Mastering Phase Noise Measurements (Part 3)

Application Note

Whether you are new to phase noise or have been measuring phase noise for years it is important to get a good understanding of the basics and to learn of new measurement techniques to improve your designs.

This series of application notes is broken up into three parts:

Part 3: How best to perform advanced measurements: additive phase noise, pulsed phase noise, and AM Noise

Note: This application is part three of a three part series. See the end of this application note to view the first two parts.

ROHDE & SCHWARZ

Table of Contents

2 Introduction

Phase noise is unintentional phase modulation on a signal that spreads the spectrum and degrades performance in many RF applications. Whether you are new to phase noise or have been measuring phase noise for years it is important to get a good understanding of the basics and to learn of new measurement techniques to improve your designs.

This series of application notes is broken up into three parts:

▪ Part 1: Understanding the basics of phase noise: why it is important, how does it impact different applications, and what causes phase noise

▪ Part 2: What are the different measurement techniques and their advantages/disadvantages: direct spectrum analyzer, phase detector, delay line discriminator and we introduce our new digital phase demodulator technique

▪ **Part 3: How best to perform advanced measurements: additive phase noise, pulsed phase noise, and AM Noise**

We will now cover part 3: Advanced Phase Noise Measurements

3 Advanced Phase Noise Measurements

Let's review some of the advanced phase noise measurements used to evaluate special device-under-tests (DUT) situations.

3.1 Additive Noise

The additive phase noise measurement technique measures the added noise of a device, such as an amplifier. The setup is a variation of the phase detector technique, with a power splitter in front of the DUT and a phase shifter added to the other path (Figure 2-1). The source noise is correlated on both sides of the phase detector inputs so that it cancels out, leaving only the added noise of the DUT to be measured. The phase shifter is used to maintain the 90 degree quadrature for maximum sensitivity, but it's also used in this measurement technique as a 180 degree calibration tool.
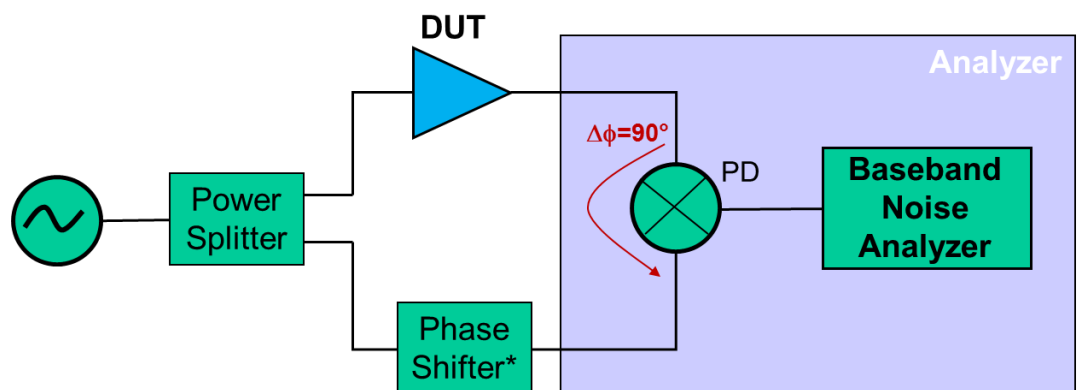

Fig. 2-1: Additive phase noise block diagram.

3.1.1 Using the Digital Phase Demodulator Technique

With the new FSWP digital phase demodulator additive phase noise measurements are as easy as pushing the "Additive phase noise" button. Internally, it re-plumbs itself to route the signal from one of the synthesizers out to the DUT plus some other changes internally (Figure 2-2). All of the measurement needs and setup are performed internally so the test engineer doesn't have to worry about calibration or phase shifters.
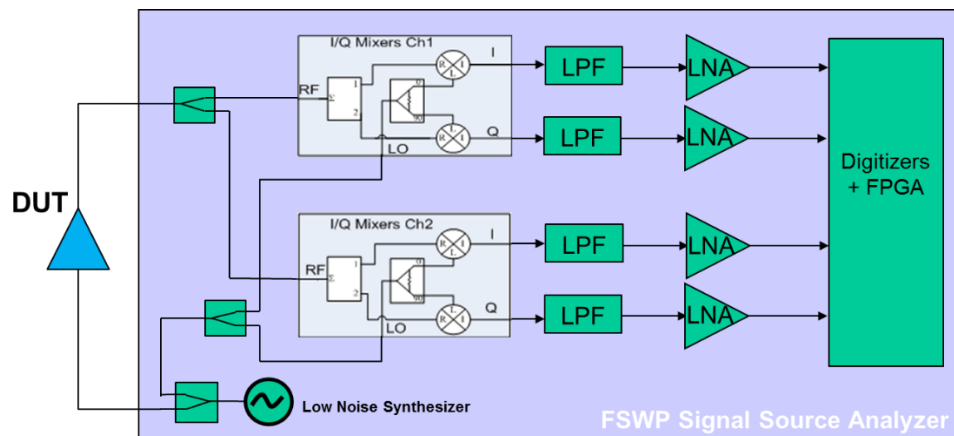
Fig. 2-2: Digital phase demodulator technique block diagram.

The additive phase noise measurement result is basically the same as a regular phase noise measurement, with the familiar curve, spot noise result, and also the gray area showing measurement margin (Figure 2-3). One interesting thing to note in this measurement result is the jitter value in the lower right corner shows 834 as or 834 attoseconds! After femtoseconds comes attoseconds, which is 10-15.

Fig. 2-3: Additive phase noise measured results.

3.2 Pulsed Measurements

With many applications requiring pulsed signals, the need for performing pulsed phase noise measurements is common. While the phase detector technique has been used for many years to perform these measurements, the pulsed signal adds a few twists.

When the pulse is on from the DUT, the phase detector will work properly with the CW reference signal. However, when the pulse is off from the DUT there would be a DC shift that throws off the phase lock loop.

To eliminate this DC shift during the off part of the burst, we have to synchronize the reference pulses with the pulses from the DUT (Figure 2-4). The pulse edges of the DUT and reference are not perfectly synchronized so switching transients will occur at pulse edges, resulting in pulse repetition frequency (PRF) feedthrough. The low pass filter (LPF) cutoff is too high to attenuate the PRF feedthrough. In order to make a sensitive phase noise measurement therefore requires a special PRF filter that is unique to a specific PRF of the DUT. A different PRF filter will be required for every PRF that needs to be measured.
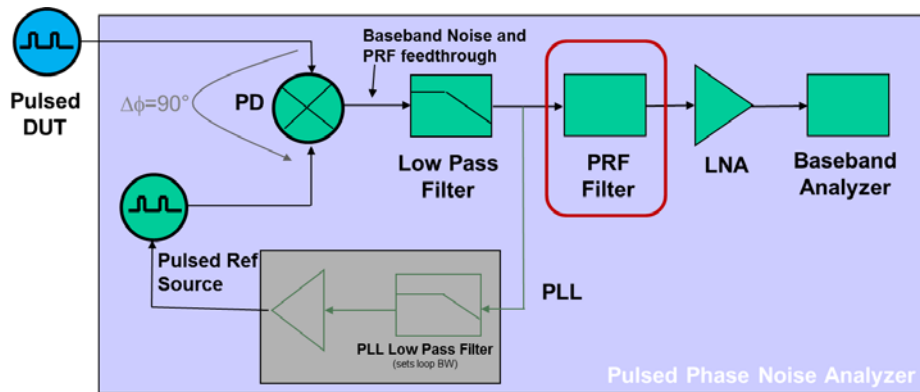

Fig. 2-4: Phase detector pulsed phase noise block diagram.

Since the PRF filter is a much narrower filter than the low-pass filter, it must a have flat passband with a sharp cutoff. Figure 2-5 shows spectrum of a pulsed CW signal that contains one line at the center frequency and many other PRF lines. The role of the PRF filter is to be narrow enough to pass the center line and attenuate all the other PRF lines.
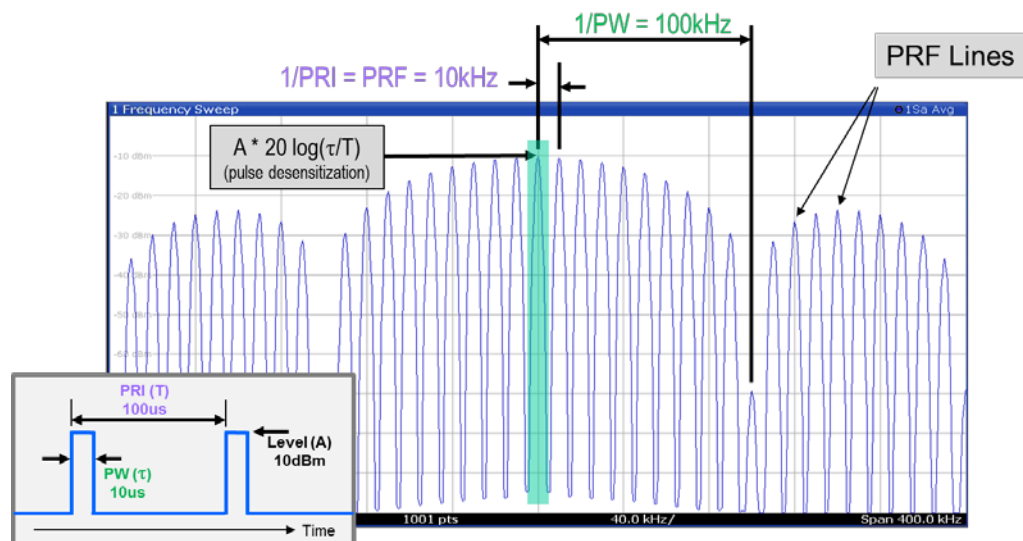

Fig. 2-5: The PRF filter is a much narrower filter than the low-pass filter and must a have flat passband with a sharp cutoff.

One problem is that the center line is lower than the pulse level due to pulse desensitization, by a factor of:

$$20*\log(\text{duty cycle})$$

In this example there is a 10% duty cycle, so the center line is 20 dB below the amplitude of the pulse. This reduces the sensitivity in the measurement. Building a PRF filter that achieves a flat passband, while having a high rejection of the PRF feed-through can be a challenge to design.

Figure 2-6 shows the example DUT's phase noise in both pulsed and CW mode. The green line is the CW phase noise measured on a spectrum analyzer, the blue line is the pulsed phase noise result. Close in the phase noise matches closely as can be seen by their overlay.

As we approach the maximum offset, PRF/2 or 5 kHz here, the divergence starts. There is roughly 6 dB higher phase noise on the pulsed signal because of the coherent combining of the adjacent lines.
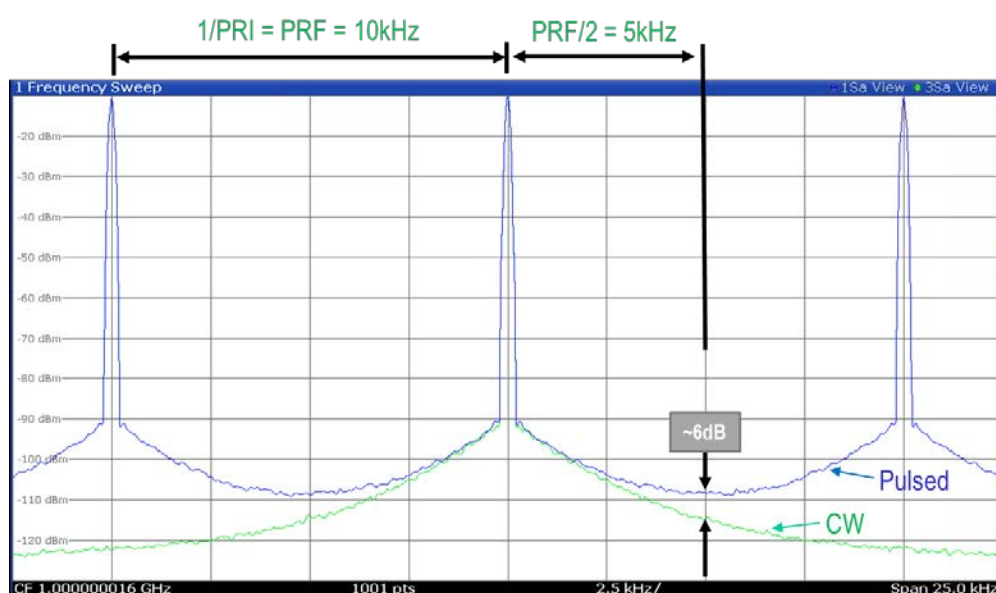

Fig. 2-6: Close in the phase noise matches closely, but divergence starts as the maximum offset of PRF/2 is approached

3.2.1   Using the Digital Phase Demodulator Technique

Now let's do the same pulse measurement using the digital phase modulator technique. The block diagram is going to be exactly the same as the CW measurement that was shown in Figure 2-2. Since there is not a diode-based mixer to be susceptible to the DC offset, the reference source does not have to be pulsed. The digitizer takes the incoming signal so there aren't PRF glitches to worry about.

The analyzer does need to know something about the pulses so that it can set itself up internally in its DSP. Pushing the "Pulse configuration" button turns it into a spectrum analyzer. The pulse width (PW) and PRI are automatically detected using a zero-span

measurement. The PW is used to set measurement gate time and the PRI is used to set maximum offset (Figure 2-7).
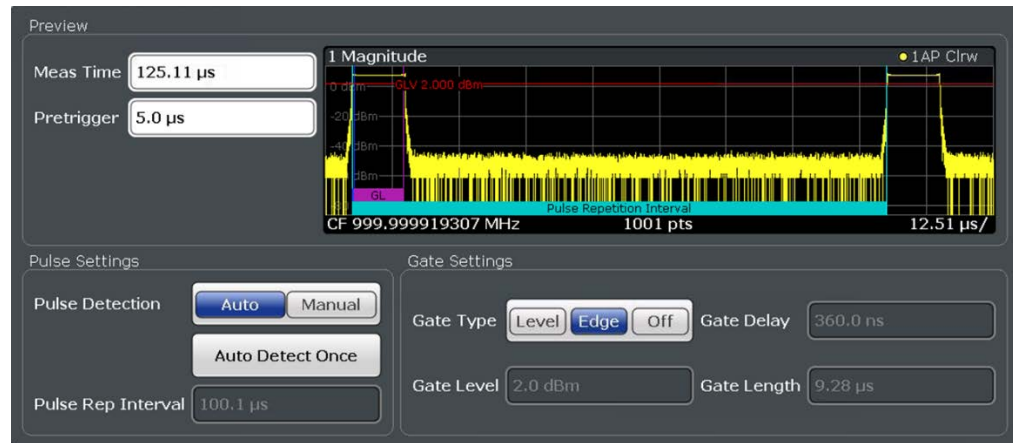

Fig. 2-7: Spectrum analyzer features are used to automatically setup for the pulse configuration

For the measurement, the analyzer automatically truncates the max offset, which in this case is 5 kHz for the 10 kHz PRF. The measurement time is identical to the CW case, and the gray area again represents the measurement margin between the DUT and the analyzer noise floor. Figure 2-8 shows the two captures of the same DUT, both CW and pulsed.

As with the spectrum analyzer result shown before, the two are matched very closely at the close-in offsets, with the divergence starting out toward PRF/2. The pulsed result starts rising up due to that coherent combining again.
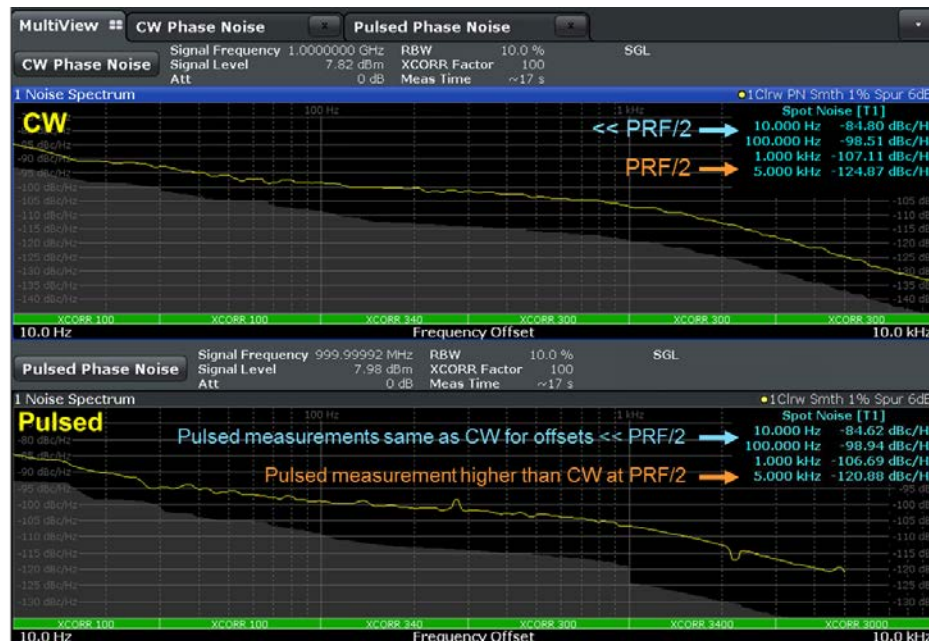

Fig. 2-8: Pulsed vs CW phase noise measurement results.

3.3 AM Noise

First let's recall the expression of our real-world sine wave:

$$V(t) = [A + E(t)] \sin(2\pi \nu t + \varphi(t)) \qquad (2)$$

> where
>
> $E(t)$ = amplitude fluctuations
>
> $\varphi(t)$ = phase fluctuations

For most of this application note we have focused on the $\varphi(t)$ or phase noise. However, $E(t)$ represents the AM noise component. AM noise is usually lower than phase noise, especially at close-in offsets. Traditional AM Noise is measured using an external diode detector along with the baseband noise analyzer (Figure 2-9). While the AM detector is insensitive to phase fluctuations and frequency, it is very sensitive to amplitude. Calibration of the measurement is done using a signal generator with a known AM modulation index.

These measurements are of low-level noise, which is very susceptible to external interference. This is a difficult setup to get good measurements. It requires the use of very well-shielded cables, preferably the whole test should be in a shielded room. Any amplitude noise that gets into that area between the AM detector and the noise analyzer will corrupt the measurement.
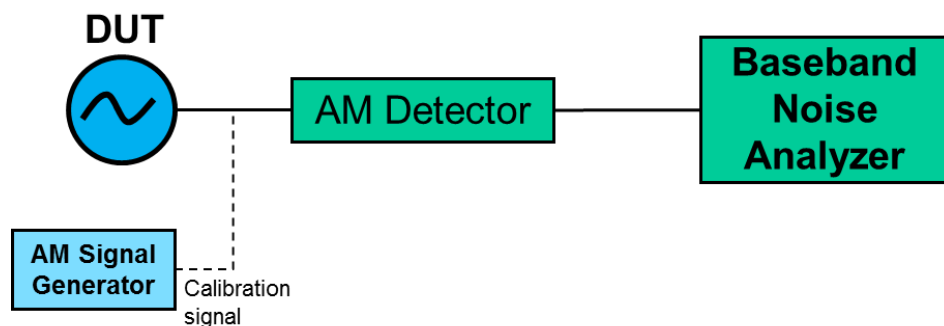

Fig. 2-9: AM detector phase noise block diagram

3.3.1 Using the Digital Phase Demodulator Technique

Once again the DUT just hooks directly up to the instrument as shown in Figure 2-2. Figure 2-10 shows the only thing that changes in the displayed results is down in the block on the right again, where all the calculations take place. Instead of doing FM and DM demodulation, the instrument is set to do AM demodulation. It's that simple. We don't have to worry about the detector diode or AM modulated source to calibrate.

One very unique aspect is that it can measure AM and phase noise simultaneously. Three measurement traces can be shown - the phase noise, the AM noise, and the total noise. Each of these can be overlaid. This technique provides an easy method for breaking out each of the phase noise components.
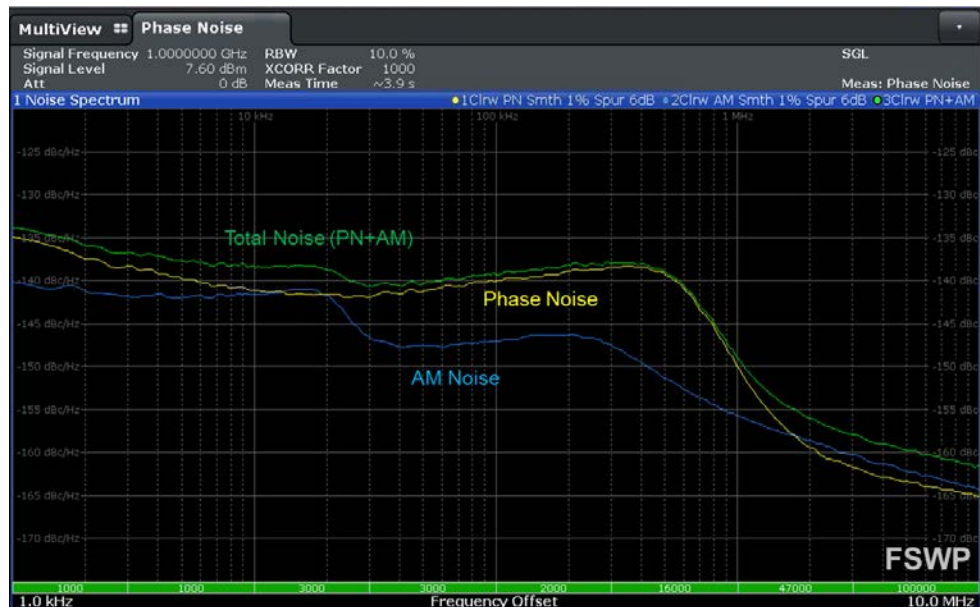
Fig. 2-10: Simultaneous measurement of AM noise and phase noise with total noise

3.4 Measurement Technique Summary

Table 2-1 summarizes each of the measurement technique's capabilities for the different types of measurements discussed – CW, additive, pulsed, and AM.

	CW	Additive	Pulsed	Pulsed-Additive	AM Noise
Direct SA	☑ Limited sensitivity and close-in offset	☒	☒	☒	☒
Phase Detector	☑	☑ Difficult cal required	☑ PRF filter required	☑ Difficult cal and PRF filter required	☑ Detector diode and AM cal source required
Delay Line Discriminator	☑ Max offset limited by sin(τ)/τ	☒	☒	☒	☒
Digital FM/AM Demodulator	☑	☑	☑	☑	☑

Table 2-1: Summary of measurement techniques.

4 Summary

Minimizing phase noise is critical to achieving the performance required by many of today's RF applications. Part 1 of this series of application notes has covered the basics of phase noise. Part 2 looked at several traditional measurement techniques and introduced a new technique using the R&S FSWP. And in this Part 3, we have covered some of the advanced phase noise measurements such as additive, pulsed and pulsed-additive measurements.

While the traditional measurement techniques for phase noise have been used for years, they are hindered by cumbersome calibration and often require additional hardware. Our new digital phase demodulation technique provides really low-noise reference sources and achieves fast correlations with simple setups that deliver state-of-the-art sensitivity and speed.

Please follow this link for more information on the R&S®FSWP Phase Noise Analyzer and VCO Tester.

∎ Part 1: Understanding the basics of phase noise: why it is important, how does it impact different applications, and what causes phase noise

∎ Part 2: What are the different measurement techniques and their advantages/disadvantages: direct spectrum analyzer, phase detector, delay line discriminator and we introduce our new digital phase demodulator technique

∎ Part 3: How best to perform advanced measurements: additive phase noise, pulsed phase noise, and AM Noise

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1 888 TEST RSA (1 888 837 87 72)
customer.support@rsa.rohde-schwarz.com

Latin America
+1 410 910 79 88
customersupport.la@rohde-schwarz.com

Asia Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86 800 810 82 28 |+86 400 650 58 96
customersupport.china@rohde-schwarz.com

Sustainable product design

▮ Environmental compatibility and eco-footprint

▮ Energy efficiency and low emissions

▮ Longevity and optimized total cost of ownership

Certified Quality Management
ISO 9001

Certified Environmental Management
ISO 14001

This and the supplied programs may only be used subject to the conditions of use set forth in the download area of the Rohde & Schwarz website.