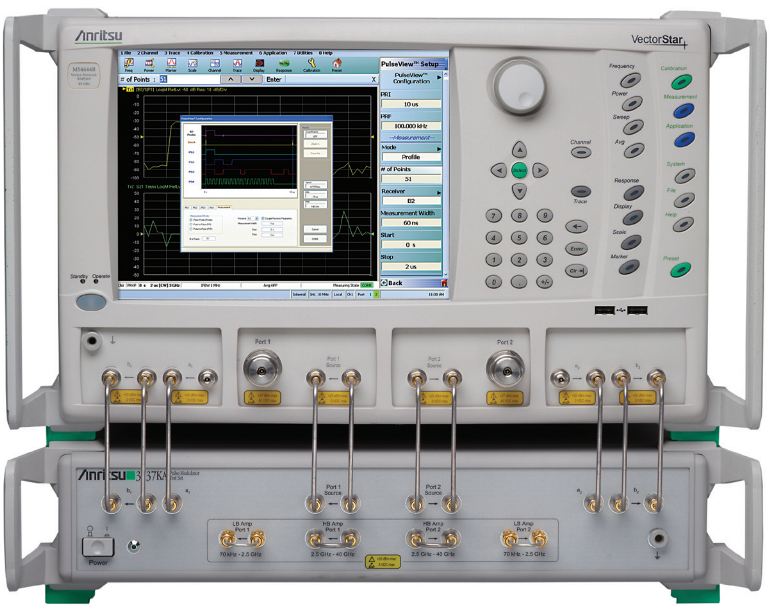
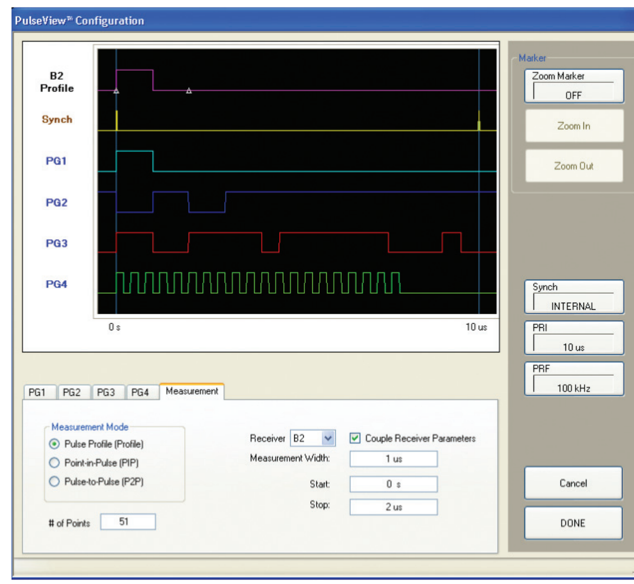
Application Note

PulseView™ Calibrations

MS4640B Series Vector Network Analyzer





Introduction

The PulseView mode in the MS464XB VNAs allows point-in-pulse, pulse profiling and pulse-to-pulse measurements and often these are performed in some calibrated sense beyond simple normalization. While these are still S-parameter measurements and all of the usual algorithms (SOLT, SOLR, SSLT, TRL, LRL, LRM…) and types (full 2-port, 1 path-2 port, full 1 port, frequency response…) still apply, there can be some setup and configuration differences to be aware of. The purpose of this note is to discuss these setup and configuration questions in the context of some common pulse measurement scenarios.

Basic configurations

The calibration implications are heavily dependent on the basic measurements configuration. Is pulsed RF stimulus being used? If not (e.g., the pulsing is only of the DUT bias or some control signal), then by definition, the calibration will be performed in a non-pulsed state. When performing pulse measurement calibrations, one must be in the PulseView application as calibrations cannot be shared between regular Transmission/Reflection and PulseView since different IF systems are used. While using the PulseView application, the desired mode (Point-In-Pulse (PIP), Pulse Profiling (PP) or Pulse-to-Pulse (P2P)) must be selected. The latter is an important point since the x-axes are not the same (frequency vs. time vs. time/number of pulses). Since this calibration is non-pulsed, the Point-In-Pulse situation is conceptually simple…a frequency sweep (or power sweep) is performed and appropriate error coefficients generated. Changing the measurement width or position (or IFBW) after calibration will only affect relative levels of trace noise and dynamic range of the results. The frequency range and point count are constrained as in regular transmission/reflection mode; although interpolation is allowed. For Pulse Profile and Pulse-to-Pulse, the calibration is essentially a CW process since the same frequency and power are used for the measurements across an axis of time…the same error coefficients, within limits of trace noise, will be generated at each point and applied to the measurement result. Again, measurement widths and positions can be changed after the calibration with only relative changes in trace noise or dynamic range. The number of points, however, cannot be changed as this would alter the indexing of the error coefficients.

If stimulus pulsing is needed (using Anritsu pulsed test sets or with external modulators), the situation can be slightly more complex. The central issue is if and to what extent one wants to calibrate out dynamics associated with the stimulus modulation process. One aspect to consider is how the reference signals (a1, a2…) are handled. The Anritsu test sets (SM68XX) have a post-modulator reference coupler that allows pulsed references to be used (in lieu of the unpulsed reference coupled internally to the VNA). Alternatively, a non-pulsed reference can be used by not connecting these paths (and both methods can be emulated using external modulators). The methods for connecting the test set in these two alternative methods are shown in Figure 1. The resulting S-parameters are different in these two cases as suggested in Figure 2 for a PP example. This is an uncalibrated measurement just to show the behaviors of the ratio and, since the paths of the reference are different in the two cases, the absolute S21 value changes slightly. The central point is again the transition behavior.

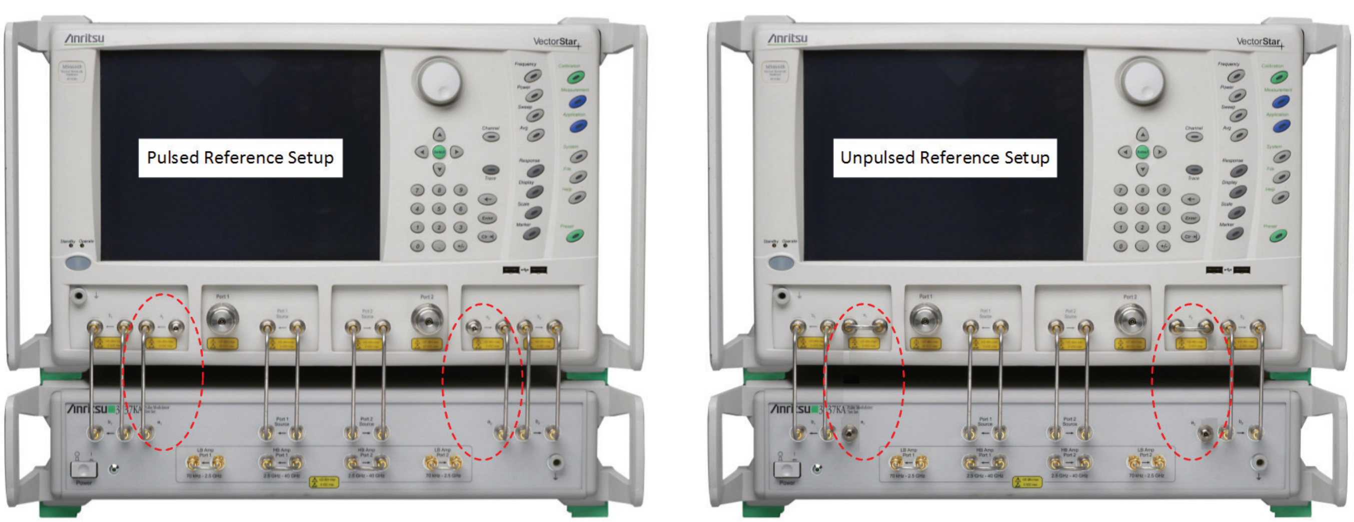


Figure 1. *Setups using the SM68XX pulsed test set with (picture on left) and without (picture on right) pulsed references are shown here (cable changes circled). Similar cable changes occur on the rear panel for frequencies less than 2.5 GHz.*

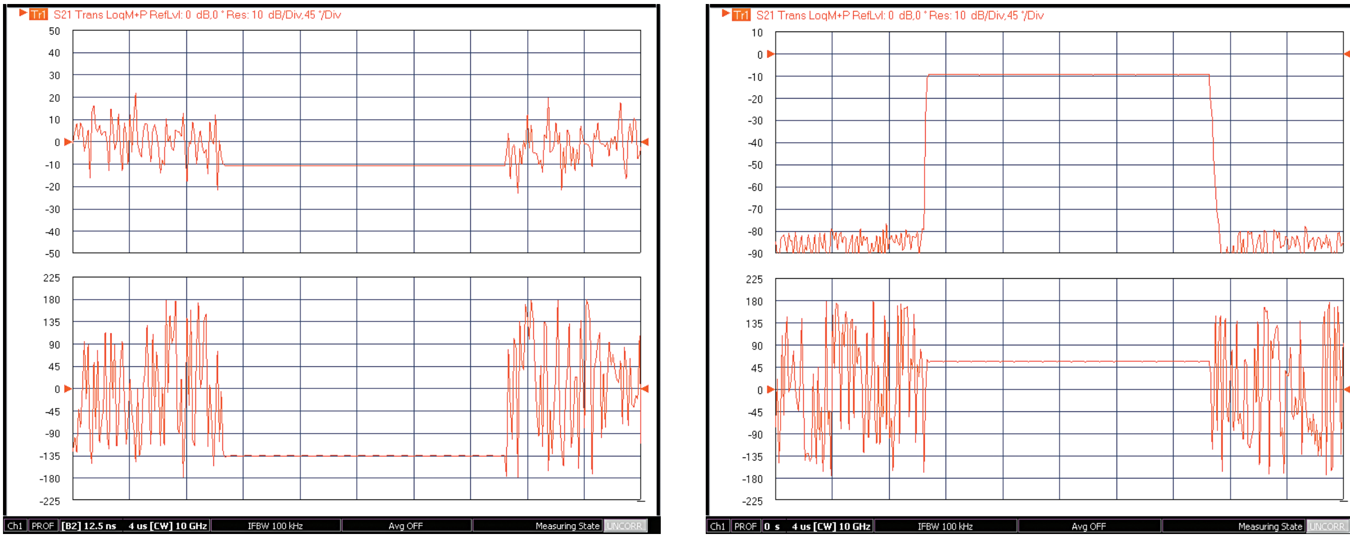


Figure 2. *Examples of a profiled transmission S-parameter are plotted for cases with (plot on left) and without (plot on right) a pulsed reference.*

One can see from Figure 2 the heart of the matter in looking at the edge behavior. When using the pulsed reference, if there are transients associated with the modulation, they may cancel in the ratioing process assuming timing is aligned (more on that later) resulting in less distortion in the DUT overshoot area. The pulsed reference also tends to reduce video ringing in the on state of the pulse in a raw sense (so that the calibration has less work to do). The pulsed reference does, however, make it much harder to look at rising edge and falling edge details (particularly further down the edges) since the reference is changing rapidly at those times as well. The choice may depend on what part of the pulse is of the most interest.

Another reason to consider a pulsed reference is the question of stability in complex setups. If pre-amplifiers, external modulators or other external structures are used, stability could be somewhat impaired by the addition of the network itself (as the pre-amplifier warms up for example) or by long runs of external cabling. By having the reference taken after these networks, which normally means it will be pulsed if pulsed stimulus is used, much of the potential drift behavior will ratio out. This can mean less frequent calibrations.

This then leads to the question of how to calibrate the system with these setups. Consider a typical output envelope from the RF modulators as shown in Figure 3. For the SM68XX test set modulators, the width of any overshoot is on the scale of a few ns and the rise time (10-90%) is typically 5ns. Thus, the sketch of the top of Figure 3 is roughly to scale for pulse widths of ~50ns. For wider pulse widths, say ~500ns, the diagram in the lower part of Figure 3 is more correct and almost all measurements are in region B.

If one is measuring in region B, it does not really matter if the calibration was performed pulsed or non-pulsed as the path is essentially static for the measurement. In some cases, particularly for higher power external modualtors, there may be some video ripple that will be a result of modulation that can be removed by calibration. Note that this assumes the modulator is in the path during the calibration, just potentially unpulsed, so that its insertion loss and mismatch are corrected by the calibration. This 'B' scenario is common in many PIP measurements where often the desire is just to keep the device pulsed (for operational or thermal reasons) but the DUT dynamics themselves are not the primary interest.

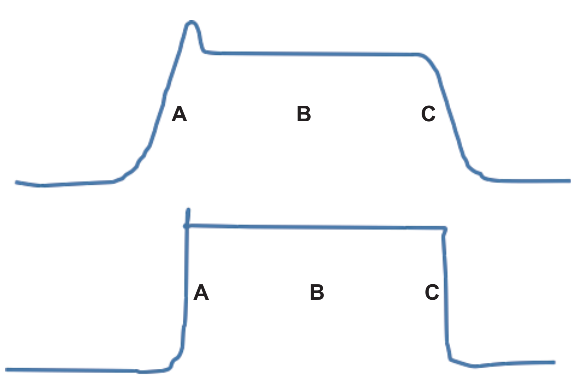


Figure 3. *Two sketches of the envelope of the modulator output are shown here. For the SM68XXX test sets, the scale for the top drawing is representative of a ~50ns pulse width and for the bottom drawing, it is about a ~500ns pulse width. For wider pulses, the zone B dominates even more. For different external modulators, the time scales may be different.*

In regions A and C, there is more going on and calibrating while pulsed can help remove artifacts, at least those fairly high up on the pulse where there is adequate signal to noise ratio. Much like with the pulsed reference, effects far down the pulse edges become harder to process when calibrated-while-pulsed.

In P2P measurements, a particular time segment is analyzed in each of a number of sequential pulses. Depending on which region in which that time segment lies, the pulsed/non-pulsed state of the instrument during calibration may not matter (again, less important in region B). In Pulse Profile measurements, often all regions are of interest and, in that case, it is usually useful to perform calibrations pulsed.

Effects of the calibration approach on uncertainty

The overall uncertainty picture in a pulsed measurement is a complex interaction of traditional VNA uncertainty terms (residual source match and directivity, tracking, linearity, repeatability…) and pulse-specific terms (bandwidth and resolution limitations, timing errors…) (e.g., [1]-[2]). The additional complication now is possible variations in calibration approaches. Consider a pulse profiling measurement with an unpulsed reference and the pulse is applied during calibration. The uncertainty can be evaluated in a Monte Carlo sense for an example case of a DUT with a fairly narrow overshoot, relatively good return loss and not enough output power to cause system compression. The result of this example calculation is shown in Figure 4 where the dotted line represents the nominal result and the other colored traces represent possible outcomes as various phases and error terms (such as repeatability) are randomized. The spread of results is fairly contained in the middle of the pulse, increases a little in the overshoot region (due to bandwidth limitations, this expansion would be much worse if not for the ~200 MHz IFBW available in the MS464XB PulseView mode), and expands more on the rising and falling edges (partly because of reduced signal levels increasing trace noise).

The same calculation with an unpulsed calibration is shown in Figure 5. In this case, the modulator overshoot is not corrected for so there is a deterministic error on the rising edge in addition to somewhat elevated scatter. There is also a bias and increased scatter on the falling edge since those modulation characteristics are also not taken into account. It should be pointed out that this is something of a worst-case example since the pulse width is relatively narrow and the DUT had a narrow overshoot on the same scale as that of the modulation. The uncertainty change in the middle of the pulse or for other time epochs is insignificant.

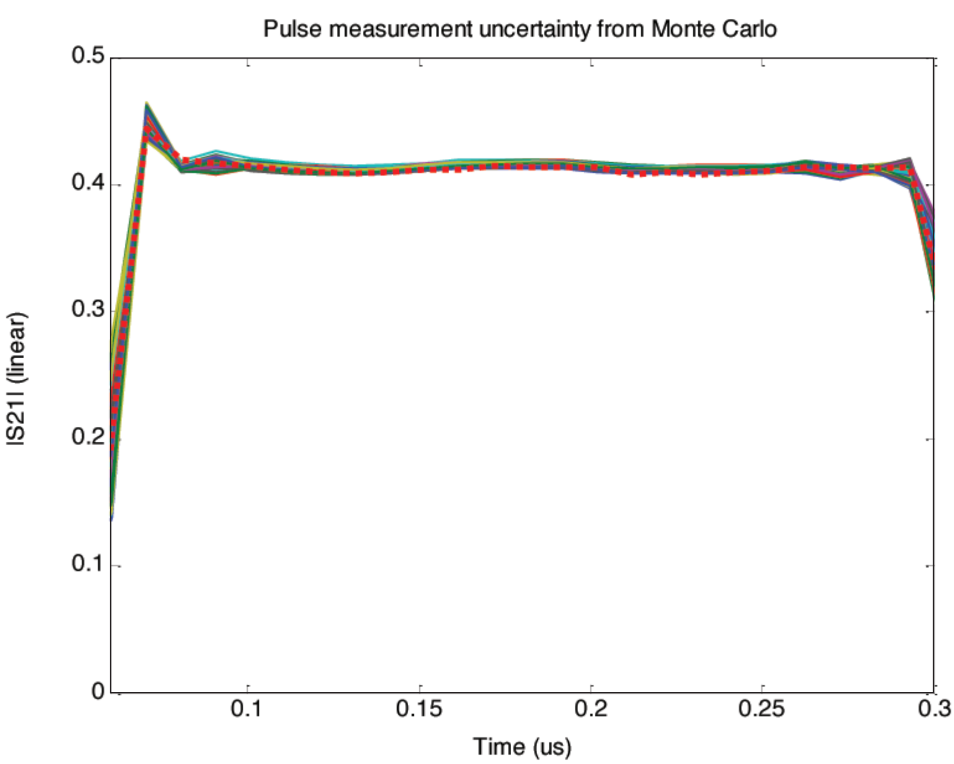


Figure 4. *An example uncertainty calculation is shown here for a pulse profiling measurement of a DUT with overshoot, no reference pulsing but with a pulsed signal used during the calibration.*

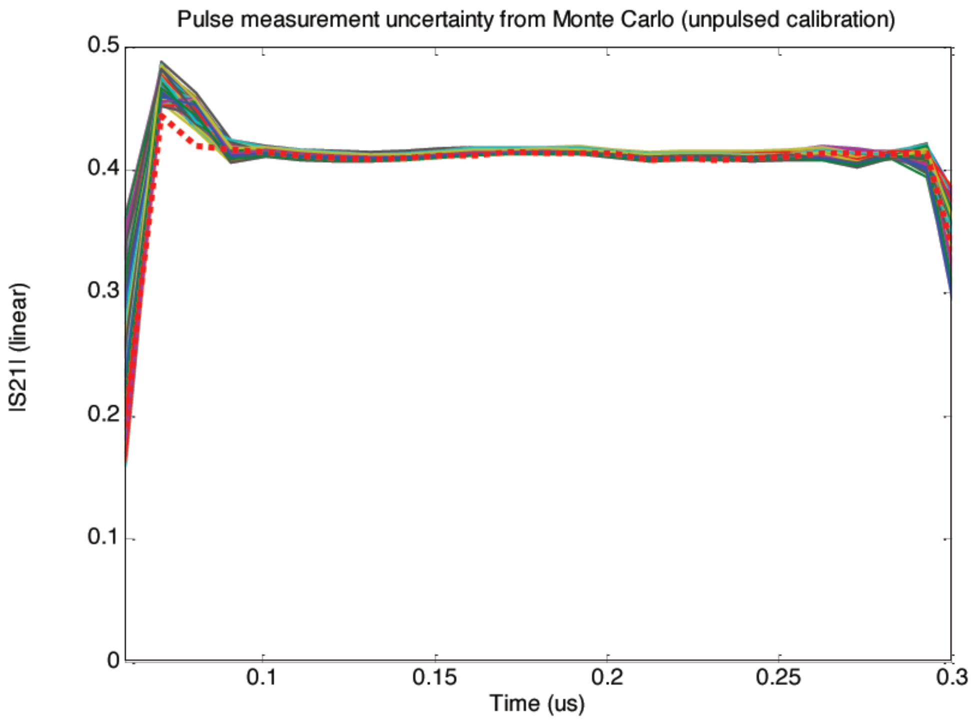


Figure 5. *An example uncertainty calculation is shown here for a pulse profiling measurement of a DUT with overshoot, no reference pulsing and no pulsed RF during calibration. This example is close to a worst-case scenario.*

Electrically large setups

Some additional calibration complications (aside from potential drift issues discussed earlier) can be introduced in electrically large setups (e.g., long cable runs between parts of the measurement apparatus) and there is a distinction based on in what parts of the setup the electrical length is added. In both cases, it is only when the electrical length change is significant to the pulse measurement resolution that action might be warranted. Thus for 2.5 ns resolution measurements, length additions on the order of 1m may start to become important.

In the first case, electrical length is added between the reference and test couplers. This might happen if a pre-amplifier is added to the setup as suggested in Figure 6. If the time delay τ1 is large relative to the resolution and if a pulsed reference is used then the reference (a) and test (b) pulse envelopes can become mistimed. This would tend to remove some of the advantages in using pulsed references discussed before and can result in uncertainty increases even further from the pulse edge as the S-parameter will be distorted over up to twice the time of misalignment. Fortunately, a solution is available to this problem by having independent receiver timing in the PulseView mode. As suggested in Figure 7, the relevant a and b receivers can be delayed relative to each other to realign the timing. The ‘Couple Receiver Parameters’ must be unchecked and then the receiver delays (for P2P or PIP) or the start/stop times (for PP) can be adjusted. In this example, there is a 50ns delay between test and reference receivers that is to be compensated.

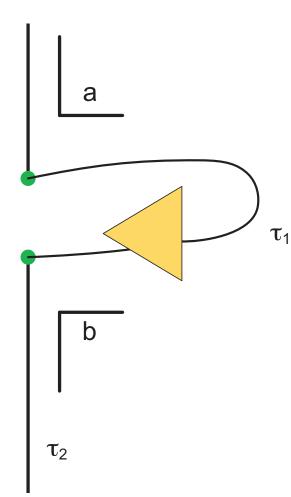


Figure 6. *An example of a pre-amplifier in the source loop adding electrical length between reference (a) and test (b) couplers is shown here.*

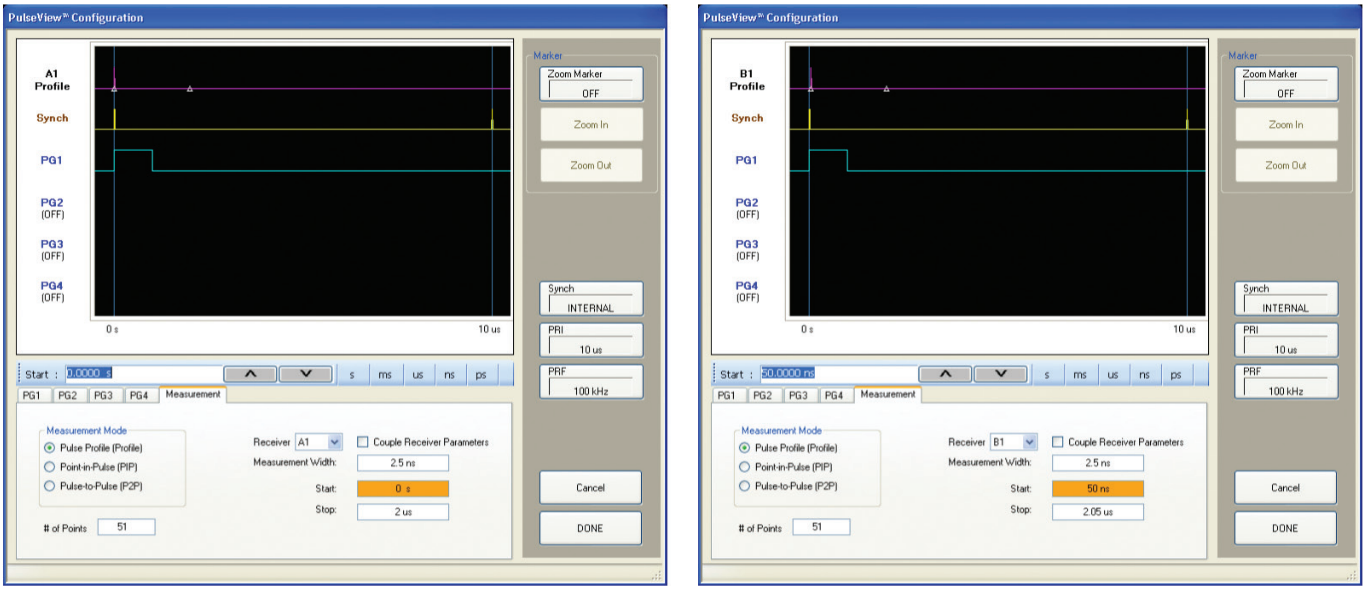


Figure 7. *Two screen shots of the PulseView configuration dialog are shown here to illustrate how the different receiver timings can be adjusted to compensate for electrical length differences. Here 'Couple Receiver Parameters' is unchecked to allow this compensation and the b1 receiver is delayed 50ns relative to the a1 receiver to account for a long pre-amplifier setup.*

Pulse Measurement Setup Recommendations

There are 4 combinations of measurement setup choices available while in the PulseView mode:

- Unpulsed reference and NO RF pulsing during calibration
- Unpulsed reference and RF pulsing during calibration
- Pulsed Reference and RF pulsing during calibration
- Pulsed Reference and NO RF pulsing during calibration

As discussed above, the choice of measurement setup depends on the type of measurement (PIP, PP or P2P) and the importance of edge behavior. This next section will give a summary of the advantages and disadvantages of using a pulsed reference as well as some examples of when to use certain setups.

Advantages of using Pulsed Reference

- Transients associated with modulation may cancel in the ratioing process resulting in less distortion, particularly in the DUT overshoot area. More valuable if working uncalibrated.
- Reduced video ringing in the on state of the pulse. More valuable if working uncalibrated.
- Effects of drift (particularly from external pre-amplifiers and higher power modulators and their associated cable runs) can be reduced.

Disadvantages of using Pulsed Reference

- Makes it harder to look at rising and falling edge details (particularly further down the pulse edges)

Unpulsed Reference, with and without RF pulsing during calibration

A calibration step will record the noise floor during the pulse-off state so resulting measurements (with calibration applied) will have results bouncing around during the off-state. The calibration does help correct for overshoot and ripple within the pulse so it will help measurements there but will not help far down on the rising or falling edges. If far-down edges effects are of interest or if data appearance during profiling is important, it is recommended to use an unpulsed calibration and the unpulsed reference measurement setup.

As stated above, pulsed RF during calibration will reduce video ringing in the on state of the pulse and reduce distortion in the DUT overshoot area. It is recommended to use pulsed calibrations when possible based on the measurement window; measurement windows in the stable on portion of the pulse.

Pulsed Reference, with or without RF pulsing during calibration

Some of the same comments as in the unpulsed reference case apply but now even in uncalibrated or non-pulsed-calibration scenarios; with these lower levels of calibration, the pulsed reference can help remove some video effects in the middle of the pulse as mentioned above.

Even with a more complete pulsed calibration, having the reference pulsed will help remove some drift effects (may be more important with an external pre-amplifier where those cables are exposed and the amp may drift) and dynamic video effects (more often with complex modulators) in the middle of the pulse and in overshoot areas. Again, it cannot help much if one is interested in far down the edges. It is recommended to use a pulsed reference when using a more drift-sensitive setup and, if it is possible, based on where the measurement window is located. It also may be useful if only non-pulsed calibrations or raw measurements are needed for other reasons.

Above and beyond the pulsed reference, a pulse calibration has the added benefit of correcting for video-related match effects. These are normally most important in electrically long setups where the simple ratioing will not correct for all of the dynamics of the pulse signal bandwidth interacting with the measurement setup.

Summary

Several aspects of S-parameter calibration while in the PulseView mode including the central importance of the basic setup (pulsed RF stimulus or not, how preamplifier loops are configured…) and the idea of the pulsed reference (using it will depend on the setup as well as how important edge dynamics are). If pulsed RF stimulus is used, it is useful to perform the calibration with that stimulus applied if upper edge dynamics are of interest and the pulses are relatively narrow (~<1 μs) or if the setup is electrically large and match effects are critical. For wider pulses or when edge dynamics are not particularly important, the calibration can be performed unpulsed with a negligible uncertainty impact.

References

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