

# Keysight X-Series Signal Analyzers

This manual provides documentation for the following Analyzers:

PXA Signal Analyzer N9030A  
EXA Signal Analyzer N9010A  
MXE EMI Receiver N9038A

MXA Signal Analyzer N9020A  
CXA Signal Analyzer N9000A

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N9068A & W9068A  
Phase Noise  
Measurement  
Application  
Measurement Guide

# Notices

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# 1 Making Measurements

## Introduction

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

- Monitor Spectrum - See “Monitor Spectrum Measurements” on page 25.

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**NOTE**

Monitor Spectrum does not measure Phase Noise, but is used initially to assure the instrument is correctly tuned to the carrier frequency.

---

- Log Plot - See “Log Plot - with Residual FM, Jitter, RMS Noise” on page 9.
- Spot Frequency - See “Spot Frequency Measurements” on page 21.

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)
  - Using a DANL Floor Reference for Cancellation
  - Creating a Low Phase Noise Reference
  - Using a Reference Trace for Cancellation
  - Saving and Recalling Reference Traces



## Log Plot - with Residual FM, Jitter, RMS Noise

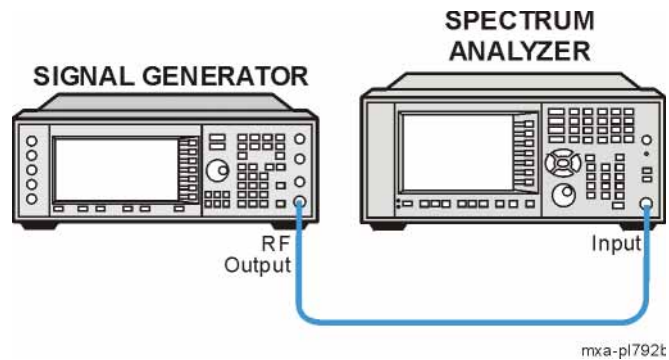
This chapter explains how to make a Log Plot measurement on a signal source. A Log Plot measures single-sideband phase noise (in dBc/Hz) versus offset frequencies on the horizontal axis shown in logarithmic scale. This allows you to view the phase noise behavior of the signal under test across many decades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

A Log Plot measurement trace will also provide Residual FM, Jitter, and RMS Noise data when the appropriate frequency marker is used. See [“Using Markers to make Integrated Noise Measurements of RMS Noise, Jitter, and Residual FM”](#) on page 12.

This example shows a signal generator under test set up to transmit RF power. The transmitting signal is connected to the RF input port of the instrument. Connect the equipment as shown.

Figure 1-1

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

| Step  | Action   | Notes  |
|---|--|--|
| <b>1</b> Enable the Phase Noise Mode  | a. Press <b>Mode</b> , Phase Noise   |  |
| <b>2</b> Preset the analyzer mode   | a. Press <b>Mode Preset</b>  |  |
| <b>3</b> 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. Press <b>Meas</b> , <b>Monitor Spectrum</b>   |  |
| <b>4</b> Set the measurement center frequency   | a. Press <b>FREQ Channel</b>   | Enter a numerical frequency using the front-panel keypad, and select a units key, such as <b>MHz</b> .<br><br>If the RF carrier is not at the center of the display you can use the knob to scroll the carrier to the center of the display. |
| <b>5</b> Initiate the measurement   | a. Press <b>Meas</b> , <b>Log Plot</b>   |  |
| <b>6</b> Tune the measurement   | a. Press <b>Auto Tune</b>  | 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.    |
| <b>7</b> Track a drifting signal  | a. Press <b>FREQ/Channel</b> , <b>Signal Tracking</b>                                      |  |
| <b>8</b> Turn ON the Decade Table   | a. Press <b>Meas Setup</b> , <b>More 1 of 2</b> , <b>Decade Table ON</b>                   | This enables you to view a table of tabular results at decade offsets.   |
| <b>9</b> Select a Phase Noise measurement Offset Range  | a. Press <b>SPAN X scale</b> , <b>Start Offset</b> or <b>Stop Offset</b> and input a value | The default display ( <a href="#">Figure 1-2 on page 11</a> ) shows the <b>Current</b> (yellow trace) and smoothed (blue trace) data.  |

| Step | Action | Notes |
|------|--------|-------|
|------|--------|-------|

Figure 1-2 Log Plot Measurement - (Default View)



|                                  |  |   |
|----------------------------------|--|---|
| <b>10</b> Increase dynamic range | a. Press <b>Meas Setup, Advanced, Overdrive ON</b> | 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 40.

|                                   |   |   |
|-----------------------------------|---|---|
| <b>11</b> Select the display view | a. Press <b>Trace/Detector</b> , select a <b>Trace (1, or 2)</b> and then select whether the data displayed is <b>Raw, Smoothed, or Blank</b> | To make viewing the display easier, you can view either the Raw or Smoothed data. |
|-----------------------------------|---|---|

|   |                      |  |
|---|----------------------|--|
| <b>12</b> Make a measurement repeatedly | a. Press <b>Cont</b> |  |
|---|----------------------|--|

| Step   | Action   | Notes   |
|--|--|---|
| 13 Trade measurement speed for improved accuracy | a. Press <b>FREQ/Channel</b> , <b>Tracking</b> , <b>Accuracy</b> and choose between <b>High (Slowest)</b> and <b>Low (Fastest)</b> . | <b>Medium</b> is the default measurement speed and accuracy<br>For more information see “Log Plot Measurements” on page 37. |

### Using Markers to make Integrated Noise Measurements of RMS Noise, Jitter, and Residual FM

When the basic Phase Noise measurement (above) is complete you can measure other noise parameters using markers.

| Step                | Action   | Notes   |
|---------------------|--|---|
| 1 Activate a marker | a. Press <b>Marker Function</b> , select a marker number ( <b>1-3</b> ) and select from the following: <ul style="list-style-type: none"> <li>▪ <b>RMS Noise</b> - Select units in degrees or radians</li> <li>▪ <b>Jitter</b> - Marker values provided in seconds</li> <li>▪ <b>Residual FM</b> - Marker values provided in Hz</li> </ul> | For more information on these topics see “Phase Noise Measurements” on page 37. |

| Step | Action                  | Notes   |
|------|-------------------------|---|
| 2    | Set an integration band | <p>a. Press <b>Band Adjust</b>, and enter values for Band/Interval Span, <b>Band/Interval Left</b> or <b>Band/Interval Right</b>.</p> <p>Band markers appear as green vertical lines in the plot, with the center frequency marked as a diamond (see <a href="#">Figure 1-3 on page 13</a>). You can also adjust the knob to set the markers visually, on screen. Because the Log Plot is not linear, and because the marker center location is shown in the linear center of the band, the Band/Interval Left marker will be farther from the center than the Band/Interval Right marker.</p> <p>The interval is that portion of the measurement spectrum between the minimum or maximum measurement frequency and the integration band marker. The minimum band/Interval Left value is 100.00000 Hz.</p> <p>The values displayed for the integration band width are based on the last measurement acquisition. Unless the <b>CONT</b> button is active, the measurement data will not be refreshed unless either the <b>SINGLE</b> or <b>Restart</b> button is pressed.</p> |

Figure 1-3

Log Plot Measurement - (Integrated Noise View)



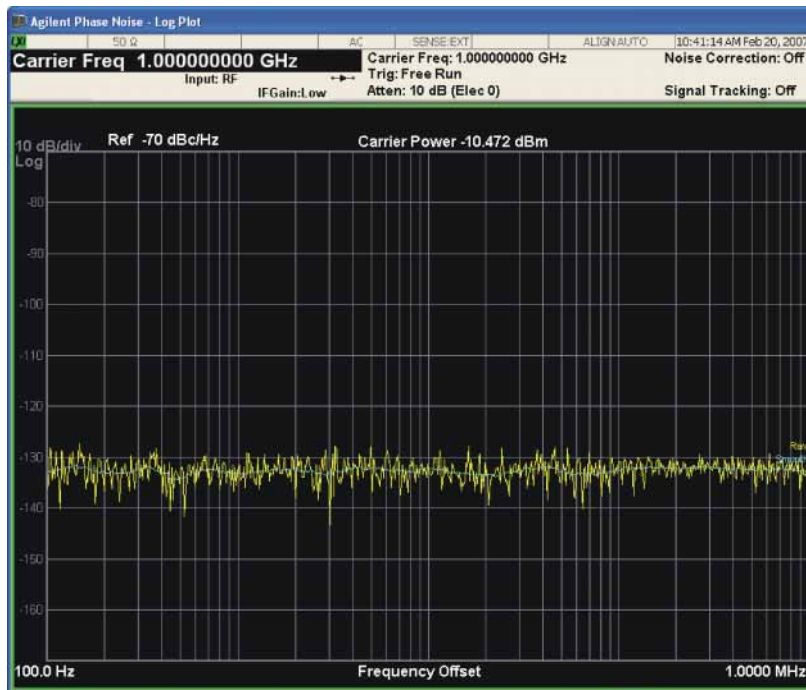
### Using Log Plot to Measure Displayed Average Noise Level (DANL Floor)

The DANL floor of a signal/spectrum analyzer limits measurement of the smallest input signals, those 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   | Notes  |
|------|--|--|
| 1    | Connect a signal source to the input of your analyzer  |  |
| 2    | Enable the Phase Noise Mode<br>a. Press <b>Mode, Phase Noise</b>                               |  |
| 3    | Preset the analyzer mode<br>a. Press <b>Mode Preset</b>  |  |
| 4    | Set the measurement center frequency<br>a. Press <b>FREQ Channel</b>                           | Enter a numerical frequency using the front-panel keypad, and select a units key, such as <b>MHz</b> .                             |
| 5    | Initiate the measurement<br>a. Press <b>Meas, Log Plot</b>                                     |  |
| 6    | Select DANL Floor as the measurement type<br>a. Press <b>Meas Setup, Meas Type, DANL Floor</b> |  |
| 7    | Turn on averaging<br>a. Press <b>Meas Setup, Avg/Hold Number, 20</b>                           | This increases measurement accuracy.   |
| 8    | Restart the measurement<br>a. Press <b>Restart</b>   | The default display, <a href="#">Figure 1-4 on page 15</a> shows the <b>Current</b> (yellow trace) and smoothed (blue trace) data. |

| Step | Action | Notes |
|------|--------|-------|
|------|--------|-------|

Figure 1-4 Log Plot Measurement - (DANL Floor Meas Type Default View)



- |    |                          |   |   |
|----|--------------------------|---|---|
| 9  | Turn ON the Decade Table | a. Press <b>Meas Setup, More 1 of 2, Decade Table ON</b>  |   |
| 10 | Select the display view  | a. Press <b>Trace/Detector</b> , select a <b>Trace (1, or 2)</b> and then select whether the data displayed is <b>Raw, Smoothed, or Blank</b> | To make viewing the display easier, you can view either the Raw or Smoothed data. |

### Using a DANL Floor Trace for Phase Noise Measurement Cancellation

Once you have measured the DANL Floor of the analyzer, you can use the trace data to cancel the instrument contribution to the measurement.

#### Step

- 1 Complete a DANL Floor measurement as described in [“Using Log Plot to Measure Displayed Average Noise Level \(DANL Floor\)”](#) on page 14.
- 2 Store a DANL Floor measurement trace as a Reference Trace as described in [“Creating a Low Phase Noise Signal Reference Trace”](#) on page 16.

**Step**

---

- 3 Use the DANL Floor Reference Trace with the Cancellation function as described in “Using a Phase Noise Reference Trace for Cancellation” on page 16.

**Creating a Low Phase Noise Signal Reference Trace**

You can use a known low phase noise source to create a reference trace that be used to characterize another source. The reference trace must cover the same frequency range as your intended measurement.

---

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

---

| Step  | Action  | Notes   |
|---|---|---|
| 1 Set up the analyzer to measure the test signal phase noise over the desired frequency range.                      | a. Press <b>Measure, Log Plot</b>                                     |   |
| 2 Connect a low phase noise signal source to the input of your analyzer and set it to the desired output frequency. |   |   |
| 3 Measure the phase noise of your reference signal.   | a. Press <b>Meas Setup, Meas Type, Phase Noise</b> and <b>Restart</b> | This measures and displays the phase noise of your test signal.<br><br>You now have a reference trace available that you can either use immediately or save for later use. See the information about saving and restoring traces later in this section. |

**Using a Phase Noise Reference Trace for Cancellation**

Cancellation is a process where a reference trace is “subtracted” from a Log Plot measurement trace, providing a more accurate result. 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 may 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 [“Log Plot Cancellation” on page 41.](#)

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 using a Log Plot measurement are different than other measurement traces. Traces saved from any other measurement except Spectrum Analysis Mode are not compatible with those saved using Log Plot measurements.

---

| Step | Action   | Notes  |
|------|--|--|
| 1    | Complete the acquisition of a Reference trace as detailed in the procedure <a href="#">“Creating a Low Phase Noise Signal Reference Trace” on page 16.</a>   |  |
| 2    | Copy the smoothed trace data in Trace 2 (cyan blue) to Trace 3 (magenta pink) for reference: <ol style="list-style-type: none"> <li>Press <b>Trace/Detector, More (1 of 2), Copy/Exchange, From Trace, Trace 2</b></li> <li>Press <b>To Trace, Trace 3</b></li> <li>Press <b>Copy Now</b></li> </ol> | You now have a reference trace stored in Trace number 3. |
| 3    | Select Cancellation <ol style="list-style-type: none"> <li>Press <b>Meas Setup, More 1 of 2, Cancellation</b></li> </ol>   |  |
| 4    | Select the reference trace <ol style="list-style-type: none"> <li>Press <b>Ref Trace, Trace 3</b></li> </ol>   |  |

| Step                      | Action   | Notes  |
|---------------------------|--|--|
| 5 Set the Threshold value | a. Press <b>Threshold</b> , and then enter a threshold level in 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 than the threshold level, then the source trace is assumed to be exactly the threshold level above the reference level. |
| 6 Turn cancellation ON    | a. Press <b>Cancellation ON</b> to toggle the setting to ON        | Any trace that is displaying smoothed data will change immediately to reflect the noise cancellation.  |

### Saving Traces for Retrieval

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

| Step                                       | Action  | Notes   |
|--|---|---|
| 1 Select the trace                         | a. Press <b>Save, Data (Export), Trace, Trace 3</b> |   |
| 2 Select the storage location and filename | a. Press <b>Save As...</b>                          | Save As... launches a menu of navigation buttons and a Windows Explorer window which opens to the default trace location:<br><br>D:\User_My_Documents\Instrument\desktop\My Documents\PNOISE\data\LPL\traces<br><br>You may use another directory or drive as desired. The default file name is "Trace_00000.csv" and the number automatically increments, adding 1 to the last number in the file. |

| Step  | Action               | Notes  |
|---|----------------------|--|
| 3 If you want to use the default file location and file name. | a. Press <b>Save</b> | <p>For future use, this reference trace can be saved to the analyzer's own internal file system (the C: drive), to a network drive, or to a removable drive via the analyzer's USB port.</p> <p>It is easiest to use a mouse to browse to another file location, and a keyboard to rename files, but the menu keys, Tab and Arrow buttons can be used effectively.</p> <p>For more information see the <b>Save/Recall</b> section in Phase Noise Help.</p> |

## Recalling Traces

All traces, including the reference traces used for noise cancellation measurement, can be loaded from a floppy disk or from the analyzer's own internal file system (C:). 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                                | Notes   |
|---|---------------------------------------|---|
| 1 Select the trace to recall  | a. Press <b>Recall, Data (Import)</b> |   |
| 2 Select a trace to receive the trace data.                         | a. Press <b>Open....</b>              | Open... launches a menu of navigation buttons and a Windows Explorer window which opens to the default trace location:<br><br>D:\\User_My_Documents\\Instrument\\desktop\\My Documents\\PNOISE\\data\\LPL\\traces |
| 3 Browse to the location, select the file name and you want to open | a. Press <b>Open</b>                  | It is easiest to use a mouse to navigate to another file location, but the buttons can be used, if desired.<br><br>For more information see the <b>Save/Recall</b> section in Phase Noise Help.                   |

---

**NOTE** This method of saving and loading traces in a Log Plot measurement is different from the normal method on ESA and PSA series Spectrum Analyzers. Traces saved from any other measurement except Spectrum Analysis Mode are incompatible with Log Plot measurements.

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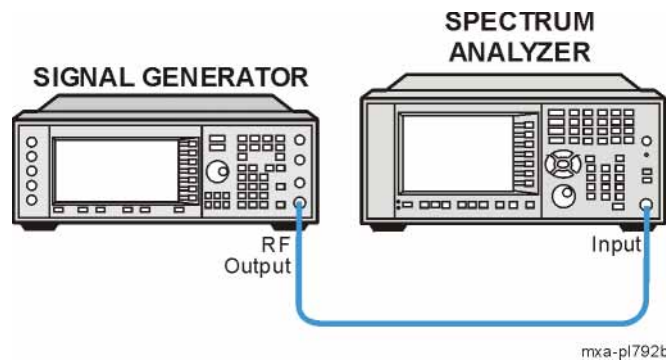
## Spot Frequency Measurements

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. The analyzer is normally set up to display a continuous sweep, although a single measurement can be performed by pressing by setting the **Sweep** option to **Single**.

This example shows a signal generator under test set up to transmit RF power. The transmitting signal is connected to the RF input port of the instrument. Connect the equipment as shown.

Figure 1-5

Spot Frequency Measurement System



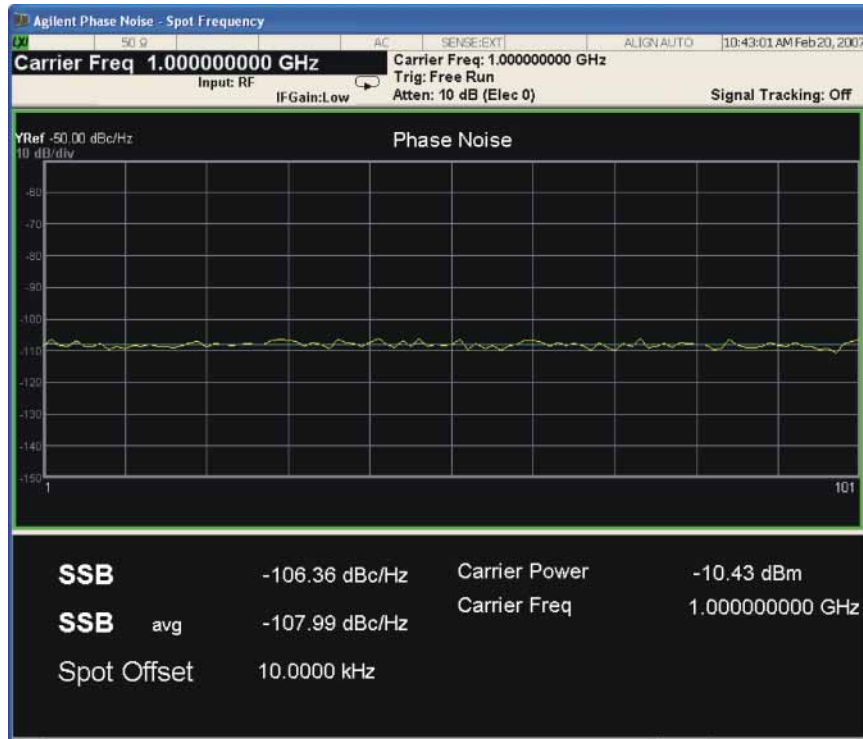
1. Using the appropriate cables and adapters, connect the output signal of the signal generator to the RF input of the analyzer.
2. For best frequency accuracy, connect a BNC cable between the 10 MHz REF IN port of the signal generator (if available) and the 10 MHz EXT REF OUT port of the analyzer.

### Basic Spot Frequency Measurement Procedure

| Step   | Action   | Notes  |
|--|--|--|
| 1 Enable the Phase Noise Mode  | a. Press <b>Mode</b> , Phase Noise             |  |
| 2 Preset the analyzer mode   | a. Press <b>Mode Preset</b>                    |  |
| 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. Press <b>Meas</b> , <b>Monitor Spectrum</b> |  |
| 4 Set the measurement center frequency   | a. Press <b>FREQ Channel</b>                   | Enter a numerical frequency using the front-panel keypad, and select a units key, such as <b>MHz</b> .<br><br>If the RF carrier is not at the center of the display you can use the knob to scroll the carrier to the center of the display.   |
| 5 Initiate the measurement   | a. Press <b>Meas</b> , <b>Spot Frequency</b>   |  |
| 6 Tune the measurement   | a. Press <b>Auto Tune</b>                      | 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.<br><br>The default display, <a href="#">Figure 1-6 on page 23</a> , shows the <b>Current</b> (yellow trace) and smoothed (blue trace) data. The measured value of Phase Noise in dBc/Hz is the vertical scale, and the horizontal scale is in Samples. |
| 7 Make a measurement repeatedly  | a. Press <b>Cont</b>                           |  |

| Step | Action | Notes |
|------|--------|-------|
|------|--------|-------|

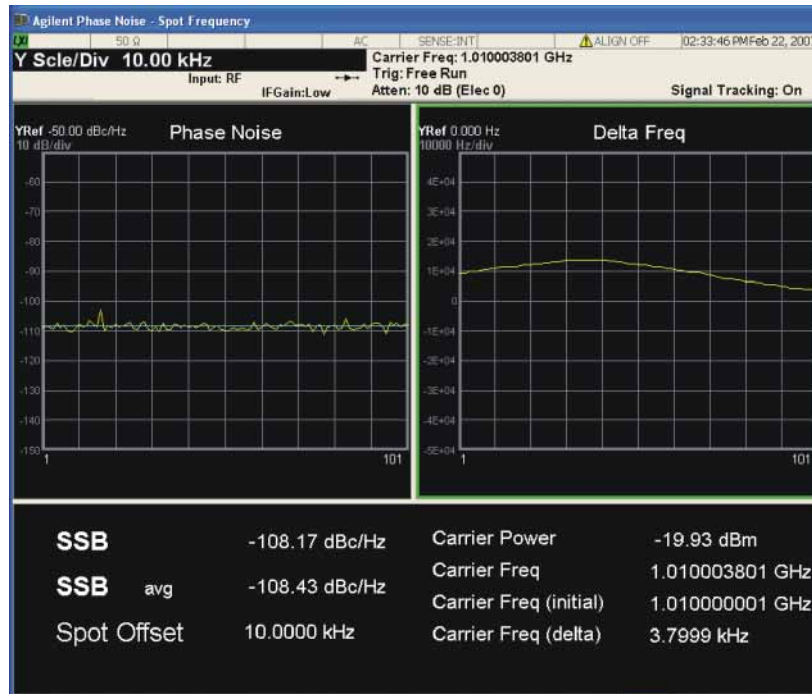
Figure 1-6 Spot Frequency Measurement - (Default View)



- |                           |   |  |
|---------------------------|---|--|
| 8 Track a drifting signal | a. Press <b>FREQ/Channel, Signal Tracking</b> to On | When signal tracking is <b>On</b> , another graph showing the change in carrier frequency over time is shown next to the spot frequency trace. The sample numbers in the horizontal scale of both graphs correspond to each other. See <a href="#">Figure 1-7 on page 24</a> |
|---------------------------|---|--|

## Spot Frequency Measurements

| Step       | Action  | Notes |
|------------|---|-------|
| Figure 1-7 | Spot Frequency Measurement - Signal Tracking ON |       |



- 9 Trade measurement speed for improved accuracy
- a. Press **FREQ/Channel**, **Tracking**, **Accuracy** and choose between **High (Slowest)** and **Low (Fastest)**. **Medium** is the default measurement speed and accuracy. Using the Fastest measurement will meet the instrument specifications, but is a good choice for strong, stable signals. Use Slowest for drifting or weaker signals.

For more information see “Spot Frequency Measurements” on page 38.

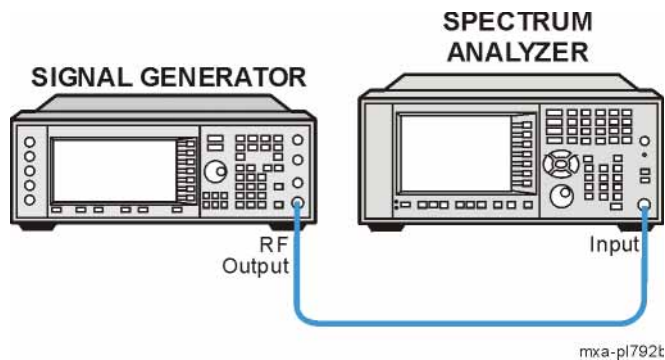


## Monitor Spectrum Measurements

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

This example shows a signal generator test set up to transmit RF power. The transmitting signal is connected to the RF input port of the analyzer. Connect the equipment as shown.

Figure 1-8 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.

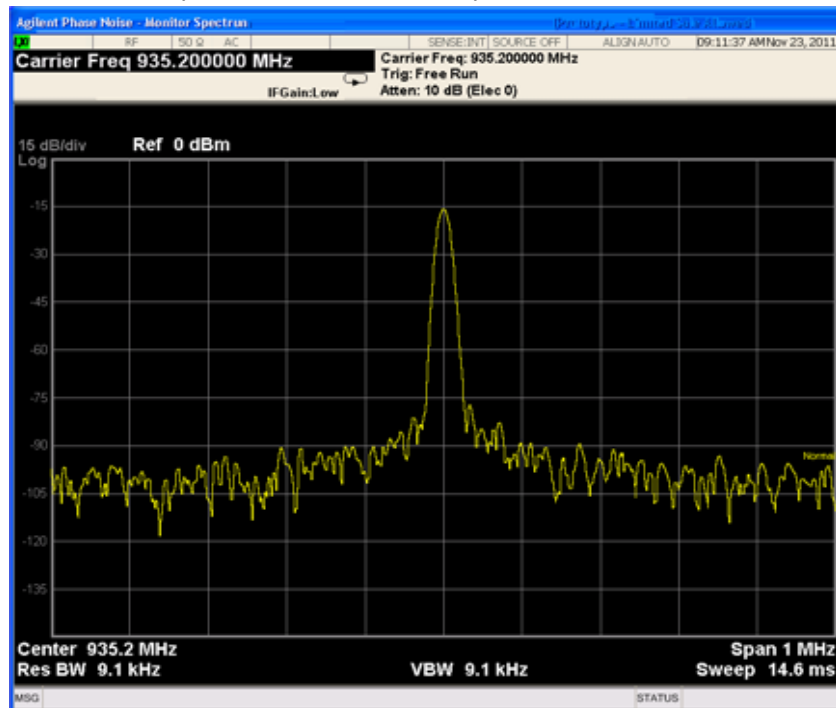
### Basic Monitor Spectrum Measurement Procedure

| Step                                 | Action  | Notes |
|--------------------------------------|---|-------|
| 1 Set up the signal source.          | <ol style="list-style-type: none"> <li>Set the mode to W-CDMA 3GPP.</li> <li>Set the frequency to 935.2 MHz.</li> <li>Set the amplitude to -15 dBm.</li> <li>Set the data format to framed.</li> <li>Set the frame repeat to continuous.</li> </ol> |       |
| 2 Connect signal source to analyzer. | <ol style="list-style-type: none"> <li>Connect the source RF OUTPUT to the analyzer RF INPUT, as shown in <a href="#">Figure 1-8 on page 25</a>.</li> </ol>   |       |
| 3 Select the Phase Noise mode.       | <ol style="list-style-type: none"> <li>Press <b>Mode, Phase Noise</b>.</li> </ol>   |       |
| 4 Preset the analyzer.               | <ol style="list-style-type: none"> <li>Press <b>Mode Preset</b>.</li> </ol>   |       |

## Monitor Spectrum Measurements

| Step | Action                                | Notes  |
|------|---------------------------------------|--|
| 5    | Set the measurement center frequency: | a. Press <b>FREQ Channel, 935.2, MHz.</b>  |
| 6    | Set the measurement span frequency:   | a. Press <b>SPAN X Scale, 1, MHz.</b>  |
| 7    | Initiate the measurement.             | a. Press <b>Meas, Monitor Spectrum.</b><br>A display with a Spectrum window appears when you activate a Spectrum measurement. See <a href="#">Figure 1-9 on page 26</a> . Changes to the <b>FREQ</b> , <b>Span</b> , or <b>AMPTD</b> settings affect only the active window. |

Figure 1-9 Monitor Spectrum Measurement - Spectrum and I/Q Waveform (Default View)



|   |                                   |   |  |
|---|-----------------------------------|---|--|
| 8 | If desired, toggle trace display. | a. Press <b>Trace/Detector, Select Trace</b> and select the trace(s) desired for display, then toggle <b>Display</b> to <b>Show</b> . | The default display shows the <b>Current</b> (yellow trace) data. To make viewing the display easier, you can view either the <b>Current</b> trace or <b>Average</b> separately. |
| 9 | To select continuous measurement. | a. Press <b>Cont.</b>   |  |

## 2 Phase Noise Measurement Concepts

## Introduction

This chapter includes the following topics:

- What is Phase Noise?
  - Definition
  - Thermal Noise
  - Other Noise Contributions
  - Single-Sideband Noise
  - AM Noise
- About Log Plot and Spot Frequency Measurements
- Improving Phase Noise Measurements
  - Smoothing, Averaging, and Filtering
  - Signal Tracking
  - Slowly Drifting Signals
  - System Noise Floor
  - Advanced Features - AM Rejection and Overdrive
- Using Cancellation for Log Plot Measurements
  - Creating DANL Floor Reference
  - Using DANL Reference for Cancellation
  - Creating a Phase Noise Reference Trace
  - Saving and Restoring Reference Traces
- Additional Phase Noise Documentation

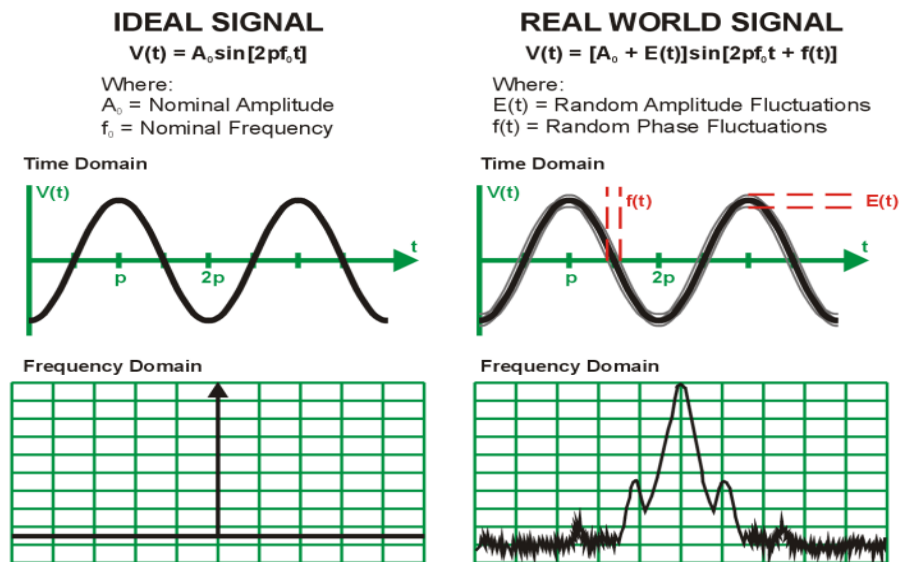
## What is Phase Noise?

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 we get to the formal definitions 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).

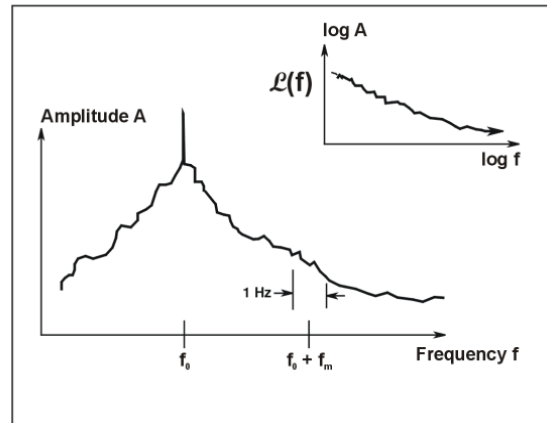
Phase Noise Measurement Concepts  
 What is Phase Noise?

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

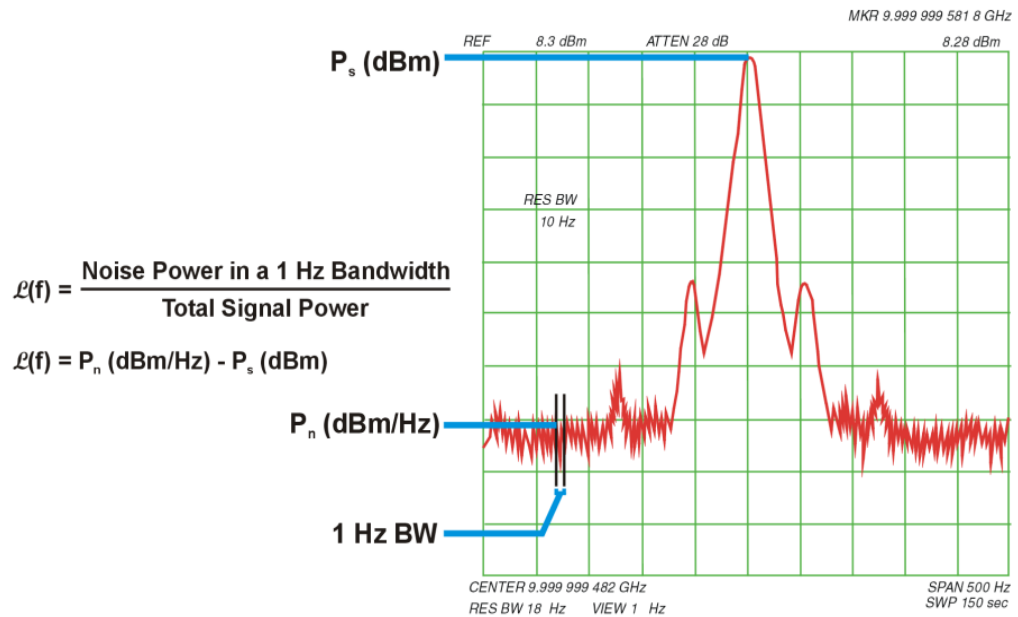


$$\mathcal{L}(f) = 10 \log \left( \frac{\text{Power 1 Hz Bandwidth}}{\text{Total Power in Full BW}} \right)$$

When measuring phase noise directly with an RF spectrum analyzer, the  $\mathcal{L}(f)$  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

$\mathcal{L}(f)$  Ratio

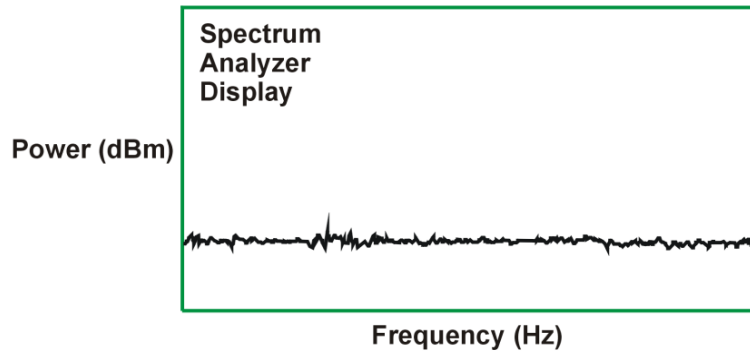


## Thermal Noise

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 ( $N_p$ )



$$N_p = kTB$$

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

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  $-174 \text{ dBm/Hz}$ . Since phase noise and AM noise contribute equally to  $kT$ , the phase noise power portion of  $kT$  is equal to  $-177 \text{ dBm/Hz}$  (3 dB less than the total  $kT$  power).

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

Phase Noise Measurement Concepts  
 What is Phase Noise?

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

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

- 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

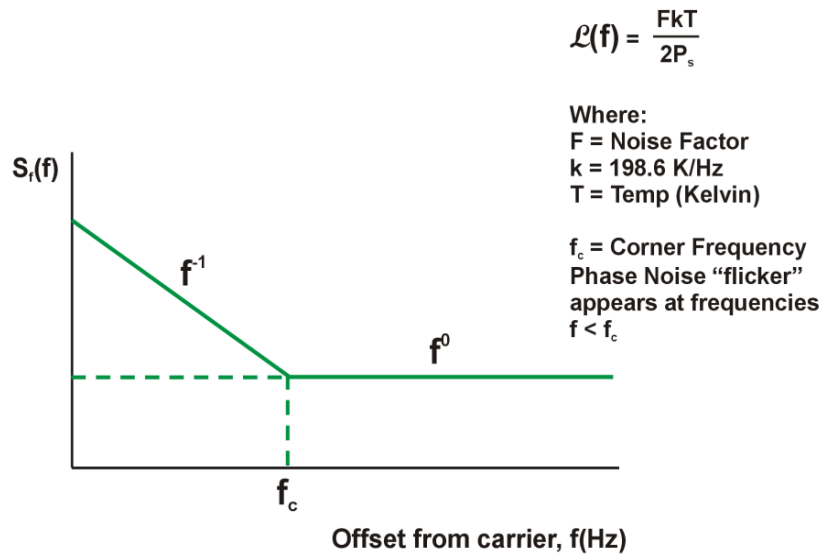
| $P_s$ [dBm] | $\mathcal{L}(f)$ [dBc/Hz] |
|-------------|---------------------------|
| +10         | -187                      |
| 0           | -177                      |
| -10         | -167                      |
| -20         | -157                      |

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 ( $f_c$ ). For offsets below  $f_c$ , 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.

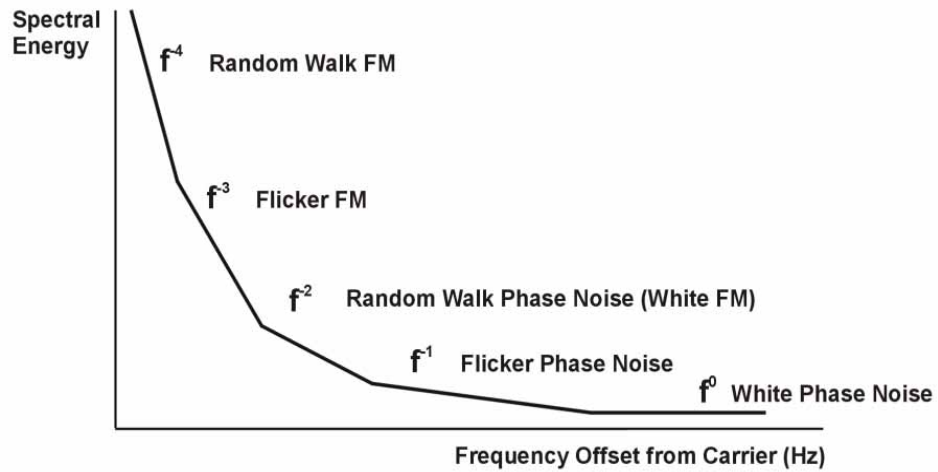
Figure 2-6 Flicker Noise





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 40.

## Phase Noise Measurement Concepts

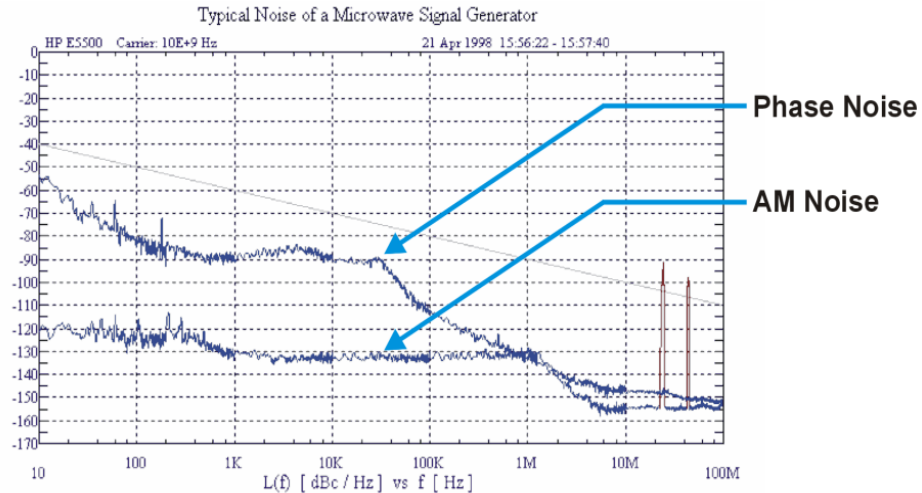
### What is Phase Noise?

Figure 2-8

AM Noise

Single Sideband AM Noise,

$$M(f) = \frac{\text{Spectral Density of one AM Modulation Sideband}}{\text{Total Sideband Power}}$$



## 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.

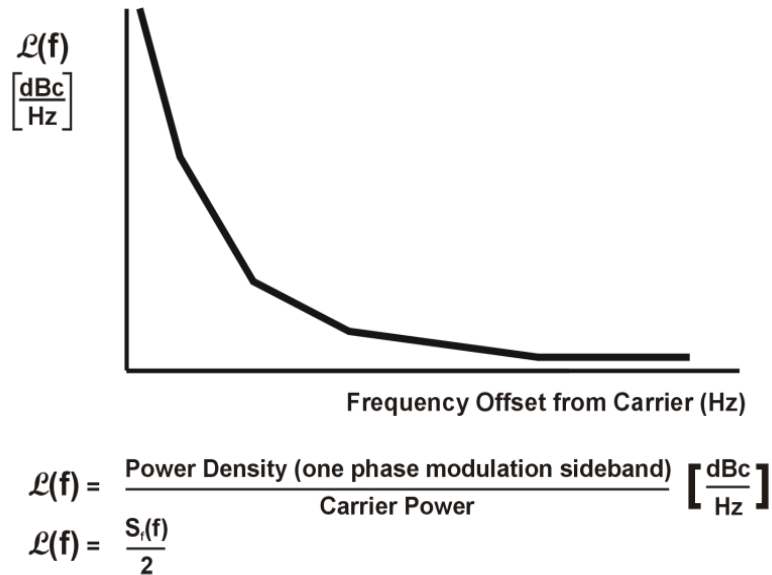
Since spurious signals are detected as FM sidebands, the presence of large spurious signals near the signal under test can greatly increase the measured level of residual FM. You can use the Monitor Spectrum measurement to determine whether these interfering signals are present.

## Single-Sideband Noise

$L(f)$  is an indirect measure of noise energy easily related to the RF power spectrum observed on a spectrum 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

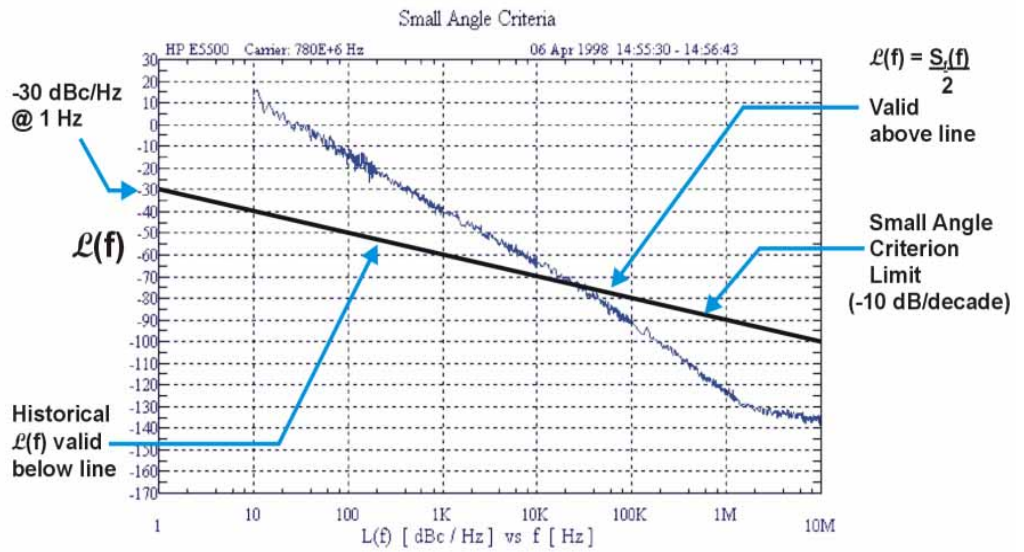


Measurements of  $L(f)$  with a spectrum analyzer typically measure phase noise when the phase variation is much less than 1 radian. Phase noise measurement systems, however, measure  $S_f(f)$ , which allows the phase variation to exceed this small angle restriction. On this graph, the typical limit 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.

Phase Noise Measurement Concepts  
What is Phase Noise?

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



## Phase Noise 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. With the default settings, 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 **Measure Log Plot** softkey or the **Restart** key allow 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 pressing **Marker, RMS Noise**. Use the RPG knob or front panel keys to select the starting point of your frequency range, and then select whether to display the result in radians or in degrees, or in seconds if **RMS Jitter** is selected. Now you can use the RPG knob or front panel keys to select the end point of your 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, use the RPG knob or front panel keys to position the marker at the start of your frequency range. Then press **Residual FM**, and use the RPG knob, or the front panel keys, to position the second marker at the end point of your 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 continuous sweep, although a single measurement can be performed by setting the sweep to **Single**.

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

## Improving Phase Noise Measurements

### Smoothing, Averaging, and Filtering

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. Video filtering can be used with both types of 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 or filtering, but less accurate than either. 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, choose the **Smoothing** softkey in **Meas Setup**, and then adjust it between 0.00% and 16.0% using either the front panel keys or the RPG knob. While inside the log plot measurement each level of smoothing can be tried without having to make a new measurement.

Video filtering can be applied to the active trace when making measurements. Additional video filtering improves the repeatability of the measurement but makes the measurement process slower. To filter a trace, choose the **Filtering** softkey in **Meas Setup**.

The averaging process (trace averaging) measured each point on multiple independent sweeps and converges on the average at each point. Trace averaging and video filtering require about the same amount of additional time to reach the same level of repeatability. The biggest difference is that with video filtering, the trace is smooth as it is being created, while with trace averaging, intermediate less smooth results are visible.

The averaging process measures each frequency point multiple times, and then calculates and plots the average value.

### 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 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 one of two methods. See [Using Log Plot to Measure Displayed Average Noise Level \(DANL Floor\)](#) for a procedure on measuring DANL Floor. See [Using a DANL Floor Trace for Phase Noise Measurement Cancellation](#) 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:

Press **Meas Setup, Advanced, Overdrive ON**

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.



## Log Plot Cancellation

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 noise floor (DANL) 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  $f_{\text{limit}}$ , where  $f_{\text{limit}}$  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 C: 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

---

- 1** Set up the analyzer as needed to measure the test signal's phase noise. (that is, Use the same frequency range as needed for your intended DUT measurement.) See [“Using Log Plot to Measure Displayed Average Noise Level \(DANL Floor\)”](#) on page 14

---

- 2** Create a reference trace. Create either a DANL reference or a signal phase noise reference. (See [“Using a DANL Floor Trace for Phase Noise Measurement Cancellation”](#) on page 15

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- 3** Save the reference trace. See [“Creating a Low Phase Noise Signal Reference Trace”](#) on page 16.)

---

- 4** Set up the analyzer so it is making a log plot measurement of the DUT's phase noise and turn on cancellation using the saved reference trace data

## 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 calculated 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.

| <b>Phase Noise of DUT relative to Phase Noise of Analyzer</b> | <b>Measurement Error Before Cancellation<sup>a</sup></b> | <b>Threshold <math>\Delta</math> Required for Maximum Cancellation</b> |
|---|--|--|
| 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 Information

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    |