APPLICATION NOTE

Optimize Settings for Improved Spectrum Analyzer Sensitivity

Improving the sensitivity of spectrum measurements is key to measuring low-level signals.

Introduction

Signal analyzers (also known as spectrum analyzers) are often used to measure low-level signals, both characterized and unknown. By utilizing noise correction, noise floor extension (NFE), and optimal signal analyzer settings, the device's best sensitivity can be achieved and therefore allow for easer detection and measurement of low-level signals.

Sensitivity of signal analyzers are generally listed in the specifications for the instrument, most commonly as either the displayed average noise level (DANL) or the noise figure (NF). DANL, given in units of dBm/Hz is specified as the amplitude of the signal analyzer's noise floor in a 1 Hertz resolution bandwidth (RBW) over a given frequency range with a 50-ohm load termination and 0 dB input attenuation. In most cases, any averaging that is applied to the signal is performed on a logarithmic scale, lowering the noise floor by 2.5 dB; this reduction is the main differentiator between DANL and NF.

The noise floor of a signal analyzer consists of two components: the noise figure, denoted as NFSA, and the thermal noise energy. The amplitude of the latter describes the amount of thermal noise energy present at the input of a signal analyzer with the same load termination as the DANL. This amplitude is often represented by the formula kTB, where the three parameters are defined as below:

- k = Boltzmann's constant (1.38 x 10-23 Joules/Kelvin)
- T = temperature of the device's surroundings (Kelvin)
- B = bandwidth in which the noise is measured (Hz)
- -2.51 dB = the under response when measuring noise using log video averaging
- 0.24 dB = correction for the noise bandwidth of the RBW filters in X-Series Signal Analyzers compared to the nominal RBW bandwidth

Generally, the bandwidth is normalized to a 1-Hz bandwidth, leading 10 x log(kTB) to equal -173.98 dBm/Hz at room temperature. DANL in a 1-Hz RBW is then given by:

$$DANL = -173.98\ dBm/Hz + NFSA - 2.51\ dB + 0.24\ dB \qquad \text{[Equation 1]}$$

Which may be rewritten as:

$$NFSA = DANL + 176.25\ dB/Hz \qquad \text{[Equation 2]}$$

*Note: when root-mean-square (RMS) averaging (instead of log video averaging) is used in DANL specifications, the 2.51 dB can be omitted from calculations.

For example: A -151 dBm/Hz DANL specification equates to a NFSA value of 25.25 (dB)

Settings That Affect Sensitivity

A properly calibrated signal analyzer, that is, one in which the display accurately reflects the signal(s) being applied at the input port, should display unity gain. Essentially, any signal applied to the input port, such as a 0-dBm signal, should be measured and displayed with a level of 0 dBm plus or minus the accuracy of the analyzer. Changes to attenuation or gain will alter this relationship.

Specifically, an increase in input attenuation will correspond to an equivalent gain increase in the signal analyzer's intermediate frequency (IF) stage. This occurs to maintain a calibrated level, or signal-to-noise ratio, on the display, which is achieved by raising the noise floor. External attenuation would produce a similar result. The formula below determines the noise floor of the signal analyzer as a function of attenuation, as well as resolution bandwidth (RBW). The equation includes a "10 x log (RBW)" term that compensates for RBWs greater than 1 Hz.

$$Noise\ Floor = DANL + Attenuation + 10\log(RBW) \qquad \text{[Equation 3]}$$

Equation 3 defines a relationship that can be used to improve the noise floor. There will often be a secondary DANL specification that covers the use of internal preamplification, in which the equations are applicable. For the case of external preamplifier use, however, the modified DANL can be found using the equation below, which is the result of the cascaded noise-figure equations, with unity gain for the signal analyzer. Considering this system as the combination of a preamplifier and a signal analyzer, the equation is more commonly denoted as the following:

$$NF_{system} = NF_{preamplifier} + [(NFSA - 1)/G_{preamplifier}]$$

[Equation 4]

Example: Let's take NFSA = 25.25 (dB) from the previous example and consider a preamplifier gain of 20 (dB) and a noise figure of 5 (dB). Converting these to power ratios and plugging them into Equation 4 looks like this:

Step 1. Convert log values to linear terms.

$$NFSA_{linear} = 10^{\frac{25.25}{10}} = 334.97$$

$$G_{preamplifier} = 10^{\frac{20}{10}} = 100$$

$$NF_{preamplifier} = 10^{\frac{5}{10}} = 3.16$$

Step 2. Plug linear values into equation 4.

$$NF_{system} = 3.16 + [(334.97 - 1)/100]$$

Step 3. Find the logarithmic value.

$NF_{system} = 10\log\,[3.16 + (334.97/100)] = 8.14\ dB$

This value can then be inserted in Equation 1 as NFSA and the new DANL with external preamplification can be determined.

In this case it improves from -151 dBm/Hz to -168 dBm/Hz.

$DANL = -174(dBm/Hz) + 8.14(dB) - 2.51(dB) = -168.37\ (dBm/Hz)$

As the example above illustrated, external preamplification can improve the noise floor a decent amount, but not without tradeoffs. In this case, the external preamplifier introduces nonlinear distortion to the system, which can inhibit the signal analyzer from measuring large signals as well. The solution to this is to use an internal preamplifier, as it can be switched on and off as the measurement needs change, rather than being active continuously. This solution is particularly useful in automated test environments for this reason.

This section explored sensitivity improvements that can be made to a signal analyzer through changes in the attenuation, RBW and preamplification settings. Most modern signal analyzers now also contain methods for measuring the noise floor and accordingly correcting for it in the measurement results of the signal, as we will see next.

Making Corrections for Noise

When a devices-under-test (DUTs) are measured with a signal analyzer, the resulting spectrum shown on the analyzer's screen is a combination of the DUT's input signal, the thermal noise, and the NFSA. When the DUT is disconnected from the input and replaced with a 50-ohm termination, the resulting trace on the analyzer's screen is purely the thermal noise and NFSA, which is defined as the analyzer's noise floor.

With improvements in signal analyzer technology, this noise floor can be measured, with the help of considerable averaging, and stored to a file known as the Correction Trace. When the DUT input signal is connected and measured, it saves the resulting trace into a file known as the Measurement Trace. Noise correction, the primary method discussed in this section, obtains the Resultant Trace, or the spectrum of the DUT input signal with the excess noise removed, by way of Equation 5 and 6:

$Resultant\ Trace = Measured\ Trace - Correction\ Trace$ [Equation 5]

$Resultant\ Trace = (DUT\ input\ signal + kTB + NFSA) - (kTB + NFSA) = DUT\ input\ sig$nal

[Equation 6]

Note that all values are converted from logarithmic (dBm) to linear milliwatts (mW) before the subtractions are performed, though the Resulting Trace is converted back to dBm and displayed that way on the screen of the signal analyzer. The reasoning for this is: 1) it allows for easier viewing of low-level signals and 2) it makes more accurate amplitude measurements due to the removal of errors supplied by the signal analyzer noise floor.

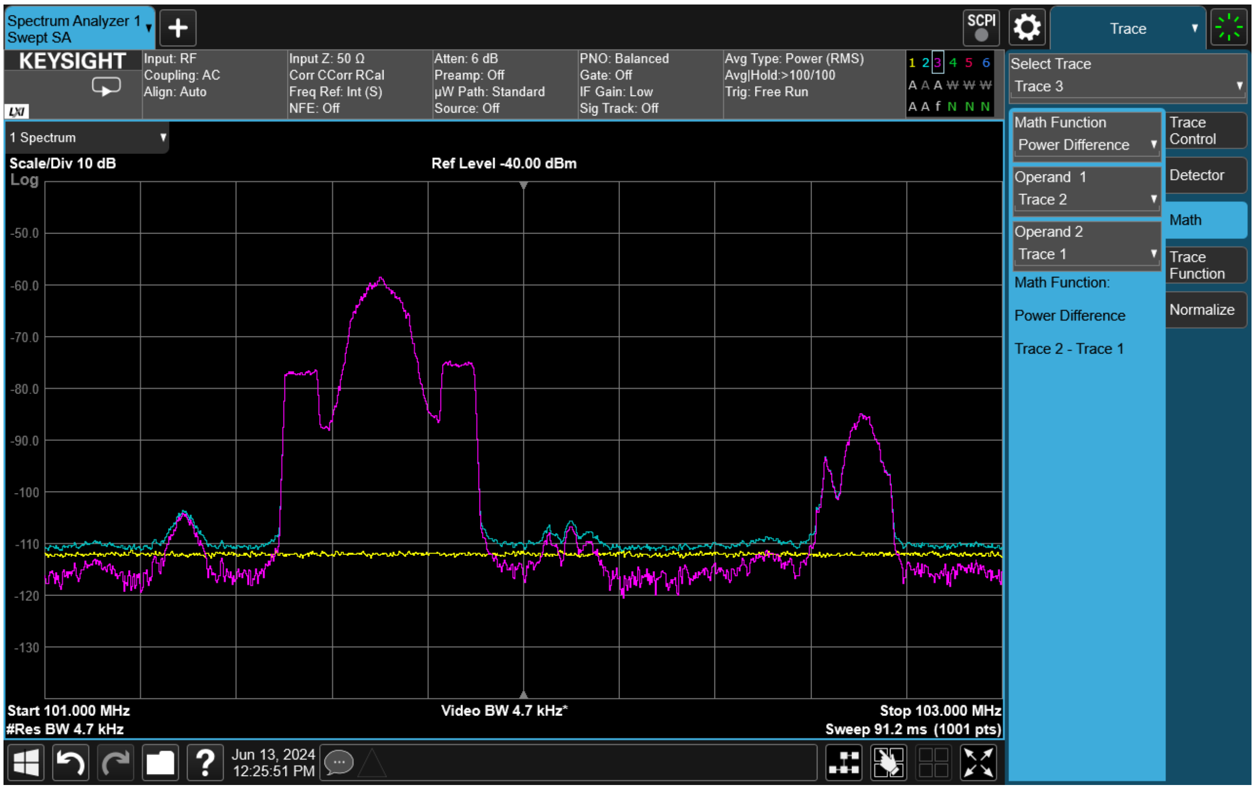

Figure 1. Shows a relatively easy method for performing noise corrections with trace math. The noise floor of the signal analyzer is first averaged with the input terminated, with these results saved to trace 1 (yellow). Then the DUT is connected, and its signal captured and saved to trace 2 (blue). Trace math is then used for a power subtraction of the two traces, with the results saved to trace 3 (purple). The noise correction shows the most benefit when the input signal is close to the noise floor of the signal analyzer. Corrections have little or no effect on larger signals, which have a much lower contribution to noise.

The main issue with this approach is that the DUT must be disconnected and a 50-ohm load connected whenever a setting is changed. A method for measuring the Correction Trace without removing the DUT is to increase the input attenuation (say to 70 dB) to raise the signal analyzer noise floor far above the DUT input signal and then save this to the Correction Trace. The Correction Trace will now contain the components shown in Equation 7.

$$Correction\ Trace = DUT\ Input\ Signal + kTB + NSFA + Atten \qquad \text{[Equation 7]}$$

If $kTB + NSFA + Atten \gg DUT\ Input\ Signal$, it is possible to omit the DUT input level and state the Correction Trace according to Equation 8.

$$Correction\ Trace = kTB + NFSA + Atten$$ [Equation 8]

By subtracting the known attenuation from Eq. 8, it is possible to get back the original Correction Trace used in the manual method shown in Equation 9.

$$Correction\ Trace = kTB + NSFA$$ [Equation 9]

The issue with this process is that the Correction Trace is valid only for the current settings of the signal analyzer. Changing settings such as center frequency, span, and RBW will invalidate the values stored in the Correction Trace. A better approach is to know the specific NFSA at all frequency points and then apply the Correction Trace for any setting.

The X-Series Signal Analyzers from Keysight Technologies utilize an advanced alignment named “Characterize Noise Floor” to measure and store the residual noise floor over the frequency range of the analyzer and over the various attenuator and signal paths, as part of its Noise Floor Extension feature (NFE; Figure 2). This data is then stored within the memory of the instrument. When a user turns on the NFE feature on the analyzer, the analyzer calculates a Correction Trace based on the current setting of the instrument and the stored noise figure values. This eliminates any need for measuring the noise floor of the analyzer, as was done in the manual procedure. This greatly simplifies the use of noise corrections and eliminates the excess time needed for measuring the noise floor of the instrument whenever a setting has changed. For NFE to function effectively, it is important to use sufficient trace averages. At least 10 trace averages are recommended.

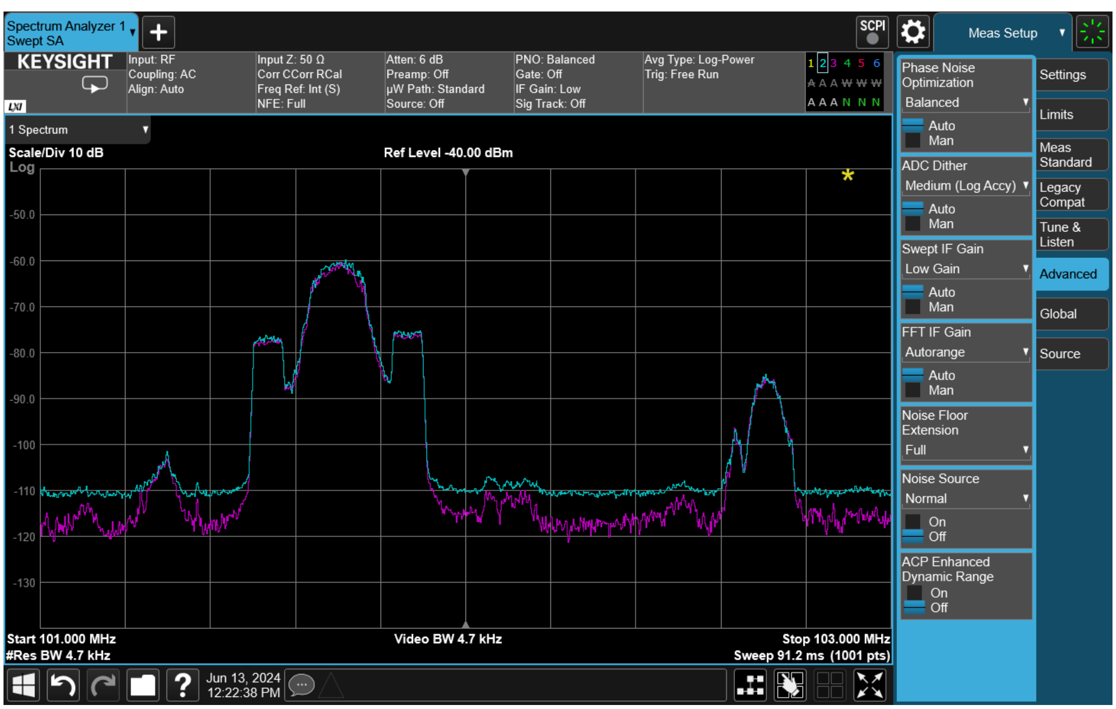

Figure 2. The Noise Floor Extension (NFE) feature in the Keysight N9040B UXA signal analyzer helps improve low-level signal sensitivity. The blue trace is the SA response without using NFE. The purple trace is the same signal after NFE is switched from off to Full. After NFE is switched to “Full” in this example, the noise floor is lowered around 10 dBm.

Follow this short guide to learn how to use the NFE feature:

Figure 3. In this scenario a fundamental signal is detected at 1 GHz as well as two lower-level signals seen on either side. Increasing the SNR would make the lower-level signals more visible. A quick way to increase the SNR is to lower the noise floor. A quick way to lower the noise floor is to use NFE. Start by pressing the third measurement bar selection at the top.

Figure 4. Next, press the "Noise Floor Extension" softkey and choose either "Adaptive" or "Full". Additionally, turn on trace averaging with a sufficient number of trace averages (≥ 10 averages)

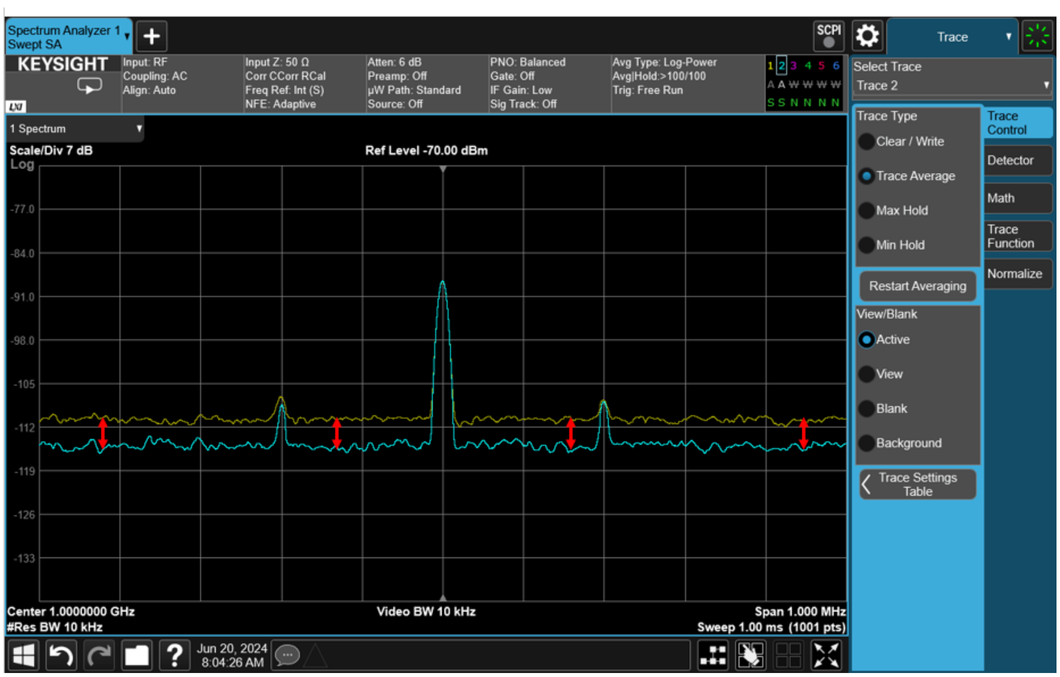

Figure 5. The blue trace is measuring the same signal, but with NFE Adaptive turned on. The noise floor decreased around 5 dB and the lower-level signals are easier to detect.

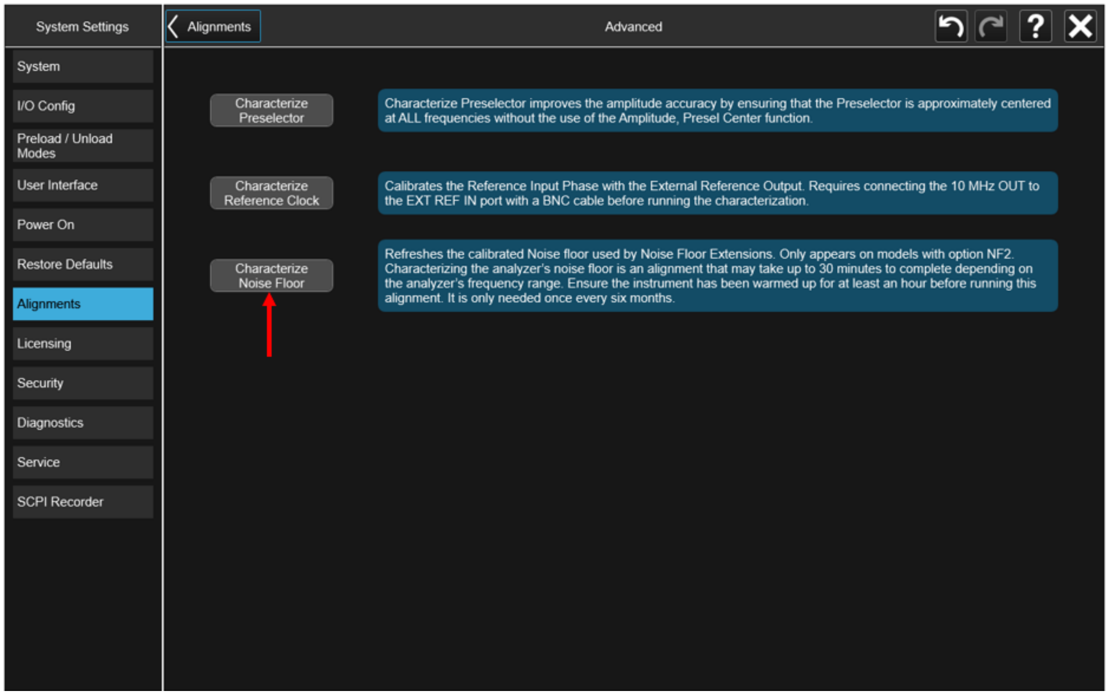

Figure 6. Shows the "Characterize Noise Floor" alignment, which can be reached by pressing "System Settings" → "Alignments" → "Advanced" → "Characterize Noise Floor". The noise floor may need to be characterized before using the NFE feature to achieve best results. The analyzer will automatically alert the customer annually when the Characterize Noise Floor alignment should be run; however, it can be run more often to ensure optimal results.

Noise Corrections in other measurements

Other applications and measurements in X-Series Analyzers additionally make use of noise corrections. The Power Suite measurements in the Spectrum Analyzers such as Adjacent Carrier Power (ACP) have had noise corrections since X-Series Signal Analyzers first launched. Additionally, other measurements such as Fast Power (FP2) have noise corrections. Additionally, whenever a known repetitive digital signal is measured repetitively, it is possible to mathematically reduce the correlated noise floor.

Conclusion

In each of the discussed methods for noise correction, the thermal noise (kTB) and NFSA are subtracted, which results in better sensitivity to detect and measure low-level signals that may have been covered by the noise floor. These methods and their results can be valid in many, but not all, cases. Problems occur when the measured values are close or equal to the noise floor of the instrument. In fact, if they are equal, the result would be negative infinity dB. Practical implementations of noise corrections normally include a threshold or a graduated level of subtraction close to the noise floor of the instrument. Also, don't forget to use sufficient averaging when applying NFE to reduce chaotic variations in the corrected noise floor.

This application note has examined some of the techniques for measuring low-level signals with a signal analyzer. It is important to be aware that sensitivity is affected by RBW, attenuation, and use of a preamplifier. Noise reduction methods, such as noise corrections and noise floor extension, can be applied to further enhance the sensitivity of the instrument. Additionally, ensure that external path losses to the signal analyzer are reduced, as they will additionally reduce sensitivity.

Resources

Using Noise Floor Extension in an X-Series Signal Analyzer (5990-5340EN)

Spectrum Analysis Basics (AN150) (5952-0292)

Dynamic Range Optimization for Distortion Measurement (5980-3079EN)

Faster Spectrum Measurements for X-Series Signal Analyzers (3123-1705.EN)

8 Errors Common to Spectrum Analysis (3122-1990.EN)

Making Fast and Accurate Power Measurements with Absolute Confidence (5992-2906EN)

Fast Power Measurements for X-Series Signal Analyzers (3120-1459.EN)

Getting the Most Out of Your X-Series Signal Analyzer (3121-1318.EN)

Time-Gated Spectrum Analysis with X-Series Signal Analyzers (3121-1446.EN)

Spectrum and Signal Analyzer Measurements and Noise (5966-4008E)

Full Bypass for X-Series Signal Analyzers (3120-1504.EN)