Keysight X-Series Signal Analyzers

This manual provides documentation for the following analyzers:

UXA Signal Analyzer N9040B

N9068C Phase Noise
Measurement
Application
Measurement Guide

KEYSIGHT
TECHNOLOGIES

Notices

Trademark Acknowledgements

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Table of Contents

1 Making Measurements

This chapter provides procedures for making the following Phase Noise measurements:

– Monitor Spectrum - See "Monitor Spectrum Measurements" on page 31.

NOTE **Monitor Spectrum does NOT measure Phase Noise, but is used initially to make sure the instrument is correctly tuned to the carrier frequency.**

– Log Plot - See "Log Plot - with RMS Noise, Residual FM, Average Noise Density" on page 9.

– Spot Frequency - See "Spot Frequency Measurements" on page 27.

Detailed instructions are also provided to help you with the following:

– Improving measurement accuracy
  – smoothing and averaging
  – signal tracking
  – viewing signal drift
– Using cancellation for Log Plot measurements
  – Measuring and displaying the displayed average noise level floor (DANL Floor)
  – Creating a low phase noise reference
  – Using a reference trace (DANL trace or low phase noise reference trace) for cancellation
  – Saving and recalling reference traces

Touch User Interface vs. Front-Panel Hardkeys

The N9040B UXA has a touch user interface (UI) that enables you to perform most of the steps for a measurement using the touch UI. The UXA also has front-panel hardkeys, which access the same drop-down menu selections. When several drop-down menu selections are required, it is faster to use the hardkeys for direct access.

See Figure 1-1. The left graph shows all the selections under the menu panel drop-down box on the touch UI and the right graph shows the hardkeys on the front panel of the instrument. All the selections under the menu panel drop-down box can be found on the front panel. Tapping a selection on the drop-down menu has the same effect as pressing the hardkeys on the front panel. While making a measurement, you can choose either method. In this document, the examples will use the drop-down menu to select the desired panel.

In addition, there are some other keys on the front panel, including some immediate-action keys like Single/Cont, Restart, Mode Preset, User Preset, and some other keys like Save, Recall. These keys are provided to make it more convenient to set parameters. With the immediate-action keys, you can execute the action by a single press without entering into the corresponding menu.

Figure 1-1 Touch UI Menu Panel vs. Front-Panel Hardkeys

Menu Panel Drop Down box on Touch UI

Hardkeys on the front panel

Log Plot - with RMS Noise, Residual FM, Average Noise Density

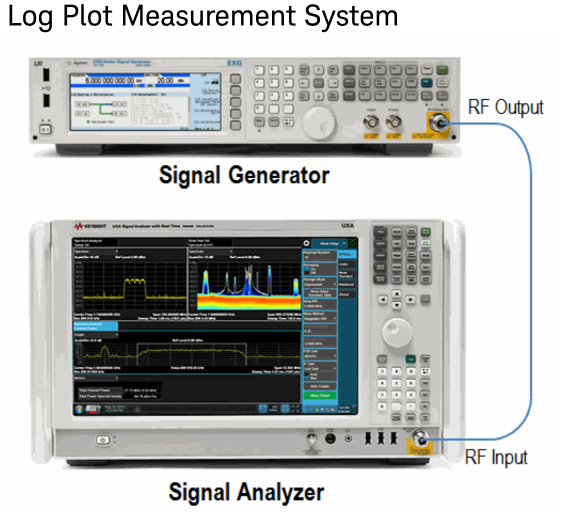
This chapter explains how to make a Log Plot measurement on a signal analyzer. The Log Plot measurement measures the single-sideband phase noise (in dBc/Hz) versus offset frequencies and the results are shown in logarithmic scale. This allows you to view the phase noise behavior of the signal under test across many decades of offset frequencies.

The procedure of the following measurements are included in this section:

– “Basic Log Plot Measurement Procedure” on page 10
– “Using Markers to Make Noise Measurements of Integrated (RMS) Noise, Residual FM, and Average Noise Density” on page 14
– “Using Log Plot to Measure Displayed Average Noise Level (DANL Floor)” on page 16
– “Creating a Low Phase Noise Signal Reference Trace” on page 19
– “Using a Reference Trace (DANL Floor or Low Phase Noise Reference) for Noise Cancellation” on page 21
– “Saving Traces for Retrieval” on page 24
– “Recalling Traces” on page 25

Figure 1-2 shows the measurement system using a signal generator and a signal analyzer to make Log Plot measurements. The signal under test is transmitted from a signal generator, and it is connected to the RF input port of the signal analyzer. Connect the equipments as shown below.

Figure 1-2 Log Plot Measurement System



1. Using the appropriate cables and adapters, connect the output signal of the signal generator to the RF input of the analyzer.
2. For best frequency accuracy, connect a BNC cable between the 10 MHz REF IN port of the signal generator (if available) and the 10 MHz EXT REF OUT port of the analyzer.

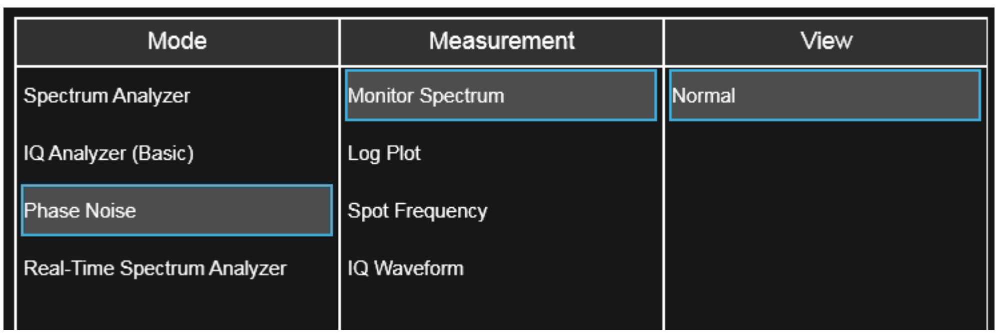
Basic Log Plot Measurement Procedure

The RF signal under test is a single-tone signal with phase noise impairment:

NOTE The real-time phase noise impairment function in the MXG/EXG signal generator is used to add phase noise impairments.

- Center frequency: 1 GHz
- Amplitude: -20 dBm
- Phase noise: -110 dBc/Hz@(1 kHz ~ 200 kHz)

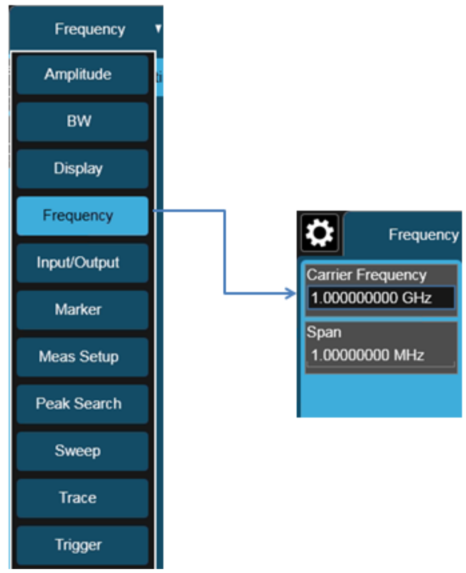
Step	Action
1 Select the Monitor Spectrum measurement in the Phase Noise mode.	a. Tap the **Spectrum Analyzer 1 Swept SA** screen tab (or press the **Mode/Meas** key) to display the Mode/Meas/View browser. b. Tap **Phase Noise** in the Mode column, **Monitor Spectrum** in the Measurement column, and **Normal** in the View column. Then tap the OK button at the bottom.



Step	Action
2 Preset the phase noise mode.	a. Tap the preset button at the top right corner of the screen.

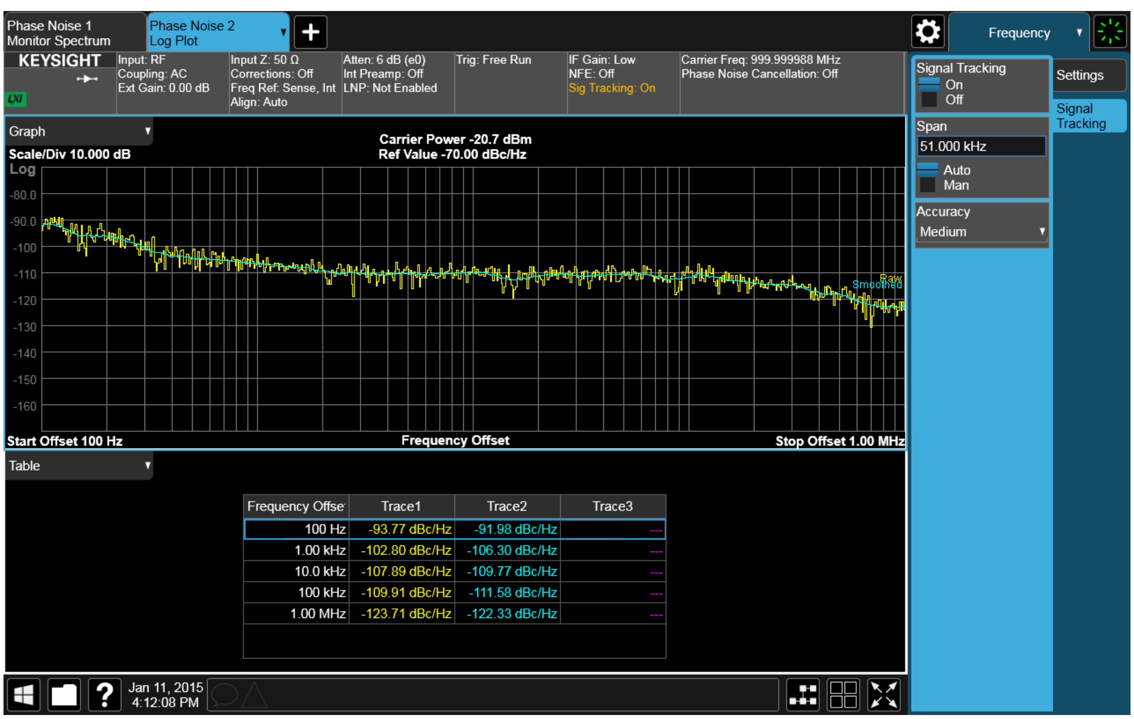
b. Tap **Mode Preset**.

NOTE You can also press the **Mode Preset** key on the front panel directly.

Step	Action
3 Verify the RF carrier is present, and the instrument is tuned to the frequency of interest using the Monitor Spectrum measurement to view the RF carrier.	**a.** Tap the menu panel drop-down box in the top right corner and select **Frequency**. **b.** Double tap **Carrier Frequency** and set the carrier frequency to 1 GHz in the pop-up window. 
4 Select the Log Plot measurement, Decade Table view to view the phase noise trace and a table of tabular results at decade offsets.	**a.** Tap the **Add Screen** button to add a screen and display the Mode/Meas/View browser.  **b.** Tap **Phase Noise** in the Mode column, **Log Plot** in the Measurement column, and **Decade Table** in the View column. Then tap the **OK** button at the bottom.
5 Tune the measurement.	On the Frequency menu panel, tap **Auto Tune**. **NOTE** If the carrier is too far off for the Auto Tune function to determine the carrier frequency, an error will be displayed at the lower right corner of the display. Go back to the Monitor Spectrum measurement and re-tune the instrument.

Step	Action
6 Track a drifting signal.	**a.** On the Frequency menu panel, tap the **Signal Tracking** tab to enter the signal tracking controls. **b.** Toggle **Signal Tracking** to **On**, and set the **Span** and **Accuracy** as needed. For the Accuracy control, you may need to trade between measurement speed and accuracy. High gives the best accuracy, but is slower. Low is faster, but has lower tracking accuracy.
7 Set the frequency offset range for the phase noise measurement.	**a.** On the Frequency menu panel, tap the **Settings** tab. **b.** Double tap **Start Offset** and enter **100 Hz** in the pop-up window. **c.** Double tap **Stop Offset** and enter **1 MHz** in the pop-up window.
8 Restart the measurement.	**a.** Tap the menu panel drop-down box in the top right corner and select **Sweep**. **b.** Tap **Restart**. **NOTE** You can also press the **Restart** key on the front panel to restart the measurement.

The Log lot measurement results should look like the graph shown below. The window on the top shows the graphical view of the measurement results, in which the yellow trace shows the current results and the blue trace shows the smoothed data. The table on the bottom shows the tabular results at decade offsets.



Step	Action
9 (Optional) If you are measuring offsets > 1 MHz, you can use the Overdrive feature to increase the dynamic range of the instrument. Overdrive uses the electronic step attenuator if available, or the mechanical step attenuator to optimize input signal levels. The measurement is slowed by the respective attenuator switching time. For more information see "Advanced Features - Using AM Rejection and Overdrive" on page 47.	**a.** Tap the menu panel drop-down box in the top right corner and select **Meas Setup**. **b.** Tap the **Advanced** tab and toggle the **Overdrive with Mech Atten (Offset > 1 MHz)** to **Enabled**.
10 The default sweep setting for the phase noise measurement is single. If you want to make measurement continuously, change the setting to continuous.	**a.** Tap the menu panel drop-down box in the top right corner and select **Sweep**. **b.** Toggle the **Sweep/Measure** control to **Continuous**. **NOTE** You can also press the **Single/Cont** key on the front panel to restart the measurement.

Using Markers to Make Noise Measurements of Integrated (RMS) Noise, Residual FM, and Average Noise Density

When the basic Phase Noise measurement (above) is complete, you can measure other noise parameters like RMS noise, residual FM, and average noise density using markers.

Step	Action
1 Select the Marker Table view in the Log Plot measurement.	**a.** Tap the **Phase Noise 1 Log Plot** screen tab (or press the **Mode/Meas** key) to display the Mode/Meas/View browser. **b.** Tap **Phase Noise** in the Mode column, **Log Plot** in the Measurement column, and **Marker Table** in the View column. Then tap the OK button at the bottom.
2 Restart the measurement.	**a.** Tap the menu panel drop-down box in the top right corner and select **Sweep**. **b.** Tap **Restart**. **NOTE** You can also press the **Restart** key on the front panel to restart the measurement.
3 Enter the marker function panel.	**a.** Tap the menu panel drop-down box in the top right corner and select **Marker**. **b.** Tap the **Marker Function** tab to enter the marker function panel.
4 Set marker function for markers. For more information on these topics, see "About Log Plot and Spot Frequency Measurements" on page 44.	**a.** Tap **Select Marker** to select a marker. **b.** Tap **Marker Frequency** and set it to **1 kHz**. **c.** Tap **Marker Function**, and select one of the following. In this example, Integrated RMS Noise is selected. – **Integrated RMS Noise** - Select units in degree, radians, second, or dBc. – **Residual FM** - Marker values provided in Hz – **Average Noise Density** - Marker values provided in dBc/Hz **d.** Tap **Integrated (RMS) Noise** and select **Degree**. **e.** Double tap **Band Span**, or **Band Left**, **Band Right**, and set values to them in the pop-up window.
5 Add more markers with marker functions.	Following the procedure in step 4, add another three markers with Integrated Noise (Jitter), Residual FM, and Average Noise Density marker functions at 10.0 kHz, 100 kHz, and 500 kHz frequency offset.

Step	Action

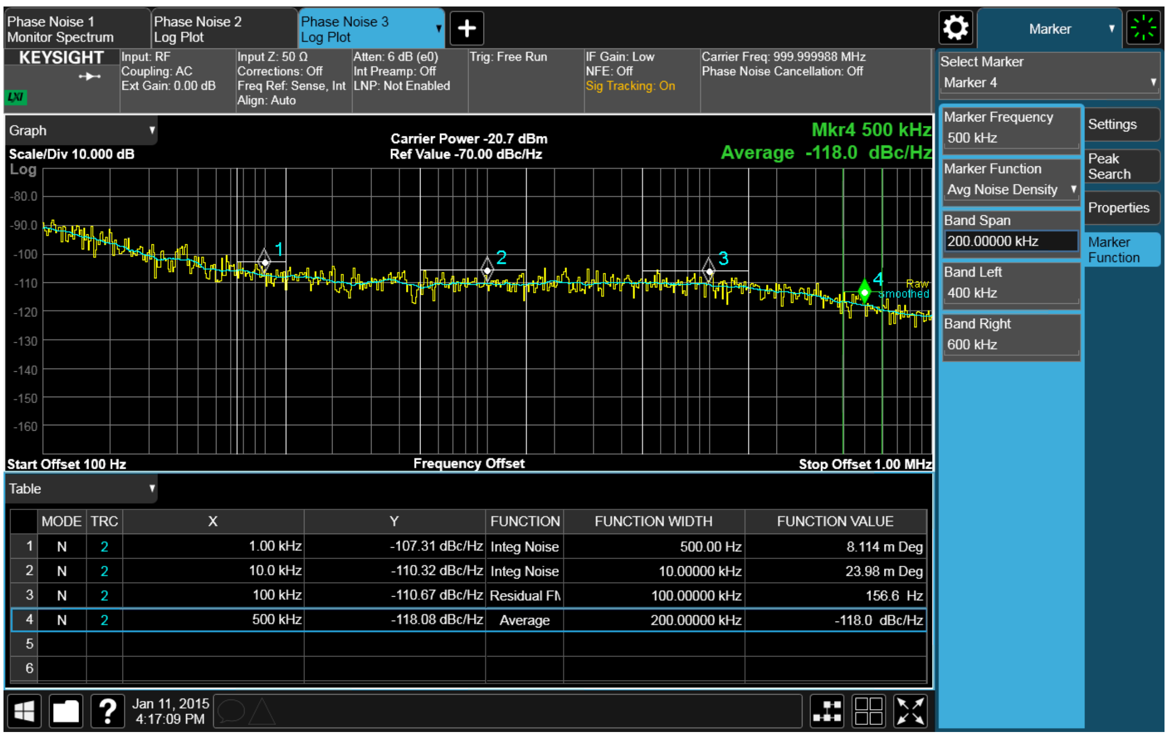
The marker function measurement results should look like the figure below. In Marker Table view, there are two windows.

- The top window shows the markers on the measured trace. Band markers appear as vertical lines in the plot with the center frequency marked as a diamond. Because the Log Plot is not linear, and because the marker center location is shown in the linear center of the band, the Band Left point will be farther from the center than the Band Right point.

  Note that the markers are placed on Trace 2 (blue trace) by default. To place them on another trace, tap the **Properties** tab, then tap **Marker Trace** to select another trace.

- The bottom window shows detailed information for each marker.

The values displayed for the integration bandwidth are based on the last measurement acquisition. Unless the Sweep/ Measure control is set to **Continuous**, the measurement data will not be refreshed unless the **Restart** key is pressed.



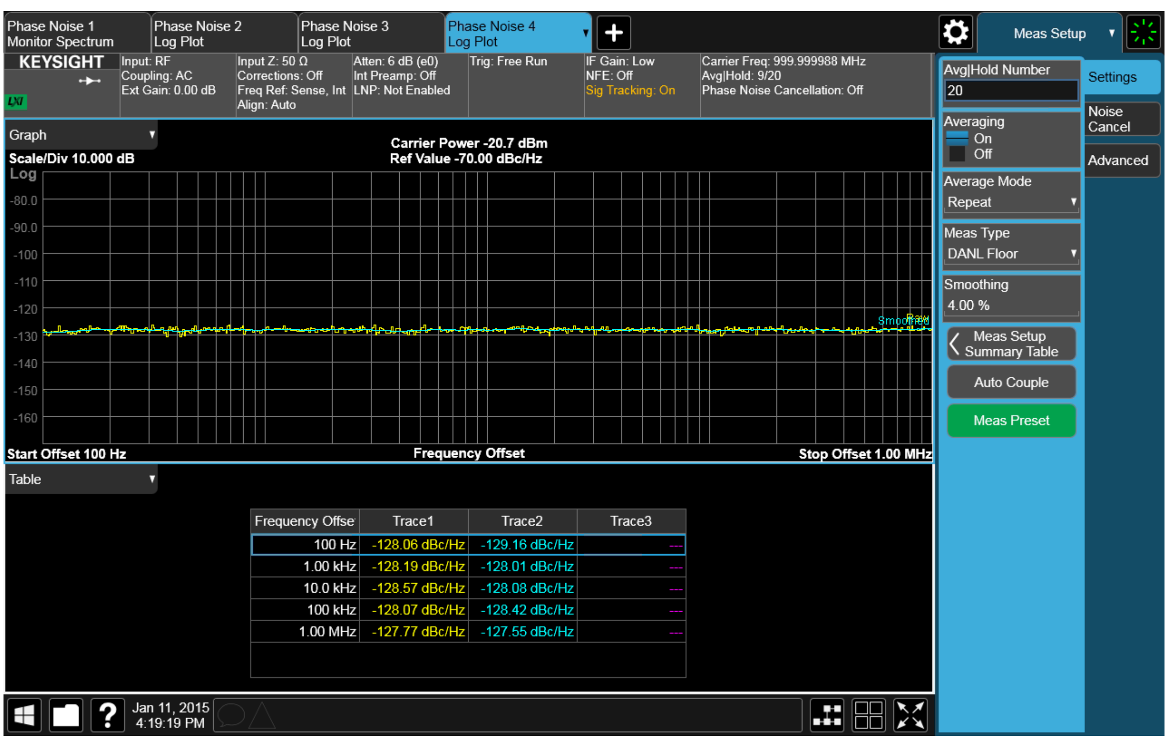
Using Log Plot to Measure Displayed Average Noise Level (DANL Floor)

The DANL floor of a signal/spectrum analyzer limits the measurement of the smallest input signals, which are usually found at the extreme offset frequencies. When the amplitude of a signal under test approaches the level of the DANL floor, significant measurement error can occur. To validate a low signal level measurement, you can measure the DANL floor of the analyzer and determine whether the measured phase noise is from the generator, or is due to the DANL contribution.

Step	Action
1 Select the Log Plot measurement in the Phase Noise mode.	**a.** Tap the Add Screen button to add a screen and display the Mode/Meas/View browser.  **b.** Tap **Phase Noise** in the Mode column, **Log Plot** in the Measurement column, and **Decade Table** in the View column. Then tap the OK button at the bottom.
2 Preset the phase noise mode.	**a.** Tap the preset button at the top right corner of the screen.  **b.** Tap **Mode Preset**. **NOTE** You can also press the **Mode Preset** key on the front panel directly. 
3 Select the Log Plot measurement in the Phase Noise mode.	**a.** Tap the **Phase Noise Monitor Spectrum** tab (or press the **Mode/Meas** key) on the top of the screen to display the Mode/Meas/View browser. **b.** Tap **Phase Noise** in the Mode column, **Log Plot** in the Measurement column, and **Decade Table** in the View column. Then tap the OK button at the bottom.
4 Tune the measurement.	**a.** Tap the menu panel drop-down box in the top right corner and select **Frequency**. **b.** Tap **Auto Tune**.

Step	Action
5 Set the frequency offset range for the phase noise measurement.	**a.** On the Frequency menu panel, tap the **Settings** tab. **b.** Double tap **Start Offset** and enter **100 Hz** in the pop-up window. **c.** Double tap **Stop Offset** and enter **1 MHz** in the pop-up window.
6 Select DANL Floor as the measurement type.	**a.** Tap the menu panel drop-down box in the top right corner and select **Meas Setup**. **b.** Tap **Meas Type** and select **DANL Floor**.
7 Turing on Averaging.	On Meas Setup menu panel, **a.** Toggle **Averaging** to **On**. **b.** Double tap **Avg|Hold Number** and set it to **20** in the pop-up window.
8 Restart the measurement.	**a.** Tap the menu panel drop-down box in the top right corner and select **Sweep**. **b.** Tap **Restart**. **NOTE** You can also press the **Restart** key on the front panel to restart the measurement.

The DANL measurement should look like the figure below, in which the yellow trace shows the current data, and the blue trace shows the smoothed data.



Step	Action
9 (Optional) Select the display view the have a clear view.	**a.** Tap the menu panel drop-down box in the top right corner and select **Trace**. **b.** Select the trace type to be **Raw** or **Smoothed** to view only one trace.

Creating a Low Phase Noise Signal Reference Trace

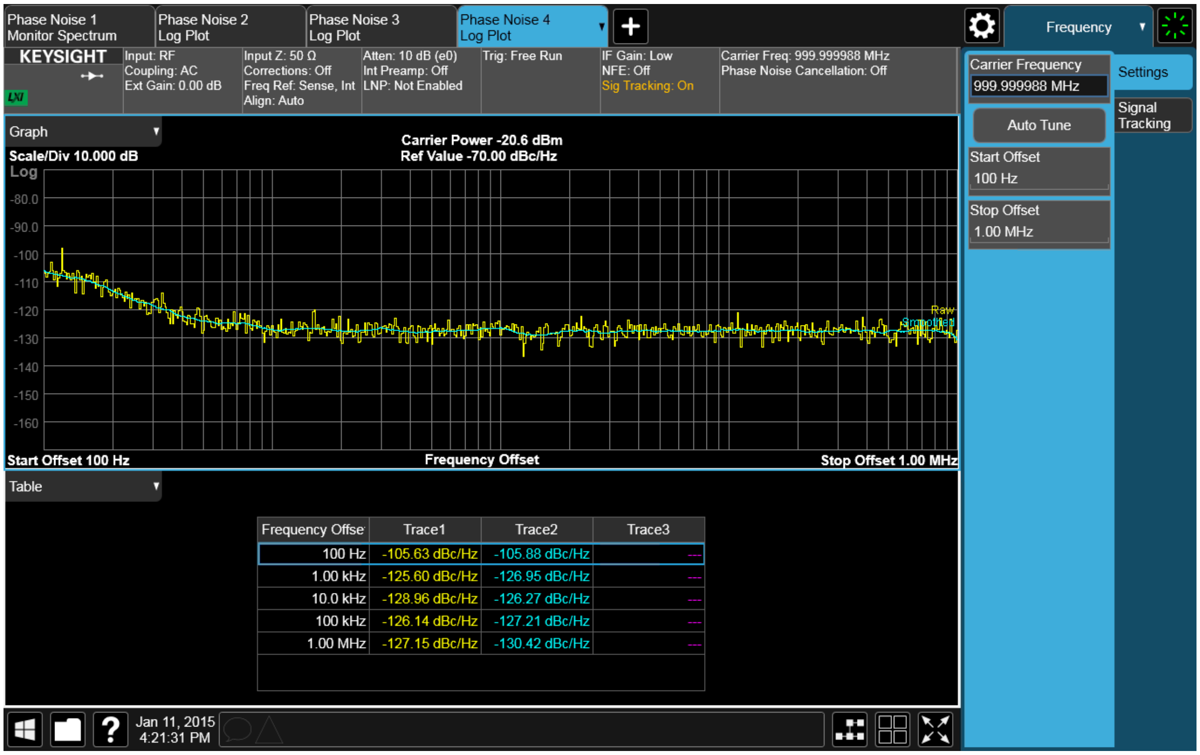
You can use a known low phase noise source to create a reference trace. The phase noise of this source should be much better than the signal analyzer’s phase noise, then the result trace will represent the signal analyzer’s internal phase noise. A reference trace from a good source that is relatively free of phase noise will let you compensate for both the phase noise and the DANL of the analyzer.

NOTE For a reference trace to be valid it must cover the same frequency range as your intended measurement.

Step	Action
1 Select the Log Plot measurement in the Phase Noise mode.	**a.** Tap the Add Screen button to add a screen and display the Mode/Meas/View browser.  **b.** Tap **Phase Noise** in the Mode column, **Log Plot** in the Measurement column, and **Decade Table** in the View column. Then tap the OK button at the bottom.
2 Connect a low phase noise signal source to the RF input of the signal analyzer and set it to the desired output frequency.	
3 Measure the phase noise of your reference signal. This measures and displays the phase noise of your test signal. You now have a reference trace available that you can either use immediately or save for later use. See “Saving Traces for Retrieval” on page 24 and “Recalling Traces” on page 25 for more information about saving and recalling traces.	**a.** Tap the menu panel drop-down box in the top right corner and select **Meas Setup**. **b.** Tap **Meas Type** and select **Phase Noise**.
4 Restart the measurement.	**a.** Tap the menu panel drop-down box in the top right corner and select **Sweep**. **b.** Tap **Restart**. **NOTE** You can also press the **Restart** key on the front panel to restart the measurement.

Step	Action

The low phase noise reference trace should look like the figure below, in which the yellow trace shows the current data, and the blue trace shows the smoothed data. It can be seen that this reference trace is much lower than the phase noise of the signal under test.



Using a Reference Trace (DANL Floor or Low Phase Noise Reference) for Noise Cancellation

Cancellation is a process where a reference trace is "subtracted" from a Log Plot measurement trace, providing more accurate results. The reference trace can be of the internal DANL Floor of the analyzer, or a Log Plot trace of a known lower phase noise source for comparison.

NOTE Cancellation can NOT be performed when making a DANL Floor measurement.

Not all Log Plot measurements will benefit from Cancellation. Neither will Cancellation improve all measurements. In general, as the phase noise of the DUT approaches the internal DANL Floor of the analyzer, cancellation provides significant improvement in accuracy, but if the noise levels approach too closely, the results become less accurate. For more information, see "Noise Cancellation on Log Plot Measurements" on page 48.

In the following example, the trace that will be used for reference is trace 2 from the previous analyzer DANL Floor measurement. As trace 2 is normally used by the instrument to show smoothed data, the reference trace will be stored in trace 3, which is not normally used by the instrument.

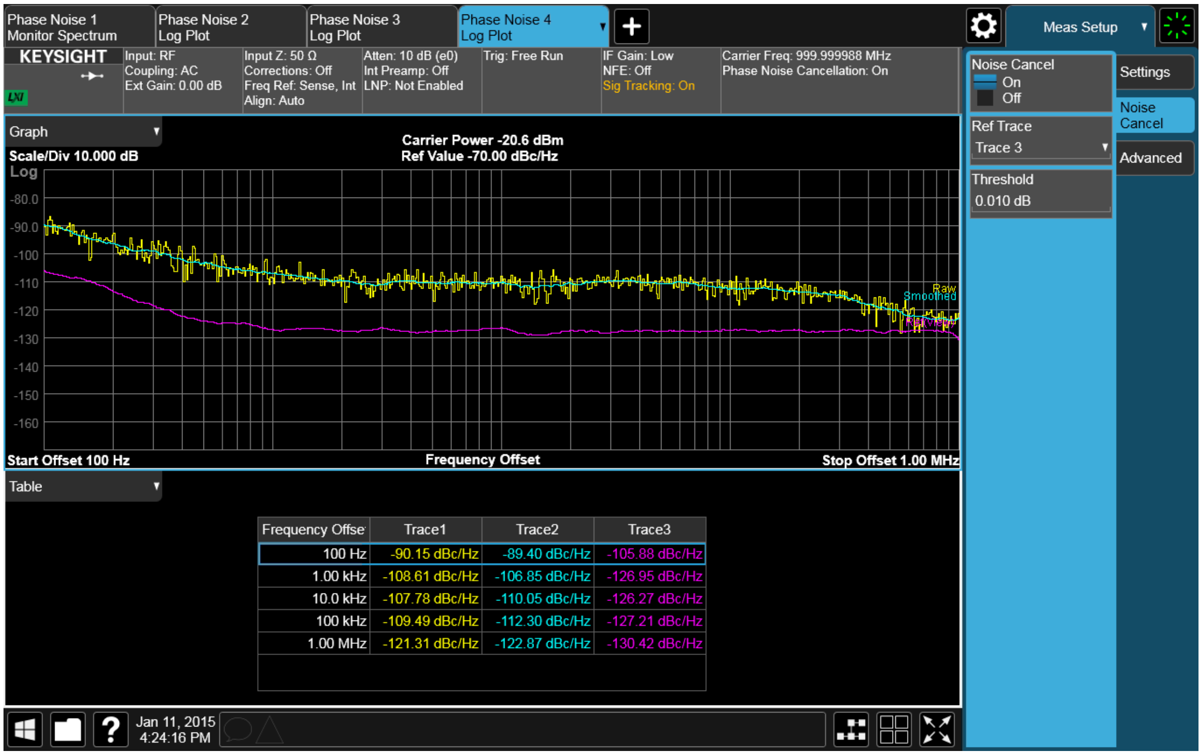
NOTE Traces saved in a Log Plot measurement are different from other measurement traces. Traces saved from any other measurement except Spectrum Analyzer Mode are not compatible with those saved in Log Plot measurements.

Step	Action
1 Complete the acquisition of a Reference trace as detailed in the procedure "Using Log Plot to Measure Displayed Average Noise Level (DANL Floor)" on page 16 or "Creating a Low Phase Noise Signal Reference Trace" on page 19. In this example, the low phase noise reference trace is used for noise cancellation.	
2 Copy the smoothed trace data in Trace 2 (cyan blue) to Trace 3 (magenta pink) for reference.	**a.** Tap the menu panel drop-down box in the top right corner and select **Trace**. **b.** Tap the **Copy/Exchange** tab. **c.** Tap **From Trace**, **Trace 2**. **d.** Tap **To Trace**, **Trace 3**. **e.** Tap **Copy Traces**.
3 Connect the signal under test to the RF input port of the signal analyzer.	

Step	Action
4 Set the Meas Type to Phase Noise to get back to the phase noise measurement. **NOTE** Cancellation can NOT be performed when making a DANL Floor measurement.	**a.** Tap the menu panel drop-down box in the top right corner and select **Meas Setup**. **b.** Tap **Meas Type**, P**hase Noise**.
5 Set noise cancellation to the phase noise measurement.	On the Meas Setup setting panel: **a.** Tap the **Noise Cancel** tab to enter the noise cancellation controls. **b.** Tap **Ref Trace**, **Trace 3**. **c.** Tap **Threshold**, **0.01 dB**. Normally you will not have to change this value. The noise cancellation measurement compares your current measurement with the reference trace on a point by point basis. At each point, the current measurement has to exceed the reference trace by at least the threshold level. If the difference between the source trace and the reference trace is less then the threshold level, then the source trace is assumed to be exactly the threshold level above the reference level. Refer to “Using Cancellation for Log Plot Measurements” on page 49 for more information. **d.** Toggle **Noise Cancel** to **On**.

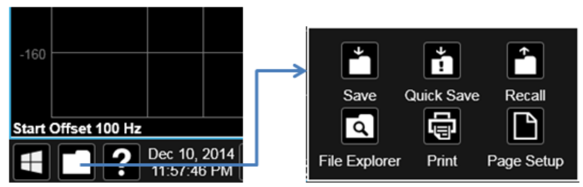
Step	Action

The phase noise results after noise cancellation should look like the figure below. The purple trace shows the reference trace used for noise cancellation. In this measurement, the phase noise of the signal under test is much higher than the reference low noise signal, so the effect of noise cancellation is not apparent.



Saving Traces for Retrieval

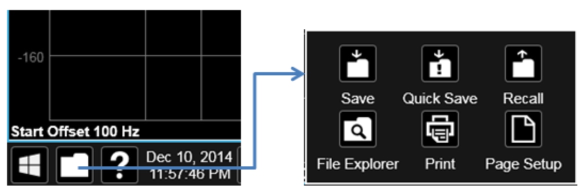
All traces, including the reference traces used for the noise cancellation measurement, can be saved to a USB disk or to the analyzer's own internal file system (D:). All traces are saved in CSV format. In this example the Reference Trace 3 from the above example will be saved.

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1 Enter the Save function.</td><td>Tap the Folder icon in the bottom left corner of the screen and select Save.

</td></tr>
<tr><td>2 Select the trace.</td><td>In the Save setting window,
a. Tap Measurement Data.
b. Select Trace 3 as the Save From Trace setting.
c. Select Trace as the Data Type.</td></tr>
<tr><td>3 Select the filename.</td><td>a. Tap Save As.
Save As launches a menu of navigation buttons and a Windows Explorer window, which opens to the default trace location:
D:\Users\Instrument\Documents\PNOISE\data\LPL\traces
The default file name is "<code>Trace_0001.csv</code>" and the number automatically increments, adding 1 to the last number in the file.
b. Tap Save.</td></tr>
</table>

Recalling Traces

All traces, including the reference traces used for noise cancellation measurement, can be loaded from a USB disk or from the analyzer's own internal file system (D:). All traces to be recalled must be saved in CSV format.

NOTE For a reference trace to be valid it must cover the same frequency range as your intended measurement.

Step	Action
1 Enter the Recall function.	Tap the Folder icon in the bottom left corner of the screen and select **Recall**. 
2 Select the trace.	In the Recall setting window, **a.** Tap **Measurement Data**. **b.** Select **Trace 3** as the **Recall From Trace** setting. **c.** Select **Trace** as the **Data Type**.
3 Select the filename.	**a.** Tap **Recall From**. Recall From launches a menu of navigation buttons and a Windows Explorer window which opens to the default trace location: D:\Users\Instrument\Documents\PNOISE\data\LPL\traces **b.** Tap the trace file name you want to recall. **c.** Tap **Recall**.

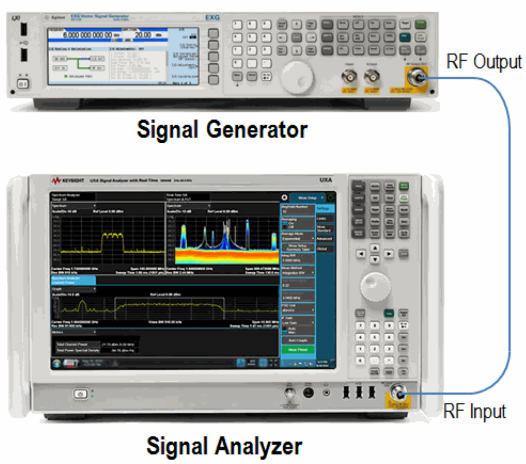
Log Plot - with RMS Noise, Residual FM, Average Noise Density

Spot Frequency Measurements

A Spot Frequency measurement is a single sideband measurement of the phase noise at a specified offset frequency from the main carrier signal. The average value of the trace points displayed on the screen is indicated by a blue line. In Phase Noise mode, the analyzer is normally set up to display a single sweep. So in the Spot Frequency measurement, you need to set the **Sweep** option to **Continuous** to perform a continuous sweep for a frequency offset.

Figure 1-3 shows the measurement system for Spot Frequency measurements, which is identical to the measurement system for Log Plot measurements. The transmitting signal is connected to the RF input port of the instrument. Connect the equipment as shown.

Figure 1-3 Spot Frequency Measurement System



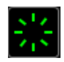
1. Using the appropriate cables and adapters, connect the output signal of the signal generator to the RF input of the analyzer.
2. For best frequency accuracy, connect a BNC cable between the 10 MHz REF IN port of the signal generator (if available) and the 10 MHz EXT REF OUT port of the analyzer.

Basic Spot Frequency Measurement Procedure

The RF signal under test is a single-tone signal with phase noise impairment:

NOTE The real-time phase noise impairment function in MXG/EXG signal generator is used to add phase noise impairments.

– Center frequency: 1 GHz
– Amplitude: -20 dBm
– Phase noise: -110 dBc/Hz@(1kHz ~ 200 kHz)

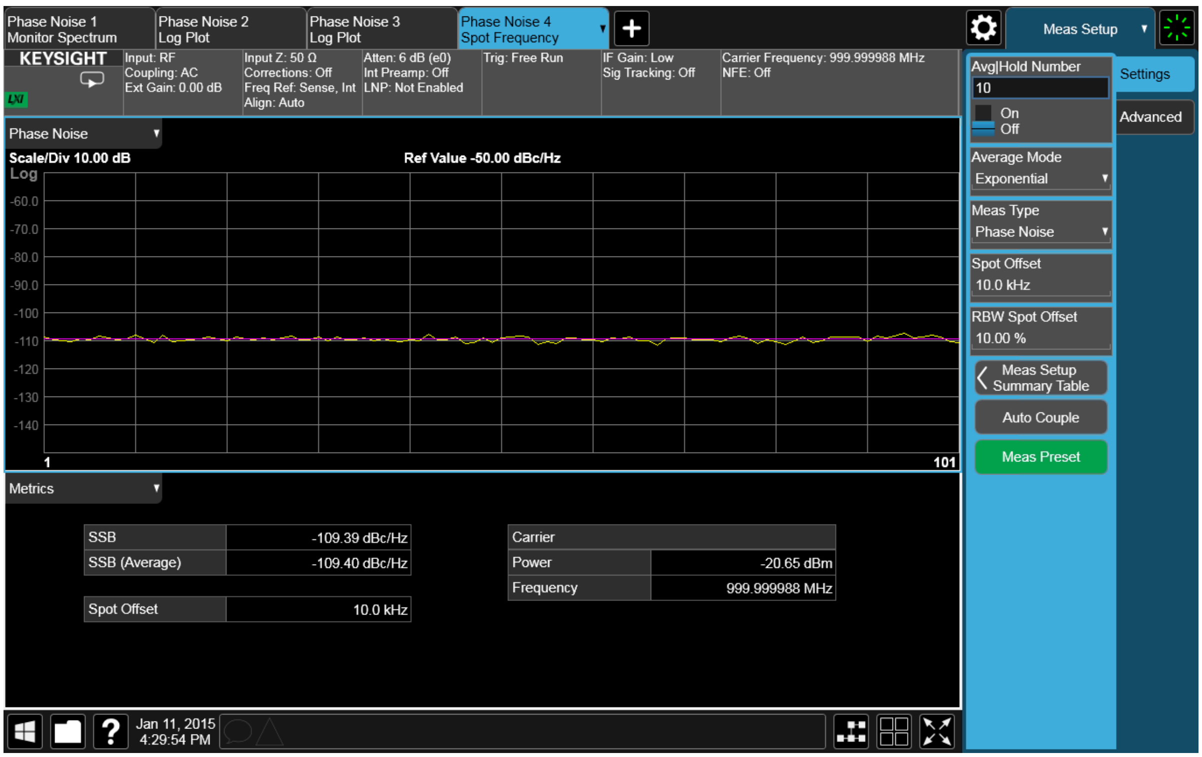
Step	Action
1 Select the Monitor Spectrum measurement in the Phase Noise mode.	**a.** Tap the **Spectrum Analyzer 1 Swept SA** screen tab (or press the **Mode/Meas** key) to display the Mode/Meas/View browser. **b.** Tap **Phase Noise** in the Mode column, **Monitor Spectrum** in the Measurement column, and **Normal** in the View column. Then tap the OK button at the bottom.
2 Preset the phase noise mode.	**a.** Tap the preset button at the top right corner of the screen.  **b.** Tap **Mode Preset**. **NOTE** You can also press the **Mode Preset** key on the front panel directly. 
3 Verify the RF carrier is present, and the instrument is tuned to the frequency of interest using the Monitor Spectrum measurement to view the RF carrier.	**a.** Tap the menu panel drop-down box in the top right corner and select **Frequency**. **b.** Double tap **Carrier Frequency** and set the carrier frequency to **1 GHz** in the pop-up window.
4 Select the Spot Frequency measurement, Graphical view to view the phase noise trace and a table of tabular results at decade offsets.	**a.** Tap the **Phase Noise 1 Monitor Spectrum** screen tab to display the Mode/Meas/View browser. **b.** Tap **Phase Noise** in the Mode column, **Spot Frequency** in the Measurement column, and **Graphical** in the View column. Then tap the OK button at the bottom.
5 Tune the measurement.	On the Frequency menu panel, tap **Auto Tune**. **NOTE** If the carrier is too far off for the Auto Tune function to determine the carrier frequency, an error will be displayed at the lower right corner of the display. Go back to the Monitor Spectrum measurement and re-tune the instrument.
6 Set the spot offset of the measurement.	**a.** Tap the menu panel drop-down box in the top right corner and select **Meas Setup**. **b.** Double tap **Spot Offset** and set it to **10 kHz** in the pop-up window.

Step	Action
7 Make a measurement continuously.	**a.** Tap the menu panel drop-down box in the top right corner and select **Sweep**. **b.** Toggle the **Sweep/Measure** control to **Continuous**.

The graphical view should look like the figure below, including two windows.

The top window shows the phase noise results at the specified frequency offset over time, with two traces. The yellow trace shows the current data and the purple trace shows the smoothed data. The vertical scale is for the measured phase noise value in dBc/Hz and the horizontal scale is in samples over time.

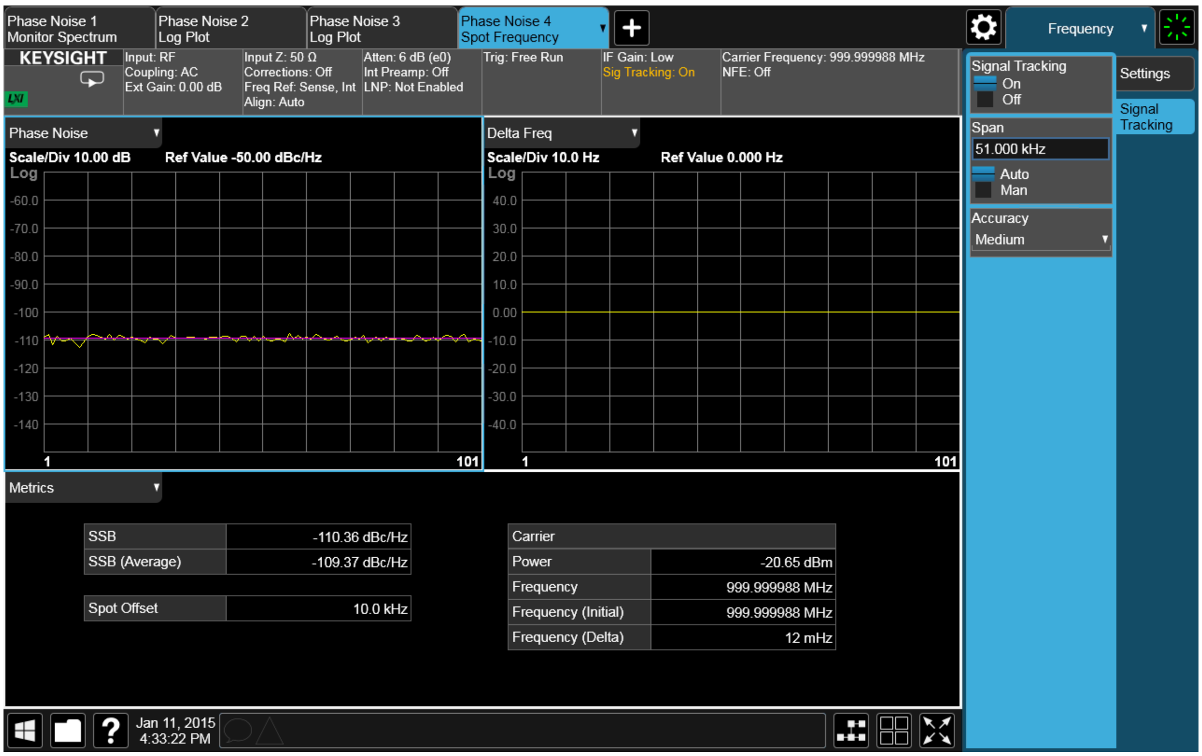
The bottom window shows the numerical results.



Step	Action
8 Track a drifting signal.	**a.** On the Frequency menu panel, tap the **Signal Tracking** tab to enter the signal tracking controls. **b.** Toggle **Signal Tracking** to **On**, and set the **Span** and **Accuracy** as needed. For the Accuracy control, you may need to trade between measurement speed and accuracy. High gives the best accuracy, but is slower. Low is faster, but has lower tracking accuracy.

Step	Action

When signal tracking is turned on, the displayed view will be changed to Signal Track view automatically as shown in the figure below. Another window showing the change in carrier frequency over time is added to the Spot Frequency measurement. And another two parameters for signal tracking, Frequency (Initial) and Frequency (Delta) are added in the bottom window.



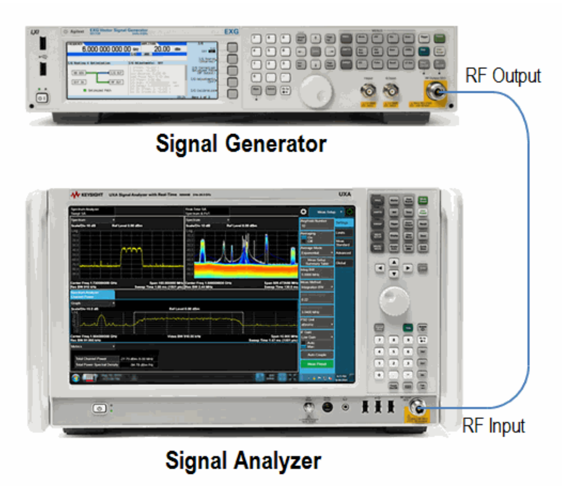
For more information, see “Spot Frequency Measurements” on page 45.

Monitor Spectrum Measurements

This chapter explains how to make a Monitor Spectrum measurement on a signal analyzer. Monitor Spectrum measurements show a spectrum domain display of the signal.

Figure 1-4 shows the measurement system for Monitor Spectrum measurements, which is identical to measurement system for Log Plot and Spot Frequency measurements. The transmitting signal from the signal generator is connected to the RF input port of the analyzer. Connect the equipment as shown.

Figure 1-4 Monitor Spectrum Measurement



1. Using the appropriate cables and adapters, connect the output signal of the signal generator to the RF input of the analyzer.
2. For best frequency accuracy, connect a BNC cable between the 10 MHz REF IN port of the signal generator (if available) and the 10 MHz EXT REF OUT port of the analyzer.

Basic Monitor Spectrum Measurement Procedure

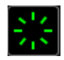
The RF signal under test is a single-tone signal with phase noise impairment:

NOTE The real-time phase noise impairment function in the MXG/EXG signal generator is used to add phase noise impairments.

— Center frequency: 1 GHz

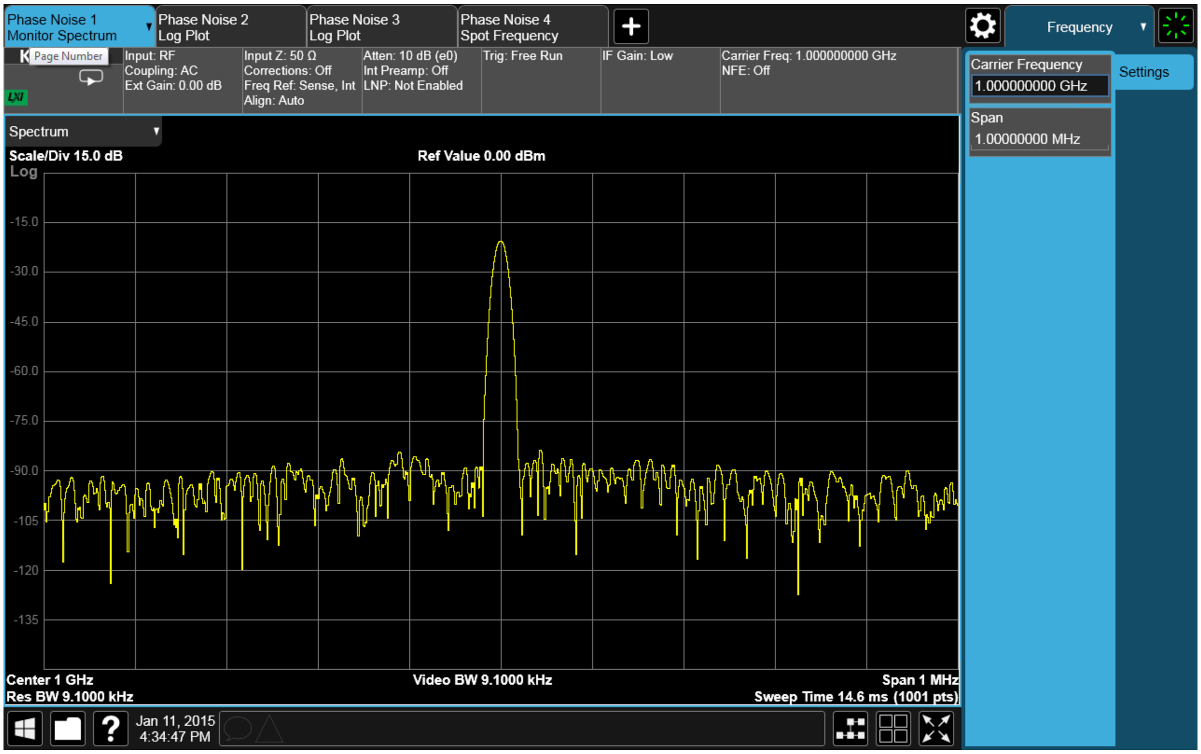
— Amplitude: -20 dBm

— Phase noise: -110 dBc/Hz@(1kHz ~ 200 kHz)

Step	Action
1 Select the Monitor Spectrum measurement in the Phase Noise mode.	**a.** Tap the **Spectrum Analyzer 1 Swept SA** screen tab (or press the **Mode/Meas** key) to display the Mode/Meas/View browser. **b.** Tap **Phase Noise** in the Mode column, **Monitor Spectrum** in the Measurement column, and **Normal** in the View column. Then tap the OK button at the bottom.
2 Preset the phase noise mode.	**a.** Tap the preset button at the top right corner of the screen.  **b.** Tap **Mode Preset**. **NOTE** You can also press the **Mode Preset** key on the front panel directly. 
3 Set the measurement center frequency.	**a.** Tap the menu panel drop-down box in the top right corner and select **Frequency**. **b.** Double tap **Carrier Frequency** and set the carrier frequency to **1 GHz** in the pop-up window.
4 Set the measurement span.	Double tap **Span** and set it to **1 MHz** in the pop-up window.

Step	Action

The Monitor Spectrum measurement results should look like the figure below.



2 Phase Noise Measurement Concepts

This chapter includes the following topics:

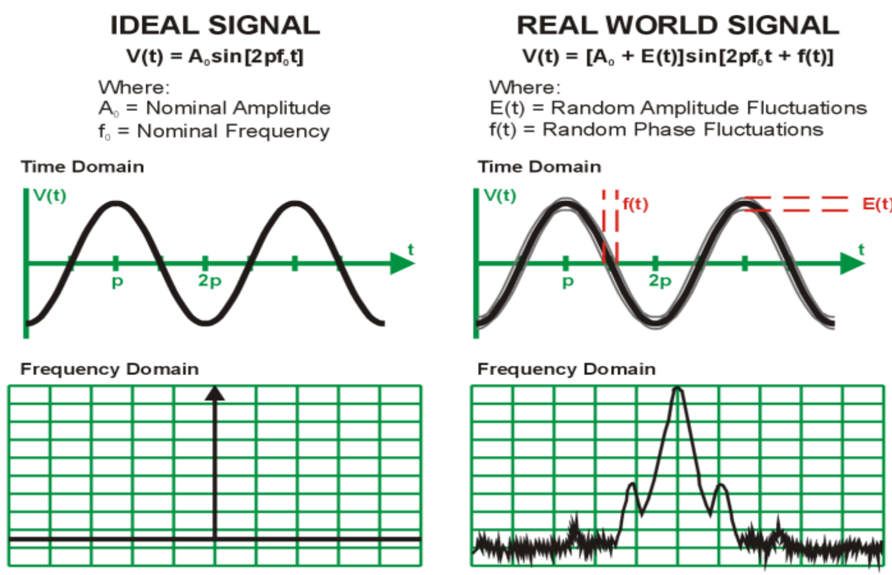
What is Phase Noise?

Phase Noise is the term used to describe the aggregate noise power of unwanted modulation products close to a signal, at a specific offset from the actual carrier frequency. As this power is higher near the carrier but can extend far into the sidebands, the usual offsets are multiples of ten to allow logarithmic scale plots of the power levels. Noise power contributions may be due to several varied mechanisms, and each will affect the carrier at different offsets. Among these are thermal noise, flicker noise, and white noise.

Before getting to the formal definition of phase noise, let's look at the difference between an ideal signal (a perfect oscillator) and a real-world signal. In the frequency domain, an ideal signal is represented by a single spectral line (Figure 2-1). The real-world signal is not a single, discrete spectral line. It is represented by a spread of spectral lines, both above and below the nominal signal frequency. They are in the form of modulation sidebands. This is due to random amplitude and phase fluctuations.

There are always small, unwanted amplitude and phase fluctuations present on a signal. Notice that frequency fluctuations are actually an added term to the phase angle portion of the time domain equation. Because phase and frequency are related, you can discuss equivalently unwanted frequency or phase fluctuations.

Figure 2-1 Ideal RF Signal vs. Real-World Signal

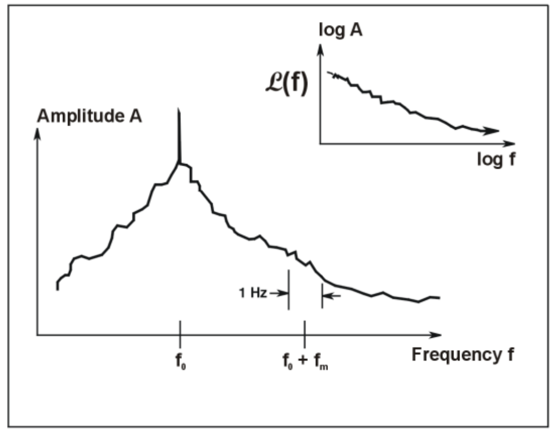


Historically, the most widely used phase noise unit of measure has been the total single sideband power within a one hertz bandwidth at a frequency **f** away from the carrier referenced to the carrier frequency power. This unit of measure is represented as a L(f) in units of dBc/Hz (Figure 2-2).

Figure 2-2 Phase Noise Unit of Measure

$\mathcal{L}(f)$ is defined as single sideband power due to phase fluctuations referenced to the carrier frequency power

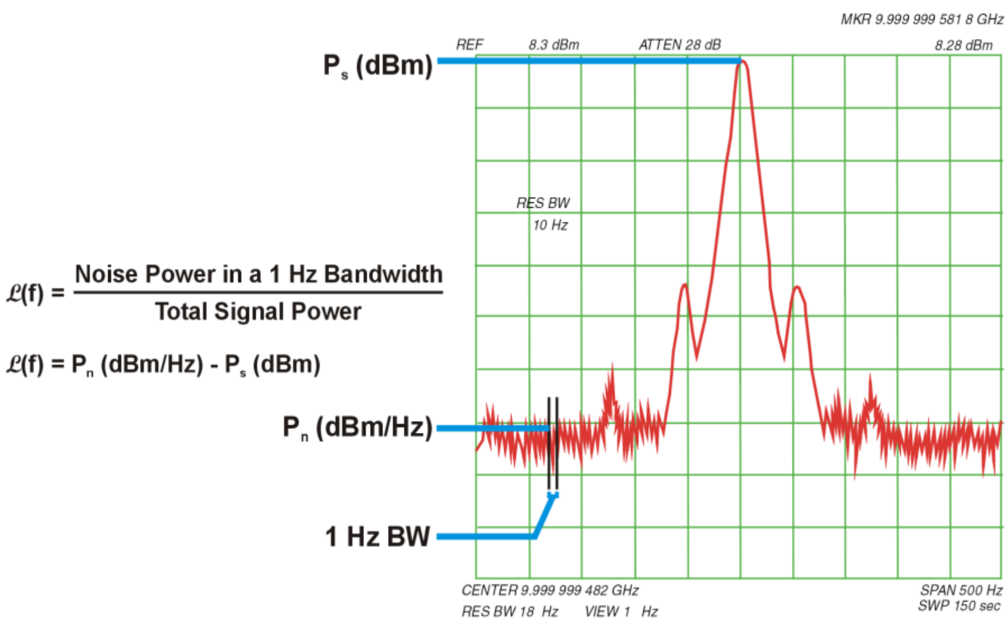
$\mathcal{L}(f)$ has units of dBc/Hz



$$\mathcal{L}(f) = 10 \log \left(\frac{\text{Power 1 Hz Bandwidth}}{\text{Total Power in Full BW}}\right)$$

When measuring phase noise directly with a RF signal analyzer, the L(f) ratio is the noise power in a 1 Hz bandwidth, offset from the carrier at the desired offset frequency, relative to the carrier signal power (Figure 2-3).

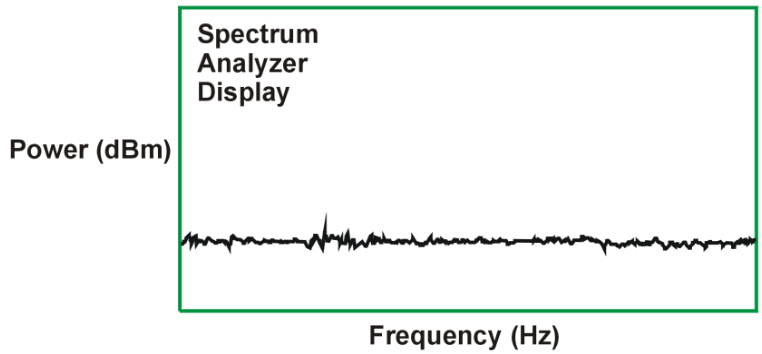
Figure 2-3 L(f) Ratio



Thermal Noise

Thermal noise (kT) is the mean available noise power from a resistor at a temperature (T) in degrees Kelvin (K). Ambient temperature is assumed to be 290 K. As the temperature of the resistor increases, the kinetic energy of its electrons increases and more power becomes available. Thermal noise is broadband and virtually flat with frequency (Figure 2-4).

Figure 2-4 Thermal Noise Power (Np)



$$N_p = kTB$$

$$\text{For } T = 290\text{ K},\ N_p = -204\ \frac{\text{dB (Watts)}}{\text{Hz}} = -174\ \frac{\text{dBm}}{\text{Hz}}$$

Thermal noise can limit the extent to which you can measure phase noise. The bandwidth, term B above, is equal to 1 for 1 Hz. Thermal noise as described by kT at room temperature is –174 dBm/Hz. Since phase noise and AM noise contribute equally to kT, the phase noise power portion of kT is equal to –177 dBm/Hz (3 dB less than the total kT power).

If the power in the carrier signal becomes a small value, for example –20 dBm, the limit to which you can measure phase noise power is the difference between the carrier signal power and the phase noise portion of kTB (–177 dBm/Hz – (–20 dBm) = –157 dBc/Hz). Higher signal powers allow phase noise to be measured to a lower dBc/Hz level (Figure 2-5).

Figure 2-5 Thermal Noise Effects on Phase Noise Measurements (1 Hz BW)

$\mathcal{L}(f) = P_n$ (dBm/Hz) - P_s (dBm)

- Total Power (kTB) = P_n (kTB) = –174 dBm/Hz
- Phase Noise and AM Noise contribute equally
- Phase Noise Power (kTB) = –177 dBm/Hz

Theoretical kTB Limits to Phase Noise Measurements for Low Signal Levels

Ps [dBm]	$\mathcal{L}(f)$ [dBc/Hz]
+10	–187
0	–177
–10	–167
–20	–157

Note: There are other measurement factors besides kTB limitations that can reduce the theoretical measurement limit significantly

Other Noise Contributions

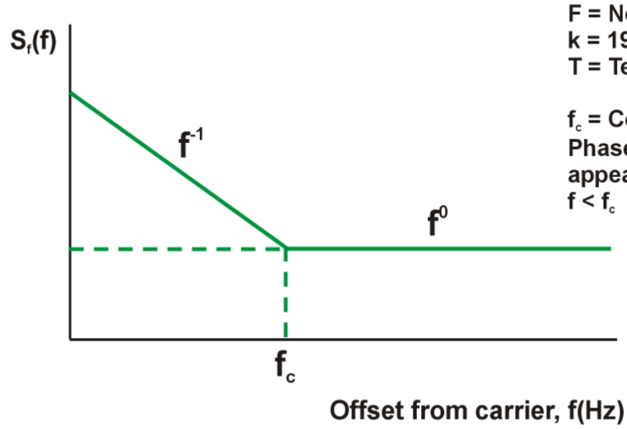
In addition to a thermal noise floor that has a relatively constant level with frequency, active devices exhibit a noise flicker characteristic that intercepts the thermal noise at an empirically determined corner frequency (fc). For offsets below fc, phase noise increases with f^{-1}. This noise is caused by defects within semiconductor lattice structures resulting in combination-recombination of charge carriers (Figure 2-6). Flicker noise power is approximately –120 dBc/Hz @ 1 Hz offset.

Figure 2-6 Flicker Noise

$$\mathcal{L}(f) = \frac{FkT}{2P_s}$$

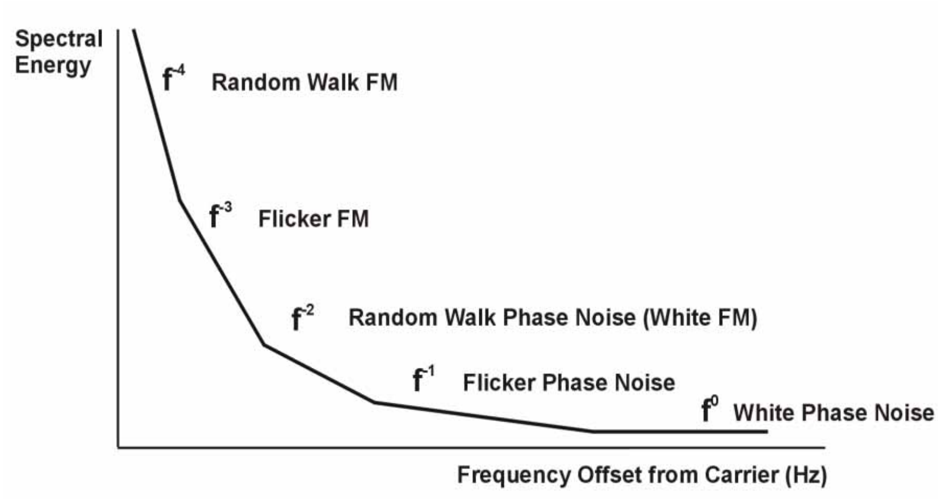
Where:
F = Noise Factor
k = 198.6 K/Hz
T = Temp (Kelvin)

f_c = Corner Frequency
Phase Noise "flicker" appears at frequencies $f < f_c$



The distribution of other sources of phase noise energy can be described in the terms given in Figure 2-7. Each of these characteristic noise distributions is due to a distinct process in the source circuitry.

Figure 2-7 Typical Phase Noise Distribution



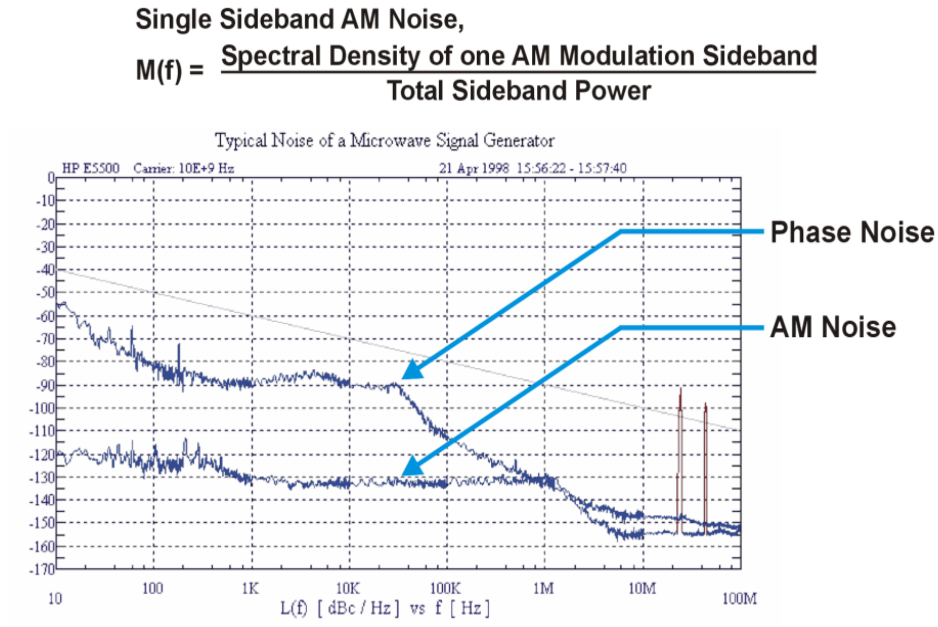
AM Noise

All carriers-with-noise have upper and lower sidebands. These sidebands can alternatively be expressed as “FM” and “AM” sidebands. Most signals measured by phase noise test systems have very little AM sideband power relative to the FM sideband power, so for most signals, measuring the upper (or lower) sideband is equivalent to measuring the FM sideband (phase noise). If the sidebands are due to broadband noise, instead of phase noise, they have equal AM and FM power and the upper sidebands have 3 dB more power than the FM sidebands.

AM noise, described here as M(f), is the power density of amplitude noise in a one hertz bandwidth relative to the carrier power. The example shown here indicates that while AM noise can often be found to be much less than phase noise, there can be offset frequencies at which the AM noise can be equal to or even exceed the value of the phase noise.

The AM Rejection feature in the Phase Noise Measurement Application removes the AM noise contribution from your phase noise measurements for offsets <1 MHz. See “Advanced Features - Using AM Rejection and Overdrive” on page 47.

Figure 2-8 AM Noise



Residual FM

Residual FM is a familiar measure of frequency instability commonly used to specify noise inside a data communications bandwidth. Residual FM is the total rms frequency deviation in a specified bandwidth. Commonly used bandwidths have been 50 Hz to 3 kHz, 300 Hz to 3 kHz, and 20 Hz to 15 kHz. Only the short-term frequency instability occurring at rates within the bandwidth is included. No information regarding the relative weighting of instability is conveyed. Therefore, the energy distribution within the bandwidth is lost.

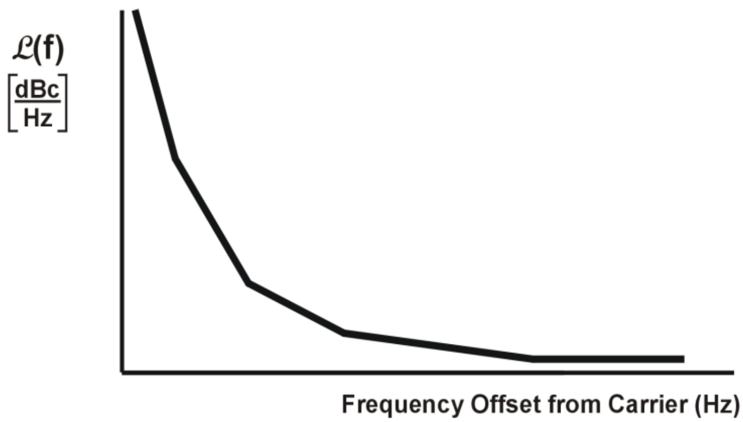
Since spurious signals are detected as FM sidebands, the presence of large spurious signals near the signal under test can greatly increase the measured level of residual FM. You can use the Monitor Spectrum measurement to determine whether these interfering signals are present.

Single-Sideband Noise

L(f) is an indirect measure of noise energy easily related to the RF power spectrum observed on a signal analyzer. The historical definition is the ratio of the power in one phase modulation sideband per hertz, to the total signal power. L(f) is usually presented logarithmically as a plot of phase modulation sidebands in the frequency domain, expressed in dB relative to the carrier power per hertz of bandwidth [dBc/Hz].

This historical definition is confusing when the bandwidth of the phase variations are well below 1 Hz because it is possible to have phase noise density values that are greater than 0 dBc/Hz even though the power in the modulation sideband is not greater than the carrier power.

Figure 2-9 Single-Sideband Phase Noise Definition



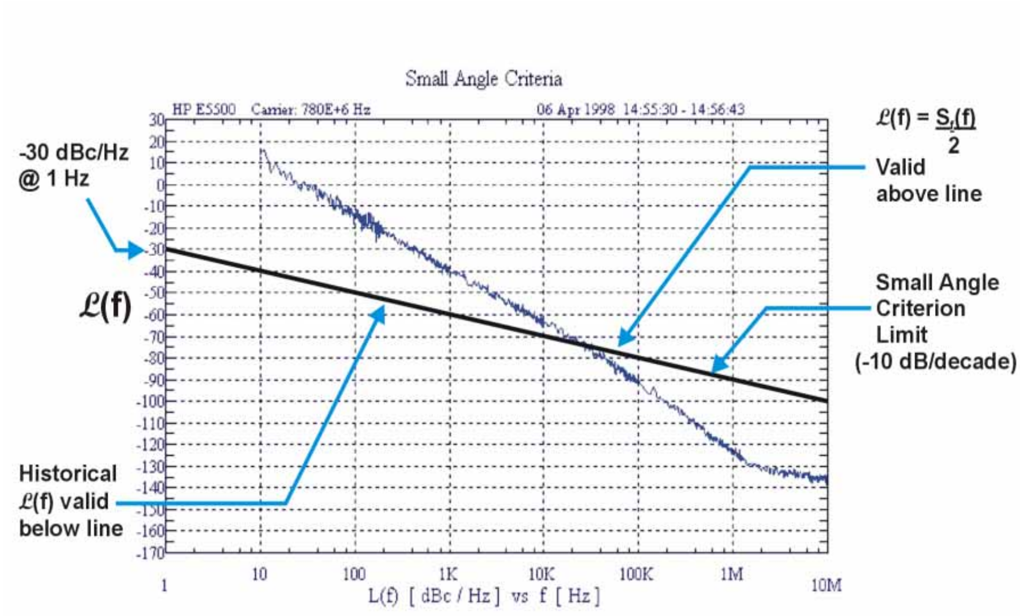
$$\mathcal{L}(f) = \frac{\text{Power Density (one phase modulation sideband)}}{\text{Carrier Power}} \left[\frac{\text{dBc}}{\text{Hz}}\right]$$

$$\mathcal{L}(f) = \frac{S_f(f)}{2}$$

Measurements of L(f) with a signal analyzer typically measure phase noise when the phase variation is much less than 1 radian. Phase noise measurement systems, however, measure $S_f(f)$, which allows the phase variation to exceed this small angle restriction. On this graph, the typical limit for the small angle criterion is a line drawn with a slope of -10 dB/decade that passes through a 1 Hz offset at -30 dBc/Hz. This represents a peak phase deviation of approximately 0.2 radians integrated over any one decade of offset frequency.

The plot of L(f) resulting from the phase noise of a free-running VCO illustrates the confusing display of measured results that can occur if the instantaneous phase modulation exceeds a small angle (Figure 2-10). Measured data, $S_f(f)/2$ (dB), is correct, but historical L(f) is obviously not an appropriate data representation as it reaches +15 dBc/Hz at a 10 Hz offset (15 dB more power at a 10 Hz offset than the total power in the signal). The new definition of L(f) $=S_f(f)/2$ allows this condition, since $S_f(f)$ in dB is relative to 1 radian. Results >0 dB simply mean that the phase variations being measured are >1 radian.

Figure 2-10 Single-Sideband Phase Noise L(f)



About Log Plot and Spot Frequency Measurements

Log Plot Measurements

The Log Plot measurement gives a display of dBc/Hz versus logarithmic frequency offset for the single sideband measurement. Trace 1, which is the yellow trace, displays the point-by-point data as measured. Trace 2, the cyan blue trace, displays a smoothed version of trace 1. The amount of smoothing is determined by the current setting of the smoothing parameter. In the Decade Table view, marker 1 is set to a frequency offset of 10 kHz, and the phase noise at that frequency is displayed numerically.

NOTE **The trace numbers, trace data, and marker data referred to (above) apply if you are using the factory default settings, but these can be changed.**

If the analyzer is set up to perform single sweeps, the **Restart** front-panel key allows a measurement to be repeated with a single key press. This is useful for seeing effects of circuit changes where the carrier and offset frequencies of interest do not change. The analyzer can also be set up to perform continuous sweeps. In this case, a new measurement will be started as soon as the previous one has completed. To make continuous sweeps, press the **Cont** (continuous sweep) front-panel key.

Up to 12 markers can be used to display various parameters of the measurement, although the default display only shows data for one marker.

Phase noise measurement results can be integrated over a selected frequency range to get the total RMS (root mean squared) noise in a given bandwidth. The frequency limits used for integration may be selected by tapping **Marker**, **Marker Function, Integrated (RMS) Noise**, and then select whether to display the result in radians, in dBc, in degrees, or in seconds if **RMS Jitter** is selected. After that, use the **Band Span**, **Band Left**, **Band Right** keys under Marker Function tab to set the integration frequency range. The results are displayed in radians, degrees, or seconds (depending on your previous selection).

RMS Residual FM over a specified range can also be displayed using markers. Using a **Normal** marker, select Residual FM marker function by tapping **Marker**, **Marker Function**, **Residual FM**, and then use the **Band Span**, **Band Left**, **Band Right** keys under Marker Function tab to set the frequency range. The display will show your frequency range and the measured RMS residual FM over this range. RMS phase noise measurements are based on the log plot data which is a single-sideband measurement. The RMS phase noise results are mathematically corrected to properly represent the true RMS phase deviation.

Spot Frequency Measurements

A Spot Frequency measurement is a single sideband measurement of the phase error at a specified offset frequency from the main carrier signal. The average value of the trace points displayed on the screen is indicated by a magenta pink line. The analyzer is normally set up to display a single sweep. To make the Spot Frequency measurements continuously, you need to set the sweep to **Continuous**.

The analyzer can be set up to track a drifting signal by tapping **Frequency, Signal Tracking** tab, and toggle **Signal Tracking** to **On**. When signal tracking is **on**, a new graph with a trace showing the change in frequency versus time is shown next to the spot frequency plot.

Improving Phase Noise Measurements

Smoothing and Averaging

Repeatability of a measured trace can be improved in several different ways. Smoothing is used with Log Plot measurements while trace averaging is used with Spot Frequency measurements.

The smoothing process averages a number of adjacent trace points from the raw trace, typically Trace 1, and displays the smoothed result in the second trace, typically Trace 2, for a Log Plot measurement. Smoothing is faster than averaging, but less accurate. Loss of accuracy is particularly noticeable when a trace has sudden changes in amplitude, for example when a carrier has a large discrete signal such as a spurious sideband. To smooth a trace, tap the **Smoothing** softkey in **Meas Setup**, and then adjust it between 0.00% and 16.0%. While inside the Log Plot measurement each level of smoothing can be tried without having to make a new measurement.

The averaging process (trace averaging) measured each point on multiple independent sweeps and converges on the average at each point.

Signal Tracking

Signal tracking can be used in all measurements to track a slowly drifting signal. When it is enabled (**On**) , the measurement will follow a slowly drifting signal by reacquiring the carrier signal at the beginning of each trace.

If the signal is not tracked correctly (such as might happen with a rapidly drifting signal), the analyzer may not completely compensate for the drift, with the off-frequency measurement causing the phase noise to appear either higher or lower than it actually is.

Slowly Drifting Signals

Spot Frequency and Log Plot measurements can be made on slowly drifting signals by making use of the signal tracking function, although the measured value may be slightly less accurate.

DANL Floor

The measurement system noise floor can have a significant effect on low phase noise measurements such as those that will typically be found at large frequency offsets. The system noise floor can be measured using the following methods. See “Using Log Plot to Measure Displayed Average Noise Level (DANL Floor)” on page 16 for a procedure on measuring DANL Floor. See “Using a Reference Trace (DANL Floor or Low Phase Noise Reference) for Noise Cancellation” on page 21 for a procedure on using the trace to improve accuracy.

Advanced Features - Using AM Rejection and Overdrive

AM Rejection

All carriers-with-noise have upper and lower sidebands. These sidebands can alternatively be expressed as “FM” and “AM” sidebands. Most signals measured by phase noise test systems have very little AM sideband power relative to the FM sideband power, so for most signals, measuring the upper (or lower) sideband is equivalent to measuring the FM sideband (phase noise). If the sidebands are due to broadband noise instead of phase noise, they have equal AM and FM power and the upper sidebands have 3 dB more power than the FM sidebands.

AM Rejection is ON by default for Phase Noise measurements for offsets <1 MHz. Therefore, if a measurement shows a step change in phase noise at 1 MHz offset, you can either change the offset or turn AM rejection OFF to determine whether AM Noise is the reason for the observed step change.

Overdrive

If you are measuring offsets > 1 MHz you can use the Overdrive feature to increase the dynamic range of the instrument. Overdrive uses the electronic step attenuator if available, or the mechanical step attenuator to optimize input signal levels. The measurement is slowed by the respective attenuator switching time. Although measurement accuracy may improve with increased dynamic range, the measurement uncertainty increases slightly with attenuator switching. To select Overdrive:

Tab **Meas Setup**, **Advanced**, and toggle **Overdrive with Mech Atten (offset>1 MHz)** to **Enabled**.

Overdrive has the advantage of allowing higher dynamic range at the extreme offsets where broadband input noise of the analyzer might otherwise dominate over the analyzer’s phase noise in setting the available dynamic range. Overdrive has the disadvantage of requiring attenuation changes between measuring the carrier power and measuring the noise density offset from that carrier. The accuracy of the phase noise measurement is the accuracy of the ratio of these two. Therefore, phase noise amplitude accuracy is degraded (by the attenuator switching uncertainty) at those offsets where overdrive occurs when it is allowed. Also, switching the attenuator slows the throughput.

Noise Cancellation on Log Plot Measurements

When you make a phase noise measurement on a given signal, the measurement result that you get is actually a combination of three different noise sources. The first is the phase noise of the signal that you are measuring. If this noise is very small, it can be hidden by the two other noise sources which are generated by the analyzer itself.

The first internal noise source is the phase noise generated by the analyzer as a side-effect of measuring an input signal. The second source is the Displayed Average Noise Level (DANL) of the analyzer. The DANL is the internally generated noise of the analyzer regardless of whether or not an input signal is present, so the DANL is derived from the noise figure of the analyzer. The DANL Floor is broadly flat across the spectrum and represents the absolute noise level below which measurements cannot be made because the signal gets lost in the analyzer noise.

The third noise source is the analyzer's own phase noise. At far offset frequencies, the analyzer's phase noise is often below the analyzer's noise floor (DANL). The DANL floor of an analyzer thus limits the range over which an analyzer can measure phase noise. By making a Log Plot measurement of the analyzer's DANL noise floor, you are able to characterize the DANL limitation on phase noise measurements.

If you make a phase noise measurement without any input signal, that measurement represents the absolute DANL floor of the analyzer. If you reference this absolute noise floor to the carrier amplitude, the DANL floor becomes a relative limit below which phase noise sidebands cannot be measured.

The Log Plot measurement accuracy on low phase noise DUTs can be improved by using the cancellation feature to remove the affects of the analyzer's internal noise. This is done by comparing a stored reference measurement with the DUT's measured phase noise.

The stored reference measurement can be generated two ways.

- If you have a signal source that has much better phase noise than the analyzer's phase noise, then you can measure that source and know that the resulting trace represents the analyzer's internal phase noise when an input signal is present.
- If you do not have a good low-phase noise source, you can make a reference measurement with no input signal. This gives you a measurement of the analyzer's noise floor (DANL).

A reference trace from a good source that is relatively free of phase noise will let you compensate for both the phase noise and the DANL of the analyzer. A reference trace that is derived from the DANL only compensates for the DANL portion of the noise, but this may be adequate for measurement conditions where the analyzer DANL is the limiting factor (for offsets above some f_{limit}, where f_{limit} is typically between 1 to 10 MHz).

For future use, this reference trace can be saved to the analyzer's own internal file system (the D: drive), to a network drive, or to a removable drive via the analyzer's USB port. It can then be used later to automatically subtracted from any subsequent Log Plot measurement to give you a more accurate result.

Cancellation Procedure Overview

Step
Set up the analyzer as needed to measure the test signal's phase noise. See "Basic Log Plot Measurement Procedure" on page 10.
Create a reference trace. You can choose to create either a DANL reference trace or a low phase noise signal reference trace. See "Using Log Plot to Measure Displayed Average Noise Level (DANL Floor)" on page 16 or "Creating a Low Phase Noise Signal Reference Trace" on page 19.
Use the reference trace for noise cancellation. See "Using a Reference Trace (DANL Floor or Low Phase Noise Reference) for Noise Cancellation" on page 21

Using Cancellation for Log Plot Measurements

Many phase noise measurements do not benefit from cancellation. If the phase noise of your DUT is more than 10 dB higher than the analyzer noise, then cancellation has almost no effect on the measurement data. The effectiveness of using the cancellation function also has a lower limit. When the phase noise of your DUT gets very close to the analyzer noise (within about 0.1 dB), the logarithmic nature of the calculation results in large, invalid cancellation values. The following table shows error cancellation values that will be applied to the measurement results for various DUT to analyzer phase noise ratios.

Phase Noise of DUT relative to Phase Noise of Analyzer	Measurement Error Before Cancellation[a]	Threshold ∆ Required for Maximum Cancellation
20 dB	0.043 dB	20.0 dB
10 dB	0.41 dB	10.41 dB
0 dB	3.01 dB	3.01 dB
–5.87 dB	6.87 dB	1.0 dB
–10 dB	10.41 dB	0.41 dB
–16.33 dB	16.43 dB	0.1 dB
–20 dB	20.04 dB	0.04 dB
–26.83 dB	26.84 dB	0.01 dB

a. Only considers error due to additive affects of analyzer noise and DUT noise.

Additional Phase Noise Documentation

The documents listed below provide more information on making phase noise measurements. They can be obtained through your local Keysight sales representative.

Keysight Part Number	Title
5952-0292	AN 150 Spectrum Analyzer Basics
5968-2081E	AN 1309 Pulsed Carrier Phase Noise Measurements
5989-5718EN	Using Clock Jitter Analysis to Reduce BER in Serial Data Applications
5988-6082EN	AN 1397-1 Lowering Cost & Improving Interoperability by Predicting Residual BER
5954-6365	AN 343-1 Vector Modulation Measurements
5952-8203	AN 283-1 Applications and Measurements of Low Phase Noise Signals Using 8662A

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