



Agilent ESA Series Spectrum Analyzers Option 219 -Noise Figure Measurements Personality and Hardware

Overview:

A key measurement in the development of devices and systems is its noise figure; considering that this figure of merit is one of the key limiting factors in the overall system's performance. The ability to make accurate noise figure measurements have significant financial benefits since a product with a guaranteed low noise figure commands a premium price. A manufacturer can however only claim this reward, if every unit manufactured can be shown to meet its specification.

- ❖ *Noise Figure Measurements are required in production to essentially demonstrate that the product meets its specification needs.*

For the upstream customer interested in the low noise figure component; perhaps the system integrator who is putting together a receiver, noise figure measurements is also of interest. They want to confirm that they are getting the performance that they have paid a premium for, and it will indeed meet their design needs.

- ❖ *Noise Figure Measurements are required downstream for customers to confirm that they are getting the performance that they have paid for.*

The engineer also has a choice to ignore this important parameter and instead over design the other aspects of their communications link.

- They can raise the transmitted signal power.* This usually translates to a more costly design in terms of engineering time spent, or higher rated components. For the case of a satellite, where the transmitter needs to generate large wattages at the frequencies required, amplifiers fabricated via the regular chip process are no longer adequate. The adoption of high power amplifiers like klystrons or magnetrons are required which are orders of magnitude larger than the regular microchip PAs (BJTs, FETs). This translates to a huge investment in paying the Boeing's, Arianne's, Lockheed Martin's, Loral's or Northrop Grumman's of this world to send the larger payload into space.
- Another way is to increase the amount of power, that the receive antennas intercepts.* This translates to a larger receive antenna aperture size which after a while becomes impractical because of environmental issues and other government regulations.

Measuring and then minimizing the noise generated in the components of your communications system, is the alternative and recommended approach. Particularly, considering that approaches like amplification and improving directivity has the same effect on the signal as on the noise.

Agilent's noise figure measurement systems are an easy to use set of tools that automate these measurements, providing high accuracy to meet many of your customer's needs at a vastly reduced cost.

SA 308: SA Enhancements

Noise Figure Lab



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Lab Objective:

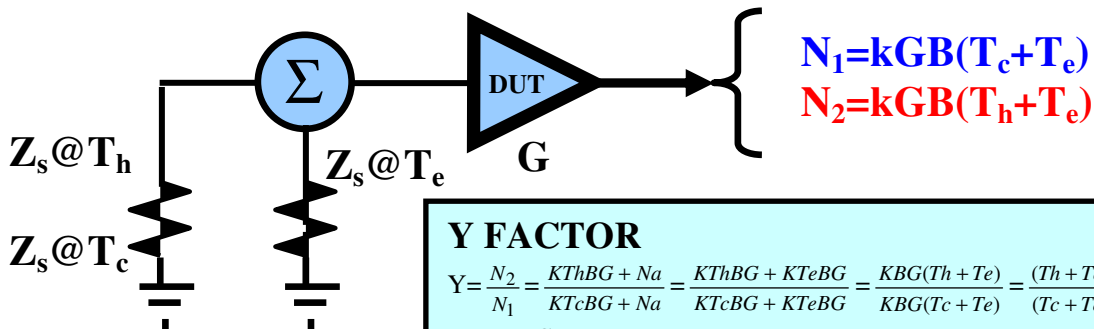
This module is specifically geared at giving you hands on experience at operating Agilent equipment to help your customers address some measurement challenges in developing systems that have to process very weak signals where Noise Figure is of paramount importance.

This lab exercise consists of the following sections:

1. **Entering Excess Noise Ratio (ENR) Values** – You will learn how to enter ENR values used by the Agilent noise figure measurement systems in the Y-Factor method to make noise figure measurements.
2. **Calibration of the noise Figure Measurement Personality and HW (Option 219)** - You will see how to make “corrected measurements” by compensating for the contribution of the ESA to the noise figure of the measurement system so an accurate measurement can be made of the D.U.T.
3. **Amplifier Noise Figure and Gain measurement in several formats** - You will make a noise figure measurement on the most common device under test, an amplifier and analyze the results using the multiple display features available for the ESA
4. **Uncertainty calculator** - You will use the built in uncertainty calculator that computes the RSS (root sum squared) measurement uncertainty to verify the overall accuracy of your measurement.
 - *SNS allows easy correction for physical temperature*
5. **Frequency Converter (mixer) noise figure measurement** - You will recognize the ability of the ESA to make a noise figure measurement on a mixer as the D.U.T.
 - *You will apply Loss compensation to familiarize yourself to the ability of the ESA to compensate for losses due to a variety of effects.*
6. **Narrow Band Noise Figure measurements** - You will make a noise figure measurement with a filter in the measurement path, to familiarize yourself with the tradeoffs involved in making a narrow band measurement.

Noise Figure Lab

Fundamentals of noise figure measurements: There is not enough time to go through the intricacies of a noise figure measurement so only a summary of equations relevant to the understanding of how a measurement is made will be shown.



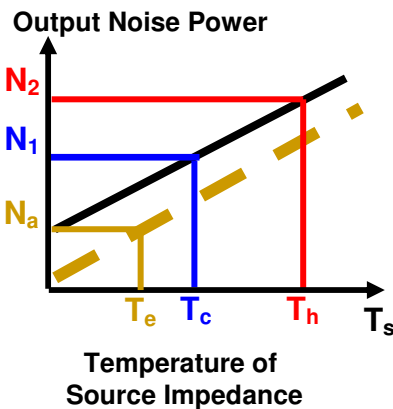
Y FACTOR

$$Y = \frac{N_2}{N_1} = \frac{kThBG + Na}{kTcBG + Na} = \frac{kThBG + kTeBG}{kTcBG + kTeBG} = \frac{kBG(Th + Te)}{kBG(Tc + Te)} = \frac{(Th + Te)}{(Tc + Te)}$$

$$Y = mX + C$$

$$YTc + YTe = Th + Te \quad \longrightarrow \quad Te(Y - 1) = Th - Ytc$$

$$Te = \frac{Th - Ytc}{Y - 1} \quad (1)$$



N_a = Added Noise generated in D.U.T.

N_1 = Noise Power level with noise source on

N_2 = Noise Power level with noise source off

$$F \text{ (Noise Figure)} = \frac{S_i/N_i}{S_o/N_o} = \frac{S_i/N_i}{G S_i / (Na + G N_i)} = \frac{G N_i + Na}{G N_i} = \frac{G K T_s B + Na}{G K T_s B}$$

$$F \text{ (Noise Figure)} = \frac{G K T_s B + G K T_e B}{G K T_s B} = \frac{G K B (T_s + T_e)}{G K T_s B} = \frac{(T_s + T_e)}{T_s}$$

$$F \text{ (Noise Figure)} = \frac{(T_s + T_e)}{T_s} \quad \longrightarrow \quad F T_s = T_s + T_e \quad \longrightarrow \quad F T_s - T_s = T_e$$

$$Te = Ts(F - 1) \quad (2) \quad \text{from (1)} \quad \longrightarrow \quad Ts(F - 1) = \frac{Th - Ytc}{Y - 1}$$

Assume $T_s = T_c$ $T_c F = T_c + \frac{Th - Ytc}{Y - 1}$

$$F = 1 + \frac{Th/T_c - Y Tc/T_c}{Y - 1} = \frac{Y - 1 + Th/T_c - Y Tc/T_c}{Y - 1}$$

Rearranging $F = 1 + \frac{Th/T_c - Y Tc/T_c}{Y - 1} = \frac{(Th/T_c - 1) - Y(Tc/T_c - 1)}{Y - 1}$

$$F = \frac{(\frac{Th - Tc}{Tc}) - Y(\frac{Tc - Tc}{Tc})}{Y - 1} \quad \therefore \quad F = \frac{(\frac{Th - Tc}{Tc})}{Y - 1}$$

$$ENR = \left(\frac{Th - Tc}{Tc} \right) \quad \therefore \quad F = \frac{ENR}{Y - 1}$$

$$NF(\text{dB}) = 10 \text{Log}(F) = 10 \text{Log} ENR - 10 \text{Log}(Y - 1) \quad (3)$$

So If we measure the Value of Y and we **Tell the analyzer what the ENR is** usually provided with the noise source, then we should be able to measure the noise figure of the device under test.

Fig 1: Theory refresher 1



Lab 0. Setting up ESA

Switch to the noise figure measurement personality (Opt. 219).

Spectrum analyzers can make many different types of measurements. The noise figure personality is only one of many modes that the ESA-E series can be operated in. This makes it a cost-effective way to expand the capability of an essential engineering tool. If the ESA is not already in the *noise figure measurement personality mode*.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Switch to the Noise figure measurement personality.	[Preset][Mode]({More 1 of 2} if necessary){Noise Figure}

Lab 1. Entering the Excess Noise Ratio (ENR) Values

All demonstrations use the **Agilent N4002A SNS Series smart noise source**, mini-circuits mixer, amplifier and 70 MHz band pass filter provided in the Demo accessory kit housed in the front panel of the ESA.

Note (1): In the following keystrokes, { } = soft key and [] = hard key.

Note (2): Optional settings are in smaller italic font for your information.

Let's proceed with providing one of the sources of data required for the Noise Figure Calculation shown in equation 1, **The ENR Data**.



Figure 2: N4002A SNS Series Noise Source available with Agilent instruments only

Entering the ENR table for a noise source manually or automatically:

The noise source used for this demonstration is the N4002A smart noise source. This noise source has a calibrated range of 10 MHz to 26.5 GHz. The SNS series broadband noise sources work with the ESA-E series to simplify measurement set-up and improve accuracy. Only available with Agilent instruments, they provide the following advantages.

- **Automatic download of Excess Noise Ratio (ENR) data to the ESA**, speeding overall setup time.
- **Electronic storage of ENR calibration data** which all but eliminates the opportunity for user error
- **Automatic sensing of the ambient temperature of the measurement environment** allowing the ESA to compensate for these changes during the measurement cycle increasing the accuracy and reliability of noise figure measurements.

Agilent is always sensitive to conservation of investment and so also provides an interface [+28V (pulsed) noise source drive output] for the large installed base of 346 series noise sources. These noise sources do not operate automatically as do the SNS Series, however, they are available with disks containing the noise source ENR data which facilitates the process.

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The ESA allows you to set the preference for which noise source drive output you want to use. Once calibration data is entered into the measurement personality, system calibration and DUT measurements can be made. In most cases a common ENR table can be used for calibration and measurements, however, in the case of mixers, for example, the frequency range of the source for measurements may be outside the range for calibration, and therefore two sources are required. This is an instance where the calibration ENR table will be different from the measurement ENR table, so the common table function is turned off.

Step 1: Preferred step with Smart noise source.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Connect the SNS to the ESA using the 11730A cable.	No key presses are required for this step. <i>It is important to note, though that the SNS should not be disconnected while the upload process is ongoing</i>
Automatic upload of ENR data from SNS Series noise source	[Meas Setup]{ENR}{SNS Setup}{Preferences Norm <u>SNS</u> } <i>Toggles to SNS if on Norm.</i> { Auto Load ENR } <u>On</u> Off <i>Toggles to On if Off.</i>
Verify that the data has correctly transferred over	[Return]{Meas & Cal Table...}

Simply connect the N4002A smart noise source to the ESA noise source output. using a 11730A cable to automatically transfer the ENR data to the NFA. This simplifies the process and reduces the possibility of user error due to incorrect entry.

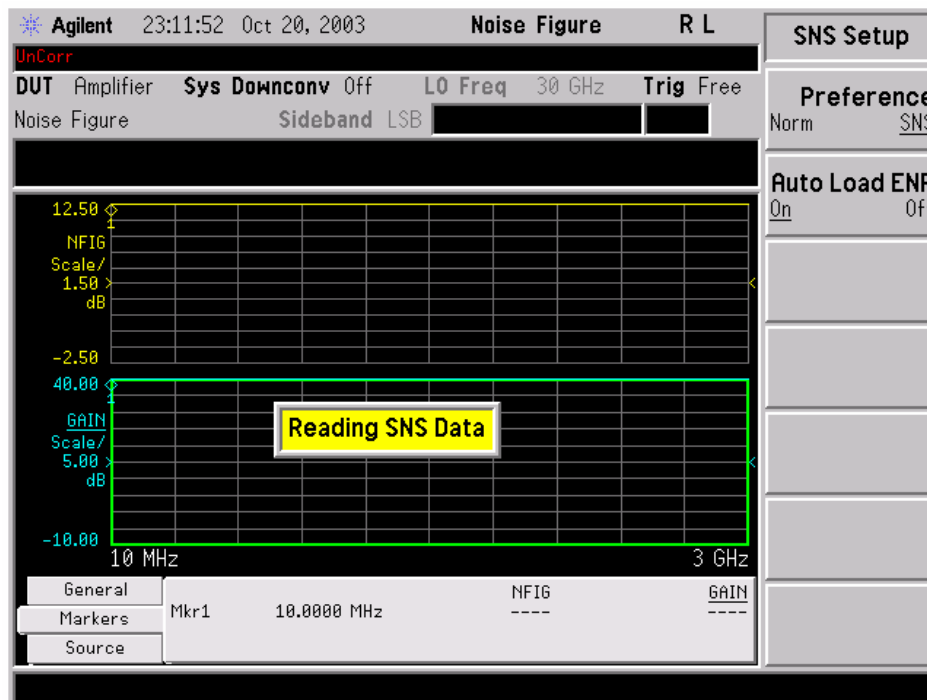


Figure 3: Automatic upload of ENR data from SNS EEPROM

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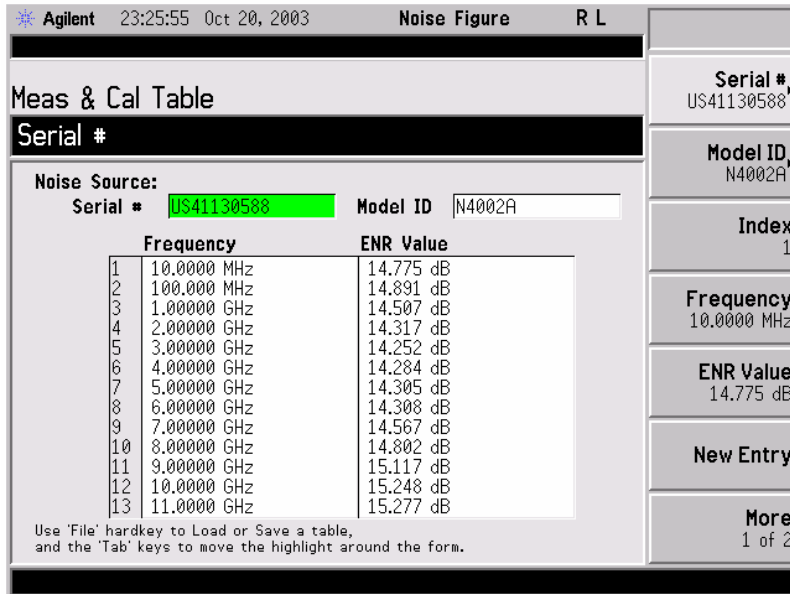


Figure 4: Common ENR Table with ENR data for N4002A smart noise source

If the noise source preference was a normal 346 Series noise source, then this is the same interface that you could have used to either enter the ENR data. The 346 Series come with a disk containing the noise source ENR data. Load it as follows.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Load the ENR numbers from disk Change directory to A:\ if not already selected	[File]{Load}{Type}{More 1 of 3}{ENR Meas/Common Table} {Dir Select}, use [↑] or [↓] arrows to select drive A for the floppy then press {Dir Select}. Highlight the ENR file name using [↑] or [↓] and then press {Load Now}
If you misplace the disks, you can enter the ENR values manually from annotation on the Noise source as follows. Add Excess Noise Ratio (ENR) serial number and model number	{Meas Setup}, {ENR}, {Meas & Cal Table} [Enter]{Serial #}. Use the numeric pad and alpha editor to enter the serial number {model ID} and enter the model number using the alpha editor and numeric key pad
Adding ENR values versus frequency The table auto sorts by frequency	Press {Index} 1, {Frequency} 10 {MHz}, {ENR Value}, 13.14 {dB}. Repeat the process for index 2 and so on.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Saving the calibration data to a floppy or the internal memory of the ESA	Press [File], {Save}, {Dir Select}, use [↑] or [↓] to select the drive A for the floppy, then press {Dir Select}. Press {Type}{More 1 of 3}{ENR Meas/Common Table} Press {Name} and use the Alpha Editor to name the file. When finished entering the name, press [Return] and {Save Now}.

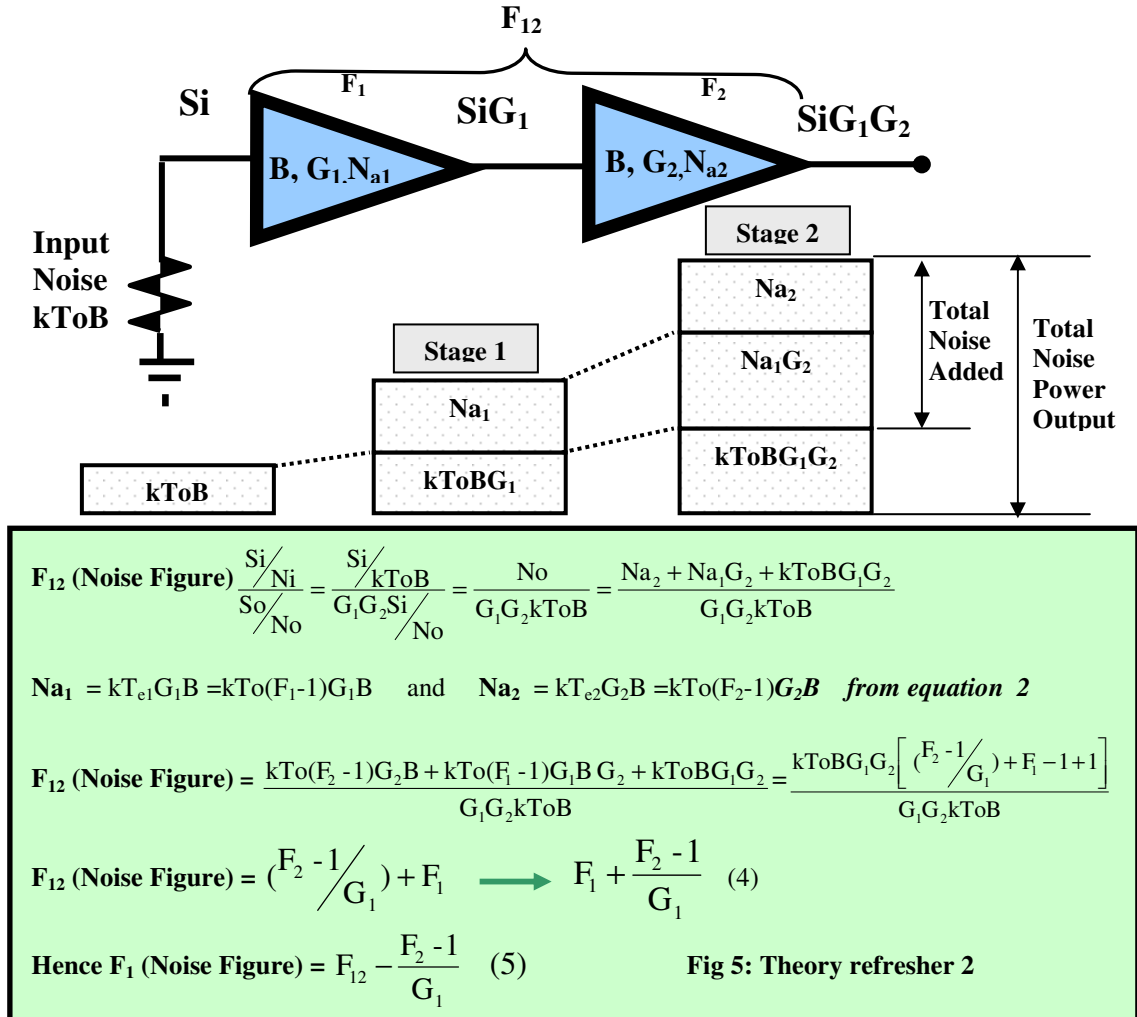
Noise Figure Lab

Noise figure measurement process summary

Measuring the noise figure of a device also 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 DUT can be calculated, after the overall noise figure is measured.

1. Enter the excess noise ratio ENR values in dB of the noise source. (Done)
2. Calibrate the measurement personality.
3. Make the Noise figure measurement using the Y-Factor method described above in equation 3.

Model the measurement system as another stage with its own noise figure and gain



So during calibration we make a measurement on just Stage 2, which is the measurement system connected to the D.U.T. This will allow us to measure F_2 as in equation 3. After that, we also measure F_{12} , which is the noise figure of the cascade. Finally, we need to determine the gain of the D.U.T., which will allow us to report the noise figure of the D.U.T., by itself. This is done as described in **figure 8: Theory refresh 3**. First let's proceed with the calibration .

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Noise Figure Lab



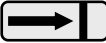
Lab 2: Calibration of the noise figure measurement personality and HW (Opt. 219)

For accurate and correct measurements of noise figure for a DUT, the system must first be calibrated. Calibration is required because the measurement system has its inherent noise figure that must be known and corrected for before a DUT can be measured as shown above.

Following is the calibration process:

- 1: Select the frequency range appropriate for the D.U.T.
- 2: Set the number of points and set the number of averages. *Any jitter in the calibration step will add to the measurement uncertainty of all subsequent measurements. Therefore a long averaging time should be used for calibration in order to reduce this source of uncertainty to a negligible level.*
- 3: If the device under test does not have gain or if the gain is low then it is recommended to have the built-in preamplifier on before calibration.

Now Perform a system calibration

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
<p>Access the DUT Setup diagram to obtain guidance on how to setup connections for calibration of an amplifier as a DUT.</p> <p><i>Press the tab keys to navigate your way around the form. When the form Highlights the diagram field "Blue" you should use the softkey to change the parameter.</i></p>	<p>[Mode Setup]{DUT Setup....}</p> <p> {Calibration}</p>
<p>Connect the SNS to the ESA input connector as described by the diagram for an amplifier</p>	<p>No key presses are required for this step.</p>

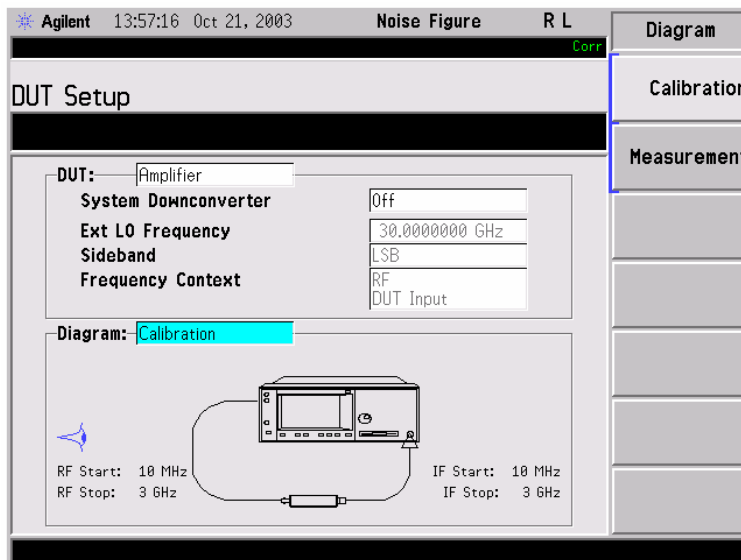


Figure 6: Device under test setup form. The DUT setup form allows the user to prepare the DLP for measuring specific devices and setups, and provides information on how to setup the instrumentation for either calibration as show above or measurement.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Set the start frequency	[Frequency] {Start Freq}, 10 MHz
Set the stop frequency	[Frequency] {Stop Freq}, 3 GHz
Set the number of points at which to measure	[Frequency] {Points}, 30 {enter}

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Set the averaging function to 15 averages	[Meas Setup] {Avg Number On} 15 {Enter}
Calibrate the measurement personality	[Meas Setup] {Calibrate} {Calibrate}

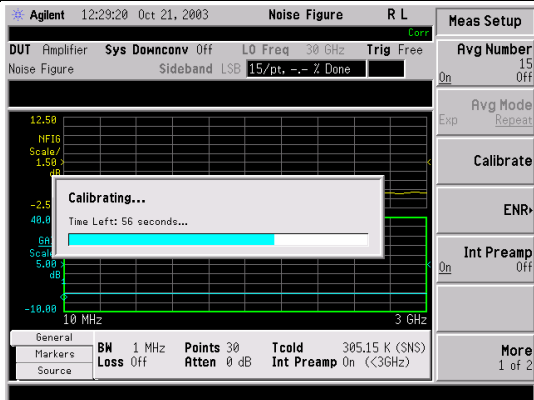
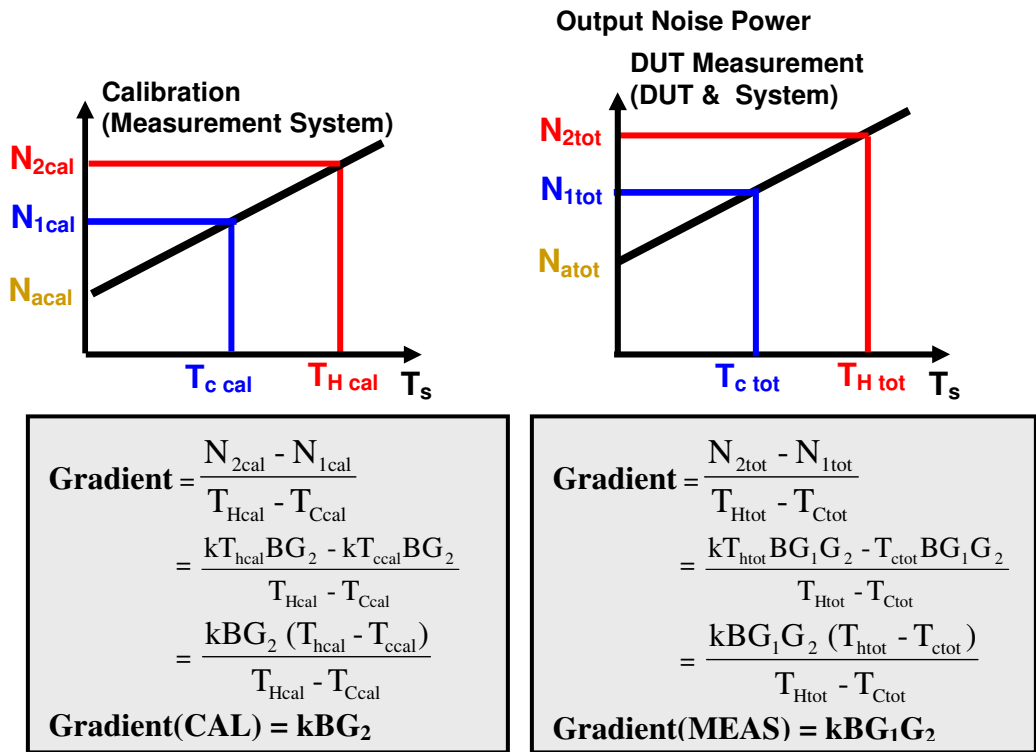


Figure 7: Calibration process on ESA. The ESA is set to sweep a number of times (defined by averaging) across the user defined frequency range, cycling through all the defined attenuator settings to ensure that a corrected noise figure measurement can be made.

While the analyzer is calibrating, a quick refresher on how gain is measured



$$\therefore G_1(D.U.T) = \frac{\text{Gradient(MEAS)}}{\text{Gradient(CAL)}} = \frac{\frac{N_{2tot} - N_{1tot}}{T_{Htot} - T_{Ctot}}}{\frac{N_{2cal} - N_{1cal}}{T_{Hcal} - T_{Ccal}}} \quad (6)$$

Since we are switching the same noise source between the same T_{hot} and T_{cold} during calibration and measurement, make $T_{Htot} = T_{Hcal}$ and $T_{Ctot} = T_{Ccal}$

$$G_1(D.U.T) = \frac{N_{2tot} - N_{1tot}}{N_{2cal} - N_{1cal}} \quad (7)$$

Figure 8: Theory refresh 3.

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Equation 7 is the ratio of difference in output noise power measured with noise source on/off for calibration and measurement setups.

Lab 3: Noise figure and gain measurements

Now that the measurement personality is calibrated with the noise source connected directly to the input, it is a simple matter to make *corrected* noise figure and gain measurements on a device. The calibration indicator on the top of your screen has changed from a red **uncorr** to a green **corr**. With no D.U.T connected, both the Gain and Noise Figure are at ~0db as expected. This is because the analyzer is displaying corrected results with the noise contribution of the measurement system removed. Since the input is noise, there is invariably some variation, however considering that most D.U.Ts have gain, from equation 5 (pg. 7), this value should become negligible

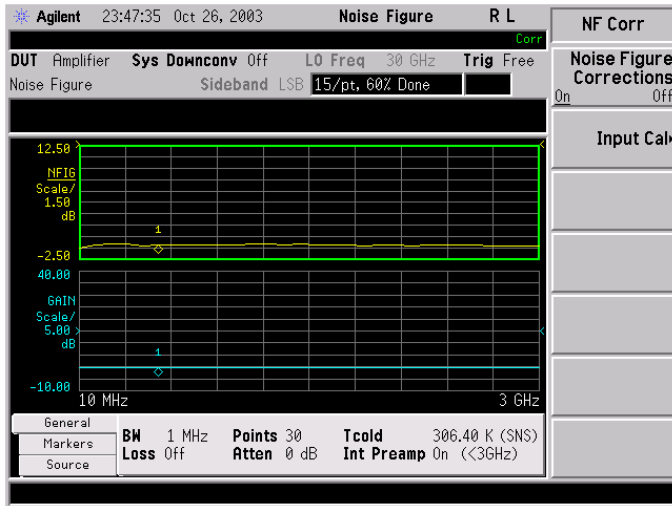


Figure 9: Corrected NF Gain measurement after calibration

To see the second stage noise figure (F_2) that has been calibrated out, proceed as follows.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
<p><i>You can reduce averaging or turn it off for a faster measurement</i></p> <p>Setup an uncorrected display to display the approximate noise figure of the measurement system</p>	<p>[Meas Setup]{ Avg On <u>Off</u>}</p> <p>[Input/Output] {Noise figure Corrections} {Noise figure Corrections On <u>Off</u>}</p>

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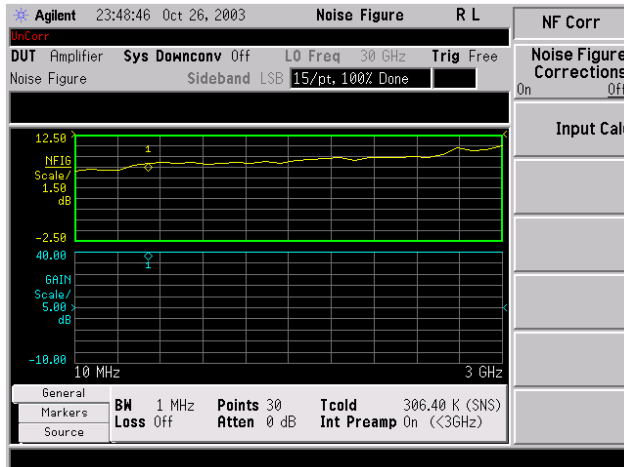
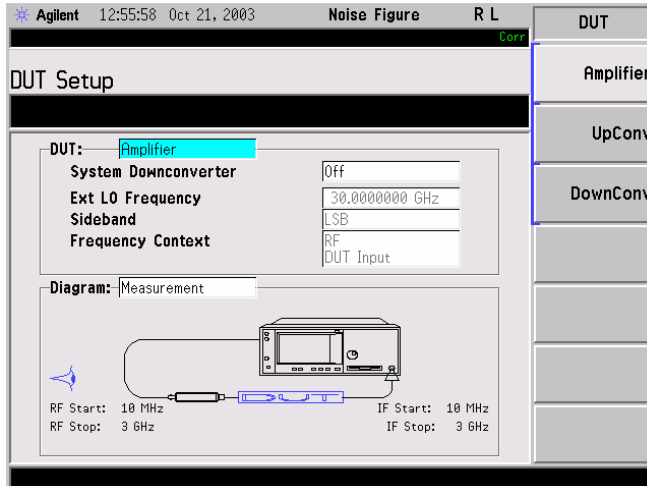


Figure 10: Uncorrected measurement, showing the approximate NF of the measurement system.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Toggle back to making a corrected measurement to proceed with rest of lab.	[Input/Output] {Noise figure Corrections} {Noise figure Corrections <u>O</u> n <u>O</u> ff}

Disconnect the noise source from the input and connect the device under test to the input and connect the noise source to the DUT as shown in figure below.



Access this menu by pressing [Mode Setup]{DUT Setup....} Press the tab keys to navigate your way around the form. When the form highlights the diagram field "Blue" you should use the softkey to change the parameter to "Measurement"

Figure 11: Device under test setup form for an amplifier measurement.

As soon as the DUT is connected to the ESA, a measurement will begin on the noise figure and gain of the amplifier because the system is already sweeping. The user has the flexibility to select single or continuous sweep based on what the intention is. *Additionally, the user can specify a lower number of averages to permit a faster measurement.*

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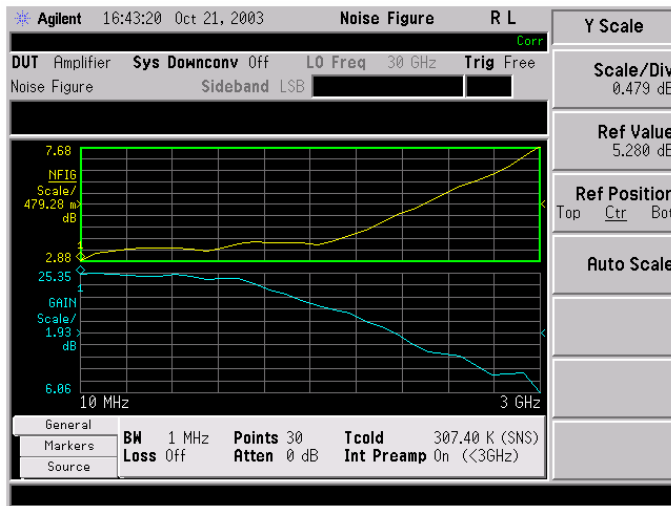


Using the display features

The noise figure measurement personality has many features to help you interpret and analyze noise figure measurements.

Perform display scaling

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Restart the measurement if necessary Expand the trace to fit the graph for a better view of the measurement using the Auto Scale function as shown in figure below.	Press [ESC] or [Return] to get out of DUT Setup screen. {Restart} for a faster response after changing DUT. Press [Amplitude] use [Next Window] to highlight the graph to be expanded then press {Auto Scale}



Scale and reference level values

The scale in dB per division and the reference values can be adjusted to give an optimized view of the measured results. The scale per division can be adjusted from 0 to 20 dB. The Reference level can be placed at the top of the graph, in the center or at the bottom. The reference level is also adjustable from -100 dB to +100 dB.

Use the Auto Scale 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.

Figure 12: Display of Noise figure and gain after auto scaling

Manually configure your display via the AMPLITUDE key as follows..

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Set the scale of the graphical view.	Press [Next Window] to highlight the graph to be changed. <i>In this case the Gain window.</i> Press {Scale/Div} and enter the new value 2 {dB}
Set the reference value Set the position of the reference.	Press [Amplitude] {Ref Value} and enter the value 20 and press dB Move the position of the Reference Value by toggling through {Ref Position <u>Ctr</u> }. <i>Notice what happens</i>

More Display Features....

Select and Zoom Active Window:

This feature allows you to highlight a window and then enlarge it for closer analysis.

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Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Highlight the window of interest	Press [Next Window] until the window you want is highlighted
Enlarge the window for closer analysis	Press [Zoom]
Switch to another window (figure 13)	Press [Next Window]

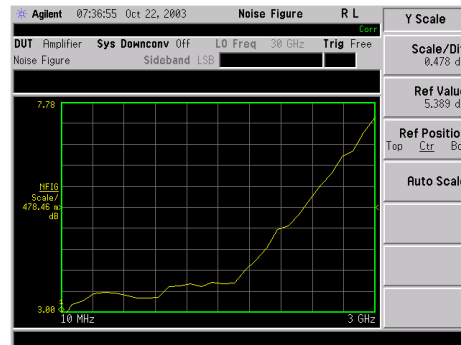


Figure 13: Full screen display of Noise figure and device gain

General, Markers and Source tabs

There are three tabs available at the bottom of the screen. These tabs are accessed using the [←] and [⇒] tab arrow keys on the front panel of the ESA. The General tab shows information about BW, number of points, Tcold value, loss, attenuator setting and internal preamplifier setting. The Marker tab gives the frequency, noise figure and gain at each of the marker readings. The Source tab has information about the noise source including serial number and model identification.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
View the General table at the bottom of display.	Use the Right and Left Tab keys at the bottom of the front panel to scroll through the tabs
View the Source tab at the bottom of the display.	Use the Right and Left Tab keys.



Figure 14: General information display



Figure 15: Noise source information: Cal information is blank because user selected common ENR table

Markers

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A total of four normal markers can be placed on the graphical display. The placement of the markers is limited to the number of equally spaced calibration points. For example, if there are 11 calibration points then the markers can be placed on each of the vertical graticule lines. Each of the normal markers can be changed to delta markers. For example marker 2 will change to marker 2 and 2R where 2R is the reference and 2 would be the delta.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
The marker function operates the same as the standard ESA-E Series.	To turn marker on, press [Marker].
Turn on marker 2	Press {Select Marker 2} and press {Normal}
Active delta marker 2. The marker table under the graphical display reflects the delta marker information.	First place the marker to a reference point using knob or up/down arrows. Press {Delta}. Move the marker relative to the reference marker.
Switch between displaying the absolute frequency of the delta marker and the reference marker frequency.	Press {Delta Pair}. Note the change in frequency above the graphical display.

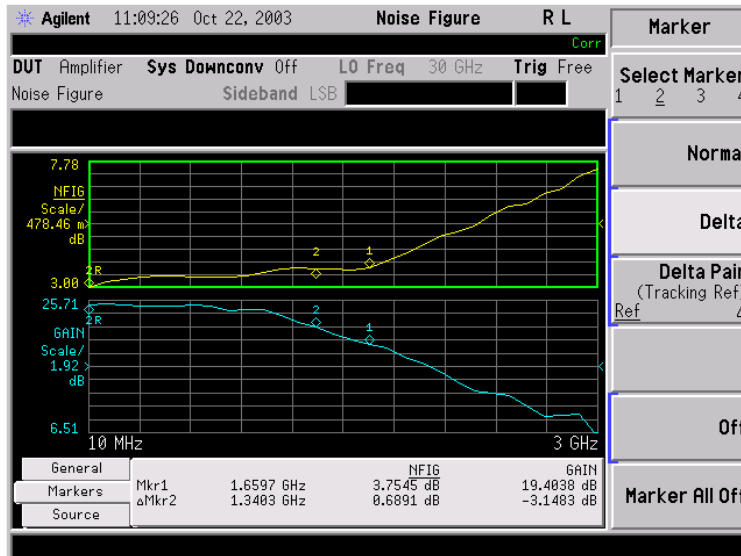


Figure 16: Display of markers and delta markers on the ESA allow noise figure and gain to be read along the entire sweep

Note that it is not necessary to toggle to the marker tab when selecting marker functions. This is automatically displayed. Additionally, the analyzer toggles to the general tab once markers are turned off.

Change format of the active window

The default view of the window is the graphical mode with noise figure in the top and gain in the bottom. The two graphs can be combined to display both traces on one graph. There are two other views available; the table mode, which some users prefer, and meter mode which provides quick and easy to read measurement information while facilitating testing.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
To combine both traces on one graph, see figure below.	Press [View/ Trace]{Combined on}.

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Activate the table mode, see figure below	Press [View/ Trace]{Table}
Activate the meter mode	Press [View/ Trace]{Meter}

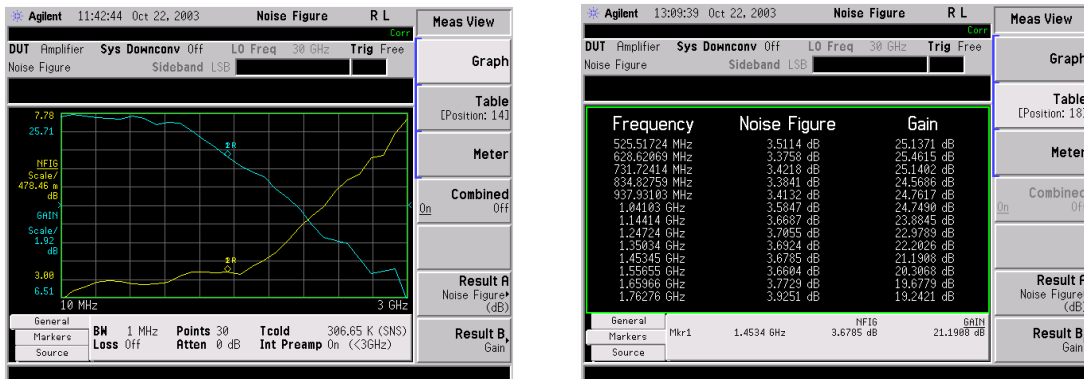


Figure 17: Combined display mode on the ESA and Table display mode on ESA.

Change the measurement result you are displaying

The default display of the ESA is noise figure and gain., however there is a separate facility for displaying 6 different types of measurement results. This can be done independently for the two windows. Depending on which one is chosen

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Activate the table mode, see figure below	Press [View/ Trace]{Result A}{T effective}
Scale the view appropriately	Press [Amplitude]{Auto Scale}

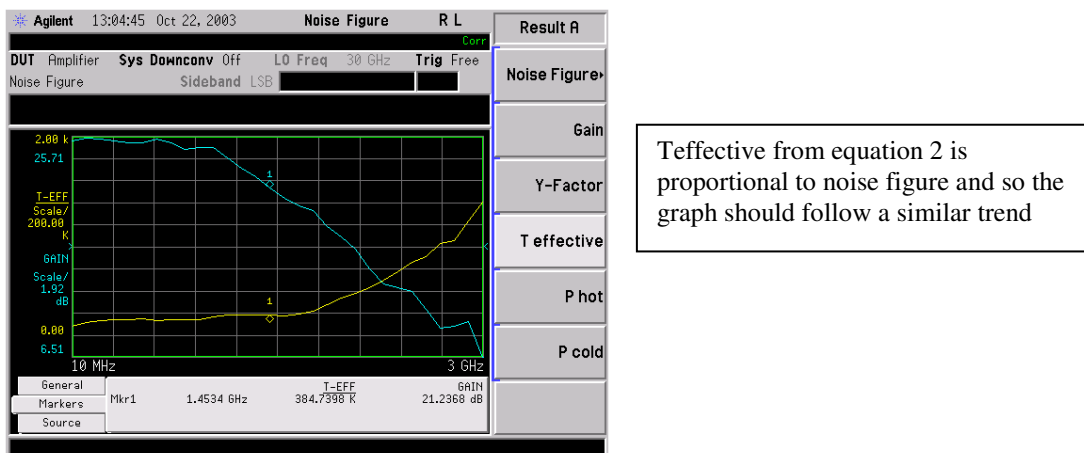


Figure 17: Different measurement result type on ESA.

Creating and testing to limit lines

In the manufacturing environment, it may be necessary to increase manufacturing through-put. This could be implemented by inserting pass/fail limit lines. By using this function, the operator can quickly and

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efficiently quantify noise figure and gain dramatically reducing the time spent testing each DUT. Up to four limit lines can be setup two for the upper graph and two for the lower graph. The two limit lines for the upper graph are designated with up arrows (soft keys), and the limit lines for the lower graph are designated with down arrows (soft keys). The limit lines can be designated as upper limit or lower limit and each can have a test pass/fail indicator.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Change view back to default noise figure	Press [View/Trace]{Result A}{Noise Figure}{Noise Figure(dB)}
Open the limit line editor, select upper limit for the upper graph and turn on the limit test.	[Display]{limits}{limit 1}{Edit}, use [←][⇒] tab keys under display to highlight Limit. Press {On}, move to Type, press {Upper}, move to Display {On}, move to Test {On}.
Insert limit values for 10 MHz, 100MHz, 1, 2 and 3 GHz Limit lines values take on the value of the set of results it is being applied to.	Use [←][⇒] tab keys to highlight point 1. Press {Frequency 10 MHz}, {Limit Value}[3]{ x 1}, {Connected Yes}, {Point 2} {Frequency 100 MHz}, {Limit Value}[4]{ x 1}, {Connected Yes}, {Point 3},{Frequency 1 GHz}, {Limit Value}[5]{ x 1}, {Connected Yes}, {Point 4},{Frequency 2 GHz}, {Limit Value}[5]{ x 1}, {Connected Yes},{Point 5},{Frequency 3 GHz}, {Limit Value}[8]{ x 1}, {Connected Yes}.

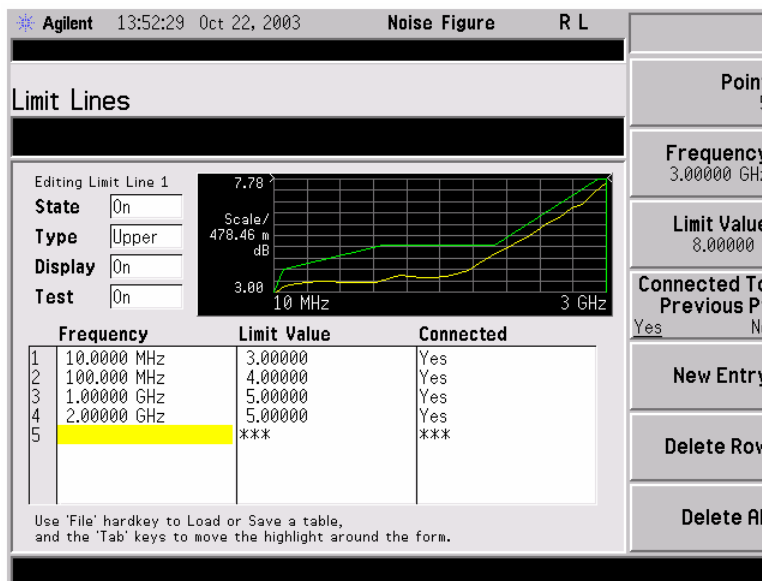


Figure 18: Limit line editor on the ESA.

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Figure 19: Measurement with limit test on, showing a passing noise figure limit test

Lab 4: Noise Figure Uncertainty Calculator

Option 219, noise figure personality has a built-in uncertainty calculator. To calculate the overall measurement uncertainty, simply choose the default noise source (N4002A for example), enter the input and output match of the device under test and the gain/noise figure of the DUT from the measurement display and the value of the uncertainty will be calculated. There are some default values for the instrument (ESA) already entered.

Using the built-in uncertainty calculator to measure the uncertainty of the measurement for:

Example:
 Frequency 525 MHz
 D.U.T. with 24.85 dB gain
 D.U.T. NF: 3.45 dB
 N4002A ENR (12 –16 dB) F<3GHz
 ESA Instrument uncertainty (Noise Figure): ±0.41 dB for this range

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Select uncertainty calculator	Press [Mode Setup], {Uncertainty Calculator}
Choose N4002A as the noise source	Use [⇒] [⇐] tab keys to highlight Noise Source Model box. Press {N4002A}
Setup the instrument NF and Gain uncertainty for ENR and frequency range of measurement. <i>Instrument noise figure ~ what you saw in lab 3 during uncorrected measurement after calibration</i>	Use [⇒] [⇐] tab keys to highlight Instrument Noise Figure and enter 8dB. Highlight Noise figure uncertainty and enter 0.41 dB Highlight Gain uncertainty and enter 0-.83 dB
Enter the Noise Figure and Gain values from the	Using tab keys to highlight DUT Noise Figure and

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measurements graph or marker table	enter 3.45 dB. (To view the marker table, press [Return] and to return to the calculator press {Uncertainty Calculator}. Then highlight DUT Gain and enter 24.45 dB.
The input and output match of the DUT is determined from the specifications sheet or measured using a network analyzer.	Highlight DUT Input Match and enter 1.5, Highlight DUT Output Match and enter 1.5.
The measurement Uncertainty is then calculated and the results is display at the bottom of the form.	

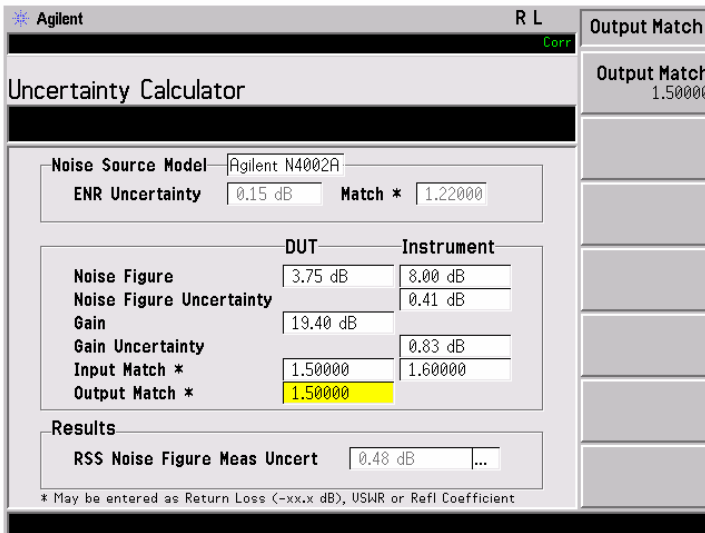


Figure 20: Uncertainty calculator display showing result for the example above.

If you have the time, you can observe the trends of uncertainty changes, i.e. increase in uncertainty as the gain decreases etc...

SNS allows easy correction for physical temperature
While on uncertainty.....

Remember from figure 1, page 3:

$$ENR = \left(\frac{T_h - T_c}{T_c} \right) : \text{We assumed that } T_s = T_c = T_o$$

The default value for Tcold used in the ESA is 296.5K. This is assumed to be the value of the noise source physical temperature when in the off condition. The ENR vs frequency tables, characterizing each noise source that was entered in Lab 1 are referenced to this. This may very well not be the case and if Tcold is not 296.5K, the ENR will not be correct leading to an error in the noise figure measurement shown below.

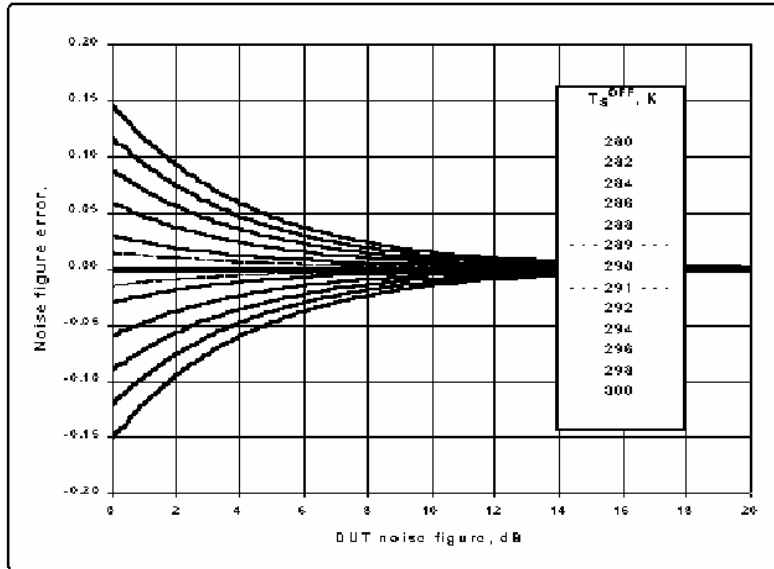


Figure 21: Magnitude of error in noise figure measurement if true Tcold is not what the instrument expects

For a D.U.T. NF of 3.5 dB, and a temp error of 8K, there is almost an additional ± 0.1 dB that needs to be added to the overall uncertainty budget!

This is why the SNS on the ESA is so valuable. They allow *automatic sensing of the ambient temperature of the measurement environment* allowing the ESA to compensate for these changes during the measurement cycle increasing the accuracy and reliability of noise figure measurements.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Automatic temperature sensing of Smart Noise Source	[Meas Setup] {ENR}{Tcold}{Preferences Norm <u>SNS</u> <i>Note that the SNS Tcold is ON. Because of this, the Tcold reported in the general tab is not the Default of 296.5K. It is the automatically sensed ambient temperature of 307.15K</i>
Use the default Tcold value	{SNS Tcold On <u>Off</u> }{User Tcold <u>Default</u> User}
You can also define your own Tcold, or sense this from the SNS instantaneously	{User Tcold <u>Default</u> <u>User</u> }{User Tcold from SNS}

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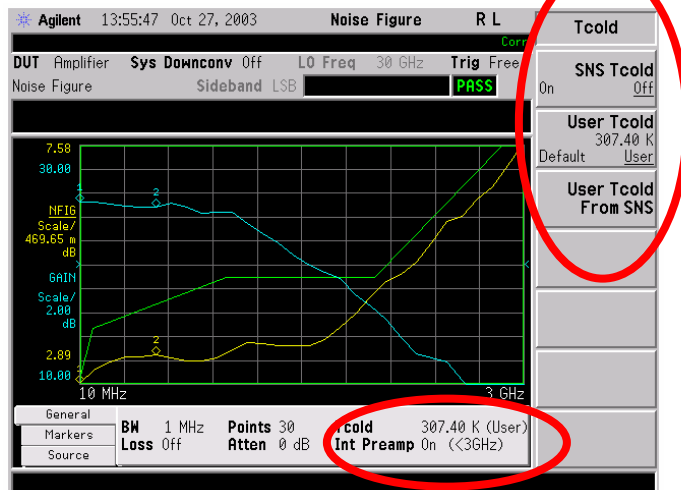


Figure 22: Automatic sensing of ambient temperature or user definable Tcold.....

Lab 5: Noise figure measurements using a mixer as the DUT

When a down conversion is included in the noise figure measurement, for example measuring the noise figure of a mixer, there are some additional setups to consider. For this example let us use a mixer as a downconverter with an IF at 70MHz, LO at 3GHz and both RF sidebands are used, 2930 and 3070MHz i.e. a DSB measurement.

- The measurement as well as calibration is made at the IF frequency.
- When an IF frequency is chosen, it is a good idea to keep the frequency as low as possible in order to avoid large differences in ENR values between the upper and lower sidebands when using DSB mode. This is because it is the ENR value at the LO that is used in the measurement (compromise since it is centered between the 2 sidebands)
- Since this device has some loss, it is recommended that the internal preamp be used.
- Compensate for two sidebands by selecting double side band.
- Any broadband noise in the LO will directly affect results. This can be solved by either a high pass or low pass filter at the LO port that removes the noise at the IF frequency. Place an IF filter at the input of the spectrum analyzer to remove LO feed through. Usually mixers have around 20dB of isolation between the LO-IF port so the high powered LO will seriously affect results.

Disconnect the amplifier from the ESA

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Setup the ESA for down conversion measurements as shown in the diagrams below. It is recommended that the internal preamp be used when measuring devices that have low gain.	Press {Meas Setup} {More 1 of 2} {Restore Meas Defaults} Press {Meas Setup} {Int Preamp <u>O</u> n Off} Press [Mode Setup] {DUT Setup...} {Down Conv}
Setup the LO frequency (figure 23) on the ESA	Move to "Ext LO frequency" using tab keys the enter 3GHz Tab to Sideband and choose DSB
Setup the fixed IF frequency	[Frequency] {Freq mode} {Fixed} {Fixed frequency} {70 MHz}
Calibration: connect the noise source to the input of the ESA.	Press [Meas setup]{Calibrate}{Calibrate}

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Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Measure the DUT: Connect the mixer IF (I) port to the ESA, the LO (L) port to the signal source and the RF (R) to the noise source.	To add more averaging, press [Meas Setup] then {Avg Number <u>On</u> }

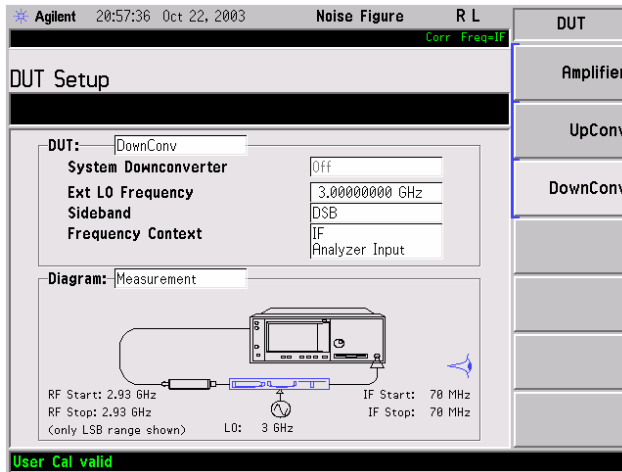


Figure 23: Setup for measuring a down-converter (mixer) at a fixed LO and fixed IF

Instructions: ESG E4438C Vector Signal generator	Keystrokes: ESG E4438C Vector Signal generator
Setup the source for + 7 dBm at 3 GHz	On E4438C press [Frequency][3] GHz [Amplitude] [7]{dBm}[RF <u>On</u>]

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Change the ESA display to meter mode, more appropriate for a single frequency measurement	[View/Trace]{Meter}

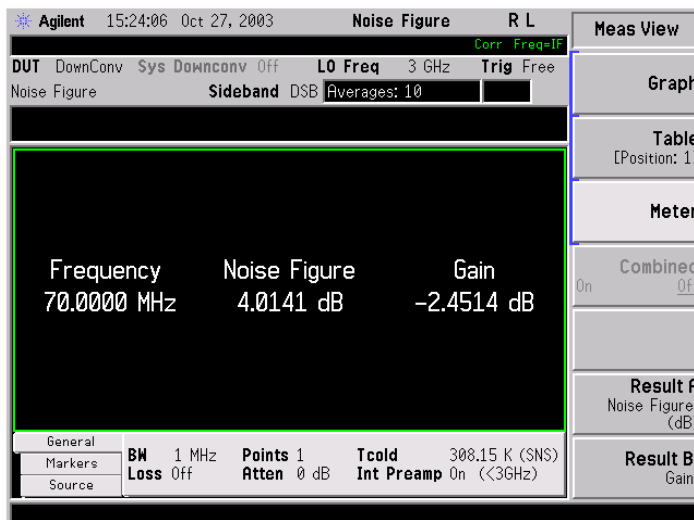
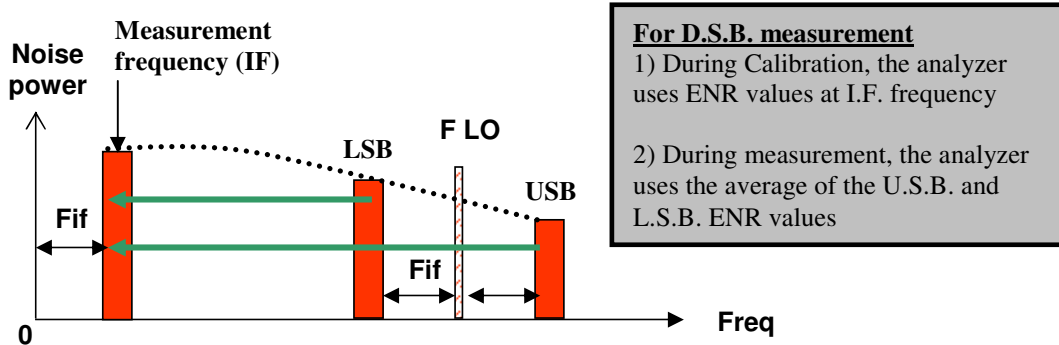


Figure 24: The meter view showing noise figure and Gain (conversion loss) of a



Noise Figure Lab

The measurement is valid for a DSB device under test, provided that there isn't too much variation of the frequency response of the D.U.T. and the ESA. This measurement could be used to estimate the SSB noise figure without having to worry much about image reject filtering. The next page outlines the differences and how one can correct for this. The details of mixer measurements are out of the scope of this lab.



For a S.S.B application, the analyzer should see the image frequency from just one sideband. So as a result, if the analyzer is using the D.S.B. measurement to approximate the S.S.B case, it will see the gain as twice what it should be. And since noise figure = (Noise power out)/(Gain * Noise power in), the noise figure will be 1/2 of what it should be in the S.S.B case. So a loss compensation of -3dB (gain of 3 dB) needs to be applied to make the S.S.B equivalent measurement.

Loss Compensation

Compensate for losses before and after the DUT. These losses can be fixed or varied versus frequency. The figures below shows the “before” and “after” setup menu. The “before” menu as well as the “after” can be setup to have a table of losses versus frequency or a fixed value. For fixed values, input a value for loss in dB and temperature in K. In our example, let's use a fixed gain (negative loss) after the DUT since we are making a fixed frequency measurement.

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Enter a fixed loss value to use as compensation after the DUT	Press [Input/Output], {Loss Comp} and {Setup}. Use the tab keys under the display to highlight the box labeled {Loss Compensation after DUT} and press {fixed}. Tab to {Fixed Value} and enter -3 dB.
The temperature of the loss must also be entered. In this case room temperature.	Tab to {Temperature} in the “before” box and enter 290 K

The loss compensation could also have been setup vs frequency in a tabular format

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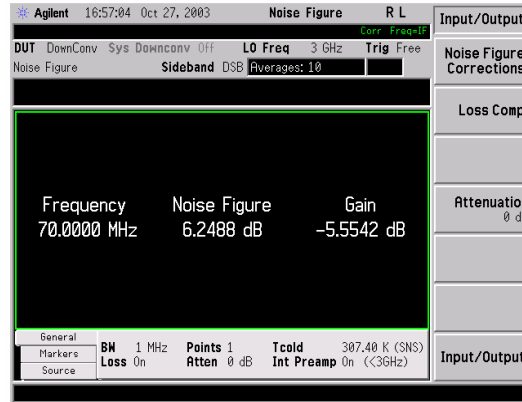
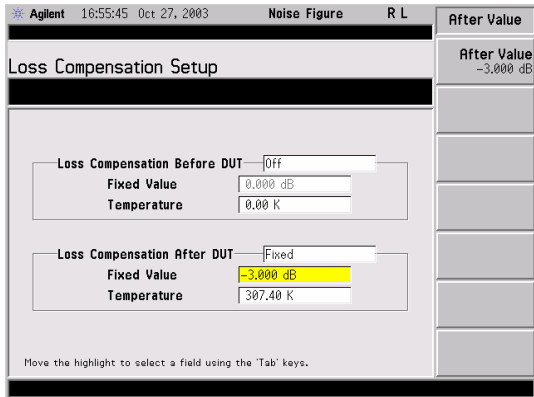


Figure 25: Loss Compensation selection table

Noise figure after loss compensation

Narrowband noise figure measurements

The noise figure measurement personality has the capability to reduce the resolution bandwidth allowing narrow bandwidth measurements. As the bandwidth narrows, the measurement jitter increases. It is recommended that the number of averages increase to reduce the jitter. In this measurement, the device under test will be an amplifier, band limited, with a band pass filter which has a center frequency of 70 MHz. The start and stop frequencies are set and the number of points to be measured are set. In this example 30 points will be used. The figure below is an example of a narrowband measurement.

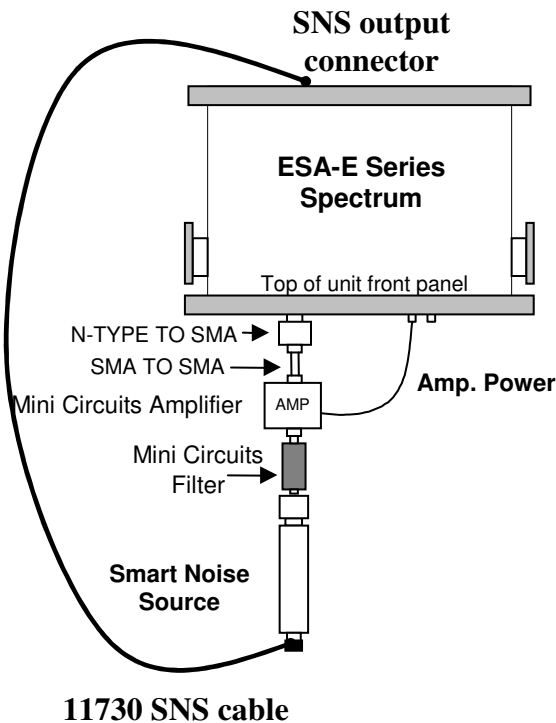


Figure 26: Connection diagram for narrow band measurements

Instructions: ESA-E series Spectrum Analyzer	Keystrokes: ESA-E series Spectrum Analyzer
Setup the ESA for narrow band measurements.	Press [Mode Setup] {DUT Setup...} {Amplifier}
Connect the noise source directly to the spectrum analyzer	

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Set start and stop frequency	[Frequency]{Freq Mode Swept}{Start Freq, 50 MHz}{Stop Freq, 90 MHz}
Set the number of measurement points	[Frequency]{Points} 30 enter
Set the resolution bandwidth	[BW/Avg], 300 kHz
To reduce measurement jitter add averaging then calibrate	[Meas Setup]{Avg Number}15{Enter}, {Calibrate}{Calibrate}
To measure the DUT connect the filter to the noise source and the other end to the input of the amplifier and the output of the amplifier to SA input.	
To achieve the display shown below	[Trace/View], {Combined On} [Amplitude]{Auto Scale}

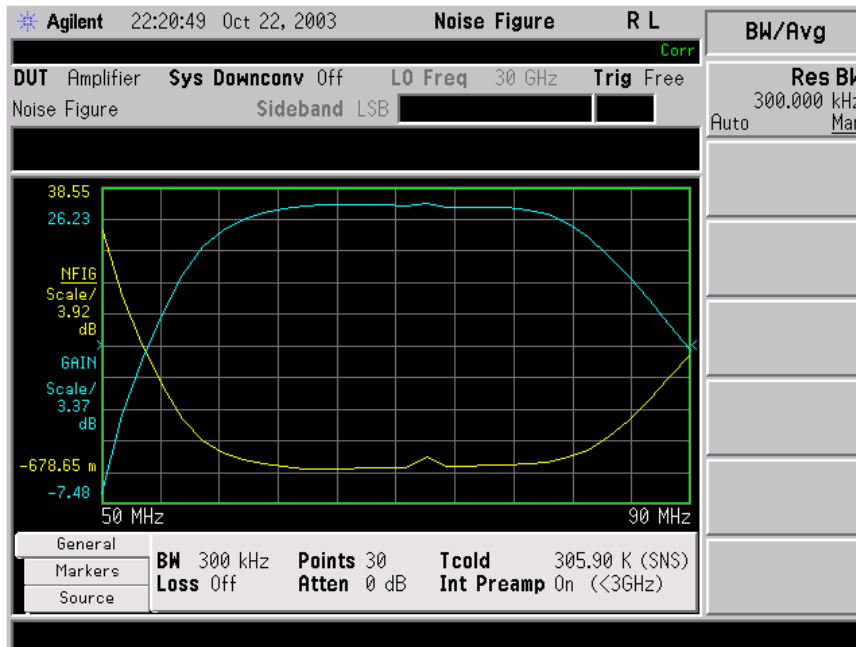


Figure 25: Narrow band measurements display of filter in cascade with amplifier.