Application Guide

RF Spectrum Analysis:

Capabilities, Specifications, and Applications

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RF Spectrum Analyzer Capabilities Contents:

Overview

Spectrum analyzers measure the RF power across frequency. This includes applications for component characterization, signal analysis, and RF debugging. Some instruments are referred to as signal analyzers and integrate more complex analysis of signal types and measurements. More complex instruments integrate RF source and measure together for network analysis. In this guide, we will discuss the primary capabilities, specifications, and applications for spectrum and signal analysis.

Spectrum Analyzers encompass a broad range of frequency analysis. This could include audio analyzers and even optical spectrum analyzers, but here we will discuss the main uses for RF spectrum analyzers. Typically, these range from 9 kHz up to as much as ~50 GHz. They are differentiated primarily by the upper end of their frequency range, their ability to separate nearby signals, and their ability to protect the signal path from noise.

Phase Noise is the specification that describes the ability to separate nearby signals. This describes how much noise power appears near to a carrier or signal. This is typically described in units of dBc/Hz at a given carrier frequency and frequency offset such as 10 kHz from the 1 GHz signal. This noise comes predominantly from frequency accuracy or the ability to accurately place the power in the correct frequency bucket. This is measured with 1 Hz bandwidth or is normalized to 1 Hz bandwidth using the dBc/Hz units. Normally, RF signal sources have better phase noise than spectrum analyzers, so you can't directly measure an RF source's phase noise with a spectrum analyzer of similar quality.

Displayed Average Noise Level or DANL describes the noise level of the analyzer. Higher quality analyzers will typically have lower DANL. DANL is typically expressed in units of dBm with a given setup. For instance, the SSA5083A describes the DANL in a table. The setup is:

20 °C to 30 °C, att = 0 dB, RBW = 1 Hz, sample detector, trace average > 50

With the Preamp either off or on and with a frequency range such as:

Preamp off	100 kHz ~ 1 MHz	-130 dBm, -143 dBm (typ.)
	1 MHz ~ 10 MHz	-143 dBm, -148 dBm (typ.)
	10 MHz ~ 1.22 GHz	-144 dBm, -148 dBm (typ.)
	1.22 GHz ~ 3.15 GHz	-140 dBm, -144 dBm (typ.)
	3.15 GHz ~ 7.22 GHz	-137 dBm, -141 dBm (typ.)
	7.22 GHz ~ 13.6 GHz	-136 dBm, -140 dBm (typ.)

These values indicate the noise floor away from signals that you can expect from an analyzer. Usually, DANL is either measured with 1 Hz RBW or calculated as normalized to 1 Hz RBW for easy comparison. For every, 10 x reduction in RBW, there should be a 10 dB reduction in noise level.

Applications

Spectrum analyzers are used for a variety of signal and component analysis methods. This includes modes for emissions testing, real-time analysis, and swept mode. In this guide we will discuss using these instruments to measure characteristics including phase noise, noise figure, and pulse measurements. We will also deal with more complex demodulation of signals including LTE, 5G NR, WiFi, and more.

Displayed Average Noise Level

Displayed Average Noise Level or DANL is the key wideband noise specification for a spectrum Analyzer. Siglent spectrum analyzers are primarily specified with these settings:

20 °C to 30 °C, att = 0 dB, RBW = 1 Hz, sample detector, trace average > 50, TG or source off if applicable

Some older models that don't have a 1 Hz RBW setting are specified as normalized values. Here are the DANL values combined:

DANL in dBm by frequency and preamp setting (typ. are typical values)

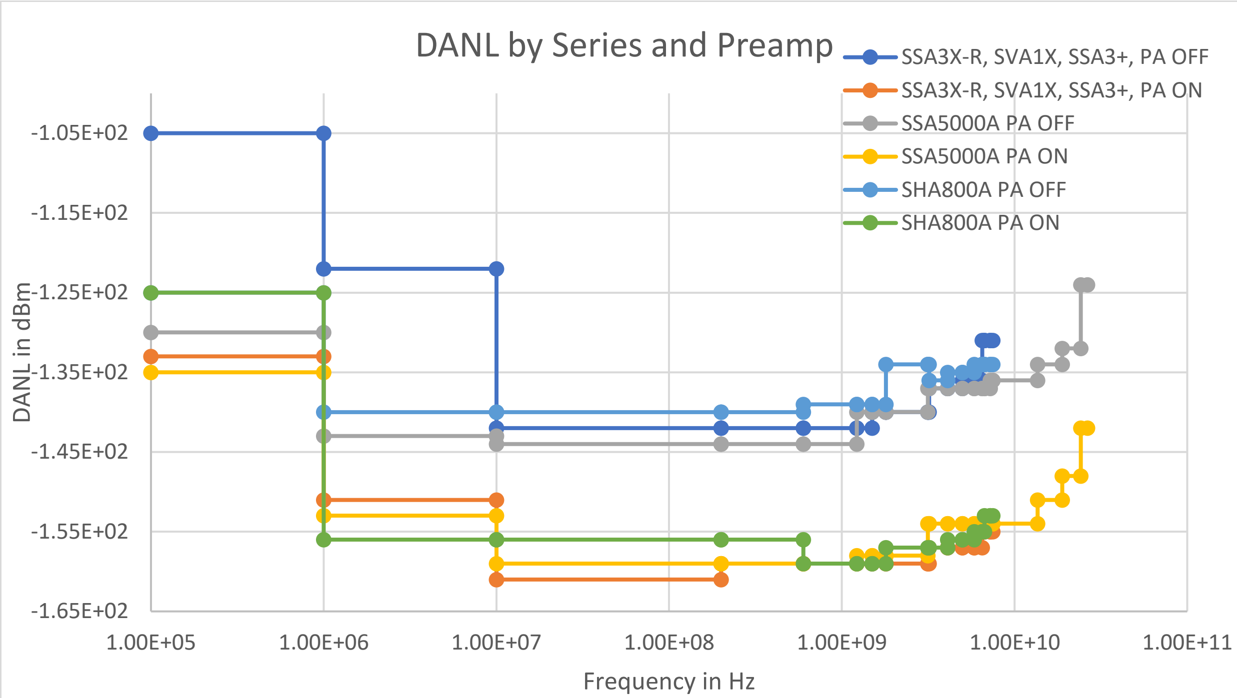
Preamp OFF

Frequency	SSA3000X-R, SSA3075X PLUS, SVA1000X	SHA800A	SSA5000A
100 kHz ~1 MHz	-105 dBm, -109 dBm (typ.)	-125 dBm, -136 dBm (typ.)	-130 dBm, -143 dBm (typ.)
1 MHz~10 MHz	-122 dBm, -126 dBm (typ.)	-140 dBm, -147 dBm (typ.)	-143 dBm, -148 dBm (typ.)
10 MHz~200 MHz	-142 dBm, -146 dBm (typ.)	-140 dBm, -147 dBm (typ.)	-144 dBm, -148 dBm (typ.)
200 MHz~600 MHz	-142 dBm, -147 dBm (typ.)	-140 dBm, -147 dBm (typ.)	-144 dBm, -148 dBm (typ.)
600 MHz~1.22 GHz	-142 dBm, -147 dBm (typ.)	-139 dBm, -145 dBm (typ.)	-144 dBm, -148 dBm (typ.)
1.22 GHz~1.5 GHz	-142 dBm, -147 dBm (typ.)	-139 dBm, -145 dBm (typ.)	-140 dBm, -144 dBm (typ.)
1.5 GHz~1.8 GHz	-140 dBm, -145 dBm (typ.)	-139 dBm, -145 dBm (typ.)	-140 dBm, -144 dBm (typ.)
1.8 GHz~3.15 GHz	-140 dBm, -145 dBm (typ.)	-134 dBm, -140 dBm (typ.)	-140 dBm, -144 dBm (typ.)
3.15 GHz~3.2 GHz	-140 dBm, -145 dBm (typ.)	-134 dBm, -140 dBm (typ.)	-137 dBm, -141 dBm (typ.)
3.2 GHz~4.1 GHz	-137 dBm, -143 dBm (typ.)	-136 dBm, -143 dBm (typ.)	-137 dBm, -141 dBm (typ.)
4.1 GHz~5.0 GHz	-137 dBm, -143 dBm (typ.)	-135 dBm, -141 dBm (typ.)	-137 dBm, -141 dBm (typ.)
5.0 GHz~5.85 GHz	-136 dBm, -141 dBm (typ.)	-135 dBm, -141 dBm (typ.)	-137 dBm, -141 dBm (typ.)
5.85 GHz~6.5 GHz	-136 dBm, -141 dBm (typ.)	-134 dBm, -140 dBm (typ.)	-137 dBm, -141 dBm (typ.)
6.5 GHz~6.7 GHz	-131 dBm, -139 dBm (typ.)	-134 dBm, -140 dBm (typ.)	-137 dBm, -141 dBm (typ.)
6.7 GHz~7.22 GHz	-131 dBm, -139 dBm (typ.)	-134 dBm, -140 dBm (typ.)	-137 dBm, -141 dBm (typ.)
7.22 GHz~7.5 GHz	-131 dBm, -139 dBm (typ.)	-134 dBm, -140 dBm (typ.)	-136 dBm, -140 dBm (typ.)
7.5 GHz ~ 13.6 GHz			-136 dBm, -140 dBm (typ.)
13.6 GHz ~ 18.9 GHz			-134 dBm, -140 dBm (typ.)
18.9 GHz ~ 24.2 GHz			-132 dBm, -137 dBm (typ.)
24.2 GHz ~ 26.5 GHz			-124 dBm, -134 dBm (typ.)

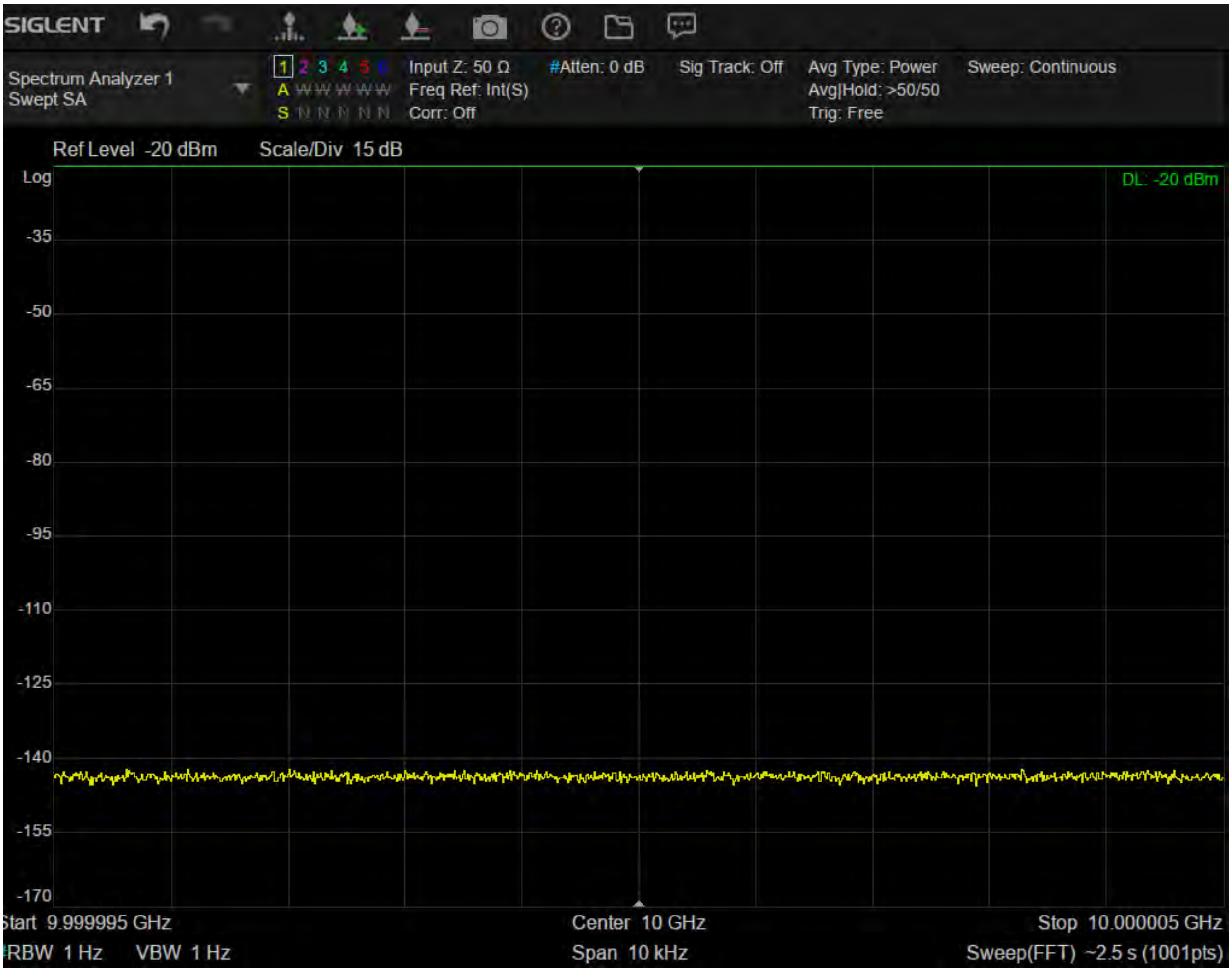
Preamp ON

Frequency	SSA3000X-R, SSA3075X PLUS, SVA1000X	SHA800A	SSA5000A
100 kHz ~1 MHz	-133 dBm, -136 dBm (typ.)	-125 dBm, -137 dBm (typ.)	-135 dBm, -148 dBm (typ.)
1 MHz~10 MHz	-151 dBm, -154 dBm (typ.)	-156 dBm, -163 dBm (typ.)	-153 dBm, -165 dBm (typ.)
10 MHz~200 MHz	-161 dBm, -165 dBm (typ.)	-156 dBm, -163 dBm (typ.)	-159 dBm, -163 dBm (typ.)
200 MHz~600 MHz	-159 dBm, -163 dBm (typ.)	-156 dBm, -163 dBm (typ.)	-159 dBm, -163 dBm (typ.)
600 MHz~1.22 GHz	-159 dBm, -163 dBm (typ.)	-159 dBm, -165 dBm (typ.)	-159 dBm, -163 dBm (typ.)
1.22 GHz~1.5 GHz	-159 dBm, -163 dBm (typ.)	-159 dBm, -165 dBm (typ.)	-158 dBm, -162 dBm (typ.)
1.5 GHz~1.8 GHz	-159 dBm, -162 dBm(typ.)	-159 dBm, -165 dBm (typ.)	-158 dBm, -162 dBm (typ.)
1.8 GHz~3.15 GHz	-159 dBm, -162 dBm(typ.)	-157 dBm, -163 dBm (typ.)	-158 dBm, -162 dBm (typ.)
3.15 GHz~3.2 GHz	-159 dBm, -162 dBm(typ.)	-157 dBm, -163 dBm (typ.)	-154 dBm, -158 dBm (typ.)
3.2 GHz~4.1 GHz	-157 dBm, -161 dBm (typ.)	-157 dBm, -163 dBm (typ.)	-154 dBm, -158 dBm (typ.)
4.1 GHz~5.0 GHz	-157 dBm, -161 dBm (typ.)	-156 dBm, -162 dBm (typ.)	-154 dBm, -158 dBm (typ.)
5.0 GHz~5.85 GHz	-157 dBm, -160 dBm (typ.)	-156 dBm, -162 dBm (typ.)	-154 dBm, -158 dBm (typ.)
5.85 GHz~6.5 GHz	-157 dBm, -160 dBm (typ.)	-155 dBm, -161 dBm (typ.)	-154 dBm, -158 dBm (typ.)
6.5 GHz~6.7 GHz	-155 dBm, -159 dBm (typ.)	-155 dBm, -161 dBm (typ.)	-154 dBm, -158 dBm (typ.)
6.7 GHz~7.22 GHz	-155 dBm, -159 dBm (typ.)	-153 dBm, -159 dBm (typ.)	-154 dBm, -158 dBm (typ.)
7.22 GHz~7.5 GHz	-155 dBm, -159 dBm (typ.)	-153 dBm, -159 dBm (typ.)	-154 dBm, -158 dBm (typ.)
7.5 GHz ~ 13.6 GHz			-154 dBm, -158 dBm (typ.)
13.6 GHz ~ 18.9 GHz			-151 dBm, -155 dBm (typ.)
18.9 GHz ~ 24.2 GHz			-148 dBm, -152 dBm (typ.)
24.2 GHz ~ 26.5 GHz			-142 dBm, -149 dBm (typ.)

These values can be charted for easy comparison:



A spectrum analyzer can be set up to measure this with a few quick steps. Select the frequency of interest, reduce the span to around 10 kHz and the RBW to 1 Hz. This gives you a sweep speed of a few seconds. Set the trace averaging to 50 and set the preamp as desired. Make sure to set the amplitude reference and scale so the DANL value will be on screen. Test with nothing connected to the front end. Allow the averaging to complete – this will take a few minutes. Here is the result on an SSA5000A at 10 GHz with the preamp set to off:



This unit appears to be 3-5 dB better than typical.

Of course, spectrum analyzers should have better DANL with the preamp on as the preamplifiers job is to amplify the signal incoming above the noise floor of the instrument. To know which setting is best for your measurement may require additional knowledge of how the amplitude reference, preamp, and attenuation settings work together.

For instance, on the SSA5000A the max reference level with the attenuator set to 0 dB and the preamp off is -20 dBm.

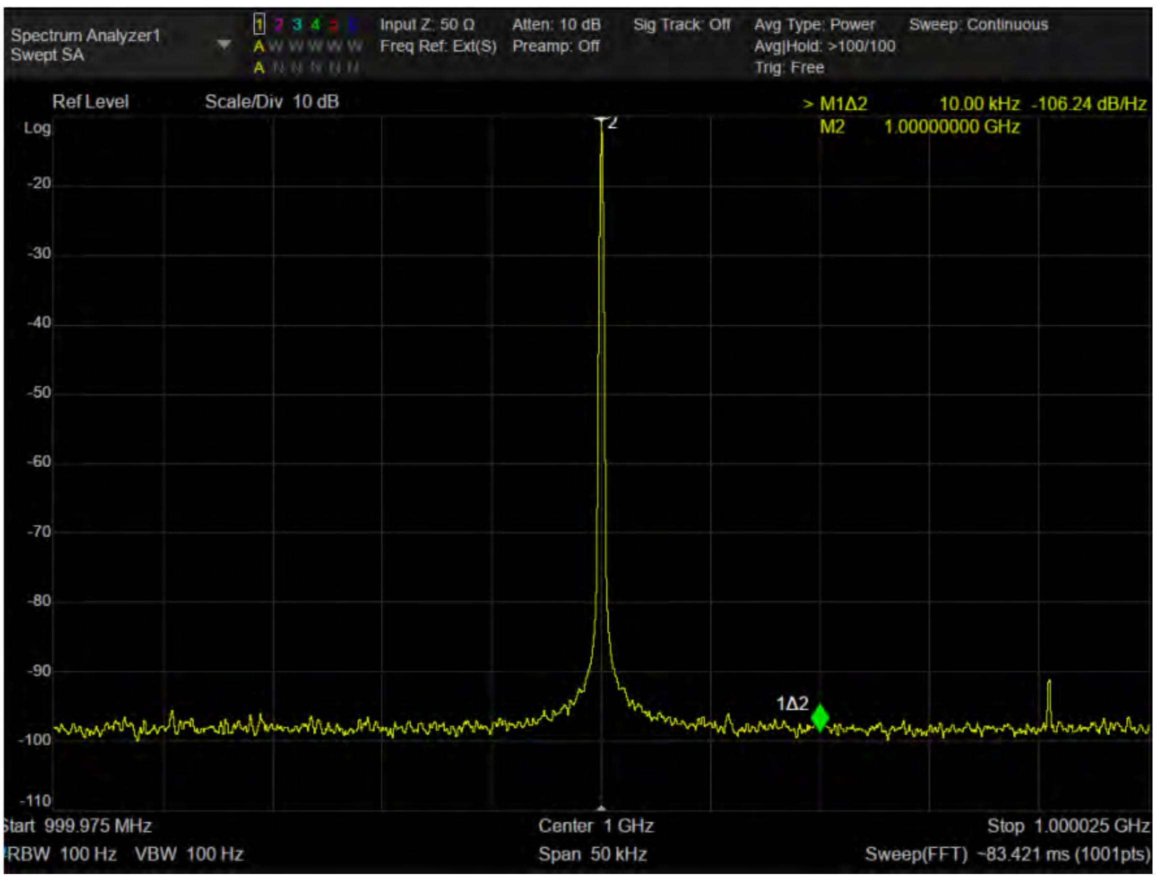
With the attenuator set to auto, you can set the reference up to 23 dBm and the attenuator will go to 44 dB. This gives you additional range to view higher power signals at the top of the display, but the attenuator setting essentially gets added to the DANL directly. Therefore, with the preamp off, at 10 GHz, in this setup, the SSA5000A has a dynamic range of about 120 dB. That is from the reference level to the DANL.

Activating the preamp will typically force the reference level to reduce a commensurate amount. The SSA5000A and other benchtop spectrum analyzers typically use a 20 dB nominal preamplifier. The handheld SHA800A series uses a 25 dB nominal preamplifier.

Understanding how the noise floor, resolution bandwidth, reference level, preamp, built in amplifier, and dynamic range are related can help when selecting the best spectrum analyzer for your application.

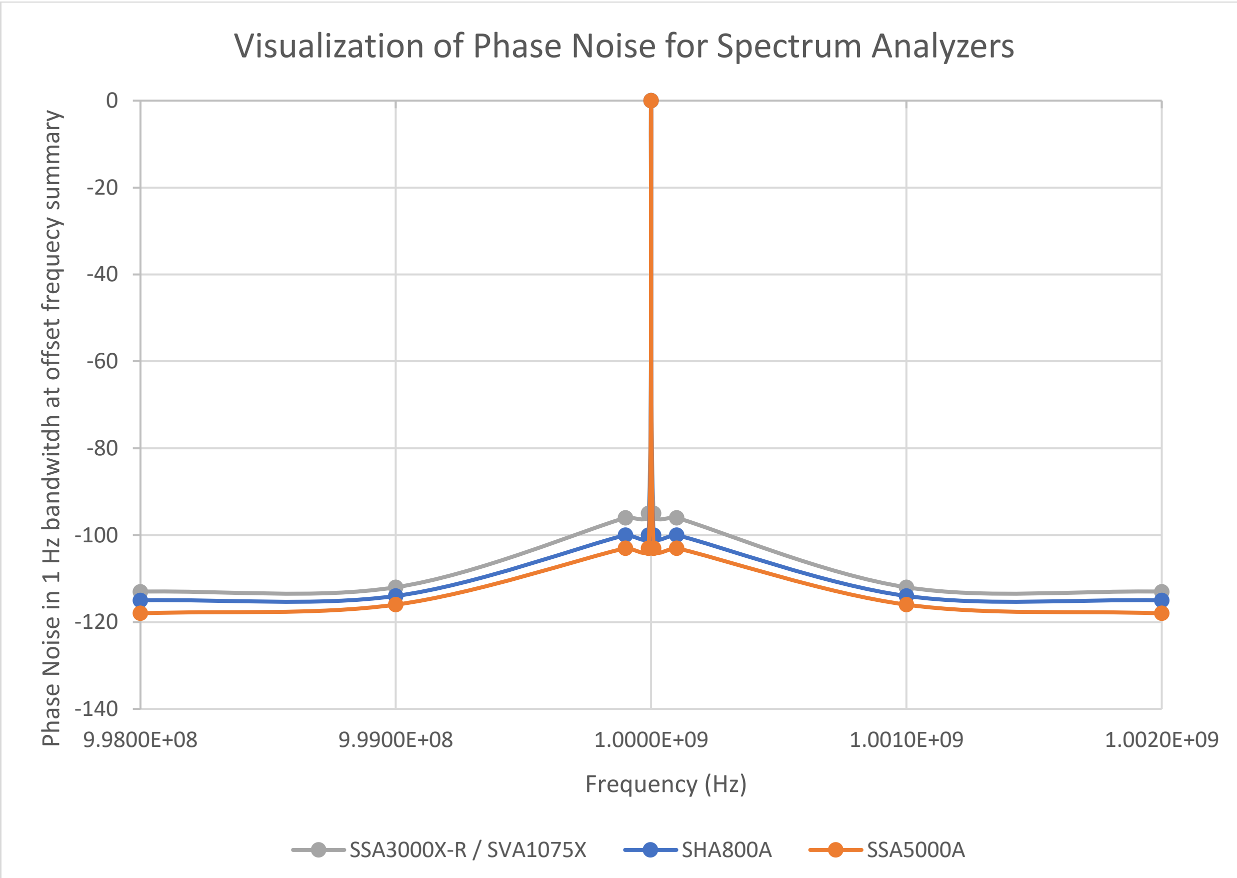
Phase Noise

Phase Noise is one of the primary specifications for a spectrum analyzer. As opposed to DANL, which is about noise away from signals, phase noise helps to explain the noise generated very close to a signal. Noise is measured in a 1 Hz bandwidth at a given offset from the carrier. Frequency accuracy is an important contributing factor for this measurement. This is about how tight the apron of a signal is at a certain setup. For instance, a 1 GHz CW carrier measured with a 1 Hz measurement bandwidth might look like this on a spectrum analyzer:

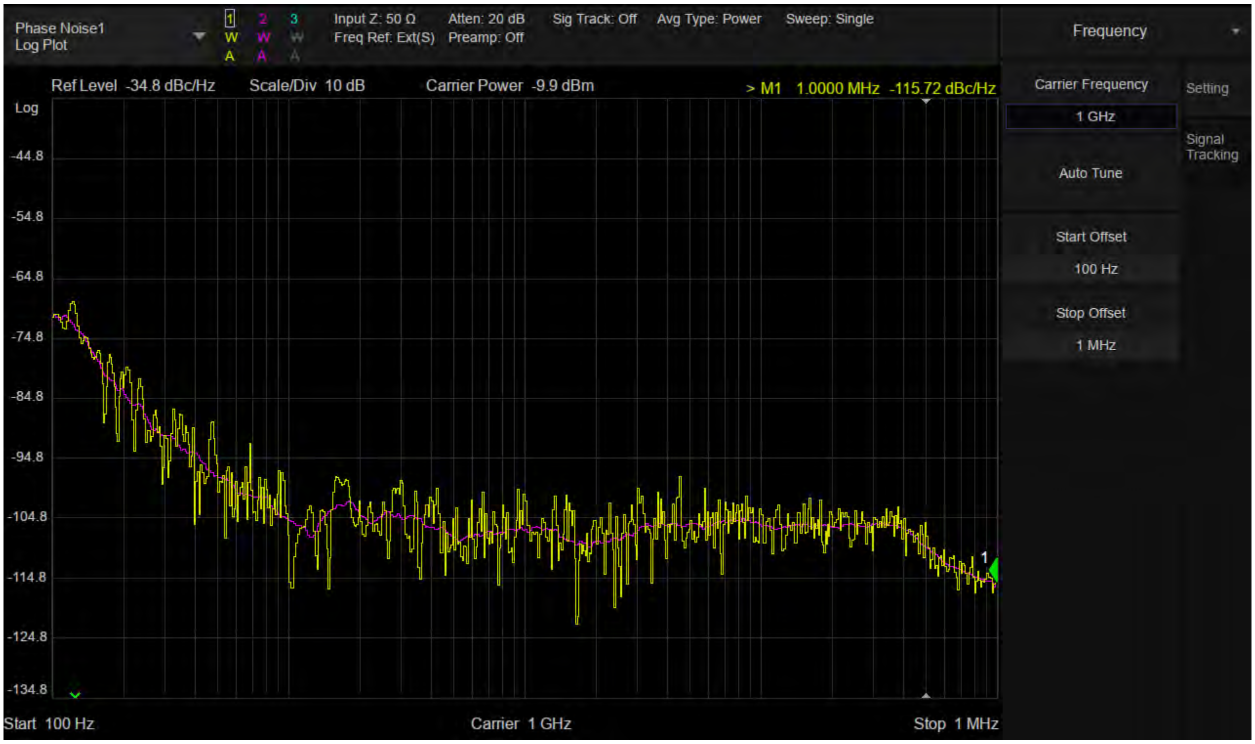


The SSB phase noise of this signal is the noise level measured down from the peak in dBc/Hz at a frequency typically 10 kHz or so from the carrier frequency.

This is another specification that shows the capability of a spectrum analyzer. This chart is a visualization of Siglent's primary spectrum analyzer models showing the various phase noise levels based on the specifications:



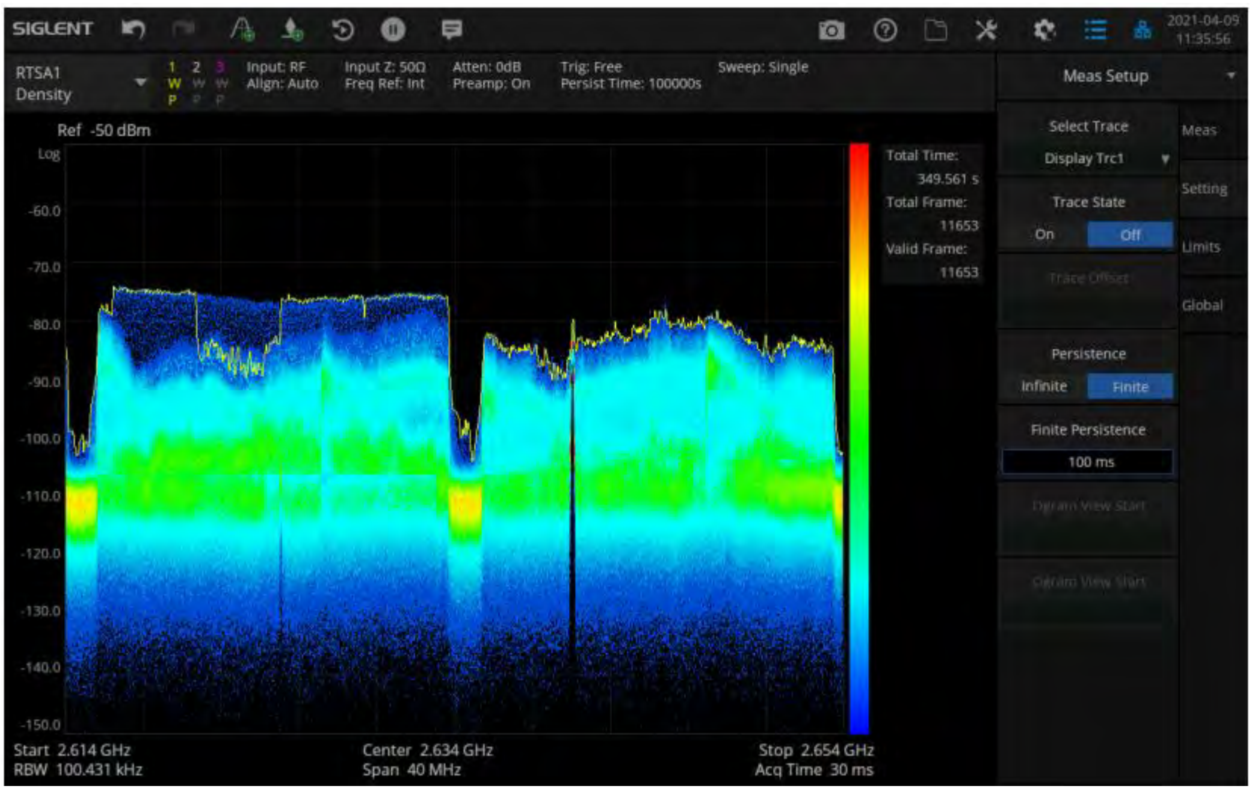
Spectrum analyzers can also be used to measure the phase noise of other RF devices or signal generators. The SSA5000A has an automated capability to make this measurement using the SSA5000-PN option. This generates a log chart that shows one side of this apron in a single chart like this:



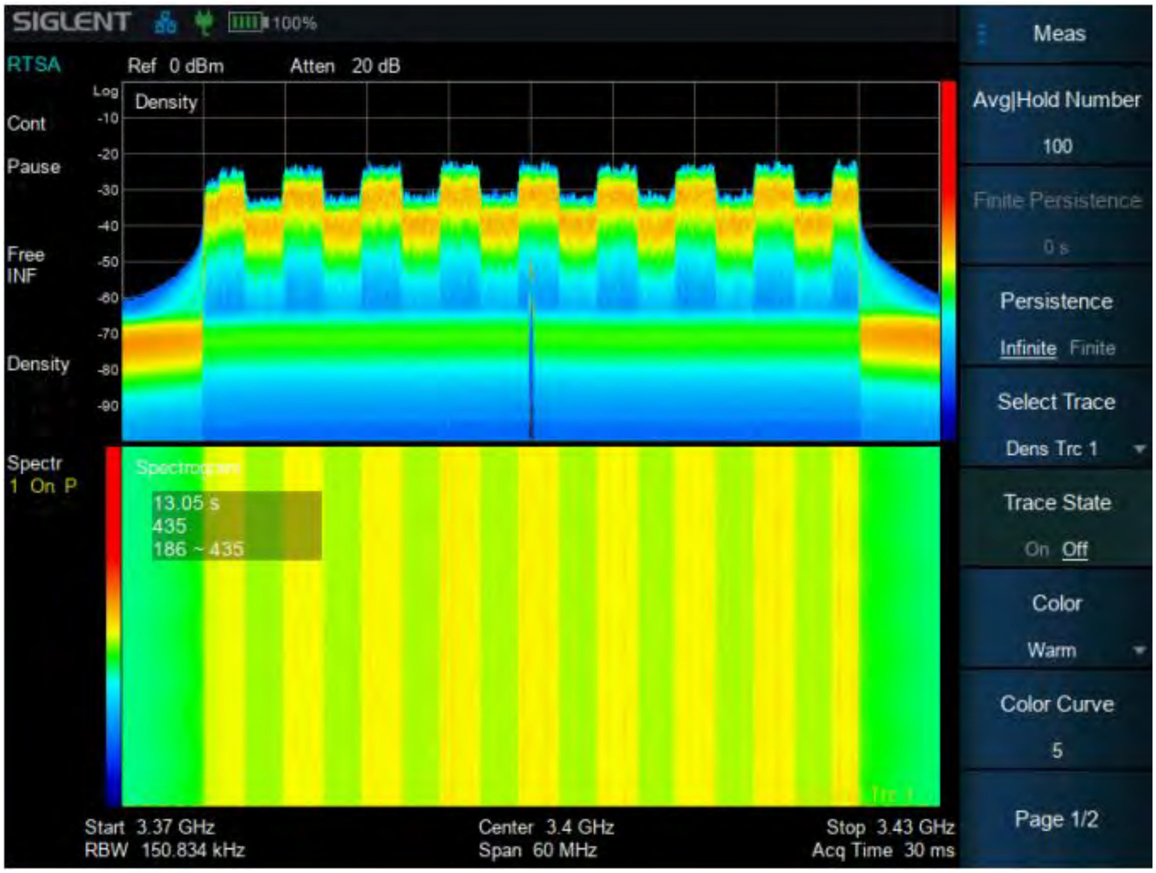
Measurements are influenced by averaging and other settings. This uses a swept measurement mode with automatic carrier identification and direct measurements at the offset frequencies to build up the combined chart. It is also important to remember that a spectrum analyzer can never measure the phase noise of a device with lower phase noise than itself. In that case, the system is just measuring noise from the analyzer itself. For this reason, it is important to select a spectrum analyzer of sufficient quality to make the measurements near a signal that are required in the application.

Real-Time Analysis

Real-Time Analysis is a separate mode from traditional swept spectrum analysis. It relies on fast analysis of Fast Fourier Transforms (FFT) of time domain data taken from the spectrum analyzers front end. The advantage of this method is it highlights dynamic signals that may come and go too quickly for swept analysis. This includes communication signals, interference, high speed RF pulses, and more. The standard view in real-time analysis is typically called "Density" and looks like this:



The X axis is frequency and the Y axis is power, just like standard swept mode while the color is used to indicate the amount of the time that that frequency/power measurement occurs in the signal. Typically, cooler colors like blue are less frequently occurring while warmer colors are the most common. This makes it possible to identify rare signal artifacts within a complex and dynamic RF spectrum. The density view can also be combined with a spectrogram:



In this image, the top half is a density view, while the bottom half is a spectrogram or waterfall chart that helps the engineer identify how the signal is changing over longer timescales. This is a common use case for frequency hopping signals or phase lock loop debugging.

There are several specifications that are critical to the operation of real-time mode. The most important of these is real-time bandwidth. One of the downsides to using the high speed FFTs for signal visualization is that it typically limits the span of the view to near the center frequency. There are also limits to the spectrum analyzer design for how wide of a span it can establish accurate power over in a single configuration. Real-Time bandwidth may also be called analysis bandwidth for some measurements. Siglent real-time analysis can be done with the following instruments:

Series	Maximum Real-Time Bandwidth (option)
SSA3000X-R	40 MHz (25 MHz is standard)
SSA5000A	25 or 40 MHz
SHA860A	40 or 110 MHz
SDS7000A	1 GHz

The SDS7000A is Siglent's 8 GHz performance oscilloscope. There is an option to use that as a real-time spectrum analyzer. It provides the widest bandwidth with a top frequency limit at the frequency of the oscilloscope: 3, 4, 6, or 8 GHz. This includes all of the views and capabilities of traditional real-time spectrum analyzers with the added benefits of higher speed and wider bandwidth for analyzing more complex signals.

Typically, for real-time spectrum analysis the RBW of the measurements are set as a ratio of the span so depending on the span settings you get a number of choices of RBW selection to optimize the view. Siglent spectrum analyzers typically have 6 RBW settings available in real time mode. This is also affected by the FFT windowing methodology. These can be selected as well. A typical list includes:

Rectangular, Blackman, Hanning, Hamming, Flattop, Blackman-Harris, Kaiser, and Gaussian

The RBW setting equates to a window length in the number of FFT points that is then put into the FFT window calculation. Typical window values are: 32, 64, 128, 256, 1024, and so on.

When considering how to set up real-time analysis, there are 2 key modes to consider. The first is gapless measurements. In this mode, the RBW tends to be set higher, allowing for longer window periods, which in turn means that the FFTs use overlapping points. In these modes, no points from the time domain capture go unused, so any signal that occurs for as little as 1 sample period is considered as part of the measurement. A great example of this is how the SDS7000A works in real time. When set with a 500 MHz real-time bandwidth, the SDS7000A is configured with a sample rate of 625 MSa/sec and a window size of 2048 samples. The FFTs are completely overlapping by approximately 976 points in this mode. Every point is then used in the measurements. The upside to this methodology is that no signal is ignored. The downside is that a short duration signal tends to be averaged down in power by the windowing. At 625 MSa/sec a sample is captured every 1.6 nanoseconds. A 2048 sample FFT window includes points from 3.27 μseconds of time. A shorter duration signal then gets averaged down by the other points in the window. So, gapless measurements use all the available samples to visualize the RF spectrum. The power may be attenuated by averaging across the window for shorter duration signals.

The other mode prioritizes power accuracy. Using the smallest available RBW selection means that you are most likely to accurately measure the power of a signal. Because the window is as short as possible, the shortest possible signals are persistent throughout the window. Any signal that persists through the entire window will be measured accurately in power.

While it is fairly simple to calculate the window length in time, further analysis is required to understand this function. The all-encompassing specification developed to simplify this is called 100% POI or probability of Intercept. We will learn more about that in the next section.

100% Probability of Intercept (POI)

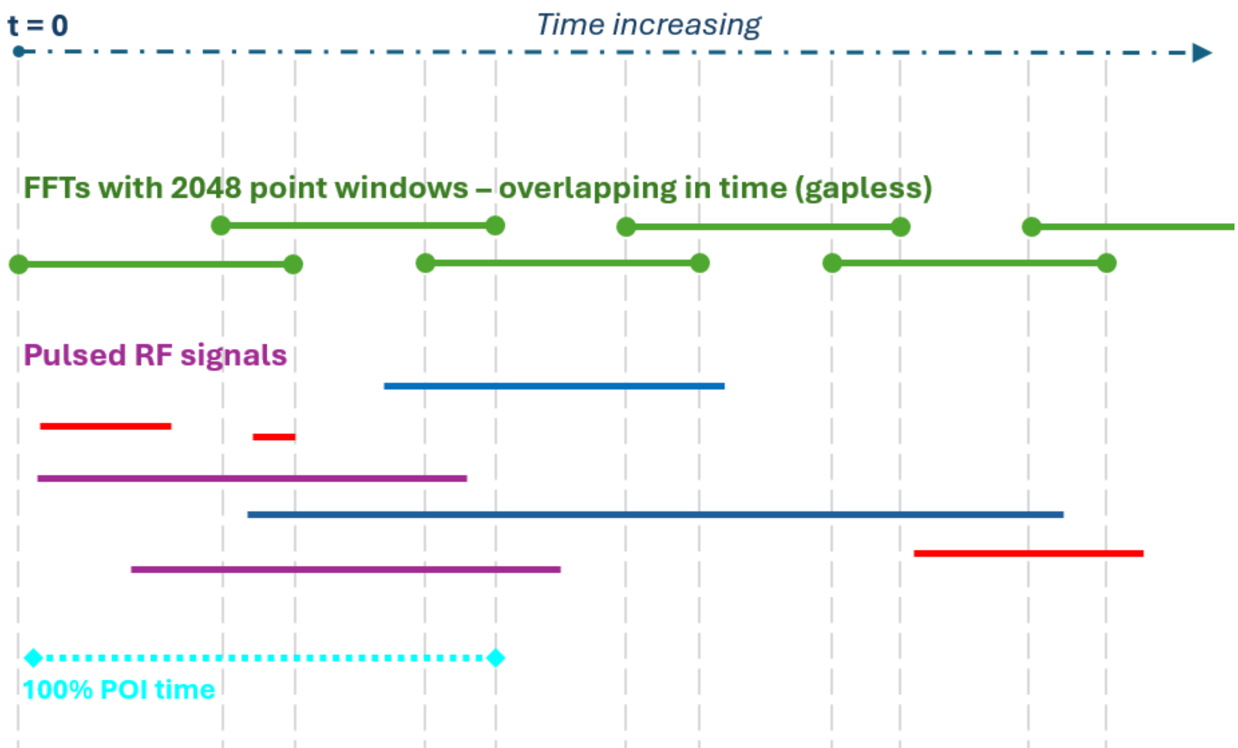
100% POI is specified in units of time. This represents the shortest time period that an RF signal within the span can persist while still being guaranteed to be correctly captured in power by the real-time analyzer.

We just discussed shortening the RBW and the window length to make the instrument more power accurate for shorter signals. The 100% POI specification takes this a step further by looking at how often the FFTs occur and any gaps between them as well as the window size.

To put simply, an RF signal must persist for the entire window to be accurately calculated in power. But, these signals are all captured asynchronously. So, how can you determine if your signal will line up with an active window?

Let’s look at 2 key examples from Siglent’s real-time options. The first is the SDS7000A configuration as we discussed before. Here, the FFTs are overlapping by 976 points.

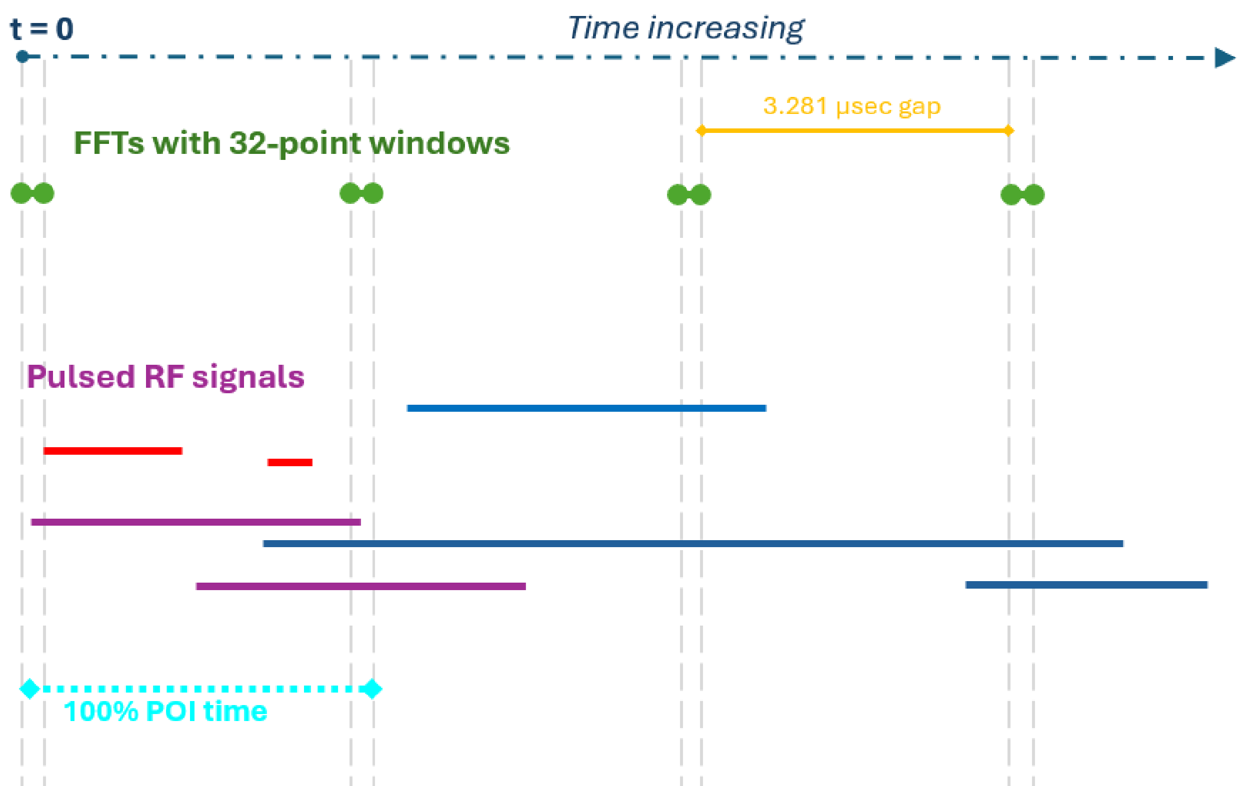
This infographic shows how this works:



The green bars represent when each FFT window is active. You can see how they overlap in time. The red RF signals are too short to be captured at the correct power because they do not persist as long as any window, but they are all incorporated into the measurements. The blue signals are captured correctly because they are on for an entire window. The purple signals are longer than one of the blue signals, however they do not line up with any of the windows completely. The leftmost purple signal is partially captured by FFT window 1, 2, and 3 but never completely. The second purple signal is captured completely by FFT #2 even though both purple signals are the same length. Therefore, the shortest duration signal that is ***guaranteed*** to be measured correctly is represented by the cyan mark. From the start of one

FFT window to the end of the window after. For the SDS7000A in this configuration, the value is 4.99 μseconds.

The second example we will take from the SHA860A. Here, the 100% POI is reduced using a smaller window that does not overlap. It looks like this:

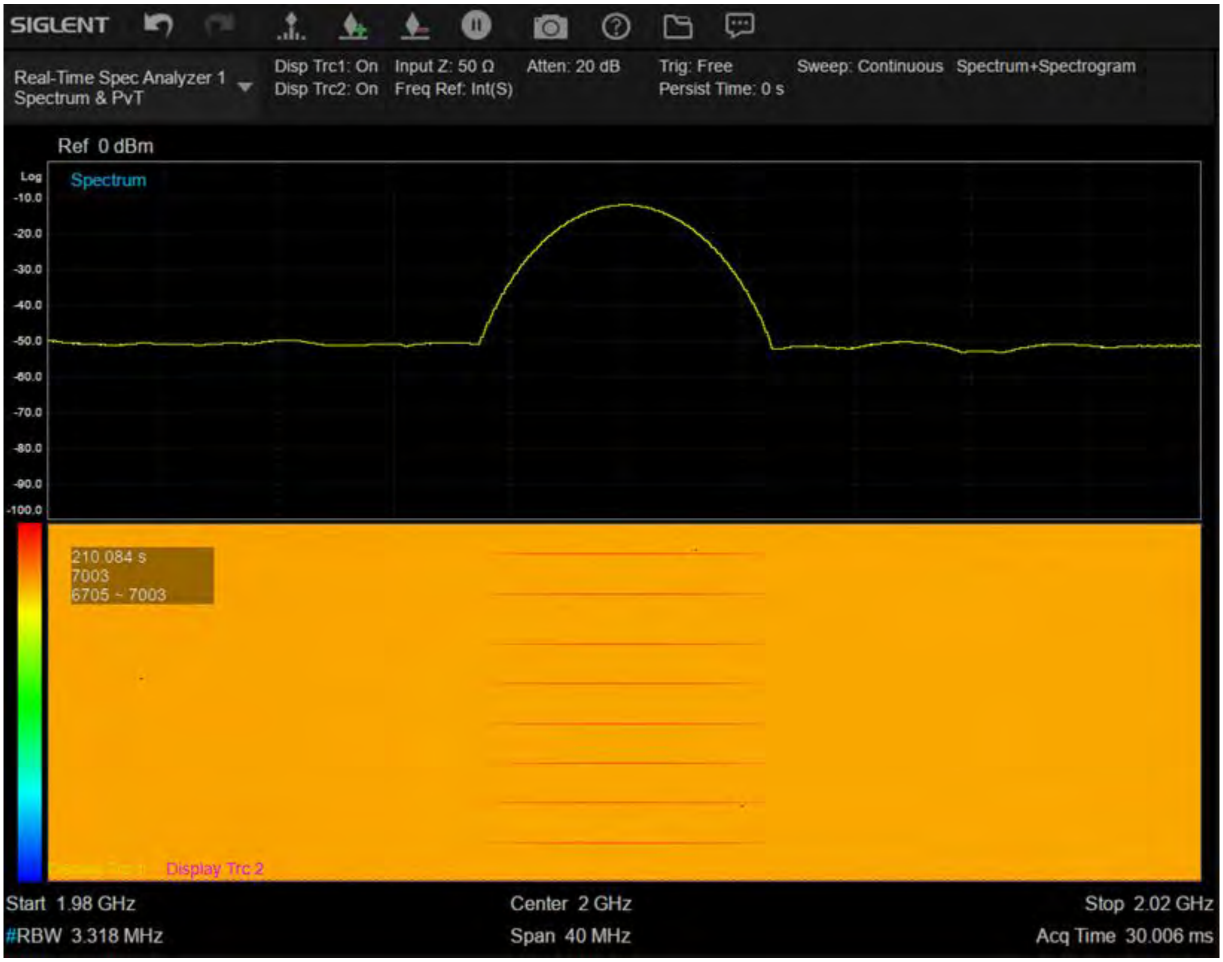


As before, the blue signals are captured as well as one of the purple signals. Here, the 2 red signals are completely ignored and do not appear at all. However, the overall 100% POI time in this configuration is 3.51 μseconds using the SHA860A series spectrum analyzer. This guarantees correct capture for the shortest possible RF pulses. Due to how the RBW and span affect the timing of the system, 100% POI is usually stated as a table. This is the table for the SSA5000A spectrum analyzer:

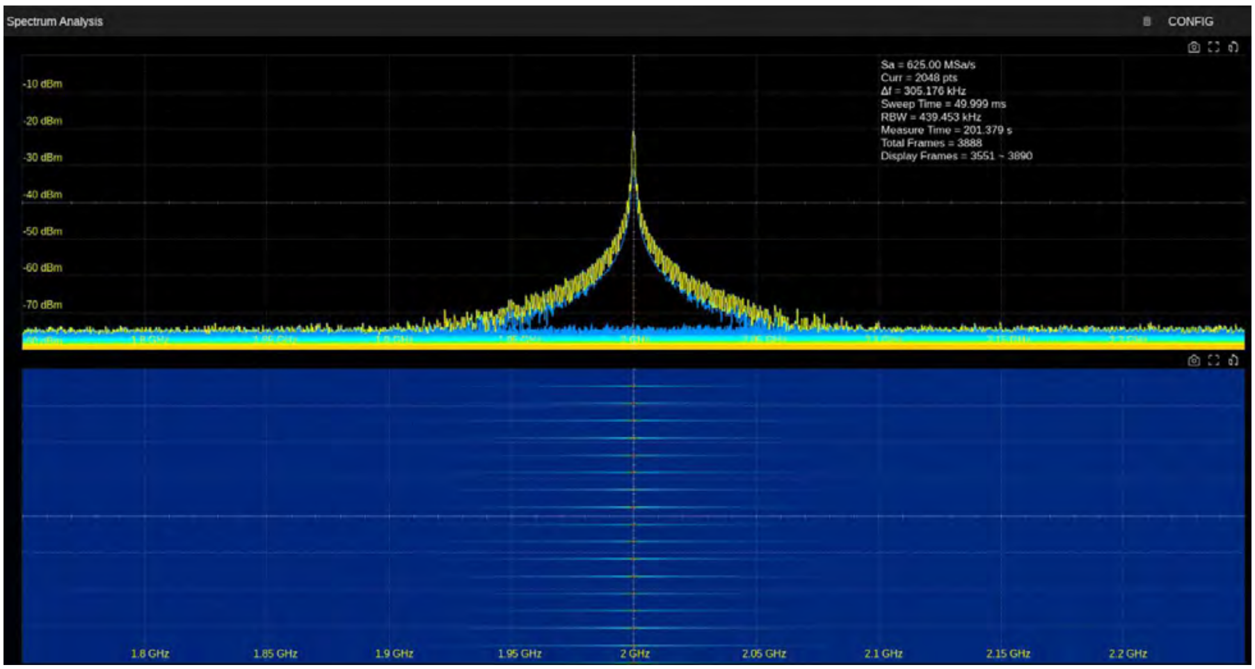
Different RBW and span, 100% POI (μs)						
Analysis BW	RBW1	RBW2	RBW3	RBW4	RBW5	RBW6
40 MHz	26.56	16.56	11.56	9.06	7.81	7.20
20 MHz	46.56	26.56	16.56	11.56	9.06	7.81
10 MHz	86.56	46.56	26.56	16.56	11.56	9.06
1 MHz	806.56	406.56	206.56	106.56	56.56	31.56

This is similar to the SHA860A in that the best POI occurs at the widest analysis bandwidth and shortest RBW (RBW6). The best 100% POI value on the SSA5000A is 7.2 μseconds.

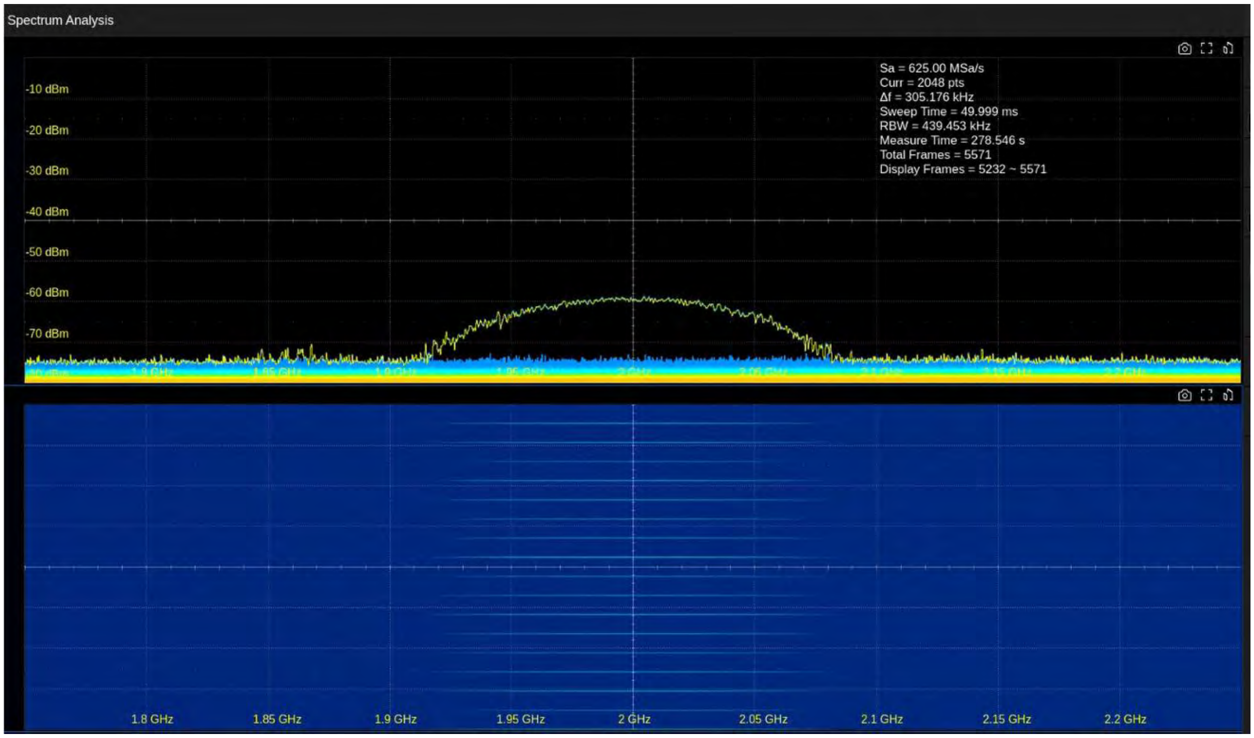
We can verify these characteristics with a simple pulsed RF signal from a signal generator. Here we are generating a 7.2 μsecond RF pulse at 2 GHz. The pulse repetition rate is once per second. Using the spectrogram view, we can capture this signal:



On the spectrogram we can see that every pulse is captured as they come onto the screen once per second. Remember, that this is being captured even though the analyzer is not triggering on the signal or operating synchronously to the source. As expected, when the pulse is shortened below the POI value, some pulses are missed entirely. Using the gapless POI approach of the SDS7000A a different output is achieved. The shorter RF pulses are attenuated and not captured correctly in power, but they are still all captured until overwhelmed by noise and averaging because of the overlapping FFTs. Here is an example screenshot with the SDS7000A set up to capture a 4.99 μsecond POI. However, we are inputting only a 1 μsecond pulse at once per second. This view shows the every pulse and a little more variance in power intensity as the short pulses overlap FFTs differently:

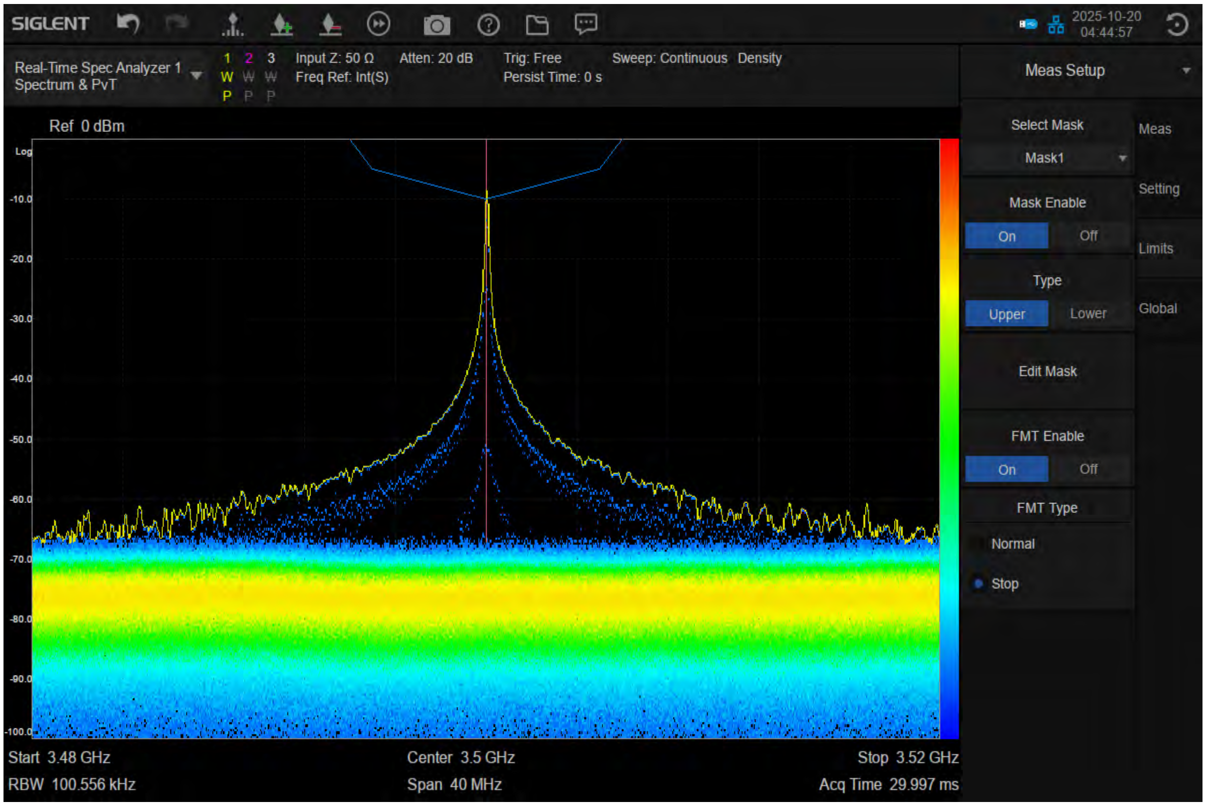


Even with pulse widths as short as 20 nsec, each pulse can still be viewed in this way as long as they rise above the noise floor. This view is with the same signal at a 20 nsec pulse width. You can see that each pulse is stll captured, but the peak power has been attenuated by the window average:



This is the best methodology for high-speed RF capture. Using gapless, real-time analysis and understanding the 100% POI specifications makes it easy to capture hard to find signals in a complex RF environment.

One additional advantage to this FFT methodology becomes clear now that we have a specification for signals that we know will be captured correctly in power. We can now scan the data and use a Frequency Mask Trigger (FMT). We identify an area of power and frequency that we wish to trigger on and visualize. The data is then scanned as it is captured and only shown when the power level is within the mask area are then visualized on the display:



This type of debugging of dynamic RF signals is the benefit of real-time analysis. Use real-time analysis in the mode and setup that best fits the application's requirements for accuracy and speed.

EMI Pre-Compliance Instrument Configuration

1. Introduction

A spectrum analyzer is a key instrument for conducting EMC testing. Analyzers with EMC-specific features have become very affordable in recent years and these are usually sold as “EMI-options” that typically include CISPR filters and Quasi-Peak (QP) detectors in addition to the standard features of spectrum analyzers.

Spectrum analyzers offer a wide range of parameter settings and need to be set up correctly in order to make measurements as close as possible to the requirements of the specific EMC standards that apply to the product’s design and end-use. EMC standard-related requirements determine the correct instrument settings of the RBW filter, video bandwidth (VBW), detector type, frequency span, and sweep time. Radiation limits and transducer characteristics also affect the required settings. Optimizing the instrument is necessary to achieve a good compromise between high sensitivity and low distortion.

Measurement plots documented in this application note are created using a Siglent SSA3021X Plus, an entry-level EMI-spectrum analyzer with an excellent price-performance ratio.

2. Relevant standards

Several standards specify EMC test setups and requirements for measurement equipment. Most prominent are the CISPR 16 and EN 61000-4 series. There are additional relevant standards, such as CISPR 25, Mil-461, DO 160, and more. This document is mainly focused on the CISPR 16.

3. Standard related requirements

3.1 Amplitude units

In RF applications, [dBm] is the predominant amplitude unit. [dBm] is a logarithmic power unit, which makes sense, as input and output impedance of RF building blocks are typically designed to 50 Ohm.

In EMC pre-compliance applications, the impedance of EUTs and power supply sources is hardly predictable. Consequently, emission limits are predominantly specified in [dBµV] and [dBµA] amplitude units. Standardized transducers such as Line Impedance Stabilized Networks (LISNs), Coupling/Decoupling Networks (CDNs), RF current probes, and others are used to establish interfaces with defined impedance, in order to connect 50 Ohm measurement equipment.

3.2 Resolution bandwidth

Typically, the resolution bandwidth filters on spectrum analyzers use Gaussian shaped Intermediate Frequency (IF) filters with adjustable bandwidths that follow a 1 –3 –10 sequence, e.g. 100 Hz, 300Hz, 1 kHz, 3kHz, 10 kHz, 30 kHz…

In order to be compliant with CISPR standards, the spectrum analyzer must additionally provide so-called CISPR-filters. Many analyzers use a Gaussian filter by default, so the user should select the EMI filter option if required.

In Figure 1 below, there is a comparison between the Gaussian and CISPR filter shapes:

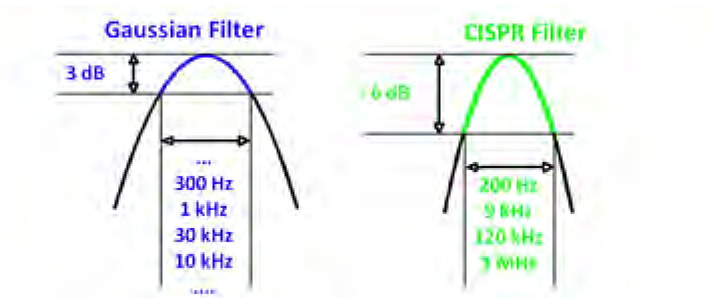


Figure 1: Gaussian and CISPR filter shapes.

Besides specifying filter shape, impulse response, and sidelobe suppression, CISPR specifies frequency bands and the corresponding filter bandwidths that should be used:

Frequency range	CISPR filter bandwidth
9 kHz – 150 kHz	200 Hz
150 kHz – 30 MHz	9 kHz
30 MHz – 1 GHz	120 kHz
Above 1 GHz	1 MHz

Table 1: CISPR frequency range and filter bandwidth setting.

The smaller the resolution bandwidth (RBW), the lower the base noise level. The base noise level is a function of the measurement instruments Displayed Average Noise Level (DANL), the measurement transducer/antenna/probe, and the environmental RF present during the measurement. You may already have observed steps in test house plots, which are caused by switching filter bandwidth. Figure 2 below shows an example of such a step where the RBW was changed from 9 kHz in the first part of the sweep to 120 kHz after 12 MHz:

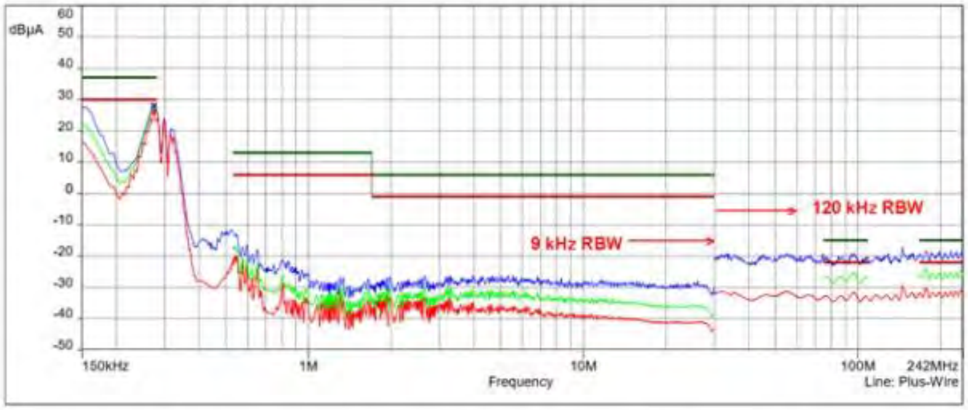


Figure 2: Transition from 9 kHz to 120 kHz RBW at 30 MHz – Note steps in the base noise level.

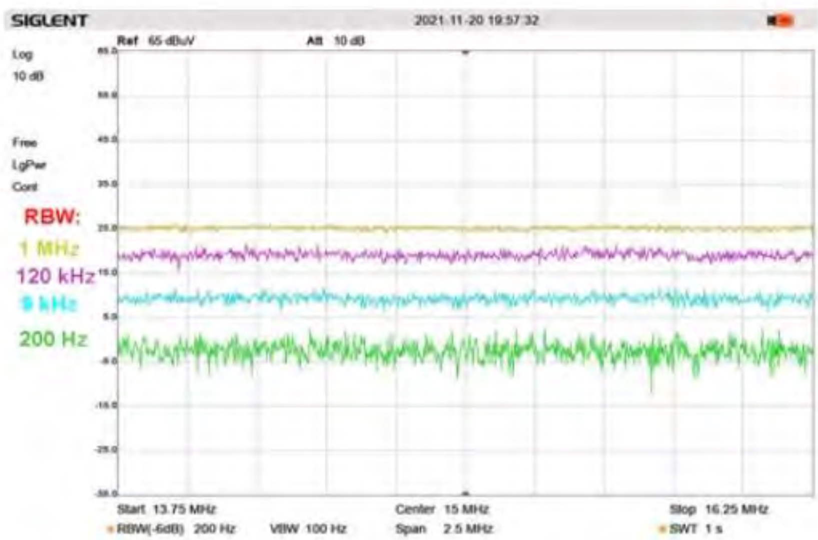


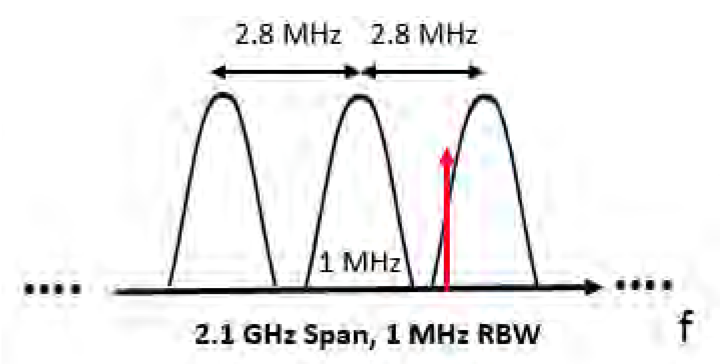
Figure 3: Spectrum analyzer DANL level versus resolution bandwidth.

3.3 Frequency resolution

Spectrum analyzers sweep across the frequency range in discrete steps. The default number of frequency steps per sweep may be set to match the number of display pixels in X-direction. The Siglent SSA3021X, as an example, has a resolution of 751 equidistant frequency points per sweep. Other common spectrum analyzers have 601 measurement points per sweep.

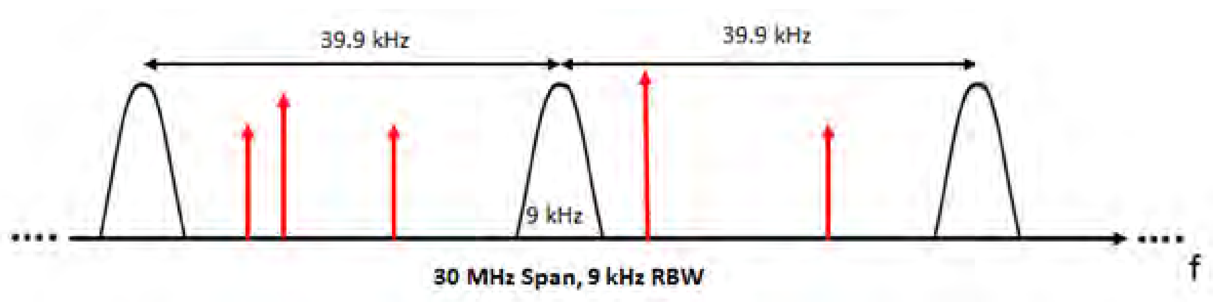
Spectrum analyzers typically power up with factory default settings where the sweep is set to full span and the RBW is set to 1 MHz.

When feeding the analyzer with a signal, it may be observed that frequency and amplitude are not displayed correctly. With a brief calculation and looking at the filter curves and spacing between adjacent frequency points and the reason becomes obvious. As an example, what if we divide the measurement span of 2.1 GHz by 751 frequency points? This results in adjacent frequency points being spaced by approximately 2.8 MHz:

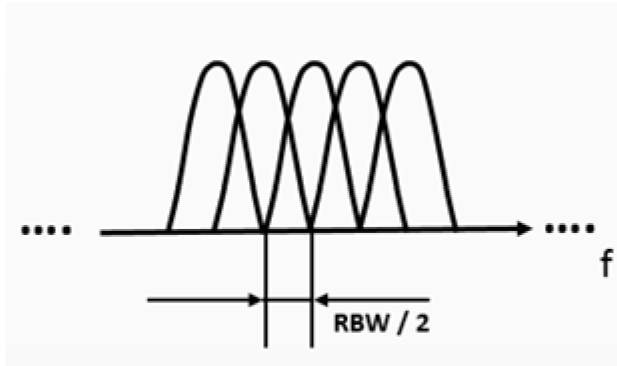


Input signals may fall in between two adjacent filter curves or into the shoulder of a filter curve. Consequently, the signal will be attenuated and the analyzer display would show a lower amplitude value – the measurement value would be incorrect. The displayed frequency will be corresponding with the center frequency of the closest measurement frequency point and the offset would be incorrect as well.

Let´s take another example and look at a typical conducted emission measurement. In most cases, this measurement covers the frequency range up to 30 MHz and requires a CISPR RBW of 9 kHz. Attempting to make a full sweep across the entire 30 MHz results in a spacing of 30 MHz / 751 = 39.9 kHz. A significant part of the spectrum would not be measured at all:



In order to cover the entire spectrum within the span of a frequency sweep, CISPR 16 specifies that adjacent frequency points shall not be spaced more than half of the resolution bandwidth. In the case of the example above, the spacing shall not be more than 9 kHz / 2 = 4.5 kHz.



With this information in mind, the frequency span settings have to be chosen in order to fulfill the frequency spacing and RBW specifications of CISPR 16:

Number of measurement points per sweep: 751 (Siglent SSA3021X)

Frequency range	CISPR filter bandwidth	Maximum frequency span
9 kHz – 150 kHz	200 Hz	75 kHz
150 kHz – 30 MHz	9 kHz	3.38 MHz
30 MHz – 1 GHz	120 kHz	45 MHz
Above 1 GHz	1 MHz	375 MHz

*Spectrum analyzers like the SSA5000A can be set to up to 10,001 sweep points for more flexible configurations.

Consequently, a conducted emission measurement for the frequency range 150 kHz to 30 MHz has to be split into at least 29.85/3.38 = 9 segments with a span of 3.38 MHz.

Doing such a measurement manually would be a tedious process. Various analyzers let you increase the default number of measurement points to a higher value. Newer analyzers also offer the capability to select standard conformant EMI measurement routines, which also ensure that adjacent measurement points have the correct frequency spacing. The disadvantage is that the resulting graph is still limited to the number of available display pixels.

Tekbox offers EMCview EMI measurement software, which splits the measurement into consecutive sweep segments. The measurement values of all sweeps are then stitched together to a single graph for easy analysis and reporting. EMCview also simplifies EMI measurements by providing a vast list of pre-configured measurements.

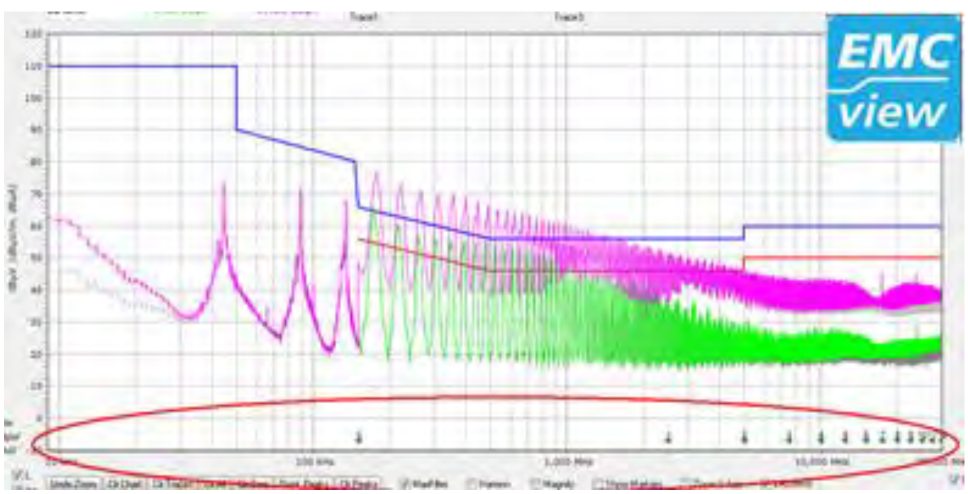


Figure 4: Conducted noise measurement with EMCview. The 30 MHz sweep is built from 12 segments with a 2.5 MHz span each.

3.4 Sweep time

CISPR 16 differs between wideband and narrowband noise. Narrowband noise is typically caused by clock signals. Wideband noise is caused by data signals. As the spectrum of data signals is caused by a more or less arbitrary bit sequence, it is dynamic and wideband. Furthermore, signals may be present or not, depending on tasks running on the controller. Sweeping too fast would miss pulses and not correctly measure the wideband noise spectrum.

Consequently, **CISPR 16** specifies **minimum** sweep times, depending on frequency range and detector:

Frequency range	Peak detector	Quasi-peak detector
9 kHz – 150 kHz	100 ms / kHz	20 s / kHz
150 kHz – 30 MHz	100 ms / MHz	200 s / MHz
30 MHz – 1 GHz	1 ms / MHz	20 s / MHz

Table 2: CISPR 16 minimum sweep times for specific frequency ranges.

CISPR 25 specifies **minimum** sweep times below:

Frequency range	Peak detector	Peak detector	Quasi-peak detector
150 kHz – 30 MHz	10 s / MHz	10 s / MHz	200 s / MHz
30 MHz – 1 GHz	100 ms / MHz	100 ms / MHz	20 s / MHz
above 1 GHz	100 ms / MHz	100 ms / MHz	n.a.

Table 3: CISPR 16 minimum sweep times for specific frequency ranges.

Longer sweep times have an averaging effect, reducing the noise level:

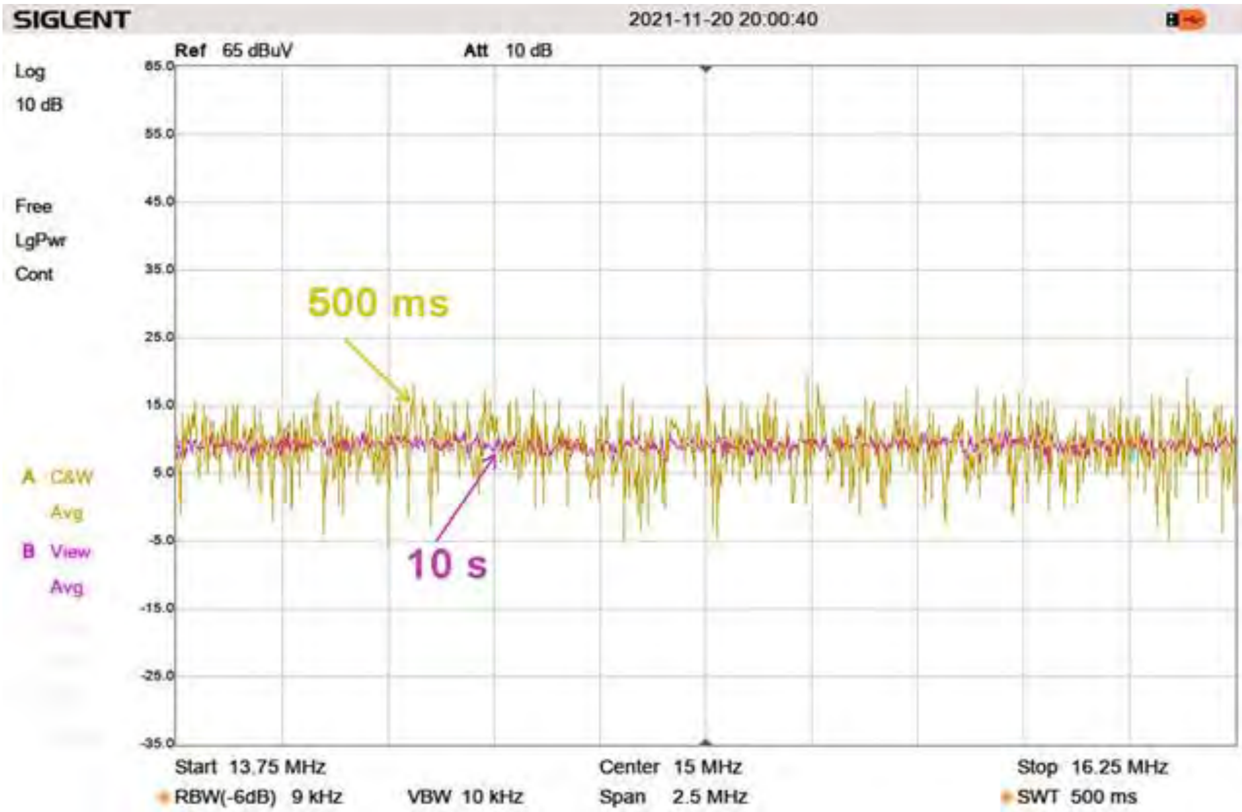


Figure 5: Analyzer DANL with 500 ms sweep time versus 10 s sweep time.

3.5 Detectors

Most conducted and radiated emission tests have limits specified for average detector and quasi-peak detector.

Whereas measurement scans with average and peak detectors can be carried out reasonably quickly, quasi-peak detectors require a measurement time of 1 second per measurement point for measurement receivers and a similarly long time for spectrum analyzers. A single, complete measurement scan may take several hours when carried out with quasi-peak detectors.

However, there is a workaround, which reduces measurement time significantly:

The measurement result of the peak detector is always higher than the measurement result of the average detector.

The measurement result of the quasi-peak detector will always be somewhere in between the results of the average and positive peak detector. The measurement result of the quasi-peak detector will never be higher than the measurement result of the positive peak detector.

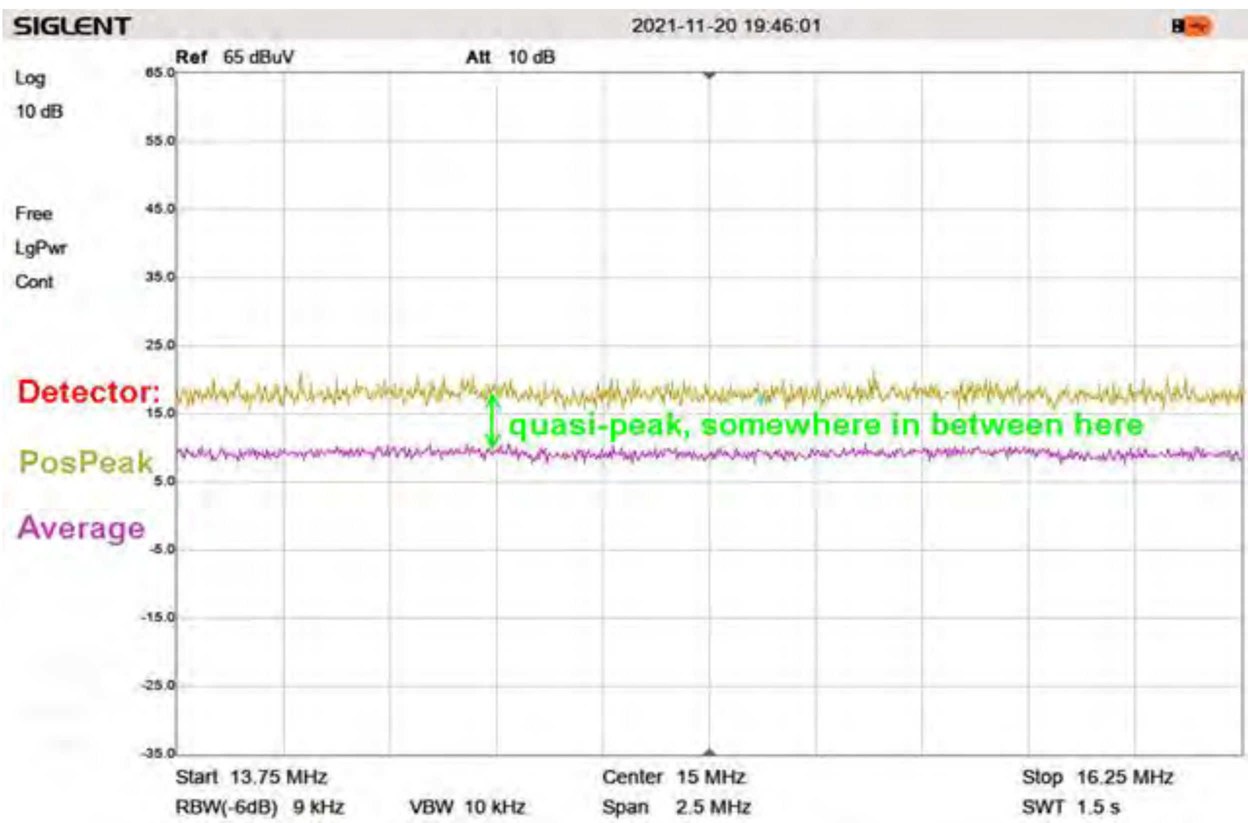


Figure 6: Example of the differences between the positive peak and average detector types.

Consequently, a complete scan will be carried out, using the peak detector and the result will be compared against the quasi-peak limits. If the peak detector measurement is within QP limits, the EUT has passed the test. If the peak detector result has a few spurious peaks, which cross the limit line, there is still the chance that the quasi-peak result is within the limits. However, if the spurious peaks are 10 dB or more above limits, the chance is pretty slim.

To verify, a selective re-measurement, using the quasi-peak detector, will be carried out at only the frequency points where the peak detector measurement crosses the limit line.

When selectively re-measuring spurious peaks with critical amplitudes, it also needs to be considered that the spurious peaks may have drifted in frequency in the time that passed between peak detector measurement and selective re-measurement with the quasi-peak detector. Peaks originating from switched-mode regulators may drift considerably over time and temperature. Doing a selective re-measurement may completely miss the spurs at a later time or have the spur frequency offset far enough to obtain a wrong measurement result. EMCview offers a selective measurement option considering frequency drift. Instead of just measuring at a single frequency, the quasi-peak measurement can be carried out across several adjacent frequency points. EMCview will then make a peak search through these frequency points to ensure capturing the correct quasi-peak amplitude.

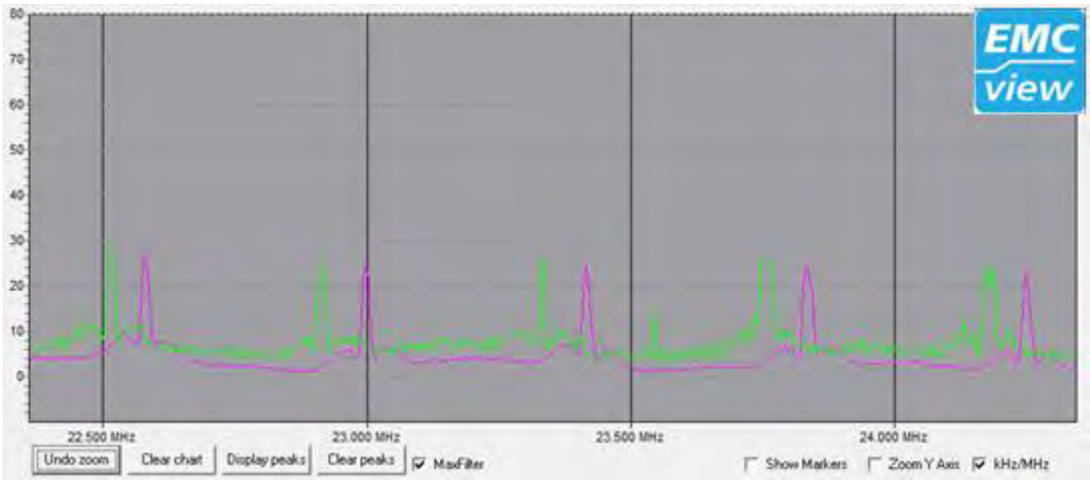


Figure 7: Example of spurious drifting over time. Both measurements were taken with the same settings, but with a time difference of 15 minutes.

The screenshot below shows a plot from a test house showing the concept of selective quasi-peak measurement. The orange graph shows the peak detector measurement with the blue markers at the frequencies, where the quasi-peak limits are violated. The red markers show the results of selectively re-measuring with the quasi-peak detector.

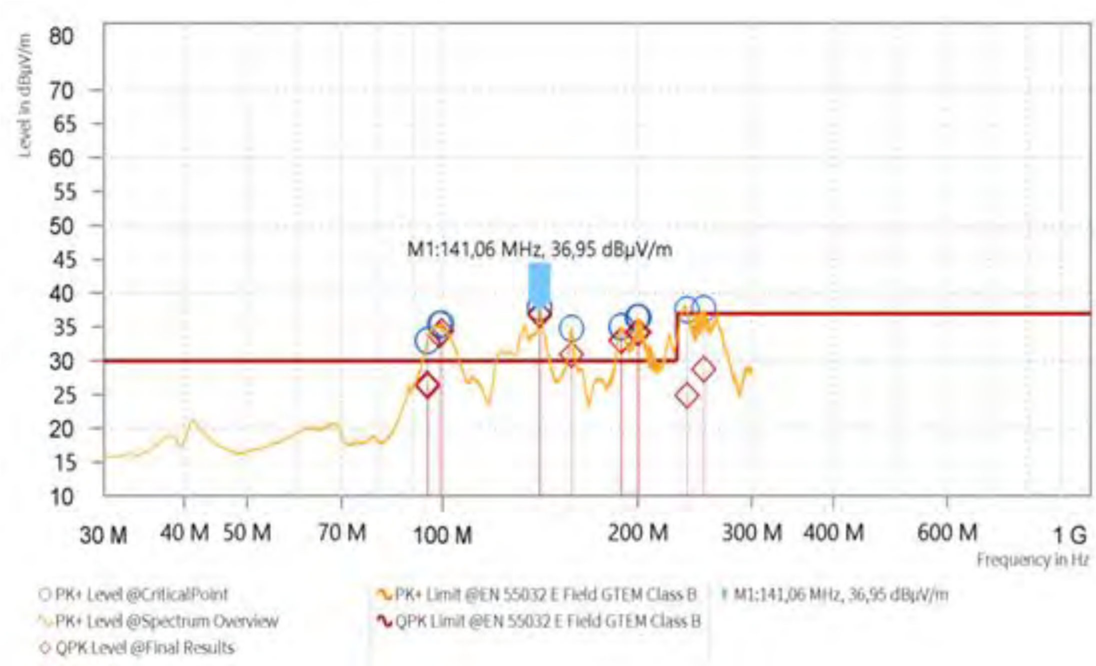


Figure 8: Example of a test house report showing selective QP scan.

4. Internal attenuator, pre-amplifier

When setting up the spectrum analyzer for any EMC measurement, careful choice of internal attenuator settings is essential.

The screenshot below shows the effect of the internal attenuator and pre-amplifier settings on the DANL of the spectrum analyzer.

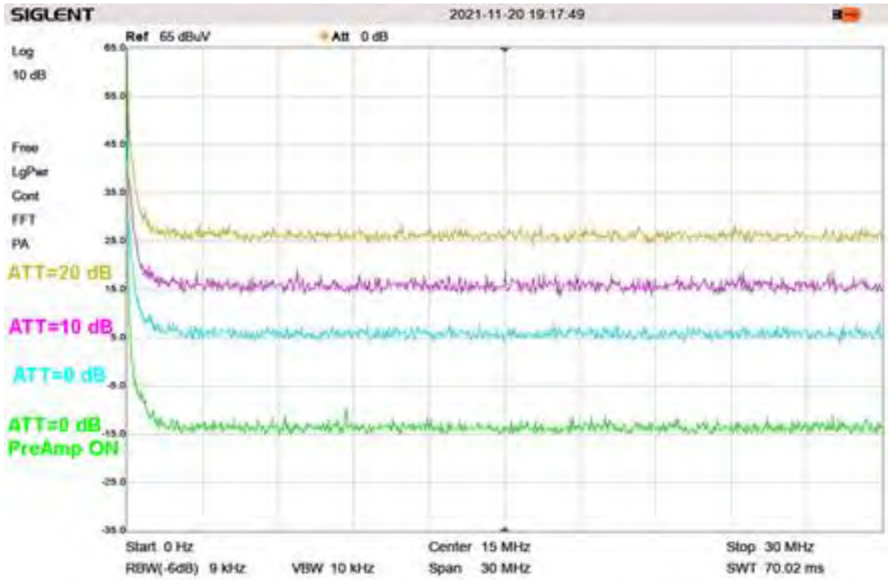


Figure 9: DANL versus internal attenuator / pre-amplifier settings. RF input terminated with 50 Ohm.

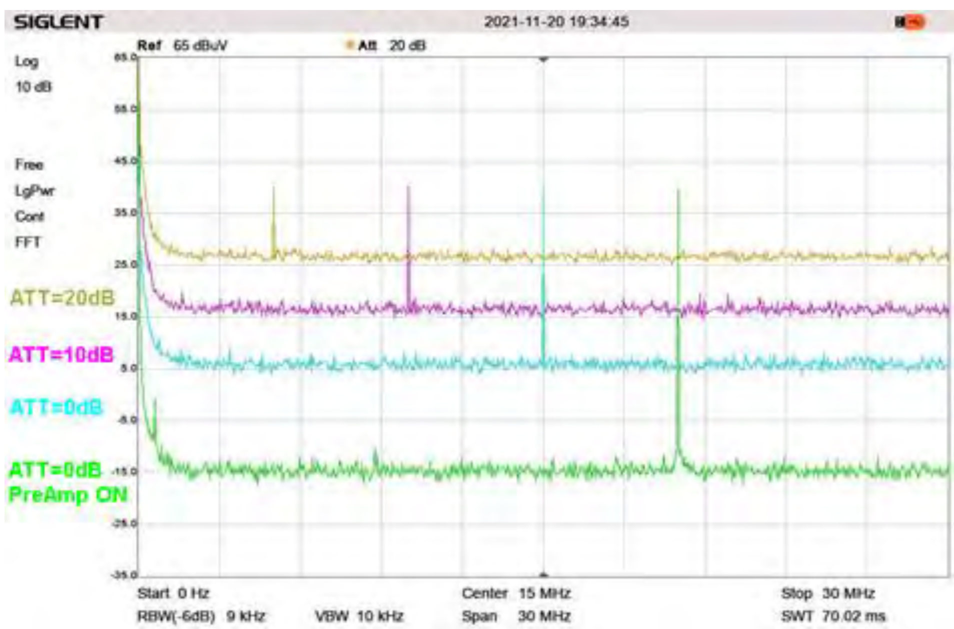


Figure 10: Power versus internal attenuator/pre-amplifier settings. RF input fed with CW signal; constant amplitude but shifted 5 MHz at each setting for better visibility.

When performing conducted emission testing, there is a high probability for high amplitude spurs. Choosing 0 dB attenuation and eventually turning on the pre-amplifier at the same time may cause intermodulation distortions and/or ADC saturation. Consequently, the default settings for most conducted emission tests in EMCview are 20 dB internal attenuation and pre-amplifier off. Some standards, however, such as CISPR 25 Class 5 conducted emissions, voltage method, have very low limit levels and require less internal attenuation.

Radiated emission measurements require very high sensitivity. Corresponding default EMCview project settings are typically 0 dB internal attenuation and pre-amplifier on.

CISPR 16 specifies that the base noise of the measurement setup has to be at least 6 dB below the limit lines in order to have sufficient dynamic range to reliably measure critical spurs.

5. Distortion considerations

The spectrum analyzer itself may produce distortion products, and potentially disturb measurements, if strong signals are applied to the RF input. As spectrum analyzers contain components with non-linear behavior such as mixers and amplifiers, they will always generate some distortion products.

This internal distortion can, at worst, completely cover up the distortions created by the Equipment Under Test (EUT).

The user needs to understand how distortion is related to the input signal, to determine for a particular measurement, whether or not the distortion caused by the analyzer, will affect the measurement.

The dominant non-linear distortions are second-order and third-order harmonics.

The second-order distortion increases as a square of the amplitude of the fundamental signal, and the third-order distortion increases as a cube.

When the fundamental power is *decreased* 1 dB, the second-order distortion *decreases* by 2 dB.

When the fundamental power is *decreased* 1 dB, the third-order distortion decreases 3 dB.

Using attenuators, it can be determined whether any spurious signals come from the signal source or whether they are generated by the spectrum analyzer.

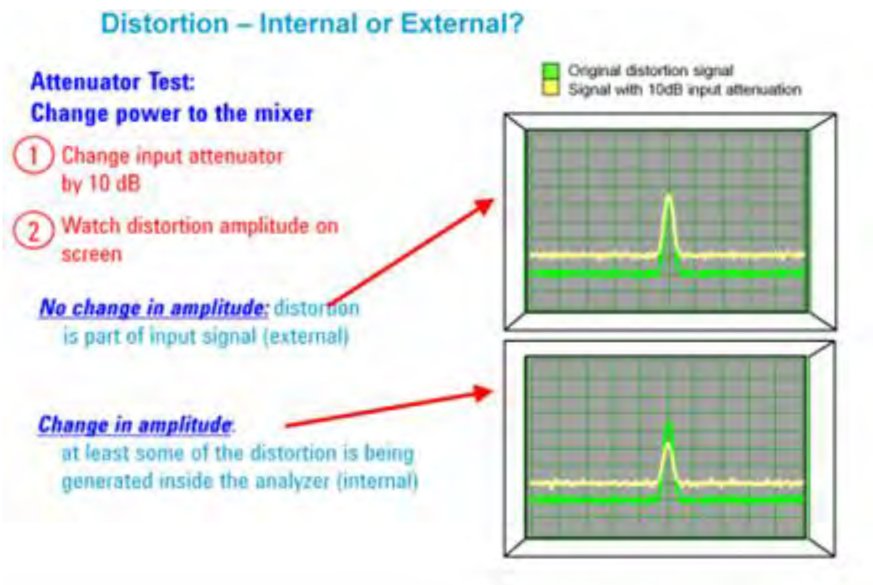


Figure 11: A technique to determine the source of distortion.

6. General sensitivity considerations

6.1 Conducted noise testing with LISN

When choosing the amplitude settings of the spectrum analyzer, compare the limit lines against the DANL of the analyzer. Figure 12 below shows that there is 80 dB of dynamic range between limit lines and DANL if the analyzer will be set to maximum sensitivity. On the other hand, CISPR 16 requires a minimum spacing of 6 dB between DANL and limit lines.

The analyzer settings should be modified to Att = 20 dB and PreAmp = OFF. This would raise the noise floor approximately 40 dB, but still leave 40 dB of dynamic range below the limit lines. The sensitivity is still more than sufficient and the risk of creating non-linear distortions or ADC saturation is significantly reduced.

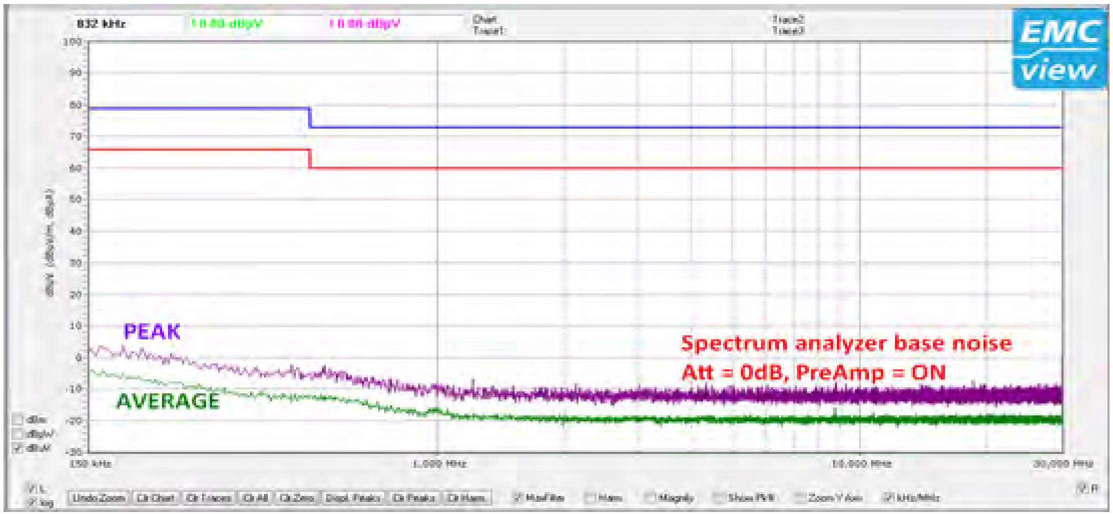


Figure 12: Example CISPR 32 Class A, conducted emissions, mains supply line.

Whenever choosing the analyzer settings, first have a look at the limit lines and then decide on the amplitude settings.

Most standards have the limits for conducted noise settings sufficiently high, to operate with at least 20 dB attenuation and without a pre-amplifier.

Exceptions are automotive standards such as CISPR 25 Class 5 or generic car manufacturer standards, which require higher sensitivity:

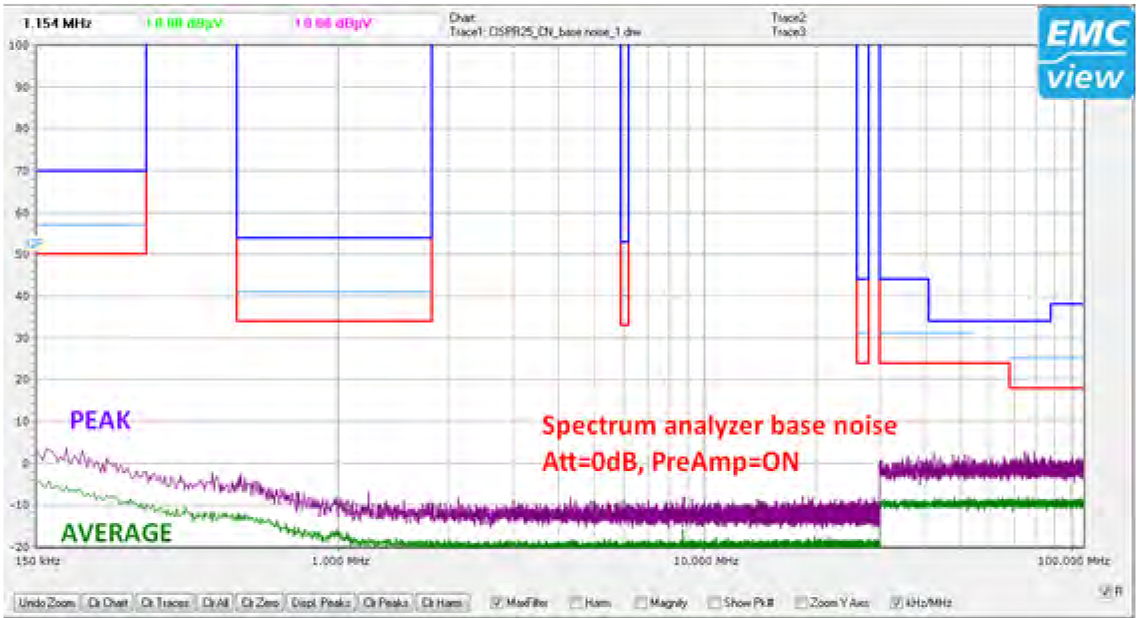


Figure 13: Example of CISPR 25 Class 5 conducted base noise level sweep.

In case of nonlinear distortion issues, the pre-amplifier could be turned off in order to leave sufficient dynamic range for the frequency range above 60 MHz.

6.2 Conducted noise testing with RF current probes

When performing conducted noise measurements with RF current monitoring probes, the trans-impedance value in dBΩ subtracted from the measurement value in dBµV gives the RF current in dBµA.

$$dB\mu A = dB\mu V - dB\Omega$$

In the case of an RF current monitoring probe with a trans-impedance of 0 dBΩ, the readings at the probe output in dBµV are equivalent to the RF current passing the probe cross-section in dBµA.

Figure 14 below shows the limits for a CISPR 25 Class 5 Current Method measurement. Note that the limits are given in dBµA.

The displayed trace corresponds to settings for maximum analyzer sensitivity: Att = 0dB, PreAmp = ON

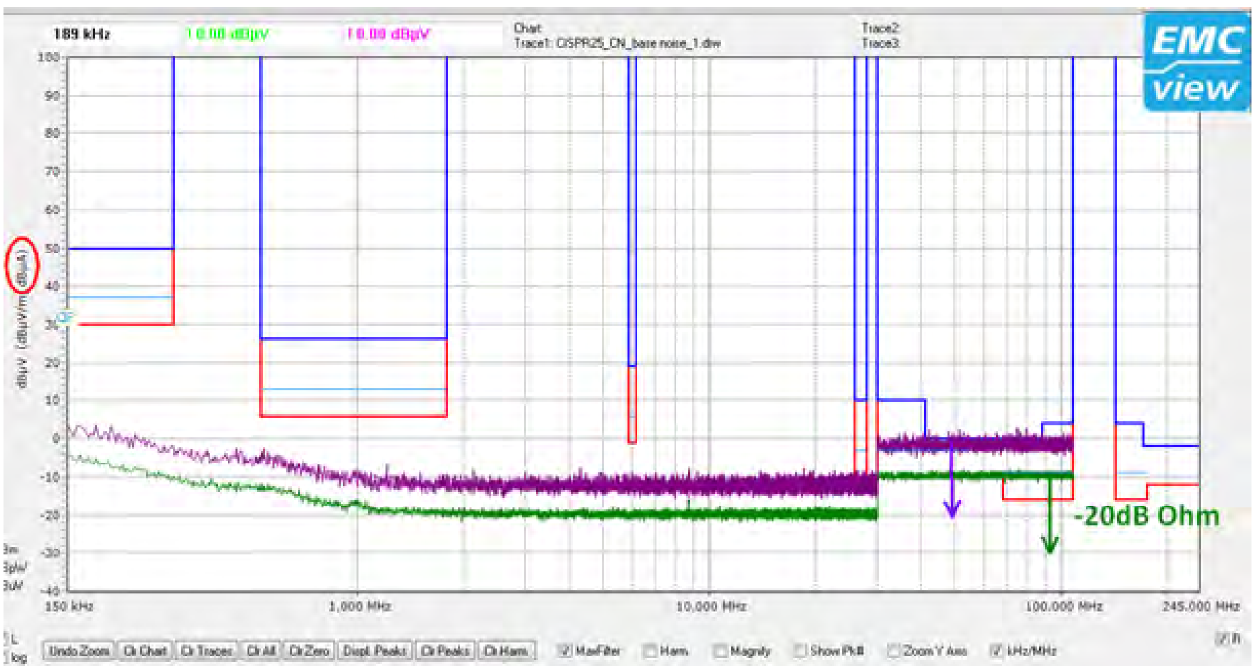


Figure 14: Example of CISPR 25 Class 5 Current Method.

If an RF current probe with a trans-impedance of 0 dBΩ would be used for this measurement, the base noise would collide with the limits above 25 MHz, even at maximum sensitivity settings.

In order to carry out a useful measurement, an RF current monitoring probe with a trans-impedance of at least 15 dBΩ to 20 dBΩ is required.

Figure 15 below shows the base noise of a CISPR 25 class 5 Current Method measurement, using a TBCP2-500 RF current monitoring probe from Tekbox with the spectrum analyzer internal attenuation set to 0 dB and the pre-amplifier turned on. This setup gives sufficient dynamic range to carry out a useful measurement:

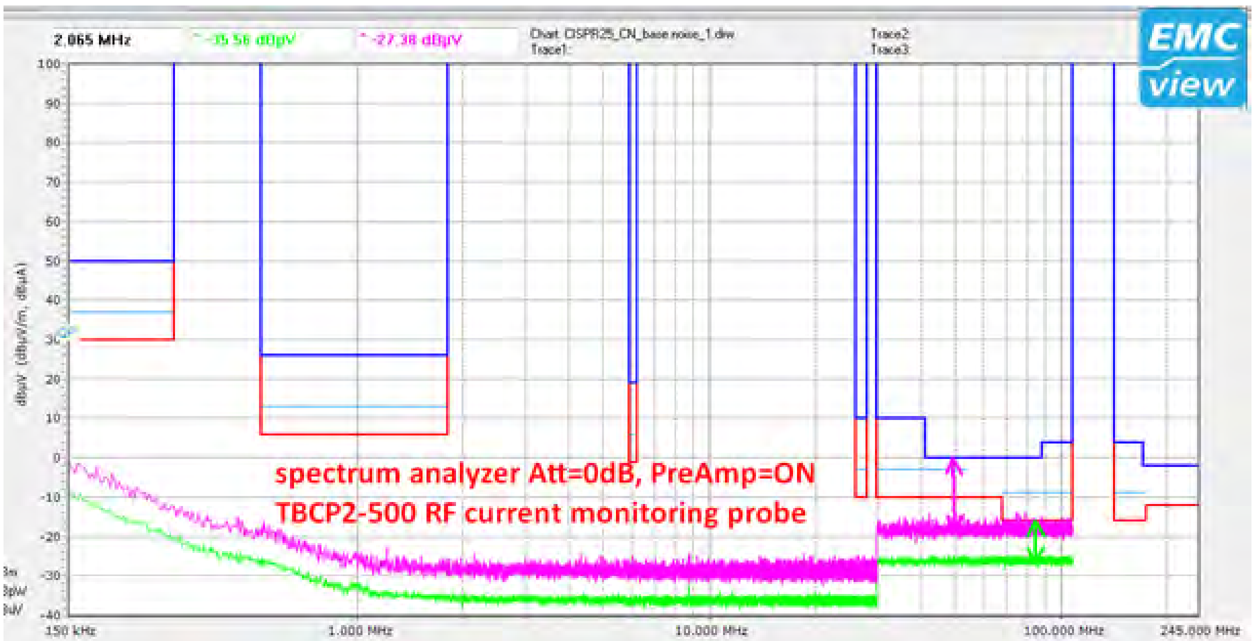


Figure 15: Example of CISPR 25 Class 5 Current Method with a Tekbox TBCP2-500 RF probe.

6.3 Radiated noise testing with TEM-cells

Transverse-Electromagnetic Cells (TEM Cells) are a stripline device for radiated emissions and immunity testing of electronic devices.

Radiated noise testing in TEM cells can be started with the analyzer sensitivity set to maximum. There is typically no big risk of overdriving or damaging the analyzer. In case of high amplitude emissions, the settings can be adjusted accordingly.

Figure 16 below shows the limits for CISPR 25 Class 5 TEM Cell versus spectrum analyzer base noise with the spectrum analyzer internal attenuation set to 0 dB and the pre-amplifier turned on.

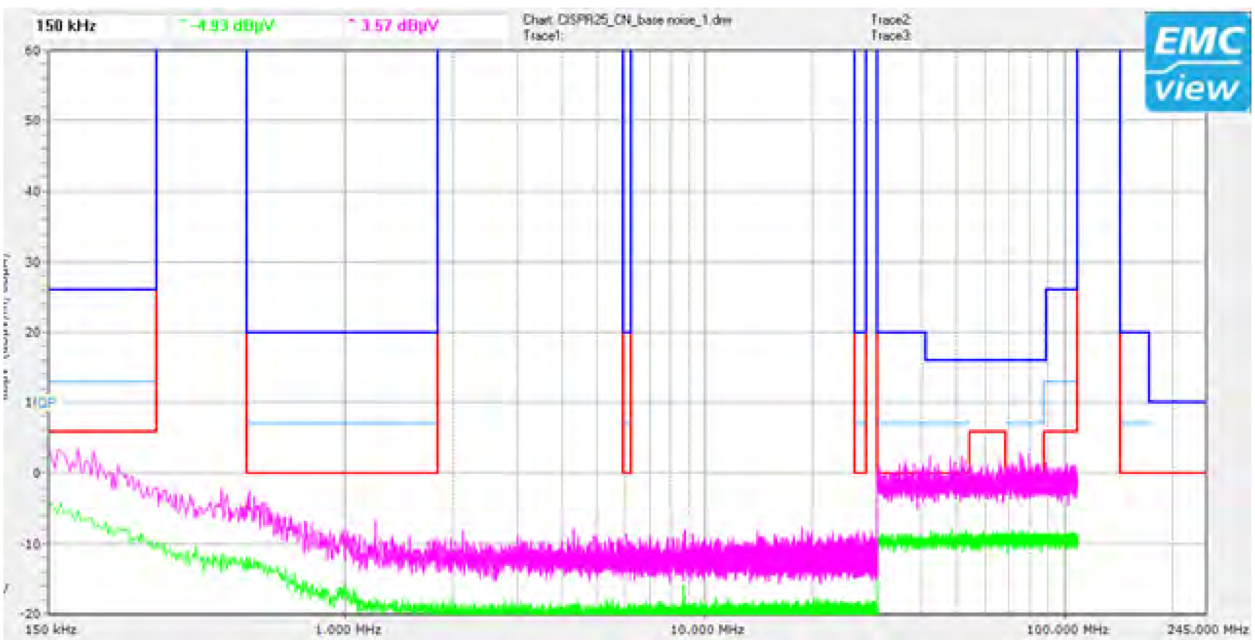


Figure 16: CISPR 25 Class 5 TEM example

6.4 Radiated noise testing with antennas

Radiated noise limits are given in dBV/m in most cases. In order to convert the measurement result from Voltage at 50 Ohm [dBµV] to field strength [dBµV/m], it is necessary to know the antenna characteristics versus frequency. Measurement antennas always come with an antenna factor table. The antenna factor needs to be added to the voltage displayed at the analyzer in order to obtain the field strength:

$$dB\mu V/m = dB\mu V + AF$$

Consequently, the antenna factor also adds to the base noise and reduces the dynamic range of the measurement.

EMC measurement antennas have typically a large bandwidth. The larger the bandwidth, the lower the gain and the higher the antenna factor.

Figure 17 below shows CISPR32 Class A radiated emission limits in dBµV/m for a measurement distance of 3 m.

The dark green graph shows the spectrum analyzer base noise in dBµV with the internal attenuation set to 0 dB and the pre-amplifier turned on.

The light blue graph shows the base noise in dBµV/m when used together with the 30 MHz – 1GHz TBMA1 biconical antenna from Tekbox.

The dark blue graph shows the base noise in dBµV/m when used together with the 30 MHz – 300MHz TBMA2 biconical antenna from Tekbox.

The light green graph shows the base noise in dBµV/m when used together with the 250 MHz – 1.3 GHz TBMA3 logarithmic periodic antenna from Tekbox.

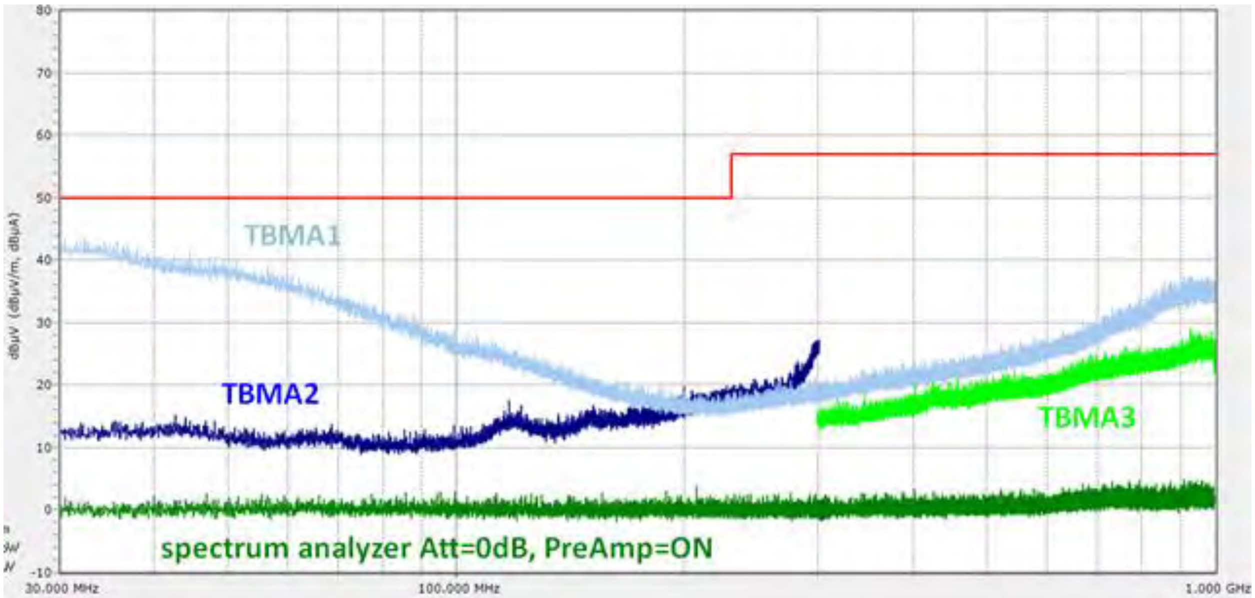


Figure 17: CISPR32 Class A radiated emissions for various antennas

Based on the above analysis of the base noise, there seems to be sufficient dynamic range for carrying out CISPR 32 Class A radiated noise measurements using the Siglent SSA3021X spectrum analyzer and any of the mentioned EMC measurement antennas from Tekbox.

However, the above graphs would only be realistic when carrying out the measurement in a shielded anechoic chamber. In reality, EMC pre-compliance radiated emission tests are often carried out in a non-shielded environment such as a development laboratory or an industrial site.

Figure 18 shows the output of the TBMA1 measurement antenna, in an industrial environment.

In the frequency range from 30 MHz to 100 MHz, the ambient noise already exceeds the CISPR 32 Class A radiated limits and severely handicaps the radiated noise measurement of any EUT. Even at higher frequencies, it will become very difficult to differentiate between ambient noise and noise originating from the EUT:

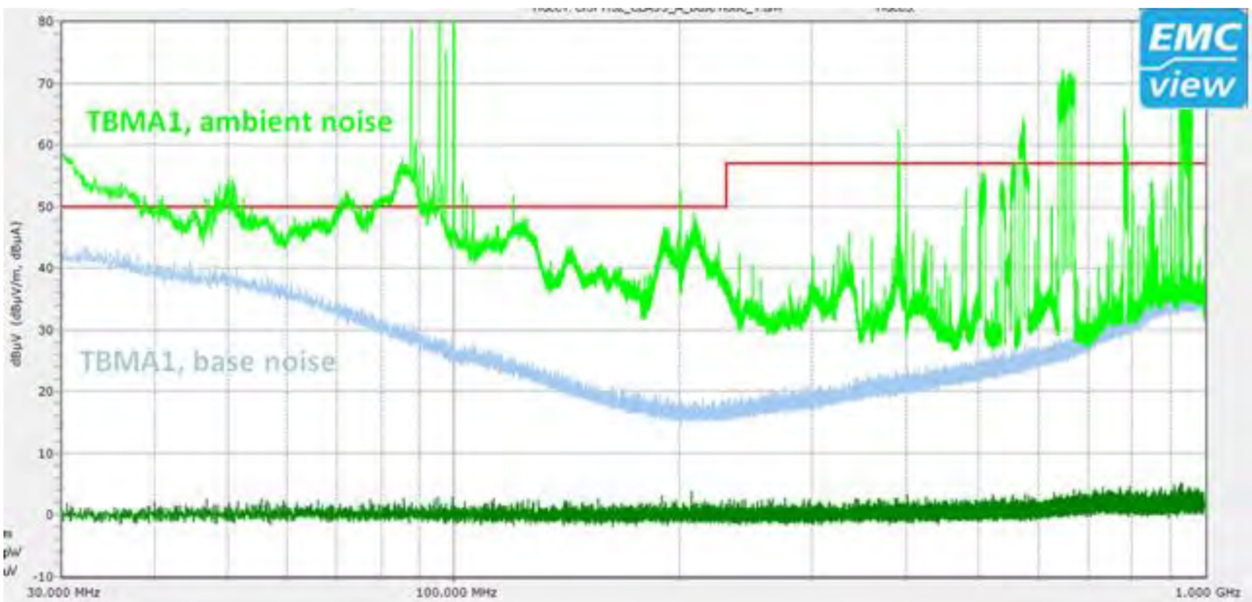


Figure 18: Example of ambient scan in an industrial environment

However, there are a few solutions to combat the ambient noise issue. Try to find a location with less ambient noise. A flat roof or a test site in a field are often less noisy than an industrial site. When measuring inside a lab, turn off all equipment nearby to eliminate noise from switched-mode power supplies.

Move the antenna closer to the EUT. Reducing the measurement distance from 3 m to 1 m is equivalent to approximately 10 dB less free space loss or lifting the limits 10 dB higher. However, consider that the antenna may move into the near field zone at lower frequencies.

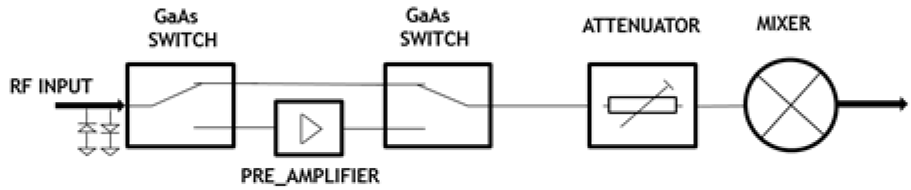
Use a lower bandwidth measurement antenna with lower antenna factors.

Measure your EUT inside a TEM cell to get a plot of the critical emissions. Knowing the frequencies of critical spurious, repeat the antenna measurement, but reduce span and RBW. Zoom in on critical frequencies, so to say.

Carry out the measurement at night, when there is typically less ambient noise.

7. Input protection

Whenever working with spectrum analyzers, be aware that excessive input power, voltage transients or ESD can destroy the RF-front end. Spectrum analyzers typically have a maximum CW input rating in the range of +20 dBm to +30 dBm. Unlike oscilloscopes, spectrum analyzer inputs are not protected or only slightly protected. A simplified RF front end is shown below:



The diodes at the input typically serve as ESD protection diodes. In order to fully protect the input with a limiter, shunt diodes would need to be combined with a series resistor to limit forward current in case of excessive input signal power. Consequently, a classic current limiting resistor solution cannot be implemented, as it would increase the input impedance of the analyzer.

A limiter could be implemented by combining it with an attenuator however, this would degrade the sensitivity of the analyzer and limit its use.

The first weak link of the input chain is the RF switch. Typical EMI spectrum analyzers use integrated GaAs switches. GaAs switches are inherently weak at low frequencies. Many GaAs switches are not even specified with respect to maximum input power at low frequencies, down to 9 kHz.

Below is an example of an "honest" data sheet of a typical GaAs switch:

HMC221B

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Control Voltage Range (A and B)	−0.2 V dc to 12 V dc
RF Input Power Level (CW Peak, V_{CTL} = 0 V/5 V)	0.36 W
10 kHz to 10 MHz	8 dBm
10 MHz to 20 MHz	10 dBm
20 MHz to 30 MHz	11 dBm
30 MHz to 250 MHz	14 dBm
250 MHz to 3.0 GHz	31 dBm
Hot Switching RF Input Power Level (CW Peak, V_{CTL} = 0 V/5 V)	
10 kHz to 250 MHz	6 dBm
250 MHz to 3.0 GHz	20 dBm

The maximum RF input power ratings versus frequency clearly show the degradation at low frequencies.

When carrying out conducted noise tests of switched-mode power supplies, the highest spurious levels occur at relatively low frequencies. Sub-harmonics are even more critical. These are typically at frequencies significantly below 100 kHz and often go completely unnoticed, as most tests start at 150 kHz. You may carry out a conducted noise test and wonder, why the analyzer beeps and displays an ADC overflow warning, despite all spurious being well below limits. What drives the attenuator into saturation may be a very high amplitude sub-harmonic at 6 kHz.

In the case that you notice that your signals are in the range of 20 dB lower than what they actually are, disaster already happened. The first GaAs switch is already damaged. In most cases, it fails with a short on the RF path and protects the following components, but in extreme cases, the damage will reach as far as the first mixer.

In order to prevent damage, you always should start investigating any new EUT using external attenuators or a combined attenuator/limiter, both also available from Tekbox. With an external 20 dB attenuator or limiter attached to the analyzer input, have a look at the spectrum at very low frequencies and ensure that there are no signals with critically high amplitude.

Alternatively, you can first connect an oscilloscope to the LISN RF output and check the EUT emissions in the time domain. In order to establish the same impedance level as with a connected spectrum analyzer, terminate the oscilloscope input with a 50 Ohm feedthrough or switch the input to 50 Ohm, if the scope offers this feature.

Here are some guidelines when performing conducted emission measurements with a LISN:

- Leave the RF output of the LISN unconnected
- Connect the EUT to the LISN
- Connect the LISN to the isolation transformer
- Power on the EUT

- Check the RF output of the LISN using a scope and/or the analyzer with an external 20 dB attenuator or combined attenuator/limiter
- Connect the RF cable from LISN output to the spectrum analyzer input
- Carry out the conducted noise scan
- Disconnect the RF cable
- Power off the EUT

NOTE: The purpose of having the analyzer disconnected during power cycling (ON/OFF) the EUT is to avoid voltage transients due to back EMF, especially of highly inductive loads such as motors or switched-mode power supplies. These signals can easily be large and fast enough to cause permanent damage to the sensitive RF front end of the analyzer.

In cases where the EUT produces subharmonics, place a suitable highpass filter at the RF input of the spectrum analyzer. The Tekbox TBFL1 transient limiter not only contains a combined attenuator/limiter, but also a 9 kHz highpass filter. If the subharmonic frequency is above 9 kHz, connect a 150 kHz highpass.

EMI Pre-Compliance Probes & Troubleshooting

Electromagnetic interference (EMI) can cause a host of problems, especially when developing a product or attempting to pass mandatory electromagnetic compliance (EMC) tests. Garbled displays, bad data, or complete malfunctions can occur when a design is affected by EMI. To minimize the effects of interference, government agencies like the Federal Communications Commission (FCC) in North America create and enforce standards that set limits on the EM output of a product type. Testing to the specifications is commonly referred to as Electromagnetic Compliance (EMC) testing.

Many EMC test failures stem from the interaction of unintentional radio frequency (RF) emissions with a circuit or element within the design itself. The electric and magnetic fields that cause this interference are not visible to the unaided eye, which can present complications when trying to isolate the root cause and minimize the effects of the EMI.

- What is causing the issue?
- Where is the source of the signal or energy causing the radiation?
- How can I fix it?

Fortunately, there are simple tools and techniques that can help identify the sources of EMI. Once you can identify the source, you can begin to build up a list of solutions to the problems. These techniques are not part of the mandatory compliance tests required to pass EMC testing. Rather, these are pre-compliance test techniques that help identify potential areas of EMI as quickly as possible without the burden of expensive test equipment and setups.

In this application note, we are going to introduce some common pre-compliance test techniques for identifying potential problematic EMI sources using near-field and current probes. These techniques can save you time and money by isolating problem areas quickly, and with a little fixturing, you can create repeatable test stations to help correlate data. This knowledge can then be used to “design for EMC” in your future products.

NOTE: Pre-compliance tests are designed to help identify and resolve issues that may hinder passing full compliance tests. Pre-compliance testing is not a replacement for full compliance testing at a certified lab.

ELECTROMAGNETIC RADIATION BASICS

In electronics, EM radiation is most commonly caused by a current flow or voltage buildup along or through a conductor. This includes traces on a PC board, discrete wires, component leads/pins, connectors, or any other metal, including the chassis, rack, or product enclosure. Recall that EM radiation is actually a combination of electric and magnetic field components. It is described as the propagation of orthogonal time-varying electric and magnetic fields as shown in **figure 1**.

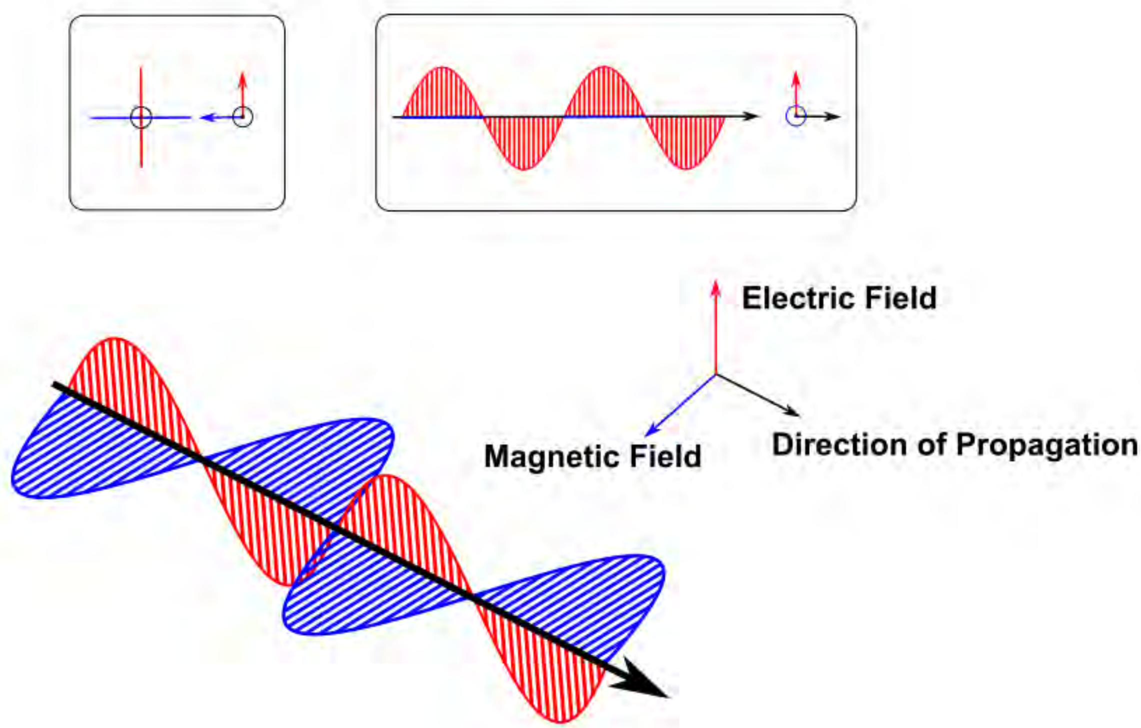


Figure 1: Electromagnetic wave propagation out of the page (top left), to the right (top right) and out of the page at an angle. Note that the E and H fields are orthogonal (90°) to one another.

While the electric (E) and magnetic (H) fields are created by the same phenomena, they physically behave quite differently in the environment. Magnetic fields are only created by moving charges (current). In most circuits, current is conducted by traces on the PC board, component pins/leas, and discrete wires. Therefore, the magnetic field tends to dominate the EM radiation produced by the traces and wires that route signals and power to different parts of the design.

Visualizing the magnetic field can be a bit easier if you go back to your Physics texts. Recall that the magnetic field of an infinitely long straight wire can be calculated by applying Ampere's law:

$$\oint_{\mathrm{loop}} \mathrm{B} \cdot \mathrm{dl} = \mu_0 \mathrm{I}$$

For a circular path centered on the wire, the summation becomes:

$$\mathrm{B} = \mu_0 \mathrm{I} / 2\pi \mathrm{r}$$

Where:

B is the magnetic field

μ_0 is the permeability of free space (a constant)

I is the current

r is the distance from the center of the conductor

Figure 2 is a physical representation of this relationship. Note, this is also described by the "right-hand-rule" wherein if you were to point the thumb of your right hand in the direction of the current flow, then the magnetic field lines form concentric rings that wrap around the conductor in the direction of your fingers.

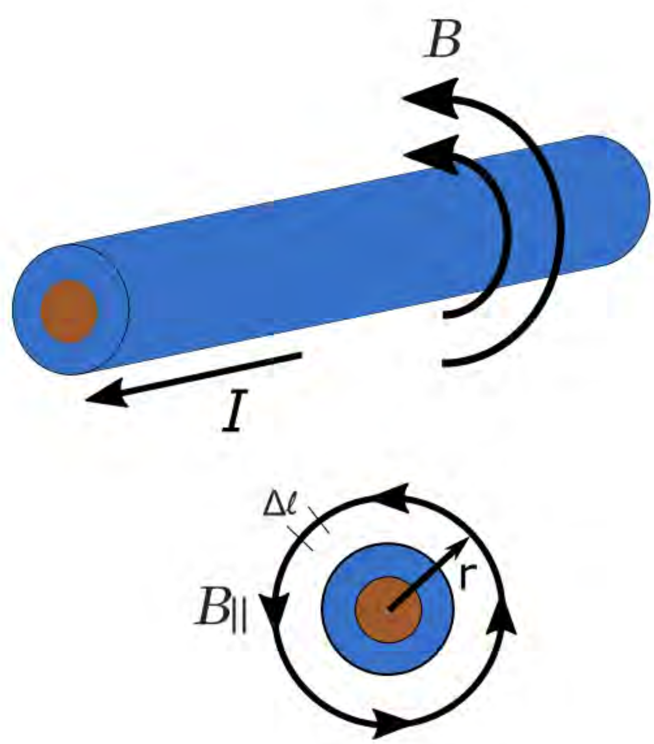


Figure 2: Magnetic field produced by a current

Unlike the magnetic field, electric fields can be created by moving or static charges. In this way, electric field effects dominate over magnetic fields when searching for EM radiation on surfaces like heatsinks or metal enclosures. The effects of the electric field also tend to dominate further away from the source (far-field). Far-field measurements are more susceptible to error due to environmental factors like radio stations, WiFi, and intentional RF. Far-field measurements, like those performed during radiated emissions portion of a compliance test, require more setup, equipment, and expertise than near-field.

By measuring the amplitude and frequency of the magnetic and electric fields that are generated by elements of a product, we can identify the areas that have the highest potential to cause EMI issues.

EQUIPMENT LIST

Here are the basic requirements for a near-field troubleshooting kit:

Spectrum Analyzer/EMI Receiver: Measures RF power with respect to frequency. The analyzer should have a maximum frequency of at least 1 GHz, DANL of -100 dBm (-40 dBuV) or less, and a minimum RBW of at least 10 kHz.

Figure 3: SSA5000A Spectrum Analyzer

Near-field probes: Commercial or handmade. Many are magnetic (H) field probes, but there are also electric (E) field probes as well.

Current probes: Commercial or handmade.

50 Ohm cable: Use a cable with connectors that mate to the near-field probes and the RF input of the spectrum analyzer. Many commercial probes can be purchased with a cable and any adapters that may be required.

PROBES

Since EMI cannot directly be observed by the human eye, we need some tools to help. Recall that moving charges in a conductor produce magnetic and electric fields that radiate throughout space from the conductor. We can use these fields to induce a voltage in a circuit. Then, measure that induced voltage and therefore indirectly measuring the strength of the original field. The two most common types of probes used in EMI troubleshooting are near-field probes and current clamps.

Magnetic field probes and current clamps operate on a similar principle. The magnetic field that flows through the "loop" area of the probe induces a voltage that can be measured (figure 4).

Larger loop areas pick up more magnetic flux, and are therefore better suited to finding smaller signals, but smaller loops offer better spatial resolution. Many kits come with multiple loop sizes (figure 5) to help strike the balance between sensitivity and spatial resolution.

Electric field probes do not generally have a loop area. They pick up the electric field similar to a monopole antenna. The rotation of an electric field probe is not critical as with the magnetic field probe, but the distance from the signal source is.
Here are some guidelines for probing:

- Measure the background radiation by powering off the device-under-test and monitor the analyzer display. Note any RF that may be caused by background or environmental conditions and retest often.
- Probe displays, communications port terminals, and any cutout/air vent/seam of the enclosure. These are common problem areas.
- E and H field probes positioned closer to the signal source will measure higher amplitudes
- H field probes oriented perpendicular to the magnetic field will measure higher amplitudes than those oriented parallel to the magnetic field.
- Since probe positioning is critical to repeatable measurements, a non-conductive fixture (wood, plastic) to position the device-under-

test (DUT) and the probe can be used. Remember, position and orientation are very important. A few millimeters or a few degrees of rotation can cause a big difference in the measured amplitude of a given magnetic field.

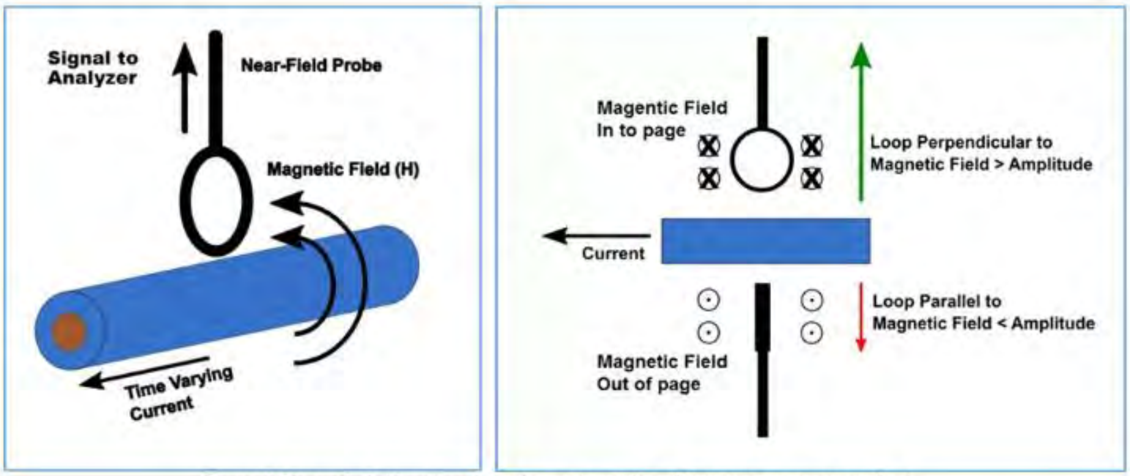


Figure 4: Magnetic field probe orientation and position affect measurement amplitude.

Figure 5: SIGLENT SRF5030 near-field probe kit.

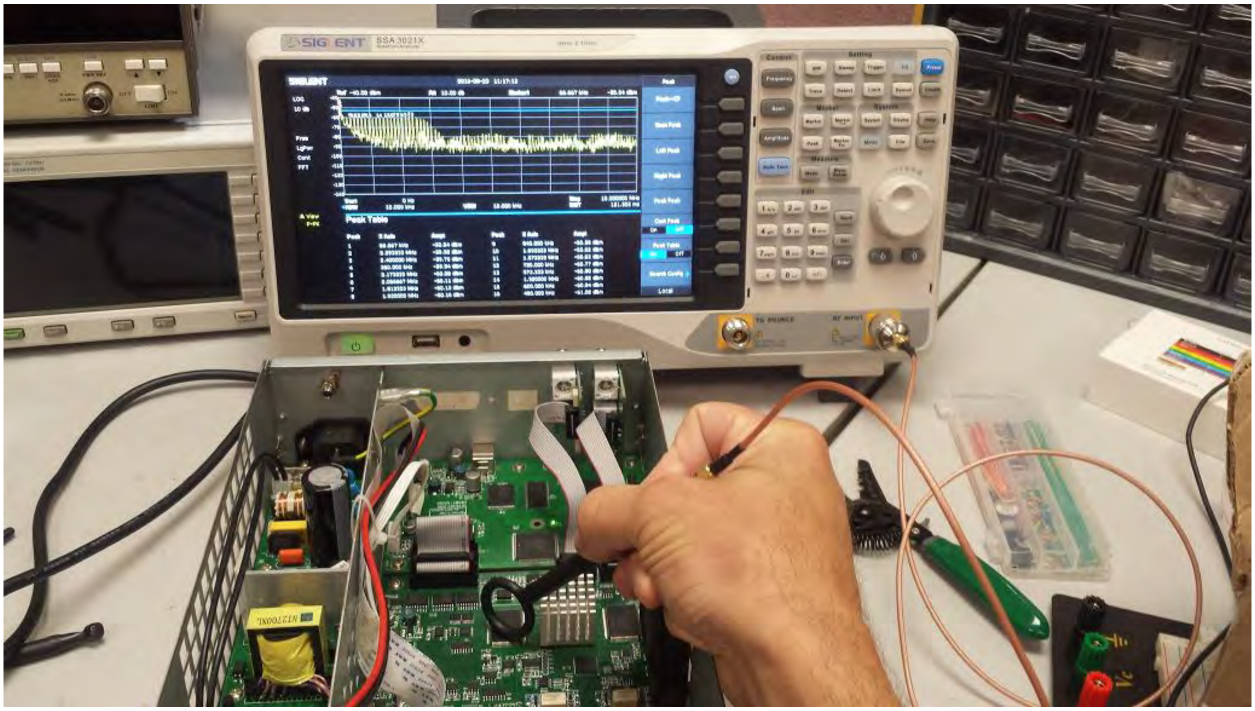


Figure 6: Probing a PCB using a SIGLENT SSA3X and SRF5030 probe.

Cables and interconnects can make very effective (and unintentional) antennas if they are not shielded/grounded correctly. Small currents flowing on the outside of the conductor can easily cause radiated emissions that can exceed the set EMC limits. A current clamp can be used with a spectrum analyzer to provide insight into the cause of radiating cables/interconnects.

Current clamps operate on the same principle as magnetic loop probes. They can be purchased or made by wrapping a few rounds of wire around a ferrite clamp and epoxy a BNC connector as shown in figure 7. Simply attach the clamp to the cable to be tested, connect it to the spectrum analyzer input, and configure the analyzer for the frequency span of interest.

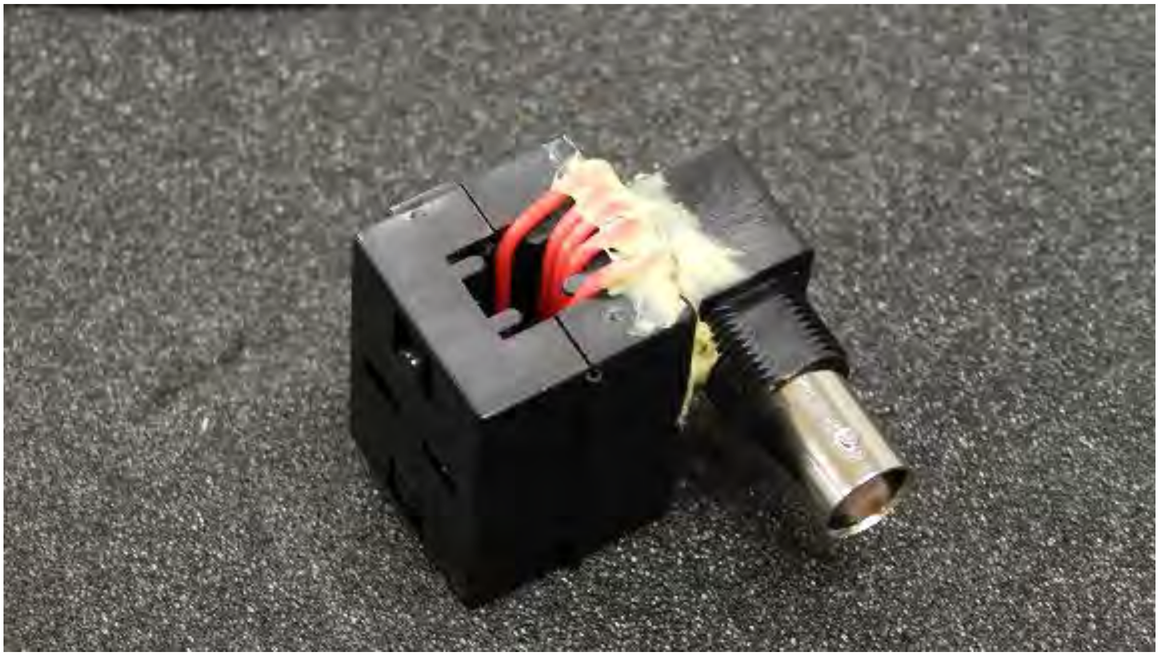


Figure 7: A handmade current clamp

Here are some guidelines for probing:

- If in doubt, add an external attenuator to the RF input of the analyzer before you start. Power cables or expected high-power applications can have signals that will damage the sensitive RF input of the analyzer.
- Test all of the cables that could be connected to the DUT. This includes the power cord, USB, Ethernet, and any other possible connections (figure 8)

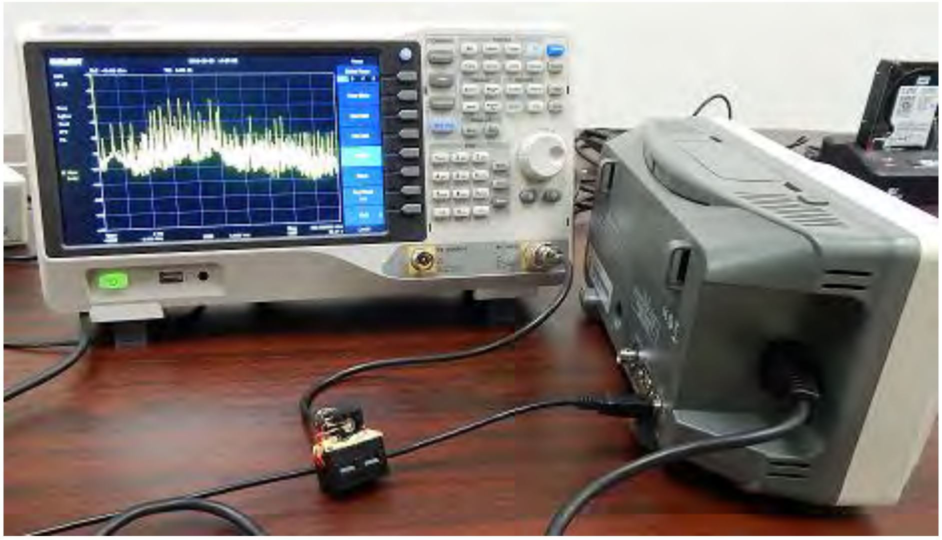


Figure 8: Measuring the RFI of a USB cable connected to a scope.

- Current clamps, especially handmade, are susceptible to picking up environmental RF that can skew or overwhelm the signals that you wish to measure. Connect and arrange all cables, probes, etc.. and then measure the environmental RF by simply keeping the DUT powered OFF. Then, compare it to measurements made with the DUT ON. It may also be a good idea to retest periodically to account for any environmental changes.

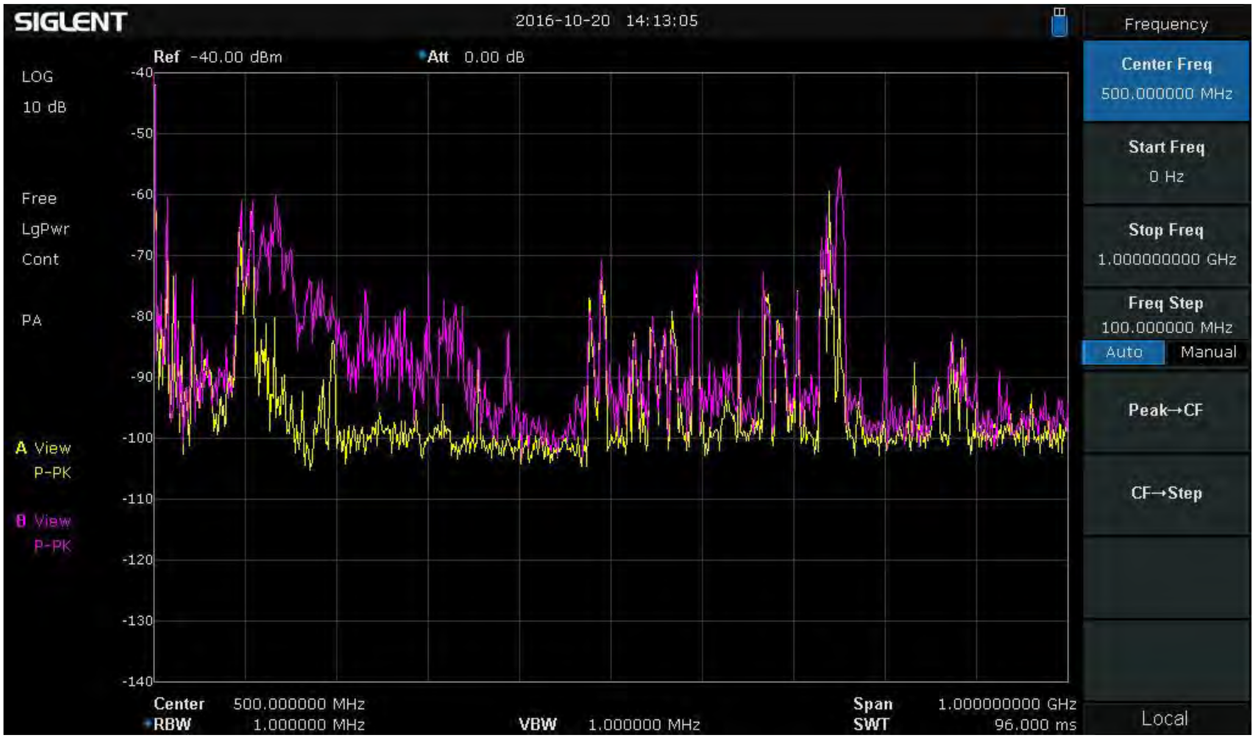


Figure 9: Traces of the environmental pickup from a current clamp (Yellow) and with the DUT powered ON (Pink).

- If you have a failed radiated emissions report, start by looking for the failed frequencies or for the first few harmonics of those frequencies.

SCANS AND EVALUATION

It is highly unlikely that data collected during probing will directly correlate to radiated emissions test performance. But, by observing the RF output of cables, switching power supplies, displays, and cutouts, you can have information that can lead to faster troubleshooting if you do happen to fail.

Here are optional techniques that can help provide more insight:

1. Most spectrum analyzers do not have pre-selection filters. If you are using a spectrum analyzer without pre-selection filters, the peaks you observe may not be real. Analyzers without pre-selection filters can create false peaks due to out-of-band signals mixing with the observed signals.

You can test the validity of a peak by adding an external attenuator (3 or 10dB should do). Real peaks will fall by the amount of the attenuator. If the peak falls by more than the attenuator, it is likely to be a false peak. Make a note of the false peaks for comparison with your compliance test results. You can also use pre-selection filters or an EMI receiver, but these tend to be cost prohibitive for most quick testing.

Figure 10 below shows a typical peak confirmation test. The yellow trace was collected without an attenuator. The Pink trace was collected with a 10 dB attenuator added to the RF input of the analyzer. In this case, the peaks drop the same amount as the added attenuation. This helps affirm that the peaks are likely real and not products of out-of-band signals.

Figure 10: Comparison of two scans using the marker table function of the SIGLENT SSA3000X spectrum analyzer. The Yellow trace was collected without attenuation while the Pink trace was collected after adding a 10 dB external attenuator.

2. Many spectrum analyzers have Max Hold trace types that will continuously hold the highest amplitudes of each frequency scan. You can enable a single trace as Clear Write to show active RF performance and enable a second trace as Max Hold. This allows you to compare changes in the DUT to the “worst case” data collected and “frozen” using Max Hold.

3. You can use markers and peak tables to clearly indicate peak frequencies and amplitudes, if available.

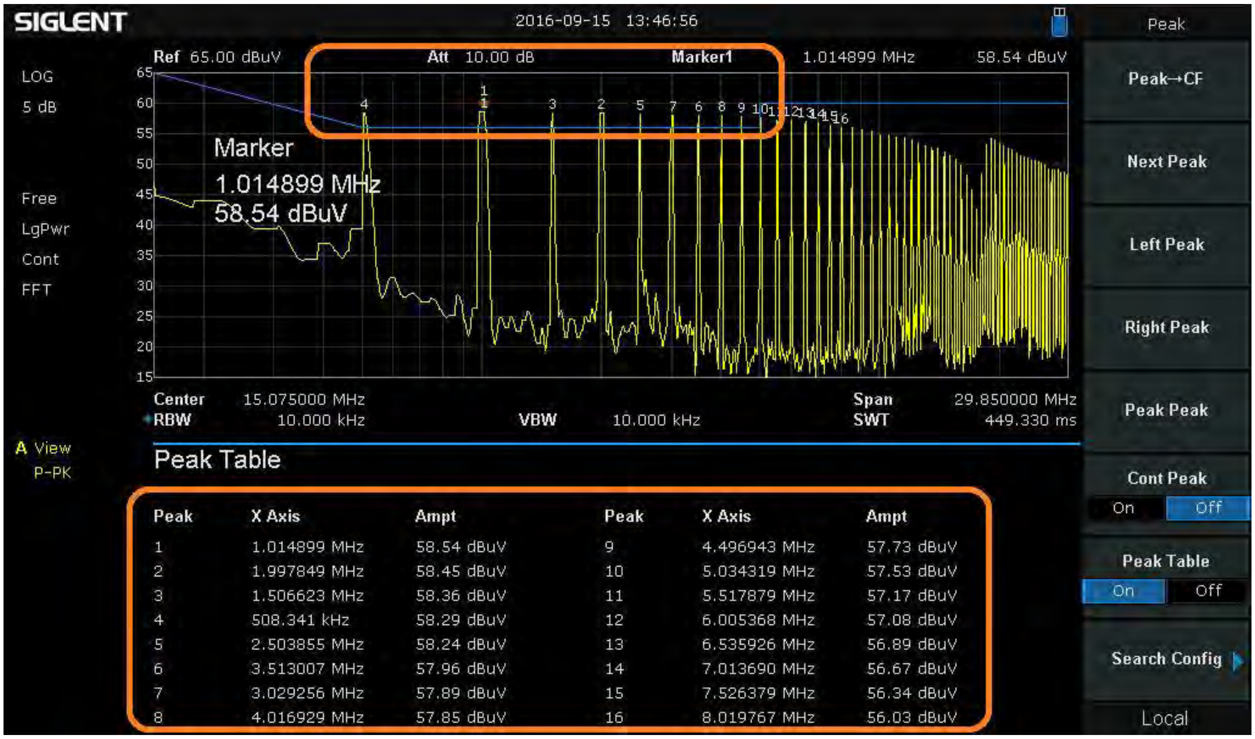


Figure 11: SSA3000X analyzer with Peak table and markers activated.

CONCLUSION

- Magnetic fields are produced by current flow. Use a magnetic (H) near-field probe to identify EM radiation near traces, wires, and ribbon/flex cables.
- Electric fields can be produced by current flow or static charge build up. Use an electric (E) near-field probe to identify EM radiation on metal surfaces like heat-sinks, enclosures, display bonding/edges, and slots/cutouts.
- Use current clamps to identify potential radiation and resonance from cables, wires, and interconnects

- Displays, cutouts/holes/seams in the chassis, ribbon cables, and communications ports/busses are the most likely cause of radiated emission failures.
- Use conductive tape or aluminum foil to cover areas of “leakage”, making sure that the covering is grounded. Rescan with the tape/foil in place to see if it has mitigated the EMI.
- Poorly terminated cables and interconnects also cause radiated issues
- Frequently measure the background effects by removing power from the device-under-test and monitor the output on an analyzer. Note any changes and their potential effects on the measurements.

With a few simple tools, you can implement an in-house pre-compliance test process that will minimize the total development time for your products, lower the cost of design, and decrease the amount of testing on future products.

EMI Pre-Compliance Conducted Emissions Testing

Conducted emissions testing involves measuring the RF energy that originates in the product and propagates along any interconnecting cables, such as power, signal, or data. Most standards focus on measuring the energy on Mains AC power lines. This is important because excessive RF on cables can cause excessive interference, especially with AM radio and other broadcast bands.

Conducted emissions testing requires a spectrum analyzer (figure 1), two bonded metal plates that function as ground planes, and a Line-Impedance-Stabilization-Network (LISN). The LISN supplies power to the device-under-test (DUT) and diverts the RF from the DUT to the spectrum analyzer, where it can be measured. Additional transient protection and attenuation can be added to help minimize the risk of damage to the sensitive RF input of the analyzer. A typical conducted emissions setup is shown in figure 2.

Figure 1: SSA5000A Spectrum Analyzer

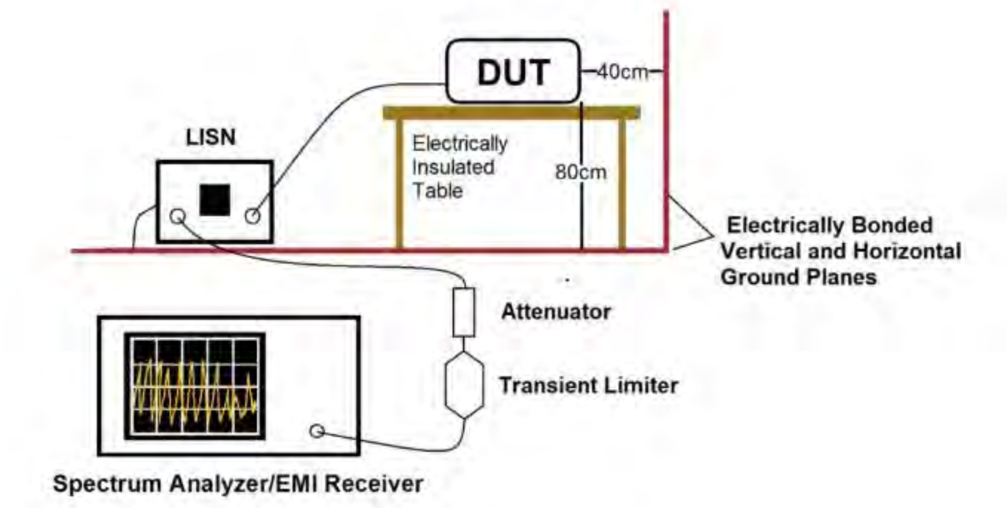


Figure 2: Typical conducted emissions compliance configuration. A transient limiter and attenuator are recommended to protect the input of the analyzer.

The cost for emulating a fully compliant conducted emissions test setup is relatively low and the setup is generally not susceptible to environmental RF. This makes correlating pre-compliance data to expected compliance performance significantly easier than with radiated emissions.

EQUIPMENT LIST

Spectrum Analyzer/EMI Receiver: Measures RF power with respect to frequency. The analyzer should have a maximum frequency of at least 1 GHz, DANL of -100dBm (-40 dBuV) or less, and a minimum RBW of at least 10 kHz.

Transient Limiter (Optional): Limits potential damage to sensitive RF input of analyzer

Attenuator (Optional): Have a few 3 dB and 10 dB attenuators on-hand to help protect the RF input of the analyzer from unexpected high power signals.

LISN: Diverts conducted radiation from DUT to spectrum analyzer/EMI receiver. Select a LISN that matches the test standards and electrical requirements for your DUT.

WARNING! Read your LISN owner's manual thoroughly. Some designs can have potentially hazardous voltages present and may require special instructions for safe operation.

Horizontal Ground plane: Conductive metal sheet sized approximately 15 cm (7") wider than the outer perimeter of the DUT plus 40 cm (15") in length to accommodate the spacing from the DUT to the vertical ground plane.

Vertical Ground plane: Conductive metal sheet sized approximately 15 cm (7") wider than the outer perimeter of the DUT plus 80 cm (30") in length to accommodate the spacing from the DUT to Horizontal ground plane. The ground planes should be electrically bonded to one another using a low impedance connection like conductive tape along the butt joint where the two planes meet.

LISN Bonding tab: Short metal conductive sheet to electrically bond/ground LISN to horizontal ground plane. A low impedance, perhaps a thin metal strap, would be preferred. Wire is not ideal.

Non-conductive table: Slightly larger than DUT. Can be wood, fiberglass, plastic. Not metal.

PHYSICAL SETUP

- Place the DUT in the center of a non-conductive table
- Place the horizontal ground plane 80 cm (30") and center just below the DUT
- Place the vertical ground plane 40 cm (15") behind and centered with the DUT. Electrically bond to the horizontal ground plane
- Electrically bond the LISN to the horizontal ground plane using the LISN bonding strap
- Place the spectrum analyzer/EMI receiver a few feet from the edge of the horizontal ground plane/test area and connect it to a power source

BACKGROUND CHECK

- Warm up the analyzer per the manufacturer's recommendations
- Power on the LISN, but do not connect the DUT at this time
- Connect the LISN RF output to the RF Input of the analyzer, including the transient limiter and a 3 or 10 dB external attenuator
- Configure the analyzer
    - Set the start frequency to 150 kHz
    - Set the stop frequency to 30 MHz
    - Set the RBW to 1 MHz
    - Set the detector to Positive Peak
    - Enter the LISN correction data into the analyzer and enable the corrections function to ensure the accuracy of the measurements
    - Many analyzers have provisions for creating limit lines. If available, you can add the specific limit line of interest to the analyzer. This eases evaluation by visibly showing the limit that you are testing against.
    - (Optional) If you are using a transient limiter, enter it's correction data into the analyzer and enable the corrections function to ensure the accuracy of the measurements.

    - (Optional) If you are using an external attenuator, enter its correction data into the analyzer and enable the corrections function to ensure the accuracy of the measurements.
    - (Optional) Many EMC standards limits are defined in the units dBuV vs. Log frequency. Most analyzers allow you to set the units to dBuV and the horizontal scale to logarithmic on the display.
- With no input connections, observe the trace on the analyzer. It should be smooth and very low in power. You can also lower the RBW to 10 kHz or the closest setting to it. These scans represent the open port noise floor of the instrument.

It is worthwhile to save these as a picture or image file to reference later. Figure 3 below shows the open port noise levels of a SIGLENT SSA3032X spectrum analyzer configured as suggested above:

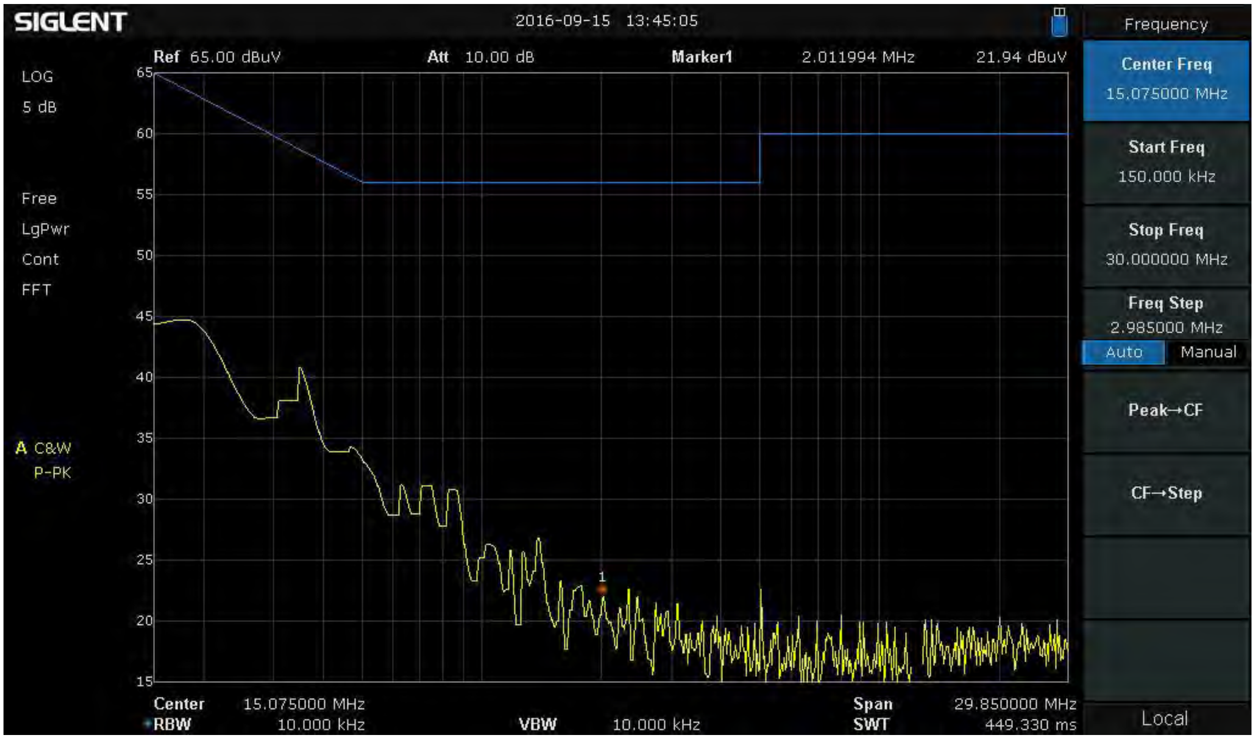


Figure 3: Open port noise floor of an SSA3032X spectrum analyzer. Note the dBuV amplitude units, log frequency scaling, and blue limit line. These features make scan evaluation more convenient.

FIRST SCAN

- Disconnect the LISN output from the analyzer input
- Connect the power cord from the DUT to the LISN. Do not coil the power cable. Make sure it lies flat and does not run between the DUT and the horizontal ground plane.
- Power on the DUT

- Re-connect the LISN RF Output to the Spectrum Analyzer RF input. NOTE: These steps add another layer of protection to the sensitive analyzer front-end. Some LISNs include features that can minimize these transients and in such cases, these steps can be considered optional.
- Observe the scan and note any peaks that are within 3dB or exceed the limit line. These are potential problem areas. NOTE: It is a good idea to capture a copy of the display either using a camera or a screen capture/print along with details notes of the experimental setup, instrument settings, and any DUT information.

Figure 4 below shows a peak scan with failures.

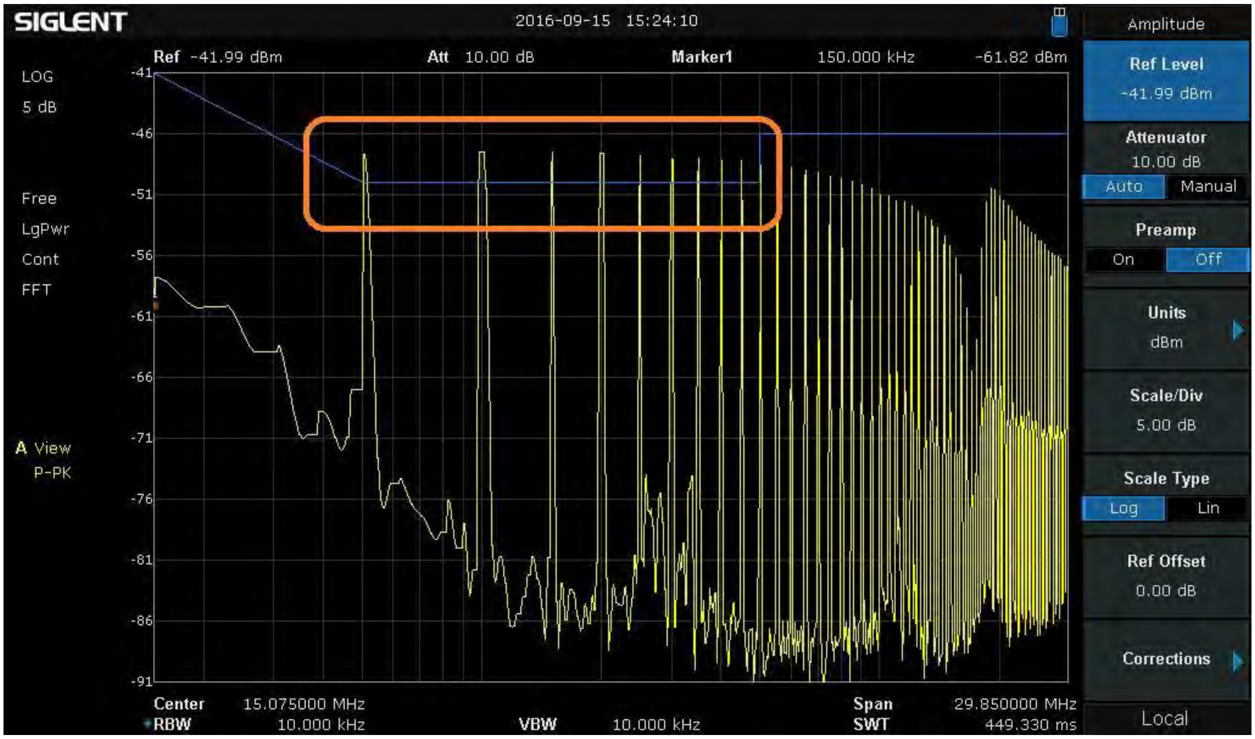


Figure 4: A preliminary scan showing peaks that exceed the Class B limits for conducted emissions, per the FCC subpart 15 for unintentional radiators.

SUCCESSIVE SCANS AND EVALUATION

The preliminary scan described above will provide a good indication of potential fault frequencies. But, the settings are not identical to those indicated in most specifications. We suggested that the following analyzer settings: RBW = 10kHz, Detector = Positive Peak, Span = 30MHz. This allows you to perform quick analysis of problematic areas and quickly gain a basic idea of the conducted emission performance of the DUT.

Here are optional techniques that can help provide more insight:

1. Most spectrum analyzers do not have pre-selection filters. If you are using a spectrum analyzer without pre-selection filters, the peaks you observe may not be real. Analyzers without pre-selection filters can create false peaks due to out-of-band signals mixing with the observed signals.

You can test the validity of a peak by adding an external attenuator (3 or 10dB should do). Real peaks will fall by the amount of the attenuator. If the peak falls by more than the attenuator, it is likely to be a false peak. Make a note of the false peaks for comparison with your compliance test results. You can also use pre-selection filters or an EMI receiver, but these tend to be cost prohibitive for most quick testing.

Figure 5 below shows a typical peak confirmation test. The yellow trace was collected without an attenuator. The Pink trace was collected with a 10 dB attenuator added to the RF input of the analyzer. In this case, the peaks drop the same amount as the added attenuation. This helps affirm that the peaks are likely real and not products of out-of-band signals.

Figure 5: Comparison of two scans using the marker table function of the SIGLENT SSA3000X spectrum analyzer. The Yellow trace was collected without attenuation while the Pink trace was collected after adding a 10 dB external attenuator.

2. Some analyzers have toolkits that more closely match the performance of true compliance receivers.

These toolkits are usually unlocked instrument options that include:

- EMI filter (6 dB shoulder vs. standard 3 dB standard IF frequency shape)
- RBW bandwidths of 200 Hz, 9 kHz, and 120 kHz
- Quasi-Peak (QP) detector

If you expect that the DUT has bursts of RF, intermittent digital communication, or transient outputs, it may be worthwhile to re-run a scan using the EMI filter, RBW bandwidth, and QP detector, if available.

Zoom in to the failing peak by setting the center frequency of the analyzer to the peak frequency of interest. Set the span to 10x the RBW specified in standard (if the specified RBW is 9 kHz, then set the span to 90 or 100 kHz), and then change the filter to EMI, the detector to QP, and RBW to 9 kHz. And observe the scan.

Scans performed using the QP detector will take much longer to perform due to the nature of this detector. QP scans will never exceed scans with a Positive Peak detector, but using the QP can limit the time spent over-engineering a solution.

3. Many spectrum analyzers have Max Hold trace types that will continuously hold the highest amplitudes of each frequency scan. You can enable a single trace as Clear Write to show active RF performance and enable a second trace as Max Hold. This allows you to compare changes in the DUT to the “worst case” data collected and “frozen” using Max Hold.

4. You can use markers and peak tables to clearly indicate peak frequencies and amplitudes, if available.

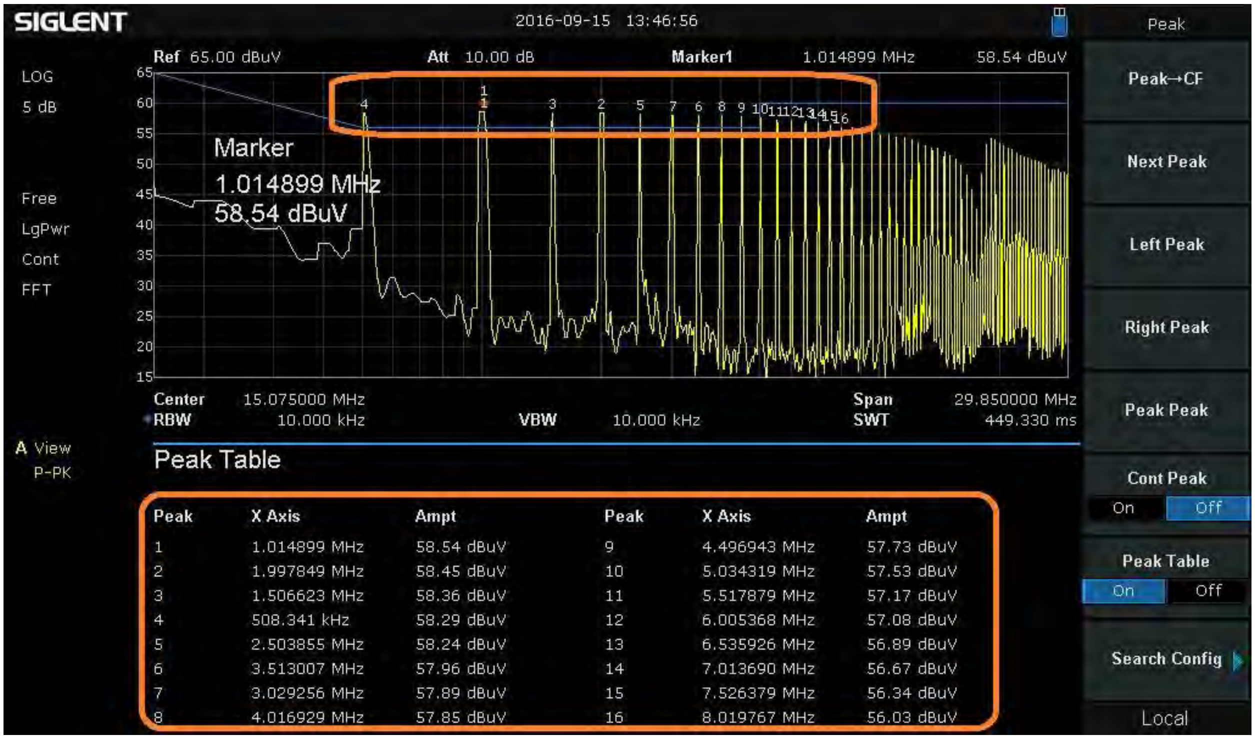


Figure 6: SSA3000X analyzer with Peak table and markers activated.

SOFTWARE

In order to ease the burden of collecting data and screenshots for your EMC reporting, SIGLENT also offers a software package called EasySpectrum. This provides a fast way to enter, store, and recall hardware correction factors, limit lines, and generate scan reports. See the SSA3000X Software page for more information.

Measurement Enviroment:

Test Data	2016-09-16	Test By	JAC
Temperature	20°	Humidity	20% RH
Test Place	electromagnetic anechoic chamber		
Test Instrumets	• SSA: SSA3032X S/N: SSA3XEA1160084 Siglent Technologies • TekBox: TEK1 XYZ TekBox		
Device Under Test	JAC_1: SDGX 12345 SIGLENT		
Reference Standard			
Test Note	Conducted Emissions Test		

Instrument Setting:

No.	Range Start(Hz)	Range Stop(Hz)	Step Size	Pre-RBW(Hz)	Meas Time(ms)	Atten(dB)	Auto Atten	PA
1	150k	30M	1/3 RBW	10000	1	10	On	Off

Previous Detector: Pos Peak
Final Detector: Qpeak
Final RBW: 120000 Hz
Final Meas Time: 1 ms

Final Result:

No.	Frequency(Hz)	Pre Ampt(dBuV)	Final Ampt(dBuV)	Corr.(dB)	Limit(dBuV)	Margin(dB)	Pass/Fail	Comment
1	10.9358M	64.42	106.99	NaN	60.00	0.00	Fail	
2	14.8362M	64.58	106.99	NaN	60.00	0.00	Fail	
3	17.1048M	64.42	106.99	NaN	60.00	0.00	Fail	
4	18.6968M	64.33	106.99	NaN	60.00	0.00	Fail	
5	19.9704M	64.13	106.99	NaN	60.00	0.00	Fail	

Limit Data:

Frequency(Hz)	Amplitude(dBuV)
150k	66.00
500k	56.00
5M	56.00
5M	60.00
30M	60.00

Traces Display:

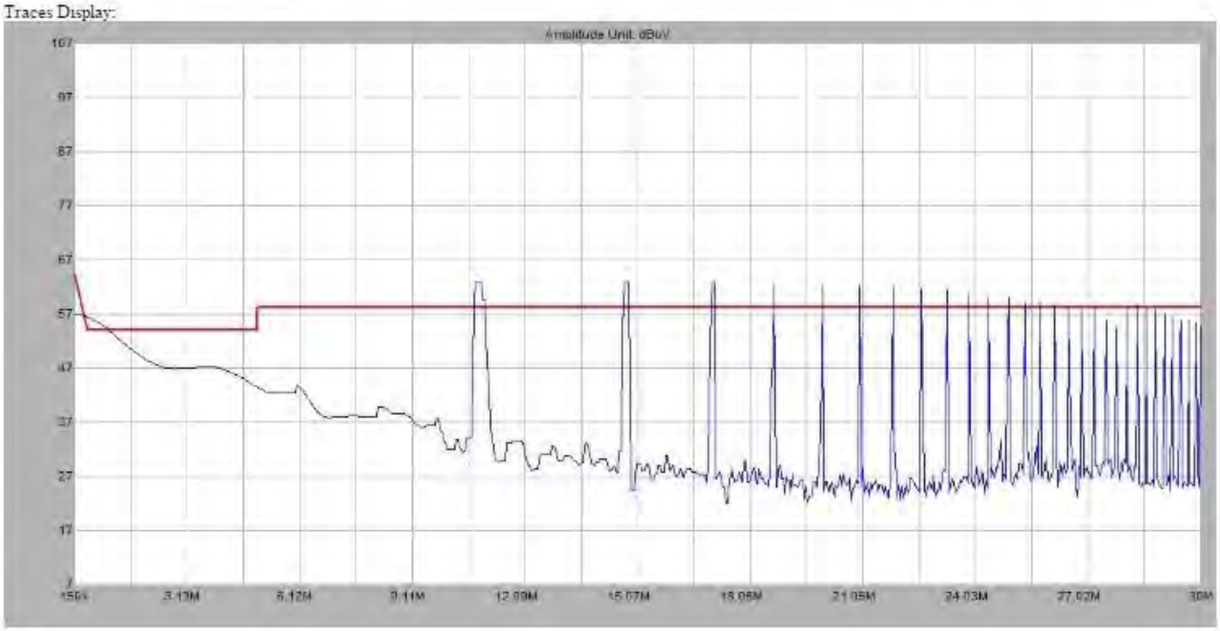


Figure 7: A sample EMI Scan report from the SIGLENT EasySpectrum Software.

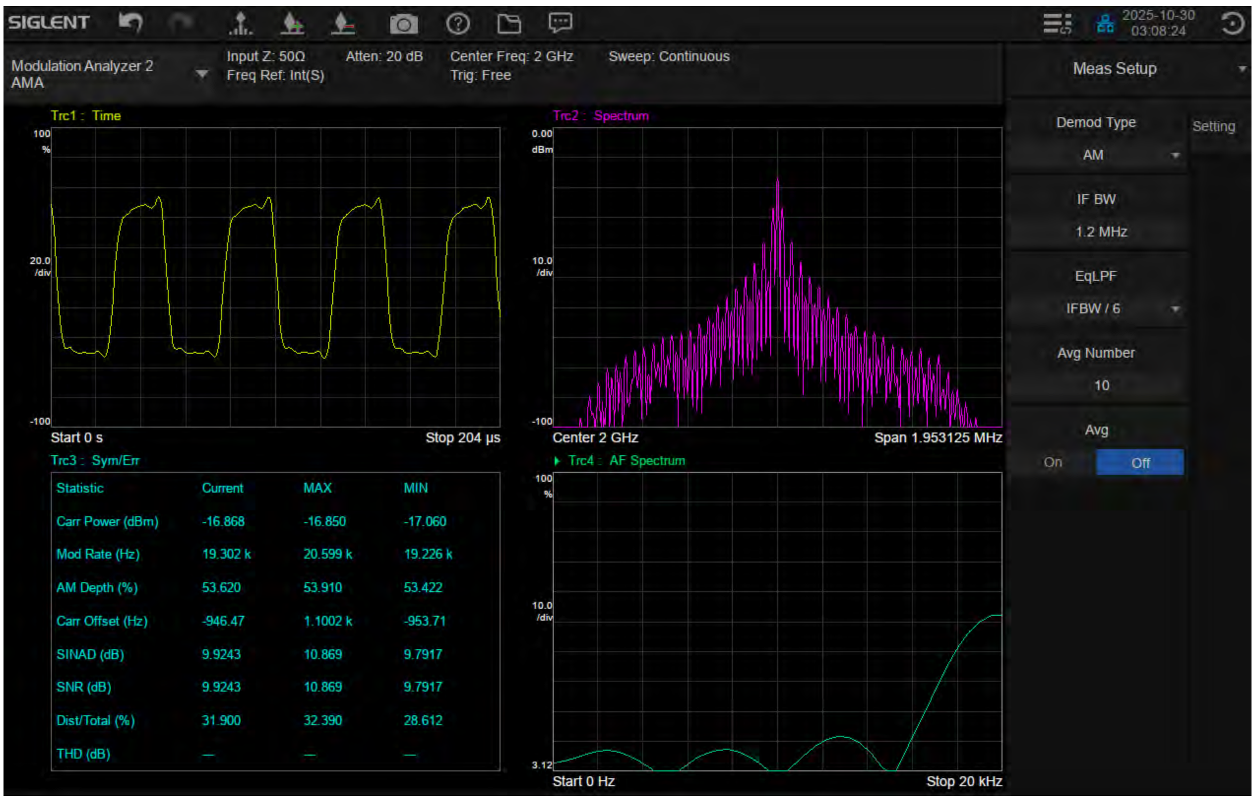
CONCLUSION

Products that are primarily powered through connections to the national energy grid need to pass conducted emissions compliance tests. While companies may choose to self-certify, it is recommended to have a third-party lab perform compliance tests. But third party labs can be expensive and scheduling time in the lab can be difficult.

With a few simple tools, you can implement an in-house pre-compliance test process that will minimize the total development time for your products, lower the cost of design, and decrease the amount of testing on future products.

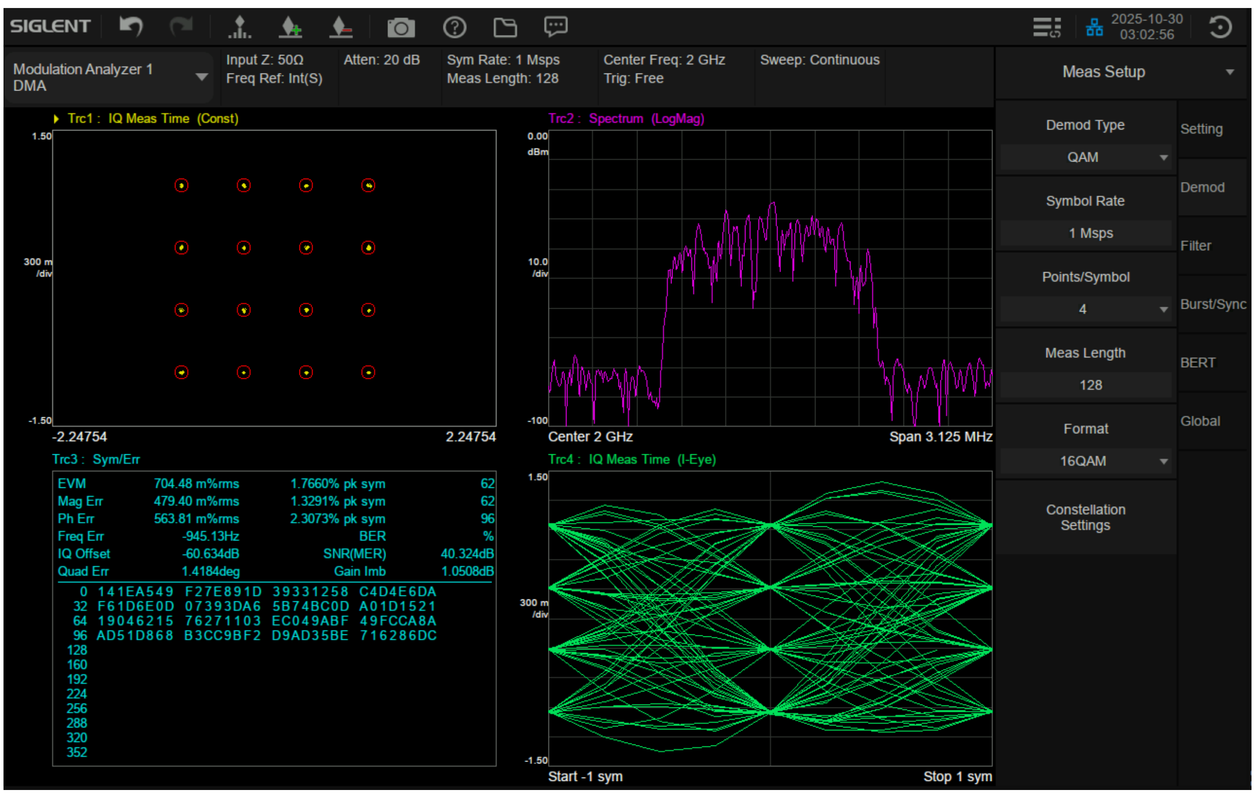
Demodulation Settings and Limits

Spectrum analyzers also often have the capability to take complex signals off of the carrier for data analysis. This can be done on analog modulated signals including amplitude, frequency, and phase modulation. Analog demodulation typically has analysis and characterization information like this AM demod display:



This makes it easy to monitor the modulation rate, depth, and distortion characteristics. Viewing the signal simultaneously in the time domain, frequency domain, and modulation spectrum simplifies debugging and problem solving significantly. Settings here include the IF bandwidth (IFBW) and filtering. On the SSA5000A, the IF bandwidth for analog modulation can be set to: 1.2MHz, 960kHz, 600kHz, 480kHz, 300kHz, 240kHz, 120kHz, 96kHz or 60kHz. Setting this value lower can improve signal to noise ratio, but there are limits. For "AM" modulation analysis, the IFBW should be more than twice the modulation frequency; for "FM" modulation analysis, the IFBW should be more than twice the sum of the frequency offset plus the modulation frequency. The EqLPF setting is a low pass filter that can additionally improve signal to noise ratios. This value is set relative to the IFBW. This must be greater than the modulation frequency. On the SSA5000A set this to: IFBW/6, IFBW/20, IFBW/60, IFBW/200, IFBW/600 or IFBW/2000.

For more complex, IQ signals there are additional settings and limitations. The standard visualization setup is shown here for a 16QAM signal:



The primary difference between this and the analog demod view is here we can demodulate the signal all the way to bits since digital data is being transmitted. The most common measurement characteristic here is called

EVM or Error Vector Magnitude. This is a calculation of how far from the ideal location on the constellation diagram the captured datapoints lie. In a modulation like QAM (Quadrature Amplitude Modulation) this value includes the relative amplitude and synchronization of the I and Q signals on this carrier. By demodulating all the way to the transmitted bits, additional analysis is possible. This includes bit error rate testing (BERT) done by comparing the captured bits to the predefined bits sent. Triggering on a bit sequence is also done using the Burst/Sync settings. This enables a test to trigger on a particular bit sequence to monitor the radio link quality.

Here are the demodulations included in the DMA option on SIGLENT spectrum analyzers:

ASK: 2ASK;

FSK: 2FSK, 4FSK, 8FSK, 16FSK;

MSK: GMSK;

PSK: BPSK, QPSK, OQPSK, 8PSK; DPSK: DBPSK, DQPSK, D8PSK, π/4 –DQPSK, π/8 –D8PSK;

QAM: 16, 32, 64, 128, 256

All of these families can demodulate the same length of symbols and can be set to the same Points/Symbol options. These are:

Measure Length 16 to 4096

Points/Symbol 4,6,8,10,12,14,16

The main difference between the 5 families' demodulation capabilities is in their highest symbol rate they can demodulate. This is tied to the points/symbol setting above as well. Here is how the families operate. Both values must be under the limit in this table in order to operate:

Family	Max Symbol Rate	Max of:[symbol rate * (Points/symbol)]
SSA3000X Plus	2.5 Msps	10 Msps
SVA1000X	2.5 Msps	10 Msps
SHA850A / SHA860A	5 Msps	20 Msps
SSA3000X-R	25 Msps	150 Msps
SSA5000A	32 Msps	150 Msps

The following sections discuss particular demodulation configurations and views as well as methods for capturing and analyzing the underlying IQ data and programming examples for capturing and transferring the data.

Advanced Demodulation (5G NR, Wifi 6/7, LTE)

As Wi-Fi continues to evolve, new spectrum comes into use as well as new modulation schemes. Wi-Fi 6 utilizes the IEEE 802.11ax standard. Among others, this also opens up 7 new 160 MHz channels in the 6 GHz band (Wifi 6E). Additionally, at its highest performance, Wi-Fi 6 utilizes 1024-QAM modulation. Emulation and demodulation of these signals requires higher sample rates. The SSG6082A-V with SigIQPro can generate 802.11ax signals across the 6 GHz band. High quality signal emulation is an important tool for modulation testing. This shows an emulated IEEE 802.11ax signal on a 160 MHz channel from the SSG6082A-V being demodulated and analyzed with SigVSA on the SDS7000A:

Wi-Fi 7 continues this evolution with significantly increased throughput and efficiency. Applications driving these advanced schemes include high density locations for multi-connection throughput as well as applications like remote medicine that require extremely low latency.

Wi-Fi 7 is implemented as IEEE 802.11be. This has a much higher theoretical throughput of 46 Gbps and can utilize 4K-QAM. The main advantages vs. Wi-Fi 6 are reduced interference and multi-channel, multi-device handling.

The SSG6082A-V with SigIQPro as well as the SDS7000A with real-time support modulation testing for IEEE 802.11be. Here is a view of a demodulated IEEE 802.11be signal showing the 4K-QAM modulation:

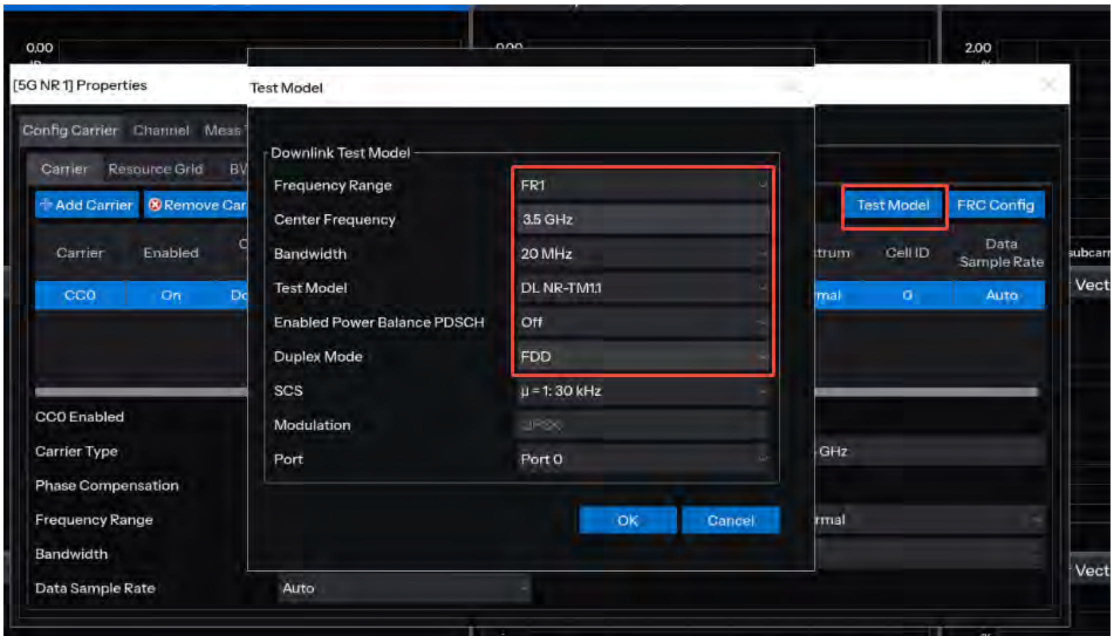
Another newer standard in use today is 5G NR or New Radio. This 5G standard is based on OFDM Orthogonal Frequency-Division Multiplexing and can be used in the FR1 band and up into the FR2 band in millimeter wave frequencies. 5G NR can improve latency as well as provide high throughput when needed.

The SSG6082A-V and SigIQPro can also generate signals for 5G NR testing. With the optional bandwidth extension, the SSG6082A-V can provide up to 625 MSymbol/sec symbol rates with 1 GHz of signal bandwidth. This provides superior signal quality for demanding signals.

Demodulation and analysis of 5G NR signals includes both single beam and multi-beam analysis using the SHA860A series:

Additional demodulation and analysis can be done with the SDS7000A and SigVSA. This includes constellation and EVM measurements:

Using SigVSA, the SDS7000A can configure the test model characteristics of a 5G NR signal customizing the analysis to the signal of interest:



The high-performance real-time capability of the SDS7000A can analyze signals on carrier up to 8 GHz with up to 1 GHz of bandwidth. The high-resolution, high-speed front end makes accurate demodulation and analysis of these signals possible.

LTE signals can also be analyzed across a multi-channel spectrum using SIGLENT measurement tools. The SHA860A series can measure channels up to 20 MHz wide for LTE Single PCI measurements including Error Vector Magnitude (EVM), Cell and Sector groups, signal power, and demodulation.

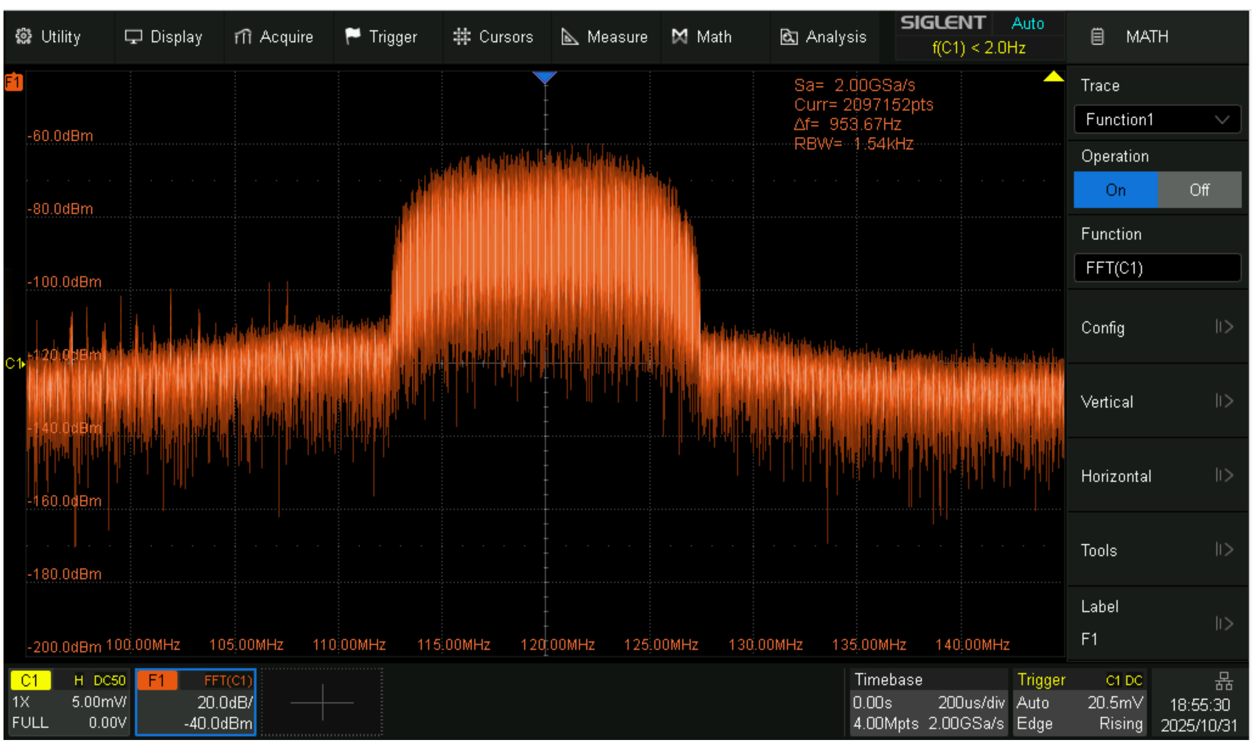
These can also be measured across multiple channels in LTE Multi PCI mode. Additional measurements can be made on higher speed LTE signals using the SDS7000A with real-time analysis. Here is the SDS7000A view of a 4G LTE signal demodulation:

These complex signals require precise emulation and analysis tools. Verifying signal parameters within the design of a specific setup can be accomplished with these modulation analysis tools.

Custom IQ Demodulation (IFO & IQA)

There are a number of methods for capturing and exporting the IQ data for custom analysis of these types of communication signals from Siglent analyzers. The first method is an analog method for IF signal capture called IFO or IF Output. This option is on the SSA5000A series. The analog IF signal is output from a BNC on the instrument rear panel. The IFO can be used is swept mode when set to zero span. The Input/Output menu enables the IF output. The IF signal appears on a 120 MHz center frequency with approximately 40 MHz of bandwidth.

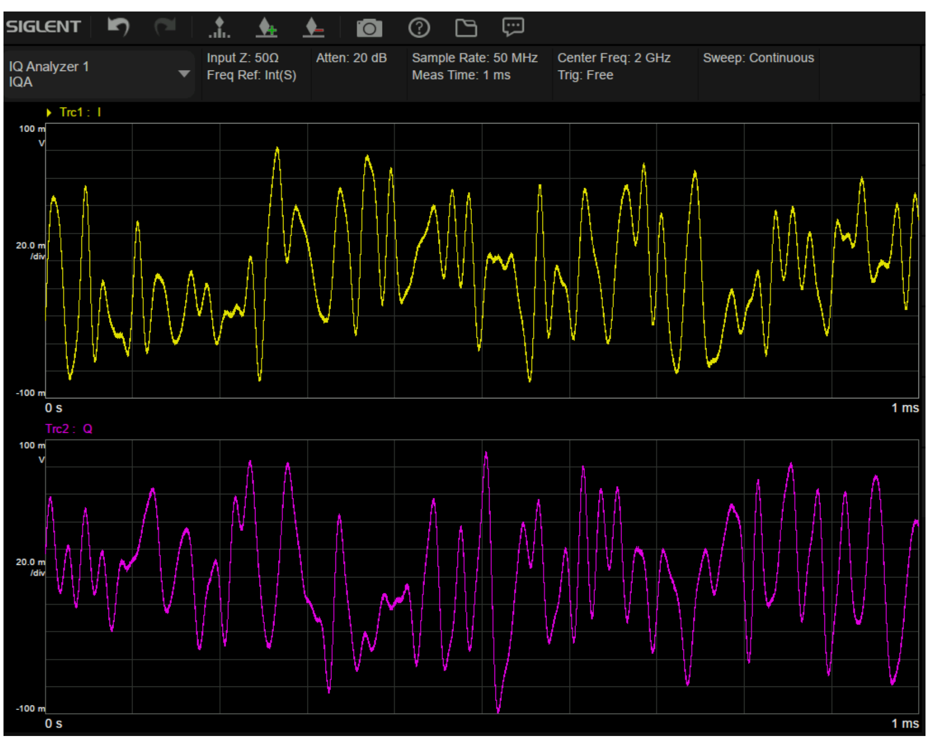
This enables higher speed digitization of signals because the carrier has been reduced to a range where it can be easily captured by an oscilloscope or digitizer. Here is an FFT of an IQ signal from the IF output shown on an oscilloscope:



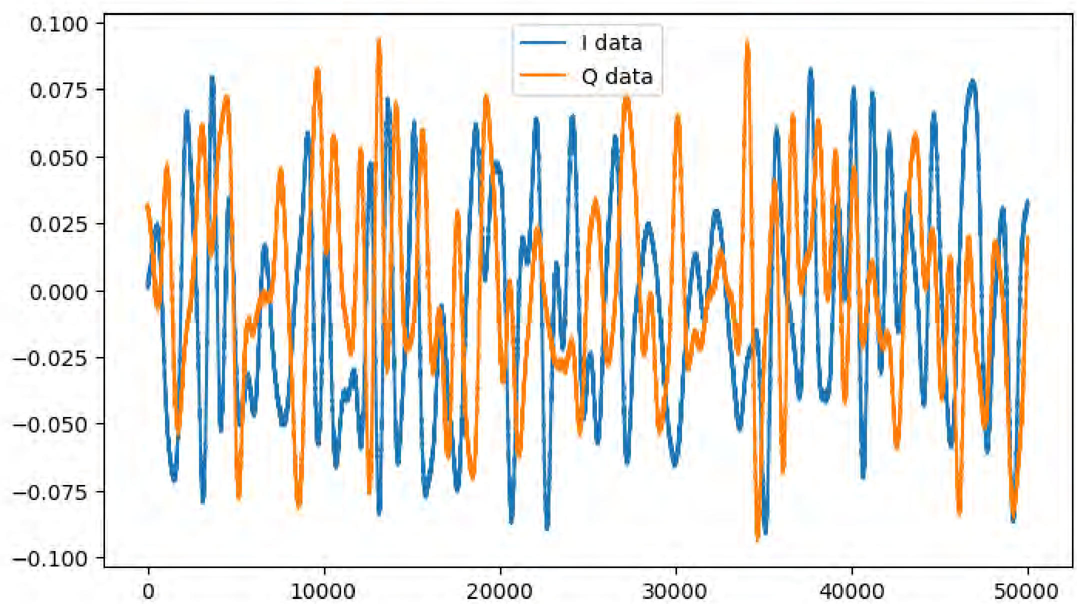
The second method is to use the analyzer to digitize the IQ data itself and then store that for further analysis. This option is called IQA for IQ Analysis. This is available on the SSA5000A and SHA800A series handhelds. Here is a comparison table for the memory depth, bandwidth, and sample rate they can provide:

Series	Max Sample Rate (MHz)	Max BW (MHz)	Bits	Max Points
SHA860A	300	110	16	250 M
SHA850A	20	5	16	250 M
SSA5000A	20	40	32	125 M

It is also possible to extract IQ data from the SDS7000A using the SigVSA tools. The IQA option also includes an additional visualization. This view makes it possible to see the changes in I and Q over time separately like so:



This data can then be moved to the computer using ":TRAC:DATA?" queries resulting in:



The raw IQ data can also be saved as a txt file and then moved later for offline analysis. On the SSA5000A, this can be done with the command:

:SAVE:RAW:IQ 1000000,"raw_iq.txt"

This data can be analyzed using the same programming methodology of the following demodulation example with these commands above when operating in IQA mode. Enter IQA mode using ":INST:SEL IQA".

Review the next section for more details on programming tips for Python and VISA.

Programming Example: Symbol Demodulation

In this programming example, we will work with a SSA5000A analyzer in DMA mode. We will configure the instrument to capture and demodulate our signal. Then, we will transfer bit, error summary, and trace data to the computer.

First, we set up our program including the VISA, matplot, and image modules we will need:

```
import pyvisa
from PIL import Image
import io
import time
from matplotlib import pyplot as plt
```

Then, we can connect to the instrument and verify it:

```
rm = pyvisa.ResourceManager()
print(rm.list_resources())
ssa5 = rm.open_resource(rm.list_resources()[3])
print(ssa5.query('*IDN?'))
```

The SSA5000A I want to communicate is the 4th in the list of resources located by the VISA list.

Then, we can enter the modulation analysis mode and configure the measurement for our signal:

```
#Configure DMA operation
ssa5.write(':INST:SEL MA')
time.sleep(6)
ssa5.write(':FREQ:CENT 2000000000')
ssa5.write(':DDEM:MOD QAM16')
ssa5.write(':DDEM:SRAT 10000000')
ssa5.write(':DDEM:SYMB:POIN 4')
ssa5.write(':DDEM:RLEN 256')
```

```
ssa5.write(':AVER:COUN 20')
ssa5.write(':AVER ON')
```

Then, we can collect the error summary and bit data:

```
#Get data:
time.sleep(1)
print('Error Summary: ')
measurement_list = [
    "1. EVM rms (% rms)","2. EVM peak (% pk)","3. symbol position of
EVM peak",
    "4.magnitude error rms (% rms)","5. magnitude error peak (%
pk)","6.symbol position of magnitude error peak",
    "7.phase error rms (deg)","8.phase error peak (deg pk)","9.symbol
position of phase error peak",
    "10. frequency error (Hz)","11. IQ offset","12. SNR(MER)
(dB)","13. quadrature error (deg)","14. gain imbalance (dB)",
                    ]
data_list = ssa5.query(':READ:DDEMod?').split(',')
for i in range(14):
    print(measurement_list[i],': ',data_list[i])


print('Bit Sequence: ',ssa5.query(':READ:DDEMod:BIT?'))
```

This data appears in the console as:

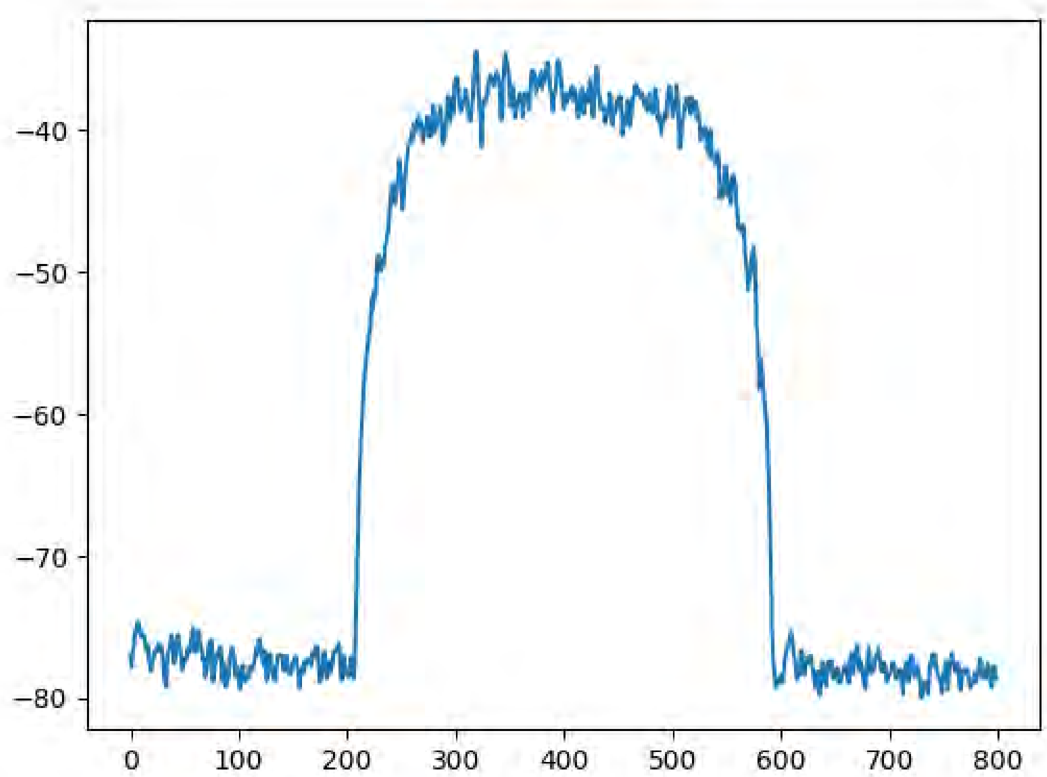
```
Error Summary:
1. EVM rms (% rms) :  1.165017733E+00
2. EVM peak (% pk) :  3.109069626E+00
3. symbol position of EVM peak :  4.600000000E+01
4.magnitude error rms (% rms) :  8.003036071E-01
5. magnitude error peak (% pk) :  2.185704739E+00
6.symbol position of magnitude error peak :  2.240000000E+02
7.phase error rms (deg) :  8.494365273E-01
8.phase error peak (deg pk) :  4.473614458E+00
9.symbol position of phase error peak :  1.570000000E+02
10. frequency error (Hz) :  -9.422211797E+02
11. IQ offset :  0.000000000E+00
12. SNR(MER) (dB) :  -6.128142583E+01
13. quadrature error (deg) :  3.598274116E+01
14. gain imbalance (dB) :  -3.809832047E+00
Bit Sequence:
```

2B052AF1268FCD888A9F55D48DB8EC132CBA8B11B1B42968046EB77516D5C9FEBF8A34
FBFF316E545F2FD913CF90B21D6B8506502DFECD4228AC681C24B157035108B4865A2E
FC598488B44D5A1DAA5537A781E0C91D95B33821CE1E567DCF55EE2DB631508650E6FE
FE14241F47298922573CB70732C9A4B19C03625EB83575

Now the program requests and shows the spectrum data in a matplot:

```
#wave data
strs11 = ssa5.query(':TRACE2:DATA?')
lists11 = strs11.split(",")
listflt = [float(x) for x in lists11]
fig = plt.figure()
ax = fig.add_subplot(111)
ax.plot(listflt)
plt.show()
```

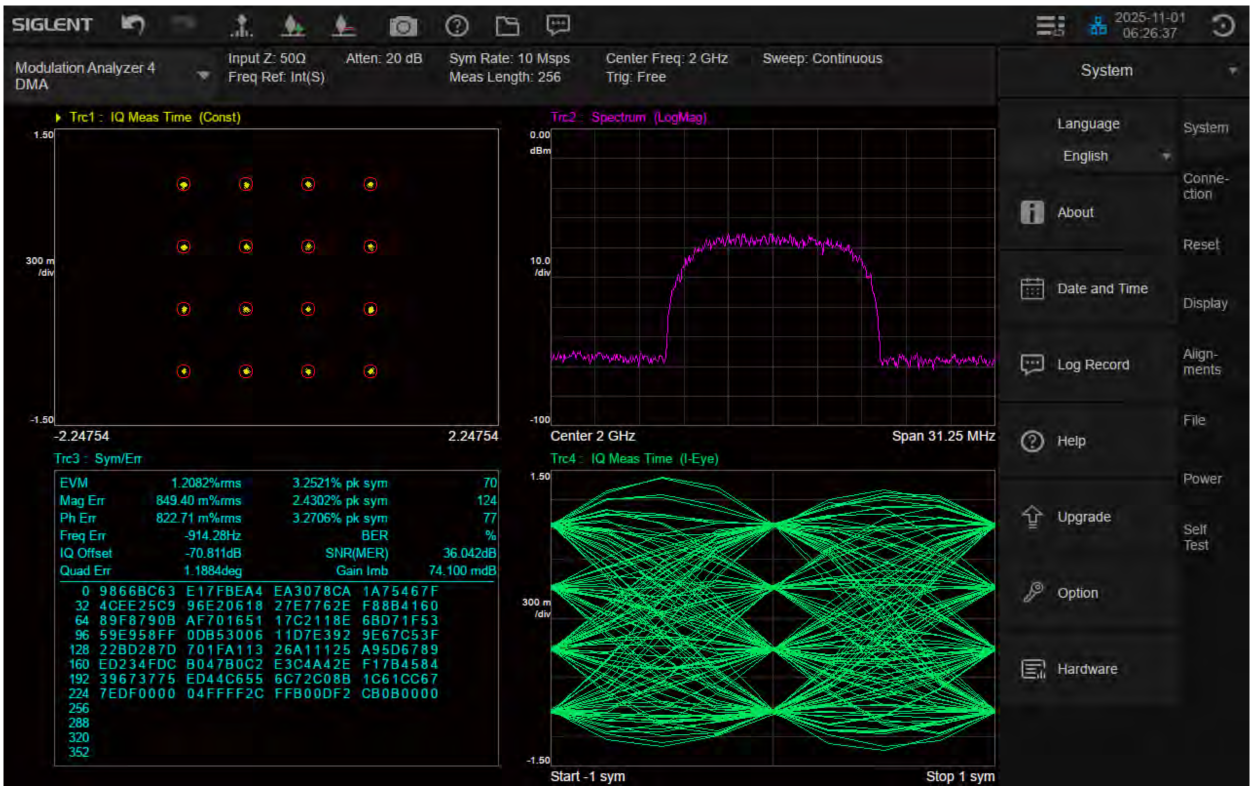
The matplot chart appears for viewing:



Lastly, once the chart is closed the program continues and captures the screenshot:

```
#capture screen shot
ssa5.write(':HCOP:SDUM:DATA?')

buff = ssa5.read_raw()

im2 = Image.open(io.BytesIO(buff))

im2.show()
```

The picture is shown on the computer:



Then the connections are closed:

```
#close connection
ssa5.close()
rm.close()
```

This example shows how to quickly configure a modulation analyzer remotely and store the data on the computer. Here is the complete program for reference:

```
import pyvisa
from PIL import Image
import io
import time
from matplotlib import pyplot as plt

rm = pyvisa.ResourceManager()
print(rm.list_resources())
ssa5 = rm.open_resource(rm.list_resources()[3])
print(ssa5.query('*IDN?'))

#Configure DMA operation
ssa5.write(':INST:SEL MA')
time.sleep(6)
ssa5.write(':FREQ:CENT 2000000000')
ssa5.write(':DDEM:MOD QAM16')
ssa5.write(':DDEM:SRAT 10000000')
ssa5.write(':DDEM:SYMB:POIN 4')
ssa5.write(':DDEM:RLEN 256')
ssa5.write(':AVER:COUN 20')
ssa5.write(':AVER ON')

#Get data:
time.sleep(1)
print('Error Summary: ')
measurement_list = [
    "1. EVM rms (% rms)","2. EVM peak (% pk)","3. symbol position of
EVM peak",
    "4.magnitude error rms (% rms)","5. magnitude error peak (%
pk)","6.symbol position of magnitude error peak",
    "7.phase error rms (deg)","8.phase error peak (deg pk)","9.symbol
position of phase error peak",
    "10. frequency error (Hz)","11. IQ offset","12. SNR(MER)
(dB)","13. quadrature error (deg)","14. gain imbalance (dB)",
                    ]
data_list = ssa5.query(':READ:DDEMod?').split(',')
for i in range(14):
    print(measurement_list[i],': ',data_list[i])


print('Bit Sequence: ',ssa5.query(':READ:DDEMod:BIT?'))
```

```
#wave data
strs11 = ssa5.query(':TRACE2:DATA?')
lists11 = strs11.split(",")
listflt = [float(x) for x in lists11]
fig = plt.figure()
ax = fig.add_subplot(111)
ax.plot(listflt)
plt.show()

#capture screen shot
ssa5.write(':HCOP:SDUM:DATA?')

buff = ssa5.read_raw()

im2 = Image.open(io.BytesIO(buff))

im2.show()

#close connection
ssa5.close()

rm.close()
```

Bluetooth Demodulation and Verification Guide

Introduction

As a wireless communication technology, Bluetooth technology is widely used in various devices and application scenarios. The article aims at RF verification of Bluetooth transmitter. Through fast one-click RF measurement, SSA5000A spectrum analyzer is transformed into a standard-based Bluetooth RF transmission tester to help you design, evaluate and manufacture Bluetooth devices. The measurement application conforms to the standard of Bluetooth core specification, and can safely verify your Bluetooth design, covering Bluetooth BR, EDR and LE. The article will demonstrate how to use the Bluetooth analysis function of SSA5000A to carry out Bluetooth analysis and measurement quickly and effectively.

Bluetooth Analysis Function

Bluetooth SIG specifies the RF test items of Bluetooth® Classic and Bluetooth® Low Energy Bluetooth measurement specifications. Tables 2 and 3 list the corresponding test items supported by SSA5000A and suitable for transmitter testing. The SIGLENT Bluetooth measurement application refers to the following Bluetooth RF test specifications:

Table 1 Supported standard versions:

Type	Bluetooth device
Standard version	Bluetooth radio frequency system specification 1.2/2.0/2.0+EDR/2.1/2.1+EDR revision 2.1.E.0 – basic rate – enhanced data rate Bluetooth Low Energy RF PHY test specification (LE RF-PHY.TS/4.0/4.2) Bluetooth RF PHY test specification (Bluetooth 5, 5.1 and 5.3)
Power	Class 1, class 2 and class 3
Frequency	Bluetooth basic rate and EDR system: 2.400 to 2.4835 GHz (f = 2402 +k MHz, k = 0, …, 78) Bluetooth low energy system: 2.400 to 2.4835 GHz (f = 2402 +kx2 MHz, k = 0, …, 39)

Table 2 Supported Classic test items

Transmitter test	TP/TRM/CA/BV-xx-C
Basic Rate (BR)	
Output power	01
Modulation characteristic	07
Initial carrier frequency tolerance	08
Carrier frequency drift	09
Enhanced Data Rate (EDR)	
EDR relative transmit power	10
EDR carrier frequency stability and modulation accuracy	11
EDR differential phase encoding	12

Table 3 Supported LE test items

Low Energy (LE)					
Transmitter test	LE 1M 1 Mb/s	LE 2M 2 Mb/s	LE 1M 1 Mb/s, SMI	LE 2M 2 Mb/s, SMI	Coded, S=8 1 Mb/s, SMI
Output power	01				
Modulation characteristics	05	10	09	11	13
Carrier frequency offset and drift	06	12			14

Configuration information

You need to install the appropriate firmware version and options on the required instruments.

Table 4 Configuration information

Type	Model	Configuration information
Signal Generation Software	SiglQPro	Optional: SiglQPro-BT
Vector Signal Generator	SSG5000X-V	Firmware: V2.1.2.4.1and above Optional: SiglQPro-BT
Arbitrary Waveform Generator	SDG7000A	Firmware: V1.1.1.32 and above Optional: SiglQPro-BT
Spectrum Analyzer	SSA5000A	Firmware: V1.1.2.2.0 and above Optional: SSA5000-BT

Measurement Parameters

SSA5000A Bluetooth analysis provides one-button measurement.

Table 5 Measurement Parameters:

Bluetooth Analysis	Basic Rate (BR)	Enhanced Data Rate (EDR)	Low Energy (LE)
Output power			
Peak power	●		●
Average power	●		●
Modulation characteristics			
ΔF1 Avg/Max	●		●
ΔF2 Avg/Max	●		●
ΔF1/ΔF2 Ratio	●		●
Initial carrier frequency tolerance (ICFT)	●		
Frequency offset			●
Carrier frequency drift			
Frequency drift	●		●
Max drift rate	●		●
Init freq drift			●
Relative transmit power			
GFSK average power		●	
DPSK average power		●	
Rel average power		●	
Frequency stability and modulation accuracy			
Freq offset w_i		●	
Freq offset w_0		●	
w_0+w_i		●	
RMS DEVM		●	
Peak DEVM		●	
Differential phase decoding			
BER		●	
Bit errors		●	
99% DEVM		●	
Guard Interval		●	

Connection Settings

Connect a PC with SigIQPro software to SSG5000X-V / SDG7000A through GPIB / LAN / USB. Complete the connection according to the setup instructions of SigIQPro, and then perform the following steps to interconnect SSG5000X-V / SDG7000A and SSA5000A:

Connect SSG5000X-V/ SDG7000A RF output port to SSA5000A RF input port.

It is suggested to connect the 10 MHz IN output of SSG5000X-V / SDG7000A to the Ext Refl port (back panel) of SSA5000A to improve the frequency accuracy.

Connections

Test Result

SSA5000A calculates the measurement results according to the Bluetooth® RF test specification, carries out Bluetooth BR/EDR/LE one-button measurement and displays a single view with four traces. The one-button measurement function can conveniently and quickly complete the test purposes listed in Table 2 and 3 at one time, and provide an overview of multiple emission tests. Users can switch from the four-trace overview to a single power, modulation and spectrum measurement display to view the results in more detail. All signal parameters can be modified independently, such as RF channel, packet type, mode type, etc. SSA5000A is helpful for users to troubleshoot flexibly in the laboratory and optimize RF design easily and quickly.

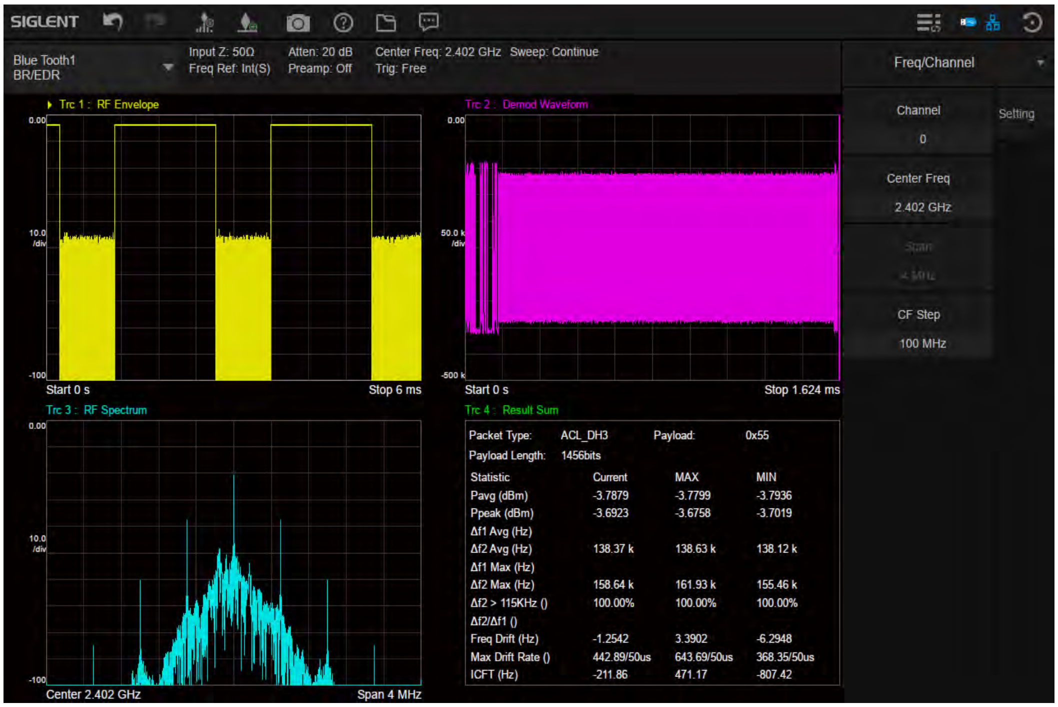


Figure 0-1 Test result

Noise Figure Measurement Guide

Introduction

A key characterization test for RF components used in radio receiver design is the noise figure (NF). As the name implies, this is essentially a measure of the noise due to the receiver components themselves. The noise figure can be found in datasheets for components like low noise amplifiers, mixers, and receiver systems. Spectrum analyzers, like the SSA5000A series, are a standard instrument for noise figure measurements. There are several methodologies used for making noise figure measurements. The SSA5000A noise figure measurement option utilizes the Y-Factor method. This is combined with a controlled 28 Vdc source (Siglent NDS28) which is controlled by the SSA5000A over USB and powers the noise source. This method also requires a noise source with a known ENR across the test frequencies of interest.

In this example, we used the Spanawave CNS346C broadband calibrated noise source.

You can learn more about these noise sources here. Any noise source powered by 28 Vdc using a BNC that has calibrated ENR data can be used.

This method measures the noise density in different test states. One with the noise source active and one with the noise source off. There is also a calibration state with the noise source but no DUT where the noise source power is on and off. The ENR of the noise source describes the noise ratio and we then use that to determine the added noise density coming from the DUT.

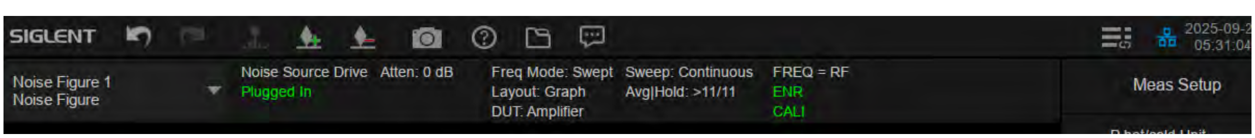
Noise Source ENR

The first step is to input the ENR data for the noise source being used. On this noise source, the ENR and frequency data is printed on the back:

On the SSA5000A, the ENR data is entered on the Measure Setup menu's edit ENR option:

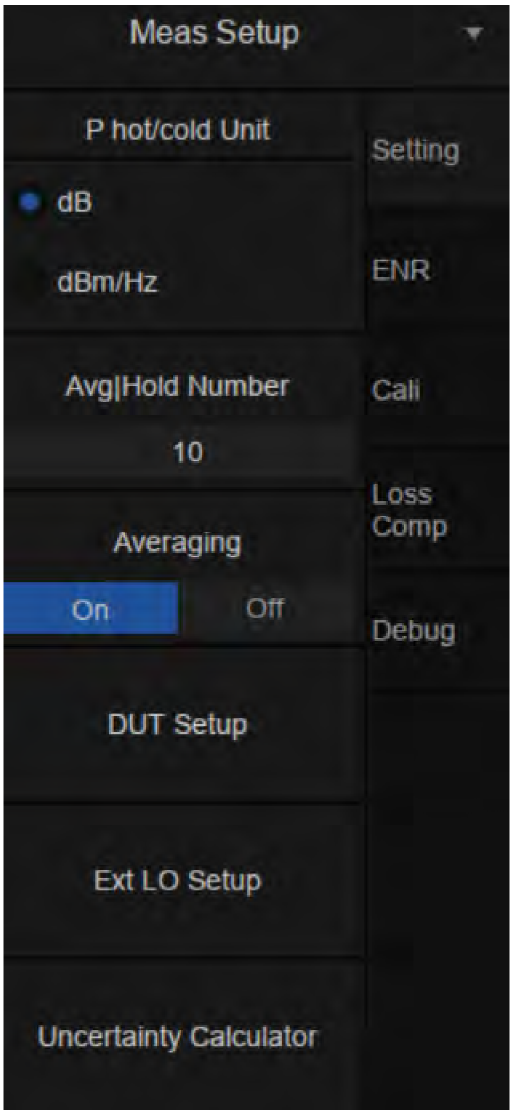
It is important to input all of the frequency values of ENR that you may be testing around. ENR data should be available across the entire frequency test range. After entering the data and setting the frequency sweep values, select Calibrate Now. The setup for calibration is:

Once calibration is complete you should have 3 green annunciators across the top of the display indicating respectively that the noise source driver is connected, the ENR values have been entered, and the calibration has been completed:



Measurement Tools

There are a few key measurement tools to remember to get the most out of your noise figure measurements. First, you do want to adjust the configuration in the measure setup menu settings:

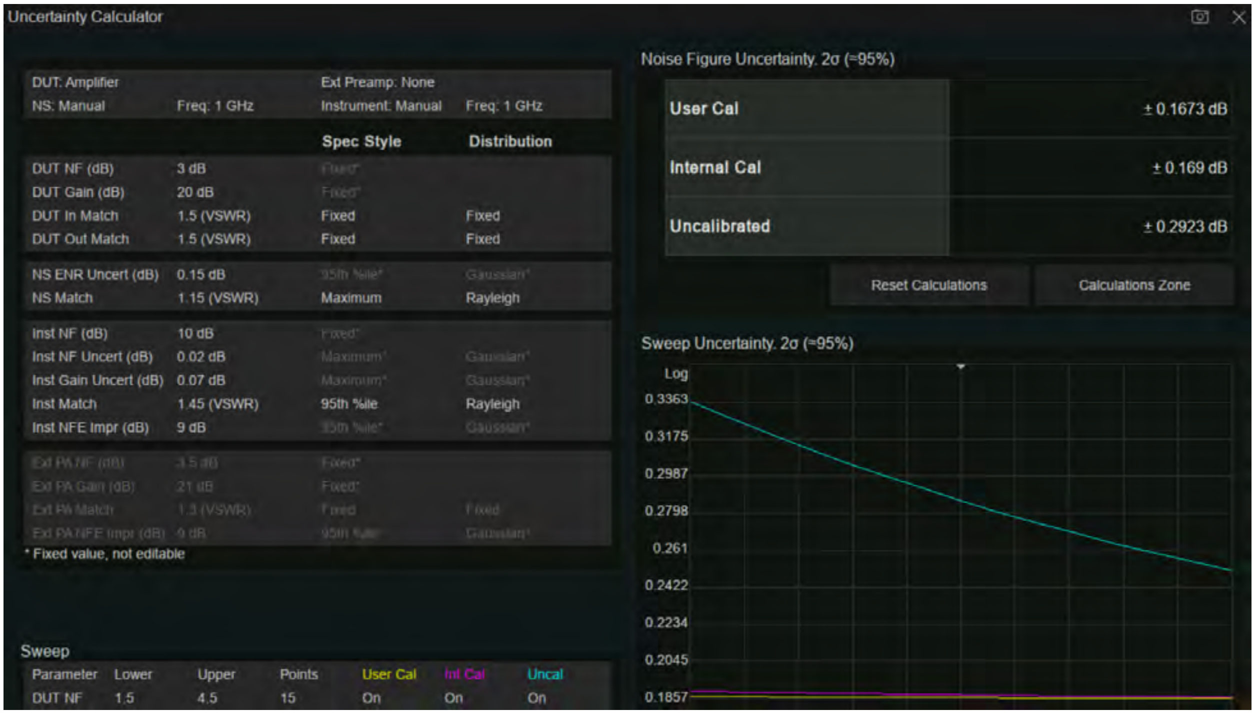


Averaging: The Avg/Hold number sets the number of sweeps from which a rolling average is constructed when the averaging is turned on. This is important for reducing measurement noise and uncertainty. For sensitive applications, select a higher average number to improve results.

DUT Setup: Use this menu to set up for amplifier or mixer testing. If using a mixer, you can configure it for up or down conversion and then also configure the external LO.

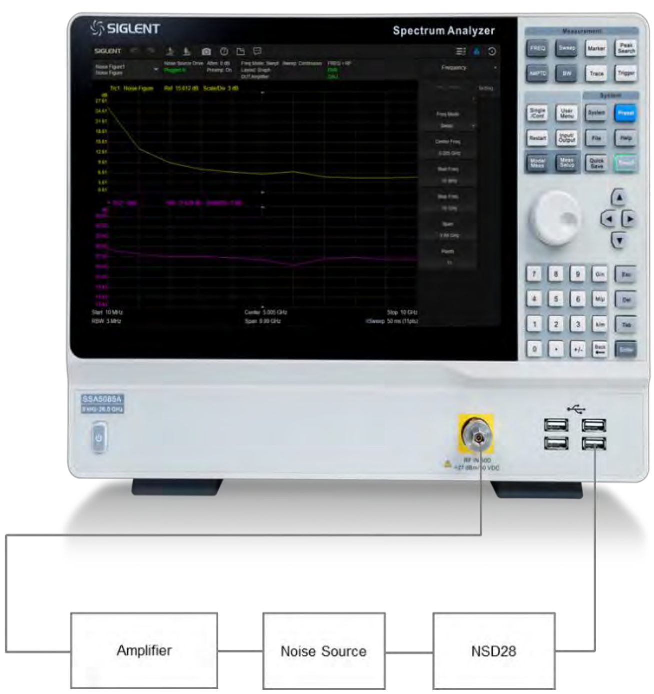
The DUT setup can also be used to configure the measurement setup including RBW, sweep points, and internal attenuation.

Uncertainty Calculator: For advanced testing, the uncertainty calculations can be adjusted by changing the setup or uncertainty of the inputs including the ENR data, calibrations, and the instrument specifications:

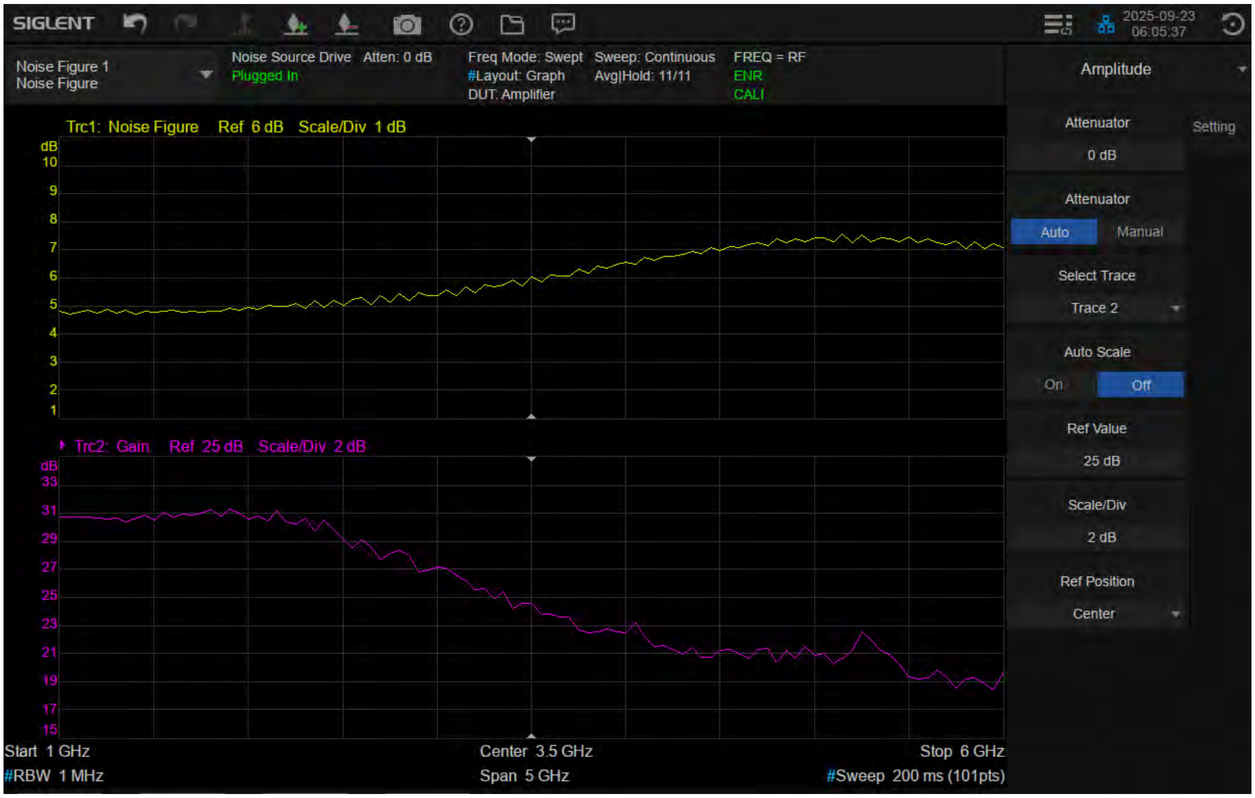


Fundamentally, the measurement settings including the averaging, RBW, and sweep points do the most to affect the signal quality for analysis.

Insert the device under test for the final measurement step as shown:



It is also suggested to simplify the gain and NF y-axis settings in the amplitude menu using whole numbers for the divisions. Use the markers to identify specific points of interest on the noise figure graph:



Use these settings to optimize the analysis for your application. It is also worth noting that while this measurement method is well suited to a wide range of NF values, there are a couple of additional things to remember. The uncertainty on high NF values can be higher than other methods. As you might expect, this method is sensitive to temperature and environmental changes between the calibration and test. Allow the instrument to warm up fully and calibrate frequently to avoid additional errors. Finally, external noise sources during the measurement or calibration can cause errors. Depending on the device and cabling used, nearby wireless signals during the test can impact the precise noise density, especially around 2.4 GHz or other ISM bands, where a lot of environmental interference could be coupled in.

Conclusion

Characterizing noise figure for RF amplifiers and mixers requires advanced analysis and a complete test system with integrated measurement parameters. Using the SSA5000A spectrum analyzer series from SIGLENT along with our noise source driver and SSA5000-NF measurement option along with a calibrated noise source such as the Spanawave CNS346C, simplifies Y method noise figure measurements across a wide range of frequencies and values.

Programming Example: Real-Time Signal Capture

Siglent spectrum analyzers allow remote control using VISA and SCPI over USB and ethernet. The command set can be found in the programming manual for each series. In addition to configuration and measurement or analysis results, these instruments also make it possible to capture and transfer the waveform data or screen images themselves directly to a computer.

Python is the preferred methodology but using VISA and SCPI this simple to do in LabVIEW and other programming languages as well. Most spectrum analyzers also support direct socket communication using the same SCPI commands. The RF instruments have a listener on port 5025.

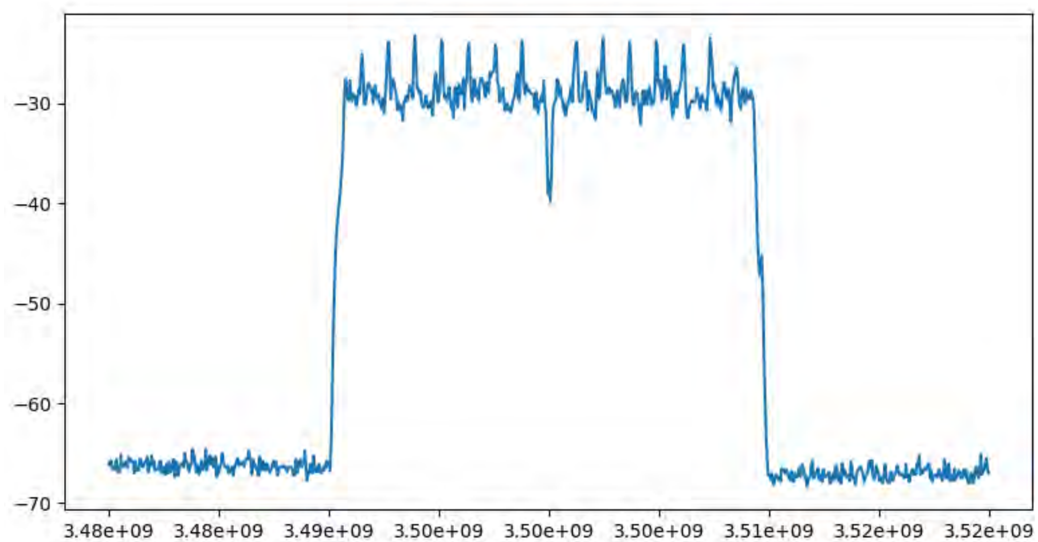
Regardless of the method, these programming examples show how to capture waveform data and chart it using matplot as well as how to save an image of the display to the PC. This program uses the SSA5000A for reference:

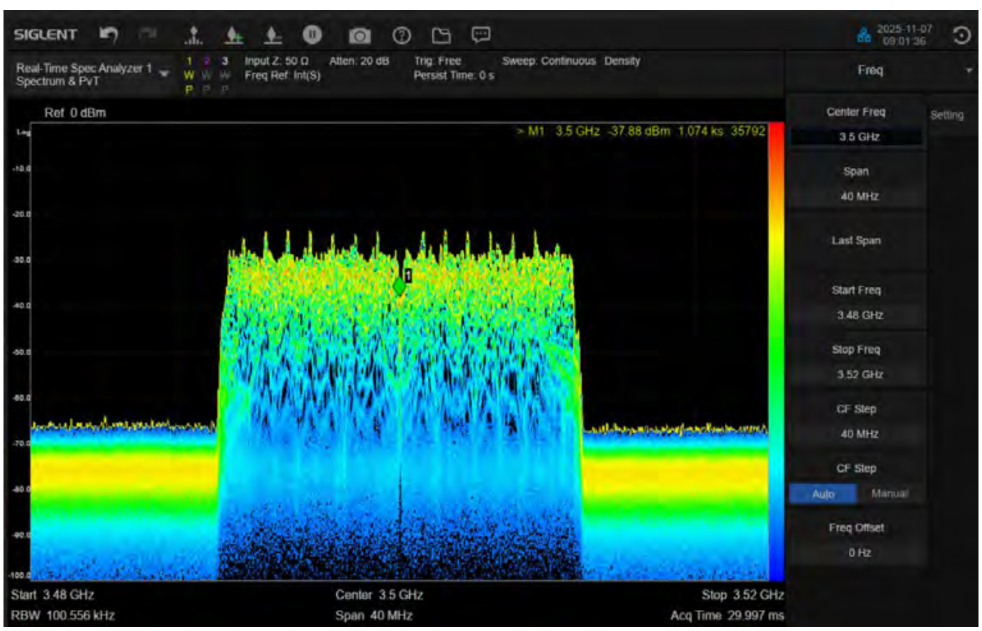
```
import pyvisa
import numpy as np
from matplotlib import pyplot as plt
import matplotlib.ticker as mtick
from PIL import Image
import io
import time

#connect to the correct instrument and ask it to identify itself
rm = pyvisa.ResourceManager()
#print(rm.list_resources())
ssa5 = rm.open_resource(rm.list_resources()[3])
print(ssa5.query('*IDN?'))

#Data Capture works in RT mode or swept

#this gets the actual data from Trace 1
ssa5.write(':FORM:TRAC:DATA ASC')

strc1 = ssa5.query(':TRACE1:DATA?')
```

```
listtrc1 = strc1.split(",")
#freqlst = freqstr.split(",")
points = len(listtrc1)+1

#create freq list points
start = float(ssa5.query(':SENS:FREQ:STAR?'))
stop = float(ssa5.query(':SENS:FREQ:STOP?'))
freqlst = np.arange(start, stop+((stop-start)/(points-1)),((stop-
start)/(points-1)))

#convert X and Y data into floats
listflt = [float(x) for x in listtrc1]
freqflt = [float(x) for x in freqlst[0:len(listflt)]]


#Collect Measurements
ssa5.write(":CALC:MARK1:STAT ON")
ssa5.write(":CALC:MARK1:X 3.5 Ghz")
print(" x is at", ssa5.query(":CALC:MARK1:X?"))
print(" y ia at", ssa5.query(":CALC:MARK1:Y?"))


time.sleep(1)

#capture screen shot
ssa5.write(':HCOP:SDUM:DATA?')

buff = ssa5.read_raw()

im2 = Image.open(io.BytesIO(buff))

im2.show()


# move trace data into a matplotlib
fig = plt.figure()

ax = fig.add_subplot(111)

ax.plot(freqflt,listflt)
ax.xaxis.set_major_formatter(mtick.FormatStrFormatter('%.2e'))


#close the session
ssa5.close()

rm.close()

plt.show()
```

The output of this program includes data in the console, a matplot, and an open image:

```
>>> %Run SSA5_data.py
Siglent Technologies,SSA5085A,SSA5AA1D7R0056,1.9.0.2.3R3t7

 x is at 3.500000000E+09

 y ia at -3.800000000E+01
```





Note the value of the visualization depth of the density display here in real-time mode vs. the data capture of a single trace in matplot. Subtle changes in these dynamic signals show up much more easily on the density view. Use all of the views and debugging tools at your disposal to get the most out of these measurement systems.

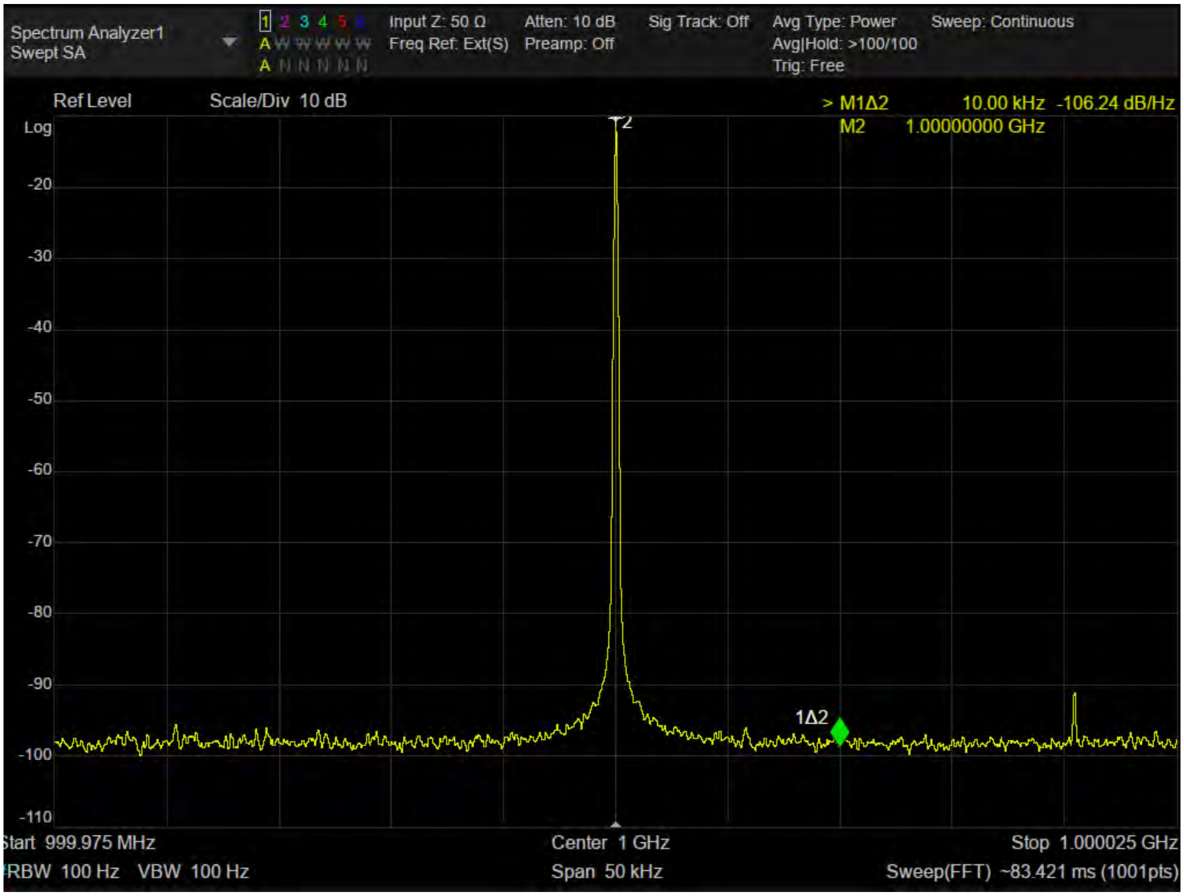
Phase Noise Measurement Guide

Introduction

A stable frequency source is a common need for many electronic devices and most RF equipment. Phase noise can be used to characterize the short-term frequency stability of these frequency sources. In this document, we will briefly describe how to use the phase noise analysis function of Siglent SSA5000A Spectrum analyzers.

Typical Phase Noise Measurement Methods

The traditional method for phase noise measurement, as shown in the figure below, is to first measure the carrier power (Pc) in dBm. Next, use the delta marker mode to set the marker to a specific frequency offset from the carrier, i.e. a point in the phase noise sideband. Then we measure the noise power (Pn) in 1 Hz bandwidth at that offset. Setting the resolution bandwidth (RBW) of the spectrum analyzer to 1Hz for scanning is often too time consuming, so the noise marker function is used to normalize the noise measured by the RBW filter to the 1Hz bandwidth. The power of the noise will be reduced by NdB after normalization, for which N=10*log(RBW/Hz). In the most cases, measuring phase noise requires repeating the process at different offsets from the carrier.



Typical Phase Noise Measurement Methods

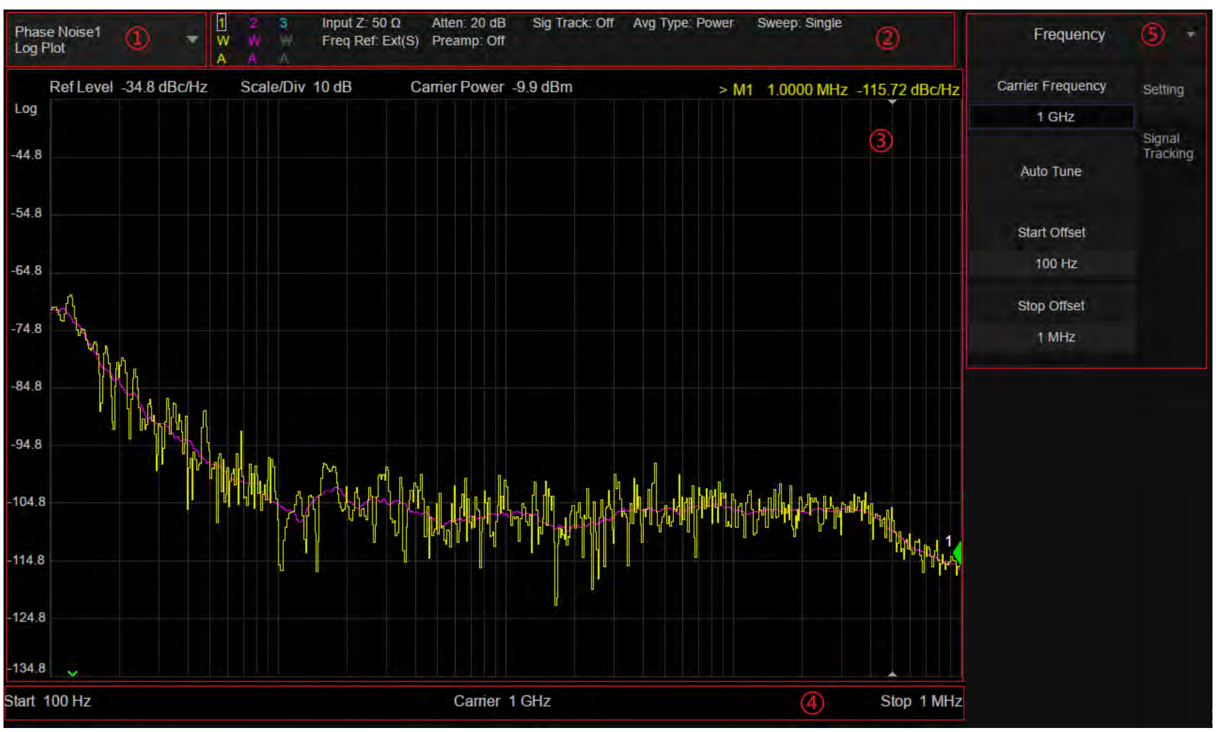
Phase noise analysis function

In practical measurements, this can be time consuming. The SSA5000A offers an automated measurement method that combines a series of automated offset measurements onto a single plot.

Click Spectrum Analyzer in the upper left corner after powering to enter the window management page. Click Phase Noise > Log Plot to add a window for phase noise analysis, and then the Spectrum analyzers will work in the phase noise measurement mode.

The working interface of phase noise analysis is similar to that of spectrum analysis, shown as follows

1. **Mode/Measure:** Indicates the current working mode and measurement function of the analyzer, and click to select from options inlcuding spectrum analysis mode, real-time spectrum mode, etc.
2. **Instrument Configuration**: Indicate the main working states of trace, interface, sweep, trigger, etc.
3. **Measurement Result:** Display the signal measurement results of the analyzer in various forms such as waveform, spectral line, cursor, table, statistics, constellation diagram, etc
4. **Sweep Parameter:** Indicate and control the main sweep parameters, such as frequency, resolution, scanning time, etc.
5. **Menu:** Complete the parameter setting of the analyzer.



Operation interface of phase noise analysis function

Frequency Settings

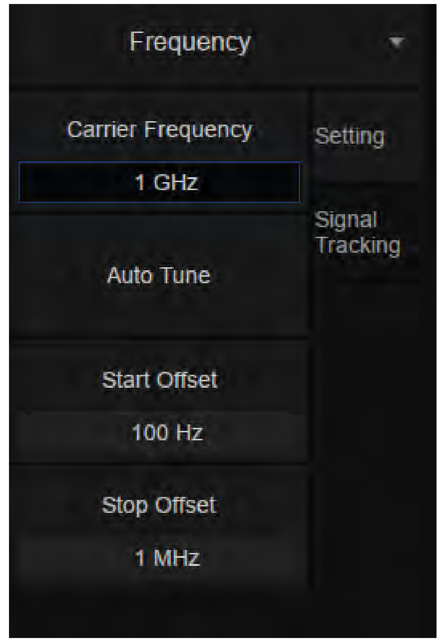


Figure 0-1Frequency Settings

Carrier Frequency: set the frequency of the carrier

Auto-tune: Spectrum analyzers will automatically locate and set the carrier frequency and set the offsets.

Start Offset: minimum offset from the carrier frequency.

Stop offset: maximum offset from the carrier frequency.

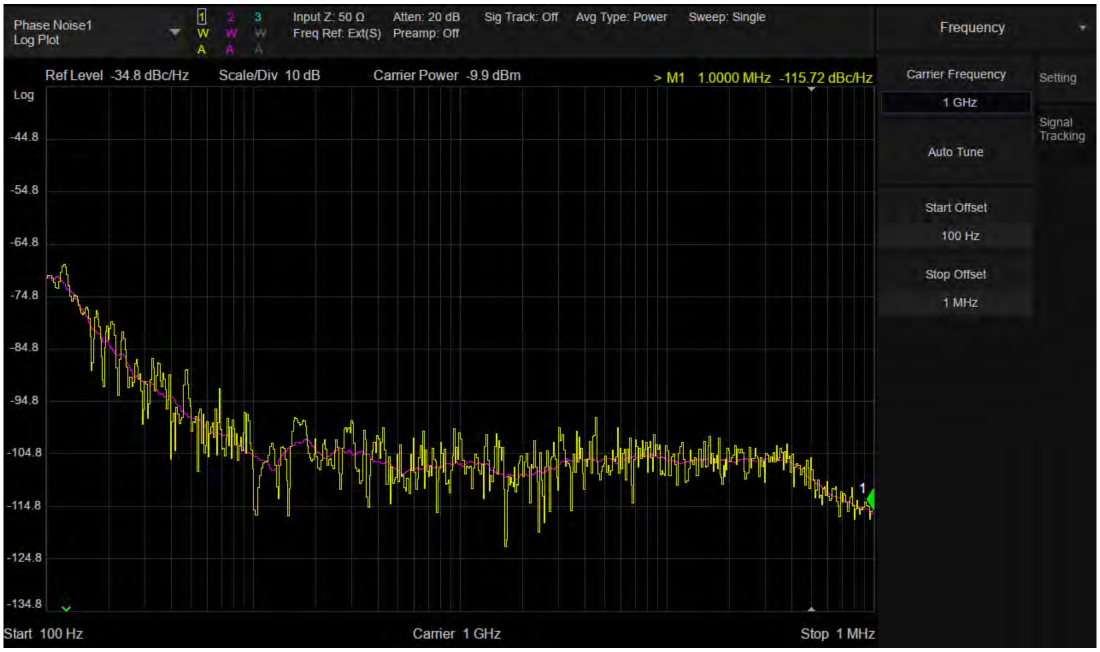
After completing the setup, the Spectrum analyzers will automate the measurement process and repeat the measurement within the defined frequency offset range.

Signal Tracking Setup

Since the input source is not always stable, it will have a frequency deviation, resulting in biased test results. This function tracks the frequency deviation within a specified range, to minimize the effects of frequency deviation.

Test results reference

The single-sideband phase noise measured within the specified frequency offset range is shown below. In the figure, the offset range is 100 Hz to 1 MHz. The log scale is used for the horizontal axis because in this way it is possible to obtain both a wider frequency range and a finer resolution when close to the carrier; smaller offsets tend to reflect the quality of the signal better than phase noise at larger frequency offsets.



Test results

Here, trace 1 is the original data and trace 2 is the smoothed single-sideband phase noise.

Advantages of SSA5000A phase noise function

Lower Displayed Average Noise Levels

When using the spectrum analyzer for phase noise measurements, the phase noise is calculated from the carrier power and the noise power at different offsets of the carrier. The noise power to be measured is generally small, and in order to keep the phase noise from being covered by the Spectrum analyzers' display average noise level (DANL), the Spectrum analyzers' display average noise level is required to be very low. The SSA5000A's display average noise level is lower than -165dBm/Hz. Users can evaluate whether the input signal amplitude is appropriate and the measurement is correct based on DANL and the phase noise of the Spectrum analyzers.

Smaller resolution bandwidth

The performance of Spectrum analyzers is highly demanded when measuring phase noise with very small offsets from the carrier. A very narrow resolution bandwidth is required to avoid measuring carrier power and noise power in an RBW filter. The SSA5000A has a minimum resolution bandwidth of 1 Hz, and the starting frequency offset in the phase noise measurement function also supports a 1 Hz setting.

Lower phase noise

The phase noise of the Spectrum analyzers can also have an effect on the test. Spectrum analyzers usually have multiple local oscillators (LOs). During testing, the spectrum analyzer's oscillators have their own phase noise, which will be added to the phase noise of the measured signal as it moves through different stages in the analyzer.

Therefore, when using a spectrum analyzer to measure phase noise, it is necessary to distinguish the phase noise in the original signal from the phase noise added by the instrument. The simplest way is to ensure that the spectrum analyzer's phase noise specifications are far superior to the device under test (DUT). Siglent's SSA5000A has a phase noise lower than −105 dBc/Hz@1GHz at 10kHz offset, which meets a considerable number of measurement requirements.

RF Pulse Measurements

Introduction

RF pulse signals are widely used in pulse modulation and testing of pulse signals is necessary for engineers working in related fields. In some critical areas such as signal design and verification require integrated time domain/frequency domain/modulation test tools for pulse signal analysis. SIGLENT SSA5000A's Pulse function provides pulse analysis that can help engineers better analyze today's dynamic signal environment.

Characterization of Pulse Signals

Figure 2-1 shows the simplest way to generate RF pulse signals. The pulse modulator can be understood as a switch. The baseband pulse controls the on and off of the signal, thereby converting the input CW signal into a radio frequency pulse signal. This process can also be understood as the time domain multiplication of CW signal and baseband pulse signal.

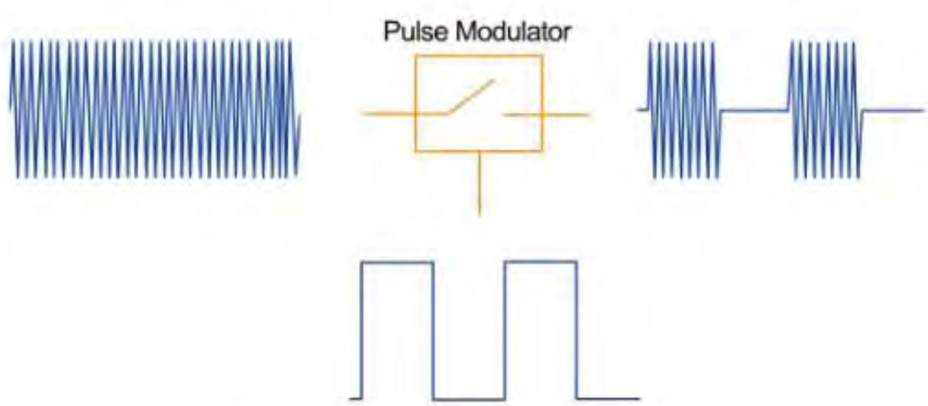


Figure 2-1 pulse modulated signal

Multiplication of two signals in the time domain is equivalent to the convolution of their spectra. The spectrum of the CW signal is theoretically a single spectrum line. According to the spectrum of the baseband pulse signal, the spectrum of the radio frequency pulse signal can be obtained as shown in Figure 2-2.

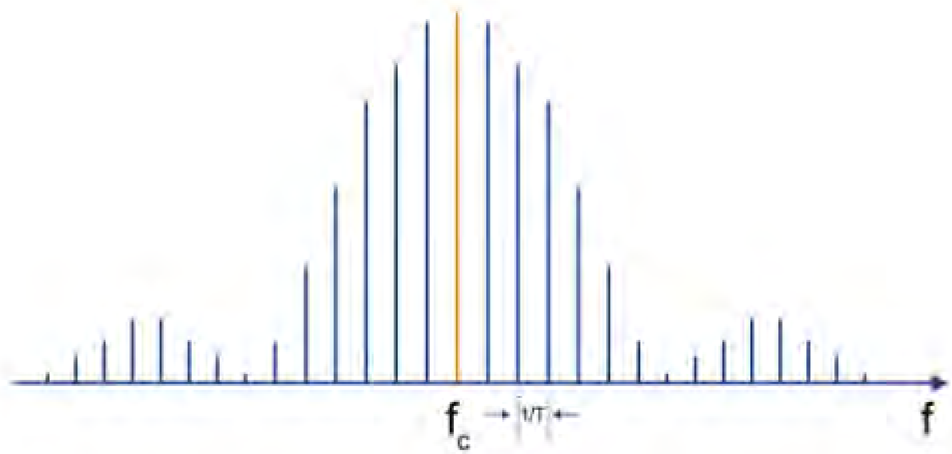


Figure 2-2 spectrum of radio frequency pulse signal

The pulse-modulated signal is a periodic signal, and its spectrum is a discrete spectrum. The amplitude of each spectral line changes according to the Sinc function. The spacing between neighboring spectral lines is the reciprocal of the baseband pulse period T. When actually testing with a spectrum analyzer, the envelope spectrum or line spectrum can be shown by setting different RBW. When the RBW is smaller than the spectral line spacing, a line spectrum is obtained; when the RBW is gradually increased, it is gradually shown as a pulse envelope spectrum.

In terms of the time domain, the greatest characteristic of the pulsed signal is the discontinuity in time domain. Burst characteristics in the time domain is a basic requirement for pulsed use and therefore the pulse signal parameters are also the main metrics for pulse signal quality assessment. The time-domain discontinuity of pulsed signals also adds to the difficulties in power and spectral testing.

In this note we will discuss time and frequency domain testing of pulses.

Analyze pulses by using the Pulse Function of the SSA5000A

Configure the SSA5000A

As a universal instrument that can handle both spectral power and bandwidth analysis, the spectrum analyzer can be used for power testing while observing the spectrum if there are no especially demanding requirements for accuracy. The pulse function of the SSA5000A can be used to measure pulse width, amplitude and time parameters. In the pulse analysis function, the spectrum analyzer is in zero-span mode. At this time, the spectrum analyzer is equal to a peak power meter, which can be used to detect the envelope of the signal at a specific frequency point with a certain bandwidth and draw the time-dependent power curve. In this case the RBW of the spectrometer is equivalent to the bandwidth of this detector. The spectrometer in zero span mode will pin the local oscillator at the center frequency, so we need to set the center frequency correctly in the frequency settings when performing pulse analysis. Actually, if the center frequency is offset a little from the actual carrier frequency, you may also get an acceptable test result, that's because most of the power of the pulse signal can pass through the IF filter.

Figure 3–1 test result of pulse test

The test results are shown in Figure 3–1, where the horizontal axis of the spectrometer is time and the vertical axis is power. The analyzer will automatically recognize the rising and falling edges of the pulse signal and calculate the power and rise/fall time during pulse switch. For narrow pulses, you can increase the analyzer's RBW for more accurate measurements. In fact, the rise time measured by the analyzer generally can't be better than the optimal rise time of the spectrum analyzer. The rise time of the analyzer is determined by the following formula: Tr=0.66/max RBW. The maximum RBW of the SSA5000A is 10MHz, which means that the rise time of the pulse must be greater than 66ns otherwise the analyzer won't give a correct result. For the line spectrum test, the VBW setting does not have much effect on the test results of the spectrum, but for the pulse test, the VBW should not be smaller than the RBW, otherwise it will result in a lower peak power. The VBW filter filters the envelope of the signal passing through the IF filter. While in pulse test, where multiple spectral lines pass through the IF filter at the same time, the synthesized envelope has it own bandwidth, and if the bandwidth is greater than the VBW bandwidth, the test result will be decreased. Generally, when testing sinusoidal signals, the VBW:RBW is selected from 1 to 3, while testing pulse signals, the VBW:RBW is generally selected 10 to minimize the effect on signal amplitude.

For pulse signals with known period, you can select periodic trigger in Trigger and set the trigger Period and pulse period to be the same. Thus, you can get a stabilized triggered pulse signal.

3.2 Result analysis

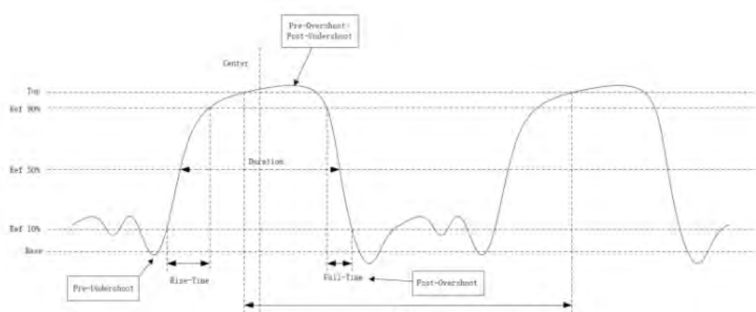


Figure 3−2 Pulse Signal Schematic

The schematic diagram of the pulse is shown in Figure 3−2, from which the individual results of the pulse measurement can be clearly seen. In the power measurements result Pospeak is the highest level on the trace and

NegPeak is the lowest level on the current trace. The spectrum analyzer calculates Amptmid = (PosPeak – NegPeak) / 2 + NegPeak. When a trace continuously passes through the pulse low reference (RefLow, 10%), pulse continuous reference (RefDuration, 50%), pulse high reference (RefHigh, 90%) (referred to as the rising edge), or when it passes through these three reference amplitudes in the opposite direction (referred to as the falling edge), mark this trace as the edge of the pulse. For a complete measurement of the parameters of the pulse, at least 3 edges are required. In pulse characteristics the pulse duration is the time difference between a positive pulse (negative pulse) passing through the pulse duration reference (RefDuration, 50%) on the rising edge (falling edge) and a falling edge (rising edge) passing through the pulse duration reference (RefDuration, 50%).

Pulse Off Time = Pulse Period – Pulse Duration. The duty cycle and frequency of the pulse can be calculated from the period and pulse width.

In the conversion characteristics, the rise-time is the time spent between the first rising edge of the pulse crossing RefLow and crossing RefHigh, and the fall time is the time spent between the first falling edge of the pulse crossing ReHigh and crossing RefLow. And the analyzer will automatically calculate the Pre-Overshoot, Pre-Undershoot, Post-Undershoot and Post-Overshoot of the pulse in dB.

Measure the pulse spectrum using the swept SA

Measuring the pulse spectrum by sweeping Spectrum Analyzer is the classic way which is commonly used by engineers in the last decades. This method is suitable for observing stable pulse signals with known pulse width and period. However, due to the limitation of the sweeping speed of the swept frequency spectrum analyzer, the analyzer has limit to track and capture the transient signals, and cannot observe the shortcut pulse signals and broadband modulated pulse signals well. When observing the Linear Spectrum using a sweep, we need to set the RBW smaller. However, when the RBW is small, the speed of data acquisition is much faster than the speed of digital processing speed, so it has a long dead time, and if there are some short disturbances, it is likely that these signals will be missed. The SSA5000A automatically switches the scan mode to FFT at 10kHz RBW or lower. In this way the analyzer will stay longer each time it tunes to a certain frequency, and will also analyze all the energy within a frequency spectrum. In this sense, the FFT can be viewed as a parallel array of IF filters operating simultaneously, thus speeding up the sweep speed. Therefore, when analyzing the spectrum of a pulsed signal, the results obtained using an FFT scan mode will be more accurate. The test results are shown in Figure 4-1.

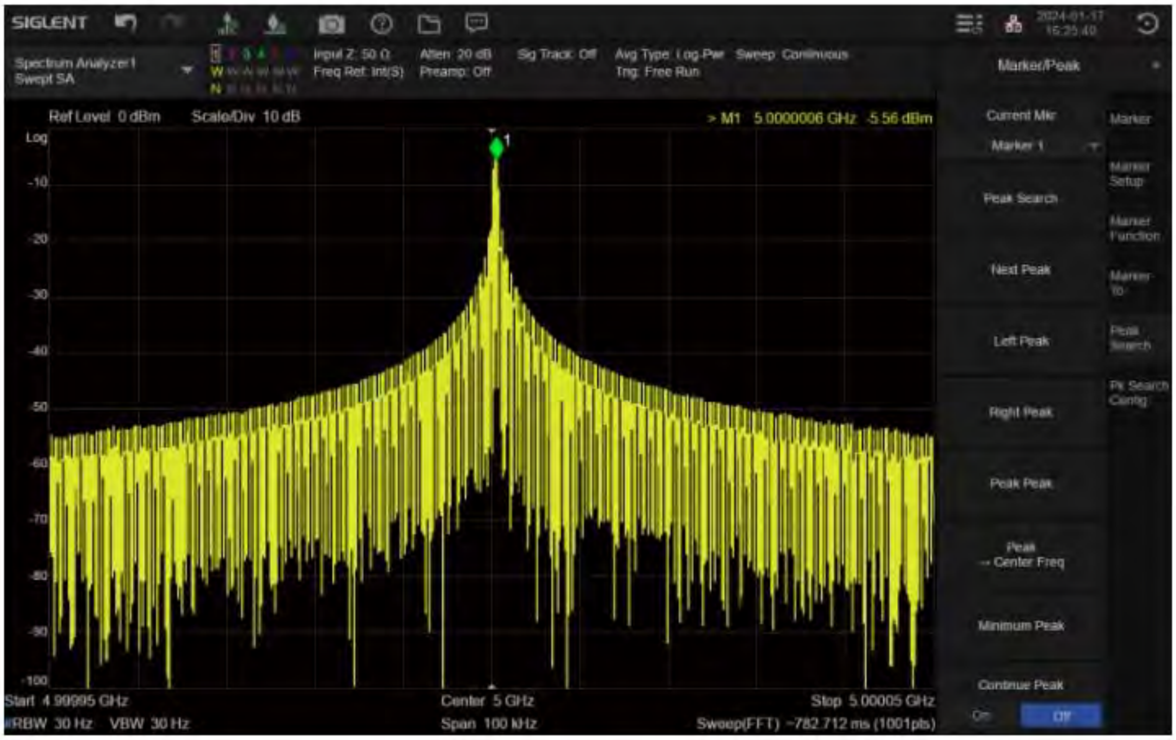


Figure 4-1 Spectrum of pulse modulation in SA mode

Measure the pulse spectrum using the RTSA

Unlike traditional swept spectrum analyzers, real-time spectrum analyzers do not perform oscillation scanning, but use a broadband ADC to sample signals within a certain bandwidth and perform spectrum calculations with the help of real-time FFT functions of FPGAs. This enables continuous spectrum generation of all ADC sample data without loss, so that no instant signal change is missed. Based on a large number of continuous FFT results, the real-time spectrometer can perform real-time frequency template triggering as well as three-dimensional displays in the time, frequency, and amplitude domains to accurately depict the signal change process. The biggest advantage of real-time spectrum analysis is the uninterrupted measurement of the spectrum and frequency-selective triggering. So, using these two advantages, RTSA is the most scientific tool for complex pulse analysis. The test result of spectrum and spectrogram in real-time spectrum mode are shown in Figure 4-2.

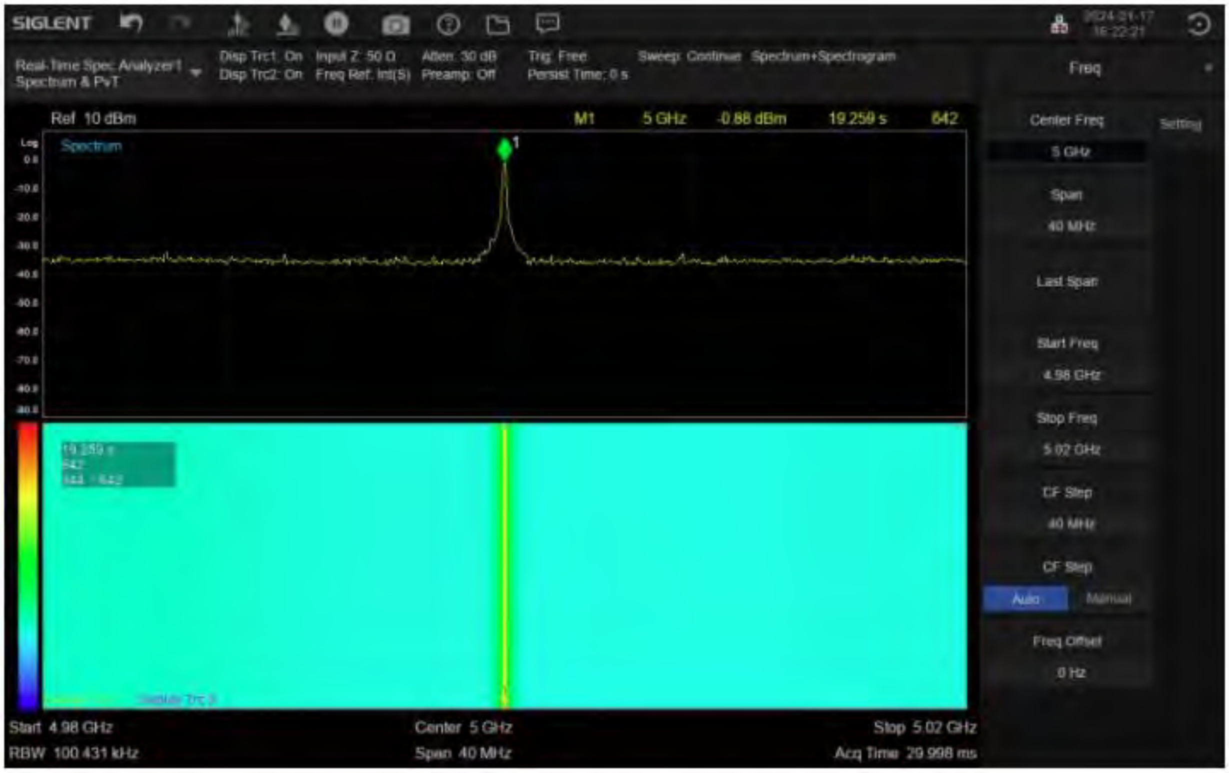


Figure 4-2 test result of spectrum and spectrogram