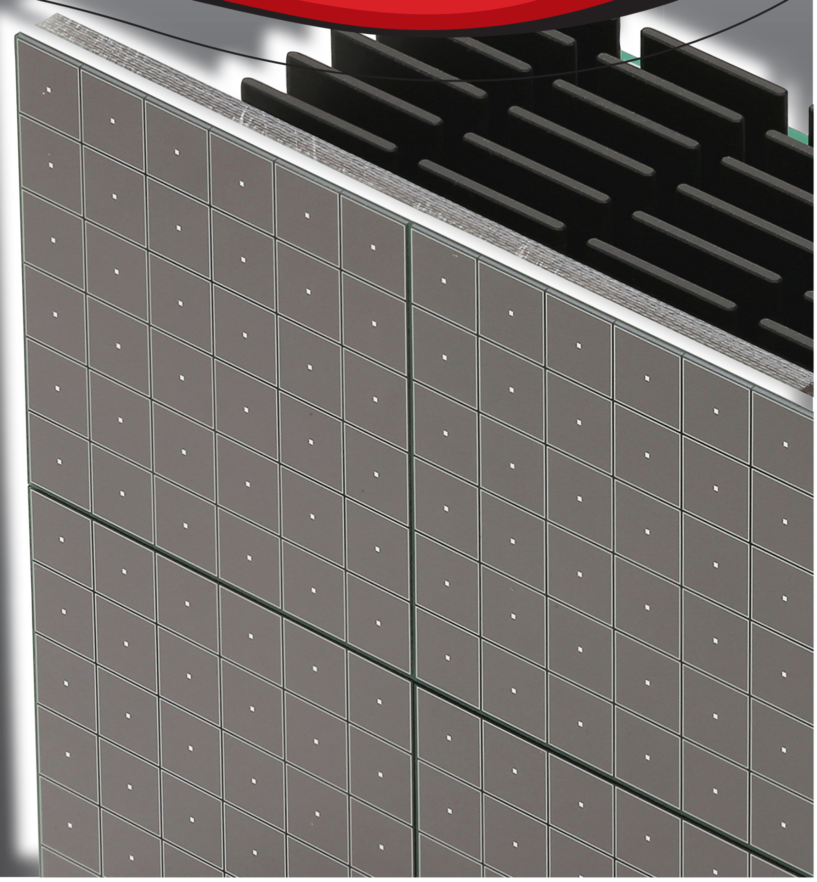
Jan. 2017

MPPC module for PET

Technical note



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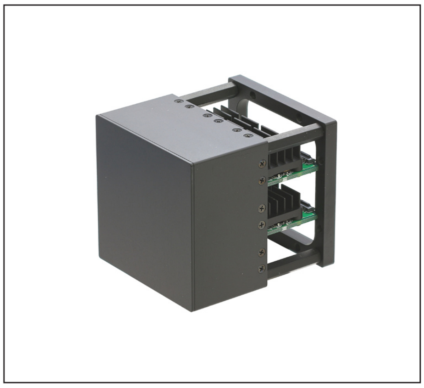
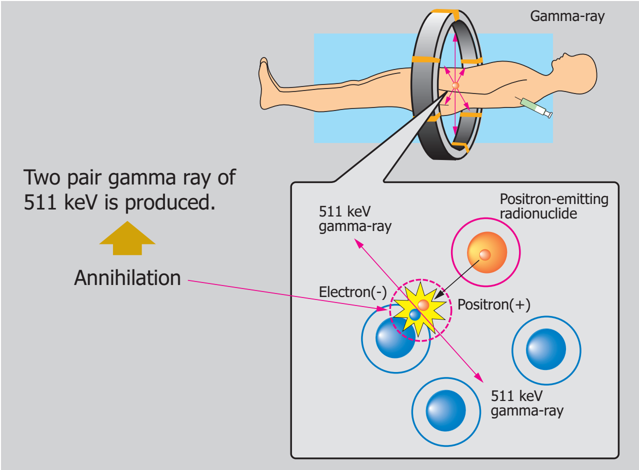
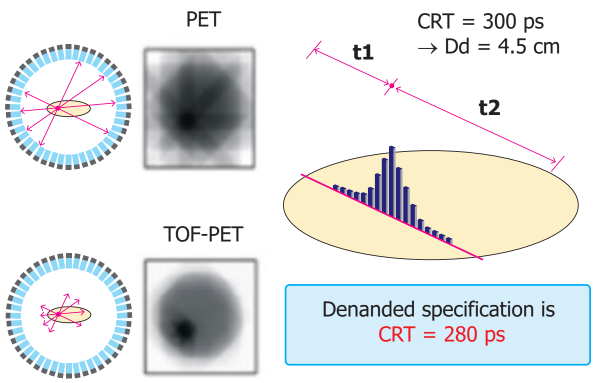
1. Overview



Hamamatsu TOF PET module has a highly accurate photon arrival timing measurement function that enables PET imaging with high sensitivity not possible with the conventional Non-TOF PET system.
This PET module is optimized to TOF-PET measurements. The module is composed of LFS (Lutetium Fine Silicate), MPPC array and signal processing circuit. The MPPC is best type for PET measurement and the circuit is optimized for Lutetium scintillator (e.g. LFS, LYSO) and MPPC.
The circuit has ASICs for output energy and timing information necessary to make TOF-PET measurements. The signal processing board is a dedicated MPPC drive power supply with an auto temperature compensation function.
The module has a good ability of coincidence resolving time (CRT) 280 ps and low power consumption. The module's components are suitable for PET application and there is big advantage for performance and cost.

Illustration of PET measurement

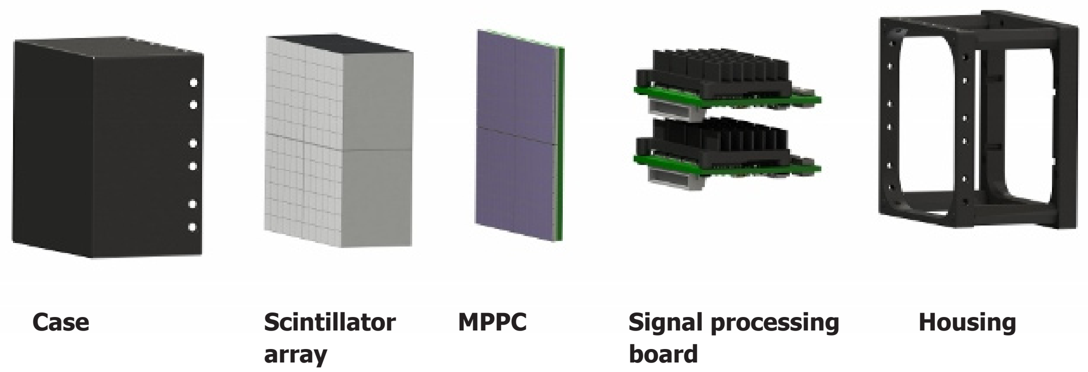




2. Structure

Hamamatsu Photonics PET module contains densely integrated components that are best suited to PET measurement. Functions necessary for high-performance PET measurement are packed in a compact space.

Exploded view of PET module

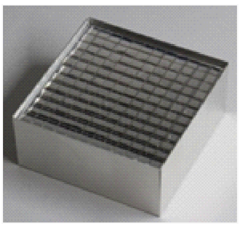


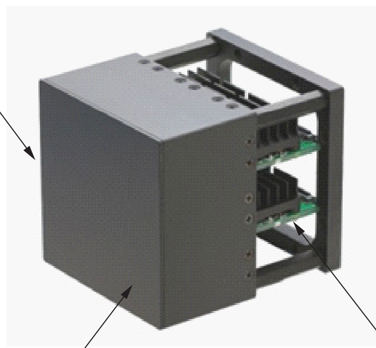
PET module for OEM

All key components are made in Hamamatsu, so Hamamatsu PET module is customizable.

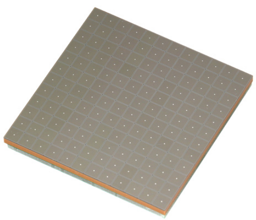
- Best type scintillator (LFS, LYSO)
- HPK has many technologies for scintillator array and assembly

Scintillator



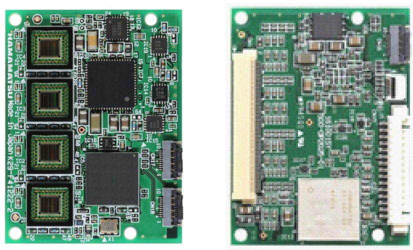


MPPC



- Best type of MPPC
- Higher PDE
- Low after pulse
- Low crosstalk

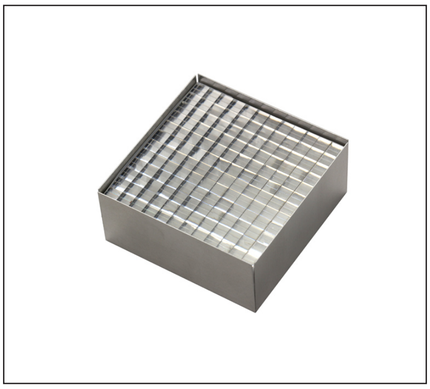
Signal processing board (built-in ASIC)



- Low power consumption
- Low cost

[1] Scintillator

Scintillators used in PET measurement require high emission intensity, fast emission rise time, short decay, and high density. These characteristics lead to fast and high S/N signals and dead time reduction, which in turn result in excellent CRT performance.
Recently, scintillators made chiefly of lutetium, as represented by LYSO, are used often. Hamamatsu PET modules use LFS (Lutetium Fine Silicate), which has almost the same characteristics as LYSO, but other scintillators can also be used upon request.
The LFS and typical scintillator characteristics are shown below.



Features

- High light output - Superior time resolution - No deliquescence unlike CsI

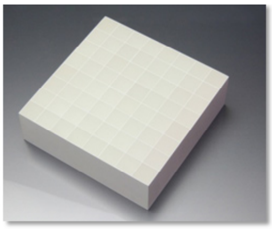
Comparison table of inorganic scintillator

Material	Density (g/cm^3)	Light yield (NaI=100%)	Decay (ns)	Application
LFS	7.35	85	33	PET, HEP
LYSO	7.25	80	41	PET, HEP
NaI: Tl	3.67	100	230	γ-ray, x-ray
CsI	4.53	120	1050	X-ray CT
CWO ($CdWO_4$)	7.68	40	5000	X-ray CT
BGO ($Bi_4Ge_3O_{12}$)	7.13	12	300	PET, HEP
PWO ($PbWO_4$)	8.20	1.3	10	HEP
GAGG	6.63	140	88	HEP

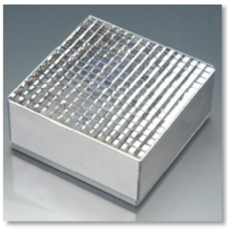
Further, the selection of an appropriate reflector for guiding the light emitted by the scintillator efficiently to the MPPC is important. In a PET module, a scintillator array arranged with the same spacing as the MPPC is combined in a standard manner. High-performance reflectors are inserted between each channel and its periphery. The standard scintillator array that Hamamatsu can provide is a reflective film type with a good balance between cost and performance.

Lineup

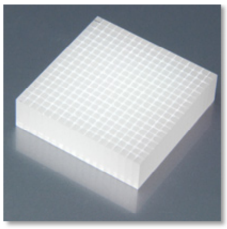
Reflective adhesive type
Ex.) CsI: 10 × 10 × 25 mm, 8 × 8 ch



Reflective film type
Ex.) LFS: 3.2 × 3.2 × 20 mm, 16 × 16 ch

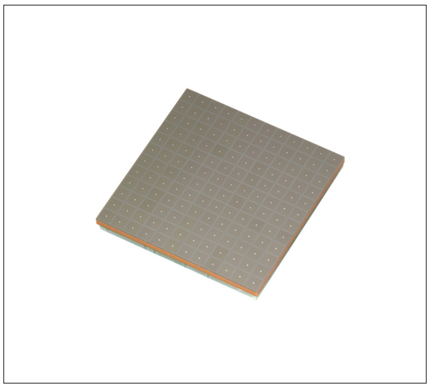


Laser processing type
Ex.) LFS: 1.2 × 1.2 × 5 mm, 18 × 18 ch



Parameters	Reflective adhesive	Reflective film	Laser processing
Separation	Best	Good	Weak
Cost	High	Middle	Low
Max.	No limit	No limit	Thickness 5 mm
Min.	1.6 mm pitch	1.2 mm pitch	1.0 mm pitch

[2] MPPC



Like the scintillator, the MPPC is also required capability to output highly dense photoelectrons with fast rise times. Our latest MPPC excels in the above characteristics and provide superb CRT performance.
Since the CRT performance improves with greater number of photoelectrons output from the MPPC, high PDE is desired for the device performance. PDE is expressed by the following equation.

PDE = Fg x QE x Pa

Fg: Fill factor QE: Quantum efficiency Pa: Avalanche probability

Normally, the recommended MPPC pixel size is 50 µm or greater in order to obtain high Fg that leads to high PDE. As the capacitive component of each pixel is low on the MPPC, the recovery time is fast. This aspect also helps to achieve high CRT performance.
The S13361 series is an MPPC suitable for PET measurement.

Features

- High PDE
- Low crosstalk
- Low noise
- Low V_{BR} operation (V_{BR} = 53 V typ.)
- High gain
- Low afterpulses
- Low capacitance
- Low Vop variation (±0.15 V)

Structure

Parameter	S13361-3050NE-04	S13361-3050AE-04	S13361-3050NE-08	S13361-3050AE-08	Unit
Number of channels	16 (4 × 4)		64 (8 × 8)		-
Effective photosensitive area/channel	3 × 3		3 × 3		mm
Pixel pitch	50		50		µm
Number of pixels	3584		3584		-
Fill factor	74		74		%
Package type	Surface mount	With connector	Surface mount	With connector	-
Window	Epoxy resin		Epoxy resin		-
Refractive index of window material	1.55		1.55		-

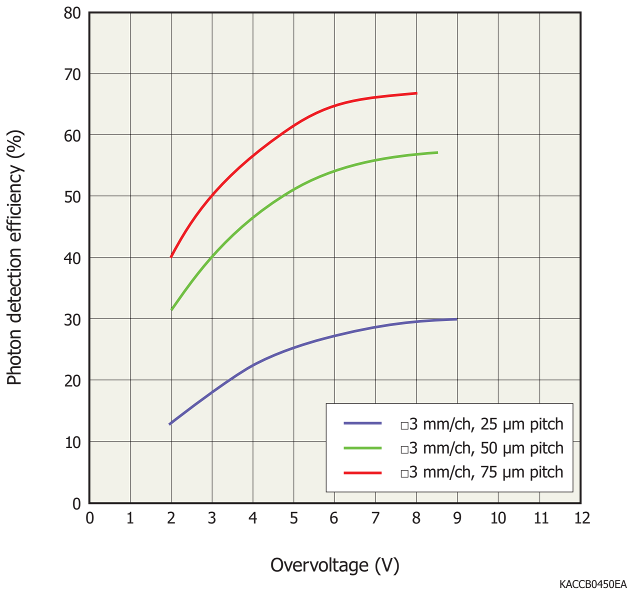
Electrical and optical characteristics (S13361 series, Typ. Ta=25 °C, Vover=3 V, unless otherwise noted)

Parameter		Symbol	Value	Unit
Spectral response range		λ	320 to 900	nm
Peak sensitivity wavelength		λp	450	nm
Photon detection efficiency (λ=λp)*1		PDE	40	%
Dark count*2	Typ.	-	0.5	Mcps
	Max.		1.5	
Terminal capacitance		Ct	320	pF
Gain		M	1.7×10^6	-
Breakdown voltage		V_{BR}	53 ± 5	V
Recommended operating voltage		Vop	V_{BR} + 3	V
Vop variation between channels	Typ.	-	±0.05	V
	Max.		±0.15	
Temperature coefficient of recommended operating voltage		ΔTVop	54	mV/°C

*1: Photon detection efficiency does not include crosstalk or afterpulses. *2: Threshold=0.5 p.e.
Note: The above characteristics were measured the operating voltage that yields the listed gain in this catalog.

Overvoltage specifications (MPPC for precision measurement typical example)

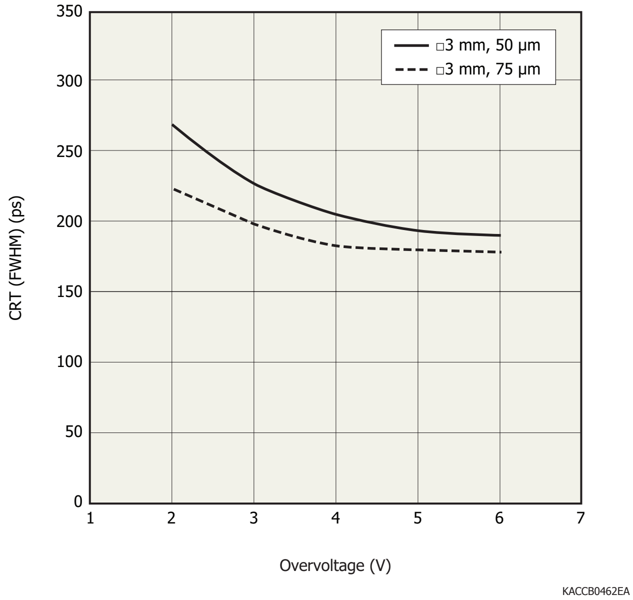
Photon detection efficiency



Pixel pitch	25 µm	50 µm	75 µm
Geometrical fill factor	47 %	74 %	82 %
PDE (λ = 450 nm)	25 %	40 %	50 %

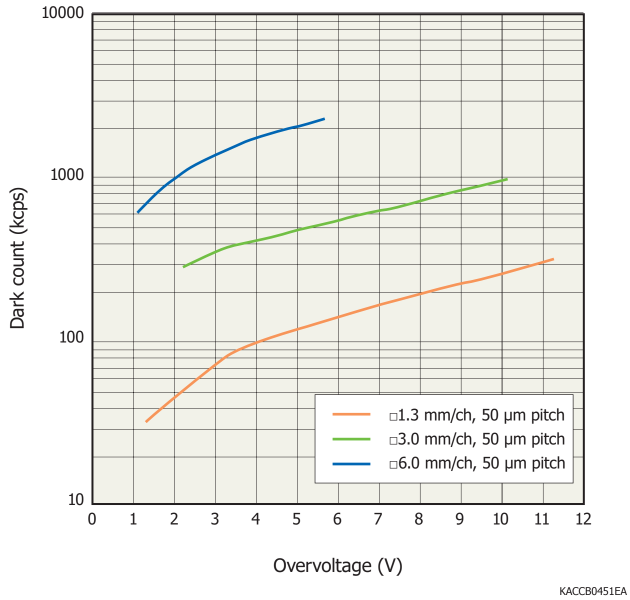
- High PDE achieved by the high fill factor and high overvoltage
- Larger pixel has higher PDE

CRT



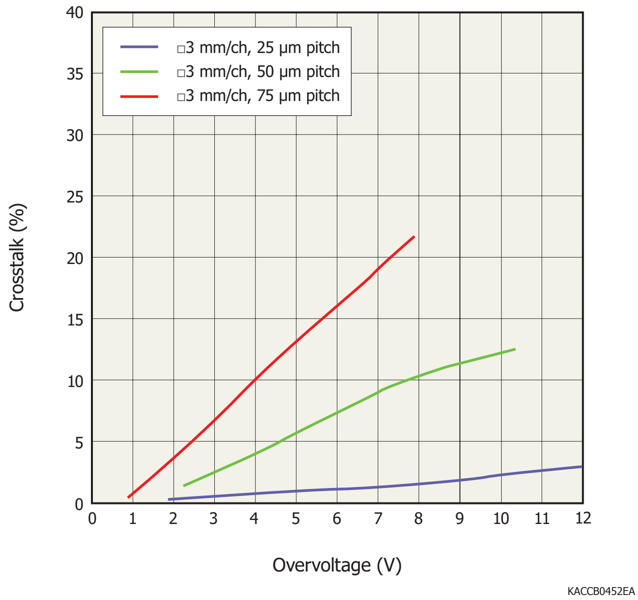
- MPPC (□3 mm) with LFS (□3.14 × 20 mm)

Dark count



- Dark count depends on active area

Crosstalk



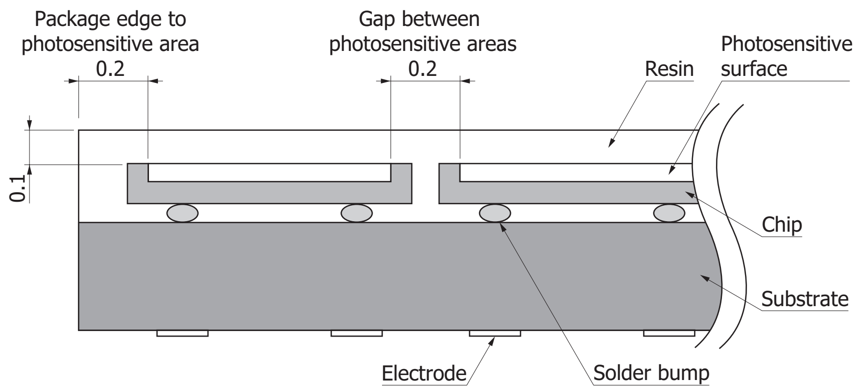
- S13361 series employs a structure that suppresses the occurrence of crosstalk
- Crosstalk depends on gain

On normal PET modules, the Vover value is set between 3 and 4 V.

■ Cross section

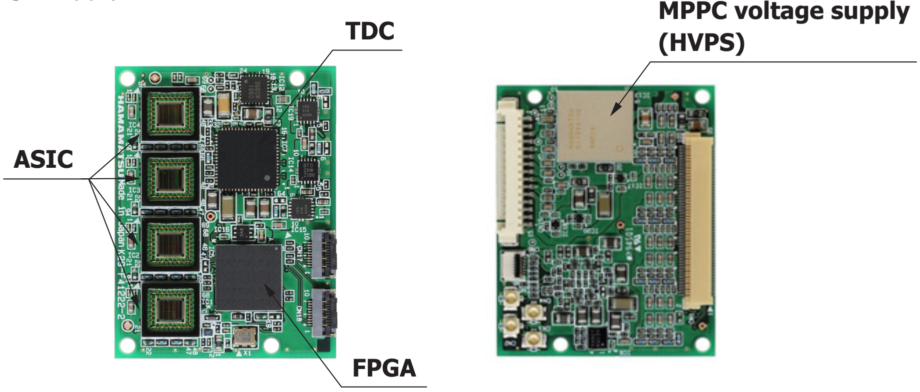
Since the MPPC array is arranged at high density and the protective resin over the photosensitive area is extremely thin, the effect of optical crosstalk is also remarkably small.
For details, refer to the MPPC technical information.

Cross section detail (unit: mm)

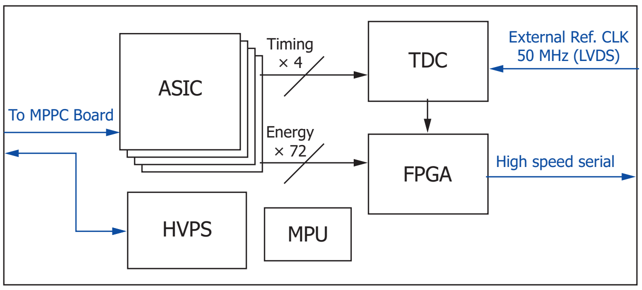


[3] Signal processing board

This signal processing board is optimized to TOF-PET measurements. The signal processing board is composed of following four main components, high speed frontend ASICs optimized to energy measurement using time-over-threshold method and arrival time measurement, a low power and high resolution TDC, a data processing FPGA, and a low noise MPPC voltage supply.



Block diagram



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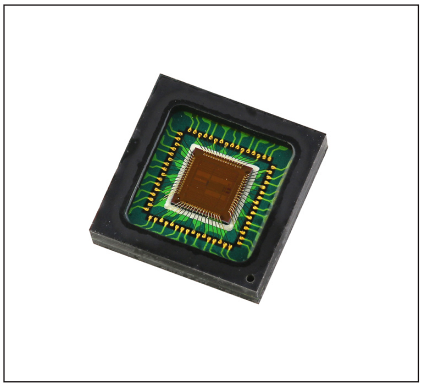
■ ASIC specification

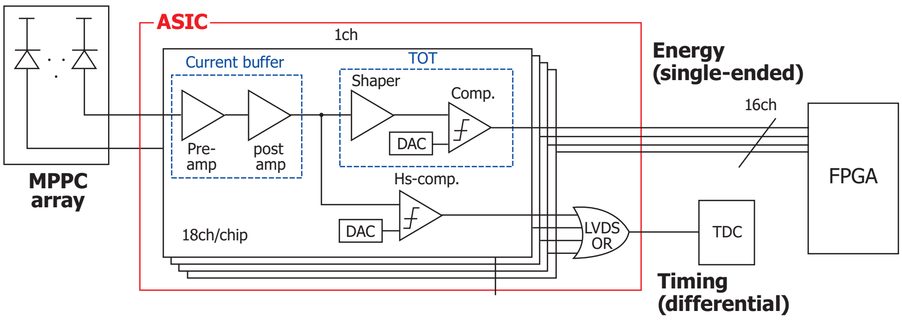
Features

The ASIC is optimized to readout of MPPC with LFS or LYSO scintillator. It consist of current buffer block, rime over threshold (TOT) block, and timing comparator block. The Energy information is outputted by TOT and timing information is outputted by high-speed comparator.



- Low power consumption: 3 mW/ch, 54 mW/chip
- Number of channels: 18 ch/chip
- CRT: < 200 ps (LFS scintillator, □3.14 mm, 20 mm)
- Energy resolution: < 15 % (LFS scintillator, □3.14 mm, 20 mm)
- High dynamic range to operate MPPC at high over-voltage: 20 mA max.
- High count rate: >1 Mcps/chip max.

Block diagram



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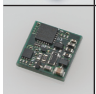
[4] Power supply for MPPC

A high-performance compact power supply is essential in optimally driving an MPPC.
Hamamatsu PET modules are equipped with a C11204-02 MPPC power supply for driving the MPPC. This compact power supply is equipped with an auto temperature compensation function that reads information from a temperature sensor mounted on the back side of the MPPC board and automatically supplies the optimum voltage to the MPPC. Note that the PET module has a single power supply mounted on the signal processing board, and this power supply applies the bias voltage to the multiple MPPC channels.
There are several MPPC power supply lineups including a high voltage MR-compatible power supply without a booster function.

Features

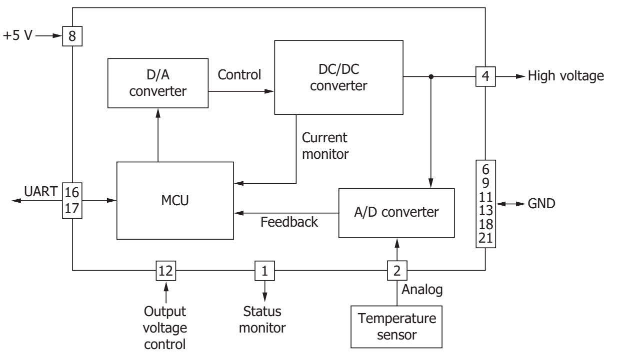
- Wide output voltage range: 40 V to 90 V (C11204-02)
- Superb temperatures stability: ±10 ppm/°C typ.
- Serial interface
- Low ripple noise: 0.2 mVp-p max.
- Finely adjustable resolution (in 1.8 mV steps)
- Over current protection

Lineup

	Type no.	Mount	Temperature stability (ppm/ °C)	Voltage boost	MR compatibility	Features
	C11204-01	Pin	±10	Inductor	No	- High precision - Low ripple noise
	C11204-02	Surface	±10	Inductor	No	- High precision - Low ripple noise - Compact 11.5 × 11.5 mm
	C11204-03	Pin	±30	External	Yes	- MR compatible - Low cost
	C11204-04	Surface	±30	External	Yes	- MR compatible - Low cost - Compact 11.5 × 11.5 mm

Block diagram examples

C11204-02



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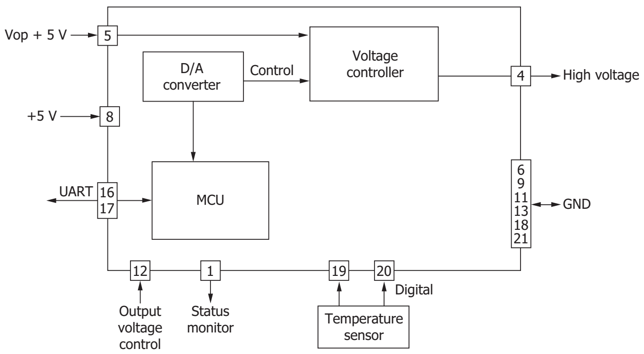
C11204-04



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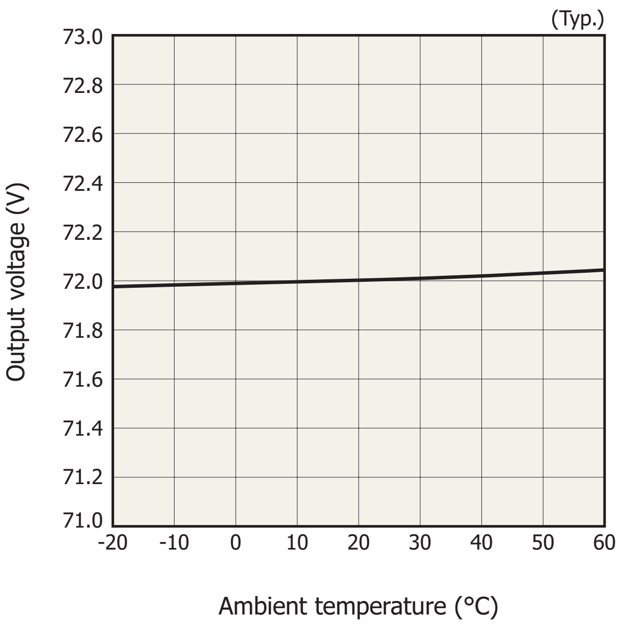
Output voltage vs. ambient temperature (C11204-02)



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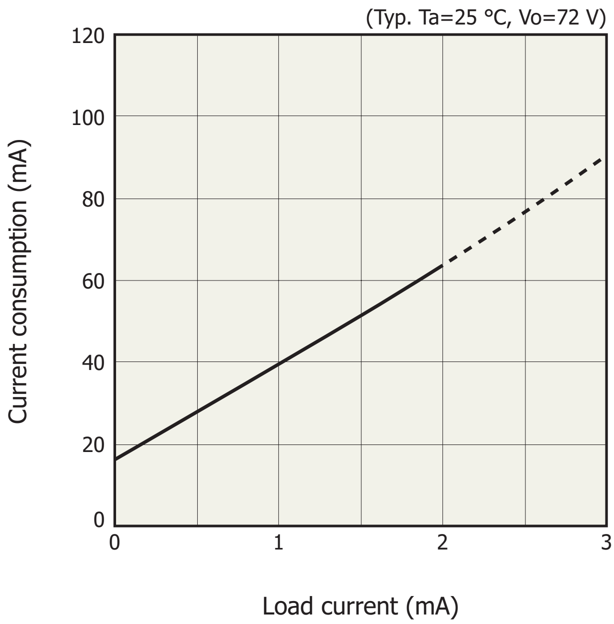
Current consumption vs. load current (C11204-02)



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3. Coincidence resolving time (CRT)

To achieve excellent CRT performance, Hamamatsu PET modules use optimal components for each section. Key parameters demanded of each component are as follows:

Scintillator
- Light output, decay time

MPPC
- Photon detection efficiency (PDE), Low after pulse, Low cross talk

Circuit
- Low noise, High dynamic range

4. Characteristics of PET module

[1] Specifications

Features

- Included all functions necessary for TOF PET
- LFS scintillator: □4.14 mm × 20 mm/ch, 12 × 12 array
- MPPC array (TSV type): □4.0 mm/ch, 12 × 12 array
- Timing resolution: 280 ps
- Automatic temperature compensation
- Digital I/F: high speed serial

Specifications example (C13500-4075LC-12)

■ Absolute maximum ratings

Parameter	Condition	Value	Unit
Supply voltage		+24	V
Operating temperature	No condensation	+15 to +35	°C
Storage temperature	No condensation	0 to +50	°C

■ Scintillator

Parameter	Value	Unit
Material	LFS	-
Dimensions / ch	4.14 × 4.14 × 20	mm
Number of channels	144 (12 × 12)	ch
Element pitch	4.2	mm

■ MPPC

Parameter	Value	Unit
MPPC type	Through-silicon via (TSV)	-
Photosensitive area size / ch	4 × 4	mm
Pixel pitch	75	μm
Number of channels	144 (12 × 12)	ch
Element pitch	4.2	mm

■ Specifications example (Typ. Ta=25 °C, Vs=+24 V, unless otherwise noted)

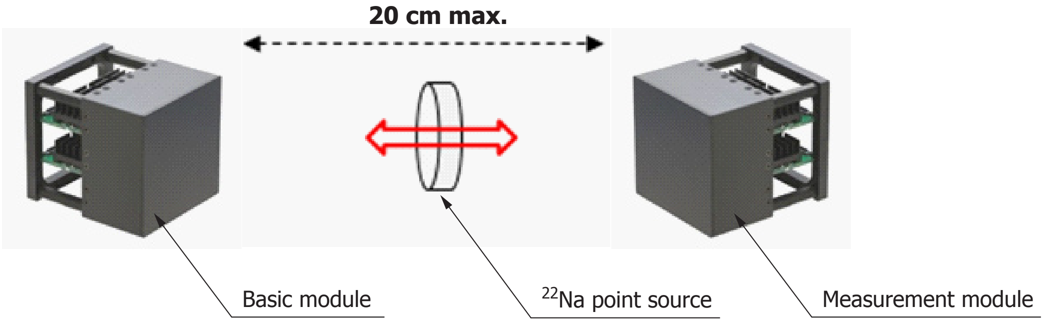
Parameter	Condition	Value	Unit
Coincidence timing resolution (FWHM)	Air cooling	280	ps
Energy resolution (FWHM)	Air cooling	12	%
Maximum count rate		500	kcps
Power supply		+24	V
Current consumption	Using C13502-02, +24 V	120	mA

[2] Characteristics for PET measurement (C13500-4075LC-12)

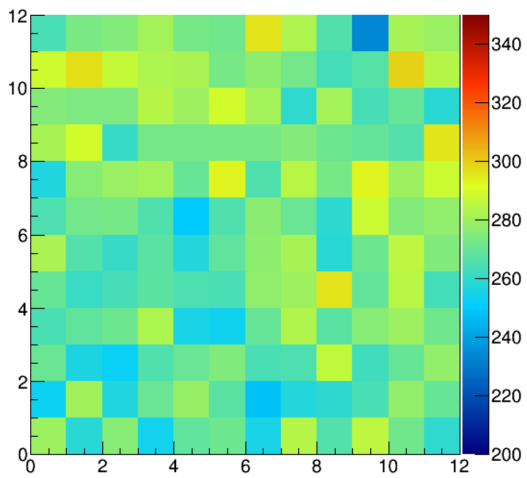
■ Example of CRT measurement

The CRT measured by pairing a reference module and measurement module a point source placed at the center between the two modules is typically 280 ps. For normal PET measurement, ^{22}Na (1 MBq) is used for the point source. In addition, the module is light-shielded, measurement is possible under room light environments. And, Vover of the MPPC for such measurements is set between 3 and 4 V.

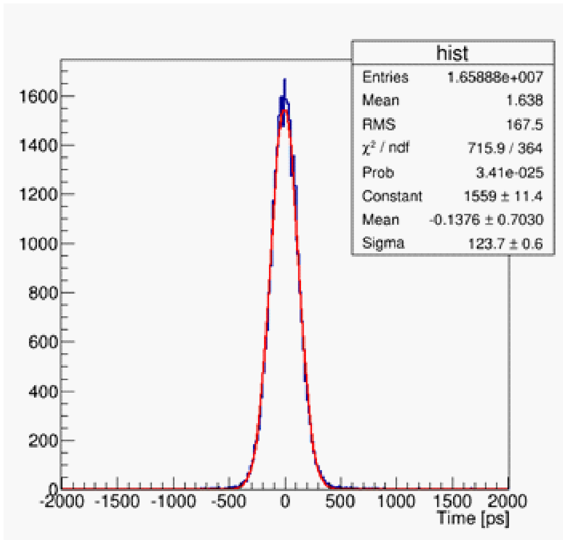
Measurement image



CRT (FWHM) value map



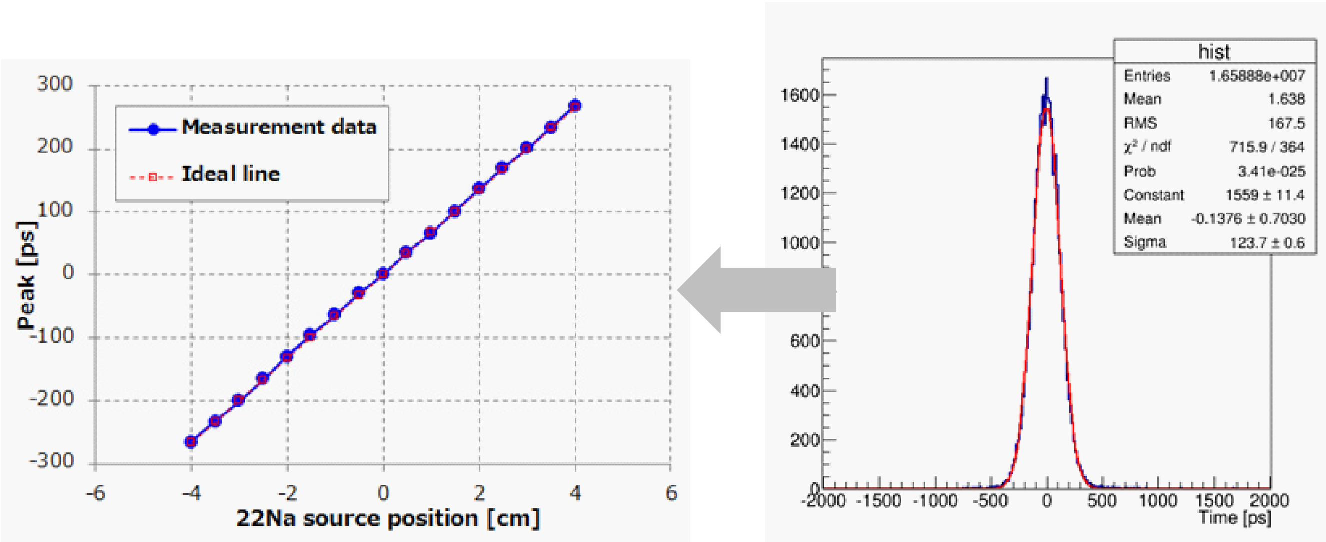
Timing spectrum of all channels



■ CRT measurement (when the point source is moved)

The peak of time spectrum shifts when the point source is moved, and the measured position converted from the time peak is well accorded with the actual position of the point source. The CRT is around 280 ps whenever the point source is located.

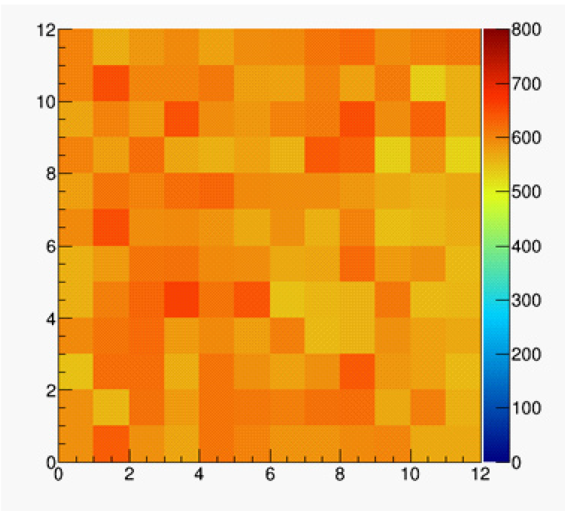
Example of measurement when the line source is moved



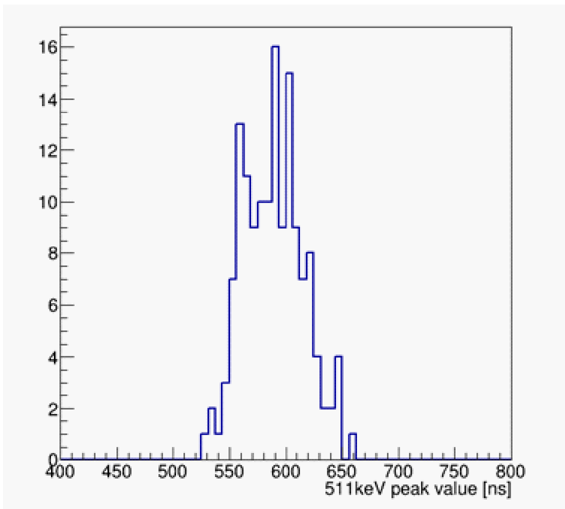
■ 511 keV peak position

The peak position at 511 keV between each channel of the PET module, in other words the variation in the signal level obtained from the MPPC, is kept within a ±10 % range.
As the Vop variation of each MPPC between MPPC arrays in a PET module is small and moreover the Vop is precisely corrected inside the PET module, even when multiple MPPCs are driven with the same voltage from a single MPPC power supply mounted on the signal processing board, excellent gain uniformity can be achieved. In addition, the fact that the variation in the light emission level of the LFS array is low is related to the small variation in the signal level.
The following graph shows the 511 keV energy peak position. The typical value is 589 ns, the minimum value 530 ns, and the maximum value 660 ns.

Value map (511 keV peak)

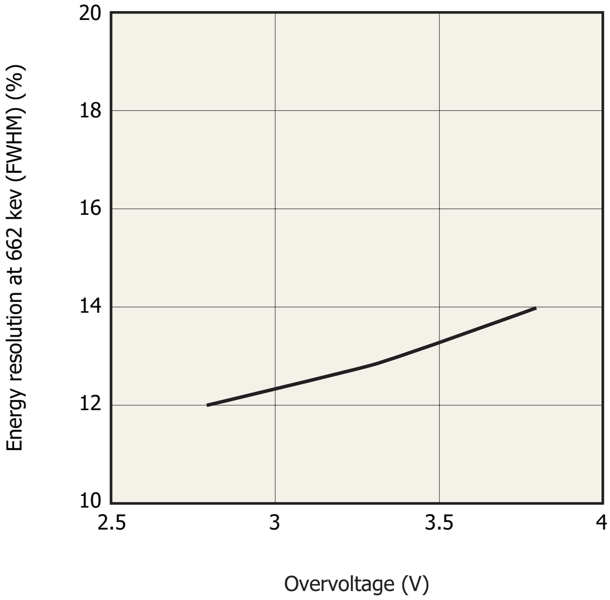


Histogram (511 keV peak)



The PET exhibits an average of about 12% energy resolution. As Vop is increased, each MPPC channel reaches saturation, which degrades energy resolution. As such, over voltage must be set to the optimum value (not too high) by taking into account energy resolution characteristics.

Energy resolution vs. overvoltage (662 keV)



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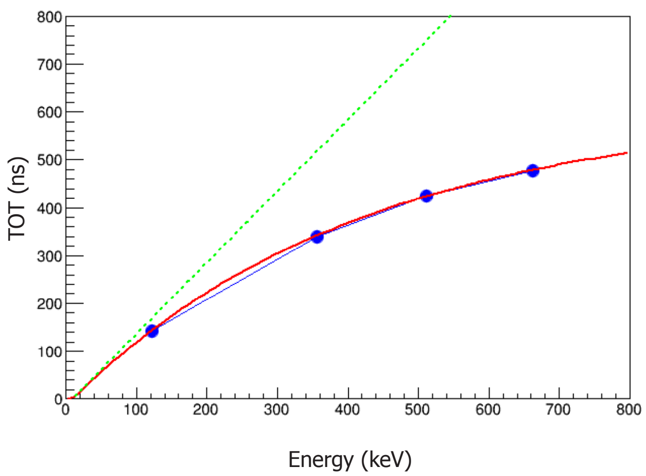
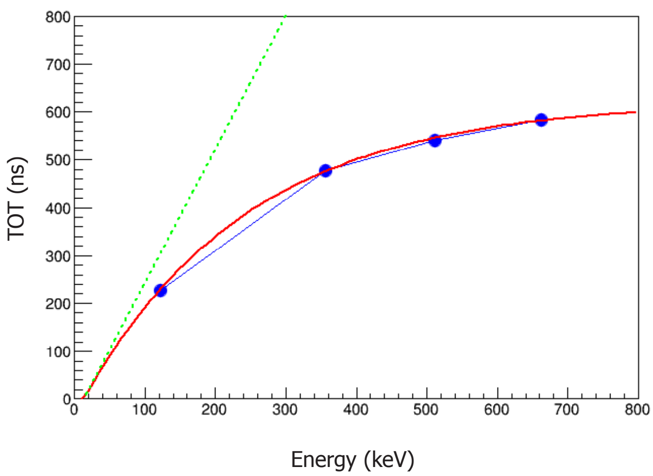
Below are an examples in which over voltage is raised too high.

Examples of linearity degradation when over voltage is raised too

Vover = 3.0 V

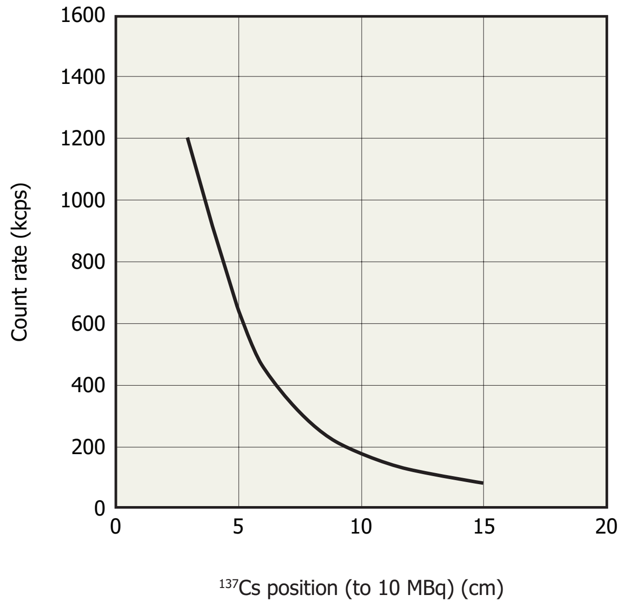


Vover = 4.0 V



The PET module characteristics vary depending on the count rate of detected events. The differences in the count rate can be verified by using a point source and changing the distance between the point source and the module. The following is an example of the count rate that is detected by the PET module with changing the position of ^{137}Cs point source.

Count rate



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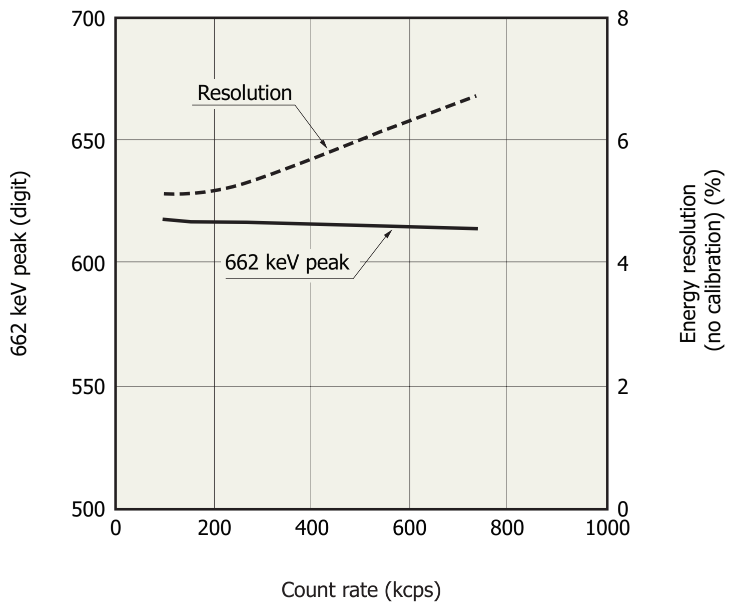
Energy resolution

The following graph shows the 662 keV peak position and energy resolution values as a function of the count rate. Even when the count rate changes, the energy peak hardly changes. The energy resolution value appears large when the count rate is high because linearity correction is not applied.

Peak position and energy resolution vs. count rate (662 keV)



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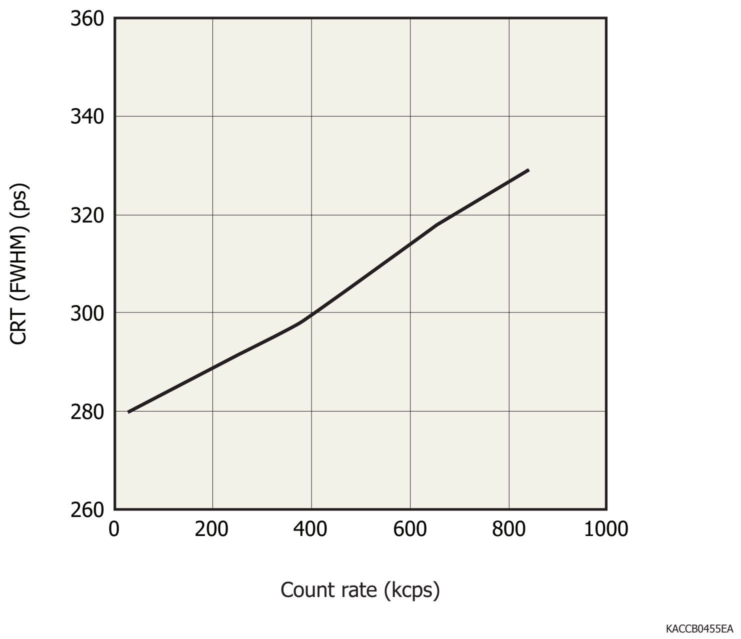
CRT (FWHM)

As the count rate increases, the CRT degrades when count rate is high because of the MPPC saturation or the upper limit of the ASIC processing capability draws near.

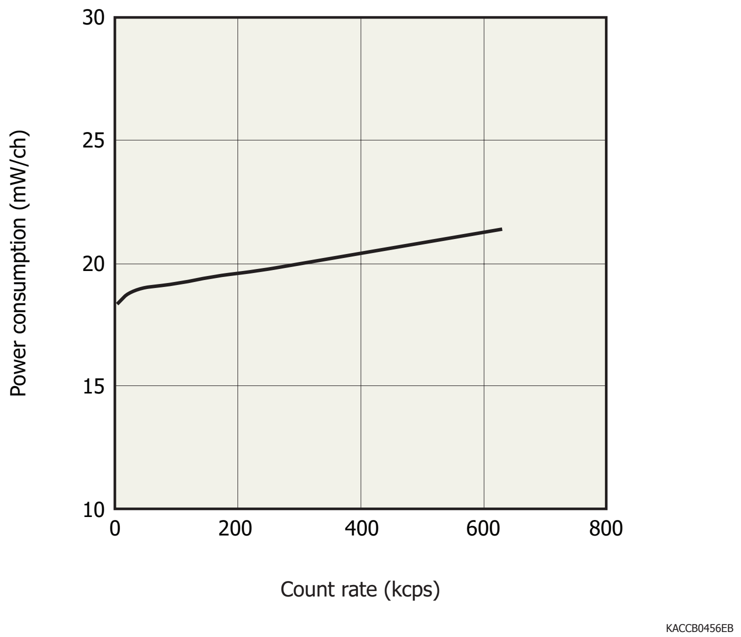
CRT vs. count rate



Power consumption

The following graph shows the power consumption of each channel. The higher the count rate, the higher the power consumption.

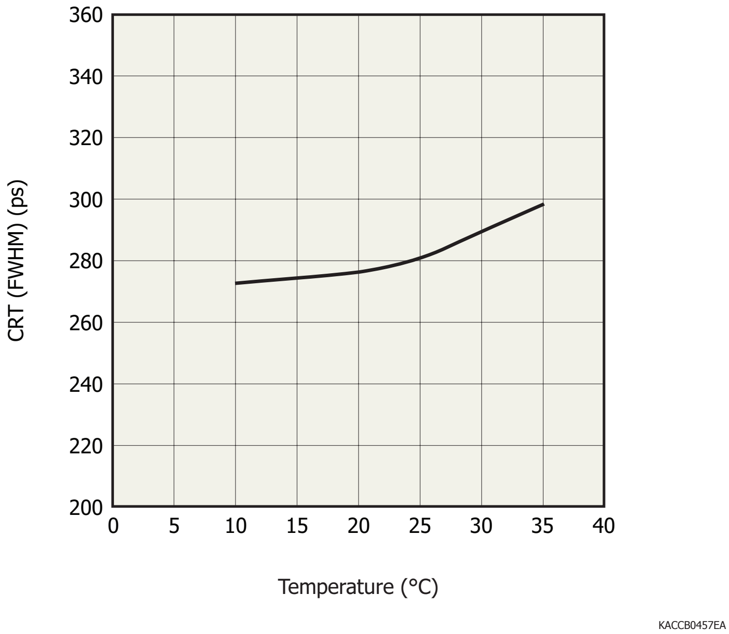
Power consumption vs. count rate



■ Temperature stability

In a high temperature environment, dark pulses due to hot carriers increase in the MPPC, and the effect of this component affects the CRT performance, degrading its characteristics. As such, when using the PET module, the MPPC, in particular, must be cooled constantly to a low temperature.

CRT vs. temperature

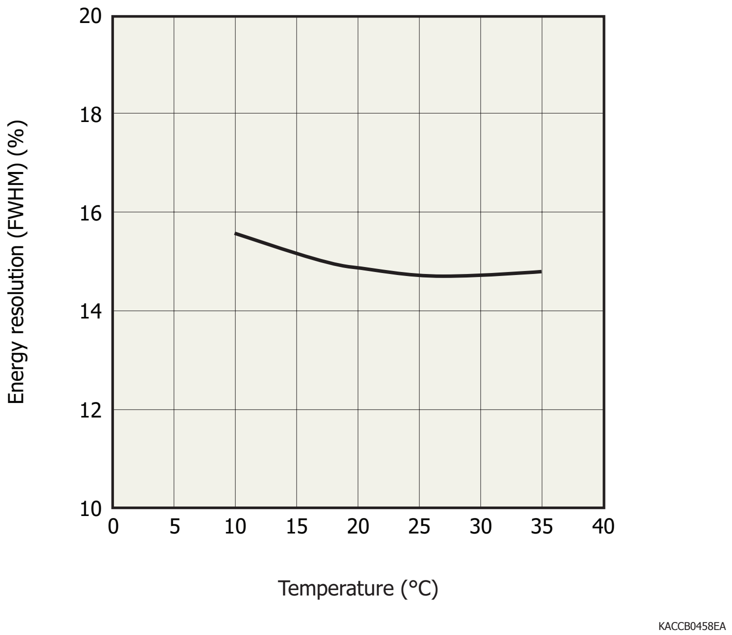


The foremost heat sources in the PET module are the ASIC, TDC, FPGA. A heat sink is attached to the signal processing board of the PET module to cool these components. As Hamamatsu uses ASICs with low power consumption, heat emission is suppressed to a low level. But, for standard modules with 144 channels less, usage in a cooled environment is recommended. In addition, if the system's thermal environment or installation space is severe, customization is also possible. The layout is designed so that the heat from the ICs hardly reaches the MPPC by connecting the MPPC and the signal processing board with FPC.

Energy resolution

The energy resolution and peak position when the temperature varies are as follows. The variation in the peak position indicates the temperature characteristics (60 mV/°C) of the MPPC's Vop, but the temperature is automatically compensated by the MPPC power supply. Further, there is hardly any effect on the power consumption when the temperature increases.

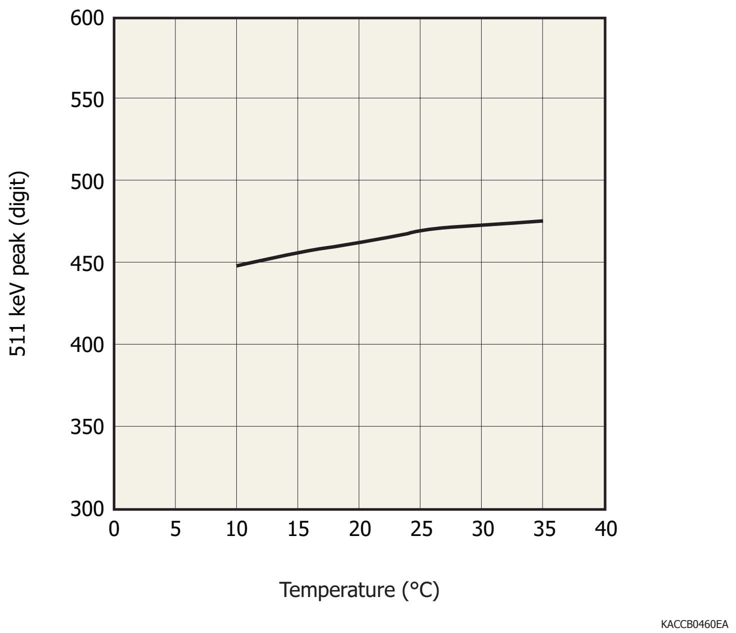
Energy resolution vs. temperature (511 keV)



Peak position

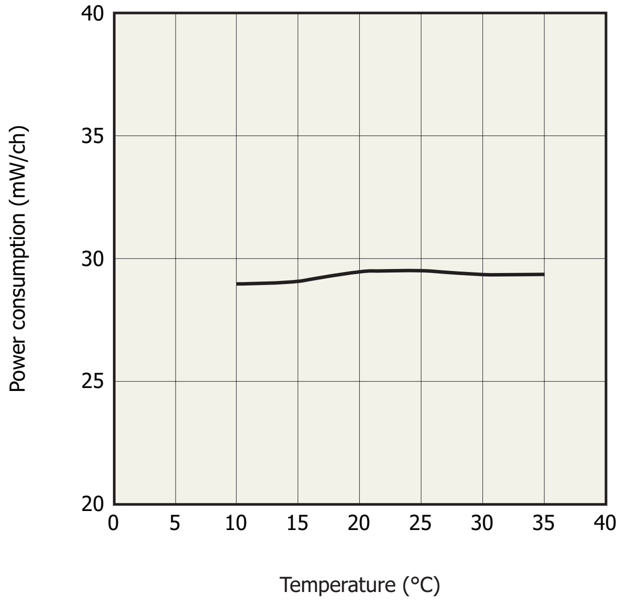
The temperature consumption of bias voltage is performed. (60 mV/°C).

Peak position vs. temperature



Power consumption

Power consumption vs. temperature



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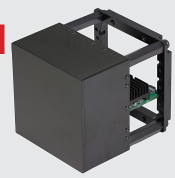
[3] Lineup

The C13500-4075LC-12 and C13500-3075LC-16 have the MPPC and scintillator coupled in a one-to-one arrangement. The C13500-4075LC-12 employs a 4 mm scintillator and is the most standard type for the whole body PET for the human body. For systems that require high resolution, the C13500-3075LC-16 is recommended.
The C13500-6075LC-16 employs a 6 mm, 8 × 8 ch MPPC. The scintillator spacing is half of the MPPC. □The 3 mm scintillator provides the same resolution as the C13500-3075LC-16, but because the total number of MPPC channels is 64, only a single signal processing board is required. This enables easy low cost, low power consumption heat radiation design. But the upper limit of the count rate is inferior to the other two products.

Type no.	C13500-4075LC-12	C13500-3075LC-16	C13500-6075LC-16 (Light sharing type)*
Photo	NEW 	NEW 	NEW 
Scintillator size / ch	4.14 × 4.14 mm (12 × 12 ch)	3.14 × 3.14 mm (16 × 16 ch)	3.14 × 3.14 mm (16 × 16 ch)
MPPC size / ch	4 × 4 mm, 75 µm pitch (12 × 12 ch)	3 × 3 mm, 75 µm pitch (16 × 16 ch)	6 × 6 mm, 75 µm pitch (8 × 8 ch)
Count rate	< 500 kcps	1 Mcps	< 250 kcps
CRT (FWHM)	< 280 ps	< 280 ps	< 400 ps
Power consumption	2.6 W	5 W	1.3 W

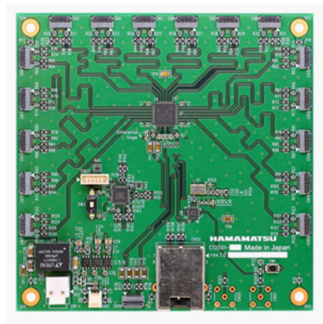
* A method in which light output from the scintillator is read out using an MPPC array with spacing greater than that of the scintillator.

■ Optional module

Hamamatsu also provides sub modules that are necessary for PET measurement.

Clock distribution unit C13501-03

The C13501-03 provides sync signals that the PET module requires. It can distribute to eight signal processing units. It is also possible to distribute to up to 128 units by using several C13501-03s. The C13501-03 is designed on the assumption that it is connected to the PET module C13500 series.

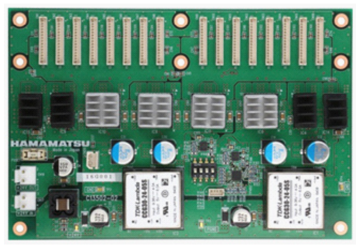


Features

- Output signal: LVDS
- Distributes to 16 units

Local power supply C13502-02

This unit is able to provide a power supply that is required for the PET module. The C13502 can distribute power to eight PET modules. This unit is the ideal power source to operate the PET module C13500 series.

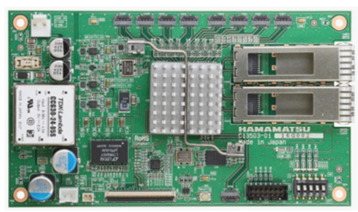


Features

- The power supply is delivered to the PET module.
- Distributes to 16 signal processing units

Relay board C13503-01

This C13503-01 gathers measurement data from PET module C13500 series and output data to PC via an optical fiber with high-speed data transfer.



Features

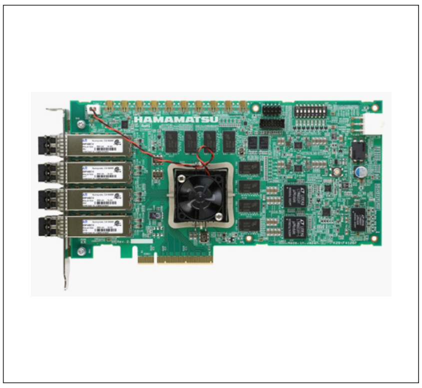
- High speed interface
  10 Gbps (SFP)
  3 Gbps (Metal)
- Connects to 8 PET modules as cascade line

Interface board C13504 series

The C13504 series attach to the PCIe connector on a PC and easily collect measurement data in a PC with high-speed data transfer by connecting C13503-01.

Features

- High speed optical interface
  C13504-01: 10 Gbps (SFP) cage × 2
  C13504-02: 10 Gbps (SFP) cage × 4
- DDR4 memory 8 GB (C13504-02)
- Windows 7/10 (64-bit), CentOS 6.7 (64-bit)

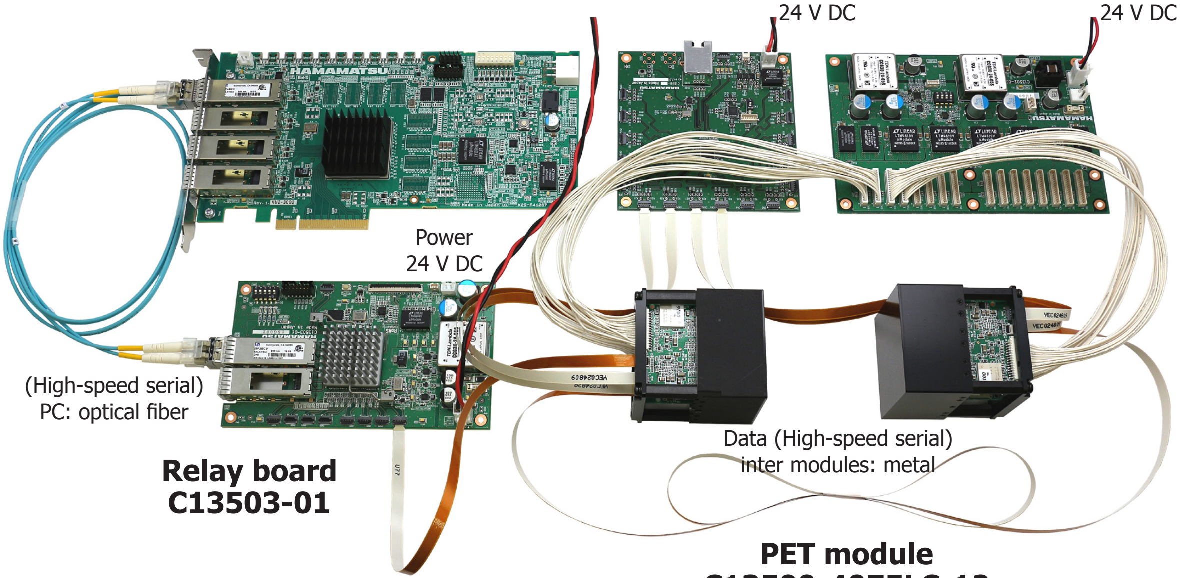


C13504-02

5. How to use

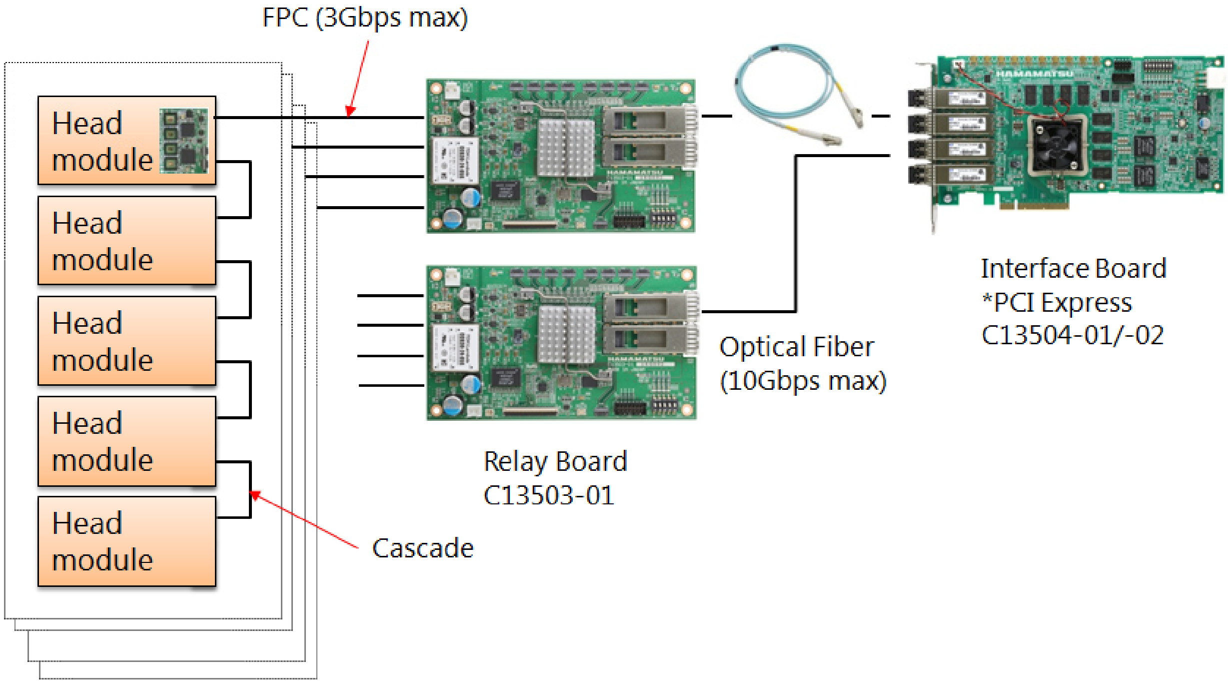
Connection method

Image of module connection



The signal processing boards of each PET module are connected in a cascaded fashion, and the last board is connected to the relay board C13503-01. The relay board is connected to the interface board with a fiber optic (SFP).

Image of cascade connections



The following is an illustration of a ring configuration.

Illustration of connection (ring configuration)

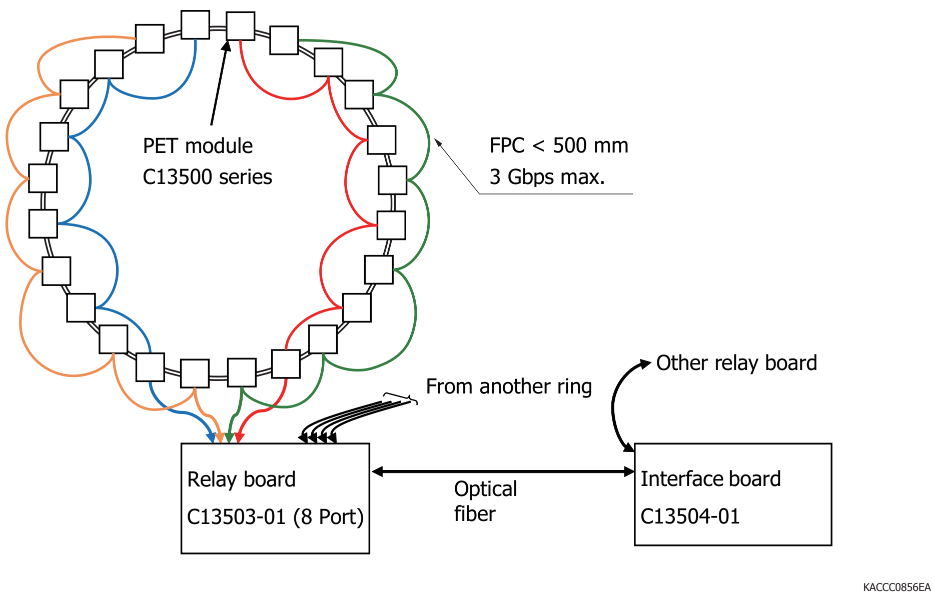
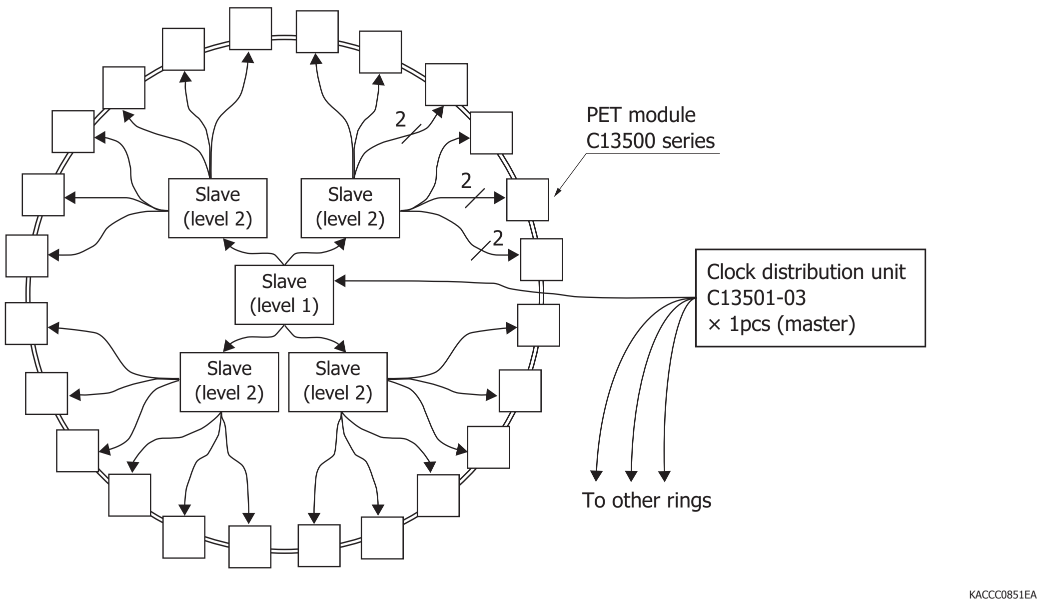


Image of connections for clock distributor

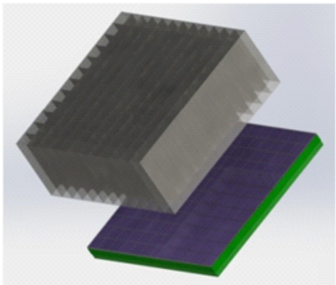


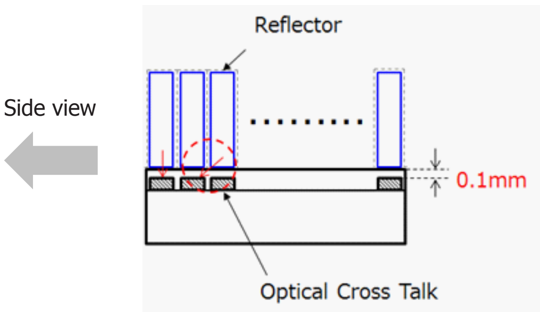
6. FAQ

Structure

Q: How are the crystals glued to MPPCs?

A: Coupled using a transparent adhesive.





The typical optical characteristics of the MPPC's protective resin and coupling resin are as follows:

- MPPC resin:
  Refractive index: 1.5 to 1.6
  Hardness: 70 to 80
- Refractive index: 1.5 to 1.6
  - Clear-type
  - Room temperature or Low-temperature curing

In addition, reflectors are inserted between each scintillator channel for optical isolation. Optical crosstalk exists between each MPPC channel, but the MPPC used in the PET module has a thin protective resin to reduce the effects of crosstalk as much as possible.

Q: How strong is the light-shielding property of the module?

A: A case with high light-shielding property is used. As such special light-shielding measures are not necessary in indoor environments.

Q: How should the PET module be cooled?

A: The area where heat is generated the most in the PET module is ICs mounted on the signal processing board. A air-cooled or water-cooled heat sink is provided on each board. So radiate the heat from the signal processing board while taking into account the conditions on the system side. Heat sinks are fixed to the board with an adhesive and screws. As a cooling guideline, at room temperature, the temperature increase ΔT on the board is 5 to 10°C. In addition, the following module, which connects the MPPC and the signal processing board with FPC to minimize the thermal effect reaching the MPPC, can also be provided.

■ Signal processing board

Q: What is the size of signal processing board?

A: The dimensions are 45.2 mm × 34.2 mm.

Q: What is the power consumption per signal processing board?

A: 1.3 W

Q: How many MPPC channels can be connected to a single signal processing board?

A: 72 channels. Each ASIC can connect to 18 MPPC channels, and each board has four pieces of ASIC.

Q: How are the MPPC and ASIC connected?

A: Connection via connectors mounted on the MPPC board and signal processing board. In addition to connector connection, an FPC connection type can be provided.

Q: Can the data cable (signal processing board) cascaded?

A: Yes

Q: How many can be cascaded of signal processing board?

A: Depends on the event rate. The limit for cascaded is 3 Gbps.

Q: Does each signal processing board needs power supply connections?

A: Yes

■ Clock distributor

Q: Does each module needs two clock connections?

A: Yes

Q: Can it be used 3 stages to support more than 128 modules?

A: A total of 17 modules will be needed - 1× master, 16× slave

Q: Are all clocks same delay? It looks that the trace delay is different.

A: There will be approximately ±25 ps skew.

Q: How was the master clock generated? What is the frequency?

A: Use the crystal oscillator on the clock board or use a pulse generator to apply the signal through the LEMO connector.
The frequency is 10 MHz or 50 MHz. The mode can be switched in the following manner.

Q: How was the master Sync generated? What is the frequency?

A: Signals can be applied according to the following flow:
a command on the PC ⇒ Sync signal generated on the relay board ⇒ applied to the clock board.
It is also possible to use a pulse generator and directly apply the signal to the clock board through the LEMO connector.
There is no frequency specification. Simply apply it once after turning the power on. Note that the clock and sync signals do not need to be synchronized.

Q: Is the Sync used as the "TDC start"? What is the requirement in terms of jitter?

A: The Sync signal simply resets the counters in the TDC and FPGA.
There is no jitter requirement for the sync signal.

■ Data acquisition

Q: How many connections does it support of Relay board?

A: 8 FPC connection is available

Q: Can the relay board is cascaded ?

A: Yes, the relay board can be cascaded via an optical fiber (SFP).

Q: What protocol does it support on the SFP?

A: Hamamatsu proprietary interface

Q: What is data format like?

A: Please see below

Name	Size [bit]	Description
Blank	3 (MSB)	Blank
Board_No	10	Board number
TDC_No	2	Channel of TDC
Index	4	Low 4 bits of Start_CT
Time	14	15.625 ps resolution fine timing data
Start_CT	32	100 ns resolution coarse timing data
Ch	7	MPPC channel
Energy	8	4 ns resolution ToT energy data
Blank	48	Blank

Q: What is needed in PC to interface with relay board?

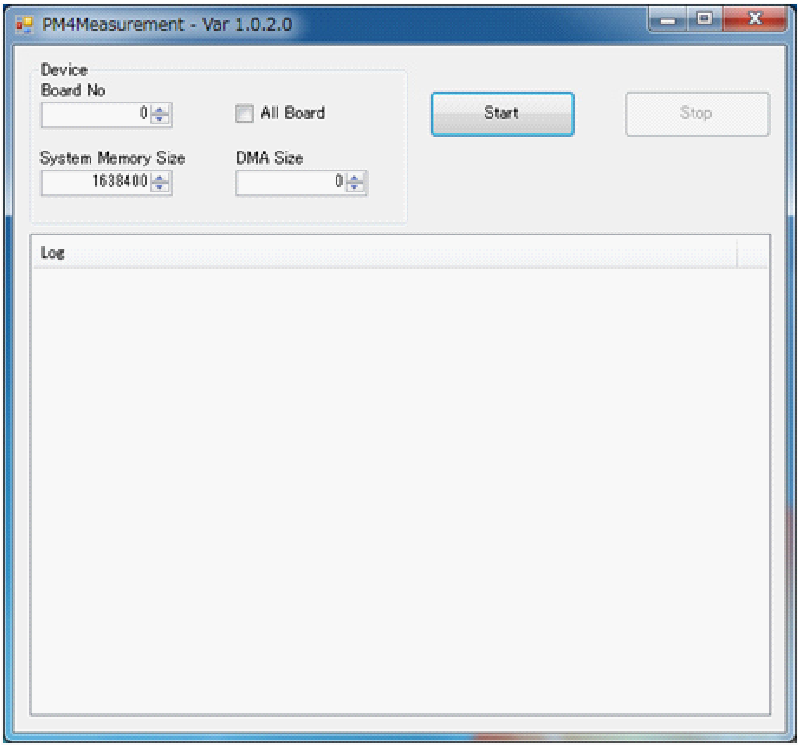
A: Fiber connector is.

Q: How to acquire data on PC?

A: The interface board copies the data onto PC memory. The application accesses the memory to acquire the data.

Q: Does Hamamatsu provide the software?

A: Sample software shown in the following figure is included.



Q: What is the max bandwidth of each metal data link?

A: 3 Gbps is.

Q: What is the max bandwidth of SFP?

A: The SFP is 12.5 Gbps and the effective bandwidth is 10 Gbps. Assuming 8 (already 16 blocks cascaded together) metal links are combined into one SFP and the total bandwidth would be 12.8 Gbps. If 3 relay boards are cascaded, the bandwidth needed is 38.4 Gbps, which is more than 10 Gbps. In other words, if the total output bandwidth is 12.5 Gbps (effective 10 Gbps) to support 320 blocks, each block would have 31.25 Mbps or 0.3125 Mcps. If 400 blocks, then 25 Mbps or 0.25 Mcps.

Q: What is the bandwidth of computer and the interface card?

A: The interface board is PCI Express 2.0 × 8. Theoretical bandwidth is 26.4 Gbps.

■ Power sequence

Q: Is there any power sequence requirement?

A: Relay board ⇒ Clock board ⇒ Power supply (PM4 board)

Q: Any protection on the power, such as overvoltage, undervoltage, overcurrent and reverse polarity?

A: The power supply board and the relay board have a fuse and rectifier.

■ Cable connection

Q: What is the max length of clock cable?

A: 1 m

Q: Do the clock cables need to be same length?

A: Yes, to prevent clock skew

Q: What is the max length of data cable?

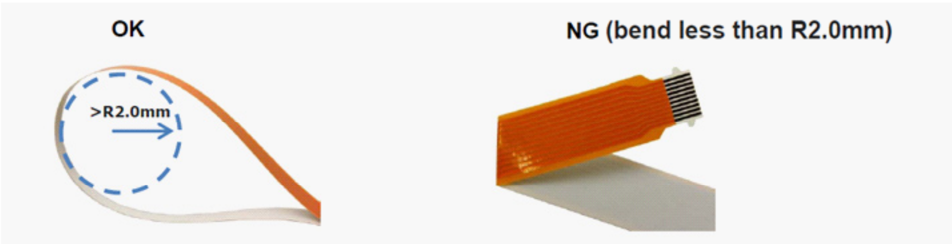
A: 1 m

Q: What is the max length of power cable?

A: 1 m

Q: Can the clock cable be twisted?

A: Bending of the FPC must be greater than R2.0.
(The FPC must not be bent so much that wrinkles remain.)
Also, do not bend the terminal area or near the terminal area (area where the reinforcing plate is present).



Q: Can the metal data cable be twisted?

A: Yes, if they are not twisted with each other.

Q: Are the MPPCs readout individually or through a resistor network?

A: Individual output (a resistive network is not used).

The content of this document is current as of January 2017.

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Cat. No. KACC9009E03 Jan. 2017