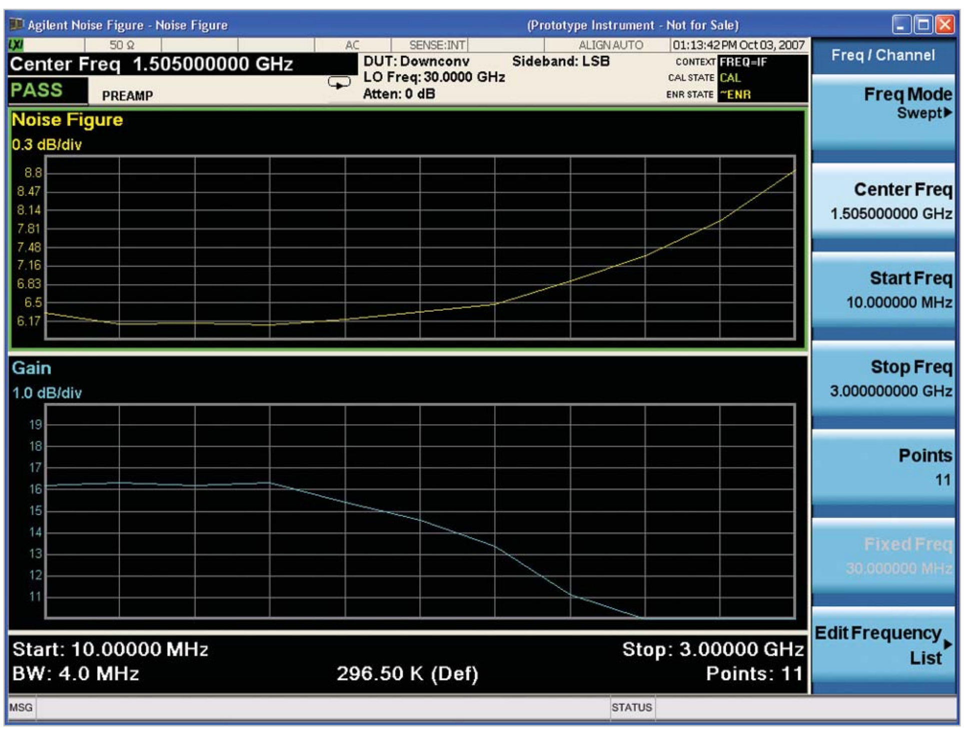
W9069A and N9069A Noise Figure Measurement Application

Technical Overview with Self-Guided Demonstration



Agilent X-Series Signal Analyzers Noise Figure Solution

A leader in noise figure solutions

Agilent Technologies

X-Series Noise Figure Measurement

Noise figure is one of the fundamental parameters that differentiates one system, amplifier, or transistor from another. In order to minimize the problems of noise generated in receiving systems, engineers can either make a weak signal stronger, or reduce the noise of that system or its individual components. Agilent's N9069A noise figure measurement application offers development engineers a simple tool to make accurate and repeatable noise figure measurements. Pair this measurement application with an Agilent X-Series signal analyzer and engineers can get fully specified results up to 3.6 GHz with the EXA, up to 7.5 GHz with the CXA, and up to 26.5 GHz with either the MXA or PXA. The speed of this application will also offer manufacturing engineers an efficient application for measuring any one of the following in their test racks without compromising speed:

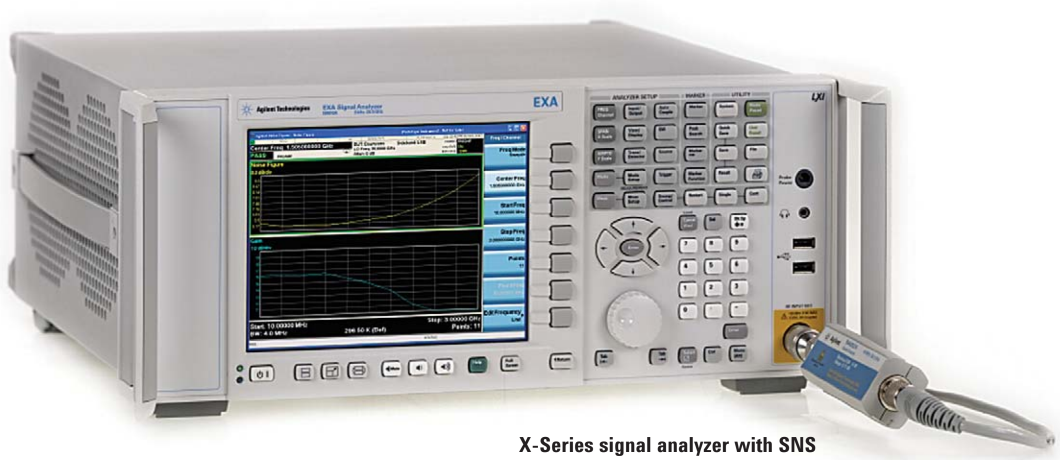
- Noise figure/factor
- Gain
- Effective temperature
- Y-factor
- Hot/cold power density

The noise figure application utilizes the Y-factor method for calculating the above values. By using a noise source, X-Series signal analyzers can determine the noise of the device under test quickly. This method is very simple as it is a ratio of two noise power levels: one measured with the noise source ON and the other with the noise source OFF. For further information on the Y-Factor technique see, *Noise Figure Measurement Accuracy: The Y-Factor Method*, Application Note 57-2 (5952-3706E).

The noise figure measurement application utilizes the easy user interface and incredible speed of the Agilent X-Series signal analyzers. The built-in help and step-by-step diagrams allow new users to start making measurements instantly and save their results quickly. When using this application on an X-Series signal analyzer, engineers will also benefit from full RF signal analysis capabilities in one instrument. In addition, the noise figure measurement application is code-compatible with previous Agilent noise figure solutions where hardware and measurements are the same. The application can be configured for remote programming via USB, LAN, or GPIB–all standard in X-Series signal analyzers.

Key features of the noise figure measurement include:

- User-defined sweep time to allow variable point averaging
- Code compatibility with ESA, PSA, and NFA
- Saved calibration data during power cycle
- External source control for variable LOs via LAN
- User-defined noise source settling time setting
- Internal uncertainty calculator
- SNS and 346 Series noise source support



X-Series signal analyzer with SNS

Noise source offerings

The traditional and cost-effective noise source is the 346 Series that operates with the full range of Agilent noise figure solutions. They are categorized by their frequency coverage as well as their excess noise ratio (ENR). Some active devices are sensitive to port match. They exhibit different noise figure values dependant on the source impedance. Noise sources will change their port impedance (SWR) as they are switched from P Hot to P Cold. Noise sources like the 346A have output circuitry that will minimize the impedance changes.

The SNS Series of noise sources, or smart noise sources, can be used in conjunction with the X-Series signal analyzers, NFA, and ESA spectrum analyzer. The SNS noise sources replicate the ENR output and frequency coverage of the 346 Series noise sources, however they have the added benefits. The ENR data is stored in an EPROM and is automatically downloaded to the instrument, saving the need to manually enter the values into the calibration table at each cardinal frequency point. In addition, a thermistor is built within the sensor to continually update the analyzer with the correct temperature, delivering automatic temperature compensation/correction within the measurement—an invaluable, time-saving benefit to engineers.

346 Series noise sources

SNS Series noise sources

Noise source comparison chart

Noise source	Frequency range	ENR–typical
346A	10 MHz to 18 GHz	5 to 7 dB
346B	10 MHz to 18 GHz	14 to 16 dB
346C	10 MHz to 26 GHz	12 to 17 dB
Q347B	33 GHz to 50 GHz	6 to 13 dB
R347B	26.5 GHz to 40 GHz	10 to 13 dB
N4000A	10 MHz to 18 GHz	4.6 to 6.5 dB
N4001A	10 MHz to 18 GHz	14 to 16 dB
N4002A	10 MHz to 26 GHz	12 to 17 dB

(Note: If the DUT noise figure is beyond 30 dB, then the Y-factor method may not be suitable and you should consider the Agilent PNA-X Option 029 for noise figure measurements on a network analyzer.)

Demonstration Preparation

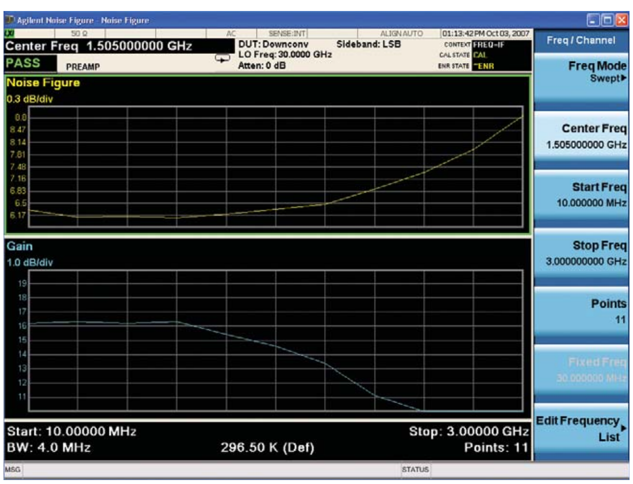
To perform the demonstrations, please prepare the following:

1. Select an X-Series signal analyzer with the corresponding noise figure measurement application.

a. N9069A
   i. N9030A PXA
   ii. N9020A MXA
   iii. N9010A EXA
b. W9069A
   i. N9000A CXA

2. Select a frequency range.

a. PXA or MXA
   i. Option 503: 20 Hz – 3.6 GHz
   ii. Option 508: 20 Hz – 8.4 GHz
   iii. Option 513: 20 Hz – 13.6 GHz
   iv. Option 526: 20 Hz – 26.5 GHz
b. EXA
   i. Option 503: 9 kHz – 3.6 GHz
   ii. Option 507: 9 kHz – 7.0 GHz
   iii. Option 513: 9 kHz – 13.6 GHz
   iv. Option 526: 9 kHz – 26.5 GHz
c. CXA
   i. Option 503: 9 kHz to 3.0 GHz
   ii. Option 507: 9 kHz to 7.5 GHz



N9069A noise figure measurement application

Note

The internal preamplifier lowers the system gain and should always be turned on to meet hard specifications. The MXA and PXA provide hard specifications up to 26.5 GHz.

3. Select an internal preamplifier.

a. PXA or MXA
   i. Option P03: 100 kHz – 3.6 GHz
   ii. Option P08: 100 kHz – 8.4 GHz
   iii. Option P13: 100 kHz – 13.6 GHz
   iv. Option P26: 100 kHz – 26.5 GHz
b. EXA
   i. Option P03: 100 kHz – 3.6 GHz
c. CXA
   i. Option P03: 100 kHz to 3.6 GHz
   ii. Option P07: 100 kHz to 7.5 GHz

4. Select a noise source—any noise source listed below will work with any configuration of signal analyzers listed above.

a. 346 Series noise sources
   (Note: you will need a cable and matching connectors to connect these noise sources to the instrument.)
   i. 346A: 10 MHz to 18 GHz, nominal ENR 6 dB
   ii. 346B: 10 MHz to 18 GHz, nominal ENR 15 dB
   iii. 346C: 10 MHz to 26.5 GHz, nominal ENR 15 dB
b. SNS Series noise sources
   (Note: You will need a 11730A cable to connect these noise sources to the instrument.)
   i. N4000A: 10 MHz to 18 GHz, nominal ENR 6 dB
   ii. N4001A: 10 MHz to 18 GHz, nominal ENR 15 dB
   iii. N4002A: 10 MHz to 26.5 GHz, nominal ENR 15 dB

Demonstrations

Measuring the noise figure of a device requires knowledge of the measurement system. Once the noise figure of the measurement instrument is known and the gain of the device under test (DUT) is known, then the noise figure of the DUT can be calculated, after which the overall noise figure is measured. With the N9069A, noise figure measurements can be made quickly and efficiently.

The demonstrations included in this guide are:

1. Entering the ENR table for SNS Series noise sources
2. Entering the ENR table for 346 Series noise sources
3. Calibration of the noise figure measurement application
4. Noise figure and gain measurements
5. Using the display features
6. Markers
7. Noise figure uncertainty calculator
8. Noise figure measurement using an amplifier as the DUT

To begin using the noise figure measurement application, enter the keystrokes: **[Mode] (More 1 of 2 if necessary) {Noise Figure}**.

(Note: Keystrokes surrounded by [ ] indicate front-panel keys, while keystrokes surrounded by { } indicate softkeys, located on the right edge of the display.)

Result Types

When using the noise figure measurement application there are seven different results that can be viewed. Brief descriptions of each of these result types are below.

Noise figure: The contribution by the device itself to thermal noise at its output. Typical noise figures range from .5 dB for very low noise devices, to 4 to 8 dB. In some systems (for example, heterodyne systems) total output noise power includes noise from other than thermal sources, such as spurious contributions from image-frequency transformation, however noise from these sources is not considered in determining the noise figure. Noise figure is expressed in dB.

Noise factor: The same description as above; however, noise factor is expressed using linear units rather than dB.

Gain: The amplification factor, also called gain, is the extent to which an analog amplifier boosts the strength of a signal. Amplification factors are usually expressed in terms of power. Gain is expressed in dB.

Y-factor: This method is very simple as it is a ratio of two noise power levels—one measured with the noise source ON and the other with the noise source OFF. For further information on the Y-Factor technique see *Noise Figure Measurement Accuracy: The Y-Factor Method*, Application Note 57-2 (5952-3706E). These values are expressed in dB.

T-Effective (Effective temperature): All types of random noise can be expressed as the equivalent amount of thermal noise that would be generated at a physical temperature (Te). Generally the word effective (or equivalent) is taken as understood, and the normal term is simply "noise temperature." These values are expressed in K.

P hot (Hot power density): This measurement is made with the noise source ON. The level of the noise floor observed on a signal analyzer depends, in part, on the selected bandwidth of the measurement. The wider the bandwidth the more noise is measured for each data point. If the instrument can display noise density, it has simply normalized the power measurements to a 1 Hz bandwidth and references it to kTB – 173.88 dBm/Hz; the displayed function is equivalent to power spectral density referenced to kTB. For example, 15 dB would mean the power spectral density = –158.88 dBm/Hz. P hot is expressed in dB.

P cold (Cold power density): This measurement is the same as P hot, however, the noise source is OFF.

Demonstration 1: *Entering the ENR table for SNS Series noise source*

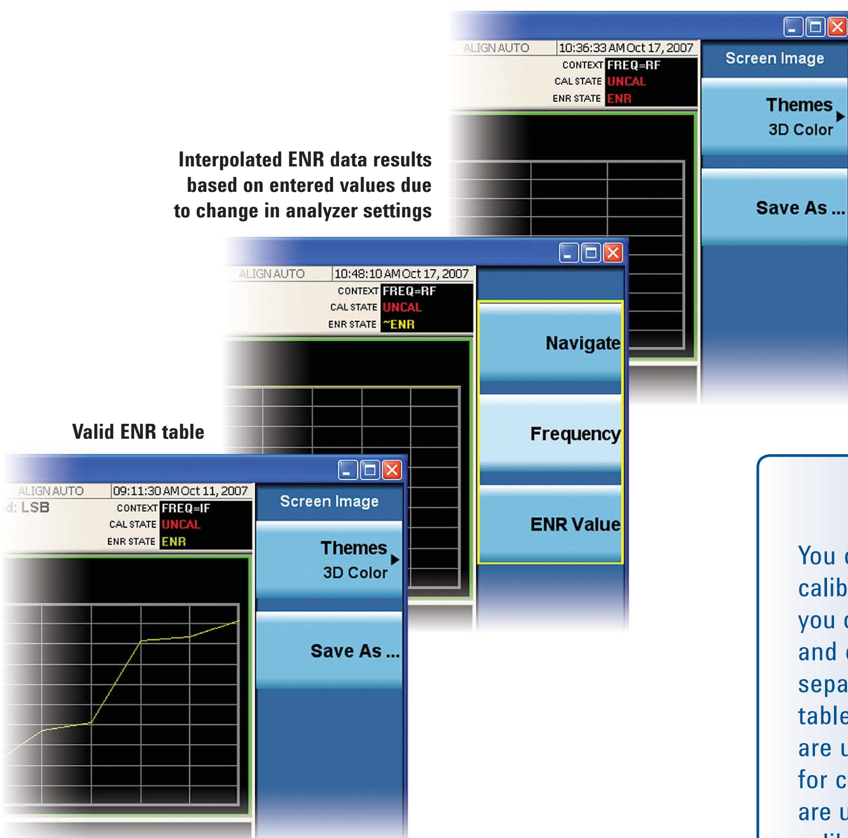
The SNS Series noise sources simplify the process of entering ENR data into your instrument. They save time by automatically downloading the ENR table when connected to an X-Series signal analyzer. Simply connect the SNS to the X-Series instrument via an 11730A cable to automatically transfer the ENR data to the signal analyzer.

Instructions	Keystrokes
Automatic upload of ENR data from the SNS noise source.	[Meas Setup] {ENR} {SNS Setup} {Noise Source} toggle to SNS(Auto) {Auto Load ENR} toggle to ON.
Connect one end of the 11730A cable to the rear panel of the instrument and the other to the SNS.	No key presses are required for this step.
Verify that the data has correctly transferred.	Look at the upper right hand corner of the screen to verify the ENR has turned to green.
Save the ENR table.	[Save] {Data} {ENR Table} to select {ENR Table} to enter menu {Meas} (Common) Table or {Cal Table} {Save As} enter name and desired location [enter] or click ok.

Invalid or empty ENR table

Interpolated ENR data results based on entered values due to change in analyzer settings

Valid ENR table



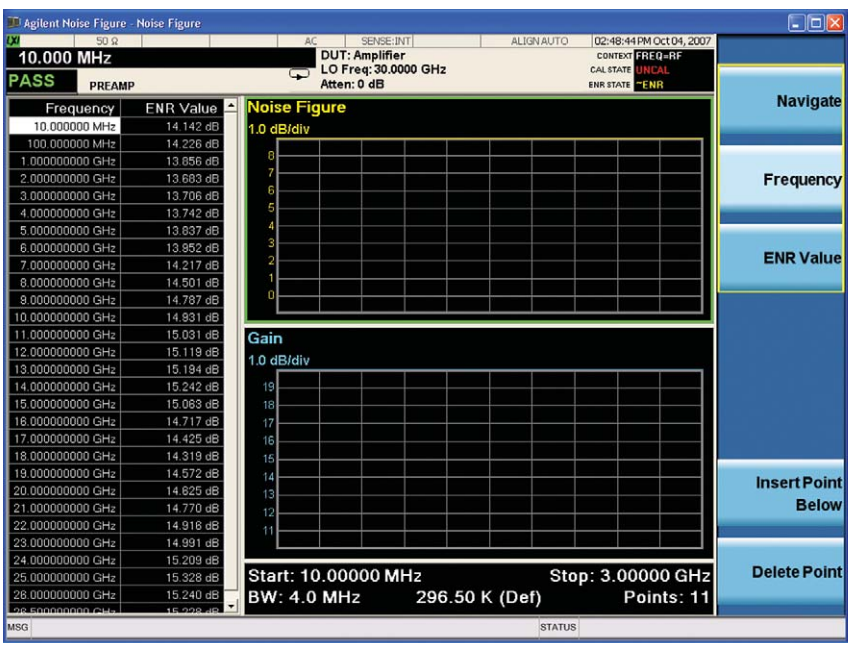
Helpful Tip

You can use the same ENR table for calibration and making measurements, or you can use separate measurement ENR and calibration ENR tables. You need separate measurement and calibration tables when separate noise sources are used for DUT measurements than for calibration (for example, when you are using frequency converters and the calibration range is different than the measurement range). Otherwise, you can select common ENR tables to save time.

Demonstration 2: *Entering the ENR table for 346 Series noise source*

This series of broadband noise sources has been designed to cover the majority of measurement applications with a range of frequencies, excess noise ratio (ENR), and coaxial connector types.

Instructions	Keystrokes
Enter the noise source serial number.	{Meas Setup} {ENR} {Meas Table} {Clear Table} {Serial #} use the alpha editor from the soft keys or connected keyboard. {Done}
Enter the model ID of the noise source.	{Model ID} use the alpha editor from the soft keys or connected keyboard. {Done}
Enter the ENR Frequency.	{Edit} {Frequency} use a connected keyboard, or front panel numeric keypad to enter the value {select appropriate units}.
Enter the ENR value.	{Edit} {ENR Value} use a connected keyboard, or front panel numeric keypad to enter the value {dB}.
Continue to enter the ENR frequencies and values until all of the frequency points of your noise source are entered.	No key presses are required for this step.
Save the ENR table.	[Save] {Data} {ENR Table} to select {ENR Table} to enter menu {Meas} (Common) Table or {Cal Table} {Save As} enter name and desired location [enter] or click ok.



Common ENR table

> **Helpful Tip**
>
> You can enter ENR data in four different ways: Manually enter the data shown above, load SNS data automatically as shown in the previous demonstration, load ENR data from a USB memory stick, or load ENR data from internal memory.

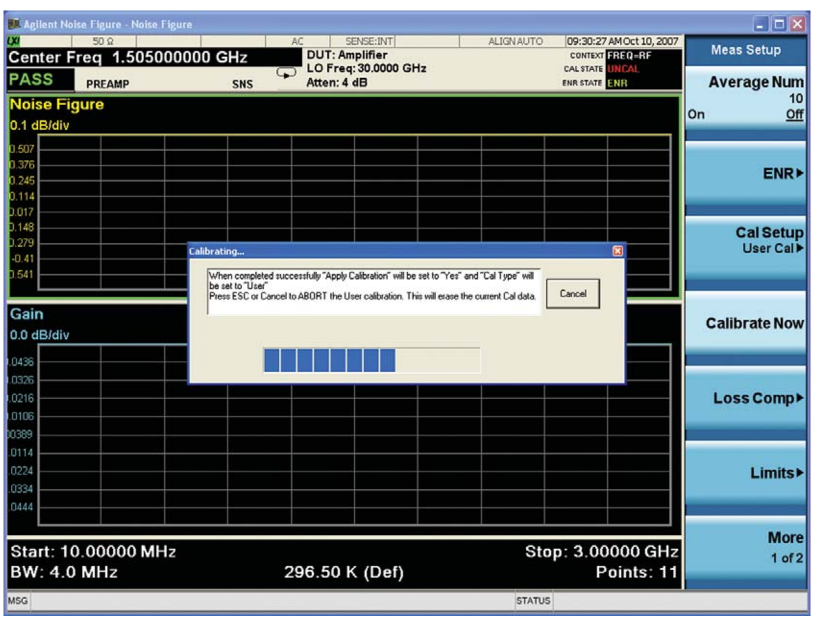
Demonstration 3: *Calibration of the noise figure measurement application*

For accurate noise figure measurements, the measurement system must first be calibrated to identify and correct the system's inherent noise figure before a DUT can be measured. The measured instrument noise figure is then removed from the total noise figure measurement so that only the DUT noise figure and gain is displayed.

There are three simple steps to calibrate the X-Series signal analyzers:

1. Select the frequency range appropriate for the DUT
2. Set the number of points and averages
3. Turn on the built-in preamplifier before beginning calibration. Default setting is ON. To find the internal preamplifier to go [AMPTD]{more}{Internal Preamp}

Instructions	Keystrokes
Connect the noise source to the rear of the X-Series signal analyzers via BNC cable for 346 series or 11730A cable for SNS series noise sources.	No key presses are required for this step.
Set the start frequency.	[Freq Channel] {Start Freq} [10] {MHz}
Set the stop frequency.	{Stop Freq} [3] {GHz}
Set the number of points.	{Points} [30] {Enter}
Set the averaging function.	[Meas Setup] {Average Num}, toggle to ON [15] {Enter}.
Calibrate the N9069A.	[Meas Setup] {Calibrate Now} [Enter] (or click OK with attached mouse).



Calibration of the noise figure measurement application

Did you know?

"User Cal" operates the same as "Calibrate" in the ESA, PSA, and NFA. No corrected results will be available until the measurement had been calibrated. Aborting the calibration will work in single and continuous mode.

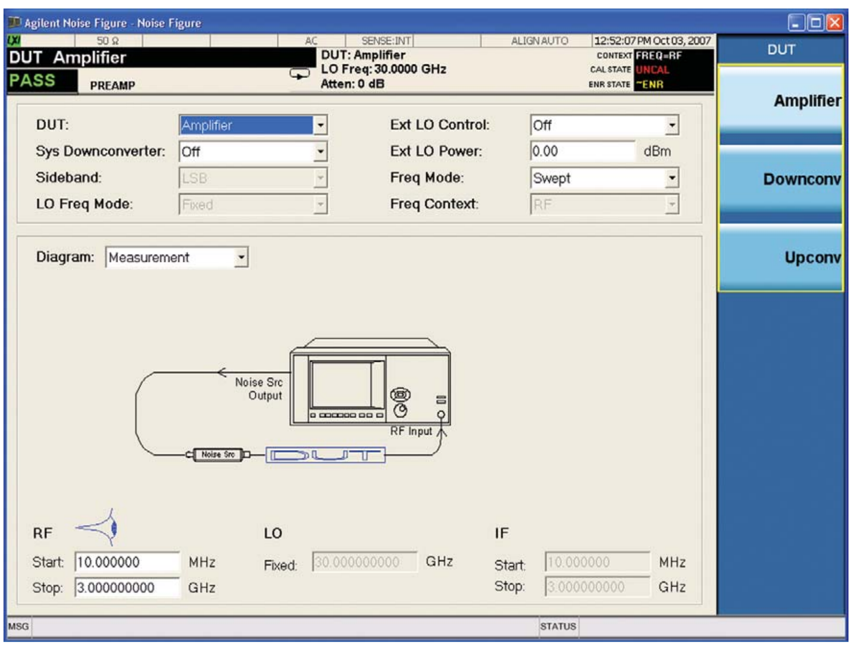
Helpful Tip

Use the {Optimize Preselector} under [meas setup] {more} in order to optimize your settings if the preselector drift is impacting your results and giving you higher errors than expected. When doing measurements above 3.6 GHz this saves time of running another calibration when you are making measurements over a period of time.

Demonstration 4: *Noise figure and gain measurements*

Now that the measurement application is calibrated with the noise source connected directly to the input, it is easy to make the noise figure and gain measurements on your device. Once the following steps are complete, the noise figure and gain of the DUT will be shown on the screen.

Instructions	**Keystrokes**
Use the visual setup guide to get started.	[Mode Setup] {DUT Setup...} {Amplifier} or select your DUT from the drop down menu with a mouse.
Disconnect the noise source from the input and connect the output of the DUT to the RF input of the signal analyzer. Connect the input of the DUT to the output of the noise source.	No key presses are required for this step.



DUT set-up menu

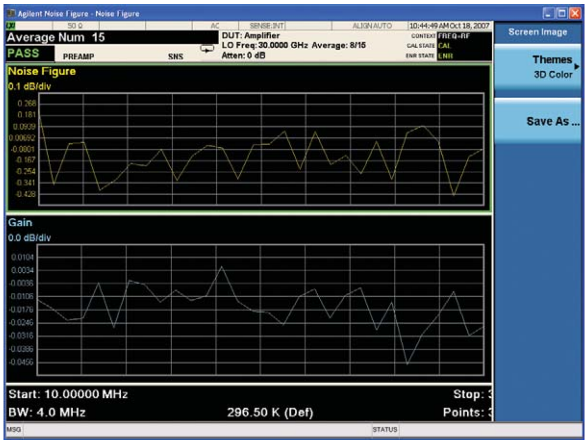
Helpful Tip

Use the Auto Scaling feature to give the broadest view of the measured trace. The lowest point will be placed at the bottom of the graph and the highest value at the top of the graph. This feature can be found under the AMPTD hard key.

Demonstration 5: *Using the display features*

The noise figure measurement application allows you to select the format in which your measurement results are displayed. Choose from three different layouts: Graph, table, and meter display.

Instructions	Keystrokes
Change the display.	[View/Display] {Layout} to select your preferred method.



Graph display:
The large screen of the X-Series signal analyzers allows for full viewing of the graph.

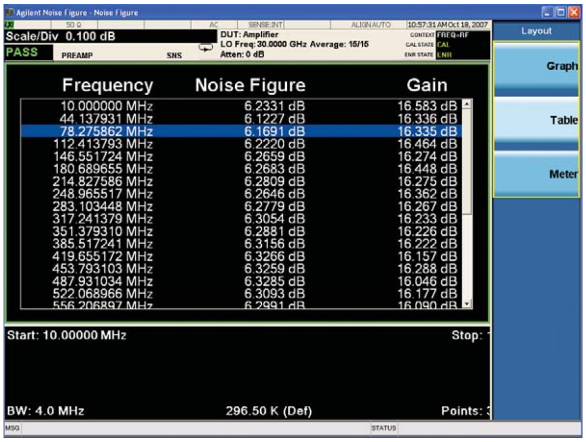
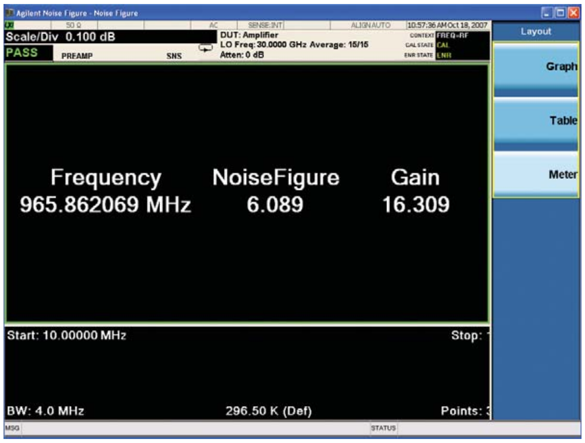
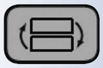


Table display:
The table has a highlighted bar that follows the measurement in process. This allows you to see the point that is being measured at any particular moment.



Meter display:
In addition to the more detailed graph and table displays, users familiar with the discontinued 8970 noise figure meter can continue to review results in the same format with the meter display view.

Helpful Tip

When viewing one of the six measurement results in graph view you can zoom in on either graph. By using the  button.

Demonstration 6: *Markers*

Markers can be used for searching a trace, and for displaying point data more accurately than with a trace alone. A total of four normal markers can be placed on the graphical display. Marker functions measure the frequency and measurement results by placing a diamond-shaped marker at a point on the trace.

Instructions	Keystrokes
Place a normal marker on the top graph.	[Marker] {Normal}
Create a delta marker.	{Delta}—Use the front panel knob to scroll the delta marker.
Create a delta marker from the top graph to the bottom graph.	{Properties} {Marker Trace} {Trace 2}—Use the front panel knob to scroll the delta marker.
Change delta marker 1 to marker 3.	{Relative To} {Marker 3}

Markers with marker table

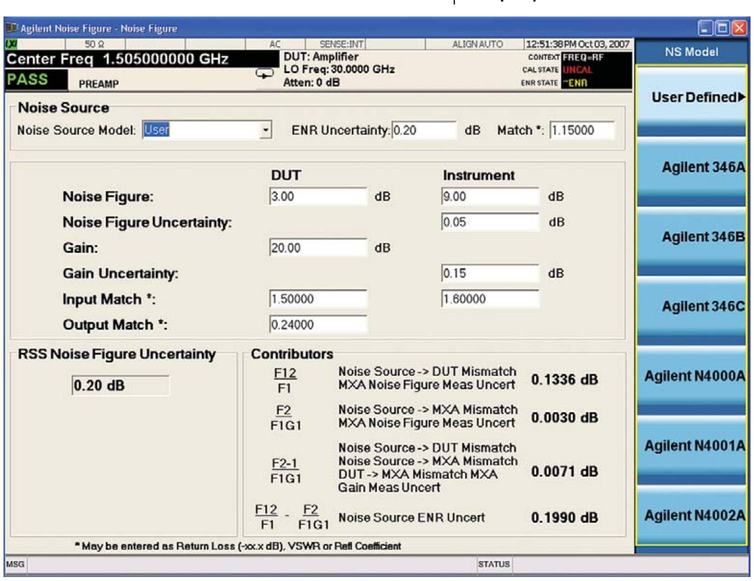
Did you know?

While in graph view you can use delta markers between two traces and also show the marker table under the [marker] key.

Demonstration 7: *Noise figure uncertainty calculator with SNS N40002A*

To compute the total uncertainty for your noise figure measurement, you need to take into account other factors besides noise figure instrument uncertainty such as: DUT noise figure, gain and match, instrument noise figure, gain uncertainty and match, and noise source ENR uncertainty and match. The computations can be performed with the uncertainty calculator included in the noise figure measurement application. Similar calculators are also available on the Agilent Web site, go to **www.agilent.com/find/nfu**. The noise figure uncertainty calculator can be used in conjunction with either the 346 or SNS Series noise sources.

Instructions	Keystrokes
Find and use the uncertainty calculator.	[Mode Setup] {Uncertainty Calculator}
Choose your source.	Use the tab keys or mouse to highlight the "Noise Source Model" box and select "Agilent N40002A."
Enter DUT and instrument values.	Use the tab keys or mouse to highlight each box. Enter the following values using either an attached keyboard or the front panel key pad: 1. DUT a. Noise figure: 3.75 dB b. Gain: 19.40 dB c. Input match: 1.50 d. Output match: 1.50 2. Instrument a. Noise figure: 8.00 dB b. Noise figure uncertainty: i. PXA: 0.02 dB ii. MXA: 0.02 dB iii. EXA: 0.03 dB iv. CXA: 0.05 dB c. Gain: .41 dB d. Gain uncertainty: i. PXA: 0.10 dB ii. MXA: 0.10 dB iii. EXA: 0.15 dB iv. CXA: 0.20 dB e. 1.80 for frequencies up to 3.6 GHz The measurement uncertainty is then calculated and the results are displayed at the bottom of the form.



Uncertainty calculator display for above example

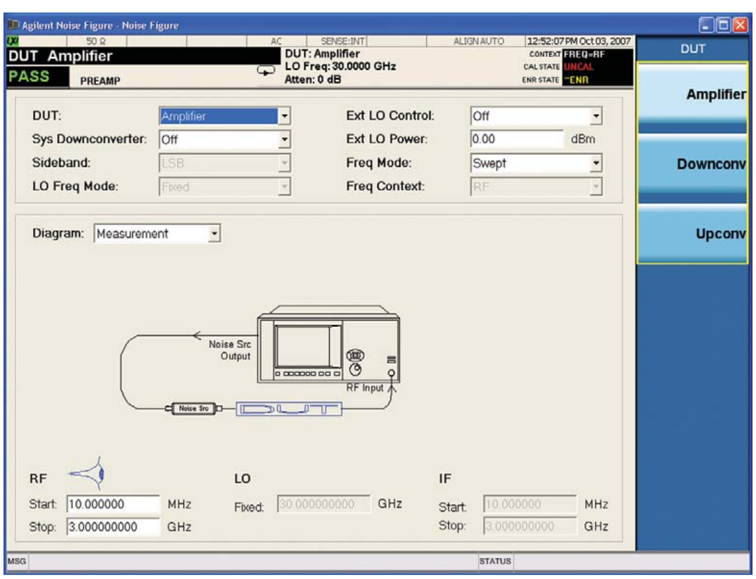
Demonstration 8: *Noise figure measurement using an amplifier as the DUT*

Noise figure measurements are made by measuring the output power of the DUT for two different input noise power levels. The high and low power inputs come from a calibrated noise source. The noise source is switched on and off in rapid succession. High power input to the analyzer uses the noise power generated when the noise source is switched on, and low power input uses the noise power generated at ambient temperature when the noise source is switched off. This section uses a DUT to show how a basic noise figure measurement and various basic operations are performed. The purpose of this measurement is to verify that the amplifier is meeting the specifications in the table below.

The example DUT specifications are as follows:

1. Frequency range: 20 MHz to 3 GHz
2. Typical gain: 20 dB
3. Minimum gain: 14 dB
4. Typical noise figure: 4.8 dB

Instructions	Keystrokes
Access the DUT setup menu.	[Mode Setup] {DUT Setup} {Amplifier} System downconverter: Off Frequency mode: Off RF start frequency: 10 MHz RF stop frequency: 3 GHz
Calibration setup.	[Meas Setup] {Cal Setup} {User Cal} Min Att = 0 dB default Max Att = 10 dB default Change attenuation up to a maximum of 40 dB based on calibration need.
Measurement attenuation.	[Ampt] {Attenuation} [0] {dB}
Calibration.	[Meas Setup] {Calibrate} [Enter]
Connect the preamplifier between the noise source and RF input of the signal analyzer.	No key presses required for this step.
View results on display.	[Meas]



Amplifier measurement setup

Did you know?

Base box alignments will be disabled between points of an NF measurement sweep as long as the full measurement sweep time is under a minute, otherwise, only enable alignments between points. Alignments will always be disabled between P cold and P hot readings for a single frequency point.

Noise figure

"Instrument uncertainty" is defined for noise figure analysis as uncertainty due to relative amplitude uncertainties encountered in the analyzer when making the measurements required for a noise figure computation. The relative amplitude uncertainty depends on, but is not identical to, the relative display scale fidelity, also known as incremental log fidelity. The uncertainty of the analyzer is multiplied within the computation by an amount that depends on the Y-Factor to give the total uncertainty of the noise figure or gain measurement. See, *Noise Figure Measurement Accuracy: The Y-Factor Method*, Application Note 57-2 (5952-3706E), for details on the use of this specification.

The N9069A is not specified for use below 10 MHz. Instrument uncertainty will nominally be the same as the 10 MHz–3.6 GHz specifications; however, performance is not warranted.

Instrument uncertainty

	Measurement range	**PXA N9030A MXA N9020A**	**EXA N9010A**	**CXA N9000A**
Noise source ENR 4-6.5 dB	0 to 20 dB	±0.02 dB	±0.03 dB	±0.05 dB
Noise source ENR 12-17 dB	0 to 30 dB	±0.025 dB	±0.03 dB	±0.05 dB
Noise source ENR 20-22 dB	0 to 35 dB	±0.03 dB	±0.03 dB	±0.10 dB
Frequency rage		10 MHz to 26.5 GHz	10 MHz to 3.6 GHz	10 MHz to 7.5 GHz

Gain

"Instrument uncertainty" is defined for gain measurements as uncertainty due to relative amplitude uncertainties encountered in the analyzer when making the measurements required for the gain computation. See, *Noise Figure Measurement Accuracy: The Y-Factor Method*, Application Note 57-2 (5952-3706E), for details on the use of this specification.

The noise figure application is not specified for use below 10 MHz. Instrument uncertainty will nominally be the same as the 10 MHz–3.6 GHz specifications, however, performance is not warranted.

The following specifications apply for DUT with gain ranges = –20 to + 40 dB.

	PXA MXA	**EXA**	**CXA**
	±0.10 dB	±0.15 dB	±0.20 dB
Frequency rage	10 MHz to 26.5 GHz	10 MHz to 3.6 GHz	10 MHz to 7.5 GHz

Note

Specifications are only valid when used with the internal preamplifier option listed on page 4.

More information about Agilent Noise Figure can be found at the Agilent website:
www.agilent.com/find/nf

More information about the X-Series signal analyzers can be found at the Agilent website:

PXA signal analyzers: **www.agilent.com/find/PXA**

MXA signal analyzers: **www.agilent.com/find/MXA**

EXA signal analzyers: **www.agilent.com/find/EXA**

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More information about X-Series applications can be found at: **www.agilent.com/find/xseries_apps.**

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