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APPLICATION NOTE

Noise Figure Measurement Using the VST3 Synthetic Noise Source

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Guide to This App Note

This application note is created with the assumption that the reader is familiar with basic Noise Figure measurement technique theory and is based on the use of a vector signal transceiver (VST) for stimulation and measurement of an RF front end device. This document scope is not meant to dive into detail around noise figure measurement theory and remains specifically focused on the Y-factor method using the synthetic noise source of the NI PXIe-5842 (NI's third-generation VST). For more information on the measurement theory, refer to the following article on ni.com:

Noise Figure Measurements: Theory and Application

Introduction

Basic Explanation of the Y-Factor Noise Figure Measurement

An important figure of merit with any active RF signal chain component is its noise contribution to the overall cascaded system. Front-end components such as power amplifiers (PAs) and low-noise amplifiers (LNAs) will introduce their own level of noise due to the physics of electrons colliding with internal materials during the flow of electrical current. The amount of this noise contribution in terms of decibels is known as the "noise figure" of a device.

In order to measure the noise figure of a component accurately, great care needs to be taken to isolate the measurement system from outside interference and also internal influence—even the analyzer making the measurement has its own noise figure to consider! There are two common methodologies for this type of measurement known as "cold source" and "Y-factor." For the purposes of this application note, we will focus on the latter.

The Y-factor method makes use of a calibrated "excess noise source" or "ENS" for short, to introduce a known stimulus to the device under test (DUT). The basic steps for such as test are to first calibrate the system in which a measurement of the ENS is taken both when turned off (T cold, where T is "temperature"), and turned on (T hot) while no DUT is inserted. This allows the analyzer noise figure and any cable or attenuator losses to be removed from the final measurement. Secondly, the measurement step also requires removing the cabled path leading to and from the DUT from the measurement by adjusting according to path characterizations. A basic block diagram is shown in Figure 1.

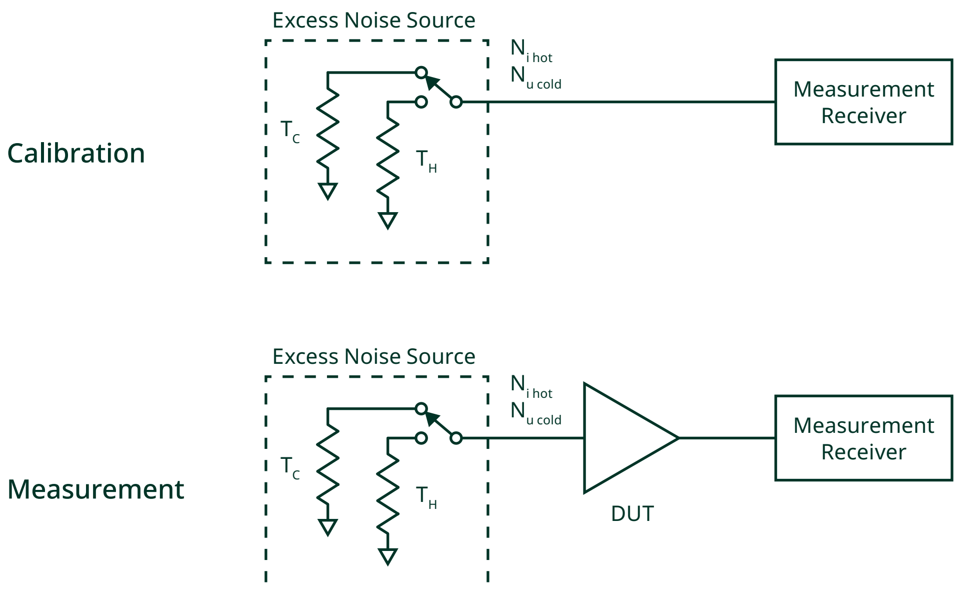

FIGURE 1

Y-Factor Measurement Setup

Finally, an EMI-protected measurement chamber should be used to enclose the DUT and protect from outside interference with the measured results.

With the ENS stimulus and response of the DUT measured at the output, the ultimate noise figure of the DUT can be calculated by finding the linear relationship or "noise factor (F)" and converting to the logarithmic version or "noise figure (NF)" by the following:

$$NF_{DUT} = 10\log_{10}(F_{DUT})$$

A complete derivation can be found in the previously linked article, "Noise Figure Measurements," but to at least call where this methodology gets its name, the Y-factor by definition is the ratio of output noise with the ENS turned on ($N_{o\ hot}$) to the noise at the output when the ENS is turned off ($N_{o\ cold}$).

$$Y = \frac{N_{o\ hot}}{N_{o\ cold}}$$

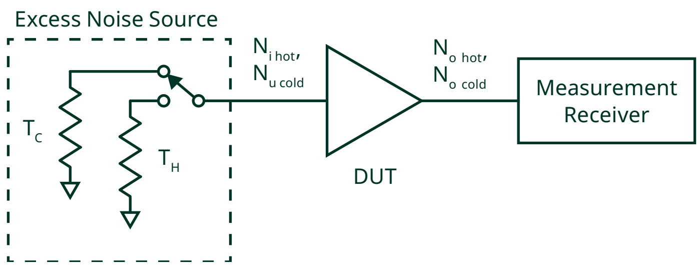

FIGURE 2

Y-Factor Measurement Setup

Where the output noise ratio is measured (denoted with N_o), the "excessive noise ratio" or "ENR" of the excess noise source (equivalent to the ratio of $N_{i\ hot}$ to $N_{i\ cold}$) is important to the equation to determine the accurate gains of the DUT under these conditions (see Figure 2). This, in effect, is how the noise figure, or noise contribution, of the DUT is ultimately determined.

A Quick Introduction of the NI PXIe-5842 and the Synthetic Noise Source Feature

The instrument used as an example for this note is the third-generation VST from NI, or the PXIe-5842. The PXIe-5842 includes a NI PXIe-5655 which is a dedicated low-phase noise, two-channel local oscillator (LO). This serves as the default “onboard” LO source for the VSG and VSA paths of the VST. As there are two independent LOs available, the generator and receiver can each independently tune while achieving best-in-class phase noise performance.

As components become more performant and the standard increases, the challenge of overcoming noise and distortion with dense constellations and wider bandwidths, so must the instrument become increasingly capable. The PXIe-5842 has improved dynamic range which translates to better inherent EVM performance, as well as a full frequency coverage of all three WLAN bands (2.4G, 5G, and 6G) in a single instrument.

A new feature of the third-generation VST is the inclusion of a “synthetic” noise source which is made possible through digital noise signal generation at the generator port (RF Out). The advantage of this is providing a single insertion point for a device under test that provides all of the typical capabilities such as single tone or modulated generation, as well as a calibrated noise source for noise figure measurements. The PXIe-5842 also supports the use of traditional external noise sources for noise figure measurements as an alternative.

Learn more about the PXIe-5842 and other PXI VSTs

Comparing Synthetic Noise Source to an External Noise Source

The ENS traditionally comes in the form of an external calibrated noise generator that is purpose-built for noise figure measurements. These sources typically use an avalanche diode to generate broadband, spectrally flat noise. The drawback of such a setup is that an RF switch must be utilized to change between the external noise source and the RF generator to accommodate the various DUT tests that are required without having to reconnect the DUT ports during automation. This introduces additional calibration and potential sources of system error or uncertainties to the measurement if not done carefully.

With the synthetic noise source option of the PXIe-5842, no changes in connection are needed during the test automation—but to be clear, there is still a cable change needed in the calibration phase of the entire system. Once calibrated, a DUT could be tested across the full test plan in terms of spectral, standard-based modulated, single tone, DC power, and noise figure measurements with a single insertion.

Naturally, we should look at the accuracy of each source in comparison to determine the uncertainty around the measurement results and establish the synthetic noise source efficacy.

Comparative Analysis

In one test experiment, an external noise source was used to measure an off-the-shelf PA along with the PXIe-5842 as the analyzer. Then to compare the results, the synthetic noise source was used to test the same DUT in the same test system.

To establish the experiment, here is a list of test conditions:

- The DUT was isolated in an EMI chamber to avoid any error from outside sources.
- The test was conducted from 50 MHz to 3.95 GHz in steps of 100 MHz to cover the frequency range of this particular PA.
- All test parameters were set according to the published datasheet of the PA.
- The test was conducted in a temperature-controlled lab and the PXIe-5842 was self-calibrated to ensure its own accuracy specifications.

The exact steps taken in this experiment are detailed in a later section of this application note, and the results can be seen in Figure 3. The worst-case difference in noise figure values is approximately 0.27 dB in this example, as the rest of the data points fall very close in agreement.

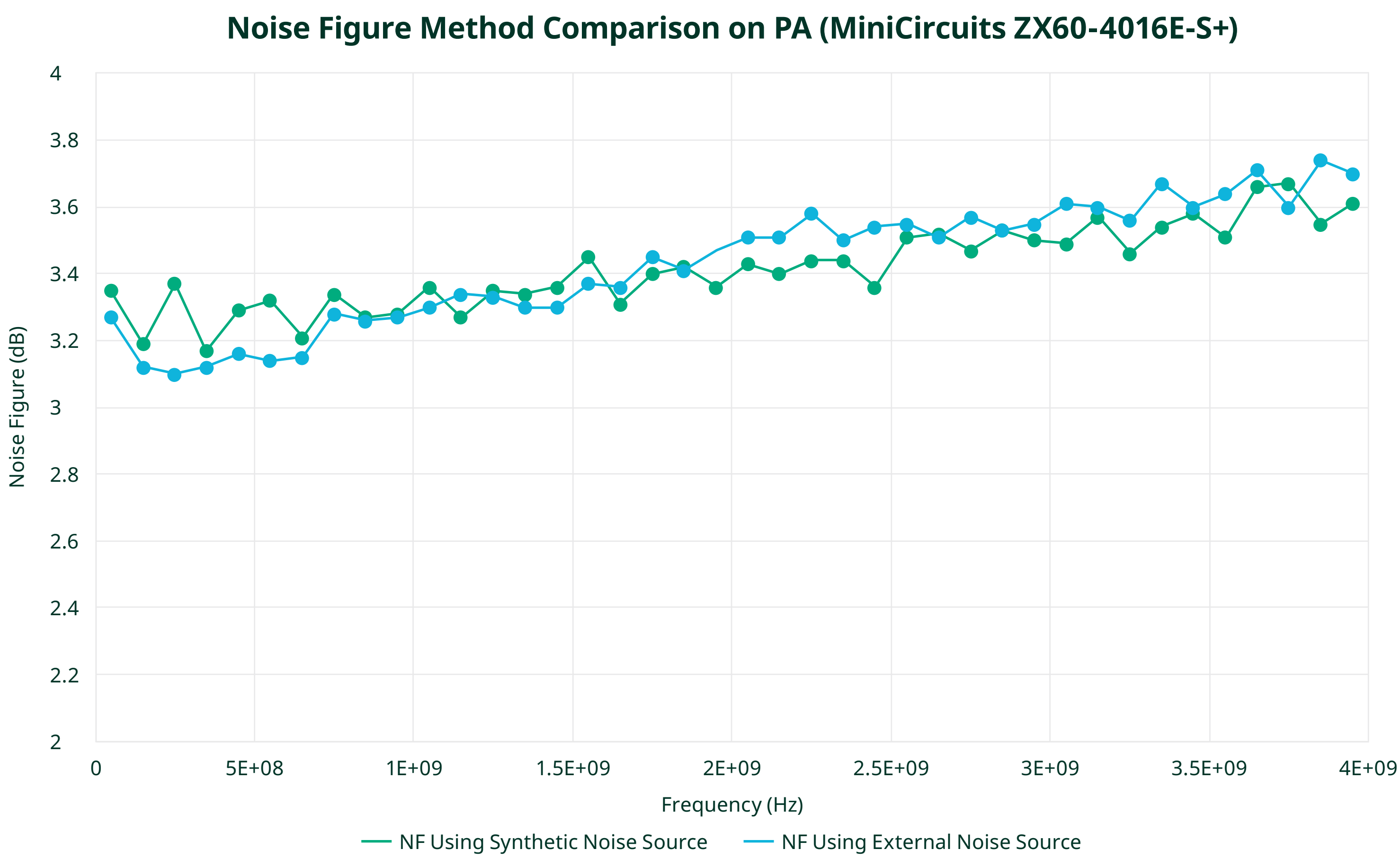

FIGURE 3

Comparison of Noise Figure with PXIe-5842 on a DUT Using an External Noise Source versus the Built-In Synthetic Noise Source

This is where understanding the inherent uncertainties of a noise figure measurement becomes very important to evaluate what the comparison means. Once again, the previously referenced and linked "Noise Figure Measurement" paper is an excellent source to read more detail about sources of uncertainty and how to reduce them in your test system. For the purposes of this note, we will simply take our DUT and instrument specifications and make use of a noise figure uncertainty calculator.

In this case, the measurement uncertainty of the test setup using the external noise source is found to be approximately ±0.26 dB > while the uncertainty of the setup using the synthetic noise source approach is around ±0.4 dB. Some of the factors that go into this calculation include the input and output impedance matches, the absolute accuracy of the excessive noise ratio (ENR), and the noise figure range of the DUT itself.

When overlaying these uncertainty ranges on the previous plot, we can get a more confident picture of how reasonably correlated these results are taking the given possible errors into account (See Figure 4).

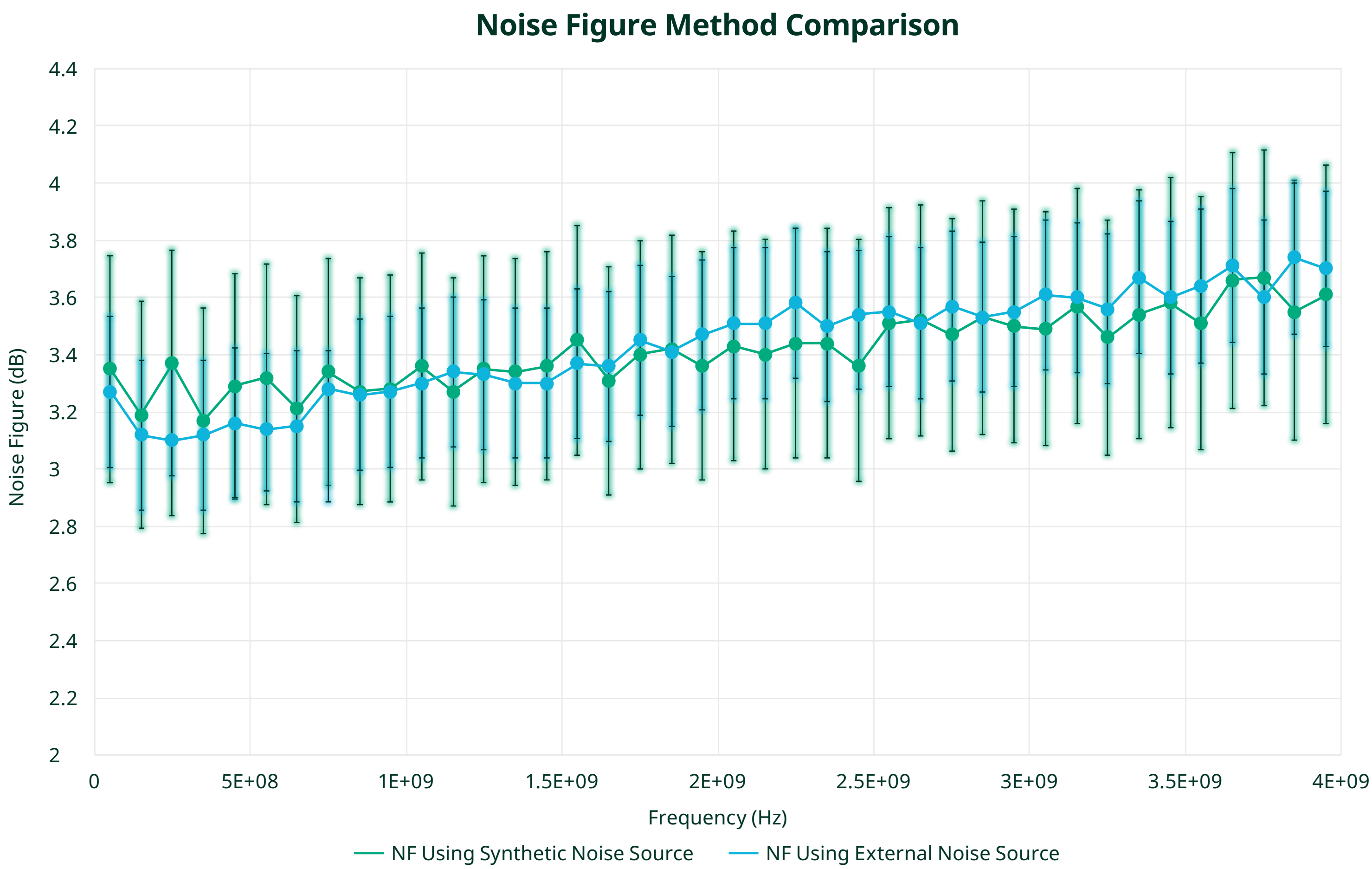

FIGURE 4

Comparison of Data with Uncertainty Error Ranges Shown

The external noise source uncertainty has a smaller error window overall, but as can be observed the measured data points fall within the overlapping ranges for every given frequency—showing a more tempered determination of the synthetic noise source efficacy.

With this experiment and results in mind, we will now walk through the steps of this test so that you, as the engineer, can measure your own DUT in the same way.

Using Synthetic Noise Source to Measure a Power Amplifier Noise Figure

Hardware Setup for Calibration Step

The initial setup for the noise figure measurement requires a calibration step in which the noise figure of the vector signal analyzer itself needs to be characterized across the same set of frequencies of the PA test so that its own contribution can be removed from the final measurement results. Additionally, it is important to characterize the VSA at the same reference level (internal analog state of the VSA) and measurement bandwidth as will be used for the final DUT measurement.

In order to complete this step, a loopback cable should be used to connect the VSG (synthetic noise source) to the VSA input, as seen in Figure 5. The contribution of the cable should also be accounted for so it can be de-embedded from this calibration. An important step not detailed in this application note is that all cables and attenuators that will be used in the test setup should be characterized across frequency on a proper VNA. This can be performed with any VNA that will yield s2p scalar losses across frequency. In this example, the same cable and 3 dB attenuator to be used for the DUT input during measurement will be used for convenience. Both cables leading to and from the DUT will include a 3 dB attenuator (to improve impedance match) and should be characterized independently.

The source measurement unit (SMU) seen in the diagram, the NI PXI-4130, will be used to power the PA during the measurement step.

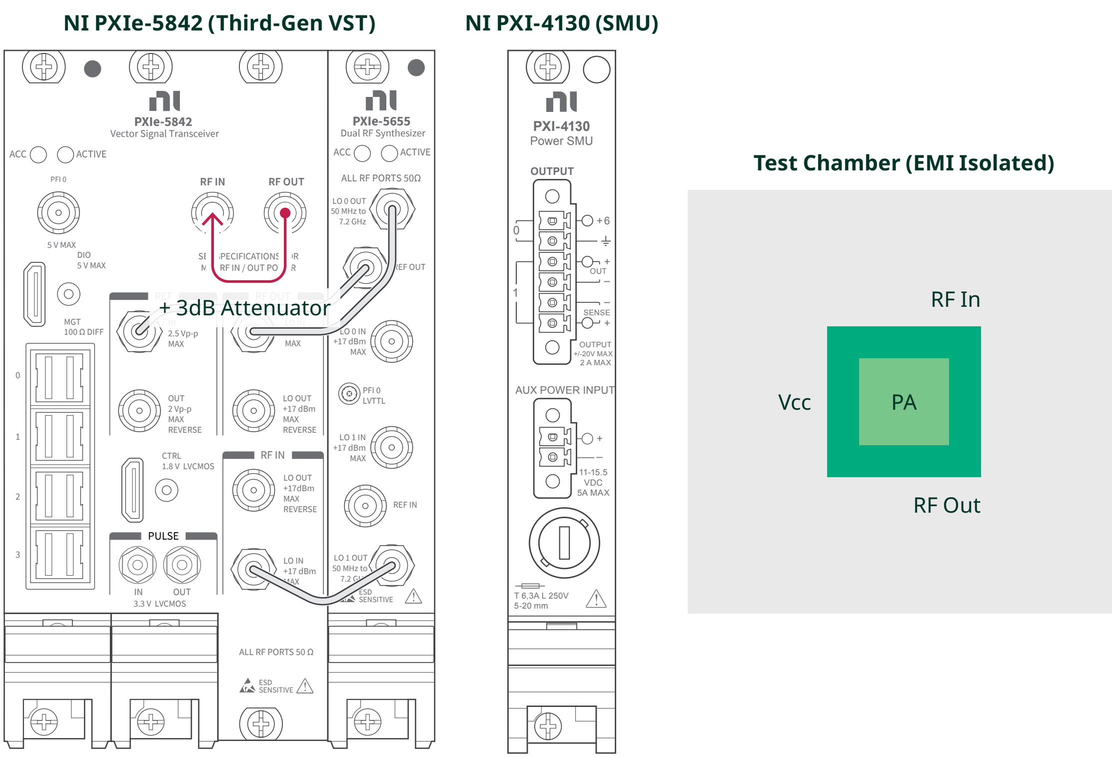

FIGURE 5

Hardware Setup Diagram for Calibration Step

The device under test (DUT) in this example is an off-the-shelf PA from MiniCircuits, model ZX60-4016E-S+, and the data sheet can be obtained **here**.

Coaxial Amplifier ZX60-4016E-S+

50 Ω 20 MHz to 4 GHz

Features

- Wide bandwidth, 20 MHz to 4 GHz
- Low noise figure, 3.9 dB typ.
- Output power up to 17.4 dBm typ.
- Protected by U.S. patent 6,790,049

Applications

- Cellular
- PCS
- Communication receivers and transmitters
- Lab
- Instrumentation
- Test equipment

CASE STYLE: GC957	
Connectors	Model
SMA	ZX60-4016E-S+

+RoHS Compliant

The + Suffix identifies RoHS Compliance.

Maximum Ratings	
Operating Temperature	-40 °C to 80 °C case
Storage Temperature	-55 °C to 100 °C
DC Voltage	12.5 V
Input Power (no damage)	13 dBm
Power	950 mW

Permanent damage max occur if any of these limits are exceeded.

Electrical Specifications at T_{AMB} = 25 °C

MODEL NO.			ZX60-4016E-S+
FREQ. (GHz)	f_L-f_u		0.02–4
DC VOLTAGE @ Pin V+ (V)			12.0
GAIN over Frequency in GHz typ. (dB)	0.1		20.1 Maximum Gain (dB)
	1.0		19.5
	2.0		18.2
	3.0		16.5
	4.0		14.9
	Min. at 2 GHz		15.7
MAXIMUM POWER (dBm) Output (1 dB comp.) typ.	f_L-f_u		17.4
			14.5
DYNAMIC RANGE	NF (dB) Typ.		3.9
	IP3 (dBm) Typ.		30.0
VSWR (:1) typ.	In	f_L-3 GHz	1.25
		3-f_u GHz	1.3
	Out	f_L-3 GHz	1.3
		3-f_u GHz	1.2
ACTIVE DIRECTIVITY (dB) Isolation Gain	Typ.		3–6
DC OPERATING CURRENT @ Pin V+ (mA)	Typ.		64
	Max.		75

FIGURE 6

Datasheet Summary for MiniCircuits ZX60-4016E-S+

In Figure 6, we can see some important values for our measurement setup: the frequency range of the DUT, the typical noise figure, and the maximum gain in dB, which is at the lower end of the frequency range—around F_c = 100 MHz.

Other information that is important to the setup and also calculating the uncertainties is the operating DC voltage and the input and output voltage standing wave ratio (VSWR) which is an indicator of impedance match in a 50-ohm system of the DUT.

The software used for the measurement is the RFmx Noise Figure personality, which you can learn more about in the following link:

RFmx Noise Figure

Calibration Steps

Once the hardware is connected as shown in the setup, the RFmx SpecAn Soft Front Panel in NI InstrumentStudio™ software can be launched and addressed to the PXIe-5842. The noise figure measurement can be added under the **ADD/REMOVE** button of the panel, which will close out all other open measurements (Figure 7).

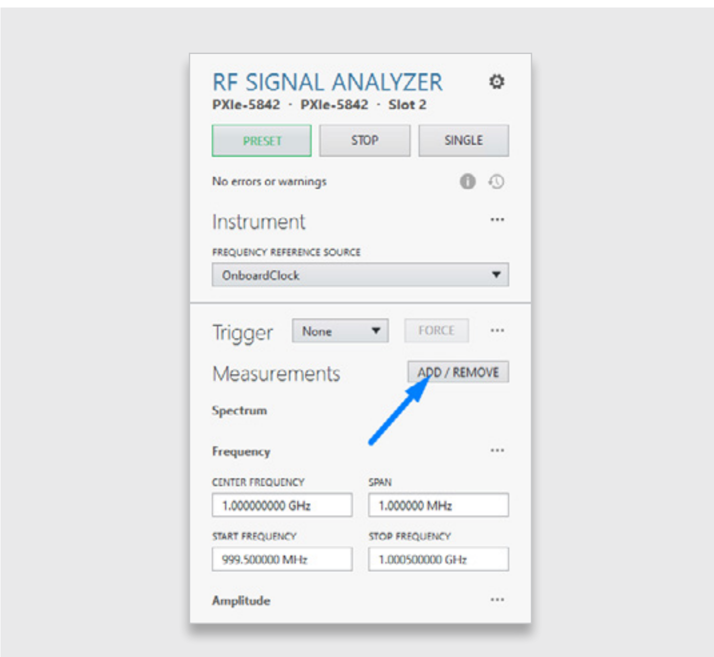

FIGURE 7

Adding the Noise Figure Measurement

With the measurement open, the sub-menu can be launched by clicking any of the three dot icons (...) on the right side of the panel. First, the ENS type needs to be changed under the **NF** sub-menu from **External Noise Source** (default) to **RF Signal Generator** which is selecting that the PXIe-5842 Vector Signal Generator is being used as the noise source (synthetic noise source) seen in Figure 8.

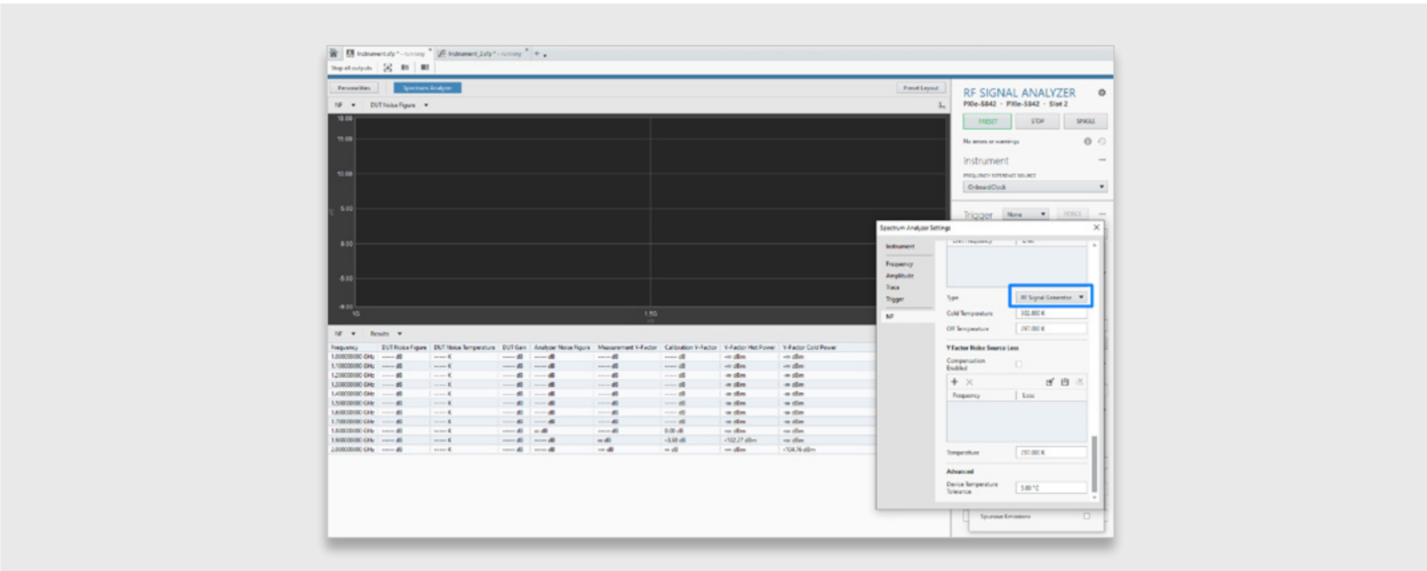

FIGURE 8

Selecting the Synthetic Noise Source for the Measurement

In order to calibrate the system in a way that is consistent with the measurement, it is important to select settings in this step that will also be used for the final measurement. We want the same parameters and the same analog state in the analyzer so we will input the following (See Figure 9):

1. **Measurement Bandwidth** = 4 MHz
   Measurement Interval = 100 ms
   This will set how wide in spectrum the noise figure will be measured across and should be set up to fall within the specification of the DUT as well as produce an acceptable frequency resolution in terms of power across the band. There is a tradeoff to be made here in terms of test time and accuracy, but this value was selected to be acceptable for both considerations in this specific setup.
2. **Start Frequency** = 50 MHz
   Stop Frequency = 4 GHz
   Step Size = 100 MHz
   This sets up the center frequency steps for the noise figure measurement.
3. **DUT Max Gain** = 20.00 dB
   DUT Max Noise Figure = 3.9 dB

These settings come directly from the DUT datasheet, as previously mentioned.

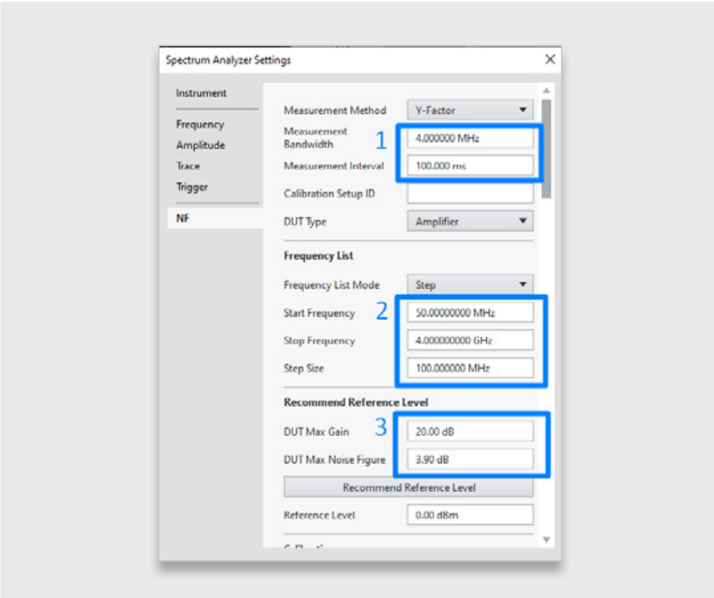

FIGURE 9
Setting Up the Calibration/Measurement Step Parameters

Additionally, scrolling further down in the sub-menu, there is a place to enter values that will allow the loopback cable used for the calibration step to be de-embedded (in order to accurately measure the analyzer noise figure across frequency steps) and a place to set the ENR of the source that we want to use for this test. The inputs are as follows (see Figure 10):

1. **Compensation Enabled** = True (checked)
   This will be enabled throughout the calibration step and remain enabled for the measurement step to maintain the relationship of the calibration setup to measurement setup.
2. **Calibration Loss Table** = [Frequency]/[Loss]
   A table of values can be input manually one step at a time or a .txt or .csv file can be input all at once using the icon with the arrow pointing into the box. Take note of Figure 10 to see an example of the .txt format. This was created from extracting the values from a standard .s2p touchstone file. Losses are input as positive values in dB (while they would be negative values in terms of gain). Where the losses from the file may not fall neatly on the frequency steps in the test list, the software will interpolate the values to adjust and apply the appropriate loss.
3. **Y Factor Noise Source** = ENR Frequency/ENR (dB)
   A table can also be input here where a source may vary in ENR across frequency. Because the external noise source used for comparison in this experiment stayed very close to 15 dB ENR, only a single frequency and value was input. This is automatically used for all frequency steps in the test list as a result.

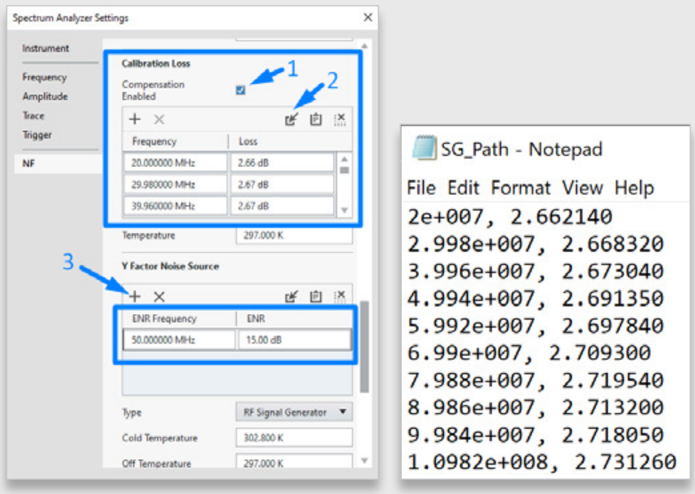

FIGURE 10

Inputting the calibration path loss values and ENR is shown on the left. An example of the TXT file format used in the table is shown on the right.

Once all of these parameters have been set, the recommended reference level for the measurement can be determined which will be used also during the calibration step as follows (see Figure 11):

1. Click **Recommend Reference Level** and the **Reference Level** field will be populated with the result (and automatically set).
2. Click the **Calibrate** button and the calibration will begin and show that it is processing. This is measuring the analyzer noise figure with the noise source turned off and turned on at each frequency, while taking the path losses into consideration.
3. Once the calibration procedure is complete, a dialog will appear to acknowledge success. Then click **OK** to clear.

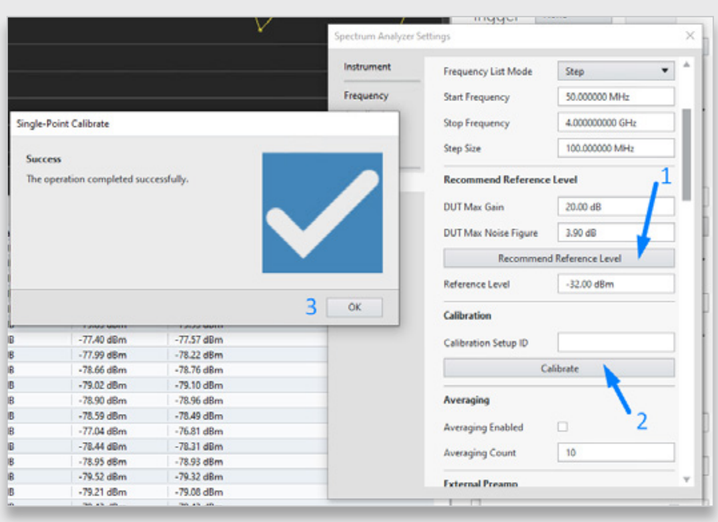

FIGURE 11

Executing the final steps for calibration.

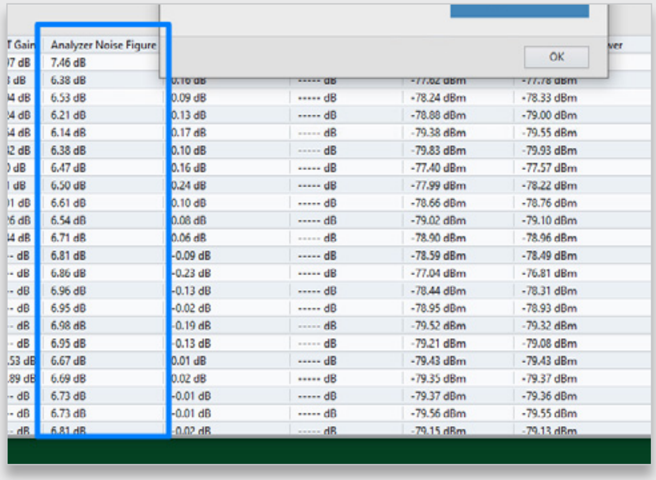

FIGURE 12

Analyzer Noise Figure Results

The values in the **Analyzer Noise Figure** column should now be shown across each frequency step in the test (Figure 12).

This puts the Soft Front Panel back into the "measurement mode." Before selecting **RUN** at the top of the panel, we can input values into the **DUT Input Loss** table of the **NF** sub-menu. Recall that the loopback cable plus 3 dB attenuator used in this calibration step will also be reused for the measurement to connect the RF Out port (the synthetic noise source) to the DUT input. So out of convenience, the same frequency vs. loss file can be input to this section while still in loopback.

What this will show is with the cable losses now accounted for and running the measurement, the **DUT Noise Figure** column and the **DUT Gain** column should show near zero values. This reflects the noise figure of the path and supports that this cabling and attenuator has been de-embedded from the upcoming measurement (see Figure 13).

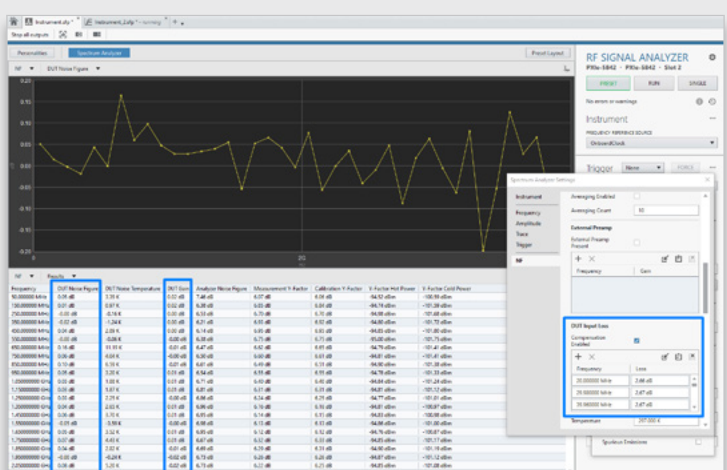

FIGURE 13

De-embedding the generator-side cabling for the DUT to show that it is being removed from the measurement before the DUT has been set up.

Hardware Setup for Measurement Step

Now that the calibration step has been completed, ensure that the panel is running by clicking **STOP** and set up the following (see Figure 14):

- The loopback cable plus 3 dB attenuator is now connected from RF Out (VSG) to RF In (DUT).
- A similar SMA cable plus another 3 dB attenuator is connected from RF Out (DUT) to RF In (VSA).
- A ground and lead wire are connected from the SMU to the DUT ground and VCC pins, respectively.
- The EMI test chamber is closed and secured to protect against outside interference.

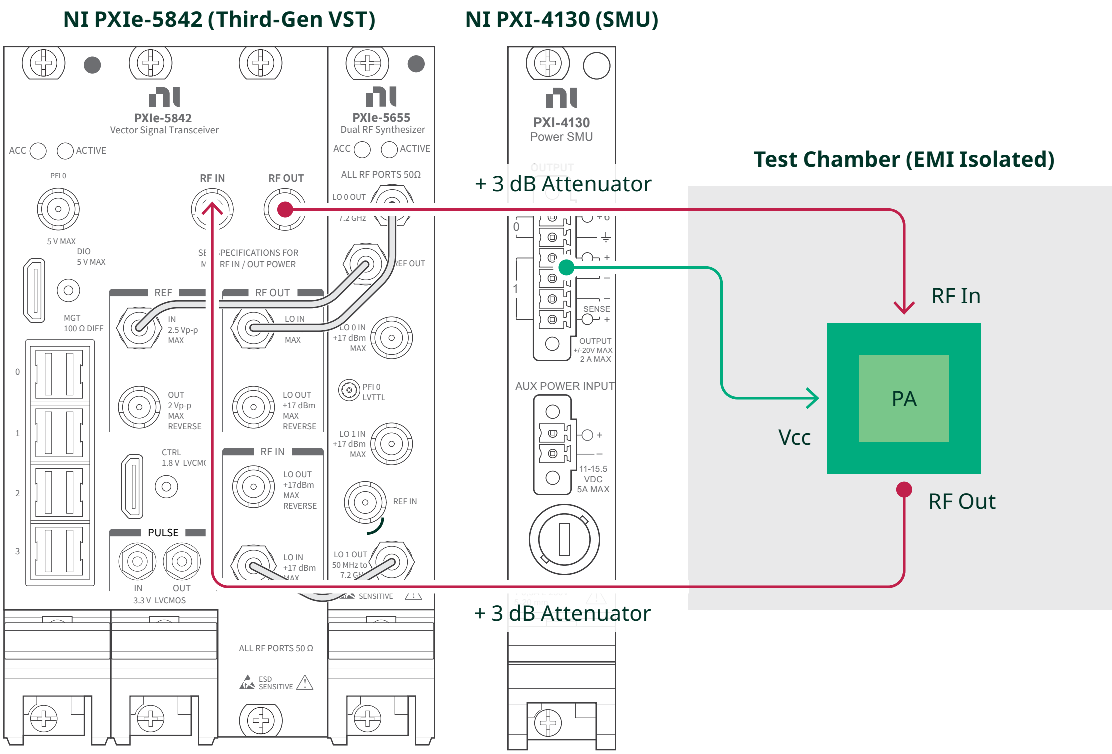

FIGURE 14

Hardware Setup Diagram for the Measurement Step

Measurement Steps and Results

Finally, with the DUT inline and connections made, the following steps can be taken for the final measurement:

1. The second cable and 3 dB attenuator passing from DUT output to VSA input now needs to be de-embedded from the measurement. The frequency vs. loss file can be input in the **DUT Output Loss** table the same as the **DUT Input Loss** table from the previous step (see Figure 15).

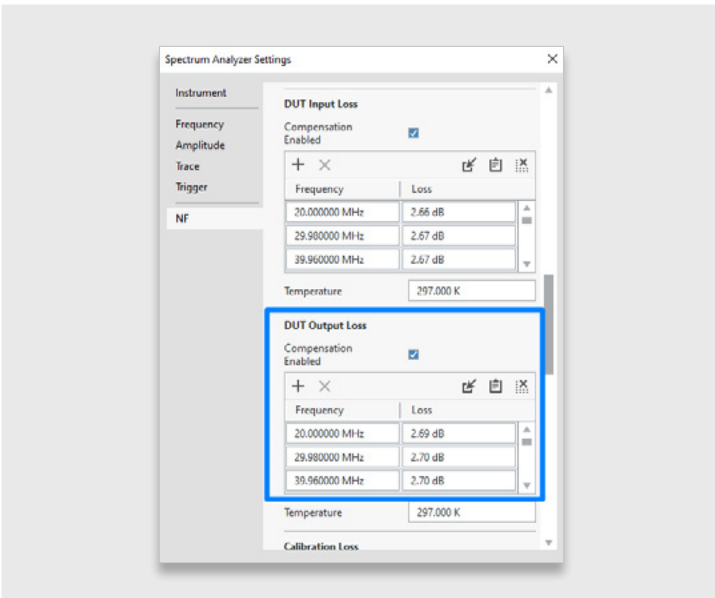

FIGURE 15

Hardware Setup Diagram for the Measurement Step

2. The DC Power panel in InstrumentStudio can then be used to power VCC using the NI PXIe-4130 (SMU), as seen in Figure 16:

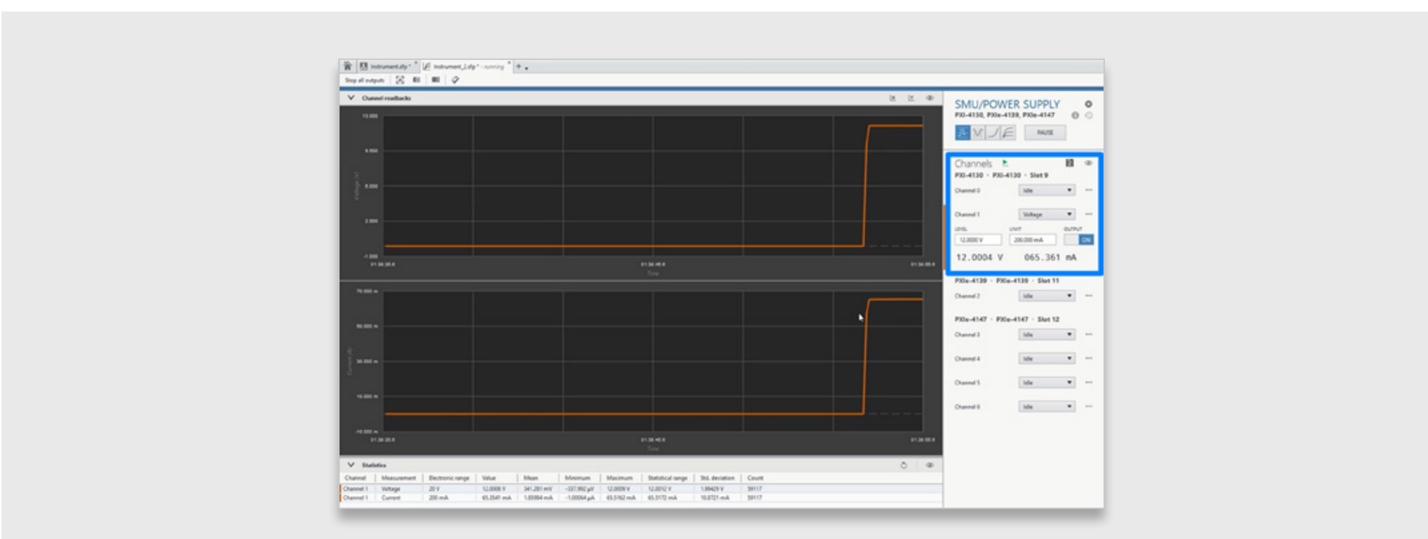

FIGURE 16

Powering the DUT with 12 V and a 200 mA Limit Using the PXI-4130

3. Click **RUN** and the measurement steps will execute resulting in the final noise figure measurements of the DUT (see Figure 17):

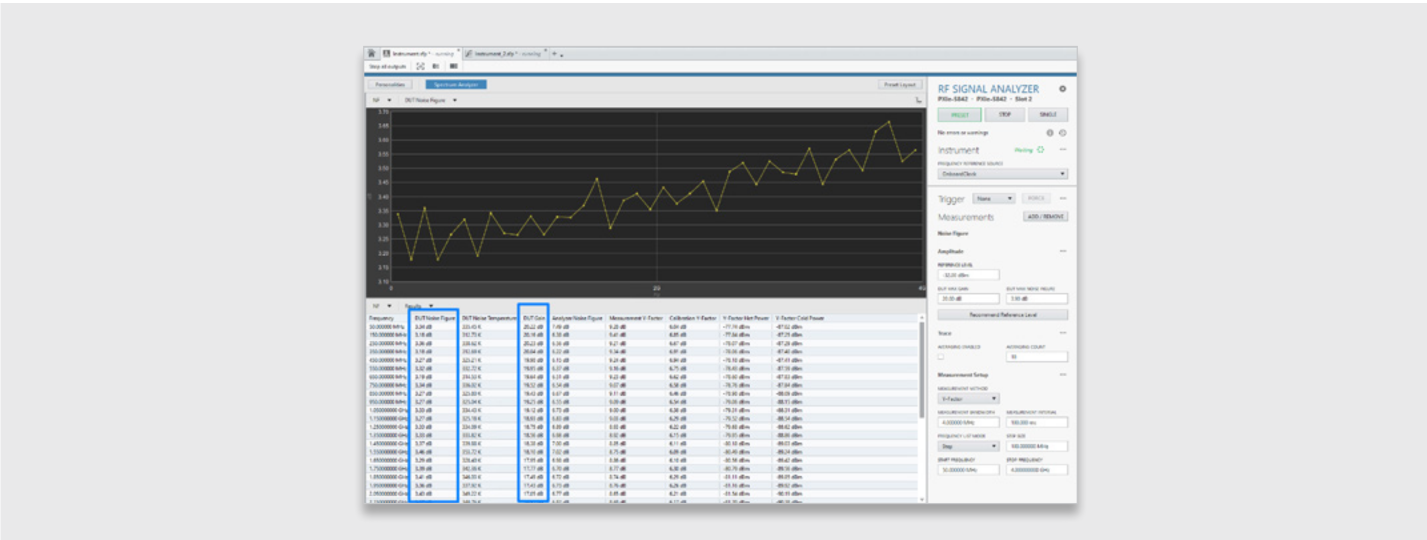

FIGURE 17

Final Measurement Results Showing DUT Noise Figure and DUT Gain per Center Frequency

Conclusion

The synthetic noise source feature of the PXIe-5842 can be utilized to simplify the RF test bench so that noise figure results can be seamlessly combined with standard-based modulated and spectral measurements by connecting to a single insertion point.

The hope is that a fair comparison between this approach and the traditional external noise source used for the Y-factor method was shown. Additionally, an example of the steps to recreate this experiment were given so that you might be able to apply to your own DUT and further qualify this approach as a good fit for your own lab.

Visit ni.com/support if you have any further questions about this or any other RF test.

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