/Inritsu

Pulse Measurements
Vector**Star**®

The Anritsu Vector**Star**™ MS4640B series of Vector Network Analyzers are capable of generating and measuring pulsed signals when equipped with Option 035 IF Digitizer and Option 042 PulseView™. Four internal signal generators are included enabling singlet, doublet, triplet, quadruplet, and/or burst signal generation. Pulse measurements include pulse profile, point-in-pulse, and pulse-to-pulse capability.

Option 035 IF Digitizer
Option 042 PulseView

Pulse Modulator Test Sets are available to pulse the RF stimulus and/or provide receiver gating[1] (modulation). The Pulse Modulator Test Set frequency range is limited to that of the VNA with which it is used.

SM6628, 70 kHz to 40 GHz. Provides the MS4642B and MS4644B VNA with source modulation.
SM6629, 70 kHz to 40 GHz. Provides the MS4642B and MS4644B VNA with source and receiver modulation.
SM6630, 70 kHz to 70 GHz. Provides the MS4645B and MS4647B VNA with source modulation.
SM6631, 70 kHz to 70 GHz. Provides the MS4645B and MS4647B VNA with source and receiver modulation.

Pulse Modulator Test Sets require direct access loops found in:

Option 051 Direct Access Loops
Options 061/062 Active Measurements Suite

Vector**Star**®

MS4640B now with:
- Option 035 IF Digitizer
- Option 042 Pulse**View**™
- Pulse Modulator Test Sets (required for RF pulsing)
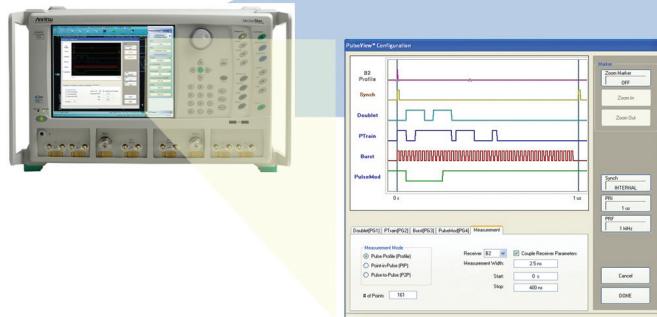
Providing:
- **An innovative high-speed digitizer architecture**
- **The industry's highest resolution measurements**
- **The longest record lengths**
- **Independent receiver measurements**
- **An intuitive graphical configuration tool**
- **Instant results on measurement parameter change**s

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[1] Receiver gating is generally only required for higher power antenna and related applications, where undesired pulses could saturate the VNA receiver.

I. Introduction

Pulsed S-parameter and related measurements are critical for many common applications:
• Tests of system and subsystems designed to operate in pulsed conditions.
• Pulsed system and subsystem measurements that may be needed examine phase and amplitude distortions at pulse onset or droop later in a pulse, as well as in cases where the subsystem was designed to operate pulsed.
• Measurement of devices and components that are designed to operate in pulsed conditions.
• Device characterization, where pulsed operation is required for thermal reasons (for example, un-mounted power devices).
• Device characterization, where pulsed operation is required to explore certain device characteristics. Trapping and thermal parameter characterization are two common tasks that benefit from pulsed measurement.

When making pulsed measurements for the applications listed above, many aspects of the test system may be of interest. A VNA is typically used when there is a need for a measurement correction, phase data, or for a more integrated test suite.

II. Pulse Capability Overview

A. Terms and synonyms

A number of other terms for pulse measurements are commonly used. This list will help to explain terms used elsewhere in this document.

Duty cycle or duty factor – Pulse width relative to the pulse period, often expressed as a percentage. Common values range from 0.01 % to 50 %. This may pertain to a stimulus RF pulse, a bias pulse, a receiver gating function, or a profiling pulse, so context matters.

PRI and PRF – Pulse repetition interval (= pulse period) and pulse repetition frequency (= pulse repetition rate). PRI=1/PRF.

Pulse width and delay – These two numbers together with the PRF uniquely define a pulse train; however, there are cases when there are multiple pulses per period (see below).

Pulse patterns (singlet, doublet, quadruplet, and burst) - Defines what occurs once during each pulse period of the master clock. The default is a single pulse, hence the term 'singlet'. Sometimes more than one pulse is required per master clock period, hence other settings are available. "Burst" is a user defined number of pulses within a period. All sub-pulse widths are the same and all intra-sub-pulse gaps are the same; see Figure 1. (Multiple pulses per period are particularly common in radar applications.)

Record length – The amount of time to be captured within a measurement. This is dependent on the PRI and duty cycle, the amount of averaging requested, and the measurement mode.

Synch pulse (T_0) – This pulse establishes global timing and can either be generated by the MS4640B Series instrument or by an external pulse generator (in which case, the MS4640B Series can accept that signal as an input). For example, when coherence is needed among pulse generators, a common synch pulse is often shared between them. Synchronization of 10 MHz timebases may be needed as well.

T_{start} and T_{stop} – These terms apply to pulse profiling setups and define the time range of interest relative to the synch pulse for profiling. Together with the number of time points, the measurement window width, and the requested averaging, these define the acquisition and processing behavior for pulse profiling. T_{start} and T_{stop} can also be used as parameters for plotting data in pulse-to-pulse measurements.

Measurement width or Aperture – This measure of time describes what portion of the pulse should be analyzed in a given measurement. For point-in-pulse and pulse-to-pulse measurements, it is the section of the pulse to be processed (with a delay parameter specifying where, relative to T_0, this window should be). For pulse profiling, this width is 'swept' across the pulse with processing across the measurement width being performed at each time step requested between T_{start} and T_{stop}.

B. Pulse measurement modes: Pulse profiling (PP), point-in-pulse (PIP), and pulse-to-pulse (P2P)

Point-in-Pulse

This measurement quantifies S-parameter data somewhere within a pulse. One may want to avoid edge effects or just measure the pulse as a whole, but the structure within the pulse is not of great interest nor is the variation from pulse to pulse.

A point-in-pulse measurement is illustrated in Figure 2. Data is acquired over a requisite length of time; the user specifies the interval of interest relative to a synch pulse T_0. This interval is usually quantified in terms of a "Delay" and a desired "Measurement Width" or aperture.

In addition, a level of averaging can be specified in which case this same interval is analyzed on multiple pulses and the results combined. Pulses are sampled with the same coherent clock and phase information is maintained.

The diagram in Figure 2 illustrates an example where the width of interest is eight samples. Only a single sample is required for measurement; about four hundred million samples are possible, limited only by the record length of the instrument.

Point-in-pulse measurements are often made with swept frequency or power and plotted as such. In these cases, the above process is simply repeated for multiple frequencies and power levels.

Pulse Profile

The pulse profile measurement focusses on the structure of data within the pulse. Characteristics like overshoot or undershoot, droop, and edge response are measured, while the frequency and power are kept constant (although they can be varied between acquisitions).

This data is normally plotted vs. time to indicate position within the pulse (measurement normally is setup as constant frequency (CW) and constant power, but more complex measurements can be orchestrated using multiple channels or setups).

Variation between pulses is often not observable in this measurement, which may represent an average over a number of pulses. One can structure the measurement, however, to look at behavior from an absolute start time with no averaging in order to look at the complete evolution over multiple pulses.

A measurement example is diagrammed in Figure 2.

A start time and a stop time (T_{start} and T_{stop}) are specified along with a number of time points relative to the synch pulse (T_0) to describe the portion of the pulse to be profiled. The measurement may begin before the physical pulse is at the DUT and end after the pulse is no longer being applied to the DUT, but the data must be interpreted appropriately in all cases.

A measurement width is also specified (eight samples in the diagram). Additional averaging can be imposed across multiple pulses, as discussed previously. As with point-in-pulse, the range of allowed widths is large. The measurement windows are allowed to overlap (and will if ($T_{stop} - T_{start}$) / (NumTimePoints – 1) < Measurement Width), which performs a variety of time-based smoothing operations on the data. A common setup is 10 to 20 non-overlapping (or slightly overlapping) profiling time points within a pulse, but application requirements may dictate very different parameter choices.

Pulse-to-Pulse

Pulse-to-pulse measurements concentrate on variations between pulses that begin with an absolute start time. This type of measurement can be described as a hybrid of the first two methods. Normally one will pick a section of the pulse to measure, and then the progression over a number of pulses is plotted (versus time or index of the pulse number).

This process is illustrated in Figure 2, where the first three pulses are shown. The delay from T_0 (Delay in this diagram) is the same for each measurement window of interest and the window in each pulse is processed separately.

Pulses are treated in an absolute fashion, so averaging of multiple pulses is not useful and is not available. As with pulse profiling, this measurement is performed at constant frequency (CW) and constant power. One could orchestrate measurements that cycled through a variety of frequencies and power levels using multiple channels or setups.

C. Pulse generation: singlet, doublet, triplet, quadruplet, and burst

The combination of Option 035 IF Digitizer and Option 042 PulseView enable use of four pulse generators. As described earlier, the definition of the types of pulses that can be generated are based on what occurs once during each pulse period of the master clock. The default is a single pulse, hence the term 'singlet'. Sometimes more than one pulse is required per master clock period, hence other settings are available. "Burst" is a user defined number of pulses within a period. All sub-pulse widths are the same and all intra-sub-pulse gaps are the same. Pulse generators can be configured as standard or inverted polarity. See Figure 1 for diagrams of the pulse generation modes and associated PulseView Configuration user interface.
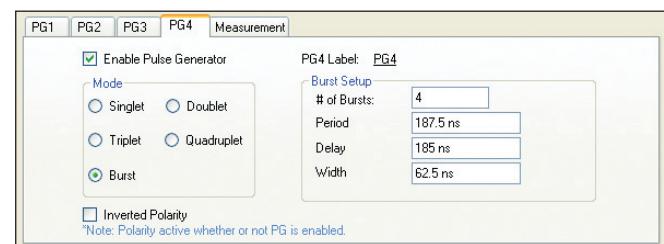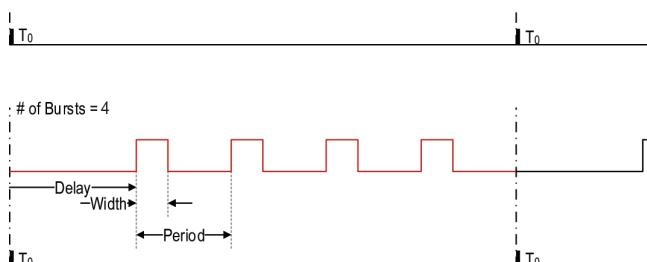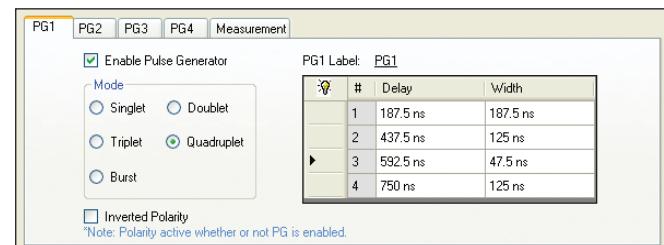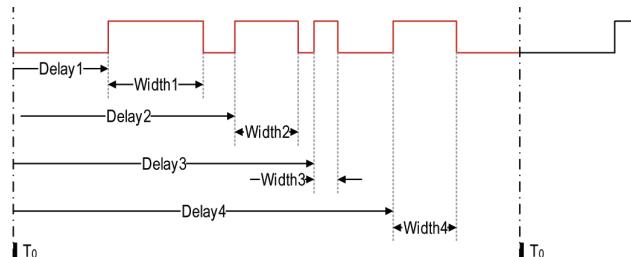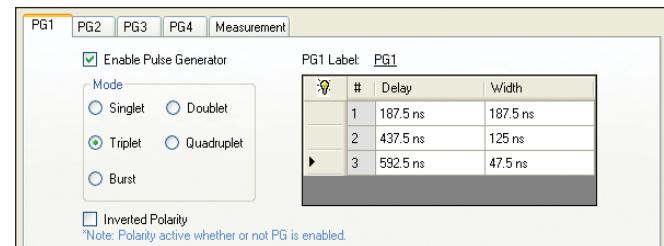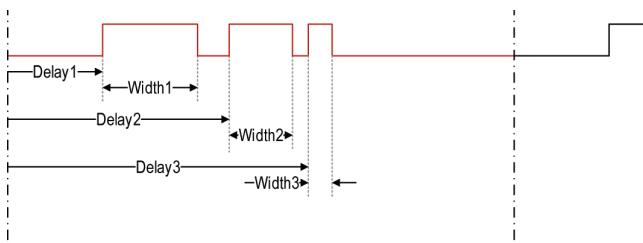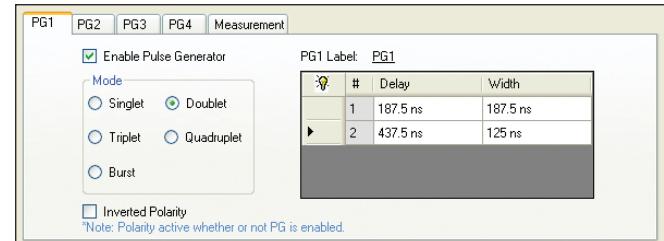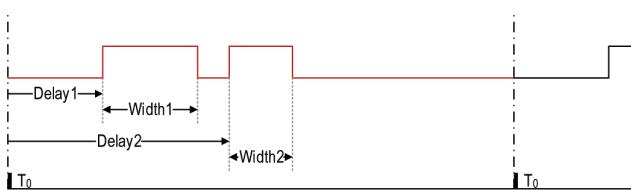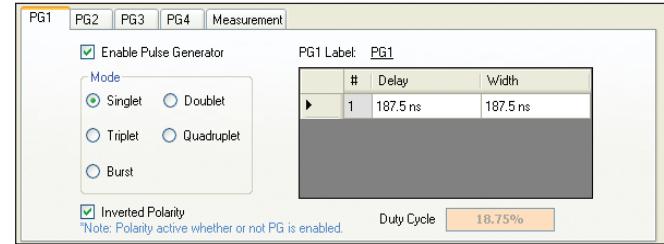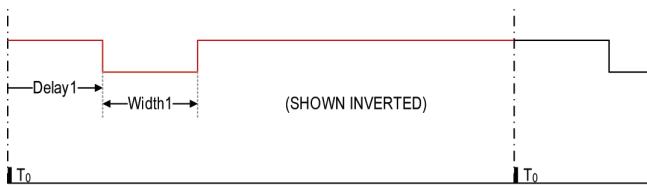
Figure 1. *Pulse Generation Modes and Associated PulseView Configuration User Interface.*
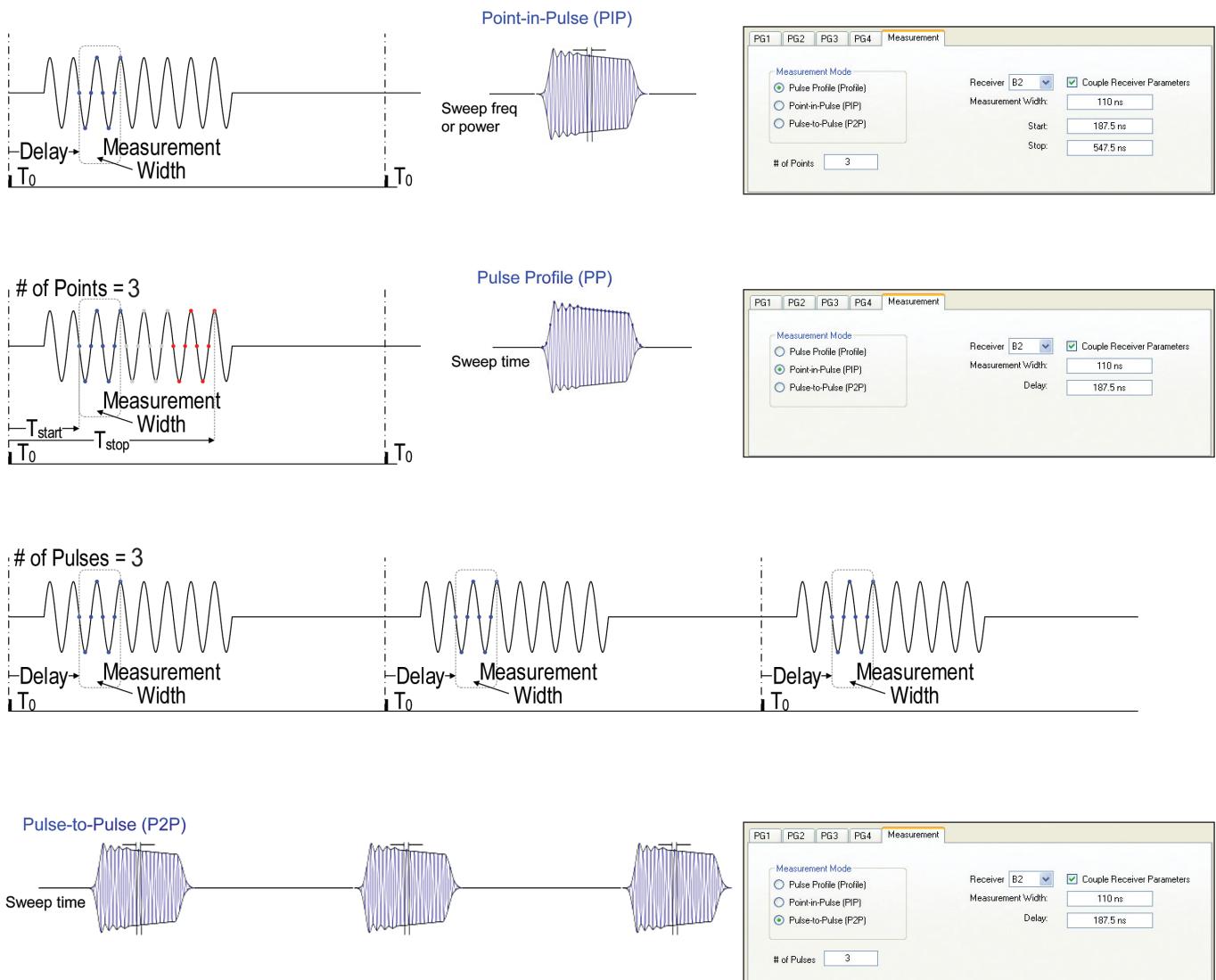
Figure 2. *Pulse Measurement Modes and Associated PulseView Configuration User Interface.*

D. RF stimulus modulation and receiver gating

To provide the DUT with a pulsed RF stimulus, a Pulse Modulator Test Set must be utilized. Pulse Modulator Test Sets also include reference coupling, which can be useful in many applications. The block diagram of a fully configured Pulse Modulator Test Set (four modulators) is shown in Figure 3. The base model has only the source path modulators and does not include the elements designated with dashed lines.
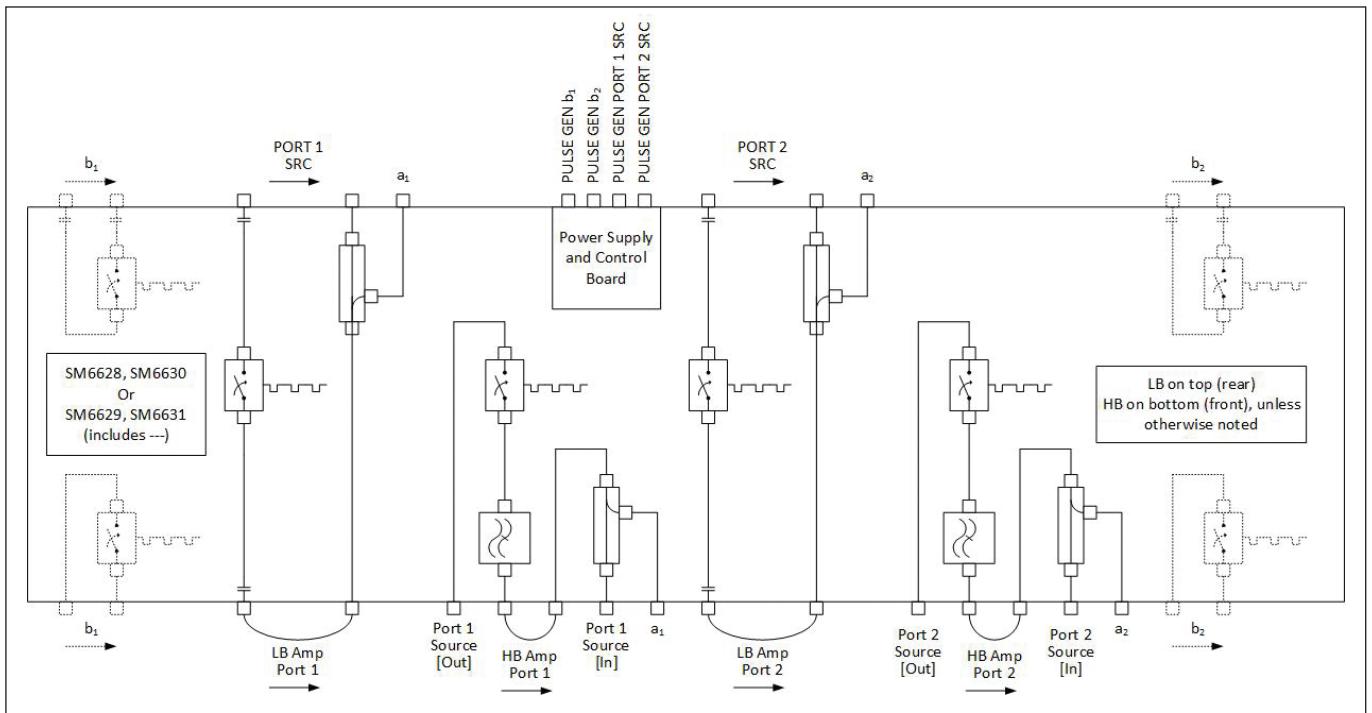
Figure 3. *Pulse Modulator Test Set Architecture.*

The receive side paths of the Pulse Modulator Test Sets (shown in dashed lines above) are typically only used in specific, very limited applications. For example, in certain antenna measurement applications, the transmit leakage pulse may be large enough to compress the receivers such that it cannot accurately measure the return pulse (which occurs later in time). An RF "Modulator" can be used to prevent this leakage pulse from being processed by the receiver so one can concentrate on the pulse from the target or some other object. This type of special receiver-side modulation is applicable to all measurement methods and is more of a tool to prevent measurement distortion rather than a tool for acquisition in itself.
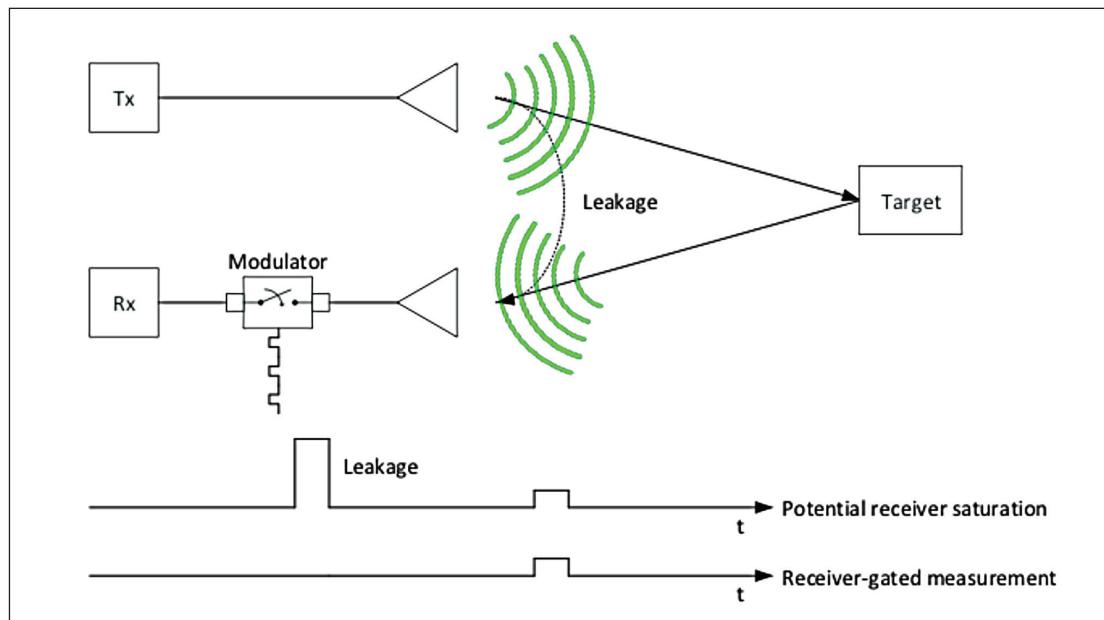
Figure 4. *Receiver-gated measurements.*

III. Pulse Measurement Setup Configurations

A. 5 examples

The diagrams and descriptions below describe five common pulse measurement setup configurations for five common measurement applications.
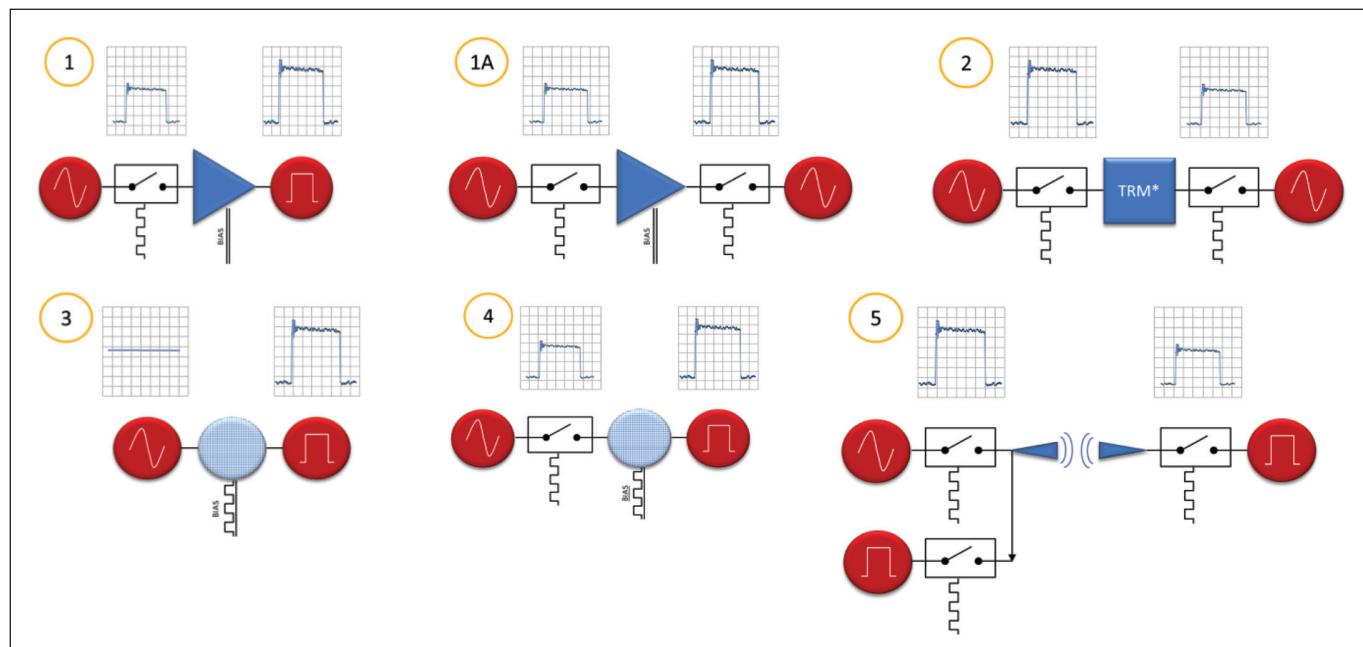
1. <u>RADAR system component test using 2-modulator test set</u>. User is testing a component in which the normal use is with a uni-directional pulse for a typical component characterization.

2. and 1A. <u>RADAR system component test using 2-modulator test set</u>. User may either be testing a component in which the normal use is with a uni-directional pulse, but the user wants to include the response to a reverse direction pulse for a complete component characterization (1A) or a T/R module in which bi-directional RF pulsing is required (2).

3. <u>On-wafer power amplifier device test with CW RF and a pulsed bias</u>. User will utilize internal pulse generators to control the bias to the on-wafer device to compensate for the lack of availability of a heat sink and to minimize the thermal effects.

4. <u>On-wafer power amplifier device test with pulsed RF and a pulsed bias using a 2- or 4-modulator test set</u>. The amplifier intended end-use is a pulsed application (commonly for use in a RADAR system component), so the user will stimulate the device with a pulsed RF signal as well as utilize internal pulse generators to control the bias to the on-wafer device to compensate for the lack of availability of a heat sink and to minimize the thermal effects. Timing between pulses is important to ensure the RF is applied to the device while it is turned on. Normal use of the device is with a uni-directional pulse, but the user wants to include the response to a reverse direction pulse for a complete component characterization.

5. <u>Bi-directional antenna test with pulsed signals</u>. User may be concerned with leakage from a large pulsed transmit signal saturating their receiver and will use a 4-modulator test set to both pulse modulate the RF as well as gate (via pulsing) the received signal.

IV. Review of Pulse Measurement Methodologies

A. "Historic" Wideband Method

The wideband pulse measurement method may be used when the majority of the RF pulse is within the bandwidth of the receiver (see below). For this section we are using the "Historic" reference because in the past most VNAs offered bandwidths only up to about 5 MHz. This has limited the wideband method to pulse widths of 200 nanoseconds or more. However, for these larger pulse widths, the wideband method has the advantage that there is no loss in dynamic range when the pulses have a low duty cycle (in contrast to the narrowband method discussed in section B).
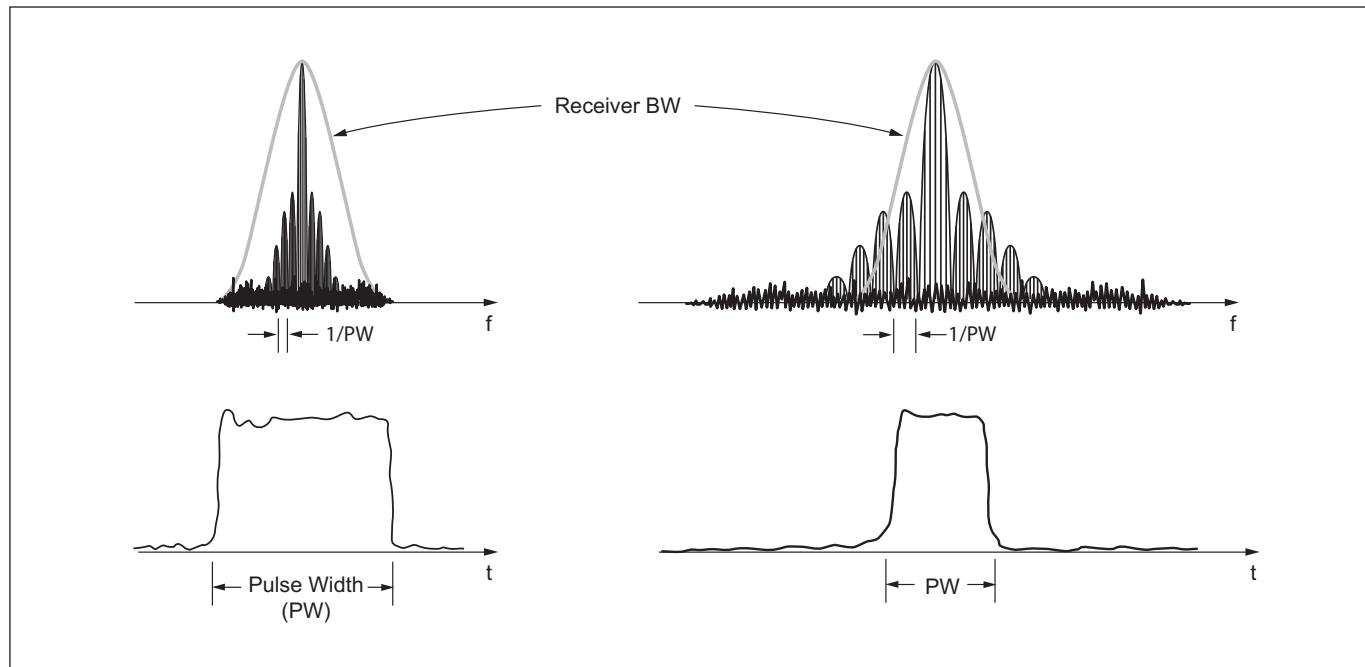
Figure 5. *"Historic" wideband pulse measurement methods were limited by narrow IFBWs.*

Limitations of the "Historic" Wideband Method

The major disadvantage of the wideband method has been the lower limit of measurable pulse widths. Basically, as the pulse width becomes narrower, the spectral energy spreads out. When too much of the pulse energy is outside the bandwidth of the receiver, the VNA can no longer detect the pulses properly. The minimum measurement window is determined by the following equation:

$T_{MW} \geq 1/IFBW$

In the past, the largest IFBW available was around 5 MHz, which translates to a minimum measurement window (T_{MW}) of 200 nanoseconds. For narrow pulses, test engineers had to use the narrowband method and take the dynamic range penalty for low duty cycles applications.

A second challenges lies in data acquisition rate of many VNAs. Even with satisfactory bandwidth, limitations can exist if the sampling rate of the analog-to-digital converter (ADC) is not adequate (with measurement grade accuracy and resolution). Most contemporary VNAs have not incorporated sufficiently high-speed digitizers for today's radar-related measurement demands, leading to poor timing resolution and inadequate pulse profiling resolution/accuracy.
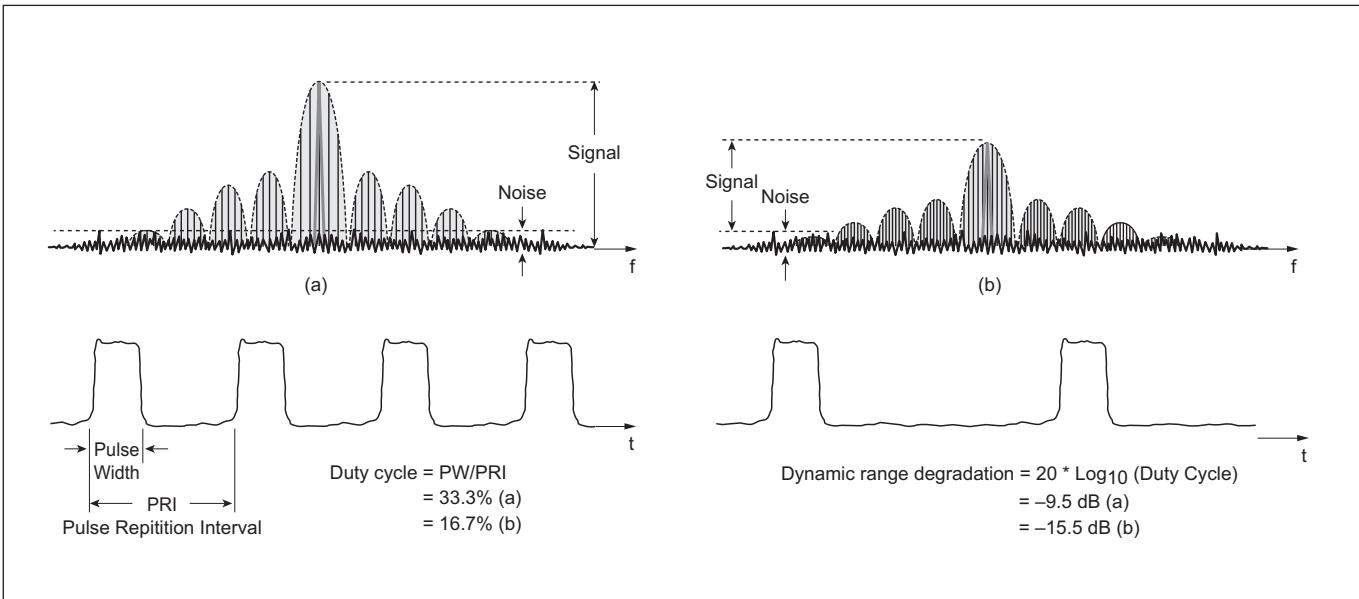
Figure 6. *"Narrowband pulse measurement method duty cycle dependence.*

B. Narrowband Measurement Method

The band-limited, or narrowband measurement method is based on the spectrum of a pulsed RF signal and capitalizes on the fact that the central spectral line carries the magnitude and phase information of the underlying RF signal, f_c (see Figure 6). After filtering out everything but this frequency, only a CW signal remains and standard VNA processing may be applied.

The advantage of this technique is that narrow pulse widths can be measured. The lower limit is primarily limited by overall system IF bandwidth (and associated aliasing avoidance) while the profiling measurement resolution is limited by the receiver gating capability. In addition, from a processing point-of-view, the band-limited method is attractive because it only involves one frequency and is an asynchronous measurement (does not require synchronization with the incoming pulse).

Limitations of the Narrowband Method

The biggest limitation of the narrowband technique is that dynamic range becomes a function of the duty cycle. Since only the central spectral line is kept, a significant amount of energy in the remaining spectrum is discarded, particularly as the duty cycle shrinks. As the duty cycle becomes smaller, there is less power in the RF carrier signal which affects this method's available dynamic range – the receiver becomes desensitized. The result is a dynamic range penalty of $20*\log_{10}$ (duty cycle). For a duty cycle of 0.1%, the available dynamic range is reduced by 60 dB.

C. High-speed digitizer method (Vector**Star**'s innovative architecture)

The high-speed digitizer measurement method represents a major technology advancement over prior test methods. While similar to the "historic" wideband method, this method is based on direct acquisition - but at a much higher data rate than was previously available. The Anritsu MS4640B VNA with options 035 and 042 (PulseView) offers a digital IF acquisition system with more than 200 MHz of bandwidth. As a result, resolutions are enhanced and time referencing becomes much more accurate. The exact acquisition method differs in that the acquisition itself is not controlled by the pulse system (except in the case of pulse-to-pulse measurements). Portions of the data can be recorded to be analyzed and correlated with the pulse pattern being used. Since no energy is being discarded in the high-speed digitizer pulse measurement method, there is no duty-cycle dependence. Full dynamic range (>100 dB normally – depending on IFBW, power levels and averaging for the MS4640B) is available.
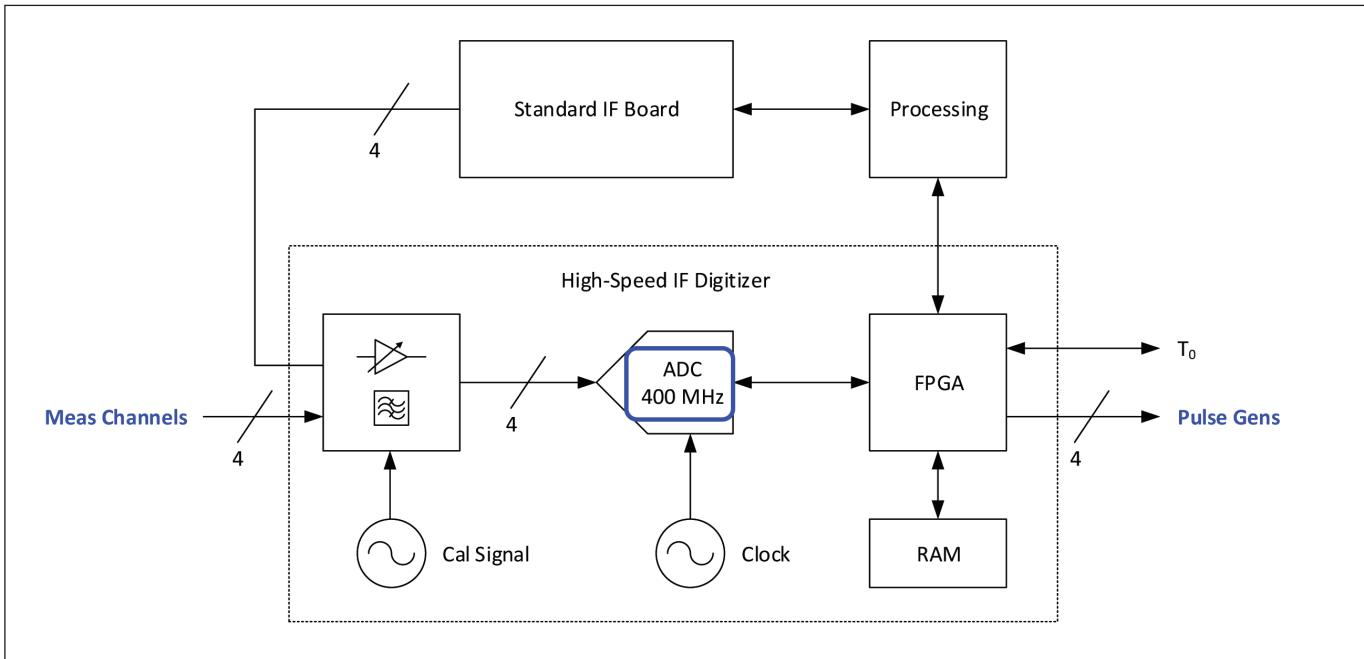
Figure 7. Block diagram Innovative High-speed digitizer architecture of Anritsu MS4640B VNA with options 035 and 042 (PulseView).

V. Example Measurements

A common goal of performing VNA-based pulse measurements is to characterize a device or component such that the design can be modified to get the behavior desired. As a result, most components on the market are well behaved and do not provide very interesting information for a measurement example. Therefore, the device-under-test (DUT) used in the measurement examples to follow has been specifically designed to exhibit behavior that will highlight aspects of the pulse measurements. Pulse modulation occurs in the DUT driven by Pulse Generator 4, but could also be achieved with one of the Anritsu Pulse Modulator Test Sets.
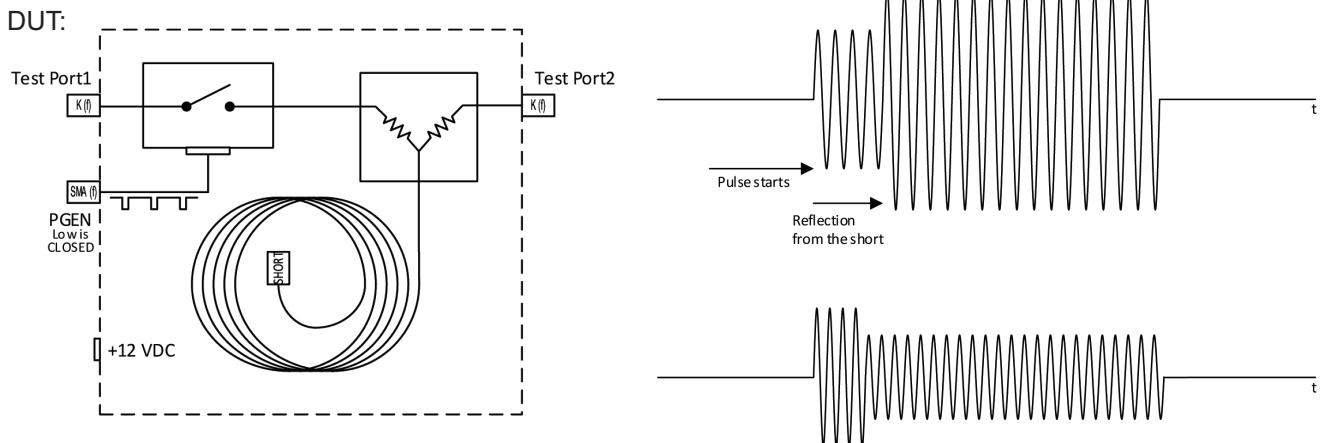
Signals reflected from the short can combine constructively or destructively.

Example DUT measurement at 10 GHz displaying the effect of incident and reflected signals combining.

A. Pulse profiling (PP)

1. UTILITIES | *Preset; Select* [OK] in Preset dialog box to preset the instrument
2. *APPLICATION*; Application | *PulseView*; [Continue] in the PulseView Application dialog box to enter the application
3. [FREQUENCY]; Frequency | Start {5 GHz}; Stop {15 GHz}; # of Points {51}
4. [POWER]; Power (Coupled) | Port 1 Power {5 dBm}
5. CHANNEL | *Averaging*; AVERAGING | Averaging {*toggle*: ON}; Averaging Factor {10}; Averaging Type {*toggle*: Per Sweep}; IFBW {1 MHz}
6. [TRACE]; Trace | # of Traces {1}; *Trace Layout*; Trace Layout {*Select* single display, top entry}
7. [RESPONSE]; Response | S21
8. [DISPLAY]; Display | *Trace Format*; Trace Format | *Log Mag*; drag Reference Position (circled arrow on measurement trace below) to position 9 (second from the top)
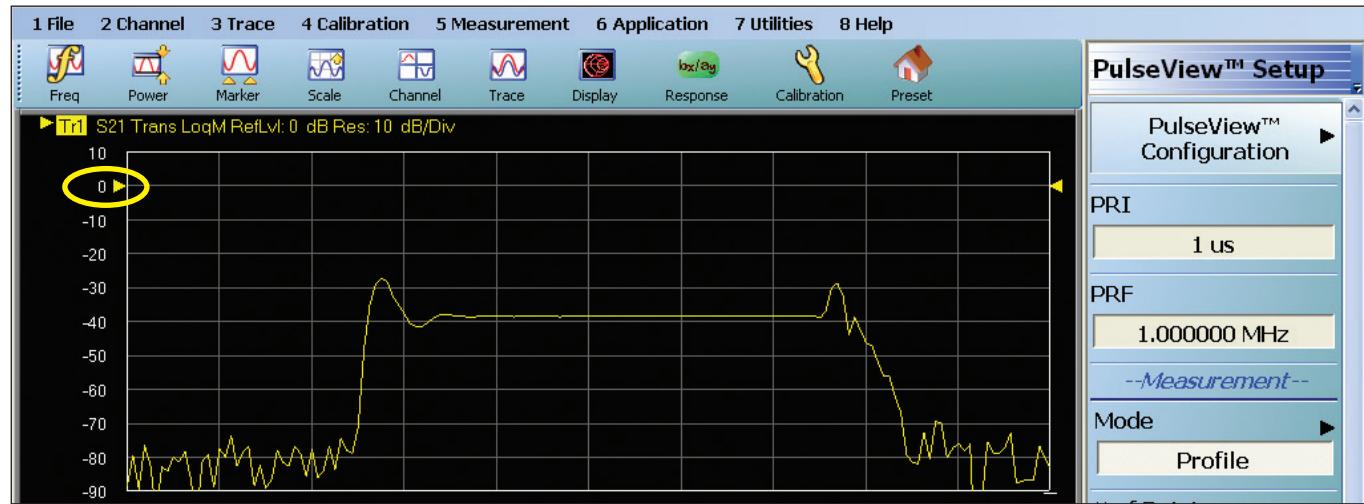
9. [Channel] Channel | # of Channels {2}; *Chan. Layout* | Chan. Layout | {Select double vertical display, third from the top entry}
10. *Click* on the Ch2 (circled entry on the bottom of the screen) to activate Channel 2
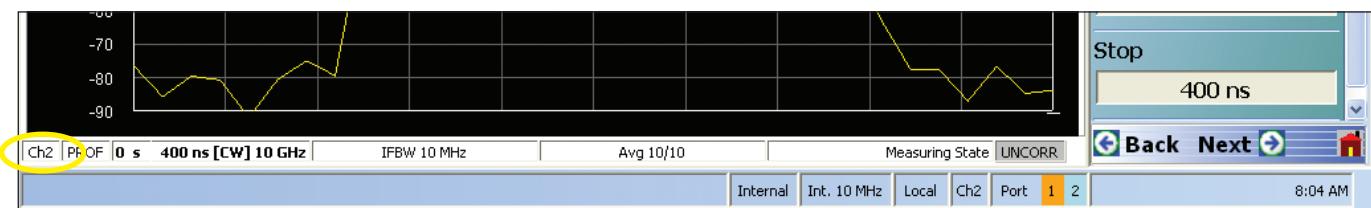
11. *APPLICATION*; Application | *PulseView*; [Continue] in the PulseView Application dialog box to enter the application
12. [FREQUENCY]; Frequency | Start {5 GHz}; Stop {15 GHz}; # of Points {51}
13. [POWER]; Power (Coupled) | Port 1 Power {5 dBm}
14. CHANNEL | *Averaging*; AVERAGING | Averaging {*toggle*: ON}; Averaging Factor {10}; Averaging Type {*toggle*: Per Sweep}; IFBW {1 MHz}
15. [TRACE]; Trace | # of Traces {1}; *Trace Layout*; Trace Layout | {*Select* single display, top entry}
16. [RESPONSE]; Response | *S21*
17. [DISPLAY]; Display | *Trace Format*; Trace Format | *Log Mag*; drag Reference Position (circled arrow on left of measurement trace) to position 9 (second from the top)
18. *APPLICATION*; Application | PulseView Setup; PULSEVIEW SETUP | *PulseView* Configuration

19. In the PulseView Configuration dialog box, perform the following:
    i. [PRI] {1 µs}
    ii. [PG4] *Select* Enable Pulse Generator; *Select* PG4 Label | {*Enter* "PulseMod" in the Edit Pulse Generator Name dialog box and [OK]}; *Select* Singlet | Delay {50 ns}; Width {200 ns}; *Select* Inverted Polarity (Note: Ensure PG1 is NOT enabled and Inverted Polarity is NOT selected.)
    iii. [Measurement] *Select* Pulse Profile (Profile); *Select* Couple Receiver Parameters; Measurement Width {12.5 ns}; Start {0 ns}; Stop {400 ns}; # of point {33}; # of points = INT(400 ns/12.5 ns) + 1 to provide non-overlapping measurement windows
    iv. [DONE]
20. [Frequency]; Frequency | CW Frequency {10 GHz}
21. CHANNEL | *Averaging*; AVERAGING | *Reset Avg Count*
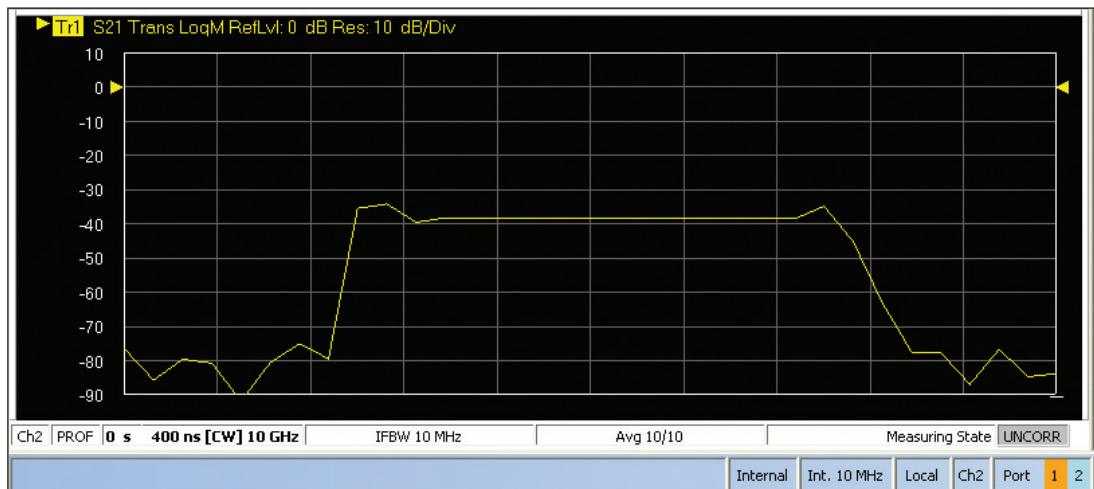
These settings simulate the response that would be seen using other VNAs prior to the introduction of the pulse measurement capability of Vector**Star** (with **PulseView**).

22. *Click* on the Ch1 (entry on the bottom of the screen) to activate Channel 1
23. *APPLICATION*; Application | PulseView Setup; PULSEVIEW SETUP | *PulseView Configuration*
24. In the PulseView Configuration dialog box, perform the following:
    i. [PRI] {1 µs}
    ii. [PG2] *Select* Enable Pulse Generator; *Select* Quadruplet | 1. Delay {0 s}; Width {50 ns}; 2. Delay {100 ns}; Width {200 ns}; 3. Delay {325 ns}; Width {100 ns}; 4. Delay {525 ns}; Width {25 ns}
    iii. [PG3] *Select* Enable Pulse Generator; *Select* Burst | # of Bursts {49}; Period {20 ns}; Delay {0 s}; Width {10 ns}
    iv. [PG4] *Select* Enable Pulse Generator; *Select* PG4 Label | {*Enter* PulseMod in the Edit Pulse Generator Name dialog box and *Select* OK}; *Select* Singlet | Delay {50 ns}; Width {200 ns}; *Select* Inverted Polarity

(Note: Ensure PG1 is NOT enabled and Inverted Polarity is NOT selected.)
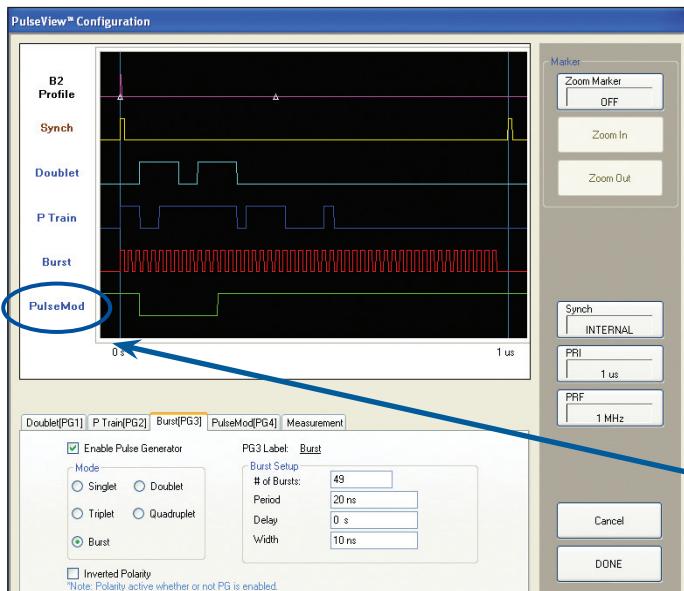
With the **PulseView™** graphical user interface, users get:
- **Visual representation of signals and measurements**
- **Simple generator configuration**
- **Multiple pulse generation option**
  – Singlet
  – Doublet
  – Triplet
  – Quadruplet
  – Burst
- **Ability to change labels for better test descriptors**

v. [Measurement] *Select* Pulse Profile (Profile); *Select* Couple Receiver Parameters; Measurement Width {2.5 ns}; Start {0 ns}; Stop {400 ns}; # of point {161}; # of points = INT(400 ns/2. 5 ns) + 1 to provide non-overlapping measurement windows

vi. [DONE]

25. [Frequency]; Frequency | CW Frequency {10 GHz}

26. CHANNEL | *Averaging*; AVERAGING | *Reset Avg Count*
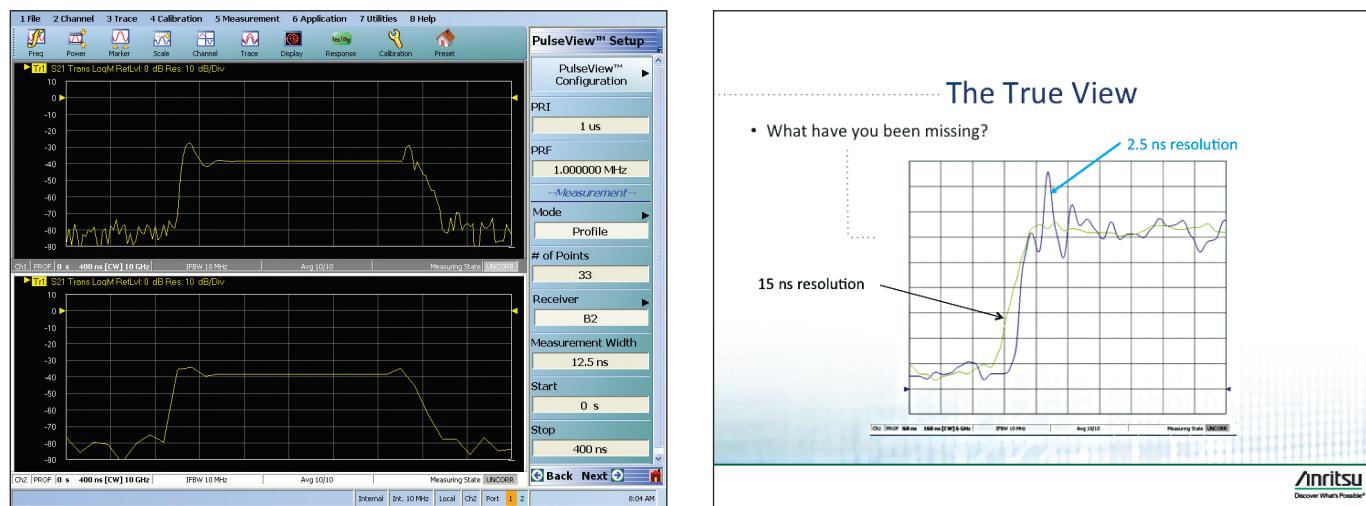
VectorStar (with **PulseView**) enables **industry-leading measurement 2.5 ns resolution**. It enables users to get a true view of their device performance and see behavior they may have been missing. In the example above, the 12.5 ns resolution measurement does not capture the full magnitude of the signal overshoot. For applications with very sensitive receivers, the full magnitude of the overshoot could be the difference of whether or not a receiver enters saturation resulting in a number of unwanted effects.

With the high resolution, designers may want to look at a variety of pulse characteristics, such as those described below.
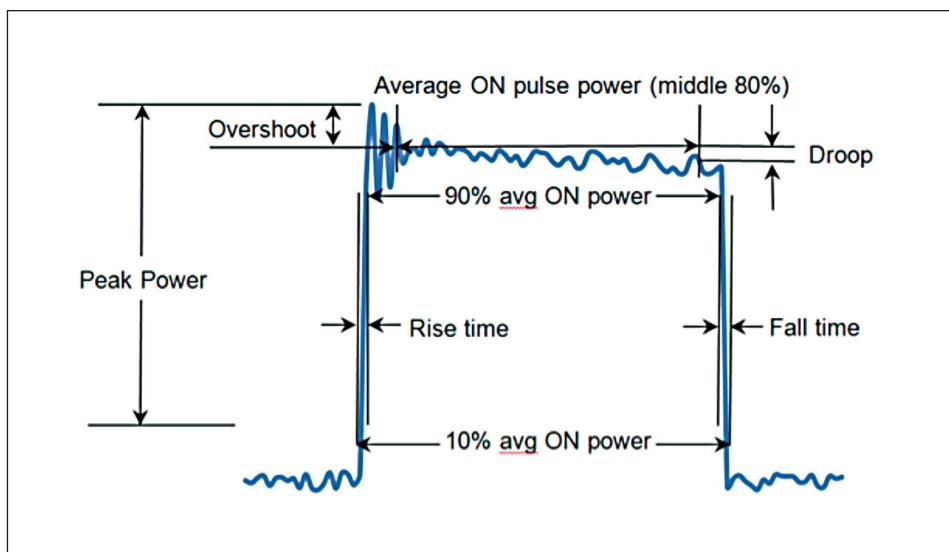

**Figure 8.** *Common Pulse Characteristics of Interest*

27. [Channel]; Channel | # of Channels {1}

Recall that in this example configuration, RF pulsing is occurring in the Pulse Demonstration Module. As a result, the reference signal is continuous wave (CW). In some applications, it may be preferable to use an Anritsu Pulse Modulator Test Set to modulate the RF stimulus either as an alternate to the DUT modulation or in addition to the DUT modulation; see Figure 9. When a Pulse Modulator Test Set is used to provide a pulsed RF stimulus, the pulsed stimulus can be the sampled and provided to the reference receivers. In that case, the user can capitalize on additional **PulseView** capability. See Figure 10 for an example configuration.
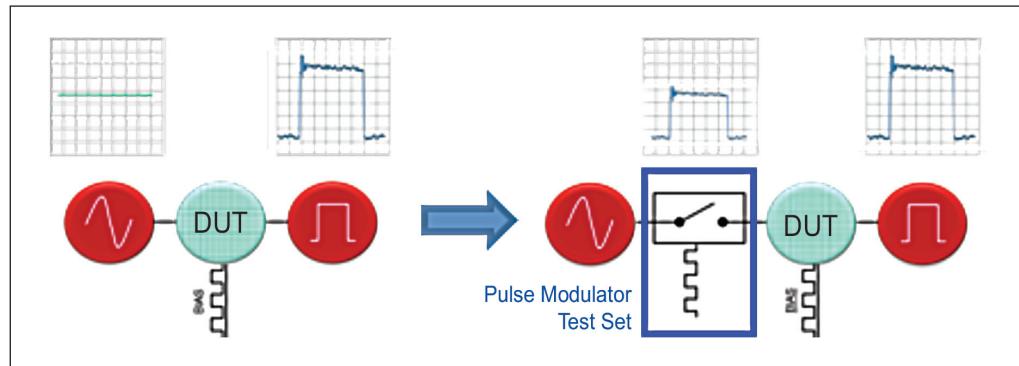
Figure 9. *An optional Anritsu Pulse Modulator Test Set enables RF stimulus modulation (and receiver gating [modulation] on some models.*

In many VNA-based pulsed measurement solutions, the receivers are coupled – which means, for the most part, the receivers all measure the pulse with the same setup. Therefore, assuming there is no delay between reference and test receivers, when the pulse is off at one, it is also off in the other. Since S_{21} is a ratio (b_2/a_1 for Vector**Star**), in the off periods of the pulse, there is essentially a 0/0 ratio which may result in a "noisy" trace (see the plot on the left below) where it can be challenging to discern pulse edge behavior.
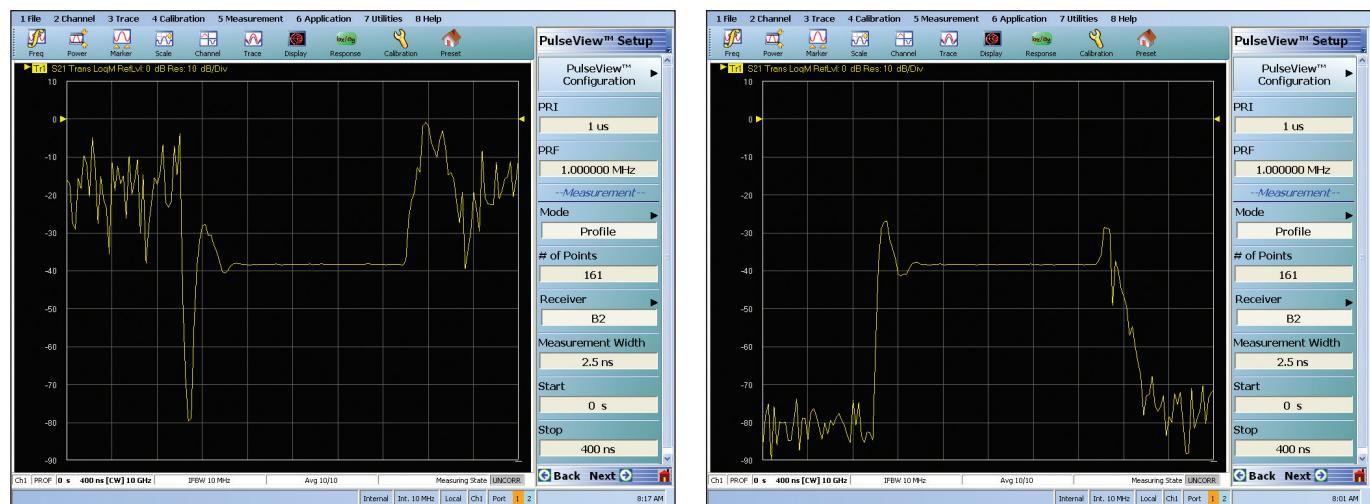
PulseView enables measurement receivers to be configured independently. With the Anritsu Pulse Modulator Test Set, the modulated stimulus can be provided to the reference receivers (e.g., a_1); see Figure 10. Each receiver can then be independently controlled to achieve specific measurement results. In many cases, the user may want to avoid the transients in the reference signal. **With independent measurement receivers**, the user can select a more stable part of the pulsed signal as the reference measurement. To demonstrate this, the Pulse Modulator Test Set will now be used in this example measurement to modulate the RF signal rather than the Pulse Demonstration Module. Then, the reference receiver will be independently controlled to make a stationary measurement (i.e., the profile start and stop times will be the same) with a width that covers a significant portion of the essentially flat part of the pulse. Despite the measurement being stationary, the number of points must remain the same across all measurement receivers.
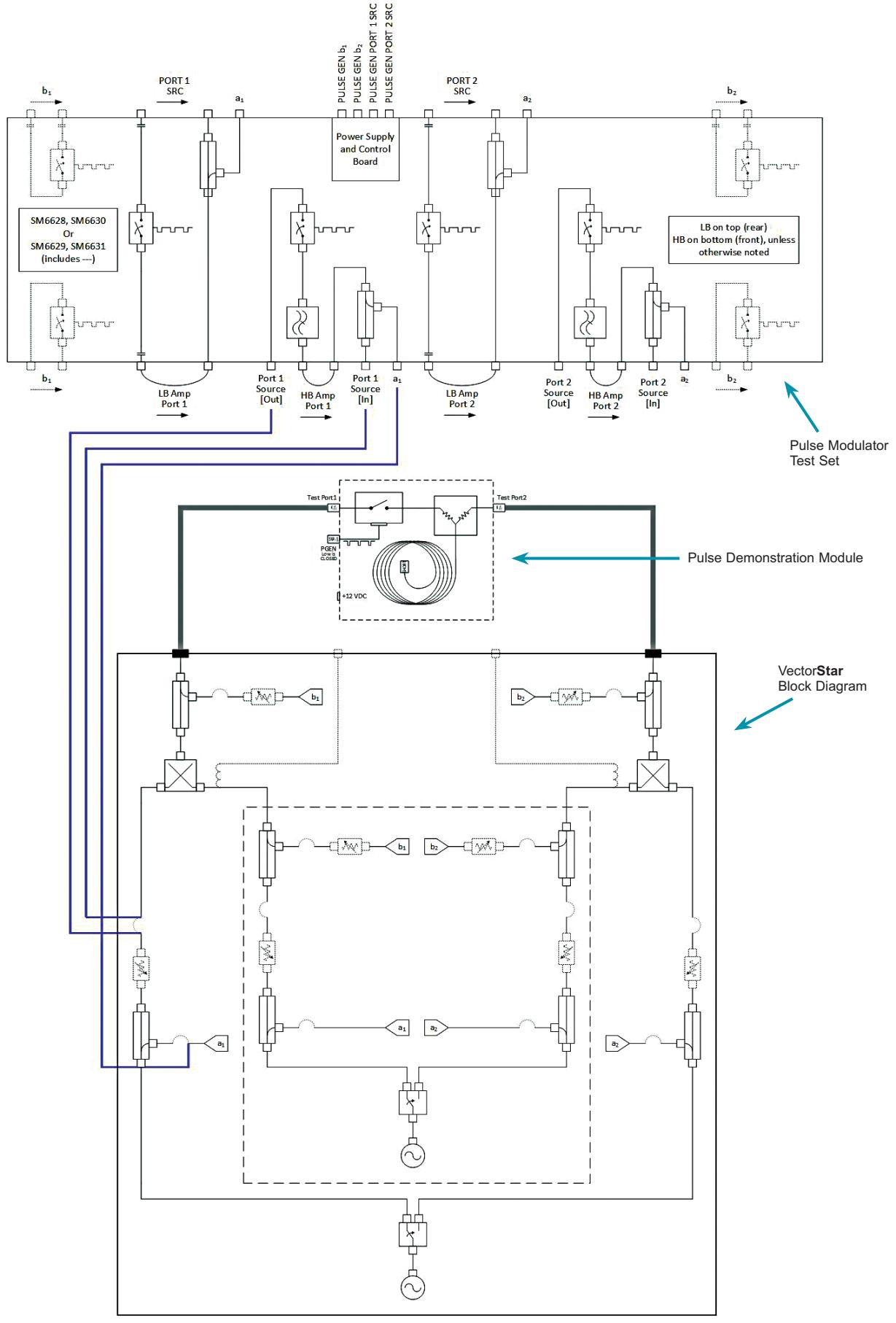
Figure 10. Example Test Configuration using a Pulse Modulator Test Set.

VectorStar Pulse Measurements

28. *APPLICATION*; Application | PulseView Setup; PULSEVIEW SETUP | *PulseView Configuration*

29. In the PulseView Configuration dialog box, perform the following:

    i. [PG4] *Deselect* }; *Deselect* Inverted Polarity

    ii. [PG1] *Select* Enable Pulse Generator; *Select* PG4 Label | {*Enter* "TestSet" in the Edit Pulse Generator Name dialog box and [OK]}; *Select* Singlet | Delay {50 ns}; Width {200 ns}; *Select* Inverted Polarity

    iii. [Measurement] *Deselect* Couple Receiver Parameters; *Select* A1 from the Receiver pull down menu; Measurement Width {100 ns}; Start {160n s}; Stop {160 ns}; leave the # of point {161}

  iv. [DONE]

The display should change from the left trace to the right trace. By doing this, **the edge behavior of the DUT (Pulse Demonstration Module) is made visible.**
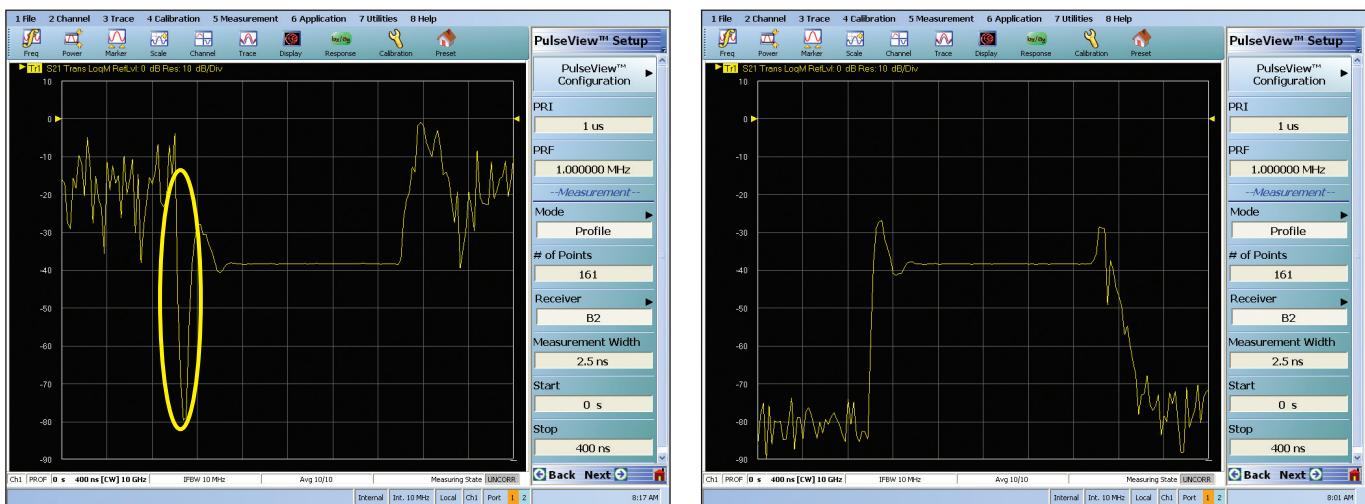
The value of independent receivers becomes more apparent when there are time delays in a measurement setup either due to the setup itself (e.g., long cable lengths to DUT) or the DUT (e.g. the DUT includes some filtering). To illustrate this concept, consider the delay between the pulse arriving at the a_1 and the pulse arriving at the b_2 receiver in the current test configuration. Given the time scale of this demonstration configuration (pulsewidth of 200 ns), the delay of the cables and DUT will be evident. In other cases, this delay may be insignificant.

30. *APPLICATION*; Application | PulseView Setup; PULSEVIEW SETUP | *PulseView Configuration*

31. In the PulseView Configuration dialog box, perform the following:

    i. [Measurement] *Select* B2 from the Receiver pull down menu; *Select* Couple Receiver Parameters to recouple the receivers

    ii. [DONE]

Since the DUT is essentially a transmission line, the expectation is that the S_{21} would be reasonably well behaved – perhaps with the exception of the pulse edges
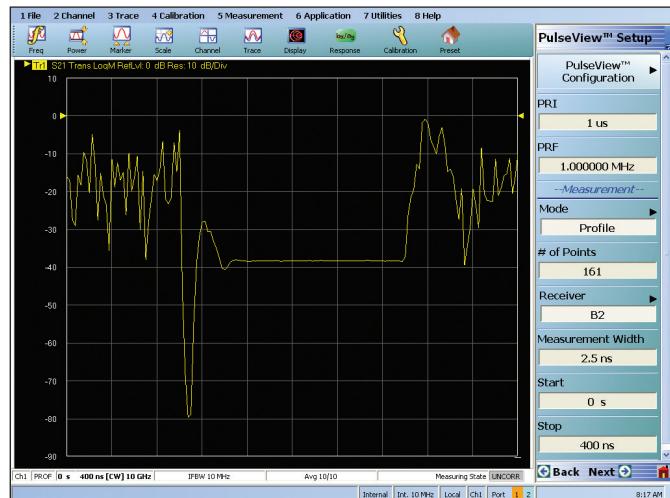
Returning to the display where receivers are coupled, there is some unusual behavior present. When a user encounters unexpected results in a ratio measurement, a common practice is to look at the elements of the ratio individually to see if any insight can be gained.

32. [RESPONSE]; Response | *User Defined*; User Defined | Numerator {B2}; Denominator {1}

33. [TRACE]; Trace | # of Traces {2}; leave as Trace Layout | {single display, top entry}

34. *Select* Trace 2 by clicking on the Tr2 identifier

35. [DISPLAY]; Display | *Trace Format*; Trace Format | {Log Mag}; drag Reference to position 9 (second from the top)
    (Note: it may be necessary to change the scale of Tr2 to match Tr1. If so, perform the following:
    [SCALE]; Scale | Resolution {10} to change it to 10 dB/div.)

36. [RESPONSE]; Response | *User Defined*; User Defined | Numerator {A1}; Denominator {1}
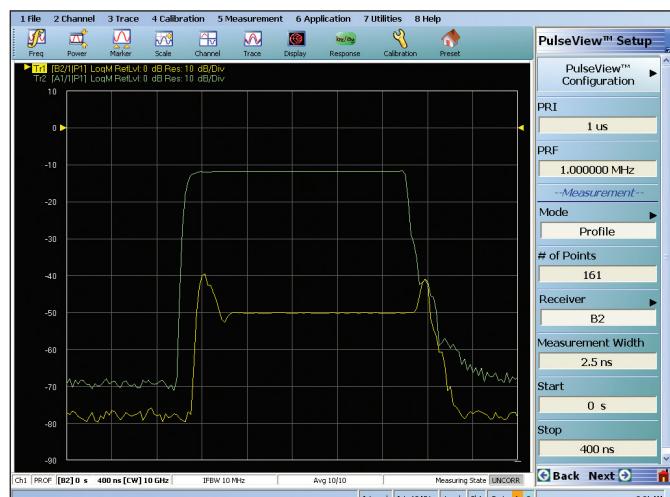
From the display, it is obvious that there is a time delay between the a_1 and b_2 measurements such that when the values are ratioed for an S_{21} value, the misalignment may lead to an unusual or unexpected plot. More importantly, the misalignment results in a S_{21} response that may not be indicative of the DUT response – especially at the pulse edges.

Using independent receiver measurement windows (gates), the user can account for misalignment and delay the b_2 measurement by ~10 ns. Moreover, **the user can adjust the delay to get the proper alignment while in the measurement window** – rather than having to go between multiple menus in competing products.

37. *APPLICATION*; Application | PulseView Setup; PULSEVIEW SETUP | *PulseView* Configuration

38. In the PulseView Configuration dialog box, perform the following:

i.   [Measurement] *Select* B2 from the Receiver pull down menu; *Deselect* Couple Receiver Parameters to uncouple the receivers

ii.   [DONE]

39. *Select* Trace 1 by clicking on the Tr2 identifier
40. PULSEVIEW SETUP | Start {10 ns}; Stop {410 ns}; adjust as desired

    (Note: it is important to keep the time interval between start and stop at 400 ns to maintain the same scale as the $a_1/1$ trace.)
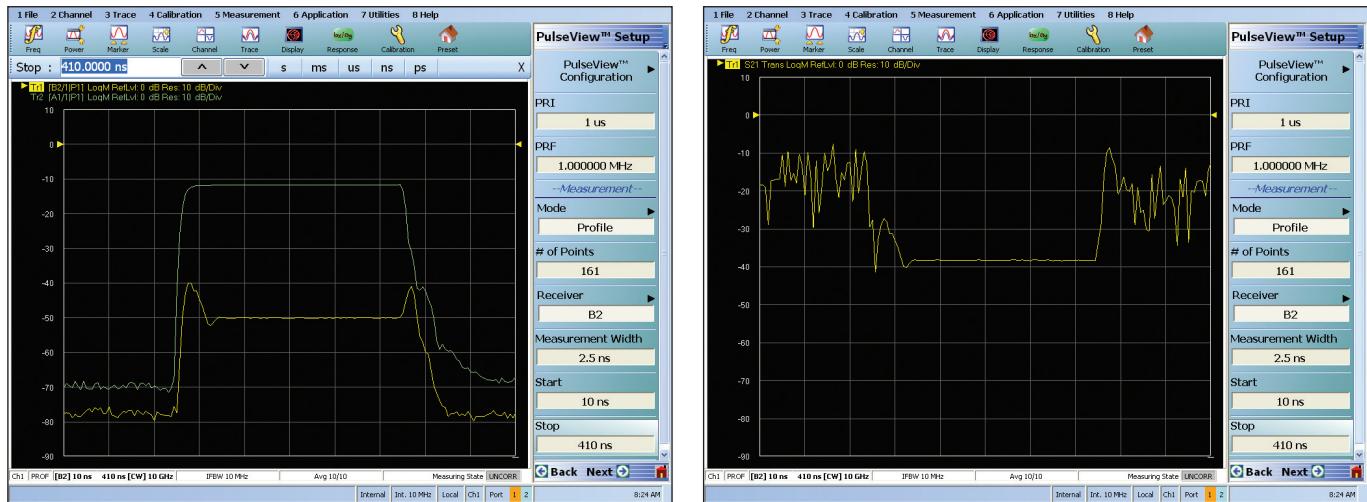
41. [TRACE]; Trace | # of Traces {1}
42. [RESPONSE]; Response | *S21*

The result is an S_{21} measurement more representative of the DUT performance.

At this point, the demonstration will be returned to the configuration where RF pulsing is occurring in the Pulse Demonstration Module, rather than the Pulse Modulator Test Set. As a result, the a1 reference signal will again will be continuous wave (CW).

43. *APPLICATION*; Application | PulseView Setup; PULSEVIEW SETUP | *PulseView Configuration*
44. In the PulseView Configuration dialog box, perform the following:
    i.   [PG1] *Deselect* }; *Deselect* Inverted Polarity
    ii. [PG4] *Select* Enable Pulse Generator; *Select* Inverted Polarity
    iii. [Measurement] Select A1 from the Receiver pull down menu; *Select* Couple Receiver Parameters to recouple the receivers
iv. [DONE]

The display should change to the familiar trace on the right.
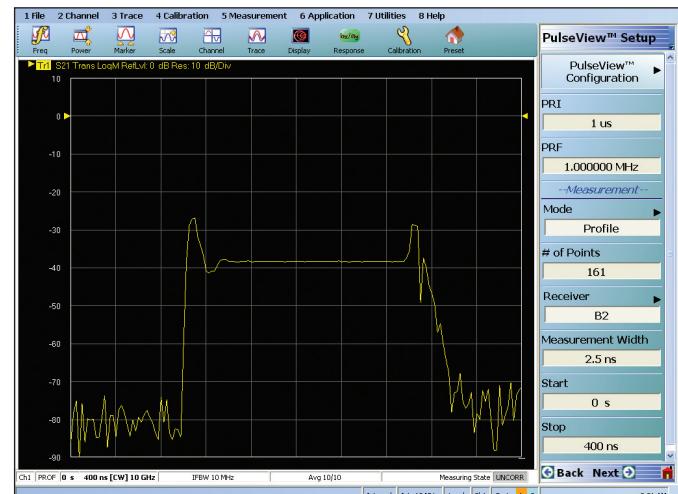
*** The remainder of this application note will assume a Pulse Modulator Test Set is not being utilized.

45. *APPLICATION*; Application | PulseView Setup; PULSEVIEW SETUP | *PulseView Configuration*

46. In the PulseView Configuration dialog box, perform the following:

i. [Measurement] *Select* Pulse Profile (Profile); *Select* B2 from the Receiver pull down list; *Select* Couple Receiver Parameters

ii. [DONE]

47. *APPLICATION*; Application | PulseView Setup | PULSEVIEW SETUP | PRI {1 µs}; PRI {10 µs}; PRI {100 µs}; return to PRI {10 µs} when finished

Note: there is **no reduction in dynamic range**, unlike the VNAs which utilize a narrowband pulse measurement method.

For this example measurement, the measurement width is 2.5 ns. The duty cycle for various PRIs would be:

PRI	Duty-Cycle	Narrowband DR Reduction
1 µs	0.25%	52 dB
10 µs	0.025%	72 dB
100 µs	0.0025%	92 dB

Narrowband Dynamic Range Reduction (dB)
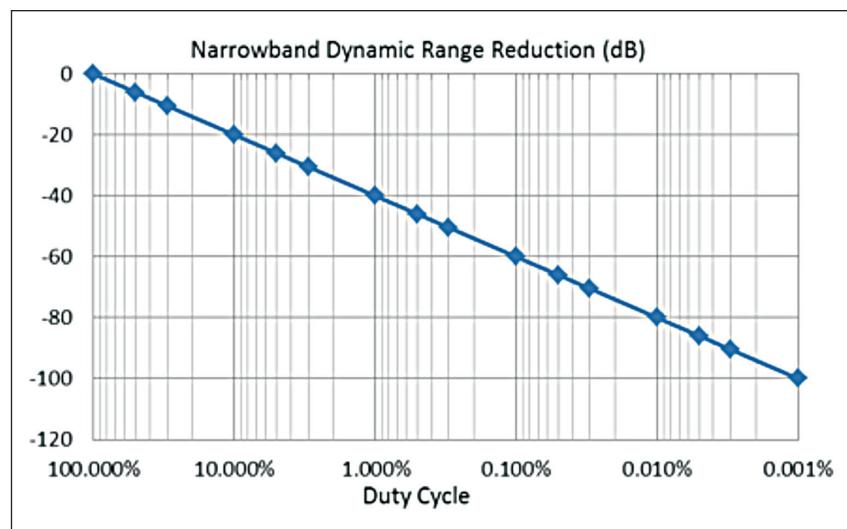
B. Point-in-pulse (PIP) – frequency and power sweeps

48. [Marker]; Markers [1] | Mkr 1 {*toggle*: ON}; Mkr 2 {toggle: ON}; *drag* markers to determine the "good" part of the pulse (where the "good" part is a stable part of the pulse avoiding edge transients)

The pulse appears to be relatively flat beginning at ~160 ns for a duration of at least 100 ns (for convenient round numbers).

Note: The modulation pulse has a delay of 50 ns, but the measured pulse edge doesn't occur until about 100 ns. The additional ~50 ns delay is due to latency in the modulator (specified at <55 ns typical) and some delay through the Pulse Demonstration Module.

49. [Marker]; Markers [1] | Mkr 1 {*toggle*: OFF}; Mkr 2 {*toggle*: OFF}
50. CHANNEL | *Averaging*; AVERAGING | Averaging {*toggle*: OFF}
51. APPLICATION; Application | PulseView Setup; PULSEVIEW SETUP | PulseView Configuration
52. In the PulseView Configuration dialog box, perform the following:

    i. [Measurement] *Select* Point-in-Pulse (PIP); *Select* Couple Receiver Parameters; Measurement Width {100 ns}; Delay {160 ns}
    ii. [Zoom Marker]
    iii. *Drag* vertical indices from right edge of display to set a zoom area and [Zoom In]
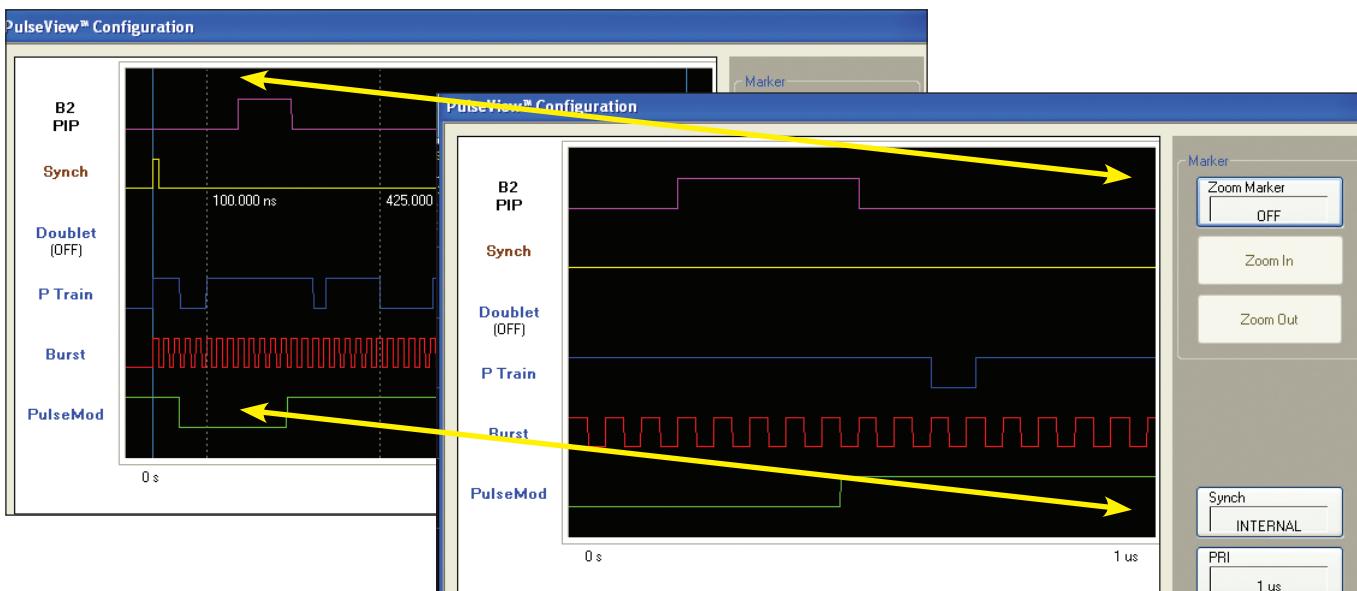
iv. *Drag* vertical line to highlight timing of various pulse waveforms
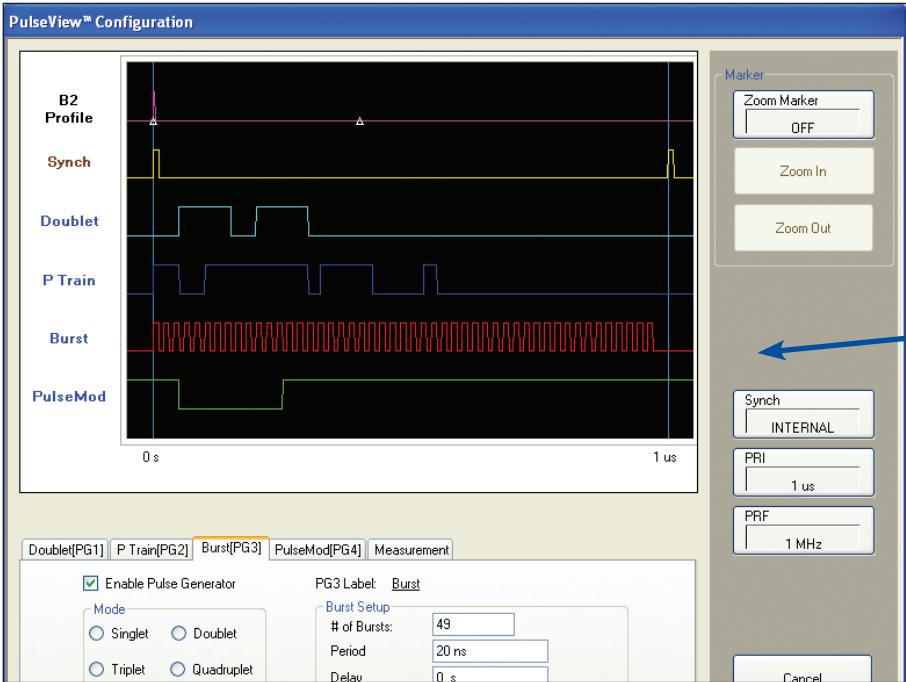
Vertical indices provide visual confirmation of intended setup – **providing greater confidence in measurement results**.

Users might want to synchronize this measurement with other equipment (e.g., pulsed IV test instruments).

[Synch]:

Internal – makes T_0 available on rear panel with <5ns delay (typical)

External – accepts external T_0 and synchronizes within 55 ns (typical)

    v. [DONE]

53. [FREQUENCY]; Frequency | CW Mode {*toggle*: OFF}; # of Points {501}
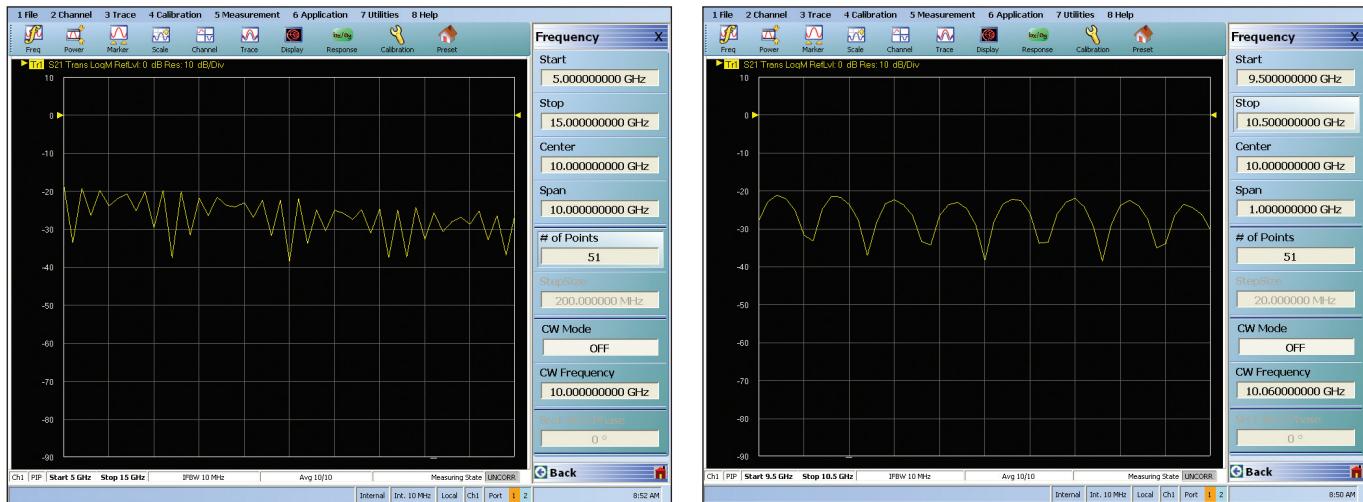
54. [FREQUENCY]; Frequency | Start {9.5 GHz}; Stop {10.5 GHz}
The "ringing" of the measurement is due to the shorted transmission line in the Pulse Demonstration Module. The spacing between nulls is ~130 MHz, where $f = v/\lambda = (0.77*300{,}000{,}000 \text{ m/s}) / (2*0.90 \text{ m})$.

Users may want to investigate behavior using various portions of the pulse (i.e., different measurement widths) at different points within the pulse (i.e., different delays).

55. PULSEVIEW SETUP | Measurement Width {10 ns}; Delay {100 ns}; to reproduce the trace below, the delay may need adjusted a few ns either way

{It may be interesting to compare the measurement results under different settings. If so, use the following procedure: [DISPLAY]; Display | *View Trace*; View Trace | *Store Data to Memory; Data & Memory*]; *Select* Data when finished.}
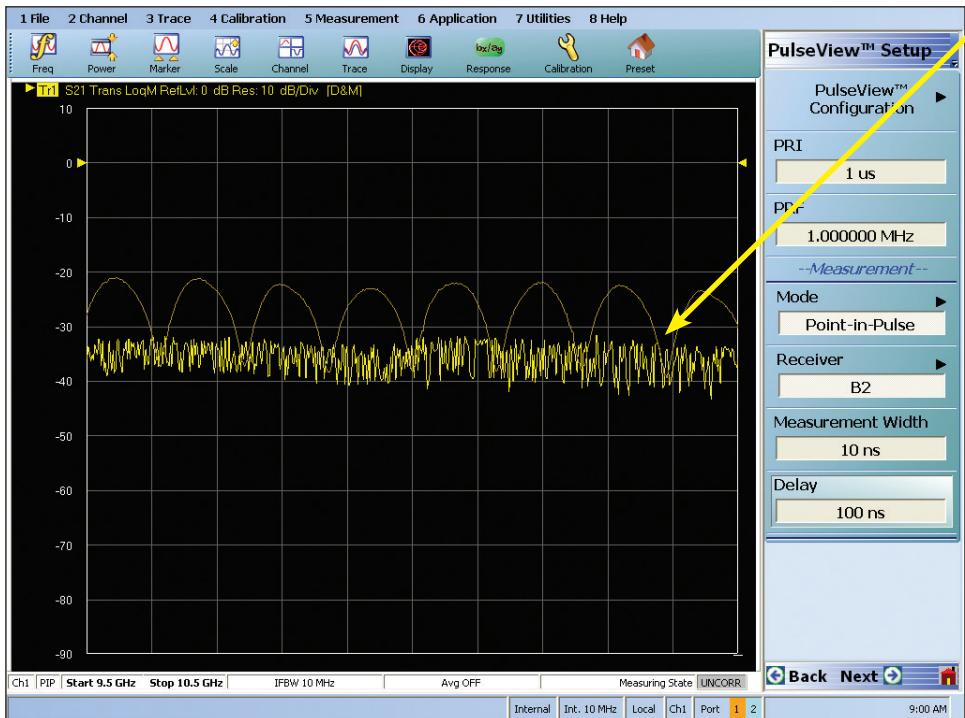
This trace shows the change in result when observing how the "overshoot" changes over frequency. It varies less than the remainder of the pulse because there is a delay before the effects of the shorted transmission line add constructively or destructively to the pulse.

Users can make measurement adjustments and **see the results instantly.**

No need to toggle back and forth between configuration windows.

56. PULSEVIEW SETUP | Measurement Width {100 ns}; Delay {160 ns}; to reproduce the trace below, the delay may need adjusted a few ns either way

Since frequency can be swept in PIP mode. It may be of interest to **measure group delay** of the DUT.

57. [DISPLAY]; Display | *Trace Format* | Trace Format | *Log Mag* and *Phase*

58. [TRACE]; Trace | # of Trace {2}; *Trace Layout*; Trace Layout | {*Select* double vertical display, third from the top entry}

59. *Select* Trace 2 by clicking on the Tr2 identifier

60. [RESPONSE]; Response | *S21*

61. [DISPLAY]; Display | *Trace Format*; Trace Format | *Group Delay*

62. [SCALE]; Scale | Auto Scale Active Trace
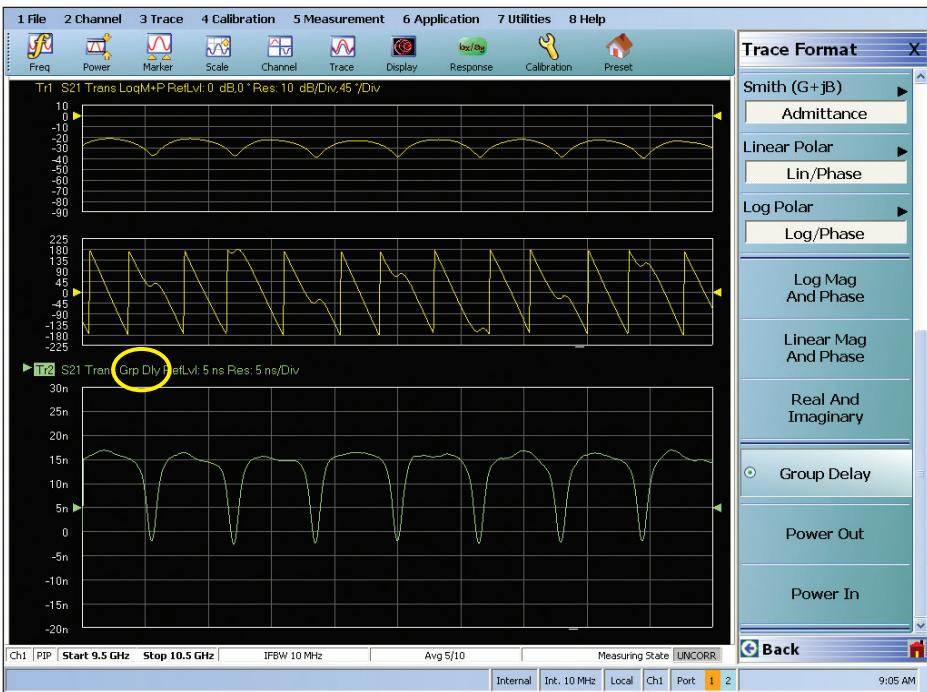
Power can also be swept while in PIP mode – which can be particularly useful for making gain compression measurements.

63. *Select* Trace 1 by clicking on the Tr1 identifier

64. [DISPLAY]; Display | *Trace Format*; Trace Format | *Log Mag*

65. [RESPONSE]; Response | *User Defined*; User Defined | Numerator {B2}; Denominator {1}

66. *Select* Trace 2 by clicking on the Tr2 identifier

67. [DISPLAY]; Display | *Trace Format*; Trace Format | {Log Mag}; drag Reference Position (circled arrow on left of measurement trace) to position 9 (second from the top)

68. [RESPONSE] | Response | *User Defined*; User Defined | Numerator {A1}; Denominator {1}

69. [TRACE]; Trace | # of Traces {2}; Trace Layout | {*Select* single display, top entry}

70. 2.CHANNEL | *3.Sweep*; Sweep Setup | *Sweep Type*; Sweep Type | *Power Sweep (CW Freq)*

71. [FREQUENCY]; Frequency | CW Frequency {10 GHz}
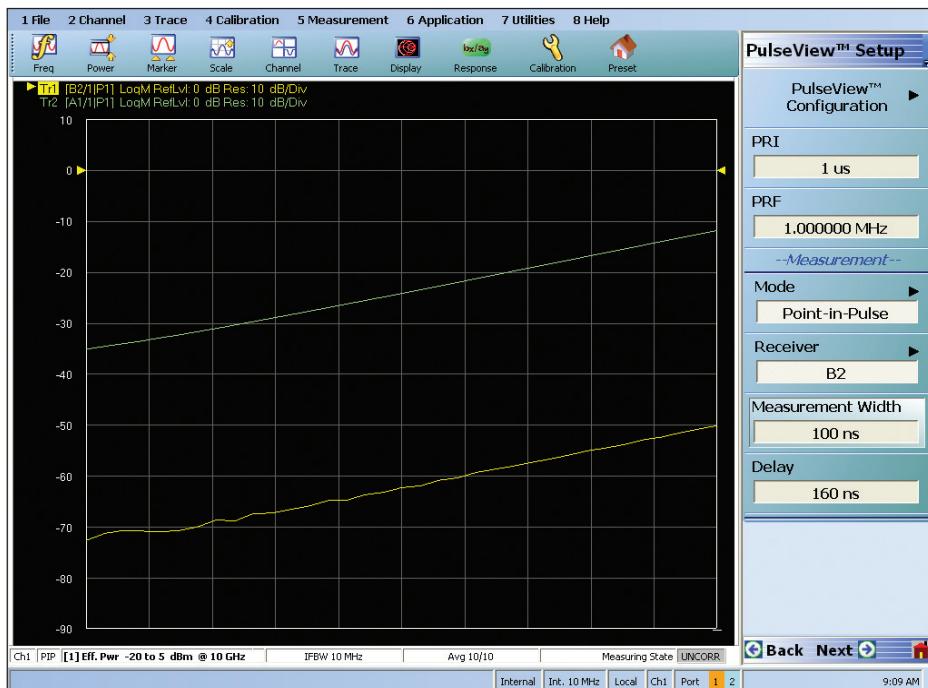
C. PULSE-TO-PULSE DEMONSTRATION

Historically, if a user wanted to measure the behavior of a DUT over multiple pulses to look for possible changes over time, the process would be to perform a pulse profile measurement over multiple pulse periods. The obvious disadvantage is that there is a great deal of useless data points (e.g. data from when the pulse is off) that is being displayed (limiting resolution of the useful data) and that is taking up data storage space (i.e. record length).

1. [TRACE]; Trace | # of Traces {1}
2. [RESPONSE]; Response | S21
3. APPLICATION | PulseView Setup; PULSEVIEW SETUP | PulseView Configuration
4. In the PulseView Configuration dialog box, perform the following:
    i. [PG4] *Select* Enable Pulse Generator; *Select* PG4 Label {PulseMod}; *Select* Singlet | Delay {0 ns}; Width {200 ns}
    ii. [Measurement] *Select* Pulse Profile (Profile); Measurement Width {2.5 ns}; Start {0 ns}; Stop {350 ns}; # of point {141}
    iii. [DONE]
5. [Marker]; Markers[1] | Mkr 1 {*toggle*: ON}; Mkr 2 {*toggle*: ON}; *drag* markers to determine the "good" part of the pulse (where the "good" part is a stable part of the pulse avoiding edge transients); a potential range could be 110 ns to 210 ns
6. [Marker]; Markers[1] | Mkr 1 {*toggle*: OFF}; Mkr 2 {*toggle*: OFF}

If the user wanted to observe DUT behavior over 9 pulses, the following procedure simulates the results that might be obtained using the historical method.

7. APPLICATION | PulseView Setup; PULSEVIEW SETUP | PulseView Configuration
8. In the PulseView Configuration dialog box, perform the following:
    i. [PRI] {10 µs}; to provide enough room to fit 9 pulses with a 1 µs period each
    ii. [PG4] *Select* Burst | Burst Setup | # of Bursts {9}; Period {1 µs}; Delay {0 ns}; Width {200 ns}
    iii. [Measurement] Stop {9.5 µs}; # of point {3801}; # of points = INT(9.5 µs/2.5 ns) + 1 to provide non-overlapping measurement windows
    iv. [DONE]
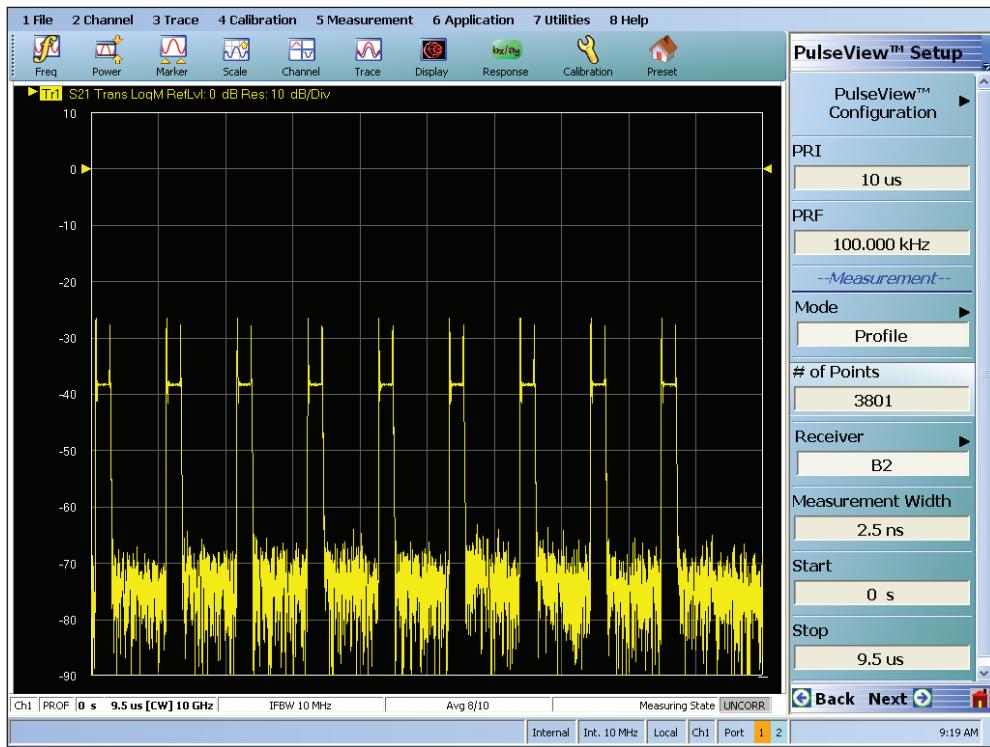
Trying to get anything more than a qualitative assessment of DUT behavior during the "good part" of the pulses would be very challenging.

9. APPLICATION | PulseView Setup; PULSEVIEW SETUP | PulseView Configuration
10. In the PulseView Configuration dialog box, perform the following:
    i. [PRI] {1 µs}; to return to actual pulse period
    ii. [PG4] *Select* Enable Pulse Generator; *Select* PG4 Label {PulseMod}; *Select* Singlet | Delay {0 ns}; Width {200 ns}
    iii. [Measurement] *Select* Pulse-to-Pulse(P2P); Measurement Width {100 ns}; Delay {110 ns}; # of pulses {9}
    iv. [DONE]
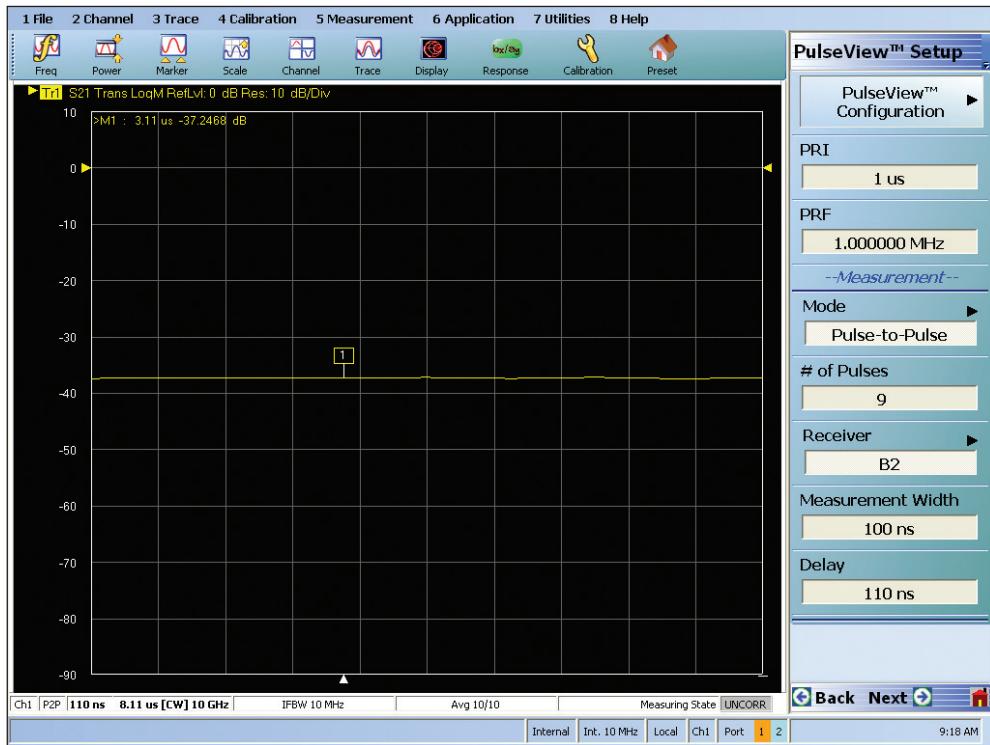
The display starts after the measurement delay and the user utilize a marker to step to each pulse value. In Pulse-to-Pulse mode, **only the requested data is displayed.**

If a user does require measurement over a long period of time, **record lengths of up to 500 ms are possible** – at full resolution! Given the number of data points required, this is only accomplished by writing the data to a file for post-processing by the user.

For a more practical example using the standard VectorStar mode capable of displaying up to 25,000 points, conduct the procedure below. A measurement with the following settings will take approximately 4 minutes to complete. Reducing the measurement width to 500 ns will reduce the update time to approximately 30 s (after the computations finish from the previous setting).

(Note: To display between 25,000 and 100,000 points, the Vector**Star** 100K mode can be used. The measurement/ display time will change reflecting the change in number of points.)

11. APPLICATION | PulseView Setup; PULSEVIEW SETUP | PulseView Configuration
12. In the PulseView Configuration dialog box, perform the following:
    i. [PRI] {100 ms}
    ii. [PG4] *Select* Burst | Burst Setup | # of Bursts {90}; Period {1 ms}; Delay {0 s}; Width {300 µs}
    iii. [Measurement] *Select* Pulse Profile (Profile); Measurement Width {5 µs}; Start {0 s}; Stop {200 ms}; # of point {20,001}; # of points = INT(200 ms/10 µs) + 1 to provide non-overlapping measurement windows
    iv. [DONE]
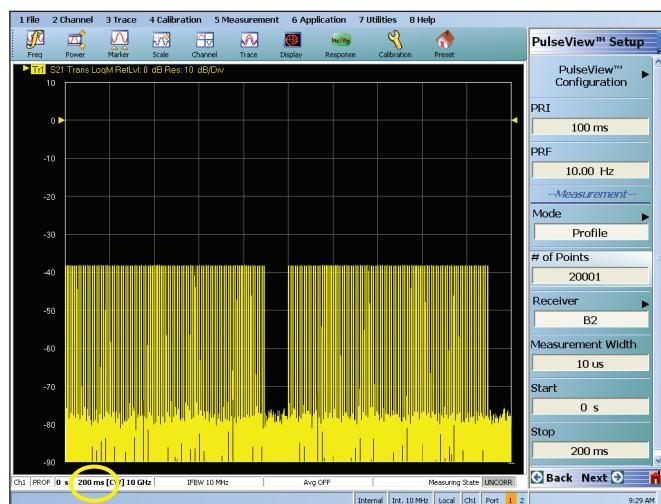
200 ms is nearly 10x better than the closest competitor.
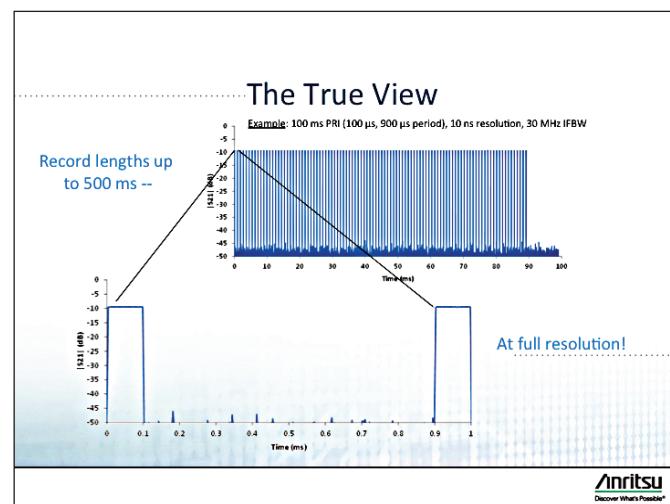
VI. Meausrement Tips and Considerations

A. Calibration

At their root, the measurements discussed in this document are still S-parameter (or perhaps unratioed parameter) measurements. Even though they are conducted in a pulsed environment, for the most part, nothing has changed in terms of availability or execution of the calibrations available. There are, however, some subtleties to keep in mind.

Power calibrations
Power calibrations are made without stimulus pulsing, as the calibration routines are not set up for peak power analysis. If a power calibration is done while stimulus pulsing is enabled, the result will represent an average power in most cases (with some odd results possible for very low PRFs).

Receiver calibrations
These are done in pulse mode and can be done with stimulus pulsing disabled (typical) or enabled. If stimulus pulsing is used, it is important to ensure the measurement window placement does not occur during an off-period in that given path.

User RF calibrations (for example, S-parameter calibrations, such as SOLT, LRL, etc.)

User RF calibrations are done while in pulsed mode. If stimulus pulsing will be used in the measurement, it should be used in calibration as well. This will allow for correction of any minor pulse distortions that may occur in the stimulus system. If using an Anritsu Pulse Modulator Test Set, reference couplers are included such that a pulsed reference can be provided to Vector**Star**. Applying this reference can help reduce trace noise and minimize any video contamination that may occur in a measurement. If the stimulus is not being pulsed (for example, only DUT or bias pulsing is being used), utilization of these additional reference signals is not needed.

Note: If the reference couplers in an Anritsu Pulse Modulator Test Set are used, the ALC detection system will still detect the un-pulsed signal, but the extra loop port should be terminated to avoid minor power inaccuracies. The ALC detection circuitry is in the reference path of the VNA, but prior to the reference access loop where the pulsed version is injected. Reference couplers are discussed in the Uncertainties section below.

All standard S-parameter calibration methods apply, the selection of which continues to be governed by the media and standards available – refer to the Vector**Star** MS4640B Series Microwave Vector Network Analyzer Measurement and Calibration Guide, part number 10410-00318 for additional information.

Although not nearly as influenced by changes in pulse parameters as the narrowband pulse measurement method, the high-speed digitizer pulse measurement method still has some calibration dependence on the pulse parameters. If those parameters change, a new calibration may be needed, depending on the uncertainty tolerance.

To understand the effect of changing pulse measurement parameters, consider the IF waveforms shown in Figure 12. They illustrate a simple 2-port transmission calibration step, where a thru line is connected and stimulus pulsing is being used.
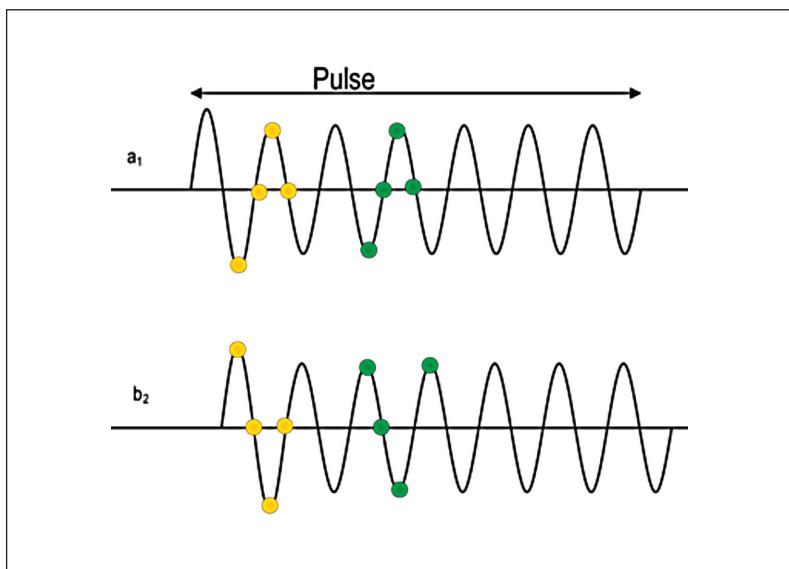
Figure 12. Example of a pulse parameter change affecting calibration.

In this example, there is overshoot on the stimulus pulse. If the measurement window is toward the front end of the pulse (yellow samples), some of the overshoot may be being measured in calibration. In some cases (a long thru line, for example), the overshoot may not be entirely symmetric (occurring at the same time) between measurement channels (a_1 and b_2, for example). If the measurement window is moved later (green samples), then there is no overshoot present and the b_2/a_1 ratio has changed. Depending on the pulse and window positions, this could cause a fractional dB error in measurement unless recalibrated. Since there is partial ratioing, the maximum error is always less than the maximum overshoot, but it could be in the 10 % to 30 % of peak overshoot in a worst-case scenario.

The decision whether to recalibrate can be affected by a number of parameters. These guidelines may help to determine whether to recalibrate the instrument:

- No stimulus pulsing is used (for example, using only bias or DUT control pulsing): With this configuration, calibrations are largely invariant to pulse parameters, and recalibration is normally not required. An exception may occur when performing an externally-triggered pulse measurement and the measurement window is close to the trigger event. In that case, experimentation with recalibration may be required to determine if there are any material effects from the measurement setup.
- Stimulus pulsing is used: As in the example of Figure 12, it may be desirable to recalibrate if it is believed that the measurements occur at a point for which there is some overshoot from the stimulus. If the test is made using an Anritsu Pulse Modulator Test Set, this overshoot is less than ~0.5 dB and only covers about the first 5 ns. If not using that time zone, or if that zone is used but ~0.1 dB impact is not significant, then one need not recalibrate. If using another stimulus modulator, one should consider its response pattern.
- Receive-side modulation is used (receiver-gating as shown in Figure 4): If one needs to operate near the edge of the modulator pulse, and if one is sensitive to small errors, then recalibration is recommended.

If pulse parameters are changed after calibration, the CORR annunciator on screen (which indicates that a calibration is applied) may change to CORR(?) to indicate the possibility that the calibration has been disturbed. The measurements may still be entirely valid based on the exact pulse measurement configuration (see the recalibration guidelines above).

B. Uncertainties

Uncertainties in pulse measurements are not often covered in great detail. In an ideal situation, possible uncertainties would be dominated by basic S-parameter uncertainties controlled by calibration kits and methods, noise floor and trace noise, linearity, repeatability, drift, and similar factors.

While it is not within the scope of this document to thoroughly analyze all of the pulse distortions possible, the most likely types of uncertainties are outlined below.

Time
When troubleshooting, address this variable first. Does the S-parameter reported at a particular time relative to T0 represent what was intended? This can be an issue due to latency in the pulse modulators, external bias systems, the DUT itself, and the VNA. A broad profiling measurement is sometimes a way of assessing the net latency and ensuring that a given time point is indeed the one of interest.

Shaping
Stimulus shape can affect the DUT output. This shaping may arise from the behavior of the RF modulators used or the behavior of any bias system pulsing that is employed. The former can normally be calibrated out, while the latter is an intrinsic part of the measurement.

Calibration
The calibration process itself may introduce some oddities as discussed earlier, particularly when stimulus RF modulation is in play. If the edges of the pulse response are of interest, then the calibration may be acting on reduced dynamic range on parts of the pulse edge resulting in elevated net trace noise.

Minimizing Uncertainties
To help reduce uncertainties, increases in averaging or reduction in IFBW in these measurements are advised– along with not trying to measure deep into the noise floor unless necessary. Power level increases can sometime also help, if the DUT can support it and one avoids receiver compression.

Nominally, 0.1 dB compression is above +10 dBm, if the step attenuators of options 061/062 are engaged. If accessing the loop paths to the receivers, compression levels will be lower by the coupling factors of the couplers/bridges. Nominally this value is 13 dB.

Other artifacts can occur with RF stimulus modulation, particularly at low frequencies. These include video energy from the pulse drive itself that can appear on the frequencies of interest.

The Anritsu Pulse Modulator Test Sets employ high pass filters for frequencies greater than 2.5 GHz. If at lower frequencies or using an external RF modulator, one may want to apply a high pass filter to the stimulus.

Other approaches to reduce uncertainties may include pre-filtering the pulse drives to soften the edges somewhat and reduce video harmonic content. As has been discussed earlier, the use of a pulsed reference signal (available in the Anritsu Pulse Modulator Test Sets for routing to the reference loops on the VNA) can help reduce these video effects somewhat.

VII. Summary

The Anritsu Vector**Star** MS4640B series of Vector Network Analyzers are capable of generating and measuring pulsed signals when equipped with Option 035 IF Digitizer and Option 042 PulseView. Four internal signal generators are included enabling singlet, doublet, triplet, quadruplet, and/or burst signal generation. Pulse measurements include pulse profile, point-in-pulse, and pulse-to-pulse capability.

Option 035 IF Digitizer
Option 042 PulseView

Pulse Modulator Test Sets are available to pulse the RF stimulus and/or provide receiver gating (modulation). The Pulse Modulator Test Set frequency range is limited to that of the VNA with which it is used.

SM6628, 70 kHz to 40 GHz. Provides the MS4642B and MS4644B VNA with source modulation.
SM6629, 70 kHz to 40 GHz. Provides the MS4642B and MS4644B VNA with source and receiver modulation.
SM6630, 70 kHz to 70 GHz. Provides the MS4645B and MS4647B VNA with source modulation.
SM6631, 70 kHz to 70 GHz. Provides the MS4645B and MS4647B VNA with source and receiver modulation.

Pulse Modulator Test Sets require direct access loops found in:

Option 051 Direct Access Loops
Options 061/062 Active Measurements Suite

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