTL signals as indicated by the following examples:

$$CBT_{16}[1:0] = CBT_{28}[0] \ || \ CBT_{18}[0]$$

$$CBT_{32}[3:0] = CBT_{48}[0] \ || \ CBT_{38}[0] \ || \ CBT_{28}[0] \ || \ CBT_{18}[0]$$

3.1 Use of the CTL Signal

HyperTransport links carry control packets and data packets, distinguished by the use of the CTL signal. The purpose of the CTL signal is to allow control packets to be inserted in the middle of long data packets and unambiguously identify per-packet CRC in retry mode.

The following rules govern packet transmission in all modes.

1. Control packets larger than four bytes must be transmitted contiguously, without deassertion of CTL.
2. Control packets inserted into data packets must not themselves have an associated data packet. When the inserted control packet is complete, data transfer continues from the point where it left off.
3. Write request and read response packets always have an associated data packet. The data packet might not immediately follow the last bit-time of its associated control packet, because other control packets may be inserted before the data packet. However, because inserted control packets cannot have associated data, there can only be one data transfer outstanding.
4. The order of operations on the link is determined by the order of the control packets. The fact that data transfer for a control packet may be delayed does not affect how it is ordered. When retry mode is enabled, embedded packets may be reordered in front of the packet in which they are embedded. Retry enabled transmitters have the obligation to not embed a control packet which would cause an ordering violation if reordered in this way. See Section 10.3.5.

3.1.1 Gen1 Protocol

The following rules govern CTL for Gen1 protocol.

1. CTL[0] is the effective value of CTL for all bytes of CAD, regardless of link width
2. CTL is asserted through all bit-times of a control packet.
3. CTL is deasserted through all bit-times of a data packet.
4. CTL may be asserted on four-byte boundaries within a data packet to insert a control packet.
5. The bit-time immediately following the last bit-time of a data packet is always the start of a control packet (CTL must be asserted).
6. CTL may only be asserted or deasserted on a four-byte boundary, starting at the point in the initialization sequence (Section 12.2) where CAD and CTL both transition from 1 to 0. This alignment must be maintained until RESET# is asserted or a disconnect sequence (Section 8.3) completes.
7. CTL may only be deasserted when data transfer due to a previously transmitted control packet is being sent.

3.1.2 Gen3 Protocol

HyperTransport 3.0 utilizes one CTL lane for each 8 bits of CAD to enhance error detection, providing 4 CTL bits for every 32 CAD bits. The 4 CTL bits encode different control, data, or CRC DWs, allowing a receiver to frame commands solely upon the CTL encoding. Without this property a single bit error may cause the wrong DW to be used as the CRC, compromising the CRC's detection properties.

Table 6. CTL Encodings

CTL[3:0]	Meaning
1111b	Command
0111b	Inserted Command
1100b	CRC for command with data
0011b	CRC for command without data
0000b	Data

- If present, inserted commands with more than one DW before the CRC revert to the normal command encoding on the second and subsequent DW's.

3.1.2.1 Command Packet Insertion

Gen3 devices default to only allowing Info packets to be inserted in data packets at Gen3 frequencies. This allows a simplification of the command decode and flow control buffer logic in Gen3 receivers while keeping the delay in the flow control exchange loop as low as possible.

- This limitation extends from the first DW of the command for the data packet until the per-packet CRC covering the command and data.
- Any NOPs inserted may still carry flow control credits and acknowledge received packets.
- If LinkTrain[CPIEn] is set, other packets without data payloads as well as info packets may be inserted.
- Command packets must not be inserted between the last doubleword of data and the CRC for a packet. This simplifies the receiver implementation.

3.1.2.2 Command Throttling

To further simplify command decode, by default only one non-Info command may be issued every 4 DWs at Gen3 frequencies.

- Because the objective is to reduce internal command bandwidth, the periodic CRC timeslot does not count toward the 4 DWs. If a CRC timeslot falls in a 4-DW period, there are 5 DWs between transmitted commands.
- If LinkTrain[DisCmdThrt] is set, there is no restriction on command issue.

3.2 Packet Structure

This section defines the basic control and data packet types and shows the position of the fields that are common to all the control packet types. All packets are multiples of four bytes long.

3.2.1 Control Packets

Control packets consist of four or eight bytes. This section shows the basic structure of each of these control packet forms.

In the tables that follow, the unlabelled packet fields are command-specific. Some common control packet fields are as follows:

- *Cmd[5:0]* is the command field that defines the packet type.
- *Isoc* indicates that this packet may have different priority and ordering requirements from other packets, as described in Appendix D.
- *UnitID[4:0]* serves to identify one of the participants in a transaction. Since all packets are transferred either to or from the host bridge at the end of the chain, either the source or destination node is implied. The value 0 is reserved for the UnitID of the host bridge. See Section 4.2 for more details on the use of UnitID. Nodes with multiple logical I/O streams can own multiple UnitID values.
- *Bridge* indicates that this response packet was placed onto the link by the host bridge, and it is used to distinguish responses traveling upstream from responses traveling downstream. In the case of two host bridges sending packets to each other on a double-ended chain, the target host bridge appears to the requesting host bridge as a HyperTransport slave device. Therefore, the bridge bit is clear on responses to requests issued from the far host bridge.
- *SeqID[3:0]* is used to tag groups of requests that are issued as part of an ordered sequence by a device and must be strongly ordered within a virtual channel. All requests between the same source and destination and within the same I/O stream and virtual channel that have matching nonzero SeqID fields must have their ordering maintained. The SeqID value of 0x0 is reserved to mean that a transaction is not part of a sequence. Transactions with this value have no sequence-ordering restrictions, although they may be ordered for other reasons as described in Chapter 6. Tunnels are required to keep requests in the same I/O stream and virtual channel with matching nonzero SeqID fields in order when forwarding them. The SeqID bits are also used to identify requests traveling in the optional VCsets other than the base set, as defined in Section 4.7.1.
- *PassPW* indicates that this packet is allowed to pass packets in the posted request channel of the same I/O stream. Otherwise, this packet must stay ordered behind them. This bit should be cleared to maintain the full producer/consumer ordering model of HyperTransport technology. Systems that do not require this ordering may set PassPW for higher performance.
- *SrcTag[4:0]* is a transaction tag that is used to uniquely identify all nonposted transactions in progress initiated by a single requester. Each UnitID can have up to 32 nonposted transactions in progress at one time. The concatenation of source UnitID and SrcTag serves to uniquely identify nonposted requests. The SrcTag field is not relevant for posted requests and is reserved. SrcTag is used to match responses with their requests.
- *Addr[63:2]* represents the doubleword address accessed by the request. Not all address bits are included in all request types. Where finer granularity is required, byte masks are used.

Reserved fields in command packets must always be driven to 0 by transmitters when originating packets and must be assumed to be undefined by receivers. Reserved fields should be preserved when forwarding packets through a tunnel or HyperTransport-to-HyperTransport bridge.

3.2.1.1 Info Packet

Info packets (defined in Table 7) are always four bytes long. They are used for nearest neighbor communication between nodes, and so exist at the lowest level of the protocol. They are not routed within the fabric, and they require no buffering in the nodes. They are not flow-controlled, and they can always be accepted by their destination.

Table 7. Info Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	<i>Command-Specific</i>		Cmd[5:0]					
1	<i>Command-Specific</i>							
2	<i>Command-Specific</i>							
3	<i>Command-Specific</i>							

3.2.1.2 Request Packet

Request packets are either four or eight bytes long, depending upon whether the request has an associated address. Table 8 shows a request packet with an address. Four-byte request packets do not contain the address field.

Table 8. Request Packet Format with Address

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	<i>Command-Specific</i>							
3	<i>Command-Specific</i>							
4	Addr[15:8]							
5	Addr[23:16]							
6	Addr[31:24]							
7	Addr[39:32]							

3.2.1.3 Packet Extensions

An address extension control doubleword may be prepended to a Read, Write, Broadcast, or Atomic RMW request to extend the address of the request to 64 bits, as shown in Table 9. No control or data packets may be transmitted between the extension doubleword and the request it affects. (Periodic CRC insertion may occur.) An extension doubleword must only be transmitted with an accompanying request. The extension doubleword and the accompanying request are ordered and flow controlled together as a single request. A request without an address extension is assumed to have Address[63:40] 0's. Address Extension doublewords of all 0's are illegal and may result in undefined operation. Creation, forwarding, and acceptance of 64-bit addresses is optional and enabled on a per-link basis, as described

in Section 7.5.4.13. These extensions do not consume any flow control credits of their own, so support of them merely increases the size of the buffer needed to carry a control packet.

Table 9. Request Packet Format with Extended Address

Bit-Time	7	6	5	4	3	2	1	0
0	00b		Cmd[5:0]=111110b					
1	Addr[47:40]							
2	Addr[55:48]							
3	Addr[63:56]							
4	SeqID[3:2]		Cmd[5:0]					
5	PassPW	SeqID[1:0]		UnitID[4:0]				
6	<i>Command-Specific</i>							
7	<i>Command-Specific</i>							
8	Addr[15:8]							
9	Addr[23:16]							
10	Addr[31:24]							
11	Addr[39:32]							

Requests may also be prepended with a Source Identifier packet extension doubleword to identify the originating device. It is differentiated from an Address Extension by bits 7:6 in the first bit-time. Table 10 shows a Source ID extension. No control or data packets other than an Address Extension may be transmitted between the source ID extension and the request it affects. If both an address and Source ID extension are applied to a request, the Source ID extension is sent first. Generation of Source ID doublewords is enabled on a per-link basis, as described in Section 7.5.4.1. Support for acceptance and forwarding of them is indicated by the Source ID Feature bit defined in Section 7.5.10.7.

Table 10. Request Packet Format with Source Identifier Packet Extension

Bit-Time	7	6	5	4	3	2	1	0
0	10b		Cmd[5:0]=111110b					
1	Device[4:0]				Function[2:0]			
2	Bus[7:0]							
3	Reserved						AddressType[1:0]	
4	SeqID[3:2]		Cmd[5:0]					
5	PassPW	SeqID[1:0]		UnitID[4:0]				
6	<i>Command-Specific</i>							
7	<i>Command-Specific</i>							
8	Addr[15:8]							
9	Addr[23:16]							
10	Addr[31:24]							
11	Addr[39:32]							

The encodings 01b and 11b in bits 7:6 of bit-time 0 are reserved

Address Type indicates if the address carried in the associated request has been translated or not, or if the request is itself a request for an upstream device to provide the correct address translation. See Appendix B.7 for the definition of packets that carry translation requests and responses as well as invalidation requests and responses.

Table 11. Address Type (AT) Field Encodings

AT[1:0]	Meaning
00b	Untranslated Address (default)
01b	Translation Request (only legal for reads)
10b	Translated Address
11b	Reserved

- If forwarding a request from another link or mapping a request from another bus that provides source identification, the bus, device, and function number of the original request is preserved.
- Devices that support Source ID Extensions must be able to regenerate CRC for forwarded packets when the SrcIdEn bit is clear.
- If mapping a request from another bus that does not explicitly provide source identification but the device and function number can be determined unambiguously, a bridge should provide the

secondary bus number and device and function numbers of the source device. Otherwise the bridge may provide its own bus, device, and function number.

- If originating a packet, the bus, device, and function number used by software to access the link control register is used.
- The bus number of a HyperTransport device or bridge comes from the Bus Number register defined in Section 7.5.15.
- An Address Type of 00b is used if the address is an untranslated (virtual) address. An Address Type of 10b is used if the address is a translated (physical) address.
- A request without a Source ID Extension is assumed to carry an untranslated address.

3.2.1.4 Response Packet

Response packets (defined in Table 12) are always four bytes long.

Table 12. Response Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	<i>Command-Specific</i>		Cmd[5:0]					
1	PassPW	Bridge	Rsv	UnitID[4:0]				
2	<i>Command-Specific</i>		Error0	<i>Command-Specific</i>				
3	Rsv/RqUID		Error1	RspVCSet			<i>Command-Specific</i>	

3.2.1.5 Command Field Encoding

The command field, shown in Table 13, is valid for all control packets.

Table 13. Command Field Encoding for All Control Packets

Code	VChan	Command	Comments/Options	Packet Type
000000	-	NOP	Null packet. Contains flow control information.	Info
000001		Reserved-HOST		
000010	NPC	Flush	Flush posted writes	Request
000011 0001xx		Reserved-HOST		
001xxx 101xxx	NPC PC	Wr (sized)	Write Request [5] Defines whether request is posted: 0: Nonposted 1: Posted [2] Defines the data length: 0: Byte 1: Doubleword	Req/Addr/Data

Code	VChan	Command	Comments/Options	Packet Type
			[1] Defines bandwidth/latency requirements: 0: Normal 1: Isochronous [0] Indicates whether access requires host cache coherence (reserved and set if access is not to host memory): 0: Noncoherent 1: Coherent	
01xxxx	NPC	Rd (sized)	Read Requests [3] RespPassPW Defines ordering requirements for response: 0: Response may not pass posted requests 1: Response may pass posted requests [2] Defines the data length: 0: Byte 1: Doubleword [1] Defines bandwidth/latency requirements: 0: Normal 1: Isochronous [0] Indicates whether access requires host cache coherence (reserved and set if access is not to host memory): 0: Noncoherent 1: Coherent	Req/Address
100xxx		Reserved-I/O		
110000	R	RdResponse	Read Response	Resp/Data
110001 110010		Reserved-HOST		
110011	R	TgtDone	Tell source of request that target is done.	Response
11010x		Reserved-HOST		
110110		Reserved-I/O		
110111	-	Extended FC	Contains Flow Control information for VCsets 0-7	Info
11100x		Reserved-HOST		
111010	PC	Broadcast	Broadcast Message	Req/Address
111011		Reserved-HOST		
111100	PC	Fence	Fence for posted requests	Request
111101	NPC	Atomic-RMW	Atomic Read-Modify-Write	Req/Addr/Data
111110	-	AddrExt/SourceID	Address Extension or Source Identifier Extension	Address
111111	-	Sync/Error	Link Synchronization and Error Packet	Info
Notes: <i>The fields in this table are defined as follows:</i>				

Code	VChan	Command	Comments/Options	Packet Type
<p><i>Code</i> is the 6-bit command encoding in each packet.</p> <p><i>VChan</i> indicates the virtual channel that the packet travels in. Info packets are only used for single-link communication and do not use buffer space, and thus are not in a virtual channel. See Section 4.7 and Section 4.8 for more information.</p> <p><i>PC</i>—Posted Command (Request) <i>NPC</i>—Nonposted Command (Request) <i>R</i>—Response</p> <p><i>Command</i> is the mnemonic used to represent the command.</p> <p><i>Comments/Options</i> gives a short description of the command and enumerates any option bits within the Code field.</p> <p><i>Packet Type</i> indicates the type of packet(s) used by the command.</p> <p><i>Reserved-I/O</i> identifies code points that are reserved for future use.</p> <p><i>Reserved-HOST</i> identifies code points that are used in a host-specific protocol and must not be used to implement future features in the HyperTransport™ I/O Link Protocol Specification.</p>				

Receiving a packet with a reserved command code is a protocol error (see Section 0) and may result in undefined operation of devices that do not implement recovery from protocol errors.

3.2.2 Data Packet

Data packets contain the data payload for transactions. Data packets follow write request and read response packets. Data packets range in length from four to 64 bytes, in multiples of four bytes (one doubleword), as indicated by the Count field of the most recent payload-bearing command. Within a doubleword, data bytes appear in their natural byte lanes. For transfers of less than a full doubleword, the data is padded with undefined bytes to achieve this byte-lane alignment.

Table 14 shows an example of an eight-byte data packet.

Table 14. Eight-Byte Data Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	Data[7:0]							
1	Data[15:8]							
2	Data[23:16]							
3	Data[31:24]							
4	Data[39:32]							
5	Data[47:40]							
6	Data[55:48]							
7	Data[63:56]							

The data packet for a sized read response is arranged with the lowest addressed doubleword returned first, and the remainder of the addressed data is returned in ascending address order by doubleword.

Sized read responses can contain any number of contiguous doublewords within a 64-byte aligned block. Although, for sized byte reads, not all bytes are guaranteed to be valid. The data cannot wrap from the most significant doubleword in the aligned 64-byte block to the least significant doubleword in the block.

Sized doubleword writes work in the same way as sized doubleword read responses and can contain anywhere from one to 16 doublewords in ascending address order.

Sized byte writes, defined in Section 4.4.1, transmit one doubleword worth of masks first, followed by from one to eight doublewords of data in ascending address order, as shown in Table 15. Mask[0] corresponds to Data[7:0], Mask[1] to Data[15:8], and so on. Thirty-two mask bits are always transmitted, regardless of the amount of data. All-zero byte masks are permitted. Interrupt and system management messages, which are composed of byte write packets to predefined address ranges, are the only byte write packets that do not require at least one doubleword of data.

Table 15. Sized Byte Write Data Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	Mask[7:0]							
1	Mask[15:8]							
2	Mask[23:16]							
3	Mask[31:24]							
4	Data[7:0]							
5	Data[15:8]							
6	Data[23:16]							
7	Data[31:24]							
8+	Packet may contain up to eight doublewords of data.							

3.2.3 Note about VC Stalls due to Command-Data Separation

Some implementations may issue a command and then not issue the corresponding data packet for an extended interval due to some internal condition. Because the data following a command must belong to the command, this can cause all VCs to stall, severely impacting throughput. Implementations like this are strongly discouraged.

Another reason why VC stalls may occur is when bridging between link speeds. A command packet from a slower link may appear on the faster link well in advance of the data packet associated with the command, preventing the insertion of any other command packet which has an associated data packet. If the rates are mismatched by a factor of 20% or more, the throughput may be noticeably impacted. Tunnels are urged to address this mismatch case by deferring the forwarding of a command packet for some number of clocks until the associated data packet can be sent out back to back.

A third case when this can happen is when a protocol is being bridged which also has the property that the command and data can be separated or stalled. Bridges are urged to consider this case and make an attempt to put a command and its associated data packet out back to back.

4 Fabric Operation

The HyperTransport™ link is a pipelined, split-transaction interconnect where transactions are tagged by the source and responses can return to the source out of order. This chapter outlines the basic operation of the link.

4.1 Topology

HyperTransport I/O fabrics are implemented as one or more *daisy chains* of HyperTransport devices, with a bridge to the host system at one end. Devices can implement either one or two links.

- A dual-link device that is not a bridge is called a *tunnel*.
- Single-link devices must always sit on the end of the chain, so only one single-link device is possible in a chain.

Direct peer-to-peer communication between devices in the chain is not allowed except when using DirectRoute (see Section 4.9.6). All packets (except for info and DirectRoute packets) travel between one device and the host bridge. This means that at a high level, the fabric appears as a group of devices directly connected to a host bridge, but not to each other. Packets flowing away from that host bridge are said to be flowing *downstream*. Packets flowing toward that host bridge from a HyperTransport device are said to be flowing *upstream*.

A single HyperTransport I/O *chain* contains no HyperTransport-to-HyperTransport bridge devices. It can contain native HyperTransport peripheral devices (like an Ethernet controller) and can also contain bridges to other interconnects (like PCI). A chain is terminated at one or both ends by a bridge. In the simplest topology, a chain connects to the host bridge at one end and has no connection at the other end.

A HyperTransport *tree* contains one or more HyperTransport-to-HyperTransport bridge devices. A HyperTransport *bridge device* has a primary link, being the upstream link in the direction of the host and one or more secondary links. Each HyperTransport chain that connects to a bridge's secondary link is assigned a unique bus number (see Section 7.2.3 for details). The HyperTransport-to-HyperTransport bridge device operates as a host bridge for devices on its secondary chain. In addition to its secondary links, a HyperTransport bridge device may have a downstream link that is associated with the same bus number as the bridge's primary link. The root of the HyperTransport tree connects to the host.

The *host* can contain multiple bridges, each supporting either a single HyperTransport I/O chain or a tree of HyperTransport I/O chains. Some example configurations and topologies are shown in Figure 5 and Figure 6. In these figures, “P” indicates a primary interface capability block and “S” indicates a secondary interface capability block. See Section 7.5 for details of these capability blocks.

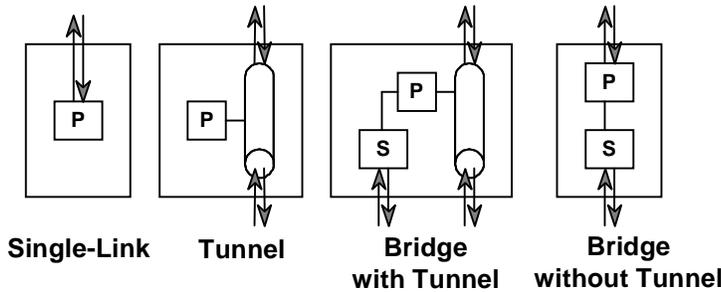


Figure 5. Example Device Configurations

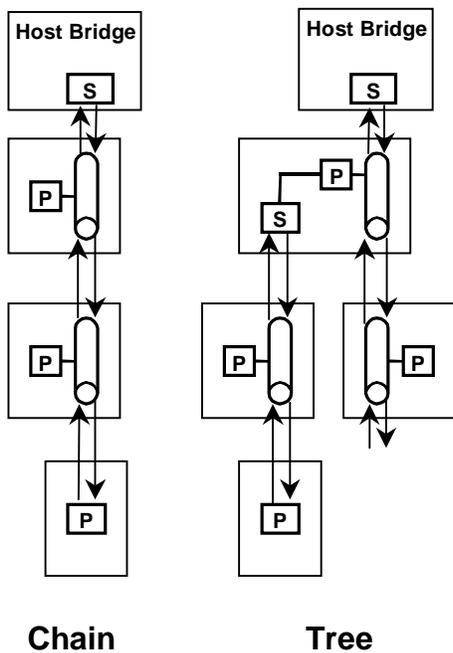


Figure 6. Example Topologies

For convenience in integrating multiple functions onto a single chip, or to allow parallelism between independent request streams, individual HyperTransport devices can use multiple UnitID values. There is no specific limit on the number of physical devices. However, there are only 31 UnitIDs available to each chain. No combination of devices that exceeds 31 UnitIDs may be connected to a single chain.

4.1.1 Double-Hosted Chains

Physically, a chain can be connected to a host bridge at each end, as long as the chain contains no single-link devices. This may be useful to provide another path to I/O devices in the event of a host bridge or link failure, or to allow sharing of I/O devices between independent hosts to implement clustering. One bridge is designated the *master bridge* for the shared chain, while the other is designated the *slave bridge*. This designation must be made before the chain is reset. (The method of doing so is beyond the scope of this specification.)

There are two types of double-hosted chains supported by HyperTransport technology: sharing and non-sharing.

- In a *sharing double-hosted chain*, traffic is allowed to flow end to end, and both hosts are able to issue requests to each other and to any device. Generally, all devices in the chain should belong to the master host to avoid a peer-to-peer transaction deadlock as described in Section 4.7. A device belongs to a host when the Master Host and Default Direction bits (defined in Section 7.5.3.2) point to that host. If devices need to be accessed from either host, the slave host may have its Act as Slave bit (defined in Section 7.5.3.3.6) set so that all requests pass through the master host to maintain ordering, as defined in Section 6.1.
- A *non-sharing double-ended chain* appears logically as two distinct daisy chains, each attached to only one host bridge. Software selects a point to break the chain in two and reconfigures the devices to divide them between the bridges in order to balance traffic. Once the chain is broken, the hosts cannot issue requests to each other until a reset.

The initialization sequence described in Section 12.3 ensures that all devices are assigned unique device numbers. In the event of a node or link failure, the sequence causes the devices on each side of the break in the chain to belong to the host bridge on that end, forcing a non-sharing chain.

Because devices accept requests from both directions in either double-hosted chain type, they must keep track of which link incoming request packets are received on and send any responses back on the same link. An interior node may see the same SrcTag active from the host bridges at both ends of the link. The node must recognize the two host bridges as having disjointed SrcTag spaces.

Double-hosted chain support for hosts is optional, but recommended. In order to support double-hosted chains, a host must implement the Double Ended and Chain Side fields of the HyperTransport Command register, specified in Section 7.5.3.3, and the host must properly accept cycles targeted to it, as described in Section 4.9.4. If a host does not support double-hosted chains, it cannot be connected to the secondary port of a bridge (for clustering).

To support a sharing double-hosted chain, the host must also implement the Device Number and Host Hide fields of the Command register, specified in Section 7.5.3.3, and deal with the ordering described in Section 6.4.

4.2 Transactions and UnitID

Since all HyperTransport transactions consist of a series of packet transfers between a device and the host bridge, the use of the UnitID field can be simply summarized in Table 16.

Table 16. UnitID Field Usage

	Upstream	Downstream
Request	UnitID is source of request (Device's UnitID)	UnitID is source of request: Host's UnitID: Clumped 0 DirectRouted: Requestor's UnitID
Response	HostReflected request: UnitID is target of request(Device's UnitID) Bridge bit clear DirectRouted request: UnitID is source of request(Requestor's UnitID) Bridge bit set	UnitID is source of request (Device's UnitID) Bridge bit set
Notes:		
<ol style="list-style-type: none"> 1. The Bridge bit in a downstream response must be set and the UnitID must be that of the request, even when the responder is a slave, not a host, as described in Section 4.9.3. 2. A Clumped 0 UnitID is either 0 itself, or any of the consecutive UnitIDs that have been clumped with 0, as defined in Section 4.6.1. 		

Host reflected peer to peer communication is implemented as a pair of HyperTransport transactions—a transaction generated by the source device and targeted at the host, and a transaction generated by the host and directed to the target device. The UnitIDs in the request and response packets associated with these two transactions follow the rules in Table 16.

4.3 Link Synchronization

The sync pattern is used to indicate that a resynchronization event has occurred in the system, such as a reset or a chain error, which requires all links to be resynchronized. The sync pattern is defined in Table 17.

Table 17. Sync Pattern Format

Bit-Time	7	6	5	4	3	2	1	0
0	11		Cmd[5:0]: 111111					
1	11111111							
2	11111111							
3	11111111							

CRC checking on a link is shut down when a sync packet is received. See Section 10.1 for a description of CRC.

All fields in a sync pattern (including the command) are all 1s. Receivers on 8-, 16-, or 32-bit links may detect a sync pattern by observing at least 16 bit-times of all 1s on byte lane 0 of the link (starting with the rising edge of CLK in 8- or 16-bit links), or by decoding at least four consecutive sync commands via its normal command decode logic. Sync patterns on 4- and 2-bit links require two times and four times the number of all-1-bit-times, respectively, as 8-bit, 16-bit, and 32-bit links.

Once a transmitter places a sync pattern onto an active link, it keeps that pattern on the link until after the link is reset and synchronized. This allows a receiver to detect sync via either method. If scrambling or unscrambling becomes misaligned in Gen3 protocol, a receiver cannot detect sync flood immediately; a sync flood will eventually be detected after all training attempts fail. See Section 12.3.16.

4.4 Requests

4.4.1 Sized Reads and Writes

The Sized Read or Write request is defined in Table 18. Sources use the Sized Read and Write requests (byte or doubleword) to initiate transactions to either memory or I/O. The data returned for Sized Reads cannot be coherently cached, as HyperTransport I/O provides no coherence primitives. Sized requests contain the starting doubleword address of the data and a set of data elements to be transferred. Bit 2 of the command field indicates whether the data elements to be transferred are bytes or doublewords, as defined in Table 13. Table 13 also defines the Coherence, Isochronous, Posted, and Response May Pass Posted Request bits in the command field.

Table 18. Sized Read or Write Request Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Mask/Count[1:0]		Compat	SrcTag[4]/ Data Error	SrcTag[3]/ Chain	SrcTag[2:0]/Rsv		
3	Addr[7:2]					Mask/Count[3:2]		
4	Addr[15:8]							
5	Addr[23:16]							
6	Addr[31:24]							
7	Addr[39:32]							

Doubleword operations can transfer any number of contiguous complete doublewords within a 64-byte aligned block. The Count field encodes the number of doubleword data elements that should be transferred, beginning at the specified address, and going in ascending order. Count codes of 0 through

15 represent 1 through 16 data elements to be transferred, respectively. Requests that cross a 64-byte boundary must be broken into multiple transactions, issued in ascending address order.

Byte reads can transfer any combination of bytes within an aligned doubleword. The Mask field is used to indicate which bytes within the doubleword are being read. Mask[0] corresponds to the lowest addressed byte, and Mask[3] corresponds to the highest addressed byte. Byte-maskable reads crossing an aligned doubleword boundary must be broken into multiple requests, each within a single doubleword. The mask bits can be ignored for reads to regions where reads are guaranteed not to have side effects. A read where all mask bits are 0 still causes host coherence action (if to memory and Cmd[0] is asserted) and still returns a RdResponse packet with one doubleword of (invalid) data.

Byte writes can transfer any combination of bytes within a naturally aligned 32-byte address region. Transfers that cross an aligned 32-byte boundary must be broken into multiple HyperTransport transactions, issued in ascending address order. Address bits [4:2] identify the first doubleword of data sent in the data packet within the 32-byte region defined by address bits [63:5]. The data packet for a byte-write operation contains byte mask information in the first doubleword of the data packet. The Count field is used to indicate the total size of the data packet in doublewords, including the byte masks, so it ranges from one to eight to indicate two through nine doublewords to be transferred. In general, it is illegal for a byte-write packet to contain byte masks and no data, meaning the Count field must contain a nonzero value. The exceptions to this are interrupt and system management messages—they take the form of byte writes to predefined address regions and do not require data to be transferred. See Section 3.2.2 for the format of the data packet. The Count field specifies the length of the data packet independent of the value of the byte masks. Nonzero byte masks for doublewords that are not sent result in undefined behavior. Byte masks may be 0 for doublewords that are sent. The entire byte mask doubleword may be 0, in which case the system performs all activities usually associated with the request. However, no data is written.

The sized command field contains a bit that indicates whether the access requires coherence action to be taken by the system for host memory accesses. If this bit is set, the host must take whatever action is appropriate to ensure that any caching agent remains coherent with system memory. Writes must cause caches to be updated or invalidated. Reads must return the latest modified copy of the data, even if main memory is stale. If the bit is clear, reads and writes can happen directly to and from main memory without polling or modifying cache states. Most devices require host hardware to maintain coherence between processor caches within the host and host memory. Some devices may not require coherence to be maintained, or may have alternative application-specific means of ensuring memory coherence, and may clear the coherent bit to indicate this to the host. The coherent bit is reserved and must be set for accesses that are not to memory address space.

Transactions also have an Isochronous bit in the command encoding associated with them that must be maintained by tunnels even when Isochronous flow control mode is disabled. Host bridges should maintain the bit when forwarding peer-to-peer requests if possible. See Appendix D for details of how this is used.

Sized Writes have a Posted bit. Besides serving as a virtual channel identifier, a set Posted bit indicates that the write request will receive no response in the fabric. The requester's buffer can be deallocated as soon as the write is transmitted. As such, the SrcTag field is reserved for posted requests. No assumptions can be made about the uniqueness or meaning of SrcTags for posted requests, either

relative to other posted requests, or to other traffic. Bit 4 of bit-time 2 (Data Error) is set in posted requests to indicate that a data error has occurred while forwarding the request. If no error is detected while forwarding the request, the bit is 0. Bit 3 of bit-time 2 (Chain) is set in posted requests to indicate that this request will be followed by another and they must be forwarded together without other posted requests interleaved. The Chain bit is currently used in Device Messages but must be honored for all posted requests. Frequent use of long chains of requests would have a negative impact on system performance and should be avoided. Requests that are chained together must have the same destination, or undefined operation results. All nonposted requests (such as Reads, Nonposted Writes, Flushes, and Atomic RMW) for a given UnitID must have a unique SrcTag value for each outstanding request. The last packet in a chain must have the chain bit clear.

Reads have a Response May Pass Posted Requests bit in the command field. This bit should be cleared to maintain the full producer/consumer ordering model of HyperTransport technology. Systems that do not require this ordering may set PassPW for higher performance. This bit is carried with the request but does not serve any purpose until the response is generated. At that time, it becomes the PassPW bit in the response.

Unlike read requests, write requests do not contain a Response May Pass Posted Requests bit. Therefore, the PassPW bit in the TgtDone packet is generally set. However, this is not strictly required—responders can choose to clear the PassPW bit in the TgtDone packet based on implementation-specific considerations. See Sections F.2.1.1 and F.2.5 for some examples.

The Compat bit is used to implement the subtractive decode necessary for boot firmware and legacy devices. When set, it indicates that address decode in the host has found no mapping for the given access, and therefore the access should be routed to the bus segment containing the subtractive decode device. As part of the initialization sequence, all HyperTransport devices determine whether they own (or are) the subtractive decode device. Accesses with the Compat bit set are always accepted by devices that own it and ignored by all other devices, regardless of address. The Compat bit may only be asserted for downstream requests. It is reserved for upstream requests and configuration space requests.

Posted Sized Write Requests which travel in VCSet=2 have a ReqVC[3:0] field created by the ReqVC[3]=SeqID[0] and ReqVC[2:0]=SrcTag[2:0]. See Section 4.7.1 for details.

4.4.2 Broadcast Message

Broadcast messages (defined in Table 19) are used by the host to communicate information to all HyperTransport devices.

Table 19. Broadcast Message Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]: 111010					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Reserved							
3	Addr[7:2]						Rsv	
4	Addr[15:8]							
5	Addr[23:16]							
6	Addr[31:24]							
7	Addr[39:32]							

Broadcast messages can only be issued by the host bridge, and they travel in the downstream direction for the entire length of the chain, being both accepted and forwarded by all devices. Features that are implemented using Broadcast messages have reserved address ranges associated with them that are recognized by all devices. All information (including potential write data) necessary to the specific type of operation being performed is carried in the address field.

Broadcasts travel in the posted channel, and the SrcTag field is reserved. No assumptions can be made about the uniqueness of SrcTags, either relative to other Broadcast messages or other traffic.

4.4.3 Flush

Flush is designed to make sure that posted writes have been observed at host memory. It applies only to requests in the same I/O stream as the flush. The Flush command is defined in Table 20.

Table 20. Flush Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]: 000010					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Rsv		Isoc	SrcTag[4:0]				
3	Reserved							

Flush functions very similarly to a Read operation, except that it returns no data. Like Reads, Flush goes in the nonposted request virtual channel. For a Flush to perform its intended function, the PassPW bit must be clear, so that the Flush pushes all requests in the posted channel ahead of it. It is expected that

Flushes are never issued as part of an ordered sequence, so their SeqID is always 0. Flush requests with PassPW set or with a nonzero SeqID are legal, but their effect is unpredictable. The Isoc bit indicates which Virtual Channel set the Flush applies to. A 0 indicates the normal Virtual Channels, and a 1 indicates the Isochronous Virtual Channels. This bit is only significant when Isochronous Flow Control is enabled. When Isochronous Flow Control is disabled, Isochronous traffic flows in the normal virtual channels and is affected by all Flushes. See Appendix D.1 for more on Isochronous Flow Control.

All nonposted requests (such as Reads, Nonposted Writes, Flushes, and Atomic RMW) for a given UnitID must have a unique SrcTag value for each outstanding request.

Note that Flush only guarantees that posted requests have been flushed to their destination within the host. If the requests are peer-to-peer, this only means that they reached their destination host bridge, not the final device.

The Flush response is returned from the host bridge when the requests have become globally visible in the host. Since there is no data, a TgtDone response with PassPW set is used.

Flush is only issued from a device to a host bridge or from one host bridge to another. Devices are never the target of a Flush so they do not need to perform the intended function. If a device at the end of the chain receives a Flush, it must decode it properly to maintain proper operation of the flow control buffers and should return a TgtDone with a Master Abort indicated.

4.4.4 Fence

Fence is designed to provide a barrier between posted writes, which applies across all UnitIDs and therefore across all I/O streams and all virtual channels. The Fence command is defined in Table 21.

Table 21. Fence Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]: 111100					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Rsv		Isoc	Reserved				
3	Reserved							

Fence goes in the posted request virtual channel and has no response. There is therefore no SrcTag field in the request packet. A Fence with PassPW clear must not pass anything in the posted channel regardless of UnitID. Packets with their PassPW bit clear must not pass a Fence regardless of UnitID. Packets with their PassPW bit set may pass a Fence.

For a Fence to perform its intended function, the PassPW bit must be clear so that the Fence pushes all requests in the posted channel ahead of it. Fence requests are never issued as part of an ordered sequence, so their SeqID should always be 0. Fence requests with PassPW set, or with a nonzero SeqID, are legal, but may have an unpredictable effect. The Isoc bit indicates which Virtual Channel set the Fence applies to. A 0 indicates the normal Virtual Channels, and a 1 indicates the Isochronous Virtual

Channels. This bit is only significant when Isochronous Flow Control is enabled. When Isochronous Flow Control is disabled, Isochronous traffic flows in the normal virtual channels and is affected by all Fences. See Appendix D.1 for more on Isochronous Flow Control.

Fence is only issued from a device to a host bridge or from one host bridge to another. Devices are never the target of a fence so they do not need to perform the intended function. If a device at the end of the chain receives a fence, it must decode it properly to maintain proper operation of the flow control buffers. The device should then drop it. The node can choose to log this as an end-of-chain error, as described in Section 10.1.6.

4.4.5 Atomic Read-Modify-Write

The optional Atomic Read-Modify-Write (RMW) request is defined in Table 22. The Atomic RMW request supports two forms of atomic RMW operation on a naturally aligned quadword location:

- Fetch and Add
- Compare and Swap

Table 22. Atomic Read-Modify-Write (RMW) Request Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]: 111101					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Count[1:0]		Compat	SrcTag[4:0]				
3	Addr[7:3]				Rsv	Count[3:2]		
4	Addr[15:8]							
5	Addr[23:16]							
6	Addr[31:24]							
7	Addr[39:32]							

The Fetch and Add operation is:

```
FetchAdd(Out, Addr, In) {
    Out = Mem[Addr];
    Mem[Addr] = Mem[Addr] + In; // Unsigned add without saturation or carry
}
```

The Compare and Swap operation is:

```
CompareSwap(Out, Addr, Compare, In) {
    Out = Mem[Addr];
    If (Mem[Addr] == Compare) Mem[Addr] = In;
}
```

These operations must be performed atomically by the target of the request, meaning that no other agent in the system may access the addressed location between the time that it is read and written on behalf of the atomic request.

A Fetch and Add request must be accompanied by one quadword of data (the input value) and have a Count field value of 1. A Compare and Swap request must be accompanied by two quadwords of data (the compare and input values) and have a Count field value of 3. The Compare value is first, followed by the input value. The value of the Count field is used to distinguish between the two request types. While the action taken when the Count field is not 1 or 3 is undefined, all devices must use the value of Count to determine the size of the data payload accompanying the request in order to forward it properly, regardless of its value.

From a transaction perspective, an Atomic RMW request is a nonposted write that generates a read response. The read response packet contains a single quadword—that being the original value at the addressed location. Note that for Compare and Swap, the value of the Count field in the response packet is different from that in the associated request packet.

It is expected that Atomic RMW requests are generated by HyperTransport I/O devices or bridges and directed to system memory (DRAM) that is controlled by the host. Therefore, the Compat bit should normally be cleared. No targets are required to support atomic operations. If a target receives an unsupported atomic operation, it may either return a one-quadword read response with Target Abort indicated, or it may perform the RMW in a non-atomic way. If a host receives an atomic operation that does not target host space, it may either reflect it as a peer-to-peer cycle or return a Target Abort.

Unlike the RdSized request packet, the Atomic RMW request packet does not contain the RespPassPW, Isoc, or Coherent bits in the command field of the packet, as defined in Table 13. The implied values of these bits are as follows:

- Coherent: 1—The addressed data may be cached.
- Isochronous: 0—Isochronous Atomic RMW requests are not supported.
- RespPassPW: 0—The response to the Atomic RMW request may not pass posted writes.
-
- All nonposted requests (such as Reads, Nonposted Writes, Flushes, and Atomic RMW) for a given UnitID must have a unique SrcTag value for each outstanding request.

4.5 Responses

4.5.1 Read Response (RdResponse)

A node that is the target of a request for data (such as Sized Read or Atomic RMW request) returns a read response packet to the source followed by a data packet that contains the requested data. The format of the read response packet is shown in Table 23.

Table 23. Read Response (RdResponse) Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	Isoc	Rsv	Cmd[5:0]: 110000					
1	PassPW	Bridge	Rsv	UnitID[4:0]				
2	Count[1:0]		Error0	SrcTag[4:0]				
3	Rsv/RqUID		Error1	Rsv/RspVCSet			Count[3:2]	

The Count field encodes the size minus 1 (in doublewords) of the data packet, so that intermediate nodes forwarding the response know how much data to expect. For doubleword read requests, the Count is just taken from the request packet. For byte read requests, the data field always fits within a single doubleword, so the Count field is always 0 (one doubleword). For Read-Modify-Write requests, the Count field is always 1 (one quadword).

The Error bits are used to indicate that an error occurred during the read. This can be due to the accessed address being non-existent, an internal error in DRAM or a cache, or other problems. The requested number of data elements are always driven to the chain, whether they are valid or not, but the Error bits indicate that the data cannot be used. The different encodings of the error bits are described in Table 24. A data packet with 1s in all data bit positions must follow a read response packet with Master Abort indicated. A data packet containing corrupt data follows a read response with Data Error indicated. A data packet containing incomplete or invalid data follows a read response with Target Abort indicated.

Table 24. Error bit encodings

Error 1	Error 0	Meaning
0	0	Normal Completion
0	1	Target Abort: Request reached target but could not be completed.
1	0	Data Error: Request completed by the target but data has been corrupted.
1	1	Master Abort: No agent on the chain accepted the request.

The Isoc bit is set to indicate that this response has special bandwidth and latency requirements, and must be set if the Isoc bit was set in the request. See Appendix D for details. The Isoc bit is required to be maintained even when passing through a tunnel with Isochronous flow control mode disabled. Host bridges should return the value of Isoc from the request when forwarding peer-to-peer responses.

The SrcTag field is copied from the request that caused the response.

When Bridge=0, RqUID contains the two least significant bits of the requestor's UnitID.

The RspVCSet is the VCSet of this response. The value is determined from the VCSet column of Table 26 with the fields from the request. Note that it is reserved in the Base and Isoc VCSet.

4.5.2 Target Done (TgtDone)

Target Done (defined in Table 25) signals that a transaction not requiring returned data (such as Sized Write or Flush) has completed at its target.

Table 25. Target Done (TgtDone) Format

Bit-Time	7	6	5	4	3	2	1	0
0	Isoc	Rsv	Cmd[5:0]: 110011					
1	PassPW	Bridge	Rsv	UnitID[4:0]				
2	Rsv		Error0	SrcTag[4:0]				
3	Rsv/RqUID		Error1	Rsv/RspVCSet			Rsv	

The target can release its command buffer as soon as it issues TgtDone. A nonposted request results in either a RdResponse or a TgtDone, but not both. TgtDone also has the Isoc, Bridge, PassPW, and Error bits, with the same behavior as the ones in RdResponse. Data Error in a TgtDone indicates that the target received the request, but detected data corruption on the write data it received.

The SrcTag field is copied from the request that caused the response.

When Bridge=0, RqUID contains the two least significant bits of the requestor's UnitID.

The RspVCSet is the VCSet of this response. The value is determined from the VCSet column of Table 26 with the fields from the request. Note that it is reserved in the Base and Isoc VCSETS.

4.6 I/O Streams

HyperTransport technology has the concept of I/O streams, which are groupings of traffic that can be treated independently by the fabric.

Because no peer-to-peer communication exists within the fabric, and all packets travel either to or from the host bridge, the traffic to or from each node in the fabric could, in theory, be treated independently by the fabric, leaving the host bridge to manage interactions between streams.

Upstream requests contain the ID of the source node, and upstream responses contain the ID of the node that generated the response. Therefore, UnitID may be used to identify I/O streams for upstream packets. Note that Fence requests occupy all UnitIDs (see Section 4.4.4 for details).

Downstream responses contain the ID of the node to which the response is being sent. However, downstream requests contain the ID of the host bridge, and not the ID of the node that is targeted by the request. Therefore, it is impossible to determine independent I/O streams in downstream request traffic, and it must be assumed that all downstream traffic (both requests and responses) is in the same stream.

The host bridge is responsible for managing interactions between streams. No stream information is propagated through the host bridge. The host bridge is responsible for maintaining ordering within the host domain in whatever fashion is appropriate.

A single physical node can be allocated multiple UnitIDs if the node generates multiple independent streams of traffic. This allows more concurrency among the traffic to and from that device. If allocating multiple UnitIDs is not done, all traffic to and from that device is ordered as a single stream, and knowledge of the possible concurrency is lost.

4.6.1 UnitID Clumping

A single UnitID only allows 32 outstanding nonposted transactions within the chain, because there are only 5 bits of SrcTag for tracking them. If a device uses more than one UnitID to achieve greater concurrency, the transactions in different UnitIDs are not required to be ordered together. Additionally, the chain host cannot issue requests in UnitIDs other than 0 or nodes on the chain do not accept them. UnitID Clumping addresses both of these shortcomings by allowing an arbitrary number of consecutive UnitIDs to be treated as one (clumped) for the purposes of ordering and routing (acceptance, forwarding, rejection). See Sections 7.5.10.6 and 7.10 for the definition of the registers that control Clumping. HyperTransport 1.05 and later devices must support clumping in one of two ways: Passive only or Full support. Passive support is when a device keeps packets with different UnitIDs ordered together, simply ignoring UnitID for upstream cycles. This allows non-host devices to achieve greater concurrency without losing ordering when passing through a Passive device. Full support requires a device to implement the Clumping Capability block to control which UnitIDs are ordered and routed together. This allows hosts to achieve greater concurrency by tracking more than 32 outstanding nonposted requests. For any device to use clumping to obtain greater concurrency, it must implement full clumping support. Note that use of passive clumping reduces the ability of devices in a chain to reorder packets and could reduce system performance.

To enable clumping on a chain, after (or during) UnitID assignment, software checks each node for the presence of a Clumping capability block, indicating full clumping support. If one does not exist, software can attempt to set the node's UnitID Reorder Disable feature bit to determine if a node implements Passive support (bit is set) or no support (bit is clear). If a node implements Full support, the UnitIDs that that node wants clumped are indicated by bit 1 and above in the Clumping Support register of the Clumping capability block. Software ORs together the results of all the reads to create a combined Clumping "Mask". If all the nodes on a chain have indicated Full support, the Clumping Support register of the host can also be read and Ored into the Clumping Mask. The Mask is then written into the Clumping Enable registers of all nodes on the chain.

Hosts may only clump UnitIDs 0 through 3 because only the two least significant bits of the requestor's UnitID are preserved in responses. This allows up to 128 outstanding nonposted requests from the host.

In the example shown in Figure 7, the first node enumerated uses three clumps of UnitIDs: 2, 3 to 4, and 5 to 6. The second node uses a single clump of UnitIDs 7 to 10. The third node uses UnitIDs 11 and 12 in a single clump, and the host uses UnitIDs 0 and 1 clumped.

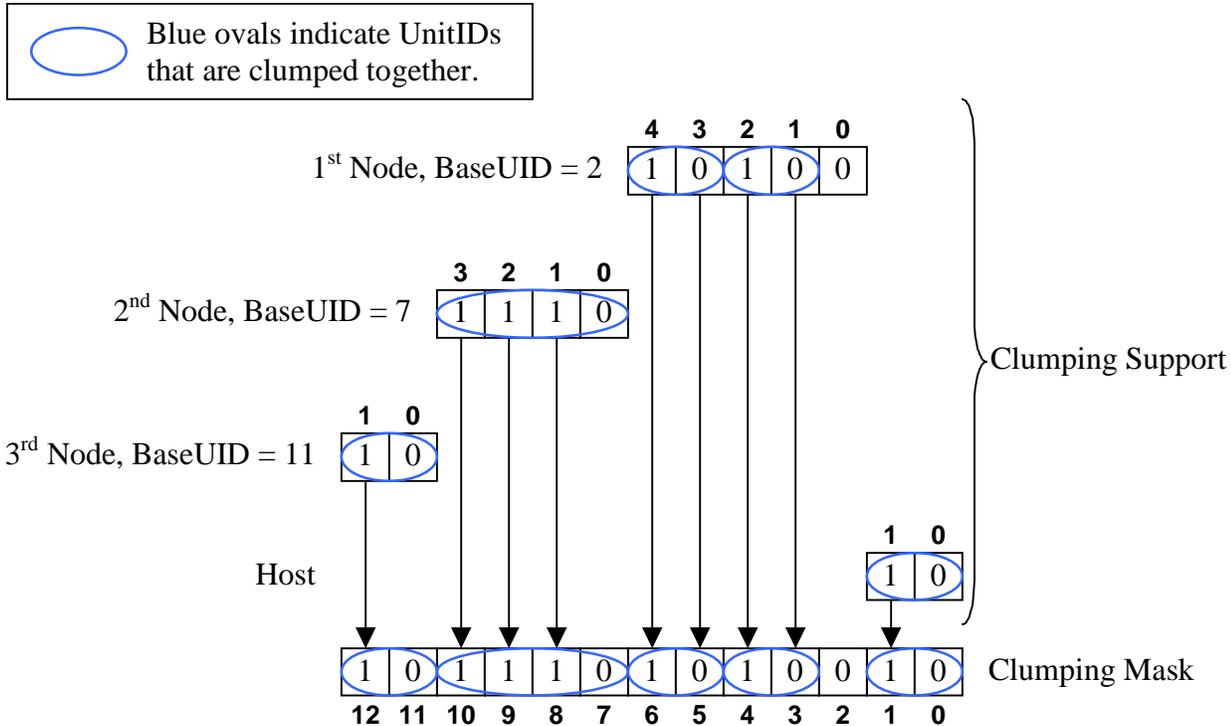


Figure 7. Clumping Configuration

4.7 Virtual Channels

4.7.1 Virtual Channel Set Definitions

HyperTransport technology divides traffic into virtual channels, in which non-info packets flow. Each virtual channel has its own dedicated packet buffer resources, so that virtual channels may not starve each other of buffers. (Virtual channels may still block each other for ordering reasons.) Flow control and buffer management is performed on a per-virtual channel basis.

Virtual channels are grouped into sets, as defined in Table 26. All HyperTransport devices are required to support the Base VC set. Support for all other VC sets is optional. Support for specific VC sets beyond the Base set and the Isoc set is indicated via the VCSet capability block (see Section 7.14.1.4).

Packets are identified as to which VCSet they belong to by the Isoc bit and the SeqID (in requests) and RspVCSet fields (in responses). The Isoc bit is present in all request and response packets. If it is clear, the packet is in the base VCSet; if it is set, the packet belongs to one of the optional VCsets.

Within the StreamVC, (VCSet = 2) the specific Request VC (ReqVC) is identified by concatenating the ReqVC[3] = SeqID[0] and ReqVC[2:0] = SrcTag[2:0] fields. The encoding was selected because of the use of SrcTag[4] for the ERROR bit and SrcTag[3] for the CHAIN bit.

Implementers must choose between enabling the optional Isoc VCs or enabling any of the other optional VCs as they reuse the same coding of SeqID. When the Isoc Flow Control Enable bit (described in

Section 7.5.4.10) is set, VCsets 0-7 are disabled. See Section 4.7.10 for a discussion of revision interworking.

Table 26. Virtual Channel Set Definitions

VCSet	Field	RspVCSet ²	Num VCs	Isoc Bit ¹	SeqID	Note
Base VCs		Rsv	3	0	X	
Isoc VCs		Rsv	3	1	X	Only when IsocFlowControlEnable is set
AltSet VCs		0	3	1	0-7	SeqID[2:0] is three bit SeqID field
NonFC VC		1	1	1	13	PostedWrite Only
Stream VCs		2	16	1	14/15	PostedWrite Only
Reserved for future standardization		3, 5 ³		1	8-9	
Implementation Specific – use for host-specific ccNUMA coherence		4 ³			12	
Implementation Specific		6-7 ³			10-11	

Notes:

1. The Isoc bit is encoded in the WrSized and RdSized Command field bit 1, in byte 2, bit 5 of Flush and Fence, and bit-time 0, bit 7 of RdResponse and TgtDone.
2. In RdResponse and TgtDone packets, the VCSet is determined by the RspVCSet field and the Isoc bit.
3. Since the definitions of VCsets 4, 6, and 7 are implementation specific, devices can only interoperate using those channels if they are designed to the same definition.

4.7.2 The Base VC Set

The base set supports three virtual channels of information:

- Posted Requests
- Nonposted Requests (reads, flushes, nonposted writes)
- Responses

Nonposted Requests may cause responses to be issued by receiving nodes. Requests received by a host bridge with the ActAsSlave bit clear may also cause downstream requests to be issued (peer-to-peer reflection). Other nodes may not make accepting a posted request dependent on the ability of that node to issue an outgoing request. Further, non-host nodes may not make acceptance of a nonposted request dependent on the ability of that node to issue an outgoing nonposted request. Additionally, these nodes may not make acceptance of any request dependent upon the receipt of a response due to a request previously issued by that node. Non-host nodes may not make acceptance of a response dependent upon the ability to issue a response or request. Finally, they may not make issuing a response dependent upon the ability to issue a request or dependent upon receipt of a response due to a previous request.

All devices must guarantee that the three virtual channels are not capable of blocking each other due to buffer management and routing issues, which is why each channel has command and data buffer space separate from the other two. However, in order to properly maintain I/O ordering, some rules are added which create dependencies between packets (in the same I/O stream) in different virtual channels. See Chapter 6.

Hosts may make acceptance of a posted request dependent on their ability to issue a posted request, but not upon the ability to issue nonposted requests or responses, and not upon receipt of a response. Hosts may make acceptance of a nonposted request dependent upon issuing a response, issuing a request, or upon receiving a response. Hosts may make acceptance of a response dependent upon the ability to issue a posted request or a response, but not upon issuing a nonposted request. Finally, hosts may make issuing a response dependent upon the ability to issue a posted request.

Note that in a shared double-hosted chain, if the chain is not partitioned between the two host bridges, there is the possibility of a deadlock. A deadlocking loop can be formed if peer-to-peer requests are issued in opposite directions by two different intermediate nodes. Each reflected peer-to-peer request coming out of a host bridge can be blocked behind a stack of requests targeting the other host bridge. The host bridge can only queue a finite number of peer-to-peer requests in from the link without issuing one. Similarly, for a host bridge connected to two chains, each of which is terminated by another host, a deadlocking loop can be formed if a device on each chain is attempting to send peer-to-peer requests to each other in the direction away from the common host bridge. See Section 4.1.1 for more information on double-hosted chains.

HyperTransport technology includes support for an optional operating mode in which the number of virtual channels is doubled to support Isochronous operation. See Appendix D for more information.

4.7.3 The Isoc VC Set

These are a set of 3 VCs described in Appendix D. This VCSet is enabled by the Isoc Flow Control Enable bit found in Section 7.5.4.10. That section also discusses the responsibilities of the system sizing software in discovering and enabling this VC Set.

4.7.4 The AltSet VCs

VCSet=0, the AltSet, is another set of 3 VCs. Similar to the Base set, the AltSet has a Posted, Nonposted, and Response VCs. These VCs follow the same ordering rules as the Base VCs.

4.7.5 The Non-FC-Isoc VC

Nodes that support VCSet=1, the Non Flow Controlled VCSet, are expected to have an unspecified number of insertion buffers and an unspecified number of thru buffers for this VC. Applications are expected to set the arbitration parameters such that this VC should experience little or no dropping.

For traffic in this class and only this class, if more insertion traffic arrives than can be inserted by a node, the traffic may be dropped. No notification is sent back to the source of the traffic. A status bit should be set locally indicating that a packet was dropped. That status bit is outside the scope of the specification.

Posted Writes is the only legal request type in this VC, no response packets are allowed. Traffic within this VC acts as if its SeqID was 0. PassPW is valid and can be used to allow reordering.

4.7.6 The StreamVC Set

VCSet=2, the StreamVC Set, has 16 possible Streaming VCs. The value of StreamSup found in Section 7.14.1.7 defines how many streaming VCs are supported. The VC number is SeqID[0] concatenated with SrcTag[2:0] (SrcTag[4:3] are used for the ERROR and CHAIN bits).

Posted Writes are the only legal request type in these VCs, no response packets are allowed. Traffic within each VC acts as if its SeqID was 0. PassPW is valid and can be used to allow reordering.

4.7.7 VCSet 3 and 5

VCSet=3 and VCSet=5 are reserved for future standardization.

4.7.8 VCSet 4

VCSet=4 is reserved for proprietary uses. A defined use for this VCSet is for ccNUMA (Cache Coherent Non-Uniform Memory Access) implementations.

4.7.9 VCSet 6-7

VCSet 6 and 7 are reserved for proprietary uses.

4.7.10 Interworking Between VCSet Implementations

This section describes how a node can interwork with nodes implementing different combinations of VCSet. Principal tools for use when interworking are the VCSetSup field as described in Section 7.14.1.4 and the L0VCSetEnb and L1VCSetEnb fields as described in Sections 7.14.1.5 and 7.14.1.6. The VCSetSup field describes which VCSet are supported by a given node. The L0VCSetEnb field enables given VCSet in the Link 0 direction. Similarly, the L1VCSetEnb field enables given VCSet in the Link 1 direction.

4.7.10.1 Emulation of 1.0x behavior

When none of the L0VCSetEnb bits are set, a node is emulating the 1.0x behavior in the Link 0 Direction. The setting of the Isoc Flow Control Enable bit for that link (Section 7.5.4.10) controls the Isoc behavior for that link. The same comment applies to L1VCSetEnb for the Link 1 direction. The L0VCSetEnb and L1VCSetEnb must boot in this mode to maximize backwards compatibility.

4.7.10.2 Passing Legacy Isoc traffic through a non-emulating node

When a node with AltSet enabled (non-emulating) is talking to a 1.0x mode node, Isoc traffic from the 1.0x mode node is put into AltSet. Note that in this mode, SeqID[3] is not useable by the 1.0x mode node. The non-emulating node should map SeqID=1000b traffic to SeqID=0001b and clear SeqID[3] of the incoming Isoc traffic in the range of SeqID=1001b to 1111b. If modifying SeqID is an issue, set both nodes in the 1.0x emulation mode as described above.

4.7.11 Added VCSet Considerations

VCSet End of Chain

If traffic appears which would be forwarded onto a VCSet for which the L0VCSetEnb or L1VCSetEnb (as appropriate) bit is cleared, it must be treated as end of chain traffic as defined in Section 10.1.6.

Requirement on the System-Sizing or Application Software

It is the job of the system-sizing or application software to determine whether both the source node and the sink node support the VCSet that is desired for that application. A given HyperTransport node is only aware of its own VCSet support and that of its immediate neighbors and has no means of determining the support offered by the destination node.

4.8 Flow Control

4.8.1 NOP Flow Control Packet

HyperTransport receivers contain the following basic types of buffers:

- Nonposted Requests
- Posted Requests
- Responses
- Nonposted Request Data
- Posted Request Data
- Response Data

Request and response buffers contain enough storage to store the largest control packet of that type, including packet extensions described in Section 3.2.1.3. All data buffers can hold 64 bytes.

Table 13 defines the virtual channels and the buffers used for each of the control packets.

These buffers are flow-controlled at the link level using a coupon-based scheme in which the transmitter contains a counter for each type of buffer at the receiver. At link reset, the transmitter clears its counters, and when reset deasserts, the receiver sends NOP packets to indicate how many buffers of each type it has available. When the transmitter sends a non-info packet, it decrements the associated counter, and when a particular counter contains a 0, the transmitter stops sending packets to the associated buffer. When the receiver frees a buffer, it sends a NOP packet to the transmitter, and the transmitter increments the associated counter.

A transmitter cannot issue a control packet that has an associated data packet unless the receiver has both the appropriate control and data buffers available. If this rule is violated, one virtual channel can block another and lead to deadlock, because commands with associated data packets cannot be interleaved on the link.

HyperTransport technology supports several optional operating modes in which the number of virtual channels and associated flow control buffer types are increased. See Section 4.7.1 and Appendix D for details.

It is the responsibility of nodes generating requests to accept the resulting responses without other dependencies. Otherwise, the response and/or response data flow control buffers may become filled with responses that are not yet ready to be accepted. This can be accomplished by preallocating enough buffer space to hold the response to a request before sending that request. In a HyperTransport bridge to a protocol that also requires requests to be accepted without dependencies, preallocation is unnecessary. Due to peer-to-peer requests, host bridges are exempt from this rule.

It is also required for deadlock avoidance that devices always accept posted requests without any other dependencies (such as issuing cycles back to the same chain or receiving responses from the chain). Due to peer-to-peer requests, host bridges are exempt from this rule.

The format of the NOP packet is shown in Table 27.

Rsv-Host is used within the NOP packet to allow link interface hardware to differentiate a HyperTransport I/O device from a host device that implements a superset of the HyperTransport I/O protocol. Such a protocol could be used for the purpose of communication between devices inside the host. The link transmitter of a HyperTransport I/O device must always place a 0 in this bit position. The link receiver of a HyperTransport I/O device must ignore the bit.

Diag is used to indicate the beginning of a CRC testing phase, as described in Appendix G. Everything following the NOP packet, until the conclusion of the current CRC test interval, is ignored. This test feature is optional—receivers are not required to implement support for this test mode. Support for this mode is indicated in bit 2 of the Feature Capability register, described in Section 7.5.10.3.

DisCon is set to indicate that the link transmitter is beginning an LDTSTOP# or error retry disconnect sequence. When this bit is set, all the buffer-release fields in the packet must be 0. See Section 8.3 for details.

Isoc is set to indicate that the flow-control information in the associated packet pertains to the Isochronous virtual channels. Isochronous flow-control information must only be sent and utilized when the link has Isochronous flow control mode enabled, as described in Section 7.5.4.10.

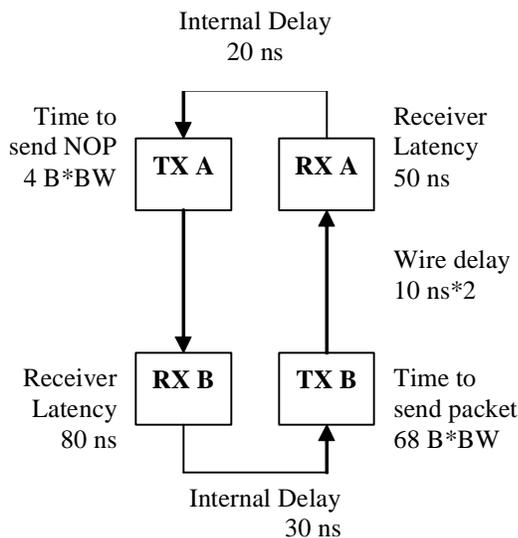
RxNextPktToAck[7:0] is required if the Error Retry Capability Block of Section 7.15 is implemented and enabled. This field is otherwise reserved. The definition and use of this field are found in Section 10.3.4.

Table 27. NOP Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	Rsv	DisCon	Cmd[5:0]: 000000					
1	ResponseData[1:0]		Response[1:0]		PostData[1:0]		PostCmd[1:0]	
2	Rsv-Host	Diag	Isoc	Rsv	NonPostData[1:0]		NonPostCmd[1:0]	
3	RxNextPktToAck [7:0]							

Each 2-bit field in the packet indicates how many buffers of each type have become available. Hence each 2-bit field can free zero, one, two, or three buffers. Receivers are not limited to having three buffers of a particular type, and they can free up additional buffers by sending additional NOP packets.

While the goal is to size each buffer at the receiver to bury the round-trip latency from the transmitted packet to the returning NOP packet, this is not strictly required by this specification. It is the responsibility of each device to guarantee that NOP packets cannot be prevented from being issued due to transmission of other traffic, to avoid starvation of the far transmitter.



Notes:

For a minimal 2-bit 400-Mbit/s link,
 Max Bandwidth: 100 Mbytes/s
 Total loop delay: 200 + 720 ns
 Data in loop = 100 Mbytes/s * 920 ns, or 92 bytes
 So, in this case, at least two buffers are needed.

For a 32-bit, 2-Gbit/s link,
 Max bandwidth: 8 Gbytes/s
 Total loop delay: 200 + 9 ns
 Data in loop = 1672 bytes
 So, at least 27 buffers would be needed to bury latency in this case.

Figure 8. Example Gen1 Data Buffer Sizing Calculation

[Figure 8](#)

Figure 8 illustrates how to calculate the number of data buffers needed to bury latency. A Gen3 device would be expected to have a higher internal clock rate and shorter latencies, allowing higher bandwidth to be handled while keeping the number of outstanding buffers reasonable, as shown in

Table 28

Table 28.

Table 28. Example Gen3 Data Buffer Sizing Calculation

Delay	Unit	Description (and assumptions)
$2 \times 180 \times 12$	ps	Wire delay (12" FR-4, each way)
2×2	UI	TX Deskew (spec max, each way)
2×1000	ps	Channel Deskew (spec max, each way)
$2 \times 4 \times 8$	UI	RX Demux, Command Decode, CRC Check, Flow Control Update (8:1 link data rate to internal clock rate, each way)
$8 + 3 \times (12 + 64)$	Bytes	NOP transmit time + 3 packet insertion delay (with CRCs)
$12 + 64$	Bytes	Packet transmit time
$6.32 \times 2.4 + 68 + 312 = 396$	UI	Total at 2.4GT/s (8-bit link)
7	Buffers	
$6.32 \times 5.2 + 68 + 312 / 2 = 256$	UI	Total at 5.2GT/s (16-bit link)
5	Buffers	

If a transmitter receives more increments than it can keep track of, it must not allow its counter to wrap, but must discard the extras (saturate). This has the effect that the link uses the maximum number of buffers that both the transmitter and receiver can support. All transmitter counters must be a minimum of four bits wide, allowing up to 15 buffers to be tracked without loss.

4.8.2 Extended Flow Control Packet

The Extended Flow Control Packet is used for managing the buffers for VCSet 0-7. Note that this packet not used for the Base and Isoc VCSet; the NOP Flow Control Packet of Section 4.8.1 is used instead. Extended flow control packets must not be sent if all extended VCSet are disabled.

Len defines the length of the Extended Flow Control Packet. If *Len*=0, the packet is one double word. If *Len*=1, the packet is two double words.

VCSet[2:0] defines which VCSet that this packet is controlling the buffers of.

VCSetRsv[3:0] is an optional, proprietary field which may be used to carry information between devices. An example use might be to adjust the ordering behavior in the next device in some proprietary way. If not used, this field must be set to 0h.

RxNextPktToAck[7:0] is used by the Retry Protocol. See Section 10.3.4 for details on this field. This field is reserved if Retry Protocol is disabled or not implemented.

Table 29. 4 Byte Extended Flow Control Packet

Bit-Time	7	6	5	4	3	2	1	0
0	Rsv	Len=0	Cmd[5:0] = 110111b					
1	VCSetRsv[3:0]			Reserved		VCSet[2:0]		
2	VCSetFree0[7:0]							
3	RxNextPktToAck[7:0]							

Table 30. 8 Byte Extended Flow Control Packet

Bit-Time	7	6	5	4	3	2	1	0
0	Rsv	Len=1	Cmd[5:0] = 110111b					
1	VCSetRsv[3:0]			Reserved		VCSet[2:0]		
2	VCSetFree0[7:0]							
3	VCSetFree1[7:0]							
4	VCSetFree2[7:0]							
5	VCSetFree3[7:0]							
6	Reserved							
7	RxNextPktToAck							

4.8.2.1 VCSetFree Definitions

The following is the definition of the VCSetFree0[7:0] field when VCSet=0, the AltSet. VCSet=0 Extended Flow Control Packets have Len=0.

Table 31. VCSetFree0 Definition for VCSet=0, the AltSet

Field	7	6	5	4	3	2	1	0
VCSetFree0	Alt0Resp[1:0]		Alt0NonPostData[1:0]		Alt0NonPostCmd[1:0]		Alt0Post[1:0]	

Note that the Posted and Response VCs in the AltSet are required to have equal numbers of command and data buffers. (Broadcast and Fence are the only posted commands without a payload, and TgtDone is rare.)

The following is the definition of the VCSetFreeX[7:0] field when VCSet=2, the StreamVCs. VCSet=2 Extended Flow Control Packets have Len=1.

Table 32. VCSetFreeX Definition for VCSet=2, the StreamVCs

Field	7	6	5	4	3	2	1	0
VCSetFree0	Stream3[1:0]		Stream2[1:0]		Stream1[1:0]		Stream0[1:0]	
VCSetFree1	Stream7[1:0]		Stream6[1:0]		Stream5[1:0]		Stream4[1:0]	
VCSetFree2	Stream11[1:0]		Stream10[1:0]		Stream9[1:0]		Stream8[1:0]	
VCSetFree3	Stream15[1:0]		Stream14[1:0]		Stream13[1:0]		Stream12[1:0]	

Each 2-bit field in VCSetFreeX indicates how many buffers of each type have become available. Hence each 2-bit field can free zero, one, two, or three buffers. Receivers are not limited to having three buffers of a particular type, and they can free up additional buffers by sending additional Extended Flow Control Packets.

4.9 Routing

HyperTransport technology has both directed and broadcast requests. Directed requests may travel in either the posted or nonposted channel; broadcast requests travel only in the posted channel. Directed packets are relayed down the chain until they reach their destination, where they are absorbed. Broadcast packets are relayed down the entire length of the chain, but they are also accepted at each node they pass through, and they are terminated by the node at the far end of the chain. Broadcast packets can only be initiated by a host bridge.

An attempt to issue or forward a new packet into the end of the chain results in one of the rejection outcomes described in Section 4.9.3.

As described in Section 4.6, clumped UnitIDs are considered to be equivalent for the purposes of routing and ordering.

4.9.1 Acceptance

A node accepts an incoming packet if any of the following are true:

- The packet is a Broadcast request.
- The packet is a directed downstream request (with a UnitID of 0 or any of the consecutive UnitIDs clumped with 0, indicating it is from a host bridge) and (for packets with a Compat bit, e.g. Section 4.4.1) the Compat bit clear, to an address owned by this node.
- The packet is a directed downstream request with a set Compat bit, and this node is either the subtractive decode device or a bridge to it.
- The packet is a directed upstream request not in the FD_0000_0000h – FF_FFFF_FFFFh range with a UnitID that the node has enabled for DirectRoute (Section 7.13.1.6) to an address owned by this node.
- The packet is a response with the Bridge bit set (indicating it is from a host bridge or a DirectRoute device) and a UnitID owned by this node.

- Tunnels must accept downstream packets from either link in a double-hosted chain.

4.9.2 Forwarding

Whenever a node forwards a packet, it always sends the packet along the direction it was previously traveling.

A node forwards an incoming packet to its outgoing link if any of the following are true:

- The packet is a Broadcast request.
- The packet is a directed downstream request with the Compat bit clear, to an address not owned by this node.
- The packet is a directed downstream request with a set Compat bit, and this node is neither the subtractive-decode device nor a bridge to it.
- The packet is a directed upstream request (with a UnitID consecutively clumped with 0, indicating that it is from an interior node) with a UnitID not enabled for DirectRoute (Section 7.13.1.6) or outside of the FD_0000_0000h – FF_FFFF_FFFFh range.
- The packet is a response with the Bridge bit set (indicating it is from a host bridge or a response from an interior upstream node to a DirectRoute request) and a UnitID that does not match this node.
- The packet is a response with the Bridge bit clear (indicating it is from an interior node).

A HyperTransport device may receive a request from one link that should be forwarded to the other link while its End of Chain and Initialization Complete Configuration Space Register (CSR) bits are still clear. In this case, the Drop on Uninitialized Link bit defined in Section 7.5.3.2.5 determines if the device 1) pends the request until the End of Chain or Initialization Complete CSR bit becomes set (indicating that the initialization attempt has completed), or 2) rejects the packet. See Section 12.3 for an example of an initialization sequence that makes use of this requirement.

A packet being forwarded to a link interface that has its End of Chain bit set is rejected. See Sections 7.5.4.6 and 7.5.4.7 for the definitions of the End of Chain and Initialization Complete CSR bits and more details on how they can affect forwarding.

4.9.3 Rejection

A device at the end of the chain is indicated by the End of Chain CSR bit (or by the Initialization Complete bit clear when the Drop on Uninitialized Link bit is set). In that case, the device is unable to forward packets or issue them in the direction of the unusable link. If a packet is rejected, one of the following actions is taken instead, depending on the type of packet:

- Broadcast requests are silently dropped—they have successfully traversed the whole chain.

- Nonposted downstream-directed requests are responded to with a TgtDone (for Writes) or Read Response (for Reads) packet with a Master Abort indicated and the Bridge bit clear. For HostReflected requests, the UnitID of the response may be either that of the requestor or that of the responding device. For DirectRouted requests, the UnitID must be that of the requester. Read responses return the requested number of doublewords with a data value of all 1 bits. See Section 10.1.6 for more details.
- Nonposted upstream-directed requests are responded to with a TgtDone (for Writes) or Read Response (for Reads) packet with a Master Abort indicated, the Bridge bit set, and a UnitID matching that of the request, even when the responder is not the host of the chain. Read responses return the requested number of doublewords with a data value of all 1 bits. See Section 10.1.6 for more details.
- Response and posted request packets are dropped. See Section 10.1.6 for more details.

4.9.4 Host Bridges

Host bridges are always at the ends of the chain, and therefore never forward packets. However, the acceptance of a packet by a host bridge usually results in action within the host.

Host bridges take the following action upon receiving a packet:

1. Downstream directed requests must be coming from another host bridge on the far end of a double-hosted chain. Type 0 configuration accesses to the device number specified in the Device Number register (see Section 7.5.3.3.3) are directed to the bridge CSRs if the host supports use in a double-hosted chain and the Host Hide bit is clear (see Section 7.5.3.3.5). Optionally, the host bridge can also implement a memory or I/O space region addressable from the far host bridge to be used for messaging in clustered systems. (A description of how this would be used and what it would look like is beyond the scope of this specification.) In that case, the bridge would respond to accesses to this area as if it were an interior node. The responses would have the Bridge bit clear and the UnitID of the requestor, unless the responding host has its Act as Slave bit set (see Section 7.5.3.3.6), in which case responses carry the value of the responding host's Device Number register, as defined in Section 7.5.3.3.3. All requests to addresses not included above are considered downstream accesses to nonexistent addresses and rejected as specified in Section 4.9.3
2. Broadcast requests must be coming from another host bridge on the far end of a double-hosted chain. They have successfully traversed the whole chain and may be silently dropped. Optionally, the host bridge could also implement a region addressable by broadcasts from the far host bridge. (A description of how this would be used and what it would look like is beyond the scope of this specification.) In that case, the bridge would handle accesses to this area as if it were an interior node, and route the broadcast to the appropriate internal target.
3. Upstream directed requests are from interior nodes, and they are accepted and handled by the node logic. Address decode within the host determines the proper destination for the request. This may be an internal destination, the same HyperTransport chain from which the request was received, or a different HyperTransport chain. When the request maps to a HyperTransport chain, it is issued on that chain with a UnitID of 0 (or a UnitID consecutively clumped with 0 if so enabled). A SrcTag (if nonposted) and SeqID are issued from the pool of tags and SeqIDs available for downstream cycles on that chain. Because the cycle is now a downstream cycle, the Compat bit may become set and the

coherence bit cleared. All other fields are passed through unchanged, except when a system host fabric implementation does not allow it.

1. A sequence of peer-to-peer requests in one I/O stream sent upstream with matching sequence IDs must be reissued downstream with matching sequence IDs.
2. Hosts may implement a compatibility chain, to which requests that map to no other target may be sent. If no compatibility chain exists and the request maps to no internal target, then the request has reached the end of chain, and is treated like a rejected cycle, as described in Section 4.9.3. Note that HyperTransport host bridges that implement bridge headers always have a target from the HyperTransport chain's point of view—the primary bus of the bridge. If no target is found on this internal bus, that error occurs internally to the bridge, not on the HyperTransport chain. In this case, an error response must be handled according to the rules of Section 10.2.1.
3. HyperTransport hosts must maintain information about nonposted peer-to-peer requests that are forwarded so that when responses are returned from the target chain, responses with the correct attributes for the original request can be issued on the source chain. (The implementation details of the structures used to maintain this information are beyond the scope of this specification.)
4. Hosts that support upstream configuration cycles must convert upstream Type 1 requests to the current bus number to downstream Type 0 requests. Hosts that do not abort the cycle. Support for upstream configuration cycles is controlled by the enable bit in Section 7.5.10.9.
4. Responses with the Bridge bit set are silently dropped. This means that a host bridge tried to respond to an interior node that did not pick up the response. The node can choose to log this error and report it as a response error, described in Section 10.1.8.
5. Response packets with the Bridge bit clear are responses to requests issued by this bridge. The host bridge matches this to one of its outstanding requests. If no match exists, the node can choose to log this error and report it as a response error, described in Section 10.1.8.

4.9.5 Fairness and Forward Progress

In order to issue packets, a node must insert them into the stream of traffic that it is forwarding. A node must guarantee that forward progress is always made by not allowing forwarded and injected traffic to starve each another. Tunnels are required to implement the method described in this section of assuring fair access to the chain for all units, approximating the round-robin behavior of a fair bus. Some HyperTransport devices may be used in applications where the fairness consideration is not relevant. One such example is a simple Southbridge that is always placed at the end of a HyperTransport chain.

4.9.5.1 Policy

Each unit is allowed to insert packets into a busy link at a rate matching that of the heaviest unit inserting traffic through it. In addition, the unit can freely use any idle time on the link. This property must be met over a window in time small enough to be responsive to the dynamic traffic patterns, yet large enough to be statistically convergent. In order for a system of units to behave consistently, each unit must implement this policy using the same algorithm as described below.

Generation of Info packets (NOP and sync) is not restricted by this algorithm, since they exist on a per-link basis and are not forwarded.

4.9.5.2 Algorithm

The algorithm consists of two parts.

- The first is the method used to calculate the insertion rate the unit can use.
- The second governs how the unit achieves that insertion rate.

This algorithm must be implemented independently for both the upstream and downstream direction to support double-hosted chain configurations. The algorithm requires no dedicated control or status registers and has no configurable parameters.

To calculate the insertion rate, the maximum packet-forwarding rate must be deduced for the heaviest downstream unit. This is done by implementing 32 3-bit counters, one for each potential downstream UnitID as well as a single 8-bit counter. Clumped UnitIDs are considered separate for the purposes of fairness. At reset, all counters are reset to 0. When a packet is forwarded the 3-bit counter corresponding to the packet's UnitID is incremented. The 8-bit counter is incremented once for every forwarded packet. When one of the 3-bit counters overflows, the value of the 8-bit counter (post increment) is captured (hereafter referred to as the denominator). All counters are then cleared. The packet rate of the worst-case downstream unit has now been calculated and is equal to 8/denominator. On average, the unit can insert eight packets for every 'denominator' packets forwarded. This insertion should be paced and not inserted as bursts. Packets can always be inserted when there are no packets waiting to be forwarded. The denominator register is set to 1 on reset.

To insert, the unit has a 6-bit counter referred to as Window, which at reset is set to 1. It also has a 1-bit register, referred to as Priority, that is cleared to 0 at reset. When a unit has packets ready to be sent on the outbound links, it decides which to send based on the following cases:

- Forward packet to send and no local packet to send—The forward packet is sent and the Window register is decremented.
- No forward packet to send and a local packet to send—The local packet is sent and the Priority register is cleared.
- Both forward packet and local packet to send—If the bit in the Priority register is set, the local packet is sent and the Priority bit is cleared. Otherwise, the forward packet is sent and the Window register is decremented.

Whenever the Window register is decremented to 0, its next value is recalculated and the Priority bit is set. In order to achieve non-integral insertion rates, the new value of the Window register must be loaded probabilistically. Each unit implements a 9-bit linear feedback shift register using the polynomial $x^9 + x^4 + 1$. It is advanced once every time the Window register value is recalculated. The Window register is loaded with $(\text{denominator} + \text{LFSR}[2:0]) \gg 3$.

Packets with the Chain bit set are ignored for counting both forwarded and inserted packets, such that each chained set of packets are counted as a single item.

4.9.5.3 Implementation Note

Care must be taken in implementing the packet insertion logic in order to avoid a potential starvation problem. The packet inserter is basically a two-input arbiter between issued packets and forwarded

packets. The packets to this arbiter are generated when there is a packet ready to go from one of these sources, and there are free buffers (as indicated by buffer release messages) at the other end of the link to receive the packet. It is possible that there is one packet to be issued and one to be forwarded, both in the same virtual channel and therefore requiring the same buffer type(s). If the forwarded packet is chosen and there is only one buffer of the needed type free, the issued packet cannot be transmitted. When the fairness logic next allows a packet to be inserted, a packet from a different virtual channel can be chosen, allowing the priority of the packet inserter to swing back to forwarding. Upon arrival of the buffer release message that would allow the blocked packet to go, the packet no longer has priority in the inserter, and therefore cannot go. If another packet in the same channel is forwarded before priority changes back to inserting, this situation can persist, starving packet insertion in a particular virtual channel.

4.9.6 DirectRoute Routing

4.9.6.1 Description of the Ordering Models

HyperTransport supports the PCI producer/consumer ordering model with no restrictions on the location of the producer, consumer, flag or data. This is done by requiring all requests to be sent to a host (secondary) interface, whereby the host interface orders all peer-to-peer requests as it reissues them downstream by renaming them with a single (clumped) UnitID. There are a number of disadvantages to this if the full generality of the producer/consumer is not required:

- Since peer-to-peer traffic must flow to the head of the chain many transactions are replicated on each link, wasting bandwidth.
- Hosts might also support only a limited number of outstanding transactions which nonposted peer-to-peer requests can consume, further reducing effective throughput.
- Extra latency is incurred for peer-to-peer traffic by requiring all requests to be routed to the head of the chain.

4.9.6.2 DirectRoute Ordering Model

The DirectRoute extension takes advantage of a weaker ordering model in which the producer/consumer model is supported, but only if the flag and data are co-located in the same device. Backward compatibility is maintained so that DirectRoute equipped devices can interoperate with non-DirectRoute equipped devices. DirectRoute traffic is only supported between a requester and a responder if both nodes support it, otherwise Host-Reflected routing must be used.

The method by which devices decide to operate using DirectRoute is outside the scope of this specification.

4.9.6.3 Configuration of DirectRoute

Refer to the DirectRoute Capability Block in Section 7.13 for information on how to configure DirectRoute.

4.9.6.4 DirectRoute Behavior Rules

Definition of NormalRequestDirection and OppositeToNormalRequestDirection

The NormalRequestDirection is the direction that the combination of MasterHost and DefaultDirection bits (Section 7.5.3) indicates for requests. The OppositeToNormalRequestDirection is the direction opposite to the NormalRequestDirection.

Definition of HostReflectedOnly

The following packets are defined as HostReflectedOnly: Fence, Flush, and Requests to the predefined address range 0xFD_0000_0000h to 0xFF_FFFF_FFFF (This address range includes the following regions: Interrupt/EOI, Legacy PIC IACK, System Management, Reserved, I/O, Configuration.)

Request Generation Rules

HostReflectedOnly requests are always sent in the NormalRequestDirection. Other requests are sent in the NormalRequestDirection unless the address within the request matches the a DirectRoute range defined by a Base and Limit register pair as described in Section 7.13.2 whose OppToNormReqDir bit is set, in which case the request is sent in the OppositeToNormalRequestDirection. See Section 4.9.6.5 below for a discussion of how to set the UnitID. For devices with only one link, requests are always sent on that link.

Response Generation Rules

Once a request is accepted, the rules for generating a response are as per Section 4.2. As with HostReflected traffic:

- Responses are issued to the link the request was received from.
- Downstream responses are issued to upstream requests.
- Upstream responses are issued to downstream requests.
- Responses to DirectRoute requests carry the UnitID of the requester, even upstream.

Application Transaction Ordering Caution

Applications that mix DirectRoute and HostReflected traffic must pay attention to the PCI producer-consumer model. Specifically, if the flag is written via a DirectRoute transaction and the data is written via a HostReflected transaction, the flag may complete before the data and violate that model.

4.9.6.5 Mixing DirectRoute and HostReflected Routing

If it is not desired to use both HostReflectedRouting and DirectRoute between two DirectRoute enabled devices, the same UnitID(s) is(are) used when sourcing both HostReflected and DirectRouted requests.

If it is desired to use both HostReflected Routing and DirectRoute between two DirectRoute enabled devices, a second UnitID or set of UnitIDs must be allocated to the requester device. The matching

DirectRouteEnable bit(s) in the responder must be cleared. These two sets of UnitIDs may not be clumped together. The assignment of a device's UnitIDs to HostReflected and DirectRoute traffic is device specific.

4.9.6.6 Disabling DirectRoute

DirectRoute is disabled by setting the DirectRoute base address to an address that is higher than the limit address. In this case, all traffic uses HostReflected Routing.

4.9.7 VCSet Arbitration

The optional VCSets 0-7 as defined in Section 7.14. There is a requirement for these VCSets to interact in defined ways with the Base VCs, the Isoc VCs, and with each other.

4.9.7.1 AltSet VCSet Arbitration

The optional AltSet VCs are at higher priority with the Base Set of VCs without allowing the Base set to be starved. The fairness algorithm as defined in Section 4.9.5 should be implemented for it.

4.9.7.2 NonFC VCSet Arbitration

The optional NonFC VC is defined to be at the highest priority, above even the Isoc VCs. The traffic for this VC is limited by the variables defined in Section 7.14.

The NonFCInterval specifies the interval between increments of the NonFCBucket leaky bucket up to the NonFCBucketDepth. Whenever a NonFC VC packet is sent, the StreamBucket is decremented by 1 to a minimum of 0. Whenever the NonFCBucket is not empty, the NonFC VCs can send a packet. When the NonFCBucket is 0, a NonFC packet may not be sent. The NonFCBucket is reset to 0.

4.9.7.3 Stream VCSet Arbitration

Streaming traffic is generally less latency dependent than load-store traffic, but often has a hard bandwidth requirement. For this reason, it can be handled with at a lower priority than the load store traffic, but with a means of guaranteeing a minimum bandwidth.

Two variables are defined in Section 7.14 to allow this interaction to be configured. The StreamInterval specifies the interval between increments of the StreamBucket or streaming leaky bucket up to the StreamBucketDepth.

Whenever a StreamVC packet is sent, the StreamBucket is decremented by 1 to a minimum of 0. Whenever the StreamBucket is not empty, the StreamVCs are at a higher priority than the BaseVCs, the Isoc VCs, and the AltSet, but lower than the Non-FC-Isoc. The StreamBucket is reset to 0.

4.9.7.4 Implementation-Specific-VC Arbitration

Since the Implementation-Specific VCs are defined to be implementation specific, their interaction with the other VCs is implementation specific. Two general rules of thumb are to not ruin the user-expected properties of the other VCs and to not cause starvation of any VC.

5 Addressing

The HyperTransport™ address map is shown in Table 33. The bulk of the address space can be used for either memory or memory-mapped I/O. The partitioning of this space into regions for each usage is implementation-specific. Unlike PCI, configuration and I/O accesses are performed with the same read and write commands used to access memory, with the upper address bits identifying the accesses instead of special command codes.

Table 33. HyperTransport Address Map

Base Address	Top Address	Size	Use
0000_0000_0000_0000h	0000_00FC_FFFF_FFFFh	1012 Gbytes	System Memory/ Memory-Mapped I/O
0000_00FD_0000_0000h	0000_00FD_F8FF_FFFFh	3984 Mbytes	Interrupt/EOI
0000_00FD_F900_0000h	0000_00FD_F90F_FFFFh	1 Mbyte	Legacy PIC IACK
0000_00FD_F910_0000h	0000_00FD_F91F_FFFFh	1 Mbyte	System Management
0000_00FD_F920_0000h	0000_00FD_F94F_FFFFh	3 Mbytes	Reserved – x86
0000_00FD_F950_0000h	0000_00FD_FAFF_FFFFh	27 Mbytes	Reserved
0000_00FD_FB00_0000h	0000_00FD_FBFf_FFFFh	16 Mbytes	Address Translation
0000_00FD_FC00_0000h	0000_00FD_FDFF_FFFFh	32 Mbytes	I/O
0000_00FD_FE00_0000h	0000_00FD_FFFF_FFFFh	32 Mbytes	Configuration
0000_00FE_0000_0000h	0000_00FE_1FFF_FFFFh	512 Mbytes	Extended Config/ Device Message
0000_00FE_2000_0000h	0000_00FF_FFFF_FFFFh	7680 Mbytes	Reserved
0000_0100_0000_0000h	FFFF_FFFF_FFFF_FFFFh	~16Exabytes	System Memory/ Memory-Mapped I/O

While the interrupt, IACK, and system management spaces may not be used by all devices, they must not be used for any other function, and all devices must forward them properly.

Some hosts only recognize interrupts with Address[31:24]=F8h.

Writes to configuration and I/O space must be nonposted and cannot cross a doubleword boundary. Posted writes or broadcasts to configuration or I/O space may result in undefined operation. Accesses of more than one doubleword to configuration or I/O space may either be handled correctly by a target or target aborted.

Similarly, writes to interrupt and system management spaces must be posted. Nonposted writes to interrupt or system management space may result in undefined operation.

Writes or broadcasts to IACK space may result in undefined operation. Upstream accesses to IACK space may result in undefined operation.

Nonposted requests to the extended configuration space access configuration registers. Posted writes to the extended configuration space are device messages. Device messages are routed by bus and device number just like configuration accesses, and also have type 0 and 1 cycles. The device and function number determine their final destination within the targeted node.

HyperTransport 1.05 and later devices must allow access to the bottom 256 bytes of register space per function through both the standard configuration space and the extended configuration space.

HyperTransport devices must have address windows aligned on 64-byte boundaries to ensure that a maximum-size request cannot cross a device boundary.

Accesses to reserved spaces are not accepted by address targets. Tunnels forward them if possible; otherwise, they are treated as normal end of chain packets.

Upstream accesses to reserved spaces are illegal and may result in undefined operation.

Upstream accesses to configuration space in some systems are illegal and may result in undefined operation.

Interrupt messages in a format not defined for the system in use are illegal and may result in undefined operation.

System Management messages in a format not defined for the system in use are illegal and may result in undefined operation.

Software is responsible for ensuring that all devices are properly configured to not send illegal upstream requests that result in undefined operation.

6 I/O Ordering

This chapter explains the ordering rules for upstream and downstream I/O traffic. *Peer-to-peer traffic* is traffic that has both its requester and target on the HyperTransport™ I/O link. Host reflected (non-DirectRoute) peer-to-peer traffic goes upstream into the host and then back downstream. For purposes of ordering, the upstream and downstream legs are considered independently. DirectRoute peer-to-peer traffic travels in only one direction on the link, and is indistinguishable from non peer-to-peer traffic.

These ordering rules only apply to the order in which operations are seen by targets at the same level of the fabric hierarchy. Consider two ordered peer-to-peer Write requests issued by a HyperTransport I/O device to two different targets on different HyperTransport I/O chains. The ordering rules on the originating HyperTransport chain ensure that the two Writes reach the host bridge in the appropriate order. The host is responsible for ensuring that the two Writes reach their target host bridges in the correct order. However, beyond that point, the Writes are in independent chains, and there is no assurance about the order in which they reach their final target. If an I/O device requires assurance of final completion, it must have a way of polling the target device to determine that the first Write has been observed before issuing the second Write, or it must use nonposted Writes.

Ordered operations that return responses (Reads or nonposted Writes) are required to complete at the target in the correct order, but no assurance is made about the order in which the returning responses are received. All HyperTransport I/O devices must accept responses out of order or restrict themselves to one outstanding nonposted request. A bridge that is between a HyperTransport device and an I/O protocol that requires responses to be returned in order must provide sufficient buffering to reorder as many responses as it may have outstanding requests. Devices must issue responses to nonposted requests only after the results of those requests are globally visible.

HyperTransport supports the same producer-consumer ordering model as PCI when the PassPW bit for requests and responses is clear and DirectRoute is disabled. In this model, a producer device anywhere in the system can generate data and modify a flag to indicate data availability to a consumer of the data anywhere in the system. The flag and data may each be located at the producer device, consumer device, or host memory. They are not required to be located in the same device as long as the consumer waits for the flag read response before issuing the data read. In the case where the consumer issues two ordered reads with non-zero sequence Ids (not waiting for the flag read response before sending the data read) producer-consumer ordering is only supported when the flag and data are co-located in the same device. The ordering rules described in this section ensure that, if the flag is modified after the data has been made available, a read of the flag by the consumer ensures that all data can be read.

When the PassPW bit is 1, these ordering rules can be relaxed for applications where the flag and data are restricted in their locations. With the use of nonzero sequence IDs, HyperTransport links can maintain ordered sequences within otherwise unordered virtual channels.

To maintain compatibility with protocols that allow write combining, the individual data beats of a posted request must be executed in the transmitted order if other accesses to the destination addresses spanned by the request can occur between the individual beats of an access. Similarly, if SeqID is

nonzero for a nonposted request, and other accesses to the destination addresses spanned by the request can occur between its individual beats, the beats of the request must be executed in order.

HyperTransport ordering semantics ensure that a configuration access followed by a second ordered transaction are delivered to a device in order. HyperTransport devices should ensure that a subsequent ordered read to the same configuration location as a previous configuration access results in the latest written data. However, devices are not required to ensure that all side effects of the first configuration access are visible before receiving the second. Software can ensure the side effects of the first configuration access have become visible by waiting for the response to the first nonposted configuration access before issuing the second transaction.

6.1 Upstream I/O Ordering

HyperTransport technology recognizes three base types of traffic—posted requests, nonposted requests, and responses—each in a separate virtual channel. These three types of traffic can be distinguished by their command encoding. Requests have a sequence ID (SeqID) tag. Requests in the same I/O stream and virtual channel with matching non-zero SeqIDs are considered part of a strongly ordered sequence.

Sequences are designed to support groups of HyperTransport transactions generated by a single request on the source I/O bus. Requests and responses both have a May Pass Posted Writes (PassPW) bit.

For definitions of I/O streams and virtual channels, see Sections 4.6 and 4.7, respectively.

The SeqIDZeroOrder is the ordering function in the Base and Isoc VCsets when SeqID=0 as per Section 3.2.1. VCSet=0 uses SeqID[2:0] field to distinguish between 7 ordered sequences. For VCSet=0, SeqIDZeroOrder is coded as SeqID[2:0] = 000b. Traffic in VCSet=1 must stay in SeqIDZeroOrder. In VCSet=2, separately within each of its 16 VCs, traffic must stay in SeqIDZeroOrder. PassPW is valid for each of VCsets 0, 1 and 2.

HyperTransport technology has the following upstream ordering rules:

1. Packets from different sources are in independent I/O streams and with the exception of the Fence requests, have no ordering guarantees. Devices receiving packets in different I/O streams may reorder them freely. If the UnitID Reorder Disable bit in the Feature register is set, then all I/O streams must be ordered together.
2. Packets in the same I/O stream and virtual channel that are part of a sequence (having matching nonzero SeqIDs) are strongly ordered (regardless of PassPW) and may not pass each other. Devices receiving them must keep them strongly ordered.
3. Packets in the same I/O stream, but not part of the same ordered sequence, use the passing rules listed in Table 34.

Table 34. Packet Ordering Rules

Row Pass Column?	Posted Request		Nonposted Request	Response	
	PassPW=0	PassPW=1		PassPW=0	PassPW=1
Posted Request, PPW=0	No ²	No ²	Yes	Yes ³	Yes ³
Posted Request, PPW=1	Yes/No ²	No ²	Yes	Yes ³	Yes ³
Nonposted Request, PPW=0	No	No	Yes/No	Yes/No	Yes/No
Nonposted Request, PPW=1	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Response, PPW=0	No	No	Yes	No	No
Response, PPW=1	Yes/No ¹	Yes/No ¹	Yes	Yes/No	No

Notes:

1. *HyperTransport implementations are strongly encouraged to allow responses with PassPW set to pass posted requests. However, they cannot rely upon this behavior system-wide to ensure deadlock-free operation. Allowing responses with PassPW set to pass posted writes creates more deterministic latency on behalf of Isochronous read traffic. See Appendix D for more details.*
2. *Ordering is not affected by the setting of the Chain bit in posted requests. The Chain bit only affects the insertion of posted requests when other posted requests are being forwarded.*
3. *Bridges may take advantage of the fact that end devices may not block either the posted request or response channels to relax the ordering of posted requests with responses to a “Yes/No”. Note that when PassPW is 0, responses must still push posted writes to maintain producer-consumer ordering.*

No—Indicates the subsequently issued transaction is not allowed to complete before the previous transaction to preserve ordering in the system. This implies an interaction between the otherwise independent virtual channels within HyperTransport technology.

Yes—Indicates the subsequently issued transaction must be able to pass the previous transaction, or deadlock may occur. This means that the packet type given in the column cannot be permitted to block the packet type given in the row at any point in the HyperTransport fabric or host.

Yes/No—Indicates the subsequently issued transaction may optionally be allowed to complete before the previous transaction if there is any advantage to doing so. There are no ordering requirements between the two transactions. However, support for reordering is not required—failure to reorder the packets does not lead to a deadlock.

6.2 Host Ordering Requirements

The host bridge and host system are required to preserve the ordering of transactions in the virtual channels provided in the HyperTransport I/O fabric as defined in Section 6.1, and to guarantee that transactions that are ordered within the HyperTransport fabric are ordered within the host. This means that, for an ordered pair of transactions, the second transaction cannot take effect in the host fabric (capturing data for a read to an internal target, exposing new data for writes and reads with side effects

to internal targets, or queuing peer-to-peer I/O for transmission to an external target) until the first transaction has reached its ordering point. The definition of this ordering point depends on the type of transactions in the ordered pair and the relationship of their targets. In the case of peer-to-peer I/O operations, the host only guarantees that the first operation has been queued for issue on its target link, and ordered with respect to requests from all other sources (Globally Ordered); it does not indicate whether the operation has reached its final target device.

Read or Write accesses from HyperTransport devices are treated differently depending on the target space within the host to which they are aimed. Accesses to cacheable system memory within the host have the strongest set of ordering requirements. Accesses to noncacheable regions (uncacheable system memory, I/O space, or memory-mapped space on an I/O device) have weaker requirements. Accesses to the reserved interrupt or system management ranges have their own special ordering requirements. The rules governing the host's processing of ordered HyperTransport I/O transactions are expressed in Table 35.

There are two defined ordering points, Globally Ordered (GO), and Globally Visible (GV). Table 35 defines what ordering point the first request in an ordered pair must reach before the second request can take effect.

Table 35. Host Ordering Rules

First Command	Second Command	Second Command Waits for the First Command to Be:
Cacheable Write	Cacheable Write w/ PassPW=0	GV
Cacheable Write	Cacheable Rd	GO
Cacheable Read	Cacheable Read or Write	GO
Non-Cacheable	Non-Cacheable w/ PassPW=0 or Non-Cacheable to same target	GO
Cacheable Write	Non-Cacheable w/ PassPW=0	GV
Cacheable Read	Non-Cacheable	GO
Non-Cacheable	Cacheable w/ PassPW=0	GO
Cacheable Write	Flush/Interrupt/ System Management/Response	GV
Cacheable Read	Flush/Interrupt/ System Management/Response	No wait requirements
Non-Cacheable	Flush/Interrupt/ System Management/Response	GO
Flush	Any	No wait requirements
Response	Response to same target	GO

First Command	Second Command	Second Command Waits for the First Command to Be:
Response	Response to different target	No wait requirements
Interrupt/System Management	Fence or Response	GV
Interrupt/System Management	Any but Fence or Response	No wait requirements
Posted Cacheable	Fence	GV
Posted Non-Cacheable	Fence	GO
Any Nonposted	Fence	No wait requirements
Fence	Any	GV

Notes:

Globally Ordered (GO)—The first transaction has reached a point where it is assured to be observed in the correct order (relative to the second transaction) from any observer in the HyperTransport fabric. The two transactions are assured to complete in order, but have not necessarily completed yet, so sideband access mechanisms such as cache agents do not necessarily receive the correct results.

Globally Visible (GV)—The first transaction is visible to all observers. That is, any access mechanism returns the new data. This means that in addition to being globally ordered, all side effects (such as cache state transitions) initiated by the first transaction have completed.

Globally Visible implies Globally Ordered, so a host may use a more restrictive rule in some cases to simplify the implementation. In the absence of sideband access mechanisms such as caching agents in the host, they are equivalent. Both ordering points apply only to targets in the chain host. They do not include effects caused by the transactions outside the host fabric.

These ordering rules apply only to the distribution of Interrupt and System Management messages to all applicable devices in the system, not necessarily to completion of all actions implied by them, such as service of an interrupt or a power-state change.

6.2.1 Host Responses to Nonposted Requests

The host cannot generate a response to a nonposted request until all side effects of the request are globally visible. For a memory request this means that all cache state transitions initiated by the request have been completed. For I/O requests, this means that data writes or read side effects have occurred. A response to a nonposted request implies that all previous ordered requests to memory are globally visible. It also implies that all previous ordered requests to I/O have been globally ordered, but it cannot be assumed that they are globally visible.

6.3 Downstream I/O Ordering

The rules for downstream ordering are the same as those for upstream ordering, with the exception that I/O streams are identified by the target of the transaction, rather than the source. The same virtual channels exist. However, UnitID may not be used to identify unique I/O request streams in the downstream direction, so it must be assumed that all downstream traffic is in the same stream. This

asymmetry in the definition of I/O streams for upstream and downstream traffic is why it is important for a node to differentiate upstream responses from downstream responses. The Bridge bit is used in the response packet for this purpose.

Once a node has accepted a packet, it has been separated from forwarded traffic and no longer must be ordered with forwarded traffic.

The host must also guarantee that peer-to-peer traffic that was part of an ordered sequence when received is also emitted downstream as an ordered sequence.

6.4 Ordering in Sharing Double-Hosted Chains

In general, upstream traffic and downstream traffic moving in the same direction along a HyperTransport chain have no ordering dependencies with respect to each other, as they are in different I/O streams. The exception is the case of communication directly between host bridges at opposite ends of a double-hosted chain, as defined in Section 4.1.1. In this case, requests from one host bridge to the other are always traveling downstream, and responses from that host bridge are traveling upstream.

In the event that one host bridge (bridge A) issues a posted write to the other (bridge B), and bridge B issues a read request to A, the read response is traveling in the same direction as the posted write. Despite the fact that the request is moving downstream and the response is moving upstream, both must be treated as being in the same I/O stream (the response must push the request if PassPW is clear) in order to support producer/consumer communication between the hosts.

In this case, both the request and response contain a Clumped UnitID of 0. Therefore, this requirement can be supported simply by doing ordering checks based solely on Clumped UnitID for upstream responses, and excluding information about whether the request they are checking against is moving upstream or downstream. If a host has its Act as Slave bit set (defined in Section 7.5.3.3.6), the Clumped UnitID of requests and responses from it must not be 0. However, the requirement to maintain ordering still exists, and the use of Clumped UnitID to achieve this can be maintained.

7 Configuration Accesses

HyperTransport™ technology implements configuration space similarly to PCI, as defined in the *PCI Local Bus Specification, Revision 2.3*. HyperTransport devices and bridges (including host bridges) must implement appropriate PCI configuration headers. Buses and devices are numbered in a fashion that maps into PCI bus and device numbers. Configuration software should be able to accomplish configuration of HyperTransport chains in a way that is indistinguishable from an equivalent PCI bus hierarchy. Configuration space is mapped to a predefined region of the HyperTransport system address space. See Chapter 5 for details.

Fields marked reserved must be ignored by reads and preserved by writes.

7.1 Configuration Cycle Types

PCI uses two types of configuration cycles, type 0 and type 1. The two types are needed because it must be possible to access the configuration space of devices on a bus without the devices knowing on which bus they are located.

Type 0 cycles are used to access devices on the current bus. They contain a function number and register number. The bus number is implicitly the current bus, although it is transmitted so that devices can be aware of their location within the system (such as for sending device messages). The device number is indicated by the IDSEL# pins, which are asserted as appropriate by the bridge. Therefore, PCI devices do not need to know their bus number or device number in order to respond to configuration accesses.

Type 1 cycles are used to transmit configuration cycles over intermediate buses. They contain bus number, device number, function number, and register number fields. Bridges forward type 1 cycles through the bus hierarchy and translate them to type 0 cycles when driving them onto their final destination bus. Host bridges can optionally implement the capability to transmit PCI special cycles to remote buses using Device 31, Function 7, Register 0, Type 1 configuration cycles.

HyperTransport technology also requires two types of configuration cycles, for the same reasons as PCI.

A HyperTransport Type 0 access is performed by issuing a RdSized or nonposted WrSized request with an address of the form shown in Table 36. They are only issued by host bridges and therefore always travel downstream. Unlike PCI, HyperTransport Type 0 accesses contain the device number, because all HyperTransport devices know what their device numbers are. HyperTransport platforms have no analog of the IDSEL# signals. Host bridges that support double-ended links respond to Type 0 accesses on their secondary interfaces at the Device Number specified in Host Interface Command register. See Section 7.5.3.3.3. Note that, in a double-hosted link, this implies that both bridges could be responding to the same address—which one you are talking to is determined by which direction the packets are traveling. This function is only intended to be used by system-sizing firmware.

Table 36. HyperTransport Type 0 Address Format

63	24	23	16	15	11	10	8	7	2
0000_00FD_FEh	Bus Number		Device Number		Function Number		Register Number		

A HyperTransport Type 1 access is performed by issuing a RdSized or nonposted WrSized request with an address of the form shown in Table 37. In general, Type 1 accesses are issued by host bridges. However, Type 1 accesses can also be issued by HyperTransport slave devices, to do peer-to-peer configuration. Support for peer-to-peer configuration is optional in hosts. If supported, the host accepts the configuration cycle, or reflects it, depending on the bus number. If the cycle targets the local chain, the host translates it from a Type 1 to a Type 0 cycle. If the cycle targets the host itself, the host accepts it. If the host does not support upstream configuration accesses, it responds to the cycle with an abort. Support for upstream configuration access is controlled by the configuration bit in Section 7.5.10.9.

Table 37. HyperTransport Type 1 Address Format

63	24	23	16	15	11	10	8	7	2
0000_00FD_FFh	Bus Number		Device Number		Function Number		Register Number		

RdSized and WrSized configuration accesses of greater than one doubleword are not supported.

Posted configuration writes are not allowed and their effect is undefined.

Extended Type 0 and 1 accesses can address both regular and extended configuration registers with nonposted requests and carry device messages with posted requests. See Chapter 13 for more on Device Messaging. Note that older host hardware and software are unable to generate extended configuration accesses so a device should not depend on them for basic functions, such as the interface capability blocks. A device may provide an access mechanism for older hosts with the extended configuration space capability block, specified in Section 7.11.

Table 38. Extended HyperTransport Type 0 Address Format

63	28	27	24	23	16	15	11	10	8	7	2
0000_00FE_0h	Upper Register Number		Bus Number		Device Number		Function Number		Lower Register Number		

Table 39. Extended HyperTransport Type 1 Address Format

63	28	27	24	23	16	15	11	10	8	7	2
0000_00FE_1h	Upper Register Number		Bus Number		Device Number		Function Number		Lower Register Number		

7.2 Configuration Space Mapping

7.2.1 Function and Register Numbering

The numbering of functions and registers within a device is device-specific, except that every implemented device number must have a function 0 containing a standard configuration header that identifies the device. Certain other standard Configuration Space Registers (CSRs) are required by the HyperTransport link specification.

7.2.2 Device Numbering

HyperTransport devices are identified by UnitIDs, which range from 00h to 1Fh. A single physical device can own multiple UnitID values. Every HyperTransport device owns the device numbers that correspond to its UnitIDs, and it must implement a configuration space (with configuration header) at the Device Number equal to its Base UnitID value. It may choose to implement configuration spaces corresponding to any number of its remaining UnitIDs, including none. Each implemented space must contain an appropriate configuration header. Unimplemented spaces must not be responded to by the device. Accesses to these device numbers are not accepted by any device on the HyperTransport chain and therefore result in a response with a Master Abort indicated.

As described in Appendix E.3, some systems require a compatibility chain that is enumerated as Bus 0. In such a system, any configuration space registers implemented in the Bus 0 space by the host must appear in the uppermost device numbers on that bus. In such a case, the number of devices (and therefore UnitIDs) available to the HyperTransport chain implementing Bus 0 is reduced accordingly. If the host were to occupy Device 0, then the HyperTransport chain could not be enumerated.

As described in Appendix F.4, some legacy operating systems may require AGP configuration registers to be implemented in the Bus 0, Device 0 range, in which case the host's configuration space registers must appear somewhere other than that range. Even though the AGP CSRs appear in Device 0, UnitID 0 is still reserved for host use so that devices can distinguish upstream cycles from downstream cycles, as described in Section 4.9. This requires the AGP bridge to consume at least one extra UnitID, as it cannot use UnitID 0.

For HyperTransport hosts that also implement AGP configuration space and require legacy operating system compatibility, the host may either:

- Make configuration space relocatable so that HyperTransport bus enumeration may occur.
- Place configuration space in the uppermost device numbers and provide a mechanism for hiding Device 0 registers to allow HyperTransport bus enumeration.

The means to accomplish either of these two actions, or perhaps other solutions to this problem, are implementation-specific and beyond the scope of this specification.

7.2.3 Bus Numbering

Each HyperTransport chain in the system is assigned a single bus number. For double-hosted physical chains, which are logically partitioned between two host bridges, each logical chain has a separate bus number.

Bus numbers are assigned by system initialization software at reset and follow the conventions used for PCI bus numbering, which require that the bus tree be numbered in a depth-first fashion. No distinction is made between PCI buses and HyperTransport chains in the numbering.

7.2.4 Software View of Extended Configuration Space

The format of the extended configuration space request packet addresses in Table 38 and Table 39 was chosen to make extension of existing hardware easy. In order to make efficient use of the new configuration space, the software view of it should be a flat, contiguous mapping of devices into the memory map, with the format shown in Table 40. The host bridge is responsible for mapping software accesses into the correct packet format.

Table 40. Extended HyperTransport Software Address Format

27	20	19	15	14	12	11	2
Bus Number		Device Number		Function Number		Register Number	

7.3 HyperTransport Device Header

Devices that sit on a HyperTransport chain and perform non-bridging functions implement device headers, as shown in Table 41. The fact that this is a device header is contained in the header type register. Connecting to two links within a HyperTransport chain does not constitute a bridging function. Fields in a HyperTransport device header are the same as defined in the *PCI Local Bus Specification, Revision 2.3*, with the exceptions listed in the following sections.

Table 41. HyperTransport Device Header Format

31	24	23	16	15	8	7	0	
Device ID				Vendor ID				00h
Status				Command				04h
Class Code						Revision ID		08h
BIST		Header Type		Latency Timer		Cache Line Size		0Ch
Base Address Registers								10h
Base Address Registers								14h
Base Address Registers								18h
Base Address Registers								1Ch
Base Address Registers								20h
Base Address Registers								24h
Cardbus CIS Pointer								28h
Subsystem ID				Subsystem Vendor ID				2Ch
Expansion ROM Base Address								30h
Reserved						Capabilities Pointer		34h
Reserved								38h
Max_Lat		Min_Gnt		Interrupt Pin		Interrupt Line		3Ch
<i>Note: Shaded registers contain minimum-required read-write bits. Other registers are read-only or contain only device-dependent bits.</i>								

Each field is defined as readable and writable by software (R/W), readable only (R/O), or readable and cleared by writing a 1 (R/C). Additionally, each field is affected by cold reset only or by both cold and warm reset.

7.3.1 Command Register: Offset 04h

The following bits are implemented in the Command register of a HyperTransport device. All other bits are not applicable and must be hardwired to 0.

7.3.1.1 I/O Space Enable (Bit 0): R/W: Warm Reset to 0

This bit must be set for the device to accept any non-compatibility accesses (requests with the Compat bit clear) to the I/O address space, as given in Chapter 5. If this device is a subtractive-decode device, requests with the Compat bit set are still accepted, regardless of the state of this bit.

7.3.1.2 Memory Space Enable (Bit 1): R/W: Warm Reset to 0

This bit must be set for the device to accept any non-compatibility accesses to the memory address space, as given in Chapter 5. If this device is a subtractive-decode device, requests with the Compat bit set are still accepted, regardless of the state of this bit.

7.3.1.3 Bus Master Enable (Bit 2): R/W: Warm Reset to 0

This bit must be set to allow the device to issue memory or I/O requests onto the HyperTransport chain. Requests from other devices on the chain may still be forwarded, independent of the state of this bit.

7.3.1.4 Data Error Response (Bit 6): R/W: Warm Reset to 0

This bit must be set to allow the device to set the Master Data Error bit of the status register. In bridges, this bit allows Data Error to be set on TgtDone responses that are being forwarded from the secondary bus to the primary bus. It has no effect on forwarding posted requests or RdResponses. Data Error indications from other devices within a chain may always be forwarded, independent of the state of this bit. Note that bridges accept a cycle on one bus and issue the cycle on another bus; unlike a tunnel, which simply forwards cycles it does not accept.

7.3.1.5 SERR# Enable (Bit 8): R/W: Warm Reset to 0

If this bit is set, the device floods all its outgoing links with sync packets when it detects an error that causes a sync flood (see Section 10.2.4). If this bit is clear, the device may not generate sync packets except as part of link initialization, although it can still propagate them from one link to the other within a chain.

7.3.1.6 Interrupt Disable (Bit 10): R/W: Warm Reset to 0

If this bit is clear, the device is allowed to assert a legacy INTx pin (if present) or send an INTx assertion message. If this bit is set, a device is not allowed to assert INTx. If a device has already sent an INTx assertion message and this bit is set, the device must send an INTx deassertion message. This bit does not affect INTx message forwarding by a bridge or host, only generation of INTx messages by an interrupt source. See Section 8.4 for more on INTx messages. This bit has no effect on MSI interrupts or HyperTransport interrupt requests.

7.3.2 Status Register: Offset 06h

The following bits are implemented in a HyperTransport device's Status register. All other bits are not applicable to HyperTransport devices and must be hardwired to 0.

7.3.2.1 Interrupt Status (Bit 3): R/O

This bit reflects the state of legacy INTx logic in the device, regardless of the state of the Interrupt Disable bit in the Command register. A 1 indicates that the interrupt source is active. A 0 indicates that the interrupt is inactive.

7.3.2.2 Capabilities List (Bit 4): R/O

This read-only bit is always set to 1, to indicate that the device has a capabilities list containing (at least) configuration information specific to HyperTransport technology.

7.3.2.3 Master Data Error (Bit 8): R/C: Cold Reset to 0

This bit is set by a device that has the Data Error Response bit set in the Command register and issues a posted request with the Data Error bit set or accepts a response with a Data Error indicated. This bit is not set if only forwarding packets with the Data Error bit set. Note that bridges accept a cycle on one bus and issue the cycle on another bus; unlike a tunnel, which simply forwards cycles it does not accept.

7.3.2.4 Signaled Target Abort (Bit 11): R/C: Cold Reset to 0

This bit is set by a HyperTransport device that returns a Target Abort for a transaction addressed to it. (As described in Section 10.2.1.)

7.3.2.5 Received Target Abort (Bit 12): R/C: Cold Reset to 0

This bit is set by a HyperTransport device that receives a Target Abort for a request it issued. (As described in Section 10.2.1.)

7.3.2.6 Received Master Abort (Bit 13): R/C: Cold Reset to 0

This bit is set by a HyperTransport device that receives a Master Abort for a request it issued. (As described in Section 10.2.1.)

7.3.2.7 Signaled System Error (Bit 14): R/C: Cold Reset to 0

This bit is set by a HyperTransport device that has flooded the link with sync packets to signal a system error. See Section 10.2.4. A device that is only forwarding sync packets from another device on the same chain should not set this bit, so that the device initiating the sync flood can be localized. Software cannot access the device (including this bit) via the flooded link until a reset has occurred.

7.3.2.8 Data Error Detected (Bit 15): R/C: Cold Reset to 0

This bit is set by a device that accepts a read response or posted request with a Data Error indicated. This bit is not set by TgtDone responses or if only forwarding packets with a Data Error indicated. Note that bridges accept a cycle on one bus and issue the cycle on another bus; unlike a tunnel, which simply forwards cycles it does not accept.

7.3.3 Cache Line Size Register: Offset 0Ch: R/O

This register is not implemented by HyperTransport devices, and returns 0s if read.

7.3.4 Latency Timer Register: Offset 0Dh: R/O

This register is not implemented by HyperTransport devices, and returns 0s if read.

7.3.5 Base Address Registers (BARs): Offsets 10-24h: R/W: Warm Reset

Base Address registers (BARs) for HyperTransport devices are implemented as described in the PCI specification. Bit 0 is read-only and indicates if a BAR is for memory or I/O space.

Table 42. Memory Space BAR Format

	N+1	N	4	3	2	1	0
Base Address			Size Bits	Prefetchable	64b	Rsv	0

Devices hardwire bits 4 through N of a memory BAR to 0 to indicate how much address space they require. For example, to allocate 4Kbytes of memory space, bits 4 through 11 would be read-only 0. Enumeration software writes 1's into the register and reads it back to determine how much space to allocate. Bit 3 indicates if the memory space allocated to the BAR is prefetchable (can be read without side effects). Bit 2 indicates if a BAR is 32 or 64 bits wide. Incoming addresses in the memory-mapped I/O space address range (as described in Chapter 5) are compared directly to the writeable bits in memory space BARs. If the memory space BARs are programmed to support 32-bit addressing, the BAR value is 0 extended to 64 bits before being compared to the address. HyperTransport devices must have memory windows aligned on 64-byte boundaries to guarantee that a maximum-size request cannot cross a device boundary and should therefore always indicate a size of at least 64 bytes. The reset value of these registers is implementation-specific, so software must initialize them before setting the Memory Space Enable bit in the Command register.

Table 43. I/O Space BAR Format

	N+1	N	2	1	0
Base Address			Size Bits	Rsv	1

Like memory space BARs, I/O space BARs have bits 2 to N hardwired to 0 to indicate the amount of address space required. Incoming addresses in the I/O space address range (which is only a 25-bit space) have only their bottom 25 bits compared to the writeable bits of the I/O space BARs. Bits 31:26 of an I/O space BAR must be 0 for a match to occur. The reset value of these registers is implementation-specific, so software must initialize them before setting the I/O Space Enable bit in the Command register.

7.3.6 CardBus CIS Pointer: Offset 28h: R/O

This register is not implemented by HyperTransport devices and returns 0s if read.

7.3.7 Capabilities Pointer: Offset 34h: R/O

Every HyperTransport device has a capabilities pointer to a linked capabilities list that contains (at least) the capability registers specific to HyperTransport devices.

7.3.8 Interrupt Line Register: Offset 3Ch: R/W: Warm Reset

The Interrupt Line register should be readable and writeable and may be used by software as a scratchpad to track interrupt routing. The reset value is implementation-specific.

7.3.9 Interrupt Pin Register: Offset 3Dh: R/O

The Interrupt Pin register is reserved, since HyperTransport devices deliver interrupts via messages and do not require any interrupt pins, although devices that generate interrupts may need to provide this register for compatibility with existing software. (Some operating systems do not correctly utilize interrupts for a function without a non-zero value in its Interrupt Pin configuration space register.)

7.3.10 Min_Gnt, and Max_Lat Registers: Offsets 3E and 3Fh: R/O

These registers are not implemented by HyperTransport devices, and they return 0s if read.

7.4 HyperTransport Bridge Headers

Devices that bridge between HyperTransport chains and other bus protocols that implement configuration mechanisms and bridge headers as described in the *PCI-to-PCI Bridge Architecture Specification Revision 1.2* (including subsidiary HyperTransport chains) implement such a bridge header, with the exceptions listed below. Note that the HyperTransport link can be the primary or secondary bus of the device, or both. Some register bits have meanings specific to HyperTransport technology only when a HyperTransport chain is connected to a specific port of the bridge. If that interface is to a non-HyperTransport bus, the requirements of that bus protocol determine the meaning of the bit.

Unless otherwise noted, the registers described in this section are reset by the reset mechanism of the primary bus and not that of the secondary bus. For a HyperTransport-to-HyperTransport bridge, this is HyperTransport RESET# of the primary chain. For a Host-to-HyperTransport bridge, this is a host-specific reset signal. Implementations that do not require the ability to reset the HyperTransport chain independently of the host may choose to combine the two.

Each field is defined as readable and writeable by software (R/W), readable only (R/O), or readable and cleared by writing a 1 (R/C). Additionally, each field is affected by only cold reset or both cold and warm reset.

Table 44. HyperTransport Bridge Header Format

31	24	23	16	15	8	7	0	
Device ID				Vendor ID				00h
Status				Command				04h
Class Code						Revision ID		08h
BIST		Header Type		Primary Latency Timer		Cache Line Size		0Ch
Base Address Register 0								10h
Base Address Register 1								14h
Secondary Latency Timer		Subordinate Bus Number		Secondary Bus Number		Primary Bus Number		18h
Secondary Status				I/O Limit		I/O Base		1Ch
Memory Limit				Memory Base				20h
Prefetchable Memory Limit				Prefetchable Memory Base				24h
Prefetchable Base Upper 32 Bits								28h
Prefetchable Limit Upper 32 Bits								2Ch
I/O Limit Upper 16 Bits				I/O Base Upper 16 Bits				30h
Reserved						Capabilities Pointer		34h
Expansion ROM Base Address								38h
Bridge Control				Interrupt Pin		Interrupt Line		3Ch
<i>Note: Shaded registers contain minimum-required read-write bits. Other registers are read-only or contain only device-dependent bits.</i>								

7.4.1 Command Register: Offset 04h

All of the Command register bits implemented in the Device Header Command register (Section 7.3.1), are implemented in bridges that have a HyperTransport link on their primary bus, and they affect operation only on the primary bus. All other bits are not applicable and must be hardwired to 0. If the Bus Master Enable bit is cleared in a bridge device, preventing forwarding of transactions to the primary bus, transactions that would be forwarded must be master-aborted on the secondary bus. If the secondary bus is a HyperTransport link, this is indicated by returning a response with Master Abort indicated.

Note that if the secondary bus is PCI, the Memory Write and Invalidate Enable (bit 4) may be implemented as a read/write bit to control generation of Memory Write and Invalidate cycles as specified by the *PCI Local Bus Specification, Revision 2.3*.

7.4.2 Status, Primary Latency Timer, Base Address, Interrupt Pin, and Interrupt Line Registers

For a bridge with a HyperTransport I/O link as its primary bus, these registers are implemented the same way as the corresponding registers in a HyperTransport device header. They are not related to the secondary bus.

7.4.3 Cache Line Size: Offset 0Ch: R/O

When both the primary and secondary buses are HyperTransport links, this register is reserved.

7.4.4 Secondary Latency Timer Register: Offset 1Bh: R/O

When the secondary bus is a HyperTransport link, this register is reserved.

7.4.5 Secondary Status Register: Offset 1Eh

When the secondary bus is a HyperTransport link, most of the bits defined in the *PCI-to-PCI Bridge Architecture Specification Revision 1.2* are not relevant and are reserved, being hardwired to 0. The exceptions are listed in the following sections.

7.4.5.1 Master Data Error (Bit 8): R/C: Cold Reset to 0

When set, this bit indicates that the bridge had the Data Error Response bit (in the Bridge Control register) set and either issued a posted request with the Data Error bit set or accepted a response with a Data Error indicated on the secondary chain.

7.4.5.2 Signaled Target-Abort (Bit 11): R/C: Cold Reset to 0

When set, this bit indicates that the bridge has issued a Target Abort on the secondary bus. (As described in Section 10.2.1.)

7.4.5.3 Received Target-Abort (Bit 12): R/C: Cold Reset to 0

If set, this bit indicates that the bridge has received a Target Abort from the secondary bus. (As described in Section 10.2.1.)

7.4.5.4 Received Master-Abort (Bit 13): R/C: Cold Reset to 0

When set, this bit indicates that the bridge has received a Master Abort from the secondary bus. (As described in Section 10.2.1.)

7.4.5.5 Detected System Error (Bit 14): R/C: Cold Reset to 0

When set, this bit indicates that the bridge detected sync packet flooding on its secondary bus. See Section 10.2.4.

7.4.5.6 Data Error Detected (Bit 15): R/C: Cold Reset to 0

When set, this bit indicates that the bridge has accepted a read response or posted request with a Data Error indicated on the secondary bus. This bit is not set when accepting a TgtDone with a Data Error indicated.

7.4.6 Memory and Prefetchable Memory Base and Limit Registers: Offsets 20-2Ch: R/W: Warm Reset

Table 45. Memory and Prefetchable Memory Base and Limit Register Format

15	4 3	1 0
Address[31:20]	Reserved	Size

The Size bit exists only in the Prefetchable Memory Base and Limit registers, and is read-only. If 1, it indicates that the Prefetchable Memory Upper registers are implemented. The value of the bit in the base and limit registers must be the same.

Bits 19:0 of the Base addresses are assumed to be 0. Bits 19:0 of the Limit addresses are assumed to be all 1's. To disable decode of a memory space (when there are no devices configured in that space on the secondary bus, for example), the Base register should be programmed to a higher value than the Limit register.

Table 46. Prefetchable Memory Upper Register Format

31	0
Address[63:32]	

It is strongly recommended that these registers be implemented to allow maximum compatibility with PCI devices.

For accesses coming in on a HyperTransport link, these registers are compared to addresses in the memory-mapped I/O range only, as defined in Chapter 5. Matching addresses are forwarded from the primary to the secondary bus, and ignored on the secondary bus. Non-matching addresses are forwarded from the secondary to the primary bus, and ignored on the primary bus. Accesses outside the memory-mapped I/O space (FD_0000_0000 to FF_FFFF_FFFF) on the secondary bus are ignored. HyperTransport devices must have windows aligned on 64-byte boundaries so that a maximum-size request cannot cross a device boundary. The reset value of these registers is implementation-specific, so firmware must initialize them before setting the Memory Space or Bus Master Enable bits in the Command register.

7.4.7 I/O Base and Limit Registers: Offsets 1C, 1D, 30, and 32h: R/W: Warm Reset

Table 47. I/O Base and Limit Register Format

7	4 3	1 0
Address[15:12]	Reserved	Size

The Size bit of the I/O Base and Limit Registers are read-only and if 1, it indicates the I/O Base and Limit Upper Registers are implemented. The value of the bit in both registers must be the same.

Bits 11:0 of the Base address are assumed to be 0. Bits 11:0 of the Limit address are assumed to be all 1's. To disable decode of the I/O space (when there are no devices configured in I/O space on the secondary bus, for example), the Base register should be programmed to a higher value than the Limit register.

Table 48. I/O Base and Limit Upper Register Format

15	0
Address[31:16]	

It is strongly recommended that these registers be implemented to allow maximum compatibility with PCI devices.

For accesses coming in on the primary (HyperTransport) link, these registers are only compared to addresses in the 32-Mbyte I/O range, as defined in Chapter 5. Only the low 25 bits of the incoming byte address are used. All bits above bit 24 are forced to 0 before the comparison. Matching addresses are forwarded from the primary to the secondary bus and ignored on the secondary bus. Non-matching addresses are forwarded from the secondary to the primary bus and ignored on the primary bus. Because HyperTransport links support only 25-bit I/O space addressing, accesses outside the 25-bit space on the secondary bus are ignored. HyperTransport devices must have windows aligned on 64-byte boundaries so that a maximum-size request cannot cross a device boundary. The reset value of these registers is implementation-specific, so firmware must initialize them before setting the I/O Space or Bus Master Enable bits in the Command register.

7.4.8 Capabilities Pointer Register: Offset 34h: R/O

Every bridge with a HyperTransport link on at least one port has a capabilities pointer to a linked capabilities list that contains (at least) the capability registers specific to HyperTransport technology.

7.4.9 Bridge Control Register: Offset 3Eh

All unspecified bits are reserved and return 0 if read.

7.4.9.1 Data Error Response Enable (Bit 0)

This bit must be set to allow the bridge to set the Master Data Error bit of the Secondary Status register. It also enables Data Error to be set in TgtDone responses that are being forwarded from the primary bus to the secondary bus. It has no effect on forwarding posted requests or RdResponses.

7.4.9.2 SERR# Enable (Bit 1): R/W: Warm Reset to 0

This bit controls the mapping of system errors from the secondary to the primary bus of the bridge. If set, and the SERR# Enable in the Command register is set, system errors propagate. System errors in HyperTransport links are indicated by flooding the chain with sync packets, as described in Section 10.2.4.

7.4.9.3 ISA Enable (Bit 2): R/W: Warm Reset to 0

This bit is implemented similarly to the way it is described in the *PCI-to-PCI Bridge Architecture Specification Revision 1.2*. For HyperTransport requests in the bottom 64 Kbytes of I/O space (see Chapter 5), this modifies the response to accesses that hit in the range defined by the I/O Base and Limit registers. If this bit is set, transactions addressing bytes 256 to 1023 of each 1Kbyte block on the primary bus are not passed to the secondary bus. Conversely, transactions addressing bytes 256 to 1023 in each 1Kbyte block on the secondary bus are passed to the primary bus.

Implementation of this bit is required for PCI compatibility.

If this bit is set when the address mapping extensions described in Appendix A are in use, the address decode behavior of the device may be undefined.

7.4.9.4 VGA Enable (Bit 3): R/W: Warm Reset to 0

This bit functions similarly to the way it is described in the *PCI-to-PCI Bridge Architecture Specification Revision 1.2*. If enabled, RdSized and WrSized operations within the address range 0_000A_0000–0_000B_FFFFh (inclusive) or within the first 64 Kbytes of the I/O range (as defined in Chapter 5), with address bits 9:0 in the (inclusive) range 3B0–3BBh or 3C0–3DFh, are forwarded from the primary to the secondary interface and are ignored on the secondary interface, overriding the values in the Memory Base and Limit and I/O Base and Limit registers.

Implementation of this bit is required for PCI compatibility.

If this bit is set when the address mapping extensions described in Appendix A are in use, the address decode behavior of the device may be undefined.

7.4.9.5 VGA 16-bit Decode (Bit 4): R/W: Warm Reset to 0

This bit functions similarly to the way it is described in the *PCI-to-PCI Bridge Architecture Specification Revision 1.2*. If this bit is set, it prevents the decoding of aliased VGA I/O accesses such that only accesses to 3B0–3BBh or 3C0–3DFh are forwarded from the primary interface to the secondary interface and ignored on the secondary interface. This bit has no affect unless VGA Enable (bit 3) is set.

7.4.9.6 Master-Abort Mode (Bit 5): R/W: Warm Reset to 0

This bit controls the behavior on the source bus when a transaction forwarded through the bridge receives a Master Abort on the target bus. (See Section 10.2.1.)

When the Master-Abort Mode bit is set, and a nonposted request forwarded from a HyperTransport chain receives a Master Abort on the target bus, the source bus request receives a Target Abort. (It is signaled as an internal error on the originating chain.)

When the Master-Abort Mode bit is clear, the request appears to complete normally on the source bus. The response returns with the Error bits clear. Writes receive a TgtDone. Reads receive a RdResponse, with the appropriate amount of data, which is all 1's.

7.4.9.7 Secondary Bus Reset (Bit 6): R/W: Warm Reset to 0

This bit allows software to reset the secondary bus of the bridge. Writing a 1 to this bit causes the bridge to force the secondary bus into reset. Writing a 0 to this bit cause the bridge to stop forcing the secondary bus into reset. The remaining details are dependent on the type of secondary bus.

This bit is required for bridges that have a HyperTransport link on their primary interface. This bit is also required for host bridges in which HyperTransport RESET# is independent of host reset.

If the secondary bus of the bridge is a HyperTransport I/O chain, writing a 1 to this bit causes the RESET# signal for that chain to be asserted. If the Warm Reset bit in the Host/Secondary Interface Command register (Section 7.5.3.3.1) is clear, the PWROK signal for that chain is simultaneously deasserted. When, after being initially set, the Secondary Bus Reset bit is cleared, the chain comes out of reset. If the Warm Reset bit is set, this simply results in the deassertion of RESET#. It is the responsibility of software to delay deasserting the reset long enough to satisfy the RESET# pulse width requirement. If the Warm Reset bit is clear, clearing the Secondary Bus Reset causes PWROK to assert. Hardware then waits for the appropriate amount of time and deasserts the RESET# pin. If the programmer wants to determine that the bus has come out of reset, software can poll the Initialization Complete bit of the Link Control register (Section 7.5.4.6).

7.4.9.8 Fast Back-to-Back Enable, Primary Discard Timer, Secondary Discard Timer, Discard Timer Status, Discard Timer SERR# Enable (Bits 11:7): R/O

All of these bits are controls for the secondary interface of the bridge. If the secondary interface is a HyperTransport link, these bits are reserved and hardwired to 0.

7.5 HyperTransport Link Capability Registers

Configuration and status information specific to HyperTransport technology is mapped into configuration space using the capabilities list methodology described in the *PCI Local Bus Specification, Revision 2.3*.

- A device with multiple HyperTransport interfaces (e.g., a HyperTransport-to-HyperTransport bridge with HyperTransport links on both the primary and secondary interface) must implement one capability block for each interface. Therefore, a single-link device would have a single primary interface block containing one active Link Control register, and a tunnel device would have a single primary interface block containing two active Link Control registers.
- A bridge would have one primary interface block containing one or two active Link Control registers (depending on whether or not the device provides a tunnel to allow a chain to continue on the primary bus) in addition to one secondary interface block for each HyperTransport bridge.
- A HyperTransport bridge header and secondary interface capability block are required for each chain.
- Only one primary interface capability block is required for a device that uses a HyperTransport link as its primary interface.

- Primary interface capability blocks always have two Link Control registers. If a link is not implemented, (such as in a single-link device), the Link Control register for that link is read-only and indicates Link Failure and End Of Chain, as described below.
- If a device is a host bridge or has a different bus for its primary interface, only secondary interface block(s) are required and bridge headers are optional.
- Every function of every device implemented in a HyperTransport node must place a HyperTransport capability list item in its configuration space, indicating the version of the specification to which it is compliant. This can be the primary or secondary interface capability if already present, or the HyperTransport Revision ID capability otherwise.

The layout of the capabilities block is determined by the value in the Capability Type field in the Command register, but the Capability ID register, Capabilities Pointer register, and Capability Type field are always the same. The offset at which the block begins is implementation-specific.

The layout of a Slave/Primary Interface block is shown in Table 49.

Table 49. Slave/Primary Interface Block Format

31	24 23	16 15	8 7	0	
Command		Capabilities Pointer		Capability ID	+00h
Link Config 0		Link Control 0			+04h
Link Config 1		Link Control 1			+08h
LinkFreqCap0		Link Error 0	Link Freq 0	Revision ID	+0Ch
LinkFreqCap1		Link Error 1	Link Freq 1	Feature	+10h
Error Handling		Enumeration Scratchpad			+14h
Reserved	Bus Number	Mem Limit Upper		Mem Base Upper	+18h
<i>Note: Shaded registers contain minimum-required read-write bits. Other registers are read-only or contain only device-dependent bits.</i>					

The layout of a Host/Secondary Interface block is shown in Table 50.

Table 50. Host/Secondary Interface Block Format

31	24 23	16 15	8 7	0	
Command		Capabilities Pointer		Capability ID	+00h
Link Config		Link Control			+04h
LinkFreqCap		Link Error	Link Freq	Revision ID	+08h
Reserved		Feature			+0Ch
Error Handling		Enumeration Scratchpad			+10h
Reserved		Mem Limit Upper		Mem Base Upper	+14h
<i>Note: Shaded registers contain minimum-required read-write bits. Other registers are read-only or contain only device-dependent bits.</i>					

Unless otherwise noted, the registers described in this section are reset by the reset mechanism of the primary bus and not that of the secondary bus. For a HyperTransport-to-HyperTransport bridge, the reset mechanism is the HyperTransport RESET# signal of the primary chain. For a Host-to-HyperTransport bridge, the reset mechanism is a host-specific reset signal. Implementations that do not require the ability to reset the HyperTransport chain independently of the host may choose to combine the two.

Registers marked “Chain Reset” are reset with which the chain they are associated. For host interface blocks, this is HyperTransport RESET#, not host reset. For device primary interface blocks, this is HyperTransport RESET# on the primary chain. For device secondary interface blocks, this is HyperTransport RESET# on the bridge’s secondary chain.

Each field is defined as readable and writeable by software (R/W), readable only (R/O), readable and settable by writing a 1 (R/S), or readable and cleared by writing a 1 (R/C). Additionally each field is affected by only cold reset or by both cold and warm reset.

7.5.1 Capability ID: Offset 00h: R/O

The capability ID for HyperTransport technology is 08h.

7.5.2 Capabilities Pointer: Offset 01h: R/O

This register contains a pointer to the next capability in the list, or a value of 00h if this is the last one.

7.5.3 Command Register: Offset 02h

The Command register contains bits used to configure the HyperTransport interface, as shown in Table 51. All unspecified bits are reserved and are hardwired to 0.

Table 51. Command Register Format

Type	15	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Slave/Pri	000		Drop on Uninit	Default Direction	Master Host	Unit Count				Base UnitID					
Host/Sec	001		Drop on Uninit	Inbound EOC Err	Act as Slave	Rsv	Host Hide	Chain Side	Device Number			Double Ended	Warm Reset		

Note: Any write to the slave command register may affect the Master Host bit, as described below.

7.5.3.1 Capability Type (Bits 15:13): R/O

This field indicates the type of information present in this capability block. For the primary and secondary interface capability blocks, there are 3 bits used in the encoding. For all other HyperTransport capability blocks, 5 bits are used. Currently, these encodings are defined as shown in Table 52.

Table 52. Capability Type Encoding

Encoding	Capability Type
000xx	Slave or Primary Interface
001xx	Host or Secondary Interface
01000	Switch
01001-01111	Reserved
10000	Interrupt Discovery and Configuration
10001	Revision ID
10010	UnitID Clumping
10011	Extended Configuration Space Access
10100	Address Mapping
10101	MSI Mapping
10110	DirectRoute
10111	VCSet
11000	Retry Mode
11001	X86 Encoding (Reserved)
11010	Gen3
11011	Function-Level Extension
11100	Power Management
11101-11111	Reserved

Primary and secondary interface encodings indicate that this block is used to configure the primary (including the interface of a HyperTransport slave device) or secondary (including the interface of a host bridge) interface of a device, respectively.

The layout of the rest of the bits of the Command register depends on the Capability Type field, as described in the following sections.

7.5.3.2 Slave/Primary Interface Command Bits

7.5.3.2.1 Base UnitID (Bits 4:0): R/W: Warm Reset to 0

This field contains the lowest numbered UnitID belonging to this device. If the device owns multiple UnitIDs, the additional ones occupy the next consecutive UnitID values above the base. The contents of this field are used to generate the UnitID field in request and response packets issued by this device, to identify responses returning to this device, and to identify configuration requests directed to this device.

7.5.3.2.2 Unit Count (Bits 9:5): R/O

This field contains the number of UnitIDs that this device requires. Therefore, the highest UnitID used by this device is given by (BaseUnitID + UnitCount – 1). If the highest UnitID used exceeds 1Fh, the behavior of the device is undefined. Some devices may have the capability to modify their Unit Count through write-once or backdoor access mechanisms. The method by which enumeration software determines and sets valid Unit Count values is system and device specific and beyond the scope of this specification.

7.5.3.2.3 Master Host (Bit 10): R/W: Warm Reset to 0

This bit indicates which link is the path to the master (or only) host bridge of the HyperTransport chain. It is readable from software, but not directly writeable. Any time the Command register is written, this bit is loaded with the link number from which the write came. For a device with only one link interface, this bit may be hardwired to point to the implemented link.

7.5.3.2.4 Default Direction (Bit 11): R/W: Warm Reset to 0

This bit determines the default direction for a HyperTransport device to send requests. A 0 indicates requests should be sent toward the master host bridge, as indicated by the Master Host bit. A 1 indicates requests should be sent in the opposite direction. For a device with only one link interface, this bit has no meaning and should be hardwired to 0. This default routing can be overridden if DirectRoute is enabled, see Section 4.9.6.

7.5.3.2.5 Drop on Uninitialized Link (Bit 12): R/W: Cold Reset to 0

This bit determines what happens to packets issued by a device or forwarded from a receiving link interface to a transmitting interface whose Initialization Complete and End of Chain bits are clear. If both are deasserted for a given link, packets to be transmitted on that link are stalled until either Initialization Complete sets (in which case they will be transmitted) or End Of Chain sets (in which case they are treated as End Of Chain packets; see Section 10.1.6). In the case where hardware is broken, it is possible that neither of these events occurs, in which case the packet can hang. If Drop on Uninitialized Link is set, a transmitter with its Initialization Complete bit clear always acts as if the End of Chain bit is set. Hosts that use the initialization sequence described in Section 12.3 are encouraged to implement a timeout counter to prevent a system-wide initialization error due to link-level initialization problems on a non-default chain. Packet forwarding behavior is described in Table 53.

Table 53. Packet Forwarding Behavior

End of Chain	Initialization Complete	Drop on Uninitialized Link	Action
1	-	-	Reject
0	1	-	Forward
0	0	1	Reject
0	0	0	Stall

7.5.3.3 Host/Secondary Interface Command Bits

7.5.3.3.1 Warm Reset (Bit 0): R/W: Warm Reset to 1

This optional bit allows a reset sequence initiated by the Secondary Bus Reset bit of the Bridge Control register (see Section 7.4.9.7) to be either warm or cold. The contents of this bit have an effect only when software initiates a reset sequence. If it is 0, PWROK is driven low as part of the sequence, causing a cold reset. It is the responsibility of the hardware to sequence PWROK and RESET# correctly. If not implemented, this bit is read-only and hardwired to 1. Changing the state of the Warm Reset bit while the Secondary Bus Reset bit is asserted results in undefined behavior.

7.5.3.3.2 Double-Ended (Bit 1): R/W: Warm Reset to 0

This bit indicates that there is another bridge at the far end of the HyperTransport chain. For bridges that do not support double-ended chains, this bit must be hardwired to 0. This bit controls no hardware. It exists as a scratchpad for software during link configuration.

7.5.3.3.3 Device Number (Bits 6:2): R/W: Cold Reset to 0

This optional register contains the device number of configuration accesses that the host bridge responds to when accessed from the chain attached to the host interface. While this is typically 0, in some cases there may be legacy software (Section 7.2.2) or ordering (Section 4.1.1) considerations that require host configuration space registers to be located somewhere other than Device 0. If not implemented, this register is read-only and hardwired to 0. When accessed from the host side, the bridge may locate its configuration space registers at a different location, so that when enumerated in a double-hosted chain, one host does not relocate the register space of another. This value in this register is used as the UnitID of hosts with the Act as Slave bit set (defined in Section 7.5.3.3.6). If the Act as Slave bit is implemented, this register must be implemented.

7.5.3.3.4 Chain Side (Bit 7): R/O

This bit indicates which side of the host bridge is being accessed. A 0 indicates that the read is coming from within the host. A 1 indicates that the read is coming from the chain attached to the host interface. In a host that does not support double-hosted chains, this bit is always 0, because there cannot be an access from the chain.

7.5.3.3.5 Host Hide (Bit 8): R/W: Warm Reset to 0

This bit, when set, causes the host's configuration space to be inaccessible from the chain attached to the host interface (any accesses to configuration space are treated as if they have reached the end of chain). When clear, the host should respond to configuration cycles from the chain. The determination of the register set to be presented to the chain is implementation-specific, although a configuration header including a host capability block must be presented for chain enumeration purposes. In a host that does not support double-hosted chains, this bit is read-only 1, because the host is never accessible from the chain.

7.5.3.3.6 Act as Slave (Bit 10): R/W: Cold Reset to 0

This optional bit, when set, causes a host to act as a slave, using the device number defined in Section 7.5.3.3.3 as the base UnitID for requests and responses that it originates, it does not set the Bridge bit on responses it generates, and follows the routing rules for ordinary nodes defined in Section 4.9. When clear, a host acts normally (uses UnitID 0, sets the Bridge bit on responses, and follows the routing rules

for hosts defined in Section 4.9.4). If a host does not support sharing double-hosted chains, this bit may be read-only 0. This bit takes effect only after a warm reset.

7.5.3.3.7 Host Inbound End of Chain Error (Bit 11): R/C: Cold Reset to 0

This bit indicates that a packet received from a far host has taken an end-of-chain error. (See Section 10.1.6.) This bit is hardwired to 0 if the device does not check for this error condition.

7.5.3.3.8 Drop on Uninitialized Link (Bit 12): R/W: Cold Reset to 0

This bit is defined in the same way as bit 12 of the Slave/Primary Interface Command register.

7.5.4 Link Control Register: Offsets 04h and 08h

Host/secondary interface blocks implement one copy of the Link Control register (defined in Table 54). Slave/primary interface blocks implement two copies of this register, one for each link. For devices that implement only one link in the chain, all bits of the second control register are reserved and hardwired to 0, except for the Link Failure, End of Chain, and Transmitter Off fields, which are hardwired to 1.

Table 54. Link Control Register

15	14	13	12	11	8	7	6	5	4	3	2	1	0
64bEn	ExtCTL	LSEn	IsocEn	CRCErr	TXOff	EOC	InitCmp	LinkFail	CFEr	CST	CFIEn	SrcIdEn	

7.5.4.1 Source ID Enable (Bit 0, SrcIdEn): R/W: Warm Reset to 0

When this bit is set, the Source ID Packet Extension defined in Section 3.2.1.3 is prepended to all requests originated on this link. These requests are defined in Table 13 and include Fences and Flushes. Forwarded requests are sent unmodified. When this bit is clear, no Source ID Packet Extensions are originated or forwarded to this link.

7.5.4.2 CRC Flood Enable (Bit 1, CFIEn): R/W: Warm Reset to 0

When this bit is set and (for slave device) SERR# Enable is set, sync flooding is initiated and the LinkFail bit is set whenever any of the CRC Error bits for this link are asserted. See Section 10.2.4. CRC checking logic runs on all lanes enabled by LinkWidthIn, and detected errors still set the CRC Error bits, regardless of the state of this bit. Note that this bit is not reset by secondary chain reset, so it is not reset in a bridge when that bridge takes a sync flooded link through warm reset. Because this may cause sync flooding to be immediately restarted after the reset sequence is complete, software should clear this bit before taking the chain out of reset.

7.5.4.3 CRC Start Test (Bit 2, CST): R/W: Warm Reset to 0

When this optional bit is written to a 1 by software, the hardware initiates a CRC test sequence on the link, as described in Appendix G. When the test sequence is complete, and CRC has been checked on all CRC intervals containing test pattern data, hardware clears the bit. Software can determine that the test has completed by reading the bit and checking the status of the CRC Error bits. Implementation of CRC test pattern generation is optional. If not implemented, this bit must be hardwired to 0. Software should

not set this bit unless it has checked the CRC Test Mode Capability bit, as defined in Section 7.5.10.3, of the device on the other side of the link.

7.5.4.4 CRC Force Error (Bit 3, CFEr): R/W: Warm Reset to 0

When this bit is set, bad periodic CRC (in non-retry mode) or bad per-packet CRC (in retry mode) is generated on all sublinks, as enabled by LinkWidthOut. The covered data is not affected. Errors are generated continuously until CFEr is cleared.

7.5.4.5 Link Failure (Bit 4, LinkFail): R/C: Evaluated at Cold Reset

The LinkFail bit is set if a failure has been detected on the link. Devices with only one HyperTransport link hardware LinkFail for the nonexistent link to 1. Devices that contain an interface that is not used by the system also set LinkFail for the unused link to 1. As described in Section 12.2, devices can identify unused links because their CAD[0] input is tied to a logical 0.

The LinkFail bit is set by hardware in the event of a link error that results in a sync flood, such as a CRC, protocol, or overflow error (See Section 10.2.4). It is not set by a device that is merely forwarding sync packets, only by a device that originates them.

7.5.4.6 Initialization Complete (Bit 5, InitCmp): R/O: Warm Chain Reset to 0

This read-only bit is reset to 0 and set by hardware when the low-level link initialization sequence (see Section 12.2) is successfully complete in both the receiver and transmitter. If there is no device on the other end of the link, or if that device is unable to properly perform the low-level link initialization protocol, the bit never gets set. A device may receive a request before initialization of all the attached links is complete. If the request needs to be forwarded to an uninitialized link, the disposition of the request is determined by the Drop On Uninitialized Link bit (see Section 7.5.3.2.5). This bit is not cleared by LDTSTOP# disconnects or retries. Hardware may report 0 during BIST or ILM.

7.5.4.7 End of Chain (Bit 6, EOC): R/W: Evaluated at Cold Chain Reset

The End of Chain bit is set to indicate that the given link is not part of the logical HyperTransport chain. Packets that are issued or forwarded to this link are either dropped or result in a Master Abort response, as appropriate (see Section 4.9.2). Packets received from this link are ignored, CRC is not checked, and sync flooding from this link is ignored and not propagated. The link receiver may be disabled by hardware to prevent DC current paths as a result of the inputs that may be invalid or floating.

Slave devices with only one HyperTransport link hardware End of Chain for the nonexistent link to 1. Devices that contain an interface that is not used by the system also set End of Chain for the unused link to 1 at cold reset. (As described in Section 12.2, devices can identify unused links on a cold reset because their CAD[0] input is tied off.) If a link fails AC Detect at cold reset, hardware sets this bit. See Section 7.16 for more details about the link training configuration bits.

If GblLinkTrain[ConnDly] and LinkTrain[HotPlugEn] are clear:

- This bit cannot be cleared by software and a write of 0 to this bit position has no effect.

- If the transmitter is still enabled (TXOff is clear) when the End of Chain bit is set, the transmitter must drive NOP packets (all CAD bits 0, with CTL asserted) with good CRC. This is required to prevent the far receiver from seeing garbage when we are no longer sending to it.
- If End of Chain is set with TXOff clear when exiting warm reset or an LDTSTOP disconnect, the device should drive warm reset signaling.
- It is the responsibility of software to make sure that no traffic is going across the link when End of Chain is set, so that the switch to NOPs does not occur in the midst of a packet.
- If retry mode is not enabled, End of Chain can be set by software by writing a 1 to indicate the logical end of the chain, or to partition a double-hosted chain into two independent logical chains.
- If retry mode is enabled, End of Chain and TXOff must not be set without ConnDly=1 or undefined operation may result. Similarly, if retry mode is enabled, TXOff must be set if End of Chain is set or undefined operation may result.

If GlblLinkTrain[ConnDly] or LinkTrain[HotPlugEn] is set:

- This bit becomes R/W.
 - If ConnDly is set, changes to this bit do not take effect until the next LDTSTOP Disconnect or warm reset.
 - If ConnDly is clear, clearing End of Chain results in undefined behavior.
-
- Software is responsible for correctly configuring the link before clearing this bit.

7.5.4.8 Transmitter Off (Bit 7, TXOff): R/W: Evaluated at Cold Chain Reset

This bit provides a mechanism to shut off a link transmitter for power savings or EMI reduction. When set, no output signals on the link toggle and are driven to electrical levels that satisfy the DC specification. For Gen3 devices, this is the PHY OFF state, defined in Section 12.3.9. When this bit is set, the link receiver should also be disabled by hardware if necessary to prevent DC current paths as a result of the inputs that may be invalid or floating. If a link fails AC Detect at cold reset, hardware sets this bit. See Section 7.16 for more details about the link training configuration bits.

If GlblLinkTrain[ConnDly] and LinkTrain[HotPlugEn] are clear:

- This bit cannot be cleared by software and a write of 0 to this bit position has no effect.
- If retry mode is not enabled, this bit can be set by software writing a 1 to the bit.

- If End of Chain is set on an active link, Transmitter Off should not be set until the transmitter has driven enough NOPs to fill the receiver's receive FIFOs.
- If retry mode is enabled, End of Chain and TXOff must not be set without ConnDly=1 or undefined operation may result. Similarly, if retry mode is enabled, TXOff must be set if End of Chain is set or undefined operation may result.

If GblLinkTrain[ConnDly] or LinkTrain[HotPlugEn] is set:

- This bit becomes R/W.
 - If ConnDly is set, changes to this bit do not take effect until the next LDTSTOP Disconnect or warm reset.
 - If ConnDly is clear, clearing TXOff results in undefined behavior.
- Software is responsible for correctly configuring the link before clearing this bit.

7.5.4.9 CRC Error (Bits 11:8, CRCErr): R/C: Cold Reset to 0

These bits are set by hardware when a CRC error is detected on an incoming link.

When a link is not in retry mode, errors are detected and reported on a per byte-lane basis where bit 8 corresponds to the least-significant byte lane. Four bits are required to cover the maximum width of 32 bits. Error bits for unimplemented (as specified by Max Link Width In, Section 7.5.5.1) or unused (as specified by Link Width In, Section 7.5.5.5) byte lanes return 0 when read.

When a link is in retry mode, only bit 8 is used and indicates an unrecoverable link error, regardless of which byte lane it occurred in. Bits 11:9 are reserved in retry mode.

7.5.4.10 Isochronous Flow Control Enable (Bit 12, IsocEn): R/W: Cold Chain Reset to 0

This optional bit controls whether Isochronous flow control, as described in Appendix D.1, is enabled for this link. The bit is set to enable Isochronous flow control mode and cleared to disable Isochronous flow control mode. Note that the Isoc bit in requests and responses is used regardless of this setting. Only Isoc flow control packets are prevented by clearing it. This bit only takes effect after a warm reset. This bit is reserved if the Isochronous flow control mode capability bit is cleared. (See Section 7.5.10.1) It is the responsibility of system-sizing software to ensure that this bit is set to the same value on both sides of the link and only set if both sides of the link have Isochronous flow control mode capability.

When a device forwards Isochronous traffic from a link that has Isochronous Flow Control enabled to a link that does not, the packet is unmodified but must be forwarded in the normal virtual channel set. Conversely, when traffic is forwarded from a link that does not have Isochronous Flow Control enabled to one that does, the packets are unmodified but are forwarded in the Isochronous virtual channel set.

7.5.4.11 LDTSTOP# Tristate Enable (Bit 13, LSEn): R/W: Cold Reset to 0

This bit controls whether the transmitter tristates the link during the disconnected state of an LDTSTOP# sequence, as described in Section 8.3. When the bit is set, the transmitter tristates the link. When the bit is clear, the transmitter continues to drive the link. This bit is reserved if the LDTSTOP# capability bit is cleared. (See Section 7.5.10.2) The behavior of the link transmitter and receiver in both the tristate and driven cases is described in Table 55. Gen3 devices use the LSSel field defined in Section 7.16.4.6 (or 7.16.4.14) to determine if the CLK lane is driven during LDTSTOP# assertion. Gen1 devices may determine this through implementation-specific means.

Inactive lanes are only controlled via GblLinkTrain[InLnSt] (Section 7.16.3), LinkTrain[RxInLnSt and TxInLnSt] (Sections 7.16.4.15 and 7.16.4.16), or CDLC (Section 8.6.4) at Gen3 frequencies. LSEn is ignored by hardware when the link is operating at Gen3 frequencies.

Table 55. LDTSTOP# Tristate Enable Bit Encoding

LDTSTOP# Tristate Enable	Link State in LDTSTOP# Disconnect State	Transmitter Behavior	Receiver Behavior
0	Driven	Active CAD lanes logical 1 CTL and inactive CAD lanes logical 0	Ignores CAD and CTL logical values.
1	Tristate	CAD and CTL placed in high impedance state. LSSel[1]=0: CLK running LSSel[1]=1: CLK placed in high impedance state	Disables DC current paths that could be created as a result of CAD, CTL and (if LSSel[1]=1) CLK inputs being tristated and ignores logical values.

7.5.4.12 Extended CTL Time (Bit 14, ExtCTL): R/W: Cold Reset to 0

If this bit is set, during the link initialization sequence in Section 12.2 following an LDTSTOP# disconnect sequence, CTL is asserted for 50 us after the point where both the transmitting device has asserted CTL and it has sampled CTL asserted from the other side of the link. If this bit is clear, CTL need only be asserted at least 16 bit-times after both sides assert CTL in 8-bit or larger links. (32 bit-times for 4-bit links, 64 bit-times for 2-bit links) Software must set this bit if the device on the other side of the link has its Extended CTL Time Required bit (Section 7.5.10.4) set. The extension allows devices using DLLs in their receivers enough time to lock to the transmit clock. This is necessary after LDTSTOP# because transmit clocks are only required to be stable at the time when CTL is asserted.

This bit is ignored by hardware when the link is operating with Gen3 protocol.

7.5.4.13 64 Bit Addressing Enable (Bit 15, 64bEn): R/W: Warm Reset to 0

If this bit is set, requests that access addresses above FF_FFFF_FFFFh can be issued or forwarded by this link interface with the Address Extension command. If this bit is clear, then any access above FF_FFFF_FFFFh is master aborted as if the end of chain was reached. Software is required to check the 64 Bit Address Feature bit for each node (described in Section 7.5.10.5) and set this bit only if the node

on the other side of the corresponding link supports 64 bit addressing. Devices that support 64-bit addressing should be placed together within a chain to ensure that 64-bit requests can be used.

7.5.5 Link Configuration Register: Offsets 06h and 0Ah

As with the Link Control register, there may be either one or two copies of the Link Configuration register, one for each link. If only one link is implemented by the device, the second register is reserved. All unspecified bits are reserved. The Link Configuration register is defined in Table 56.

As described in the following subsections, software updates to the upper half of this register take effect after a warm reset sequence and, depending on the field, also after an LDTSTOP# disconnect sequence.

Table 56. Link Configuration Register Definition

15	14	12	11	10	8	7	6	4	3	2	0
Dw Fc Out En	LinkWidthOut		Dw Fc In En	LinkWidthIn		Dw Dc Out	MaxLinkWidthOut		Dw Fc In	MaxLinkWidthIn	

7.5.5.1 Max Link Width In (Bits 2:0): R/O

This field contains three bits that indicate the physical width of the incoming side of the HyperTransport link implemented by this device. Unganged links indicate a maximum width of 8 bits.

The encodings are as shown in Table 57

Table 57. Max Link Width In Bit Field Encoding

LinkWidth[2:0]	Width
000	8 bits
001	16 bits
010	Reserved
011	32 bits
100	2 bits
101	4 bits
110	Reserved
111	Link physically not connected

7.5.5.2 Doubleword Flow Control In (DwFcIn, Bit 3): R/O

This bit is set to indicate that this receiver is capable of doubleword-based data buffer flow control.

7.5.5.3 Max Link Width Out (Bits 6:4): R/O

This field contains three bits that indicate the physical width of the outgoing side of the HyperTransport link implemented by this device. It uses the same encodings as the MaxLinkWidthIn field. Unganged links indicate a maximum width of 8 bits.

7.5.5.4 Doubleword Flow Control Out (DwFcOut, Bit 7): R/O

This bit is set to indicate that this transmitter is capable of doubleword-based data buffer flow control.

7.5.5.5 Link Width In (Bits 10:8): R/W: Cold Chain Reset

This field controls the utilized width (which may not exceed the physical width) of the incoming side of the links of the HyperTransport link implemented by this device. It uses the same encoding as the MaxLinkWidthIn field. After cold reset, this field is initialized by hardware based on the results of the link-width negotiation sequence described in Section 12.2. This sequence also identifies physically unconnected links. Based on sizing the devices at both ends of the link, software can then write a different value into the register. The chain must pass through warm reset or an LDTSTOP# disconnect sequence for the new width values to be reflected on the link.

The LinkWidthIn CSR in the link receiver must match the LinkWidthOut CSR in the link transmitter of the device on the other side of the link. The LinkWidthIn and LinkWidthOut registers within the same device are not required to have matching values. If two sides of a link are programmed to different widths when a RESET# or LDTSTOP# assertion occurs, the link cannot complete the initialization sequence. The system design must ensure that RESET# or LDTSTOP# are not asserted while software is writing new link width values. The means to ensure this is system-specific and beyond the scope of this specification.

See Section 12.3.20 for more details on requirements for link width changes at Gen3 frequencies.

See Section 8.6.7 for details on CDLW, in which link width is controlled by hardware. This field must not be modified after CLMC is enabled.

7.5.5.6 Doubleword Flow Control In Enable (DwFcInEn, Bit 11): R/W: Cold Chain Reset to 0

This optional bit may be set to program the receiver into doubleword-based flow control mode. After checking that devices on both sides of a link support this mode (by reading the bits defined in Sections 7.5.5.2 and 7.5.5.4), software may set this bit and/or the Doubleword Flow Control Out Enable bit. The chain must pass through warm reset for the new flow control method to be used on the link. See appendix H for more details about this mode.

7.5.5.7 Link Width Out (Bits 14:12): R/W: Cold Chain Reset

This field is similar to the LinkWidthIn field, except that it controls the utilized width of the outgoing side of the links implemented by this device. Like LinkWidthIn, this field is initialized after cold reset by hardware based on the results of the link width negotiation sequence described in Section 12.2. Byte lanes that are disabled due to the LinkWidthOut value being set narrower than the physically

implemented width of the link have their transmitters shut down in the same way as if Transmitter Off was set in Gen1 devices. Inactive lane behavior in Gen3 devices is controlled by the InLnSt registers specified in Sections 7.16.3.2 or 7.16.4.15 and 7.16.4.16.

7.5.5.8 Doubleword Flow Control Out Enable (DwFcOutEn, Bit 15): R/W: Cold Chain Reset to 0

This optional bit is similar to DwFcInEn, except that it puts the transmitter into doubleword-based flow control mode.

7.5.6 Revision ID Register: Offset 08h or 0Ch: R/O

The Revision ID register is defined as shown in Table 58.

Table 58. Revision ID Register Definition

7	5	4	0
MajorRev		MinorRev	
<p>Note: the following codings exist:</p> <p>20h – Revision 1.00</p> <p>21h – Revision 1.01</p> <p>22h – Revision 1.02</p> <p>23h – Revision 1.03</p> <p>24h – Revision 1.04</p> <p>25h – Revision 1.05</p> <p>2Ah – Revision 1.10</p> <p>40h – Revision 2.00</p> <p>60h – Revision 3.00</p>			

7.5.6.1 Minor Revision (Bits 4:0)

This field contains the minor revision of the *HyperTransport™ I/O Link Protocol Specification* to which the particular implementation conforms.

7.5.6.2 MajorRevision (Bits 7:5)

This field contains the major revision of the *HyperTransport™ I/O Link Protocol Specification* to which the particular implementation conforms.

7.5.7 Link Frequency Register: Offsets 09h or 0Dh and 11h (Bits 3:0): R/W: Cold Reset to 0

As with the Link Control and Link Configuration registers, there may be either one or two copies of the Link Frequency register, one for each link. If the device only implements one link, the second register is reserved.

The Link Frequency register specifies the operating frequency of the link’s transmitter clock—the data rate is twice this value. The encoding of this field is shown in Table 59.

Table 59. Link Frequency Bit Field Encoding

Link Frequency Encoding	Transmitter Clock Frequency (MHz)
0000	200 (default)
0001	300
0010	400
0011	500
0100	600
0101	800
0110	1000
0111	1200*
1000	1400*
1001	1600*
1010	1800
1011	2000
1100	2200
1101	2400
1110	2600
1111	Vendor-Specific
<p><i>Note: These frequencies were defined in revision 2.00 of the specification but are redefined electrically in revision 3.00. The presence of a Gen3 capability block indicates that a device implements the Gen3 electrical behavior for these frequencies. Gen1 and Gen3 devices are not interoperable at these frequencies.</i></p>	

Software can write a nonzero value to this register, and that value takes effect as a result of either a warm reset or LDTSTOP# disconnect sequence on the associated chain. For host interface blocks, the change is effected by HyperTransport RESET#, not host reset. For secondary interface blocks, the change is effected by HyperTransport RESET# on the bridge’s secondary chain. If two sides of a link

are programmed to different frequencies when a RESET# or LDTSTOP# assertion occurs, the link cannot complete the initialization sequence. The system design must ensure that RESET# or LDTSTOP# are not asserted while software is writing new link frequency values. The means to ensure this is system-specific and beyond the scope of this specification.

See Section 11.1 for a definition of the HyperTransport clocking modes, and for how the Link Frequency register controls the HyperTransport transmitter frequency in each mode. In asynchronous and pseudo-synchronous modes, the Link Frequency register specifies the maximum operating frequency. In synchronous mode, both the receiver and transmitter operate at the programmed frequency. The Link Frequency register on both sides of the link should always be programmed to the same value.

HyperTransport devices are not required to support all the transmitter clock frequencies in Table 59. All HyperTransport devices must support a 200-MHz synchronous link.

In some systems, the asserting edge of RESET# could be observed at significantly different times by two linked devices. If the transmitter changes frequency too quickly after RESET#, the receive FIFO in the device that observes RESET# later may capture incorrect data or false errors. To avoid this, transmitters used in these systems should not change their output frequency until 2 microseconds after observing the assertion of RESET# when operating with Gen1 protocol. Gen3 protocol avoids this issue as detailed in Section 12.3.17.

See Section 8.6.9 for details on CDLF, in which link frequency is controlled by hardware. This field must not be modified after CLMC is enabled.

- Software is required to enable retry mode and scrambling when Gen3 frequencies are programmed.
- Software is required to set GlibLinkTrain[T0Time] to the time required to retrain the DLL and phase recovery mechanism. If software does not have the means to determine this, the maximum value of 200us is recommended to ensure link function.
- The transmitter frequency must be within +300ppm/-5300ppm of the programmed value at Gen3 frequencies, even in asynchronous clocking mode.
- AC-coupled links default to 1.2GHz.

7.5.8 Link Error Register: Offsets 09h or 0Dh and 11h (Bits 7:4)

The Link Error register (defined in Table 60) occupies bits 7:4 of the byte containing the Link Frequency register. It contains error control and log bits for the link. Devices that do not check for one or more error conditions should hardwire the log bits for those conditions to 0.

Table 60. Link Error Register Definition

7	6	5	4
CTL Timeout	End of Chain Error	Overflow Error	Protocol Error

7.5.8.1 Protocol Error (Bit 4): R/C: Cold Reset to 0

This bit indicates a protocol error has been detected on the link. See Section 10.1.4.

7.5.8.2 Overflow Error (Bit 5): R/C: Cold Reset to 0

This bit indicates a receive buffer overflow error has been detected on the link. See Section 10.1.5.

7.5.8.3 End Of Chain Error (Bit 6): R/C: Cold Reset to 0

This bit indicates that a posted request or response packet has been given to this transmitter to be issued which cannot be, due to any of the reasons listed in Section 10.1.6.

7.5.8.4 CTL Timeout (Bit 7): R/W: Warm Reset to 0

This bit indicates how long CTL may be low before a device indicates a protocol error. A 0 in this bit indicates 1 millisecond; a 1 indicates 1 full second. See Section 0. This bit is optional for devices that do not detect protocol errors.

7.5.9 Link Frequency Capability Register: Offsets 0Ah or 0Eh and 12h: R/O

The Link Frequency Capability register (LinkFreqCap) is a 16-bit read only register that indicates the clock frequency capabilities of the associated link. Each bit in LinkFreqCap corresponds to one of the 16 possible encodings of the Link Frequency register as defined in Section 7.5.7. Bit N of LinkFreqCap corresponds to encoding N of the LinkFreq field. A 1 in LinkFreqCap means that the link supports the corresponding link frequency, and a 0 means the link does not support that frequency. Bit [0] of LinkFreqCap must be 1, since all links are required to support 200-MHz operation. A 1 in bit [15] indicates that vendor-specific frequencies are available, the use and support of which are beyond the scope of this specification.

The read-only value in LinkFreqCap specifies the frequency capabilities of the link independent of other practical constraints. For example, a specific device with multiple HyperTransport links may require all the links to run at the same frequency, or the system's electrical parameters may impose frequency restrictions on a specific link's operation that are not reflected in the Link FreqCap value. System firmware must deal with these system-specific requirements.

7.5.10 Feature Capability Register: Offset 0Ch or 10h

This register contains bits to indicate which optional features are supported by this device. All unspecified bits are reserved. The feature register is 16 bits in hosts, and 8 bits in non-host devices.

Table 61 Feature Capability Register Layout

9	8	7	6	5	4	3	2	1	0
Upstream Config Enable	Extended Register Set	Rsv	Source ID	UnitID Reorder Disable	64 Bit Addressing	Extended CTL Time	CRC Test Mode	LDTSTOP#	Isochronous Flow Control

7.5.10.1 Isochronous Flow Control Mode (Bit 0): R/O

This bit is set to indicate that the device is capable of supporting Isochronous flow control as defined in Appendix D.1, and clear to indicate that the device is not. Isochronous flow control is enabled by bit 12 of the Link Control register.

7.5.10.2 LDTSTOP# (Bit 1) : R/O

This bit is set to indicate that the associated interface supports the LDTSTOP# protocol, as described in Section 8.3, and clear to indicate that it does not.

7.5.10.3 CRC Test Mode (Bit 2) : R/O

This bit is set to indicate that the associated interface supports the CRC Testing Mode, as described in Appendix G, and clear to indicate that it does not.

7.5.10.4 Extended CTL Time Required (Bit 3) : R/O

This bit is set to indicate that this device requires CTL to be asserted for 50 us during the initialization sequence specified in Section 12.2 after an LDTSTOP# disconnect.

7.5.10.5 64 Bit Addressing (Bit 4) : R/O

This bit is set to indicate that this node supports 64 bit addresses by accepting and forwarding Address Extension command doublewords.

7.5.10.6 UnitID Reorder Disable (Bit 5) : R/W: Warm Reset to 0

This bit is set to indicate that this node keeps packets with different UnitIDs ordered together, ignoring UnitID for upstream cycles. This restricted ordering model allows a node to support UnitID Clumping in the passive manner, without requiring the full Clumping capability block to control which UnitIDs need to be ordered together. When this bit is clear, the node is allowed to order upstream traffic in different UnitIDs separately. This bit must be implemented in HyperTransport 1.05 and later devices that order traffic in different UnitIDs separately. Devices that always keep traffic in different UnitIDs together hardwire this bit to 1. Devices compatible with HyperTransport Revision 1.04 and earlier have this bit reserved (read-only 0), indicating that they may reorder traffic in different UnitIDs. A method of

determining if these devices do or do not reorder is beyond the scope of the specification so it is not generally possible to support passive clumping with those devices. See Section 4.6.1 for more on Clumping.

7.5.10.7 Source Identification Extension (Bit 6): R/O

This bit is set to indicate that this device supports receiving (and in tunnels, forwarding) the Source ID Packet Extension defined in Section 3.2.1.3 and enabled by LinkControl[SrcIdEn], defined in Section 7.5.4.1.

7.5.10.8 Extended Register Set (Bit 8) : R/O

This bit is set to indicate that the associated interface includes the Enumeration Scratchpad, Error Handling, and Memory Base/Limit Upper registers. If this bit is 0, software should not attempt to access these registers, since they may have alternative functions.

This bit exists in host/secondary interface blocks only, because the extended register set represented by this bit is required in all non-host devices, bridges, and switches. The extended register set is strongly recommended for hosts as well, but optional due to the configuration space constraints of some host implementations.

7.5.10.9 Upstream Configuration Enable (Bit 9): R/W: Warm Reset to 1

This bit is set to indicate that the associated interface handles upstream configuration space requests. If clear, all upstream configuration requests are rejected. System hosts may hardwire this bit to 0 if they never support upstream configuration.

7.5.11 Enumeration Scratchpad Register: Offset 10h or 14h: R/W: Cold Reset to 0

This register provides a scratchpad for enumeration software. Devices that support ungangling must implement this register. System hosts may provide this function via other means. This register is only present in hosts if the Extended Register Set bit is set in the Feature Capability register.

7.5.12 Error Handling Register: Offset 12h or 16h

The Error Handling register (defined in Table 62) contains routing enables from the various error log bits to the various error reporting mechanisms, as well as the Chain Fail and Response Error status bits. For definitions of the reporting mechanisms, see Section 10.2. Devices that do not check for one or more error conditions should hardwire the log and enable bits for those conditions to 0. This register is only present in hosts if the Extended Register Set bit is set in the Feature Capability register.

Table 62. Error Handling Register Definition

Byte	7	6	5	4	3	2	1	0
0	SERR Fatal Enable	CRC Fatal Enable	Resp Fatal Enable	EOC Fatal Enable	Overflow Fatal Enable	Prot Fatal Enable	Overflow Flood Enable	Prot Flood Enable
1	SERR NonFatal Enable	CRC NonFatal Enable	Resp NonFatal Enable	EOC NonFatal Enable	Overflow NonFatal Enable	Prot NonFatal Enable	Response Error	Chain Fail

7.5.12.1 Protocol Error Flood Enable (Bit 0): R/W: Warm Reset to 0

When this bit is set and (for slave device) SERR# Enable is set, this bit causes the link to be flooded with sync packets whenever the Protocol Error bit is asserted in (one of) the Link Error register(s). See Section 10.2.4. As with the CRC Flood Enable, this bit is not cleared by secondary chain reset in a bridge, so it may need to be cleared during a secondary bus reset or sync flooding could recur after reset.

7.5.12.2 Overflow Error Flood Enable (Bit 1): R/W: Warm Reset to 0

When this bit is set and (for slave device) SERR# Enable is set, this bit causes the link to be flooded with sync packets whenever the Overflow Error bit is asserted in (one of) the Link Error register(s). See Section 10.2.4. As with the CRC Flood Enable, this bit is not cleared by secondary chain reset in a bridge, so it may need to be cleared during a secondary bus reset or sync flooding could recur after reset.

7.5.12.3 Protocol Error Fatal Enable (Bit 2): R/W: Warm Reset to 0

When asserted, this bit causes the fatal error interrupt to be asserted whenever the Protocol Error bit is asserted in (one of) the Link Error register(s). If the fatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.4 Overflow Error Fatal Enable (Bit 3): R/W: Warm Reset to 0

When asserted, this bit causes the fatal error interrupt to be asserted whenever the Overflow Error bit is asserted in (one of) the Link Error register(s). If the fatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.5 End of Chain Error Fatal Enable (Bit 4): R/W: Warm Reset to 0

When asserted, this bit causes the fatal error interrupt to be asserted whenever the End of Chain Error bit is asserted in (one of) the Link Error register(s), or the Inbound End of Chain Error bit is set in the Host Command register. If the fatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.6 Response Error Fatal Enable (Bit 5): R/W: Warm Reset to 0

When asserted, this bit causes the fatal error interrupt whenever the Response Error bit (9) is asserted. If the fatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.7 CRC Error Fatal Enable (Bit 6): R/W: Warm Reset to 0

When asserted, this bit causes the fatal error interrupt whenever any of the CRC Error bits are asserted in (either of) the Link Control register(s). If the fatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.8 System Error Fatal Enable (Bit 7): R/W: Warm Reset to 0

This bit is implemented for host interfaces only. For slave interfaces, it is hardwired to 0.

When asserted in a host, this bit causes the fatal error interrupt whenever the System Error Detected bit is asserted in the Secondary Status register. If the fatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.9 Chain Fail (Bit 8): R/O: Warm Chain Reset to 0

This bit indicates that the chain has gone down. It is set whenever a device detects sync flooding or a sync-flood generating error. It is cleared by reset of the failed chain.

7.5.12.10 Response Error (Bit 9): R/C: Cold Reset to 0

This bit indicates that the given interface has received a response error. (See Section 10.1.8.)

7.5.12.11 Protocol Error Nonfatal Enable (Bit 10): R/W: Warm Reset to 0

When asserted, this bit causes the nonfatal error interrupt to be asserted whenever the Protocol Error bit is asserted in (one of) the Link Error register(s). If the nonfatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.12 Overflow Error Nonfatal Enable (Bit 11): R/W: Warm Reset to 0

When asserted, this bit causes the nonfatal error interrupt to be asserted whenever the Overflow Error bit is asserted in (one of) the Link Error register(s). If the nonfatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.13 End of Chain Error Nonfatal Enable (Bit 12): R/W: Warm Reset to 0

When asserted, this bit causes the nonfatal error interrupt to be asserted whenever the End of Chain Error bit is asserted in (one of) the Link Error register(s), or the Inbound End of Chain Error bit is set in the Host Command register. If the nonfatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.14 Response Error Nonfatal Enable (Bit 13): R/W: Warm Reset to 0

If asserted, this bit causes the nonfatal error interrupt whenever the Response Error bit (9) is asserted. If the nonfatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.15 CRC Error Nonfatal Enable (Bit 14): R/W: Warm Reset to 0

When asserted, this bit causes the nonfatal error interrupt whenever any of the CRC Error bits are asserted in (either of) the Link Control register(s). If the nonfatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.12.16 System Error Nonfatal Enable (Bit 15): R/W: Warm Reset to 0

This bit is implemented for host interfaces only. For slave interfaces, it is hardwired to 0.

When asserted in a host, this bit causes the nonfatal error interrupt whenever the System Error Detected bit is asserted in the Secondary Status register. If the nonfatal error interrupt is not implemented, this bit is hardwired to 0.

7.5.13 Memory Base Upper 8 Bits: Offset 14h or 18h: R/W: Warm Reset to 0

This register extends the Nonprefetchable Memory Base register, defined for bridges in Section 7.4.6, to 40 bits. Nodes that implement multiple bridge headers sharing a single HyperTransport primary interface use the base and limit extension values in the primary capability block for all bridges. Bridges containing HyperTransport secondary capability blocks use the values in that block, unless their primary interface is also a HyperTransport link, in which case they use the values from the appropriate primary capability block. In that case, the values from the secondary capability block are unused. Software can determine which devices are affected by this register by reading the BaseUnitID and UnitCount fields of the HyperTransport Command register in the primary interface. If a 64-bit Address Remapping Capability, defined in Section 7.8, is present, this register is reserved. This register is only present in hosts if the Extended Register Set bit is set in the Feature Capability register.

7.5.14 Memory Limit Upper 8 Bits: Offset 15h or 19h: R/W: Warm Reset to 0

This register extends the Nonprefetchable Memory Limit register, defined for bridges in Section 7.4.6, to 40 bits and has the same requirements as the Base extension register defined in Section 7.5.13. If a 64-bit Address Remapping Capability, defined in Section 7.8, is present, this register is reserved. This register is only present in hosts if the Extended Register Set bit is set in the Feature Capability register.

7.5.15 Bus Number: Offset 1Ah: R/O: Warm Reset to 0

This register contains the value of bus number captured from Type 0 Configuration writes. This register must be implemented in all devices that initiate Device Messages or support Source ID Extensions. This register is not present in hosts.

7.6 Interrupt Discovery and Configuration Capability Block

As shown in Table 63, the Interrupt Discovery and Configuration Capability block defines an optional mechanism to declare how many interrupt sources each HyperTransport function can generate and

allows software to configure each interrupt independently. Each function can have its own capability block, facilitating a mapping of interrupts to functions. An alternative means of controlling interrupt generation is to implement a MSI or MSI-X capability, as defined in the *PCI Local Bus Specification* Revision 3.0, and a HyperTransport MSI Mapping capability, defined in Section 7.12. Existing software may not be able to use this mechanism, so an additional, alternative means of configuring interrupts (described in Appendix F.1.4) may be required for compatibility. Interrupts are described in Chapter 9.

Table 63. Interrupt Discovery and Configuration Capability Block Definition

31	24	23	16	15	8	7	0	
Capability Type		Index		Capabilities Pointer		Capability ID		+00h
Dataport								+04h

- *Capability ID* is read-only 08h to indicate that this is a HyperTransport capability list item.
- *Capabilities Pointer* is a read-only register pointing to the next item in the capability list, or 00h if this is the last item.
- *Interrupt Register Index* selects the interrupt definition register to be accessed through the dataport defined below.
- *Capability Type* is read-only 80h to indicate that this is an interrupt discovery and configuration block.
- *Interrupt Register Dataport* provides read or write access to the interrupt definition register selected by the index defined above. This port should only be accessed as a whole doubleword. All indexes not listed are reserved and should read 0s.

7.6.1 Last Interrupt: Index 01h: R/O

Bits 23:16 contain the last interrupt message defined by this device. Interrupt definitions are numbered beginning with 0, so a device that defines four interrupts would have the value 3 in this field.

7.6.2 Interrupt Definition Registers: Index 10h and Higher: Warm Reset

Each interrupt message defined by a device has a 64-bit definition register, consuming two indexes. Interrupt 0 would occupy indexes 10 and 11h, interrupt 1 uses 12 and 13h, etc. Bits 31:0 are accessed through the lower (even) index and bits 63:32 are accessed through the high (odd) index. These bits are defined in Table 64.

Table 64. Interrupt Definition Registers

Bit	R/W	Reset	Description
63	R/C	0	Waiting for EOI: If RQEOI is 1, then this bit is set by hardware when an interrupt request is sent and cleared by hardware when the EOI is returned. Software may write a 1 to this bit to clear it without an EOI.
62	R/W	0	PassPW: When 1, interrupt messages are sent with the PassPW bit set and no ordering of the message with other upstream cycles is guaranteed. When 0, interrupt messages are sent with PassPW clear, and the device must ensure that the interrupt message cannot pass upstream posted cycles within its queues. If a device supports only one of these behaviors, this bit is read-only and indicates which behavior is supported.
61:56	R/O	0	Reserved
55:32	R/W	0	IntrInfo[55:32]
31:24	R/W	F8h	IntrInfo[31:24]: Must default to F8h for compatibility with HyperTransport 1.01 and earlier devices. Values of F9 or above must not be used or conflicts with non-interrupt address spaces (defined in Chapter 5) result. Some hosts only recognize interrupts with this field set to F8h.
23: 6	R/W	0	IntrInfo[23:6]
5	R/W	0	IntrInfo[5]: Request EOI: When set, after each interrupt request is sent, the device waits for the Waiting for EOI bit to be cleared before sending another interrupt.
4: 2	R/W	0	IntrInfo[4:2]: Message Type. Some devices may allow only certain application-specific combinations of message type with other bits. See Appendix F.1 for one example.
1	R/W	0	Polarity: For external interrupt sources, when this bit is set, the interrupt signal is active-low. When clear, the interrupt signal is active-high. For internal interrupt sources, this bit is reserved.
0	R/W	1	Mask: When this bit is set, interrupt messages must not be sent from this source.

7.7 40 bit Address Remapping Capability Block

This configuration space capability block defines the location of the downstream memory windows on the secondary bus and defines 0 to 15 upstream memory windows on the secondary bus that are mapped to different addresses on the primary bus. See Appendix A for use of this capability. All registers assume their default values upon warm reset. This capability is recommended for all bridges that have a HyperTransport link as their primary interface. The Address Remapping Capability Block is defined in Table 65.

Table 65. 40 bit Address Remapping Capability Block Definition

31	28	27	26-25	24	20	19	16	15	8	7	0	
Cap. Type			Map Type	I/O Size	# of DMA Mappings		Capabilities Pointer		Capability ID			+00h
SBNPCtrl		Reserved			Secondary Bus Non-Prefetchable Window Base							+04h
SBPreCtrl		Reserved			Secondary Bus Prefetchable Window Base							+08h
DMACtrl N		Reserved					DMA Primary Base N					+8N+4h
DMA Secondary Base N					DMA Secondary Limit N							+8N+8h

7.7.1 Capability Header

7.7.1.1 Capability ID: R/O

The value 08h indicates that this is a HyperTransport capability list item.

7.7.1.2 Capabilities Pointer: R/O

This field points to the next item in the capability list, or 00h if this is the last item.

7.7.1.3 Number of DMA Mappings: R/O

This field indicates how many (if any) DMA Primary/Secondary register sets are defined by this register block. In a HyperTransport-to-PCI bridge, at least one per REQ/GNT pair is suggested.

7.7.1.4 I/O Size: R/W: Warm Reset to 0

This field defines how many bits of downstream I/O addresses are discarded. The default is 0 to pass all 25 bits of a HyperTransport I/O cycle. All discarded address bits are 0s on the secondary bus. There may be a limited number of valid settings of this field for some devices.

7.7.1.5 Mapping Type: R/O

This field is 0 for the 40-bit address mapping definition.

7.7.1.6 Capability Type: R/O

The value 10100b indicates this is an address mapping extension block.

7.7.2 Secondary Bus Window Control Registers: R/W: Warm Reset to 0

(SBNPCtrl and SBPreCtrl above)

Table 66. Secondary Bus Window Control Register Definition

3	2	1	0
Enable	Isochronous	NonCoherent	Compat

- *Compat* indicates if downstream requests that pass through this memory window have the compat bit set.
- *NonCoherent* indicates if downstream requests that pass through this memory window have the coherent bit cleared, allowing hosts to relax memory ordering.
- *Isochronous* indicates if downstream requests that pass through this memory window have the Isoc bit set. If this device has Isochronous Flow Control enabled, the requests are issued in one of the Isoc virtual channels.
- *Enable* controls if downstream requests are modified.

7.7.3 Secondary Bus Window Base Registers: R/W: Warm Reset to 0

The secondary bus prefetchable and non-prefetchable window base fields define base address bits 39:20 of their respective memory windows on the secondary bus for downstream cycles. Each window has an Enable bit in the control register, which when clear (the default) disables any address mapping of cycles in the primary bus windows of that type.

7.7.4 DMA Window Control Register: R/W: Warm Reset to 0

Table 67. DMA Window Control Register Definition

3	2	1	0
Enable	Isochronous	NonCoherent	Reserved

- *NonCoherent* indicates if upstream requests that pass through this DMA window have the coherent bit cleared, allowing hosts to relax memory ordering.
- *Isochronous* indicates if upstream requests that pass through this DMA window have the Isoc bit set. If this device has Isochronous Flow Control enabled, the requests are issued in one of the Isoc virtual channels.
- *Enable* controls if upstream requests are compared against this DMA window.

7.7.5 DMA Primary Base Register: R/W: Warm Reset to 0

When the Enable bit of the control register is set, this register defines base address bits 39:24 on the primary bus for a DMA mapping.

7.7.6 DMA Secondary Base and Limit Registers: R/W: Warm Reset to 0

When enabled, each register pair defines bits 39:24 of the base and limit of an upstream memory window on the secondary bus, which are mapped to the memory window starting at the corresponding primary base on the primary bus. (As with a PCI bridge, the unspecified least significant bits of base are assumed to be 0s and the LSBs of limit are assumed to be 1s.) Upstream cycles on the secondary bus outside the DMA windows and downstream memory windows are passed to the primary bus unmodified.

7.8 64 bit Address Remapping Capability

HyperTransport bridges supporting 64-bit addressing implement this extended capability type instead of the 40-bit capability type. This type allows more DMA windows to be defined, consumes less configuration space than the 40-bit type, and replaces the non-prefetchable memory base and limit register extensions. Bridges that support 40-bit addressing may implement a 40-bit remapping capability, a 64-bit capability, or neither. Bridges that support 64-bit addressing must implement a 64-bit remapping capability or none.

Table 68. 64 bit Address Remapping Capability Block Definition

31	27	26-25	24	20	19	16	15	8	7	6	5	0	Offset
Cap. Type		Map Type	I/O Size	# of DMA Mappings		Capabilities Pointer		Capability ID					+00h
Reserved										Index		+04h	
Data Lower												+08h	
Data Upper												+0Ch	

7.8.1 Capability Header

7.8.1.1 Capability ID: R/O

The value 08h indicates that this is a HyperTransport capability list item.

7.8.1.2 Capabilities Pointer: R/O

This field points to the next item in the capability list, or 00h if this is the last item.

7.8.1.3 Number of DMA Mappings: R/O

This field indicates how many (if any) DMA Primary/Secondary register sets are defined by this register block. In a HyperTransport-to-PCI bridge, at least one per REQ/GNT pair is suggested.

7.8.1.4 I/O Size: R/W: Warm Reset to 0

This field defines how many bits of downstream I/O addresses are discarded. The default is 0 to pass all 25 bits of a HyperTransport I/O cycle. All discarded address bits are 0s on the secondary bus. There may be a limited number of valid settings of this field for some devices.

7.8.1.5 Mapping Type: R/O

This field is 1 for the 64-bit address mapping definition. Higher values are reserved for future extensions.

7.8.1.6 Capability Type: R/O

The value 10100b indicates this is an address mapping extension block.

7.8.2 Index and Data Registers

The index field specifies one of many 64-bit registers to access through the lower and upper data registers. These registers are summarized in Table 69.

Table 69. 64-bit Address Remap Indexed Registers

Index	31	20 19	4 3	0
0h	Secondary Bus Non-Prefetchable Window Base Lower	Reserved		SBNPCtrl
	Secondary Bus Non-Prefetchable Window Base Upper			
1h	Secondary Bus Prefetchable Window Base Lower	Reserved		SBPreCtrl
	Secondary Bus Prefetchable Window Base			
2h	Primary Bus Non-Prefetchable Window Base Upper			
	Primary Bus Non-Prefetchable Window Limit Upper			
3h	Reserved			
4Nh	DMA Primary Base N Lower	Reserved		DMACtrl N
	DMA Primary Base N Upper			
4N+1h	DMA Secondary Base N Lower	Reserved		
	DMA Secondary Base N Upper			

Index	31	20	19	4	3	0
4N+2h	DMA Secondary Limit N Lower			Reserved		
	DMA Secondary Limit N Upper					
4N+3h	Reserved					

The SBNPCtrl (Secondary Bus Non-Prefetchable Control), SBPreCtrl (Secondary Bus Prefetchable Control), and DMACtrl (DMA Control) fields have the same meaning as in the 40-bit remap capability.

The Secondary Bus Non-Prefetchable Window Base Lower and Upper fields combine to define bits 63:20 of the non-prefetchable memory window base on the secondary bus.

Similarly, the Secondary Bus Prefetchable Window Base Lower and Upper fields combine to define bits 63:20 of the prefetchable memory window base on the secondary bus.

The Primary Bus Non-Prefetchable Window Base and Limit Upper fields replace the registers specified for 40-bit bridges in Sections 7.5.13 and 7.5.14, while extending them to 64-bit capability.

The DMA Primary and Secondary Base and Limit Lower and Upper registers have the same meaning and use as in the 40-bit remap capability, but define bits 63:20 of those remappings.

7.9 Revision ID Capability

As shown in Table 70, the Revision ID Capability block indicates the revision of the HyperTransport specification to which this node is compliant. Every function of every device implemented in a HyperTransport node must place a HyperTransport capability list item in its configuration space, indicating the version of the specification to which it is compliant. This can be the primary or secondary interface capability if already present, or the HyperTransport Revision ID capability otherwise.

Table 70. Revision ID Capability Block Definition

31	24	23	16	15	8	7	0
Capability Type		Revision ID		Capabilities Pointer		Capability ID	

- *Capability ID* is read-only 08h to indicate that this is a HyperTransport capability list item.
- *Capabilities Pointer* is a read-only register pointing to the next item in the capability list, or 00h if this is the last item.
- *Revision ID* indicates the revision of this specification to which this node is compliant. It follows the format of the Revision ID register in Section 7.5.6
- *Capability Type* is read-only 88h to indicate that this is a Revision ID capability block.

7.10 UnitID Clumping Capability

This capability allows a device to indicate which UnitIDs it would like to combine in order to obtain greater concurrency and allows software to control which UnitIDs are to be treated as equivalent. See Section 4.6.1 for more on UnitID Clumping. Only the first device in a node contains a Clumping capability block.

Table 71. Clumping Capability Block Definition

31	27	26	16	15	8	7	1	0	Offset
Capability Type		Reserved			Capabilities Pointer		Capability ID		+00h
Clumping Support								Rsv	+04h
Clumping Enable								Rsv	+08h

The capability ID is 8h as with all HyperTransport capabilities. The capability type is 10010b.

7.10.1 UnitID Clumping Support (Offset 4h): R/O

This read-only register indicates which of the UnitIDs this device can clump. If Bit 1 is set, that indicates that the UnitID at BaseUnitID+1 can be clumped with BaseUnitID. Bit N set indicates that BaseUnitID+N can be clumped with BaseUnitID+N-1. The clumping support register only has as many valid bits as the node has UnitIDs, as indicated by the UnitCount field of the HyperTransport Command register for non-host devices, described in Section 7.5.3.2.2. Host devices don't have a UnitCount field, and are required to have all their UnitIDs clumped together. Host devices therefore must have a value of 0000b, 0010b, 0110b, or 1110b in this register to indicate 1, 2, 3, or 4 UnitIDs that can be clumped. They are limited to only four clumped UnitIDs because only the two least significant bits of the requestor's UnitID are preserved in responses to keep them unique.

Because the BaseUnitID cannot be clumped with a prior UnitID, bit 0 is not needed for indicating per-UnitID clumping capability in a device.

7.10.2 UnitID Clumping Enable (Offset 8h): R/W: Warm Reset to 0

This register controls which UnitIDs are to be ordered together. Bit 0 is read-only 0. If Bit 1 is set, then requests and responses with UnitID=1 are to be ordered with those of UnitID 0. If Bit N is set, traffic with UnitID=N is ordered with traffic of UnitID=N-1.

Software is responsible for enabling clumping on a chain only if all devices support it. This is especially important for clumping with UnitID 0, because devices that do not support clumping cannot recognize requests other than UnitID 0 as being from the host. If clumping is enabled with other UnitIDs and there are devices on the chain without clumping support that do reorder by UnitID, ordering within a set of clumped UnitIDs is lost. The clumping enable bit for a UnitID may only be changed if there are no outstanding transactions for that UnitID.

Hosts may only clump UnitIDs 0 through 3 because only the two least significant bits of the requestor's UnitID are preserved in responses.

Note that in a sharing double-hosted chain where the slave host does not have ActAsSlave set, enough UnitIDs for the larger of the two hosts must be allocated.

7.11 Extended Configuration Space Access Capability

This optional capability allows a device or bridge to provide access to the extended register space of its own functions or to that of devices on the other side of a bridge.

Table 72. Extended Configuration Space Access Capability Block Definition

31	29	28	27	26	20	19	16	15	12	11	8	7	2	1	0	Offset
Capability Type				Reserved				Capabilities Pointer				Capability ID			+00h	
Rsv	Type	Bus Number			Device		Function		Register [11:2]			Rsv	+04h			
Data														+08h		

The capability ID is 8h as with all HyperTransport capabilities. The capability type is 10011b.

Software writes the address of the configuration space register to be accessed into Offset 4h, and may then read or write Offset 8h to access the data in that register. For bridges, the Type, Bus Number, and Device number are used to determine if the register being accessed is within the bridge node or on the other side of the bridge. If the device containing the capability is not a bridge, the Type, Bus, and Device number fields are reserved and ignored, and the capability only allows access to the device itself.

Bridge devices decode the type bit, bus number, and device number to determine how to route the access. Type 0 accesses are routed to the bridge's local CSRs. Type 1 accesses to the bridge's secondary bus number are converted to type 0 configuration accesses. Type 1 accesses to bus numbers above the secondary bus, up to and including the subordinate bus number, are passed through as type 1 configuration accesses. Accesses that don't map to any of these targets receive a target abort response.

Errors encountered by the bridge are translated to the source side as they would be for any cycle that crosses a bridge. (If master abort mode is set, a master abort of the access on the destination bus becomes a target abort of the access of Offset 8h and so on.)

7.12 MSI Mapping Capability

This capability is used by PCI bridges to define the address range where Message Signaled Interrupts are mapped to HyperTransport Interrupt messages. There must be an MSI mapping capability in each device number that supports MSI mapping, preferably in function 0. The capability affects MSI's generated in all functions of that device. It is expected that all MSI mapping capabilities found in a system are programmed with the same address.

When software finds an MSI mapping capability in a device and it is enabled, then all MSI (or MSI-X) capabilities in that device programmed to generate MSI's to the address programmed in the MSI mapping capability generate HyperTransport interrupt messages. If the device containing the enabled MSI mapping capability has a PCI Header Type value of 1 (bridge header), then all MSI's sent to the address programmed in the MSI mapping capability from devices below the bridge in the bus hierarchy are mapped to HyperTransport interrupt messages.

Table 73. MSI Mapping Capability

31	27	26	18	17	16	15	8	7	0	Offset
Capability Type		Rsv		Fixd	En	Capabilities Pointer		Capability ID		+00h
Address[31:20]				Reserved						+04h
Address[63:32]										+08h

Capability ID is read-only 08h to indicate this is a HyperTransport capability list item.

Capabilities Pointer is a read-only register pointing to the next item in the capability list, or 00h if this is the last item.

En is a read-write bit indicating if the mapping is active. It is cleared upon warm reset. This bit may optionally be read-only 1.

Fixd is a read-only bit indicating if the next two doublewords for programming address are present in the capability. If set, the address for mapping MSIs is fixed at 0000_0000_FEE_x_xxxxh and this capability block is one doubleword long. If clear, the address is programmable with the Address fields below and this capability block is three doublewords long.

Capability Type is read-only 10101b to indicate that this is an MSI Mapping Capability block.

Address[31:20] is a read-write field that holds the lower portion of the base address where the mapping of MSIs takes place. It is set to FEEh upon warm reset.

Address[63:32] is a read-write field that holds the upper portion of the base address for MSI mapping. It is cleared upon warm reset.

7.13 DirectRoute Capability

HyperTransport devices supporting DirectRoute per Section 4.9.6 must implement this extended capability type. Since DirectRoute is used to control peer-to-peer traffic, host interfaces never have DirectRoute capability.

Table 74. DirectRoute Capability Block Definition

31	27	26-25	24	20	19	16	15	8	7	0	Offset
Cap. Type	Rsv	Index		NumDirect RouteSpaces		Capabilities Pointer		Capability ID			+00h
DirectRouteEnable											+04h
DataPort											+08h

7.13.1 Capability Header

7.13.1.1 Capability ID: R/O

The value 08h indicates that this is a HyperTransport capability list item.

7.13.1.2 Capabilities Pointer: R/O

This field points to the next item in the capability list, or 00h if this is the last item.

7.13.1.3 NumberDirectRoute Spaces: R/O

This field indicates how many (if any) DirectRoute address ranges are defined by this register block. If DirectRoute is supported, at least 2 spaces must be supported.

7.13.1.4 Index: R/W: Warm Reset to 00000b

The value indexes writes of the DataPort value into the DirectRoute Base/Limit Registers.

7.13.1.5 Capability Type: R/O

The value 10110b indicates this is a DirectRoute Capability block.

7.13.1.6 DirectRouteEnable: R/W : Warm Reset to 0

Each device contains a 32-bit DirectRouteEnable vector indexed by UnitID, indicating which UnitIDs carry DirectRoute traffic. A 1 indicates that the corresponding UnitID supports DirectRoute traffic. Its reset value is all 0. Bit 0 corresponds to UnitID 0 and should be read only and set to 0.

7.13.1.7 DataPort: R/W

Data to be written to or read from the DirectRoute Base/Limit Register pointed to by the Index.

7.13.2 DirectRoute Base/Limit Registers

This field specifies the Base/Limit register pairs, which define the address regions where DirectRoute is used per Section 4.9.6. These registers are summarized in Table 75.

Table 75. DirectRoute Indexed Registers

Index	31	20 19	8 7	1	0
4N	DirectRoute Base N Lower			Rsv	OppToNorm ReqDir
4N+1h	DirectRoute Base N Upper				
4N+2h	DirectRoute Limit N Lower			Reserved	
4N+3h	DirectRoute Limit N Upper				

7.13.2.1 OppToNormReqDir: R/W Warm Reset to 0

When Set, DirectRoute packets matching this Base-Limit address pair are sent in the OppositeToNormalRequestDirection (Section 4.9.6.4). When clear, DirectRoute packets matching this Base-Limit address pair are sent in the NormalRequestDirection.

7.13.2.2 DirectRouteBase: R/W Warm Reset to 000000h

The DirectRoute Base Lower and Upper fields combine to define bits 63:8 of the DirectRoute address window base.

7.13.2.3 DirectRouteLimit: R/W Warm Reset to 000000h

The DirectRoute Limit Lower and Upper fields combine to define bits 63:8 of the DirectRoute address window Limit.

7.14 VCSet Capability

HyperTransport nodes must implement this extended capability type if they implement anything more than the Base and Isoc VCsets as defined in Section 4.7.

Table 76. VCSet Capability Block Definition

31	27	26	24	16	15	8	7	0	Offset
Cap. Type		Rsv			Capabilities Pointer		Capability ID		+00h
Rsv			L0EnbVCSet		L1EnbVCSet		VCSetSup		+04h
Reserved			StreamSup		StreamInterval		StreamBucketDepth		+08h
Reserved			Reserved		NonFCInterval		NonFCBucketDepth		+0Ch

7.14.1 Capability Header

7.14.1.1 Capability ID: R/O

The value 08h indicates that this is a HyperTransport capability list item.

7.14.1.2 Capabilities Pointer: R/O

This field points to the next item in the capability list, or 00h if this is the last item.

7.14.1.3 Capability Type: R/O

The value 10111b indicates this is a VCSet Capability block.

7.14.1.4 VCSetSup: R/O

A Read-Only CSR field VCSetSup indicating which VCSetS this node supports. This is used by configuration software to determine which VCSetS are possible to use. VCSetSup[0] corresponds to VCSet = 0.

7.14.1.5 L0EnbVCSet: R/W : Cold Reset to 00h

Indicates which VCSetS are supported and enabled on Link 0. L0EnbVCSet[0] corresponds to VCSet=0 on Link 0.

7.14.1.6 L1EnbVCSet: R/W : Cold Reset to 00h

Indicates which VCSetS are supported and enabled on Link 1. This field is Reserved for interfaces having a single link. L1EnbVCSet[0] corresponds to VCSet=0 on Link 1.

7.14.1.7 StreamSup: R/O

A Read-Only CSR field indicating how many Streaming VCs this device implements. When 00b the device supports Streaming VC 0. When 01b, the device supports Streaming VCs 0-3. When 10b, the device supports Streaming VCs 0-15. Bits 2-7 are reserved.

7.14.1.8 StreamInterval: R/W : Cold Reset to 00h

This is an eight bit field per node. Specifies the interval between increments of the streaming leaky bucket. Expressed as the exponent of 2 of the interval defined as the interval at which the StreamBucket is incremented in units of 100ps. A value of 10h would then translate into a timer which increments the StreamBucket every $2^{10} \times 100\text{ps}$ or 6.55 microseconds.

Whenever a StreamVC packet is sent, the StreamBucket is decremented by 1 to a minimum of 0. Whenever the StreamBucket is not empty, the StreamVCs are at a higher priority than the BaseVCs, the Isoc VCs, and the AltSet, but lower than the Non-FC-Isoc. The StreamBucket is reset to 0.

7.14.1.9 StreamBucketDepth: R/W : Cold Reset to 00h

This is an eight bit field per node. Specifies the maximum depth of the streaming bucket.

7.14.1.10 NonFCInterval: R/W : Cold Reset to 00h

This is an eight bit field per node. Specifies the interval between increments of the NonFCBucket leaky bucket. Expressed as the exponent of 2 of the interval defined as the interval at which the NonFCBucket is incremented in units of 100ps. A value of 10h would then translate into a timer which increments the NonFCBucket every $2^{16} \times 100ps$ or 6.55 microseconds.

Whenever a NonFC VC packet is sent, the NonFCBucket is decremented by 1 to a minimum of 0. Whenever the NonFCBucket is not empty, the NonFC VCs can send a packet. When the NonFCBucket is 0, no NonFC packet may be sent. The NonFCBucket is reset to 0.

7.14.1.11 NonFCBucketDepth: R/W : Cold Reset to 00h

This is an eight bit field per node. Specifies the maximum depth of the NonFCBucket.

7.15 Error Retry Capability

This capability type is not used in devices that do not support Gen3 frequencies.

Retry mode is configured and monitored by a set of registers in a configuration space capability block, as shown in Table 77.

Table 77. Retry Mode Configuration Registers

31	27	26-24	23	16	15	8	7	0		
Capability Type		Reserved			Capabilities Pointer		Capability ID		+00h	
Status 1			Control 1		Status 0		Control 0		+04h	
Retry Count 1					Retry Count 0					+08h

7.15.1 Capability Registers R/O

- *Capability ID* is 08h to indicate that this is an HyperTransport capability list item.
- *Capabilities Pointer* points to the next item in the capability list, or 00h if this is the last item.
- *Capability Type* is 11000b to indicate that this is an Error Retry Capability.

7.15.2 Control Register

There is an 8-bit control register for each link (Control 0 for link 0 and Control 1 for link 1), summarized in Table 78. Control 1 is reserved for single-link devices.

Table 78. Retry Control Register

7	6	5	4	3	2	1	0
Short Attempts		Retry Fatal Enable	Retry Nonfatal Enable	Force Single Stomp	Rollover Nonfatal Enable	Force Single Error	Link Retry Enable

7.15.2.1 Link Retry Enable (Bit 0): R/W: Evaluated at Cold Reset

If set, the link enters retry mode at the next warm reset. If cleared, the link exits retry mode at the next warm reset. Set by hardware if an AC-coupled link is detected when exiting cold reset.

7.15.2.2 Force Single Error (Bit 1): R/S: Warm Reset to 0

This bit is used by diagnostic software to test the error detection and retry logic of the link. When set, it forces a CRC error in one packet from the transmitter. This bit is cleared by hardware after the error has been forced.

7.15.2.3 Rollover Nonfatal Enable (Bit 2): R/W: Warm Reset to 0

When set, a nonfatal [error](#) interrupt is generated each time the retry counter rolls over.

7.15.2.4 Force Single Stomp (Bit 3): R/S: Warm Reset to 0

This bit is used by diagnostic software to test the error detection and retry logic of the link. When set, it forces a CRC Stomp in one packet from the transmitter. This bit is cleared by hardware after the error has been forced.

7.15.2.5 Retry Nonfatal Enable (Bit 4): R/W: Warm Reset to 0

When set, a nonfatal [error](#) interrupt is generated each time the receive interface enters retry state.

7.15.2.6 Retry Fatal Enable (Bit 5): R/W: Warm Reset to 0

When set, a fatal [error](#) interrupt is generated each time the receive interface enters retry state.

7.15.2.7 Short Attempts (Bits 7:6): R/W: Warm Reset to 3

This field controls the number of short retry attempts that are allowed (See Sections 10.3.8 and 12.3.2). If this field is set to 0 (no short attempts allowed), a per-packet CRC error results in a full training attempt.

7.15.3 Status Register

There is an 8-bit status register for each link (Status 0 for link 0, Status 1 for link 1), summarized in Table 79. Status 1 is reserved for single-link devices.

Table 79. Retry Status Register

7	6	5	4	3	2	1	0
Reserved					Stomp Received	Count Rollover	Retry Sent

7.15.3.1 Retry Sent (Bit 0): R/C: Cold Reset to 0

This bit indicates that this link sent a disconnect NOP packet to enter retry mode due to a link error.

7.15.3.2 Count Rollover (Bit 1): R/C: Cold Reset to 0

This bit indicates that the most significant bit of the retry counter rolled over.

7.15.3.3 Stomp Received (Bit 2): R/C: Cold Reset to 0

This bit indicates that a stomped packet was received on this link.

7.15.4 Retry Count: R/W: Cold Reset to 0

This 16-bit counter is incremented by hardware each time a retry is attempted or a training timer times out due to a link error. If the counter value is FFFFh it increments to 0000h and the Count Rollover bit is set. There is one of these registers for each link (Retry Count 0 for link 0, Retry Count 1 for link 1). Retry Count 1 is reserved for single-link devices.

7.16 Gen3 Capability

This capability must be present in devices that support Gen3 frequencies.

Synchronous caves (single-link devices that do not support asynchronous clocking mode) may implement the minimal set of registers in a 6 DW capability, while hosts, tunnels, and caves that support asynchronous clocking mode must implement the full sets of registers in a 10 DW capability.

System hosts that implement multiple links may arrange registers differently to fit them into their available configuration space.

Link Training 1, Transmitter Configuration 1, and Receiver Configuration 1 are reserved in caves.

The recommended location of the Gen3 Capability is in the conventional (non-extended) configuration space of the device, preferably in function 0 if there is sufficient register space.

Table 80. Gen3 Configuration Registers

31	24	23	18	17	16	15	8	7	0		
Capability Type		Reserved		Index=00b		Capabilities Pointer		Capability ID		+00h	
Global Link Training											+04h
Transmitter Configuration 0											+08h
Receiver Configuration 0											+0Ch
Link Training 0											+10h
Reserved											+14h
Transmitter Configuration 1											+18h
Receiver Configuration 1											+1Ch
Link Training 1											+20h
BIST Control											+24h

7.16.1 Capability Registers R/O

- *Capability ID* is 08h to indicate that this is a HyperTransport capability list item.
- *Capabilities Pointer* points to the next item in the capability list, or 00h if this is the last item.
- *Index* is a read-write field that selects which register set is being accessed. 00b selects the regular link configuration register set. 01b selects the receiver BIST register set. 10b selects the transmitter BIST register set. 11b is reserved. Reserved in devices without BIST.
- *Capability Type* is read-only D0h to indicate that this is a Gen3 capability block.

The receiver and transmitter BIST register sets independently control the patterns generated for transmitting data and checking received data.

Table 81. BIST Receive Registers

31	24	23	18	17	16	15	8	7	0		
Capability Type		Reserved		Index=01b		Capabilities Pointer		Capability ID		+00h	
Receiver Pattern Control											+04h
Receiver Pattern Buffer 1											+08h
Receiver Mask											+0Ch
Receiver Inversion											+10h
Receiver Pattern Buffer 2											+14h
Receiver Pattern Buffer 2 Select											+18h
Receiver Pattern Buffer Extension											+1Ch
Receiver Scramble											+20h
Receiver Error											+24h

Table 82. BIST Transmit Registers

31	24	23	18	17	16	15	8	7	0		
Capability Type		Reserved		Index=10b		Capabilities Pointer		Capability ID		+00h	
Transmitter Pattern Control											+04h
Transmitter Pattern Buffer 1											+08h
Transmitter Mask											+0Ch
Transmitter Inversion											+10h
Transmitter Pattern Buffer 2											+14h
Transmitter Pattern Buffer 2 Select											+18h
Transmitter Pattern Buffer Extension											+1Ch
Transmitter Scramble											+20h
Reserved											+24h

7.16.2 Capability Enumeration (Bits 23:18, CapEnum): R/O

This register contains read-only bits that indicate which features are implemented in a device.

Table 83. CapEnum Register

23	22	21	20	19	18
Reserved	SLCC	LS3C	CPIC	BC	UCC

7.16.2.1 Unthrottled Command Capable (Bit 18, UCC)

Indicates the device can accept an unthrottled flow of commands, so that the device on the other side of the link can have LinkTrain[DisCmdThrt] set.

7.16.2.2 BIST Capable (Bit 19, BC)

Indicates the device implements the full 10DW capability and *Index* is a read-write field.

7.16.2.3 Command Packet Insertion Capable (Bit 20, CPIC)

Indicates the device can decode any command packet inserted within a data packet at Gen3 frequencies, so that the device on the other side of the link can have LinkTrain[CPIEn] set.

7.16.2.4 LS3 Capable (Bit 21, LS3C)

Indicates the device implements the optional LS3 state during *Disconnected* and the LSSel[0] bits are present.

7.16.2.5 Split Link Control Capable (Bit 22, SLCC)

Indicates the device implements separate InLnSt and LSSel fields for the transmit and receive paths. When 1, GblLinkTrain[InLnSt] is reserved, LinkTrain[LSSel] becomes RxLSSel, and RxInLnSt, TxInLnSt, and TxLSSel are added to LinkTrain.

7.16.3 Global Link Training

This register controls both links of a tunnel.

Table 84. GblLinkTrain

31:13	22:17	16:13	12	11:10	9	8	7:6	5:0
Reserved	FullT0Time	Reserved	LinkSel	RetryForce	RXCALen	ConnDly	Rsv/InLnSt	T0Time

7.16.3.1 T0 Time (Bits 5:0, T0Time): R/W: Cold Reset to 3Ah

Defines the amount of time to spend in *Training 0* after *Disconnected*. To allow for finer increments in small delays, the encoding is broken into a two-bit scale (0.1, 0.5, 2.0, or 20us) and a 4-bit increment, as shown in Table 85. This field must not be modified after CLMC is enabled. See Section 12.3 for more information about Gen3 initialization and training.

Table 85. T0Time Encodings

T0Time [3:0]	T0Time[5:4]			
	0	1	2	3
0	0.0us	0.0us	0us	0us
1	0.1us	0.5us	2us	20us
2	0.2us	1.0us	4us	40us
3	0.3us	1.5us	6us	60us

T0Time [3:0]	T0Time[5:4]			
	0	1	2	3
4	0.4us	2.0us	8us	80us
5	0.5us	2.5us	10us	100us
6	0.6us	3.0us	12us	120us
7	0.7us	3.5us	14us	140us
8	0.8us	4.0us	16us	160us
9	0.9us	4.5us	18us	180us
A	1.0us	5.0us	20us	200us
B	1.1us	5.5us	22us	Reserved
C	1.2us	6.0us	24us	
D	1.3us	6.5us	26us	
E	1.4us	7.0us	28us	
F	1.5us	7.5us	30us	

Programmed time may be exceeded by 10% or 100ns, whichever is greater to allow implementation flexibility.

7.16.3.2 Inactive Lane State (Bits 7:6, InLnSt): R/W: Cold Reset to 0

Controls the state of inactive lanes above the width programmed in LinkControl[WidthIn/Out] in Gen3 devices, regardless of link frequency. When CDLW, defined in Section 8.6.7, is active, lanes below the width programmed in WidthIn/Out but above the active width are controlled by CDLC, defined in Section 8.6.4. This field must not be modified after CLMC is enabled. Takes effect at an *LDTSTOP Disconnect or Warm Reset*. (See Table 117 for definitions of PHY states in DC and AC modes.) See Section 12.3 for more information about Gen3 initialization and training.

Table 86. Inactive Lane State

InLnSt	Behavior
00b	Same as <i>Warm Reset</i> (Except CAD is logical 0 in DC)
01b	Same as <i>PHY OFF</i>
10b	Same as <i>Operational</i> CTL&CAD undefined data, scrambled per LinkTrain[ScrEn]
11b	Same as <i>Disconnected</i> per LSSel

Software is required to program T0Time appropriately when reactivating lanes to provide time for them to train, unless they had previously been trained and the DLL and phase recovery mechanism for the

inactive lanes had been kept locked on the data eye with scrambled data. If software cannot determine how much additional training is required, the value of FullT0Time is recommended to ensure link function.

If CapEnum[SLCC]=1, this field is reserved and LinkTrain[TxInLnSt and RxInLnSt] control the transmitter and receiver inactive lanes independently.

7.16.3.3 Connect Delay (Bit 8, ConnDly): R/W: Cold Reset to 0

Delays the effect of Transmitter Off as described in Section 7.5.4.8 and End Of Chain as described in Section 7.5.4.7 until the next *LDTSTOP Disconnect or Warm Reset*. This allows software on just one side of the link to coordinate clean changes in link configuration for hot plug or partitioning. This is also used to enable links for standalone electrical compliance testing regardless of whether a device supports hot plug. This bit must not be modified after CLMC is enabled.

7.16.3.4 Receiver Calibration Enable (Bit 9, RXCalEn): R/W: Cold Reset to 0

Enables internal calibration of the receiver at the beginning of *Training 1*. Reserved in devices that do not require receiver calibration. See Section 12.3 for more information about Gen3 initialization and training.

7.16.3.5 Retry Force (Bits 11:10, RetryForce): R/W: Cold Reset to 0

Enables periodic forcing of retries to resynchronize the scrambler. This allows logic analyzers to sample limited windows of operation without needing to track scrambler state from link initialization.

00b	No forced retries
01b	Force retry after 250us of operation
10b	Force retry after 500us
11b	Force retry after 1ms

7.16.3.6 Link Select (Bit 12, LinkSel): R/W: Cold Reset to 0

Selects which link of a tunnel is affected by LinkTrain[BISTEn] and [ILMEn] or the BIST register sets. Reserved in hosts and caves.

7.16.3.7 Full T0 Time (Bits 22:17, FullT0Time): R/W: Cold Reset to 3Ah

Defines the amount of time to spend in *Training 0* when full training is required. See T0Time for encoding, with 000000b reserved. If not implemented, the field is read-only 0 and the default of 200us is used when full training is required.

7.16.4 Link Training

There is an instance of this register for each link in a tunnel. Caves only implement one instance of this register. See Section 12.3 for more information about Gen3 initialization and training.

Table 87. LinkTrain Register

31:28	27	26:25	24:23	22:21	20	19:16	15	14	
Reserved	LS1D	TxInLnSt	RxInLnSt	TxLSSel	CPIEn	SerLane	Reserved	DisCmdThrt	
13:12	11	10	9	8:7	6:4	3	2	1	0
LaneSel	ILMEn	BISTEn	HotPlugEn	RxLSSel	TotalAttempts	ScrEn	8b10b	AC	Ganged

7.16.4.1 Ganged (Bit 0): R/W: Evaluated at Cold Reset

Link is ganged. Takes effect at a *Warm Reset*.

When set, the capabilities associated with sublink 1 disappear and link width is 16 or greater.

When clear, the capabilities associated with sublink 1 operate independently and sublinks report 8-bit link width. (The behavior of unganging in 32-bit links is not fully defined at this time.)

Reserved and read-only 1 in links that do not support unganging, such as 8-bit or smaller links.

The capability with lowest numbered [Bus, Device, Function, Offset] in a device is generally associated with sublink 0.

Devices that support unganging must implement the enumeration scratchpad register defined in Section 7.5.11. System hosts may enable enumeration via other means. Software is responsible for using the enumeration scratchpad or other fields it modifies during enumeration to identify all sublinks connecting two devices, setting the Ganged bit on sublink 0, and initiating a *Warm Reset*, ensuring that sublinks operate correctly. The protocol does not support discovery of arbitrary system topologies. Software must be aware of the system topology.

7.16.4.2 AC (Bit 1): R/W: Evaluated at Cold Reset

This bit is reserved in links that only support DC-coupled operation. Link is AC-coupled. Hardware sets or clears this bit exiting cold reset. This bit is ignored at Gen1 frequencies. Except for debug or test purposes, 8b10b encoding must be enabled by software if it sets this bit. This bit takes effect at a *Warm Reset*. See Section 12.3 for more information about Gen3 initialization.

7.16.4.3 8b10b Enable (Bit 2, 8b10b): R/W: Evaluated at Cold Reset

This bit is optional in links that only support DC-coupled operation. Hardware sets or clears this bit exiting cold reset. Takes effect at an *LDTSTOP Disconnect* or *Warm Reset*. This bit must be set for AC-coupled operation. 8b10b encoding may only be disabled in AC-coupled links for debug or test purposes

only. This bit is ignored in ILM and Gen1 protocol. Software is responsible for choosing BIST test patterns that are DC-balanced if 8b10b encoding is not enabled. See Section 2.3 for more information about 8b10b encoding. See Section 12.3 for more information about Gen3 initialization. This bit must not be modified after CLMC is enabled.

7.16.4.4 Scrambler Enable (Bit 3, ScrEn): R/W: Evaluated at Cold Reset

Hardware sets or clears this bit exiting cold reset. Takes effect at an *LDTSTOP Disconnect or Warm Reset*. Software is required to set this bit when transitioning from Gen1 to Gen3 frequencies. The scrambler may only be disabled at these frequencies for debug or test purposes. This bit is ignored in Gen1 protocol. This bit is ignored in ILM and BIST, as BIST controls scrambling on a per-lane basis and ILM devices only pass data without modification. See Section 2.1.4 for more information about scrambling. See Section 12.3 for more information about Gen3 initialization. This bit must not be modified after CLMC is enabled.

7.16.4.5 Total Attempts (Bits 6:4, TotalAttempts): R/W: Cold Reset to 7

Controls the total number of short and long link retry attempts made. The value written to this field must be greater than or equal to the value written to Retry Control[Short Attempts] as defined in Section 7.15.2.7.

7.16.4.6 Receiver LS Select (Bits 8:7, RxLSSel): R/W: Cold Reset to 0

Defines the receiver link state during *Disconnected* or (for lanes above LinkControl[LinkWidthIn] when InLnSt=11b) *Inactive*. If CapEnum[SLCC] is 0, this field also controls the transmitter link state. This field must not be modified after CLMC is enabled.

Encoding	Meaning
00b	LS1: CLK L0, CAD and CTL TXIDLE (TXHIZ See 7.5.4.11 for Gen1)
01b	LS0: CLK, CAD, and CTL L0 CTL & CAD undefined scrambled data for Gen3 frequencies Active CAD logical 1, CTL and inactive CAD logical 0 for Gen1
10b	LS2: CLK, CAD, and CTL TXIDLE (See 7.5.4.11 TXHIZ for Gen1)
11b	LS3: CLK, CAD, and CTL in PHY OFF

See Section 7.5.4.11 for details of behavior at Gen1 frequencies.

7.16.4.7 Hot Plug Enable (Bit 9, HotPlugEn): R/W: Cold Reset to 0

Enables protocol and electrical features for hot pluggable links. Reserved in devices that do not support hot plug. When set, the Tmr1 timeout is disabled and the electrical behavior in *PHY OFF* is modified which allows relaxed signal skew and protects the device from damage during attach and detach events. Software is responsible for increasing T0Time when HotPlugEn is set because the increased LDTSTOP# skew allowed prevents hardware from ensuring that the receiver can prepare for link

disconnects. Software and/or service processor monitoring of the link is required when HotPlugEn is set because the Tmr1 timeout does not ensure that sync flood propagates under all circumstances. See Section 16 for more information about hot plug. This bit must not be modified after CLMC is enabled.

7.16.4.8 Built-In Self-Test Enable (Bit 10, BISTEn): R/W: Cold Reset to 0

Enables BIST for receiver and transmitter upon the next *LDTSTOP Disconnect* or warm reset. Cleared by hardware upon the subsequent *LDTSTOP Disconnect* or warm reset. See Section 15.1 for more information about BIST. This bit must not be modified after CLMC is enabled.

7.16.4.9 Internal Loopback Mode Enable (Bit 11, ILMEn): R/W: Cold Reset to 0

Enables ILM for receiver and transmitter upon the next *LDTSTOP Disconnect* or warm reset. Cleared by hardware upon the subsequent *LDTSTOP Disconnect* or warm reset. See Section 15.2 for more information about ILM. This bit must not be modified after CLMC is enabled.

7.16.4.10 Lane Select (Bits 13:12, LaneSel): R/W: Cold Reset to 0

This field allows testing of asymmetric links and allows isolation of errors to the uplink or downlink in symmetric links.

In ILM mode, selects the number of lanes by which data is rotated before being transmitted by the loopback. 2-bit links rotate by 0 or 1 lanes; 4-bit links rotate by 1, 2, or 3 lanes; 8-bit links rotate by 2, 4, or 6 lanes; 16-bit links rotate by 4, 9, or 13 lanes; 32-bit links rotate by 9, 18, or 27 lanes. See Table 88 for details. If the receiver is wider than the transmitter, this field essentially selects which lanes to forward. If the transmitter is wider than the receiver, the rotated results are repeated as shown in Figure 9 to provide patterns for all transmit lanes.

In BIST mode, selects the number of lanes by which data is rotated prior to descrambling in the receiver. In a device with a BIST engine smaller than the active link width, LaneSel essentially selects which portion of the link is checked in the receiver during BIST, as described in Section 7.16.7.6.

Lane Select must be configured identically in both the BIST and ILM device when used together for link test. Bit 12 must be 0 in Gen1 protocol so that CTL from the BIST transmitter lines up with CTL in the BIST receiver.

Table 88. LaneSel Mappings for ILM

32-bit Receiver or Transmitter			
	LaneSel		
RX	01b	10b	11b
CTL3	CTL2	CTL1	CTL0
31	23	15	7
30	22	14	6
29	21	13	5
28	20	12	4
27	19	11	3
26	18	10	2
25	17	9	1
24	16	8	0
CTL2	CTL1	CTL0	CTL3
23	15	7	31
22	14	6	30
21	13	5	29
20	12	4	28
19	11	3	27
18	10	2	26
17	9	1	25
16	8	0	24
CTL1	CTL0	CTL3	CTL2
15	7	31	23
14	6	30	22
13	5	29	21
12	4	28	20
11	3	27	19
10	2	26	18
9	1	25	17
8	0	24	16

16-bit Receiver or Transmitter			
	LaneSel		
RX	01b	10b	11b
CTL1	12	CTL0	4
15	11	7	3
14	10	6	2
13	9	5	1
12	8	4	0
11	CTL0	3	CTL1
10	7	2	15
9	6	1	14
8	5	0	13
CTL0	4	CTL1	12
7	3	15	11
6	2	14	10
5	1	13	9
4	0	12	8
3	CTL1	11	CTL0
2	15	10	7
1	14	9	6
0	13	8	5

8-bit Receiver or Transmitter			
	LaneSel		
RX	01b	10b	11b
CTL0	6	4	2
7	5	3	1
6	4	2	0
5	3	1	CTL0
4	2	0	7
3	1	CTL0	6
2	0	7	5
1	CTL0	6	4
0	7	5	3

4-bit Receiver or Transmitter			
	LaneSel		
RX	01b	10b	11b
CTL0	3	2	1
3	2	1	0
2	1	0	CTL0
1	0	CTL0	3
0	CTL0	3	2

2-bit Receiver or Transmitter		
	LaneSel	
RX	01b	10b
CTL0	1	0
1	0	CTL0
0	CTL0	1

32-bit Receiver or Transmitter			
	LaneSel		
RX	01b	10b	11b
CTL0	CTL3	CTL2	CTL1
7	31	23	15
6	30	22	14
5	29	21	13
4	28	20	12
3	27	19	11
2	26	18	10
1	25	17	9
0	24	16	8

16-bit Receiver or Transmitter			
	LaneSel		
RX	01b	10b	11b

8-bit Receiver or Transmitter			
	LaneSel		
RX	01b	10b	11b

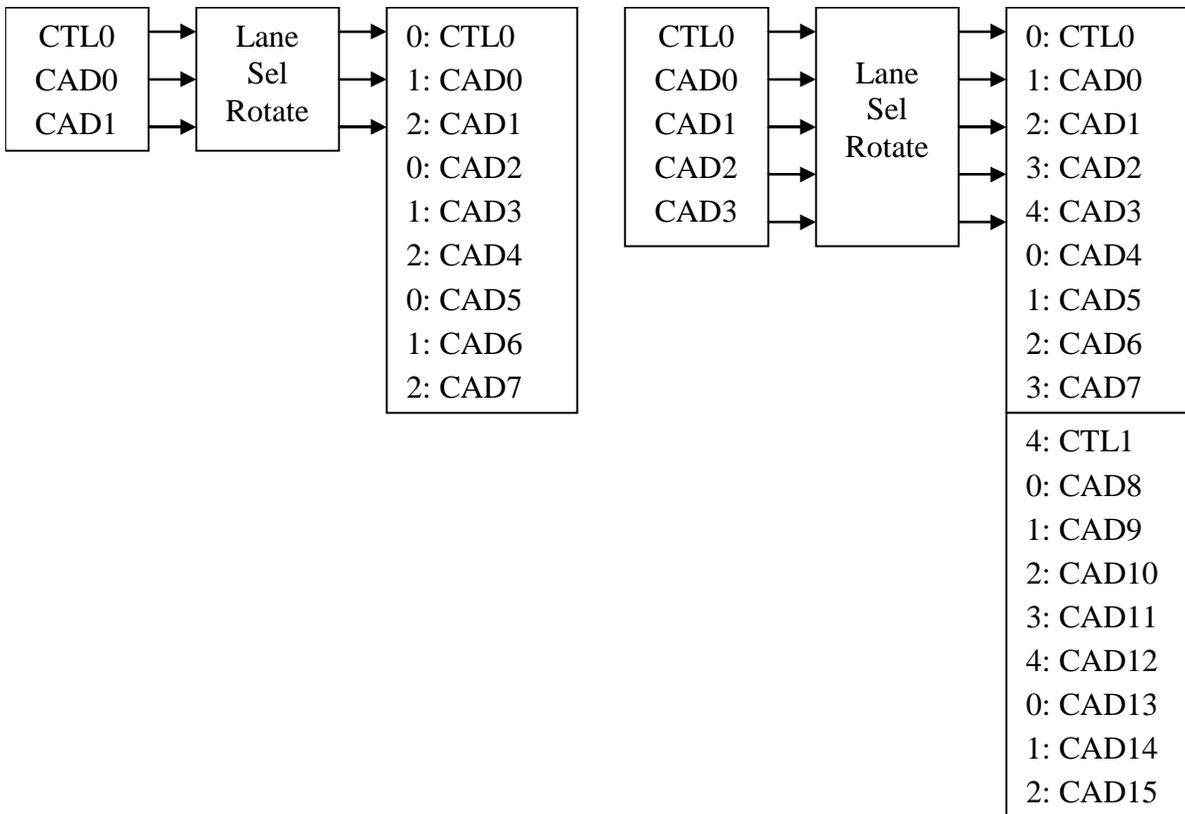


Figure 9. ILM Lane Mapping for Wide Transmitters

7.16.4.11 Disable Command Throttling (Bit 14, DisCmdThrt): R/W: Cold Reset to 0

When set, the device may issue more than one command for every 4 DWs transmitted. See Section 3.1.2.2 for more information about command throttling.

7.16.4.12 Serial Lane Select (Bits 19:16, SerLane): R/W: Cold Reset to 0

This field is optional. In ILM, this field selects one transmitter lane in each byte that maintains loopback function while all other lanes transmit scrambled 0's.

SerLane	Lane Transmitted
00h	All (no scrambling)
01h	CAD0,8,16,24
02h	CAD1,9,17,25
03h	CAD2,10,18,26
04h	CAD3,11,19,27
05h	CAD4,12,20,28
06h	CAD5,13,21,29
07h	CAD6,14,22,30
08h	CAD7,15,23,31
09h	CTL0,1,2,3
A-Fh	Reserved

7.16.4.13 Command Packet Insertion Enable (Bit 20, CPIEn): R/W: Cold Reset to 0

This bit is optional. When set, a device may insert non-info commands within data packets at Gen3 frequencies. See Section 3.1.2.1 for more information about command packet insertion.

7.16.4.14 Transmitter LS Select (Bits 22:21, TxLSSel): R/W: Cold Reset to 0

This field controls the transmit link state during *Disconnected* or (for lanes above LinkControl[LinkWidthOut] when InLnSt=11b) *Inactive*. This field is reserved if CapEnum[SLCC] is 0. See RxLSSel for encodings. This field must not be modified after CLMC is enabled.

7.16.4.15 Receiver Inactive Lane State (Bits 24:23, RxInLnSt): R/W: Cold Reset to 0

Controls the state of inactive receiver lanes above the width programmed in LinkControl[WidthIn] in Gen3 devices when CapEnum[SLCC] is 1. This field is reserved if CapEnum[SLCC] is 0. See GblLinkTrain[InLnSt] for encodings. This field must not be modified after CLMC is enabled.

7.16.4.16 Transmitter Inactive Lane State (Bits 26:25, TxInLnSt): R/W: Cold Reset to 0

Controls the state of inactive transmitter lanes above the width programmed in LinkControl[WidthOut] in Gen3 devices when CapEnum[SLCC] is 1. This field is reserved if CapEnum[SLCC] is 0. See GblLinkTrain[InLnSt] for encodings. This field must not be modified after CLMC is enabled.

7.16.4.17 LS1 Clock Divide Enable (Bit 27, LS1D): R/W: Cold Reset to 0

This bit is optional. If set, TXCLK frequency is divided by 16, 32, or 64 during LS1. This bit must not be modified when the link is in LS1 or CLMC is active.

7.16.5 Transmitter Configuration

Table 89. TXConfig Register

31	30	29	28:24	23:21	20:16
DeempEn	PreEn	Rsv	DL1	Reserved	MgnLvl

15:13	12:8	7	6	5	4:0
Cmpl	DL2	Rsv	MapDL2	Rsv	DP1

All settings only take effect at an *LDTSTOP Disconnect or Warm Reset*. This register must not be modified after CLMC is enabled.

7.16.5.1 Transmitter Precursor De_emphasis (Bits 4:0, DP1): R/W: Cold Reset to 0

If an implementation does not support 32 steps of de_emphasis, it may reserve bits 0 and up. A value of 0 corresponds to no de_emphasis and the maximum implemented value corresponds to 50% of full swing. The minimum implementation is 2 bits although a 4-bit or greater linear encoding provides flexibility for different channels.

7.16.5.2 Postcursor 2 Mapping Enable (Bit 6, MapDL2): R/W: Cold Reset to 0

When 0, the value of DL2 is ignored. When 1, the amount of de_emphasis specified in DL2 is applied in addition to that of DL1.

7.16.5.3 Transmitter Second Postcursor De_emphasis (Bits 12:8, DL2): R/W: Cold Reset to 0

See DP1 for encoding.

7.16.5.4 DC Compliance Test (Bits 15:13, Cmpl): R/W: Cold Reset to 0

This field is used to force all lanes of the transmitter to different states to allow measurement of DC specifications.

000b	Normal operation
001b	TXHIZ
010b	TXL0, logical 0
011b	TXL0, logical 1
100b	TXACDETECT
101b	TXIDLE
110-111b	Reserved

7.16.5.5 Margin Level (Bits 20:16, MgnLvl): R/W: Cold Reset to 0

If an implementation does not support 32 steps of margining, it may reserve bits 16 and up. A value of 0 corresponds to no margining and the maximum implemented value corresponds to the smallest possible normal deemphasized swing. See Section 30 for more on margining.

7.16.5.6 Transmitter Postcursor De-emphasis (Bits 28:24, DL1): R/W: Cold Reset to -3dB

See DP1 for encoding.

7.16.5.7 Precursor De-emphasis Enable (Bit 30, PreEn): R/W: Cold Reset to 0

When 0, the value of DP1 is ignored. When 1, the amount of precursor de-emphasis specified in DP1 is applied.

7.16.5.8 De-emphasis Enable (Bit 31, DeempEn): R/W: Evaluated at Cold Reset

Hardware sets or clears this bit exiting cold reset. When 0, the value of DL1 is ignored. When 1, the amount of postcursor de-emphasis specified in DL1 is applied. This bit is ignored at Gen1 frequencies.

7.16.6 Receiver Configuration

Table 90. RXConfig Register

31	30	29:23	22:16	15	14:10	9:8	7:2	1:0
MgnEn	MgnDir	Reserved	MgnIndx	EQEn	Reserved	EQLvl	Reserved	Cmpl

All settings only take effect at an *LDTSTOP Disconnect* or *Warm Reset*. This register must not be modified after CLMC is enabled.

7.16.6.1 Compliance (Bits 1:0, Cmpl)

This field is used to force all lanes of the receiver to different states to allow compliance measurements.

00b	Normal operation (Termination controlled by LinkTrain[AC])
-----	--

01b	RXDCDETECT
10b	RXOFF
11b	Reserved

7.16.6.2 Equalizer Level (Bits 9:8, EQLvl): R/W: Cold Reset to 0

Controls the level of receiver equalization used. 00b= 25mV. All other encodings reserved.

7.16.6.3 Equalizer Enable (Bit 15, EQEn): R/W: Cold Reset to 0

Enables decision-feedback equalization in the receiver.

7.16.6.4 Margin Index (Bits 22:16, MgnIndx): R/W: Cold Reset to 0

Controls how many receive phase steps early or late data is to be sampled relative to where the phase recovery logic normally samples. If an implementation does not support 128 steps per bit-time, it may reserve bits 20 and down. See Section 30 for more on margining.

7.16.6.5 Margin Direction (Bit 30, MgnDir): R/W: Cold Reset to 0

0=input is sampled later; 1=input is sampled earlier

7.16.6.6 Margin Enable (Bit 31, MgnEn): R/W: Cold Reset to 0

Enables time margining by moving the receive data eye as programmed by MgnIndx and MgnDir.

7.16.7 BIST Control

Optional in caves that do not support asynchronous clocking mode.

Table 91. BISTCtl Register

31	30:27	26:16	15:13	12:8	7:6	5	4:2	1	0
Width	Reserved	ErrCnt	Reserved	ErrLnNum	ErrStat	InvRotEn	Reserved	RxDis	Reserved

7.16.7.1 Receiver Disable (Bit 1, RxDis): R/W: Cold Reset to 0

This bit disables checking of BIST patterns in the receiver if BIST is already active. An LDTSTOP# or RESET# assertion is still required to exit BIST. If BIST has not started yet, this bit additionally removes any dependency on receiver link training, such that the transmitter sequences through the minimum training sets and begins sending BIST patterns at the completion of training.

7.16.7.2 Inversion Rotate Enable (Bit 5, InvRotEn): R/W: Cold Reset to 0

Enables rotation of the Inversion register in both receiver and transmitter at the completion of each BIST loop.

7.16.7.3 Error Status (Bits 7:6, ErrStat): R/C: Cold Reset to 0

Set by hardware upon detection of the first error by the BIST receiver. Software may clear this field by writing all ones to it. Writes other than all-zeroes or all-ones may result in undefined operation. Hardware may indicate a status of 01b until training completes successfully. This field has no meaning and should be ignored when BIST is entered while RxDis is set.

00b	No Error
01b	Training Error
10b	Pattern Miscompare
11b	Reserved

7.16.7.4 Error Lane Number (Bits 12:8, ErrLnNum): R/C: Cold Reset to 0

Set by hardware upon detection of the first error by the BIST receiver. If multiple bits fail then the highest-numbered bit is recorded. Software may clear this field by writing all ones to it. Writes other than all-zeroes or all-ones may result in undefined operation.

ErrLnNum	Lane	ErrLnNum	Lane
0	CAD0	9	CAD8
1	CAD1	10	CAD9
2	CAD2	11	CAD10
3	CAD3	12	CAD11
4	CAD4	13	CAD12
5	CAD5	14	CAD13
6	CAD6	15	CAD14
7	CAD7	16	CAD15
8	CTL0	17	CTL1

All other values reserved.

7.16.7.5 Error Count (Bits 26:16, ErrCnt): R/C: Cold Reset to 0

Incremented by hardware upon detection of each error on any lane. Software may clear this field by writing all ones to it. Writes other than all-zeroes or all-ones may result in undefined operation. This counter saturates at 7FFh.

7.16.7.6 Width (Bit 31): R/O

Indicates the implemented width of the BIST engine. 0= 8 bits, 1= 16 bits. In devices with 16-bit links and 8-bit BIST engines, the same patterns are transmitted on the upper and lower lanes. The upper bit of LinkTrain[LaneSel] chooses which half of the link is checked in the receiver. In a device with a 32-bit link and an 8-bit BIST engine both bits of LinkTrain[LaneSel] choose the portion of the link checked in the receiver.

7.16.8 Pattern Control

Table 92. PatCtl Register

31:26	25:21	20	19:13	12:10	9:3	2:0
Reserved	ConstCnt	ConstSel	ModCnt	ModSel	PatCnt	Order

7.16.8.1 Order (Bits 2:0): R/W: Cold Reset to 0

Selects the order in which each pattern is sent.

000b	Pattern Buffer, Modulo-N Counter, Constant Generator
001b	Pattern Buffer, Constant Generator, Modulo-N Counter
010b	Modulo-N Counter, Pattern Buffer, Constant Generator
011b	Modulo-N Counter, Constant Generator, Pattern Buffer
100b	Constant Generator, Pattern Buffer, Modulo-N Counter
101b	Constant Generator, Modulo-N Counter, Pattern Buffer
110, 111b	reserved

7.16.8.2 Pattern Buffer Count (Bits 9:3, PatCnt): R/W: Cold Reset to 0

Selects the number of times to repeat the chosen Pattern Buffer, 0 to 127.

7.16.8.3 Modulo-N Select (Bits 12:10, ModSel): R/W: Cold Reset to 0

Selects the pattern send by the Modulo-N counter:

001b	L/2 – 0101_0101_0101_0101_0101_0101b
010b	L/4 – 0011_0011_0011_0011_0011_0011b
011b	L/6 – 0001_1100_0111_0001_1100_0111b
100b	L/8 – 0000_1111_0000_1111_0000_1111b
110b	L/24 – 0000_0000_0000_1111_1111_1111b
All Others	Reserved

7.16.8.4 Modulo-N Count (Bits 19:13, ModCnt): R/W: Cold Reset to 0

Selects the number of times to repeat the Modulo-N counter pattern, 0 to 127.

7.16.8.5 Constant Generator Select (Bit 20, ConstSel): R/W: Cold Reset to 0

Selects 0 or 1 to send for the time the constant generator is selected.

7.16.8.6 Constant Generator Count (Bits 25:21, ConstCnt): R/W: Cold Reset to 0

Selects the number of times to repeat the chosen constant, in multiples of 24 bits.

00000b: 0 (disabled)

00001b: 24 bits

...

11111b: 24*31=744 bits

7.16.9 Pattern Buffer 1: R/W: Cold Reset to Implementation-Specific Value

Holds the first 24 bits of Pattern Buffer 1

Table 93. PatBuf1 Register

31:24	23:0
Reserved	Pattern 1 [23:0]

7.16.10 Mask: R/W: Cold Reset to 3FFFFh

Table 94. Mask Register

31:18	17	16	15	14	13	12	11	10	9
Reserved	CTL1	CAD15	CAD14	CAD13	CAD12	CAD11	CAD10	CAD9	CAD8
8	7	6	5	4	3	2	1	0	
CTL0	CAD7	CAD6	CAD5	CAD4	CAD3	CAD2	CAD1	CAD0	

Selects lanes where the BIST patterns are masked off. In the transmitter, logical 0's are sent on the selected lanes (and scrambled if selected by the Scramble register). In the receiver, the selected lanes are ignored. 1= lane active, 0=lane masked.

7.16.11 Inversion: R/W: Cold Reset to 0

Selects lanes to invert in both the transmitter and receiver. See the Mask register for the mapping of bits in this register to lanes. When BISTCtl[InvRotEn] is set, the bits corresponding to active lanes with rotate to the left at the completion of each BIST loop. 1= lane inverted, 0= lane unmodified.

For example, when width is 16 bits, $\text{Inversion}[17:0]=\{\text{Inversion}[16:0],\text{Inversion}[17]\}$;

When 2 bits, $\{\text{Inversion}[8],\text{Inversion}[1:0]\}=\{\text{Inversion}[1],\text{Inversion}[0],\text{Inversion}[8]\}$.

If the transmitter and receiver are different widths, inversion rotation can only be used for 32/16 or 16/8 bit links and the initial pattern in the inversion register must repeat on 9-bit boundaries.

7.16.12 Pattern Buffer 2: R/W: Cold Reset to Implementation-Specific Value

Holds the first 24 bits of Pattern Buffer 2

Table 95. PatBuf2 Register

31:24	23:0
Reserved	Pattern 2 [23:0]

7.16.13 Pattern Buffer 2 Enable: R/W: Cold Reset to 0

Selects lanes that use Pattern Buffer 2 instead of Pattern Buffer 1. See the Mask register for the mapping of bits in this register to lanes. 1= buffer 2 selected, 0= buffer 1 selected.

7.16.14 Pattern Buffer Extension: R/W: Cold Reset to Implementation-Specific Value

Holds the upper 16 bits of Pattern Buffer 1 and 2

Table 96. Pattern Buffer Extension Register

31:16	15:0
Pattern Buffer 2 [39:24]	Pattern Buffer 1 [39:24]

7.16.15 Scramble: R/W: Cold Reset to 0

Selects lanes to scramble in both the transmitter and receiver. See the Mask register for the mapping of bits in this register to lanes. Software is responsible for setting LinkTrain[LaneSel] to 00b in ILM devices when scrambling is used.

7.16.16 Receiver Error: R/W: Cold Reset to 0

Indicates lanes that had errors. See the Mask register for the mapping of bits in this register to lanes. Software may clear this register by writing 0's to it.

7.17 Function-Level Extension Capability

This capability may be included in any function of a HyperTransport device to control features not related to the HyperTransport link(s) in the device.

Table 97. Function-Level Extension Registers

31	24	23	16	15	8	7	0		
Capability Type		Length			Capabilities Pointer		Capability ID		+00h
Extension 1									+04h
...									
Extension N									

7.17.1 Capability Registers R/O

- *Capability ID* is 08h to indicate that this is a HyperTransport capability list item.
- *Capabilities Pointer* points to the next item in the capability list, or 00h if this is the last item.
- *Length* is a read-only field that indicates how many extension DWs are in the capability.
- *Capability Type* is read-only D8h to indicate that this is a Function-Level Extension capability block.

Any combination of extension DWs can be listed in this capability. Each extension DW has an 8-bit Extension ID field to identify which possible extension it controls.

Table 98. Extension Register Format

31	8 7	0
Extension-Specific Fields		Extension ID

Table 99. Extension ID Encodings

Encoding	Extension
00h	Function-Level Reset
01-FFh	Reserved

7.17.2 Function-Level Reset Extension

Table 100. Function-Level Reset Extension DW

31	9 8 7	0
Reserved		FLR Feature ID

7.17.2.1 Feature ID (Bits 7:0): R/O

This field is 00h to indicate that this is a Function-Level Reset Extension DW.

7.17.2.2 Function-Level Reset (Bit 8, FLR): W/O

A write of 1 to this bit causes a reset of all state in this function that is not explicitly stated to be preserved. Reads of this bit always return 0.

7.18 Power Management Capability Block

This capability configures the Link Power Management Control mechanism defined in Section 8.6.

31	27 26	20 19	16 15	8 7	0
Capability Type	Reserved	Index	Capability Pointer	Capability ID	+00h
Data Port					+04h

Capability ID: The value 08h indicates that this is a HyperTransport technology capability list item.

Capabilities Pointer: This field points to the next item in the capability list, or 00h if this is the last item.

Index: The value indexes reads and writes of the DataPort value into the Power Management Registers.

Capability Type: This field is 11100b to indicate this is a Power Management capability block.

Data Port: Data to be written to or read from the Power Management Register pointed to by the Index.

7.18.1 Index 0h: Power Management Feature Config

31	22	21	20	19	18	17	16	15	6	5	4	3	2	1	0							
Reserved								CDLREn	CILREn	CDLFEEn	CDLWEn	CDLDEn	CDLCEn	Reserved			CDLRCap	CILRCap	CDLFCap	CDLWCcap	CDLDCap	CDLCCap

Index 0h must be implemented by devices supporting any power management features. Enable bits associated with capability bits that read 0 are reserved.

7.18.1.1 Centralized Disconnected Lane Refresh Enable (Bit 21, CDLREn): R/W: Warm Reset to 0

1b=Enables the CLMC to execute CDLR sequencing (chipset only). When CDLREn=1b the host and chipset must be capable of executing CDLR sequencing (refer to Section 8.6.6 for details on CDLR).

7.18.1.2 Centralized Inactive Lane Refresh Enable (Bit 20, CILREn): R/W: Cold Reset to 0

1b=Enables the CLMC to execute CILR sequencing (chipset only). When CILREn=1b the host and chipset must be capable of executing CILR sequencing (refer to Section 8.6.8 and Figure 12 for details on CILR).

7.18.1.3 Centralized Dynamic Link Frequency Enable (Bit 19, CDLFEEn): R/W: Cold Reset to 0

1b=Enables the CLMC to execute CDLF sequencing (chipset only). When CDLFEEn=1b the host and chipset must appropriately respond to link frequency override SM commands (refer to Section 8.6.11) and CLMC control feature sequencing for CDLF (Refer to Figure 11).

7.18.1.4 Centralized Dynamic Link Width Enable (Bit 18, CDLWEn): R/W: Cold Reset to 0

1b=Enables the CLMC to execute CDLW sequencing (chipset only). When CDLWEn=1b the host and chipset must appropriately respond to link width override SM commands (refer to Section 8.6.11) and CLMC control feature sequencing for CDLW (Refer to Figure 11).

7.18.1.5 Centralized Dynamic Link Disconnect Enable (Bit 17, CDLDEn): R/W: Warm Reset to 0

1b=Enables the CLMC to execute CDLD sequencing (chipset only). When CDLDEn=1b the host and chipset must appropriately respond to CLMC control feature sequencing for CDLD (Refer to Figure 11).

7.18.1.6 Centralized Dynamic Link Configuration Enable (Bit 16, CDLCEn): R/W: Warm Reset to 0

1b=Enables the CLMC to execute CDLC sequencing (chipset only). When CDLCEn=1b the host and chipset must appropriately respond to link management SM commands (refer to Section 8.6.11) and CLMC control feature sequencing for CDLC (Refer to Figure 11).

7.18.1.7 Centralized Disabled Lane Refresh Capability (Bit 5, CDLRCap): R/O

1b=CDLR is supported.

7.18.1.8 Centralized Inactive Lane Refresh Capability (Bit 4, CILRCap): R/O

1b=CILR is supported.

7.18.1.9 Centralized Dynamic Link Frequency Capability (Bit 3, CDLFCap): R/O

1b=CDLF is supported. Power management capability index 1h must be implemented if CDLFCap=1b.

7.18.1.10 Centralized Dynamic Link Width Capability (Bit 2, CDLWCap): R/O

1b=CDLW is supported.

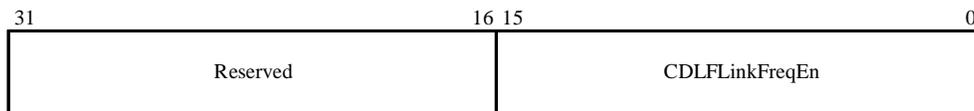
7.18.1.11 Centralized Dynamic Link Disconnect Capability (Bit 1, CDLDCap): R/O

1b=CDLD is supported.

7.18.1.12 Centralized Dynamic Link Configuration Capability (Bit 0, CDLCCap): R/O

1b=CDLD is supported.

7.18.2 Index 1h: CDLF Config

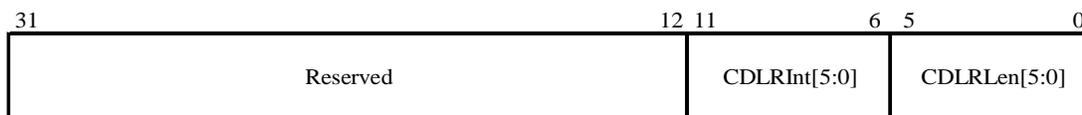


Index 1h must be implemented by chipset devices reporting CDLFCap=1b.

7.18.2.1 Centralized Dynamic Link Frequency Enable (Bits 15:0, CDLFLinkFreqEn): R/W: Warm Reset to 0

1b in any position enables the corresponding frequency for use by the CLMC with CDLF. Refer to the Link Frequency Capability register for encoding.

7.18.3 Index 2h: CDLR Config



7.18.3.1 Centralized Dynamic Link Refresh Interval (Bits 11:6, CDLRInt): R/W: Warm Reset to 0

Indicates the maximum amount of time the CDLC allows the link to spend in the disconnected state before initiating CDLR sequencing by deasserting LDTSTOP# (Refer to Section Figure 13 for CDLR LDTSTOP# control details). The encoding of this field is implementation-specific; an encoding that includes a well-populated range from 10us to 25ms is recommended.

7.18.3.2 Centralized Dynamic Link Refresh Length (Bits 5:0, CDLRLen): R/W: Warm Reset to 0

Indicates the minimum amount of time the CDLC keeps LDTSTOP# deasserted during CDLR (Refer to Section Figure 13 for CDLR LDTSTOP# control details). Refer to Table 85 for encoding.

8 System Management

HyperTransport™ technology includes features that can be deployed in x86 systems to implement legacy behaviors or to implement system-level behaviors such as low-power state transitions. These features are also useful for non-x86 systems that require power management, and LDTSTOP# provides a faster method to change link frequency and width than warm reset. From the perspective of this specification, support of power management by devices other than the system management controller (typically part of the Southbridge) is optional. However, all devices must be capable of forwarding system management packets upstream and downstream. LDTSTOP# support is required in x86 systems.

HyperTransport system management supports several system-level functions. This chapter lists each of the functions and the means by which they are implemented using HyperTransport system management messages. The term system management controller (SMC) is used in this chapter to denote the HyperTransport device that controls system management state transition and legacy x86 pin sequencing.

8.1 Command Mapping

The system management controller (SMC) generates upstream system management requests by directing a posted byte WrSized packet to the system management address range defined in Chapter 5. The count field is always 0, which indicates that only a single doubleword data packet follows the write, and it contains byte masks, not data. The byte masks are not used by the system management request and must always be all 0 bits. Because system management requests do not carry any data, Chain and Data Error must be 0. The format of these packets is as shown in Table 101.

Table 101. System Management Request WrSized Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]: 101001					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Count[1:0]		Reserved	Data Error	Chain	Reserved		
3	Rsv					Count[3:2]		
4	SysMgtCmd[7:0]							
5	Addr[23:20]				SysMgtCmd[11:8]			
6	Addr[31:24]							
7	Addr[39:32]							

The host generates downstream system management requests by sending a broadcast packet down all the HyperTransport I/O chains in the system. The address range in the broadcast packet identifies it as a system management request. The format of this packet is shown in Table 102.

Table 102. System Management Request Broadcast Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]: 111010					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Reserved							
3	Reserved							
4	SysMgtCmd[7:0]							
5	Addr[23:20]				SysMgtCmd[11:8]			
6	Addr[31:24]							
7	Addr[39:32]							

For both upstream and downstream cases, the type of system management request (SysMgtCmd[11:0]) is encoded as shown in Table 103. Gen3 devices are required to decode all 12 bits of SysMgtCmd.

Table 103. System Management Request Type Encoding

SysMgtCmd	Command Type
0000 0000 xxxx	Reserved
0000 00xx xxxx	x86 Encoding, see Appendix F.2.1
0000 0100 xxxx	SHUTDOWN Bits [3:0]: Implementation-specific
0000 0101 xxxx	HALT Bits [3:0]: Implementation-specific
0000 011x xxxx	x86 Encoding, see Appendix F.2.1
0000 100x xxxx	x86 Encoding, see Appendix F.2.1
0000 1010 xxxx	x86 Encoding, see Appendix F.2.1
0000 1011 xxxx	INTx Message Bits [3:2]: INTA/B/C/D select Bit [1]: Assert=1, Deassert=0 Bit [0]: Reserved
0000 110x xxxx	x86 Encoding, see Appendix F.2.1
0000 1110 0000	INT_PENDING
0000 1110 0001	x86 Encoding, see Appendix F.2.1
0000 1110 0010- 0000 1111 1111	Vendor Defined Virtual Wire Message

SysMgtCmd	Command Type
0001 0xxx xxxx	CLMC Encoding, see Section 8.6.11 Must not be issued unless enabled by software to prevent aliasing in Gen1 devices that do not decode bits 11:8
0001 1xxx xxxx- 0010 xxxx xxxx	x86 Encodings, see Appendix F.2.1
0011 0000 0000- 1111 1111 1111	Reserved Must not be issued unless enabled by software to prevent aliasing in Gen1 devices that do not decode bits 11:8

8.2 Special Cycles

The special cycles carried by system management packets are as follows:

- HALT—Generated by processor in response to execution of a HALT instruction.
- SHUTDOWN—Generated by processor in response to a catastrophic error.

These packets originate from the host and are broadcast downstream to all HyperTransport I/O devices in the system.

8.3 Disconnecting and Reconnecting HyperTransport™ Links

The *HyperTransport™ I/O Link Protocol Specification* comprehends the need for system states in which the HyperTransport links are disabled to save power, and therefore includes two features to facilitate this behavior. While these features have been described elsewhere in the specification, this section defines their use. These features are:

- Disconnect form of the NOP packet
- LDTSTOP# signal

The system-level conditions that control the assertion and deassertion of LDTSTOP# are outside the scope of this specification. However, the following rules govern the use of LDTSTOP# and the disconnection and reconnection of the HyperTransport link in all modes.

1. LDTSTOP# timing is specified in Section 2.1. LDTSTOP# assertion must not occur while new link frequency and width values are being assigned by link-sizing software, or undefined operation may occur. (This is because both sides of a link must have link width and frequency programmed, and if one side has been programmed with new values and the other has not yet been programmed, the width and/or frequency of the two sides does not match.)

2. After reconnecting to the link, the first transmitted packet after the initialization sequence must be a control packet, as implied by the state transitions of the CTL signal during link initialization. This is true even if the link was disconnected in the middle of a data packet transmission.
3. The CRC logic on either side of the link should be re-initialized after a disconnect sequence in exactly the same way as for a reset sequence.
4. LDTSTOP# should not be reasserted until all links have attempted to reconnect to avoid invalid link states. The means to ensure this across all possible device combinations is beyond the scope of this specification, although it is expected that this is under software control.

The following rules govern disconnection and reconnection for Gen1 protocol.

1. A transmitter that perceives the assertion of LDTSTOP# finishes sending any control packet that is in progress and then sends a disconnect NOP packet (bit 6 in the first bit-time set). After sending this packet, the transmitter continues to send disconnect NOP packets through the end of the current CRC window (if the window is incomplete) and continuing through the transmission of the CRC bits for the current window. After sending the CRC bits for the current window, the transmitter continues to drive disconnect NOP packets on the link for no less than 64 bit-times, after which point the transmitter waits for the corresponding receiver on the same device to complete its disconnect sequence, and then disables its drivers (if enabled by the LDTSTOP# Tristate Enable bit described in Section 7.5.4.11) and puts any link width or frequency change into effect. No CRC bits are transmitted for the last (partial) CRC window, which only contains disconnect NOP packets. Since the HyperTransport protocol allows control packets (including disconnect NOP packets) to be inserted in the middle of data packets, and since transmitters react to the assertion of LDTSTOP# on control packet boundaries, a given data packet could be distributed amongst two or more devices after the disconnect sequence is complete. The disconnect sequence is defined to be complete for timing purposes at the transmitter when the last CRC is transmitted at the pins.
2. A receiver that receives the disconnect NOP packet continues to operate through the end of the current CRC window and into the next CRC window until it receives the CRC bits for the current window. After sampling the CRC bits for the current window, the receiver disables its input receivers to the extent required by the LDTSTOP# Tristate Enable bit described in Section 7.5.4.11. The disconnect sequence is defined to be complete for timing purposes at the receiver when the last CRC is received at the pins.
3. Note that LDTSTOP# can deassert either before or after the link disconnection sequence is complete. A link transmitter is not sensitive to the deassertion of LDTSTOP# until both its disconnect sequence as described in step 2 is complete, and the disconnect sequence for the associated receiver on the same device is complete.
A link receiver is not sensitive to the deassertion of LDTSTOP# until both its disconnect sequence is complete and the disconnect sequence for the associated transmitter on the same device is complete.
4. A transmitter that perceives and is sensitive to the deassertion of LDTSTOP# enables its drivers as soon as the implementation allows, begins toggling the CLK with a minimum frequency of 5MHz and places the link in the state associated with the beginning of the initialization sequence (CTL = 0, CAD = 1s, CLK toggling). The transmitter is required to have CLK running and CTL = 0 within 400ns of LDTSTOP# deassertion at the transmitter's pin or completion of the disconnect sequence, whichever comes later. This assures that the receive logic has a clock source. However, the clock frequency is initially undefined coming out of the disconnect state and may be anything between 5MHz and the currently programmed frequency. The transmitter must ramp the clock to the

programmed frequency before asserting CTL as part of the link initialization sequence.

A receiver that perceives and is sensitive to the deassertion of LDTSTOP# waits at least 1 us before enabling its inputs. This 1-us delay is required to prevent a device from enabling its input receivers while the signals are invalid before the transmitter on the other side of the link has perceived and reacted to the deassertion of LDTSTOP#.

When a transmitter's corresponding receiver on the same device has been enabled, it is free to begin the initialization sequence described in Section 12.2.

5. Link disconnect and reconnect sequences do not cause flow control buffers to be flushed, nor do they cause flow control buffer counts to be reset.
6. Receivers must synchronize CAD and CTL and complete their disconnect sequence within 64 bit-times after the last CRC arriving at their pins. CLK is permitted to stop 64 bit-times after the last CRC arrives, so any logic dependent on it must have completed its work.

The electrical state of the HyperTransport link at Gen1 frequencies during the disconnect state is controlled by configuration bits, as described in Section 7.5.4.11.

Disconnect and reconnect of the link in Gen3 protocol is described with the other training and initialization states in Section 12.3.

8.4 INTx Virtual Wire Messages

Instead of using physical wires for PCI shared interrupts, a HyperTransport node may issue this upstream virtual wire message. Bits 3:2 of the system management command identify which wire is changing state (00=INTA, 01=INTB, 10=INTC, 11=INTD) and bit 1 indicates if the wire is being asserted or not. The UnitID of the virtual wire message must be the device number of the source of the interrupt. Devices must issue one deassertion message corresponding to each assertion message to ensure a consistent interrupt state within the host.

Hosts, switches, and bridges must maintain the accumulated state of each of the 4 virtual wires for each of the possible 32 devices on a chain. At warm reset all interrupts are assumed to be deasserted. The bridge (in the case of a host or switch, each logical bridge within the device) must then combine the state of the devices below it into 4 virtual wires of its own and send INTx messages when the state of any of those 4 resulting wires changes. In order to emulate PCI interrupt routing expected by software, the virtual wire modified at the bridge corresponds to the virtual wire sent by the device plus the two least-significant bits of the device on the chain that sent the interrupt, as shown in Table 104.

Table 104. INTx Message Mapping at a Bridge

Device [1:0]	INTx Message	Wire Modified
00	INTA (00)	INTA (00)
	INTB (01)	INTB (01)
	INTC (10)	INTC (10)
	INTD (11)	INTD (11)
01	INTA (00)	INTB(01)
	INTB (01)	INTC (10)
	INTC (10)	INTD (11)
	INTD (11)	INTA (00)
10	INTA (00)	INTC (10)
	INTB (01)	INTD (11)
	INTC (10)	INTA (00)
	INTD (11)	INTB (01)
11	INTA (00)	INTD (11)
	INTB (01)	INTA (00)
	INTC (10)	INTB (01)
	INTD (11)	INTC (10)

The UnitID of virtual wire messages sent by the bridge on the primary chain is the device number of the bridge.

Once an INTx message reaches the host and is accumulated into the virtual wire state there, if the host itself does not handle interrupts directly, it issues an INTx message downstream on all chains as a broadcast so the interrupt controller can handle the interrupt.

8.5 INT_Pending Message

If interrupt messages can be delivered to the processor without the knowledge of the System Management Controller, it is possible for interrupts to be delivered when the processor is unable to handle them. This situation can occur even when the SMC and an interrupt controller are integrated into a single “Southbridge” device.

The processor sends this message to the SMC so it can assure that the system is in a state that allows the interrupt to be handled. This is done in two situations:

1. An interrupt is pending prior to entering a STOP_GRANT state where the processor will be unable to handle the interrupt
2. An interrupt is received while in a STOP_GRANT state where the processor is unable to handle the interrupt

When the SMC receives this message, it is required to transition the system to a state where the processor is able to handle interrupts.

Note that to send an interrupt message when LDTSTOP# is asserted (or about to be asserted), a device would have to assert LDTREQ#. In systems where this causes the southbridge to wake the processor, this removes the need for the processor itself to have a LDTREQ# signal unless the processor can generate interrupts it cannot handle in a STOP_GRANT state. This also removes the need for the processor to issue INT_PENDING messages in or entering a STOP_GRANT state where LDTSTOP# will be asserted. In systems where traffic can be present not requiring the host to wake, devices must not issue interrupts between STPCLK and STOP_GRANT unless the host implements LDTREQ# or they have a mechanism other than LDTREQ# to bring the host out of C3. See Section F.2.4 for more details on usage of LDTREQ#.

This mechanism allows one or more interrupt controllers to operate independently from the SMC without sideband communication. It also allows for edge-triggered interrupt events, where it is impossible for the SMC to know when service of the interrupt within the processor is complete.

While the processor must issue an INT_PENDING message for the first interrupt received in STOP_GRANT, it may or may not issue additional INT_PENDING messages for subsequent interrupts received. The SMC must drop any INT_PENDING messages received after exiting STPCLK, such that any INT_PENDING messages issued before a new STPCLK entry are ignored.

8.6 Centralized Link Power Management Control

Centralized link power management control refers to link power management features that are controlled by a centralized link management controller (CLMC). Only one CLMC exists in the system. CLMC functionality is embedded in the system management controller (SMC). Centralized link power management control is only supported in systems with the following attributes:

- § A single processor (host)
- § A single source for LDTSTOP# control (the CLMC)

Some of the centralized link power management features also require LDTREQ# support in the SMC/CLMC. The CLMC controls both directions of the link (illustrated as the CLMC control domain in [Figure 10](#) ~~Figure 10~~).

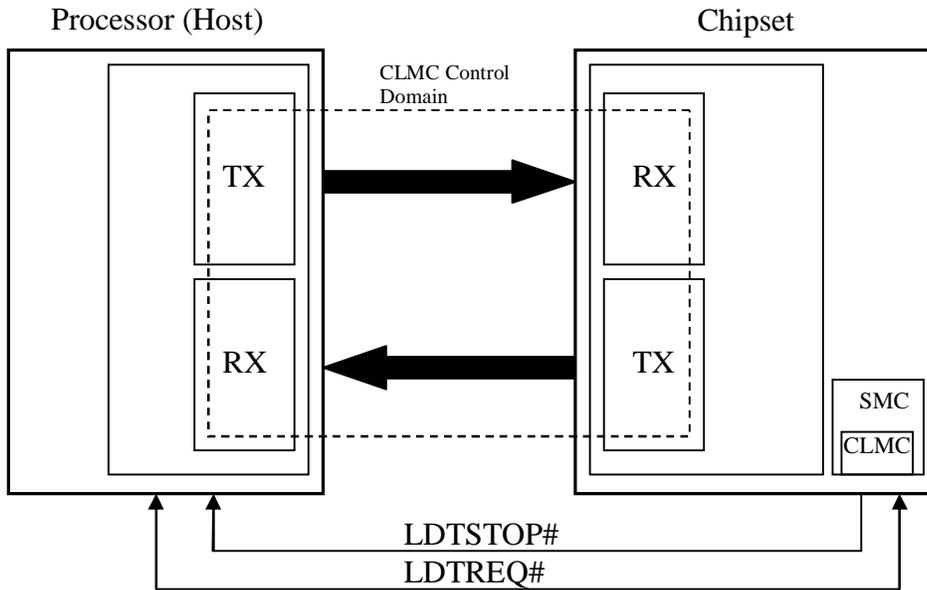


Figure 10. Centralized Link Power Management Control Topology

8.6.1 Features

Centralized link power management control supports six features. Four of these features are categorized as control features, and two are categorized as refresh features. Control features allow the CLMC to enforce a link power management policy by controlling link configuration settings, link disconnection, link width, and link frequency. Link control features are supported at Gen1 or Gen3 frequencies. The following are link control features:

- § Centralized dynamic link configuration (CDLC)
- § Centralized dynamic link disconnection (CDLD)
- § Centralized dynamic link width (CDLW)
- § Centralized dynamic link frequency (CDLF)

Refresh features allow the CLMC to proactively manage resume latency for inactive or disconnected lanes. Link refresh features are supported at Gen3 frequencies only. The following are link refresh features:

- § Centralized disconnected link refresh (CDLR)
- § Centralized inactive lane refresh (CILR)

CLMC power management features are defined to allow the CLMC to dynamically optimize link power consumption versus link bandwidth and resume latency requirements. Multiple CLMC control feature commands can be combined and applied in a single sequence. CLMC sequencing requires LDTSTOP# assertion for all control features. CLMC refresh feature sequencing is independent from CLMC control feature sequencing.

8.6.2 Software Access Restrictions

When any CLMC control feature is enabled software must not modify any settings that can prevent proper link reconnection or proper link operation if interrupted by LDTSTOP# assertion. This includes the following list of registers, and any implementation specific registers (including LMM registers) that can cause the symptoms noted above if interrupted by LDTSTOP# assertion:

- § LinkConfiguration[LinkWidthIn]
- § LinkConfiguration[LinkWidthOut]
- § Link Frequency Register
- § GblLinkTrain[T0Time]
- § GblLinkTrain[InLnSt] (if present)
- § GblLinkTrain[ConnDly]
- § LinkTrain[8b10b]
- § LinkTrain[ScrEn]
- § LinkTrain[RxLSSel and TxLSSel (if present)]
- § LinkTrain[HotPlugEn]
- § LinkTrain[BISTEn and ILMEn]
- § LinkTrain[RxInLnSt and TxInLnSt] (if present)
- § LinkTrain[LS1D]
- § TxConfig Register
- § RxConfig Register

If any CLMC control features are enabled, software is allowed to access these fields after issuing a warm reset.

8.6.3 Non-CLMC Hardware Access Restrictions

The CLMC sequencing defined in Section 8.6.10 prevents STPCLK assertion and resulting LDTSTOP# assertions from interacting with CLMC sequencing. All STPCLK assertion requests and LDTSTOP# assertions for non-CLMC events are suspended during CLMC sequencing. Non-CLMC hardware accesses to registers (e.g. host link width accesses for bandwidth matching) must occur between STPCLK assertion and STPCLK deassertion messages to prevent corrupting CLMC sequencing.

8.6.4 Centralized Dynamic Link Configuration (CDLC)

The CLMC can dynamically configure device specific link features that affect link power consumption through link management SM commands and an associated LDTSTOP# assertion event for synchronization. Link management SM commands contain a 4-bit link management action field (LMAF). The LMAF code in a link management SM command is used to index into BIOS-programmable link management mode (LMM) configuration registers. LMM register definition is device specific, and can be used to give the CLMC dynamic control over parameters defined within the Gen3 capability block (e.g. T0Time), or device specific features outside the scope of this specification. Devices must provide LMM register control bits for all features.

LMAF 0h is the cold and warm reset value for all devices.

8.6.4.1 CDLC Software Initialization Requirements

Software is responsible for configuring LMM register settings in both devices and enabling LMAF codes in the CLMC for proper link operation. Software must check that both devices report CDLCCap=1b before enabling this feature. Software must set CDLCEn=1b in the host before setting CDLCEn=1b in the chipset. Once enabled by software, CDLC can only be disabled with a warm reset.

8.6.4.2 Combining Commands with CDLC

CDLC can be combined with other CLMC control feature SM commands to take effect on the same LDTSTOP# assertion. Refer to Figure 11 for the required CLMC sequencing.

8.6.5 Centralized Dynamic Link Disconnection (CDLD)

Centralized dynamic link disconnection allows the CLMC to disconnect the link by asserting LDTSTOP# without STPCLK/STOP_GRANT system management messaging between the host and chipset. CDLD requires LDTREQ# support in the CLMC. The conditions used to enter and exit CDLD are CLMC implementation specific and are outside the scope of this specification. To minimize the reconnect latency, CDLR can be performed periodically. Refer to Section 8.6.6 for details on CDLR.

x86 systems that support CDLD have special requirements for the behavior of LDTSTOP# and LDTREQ# with respect to C3 state. See Section F.2.4, mode 2, for details.

8.6.5.1 CDLD Software Initialization Requirements

Software must check that both devices report CDLDCap=1b before enabling this feature. Software must set CDLDEN=1b in the host before setting CDLDEN=1b in the chipset. Once enabled by software, CDLD can only be disabled with a warm reset.

8.6.5.2 Combining Commands with CDLD

CDLD can be combined with other CLMC control feature SM commands in the CLMC sequencing defined in Figure 11 by extending LDTSTOP# assertion time.

8.6.6 Centralized Disconnected Link Refresh (CDLR)

Centralized disconnected link refresh allows the CLMC to refresh DLL and phase recovery lock of a disconnected link by controlling LDTSTOP#. This allows the CLMC to effectively reduce link reconnection latency when using CDLD by keeping DLL and phase recovery logic trained.

CDLR can be applied periodically to minimize reconnection latency by reducing or eliminating T0 training time at link reconnection. Devices that support CDLR have implementation specific hardware mechanisms for tracking T0 training time requirements. Each device must take CDLR training time into account when determining the amount of T0 training time required at link reconnection. The interval

between CDLR refreshes is determined by CDLRInt[5:0], and the length of the refresh is determined by CDLRLen[5:0] (Refer to Section 7.18 for CDLR configuration details and Section 8.6.10 for CDLR sequencing).

8.6.6.1 CDLR Software Initialization Requirements

The CLMC applies CDLR based on the CDLRInt[5:0] and CDLRLen[5:0] settings (Refer to Section 7.18 for details on CDLR configuration). Software must understand the receiver T0 training time requirements for both the host and chipset to optimize the power savings and reconnection latency of the link using the CDLR capabilities of the CLMC. The required T0 training time is a function of link idle time and can also be affected by other parameters (e.g. DisLnSt). The CDLRInt[5:0] and CDLRLen[5:0] settings must account for other factors that influence the amount of time spent in T0 training for a fixed assertion time of LDTSTOP# (e.g. LDTSTOP# skew, TX clock stabilization time if exiting LS2 or LS3).

Software must check that both devices report CDLRCap=1b before enabling this feature. Software must set the host CDLREn=1 before setting the chipset CDLREn=1. Once enabled by software, CDLR can only be disabled with a warm reset.

8.6.6.2 Combining Commands with CDLR

CDLR is a refresh feature and is used independently from other CLMC sequencing. Refer to Section 8.6.10 for CDLR sequencing.

8.6.7 Centralized Dynamic Link Width (CDLW)

Centralized dynamic link width allows the CLMC to dynamically vary the link width using link width override SM commands and an associated LDTSTOP# assertion event for synchronization. Reducing link width reduces link power consumption based on the electrical state of the inactive lanes (determined by GlblLinkTrain[InLnSt] or LinkTrain[RxInLnSt and TxInLnSt] and LinkTrain[RxLSSel and TxLSSel] for the lanes above the software-programmed width or the override values provided for lanes below that width by CDLC). The conditions used to invoke CDLW are CLMC implementation specific and outside the scope of this specification.

CDLW events do not update the legacy link width register values. Separate registers are used to store the width in/out values from a link width override SM command. These registers are used by the link width arbitration logic and should only be updated by hardware when a link width override SM command is received. Hardware arbitration logic chooses the smallest link width from LinkConfiguration[LinkWidthIn/Out] and the CDLW width in/out registers. The arbitration is independent for width in and width out. This allows asymmetric link width configurations to resolve to the lowest requested width for each uni-directional connection. CDLW must not increase link width above that programmed in Link Configuration or undefined operation may result.

A link width increase due to a CDLW event must retrain the previously inactive lanes. To minimize the reconnect latency, CILR can be performed periodically or prior to the LDTSTOP# assertion event that synchronizes the link width increase. Refer to Section 8.6.8 for details on CILR.

8.6.7.1 CDLW Software Initialization Requirements

Software must check that both devices report CDLWCap=1b before enabling this feature. Software must set the host CDLWEn=1 before setting the chipset CDLWEn=1. Once enabled by software, CDLW can only be disabled with a warm reset.

8.6.7.2 Combining Commands with CDLW

CDLW can be combined with other CLMC control feature SM commands to take effect on the same LDTSTOP# assertion. Refer to Figure 11 for the required CLMC sequencing.

8.6.8 Centralized Inactive Lane Refresh (CILR)

Centralized inactive lane refresh allows the CLMC to refresh DLL and phase recovery lock for lanes made inactive by CDLW without affecting operational lanes. This allows the CLMC to effectively reduce link reconnection latency for CDLW width increase commands by allowing T0 training to occur while other link lanes are operational. Link refresh SM commands are used to synchronize the host and chipset transmitter and receiver actions. Refer to Section 8.6.10 for the required CLMC sequencing. CILR cannot be used when the link is disconnected (LDTSTOP# is asserted).

CILR can be applied periodically or opportunistically (e.g. just before a CDLW width increase command) to minimize reconnection latency by reducing or eliminating T0 training time at link reconnection. Each device must take CILR training time into account when determining the amount of T0 training time required at link reconnection. The conditions used to invoke CILR are CLMC implementation specific and are outside the scope of this specification.

Devices that support CILR have implementation specific hardware mechanisms for tracking T0 training time requirements. The CLMC has an implementation specific method to determine when to apply CILR.

8.6.8.1 CILR Software Initialization Requirements

Software must understand the receiver T0 training time requirements for both the host and chipset to optimize power savings and reconnection latency of the link using the CILR capabilities of the CLMC. The required T0 training time is a function of link idle time and can also be affected by other parameters (e.g. LSSel).

Software must check that both devices report CILRCap=1b before enabling this feature. Software must set the host CILREn=1 before setting the chipset CILREn=1. Once enabled by software, CILR can only be disabled with a warm reset.

8.6.8.2 Combining Commands with CILR

CILR is a refresh feature and is used independently from other CLMC features. Refer to Figure 12 for the required CLMC sequencing.

8.6.9 Centralized Dynamic Link Frequency (CDLF)

Centralized dynamic link frequency allows the CLMC to dynamically vary the link frequency using link frequency override SM commands and an associated LDTSTOP# assertion event for synchronization. Link frequency can be dynamically varied within Gen1 frequencies and within Gen3 frequencies, but cannot be used to switch between Gen1 and Gen3 frequencies. The conditions used to invoke CDLF are CLMC implementation specific and outside the scope of this specification.

CDLF events do not update the legacy link frequency register value. A separate register is used to store the frequency value from a link frequency override SM command. This register is used by the link frequency arbitration logic and should only be updated by hardware when a link frequency override SM command is received. The CDLF frequency register is set to the maximum frequency supported by the device at cold and warm reset. Hardware arbitration logic chooses the lowest link frequency from the legacy link frequency register and the CDLF frequency register.

8.6.9.1 CDLF Protocol and Electrical Requirements

~~CDLF is only supported using Gen3 protocol.~~

When switching frequencies using CDLF commands, each device is responsible for automatically altering settings necessary to conform to the appropriate electrical specifications (e.g. altering, enabling, or disabling equalization, de-emphasis, etc.). Implementation to achieve electrical compliance is device specific. Hardware should override but not modify software configured register settings necessary to maintain electrical compliance. In the event of a warm or cold reset (CDLFE_n reset to 0) any hardware overrides to register settings should be removed allowing the link to reconnect in the software configured state.

8.6.9.2 CDLF Software Initialization Requirements

Software must set PLL lock time in the CS to the greater requirement of the host and CS. Software is responsible for properly translating any device specific limitations on CDLF operation (e.g. for electrical compliance) into the appropriate CDLFLinkFreqEn[15:0] settings. The frequency set by software in the link frequency register must be enabled in CDLFLinkFreqEn[15:0]. Software must check that both devices report CDLFCap=1b before enabling this feature. Software must set the host CDLFE_n=1 before setting the chipset CDLFE_n=1. Once enabled by software, CDLF can only be disabled with a warm reset.

8.6.9.3 Combining Commands with CDLF

CDLF can be combined with other CLMC control feature SM commands to take effect on the same LDTSTOP# assertion. Note that T0 training time is always the Tmr0 maximum after the LDTSTOP# deassertion following a CDLF command. This overrides any training performed using CILR or CDLR prior to the LDTSTOP# assertion on which the link frequency is changed due to the CDLF link frequency override SM command. Refer to Figure 11 for the required CLMC sequencing.

8.6.10 CLMC Sequencing

The following figures define the required CLMC sequencing for CLMC features. These figures assume all CLMC features are enabled. Additional CLMC logic is required to ensure only enabled sequences are allowed.

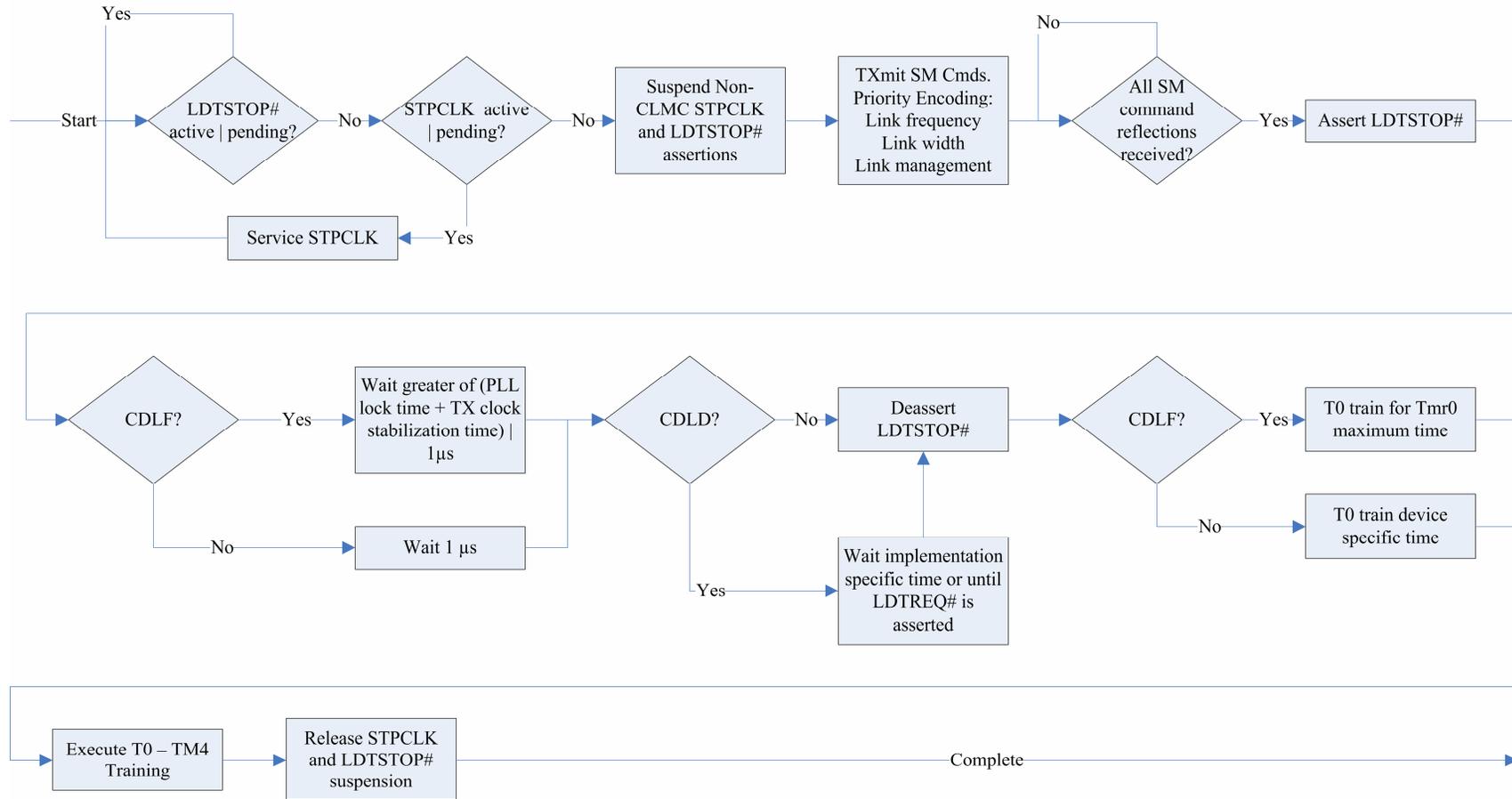


Figure 11. CLMC Control Feature Sequencing Diagram

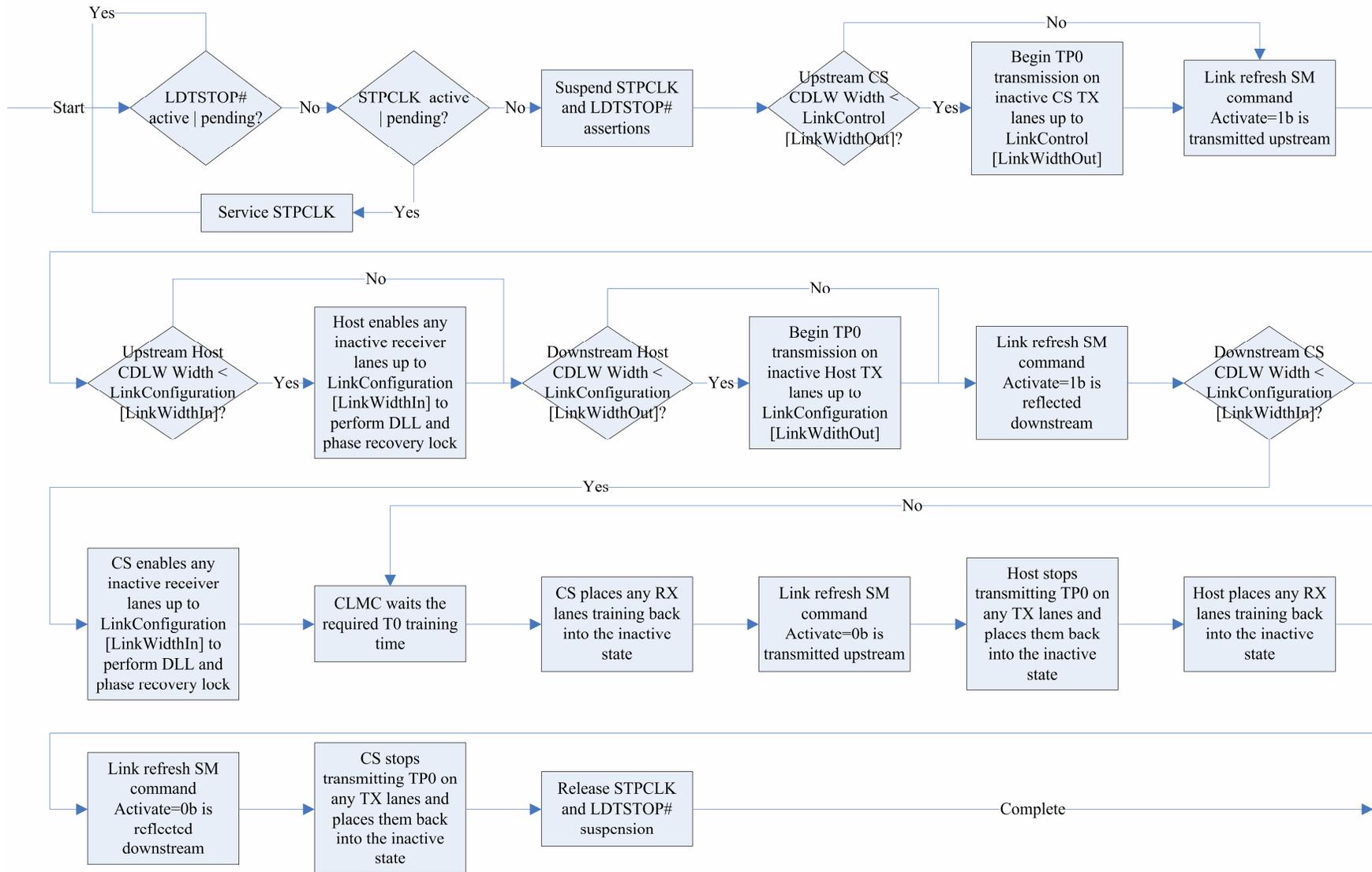


Figure 12. CLMC Sequencing Diagram for CILR

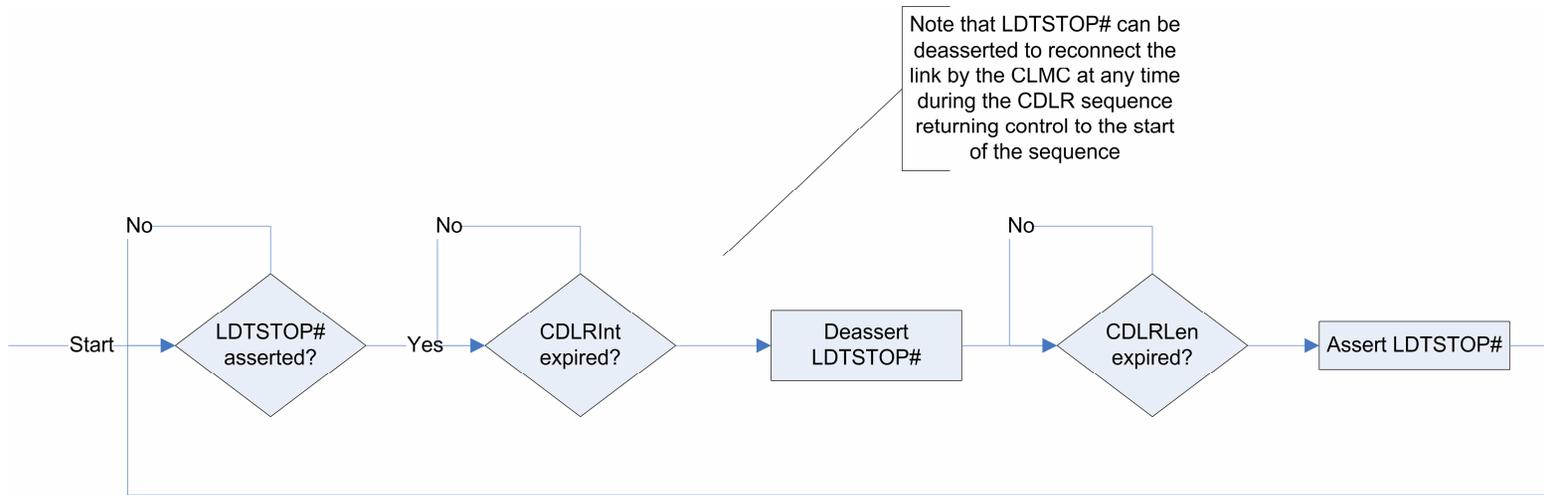


Figure 13. CLMC Sequencing Diagram for CDLR

8.6.11 CLMC System Management Commands

SysMgtCmd	Command Type
0001 00xx xxxx	Link width override [5:3]: Upstream link width [2:0]: Downstream link width Width encodings follow the defined LinkWidthIn/Out encodings for LinkConfiguration[LinkWidthIn/Out]
0001 0100 xxxx	Link frequency override Link Frequency[3:0]: Link frequency Frequency encoding follows the defined link frequency encoding for the legacy link frequency register.
0001 0101 xxxx	Link Management [3:0]: LMAF 0h: Cold and warm reset value for all devices. 1h – Fh: Device specific.
0001 0110 xxxx	Link Refresh [3]: Activate 0b: Link refresh inactive 1b: Link refresh active [2:0]: Implementation-specific
0001 0111 xxxx	Reserved for extended link frequency override

8.7 Vendor-Defined Virtual Wire Messages

The system management command range 0E2-0FFh is set aside for virtual wire messages not otherwise defined in this specification. Hosts, switches, and bridges are required to pass them upstream and broadcast them downstream. Tunnels are required to forward them. No accumulation of these messages is done and no extra state needs to be maintained by hosts, switches, or bridges. Devices that receive these messages could have configuration bits to control how many transmitters exist for any given message, or the payload or other bits could be used to identify the sending device. Devices that transmit or receive these messages must implement a configuration mechanism to control which command encodings are used for each message, so that software may resolve conflicts between different vendor's usage of the messages. Each device should consume as few command encodings as possible to allow for future expansion and interoperability with devices from other vendors.

9 Interrupts

HyperTransport™ technology provides a generic message-based interrupt system. Usage of the information carried in the messages is implementation-specific. See Appendix F.1 for x86-specific usage. One programming model for discovery and configuration of interrupts in a HyperTransport device is described in Section 7.6. Another is to use the MSI or MSI-X capability defined in the *PCI Local Bus Specification Revision 3.0* in combination with the HyperTransport MSI Mapping capability defined in Section 7.12.

9.1 Interrupt Requests

All interrupt requests, regardless of interrupt class, are sent from the interrupting device to the host bridge using posted byte WrSized packets to the reserved range defined in Chapter 5. The Count field is always 0, which indicates that only a single doubleword data packet follows the write. The doubleword data packet is not used to carry byte masks; instead, it is used to carry interrupt information, as described below. Some systems limit the use of IntrInfo (see Appendix F.1 for one example). Software is required to configure devices to send only interrupt requests that are valid for the host. The format of interrupt-request packets is shown in Table 105.

Table 105. Interrupt Request Packet Format

Bit-Time	CTL	7	6	5	4	3	2	1	0
0	1	SeqID[3:2]		Cmd[5:0]: 1010X1					
1	1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	1	Count[1:0]		Rsv	Reserved				
3	1	IntrInfo[7:2]					Count[3:2]		
4	1	IntrInfo[15:8]							
5	1	IntrInfo[23:16]							
6	1	IntrInfo[31:24]							
7	1	Addr[39:32]							
8	0	IntrInfo[39:32]							
9	0	IntrInfo[47:40]							
10	0	IntrInfo[55:48]							
11	0	Reserved							

The host bridge is then responsible for delivery to the correct internal target or targets.

Application Note

Because interrupt request packets travel in the posted channel, they push posted writes with the same UnitID as the interrupt request if the PassPW bit in the interrupt request packet is clear. Therefore, all preceding posted writes with the same UnitID, source, and target as the interrupt request will be visible at their targets within the host before the interrupt is delivered. If a flush is used to push posted writes before the interrupt request is sent, the PassPW bit in the interrupt request may be set. A fence may be issued ahead of the flush (or interrupt request with PassPW clear) to push posted writes in all UnitIDs upstream of the device sending the interrupt request.

The type of interrupt is identified by IntrInfo[4:2], and the meaning is implementation-specific, with the exception that Type 111b is reserved for the End of Interrupt (EOI) message.

Interrupts may require an EOI indication to acknowledge the servicing of the interrupt, controlled by IntrInfo[5] (RQEOI). A subsequent interrupt from that source shall not be sent until the Waiting for EOI bit is cleared. IntrInfo[31:8] is returned in the EOI message, although some hosts may not support use of all bits. IntrInfo[7:6] may have special meanings in some systems, and therefore their use may be restricted. (See Appendix F.1 for one example of when IntrInfo is restricted.) Host bridges must accept multiple interrupt requests without blocking the posted channel.

Note that devices using MSI generally do not support EOI messages because they are not defined in PCI, so the RQEOI bit should not be set.

9.2 End of Interrupt (EOI)

EOI messages are sent in Broadcast message packets to all nodes across the HyperTransport I/O fabric. Each device is responsible both for accepting the EOI and clearing outstanding interrupts associated with the specified IntrInfo, and for passing the EOI down the chain. Some systems limit the use of IntrInfo, see Appendix F.1 for an example. The format of an EOI packet is shown in Table 106.

Table 106. EOI Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]: 111010					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Reserved							
3	Reserved			MT[2:0]=111b			Rsv	
4	IntrInfo[15:8]							
5	IntrInfo[23:16]							
6	IntrInfo[31:24]							
7	Addr[39:32]							

EOIs use the same reserved address range as interrupt requests. The IntrInfo[4:2] field must always contain the value 111 (EOI). IntrInfo[31:8] duplicates IntrInfo[31:8] from the interrupt being acknowledged. The exception is that IntrInfo[15:8] in EOI may be 00h to match any value of

IntrInfo[15:8] in the interrupt definition as a “wildcard” value for system hosts that do not return it in EOI. EOI may only be sent downstream.

As an alternative to sending EOI if the function that sent the interrupt can be uniquely identified, a configuration space write to the Interrupt Definition register (defined in Section 7.6.2) can be performed to clear the Waiting for EOI bit. This completes service of the interrupt, and enables the interrupting function to send more interrupts.

10 Error Handling

10.1 Error Conditions

This specification defines a variety of error conditions. Each detectable error condition has one or more log bits associated with it, which are set when that condition is detected. The log bits are persistent through warm reset and are cleared by software writes of 1s. Implementation of all error checking logic beyond CRC checking is optional. Devices that do not check for one or more error conditions should hardwire the log bits for those conditions to 0. For reporting methods, see Section 10.2.

Depending on signaling conditions and synchronization between devices, one device may detect a reset before another and start driving reset signaling (CTL=0, CAD=1s). To prevent logging false errors in Gen1 protocol mode, if CTL is deasserted when an error is detected, a device should drop the affected packet but otherwise delay responding to that error until CTL is asserted, or if RESET# is asserted first, the error is dropped. If CTL is deasserted for longer than the time specified by the CTL Timeout bit, a protocol error is logged immediately.

If RESET# is detected by a transmitting device before the receiving device during a data packet, some or all of the data may be received as 0's instead of the original values in Gen1 protocol mode. While some devices are immune to the corruption that results due to higher-level protocol requirements before committing data to action, other devices need to specifically eliminate this corruption. In order to achieve this, devices that are vulnerable to this corruption must not commit data to action until a subsequent control packet has been received.

10.1.1 Transmission Errors: 8-Bit, 16-Bit, and 32-Bit Links (non-retry)

A 32-bit cyclic redundancy code (CRC) covers HyperTransport™ links operating without retry. The CRC is calculated on each sublink independently and covers the link as a whole, not individual packets. CTL is included in the CRC calculation. In each bit-time, CAD is operated on first, beginning with bit 0, followed by CTL. For 16- and 32-bit links, only sublink 0 uses its CTL signal, while a CTL value of 0 (Data) is used for sublinks 1 to 3.

The periodic CRC is computed over 512 bit-times. Each new CRC value is stuffed onto the CAD bits of the link 64 bit-times after the end of the 512-bit-time window and occupies the link for 4 bit-times. Therefore, bit-times 64–67 (the first bit-time being 0) of each CRC window after the first contain the CRC value for the previous window. There is no CRC transmission during the first 512-bit-time window after the link is initialized, and the value of the transmitted CRC bits is not included in the CRC calculation for the current window. Therefore, each CRC window after the first is 516 bit-times in length—512 of which are included in the calculation of the CRC that will be transmitted in the next window. There is no indication on the bus that CRC information is being transmitted. It is the responsibility of the parties on both ends of the link to count bit-times from the beginning of the first

valid packet after link synchronization to determine the boundaries of the CRC windows. During transmission of the CRC, the CTL bit must be driven to a value of 1 (Control).

For example, the contents of 8-,16- and 32-bit links during the first three CRC windows after link synchronization are shown in Table 107.

Table 107. CRC Window Contents After Link Synchronization

CRC Window After Sync	Number of Bit-Times	Link Contains
1 st	512	Payload for first window
2 nd	64	Payload for second window
	4	CRC of first window
	448	Payload for second window
3 rd	64	Payload for third window
	4	CRC for second window
	448	Payload for third window

The polynomial used to generate the CRC is:

$$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

The CRC is calculated by computing the remainder resulting from the division of the data by the CRC polynomial. The register used to perform the calculation is seeded with all 1 bits at the beginning of each CRC window. Note that, in the classical CRC definition, thirty-two 0 bits are appended to the end of the data word before performing the division to cover error bursts that can span both the CRC and the data it covers which can be adjacent. This is not done in HyperTransport links because the CRC and the data it covers are never adjacent, allowing more efficient parallel implementations of the calculation. The CRC bits are inverted before being transmitted on the link to catch a wider range of bit errors.

The code below shows the calculation performed on the CRC accumulation register across a single bit-time (9 bits) of data.

```
static uint poly = 0x04C11DB7; /* the polynomial */
uint compute_crc(uint data, uint crc)
{
    int i;
    for (i=0; i<9; ++i) {
        uint tmp = crc >> 31; /* store highest bit */
        crc = (crc << 1) | ((data >> i) & 1); /* shift message in */
        crc = (tmp) ? crc ^ poly : crc; /* subtract poly if greater */
    };
    return crc;
};
```

Detection of a link error on any byte lane causes the appropriate CRC error bit to be asserted in the Link Control CSR. A CRC error must be assumed to have corrupted both data and control information, allowing the link interface to reach an indeterminate state. Corrupted information may have been passed to other interfaces of the device. CRC errors may be mapped to cause sync flooding, fatal, or nonfatal error interrupts.

It is possible that a sync flood may begin just before or at the bit-time where the CRC is transmitted, resulting in some or all bits of the CRC being transmitted as 1s. In this situation, a device should recognize the sync flood instead of detecting a CRC error. In order to guarantee this, a device should delay setting the CRC error bit(s) of the Link Control CSR until a sync flood has been ruled out (typically 16 bit-times).

10.1.2 Transmission Errors: 2-Bit and 4-Bit Links (non-retry)

For the purpose of CRC coverage, 2- and 4-bit links are analogous to 8-bit links running at quarter and half speed, respectively. That is, the CRC value generated for 2- or 4-bit links is identical to that generated for an 8-bit link carrying the same values. The extra CTL values are not used by the receiver and are not included in the CRC calculation.

Table 108 summarizes the CRC differences between 2-bit, 4-bit, and 8-bit (or wider) links.

Table 108. CRC Values for Different Link Widths

What	8-Bit	4-Bit	2-Bit
CRC calculation (LSB first) (" " means concatenation)	CTL CAD[7:0]	CTL ₀ CAD ₁ [3:0] CAD ₀ [3:0]	CTL ₀ CAD ₃ [1:0] CAD ₂ [1:0] CAD ₁ [1:0] CAD ₀ [1:0]
CRC window size	512 bit-times	1024 bit-times	2048 bit-times
CRC value stuffed onto CAD:	64 bit-times after start of window	128 bit-times after start of window	256 bit-times after start of window
CRC transmission length	4 bit-times	8 bit-times	16 bit-times
CRC test mode duration	512 bit-times	1024 bit-times	2048 bit-times

10.1.3 Transmission Errors: Retry Mode

Gen3 protocol incorporates a hardware-based retry mode that allows recovery from soft errors at the link level to improve system reliability. The error detection mechanism uses a 32-bit CRC appended to every packet. The periodic-CRC-based mechanism is not used when retry mode is in use, however the timeslots for periodic CRC transmission are still present to allow asynchronous clock operation. The control and status register bits for the periodic CRC are reassigned to handle unrecoverable errors.

As in periodic CRC mode, the CRC in retry mode is computed on the entire packet, including control header, CTL bits, and data. The same polynomial as the periodic CRC is used, the CRC register is initialized to all 1's, and the CRC is bitwise inverted before being transmitted.

There are several differences in the use of CRC in retry mode:

- The CRC register is initialized at the beginning of every packet.
- The data used to calculate CRC is independent of the size of the link, unlike in periodic CRC mode, where a separate CRC was calculated for each 8 bits of link width. This pseudo-code illustrates how CAD and CTL from each bit-time of each doubleword of a packet are combined for processing:

```
case (size) {
2: data = {CTL12, CAD15[1:0], CAD14[1:0], CAD13[1:0], CAD12[1:0]
           ,CTL8, CAD11[1:0], CAD10[1:0], CAD9[1:0], CAD8[1:0]
           ,CTL4, CAD7[1:0], CAD6[1:0], CAD5[1:0], CAD4[1:0]
           ,CTL0, CAD3[1:0], CAD2[1:0], CAD1[1:0], CAD0[1:0]}
```

```

4: data = {CTL6, CAD7[3:0], CAD6[3:0], CTL4, CAD5[3:0], CAD4[3:0]
           ,CTL2, CAD3[3:0], CAD2[3:0], CTL0, CAD1[3:0], CAD0[3:0]}
8: data = {CTL3, CAD3[7:0], CTL2, CAD2[7:0]
           ,CTL1, CAD1[7:0], CTL0, CAD0[7:0]}
16: data = {CTL1[1], CAD1[15:8], CTL1[0], CAD1[7:0]
            ,CTL0[1], CAD0[15:8], CTL0[0], CAD0[7:0]}
32: data = {CTL[3], CAD[31:24], CTL[2], CAD[23:16]
            ,CTL[1], CAD[15:8], CTL[0], CAD[7:0]}
    }
    
```

- The CRC algorithm is modified to protect against burst errors affecting both the packet and CRC, as in a classical CRC. This pseudo-code illustrates the algorithm used:

```

static uint poly = 0x04C11DB7; /* the polynomial */
uint compute_crc(uint data, uint crc) {
int i;
for (i=0; i<36; ++i) {
/* xor highest bit w/ message: */
uint tmp = ((crc >> 31) & 1)^((data >> i) & 1);

/* subtract poly if greater: */
crc = (tmp) ? (crc << 1)^ poly : (crc << 1);
};
return crc;
};
    
```

- The timeslot for periodic CRC transmission is still present, however CAD and CTL for the timeslot is undefined and neither included in CRC calculation nor checked by receivers. This provides padding to allow asynchronous clocking mode receivers to catch up with transmitters.
- CRC is transmitted at the end of every packet and is distinguished by the CTL encoding, as described in Section 3.1.2.
- Packets must not be separated from their CRC except by insertion of the periodic CRC timeslot.
- CRC calculation for control packets inserted into data is completely independent from calculation for the enclosing packet.
- Address and Source ID extension doublewords are considered part of the command they modify, and are covered by the same CRC, not a separate one.

- Sync flood is considered a link state, so sync packets do not have CRC. All other packets (including NOPs and Disconnect NOPs) have CRC.
- Receivers validate a packet by checking that the CRC matches the expected value for the packet.
- The conventional CRC-32 calculation used for the periodic CRC and other applications can be used instead, provided the CRC register is initialized to 0x46AF6449 and 32 0's are processed after the data, before the CRC is inverted and transmitted or checked against the received CRC. This alternative may be useful for software models where a 32-bit implementation is more efficient than the 36-bit implementation typically used in hardware.

10.1.4 Protocol Errors

Protocol errors represent basic failings of the low-level packet protocol. Detectable protocol errors include the following framing errors:

- CTL transition on other than a 4-byte boundary, except during diagnostic modes or as per Section 3.1.2
- CTL deassertion when data transfer is not pending, except during diagnostic mode or as per Section 3.1.2
- Command with associated data packet inserted when data transfer due to a previous command is pending
- Reserved command encoding detected in a control packet
- CTL deassert time exceeds time value set by CTL Timeout bit (Section 7.5.8.4). This check does not apply when in retry mode.
- CTL deasserted during periodic CRC transmission except as per Section 3.1.2
- Address Extension Command followed by a packet other than a command with address
- Source ID Extension Command followed by a packet other than an address extension or request
- Unexpected CTL encoding, Cmd[5:0] value, or Count[3:0]; including errors in the CTL encoding for the per-packet CRC

Additional “non-framing” protocol errors include:

- *RxNextPktToAck* received (in a NOP with validated CRC) for a packet that has not been sent
- Inconsistency in other fields when all Cmd, Count, CTL, and CRC checks pass

In Gen1 protocol, detection of any protocol error results in the immediate setting of Link Error [Protocol Error]. At this point, framing on the link must be assumed to have been lost, and the link interface may go to an indeterminate state.

In Gen3 protocol, a framing error only results in a retry, as defined by Section 10.3. Non-framing errors may result in either a retry or immediate setting of Link Error [Protocol Error].

Protocol errors may be mapped to sync flood, fatal or nonfatal error interrupts.

10.1.5 Receive Buffer Overflow Errors

The HyperTransport flow control mechanism is supposed to ensure that received packets always have buffer space awaiting them. In the event that a packet is received that has no buffer available to receive it, the Overflow Error bit is set in the Link Error CSR. Since this can only happen if packet-tracking state has been corrupted, the link interface must be assumed to be in an indeterminate state. Overflow errors may be mapped to sync flood, fatal, or nonfatal error interrupts. In retry mode a receive buffer overflow must not be logged until after CRC for the received packet(s) has been validated.

10.1.6 End of Chain Errors

Directed packets (request or response) hit the end of a HyperTransport chain when they are forwarded the length of the chain without being accepted by any device along the way and reach a transmitter that is unable to transmit them for any of the following reasons:

- The End of Chain bit is set (Section 7.5.4.7)
- The Initialization Complete bit (Section 7.5.4.6) is clear and the Drop On Uninitialized Link bit (Sections 7.5.3.2.5/7.5.3.3.8) is set
- The Packet is a request containing a 64 bit address, but the 64 bit address enable (Section 7.5.4.13) is clear
- The packet is in a VCSet which is not enabled (Section 7.14.1.5/7.14.1.6)

Once the end of chain is reached, there is nowhere to forward the packet, so it is dropped.

For nonposted requests, hitting the end of chain is indicated by generating an appropriate response (RdResponse or TgtDone) for the request, with both Error bits set (Master Abort), and all read data as Fs. No logging is required, and no further action is taken.

For posted requests and responses, returning an error response is not possible. Accordingly, the fact that the packet was dropped is indicated by setting the End of Chain Error bit in the Link Error CSR of the link interface containing the disabled transmitter. Rejecting a Device Message with the Silent Drop bit set does not cause the End Of Chain Error bit to be set.

In double-hosted systems, a second type of End of Chain error is possible, where a posted request or response packet is received from one host by the other host and is not of a type that the receiving host accepts. In this case, there is no associated transmitter. The dropped packet is logged by asserting the Host Inbound End of Chain Error bit in the Error Status register.

End of Chain errors may be mapped to fatal or nonfatal error interrupts. In retry mode end of chain errors must not be logged until after CRC for the received packet(s) has been validated.

10.1.7 Chain Down Errors

Host interfaces are required to store state for nonposted requests that they issue to a HyperTransport chain, in order to match the SrcTag of the response with the original request. It is possible for the HyperTransport chain to come down after a nonposted request has been issued to it, but before the response is received. This can occur because of sync flooding on the chain or the assertion of HyperTransport RESET#. If this occurs, the host must flush the state of all outstanding nonposted requests and return Target Abort responses for them. No logging occurs on the host interface. Signaled Target Abort may be asserted on the primary interface of the bridge, depending on what that interface connects to.

Slave devices are assumed to have all internal state reset on HyperTransport RESET#, and all subsidiary buses reset. Therefore, there is normally no need to flush nonposted request state in a slave device due to a chain going down. However, if some type of intelligent slave was implemented that maintained state through a HyperTransport RESET#, this device would need to flush its nonposted request state as well, and log appropriate error state.

10.1.8 Response Errors

Several types of errors are possible in which a response is received by a device that does not properly match a request:

- Response received by a device that does not have a request outstanding with that SrcTag.
- RdResponse received in response to a WrSized or Flush request.
- TgtDone received in response to a RdSized or Atomic Read-Modify-Write request.
- RdResponse received in response to a RdSized request with a Count field not matching the original request.
- RdResponse received in response to an Atomic Read-Modify-Write request with a Count field not equal to 1.

All of these errors are logged by setting the Response Error bit of the Error Status CSR. Response errors may be mapped to fatal or nonfatal error interrupts. In retry mode response errors must not be logged until after CRC for the received packet(s) has been validated.

10.2 Error Reporting

HyperTransport devices detecting errors have several ways to report those errors to the system. They are listed here in order of increasing severity.

10.2.1 Error Responses

For nonposted requests that encounter an error condition, a HyperTransport error response may be issued. This is the preferred means of error signaling, where possible, because the error is localized to a particular transaction and indicated to the requester of that transaction, which may then take appropriate

action. Error responses are indicated by the presence of an asserted Error bit in the response packet. There are three subtypes of error responses, indicated by the state of the Error bits in the packet.

A Target Abort indicates that the device receiving the request took an error. If the transaction was a read, the returning data cannot be used. If the transaction was a write, the target location must be assumed to have gone to an undefined state. Devices receiving a Target Abort response set the Received Target Abort bit in their Status CSR or (for bridges receiving the response on their secondary bus) their Secondary Status CSR. Devices driving a Target Abort response set the Signaled Target Abort bit in their Status CSR or Secondary Status CSR, as appropriate. Target Abort responses pass through bridges as Target Abort responses.

A Data Error indicates that the device receiving the request detected an error in the data, such as a parity or ECC mismatch on another bus or memory. If the transaction was a read, the returning data cannot be used. If the transaction was a write, the target location must be assumed to have gone to an undefined state. Devices with the Data Error Response bit set that receive a Data Error response set the Master Data Error bit in their Status CSR or (for bridges receiving the response on their secondary bus) their Secondary Status CSR. Devices driving a TgtDone with Data Error set the Data Error Detected bit in their Status CSR or Secondary Status CSR, as appropriate.

A Master Abort indicates that a directed request failed to find a device on the chain that would accept it. Devices receiving a Master Abort response set the Received Master Abort bit in their Status CSR or (for bridges receiving the response on their secondary bus) their Secondary Status CSR. Master Abort responses propagate through HyperTransport bridges in the same manner as Master Aborts through PCI bridges – they are either converted to normal (non-error) responses or to Target Abort responses, depending on the state of the Master Abort Mode bit of the Bridge Control CSR. All Fs are returned as data for read responses.

10.2.2 Data Error in Posted Requests

The Data Error bit in posted requests may be set, indicating that the data being carried has been corrupted. This could have occurred on the source bus, an intermediate bus, or within a data buffer in a device. Devices that receive a request with Data Error indicated set the Data Error Detected bit in the Status register or (for bridges receiving the request on their secondary bus) Secondary Status register. Devices that send a posted request with Data Error indicated set the Master Data Error bit in their Status register if Data Error Response is set in their Command register. Bridges sending a posted request with data error on their secondary bus set the Master Data Error bit in their Secondary Status Register if Data Error Response is set in their Bridge Control register.

10.2.3 Error Interrupts

HyperTransport technology optionally defines two severity levels of error interrupt, [fatal error](#) and [nonfatal error](#). These may be used to report error conditions to the host which cannot be reported via an error response, but which do not prevent the HyperTransport chain from transmitting packets. The [fatal](#) and [nonfatal error](#) interrupts are implemented by providing the capability to generate two types of

interrupt packets and additionally may be provided by external interrupt pins on a HyperTransport device. Devices that do not implement either should hardwire the enables for that interrupt to 0.

10.2.4 Sync Flooding

Sync packet flooding is used to report errors to the host that cannot be signaled by any other in-band means, due to the chain reaching a state where it can no longer be trusted to transmit packets. Sync flooding also has the effect of putting the entire chain into an inactive state after an error has been taken, with the intent of shutting down transmission before potentially corrupted data reaches its final destination. Devices detecting a sync flood must assume any data that they have recently received may be corrupted, and they should stop transferring data to other interfaces as quickly as possible. Once sync flooding has occurred, a warm reset of the chain is required to re-enable normal functioning of the chain. Because error status bits are persistent through warm reset, they can be polled to determine the cause of the sync flood event.

When an error that causes sync flooding is detected, the detecting device drives sync packets (CAD and CTL to all 1s) on its active lanes. This is recognized by devices at the other ends of the links as a sync packet, even if the nodes are out of sync or the clock has been corrupted. Any device detecting sync flooding on one of its receivers after link initialization has completed drives sync packets on its transmitter(s), including the one back to the device it received the sync flood from. All transmitters, once flooding, continue to drive sync packets until reset. In this way, the sync flood propagates the entire length of the chain in both directions. CRC is not generated on links transmitting sync packets, nor is it checked on incoming links on which a sync packet has been detected. All devices participating in the flooding set the Chain Fail bit in the Error Status register, whether they initiated it or are just propagating it.

If scrambling or unscrambling becomes misaligned in Gen3 protocol, a receiver cannot detect sync flood immediately; a sync flood will eventually be detected after all training attempts fail. See Section 12.3.16.

Sync flood initiation by a HyperTransport device is analogous to SERR# assertion by a PCI device. Devices must have the SERR# Enable bit of the Command register set in order to initiate sync flooding. Devices initiating sync flooding set the Signaled System Error bit in the Status register. Sync flood propagation from the secondary to the primary interface of a HyperTransport-to-HyperTransport bridge is analogous to SERR# propagation through a PCI-PCI bridge. The bridge sets the Detected System Error bit in its Secondary Status register when it detects the sync flooding, as long as it is not the initiator of the sync flood. The SERR# Enable bit of the Bridge Control register must be set in order for the secondary interface to propagate the sync flood information to the primary interface. The primary interface in turn uses the SERR# Enable bit of the Command register to determine whether to propagate the sync flood to the primary bus. If propagating the sync flood to the next bus up (or to the host) is not desired, the sync flood may at this point be converted to a fatal error interrupt or a nonfatal error interrupt.

Sync flood propagation from device to device along a chain is analogous to SERR# assertion propagating along the bus in PCI. No enables are required for sync flood propagation within a chain.

Sync flooding always propagates from the primary to the secondary interface of HyperTransport-to-HyperTransport bridges. Bridges can also initiate sync flooding on their secondary bus due to internal errors. This has no analog in PCI. It conveys no error information and is merely used to disable links on subsidiary chains and to stop traffic as quickly as possible. No enables are required.

10.2.5 Error Routing CSRs

Table 109 shows the CSR fields used to log each error type and route error assertion to the appropriate reporting method. Entries are of the form Register/Subfield.

All checked-for error conditions have a log bit associated with them. The “enable” columns in Table 109 give the CSR bit that routes that error condition to the appropriate response. If the log bit is asserted with that enable, the error notification occurs.

Table 109. Error Routing Registers

Error Type	Log Bit	Flood Enable	Fatal Error Enable	Nonfatal Error Enable
Protocol	LinkErr/ProtErr	ErrHnd/ProtFloodEn	ErrHnd/ProtFatalEn	ErrHnd/ProtNonFatalEn
Overflow	LinkErr/OvfErr	ErrHnd/OvfFloodEn	ErrHnd/OvfFatalEn	ErrHnd/OvfNonFatalEn
EOC	LinkErr/EocErr		ErrHnd/EocFatalEn	ErrHnd/EocNonFatalEn
Inbound EOC*	HstCmd/InbEocErr*			
Response	ErrHnd/RespErr		ErrHnd/RespFatalEn	ErrHnd/RespNonFatalEn
CRC	LinkCtrl/CrcErr[3:0]	LinkCtrl/CrcFloodEn	ErrHnd/CrcFatalEn	ErrHnd/CrcNonFatalEn
SERR*	SecStatus/SerrDet*	BridgeCtrl/SerrEn	ErrHnd/SerrFatalEn*	ErrHnd/SerrNonFatalEn*

Notes:

* --Indicates host-only bits. These error conditions are not checked in slaves, and the CSR bits are reserved in slaves.
 Shaded enable boxes indicate that the given error type may not be mapped to the given reporting method.
 Sync flooding can only be initiated on the primary link by a device if the SERR# Enable bit in the Command register (7.3.1.4) is set.

10.3 Error Retry Protocol

10.3.1 Overview

Retry mode improves the reliability of an I/O system based on HyperTransport links. This mode uses a hardware-based retry to attempt recovery from soft errors at the link level.

The error detection and recovery process ensures that all packets are transferred from the transmitter to the receiver exactly once. Transactions are replayed in an order that satisfies the HyperTransport ordering rules described in Sections 3.1 and 6, with the exception that embedded packets are considered unordered with respect to the packet in which they are embedded.

The retry process uses a history structure on the transmit side of each link, packet counters, and acknowledge bits in the NOP packet. Every NOP carries a packet count to acknowledge the last packet received without an error. The receiver checks CRC on every packet. If an error is detected, the packet is discarded and a retry handshake is initiated. The transmitter reissues the packets from the failing packet on. If an error cannot be recovered after a programmable number of retry attempts, then the link is declared to have suffered an unrecoverable error and an interrupt or sync flood is generated if so enabled.

Each link implements log bits and a retry counter that enable higher-level software to monitor the health of the link since link errors are corrected in hardware without high-level intervention.

The periodic-CRC-based mechanism defined in Section 10.1.1 is not used when a link is in Retry Mode, however the timeslots for its transmission are still reserved to allow asynchronous clock operation. The control and status bits for the periodic CRC are reassigned to handle unrecoverable errors.

10.3.2 Retry Mode Entry and Exit

The LinkRetryEnable bit (See Section 7.15.2.1) is set to ‘1’ to enable retry mode. A link interface enters retry mode on warm reset (not LDTSTOP#) when LinkRetryEnable is set and exits retry mode on warm reset when LinkRetryEnable is clear. Software must ensure that LinkRetryEnable is programmed to the same value on both sides of a link before initiating a warm reset.

10.3.3 Speculative Forwarding and Stomping

The simplest implementation of retry mode in a tunnel is to store incoming packets and only forward or accept them after they have been validated. To reduce latency, a tunnel may begin speculatively forwarding a packet before CRC for the packet has been received and checked. If the packet is not validated, it is “stomped” by modifying the CRC when transmitted.

Tunnels that implement speculative forwarding must follow these rules:

- Stomped packets are marked by sending the inverse of the correct CRC for the packet.
- Tunnels must only begin forwarding a packet if the packet can be validated before the CRC must be sent.
- Speculatively forwarded packets must be valid commands with available flow control credits.
- Speculative forwarding may only be done to links in retry mode.
- Info packets may not be stomped.

All devices must receive stomped packets correctly to prevent false errors:

- When a stomped packet is received, it should be discarded without error or retry.
- The correct flow control credits for the stomped packet must be freed (the receiving device must send credits after the packet has been discarded) to prevent deadlocks. If a stomped packet overflows a flow control buffer, it is treated like any other overflow, as described in Section 10.1.5.
- The receiver must not assume that a stomped command can be resent. It is possible that it had a corrupted command code or other attributes that completely changed the nature of the packet.

10.3.4 Packet History and Acknowledgement

The transmit side of each link maintains a history structure containing an implementation-dependent number of entries that keep track of each packet, and an 8-bit counter called *TxNextPktToAck* that is incremented on each unstomped transmitted non-info packet. The history structure may be a simple in-order buffer of all transmitted packets or part of a more sophisticated scheduler. The receiver maintains a corresponding 8-bit *RxNextPktToAck* counter. *RxNextPktToAck* is returned to the other side of the link to acknowledge packets that have been successfully received.

TxNextPktToAck requirements:

- Cleared to 0 on warm or cold reset
- State maintained on retry or LDTSTOP# disconnect and reconnect
- Not incremented for stomped packets or info packets
- Incremented when the last bit-time of a non-info packet is sent

History structure requirements:

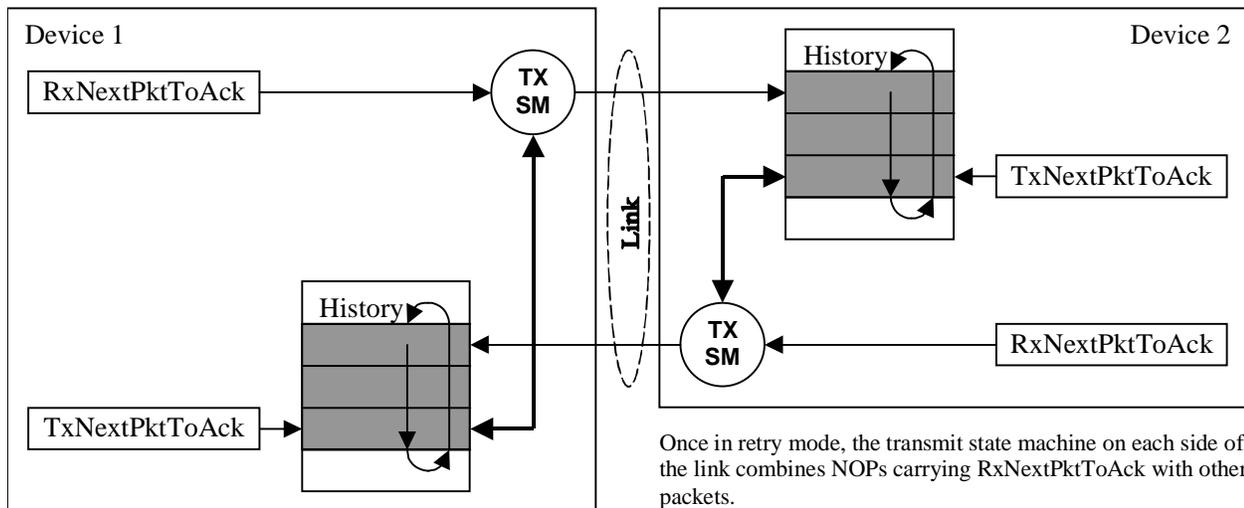
- All entries are removed on warm or cold reset.
- Each entry includes the value of *TxNextPktToAck* and the packet sent.
- Stomped packets are not committed to the history structure.
- Info packets are not committed to the history structure.
- Non-info packets are committed to the history structure when the last bit-time is sent.
- Packets too large for the available space in the history structure must not be sent.
- Control packets must not be inserted within data packets if they would prevent the enveloping data packet from fitting in the history structure.

- Packets are acknowledged when a validated info packet is received containing the value of *RxNextPktToAck* greater than or equal to *TxNextPktToAck* in the packet's entry. Entries are removed from the structure when the packets they hold are acknowledged. This implies that when control packets are inserted within data packets, the history structure must support out-of-order removal of inserted control packets.
- No more than 128 unacknowledged packets may be outstanding at a time.

RxNextPktToAck requirements:

- Cleared to 0 on warm or cold reset
- State maintained on retry or LDTSTOP# disconnect and reconnect
- Not incremented for stumped packets or info packets
- Incremented on each validated non-info packet
- All NOP packets carry the value of *RxNextPktToAck*.
- Must be incremented at the same time or before the flow control buffer consumed by the packet is released.

Because the *NextPktToAck* counters are reset to 0, the first non-info packet transmitted after reset is packet '1'. Note that when a command packet is embedded in a data packet, its *NextPktToAck* count is smaller than the count for enveloping data packet. Also note that because more than one packet may be sent between NOPs, the value of *RxNextPktToAck* may be seen incrementing by more than 1 (modulo 256) at the receiver.



Once in retry mode, the transmit state machine on each side of the link combines NOPs carrying *RxNextPktToAck* with other packets. The oldest active packet in the History structure is pointed to by *RxNextPktToAck* from the other side of the link. The newest active packet in the History structure is pointed to by each side's own *TxNextPktToAck*.

Figure 14. Illustration of Packet History and Counters

10.3.5 Control Packet Insertion

If a control packet is inserted within a data packet, the embedded command packet may be successfully received and the data packet corrupted. In this situation, a receiver might accept the two in reverse order from how they are sent, since the entire command associated with the data must be retried after the embedded command may have already been acknowledged.

- A transmitter must ensure that there are no ordering relationships between an embedded command packet and the enveloping data packet when retry mode is active. Alternatively, a transmitter design may opt not to embed packets while in retry mode for simplicity.

10.3.6 Receiver Requirements

- A receiver may only act on a received packet when the entire packet has been validated by the receiver, unless the receiving device can guarantee that the side effects of acting on a corrupt packet are benign and fully reversible. Stomped packets are not valid.
- Protocol, Overflow, End of Chain, and Response errors in received packets are not logged until the packets have been validated.
- A tunnel may either store packets and forward them only after validating them or speculatively forward them as they are received and stomp packets received in error. Note that because a stomped packet is not received successfully, *RxNextPktToAck* is not incremented for it.
- To prevent false error logging, a protocol or CRC error must not be logged until a sync flood can be ruled out as the possible cause of CTL or CAD not matching the expected behavior.
- Receivers that recognize sync floods by decoding the command field must receive at least 4 consecutive Sync packets before acting on a sync flood. (The time this takes is implementation-dependent due to pipelining, buffering, and where in the implementation sync floods and errors are detected; typically the length of time that it takes to detect a sync flood.)
- Receivers must zero all flow control credits for the link upon retry, so transmitters must re-send all credits upon reconnection to ensure that no incorrect state is maintained from info packets that could have been corrupted.

10.3.7 Reconnection

Both sides complete the reconnect sequence for retries and LDTSTOP disconnects as follows:

1. Complete the training and initialization sequence to reach *Operational*
2. Send NOPs to establish *RxNextPktToAck* and the correct flow control buffer counts
3. Wait to receive NOPs with *RxNextPktToAck* and new flow control buffer credits
4. Replay any packets in the history structure starting at *RxNextPktToAck+1* and resume normal operation.

This sequence causes both sides of the link to reinitialize and reestablish flow control. The exchange of packet counter values is required to prevent duplication of valid packets.

- Both sides of the link must issue at least as many buffer credits of each type as had been available before the retry to prevent deadlocks.
- Control packet insertion while replaying packets from the history structure could cause ordering issues as described in Section 10.3.5, in addition to requiring the capability to remove entries from the history structure out of order.
- Packets from the replay buffer may be reordered with respect to each other or other packets queued for transmission in an implementation-specific manner, as long as ordering rules are followed.

If a simultaneous error occurs on both sides of the link (or the disconnect NOP is corrupted for a retry on one side), both sides enter the retry state. The retry process is initiated on both sides of the link.

An error on only one side of the link is contained because the working side carries a NOP with *Discon* set to cleanly bring down the receiver for the good side of the link.

10.3.8 Multiple Retry Attempts

It is possible for either a subsequent soft link error or a hard link error to prevent a reconnection attempt from completing successfully. Hard link errors such as CAD signals stuck low or high are detected by stricter checking of the initialization sequence in retry mode. CAD signals stuck together are detected by CRC covering the info packets sent at the conclusion of every reconnect attempt (used to reinitialize the packet counters and flow control buffers). Timers prevent any hang of the initialization sequence from hanging the entire system without error. The Short Attempts field (See Section 7.16.4.5) controls how many retry attempts are allowed before an error is declared unrecoverable.

The number of retries is tracked with the *RxRetries* counter which is a 4 bit field. It is used as follows:

- *RxRetries* is cleared to 0 at warm reset.
- When a retry is initiated due to a CRC or protocol error, *RxRetries* is incremented.

- When a reconnection attempt is unsuccessful and another retry is attempted, *RxRetries* is incremented.
- When *RxRetries* is incremented to a value greater than that programmed in `LinkTrain[TotalAttempts]`, this is an unrecoverable error, and the process defined in Section 10.3.8 is followed.
- *RxRetries* is cleared to 0 when valid NOPs are received after the link is reinitialized.
- *RxRetries* stops incrementing when it reaches 8 and no further unrecoverable errors are logged.
- Link width, frequency, and other properties that are changed by LDTSTOP disconnect or warm reset are not changed by a retry attempt.

A retry initially makes the number of short attempts allowed by `Retry Control[Short Attempts]` as defined in Section 7.15.2.7. If those attempts fail, the device makes full training attempts, up to the total number of attempts allowed by `LinkTrain [Total Attempts]` as defined in Section 7.16.4.5.

10.3.9 Reporting an Unrecoverable Link Error

A link can be declared to have encountered an unrecoverable error by the error detection and recovery process defined in Section 10.3.8.

- An unrecoverable error causes CRC Error bit 0 to be set. The link continues retry attempts unless it is reset or sync flooding begins.

When retry mode is disabled, the CRC Flood Enable, CRC Fatal Enable, and CRC Nonfatal Enable bits are used for controlling the response to failures in the periodic CRC check, however when retry mode is enabled, these bits are used for unrecoverable link error reporting. In both modes, sync flooding or an interrupt results if the appropriate enable is set at the time a CRC Error bit becomes set.

The unrecoverable error handling mechanism on a link in retry mode can be tested by writing the CRC Force Error bit. (See Section 7.5.4.4)

- Setting the CRC Force Error bit in retry mode causes the link to produce bad (not stamped) CRC values.

10.3.10 Retry Logging and Statistics

The link level retry process hides a number of errors that can occur at the hardware level. A set of event log bits and counters is maintained on each link for monitoring by higher-level software.

- A link that enters the retry state sets the Retry Sent bit.
- A device generates a fatal error interrupt if the Retry Fatal Enable bit of the Retry Control register is set when the Retry Sent bit becomes set.
- A device generates a nonfatal error interrupt if the Retry Nonfatal Enable bit is set when the Retry Sent bit becomes set.

- The Retry Count register is incremented when a retry is initiated or a training timer times out. It is cleared by writing a 0 to it.

| Software handling a fatal or nonfatal error interrupt can check the state of the Retry Sent log bit to determine the cause of the interrupt.

11 Clocking

HyperTransport™ systems consist of devices connected by HyperTransport links. Devices within a HyperTransport fabric may or may not be clocked by clocks derived from the same frequency source. Section 11.1 describes the clock source requirements for HyperTransport devices.

11.1 Clocking Mode Definitions

Each HyperTransport device has a transmit clock, which is used to generate its CLK outputs, and a receive clock, to which incoming packets are synchronized in the receiver.

Three operating modes of HyperTransport devices are defined.

- In *Synchronous (Sync)* mode, each transmit clock must be derived from the same time base as the receive clock in the device to which it is connected. In addition, the transmit clocks from each side of the link must operate at the frequency programmed by their respective Link Frequency registers. Both the receiver and transmitter of a given side of the link operate at the same frequency, because there is only one Link Frequency register for each side of the link.
- In *Pseudo-synchronous (Pseudo-sync)* mode, each transmit clock must be derived from the same time base as the receive clock in the device to which it is connected. The transmit clock frequency for either device may be arbitrarily lower than the frequency programmed into its Link Frequency register and must not exceed the maximum allowed receive clock frequency in the other device. The maximum allowed receive clock frequency of a link is the highest frequency indicated in the Frequency Capability register.
- In *Asynchronous (Async)* mode, each transmit clock need not be derived from the same time base as the receive clock in the device to which it is connected. In order to cope with frequency error due to running nominally matched transmitter/receiver pairs from different time bases, the maximum that the transmit clock can exceed the frequency programmed into the Link Frequency registers must be restricted. The allowable variation for Gen1 and Gen3 is shown in Table 110.
- In *Arbitrary-async* mode, the transmit clock may be arbitrarily lower than the frequency programmed into its Link Frequency register and must not exceed the maximum allowed receive clock frequency by more than 300ppm in the other device. See Section 11.3 for a description of one scheme for handling this situation.

Table 110. Async Mode Transmit Clock Tolerance

System:	Gen1	Gen3
Ftx-max	F + 1000ppm	F + 300ppm
Ftx-min	F – 1000ppm	F – 5300ppm

Results in:

Frx-max	F + 2000ppm	F + 5600ppm
Frx-min	F – 2000ppm	F – 5600ppm

All HyperTransport devices must support Sync mode operation. Devices may also implement Pseudo-sync and Async modes based on their unique requirements. The means by which the operating mode is selected for a device that can support multiple modes is outside the scope of this specification.

11.2 Receive FIFO

Each HyperTransport receiver contains a FIFO that is clocked by the transmitter. See Section 24.4 for the details of this structure and the guidelines that govern its design. This section introduces the receive FIFO to motivate the discussion in Sections 11.3 and 12.2.

The FIFO (shown in Figure 15) is sized to absorb the *dynamic variation* between the transmitter’s clock and the receiver’s clock. Some sources of this dynamic variation are:

- Temperature
- Voltage (either of the transmitter or the receiver)
- Accumulated phase error in a PLL
- Noise that affects the clock and data in the same way. (If the noise affected clock and data differently then this would affect the maximum bit rate, not the buffer depth.)

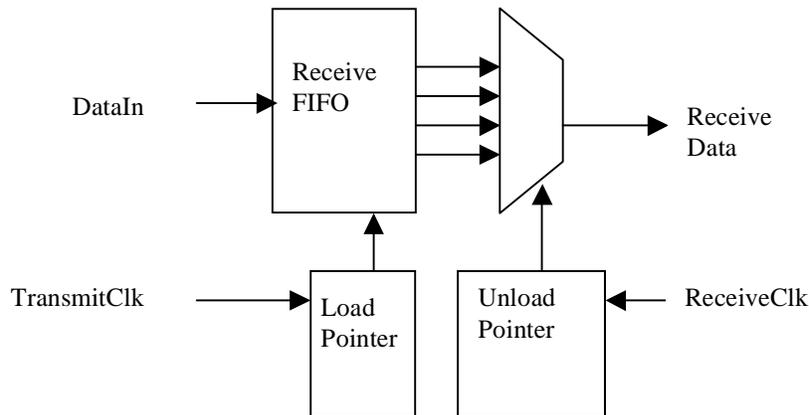


Figure 15. Receive FIFO

For links that are wider than 8 bits, the FIFO absorbs the difference in delay between 8-bit segments of the link. For links in which the two connected devices are clocked by different sources, the FIFO absorbs the frequency variation. See Section 11.3. Also, the FIFO can be used to provide buffering between a narrow high-speed link and a wider slower data path inside a receiver.

Clocking successive bit-times into different FIFO entry flops serves to increase the valid time of each flop. Before operating the link, the load and unload pointers must be initialized relative to each other. The sequence that supports this requirement is described in Section 12.2.

11.3 Async Mode Implementation Example

In Async mode, the transmit clock in one device and the receive clock in the other device are not derived from the same time base. The relationship between the FIFO load pointer and unload pointer may have to be adjusted dynamically.

If the receive clock is faster than the transmit clock, then the unload pointer occasionally has to be frozen. This situation can occur in Pseudo-sync and both Async modes.

If the receive clock is slower than the transmit clock, one method for ensuring that the transmitter does not overrun the receiver is described below. Note that this situation can only occur in Async mode. The transmitter frequency can exceed its programmed frequency by no more than 1000 ppm and can exceed the receiver's frequency by no more than 2000 ppm. This is less than the rate at which CRC bits are inserted onto the link (4 parts in 1092 for the first CRC window after initialization). CRC bits are sent by the transmitter and recomputed by the receiver. The receiver recomputes the CRC bits from the packet stream that is registered into the receiver's clock domain from the receive FIFO. The CRC bits are not placed directly into the receive FIFO, however. Instead, the CRC bits are placed into dedicated flops that are clocked by the transmit clock, and the bits are evaluated by receive-clock logic only after sufficient time has passed to ensure that these flops can be reliably sampled. Since the CRC bits only appear every 512 bit-times there is a sufficiently large sample window for these flops. By not placing CRC bits into

the receive FIFO and therefore not incrementing the unload pointer, the receiver can always keep up with the transmitter.

11.4 Link Frequency Initialization and Selection

Cold reset initializes HyperTransport I/O link transmitters to a link clock frequency of 200 MHz. All HyperTransport I/O link receivers must support a HyperTransport frequency of at least 200 MHz. Initialization firmware can reprogram the link transmitter frequencies and initiate a warm reset or LDTSTOP# disconnect sequence to invoke the change to the link clock frequencies. See Section 7.5.7 for details.

12 Reset and Initialization

12.1 Definition of Reset

Two types of reset are defined at the fabric level as follows:

- *Cold reset*—Node logic is reset. All links are reset. UnitIDs are assigned. All CSRs are reset. Cold reset is caused by the deassertion of PWROK together with the assertion of RESET#. Note that this sequence may be initiated under software control.
- *Warm reset*—Same as cold reset, except that CSRs defined to be persistent (expected to be mostly error state) are not reset. Warm reset is caused by asserting RESET# and keeping PWROK asserted. It may be initiated under software control. The system must ensure that warm reset does not occur during changes in link frequency or width settings, or else the link may not complete initialization.

The means by which PWROK and RESET# are generated within a specific system are outside of the scope of this specification.

12.2 System Powerup, Reset, and Low-Level Link Initialization

For a cold reset sequence:

- PWROK is asserted at least 1 ms after the power and clock sources for all HyperTransport™ devices have become stable.
- RESET# must be asserted 1 ms before PWROK is asserted
- RESET# must remain asserted for at least 1 ms beyond the assertion of PWROK.
- Since the state of RESET# is undefined during some of the time before PWROK is asserted, PWROK deassertion should be combined with RESET# to generate internal resets.

General rules for RESET#:

- RESET# must remain asserted at both ends of the link until the CLK signal from all transmitters is stable.
- For a warm reset sequence, RESET# must be asserted for at least 1 ms.
- Gen3 devices must output a stable TXCLK within 1ms of RESET# assertion.
- Gen1 devices may drive RESET# to extend it until TXCLK is stable.

- Systems that do not allow RESET# to be extended must provide enough time for all devices to drive a stable TXCLK. For FPGAs, this can take 500ms or more.

LDTSTOP# must be deasserted at least 1 us before RESET# is deasserted, and it must remain deasserted until the link has completed the synchronization sequence described below. A cold reset initializes the link in both directions to the minimum width of both receivers and transmitters up to 8 bits, enabling transactions to flow across the link. If it is desired to run with asymmetric widths, or widths over 8 bits, software is required to program the link width CSRs, and then perform a warm reset or link disconnect sequence for the new values to take effect.

A HyperTransport device that does not support hot plug or AC-coupled operation whose receiver is connected to a narrower transmitter on another device must have its unused CAD inputs connected to a logical 0. A device whose HyperTransport link is not used in the system and does not support hot plug or AC-coupled operation must have its CLK, CTL and CAD inputs connected to a logical 0.

While RESET# is asserted during a cold reset, each device’s transmitter drives CLK on all implemented byte lanes, drives its CTL signals to a logical 0, and drives all implemented output CAD signals to a value that is based on the width of its receiver, according to Table 111. Gen1 devices and Gen3 devices that are DC-coupled must hold this value through reset. In Gen1 protocol, CAD must be held until after the device has asserted its own CTL signal and sampled the assertion of the CTL signal driven from the other device. (This assures that each device can sample CAD safely, even if the device takes considerable time after reset to stabilize clocks and sample CAD.) If the transmitter is narrower than the receiver, all the output CAD signals are driven to a logical 1.

Table 111. CAD Value Driven by Transmitter Based on Receiver Width

Receiver Width (Bits)	Transmitter Width (Bits)	CAD[31:0] Value Driven ¹
x	2	0000 0003
2	X	
4, 8, 16, 32	4	0000 000F
4	8, 16, 32	
8, 16, 32	8	0000_00FF ²
	16	0000 FFFF ²
	32	FFFF FFFF ²

Notes:

1. Transmitters only drive as many bits as implemented. Higher bits are tied to logical 0 in the board design.
2. In devices with both transmitter and receiver 8 bits or larger, all bits implemented by the transmitter are simply driven to 1 for backwards compatibility.

At the deasserting edge of cold RESET#, each Gen1 device samples its input CAD signals and uses this sampled value to determine its transmitter and receiver widths, according to Table 112. Gen3 devices sample CAD and CTL earlier than Gen1 devices, as described in Section 12.3.4. The result of this process is reflected in the cold reset values of the LinkWidthIn and LinkWidthOut registers. If all CAD inputs are logical 0, the link is unused, and the End of Chain bit in the Link Control register are set.

If the upstream and downstream widths of a link are different, then at cold reset, they initialize to the smaller of the two widths, up to 8 bits. Software can reprogram the link to use the maximum upstream and downstream width possible after enumeration.

Table 112. CAD Value Sampled for Transmitter and Receiver Width

Incoming CAD [31:0] Value Sampled (Hex)	Transmitter and Receiver Widths (Bits)
0000 0000	N/A ¹
0000 0003	2
0000 000F	Smallest of (4 bits, Receiver width, Transmitter width)
xxxx xxFF	Smallest of (8 bits, Receiver width, Transmitter width) ²
Notes:	
1. Unused Link	
2. To maintain backward compatibility, links initialize to a maximum of 8 bits after cold reset.	

Warm reset preserves the transmitter and receiver widths programmed by software, so it is slightly different than cold reset. While RESET# is asserted during a warm reset, each DC-coupled HyperTransport device drives its outbound link(s) to the state listed in Table 113.

Table 113. Signal States During Reset

Signal	State During Reset
CLK	Toggling for all byte lanes
CTL	Logic 0
CAD[n-1:0] (programmed width)	Logic 1
CAD[31:n] (if present)	Logically undefined but within DC electrical specification. Logic 0 recommended for easier debug.

Note that this state does not correspond to any particular HyperTransport packet type.

12.2.1 Gen1 Protocol Link Initialization

The link initialization sequence from this point forward in time involves transmitting and receiving values on the CTL and CAD signals, and it is the same for cold and warm reset. The timing of the sequence described below, in terms of bit-times, is the same for 8-, 16-, and 32-bit links. The bit-time counts for 4- and 2-bit links should be doubled and quadrupled, respectively.

The discussion below refers to the CLK edges (rising or falling) across which the transmitter places new values on the CTL and CAD signals. Implied in this text is that the receiver registers the new data (using the transmitted clock) using that the same clock edge (rising or falling). The transmitter's physical interface to the link delays the clock relative to the data in order to position the clock in the middle of the data window.

A device-specific time after the deassertion of RESET#, each device asserts its CTL signal across a rising CLK edge, initiating a sync sequence. The timing of this transition as observed at the receiver is shown in Figure 16.

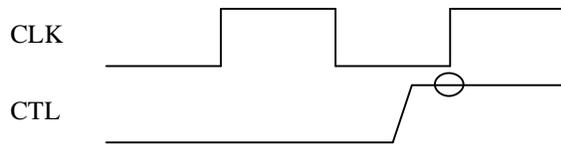


Figure 16. Sync Sequence Timing for Link Initialization

The assertion of the CTL signal serves to indicate to the device at the other side of the link that this device is ready to initialize the link. Devices perform whatever device-specific functions they may require between the time RESET# is deasserted and the time they assert CTL. This may include ramping their internal clocks to full frequency, initializing the receivers, and reading configuration state from off-chip.

When a device has asserted its own CTL signal and sampled the assertion of the CTL signal driven from the other device, it continues to drive the sync state for 16 bit-times (or 50 μ s after an LDTSTOP# disconnect, as specified by the Extended CTL Time bit in Section 7.5.4.12) and then inverts both CAD and CTL across a rising clock edge.

From this point until the initialization sequence is complete, unused bits of CAD (and in Gen3 devices operating with Gen1 protocol, CTL[1]) are logically undefined, but the transmitter must drive to electrical levels that satisfy the DC specification. Logic 0s are recommended for easier debug.

The deassertion of the incoming CTL/CAD signals across a rising CLK edge is used in the transmit clock domain within each receiver to initialize the load pointer. The deassertion of the incoming CTL and CAD signals is synchronized to the core clock domain and used to initialize the unload pointer within each receiver. The length and uncertainty of this synchronizer must be included to determine the proper relationship between the load pointer and the unload pointer. Note that CTL cannot be used to initialize the pointers for byte lanes other than 0 in a multi-byte link, as CTL only exists within the byte 0 transmit clock domain. After this point, all transitions of CTL must be on a 4-byte boundary.

Each device continues to drive this state on its outbound links for the number of bit-times shown in the table below. The time in this state is limited to allow devices in async clocking mode to bound the amount of receive FIFO space required to absorb the frequency difference between the clocks on either side of the FIFO.

Each device then drives the CAD signals to logic 1 on a 4-byte boundary across a rising CLK edge, while leaving the CTL signal deasserted, for exactly four bit-times. The transition from all CAD signals deasserted to all CAD signals asserted serves to frame incoming packets. The first bit-time after these four must have CTL asserted, and is both the first bit-time of a new command packet and the first bit-time of the first CRC window. It also occurs across a rising CLK edge.

Once the initialization sequence is complete, the transmitter should always drive unused bits of CAD to logic 0 to reduce noise and power.

The entire sequence is shown in Table 114.

Table 114. Values of CTL and CAD During Link Initialization Sequence

CTL	CAD	Duration: 8-, 16-, and 32-Bit Links (Bit-Times)	Duration: 2- and 4-Bit Links (Bit-Times)	Notes
0	1	N/A	N/A	Value held during reset
1	1	16 (minimum)	64/32 (minimum)	CTL asserts device-specific time after RESET# deasserts Pattern held at least 16/32/64 bit-times after both devices sample assertion of CTL (50 us following LDTSTOP# if CTL extended).
0	0	512+4N	2048+16N/1024+8N	1->0 transition on incoming CTL/CAD initializes load pointer in transmit clock time domain 1->0 transition on incoming CTL/CAD synchronized to core clock and used to initialize unload pointer in receive clock time domain
0	1	4	16/8	0->1 transition on CAD serves to frame incoming packets
1	??	N/A	N/A	0->1 transition on CTL defines start of first control packet and represents first bit-time of first CRC window
Note: <i>N can be any integer from 0 to 128.</i>				

Using the initialization sequence as defined in the above section, synchronous, pseudo-synchronous, and asynchronous devices can inter-operate as long as they share a common input clock.

12.3 Gen3 Link Protocol and Initialization

Gen3 protocol adds one phase to the 3-phase initialization sequence of Gen1 protocol, and each phase is modified to allow the phase recovery mechanism in the receiver to begin tracking the data eye. Each phase carries a unique training pattern and is not scrambled.

Table 115. Transmit States

Name	Drive
TXL0	50 Ohm differential (logical 0 or 1)
TXGNDTRM	50 Ohm to ground (single-ended)
TXACDETECT	Weak pull to 0.5v (single-ended)
TXIDLE	Weak pull to $V_{LDT}/2$ (single-ended)
TXHIZ	High Impedance

Table 116. Receive Termination States

Name	Termination
RXACTRM	50 Ohm center-tap to termination voltage (Ground for hot-plug)
RXDIFF	100 Ohm differential
RXDCDETECT	Weak pull to ground (single-ended)
RXOFF	Differential amplifier disabled (Termination may be enabled or disabled)

Table 117. PHY States

State	Transmitter			Receiver	DLL	Phase Recovery
	Gen1 Freq	DC Gen3 Freq	AC	DC/AC		
Unpowered	Undefined	Undefined	Undefined	RXOFF	-	-
PWROK=0 ⁵	Undefined/ TXGNDTRM ³	Undefined/ TXGNDTRM ³	TXGNDTRM ³	Undefined	Stopped	Off
<i>Cold Reset</i> ¹	TXL0	TXL0	-	RXDCDETECT	On	Off
<i>AC Detect</i>	-	-	TXACDETECT	RXACTRM	On	Off
<i>Warm Reset</i>	TXL0	TXL0	CLK: TXL0 Other: TXIDLE	RXDIFF/ RXACTRM	On	Off
<i>L0 or LS0</i>	TXL0	TXL0	TXL0	RXDIFF/ RXACTRM	On	On
<i>Disconnected (LS1)</i>	CLK:TXL0 Other:TXHIZ ⁴	CLK:TXL0 Other:TXIDLE	CLK: TXL0 Other:TXIDLE	RXDIFF/ RXACTRM	On	Hold
<i>Disconnected (LS2)</i>	TXHIZ ⁴	TXIDLE	TXIDLE	RXDIFF/ RXACTRM	Hold	Hold
<i>PHY OFF or LS3</i>	TXHIZ ² / TXGNDTRM ³	TXHIZ ² / TXGNDTRM ³	TXGNDTRM ³	RXOFF ² / RXACTRM ³	Off	Off

State	Transmitter			Receiver	DLL	Phase
	Gen1 Freq	DC Gen3 Freq	AC	DC/AC		Recovery
Device behavior where the PHY state is “Undefined” is implementation-specific.						
1. Links begin Cold Reset in DC mode and switch to AC Detect if DC coupling is not detected						
2. When LinkTrain[HotPlugEn] is set, the transmitter must be in the TXGNDTRM state and the receiver must be in RXACTRM. When HotPlugEn is clear, the transmitter may be in either TXHIZ (for DC links) or TXGNDTRM (for DC and AC links), and the receiver should be in RXOFF to prevent current draw due to inputs that are tied off.						
3. The specification for drive and termination impedance in inactive links is relaxed when PWROK=0 and in PHY OFF relative to the specification for active links, as indicated in the electrical specification.						
4. Gen1 Operation: transmitter lanes tristated only if Link Control[LdtstopTristateEn] is set. If LdtstopTristateEn is clear, all transmitter lanes stay in TXL0 during Disconnected.						
5. Devices that do not support hotplug or AC-coupled operation do not have any transmitter requirements until PWROK is asserted. Gen3 devices that do support hotplug or AC-coupled operation must place transmitters in TXGNDTRM when PWROK is deasserted.						

- The platform should not tie off the inputs of hot pluggable devices or they could burn extra power through the termination resistors.
- Any logic and circuits required to compensate for process, temperature, or supply voltage variations is implementation-specific. It is expected (but not required) that these structures are disabled during *PHY OFF*.

Implementation Note: Receiver DLL Locking

A typical receiver implementation includes a DLL for tracking the link clock. It needs to be relocked in these circumstances after LDTSTOP# deassertion:

- Width increase when InLnSt was 01
- Width increase when InLnSt was 11 (with LS2/3) and inactive lane idle timer expired or not implemented
- Exit from LS3 or *PHY OFF*
- Frequency change
- Idle Timer (See Section 12.3.19) expiration in LS2

Additionally, the DLL needs to relock when exiting Warm Reset, and (in some implementations) at all LDTSTOP deassertions when HotPlugEn is set to tolerate large LDTSTOP skews with LSSel[1]=1.

Table 118. Supported Modes

Frequency	200-1000MHz	1200-2600MHz	
Coupling	DC	DC	AC
Termination	DIFF	DIFF	GND
8b10b	Off	Off	On

Frequency	200-1000MHz	1200-2600MHz	
Coupling	DC	DC	AC
Scrambling	Off	On	On
Training&Retry	No	Required	Required
Hot Plug	Optional	Optional	Optional
CTL Lines (16-bit links)	1	2	2

In link testing any combination of modes may be used. AC-coupled link support is optional.

Devices that have high-skew PWROK, LDTSTOP#, or RESET# connections (such as those connected with cables or otherwise dependent on service processors for sideband signaling) must support hot plug, as detailed in Section 2.1.

12.3.3 Training Patterns

Training patterns are chosen to provide a DC-balanced data pattern, sufficient transition density for rapid phase recovery centering, and sufficient Hamming distance from each other. The training patterns are the same in both DC and AC-coupled operation, all are DC-balanced, and TP3 and TM4 are chosen to have correct running disparity so that the 8b10b decoder can be started as soon as the receiver starts the FIFO write pointer. The same pattern is repeated on each active CAD and CTL line.

Table 119. Training Patterns

Training Pattern 0	0011111010 0001101011 0001011011 1001010100 AC: K28.5- D8.0+ D23.0+ D9.0+ DC: 3E86B 16E54	Hamming Distance from previous pattern
Training Pattern 1	0011111010 0001101011 1100010100 1110010100 AC: K28.5- D8.0+ D3.0+ D8.0- DC: 3E86B C5394	10 bits
Training Pattern 2	1100000101 1100011011 0001101011 1100101001 AC: K28.5+ D3.0- D8.0+ D19.1- DC: C171B 1AF29	30 bits
Training Pattern 3	0011111010 1010010100 0101011011 0010010110 AC: K28.5- D5.0+ D10.0- D27.6+ DC: 3EA94 56C96	28 bits

Training Marker 4	1101101000 1101101000 1101101000 1101101000 AC: K27.7- K27.7- K27.7- K27.7- DC: DA368 DA368	26 bits
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12.3.4 Cold Reset

After a cold reset each link attempts to determine if it is connected.

Link detection is required to ensure that training patterns are not driven into an unpowered device.

Devices with 16-bit links may optionally treat them as two 8-bit sublinks, a capability called “unganging”. 16-bit devices indicate if they support unganging by the value driven on the CTL[1] lane; 0 indicates unganging supported, while 1 indicates unganging is not supported and both halves must be treated as a single link. If both sides of the link support unganging, the two sublinks are detected and trained separately and software must enumerate them correctly. Otherwise, the two sublinks are ganged as one. Devices that support unganging must implement the enumeration scratchpad register defined in Section 7.5.11. System hosts may enable enumeration via other means.

There are no provisions for cold reset link width negotiation of AC-coupled links. Therefore they must start at 8 bits and can only be reduced to 2 or 4 bits or increased to 16 bits under software control.

Entry Condition	PWROK deasserted
Transmitter Requirements	TXGNDTRM before PWROK asserted if device supports hotplug TXL0 when PWROK asserted <ul style="list-style-type: none"> • Logical 1 on CAD[15:0] and logical 0 on CTL[0] and CLK • If unganging is supported, logical 0 on CTL[1] • Else, logical 1 on CTL[1] • CTL[1:0] must be valid within 100us of PWROK assertion and stable until RESET# deasserts
Receiver Requirements	RXDCDETECT when PWROK asserted
Exit Condition	When PWROK asserted: <ul style="list-style-type: none"> • PHY Compensation logic begins initialization • Wait at least 300 us • If hotplug or AC supported, execute <i>DC Detect Phase 1</i> • Transmitter drives CLK, ramping to 200MHz • When RESET# deasserted: <ul style="list-style-type: none"> ○ Execute <i>DC Detect Phase 2</i>
Error Conditions	If DLL fails to spin up, the link is not connected properly, or there is a fault in receiver or transmitter logic, the link could fail to exit <i>Cold Reset</i> . If the system can boot without this link, software should timeout and put the link in <i>PHY OFF</i> by setting Link Control[TXOff].

- PWROK assertion skew must be less than 200us in DC-coupled links for this sequence to function.

- *DC Detect Phase 1* must complete and CLK must be at 200MHz before RESET# deasserts on either side of the link. This implies that devices must complete *DC Detect Phase 1* within 1ms of PWROK assertion.
- If receiver calibration is required at cold reset, it should be done during *DC Detect Phase 1*, when protocol ensures that the CAD and CTL inputs are stable if the PWROK skew requirement is met.
- Unganged links train each sublink independently.
- When a 16-bit Gen3 device is attached to a Gen1 device, RXCTL[1] should be tied to logical 1 to force the link into ganged mode.
- CTL[3] and CTL[2] operate similarly for unganging of 32-bit links.

12.3.4.1 DC Detect Phase 1

- If unganging is supported, receiver samples CTL[1]
 - If not Differentially Driven (CTL_L low and CTL_H low)
 - § Wait until 700us after PWROK assertion
 - § If AC is supported, sublink 1 sets LinkTrain[AC] and goes to *AC Detect*
 - § Else sublink 1:
 - Sets Link Control[LinkFail], [EOC], and [TXOff]
 - Goes to *PHY OFF* (includes any ganged sublinks)
 - Else sublink 1 remains at default state
- Receiver samples CTL[0]
 - If not Differentially Driven:
 - § Wait until 700us after PWROK assertion
 - § If AC is supported, sublink 0 sets LinkTrain[AC] and goes to *AC Detect*
 - § Else sublink 0:
 - Sets Link Control[LinkFail], [EOC], and [TXOff]
 - Goes to *PHY OFF* (includes any ganged sublinks)
 - § If unganging not supported
 - Set GblLinkTrain[InLnSt] (or LinkTrain[TxInLnSt] as appropriate) to 10b
 - Sublink 1 goes to *Inactive*
 - § Else sublink 1 remains at default state
 - Else sublink 0 (and any ganged sublinks) remains at default state

12.3.4.2 DC Detect Phase 2

- LinkTrain[Ganged] and LinkControl[TXOff, EOC, LinkFail] defaults clear
- If unganging is supported and CTL[1] at phase 1 was logical 0, sublink 1:
 - Receiver samples CAD[8]
 - § If logical 0:
 - Sets Link Control[LinkFail], [EOC], and [TXOff]
 - Go to *PHY OFF*
 - § Else when receiver is ready:
 - Go through Gen1 Initialization in Section 12.2.1
- Else Sublink 0 sets LinkTrain[Ganged]
- Receiver samples CAD[0]
 - If logical 0, sublink 0 (and sublink 1 if link is ganged):
 - § Sets Link Control[LinkFail], [EOC], and [TXOff]
 - § Goes to *PHY OFF*
 - When receiver is ready:
 - § Sublink 0 goes through Gen1 Initialization
 - § Sublink 1 (if link is ganged) goes to *Inactive*

Devices are recommended to implement a timeout to set Link Control [LinkFail] if Gen1 initialization has not completed on DC connected links within 1 second of RESET# deassertion.

12.3.5 AC Detect

If the receiver does not see valid DC differential levels there is either an AC-coupled device attached or no device.

Entry Condition	<i>Cold Reset</i> did not detect a DC-coupled link
Transmitter Requirements	PLL ramping for a 1200MHz link RESET# asserted: TXGNDTRM RESET# deasserted: TXACDETECT on CAD_H[0] only Link detected: CTL and CAD TXIDLE, CLK TXL0
Receiver Requirements	RXACTRM
Exit Condition	<ul style="list-style-type: none"> • When RESET# deasserted: • The voltage ramp on the CAD[0] pads is observed for less than 13ms • Wait until 13 to 13.1ms after RESET# deassertion • If receiver was detected (slow voltage ramp) <ul style="list-style-type: none"> ○ Enable retry mode (set RetryEn bit) ○ Switch CAD[7:0] and CTL to TXIDLE ○ Drive CLK in TXL0 ○ Set LinkTrain[8b10b and ScrEn] and TXConfig[DeempEn] ○ When CLK is at 1200MHz transmitter goes to <i>Training 0</i> ○ 13.2ms after RESET# deassertion if receiver is ready, go to <i>Training 0</i> • Else Set Link Control[LinkFail], [EOC], and [TXOff] <ul style="list-style-type: none"> ○ Go to <i>PHY OFF</i> (includes any ganged sublinks)
Error Conditions	If DLL fails to spin up, the link is not connected properly, or there is a fault in receiver or transmitter logic, the link could fail to exit <i>AC Detect</i> . If the system can boot without this link, software should timeout and put the link in <i>PHY OFF</i> by setting Link Control[TXOff].

AC-coupled links go directly to high-speed operation so that the coupling capacitors do not need to be sized to support legacy frequencies.

- Receiver termination must be valid before RESET# deasserts.
- TXCLK must be at 1200MHz within 13.1ms of RESET# deassertion if a receiver is detected.
- RESET# deassertion skew must be less than 100us for this sequence to function.
- RESET# must not reassert, LDTSTOP# must not be asserted, and software must not modify link parameters until all links have reached *Operational* (or *Sync Flood* due to training failure) to ensure that all links have reached a deterministic state after a cold reset. A timer of at least 22ms should be implemented in host software or hardware to ensure this is not violated. If this is violated then undefined operation may result.

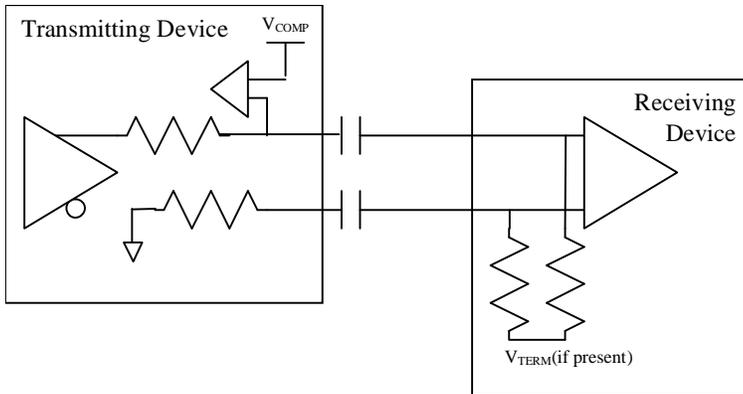


Figure 18. AC Detect Circuit

To perform AC Detection, the transmitter switches CAD_H[0] from the TXGNDTRM state to a weak pull up to a common-mode voltage ($V_{TX-AC-DETECT}$). Comparators monitor the output pads to detect how quickly the channel reaches a selected threshold voltage (V_{COMP}). If the outputs are not connected (or connected to a device in the PHY OFF state), they reach the threshold voltage faster than if they are connected. The exact delays depend on the output impedance of the transmitter, the coupling capacitance used, and the values of $V_{TX-AC-DETECT}$ and V_{COMP} , and are therefore implementation specific. Additionally, the effective impedance and capacitance of the circuit vary depending on the impedance with which the receiver common-mode point is terminated (if at all).

The selected sample time must be later than the longest time it takes for an unconnected link to reach $V_{COMP-MAX}$, but earlier than the shortest time it takes for a connected link to reach $V_{COMP-MIN}$, with tolerance for at least 100mV of noise. Taking 3 samples in succession is recommended for greater noise immunity.

For example, if the transmitter's impedance ranges from 2K to 3KOhm, $V_{TX-AC-DETECT}$ is $V_{LDT}/3$, V_{COMP} is $V_{LDT}/6$, and 5% tolerance is allowed on the voltage references in addition to V_{LDT} range:

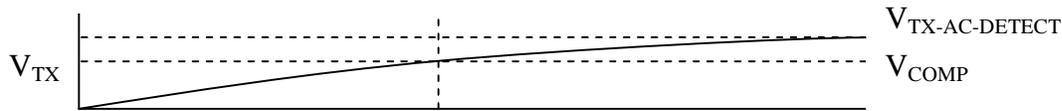
$$T_{UNCONNECTED-MAX} = -3KOhm * 3nF * \ln(1 - (1.14V/6 + 50mV)/(1.14V/3)) * 1.05 = 9.8us$$

$$T_{CONNECTED-MIN} = -2KOhm * 75nF/2 * \ln(1 - (1.14V/6 - 50mV)/(1.14V/3)) * 0.95 = 32.3us$$

Therefore the optimum time to sample (using logarithmic averaging) is approximately 18us.

Different implementations may have different circuits for the transmit voltages and compare voltages and therefore may apply tolerances differently. Greater immunity to noise could be achieved by limiting the allowed range of coupling capacitor values, at the expense of limiting platform flexibility.

Terminated output



Unterminated output

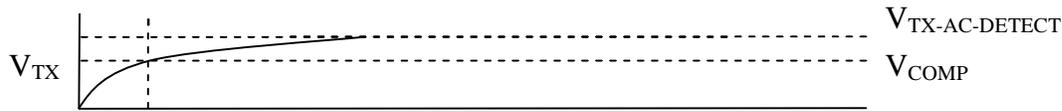


Figure 19. AC Detect Timing

If the pads do not reach the selected common-mode voltage within the maximum time a connected device takes, the outputs could be shorted to ground ~~or connected to a device in the PHY OFF state~~, and this condition ~~must~~ may optionally be treated as if a receiver was not detected. Similar to choosing the first sampling time, a ~~second-final~~ second sampling time must be chosen greater than the time it takes for voltage to ramp with an active AC-coupled device, ~~but less than the time it takes for voltage to ramp with a disabled AC-coupled device~~. Using the same parameters as the example above:

$$T_{\text{ACTIVE-MAX}} = -3\text{K}\Omega * 200\text{nF} * \ln(1 - (1.14\text{V}/6 + 50\text{mV}) / (1.14\text{V}/3)) * 1.05 = 652\mu\text{s}$$

$$T_{\text{DISABLED-MIN}} = -52\text{K}\Omega * 75\text{nF} / 2 * \ln(1 - (1.14\text{V}/6 - 50\text{mV}) / (1.14\text{V}/3)) * 0.95 = 840\mu\text{s}$$

Therefore the optimum time to sample again (using logarithmic averaging) is approximately 750us.

It's possible to wait until the 13ms of AC Detect are complete, but sampling earlier allows more time to configure the device for the correct mode. Note that if the outputs are shorted at a point after the coupling capacitors, this condition will be indistinguishable from a connected device, but will not cause damage to the transmitter.

12.3.6 Inactive

Inactive lanes are placed in this state.

Entry Condition	Upper lanes left inactive at cold reset or after link width reduced
Transmitter and Receiver Requirements	GlblLinkTrain[InLnSt] or LinkTrain[RxInLnSt and TxInLnSt] sets behavior <ul style="list-style-type: none"> • If LDTSTOP# asserted with InLnSt==00b, 10b, or (with LSSel==01b) 11b: <ul style="list-style-type: none"> • Receiver prepares to hold data eye position without any transitions within 100ns • If InLnSt==10b or (with LSSel==01b) 11b, transmitter continues sending scrambled data for 200 to 300ns • Go to <i>Disconnected</i> but return to <i>Inactive</i> instead of <i>Operational</i> when training completes. • If host receives (or chipset is preparing to issue) a link refresh system management active command, inactive lanes below Link Control[WidthIn/Out] go to <i>Refresh</i>
Exit Condition	If link width increased: <ul style="list-style-type: none"> • If RESET# asserted go to <i>Warm Reset</i> • If LDTSTOP# asserted go to <i>Disconnected</i>

Inactive lanes being refreshed do not have to be aligned with the active lanes.

A 16-bit device that does not support unganging but does support AC-coupled operation must send TP1's on CAD[15:8] and CTL[1] in the *Inactive* state if InLnSt==10b and lower sublink is active.

12.3.7 Refresh

Inactive lanes below the software-programmed width are placed in this state during CILR operation.

Transmitter Entry Condition	For chipset: prepares to issue link refresh system management active command For host: receives link refresh system management active command
Receiver Entry Condition	For host: receives link refresh system management active command For chipset: receives link refresh system management active command
Transmitter and Receiver Requirements	<ul style="list-style-type: none"> • Transmitter goes to TXL0 and sends TP0's • Receiver DLL and phase recovery mechanism active • Host reflects link refresh system management active command
Transmitter Exit Condition	Receives link refresh system management inactive command and returns to <i>Inactive</i>
Receiver Exit Condition	For chipset: <ul style="list-style-type: none"> • Wait for implementation-specific T0 Time • Prepares to hold data eye position without any transitions • Issues link refresh system management inactive command • Wait for link refresh system management inactive command • Returns to <i>Inactive</i> For host: <ul style="list-style-type: none"> • Receives link refresh system management inactive command • Prepares to hold data eye position without any transitions • Reflects link refresh system management inactive command • Returns to <i>Inactive</i>

12.3.8 Warm Reset

DC-coupled Gen3 frequency links use the same warm reset signaling on active lanes as Gen1 frequency links, while AC-coupled links go to TXIDLE on all active lanes except CLK.

Entry Condition	Gen3 frequency, PWROK asserted and RESET# asserted with LinkControl[TXOff]=0 in any state except <i>Cold Reset or AC Detect</i>
Transmitter Requirements	DC: CTL and CAD TXL0: CTL logical 0 and CAD logical 1 AC: CTL and CAD TXIDLE CLK TXL0: must be at programmed frequency before RESET# deassertion
Receiver Requirements	DC: RXDIFF AC: RXACTRM
Exit Condition	<ul style="list-style-type: none"> When RESET# deasserted and receiver ready, go to <i>Training 0</i> with Tmr0 of GblLinkTrain[FullT0Time] If LinkControl[TXOff] is set, go to <i>PHY OFF</i>.
Error Conditions	If the PLL fails to relock, the link is no longer connected properly, or there is a fault in receiver or transmitter logic, the link could fail to exit <i>Warm Reset</i> . If the system can operate without this link, software should timeout and put the link in <i>PHY OFF</i> by setting Link Control[TXOff and EOC].

Note that, unlike Gen1 frequency signaling, the skew between each CTL or CAD lane and the CLK lane can be greater than one bit-time at Gen3 frequencies, therefore the relationship between the rising edge of CLK and any initialization transitions cannot be ensured.

DC-coupled Ganged links must drive CTL[1] to logical 0 during *Warm Reset*. This prevents false sync flood detection with high reset skew when a link transitions from unganged to ganged under software control.

Because a link may be in *Warm Reset* indefinitely, hardware must relock the DLL when exiting this state in case the link frequency has drifted due to temperature or voltage changes.

12.3.9 PHY OFF

Software may set the Transmitter Off bit on unused links to save power and reduce EMI.

Entry Condition	LinkControl[TXOff]=1 in any state when PWROK is asserted
Transmitter Requirements	DC(with LinkTrain[HotPlugEn]=0): TXGNDTRM or TXHIZ DC(with LinkTrain[HotPlugEn]=1) or AC: TXGNDTRM
Receiver Requirements	DC(with LinkTrain[HotPlugEn]=0): RXOFF DC(with LinkTrain[HotPlugEn]=1) or AC: RXACTRM <ul style="list-style-type: none"> Receiver calibration settings must be maintained in devices that support LS3
Exit Condition	<ul style="list-style-type: none"> If RESET# asserted with TXOff cleared: <ul style="list-style-type: none"> Initialize PHY Compensation logic Go to <i>Warm Reset</i> If LDTSTOP# asserted with TXOff cleared: <ul style="list-style-type: none"> Initialize PHY Compensation/ logic Go to <i>Disconnected</i>

Note that, once a link is ungangled, it can only be gangled by software or a cold reset.

Note that a full link detect sequence is not performed by hardware when bringing a link out of *PHY OFF*. Software is responsible for ensuring that both sides of the link are correctly programmed with matching termination, frequency, and width. If TXOff is cleared without ConnDly set, undefined operation may result.

When bringing an AC link out of *PHY OFF*, software must set T0Time to 200us and clear RxLSSel[1] and TxLSSel[1]. LDTSTOP# must be asserted long enough to lock the PLL such that the link clock is at frequency before LDTSTOP# deassertion, allowing DLL lock.

If unused inputs are unterminated, software is responsible for setting HotPlugEn so that the inputs are placed in RXACTRM to protect the device from transient voltage spikes and noise.

12.3.10 Training 0

Training pattern 0 (TP0) is sent on CTL and CAD lanes to provide a multifrequency and unique pattern for the receive phase recovery mechanism to track. When exiting *AC Detect*, the transmitter of a device reaches this state at least 100us before the receiver on that device.

Entry Condition	End of <i>Warm Reset</i> , short retry failure, or recovery from a disconnect
Transmitter Requirements	TXL0: TP0 sent on CTL and CAD lanes; CLK running at programmed frequency
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • DLL locking on CLK • Phase Recovery mechanism seeking data eye
Exit Condition	<ul style="list-style-type: none"> • If RESET# asserted, go to <i>Warm Reset</i> • If LDTSTOP# asserted <ul style="list-style-type: none"> ○ Receiver prepares to hold data eye position without any transitions within 100ns ○ Transmitter continues sending training patterns for 200 to 300ns ○ Go to <i>Disconnected</i> • Wait for <i>Tmr0</i> to timeout for phase recovery tracking • Go to <i>Training 1</i>

Note that the AC-coupling capacitors must charge (if following *Cold Reset* or *PHY OFF*), the receiver DLL must lock (if frequency changed), and the phase recovery mechanism must lock within the *Tmr0* period.

- To simplify implementation, the first TP0 sent may start at any location within the training pattern, but the transmitter must not drive static logical values into an AC-coupled link at any time or the DC balance of the link would be disturbed. This is especially important exiting *Disconnected* or *Retry Disconnect*.
- LDTSTOP# assertion overrides *Tmr0*
- *Tmr0* begins after the transmitter begins sending TP0 on all active lanes and (when reconnecting after an *LDTSTOP Disconnect* or exiting *AC Detect*) the receiver has reached *Training 0*.
- When exiting *Warm Reset* the transmitter must begin sending TP0 within 100us of RESET# deassertion.
- If *Tmr0* is set to 0us, it is recommended that at least one whole TP0 is sent before transitioning to *Training 1* to provide a reference point for test systems, however *Training 0* may be skipped completely if the implementation allows it.

12.3.11 Training 1

Training pattern 1 (TP1) is sent on CTL and CAD lanes to begin the training handshake.

Entry Condition	Completion of <i>Training 0</i> or recovery from a short disconnect
Transmitter Requirements	TXL0: TP1 sent on CTL and CAD lanes; CLK running at programmed frequency
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • If GblLinkTrain[RXCalEn], perform receiver calibration if necessary before seeking TP1 or TP2 • Phase recovery mechanism locking on the data eye • 8b10b decoder seeking symbol alignment
Exit Condition	<ul style="list-style-type: none"> • If RESET# asserted, go to <i>Warm Reset</i> • If LDTSTOP# asserted <ul style="list-style-type: none"> ○ Receiver prepares to hold data eye position without any transitions within 100ns ○ Transmitter continues sending training patterns for 200 to 300ns ○ Go to <i>Disconnected</i> • If the receiver on a lane has seen TP1 or TP2 8 times in a row without error, it goes to <i>Training 2</i> • After all receiver lanes have transitioned to <i>Training 2</i>, the transmitter goes to <i>Training 2</i> at the end of a TP1 transmission • If <i>Tmr1</i> times out, increment Retry Count and <i>RxRetries</i> <ul style="list-style-type: none"> ○ If Retry Control[Short Attempts] is exceeded: <ul style="list-style-type: none"> • If LinkTrain[Total Attempts] is exceeded: <ul style="list-style-type: none"> • Set Link Control[<i>CRC Error0</i>] • Set Link Control[<i>LinkFail</i>] • Enable scrambling • Go to <i>Sync Flood</i> • Else return to <i>Training 0</i> with <i>Tmr0</i> of GblLinkTrain[FullT0Time] ○ Else all lanes restart <i>Training 0</i> without change to <i>Tmr0</i>
Error Conditions	<ul style="list-style-type: none"> • If one side of the link does not complete <i>Training 1</i> prior to <i>Tmr1</i> expiring, the side where <i>Tmr1</i> expired falls back to <i>Training 0</i> then reattempts the handshake. • If any lane fails to see TP1 or TP2 8 times in a row without error, <i>Tmr1</i> expires and all lanes fall back to <i>Training 0</i>.

Note that it is possible for the receiver on the other side of the link to move to *Training 2* before this one, which is why reception of either training pattern completes *Training 1*.

Because each lane is likely to have different delay and noise, each receiver lane can detect the required number of training patterns to transition to *Training 2* at different times.

- All receiver training pattern counts reset when this state is entered.
- Any number of TP1s followed by TP2s can combine to satisfy the count of 8 training patterns. 8 of a single training pattern are not required. All 8 training patterns must be received without error.
- The transmitter must send a minimum of 8 TP1s before exiting this state. This requirement is fulfilled naturally by the requirement to receive 8 TPs before exiting the state.
- LDTSTOP# assertion overrides Tmr1
- LinkTrain[HotPlugEn] disables Tmr1
- Tmr1 only runs for reconnection following a training timeout, *LDTSTOP* or *Retry Disconnect*. It does not run immediately following a warm or cold reset.

Implementation Note: Receiver Calibration

If periodic receiver calibration (such as DC offset cancellation) is required by a device after power-up (and enabled by GlbLinkTrain[RXCalEn]) it should be performed when the link enters *Training 1* after a disconnect or reset, delaying reception of TP1 or TP2 by the link layer. It is expected that only minor adjustments are required and therefore complete in approximately 500ns so that there is not be a major impact on the latency of outstanding requests or upon the bandwidth delivered. It is important to keep this delay bounded so that systems carrying isochronous traffic have known buffering requirements. Systems with very strong latency requirements (such as those with UMA graphics) may need to run with receiver calibration disabled and therefore require greater margin to compensate for the lack of calibration during normal operation.

If LDTSTOP# or RESET# asserts during calibration, the transmitter must react normally to the event, but the receiver may either complete calibration or end it early to react to the event.

When hot plug is enabled, devices may need to run receiver calibration for an extended time then restart Training 0 after a cold reset. This may be necessary if the platform cannot ensure that all devices are powered before PWROK is asserted to any device, resulting in the receiver inputs having an undefined state during cold reset receiver calibration.

12.3.12 Training 2

Training pattern 2 (TP2) is sent on CTL and CAD lanes to complete the training handshake. The transmitter state and each receiver lane state diverge from the exit of *Training 1* until they converge in *Operational*.

After *Training 2*, the per-lane logic on the receiver side of the FIFO has completed its role in training and further progress is made by logic on the core side of the FIFO.

Entry Condition	Completion of <i>Training 1</i>
Transmitter Requirements	TXL0: TP2 sent on CTL and CAD lanes; CLK running at programmed frequency
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • Phase Recovery mechanism maintaining lock on the data eye • 8b10b symbol alignment locked
Transmitter Exit Condition	<ul style="list-style-type: none"> • If RESET# asserted, go to <i>Warm Reset</i> • If LDTSTOP# asserted <ul style="list-style-type: none"> ○ Continue sending training patterns for 200 to 300ns ○ Go to <i>Disconnected</i> • Wait for one complete TP2 to be received without error on any lane <ul style="list-style-type: none"> ○ The transmitter sends 8 more complete TP2s, then goes to <i>Training 3</i> at the end of a TP2 transmission.
Receiver Exit Condition	<ul style="list-style-type: none"> • If RESET# asserted, go to <i>Warm Reset</i> • If LDTSTOP# asserted <ul style="list-style-type: none"> ○ Prepare to hold data eye position without any transitions within 100ns ○ Go to <i>Disconnected</i> • Each active lane waits for one complete TP2 to be received without error then: <ul style="list-style-type: none"> ○ If anything but TP2 is seen by a lane in the first 10 bits of the training pattern, the receiver for that lane starts the FIFO write pointer and that lane goes to <i>Training 3</i>. • If a <i>Tmr2</i> timeout occurs and any receiver lane remains in <i>Training 2</i>, Increment Retry Count and <i>RxRetries</i> <ul style="list-style-type: none"> ○ If Retry Control[Short Attempts] is exceeded: <ul style="list-style-type: none"> • If LinkTrain[Total Attempts] is exceeded: <ul style="list-style-type: none"> • Set Link Control[CRC Error0] • Set Link Control[LinkFail] • Enable scrambling • All active TX and RX lanes go to <i>Sync Flood</i> • Else all active TX and RX lanes return to <i>Training 0</i> with <i>Tmr0</i> of GlibLinkTrain[FullT0Time] ○ Else all active TX and RX lanes return to <i>Training 0</i> without change to <i>Tmr0</i>

Error Conditions	<ul style="list-style-type: none">• If any receiver lane sees an error in the TP2->TP3 transition, that lane may start the FIFO write pointer at the wrong time and link initialization for that lane will fail after the transition to <i>Operational</i>, causing another initialization attempt.• If any receiver lane continues to see TP2 after the Tmr2 timeout, all receiver lanes and the transmitter fall back to <i>Training 0</i>.
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- Tmr2 starts when the transmitter and all receiver lanes have reached *Training 2*.
- LDTSTOP# assertion overrides Tmr2

12.3.13 Training 3

Training pattern 3 (TP3) is sent on CTL and CAD lanes to maintain phase recovery lock, initialize the receive FIFO, and provide time for the receiver to start the FIFO read pointers. Training Marker 4 (TM4) is sent at the end of this state to mark the end of training and the transition to *Operational*.

Entry Condition	Completion of <i>Training 2</i>
Transmitter Requirements	TXL0: TP3 sent on CTL and CAD lanes; CLK running at programmed frequency
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> Phase Recovery mechanism maintaining lock on the data eye
Transmitter Exit Condition	<ul style="list-style-type: none"> If RESET# asserted, go to <i>Warm Reset</i> When 8 TP3s have been sent <ul style="list-style-type: none"> Send a single TM4 Initialize the scrambler and enable it for transition to <i>Operational</i> or (for inactive lanes) <i>Inactive</i> immediately after TM4
Receiver Exit Condition	<ul style="list-style-type: none"> If RESET# asserted, go to <i>Warm Reset</i> If LDTSTOP# asserted, the receiver must prepare to hold data eye position without any transitions within 100ns and all active receiver lanes go to <i>Disconnected</i> by the time the transmitter does When TM4 is received on any lane, the receiver: <ul style="list-style-type: none"> Initializes the descrambler Begins tracking 8b10b disparity and decode errors Starts receiving valid data The receiver goes to <i>Operational</i> or (for inactive lanes) <i>Inactive</i> when the link has been deskewed and a TM4 has been received on any lane ¹ If <i>Tmr3</i> timeout occurs, Increment Retry Count and <i>RxRetries</i> <ul style="list-style-type: none"> If Retry Control[Short Attempts] is exceeded: <ul style="list-style-type: none"> If LinkTrain[Total Attempts] is exceeded: <ul style="list-style-type: none"> Set Link Control[CRC Error0] Set Link Control[LinkFail] Enable scrambling Go to <i>Sync Flood</i> Else return to <i>Training 0</i> with Tmr0 of GblLinkTrain[FullT0Time] Else return to <i>Training 0</i> without change to Tmr0

Error Conditions	<ul style="list-style-type: none"> • If the Tmr3 timeout occurs before the link has been deskewed and a TM4 has been received on any active lane, the transmitter and all receiver lanes fall back to <i>Training 0</i> regardless of what state they have reached. If the transmitter has reached <i>Operational</i> it must transition through <i>Retry Disconnect</i> to <i>Training 0</i> to avoid false error logging in the receiver. Tmr0 may remain unchanged unless Retry Control[Short Attempts] is exceeded. • If the time between the first active lane seeing TM4 and all active lanes seeing TM4 is greater than the worst case lane to lane skew supported by the receiver then it is recommended that this be treated like a Tmr3 timeout but with Tmr0 of 0us.
<p><i>1 Receivers may deskew on the TP2->TP3 transition or on the reception of a TM4. It is highly recommended that implementations validate that TM4 is received on all lanes.</i></p>	

Note that the transmitter is not required to go to *Disconnected* immediately upon observing LDTSTOP# asserted, as there is enough time allowed for it to complete *Training 3*, transition to *Operational*, and then to *LDTSTOP Disconnect*.

- The receiver cannot necessarily complete *Training 3* and observe a Disconnect packet in *Operational* before the transmitter reaches *Disconnected*. Therefore the receiver may need to transition directly to *Disconnected* with the transmitter to maintain forward progress and maintain proper link operation.
- The Tmr3 period begins as soon as the first receiver lane or the transmitter enters *Training 3*.
- The maximum difference in frequency allowed in Gen3 asynchronous clocking mode is +/-300ppm (for reference oscillator drift) minus up to 5000ppm (for spread spectrum clocking), for a total of 5600ppm. Because this implies a 4-bit slip every 714 bits, an implementation must either wait until TM4 to start the FIFO read pointer, or allow extra pointer separation to absorb the largest slip an implementation can observe from the time it starts the read pointer during *Training 3* until the first periodic CRC timeslot occurs after 512+64 bit-times in *Operational*.
- While the electrical specification limits lane-to-lane skew to under 5 bit-times on a sublink, the receive FIFO must tolerate even greater skews for certain circumstances:
 - When links greater than 8 bits are used, at least 8 bit-times (due to skew between bytes).
 - When an ILM device provides the loopback for BIST, the BIST device's receive FIFO must tolerate at least 2*5 bit-times (15 for 16-bit or wider links) plus at least one core clock period (up to 8 bit-times) of the ILM device.
 - When FPGAs are used.

12.3.14 Operational

Entry Condition	Completion of <i>Training 3</i>
Transmitter Requirements	TXL0: Scrambling enabled on CTL and CAD lanes; CLK running at programmed frequency <ul style="list-style-type: none"> • In AC mode, the first characters sent must assume negative running disparity • Send NOPs to establish <i>RxNxtPktToAck</i> and flow control buffer counts • Wait to receive NOPs with <i>RxNxtPktToAck</i> and flow control buffer credits • Replay any packets in the history structure starting at <i>RxNxtPktToAck+1</i>
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • Phase Recovery mechanism maintaining lock on the data eye
Exit Condition	<ul style="list-style-type: none"> • If RESET# asserted, go to <i>Warm Reset</i> • If LDTSTOP# asserted, go to <i>LDTSTOP Disconnect</i> • If a sync flood is initiated or received, all links go to <i>Sync Flood</i>
Retry Conditions	<ul style="list-style-type: none"> • If an error (protocol, CRC, symbol decode, or disparity) is received, go to <i>Retry Disconnect</i> • If a disconnect NOP is received immediately followed by a non-disconnect NOP, go to <i>Retry Disconnect</i>. • If two consecutive disconnect NOPs are received, go to <i>LDTSTOP Disconnect</i>. • If the receiver reaches <i>Operational</i> and detects an error or receives a Disconnect packet before the transmitter reaches <i>Operational</i>, the receiver immediately goes to <i>Retry Disconnect</i>. When the transmitter reaches <i>Operational</i> it will transition to <i>Retry Disconnect</i>.

- When a packet has been received with good CRC, set Link Control[Init Complete] and clear *RxRetries*.
- The first bit-time sent is with the scrambler state at all-1's.

12.3.15 BIST

The *BIST* state has the same PHY requirements as *Operational* but has no protocol other than transmitting and checking the patterns generated by the BIST engine.

Entry Condition	Completion of <i>Training 3</i>
Transmitter Requirements	TXL0: Scrambling enabled on CTL and CAD lanes per BIST Scramble Enable register; CLK running at programmed frequency <ul style="list-style-type: none"> • Send patterns generated by the BIST engine without any gaps after TM4
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • If BISTCtl[RxDIS]=0: Phase Recovery mechanism maintaining lock on the data eye
Exit Conditions	<ul style="list-style-type: none"> • If RESET# asserted, clear LinkControl[BISTEN] and go to <i>Warm Reset</i> • If LDTSTOP# asserted: <ul style="list-style-type: none"> ○ Receiver prepares to hold data eye position without any transitions within 100ns ○ Transmitter continues to send BIST patterns for 200 to 300ns ○ Clear LinkControl[BISTEN] ○ Go to <i>Disconnected</i>

12.3.16 Sync Flood

During a sync flood, the scramblers must operate without interruption during the transition from *Operational* and continue to operate until RESET# is asserted.

Entry Condition	Unrecoverable error during <i>Training</i> or <i>Retry Disconnect</i> or sync flood initiated or received during <i>Operational</i>
Transmitter Requirements	TXL0: Scrambled 1's on CTL and CAD lanes; CLK running at programmed frequency
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • Ignored.
Exit Condition	If RESET# asserted, go to <i>Warm Reset</i>
Error Conditions	<ul style="list-style-type: none"> • If one side of the link begins sync flooding but the other side does not recognize it due to errors, the side that initiated the sync flood maintains it while the other side attempts retries until the number of allowed attempts is exhausted, then enters sync flood itself. • If a sync flood is transmitted (to signal SERR) without errors, it is recognized by the receiver and quickly propagated.

- If Link Control[CRC Flood Enable] is set and there is an unrecoverable link error during *Training or Retry Disconnect*, the device transitions all links to *Sync Flood* to propagate it. If LinkControl[CRC Flood Enable] is clear, only this link is flooded and LinkControl[LinkFail] is not set.
- If a sync flood is initiated or received in *Operational*, all links go to *Sync Flood* to propagate it regardless of Link Control[CRC Flood Enable].
- If a link reaches *Sync Flood* due to a training failure after *Cold Reset*, software should set Link Control [TXOff and EOC] to disable the link and prevent unnecessary noise and power consumption.
- Entry to *Sync Flood* does not have to be on a legal packet boundary. See Section 10.3.6 for receiver requirements for deferring errors while detecting sync floods.

12.3.17 Retry Disconnect

The transmitter must cleanly transition out of *Operational* to avoid false error logging on either side of the link while the receiver ignores any errors and continues to track the phase of transitions.

Entry Condition	Retry condition detected while in <i>Operational</i>
Transmitter Requirements	TXL0: Scrambling enabled on CTL and CAD lanes; CLK running at programmed frequency
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • Freeze the value of <i>RxNextPktToAck</i> • Stomp or drop any unvalidated packets being forwarded from this link • Zero all flow control credits from this link • Phase Recovery mechanism maintaining lock on the data eye • The transition from the last Disconnect packet to the first TP0 or TP1 does not necessarily occur on a symbol boundary, so the receiver must ignore any disparity or decode errors in <i>Retry Disconnect</i>. • If LDTSTOP# asserted: <ul style="list-style-type: none"> ○ Receiver prepares to hold data eye position without any transitions within 100ns
Exit Condition	<ul style="list-style-type: none"> • If RESET# asserted, go to <i>Warm Reset</i> • If 4 consecutive sync packets received, go to <i>Sync Flood</i> • Transmitter completes sending current packet • Transmitter sends one Disconnect packet followed by NOPs for 200 to 300ns • If LDTSTOP# asserted: <ul style="list-style-type: none"> ○ Continue sending NOPs for 200 to 300ns after LDTSTOP# assertion ○ Go to <i>Disconnected</i> • Else, Increment Retry Count and <i>RxRetries</i> <ul style="list-style-type: none"> ○ If Retry Control[Short Attempts] is exceeded: <ul style="list-style-type: none"> • If LinkTrain[Total Attempts] is exceeded: <ul style="list-style-type: none"> • Set Link Control[CRC Error0] • Set Link Control[LinkFail] • Enable scrambling • Go to <i>Sync Flood</i> • Else go to <i>Training 0</i> with Tmr0 of GblLinkTrain[FullT0Time] for Retry ○ Else go to <i>Training 0</i> with Tmr0 of 0us for Retry

Note that any disconnect transitions through this state if the sampling of LDTSTOP# is delayed relative to the device on the other side of the link. As a result of synchronization effects, if the delay is close enough, it can appear to change from one disconnect to the next.

By delaying the increment of Retry Count until after the transmitter has sent NOPs for over 200ns, up to 200ns skew in RESET# assertion between two devices can be handled safely without false errors being logged.

- If RESET# assertion skew between two devices is greater than 200ns, LDTSTOP# must be asserted at least 200ns before RESET# to avoid logging false retry attempts.
- The transmitter may transition from sending NOPs to *Training 0* at any bit-time within a NOP and the first TP0 may be corrupted by FIFO pointer updates, but the transmitter must not output a static value on the link or the phase recovery mechanism could lose lock and the common-mode voltage of an AC-coupled link could drift far enough out of position to cause link errors.
- The NOPs sent in this state must have 0's in the Diag bit and all buffer release fields.
- When re-entering *Operational* after going through training, both sides of the links reconnect as described in Section 10.3.7.

12.3.18 LDTSTOP Disconnect

The transmitter must cleanly transition out of *Operational* to avoid false error logging on either side of the link while the receiver prepares to be disconnected.

Entry Condition	LDTSTOP# assertion while in <i>Operational</i>
Transmitter Requirements	TXL0: Scrambling enabled on CTL and CAD lanes; CLK holding current frequency
Receiver Requirements	DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • DLL maintaining lock on CLK • Optionally continue processing any valid packets until either a Disconnect packet received or the link exits to <i>Disconnected</i> • Freeze the value of <i>RxNextPktToAck</i> • Zero all flow control credits from this link • Phase Recovery mechanism prepares to hold data eye position without any transitions within 100ns
Exit Condition	<ul style="list-style-type: none"> • If RESET# asserted, go to <i>Warm Reset</i> • Transmitter completes sending current packet • Transmitter sends Disconnect packets for 200 to 300ns¹ • Go to <i>Disconnected</i>
1. If LDTSTOP# asserted while the transmitter was in <i>Training 3</i> , the time that the transmitter was sending training patterns may count for this requirement, however the transmitter must always send at least 4 disconnect packets before disconnecting	

- The transmitter may transition from sending Disconnect packets to *Disconnected* at any bit-time within a NOP, but the transmitter must not output a static value on the link or the common-mode voltage of an AC-coupled link could drift far enough out of position to cause link errors.

12.3.19 Disconnected

The link goes to an idle state, and if directed by power management logic, places the PHY in LS1, LS2, or LS3 to save power. When LDTSTOP# is deasserted, the link transitions back to L0 for training.

Entry Condition	LDTSTOP# assertion with LinkControl[TXOff]=0 or completion of <i>LDTSTOP Disconnect</i>
Transmitter Requirements	See LinkTrain[TxLSSel] <ul style="list-style-type: none"> • PLL relocking to new frequency if necessary • If entering LS1D, TXCLK switches to divided frequency
Receiver Requirements	If LinkTrain[RxLSSel]=11b, per PHY OFF Else DC: RXDIFF AC: RXACTRM <ul style="list-style-type: none"> • If LS1, 2, or 3 is being entered, disable CTL and CAD inputs • If LS2 or 3 is being entered, disable CLK input also • If not entering LS2 or 3 and frequency is not changing, DLL maintaining lock
Exit Condition	<ul style="list-style-type: none"> • If RESET# asserted, go to <i>Warm Reset</i> • If link width reduced, inactive lanes go to <i>Inactive</i> • If TXOff is set, go to <i>PHY OFF</i> • Wait for LDTSTOP# to assert • When LDTSTOP# is deasserted: <ul style="list-style-type: none"> • TXCLK must return to TXL0 and be at programmed frequency within 900ns • When transmitter is ready: <ul style="list-style-type: none"> ○ If Idle Timer exceeded the maximum allowed idle time, go to <i>Training 0</i> for the time specified by GblLinkTrain[FullT0Time] ○ Else go to <i>Training 0</i> for the time programmed in GblLinkTrain[T0Time] • Receiver waits 1000ns after LDTSTOP# was deasserted then goes to <i>Training 0</i> when ready

- Note that the devices on either side of the link may have different requirements for Tmr0. In the event that they spend different periods in *Training 0*, it simply takes a longer time to complete training, because the timeout for completion of *Training 1* is chosen to exceed the maximum time allowed in *Training 0*. V_{LDT} must remain valid during *Disconnected* for the receiver DLL and phase recovery mechanism to maintain the data eye position.
- The system design must ensure that LDTSTOP# is asserted long enough (100us greater than the LDTSTOP# skew if not programmable) during frequency changes for the PLL to reach the programmed frequency.
- While LDTSTOP# remains asserted, and the programmed frequency has changed, CLK frequency may be much faster or slower than the programmed frequency.
- CLK must be running at the programmed frequency within 900ns of LDTSTOP# deassertion. If system or device limitations prevent this, RxLSSel[1] and TxLSSel[1] must be 0 so that the DLL in the connected device has a clock to track.

- The receiver DLL may begin tracking CLK and the phase recovery mechanism may begin seeking the data eye 1000ns after LDTSTOP# deassertion. The DLL must relock on frequency changes.
- If the device cannot transition to *Training 0* within 900ns, T0Time must be programmed to the greater of the values required by each side of the link.
- The phase recovery mechanism must achieve lock eventually even in the event that a transmitter delays transitioning CAD and CTL lanes from electrical idle to training, or if LDTSTOP skew causes the same effect to be seen. Software is responsible for increasing T0Time appropriately in these situations.
- TXCLK must not glitch when entering or exiting LS1D; Frequency may vary between the link frequency and the divided frequency when entering or exiting LS1D, but must never exceed the link frequency.
- When re-entering *Operational* after going through training, both sides of the links reconnect as described in Section 10.3.7.
- When transitioning to LS0 or inactive lanes to InLnSt==10b (or 11b with LSSel==01b), there is no need for the receiver to freeze the DLL or phase recovery mechanism as there will still be link activity to track.

Implementation Note: Idle Timer

In some systems (such as mobile systems using UMA), GblLinkTrain[T0Time] needs to be programmed for a short period to prevent exceeding the latency limits required by isochronous traffic. Devices used in these systems need an Idle Timer to monitor how long the link remains in *Disconnected*. These devices must be characterized for how long they can remain in *Disconnected* and still recover DLL lock and data eye phase recovery within the programmed T0Time. If the Idle Timer exceeds the characterized period, the device must override T0Time and stay in *Training 0* for the time specified by GblLinkTrain[FullT0Time]. The means of programming the allowed Idle Timer is implementation-specific.

Because TXCLK runs during LS0 and 1, the DLL does not lose lock so the idle timer is typically not needed if LS0 or 1 is used during *Disconnected*.

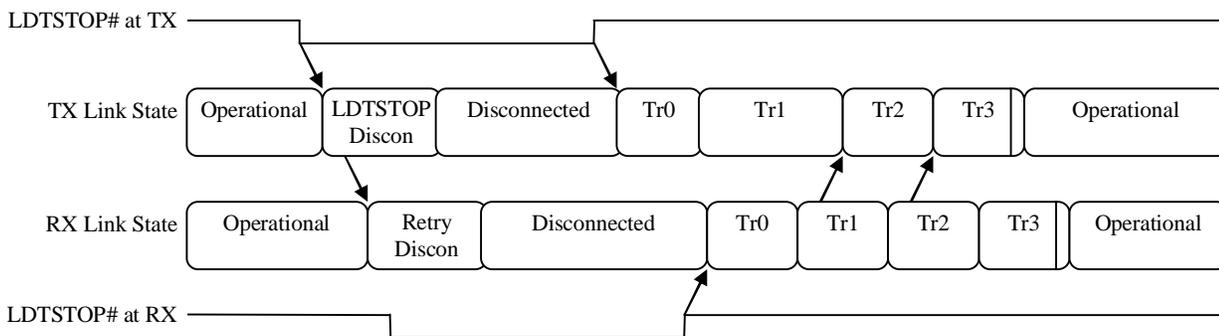
Another idle timer may be implemented to track how long inactive lanes remain in the Inactive state. This can be useful if the receiver supports fast recovery from the Inactive state. If CLMC is active, this Inactive Lane Idle Timer should not monitor lanes above the width programmed in the Link Configuration register since it is illegal for software to increase the width until a warm reset deactivates CLMC.

Table 120. Disconnect/Reconnect Timing Budget (ns)

1000	LDTSTOP# Minimum Assertion Time (in parallel with TX+RX Disconnect Delay)
1000	RX Reconnect Delay (LDTSTOP# skew+TX reconnect delay)
10	Phase Recovery
450	Initialization (TP1*9+TP2*9+TP3*8+TM4=1080 bit-times)
33	Flow Control Setup (<10 NOPs=80 bytes)
2493	Total

1. Assumes 2.4GT/s on a 8-bit link (worst case for Gen3 frequencies).
 2. 4-bit operation adds 33ns to flow control setup. 2-bit operation adds 100ns.
 3. Does not include roundtrip handshake travel times or any time in Training 0.
 4. Does not include receiver calibration during Training 1.

Normal LDTSTOP:



LDTSTOP during Retry:

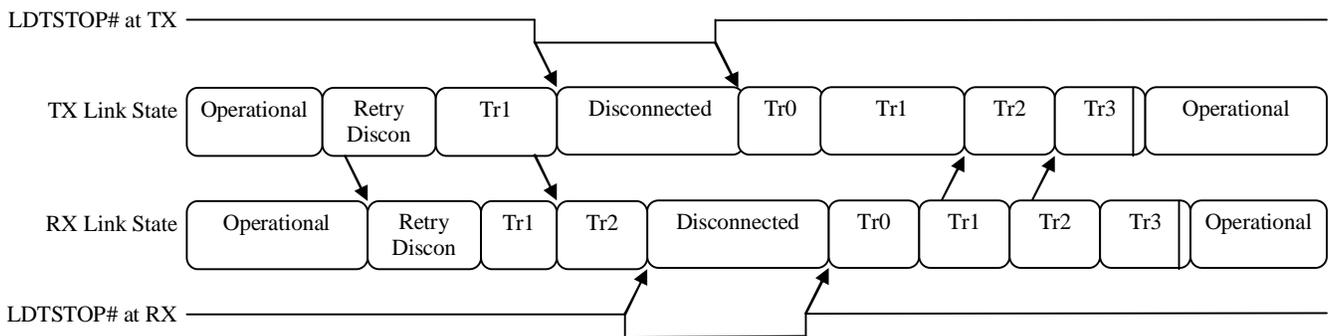


Figure 20. Example LDTSTOP Disconnect Sequences

12.3.20 Link Width Changes

A change in link width requires a disconnect and reconnect of the link and an increase requires time to train the phase recovery mechanism on the additional lanes. However, once trained, inactive lanes can be kept trained while active lanes are still in *Operational*. To make this possible, Gb1LinkTrain[InLnSt] or LinkTrain[TxInLnSt] can cause inactive lanes to carry the scrambler pattern until an *LDTSTOP*

Disconnect or Warm Reset places the inactive lanes in *Training*. This allows the link width to be varied over time without causing a stall in link operation each time the link width is increased.

- Software is responsible for setting `GlbLinkTrain[T0Time]` to the time required to train new lanes.
- Hardware must relock the DLL in the circumstances enumerated in the implementation note in Section 12.3.2.

12.3.21 Retry Timing

A retry requires a disconnect and reconnect of the link, but because power does not need to be saved during a retry, the transmitter goes directly to *Training 1* instead of an idle state. This keeps the phase recovery mechanism locked on the data eye.

Table 121. Retry Timing Budget (ns)

333	TX Disconnect Delay (longest packet=80 bytes)+300ns
40	RX Disconnect Delay (longest packet+2 NOPs=96 bytes)
450	Initialization (TP1*9+TP2*9+TP3*8+TM4=1080 bit-times)
33	Flow Control Setup (<10 NOPs=80 bytes)
856	Total

The bit error rate (BER) of HyperTransport links is expected to be low enough that there is virtually no bandwidth loss due to retries. Because retry operates independently on each link, the BER impact on performance would only degrade with the number of sublinks between any two points in a system, not with the total number of links in a system.

12.3.22 Gen3 FPGA Implementation Issues

There are several issues that may make HyperTransport 3.0 difficult to implement in a typical FPGA.

- The high-speed transceiver needs to be bypassed during *Cold Reset and AC Detect* for link detect and booting. This could be avoided with software or side-band configuration of the link.
- Electrical requirements for high speeds include equalization, limiting link frequency.
- FPGAs may require greater lane-to-lane skew budgets due to reduced ability to optimize I/O placement and package routing. This would increase the effective jitter seen at the receiver, resulting in reduced margin and limiting link frequency. If the skew is too high it can exceed the ability of the receiver FIFO to deskew the lanes.

12.4 I/O Chain Initialization

I/O chain initialization is largely software driven. A sample initialization sequence consists of the following steps:

1. One or more reset sequence initiators assert RESET# (and possibly deassert PWROK). Each initiator must sequence the PWROK and RESET# signals according to the rules defined in Section 12.2. Multiple initiators may or may not release (deassert) RESET# at the same time. In any event, the last initiator to release RESET# determines when the initialization sequence begins. Note this means that each initiator must sample as well as drive RESET#. Gen3 devices other than the host (or another central resource) of a chain must not drive PWROK or RESET# to allow adequate buffering of these signals and keep the timing of these events bounded.
PWROK and RESET# are propagated from the primary side of a bridge to the secondary side, but not from secondary to primary.

2. The low-level link initialization sequence described in Section 12.2 takes place between each node in the chain.
3. Each node sends buffer-release packets to inform the transmitter(s) to which it connects how many buffers it contains.

In a double hosted chain, the host bridge at one end of the chain is designated the master host bridge, and the other the slave. How a host bridge determines whether it is a master or slave is outside the scope of this specification.

4. The slave host bridge, if any, goes to sleep and waits for the master host to initialize the chain, so that only one host accesses the HyperTransport command registers (causing the Master Host bit to change) of any one device at a time. The method of ensuring this (timers, sideband signals, etc.) is implementation-specific. The master host bridge proceeds with the initialization sequence. At the beginning of the sequence, nextFreeID = 01h, unless the host has bits set in the Clumping Support register of a Clumping capability block, in which case nextFreeID is 2, 3, or 4, depending on how many UnitIDs the host consumes. clumpMask is initialized to 0000_0000h.
5. The master host bridge checks the Initialization Complete bit for the outgoing link of the last initialized device on the chain (initially its own) to determine if a device has been detected at the other end of the link. It also checks the error bits to see if the link has taken any errors since reset. If there is no device, or the link is taking errors, chain sizing is complete—proceed to step 10.
6. Software issues CSR accesses to Device Number 00h, which is the Base UnitID that all devices assume at reset, and which is also the default responded to by host bridges. The reads are responded to by the first uninitialized device on the chain. By reading the Class Code, Vendor ID, and Device ID, software can determine the type of device with which it is talking. Performing a write to the Command register (without changing any fields) causes the Master Host bit to get set, which indicates which link on that device is pointing toward the host bridge. By polling the CRC, Protocol, Overflow, and End of Chain Error bits for that link (see Sections 7.5.4.9 and 7.5.10), software can determine that the device is not seeing errors on the link between it and the host. Software can then set the Flood, Fatal, and/or Nonfatal Enable bits for the link from both ends. If the link is taking errors, chain sizing is complete, proceed to step 10.

7. Software reads the Unit Count field. If nextFreeID+UnitCount exceeds the largest available UnitID value for the chain (typically 31), the device cannot be initialized and the device before it in the chain must have the End Of Chain bit set. Initialization is done.
8. If clumping is to be used, software checks the device for a Clumping capability block. If present, the device has full clumping support. If not, Software sets the partialClumping flag, indicating that full clumping cannot be used from this device to the end of the chain. If a Clumping capability was not found, software attempts to set the UnitID Reorder Disable bit in the Feature register. If this bit cannot be set (in pre-1.05 devices), then software sets the noClumping flag, indicating that no clumping can be used from this device to the end of the chain.
If the device has a Clumping capability and the no clumping flag has not been set, then bits 1 to UnitCount-1 of the Clumping Support register are Ored into clumpMask, beginning at bit nextFreeID+1.
9. Software writes the Base UnitID with nextFreeID, and increments nextFreeID by the Unit Count value of the device. Now that the device no longer responds to accesses to 00h, the process can be repeated for the next link, starting back at step 5. If a slave host bridge has been reached, software sets the Double-Ended bit on both that bridge and the master host bridge, and proceeds to step 11 for link partitioning.
10. At this point, an end to the chain has been found without reaching another host bridge. Software sets the End of Chain and TXOff bits for the last link in the chain, and chain initialization is complete. If there is a bridge at the other end and the sizing algorithm has not reached it due to a break in the chain, it wakes up after the master host has completed initialization, finds its Double-Ended bit clear, and sizes the chain from the other end to the break, starting at step 5. The result is two single-ended chains, each with a master host bridge. Initialization is done.
11. At this point, the entire chain has been sized and found to have host bridges at both ends. When the slave host bridge wakes up, it finds its Double-Ended bit set and knows that no sizing is required on its part. All intermediate devices have their Master Host bit pointing towards the master host bridge. In a non-sharing double-hosted chain, software must select the location at which it wishes to break the chain and then access the nodes on either side of the break from the host bridge on that side. First, the End of Chain bit for the link to be broken is set from each side while the link is idle. When both devices are ignoring the link, the TXOff bit for each side can be set. At this point, the slave host bridge should write the HyperTransport command registers of all devices on its side of the break so that Master Host and Default Direction point towards it.

In a sharing double-hosted chain, the peer-to-peer deadlock loop described in Section 4.7 may make load balancing impossible, since all devices must have their Master Host bits pointing towards the master host bridge.

If peer-to-peer transactions are not used in a sharing double-hosted chain, load balancing can be achieved by changing the Master Host and/or Default Direction bits on some of the devices in the chain, resulting in a “soft” partitioning.

In any chain configuration, partitioning must be done before setting the bus master enable bits in the devices, as described in Section 7.3.1.3.

The initialization process can be made more robust by providing a facility to time out the CSR accesses used for sizing, in the event that a device fails to respond. This possibility is beyond the scope of this specification.

Once the above sequence has been completed, software checks the `noClumping` and `passiveClumping` flags. If either has been set, then the host may not itself use UnitID clumping. Otherwise, bits 1 to 3 of the host's Clumping Support register are Ored into `clumpingMask`.

Software can now write `clumpingMask` into the Clumping Enable register of each device on the chain that has a Clumping capability block.

12.4.1 Finding the Firmware ROM

System implementations can be built in which software initialization code is stored in a firmware ROM that resides behind a default bridge on one of several HyperTransport I/O chains connected to the host. Further, system implementations can be built that do not require the host to be hardware-configured to identify the I/O chain that contains the default bridge. One possible method of initializing a system with these two characteristics involves a host that after reset sends a firmware code-fetch down each I/O chain connected to it. The I/O chain that contains the default bridge responds without error, while all the other I/O chains respond with a Master Abort. This allows the host to identify the compatibility I/O chain, and subsequent firmware fetches can be directed down that chain only. To ensure that this method works even when devices on the compatibility chain are slow to initialize, the Drop on Uninitialized Link bit, described in Section 7.5.3.2.5, is inactive by default. Once the compatibility chain has been successfully accessed, the Drop on Uninitialized Link bit should be set to prevent hangs if a link becomes inoperable.

12.5 Link Width Initialization

Note that the hardware-sequenced link-width negotiation sequence described in Section 12.2 does not result in the links operating at their maximum width potential. 16-bit, 32-bit, and asymmetrically-sized operation must be enabled by a software initialization step. Each link controller contains two pairs of control register fields relating to the width of the link, as follows:

- A pair of fields that are hardwired to indicate the maximum supported widths of the inbound and outbound links.
- A pair of fields that are initialized after a cold reset to a particular value based on the result of the link-width negotiation sequence, as described in Section 12.2. This pair of fields controls the actual link width and is persistent across a warm reset.

At cold reset, all links power-up and synchronize as described in Section 12.2. Firmware (or BIOS) interrogates all the links in the system, reprograms all the links to the desired width, and then takes the system through a warm reset to change the link widths. See Section 7.5.5 for details on the Link Configuration register, which contains the Link Width fields.

After a HyperTransport disconnect-reconnect sequence, devices that implement the LDTSTOP# protocol described in Section 8.3 are required to update their link widths in exactly the same way as they

do after a warm reset sequence. This allows initialization software for systems built from such devices to use the LDTSTOP# protocol rather than warm reset to invoke link width changes.

12.6 Link Frequency Initialization

At cold reset, all DC-coupled links power-up with 200-MHz clocks. AC-coupled links power-up with 1200MHz clocks. For each link, firmware reads the Frequency Capability register, described in Section 7.5.9, of each device to determine the supported clock frequencies. The reported frequency capability of each device, combined with system-specific knowledge of the board layout and power requirements is used to determine the frequency to be used for each link. Firmware writes the Frequency register, described in Section 7.5.7, for both devices of each link to set the frequency to be used. Once all devices have been configured, firmware initiates an LDTSTOP# or RESET# of the affected buses to cause the new frequency to take effect.

13 Device Messaging

Device messages can be up to 4KBytes in length and are composed of one or more message Fragments. Each message Fragment consists of one request carrying header information possibly followed by multiple requests carrying data. All but the last Fragment of a message must carry a multiple of 128 Bytes of data. All data requests but the last request of the last Fragment must carry a full 64 bytes of data. Requests in device messages are routed by bus and device number just like configuration accesses, and also have type 0 and 1 cycles. The device and function number determine their final destination within the targeted node. The remainder of the address carries fields specific to device messages. Note that all bridges must handle both upstream and downstream type 1 device messages regardless of if they support upstream configuration cycles, including conversion to type 0 when the message reaches the destination bus.

Table 122. Device Message Header Request Format

Bit-Time	CTL	7	6	5	4	3	2	1	0	
0	1	SeqID[3:2]		Cmd[5:0]: 1011xx						
1	1	PassPW	SeqID[1:0]		UnitID[4:0]					
2	1	Count[1:0]		Rsv	DataError	Chain	Reserved			
3	1	Reserved		Translation Permitted	Route Type	Silent Drop	Initial Fragment	Count[3:2]		
4	1	Destination Device Number/Rsv					Destination Function Number/Rsv			
5	1	Destination Bus Number/Rsv								
6	1	Addr[31:29]: 000b			Type: 0/1	Byte Count[11:8]/Reserved				
7	1	Addr[39:32]: FEh								
8	0	Source Device Number					Source Function Number			
9	0	Source Bus Number								
10	0	Byte Count[7:0]/Reserved								
11	0	Class-Specific[7:0]								
12	0	Class-Specific[15:8]								
13	0	Class-Specific[23:16]								
14	0	Class-Specific[31:24]								
15	0	Class-Specific[39:32]								

Count indicates the number of doublewords of data payload that accompanies the command header for an individual request in a fragment, as it does for any HyperTransport write request.

Initial Fragment indicates if this fragment is the first in a message.

Silent Drop indicates if the destination function should drop the message without logging any errors, in the event the destination does not support the specific message.

Route Type indicates if the destination bus, device, and function numbers should be used. If set, the message should be routed to the system host and the destination bus, device, and function numbers are reserved.

Translation Permitted indicates if the message meets the requirements of the *PCI Express to PCI/PCI-X Bridge Specification, Rev 1.0*. If this bit is set, forwarding of the message between PCI-X and PCI Express buses is supported.

Chain indicates if there are more requests coming in a fragment. HyperTransport devices are required to not insert any posted requests between the individual requests of a fragment. This is to ensure that the fragment is transported atomically across the fabric so that it can be reassembled at the destination without more buffering than is needed to store a single fragment. (If other messages or posted writes were allowed to be inserted between the individual requests of a fragment, an unbounded amount of buffer space would be required to reassemble the fragment.) See Figure 21 for an example of how fragments are used. All HyperTransport 1.05 and later devices must accept and forward device messages and fragments of any length. In a system containing a mix of 1.05 (or later) and older devices, nodes using device messages should be located together on the chain to ensure that fragments arrive intact.

The first request of a fragment carries only header information. Any data payload is carried in the second and subsequent requests of the fragment. A device message without a data payload must have the Chain bit clear in the first (and only) request of the fragment. In this case, the ByteCount field is reserved and ignored.

ByteCount is the number of bytes of valid data to be carried in the entire device message. 001h indicates 1 byte, FFFh indicates 4095 bytes, and 000h indicates a maximum of 4096 bytes. The byte count is adjusted for each fragment of a device message with the amount of data remaining. HyperTransport data packets are always padded to full doublewords, regardless of the byte count.

The source bus, device and function numbers identify the initiator of the message.

Class-specific is defined by the application in use.

Table 123. Device Message Data Request Format

Bit-Time	CTL	7	6	5	4	3	2	1	0	
0	1	SeqID[3:2]		Cmd[5:0]: 1011xx						
1	1	PassPW	SeqID[1:0]		UnitID[4:0]					
2	1	Count[1:0]		Rsv	DataError	Chain	Reserved			
3	1	Reserved		Translation Permitted	Route Type	Silent Drop	Initial Fragment	Count[3:2]		
4	1	Destination Device Number/Rsv					Destination Function Number/Rsv			
5	1	Destination Bus Number/Rsv								
6	1	Addr[31:29]: 000b			Type: 0/1	Byte Count[11:8]				
7	1	Addr[39:32]: FEh								
8	0	Data[7:0]								
9	0	Data[15:8]								
10	0	Data[23:16]								
11+	0	Each request may carry up to 64 bytes of data								

All fields of a data request’s control packet except Chain, DataError, and Count must match that of the associated header request.

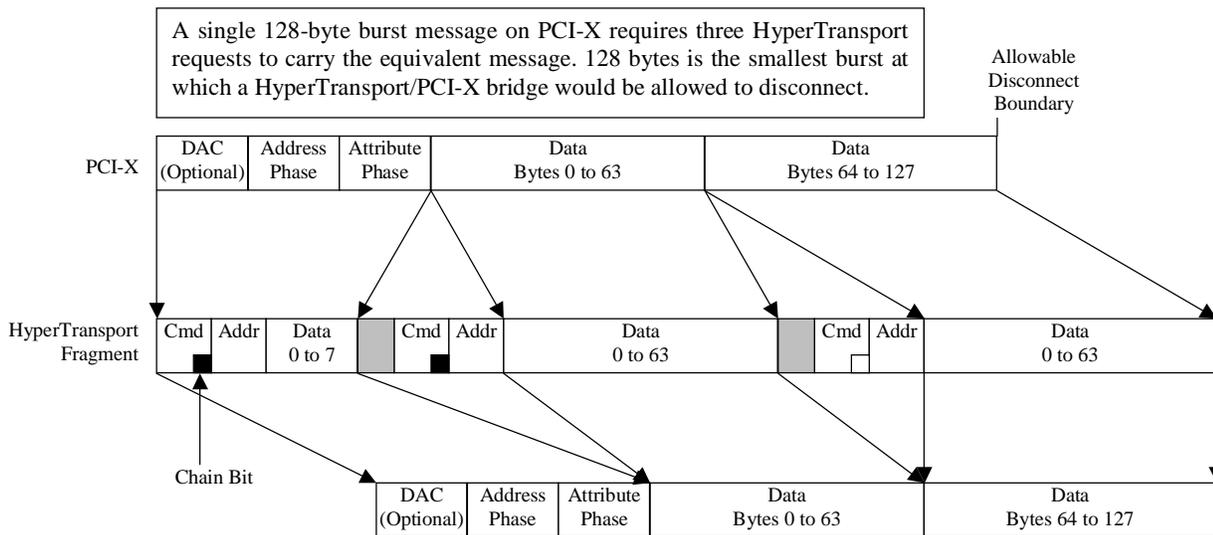


Figure 21. Fragment Use for PCI-X Messaging

Section 2.8.6 of the *PCI Express to PCI/PCI-X Bridge Specification, Rev 1.0* defines the mapping between PCI Express Vendor-Defined Messages and PCI-X Device-ID Messages. Table 124 additionally shows the mapping between these two message formats and HyperTransport Device Messages.

Table 124. PCI-X, HyperTransport, and PCI Express Message Mapping

Field	PCI-X Device ID Message	HyperTransport Device Message	PCI Express Vendor-Defined Msg
Completer Function	Addr[10:8]	Addr[10:8]	Byte 9 [2:0]
Completer Device	Addr[15:11]	Addr[15:11]	Byte 9 [7:3]
Completer Bus	Addr[23:16]	Addr[23:16]	Byte 8 [7:0]
Message Class [0]	Addr[24]	Addr[5]	-
Translation Permitted	-	Addr[5]	Byte 14 [7]
Silent Drop	Addr[30]	Addr[3]	Byte 7 [0]
Route Type	Addr[31] 0 for Dest. ID 1 for Host	Addr[4]	Byte 0 [2:0] 0 for Root 2 for ID
Byte Count [11:0] ¹	Attr[35:32] and Attr[7:0]	Addr[27:24] and Data[23:16]	Byte 14 [3:0] and Byte 15 [7:0]
Requestor Function	Attr[10:8]	Data[2:0]	Byte 5 [2:0]
Requestor Device	Attr[15:11]	Data[7:3]	Byte 5 [7:3]
Requestor Bus	Attr[23:16]	Data[15:8]	Byte 4 [7:0]
Relaxed Ordering	Attr[29] reserved=0	PassPW	Byte 2 [5] reserved=0
No Snoop	Attr[30] reserved=0	!Cmd[0]	Byte 2 [4] reserved=0
Initial Request ²	Attr[31]	Addr[2]	Byte 14 [4]
Vendor ID [15:0]	Addr[47:32]	Data[47:32]	Bytes 10 and 11
Mapped Bits [15:0]	Addr[63:48]	Data[63:48]	Bytes 12 and 13
Class-Specific [7:0]	Addr[7:0]	Data[31:24]	-
Tag [4:0]	Attr[28:24]	-	Byte 6 [4:0]
Notes:			
1. PCI-X DIMs always carry a data payload.			
2. Initial Request must be cleared when splitting a message on Max_Payload_Size (PCI Express) or Allowable Disconnect Boundaries (PCI-X).			

14 Streaming Packet

14.1 Streaming Semantics

This section defines a set of conventions for associating stream semantics with memory addresses. With stream semantics, successive writes to the same address convey additional values, which are concatenated to the stream of values. This is in comparison with storage semantics that define load/store operations on addresses.

Storage semantics and these streaming semantics coexist within the HyperTransport address space. The endpoint devices use the address space(s) defined by a locally defined BAR to determine whether the transaction uses storage semantics or streaming semantics. Intervening devices (tunnels or bridges) do not need to understand the distinction between storage and streaming addresses; they route the transaction normally. For streaming semantics, the address bits above bit 7 which fall within a locally defined BAR designate logical streams of messages; address bits 7 and below describe the current segment within the stream. Hardware at the source and destination of each message must map the stream of segments to memory buffers (or FIFOs or other data sources and sinks). The upper address bits above 7 within the locally defined BAR can be thought of as identifying a “virtual FIFOs” rather than a block of memory.

These streaming semantics are only defined for use with posted write commands.

14.2 Streaming Message Segmentation

Messages up to 64 bytes long are transferred as single transactions. Messages longer than 64 bytes are transferred in 64 byte segments, with a separate Posted Write transaction for each segment. When a message is not a multiple of 64 bytes the final segment of the message is padded to the next 32-bit doubleword boundary. In this case the rightmost (least significant) bytes of the last double word are valid and the leftmost (most significant) bytes of the last doubleword are pad.

Sequence integrity of segments within segmented messages is maintained by sourcing all messages in the same stream from a single node. (This rule does not preclude a node from sending interspersed segments or messages of different streams, i.e. with different addresses.) Sequence integrity of messages within a stream can be maintained by transferring all messages in the same stream in a common ordered sequence. (This rule does not preclude multiple message streams in the same ordered sequence.)

14.3 End Device Responsibilities

The devices which source and sink Streaming Request Packets have the following specific requirements, the fulfillment of which is beyond the scope of the specification:

1. Having a locally defined BAR which defines which memory addresses are to be defined with Streaming semantics instead of the load-store semantics
2. Advertising to other devices the location of this BAR and the number of logical streams supported.
3. Coordinating with other devices on the use of the various logical streams in a destination device.
4. Queuing and then selecting the next Message on a given logical stream which is to be turned into a sequence of Streaming Request Packets.
5. Interleaving the Streaming Request Packets from the various logical streams on the link according to a defined algorithm.
6. Consuming and/or storing the messages which have been reassembled from the Streaming Request Packets.
7. Defining a Maximum Message size which is accepted by the implementation and allowing the device to be configured with a smaller Maximum Message size. This is important for interoperability with other Packet systems and is commonly referred to as the MTU or Message Transfer Unit size.
8. Encapsulating higher or equivalent level protocols as needed.
9. Maintaining statistics on a Message basis if required.
10. Maintaining statistics on Aborts, Messages that are too long, or other error conditions.
11. Inserting or removing any Message level error detection fields if required.

14.4 Streaming Request Packet Format

Table 125 shows the format of the Streaming Request Packet which is a specific instantiation of a Posted Write Command as shown in Section 4.4.1.

Table 125 Streaming Request Packet Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]=1011xx					
1	PassPW	SeqID[1]	SeqID[0]/ ReqVC[3]	UnitID[4:0]				
2	Count[1:0]		Compat	Data Error	Chain	Rsv/ReqVC[2:0]		
3	SOM	EOM	Rsv	FormatID =0	Bcount[1:0]		Count[3:2]	
4	Addr[15:8]							
5	Addr[23:16]							
6	Addr[31:24]							
7	Addr[39:32]							

This message is a Posted Write with the following settings: Cmd[2] set to 1b to indicate doubleword data length. Cmd[1] (Isoc) set as per the application requirement. Cmd[0] (Coherent) set as per the application requirement.

DataError and *Chain* as per the definition in Section 4.4.1

ReqVC[3:0] indicate which VC this packet is in for VCSet=2 traffic.

Count[3:0] must be all ones except for the last segment of a message (*i.e.* EOM bit set or Bcount > 0).

Bcount[1:0] When EOM is set - equals the number of valid bytes (minus 1) in the final (32-bit) double word. When EOM is cleared – Bcount = 2'b00 indicates valid data, Bcount = 2'b01 indicates Abort, Bcount = 2'b10 and Bcount = 2'b11 are reserved. After an Abort any subsequent segments with the same stream identifier (Addr[39:8]) are discarded until the next SOM.

EOM is the End of Message flag. When set, this packet contains the last segment of a message. When clear, there is at least one additional segment of this message to follow.

SOM is the Start of Message flag. When set, this packet contains the first segment of a message. When clear, this packet is not the first segment of this message.

FormatID – set to 0b - indicates that this message, which is defined only in the range of the locally defined BAR is in Streaming Request Packet Format. If FormatID is set to 1b, the message is defined as per Appendix K.

Addr[39:8] (and *Addr[63:40]* of 64 bit addressed messages) designate the Streaming request stream. Request messages are routed based on these bits. Message streams coexist with other memory addresses in different blocks of the address space. Any mapping may be used that is compatible with HyperTransport address assignment rules.

The streaming data is transferred in the associated data packet after the Streaming Request packet.

15 Gen3 Link Test Support

Link Test is expected to be required in two system topologies. For point-to-point synchronous links, Built-In Self Test (BIST) and Internal Loopback Mode (ILM) can be used in combination to test the link with continuous patterns that are almost completely arbitrary. If a chain contains tunnels or has asynchronous links, the tunnels and any devices with asynchronous links must implement BIST so that the BIST engine in one device can generate patterns and the BIST engine in the other device can check them.

- Software must quiesce any traffic on the link that would hang the rest of the system due to dependencies.
- Software must set all links in the chain to be tested to the same frequency.
- ILM support is required at all implemented Gen3 frequencies.
- Gen3 chain hosts (system hosts, bridges, or switches with downstream Gen3 frequency support), tunnels with downstream Gen3 frequency support, and all devices that support asynchronous clocking mode at Gen3 frequencies must implement BIST at all implemented Gen3 frequencies.
- Transmit-only BIST support is recommended in all other devices.
- ILM and BIST support is recommended at Gen1 frequencies.
- LDTSTOP# skew must meet the Gen3 requirement in Section 2.1 to avoid false errors when using LDTSTOP# to exit BIST. Otherwise, BIST receivers must be disabled via a sideband method before disabling transmitters (via sideband method or via LDTSTOP# assertion).

ILM is also used outside of a system for standalone compliance testing.

- The device that controls LDTSTOP# and RESET# (typically the Southbridge) must provide a mechanism that software can trigger to assert LDTSTOP# or RESET# for the minimum period, then wait a programmable time for link test to run, and finally assert LDTSTOP# or RESET# again for the minimum period to return the system to normal operation. The programmable time must include a minimum value between 1 and 4 μ s, a value between 1 and 4ms, and an unlimited time where an access through the serial interface is required to end the test. Other times are highly recommended.

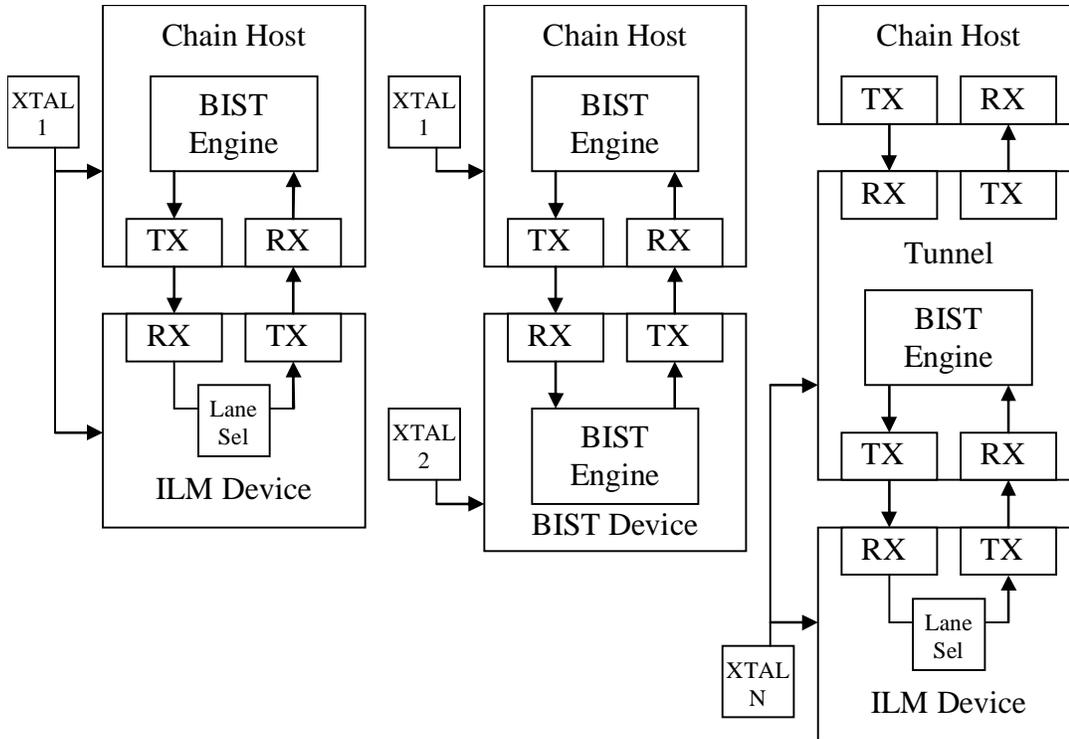


Figure 22. Link Test Topologies

15.1 Built-In Self Test

When used in a standalone test environment, a simple loopback cable or a test board provides the loopback external to the device.

When used in a system, devices directly attached to the device programmed for BIST are programmed for either BIST or ILM by software. Each BIST device integrates a BIST engine to generate and check programmable test patterns.

The sequence to enter BIST is:

1. LinkTest[BistEn] (and LinkSel if applicable) is set by software
2. LDTSTOP# or RESET# is asserted
3. Link disconnect is executed normally
4. After LDTSTOP# or RESET# is deasserted, *Training 0 to 3* are executed normally. If using Gen1 protocol, TXCTL must be held at logical 0 and RXCTL must be ignored for at least 1500ns after LDTSTOP# deassertion to delay initialization until the other side of the link is ready for testing. In Gen3 protocol if RESET# is used to enter loopback, the ILM device might consume a significant amount of *Training 0* to lock its DLL, so BIST devices should double the normal T0Time to 400us to ensure the BIST receiver sees enough training.
5. BIST patterns immediately follow the end of training. If using Gen1 protocol, the first bit of CTL after training is not necessarily a 1.

6. If LDTSTOP# is asserted again, the receiver stops checking BIST patterns and prepares to hold data eye position without any transitions within 100ns. The transmitter continues sending BIST patterns for 200 to 300ns, then transitions to *Disconnected*.
 7. If RESET# is asserted, the link transitions to *Warm Reset* immediately.
- The periodic CRC time slot is not transmitted, so BIST patterns are sent without interruption for the duration of the test
 - ILM devices do not remove lane-to-lane skew, so at least 23 bit-times of skew must be removed by the BIST receive FIFO. Removal of up to 32 bit-times of skew is recommended for maximum interoperability.
 - If one BIST device samples RESET# after the attached device in ILM or BIST then it cannot cleanly end BIST without observing false errors. There are two possible ways to avoid this:
 1. LDTSTOP# may be asserted before either device samples RESET#
 2. BISTCtl[RxDis] can be set or all bits of RxMask can be cleared to stop checking patterns before the end of the test.
 - If BISTCtl[RxDis] is set, the receiver is ignored and the minimum number of Training Patterns are sent in *Training 1 and 2* when entering BIST.
 - Support for BIST using Gen1 protocol is optional.
 - If a device is powered up without any test equipment providing stimulus to the receiver, LinkControl[TXOff] and [EndOfChain] need to be cleared after setting G1bLinkTrain[ConnDly] to initialize the link.

The BIST engine generates three basic patterns on all lanes:

- 32-bit pattern 1 or 2, 40 bits configured by the Pattern Buffer 1, 2, and Extension registers
 - Modulo-N counter, 24 bits, L/2, 4, 6, 8, or 24 configured by PatCtl[ModSel]
 - Constant 0 or 1, 24 bits configured by PatCtl[CnstSel]
- Each pattern is sent 0 to 127 times in a row (0 to 31 for Constant 0/1) within each overall loop, configured by PatCtl[PatCnt, ModCnt, and CnstCnt].
 - The order in which patterns are sent in each overall loop is configured by PatCtl[Order].
 - Any combination of lanes can be masked off by the Mask register.
 - Any combination of lanes can be replaced by the scrambler pattern for that lane by the Scramble register.
 - Any combination of lanes can be inverted by the Inversion register.
 - The Inversion register rotates by 1 at the end of each overall loop if enabled by BISTCtl[InvRotEn].
 - 8b10b encoding can only be enabled on all lanes or none, as controlled by LinkTrain[8b10b].

15.2 Internal Loopback Mode (ILM)

Gen3 devices must implement Internal Loopback Mode in which traffic received on a link is internally looped to the transmitter of that link. When used in a standalone test environment, the ILM device would typically be attached directly to a bit error rate tester (BERT) or other test devices. For use with a single-channel SerBERT, LinkTrain[SerLane] can choose a single transmitter lane in each byte that operates in ILM while all other lanes send scrambled 0's. When used in a system, a BIST device is directly attached to the ILM device.

ILM devices should limit the amount of skew they introduce when forwarding to 8 bit-times. This allows one core clock of skew across lanes to allow for synchronization error, assuming a 8:1 ratio between link data rate and core clock rate. While some BIST devices and test equipment might tolerate higher skews, it is not guaranteed by the specification.

The sequence to enter ILM is:

1. LinkTest[ILMEn] is set by software
2. LDTSTOP# or RESET# is asserted
3. Link disconnect is executed normally
4. After LDTSTOP# or RESET# is deasserted, the receiver's DLL must lock, then the sync FIFO pointers can begin running with a fixed, maximum distance between read and write pointers to allow for voltage and temperature drift during the test. If using Gen1 protocol, when exiting reset the transmitter must not assert CTL when switching from reset signaling to loopback.
5. Once the sync FIFO pointers are running the transmitter forwards all lanes from the receiver, with the rotation specified by LinkTrain[LaneSel].
6. The periodic CRC time slot is not tracked, and lane-to-lane skew is not removed.
7. If LDTSTOP# is asserted again, the receiver prepares to hold data eye position without any transitions within 100ns. The transmitter continues forwarding for 200 to 300ns, then transitions to *Disconnected*.
8. If RESET# is asserted, the link transitions to *Warm Reset* immediately.

15.3 Compliance Testing

All Gen3 devices must provide access to several registers for compliance testing via a JTAG or SMBus serial interface. A 10MHz or faster JTAG interface is preferred.

- Link Control
- Link Frequency
- Link Training
- Transmitter Configuration
- Receiver Configuration
- BIST Control (if present)
- Receiver BIST register set (if present)
- Transmitter BIST register set (if present)

Access to all HyperTransport registers and any nonstandard registers required to configure and control the link is recommended. To ensure that the link is tested in realistic conditions, the serial interface should provide control of a mechanism to exercise any other high-speed interfaces or logic that can cause noise on the HyperTransport link under test or the power supplies it uses.

16 Hot Plug

Gen3 protocol includes features allowing devices to be added or removed from the fabric without otherwise disrupting operation. Hot-add and hot-remove depend on system logic and software to manage power and sideband signals for all devices, properly configure registers, and handle user interaction to schedule and execute hot plug events. Additions to the protocol ensure that, when devices are properly configured, the CLK, CTL, and CAD signals are correctly controlled to allow plug events and protect the devices from any electrical damage. The platform design and software are responsible for detecting new devices and quiescing devices before detach. There is no protocol support for detecting surprise attach or detach.

- Power, PWROK, RESET#, and LDTSTOP# to the pluggable devices and across cables need to be individually controlled by the platform. Platform-specific software and hardware (such as service processors on each board) must communicate the state of these signals between devices via an unspecified sideband mechanism. If the sideband mechanism cannot meet the normal skew requirements of these signals, software must explicitly initialize the link since the hardware cold reset link detection mechanism can fail.
- Software (or a service processor) is responsible for correctly configuring these fields before clearing Link Control[TXOff] to avoid extra disconnects:
 - GblLinkTrain[ConnDly], LinkTrain[HotPlugEn]
 - LinkTest[ScrEn], [8b10b]
 - Link Frequency
 - Link Width
 - Link Control[End Of Chain]
- Isolation of sync floods between domains is via software setting TXOff.
- Software is responsible for cleaning up outstanding transactions on links that fail. Hardware support for this is optional, therefore a warm reset of some devices may be required to support continued operation.
- Changing link termination (LinkTrain[AC]), ganging (LinkTrain[Ganged]), or retry mode (Retry Control[Retry Enable]) requires a *Warm Reset*. In order to add a device to a system using only an LDTSTOP# assertion, the added device must be configured to match these link properties of the device(s) that are already operational.
- HotPlugEn causes link termination in the PHY OFF state to be modified so that the receiver and transmitter are protected from electrical transients during attach or detach events.
- Hot-add method 1:
 1. Via software and/or a service processor sideband access mechanism, configure both sides of the link to have matching link speed and width.
 2. Set LinkTrain[HotPlugEn].
 3. Set GblLinkTrain[ConnDly] on both sides.

4. Clear LinkControl[TXOff] and [EndOfChain] for the target links.
 5. Assert LDTSTOP# or RESET# long enough for PLLs in both devices to reach the programmed frequency.
- Hot-add method 2:
 - The platform provides independent control of power and PWROK to the added device allowing the existing device to begin training (with Tmr1 disabled by HotPlugEn) with the correct termination between power-up and PWROK assertion of the added device. The added device can correctly detect the existing device at *Cold Reset*. Software is responsible for later discovering the capabilities of the device and configuring link parameters on both sides of the link. This method allows hot-add of legacy devices without JTAG or SMBus access or hot-plug in systems without service processors that can access the JTAG or SMBus interfaces. For DC links, software must clear LinkTrain[AC] in the existing device with a warm reset prior to adding the legacy device since unterminated inputs set the AC bit during the *AC Detect* state. The added legacy device must still meet the electrical requirements of a HyperTransport 3.0 hot plug device when unpowered and when powered with PWROK=0 to avoid damage due to transients and allow correct receiver calibration.
 - Hot-remove method:
 1. Set GlibLinkTrain[ConnDly] on both sides of the target links.
 2. Set LinkControl[TXOff] and [EndOfChain] for the target links.
 3. Assert LDTSTOP# or RESET# to disconnect the links.

Protocol Appendices

A Address Remapping Capability

HyperTransport™ technology is meant to provide a high-bandwidth backbone for I/O systems, which are likely to contain a variety of other buses with varying addressing capabilities. If multiple buses with limited address space are to be combined, then it is helpful to map the smaller address spaces of individual buses into different locations within the HyperTransport address map. The capability block defined in Section 7.7, combined with a HyperTransport bridge header defined in Section 7.4 provides the programming interface for controlling three mechanisms. When these mechanisms are in use, setting the bits in the bridge header that affect address decoding (VGA Enable and ISA Enable) may result in undefined address decode behavior.

A.1 I/O Space Aliasing

The I/O Size register indicates the number of upper bits of I/O address space that are not used when forwarding downstream I/O space cycles to the secondary bus. This allows I/O addresses to be translated down into the address range that is available on the secondary bus.

In Figure 23, the I/O Window for the first PCI bridge (defined by the I/O Base and Limit registers) is 10_0000–17_FFFFh, with an I/O size of 6 to create a 19-bit PCI I/O space. The second bridge has an I/O Window of 40_0000–4F_FFFFh, with an I/O size of 5 for a 20-bit PCI I/O space. Because some PCI devices only support 16-bit I/O decoding, this allows more devices than would be possible on a single PCI bus.

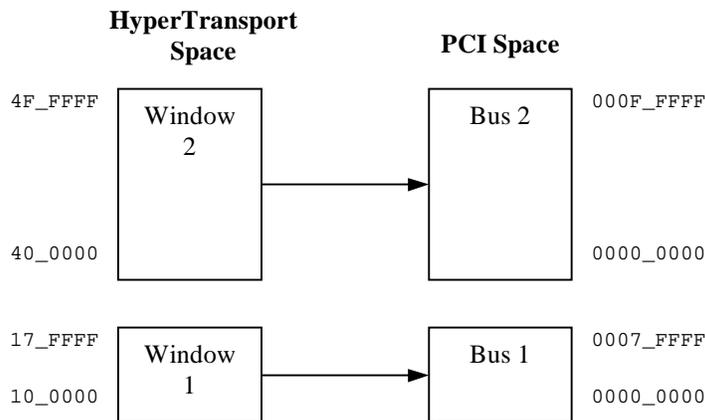


Figure 23. I/O Space Aliasing

A.2 Memory Space Mapping

The Secondary Bus Prefetchable Window Base and Secondary Bus Non-Prefetchable Window Base registers allow downstream accesses to be mapped to arbitrary positions in secondary bus memory space. While the Memory Base and Limit registers always define the range of addresses to be claimed on the primary bus and forwarded to the secondary bus, cycles that are claimed have their addresses modified because of the difference in the base addresses of the windows on the two buses, as these equations describe:

$$\begin{aligned} \text{PriSecNPDiff} &= \text{PriNPBase} - \text{SecNPBase} \\ \text{SecNPAddr} &= \text{PriNPAddr} - \text{PriSecNPDiff} \end{aligned}$$

$$\begin{aligned} \text{PriSecPFDiff} &= \text{PriPFBase} - \text{SecPFBase} \\ \text{SecPFAddr} &= \text{PriPFAddr} - \text{PriSecPFDiff} \end{aligned}$$

Because the addresses of the downstream memory windows on the secondary bus have been shifted from their locations on the primary bus, the address range of cycles that a bridge does not claim on the secondary bus must also be shifted. Therefore, memory cycles with addresses from SecNPBase to SecNPLimit or from SecFPBase to SecFPLimit are not claimed by the bridge on the secondary bus.

$$\begin{aligned} \text{SecNPLimit} &= \text{PriNPLimit} - \text{PriSecNPDiff} \\ \text{SecFPLimit} &= \text{PriFPLimit} - \text{PriSecPFDiff} \end{aligned}$$

Once claimed, a memory cycle forwarded from the secondary bus to the primary bus has its address modified according to the DMA Windows in the following section.

A.3 DMA Window Remapping

The DMA Secondary Base, DMA Primary Base, and DMA Secondary Limit registers define memory windows in the secondary bus memory space that are mapped to arbitrary positions on the primary bus. The resulting location of the DMA window on the primary bus is defined by these equations:

$$\begin{aligned} \text{PriSecDMADiff} &= \text{PriDMABase} - \text{SecDMABase} \\ \text{PriDMALimit} &= \text{SecDMALimit} + \text{PriSecDMADiff} \end{aligned}$$

A cycle whose address falls within a DMA window on the secondary bus has its address on the primary bus modified by this equation:

$$\text{PriDMAAddr} = \text{SecDMAAddr} + \text{PriSecDMADiff}$$

Accesses outside both the secondary bus DMA windows and the secondary bus memory windows defined above are passed upstream with unmodified addresses.

Software should ensure that the locations of the DMA windows on the secondary bus are outside of the secondary bus memory windows and that the DMA windows on the primary bus are outside of the primary bus memory windows, or undefined operation may result.

Figure 24 illustrates this example usage in a HyperTransport-to-PCI bridge:

Sec Bus Non-Prefetchable Base = 00_000h, Prefetchable Base = 00_C00h
 DMA Sec Base1 = 00_40h, DMA Sec Limit1 = 00_7F, DMA Pri Base1 = 0C_C0
 DMA Sec Base2 = 00_80h, DMA Sec Limit2 = 00_BF, DMA Pri Base2 = 0C_80
 Bridge Header has NP base and limit of 08_8000_0000 and 08_BFFF_FFFF
 Bridge Header has P base and limit of 09_C000_0000 and 0A_FFFF_FFFF

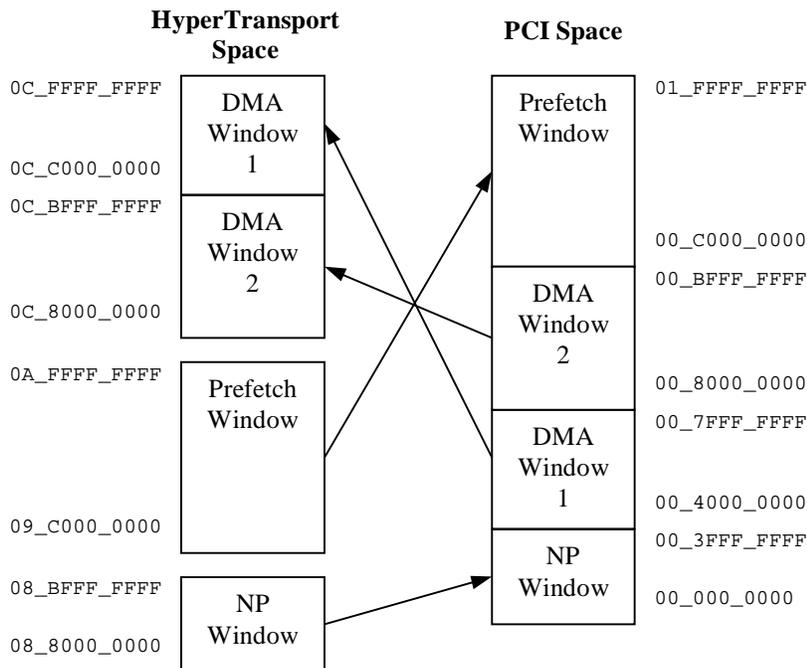


Figure 24. Memory Window Remapping

B Ordering Rules and Mapping of Other I/O Protocols

Ordering requirements for request packets are determined by their requester, and they follow the request all the way to the destination. Ordering rules for responses are also determined by the original requester and are taken from the request packet.

This appendix provides the mapping from the traffic types of each of the supported protocols to HyperTransport™ packet fields.

HyperTransport technology is intended to support connections to I/O bridges that use a variety of I/O protocols. At this time, there are four supported I/O bus protocols identified, PCI, PCI-X, AGP, and host processors, each of which has different ordering requirements, as described in this appendix.

B.1 Processors

Processors should generate nonposted writes for I/O and configuration space. It is implementation-specific as to whether processors generate posted or nonposted writes for memory-mapped I/O.

In order to safely implement the producer-consumer model in all configurations, processor requests should follow PCI ordering rules, with the PassPW bit always clear on requests.

Because I/O space cycles cannot cross doubleword boundaries, unaligned accesses by a processor that cross a doubleword boundary must be broken into successive HyperTransport cycles that ensure correct order of operation for the particular processor architecture.

B.2 PCI

B.2.1 Ordering

The PCI ordering rules listed in Table 126 are taken from the *PCI Local Bus Specification, Revision 2.3*, Appendix E. See that specification for more information.

Table 126. PCI Bus Transaction Ordering Rules

Row Pass Column?	Posted Memory Write (PMW)	Delayed Read Request (DRR)	Delayed Write Request (DWR)	Delayed Read Completion (DRC)	Delayed Write Completion (DWC)
PMW	No	Yes	Yes	Yes	Yes
DRR	No	Yes/No	Yes/No	Yes/No	Yes/No
DWR	No	Yes/No	Yes/No	Yes/No	Yes/No
DRC	No	Yes	Yes	Yes/No	Yes/No
DWC	Yes/No	Yes	Yes	Yes/No	Yes/No

Notes:

No—Indicates that the subsequently issued transaction is not allowed to complete before the previous transaction to preserve ordering in the system.

Yes—Indicates that the subsequently issued transaction must be allowed to complete before the previous transaction or deadlock may occur. Reasons for all eight Yes entries are given in the PCI specification. However, it indicates that the four Yes entries in the first row are only required for backward compatibility with earlier revisions of the specification. For the PMW/DRR and PMW/DWR cases, there is an additional reason^{3/4}they are required to be Yes because the fourth row requires DRCs to be able to pass DRRs and DWRs. In the case where a DRR or DWR occurs followed by a PMW and followed by a DRC, the PMW must pass the DRR/DWR in order to allow the DRC to do so, because the DRC may not pass the PMW.

Yes/No—Indicates the subsequently issued transaction may be allowed to complete before the previous transaction. There are no ordering requirements between the transactions.

B.2.2 Command Mapping

Table 127 shows the mapping of PCI transaction types to HyperTransport packet types and Table 128 shows the mapping in the opposite direction.

Table 127. PCI Transaction Mapping to HyperTransport Packets

PCI Transaction Type	HyperTransport Packet Type
Posted Memory Write (PMW)	WrSized, Posted, PassPW = 0, DataError = PERR ²
Delayed Read Request (DRR)	RdSized, PassPW = 0, RespPassPW = 0
Delayed Write Request (DWR) ³	WrSized, Nonposted, PassPW = 0
Delayed Read Completion (DRC)	RdResponse, PassPW = 0 (from request packet), DataError = PERR ²
Delayed Write Completion (DWC)	TgtDone, PassPW = 1 ¹ , DataError = PERR ⁴
<p><i>Note:</i></p> <ol style="list-style-type: none"> In some cases, the PassPW bit must be clear in a TgtDone. See Sections F.2.1.1 and F.2.5 for some examples. DataError is set if the bridge detected a data parity error. If a data parity error is detected in a nonposted write and the Parity Error Response Enable bit is set, then the write is discarded. DataError is set on PERR detection for DWC only if the Data Error Response Enable is set for the HyperTransport interface. 	

All PCI requests use a sequence ID of 0. Note that some applications may erroneously expect beats of read bursts on PCI to be executed in-order at the target. PCI does not require this behavior, but if it is desired, the HyperTransport read requests for such a burst must have matching non-zero sequence IDs. This ordering is only possible when all beats of the read have the same target.

PCI is capable of generating operations with discontinuous byte masks. If this occurs for read requests that cross aligned doubleword boundaries, they must be broken on doubleword boundaries into multiple transactions in the HyperTransport protocol. Similarly, write requests with discontinuous byte masks must be broken at 32-byte boundaries.

Configuration and I/O requests must be broken on doubleword boundaries. Write requests with contiguous byte masks must be broken at 64-byte boundaries. Posted writes that are broken into multiple HyperTransport requests must be issued in ascending order by address.

To support PCI 2.0 and earlier bus segments in a system, HyperTransport to PCI bridges must allocate enough buffer space to hold the response to a HyperTransport request before sending that request. Otherwise, the HyperTransport bridge cannot sink all responses without dependencies, as required by Section C.2.2.

Because PCI does not provide the same sequence ordering requirements as HyperTransport, in order to maintain correct behavior when mapping HyperTransport requests to PCI requests, all nonposted

HyperTransport requests to a PCI bus that contain matching non-zero SeqID values are required to complete on that bus prior to initiating subsequent nonposted requests to that bus with the same SeqID value.

Table 128. HyperTransport Packet Mapping to PCI Transactions

HyperTransport Packet Type	PCI Transaction Type
WrSized to Memory Space ¹	Posted Memory Write (PMW) ^{3,5}
WrSized to Configuration or I/O Space	Delayed Write Request (DWR) ²
RdSized of Memory, Configuration, or I/O Space	Delayed Read Request (DRR) ^{2,5}
RdSized of Legacy PIC IACK Space	Interrupt Acknowledge
RdResponse	Delayed Read Completion (DRC) ³
TgtDone	Delayed Write Completion (DWC), PERR = DataError ⁴
<p>Notes:</p> <ol style="list-style-type: none"> 1. A nonposted write to memory space still results in a posted write on the PCI bus. The HyperTransport-to-PCI bridge must respond with a TgtDone after all data phases for the write have completed. 2. While the decision to delay a request is actually made by the target, these cycles cannot be posted and must result in a RdResponse or TgtDone on the HyperTransport Link after their completion. 3. If the DataError bit is set, the bridge should send incorrect parity to alert the receiver that the data is corrupt. 4. Assertion of PERR for a data error is gated by the Parity Error Response Enable for the PCI interface. 5. The actual cycle type of memory accesses may vary depending on the value of the Memory Write and Invalidate Enable bit of the Command register and the value of the Cache Line Size register. 	

B.3 AGP

B.3.1 Ordering

These ordering rules are taken from the *Accelerated Graphics Port (AGP) Interface Specification, Revision 2.0*, Section 3.4. See that specification for more information.

AGP essentially consists of three separate channels, each with its own distinct ordering rules. No ordering is maintained between the three channels—traffic is completely independent. First, AGP contains a modified PCI channel, which maintains PCI ordering. The other two channels are called the high-priority (HP) and low-priority (LP) AGP channels.

The ordering rules presented here for reads are somewhat different from what appears in the AGP specification. That document defines ordering between reads in terms of the order that data is returned to the requesting device. We are concerned here with the order in which the reads are seen at the target—the I/O bridges can reorder returning read data if necessary. This leads to a slightly relaxed set of rules.

B.3.1.1 HP AGP Ordering Rules

1. Writes may not pass writes.

B.3.1.2 LP AGP Ordering Rules

1. Reads (including flushes) may not pass writes.
2. Writes may not pass writes.
3. Fences may not pass other transactions or be passed by other transactions.

AGP may also generate requests with discontinuous byte masks, with the same rules as PCI.

B.3.2 Command Mapping

The three channels of AGP are all completely independent as far as ordering is concerned, so (for optimal performance) a HyperTransport Link-to-AGP I/O bridge should assign each of these I/O streams to a separate UnitID.

The PCI channel of AGP uses the PCI mapping listed in Table 127.

The LP and HP channels never accept requests, so there is no need to specify the ordering of returning responses with respect to requests.

Table 129 shows the mapping of HP AGP transaction types to HyperTransport packet types.

Table 129. HP AGP Transaction Mapping to HyperTransport Packets

HP AGP Transaction Type	HyperTransport Packet Type
HP Write	WrSized, Posted, PassPW = 1
HP Read	RdSized, PassPW = 1, RespPassPW = 1

HP writes are placed in the posted request channel, while reads are placed in the nonposted request channel. Within each of these virtual channels, a single sequence ID is used to force the traffic to remain strongly ordered.

The PassPW and RespPassPW bits are set for reads because they are independent of the write traffic in the channel. The PassPW bit for writes does not matter in a pure HP AGP channel, because all the posted writes in the channel are strongly ordered due to the sequence ID anyway. But, if traffic from this channel were ever mixed with another I/O stream, having it set would minimize the interaction between the two.

There are two possible mappings of LP AGP traffic into the HyperTransport protocol. The first puts all traffic in the HyperTransport protocol nonposted channel as shown in Table 130.

Table 130. Simple LP AGP Transaction Mapping to HyperTransport

LP AGP Transaction Type	HyperTransport Packet Type
LP Write	WrSized, Nonposted, PassPW = 1
LP Read	RdSized, PassPW = 1, RespPassPW = 1
LP Flush	None (wait for all outstanding writes to complete)
LP Fence	None

All transfers in the low-priority channel are in the same virtual channel (nonposted requests), and they are all assigned to the same non-zero sequence ID, which keeps them strongly ordered. While this is a stronger ordering rule than required by AGP, it is sufficient. Since all transactions are strongly ordered, there is no need to do anything with a fence request.

Even though LP Writes are not posted in this mapping into the HyperTransport protocol, they can still be posted from the AGP point of view. The transaction can complete on the AGP bus without waiting for TgtDone in the HyperTransport protocol. However, the I/O bridge must remember that TgtDone is outstanding and not retire the buffer or SrcTag until it is received. Since the writes are not posted, there is also no need to issue an explicit HyperTransport flush packet. The I/O bridge can simply wait for TgtDone to be received for all outstanding writes and then complete the flush operation on the AGP bus.

The values of the PassPW and RespPassPW bits do not matter in this mapping of a pure LP AGP channel, because there are no posted writes in this channel in either direction in the HyperTransport protocol. However, if the traffic in this channel were ever to be combined with another I/O stream, setting them both would minimize the interactions with that stream.

The second mapping of LP AGP onto the HyperTransport protocol as shown in Table 131 puts LP writes in the posted channel:

Table 131. Alternate LP AGP Transaction Mapping to HyperTransport

LP AGP Transaction Type	HyperTransport Packet Type
LP Write	WrSized, Posted, PassPW = 0
LP Read	RdSized, PassPW = 0, RespPassPW = 1
LP Flush	Flush, PassPW = 0
LP Fence	None (wait for all outstanding read responses)

No use of nonzero sequence IDs is required. Ordering between LP writes is maintained by the fact that they are in the posted channel with their PassPW bits clear. LP reads are prevented from passing LP writes for the same reason. Flush operations use the HyperTransport flush packet. Fences still do not result in HyperTransport packets being sent, but they do require action in this mapping. Because no operation can pass a write, fences only need to be concerned with preventing other operations from passing reads. Therefore, they can be implemented by stalling all subsequent requests until responses have been received to all outstanding read requests.

As above, the value of RespPassPW on reads is not important in a pure LP AGP channel, but setting it may ease some interaction problems in a mixed channel.

B.4 PCI-X

B.4.1 Ordering

These ordering rules are taken from the *PCI-X Protocol Specification, Revision 2.0a*. See that specification for more information.

Table 132. PCI-X Transaction Ordering Rules

Row Pass Column?	Posted Memory Write (PMW)	Splittable Read Request (SRR)	Splittable Write Request (SWR)	Read Completion (RC)	Write Completion (WC)
PMW	RO = 0: No RO = 1: Yes/No	Yes	Yes	Yes	Yes
SRR	No	Yes/No	Yes/No	Yes/No	Yes/No
SWR	No	Yes/No	Yes/No	Yes/No	Yes/No
RC	RO = 0: No RO = 1: Yes/No	Yes	Yes	Yes/No	Yes/No
WC	Yes/No	Yes	Yes	Yes/No	Yes/No

Notes:

- The definitions of **Yes**, **No**, and **Yes/No** are the same as in the PCI Ordering Rules table. The rows and columns here map exactly onto the corresponding ones in the PCI table, with Splittable Reads and Writes being similar to Delayed Reads and Writes.

RO is the PCI-X Relaxed Ordering bit.

PCI and PCI-X ordering rules are very similar, with the exception of the Relaxed Ordering bit (RO in the table), which when set allows posted writes to be passed by other posted writes or read completions.

B.4.2 Command Mapping

Table 133 shows the mapping of PCI-X transaction types to HyperTransport packet types and Table 135 shows the mapping in the opposite direction.

Table 133. PCI-X Transaction Mappings to HyperTransport Packets

PCI-X Transaction Type	HyperTransport Packet Type
Posted Memory Write (PMW)	WrSized, Posted, PassPW = RO , Coherent = !No Snoop, DataError = PERR ⁴
Splittable Write Request (SWR) ⁵	WrSized, Nonposted, PassPW = 0, Coherent = 1
Splittable Read Request (SRR)	RdSized, PassPW = 0, RespPassPW = RO , Coherent = !No Snoop
Immediate Write Completion (IWC)	TgtDone, PassPW = 1 ² , DataError = PERR ⁶
Immediate Read Completion (IRC)	RdResponse, PassPW = original RespPassPW, DataError = PERR ⁴
Split Write Completion (SWC)	TgtDone, PassPW = 1 ² , see Table 134 for errors
Split Read Completion (SRC)	RdResponse, PassPW = original RespPassPW, see Table 134 for errors

PCI-X Transaction Type	HyperTransport Packet Type
Device ID Message (DIM) ⁷	First WrSized, Posted, PassPW = RO , Coherent = !NoSnoop, DataError=PERR ⁴ , Chain=1, Address[5:2] = {Message Class[0], Route Type, Silent Drop, Initial Request}, Address[27:24] = Byte Count [11:8], Data[15:0] = Requestor ID, Data[23:16] = Byte Count[7:0], Data[31:24] = Address[7:0] (Class Specific), Data[63:32] = Address[63:32] (Class Specific) Second and (if needed) Third WrSized have Chain=1, Data carries PCI-X Data, Last WrSized has Chain=0
Notes: <ol style="list-style-type: none"> 1. RO is the PCI-X Relaxed Ordering bit. 2. In some cases, the PassPW bit must be clear in a TgtDone. See Sections F.2.1.1 and F.2.5 for some examples. 3. The ‘!’ character indicates logical inversion. 4. DataError is set if the bridge detected a parity error or (in mode 2) an uncorrectable ECC data error. 5. Splittable Write requests with uncorrectable data errors are discarded if the Parity Error Response Enable is set. 6. DataError is set on PERR detection for SWC only if the Data Error Response Enable is set for the HyperTransport interface. 7. This mapping only includes Message Classes 0 and 1 at this time. More mappings can be defined as needed using reserved bits in the HyperTransport Device Message Address. DIMs must be broken into 128 Byte Fragments on each Allowable Disconnect Boundary. 	

All PCI-X transactions use a HyperTransport sequence ID of 0. Note that some applications may erroneously expect beats of read bursts on PCI-X to be executed in-order at the target. PCI-X does not require this behavior, but if it is desired, the HyperTransport read requests for such a burst must have matching non-zero sequence IDs. This ordering is only possible when all beats of the read have the same target.

Similarly to PCI, PCI-X may also have requests with discontinuous byte enables, which may need to be broken in multiple transactions following the same rules as for PCI. The only exception is that Posted writes with the Relaxed Ordering bit set do not need to be issued in ascending address order. As in PCI to HyperTransport packet mapping, PCI-X Configuration and I/O requests must be broken at doubleword boundaries.

To support PCI 2.0 and earlier bus segments in a system, HyperTransport to PCI-X bridges must allocate enough buffer space to hold the response to a HyperTransport request before sending that request. Otherwise, the HyperTransport bridge cannot sink all responses without dependencies, as required by Section C.2.2.

Table 134. PCI-X Completion Code Mappings to HyperTransport Encodings

Class	Index	Meaning	Result
0	00h	Normal Write Completion ¹	No Error
1 (Bridge)	00h	Master Abort	Target Abort (if Master Abort Mode set) Normal Completion otherwise Data all 1's in either case
	01h	Target Abort	Target Abort
	02h	Uncorrectable Split Write Data Error ¹	Data Error ²
2 (Completer)	00h	Byte Count Out of Range	Target Abort
	01h	Uncorrectable Split Write Data Error ¹	Data Error ²
	8Xh	Device-Specific Error	Target Abort
Notes: 1. These results are only possible in Split Write Completions. 2. Data error is only indicated if the Data Error Response Enable is set for the HyperTransport interface.			

Because PCI-X does not provide the same sequence ordering requirements as HyperTransport, in order to maintain correct behavior when mapping HyperTransport requests to PCI-X requests, all nonposted HyperTransport requests to a PCI-X bus that contain matching non-zero SeqID values are required to complete on that bus prior to initiating subsequent nonposted requests to that bus with the same SeqID value.

Table 135. HyperTransport Packet Mappings to PCI-X Transactions

HyperTransport Packet Type	PCI-X Transaction Type
WrSized to Memory Space ²	Posted Memory Write (PMW) ⁵ , RO = PassPW ¹ , No Snoop = !Coherent
WrSized to Configuration or I/O Space	Splittable Write Request (SWR) ³
RdSized to Memory Space	Splittable Read Request (SRR) ³ , RO = RespPassPW ¹ , No Snoop = !Coherent
RdSized to Configuration or I/O Space	Splittable Read Request (SRR) ³

HyperTransport Packet Type	PCI-X Transaction Type
RdResponse	Split or Immediate Read Completion (SRC) ⁵ , RO from original request
	Split Completion Message, see Table 136 for Class/Index
TgtDone	Immediate Write Completion (IWC), PERR = DataError ⁶
	Split Completion Message, see Table 136 for Class/Index
Posted WrSized to Extended Configuration space If Chain=0 on first WrSized, no Data. Otherwise, Second and subsequent WrSized carry data. Last WrSized has Chain=0.	Device ID Message (DIM) ⁵ , RO = PassPW ¹ , No Snoop = !Coherent, Route Type = Addr[4], Silent Drop = Addr[3], Initial Request = Addr[2], Byte Count = {Address[27:24], Data[23:16]}, Requestor ID = Data[15:0], Message Class[0] = Addr[5], Address[7:0] (Class Specific) = Data[31:24], Address[63:32] (Class Specific) = Data[63:32]
<p>Notes:</p> <ol style="list-style-type: none"> 1. RO is the PCI-X Relaxed Ordering bit. 2. A nonposted write to memory space still results in a posted write on the PCI-X bus. The HyperTransport to PCI-X bridge must respond with a TgtDone after all data phases for the write have completed. 3. While the decision to split a request is actually made by the target, these cycles cannot be posted and must result in a RdResponse or TgtDone on the HyperTransport Link after their completion. 4. The ‘!’ character indicates logical inversion. 5. If the DataError bit is set, the bridge should send incorrect parity (or stomped ECC in mode 2) to alert the receiver that the data is corrupt. 6. Assertion of PERR for an uncorrectable data error is gated by the Parity Error Response Enable for the PCI-X interface. 	

Table 136. HyperTransport Error Mappings to PCI-X Completion Errors

Error Encoding	Class	Index
Data Error	1	02h*
Target Abort	1	01h
Master Abort	1	00h

*Data error is only indicated if the Parity Error Response Enable is set for the PCI-X interface. The Data Error Completion Message is only used for TgtDone responses because Read responses indicate data error with stomped parity/ECC.

B.5 Message Signaled Interrupts

PCI, PCI-X, and PCI Express define Message Signaled Interrupts (MSIs), which carry 16 bits of data representing an interrupt to a software-defined address. In order to support MSIs with the minimum of hardware, HyperTransport to PCI, PCI-X, or PCI Express bridges should implement the mapping of MSIs to HyperTransport Interrupt packets defined in Table 137 for memory writes to an address range defined in Section 7.12.

Table 137. PCI MSI to HyperTransport Packet Mapping

MSI Field	HyperTransport Interrupt Field
Address[2],Data[15,10:8]	IntrInfo[6:2] (x86 DM, RQEIO, MT[2:0])
Address[19:12]	IntrInfo[15:8] (x86 Destination[7:0])
Data[7:0]	IntrInfo[23:16] (x86 Vector)
Address[11:4]	IntrInfo[39:32] (x86 Destination[15:8])
Address[30:20]	IntrInfo[50:40] (x86 Destination[26:16])
Address[3]	IntrInfo[51] (x86 Destination[27])
Data[14:11]	IntrInfo[55:52] (x86 Destination[31:28])
Notes: <ol style="list-style-type: none"> 1. Data[15]/IntrInfo[5] (x86 RQEIO) must be set to 0 by software in PCI and PCI-X devices because they do not receive HyperTransport End Of Interrupt broadcasts. 2. Data[10:8]/IntrInfo[4:2] (x86 Message Type) can be either 000b for Fixed-destination delivery or 001b for Lowest-Priority delivery. 3. IntrInfo[7] (x86 MT[3]) is 0b. 4. IntrInfo[31:24] is F8h 	

B.6 PCI Express

B.6.1 Ordering

These ordering rules are taken from the *PCI Express Base Specification, Revision 1.0a*. See that specification for more information.

Table 138. PCI Express Transaction Ordering Rules

Row Pass Column?	Posted Write or Message Request (PWR)	Nonposted Read Request (NRR)	Nonposted Write Request (NWR)	Read Completion (RC)	Write Completion (WC)
PWR	RO = 0: No RO = 1: Yes/No	Yes	Yes	Yes ²	Yes ²
NRR	No	Yes/No	Yes/No	Yes/No	Yes/No
NWR	No	Yes/No	Yes/No	Yes/No	Yes/No
RC	RO = 0: No RO = 1: Yes/No	Yes	Yes	Yes/No ³	Yes/No
WC	Yes/No	Yes	Yes	Yes/No	Yes/No

Notes:

- The definitions of **Yes**, **No**, and **Yes/No** are the same as in the *PCI Ordering Rules* table. The rows and columns here map exactly onto the corresponding ones in the *PCI* table, with Nonposted Reads and Writes being similar to Delayed Reads and Writes.
- PCI Express* allows Posted requests to be blocked by Completions (except in bridges to conventional *PCI* buses), motivating the *PCI Express* requirement that endpoints must advertise infinite completion flow control credits and/or pre-allocate storage for any completions it may receive before issuing requests.
- Multiple Read Completions for a single Request (have the same Transaction ID) must be returned in address order. **RO** is the *PCI Express Relaxed Ordering* bit.

PCI-X and *PCI Express* ordering rules are nearly identical. Posted cycles can be blocked by completions within *Express* fabrics because the deadlock conditions allowed in conventional *PCI* are not allowed in *Express* fabrics.

B.6.2 Command Mapping

Table 139 shows the mapping of PCI Express transaction types to HyperTransport packet types and Table 140 shows the mapping in the opposite direction.

Table 139. PCI Express Transaction Mappings to HyperTransport Packets

Express Transaction Type	HyperTransport Packet Type
Memory Write (MWr)	WrSized, Posted, PassPW = RO , Coherent = !No Snoop, DataError = EP ⁴
I/O or Configuration (Nonposted) Write Request (IOWr, CfgWr) ⁵	WrSized, Nonposted, PassPW = 0, Coherent = 1
Read Request (MRd, MrdLk ⁷ , IORd, CfgRd)	RdSized, PassPW = 0, RespPassPW = RO , Coherent = !No Snoop
Write Completion (Cpl)	TgtDone, PassPW = 1 ² , DataError = EP ⁴
Read Completion (Cpl, CplID, CpILk ⁷ , CplDLk ⁷)	RdResponse, PassPW = original RespPassPW, DataError = EP ⁴
Message w/o Data (Msg) ⁶	WrSized, Posted, PassPW = RO , Coherent = !NoSnoop, DataError= EP ⁴ , Chain=0, Address[5] = Translation Permitted, Address[4] = 0 for Routed by ID (r=010) or 1 for Routed to Root Complex (r=000), Address[3] = Message Code[0], Address[2] = Initial Request, Address[27:24] = Byte Count[11:8], Data[15:0] = Requestor ID, Data[23:16] = Byte Count[7:0], Data[31:24] = 00h, Data[63:48] = Mapped Bits[15:0], Data[47:32] = Vendor ID

Express Transaction Type	HyperTransport Packet Type
Message w/ Data (MsgD) ⁶	First WrSized same as above but Chain=1, Second and (if needed) Third WrSized have Chain=1, Data carries Message Data, Last WrSized has Chain=0
<p>Notes:</p> <ol style="list-style-type: none"> RO is the PCI Express Relaxed Ordering attribute bit. No Snoop is the other attribute bit. In some cases, the PassPW bit must be clear in a TgtDone. See Sections F.2.1 and F.2.5 for some examples. The ‘!’ character indicates logical inversion. DataError is set if the bridge received a packet with the EP bit set or an ECRC error in the TLP digest. Nonposted Write requests with uncorrectable data errors are rejected (return Completion w/ Unsupported Request status) if the Parity Error Response Enable is set. This mapping only includes Vendor Defined Types 0 and 1 routed by ID or to root complex at this time. More mappings can be defined as needed using reserved bits in the HyperTransport Device Message Address. Messages should be broken into 128 Byte Fragments for PCI-X compatibility, with Initial Request cleared for all but the first fragment of each message. HyperTransport does not support locked reads, so they are handled as ordinary read requests, however the correct completion type must be sent when the response is available. 	

All PCI Express transactions use a HyperTransport sequence ID of 0.

When a single Express Read must be broken into multiple HyperTransport read requests, the HyperTransport/Express bridge must buffer and reorder all outstanding responses for a single Express read before returning any completions to ensure that they are returned in address order.

Similarly to PCI, PCI Express may also have requests with discontinuous byte enables, which may need to be broken in multiple transactions following the same rules as for PCI. The only exception is that Posted writes with the Relaxed Ordering bit set do not need to be issued in ascending address order. Unlike PCI, PCI Express Configuration and I/O requests are limited to a single doubleword in length, and therefore always directly map to HyperTransport requests.

An Express device is allowed to respond to configuration requests with a Configuration Request Retry completion status. The bridge is acting as a root complex, and therefore must either terminate the transaction on the HyperTransport link with a target abort, returning data of all 1’s on reads, or retry the request on the Express link.

An Unsupported Request error in Express is equivalent to a Master Abort in HyperTransport. Unsupported Request completions from PCI-Express are mapped to Target Abort or a normal completion to HyperTransport as specified by the Master-Abort Mode bit of the Bridge Control register (see Section 7.4.9.6). Master Abort responses from HyperTransport are always mapped to Unsupported Request completions to PCI-Express.

A Completer Abort in Express maps to a Target Abort in HyperTransport and vice-versa.

Table 140. HyperTransport Packet Mappings to PCI Express Transactions

HyperTransport Packet Type	PCI Express Transaction Type
WrSized to Memory Space ²	MWr ⁴ , RO = PassPW ¹ , No Snoop = !Coherent ⁷
WrSized to Configuration or I/O Space	CfgWr0, CfgWr1, or IOWr
RdSized to Memory Space	MRd, RO = RespPassPW ¹ , No Snoop = !Coherent ⁷
RdSized to Configuration or I/O Space	CfgRd0, CfgRd1, or IORd
RdResponse	Cpl ⁵ or CplD ⁴ , RO from original request
TgtDone	Cpl ⁶
Posted WrSized to Extended Configuration space If Chain=0 on first WrSized, no Data. Otherwise, Second and subsequent WrSized carry data. Last WrSized has Chain=0.	Msg or MsgD ⁴ , RO = PassPW ¹ , No Snoop = !Coherent ⁷ , r[2:0] = 010b if Route Type = 0 or 000b if Route Type = 1, Vendor ID = Data[47:32], Mapped Bits = Data[63:48], Translation Permitted = Addr[5], Initial Request = Addr[2], Byte Count = Byte Count, Requestor ID = Data[15:0], Message Code = {0111111b, Silent Drop}
Notes: 1. RO is the PCI Express Relaxed Ordering bit. If the Enable Relaxed Ordering bit in the PCI Express Device Control register is cleared, the RO bit must not be set in requests, regardless of the value of PassPW or RespPassPW. 2. A nonposted write to memory space still results in a posted write on the PCI Express bus. The HyperTransport to PCI Express bridge must respond with a TgtDone after all data phases for the write have completed. 3. The ‘!’ character indicates logical inversion. 4. If the DataError bit is set, the bridge should set the EP bit to alert the receiver that the data is corrupt. 5. If there is a Master or Target Abort in the transaction, a Completion without data must be returned for a read. 6. If the DataError bit is set, the bridge must not set the EP bit and should indicate an Unsupported Request. 7. If the Enable No Snoop bit in the PCI Express Device Control register is cleared, the No Snoop bit must not be set in requests, regardless of the value of the Coherent bit.	

PCI Express has more restrictive byte enable rules than conventional PCI or HyperTransport, so the bridge must break up memory writes with discontinuous byte enables on 64-bit boundaries.

Because PCI Express does not provide the same sequence ordering requirements as HyperTransport, in order to maintain correct behavior when mapping HyperTransport requests to PCI Express requests, all nonposted HyperTransport requests to a PCI Express bus that contain matching non-zero SeqID values are required to complete on that bus prior to initiating subsequent nonposted requests to that bus with the same SeqID value.

B.6.3 System Management Considerations

ERR_FATAL, ERR_NONFATAL, and ERR_COR messages from Express cause sync flood if enabled by the corresponding bits of the Root Control register of the PCI Express Capability and the SERR# Enable bit of the Command register is set. ERR_FATAL may be mapped to the HyperTransport fatal error interrupt, and ERR_NONFATAL and ERR_COR may be mapped to the nonfatal error interrupt in an implementation-specific way.

The handling of various messages by a HyperTransport to PCI Express bridge is different depending on if the system management controller (SMC) and legacy Programmable Interrupt Controller (PIC) are integrated into the same physical device as the bridge. Note that there can only be one SMC in the system.

B.6.3.1 Bridge with SMC and PIC

- Accept INTx messages coming downstream from the HyperTransport host and upstream from Express ports.
- INTx physical wires are inputs for legacy compatibility
- Accept PME messages from Express.
- Initiate and wait for completion of the PME_Turn_Off/PME_TO_Ack handshake when entering a power state that removes power from an Express device and/or stops its reference clock.

B.6.3.2 Bridge without SMC and PIC

- Combine INTx messages from Express ports with locally generated messages and send them upstream to the host.
- INTx physical wires are outputs for legacy compatibility
- Assert a physical PME# pin when Express PME messages are received.
- Send PME_Turn_Off message on all ports when a STOP_GRANT message is received with a system management action field (SMAF) that indicates power or reference clocks will be removed.

If the bridge has auxiliary power to support reception of Express wakeup beacons, it should assert a physical WAKE# pin when beacon signaling is received.

The SMC must ensure there is enough time between when it receives STOP_GRANT and power (or reference clocking) is removed for all devices to receive PME_Turn_Off and enter the L2/3 ready state.

The mapping between HyperTransport messages and PCI Express messages that would allow the SMC and PIC to exist on a PCI Express port has not been defined because the Express base specification and

existing power management software depends on the SMC being a part of the root complex (bus 0) and therefore above the bridge. Express also specification forbids subtractive decode bridges, which would be required to deliver requests to legacy devices that typically coexist with the SMC. The messages that are not mapped include System Management messages, Interrupt Acknowledge requests, End of Interrupt messages, and x86-specific messages.

B.7 Address Translation Packets

PCI Express defines Address Translation Services to allow endpoint devices or bridges to improve I/O performance. This appendix provides the HyperTransport packet formats needed to provide these services in systems using HyperTransport links.

B.7.1 Address Translation Request

A device in a system that supports distributed address translation tables may issue an upstream request for address translations. The format for such a request is shown in Table 141. The address in the request is the first virtual address to be translated. Count indicates the number of consecutive address ranges to translate. Legal values of Count are $2N-1$, where N is the number of address ranges to translate. An illegal Count value results in a target abort response, as is appropriate for any illegal request. The size of address ranges are system-dependent, but are always an integer number of 4K pages.

Table 141. Address Translation Request

Bit-Time	7	6	5	4	3	2	1	0
0	10b		Cmd[5:0]=111110b					
1	Device[4:0]				Function[2:0]			
2	Bus[7:0]							
3	Reserved						AddressType[1:0]=01b	
4	SeqID[3:2]		Cmd[5:0]=01x1x0b					
5	PassPW	SeqID[1:0]		UnitID[4:0]				
6	Count[1:0]		Compat=0		SrcTag[4:0]			
7	Ignored						Count[3:2]	
8	Virtual Addr[15:12]				Ignored			
9	Virtual Addr[23:16]							
10	Virtual Addr[31:24]							
11	Virtual Addr[39:32]							

B.7.2 Address Translation Response

The response to an address translation request is a read response with count 2N-1, containing a 64-bit translated (physical) address payload in each 2 DW's. Only 8 translated address payloads may be returned in one response. When bridging from PCI-Express, additional translated addresses in the completion(s) for a request may be discarded by the bridge.

Table 142. Address Translation Response Format

Bit-Time	CTL	7	6	5	4	3	2	1	0
0	1	Isoc	Rsv	Cmd[5:0]: 110000					
1	1	PassPW	Bridge	Rsv	UnitID[4:0]				
2	1	Count[1:0]		Error0	SrcTag[4:0]				
3	1	Rsv/RqUID		Error1	Rsv/RspVCSet			Count[3:2]	
4	0	Payload 1 Byte 0							
5	0	Payload 1 Byte 1							
...	0	...							
3+8N	0	Payload N Byte 7							

Table 143. Address Translation Response Payload

Byte	7	6	5	4	3	2	1	0
0	Reserved					U	W	R
1	Physical Addr1[15:12]				Size	Coherent	Reserved	
2	Physical Addr1[23:16]							
3	Physical Addr1[31:24]							
4	Physical Addr1[39:32]							
5	Physical Addr1[47:40]							
...	...							
7	Physical AddrN[63:56]							

Read Permission (R): 1= Reads to the region are allowed

Write Permission (W): 1= Writes to the region are allowed

Untranslated (U): 1= Requests to the region must be issued as untranslated (AT=00b)

Coherent: 1= Coherent bit must be set for requests to the region

Size: 0= Region is a fixed 4KB size; 1= Size is indicated by the least-significant 0 in address bits 12 and above, as shown in Table 144.

Table 144. Region Size Encodings

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11 (size)	Region Size	
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0	4KB
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	0	1	8KB
...																			1	1	...	
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4GB

B.7.3 Translation Invalidation Request

A device that maintains address translation tables may issue a request to invalidate a previously sent address translation. The format for such a request is shown in Table 145. Because both the request and response use posted writes, the InvRsp bit is used to differentiate them.

Table 145. Translation Invalidation Request

Bit-Time	CTL	7	6	5	4	3	2	1	0
0	1	10b		Cmd[5:0]=111110b					
1	1	Device[4:0]				Function[2:0]			
2	1	Bus[7:0]							
3	1	Reserved						AddressType[1:0]=00b	
4	1	SeqID[3:2]		Cmd[5:0]=1011x0b					
5	1	PassPW	SeqID[1:0]		UnitID[4:0]				
6	1	Count[1:0]=01b		Compat=0	Data Error	Chain=0	Reserved		
7	1	Reserved				InvRsp=0	Count[3:2]=00b		
8	1	Target Device[4:0]				Target Function[2:0]			
9	1	Target Bus[7:0]							
10	1	Addr[31:24]=FBh							
11	1	Addr[39:32]=FDh							
12	0	Invalidation Tag[4:0]				Reserved			
13	0	Virtual Addr[15:12]			Size	Reserved			
14	0	Virtual Addr[23:16]							
15	0	Virtual Addr[31:24]							
16	0	Virtual Addr[39:32]							
17	0	Virtual Addr[47:40]							
18	0	Virtual Addr[53:48]							
19	0	Virtual Addr[63:54]							

B.7.4 Translation Invalidation Response

The format for an invalidation response is shown in Table 146. Because multiple responses may be combined, the Invalidation Tag Vector contains one bit for each of the possible 32 Invalidation Tag values from an invalidation request. Because a separate response is required for normal and isochronous channels on HyperTransport links and for each Traffic Class on a PCI-Express link, the Completion Count field indicates how many responses will be sent for the invalidation. A completion count encoding of 000b indicates 8 responses, 001b one response, 010b two responses, and so on.

Table 146. Translation Invalidation Response

Bit-Time	CTL	7	6	5	4	3	2	1	0
0	1	10b		Cmd[5:0]=111110b					
1	1	Device[4:0]				Function[2:0]			
2	1	Bus[7:0]							
3	1	Reserved						AddressType[1:0]=00b	
4	1	SeqID[3:2]		Cmd[5:0]=1011x0b					
5	1	PassPW=0	SeqID[1:0]		UnitID[4:0]				
6	1	Count[1:0]=00b		Compat=0	Data Error	Chain=0	Reserved		
7	1	Reserved		Completion Count[2:0]			InvRsp=1	Count[3:2]=00b	
8	1	Target Device[4:0]				Target Function[2:0]			
9	1	Target Bus[7:0]							
10	1	Addr[31:24]=FBh							
11	1	Addr[39:32]=FDh							
12	0	Invalidation Tag Vector[7:0]							
13	0	Invalidation Tag Vector[15:8]							
14	0	Invalidation Tag Vector[23:16]							
15	0	Invalidation Tag Vector[31:24]							

C Summary of Deadlock Scenarios

Several scenarios have been mentioned throughout this specification that could cause deadlocks in HyperTransport™ systems. This appendix summarizes them and provides more information about their possible causes and how they are avoided.

C.1 Reflection/Forwarding Loops

C.1.1 Problem

In order to provide the same producer/consumer ordering behavior as PCI, peer-to-peer requests must be reflected through the host of a HyperTransport chain. This results in the host creating dependencies in upstream traffic upon downstream traffic when the host reissues upstream requests as downstream requests. If any other device in the chain also reflects traffic in the same virtual channel, a loop forms and if the number of packets in that channel exceed the amount of buffering available, the loop deadlocks because traffic can no longer be drained from the loop to make room for new traffic. An example, illustrated in Figure 25, is a device relying on host memory to sink traffic. In this example, downstream traffic targeting the reflecting device is reissued upstream to the host, making progress of downstream traffic through the reflecting device dependent upon the upstream flow of traffic out from the reflecting device. The loop forms when a source device at the bottom of the chain has its upstream traffic reflected downstream by the host for peer-to-peer access. If the reflecting device is unable to sink all the traffic from the host, the peer-to-peer traffic backs up the downstream channel, into the host, and then back up the upstream channel. At this point, the peer-to-peer traffic and reflected traffic are blocking each other and the system deadlocks. An even worse case is when the peer-to-peer traffic is targeting the reflecting device, in which case the reflecting device must sink all the traffic from the host in addition to all the peer-to-peer traffic targeting it to avoid a deadlock.

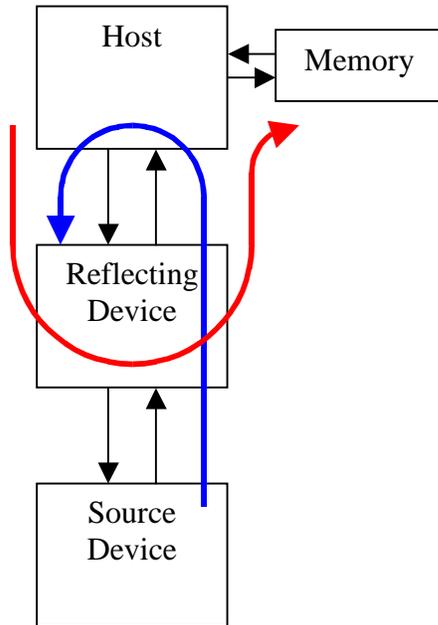


Figure 25. Reflection Example

Double-hosted chains can have the same problems, unless all requests are issued in the direction of the master host. This is because requests directed down to the slave host may be reflected upstream if the slave host does not accept them. Combining this reflected traffic with peer-to-peer traffic reflected off the master host creates a loop that can result in deadlock, as mentioned in Section 4.1.1.

C.1.2 Solution 1: Avoidance

Section 4.7 avoids these deadlocks by placing these requirements on devices:

- Do not make acceptance of a posted request dependent upon the ability to issue another request.
- Do not make acceptance of a nonposted request dependent upon the ability to issue another nonposted request.
- Do not make acceptance of a request dependent upon receipt of a response.
- Do not make issuance of a response dependent upon the ability to issue a nonposted request.
- Do not make issuance of a response dependent upon receipt of a response.

In order to comply with these requirements, whatever operations the reflecting device would have performed before sending data upstream to host memory must instead be performed by the host. Some example operations are address translation, such as the Graphics Aperture Remapping Table for Advanced Graphics Port support, and data modification. This solution may also result in different ordering behavior than the actual reflection by the device would have exhibited.

The above rules do not apply to the host bridge of a chain. In a double-hosted chain, only one of the hosts may violate the rules to provide peer-to-peer reflection as the host bridge. The other host must have its ActAsSlave bit set and follow the rules.

C.1.3 Solution 2: Switching Channels

If the host, reflecting device, and all devices (if any) between them support Isochronous flow control (see Section D.1), and the traffic to be reflected and peer-to-peer traffic flowing within the chain is not Isochronous, then reflected normal traffic can be sent in the Isochronous channels.

C.1.4 Solution 3: Modifying Requests

A less costly solution that is possible in some systems is to modify requests flowing through the host and reflecting device to avoid the deadlock.

1. Define a “Reflection Region” known to the host and reflecting device, likely an address base/limit register pair.
2. The host forces all downstream requests to the reflection region to be nonposted, allowing all outstanding requests to be accounted for. This is only deadlock-free for requests originating from the host, not from other chains.
3. The reflecting device only responds to the downstream request after the upstream reflection has completed. Writes can be reflected as posted requests, allowing the response to the downstream request to be issued as soon as the upstream cycle is issued.
4. The host is programmed with the buffer depth of the reflecting device and must not issue more requests to the reflection region than the reflecting device can handle.
5. The reflecting device monitors upstream traffic and if the address of an upstream request is within the reflection region, the reflecting device modifies the request before forwarding it, such that the resulting request no longer targets the reflection region and instead targets host memory, removing the request from the deadlock loop. The ordering of the modified packets must not be affected by the modification. There cannot be any devices between the host and the reflecting device initiating peer-to-peer requests to the reflection region.

An alternative solution for reflecting devices in systems where there is no peer-to-peer traffic other than to the reflection region is to convert upstream posted writes to the reflection region to nonposted writes. This allows them to be counted and throttled, such that the reflecting device can ensure that it has enough resources to sink all requests from the host and all peer-to-peer accesses to the reflection region without blocking the nonposted buffers in the loop between the host and the reflecting device. Note that the converted upstream writes need to be issued with a UnitID of the reflecting device, and with unique SrcTags issued from the pool of tags available to the reflecting device.

6. Only accesses to memory or I/O space may be reflected. The reflections must target memory space.

C.2 Packet Issue and Acceptance

This section contains two requirements for deadlock avoidance: control/data buffer dependency and response buffer dependency.

C.2.1 Control/Data Buffer Dependency

A control packet that has an associated data packet cannot be issued unless both control and data buffers exist for accepting the packet. Because data packets for different command packets cannot be distinguished on the link, only one command with associated data is allowed to be issued at one time. If a command having an associated data packet was issued when no data buffer was free to accept it, no other commands with associated data could issue, either. This creates a new dependency of the later command with data upon the first. If both commands are in the same virtual channel, this is not a problem, however, if the subsequent command is required to pass the first according to the ordering rules of Section 6.1, this can result in a deadlock.

For example, a nonposted command buffer, a posted command buffer, and a posted data buffer could be free. If a device issued a nonposted write command, and then a posted write needed to be sent, the posted write would be blocked until the nonposted data buffer became free. Because the posted write is now stuck behind the nonposted write, the deadlock described in Section C.5.1 could occur.

C.2.2 Response Buffer Dependency

A device cannot issue a nonposted request unless the device can accept the response that results. If a device issued more nonposted requests upstream than it had resources available to sink the resulting downstream responses, then the downstream response buffers throughout the chain above the device would fill, preventing the flow of both host and peer-to-peer responses, which in turn would result in a deadlock.

C.2.3 Posted Request Acceptance

A device must sink posted requests targeting it without other dependencies. Posted requests must make forward progress in the system or they could block all traffic, due to ordering rules that do not allow other packets to pass posted writes.

C.3 Legacy Buses

As described in Section E.1, ISA and LPC both present the problem that once a transaction begins, no other transactions can begin until the prior transaction completes. This results in two possible deadlock scenarios:

C.3.1 Host/DMA Deadlock

If an ISA or LPC bus master (or the legacy DMA controller itself) initiates a read of host memory (or any nonposted upstream request) and the host issues a posted write (or any posted cycle) to the ISA or LPC bus before the read response returns to the ISA/LPC device, the read response can become stuck behind the posted write. The preferred solution is to require all requests sent to the ISA/LPC bus to be nonposted. Because responses are required to be able to pass nonposted requests, the deadlock cannot occur. Requests to the ISA/LPC bus are identified through both positively decoded spaces known to be allocated to the legacy bus, and any requests that have a subtractively decoded destination (compat bit set).

C.3.2 Peer-to-Peer Deadlock

Because the ISA or LPC bus is unable to sink any requests while it waits for a response to its own DMA requests, it is possible for the downstream nonposted request channel to fill, which in turn causes upstream nonposted peer requests to the host to block, which prevents the ISA/LPC bridge from making forward progress on its own nonposted requests. The solution to this issue is for the host to limit the number of requests it makes to the ISA/LPC bus to a known number of requests (typically one) that the bridge can sink. Because the host cannot limit peer requests without eventually blocking the upstream nonposted channel (and causing another deadlock), no peer requests to the ISA/LPC bus are allowed.

Peer requests to devices below the ISA/LPC bridge on the chain (including other devices in the same node as the ISA/LPC bridge) cannot be performed without deadlock unless the ISA/LPC bridge sinks the abovementioned known number of requests without blocking requests forwarded down the chain (or to other devices within the same node). This can be implemented with a buffer (or set of buffers) in the bridge node reserved for requests targeting the bridge, separate from the buffering for other requests.

C.4 System Management

The system management controller (typically located in the Southbridge or I/O Hub device) must sink system management messages regardless of other traffic (such as accesses to legacy buses), as required in Section F.2. If the SMC did not sink SM messages without dependencies, then the downstream posted channel would fill, blocking all other traffic and could cause many of the deadlock scenarios described throughout this appendix. This is a specific case of the above rule that posted requests must make forward progress in the system.

Section F.2.3 describes a power management/throttling deadlock between the host and the SMC. Normally, after sending a STPCLK assertion message, the SMC is required to wait for a STOP_GRANT message from the host and send a STPCLK deassertion message before sending any subsequent STPCLK assertion messages. If the SMC sends an unsolicited STPCLK assertion message for throttling, and receives a nonposted request to initiate a system state transition requiring a subsequent STPCLK assertion, the SMC must issue the subsequent STPCLK assertion without waiting for a STOP_GRANT. This is because the host cannot respond to throttling STPCLK assertions while waiting for a state transition to occur.

C.5 PCI Requirements

Because HyperTransport ordering rules share many of the requirements of PCI ordering rules, there are certain requirements inherited from PCI for deadlock avoidance.

C.5.1 Posted Requests Must Pass Nonposted Requests

As described in the *PCI Local Bus Specification*, Revision 2.3, Appendix E, rule 5, posted requests must be allowed to pass stalled nonposted requests to avoid deadlocks. Referring to Figure 26, one example deadlock scenario involves two bridges (X and Z) that do not support delayed (split) transactions on either side of a bridge that does (Y).

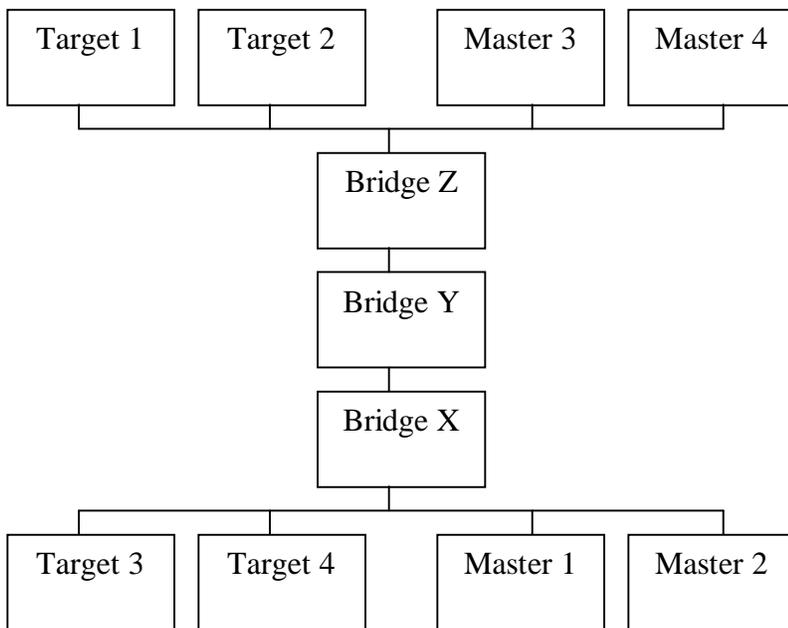


Figure 26. Example PCI System

Assume that reads have been issued from Master 1 to Target 1 and from Master 3 to Target 3, and both are delayed by bridge Y. Masters 2 and 4 issue a series of writes to Targets 2 and 4, respectively, which are posted in bridges X and Z. In order for either bridge X or Y to complete the reads and comply with the producer/consumer ordering model requirement that read responses cannot pass posted writes, they must flush their posted writes to bridge Y. Since bridge Y has limited resources for buffering the writes and the number of writes is unlimited, bridge Y must be allowed to reorder the posted writes past the reads or the system would be unable to make progress.

Substitute a HyperTransport chain for bridge Y, and this scenario becomes immediately relevant to all HyperTransport devices. Additionally, following this rule throughout a HyperTransport chain allows the posted channel to carry requests that need to be assured of forward progress, such as interrupts and system management messages.

C.5.2 Responses Must Pass Nonposted Requests

Rule 6 of PCI Appendix E requires responses (delayed completions) to be able to pass nonposted (delayed) requests to avoid a deadlock when two devices capable of split (delayed) transactions send nonposted requests to each other. For example, if Bridge A sends nonposted request 1 down to the secondary bus and bridge B sends nonposted request 2 up to the primary bus, the response (completion) of transaction 1 cannot make upstream progress if it is stuck behind request 2, which cannot make progress because response 2 is stuck behind request 1.

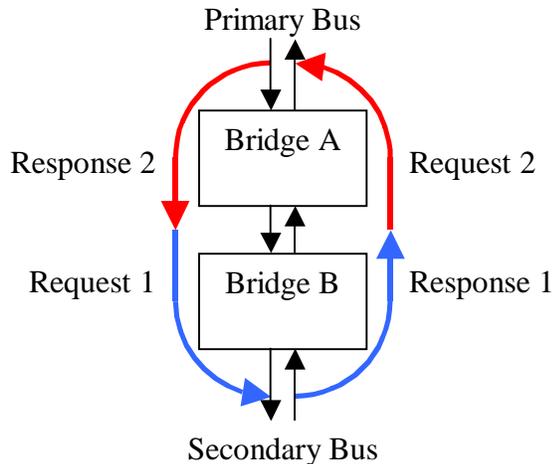


Figure 27. Request/Response Deadlock Loop

C.5.3 Posted Requests Must Pass Responses

PCI Rule 7 requires posted requests to be able to pass responses (delayed completions) and again refers to Figure 26 for an example. Assume that bridge Y has responses at the head of its queues in each direction, bridge X is full of downstream posted write data, and bridge Z is full of upstream posted write data. Bridges X and Z cannot complete their posted writes and retry their reads to accept the responses once bridge Y fills with posted write data in both directions (again we assume that bridge Y has limited resources for storing requests and the masters providing X and Z with data are not limited), and bridge Y cannot accept more posted write data until it completes its reads and delivers the responses, unless it is allowed to reorder the posted writes past the responses.

D Considerations for Isochronous Traffic

A problem relative to bounding latency for Isochronous traffic is the presence in the system of a very slow I/O device that is the target of posted requests. This situation can cause other requesters in the system to experience large and unpredictable latencies. Since HyperTransport™ devices are not required to reorder responses, downstream responses with PassPW set can get stuck behind responses with PassPW clear, which are in turn stuck behind the posted requests. In addition, peer-to-peer traffic directed at the slow device can back up the upstream posted channel as well.

The most complete solution to this problem would be to implement Isochronous flow control mode as defined in Section D.1. However, a simpler solution may be possible for most systems and is defined in Section D.2.

D.1 Isochronous Flow Control Mode (Optional)

In Isochronous (ISOC) flow control mode, there are two classes of service defined. The high-priority service class is intended to support Isochronous traffic, and the low-priority service class is intended for all other traffic. The following HyperTransport technology features support the high-priority service class:

- Dedicated posted command, nonposted command and response virtual channels—the ISOC virtual channels.
- Dedicated flow control buffers in support of the ISOC virtual channels.
- The Isoc bits in the read and write command fields identify commands that should travel in the ISOC channels.
- The Isoc bit in the read response and target done packets identify responses that should travel in the ISOC response channels.
- The Isoc bit in the NOP packet identifies buffer release packets for the ISOC virtual channels.
- Broadcast, Atomic RMW packets do not travel in or affect the ISOC virtual channels.
- Fence and Flush travel in and affect the ISOC virtual channels when their Isoc bit is 1. Fence and Flush with their Isoc bit not equal to 1 do not affect the ISOC virtual channels.

The following rules govern device operation in ISOC flow control mode:

1. All devices disable ISOC flow control mode after a cold reset. Software may enable ISOC flow control and sequence the chain through a warm reset to enable ISOC flow control mode. See Section 7.5.4.10 for details.
2. There are no ordering constraints between transactions in the ISOC and non-ISOC channels. Furthermore, ISOC traffic is invisible to the fairness algorithm implemented for non-ISOC traffic required by Section 4.9.5.
3. The ordering constraints for transactions within in the ISOC channels are identical to those for transactions within the non-ISOC channel, as defined in Chapter 6.
4. High-priority traffic must always be serviced before low-priority traffic, and there is no guarantee against high-priority traffic starving low-priority traffic, although it is expected that the total ISOC

bandwidth would never exceed the overall available bandwidth. This eliminates the need for a fairness algorithm (like that in Section 4.9.5) to regulate the insertion of ISOC traffic.

5. ISOC flow control is enabled on a per-link basis to allow ISOC requests and responses to “tunnel” through non-ISOC devices on a chain.

It is intended that Isochronous sources generate requests with the Isoc bit set in order to get service from the system with deterministic worst-case latency. The actual latency and bandwidth guarantee for ISOC requests is system-dependent and outside the scope of this specification.

D.2 Normal Flow Control Mode

There are systems in which Isochronous traffic is an important consideration, but the cost of ISOC flow control mode is prohibitive. If these systems do not require the ordering rule in which downstream responses are not allowed to pass downstream posted requests and do not require peer-to-peer traffic on the same chain as Isochronous traffic, the following steps can be taken.

1. Build an operating mode in which the host sets the PassPW bit in all downstream responses.
2. Build HyperTransport device implementations in which responses with PassPW set pass stalled posted requests.
3. Do not populate Isochronous devices on the same HyperTransport chain as devices that generate peer-to-peer traffic.

Normal flow control mode is characterized as follows:

- There are no dedicated ISOC virtual channels.
- The Isoc bit in the NOP packet must be 0.

The Isoc bit in the read, write, RdResponse, and TgtDone commands may be either set or cleared. ISOC commands may be used in normal mode in simple, bounded systems in order to get lower latency service for Isochronous sources. The rules which govern the system’s behavior on behalf of Isoc requests in normal mode and the latency assurances provided to those requests are platform-specific and outside the scope of this specification. In normal mode, HyperTransport devices may ignore the Isoc bit, but must preserve it so that ISOC requests and responses may be handled properly by ISOC devices on either side of non-ISOC devices. If any device (including non-ISOC devices) receives a nonposted request with the Isoc bit set, the Isoc bit must be set in the response.

E Southbridges and Compatibility Buses

This appendix provides some considerations for including compatibility buses (such as ISA or LPC) and Southbridges in systems based on HyperTransport™ technology.

E.1 ISA/LPC Deadlock Case

A system that contains an ISA or Low Pin Count (LPC) DMA controller or supports ISA/LPC bus masters has a particular deadlock scenario that needs to be addressed. Since ISA and LPC do not support retry, a downstream posted write could block a response to a nonposted request from the ISA or LPC bus, causing deadlock.

One solution to this problem is for the host to decode programmed I/O requests to the ISA/LPC memory range and emit all such requests in the nonposted channel. Alternatively, the host could avoid the implementation of a positive decode for the ISA/LPC memory range and emit all default requests (those with the Compat bit set) in the nonposted channel. This solution does not permit peer-to-peer requests to be issued from or to ISA/LPC devices, since such requests may result in deadlock.

There is an additional source of deadlocks involving nonposted peer-to-peer cycles in the same chain as the ISA/LPC bridge. If the host issues multiple outstanding nonposted requests to the ISA/LPC bus, and the ISA/LPC bridge is not able to buffer them all, the nonposted flow-control buffers could fill up downstream. Nonposted peer-to-peer cycles going upstream would not complete, filling upstream nonposted buffers. At this point, nonposted requests issued upstream on behalf of the ISA/LPC bus could not complete, and because ISA and LPC do not support retry, the host-issued nonposted requests can never complete, either, causing a deadlock.

The solution is to either not allow nonposted peer-to-peer activity on the same chain as an ISA/LPC bridge, or only allow the host to issue a single outstanding request to ISA/LPC or multiple outstanding requests to other spaces, but not a mix of the two. Furthermore, the host must continue to service the peer-to-peer requests in either case, or the upstream nonposted buffers could fill and create a deadlock. Because the host only issues one request to ISA/LPC at a time, and they must not interfere with peer-to-peer cycles, the SeqID for requests to ISA/LPC is always 0.

E.2 ISA/LPC Write Post Flushing

Some ISA or LPC bridges require the ability to know when all posted writes they have issued are guaranteed to be globally visible. This requirement is typically handled by having a WSC# (Write Snoop Complete) pin on the Southbridge, which is asserted whenever all previously posted writes are guaranteed to be visible to all processors.

No direct HyperTransport protocol support is required for a HyperTransport-to-PCI bridge to implement the WSC# bit. The HyperTransport-to-PCI bridge can follow each posted write from the ISA/LPC bridge with a HyperTransport flush request. The response to the flush guarantees that the posted write is

globally visible. The HyperTransport-to-PCI bridge can then keep its WSC# pin asserted whenever it has no flushes outstanding.

E.3 Subtractive Decoding

This section provides some considerations for including a subtractive decoding device or bridge in a system based on HyperTransport technology.

E.3.1 Subtractive Decode in the General Case

Since HyperTransport devices in a chain do not sit on the same bus, they cannot normally perform subtractive decode by waiting to see which requests are not responded to by other devices on the chain. Subtractive decoding devices and bridges are supported in HyperTransport technology using the Compat bit. All hosts connecting to HyperTransport I/O chains are required to have registers that specify positive decode ranges for all HyperTransport I/O devices and bridges. One of these I/O chains may also include a subtractive bridge (potentially to a PCI, ISA, or LPC bus). Requests that do not match any of the positive ranges are routed to the HyperTransport I/O chain containing the subtractive bridge (the *compatibility chain*) with the Compat bit set. The Compat bit indicates to the subtractive bridge that it should claim the request, regardless of address. Requests that are within the positively decoded ranges of the compatibility HyperTransport I/O chain do not have the Compat bit set and are passed down the chain to be detected by positively decoded devices and bridges, like any other HyperTransport I/O chain.

It is worth noting that a system which sets up the subtractive decode path in hardware can access memory and I/O spaces owned by the subtractive device without requiring software initialization of the link. This is true even though the devices on the HyperTransport chain have not had their UnitIDs programmed to nonzero values—the Compat bit causes accesses to reach the subtractive device.

E.3.2 Subtractive Decode in x86 Legacy Systems

Some x86 systems may have legacy software considerations (such as Cardbus legacy compatibility and power-management requirements) that require the compatibility chain to be numbered as Configuration Bus Number 0. In such a system the host bridge that controls the compatibility chain must be identified with a device configuration header rather than a bridge header. This bridge still requires a positive decode range so that it knows whether to set the Compat bit for transactions that do not fall in this (or any other) range. Therefore implementation-specific range registers need to be defined for this bridge.

E.3.3 Subtractive Decode in the Simplest Case

Another way to support subtractive decode in small systems based on HyperTransport technology is to place the subtractive decode device on the end of a single-hosted HyperTransport chain. In that case, the subtractive device can safely assume that all requests that reach it are destined for it.

E.3.4 Subtractive Decode Behind a PCI Bridge

If the subtractive target on the HyperTransport chain is a bridge to PCI, there are several additional issues.

The most straightforward approach is to build a HyperTransport-to-PCI bridge that performs subtractive decode and implements a standard PCI bridge header. See the *PCI to PCI Bridge Architecture Specification, Revision 1.2*, for a description of subtractive decoding PCI to PCI bridges.

- The bridge performs subtractive decode using the Compat bit, as described above, for transactions that originate on the primary bus.
- The bridge performs positive decode for transactions that originate on the secondary bus. It forwards to its primary bus any transaction that originates on the secondary bus and does not fall inside the address ranges programmed into the bridge header. This implies that peer-to-peer transactions targeted at a subtractive decoding device on the secondary bus and sourced on either the secondary or subordinate buses are not supported.
- The secondary bus segment is by definition not Bus 0, because configuration software encounters a bridge header and numbers the bus accordingly. This may not be compatible with some legacy software requirements.

Some legacy systems may require that the compatibility bus be Bus 0, which is not allowed to be behind another bridge. Therefore, another approach can be used that allows the PCI bus that contains the subtractive decode device to be configured as Bus 0. In this approach, the HyperTransport-to-PCI bridge implements a function header rather than a bridge header.

- The bridge performs subtractive decode for transactions that originate on the primary bus, using the Compat bit.
- The bridge claims all transactions that originate on the secondary bus and forwards them to the primary bus, but it does not do this subtractively. This implies that peer-to-peer transactions that are targeted at devices on the secondary bus and sourced on either the secondary or subordinate buses are not supported.
- The primary interface of the bridge must be a device on Bus 0 so that configuration cycles can reach it.

E.4 VGA Palette Snooping

The *PCI Local Bus and Bridge Architecture* specifications define VGA palette snooping. This allows a device on the same bus as the device owning the VGA palette range or a bridge that forwards the VGA palette range to pick up write data as the access goes by.

No direct support for VGA palette snooping is provided in the HyperTransport protocol. It can be supported at a level above the HyperTransport protocol by designating an address range as an alias of the VGA palette range and by having the host bridge generate a posted write to the alias as well as the write to the original address. The snooping device must recognize the aliased write and translate it back to the VGA palette range before forwarding or operating on it. The details of this mechanism are implementation-specific.

F Required Behavior in x86 Platforms

This appendix specifies mandatory behavior of HyperTransport™ devices designed for x86 platforms.

While optional for some HyperTransport devices, the following features are required for devices in x86 platforms:

- LDTSTOP# pin
- LDTSTOP# Tristate Enable bit
- Support for LDTSTOP# disconnect sequences and the Discon bit of NOP packets
- LDTSTOP# is input-only to all devices except the system management controller (Southbridge)
- VGAEN and ISAEN bits in all bridges
- Upstream accesses to configuration space are illegal, therefore hosts have the Host Hide bit (see Section 7.5.3.3.5) read-only as 1 and the Upstream Configuration Enable (see Section 7.5.10.9) as 0.
- Hosts should provide a BAR to create a 256MB nonposted memory-mapped I/O region. Within this region, accesses in the format of Table 40 should be converted to HyperTransport configuration cycles. If bits 11:8 of the register number are 0, the standard cycle formats in Table 36 and Table 37 should be used for compatibility with existing devices. If bits 11:8 of the register number are not 0, the formats of Table 38 and Table 39 should be used.
- RESET# is input-only to all devices except the system management controller or HTX slot(s).

F.1 Interrupts

x86 HyperTransport systems can use interrupt requests (see Section 9.1) instead of an APIC bus or discrete pins. Table 147 shows the format of x86 interrupt-request packets. Some HyperTransport devices (such as disk controllers or network adaptors) may still need discrete pins for use with legacy operating systems that do not support APIC or HyperTransport interrupt discovery and configuration for boot.

F.1.1 Interrupt Request

Table 147. x86 Interrupt Request Packet Format

Bit-Time	CTL	7	6	5	4	3	2	1	0
0	1	SeqID[3:2]		Cmd[5:0]: 1010X1					
1	1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	1	Count[1:0]		Reserved					
3	1	MT[3]	DM	RQEOI	MT[2:0]			Count[3:2]	
4	1	IntrDest[7:0]							
5	1	Vector[7:0]							
6	1	Address[31:24]							
7	1	Address[39:32]							
8	0	IntrDest[15:8]							
9	0	IntrDest[23:16]							
10	0	IntrDest[31:24]							
11	0	Reserved							
Note: Address [39:24] must be FDF8h in x86 systems.									

There are three classes of interrupts supported in x86 HyperTransport systems:

- Lowest-priority (Arbitrated) (~~Low Priority~~)
- Fixed
- Non-vectorred

Arbitrated-Lowest-priority interrupts are only delivered to one of the addressed destinations within the host targeted by the interrupt. The ultimate target is either the lowest priority destination or a destination that is already servicing the same interrupt source (the focus processor). Arbitrated-Lowest-priority interrupts have 256 possible sources. Each interrupt source is identified by an 8-bit vector ID.

Fixed interrupts are delivered to all destinations addressed by the interrupt message. They can be used to send single, multicast, or broadcast interrupts. Fixed interrupts also have 256 possible sources, identified by vector ID.

Nonvectorred interrupts do not carry source information. Therefore, the vector must be 00h. They consist of the following types:

- SMI
- NMI
- INIT

- ExtInt (Legacy PIC)

The set of potential destinations is determined by the IntrDest and Destination Mode (DM) fields. The DM field determines if IntrDest represents a physical identifier or a logical identifier, as shown in Table 148.

Table 148. Destination Mode Bit Field Encoding

DM	Destination Mode
0	Physical
1	Logical

In Physical mode, IntrDest[31:8] must be 0, and each interrupt destination (processor) within the host is assigned a unique 8-bit physical ID. The physical ID 0xFF is reserved and is used to indicate that the interrupt should be broadcast to all possible destinations. A destination is considered a target for a physical mode interrupt if its ID matches IntrDest[7:0] or if IntrDest[7:0] equals 0xFF.

In Logical mode, each interrupt destination is assigned a 32-bit logical ID. The determination of what constitutes a valid logical ID is system-specific, and the method of comparison of logical ID to IntrDest[31:0] is programmable. For example, a system can choose a one-hot address representation, assigning one bit to each processor (limited to 32 processors), or it can define a portion of the logical address to be fully decoded and the rest of the bits to be one-hot encoded.

Not all x86 platforms support IntrDest[31:8]. See platform-specific documentation to determine if this feature is available.

~~Arbitrated-Lowest-priority~~ and fixed interrupts can be edge-triggered or level-sensitive, as identified by the Trigger Mode (TM) field, carried in the RQEOI bit of the HyperTransport interrupt request. Edge-sensitive and level-sensitive interrupts cannot be mapped to the same vector.

Trigger Mode is encoded as shown in Table 149.

Table 149. Trigger Mode Bit Field Encoding

RQEOI	Trigger Mode
0	Edge
1	Level

Level-sensitive interrupts require an End of Interrupt (EOI) message (described below) to be transmitted to acknowledge the servicing of the interrupt. A subsequent level-sensitive interrupt using the same vector is not sent until an EOI message has been received. Edge-triggered interrupts do not signal the servicing of the interrupt. Only the vector is returned in the EOI.

Non-vectorized interrupts are always edge-triggered and therefore no HyperTransport EOI is used.

The type of interrupt is identified by the Message Type (MT) field.

Table 150 summarizes the allowed combinations of these fields (all combinations not listed are reserved).

Table 150. Interrupt Request Bit Field Encoding Summary

MT[3:0]	Message Type	RQEOI	Vector	DM	Dest
0_000	Fixed	0 or 1	0–FFh	0	0–FFh
				1	0–FFFF_FFFFh
0_001	Arbitrated Lowest-priority			0	0–FFh
				1	0–FFFF_FFFFh
0_010	SMI	0	0	0	FFh
0_011	NMI				
0_100	INIT				
0_101	Startup (Host Only)				
0_110	ExtInt	0	0	0	0–FFh
1_011	Legacy PIC NMI (LINT1)				FFh
1_110	Legacy PIC ExtInt (LINT0)				
x_111	Reserved(EOI)				

Startup messages are used in interprocessor communication only. They are similar to fixed interrupts in that they carry a vector, but they have their own Message Type.

HyperTransport I/O host bridges must not combine multiple interrupt transactions into a single transaction within the host.

All other encodings are reserved and may result in undefined behavior.

F.1.2 Standard EOI

Table 151 shows the format of the EOI returned by the host to indicate that an interrupt request with RQEOI=1 has been serviced.

Table 151. Standard End-of-Interrupt (EOI) Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]: 111010					
1	PassPW	SeqID[1:0]		UnitID[4:0]				
2	Reserved							
3	Rsv			MT[2:0]=111b			Rsv	
4	Reserved							
5	Vector[7:0]							
6	Addr[31:24]							
7	Addr[39:32]							

F.1.3 Legacy PIC (8259) Interrupt Request, Acknowledge, and EOI

The PIC is assumed to reside in the Southbridge. Interrupts are requested using the ExtInt message type as described above. The processor that services the interrupt request issues an interrupt acknowledge cycle to the Southbridge. An interrupt acknowledge transaction can be directed to the interrupt controller by performing a byte read within the reserved IACK range defined in Chapter 5. Any read within this address range generates a RdSized request with the Compat bit set. This request packet is routed directly to the Southbridge if the Southbridge is a native HyperTransport device. If the Southbridge is implemented as a PCI device, then the request packet is routed to the intervening HyperTransport-to-PCI bridge. The bridge generates an interrupt acknowledge cycle on the PCI.

In both cases, the interrupt vector is returned in the eight least-significant bits of the RdResponse, independent of the byte masks in the RdSized request. The 24 most-significant bits are 0.

Even when legacy PIC interrupts are configured as level-sensitive, the HyperTransport interrupt request is sent as edge mode to indicate that a HyperTransport EOI is not used. EOI to the legacy PIC is performed as an I/O access to the PIC address, not a HyperTransport EOI.

In normal operation, the Legacy PIC issues a single ExtInt request when an interrupt is pending and the host issues an IACK request to determine the source of the interrupt and enable further interrupt requests. Once the PIC receives an IACK request, it responds with the vector for the active interrupt. After servicing the interrupt, if this interrupt or another one still requires service, the PIC issues another ExtInt request. The host must be able to accept a new ExtInt immediately after issuing an IACK request. Under certain conditions (such as a noisy or unusually frequent interrupt source), the PIC may issue multiple ExtInt requests between IACK requests. Proper host behavior in this case is to treat the multiple requests as a single interrupt service request, but must ensure that once an IACK request has been issued, further ExtInt requests result in another IACK request.

F.1.4 Alternate Interrupt Discovery and Configuration Mechanism

For compatibility with existing software, HyperTransport devices that generate interrupts may need to provide a memory-mapped version of the interrupt discovery and configuration register set in addition to the one described in Section 7.6. The memory-mapped register set is comparable to a standard IOAPIC register set, and the redirection table entries would have the layout shown in Table 152. This register set only provides legacy software an alternate way to access the relevant subset of the registers described in Section 7.6. It does not provide any new state or registers, only a second location in address space with fields rearranged for legacy compatibility. Bits that are not accessed through this mechanism are unaffected by it, and retain the values written to them by the configuration-space mechanism.

Table 152. Redirection Table Format

Bit	R/W	Reset	Description
63:56	R/W	0	IntrInfo[15:8] Destination
55:32	R/W	0	IntrInfo[55:32] Extended Destination: If a device does not support 32-bit destinations, this field is read-only 0.
31:17	R/O	0	Reserved. Note that IntrInfo[31:24] (Extended Address) and IntrInfo[7] (MT[3]) can only be accessed through the configuration mechanism detailed in Section 7.6.
16	R/W	1	Mask: When this bit is set, the interrupt is masked.
15	R/W	0	IntrInfo[5] Request EOI: If set, after each interrupt request is sent the device waits for the Waiting for EOI bit to be cleared before sending another interrupt.
14	R/O	0	Waiting for EOI: If RQEIO is 1, then this bit is set by hardware when an interrupt request is sent and cleared by hardware when the EOI is returned.
13	R/W	0	Polarity: For external interrupt sources, when this bit is set, the interrupt signal is active-low. If clear, the interrupt signal is active-high. For internal interrupt sources, this bit is reserved.
12	R/O	0	Reserved
11	R/W	0	IntrInfo[6] Destination Mode: 0=Physical, 1=Logical

Bit	R/W	Reset	Description	Encoding	Message Type
10: 8	R/W	0	IntrInfo[4:2] Message Type[2:0] * Note that the register encoding for some messages is different from the encoding sent in the interrupt request. The <i>Startup</i> message is only used for inter-processor communication, not for I/O devices.	000	Fixed
				001	<u>Lowest-priority</u>
				010	SMI
				011	Reserved
				*100	NMI
				*101	INIT
				*110	Reserved (<i>Startup</i>)
				*111	ExtInt
7: 0	R/W	0	IntrInfo[23:16] Vector		

F.2 System Management

The system Southbridge is defined, in part, to include the platform system management logic that controls ACPI-defined and platform-specific system state transitions. In order to power-manage the system properly, the Southbridge is expected to reside on Bus 0. The Southbridge and host use HyperTransport system management messages to facilitate system state transitions.

Devices with both an ISA/LPC interface and system management logic (i.e., a Southbridge) must accept downstream SM messages even when a ISA/LPC master is in control of the bus in order to maintain the correct virtual wire behavior and prevent deadlocks. This is because SM messages travel in the posted channel. If the Southbridge allowed the posted channel to back up, responses to reads of system memory executed on behalf of an ISA/LPC master would not pass the SM messages.

x86-platform Southbridges are required to include BIOS-programmable configuration registers called system management action fields (SMAF). These specify the value for bits 3:1 of the STPCLK assertion system management message sent from the Southbridge to the host, based on the system state transition being executed. The Southbridge is required to provide separate BIOS-programmable SMAF registers for (1) each ACPI-defined state (as well as throttling) supported by the Southbridge, and (2) host-initiated Voltage ID/Frequency ID (VID/FID) changes. These registers are to be programmed by BIOS after boot, prior to any system state transitions from the fully operational state.

x86-platform HyperTransport devices monitor the SMAF value broadcast with the STOP_GRANT special cycle and take the appropriate power management actions based upon the SMAF value.

The Southbridge is required to control LDTSTOP# in support of VID/FID change. It may optionally be asserted during other system state transitions and HyperTransport link width or frequency changes as well. No other devices are allowed to control LDTSTOP#, and LDTSTOP# must not be asserted without a prior STOP_GRANT message, as described in the sequence below.

In the ACPI-defined S3, S4, and S5 states, RESET# is asserted and PWROK is deasserted.

All system state transitions and HyperTransport link width or frequency changes forced by LDTSTOP# follow this sequence:

1. The sequence starts with one of the following three methods: (1) the host accesses a Southbridge register (as is the case with ACPI-defined system and CPU sleep state transitions), (2) the host sends a VID/FID change system management cycle to the Southbridge, or (3) the Southbridge logic initiates the sequence without a HyperTransport transaction (as is the case with throttling).
2. The Southbridge responds by sending a STPCLK assertion system management message to the host with UnitID matching the UnitID of the response to the host access from step 1, if a response is required. Bits 3:1 of this message contain the SMAF value associated with the system state transition being executed. The host broadcasts the STPCLK assertion message down all chains.
3. After the STPCLK assertion message is sent to the host, the Southbridge may send the response to the initiating transaction from step 1, if a response is required, with the PassPW bit cleared. Such responses are required to follow the STPCLK assertion system management message to guarantee that the host does not execute any additional instructions after the initiating command of step 1, as is required by some operating systems.
4. The host is required to respond to the STPCLK assertion system management message by broadcasting a STOP_GRANT system management message down all chains. This is intended to indicate that the host is ready for the next step in the state transition.

Note: There may be an arbitrarily large delay from the STPCLK assertion message to the STOP_GRANT message. The Southbridge is required to wait for the STOP_GRANT system management message prior to sending a STPCLK deassertion system management message.

The following steps assume that RESET# is not asserted as part of the system power state transition; if RESET# is asserted, it must be asserted after the STOP_GRANT system management message is received by the Southbridge; the resume that occurs after the reset is as specified in Chapter 12. Note: There are platform level exceptions to the previously stated rules. For example, in response to an ACPI-defined Power Button Override event, a Thermal Protection event, or other mechanisms beyond the scope of this specification, there is a direct transition to S5 that skips the STPCLK/STOP_GRANT protocol.

5. The Southbridge may assert LDTSTOP# a system-specific time after the STOP_GRANT system management message is received, based upon SMAF value. The SMAF code mapping is beyond the scope of this specification. The delay between reception of STOP_GRANT and LDTSTOP# assertion should allow enough time for STOP_GRANT to have reached all other devices in the system. The Southbridge is required to assert LDTSTOP# if any of the following occurs:
 - A VID/FID transition is being executed.
 - The HyperTransport link width or frequency is being transitioned without RESET# assertion.
 - The ACPI defined C3 processor state is being entered.
 - S1 state is being entered.
 - The S3 state is being entered.
6. If LDTSTOP# was asserted, then it may be deasserted, as required by the system management logic.

7. After LDTSTOP# is deasserted, the Southbridge is required to send the STPCLK deassertion system management message to the host in order for the host to resume to the fully operational state. The host broadcasts that STPCLK message down all chains. The STPCLK deassertion message is not sent upon resume from any state in which PWROK was deasserted or RESET# is asserted. This covers S3, S4, S5, and G3 (mechanical off). The STPCLK deassertion message is sent to exit any STOP_GRANT state in which PWROK is not deasserted and RESET# is not asserted.

To meet platform power consumption requirements, devices in the system may need to gate clocks, stop PLLs, or power down portions of the design after LDTSTOP# assertion. A device is enabled to take these steps when it receives a STOP_GRANT cycle with a specific SMAF value prior to LDTSTOP# assertion.

In the event that a STOP_GRANT does not reach the device before LDTSTOP# assertion (perhaps due to unusual delays or a large system), the device cannot take the additional power management actions. When a STPCLK deassertion is received, devices should purge the previous SMAF code that was not acted on to prevent a device from reacting to a "stale" STOP_GRANT SMAF code that is no longer valid. Reacting to a stale STOP_GRANT could result in a device taking an in-appropriate power management action. System-level mechanisms for ensuring that the STOP_GRANT SMAF is always recognized before LDTSTOP# is asserted are beyond the scope of this specification.

F.2.1 Command Encoding

For both upstream and downstream cases, the type of system management request (SysMgtCmd[11:0]) is encoded as shown in Table 153.

Table 153. System Management Request Command Encoding

SysMgtCmd	Command Type
0000 0000 xxxx	Reserved
0000 0001 xxxx	x86 legacy inputs to the processor. New state of signal: [0]: IGNNE [1]: A20M [2]: Reserved [3]: Reserved
0000 0010 xxxx	x86 legacy output from the processor. New state of signal: [0]: FERR [3:1]: Reserved
0000 0011 xxxx	[0]: STPCLK [3:1]: SMAF
0000 0100 xxxx	SHUTDOWN [3:0]: Implementation-specific

SysMgtCmd	Command Type
0000 0101 xxxx	HALT [2:0]: Implementation-specific [3]: 0=Halt State Entered, 1=Halt state Exited
0000 0110 xxxx	STOP_GRANT [0]: Reserved [3:1]: SMAF
0000 0111 xxxx	VID/FID Change [3:0]: Implementation-specific
0000 1000 xxxx	WBINVD [3:0]: Implementation-specific
0000 1001 xxxx	INVD [3:0]: Implementation-specific
0000 1010 xxxx	[0]: SMIACK [3:1]: Implementation-specific
0000 1011 xxxx	INTx Message (See Section 8.4) Bits [3:2]: INTA/B/C/D select Bit [1]: Assert=1, Deassert=0 Bit [0]: Reserved The behavior of the CPU is undefined if an INTX counter overflows or underflows due to extra asserts or deasserts.
0000 1100 xxx0	On-Die-Throttling Stopped [3:1]: Implementation-specific
0000 1100 xxx1	On-Die-Throttling Active [3:1]: Implementation-specific
0000 1101 xxx0	Reserved
0000 1101 xxx1	Processor Thermal Trip Point Crossed [3:1]: Implementation-specific
0000 1110 0000	INT_PENDING (See Section 8.5)
0000 1110 0001	x86_ENCODING (Reserved)
0000 1110 0010- 0000 1111 1111	Vendor Defined Virtual Wire Messages (See Section 8.7)
0001 0xxx xxxx	CLMC Encoding (See Section 8.6.11)

SysMgtCmd	Command Type	
0001 1xxx xxxx	Core P-state change [6:3]: Core number 0000b: Core 0 0001b: Core 1 ... 1111b: Core 15	[2:0]: P-state 000b: P0 (max) 001b: P1 ... 111b: P7
<i>Implementation Note: The chipset should provide software programmable registers for the number of cores and the number of P-states. Software should configure these registers before enabling P-states to allow the CLMC to properly track P-state changes per core. Core P-state change commands are downstream only.</i>		
0010 0xxx xxxx	Extended Core P-state change [6:3]: Core number 0000b: Core 0 ... 1111b: Core 15	[2:0]: P-state 000b: P8 ... 111b: P15
0010 1xxx xxxx	C-state change [6:3]: Core number 0000b: Core 0 ... 1111b: Core 15	[2:0]: C-state 000b: C0 (run) ... 111b: C7
0011 0000 0000-1111 1111 1111	Reserved	

F.2.1.1 x86 Legacy Signals: Inputs to the Processor

The information associated with the x86 legacy signals is transported using system management packets in HyperTransport systems. The legacy signals that are inputs to processors are as follows:

- IGNNE
- A20M
- STPCLK

These packets originate from the SMC and are sent upstream to the host as posted writes. They are then reflected down all HyperTransport I/O chains as broadcast packets. For each bit, a 1 represents an assertion of the associated legacy pin, and a 0 represents a deassertion of that pin.

When the A20M or STPCLK virtual wire is changed as a result of a nonposted host request, the message signaling the change in state of the virtual wire must be perceived by the host before the response to the host request. In order to achieve this behavior, the following conditions must be met:

- The UnitID of the virtual wire message must match the UnitID of the response.
- The PassPW bit in the response must be clear, even if it is a TgtDone.
- The host must not execute any instructions beyond the one that requested the change in state until the side effects of the virtual wire message have occurred.

F.2.1.2 x86 Legacy Signals: Outputs from the Processor

The legacy signals that are outputs from processors are as follows:

- FERR
- SMIACK

These packets originate from the host and are broadcast downstream to all HyperTransport I/O devices in the system. For each bit, a 1 represents an assertion of the associated legacy pin, and a 0 represents a deassertion of that pin.

The legacy pin represented by SMIACK is asserted when the processor enters system management mode (SMM) and is deasserted when the processor exits SMM.

F.2.1.3 x86 Special Cycles

The special cycles carried by system management packets are as follows:

- HALT—Generated by processor in response to execution of a HALT instruction
- SHUTDOWN—Generated by processor in response to a catastrophic error
- STOP_GRANT—Generated by processor in response to a STPCLK assertion
- VID/FID Change—Generated by processor in response to a software controlled voltage (VID) or frequency (FID) change
- WBINVD—Generated by processor in response to execution of a WBINVD instruction
- INVD—Generated by processor in response to execution of an INVD instruction

These packets originate from the host and are broadcast downstream to all HyperTransport I/O devices in the system.

F.2.2 VID/FID Changes

The Southbridge is required to support VID/FID changes as follows:

- Execute the system state transition specified in Section F.2 in response to the VID/FID message from the host.
- Assert LDTSTOP# as described in the above sequence.

- Include a BIOS-programmable configuration register that specifies the LDTSTOP# assertion time associated with VID/FID change system state transitions. Values ranging from 1 microsecond to 100 microseconds are recommended.

F.2.3 Throttling

Throttling differs from most system state transitions in that the Southbridge sends STPCLK assertion messages to the host without direct initiating messages. Because of this, the possibility of a deadlock exists when the host initiates a system state transition simultaneously with a STPCLK assertion message from the Southbridge. Therefore, to avoid this possibility, the following Southbridge requirements exist:

- If a STPCLK assertion message for throttling is sent from the Southbridge and then a system state transition is initiated via a nonposted access from the host to the Southbridge prior to the STOP_GRANT message for throttling, then the Southbridge is required to send another STPCLK assertion message to the host with the SMAF field programmed for the host-initiated system state transition. The response to the host access must then follow.
- If a STPCLK assertion message for throttling is sent from the Southbridge and then a system state transition is initiated via a posted access from the host to the Southbridge (such as the VID/FID system management cycle), then the Southbridge is required to (1) wait for the STOP_GRANT system management message from the host, (2) send a STPCLK deassertion message, and (3) send the STPCLK assertion message to the host with the SMAF field programmed for the host-initiated system state transition.

There is no deadlock possibility when roughly coincident throttling STPCLK assertion messages occur with interrupt requests. They are naturally resolved as follows:

- If a STPCLK assertion message for throttling is sent from the Southbridge simultaneously with a host-initiated nonposted command that results in an interrupt request (e.g., SMI), then the Southbridge sends the interrupt request to the host followed by the response to the nonposted command. The host is required to send the STOP_GRANT system management message after it receives the response.
- If an asynchronous interrupt request (not initiated by a host nonposted request) is received by the host after the STPCLK assertion message, then the interrupt request is accepted by the host, regardless of whether the STOP_GRANT system management message has been sent. However, the host might not act on the interrupt request until the STPCLK deassertion message is received by the host.

F.2.4 C3 System State Transitions and LDTREQ#

It is possible that LDTSTOP# can be asserted during sleep states such as ACPI-defined C3. A Southbridge on such a platform is required to deassert LDTSTOP# when any devices require use of the chain. This may be accomplished with the LDTREQ# signal.

LDTREQ# is an open-drain signal connected to all HyperTransport devices on the platform that are capable of generating bus master activity while the host is in such a sleep state.

There are two modes the system may operate in, depending on if traffic is allowed to flow during sleep states.

1. If all traffic is assumed to require the host to wake from C3, the Southbridge responds to LDTREQ# by:
 - Setting the ACPI-defined BM_STS bit to a 1.
 - Deasserting LDTSTOP# if asserted.
 - Transitioning the host to the C0 state if the host is in the C3 state.
 - To prevent setting BM_STS and disrupting C3 operation in this mode, the host must not assert LDTREQ# when initiating transactions when the Southbridge is operating this way.
 - Devices assert LDTREQ# whenever they have an outstanding transaction in the HyperTransport fabric or they need to inject a new transaction into the fabric.
 - Devices do not assert LDTREQ# for HyperTransport transactions they forward.
2. In systems supporting traffic that does not require the host to wake from C3:
 - The Southbridge may simply deassert LDTSTOP# in response to LDTREQ# to allow the traffic to flow without setting BM_STS or waking the host from C3.
 - Interrupts cause the southbridge to issue a STPCLK deassertion to wake the host from C3.
 - LDTSTOP#/LDTREQ# is decoupled from the host C-state.
 - LDTREQ# is asserted by any device with any non-info packet in its transmit buffers

F.2.5 SMI and STPCLK

The system Southbridge is the only device that is allowed to generate STPCLK system management messages. Since both SMI and STPCLK messages replace legacy signals, they have special ordering requirements to remain compatible with legacy behavior. In legacy systems, both of these signals have the following behavior:

1. The host causes the signal to be asserted with an instruction that (1) requires a response and (2) allows for no further instruction execution until the response is received.
2. The host detects the assertion of the signal prior to the response.
3. After the response, the host responds to the signal (by taking the SMI interrupt or initiating the STPCLK sequence) prior to executing any more instructions.

Thus, to replicate this behavior, the following requirements exist:

- The Southbridge may generate SMI or STPCLK messages in response to host-initiated transactions. If the host-initiated transaction requires a response, then the response is required to follow the SMI or STPCLK message upstream.
- The UnitID and Isoc bit of the SMI or STPCLK message must match those of the response, or the upstream ordering between the two is not ensured.

- In order to guarantee that the response to the host does not pass the SMI or STPCLK message, the PassPW bit in the response must be clear, even if it is a TgtDone.
- As long as the SMI or STPCLK message is received prior to the response to the initiating instruction, the host is required to guarantee that it execute no more instructions beyond the initiating instruction, before it responds to the SMI or STPCLK message.

The host bridge responds to SMI with the SMIACK assertion system management message down all HyperTransport chains. In some systems, the host bridge may send more than one SMIACK assertion for an SMI. The Southbridge should tolerate this and is allowed to act on the first SMIACK assertion received.

F.2.6 Default State of Virtual Wires

It is required that the state of the virtual wires in the Southbridge and the host match after reset. The default state for all virtual wires, including all interrupts, IGNNE, A20M, FERR, STPCLK, and SMIACK, is deasserted.

F.3 Initialization Issues

Hosts on x86 platforms may not be capable of accepting upstream requests until initialized by software. Therefore, it is required that after deassertion of RESET# or transmission of an INIT interrupt message, no upstream system management messages, interrupt requests, fences or flushes be generated until enabled by the host. The method used to meet this requirement is outside the scope of this specification. Note that upstream sized read and write requests to memory and I/O space are also disabled after RESET# by the Bus Master Enable configuration bit, as described in Section 7.3.1.3.

F.4 AGP Bridge Issues

Some legacy operating systems require that the location of AGP-specific configuration registers must be hardwired as follows:

- The AGP-defined capabilities header must be in Bus 0, Device 0, Function 0.
- The AGP aperture base address register must be at Bus 0, Device 0, Function 0, Offset 10h.

Therefore, to meet these requirements, it is recommended that AGP devices be designed as follows:

- The AGP bridge resides on the HyperTransport chain specified to be Bus 0.
- The AGP device uses multiple UnitIDs.
- The base UnitID register is programmed to 0 after the conclusion of I/O chain initialization. A different UnitID value must be used during the initialization sequence (See Section 12.3).
- The device number that matches the base UnitID register contains the capabilities header and the AGP aperture base address register (at Offset 10h).
- The device number that is one greater than base UnitID is used for the PCI-to-PCI bridge header that corresponds to the AGP bridge.

- The UnitID that matches the base (0) is not used for any AGP-initiated I/O streams or responses so that there is no conflict with host-initiated I/O streams or responses. Only the UnitIDs greater than the base are used for I/O streams.
- It is expected that the AGP-defined graphics address remapping table (GART) is located in the host. Therefore, the AGP aperture base address register and any other registers that are located in the AGP device but required by the host are copied via software into implementation-specific host registers.

In the situation described above, the host's configuration registers should be placed somewhere other than Device 0, in order to avoid conflicting with the predefined AGP registers. In a sharing double-hosted chain, this requires the hosts to implement the Device Number field (defined in Section 7.5.3.3.3) so that the hosts may address each other after the AGP bridge has assumed Device 0.

Note that if legacy OS support is not required, the AGP device's base UnitID register may be programmed to any value compliant with the HyperTransport protocol.

F.5 Configuration Space Access Mechanism

All x86 HyperTransport host bridges must implement the configuration transaction mechanism described in Section 3.2.2.3.2 of the *PCI Local Bus Specification*, Revision 2.3, for generating configuration space accesses. This mechanism entails a 32-bit address register at I/O space CF8h and a 32-bit data register at I/O space CFCh. x86 processor accesses to these I/O space registers result in the appropriate HyperTransport configuration transaction, as defined in Section 7.1.

G CRC Testing Mode

Writing a 1 to the CRC Start Test bit of the Link Control register (see Section 7.5.4.3) causes the transmitter to enter CRC diagnostic mode.

- The transmitter begins by issuing a NOP packet with its Diag bit set, which instructs the receiver to ignore the CAD and CTL signals for the following 512 bit-times in each byte lane, not counting the bit-times allotted to CRC stuffing.
- The transmitter can then drive any pattern it wants on the CAD and CTL signals (other than during CRC stuffing), even to the extent of allowing CTL to change state between arbitrary bit-times, with one exception. The test pattern may not contain four consecutive bit-times of all 1 bits on any byte lane (CAD and CTL signals), as that could be interpreted by the receiver as a sync packet. How the transmitter decides what to transmit as a test pattern is beyond the scope of this specification.
- CRC is still generated and checked for the interval, and CRC stuffing occurs normally, but the received data is ignored, and packet generating and tracking state machines are suspended in the state they were in when the diagnostic NOP was received.
- CRC errors detected during this time are logged by setting the CRC Error bits, and treated as fatal if the CRC Flood Enable bit is set.
- If the CRC Force Error bit (Section 7.5.4.4) is set when the CRC Start Test bit is set, the test pattern must contain at least one CRC error in each active byte lane.
- When the test interval has completed, and the last CRC covering any part of the test interval has been stuffed, hardware clears the CRC Start Test bit in the transmitter.
- Packet transmission resumes from the suspended state, which may be in the middle of a data packet.

This test mode should not be used unless both sides of the link indicate support for it in bit 2 of the Feature Capability register as defined in Section 7.5.10.3. This mechanism is not defined for links in Retry mode.

H Doubleword-Based Data Buffer Flow Control

HyperTransport™ technology provides an operating mode in which posted request data, nonposted request data, and response data buffers are flow controlled with doubleword granularity. In this mode, the command packets (posted requests, nonposted requests and responses) are still flow-controlled using packet size granularity. All HyperTransport devices must support the 64-byte granular flow-control mode as previously described. Further, 64-byte granular flow control is the default operation for all devices after cold reset (see Section 12.1 for the definition of cold reset). Initialization firmware can determine the capability of devices on either side of a link, and if they support doubleword-based flow control, program them to operate in that mode. Switching between flow-control modes requires cycling through a software-initiated warm reset. An LDTSTOP# disconnect sequence cannot be used to switch between flow-control modes because flow-control buffer state must be kept consistent across LDTSTOP# disconnects.

Table 154 shows the NOP packet format for doubleword-based flow control. In this mode, the 2-bit data buffer flow-control fields previously described are interpreted as the upper two bits of a 5-bit flow-control field. There are three 5-bit fields in total, each corresponding to one of the three virtual data channels. Each 5-bit field indicates to the transmitter that the receiver is freeing from 0 to 31 doublewords of data buffer within a channel. The byte mask doubleword for sized byte writes is included as data in the doubleword-based flow-control calculation by both the transmitter and the receiver.

Table 154. NOP Packet Format for Doubleword-Based Flow Control

Bit-Time	7	6	5	4	3	2	1	0
0	Rsv	DisCon	Cmd[5:0]					
1	ResponseData[4:3]		Response[1:0]		PostData[4:3]		PostCmd[1:0]	
2	0	Diag	Isoc	RespData[2]	NonPostData[4:3]		NonPostCmd[1:0]	
3	ResponseData[1:0]		PostData[2:0]			NonPostData[2:0]		

As in packet-based data buffer flow control mode, if a transmitter receives more increments than it can keep track of, it must not allow its counter to wrap, but must discard the extras. This has the effect that the link uses the maximum amount of buffer storage that both the transmitter and receiver can support. All transmitter counters must be a minimum of six bits wide, allowing up to 63 doublewords of buffer storage to be tracked without loss.

Doubleword-based flow control is expected to be deployed only in special circumstances where large block-sized, high-performance transfers are not important to the operation of the HyperTransport device within the system. All HyperTransport devices must support 64-byte flow-control mode and are encouraged to implement a large enough 64-byte buffer pool to fully utilize the HyperTransport links in the system applications envisioned for that device.

Doubleword-based flow control cannot be used on a link in Retry Mode.

I Switches

I.1 Overview

The general model for a HyperTransport™ switch is a set of ‘m’ primary ports interconnected with a set of ‘n’ secondary ports.

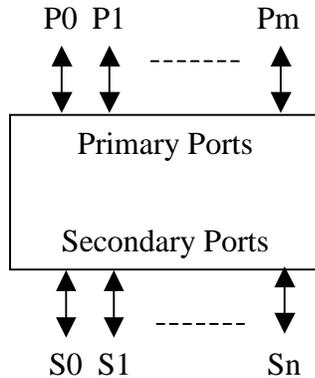


Figure 28. External Model of a Switch

A switch provides the following advantages over a chain:

- Partitioning and fail-over support
- Latency reduction
- Reduction in bandwidth hot spots
- Interconnection of greater than 32 devices
- Concatenation of multiple width busses
- Enables the use of connectors without the loss of connectivity for unpopulated slots
- Reset isolation between chains

Logically a switch appears to software as a tree of PCI devices and bridges, as shown in Figure 29.

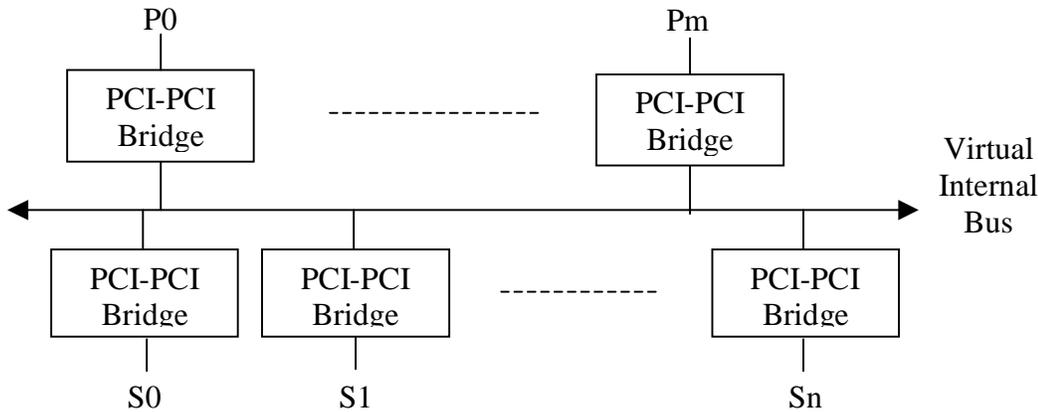


Figure 29. Logical Model of a Switch

I.1.1 Definitions

- *Primary Port*—A switch port that implements a tunnel or cave interface
- *Secondary Port*—A switch port that implements a host interface
- *Ingress Port*—The switch port receiving an incoming packet from an external chain
- *Egress Port*—The switch port transmitting an outgoing packet to an external chain
- *Forwarding*—The process of routing a packet from an ingress port to an egress port; During this process some fields of the packet may be modified, such as the SrcTag, UnitId, and Address fields.
- *Downstream traffic*—Packets being forwarded from a primary port to secondary port
- *Upstream traffic*—Packets being forwarded from a secondary port to a primary port
- *Peer-to-peer traffic*—Packets being forwarded from one secondary port to a different secondary port
- *Reflection traffic*—Packets being forwarded from a secondary port to the same secondary port
- *Partition*—A group of primary and secondary ports configured to allow packets to be forwarded to each other
- *SIP bit*—A value read out of a Serial Programmable Read-Only-Memory at power up used to configure the hardware
- *Strapping pin*—An external interface pin used to statically configure HW options
- *Reachable Port*—A destination port enabled to receive forwarded requests via the source port's Partition Mask register or Default Port field of the Switch Info register

- *Compatibility Port*—The destination port selected by the Default Port field of the Switch Info register of the source port
- *Virtual Internal Bus*—An abstract bus that interconnects all primary and secondary ports in the same partition within the switch
- *Virtual Tunnel*—A primary and secondary port interconnected through a switch such that it appears that the switch interconnecting the two is a tunnel. There are no logical bridges between the primary and secondary interfaces of a virtual tunnel.

I.2 Operation

I.2.1 Ports

HyperTransport switches support the forwarding of upstream, downstream, reflection, and peer-to-peer traffic. Forwarding of traffic from a primary port to a primary port is not allowed. Read and write requests are routed based upon address. Responses are routed based upon state maintained from matching requests. All other packet types are routed based upon whether the ingress and egress ports are primary or secondary ports.

The configuration mechanism used to determine whether a switch port is a primary or secondary port is not defined by this specification and is implementation specific. A switch may hardwire ports as primary/secondary or use a dynamic method for determining the port type such as sampling a strapping pin or reading a SIP bit at power-up.

Primary ports are HyperTransport tunnel/single ended slave interfaces; they do one of the following:

- Forward a downstream packet to a secondary port
- Generate a response to a nonposted request
- Drop a posted request.

Secondary ports are HyperTransport host interfaces; they do one of the following:

- Forward an upstream packet to a primary port.
- Forward a peer-to-peer packet to a secondary port.
- Forward a reflected packet to the same secondary port.
- Generate a response to nonposted request.
- Drop a posted request.

I.2.2 Partitions

Each port implements a Partition Mask register and the Default Port field of the Switch Info register. These registers determine which ports are valid forwarding destinations. By coordinating the Partition Mask bits on all ports, primary and secondary ports may be partitioned into subsets that create distinct and disjoint trees for each primary port. Hardware does not enforce that all partitions are disjoint and the registers may be configured such that partitions overlap. The application and methods for setting up such overlapping subsets and their correct operation are beyond the scope of this specification. A switch implementation may choose to not support partitioning, in which case all ports belong to the same partition. Alternatively, implementations may choose to hardwire the Partition Mask or use a dynamic method to indicate the partition mask such as sampling a strapping pin or reading SIP bits at power-up. Two ports are considered to be in the same partition only if both ports are in each other's partition masks.

I.2.2.1 Upstream Forwarding Port

For a secondary port, the Partition Mask bits corresponding to primary ports are ignored for upstream routing. Each secondary port designates a single primary as the forwarding port for upstream traffic via the Default Port field. The range registers contained in the configuration header belonging to the default port is used for subtractive decode to decide if the request should be forwarded upstream. If the upstream forwarding port is set to a secondary port, the results are undefined.

I.2.2.2 Compatibility Port

Each primary port uses the Default Port field to indicate which secondary port is the compatibility port. The compatibility port must be one of the enabled secondary ports in the partition register or it would not be useable. This allows a single compatibility bus to be shared by all partitions. If the compatibility port is set to a primary port, the results are undefined.

I.2.3 Compatibility Accesses

When a secondary port receives a packet with the Compat bit set, the Compat bit is ignored for decode purposes. If a packet is being forwarded from one secondary port to another secondary port, the Compat bit is cleared.

When a primary port receives a packet with the Compat bit set, the packet is forwarded to the compatibility port.

After cold reset the Decode Enable bit of the Switch Info register is 0, so the switch must route all non-configuration traffic from the primary ports to the default compatibility port without requiring software initialization of any registers. The method for determining the default compatibility port after cold reset is implementation-specific. Software must set the Decode Enable bit after initialization to enable normal decode.

Note that the compatibility port must be one of the ports enabled in the partition mask of the ingress port

or packets forwarded to it are rejected.

I.2.4 Configuration Accesses

Each port has a capability block. Primary ports have a HyperTransport bridge header with a primary link capability block. Secondary ports have a HyperTransport bridge header with a secondary link capability block. A bridge header can be accessed via a type 0 configuration access from the owning port. All secondary bridge headers are accessible via type 1 configuration cycles from any primary port provided that the primary port has the secondary port's partition bit set and the secondary port has the primary port's partition bit set.

Secondary port bridge headers reside on the internal virtual bus within the switch. The secondary port bridge header's device number on the virtual internal bus corresponds to the secondary port number. Secondary bridge headers can be accessed from any port in the same partition via a type 1 configuration access with a bus number matching that of the virtual internal bus. Secondary port bridge headers may also be accessed with a type 0 configuration access to the value of the Device Number field (default value 0) of the HyperTransport Command register in the capability block for the corresponding secondary port. Upstream configuration accesses are only allowed if the Upstream Configuration Enable bit (see Section 7.5.10.9) is set.

For each secondary port, the port's bus address space is determined via the Secondary and Subordinate Bus Number registers in the bridge header corresponding to that port. Type 1 configuration accesses received on primary ports are forwarded to secondary ports based on these registers and the partition mask in the primary bridge header.

Forwarding of type 1 configuration requests is supported from a secondary port to a primary port.

The internal virtual bus number may be different for each port. The internal bus number for downstream accesses is configured via the Secondary Bus Number register in the primary port bridge header. The internal bus number for upstream accesses is configured via the Primary Bus Number register in the secondary port. In most systems, these should all be set to the same value within a partition. It is possible in complex applications, with multiple primary and secondary ports, that these fields may not match. In this case, the perceived bus number of the virtual internal bus is different depending upon the ingress port of the configuration access. The configuration and usage of such systems is beyond the scope of this specification.

I.2.5 Packet and Event Routing

Routing of packets and events is constrained by the partition mask and default port field. Packets and events (such as reset and sync flood) may only be propagated to ports within the same partition.

In the descriptions that follow, upstream transactions refer to transactions entering a secondary port. Downstream transactions refer to requests entering a primary port.

For secondary ports, the Act as Slave bit of the HyperTransport Command register is assumed to be hardwired to 0.

I.2.5.1 Flush Routing

Upstream Flush packets are forwarded to the port specified in the Default Port CSR of the ingress port.

Downstream Flush packets are replied to with a Master Abort response.

I.2.5.2 Fence Routing

Upstream Fence packets are forwarded to the port specified in the Default Port CSR of the ingress port.

Downstream Fence packets are dropped and the End Of Chain Error CSR is set in the ingress port.

I.2.5.3 Response Routing

Response routing is identical for both Read Response and Target Done responses. A switch must maintain a table (or other suitable method) of outstanding nonposted requests that pass through it. Typically, each nonposted request that arrives creates an entry in the table storing the original SrcTag, SeqID, UnitID, and ingress port. This allows the switch to reassign these fields to available values on the egress port. When the response to the request arrives, the table is used to match up the new SrcTag with the original request and the response can be forwarded to the original ingress port.

Switches are required to pass the data payload of read responses without modification, even when forwarding responses with the Error bits set.

I.2.5.3.1 Upstream response routing

If (bridge bit is set) then

Set Host Inbound End of Chain Error CSR of the ingress port and drop packet.

Else if (response SrcTag matches outstanding request table) then

Route packet to port number specified in outstanding request table.

Else Set Response Error CSR of ingress port and drop packet.

If (upstream response is being forwarded and packet is a Master Abort) then:

If (egress and ingress ports are the same) then

Forward packet

Else if (Master Abort Mode CSR of ingress port is set) then

Set Received Master Abort CSR in secondary status register of ingress port.

Set Signaled Target Abort CSR in status register of ingress port.

Convert packet to a Target Abort packet and forward

If (egress port is a primary port) then

Set Received Target Abort CSR in secondary status register of egress port

Set Signaled Target Abort CSR in status register of egress port

Else

Set Received Target Abort CSR in status register of egress port

Set Signaled Target Abort CSR in secondary status register of egress port

Else

Set Received Master Abort CSR in secondary status register of ingress port

Convert packet to normal response (Error=0) and forward

If (upstream response is being forwarded and packet is a Target Abort) then:

If (egress and ingress ports are the same) then

Forward packet

Else

Set Received Target Abort CSR in secondary status register of ingress port.

Set Signaled Target Abort CSR in status register of ingress port.

Forward packet

If (egress port is a primary port) then

Set Received Target Abort CSR in secondary status register of egress port

Set Signaled Target Abort CSR in status register of egress port

Else

Set Received Target Abort CSR in status register of egress port

Set Signaled Target Abort CSR in secondary status register of egress port

1.2.5.3.2 Downstream response routing

If (bridge bit is clear or UnitID of response does not match ingress port UnitID) then

Set End of Chain Error CSR and drop packet.

Else if (response SrcTag matches outstanding request table) then

Route packet to port number specified in outstanding request table.

Else Set Response Error CSR in ingress port and drop packet.

If (downstream response is being forwarded and packet is a Master Abort) then:

If (Master Abort Mode CSR of ingress port is set) then

Set Received Master Abort CSR in status register of ingress port.

Set Signaled Target Abort CSR in secondary status register of ingress port.

Convert packet to a Target Abort packet and forward

Set Received Target Abort CSR in status register of egress port

Set Signaled Target Abort CSR in secondary status register of egress port

Else

Set Received Master Abort CSR in status register of ingress port

Convert packet to normal response (Error=0) and forward

If (downstream response is being forwarded and packet is a Target Abort) then:

Set Received Target Abort CSR in status register of ingress port.

Set Signaled Target Abort CSR in secondary status register of ingress port.

Forward packet

Set Received Target Abort CSR in status register of egress port

Set Signaled Target Abort CSR in secondary status register of egress port

I.2.5.4 Broadcast Routing

Upstream Broadcast packets are dropped.

Downstream Broadcast packets are forwarded to all secondary ports within the partition.

I.2.5.5 Sync Flood Routing

All downstream sync flood events are forwarded to all secondary ports in the same partition, but the Received System Error and Signaled System Error status bits are not set.

Upstream sync flood events:

Reflect sync flood events downward on the ingress port.

Set Received System Error CSR in the secondary status register of the ingress port

If (SERR# Enable in the bridge control register of the ingress port is clear or

SERR# Enable in the command register of the ingress port is clear) then

No further action is taken

Else

Set Signaled System Error in status register of ingress port

Use the following procedure for sync flood routing from the Virtual Internal Bus:

Sync flood routing from the Virtual Internal Bus

For each primary port in the same partition:

Set Received System Error in secondary status register of port

If (SERR# Enable in the bridge control register of the port is clear or

SERR# Enable in the command register of the ports is clear) then

No further action is taken

Else

Forward sync flood event to port

Set Signaled System Error in status register of port

For each secondary port in the same partition (except ingress port):

Forward sync flood event to port

I.2.5.6 Reset Routing

All downstream RESET# events are forwarded to all secondary ports in the same partition.

All upstream RESET# events reset the secondary interface (not the CSRs, except where chain reset is noted) and drop all outstanding requests. Upstream RESET# events are not forwarded.

Warm resets are forwarded as warm resets and cold resets are forwarded as cold resets.

I.2.5.7 Address Based Request Routing

Address matches in the following sections refer to base/limit CSR comparisons with addresses in Read, Write, and Atomic RMW accesses. The base/limit regions for the reserved HyperTransport address spaces are fixed and not specified in CSRs. In addition to the Memory and IO base/limit registers implemented in the bridge header, switches may implement up to 16 additional memory base/limit registers in the switch capability block.

When the Enable Decode bit in the Switch Info register of the ingress port is clear, all downstream Memory and IO requests are routed to the default port independent of the state of the Memory and IO Space Enable bits in the Command register and the state of the range registers.

Upstream routing of memory or IO space requests is disabled when the Master Enable bit in the Command register of the ingress port is clear. Corresponding requests should be reflected on the ingress port to maintain peer-to-peer communication.

If the Master Enable bit is set on a secondary ingress port but clear on the primary egress port, memory or IO space requests are master aborted on the virtual internal bus.

Downstream routing of memory requests is disabled when the Memory Space Enable bit is clear. Downstream routing of IO requests is disabled when the IO Space Enable bit is clear. The state of the IO and Memory Space Enable bits are ignored if the Enable Decode CSR is clear or if the request has the Compat bit set.

Interrupt and system management messages are always forwarded independent of the state of the primary and secondary Memory Space, IO Space, or Master Enable bits.

Switches are required to implement the ISA Enable and VGA Enable bits of the Bridge Control register.

I.2.5.7.1 Compat Access Routing

Downstream accesses with the COMPAT bit set are routed to the port specified by the DEFAULT PORT CSR in the ingress port.

Upstream accesses with the COMPAT bit set are forwarded ignoring the state of the COMPAT bit. If a request is being routed from one secondary port to another then the COMPAT bit is cleared.

I.2.5.7.2 Memory/IO Space Routing

In the following pseudo code, a downstream range register hit is defined as follows:

```
DS range register hit = (address >= base) and (address <= limit) and  
EnableDecode set and appropriate SpaceEn set
```

An upstream range register hit is defined as:

US range register hit = (address >= base) and (address <= limit) or
BusMasterEn clear

Downstream Nonposted Routing

If (Misses base/limit registers of ingress port) then

Return a Master Abort Response

Else if (Misses all secondary base/limit registers or

Hits multiple secondary ports base/limit registers) then

Set Received Master Abort in secondary status register of ingress port

If (Master Abort Mode CSR of ingress port is set) then

Return Target Abort response

Set Signaled Target Abort CSR in status register of ingress port

Else

Return Normal response, if read response return all 1's data.

Else

Forward request to matching port.

Downstream Posted Routing

If (Misses base/limit registers of ingress port) then

Set EndOfChain Error bit in Link Error register and drop packet

Else if (Misses all secondary base/limit registers or

Hits multiple secondary ports base/limit registers) then

Drop packet

Set Received Master Abort in secondary status register of ingress port

If (Master Abort Mode CSR of ingress port is set) then

If (VIB Flood and SERR# Enable bits are set) then

Set Signaled System Error in status register of ingress port

Sync flood ingress chain

Else if (VIB Fatal bit is set) issue fatal error interrupt

Else if (VIB Nonfatal bit is set) issue nonfatal error interrupt

Else

Forward request to matching port

Upstream Nonposted Routing

If (Hits base/limit registers of ingress port) then

 Reflect request to ingress port

Else if (Hits base/limit register on default primary port and either

 Misses base/limit registers on all secondary ports or

 Hits multiple secondary ports base/limit registers) then

 Set Received Master Abort CSR in status register of ingress port

 If (Master Abort Mode CSR is set) then

 Return Target Abort response

 Set Signaled Target Abort CSR in secondary status register of ingress port

 Else Return normal response, if read response return all 1's data.

Else if (Hits base/limit registers on default primary port and

 Hits base/limit pair on exactly one secondary port) then

 Forward request to the matching secondary port

Else Forward request to default primary port

Upstream Posted Routing

If (Hits base/limit registers of ingress port) then

 Reflect request to ingress port

Else if (Hits base/limit register on default primary port and either

 Misses base/limit registers on all secondary ports or

 Hits multiple secondary ports base/limit registers) then

Drop packet

Set Received Master Abort CSR in status register of ingress port

If (Master Abort Mode CSR is set) then

 If (VIB Flood and SERR# Enable bits are set) then

 Set Signaled System Error in status register of ingress port

 Sync flood ingress chain

 Follow the procedure for sync flood routing from the Virtual Internal Bus

 Else if (VIB Fatal bit is set) issue fatal error interrupt

 Else if (VIB Nonfatal bit is set) issue nonfatal error interrupt

Else if (Hits base/limit registers on default primary port and

 Hits base/limit pair on exactly one secondary port) then

 Forward request to the matching secondary port

Else Forward request to default primary port

1.2.5.7.3 Configuration Space Routing

In the following pseudo code, a bus range match is defined as follows:

bus range match = (bus# >= SEC) and (bus# <= SUB)

Downstream Type 0 Routing

If (Request Device Number matches ingress port UnitID) then

 Access ingress port CSRs.

Else Return Master Abort response.

Upstream Type 0 Routing

If (Request Device Number matches Device Number CSR in ingress port and
Host Hide CSR in ingress port is clear and Upstream Config is set) then

Access ingress port CSRs

Else

Return Master Abort response

Downstream Type 1 Routing

If (Request Bus Number does not match bus range of ingress port) then

Return Master Abort response

Else if (Request Bus Number matches Secondary bus number of ingress port) then

If (Request Device Number matches port number in this partition) then

Access port number's CSRs

Else

Set Received Master Abort in secondary status register of ingress port

If (Master Abort Mode in ingress port is set) then

Return Target Abort response

Set Signaled Target Abort CSR in status register of ingress port

Else

Return normal response, read response return all 1's data

Else if (Request Bus Number matches multiple secondary ports bus ranges) then

Set Received Master Abort in secondary status register of ingress port

If (Master Abort Mode in ingress port is set) then

Return Target Abort response

Set Signaled Target Abort in status register of ingress port

Else

Return normal response, read response return all 1's data

Else if (Request Bus Number matches Secondary Bus Number of matching port) then

Convert request to type 0 and forward to matching port

Else

Forward request to matching port

Upstream Type 1 Routing

If (Request Bus Number matches ingress port's Secondary Bus Number) then

- If (Device Number matches ingress port's device number and
Host Hide CSR in ingress port is clear) then
 - Access ingress port's CSRs
 - Else Reflect request on ingress port, converting to a type 0 request
- Else if (Request Bus Number matches bus range of ingress port) then
 - Reflect request on ingress port
- Else if (Request Bus Number matches Primary Bus Number of ingress port) then
 - If (Device number matches port number in this partition) then
 - Access matching port's CSRs
 - Else
 - Set Received Master Abort in status register of ingress port
 - If (Master Abort Mode CSR of ingress port is set) then
 - Return Target Abort response
 - Set Signaled Target Abort in secondary status register of ingress port
 - Else Return normal response, read response returns all 1's data
- Else if (Request Bus Number does not match bus range of default primary port) then
 - Forward request to default primary port
- Else if (Request Bus Number matches multiple or none of secondary ports bus ranges) then
 - Set Received Master Abort in status register of ingress port
 - If (Master Abort Mode of ingress port is set) then
 - Return Target Abort response
 - Set Signaled Target Abort in secondary status register of ingress port
 - Else Return normal response, read response returns all 1's data
- Else if (Request Bus Number matches exactly one secondary bus number) then
 - Forward request to egress port converting to type 0
- Else Forward request to egress port

Note that upstream configuration cycles are aborted if the Upstream Configuration bit is cleared. (See Section 7.5.10.9)

1.2.5.7.4 Device Message Routing

As in configuration space routing, a bus range match is defined as follows:

bus range match = (bus# >= SEC) and (bus# <= SUB)

Downstream Type 0 Routing

If (Request Device Number matches ingress port UnitID) then

 Deliver message to local port (if it exists)

Else

 Set EndOfChain Error bit in Link Error register and drop packet

Upstream Type 0 Routing

If (Request Device Number matches Device Number CSR in ingress port and

 Host Hide CSR in ingress port is clear) then

 Deliver message to local port (if it exists)

Else

 Set EndOfChain Error bit in Link Error register and drop packet

Downstream Type 1 Routing

If (Request Bus Number does not match bus range of ingress port) then

Set EndOfChain Error bit in Link Error register and drop packet

Else if (Request Bus Number matches Secondary bus number of ingress port) then

If (Request Device Number matches port number in this partition) then

Deliver message to local port (if it exists)

Else

Drop packet

Set Received Master Abort in secondary status register of ingress port

If (Master Abort Mode in ingress port is set) then

If (VIB Flood and SERR# Enable bits are set) then

Set Signaled System Error in status register of ingress port

Sync flood ingress chain

Else if (VIB Fatal bit is set) issue fatal error interrupt

Else if (VIB Nonfatal bit is set) issue nonfatal error interrupt

Else if (Request Bus Number matches multiple secondary ports bus ranges) then

Drop packet

Set Received Master Abort in secondary status register of ingress port

If (Master Abort Mode in ingress port is set) then

If (VIB Flood and SERR# Enable bits are set) then

Set Signaled System Error in status register of ingress port

Sync flood ingress chain

Else if (VIB Fatal bit is set) issue fatal error interrupt

Else if (VIB Nonfatal bit is set) issue nonfatal error interrupt

Else if (Request Bus Number matches Secondary Bus Number of matching port) then

Convert request to type 0 and forward to matching port

Else

Forward request to matching port

Upstream Type 1 Routing

If (Request Bus Number matches ingress port's Secondary Bus Number) then
 Reflect request on ingress port, converting to a type 0 request

Else if (Request Bus Number matches bus range of ingress port) then
 Reflect request on ingress port

Else if (Request Bus Number matches Primary Bus Number of ingress port) then
 If (Device number matches port number in this partition) then
 Deliver message to local port (if it exists)

 Else Drop packet
 Set Received Master Abort in status register of ingress port
 If (Master Abort Mode CSR of ingress port is set) then
 If (VIB Flood and SERR# Enable bits are set) then
 Set Signaled System Error in status register of ingress port
 Sync flood ingress chain
 Else if (VIB Fatal bit is set) issue fatal error interrupt
 Else if (VIB Nonfatal bit is set) issue nonfatal error interrupt

Else if (Request Bus Number does not match bus range of default primary port) then
 Forward request to default primary port

Else if (Request Bus Number matches multiple or none of secondary ports bus ranges) then
 Drop packet
 Set Received Master Abort in status register of ingress port
 If (Master Abort Mode of ingress port is set) then
 If (VIB Flood and SERR# Enable bits are set) then
 Set Signaled System Error in status register of ingress port
 Sync flood ingress chain
 Else if (VIB Fatal bit is set) issue fatal error interrupt
 Else if (VIB Nonfatal bit is set) issue nonfatal error interrupt

Else if (Request Bus Number matches exactly one secondary bus number) then
 Forward request to egress port converting to type 0

Else Forward request to egress port

1.2.5.7.5 Interrupt Packet Routing

Upstream Interrupt packets received on a secondary port are routed to the default upstream primary port.

Downstream Interrupt requests result in undefined behavior.

Broadcast EOI interrupt packets are routed as described previously in the Broadcast Routing section.

1.2.5.7.6 IACK Packet Routing

Downstream IACK requests are forwarded to the compatibility port.

Upstream IACK requests result in undefined behavior.

1.2.5.7.7 System Management Packet Routing

Upstream system management packets (including INTx virtual wire messages) are routed to the default upstream primary port. Note that INTx messages need to be accumulated and modified at each port as described in Section 8.4, because each port is logically a bridge.

Downstream nonposted System Management requests result in undefined behavior.

Broadcast System Management packets are routed as described previously in the Broadcast Routing section.

1.2.6 LDTSTOP# and LDTREQ#

Switches implement an LDTSTOP# signal for each port and support the disconnect/reconnect protocol described in Section 8.3. LDTSTOP# is controlled by an external agent, such as a system management controller, the system host, or a service processor. Switches also implement an LDTREQ# signal for each port to wake up disconnected links in order to send interrupt messages or forward packets. If LDTSTOP# is active at different times for ports in the same partition, then traffic in that partition could become blocked until all ports have reconnected.

1.2.7 Error management

During a reset or sync flood event, the switch must continue to operate without livelock or deadlock on the active ports. To achieve this, the corresponding inactive ports must reject all outstanding and new requests routed to it. Additionally switches must ensure that when the ports become active, no latent orphan responses are forwarded to the previous inactive ports.

Reset and sync flood of ports in a partition should not affect operation of ports in disjoint partitions.

I.2.8 Cascading Switches

When cascading switches only a primary port may be connected to a secondary port. The connection of a primary port to a primary port and a secondary port to a secondary port is not allowed. If the switches are not strictly connected in a tree for redundancy or fail-over reasons, software must ensure during the configuration process that no loops exist and that the topology is deadlock free.

I.2.9 Topology and Ordering Considerations

In order to guarantee support for full producer/consumer ordering, the topology and switch configuration must guarantee the following:

- There must be a single unique path between each pair of devices.
- The interconnection between all devices must be a tree topology with no loops.

Switches must ensure that merged streams of ordered access are transmitted in consistent ordered sequences. Consider the following sequences:

Ingress requests – Transaction Label (ingress port -> egress port):

A(0->2) followed by B(0->3)

C(1->3) followed by D(1->2)

Egress orderings:

Port 2 A then D, Port3 B then C - Valid ordering

Port 2 D then A, Port3 B then C - **Invalid ordering**

Port 2 A then D, Port3 C then B - Valid ordering

Port 2 D then A, Port3 C then B - Valid ordering

Pairs of transactions sequenced using a non-zero Sequence ID are only consider to be ordered by the switch if the pairs share the same ingress and egress ports.

I.2.10 Hot Plug

The unit of hot plug is the chain. A device in a chain connected to a secondary port of a switch may be hot plugged by forcing cold reset for the corresponding chain. Each secondary port of the switch has a HOT_PLUG# pin. When this pin is asserted, the switch drives cold reset on the corresponding secondary port and tristates the port's transmit buffers. While the port is in reset, the switch must terminate all outstanding nonposted requests on the chain. After the chain has been reconfigured, the HOT_PLUG# pin is deasserted. The switch port then exits cold reset. and proceeds with the

initialization sequence. Note that all CSRs in the chain are reset and the chain must be reinitialized via software.

The status of the HOT_PLUG# pin can be read via the HP CSR bit.

I.2.11 Virtual Tunnels

A secondary port may be bound to a primary port as virtual tunnel. Virtual tunnel support is optional. The method for configuring Virtual Tunnel mode is implementation specific.

When a virtual tunnel is configured, a primary and secondary port appear to be joined as a tunnel device. The secondary port's bridge header is inaccessible. The secondary bus's link capability registers appear as link 1 registers in the primary interface's capability block. The secondary port's RESET#, PWROK, LDTSTOP#, and HOT_PLUG# pins are not used because the device attached to the secondary port share those pins with the primary port.

When virtual tunneling is enabled between two ports, the forwarding rules between those ports are the same as for a true tunneling device. The primary port's bridge header has no effect on the secondary port and the secondary port cannot forward traffic to or from any port other than the primary.

I.2.12 Port Splitting

To provide more flexibility in use, a switch may optionally split one port into two or more smaller ports. This splitting would be controlled by a strapping pin or SIP bits. For example, a switch which implements two 16-bit secondary ports could have an alternate configuration in which four 8-bit ports can be implemented. Additional CTL, RESET#, LDTSTOP#, and other pins would be required, as would additional bridge headers and switch capability blocks in configuration space. The details of such an implementation are device-specific and beyond the scope of this specification.

I.3 Switch Configuration

I.3.1 Bridge Headers

Primary and Secondary ports of a switch implement bridge headers as described in Section 7.4, with these exceptions:

- The Secondary Bus Reset bit in the Bridge Control register of a primary port's bridge header controls reset of the virtual internal bus and all secondary ports in the corresponding partition.

Traffic flowing between a primary port and the virtual internal bus is controlled by the primary port's bridge header.

Traffic flowing between a secondary port and the virtual internal bus is controlled by the secondary port's bridge header.

I.3.2 Interface Capability Blocks

Each primary port implements a Slave/Primary Interface capability block as specified in Section 7.5. When the primary port is configured in normal switch operating mode, link 0 corresponds to the primary port. Link 1 is a dead link. When the primary port is configured to form a virtual tunnel with a secondary port, link 1 corresponds to the virtual tunnel port. In this mode, the bridge header for the virtual tunnel port is not visible.

Each secondary port implements a Host/Secondary Interface capability block. The Act as Slave bit of the HyperTransport Command register may be read only and hardwired to 0. Optionally, a switch may implement the Act As Slave bit functionality. If set, requests received by the secondary port that would have been reflected are rejected instead. In addition, the Device Number field must be implemented, and the bridge bit is not set on responses sent by the affected port. A switch port that implements Act As Slave functionality must implement the Chain Side and Host Hide bits, which allows system firmware to enumerate and configure the topologies possible with Act As Slave, and then hide the extra complexity from standard PCI enumeration code. Special attention must be paid to prevent deadlock loops and other problems inherent in non-tree topologies. See Section 7.5.3.3.6 for more on Act As Slave.

Switches should also implement an address remapping capability block and a UnitID Clumping capability block for each port and an interrupt capability block for primary ports, to control generation of fatal and nonfatal [error](#) interrupt messages. If an interrupt condition is detected by a secondary port, the interrupt is sent by the default primary port identified by the Switch Info register of the secondary port.

I.3.3 Switch Capability Block

Each switch port implements a capability block containing partition and port routing information. The current definition allows for switches with up to 32 ports.

Table 155 Switch Capability Block

31	16	15	8	7	0	
Switch Command		Capabilities Pointer		Capability ID		+00h
Partition Mask						+04h
Switch Info						+08h
Performance Counter Data						+0Ch
Base/Limit Range Data						+10h
Secondary Base Data						+14h

For a primary port, unless otherwise noted, these registers are reset upon a primary port cold reset. For a secondary port, unless otherwise noted, these registers are reset upon a primary port cold reset when the

secondary port is in the primary port’s partition mask. All Reserved bits are reserved for future expansion, and should be hardwired to 0.

I.3.3.1 Capability ID: Offset 00h: R/O

This is a read-only register. The capability ID for HyperTransport is 08h.

I.3.3.2 Capabilities Pointer: Offset 01h: R/O

This read-only register contains a pointer to the next capability in the list, or a value of 00h if this is the last one.

I.3.3.3 Switch Command Register: Offset 02h: R/O

15	11	10	9	8	7	6	0
01000	VIB Nonfatal	VIB Fatal	VIB Flood	VIB Error	Reserved		

I.3.3.3.1 VIB Error (Bit 7): R/C: Cold Reset to 0

This bit indicates that a posted request from this port aborted on the virtual internal bus with the Master Abort Mode set. The bit can be cleared by writing a 1 to it.

I.3.3.3.2 VIB Flood (Bit 8): R/W: Warm Reset to 0

When both this bit and the SERR# Enable bit is set, a sync flood results from the VIB Error bit. This is the setting required to emulate PCI behavior for the virtual internal bus. When 0, a sync flood does not result. This bit only affects posted requests that originated from this port.

I.3.3.3.3 VIB Fatal (Bit 9): R/W: Warm Reset to 0

When set, this bit allows a fatal error interrupt to result from the VIB Error bit. When 0, a fatal error interrupt does not result. This bit only affects posted requests that originated from this port.

I.3.3.3.4 VIB Nonfatal (Bit 10): R/W: Warm Reset to 0

When set, this bit allows a nonfatal error interrupt to result from the VIB Error bit. When 0, a nonfatal error interrupt does not result. This bit only affects posted requests that originated from this port.

I.3.3.3.5 Capability Type (Bits 15:12): R/O

These 5 bits are hardwired to 01000b to indicate that this is a Switch Capability List Item.

I.3.3.4 Partition Mask: Offset 04h: R/W: Cold Reset

This bit mask specifies which ports are enabled to receive forwarded packets. Bit 0 corresponds to port 0. A 1 indicates that the port is enabled to receive forwarded packets. Bits corresponding to nonexistent ports are hardwired to 0. The bit corresponding to the owning port is hardwired to a 1.

For a primary port, a 1 indicates the corresponding secondary port is a valid destination for forwarded packets or events from this primary port.

For a secondary port, a 1 in a position corresponding to another secondary port indicates that secondary port is a valid destination for peer-to-peer traffic from this secondary port. A 1 in a position corresponding to a primary port indicates that primary port is reachable with regard to forwarded packets and events from this secondary port.

This register is reset to all 1’s for implemented ports. An implementation that does not support partitioning shall hardwire this mask with a 1 in each position corresponding to an implemented port. This field is persistent though warm reset and only takes effect following a reset or LDTSTOP event.

I.3.3.5 Switch Info: Offset 08h

31	24	23	22	21	16	15	12	11	8	7	6	5	4	0
Reserved	Hide	HP	BLR Index	Reserved	Perf Index	Rsv	CR	EN	Default Port					

I.3.3.5.1 Default Port (Bits 4:0): R/W: Cold Reset

For a primary port, this field identifies the secondary port to which packets with the Compat bit set are forwarded.

For a secondary port, this field identifies the upstream forwarding port. This port is the destination for all upstream traffic.

Upon cold reset, the default port field should be initialized to its hardware default value. The hardware default value is implementation-specific and beyond the scope of this specification.

An implementation may choose to not allow software reconfiguration of the default port. In this case, this register should be read only and hardwired to the default port index. This field is persistent though warm reset and only takes effect following a reset or LDTSTOP event.

I.3.3.5.2 Enable Decode (EN, Bit 5): R/W: Warm Reset to 0

For a primary port this bit controls decode enable. When the bit is clear all non-configuration requests are forwarded to the specified default secondary port. If the compatibility port is not in the same partition as the ingress node, these requests are master aborted. When set, all requests are decoded and routed as normal. Software must setup or disable all implemented Base/Limit registers before setting

this enable. Regardless of the value of this bit, no request may be forwarded to the compatibility port if it is not in the same partition as the ingress port.

For a secondary port, this bit is reserved and should be 0.

1.3.3.5.3 Cold Reset (CR, Bit 6): R/W: Warm Reset to 0

This optional bit allows a reset of the Virtual Internal Bus initiated by the Secondary Bus Reset bit of the Bridge Control register in a primary port to be either warm or cold. The contents of this bit have an effect only when software initiates a reset sequence. If it is 1, the Virtual Internal Bus and all secondary ports in the same partition as the primary port initiating the reset are cold reset, resulting in PWROK driven low on affected secondary ports and resetting all CSRs in them. It is the responsibility of the hardware to sequence PWROK and RESET# correctly. If not implemented, this bit is read-only and hardwired to 1. Changing the state of this bit while the Secondary Bus Reset bit is asserted may result in undefined behavior.

1.3.3.5.4 Performance Counter Index (Bits 11:8): R/W: Warm Reset to 0

This field controls which performance counter is to be accessed through the Performance Counter Data register. Encodings which are Reserved or correspond to unimplemented performance counters return 0 when read. This field is cleared to 0 upon reset.

1.3.3.5.5 Base/Limit Range (BLR) Index (Bits 21:16): R/W: Warm Reset to 0

This field controls which Base/Limit Range Register is to be accessed through the Base/Limit Range Data register and which Secondary Base Register is accessed through the Secondary Base Data register. Encodings which are Reserved or correspond to unimplemented performance counters return 0 when read. This field is set to 0 upon reset.

1.3.3.5.6 Hot Plug (HP, Bit 22): R/O

Hot Plug is a read only bit that returns the current state of the HOT_PLUG# pin. The value of this field is reserved for primary ports.

1.3.3.5.7 Hide Port (Bit 23): R/W: Cold Reset to 0

The Hide Port bit exists in Primary ports only. In secondary ports, it is reserved. When set, the configuration space of the port is not accessible from the virtual internal bus and reads or writes result in a master abort on the virtual internal bus.

1.3.3.6 Performance Counters: Offset 0Ch: R/O: Warm Reset to 0

Performance counters are accessed by writing the Performance Counter Index field of the Switch Info register with the index corresponding to the desired counter. The Performance Counter Data register

may then be read, returning the value of the selected counter. Upon being read, the indexed counter is cleared. The counters saturate upon reaching a full count, allowing overflow detection. Undefined operation results if the counters are written during normal operation. They are writeable only for test purposes.

Perf Index	Indexed Counter
0h	Posted Command Receive Counter
1h	Nonposted Command Receive Counter
2h	Response Command Receive Counter
3h	Posted DW Receive Counter
4h	Nonposted DW Receive Counter
5h	Response DW Receive Counter
6h	Posted Command Transmit Counter
7h	Nonposted Command Transmit Counter
8h	Response Command Transmit Counter
9h	Posted DW Transmit Counter
Ah	Nonposted DW Transmit Counter
Bh	Response DW Transmit Counter
Fh – Ch	Reserved (0x00000000)

1.3.3.6.1 (Posted, Nonposted, Response) Command Receive Counters

These counters maintain a count of all received command packets for the corresponding channel.

1.3.3.6.2 (Posted, Nonposted, Response) DW Receive Counters

These counters maintain a count of the number of doublewords received for each command packet, including data, for the corresponding channel.

1.3.3.6.3 (Posted, Nonposted, Response) Command Transmit Counters

These counters maintain a count of all transmitted command packets for the corresponding channel.

1.3.3.6.4 (Posted, Nonposted, Response) DW Transmit Counters

These counters maintain a count of the number of doublewords transmitted for each command packet, including data, for the corresponding channel.

I.3.3.7 Base/Limit Range Registers (BLR): Offset 10h: R/W: Warm Reset

The extended base/limit memory range registers are accessed by writing the BLR Index field of the Switch Info register with the index corresponding to the desired register. The Base/Limit Range Data register may then be read, returning the value of the selected register, or written to set the contents of the register. All base/limit registers are 64 bits in length. All regions have 8 Mbyte granularity and bits [23:0] of the Base and Limit registers are reserved, with the exception of bit 0 of the base, which is the enable. When the enable bit is 1, the range register takes effect. When the enable bit is 0, the range is not decoded. As in the limit registers defined in Section 7.4.6, bits [23:0] of the limit are assumed to be 1's and the base should be set to a higher value than the limit to disable a decode range.

BLR Index bits[1:0] indicate which 32 bit register to access according to the following table:

BLR[1:0]	Register Accessed
0h	Base[31: 1], Enable
1h	Base[63:32]
2h	Limit[31: 0]
3h	Limit[63:32]

BLR Index[5:2] specifies which base/limit pair is being accessed. Implementations may choose to not implement all 16 base/limit pairs. Unimplemented pairs should have Limit hardwired to 0's and Base hardwired to 1's.

I.3.3.8 Secondary Base Registers: Offset 14h: R/W: Warm Reset

The location of each range on the secondary side of a port is determined by these registers. For a primary port, this is the virtual internal bus and for a secondary port, this is the chain. As with the Base/Limit registers, the secondary base registers are 64 bits in length with 8 Mbyte granularity. Bits [23:0] of each register are reserved, with the exception of bit 0 of the lower doubleword, which is the enable. When the enable bit is 1, the secondary base register takes effect, altering the decode behavior on the secondary side of the port, and causing all addresses within the affected range to be translated by the difference of the two base registers. When the enable bit is 0, both sides of a port use the same decode ranges. BLR Index bit 1 indicates which doubleword of the secondary base is being accessed.

BLR[1]	Register Accessed
0	Secondary Base[31:1], Enable
1	Secondary Base[63:32]

I.4 Switch Requirements for x86 Systems

Switches used in x86 systems must implement Virtual tunneling support.

J Quick Reference for x86 Systems

Code	Hex	VChan	Command	Comments/Options	Packet Type
000000	00	-	NOP	Null packet. Contains flow control information.	Info
000010	02	NPC	Flush	Flush Posted Writes within one I/O stream.	Request
001xxx 101xxx	08 28	NPC PC	Wr (sized)	Write Request [5] Defines whether request is posted: 0: Nonposted 1: Posted [2] Defines the data length: 0: Byte 1: Doubleword [1] Defines bandwidth/latency requirements: 0: Normal 1: Isochronous [0] Indicates whether access requires host cache coherence (reserved and set if access is not to host memory): 0: Noncoherent 1: Coherent	Req/Addr/Data
01xxxx	1x	NPC	Rd (sized)	Read Request [3] Defines ordering requirements for response: 0: Response may not pass posted requests 1: Response may pass posted requests [2] Defines the data length: 0: Byte 1: Doubleword [1] Defines bandwidth/latency requirements: 0: Normal 1: Isochronous [0] Indicates whether access requires host cache coherence (reserved and set if access is not to host memory): 0: Noncoherent 1: Coherent	Req/Address
110000	30	R	RdResponse	Read Response	Resp/Data
110011	33	R	TgtDone	Tell source of request that target is done.	Response
111010	3A	PC	Broadcast	Broadcast Message	Req/Address
111100	3C	PC	Fence	Fence Posted Writes within all I/O streams.	Request
111101	3D	NPC	Atomic-RMW	Atomic Read-Modify-Write	Req/Addr/Data
111110	3E	-	AddrExt	Address Extension	Address
111111	3F	-	Sync/Error	Link Synchronization and Error Packet	Info

PCI Command Encodings

Code	Hex	Command	Posted
0000	0	Interrupt Acknowledge	
0001	1	Special Cycle	•
0010	2	I/O Read	
0011	3	I/O Write	
0110	6	Memory Read	
0111	7	Memory Write	•
1010	A	Configuration Read	
1011	B	Configuration Write	
1100	C	Memory Read Multiple	
1101	D	Dual Address Cycle	
1110	E	Memory Read Line	
1111	F	Mem Write and Invalidate	•

HyperTransport™ Address Map

Base Address	Top Address	Size	Use
00_0000_0000	FC_FFFF_FFFF	1012 GB	System Memory/ Memory-Mapped I/O
FD_0000_0000	FD_F8FF_FFFF	3984 MB	Interrupt/EOI *
FD_F900_0000	FD_F90F_FFFF	1 MB	Legacy PIC IACK
FD_F910_0000	FD_F91F_FFFF	1 MB	System Management
FD_F920_0000	FD_F94F_FFFF	3 MB	Reserved – x86
FD_F950_0000	FD_FAFF_FFFF	27 MB	Reserved
FD_FB00_0000	FD_FBF_FFFF	16 MB	Address Translation
FD_FC00_0000	FD_FDF_FFFF	32 MB	I/O
FD_FE00_0000	FD_FFFF_FFFF	32 MB	Configuration
FE_0000_0000	FE_1FFF_FFFF	512MB	Ext Config/DevMsg
FE_2000_0000	FF_FFFF_FFFF	7680 MB	Reserved
100_0000_0000	FFF_FFFF_FFFF_FFFF	~16 EB	Extended Memory

* FD_0000_0000 to FD_F7FF_FFFF are reserved in x86 systems

Read/Write/Broadcast (Downstream Only) / Atomic Read-Modify-Write

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]			Cmd[5:0]				
1	PassPW	SeqID[1:0]			UnitID[4:0]			
2	Mask/Count[1:0]		Compat	SrcTag[4]/ DataError	SrcTag[3]/ Chain	SrcTag[2:0]		
3	Addr[7:2]						Mask/Count[3:2]	
4	Addr[15:8]							
5	Addr[23:16]							
6	Addr[31:24]							
7	Addr[39:32]							

There are two types of Read-Modify-Write Request, carrying either one or two quadwords (QW) of data:
Type 0: Fetch and Add has Count = 1; Type 1: Compare and Swap has Count = 3

Flush/Fence (Upstream Only)

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]			Cmd[5:0]				
1	PassPW	SeqID[1:0]			UnitID[4:0]			
2	Rsv		Isoc	SrcTag[4:0]/Rsv				
3	Rsv							

Read Response/Target Done

Bit-Time	7	6	5	4	3	2	1	0
0	Isoc	Rsv	Cmd[5:0]					
1	PassPW	Bridge		Rsv	UnitID[4:0]			
2	Count[1:0]/Rsv		Error0	SrcTag[4:0]				
3	RqUID		Error1	RspVCSets			Count[3:2]/Rsv	

NOP

Bit-Time	7	6	5	4	3	2	1	0
0	Rsv	Discon	Cmd[5:0]					
1	ResponseData[1:0]		Response[1:0]		PostData[1:0]		PostCmd[1:0]	
2	0	Diag	Isoc	Rsv	NonPostData[1:0]		NonPostCmd[1:0]	
3	RxNextPktToAck [7:0]							

Configuration Cycle Addressing (Nonposted) in HyperTransport™ Technology (PCI carries type in bit 0)

FDFF/DFDF	Bus Number	Device Number	Function Number	Register Number	00					
39	24	23	16	15	11	10	8	7	2	1:0

FDFF is used for Type 0 cycles. FDFF is used for Type 1 cycles.
Type 1 cycles are also used to send special cycles to other buses ((15:0)=FF00).

Interrupt Request Addressing (Byte Posted Write) / End-of-Interrupt Addressing (Broadcast)

FDFF	Vector	Destination	MT[3]	DM	TM	Message type	00				
39	24	23	16	15	8	7	6	5	4	2	1:0

DM: Destination Mode. 0 = Physical/EOI, 1 = Logical
TM: Trigger Mode. 0 = Edge/EOI, 1 = Level
Message Types: 0 = Fixed, 1 = Lowest Priority Mode, 2 = SMI, 3 = NMI, 4 = INIT, 5 = Startup,
6 = External (Legacy PIC) INTR ([23:0]=00FF18), 7 = APIC EOI (Destination=0)

System Management (Special Cycle) Address Encoding (Byte PW Upstream, Broadcast Downstream)

FDF91	Rsv	CLMC	Command Type	Payload	Reserved	00				
39	20	19:17	16	15	12	11	8	7	2	1:0

Command Types: To CPU 1: Payload[1] = A20M Virtual Wire; Payload[0] = IGNE Virtual Wire
3: Payload[0] = STPCLK Virtual Wire, 11: Payload[3:2] = INTx select, [1] = Assert
15-16: Vendor-defined Virtual Wires
From CPU 2: Payload[0] = FERR Virtual Wire, 4: Shutdown, 5: Halt, 6: Stop-Grant,
7: VID/FID Change, 8: WBINVD, 9: INVD, 10: Payload[0]=SMIACK Virtual Wire,
12: Payload[0] = On-Die-Throttling, 13: Thermal Trip Point Crossed, 14: INT
PendingPayload[3:1] = System Management Action Field (STPCLK and Stop-Grant)
CLMC Commands: 00xxb: {Cmd[1:0],Payload[3]}=Upstream Width, Payload[2:0]=Downstream Width
0100b: Payload[3:0]=Frequency, 0101b: Payload[3:0]=LMAF, 0110b: Payload[3]=Link Refresh

K End-to-End Flow Control

K.1 Description of End to End Flow Control

In applications which require more than 16 StreamVC channels, the following flow control packet may be layered on top of HyperTransport to carry end to end flow control information for up to 256 separate streams per message. These streams may be carried over the 16 streaming VCs or in any other VC in user defined combinations. This mechanism can support many millions of streams by sending a separate flow control packet for each block of 256 streams.

The Streaming Flow Control Request Packet conveys flow control information to the opposite endpoint of the bi-directional streaming message flow. The two ends of that bi-directional flow use different addresses that are associated with each other. Additionally, the flow control packets are located at separate addresses. The means of providing that association is application dependent. A typical application might have configuration software that makes these associations as well as configures and enables the various message streams.

Streaming Flow Control Request Packets may travel in any VCSet as per the application requirements. It is important to consider the latency properties of both these flow control packets and the streams they control. A good initial choice might be to use the same VCSet for the flow control messages as was used for the streams that they control.

K.2 Streaming End-to-End Flow Control Request Format

Table 156 shows the format of the Streaming End-to-End Flow Control Request packet. This packet is a specific instantiation of a Posted Write Command and has a similar format as the Streaming Message Request Packet in Section 14.4.

Table 156 Streaming End-to-End Flow Control Request Format

Bit-Time	7	6	5	4	3	2	1	0
0	SeqID[3:2]		Cmd[5:0]=1011xx					
1	PassPW	SeqID[1]	SeqID[0]/ ReqVC[3]	UnitID[4:0]				
2	Count[1:0]		Rsv	DataError	Chain	Rsv/ReqVC[2:0]		
3	Rsv	ExtFormat ID=0	Rsv	FormatID =1	Rsv		Count[3:2]	
4	Addr[15:8]							
5	Addr[23:16]							
6	Addr[31:24]							
7	Addr[39:32]							

This message is a Posted Write with the following settings: Cmd{2} set to 1b to indicate doubleword data length. Cmd[1] (Isoc) set as per the application requirement. Cmd[0] (Coherent) set as per the application requirement.

DataError and *Chain* as per the definition in Section 4.4.1

ReqVC[3:0] indicate which VC this packet is in for VCSet=2 traffic.

ExtFormatID – set to 0 – indicates that this packet, which is defined only in the range of the StreamAddressBase-Limit pair, is in Message Flow Control Request Format. The value of 1 is reserved for future standardization

FormatID – set to 1 – indicates that this packet, which is defined only in the range of a locally defined address BAR, is not in Streaming Message Request Packet Format.

Count[3:0]: Used to indicate the total size of the data packet in doublewords.

Addr[39:8] designates the base address for this flow control message. The structuring and mapping of these bits is application dependent, and message streams must coexist with other memory addresses in different blocks of the address space. Any mapping may be used that is compatible with HyperTransport address assignment rules. The mapping between the addresses used by each end of the bi-directional flow is also application dependent. The address that this node uses to sink the associated Message Packet in the reverse direction is known as ReverseDataAddr[39:8]

The flow control data is transferred in the associated data packet after the Message Flow Control Request packet as shown in Table 157.

Table 157 Message Flow Control Data Packet Format (first doubleword)

Bit-Time	7	6	5	4	3	2	1	0
0	FCVC3[1:0]		FCVC2[1:0]		FCVC1[1:0]		FCVC0[1:0]	
1	FCVC7[1:0]		FCVC6[1:0]		FCVC5[1:0]		FCVC4[1:0]	
2	FCVC11[1:0]		FCVC10[1:0]		FCVC9[1:0]		FCVC8[1:0]	
3	FCVC15[1:0]		FCVC14[1:0]		FCVC13[1:0]		FCVC12[1:0]	

The FCVC(N) words specify the Message Stream which arrives at address ReverseDataAddr[39:8] + N*256

The Mth doubleword indexes further to ReverseDataAddr[39:8] + (M*16 + N)*256

Each Message Flow Control Data Packet can flow control up to 256 streams.

K.3 End System Responsibilities

The End systems which source and sink these messages are responsible for the following items which are all beyond the scope of the specification:

1. The means of declaring and configuring the capability of using end-to-end flow control including the number of end-to-end contexts that can be supported and their properties.
2. Coordination of the use of these end-to-end contexts in a given destinations between devices.
3. The creation of a locally defined address BAR which defines the address region where messaging semantics and/or end-to-end flow control is used.
4. The meaning of the FCVCx bits. A suggested mapping of these bits is the SPI 4.2 interface, which is available publicly from the Optical Interface Forum at www.oiforum.com under “OIF Electrical Interface Implementation Agreements”. That specification describes three encodings for a similar channelized flow control mechanism.
5. The mapping of the channels to the 16 Streaming VCs or to any other VC or VCs.
6. The timing of the generation of these packets.
7. The timing of the response to these packets.
8. The functional response to these packets. The SPI-4.2 Implementation Agreement provides that two parameters MaxBurst1 and 2 be used to define the response to two of the flow control field encodings. In that document, differing amounts of data may be sent in response to different flow control indications.
9. The means of configuring these or other parameters in the end systems.

10. The mapping of these channels to the channels in external interfaces such as to the channels of multichannel Ethernet or SONET/SDH interface device.
11. The other end system responsibilities as per Section 14.

L 8b10b Encoding

This appendix defines the 8b10b encodings used in Section 2.3.

Table 158. Normal 8b10b Symbol Encodings

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D0.0	00	000 00000	100111 0100	011000 1011
D1.0	01	000 00001	011101 0100	100010 1011
D2.0	02	000 00010	101101 0100	010010 1011
D3.0	03	000 00011	110001 1011	110001 0100
D4.0	04	000 00100	110101 0100	001010 1011
D5.0	05	000 00101	101001 1011	101001 0100
D6.0	06	000 00110	011001 1011	011001 0100
D7.0	07	000 00111	111000 1011	000111 0100
D8.0	08	000 01000	111001 0100	000110 1011
D9.0	09	000 01001	100101 1011	100101 0100
D10.0	0A	000 01010	010101 1011	010101 0100
D11.0	0B	000 01011	110100 1011	110100 0100
D12.0	0C	000 01100	001101 1011	001101 0100
D13.0	0D	000 01101	101100 1011	101100 0100
D14.0	0E	000 01110	011100 1011	011100 0100
D15.0	0F	000 01111	010111 0100	101000 1011
D16.0	10	000 10000	011011 0100	100100 1011
D17.0	11	000 10001	100011 1011	100011 0100
D18.0	12	000 10010	010011 1011	010011 0100
D19.0	13	000 10011	110010 1011	110010 0100
D20.0	14	000 10100	001011 1011	001011 0100
D21.0	15	000 10101	101010 1011	101010 0100
D22.0	16	000 10110	011010 1011	011010 0100

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D23.0	17	000 10111	111010 0100	000101 1011
D24.0	18	000 11000	110011 0100	001100 1011
D25.0	19	000 11001	100110 1011	100110 0100
D26.0	1A	000 11010	010110 1011	010110 0100
D27.0	1B	000 11011	110110 0100	001001 1011
D28.0	1C	000 11100	001110 1011	001110 0100
D29.0	1D	000 11101	101110 0100	010001 1011
D30.0	1E	000 11110	011110 0100	100001 1011
D31.0	1F	000 11111	101011 0100	010100 1011
D0.1	20	001 00000	100111 1001	011000 1001
D1.1	21	001 00001	011101 1001	100010 1001
D2.1	22	001 00010	101101 1001	010010 1001
D3.1	23	001 00011	110001 1001	110001 1001
D4.1	24	001 00100	110101 1001	001010 1001
D5.1	25	001 00101	101001 1001	101001 1001
D6.1	26	001 00110	011001 1001	011001 1001
D7.1	27	001 00111	111000 1001	000111 1001
D8.1	28	001 01000	111001 1001	000110 1001
D9.1	29	001 01001	100101 1001	100101 1001
D10.1	2A	001 01010	010101 1001	010101 1001
D11.1	2B	001 01011	110100 1001	110100 1001
D12.1	2C	001 01100	001101 1001	001101 1001
D13.1	2D	001 01101	101100 1001	101100 1001
D14.1	2E	001 01110	011100 1001	011100 1001
D15.1	2F	001 01111	010111 1001	101000 1001
D16.1	30	001 10000	011011 1001	100100 1001
D17.1	31	001 10001	100011 1001	100011 1001
D18.1	32	001 10010	010011 1001	010011 1001

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D19.1	33	001 10011	110010 1001	110010 1001
D20.1	34	001 10100	001011 1001	001011 1001
D21.1	35	001 10101	101010 1001	101010 1001
D22.1	36	001 10110	011010 1001	011010 1001
D23.1	37	001 10111	111010 1001	000101 1001
D24.1	38	001 11000	110011 1001	001100 1001
D25.1	39	001 11001	100110 1001	100110 1001
D26.1	3A	001 11010	010110 1001	010110 1001
D27.1	3B	001 11011	110110 1001	001001 1001
D28.1	3C	001 11100	001110 1001	001110 1001
D29.1	3D	001 11101	101110 1001	010001 1001
D30.1	3E	001 11110	011110 1001	100001 1001
D31.1	3F	001 11111	101011 1001	010100 1001
D0.2	40	010 00000	100111 0101	011000 0101
D1.2	41	010 00001	011101 0101	100010 0101
D2.2	42	010 00010	101101 0101	010010 0101
D3.2	43	010 00011	110001 0101	110001 0101
D4.2	44	010 00100	110101 0101	001010 0101
D5.2	45	010 00101	101001 0101	101001 0101
D6.2	46	010 00110	011001 0101	011001 0101
D7.2	47	010 00111	111000 0101	000111 0101
D8.2	48	010 01000	111001 0101	000110 0101
D9.2	49	010 01001	100101 0101	100101 0101
D10.2	4A	010 01010	010101 0101	010101 0101
D11.2	4B	010 01011	110100 0101	110100 0101
D12.2	4C	010 01100	001101 0101	001101 0101
D13.2	4D	010 01101	101100 0101	101100 0101
D14.2	4E	010 01110	011100 0101	011100 0101

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D15.2	4F	010 01111	010111 0101	101000 0101
D16.2	50	010 10000	011011 0101	100100 0101
D17.2	51	010 10001	100011 0101	100011 0101
D18.2	52	010 10010	010011 0101	010011 0101
D19.2	53	010 10011	110010 0101	110010 0101
D20.2	54	010 10100	001011 0101	001011 0101
D21.2	55	010 10101	101010 0101	101010 0101
D22.2	56	010 10110	011010 0101	011010 0101
D23.2	57	010 10111	111010 0101	000101 0101
D24.2	58	010 11000	110011 0101	001100 0101
D25.2	59	010 11001	100110 0101	100110 0101
D26.2	5A	010 11010	010110 0101	010110 0101
D27.2	5B	010 11011	110110 0101	001001 0101
D28.2	5C	010 11100	001110 0101	001110 0101
D29.2	5D	010 11101	101110 0101	010001 0101
D30.2	5E	010 11110	011110 0101	100001 0101
D31.2	5F	010 11111	101011 0101	010100 0101
D0.3	60	011 00000	100111 0011	011000 1100
D1.3	61	011 00001	011101 0011	100010 1100
D2.3	62	011 00010	101101 0011	010010 1100
D3.3	63	011 00011	110001 1100	110001 0011
D4.3	64	011 00100	110101 0011	001010 1100
D5.3	65	011 00101	101001 1100	101001 0011
D6.3	66	011 00110	011001 1100	011001 0011
D7.3	67	011 00111	111000 1100	000111 0011
D8.3	68	011 01000	111001 0011	000110 1100
D9.3	69	011 01001	100101 1100	100101 0011
D10.3	6A	011 01010	010101 1100	010101 0011

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D11.3	6B	011 01011	110100 1100	110100 0011
D12.3	6C	011 01100	001101 1100	001101 0011
D13.3	6D	011 01101	101100 1100	101100 0011
D14.3	6E	011 01110	011100 1100	011100 0011
D15.3	6F	011 01111	010111 0011	101000 1100
D16.3	70	011 10000	011011 0011	100100 1100
D17.3	71	011 10001	100011 1100	100011 0011
D18.3	72	011 10010	010011 1100	010011 0011
D19.3	73	011 10011	110010 1100	110010 0011
D20.3	74	011 10100	001011 1100	001011 0011
D21.3	75	011 10101	101010 1100	101010 0011
D22.3	76	011 10110	011010 1100	011010 0011
D23.3	77	011 10111	111010 0011	000101 1100
D24.3	78	011 11000	110011 0011	001100 1100
D25.3	79	011 11001	100110 1100	100110 0011
D26.3	7A	011 11010	010110 1100	010110 0011
D27.3	7B	011 11011	110110 0011	001001 1100
D28.3	7C	011 11100	001110 1100	001110 0011
D29.3	7D	011 11101	101110 0011	010001 1100
D30.3	7E	011 11110	011110 0011	100001 1100
D31.3	7F	011 11111	101011 0011	010100 1100
D0.4	80	100 00000	100111 0010	011000 1101
D1.4	81	100 00001	011101 0010	100010 1101
D2.4	82	100 00010	101101 0010	010010 1101
D3.4	83	100 00011	110001 1101	110001 0010
D4.4	84	100 00100	110101 0010	001010 1101
D5.4	85	100 00101	101001 1101	101001 0010
D6.4	86	100 00110	011001 1101	011001 0010

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D7.4	87	100 00111	111000 1101	000111 0010
D8.4	88	100 01000	111001 0010	000110 1101
D9.4	89	100 01001	100101 1101	100101 0010
D10.4	8A	100 01010	010101 1101	010101 0010
D11.4	8B	100 01011	110100 1101	110100 0010
D12.4	8C	100 01100	001101 1101	001101 0010
D13.4	8D	100 01101	101100 1101	101100 0010
D14.4	8E	100 01110	011100 1101	011100 0010
D15.4	8F	100 01111	010111 0010	101000 1101
D16.4	90	100 10000	011011 0010	100100 1101
D17.4	91	100 10001	100011 1101	100011 0010
D18.4	92	100 10010	010011 1101	010011 0010
D19.4	93	100 10011	110010 1101	110010 0010
D20.4	94	100 10100	001011 1101	001011 0010
D21.4	95	100 10101	101010 1101	101010 0010
D22.4	96	100 10110	011010 1101	011010 0010
D23.4	97	100 10111	111010 0010	000101 1101
D24.4	98	100 11000	110011 0010	001100 1101
D25.4	99	100 11001	100110 1101	100110 0010
D26.4	9A	100 11010	010110 1101	010110 0010
D27.4	9B	100 11011	110110 0010	001001 1101
D28.4	9C	100 11100	001110 1101	001110 0010
D29.4	9D	100 11101	101110 0010	010001 1101
D30.4	9E	100 11110	011110 0010	100001 1101
D31.4	9F	100 11111	101011 0010	010100 1101
D0.5	A0	101 00000	100111 1010	011000 1010
D1.5	A1	101 00001	011101 1010	100010 1010
D2.5	A2	101 00010	101101 1010	010010 1010

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D3.5	A3	101 00011	110001 1010	110001 1010
D4.5	A4	101 00100	110101 1010	001010 1010
D5.5	A5	101 00101	101001 1010	101001 1010
D6.5	A6	101 00110	011001 1010	011001 1010
D7.5	A7	101 00111	111000 1010	000111 1010
D8.5	A8	101 01000	111001 1010	000110 1010
D9.5	A9	101 01001	100101 1010	100101 1010
D10.5	AA	101 01010	010101 1010	010101 1010
D11.5	AB	101 01011	110100 1010	110100 1010
D12.5	AC	101 01100	001101 1010	001101 1010
D13.5	AD	101 01101	101100 1010	101100 1010
D14.5	AE	101 01110	011100 1010	011100 1010
D15.5	AF	101 01111	010111 1010	101000 1010
D16.5	B0	101 10000	011011 1010	100100 1010
D17.5	B1	101 10001	100011 1010	100011 1010
D18.5	B2	101 10010	010011 1010	010011 1010
D19.5	B3	101 10011	110010 1010	110010 1010
D20.5	B4	101 10100	001011 1010	001011 1010
D21.5	B5	101 10101	101010 1010	101010 1010
D22.5	B6	101 10110	011010 1010	011010 1010
D23.5	B7	101 10111	111010 1010	000101 1010
D24.5	B8	101 11000	110011 1010	001100 1010
D25.5	B9	101 11001	100110 1010	100110 1010
D26.5	BA	101 11010	010110 1010	010110 1010
D27.5	BB	101 11011	110110 1010	001001 1010
D28.5	BC	101 11100	001110 1010	001110 1010
D29.5	BD	101 11101	101110 1010	010001 1010
D30.5	BE	101 11110	011110 1010	100001 1010

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D31.5	BF	101 11111	101011 1010	010100 1010
D0.6	C0	110 00000	100111 0110	011000 0110
D1.6	C1	110 00001	011101 0110	100010 0110
D2.6	C2	110 00010	101101 0110	010010 0110
D3.6	C3	110 00011	110001 0110	110001 0110
D4.6	C4	110 00100	110101 0110	001010 0110
D5.6	C5	110 00101	101001 0110	101001 0110
D6.6	C6	110 00110	011001 0110	011001 0110
D7.6	C7	110 00111	111000 0110	000111 0110
D8.6	C8	110 01000	111001 0110	000110 0110
D9.6	C9	110 01001	100101 0110	100101 0110
D10.6	CA	110 01010	010101 0110	010101 0110
D11.6	CB	110 01011	110100 0110	110100 0110
D12.6	CC	110 01100	001101 0110	001101 0110
D13.6	CD	110 01101	101100 0110	101100 0110
D14.6	CE	110 01110	011100 0110	011100 0110
D15.6	CF	110 01111	010111 0110	101000 0110
D16.6	D0	110 10000	011011 0110	100100 0110
D17.6	D1	110 10001	100011 0110	100011 0110
D18.6	D2	110 10010	010011 0110	010011 0110
D19.6	D3	110 10011	110010 0110	110010 0110
D20.6	D4	110 10100	001011 0110	001011 0110
D21.6	D5	110 10101	101010 0110	101010 0110
D22.6	D6	110 10110	011010 0110	011010 0110
D23.6	D7	110 10111	111010 0110	000101 0110
D24.6	D8	110 11000	110011 0110	001100 0110
D25.6	D9	110 11001	100110 0110	100110 0110
D26.6	DA	110 11010	010110 0110	010110 0110

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D27.6	DB	110 11011	110110 0110	001001 0110
D28.6	DC	110 11100	001110 0110	001110 0110
D29.6	DD	110 11101	101110 0110	010001 0110
D30.6	DE	110 11110	011110 0110	100001 0110
D31.6	DF	110 11111	101011 0110	010100 0110
D0.7	E0	111 00000	100111 0001	011000 1110
D1.7	E1	111 00001	011101 0001	100010 1110
D2.7	E2	111 00010	101101 0001	010010 1110
D3.7	E3	111 00011	110001 1110	110001 0001
D4.7	E4	111 00100	110101 0001	001010 1110
D5.7	E5	111 00101	101001 1110	101001 0001
D6.7	E6	111 00110	011001 1110	011001 0001
D7.7	E7	111 00111	111000 1110	000111 0001
D8.7	E8	111 01000	111001 0001	000110 1110
D9.7	E9	111 01001	100101 1110	100101 0001
D10.7	EA	111 01010	010101 1110	010101 0001
D11.7	EB	111 01011	110100 1110	110100 1000
D12.7	EC	111 01100	001101 1110	001101 0001
D13.7	ED	111 01101	101100 1110	101100 1000
D14.7	EE	111 01110	011100 1110	011100 1000
D15.7	EF	111 01111	010111 0001	101000 1110
D16.7	F0	111 10000	011011 0001	100100 1110
D17.7	F1	111 10001	100011 0111	100011 0001
D18.7	F2	111 10010	010011 0111	010011 0001
D19.7	F3	111 10011	110010 1110	110010 0001
D20.7	F4	111 10100	001011 0111	001011 0001
D21.7	F5	111 10101	101010 1110	101010 0001
D22.7	F6	111 10110	011010 1110	011010 0001

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
D23.7	F7	111 10111	111010 0001	000101 1110
D24.7	F8	111 11000	110011 0001	001100 1110
D25.7	F9	111 11001	100110 1110	100110 0001
D26.7	FA	111 11010	010110 1110	010110 0001
D27.7	FB	111 11011	110110 0001	001001 1110
D28.7	FC	111 11100	001110 1110	001110 0001
D29.7	FD	111 11101	101110 0001	010001 1110
D30.7	FE	111 11110	011110 0001	100001 1110
D31.7	FF	111 11111	101011 0001	010100 1110

Table 159. Special 8b10b Symbol Encodings

Symbol Name	Data Value (hex)	Unencoded Bits HGF EDCBA (binary)	Encoded Bits with Negative Running Disparity abcdei fghj (binary)	Encoded Bits with Positive Running Disparity abcdei fghj (binary)
K28.5	BC	101 11100	001111 1010	110000 0101
K27.7	FB	111 11011	110110 1000	Not Used

Section 2 – Electrical Interface

17 HyperTransport™ Link Overview

The HyperTransport™ link is designed to deliver a scalable and high performance interconnect between CPU, memory, and IO devices. The HyperTransport link uses low-swing differential signaling with on-die differential termination to achieve high data rates: 400 million transfers per second (MT/s) to 2.0 GT/s with Gen1 signaling and 2.4 to 5.2 GT/s with Gen3 signaling. The HyperTransport link uses scalable frequency and data width to achieve scalable bandwidth.

This specification uses Gen1 to refer to both HyperTransport 1.0 and 2.0 signaling modes as these are fundamentally the same, and uses Gen3, Gen3_{DC} and Gen3_{AC} to refer to common, DC specific and AC specific characteristics respectively.

The HyperTransport link electrical specification provides for very high speed data rates by taking advantage of the inherent common-mode noise rejection and low skew properties of low-swing differential signals. On-die differential termination is included to increase the signal-to-noise ratio seen at the receiver while allowing for very simple system interconnect designs. The electrical requirements support multiple driver implementations and simple receiver data recovery methods that can be implemented in multiple logic process generations. To support the higher data transfer rates of 2.4GT/s and 2.8GT/s in HyperTransport 2.0 devices, a simple transmit equalization scheme is defined that uses a 1 bit history to de-emphasize the differential amplitude generated by the transmitter when transmitting a continuous run of 1's or 0's. HyperTransport 2.0 devices are not compatible with Gen3 devices at 2.4 and 2.8 GT/s.

For backwards compatibility reasons a Gen3_{DC} link initializes in the same way as a Gen1 link at 400MT/s, this is the minimum Gen1 supported frequency for Gen3 devices. The specification defines a tighter set of timings for 400MT/s on a Gen3 device to allow for the relaxed CLK/CAD flight time matching of Gen3 electricals. The 400MT/s operating mode allows a relaxed timing power-on default speed for network explorations and configuration. It also provides a robust power-on default mode for hardware tests and diagnostics.

A device connected as Gen3_{AC} initializes at the minimum Gen3 frequency of 2.4GT/s with defined fixed equalization settings. This is the minimum required frequency that a Gen3_{AC} device is required to support. Gen3 protocol detects if a device is DC or AC coupled during power-up initialization.

The high frequency loss characteristics of a typical FR4 printed circuit boards cause significant distortion to signals at data rates beyond 2.0GT/s. To mitigate these effects Gen3 electricals use transmitter equalization to approximately compensate for these high frequency losses. Gen3_{AC} specifies additional transmit equalization settings and optional receiver decision feedback equalization.

The HyperTransport link consists of two independent source synchronous clocked unidirectional sets of wires. Each set of wires includes CADOUT [n:0], CLKOUT[m:0], and CTL[m:0], where n=1, 3, 7, 15,

or 31, and $m=0, 0, 0, 1, \text{ or } 3$, respectively. Gen1 protocol only uses a single CTL signal per link. Gen3 protocol uses m CTL signals per link. HyperTransport link packets are carried on the high speed CADOUT and CTLOUT wires and timed to CLKOUT, which is nominally 90° delayed from CADOUT and CTLOUT. In the receiver, the packets are received on high speed CADIN and CTLIN wires and captured by simple sampling with CLKIN at Gen1 frequencies. The transfer timing requirements for data capture at the receiver is defined in this specification. At Gen3 frequencies, the receiver uses the CLKIN to time a clock data alignment circuit which generates a data sample clock per bit to capture data. Data from the transmitter is scrambled once the link is initialized to provide a reasonable transition density for the clock data alignment circuit. Once captured from the interconnect, the packet must be passed into the receive clock domain which may or may not be derived from the same frequency source as the transmit clock domain. The ability to pass the packets between these two clock domains depends upon the clocking mode and the accumulated phase error between them. The accumulated phase error between the transmit and receiver clock domains is defined as phase recovery timing in this specification.

CADOUT, CTLOUT, and CLKOUT signals use differential drivers and have a point-to-point topology from the transmitter to the receiver. The receiver provides on-die differential termination as defined in this specification. The AC and DC device output and input voltage requirements are defined in this specification.

HyperTransport 3.0 protocol supports an optional AC coupled mode which uses external coupling capacitors at the transmitter end of the link to provide DC common-mode isolation between each end of the link. This enables physical topologies that span multiple boards with connectors as well as cabling solutions. To provide DC balance the data is encoded using industry standard 8b10b format, this combined with better equalization allows longer reach than can be achieved with the DC coupled link. Note there is a bandwidth and latency penalty incurred with using AC coupling.

In addition to the low-swing differential signals, HyperTransport technology defines four single-ended open drain signals used for link reset and power down initiation and cessation. In a Gen3 system these signals may either be pulled up to 2.5v or V_{LDT} (1.2v). Level shifters must be used to convert between 2.5v and V_{LDT} domains in systems that use mixed signaling levels. PWROK is a required input to each HyperTransport device to indicate that all required system power supplies are within specification and that the reference clock is within specification. PWROK is driven by system reset logic. RESET# is a required input to each HyperTransport device to indicate the system reset state. RESET# is driven by system reset logic. LDTSTOP# and LDTREQ# are used in systems requiring power management to signal requests for power related system activities. The AC and DC device output and input requirements for these signals are defined in this specification.

Figure 30 shows the basic HyperTransport link interconnect for up to 32-bit links. Table 160 describes the link signal types.

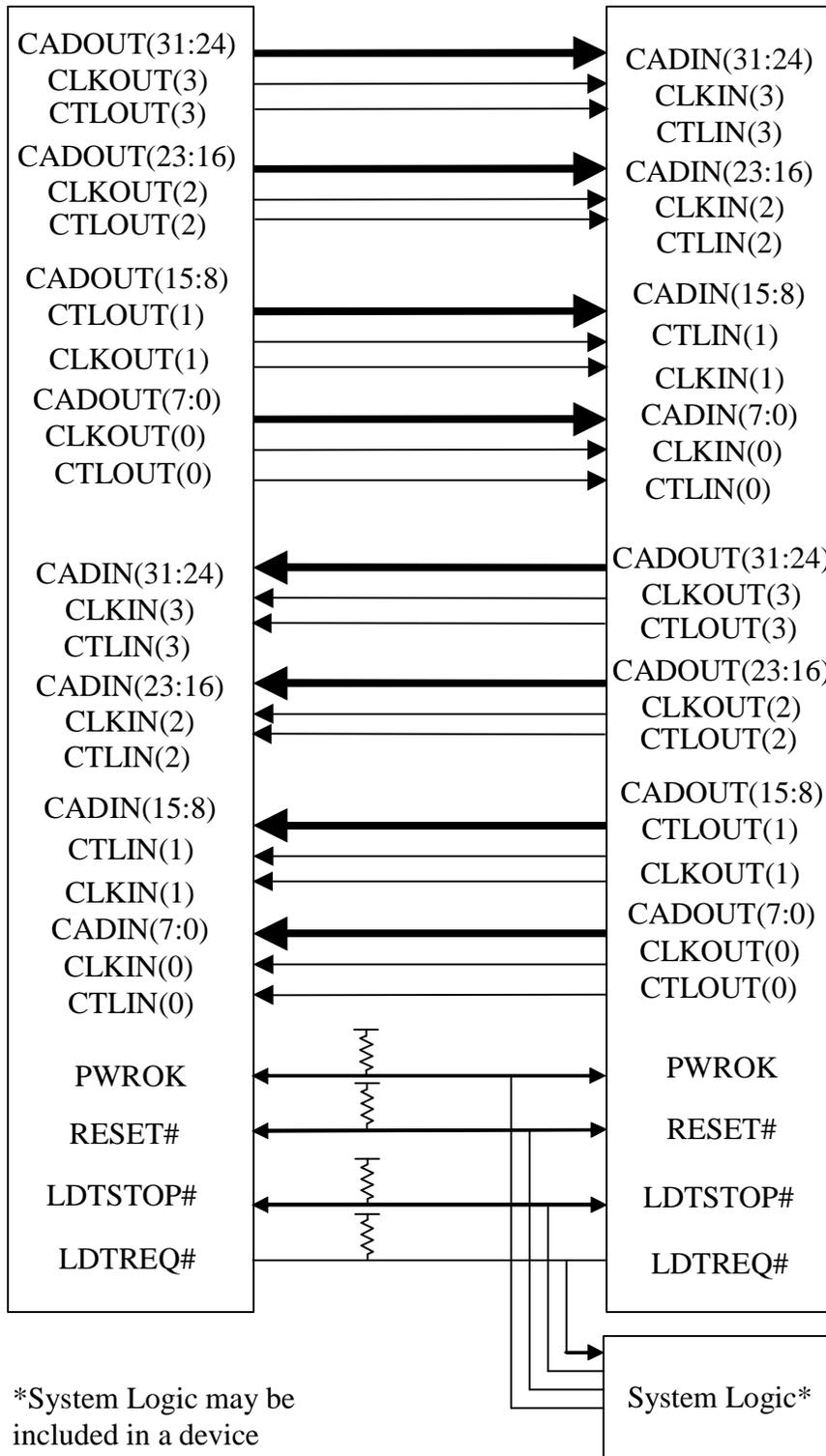


Figure 30. HyperTransport Link Interconnect

Table 160. HyperTransport Link Signal Types

Name	Driver Type	Receiver Type
CADOUT / CADIN	Differential	Differential, terminated
CLKOUT / CLKIN	Differential	Differential, terminated
CTLOUT / CTLIN	Differential	Differential, terminated
LDTSTOP# ¹	Open Drain	Single-ended 2.5V tolerant LVCMOS or V_{LDT} referenced open drain
LDTREQ# ^{1,3}	Open Drain	Single-ended 2.5V tolerant LVCMOS or V_{LDT} referenced open drain
PWROK ^{1,2}	Open Drain	Single-ended 2.5V tolerant LVCMOS or V_{LDT} referenced open drain
RESET# ^{1,2}	Open Drain	Single-ended 2.5V tolerant LVCMOS or V_{LDT} referenced open drain
Notes: <ol style="list-style-type: none"> 1. These signals require a single pullup resistor on the system board for required functionality. The value of this resistor is required to be $\geq 1\text{ KW}$. Routing on PCB of these signals must be done in a daisy-chain fashion, with any stubs being less than 1" in length. 2. Some devices may use these signals as both input and output if LVCMOS. Otherwise they are input-only. 3. Optional, used for power management 		

18 Common Specifications

A HyperTransport™ device has three types of signals that are described in this specification by their function, namely low speed single ended signals, transmit signals and receive signals. All of these must conform to a set of common specifications that bound the usage model for the device.

18.1 ESD tolerance

All I/O and power pins for a Gen3 device must withstand 2000 V of ESD using the human body model (HBM) and 500 V of ESD using the charged device model (CDM) without damage. Class 2 per JEDEC JESE22-A114-A.

18.2 Short Circuit

All I/Os for a Gen3 device must withstand a short-circuit to ground for 1sec without permanent damage.

18.3 Hot-plug

A device that supports hot plug may be connected or disconnected to a system with all combinations of the system being powered and the device being powered. All I/Os must survive this operation without damage and in the case of being connected, become operational through the normal initialization and training sequence.

19 Single ended signals

The open drain single ended signals provide a sideband method of controlling device and link initialization as well as power management control. To provide backward compatibility for Gen1 devices and also to comprehend the need for voltage scaling in current and future silicon devices this specification introduces two signaling voltage levels for these signals based on legacy 2.5v LVCMOS and a new V_{LDT} reference open drain signaling level.

These different signaling levels can coexist in the same system by using a level shifter to translate between the two different signaling domains. If a system only uses Gen3 devices then there is no requirement to implement the 2.5v signaling domain.

Gen1 electricals allow a HyperTransport device to delay the assertion and deassertion of PWROK and RESET#. Gen3 electricals do not allow this to avoid the requirement to bi-directionally signal between the two signaling voltage domains on a single wire.

Signal	Driven by	Received by	Function
PWROK ¹	System Logic	All HyperTransport devices	Power supplies up and within tolerance
RESET# ¹	System Logic	All HyperTransport devices	System wide warm reset
LDTSTOP#	System Logic	All HyperTransport devices	Stops and starts link during normal operation
LDTREQ# ²	IO device	System Logic	Wired-or request line for I/O device to initiate wake up

Notes:

1. Gen1 devices may drive these signals in the 2.5v domain
2. Gen1 and Gen3 devices may drive this signal in either voltage domain; Direction of voltage translator determined by voltage level of System Logic

20 Supply Characteristics

The supply for HyperTransport™ link drivers and receivers is a single fixed supply. The differential nature of HyperTransport link switching minimizes the current transients required of the VLDT supply when compared to single-ended systems, however the requirements and the design of the VLDT regulation and distribution system must be considered carefully. Voltage mode drives implemented completely in the VLDT domain can cause significant noise on VLDT. The AC impedance of the VLDT distribution system must be considered along with the transient requirements of the link in order to maintain the specified VLDT tolerance. The VLDT supply needs only to source current.

Table 161. HyperTransport™ Link Power Supply Characteristics

Parameter	Description	Min	Typical	Max	Units
VLDT	HyperTransport Link Supply Voltage ¹	1.14	1.2	1.26	V
VLDT tolerance	VLDT supply tolerance ¹	-5		+5	%

Notes:

1. Measured at the external connection to the HyperTransport device package. The VLDT as measured on the die should maintain a 1.1V to 1.3V range under all conditions. This $\pm 100\text{mV}$ variation at the die is considered when defining the DC output characteristics in this specification.

21 Power Requirements

HyperTransport™ link power consumption per differential pair under DC conditions is calculated from specified R_{ON} and R_{TT} values.

Table 162. Power Requirements

Parameter	Description	Min	Typ	Max	Units
P_{DC}	DC power per output bit ¹ 400MT/s to 2.0GT/s	5.5	7.2	9.4	mW
	DC power per output bit ¹ 2.4GT/s	7.5	9.8	12.8	mW
	DC power per output bit ¹ 2.8GT/s	8.3	10.9	14.2	mW
P_{AC}	AC power per output bit ^{1,2}			66	mW
P_{TAC}	Transmitter AC power per bit ^{1,2,3}			53	mW
P_{RAC}	Receiver AC power per bit ^{1,2}			13	mW
<p>Notes:</p> <ol style="list-style-type: none"> Includes both true and complement drivers or receivers with VLDT, R_{ON}, and R_{TERM} at min, typical, or maximum as required. An estimate that includes both differential transmitters and receivers operating at maximum data rate, actual implementations are expected to vary from these numbers. Implementations that supply much of the pre-driver from a supply other than VLDT can consume much less than this specified maximum. 					

22 Gen1 Link Characteristics

22.1 Input/Output DC Voltage Characteristics

The DC characteristics are valid and should be measured only when the circuitry has assumed steady-state conditions. Steady-state is attained when there are no transient effects present in the driver, receiver, interconnect, supply circuitry, or distribution paths. The use of switching waveforms to illustrate ΔV_{OD} , ΔV_{ID} , ΔV_{OCM} , and ΔV_{ICM} definitions does not imply that these measurements are taken under switching conditions, only that the values of two different logic states be compared. These DC specifications are to be used for circuit verification and characterization, system validation, and production test.

22.1.1 Impedance Requirements

R_{TT} is the value of the differential input impedance of the receiver under DC conditions implemented with an on-die differential terminating resistor. This specification must be supported by any compensation technique used within the receiver across all device specific process, voltage, and temperature operating points. The R_{TT} value is defined to match the Z_{OD} of the coupled transmission lines.

R_{ON} is the driver output impedance under DC conditions. This range must be maintained over the valid V_{OD} and V_{ODDE} range. This specification must be supported by any compensation technique used within the output driver across all device specific process, voltage, and temperature operating points. The R_{ON} value is defined to match one-half of the Z_{OD} of the transmission lines.

DR_{ON} (pullup) is the allowable difference in the driver output impedance between the true and complement when driving a logic 0 and when driving a logic 1 (additionally defined as when true is driven high and when complement is driven high). ΔR_{ON} (pullup) is defined to limit differences in both output rising edge slew rate and the resulting differential skew and crossing point shift.

DR_{ON} (pulldown) is the allowable difference in the driver output impedance between the true and complement when driving a logic 1 and when driving a logic 0 (additionally defined as when true is driven low and when complement is driven low). ΔR_{ON} (pulldown) is defined to limit the differences in both output falling-edge slew rate and the resulting differential skew and crossing point shift.

Table 163 gives the DC specifications for these parameters.

Table 163. R_{TT} and R_{ON} DC Specifications

Parameter	Description	Min	Typical	Max	Units
R _{TT}	Differential Termination	90	100	110	Ω
R _{ON}	Driver Output Impedance	45	50	55	Ω
ΔR _{ON} (pullup)	High Drive Impedance Magnitude Change	0		5	%
ΔR _{ON} (pulldown)	Low Drive Impedance Magnitude Change	0		5	%

22.2 DC Output Voltage Requirements

These specifications place requirements on the driver and are derived from the specified R_{ON} and R_{TT} tolerance or ΔR_{ON} (pulldown) or ΔR_{ON} (pullup) tolerances.

22.2.1 ATE Test Environment

The specified values are valid and should be tested directly at the transmitter output pins DO+ and DO-. Automated test equipment power supplies, supply distribution, and signal interconnect should be designed to provide best case operating conditions such that the ATE equipment can then effectively apply guard band to production test points as necessary. For output signals specifically, this requirement means driving an ideal 100-Ω Z_{OD} environment.

22.2.2 Reference System Load

The following reference system load is provided for simulation or system test environments where the more realistic system load is desired.

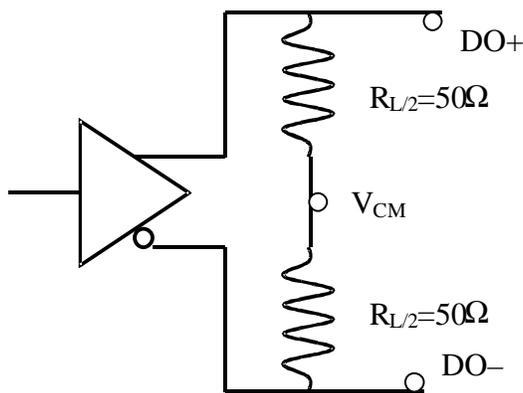


Figure 31. DC Output Reference System Load

22.2.3 Output Voltage Parameter Descriptions

$V_{OD(DC)}$ is the differential output voltage or the voltage difference between true and complement under DC conditions. V_{OD} is equal to $|DO+ - DO-|$ in Figure 32.

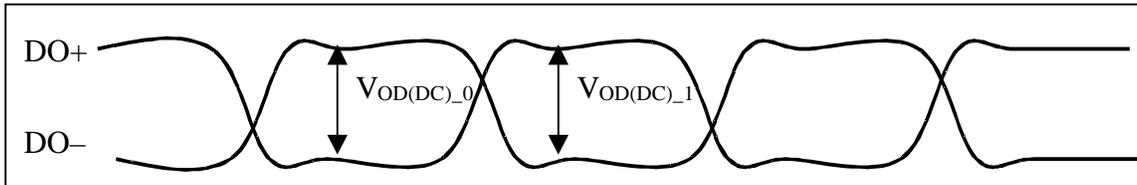


Figure 32. $V_{OD(DC)}$

$V_{ODDE(DC)}$ is the differential output voltage or the voltage difference between true and complement when the transmitter is sending the de-emphasized voltage level. This level is only transmitted for data rates of 2.4 GT/s and 2.8 GT/s and whenever the previous and current bits have the same binary value as shown in Figure 33. $V_{ODDE(DC)}$ is measured as a ratio of the actual $V_{OD(DC)}$ transmitted on a 1 to 0 or 0 to 1 transition.

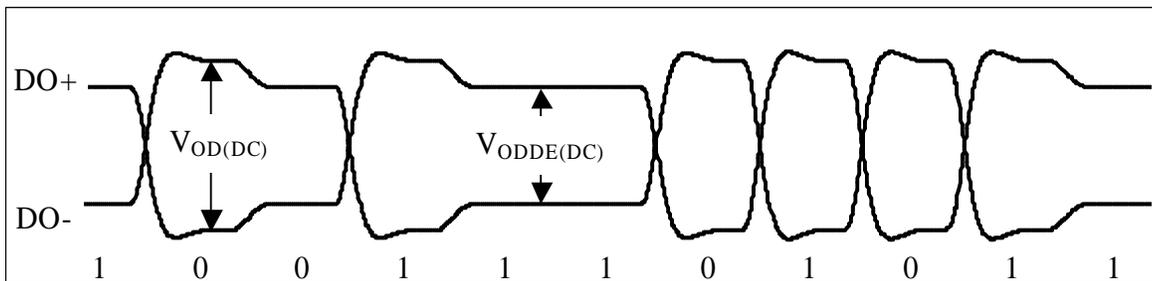


Figure 33. $V_{ODDE(DC)}$

$\Delta V_{OD(DC)}$ is the change in magnitude between the differential output voltage while driving a logic 0 and while driving a logic 1. $\Delta V_{OD(DC)}$ is equal to $V_{OD(DC)_0} - V_{OD(DC)_1}$.

$V_{OCM(DC)}$ is the output common-mode voltage defined as the average of the true voltage magnitude and the complement voltage magnitude relative to ground under DC conditions. V_{OCM} is not directly measurable under operation unless the output load circuit is used and the V_{OCM} measured at the point marked V_{CM} . In operational systems this value is derived using the following equation. V_{OCM} is equal to $(DO+ + DO-) / 2$ in Figure 34.

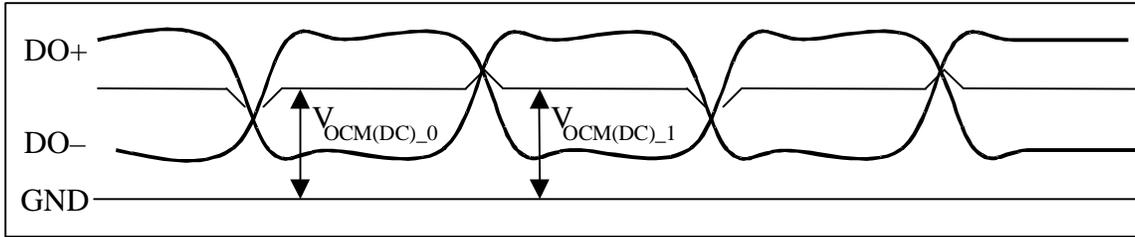


Figure 34. $V_{OCM(DC)}$

$\Delta V_{OCM(DC)}$ is the change in magnitude between the output common-mode voltage while driving a logic 0 and while driving a logic 1 under DC conditions. $\Delta V_{OCM(DC)}$ is equal to $V_{OCM(DC)_1} - V_{OCM(DC)_0}$. $\Delta V_{OCM(DC)}$ includes the variation in common-mode voltage when switching between $V_{OD(DC)}$ and $V_{ODDE(DC)}$.

22.3 DC Input Requirements

These parameters place requirements on the receiver and are derived from the output parameters and interconnect effects.

22.3.1 ATE Test Environment

The specified values are valid and should be tested directly at the receiver input pins RI+ and RI-. Automated test equipment power supplies, supply distribution, and signal line losses should be calibrated such that the parameters are tested directly at the receiver inputs. Detailed requirements are ATE equipment specific and beyond the scope of this document.

22.3.2 Input Parameter Descriptions

V_{ID} is the input differential voltage or the voltage difference between the true and complement under DC conditions. V_{ID} is equal to $|RI+ - RI-|$ in Figure 35.

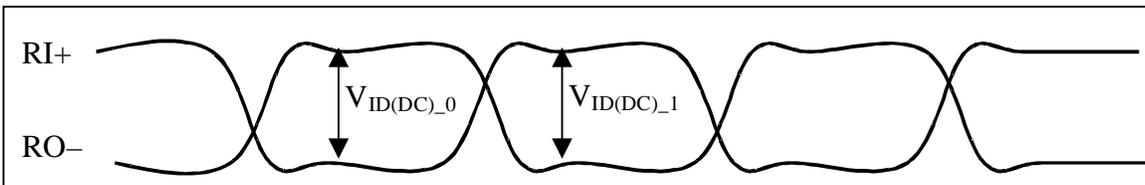


Figure 35. $V_{ID(DC)}$

$\Delta V_{ID(DC)}$ is the change in magnitude between the input differential voltage while receiving a logic 0 and while receiving a logic 1. $\Delta V_{ID(DC)}$ is equal to $V_{ID(DC)_0} - V_{ID(DC)_1}$.

V_{ICM} is the input common-mode voltage defined as the average of the true voltage magnitude and the complement voltage magnitude relative to ground under DC conditions. V_{ICM} is equal to $(RI+ + RI-)/2$ in Figure 36.

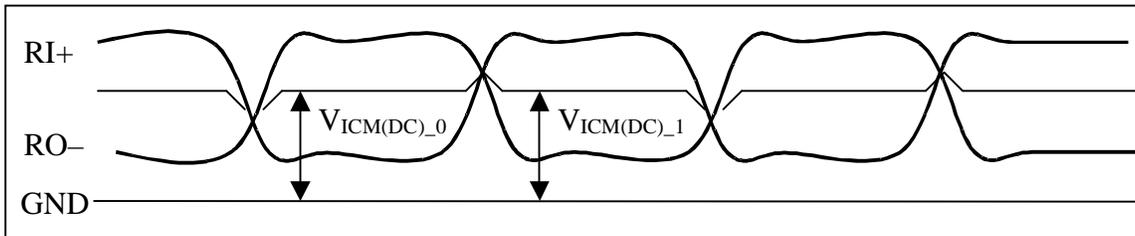


Figure 36. $V_{ICM(DC)}$

$\Delta V_{ICM(DC)}$ is the change in magnitude between the input common-mode voltage while driving a logic 0 and while driving a logic 1. $\Delta V_{ICM(DC)}$ is equal to $V_{ICM(DC)_1} - V_{ICM(DC)_0}$.

22.4 Differential Signal DC Specifications

Table 164 defines the allowed values for each of the DC characteristics. More detail regarding the derivation of these values is included in Appendix M.

Table 164. HyperTransport™ Link Differential Signal DC Specifications

Parameter	Description	Min ¹	Typical ²	Max ³	Units
$V_{OD(DC)}$	Differential Output Voltage ⁴	495	600	715	mV
$V_{ODDE(DC)}$	De-emphasized Differential Output Voltage for 2.4 GT/s ⁵	0.78	0.80	0.82	$V_{OD(DC)}$
	De-emphasized Differential Output Voltage for 2.8 GT/s ⁵	0.68	0.70	0.72	$V_{OD(DC)}$
$\Delta V_{OD(DC)}$	Change in V_{OD} Magnitude	-15		15	mV
$V_{OCM(DC)}$	Output common-mode voltage ⁴	495	600	715	mV
$\Delta V_{OCM(DC)}$	Change in V_{OCM} magnitude	-15		15	mV
$V_{ID(DC)}$	Input differential voltage from 400 MT/s to 1.6 GT/s	200	600	1000	mV
	Input differential voltage from 2.0 GT/s to 2.8 GT/s	100	600	1000	mV
$\Delta V_{ID(DC)}$	Change in V_{ID} magnitude	-15		15	mV
$V_{ICM(DC)}$	Input common-mode voltage	440	600	780	mV

$\Delta V_{ICM(DC)}$	Change in V_{ICM} magnitude	-15		15	mV
Notes: <ol style="list-style-type: none"> 1. Minimum values assume $V_{LDT} = V_{LDT_min}$ as a measurement condition. 2. Typical values assume $V_{LDT} = V_{LDT_typ}$ as a measurement condition. 3. Maximum values assume $V_{LDT} = V_{LDT_max}$ as a measurement condition. 4. See Appendix M for derivation of V_{OD} and V_{OCM}. 5. Measured as a ratio of the $V_{OD(DC)}$ transmitted on a 1 to 0 or 0 to 1 transition into the test load. 					

22.5 Single-Ended Signal AC/DC Specifications

Table 165 defines the allowed values for the single-ended signals defined by the HyperTransport technology.

Table 165. HyperTransport™ Link Single-Ended Signal AC/DC Specifications

Symbol	Parameter	Test Conditions	Min	Typical	Max	Unit
V_{DD}^2	DC Supply Voltage		2.37	2.5	2.63	V
V_{IH}	High Level Input Voltage	$V_{OUT} \geq V_{VOH(min)}$	1.7		$V_{DD} + 0.3$	V
$V_{IH-1.2}$	High Level Input Voltage	$V_{OUT} \geq V_{VOH(min)}$	$V_{LDT} * 0.7$		$V_{LDT} + 0.3$	V
V_{IL}	Low Level Input Voltage	$V_{OUT} \leq V_{VOL(max)}$	-0.3		0.7	V
$V_{IL-1.2}$	Low Level Input Voltage	$V_{OUT} \leq V_{VOL(max)}$	-0.3		$V_{LDT} * 0.3$	V
T_{IRF}	Input rising and falling slew rate	$V_{IL} < V_{IN} < V_{IH}$, monotonic ¹	0.01			V / ns
V_{OL}	Low Level Output Voltage	$V_{DD} = \text{min},$ $V_I = V_{IH} \text{ or } V_{IL}$	$I_{OL} = 2 \text{ mA}$		0.7	V
$V_{OL-1.2}$	Low Level Output Voltage	$V_{DD} = \text{min},$ $V_I = V_{IH} \text{ or } V_{IL}$	$I_{OL} = 2 \text{ mA}$		0.1	V
I_I	Input Current	$V_{DD} = \text{max}, V_I = V_{DD} \text{ or } \text{GND}$			± 500	μA
Notes: <ol style="list-style-type: none"> 1. This rising edge is only guaranteed to be monotonic if the pull-up resistor is $\geq 1\text{K}\Omega$ and routing of these signals is done in a daisy chain fashion 2. Only applies to 2.5V LVCMOS I/O's, otherwise V_{LDT} is the power supply 						

22.6 Input/Output AC Voltage Characteristics

The AC characteristics are valid and should be measured only when the circuitry has not yet reached steady-state conditions. This is the normal operating state of the link and considers that signals are switching and contain noise induced by crosstalk, reflections, inter-symbol interference, and other effects. Power supplies contain noise induced from simultaneous switching, resonance, and other effects. These AC characteristics are to be used to circuit verification and system characterization and validation. Testing many of these parameters might not be possible in a production test flow. These specifications must be guaranteed by design or characterized across process, voltage, and temperature for a given product. Some electrical parameters are specified differently for links designed to operate at different data rates. Additionally, the required interconnect and test load circuits vary for links designed to operate in these two frequency ranges.

This specification defines AC voltage characteristics at the die pad and device pins. The signal that can be observed in a system at the device pin is in general a distorted version of the signal at the device pad because of the effect of the device package impedance and pad input capacitance on the interconnect channel. Furthermore it can often be difficult to probe even at the device package pin because of the PCB breakout pattern further distorting the signal that is observed. Device and system designers must compensate for the effects of observing the signal at a distance from the device pad.

22.7 Impedance Requirements

R_{TT} is the value of the differential input impedance of the receiver under AC conditions implemented with an on-die differential terminating resistor. Techniques used to compensate R_{TT} for changes due to P, V, or T fluctuations can result in R_{TT} having a non-linear I-V curve; therefore R_{TT} is specified under AC conditions and should be characterized or guaranteed over all process, voltage, and temperature operating points. For devices rated at 2.4 GT/s and 2.8 GT/s R_{TT} is split into two resistors R_{TT+} and R_{TT-} of approximately equal value.

R_{ON} (pullup) is the driver output impedance while driving high under AC conditions. This value and tolerance must be maintained from $0.5 * V_{LDT_nom}$ to V_{LDT_nom} . R_{ON} (pulldown) is the driver output impedance while driving low under AC conditions. This value and tolerance must be maintained from 0V to $0.5 * V_{LDT}$. Techniques used to compensate the output driver for changes due to P, V, or T variations can result in the driver having a non-linear I-V curve; therefore R_{ON} is specified under AC conditions and should be characterized or guaranteed over all process, voltage, and temperature operating points.

C_{OUT} is the driver output pad capacitance and is limited to act, along with the recommended transmitter package trace single-ended impedance of 35–65 Ω and maximum length of less than 850 mils, to create a matched impedance between the driver R_{ON} and the characteristic impedance of the package trace.

C_{IN} is the receiver input pad capacitance and is limited to act, along with the recommended receiver package trace single-ended impedance of 35–65 Ω and maximum length of less than 850 mils, to create a matched impedance between the interconnect transmission line and the characteristic impedance of the receiver package and input pad.

C_{CM} is a common-mode decoupling capacitor that provides high frequency common-mode termination by decoupling the center tap of R_{TT+} and R_{TT-} to ground. The capacitor is required for 2.4GT/s and 2.8GT/s and is recommended for other data rates to help reduce V_{ICMAC} .

Table 166 gives the AC impedance specifications for these parameters.

Table 166. AC Impedance Specifications

Parameter	Description	Min	Typ	Max	Units
R_{TT}^1	Differential Termination	90	100	110	Ω
R_{TT+}	True signal portion of differential termination	0.46 * R_{TT}		0.54 * R_{TT}	
R_{TT-}	Complement signal portion of differential termination		R_{TT-} R_{TT+}		
$R_{ON}(\text{pullup})^2$	Driver Output Impedance driving high	45	50	55	Ω
$R_{ON}(\text{pulldown})^3$	Driver Output Impedance driving low	45	50	55	Ω
C_{OUT}^4	Output pad capacitance for devices rated from 2.4 GT/s to 2.8 GT/s.			1.5	pF
	Output pad capacitance for devices rated from 1.0 GT/s to 2.0 GT/s.			3	pF
	Output pad capacitance for devices rated from 400 MT/s to 800 MT/s.			5	pF
C_{IN}^4	Input pad capacitance for devices rated from 2.4 GT/s to 2.8 GT/s.			1	pF
	Input pad capacitance for devices rated from 1.0 GT/s to 2.0 GT/s.			2	pF
	Input pad capacitance for devices rated from 400 MT/s to 800 MT/s			5	pF
C_{CM}^5	Common-mode decoupling for devices rated from 2.4 GT/s to 2.8 GT/s	20			pF

Notes:

- R_{TT} range is valid for input V_{ID} of $0.25 * VLDT$ and $0.75 * VLDT$ or between $0.285V$ and $0.945V$
- $R_{ON}(\text{pullup})$ range is valid for outputs between $0.5 * VLDT$ and $VLDT$
- $R_{ON}(\text{pulldown})$ range is valid for outputs between $0V$ and $0.5 * VLDT$
- C_{IN} and C_{OUT} are measured with a Time Domain Reflectometer (TDR) set to a low repeat rate or other equivalent measurement technique.
- C_{CM} is measured by driving both true and complement data in phase with a TDR or equivalent measurement technique.

22.8 AC Output Requirements

These parameters place requirements on the driver and add, to the DC signal characteristics, both supply and signal noise caused by signal transitions under AC conditions.

22.8.1 ATE Test Environment

In a dedicated ATE test environment, the device under test should drive an ideal load under ideal conditions. This implies that automated test equipment power supplies, supply distribution, and signal interconnect be designed as to provide best case operating conditions. This design allows the test engineer to accurately characterize the device performance and to define the production test point and guard band such that devices meet the specified characteristics in system or reference system environments.

22.8.2 Reference System Load

The following reference system load is provided for simulation or system test environments.

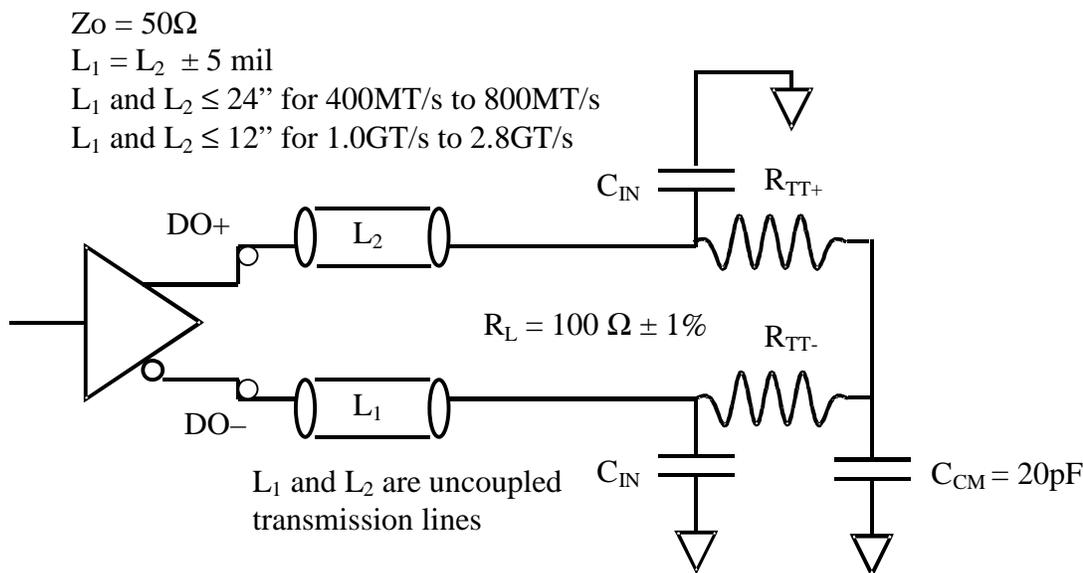


Figure 37. AC Reference System Load (See [Table 166](#) for C_{IN} , R_{TT+} and R_{TT-})

At the higher data rates and faster slew rates the exact lengths of the transmission lines L_1 and L_2 should be chosen to minimize the distortion caused by the reflection from C_{IN} on the rising and falling edges of the transmit waveform. This requires the flight time through L_1 and L_2 to be approximately $(N+0.5)/2$ bit-times, where N can vary from 0 to 11 for the maximum data rate of 2.8 GT/s.

22.8.2.1 Output Parameter Descriptions

V_{OD} is the differential output voltage or the voltage difference between true and complement under AC conditions. V_{OD} is equal to $|DO+ - DO-|$ in Figure 38.

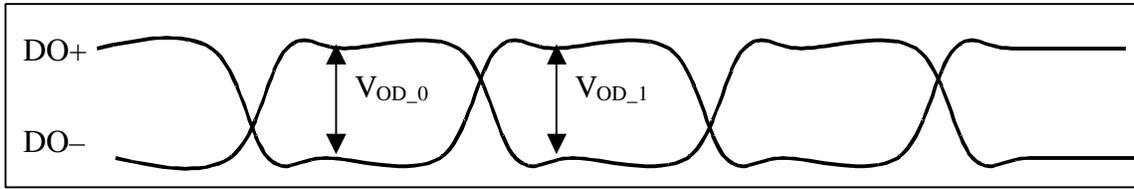


Figure 38. V_{OD} AC

ΔV_{OD} is the change in magnitude between the differential output voltage while driving a logic 0 and while driving a logic 1. ΔV_{OD} is equal to $V_{OD_0} - V_{OD_1}$.

V_{ODDE} is the differential output voltage or the voltage difference between true and complement when the transmitter is sending the de-emphasized voltage level. This level is only transmitted for data rates of 2.4 GT/s and 2.8 GT/s and whenever the previous and current bits have the same binary value as shown in Figure 39. V_{ODDE} is measured as a ratio of the actual V_{OD} transmitted on a 1 to 0 or 0 to 1 transition.

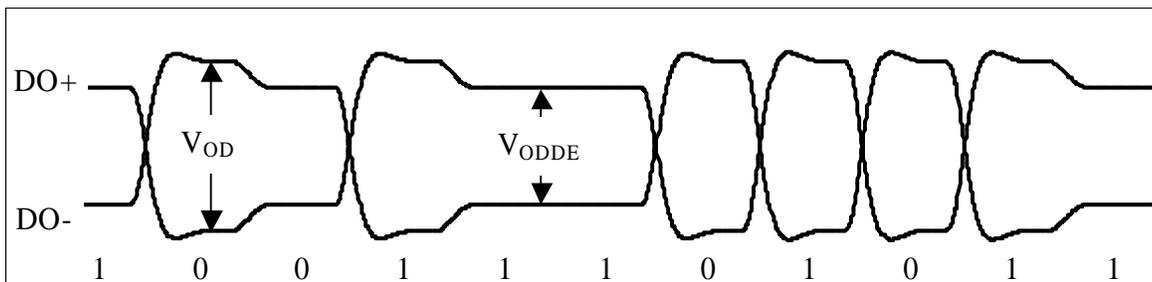


Figure 39. V_{ODDE} AC

V_{OCM} is the output common-mode voltage defined as the average of the true voltage magnitude and the complement voltage magnitude relative to ground under AC conditions. V_{OCM} is equal to $(DO+ + DO-)/2$ in Figure 40. V_{OCM} can be measured at any point in time, including but not limited to the crossing point, and has no periodicity requirements.

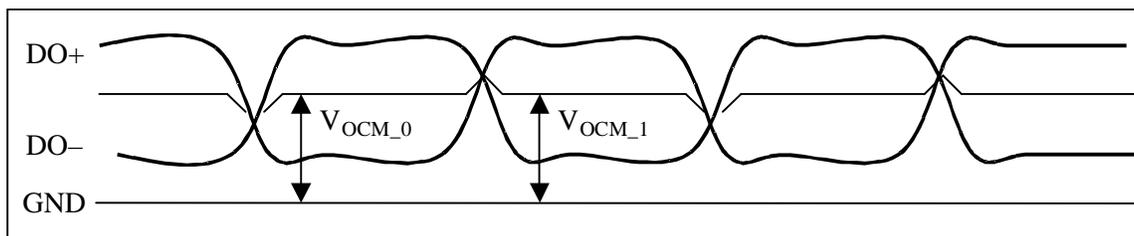


Figure 40. V_{OCM} AC

ΔV_{OCM} is the peak change in magnitude between the output common-mode voltage while driving a logic 0 and while driving a logic 1 under AC conditions. ΔV_{OCM} is equal to $V_{OCM_1} - V_{OCM_0}$.

T_{OR} is the input rising differential slew rate (logic 0 => logic 1) rate. T_{OR} is measured differentially between -200 mV and $+200$ mV.

T_{OF} is the input falling differential slew rate (logic 1 => logic 0) rate. T_{OF} is measured differentially between $+200$ mV and -200 mV.

22.9 AC Input Requirements

These parameters place requirements on the receiver and are derived from the output parameters.

22.9.1 ATE Test Environment

In a dedicated ATE test environment, the device under test should be driven by an ideal driver through ideal interconnect under ideal conditions. This implies that automated test equipment power supplies, supply distribution, and signal interconnect be designed as to provide best case operating conditions and not mimic a reference system load. This design allows the test engineer to accurately characterize the device performance and to define the production test point and guard band such that devices meet the specified characteristics in system or reference system environments.

22.9.2 Input Parameter Descriptions

V_{ID} is the input differential voltage or the voltage difference between the true and complement under AC conditions. V_{ID} is equal to $|RI+ - RI-|$ in Figure 41.

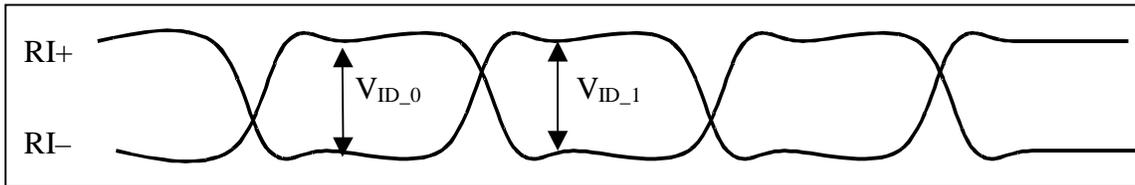


Figure 41. V_{ID} AC

ΔV_{ID} is the change in magnitude between the input differential voltage while receiving a logic 0 and while receiving a logic 1. ΔV_{ID} is equal to $V_{ID_0} - V_{ID_1}$.

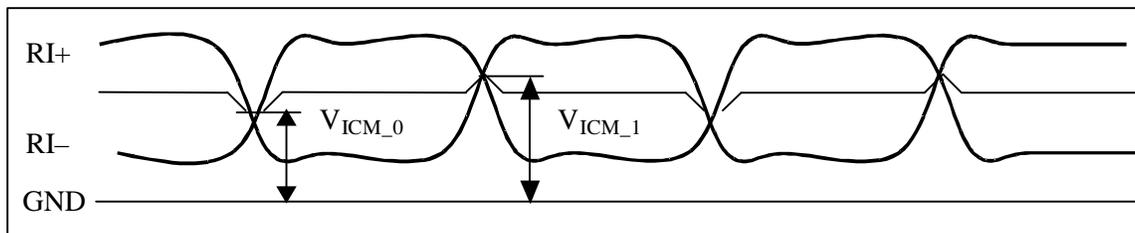


Figure 42. V_{ICM} AC

DV_{ICMAC} is the peak to peak magnitude of the instantaneous change in the input common-mode voltage relative to ground, equal to the difference between V_{ICM_1} and V_{ICM_0} in Figure 42.

T_R is the input rising differential slew rate (logic 0 => logic 1). T_{IR} is measured differentially between – 100 mV and + 100 mV.

T_F is the input falling differential slew rate (logic 1 => logic 0). T_{IF} is measured differentially between + 100 mV and – 100 mV.

22.10 Differential Signal AC Specifications

Table 167 defines the allowed values for each of the AC characteristics. More detail regarding the derivation of these values is included in Appendix M.

Table 167. HyperTransport™ Link Differential Signal AC Specifications

Parameter	Description	Min	Typ	Max	Units
V_{OD}	Differential Output Voltage	400	600	820	mV
V_{ODDE}	De-Emphasized Differential Output Voltage for 2.4 GT/s ⁴	0.77	0.80	0.83	$V_{OD(AC)}$
	De-Emphasized Differential Output Voltage for 2.8 GT/s ⁴	0.67	0.70	0.73	$V_{OD(AC)}$
ΔV_{OD}	Change in V_{OD} Magnitude	–75		75	mV
V_{OCM}	Output common-mode voltage	440	600	780	mV
ΔV_{OCM}	Change in V_{OCM} magnitude	–50		50	mV
T_{OR} ³	Output rising slew rate	2.5		8.0	V/ns
T_{OF} ³	Output falling slew rate	2.5		8.0	V/ns
V_{ID} ²	Input differential voltage from 2.0 GT/s to 2.8 GT/s	200		900	mV
	Input differential voltage from 400 MT/s to 1.6 GT/s	300	600	900	mV
ΔV_{ID} ²	Change in V_{ID} magnitude	–125		125	mV
V_{ICMAC} ²	Peak to peak magnitude of input common-mode voltage			350	mV
T_R ^{1,2}	Input rising slew rate	2.0		8.0	V / ns
T_F ^{1,2}	Input falling slew rate	2.0		8.0	V / ns

Parameter	Description	Min	Typ	Max	Units
<i>Notes:</i>					
1. Input edge rates are measured differentially between $\pm 100\text{mV}$.					
2. Measured or simulated at die pad. The waveform measured at the device pins or at some point close to the device pins can be significantly different to the waveform at the devices die pad because of impedance discontinuities between the PCB and package and the reflections from the input capacitance of the device.					
3. Output edge rates are measured differentially between $\pm 200\text{mV}$.					
4. Measured as a ratio of the V_{OD} transmitted on a 1 to 0 or 0 to 1 transition into the test load.					

23 Gen1 Link Transfer Timing Characteristics

The HyperTransport™ link uses a source synchronous clocked transfers to transmit and receive packets across the interconnect. Transfer timing is dependent upon the devices outputs, the interconnect, and the receiver inputs to minimize skew induced between signal edges. The amount of skew directly corresponds to the link frequency that can be attained.

The HyperTransport technology defines the required output skew, the interconnect skew, and the receiver input skew required to close timing for each of the specified link frequencies. The HyperTransport link uses a simple timing methodology that accounts for simultaneous worst case combinations of uncertainties. This timing methodology is a pessimistic approach that attempts to cover all cases that could occur in operational systems. Timing is defined to provide zero additional margin, which places the requirement on transmitter, interconnect, and receiver designers to meet these specifications over all process, voltage, and temperature corners.

23.1 Signal Groups

HyperTransport link transfer timing generally describes the timing required between the CAD/CTL signal group and the associated CLK signal. The definition of signals included in these groups varies by link width.

Table 168. Signal Groups for Transfer Timing

Link Width (TX or RX)	Group Names	Signals	Associated clock
2-Bit (TX)	CAD/CTL0UT	CADOUT[1:0], CTL0UT	CLKOUT
4-Bit (TX)	CAD/CTL0UT	CADOUT[3:0], CTL0UT	CLKOUT
8-Bit (TX)	CAD/CTL0UT	CADOUT[7:0], CTL0UT	CLKOUT
16-Bit (TX)	CAD/CTL0UT_0	CADOUT[7:0], CTL0UT	CLKOUT[0]
	CADOUT_1	CADOUT[15:8]	CLKOUT[1]
32-Bit (TX)	CAD/CTL0UT_0	CADOUT[7:0], CTL0UT	CLKOUT[0]
	CADOUT_1	CADOUT[15:8]	CLKOUT[1]
	CADOUT_2	CADOUT[23:16]	CLKOUT[2]
	CADOUT_3	CADOUT[31:24]	CLKOUT[3]

Link Width (TX or RX)	Group Names	Signals	Associated clock
2-Bit (RX)	CAD/CTLIN	CADIN[1:0], CTLIN	CLKIN
4-Bit (RX)	CAD/CTLIN	CADIN[3:0], CTLIN	CLKIN
8-Bit (RX)	CAD/CTLIN	CADIN[7:0], CTLIN	CLKIN
16-Bit (RX)	CAD/CTLIN_0	CADIN[7:0], CTLIN	CLKIN[0]
	CADIN_1	CADIN[15:8]	CLKIN[1]
32-Bit (RX)	CAD/CTLIN_0	CADIN[7:0], CTLIN	CLKIN[0]
	CADIN_1	CADIN[15:8]	CLKIN[1]
	CADIN_2	CADIN[23:16]	CLKIN[2]
	CADIN_3	CADIN[31:24]	CLKIN[3]

23.2 Device Output Timing Characteristics

23.2.1 Differential Output Skew

T_{ODIFF} defines the allowable output differential skew as defined by the time difference measured in a single-ended fashion at the midpoint of the transition of the true signal and the midpoint of the transition of the complement signal at the device's output pins.

Differential output skew is limited primarily by ΔV_{OCM} such that at the given minimum output edge rate differential skew would cause a violation of ΔV_{OCM} before violating the output differential skew specification.

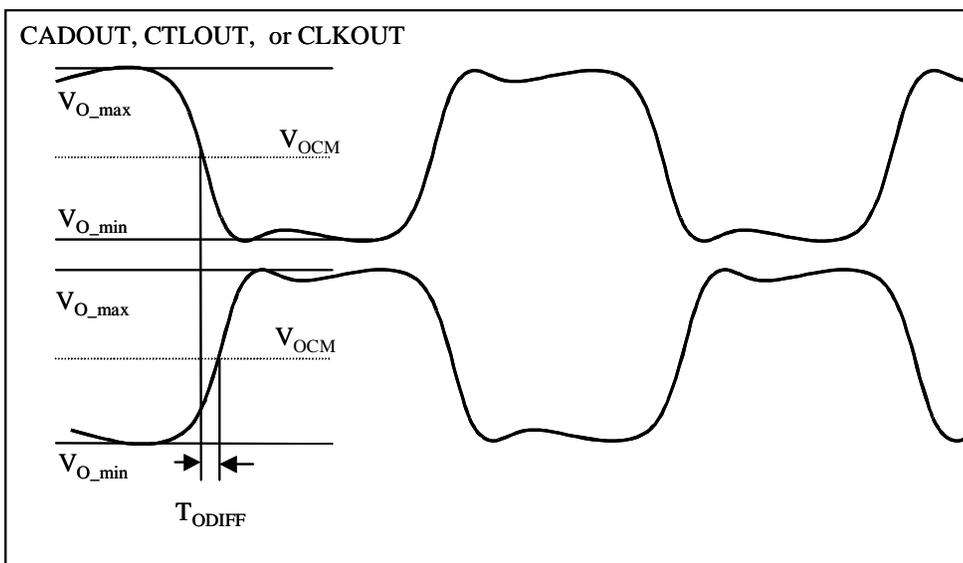


Figure 43. T_{ODIFF}

23.2.2 $T_{cadvalid}$

T_{CADV} defines the CAD/CTLOUT valid time from CAD/CTLOUT to CLKOUT or from CLKOUT to CAD/CTLOUT and is simultaneously an aggregate measurement of the accuracy of the transmitter to place the CAD/CTLOUT edges relative to CLKOUT edge, the minimum CLKOUT bit-time and, the CAD/CTLOUT group skew.

Nominally, CLKOUT is driven delayed by one-half of a bit-time from the CAD/CTLOUT transitions. This delay provides required setup and hold time to and from the CLKOUT edge at the receiver and therefore allows for simple data recovery. T_{CADV_min} is measured at the device pins from the crossing point of either the latest CAD/CTLOUT transition to the crossing point of the CLKOUT transition or the CLKOUT transition to the earliest CAD/CTLOUT transition. T_{CADV_max} is measured at the device pins from either the crossing point of the earliest CAD/CTLOUT transition to the crossing point of the CLKOUT transition or the CLKOUT transition to the latest CAD/CTLOUT transition.

Because T_{CADV} is an aggregate measure of different uncertainties, it must be measured over a large number of samples and under conditions defined to maximize CADOUT/CTL0UT group skew, CLKOUT edge placement error, and CLKOUT phase compression.

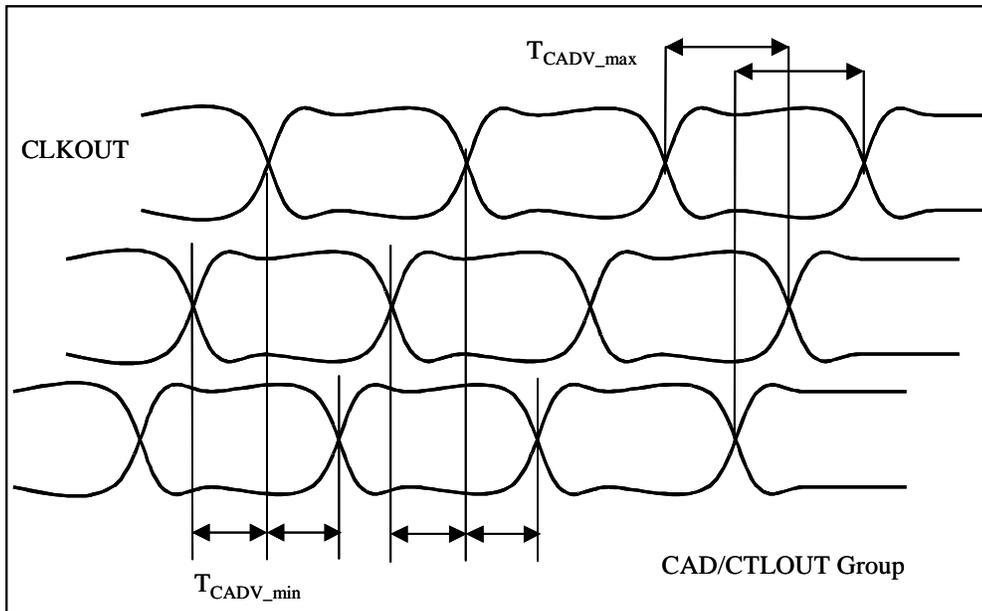


Figure 44. T_{CADV}

23.3 Device Input Timing Characteristics

23.3.1 Input Differential Skew

T_{IDIFF} defines the allowable input differential skew as defined by the time difference measured in a single-ended fashion at the midpoint of the transition of the true signal and the midpoint of the transition of the complement signal.

Differential input skew is limited primarily by ΔV_{ICM} such that at the given minimum output edge rate differential skew would cause a violation of ΔV_{ICM} before violating the output differential skew specification.

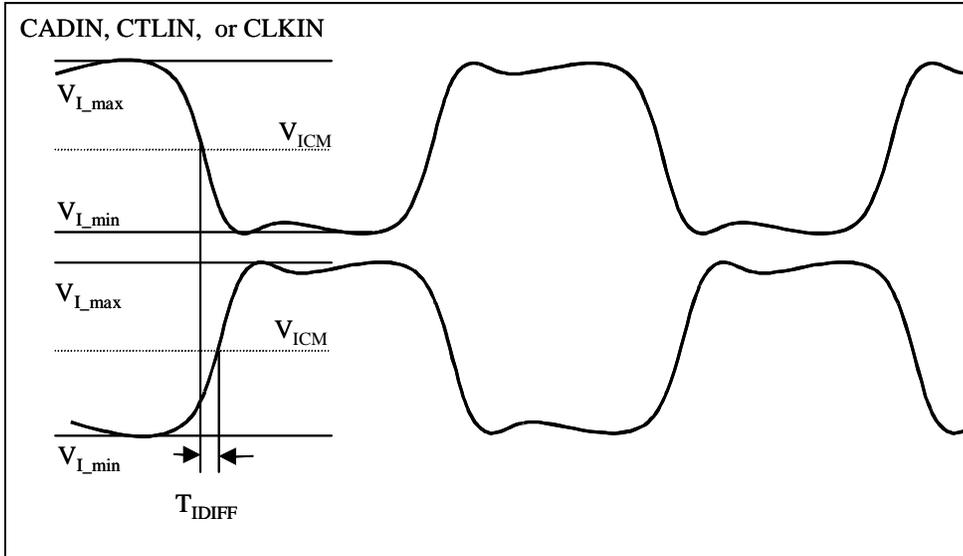


Figure 45. T_{IDIFF}

23.3.2 Tsu and Thd

T_{SU} defines the receiver's required input setup time at the device's die pads. T_{SU} is measured from the crossing point of the last CADIN transition to the CLKIN transition crossing point. T_{SU} accounts for receiver package skew, distribution skew, and device input setup time. T_{HD} defines the receiver's required input hold time. T_{HD} is measured at the device's die pads from the crossing point of the earliest CADIN transition to the CLKIN transition crossing point. T_{HD} accounts for receiver package skew, distribution skew, and device input hold time. As T_{SU} and T_{HD} are measured at the zero differential crossing point, they do not cover the required time to attain V_{ID_min} (AC) at the specified minimum input edge rates.

In the following figure, T_{SU_max} represents the maximum setup time that the device can require. This corresponds to the minimum setup time that the system can provide to the device input.

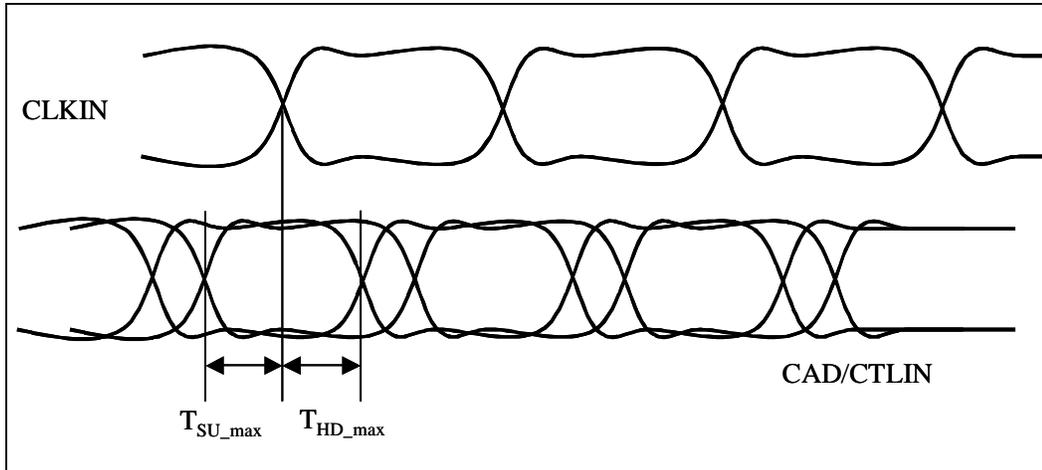


Figure 46. T_{SU} and T_{HD}

23.4 Interconnect Timing Characteristics

23.4.1 $T_{cadvrs/rh}$

$T_{CADVRS/RH}$ defines the remaining CADIN valid times to CLKIN (T_{CADVRS}) and from CLKIN to CADIN (T_{CADVRH}) measured at the receiver input pins. $T_{CADVRS/RH}$ are used as an aggregate and accumulative measure of the timing uncertainty composed of device output skew, clock edge placement error, and interconnect skew at the device inputs. As such, $T_{CADVRS/RH}$ must be measured over a large number of samples and conditions which maximize device output skew, interconnect skew, and clock edge placement error. T_{CADVRS} is measured from the crossing point of the last transitioning CADIN signal to the crossing point of the CLKIN transitioning signal at the receiver. T_{CADVRH} is measured from the CLKIN transitioning signal to the first CADIN signal at the receiver.

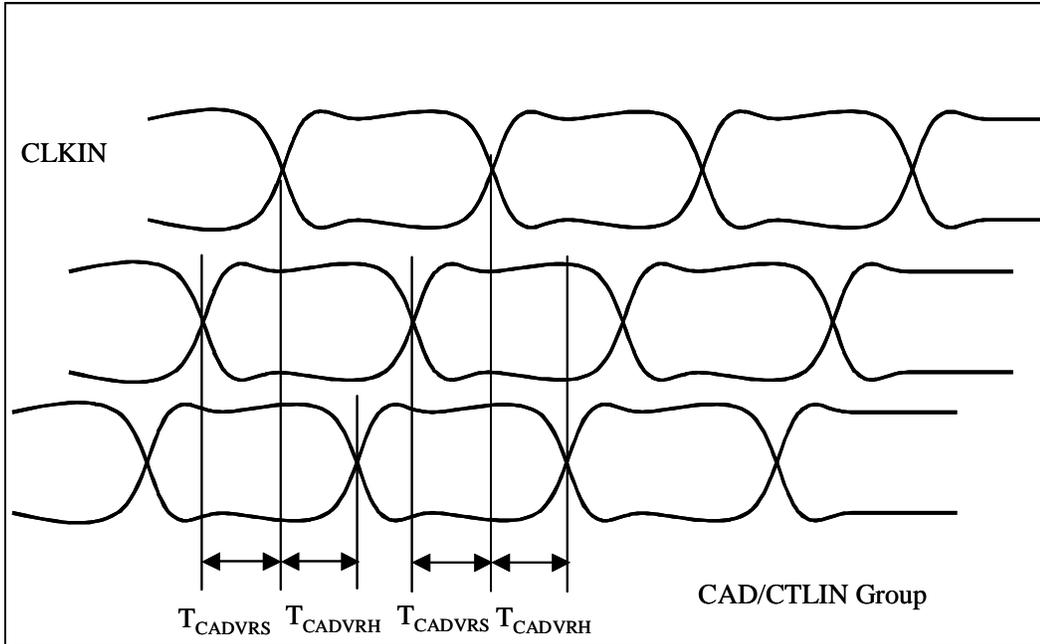


Figure 47. T_{CADVRS}/T_{CADVRH}

23.5 Transfer Timing Characteristics

Table 169 defines the allowed values for the transfer timing characteristics.

Table 169. HyperTransport™ Link Transfer Timing Specifications

Parameter	Description	Link Speed	Min	Max	Units
T_{ODIFF}^1	Output differential skew	400 MT/s		70	ps
		600 MT/s		70	ps
		800 MT/s		70	ps
		1000 MT/s		60	ps
		1200 MT/s		60	ps
		1600 MT/s		60	ps
		2000 MT/s		60	ps
		2400 MT/s		40	ps
T_{IDIFF}^2	Input differential skew	400 MT/s		90	ps
		600 MT/s		90	ps
		800 MT/s		90	ps
		1000 MT/s		65	ps
		1200 MT/s		65	ps
		1600 MT/s		65	ps
		2000 MT/s		65	ps
		2400 MT/s		45	ps
		2800 MT/s		45	ps

Parameter	Description	Link Speed	Min	Max	Units
T _{CADV} ¹	Transmitter output CAD/CTLOUT valid relative to CLKOUT	400 MT/s	695	1805	ps
		600 MT/s	467	1200	ps
		800 MT/s	345	905	ps
		1000 MT/s	280	720	ps
		1200 MT/s	234	600	ps
		1600 MT/s	166	459	ps
		2000 MT/s	183 ⁴		ps
		2400 MT/s	123		ps
T _{CADVRS} ²	Receiver input CADIN valid time to CLKIN	400 MT/s	460		ps
		600 MT/s	312		ps
		800 MT/s	225		ps
		1000 MT/s	194		ps
		1200 MT/s	166		ps
		1600 MT/s	120		ps
		2000 MT/s	92		ps
		2400 MT/s	86		ps
T _{CADVRS} ²	Receiver input CADIN valid time from CLKIN	400 MT/s	460		ps
		600 MT/s	312		ps
		800 MT/s	225		ps
		1000 MT/s	194		ps
		1200 MT/s	166		ps
		1600 MT/s	120		ps
		2000 MT/s	105		ps
		2400 MT/s	86		ps
2800 MT/s	78		ps		

Parameter	Description	Link Speed	Min	Max	Units
T _{SU} ³	Receiver input setup time	400 MT/s	0	250	ps
		600 MT/s	0	215	ps
		800 MT/s	0	175	ps
		1000 MT/s	0	153	ps
		1200 MT/s	0	138	ps
		1600 MT/s	0	110	ps
		2000 MT/s	0	85	ps
		2400 MT/s	0	79	ps
T _{HD} ³	Receiver input hold time	400 MT/s	0	250	ps
		600 MT/s	0	215	ps
		800 MT/s	0	175	ps
		1000 MT/s	0	153	ps
		1200 MT/s	0	138	ps
		1600 MT/s	0	110	ps
		2000 MT/s	0	98	ps
		2400 MT/s	0	79	ps
2800 MT/s	0	71	ps		

Notes:

1. Measured at the transmitter pins into the ideal test load shown in Figure 37.
2. Measured at the receiver pins.
3. Measured or simulated at receiver die pad.
4. T_{CADV} of 183ps for 2GT/s implies a maximum TX CAD to CLK skew of 67ps at the device pins. This tighter TX skew spec is required to accommodate the greater T_{PCB_JITTER_SU} that occurs at 2GT/s as a result of the allowed input capacitance and lack of de-emphasis to compensate for channel loss.

24 Phase Recovery Timing Characteristics

In addition to recovering the data from the interconnect, the receiver is responsible for passing this data from the link transmit clock domain to the device specific receive clock domain.

In general, clock forwarding data recovery methods require a FIFO in the receiver that is written in the transmit clock domain and read in the receive clock domain. The design and operation of this FIFO must account for the dynamic variations in phase between the transmit clock domain (TCLK) and the receive clock domain (RCLK). The FIFO depth must be large enough to store all transmitted data until it has been safely read into the receive clock domain. The separation from the write pointer to which the FIFO data is written and the read pointer from which the FIFO location is read (write-to-read separation) must be large enough to ensure the FIFO location can be read into the receive clock domain. Additionally, the separation from the read pointer from which the FIFO location is read to the write pointer location at which the FIFO location is overwritten (read-to-overwrite separation) must be large enough to avoid the FIFO location being overwritten prior to being read into the receive clock domain. The pointer initialization occurs at link initialization and consists of initializing the write pointer and setting the read pointer to a location that simultaneously satisfies both conditions stated above. Whether the read pointer location remains static or is periodically updated depends upon the clocking mode of the link.

24.1 Receiver Modes of Operation

Section 11.1 defines three different clocking modes of the receiver: synchronous, pseudo-synchronous, and asynchronous. Only the synchronous clocking mode is fully specified in this revision of this specification.

24.1.1 Synchronous Operation

In synchronous mode, each transmit clock must be derived from the same time base as the receive clock in the device to which it is connected. This eliminates any frequency difference between the transmit and receiver clock domains. A receive FIFO implemented to support synchronous clocking mode needs only to initialize the read pointer at link initialization. No additional updates to the read pointer are necessary.

24.1.2 Pseudo Synchronous Operation

In pseudo-synchronous mode, each transmit clock must be derived from the same time base as the receive clock in the device to which it is connected. The HyperTransport™ link output clock frequency for either device may be arbitrarily lower than the frequency programmed into its LinkFreq register, and must not exceed the maximum allowed receive clock frequency in the other device. The maximum allowed receive clock frequency of a link is the highest frequency indicated in the frequency capability register. A receive FIFO implemented to support pseudo-synchronous mode must both initialize the read pointer at link initialization and must periodically be kept from incrementing in order to maintain the

required read-to-write pointer separation. This clocking mode will be fully specified in a future revision of this specification.

24.1.3 Asynchronous Operation

In asynchronous mode, each transmit clock need not be derived from the same time base as the receive clock in the device to which it is connected. In order to cope with the frequency error due to running nominally matched transmitter/receiver pairs from different time bases, the maximum CLKOUT frequency for one device can exceed the maximum receive clock frequency in the other device by no more than 2000 parts per million. An example of how this might be implemented is included in Section 11.3. This clocking mode will be fully specified in a future revision of this specification.

24.2 Phase Recovery Timing Variations

The required FIFO depth and write-to-read pointer separation are dependent upon the following long term timing uncertainties.

Temperature variations of active circuitry along the clock generation and distribution paths:

Local and temporal temperature variations affect the phase error, duty cycle, and phase compression of both the transmitter and receiver PLLs. Temperature variations affect the delay with which the various clocks are distributed.

Voltage variations of active circuitry along the clock generation and distribution paths:

Local and temporal supply voltage variations (within the specified limits) affect the phase error, duty cycle, and phase compression (jitter) of both the transmitter and receiver PLLs. Voltage variations also affect the distribution path delays.

Accumulated phase error in any of the clock generating phase lock loops:

The receiver and transmitter PLLs accumulate phase error relative to the reference clock due to inherent error in generating and comparing the voltages nodes to generate the desired output frequency.

Uncorrelated noise between TCLK and RCLK:

The transmit clock and the receive clock contain uncorrelated noise induced by various means (crosstalk, simultaneous switching outputs, etc) that affect their relative phase error.

Reference clock spread spectrum clocking phase error induced by distribution path variations:

Spread spectrum clocking techniques used to lessen a system's peak electromagnetic emissions induce phase error between the transmit and receive clocks by the modulation frequency and the difference in delay through the distribution paths of each clock domain.

24.2.1 Uncertainty When Initializing the Pointers

TCLK to RCLK phase error during initialization:

Section 12.2 states that the read pointer is initialized after the CTL/CADOUT signals are sampled low in the core clock domain. It cannot be assumed, however, that the initial transition of the CTL/CADOUT signal was driven into the FIFO with a CLKOUT edge that had minimum or maximum skew relative to any RCLK edge. Therefore, the receive FIFO must be sized and the read pointer initialized to cover both of the following cases:

- The initial CLKOUT is driven at the earliest possible time with respect to RCLK, and subsequent edges are driven at the latest possible time with respect to RCLK (and therefore write data into the FIFO later) and still require the minimum write-to-read pointer separation.
- The initial CLKOUT is driven at the latest possible time with respect to RCLK, and subsequent edges are driven at the earliest possible time with respect to RCLK (and therefore write data into the FIFO earlier) and still require the minimum read-to-overwrite pointer separation.

Accounting for both of these cases in the FIFO design requires that the FIFO depth account for two times the dynamic timing variations due to temperature, voltage, and noise changes since the read pointer initialization methods could be in error by, at most, the sum of these variations.

Inherent sampling error in detecting the initial CTLIN transition in the receive clock domain:

Sampling the CADIN/CTLIN deassertion in the receive clock domain might have a synchronization error of up to 1 receive clock bit-time for most implementations. This sampling error results in the pointers being initialized up to one receive clock early or late from the ideal timing standard.

24.2.2 Other Factors Affecting FIFO Size and Read Pointer Separation

Frequency and/or width translation using the receive FIFO:

The FIFO in some implementations is used to translate TCLK to RCLK frequency and link to core width. Other implementations may translate from link speed and width to some slower and wider intermediary operation prior to the FIFO. For implementations that use the FIFO to perform this translation, the FIFO must be made large enough to absorb and store a full receive line until that full line can be read into the receive clock domain. For example, a transmit data rate of 1600 MT/s at one byte wide writing a FIFO that is read with a core clock of 200 MT/s at 8 bytes wide would need to allow 7 additional FIFO locations (at transmit rate) to store the additional 7 bytes until read into the receive clock domain without being overwritten. Additionally, the FIFO needs to contain 7 locations (at transmit rate) as to ensure that all 8 bytes of data had been successfully written prior to reading.

Cross byte skew between CLKIN signals for multibyte link implementations:

The receive FIFO size must also account for variations in CLKIN signals for multibyte link implementations. The uncertainty between any two CLKIN signals must be added to the overall TCLK uncertainty in order to ensure that data written into FIFO with the CLKIN having the largest accumulated phase error to the receive clock can be read properly. This skew contains both a constant (path length mismatch) and a time variant portion (voltage, temperature, and noise dependent).

CADIN/CTLIN synchronization time:

Since sampling the initial CTL/CADOUT signal in the RCLK domain has some synchronization delay, this device specific synchronization delay should be removed from the initial read pointer.

24.3 Phase Recovery Timing Characteristics

In Table 170:

Trefclk defines maximum reference clock phase error allowed between the transmitter and receiver.

TxmtPLL defines the maximum phase error of the transmit clock due to PLL temperature variations, voltage variations, and accumulated phase error.

Txmttransfer defines the maximum phase error of the transmit clock due to noise.

Tbytlanevar defines the maximum time variant phase error between CLKIN signals to the receiver and therefore the maximum additional phase error between TCLK and RCLK.

Tbytlaneconst defines the maximum constant phase error between CLKIN signals to the receiver due to distribution path length mismatch.

TrcvPLL defines the maximum phase error of the receive clock due to PLL temperature variations, voltage variations, and accumulated phase error.

Trcvtransfer defines the maximum phase error in the transmitter clock due to uncertainty on the receiver package, receiver pad, and receiver clock distribution.

Table 170. HyperTransport™ Link Phase Recovery Timing Characteristics

Parameter	Description	Link Speed	Min	Max	Units
Trefclk	Uncertainty in CLKIN relative to RCLK due to reference clock variations between transmitter and receiver	Any		733	ps
TxmtPLL	Uncertainty in CLKIN relative to RCLK due to accumulated phase error due to PLL run-out and low frequency supply variations	Any		3500	ps
Txmttransfer	Uncertainty in CLKIN relative to RCLK due to transmitter and interconnect transfer effects	400 MT/s 600 MT/s 800 MT/s 1000 MT/s 1200 MT/s 1600 MT/s 2000 MT/s 2400 MT/s 2800 MT/s		918 592 469 358 295 228 105 51 51	ps ps ps ps ps ps ps ps ps
Tbytlanevar	Variable uncertainty in CLKIN relative to RCLK due to multiple versions of CLKIN	Any		250	ps
Tbytlaneconst	Constant uncertainty in CLKIN relative to RCLK due to CLKIN distribution path length mismatch	Any		1000	ps
TrcvPLL	Uncertainty in RCLK relative to CLKIN due to accumulated phase error due to PLL run-out and low frequency supply variations	Any		3500	ps
Trcvtransfer	Uncertainty in CLKIN relative to RCLK due to receiver package and receiver transfer effects	400 MT/s 600 MT/s 800 MT/s 1000 MT/s 1200 MT/s 1600 MT/s 2000 MT/s 2400 MT/s 2800 MT/s		425 250 188 130 109 81 65 54 46	ps ps ps ps ps ps ps ps ps

Note: This table represents the absolute worst case timings that a receiver can assume about another HyperTransport transmitter and the interconnecting channel. To minimize latency the initial distance between write and read pointers in the receive FIFO may be reduced based on actual measurements and characterization of a link in a system.

24.4 Reconciling Phase Recovery Timing to Receiver FIFO Depth and Read Pointer Initialization

24.4.1 Read Pointer Initialization

The initial read-to-write pointer separation must account for all of the factors outlined above. While many of these factors are implementation specific, a nominal implementation (TCLK and RCLK of equal frequency) would initialize the read pointer according to the following relationship:

Maximum time variant phase error = $T_{refclk} + T_{xmtPLL} + T_{xmttransfer} + T_{bytelinevar} + T_{rcvPLL} + T_{rcvtransfer}$

Maximum constant phase error = $T_{bytelineconst}$

Maximum CADIN/CTLIN sampling error = 1 RCLK bit-time

Minimum read-to-write pointer separation > Maximum time variant phase error + Maximum CADIN/CTLIN sampling error) + $\frac{1}{2}$ Maximum additional constant phase error

Under controlled conditions, the Minimum read-to-write pointer separation may be further reduced to lower latency.

24.4.2 Minimum FIFO Depth

The minimum FIFO depth chosen for any implementation must be sized to accommodate both the read-to-write pointer separation and the read-to-overwrite pointer separation:

FIFO phase error > $2 * (\text{Minimum read-to-write pointer}) + T_{bit}$

Minimum FIFO lines (TCLK) = FIFO phase error / T_{bit} (rounded up to whole integer)

25 Gen3 HyperTransport Link Components

To make any specification useful at high data rates and the associated microwave frequencies it is necessary to define parameters that can be practically and accurately measured on real hardware with available test equipment. This makes the specification and measurement methodologies closely intertwined and, in this document, are by implication synonymous. The specification is defined to allow any parameter to either be tested by simulation or be physically measured with a suitable lab based characterization setup. It is worth noting that there are a number of electrical parameters that define device operation that cannot be measured economically with high volume production testers. It is the responsibility of a manufacturer of a HyperTransport™ device to establish high correlation between characterization measurements and production test such that non-compliant devices are correctly identified in production test.

There are three component parts to a HyperTransport link defined in this electrical specification, the transmitter, the interconnect (or channel) and the receiver. To ensure inter-operability between devices from different manufactures the specification uses two measurement planes to define limits for interoperability. These are illustrated below in Figure 48 along with how each part is measured in isolation.

The same compliance test configuration is used for both Gen3_{DC} and Gen3_{AC} devices with different appropriately adjusted signaling levels. Gen3_{AC} devices are required to be compliant with all Gen3 common and Gen3_{DC} specifications. The coupling capacitors used by Gen3_{AC} do not need to be included in the compliance testing of the devices as these are part of the channel compliance testing.

25.1 Reference planes

The reference planes are chosen to be at the device pins as this is the closest easily observable measurement point of the component parts of the system. The path from the device pin to the silicon die pad can introduce additional distortion into a waveform and it is the device designers responsibility to convert pin level definitions from a 50 Ohm reference plane into the appropriate voltage waveforms that need to be generated or are received at the die pad. As Gen3 electricals use differential signaling and a clock forwarded interface there are a minimum of four 50 Ohm single ended connections required at each reference plane to make a timing measurement.

25.2 Compliance test fixtures

To ensure consistent measurement results for compliance testing at Gen3 frequencies, carefully designed test fixtures are required that use high quality microwave techniques to connect 50 Ohm test equipment to the device under test. This implies multiple coaxial connections each making single port measurements that are combined mathematically to yield differential and common-mode voltage measurements at the defined reference planes.

Although it is feasible to probe the pins of a device with high bandwidth differential probes during normal operation the measurements taken are not guaranteed for compliant components to be equivalent

to the limits defined in this specification. There are three main reasons for this. 1) It is very difficult at microwave frequencies to probe a signal without disturbing its characteristics. 2) The specification uses the concept of a 50 Ohm reference plane for measurement and signal generation to control reflections in the measurement, which means signaling levels are different when devices that are at the extremes of allowable impedance are connected together. 3) The devices' return loss allow significant reflections to occur during normal operation which further distorts the measurement.

The reference planes provide a convenient method of carrying out calibrated measurements, however the signaling levels observed and delivered by test equipment at these reference planes are different than the signals seen at the pads of a silicon device. It is the designer's responsibility to take into account the device package characteristics in deriving the compliant signal levels at the silicon devices transmit and receive pads.

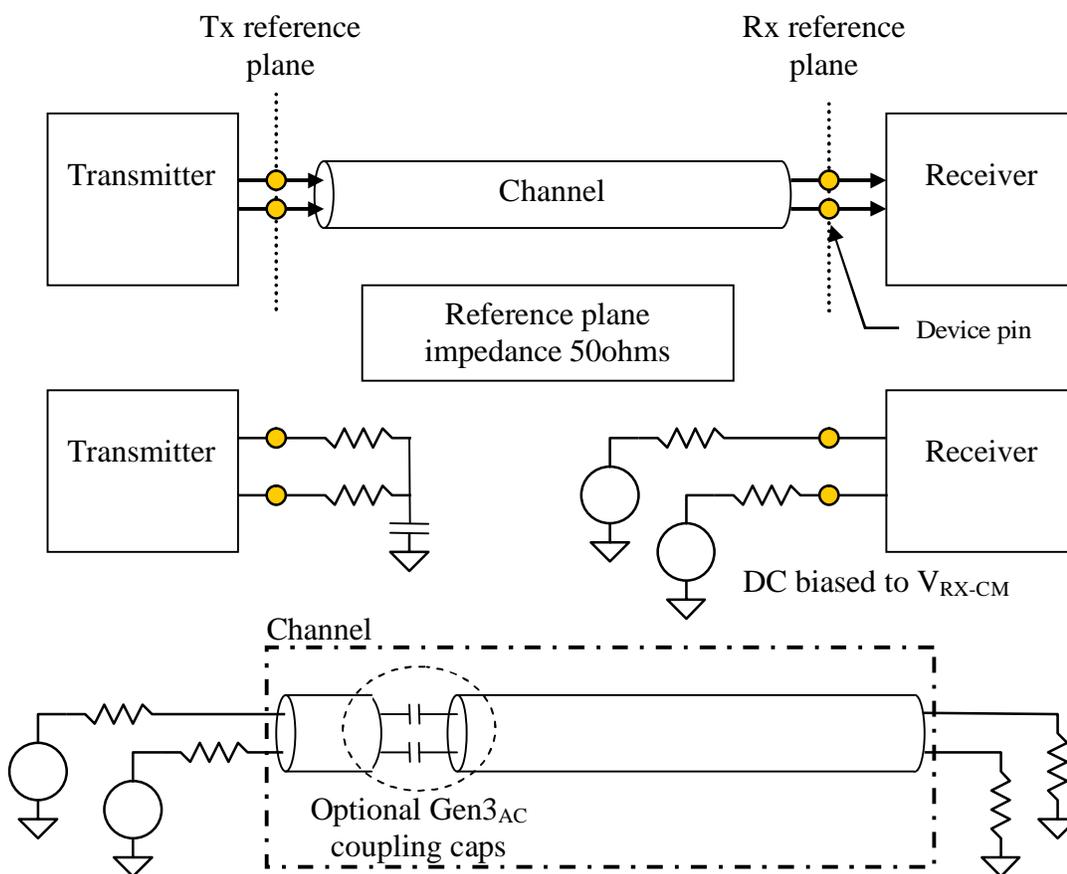


Figure 48. Measurement methodology of HyperTransport™ link components

25.3 Transmitter relative time measurement

The HyperTransport link uses a source synchronous bus, which means that timing information of CADOUT from the transmitter is always defined relative to CLKOUT signal. Measurements of the transmitter at its reference plane therefore always require a minimum of four single ended channels to construct the required differential and common-mode waveforms for CADOUT relative to the CLKOUT signal.

25.4 Receiver measurement

Measurements of the receiver can only be carried out by observing its ability to correctly capture data. To do this test equipment must be used to construct a differential clock and data signal that contains a specified voltage waveform with specified jitter characteristics relative to the clock. To observe if the device has correctly captured the data, an internal loopback path is defined that echoes back the data on a corresponding transmitter output pin. This output data has a deterministic delay to the input data and can be compared externally to check for errors. This receiver internal loopback mode allows basic input receiver testing as well as comprehensive jitter tolerance and BER testing.

25.5 Channel definition

At Gen3 frequencies it is necessary to define the characteristics of the interconnect channel to ensure that a compliant transmitter and receiver connected by a channel interoperate. The most accurate way of measuring a channel is in the frequency domain which can be done with a Vector Network Analyzer (VNA) and an appropriate microwave calibration technique. However the complexity of the frequency domain response that is sufficient to be compliant with this specification makes it impractical to use it as a basis of this specification. Therefore the time domain impulse response of the channel convolved with a transmit waveform is used instead that can be mathematically derived or simulated from a frequency domain response. A behavioral transmitter generating random data is used that represents a worst case compliant transmitter, including de-emphasis and transmit pulse width jitter. When this is convolved with the channel impulse response the so called jitter magnification of the channel is correctly captured. The results of this convolution are then used to build a cumulative receiver data eye. The voltage and time characteristics of the resulting data eye are defined in this specification.

25.6 System clocking

The system reference clock for Gen3 devices has relaxed phase jitter requirements because the transmitted forward clock provides an accurate estimate of the transmitted frequency and phase of each CAD and CTL bit within each clock group of a link. The maximum transport delay skew between CLK and CAD/CTL at the receiver limits the amount of reference clock jitter that is seen by the receiver.

The system reference clock phase jitter contribution to T_{TX-EYE} can be calculated by multiplying the phase noise of the reference clock by the transfer function of the transmit PLL and the phase delay difference function. The following expression can be used to calculate the system reference clock phase jitter rejection:

$$Jitter\ rejection = \left(1 - e^{-sT_D}\right) \left(\frac{s2\zeta\omega_n + \omega_n^2}{s^2 + s2\zeta\omega_n + \omega_n^2} \right)$$

Where T_D represents the max transport delay difference between CLK and CAD/CTL between transmitter and receiver and ω_n and ζ represent the natural frequency and damping factor of a 2nd order PLL, which is assumed to be a good approximation of the phase jitter transfer function of the transmit PLL.

Figure 49 illustrates this rejection for different PLL closed loop bandwidths, with a jitter peaking of 3dB and a transport delay of 1ns. T_{TX-EYE} is measured with a reference clock that has phase jitter that is representative of the systems reference clock so the rejection of the reference clock jitter is included in this measurement. As can be see the reference clock jitter rejection is a strong function of the transmit PLL bandwidth, but as this effect is included in the T_{TX-EYE} measurement there is no requirement for Gen3 electricals to specify transmit PLL jitter transfer characteristics.

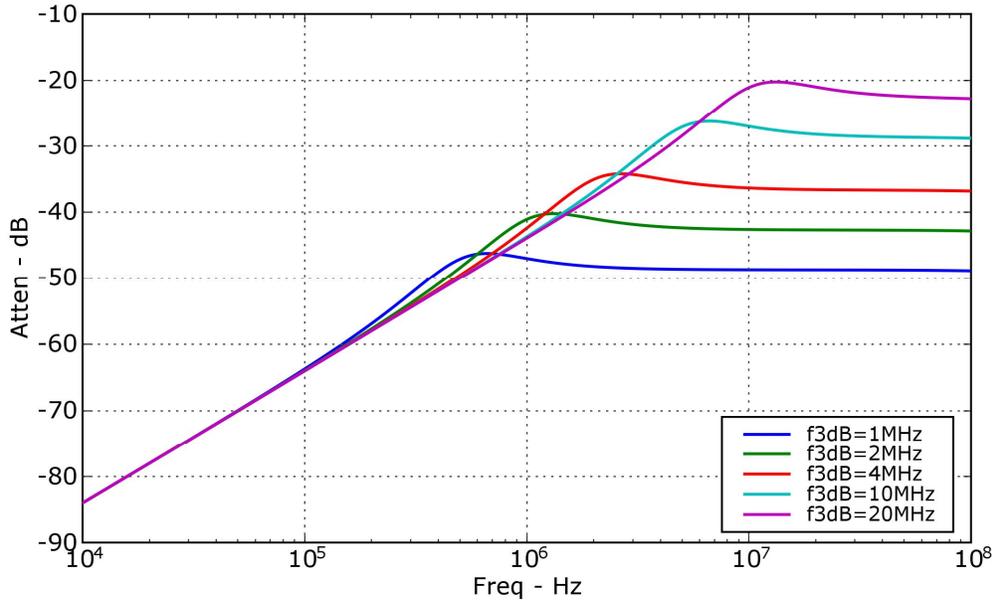


Figure 49. System reference clock jitter rejection

The reference clock frequency for a Gen3 device must be within ± 300 ppm of its nominal frequency so that the transmitted data rate is within ± 300 ppm of its required data rate. Gen3 devices at each end of a link may have their reference clocks derived from the same or separate frequency sources.

The reference clock sources may be spread spectrum modulated with up to a 0.5% frequency downspread at a frequency modulation rate of 30kHz-33kHz. If the clocks are independent the spread spectrum modulation does not need to be synchronized.

26 Gen3 Transmitter Specification

The HyperTransport link is specified assuming a voltage mode driver that has a nominal source impedance of 50 Ohms and a loaded single ended swing of 50% of the VLDT supply. As the voltage swing is determined by the transmitter supply voltage this is also specified for the transmitter. Alternative output structures can be feasibly designed that meet the pin specifications but these are not contemplated in this specification.

26.1 Transmitter return loss

To bound the amount of energy reflected off of the transmitter in a highly reflective and high crosstalk environment the transmitters differential and common-mode return loss is specified by means of a frequency dependent mask from 50MHz to the fundamental of the maximum bit rate of 2.6GHz. See Figure 50.

The low frequency end of this mask is within the frequency range of most 2-port VNA's and is sufficiently close to DC to provide an accurate bound on the voltage swing of the transmitter into the reference plane load of 50 Ohms.

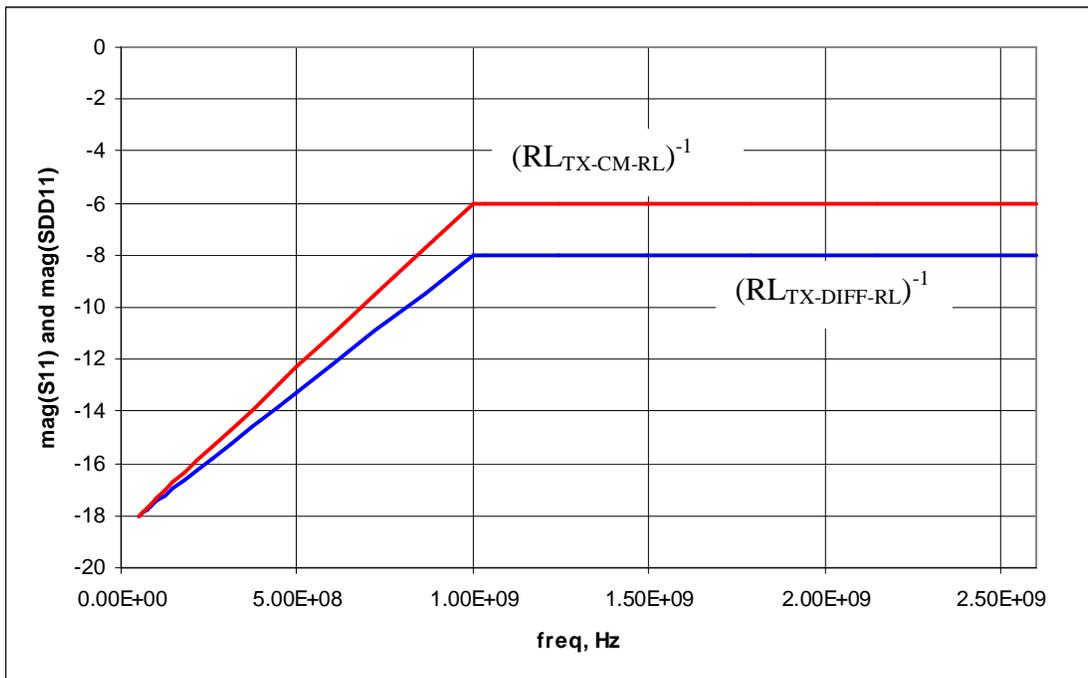


Figure 50. Transmit return loss mask

The measurement of return loss needs to be carried out with the device powered up driving a continuous logic 1 and 0 into the reference plane that is biased from VLDT*0.25 to VLDT*0.75. Two single port S11 measurements need to be made for each half of the differential output, these results then need to be

combined into the mixed mode differential S-parameter matrix and SDD11 extracted. Note return loss is the reciprocal of S11 and SDD11.

26.2 Transmit de-emphasis

To compensate for the high frequency loss characteristics of the channel the transmitter uses a programmable amount of de-emphasis (i.e. the differential output level that is transmitted after remaining at the same logic level for more than 1 bit-time). Figure 51 shows a typical transmitter waveform with -6dB of de-emphasis, where the de-emphasis level in dB is calculated from:

$$DE = 20 \cdot \log_{10} \left(\frac{V_{TX-DIFF-DE}}{V_{TX-DIFF}} \right)$$

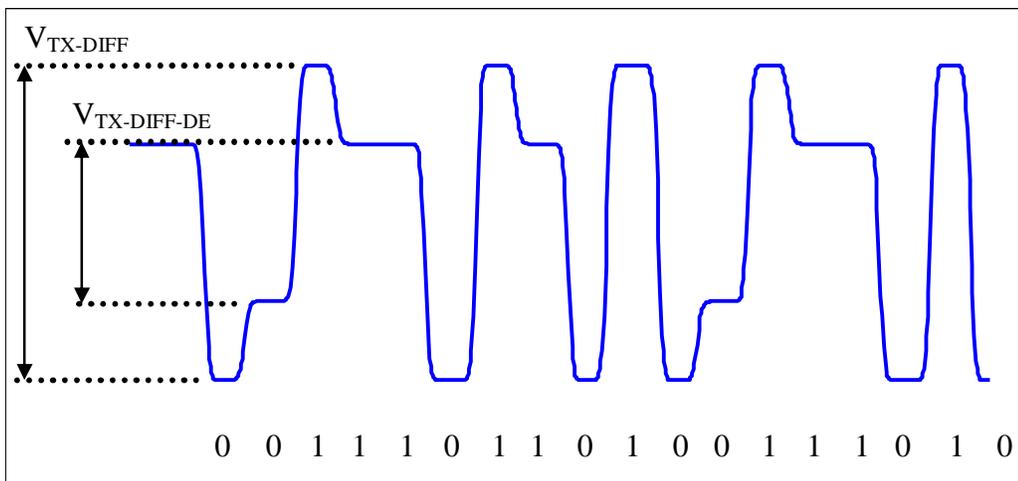


Figure 51. Differential transmitter post-cursor de-emphasized waveform

In this specification this equalization is described as post-cursor de-emphasis as the amplitude is changed after the transition to a new logic value. Gen3_{AC} extends this further by providing an additional de-emphasis level that can be defined to be transmitted in the bit-time before the transition, this is referred to as a pre-cursor de-emphasis and is only useful for long channels (>20”) with low forward crosstalk and so are not required for Gen3_{DC}.

26.2.1 Gen3 DC transmit de-emphasis

The specification defines three post-cursor de-emphasis settings for Gen3_{DC}, -3db, -6dB and -8dB which have been found sufficient to provide a compliant data eye for the target Gen3_{DC} channel topologies up to 5.2GT/s. The different de-emphasis settings are selected at system initialization by programming configuration registers at each end of the link whilst the link is running at the minimum Gen1 frequency of 400MT/s; at this data rate no de-emphasis is required. Normally BIOS sets these CSR’s which determine data rate and de-emphasis based on its knowledge of the devices at each end of a link and its a priori knowledge of the loss characteristics of the channel between them.

26.2.2 Gen3 AC transmit de-emphasis

To support longer high loss channels for Gen3_{AC} an additional post-cursor setting of -11dB is defined as well as a pre-cursor setting of -8dB. Figure 52 shows the resulting differential transmit waveform with -11dB and -8dB settings. As can be seen there is an additional differential voltage level generated with pre- and post-cursor equalization which is slightly lower than $V_{TX-DIFF}$.

The pre-cursor setting is normally only enabled with a -11dB post-cursor setting, giving a 3dB boost to the signal in the opposite direction to the upcoming transition to help correct for dispersion in high loss channels. As the -11dB setting reduces the differential amplitude to ~254mV it is only be suitable for high loss channels with minimal forward crosstalk.

The waveform shown in Figure 52 shows the response of a 3-tap FIR filter and the implementation of the transmitter should implement the following equation:

$$V_{TX} = V_{PK} [d_{[n+1]}c_{[0]} + d_{[n]}c_{[1]} + d_{[n-1]}c_{[2]}]$$

Where $d_{[n]}$ represents the current value of the data being transmitted, with +1 for logic 1 and -1 for logic 0, the magnitude of the coefficients $c_{[j]}$ sum to 1.0 and V_{PK} is the peak output voltage of the transmitter. The coefficients $c_{[0]}$ and $c_{[2]}$ are referred to the pre and post-cursors coefficients respectively.

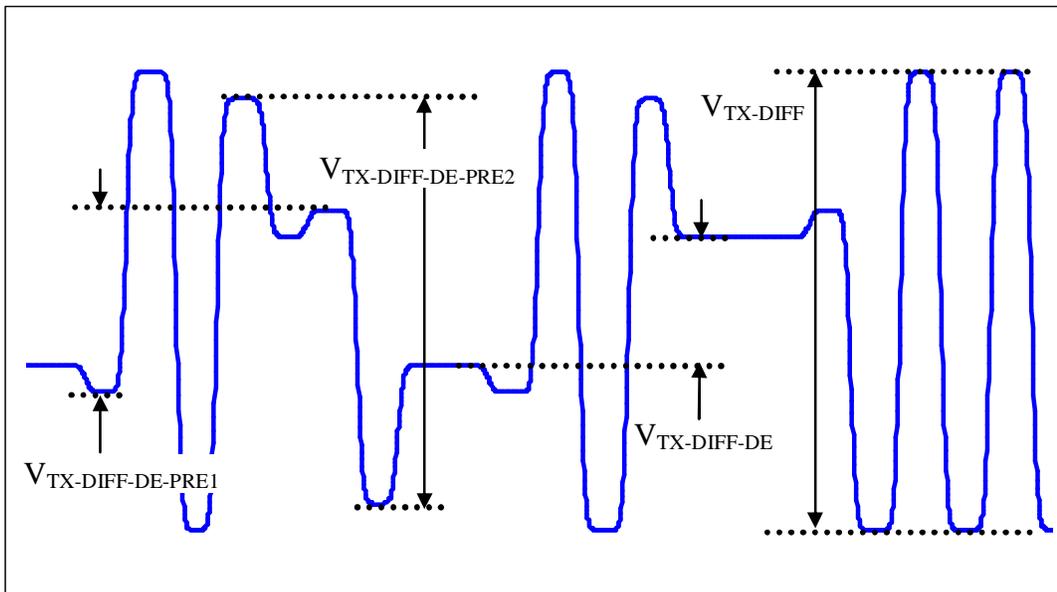


Figure 52. Transmit with pre- and post-cursor de-emphasis

As in Gen3_{DC} the data rate and equalization settings for each link in the system are normally set by the BIOS during link initialization, for Gen3_{AC} the data rate used for this initialization is 2.4GT/s with a fixed post-cursor de-emphasis of -3dB and receiver DFE disabled.

26.3 Transmitter transition time and pulse width

The rise and fall times are defined as the time to transition from 20% to 80% of that edges swing. The minimum pulse width is defined as the time between the 50% points on the transitions either side of the pulse. As the voltage swing of the output driver varies depending on the data pattern being transmitted the voltage threshold for the measurement must also be adjusted to correctly measure the timing parameter. These measurements are illustrated in Figure 53.

Transmitters have significant jitter at these data rates and so these measurements must be taken over many samples running a complex data pattern on the lane being measured as well as all the aggressor lanes and the minimum and maximum calculated for each parameter.

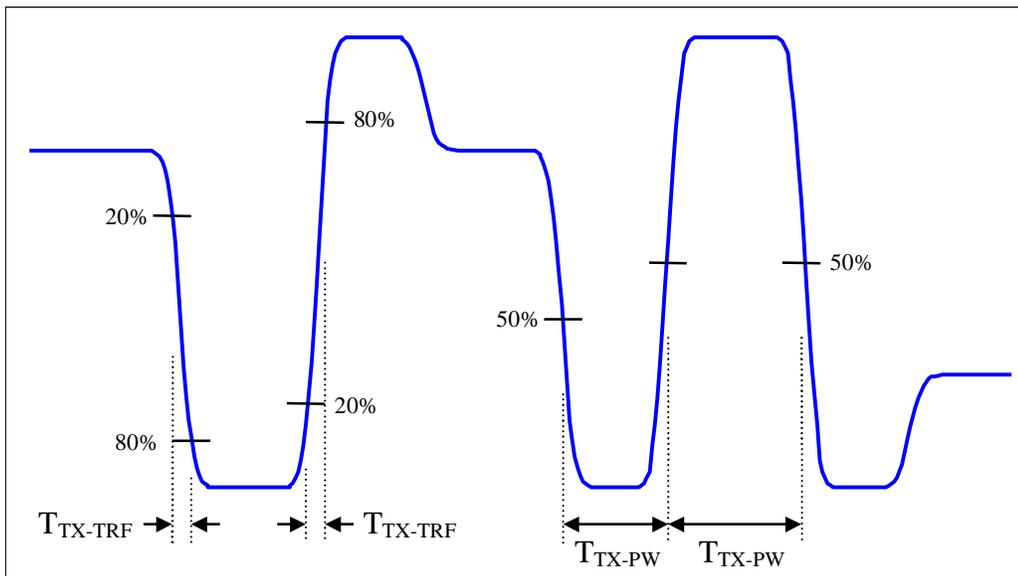


Figure 53. Rise time, fall time and pulse width measurements

26.4 Transmit data eye

To quantify the jitter generated by the transmitter as perceived by the receiver it is necessary to generate a cumulative data eye of the transmit waveform that is constructed from voltage time samples of that waveform. As HyperTransport uses a forward clock the relative timing differences between CLKOUT and CAD/CTLOUT are the most significant jitter terms that affect the receiver timing. The receiver has a data phase tracking loop to adjust its sample clock so only the frequency components of the jitter that are above the tracking bandwidth of this loop need be considered.

26.4.1 Receiver phase tracking bandwidth

The minimum tracking bandwidth required by the phase tracking circuit of the receiver is specified by $BW_{RX-TRACK}$ (see

[Table 173](#)

Table 173) to ensure inter-operability. The tracking bandwidth is selected to provide maximum flexibility in the implementation whilst ensuring low frequency tracking of SSC, CLK to CAD drift and reasonable bit-lock times. This tracking bandwidth may be used in the construction of the transmit data eye to filter out jitter components that the receiver can track.

26.4.2 CLK to CAD skew for TX eye measurement

As the receiver uses the instantaneous phase of the CLKIN when it arrives at the receiver input pins to clock its data phase alignment circuitry, it is also necessary to consider the skew introduced by the channel between CLKIN and CAD/CTL. The maximum channel induced skew is $T_{\text{CH-CAD-CLK}}$ (see

Table 172

Table 172), which means that the receiver could be using the phase of the CLKIN that was transmitted either before or after the data bit that is being captured. To measure the relevant jitter of the transmitter data eye it is necessary to construct the data eye from a clock edge that is time shifted relative to the CAD data bit that is accumulated. Within the receiver, the CLKIN signal is assumed to trigger a circuit that generates a digitally controlled delay indexed across the eye to the optimal sampling point. The receiver has to therefore insert additional delay from the CLKIN signal to its internal sample clock; this additional delay is not visible externally but is assumed to be less than 3 UI. The additional delay inserted by the receiver means that the nearest early CLKIN edge is always the largest time offset from the clock edge that triggers the phase alignment circuit and the sample clock in the center of the data eye. From this we can define the rule for constructing the transmit data eye as using the closest earlier clock edge that is greater than $T_{\text{CH-CAD-CLK}} + 3.5\text{UI}$ earlier than the start of the accumulated bit.

The transmitter can introduce duty cycle distortion (DCD) on the CLK signal which can significantly reduce the width of a received data eye at the receiver if both edges of CLK are used without any correction. It is assumed that a receiver uses some method to correct for this CLK DCD and so the transmitter is measured using an algorithmically corrected duty cycle. The CLK used for the receiver compliance test must be generated with worst case transmit clock DCD so validating the receivers tolerance to CLK DCD.

26.4.3 Transmit de-emphasize compensation

As the transmitter is de-emphasized it is also necessary to compensate for the variation in the voltage level for the 50% crossing point of a transition as well as the mismatch between the selected de-emphasis and the actual de-emphasis the transmitter generates.

26.4.4 Construction of the cumulative transmit data eye

These various measurements can be implemented by post processing of a voltage time record from a real time scope. The voltage records for the transitions that form a data eye can be accumulated to establish the transmitter compliance cumulative data eye as well as other transmitter compliance measurements.

To correctly consider the statistical nature of the jitter the eye needs to be constructed with sufficient samples to reliably extrapolate the eye width and height at the required Bit Error Rate or Ratio (BER) for the link. Gen3 electricals define this as 10^{-12} .

It should be noted that current state of the art real time digitizing scopes have a significant analog sampling noise floor and are limited in their sampling rate and time base accuracy; therefore some method for averaging these voltage time records is needed to lower the affect of the scopes noise floor on the measurement. It may also be necessary to calibrate the phase noise floor of the measurement system so that this can be de-convolved from the measurement.

26.4.5 Example TX eye measurement

Figure 54 shows an ideal CAD data eye constructed from a CLK that occurred prior to the CAD transition, meeting the requirement of $T_{CH-CAD-CLK} + 3.5UI$ at 5.2GT/s. As can be seen the zero crossing time for the de-emphasized swing is different to that of the full swing, causing a reduction in the data eye width on the right hand side of the cumulative eye, an equivalent effect occurs on right side of the eye which causes the left hand edge of the cumulative to be incorrectly measured.

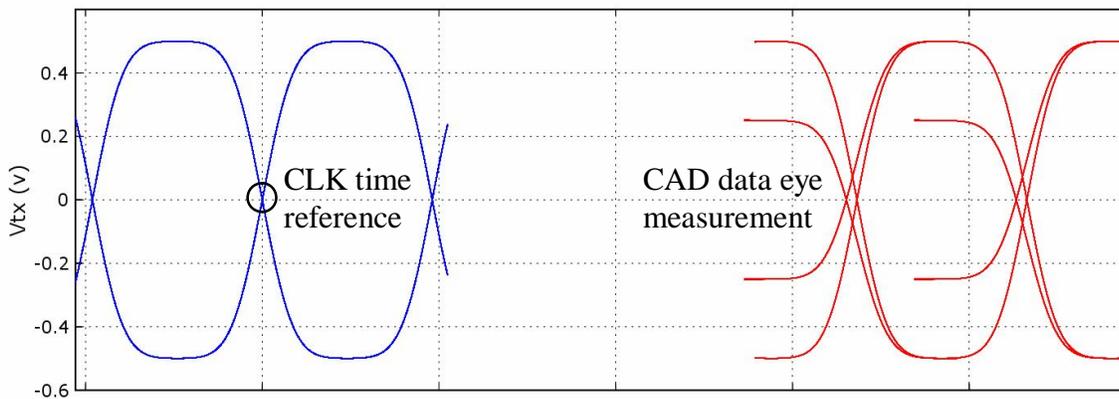


Figure 54. CLK to CAD ideal eye with -6dB of de-emphasis

Figure 55 shows the same waveform with jitter applied between CLK and CAD which shows clearly the amplitudes for the full swing and de-emphasized differential voltage swing. This cumulated eye method allows $V_{TX-DIFF}$ and $V_{TX-DIFF-DE6}$ to be measured.

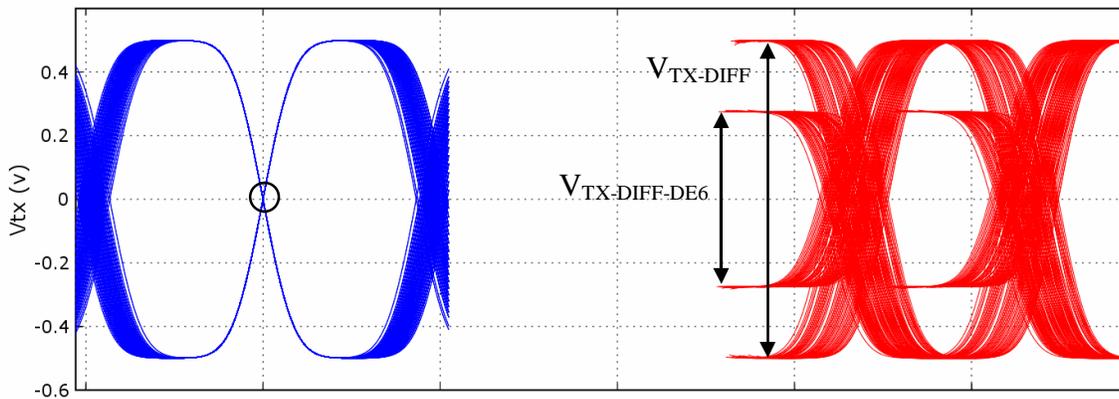


Figure 55. CLK to CAD data eye with some transmit jitter

In Figure 56 the CAD data eye is equalized by applying an algorithm to the post processed voltage and time samples. This scales the full swing amplitude by the de-emphasis setting and scales and shifts the de-emphasized swing as shown by the following pseudo code:

```
IF fullswing :
    scale = deemp;  offset = 0.0
ELSEIF previousBit == 1:
    scale =  $\frac{2 \cdot deemp}{1 + deemp}$ ;  offset =  $\frac{1 - scale}{4}$ 
ELSE :
    scale =  $\frac{2 \cdot deemp}{1 + deemp}$ ;  offset =  $-\frac{1 - scale}{4}$ 
```

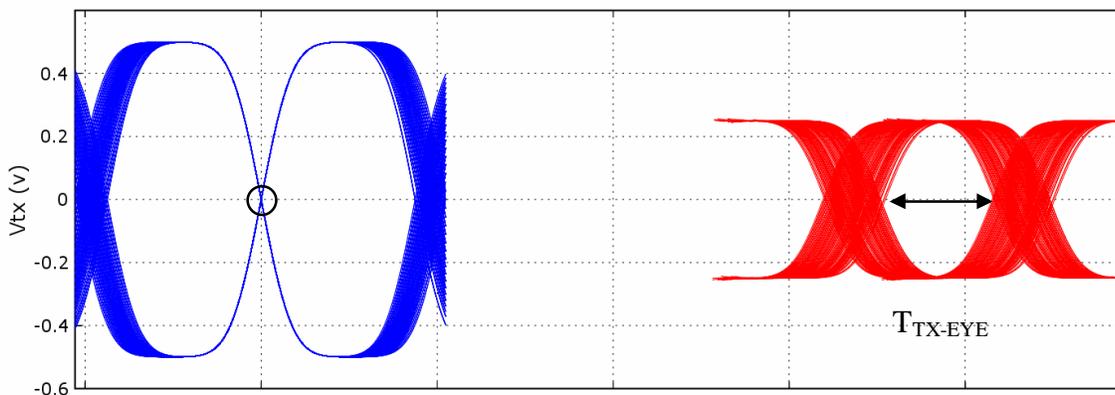


Figure 56. Transmit CLK to CAD data eye equalized

26.5 Transmitter in-band low speed signaling

To support in-band detection of link type, hot-plug and preserving common-mode DC offset across coupling capacitors when the link is idle several low speed transmit states are defined in the protocol section of this specification. This electrical section specifies the electrical levels required for these states.

26.5.1 TXGNDTRM

The transmitter is powered up and disabled in this state, both true and complement outputs are driven to 0v with a low output impedance specified by Z_{TX-GND} . This is the quiescent state used by a link that may be hot-plugged.

26.5.2 TXIDLE

This state allows the DC common-mode and the charge across the AC coupling capacitors to be preserved during power saving states so allowing a rapid transition into the active L0 state. The voltage driven on the outputs in this state is measured relative to the common-mode voltage whilst active and is specified with $V_{IDLE-CM-DELTA}$. To avoid excess differential voltage to build up across the two coupling capacitors the differential voltage must be clamped to zero to meet the $V_{TX-IDLE-DIFF}$. The output impedance of the driver is high in this state to avoid excessive static current and is specified with $Z_{TX-IDLE}$.

26.5.3 TXACDETECT

For Gen3_{AC} and optional in-band detection mode is defined that allows a transmitter to determine if an AC coupled device is connected either at power-up or during a hot-plug event. The method used is to transition one of the transmitter output pins from the TXGNDTRM state to a voltage specified by $V_{TX-AC-DETECT-STEP}$ with an impedance specified by $Z_{TX-AC-DETECT}$ whilst driving the other transmit output pin to ground with $Z_{TX-GND-TRM}$ and to measure the time for the output pin to charge to some percentage of $V_{TX-AC-DETECT-STEP}$. If a device is AC connected and powered-up with its input termination enabled a longer transition time is measured than if the link is disconnected. This effectively measures the differential time constant of the coupling capacitors and operates correctly whether the receiver’s inputs are terminated to ground or terminated differentially.

26.5.4 TXHIZ

For Gen1 applications the transmitter is placed into high impedance during this state.

26.6 Transmitter electrical parameters

[Table 171](#)

~~Table 171~~ defines the electrical parameters that are required to be measured to determine if a Gen3 transmitter is compliant with the specification. All measurements to be made at the device pins into a reference plane load of 50 Ohms biased to the DC common-mode of the transmitter.

Table 171. Transmitter electrical specification

Symbol	Parameter	Min	Max	Units	Comments
UI	Unit Interval (bit-time)	192.25	418.88	ps	2.4GT/s to 5.2GT/s with a +/-300ppm frequency source and 0.5% SSC downspread. Legal data rates are 2.4, 2.8, 3.2, 3.6, 4.0, 4.4, 4.8 and 5.2GT/s

Symbol	Parameter	Min	Max	Units	Comments
V_{LDT}	Transmitter supply voltage	1.14	1.26	V	Only applicable to Gen3 devices that use voltage mode drivers, electrical specification assumes on die variations in this supply do not exceed +/-100mV of the 1.2v nominal.
$V_{TX-DIFF}$	Differential peak-peak output swing	900	1500	mV	Minimum measured for a lone pulse high or low, maximum measured with zero de-emphasis.
$V_{TX-DIFF-DE3}$	Differential post-cursor de-emphasized output swing ratio -3dB	-2.5	-3.5	dB	Measured sending continuous logic 1 or 0 for at least 4UI.
$V_{TX-DIFF-DE6}$	Differential post-cursor de-emphasized output swing ratio -6dB	-5.5	-6.5	dB	
$V_{TX-DIFF-DE8}$	Differential post-cursor de-emphasized output swing ratio -8dB	-7.3	-8.7	dB	
$V_{TX-DIFF-DE11}$	Gen3 _{AC} differential post-cursor de-emphasized output swing ratio -11dB	-10	-12	dB	
$V_{TX-DIFF-DE8-PRE1}$	Gen3 _{AC} differential pre-cursor de-emphasized output swing ratio for 1 st bit	-7.3	-8.7	dB	Measured the bit before a transition after sending a continuous logic 1 or 0 for at least 3UI at $V_{TX-DIFF-DE8}$.
$V_{TX-DIFF-DE8-PRE2}$	Gen3 _{AC} differential precursor de-emphasized output swing ratio for 2 nd bit	-0.85	-1.35	dB	Measured the bit after the transition from sending a continuous 1 or 0 for at least 3UI to sending a continuous 0 or 1 for at least 3UI
$V_{TX-CM-DC}$	DC common mode output voltage	550	700	mV	$(V_{D+}+V_{D-})/2$ filtered with a low pass filter corner frequency 0.1MHz.
$V_{TX-CM-AC}$	AC peak to peak common mode voltage		150	mV	$(V_{D+}+V_{D-})/2$ maximum peak-peak accumulated over compliance test pattern of 10 ⁶ UI. Device must be fully active during compliance test.

Symbol	Parameter	Min	Max	Units	Comments
T _{TX-EYE}	Cumulative transmitter eye width	0.75		UI	Measured or extrapolated to 10 ⁻¹² BER time shifted by T _{CH-CAD-CLK} and equalized transmit eye.
T _{TX-DJ-DD}	Maximum transmit deterministic jitter		0.15	UI	Extrapolated from jitter distribution using dual dirac jitter model. See section 27.4.
T _{TX-DCD}	Maximum CAD and CLK duty cycle distortion	0.05		UI	Maximum pulse width deviation from 1UI measured over 10 ⁶ UI.
T _{TX-CAD-PW}	Minimum CAD output pulse width	0.90		UI	Measured at 50% level of edges voltage transition measured over 10 ⁶ UI.
T _{TX-CLK-CAD}	Maximum skew allowed between CLK and any CAD in clock forward group	-0.5	0.5	UI	Transmitter is allowed to place either edge of CLK anywhere within the UI for Gen3 operation.
T _{TX-CAD-CAD}	Maximum skew between any two CAD's across both byte groups		2.0	UI	Measured for the same logical byte in time for each byte group.
T _{CADV-400}	CAD and CTL valid time before and after CLK for 400MT/s only	850		ps	This is a tighter requirement than Gen1 to support the relaxed CLK to CAD routing rules for Gen3 operation.
T _{TX-TRF}	Differential output rise and fall time	30		ps	Measured at 20% to 80% of edges voltage transition
T _{TX-TRF-MATCH}	Miss match between rise and fall times		20	ps	
RL _{TX-DIFF-HF}	Differential return loss at high frequency	8		dB	Constant between 1GHz and 2.6GHz
RL _{TX-DIFF-LF}	Differential return loss at low frequency	18		dB	Measured at 50MHz with a linear slope to RL _{TX-DIFF-HF} at 1GHz.
RL _{TX-CM-HF}	Common-mode return loss at high frequency	6		dB	Constant between 1GHz and 2.6GHz

Symbol	Parameter	Min	Max	Units	Comments
$RL_{TX-CM-LF}$	Common-mode return loss at low frequency	18		dB	Measured at 50MHz with a linear slope to $RL_{TX-CM-HF}$ at 1GHz.
$V_{TX-AC-DETECT-STEP}$	Gen3 _{AC} detect voltage step		0.5	V	Positive step starting at 0v.
$Z_{TX-AC-DETECT}$	Gen3 _{AC} detect output impedance	1	5	k Ω	
$V_{TX-IDLE-CM-DELTA}$	Gen3 _{AC} electrical idle common-mode voltage delta		100	mV	Absolute difference between common-mode voltage between L0 and electrical idle.
$V_{TX-IDLE-DIFF-PK}$	Gen3 _{AC} peak differential voltage in electrical idle		10	mV	
Z_{TX-400}	Single ended output impedance 400MT/s only	45	55	Ω	Required for backward compatibility when signaling to a Gen1 device.
$Z_{TX-IDLE}$	Gen3 _{AC} electrical idle single ended output impedance	1	20	k Ω	Measured at common-mode voltage in electrical idle.
Z_{TX-GND}	Transmitter single ended output impedance to ground during TXGNDTRM	20	70	Ω	Measured at 0v.
Z_{TX-HIZ}	Transmitter output impedance when disabled	5		k Ω	
$C_{TX-AC-COUP}$	External transmitter coupling capacitor	75	200	nF	Placed on PCB near transmitter pins.

27 Gen3 Channel Specification

There are a multitude of possible channel configurations and topologies that can be used with Gen3 electricals. These can range from short connections on a 4-layer motherboard with outer layer routing to more complex layer transitioning topologies that might include a connector and a second board. It is impractical to define physical definitions for the rich set of viable channel configurations for Gen3 electricals, so instead we define the time domain properties of the channel by means of a simulation methodology.

27.1 Channel response

An arbitrary channel can be fully defined by multi-port S-parameters that can either be measured or created from detailed modeling of each of the structures that make up the interconnect. For a differential signaling system that routes the individual differential pairs per link on a single layer most of the channels properties can be determined from a center victim pair and its two closest neighbors (aggressors on the wanted signal). Some physical structures that are 3D in nature such as connectors, sockets etc. can extend the field of coupling to more than the two adjacent neighbors, in these situations additional aggressors need to be considered in the channel analysis.

27.1.1 Minimum channel model

In the simpler case of 3 pairs routed largely adjacent between two devices, a 12 port frequency dependent S-parameter matrix with information to at least 10GHz provides all the information needed. This defines all forms of channel distortion, such as reflections, crosstalk and inter-symbol interference. However the information contained in these S-parameters can be difficult to interpret for broadband applications because of structure resonances and non-linear phase delay characteristics.

27.1.2 Including transmitter and receiver return loss

Once a model of the channel has been derived (either by measurement, field solving or any other valid technique that has good correlation with the physical channel of interest) it must be combined with the S-parameter data for the worst case transmitter and receiver return loss against frequency mask. This combining can be done in either the frequency or time domain depending on which is most convenient. Including the transmitter and receiver return loss is critical to capture reflections from these terminations.

27.1.3 DC offsets

With a Gen3_{DC} link there is a limit to the amount of common-mode DC offset that can be introduced by the channel. This DC offset needs to be modeled for a given topology and confirmed that it does not violate the channel specification. This involves consideration of worst case differential DC current flows within the ground power plane, i.e. devices and/or subsystems at maximum and minimum power consumption.

27.1.4 AC coupling

A Gen3_{AC} link uses coupling capacitors placed near the transmitter pins, the PCB connections from the transmit device pin to these capacitors and their associated pads, vias and parasitics are included in the channel model.

27.2 Simulation environment

A behavioral model for the transmitter is defined that represents a worst case compliant transmitter. This model includes transmit de-emphasis and transmit pulse width jitter; both of these effects must be included so they get correctly convolved with the channels response to generate the cumulative receive eye. Other jitter effects that are measured as part of the transmitter specification can be combined by adding linearly to the jitter simulated with the channel methodology.

To avoid lengthy simulation times and the difficulty of finding worst case data and jitter patterns that are significant at the target BER a statistical approach is used to compute a time domain data eye opening. This technique convolves the step response of the channel with a probability distribution of data patterns and transmitter edge positions of victim and aggressors to calculate a probability contour map of data eye at the end of the channel. A software tool called jEye is provided as a supplement of this specification that carries out this calculation from channel step response data. A separate white paper describes the algorithms used in jEye along with user documentation. [Note: jEye is currently available to HyperTransport Technical Working Group members.]

27.2.1 Channel step response

All of the channel information can be represented in the time domain from the step response of the behavioral transmitter driving the channel normalized to the worst case TX and RX return loss. A step waveform is transmitted into the channel for each victim signal and aggressor signal in turn. Each step response is measured at the victim output from the channel. These responses may be generated using time domain simulation or derived mathematically from the s-parameter models, however they need to be converted to a textual table model for input to jEye.

27.2.2 Coupling from CAD to CLK

To correctly evaluate the effects of channel crosstalk on to CLK, it needs to be modeled as a victim. jEye can then be used to calculate the jitter on the CLK at the end of the channel. As there is correlation between the jitter on CAD/CTL and the CLK, jEye calculates the effective eye closure relative to the worst case CLK jitter.

To ensure that a receiver can tolerate the jitter that the channel adds to CLK the maximum peak to peak jitter added by the channel is specified. The receiver is then tested with both zero and maximum high frequency channel induced CLK jitter with a constant minimum CAD eye opening relative to the CLK. The high frequency jitter added to the clock is defined to be greater than bitrate/10.

27.2.3 High volume manufacturing variations

Manufacturing variation of the PCB and packaging materials as well as voltage swings of the transmitter and return-loss of transmitter and receiver also need to be considered in determining the worst case data eye for the channel topology under consideration. In general some form of sensitivity analysis or statistical technique is required to find worst case data eye versus manufacturing variations.

27.3 Channel compliance data eye

Once jEye has been successfully run a cumulative data eye contour plot is produced that shows the eye opening as a function of time, voltage and probability. The contour at the target BER of 10^{-12} is measured to obtain the V_{CH-EYE} and T_{CH-EYE} . Also generated from the tool is a measurement of $V_{CH-CM-AC}$ which is the channel induced AC common-mode. As all of the lower frequency jitter effects are included in the timing budget by linear addition it is sufficient to construct the data eye relative to both edges of the CLK. Figure 57 shows the results of a channel compliance simulation, the black diamond indicating the passing limit for the channel.

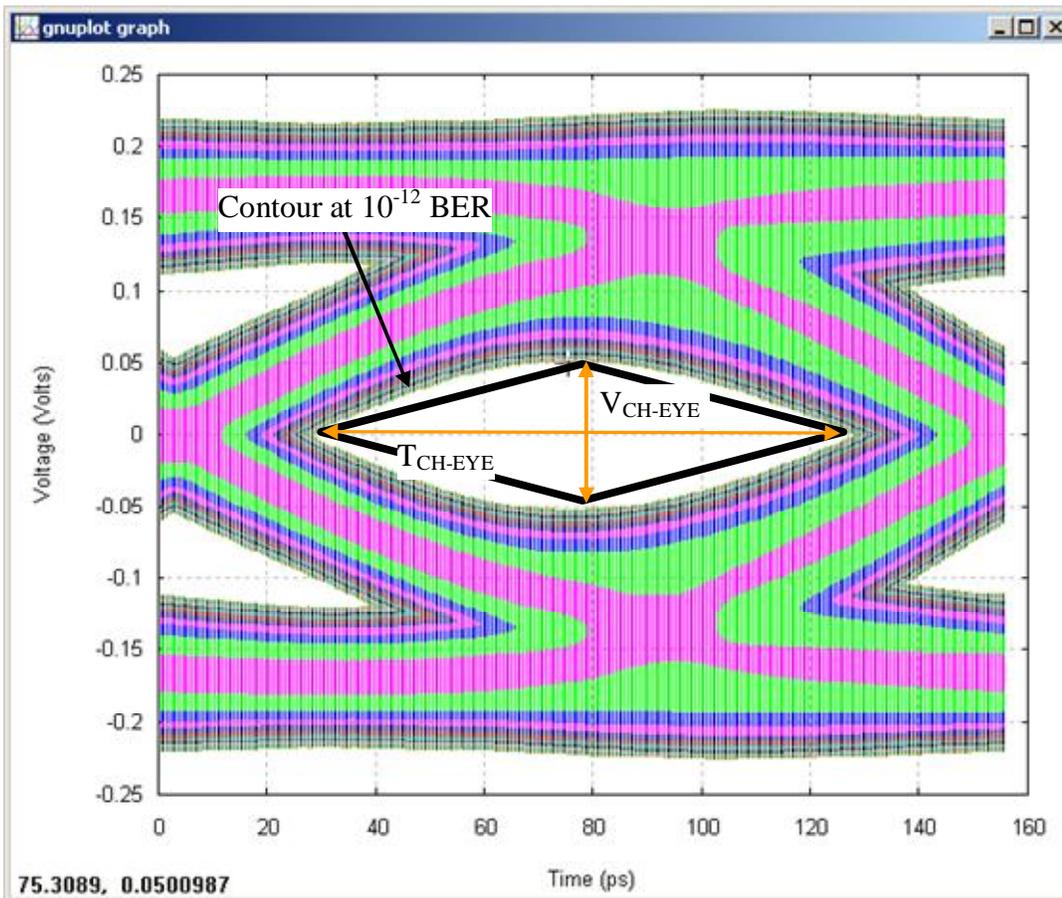


Figure 57. Channel compliance eye diagram

The measurement of T_{CH-EYE} has to include the jitter added to CLK from crosstalk in the channel. As Gen3 protocol uses scrambled data with different seeds per lane we can consider this crosstalk induced

jitter on the CLK to be uncorrelated with the lanes within that clock forward group. To model the impact of this CLK jitter, jEye is used to measure the jitter distribution on the CLK line in the channel using a 1010 data pattern and an RMS estimate fitted. This RMS jitter is then RSS with the jitter distribution of each CAD line to arrive at a final T_{CH-EYE} .

Other channel parameters not modeled by jEye need to be established by some other means, such as conventional time or frequency domain based simulator or by measurement.

27.3.1 Equalization

Gen3 electricals provide a number of fixed transmitter equalization settings, additional Gen3_{AC} provides optional receiver equalization settings. These settings are configured during the initialization of the link at the lowest operating frequency. In the case of Gen3_{AC} it is necessary to ensure that, for each channel in the system, the link functions with positive margin at 2.4GT/s with the default transmit de-emphasis of -3dB.

If the links are to be operated at data rate higher than 2.4GT/s it is necessary to select the optimum equalizer settings for each link in the system for the required operating data rate by simulation with jEye. This is largely an iterative operation over the possible range of equalizer settings that needs to consider the likely manufacturing variations of each links' channel, transmit and receiver characteristics. As the manufacturing variations are significant a compromise set of equalizer settings needs to be found that provides positive margin for all channel specifications for the range of manufacturing conditions. Note that Gen3_{AC} receiver equalization is optional, so this needs to be considered when choosing the best equalizer settings for a particular device to device link.

27.4 Gen3 to Gen1 interoperability

Gen3 electricals allow a relaxed CLK to CAD timing skew of $T_{CH-CAD-CLK}$ shown in

[Table 172](#)

~~Table 172~~ below. This skew exceeds that allowed for Gen1 electricals, so a link that connects between a Gen3 device and a Gen1 device must use the tighter skew requirements defined by Gen1 for the maximum required Gen1 frequency.

Gen3 devices use Gen1 protocol at 400MT/s for link initialization. If the Gen3 device is connected to a Gen1-only device then the link must meet the tighter requirements of the Gen1 electrical spec at 400MT/s. If the two devices at each end of the link are both Gen3 devices then the looser $T_{CH-CAD-CLK}$ can be used.

27.5 Channel compliance parameters

The following table defines the minimum requirements for a compliant channel. The parameters should be measured at all the data rates and modes that the link uses for each channel. All measurements are to be made between the transmitter and receiver reference planes, defined as the package pins of the devices at each end of the link.

Table 172. Channel compliance specification

Symbol	Parameter	Min	Max	Units	Comments
T_{CH-EYE}	Cumulative data eye width at the end of channel	0.55		UI	Simulated with jEye using worst case TX assumptions for jitter, amplitude and return loss and measured channel $T_{CH-CLK-DJ}$.
$T_{CH-CLK-TJ}$	Total jitter added to the CLK by the channel		0.1	UI	The maximum HF jitter added to receiver CLK during compliance testing. This jitter is assumed to have correlation to CAD jitter and so added linearly.
V_{CH-TX}	Differential peak-peak swing for behavioral transmitter		900	mV	Measured into ideal 100 Ohm differential load sending 1010 data pattern
$V_{CH-EYE-DC}$	Gen3 _{DC} cumulative differential data eye height at the end of the channel	140		mV	Measured with worst case Rx return loss
$V_{CH-EYE-AC}$	Gen3 _{AC} cumulative differential data eye height at the end of the channel	100		mV	Measured with worst case Rx return loss
$V_{CH-DIFF-RATIO}$	Voltage ratio between the peak differential amplitude of adjacent bits		4	--	
$V_{CH-EYE-DFE25}$	Gen3 _{AC} cumulative differential data eye height when using receiver DFE setting of 25mV	50		mV	Only applies to CAD/CTL, CLK must still meet $V_{CH-EYE-AC}$.
$V_{CH-DIFF-RATIO-DFE25}$	Gen3 _{AC} voltage ratio between the peak differential amplitude of adjacent bits when using DFE setting of 25mV	2.5	7.5	--	Measured on the bit that causes the minimum eye height
$V_{CH-CM-PP}$	Maximum peak-peak AC common-mode noise caused by the channel		200	mV	This includes all crosstalk and differential to common-mode conversion of the channel, measured with jEye.

Symbol	Parameter	Min	Max	Units	Comments
$V_{CH-CM-DC}$	Gen3 _{DC} maximum DC offset between ground of two devices		50	mV	Measured under worst case power conditions at two ends of the link
$Z_{CH-ZDIFF}$	Channel differential impedance	80	106	Ω	Measured at bitrate/2.
$T_{CH-CAD-CLK}$	Maximum time delay difference between any CAD and CLK in a byte group		350	ps	Only for Gen3 to Gen3 device connections, see section 27.4 for discussion. Note this allows a maximum skew between two CAD's of the same group to be 700ps.
$T_{CH-CAD-CAD}$	Maximum time delay difference between any two CAD's across both byte groups		1000	ps	

28 Gen3 Receiver Specification

The receiver is specified by its measured input characteristics and its ability to correctly sample a defined input waveform with a BER of 10^{-12} . The input waveform definition includes all of the distortions that a compliant channel can cause to the waveform generated by the transmitter. This includes amplitude distortions caused by ISI and crosstalk to both differential and common mode propagation as well as the various jitter terms that close the width of the eye.

28.1 Receiver return loss

To maximize the power transfer to the receiver from the transmission line and to bound the amount of energy reflected back to the source, the differential and common-mode return loss is specified by means of a frequency dependent mask from 50MHz to the fundamental of the maximum bit rate of 2.6GHz. See Figure 58.

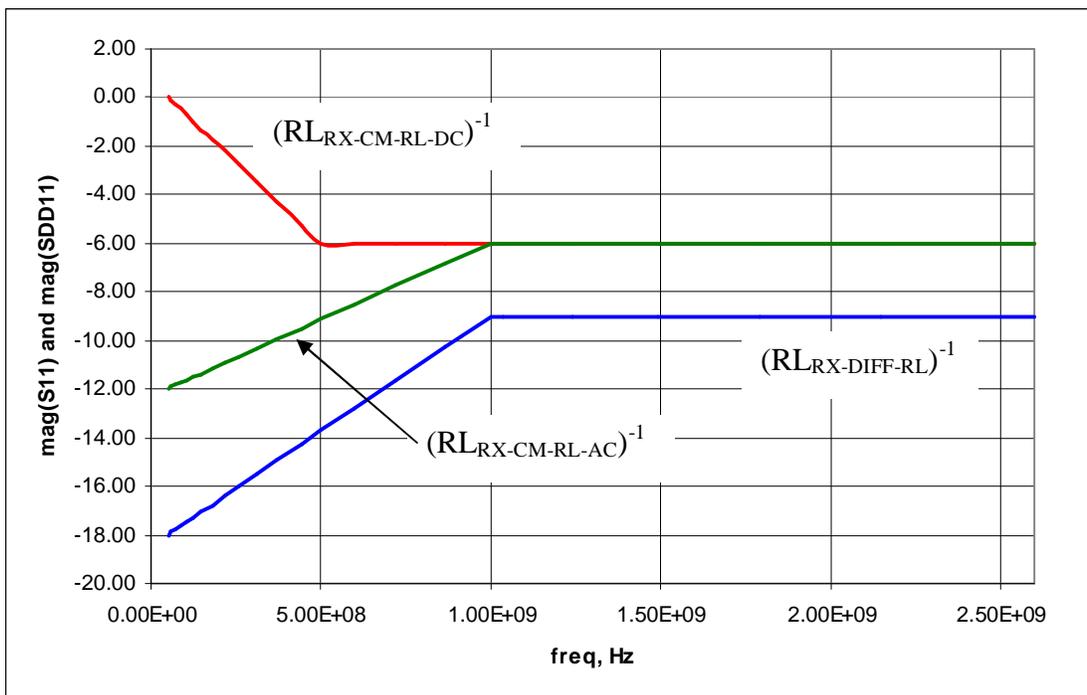


Figure 58. Receiver return loss mask

The low frequency end of this mask is within the frequency range of most 2-port VNA's and is sufficiently close to DC to provide an accurate bound on the voltage swing seen at the receivers input.

The measurement of return loss needs to be carried out with the device powered up biased over the range of VLDT*0.25 to VLDT*0.75. Two single port S11 measurements need to be made for each half

of the differential input, these results then need to be combined into the mixed mode differential S-parameter matrix and SDD11 extracted. Note return loss is the reciprocal of S11 and SDD11.

28.1.1 Gen3 DC receiver common-mode termination

The low frequency characteristics of the common-mode return loss are a function of the differential termination between the two halves of the differential pair and the common-mode decoupling capacitor that is placed between the center tap of these resistors and ground. A typical receiver input termination network is shown in Figure 59, note the common-mode clamp is not required by a device that does not support Gen3_{AC}.

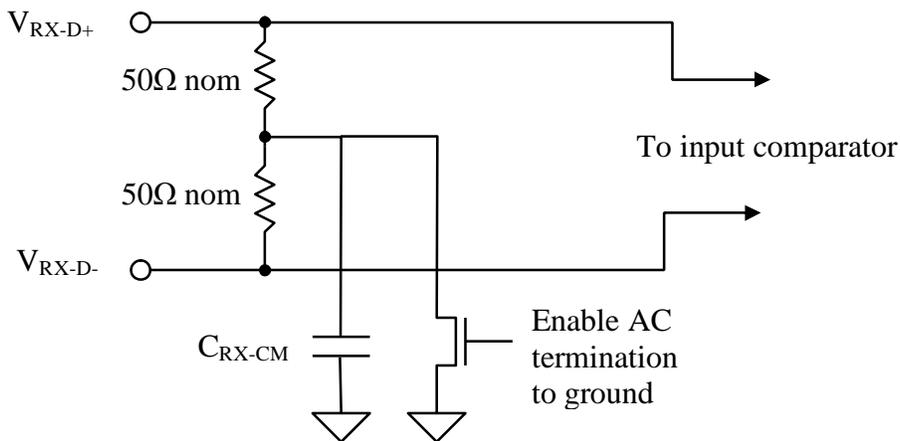


Figure 59. Receiver input termination

28.1.2 Gen3 AC receiver common-mode termination

For Gen3_{AC} operation the receiver may be either terminated differentially as per Gen3_{DC} or terminated to ground by enabling the clamp transistor shown in Figure 59. The common-mode DC termination resistance has a relaxed specification to minimize the implementation cost of this termination mode. If a device uses differential termination for Gen3_{AC} it is responsible for setting its required DC input common-mode voltage.

28.2 Receiver voltage measurements

To validate that the receiver operates from a compliant channel driven by a compliant transmitter, the voltage waveforms that a receiver has to correctly sample in a system need to be defined. To validate that the receiver will correctly sample these waveforms, they are created by the receiver compliance test setup as measured into a 50 Ohm reference load. Once these waveforms are calibrated into this reference load they are applied to the receiver to validate that the target BER is met.

28.2.1 Minimum receive pulse

The minimum receiver pulse bounds the highest frequency components that the receiver has to respond to. It is generally larger than the cumulative eye width T_{RX-EYE} as it represents a single isolated pulse in

the data stream. Figure 60 shows a minimum receive pulse in a cumulative receive data eye, in this example you can see the difference between T_{RX-EYE} and T_{RX-PW} .

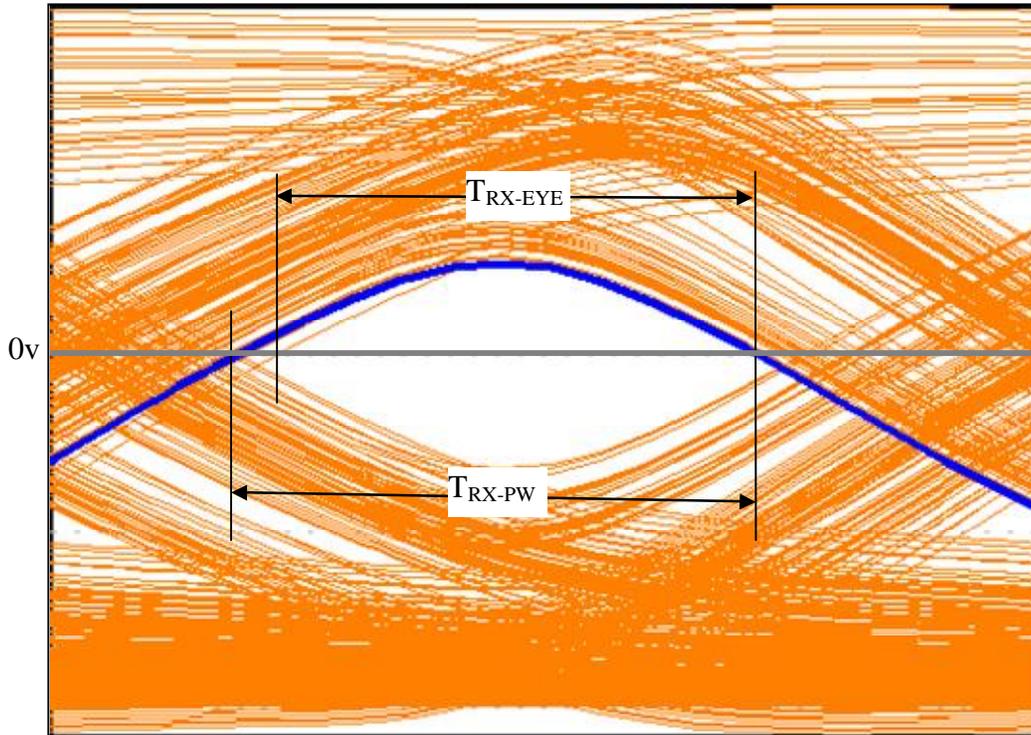


Figure 60. Receiver cumulative eye showing min-pulse width

28.2.2 Receiver differential voltage adjacent bit ratio

To measure the effective ISI of the channel, the differential peak amplitude of a lone pulse is compared with the magnitude of the preceding bit. This is illustrated in Figure 61 below. The differential peak magnitude is measured over the range of 1.5UI before the peak of the lone pulse. $V_{RX-DIFF-RATIO}$ is defined as the ratio between

$V_{RX-DIFF-PK-n-1}/V_{RX-DIFF-PK-n}$. The maximum value of this ratio bounds the worst case input swing the receiver may see and still correctly preserve the crossing time at 0v. The minimum value of this bounds the minimum input swing seen by the receiver when DFE is enabled.

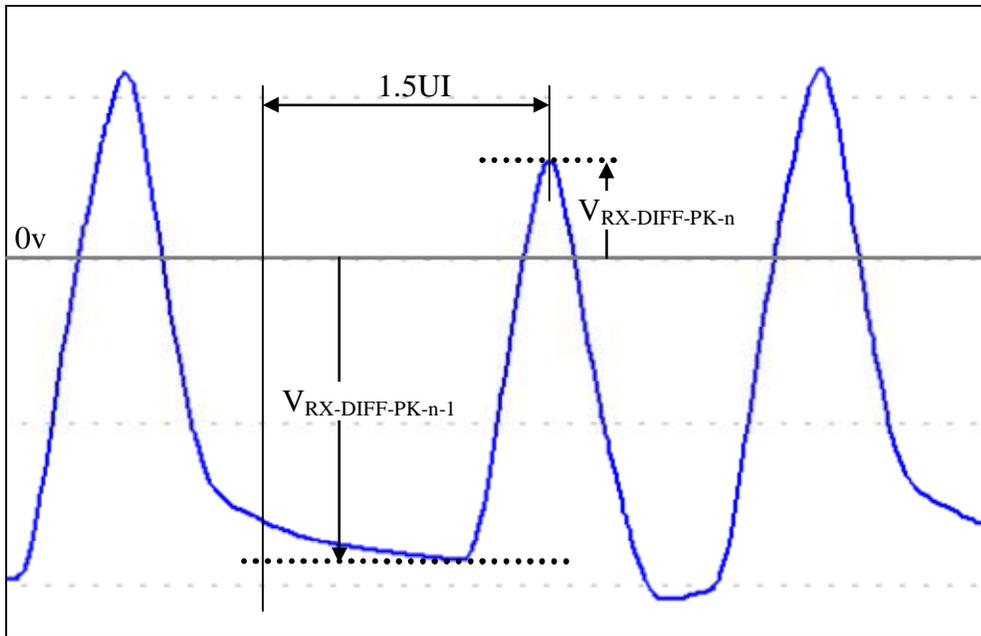


Figure 61. Receiver adjacent bit ratio

28.2.3 Gen3 AC receiver equalization

To support long channels in the optional Gen3_{AC} mode of operation, an optional single bit history receiver Decision Feedback Equalizer (DFE) is defined with a shifted threshold level of $\pm 25\text{mV}$. This equalizer uses the logic level from the previous data value to change the threshold voltage of the input sampler in a direction that causes it to switch sooner when the data bit transitions to a new logic level. The DFE has the effect of increasing the amplitude of the eye opening as seen by the input sampler and effectively boosts the HF energy in the received signal. This also increases the width of a lone pulse, improving the timing margin for the receiver. Figure 62 illustrates how an idealized DFE circuit would work, changing the slicing threshold voltage as a function of data pattern.

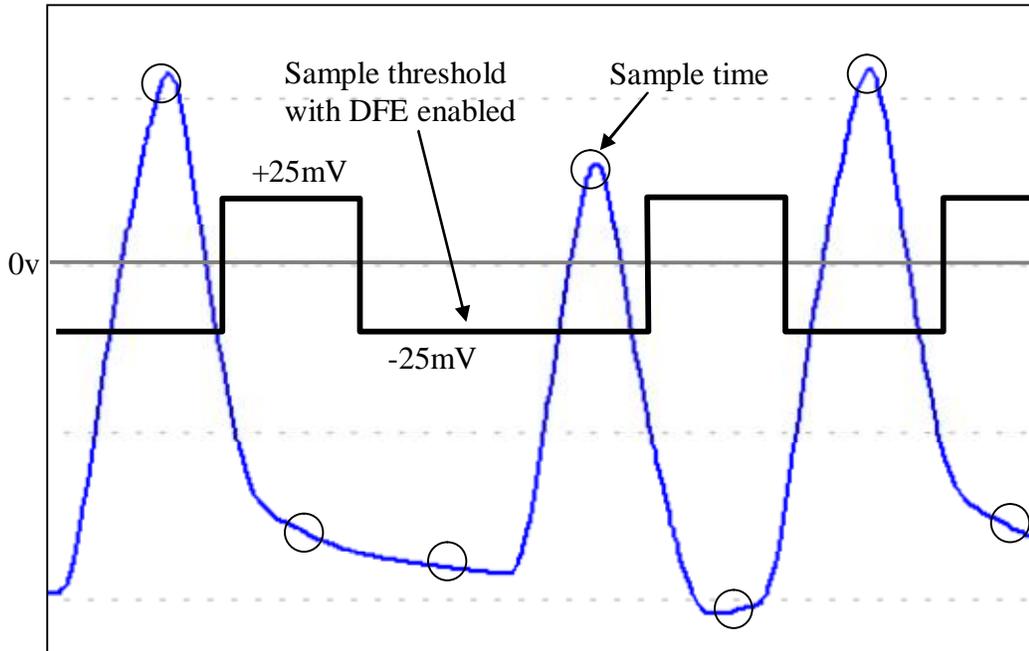


Figure 62. Receiver DFE

28.3 Receiver termination and in-band detect

To support in-band signaling, Gen3_{DC} and optionally Gen3_{AC} different DC termination modes are defined for the receiver that indicate the state of the receiver. These usage of these states are defined in the protocol section of this specification, this electrical section describes the externally visible electrical states.

28.3.1 RXDIFF

This is the normal active differential termination defined for Gen1 and Gen3_{DC}, it implemented with a center taped resistor connected between true and complement inputs to the receiver. Its impedance is defined by the receiver's differential input return loss.

28.3.2 RXACTRM

This termination mode is used to support hot-plug in Gen3_{DC} and for Gen3_{AC} and is entered as directed by the protocol layer. The DC termination impedance is specified by $Z_{RX-AC-TRM}$.

28.3.3 RXOFF

This is the high-impedance inactive state of the receiver's common-mode termination and needs to be met with and without DC power applied. The voltage range over which a high-impedance is measured is limited to avoid turn-on of parasitic devices. Its impedance is defined by Z_{RX-OFF} . The input receiver's amplifier should be disabled in this mode to avoid unnecessary power consumption.

28.3.4 RXDCDETECT

A device may optionally use this state to detect if it connected to a DC coupled link. It requires a weak pull-down to ground defined by $Z_{RX-RC-DETECT}$ and an additional low speed single ended input comparator that detects if an input is at 0v or VLDT.

28.4 Receiver input compliance

The methodology is to create an input waveform from test setup into a test load at the calibration reference plane (instead of the device under test) that is calibrated to meet the various compliancy requirements defined in the receiver specification. Once this signal has been calibrated it is connected to the device under test and its BER is measured. Figure 63 shows a typical setup for measuring the receiver.

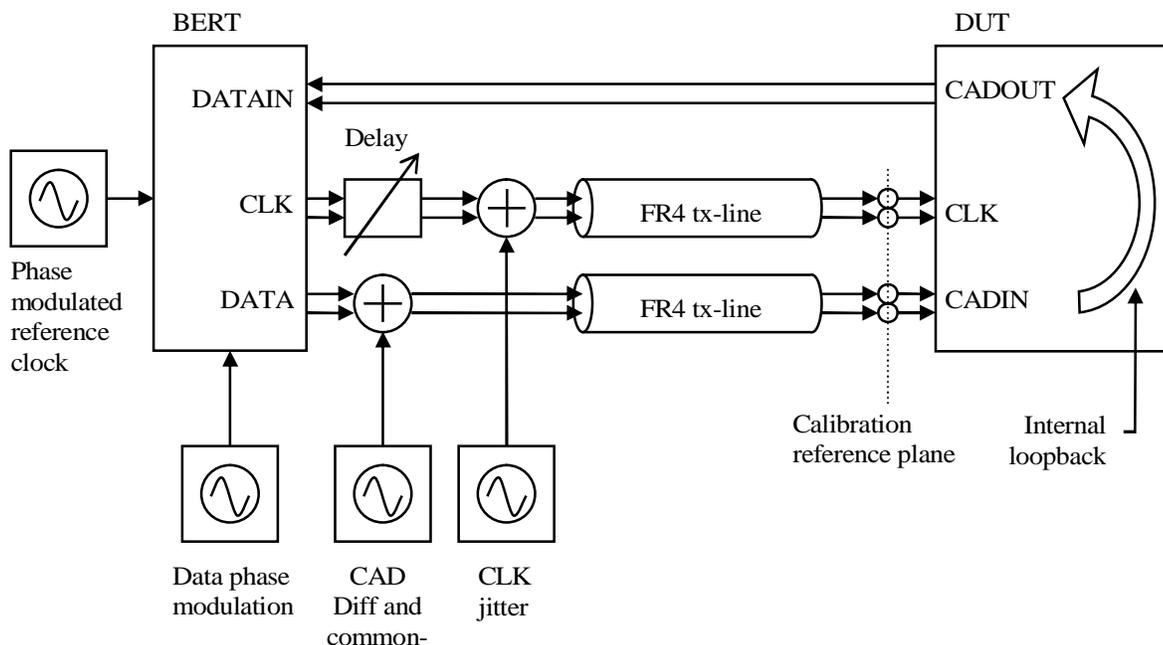


Figure 63. Receiver input compliance test setup

The BERT (bit error rate tester) is typically configured to generate a PRBS (pseudo-random bit sequence) data pattern (run length of $\geq 2^{23}-1$) for the test that the DUT samples and loops back to the BERT with a constant delay. The data pattern is phase modulated relative to the CLK to represent the jitter introduced between CLK and CAD by the transmitter, transport delay differences and crosstalk in the channel. This phase modulation is calibrated to generate specified amplitude of periodic jitter above and below the tracking bandwidth of the receiver's phase recovery mechanism and an amount of random jitter to represent the RJ present on the transmitter output. The data is also amplitude shifted, both differentially and common-mode to represent the effects of crosstalk in the channel. Finally the signal is driven through a calibrated FR4 PCB differential transmission line to introduce a controlled amount of ISI. Typically a BERT does not have any equalization and so the length of the FR4 channel is selected

to introduce a representative amount of ISI for a compliant channel. The ISI of the FR4 channel is calibrated to the same differential voltage ratio between bit n and bit n-1 as the receiver.

The CLK follows a similar path to CAD from BERT to DUT it is delayed to align the correct edge with the CAD data eye. The worst case DCD and channel induced jitter is added to the CLK and its amplitude is adjusted to be representative of a worst case compliant channel at the data rate under test. Note that HyperTransport links use a half rate clock, i.e. both edges of the CLK clock the data, this may need to be divided from the full rate clock often provided from a BERT.

The DUT is tested with and without CLK jitter added, in both cases the applied clock eye opening relative to CLK is the same. The CLK jitter introduced represents channel crosstalk and so its frequency components need to be close to bit rate.

As all of the waveform parameters are adjustable calibration measurements can be taken at the calibration reference plane that calibrates each noise contribution individually and combined to achieve the correct maximum compliant received data's distortion.

28.5 Receiver electrical parameters

The following table defines the input characteristics of the receiver and the voltage time characteristics of its input waveform. These values are measured from a 50 Ohm source driving an ideal 50 Ohm load. Actual values a receiver sees at its pads will vary from these values depending on receiver's package and input return loss.

Table 173. Receiver electrical specification

Symbol	Parameter	Min	Max	Units	Comments
$V_{RX-DIFF-DC}$	Gen3 _{DC} cumulative peak-peak differential input voltage	170	1800	mV	Applied to Rx pins from a 50 Ohm source. The peak differential voltage is approximated to be 50% of the peak-peak.
$V_{RX-DIFF-AC}$	Gen3 _{AC} cumulative peak-peak differential input voltage	120	1600	mV	Applied to the Rx pins from a 50 Ohm source with DFE disabled. Note transmit de-emphasis must be programmed to ensure max is not exceeded.
$V_{RX-DIFF-RATIO-DC}$	Ratio between the peak differential amplitude between adjacent bits		4	--	Measured over a 1.5UI interval. Only applies to CAD and CTL, CLK has a ratio of approx 1.0. Receiver must meet all other input requirements when this occurs.

Symbol	Parameter	Min	Max	Units	Comments
$V_{RX-DIFF-DFE25}$	Gen3 _{AC} cumulative peak-peak differential input voltage with DFE set to 25mV	70		mV	Only applies to CAD/CTL, CLK must still meet $V_{RX-DIFF-AC}$.
$V_{RX-DIFF-RATIO-DFE25}$	Gen3 _{AC} ratio between the peak differential amplitude between adjacent bits with DFE set to 25mV	2.5	7.5	--	Measured on the bit that causes the minimum eye height. Measured over a 1.5UI interval.
$V_{RX-CM-DC-DC}$	Gen3 _{DC} receiver DC common-mode input voltage	480	750	mV	
$V_{RX-CM-AC}$	Peak-Peak AC common-mode		350	mV	<u>Applies to both DC and AC mode links.</u> Measured with a high pass filter with a corner frequency of 0.1MHz. Receiver must meet all other input requirements when this occurs.
T_{RX-EYE}	Cumulative receive total eye width	0.4		UI	Receiver jitter tolerance. Eye width is measured at the BER of 10^{-12} relative to CLK.
$T_{RX-DJ-DD}$	Maximum deterministic jitter receiver must tolerate		0.50	UI	Extrapolated from jitter distribution using dual dirac jitter model at calibration plane. See section 29.1.
$T_{RX-CLK-TJ-HF}$	High frequency total jitter on CLK	0.03	0.10	UI	Applied to receiver's CLK during jitter tolerance. Represents HF crosstalk in channel to the CLK. Measured with a high pass phase filter with corner frequency of bitrate/10.
$T_{RX-CAD-PW}$	Minimum width pulse at 0v differential of CAD	0.55		UI	
$T_{RX-CLK-PW}$	Minimum width pulse at 0v differential of CLK	0.85		UI	Channel increases transmitter's DCD of CLK.

Symbol	Parameter	Min	Max	Units	Comments
T_{RX-TRF}	Receiver input rise and fall time	50		ps	Measured at 20%-80% crossing levels for a given transition
$RL_{RX-DIFF-HF}$	Receiver input return loss at high frequency	9		dB	Measured from 1GHz to 2.6GHz
$RL_{RX-DIFF-LF}$	Receiver differential input return loss at low frequency	18		dB	Measured at 50MHz with a linear slope to $RL_{RX-DIFF-HF}$ at 1GHz.
$RL_{RX-CM-HF}$	Receiver common-mode input return loss at high frequency	6		dB	Measured from 500MHz to 2.6GHz
$RL_{RX-CM-LF-DC}$	Gen3 _{DC} receiver common-mode input return loss at low frequency	0		dB	Measured at 50MHz with a linear slope to $RL_{RX-CM-HF}$ at 500MHz.
$RL_{RX-CM-LF-AC}$	Gen3 _{AC} receiver common-mode input return loss at low frequency	12		dB	Only applies if receiver terminates to ground, see Section 28.1.2. Measured at 50MHz with a linear slope to $RL_{RX-CM-HF}$ at 500MHz.
$C_{RX-CM-DC}$	Receiver input common-mode decoupling capacitance	20		pF	Connected between input termination center tap and ground
$Z_{RX-AC-TRM}$	Hot-plug DC input resistance to ground.		85	Ω	Measured at 0v for each receiver input.
Z_{RX-OFF}	Receiver input resistance when receiver is turned off	50		k Ω	Measured from 0v-0.5v with and without DC power applied to the device.
$Z_{RX-DC-DETECT}$	Receiver input resistance to ground during detect	1	20	k Ω	Used by receiver to detect if DC coupled. Only required on devices that carry out in-band Detect at the receiver. Measured from 0v to VLDT.
$BW_{RX-TRACK}$	Receivers data phase tracking bandwidth	0.1		MHz	The -3dB bandwidth for 20ps pk-pk sinusoidal phase modulation applied between CLK and CAD/CTL during compliance testing.

Symbol	Parameter	Min	Max	Units	Comments
T _{CLK-CAD-SKEW}	Maximum skew a receiver can have between CLK and any CAD in a byte in Gen3		350 ± 0.5UI	ps	TX is allowed to use any phase relationship between CLK and CAD, so the delay between any two CAD's within a byte group is 700ps+1UI
T _{CAD-CAD-SKEW}	Maximum skew a receiver can have between any two CAD's across both byte groups		1000+ 2UI	ps	
T _{CADVRSH-400}	Minimum CAD valid time before and after clock in 400MT/s mode	400		ps	This meets Gen1 requirements at device pins for interoperability.

29 Gen3 Link Layer Timing Budget

The three components parts of the link, transmitter, channel and receiver each contribute to the closure of the data eye at the receiver. This section shows the methodology of how the overall timing budget is closed from these individual component timing budgets.

29.1 Jitter model

At data rates above 2.0GT/s it becomes no longer possible to use a worse case analysis of jitter where all total jitter components of the budget are algebraically summed in a linear fashion. There are several different models possible for convolving the various jitter components of each part of the timing budget, this specification uses a dual dirac definition for deterministic jitter or jitter that has a high likelihood of occurring and a Gaussian distribution fit to the remainder of the jitter.

The total system jitter budget can be expressed as follows:

$$\text{Total System Jitter} = \sum DJ_C + 2Q_{BER} \sqrt{\sum RJ_C^2} \leq 1.0UI$$

Where DJ_C and RJ_C are the DJ and RJ of each system component that contributes to the total system jitter and Q_{BER} is 7.03 for a system level BER of 10^{-12} .⁽¹⁾

One of the difficulties with this approach is the separation of DJ and RJ from a measurement because there are many possible methods of doing this. Alternative methods can give widely different results depending on the actual phase jitter frequency spectrum and the sample sizes used. To standardize, the method for extraction of DJ and RJ is defined as well as the minimum sample sizes to ensure good estimates. To avoid confusion with other definitions of DJ this document uses the term DJ-DD which specifically refers to the value obtained from this method of separation.

The basic principle for measurement is to accumulate enough phase samples ($>10^8$) to plot a meaningful jitter distribution. This is binned with a fine resolution and then the probabilities plotted on the y-axis are transformed by the inverse normal cumulative distribution function to linearize any Gaussian distributions in the data. The transformed axis is conventionally notated the Q axis and its units are equivalent to the sigmas used in a Gaussian distribution. The resulting distribution shows a linear tail region in this coordinate system which can be extrapolated in two directions. The intersection of these extrapolations with the Q=0 line provides a definition of DJ-DD for the distribution. The intersection of these extrapolations with the Q=7 line corresponds to the TJ of the distribution at 10⁻¹², the target BER.

The validity of this extrapolation can be correlated with an actual measurement with a BERT at a sample size of say 10^{13} or more, so providing confidence in the measurements that can only be made with a real time scope at a substantially lower sample size.

⁽¹⁾ It is possible to design systems based on this specification that can achieve BER of less than 10^{-12} but this is beyond the scope of this document.

Figure 64 shows a typical distribution of a CLK to CAD measurement from which the extrapolated DJ-DD is 0.06UI and the TJ at 10-12 is 0.21UI, which implies an RJ of 2ps RMS at 5.2GT/s.

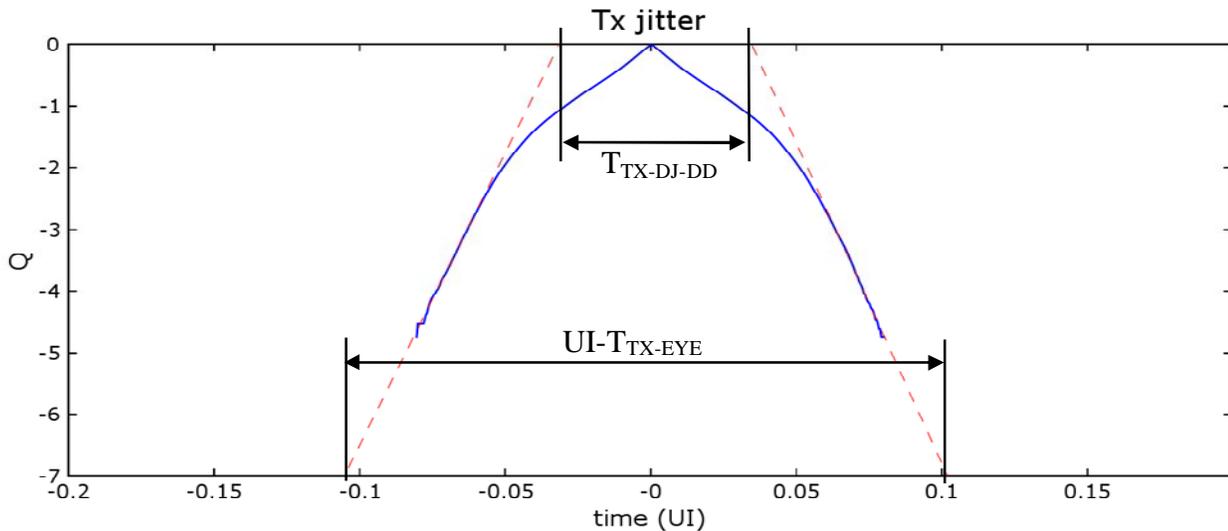


Figure 64. Transmit CAD jitter plotted on Q axis

29.2 Timing budget

The following table shows the timing budget that is implied by the timing specifications of transmitter, channel and receiver.

Table 174. Link timing budget

Symbol	Bit Rate	2.4 416.67	4.0 250.00	5.2 192.31	Units	Comment
T_{TX-EYE}	Cumulative transmitter eye width	0.75	0.75	0.75	UI	
		313	188	144	ps	
$T_{TX-DJ-DD}$	Maximum transmitter deterministic jitter	0.15	0.15	0.15	UI	
		63	38	29	ps	
	Transmit total jitter	0.25	0.25	0.25	UI	Calculated from $1-T_{TX-EYE}$
		104	63	48	ps	
	Transmit random jitter	0.007	0.007	0.007	UI	Implied RJ assuming TX is at maximum T_{TX-EYE} and $T_{TX-DJ-DD}$
		3.0	1.8	1.4	ps	
T_{CH-EYE}	Cumulative data	0.55	0.55	0.55	UI	

Symbol	Bit Rate	2.4 <i>416.67</i>	4.0 <i>250.00</i>	5.2 <i>192.31</i>	Units	Comment
	eye width from channel	<i>229</i>	<i>138</i>	<i>106</i>	<i>ps</i>	
T _{TX-PW}	Transmit minimum pulse width	0.9 <i>375</i>	0.9 <i>225</i>	0.9 <i>173</i>	UI <i>ps</i>	
	Channel deterministic jitter	0.35 <i>146</i>	0.35 <i>88</i>	0.35 <i>67</i>	UI <i>ps</i>	Calculated from (1-T _{CH-EYE})-(1-T _{TX-PW})
T _{RX-EYE}	Cumulative receiver total eye width	0.40 <i>167</i>	0.40 <i>100</i>	0.40 <i>77</i>	UI <i>ps</i>	
T _{RX-DJ_DD}	Receiver tolerance to deterministic jitter	0.50 <i>208</i>	0.50 <i>125</i>	0.50 <i>96</i>	UI <i>ps</i>	
	Receiver sample clock total jitter	0.46 <i>191</i>	0.46 <i>115</i>	0.46 <i>88</i>	UI <i>ps</i>	Implied sample clock TJ calculated from TX DJ and Ch DJ and RSS of RJ's
	Receiver sample clock deterministic jitter	0.36 <i>149</i>	0.36 <i>90</i>	0.36 <i>69</i>	UI <i>ps</i>	Implied sample clock DJ
	Receiver sample clock random jitter	0.007 <i>3.0</i>	0.007 <i>1.8</i>	0.007 <i>1.4</i>	UI <i>ps</i>	Implied Rx RJ

30 Gen3 Voltage and Time Margining

At Gen3 frequencies it is very difficult to make a system level measurement at the device pins and draw any useful conclusions about the signal at the device pad. It is therefore difficult to establish the amount of operating margin a particular system has. Even if it was feasible to probe at the device pad, this still does not tell us how the receiver input amplifier responds to the complex voltage waveforms delivered by a channel. Whilst it might be possible get some degree of confidence by globally voltage- and frequency-margining a system, it does not provide any direct information about the critical electrical parameters of a specific link, namely the time margin at the receivers input sampling flop.

To provide a viable solution to this problem as well as a convenient method to stress a link during production test, this specification defines two ways to margin the receiver's data eye. These mechanisms can be used either in a test or characterization environment or as part of a system level hardware diagnostic.

30.1 Voltage margining

The most straightforward method of voltage margining is to extend the operating range of the transmitters' output driver such that the voltage swing for full-swing and de-emphasized swing can be scaled by a programmable amount. It is not necessary for these additional output levels be calibrated, they are just required to be monotonic and with sufficient steps to approach and pass through the failing point of a link. If the implemented margining steps do not provide enough precision, V_{LDT} may be varied within the allowed range of operation to create intermediate transmit voltage swings.

The implementation of voltage margining is design specific, however at a minimum it should be implemented in the transmitter and a minimum of 16 levels of drive swing should be provided from full swing to 25% of full swing or smaller. The step size must be no greater than 5%.

30.2 Time margining

The data clock phase alignment circuit in each bit provides some method of creating one or more sample clocks that can be indexed across the CLKIN period to sample as a minimum the data edge transition and the center of the data eye. For architectures that have only one sample clock phase a symmetrical sampling error can be introduced by adding a phase modulating offset to this clock that is at a frequency above the tracking bandwidth of the data phase tracking loop. The phase modulation waveform should be chosen to maximize the dwell time at the two extremes of the phase modulation offset, for example a truncated triangular waveform. For architectures with separate edge and data samples a static offset can be introduced in the data samples position.

The implementation of the phase alignment and time margining method is design specific, at a minimum it must be implemented in the receiver and a sampling error of at least $\pm 0.25UI$ can be introduced with a minimum of 16 steps in each direction from the optimal sampling point. $0.5UI$ or more of sampling error is recommended to allow for margining of short and/or low frequency links.

30.3 BER estimation from margin testing

In general it is expected that the failure point of the link in system testing is very steep, that is a small adjustment of timing or voltage margin can take a link from a low BER to a very high BER. The minimum recommendations above are not sufficient to accurately plot out the failure point as the step size in most situations is too coarse. But using a combination of frequency margining and V_{LDT} margining with the described voltage and time margining allows a BER contour to be plotted and so some estimate of system level BER is possible.

These inbuilt test features should not be considered sufficient to establish compliance of transmitter, receiver or channel; however they provide a quick and valuable system level method of establishing robustness of the link over a wide range of manufacturing tolerances.

30.4 Out of band control of test modes

To margin a Gen3 device to failure, operate the link in loopback mode, invoke compliance test modes, and reliably collect failure information, Gen3 devices must provide a sideband control mechanism to allow read and write access to internal CSR's that reside in PCI configuration address space.

Gen3 devices must also provide a means to enable the maximum supply current to be drawn from all power supplies during compliance testing to emulate the noise affects of the circuitry unrelated to the Gen3 interface. This may require some form of internal self-test to be enabled on unrelated core and I/O circuitry during compliance testing.

Gen3 devices must provide either a JTAG or SMBus interface to access these compliance testing mechanisms.

31 Gen3 Phase Recovery to Core Clock Domain

In addition to recovering data from the channel the receiver is also responsible for passing this data from the received clock domain to the internal core clock domain. Gen3 electricals allow the transmitter and receiver clocks to be derived from different frequency sources as long as the resulting link frequencies are within ± 600 ppm of each other. Additionally, Gen3 electricals allow the two separate clock domains to both use spread spectrum clocking (SSC) that is not synchronized, which introduces a further 0.5% difference in frequency between transmitter and receiver. The receiver sync FIFO is responsible for transferring data from the received clock domain to the local core clock domain. To track the large variations in phase between clock domains it must continually adjust its read pointer based on the received clock phase.

31.1 Data rate matching

For the receiver's sync FIFO to match the incoming data rate, it needs to slow down and speed up the rate at which data is transferred from the sync FIFO to the core clock domain. To avoid the requirement that the core clock domain must run at a faster rate than the data rate of the link, it is anticipated that implementations take advantage of the periodic CRC interval to adjust the position of the read pointer. Other implementations are possible if the core clock frequency supports a data rate higher than the link data rate.

The periodic CRC is transmitted once every 516 bit-times and occupies a constant $4/516$ or 0.76% of the link bandwidth regardless of link width. As this CRC can be checked in parallel to the data being transferred the time occupied by the CRC can be used to speed up the average rate the core reads data from the sync FIFO.

Figure 65 illustrates the phase tracking across the sync FIFO using the periodic CRC interval to make a phase adjustment of the read pointer. This example is for a 5.2GT/s link with a 600ppm frequency difference between receiver clock and core clock, each clock frequency modulated with 0.5% downspread SSC, receive clock at 30kHz and core clock at 33kHz. The tracking error determines the average sync FIFO latency which is proportional to data rate, its magnitude is bounded by the phase adjustment step and the precision of the comparison of the receive clock and core clock phase.

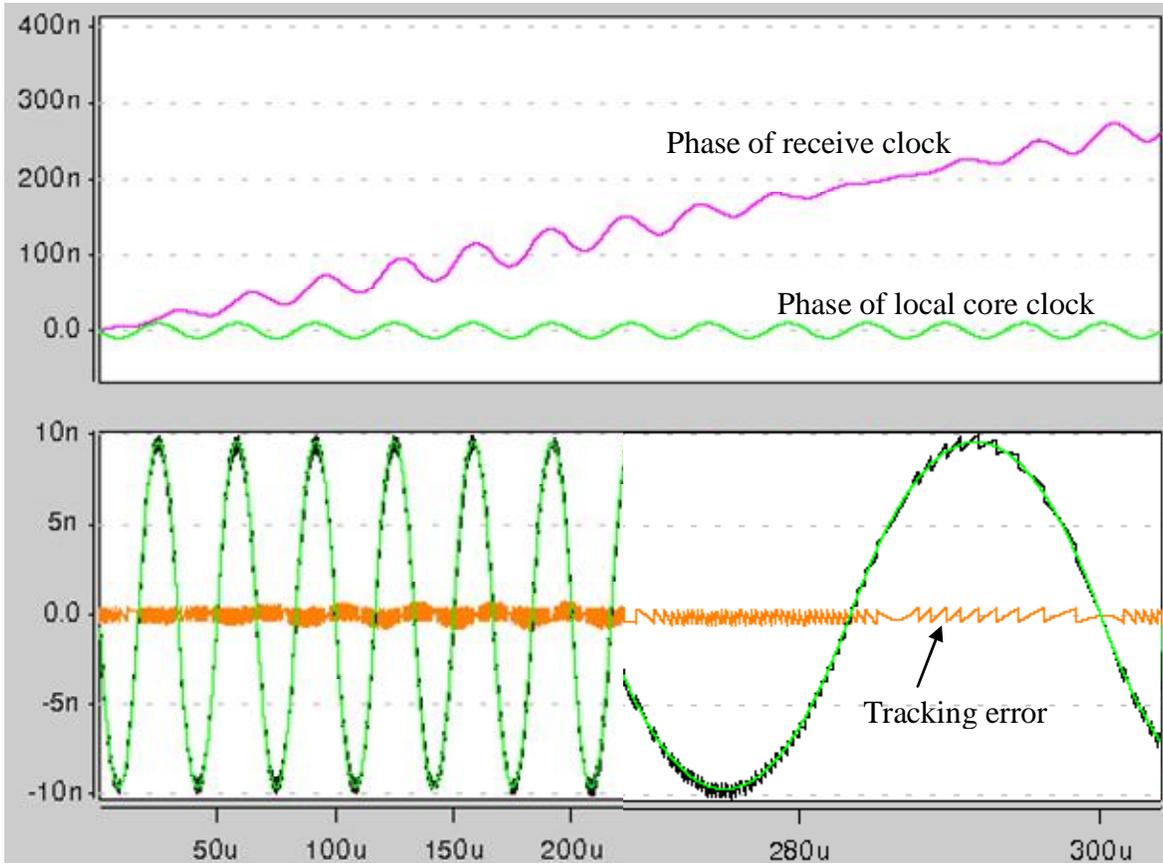


Figure 65. Phase tracking across receiver sync-fifo

Electrical Interface Appendices

M Example Gen3 Channel Topologies

This informative appendix provides some examples of typical channel configurations, their characteristics as measured by the channel compliance methodology and suggested equalizer settings.

M.1 Motherboard only, 3” total channel length

M.2 Motherboard only, 12” total channel length

M.3 Motherboard to riser card with one connector, 18” total channel length

M.4 Backplane with two connectors, 30” total channel length

M.5 Cabled link, 10’ cable

N Gen1 DC and AC Characteristics and Relationships

N.1 DC Parameters

The DC characteristics of the HyperTransport™ link are derived from the allowed variations in V_{LDT} , R_{ON} , and R_{TT} . The relationships used for V_{OD} and V_{OCM} are shown below.

Note: V_{LDT_min} and V_{LDT_max} are assumed to be 1.1V and 1.3V respectively to account for the minimum and maximum supply levels at the driver or receiver.

V_{OD} DC values are calculated from the following relationships:

$$V_{OD_min} > V_{LDT_min} * R_{TT_min} / (R_{ON_max} + R_{TT_min} + R_{ON_max})$$

$$V_{OD_max} < V_{LDT_max} * R_{TT_max} / (R_{ON_min} + R_{TT_max} + R_{ON_min})$$

V_{OCM} DC values are calculated from the following relationships:

$$V_{OCM_min} > V_{LDT_min} * (((R_{TT_min} + R_{ON_min}) / (R_{TT_min} + R_{ON_min} + R_{ON_max})) + (R_{ON_min} / (R_{ON_min} + R_{TT_min} + R_{ON_max}))) / 2$$

$$V_{OCM_max} < V_{LDT_max} * (((R_{TT_min} + R_{ON_max}) / (R_{TT_min} + R_{ON_max} + R_{ON_min})) + (R_{ON_min} / (R_{ON_min} + R_{TT_max} + R_{ON_min}))) / 2$$

N.2 Relationships Between AC and DC Parameters

The relationships between AC and DC parameters allow for the existence of AC noise on the signals in addition to the maximum V_{LDT} noise allowed. Table 175 shows the considered AC power supply noise and the remaining signal noise margin. Note that the minimum specifications of V_{OD} , V_{OCM} , V_{ID} , and V_{ICM} already account for -100mV of supply noise from the nominal.

Table 175. Relationships Between AC and DC Parameters

Parameter	Min (DC)	Min (AC)	Signal Noise
V_{OD}	495 mV	400 mV	95 mV
V_{OCM}	495 mV	440 mV	55 mV
V_{ID} 400 MT/s to 1.6 GT/s	200 mV	300 mV	100 mV
V_{ID} 2.0 GT/s to 2.8 GT/s	100 mV	200 mV	100 mV
V_{ICM}	440 mV	385 mV	55 mV

N.3 Relationships Between Output and Input Parameters

The relationships between output and input parameters comprehends the inclusion of noise and attenuation on the interconnect. Table 176 shows the allow degradation in each of the output parameters from transmitter to receiver.

Table 176. Relationships Between Output and Input Parameters

Parameter	Output	Input	Loss
V _{OD(DC)} 400 MT/s to 1.6 GT/s	495 mV	200 mV	295 mV
V _{OD(DC)} 2.0 GT/s to 2.8 GT/s	495 mV	100 mV	395 mV
V _{OD(AC)} 400 MT/s to 1.6 GT/s	400 mV	300 mV	100 mV
V _{OD(AC)} 2.0 GT/s to 2.8 GT/s	400 mV	200 mV	200 mV
V _{OCM(DC)}	495 mV	440 mV	55 mV
V _{OCM(AC)}	440 mV	385 mV	55 mV

O Gen1 Package and PCB Skew Assumptions

O.1 Transmitter and Receiver Package Skew

The transmitter and receiver package induce additional skew between signals associated with the variation in signal trace lengths. Note that there is a requirement to match the CLK package trace length to the median length of the CAD/CTL trace lengths to ensure an amount of symmetry between the uncertainties seen in relation between these two types of signals. Both the allowed CAD/CTL skew induced by the overall package trace length mismatch and the relative CLK to CAD/CTL skew are listed.

Table 177. Package Skew

Symbol	Description	400 MT/s	600 MT/s	800 MT/s	1.0 GT/s	1.2 GT/s	1.6 GT/s	2.0+ GT/s	Unit
T _{PKG_PP_SKEW}	Uncertainty in CAD/CTL relative to CLK due to package trace length mismatch	50	40	25	20	13	10	7	ps
T _{PKG_WP_SKEW}	Within pair Differential skew of CAD/CTL and CLK due to package trace length mismatch						10	7	ps
T _{PKG_CC_SKEW}	Uncertainty in CAD/CTL relative to other CAD/CTL due to package trace length mismatch	100	80	50	40	26	20	14	ps

O.2 PCB Skew

The PCB induces skew due to both transmission line effects and route length mismatch. Note again the requirement to match the PCB trace route length of the CLK transmission line to the median of the CAD/CTL lengths to which it is associated.

Table 178. PCB Skew

Symbol	Description	400 MT/s	600 MT/s	800 MT/s	1.0 GT/s	1.2 GT/s	1.6 GT/s	2.0 GT/s	2.4 GT/s	2.8 GT/s	Unit
T _{PCB_PP_SKEW}	Uncertainty in CADIN relative to CLKIN due to PCB trace length mismatch	50	50	30	20	15	10	10	10	10	ps
T _{PCB_WP_SKEW}	Within pair differential skew of CAD/CTL and	25	25	15	10	7.5	5	5	5	5	ps

	CLK due to PCB trace length mismatch										
T _{PCB_CC_SKEW}	Uncertainty in CADIN relative to other CADIN due to PCB trace length mismatch	100	100	60	40	30	20	20	20	20	ps
T _{PCB_JITTER_SU} ¹	PCB interconnect induced jitter caused by reflections, ISI, and crosstalk CAD/CTL setup side of CLK	185	105	90	66	53	40	81	27	22	ps
T _{PCB_JITTER_HD} ¹	PCB interconnect induced jitter caused by reflections, ISI, and crosstalk CAD/CTL hold side of CLK	185	105	90	66	53	40	68	27	22	ps

Notes:

1. For data rates of 400 MT/s to 800 MT/s the maximum channel length is 24", for data rates of 1.0 GT/s to 2.8 GT/s the maximum channel length is 12".
2. The PCB jitter shown in this table includes all variations of allowable channel length, variations for PCB manufacturing tolerance, worse case miss-match between package and PCB as well as the effects of impedance miss-match, crosstalk and reflection on CLK to CAD/CTL timing. The device timing budgets in this specification are based on these worse case assumptions and they represent the available budget in the specification for channel jitter. Careful design and simulation of the channel allows alternative implementations that go beyond the scope of this specification, including, but not limited to, longer channel lengths and connectors.