VNA's High-Speed Architecture Advances Radar Pulse Measurement Timing Resolution and Accuracy

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Increasing demand on radar systems is driving the requirement for more accurate measurements. Whether you're tracking high speed targets or detecting slow, low, and small objects - better pulse measurement tools are needed. Advances in radar systems are requiring greater precision to measure narrower pulse widths and/or have a need to examine intra-pulse behavior with finer resolution – including a closer look at rise/fall edge effects or the profile within a pulse compression signal. These radar demands have created challenges for existing pulse measurement test systems – until now.

This white paper introduces a new VNA platform that takes advantage of a high-speed digitizing architecture to offer the industry's highest level of measurement resolution and timing accuracy. The architecture also capitalizes on deep memory to observe DUT behavior over longer periods of time (without sacrificing resolution) – whether looking for thermal and trapping effects in devices or measuring DUTs with lower pulse repetition frequencies. The white paper will also present how the platform's four independent receiver measurement windows enable reference position control to support various calibration and system timing needs, which may otherwise have masked DUT rise/fall behavior. Finally, it introduces a new pulse measurement user interface that offers real-time parameter modifications for increased confidence in setting up your measurement.

High-Speed Digitizer Method Overview

A number of methods are currently being used to make pulse measurements, including narrowband or band-limited methods, triggered methods and wideband methods. Unfortunately, they all come with limitations and trade-offs. The high-speed digitizer measurement method represents major technology advancement over all prior pulse measurement 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 Vector Network Analyzer (VNA) with options 035 and 042 (PulseView™) offers a digital IF acquisition system with more than 200 MHz of bandwidth. As a result, resolution is enhanced and time referencing becomes much more accurate. The exact acquisition method differs in that the acquisition itself is not constrained by real-time synchronization with pulse system (except in the case of pulse-to-pulse measurements). Data is recorded for analysis and correlated with the pulse pattern being used. This new acquisition system virtually eliminates the limitations and trade-offs required by all prior test methods.

Architecture Review

To explore the high-speed digitizer method in more depth, consider the acquisition system of the Anritsu MS4640B shown in Figure 1. IF signals are generated by the downconverters in the MS4640B. When equipped with Options 035 and 042 (PulseView™), the standard IF system is bypassed and signals are routed to a special high-speed digitizing IF board. This board consists of analog processing (filtering, gain, calibration, etc.) with much wider bandwidth than that of the standard IF system, which enables the measurement of far narrower pulses. This board also houses fast analog-to-digital converters, pulse generators, and digital processing components. The VNA includes 4 independent receiver measurement windows (gates), which provide users with reference position control to correct for undesired measurement setup transient behaviors and to account for any path delays/system timing issues. Deep memory is used to store the data coming in from the converters. As a result, the Anritsu MS4640B can acquire long time records of more than 0.5 seconds with full resolution.

Acquired data is keyed with the T_0 synch information. For the pulse measurement processing, the data of interest is selected (relative to T_0) and run through the appropriate conversions to the frequency domain. Then S-parameters are created and the appropriate calibrations applied. Since the processing is relative to these time markers and not any of the pulses per se, there is considerable flexibility on where in time one can look at the results. This becomes particularly valuable in complex pulse situations, where there may be long delay lines, significant group delay, many sub-pulses present, or when synchronization with other equipment is needed.

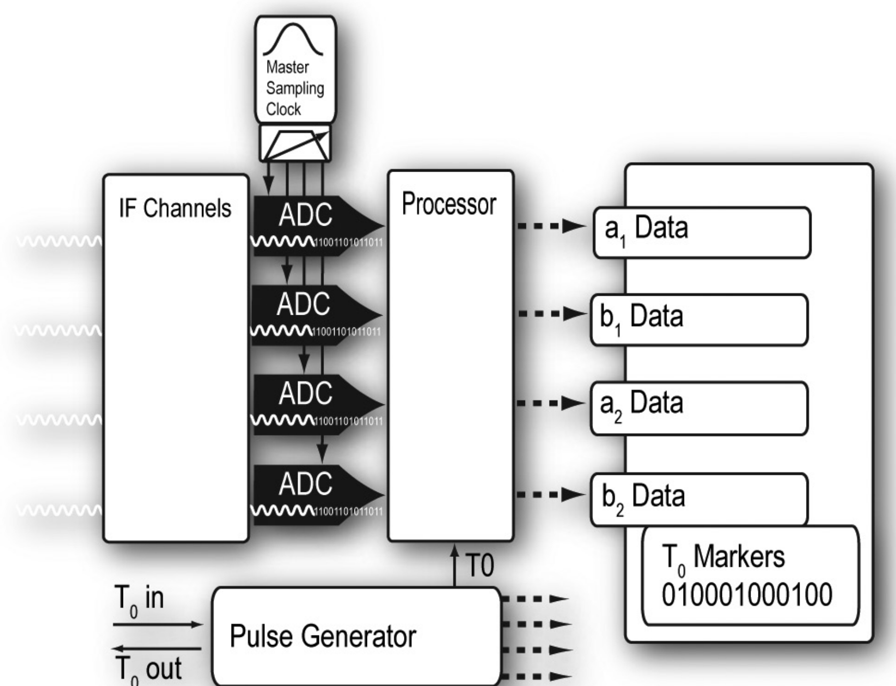


Figure 1. *The data acquisition system in the MS4640B VNA with Options 035 and 042 (PulseView™) enables the highest resolution and timing accuracy for pulse measurements.*

Measurement Setup

With a wide array of applications and DUTs, many test configurations involving pulsed stimulus, receiver gating, and pulsed DUT bias/control may be of interest. An example system setup using the high-speed digitizer pulse measurement method is illustrated in Figure 2. Two pulsed bias supplies were used in this example along with stimulus pulsing. The Anritsu MS4640B equipped with Options 035 and 042 (PulseView™) includes a four channel internal pulse generator for driving bias pulsers, DUT control, RF stimulus modulators and/or RF receiver-side modulators (available in optional Pulse Modulator Test Sets). No pulse generator channels are used to control the pulse measurement or profiling directly, as this is handled internally. Input/output access to the T_0 synch pulse is also provided for synchronization between external equipment (e.g., pulse generators) and the internal timing system (as might be needed in more complex bias situations). When an absolute start time is important, measurements may be synchronized via an externally provided synch. This is sometimes used for pulse-to-pulse and related measurements.

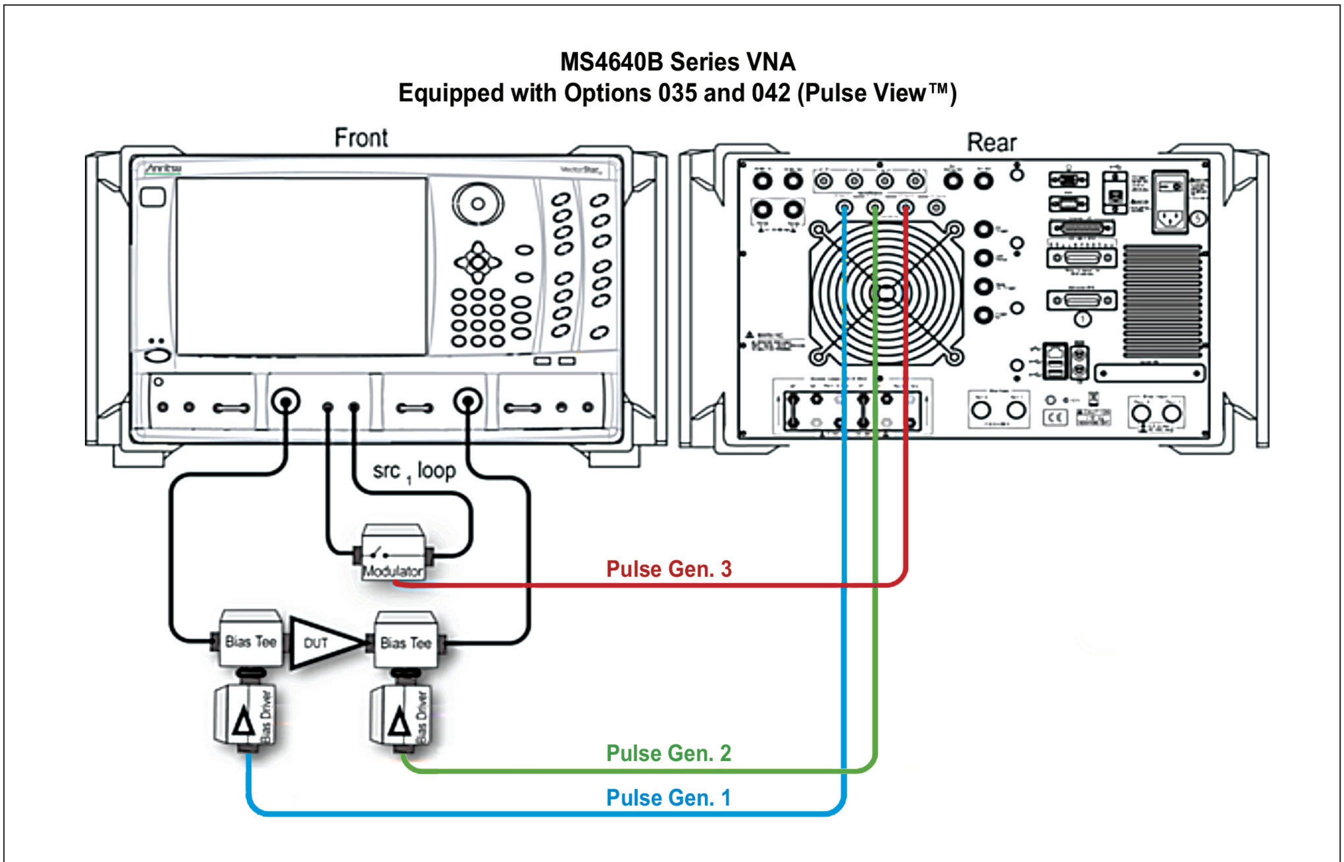


Figure 2. *An example setup of the high-speed digitizer measurement method of the MS4640B with Options 035 and 042 (PulseView™). Not all of the pulse connections shown need be used (or additional ones may be used).*

Less Calibration, More Certainty

Traditional pulse measurement methods can be very sensitive to changes in pulse parameters and often require frequent re-calibration. For example, with the narrowband method, small changes in the pulse parameters can alter the signal spectrum and increase uncertainty without recalibration. With the triggered pulse measurement method, small changes in measurement system timing can lead to significant increases in uncertainty. Combining the excellent measurement resolution and timing accuracy with the ability to independently adjust receiver timing of the high-speed digitizer method significantly reduces the need for recalibration and minimizes uncertainty. Guidelines for when to recalibrate are presented below, based on measurement conditions:

- **No RF stimulus pulsing** (i.e., only bias or DUT control pulsing is used): With this configuration, calibrations are largely invariant to pulse parameters and usually recalibration is not required. An exception may occur when performing an externally-triggered pulse-to-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.
- **RF Stimulus pulsing is used:** It may be desirable to recalibrate, if it is believed that the measurements occur at point when there is some overshoot from the stimulus modulator.
- **Receive-side modulation is used:** If the measurement is being done near the edge of the modulator pulse, recalibration may be required. In that case, experimentation with recalibration may be required to determine if there are any material effects from the measurement setup.

Advantages of the High-Speed Digitizer Method

With the incorporation of a high-speed digitizing pulse measurement method, many advantages can be realized. For example, the users can:

- ***Gain better insight into edge or intra-pulse behavior***
- ***Avert issues with high trigger latencies***

By using a high-speed digitizer and performing the alignment with pulse data in a post-processing sense, one avoids the triggering latency issues associated with triggered measurements and potential jitter/inconsistency problems with that triggering. The resolution is set mainly by the acquisition rate instead. The Anritsu MS4640B with Options 035 and 042 (PulseView™) offers a 400 MS/s data acquisition rate, the fastest available in a VNA. As a result, the time resolution is on the order of 2.5 ns. For alignment with the internal synchronization signal (T_0), the jitter level is in the low picoseconds; when the MS4640B is presented with an external synch, there may be latency in the tens of nanoseconds range as the internal system must lock onto the external pulse. In addition, the higher resolution enables the precision to measure narrower pulse widths and/or examine intra-pulse behavior with finer resolution – including a closer look at rise/fall edge effects or the profile within a pulse compression signal.

• *Avoid masking DUT performance with measurement system performance*

Even for full correction, no receive-side modulators are required and the on-off ratio, bandwidth, rise-time and video limitations of those structures are no longer an issue. Any bandwidth limitations would be result of a VNA's receiver IF. In its nominal operating state, the Anritsu MS4640B has an IF bandwidth of greater than 200 MHz. Figure 3 is a plot of the output of Anritsu MS4640B IF sub-system when presented with an input pulse 5 ns wide and 1 ns rise and fall times. Artifacts include some edge softening but the distortion is relatively small (especially when compared to narrowband systems). The amplitude was not scaled for this plot and the time shift is due to group delay in the system that is accounted for in the measurement process. This example shows that a sufficiently wide IF relative to the pulse shapes of interest is important to measuring the DUT characteristics rather than those of the instrumentation.

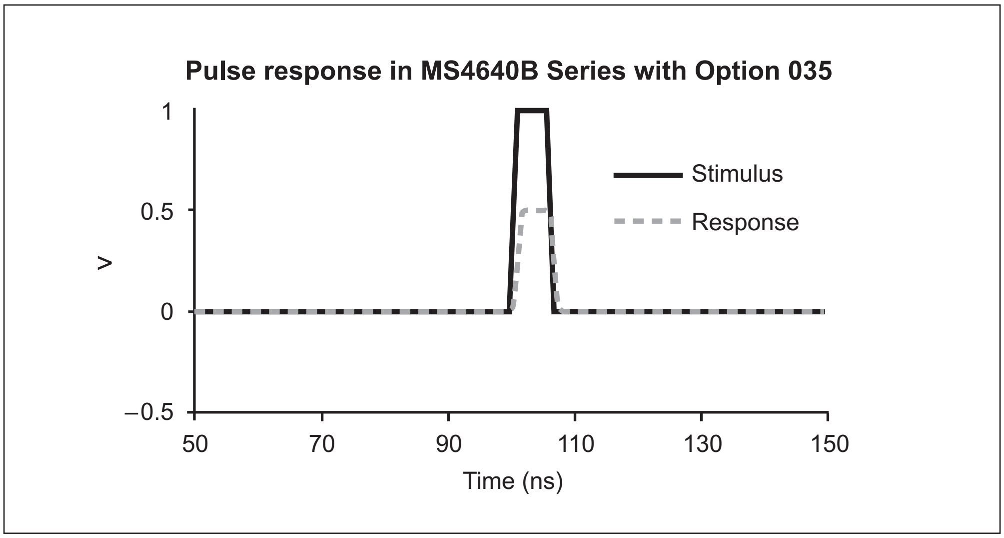


Figure 3. *Effect of the IF bandwidth on the pulse shape using the high-speed digitizer pulse measurement method. The stimulus was a 5 ns wide DUT pulse with 1ns rise and fall times.*

• *Eliminate duty cycle-related dynamic range reduction*

Since no energy is being discarded in the high-speed digitizer pulse measurement method (in contrast to the narrowband 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.

• *Extend investigation of time varying events without sacrificing resolution*

• *Utilize flexibility to make measurements on a wide variety of radar systems*

With the MS4640B, narrow pulses and fast edges can be captured with a minimum resolution[1] of approximately 2.5 ns. Since the memory is very deep, very low duty cycles and low repetition rates are supported without sacrificing resolution. The long data records enable the pulsed signals to be dissected into any of the desired pulse measurement modes. This enables the flexibility to make highly accurate measurements on a wide variety of radar systems.

[1] For pulse repetition rates in the Hz range and slower, regular triggered methods are sufficient.

Benefits of the Independent Receiver Gates

Gating of the receivers can be handled independently because the alignment with pulse data in a post-processing sense. The ability to have independent receiver gates can be used in many ways. While other test solutions are limited to coupled receivers, the independent receiver measurement windows (gates) enable reference position control to support various system timing needs and expose DUT rise/fall behavior.

- ***Account for measurement system/DUT delays***

Independent receiver gates can be a very effective way to account for 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 following example. A user wants to measure the gain (S_{21}) of an amplifier during a 400 ns pulse (delayed about 100 ns from T_0) at 1 GHz with 0 dBm input power. The expectation is a fairly flat gain of ~ 20 dB over the 400 ns. The measurement observed is shown below in Figure 4. Because the result is quite different than the expectation, the user looks at the a_1 and b_2 traces, shown below in Figure 5. As a result, it is determined that the amplifier exhibits roughly a 100 ns group delay. With coupled receivers, there is only roughly a 150 ns window in which may produce a representative S_{21} measurement – but even then it is based on a ratio of different parts of the pulse. If the user wanted to look at the amplifier response over frequency, the point-in-pulse measurement would have to be delayed ~250 ns with a 150 ns measurement width – outside of which, valuable device behavior may be lost.

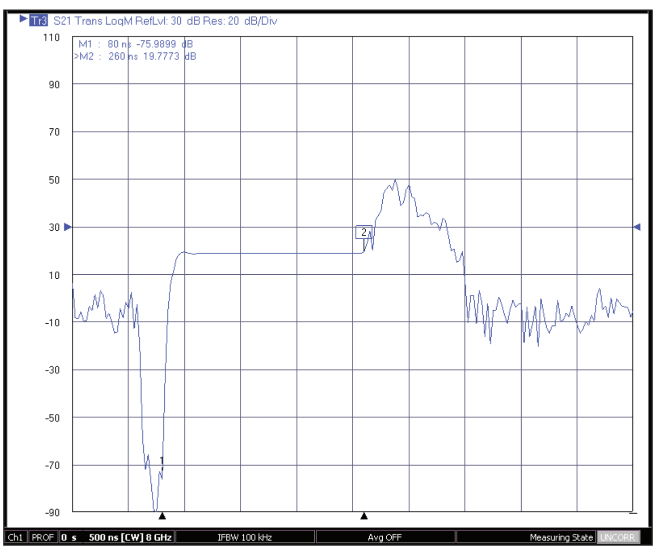


Figure 4. *An S_{21} of an amplifier using coupled receivers shows a poor gain result.*

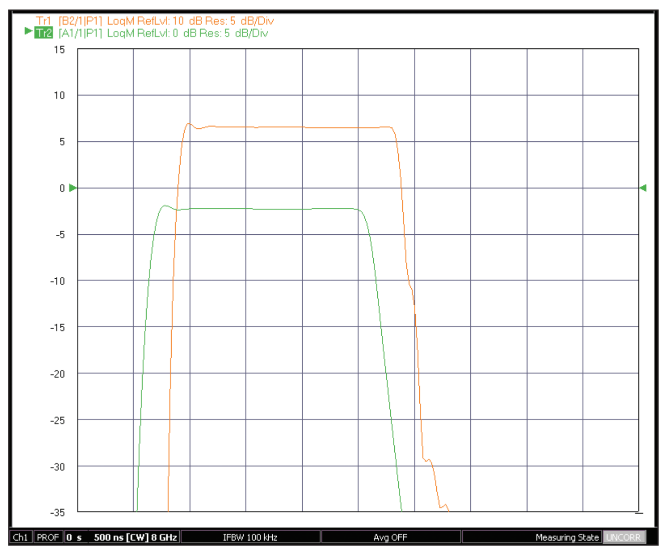


Figure 5. *The a_1 and b_2 traces of an amplifier measurement show the amplifier exhibits roughly a 100 ns group delay. With coupled receivers, the S_{21} measurement is misaligned producing errant results.*

With the use of independent receiver measurement windows (gates), the user could account for the group delay and delay the b_2 measurement by an additional 100 ns; see Figure 6 (a). The results are shown below in Figure 6 (b).

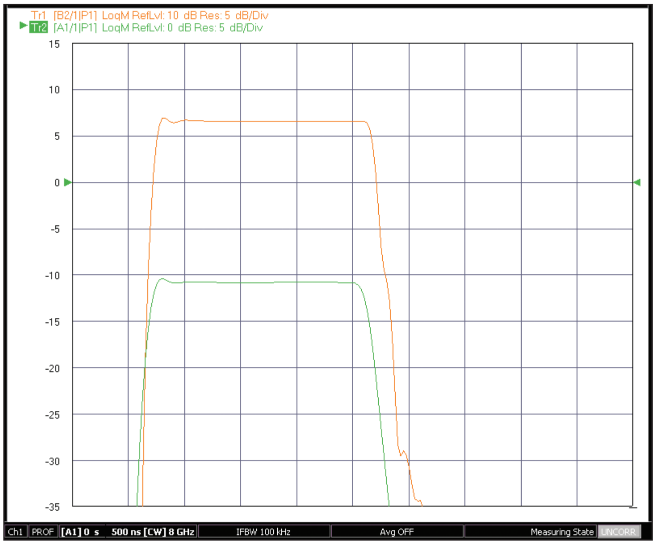


Figure 6 (a). *Independent receiver gates allow the user to account for delays between a_1 and b_2 receiver measurements.*

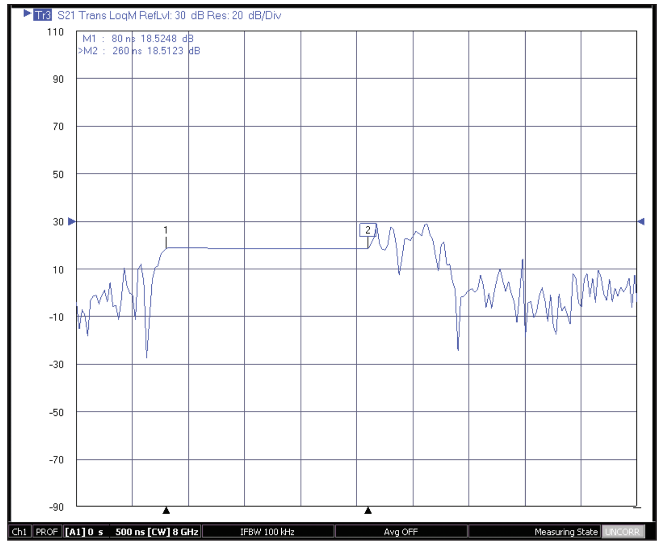


Figure 6 (b). *As a result, the user gets an accurate S_{21} measurement of the amplifier.*

This same concept could apply if rather than group delay, there was delay in the measurement setup. For example, if stimulus pulsing is used, there is often some latency due to the pulse modulator (<35 ns for the Anritsu Pulse Modulator Test Sets). Moreover, the pulse modulation may occur after the a_1 reference signal is measured. The user will want to make sure that delay is accounted for in the b_2 measurement.

- ***Get more accurate calibrations***
- ***Calibrate less often***

Independent receivers also offer some advantages in calibration. Consider the case when the user would prefer to calibrate his measurement using a pulsed stimulus to allow for correction of minor pulse distortions in the stimulus system. If using the Anritsu Pulse Modulator Test Set, extra reference couplers are provided so that a pulsed reference can be provided to the system. This can help reduce trace noise and the influence of video contamination in the measurement if stimulus pulsing is being used.

To understand this effect, consider the IF waveforms shown in Fig. 7 for a simple 2-port transmission calibration step. A thru line is connected and stimulus pulsing is being used. Suppose there is some overshoot on the stimulus pulse. If the measurement receivers are coupled and the calibration is in the middle of the pulse (green samples), then as long as follow-on measurements stay away from the edge of the pulse, the calibration error will be very small. However, if measurements are made near the front end of the pulse (yellow samples), some of the overshoot may be measured. Moreover, if there is any asymmetry between channels, the b_2/a_1 ratio will change. Depending on the pulse and window positions, this could cause a fractional dB error in the measurement unless recalibrated. If the receiver gates were independent and the asymmetry between channels was taken into account, the measurement window could change throughout the pulse without the need to recalibrate.

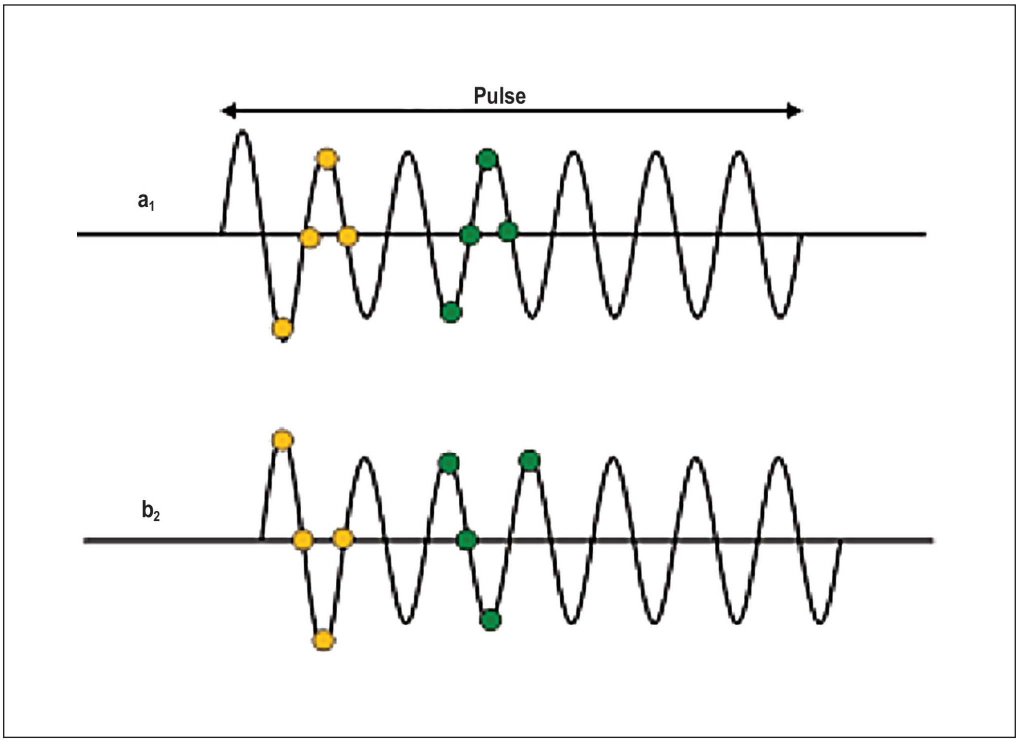


Figure 7. *Possible cause for recalibration when using coupled receivers.*

Improving Radar Pulse Measurements

Radar applications use a number of common S-parameter measurements and pulse profiling techniques. This section discusses the three most common measurement modes and highlights a new graphical user interface that helps ensure the proper measurement timing.

Point-in-Pulse Measurements

The point-in-pulse measurement quantifies S-parameter data at any point in time within a pulse. The measurements are made with swept frequency or power and plotted accordingly. This measurement mode is useful when trying to avoid possible edge effects of the pulse. For example, amplifiers often have settling effects at the beginning of the pulse. Point-in-pulse measurements are useful when you need to 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.

From the point-of-view of the measurement system, it is normally only the delay and measurement/acquisition width that must be specified. To further understand the high-speed digitizer acquisition process, consider the point-in-pulse measurement shown in Figure 8. In this case, the data of interest (denoted with x's) begins at some number of samples (time =T_1) after the T_0 edge. The time domain data is converted into a single frequency domain point. Had a smaller measurement width been entered, fewer x's would have been taken. In this way, the width acts as an effective processing bandwidth (i.e., an IFBW). The result can also be averaged over multiple pulses to reduce trace noise or increase effective dynamic range. In this case, the x's will be collected after multiple T_0 high markers until the desired level of averaging is complete. During the acquisition, the pulse timing is coherent with the ADC clock to maintain phase.

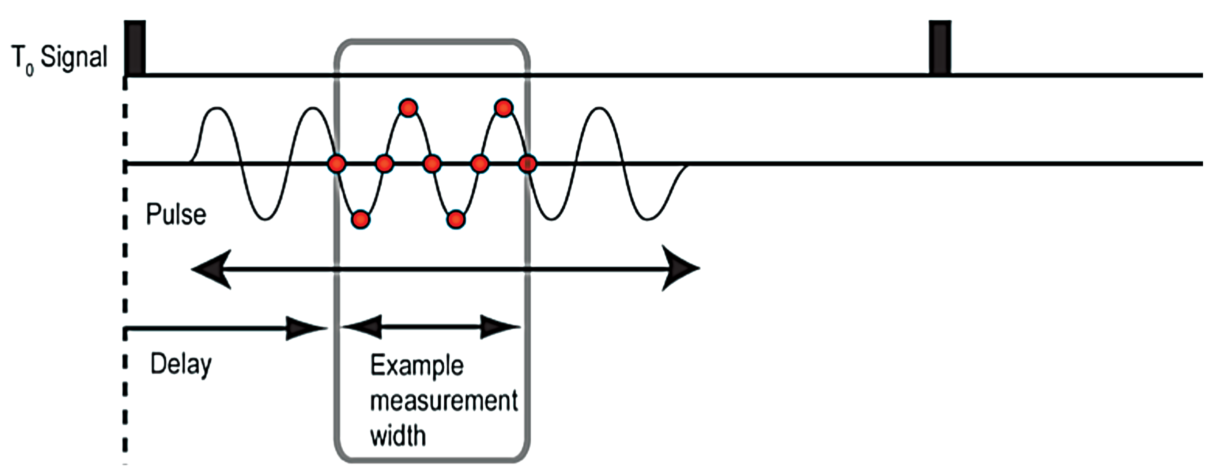


Figure 8. *Example point-in-pulse measurement.*

Pulse Profile Measurements

The pulse profiling measurement focuses on the structure of data within the pulse. The measurements are made in the time domain, while the frequency and power are kept constant. This measurement mode is useful for determining pulse characteristics such as overshoot/ undershoot, droop, and edge response (e.g., rise/fall time).

With the high-speed digitizer measurement method, pulse profiling measurements are processed in a similar way as the point-in-pulse. For pulse profiling, a single acquisition is completed (based on time span of interest, PRI, and requested averaging). That data is sequentially processed using the selected measurement width at each of the requested time points; if averaging is enabled, the process is repeated over multiple pulses.

The Pulse Setup menu is visible while measurements are being made, enabling the user to confirm they are making the intended measurement (e.g., making a profile measurement rather than a point-in-pulse measurement). It offers the additional advantage of enabling the user to view the effect of changes to the measurement setup in real-time.

For example, a user may want to examine the rising edge of measured pulse and then profile the main portion of the pulse without having to go back and forth between configuration and measurement screens; see Figure 9.

(a) Profile measurement examining leading edge of pulse.

(b) Start/stop times widened to observe behavior over the entire pulse.

***Figure 9.** The Pulse Setup menu enables the user to confirm they are making the intended measurement and view the effect of changes to the measurement setup in real-time.*

Pulse-to-Pulse

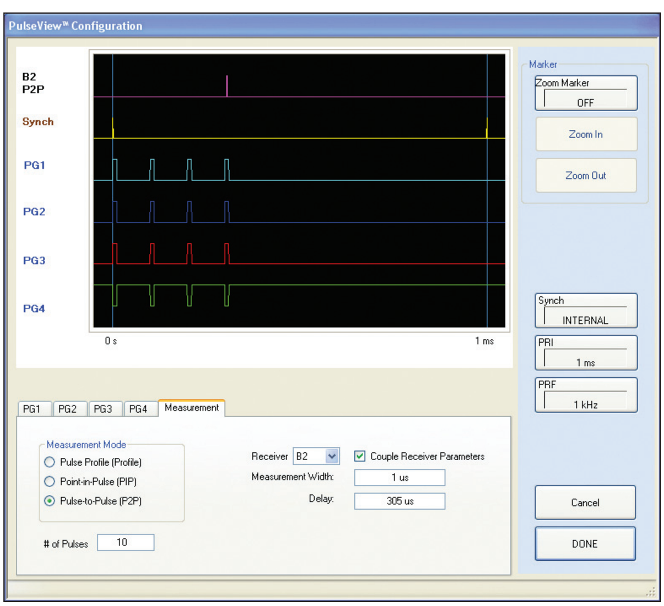
The pulse-to-pulse measurement quantifies variations between pulses in a pulse stream. The measurements are also made in the time domain, while the frequency and power are kept constant. This measurement mode is useful when trying to determine whether the pulse characteristics are varying over time. For example, high power amplifiers may have thermal effects which can cause variances in the gain or phase.

From a measurement point-of-view, pulse-to-pulse measurements are something of a hybrid of point-in-pulse and pulse profiling. In the sense of the former, we are looking at a single window per period (relative to T_0). In the sense of the latter, we are collecting and plotting data versus time with frequency and power held constant (within this one measurement anyway). Averaging between pulses is not possible.

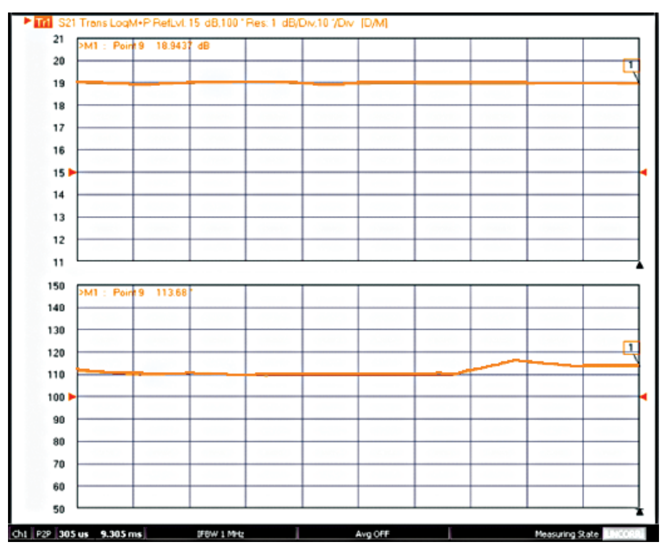
To coordinate this absolute timing, normally some external or manual triggering is used to begin the sequence of events. For this example, the manual trigger on the VNA was used. When executed, the pulse generator outputs will activate and, in this case, begin applying bias and RF to the device. It is desired to capture the evolution of S_{21} of the DUT over the first 10 pulses. The PRI is 1 ms and quadruplet pulsing on both bias (3 supplies for this DUT) and RF are desired. The relative delays are 100 µs between each leading edge of the quadruplet and the width of each sub-pulse is 10 µs. The desired measurement window is 1 µs centered within the last pulse of the quadruplet.

The Pulse configuration dialog box is shown in Figure 10 (a). Here, we are back to coupled parameters and the measurement (for all channels) is roughly centered within the final pulse of the quadruplet. The three external bias systems required positive polarity while the RF stimulus requires, as usual, inverted polarity.

The data for this measurement is shown in Figure 10 (b). The magnitude shows little variation over the 10 pulses (<0.1 dB) while the phase shows up to 5 degrees of variation towards the end of the measurement cycle.



(a) Pulse-to-pulse example setup dialog.



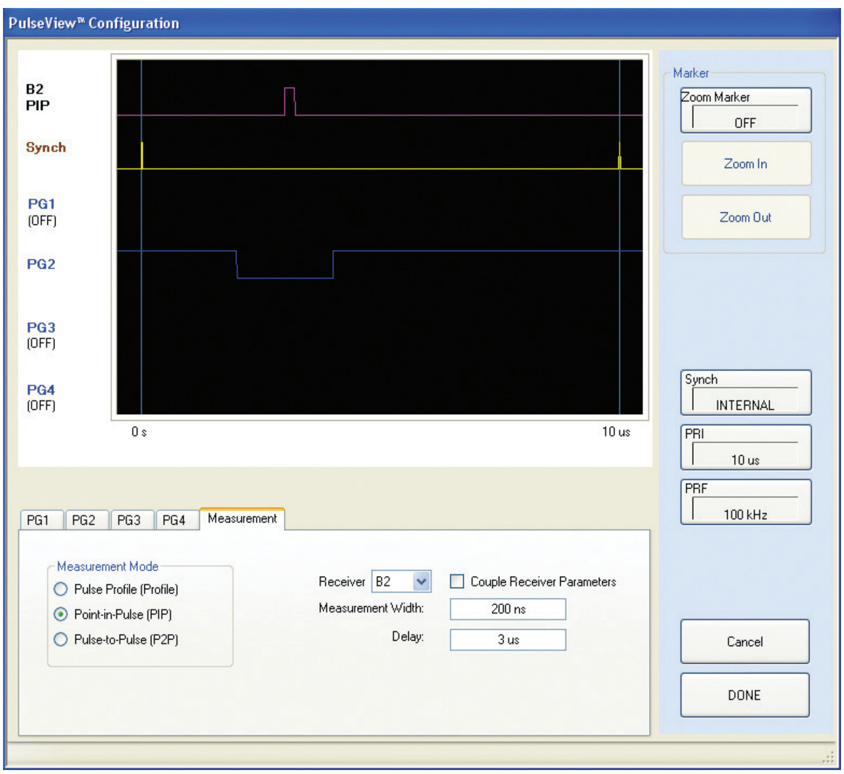
(b) Pulse-to-pulse measurement results.

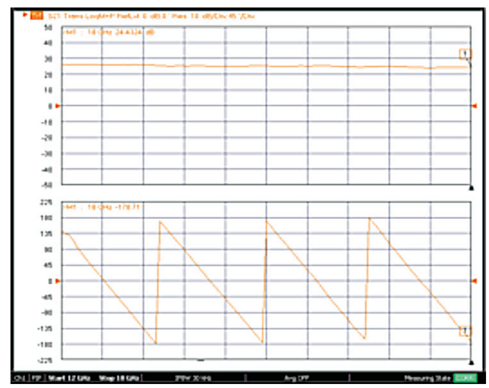
Figure 10. *The Pulse configuration dialog box shows the measurement (for all channels) is roughly centered within the final pulse of the quadruplet.*

- ***Have greater measurement confidence***

Traditionally, with many potential measurement setup configurations and the criticality of proper timing between stimulus and measurement acquisition windows, it can be difficult to have confidence that one is making a valid measurement and/or measuring the intended behavior. Often the pulse measurement user interface for VNAs has been text-based. The Anritsu MG4640B with Options 035 and 042 offers a graphical user interface that enables users to visually confirm that a measurement is being made with the proper setup.

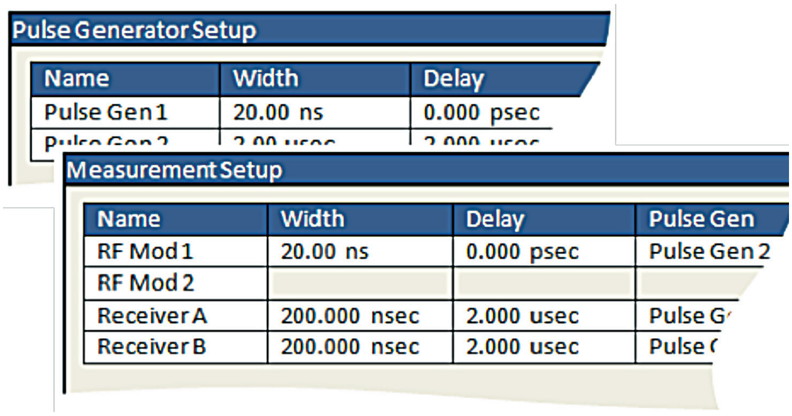
Figure 11 highlights an example of a point-in-pulse gain measurement. From the Pulse Configuration screen, it can be easily seen that the b_2 measurement is nearly centered in the stimulus pulse – avoiding potential edge effects. The result is the S_{21} measurement shown on the left. However, if one was using a text-based interface, it could be easy for the user to lose track of the timing and have the measurement too close to the stimulus pulse edge and include some unwanted behavior (Figure 12). The resultant gain measurement is much lower in magnitude and poorly behaved.



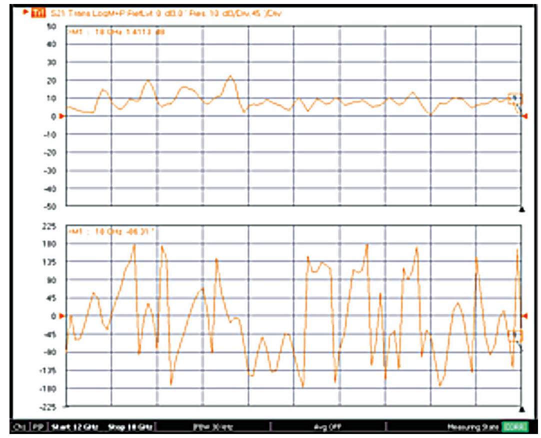


(a) {left} Point-in-pulse measurement configuration, (b) {top-right} Accurate measurement with a 3 µs delay from T_0.

Figure 11. *Anritsu MG4640B offers a graphical user interface that enables users to visually confirm that a measurement is being made with the proper setup.*



(a) Representative text-based interface with measurement setup error.



(b) Affecting measured results (2 µs delay from T_0).

Figure 12. *Prior text-based interfaces lack the ability to visualize timing, which makes it easy for the user to lose track of the measurement timing and include some unwanted behavior.*

Summary

Demanding requirements for radar systems call for more accurate measurements. The Anritsu MS4640B with its high-speed digitizer architecture offers the industry's highest level of resolution and timing accuracy. It eliminates the trade-offs between dynamic range and duty cycle and ensures that you don't miss behaviors masked by lower resolution alternatives. Its four independent receiver measurement windows correct for undesired measurement setup transient behaviors to preserve information about your DUT transients. The pulse measurement user interface offers real-time parameter modifications for increased confidence when setting up your measurement. The Anritsu MS4640B with options 035 and 042 (PulseView™) enable users to have confidence on the cutting-edge of performance.

The VectorStar® family is Anritsu's Premium VNA line, offering the highest overall performance on a modern platform. The MS4640B Series offers the best performance covering a span of 70 kHz to 70 GHz. For broadband applications, the ME7838A Series offers superior coverage spanning a range from 70 kHz to 110 GHz in a single 1 mm coaxial test port. For multiport applications the MN469xB provides 4 port measurements and the VectorStar 12-Port System provides maximum performance up to 70 GHz. The SM6430 VectorStar Nonlinear system is the most complete high performance nonlinear analysis system available, including flexible upgrade paths.

The Anritsu MS4640B Vector Network Analyzer offers a new level of performance for device modeling engineers struggling to accurately and reliably characterize their devices, for R&D engineers pushing the last fraction of a dB out of their state-of-the-art designs, and for the manufacturing engineer trying to maximize throughput without sacrificing accuracy.

Anritsu's MS4640B VNA offers the broadest coverage in a single instrument, 70 kHz to 70 GHz. The additional two decades at the low end are even more impressive than the guaranteed 70 GHz coverage on the high end, for better device modeling without having to switch to another RF VNA. The industry leading 100 dB dynamic range at 70 GHz, coupled with excellent raw performance, will offer the best accuracy and stability to the toughest measurements. And when you can achieve synthesized sweeps at the industry fastest 20 µs/point, while achieving greater than 80 dB sensitivity, the result is the best all-around VNA available on the market today, and for a long time to come.

Anritsu's VNA is destined to become the ideal microwave VNA platform, built on an Open Windows architecture, with unlimited potential such as 100,001 points in single channel mode, with versatile connectivity, and intuitive interface. Backed by the industry's first standard 3-year VNA warranty and the most responsive sales support team, the MS4640B is the VNA of choice for the discerning engineer.

When equipped with Option 035 and Option 042 (PulseView™), the Anritsu MS4640B Vector Network Analyzer includes the capability to generate and measure pulsed signals. 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.

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