Pulse-to-pulse stability measurements

Anritsu Company

Pulse-to-pulse stability analysis, the measure of variation of amplitude and phase amongst a burst of pulses, can be a critical measurement in radar, device characterization and other systems studies. In a radar context, that stability may establish the detection limits (either in terms of cross-section or speed) in a dense environment. In device characterization, poor pulse-to-pulse stability in the measurement may limit the detection of second- and lower-order trapping and thermal time constant effects. This note will discuss some of the attributes of the pulse-to-pulse (P2P) measurement with the MS464XB VNA (options 035 and 042), the intrinsic stability measures, and how the performance can be optimized.

Background

In many pulse measurement scenarios, the time evolution of a parameter between pulses and within a pulse can be of interest. Particularly on the longer time scales, there is also a distinction between variations when a device first turns on versus that when it has been operating for some time (see Fig. 1). Differences may be due to thermal issues, interaction with a control system, or other factors. From a measurement perspective, this is primarily a difference in how the measurement is triggered to ensure that the data is taken at the desired point in the time evolution of the DUT.

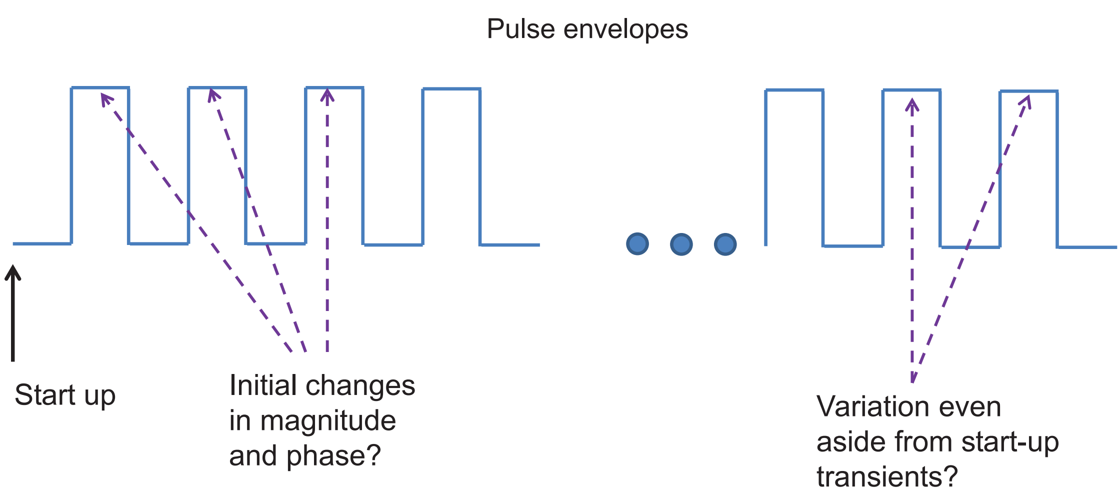

Figure 1. *The pulse-to-pulse (P2P) measurement situation and the distinction between start-up-related and quasi-steady-state measurements are shown here.*

There are many numerical definitions that have been employed to quantify P2P variation (e.g., [1]) but some of the more common, when using direct digitization, are based on a RMS-like quantity that is either relative to the mean value or relative to a neighboring value. Depending on the nature of the data, these two definitions can give different results. Sometimes, the magnitude and phase of the response parameter are analyzed separately. The phase expressions are the least ambiguous and can be written as

$$S_{phase,mean} = 10 \cdot \log_{10}\left[\frac{1}{N}\sum_{i=1}^{N}\left(\Phi_i - <\Phi>\right)^2\right]$$

$$S_{phase,adj} = 10 \cdot \log_{10}\left[\frac{1}{N-1}\sum_{i=1}^{N-1}\left(\Phi_i - \Phi_{i+1}\right)^2\right]$$

Where *N* is the number of pulses or measurements being analyzed and <*Φ*> is the mean phase value across those measurements (and all of the phase values *Φ* are those of the parameter of interest, such as S_{21}, usually in degree terms). Sometimes a minus sign is present in these definitions to make the resulting dB value positive. In terms of magnitude, there is the additional question on if the linear or log magnitudes should be processed as part of the statistics. Log magnitude processing is often used but this does produce a number of numerical issues if the variations are significant.

$$S_{mag,mean} = 10 \cdot \log_{10}\left[\frac{\sum_{i=1}^{N}\left(M_i - <M>\right)^2}{N \bullet <M>^2}\right]$$

$$S_{mag,adj} = 10 \cdot \log_{10}\left[\frac{\sum_{i=1}^{N-1}\left(M_{i+1} - M_i\right)^2}{(N-1) \bullet <M>^2}\right]$$

Where *M* is the magnitude in dB terms of the parameter of interest (such as S_{21}) and <*M*> is the average of that magnitude across the *N* measurements. Still yet another definition is based on the summed vector differences.

$$S_{vector,mean} = 10 \cdot \log_{10}\left[\frac{\sum_{i=1}^{N}\left|X_{i+1} - <X>\right|^2}{N \bullet <M>^2}\right]$$

$$S_{vector,adj} = 10 \cdot \log_{10}\left[\frac{\sum_{i=1}^{N-1}\left|X_{i+1} - X_i\right|^2}{(N-1) \bullet <M>^2}\right]$$

Where *X* is the complex variable (S_{21} for example) and the || denotes magnitude of the complex difference. Normally this definition is applied against linear magnitude rather than log magnitude. The final result in all cases, however, is expressed in dB terms.

One may note some ambiguity in the above with regard to the term ‘measurements’. Classically, this has meant one measurement per pulse, over some defined measurement window somewhere within the pulse, but it could also refer to profiling-like measurements at multiple smaller windows within a pulse (e.g., [3]). These different meanings are used to evaluate different effects since the inherent time constants are quite different.

Both types of measurements are supported in the MS464XB. In a profile sense, the data presentation is all based on (normally) smaller measurement windows giving high time resolution (see Fig. 2). As always in pulsed measurements, the phase of the transmission parameter has little meaning when the pulse is off. Since the on-off ratio of the pulse in this example measurement exceeded 100 dB, the phase in the off-state is noise-like.

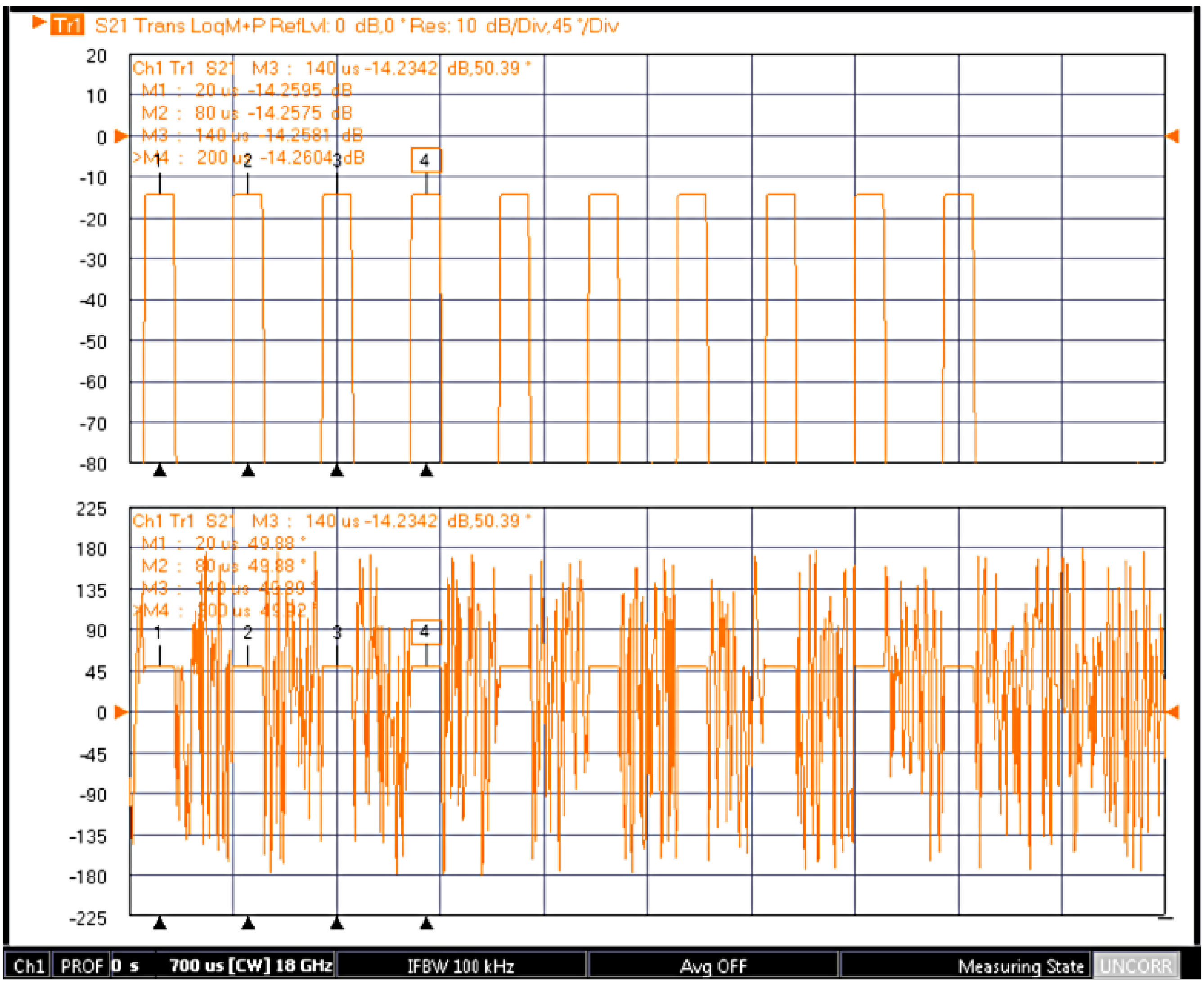

Figure 2. *An example profiling-like pulse-to-pulse measurement is shown here. The resolution can be very high (to 2.5ns with the MS464XB) and allow detailed analysis.*

In the P2P mode, a single window per pulse is used and the resulting displayed data is simplified (see Fig. 3). The window can be made consistent with DUT system operation and is often on a slower time scale. Some forms of stability statistics (more in an absolute variation sense than the dB-relative definitions discussed above) are immediately available. In the particular example below, measurements on 50 sequential pulses are represented and can come from a cold start. By this we mean it is possible to set up triggering so that there is no excitation (DC or RF) of the DUT prior to the first pulse measurement if it is desired to examine initial start-up characteristics.

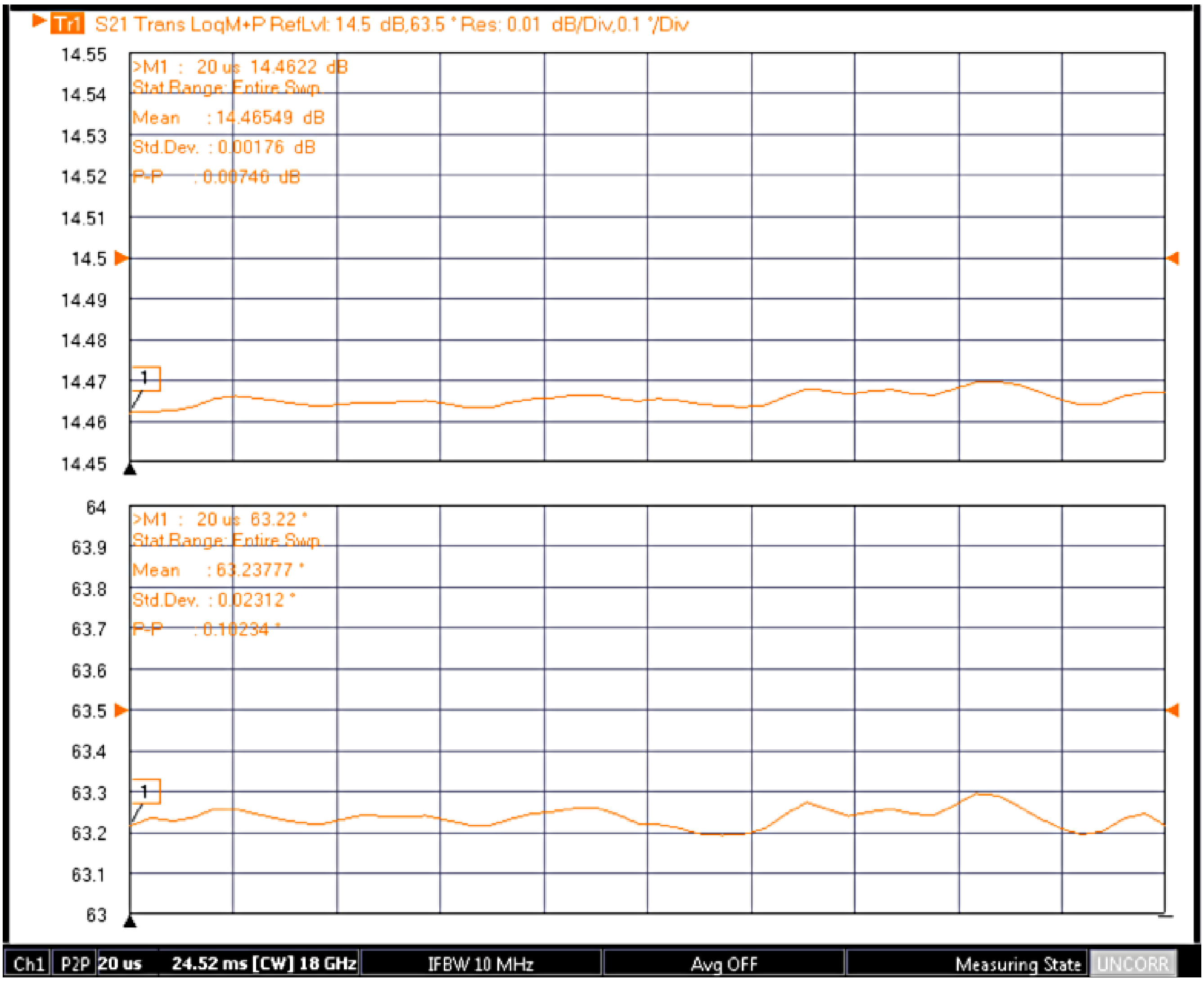

Figure 3. *An example classical P2P measurement is shown here where one measurement is performed per pulse. If the behavior in a particular part of a pulse is all that is of interest, this can be an easier way to visualize longer-time-scale distortions.*

Returning to the earlier definitions of stability, we can look at this example measurement in terms of both sets. If one compared the magnitude-based definitions, one gets a value of -78.4 dB for the mean-referenced version and –59.1 dB for the adjacent-referenced version. The difference may suggest a dominance of short-term variations. Looking at some of the definitions on a pulse-by-pulse basis (the above definitions without the summation sign); one can get an idea of the magnitude of differences between definitions possible even for a relatively stable device. Four of the possible combinations are plotted in Fig. 4. The magnitude only metric shows considerable differences between basing the result of a mean reference or an adjacent reference. The vector-metric shows less of that variation and that may be more useful in certain cases.

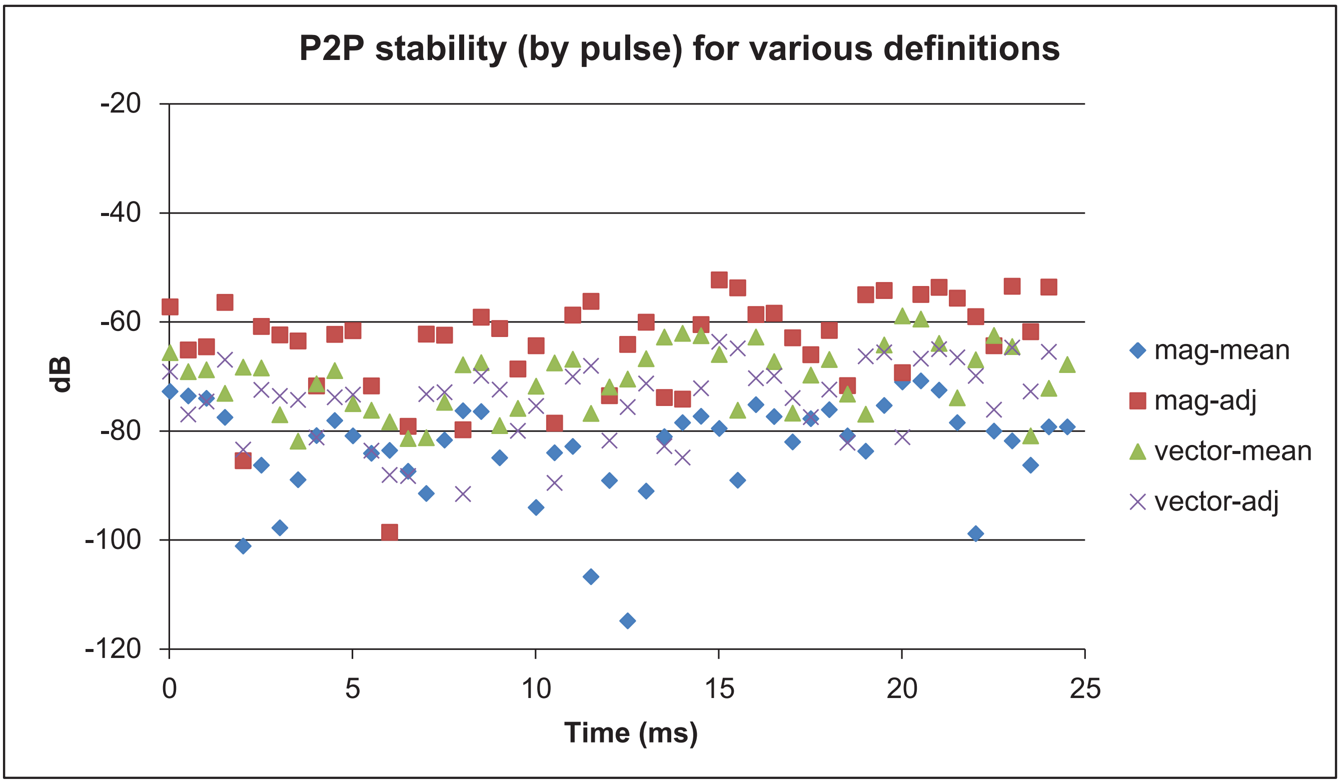

Figure 4. *Some of the pulse-to-pulse stability metrics are plotted here for a set of example data. The individual terms in the summations presented in the text are plotted to help show the differences more clearly.*

Measurement Considerations

While there may be a myriad of possible mechanisms within the DUT that could lead to pulse-to-pulse instability, a first order of business may be to understand and minimize those instabilities from the measurement system itself. Some common candidates:

– Noise floor and trace noise

– Linearity effects

– Cable drift (thermal, vibrational or otherwise)

– Overall measurement system RF stability

In terms of noise and linearity, one optimization is in signal level into the VNA. If using the regular test ports, an optimal signal level in terms of both linearity and noise is in the –10 to +5 dBm range. If using b1 or b2 direct access ports (which bypass the coupler), the optimal levels are somewhat lower: between –23 and –8 dBm. One can check the received amplitude by looking at the unratioed b2/1 or b1/1 parameters (depending on the DUT direction being measured and with which stimulus port) with no calibrations or normalizations applied: the ideal is no higher than –5 dB but generally as high as possible below that value.

Another factor that impacts noise performance is the measurement window. Although this may be dictated by the given test protocol, generally the wider the measurement window, the better for noise performance until one starts running into pulse edge distortions. A simple pictorial representation of these concepts is shown in Fig. 5.

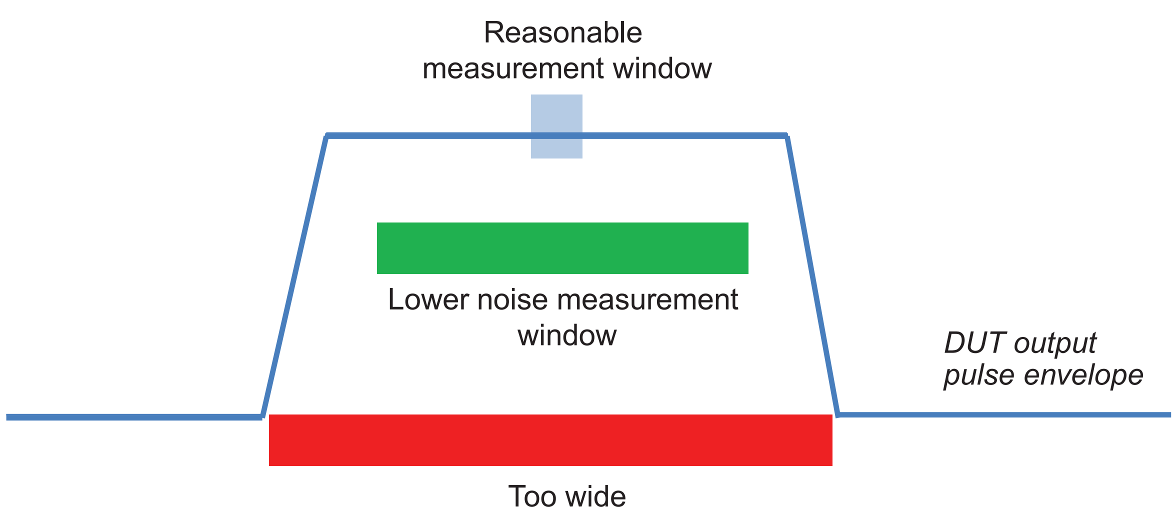

Figure 5. *While many measurement window widths can be used, optimizing the width (if possible for a given application) can result in improved noise performance.*

The above reasoning follows since the wider measurement window implicitly forces the averaging of additional ADC samples and thus reduces the effective noise floor. Of course, if the test or time resolution requirements dictate a narrower window, this can be accomplished.

Cable drift is sometimes more difficult to identify as a measurement issue but can often be important, particularly when longer time constants are involved. Higher quality cables, minimized cable run length and thermal/vibration isolation can all help.

Internal instrument stability can sometimes play a role as well, again particularly for longer time constants. Typical instrument stabilities are < 0.005 dB/0.05 degrees over moderate time scales but improvements on that can be had with special metrology-equipped versions of the instrumentation.

In the hardware-space of the MS464XB, the basic instrument stability (whether with or without the optional RF stimulus modulators) and linearity is adequate for many pulse-to-pulse stability measurement applications. The residual stability at 40 GHz is plotted in Fig. 6 for a typical setup driving direct into the instrument's port 2, using RF stimulus modulation and a final signal level of –5 dBm. The values are generally lower at lower frequencies so this plot is, in some sense, a worst-case scenario... but care was taken with minimal cable lengths and good environmental stability. A 100 μs pulse period was used with a variety of measurement window widths which may be needed depending on the application. One can see some elevation at the narrowest measurement window width and the noise reduction is less of a factor.

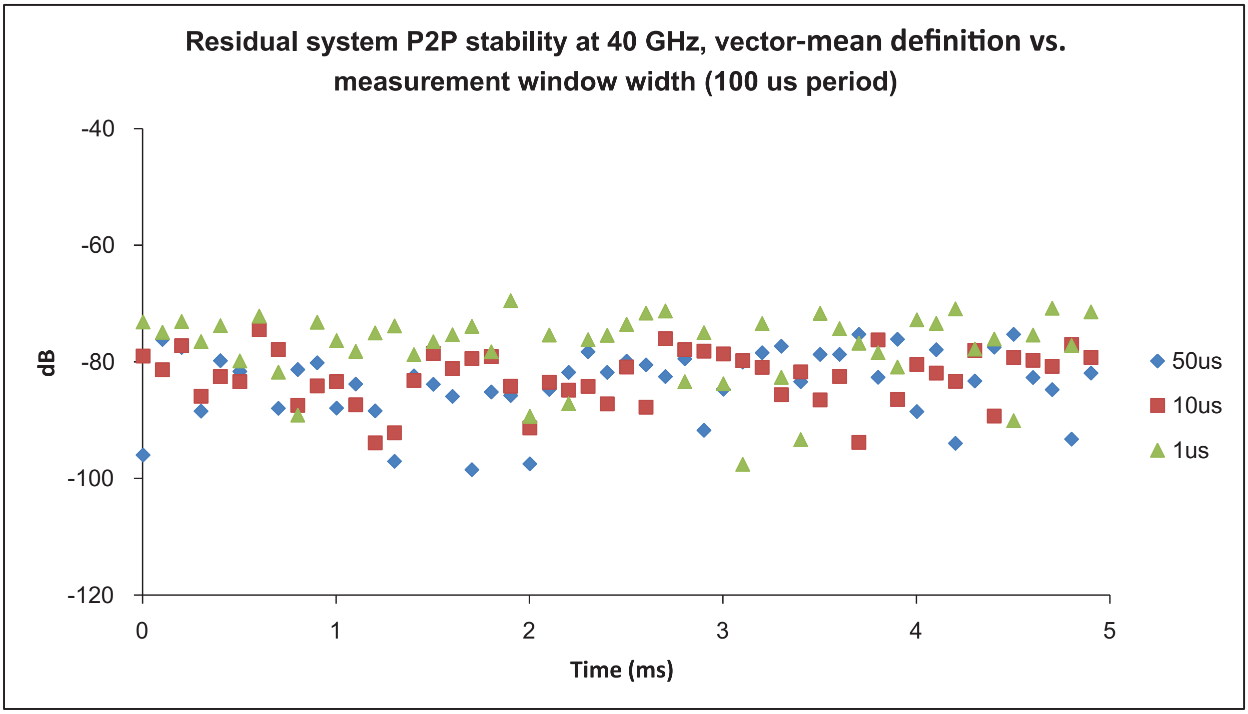

Figure 6. *Example residual P2P stabilities for the MS464XB at 40 GHz for a variety of measurement window widths are plotted here. This value would apply equally for a start-up transient kind of measurement or a quasi-steady-state measurement*

Summary

Pulse-to-pulse stability measurements can be important for applications ranging from radar to device characterization and modeling. A wide variety of metrics exist for presenting the data and the numeric differences can be significant so understanding the details of the definitions can be important. For any of these metrics, good measurement system pulse-to-pulse stability is useful. Instrument configurations with improved performance along with some optimization hints have been presented.

References

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