

Keysight N5511A Phase Noise Test System

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Documentation is updated periodically. For the latest information about these products, including instrument software upgrades, application information, and product information, browse to one of the following URLs, according to the name of your product:

<http://www.keysight.com/find/n5511a>

To receive the latest updates by email, subscribe to Keysight Email Updates at the following URL:

<http://www.keysight.com/find/MyKeysight>

Information on preventing instrument damage can be found at:

www.keysight.com/find/PreventingInstrumentRepair

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Periodically, Keysight releases software updates to fix known defects and incorporate product enhancements. To search for software updates for your product, go to the Keysight Technical Support website at:

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1 Getting Started

[“Introduction” on page 14](#)

[“Documentation Map” on page 15](#)

[“Additional Documentation” on page 16](#)

[“System Overview” on page 17](#)

Introduction

This guide introduces you to the Keysight N5511A Phase Noise Test System software and hardware. It provides procedures for configuring the N5510 Phase Noise Measurement software, executing measurements, evaluating results, and using the advanced software features. It also covers phase noise basics and measurement fundamentals to get you started.

Use **Table 1-1** on **page 15** as a guide to:

- Learning about the N5511A phase noise test system
- Learning about phase noise basics and measurement fundamentals
- Using the N5511A system to make specific phase noise measurements.

In this guide you'll also find information on system connections and specifications, and procedures for re-installing phase-noise-specific hardware and software in the system PC.

NOTE

Installation information for your system is provided in the Keysight N5511A Phase Noise Test System Getting Started Guide.

Documentation Map

Table 1-1 N5511A user's guide map

Learning about the N5511A System	Learning Phase Noise Basics & Measurement Fundamentals	Using the N5511A for Specific Phase Noise Measurements
Chapter 1, "Getting Started"		
Chapter 2, "Introduction"	Chapter 3, "Phase Noise Basics"	
Chapter 4, "Expanding Your Measurement Experience"	Chapter 5, "Absolute Measurement Fundamentals"	Chapter 6, "Absolute Measurement Examples"
	Chapter 7, "Residual and Additive Noise Measurement Fundamentals"	Chapter 8, "Residual Measurement Examples"
	Chapter 9, "FM Discriminator Fundamentals"	Chapter 10, "FM Discriminator Measurement Examples"
	Chapter 11, "AM Noise Measurement Fundamentals"	Chapter 12, "AM Noise Measurement Examples"
		Chapter 13, "Baseband Noise Measurement Example"
		Chapter 14, "Evaluating Your Measurement Results"
		Chapter 15, "Advanced Software Features"
		Chapter 16, "Reference Graphs and Tables"
Chapter 17, "System Specifications"		
Chapter 18, "System Interconnections"		
Chapter 19, "Preventive Maintenance"		

Additional Documentation

The N5511A system documentation includes:

- Keysight N5511A Phase Noise Test System Installation Guide
- Keysight N5511A Series Phase Noise Test Systems SCPI Command Reference

System Overview

The Keysight N5511A Phase Noise Test System provides flexible sets of measurements on one-port devices such as voltage controlled oscillators (VCOs), dielectric resonator oscillators (DROs), crystal oscillators, and synthesizers, and on two-port devices such as amplifiers and frequency converters. The N5511A system measures absolute and residual phase noise, and AM noise for CW and pulsed signals. It operates in the frequency range of 50 kHz to 40 GHz.

The N5511A Phase Noise Test System combines standard instruments, phase noise measurement components, and PC software for maximum flexibility and re-use of assets. The system PC operates under Windows 10 Professional and controls the system through the N5510 measurement software. The N5510 software enables many stand-alone instruments to work in the system. This stand-alone instrument architecture easily configures for various measurement techniques, including the absolute phase noise PLL/reference-source technique, and delay-line and FM-discriminator methods.

The N5511A system is available as a benchtop model. Due to the system's flexibility, the hardware in the system varies greatly with the options selected. You may be installing instruments you already own in the system as well. A typical N5511A system includes these components:

- N5511A PXIe chassis
- M9037A Controller with removable SSD drive with Windows 10 Professional
- Keysight N5510 Phase Noise Measurement software
- M9550A Phase Detector 1 or 2
- M9551A Data Converter
- M9300A Frequency Reference
- Microwave Power Splitter

Customer provided monitor with display port cable, keyboard, mouse, and RF source(s).

Additional instruments may include a spectrum analyzer, oscilloscope, RF counter, and power meter.

For detailed information on the instruments in your Keysight N5511A Phase Noise Test System, refer to the individual instrument user guides.

Figure 1-1 Keysight N5511A benchtop system



Figure 1-1 shows the N5511A Phase Noise Test System.

The N5511A can replace earlier Keysight E5505A phase noise systems. The N5511A system uses a LAN or USB/GPIB port to communicate with the assets in the system. However, the N5511A system and N5510 software are backwards compatible with earlier E5505A systems and instruments. You may easily integrate existing assets into your N5511A system. Figure 1-2 and Table 1-2 show the N5511A and earlier-model equivalents.

GPIB communication is done by using an 82357B GPIB to USB interface adapter.

Figure 1-2 Keysight E5505A system comparison to N5511A system

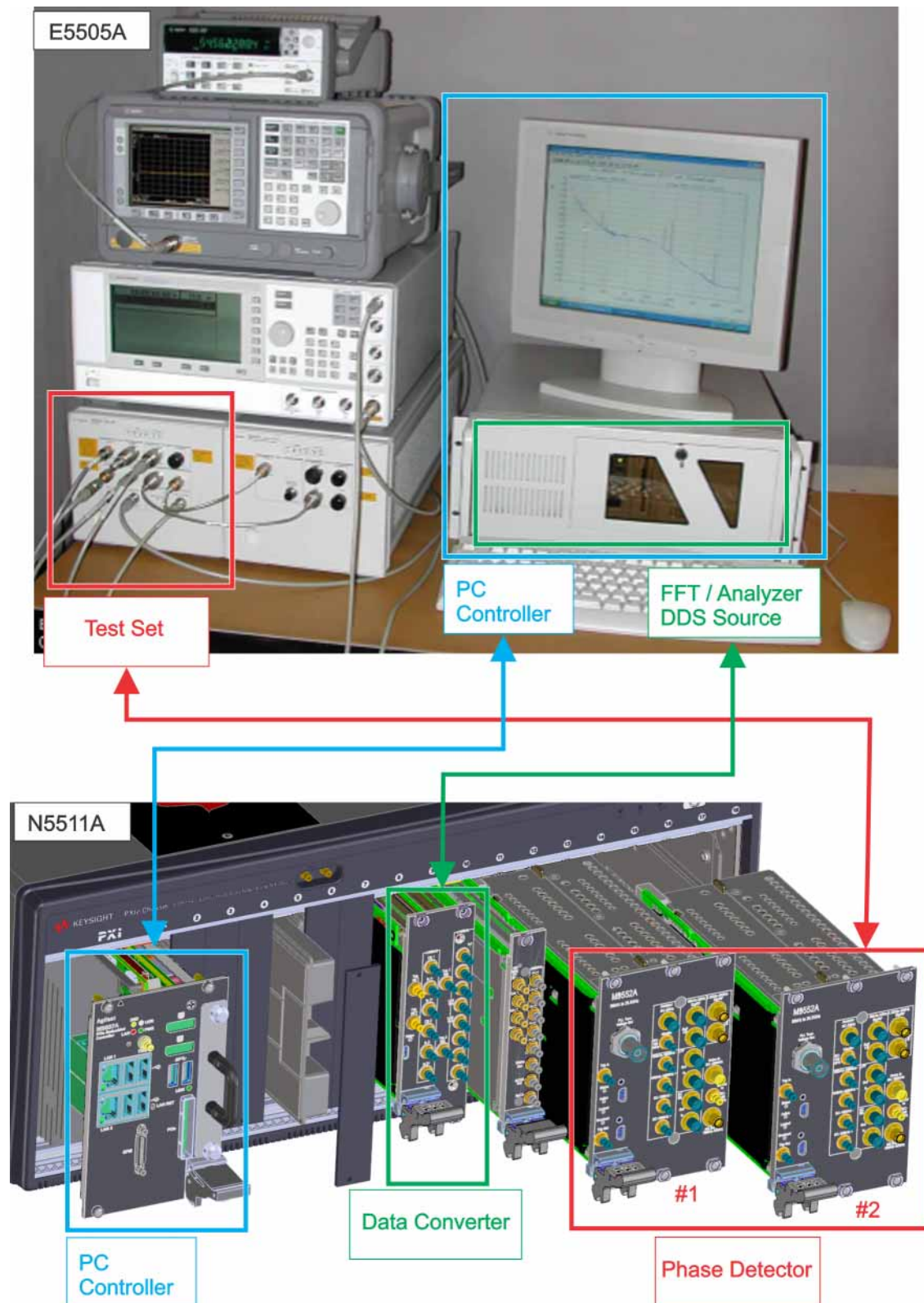


Table 1-2 **Equivalent system/instrument model numbers**

System or Instrument	Number	Old Number
Phase Noise Test System	N5511A	E5505A
50 kHz - 40 GHz phase detector	M9550A	N5500A-201 50kHz - 26.5 GHz Baseband Test Set
FFT/ Data Converter DC - 160 MHz	M9551A	E5505A-RHK PC with data converter card and swept analyzer

2 Introduction

[“Introducing the GUI” on page 22](#)

[“Designing to Meet Your Needs” on page 24](#)

[“N5511A Operation: A Guided Tour” on page 25](#)

[“Powering the System On” on page 26](#)

[“Starting the Measurement Software” on page 27](#)

[“Powering the System Off” on page 30](#)

Introducing the GUI

The graphical user interface (GUI) gives the user instant access to all measurement functions, making it easy to configure a system and define or initiate measurements. The most frequently used functions are displayed as icons on a toolbar, allowing quick and easy access to the measurement information.

The forms-based graphical interaction helps you define your measurement quickly and easily. Each form tab is labeled with its content, preventing you from getting lost in the defining process.

The system provides three default segment tables. To obtain a quick look at your data, select the “fast” quality level. If it is important to have more frequency resolution to separate spurious signals, use the “normal” and “high resolution” quality levels. If you need to customize the offset range beyond the defaults provided, tailor the measurement segment tables to meet your needs and save them as a custom selection.

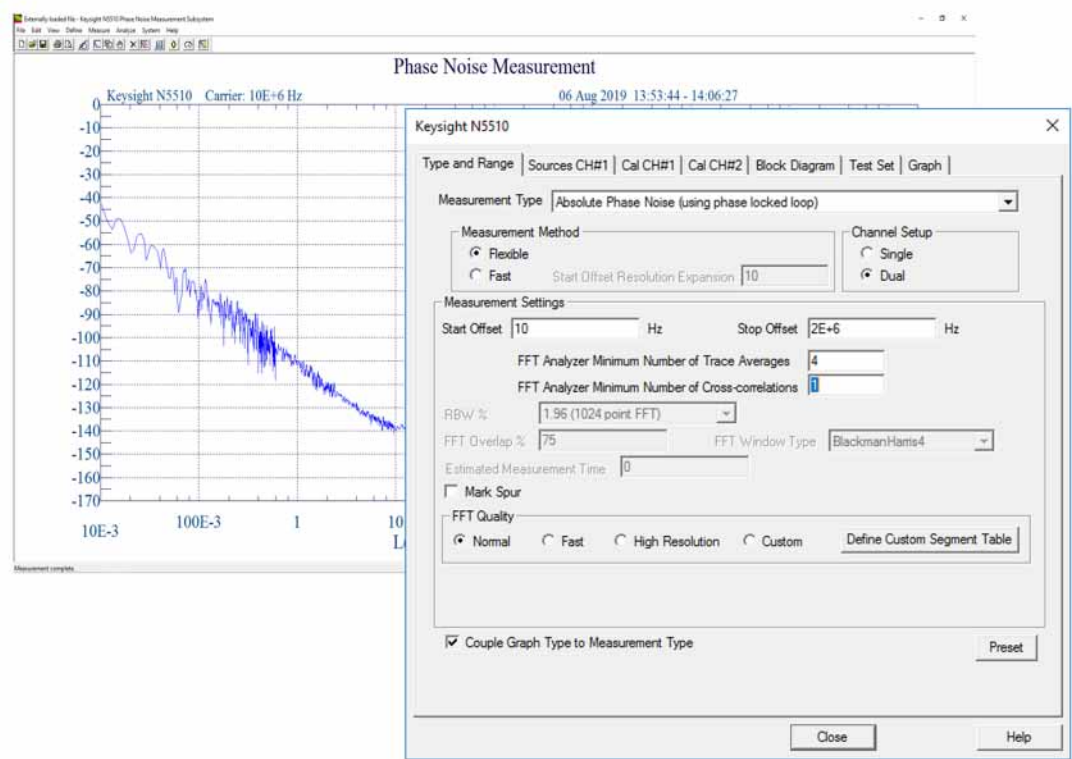
You can place up to nine markers on the data trace that can be plotted with the measured data.

Other features include:

- Plotting data without spurs
- Tabular listing of spurs
- Plotting in alternate bandwidths
- Parameter summary
- Color printouts to any supported color printer

Figure 2-1 shows an example of the GUI.

Figure 2-1 N5510 graphical user interface (GUI)



Designing to Meet Your Needs

The N5511A Phase Noise Test System is a high performance measurement tool that enables you to fully evaluate the noise characteristics of your electronic instruments and components with unprecedented speed and ease. The phase noise measurement system provides you with the flexibility needed to meet today's broad range of noise measurement requirements.

In order to use the phase noise system effectively, it is important that you have a good understanding of the noise measurement you are making. This manual is designed to help you gain that understanding and quickly progress from a beginning user of the phase noise system to a proficient user of the system's basic measurement capabilities.

NOTE

If you have just received your system or need help with connecting the hardware or loading software, refer to your Keysight N5511A Phase Noise Test System Installation Guide now. Once you have completed the installation procedures, return to **"N5511A Operation: A Guided Tour"** to begin learning how to make noise measurements with the system.

Beginning

The section **"N5511A Operation: A Guided Tour"** contains a step-by-step procedure for completing a phase noise measurement. This measurement demonstration introduces system operating fundamentals for whatever type of device you plan to measure.

Once you are familiar with the information in this chapter, you should be prepared to start **Chapter 4, "Expanding Your Measurement Experience"**. After you have completed that chapter, refer to **Chapter 14, "Evaluating Your Measurement Results"** for help in analyzing and verifying your test results.

N5511A Operation: A Guided Tour

This measurement demonstration introduces you to the system's operation by guiding you through an actual phase noise measurement.

You will be measuring the phase noise of the Keysight N5500A Phase Noise Test Set's low noise amplifier. (The measurement made in this demonstration is the same measurement that is made to verify the system's operation.)

As you step through the measurement procedures, you will soon discover that the phase noise measurement system offers enormous flexibility for measuring the noise characteristics of your signal sources and two-port devices.

Required equipment

The equipment shipped with this system is all that is required to complete this demonstration. (Refer to the N5511A Phase Noise Test System Installation Guide if you need information about setting up the hardware or installing the software.)

How to begin

Follow the setup procedures beginning on the next page. The phase noise measurement system displays a setup diagram that shows you the front panel cable connections to make for this measurement.

NOTE

If you need additional information about connecting instruments, refer to **Chapter 18, "System Interconnections"**.

Powering the System On

Connect your system to an appropriate AC power source using the power cord provided.

The N5511A system is shipped with an AC power cord appropriate for your location.

WARNING

Before applying power, make sure the AC power input and the location of the system meet the requirements given in the Getting Started guide for your system. Failure to do so may result in damage to the system or personal injury.

NOTE

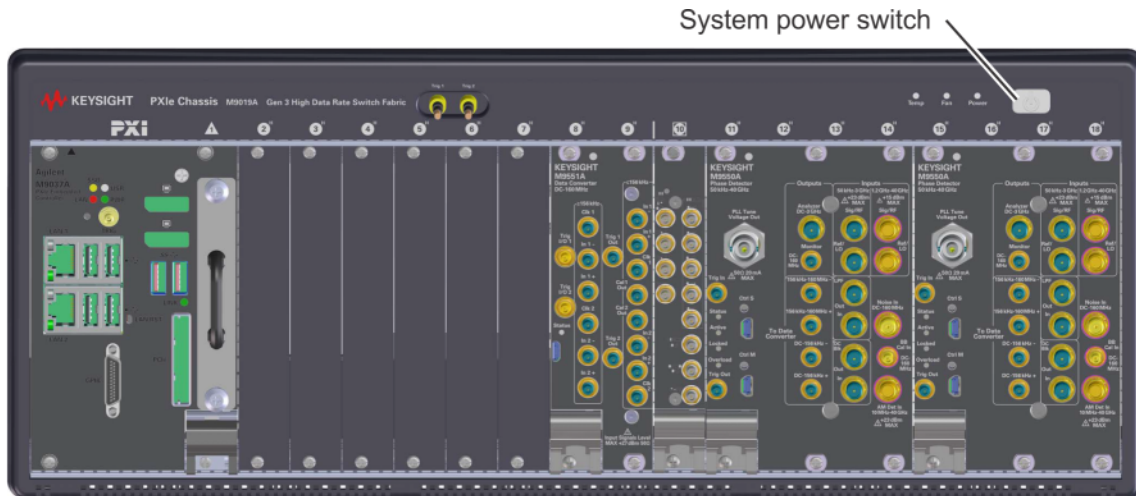
Warm-up Time: The downconverter and RF source instruments contain ovenized oscillators which must warm up for 30 minutes to produce accurate measurements.

Standby Mode: The RF source uses a standby mode to keep the ovenized oscillator warm when the instrument is connected (plugged in) to AC power, even when the power switch is in the off position. To completely shut down the instrument, you must disconnect it from the AC power supply.

The N5511A Benchtop system consists of an N5511A Phase Noise Test System with one or two test sets installed. You must connect a monitor, keyboard, and mouse before powering on the system.

Press the system power switch.

Figure 2-2 Power on the N5511A System



To power on a racked system

1. Press the system power switch (front, top right of the rack) to the on position.
2. Verify that all instrument power switches are on.
3. Allow the system to warm up for 30 minutes.

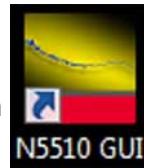
Starting the Measurement Software

The N5510 software is pre-installed on the N5511A Phase Noise system.

CAUTION

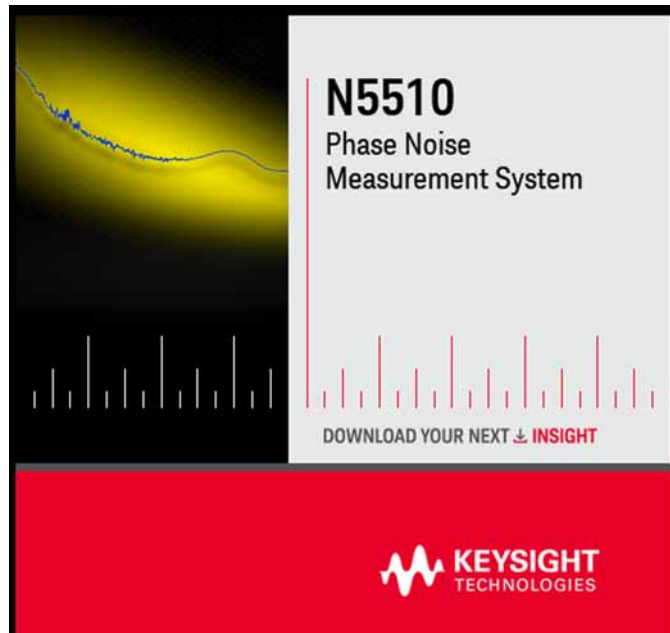
Keysight Technologies, Inc. **has not provided internet security software** for this N5511A Phase Noise Test System. Connecting the PC to a Local Area Network (LAN), without first installing internet security software (firewall, virus protection, etc) puts both your PC and data at risk. If you decide to connect the N5511A to a LAN, without first installing internet security software, you do so at your own risk.

Keysight recommends turning on Windows updates and installing updates when available from Microsoft.



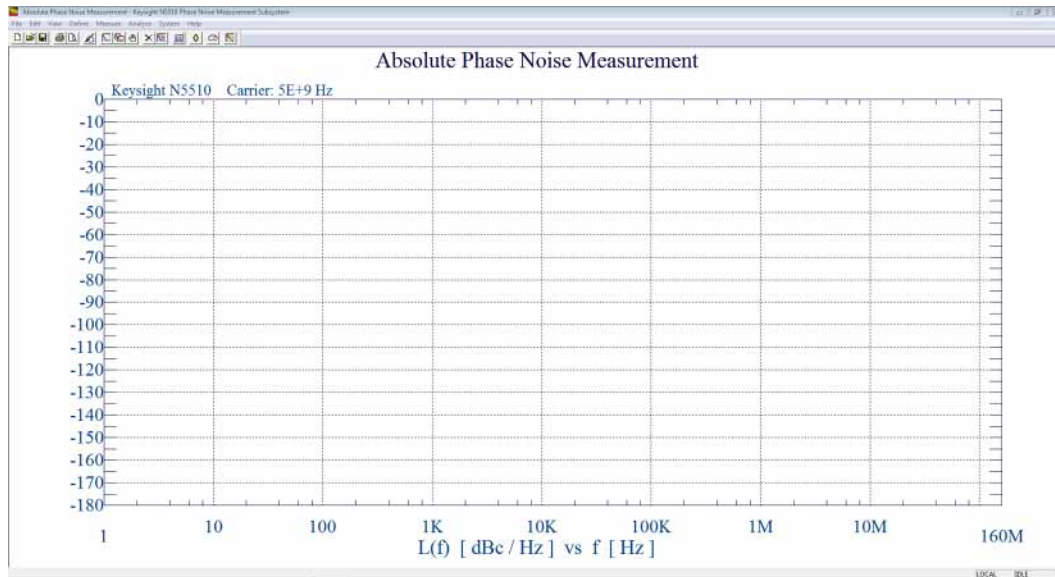
Choose the N5510 software icon to launch the user interface.

Figure 2-3 Splash Screen



1. To start the program, double-click on the N5510 icon on the desktop shortcut (shown above), or navigate to the N5510 User Interface through the Windows start menu. Click **Start > All Programs > Keysight N5510 > N5510 User Interface**.
2. When the program starts, the main N5510 measurement window appears (see **Figure 2-4**). It shows the phase noise graph.

Figure 2-4 Main N5510 user interface window



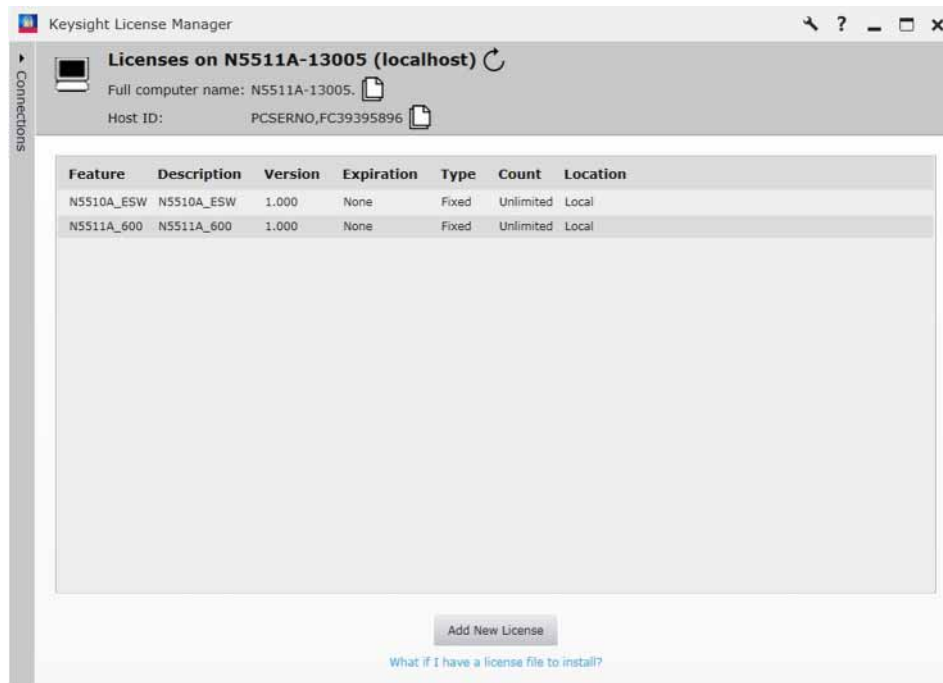
Verify License Key is Installed

NOTE

The N5511A will have the license key already installed, but if you ever need to install the license key, use the following procedure.

3. Use the Keysight License Manager to see the license keys installed. **Start > All Programs > Keysight License Manager > Keysight License Manager**
4. Verify the licenses are installed.

Figure 2-5 Keysight License Manager



Powering the System Off

- 1. On the N5510 software menu, select File\Exit, Start icon, then shut down. Always shut down the N5510 software before powering off the N5511A system.**
- 2. Use the Start menu to shut down the PC. Press the power switch on each instrument to the off position.**

If you receive error messages during the power on or off procedures, or during operation, use the Windows event log for detailed information on the errors.

3 Phase Noise Basics

[“What is Phase Noise?” on page 32](#)

[“Ideal vs Real Word Signals” on page 33](#)

[“Phase terms” on page 34](#)

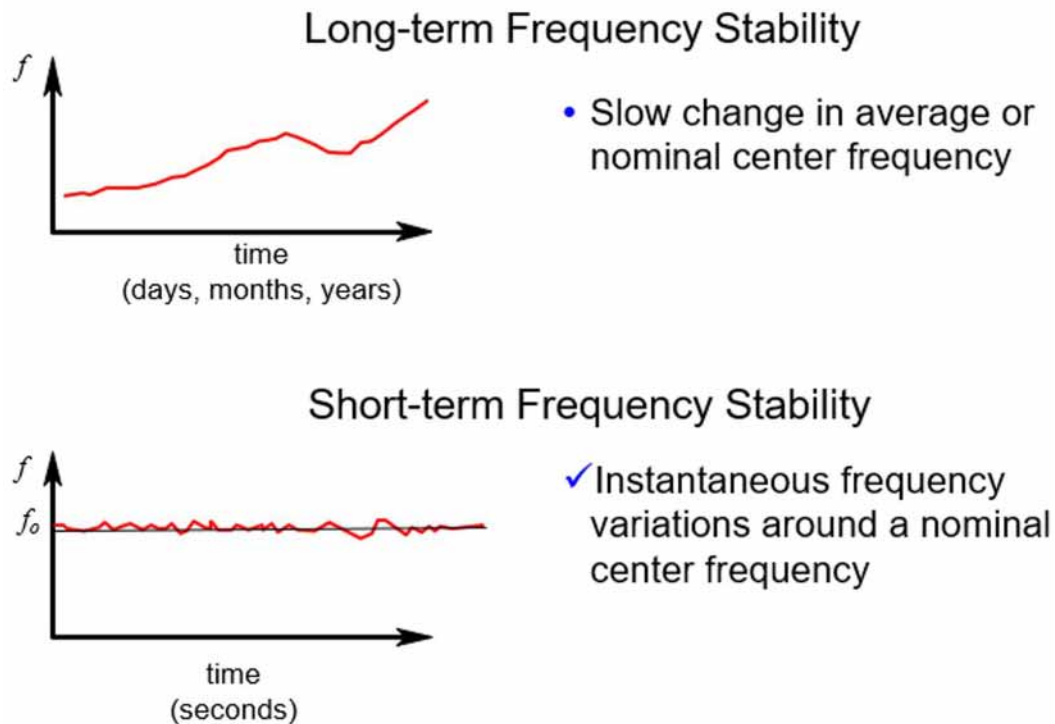
What is Phase Noise?

Frequency stability can be defined as the degree to which an oscillating source produces the same frequency throughout a specified period of time. Every RF and microwave source exhibit some amount of frequency instability.

This stability can be broken down into two components:

- long-term stability
- short-term stability

Figure 3-1 Frequency Stability



Long-term stability describes the frequency variations that occur over long time periods, expressed in parts per million per hour, day, month, or year.

Short-term stability contains all elements causing frequency changes about the nominal frequency of less than a few seconds duration. The chapter deals with short-term stability.

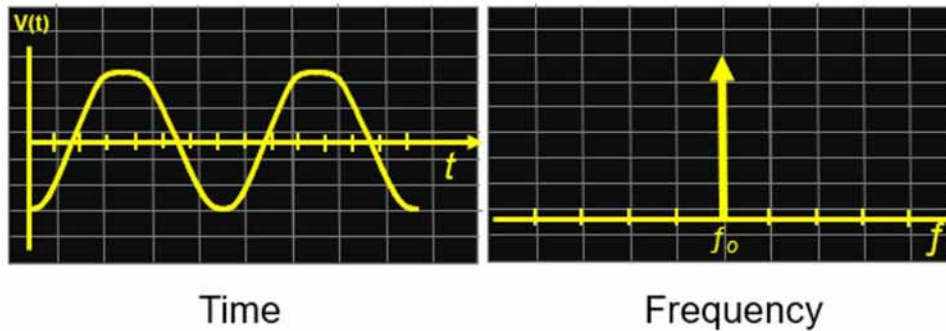
Ideal vs Real World Signals

Mathematically, an ideal sine wave can be described by

$$V(t) = A_o \sin(2\pi f_o t)$$

Where A_o = nominal amplitude, f_o = nominal frequency. In the time domain, this signal is a perfect sinusoidal waveform, and in the frequency domain, it is represented by a single spectral line. See [Figure 3-2](#).

Figure 3-2 Single Spectral Line

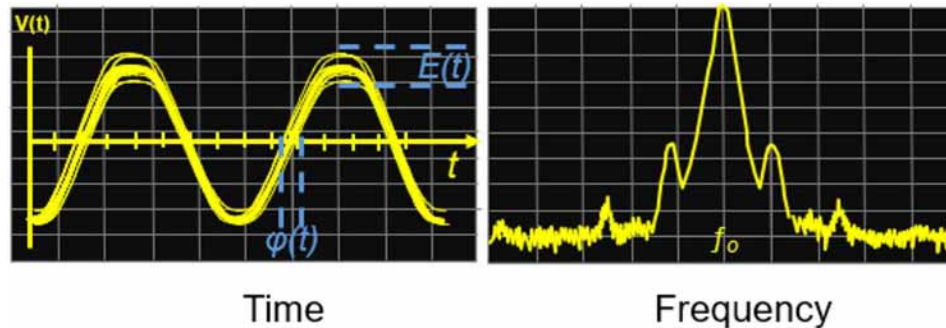


In practice however, there are always small, unwanted amplitude and phase fluctuations present on the signal. An actual signal is better modeled by

$$V(t) = (A_o + E(t)) \sin(2\pi f_o t + \phi(t))$$

Where $E(t)$ = Amplitude fluctuations, and $\phi(t)$ = randomly fluctuating phase term, or phase noise. This randomly fluctuating phase term could be observed on an ideal RF analyzer (one which has no sideband noise of its own) as seen in [Figure 3-3](#). The signal is now represented by a spread of spectral lines - both above and below the nominal signal frequency in the form of modulation sidebands due to the random amplitude and phase fluctuations.

Figure 3-3 Spread of Spectral Lines



Phase terms

There are two types of fluctuating phase terms:

- spurious signals
- phase noise

Spurious signals

The first are discrete signals appearing as distinct components in the spectral density plot. These signals, commonly called spurious, can be related to known phenomena in the signal source such as power line frequency, vibration frequencies, or mixer products.

Phase noise

The second type of phase instability is random in nature and is commonly called phase noise. The sources of random sideband noise in an oscillator include thermal noise, shot noise, and flicker noise. Many terms exist to quantify the characteristic randomness of phase noise. Essentially, all methods measure the frequency or phase deviation of the source under test in the frequency or time domain. Since frequency and phase are related to each other, all of these terms are also related.

Spectral density

One fundamental description of phase instability or phase noise is spectral density of phase fluctuations on a per-Hertz basis. The term spectral density describes the energy distribution as a continuous function, expressed in units of variance per unit bandwidth. We can convert rms phase fluctuations into a spectral density by dividing by the bandwidth of the noise skirts:

$$S_{\phi}(f) = \phi_{RMS}^2 \left(\frac{1}{BW} \right) \left(\frac{rads^2}{Hz} \right)$$

Where BW (bandwidth) is negligible with respect to any changes in $S_{\phi}(f)$.

Because phase modulation is a symmetric process (both sidebands are identical), we need only consider one of the noise side skirts. We use the right-hand side noise side skirt and call that $\mathcal{L}(f)$. $\mathcal{L}(f)$ is directly related to by a simple approximation which has generally negligible error if the modulation sidebands are such that the total phase deviation are much less than 1 radian ($\Delta\phi_{pk} \ll 1$ radian).

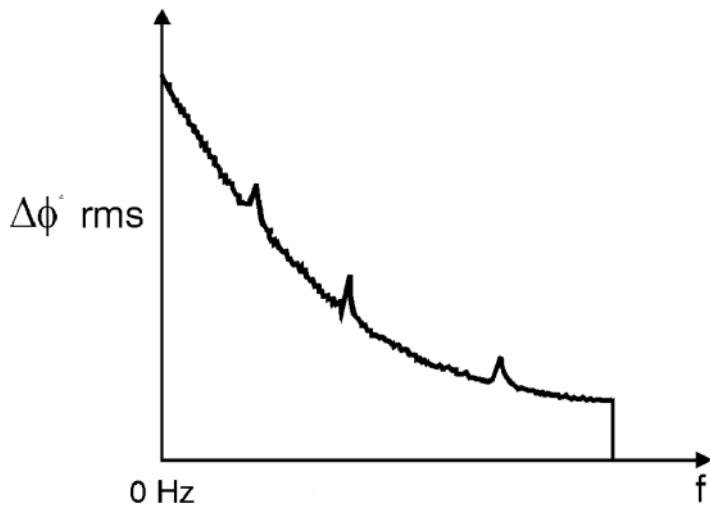
$$\mathcal{L}(f) = \frac{S_{\phi}(f)}{2} = \frac{\phi_{RMS}^2}{2} \left(\frac{1}{BW} \right) \left(\frac{rads^2}{Hz} \right)$$

L(f)

Another useful measure of noise energy is $L(f)$, which is then directly related to $S_{\phi}(f)$ by a simple approximation which has generally negligible error if the modulation sidebands are such that the total phase deviation are much less than 1 radian ($\Delta\phi_{pk} \ll 1$ radian).

$$L(f) = \frac{1}{2} S_{\Delta\phi}(f)$$

Figure 3-4 CW signal sidebands viewed in the frequency domain



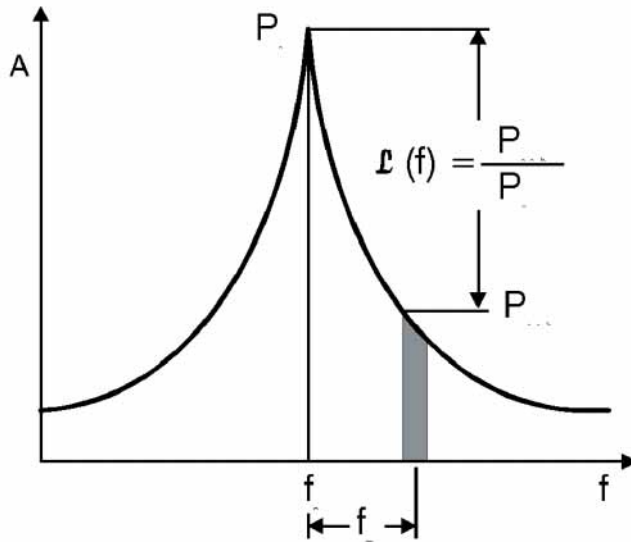
$L(f)$ is an indirect measurement of noise energy easily related to the RF power spectrum observed on an RF analyzer. **Figure 3-5** shows that the National Institute of Standards and Technology (NIST) defines $L(f)$ as the ratio of the power--at an offset (f) Hertz away from the carrier. The phase modulation sideband is based on a per Hertz of bandwidth spectral density and or offset frequency in one phase modulation sideband, on a per Hertz of bandwidth spectral density and (f) equals the Fourier frequency or offset frequency.

$$L(f) = \frac{\text{power density (in one phase modulation sideband)}}{\text{total signal power}} = \frac{P_{ssb}}{P_s}$$

= single sideband (SSB) phase noise to carrier ration (per Hertz)

Figure 3-5

Deriving $L(f)$ from a RF analyzer display

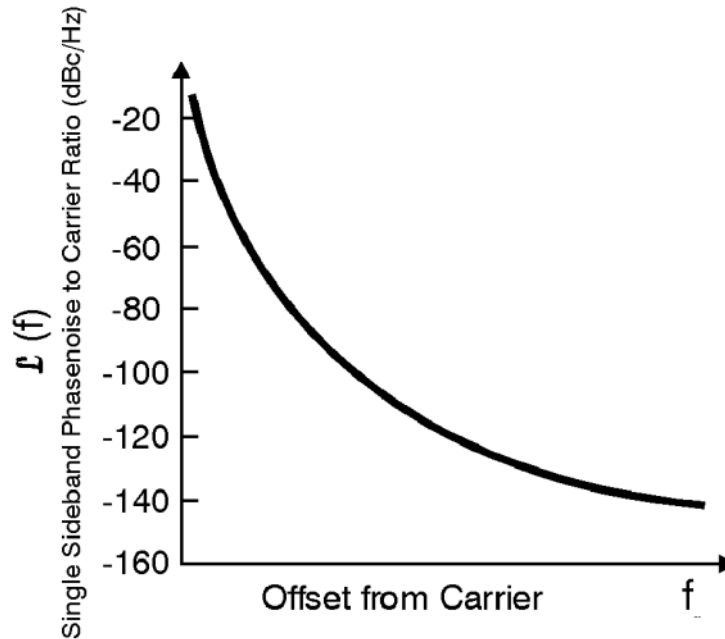


$L(f)$ is usually presented logarithmically as a spectral density plot of the phase modulation sidebands in the frequency domain, expressed in dB relative to the carrier per Hz (dBc/Hz) as shown in [Figure 3-6](#). This chapter, except where noted otherwise, uses the logarithmic form of $L(f)$ as follows:

$$S_{\Delta f}(f) = 2f^2 L(f)$$

Figure 3-6

$L(f)$ Described Logarithmically as a Function of Offset Frequency



Caution must be exercised when $L(f)$ is calculated from the spectral density of the phase fluctuations $S_{\phi}(f)$ because the calculation of $L(f)$ is dependent on the small angle criterion. **Figure 3-7**, the measured phase noise of a free running VCO described in units of $L(f)$, illustrates the erroneous results that can occur if the instantaneous phase modulation exceeds a small angle line. Approaching the carrier $L(f)$ obviously increases in error as it indicates a relative level of +45 dBc/Hz at a 1 Hz offset (45 dB more noise power at a 1 Hz offset in a 1 Hz bandwidth than in the total power of the signal); which is of course invalid.

Figure 3-7 shows a 10 dB/decade line drawn over the plot, indicating a peak phase deviation of 0.2 radians integrated over any one decade of offset frequency. At approximately 0.2 radians the power in the higher order sidebands of the phase modulation is still insignificant compared to the power in the first order sideband which insures that the calculation of $L(f)$ remains valid. Above the line the plot of $L(f)$ becomes increasingly invalid, and $S_{\phi}(f)$ must be used to represent the phase noise of the signal.

Figure 3-7 Region of validity of $L(f)$



Phase Noise Basics

What is Phase Noise?

4 Expanding Your Measurement Experience

[“GUI Features” on page 40](#)

[“Viewing Markers” on page 40](#)

[“Display Preferences” on page 41](#)

[“Omitting Spurs” on page 43](#)

[“Displaying the Parameter Summary” on page 45](#)

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[“Toolbar” on page 53](#)

GUI Features

Viewing Markers

The marker function allows you to display the exact frequency and amplitude of any point on the results graph.

To access the marker function, on the **View** menu, click **Markers**. In the dialog box containing Marker buttons at the bottom of the application, up to nine markers may be added. To add a marker, click **Add Marker** at the bottom of the display and to remove a highlighted marker, click the **Delete Marker** button at the bottom of the display. Markers are added to the latest measured trace on the display.

Figure 4-1 View Markers

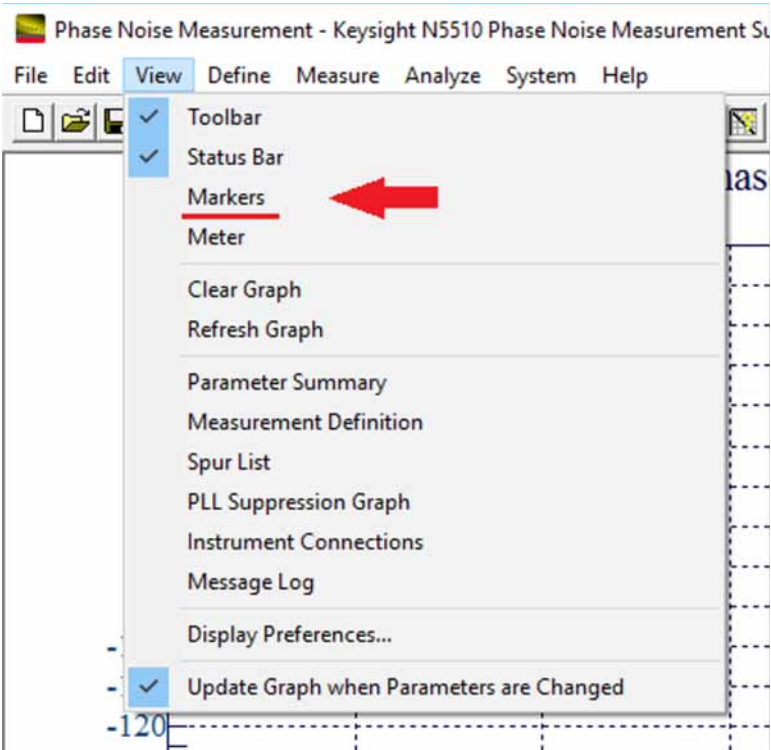
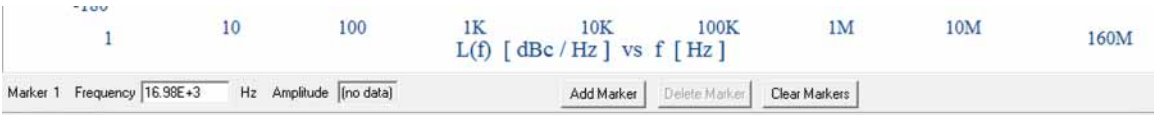


Figure 4-2 Add/Delete Markers



Display Preferences

N5510 User Interface display colors are highly customizable. Navigate to **View, Display Parameters**. The following menu will appear allowing the ability for the user to customize the colors of various items on the display.

NOTE

Changing the noise color will affect the noise trace of the next measurement, not the currently displayed trace.

Figure 4-3

View Display Preferences

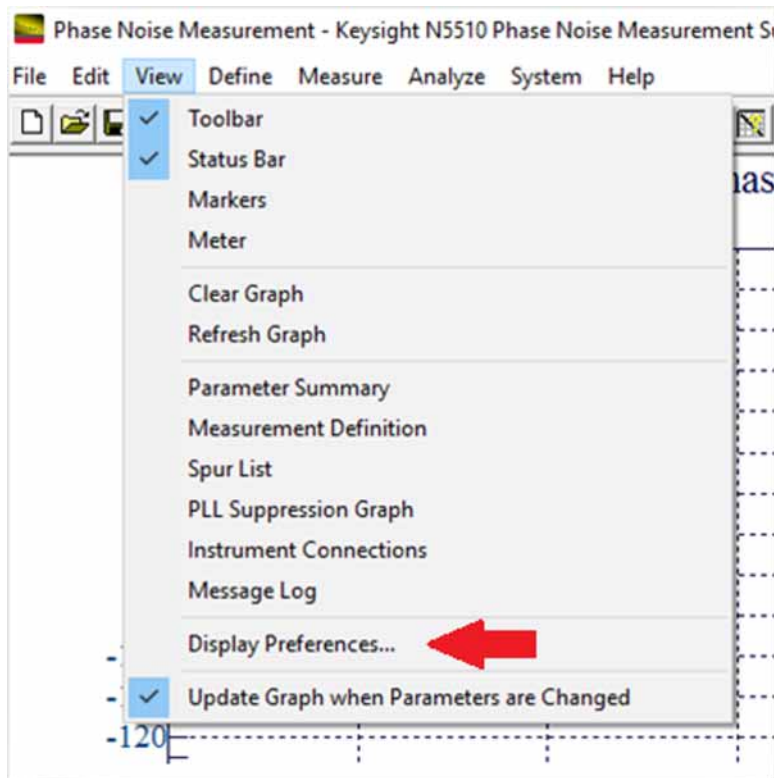
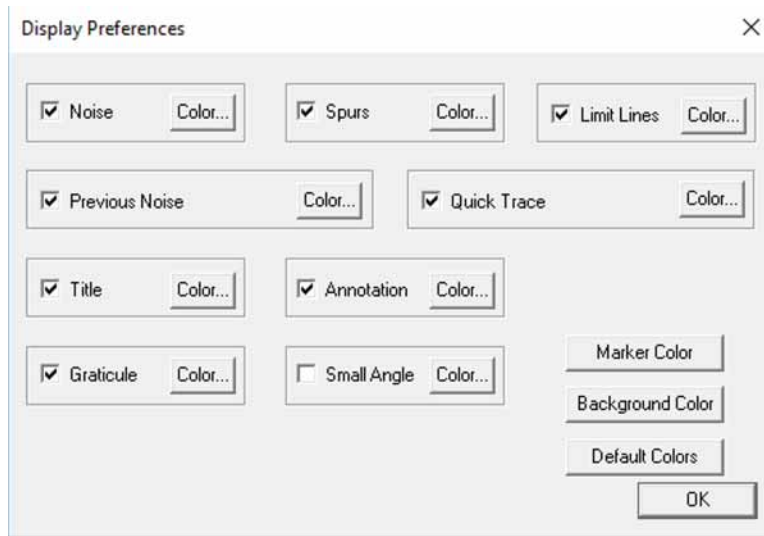


Figure 4-4 Display Preferences Window

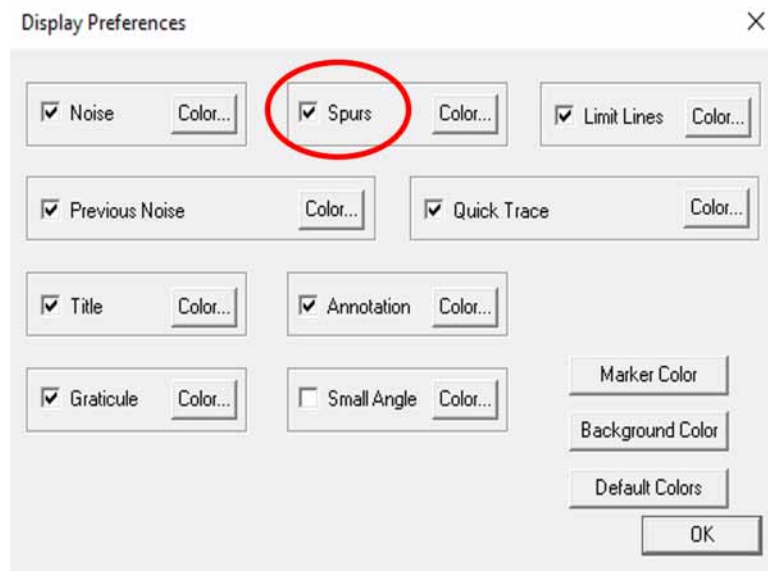


Omitting Spurs

The Omit Spurs function plots the currently loaded results without displaying any spurs that may be present. The ability to omit or view spurs is conditional on the 'Mark Spurs' option under the Type and Range tab of the measurement definition being checked.

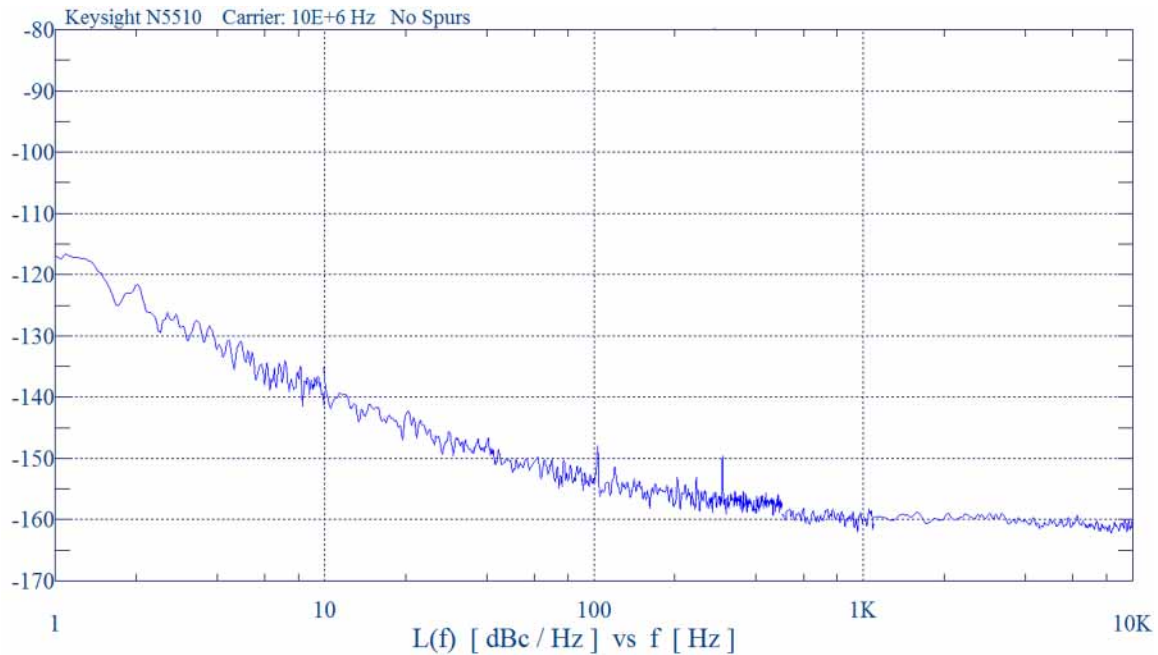
1. On the **View** menu, click **Display Preferences**.
2. In the **Display Preferences** dialog box, uncheck **Spurs** and click **OK**. See [Figure 4-5](#).

Figure 4-5 Uncheck spurs



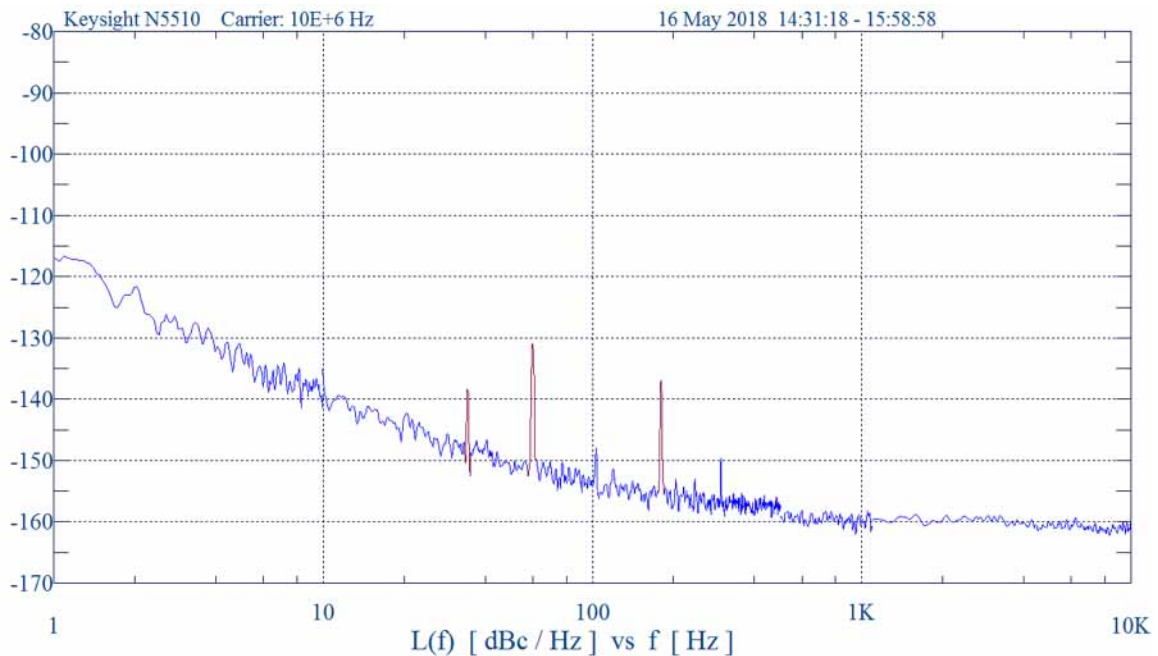
3. The graph is displayed without spurs. See [Figure 4-6](#).

Figure 4-6 Graph displayed without spurs



4. To re-display the spurs, check **Spurs** in the **Display Preferences** dialog box. This feature can also be accessed by right-clicking on the plot and unselecting **View Spurs**. [Figure 4-7](#) shows the graph displayed with spurs.

Figure 4-7 Graph displayed with spurs

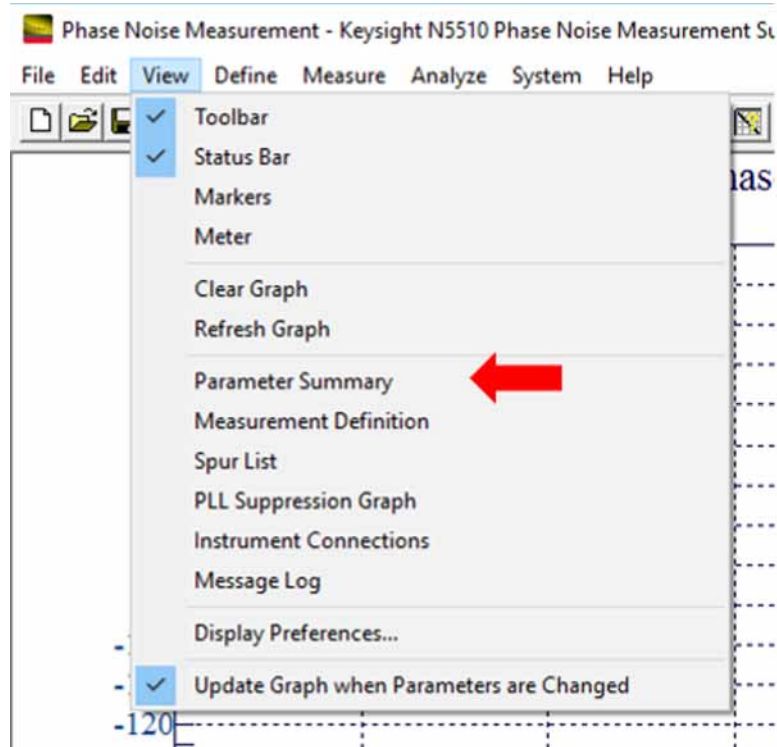


Displaying the Parameter Summary

The Parameter Summary function allows you to quickly review the measurement parameter entries that were used for this measurement. The parameter summary data is included when you print the graph.

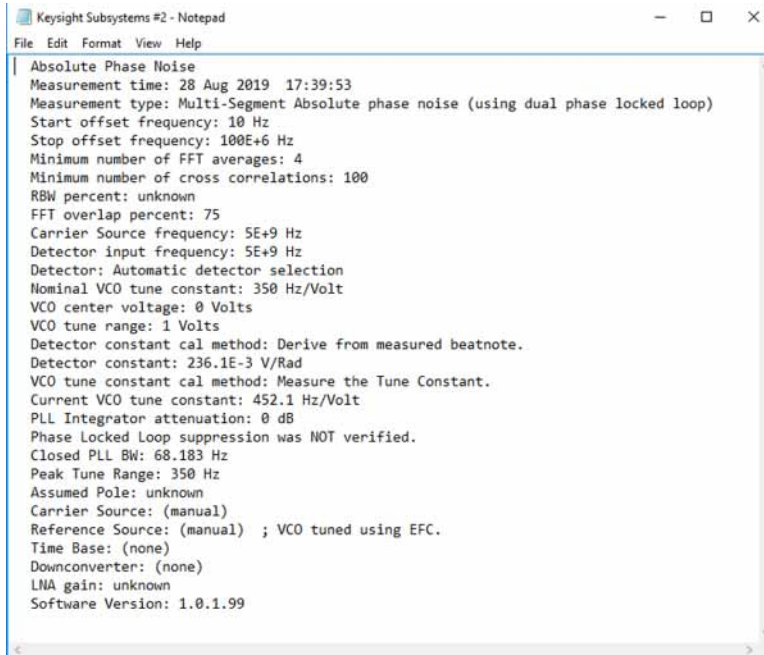
1. On the **View** menu, click **Parameter Summary**. See [Figure 4-8](#).

Figure 4-8 Navigate to Parameter Summary



2. The **Parameter Summary Notepad** dialog box appears. The data can be printed or changed using standard Notepad functionality. See [Figure 4-9](#).

Figure 4-9 Parameter summary notepad



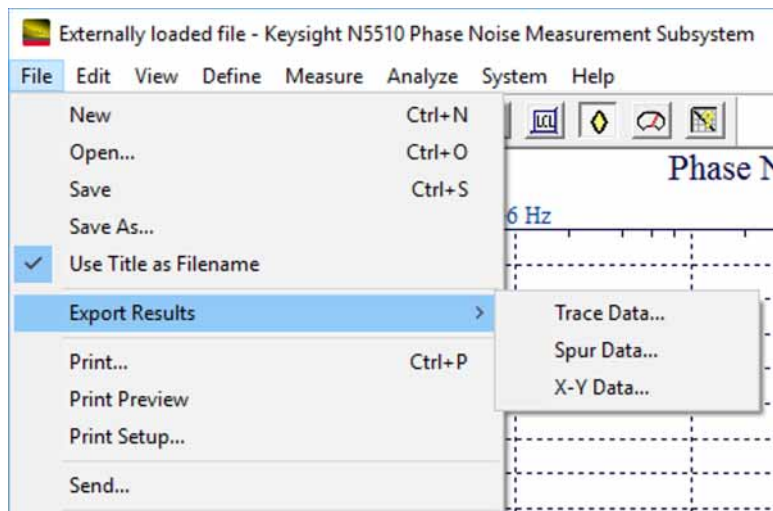
Exporting Measurement Results

The Export Measurement Results function exports data in one of three types:

- Exporting Trace Data
- Exporting Spur Data
- Exporting X-Y Data

1. To export measurement results, on the **File** menu, point to **Export Results**, then click on either **Trace Data**, **Spur Data**, or **X-Y Data**. See [Figure 4-10](#).

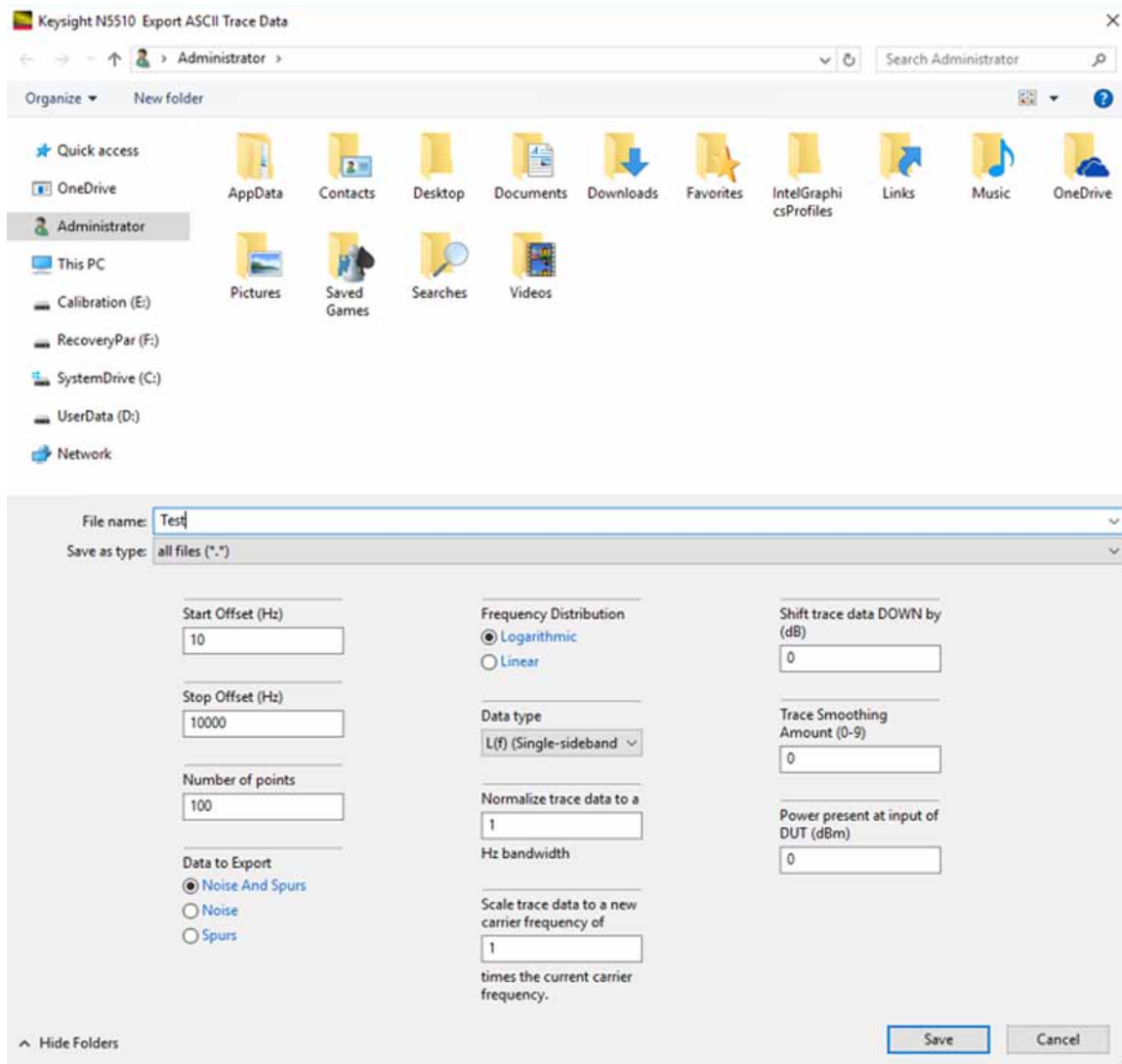
Figure 4-10 Export results choices



Exporting Trace Data

1. On the File menu, point to Export Results, then click on Trace Data. See [Figure 4-11](#).

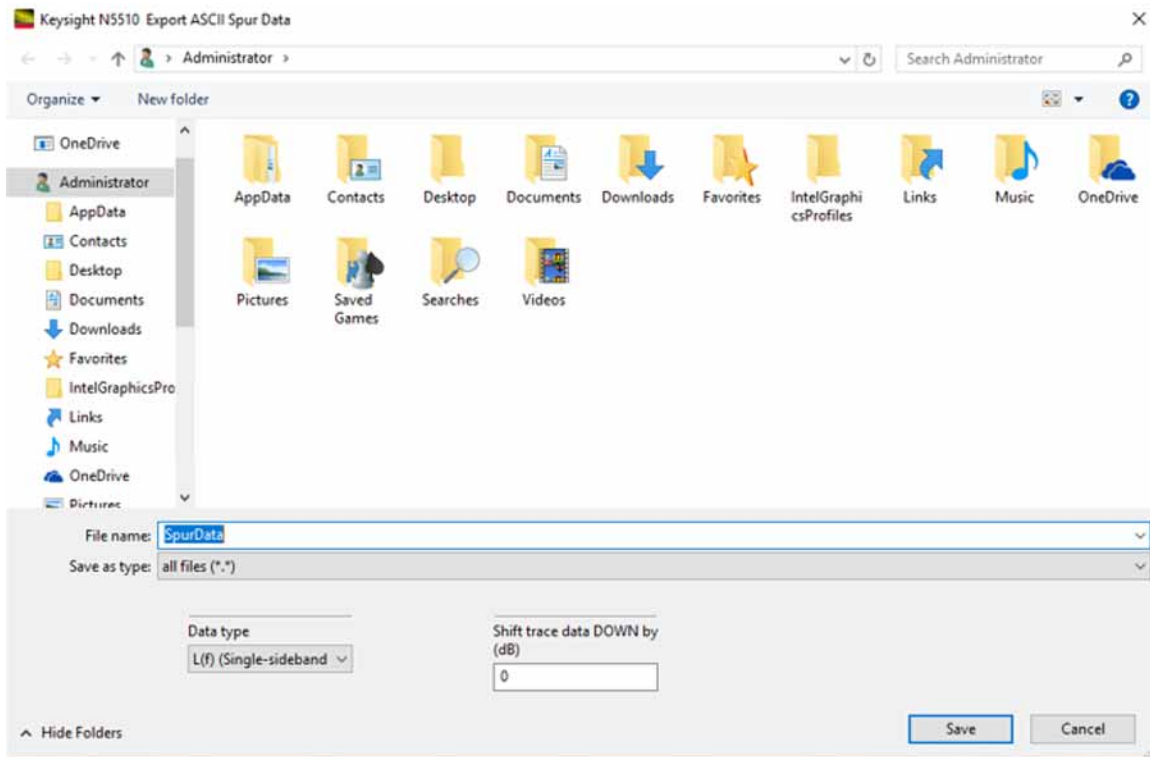
Figure 4-11 Trace data results



Exporting spur data

1. On the File menu, point to Export Results, then click on Spur Data. See [Figure 4-12](#).

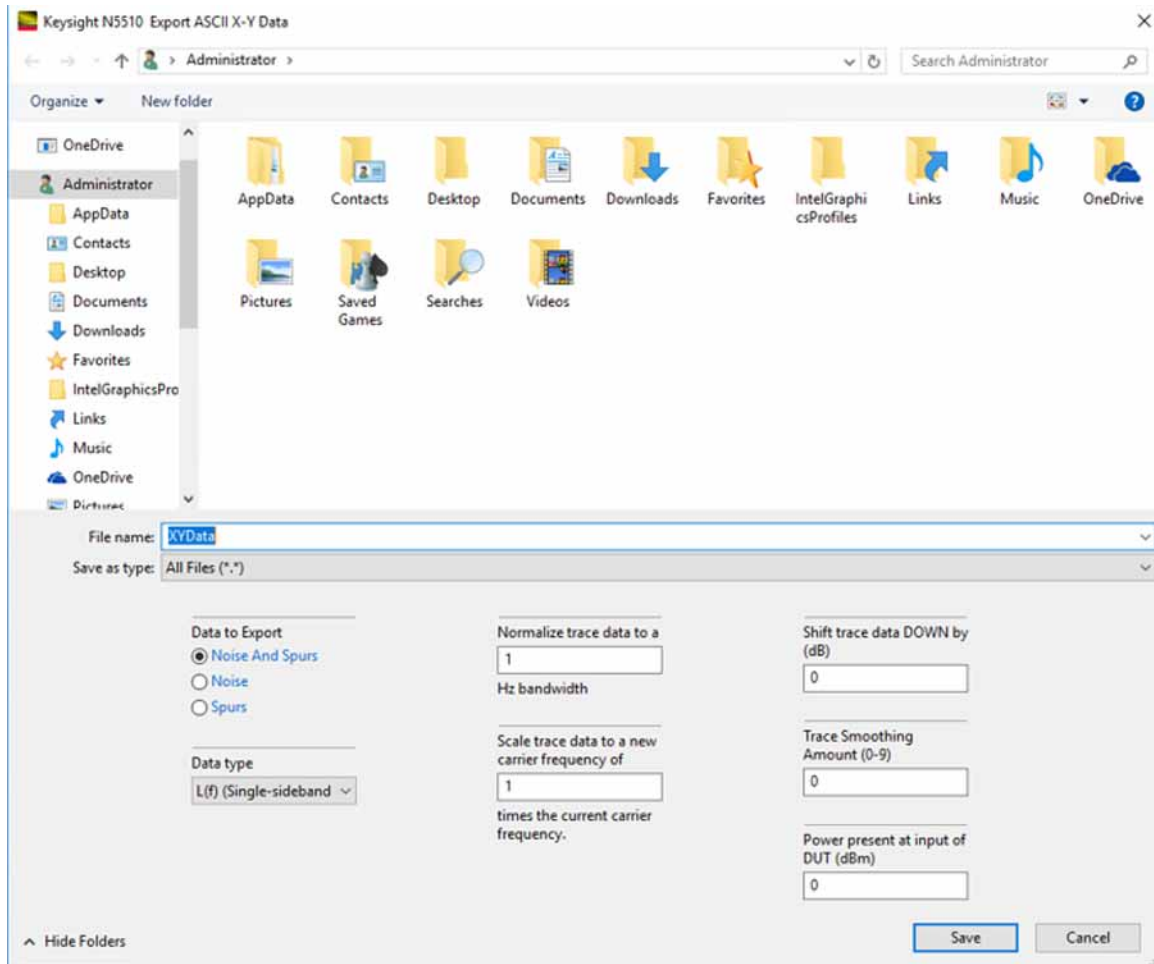
Figure 4-12 Spur data results



Exporting X-Y Data

1. On the File menu, point to Export Results, then click on X-Y Data. See [Figure 4-13](#).

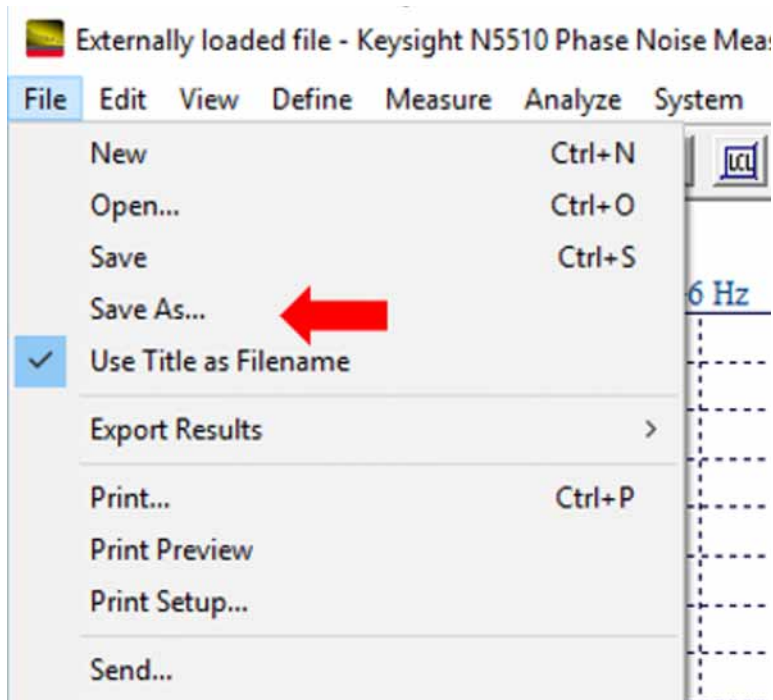
Figure 4-13 X-Y data results



Saving Measurement State

The current measurement state can be saved as a .pnx file. This will save all of the measurement parameters as well as the trace that is on the plot. Click **File**, **Save as...** Select **Use Title as Filename** to name the file using the title of the graph.

Figure 4-14 Saving Measurement State

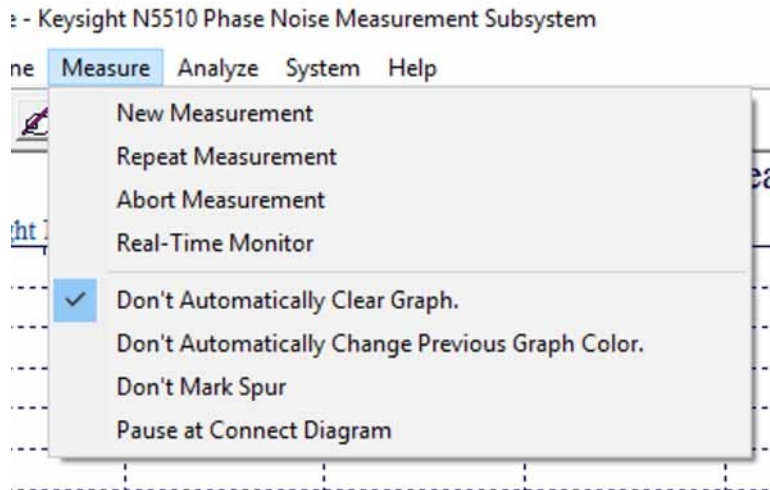


Recall Measurement State

A .pnx file can be opened to recall a previously saved state. Navigate to **File**, **Open** and browse to the state file to recall. Note, N5510 Phase Noise Measurement Software can recall legacy files in a .pnm format as well. Multiple .pnx files can be recalled, resulting in overlaying traces with the active measurement parameters being those of the last recalled file.

Measurement Preferences

Figure 4-15 Measurement Preferences



Pause At Connection Diagram: check to skip Connection Diagram when a New Measurement is initiated.

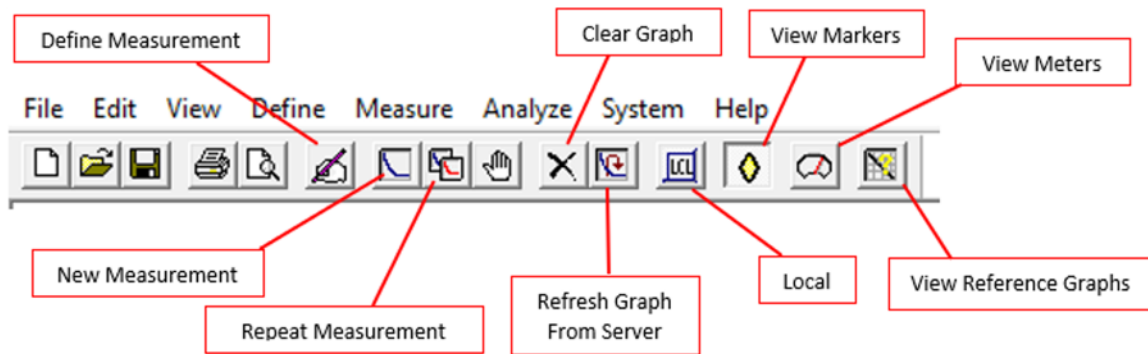
Don't Automatically Clear Graph: when restarting a measurement, the default behavior is for the current trace to be cleared. To retain the trace, uncheck this option.

Don't Automatically change Previous Graph Color: when retaining a trace, the application defaults the previous trace to a different color to not conflict with the new trace. To keep the previous trace color, uncheck this option.

Don't Mark Spur: spurs will not be marked as spurs.

Toolbar

Figure 4-16 Toolbar selections



5 Absolute Measurement Fundamentals

[“The Phase-Lock-Loop Technique” on page 56](#)

[“The Phase-Lock Loop Circuit” on page 60](#)

[“What Sets the Measurement Noise Floor?” on page 63](#)

[“Selecting a Reference \(Single Channel\)” on page 65](#)

[“Estimating the Tuning Constant” on page 71](#)

[“Tracking Frequency Drift” on page 72](#)

[“Changing the PTR” on page 74](#)

[“Minimizing Injection Locking” on page 76](#)

[“Inserting a Device” on page 79](#)

[“Evaluating Noise Above the Small Angle Line” on page 82](#)

[“Calibration” on page 86](#)

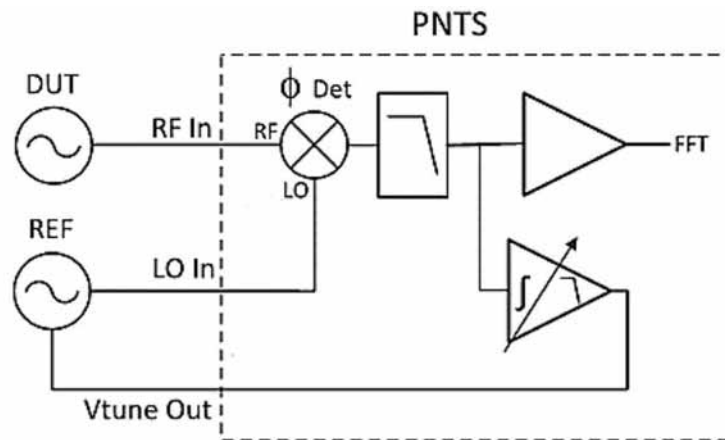
The Phase-Lock-Loop Technique

Single Channel

The phase lock loop measurement technique for a single channel setup requires two signal sources; the device-under-test and a reference source. This measurement type requires that one of the two sources is a voltage-controlled-oscillator (VCO).

In a PLL configuration, the reference source is locked in quadrature with the DUT, which means that the signal from the references is 90 degrees out of phase with the DUT. The signals from the DUT and the reference serve as the RF and LO inputs to the phase detector. The carrier is canceled by the phase detector, leaving only noise components in the resultant measurement.

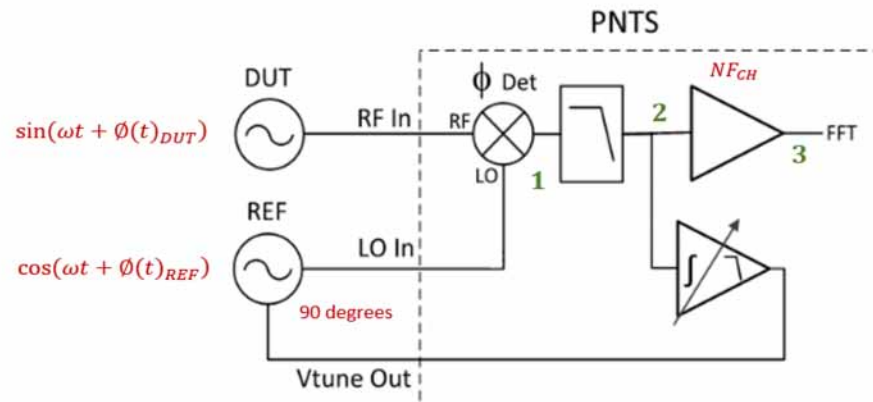
Figure 5-1 Single Channel Phase Lock Loop



A closer look:

Figure 5-2 shows a high-level walk-through of the theory behind the single channel PLL measurement technique.

Figure 5-2 Single Channel PLL Theory



Let the input signal from the DUT be denoted by $\sin(\omega t + \phi(t)_{DUT})$

Let the signal from the reference be denoted by $\cos(\omega t + \phi(t)_{REF})$ -recall the reference is locked in quadrature.

Let the noise floor of the system be denoted by NF_{CH}

Consider the sum and difference trigonometric formula:

$$\sin(A) \cos(B) = \frac{1}{2} \sin(A - B) - \frac{1}{2} \sin(A + B)$$

1. The output of the phase detector therefore is:

$$\sin(\omega t + \phi(t)_{DUT}) \cos(\omega t + \phi(t)_{REF}) = \frac{1}{2} \sin(\omega t + \phi(t)_{DUT} - \omega t - \phi(t)_{REF}) - \frac{1}{2} \sin(\omega t + \phi(t)_{DUT} + \omega t + \phi(t)_{REF})$$

2. The output of the phase detector therefore is:

$$\begin{aligned} \sin(\omega t + \phi(t)_{DUT}) \cos(\omega t + \phi(t)_{REF}) &= \frac{1}{2} \sin(\omega t + \phi(t)_{DUT} - \omega t - \phi(t)_{REF}) - \frac{1}{2} \sin(\omega t + \phi(t)_{DUT} + \omega t + \phi(t)_{REF}) \\ &= \frac{1}{2} \sin(\phi(t)_{DUT} - \phi(t)_{REF}) \end{aligned}$$

Consider the small angle theorem $\sin(A)=A$. The filtered output will be represented as:

$$\phi(t)_{DUT} - \phi(t)_{REF}$$

3. Noise contributed from the channel internally is added to the overall output. The FFT output can be represented as a sum:

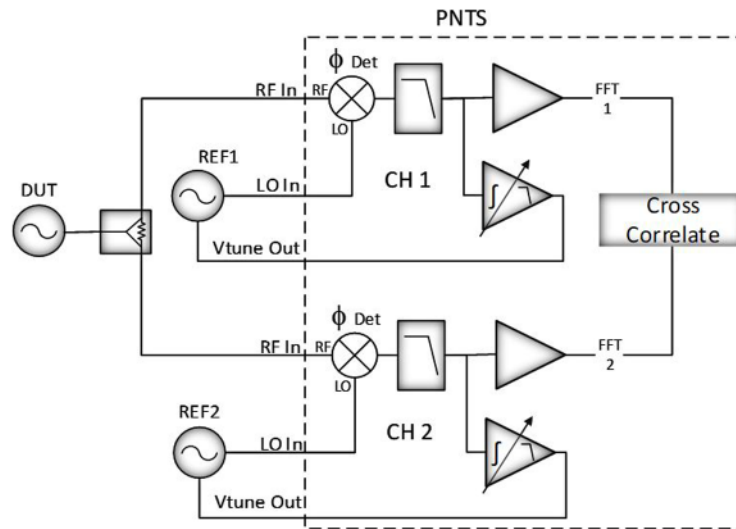
$$FFT = \phi(t)_{DUT} + \phi(t)_{REF} + NF_{CH}$$

When using the PLL technique in a single channel configuration, the overall output will include the phase noise of reference and the noise floor of the system. If the phase noise of the DUT is better than the phase noise of the reference, the phase noise of the reference will limit the dynamic range. If the DUT is better than the noise floor of the system, the measurement will also not result in the true performance of the device under test. A method to significantly increase dynamic range is to perform a dual-channel measurement instead of single channel.

Dual Channel

N5511A has the option for a second phase detector module, which allows for dual-channel cross correlation. In a dual channel setup, the DUT signal is split to provide the input signal to each of the phase detector modules. Two separate reference sources are required to provide a reference to each of the phase detectors. The result of this setup is having two separate single channel measurements with a common DUT signal, allowing for uncorrelated noise of the two references as well as the noise contributions from the detectors to be removed by cross-correlation.

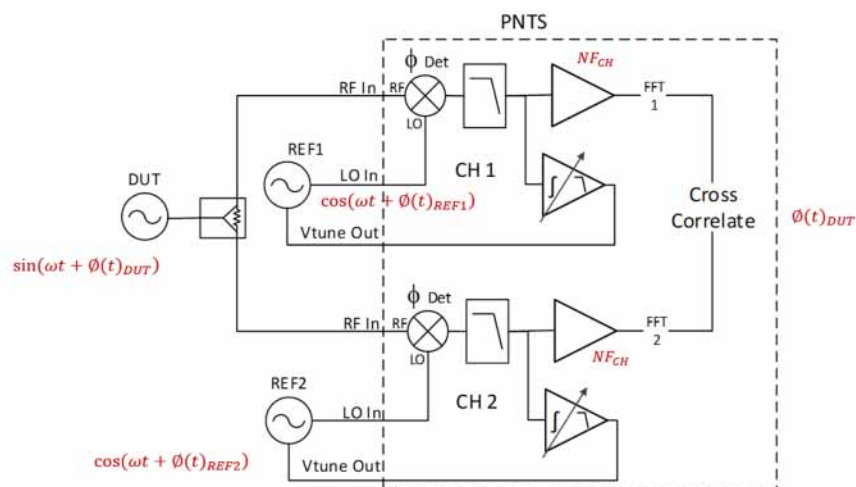
Figure 5-3 Dual Channel Phase Lock Loop



A closer look:

Figure 5-4 shows a high-level walk-through of the theory behind the dual channel PLL measurement technique.

Figure 5-4 Dual Channel PLL Theory



Following the logic used in a single channel measurement, the output of each of the channels in a dual-channel, measurement can be represented as follows:

$$FFT_1 = \phi(t)_{dut} + \phi(t)_{REF1} + NF_{ch1}$$

$$FFT_2 = \phi(t)_{dut} + \phi(t)_{REF2} + NF_{ch2}$$

The two outputs are cross-correlated, resulting in the phase noise of the DUT. A dual-channel measurement removes the uncorrelated noise of the references and the phase detectors, therefore eliminating the limiting factors in a single channel measurement that could limit the dynamic range of the measurement.

$$XCORR(FFT_1, FFT_2) = \phi(t)_{DUT}$$

The Phase-Lock Loop Circuit

The Capture and Drift tracking ranges

Like other PLL circuits, the phase lock loop created for the measurement has a Capture Range and a drift tracking range. The Capture Range is equal to 5% of the system's peak tuning range, and the drift tracking range is equal to 24% of the system's peak tuning range.

The system's peak tuning range is derived from the tuning characteristics of the VCO source used for the measurement. **Figure 5-5** illustrates the relationship that typically exists between the VCO's peak-to-peak tuning range and the tuning range of the system. The system's drift tracking range is limited to a small portion of the peak tuning range to minimize the possibility of measurement accuracy degradation caused by non-linearity across the VCO's tuning range.

Peak tune range (PTR)

The peak tuning range is determined using two parameters:

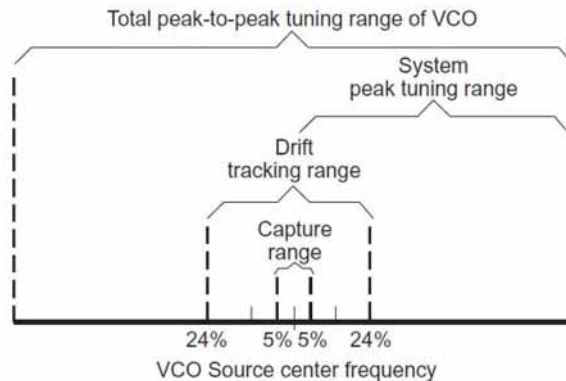
- VCO tuning sensitivity (Hz/Volt)
- Total voltage tuning range (Volts)

$$\text{PTR} = (\text{VCO Tuning Sensitivity}) \times (\text{Total Voltage Tuning Range})$$

$$\text{PTR} = (100 \text{ Hz/V}) \times (10 \text{ V}) = 1000 \text{ Hz}$$

Figure 5-5

Capture and Drift-Tracking Range with Tuning Range of VCO



As an example:

A Peak Tuning Range of 1000 Hz provides the following ranges:

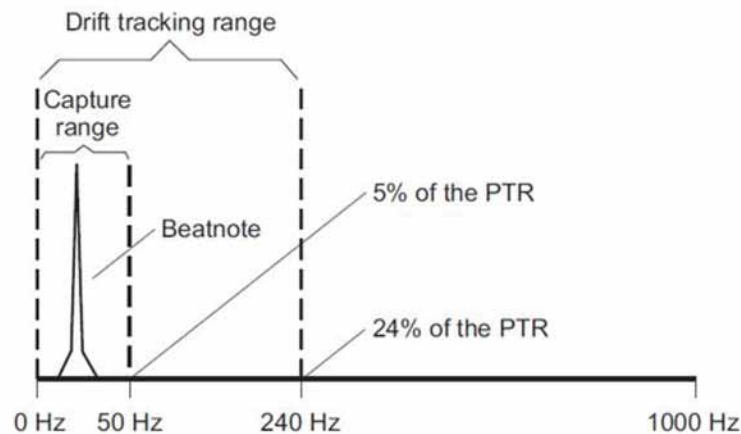
$$\text{Capture Range} = 0.05 \times 1000 \text{ Hz} = 50 \text{ Hz}$$

$$\text{Drift Tracking Range} = 0.24 \times 1000 \text{ Hz} = 240 \text{ Hz}$$

Tuning Requirements

The peak tuning range required for a measurement depends on the frequency stability of the sources used. The signals from the sources are mixed in each of the channel's phase detectors to create a beat note. In order for the loop to acquire lock, the center frequencies of the sources must be close enough together to create a beat note that is within the system's Capture Range. Once the loop is locked, the frequency of the beat note must remain within the drift tracking range for the duration of the measurement. In **Figure 5-6**, the ranges calculated in the previous example are marked to show their relationship to the beat note frequency.

Figure 5-6 Capture and Drift-Tracking Ranges and Beat Note Frequency



If the beat note does not remain within the drift tracking range during the measurement, the out of lock detector is set and the System stops the measurement. If this happens, you need to increase the system's drift tracking range by increasing the system's peak tuning range (if possible) or by selecting a VCO source with a greater tuning range.

Selecting the VCO Source

Although you must select a VCO source that provides a sufficient tuning range to permit the system to track the beat note, keep in mind that a wide tuning range typically means a higher noise level on the VCO source signal. When the VCO source for your measurement is also the reference source, this trade-off can make reference source selection the most critical aspect of your measurement setup.

Specifying your VCO Source

When you set up your PLL measurement, you need to know four things about the tuning characteristics of the VCO source you are using. The System determines the VCO source's peak tuning range from these four parameters.

- Tuning Constant, estimated tuning sensitivity (Hz/V)
- Center Voltage of Tuning Range, (V)
- Tune Range of VCO, ($\pm V$)
- Input Resistance of Tuning Port, (ohms) if the tuning constant is not to be measured.

The measurement examples in the next chapter that recommend a specific VCO source provides you with the tuning parameters for the specified source.

What Sets the Measurement Noise Floor?

The noise floor for your measurement is set by two things:

- The noise floor of the phase detector and low-noise amplifier (LNA)
- The noise level of the reference source you are using

The System Noise Floor

The noise floor of the system is directly related to the amplitude of the input signal at the R input port of the system's phase detector. **Table 5-1** shows the amplitude ranges for the L and R ports.

Table 5-1 Amplitude ranges for L and R ports

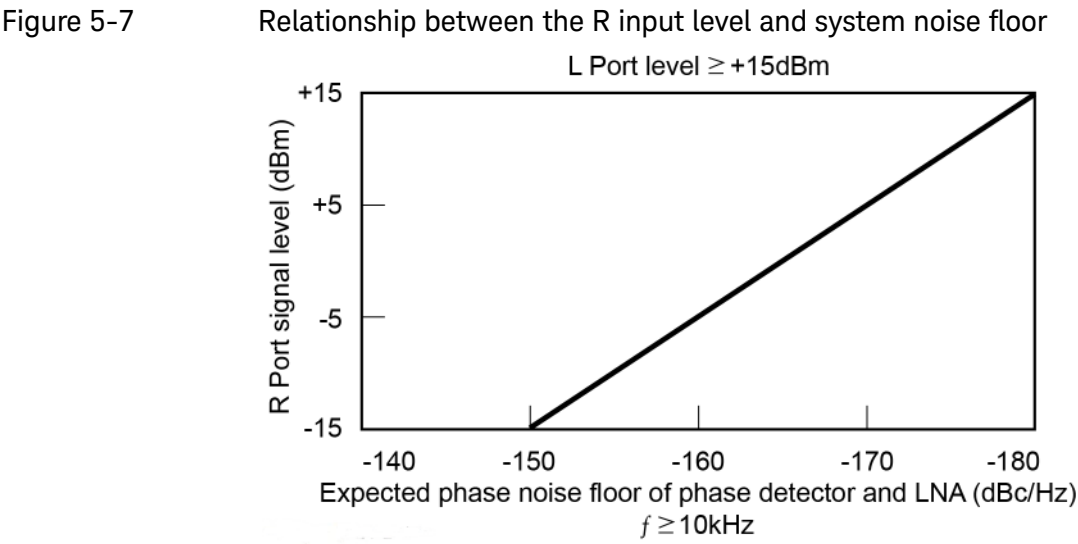
Phase Detector				
50 kHz to 1.6 GHz		1.2 to 26.5 GHz ^a		50 kHz to 26.5 GHz ^b
Ref Input (L Port)	Signal Input (R Port)	Ref Input (L Port)	Signal Input (R Port)	AM Noise
+ 15 dBm	0 dBm	+ 7 dBm	0 dBm	0 dBm
to	to	to	to	to
+ 23 dBm	+ 23 dBm	+ 10 dBm	+ 5 dBm	20 dBm

a. Phase noise test set Options 001 and 201 with no attenuation.

b. Phase noise test set Option 001 with no attenuation.

If the L port (Reference Input) signal is within the amplitude range shown in **Table 5-1**, the signal level at the R (Signal Input) port sets the noise floor for the system.

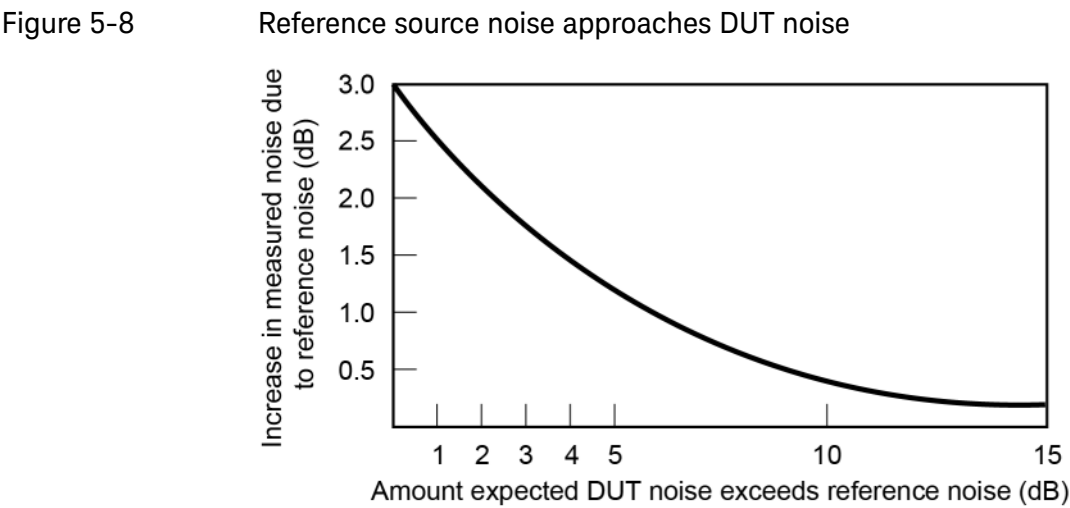
Figure 5-7 shows the relationship between the R (signal) input level and the system noise floor.



The Noise Level of the Reference Source

Unless it is below the system’s noise floor, the noise level of the source you are using as the reference source sets the noise floor for the measurement. When you set up your measurement, you want to use a reference source with a noise level that is at or below the level of the source you are going to measure.

Figure 5-8 demonstrates that as the noise level of the reference source approaches the noise level of the DUT, the level measured by the System (which is the sum of all noise sources affecting the system) is increased above the actual noise level of the DUT.

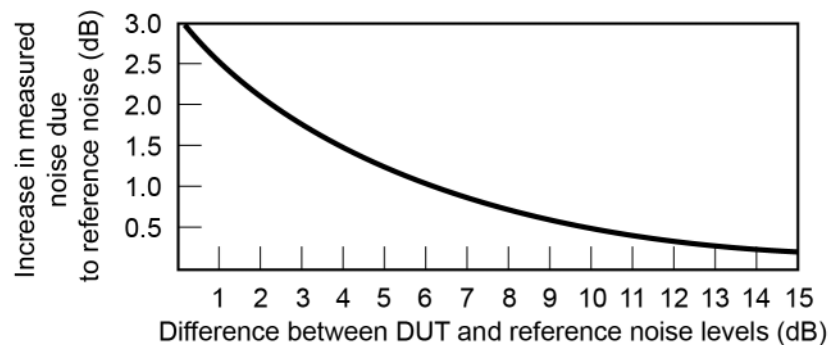


Selecting a Reference (Single Channel)

Selecting an appropriate reference source is critical when you are making a phase noise measurement using the phase lock loop technique. The key to selecting a reference source is to compare the noise level of the reference with the expected noise level of the DUT. In general, the lower the reference source's noise level is below the expected noise level of the DUT the better. (Keep in mind that you only need to be concerned about the reference source's noise level within the frequency offset range over which you plan to measure the DUT.)

As shown by the graph in **Figure 5-9**, the further the reference source's noise level is below the noise level of the DUT, the less the reference source's noise contributes to the measurement results.

Figure 5-9 DUT noise approaches reference noise



Using a Similar Device

The test system performs best when you are able to use a device similar to the DUT as the reference source for your PLL measurement. Of course one of the devices must be capable of being voltage tuned by the system to do this.

To select a similar device for use as the reference source, you must establish that the noise level of the reference source device is adequate to measure your DUT. The Three Source Comparison technique enables you to establish the actual noise levels of three comparable devices when two devices are available in addition to the DUT.

If only one device is available in addition to the DUT, you can perform the Phase Noise Using a Phase Locked Loop Measurement using these two devices and know that the noise level of each of the devices is at least as good as the measured results. (The measured results represent the sum of the noise of both devices.)

Using a Signal Generator

When using a signal generator as a reference source, it is important that the generator's noise characteristics are adequate for measuring your device.

Selecting a Reference (Dual Channel)

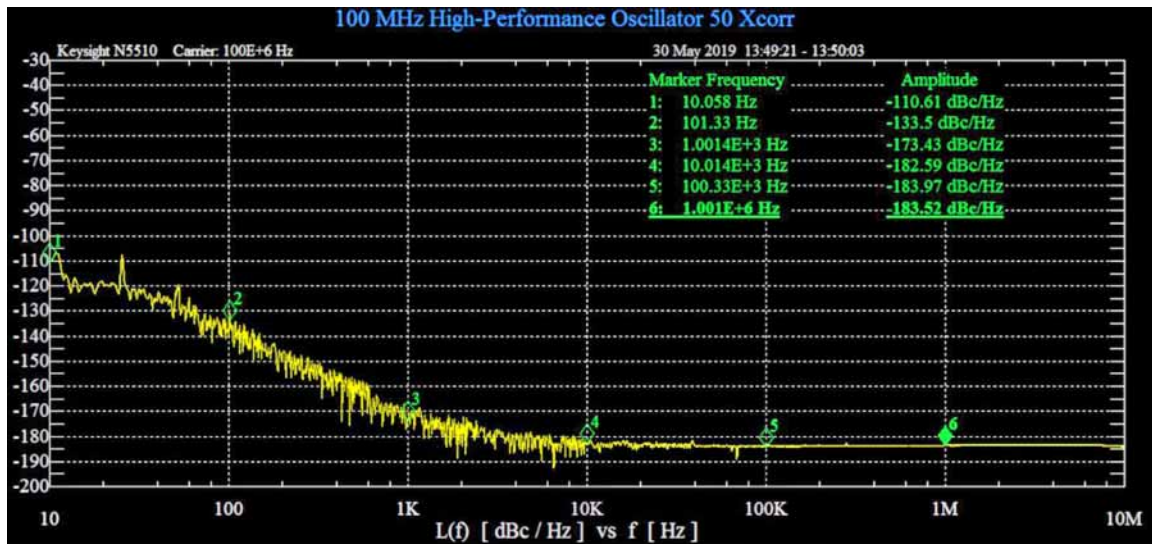
Selecting references for a dual channel measurement can be less critical than in a single channel setup. The one true requirement is that the references are capable of being voltage tuned. With cross-correlation, PNTS removes any noise that doesn't originate from the DUT and achieves an ultimate sensitivity established by thermal phase noise at -177 dBm/Hz. However, the greater the amount of uncorrelated noise present in the system, the more time it takes for the system to remove it. This translates to low-performance reference sources causing a longer measurement time if their phase noise is significantly worse than the device being tested.

If the references are identical or better in performance than the device under test, the N5511A measurement sensitivity starts at the DUT phase noise performance level. This means the cross-correlation process starts out at this sensitivity and this system sensitivity only improves as cross-correlations are processed. This can be quantified by saying that for a 10 times increase in the number of cross-correlations, there is a 5 dB reduction in uncorrelated noise (and 5 dB improvement in PNTS system sensitivity). Therefore, in order to minimize the time required to measure the DUT, references should be as good or even better than the DUT.

User devices today often exceed the best signal generator's (or internal references in some phase noise systems) phase noise performance. In scenarios like this, the flexibility of N5511A allows for copies of the DUT to be used as references in order to measure high performance devices without taking a toll on time from cross-correlating out noise from low-performing references. **Figure 5-10**, **Figure 5-11**, and **Figure 5-11** show examples of DUTs being measured using copies of the same high performance device as references.

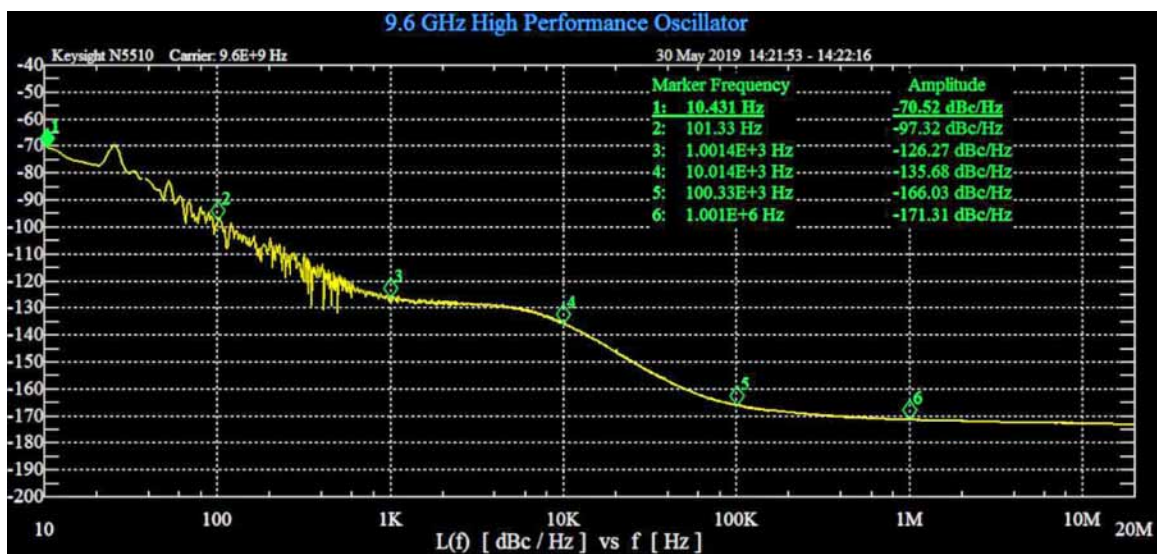
Example 1: Using a 100 MHz high-performance DUT as both REF1 and REF2 significantly reduces the number of cross-correlations - resulting in a dramatic reduction in measurement time (~40 second to get to a -184 dBc/Hz correlated device noise floor).

Figure 5-10 Using a 100 MHz High-Performance DUT



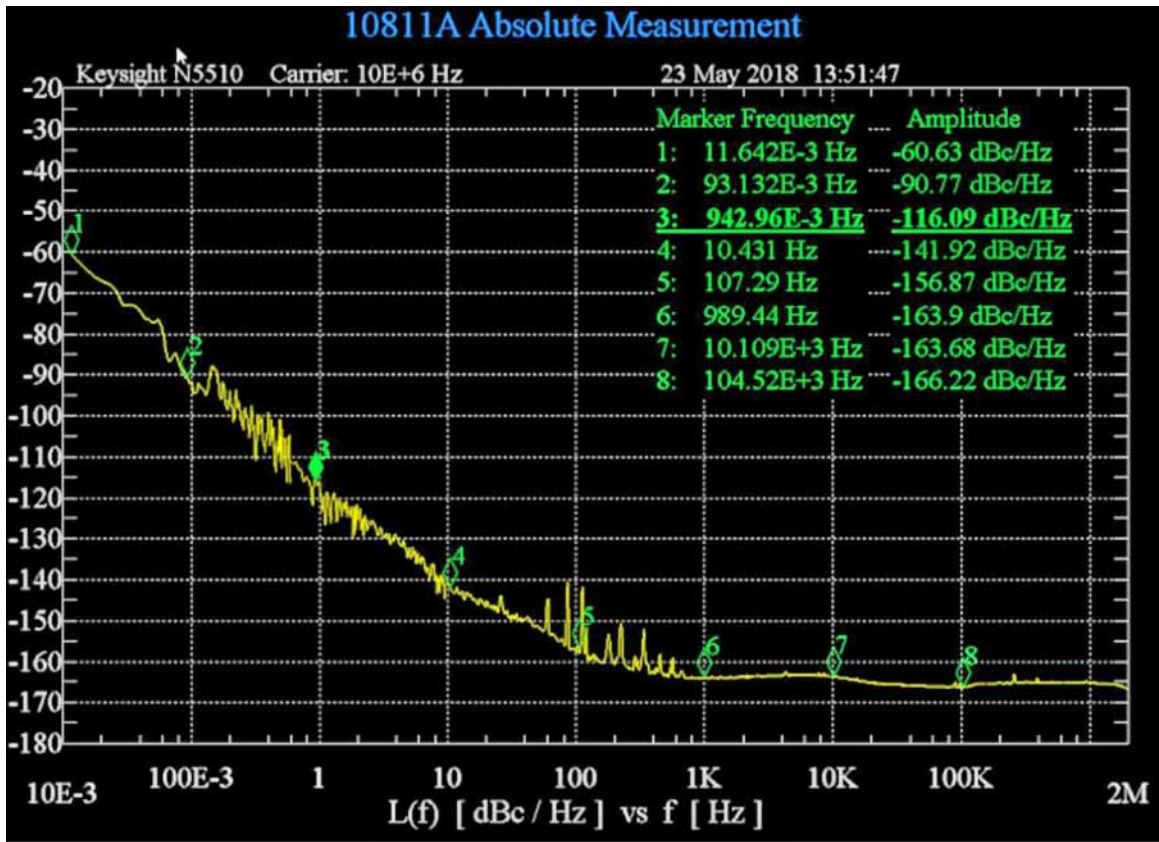
Example 2: Using a 9.6 GHz high-performance DUT as both REF1 and REF2 significantly reduces the number of cross-correlations - resulting in a dramatic reduction in measurement time (~25 second to get to a -171 dBc/Hz correlated device phase noise floor).

Figure 5-11 Using a 9.6 GHz High-Performance DUT



Example 3: Using a 10MHz high-performance DUT as both REF1 and REF2 significantly reduces the number of cross-correlations - resulting in a dramatic reduction in measurement time (~20 minutes to get to a -60 dBc/Hz correlated device phase noise floor at a .01 Hz offset).

Figure 5-12 Using a 10 MHz High-Performance DUT



Tuning Requirements

Often the reference source you select also serves as the VCO source for the PLL measurement. (The VCO source can be either the DUT or the reference source.) To configure a PLL measurement, you need to know the following tuning information about the VCO source you are using.

- Tuning Constant (Hz/V) (within a factor of 2)
- Tuning Voltage Range (V)
- Center Voltage of Tuning Range (V)
- Input Resistance of Tuning Port (W)

The primary consideration when evaluating a potential VCO source for your measurement is whether it provides the test system with sufficient capture and drift tracking ranges to maintain lock throughout the measurement. To make this determination, you must estimate what the drift range of the sources you are using will be over the measurement period (thirty minutes maximum). (Details on the relationship between the capture and drift tracking ranges and the tuning range of the VCO source are provided in [Table 5-2](#). This information helps you evaluate your VCO source based on the estimated drift of your sources.)

[Table 5-2](#) lists the tuning parameters for several VCO options.

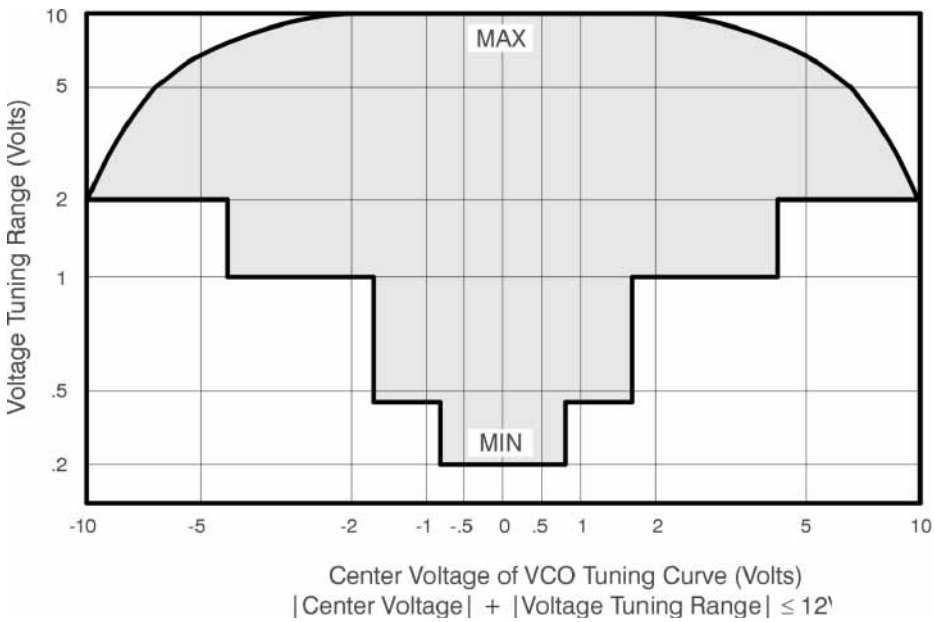
Table 5-2 Tuning Characteristics of Various VCO Source Options

VCO Source	Carrier Freq.	Tuning Constant (Hz/V)	Center Voltage (V)	Voltage Tuning Range (\pm V)	Input Resistance (W)	Tuning Calibration Method
Keysight E8257D						Measure
EFC	ν_0	$7 \text{ E} - 8 \times \nu_0$	0	5	$1 \text{ E} + 6$	Compute
DCFM	ν_0	FM Deviation	0	10	50 600	Compute
Keysight 8662/3A						
EFC	ν_0	$5 \text{ E} - 9 \times \nu_0$	0	10	$1 \text{ E} + 6$	Measure
DCFM		FM Deviation	0	10	1 K (8662) 600 (8663)	Compute Compute
Keysight 8642A/B		FM Deviation	0	10	600	Compute
Keysight 8644B		FM Deviation	0	10	600	Compute
Other Signal Generator						
DCFM Calibrated for $\pm 1\text{V}$		FM Deviation	0	10	Rin	Compute

Table 5-2 Tuning Characteristics of Various VCO Source Options

VCO Source	Carrier Freq.	Tuning Constant (Hz/V)	Center Voltage (V)	Voltage Tuning Range (± V)	Input Resistance (W)	Tuning Calibration Method
Other User VCO Source		Estimated within a factor of 2	-10 to +10	See Figure 5-13	1 E + 6	Measure

Figure 5-13 Voltage tuning range limits relative to center voltage of the VCO tuning curve



Estimating the Tuning Constant

The VCO tuning constant is the tuning sensitivity of the VCO source in Hz/V. The required accuracy of the entered tuning constant value depends on the VCO tuning constant calibration method specified for the measurement. The calibration method is selected in the Calibration Process menu. **Table 5-3** lists the calibration method choices and the tuning constant accuracy required for each.

Table 5-3 VCO tuning constant calibration method

VCO Tuning Constant Calibration Method (selected in calibration screen)	Required Tuning Constant Accuracy (entered in parameter screen)
Use the current tuning constant (must be accurate from a previous measurement of the same source).	Within a factor of 2 of actual value. (Enter 1 E + 6 for Input Resistance.)
Measure the VCO tuning constant	Within a factor of 2 of actual value. (Enter 1 E + 6 for Input Resistance.)

Tracking Frequency Drift

The system's frequency drift tracking capability for the phase lock loop measurement is directly related to the tuning range of the VCO source being used. The system's drift tracking range is approximately 24% of the peak tuning range (PTR) of the VCO.

$$\text{PTR} = \text{VCO Tuning Constant} \times \text{Voltage Tuning Range}$$

This is the frequency range within which the beat note signal created by the test set's phase detector must remain throughout the measurement period. In addition, the beat note signal must remain within the system's Capture Range (5% of the PTR) during the time it takes the system to calibrate and lock the phase lock loop.

The stability of the beat note is a function of the combined frequency stability of the sources being used for the measurement. If beat note drift prevents the beat note from remaining within the Capture Range long enough for the system to attain phase lock, the computer informs you by displaying a message. If the beat note drifts beyond the drift tracking range during the measurement, the computer stops the measurement and inform you that the system has lost lock.

Evaluating beat note drift

The Checking the beat note section included in each phase lock loop measurement example in this chapter provides a procedure for adjusting the beat note to within the Capture Range set for the measurement. If you have not done so already, verify that the beat note signal can be tuned to within the Capture Range and that it will remain within the range.

Continue to observe the beat note and verify that it will not drift beyond the drift tracking range (24% of the PTR) during the measurement period. The length of the measurement period is primarily a function of the frequency offset range specified for the measurement (Start to Stop Frequency).

Action

If beat note drift exceeds the limits of the Capture or drift tracking ranges set for your measurement, the system is not able to complete the measurement. You have two possible alternatives.

1. Minimize beat note drift.

- By Allowing sources to warm-up sufficiently.
- By Selecting a different reference source with less drift.

2. Increase the capture and drift tracking Ranges.

- By Selecting a measurement example in this chapter that specifies a drift rate compatible with the beat note drift rate you have observed.
- By Increasing the peak tuning range for the measurement. (Further information about increasing the PTR is provided in Changing the PTR.)

Changing the PTR

The peak tuning range (PTR) for the phase lock loop measurement is set by the tune range entered for the VCO and the VCO's tuning constant. (If the calibration technique is set to measure the VCO tuning constant, the measured value is used to determine the system's PTR.)

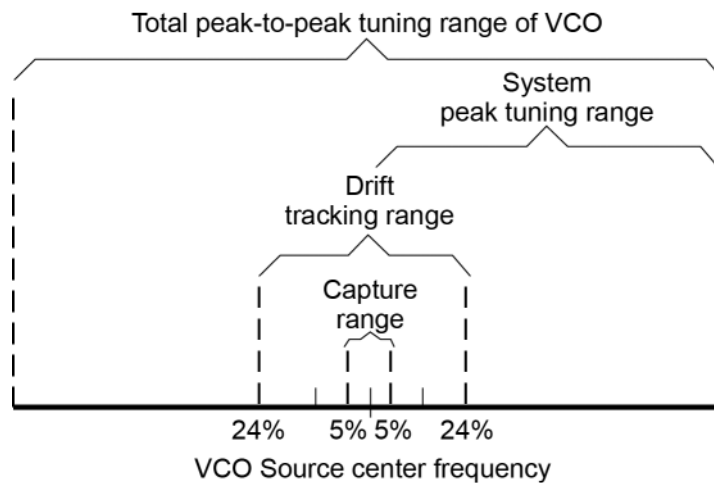
$$\text{PTR} = \text{VCO Tuning Constant} \times \text{Voltage Tuning Range}$$

From the PTR, the phase noise software derives the capture and drift tracking Ranges for the measurement. These ranges set the frequency stability requirements for the sources being used.

The PTR also determines the phase lock loop (PLL) bandwidth for the measurement. An important attribute of the PLL bandwidth is that it suppresses the close-in noise which would otherwise prevent the system from locking the loop.

Figure 5-14

Peak tuning range



The Tuning Qualifications

Changing the PTR is accomplished by changing the tune range of VCO value or the VCO tuning constant value or both. There are several ways this can be done. However, when considering these or any other options for changing the PTR, it is important to remember that the VCO source must always meet the following tuning qualifications.

- The tuning response of the VCO source must always remain monotonic.
- The VCO source's output level must remain constant across its tuning range.

As long as these qualifications are met, and the software does not indicate any difficulty in establishing its calibration criteria, an increase in PTR will not degrade the system's measurement accuracy.

The following methods may be considered for increasing or decreasing the PTR.

Voltage controlled oscillators

- 1. Select a different VCO source that has the tuning capabilities needed for the measurement.**
- 2. Increase the tune range of the VCO source.**

CAUTION

Be careful not to exceed the input voltage limitations of the Tune Port on the VCO source.

NOTE

Increasing the tune range of the VCO is only valid as long as the VCO source is able to continuously meet the previously mentioned tuning qualifications.

Minimizing Injection Locking

Injection locking occurs when a signal feeds back into an oscillator through its output path. This can cause the oscillator to become locked to the injected signal rather than to the reference signal for the phase locked loop.

Injection locking is possible whenever the buffering at the output of an oscillator is not sufficient to prevent a signal from entering. If the injection locking occurs at an offset frequency that is not well within the PLL bandwidth set for the measurement, it can cause the system to lose phase lock.

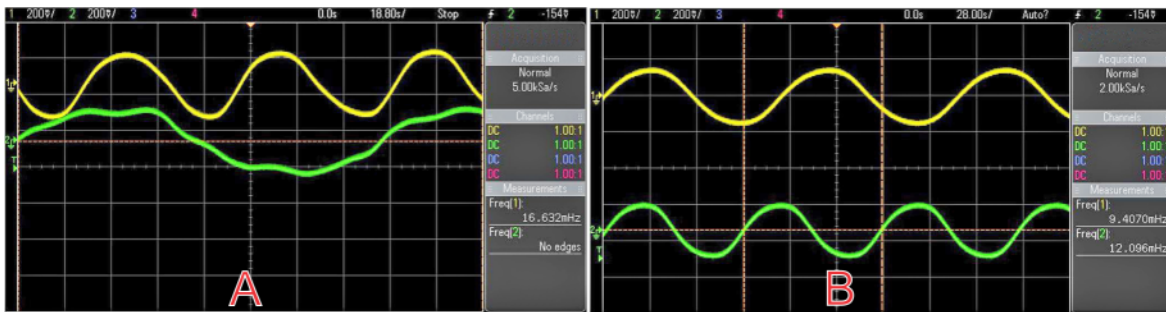
Adding Isolation

The best way to prevent injection locking is to isolate the output of the source being injection locked (typically the DUT) by increasing the buffering at its output. This can be accomplished by inserting a low noise amplifier and/or an attenuator between the output of the source being injection locked and the test set. (Refer to **“Inserting a Device”** in this section.

In N5511A, one can troubleshoot isolation issues through an oscilloscope connected to the Monitor outputs of the phase detector modules.

Figure 5-15 shows the beat notes from an absolute phase noise measurement of a 10 MHz OCXO. Notice the impurity of the signal present at the output of the phase detector. This reflects isolation issues. By adding isolation in each channel, in this case by using amplifiers, the issue is improved.

Figure 5-15 Beat Notes from an Absolute Phase Noise Measurement of a 10 MHz OCXO



- A) Monitor output with beat notes showing isolation issues
- B) Monitor output after isolation is added

Increasing the PLL Bandwidth

If the injection locking bandwidth is less or equal to the PLL bandwidth, it may be possible to increase the PLL bandwidth sufficiently to complete the measurement. The PLL bandwidth is increased by increasing the peak tuning range (PTR) for the measurement.

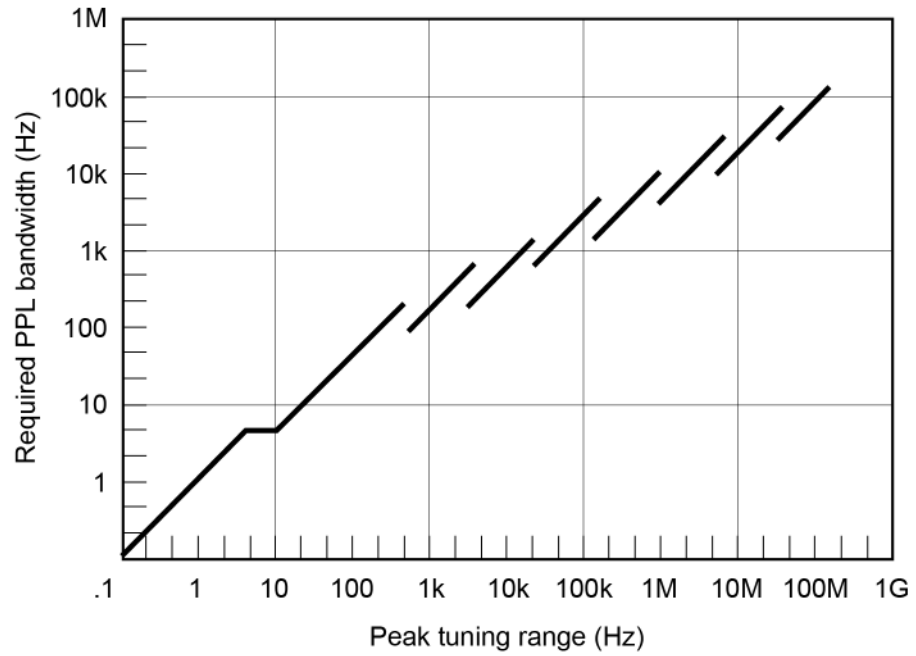
NOTE

The PTR for the measurement is set by the tuning characteristics of the VCO source you are using. **Figure 5-16** shows that increasing the PLL bandwidth can require a substantially larger increase in the PTR. For information on the limitations of increasing the PTR, refer to **“Changing the PTR”** in this section.

To estimate the PTR needed to prevent injection locking from causing the system to lose lock:

1. Determine the injection locking bandwidth. Tune the beat note toward 0 Hz using the procedure described in the Checking the beat note section of each phase lock loop measurement example in this chapter. When the injection locking occurs, the beat note disappears. The injection locking bandwidth is the frequency of the beat note just prior to where the injection locking occurs as the beat note is tuned toward 0 Hz.
2. Multiply the injection locking bandwidth by 2 to determine the minimum PLL bandwidth required to prevent the injection locking from causing the system to lose lock. (To prevent accuracy degradation, it may be necessary to increase the PLL bandwidth to 4 X the injection locking bandwidth. The computer informs you during the measurement if the possibility of accuracy degradation exists.)
3. Locate the required PLL bandwidth in **Figure 5-16** to determine the PTR required for the measurement. (For details on increasing the PTR, refer to **“Changing the PTR”** in this section.

Figure 5-16 Peak tuning range (PTR) Required by injection locking.



Inserting a Device

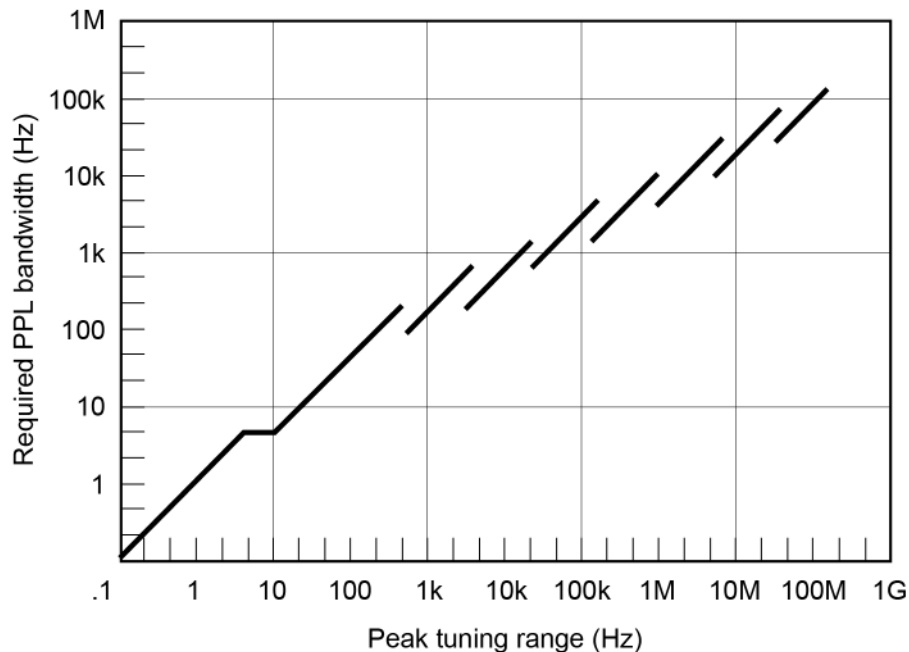
An attenuator

You may find that some of your measurement setups require an in-line device such as an attenuator in one of the signal source paths. (For example, you may find it necessary to insert an attenuator at the output of a DUT to prevent it from being injection-locked to the reference source.) The primary consideration when inserting an attenuator is that the signal source has sufficient output amplitude to maintain the required signal level at the test set's phase detector input port. The signal level required for the measurement depends on the noise floor level needed to measure the DUT.

Figure 5-17 shows the relationship between the signal level at the R port and the measurement noise floor.

Figure 5-17

Measurement noise floor relative to R-Port signal level



This is an important consideration in a single channel configuration. For a dual channel configuration, equal attenuation can be placed in both channels. This flexibility allows for cross-correlation to remove the effects of the attenuators and recover the SNR prior to the signal of the DUT being split.

An amplifier

If a source is not able to provide a sufficient output level, or if additional isolation is needed at the output, it may be necessary to insert a low phase-noise RF amplifier at the output of the source.

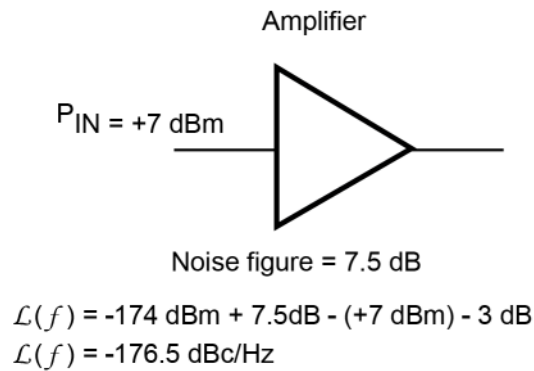
Note, however, that the noise of the inserted amplifier is also summed into the measured noise level along with the noise of the source in a single channel measurement.

Use the following equation to estimate what the measurement noise floor is as a result of the added noise of an inserted amplifier: **Figure 5-18** shows an example.

$$L(f) \text{ out} = -174 \text{ dB} + \text{Amplifier Noise Figure} - \text{Power into Amplifier} - 3 \text{ dB}$$

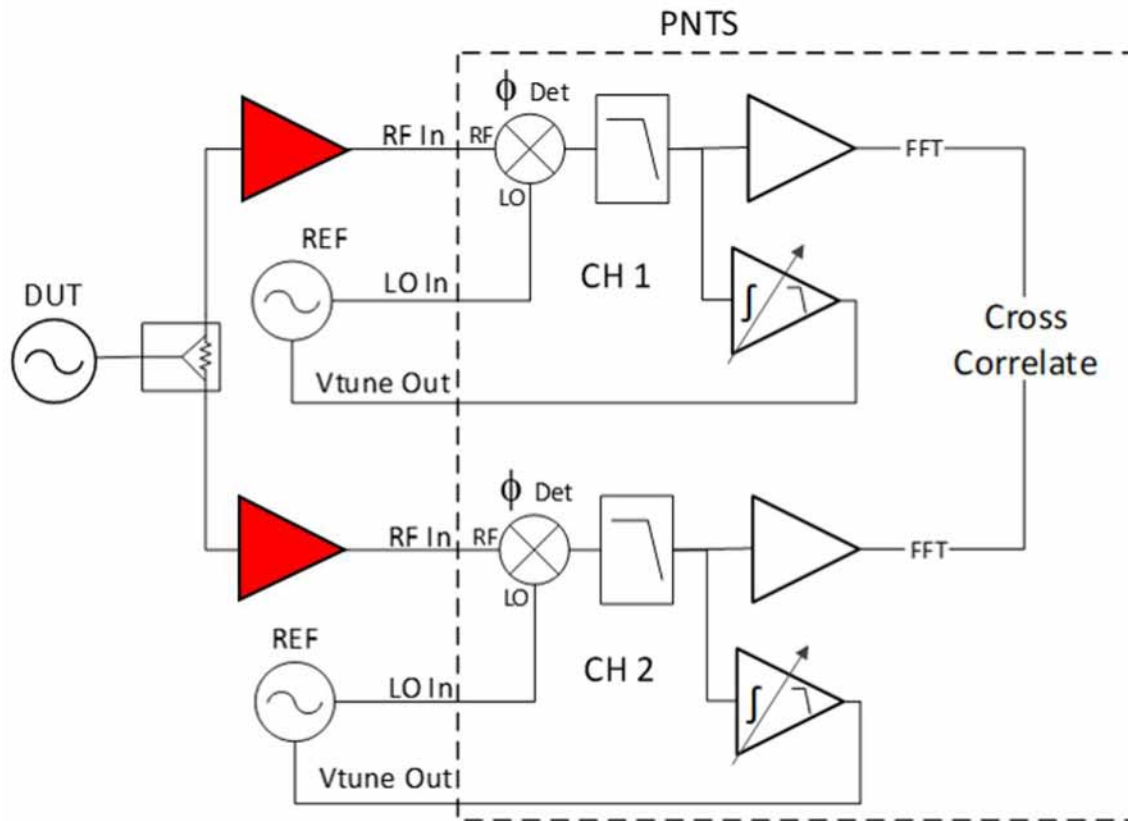
Figure 5-18

Measurement noise floor as a result of an added attenuator



The N5511A's dual channel cross-correlation capability offers a unique advantage when performing measurements requiring amplifiers. In a dual channel configuration, amplifiers of identical gain can be placed in each of the separate channel paths. See [Figure 5-19](#).

Figure 5-19 Dual Channel Configuration



When a measurement is configured in such manner, the noise contribution from the amplifiers is removed by cross-correlation due to their noise being uncorrelated. This enables the resulting noise floor measured to be the true performance of the DUT. This technique also means that the performance of the amplifiers need not be a critical factor; however, one must be considerate of the impact that higher noise amplifiers will have on the number of cross-correlations required to reach the correlated noise floor of the DUT.

Evaluating Noise Above the Small Angle Line

If the average noise level on the input signals exceeds approximately 0.1 radians RMS integrated outside of the Phase Lock Loop (PLL) bandwidth, it can prevent the system from attaining phase lock.

The following procedure allows you to evaluate the beat note created between the two sources being measured. The intent is to verify that the PLL bandwidth is adequate to prevent the noise on the two sources from causing the system to lose lock.

If the computer is displaying the hardware Connect Diagram you are ready to begin this procedure. (If it is not, begin a New Measurement and proceed until the hardware Connect Diagram appears on the display.)

Determining the Phase-Lock-Loop bandwidth

1. Determine the Peak Tuning Range (PTR) of your VCO by multiplying the VCO Tuning Constant by the Tune Range of VCO value entered. (If the phase noise software has measured the VCO Tuning Constant, use the measured value.)

$$\text{PTR} = \text{VCO Tuning Constant} \times \text{Voltage Tuning}$$

For Example:

$$\text{PTR} = 100 \frac{\text{Hz}}{\text{V}} \times 10\text{V} = 1 \text{ kHz}$$

2. Estimate the Phase Lock Loop (PLL) bandwidth for the measurement using the PTR of your VCO and the graph in [Figure 5-20](#).

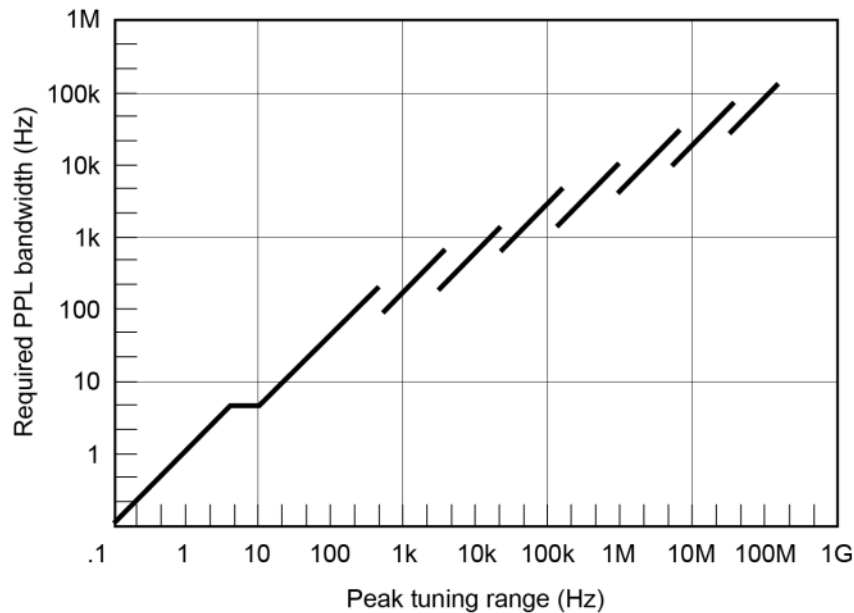
Observing the beat note

If the beat note frequency is below 100 kHz it appears on the analyzer's display in both the frequency domain and the time domain. If the beat note does not appear on the RF analyzer, then the beat note is either greater than 100 kHz or it does not exist.

If incrementing the frequency of one of the sources does not produce a beat note within 100 kHz, you need to verify the presence of an output signal from each source before proceeding.

Figure 5-20

Phase lock loop bandwidth provided by the peak tuning range



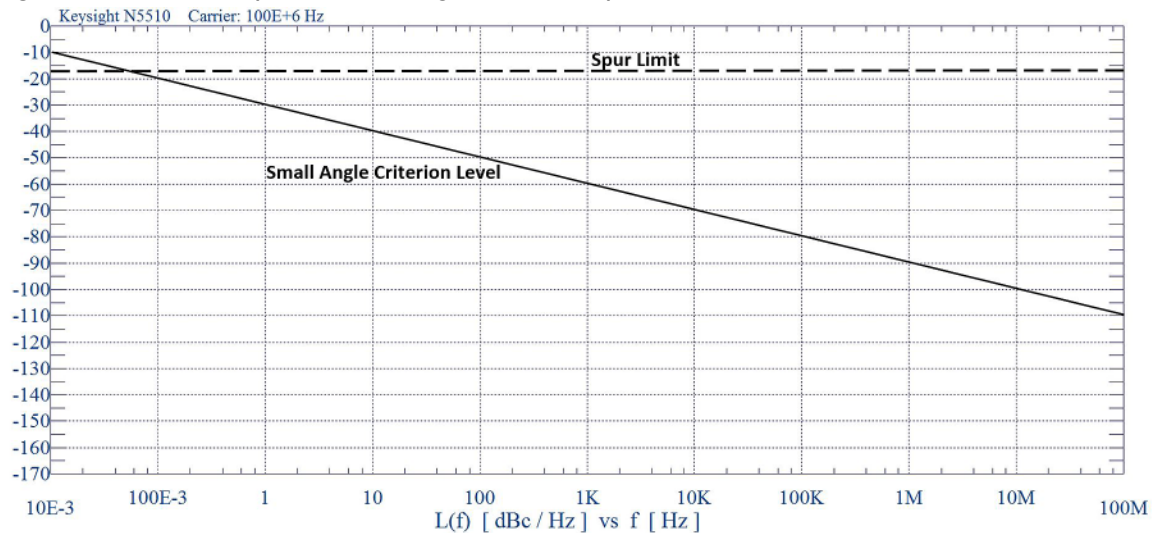
1. Once the beat note is displayed, Auto Tune the analyzer.
2. Set the span width on the signal analyzer to approximately 4 x PLL bandwidth. Adjust the beat note to position it near the center of the display.

NOTE

If you are not able to tune the beat note to 2 X PLL bandwidth (center of display) due to frequency drift, refer to Tracking Frequency Drift in this section for information about measuring drifting signals. If you are able to locate the beat note, but it distorts and then disappears as you adjust it towards 0 Hz, then your sources are injection locking to each other. Set the beat note to the lowest frequency possible before injection locking occurs and then refer to **“Minimizing Injection Locking”** on [page 76](#) for recommended actions.

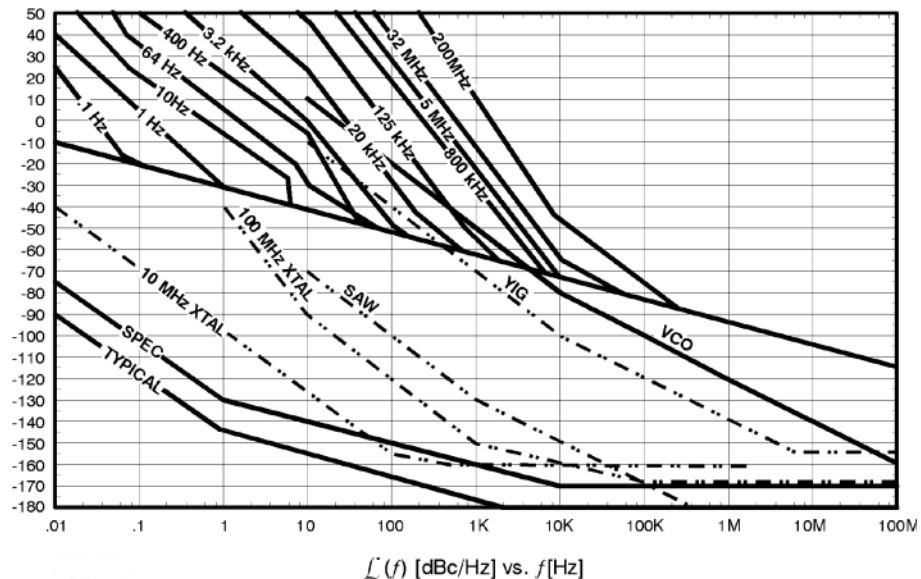
- a. Turn on trace averaging.
 - b. Perform Peak Search.
3. Set a Delta Marker.
On the analyzer, offset the marker by the PLL bandwidth. Read the offset frequency and noise level indicated at the bottom of the display.
4. Compare the average noise level at the PLL bandwidth offset to the small angle criterion level shown on the graph in [Figure 5-21](#). The average noise level of the signal must remain below the small angle line at all offset frequencies beyond the PLL bandwidth. (The small angle line applies only to the level of the average noise. Spur levels that exceed the small angle line do not degrade measurement accuracy provided they do not exceed -40 dBc.)

Figure 5-21 Graph of small angle line and spur limit



5. Continue moving the marker to the right to verify that the average noise level remains below the small angle line.
6. Increase the span by a factor of ten by selecting FREQ and SPAN. Continue comparing the noise level to the graph.
7. Continue to increase the span width and compare the noise level out to 100 kHz. (If the noise level exceeds the small angle line at any offset frequency beyond the PLL bandwidth, note the offset frequency and level of the noise. Use the graph in [Figure 5-22](#) to determine the Peak Tuning Range (PTR) necessary to provide a sufficient PLL bandwidth to make the measurement.

Figure 5-22 Requirements for noise exceeding small angle limit



Measurement options

If the observed level exceeded the small angle line at any point beyond the PLL bandwidth set for the measurement, you need to consider one of the following measurement options.

1. Evaluate your source using the noise data provided by the RF analyzer in the procedure you just performed.
2. Increase the PTR if possible, to provide a sufficient PLL bandwidth to suppress the noise. (For information on increasing the PTR, refer to Changing the PTR in this section.)
3. Reduce the noise level of the signal sources.
4. Use the Discriminator technique to measure the phase noise level of your source.

Calibration

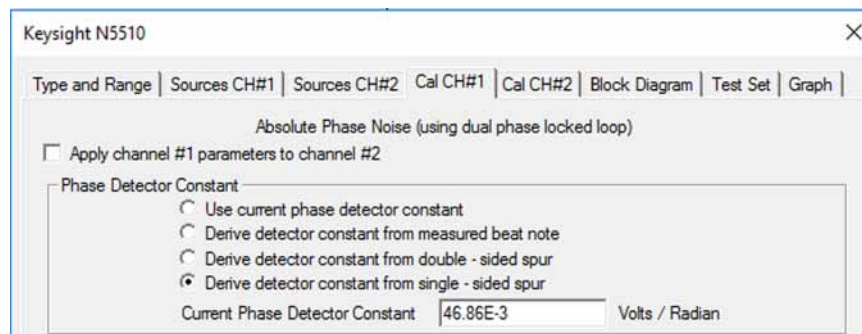
Overview

User calibrations are used to establish a reference constant for relative measurements made on the system. For absolute measurements, the amplitude of the carrier needs to be determined before the measurement since the carrier is removed from the measurement when quadrature is established. In absolute measurements various parameter of the reference need to be measured. The type of calibration to be used is determined by the system configuration and equipment availability. User calibrations need to be run every time there is a change to the system or DUT parameters.

For absolute measurements, the N5511A supports four different options for calibration, see **Figure 5-23**:

- Use current phase detector constant
- Derive detector constant from measured beat note
- Derive detector constant from single-sided spur
- Derive detector constant from double-sided spur

Figure 5-23 Phase Detector Calibration Options



Measured Beat Note

The measured beat note calibration method is the most common user calibration and is the least complex. This method does not require an additional source to set a calibration tone and is therefore the best option when hardware is limited. The beat note frequency for each channel is set by the relative frequency difference between the DUT and the reference in the respective channel. If the DUT and reference are very accurate sources set at the same frequency, the resulting beat note will be very close to 0 Hz. The advantage is this is a simple method of calibration. The disadvantage is it

Advantages

- Simple method of calibration

Disadvantages

- Requires two RF sources, separated by 0.1 Hz to 50 MHz at the phase detector. The calibration source output power must be manually adjusted to the same level as the power splitter output it replaces (requires a power meter).

Searching for the beat note will require that you adjust the center frequency of one of the sources above and below the frequency of the other source until the beat note appears on the oscilloscope's display. If incrementing the frequency of one of the sources does not produce a beat note, you will need to verify the presence of an output signal from each source before proceeding.

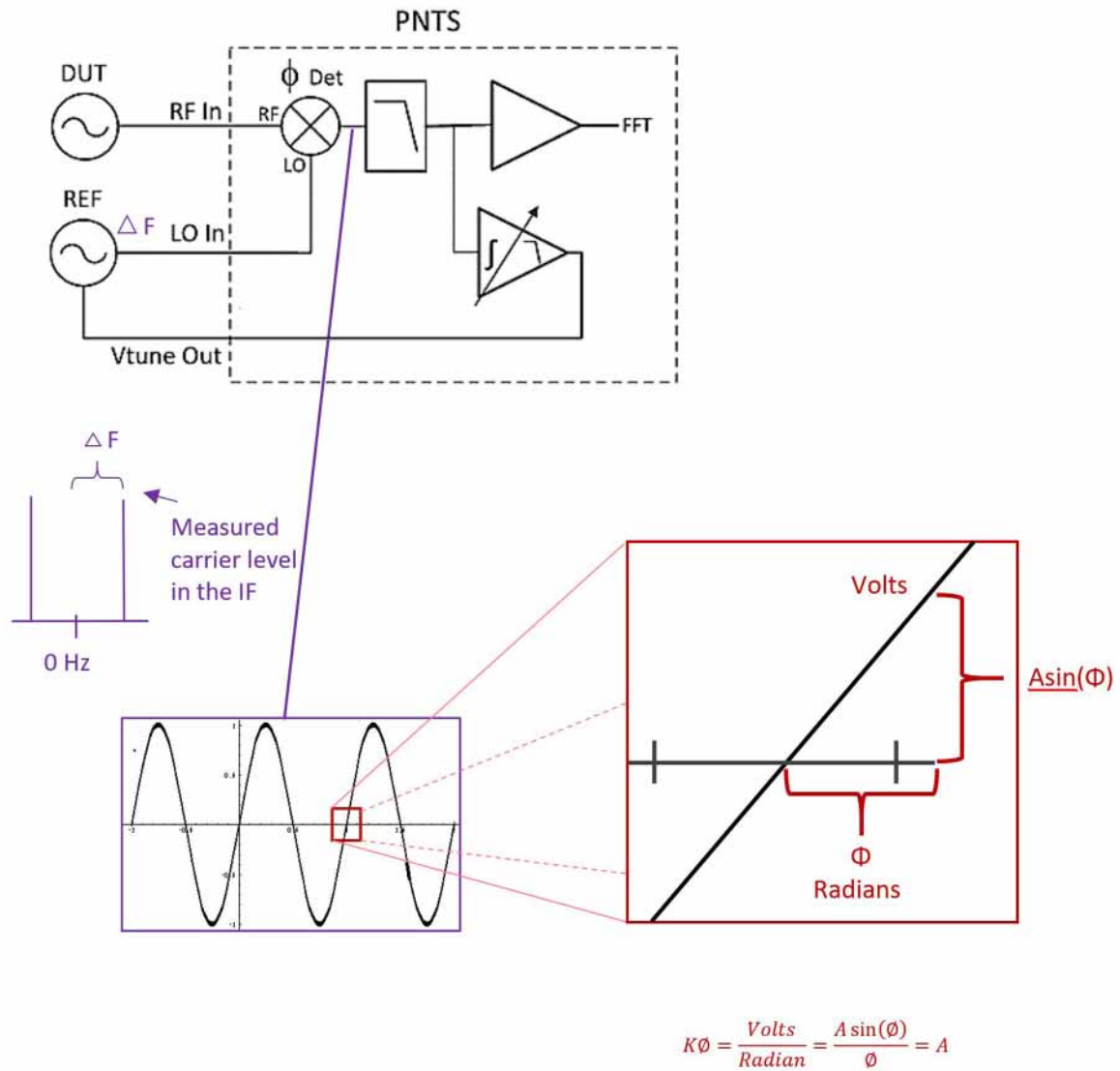
Theory

Recall the diagram for a single channel setup, [Figure 5-24](#). A "beat note" is established by shifting the frequency of the reference by 10% of the peak tune range. This delta frequency will show up as a spur in the IF at the amplitude of the carrier minus any losses.

The slope is measured in the linear region of the sinusoid and using the "small angle" theorem V_{peak} is determined. This value is then used to calculate the dBc values when the phase noise is measured.

Beat note user calibration works identically in the dual channel setup, with the only difference being that the calibration is performed separately by the instrument for each of the phase detector modules.

Figure 5-24 Beat Note Single Channel



Checking the Beat Note

While the connect diagram is still displayed, use an oscilloscope (connected to the Monitor port on the test set) or a counter to check the beat note being created between the reference source and your DUT. The objective of checking the beat note is to ensure that the center frequencies of the two sources are close enough in frequency to create a beat note that is within the capture range of the system. The phase lock loop (PLL) capture range is 5% of the peak tuning range of the VCO source you are using. (The peak tuning range for your VCO can be estimated by multiplying the VCO tuning constant by the tune range of VCO. Refer to [Chapter 14, “Evaluating Your Measurement Results”](#) if you are not familiar with the relationship between the PLL capture range and the peak tuning range of the VCO.

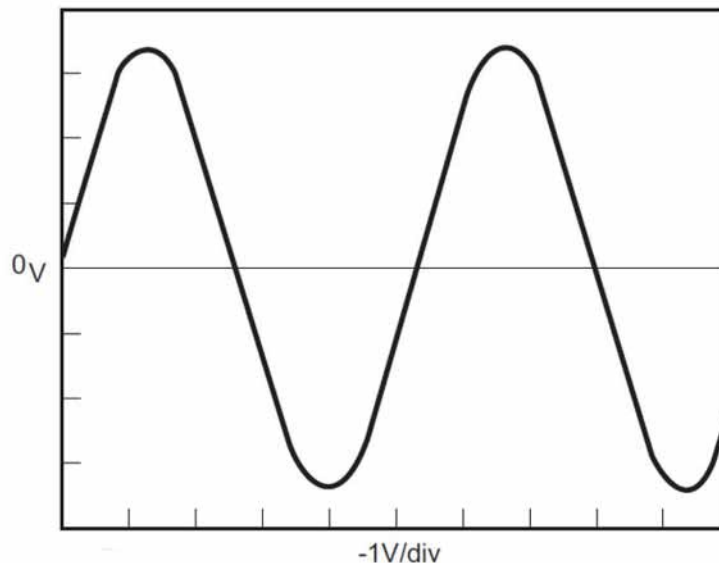
NOTE

If the center frequencies of the sources are not close enough to create a beat note within the capture range, the system will not be able to complete its measurement.

The beat note frequency is set by the relative frequency difference between the two sources. If you have two very accurate sources set at the same frequency, the resulting beat note will be very close to 0 Hz. Searching for the beat note will require that you adjust the center frequency of one of the sources above and below the frequency of the other source until the beat note appears on the oscilloscope's display. If incrementing the frequency of one of the sources does not produce a beat note, you will need to verify the presence of an output signal from each source before proceeding.

Figure 5-25

Oscilloscope Display of Beat Note from Test Set Monitor Port



Estimate the system's capture range (using the VCO source parameters entered for this measurement). The estimated VCO tuning constant must be accurate within a factor of 2. A procedure for **“Estimating the Tuning Constant”** is located in this chapter.

$$\text{Capture Range (Hz)} = \frac{\text{VCO Tuning Constant} \left(\frac{\text{Hz}}{\text{V}} \right) \times \text{Tuning Range (V)}}{10}$$
$$\text{Capture Range (Hz)} = \frac{\left(\frac{\text{Hz}}{\text{V}} \right) \times (V)}{10} = \text{_____ (Hz)}$$

NOTE

If you are able to locate the beat note, but it distorts and then disappears as you adjust it towards 0 Hz, your sources are injection locking to each other. Set the beat note to the lowest frequency possible before injection locking occurs and then refer to the **“Minimizing Injection Locking”** section of this chapter for recommended actions.

NOTE

If you are not able to tune the beat note to within the capture range due to frequency drift, refer to the **“Tracking Frequency Drift”** section of this chapter for information about measuring drifting signals.

Single-sided Spur

Another common calibration method is using a single-sided spur. Single-sided spur method and double-sided spur method are the two most accurate calibration methods. **Figure 5-26** shows the setup for a measurement using the single channel single-sided spur calibration. **Figure 5-27** shows the setup for a measurement using the dual channel single-sided spur calibration.

Figure 5-26 Single Channel SSB Cal

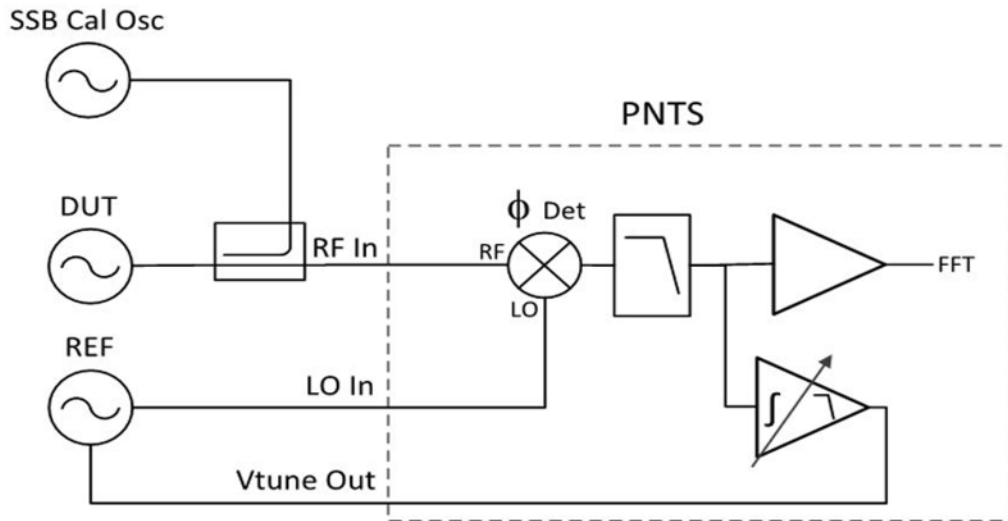
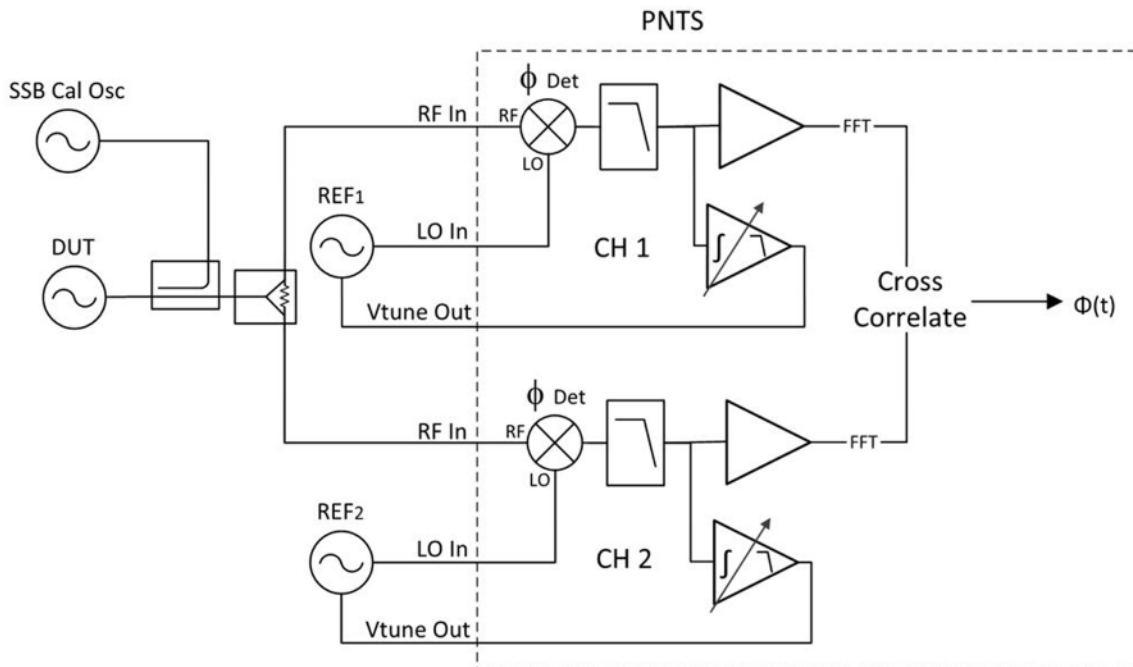


Figure 5-27 Dual Channel SSB Cal



Requirements:

- This calibration method requires a third source to generate a single sided spur, in the case of a single channel measurement. For a dual channel measurement, a fourth source will be required.
- An external power combiner (or directional coupler) to add the calibration spur to the frequency carrier under test. The calibration spur must have an amplitude -100 dB and -20 dB relative to the carrier amplitude. The offset frequency of the spur must be 20 Hz and 20 MHz.
- A spectrum analyzer or other means to measure the single sided spur relative to the carrier signal

The equipment setup for this calibration option is similar to the others except that an additional source and a power splitter have been added so that the spur can be summed with the input carrier frequency.

Advantages

- Calibration is done under actual measurement conditions so all non-linearities and harmonics of the phase detector are calibrated out.

Disadvantages

- Requires an extra RF sources that can be set between 10 Hz and up to 50 MHz (depending on the baseband analyzer used) from the carrier source frequency.
- Requires an RF spectrum analyzer for manual measurement of the signal-to-spur ratio and the spur offset frequency.

For a single-sided spur user calibration, a spur is combined with the DUT carrier. The relative amplitude of the spur is set to a convenient level. An analyzer is typically used to measure the relative amplitude as well as offset of the spur. The dBc value and offset is entered in the Cal tab of the Define Measurement menu shown in **Figure 5-28**.

Figure 5-28 Define Measurement Menu - Cal: Known Spurs Parameters

Keysight N5510 ✕

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Absolute Phase Noise (using dual phase locked loop)

☐ Apply channel #1 parameters to channel #2

Phase Detector Constant

- ☐ Use current phase detector constant
- ☐ Derive detector constant from measured beat note
- ☐ Derive detector constant from double - sided spur
- ☒ Derive detector constant from single - sided spur

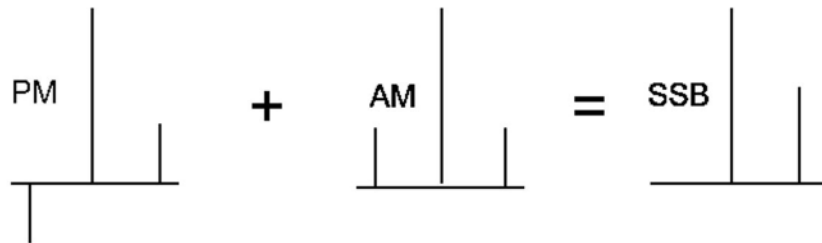
Current Phase Detector Constant Volts / Radian

Known Spur Parameters

Offset Frequency Hz Amplitude dBc

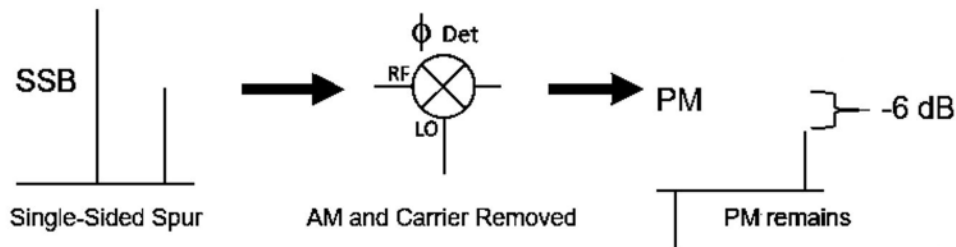
The model of a single sided spur is a narrow-band PM signal summed with an amplitude modulated signal of the same depth. The summation constructively adds in voltage to the upper sideband in this case and destructively adds to the lower sideband. This has the effect of increasing the upper sideband by 6 dB and eliminating the lower sideband.

Figure 5-29 Single Sided Spur



When the phase modulation is detected in the phase detector, the AM component is rejected. This detection process reveals the lower sideband but reduces the upper sideband by 6 dB. The software takes this into account during the calibration process.

Figure 5-30 AM and Carrier Removal



As a result, the measured cal tone by the system will be 6 dB lower compared to the measured amplitude by the analyzer when setting the SSB tone. **Figure 5-31** shows an example of spur set to -40 dBc at a 10 kHz offset, showing how the system will detect a -46 dBc spur.

Figure 5-31 Measured Cal Tone



Double-sided Spur

The double-sided spur method, along with single-side spur is the most accurate user calibration. This calibration method conveniently needs no extra RF source, if the DUT is capable of being phase or amplitude modulated at the carrier frequency. When performing a double-sided spur user calibration, the calibration is done under actual measurement conditions so all non-linearities and harmonics of the phase detector are calibrated out. The offset frequency or modulation frequency must be between 10 Hz and the maximum (See the table from the “**Measured Beat Note**” section on [page 87](#)). The resultant sideband spurs from the phase modulation must have amplitudes that are -100 dB and -20 dB relative to the carrier amplitude.

Advantages

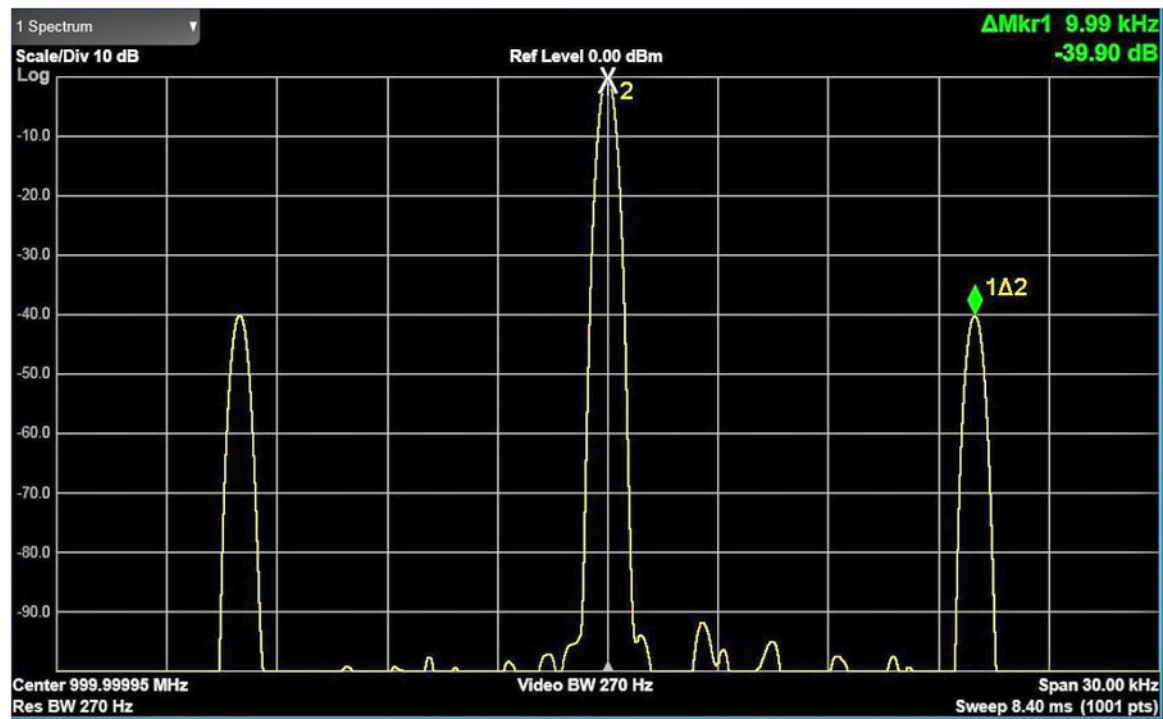
- Calibration is done under actual measurement conditions so all non-linearities and harmonics of the phase detector are calibrated out.
- No additional RF source is needed

Disadvantages

- Requires a phase modulator which operates at the desired carrier frequency.
- Requires RF spectrum analyzer for manual measurement of Φ M sidebands or preferably a modulation analyzer.

The double-sided spur user calibration method connection setup is the standard absolute measurement setup shown in [Figure 5-1](#) on [page 56](#) and in [Figure 5-3](#) on [page 58](#). [Figure 5-32](#) shows an example of a phase modulated carrier with the upper side band measuring -40 dBc at a 10 kHz offset.

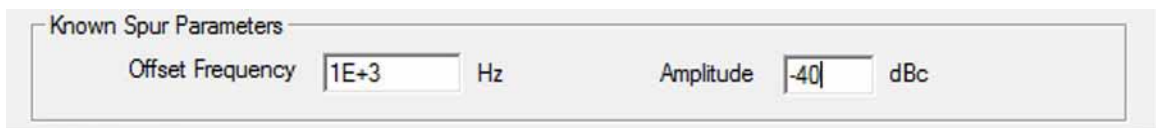
Figure 5-32 Double-Sided Spur Method



When measuring phase noise, the carrier is modulated with a known PM depth. This value relative to the carrier as well as the modulating rate is entered in the software under the Cal tab.

In the example in [Figure 5-33](#), the system measures a tone at -40 dBc

Figure 5-33 Known Spur Parameters



The system is phase locked and the modulating tone measured. In this case, the tone is a double-sideband PM tone so there is no AM to reject, so the entered value in the application is used to determine the amplitude of the carrier.

6 Absolute Measurement Examples

[“Example Overviews” on page 98](#)

[“Input Ports” on page 99](#)

[“Single Channel Measurement” on page 100](#)

[“Dual Channel \(EFC\)” on page 117](#)

[“Dual Channel \(DCFM\)” on page 134](#)

[“OCXO Dual Channel Measurement” on page 150](#)

Example Overviews

This chapter contains 6 different measurement examples to show how to perform an absolute phase noise measurement using the N5511A Phase Noise Test System. The guide demonstrates single channel and dual channel absolute phase noise measurements. The following are the examples:

- Single Channel Measurement
 - Single channel measurement of an E8257D PSG UNY using beat note user calibration method and EFC tuning mode.
- Dual Channel (using EFC)
 - Dual channel measurement of an E8257D PSG UNY at 1 GHz using beat note user calibration method and EFC tuning mode. The example features the use of two other E8257D PSG UNY as references.
- Dual Channel (using DCFM)
 - Dual channel measurement of an E8257D PSG UNY at 10 GHz using beat note user calibration method and DCFM tuning mode. The example features the use of two other E8257D PSG UNY as references.
- OCXO Dual Channel Measurement
 - Dual channel measurement of a 10 MHz OCXO using beat note user calibration method and EFC tuning mode. Example features the two copies of DUT as references.

Input Ports

The N5511A Phase Noise Tests System phase detector frequency specification are the following.

	Low Frequency Inputs (SMA) All Options	High Frequency Inputs (Type K) Option 526	High Frequency Inputs (Type K) Option 540	AM Noise Input (SMA) All Options
Carrier frequency range	50 kHz to 3 GHz	1.2 GHz to 26.5 GHz	1.2 GHz to 40 GHz	50 kHz to 40 GHz
RF input power	0 dBm to +23 dBm	0 dBm to +15 dBm	0 dBm to +15 dBm	0 dBm to +30 dBm
LO input power	+15 dBm to +23 dBm	+7 dBm to +15 dBm	+7 dBm to +15 dBm	N/A

For optimal performance, however, when performing a measurement, N5510 software defaults to detector selections that do not match the hardware capabilities. When performing a measurement, the software default detector selections use the following guidelines:

Low Frequency Inputs	50 kHz to 1.6 GHz
High Frequency Inputs	1.6 GHz and above

This can be overwritten by manually selecting the detector to be utilized in the measurement setup, as long as the input signal is within the hardware specifications of the detector input.

Single Channel Measurement

A single channel measurement will be a very familiar experience on the N5511A PNTS for those that have used the E5500 system before. In a single channel measurement, the phase noise of the reference source will contribute to the overall phase noise of the measurement -therefore, it is very important to have a reference source that has much lower (better) phase noise than the phase noise of the DUT. The basic idea is we will use one PSG signal generator as a reference source and one PSG as the device under test (DUT).

Required equipment

- Two SMA 3.5 mm cables - ideal lengths: approximately 20 inch
- One BNC-to-BNC cable
- Two signal sources: one source acting as a DUT and the other source acting as a reference (REF) with external frequency control (EFC) capability
- One Keysight N5511A (PNTS) Phase Noise Test Set
- One oscilloscope
- One SMB-BNC cable, or appropriate cable for connection from M9550A monitor port to oscilloscope

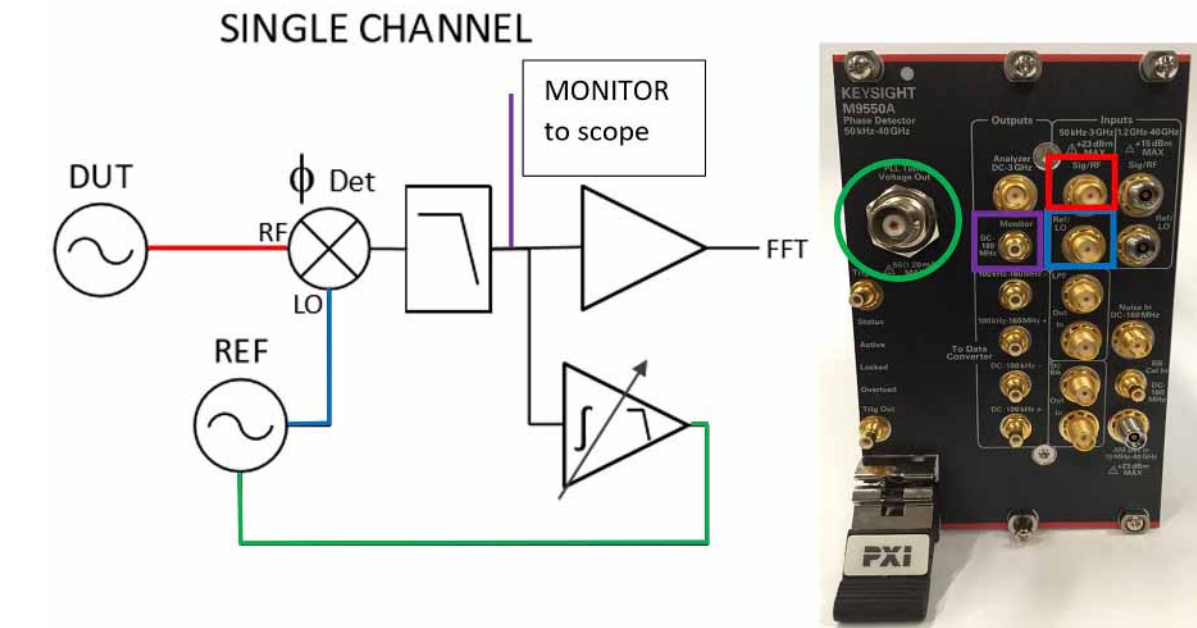
NOTE

Reference Source: This setup calls for a tunable reference source with the same center frequency as the DUT. In order for the noise measurement results to accurately represent the noise of the DUT, the noise level of the reference source should be below the expected noise level of the DUT.

Test Setup

Figure 6-1 shows the configuration used for the Single Channel measurement.

Figure 6-1 Single Channel Measurement Setup



Connectors on M9550A	Connects to
Green	EFC Out on rear of PSG
Purple	Scope Monitor
Red	DUT source RF Out
Blue	Reference Source RF out

1) CH 1 PLL Tune Line	Connect the Ch 1 PLL Tune Voltage Out port (green) of the M9550A phase detector module inside the PNTS chassis to the EFC port at the back of the REF (PSG as reference) source using the BNC-to-BNC cable.
2) DUT to Sig/RF on PNTS	Connect the RF output of the DUT source to the high-band RF input (1.2 to 40 GHz) labeled "Sig/RF" on the M9550 phase detector module using an SMA cable
3) REF to Ref/LO on PNTS	Connect the RF output port of the REF source to the high-band RF input (1.2 to 40 GHz) labeled "Ref/LO" on the M9550 phase detector module (blue) using an SMA cable
4) MONITOR output to Scope	Connect SMB-to-BNC cable from the "Monitor" output on the M9550 phase detector (purple) to channel 1 of the oscilloscope

Configuring Equipment

Configure the DUT and source for this measurement:

1) Set up DUT PSG	Frequency: 1 GHz Amplitude: 11 dBm RF On/Off: RF ON Mod On/Off: MOD OFF
2) Set up REF PSG	Frequency: 1 GHz Amplitude: 14 dBm RF On/Off: RF ON Mod On/Off: MOD OFF

NOTE

The RF power of the DUT source must be at least 3 dB lower than that of the REF source

Measurement Procedure

Measurement Type and Range

At the top of the main application window, click "Define" and then select "Measurement..." from the drop-down menu.

Define, Measurement, Type and Range

The following window will appear:

Figure 6-2 Type and Range Tab

The screenshot shows the 'Keysight N5510' window with the 'Type and Range' tab selected. The 'Measurement Type' is set to 'Absolute Phase Noise (using phase locked loop)'. Under 'Measurement Method', 'Fast' is selected with a 'Start Offset Resolution Expansion' of 10. Under 'Channel Setup', 'Dual' is selected. The 'Measurement Settings' section includes 'Start Offset' (1 Hz), 'Stop Offset' (160E+6 Hz), 'FFT Analyzer Minimum Number of Trace Averages' (4), 'FFT Analyzer Minimum Number of Cross-correlations' (1), 'RBW %' (1.96 (1024 point FFT)), 'FFT Overlap %' (75), 'FFT Window Type' (BlackmanHarris4), and 'Estimated Measurement Time' (0). The 'FFT Quality' section has 'Normal' selected, with options for 'Fast', 'High Resolution', and 'Custom'. A 'View Segment Table' button is present. At the bottom, 'Couple Graph Type to Measurement Type' is checked, and there are 'Preset', 'Close', and 'Help' buttons.

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Measurement Type: Absolute Phase Noise (using phase locked loop)

Measurement Method:
☐ Flexible
☒ Fast Start Offset Resolution Expansion: 10

Channel Setup:
☐ Single
☒ Dual

Measurement Settings:
Start Offset: 1 Hz Stop Offset: 160E+6 Hz
FFT Analyzer Minimum Number of Trace Averages: 4
FFT Analyzer Minimum Number of Cross-correlations: 1
RBW %: 1.96 (1024 point FFT)
FFT Overlap %: 75 FFT Window Type: BlackmanHarris4
Estimated Measurement Time: 0

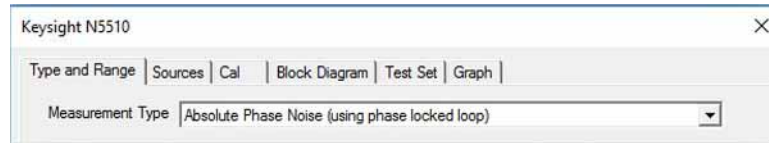
FFT Quality:
☒ Normal ☐ Fast ☐ High Resolution ☐ Custom View Segment Table

☒ Couple Graph Type to Measurement Type Preset

Close Help

1) Choose Measurement Type

Measurement Type: Absolute Phase Noise (using phase locked loop)



2) Choose Measurement Method

Flexible is "single segment" measurement method where every segment is captured independently and after the previous segment has been measured (this is how E5500 works).

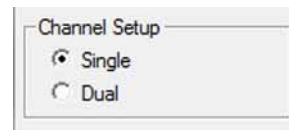
Fast is "multi-segment", where segments are being measured in parallel. This option allows for a live view of the data acquisition of the measurement.

Measurement Method: Flexible



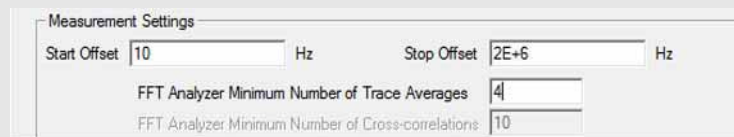
3) Choose Channel Setup

Channel Setup: Single



4) Set Start and Stop Offsets

Start Offset: 10 Hz
Stop Offset: 2 MHz



Source Calibration

Next, we will configure the settings for the DUT and the reference sources. Navigate to the Source tab at the top of the current window.

The following window will appear:

Figure 6-3 Source Tab

The screenshot shows the 'Keysight N5510' window with the 'Sources' tab selected. The window title bar includes a close button (X). The tab bar at the top contains 'Type and Range', 'Sources', 'Cal', 'Block Diagram', 'Test Set', and 'Graph'. The main content area is titled 'Absolute Phase Noise (using a phase locked loop)'. It contains three main sections: 'Carrier Source', 'Detector Input Frequency', and 'Reference Source'. The 'Carrier Source' section has 'Frequency' set to '1E+9' Hz and 'Power' set to '10' dBm. The 'Detector Input Frequency' section has 'Frequency' set to '1E+9' Hz. The 'Reference Source' section has 'Frequency' set to '1E+9' Hz and 'Power' set to '10' dBm. Below these is the 'VCO Tuning Parameters' section, which includes 'Nominal Tune Constant' (10E+3 Hz / Volt), 'Center Voltage' (0 Volts), 'Tune Range +/-' (1 Volts), 'Input Resistance' (1E+6 Ohms), and 'Maximum Allowed Deviation from Center Voltage' (1 Volts). A note states: 'The Tune Range is within the limits of from +/- 0.20 to +/- 10.00 Volts, as required by the current Center Voltage setting.' A 'Preset' button is located to the right of this note. At the bottom of the window are 'Close' and 'Help' buttons.

Keysight N5510

Type and Range Sources Cal Block Diagram Test Set Graph

Absolute Phase Noise (using a phase locked loop)

Carrier Source

Frequency 1E+9 Hz Power 10 dBm

Detector Input Frequency

1E+9 Hz

Reference Source

Frequency 1E+9 Hz Power 10 dBm

VCO Tuning Parameters

Nominal Tune Constant 10E+3 Hz / Volt Center Voltage 0 Volts

Tune Range +/- 1 Volts Input Resistance 1E+6 Ohms

Maximum Allowed Deviation from Center Voltage 1 Volts

The Tune Range is within the limits of
from +/- 0.20 to +/- 10.00 Volts,
as required by the current Center Voltage setting.

Preset

Close Help

1) Set Carrier Source (DUT) Settings

Frequency: 1E+9 (1 GHz)
Power: 11 dBm

Absolute Phase Noise (using a phase locked loop)

Carrier Source

Frequency: 1E+9 Hz Power: 11 dBm

2) Set Reference Source (REF) Settings

Detector Input Frequency: 1E+9 (1 GHz)
Power: 14 dBm

Detector Input Frequency: 1E+9 Hz

Reference Source

Frequency: 1E+9 Hz Power: 14 dBm

3) VCO Tuning Parameters

Nominal Tune Constant: 70 Hz/V
Tune Range: 0.5 V
Input Resistance: 1E+6 (1MΩ)

VCO Tuning Parameters

Nominal Tune Constant: 70 Hz / Volt Center Voltage: 0 Volts

Tune Range +/-: 500E-3 Volts Input Resistance: 1E+6 Ohms

Maximum Allowed Deviation from Center Voltage: 1 Volts

The Tune Range is within the limits of from +/- 0.20 to +/- 10.00 Volts, as required by the current Center Voltage setting.

Preset

NOTE

Note that the source parameters entered for step 3 above may not be appropriate for the reference source you are using. To change these values, refer to [Table 6-1](#) below.

Table 6-1 Tuning Characteristics for Various Sources

VCO Source	Carrier Freq	Tuning Constant (Hz/V)	Center Voltage (V)	Voltage Tuning Range (± V)	Input Resistance (Ω)	Tuning Calibration Method
Keysight 8257D						Measure
EFC	ν_0	$7 \text{ E} - 8 \times \nu_0$	0	5	$1 \text{ E} + 6$	Compute
DCFM	ν_0	FM Deviation	0	10	50 600	Compute
Keysight 8662/3A						Measure
EFC	ν_0	$5 \text{ E} - 9 \times \nu_0$	0	10	$1 \text{ E} + 6$	Compute
DCFM		FM Deviation	0	10	1 K (8662) 600 (8663)	Compute
Keysight 8642A/B		FM Deviation	0	10	600	Compute
Keysight 8644B		FM Deviation	0	10	600	Compute
Other Signal Generator		FM Deviation	0	10	R_{in}	Compute
Other User VCO Source		Estimated within a factor of 2	-10 to +10		$1 \text{ E} + 6$	Measure

Cal Configuration

Navigate to the Cal tab.

The following window will appear:

Figure 6-4 Cal Tab

The screenshot shows the 'Cal' tab of the Keysight N5510 software interface. The window has a title bar 'Keysight N5510' and a close button 'X'. Below the title bar are five tabs: 'Type and Range', 'Sources', 'Cal' (selected), 'Block Diagram', 'Test Set', and 'Graph'. The main content area is titled 'Absolute Phase Noise (using a phase locked loop)' and contains several sections:

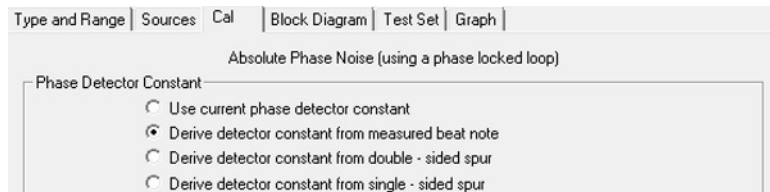
- Phase Detector Constant:** Four radio buttons are present: 'Use current phase detector constant', 'Derive detector constant from measured beat note', 'Derive detector constant from double - sided spur', and 'Derive detector constant from single - sided spur' (which is selected). Below these is a text field 'Current Phase Detector Constant' with the value '1E-6' and the unit 'Volts / Radian'.
- Known Spur Parameters:** Two text fields: 'Offset Frequency' with the value '1' and unit 'Hz', and 'Amplitude' with the value '-130' and unit 'dBc'.
- VCO Tune Constant:** Three radio buttons: 'Use current VCO tune constant', 'Measure VCO tune constant' (selected), and 'Calculate from expected VCO tune constant using tune port resistance'. Below are two text fields: 'Current VCO Tune Constant' with '1E+6' and 'Hz / Volt', and 'Expected VCO Tune Constant' with '10E+3' and 'Hz / Volt'.
- Phase Locked Loop Suppression:** A checked checkbox 'Verify calculated phase locked loop suppression' and an unchecked checkbox 'Always Show Suppression Graph'. Below is a text field 'Maximum Suppression Error Limit' with the value '1' and unit 'dB'. At the bottom of this section are three radio buttons: 'Use theoretical values', 'Use adjusted values' (selected), and 'Show Suppression Graph'.

At the bottom right of the main content area is a 'Preset' button. At the very bottom of the window are two buttons: 'Close' and 'Help'.

For this lab we will use Beat Note Cal. Refer to the Cal Demo guide for details on using other cal methods.

1) Configure Phase Detector Constant Settings

Phase Detector Constant: Derive detector constant from measured beat note



Type and Range | Sources | Cal | Block Diagram | Test Set | Graph |

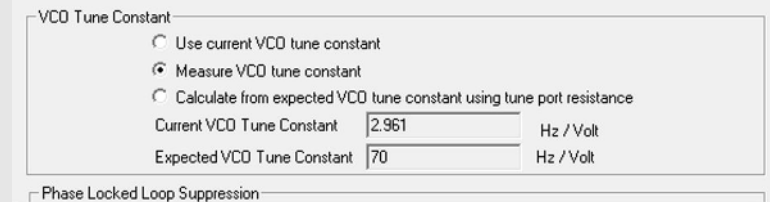
Absolute Phase Noise (using a phase locked loop)

Phase Detector Constant

- ☐ Use current phase detector constant
- ☒ Derive detector constant from measured beat note
- ☐ Derive detector constant from double - sided spur
- ☐ Derive detector constant from single - sided spur

2) Configure VCO Tune Constant Settings

VCO Tune Constant: Measure VCO tune constant



VCO Tune Constant

- ☐ Use current VCO tune constant
- ☒ Measure VCO tune constant
- ☐ Calculate from expected VCO tune constant using tune port resistance

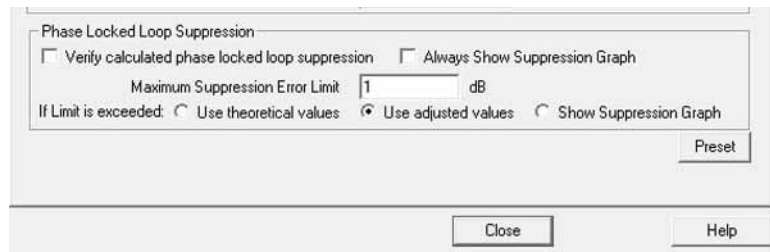
Current VCO Tune Constant: 2.961 Hz / Volt

Expected VCO Tune Constant: 70 Hz / Volt

☐ Phase Locked Loop Suppression

3) Phase Locked Loop Suppression

Uncheck "Verify calculated phase locked loop suppression"



Phase Locked Loop Suppression

☐ Verify calculated phase locked loop suppression ☐ Always Show Suppression Graph

Maximum Suppression Error Limit: 1 dB

If Limit is exceeded: ☐ Use theoretical values ☒ Use adjusted values ☐ Show Suppression Graph

Preset

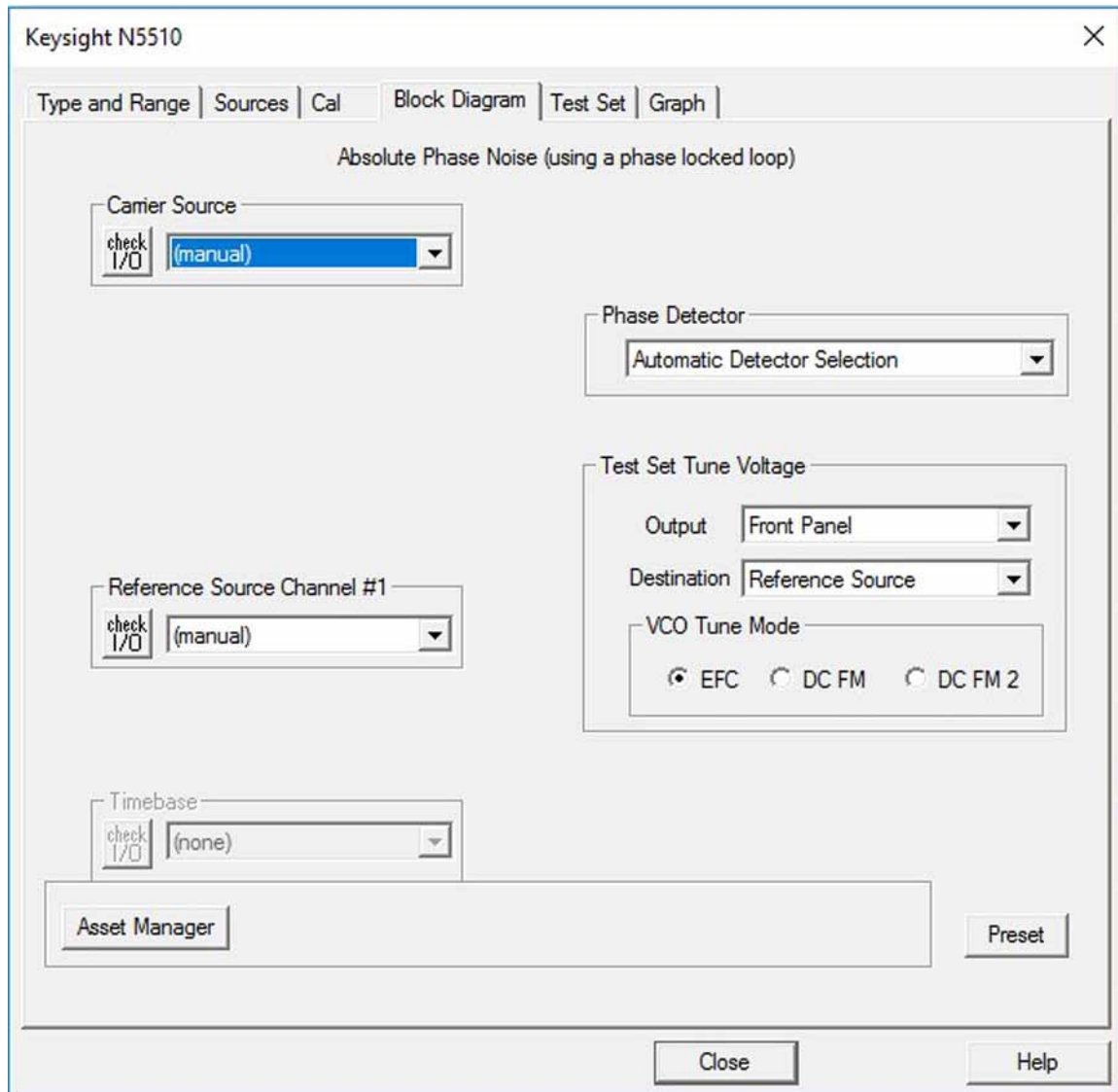
Close Help

Block Diagram Configuration

Navigate to the Block Diagram tab.

The following window will appear:

Figure 6-5 Block Diagram Tab



1) Phase Detector

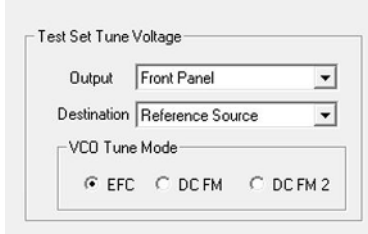
Phase Detector: Automatic Detection
Selection



A screenshot of a software interface showing a dropdown menu labeled "Phase Detector". The menu is open, displaying "Automatic Detector Selection" as the selected option.

2) Test Set Tune Voltage

VCO Tune Mode: EFC



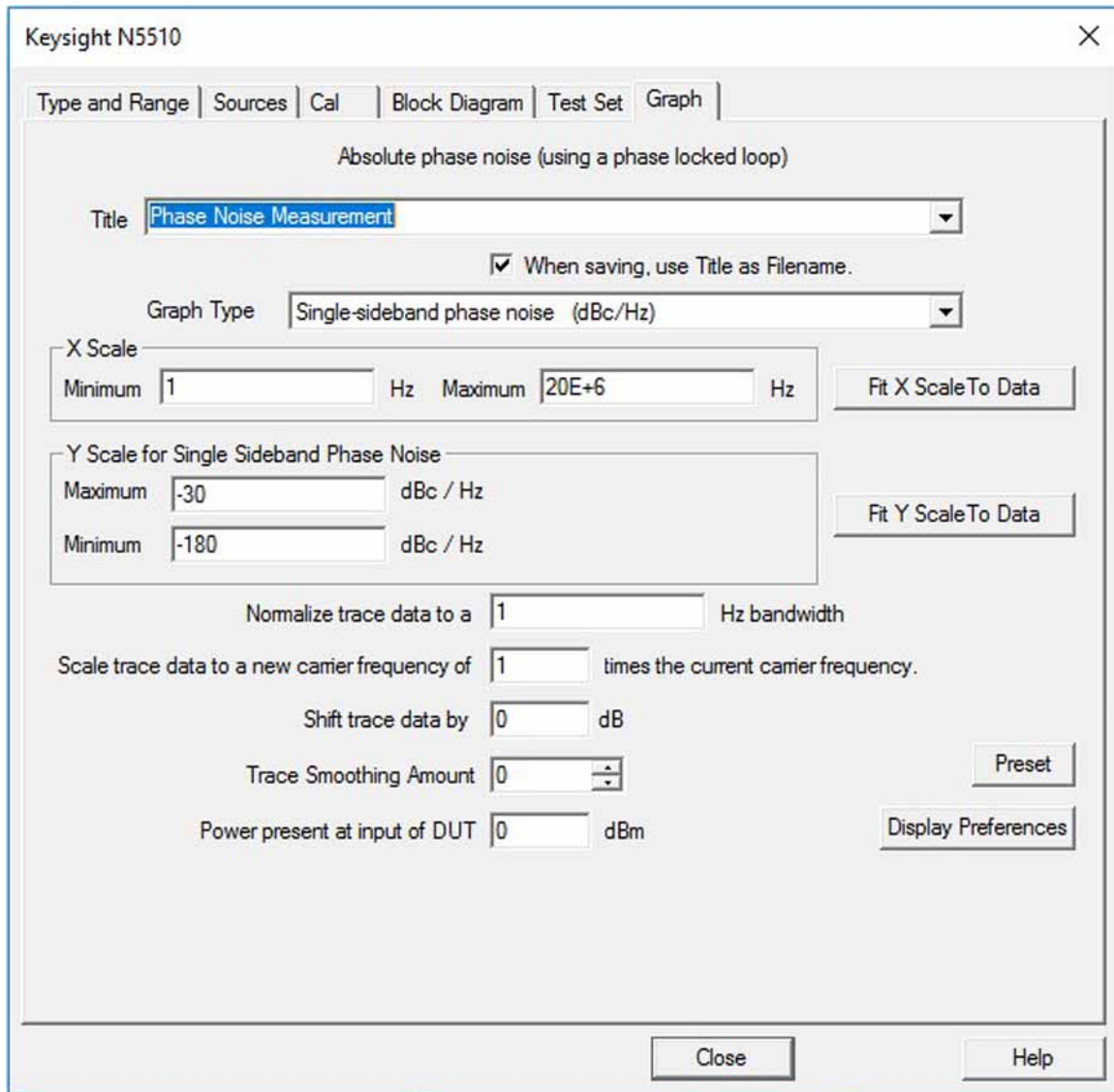
A screenshot of a software window titled "Test Set Tune Voltage". It contains two dropdown menus: "Output" set to "Front Panel" and "Destination" set to "Reference Source". Below these is a section titled "VCO Tune Mode" with three radio button options: "EFC" (which is selected), "DC FM", and "DC FM 2".

Configure Graph

Navigate to the Graph tab.

The following window will appear:

Figure 6-6 Graph Tab



The image shows the 'Keysight N5510' software window with the 'Graph' tab selected. The window title is 'Keysight N5510'. The tabs at the top are 'Type and Range', 'Sources', 'Cal', 'Block Diagram', 'Test Set', and 'Graph'. The main area is titled 'Absolute phase noise (using a phase locked loop)'. It contains several configuration options: 'Title' is set to 'Phase Noise Measurement'; a checkbox 'When saving, use Title as Filename.' is checked; 'Graph Type' is set to 'Single-sideband phase noise (dBc/Hz)'; 'X Scale' has 'Minimum' at '1 Hz' and 'Maximum' at '20E+6 Hz', with a 'Fit X Scale To Data' button; 'Y Scale for Single Sideband Phase Noise' has 'Maximum' at '-30 dBc / Hz' and 'Minimum' at '-180 dBc / Hz', with a 'Fit Y Scale To Data' button; 'Normalize trace data to a' is set to '1 Hz bandwidth'; 'Scale trace data to a new carrier frequency of' is set to '1 times the current carrier frequency.'; 'Shift trace data by' is set to '0 dB'; 'Trace Smoothing Amount' is set to '0'; 'Power present at input of DUT' is set to '0 dBm'; and there are 'Preset' and 'Display Preferences' buttons. At the bottom are 'Close' and 'Help' buttons.

Keysight N5510

Type and Range | Sources | Cal | Block Diagram | Test Set | Graph

Absolute phase noise (using a phase locked loop)

Title: Phase Noise Measurement

☒ When saving, use Title as Filename.

Graph Type: Single-sideband phase noise (dBc/Hz)

X Scale

Minimum: 1 Hz Maximum: 20E+6 Hz

Fit X Scale To Data

Y Scale for Single Sideband Phase Noise

Maximum: -30 dBc / Hz

Minimum: -180 dBc / Hz

Fit Y Scale To Data

Normalize trace data to a 1 Hz bandwidth

Scale trace data to a new carrier frequency of 1 times the current carrier frequency.

Shift trace data by 0 dB

Trace Smoothing Amount: 0

Power present at input of DUT: 0 dBm

Preset

Display Preferences

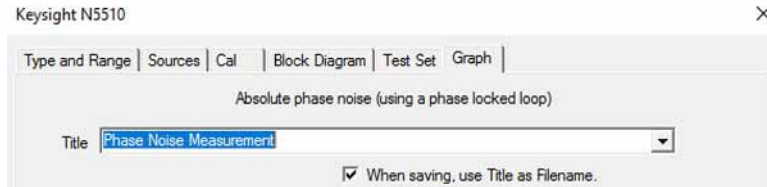
Close Help

Absolute Measurement Examples

Single Channel Measurement

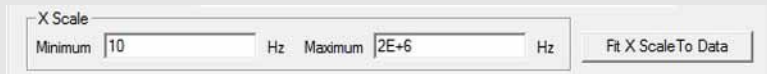
1) Set Title

You can set the title to whatever you want, but it is quite helpful to set the title to correspond to the measurement you are making (e.g. center frequency, DUT, absolute/residual measurement, number of FFT points, etc)



2) Set X-Scale

X -Scale Minimum: 10 Hz
X-Scale Maximum: 2E+6 (2 MHz)



3) Set Y-Scale

Y-Scale Maximum: 0 dBc/Hz
Y-Scale Minimum: -170 dBc/Hz

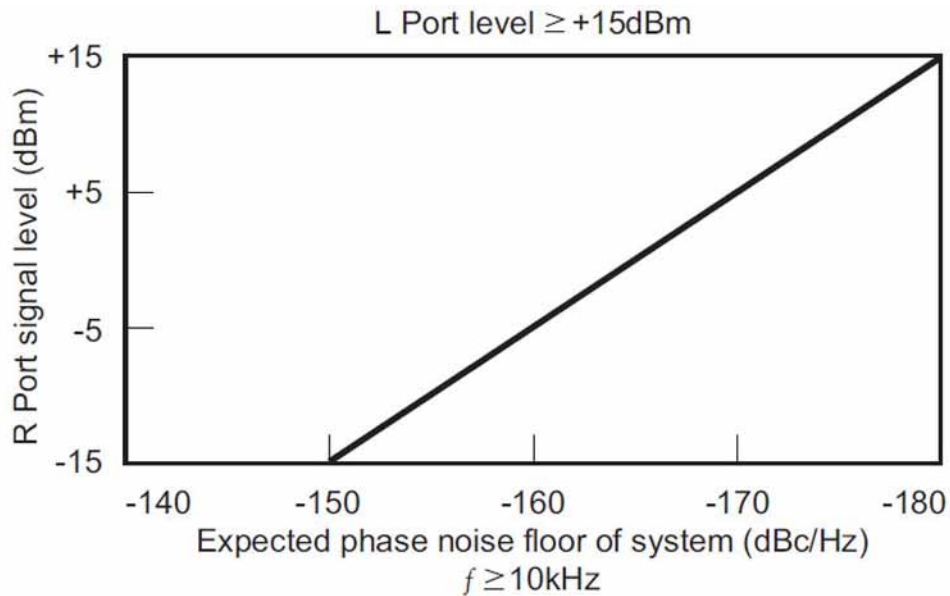


Setup considerations for stable RF oscillator measurement

Measurement Noise Floor

In a single channel measurement, the signal amplitude at the test set's R input (Signal Input) port sets the measurement noise floor level. Use [Figure 6-7](#) to determine the amplitude required to provide a noise floor level that is below the expected noise floor of your DUT. (The [“Checking the Beat Note”](#) procedure below will provide you with an opportunity to estimate the measurement noise floor that your DUT will provide.)

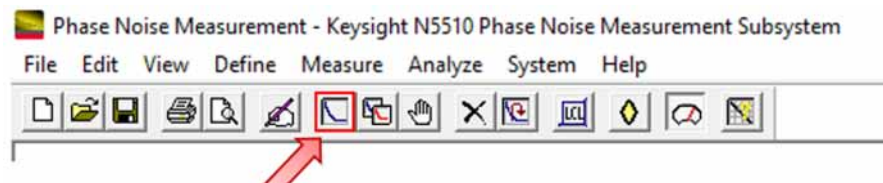
Figure 6-7 Noise Floor for the Stable RF Oscillator Measurement



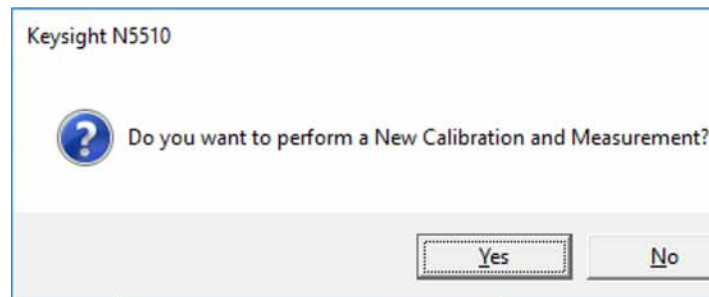
If the output amplitude of your DUT is not sufficient to provide an adequate measurement noise floor, it is necessary to insert a low-noise amplifier between the DUT and the test set. Refer to [“Inserting a Device” on page 79](#) for details on determining the amplifier noise effect on the measured noise floor.

New Measurement

Close Define Window. From the File Menu: **Measure, New Measurement.**



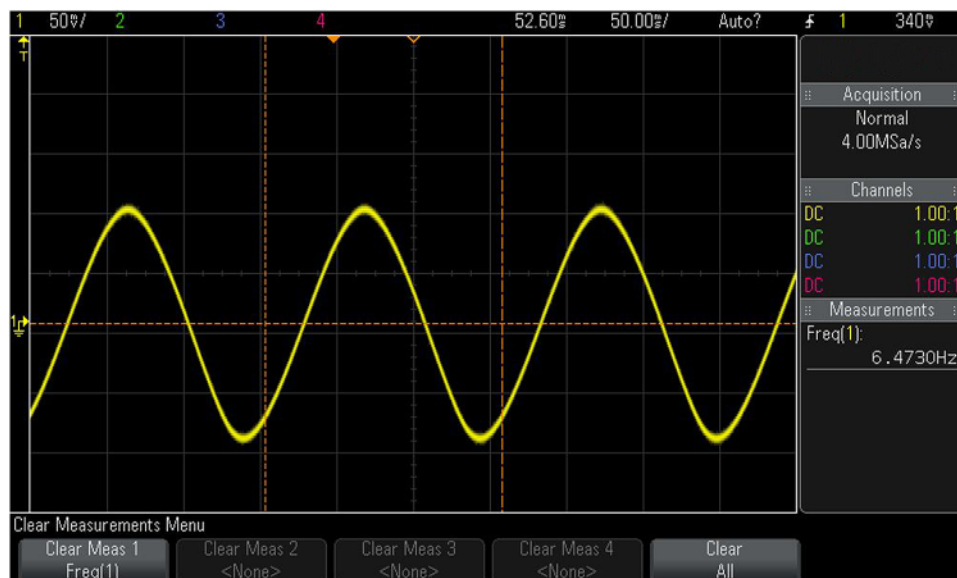
When the "Do you want to perform a New Calibration and Measurement?" prompt appears, click **Yes**.



Checking the Beat Note

While the connect diagram is still displayed, use an oscilloscope (connected to the Monitor port on the test set) or a counter to check the beat note being created between the reference source and your DUT.

Figure 6-8 Oscilloscope displaying monitor output of phase detector



The objective of checking the beat note is to ensure that the center frequencies of the two sources are close enough in frequency to create a beat note that is within the capture range of the system. The phase lock loop (PLL) capture range is 5% of the peak tuning range of the VCO source you are using. (The

peak tuning range for your VCO can be estimated by multiplying the VCO tuning constant by the tune range of VCO. Refer to [Chapter 14, “Evaluating Your Measurement Results”](#) if you are not familiar with the relationship between the PLL capture range and the peak tuning range of the VCO. The beat note frequency is set by the relative frequency difference between the two sources. If you have two very accurate sources set at the same frequency, the resulting beat note will be very close to 0 Hz. Searching for the beat note will require that you adjust the center frequency of one of the sources above and below the frequency of the other source until the beat note appears on the oscilloscope's display. If incrementing the frequency of one of the sources does not produce a beat note, you will need to verify the presence of an output signal from each source before proceeding.

NOTE

If the center frequencies of the sources are not close enough to create a beat note within the capture range, the system will not be able to complete its measurement.

Figure 6-9 Pause point window for when a beat note needs to be tuned

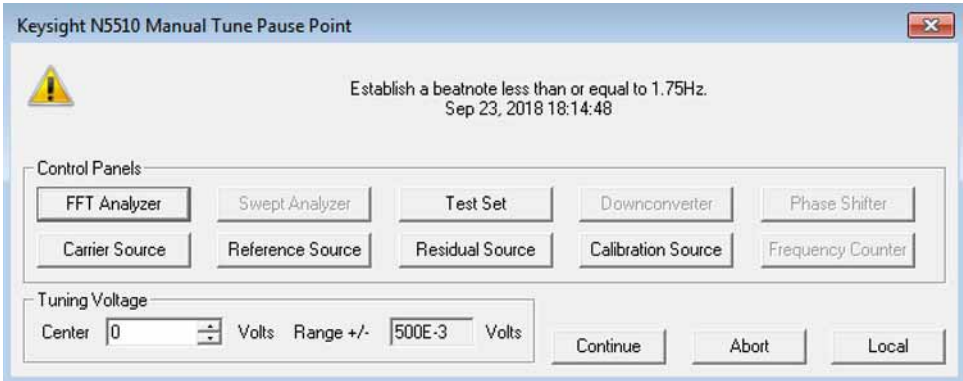
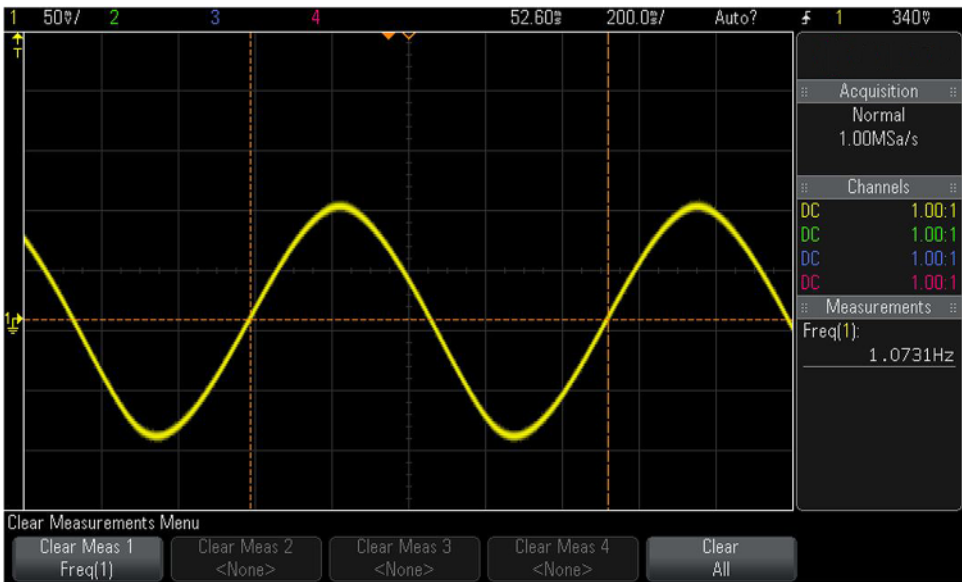


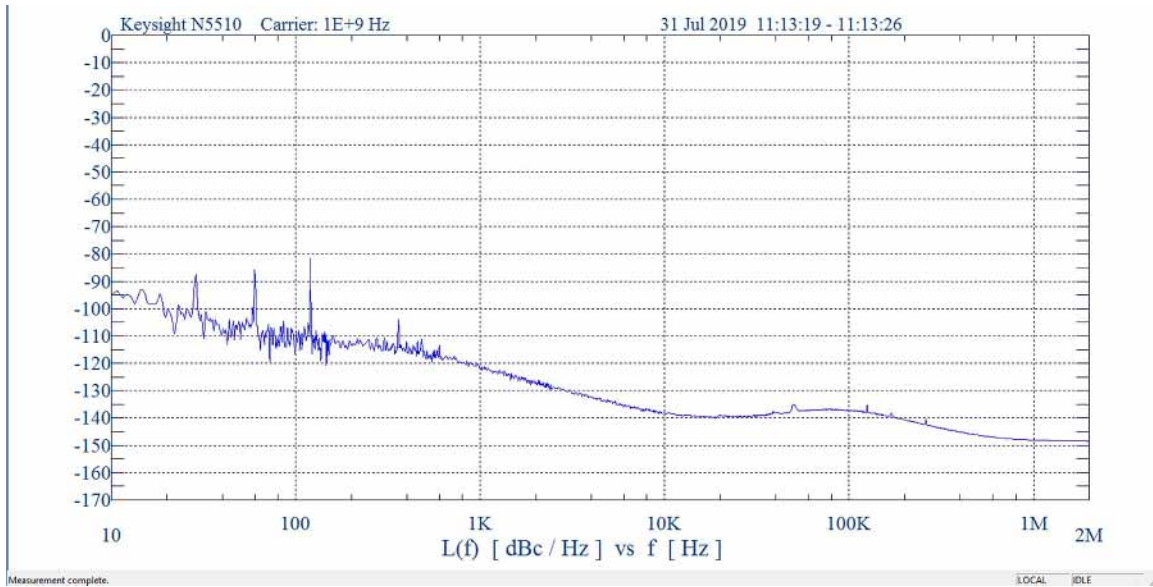
Figure 6-10 Monitor output displaying adjusted beat note within specified range



Click the **Continue** button when you have completed the beat note check and are ready to make the measurement.

When the measurement is complete, refer to **Chapter 14, “Evaluating Your Measurement Results”** for help in evaluating your measurement results. **Figure 6-11** shows the result of this measurement example.

Figure 6-11 Single Channel Measurement Results



Dual Channel (EFC)

A key feature of the N5511A PNTS is the ability to cross-correlate noise. Using two channels instead of one can allow for a faster measurement when measuring a high performance DUT. A two-channel measurement requires two references and the DUT.

This example steps through measuring a E8257D PSG UNY as a DUT, using two other E8257D PSG UNYs as references.

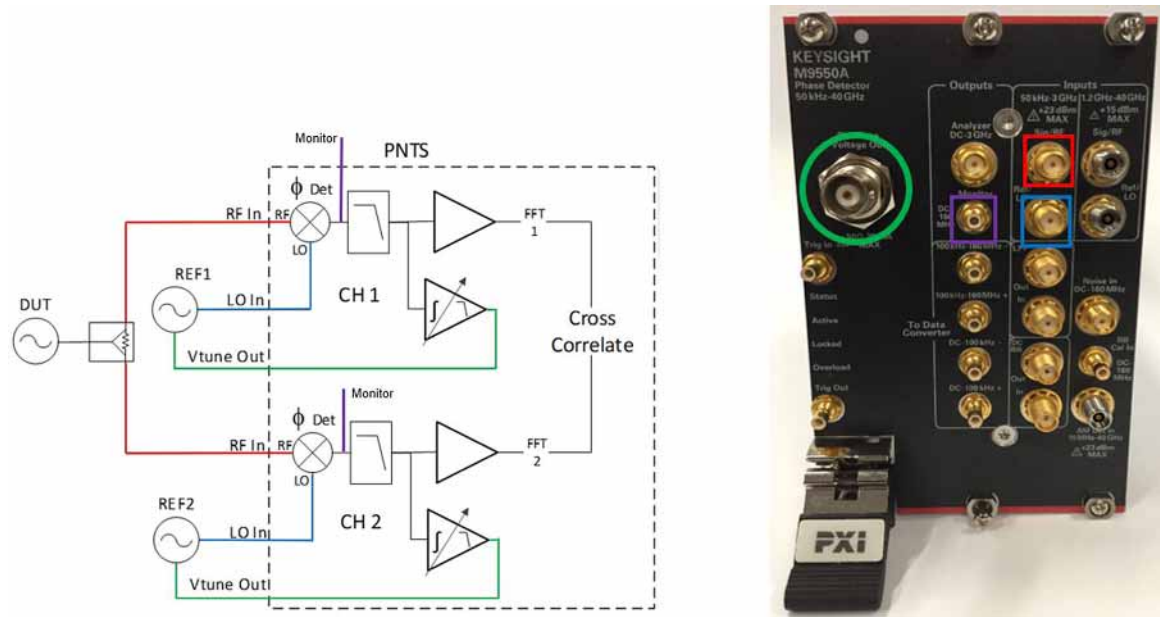
Required equipment

- Keysight N5511A Phase Noise Test System
- Keysight E8257D PSG UNY signal sources (x3), one PSG acting as a DUT and the other two as references (REF) with external frequency control (EFC) capability
- 3.5 mm cables (x5)
- BNC-to-BNC cables (x2)
- Oscilloscope: Keysight Infinivision MSO-X 3054A (or similar with high-impedance inputs)
- SMB-BNC cables (x2)
- Power Divider (functional at 1 GHz)

Test Setup

Figure 6-12 shows the configuration for a Dual Channel (EFC) measurement.

Figure 6-12 Dual Channel (EFC) Measurement Setup



Connectors on M9550A	Connects to
Green	EFC Out on rear of PSG
Purple	Oscilloscope
Red	DUT source RF (after splitter)
Blue	Reference Source RF out

NOTE

Both phase detector modules have identical connections using separate reference sources

Absolute Measurement Examples
Dual Channel (EFC)

1) CH 1 PLL Tune	Connect the Ch 1 PLL Tune Out port of the PNTS to the 10 MHz EFC port at the back of the REF1 source using the 6-foot BNC-to-BNC cable.
2) CH 2 PLL Tune	Connect the Ch 2 PLL Tune Out port of the PNTS to the 10 MHz EFC port at the back of the REF2 source using the 6-foot BNC-to-BNC cable.
3) DUT RF to Splitter	Connect the RF output of the DUT to the RF splitter.
4) Splitter to RF IN 1	Connect splitter out 1 to the RF1 LB port of the PNTS using the 12-inch cable.
5) Splitter to RF IN 2	Connect splitter out 1 to the RF1 LB port of the PNTS using the 12-inch cable.
6) REF 1 to LO IN 1 PNTS	Connect the RF port of the REF1 source to the LO1 LB port of the PNTS using the 20-inch cable.
7) REF 2 to LO IN 2 PNTS	Connect the RF port of the REF2 source to the LO2 LB port of the PNTS using the 20-inch cable.
8) Oscilloscope	Connect SMB cables to the Monitor outputs on each of the phase detectors. Connect the other ends to the oscilloscope.

Configuring Equipment

Configure the equipment to the settings for this lab:

1) Power	Power on all the equipment: Keysight N5511A PNTS, PSGs
2) Set up the DUT	Frequency, 1 GHz Amplitude, 14 dBm RF On/Off, On
3) Set up REF 1	Frequency, 1 GHz Amplitude, 14 dBm RF On/Off, On
4) Set up REF 2	Frequency, 1 GHz Amplitude, 14 dBm RF On/Off, On

Measurement Procedure

Measurement Type and Range

At the top of the main application window, click "Define" and then select "Measurement..." from the drop-down menu.

Define, Measurement, Type and Range

The following window will appear:

Figure 6-13 Type and Range Tab

The screenshot shows the 'Keysight N5510' window with the 'Type and Range' tab selected. The 'Measurement Type' is set to 'Absolute Phase Noise (using phase locked loop)'. Under 'Measurement Method', 'Fast' is selected with a 'Start Offset Resolution Expansion' of 10. Under 'Channel Setup', 'Dual' is selected. The 'Measurement Settings' section includes 'Start Offset' at 1 Hz, 'Stop Offset' at 160E+6 Hz, 'FFT Analyzer Minimum Number of Trace Averages' at 4, 'FFT Analyzer Minimum Number of Cross-correlations' at 1, 'RBW %' at 1.96 (1024 point FFT), 'FFT Overlap %' at 75, and 'FFT Window Type' set to BlackmanHarris4. The 'Estimated Measurement Time' is 0. Under 'FFT Quality', 'Normal' is selected. A 'View Segment Table' button is present. At the bottom, 'Couple Graph Type to Measurement Type' is checked, and there are 'Preset', 'Close', and 'Help' buttons.

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Measurement Type: Absolute Phase Noise (using phase locked loop)

Measurement Method:
☐ Flexible
☒ Fast Start Offset Resolution Expansion: 10

Channel Setup:
☐ Single
☒ Dual

Measurement Settings

Start Offset: 1 Hz Stop Offset: 160E+6 Hz

FFT Analyzer Minimum Number of Trace Averages: 4

FFT Analyzer Minimum Number of Cross-correlations: 1

RBW %: 1.96 (1024 point FFT)

FFT Overlap %: 75 FFT Window Type: BlackmanHarris4

Estimated Measurement Time: 0

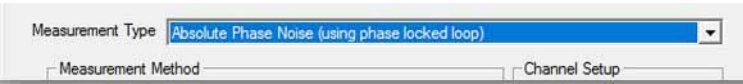
FFT Quality:
☒ Normal ☐ Fast ☐ High Resolution ☐ Custom View Segment Table

☒ Couple Graph Type to Measurement Type Preset

Close Help

1) Choose Measurement Type

Measurement Type: Absolute Phase Noise (using phase locked loop)



Measurement Type: Absolute Phase Noise (using phase locked loop)

2) Choose Measurement Method

Flexible is "single segment" measurement method where every segment is captured independently and after the previous segment has been measured (this is how E5500 measures).

Fast is "multi-segment", where segments are being measured in parallel. This option allows for a live view of the data acquisition of the measurement.

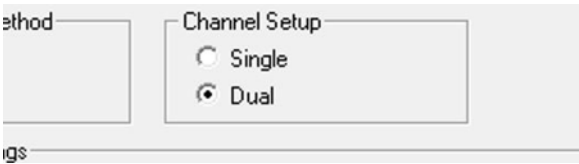
Measurement Method: Fast



Measurement Method: Fast Start Offset Resolution Expansion: 10

3) Choose Channel Setup

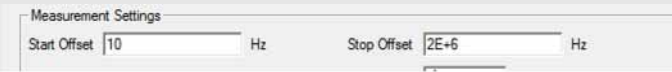
Channel Setup: Dual



Channel Setup: Dual

4) Set Start and Stop Offsets

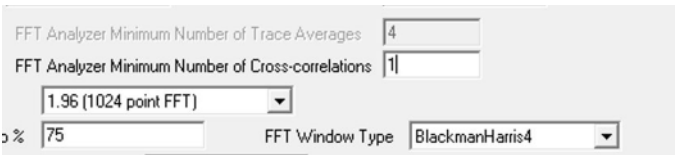
Start Offset: 10 Hz
Stop Offset: 2 MHz



Measurement Settings: Start Offset: 10 Hz Stop Offset: 2E+6 Hz

5) Set Number of Cross-Correlations

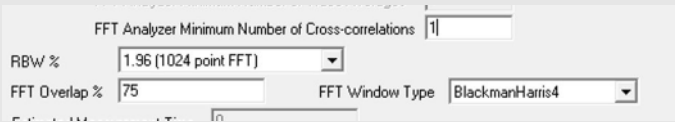
FFT Analyzer Minimum number of cross-correlations: 1



FFT Analyzer Minimum Number of Cross-correlations: 1
RBW %: 1.96 (1024 point FFT)
FFT Window Type: BlackmanHarris4

6) Set FFT Size

RBW %: 1.96 (1024 point FFT)



FFT Analyzer Minimum Number of Cross-correlations: 1
RBW %: 1.96 (1024 point FFT)
FFT Overlap %: 75
FFT Window Type: BlackmanHarris4

Source Configuration

Next, we will configure the settings for the DUT and the reference sources. Navigate to the Source tab at the top of the current window.

The following window will appear:

Figure 6-14 Source Tab

The screenshot shows the 'Keysight N5510' window with the 'Sources CH#1' tab selected. The window has a title bar with a close button (X) and a tab bar with the following tabs: 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram', 'Test Set', and 'Graph'. The main content area is titled 'Absolute Phase Noise (using dual channels)' and includes a checkbox labeled 'Apply channel #1 parameters to channel #2'. Below this, there are three main sections: 'Carrier Source', 'Detector Input Frequency', and 'Reference Source'. The 'Carrier Source' section has 'Frequency' set to '1E+9' Hz and 'Power' set to '10' dBm. The 'Detector Input Frequency' section has 'Frequency' set to '1E+9' Hz. The 'Reference Source' section has 'Frequency' set to '1E+9' Hz and 'Power' set to '10' dBm. Below these sections is the 'VCO Tuning Parameters' section, which includes 'Nominal Tune Constant' (10E+3 Hz / Volt), 'Center Voltage' (0 Volts), 'Tune Range +/-' (1 Volts), 'Input Resistance' (1E+6 Ohms), and 'Maximum Allowed Deviation from Center Voltage' (1 Volts). A message states: 'The Tune Range is within the limits of from +/- 0.20 to +/- 10.00 Volts, as required by the current Center Voltage setting.' There is a 'Preset' button next to this message. At the bottom of the window are 'Close' and 'Help' buttons.

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Absolute Phase Noise (using dual channels)

☐ Apply channel #1 parameters to channel #2

Carrier Source

Frequency 1E+9 Hz Power 10 dBm

Detector Input Frequency

Frequency 1E+9 Hz

Reference Source

Frequency 1E+9 Hz Power 10 dBm

VCO Tuning Parameters

Nominal Tune Constant 10E+3 Hz / Volt Center Voltage 0 Volts

Tune Range +/- 1 Volts Input Resistance 1E+6 Ohms

Maximum Allowed Deviation from Center Voltage 1 Volts

The Tune Range is within the limits of
from +/- 0.20 to +/- 10.00 Volts,
as required by the current Center Voltage setting.

Preset

Close Help

1) Set Carrier Source Settings

Frequency: 1 GHz
Power: 14 dBm

Type and Range Sources CH#1 Sources CH#2 Cal CH#1 Cal CH#2 Block Diagram Test Set Graph

Absolute Phase Noise (using dual channels)
☐ Apply channel #1 parameters to channel #2

Carrier Source
Frequency 1E+9 Hz Power 14 dBm

Detector Input Frequency 1E+9 Hz

Reference Source
Frequency 1E+9 Hz Power 14 dBm

2) Set Detector Input Frequency

Detector Input Frequency: 1 GHz

☐ Apply channel #1 parameters to channel #2

Detector Input Frequency 1E+9 Hz

Reference Source
Frequency 1E+9 Hz Power 14 dBm

3) Set Reference Source Settings

Frequency: 1 GHz
Power: 14 dBm

☐ Apply channel #1 parameters to channel #2

Detector Input Frequency 1E+9 Hz

Reference Source
Frequency 1E+9 Hz Power 14 dBm

4) VCO Tuning Parameters

Nominal Tune Constant: 70 Hz/V
Tune Range: 5 V
Input resistance: 1 MOhm

VCO Tuning Parameters

Nominal Tune Constant 70 Hz / Volt Center Voltage 0 Volts
Tune Range +/- 500E-3 Volts Input Resistance 1E+6 Ohms
Maximum Allowed Deviation from Center Voltage 1 Volts

The Tune Range is within the limits of
from +/- 0.20 to +/- 10.00 Volts,
as required by the current Center Voltage setting.

Preset

5) Configure Source #2

Uncheck "Apply channel #1 parameters to channel #2". Navigate to Source #2 tab. Apply same frequency and VCO Tuning parameters as Source #1.

Cal Configuration

Navigate to the Cal tab.

The following window will appear:

Figure 6-15 Cal Tab

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Absolute Phase Noise (using dual phase locked loop)

☐ Apply channel #1 parameters to channel #2

Phase Detector Constant

☐ Use current phase detector constant

☐ Derive detector constant from measured beat note

☐ Derive detector constant from double - sided spur

☒ Derive detector constant from single - sided spur

Current Phase Detector Constant Volts / Radian

Known Spur Parameters

Offset Frequency Hz Amplitude dBc

VCO Tune Constant

☐ Use current VCO tune constant

☒ Measure VCO tune constant

☐ Calculate from expected VCO tune constant using tune port resistance

Current VCO Tune Constant Hz / Volt

Expected VCO Tune Constant Hz / Volt

Phase Locked Loop Suppression

☒ Verify calculated phase locked loop suppression ☐ Always Show Suppression Graph

Maximum Suppression Error Limit dB

If Limit is exceeded: ☐ Use theoretical values ☒ Use adjusted values ☐ Show Suppression Graph

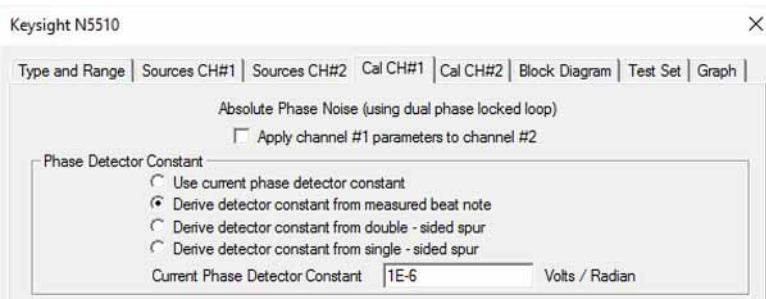
Preset

Close Help

For this tab we will use Beat Note Cal. Refer to the Cal Demo guide for details on using other cal methods.

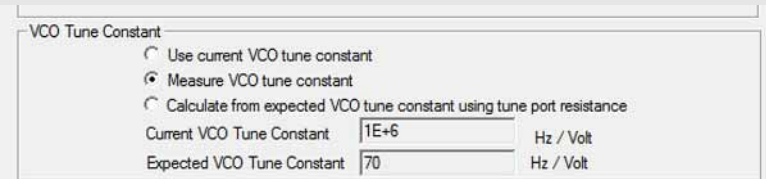
1) Configure Phase Detector
Constant Settings

Phase Detector Constant: Derive
detector constant from measured
beat note



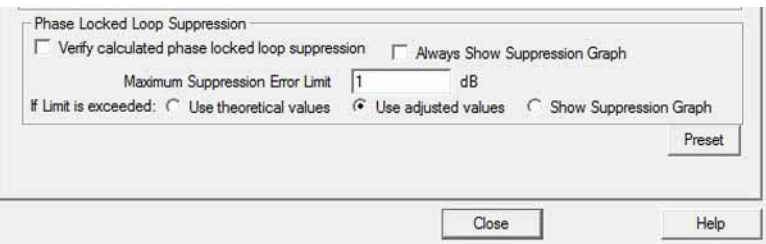
2) Configure VCO Tune
Constant Settings

VCO Tune Constant: Measure VCO
tune constant



3) Phase Locked Loop
Suppression

Uncheck "Verify calculated phase
locked loop suppression"



Block Diagram Configuration

Navigate to the Block Diagram tab.

The following window will appear:

Figure 6-16 Block Diagram Tab

The screenshot shows the 'Keysight N5510' software window with the 'Block Diagram' tab selected. The window title bar includes a close button (X). The tab bar at the top contains: 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram' (active), 'Test Set', and 'Graph'. The main content area is titled 'Absolute Phase Noise (using a phase locked loop)'. It contains several configuration sections: 'Carrier Source' with a 'check I/O' button and a dropdown menu set to '(manual)'; 'Phase Detector' with a dropdown menu set to 'Automatic Detector Selection'; a checkbox 'Use single reference source for both channels' which is unchecked; 'Reference Source Channel #1' and 'Reference Source Channel #2', each with a 'check I/O' button and a dropdown menu set to '(manual)'; 'Timebase' with a 'check I/O' button and a dropdown menu set to '(none)'; 'Test Set Tune Voltage' with 'Output' set to 'Front Panel' and 'Destination' set to 'Reference Source'; and 'VCO Tune Mode' with three radio buttons: 'EFC' (selected), 'DC FM', and 'DC FM 2'. At the bottom left is an 'Asset Manager' button, and at the bottom right is a 'Preset' button. The footer bar contains 'Close' and 'Help' buttons.

1) Phase Detector

Phase Detector: Automatic Detection
Selection

Phase Detector

Automatic Detector Selection

2) Test Set Tune Voltage

VCO Tune Mode: EFC

☐ Use single reference source for both channels

Reference Source Channel #1

check
I/O

(manual)

Reference Source Channel #2

check
I/O

(manual)

Test Set Tune Voltage

Output Front Panel

Destination Reference Source

VCO Tune Mode

☒ EFC

☐ DC FM

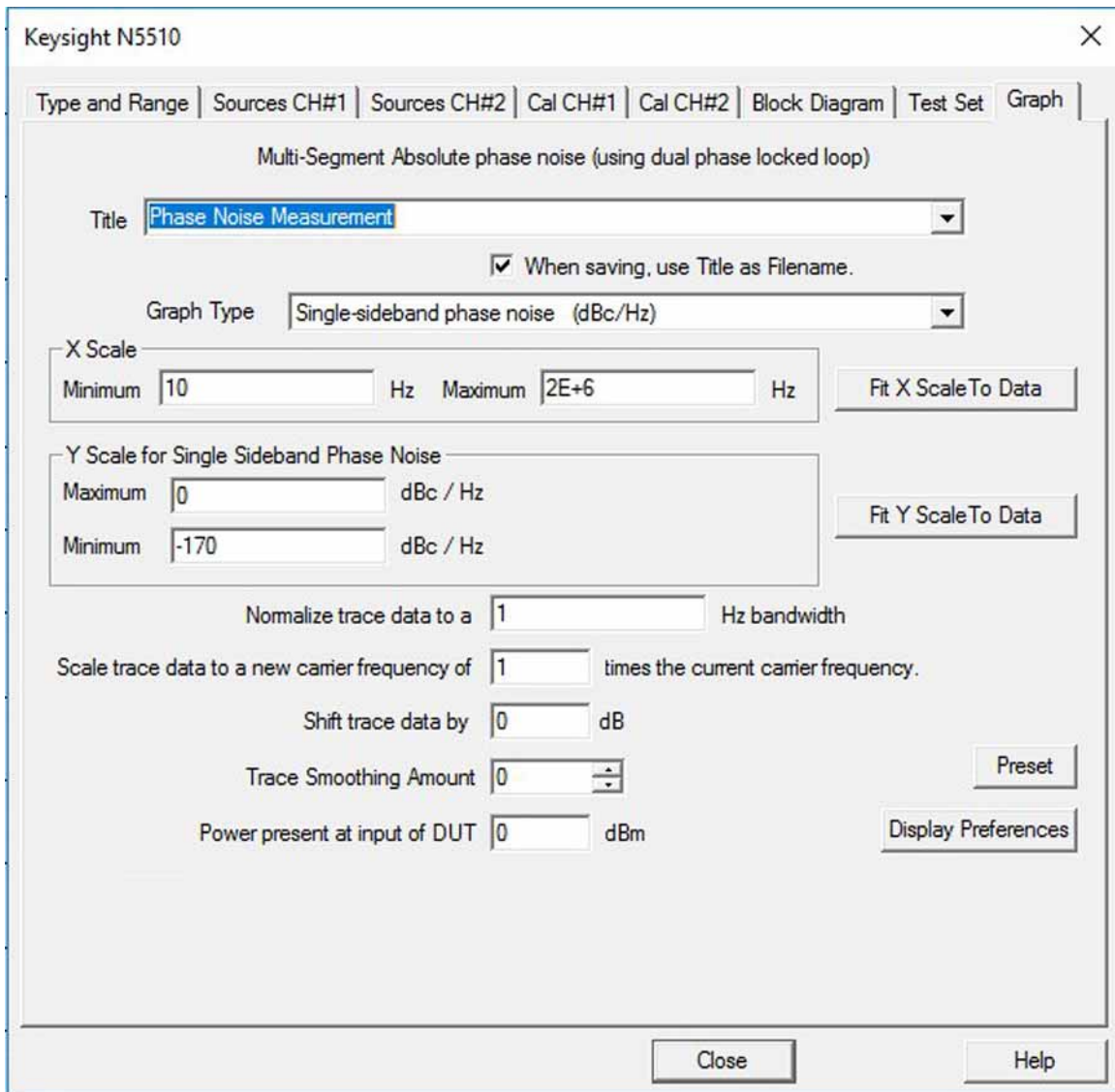
☐ DC FM 2

Configure Graph

Navigate to the Graph tab.

The following window will appear:

Figure 6-17 Graph Tab



The image shows the 'Graph' tab of the Keysight N5510 configuration window. The window has a title bar 'Keysight N5510' and a close button. Below the title bar is a tabbed interface with the following tabs: 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram', 'Test Set', and 'Graph'. The 'Graph' tab is selected. The main content area is titled 'Multi-Segment Absolute phase noise (using dual phase locked loop)'. It contains the following fields and controls:

- Title:** A dropdown menu with 'Phase Noise Measurement' selected.
- ☒ When saving, use Title as Filename.
- Graph Type:** A dropdown menu with 'Single-sideband phase noise (dBc/Hz)' selected.
- X Scale:** A group box containing:
 - Minimum:** A text field with '10' and a unit 'Hz'.
 - Maximum:** A text field with '2E+6' and a unit 'Hz'.
 - Fit X Scale To Data:** A button.
- Y Scale for Single Sideband Phase Noise:** A group box containing:
 - Maximum:** A text field with '0' and a unit 'dBc / Hz'.
 - Minimum:** A text field with '-170' and a unit 'dBc / Hz'.
 - Fit Y Scale To Data:** A button.
- Normalize trace data to a:** A text field with '1' and a unit 'Hz bandwidth'.
- Scale trace data to a new carrier frequency of:** A text field with '1' and a unit 'times the current carrier frequency'.
- Shift trace data by:** A text field with '0' and a unit 'dB'.
- Trace Smoothing Amount:** A text field with '0' and a spin button.
- Power present at input of DUT:** A text field with '0' and a unit 'dBm'.
- Preset:** A button.
- Display Preferences:** A button.

At the bottom of the window are two buttons: 'Close' and 'Help'.

1) Set Title

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph |

Multi-Segment Absolute phase noise (using dual phase locked loop)

Title

☒ When saving, use Title as Filename.

Graph Type

2) Set X-Scale

X -Scale Minimum: 10 Hz
X-Scale Maximum: 2 MHz

X Scale

Minimum Hz Maximum Hz

3) Set Y-Scale

Y-Scale Maximum: 0 dBc/Hz
Y-Scale Minimum: -170 dBc/Hz

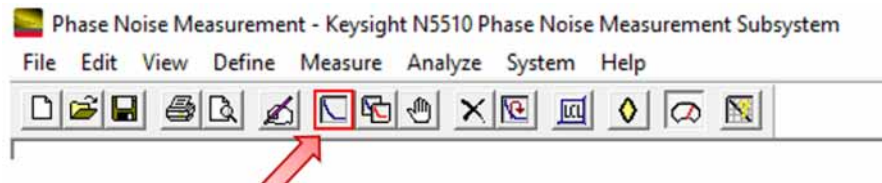
Y Scale for Single Sideband Phase Noise

Maximum dBc / Hz

Minimum dBc / Hz

New Measurement

Close Define Window. From the File Menu: **Measure, New Measurement.**

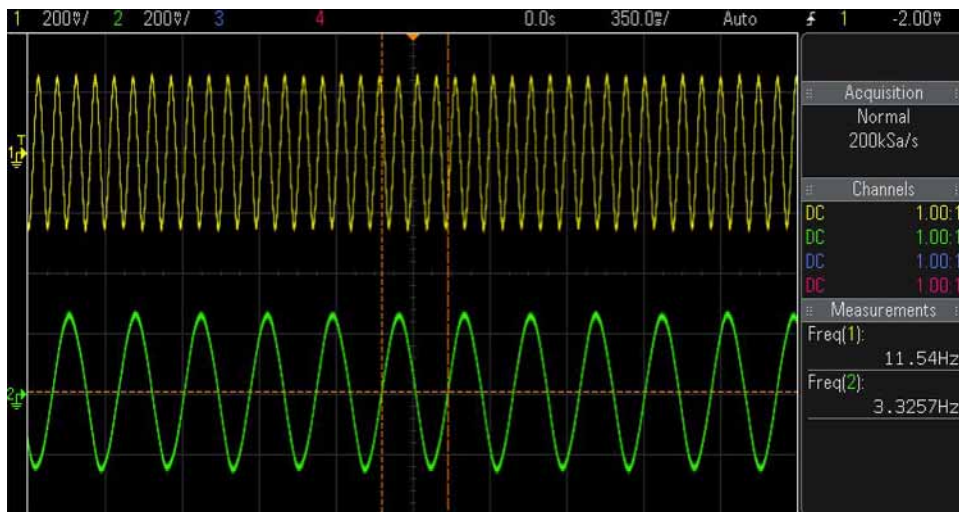


If the beat note is not within the frequency range required, the software will prompt to tune the reference.

Checking the Beat Note

Use an oscilloscope (connected to the Monitor port on the test set) or a counter to check the beat note being created between the reference source and your DUT.

Figure 6-18 Oscilloscope displaying monitor output of phase detector



The objective of checking the beat note is to ensure that the center frequencies of the two sources are close enough in frequency to create a beat note that is within the capture range of the system. The phase lock loop (PLL) capture range is 5% of the peak tuning range of the VCO source you are using. (The peak tuning range for your VCO can be estimated by multiplying the VCO tuning constant by the tune range of VCO. Refer to [Chapter 14, "Evaluating Your Measurement Results"](#) if you are not familiar with the relationship between the PLL capture range and the peak tuning range of the VCO. The beat note frequency is set by the relative frequency difference between the two sources. If you have two very accurate sources set at the same frequency, the resulting beat note will be very close to 0 Hz. Searching for the beat note will require that you adjust the center frequency of one of the sources above and below the frequency of the other source until the beat note appears on the

oscilloscope's display. If incrementing the frequency of one of the sources does not produce a beat note, you will need to verify the presence of an output signal from each source before proceeding.

NOTE

If the center frequencies of the sources are not close enough to create a beat note within the capture range, the system will not be able to complete its measurement.

Figure 6-19 shows the Manual Tune Pause Point, which is triggered during calibration if the beat note of one of the references is out of the desired range. The window will specify which channel needs to be tuned.

Figure 6-19 Manual Tune Pause Point

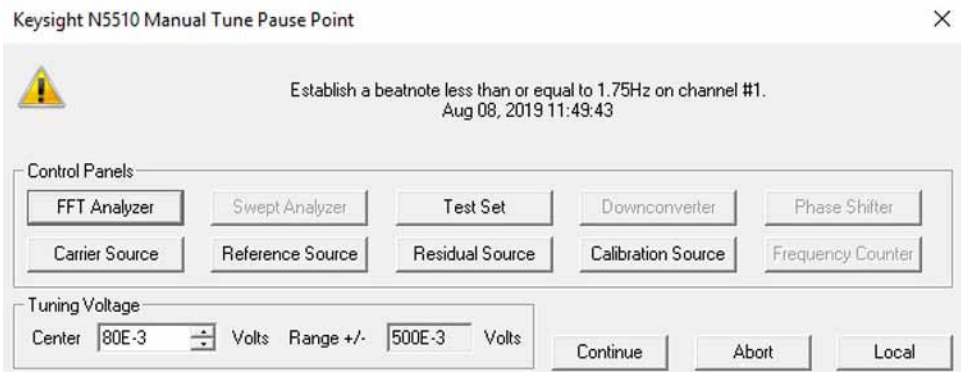
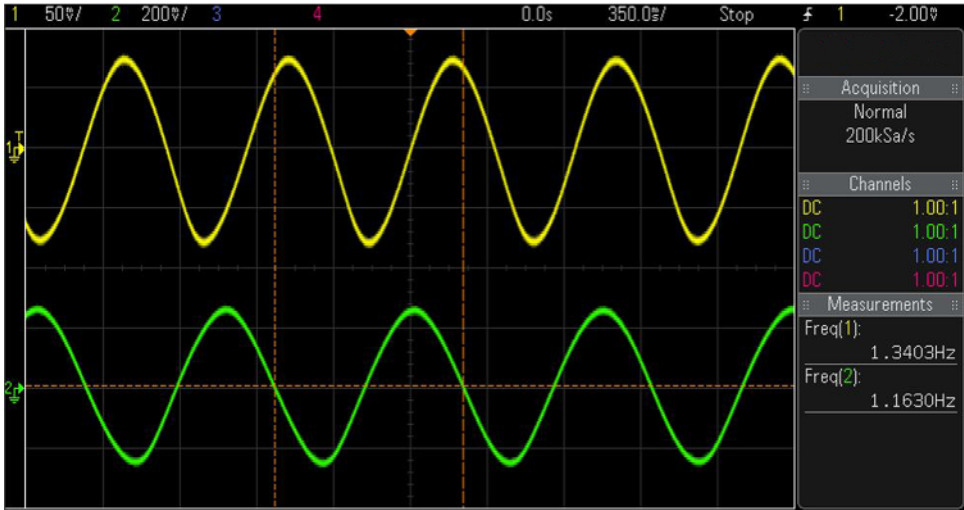


Figure 6-20 Oscilloscope display of beat notes from test set monitor ports



Click the **Continue** button on the tune pause window(s) when you have completed the beatnote check and are ready to make the measurement.

Absolute Measurement Examples Dual Channel (EFC)

When the measurement is complete, refer to **Chapter 14, “Evaluating Your Measurement Results”** for help in evaluating your measurement results. **Figure 6-21** shows the result of this measurement example.

Figure 6-21 Dual Channel (EFC) Measurement Results

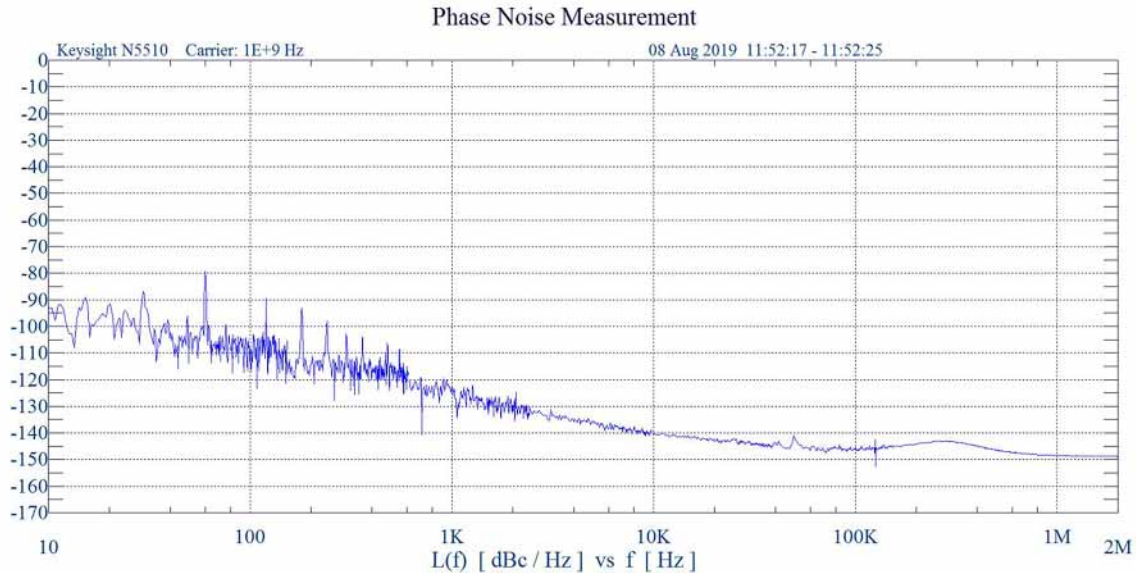
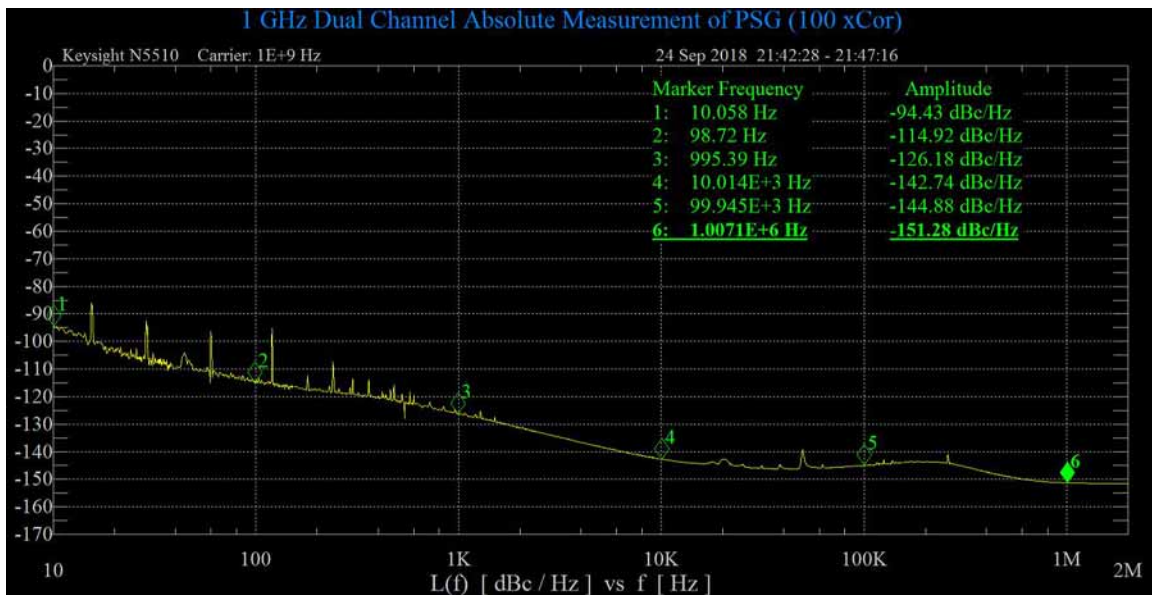


Figure 6-22 shows an identical measurement except with a higher number of cross-correlations.

Figure 6-22 Dual Channel Fast Measurement 100 cross-correlations (no averages) with markers



Absolute Measurement Examples
Dual Channel (DCFM)

Connectors on M9550A	Connects to
Green	Ext 1 on PSG reference
Purple	Oscilloscope
Red	DUT source RF (after splitter)
Blue	Reference Source RF out

NOTE

Both phase detector modules have identical connections using separate reference sources

1) CH 1 PLL Tune	Connect the Ch 1 PLL Tune Out port of the PNTS to the EXT1 port on the front of REF1 source using a BNC-to-BNC cable.
2) CH 2 PLL Tune	Connect the Ch 2 PLL Tune Out port of the PNTS to the EXT1 port on the front of REF2 sources using a BNC-to-BNC cable.
3) DUT RF to Splitter	Connect the RF output of the DUT to the RF splitter.
4) Splitter to RF IN 1	Connect splitter out 1 to the RF1 LB port of the PNTS using the 12-inch cable.
5) Splitter to RF IN 2	Connect splitter out 1 to the RF1 LB port of the PNTS using the 12-inch cable.
6) REF 1 to LO IN 1 PNTS	Connect the RF port of the REF1 source to the LO1 LB port of the PNTS using the 20-inch cable.
7) REF 2 to LO IN 2 PNTS	Connect the RF port of the REF2 source to the LO2 LB port of the PNTS using the 20-inch cable.
8) Oscilloscope	Connect SMB cables to the Monitor outputs on each of the phase detectors. Connect the other ends to the oscilloscope.

Configuring Equipment

Configure the equipment to the settings for this lab:

1) Power	Power on all the equipment: Keysight N5511A PNTS, PSGs
2) Set up the DUT	Frequency, 1 GHz Amplitude, 14 dBm RF On/Off, On
3) Set up REF 1	Frequency, 1 GHz Amplitude, 14 dBm FM, FM Dev, 1 kHz More, Ext Impedance, 600 Ohm RF On/Off, On Mod, On
4) Set up REF 2	Frequency, 1 GHz Amplitude, 14 dBm FM, FM Dev, 1 kHz More, Ext Impedance, 600 Ohm RF On/Off, On Mod, On

Measurement Procedure

Measurement Type and Range

At the top of the main application window, click "Define" and then select "Measurement..." from the drop-down menu.

Define, Measurement, Type and Range

The following window will appear:

Figure 6-24 Type and Range Tab

The screenshot shows the 'Keysight N5510' window with the 'Type and Range' tab selected. The 'Measurement Type' dropdown is set to 'Absolute Phase Noise (using phase locked loop)'. Under 'Measurement Method', 'Fast' is selected with a 'Start Offset Resolution Expansion' of 10. Under 'Channel Setup', 'Dual' is selected. The 'Measurement Settings' section includes 'Start Offset' (1 Hz), 'Stop Offset' (160E+6 Hz), 'FFT Analyzer Minimum Number of Trace Averages' (4), 'FFT Analyzer Minimum Number of Cross-correlations' (1), 'RBW %' (1.96 (1024 point FFT)), 'FFT Overlap %' (75), 'FFT Window Type' (BlackmanHarris4), and 'Estimated Measurement Time' (0). The 'FFT Quality' section has 'Normal' selected, with options for 'Fast', 'High Resolution', and 'Custom'. A 'View Segment Table' button is present. At the bottom, 'Couple Graph Type to Measurement Type' is checked, and there are 'Preset', 'Close', and 'Help' buttons.

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Measurement Type: Absolute Phase Noise (using phase locked loop)

Measurement Method:
☐ Flexible
☒ Fast Start Offset Resolution Expansion: 10

Channel Setup:
☐ Single
☒ Dual

Measurement Settings

Start Offset: 1 Hz Stop Offset: 160E+6 Hz

FFT Analyzer Minimum Number of Trace Averages: 4

FFT Analyzer Minimum Number of Cross-correlations: 1

RBW %: 1.96 (1024 point FFT)

FFT Overlap %: 75 FFT Window Type: BlackmanHarris4

Estimated Measurement Time: 0

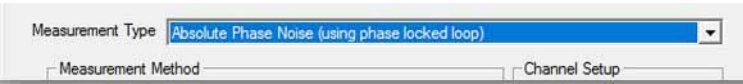
FFT Quality:
☒ Normal ☐ Fast ☐ High Resolution ☐ Custom View Segment Table

☒ Couple Graph Type to Measurement Type Preset

Close Help

1) Choose Measurement Type

Measurement Type: Absolute Phase Noise (using phase locked loop)



Measurement Type: Absolute Phase Noise (using phase locked loop)

2) Choose Measurement Method

Flexible is "single segment" measurement method where every segment is captured independently and after the previous segment has been measured (this is how E5500 measures).

Fast is "multi-segment", where segments are being measured in parallel. This option allows for a live view of the data acquisition of the measurement.

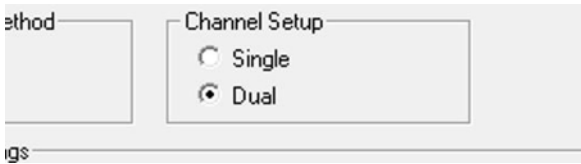
Measurement Method: Fast



Measurement Method: Fast Start Offset Resolution Expansion: 10

3) Choose Channel Setup

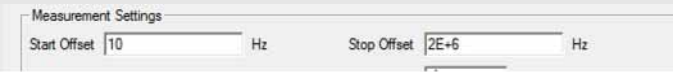
Channel Setup: Dual



Channel Setup: Dual

4) Set Start and Stop Offsets

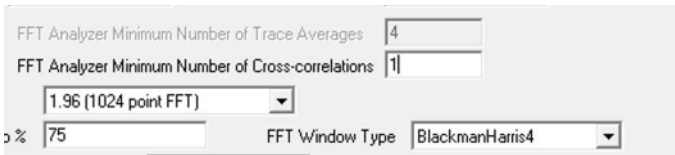
Start Offset: 10 Hz
Stop Offset: 2 MHz



Measurement Settings: Start Offset: 10 Hz Stop Offset: 2E+6 Hz

5) Set Number of Cross-Correlations

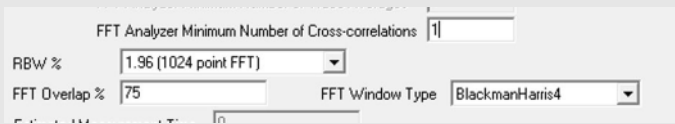
FFT Analyzer Minimum number of cross-correlations: 1



FFT Analyzer Minimum Number of Cross-correlations: 1
RBW %: 1.96 (1024 point FFT)
FFT Window Type: BlackmanHarris4

6) Set FFT Size

RBW %: 1.96 (1024 point FFT)



FFT Analyzer Minimum Number of Cross-correlations: 1
RBW %: 1.96 (1024 point FFT)
FFT Overlap %: 75
FFT Window Type: BlackmanHarris4

Source Configuration

Next, we will configure the settings for the DUT and the reference sources. Navigate to the Source tab at the top of the current window.

The following window will appear:

Figure 6-25 Source Tab

The screenshot shows the 'Keysight N5510' window with the 'Sources CH#1' tab selected. The window has a title bar with a close button (X) and a tab bar with the following tabs: 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram', 'Test Set', and 'Graph'. The main content area is titled 'Absolute Phase Noise (using dual channels)' and contains a checkbox 'Apply channel #1 parameters to channel #2' which is unchecked. Below this, there are three main sections: 'Carrier Source', 'Detector Input Frequency', and 'Reference Source'. The 'Carrier Source' section has 'Frequency' set to '1E+9' Hz and 'Power' set to '10' dBm. The 'Detector Input Frequency' section has 'Frequency' set to '1E+9' Hz. The 'Reference Source' section has 'Frequency' set to '1E+9' Hz and 'Power' set to '10' dBm. Below these sections is the 'VCO Tuning Parameters' section, which includes 'Nominal Tune Constant' set to '10E+3' Hz / Volt, 'Center Voltage' set to '0' Volts, 'Tune Range +/-' set to '1' Volts, 'Input Resistance' set to '1E+6' Ohms, and 'Maximum Allowed Deviation from Center Voltage' set to '1' Volts. A note states: 'The Tune Range is within the limits of from +/- 0.20 to +/- 10.00 Volts, as required by the current Center Voltage setting.' There is a 'Preset' button to the right of this note. At the bottom of the window are 'Close' and 'Help' buttons.

Keysight N5510

Type and Range Sources CH#1 Sources CH#2 Cal CH#1 Cal CH#2 Block Diagram Test Set Graph

Absolute Phase Noise (using dual channels)

☐ Apply channel #1 parameters to channel #2

Carrier Source

Frequency 1E+9 Hz Power 10 dBm

Detector Input Frequency

1E+9 Hz

Reference Source

Frequency 1E+9 Hz Power 10 dBm

VCO Tuning Parameters

Nominal Tune Constant 10E+3 Hz / Volt Center Voltage 0 Volts

Tune Range +/- 1 Volts Input Resistance 1E+6 Ohms

Maximum Allowed Deviation from Center Voltage 1 Volts

The Tune Range is within the limits of
from +/- 0.20 to +/- 10.00 Volts,
as required by the current Center Voltage setting.

Preset

Close Help

1) Set Carrier Source Settings

Frequency: 1 GHz
Power: 14 dBm

Type and Range Sources CH#1 Sources CH#2 Cal CH#1 Cal CH#2 Block Diagram Test Set Graph

Absolute Phase Noise (using dual channels)
☐ Apply channel #1 parameters to channel #2

Carrier Source
Frequency 1E+9 Hz Power 14 dBm

Detector Input Frequency
1E+9 Hz

Reference Source
Frequency 1E+9 Hz Power 14 dBm

2) Set Detector Input Frequency

Detector Input Frequency: 1 GHz

☐ Apply channel #1 parameters to channel #2

Detector Input Frequency
1E+9 Hz

Reference Source
Frequency 1E+9 Hz Power 14 dBm

3) Set Reference Source Settings

Frequency: 1 GHz
Power: 14 dBm

☐ Apply channel #1 parameters to channel #2

Detector Input Frequency
1E+9 Hz

Reference Source
Frequency 1E+9 Hz Power 14 dBm

4) VCO Tuning Parameters

Nominal Tune Constant: 1000 Hz/V
Tune Range: 1 V
Input resistance: 1 MOhm

VCO Tuning Parameters

Nominal Tune Constant 1E+3 Hz / Volt Center Voltage 0 Volts

Tune Range +/- 1 Volts Input Resistance 600 Ohms

Maximum Allowed Deviation from Center Voltage 1 Volts

The Tune Range is within the limits of
from +/- 0.20 to +/- 10.00 Volts.

Preset

5) Configure Source #2

Uncheck "Apply channel #1 parameters to channel #2". Navigate to Source #2 tab. Apply same frequency and VCO Tuning parameters as Source #1.

Cal Configuration

Navigate to the Cal tab.

The following window will appear:

Figure 6-26 Cal Tab

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Absolute Phase Noise (using dual phase locked loop)

☐ Apply channel #1 parameters to channel #2

Phase Detector Constant

☐ Use current phase detector constant

☐ Derive detector constant from measured beat note

☐ Derive detector constant from double - sided spur

☒ Derive detector constant from single - sided spur

Current Phase Detector Constant Volts / Radian

Known Spur Parameters

Offset Frequency Hz Amplitude dBc

VCO Tune Constant

☐ Use current VCO tune constant

☒ Measure VCO tune constant

☐ Calculate from expected VCO tune constant using tune port resistance

Current VCO Tune Constant Hz / Volt

Expected VCO Tune Constant Hz / Volt

Phase Locked Loop Suppression

☒ Verify calculated phase locked loop suppression ☐ Always Show Suppression Graph

Maximum Suppression Error Limit dB

If Limit is exceeded: ☐ Use theoretical values ☒ Use adjusted values ☐ Show Suppression Graph

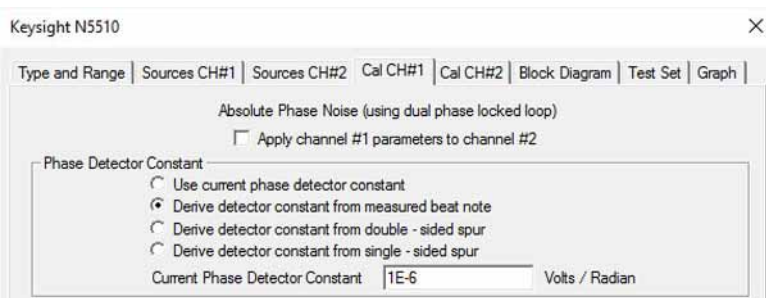
Preset

Close Help

For this tab we will use Beat Note Cal. Refer to the Cal Demo guide for details on using other cal methods.

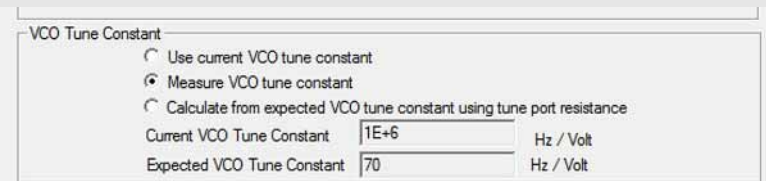
1) Configure Phase Detector Constant Settings

Phase Detector Constant: Derive detector constant from measured beat note



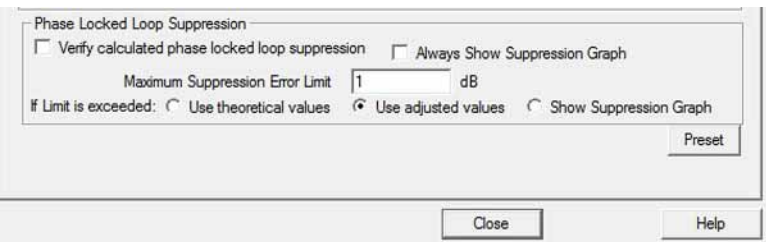
2) Configure VCO Tune Constant Settings

VCO Tune Constant: Measure VCO tune constant



3) Phase Locked Loop Suppression

Uncheck "Verify calculated phase locked loop suppression"



Block Diagram Configuration

Navigate to the Block Diagram tab.

The following window will appear:

Figure 6-27 Block Diagram Tab

The screenshot shows the 'Keysight N5510' software window with the 'Block Diagram' tab selected. The window title bar includes a close button (X). The tab bar at the top contains: 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram' (active), 'Test Set', and 'Graph'. The main content area is titled 'Absolute Phase Noise (using a phase locked loop)'. It contains several configuration sections: 'Carrier Source' with a 'check I/O' button and a dropdown menu set to '(manual)'; 'Phase Detector' with a dropdown menu set to 'Automatic Detector Selection'; a checkbox 'Use single reference source for both channels' which is unchecked; 'Reference Source Channel #1' and 'Reference Source Channel #2', each with a 'check I/O' button and a dropdown menu set to '(manual)'; 'Timebase' with a 'check I/O' button and a dropdown menu set to '(none)'; 'Test Set Tune Voltage' with 'Output' set to 'Front Panel' and 'Destination' set to 'Reference Source'; and 'VCO Tune Mode' with three radio buttons: 'EFC' (selected), 'DC FM', and 'DC FM 2'. At the bottom left is an 'Asset Manager' button, and at the bottom right is a 'Preset' button. The footer bar contains 'Close' and 'Help' buttons.

1) Phase Detector

Phase Detector: Automatic Detection
Selection

Phase Detector

Automatic Detector Selection

2) Test Set Tune Voltage

VCO Tune Mode: DCFM

Test Set Tune Voltage

OutputFront Panel

DestinationReference Source

VCO Tune Mode

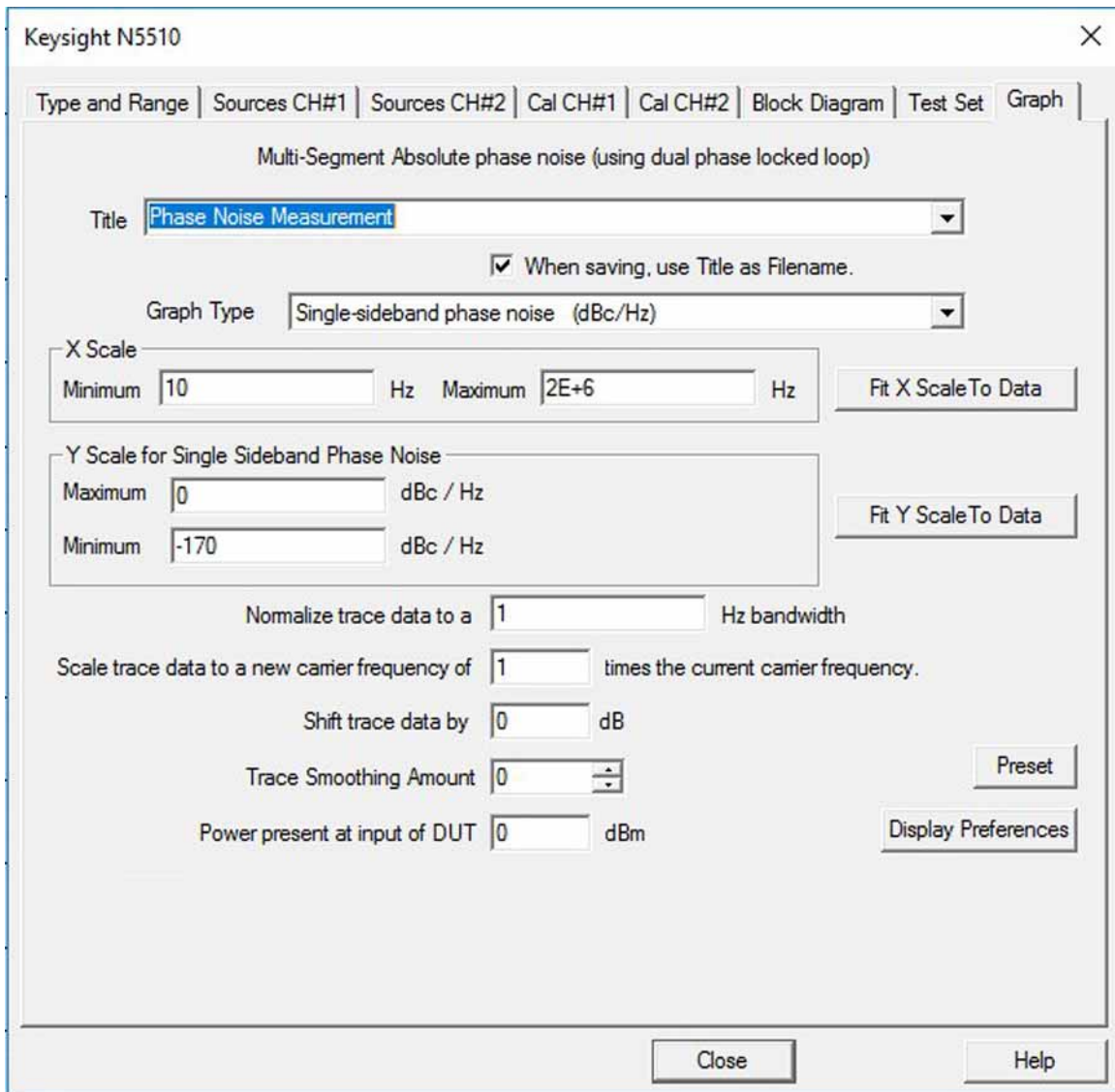
☐ EFC☒ DC FM☐ DC FM 2

Configure Graph

Navigate to the Graph tab.

The following window will appear:

Figure 6-28 Graph Tab



The image shows the 'Graph' tab of the Keysight N5510 configuration window. The window has a title bar 'Keysight N5510' and a close button. Below the title bar is a tabbed interface with the following tabs: 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram', 'Test Set', and 'Graph'. The 'Graph' tab is selected. The main content area is titled 'Multi-Segment Absolute phase noise (using dual phase locked loop)'. It contains the following fields and controls:

- Title:** A dropdown menu with 'Phase Noise Measurement' selected.
- ☒ When saving, use Title as Filename.
- Graph Type:** A dropdown menu with 'Single-sideband phase noise (dBc/Hz)' selected.
- X Scale:** A group box containing:
 - Minimum:** 10 Hz
 - Maximum:** 2E+6 Hz
 - Fit X Scale To Data:** A button.
- Y Scale for Single Sideband Phase Noise:** A group box containing:
 - Maximum:** 0 dBc / Hz
 - Minimum:** -170 dBc / Hz
 - Fit Y Scale To Data:** A button.
- Normalize trace data to a:** 1 Hz bandwidth
- Scale trace data to a new carrier frequency of:** 1 times the current carrier frequency.
- Shift trace data by:** 0 dB
- Trace Smoothing Amount:** 0 (with a spin button)
- Power present at input of DUT:** 0 dBm
- Preset:** A button.
- Display Preferences:** A button.

At the bottom of the window are two buttons: 'Close' and 'Help'.

1) Set Title

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Multi-Segment Absolute phase noise (using dual phase locked loop)

Title

Phase Noise Measurement

☒ When saving, use Title as Filename.

Graph Type

Single-sideband phase noise (dBc/Hz)

2) Set X-Scale

X -Scale Minimum: 10 Hz
X-Scale Maximum: 2 MHz

X Scale

Minimum

10

 Hz Maximum

2E+6

 Hz

Fit X Scale To Data

3) Set Y-Scale

Y-Scale Maximum: 0 dBc/Hz
Y-Scale Minimum: -170 dBc/Hz

Y Scale for Single Sideband Phase Noise

Maximum

0

 dBc / Hz

Minimum

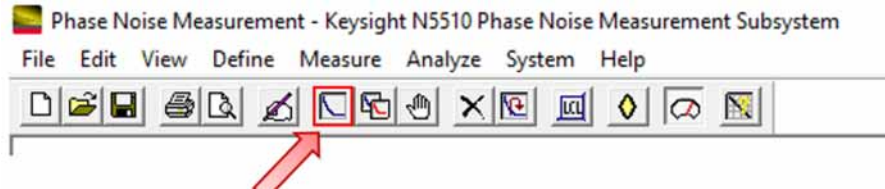
-170

 dBc / Hz

Fit Y Scale To Data

New Measurement

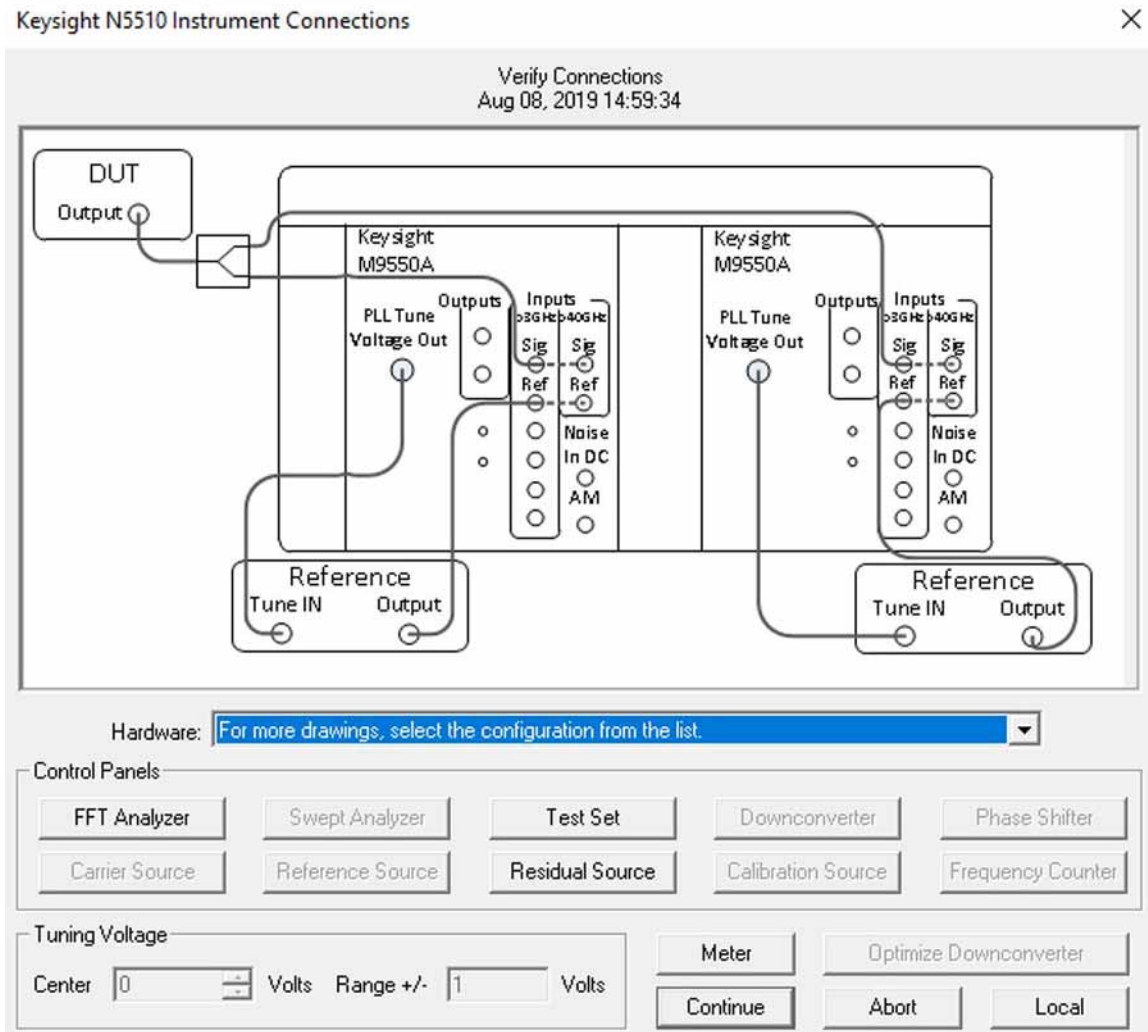
Close Define Window. From the File Menu: **Measure, New Measurement.**



Connection Diagram:

If connection diagram is enabled (see [Chapter 4, “Expanding Your Measurement Experience”](#)), verify the connections as indicated by the diagram, and click **Continue**.

Figure 6-29 Instrument Connections



If the beat note is not within the frequency range required, the software will prompt to tune the reference.

Checking the Beat Note

Use an oscilloscope (connected to the monitor port on the test set) or a counter to check the beat note being created between the reference source and your DUT in each channel. The objective of checking the beat note is to ensure that the center frequencies of the two references are close enough in frequency with the DUT to create a beatnote that is within the capture range of the system.

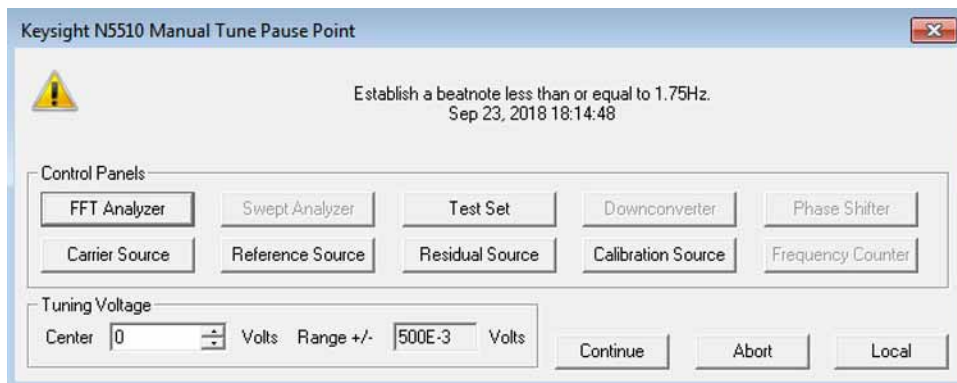
The phase lock loop (PLL) capture range is 5% of the peak tuning range of the VCO source you are using. (The peak tuning range for your VCO can be estimated by multiplying the VCO tuning constant by the tune range of VCO. Refer to [Chapter 14, “Evaluating Your Measurement Results”](#) if you are not familiar with the relationship between the PLL capture range and the peak tuning range of the VCO. The beat note frequency is set by the relative frequency difference between the two sources. If you have two very accurate sources set at the same frequency, the resulting beat note will be very close to 0 Hz. Searching for the beat note will require that you adjust the center frequency of one of the sources above and below the frequency of the other source until the beat note appears on the oscilloscope's display. If incrementing the frequency of one of the sources does not produce a beat note, you will need to verify the presence of an output signal from each source before proceeding.

NOTE

If the center frequencies of the sources are not close enough to create a beat note within the capture range, the system will not be able to complete its measurement.

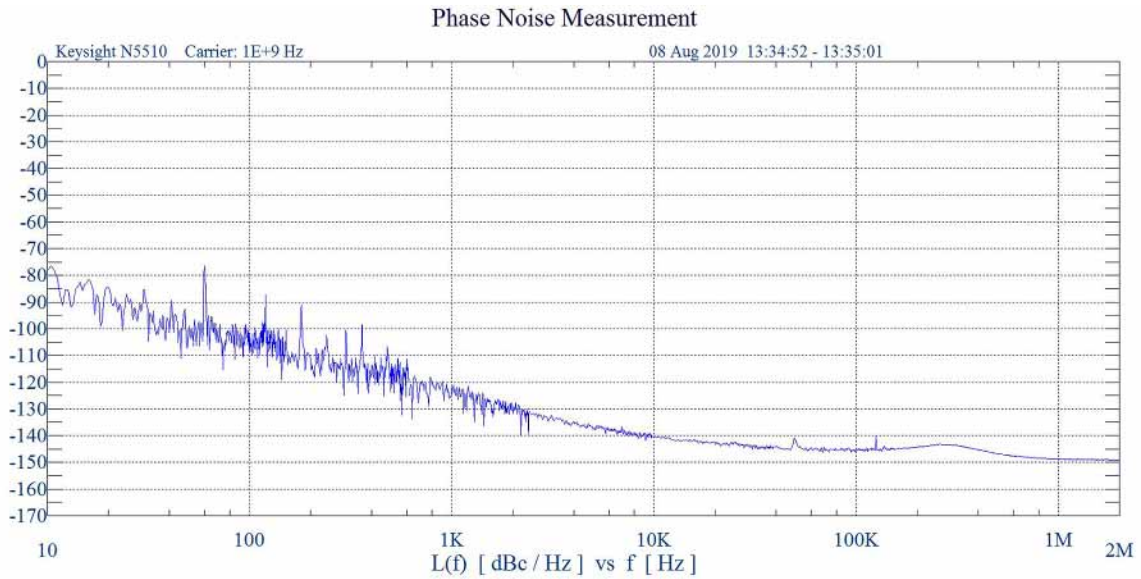
Figure 6-30 shows the Manual Tune Pause Point, which is triggered during calibration if the beat note of one of the references is out of the desired range. The window will specify which channel needs to be tuned.

Figure 6-30 Manual Tune Pause Point



When the measurement is complete, refer to [Chapter 14, “Evaluating Your Measurement Results”](#) for help in evaluating your measurement results. [Figure 6-31](#) shows the result of this measurement example.

Figure 6-31 Dual Channel (DCFM) Measurement Results



OCXO Dual Channel Measurement

This measurement example will help you measure the absolute phase noise of a stable OCXO.

CAUTION

To prevent damage to the test system's hardware components, verify that the input signal is within the test system's power limits. Refer to the N5511A Data Sheet online.

Required equipment

- DUT
- References (must be tunable and at the same frequency as the DUT)
- Cables (x7) and adapters to connect DUT, reference RFs, and reference V_{tune} ports

NOTE

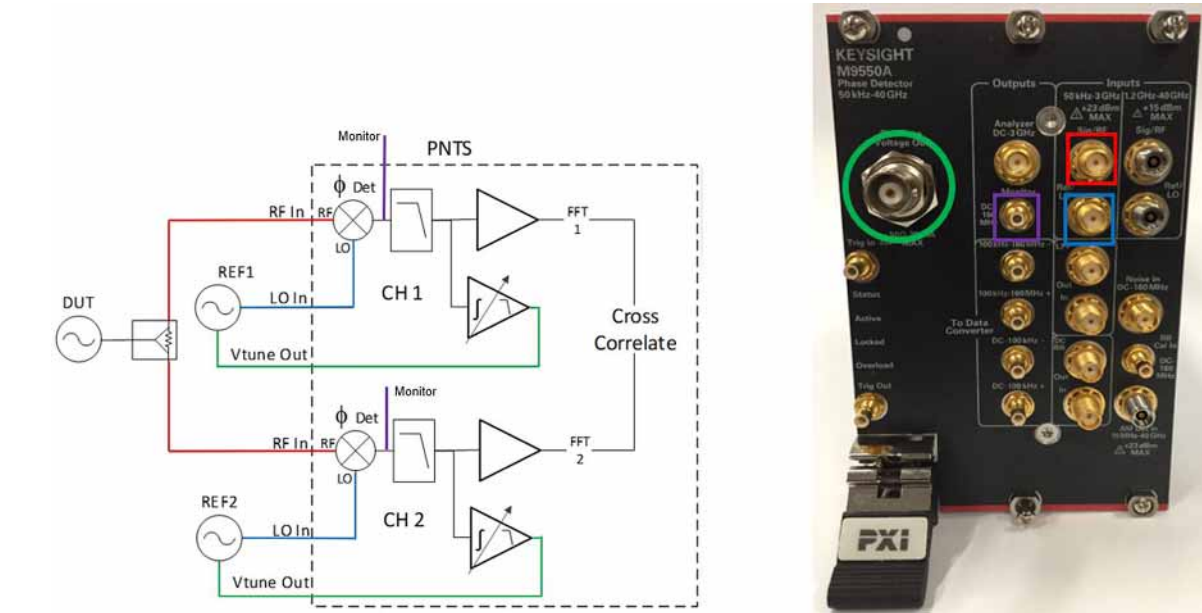
The most ideal references are devices that are of identical or even better phase noise performance than the DUT. This will minimize the amount of cross-correlations needed to measure the DUT. This example features a 10 MHz OCXO in the PSG option UNY as a DUT, using two identical OCXOs as references.

- Keysight N5511A Phase Noise Test System
- Oscilloscope: Keysight InfiniVision MSO-X 3054A (or similar with high-impedance inputs)
- SMB-BNC cables (x2) to connect monitor outputs to oscilloscope
- Power Divider (operational at carrier frequency)

Test Setup

Figure 6-32 shows the configuration used for an OCXO Dual Channel measurement.

Figure 6-32 OCXO Dual Channel measurement configuration



Connectors on M9550A	Connects to
Green	V _{tune} port of reference
Purple	Scope monitor
Red	DUT source RF (after splitter)
Blue	Reference Source RF out

NOTE

Both phase detector modules have identical connections using separate reference sources

Absolute Measurement Examples
OCXO Dual Channel Measurement

1) CH 1 PLL Tune	Connect the Ch 1 PLL Tune Out port of the PNTS to the V_{tune} port on the front of OCXO REF1.
2) CH 2 PLL Tune	Connect the Ch 2 PLL Tune Out port of the PNTS to the V_{tune} port on the front of OCXO REF2.
3) DUT RF to Splitter	Connect the RF output of the DUT to the RF splitter.
4) Splitter to RF IN 1	Connect splitter out 1 to the RF1 LB port of the PNTS using the 12-inch cable.
5) Splitter to RF IN 2	Connect splitter out 1 to the RF1 LB port of the PNTS using the 12-inch cable.
6) REF 1 to LO IN 1 PNTS	Connect the RF port of the REF1 OCXO to the LO IN1 LB port of the PNTS.
7) REF 2 to LO IN 2 PNTS	Connect the RF port of the REF2 OCXO to the LO IN2 LB port of the PNTS.
8) Oscilloscope	Connect SMB cables to the Monitor outputs on each of the phase detectors. Connect the other ends to the oscilloscope.

Configuring Equipment

Configure the equipment to the settings for this lab:

1) Power

Power on all the equipment: Keysight N5511A PNTS, DUT OCXO, Reference OCXOs. Allow for oscillators to warm up according to their specifications in order to perform an optimum measurement.

Measurement Procedure

Measurement Type and Range

At the top of the main application window, click "Define" and then select "Measurement..." from the drop-down menu.

Define, Measurement, Type and Range

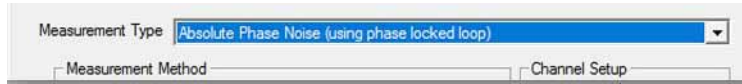
The following window will appear:

Figure 6-33 Type and Range Tab

The screenshot shows the 'Keysight N5510' application window with the 'Type and Range' tab selected. The window has a title bar with a close button (X) and a menu bar with options: Type and Range, Sources CH#1, Sources CH#2, Cal CH#1, Cal CH#2, Block Diagram, Test Set, and Graph. The 'Measurement Type' dropdown is set to 'Absolute Phase Noise (using phase locked loop)'. Below this, the 'Measurement Method' section has radio buttons for 'Flexible' and 'Fast' (selected), with a 'Start Offset Resolution Expansion' field set to '10'. The 'Channel Setup' section has radio buttons for 'Single' and 'Dual' (selected). The 'Measurement Settings' section includes 'Start Offset' (1 Hz), 'Stop Offset' (160E+6 Hz), 'FFT Analyzer Minimum Number of Trace Averages' (4), 'FFT Analyzer Minimum Number of Cross-correlations' (1), 'RBW %' (1.96 (1024 point FFT)), 'FFT Overlap %' (75), 'FFT Window Type' (BlackmanHarris4), and 'Estimated Measurement Time' (0). The 'FFT Quality' section has radio buttons for 'Normal' (selected), 'Fast', 'High Resolution', and 'Custom', along with a 'View Segment Table' button. At the bottom, there is a checkbox for 'Couple Graph Type to Measurement Type' (checked) and a 'Preset' button. The window also has 'Close' and 'Help' buttons at the bottom right.

1) Choose Measurement Type

Measurement Type: Absolute Phase Noise (using phase locked loop)



Measurement Type: Absolute Phase Noise (using phase locked loop)

Measurement Method: Channel Setup

2) Choose Measurement Method

Flexible is "single segment" measurement method where every segment is captured independently and after the previous segment has been measured (this is how E5500 measures).

Fast is "multi-segment", where segments are being measured in parallel. This option allows for a live view of the data acquisition of the measurement.

Measurement Method: Fast



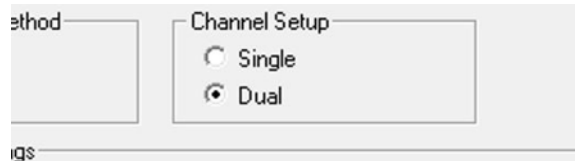
Measurement Method

☐ Flexible

☒ Fast Start Offset Resolution Expansion: 10

3) Choose Channel Setup

Channel Setup: Dual



Channel Setup

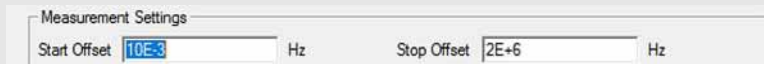
☐ Single

☒ Dual

4) Set Start and Stop Offsets

Start Offset: .01 Hz

Stop Offset: 2 MHz

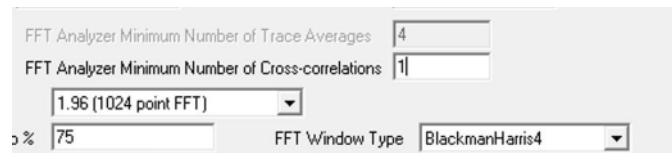


Measurement Settings

Start Offset: 10E-3 Hz Stop Offset: 2E+6 Hz

5) Set Number of Cross-Correlations

FFT Analyzer Minimum number of cross-correlations: 1



FFT Analyzer Minimum Number of Trace Averages: 4

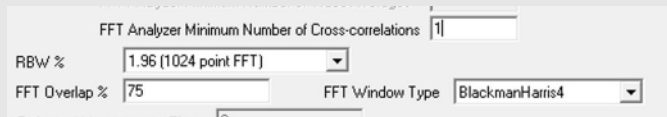
FFT Analyzer Minimum Number of Cross-correlations: 1

RBW %: 1.96 (1024 point FFT)

FFT Window Type: BlackmanHarris4

6) Set FFT Size

RBW %: 1.96 (1024 point FFT)



FFT Analyzer Minimum Number of Cross-correlations: 1

RBW %: 1.96 (1024 point FFT)

FFT Overlap %: 75 FFT Window Type: BlackmanHarris4

Source Configuration

Next, we will configure the settings for the DUT and the reference sources. Navigate to the Source tab at the top of the current window.

The following window will appear:

Figure 6-34 Source Tab

The screenshot shows the 'Keysight N5510' window with the 'Sources CH#1' tab selected. The window has a title bar with a close button (X) and a tab bar with the following tabs: 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram', 'Test Set', and 'Graph'. The main content area is titled 'Absolute Phase Noise (using dual channels)' and contains a checkbox 'Apply channel #1 parameters to channel #2' which is unchecked. Below this, there are three main sections: 'Carrier Source', 'Detector Input Frequency', and 'Reference Source'. The 'Carrier Source' section has 'Frequency' set to '1E+9' Hz and 'Power' set to '10' dBm. The 'Detector Input Frequency' section has 'Frequency' set to '1E+9' Hz. The 'Reference Source' section has 'Frequency' set to '1E+9' Hz and 'Power' set to '10' dBm. Below these sections is the 'VCO Tuning Parameters' section, which includes 'Nominal Tune Constant' set to '10E+3' Hz / Volt, 'Center Voltage' set to '0' Volts, 'Tune Range +/-' set to '1' Volts, 'Input Resistance' set to '1E+6' Ohms, and 'Maximum Allowed Deviation from Center Voltage' set to '1' Volts. A message states: 'The Tune Range is within the limits of from +/- 0.20 to +/- 10.00 Volts, as required by the current Center Voltage setting.' There is a 'Preset' button to the right of this message. At the bottom of the window are 'Close' and 'Help' buttons.

Keysight N5510

Type and Range Sources CH#1 Sources CH#2 Cal CH#1 Cal CH#2 Block Diagram Test Set Graph

Absolute Phase Noise (using dual channels)

☐ Apply channel #1 parameters to channel #2

Carrier Source

Frequency 1E+9 Hz Power 10 dBm

Detector Input Frequency

1E+9 Hz

Reference Source

Frequency 1E+9 Hz Power 10 dBm

VCO Tuning Parameters

Nominal Tune Constant 10E+3 Hz / Volt Center Voltage 0 Volts

Tune Range +/- 1 Volts Input Resistance 1E+6 Ohms

Maximum Allowed Deviation from Center Voltage 1 Volts

The Tune Range is within the limits of
from +/- 0.20 to +/- 10.00 Volts,
as required by the current Center Voltage setting.

Preset

Close Help

Absolute Measurement Examples

OCXO Dual Channel Measurement

1) Set Carrier Source Settings

Frequency: 10 MHz
Power: 10 dBm

Carrier Source		
Frequency	10E+6	Hz
Power	10	dBm

2) Set Detector Input Frequency

Detector Input Frequency: 10 MHz

Detector Input Frequency			Reference Source		
Frequency	10E+6	Hz	Frequency	10E+6	Hz
			Power	10	dBm

3) Set Reference Source Settings

Frequency: 10 MHz
Power: 10 dBm

Detector Input Frequency			Reference Source		
Frequency	10E+6	Hz	Frequency	10E+6	Hz
			Power	10	dBm

4) VCO Tuning Parameters

Nominal Tune Constant: .7 Hz/V
Tune Range: .5 V
Input resistance: 1 MOhm

VCO Tuning Parameters					
Nominal Tune Constant	700E-3	Hz / Volt	Center Voltage	0	Volts
Tune Range +/-	500E-3	Volts	Input Resistance	1E+6	Ohms
Maximum Allowed Deviation from Center Voltage				1	Volts
The Tune Range is within the limits of from +/- 0.20 to +/- 10.00 Volts, as required by the current Center Voltage setting.					
					Preset

5) Configure Source #2

Uncheck "Apply channel #1 parameters to channel #2". Navigate to Source #2 tab. Apply same frequency and VCO Tuning parameters as Source #1.

Cal Configuration

Navigate to the Cal tab.

The following window will appear:

Figure 6-35 Cal Tab

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Absolute Phase Noise (using dual phase locked loop)

☐ Apply channel #1 parameters to channel #2

Phase Detector Constant

- ☐ Use current phase detector constant
- ☐ Derive detector constant from measured beat note
- ☐ Derive detector constant from double - sided spur
- ☒ Derive detector constant from single - sided spur

Current Phase Detector Constant Volts / Radian

Known Spur Parameters

Offset Frequency Hz Amplitude dBc

VCO Tune Constant

- ☐ Use current VCO tune constant
- ☒ Measure VCO tune constant
- ☐ Calculate from expected VCO tune constant using tune port resistance

Current VCO Tune Constant Hz / Volt

Expected VCO Tune Constant Hz / Volt

Phase Locked Loop Suppression

☒ Verify calculated phase locked loop suppression ☐ Always Show Suppression Graph

Maximum Suppression Error Limit dB

If Limit is exceeded: ☐ Use theoretical values ☒ Use adjusted values ☐ Show Suppression Graph

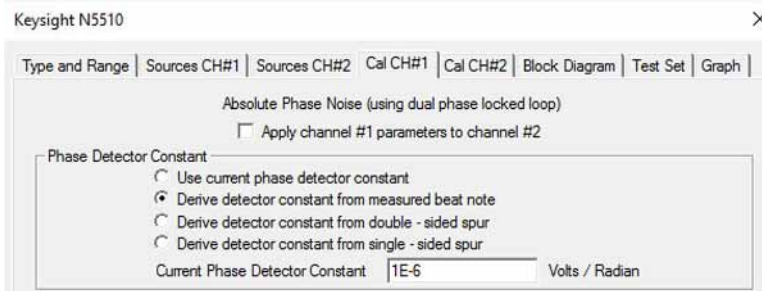
Preset

Close Help

For this tab we will use Beat Note Cal. Refer to the Cal Demo guide for details on using other cal methods.

1) Configure Phase Detector Constant Settings

Phase Detector Constant: Derive detector constant from measured beat note



Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph

Absolute Phase Noise (using dual phase locked loop)

☐ Apply channel #1 parameters to channel #2

Phase Detector Constant

☐ Use current phase detector constant

☒ Derive detector constant from measured beat note

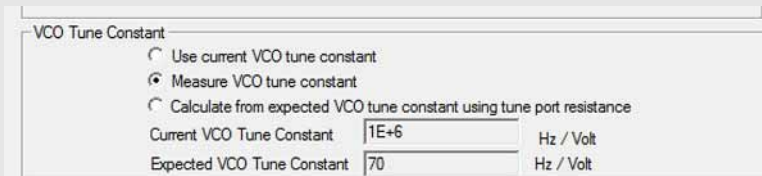
☐ Derive detector constant from double - sided spur

☐ Derive detector constant from single - sided spur

Current Phase Detector Constant Volts / Radian

2) Configure VCO Tune Constant Settings

VCO Tune Constant: Measure VCO tune constant



VCO Tune Constant

☐ Use current VCO tune constant

☒ Measure VCO tune constant

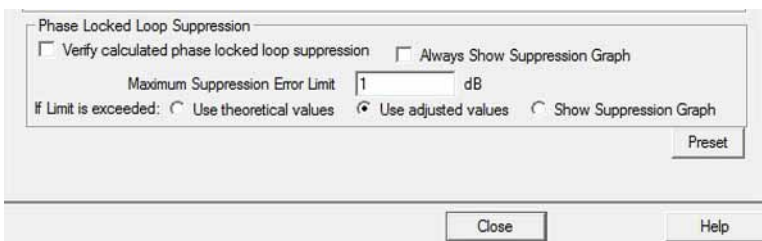
☐ Calculate from expected VCO tune constant using tune port resistance

Current VCO Tune Constant Hz / Volt

Expected VCO Tune Constant Hz / Volt

3) Phase Locked Loop Suppression

Uncheck "Verify calculated phase locked loop suppression"



Phase Locked Loop Suppression

☐ Verify calculated phase locked loop suppression ☐ Always Show Suppression Graph

Maximum Suppression Error Limit dB

If Limit is exceeded: ☐ Use theoretical values ☒ Use adjusted values ☐ Show Suppression Graph

Preset

Close Help

Block Diagram Configuration

Navigate to the Block Diagram tab.

The following window will appear:

Figure 6-36 Block Diagram Tab

The screenshot shows the 'Keysight N5510' software window with the 'Block Diagram' tab selected. The window title is 'Keysight N5510'. The tabs at the top are 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram', 'Test Set', and 'Graph'. The main area is titled 'Absolute Phase Noise (using a phase locked loop)'. It contains several configuration sections: 'Carrier Source' with a 'check I/O' button and a dropdown menu set to '(manual)'; 'Phase Detector' with a dropdown menu set to 'Automatic Detector Selection'; a checkbox 'Use single reference source for both channels' which is unchecked; 'Reference Source Channel #1' and 'Reference Source Channel #2' each with a 'check I/O' button and a dropdown menu set to '(manual)'; 'Timebase' with a 'check I/O' button and a dropdown menu set to '(none)'; 'Test Set Tune Voltage' with 'Output' set to 'Front Panel' and 'Destination' set to 'Reference Source'; and 'VCO Tune Mode' with three radio buttons: 'EFC' (selected), 'DC FM', and 'DC FM 2'. At the bottom left is an 'Asset Manager' button, and at the bottom right is a 'Preset' button. The very bottom of the window has 'Close' and 'Help' buttons.

1) Phase Detector

Phase Detector: Automatic Detection
Selection

Phase Detector

Automatic Detector Selection

2) Test Set Tune Voltage

VCO Tune Mode: EFC

Test Set Tune Voltage

OutputFront Panel

DestinationReference Source

VCO Tune Mode

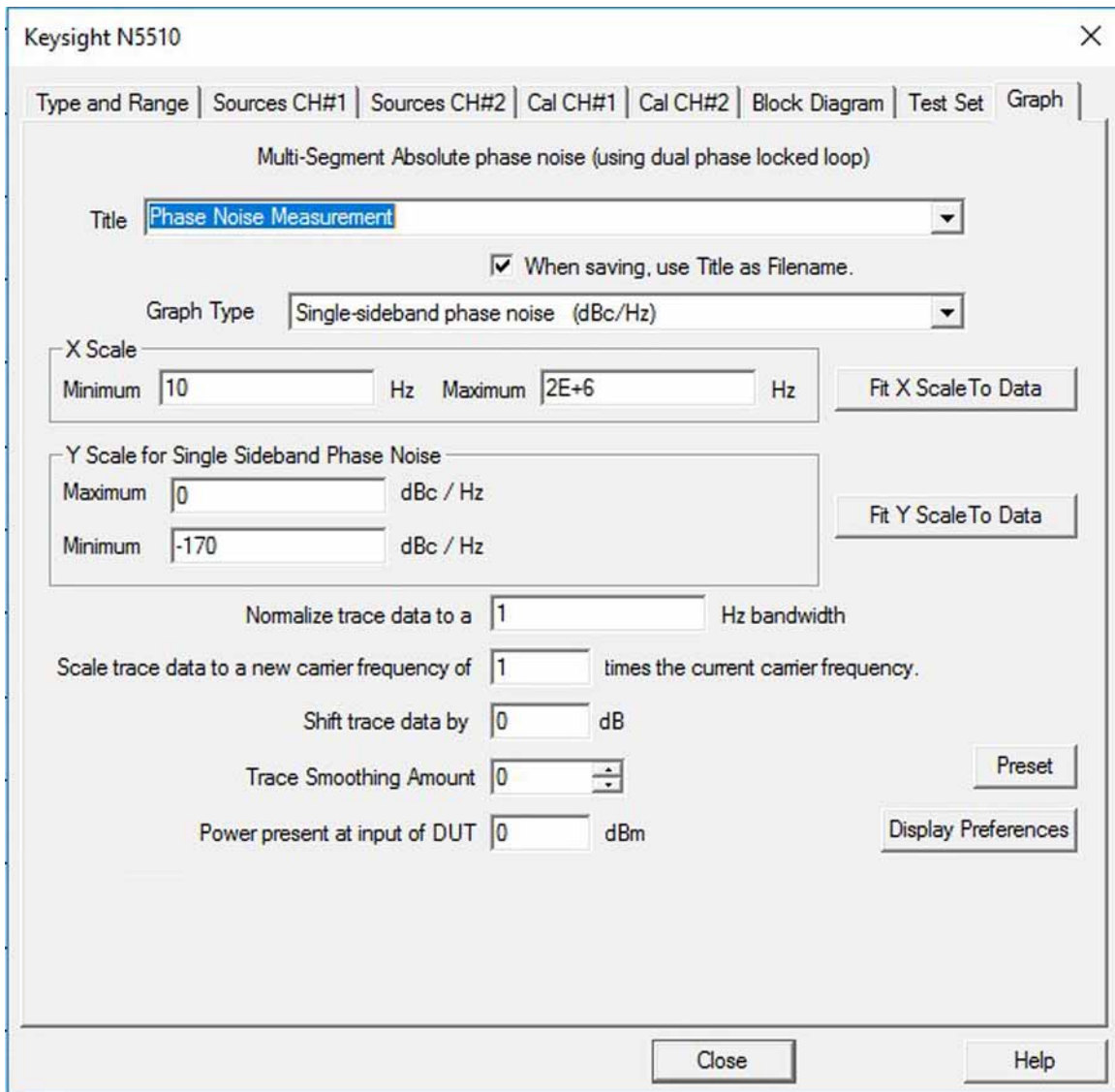
☒ EFC☐ DCFM☐ DCFM 2

Configure Graph

Navigate to the Graph tab.

The following window will appear:

Figure 6-37 Graph Tab



The image shows the 'Graph' tab of the Keysight N5510 configuration window. The window has a title bar 'Keysight N5510' and a close button. Below the title bar is a tabbed interface with the following tabs: 'Type and Range', 'Sources CH#1', 'Sources CH#2', 'Cal CH#1', 'Cal CH#2', 'Block Diagram', 'Test Set', and 'Graph'. The 'Graph' tab is selected. The main area of the window is titled 'Multi-Segment Absolute phase noise (using dual phase locked loop)'. It contains the following controls:

- Title:** A dropdown menu with 'Phase Noise Measurement' selected.
- When saving, use Title as Filename:** A checked checkbox.
- Graph Type:** A dropdown menu with 'Single-sideband phase noise (dBc/Hz)' selected.
- X Scale:** A section with 'Minimum' (10 Hz) and 'Maximum' (2E+6 Hz) input fields, and a 'Fit X Scale To Data' button.
- Y Scale for Single Sideband Phase Noise:** A section with 'Maximum' (0 dBc / Hz) and 'Minimum' (-170 dBc / Hz) input fields, and a 'Fit Y Scale To Data' button.
- Normalize trace data to a** 1 Hz bandwidth.
- Scale trace data to a new carrier frequency of** 1 times the current carrier frequency.
- Shift trace data by** 0 dB.
- Trace Smoothing Amount:** A spinner control set to 0.
- Power present at input of DUT:** 0 dBm.
- Buttons:** 'Preset' and 'Display Preferences' are located on the right side of the main area.
- Footer:** 'Close' and 'Help' buttons are located at the bottom right of the window.

1) Set Title

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph |

Multi-Segment Absolute phase noise (using dual phase locked loop)

Title

☒ When saving, use Title as Filename.

Graph Type

2) Set X-Scale

X -Scale Minimum: 10 Hz
X-Scale Maximum: 2 MHz

X Scale

Minimum Hz Maximum Hz

3) Set Y-Scale

Y-Scale Maximum: 0 dBc/Hz
Y-Scale Minimum: -170 dBc/Hz

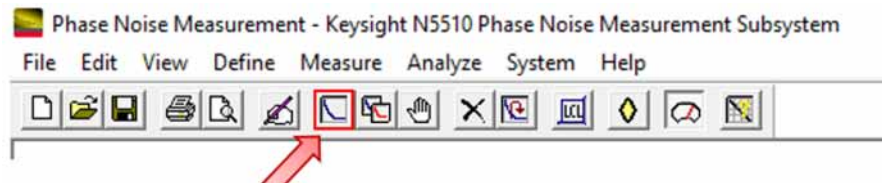
Y Scale for Single Sideband Phase Noise

Maximum dBc / Hz

Minimum dBc / Hz

New Measurement

Close Define Window. From the File Menu: **Measure, New Measurement.**



If the beat note is not within the frequency range required, the software will prompt to tune the reference.

Checking the Beat Note

Use an oscilloscope (connected to the monitor port on the test set) or a counter to check the beat note being created between the reference source and your DUT in each channel.

The objective of checking the beat note is to ensure that the center frequencies of the two references are close enough in frequency with the DUT to create a beatnote that is within the capture range of the system.

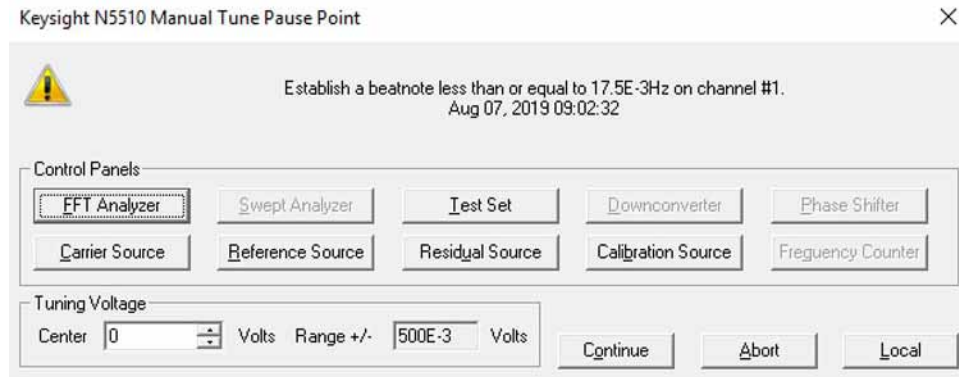
The phase lock loop (PLL) capture range is 5% of the peak tuning range of the VCO source you are using. (The peak tuning range for your VCO can be estimated by multiplying the VCO tuning constant by the tune range of VCO. Refer to **Chapter 14, “Evaluating Your Measurement Results”** if you are not familiar with the relationship between the PLL capture range and the peak tuning range of the VCO. The beat note frequency is set by the relative frequency difference between the two sources. If you have two very accurate sources set at the same frequency, the resulting beat note will be very close to 0 Hz. Searching for the beat note will require that you adjust the center frequency of one of the sources above and below the frequency of the other source until the beat note appears on the oscilloscope's display. If incrementing the frequency of one of the sources does not produce a beat note, you will need to verify the presence of an output signal from each source before proceeding.

NOTE

If the center frequencies of the sources are not close enough to create a beat note within the capture range, the system will not be able to complete its measurement.

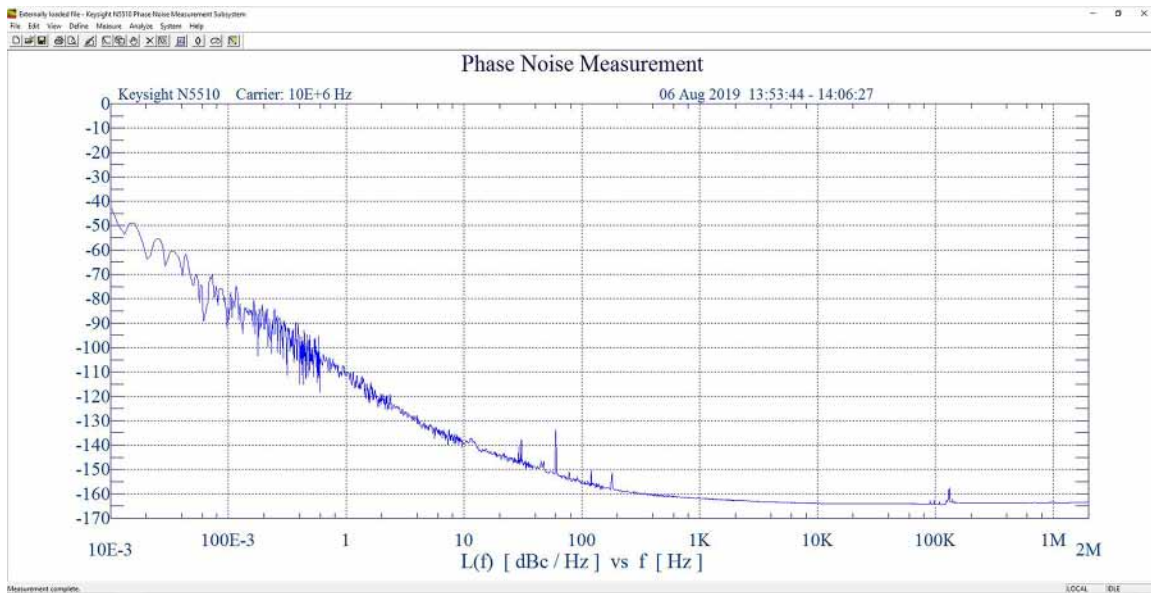
Figure 6-30 shows the Manual Tune Pause Point, which is triggered during calibration if the beat note of one of the references is out of the desired range. The window will specify which channel needs to be tuned.

Figure 6-38 Manual Tune Pause Point



When the measurement is complete, refer to **Chapter 14, “Evaluating Your Measurement Results”** for help in evaluating your measurement results. **Figure 6-39** shows the result of this measurement example.

Figure 6-39 OCXO Dual Channel Measurement Results



7 Residual and Additive Noise Measurement Fundamentals

[“What is Residual Noise?” on page 168](#)

[“Fundamental Measurement Technique” on page 170](#)

[“Assumptions” on page 172](#)

[“Frequency translation devices” on page 173](#)

[“Calibrating the Measurement” on page 175](#)

[“Measurement Difficulties” on page 186](#)

What is Residual Noise?

Residual or two-port noise is the noise added to a signal when the signal is processed by a two-port device. Such devices include amplifiers, dividers, filters, mixers, multipliers, phase-locked loop synthesizers or any other two-port electronic networks. Residual noise is composed of both AM and FM components.

The noise mechanisms

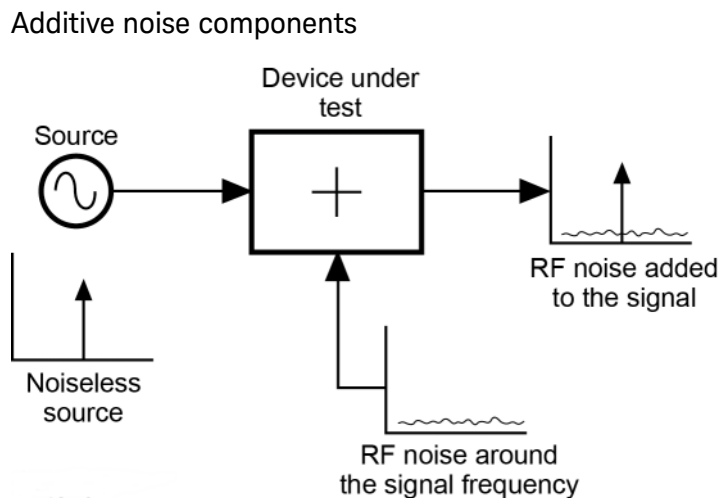
Residual noise is the sum of two basic noise mechanisms:

- additive noise
- multiplicative noise

Additive noise

Additive noise is the noise generated by the two-port device at or near the signal frequency which adds in a linear fashion to the signal. See [Figure 7-1](#).

Figure 7-1

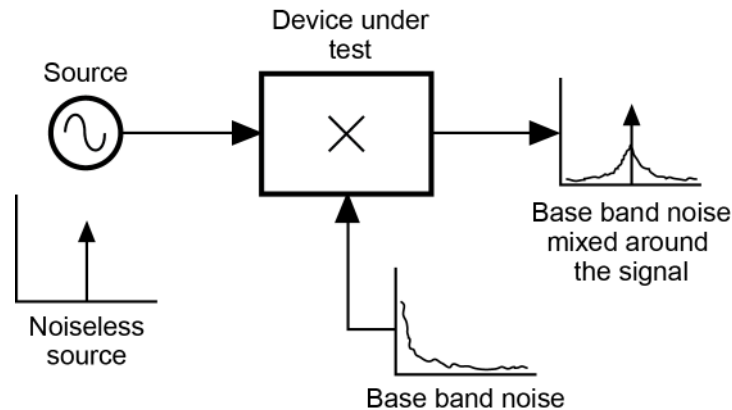


Multiplicative noise

This noise has two known causes. The first, is an intrinsic, direct, phase modulation with a $1/f$ spectral density and the exact origin of this noise component is unknown. The second, in the case of amplifiers or multipliers, is noise which may modulate an RF signal by the multiplication of baseband noise with the signal. This mixing is due to any non-linearities in the two-port network. The baseband noise may be produced by the active device(s) of the internal network, or may come from low-frequency noise on the signal or power supply. See [Figure 7-2](#).

Figure 7-2

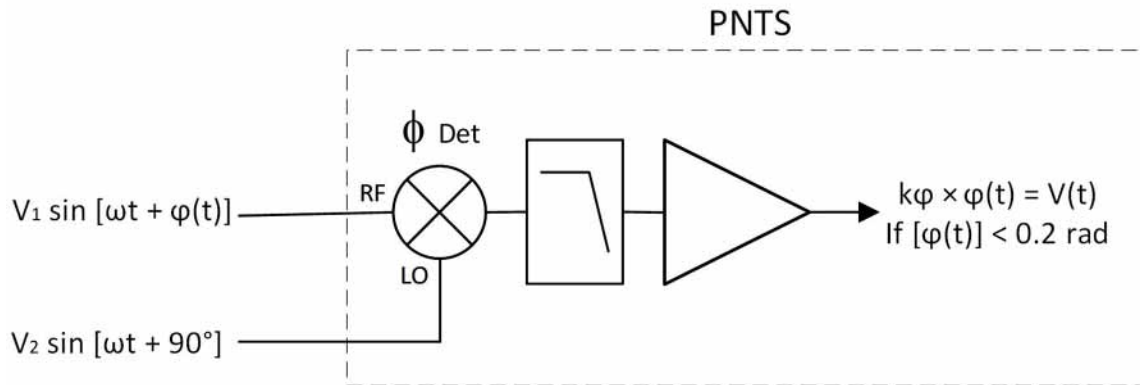
Multiplicative noise components



Fundamental Measurement Technique

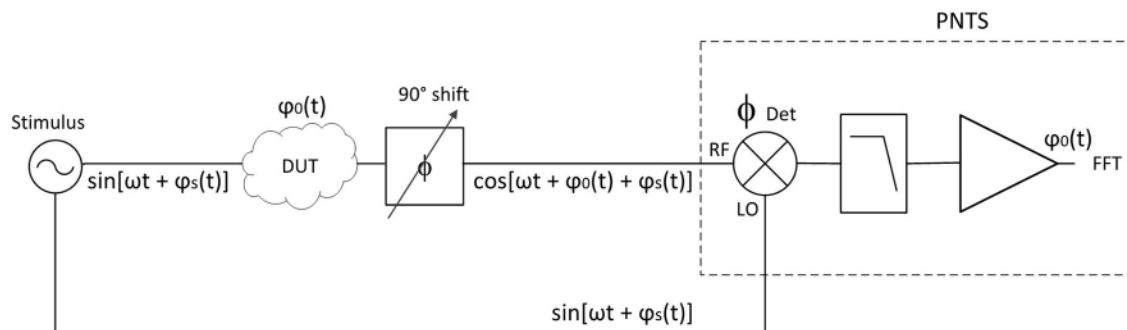
N5511A utilizes the quadrature technique to perform a residual measurement. Establishing quadrature is used to cancel the noise not pertinent to the phase noise of DUT. As shown in **Figure 7-3**, quadrature is established when the two inputs to the phase detector are 90° out of phase. This 90° phase shift can be accomplished using line stretchers.

Figure 7-3 Quadrature Technique



When measuring a two-port device, the source noise in each of the two phase detector paths is correlated at the phase detector for the frequency offset range of interest. When the source noise is correlated at the phase detector, the source phase noise cancels, leaving only the additive phase noise of the DUT. **Figure 7-4** shows this principle for a single channel configuration.

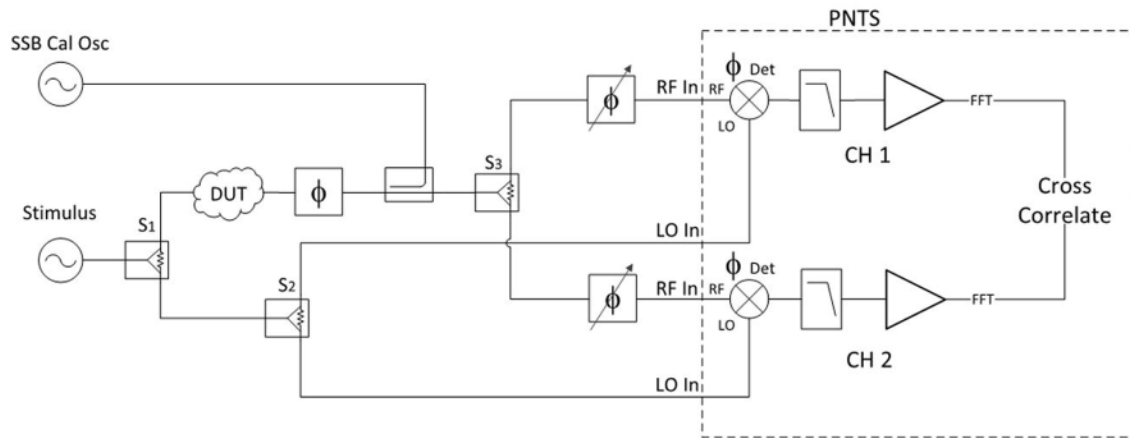
Figure 7-4 Single Channel Configuration



Using trigonometric identities, the additive noise of the DUT is the remaining component at the output of the phase detector, assuming that $\phi_0 < 0.2 \text{ rad}$.

For a dual channel cross-correlated measurement, **Figure 7-5**, the same measurement theory holds. The stimulus signal is split to the LO inputs of each of the two phase detectors. Similarly, the signal that passes through the DUT is split to the RF inputs of each of the two phase detectors. Quadrature is established separately for each of the phase detectors, thus requiring two phase shifters. The output of each phase detector is the additive noise of the DUT, and any additive noise corresponding to internal amplifiers in each of the channels is removed by cross-correlation.

Figure 7-5 Dual Channel Configuration



Assumptions

The following are some basic assumptions regarding Residual Phase Noise measurements. If these assumptions are not valid they will affect the measured results.

- The source noise in each of the two phase detector paths is correlated at the phase detector for the frequency offset range of interest.
- Source AM noise is comparatively small. A typical mixer-type phase detector only has about 20 to 30 dB of AM noise rejection. If the AM component of the signal is greater than 20 to 30 dB above the residual phase noise, it will contribute to the residual phase noise measurement and show the residual phase noise as being greater than it really is.
- The DUT does not exhibit a bandpass filter function. A bandpass filter type response will cause the source noise to be decorrelated at the edge of the filter. This decorrelation of the noise causes the system to measure the source noise level directly at offsets beyond the filter bandwidth.

Frequency translation devices

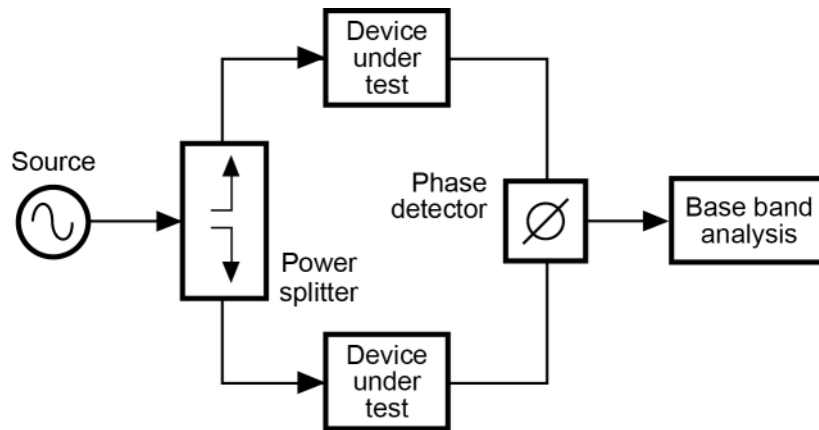
If the DUT is a frequency translating device (such as a divider, multiplier, or mixer), then one DUT must be put in each path. The result is the sum of the noise from each DUT. In other words, each DUT is at least as quiet as the measured result.

If the DUTs are identical, a possible (but not recommended) assumption is that the noise of each DUT is half the measured result, or 3 dB less. All that really can be concluded is that the noise level of one of the DUTs is at least 3 dB lower than the measured result at any particular offset frequency.

If a more precise determination is required at any particular offset frequency, a third DUT must also be measured against the other two DUTs. The data from each of the three measurements can then be processed by the phase noise software to give the noise of each of the individual DUTs. See [Figure 7-6](#).

Figure 7-6

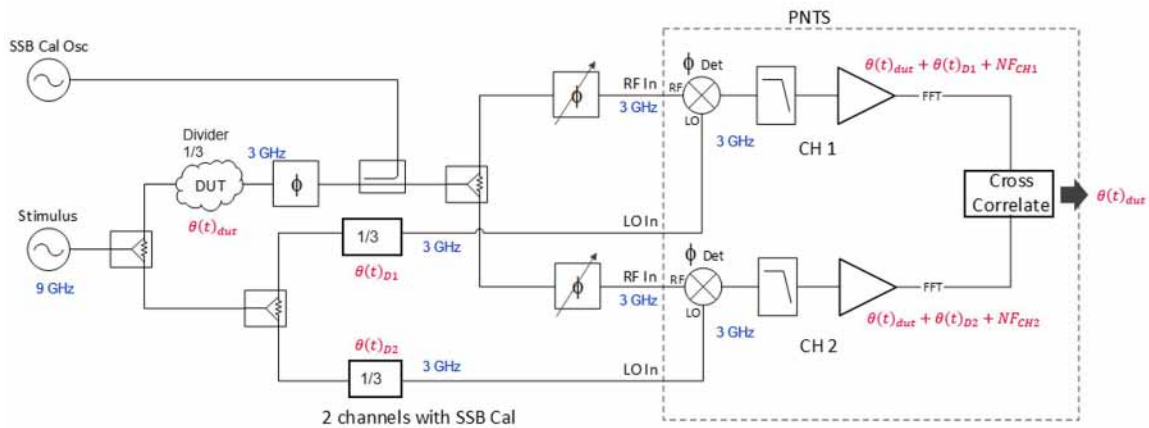
Measurement setup for two similar DUTs



In the case of a dual channel additive measurement on a frequency translating device, 3 devices are needed, see **Figure 7-7**. One of the devices will be the DUT. Because the LO inputs of the phase detectors must be at the same frequency as the RF input, two additional devices are needed. These are inserted in the LO paths for each channel. These translating devices need not be identical to the DUT, but must have the same translating factor.

Performance of each of the two devices is not critical, as noise contributions from each will be removed by cross-correlation since they are in separate channels. The only factor that can be affected is time, as worse performing devices will impact the amount of cross-correlations required to reach the noise floor of the DUT.

Figure 7-7 Dual Channel Measurement Setup Example for Frequency Translating Device



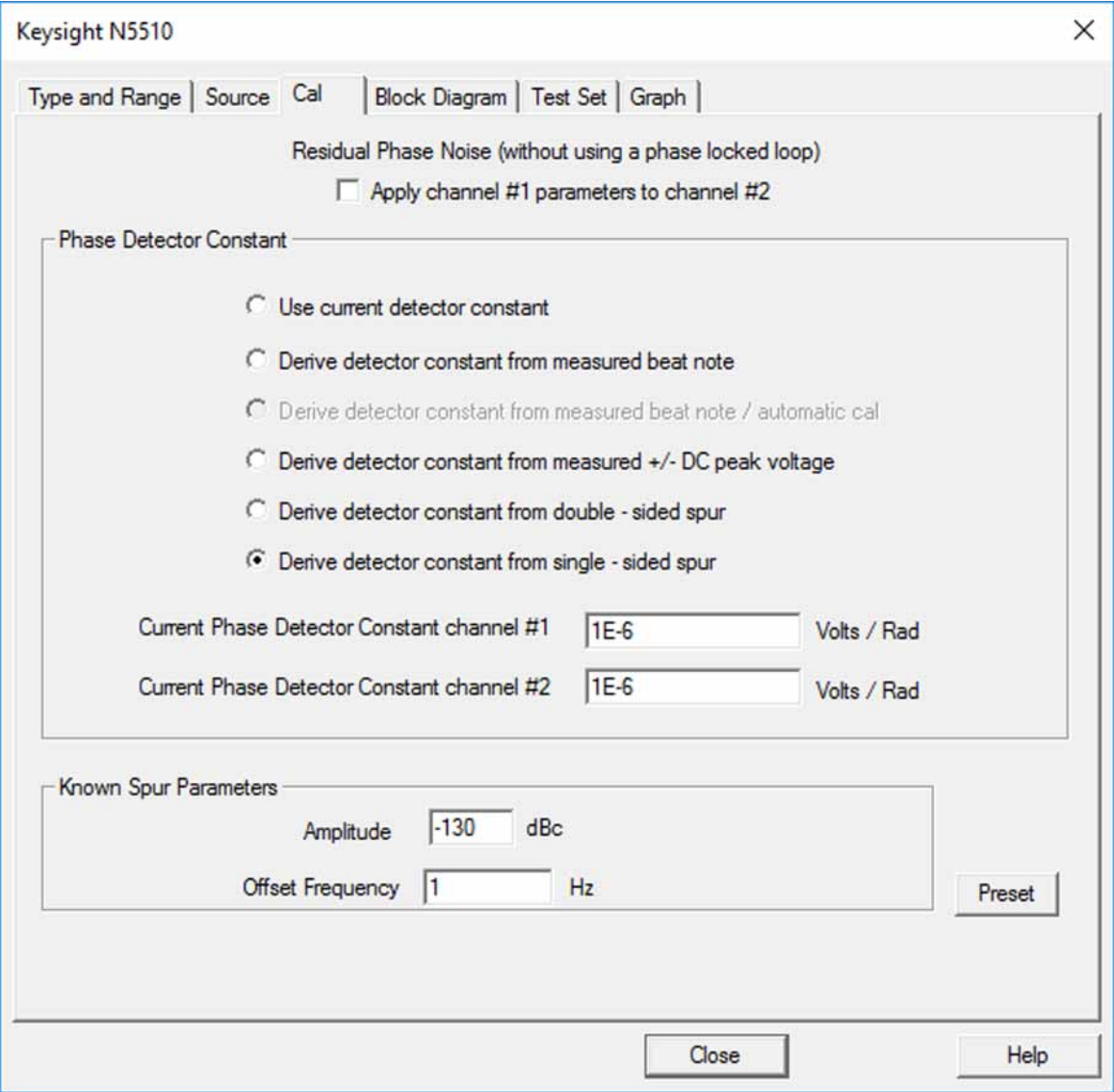
Calibrating the Measurement

In the N5511A Phase Noise Test System, residual phase noise measurements are made by selecting Residual Phase Noise (without using a phase locked loop).

There are five calibration methods that to choose from for calibrating a two-port measurement. The configuration for each method is provided on the following pages. Once configured, the application provides instructions while performing the calibration. The advantages and disadvantages of each method are also provided to help you select the best method for your application.

- Use current phase detector constant
- Derive detector constant from measured beat note
- Derive detector constant from measured +/- DC peak voltage
- Derive detector constant from double-sided spur
- Derive detector constant from single-sided spur

Figure 7-8 Calibration Selections



The method used will mainly be determined by the sources and equipment available to you.

NOTE

When calibrating the system for measurements, remember that the calibration is only as accurate as the data input to the system software.

User entry of phase detector constant

This calibration option requires that you know the phase detector constant for the specific measurement to be made. The phase detector constant can be estimated from the source power levels (or a monitor oscilloscope) or it can be determined using one of the other calibration methods. Once determined, the phase detector constant can be entered directly into the system software without going through a calibration sequence. Remember, however, that the phase detector constant is unique to a particular set of sources, the RF level into the phase detector and the test configuration.

Advantages

- Easy method for calibrating the measurement system.
- Requires little additional equipment: only an RF power meter to manually measure the drive levels into the phase detector or monitor oscilloscope.
- Fastest method of calibration. If the same power levels are always at the phase detector, (as in the case of leveled outputs), the phase detector sensitivity will always be essentially the same (within a dB or two). If this accuracy is adequate, it is not necessary to recalibrate.
- Only one RF source is required.
- Very quick method of estimating the phase detector constant and noise floor to verify other calibration methods and check available dynamic range.

Disadvantages

- The user entry of the phase detector constant is the least accurate of all the calibration methods.
- Does not take into account the amount of power at harmonics of the signal.

Measured Beat Note

This calibration option requires that one of the input frequency sources be tunable such that a beat note can be acquired from the two sources. For the system to calibrate, use one of the following suggested beat note frequency ranges:

Carrier Frequency	Suggested Beat Note Frequency Range
< 500 kHz	10 Hz to 10 kHz
< 5 MHz	10 Hz to 100 kHz
< 50 MHz	10 Hz to 1 MHz
< 250 MHz	10 Hz to 10 MHz
> 250 MHz	10 Hz to 50 MHz

or 1/2 the frequency range of the configured analyzer, or whichever is lower.

Advantages

- Simple method of calibration.

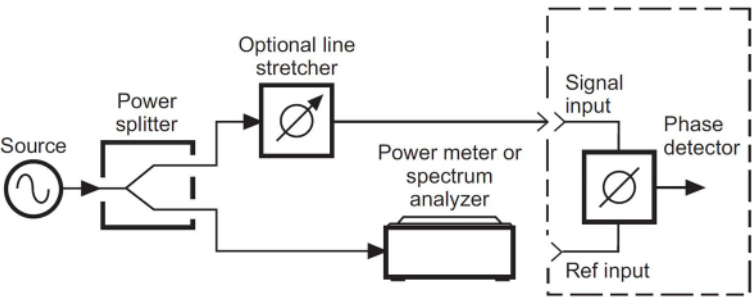
Disadvantages

- Requires two RF sources (or 3 if dual-channel measurement), separated by 0.1 Hz to 50 MHz at the phase detector. The calibration source output power must be manually adjusted to the same level as the power splitter output it replaces (requires a power meter).

Figure 7-9 shows how to initially set up a single channel measurement to use a beat note cal. The power level at the LO input is measured.

Figure 7-9

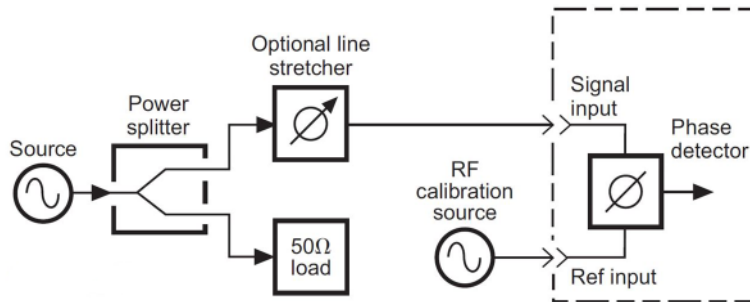
Single Channel Measurement using Beat Note Cal



A reference source is then inserted. The power level of this calibration source is adjusted to the same output power as the measured output power of the power splitter. The splitter is terminated at this path.

Figure 7-10

Calibration Source Beat Note Injection



At this point, the measurement can be started. Once a beat note is established and within the system's acceptable range, the calibration constant will be measured. The calibration source is then removed, the splitter's termination removed, and this path of the splitter is connected directly to the LO input of the phase detector module.

Quadrature will need to be established using the phase shifter and the quadrature meters in the display. Quadrature is achieved when the meter on the front panel of the phase noise interface is set to zero.

This method can be used in a dual channel setup as well, where the calibration is performed on each of the separated phase detectors.

See the absolute measurement calibrations section on [page 86](#) for more detailed theory about how beat note calibration works.

Measured \pm DC Peak Voltage

Advantages

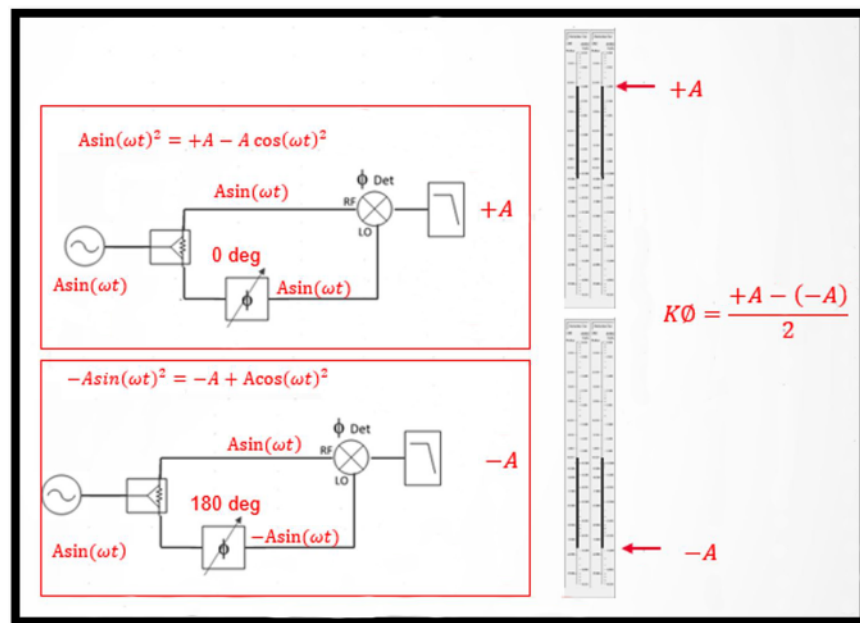
- Easy method for calibrating the measurement system.
- This calibration technique can be performed using the baseband analyzer.
- Fastest method of calibration. If, for example, the same power levels are always at the phase detector, as in the case of leveled, or limited outputs, the phase detector sensitivity will always be essentially equivalent (within one or two dB). Recalibration becomes unnecessary if this accuracy is adequate.
- Only one RF source is required.
- Measures the phase detector gain in the actual measurement configuration. This technique requires you to adjust off of quadrature to both the positive and the negative peak output of the Phase Detector. This is done by either adjusting the phase shifter or the frequency of the source. An oscilloscope or voltmeter can optionally be used for setting the positive and negative peaks.

Disadvantages

- Has only moderate accuracy compared to the other calibration methods.
- Does not take into account the amount of phase detector harmonic distortion relative to the measured phase detector gain, hence the phase detector must operate in its linear region.
- Requires manual adjustments to the source and/or phase shifter to find the phase detector's positive and negative output peaks. The system will read the value of the positive and negative peak and automatically calculate the mean of the peak voltages which is the phase detector constant used by the system.

The DC peak voltage method is a very convenient calibration for residual measurements as a cal source is not needed. The user adjusts the phase shift until a peak positive voltage is measured and then adjusted again to measure a minimum negative voltage. The meters on the application are used to identify these peaks. **Figure 7-11** shows how the meters operate as well as a mathematical representation of \pm DC peak voltage cal. Measuring the peak positive voltage means adjusting the phase shifter(s) so that the LO path of each channel is in phase with the RF path into the mixer. To measure the minimum negative voltage, the phase shifter(s) are adjusted so that the LO path into the phase detector is 180 degrees out of phase relative to the RF input.

Figure 7-11 \pm DC Peak Voltage



This method has moderate accuracy since it is measuring the signal in the IF after the mixer, at which point the signal present may not be a perfect sinusoid. This causes the peak value measured to be inaccurate which can affect the $K\phi$ by as much as 2 dB. In many cases this may not be an issue.

Double-Sided Spur

This calibration option has the following requirements:

- One of the input frequency sources must be capable of being phase modulated.
- The resultant sideband spurs from the phase modulation must have amplitudes that are -100 dB and -20 dB relative to the carrier amplitude.
- The offset frequency or modulation frequency must be between 10 Hz and maximum (See the "Measured beat note" section on [page 87](#)).

Advantages

- Requires only one RF source.
- Calibration is done under actual measurement conditions so all non-linearities and harmonics of the phase detector are calibrated out.

NOTE

Because the calibration is performed under actual measurement conditions, the Double-sided Spur Method and the Single-sided Spur Method are the two most accurate calibration methods.

Disadvantages

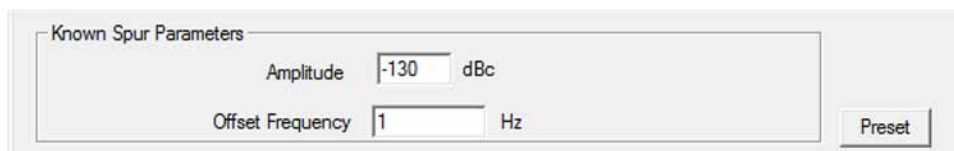
- Requires RF source used to have modulation capabilities else a phase modulator which operates at the desired carrier frequency.
- Requires audio calibration source.
- Requires RF spectrum analyzer for manual measurement of Φ M sidebands or preferably a modulation analyzer.

NOTE

Most phase modulators are typically narrow-band devices; therefore, a wide range of test frequencies may require multiple phase modulator.

For a dual-sided spur cal, turn on phase modulation on the stimulus to create a narrowband sideband at a known amplitude and offset relative to the carrier. Enter the offset and level in the Known Spur Parameters section in the Cal tab of the Define Measurement menu.

Figure 7-12 Known Spur Parameters



Known Spur Parameters

Amplitude dBc

Offset Frequency Hz

Figure 7-13 shows how a single channel measurement is configured using a phase modulator and how the tone is measured using this setup, a concept that can be extended to a dual channel setup as well by splitting the phase modulator to both LO channel paths.

Figure 7-13 Single Channel Measurement with Phase Modulator

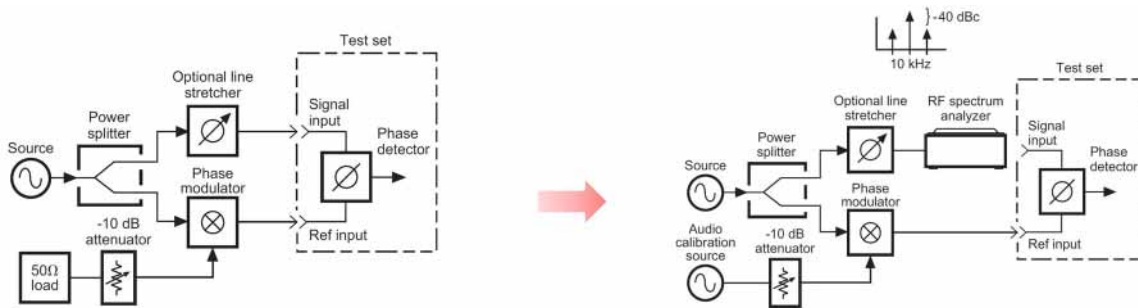
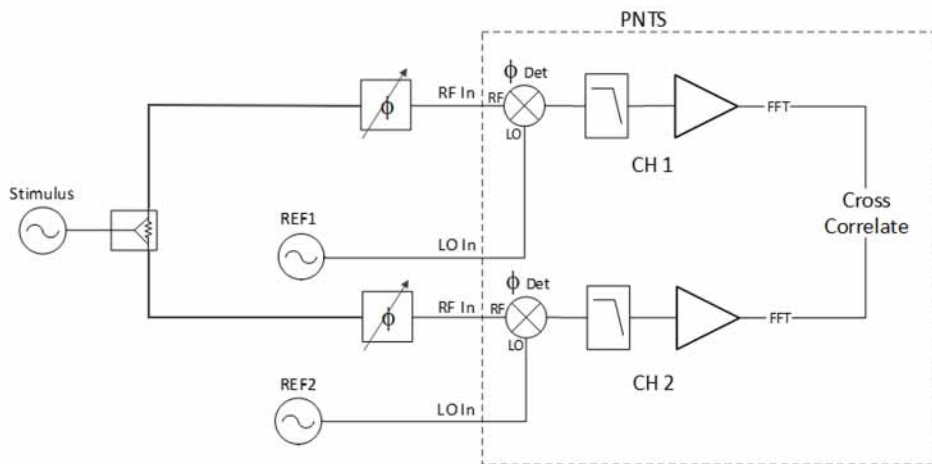


Figure 7-14 shows the setup for a dual channel residual measurement, where the stimulus provides the carrier that is modulated to perform the double-sided spur cal. If the stimulus is not capable of being phase modulated, a separate phase modulator can be used.

Figure 7-14 Dual Channel Residual Measurement



See the absolute measurement calibrations section on [page 86](#) for more detailed theory about how double-sided spur calibration works.

Single-Sided Spur

This calibration option has the following requirements:

- A second source to generate a single sided spur.
- An external power combiner (or directional coupler) to add the calibration spur to the frequency carrier under test. The calibration spur must have an amplitude -100 dB and -20 dB relative to the carrier amplitude. The offset frequency of the spur must be 20 Hz and 20 MHz.
- A spectrum analyzer or other means to measure the single sided spur relative to the carrier signal. You will find that the equipment setup for this calibration option is similar to the others except that an additional source and a power splitter have been added so that the spur can be summed with the input carrier frequency.

Advantages

- Calibration is done under actual measurement conditions so all non-linearities and harmonics of the phase detector are calibrated out.

Disadvantages

- Requires a second RF source that can be set between 10 Hz and up to 50 MHz (depending on the baseband analyzer used) from the carrier source frequency.
- Requires an RF spectrum analyzer for manual measurement of the signal-to-spur ratio and the spur offset frequency.
- The figures below show a single and dual channel measurement configurations for using a single-sided spur calibration.

Figure 7-15 One Channel with SSB Cal

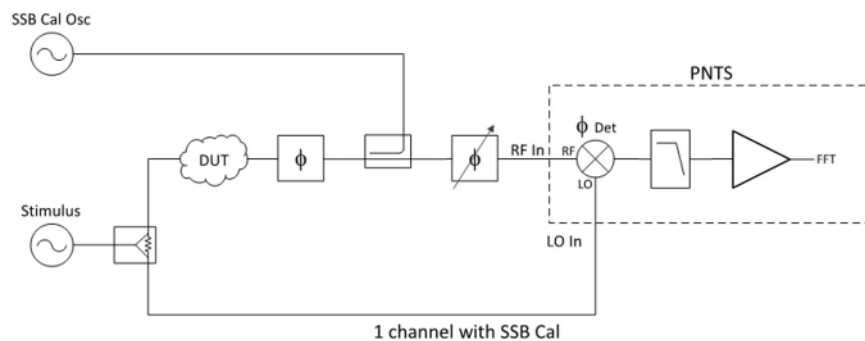
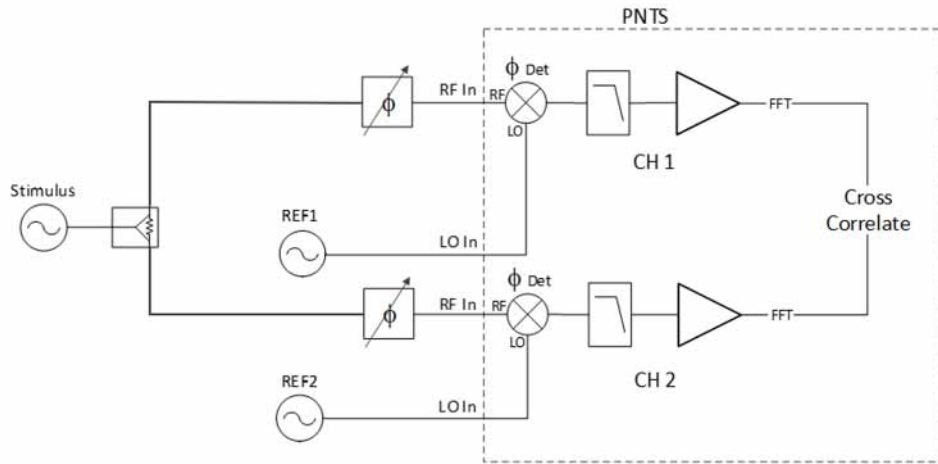


Figure 7-16 Two Channels with SSB Cal



The carrier-to-single-sided-spur ratio out of the coupler and the offset frequency of the spur is measured with an analyzer. The RF calibration source should be adjusted such that the sidebands are between -30 and -60 dB below the carrier and the frequency offset of the spur between 10 Hz and 50 MHz. Enter the offset and relative power level of the single sided spur in the Known Spur Parameters section in the Cal tab of the Define Measurement menu.

Figure 7-17 Known Spur Parameters

The screenshot shows the 'Known Spur Parameters' dialog box. It contains two input fields: 'Amplitude' set to '-130 dBc' and 'Offset Frequency' set to '1 Hz'. There is a 'Preset' button on the right side of the dialog.

See the absolute measurement calibrations section on [page 86](#) for more detailed theory about how single-sided spur calibration works.

Measurement Difficulties

Chapter 14, “Evaluating Your Measurement Results” contains troubleshooting information to be used after the measurement has been made, and a plot has been obtained.

When making phase noise measurements it is important to keep your equipment connected until the measurements have been made, all problems corrected, and the results have been evaluated to make sure that the measurement is valid. If the equipment is disconnected before the results have been fully evaluated, it may be difficult to troubleshoot the measurement.

System connections

The first thing to check if problems occur is the instrument connections and settings as this is the most common error. It is also important to make sure the levels are correct into the test set phase detector inputs.

8 Residual Measurement Examples

[“Amplifier Measurement Example - Single Channel” on page 188](#)

[“Amplifier Measurement Example - Dual Channel” on page 202](#)

Amplifier Measurement Example - Single Channel

This example contains information about measuring the residual noise of two-port devices. It demonstrates a residual phase noise measurement for an RF Amplifier. Refer to **Chapter 7, “Residual and Additive Noise Measurement Fundamentals”** for more information about residual phase noise measurements.

CAUTION

To prevent damage to the test system's hardware components, verify that the input signal is within the test system's power limits. Refer to the N5511A Data Sheet online.

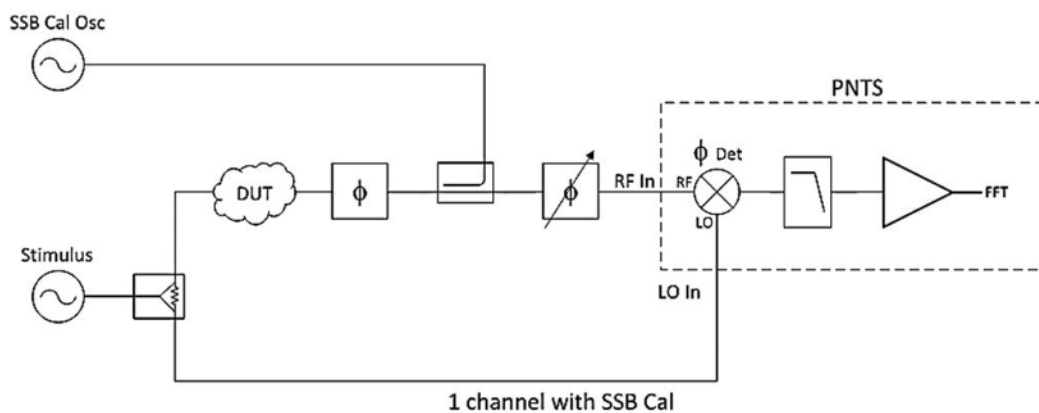
Required equipment

- RF amplifier
- Stimulus source (at frequency under test) - for this example, an E8257D PSG will be used
- RF calibration source
- Coaxial cables and adapters necessary to connect the DUT and reference source to the test set.

Connections

Setup the measurement using the following connection diagram.

Figure 8-1 Setup for Single Channel measurement



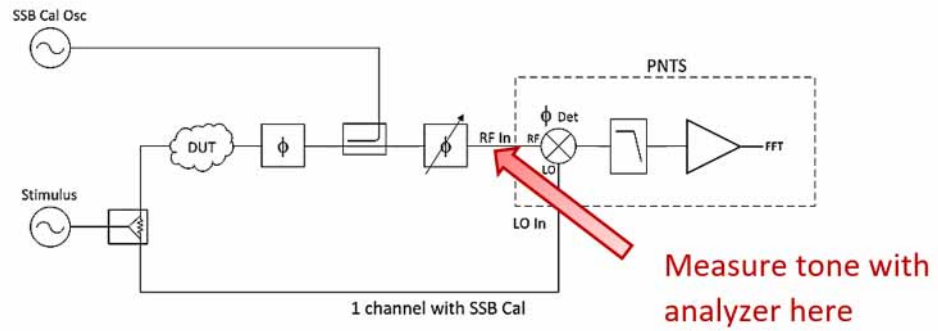
Configuring Equipment

Set Up stimulus PSG

Frequency: 1 GHz
Amplitude: 14 dBm

Set SSB Cal Tone

Set the cal source to be at a 1 kHz offset from the stimulus carrier at the output of the coupler and -40 dB relative to the carrier. A signal analyzer should be used to verify the cal tone.



Measurement Procedure

Start the N5510 application.

Measurement Type and Range

At the top of the main application window, click **Define** and select **Measurement** from the drop-down menu.

Define --> Measurement

The following window will appear:

Figure 8-2 Measurement Type and Range

The screenshot shows the 'Keysight N5510' dialog box with the 'Type and Range' tab selected. The 'Measurement Type' is set to 'Absolute Phase Noise (using phase locked loop)'. Under 'Measurement Method', 'Fast' is selected with a 'Start Offset Resolution Expansion' of 10. Under 'Channel Setup', 'Dual' is selected. The 'Measurement Settings' section includes 'Start Offset' (1 Hz), 'Stop Offset' (160E+6 Hz), 'FFT Analyzer Minimum Number of Trace Averages' (4), 'FFT Analyzer Minimum Number of Cross-correlations' (1), 'RBW %' (1.96 (1024 point FFT)), 'FFT Overlap %' (75), and 'FFT Window Type' (BlackmanHarris4). The 'Estimated Measurement Time' field is empty. Under 'FFT Quality', 'Normal' is selected. A 'View Segment Table' button is present. At the bottom, the 'Couple Graph Type to Measurement Type' checkbox is checked, and there are 'Preset', 'Close', and 'Help' buttons.

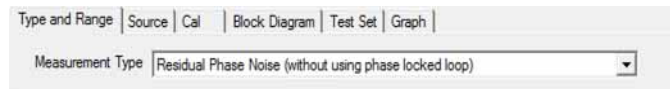
Navigate to the **Type and Range** tab from the Define Measurement window

Residual Measurement Examples

Amplifier Measurement Example - Single Channel

1) Choose Measurement Type

Measurement Type: Residual Phase Noise (without using phase locked loop)



The screenshot shows a software interface with a tabbed menu at the top containing 'Type and Range', 'Source', 'Cal', 'Block Diagram', 'Test Set', and 'Graph'. The 'Type and Range' tab is active. Below the tabs is a dropdown menu labeled 'Measurement Type' which is set to 'Residual Phase Noise (without using phase locked loop)'.

2) Choose Channel Setup

Channel Setup: Single



The screenshot shows two configuration panels. The 'Measurement Method' panel on the left has radio buttons for 'Flexible' and 'Fast' (which is selected), and a text field for 'Start Offset Resolution Expansion' set to '10'. The 'Channel Setup' panel on the right has radio buttons for 'Single' (which is selected) and 'Dual'.

3) Set Start and Stop Offsets

Start Offset: 10 Hz
Stop Offset: 160 MHz

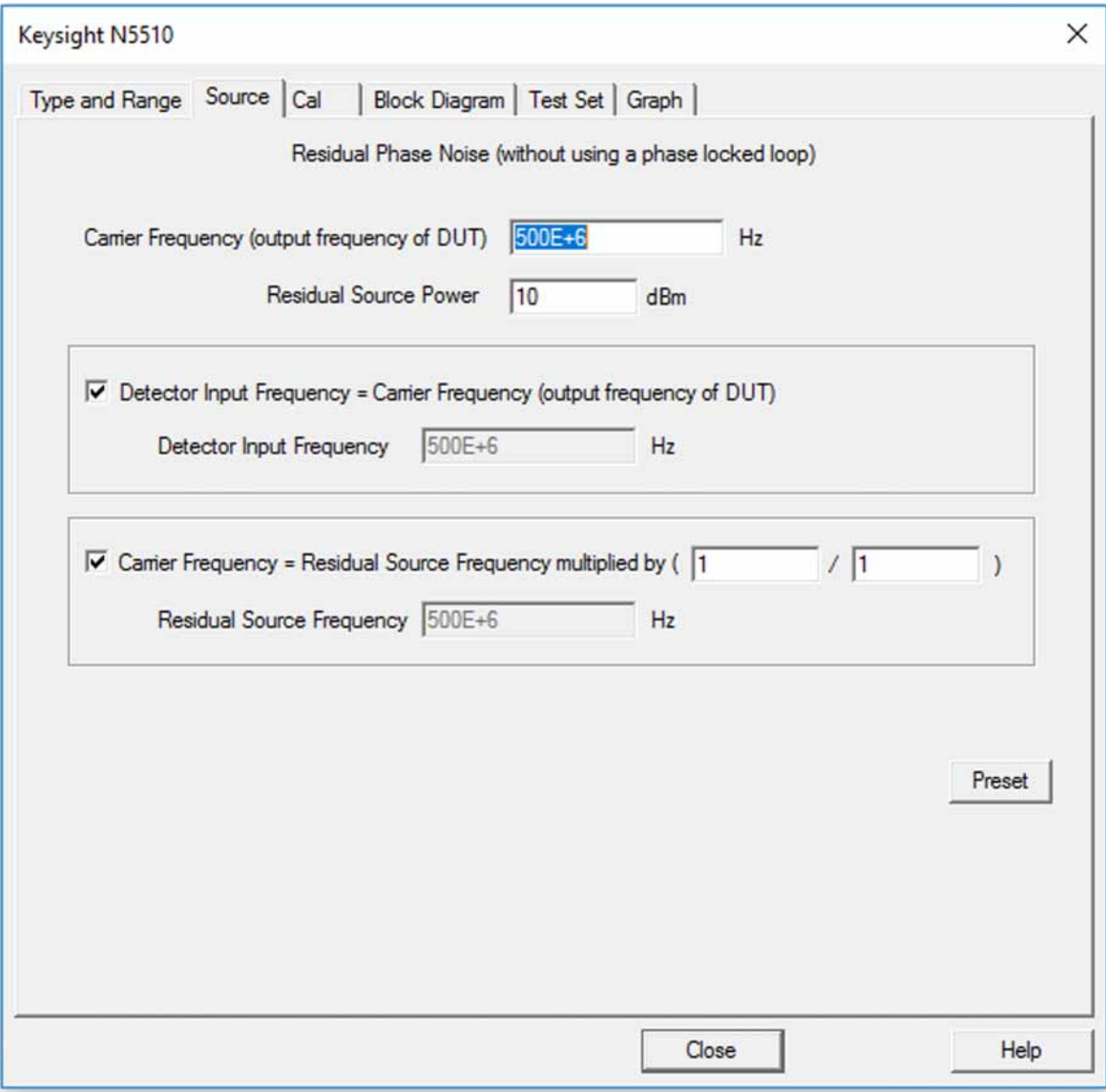


The screenshot shows the 'Measurement Settings' panel. It contains two text fields for frequency offsets: 'Start Offset' set to '10' Hz and 'Stop Offset' set to '160E+6' Hz. Below these are two more text fields: 'FFT Analyzer Minimum Number of Trace Averages' set to '4' and 'FFT Analyzer Minimum Number of Cross-correlations' set to '1'.

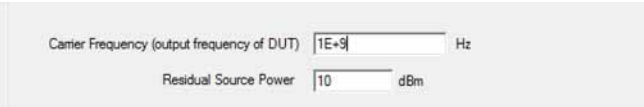
Source Configuration

Next, we will configure the settings for the DUT and the reference source (REF). Navigate to the **Source** tab at the top of the current window and the following will appear:

Figure 8-3 Source Configuration



- 1) Set Carrier
Carrier Frequency: 1 GHz



Cal Confirmation

Navigate to the **Cal** tab from the Define Measurement window. The following window will appear:

Figure 8-4 Cal Confirmation

Keysight N5510

Type and Range | Source | **Cal** | Test Set | Graph

Residual Phase Noise (without using a phase locked loop)

Phase Detector Constant

- ☐ Use current detector constant
- ☐ Derive detector constant from measured beat note
- ☐ Derive detector constant from measured beat note / automatic cal
- ☐ Derive detector constant from measured +/- DC peak voltage
- ☐ Derive detector constant from double - sided spur
- ☒ Derive detector constant from single - sided spur

Current Phase Detector Constant channel #1 Volts / Rad

Known Spur Parameters

Amplitude dBc

Offset Frequency Hz

Preset

Close Help

Residual Measurement Examples
Amplifier Measurement Example - Single Channel

1) Configure Phase Detector

Constant Cal

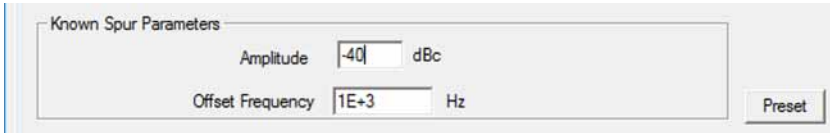
Derive detector constant from
single-sided spur

- ☐ Derive detector constant from double - sided spur
☒ Derive detector constant from single - sided spur

2) Known Spur Parameters

Amplitude: -40 dBc

Offset Frequency: 1 kHz



Known Spur Parameters

Amplitude dBc

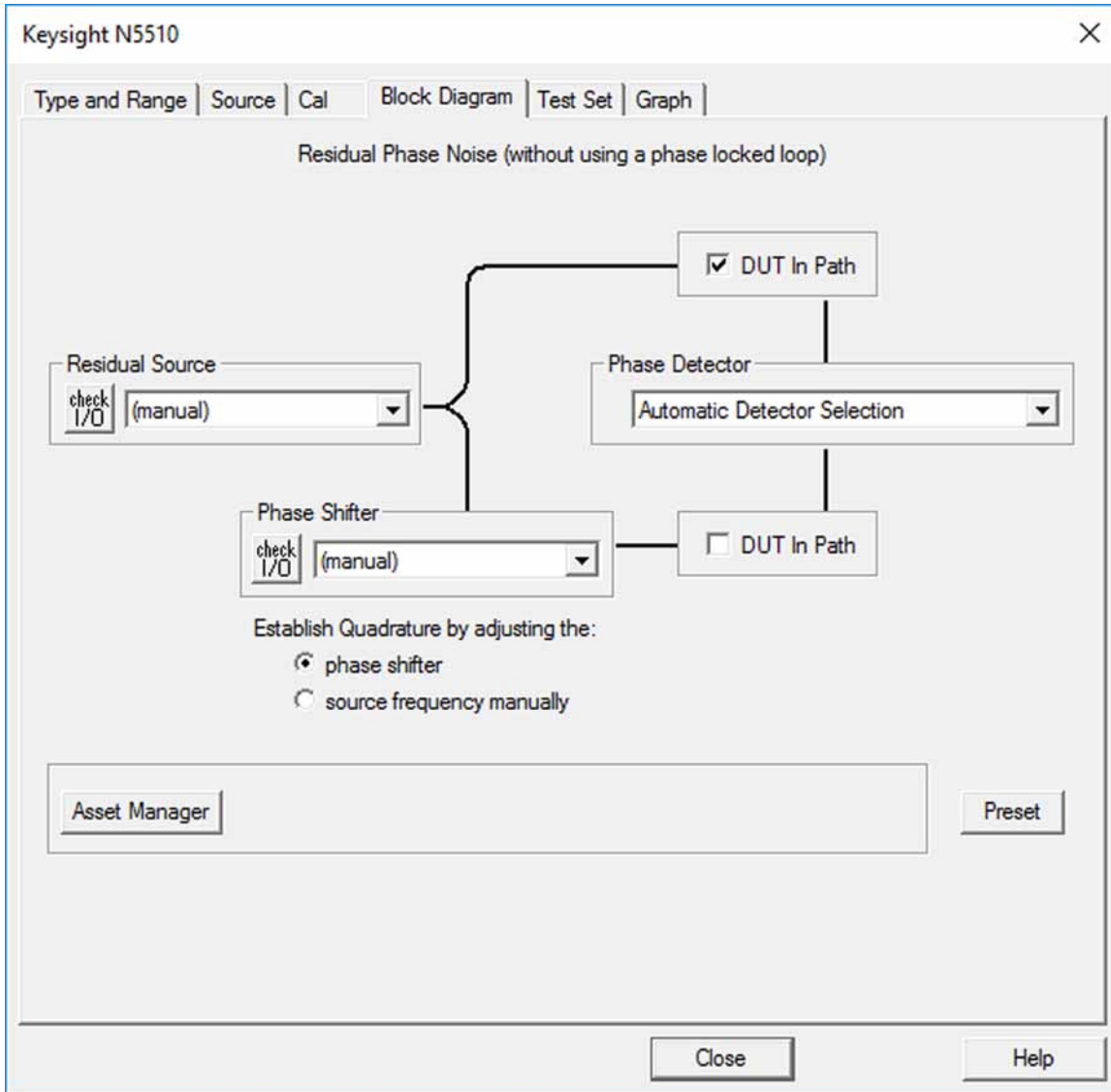
Offset Frequency Hz

Preset

Block Diagram Set Up

Choose the **Block Diagram** tab from the Define Measurement window. The following window will appear:

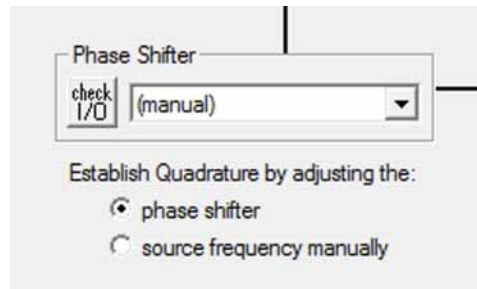
Figure 8-5 Block Diagram



Residual Measurement Examples
Amplifier Measurement Example - Single Channel

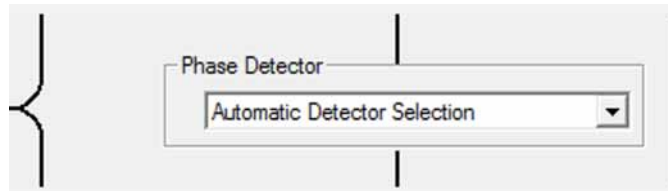
1) Phase Shifter

Select Manual from the Phase
Shifter pull-down



2) Phase Detector

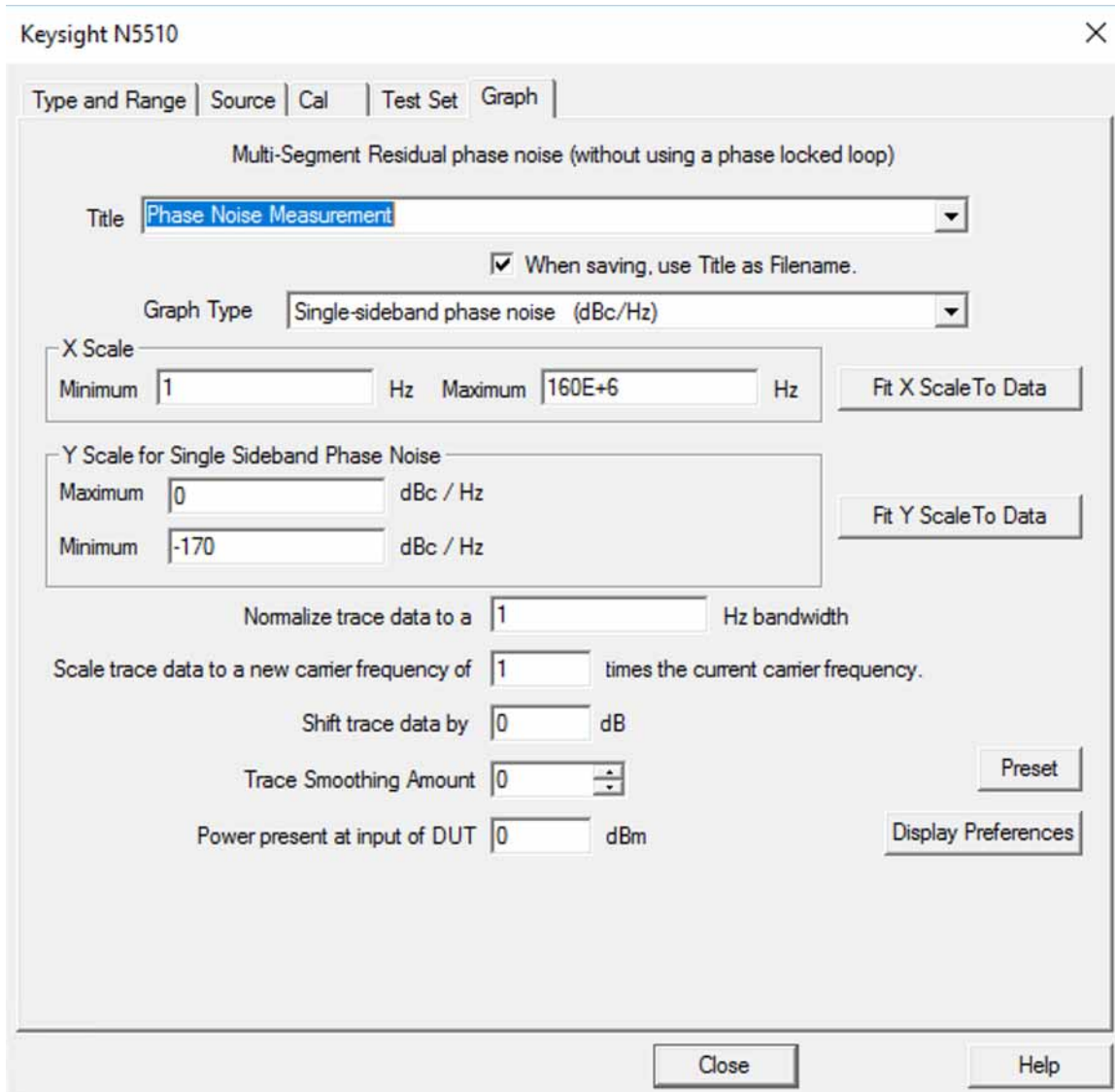
Select Automatic Detector from
the Phase Detector pull-down



Graph Configuration

Navigate to the **Graph** tab. The following window will appear:

Figure 8-6 Graph Configuration



The image shows the 'Graph Configuration' window of the Keysight N5510. The window has a title bar 'Keysight N5510' and a close button 'X'. Below the title bar is a tabbed interface with 'Type and Range', 'Source', 'Cal', 'Test Set', and 'Graph' tabs. The 'Graph' tab is selected. The main area is titled 'Multi-Segment Residual phase noise (without using a phase locked loop)'. It contains several configuration options: 'Title' is set to 'Phase Noise Measurement' with a dropdown arrow; a checkbox 'When saving, use Title as Filename.' is checked; 'Graph Type' is set to 'Single-sideband phase noise (dBc/Hz)' with a dropdown arrow; 'X Scale' has 'Minimum' set to '1' Hz and 'Maximum' set to '160E+6' Hz, with a 'Fit X Scale To Data' button; 'Y Scale for Single Sideband Phase Noise' has 'Maximum' set to '0' dBc / Hz and 'Minimum' set to '-170' dBc / Hz, with a 'Fit Y Scale To Data' button; 'Normalize trace data to a' is set to '1' Hz bandwidth; 'Scale trace data to a new carrier frequency of' is set to '1' times the current carrier frequency; 'Shift trace data by' is set to '0' dB; 'Trace Smoothing Amount' is set to '0' with a spinner; 'Power present at input of DUT' is set to '0' dBm; and buttons for 'Preset' and 'Display Preferences' are on the right. At the bottom are 'Close' and 'Help' buttons.

Keysight N5510

Type and Range | Source | Cal | Test Set | Graph

Multi-Segment Residual phase noise (without using a phase locked loop)

Title: Phase Noise Measurement

☒ When saving, use Title as Filename.

Graph Type: Single-sideband phase noise (dBc/Hz)

X Scale

Minimum: 1 Hz Maximum: 160E+6 Hz

Fit X Scale To Data

Y Scale for Single Sideband Phase Noise

Maximum: 0 dBc / Hz

Minimum: -170 dBc / Hz

Fit Y Scale To Data

Normalize trace data to a 1 Hz bandwidth

Scale trace data to a new carrier frequency of 1 times the current carrier frequency.

Shift trace data by 0 dB

Trace Smoothing Amount: 0

Power present at input of DUT: 0 dBm

Preset

Display Preferences

Close Help

Residual Measurement Examples
Amplifier Measurement Example - Single Channel

Set the graph parameters for graph display.

1) Set X Scale

X Scale Minimum: 1 Hz
X Scale Maximum: 20 MHz



The 'X Scale' dialog box contains two input fields: 'Minimum' with the value '1' and 'Maximum' with the value '20E+6'. Both fields are followed by the unit 'Hz'. A 'Fit X Scale' button is located to the right of the 'Maximum' field.

2) Set Y Scale

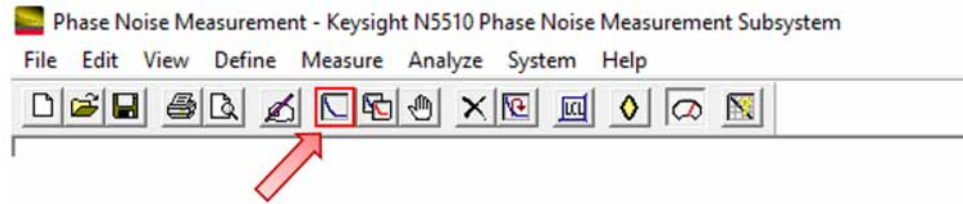
Y Scale Minimum:
-30 dBc/Hz
Y Scale Maximum:
-180 dBc/Hz



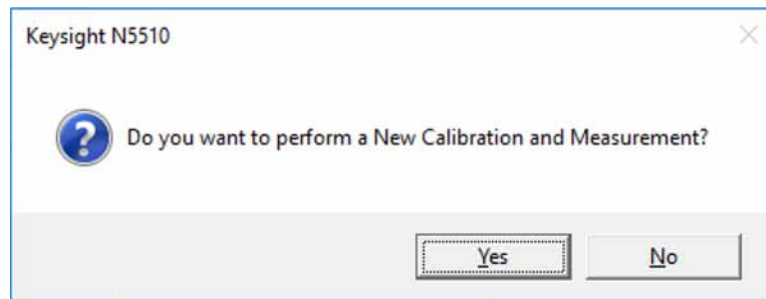
The 'Y Scale for Single Sideband Phase Noise' dialog box contains two input fields: 'Maximum' with the value '-30' and 'Minimum' with the value '-180'. Both fields are followed by the unit 'dBc / Hz'. A 'Fit Y Scale To Data' button is located to the right of the 'Minimum' field.

Start a New Measurement

To start a new measurement, click on the icon shown below:



When the **Do you want to perform a New Calibration and Measurement?** prompt appears, click **Yes**.



When the **Connect Diagram** dialog box appears, click on the hardware down arrow and select your hardware configuration from the pull-down list. Click **Continue**.

CAUTION

To prevent damage to the test system's hardware components, verify that the input signal is within the test system's power limits. Refer to the N5511A Data Sheet online.

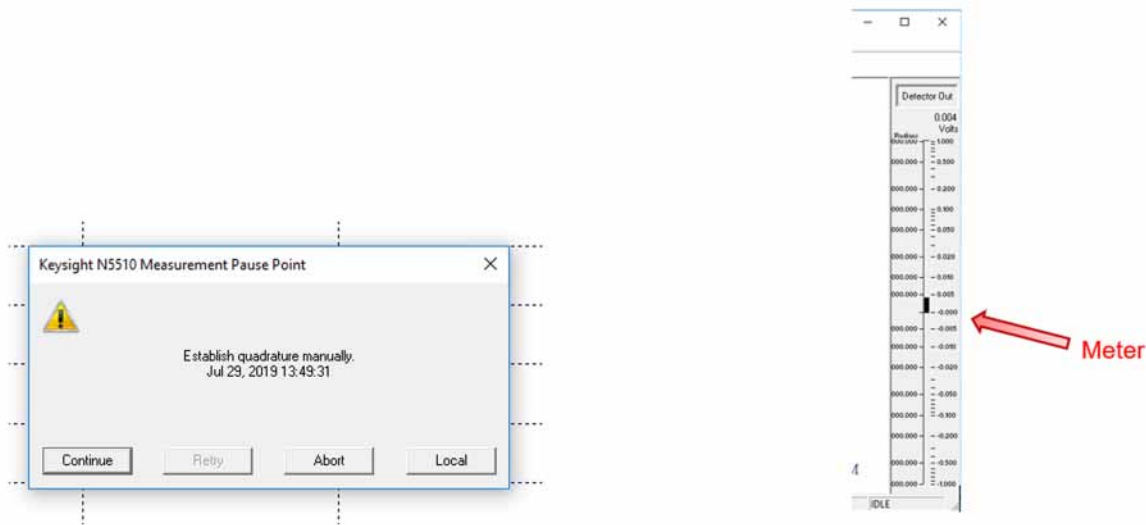
Making the Measurement

Calibrate the measurement using Single-Sided Spur calibration.

Refer to **Chapter 7, “Residual and Additive Noise Measurement Fundamentals”** for more information about residual phase noise measurements calibration types.

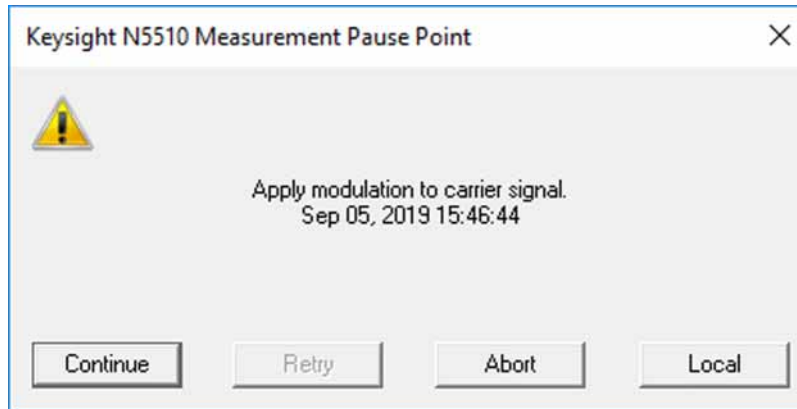
If the software prompts to **Establish Quadrature Manually** adjust the phase difference at the phase detector until the voltmeter at the right-hand side of the display, shown below, reads approximately 0 V. Click **Continue**.

Figure 8-7 Establish Quadrature Manually



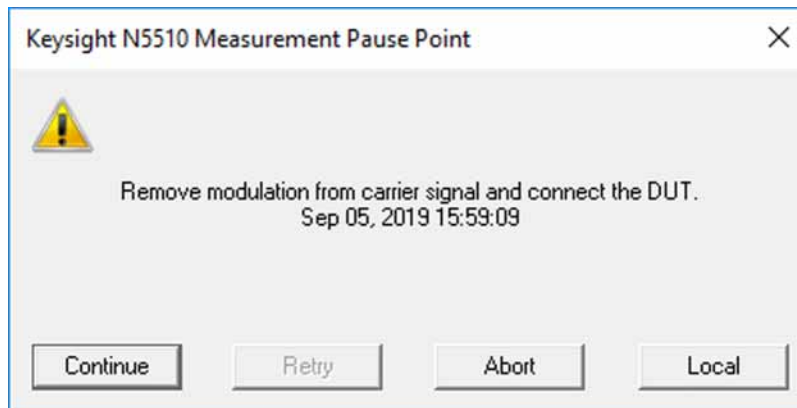
The system will then prompt you to Apply Modulation to the Carrier. At this moment, turn on the RF from the calibration source.

Figure 8-8 Apply Modulation



The system will prompt you to Remove Modulation. Turn off calibration source RF.

Figure 8-9 Remove Modulation



The system will now measure the noise data. The segment data will be displayed on the computer screen as the data is taken until all segments have been taken over the entire range you specified in the Measurement definition's Type and Range.

Amplifier Measurement Example - Dual Channel

This example contains information about measuring the residual noise of two-port devices. It demonstrates a residual phase noise measurement for an RF Amplifier. Refer to **Chapter 7, “Residual and Additive Noise Measurement Fundamentals”** for more information about residual phase noise measurements.

CAUTION

To prevent damage to the test system's hardware components, verify that the input signal is within the test system's power limits. Refer to the N5511A Data Sheet online.

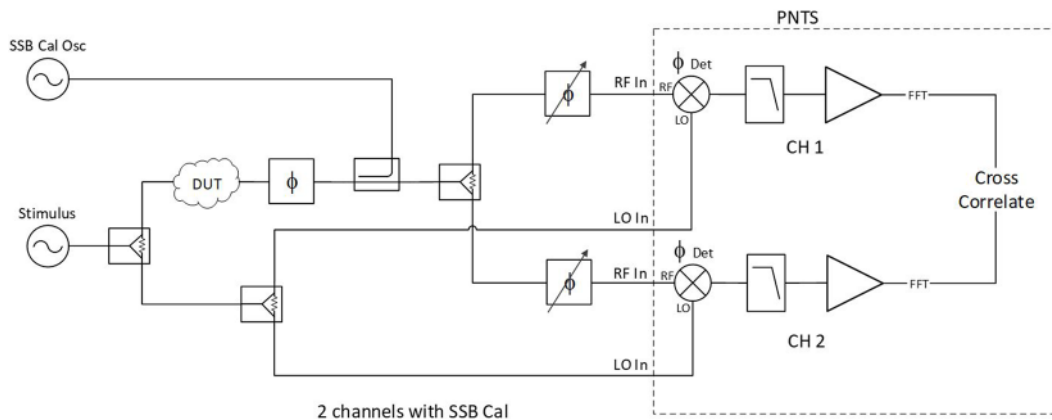
Required equipment

- RF amplifier
- Stimulus source (at frequency under test) - for this example, an E8257D PSG will be used
- RF calibration source
- Coaxial cables and adapters necessary to connect the DUT and reference source to the test set.

Connections

Setup the measurement using the following connection diagram.

Figure 8-10 Setup for Dual Channel measurement



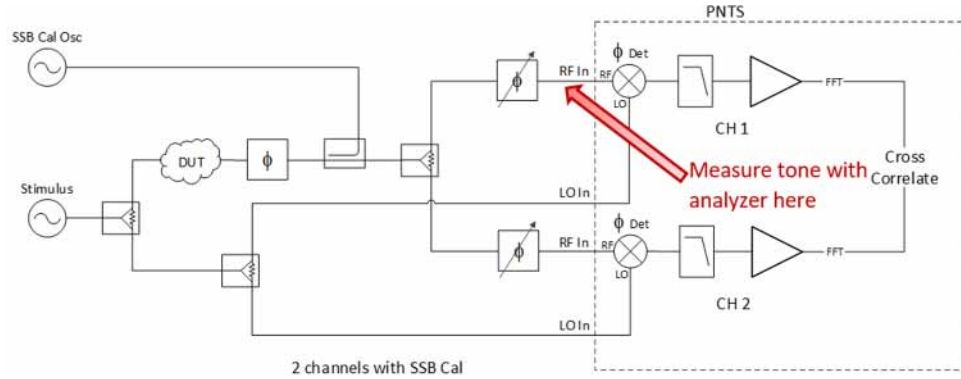
Configuring Equipment

Set Up stimulus PSG

Frequency: 1 GHz
Amplitude: 14 dBm

Set SSB Cal Tone

Set the cal source to be at a 1 kHz offset from the stimulus carrier at the output of the coupler and -40 dB relative to the carrier. A signal analyzer should be used to verify the cal tone.



Measurement Procedure

Start the N5510 application.

Measurement Type and Range

At the top of the main application window, click **Define** and select **Measurement** from the drop-down menu.

Define --> Measurement

The following window will appear:

Figure 8-11 Measurement Type and Range

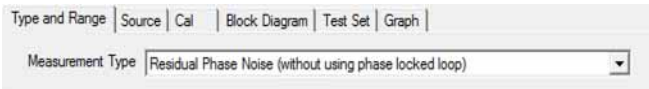
The screenshot shows the 'Keysight N5510' dialog box with the 'Type and Range' tab selected. The 'Measurement Type' is set to 'Absolute Phase Noise (using phase locked loop)'. Under 'Measurement Method', 'Fast' is selected with a 'Start Offset Resolution Expansion' of 10. Under 'Channel Setup', 'Dual' is selected. The 'Measurement Settings' section includes 'Start Offset' (1 Hz), 'Stop Offset' (160E+6 Hz), 'FFT Analyzer Minimum Number of Trace Averages' (4), 'FFT Analyzer Minimum Number of Cross-correlations' (1), 'RBW %' (1.96 (1024 point FFT)), 'FFT Overlap %' (75), and 'FFT Window Type' (BlackmanHarris4). The 'Estimated Measurement Time' field is empty. Under 'FFT Quality', 'Normal' is selected. A 'View Segment Table' button is present. At the bottom, the 'Couple Graph Type to Measurement Type' checkbox is checked, and there are 'Preset', 'Close', and 'Help' buttons.

Navigate to the **Type and Range** tab from the Define Measurement window

Residual Measurement Examples
Amplifier Measurement Example - Dual Channel

1) Choose Measurement Type

Measurement Type: Residual Phase Noise (without using phase locked loop)



The screenshot shows a software interface with a tabbed menu at the top containing 'Type and Range', 'Source', 'Cal', 'Block Diagram', 'Test Set', and 'Graph'. Below the tabs is a dropdown menu labeled 'Measurement Type' which is currently set to 'Residual Phase Noise (without using phase locked loop)'.

2) Choose Channel Setup

Channel Setup: Single



The screenshot shows two panels. The 'Measurement Method' panel on the left has radio buttons for 'Flexible' and 'Fast' (which is selected), and a text box for 'Start Offset Resolution Expansion' set to '10'. The 'Channel Setup' panel on the right has radio buttons for 'Single' and 'Dual' (which is selected).

3) Cross-correlations

FFT Analyzer Minimum Number of Cross-Correlations



The screenshot shows a single text box labeled 'FFT Analyzer Minimum Number of Cross-correlations' with the value '10' entered.

4) Set Start and Stop Offsets

Start Offset: 10 Hz
Stop Offset: 160 MHz

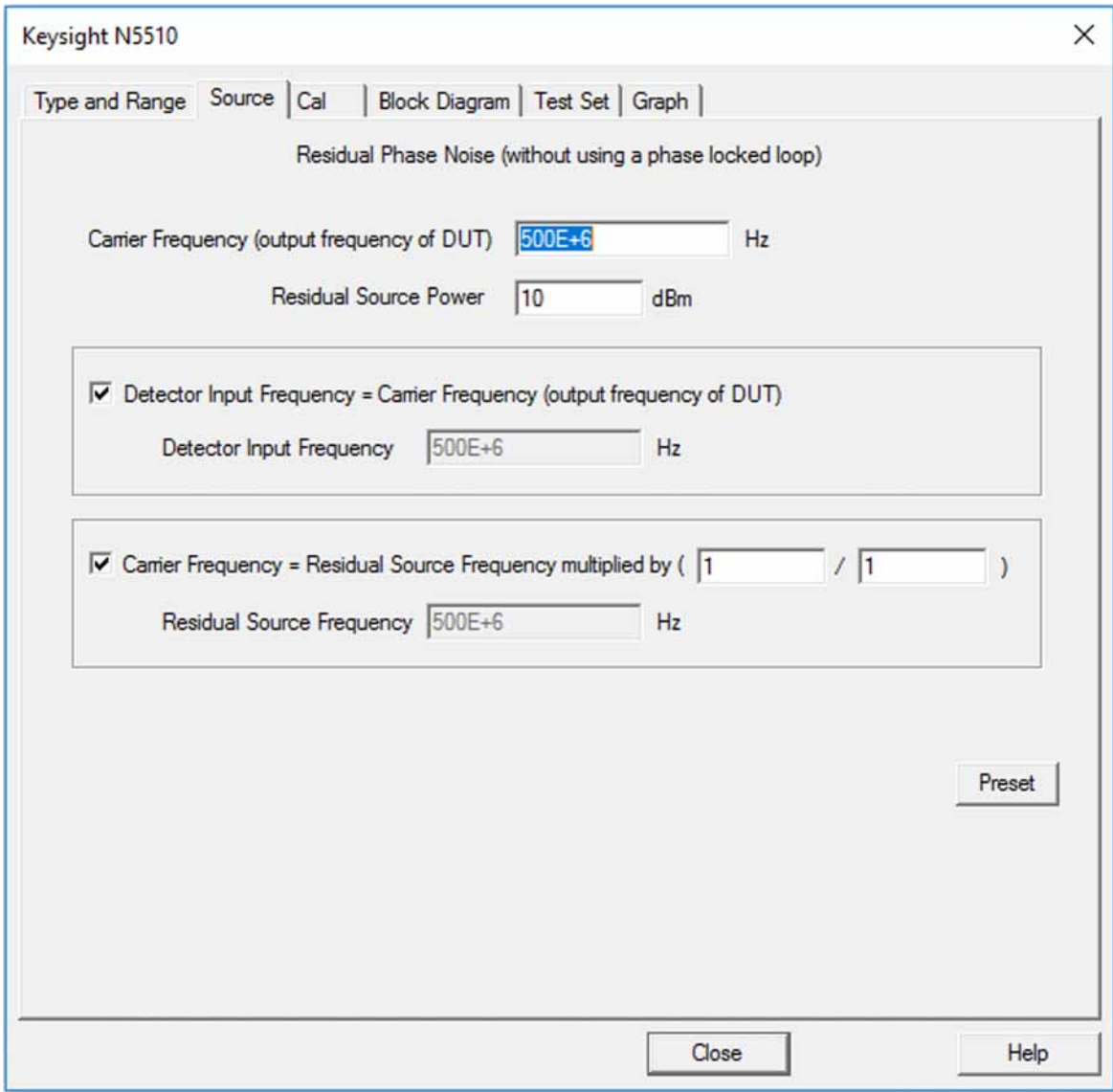


The screenshot shows a 'Measurement Settings' panel. It contains two text boxes for 'Start Offset' (set to '10') and 'Stop Offset' (set to '160E+6'), both followed by 'Hz'. Below these are two more text boxes: 'FFT Analyzer Minimum Number of Trace Averages' set to '4' and 'FFT Analyzer Minimum Number of Cross-correlations' set to '1'.

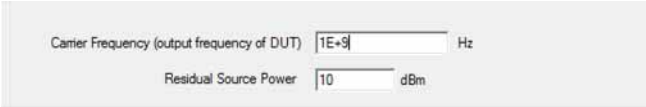
Source Configuration

Next, we will configure the settings for the DUT and the reference source (REF). Navigate to the **Source** tab at the top of the current window and the following will appear:

Figure 8-12 Source Configuration



- 1) Set Carrier
Carrier Frequency: 1 GHz



Cal Confirmation

Navigate to the **Cal** tab from the Define Measurement window. The following window will appear:

Figure 8-13 Cal Confirmation

Keysight N5510

Type and Range | Source | **Cal** | Block Diagram | Test Set | Graph

Residual Phase Noise (without using a phase locked loop)

☐ Apply channel #1 parameters to channel #2

Phase Detector Constant

☐ Use current detector constant

☐ Derive detector constant from measured beat note

☐ Derive detector constant from measured beat note / automatic cal

☐ Derive detector constant from measured +/- DC peak voltage

☐ Derive detector constant from double - sided spur

☒ Derive detector constant from single - sided spur

Current Phase Detector Constant channel #1 Volts / Rad

Current Phase Detector Constant channel #2 Volts / Rad

Known Spur Parameters

Amplitude dBc

Offset Frequency Hz

Preset

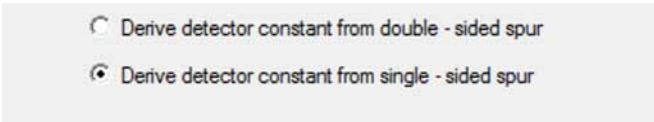
Close Help

Residual Measurement Examples

Amplifier Measurement Example - Dual Channel


1) Configure Phase Detector Constant Cal

Derive detector constant from
single-sided spur

- 
- ☐ Derive detector constant from double - sided spur
- ☒ Derive detector constant from single - sided spur

2) Known Spur Parameters

Amplitude: -40 dBc
Offset Frequency: 1 kHz



Known Spur Parameters

Amplitude dBc

Offset Frequency Hz

Block Diagram Set Up

Choose the **Block Diagram** tab from the Define Measurement window. The following window will appear:

Figure 8-14 Block Diagram

The image shows the 'Keysight N5510' software window with the 'Block Diagram' tab selected. The window title is 'Keysight N5510' with a close button (X) in the top right corner. The tab bar at the top includes 'Type and Range', 'Source', 'Cal', 'Block Diagram' (selected), 'Test Set', and 'Graph'. The main content area is titled 'Cross Correlated Residual Phase Noise (without using a phase locked loop)'. It contains several configuration sections: 'Residual Source' with a 'check I/O' button and a dropdown menu set to '(manual)'; 'Phase Detector' with a dropdown menu set to 'Automatic Detector Selection'; 'Phase Shifter CH #1' with a 'check I/O' button and a dropdown menu set to '(manual)'; and 'Phase Shifter CH #2' with a 'check I/O' button and a dropdown menu set to '(none)'. There are two identical radio button groups for 'Establish Quadrature by adjusting the:', each with 'phase shifter' selected and 'source frequency manually' unselected. A checkbox 'Use single phase shifter for both channels' is present and unchecked. At the bottom, there is an 'Asset Manager' button, a 'Preset' button, and 'Close' and 'Help' buttons.

Keysight N5510

Type and Range | Source | Cal | **Block Diagram** | Test Set | Graph

Cross Correlated Residual Phase Noise (without using a phase locked loop)

Residual Source: (manual)

Phase Detector: Automatic Detector Selection

☐ Use single phase shifter for both channels

Phase Shifter CH #1: (manual)

Phase Shifter CH #2: (none)

Establish Quadrature by adjusting the:

☒ phase shifter
☐ source frequency manually

Establish Quadrature by adjusting the:

☒ phase shifter
☐ source frequency manually

Asset Manager

Preset

Close Help

1) Phase Shifter

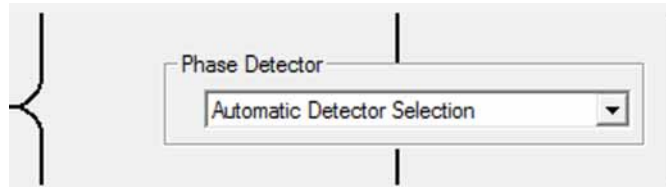
Select Manual from the Phase Shifter pull-down



The screenshot shows two identical control panels for 'Phase Shifter CH #1' and 'Phase Shifter CH #2'. Each panel has a 'check I/O' checkbox and a pull-down menu currently set to '(manual)'. Below these, the text 'Establish Quadrature by adjusting the:' is followed by two radio button options: 'phase shifter' (which is selected) and 'source frequency manually'.

2) Phase Detector

Select Automatic Detector from the Phase Detector pull-down

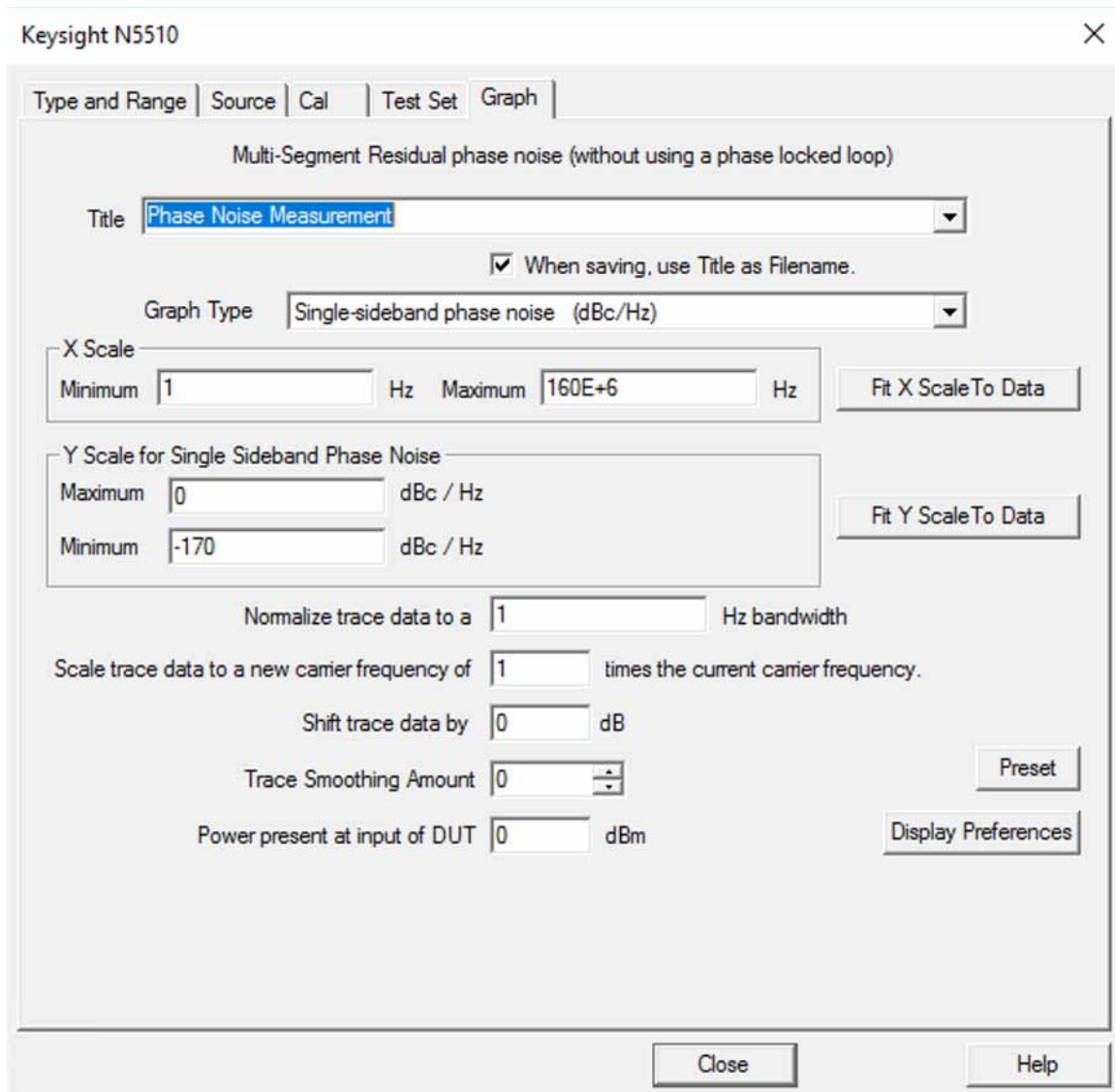


The screenshot shows a 'Phase Detector' control panel. It features a pull-down menu that is currently set to 'Automatic Detector Selection'. The panel is flanked by vertical lines on both sides.

Graph Configuration

Navigate to the **Graph** tab. The following window will appear:

Figure 8-15 Graph Confirmation



The image shows the 'Graph Confirmation' dialog box for the Keysight N5510. The dialog has a title bar 'Keysight N5510' and a close button 'X'. It contains several tabs: 'Type and Range', 'Source', 'Cal', 'Test Set', and 'Graph'. The 'Graph' tab is selected. The main content area is titled 'Multi-Segment Residual phase noise (without using a phase locked loop)'. It includes a 'Title' dropdown menu set to 'Phase Noise Measurement', a checkbox 'When saving, use Title as Filename.' which is checked, and a 'Graph Type' dropdown menu set to 'Single-sideband phase noise (dBc/Hz)'. Below these are two scale sections: 'X Scale' with 'Minimum' set to '1' Hz and 'Maximum' set to '160E+6' Hz, and 'Y Scale for Single Sideband Phase Noise' with 'Maximum' set to '0' dBc / Hz and 'Minimum' set to '-170' dBc / Hz. There are buttons 'Fit X Scale To Data' and 'Fit Y Scale To Data'. Further down are fields for 'Normalize trace data to a' (set to '1' Hz bandwidth), 'Scale trace data to a new carrier frequency of' (set to '1' times the current carrier frequency), 'Shift trace data by' (set to '0' dB), 'Trace Smoothing Amount' (set to '0' with a spinner), and 'Power present at input of DUT' (set to '0' dBm). There are buttons 'Preset' and 'Display Preferences'. At the bottom are 'Close' and 'Help' buttons.

Keysight N5510

Type and Range | Source | Cal | Test Set | Graph

Multi-Segment Residual phase noise (without using a phase locked loop)

Title: Phase Noise Measurement

☒ When saving, use Title as Filename.

Graph Type: Single-sideband phase noise (dBc/Hz)

X Scale

Minimum: 1 Hz Maximum: 160E+6 Hz

Fit X Scale To Data

Y Scale for Single Sideband Phase Noise

Maximum: 0 dBc / Hz

Minimum: -170 dBc / Hz

Fit Y Scale To Data

Normalize trace data to a 1 Hz bandwidth

Scale trace data to a new carrier frequency of 1 times the current carrier frequency.

Shift trace data by 0 dB

Trace Smoothing Amount: 0

Preset

Power present at input of DUT: 0 dBm

Display Preferences

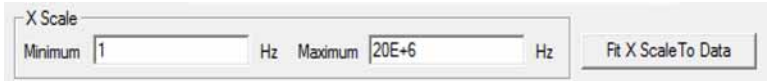
Close Help

Set the graph parameters for graph display.

Residual Measurement Examples
Amplifier Measurement Example - Dual Channel

1) Set X Scale

X Scale Minimum: 1 Hz
X Scale Maximum: 20 MHz



The X Scale dialog box contains a title bar 'X Scale'. Below it, there are two input fields: 'Minimum' with the value '1' and 'Maximum' with the value '20E+6'. Both fields are followed by the unit 'Hz'. To the right of these fields is a button labeled 'Fit X Scale To Data'.

2) Set Y Scale

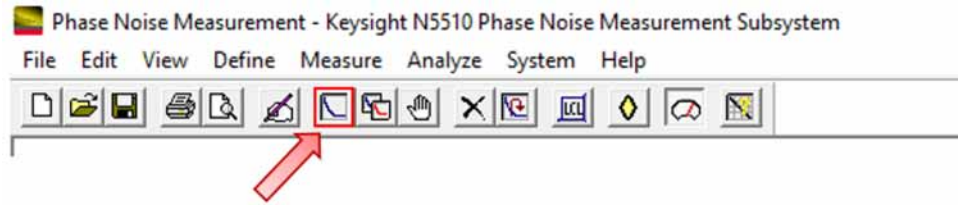
Y Scale Minimum:
-30 dBc/Hz
Y Scale Maximum:
-180 dBc/Hz



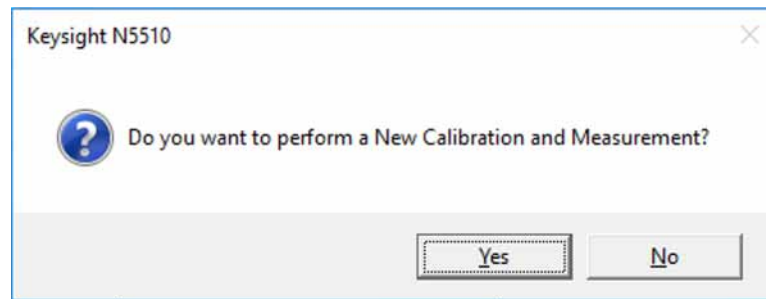
The Y Scale for Single Sideband Phase Noise dialog box has a title bar 'Y Scale for Single Sideband Phase Noise'. It contains two input fields: 'Maximum' with the value '-30' and 'Minimum' with the value '-180'. Both fields are followed by the unit 'dBc / Hz'. To the right of these fields is a button labeled 'Fit Y Scale To Data'.

Start a New Measurement

To start a new measurement, click on the icon shown below:



When the **Do you want to perform a New Calibration and Measurement?** prompt appears, click **Yes**.



When the **Connect Diagram** dialog box appears, click on the hardware down arrow and select your hardware configuration from the pull-down list. Click **Continue**.

CAUTION

To prevent damage to the test system's hardware components, verify that the input signal is within the test system's power limits. Refer to the N5511A Data Sheet online.

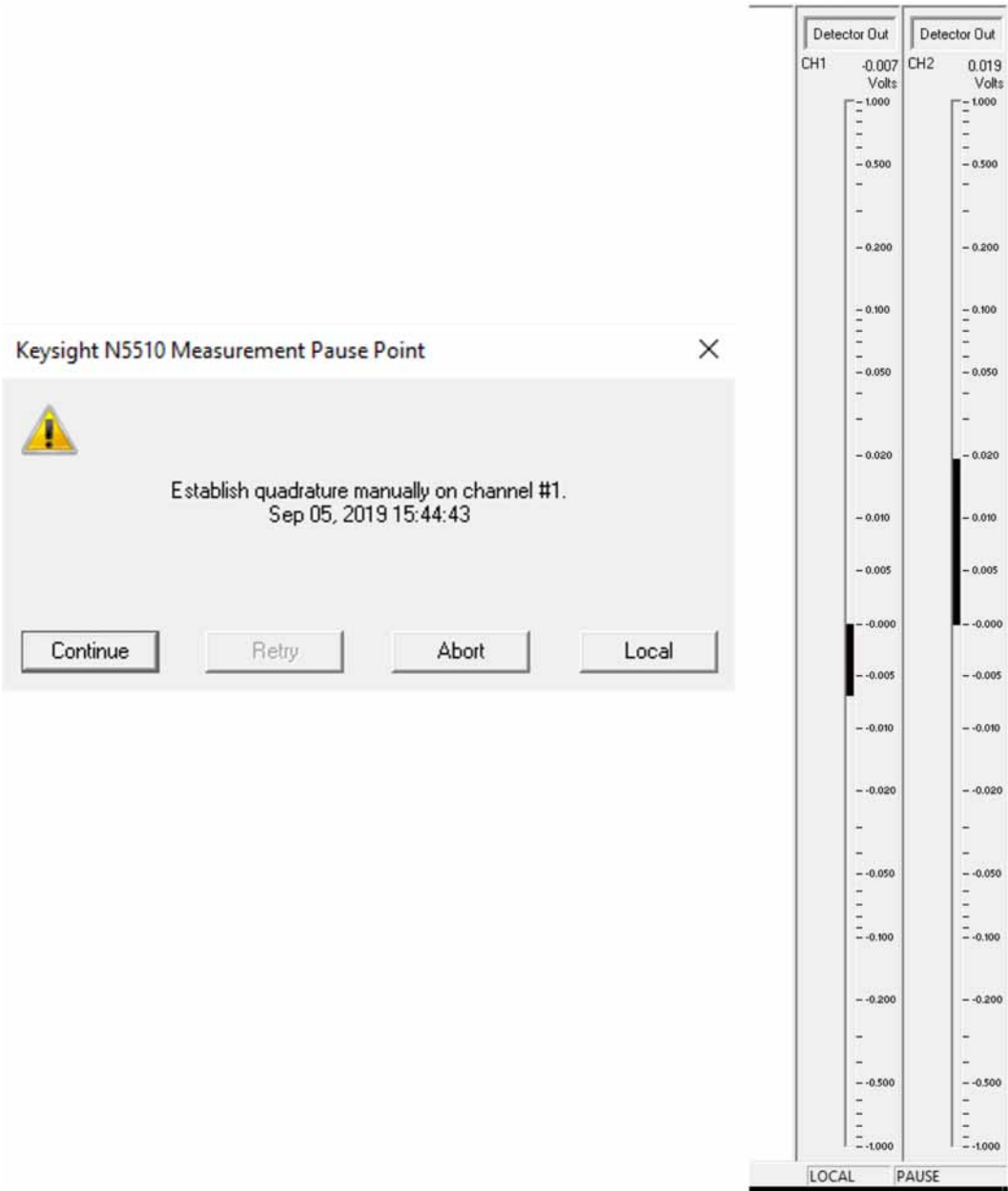
Making the Measurement

Calibrate the measurement using Single-Sided Spur calibration.

Refer to **Chapter 7, “Residual and Additive Noise Measurement Fundamentals”** for more information about residual phase noise measurements calibration types.

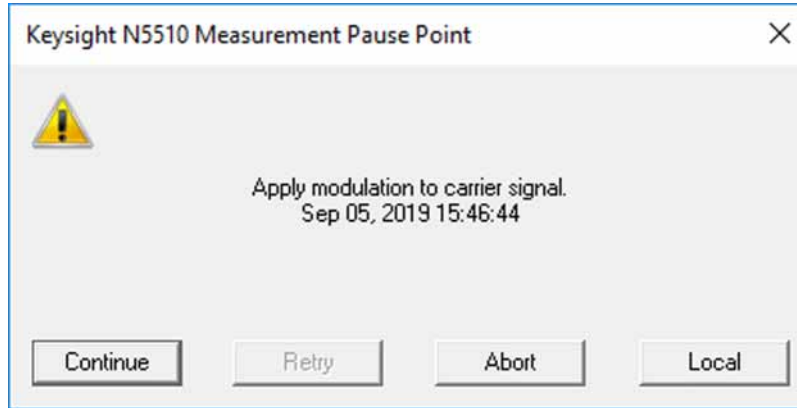
If the software prompts to **Establish Quadrature Manually** adjust the phase difference at the phase detector until the voltmeter at the right-hand side of the display, shown below, reads approximately 0 V. Click **Continue**. The software will prompt to establish quadrature for each channel.

Figure 8-16 Establish Quadrature Manually



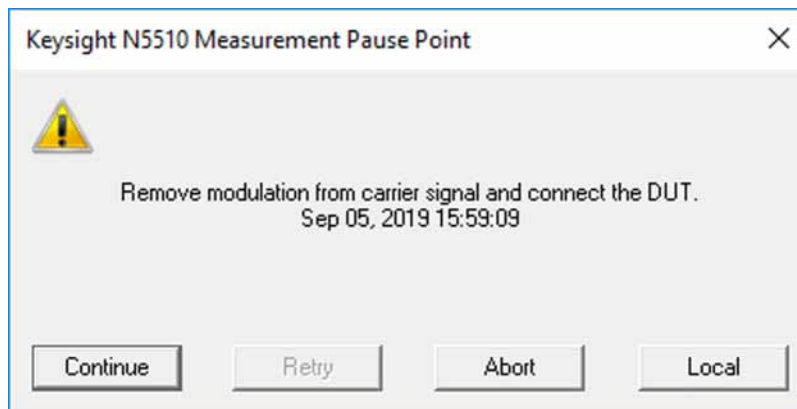
The system will then prompt you to Apply Modulation to the Carrier. At this moment, turn on the RF from the calibration source.

Figure 8-17 **Apply Modulation**



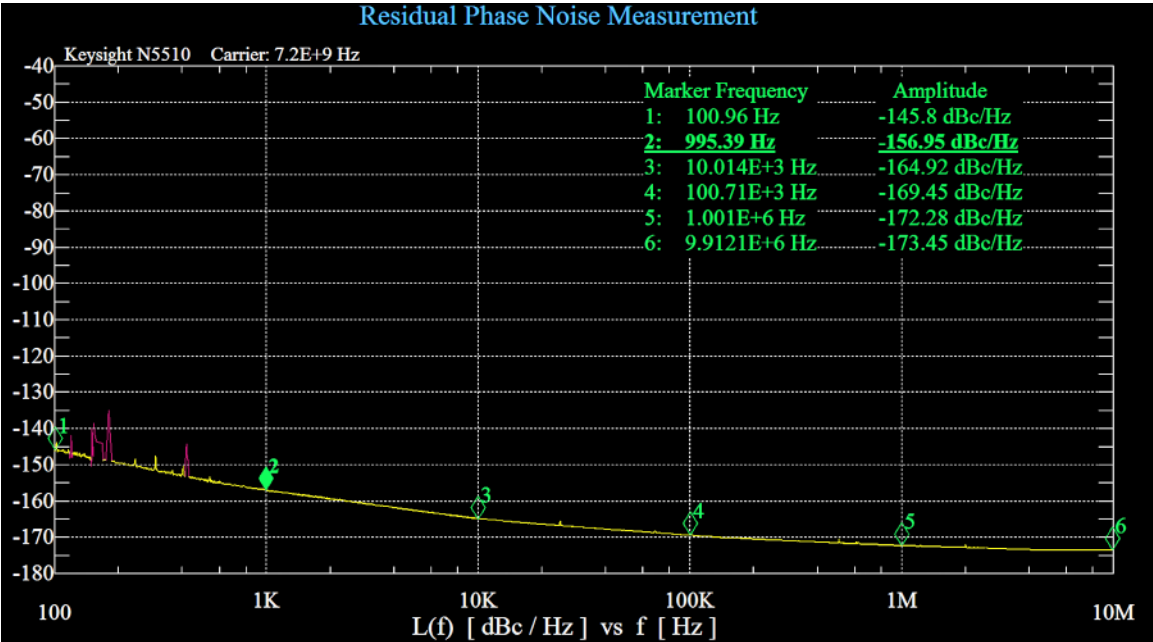
The system will prompt you to Remove Modulation. Turn off calibration source RF.

Figure 8-18 **Remove Modulation**



The system will now measure the noise data. The segment data will be displayed on the computer screen as the data is taken until all segments have been taken over the entire range you specified in the Measurement definition's Type and Range.

Figure 8-19 Additive Phase Noise Measurement



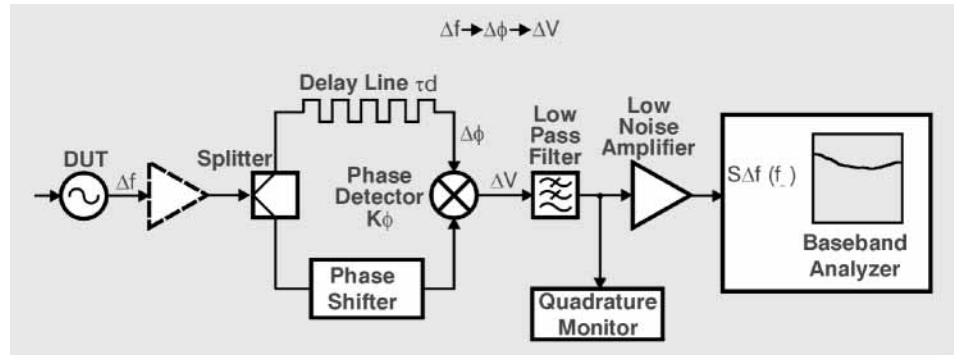
9 FM Discriminator Fundamentals

[“The Frequency Discriminator Method” on page 218](#)

The Frequency Discriminator Method

Unlike the phase detector method, the frequency discriminator method does not require a second reference source phase locked to the source under test. See [Figure 9-1](#).

Figure 9-1 Basic delay line/mixer frequency discriminator method



This makes the frequency discriminator method extremely useful for measuring sources that are difficult to phase lock, including sources that are microphonic or drift quickly. It can also be used to measure sources with high-level, low-rate phase noise, or high close-in spurious sidebands, conditions which can pose serious problems for the phase detector method. A wide-band delay line frequency discriminator is easy to implement using the N5511A Phase Noise Test System and common coaxial cable.

Basic theory

The delay line implementation of the frequency discriminator ([Figure 9-1](#)) converts short-term frequency fluctuations of a source into voltage fluctuations that can be measured by a baseband analyzer. The conversion is a two-part process, first converting the frequency fluctuations into phase fluctuations, and then converting the phase fluctuations to voltage fluctuations.

The frequency fluctuation to phase fluctuation transformation ($\Delta f \rightarrow \Delta \Phi$) takes place in the delay line. The nominal frequency arrives at the double-balanced mixer at a particular phase. As the frequency changes slightly, the phase shift incurred in the fixed delay time will change proportionally. The delay line converts the frequency change at the line input to a phase change at the line output when compared to the undelayed signal arriving at the mixer in the second path.

The double-balanced mixer, acting as a phase detector, transforms the instantaneous phase fluctuations into voltage fluctuations ($\Delta \Phi \rightarrow V$). With the two input signals 90° out of phase (phase quadrature), the voltage out is proportional to the input phase fluctuations. The voltage fluctuations can then be measured by the baseband analyzer and converted to phase noise units.

The discriminator transfer response

The important equation is the final magnitude of the transfer response.

$$\Delta V(f_m) = K\phi 2\pi\tau_d \Delta f(f_m) \frac{\sin(\pi f_m \tau_d)}{(\pi f_m \tau_d)}$$

Where $\Delta V(f_m)$ represents the voltage fluctuations out of the discriminator and $\Delta f(f_m)$ represents the frequency fluctuations of the DUT. $K\phi$ is the phase detector constant (phase to voltage translation). τ_d is the amount of delay provided by the delay line and f_m is the frequency offset from the carrier that the phase noise measurement is made.

System sensitivity

A frequency discriminator's system sensitivity is determined by the transfer response. As shown below, it is desirable to make both the phase detector constant $K\phi$ and the amount of delay τ_d large so that the voltage fluctuations ΔV out of a frequency discriminator will be measurable for even small fluctuations Δf .

$$\Delta V(f_m) = \left[K\phi 2\pi\tau_d \frac{\sin(\pi f_m \tau_d)}{(\pi f_m \tau_d)} \right] (\Delta f(f_m))$$

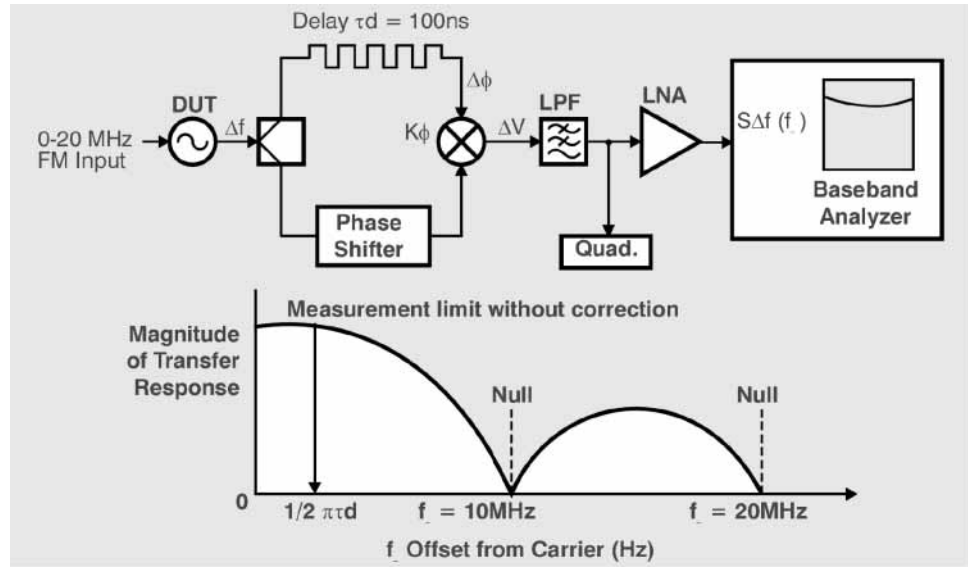
NOTE

The system sensitivity is independent of carrier frequency f_o .

The magnitude of the sinusoidal output term of the frequency discriminator is proportional to $\frac{\sin(\pi f_m \tau_d)}{(\pi f_m \tau_d)}$. This implies that the output response will have peaks and nulls, with the first null occurring at $n = 1/\tau$. Increasing the rate of a modulation signal applied to the system will cause nulls to appear at frequency multiples of $1/\tau_d$ (Figure 9-2).

Figure 9-2

Nulls in sensitivity of delay line discriminator



To avoid having to compensate for $\sin(x)/x$ response, measurements are typically made at offset frequencies (f_m) much less $1/2\tau d$. It is possible to measure at offset frequencies out to and beyond the null by scaling the measured results using the transfer equation. However, the sensitivity of the system get very poor results near the nulls.

The transfer function shows that increasing the delay τd increases the sensitivity of the system. However, increasing τd also decreases the offset frequencies (f_m) that can be measured without compensating for the $\sin(x)/x$ response. For example, a 200 ns delay line will have better sensitivity close to carrier than a 50 ns delay line., but will not be usable beyond 2.5 MHz offsets without compensating for the $\sin(x)/x$ response; the 50 ns line is usable to offsets of 10 MHz.

Increasing the delay τd , also increases the attenuation of the line. While this has no direct effect on the sensitivity provided by the delay line, it does reduce the signal into the phase detector and can result in decreased $K\Phi$ and decreased system sensitivity.

The phase detector constant $K\Phi$ equals the slope of the mixer sine wave output at the zero crossings. When the mixer is not in compression, $K\Phi$ equals $K_L V_R$ where K_L is the mixer efficiency and V_R is the voltage into the Signal Input port (R port) of the mixer. V_R is also the voltage available at the output of the delay line.

Optimum sensitivity

If measurements are made such that the offset frequency of interest (f_m) is $< 1/2\pi\tau_d$ the $\sin(x)/x$ term can be ignored and the transfer response can be reduced to $\Delta V(f_m) = K_d\Delta f(f_m) = K\Phi\pi\tau_d\Delta f(f_m)$

where K_d is the discriminator constant.

The reduced transfer equation implies that a frequency discriminator's system sensitivity can be increased simply by increasing the delay τ_d or by increasing the phase detector constant $K\Phi$. This assumption is not completely correct. $K\Phi$ is dependent on the signal level provided by the delay line and cannot exceed a device dependent maximum. This maximum is achieved when the phase detector is operating in compression¹. Increasing the delay τ_d will reduce the signal level out of the delay line often reducing the sensitivity of the phase detector. Optimum system sensitivity is obtained in a trade-off between delay and attenuation.

$$\text{Sensitivity} = K_L V_{in} LX(10)^{-LZ/20}$$

Where K_L is the phase detector efficiency, V_{in} is the signal voltage into the delay line, LX (dB) is the sensitivity provided by the delay line and LZ is the attenuation of the delay line. Taking the derivative with respect to the length L to find the maximum of this equation results in

$$LZ = 8.7 \text{ dB of attenuation}$$

The optimum sensitivity of a system with the phase detector operating out of results from using a length of coaxial line that has 8.7 dB of attenuation.

One way to increase the sensitivity of the discriminator when the phase detector is out of compression is to increase the signal into the delay line. This can be accomplished with an RF amplifier before the signal splitter. The noise of the RF amplifier will not degrade the measurement if the two-port noise of the amplifier is much less than the noise of the DUT. However, some attenuation may be needed in the signal path to the reference input to the double-balanced mixer (phase detector) to protect it from excessive power levels.

If the amplifier signal puts the phase detector into compression, $K\Phi$ is at its maximum and system sensitivity is now dependent on the length of the delay τ_d . For maximum sensitivity more delay can be added until the signal level out of the delay line is 8.7 dB below the phase detector compression point.

1. Compression: The level of the output signal at which the gain of a device is reduced by a specific amount, usually expressed in decibels (dB), as in the 1 dB compression point.

The following example illustrates how to choose a delay line that provided the optimum sensitivity given certain system parameters. (See [Table 9-1](#)).

Table 9-1 **Choosing a delay line**

Parameters	
Source signal level	+7dBm
Mixer compression point	+3 dBm
Delay line attenuation at source carrier frequency	30 dB per 100 ns of Delay
Highest offset frequency of interest	5 MHz

1. To avoid having to correct for the $\sin(x)/x$ response choose the delay such that:

A delay τ_d of 32 ns or less can be used for offset frequencies out to 5 MHz.

2. The attenuation for 32 ns of delay is 30 dB x 32 ns/100 ns or 9.6 dB. The total signal attenuation through the splitter and the delay line is 15.6 dB. The signal level out of the delay line is -8.6 dBm which is 11.6 dB below the phase detector compression point. Improved sensitivity can be achieved by reducing the length of the delay or by using a more efficient line so that the signal level out is -5.7 dBm or 8.7 dB below the mixer compression point.

Careful delay line selection is crucial for good system sensitivity. In cases where the phase detector is operating out of compression, sensitivity can be increased by using a low loss delay line, or by amplifying the signal from the DUT. Because attenuation in coaxial lines is frequency dependent, optimum system sensitivity will be achieved with different lengths of line for different carrier frequencies.

10 FM Discriminator Measurement Examples

[“Introduction” on page 224](#)

[“FM Discriminator Single Channel Measurement using Double-Sided Spur Calibration” on page 225](#)

[“FM Discriminator Single Channel Measurement using FM Rate and Deviation Calibration” on page 240](#)

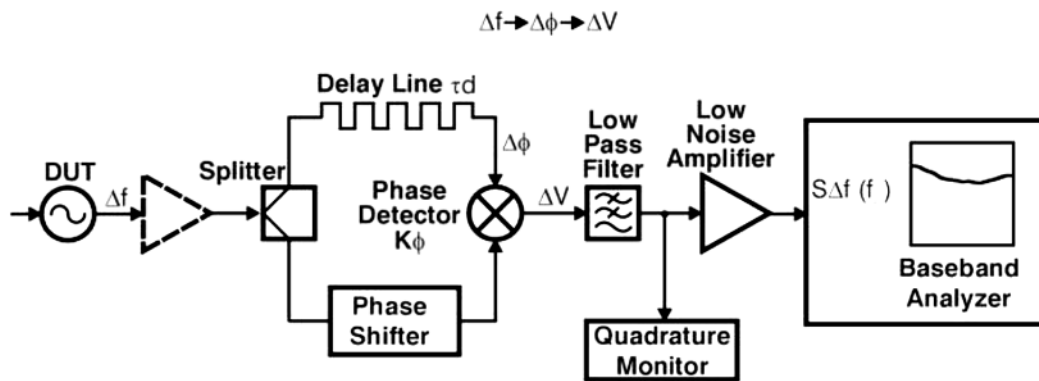
Introduction

These two measurement examples demonstrate the FM Discriminator measurement technique for measuring the phase noise of a signal source using two different calibration methods.

These measurement techniques work well for measuring free-running oscillators that drift over a range that exceeds the tuning range limits of the phase-locked-loop measurement technique. The Discriminator measurement is also useful for measuring sources when a VCO reference source is not available to provide adequate drift tracking.

The setup for a discriminator measurement uses a delay line to convert frequency fluctuations to phase fluctuations and a phase shifter to set quadrature at the phase detector.

Figure 10-1 FM Discriminator measurement setup



In the Discriminator measurement, the source is placed ahead of the power splitter. One output of the splitter feeds a delay line with enough delay to decorrelate the source noise. The delay line generates a phase shift proportional to the frequency. The phase shift is measured in the phase detector by comparing the delay output with the other output from the splitter. The output of the phase detector is a voltage proportional to the frequency fluctuations of the source.

For more information about FM Discrimination basics, refer to [Chapter 9, “FM Discriminator Fundamentals”](#).

FM Discriminator Single Channel Measurement using Double-Sided Spur Calibration

CAUTION

To prevent damage to the test set's components, *do not* apply a signal beyond the systems specifications. Refer to the data sheet for power specifications.

Required Equipment

Table 10-1 shows equipment required for this example in addition to the phase noise test system and your DUT.

NOTE

To ensure accurate measurements allow the DUT and measurement equipment to warm up at least 30 minutes before making the noise measurement.

Table 10-1 Required Equipment for the FM Discriminator Measurement Example

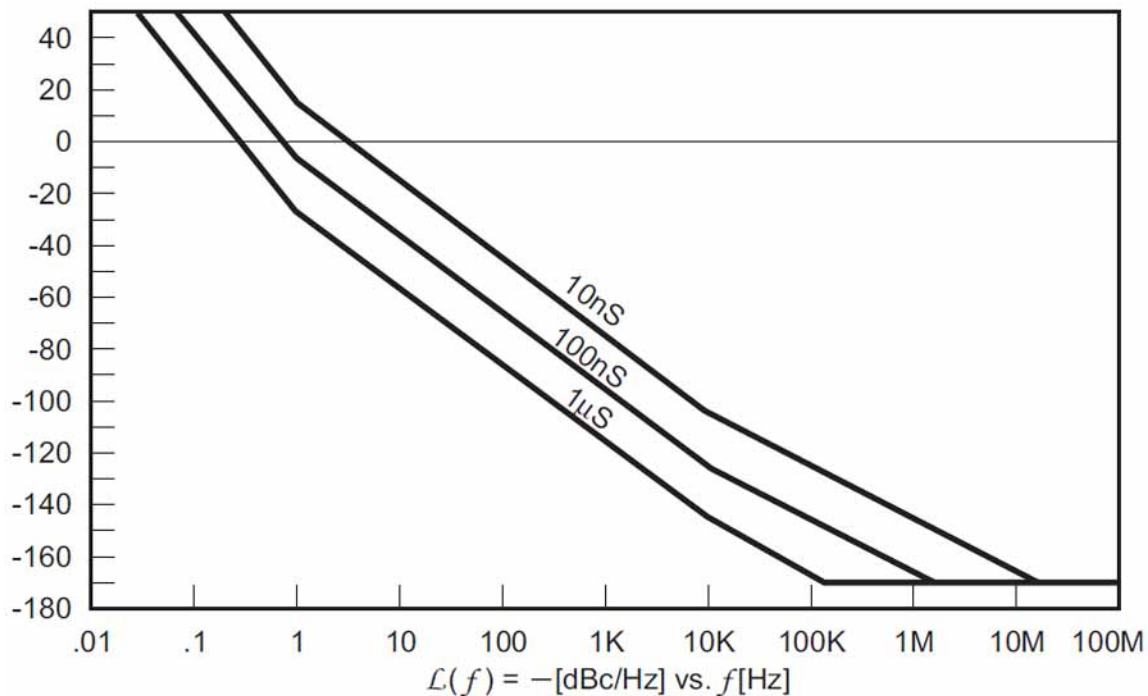
Equipment	Quantity	Comments
Signal Generator	1	+19 dBm output level at tested carrier frequency. Calibrated FM at a 20 kHz rate with 10 kHz Peak Deviation.
Power Splitter	1	NARDA 30183
Delay Line		Delay (or length) adequate to decorrelate source noise.
Phase Shifter	1	$\pm 180^\circ$ phase shifter at lowest carrier frequency tested.

Determining the discriminator (delay line) length

Perform the following steps to determine the minimum delay line length (τ) possible to provide an adequate noise to measure the source.

1. Determine the delay necessary to provide a discriminator noise floor that is below the expected noise level of the DUT. **Figure 10-2** shows the noise floor of the discriminator for given delay times (t).
2. Determine the length of coax required to provide the necessary delay (τ). (Eight feet of BNC cable will provide 12 ns of delay for this example.)
3. Determine the loss in the delay line. Verify that the signal source will be able to provide a power level at the output of the delay line of between +5 and +17 ICBM. Be sure to take into account an additional 4 to 6 dB of loss in the power splitter. (The loss across 8 feet of BNC cable specified in this example is negligible.) The test set Signal and Reference inputs requires +15 ICBM.

Figure 10-2 Discriminator noise floor as a function of delay time



Define the measurement

Measurement Type and Range

From the **Define** menu, navigate to the Measurement window. Refer to [Figure 10-3](#).

1. Choose the Type and Range tab.
2. From the Measurement Type pull-down in Type and Range tab, select Absolute Phase Noise (using an FM discriminator).

Figure 10-3 Select the Measurement Type

Keysight N5510

Type and Range | Source | Cal | Block Diagram | Test Set | Graph

Measurement Type: **Absolute Phase Noise (using FM discriminator)**

Measurement Method:

- ☐ Flexible
- ☒ Fast

Start Offset Resolution Expansion: 10

Channel Setup:

- ☒ Single
- ☐ Dual

Measurement Settings:

Start Offset: 10 Hz Stop Offset: 100E+6 Hz

FFT Analyzer Minimum Number of Trace Averages: 4

FFT Analyzer Minimum Number of Cross-correlations: 1

RBW %: 1.96 (1024 point FFT)

FFT Overlap %: 75 FFT Window Type: BlackmanHarris4

Estimated Measurement Time: 0

FFT Quality:

- ☒ Normal
- ☐ Fast
- ☐ High Resolution
- ☐ Custom

[View Segment Table](#)

☒ Couple Graph Type to Measurement Type

[Preset](#) [Close](#) [Help](#)

Source Calibration

1. Choose the Source tab. Refer to [Figure 10-4](#).
2. Enter the carrier (center) frequency of your DUT (5 MHz to 1.6 GHz). Enter the same frequency for the detector input frequency.

Figure 10-4 Enter Frequencies in the Source Tab

The screenshot shows the 'Keysight N5510' dialog box with the 'Source' tab selected. The dialog has a title bar with a close button (X). Below the title bar are tabs: 'Type and Range', 'Source', 'Cal', 'Block Diagram', 'Test Set', and 'Graph'. The 'Source' tab is active, showing the 'Absolute Phase Noise (using an FM discriminator)' section. This section contains two input fields: 'Carrier Source' and 'Detector Input'. The 'Carrier Source' field has 'Frequency' set to '1.027E+9' Hz and 'Power' set to '19' dBm. The 'Detector Input' field has 'Frequency' set to '1.027E+9' Hz. At the bottom right of the dialog is a 'Preset' button. At the bottom of the dialog are 'Close' and 'Help' buttons.

Keysight N5510

Type and Range | Source | Cal | Block Diagram | Test Set | Graph

Absolute Phase Noise (using an FM discriminator)

Carrier Source

Frequency 1.027E+9 Hz Power 19 dBm

Detector Input

Frequency 1.027E+9 Hz

Preset

Close Help

Cal Configuration

1. Choose the Cal tab. Refer to [Figure 10-5](#).
2. Feed the output from a modulated calibration source into a spectrum analyzer and measure the 1st modulation sideband frequency and power relative to the carrier's frequency and power. Enter the parameters in the following step.
3. Set the **Know Spur Parameters Offset Frequency** and **Amplitude** for the spur you plan to use for calibration purposes. This calibration method requires that you enter the offset and amplitude for a known spur.

Figure 10-5 Enter Parameters in the Cal Tab

Keysight N5510

Type and Range | Source | **Cal** | Block Diagram | Test Set | Graph

Absolute Phase Noise (using an FM discriminator)

FM Discriminator Constant

☐ Use current FM discriminator constant
☒ Derive constant from double - sided spur
☐ Derive constant from FM rate and deviation

Current FM Discriminator Constant channel #1 Volts / Hz

Known Spur Parameters

Offset Frequency Hz Amplitude dBc

Calibration Source

☒ I/O (manual) Frequency Hz Power dBm

Frequency Modulation

FM Rate Hz FM Deviation Hz

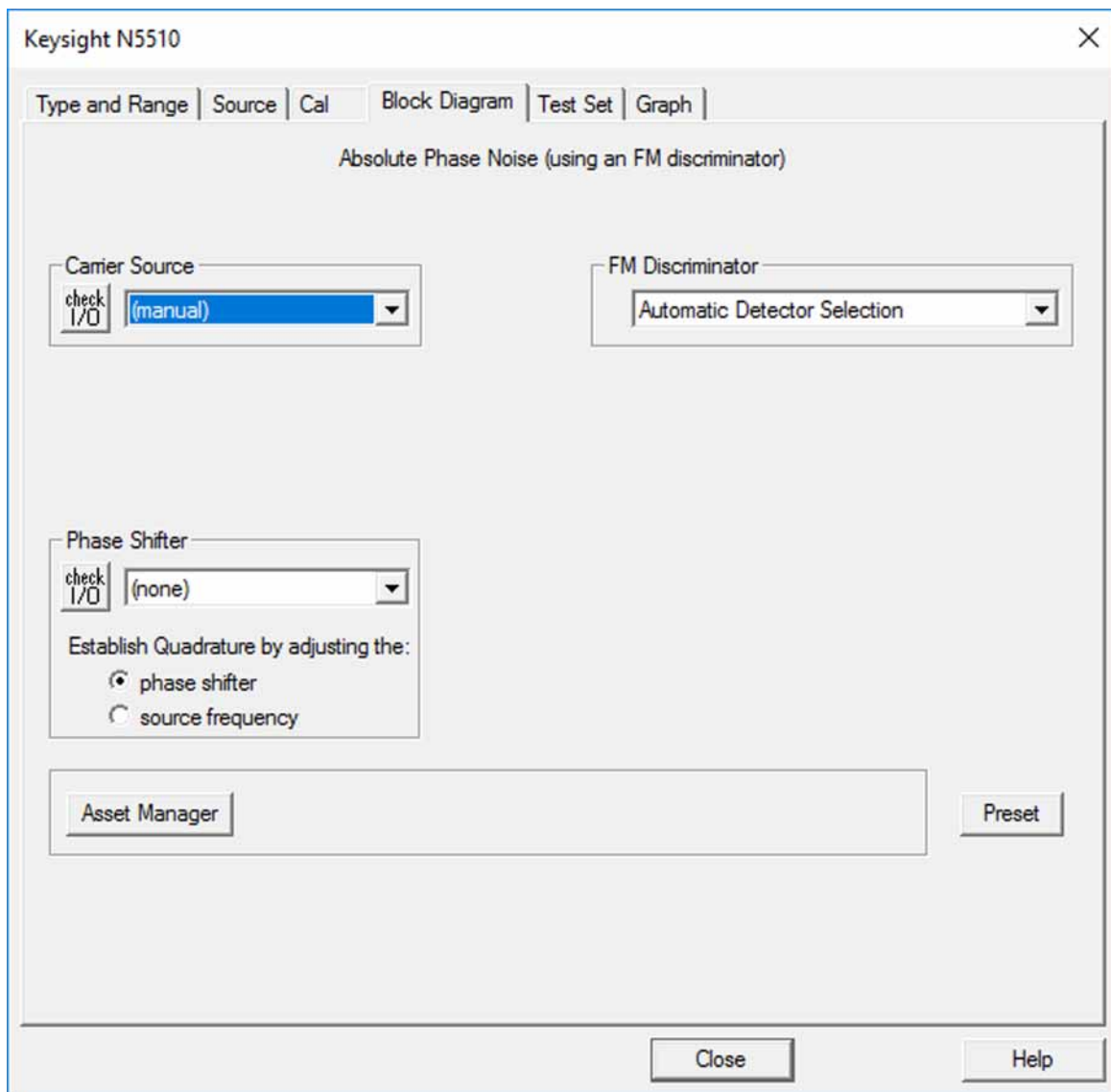
Asset Manager Preset

Close Help

Block Diagram Configuration

1. Choose the Block Diagram tab. Refer to [Figure 10-6](#).
2. From the **Reference Source** pull-down, select **Manual**.
3. From the **Phase Detector** pull-down, select **Automatic Detector Selection**.

Figure 10-6 Select Parameters in the Block Diagram Tab



Configure Graph

1. Choose the Graph tab. Refer to [Figure 10-7](#).
2. Enter a graph description of your choice.

Figure 10-7 Select Graph Description in the Graph Tab

Keysight N5510

Type and Range | Source | Cal | Block Diagram | Test Set | Graph

Multi-Segment Absolute phase noise (using an FM discriminator)

Title: **FM Discrim - 50 ns dly - 1.027GHz, +19 dBm out, VCO, DSS**

☒ When saving, use Title as Filename.

Graph Type: Single-sideband phase noise (dBc/Hz)

X Scale
Minimum: 10 Hz Maximum: 100E+6 Hz **Fit X Scale To Data**

Y Scale for Single Sideband Phase Noise
Maximum: 10 dBc / Hz **Fit Y Scale To Data**
Minimum: -190 dBc / Hz

Normalize trace data to a 1 Hz bandwidth

Scale trace data to a new carrier frequency of 1 times the current carrier frequency.

Shift trace data by 0 dB

Trace Smoothing Amount: 0 **Preset**

Power present at input of DUT: 0 dBm **Display Preferences**

Close **Help**

When you have completed these operations, click the **Close** button.

Setup considerations

Connecting cables

The best results will be obtained if semi-rigid coaxial cables are used to connect the components used in the measurement; however, BNC cables have been specified because they are more widely available. Using BNC cables may degrade the close-in phase noise results and, while adequate for this example, should not be used for an actual measurement on an unknown device unless absolutely necessary.

Measurement environment

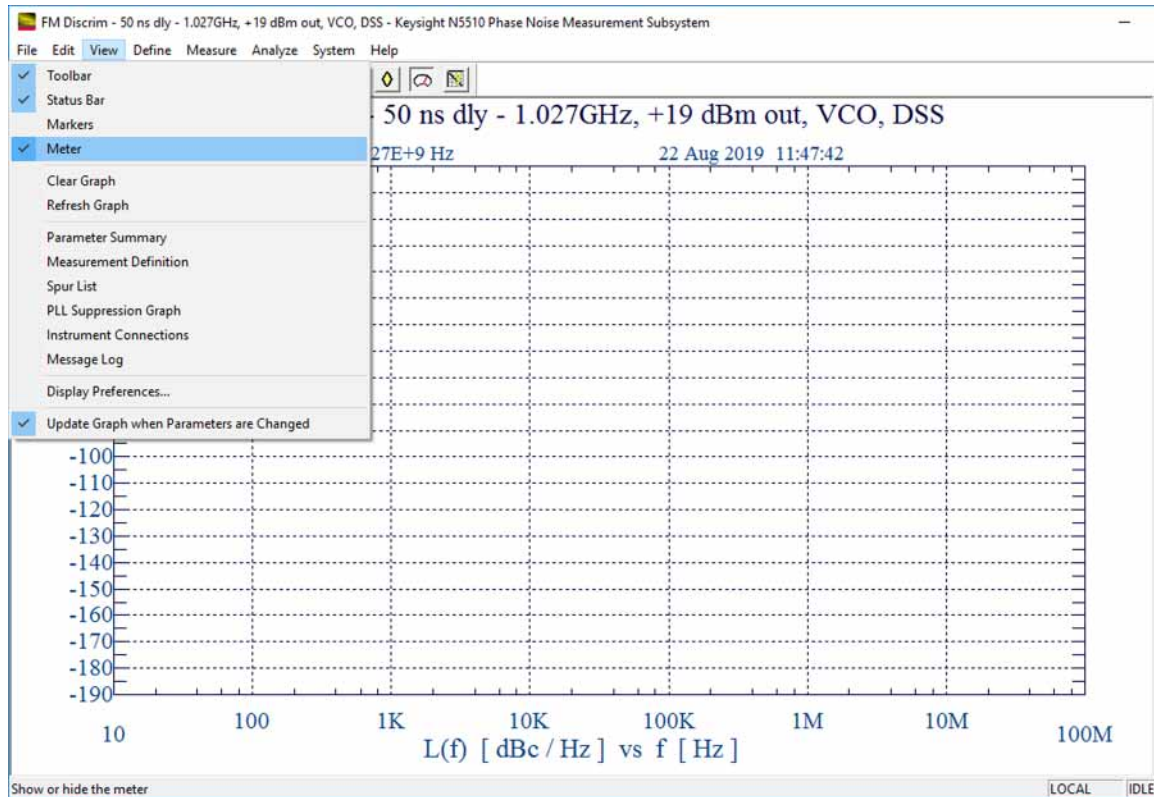
The low noise floors typical of these devices may require that special attention be given to the measurement environment. The following precautions will help ensure reliable test results:

- Filtering on power supply lines
- Protection from microphonics
- Shielding from air currents may be necessary.

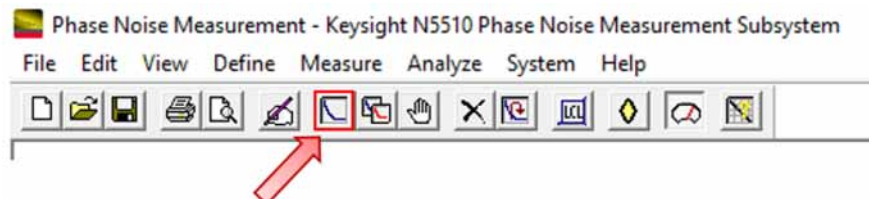
Beginning the measurement

1. From the **View** menu, choose **Meter** to select the quadrature meter. See [Figure 10-8](#).

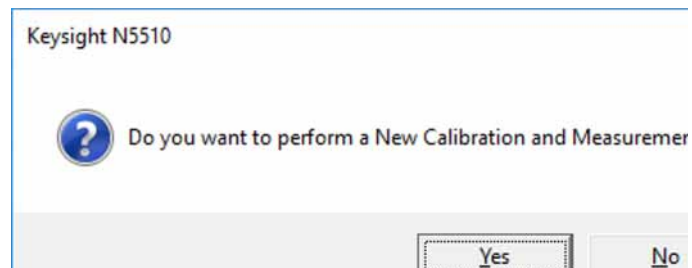
Figure 10-8 Select meter from view menu



2. From the **Measurement** menu, choose **New Measurement**.

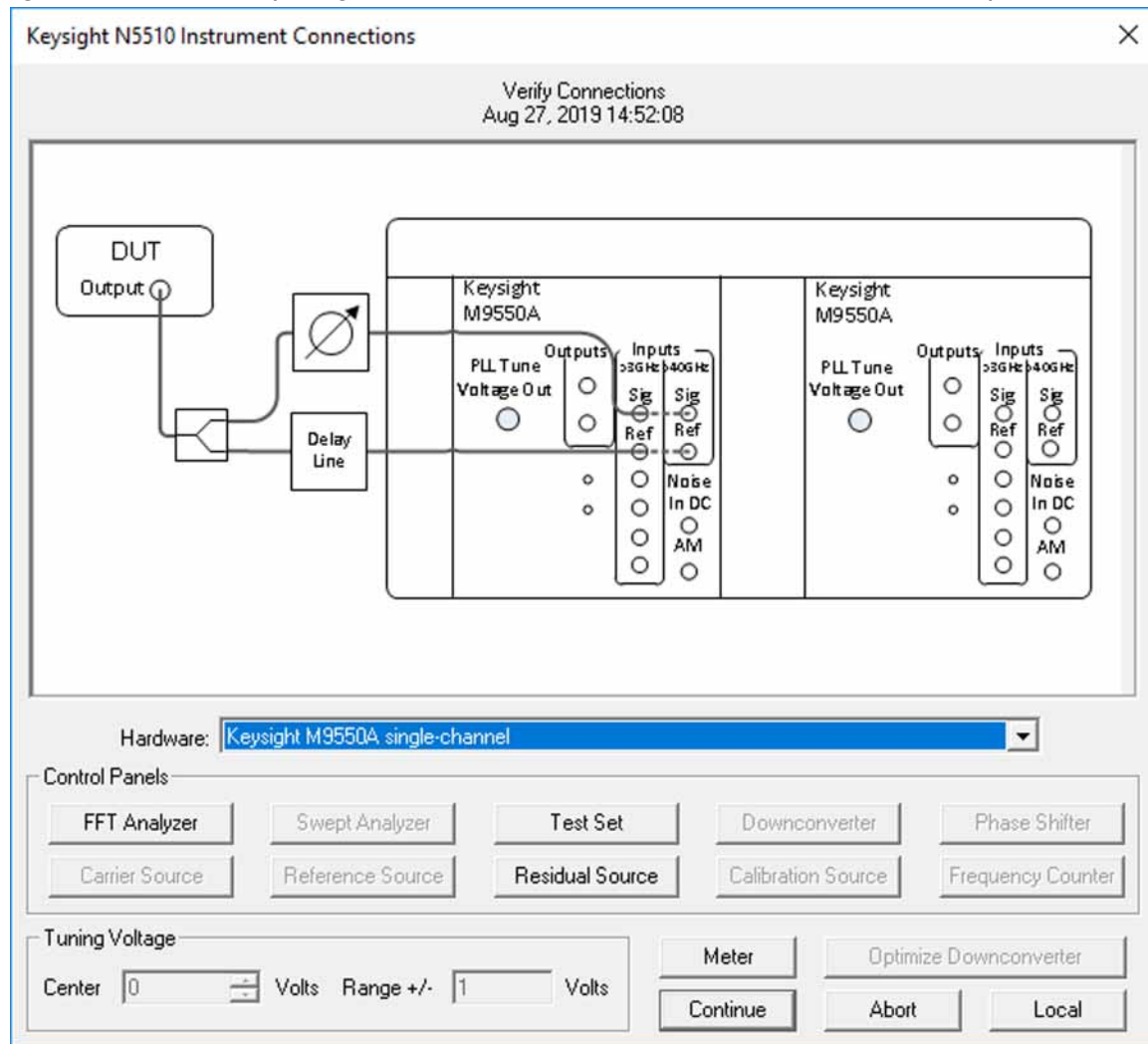


3. When the **Do you want to perform a New Calibration and Measurement?** prompt appears, click **Yes**.



4. When the **Connect Diagram** dialog box appears, click on the hardware pull-down arrow and select your hardware configuration from the list. See [Figure 10-9](#).

Figure 10-9 Setup diagram for the FM discrimination measurement example



CAUTION

The test set's signal input is subject to the limits and characteristics referenced in the data sheet.

Making the measurement

1. Press the **Continue** button when you are ready to make the measurement.

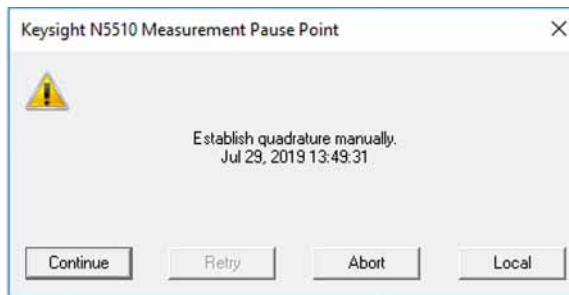
Calibrating the measurement

The calibration procedure determines the discriminator constant to use in the transfer response by measuring the system response to a known FM signal.

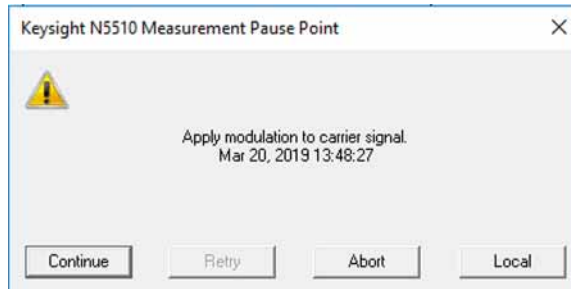
NOTE

Note that the system must be operating in quadrature during calibration.

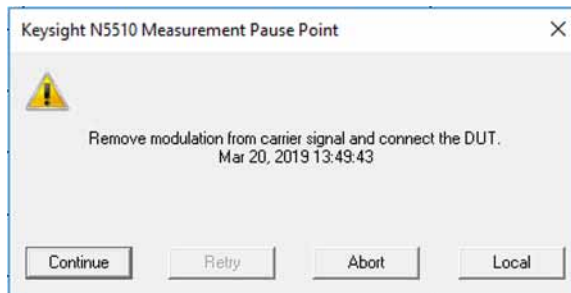
2. Establish quadrature by adjusting the phase shifter until the meter indicates 0 volts, then press **Continue**.



3. Apply modulation to the carrier signal, then press **Continue**.



4. Remove the modulation from the carrier and connect your DUT.



5. The system can now run the measurement. At the appropriate point, re-establish quadrature and continue the measurement.

The segment data will be displayed on the computer screen as the data is taken until all segments have been taken over the entire range you specified in the Measurement definition's Type and Range.

When the measurement is complete

When the measurement is complete, refer to **Chapter 14, "Evaluating Your Measurement Results"** for help in evaluating your measurement results. (If the test system has problems completing the measurement, it will inform you by placing a message on the computer display.

Figure 10-10 shows a typical absolute measurement using FM discrimination.

Figure 10-10 Typical phase noise curve using double-sided spur calibration

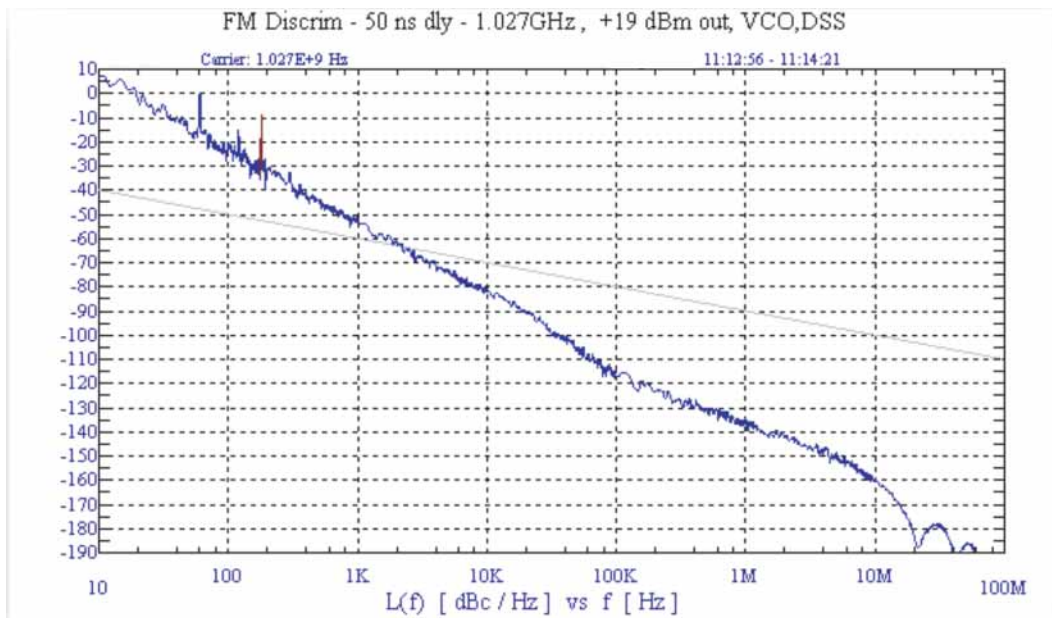


Table 10-2 **Parameter data for the double-sided spur calibration example**

Step	Parameters	Data
1	Type and Range Tab	
	Measurement Type	Absolute Phase Noise (using an FM Discriminator)
	Channel	Single
	Start Frequency	10 Hz
	Stop Frequency	100 E + 6 Hz
	Minimum Number of Averages	4
	FFT Quality	Normal
	Swept Quality	Fast
2	Sources Tab	
	Carrier Source	
	Frequency	1.027 E + 9 Hz
	Power	19 dBm
	Detector Input	
	Frequency	1.027 E +9 Hz
3	Cal Tab	
	FM Discriminator Constant	Derive constant from double-sided spur
	Current Phase Detector Constant	82.25 E-9
	Known Spur Parameters	
	Offset Frequency	20 E + 3 Hz
	Amplitude	-12 dBc
	Calibration Source	
	Frequency	1.027 E + 9 Hz
	Power	16 dBm
4	Block Diagram Tab	
	Carrier Source	Manual
	Phase Shifter	Manual
	Phase Detector	Automatic Detector Selection
	Establish Quadrature by adjusting the	phase shifter

Table 10-2 **Parameter data for the double-sided spur calibration example**

Step	Parameters	Data
5	Test Set Tab	The test parameters do not apply to this measurement example.
6	Graph Tab	
	Title	FM Discrim – 50 ns dly – 1.027GHz, +19 dBm out, VCO,DSS
	Graph Type	Single-sideband Noise (dBc/Hz)
	X Scale Minimum	10 Hz
	X Scale Maximum	100 E + 6 Hz
	Y Scale Minimum	10 dBc/Hz
	Y Scale Maximum	–190 dBc/Hz
	Normalize trace data to a:	1 Hz bandwidth
	Scale trace data to a new carrier frequency of:	1 times the current carrier frequency
	Shift trace data DOWN by	0 dB
	Trace Smoothing Amount	0
	Power present at input of DUT	0 dB

FM Discriminator Single Channel Measurement using FM Rate and Deviation Calibration

CAUTION

To prevent damage to the test set's components, *do not* apply a signal beyond the systems specifications. Refer to the data sheet for power specifications.

NOTE

In order to use the FM rate and deviation calibration method you must have a signal source that is calibrated for FM modulation rate and FM deviation parameters. All Keysight Technologies signal generators meet this requirement.

Required Equipment

Table 10-3 shows equipment required for this example in addition to the phase noise test system and your DUT.

NOTE

To ensure accurate measurements allow the DUT and measurement equipment to warm up at least 30 minutes before making the noise measurement.

Table 10-3 Required Equipment for the FM Discriminator Measurement Example

Equipment	Quantity	Comments
Signal Generator	1	+19 dBm output level at tested carrier frequency. Calibrated FM at a 20 kHz rate with 10 kHz Peak Deviation.
Power Splitter	1	NARDA 30183
Delay Line		Delay (or length) adequate to decorrelate source noise.
Phase Shifter	1	$\pm 180^\circ$ phase shifter at lowest carrier frequency tested.

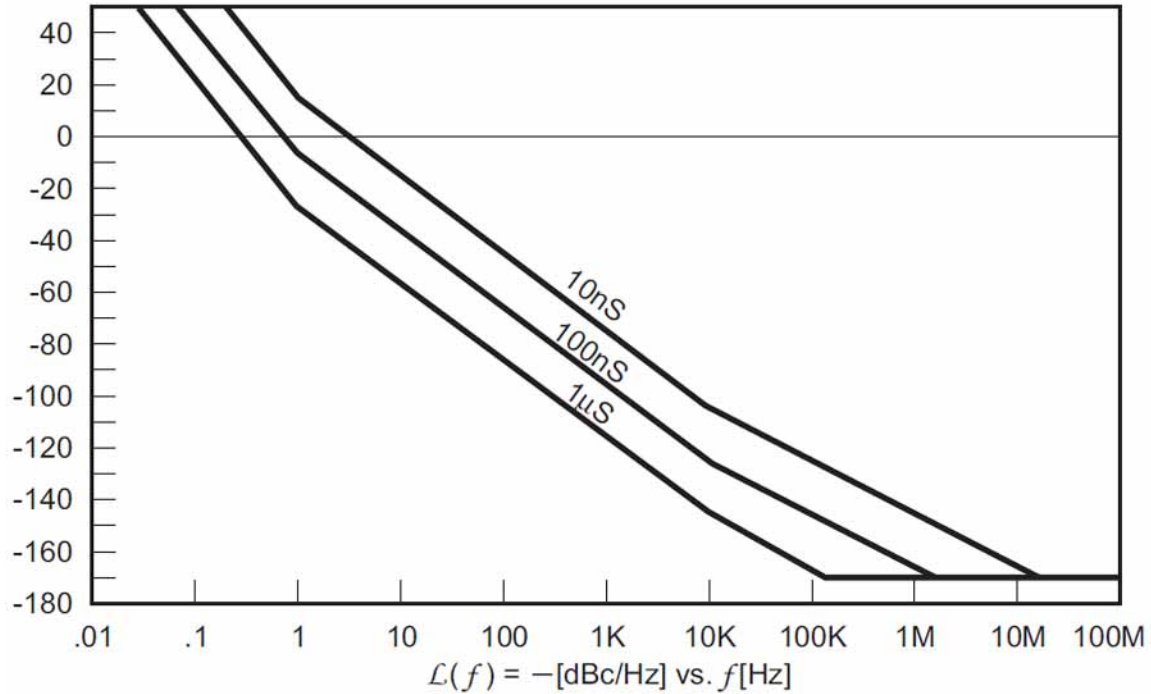
Determining the discriminator (delay line) length

Perform the following steps to determine the minimum delay line length (τ) possible to provide an adequate noise to measure the source.

1. Determine the delay necessary to provide a discriminator noise floor that is below the expected noise level of the DUT. **Figure 10-11** shows the noise floor of the discriminator for given delay times (t).
2. Determine the length of coax required to provide the necessary delay (τ). (Eight feet of BNC cable will provide 12 ns of delay for this example.)
3. Determine the loss in the delay line. Verify that the signal source will be able to provide a power level at the output of the delay line of between +5 and +17 ICBM. Be sure to take into account an additional 4 to 6 dB of loss

in the power splitter. (The loss across 8 feet of BNC cable specified in this example is negligible.) The test set Signal and Reference inputs requires +15 ICBM.

Figure 10-11 Discriminator noise floor as a function of delay time



Define the measurement

Measurement Type and Range

From the **Define** menu, navigate to the Measurement window. Refer to **Figure 10-12**.

1. Choose the Type and Range tab.
2. From the Measurement Type pull-down in Type and Range tab, select Absolute Phase Noise (using an FM discriminator).

Figure 10-12 Select the Measurement Type

The screenshot shows the 'Keysight N5510' dialog box with the 'Type and Range' tab selected. The 'Measurement Type' dropdown is set to 'Absolute Phase Noise (using FM discriminator)'. The 'Measurement Method' section has 'Fast' selected. The 'Channel Setup' section has 'Single' selected. The 'Measurement Settings' section includes fields for 'Start Offset' (10 Hz), 'Stop Offset' (100E+6 Hz), 'FFT Analyzer Minimum Number of Trace Averages' (4), 'FFT Analyzer Minimum Number of Cross-correlations' (1), 'RBW %' (1.96 (1024 point FFT)), 'FFT Overlap %' (75), 'FFT Window Type' (BlackmanHarris4), and 'Estimated Measurement Time' (0). The 'FFT Quality' section has 'Normal' selected. A 'View Segment Table' button is present. At the bottom, there is a checkbox for 'Couple Graph Type to Measurement Type' which is checked, and a 'Preset' button. The 'Close' and 'Help' buttons are at the bottom right.

Keysight N5510

Type and Range | Source | Cal | Block Diagram | Test Set | Graph

Measurement Type: Absolute Phase Noise (using FM discriminator)

Measurement Method:
☐ Flexible
☒ Fast Start Offset Resolution Expansion: 10

Channel Setup:
☒ Single
☐ Dual

Measurement Settings:
Start Offset: 10 Hz Stop Offset: 100E+6 Hz
FFT Analyzer Minimum Number of Trace Averages: 4
FFT Analyzer Minimum Number of Cross-correlations: 1
RBW %: 1.96 (1024 point FFT)
FFT Overlap %: 75 FFT Window Type: BlackmanHarris4
Estimated Measurement Time: 0

FFT Quality:
☒ Normal ☐ Fast ☐ High Resolution ☐ Custom View Segment Table

☒ Couple Graph Type to Measurement Type Preset

Close Help

Source Calibration

1. Choose the Source tab. Refer to [Figure 10-13](#).
2. Enter the carrier (center) frequency of your DUT (5 MHz to 1.6 GHz). Enter the same frequency for the detector input frequency.

Figure 10-13 Enter Frequencies in the Source Tab

The screenshot shows the 'Keysight N5510' dialog box with the 'Source' tab selected. The 'Carrier Source' section has 'Frequency' set to '1.027E+9' Hz and 'Power' set to '19' dBm. The 'Detector Input' section has 'Frequency' set to '1.027E+9' Hz. A 'Preset' button is located in the bottom right of the main area. 'Close' and 'Help' buttons are at the bottom of the dialog.

Section	Parameter	Value	Unit
Carrier Source	Frequency	1.027E+9	Hz
	Power	19	dBm
Detector Input	Frequency	1.027E+9	Hz

Cal Configuration

1. Choose the Cal tab. Refer to [Figure 10-14](#).
2. Select **Derive constant from FM rate and deviation** as the calibration method.
3. Set the **FM Rate** to 20 kHz and **FM Deviation** to 10 kHz, which are the recommended FM rate and deviation.

Figure 10-14 Enter Parameters in the Cal Tab

The screenshot shows the 'Keysight N5510' software window with the 'Cal' tab selected. The window title is 'Keysight N5510' with a close button (X) in the top right corner. The 'Cal' tab is active, showing the 'Absolute Phase Noise (using an FM discriminator)' section. Below this, there are three main sections: 'FM Discriminator Constant', 'Known Spur Parameters', and 'Calibration Source'. The 'FM Discriminator Constant' section has three radio buttons: 'Use current FM discriminator constant', 'Derive constant from double - sided spur', and 'Derive constant from FM rate and deviation' (which is selected). Below these is a text field for 'Current FM Discriminator Constant channel #1' with the value '82.72E-9' and the unit 'Volts / Hz'. The 'Known Spur Parameters' section has two text fields: 'Offset Frequency' with the value '1' and unit 'Hz', and 'Amplitude' with the value '-6' and unit 'dBc'. The 'Calibration Source' section has a 'check I/O' button, a dropdown menu set to '(manual)', a 'Frequency' text field with the value '1.027E+9' and unit 'Hz', and a 'Power' text field with the value '16' and unit 'dBm'. Below these is a 'Frequency Modulation' section with two text fields: 'FM Rate' with the value '20E+3' and unit 'Hz', and 'FM Deviation' with the value '10E+3' and unit 'Hz'. At the bottom of the window, there is an 'Asset Manager' button on the left, a 'Preset' button on the right, and 'Close' and 'Help' buttons at the very bottom.

Keysight N5510

Type and Range | Source | **Cal** | Block Diagram | Test Set | Graph

Absolute Phase Noise (using an FM discriminator)

FM Discriminator Constant

☐ Use current FM discriminator constant

☐ Derive constant from double - sided spur

☒ Derive constant from FM rate and deviation

Current FM Discriminator Constant channel #1 Volts / Hz

Known Spur Parameters

Offset Frequency Hz Amplitude dBc

Calibration Source

(manual) Frequency Hz Power dBm

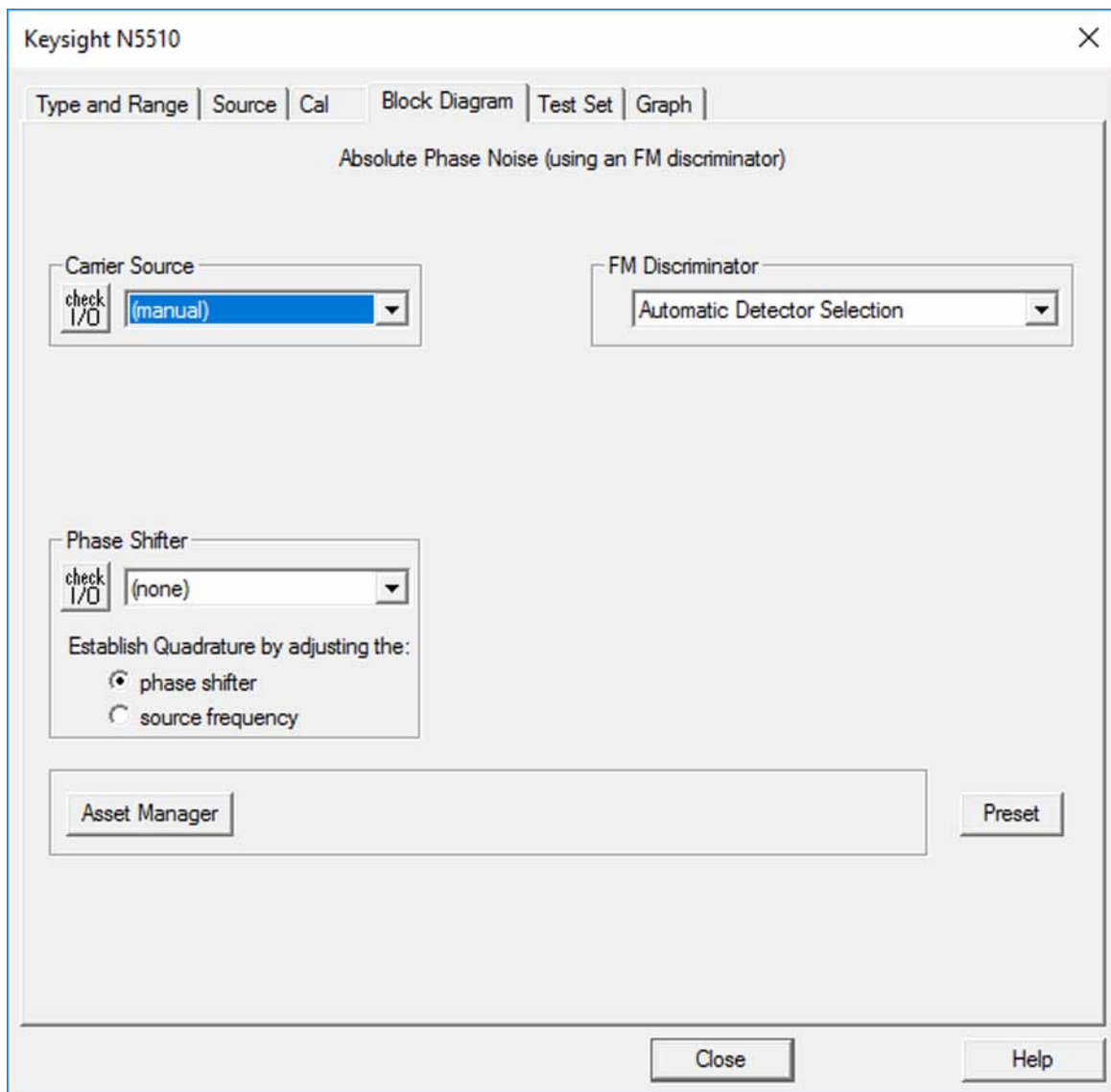
Frequency Modulation

FM Rate Hz FM Deviation Hz

Block Diagram Configuration

1. Choose the Block Diagram tab. Refer to [Figure 10-15](#).
2. From the **Reference Source** pull-down, select **Manual**.
3. From the **Phase Detector** pull-down, select **Automatic Detector Selection**.

Figure 10-15 Select Parameters in the Block Diagram Tab



Configure Graph

1. Choose the Graph tab. Refer to [Figure 10-16](#).
2. Enter a graph description of your choice.

Figure 10-16 Select Graph Description in the Graph Tab

Keysight N5510

Type and Range | Source | Cal | Block Diagram | Test Set | Graph

Multi-Segment Absolute phase noise (using an FM discriminator)

Title: **FM Discrim - 50 ns dly - 1.027GHz, +19 dBm out, VCO, DSS**

☒ When saving, use Title as Filename.

Graph Type: Single-sideband phase noise (dBc/Hz)

X Scale
Minimum: 10 Hz Maximum: 100E+6 Hz **Fit X Scale To Data**

Y Scale for Single Sideband Phase Noise
Maximum: 10 dBc / Hz **Fit Y Scale To Data**
Minimum: -190 dBc / Hz

Normalize trace data to a 1 Hz bandwidth

Scale trace data to a new carrier frequency of 1 times the current carrier frequency.

Shift trace data by 0 dB

Trace Smoothing Amount 0 **Preset**

Power present at input of DUT 0 dBm **Display Preferences**

Close **Help**

When you have completed these operations, click the **Close** button.

Setup considerations

Connecting cables

The best results will be obtained if semi-rigid coaxial cables are used to connect the components used in the measurement; however, BNC cables have been specified because they are more widely available. Using BNC cables may degrade the close-in phase noise results and, while adequate for this example, should not be used for an actual measurement on an unknown device unless absolutely necessary.

Measurement environment

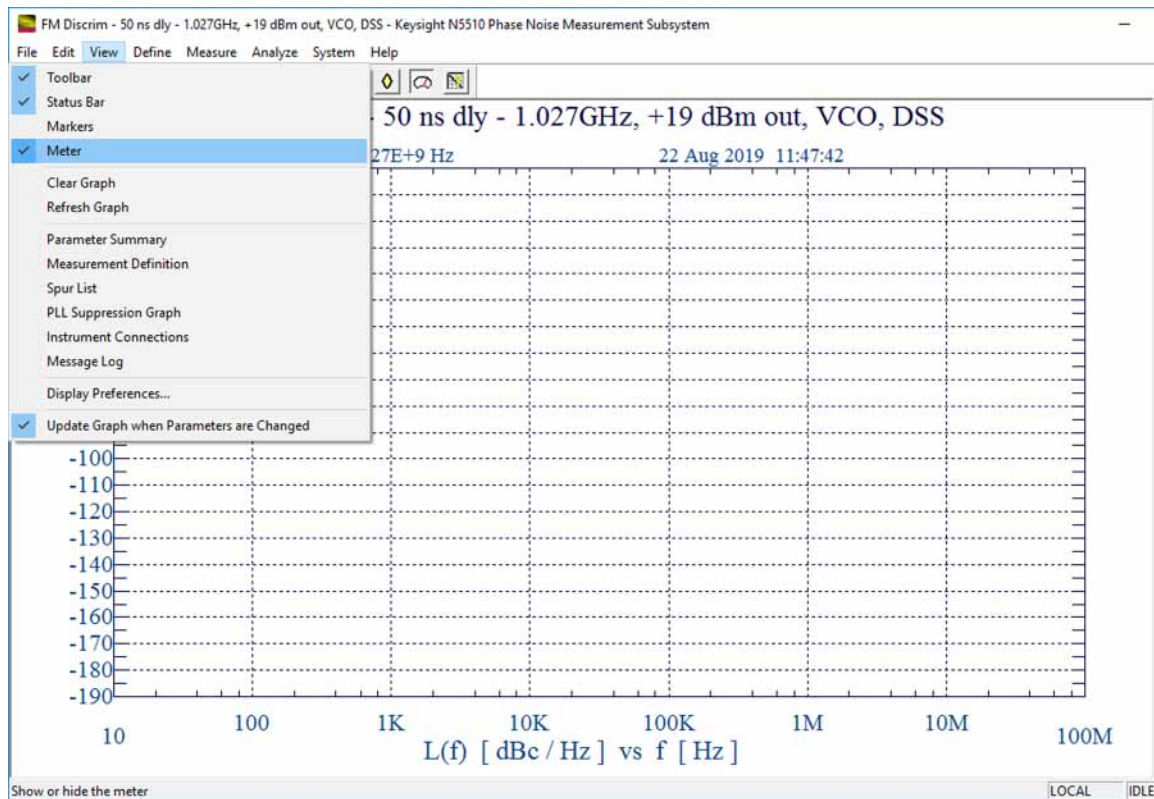
The low noise floors typical of these devices may require that special attention be given to the measurement environment. The following precautions will help ensure reliable test results:

- Filtering on power supply lines
- Protection from microphonics
- Shielding from air currents may be necessary.

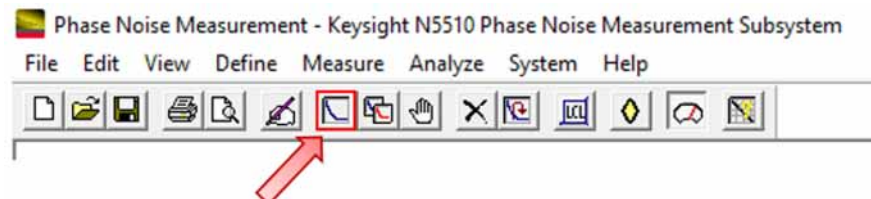
Beginning the measurement

1. From the **View** menu, choose **Meter** to select the quadrature meter. See [Figure 10-17](#).

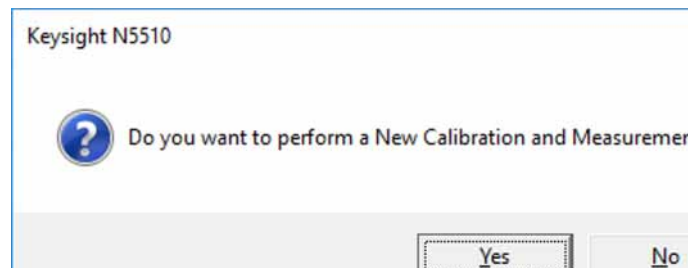
Figure 10-17 Select meter from view menu



2. From the **Measurement** menu, choose **New Measurement**.

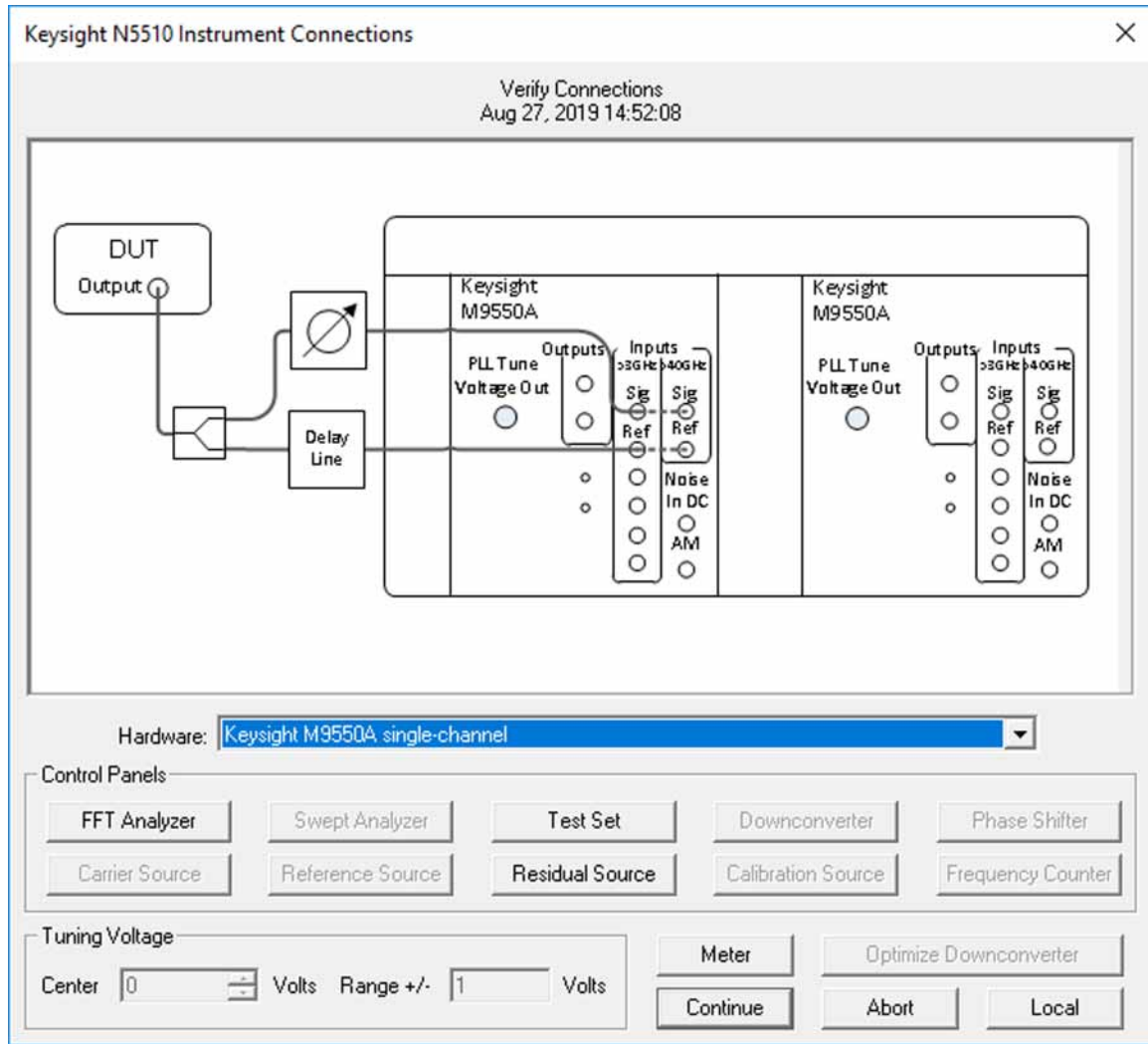


3. When the **Do you want to perform a New Calibration and Measurement?** prompt appears, click **Yes**.



4. When the **Connect Diagram** dialog box appears, click on the hardware pull-down arrow and select your hardware configuration from the list. See [Figure 10-18](#).

Figure 10-18 Setup diagram for the FM discrimination measurement example



CAUTION

The test set's signal input is subject to the limits and characteristics referenced in the data sheet.

Making the measurement

1. Press the **Continue** button when you are ready to make the measurement.

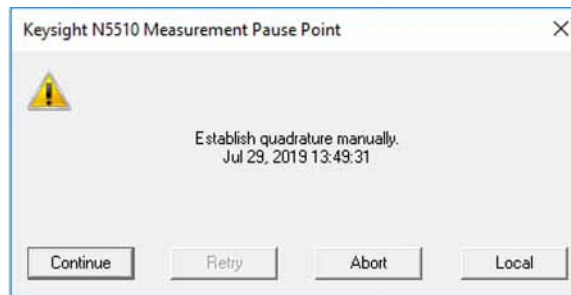
Calibrating the measurement

The calibration procedure determines the discriminator constant to use in the transfer response by measuring the system response to a known FM signal.

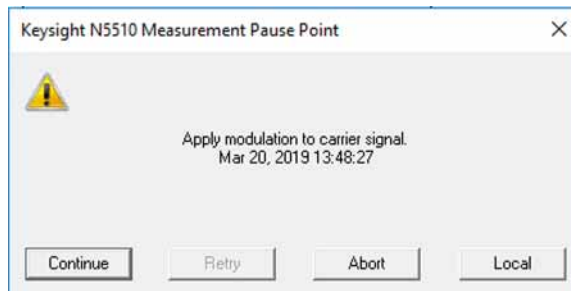
NOTE

Note that the system must be operating in quadrature during calibration.

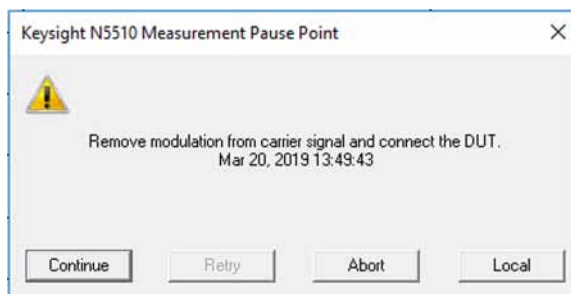
2. Establish quadrature by adjusting the phase shifter until the meter indicates 0 volts, then press **Continue**.



3. Apply modulation to the carrier signal, then press **Continue**.



4. Remove the modulation from the carrier and connect your DUT.



5. The system can now run the measurement. At the appropriate point, re-establish quadrature and continue the measurement.

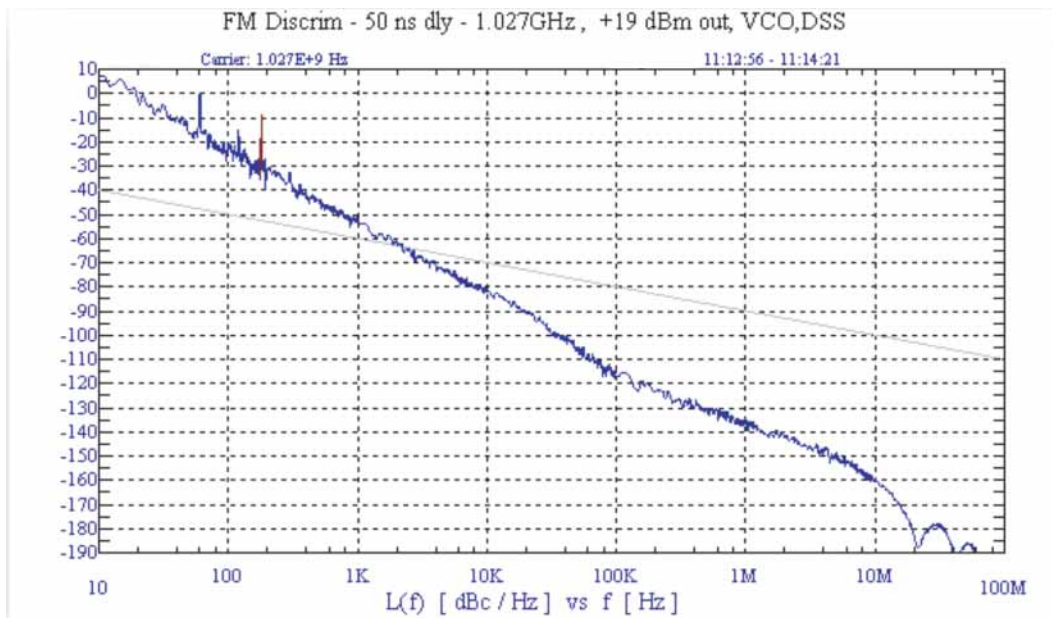
The segment data will be displayed on the computer screen as the data is taken until all segments have been taken over the entire range you specified in the Measurement definition's Type and Range.

When the measurement is complete

When the measurement is complete, refer to **Chapter 14, "Evaluating Your Measurement Results"** for help in evaluating your measurement results. (If the test system has problems completing the measurement, it will inform you by placing a message on the computer display.

Figure 10-19 shows a typical absolute measurement using FM discrimination.

Figure 10-19 Typical phase noise curve using FM Rate and Deviation calibration



FM Discriminator Measurement Examples
 FM Discriminator Single Channel Measurement using FM Rate and Deviation
 Calibration

Table 10-4 **Parameter data for the FM Rate and Deviation calibration example**

Step	Parameters	Data
1	Type and Range Tab	
	Measurement Type	Absolute Phase Noise (using an FM Discriminator)
	Channel	Single
	Start Frequency	10 Hz
	Stop Frequency	100 E + 6 Hz
	Minimum Number of Averages	4
	FFT Quality	Normal
	Swept Quality	Fast
2	Sources Tab	
	Carrier Source	
	Frequency	1.027 E + 9 Hz
	Power	19 dBm
	Detector Input	
	Frequency	1.027 E +9 Hz
3	Cal Tab	
	FM Discriminator Constant	Derive detector from FM rate and deviation
	Current FM Discriminator Constant	82.72 E-9
	Known Spur Parameters	
	Offset Frequency	1 Hz
	Amplitude	-6 dBc
	Calibration Source	
	Frequency	1.027 E + 9 Hz
	Power	16 dBm
4	Block Diagram Tab	
	Carrier Source	Manual
	Phase Shifter	Manual
	FM Discriminator	Automatic Detector Selection
	Establish Quadrature by adjusting the	phase shifter

FM Discriminator Measurement Examples
 FM Discriminator Single Channel Measurement using FM Rate and Deviation
 Calibration

Table 10-4 **Parameter data for the FM Rate and Deviation calibration example**

Step	Parameters	Data
5	Test Set Tab	The test parameters do not apply to this measurement example.
6	Graph Tab	
	Title	FM Discrim – 50 ns dly – 1.027GHz, +19 dBm out, VCO,DSS
	Graph Type	Single-sideband Noise (dBc/Hz)
	X Scale Minimum	10 Hz
	X Scale Maximum	100 E + 6 Hz
	Y Scale Minimum	10 dBc/Hz
	Y Scale Maximum	–190 dBc/Hz
	Normalize trace data to a:	1 Hz bandwidth
	Scale trace data to a new carrier frequency of:	1 times the current carrier frequency
	Shift trace data DOWN by	0 dB
	Trace Smoothing Amount	0
	Power present at input of DUT	0 dB

11 AM Noise Measurement Fundamentals

[“AM-Noise Measurement Theory of Operation” on page 256](#)

[“Amplitude Noise Measurement” on page 257](#)

[“Calibration and Measurement General Guidelines” on page 260](#)

[“User entry of phase detector constant” on page 261](#)

[“Double-Sided Spur” on page 263](#)

[“Single-Sided Spur” on page 267](#)

AM-Noise Measurement Theory of Operation

Basic noise measurement

The N5510 phase noise measurement software uses the following process to measure carrier noise by:

- Calibrating the noise detector sensitivity.
- Measuring the recovered baseband noise out of the detector.
- Calculating the noise around the signal by correcting the measured data by the detector sensitivity.
- Displaying the measured noise data in the required format.

Given a detector calibration, the system looks at the signal out of the detector as just a noise voltage which must be measured over a band of frequencies regardless of the signal's origin.

The detector calibration is accomplished by applying a known signal to the detector. The known signal is then measured at baseband. Finally, the transfer function between the known signal and the measured baseband signal is calculated.

Phase noise measurement

In the case of small angle phase modulation (<0.1 rad), the modulation sideband amplitude is constant with increasing modulation frequency. The phase detector gain can thus be measured at a single offset frequency, and the same constant will apply at all offset frequencies.

- In the case of calibrating with phase modulation sidebands, the system requires the carrier-to-sideband ratio and the frequency offset of the sidebands. The offset frequency is equal to the baseband modulation frequency. The ratio of the baseband signal voltage to the carrier-to-sideband ratio is the sensitivity of the detector.
- In the case of calibrating with a single-sided spur, it can be shown that a single-sided spur is equal to a PM signal plus an AM signal. The modulation sidebands for both are 6 dB below the original single-sided spur. Since the phase detector attenuates the AM by more than 30 dB, the calibration constant can be measured as in the previous case, but with an additional 6 dB correction factor.

Amplitude Noise Measurement

The level of amplitude modulation sidebands is also constant with increasing modulation frequency. The AM detector gain can thus be measured at a single offset frequency and the same constant will apply at all offset frequencies. Replacing the phase detector with an AM detector, the AM noise measurement can be calibrated in the same way as PM noise measurement, except the phase modulation must be replaced with amplitude modulation.

The AM noise measurement is a characterization of a source. The residual AM noise of a DUT can only be made by using a source with lower AM noise, then subtracting that AM noise from the measured output noise of the DUT. The noise floor of this technique is the noise floor of the source.

AM noise measurement block diagrams

Figure 11-1 Single Channel AM Measurement

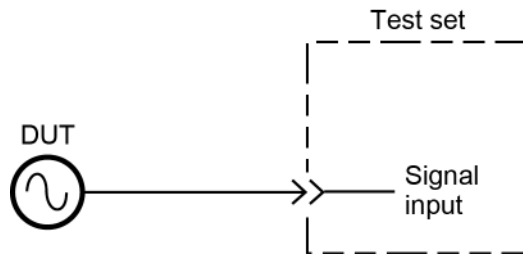
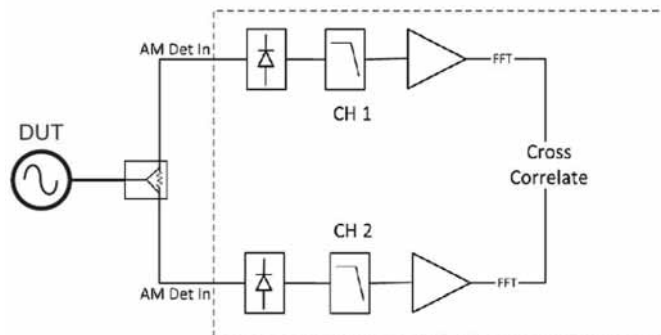


Figure 11-2 Dual Channel AM Measurement

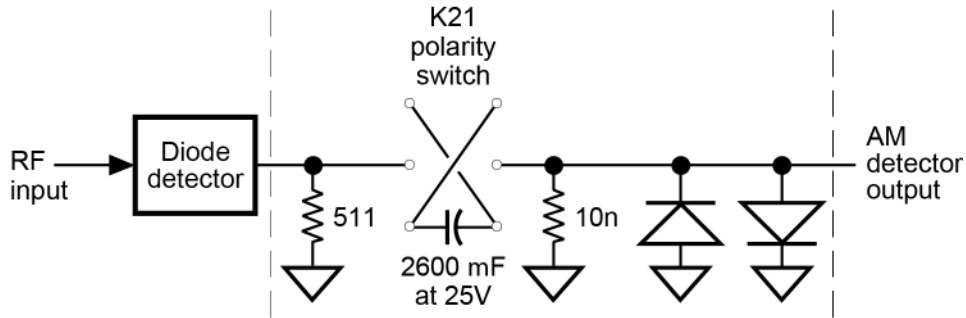


Using an External AM Detector

The following is an example of how an external detector can be utilized to connect into the noise inputs of the phase detector module(s) of the N5511A. This is the same as how an AM noise measurement would be traditionally performed on the e5500 test set.

Figure 11-3

AM detector schematic



AM detector specifications

Detector type low barrier Schottky diode

Carrier frequency range 10 MHz to 26.5 GHz

Maximum input power +23 dBm

Minimum input power 0 dBm

Output bandwidth 1 Hz to 40 MHz

AM detector considerations

CAUTION

The phase noise test set must be DC blocked when using its Noise Input or internal AM detector. The test set will not tolerate more than ± 2 mV DC Input without overloading the LNA. A DC block must be connected in series after the AM Detector to remove the DC component. The 70429A Option K21 is designed specifically for this purpose or the internal DC blocking filter in either the N5500A or N5507A may be used.

- The AM detector consists of an Keysight 33330C Low-Barrier Schottky Diode Detector and an AM detector filter (Keysight 70429A K21).
- The detector, for example, is an 33330C Low-Barrier Schottky-Diode Detector. The Schottky detectors will handle more power than the point contact detectors, and are equally as sensitive and quiet.
- The AM detector output blocking capacitor in the 70429A Option K21, N5500A Option 001, or N5507A prevents the DC voltage component of the demodulated signal from saturating the system's low noise amplifier (LNA). The value of this capacitor sets the lower frequency limit of the demodulated output.

- Carrier feedthrough in the detector may be excessive for frequencies below a few hundred megahertz. The LNA is protected from saturation by the internal filters used to absorb phase detector feedthrough and unwanted mixer products.
- The AC load on the detector is 50 Ω , set by the input impedance of the LNA in the test system. The 50 ohm load increases the detector bandwidth up to more than 100 MHz.

N5511A has an internal AM detector in the phase detector module(s). This eliminates the need for external detection and DC blocking.

Table 11-1 Internal AM Detector Specifications

Carrier Frequency Range	Maximum Input Power
10 MHz to 40 GHz	+23 dBm

See the data sheet for specifications of the internal AM detector:
<http://www.keysight.com/find/n5511a>

Calibration and Measurement General Guidelines

NOTE

The following general guidelines should be considered when setting up and making an AM-noise measurement.

- Although AM noise measurements are less vulnerable than residual phase-noise measurements to noise induced by vibration and temperature fluctuation, care should be taken to ensure that all connections are tight and that all cables are electrically sound.
- The noise floor of the detector may degrade as power increases above +15 dBm. Noise in the region of the detector is best measured with about +10 dBm of drive level. The noise floor is best measured with about +20 dBm of drive level. This level can be deleted once the original spur is detected. In a dual channel configuration, the internal noise floor can be reduced by cross-correlation and can thus make these power considerations less critical.
- An amplifier (amplifiers if dual channel) must be used in cases where the signal level out of the DUT is too small to drive the AM detector or is inadequate to produce a low enough measurement noise floor. In this case the amplifier should have the following characteristics.
 - It should have the lowest possible noise figure, and the greatest possible dynamic range.
 - It should have only enough gain to get the required signal levels. Excess gain leads to amplifiers operating in gain compression, increasing their likelihood of suppressing the AM noise to be measured.
 - The amplifier's sensitivity to power supply noise and the supply noise itself must both be minimized.

User entry of phase detector constant

Advantages

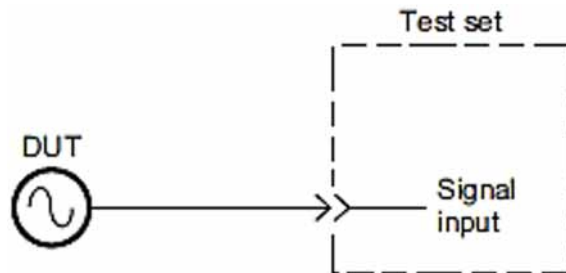
- Easy method of calibrating the measurement system.
- Will measure DUT without modulation capability.
- Requires only an RF power meter to measure drive levels into the AM detector.
- Fastest method of calibration. If the same power levels are always at the AM detector, as in the case of leveled outputs, the AM detector sensitivity will always be essentially the same.
- Very quick method of estimating the equivalent phase detector constant.

Disadvantages

- It is the least accurate of the calibration methods.
- It does not take into account the amount of power at harmonics of the signal.

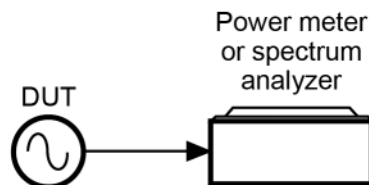
1. Using information shown in **Figure 11-4** and **Figure 11-5**, Connect the circuit and tighten all connections.

Figure 11-4 Phase detector constant AM noise setup



2. Measure the power which will be applied to the AM detector (see **Figure 11-5**).

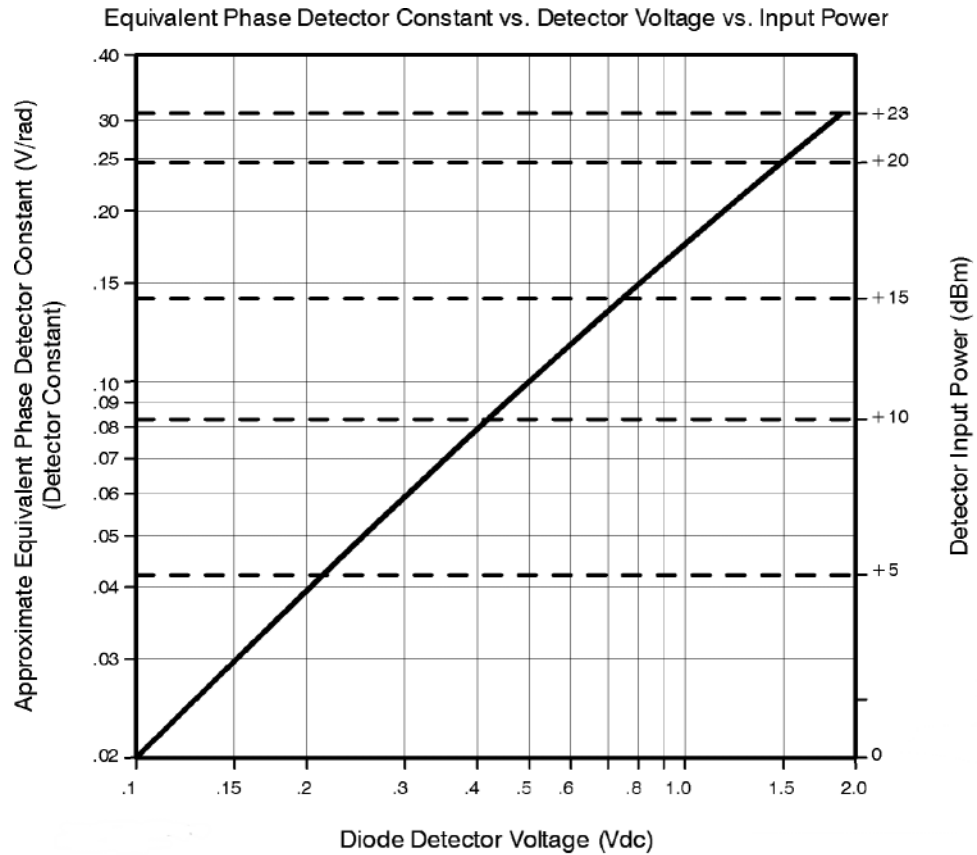
Figure 11-5 AM noise calibration setup



3. Locate the drive level on the AM sensitivity graph (**Figure 11-6**), and enter the data.

4. Measure the noise data and interpret the results. The measured data will be plotted as single-sideband AM noise in dBc/Hz.

Figure 11-6 AM detector sensitivity graph



Double-Sided Spur

Example 1

Advantages

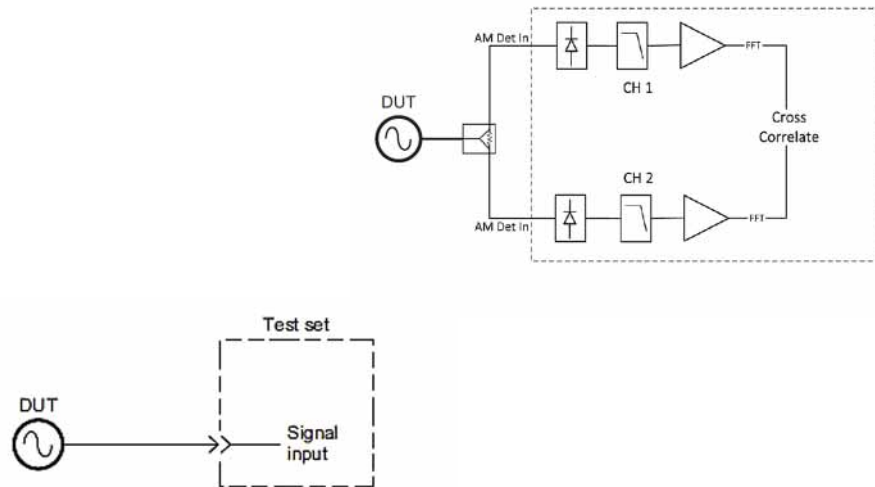
- Requires only one RF source (DUT)
- Calibration is done under actual measurement conditions so all non-linearities and harmonics of the AM detector are calibrated out. The double-sided spur method and the single-sided-spur method are the two most accurate methods for this reason.

Disadvantages

- Required that the DUT have adjustable AM which may also be turned off.
- Requires the AM of the DUT to be extremely accurate; otherwise a modulation analyzer, for manual measurement of AM sidebands is required.

1. Connect circuit as shown in **Figure 11-7**, and tighten all connections.

Figure 11-7 Setup for single channel and dual channel instruments



2. Measure the power which will be applied to the AM detector. It must be between 0 and +23 dBm.

3. Measure the carrier-to-sideband ratio of the AM at the AM detector's input with a signal analyzer. The source should be adjusted such that the sidebands are between -30 and -60 dB below the carrier with a modulation rate between 10 Hz and 20 MHz.

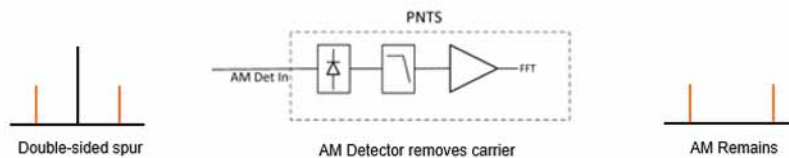
NOTE

The carrier-to-sideband ratio $\frac{C}{sb}$ for AM is:

$$\frac{C}{sb} = 20\log\left(\frac{\text{percentAM}}{100}\right) = 6dB$$

These values are directly entered into the software. When measurement is performed, there will not be a 6 dB difference as observed in an absolute or residual measurement as AM is not being suppressed in this measurement. See [Figure 11-8](#).

Figure 11-8 AM Detector removes carrier



NOTE

For a dual channel or single channel, the tone-measuring process is identical, as the power level is measured relative to the carrier in both cases.

4. Reconnect the AM detector and enter the carrier-to-sideband ratio and modulation frequency.
5. Run New Measurement. The AM detector calibration constant will be measured.
6. The application will prompt to turn off AM.
7. Measure noise data and interpret the results.

Example 2

Advantages

- Will measure source without modulation capability.

- Calibration is done under actual measurement conditions so all non-linearities and harmonics of the AM detector are calibrated out. The double-sided spur method and the single-sided-spur method are the two most accurate methods for this reason.

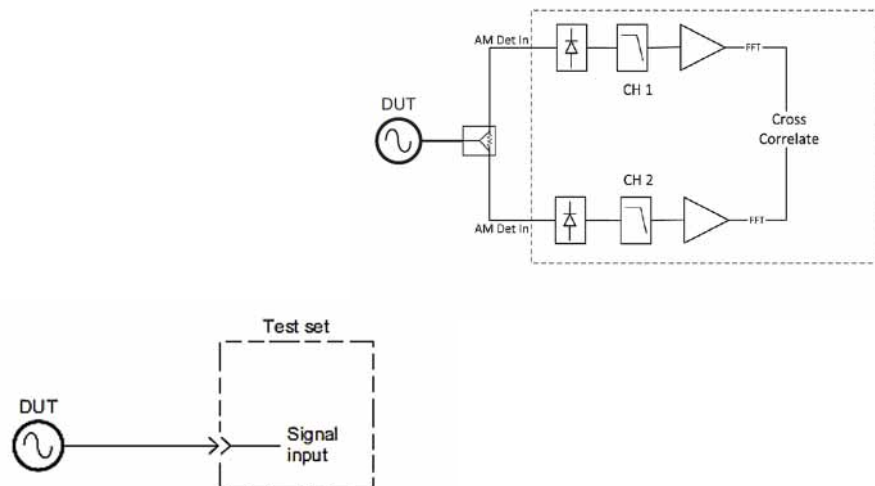
Disadvantages

- Requires a second RF source with very accurate AM modulation and output power sufficient to match the DUT. If the AM modulation is not very accurate, a modulation analyzer must be used to make manual measurement of the AM sidebands.

This method is identical to method 1, however a reference with modulation capabilities is used to calibrate the measurement.

1. Connect the device under test in a single channel or dual channel configuration. See [Figure 11-9](#).

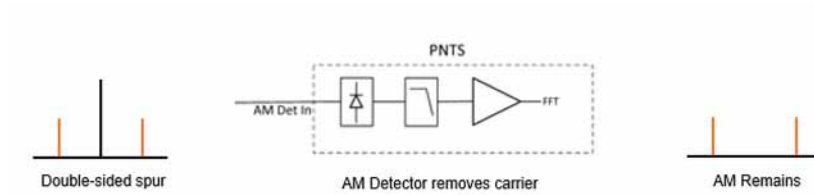
Figure 11-9 Double-Sided spur AM noise setup (method 2, example 1)



2. Measure the power which will be applied to the AM detector.
3. Replace the DUT with a source with AM. Set the output power equal to the power measured. The source should be adjusted such that the sidebands are between -30 dB and -60 dB below the carrier with a modulation rate between 10 Hz and 20 MHz.

These values are directly entered into the software. When measurement is performed, there will not be a 6 dB difference as observed in an absolute or residual measurement as AM is not being suppressed in this measurement. See [Figure 11-10](#).

Figure 11-10 AM Detector removes carrier



4. Enter the carrier-to-sideband ratio and offset frequency, then measure the calibration constant.
5. Remove the AM source and reconnect the DUT.
6. Measure noise data and interpret the results.

NOTE

The quadrature meter should be at zero volts due to the blocking capacitor at the AM detector's output.

Single-Sided Spur

Advantages

- Will measure source without modulation capability.
- Calibration is done under actual measurement conditions so all non-linearities and harmonics of the AM detector are calibrated out. The double-sided spur method and the single-sided-spur method are the two most accurate methods for this reason.

Disadvantages

- Requires 2 RF sources, which must be between 10 Hz and 40 MHz apart in frequency.
- Requires an RF spectrum analyzer for manual measurement of the signal-to-spur ratio and spur offset.

1. Connect circuit as shown in **Figure 11-11** or **Figure 11-11**, depending on whether the measurement will be single or dual channel.

Figure 11-11 Single Channel AM noise measurement setup

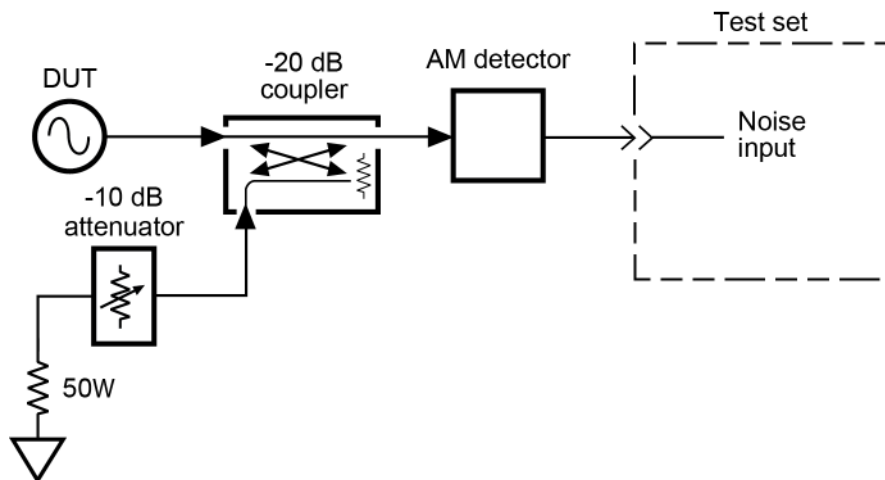
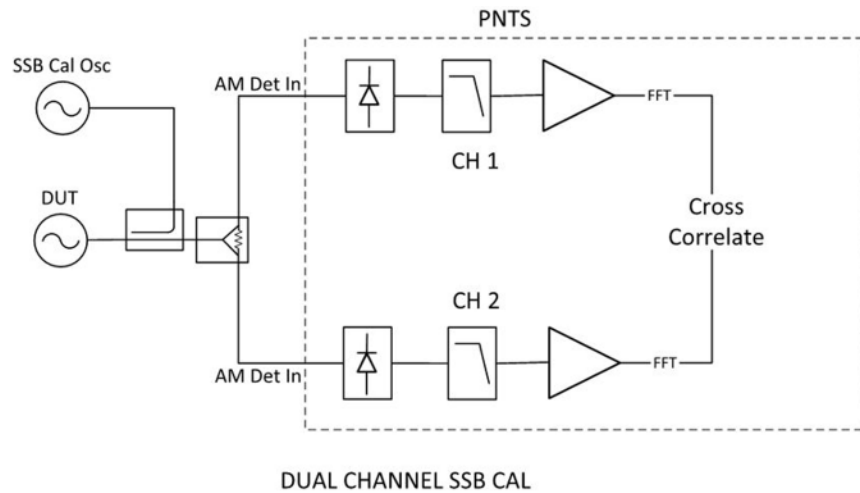
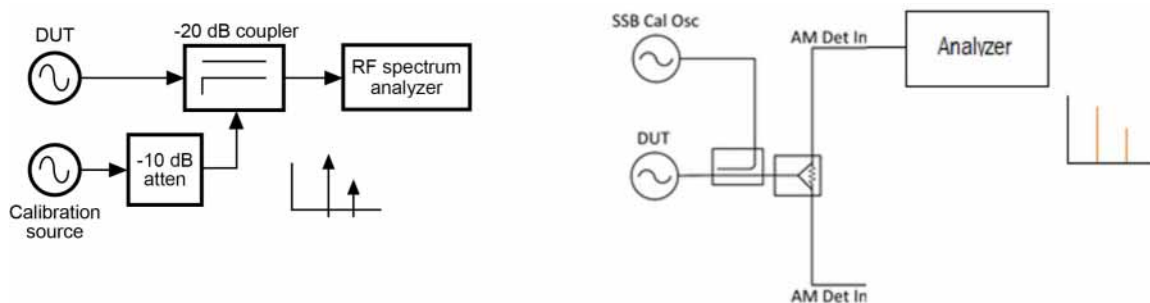


Figure 11-12 Dual Channel AM noise measurement setup using single-sided spur



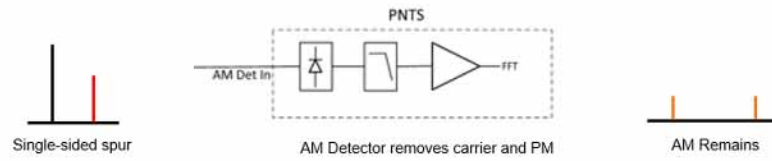
2. Measure the power which will be applied to the AM detector. It must be between 0 and +23 dBm.
3. Measure the carrier-to-single-sided-spur ratio and the spur offset at the input to the AM detector with an RF spectrum analyzer. See [Figure 11-13](#). The spur should be adjusted such that it is between -30 and -60 dBc, with a carrier offset of 10 Hz to 20 MHz.

Figure 11-13 Measuring relative spur level



4. Enter the relative power level and offset of the tone into the measurement definition in the software. The AM detector will remove the PM component, thus the end result in the measurement will be a spur that is 6 dB lower than what the analyzer measured. See [Figure 11-14](#).

Figure 11-14 AM Detector removes carrier



5. Reconnect DUT signal to the AM detector(s).
6. Begin measurement following on-screen instructions for turning spur on/off.
7. Measure noise data and interpret the results.

12 AM Noise Measurement Examples

[“AM Noise Measurement Examples” on page 272](#)

AM Noise Measurement Examples

This example demonstrates a dual-channel AM noise measurement of an E8257D signal generator. For more information about various calibration techniques, refer to **Chapter 11, “AM Noise Measurement Fundamentals”**.

This measurement uses the double-sided spur calibration method. The measurement of a source with amplitude modulation capability is among the simplest of the AM noise measurements. The modulation sidebands used to calibrate the AM detector are generated by the DUT.

CAUTION

To prevent damage to the test set's components, ensure that the input level does not exceed the damage level of the detector. Use proper attenuation if is limit is to be exceeded.

Required equipment

This measurement requires an E8257D in addition to the phase noise test system and your DUT. You also need the coaxial cables and adapters necessary to connect the DUT and reference source to the test set.

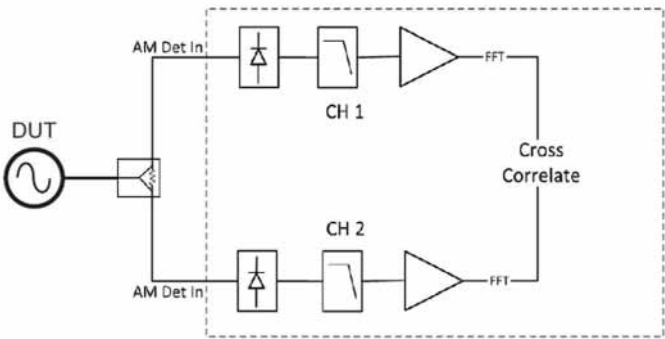
NOTE

To ensure accurate measurements allow the DUT and measurement equipment to warm up at least 30 minutes before making the noise measurement.

Test Setup

Figure 12-1 shows the configuration used for an AM noise measurement.

Figure 12-1 AM noise measurement configuration



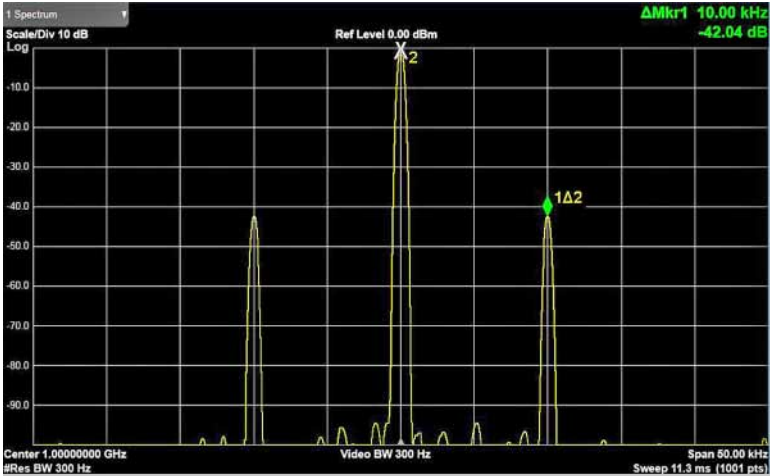
1) Connect DUT

Connect the E8257D PSG to a splitter. Connect each path of the splitter to the AM detector input on each of the phase detector modules.

Configuring Equipment

Configure the equipment to the settings for this lab:

1) Power	Power on all the equipment: Keysight N5511A PNTS, E8257D PSG
2) Set up the DUT carrier signal	Frequency, 1 GHz Amplitude, 14 dBm RF On/Off, On
3) Set up modulating tone	AM, AM Depth, 1.5% AM Rate, 10 kHz
4) Measure tone	Use an analyzer to measure the calibration tone's power level and offset relative to the carrier.



The screenshot shows a spectrum analyzer display with a black background and a yellow trace. The carrier signal is a sharp peak at 0 dBm. The modulating tone is a smaller peak at -42.04 dB, labeled 1Δ2. The x-axis is frequency in GHz, and the y-axis is power in dB. The display includes various settings like Scale/Div 10 dB, Log, Ref Level 0.00 dBm, Center 1.00000000 GHz, Video BW 300 Hz, Span 50.00 kHz, and Sweep 11.3 ms (1001 pts).

Reconnect DUT to test set	See Figure 12-1
---------------------------	------------------------

Measurement Procedure

Measurement Type and Range

File, New

Do you want to see the measurement parameters to default values? **Yes**

At the top of the main application window, click "Define" and then select "Measurement..." from the drop-down menu.

Define, Measurement, Type and Range

This window will appear:

Figure 12-2 Type and Range Tab

The screenshot shows the 'Keysight N5510' application window with the 'Type and Range' tab selected. The 'Measurement Type' is set to 'Absolute Phase Noise (using phase locked loop)'. The 'Measurement Method' has 'Flexible' selected and 'Fast' as an option, with a 'Start Offset Resolution Expansion' of 10. The 'Channel Setup' has 'Single' selected and 'Dual' as an option. The 'Measurement Settings' section includes 'Start Offset' (1 Hz), 'Stop Offset' (160E+6 Hz), 'FFT Analyzer Minimum Number of Trace Averages' (4), 'FFT Analyzer Minimum Number of Cross-correlations' (1), 'RBW %' (1.96 (1024 point FFT)), 'FFT Overlap %' (75), 'FFT Window Type' (BlackmanHarris4), and 'Estimated Measurement Time' (0). The 'FFT Quality' section has 'Normal' selected, with 'Fast', 'High Resolution', and 'Custom' as other options. A 'View Segment Table' button is present. At the bottom, the 'Couple Graph Type to Measurement Type' checkbox is checked, and there are 'Preset', 'Close', and 'Help' buttons.

Keysight N5510

Type and Range | Sources CH#1 | Sources CH#2 | Cal CH#1 | Cal CH#2 | Block Diagram | Test Set | Graph |

Measurement Type: Absolute Phase Noise (using phase locked loop)

Measurement Method:
☐ Flexible
☒ Fast Start Offset Resolution Expansion: 10

Channel Setup:
☐ Single
☒ Dual

Measurement Settings:
Start Offset: 1 Hz Stop Offset: 160E+6 Hz
FFT Analyzer Minimum Number of Trace Averages: 4
FFT Analyzer Minimum Number of Cross-correlations: 1
RBW %: 1.96 (1024 point FFT)
FFT Overlap %: 75 FFT Window Type: BlackmanHarris4
Estimated Measurement Time: 0

FFT Quality:
☒ Normal ☐ Fast ☐ High Resolution ☐ Custom View Segment Table

☒ Couple Graph Type to Measurement Type Preset

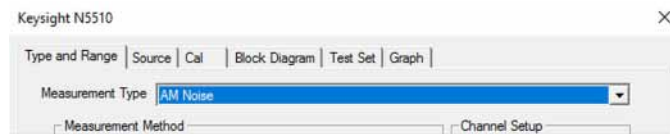
Close Help

AM Noise Measurement Examples

AM Noise Measurement Examples

1) Choose Measurement Type

Measurement Type: AM Noise



2) Choose Measurement Method

Flexible is "single segment" measurement method where every segment is captured independently and after the previous segment has been measured.

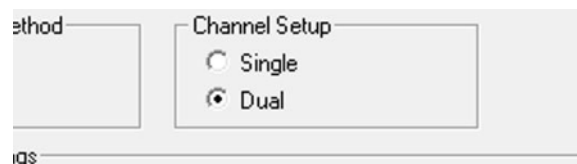
Fast is "multi-segment", where segments are being measured in parallel. This option allows for a live view of the data acquisition of the measurement.

Measurement Method: Fast



3) Choose Channel Setup

Channel Setup: Dual



4) Set Start and Stop Offsets

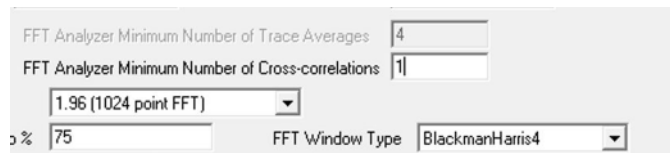
Start Offset: 10 Hz

Stop Offset: 2 MHz



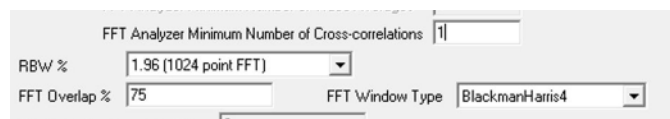
5) Set Number of Cross-Correlations

FFT Analyzer Minimum number of cross-correlations: 1



6) Set FFT Size

RBW %: 1.96 (1024 point FFT)

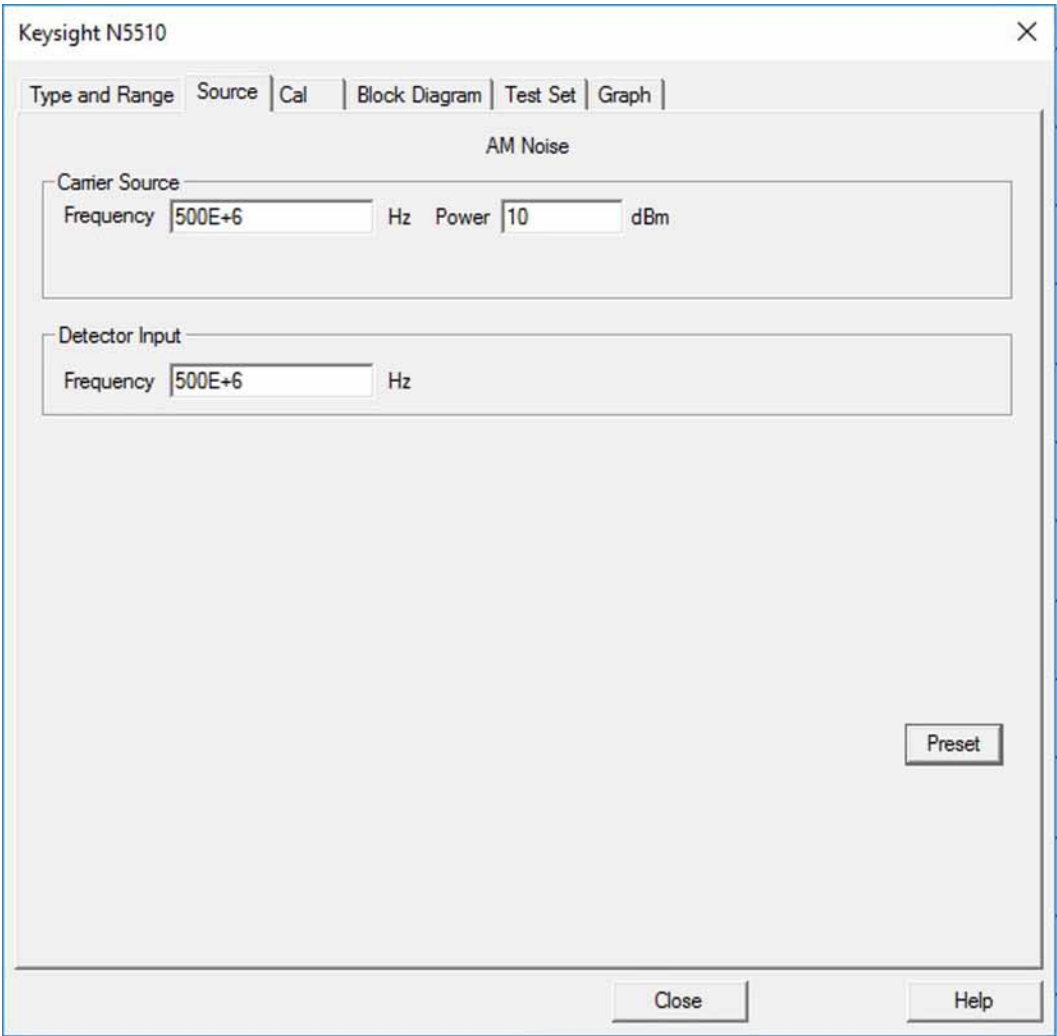


Source Calibration

Next, we will configure the settings for the DUT and the reference sources. Navigate to the Source tab at the top of the current window.

This window will appear:

Figure 12-3 Source Tab



1) Set Carrier Source Settings

Frequency: 1 GHz
Power: 10 dBm



2) Set Detector Input Frequency



Cal Configuration

Navigate to the Cal tab.

This window will appear:

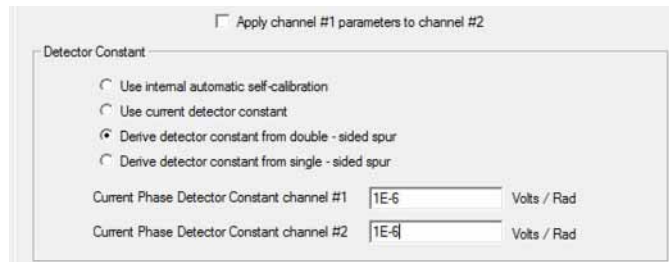
Figure 12-4 Cal Tab

The screenshot shows the 'Keysight N5510' window with the 'Cal' tab selected. The window has a title bar with a close button (X). Below the title bar is a tabbed interface with tabs for 'Type and Range', 'Source', 'Cal', 'Block Diagram', 'Test Set', and 'Graph'. The 'Cal' tab is active, displaying the 'AM Noise' configuration section. This section includes a checkbox for 'Apply channel #1 parameters to channel #2'. Below this is a 'Detector Constant' section with four radio button options: 'Use internal automatic self-calibration', 'Use current detector constant', 'Derive detector constant from double - sided spur', and 'Derive detector constant from single - sided spur'. There are two input fields for 'Current Phase Detector Constant' for channel #1 and channel #2, both set to '1E-6' Volts / Rad. Below this is a 'Known Spur Parameters' section with input fields for 'Offset Frequency' (set to '1' Hz) and 'Amplitude' (set to '-130' dBc). The 'Calibration Source' section includes a 'check I/O' button, a dropdown menu set to '(manual)', and input fields for 'Frequency' (set to '500E+6' Hz) and 'Power' (set to '10' dBm). At the bottom of the window are buttons for 'Asset Manager', 'Preset', 'Close', and 'Help'.

For this tab we will use Beat Note Cal. Refer to the Cal Demo guide for details on using other cal methods.

1) Configure Phase Detector Constant
Settings

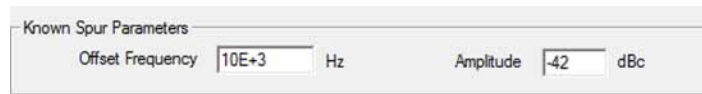
Phase Detector Constant: Derive
detector constant from double-sided
spur



The screenshot shows a dialog box titled "Apply channel #1 parameters to channel #2". Inside, there is a section labeled "Detector Constant" with four radio button options: "Use internal automatic self-calibration", "Use current detector constant", "Derive detector constant from double - sided spur" (which is selected), and "Derive detector constant from single - sided spur". Below these options, there are two input fields: "Current Phase Detector Constant channel #1" with a value of "1E-6" and "Current Phase Detector Constant channel #2" with a value of "1E-6". Both fields are followed by the unit "Volts / Rad".

2) Configure Known Spur

Offset Frequency: 10 kHz
Amplitude: -42 dBc.



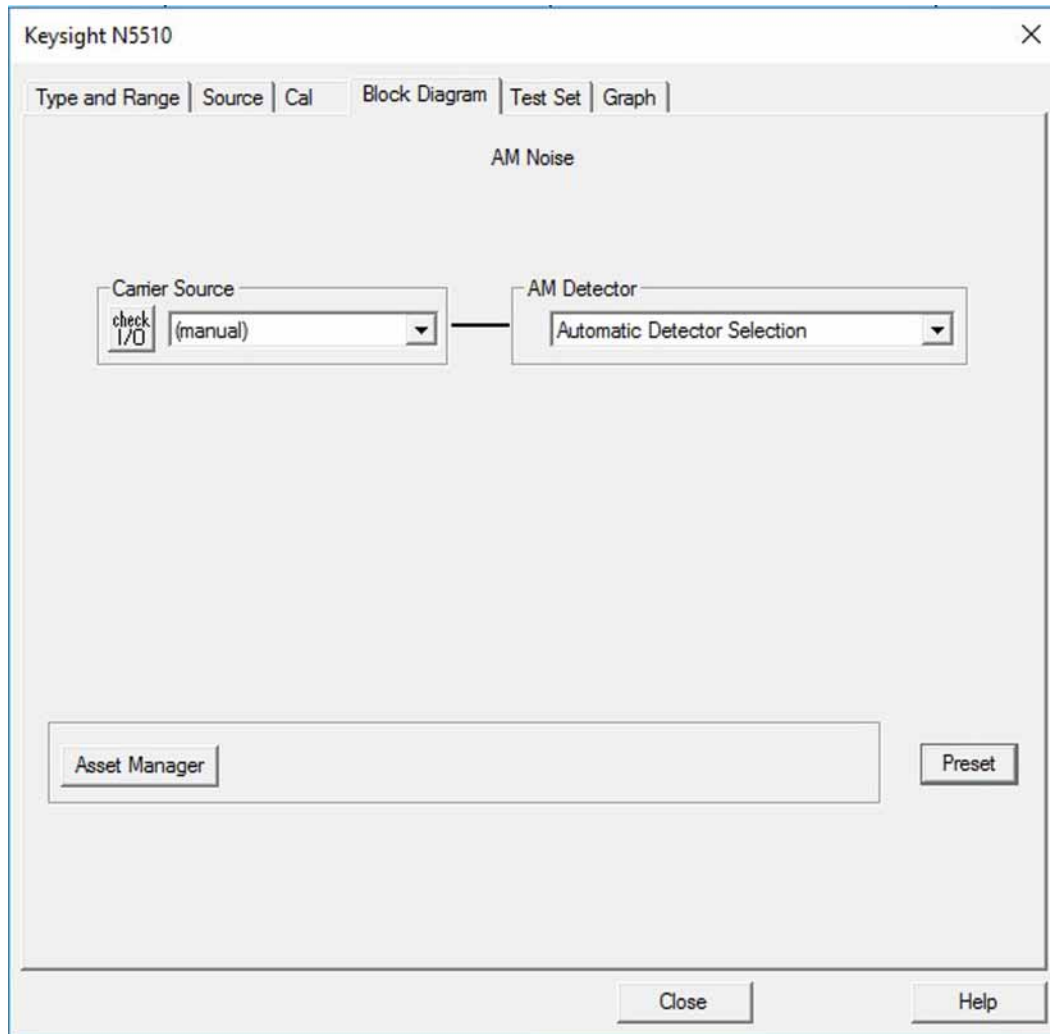
The screenshot shows a dialog box titled "Known Spur Parameters". It contains two input fields: "Offset Frequency" with a value of "10E+3" followed by the unit "Hz", and "Amplitude" with a value of "-42" followed by the unit "dBc".

Block Diagram Configuration

Navigate to the Block Diagram tab.

This window will appear:

Figure 12-5 Block Diagram Tab



1) Phase Detector

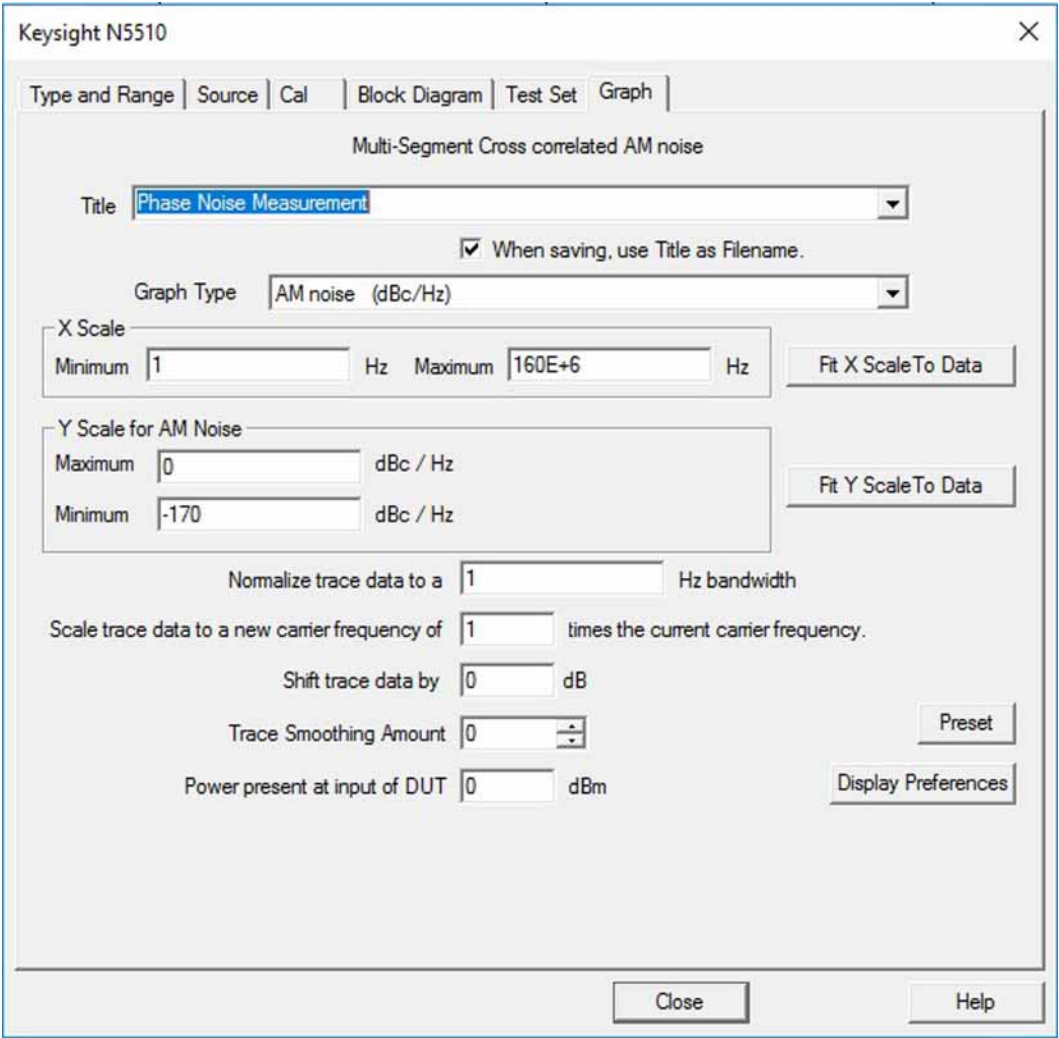
AM Detector: Test Set AM Detector



Configure Graph

Navigate to the Graph tab.
This window will appear:

Figure 12-6 Graph Tab



AM Noise Measurement Examples

AM Noise Measurement Examples

1) Set Title

Multi-Segment Cross correlated AM noise

Title

☒ When saving, use Title as Filename.

Graph Type

2) Set X-Scale

X -Scale Minimum: 10 Hz
X-Scale Maximum: 2 MHz

Graph Type

X Scale

Minimum Hz Maximum Hz

3) Set Y-Scale

Y-Scale Maximum: 0 dBc/Hz
Y-Scale Minimum: -170 dBc/Hz

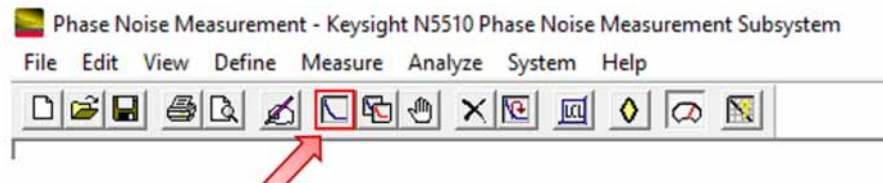
Y Scale for Single Sideband Phase Noise

Maximum dBc / Hz

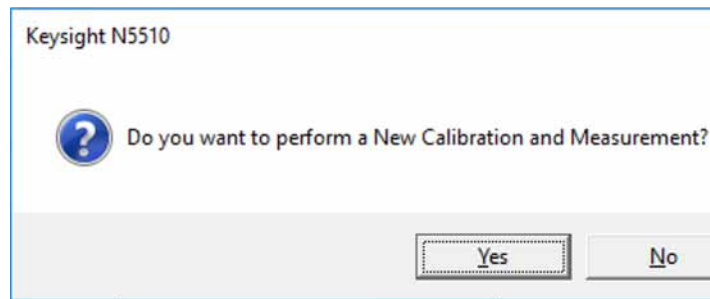
Minimum dBc / Hz

New Measurement

Close Define Window. From the File Menu: **Measure, New Measurement.**



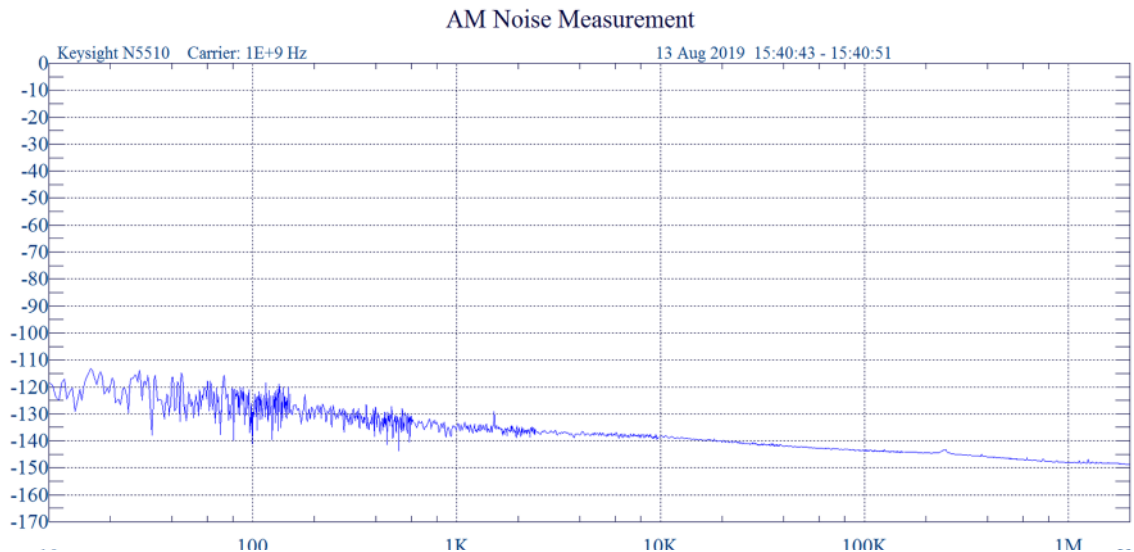
When the "Do you want to perform a New Calibration and Measurement?" prompt appears, click **Yes**.



Software will prompt to turn on and then to turn off modulation.

Measure noise data and interpret the results.

Figure 12-7 AM Noise Measurement Results



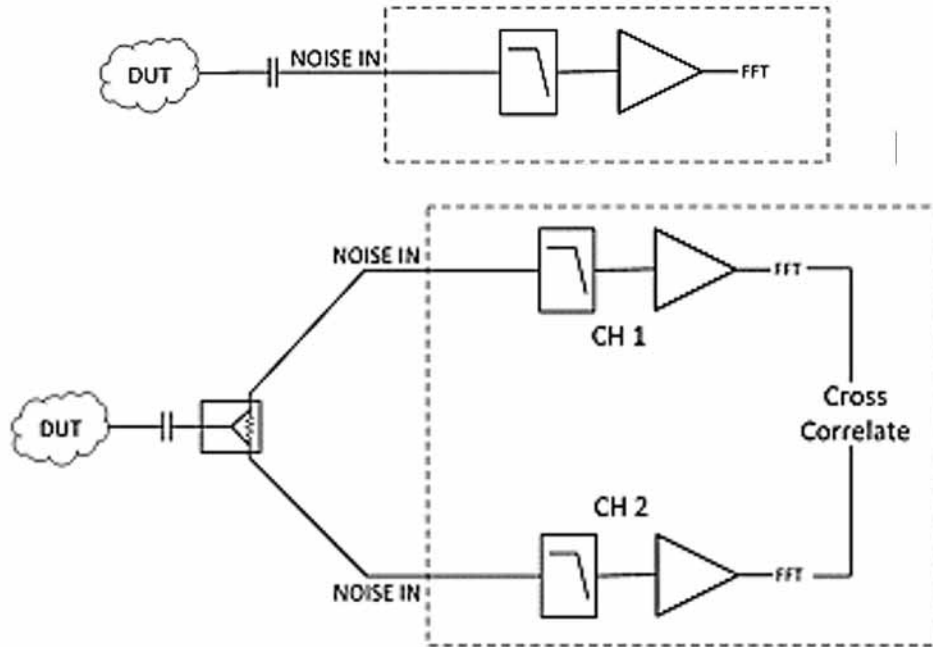
13 Baseband Noise Measurement Example

[“Baseband Noise with Test Set Measurement Example” on page 285](#)

Baseband Noise Measurements

Baseband noise measurements can be performed in either single or dual channel mode. The baseband noise paths are calibrated in N5511A, and therefore there is no user calibration required. The figures below show the configuration for a baseband noise measurement for single channel and dual channel configurations.

Figure 13-1 Baseband Noise Measurement Setup for Single Channel and Dual Channel



Baseband Noise with Test Set Measurement Example

This measurement example will help you measure the noise voltage of a source.

NOTE

To ensure accurate measurements allow the DUT and measurement equipment to warm up at least 30 minutes before making the noise measurement.

Define Measurement

At the top of the main application window, click "Define" and then select "Measurement..." from the drop-down menu.

Define, Measurement, Measurement Type: Baseband Noise (using test set)

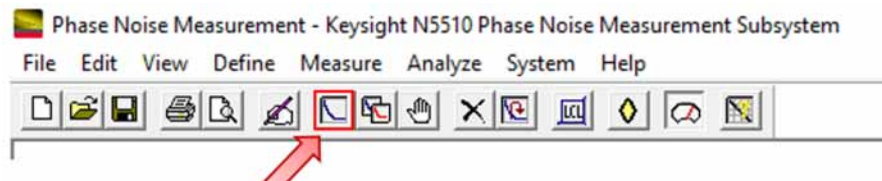
Connect a noise source to the test set using one of the configurations as shown in **Figure 13-1**.

CAUTION

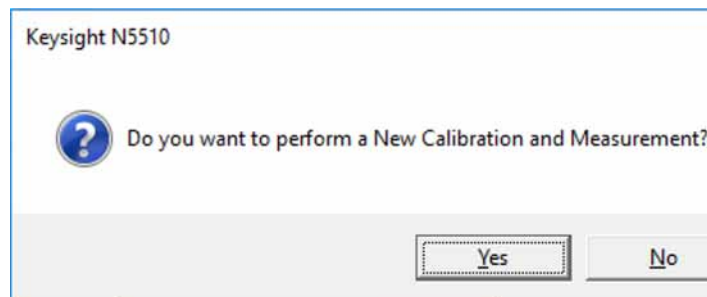
Ensure there is no DC present in the signal at the inputs to the test set to prevent damage to the test set.

New Measurement

Close Define Window. From the File Menu: **Measure, New Measurement**.



When the "Do you want to perform a New Calibration and Measurement?" prompt appears, click **Yes**.



Baseband Noise Measurement Example
Baseband Noise with Test Set Measurement Example

The connection diagram will show the configuration setup. Press **Continue**.

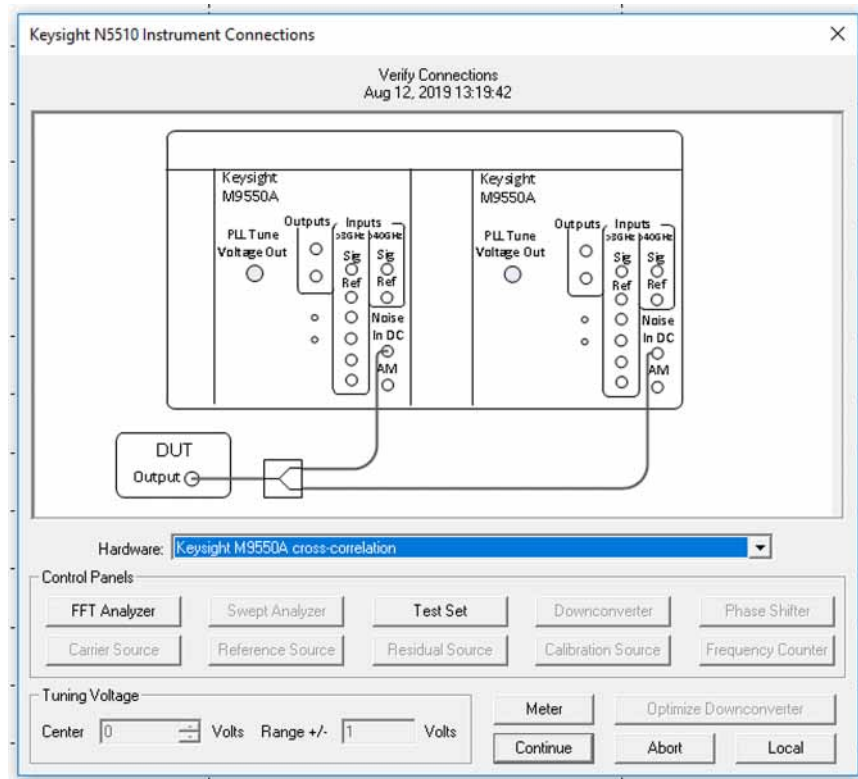


Figure 13-2 shows a typical phase noise curve for a baseband noise measurement using the test set.

Figure 13-2 Phase Noise Curve for Baseband Noise Measurement using Test Set

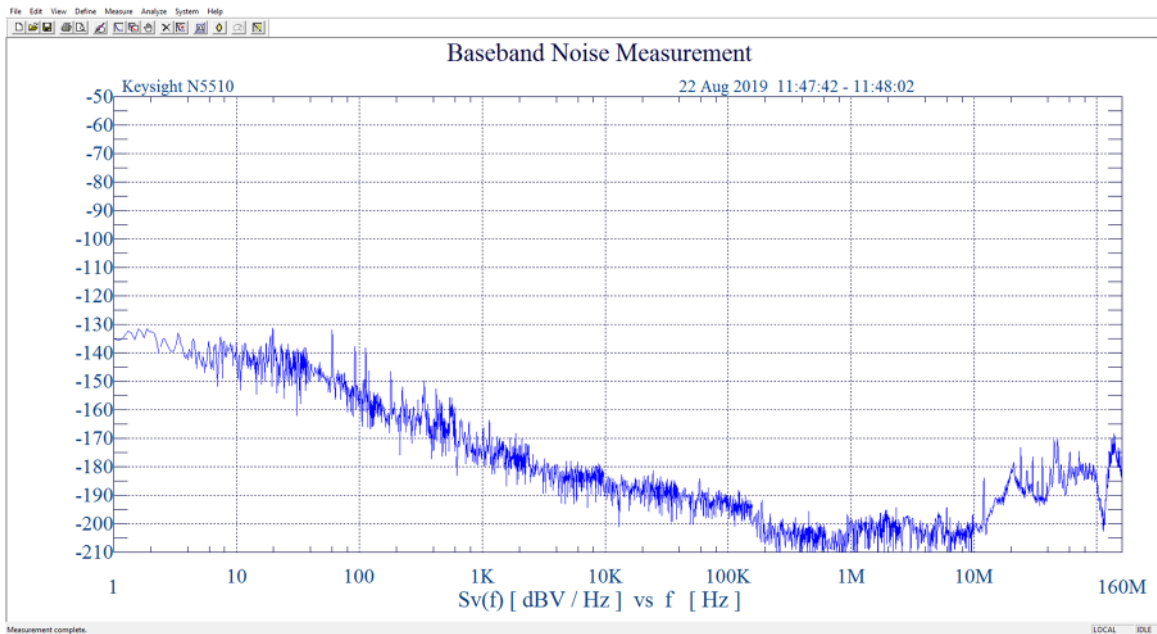


Table 13-1 lists the parameter data used for this measurement example.

Table 13-1 Parameter data for the baseband using a test set measurement

Step	Parameters	Data
1	Type and Range Tab	
	Measurement Type	Baseband Noise (using a test set)
	Start Frequency	10 Hz
	Stop Frequency	160 E + 6 Hz
	Averages	1
	Cross-correlations	1
	Channel Setup	Dual
	Quality	Fast
2	Cal Tab	
	Gain preceding noise input	0 dB
3	Block Diagram Tab	
	Noise Source	Test Set Noise Input
4	Test Set Tab	
	Input Attenuation	0 dB
	LNA Low Pass Filter	20 MHz (Auto checked)
	LNA Gain	Auto Gain (Minimum Auto Gain -14 dB)
	DC Block	Not checked
	PLL Integrator Attenuation	0 dBm
5	Graph Tab	
	Title	Baseband using the N5500A test set
	Graph Type	Baseband Noise (dBV)
	X Scale Minimum	1 Hz
	X Scale Maximum	160 E + 6 Hz
	Y Scale Minimum	-50 dBV/Hz
	Y Scale Maximum	-210 dBV/Hz
	Normalize trace data to a:	1 Hz bandwidth
	Scale trace data to a new carrier frequency of:	1 times the current carrier frequency
	Shift trace data DOWN by	0 dB
	Trace Smoothing Amount	0
	Power present at input of DUT	0 dB

14 Evaluating Your Measurement Results

[“Evaluating the Results” on page 290](#)

[“Gathering More Data” on page 293](#)

[“Outputting the Results” on page 294](#)

[“Graph of Results” on page 295](#)

[“Omit Spurs” on page 297](#)

[“Problem Solving” on page 302](#)

Evaluating the Results

This chapter contains information to help you evaluate and output the results of your noise measurements. The purpose of the evaluation is to verify that the noise graph accurately represents the noise characteristics of your DUT. To use the information in this chapter, you should have completed your noise measurement, and the computer should be displaying a graph of its measurement results. Storing the measurement results in the Result File is recommended for each measurement.

These steps provide an overview of the evaluation process.

- Look for obvious problems on the graph such as discontinuity (breaks).
- Compare the graph against known or expected data.
- If necessary, gather additional data about the noise characteristics of the DUT.

Looking for obvious problems

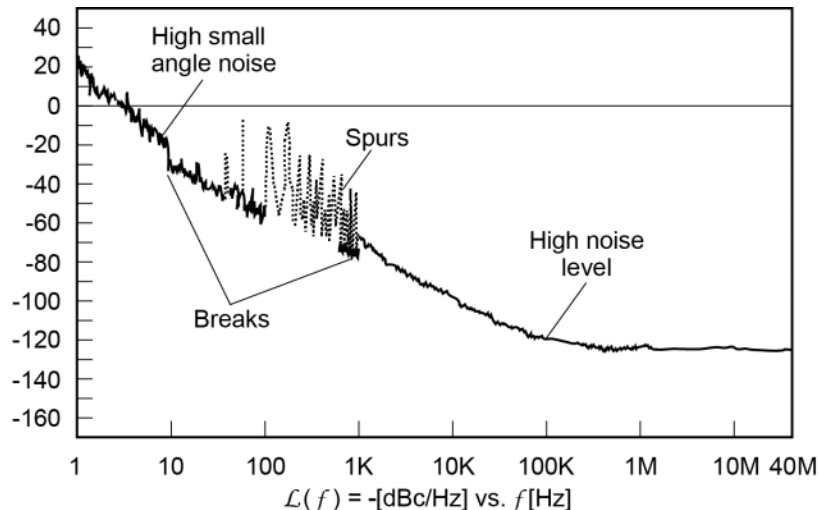
Some obvious problems on a graph are as follows:

- Discontinuities or breaks in the graph.
- A higher than expected noise level.
- Spurs that you cannot account for.
- Noise that exceeds the small angle criterion line on a $L(f)$ graph.

Figure 14-1 provides a graphical example of these problems. If one or more of these problems appear on your graph, refer to **“Problem Solving” on page 302** for recommended actions.

Figure 14-1

Noise plot showing obvious problems



Comparing against expected data

If none of the problems listed appears on your graph, there still may be problems or uncertainties that are not obvious at first glance. These uncertainties can be evaluated by comparing your measurement results against the following data:

- The noise characteristics expected for your DUT.
- The noise floor and accuracy specifications of the phase noise test system.
- The noise characteristics of the signal source used as the reference source.

The device under test

If you are testing a product for which published specifications exist, compare the measurement results against the noise and spur characteristics specified for the product. If the product is operating correctly, the noise graph provided by the phase noise system should be within the noise limits specified for the product.

If the device is a prototype or breadboard circuit, it may be possible to estimate its general noise characteristics using the characteristics of a similar type of circuit operating in a similar manner.

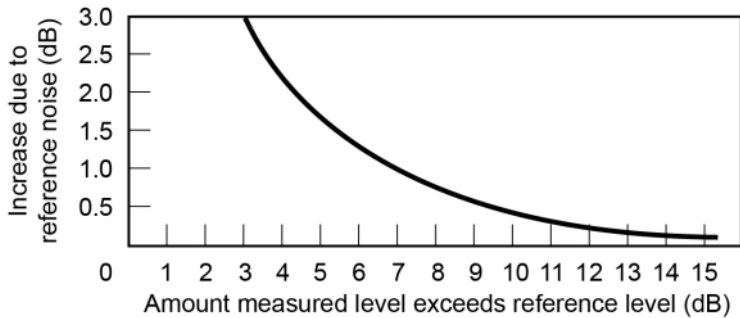
The reference source

It is important that you know the noise and spur characteristics of your reference source when you are making phase noise measurements. (The noise measurement results provided when using this technique reflect the sum of all contributing noise sources in the system.)

The best way to determine the noise characteristics of the reference source is to measure them. If three comparable sources are available, the Three Source Comparison technique can be used to determine the absolute noise level of each of the three sources. If you are using as your reference source, a source for which published specifications exist, compare your measurement results against the noise and spur characteristics specified for that source.

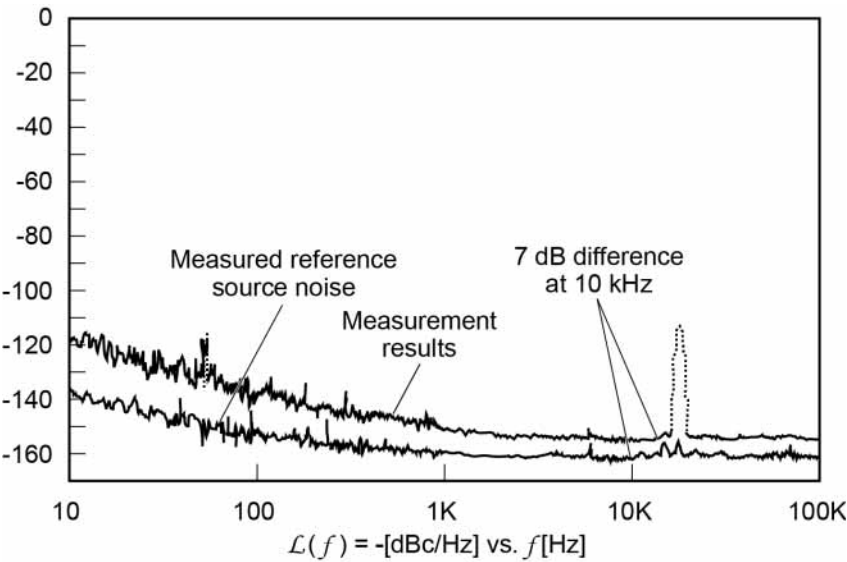
If you have obtained an actual (measured) noise curve for the reference source you are using, you can use it to determine if your measurement results have been increased by the noise of the reference source. To do this, determine the difference (in dB) between the level of the results graph and that of the reference source. Then use the graph shown in **Figure 14-2** to determine if the measurement results need to be decreased to reflect the actual noise level of the DUT.

Figure 14-2 Compensation for added reference source noise



For example, applying to the graph the 7 dB difference in noise levels at 10 Hz, reveals that the measured results should be decreased by about 1 dB at 10 kHz to reflect the actual noise of the DUT. See [Figure 14-3](#).

Figure 14-3 Measurement results and reference source noise



Gathering More Data

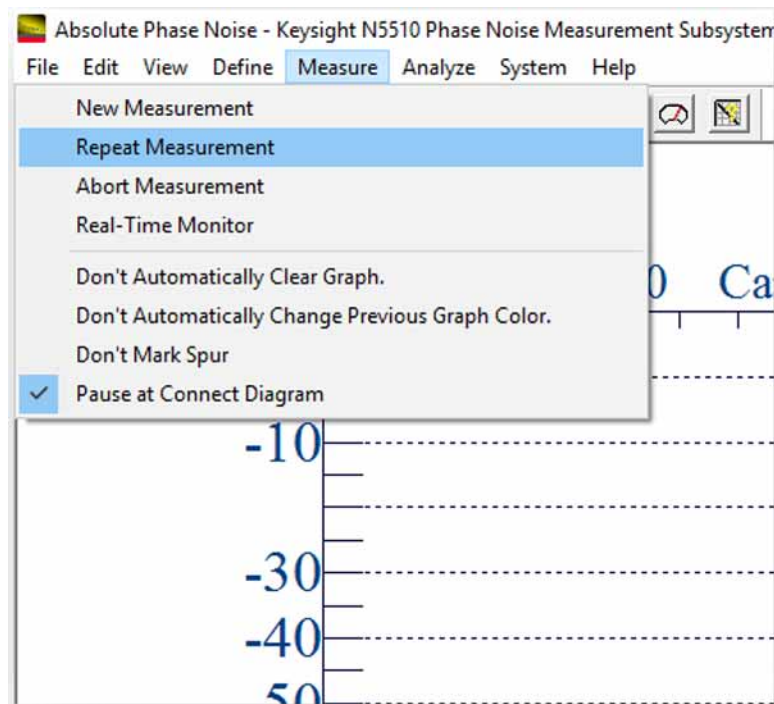
Repeating the measurement

Making phase noise measurements is often an iterative process. The information derived from the first measurement will sometimes indicate that changes to the measurement setup are necessary for measuring a particular device. When you make changes to the measurement setup (such as trying a different signal source, shortening cables, or any other action recommended in **“Problem Solving” on page 302**), repeating the measurement after each change allows you to check the effect that the change has had on the total noise graph.

To repeat a measurement, on the Measurement menu, click Repeat Measurement. See **Figure 14-4**.

Figure 14-4

Repeating a measurement



Doing more research

If you are still uncertain about the validity of the measurement results, it may be necessary to do further research to find other validating data for your measurement. Additional information (such as typical noise curves for devices similar to the DUT or data sheets for components used in the device) can often provide insights into the expected performance of the DUT.

Outputting the Results

To generate a printed hardcopy of your test results, you must have a printer connected to the computer.

Using a printer

To print the phase noise graph along with the parameter summary data, select File/Print on the menu.

Graph of Results

Use the Graph of Results to display and evaluate your measurement results. The Graph of Results screen is automatically displayed as a measurement is being made. However, you can also access the Graph of Results functions from the main graph menu. You can load a result file using the File/System functions, and then display the results.

The following functions are available to help you evaluate your results:

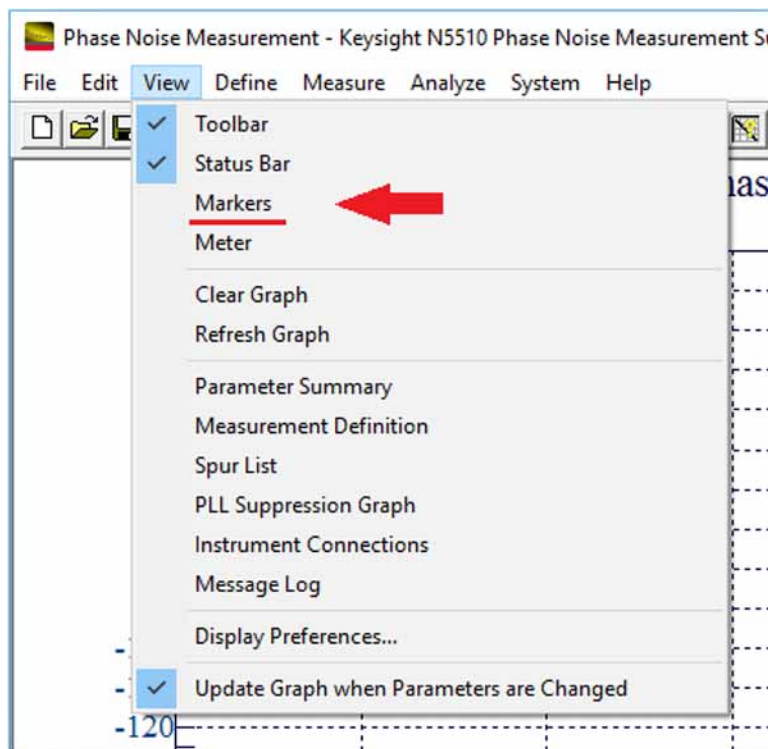
- “Marker” on page 295
- “Omit Spurs” on page 297
- “Parameter summary” on page 300

Marker

The marker function allows you to display the exact frequency and amplitude of any point on the results graph. To access the marker function:

1. On the View menu, click Markers. See Figure 14-5.

Figure 14-5 Navigate to marker



2. To remove the highlighted marker, click the Delete button. You may add as many as nine markers. See Figure 14-6.

Figure 14-6 Add and delete markers

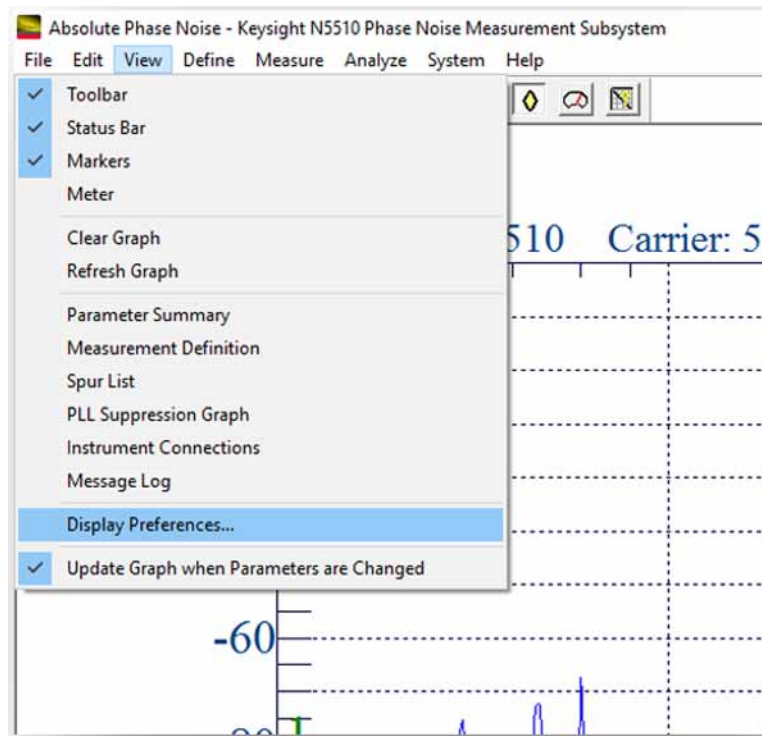


Omit Spurs

Omit Spurs plots the currently loaded results without displaying any spurs that may be present.

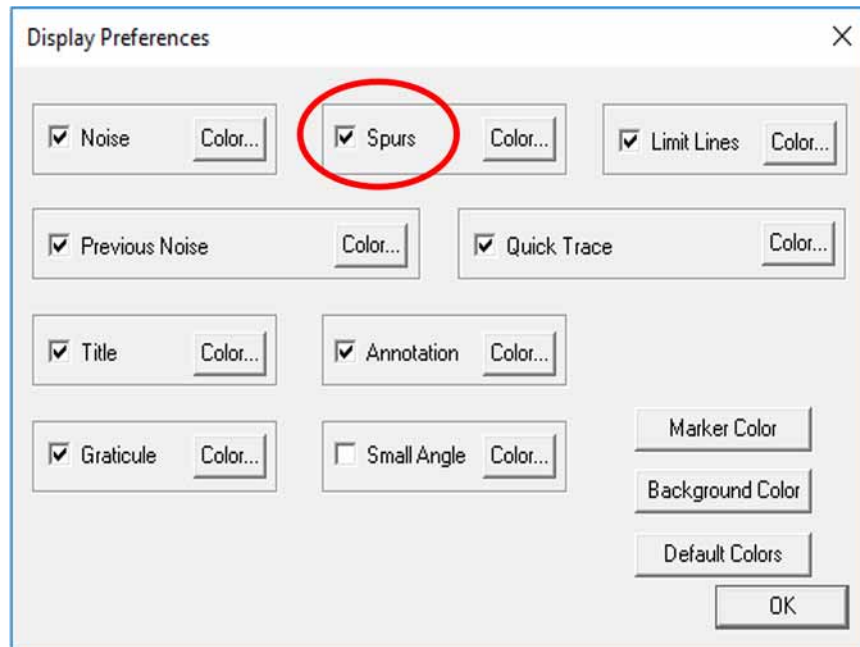
1. On the View menu, click Display Preferences. See [Figure 14-7](#).

Figure 14-7 Select display preferences



2. In the Display Preferences dialog box, uncheck Spurs. See [Figure 14-8](#). Click OK.

Figure 14-8 Uncheck spurs



3. The Graph will be displayed without spurs (Figure 14-9). To re-display the spurs, check Spurs in the Display Preferences dialog box.

Figure 14-9 Graph without spurs

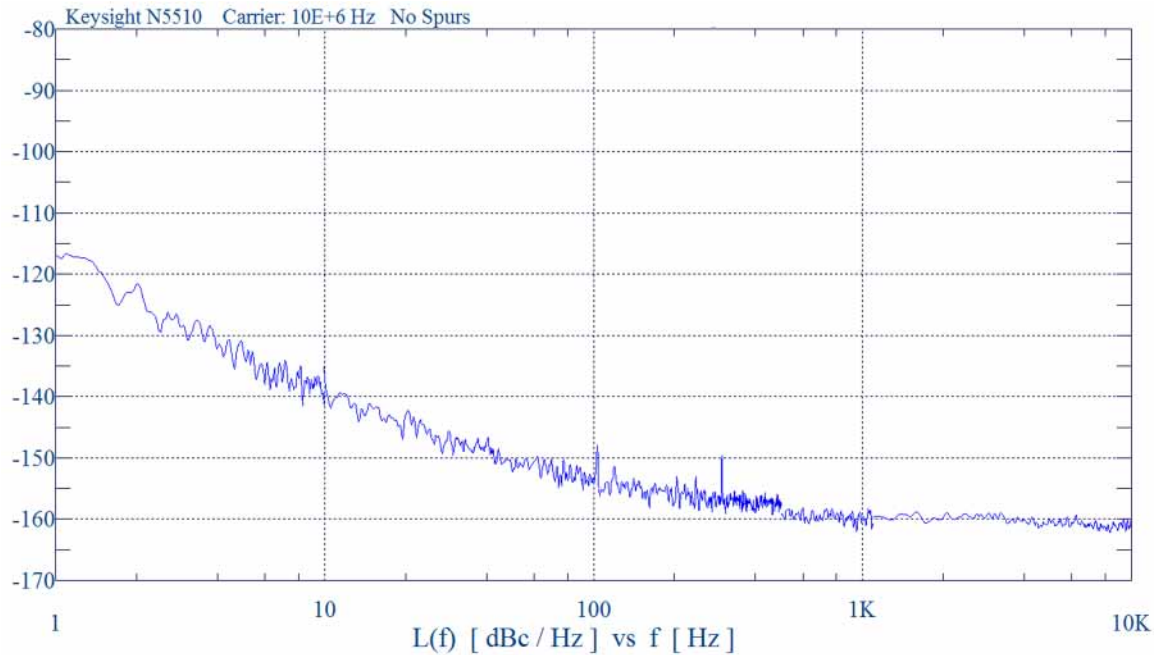
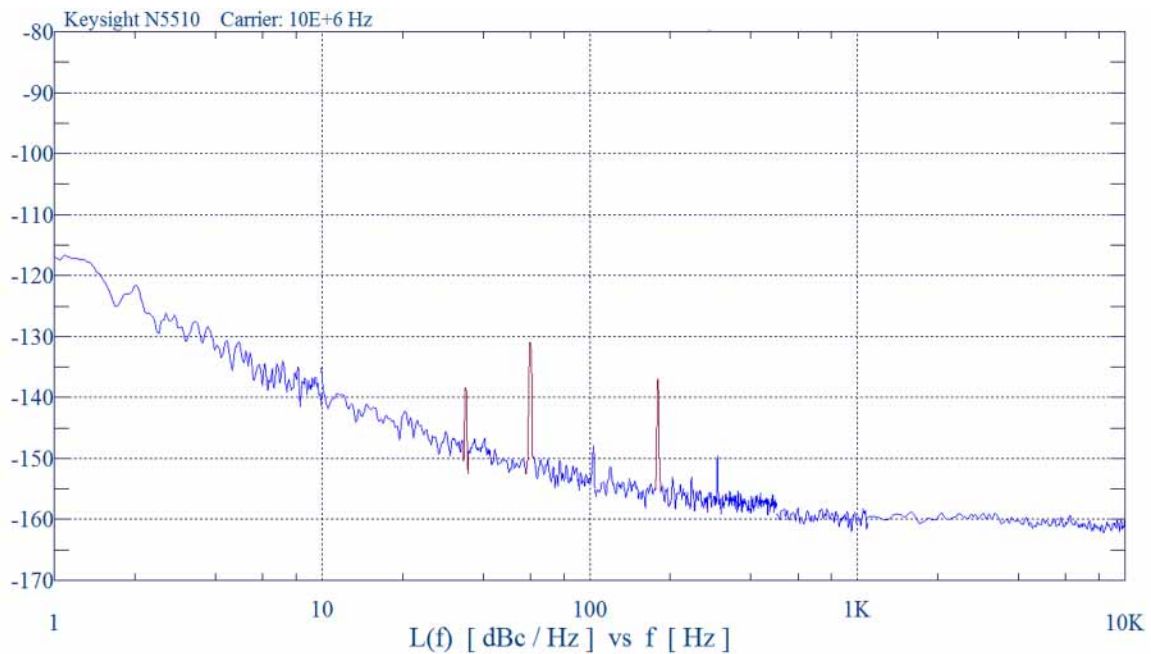


Figure 14-10 Graph with spurs

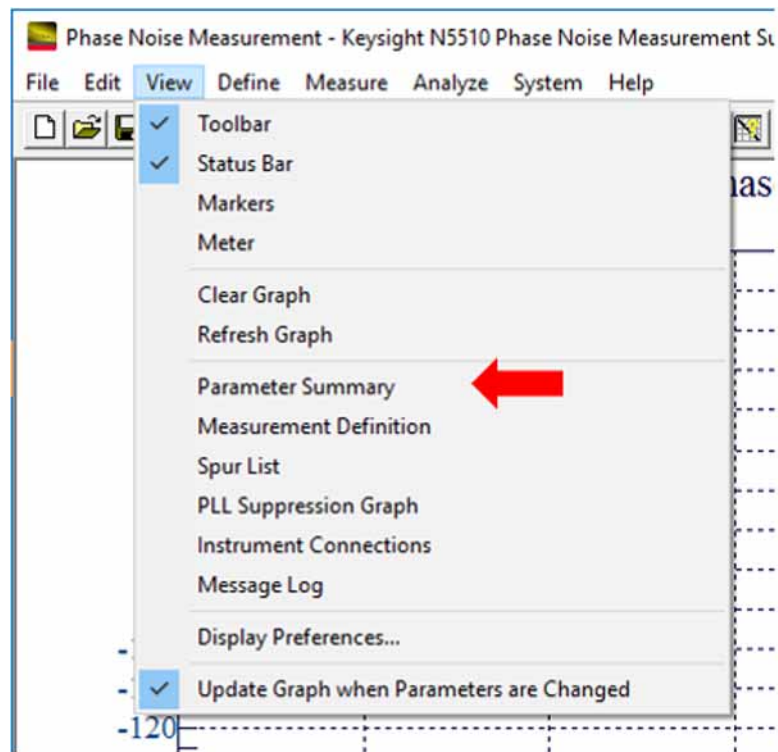


Parameter summary

The Parameter Summary function allows you to quickly review the measurement parameter entries that were used for this measurement. The parameter summary data is included when you print the graph.

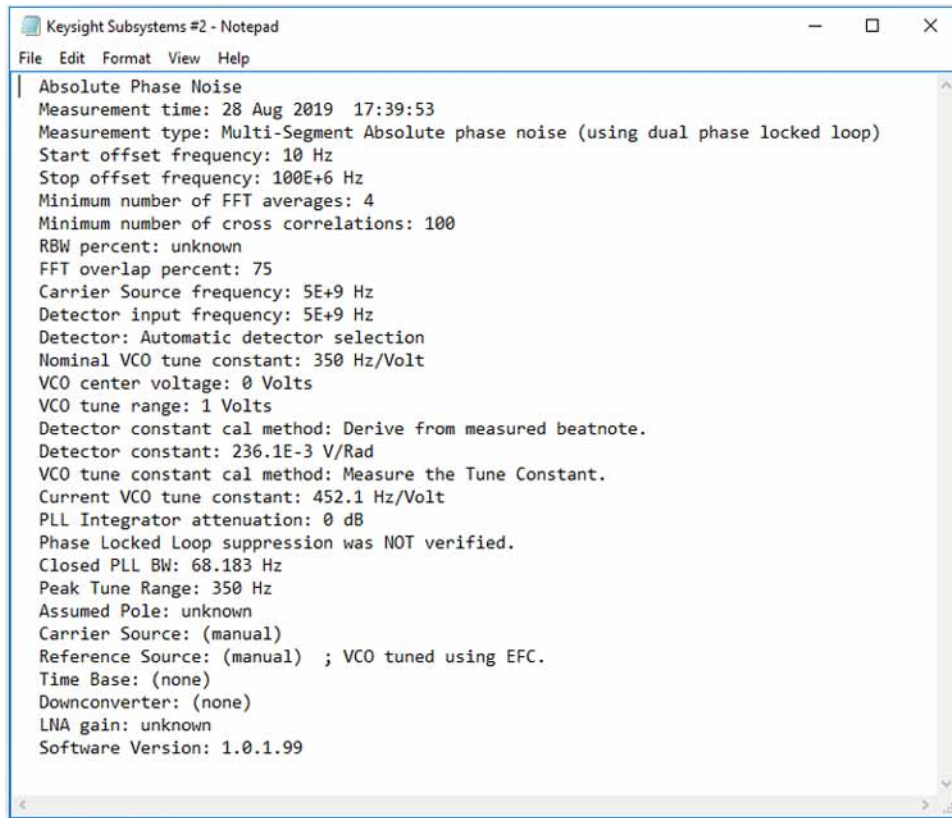
1. On the View menu, click Parameter Summary (Figure 14-11).

Figure 14-11 Navigate to parameter summary



2. The Parameter Summary Notepad dialog box appears (Figure 14-12). The data can be printed or changed using standard Notepad functionality.

Figure 14-12 Parameter summary notepad



Problem Solving

Table 14-1 List of topics that discuss problem solving in this chapter

If you need to know:	Refer To:
What to do about breaks in the noise graph	Discontinuity in the Graph
How to verify a noise level that is higher than expected	High Noise Level
How to verify unexpected spurs on the graph	Spurs on the Graph
How to interpret noise above the small angle line	Small Angle Line

Discontinuity in the graph

Because noise distribution is continuous, a break in the graph is evidence of a measurement problem. Discontinuity in the graph will normally appear at the sweep-segment connections.

Table 14-2 identifies the circumstances that can cause discontinuity in the graph.

Table 14-2 Potential causes of discontinuity in the graph

Circumstance	Description	Recommended Action
Break between segments where closely spaced spurs are resolved in one segment but not in the next.	Closely spaced spurs that are resolved in one sweep-segment but not in the next can cause an apparent jump in the noise where they are not resolved.	Use the Real-time Monitor to evaluate the noise spectrum at the break frequency on the graph. To eliminate the break in the graph, you may find it necessary to change the Sweep-Segment Ranges so that the measurement resolution remains constant over the frequency range where the spurs are located.
Erratic Noise: One or more segments out of line with the rest of the graph.	This occurs when the noise level of the source being used is inconsistent over time. The time-varying noise level causes the overall noise present when one segment is being measured to differ from the level present during the period when the next segment is measured.	Repeat the noise measurement several times for the segment that does not match the rest of the graph, and check for a change in its overall noise level.

Table 14-2 **Potential causes of discontinuity in the graph**

Circumstance	Description	Recommended Action
Break at the upper edge of the segment below PLL Bandwidth ≥ 4 .	Accuracy degradation of more than 1 or 2 dB can result in a break in the graph at the internal changeover frequency between the phase detector portion of the measurement and the voltage controlled oscillator tune line measurement. The accuracy degradation can be caused by: An inaccurate Tuning or Phase Detector Constant Injection locking, or Noise near or above the small angle line at an offset equal to the PLL Bandwidth for the measurement.	Check the Parameter Summary list provided for your results graph to see if any accuracy degradation was noted. If the Tuning constant and Phase Detector constant were not measured by the phase detector system, verify their accuracy by selecting the Measured calibration method and then initiating a New Measurement. If you suspect injection locking or noise above the small angle line, refer to the Problem Solving section of Chapter 3 for specific actions.
Small Break at 100 kHz, 10 kHz, or 1 kHz		

Higher noise level

The noise level measured by the test system reflects the sum of all of the noise sources affecting the system. This includes noise sources within the system as well as external noise sources. If the general noise level measured for your device is much higher than you expected, begin evaluating each of the potential noise sources. The following table will help you identify and evaluate many of the potential causes of a high noise floor.

Spurs on the graph

Except for marked spurs, all data on the graph is normalized to a 1 Hz bandwidth. This bandwidth correction factor makes the measurement appear more sensitive than it really is. Marked spurs are plotted without bandwidth correction however, to present their true level as measured.

Refer to **Table 14-3**. The spur marking criterion is a detected upward change of more than X dB (where X is the value shown below) within 4 data points (a single data point noise peak will not be marked as a spur). Note that the effective noise floor for detecting spurs is above the plotted 1 Hz bandwidth noise by the bandwidth correction factor.

Table 14-3 **Spurs on the graph**

Offset Frequency	Number of Averages	Upward Change for Marking Spurs (dB)
< 100 kHz	<4	30
	≥4	17
	≥8	12
	≥30	12
>100 kHz	Any	4

To list the marked spurs

A list of spurs can be displayed by accessing the Spurs List function in the View menu.

Forest of spurs

A so called forest of spurs is a group of closely spaced spurs on the phase noise plot. A forest of spurs is often caused by improper shielding that allows stray RF energy to be picked up by the DUT wiring, etc. A breadboarded or prototype circuit should be well shielded from external RF fields when phase noise measurements are being made.

Table 14-4 shows actions to take to eliminate spurs.

Table 14-4 **Actions to eliminate spurs**

Spur Sources	Description	Recommended Action
Internal	Potential spur sources within the measurement system include the phase noise system, the DUT, and the reference source. Typical system spurs are -120 dBc, and they occur at the power line and system vibration frequencies in the range of from 25 Hz to 1 kHz, and above 10 MHz.	If you do not have a plot of the system's noise and spur characteristics, perform the system Noise Floor Test. If you suspect that the DUT or the reference source may be the spur source, check each source using a spectrum analyzer or measuring receiver (such as an Keysight 8902A). Also, if additional sources are available, try exchanging each of the sources and repeating the measurement.
External	Spur sources external to the system may be either mechanical or electrical. When using the Phase Lock Loop measurement technique, the system's susceptibility to external spur sources increases with increases in the Peak Tuning Range set by the VCO source.	Shorten coaxial cables as much as possible (particularly the Tune Voltage Output cable). Make sure all cable connections are tight. It may be possible to identify an external spur source using a spectrum analyzer with a pick-up coil or an antenna connected to it.
Electrical	Electrically generated spurs can be caused by electrical oscillation, either internal or external to the measurement system. The list of potential spur sources is long and varied. Many times the spur will not be at the fundamental frequency of the source, but may be a harmonic of the source signal. Some typical causes of electrical spurs are power lines, radio broadcasting stations, computers and computer peripherals (any device that generates high frequency square waves), and sum and difference products of oscillators that are not isolated from one another in an instrument such as a signal generator.	The frequency of the spur and patterns of multiple spurs are the most useful parameters for determining the source of spurs. The spur frequency can be estimated from the graph, or pinpointed using either the Marker graphic function which provides a resolution of from 0.1% to 0.2% or by using the spur listing function.
Mechanical	Mechanically generated spurs are usually at frequencies below 1 kHz. The source of a mechanically generated spur is typically external to the measurement system.	Try turning off or moving fans, motors, or other mechanical devices that oscillate at a specific frequency. (Temporarily blocking the airflow through a fan may alter its speed enough to discern a frequency shift in a spur that is being caused by the fan.)

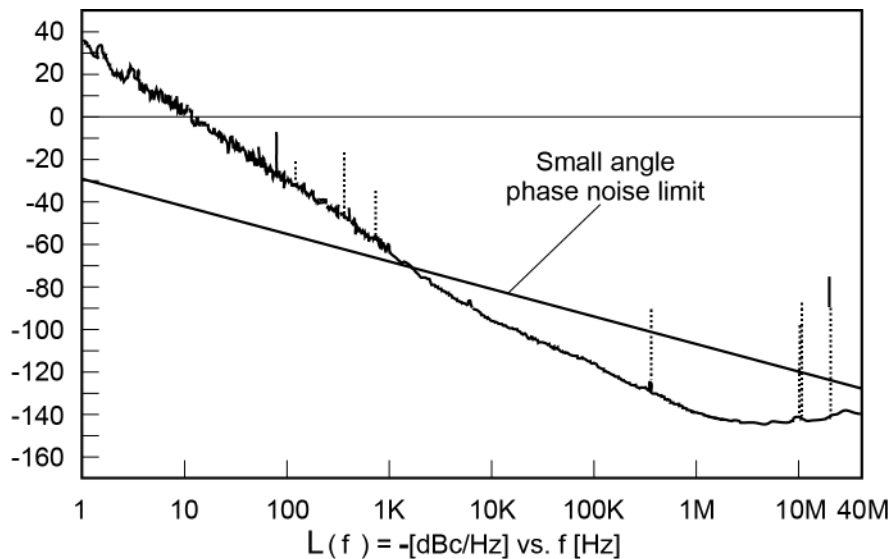
Small angle line

Caution must be exercised where $L(f)$ is calculated from the spectral density of the phase modulation $S\phi(f)/2$ because of the small angle criterion. Refer to **Figure 14-13**. Below the line, the plot of $L(f)$ is correct; above the line, $L(f)$ is increasingly invalid and $S\phi(f)$ must be used to accurately represent the phase noise of the signal. To accurately plot noise that exceeds the small angle line, select the Spectral Density of Phase Modulation (dB/Hz) graph type ($S\phi(f)$). $L(f)$ raises the noise floor by 3 dB.

The -10 dB per decade line is drawn on the plot for an instantaneous phase deviation of 0.2 radians integrated over any one decade of offset frequency. At approximately 0.2 radians, the power in the higher order sideband of the phase modulation is still insignificant compared to the power in the first order sideband. This ensures that the calculation of $L(f)$ is still valid.

Figure 14-13

$L(f)$ is only valid for noise levels below the small angle line



15 Advanced Software Features

[“Introduction” on page 308](#)

[“Phase-Lock-Loop Suppression” on page 309](#)

[“PLL suppression parameters” on page 310](#)

[“Ignore-Out-Of-Lock Mode” on page 312](#)

[“PLL Suppression Verification Process” on page 313](#)

[“Blanking Frequency and Amplitude Information on the Phase Noise Graph” on page 322](#)

[“Accuracy degradation” on page 321](#)

[“Security level procedure” on page 322](#)

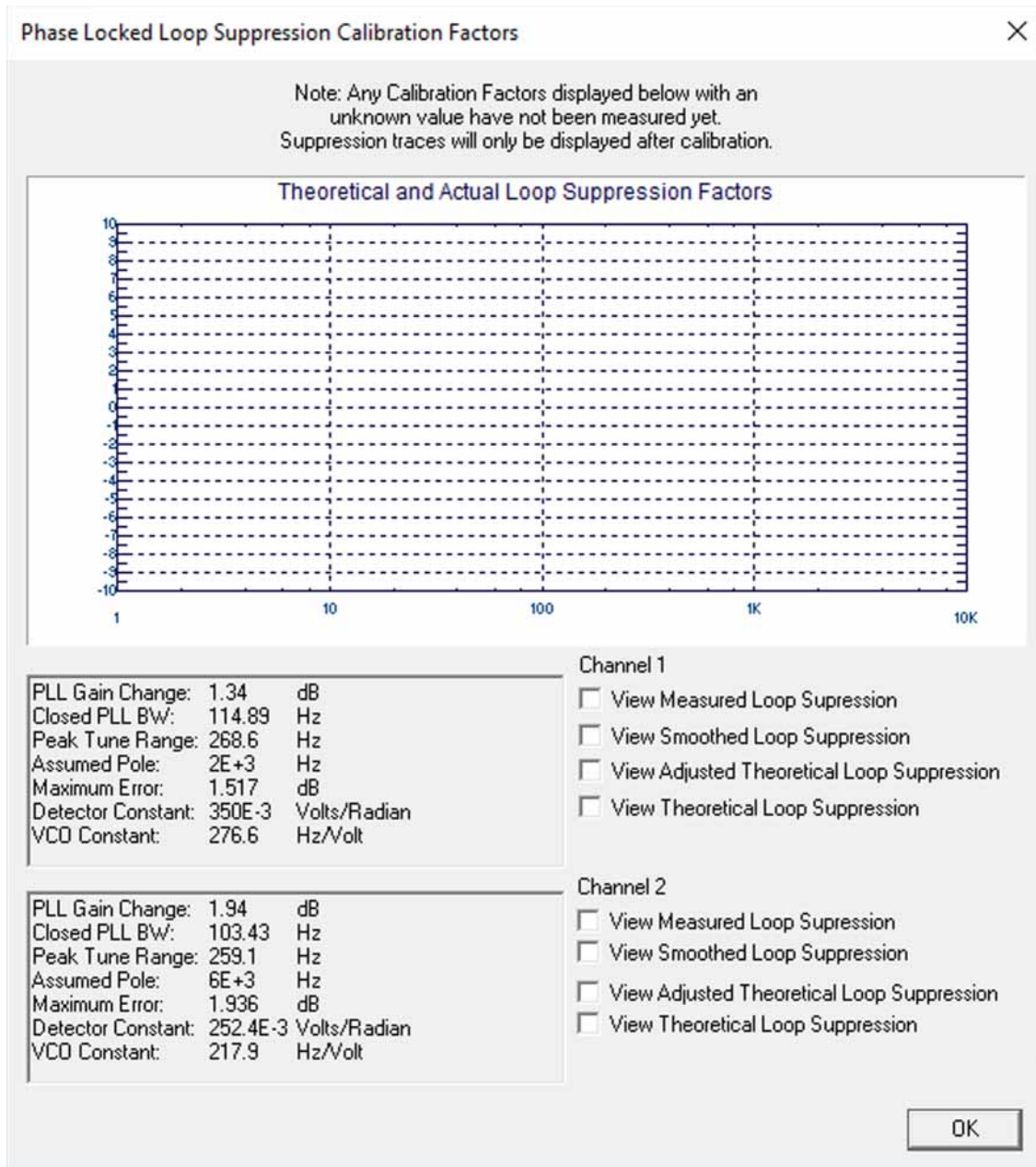
Introduction

The N5511 Phase Noise Measurement System software feature **Advanced Functions** allows you to manipulate the test system or to customize a measurement using the extended capabilities of the N5510 software. This chapter describes each of these advanced functions. Keysight recommends that only users who understand how the measurement and the test system are affected by each function use the **Advanced Functions** feature.

Phase-Lock-Loop Suppression

Selecting “PLL Suppression Curve” on the View menu causes the software to display the PLL Suppression Curve plot, as shown in **Figure 15-1**, when it is verified during measurement calibration. The plot appears whether or not an accuracy degradation occurs.

Figure 15-1 PLL suppression verification graph



PLL suppression parameters

The following measurement parameters are displayed along with the PLL Suppression Curve.

PLL gain change

This is the amount of gain change required to fit the Theoretical Loop Suppression curve to the measured loop suppression. A PLL Gain Change of greater than 1 dB creates an accuracy degradation (ACCY. DEGRADED) error. If an accuracy degradation is detected, the amount of error is determined from either the PLL Gain Change or the Maximum Error, whichever is larger. The degradation itself is 1 dB less than the greater of these. The parameters of the theoretical loop suppression that are modified are Peak Tune Range (basically open loop gain) and Assumed Pole (for example a pole on the VCO tune port that may cause peaking).

Max Error

Maximum Error is the largest difference between the smoothed measured loop suppression and the adjusted theoretical loop suppression in the frequency range plotted for the smoothed measured loop suppression.

The frequency of the assumed pole is normally much greater than the Closed PLL BW and there is no loop peaking. If the smoothed measured PLL suppression shows peaking, the assumed pole is shifted down in frequency to simulate the extra phase shift that caused the peaking. If the peaking is really due to a single pole at a frequency near the Closed PLL BW, the adjusted theoretical loop suppression and smoothed measured loop suppression will show a good match and the maximum error will be small.

The four points on the Loop Suppression graph marked with arrows (ranging from the peak down to approximately -8 dB) are the points over which the Maximum Error is determined. An error of greater than 1 dB results in an accuracy degradation.

Closed PLL bandwidth

This is the predicted Phase Lock Loop Bandwidth for the measurement. The predicted PLL BW is based on the predicted PTR. The Closed PLL BW will not be adjusted as a result of an accuracy degradation. If an accuracy degradation is detected, the amount of error is determined from either the PLL Gain Change or the Maximum Error, whichever is larger. The degradation itself is 1 dB less than the greater of these.

Peak tune range

This is the Peak Tuning Range (PTR) for the measurement determined from the VCO Tune Constant and the Tune Range of VCO. This is the key parameter in determining the PLL properties, the Drift Tracking Range, and the ability to phase lock sources with high close in noise.

The PTR displayed should be approximately equal to the product of the VCO Tune Constant times the Tune Range of VCO. This is not the case when a significant accuracy degradation is detected (4 dB) by the Loop Suppression Verification. In this case, the PTR and Assumed Pole are adjusted when fitting the Theoretical Loop Suppression to the smoothed measured Loop Suppression, and the test system will display the adjusted PTR. If the PTR must be adjusted by more than 1 dB, as indicated by an accuracy degradation of greater than 0 dB, the Phase Detector Constant or the VCO Tune Constant is in error at frequency offsets near the PLL BW, or the PLL BW is being affected by some other problem such as injection locking.

Assumed pole

This is the frequency of the Assumed Pole required to adjust the Theoretical Loop suppression to match the smoothed measured Loop suppression. The Assumed Pole frequency is normally much greater than the Closed PLL BW. An Assumed Pole frequency of less than 10 X PLL BW is an indication of peaking on the PLL Suppression curve. For PLL BWs less than 20 kHz, an Assumed Pole of less than 10 X PLL BW indicates a delay or phase shift in the VCO Tune Port. For PLL BWs greater than 20 kHz, the Assumed Pole may be adjusted to less than 10 X PLL BW to account for phase shifts in the test set.

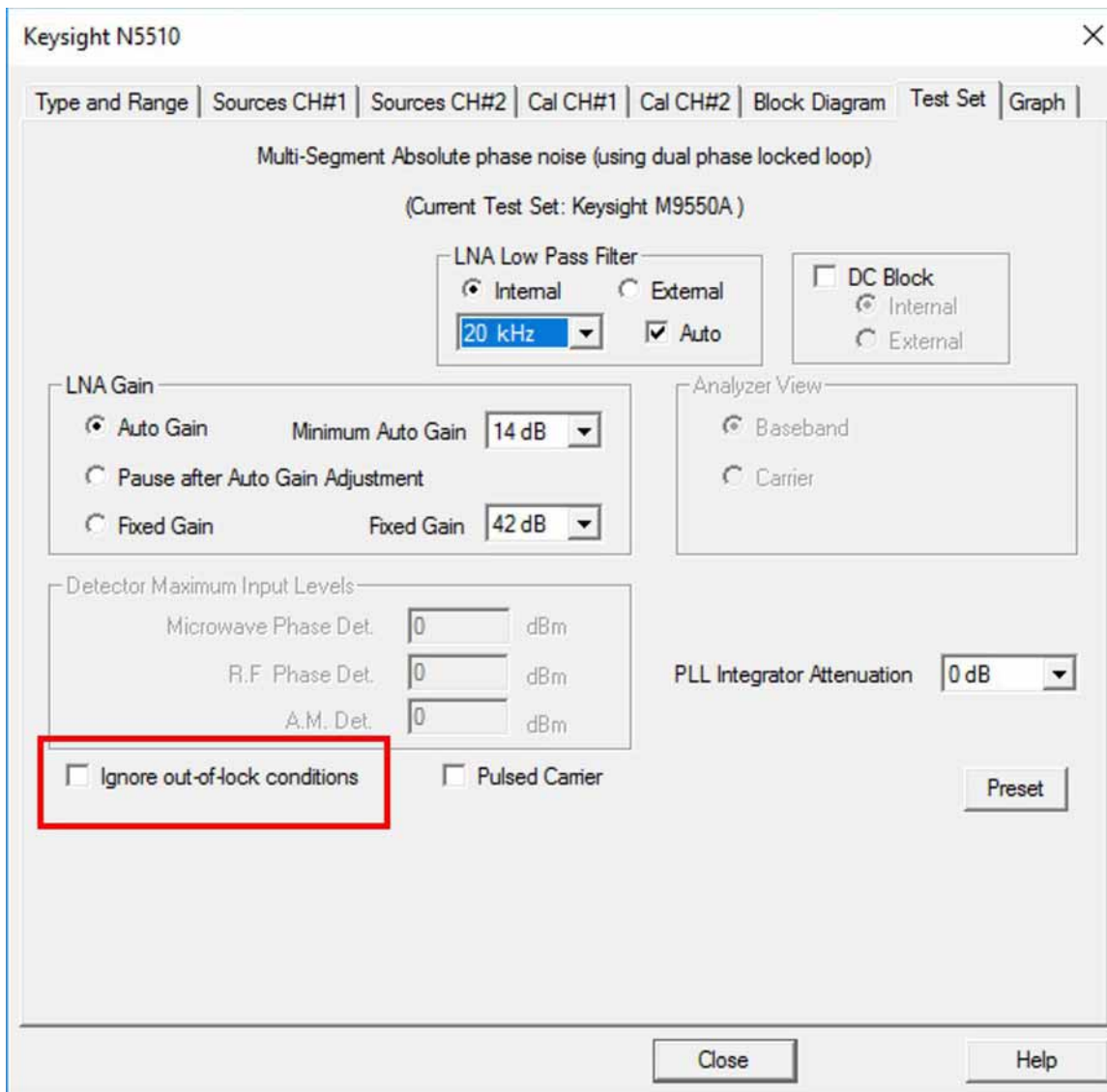
Detector constant

This is the phase Detector Constant (sensitivity of the phase detector) used for the measurement. The accuracy of the Phase Detector Constant is verified if the PLL suppression is verified. The accuracy of the phase Detector Constant determines the accuracy of the noise measurement.

The phase Detector Constant value, along with the LNA In/Out parameter, determines the Keysight N5511A system noise floor, exclusive of the reference source. "VCO CONSTANT" is the VCO Tune Constant used for the measurement. The accuracy of the VCO Tune Constant determines the accuracy of the PLL noise measurement for offset frequencies in segments where the entire plotted frequency range is less than the PLL BW / 4. The accuracy of the VCO Tune Constant is verified if the PLL Suppression is verified. The VCO Tune Constant times the Tune Range of VCO determines the Peak Tune Range (PTR) value for the measurement. The PTR sets the drift tracking and close-in noise suppression capabilities of the test system.

Ignore-Out-Of-Lock Mode

Figure 15-2 Ignore out-of-lock conditions



The Ignore Out Of Lock test mode enables all of the troubleshooting mode functions, plus it causes the software to not check for an out-of-lock condition before or during a measurement. This allows you to measure sources with high close-in noise that normally would cause an out-of-lock condition and stop the measurement. When Ignore Out Of Lock is selected, the user is responsible for monitoring phase lock. This can be accomplished using an oscilloscope connected to the test set Aux. Monitor port to verify the absence of a beat note and monitor the DC output level.

- When Ignore Out Of Lock is selected, the test system does not verify the phase lock of the measurement. The user must ensure that the measurement maintains phase lock during the measurement.

PLL Suppression Verification Process

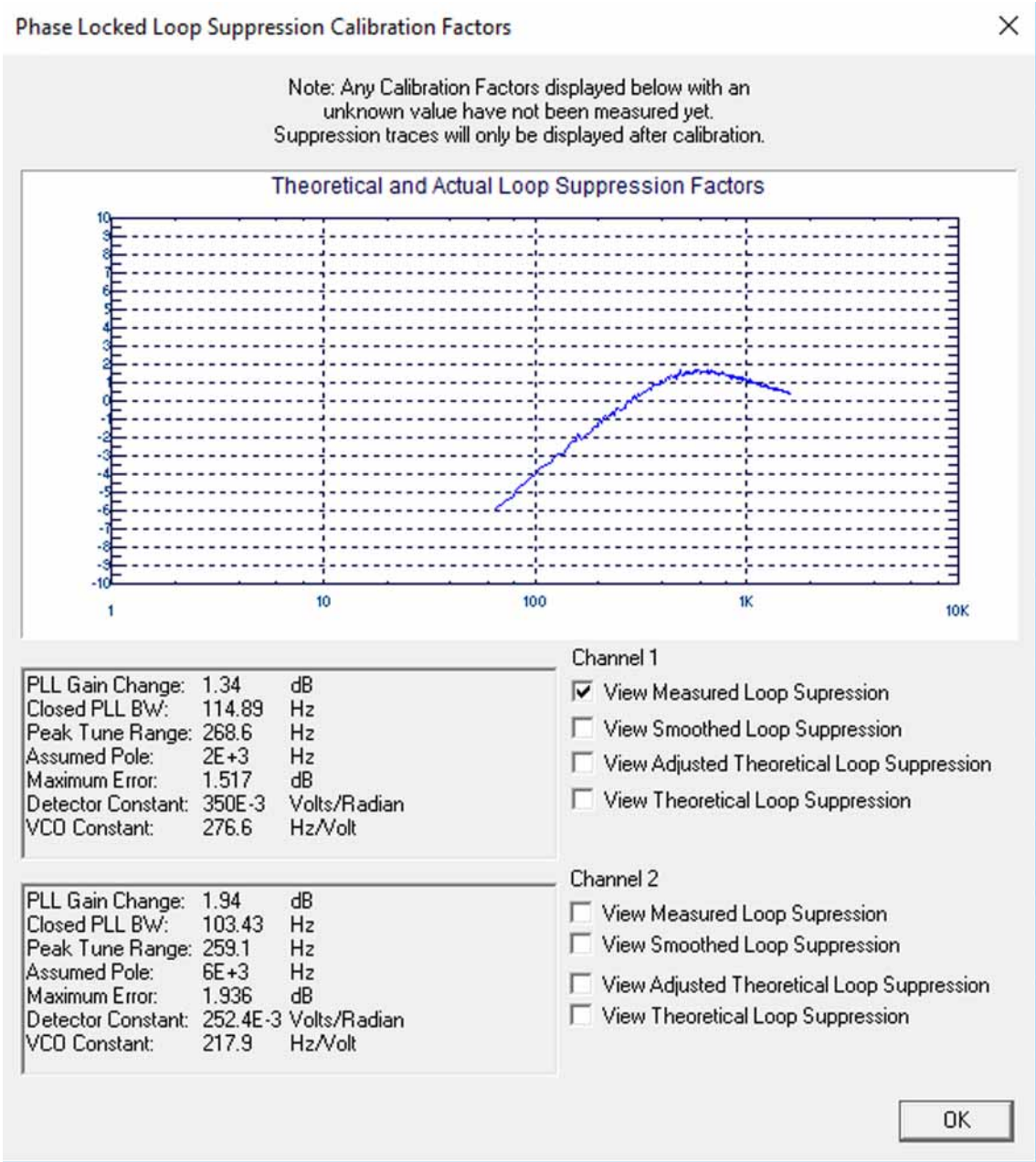
When “Verify calculated phase locked loop suppression” is selected, it is recommended that “Always Show Suppression Graph” also be selected. Verifying phase locked loop suppression is a function which is very useful in detecting errors in the phase detector constant or tune constant, the tune constant linearity, limited VCO tune port bandwidth conditions, and injection locking conditions. If the DUT is well behaved (injection locking issues do not exist or have been eliminated) and the reference source is well behaved (well-known tuning characteristics or a system-controlled RF signal generator) then the need to select PLL suppression verification is minimal.

To verify PLL suppression, an internal chirp signal is used.

PLL suppression information

The PLL Suppression View graph has been updated to allow measured, calculated (adjusted), and theoretical information to be examined more closely. When the “Always Show Suppression Graph” is selected, the following graph (Figure 15-3) is provided.

Figure 15-3 Default PLL suppression verification graph



There are four different curves available for this graph:

- a. “Measured” loop suppression curve (Figure 15-4)—this is the result of the loop suppression measurement performed by the N5511A system.
- b. “Smoothed” measured suppression curve (Figure 15-5)—this is a curve-fit representation of the measured results, it is used to compare with the “theoretical” loop suppression.
- c. “Theoretical” suppression curve (Figure 15-6)—this is the predicted loop suppression based on the initial loop parameters defined/selected for this particular measurement (k_{phi} , k_{vco} , loop bandwidth, filters, gain, etc.).
- d. “Adjusted” theoretical suppression curve (Figure 15-7 through Figure 15-9) —this is the new “adjusted” theoretical value of suppression for this measurement. It is based on changing loop parameters (in the theoretical response) to match the “smoothed” measured curve as closely as possible.

Figure 15-4 Measured loop suppression curve

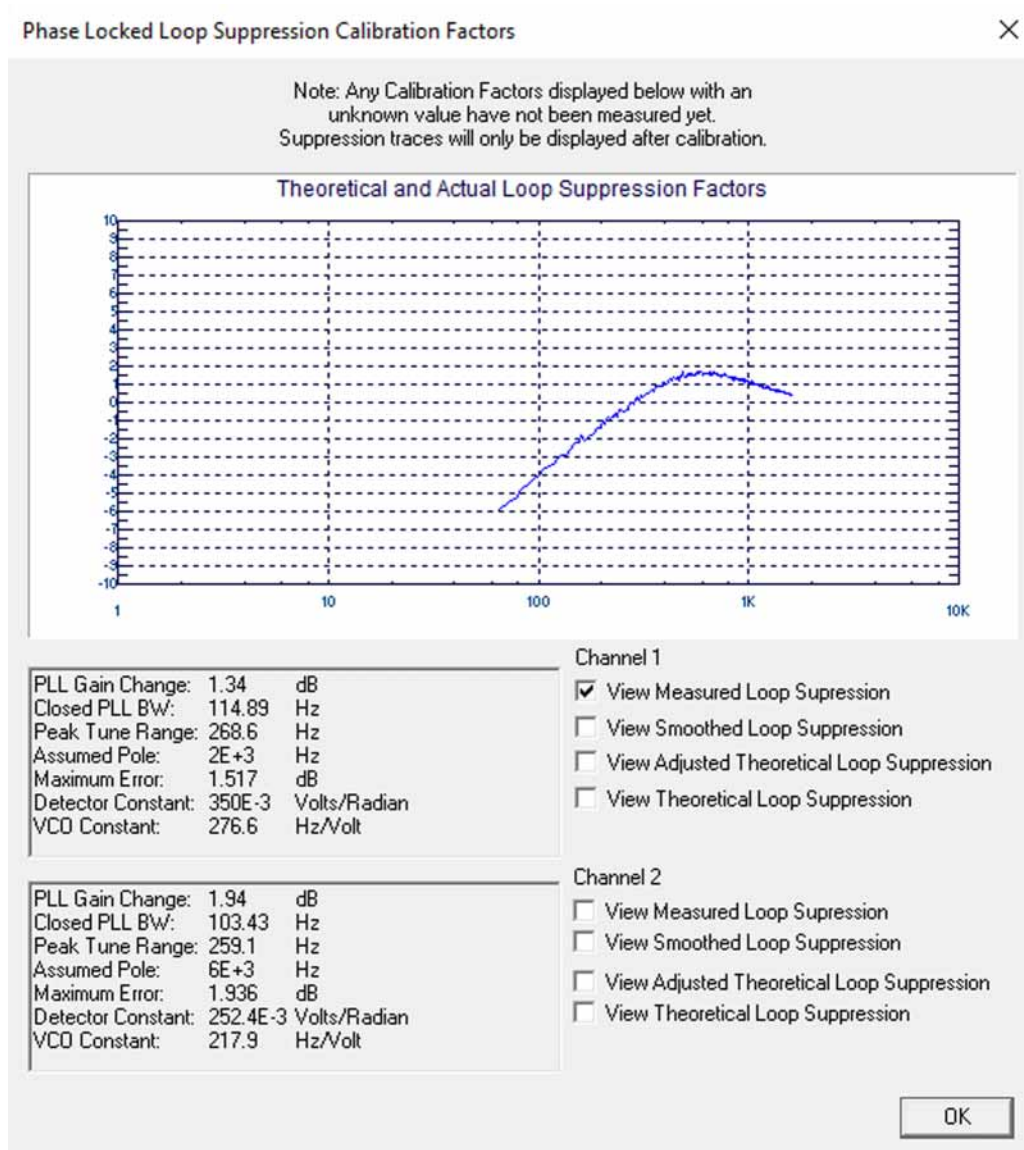


Figure 15-5 Smoothed loop suppression curve

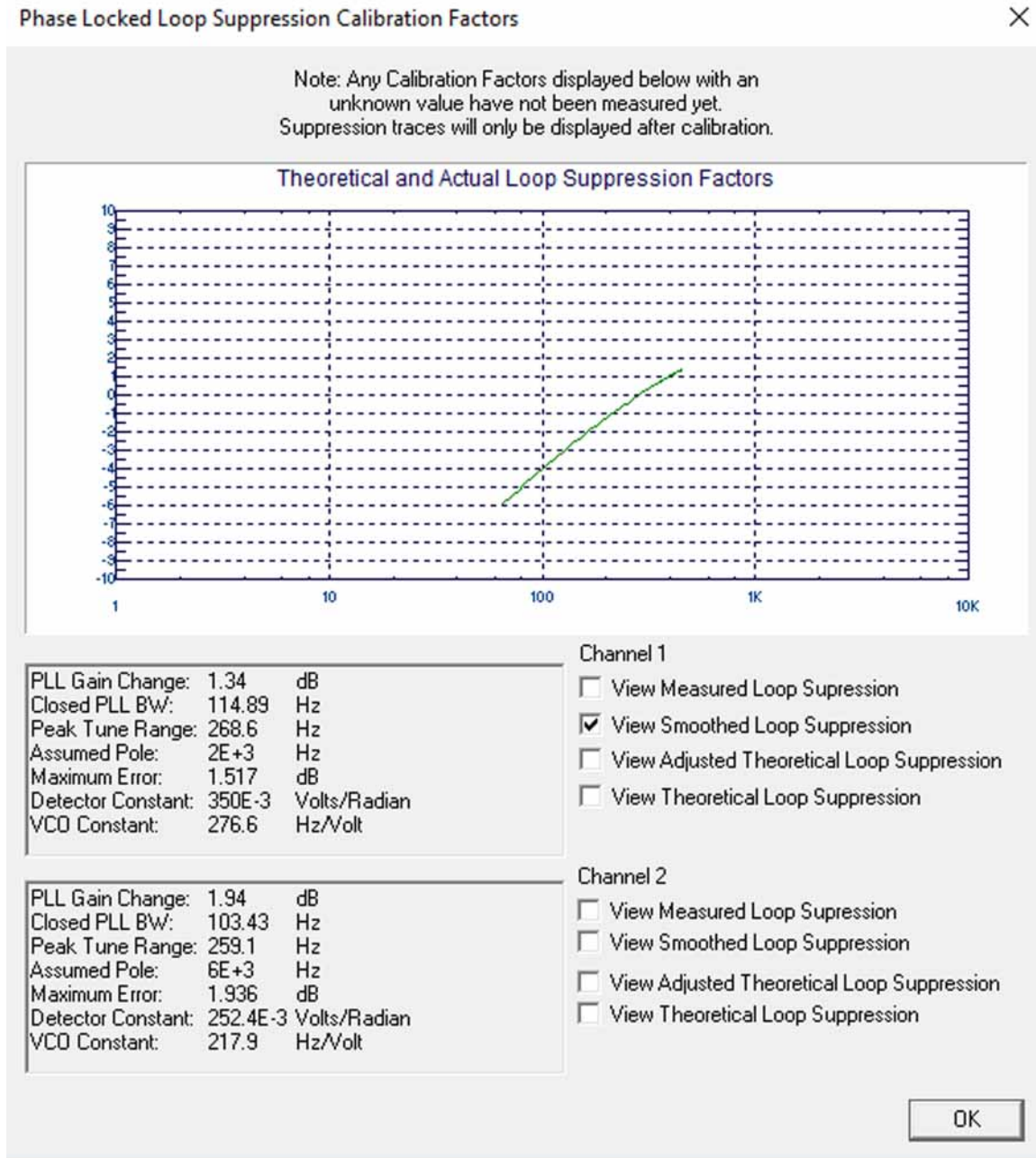


Figure 15-6 Theoretical loop suppression curve

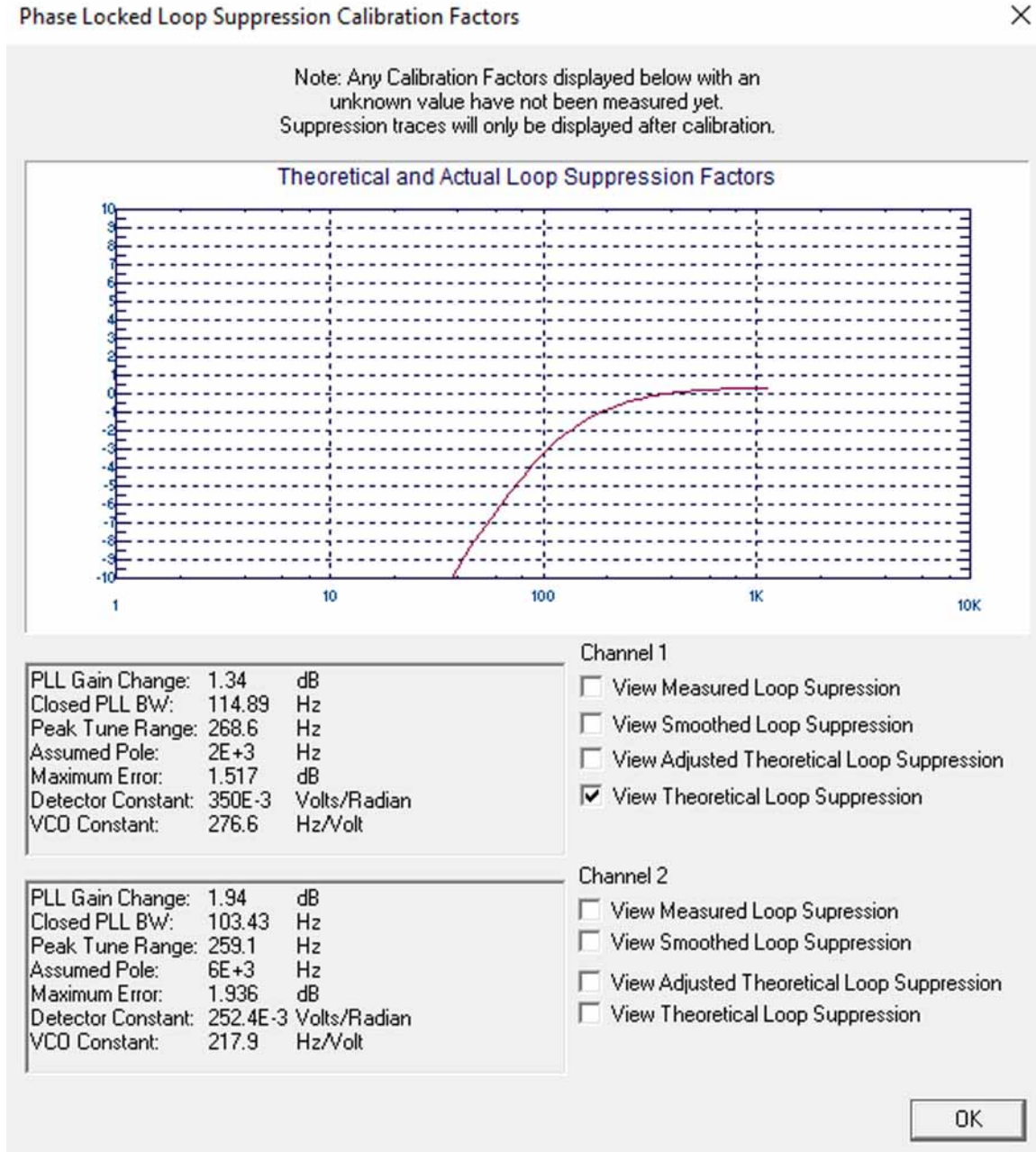


Figure 15-7 Smoothed vs. theoretical loop suppression curve

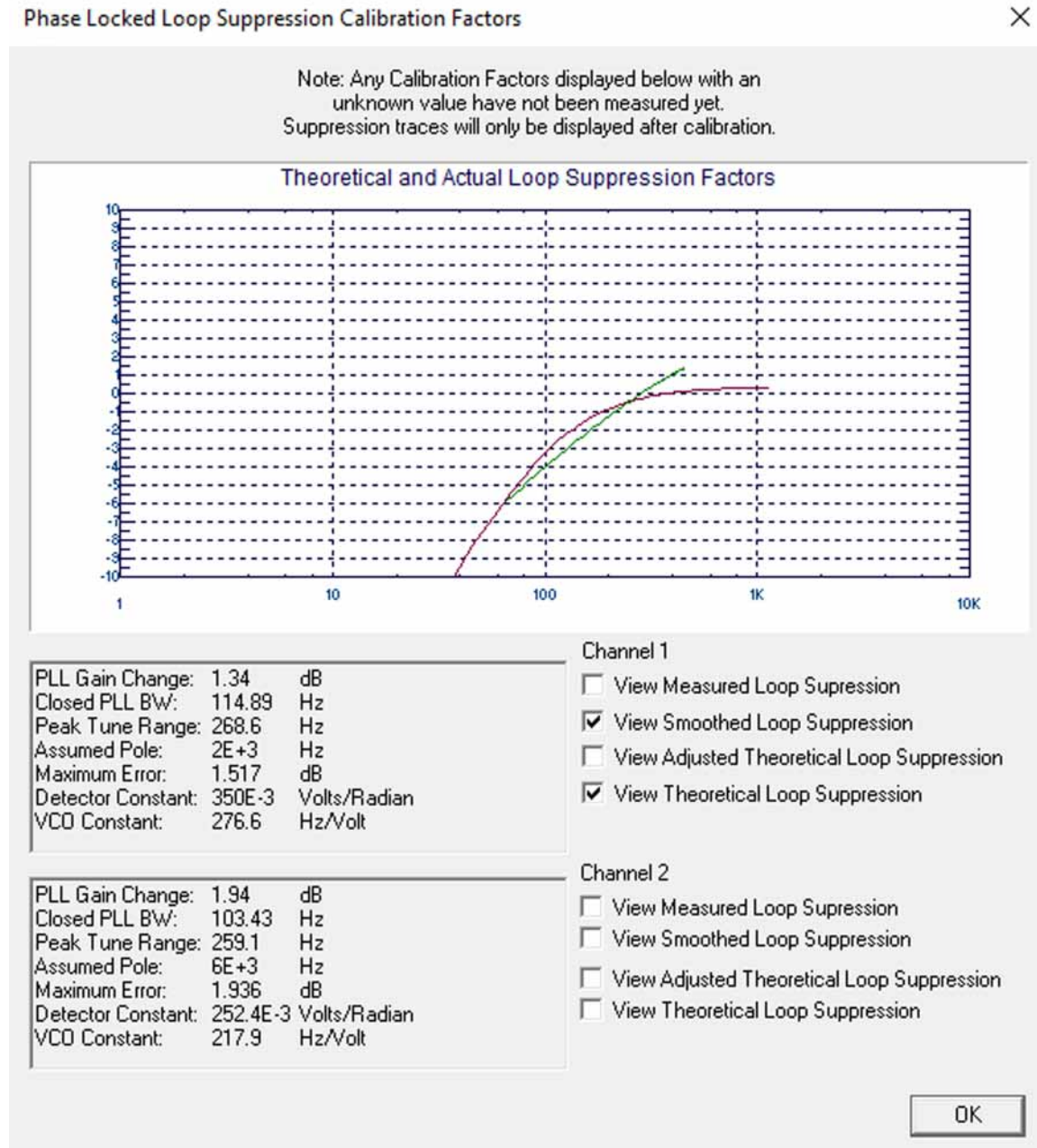


Figure 15-8 Smoothed vs. Adjusted theoretical loop suppression curve

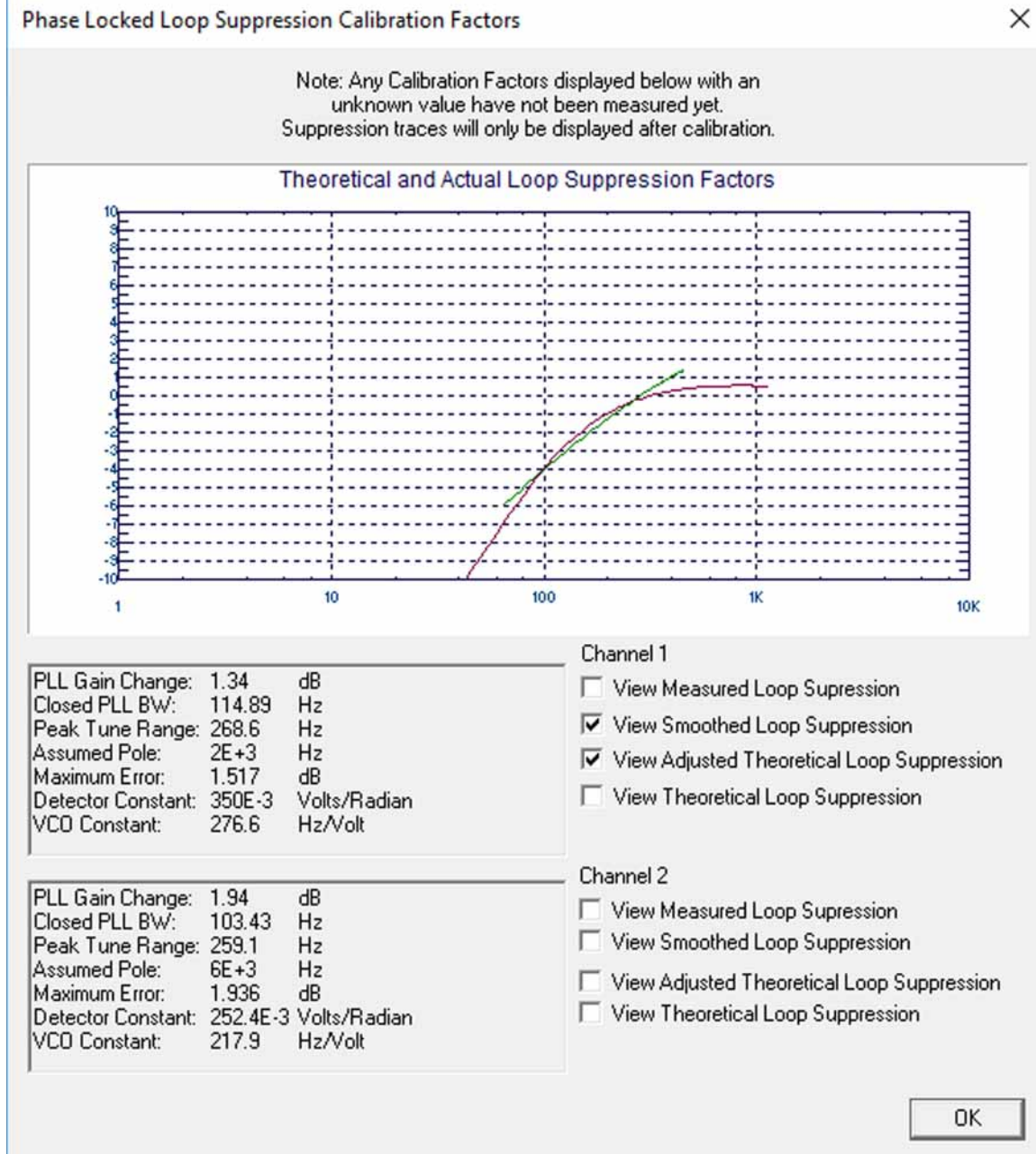
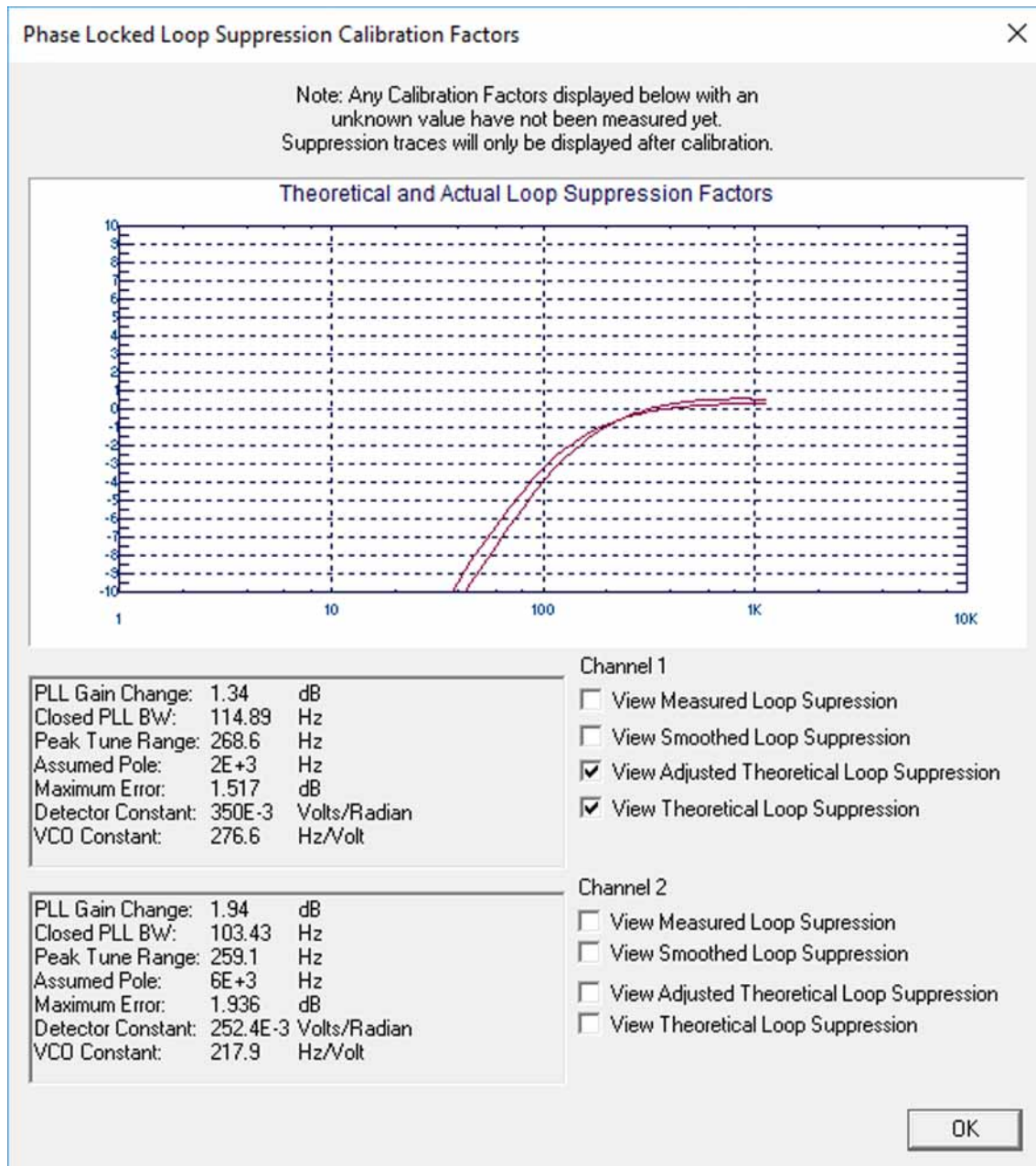


Figure 15-9 Adjusted theoretical vs. theoretical loop suppression curve



Accuracy degradation

Accuracy specification degradation is determined by taking the larger of Maximum Error and magnitude of PLL Gain Change and then subtracting 1 dB.

Blanking Frequency and Amplitude Information on the Phase Noise Graph

CAUTION

Implementing either of the “secured” levels described in this section is not reversible. Once the frequency or frequency/amplitude data has been blanked, it can not be recovered. If you need a permanent copy of the data, you can print out the graph and parameter summary before you secure the data and store the printed data to a secured location.

NOTE

An alternate method of storing classified data is to save the measurement test file (*.pnx), including the real frequency/amplitude data onto a floppy diskette and securing the diskette. It can then be recalled at a later data.

Security level procedure

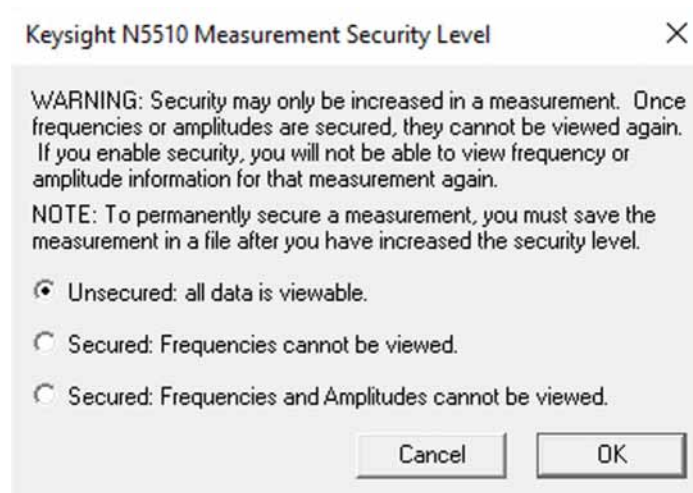
From the Define Menu, choose Security Level.

Unsecured: all data is viewable

When “Unsecured all data is viewable” is selected, all frequency and amplitude information is displayed on the phase noise graph. See [Figure 15-10](#).

Figure 15-10

Choosing levels of security



Secured: Frequencies Cannot be Viewed

When “Secured: Frequencies cannot be viewed” is selected, all frequency information is blanked on the phase noise graph. See [Figure 15-11](#) and [Figure 15-12](#).

Figure 15-11 Choosing levels of security

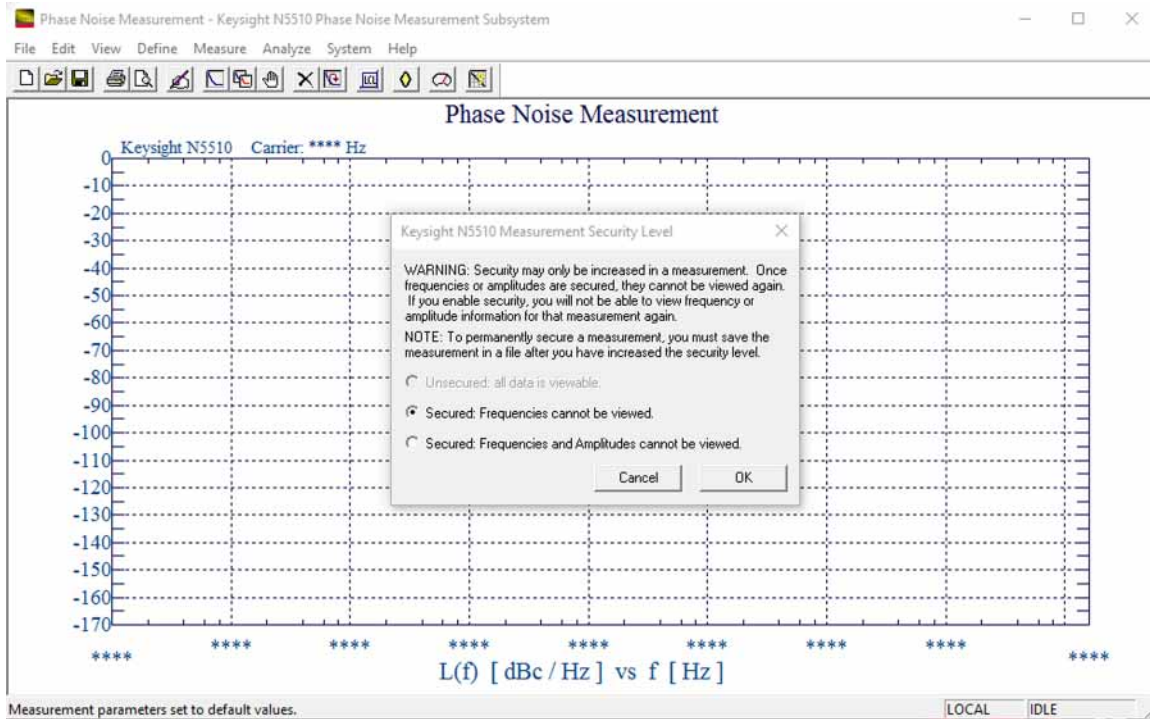
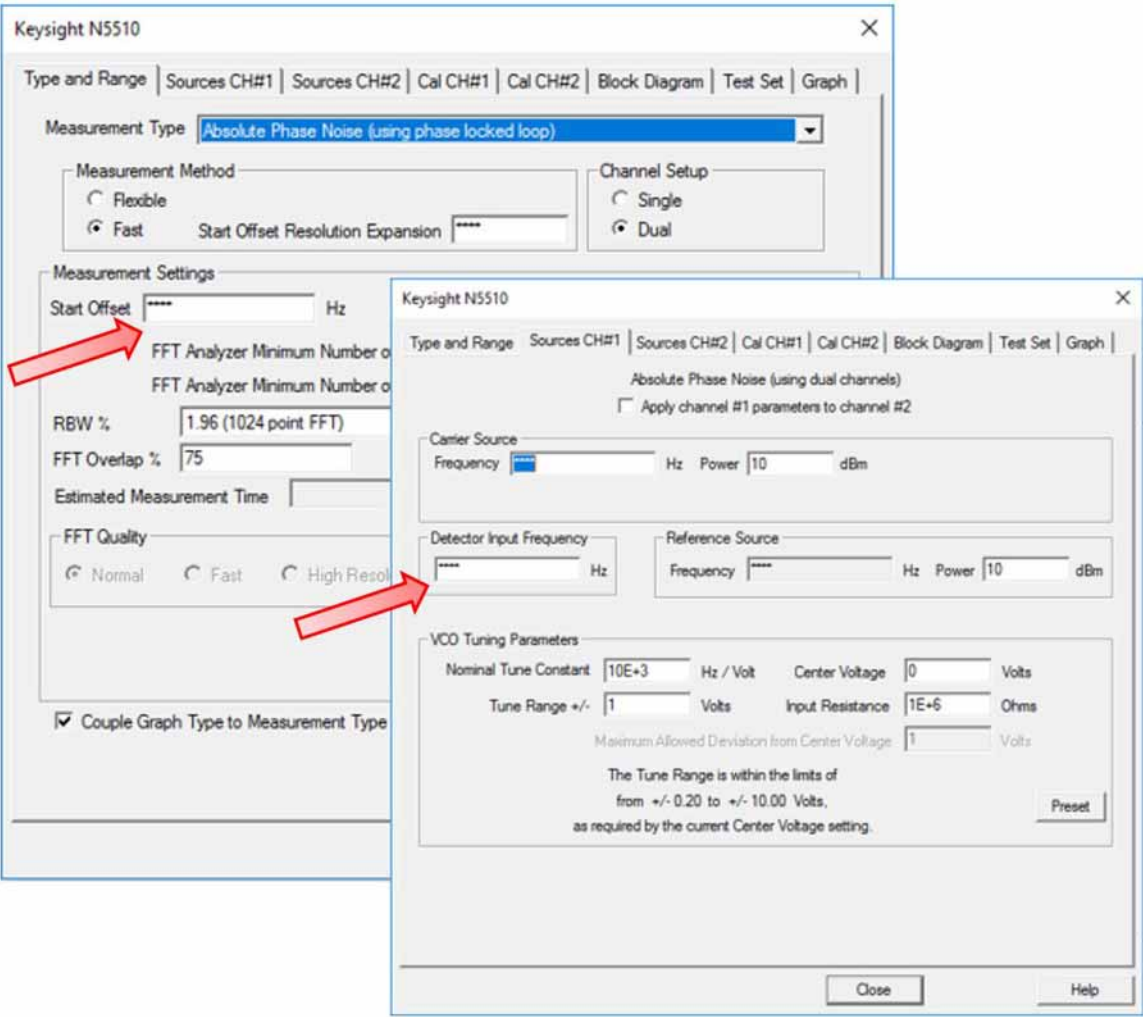


Figure 15-12 Secured: frequencies cannot be viewed



Secured: Frequencies and Amplitudes cannot be viewed

When “Secured: Frequencies and Amplitudes cannot be viewed” is selected, all frequency and amplitude information is blanked on the phase noise graph. See [Figure 15-13](#) and [Figure 15-14](#).

Figure 15-13 Choosing levels of security

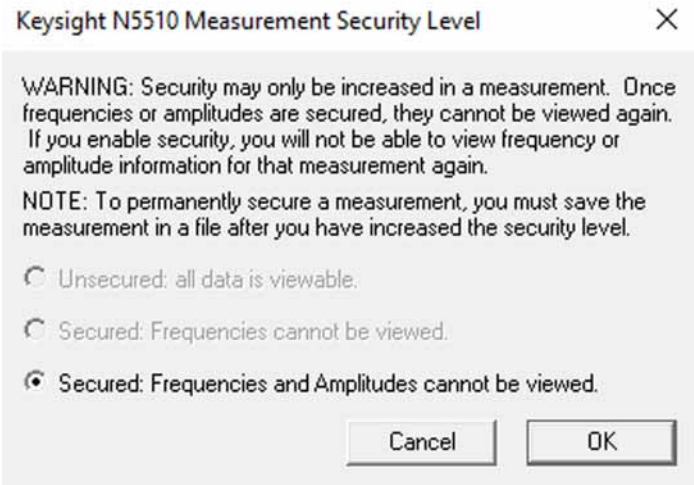
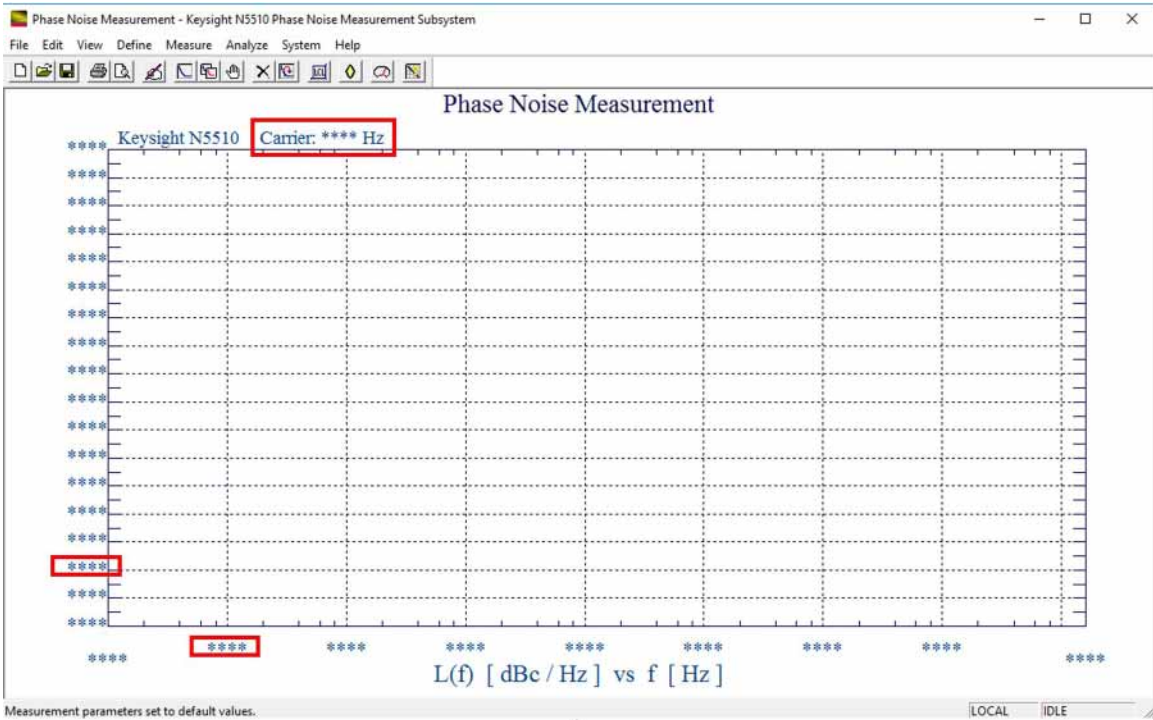


Figure 15-14 Secured: frequencies and amplitudes cannot be viewed



16 Reference Graphs and Tables

[“Approximate System Noise Floor vs. R Port Signal Level” on page 328](#)

[“Phase Noise Floor and Region of Validity” on page 329](#)

[“Phase Noise Level of Various Keysight Sources” on page 330](#)

[“Increase in Measured Noise as Ref Source Approaches DUT Noise” on page 331](#)

[“Approximate Sensitivity of Delay Line Discriminator” on page 332](#)

[“AM Calibration” on page 333](#)

[“Voltage Controlled Source Tuning Requirements” on page 334](#)

[“Tune Range of VCO for Center Voltage” on page 335](#)

[“Phase Lock Loop Bandwidth vs. Peak Tuning Range” on page 337](#)

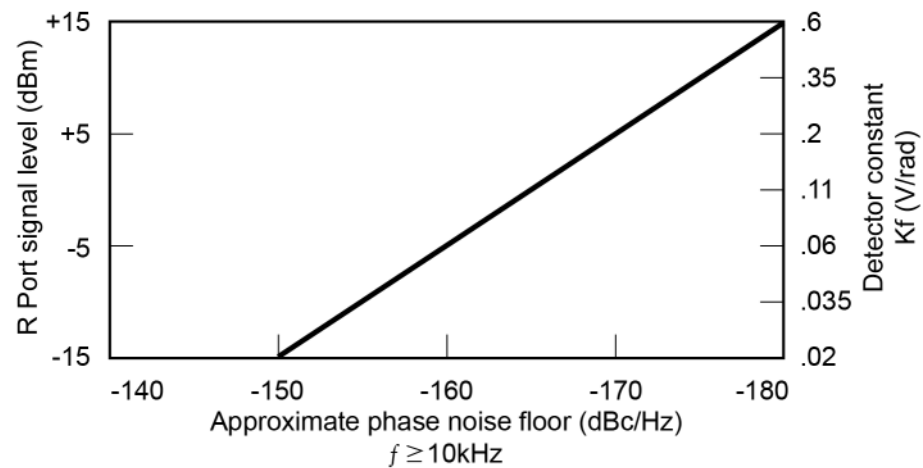
[“Noise Floor Limits Due to Peak Tuning Range” on page 338](#)

Approximate System Noise Floor vs. R Port Signal Level

The sensitivity of the phase noise measurement system can be improved by increasing the signal power at the R input port (Signal Input) of the phase detector in the test set. **Figure 16-1** illustrates the approximate noise floor of the N5500A test set for a range of R input port signal levels from -15 dBm to +15 dBm. These estimates of sensitivity assume the signal level at the L port is appropriate for either the microwave or the RF mixer that is used (+7 dBm or +15 dBm, respectively). The approximate phase detector calibration constant that results from the input signal level at the R port is shown on the right side of the graph.

Figure 16-1

Noise floor for R input port

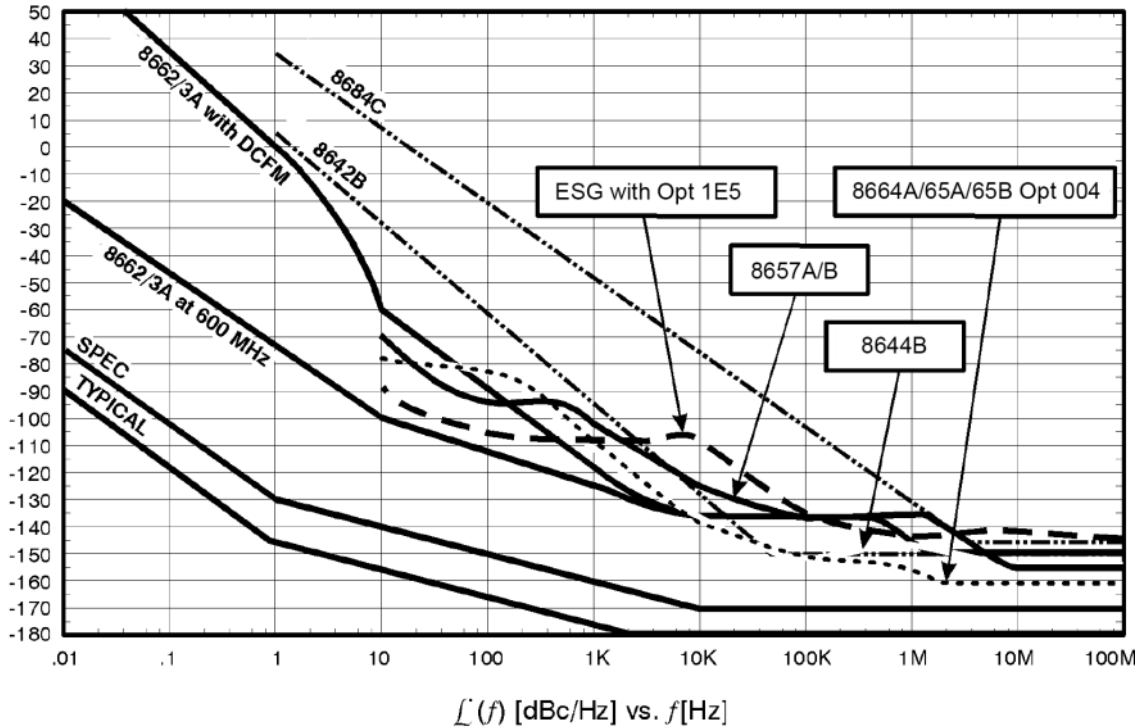


Phase Noise Floor and Region of Validity

Caution must be exercised when $L(f)$ is calculated from the spectral density of the phase fluctuations, $S\phi(f)$ because of the small angle criterion. The -10 dB/decade line is drawn on the plot for an instantaneous phase deviation of 0.2 radians integrated over any one decade of offset frequency. At approximately 0.2 radians, the power in the higher order sidebands of the phase modulation is still insignificant compared to the power in the first order sideband which ensures the calculation of $L(f)$ is still valid. As shown in **Figure 16-2**, the line plot of $L(f)$ is correct; above the line, $L(f)$ is increasingly invalid and $S\phi(f)$ must be used to represent the phase noise of the signal. ($S\phi(f)$ is valid both above and below the line.) When using the $L(f)$ graph to compute $S\phi(f)$, add 3 dB to the Level.

$$S\phi(f) = 2 (L(f)) \text{ or } S\phi(f)_{\text{dB}} = L(f)_{\text{dBc}} + 3 \text{ dB}$$

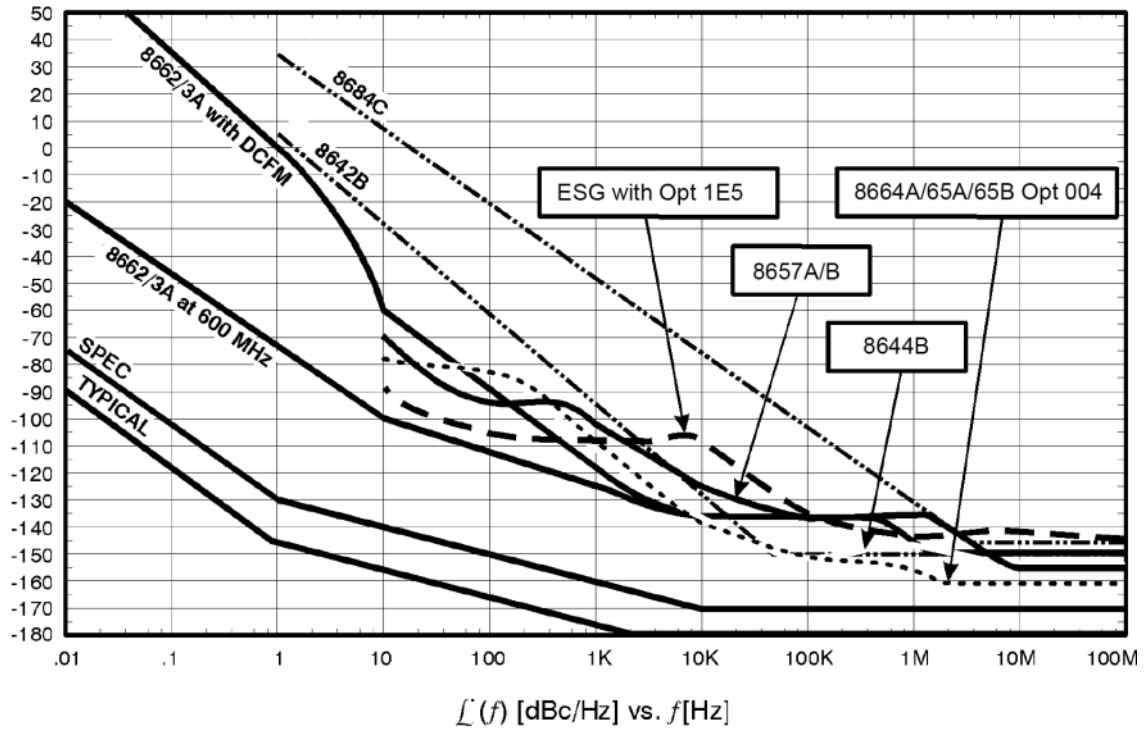
Figure 16-2 Region of validity



Phase Noise Level of Various Keysight Sources

The graph in **Figure 16-3** indicates the level of phase noise that has been measured for several potential reference sources at specific frequencies. Depending on the sensitivity that is required at the offset to be measured, a single reference source may suffice or several different references may be needed to achieve the necessary sensitivity at different offsets.

Figure 16-3 Noise level for various reference sources

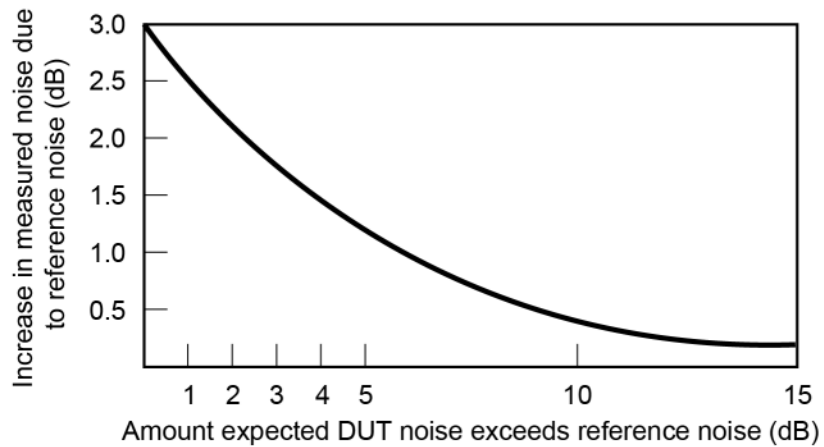


Increase in Measured Noise as Ref Source Approaches DUT Noise

The graph shown in **Figure 16-4** demonstrates that as the noise level of the reference source approaches the noise level of the DUT, the level measured by the software (which is the sum of all sources affecting the test system) is increased above the actual noise level of the DUT.

Figure 16-4

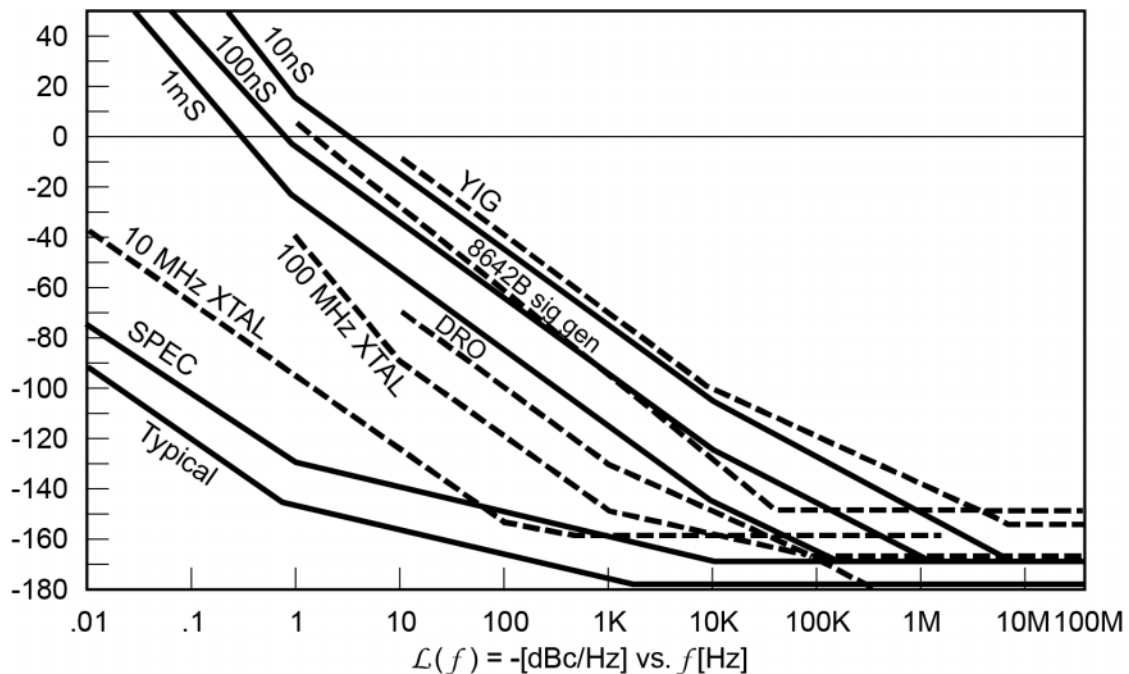
Reference source and DUT noise levels



Approximate Sensitivity of Delay Line Discriminator

The dependence of a frequency discriminator's sensitivity on the offset frequency is obvious in the graph in **Figure 16-5**. By comparing the sensitivity specified for the phase detector to the delay line sensitivity, it is apparent the delay line sensitivity is “tipped up” by 20 dB/decade beginning at an offset of $1/2\pi\tau$. The sensitivity graphs indicate the delay line frequency discriminator can be used to measure some types of sources with useful sensitivity. Longer delay lines improve sensitivity, but eventually the loss in the delay line will exceed the available power of the source and cancel any further improvement. Also, longer delay lines limit the maximum offset frequency that can be measured.

Figure 16-5 Delay line discriminator sensitivity

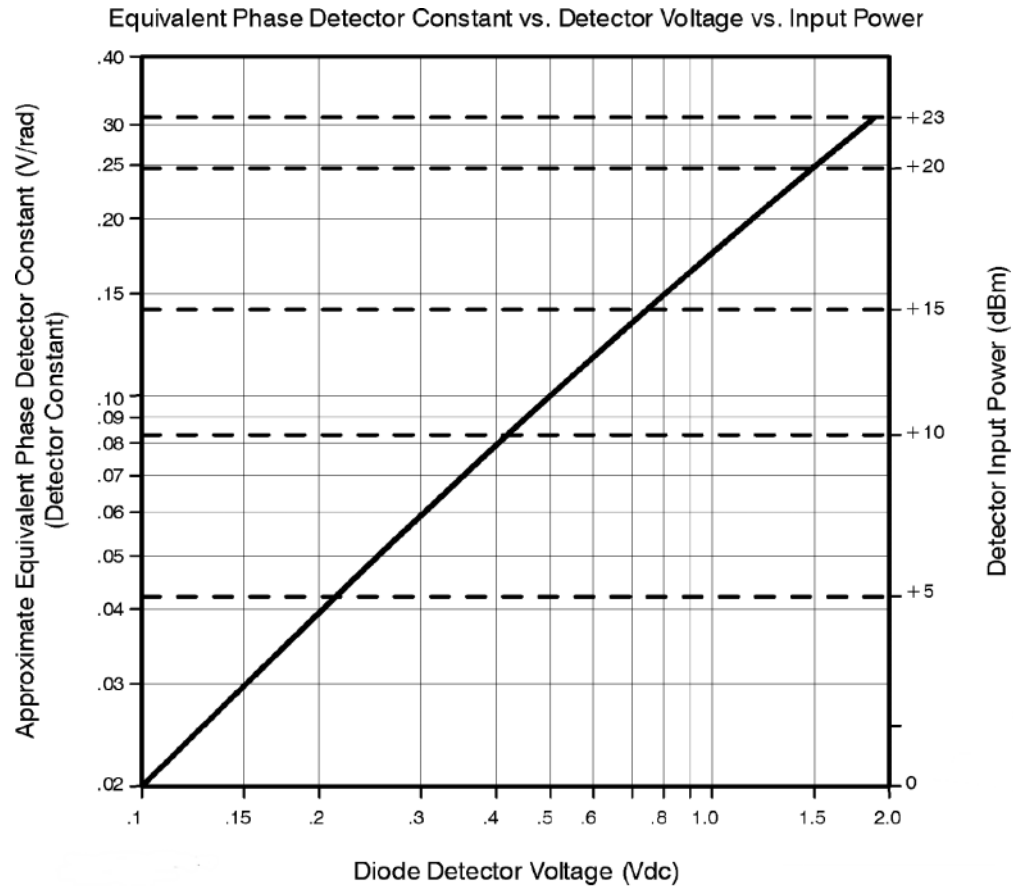


AM Calibration

The AM detector sensitivity graph in **Figure 16-6** is used to determine the equivalent phase Detector Constant from the measured AM Detector input level or from the diode detector's DC voltage. The equivalent phase detector constant (phase slope) is read from the left side of the graph while the approximate detector input power is read from the right side of the graph.

Figure 16-6

AM detector sensitivity



Voltage Controlled Source Tuning Requirements

Peak Tuning Range (PTR) » Tune Range of VCO x VCO Tune Constant.

Min. PTR = 0.1 Hz

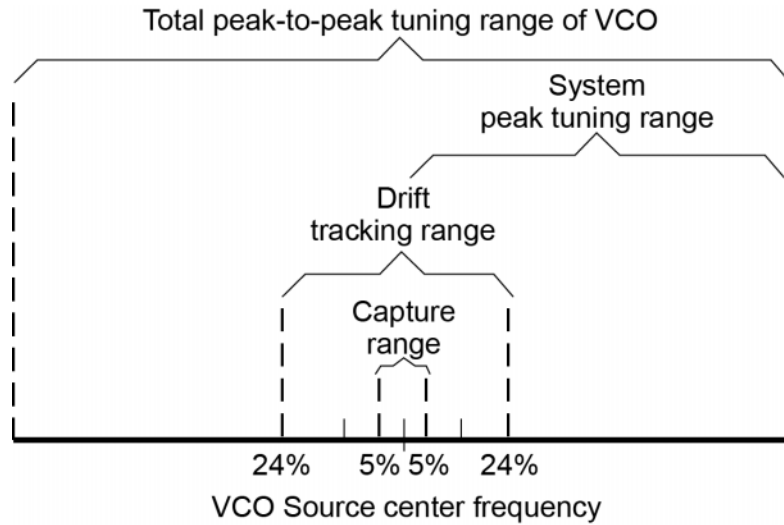
Max. PTR = Up to 200 MHz, depending on analyzer and phase detector LPF.

Drift Tracking Range = Allowable Drift During Measurement

The tuning range that the software actually uses to maintain quadrature is limited to a fraction of the peak tuning range (PTR) to ensure that the tuning slope is well behaved and the VCO Tune Constant remains accurate. After phase lock is established, the test system monitors the tuning voltage required to maintain lock. If the tuning voltage exceeds 5% of the PTR during the measurement, the test system again informs the user and requests the oscillator be retuned or the problem be otherwise corrected before proceeding with the measurement. These limits have been found to guarantee good results. Refer to [Figure 16-7](#).

Figure 16-7

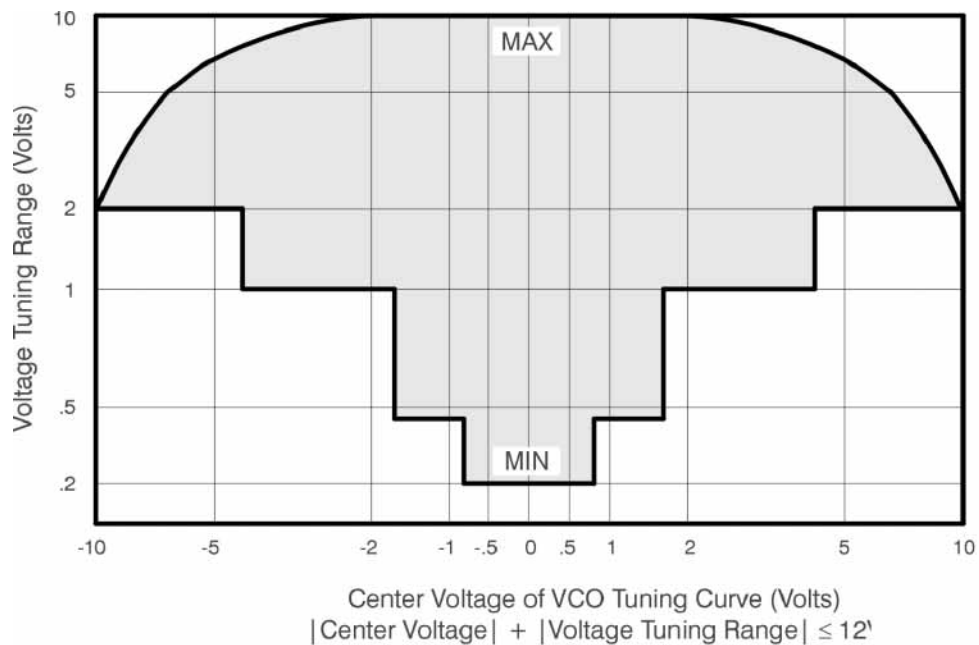
Tuning voltage required for phase lock



Tune Range of VCO for Center Voltage

The graph in **Figure 16-8** outlines the minimum to maximum Tune Range of VCO that the software provides for a given center voltage. The Tune range of VCO decreases as the absolute value of the center voltage increases due to hardware limitations of the test system.

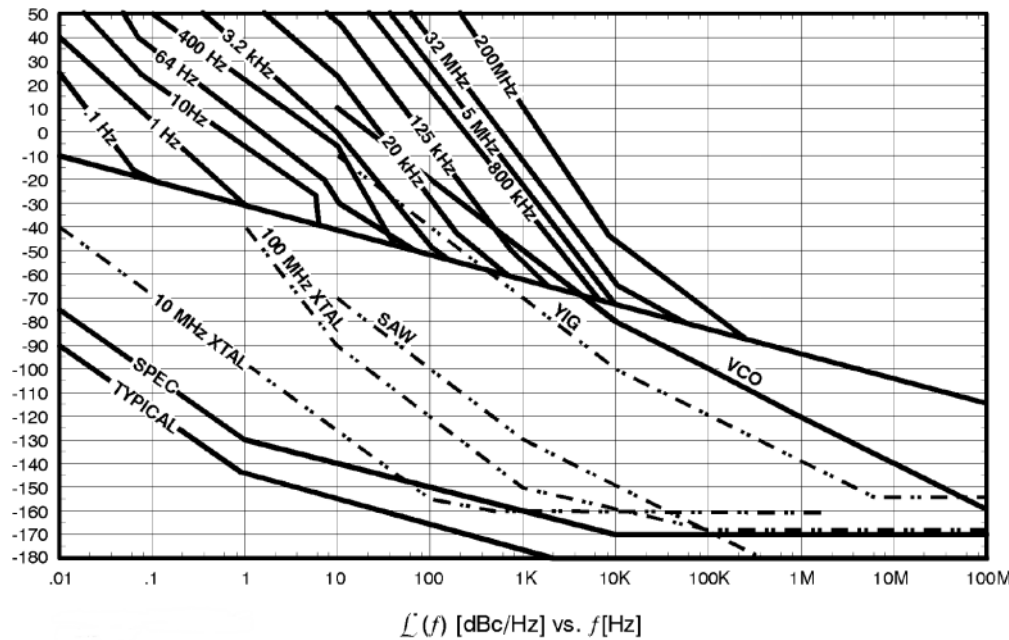
Figure 16-8 Tune range of VCO for center voltage



Peak Tuning Range Required by Noise Level

The graph in **Figure 16-9** provides a comparison between the typical phase noise level of a variety of sources and the minimum tuning range that is necessary for the test system to create a phase lock loop of sufficient bandwidth to make the measurement. Sources with higher phase noise require a wider Peak Tuning Range.

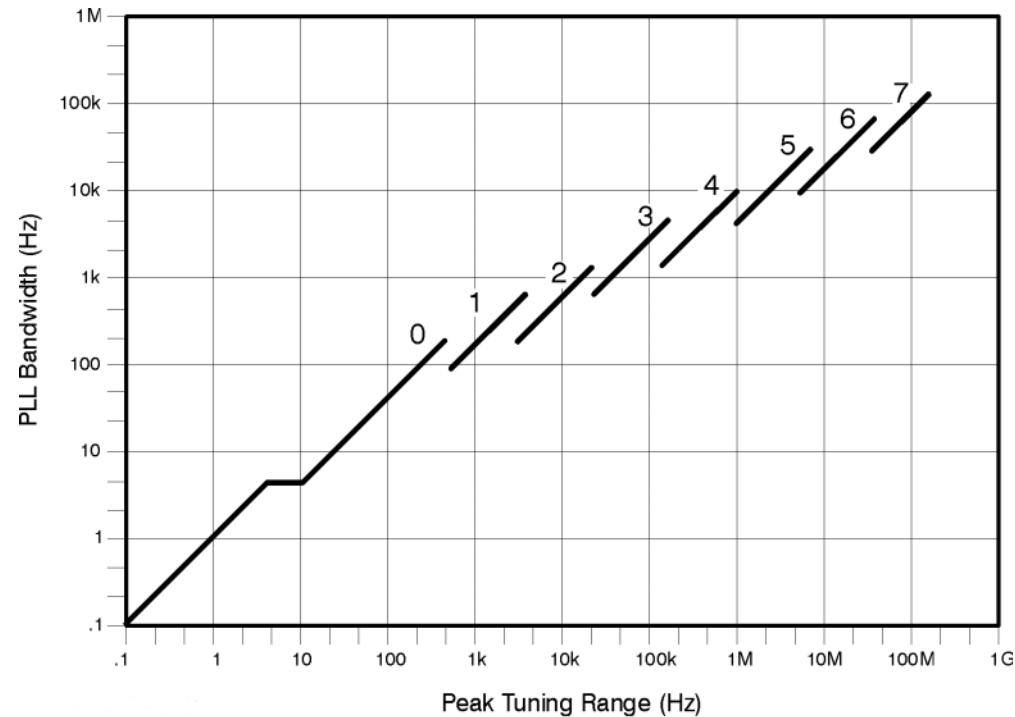
Figure 16-9 Typical source noise level vs. minimum tuning range



Phase Lock Loop Bandwidth vs. Peak Tuning Range

The graph in **Figure 16-10** illustrates the closed Phase Lock Loop Bandwidth (PLL BW) chosen by the test system as a function of the Peak Tuning Range of the source. Knowing the approximate closed PLL BW allows you to verify that there is sufficient bandwidth on the tuning port and that sufficient source isolation is present to prevent injection locking.

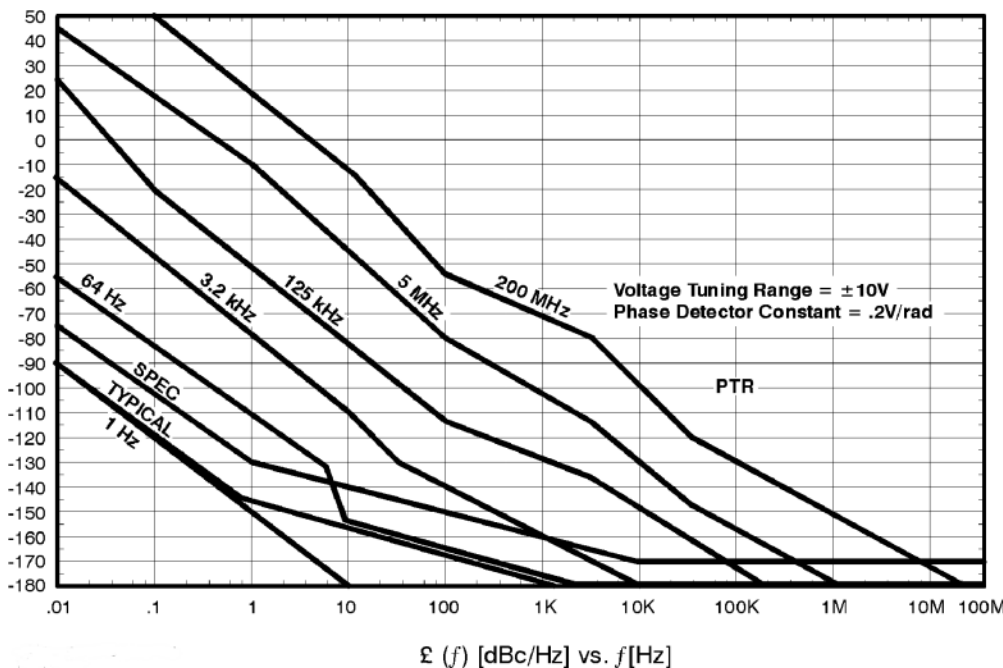
Figure 16-10 PLL BW vs. peak tuning range



Noise Floor Limits Due to Peak Tuning Range

The graph in **Figure 16-11** illustrates the equivalent phase noise at the Peak Tuning Range entered for the source due to the inherent noise at the test set Tune Voltage Output port. (A Tune Range of VCO ± 10 V and phase Detector Constant of 0.2V/Rad is assumed.)

Figure 16-11 Noise at source's peak tuning range



Tuning Characteristics of Various VCO Source Options

Table 16-1 Tuning parameters for several VCO options

VCO Source	Carrier Freq.	Tuning Constant (Hz/V)	Center Voltage (V)	Voltage Tuning Range (\pm V)	Input Resistance (Ω)	Tuning Calibration Method
Keysight 8257D						Measure
EFC	ν_0	$7 \text{ E} - 8 \times \nu_0$	0	5	$1 \text{ E} + 6$	Compute
DCFM	ν_0	FM Deviation	0	10	50 600	Compute
Keysight 8662/3A						
EFC	ν_0	$5 \text{ E} - 9 \times \nu_0$	0	10	$1 \text{ E} + 6$	Measure
DCFM		FM Deviation	0	10	1 K (8662) 600 (8663)	Calculate Calculate
Keysight 8642A/B		FM Deviation	0	10	600	Calculate
Keysight 8643A/44B		FM Deviation	0	10	600	Calculate
Keysight 8664A Keysight 8665A/B		FM Deviation	0	5 (See Caution Below)	600	Calculate
Other Signal Generator						
DCFM Calibrated for $\pm 1\text{V}$		FM Deviation	0	10	R_{in}	Calculate
Other User VCO Source		Estimated within a factor of 2	-10 to +10	See “Tune Range of VCO for Center Voltage” on page 335	$1 \text{ E} + 6$	Measure

CAUTION

Exceeding 5 volts maximum voltage tuning range for the 8664A and 8665A/B may damage equipment.

17 System Specifications

[“System Specifications” on page 342](#)

[“Power requirements” on page 344](#)

System Specifications

This section contains mechanical and environmental specifications, operating characteristics, power requirements, and PC requirements for the system.

Table 17-1 contains the mechanical and environmental specifications for a system. **Table 17-2** shows the system’s operating characteristics.

The N5511A Phase Noise Test System is designed for indoor use only.

NOTE

This product is designed for use in Installation Category II and Pollution Degree 2.

Table 17-1 Mechanical and environmental specifications

Specifications	Values
Temperature:	
Operating	0 °C to 55 °C (32 °F to 131 °F)
Non-operating/storage	-40 °C to 70 °C (-40 °F to 158 °F)
Altitude	9842.5 ft (3000 m)
Relative humidity	Maximum Relative Humidity (non-condensing): 95% RH up to 40° C, decreases linearly to 45% RH at 55° C ^a
Air flow space required	Refer to the section "Equipment Installation" in the Getting Stared Guide for air flow requirements for bench top systems as well as rack mount systems.
System weight:	
Approximate, typical	46 lbs (21 kg)
System dimensions:	
Height	192 mm (7.5 in)
Width	445 mm (17.5 in)
Depth	466 mm (18.3 in)

a. From 40° C to 55° C, the maximum % Relative Humidity follows the line of constant dew point.

Table 17-2 Operating characteristics

Warm up time required	30 minutes
Carrier frequency Input Range	50 kHz to 40 GHz
System noise response	-175 dBc/Hz typically (>10 kHz offsets)
System spurious response	≤ 120 dBc typically
External noise input port	0.01 Hz to 160 MHz
Measurement accuracy	±2 dB (<1.0 MHz offsets) ±4 dB (<160 MHz offsets)

Power requirements

The flexibility of the N5511A system configuration results in a significant range of power requirements, depending on the type and number of instruments in a system. **Table 17-3** shows the power requirements of the N5511A chassis/test set. **Table 17-4** provides the maximum requirements for individual instruments so that you can determine the requirements of your specific system. It also provides the maximum current drawn by an N5511A system that contains one of each type of instrument listed in the table.

Table 17-3 N5511A Chassis/Test Set power requirements

	100/120 VAC 50/60Hz	220/140 VAC 50/60Hz
N5511A chassis/test set	1000W Max	1200W Max

The instrument can operate with mains supply voltage fluctuations up to $\pm 10\%$ of the nominal voltage.

CAUTION

This instrument has auto-ranging line voltage input, be sure the supply voltage is within the specified range and voltage fluctuations do not to exceed 10 percent of the nominal supply voltage.

The N5511A system is shipped with AC power cords appropriate for your location.

Table 17-4 Example Test System - maximum AC power requirements

Component	115 VAC	230 VAC
Display (LCD)	Refer to specific product data sheet	
N5511A chassis/test set	2.3 A (110/120 VAC 280 W)	2 A (220/240 VAC)
Spectrum analyzer	Refer to specific product data sheet	
Frequency counter	Refer to specific product data sheet	
Oscilloscope	Refer to specific product data sheet	
RF Source E8257D	~ 2.2 A	~ 1.1 A

For information on an instrument's power line module, see the instrument's separate user's guide.

18 System Interconnections

“N5511A System Modules” on page 346

“Making Connections” on page 347

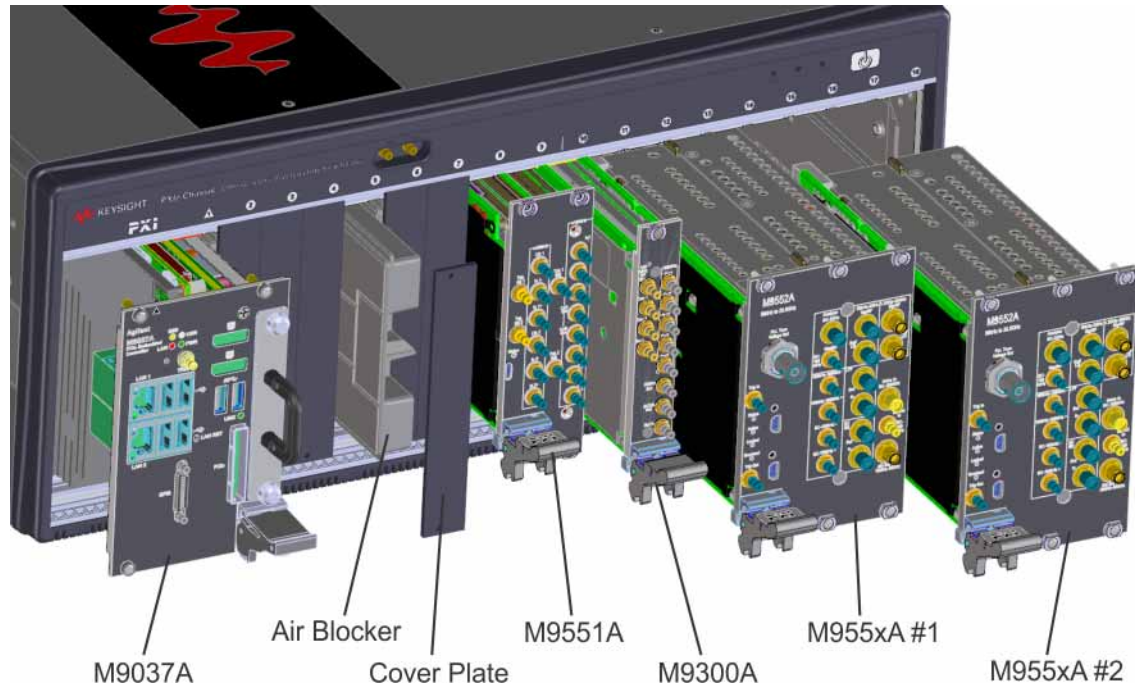
“N5511A Two Channel Cable Connections” on page 349

“System Connectors” on page 354

This chapter contains information and diagrams for connecting the instruments in a racked or benchtop N5511A system.

N5511A System Modules

Figure 18-1 N5511A System Modules



Making Connections

Use the information in this section to connect your system hardware.

CAUTION

Make all system hardware connections without AC power applied. Failure to do so may result in damage to the hardware. Make connections in a properly grounded environment. Keysight recommends wearing grounding wrist or foot straps. Failure to do so may result in damage to the hardware.

1. Verify all cables connected to instruments with the appropriate connectors and adapters, using the following pages in this section.
2. You may connect other assets (in addition to those supplied with the system) either at this time or after running the confidence test.
3. Lastly, connect the power cord(s) to the AC power supply.

Before connecting the cables to any device:

- Check all connectors for wear or dirt.
- When making the connection, torque the connector to the proper value.

Proper Connector Torque

- Provides more accurate measurements
- Keeps moisture out of the connectors
- Eliminates radio frequency interference (RFI) from affecting your measurements

The torque required depends on the type of connector. Refer to **Table 18-1**. Do not overtighten the connector.

Never exceed the recommended torque when attaching cables.

Table 18-1 Proper Connector Torque

Connector	Torque cm-kg	Torque N-cm	Torque in-lbs	Wrench P/N
Type-N	52	508	45	hand tighten
3.5 mm	9.2	90	8	8710-1765

Connecting a Display to your System

The N5511A Phase noise test system does not have a display.

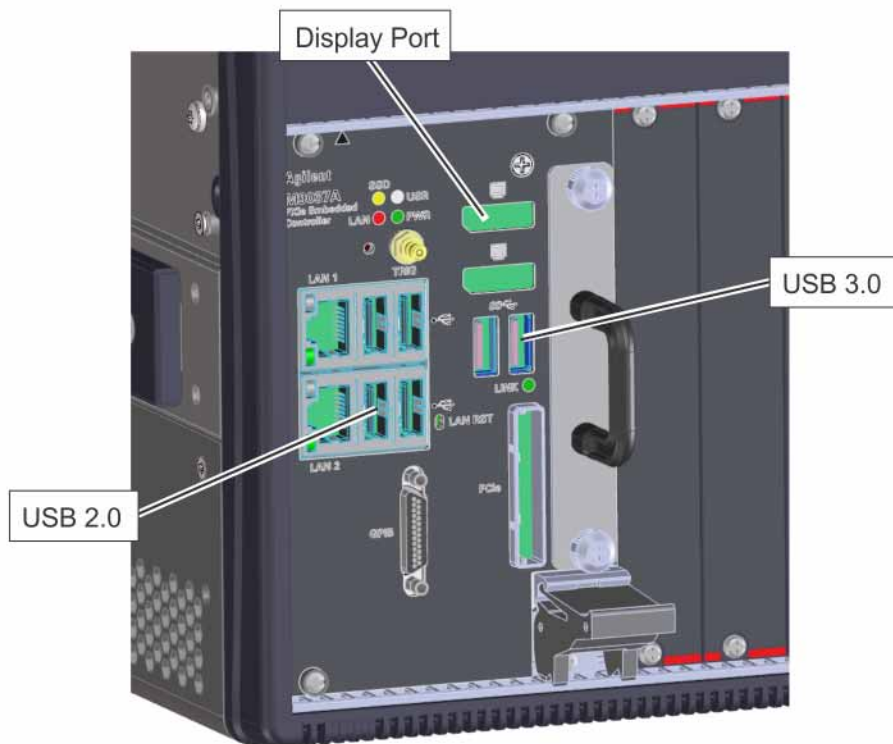
You will have to provide a monitor to view the user interface. Connect a display port cable to the M9037A controller display port connection and your monitor.

NOTE

You can use an adapter for other monitor cable types to the display port.

Figure 18-2

M9037A Controller Display Port



Connect a USB keyboard and mouse to the USB 2.0 ports.

NOTE

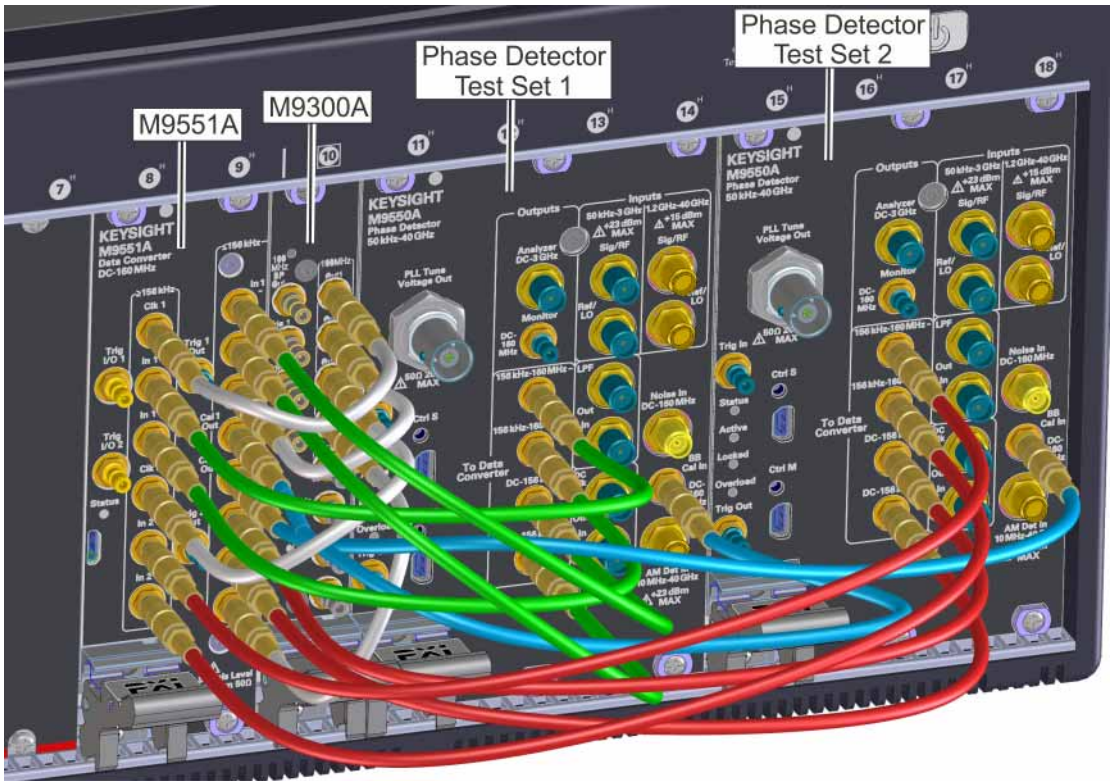
Proper ergonomics should be considered when using accessories such as a keyboard or a mouse.

N5511A Two Channel Cable Connections

NOTE

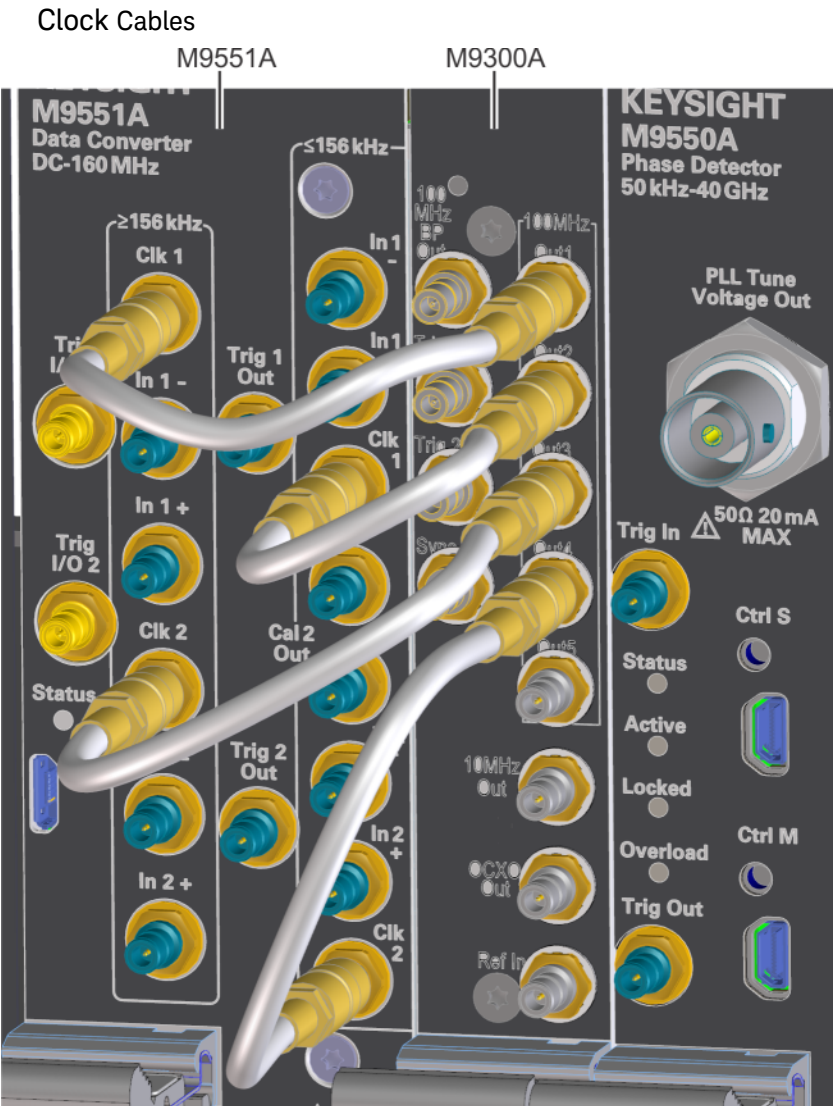
Cable colors are for identifying purposes only.

Figure 18-3 All Cables



Cable Color	Cable Group	Cable Part Numbers
White	Clock	8120-5091 (120 mm)
Green	Phase Detector Test Set 1	8121-2175 (300 mm)
Red	Phase Detector Test Set 2	8121-2175 (300 mm)
Blue	FFT/Data Converter	8121-2175 (300 mm)

Figure 18-4



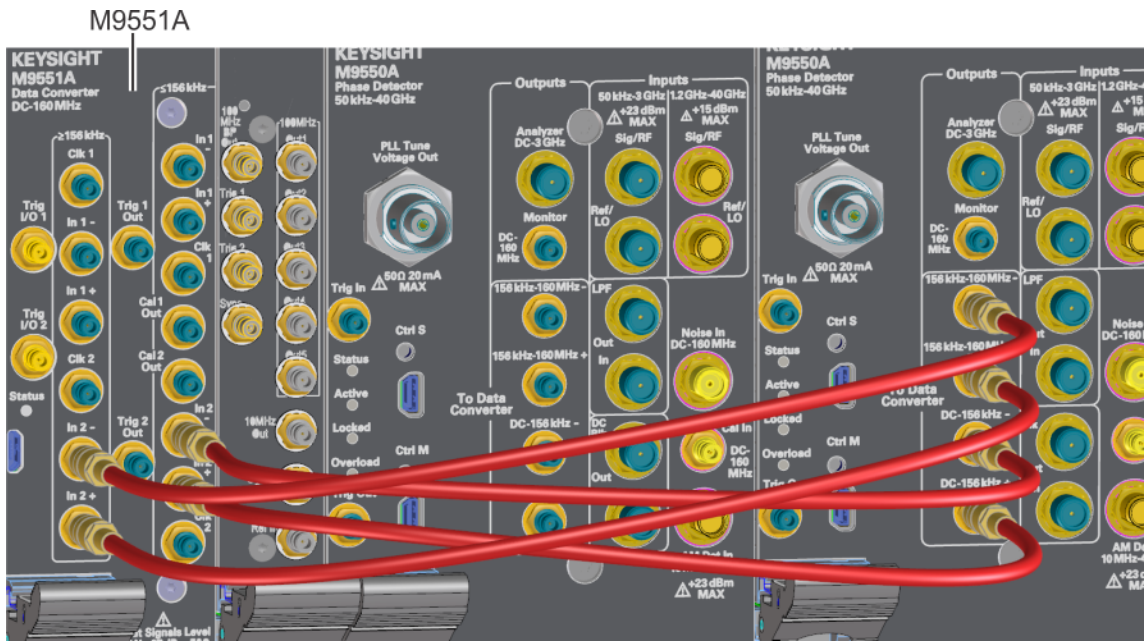
Clock Cable Connections All Cables Part # 8120-5091 (120 mm)	
M9551A	M9300A
≥ 156 kHz Clk 1	100 MHz Out 1
≤ 156 kHz Clk 1	100 MHz Out 2
≥ 156 kHz Clk 2	100 MHz Out 3
≤ 156 kHz Clk 2	100 MHz Out 4

Figure 18-5 Phase Noise Test Set 1 Cables



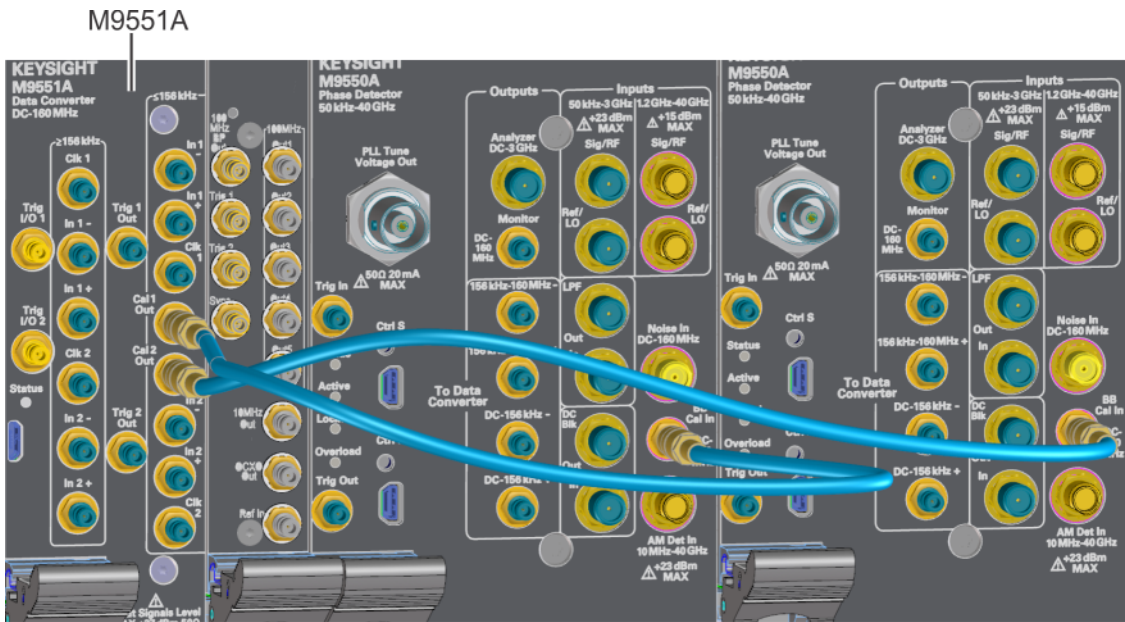
Phase Noise Test Set 1 Cable Connections All Cables Part # 8121-2175 (300 mm)	
M9551A	M955xA
≥ 156 kHz IN 1 –	156 kHz - 100 MHz –
≥ 156 kHz IN 1 +	156 kHz - 100 MHz +
≤ 156 kHz IN 1 –	DC - 156 kHz –
≤ 156 kHz IN 1 +	DC - 156 kHz +

Figure 18-6 Phase Noise Test Set 2 Cables



Phase Noise Test Set 2 Cable Connections All Cables Part # 8121-2175 (300 mm)	
M9551A	M955xA
≥ 156 kHz IN 2 –	156 kHz - 100 MHz –
≥ 156 kHz IN 2 +	156 kHz - 100 MHz +
≤ 156 kHz IN 2 –	DC - 156 kHz –
≤ 156 kHz IN 2 +	DC - 156 kHz +

Figure 18-7 FFT - Data Converter Cables



FFT - Data Converter Cable Connections All Cables Part # 8121-5091	
M9551A	M955xA
≤ 156 kHz CAL 1	BB Cal In DC - 100 MHz TEST SET 1
≤ 156 kHz CAL 2	BB Cal In DC - 100 MHz TEST SET 2

System Connectors

The following figures and tables show the connectors and adapters for the main N5511A system. It includes the type and quantity for each module in the system.

Figure 18-8 M9300A Connectors



Table 18-2 M9300A Connectors

Description	Qty
RF SMB, Male Straight Edge-mount, 50 Ω , 4 GHz	12

Figure 18-9 M9550A Connectors

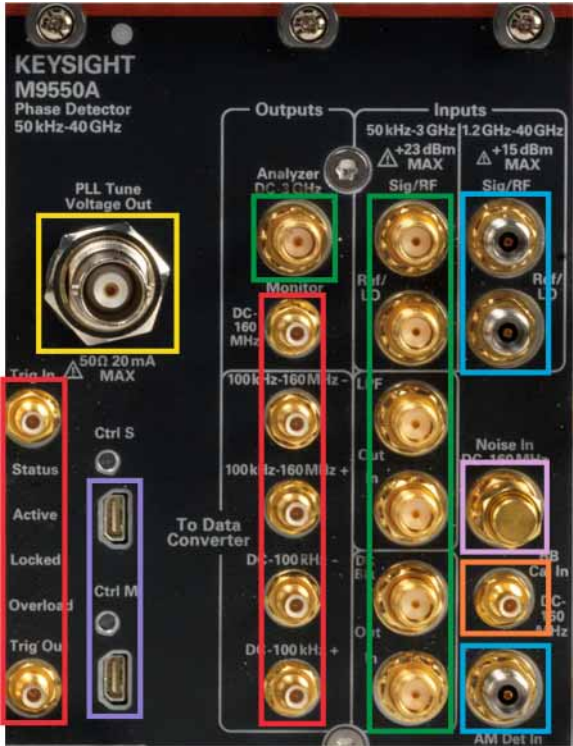


Table 18-3 M9550A Connectors

Description	Qty
Adapter-Coaxial straight, Female-K-Female-K	3
Adapter-Coaxial Straight Bulkhead, SMB-Jack MMCX-Jack, 50 Ω , 6 GHz	1
Adapter-Coaxial Straight Bulkhead, SMA-Jack MMCX-Jack, 50 Ω , 6 GHz	1
RF SMB, Male Straight Edge-mount, 50 Ω , 4 GHz	7
RF BNC Receptacle Edge-mount SMT, 50 Ω	1
HDMI Receptacle, Right-angle SMT, 19-POS 0.40 mm, 30V, 0.8A, 2-Row	2
RF SMA, Jack straight SMT, 50 Ω , 18 GHz	7

Figure 18-10 M9551A Connectors

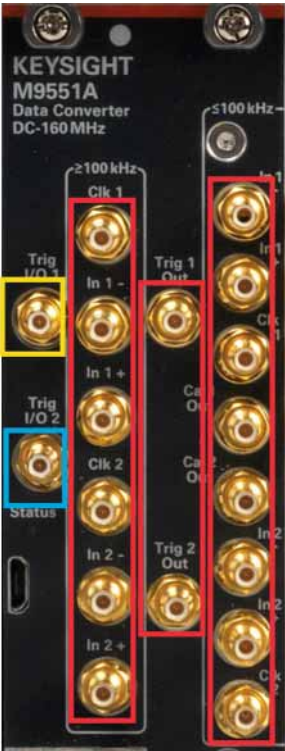


Table 18-4 M9551A Connectors

Description	Qty
RF SMB, Male Straight Edge-mount, 50 Ω , 4 GHz	16
Micro-USB Type-B Receptacle Right-angle SMT 5-POS 0.65mm 30VAC 1.8A 1-Row 1-Port	1
SMB Straight Jack Bulkhead to I-PEX MHF I + 1.13 Mini Cable Assy RSP-168036-06	1

19 Preventive Maintenance

[“Using, Inspecting, and Cleaning RF Connectors” on page 358](#)

[“General Procedures and Techniques” on page 361](#)

[“Instrument Removal” on page 364](#)

[“Instrument Installation” on page 367](#)

[“Using, Inspecting, and Cleaning RF Connectors” on page 358](#)

[“Repeatability” on page 358](#)

[“RF Cable and Connector Care” on page 358](#)

[“Connector Wear and Damage” on page 359](#)

[“2.92 Connector Precautions” on page 359](#)

[“Cleaning Procedure” on page 360](#)

Using, Inspecting, and Cleaning RF Connectors

Taking proper care of cables and connectors will protect your system's ability to make accurate measurements. One of the main sources of measurement inaccuracy can be caused by improperly made connections or by dirty or damaged connectors.

The condition of system connectors affects measurement accuracy and repeatability. Worn, out-of-tolerance, or dirty connectors degrade these measurement performance characteristics.

Repeatability

If you make two identical measurements with your system, the differences should be so small that they will not affect the value of the measurement. Repeatability (the amount of similarity from one measurement to another of the same type) can be affected by:

- Dirty or damaged connectors
- Connections that have been made without using proper torque techniques (this applies primarily when connectors in the system have been disconnected, then reconnected).

CAUTION

Static-Sensitive Devices - This system contains instruments and devices that are static-sensitive. Always take proper electrostatic precautions before touching the center conductor of any connector, or the center conductor of any cable that is connected to any system instrument. Handle instruments and devices only when wearing a grounded wrist or foot strap. When handling devices on a work bench, make sure you are working on an anti-static work surface.

RF Cable and Connector Care

Connectors are the most critical link in a precision measurement system. These devices are manufactured to extremely precise tolerances and must be used and maintained with care to protect the measurement accuracy and repeatability of your system.

To extend the life of your cables or connectors:

- Avoid repeated bending of cables—a single sharp bend can ruin a cable instantly.
- Avoid repeated connection and disconnection of cable connectors.
- Inspect the connectors before connection; look for dirt, nicks, and other signs of damage or wear. A bad connector can ruin the good connector instantly.
- Clean dirty connectors. Dirt and foreign matter can cause poor electrical connections and may damage the connector.
- Minimize the number of times you bend cables.

- Never bend a cable at a sharp angle.
- Do not bend cables near the connectors.
- If any of the cables will be flexed repeatedly, buy a back-up cable. This will allow immediate replacement and will minimize system down time.

Before connecting the cables to any device:

- Check all connectors for wear or dirt.
- When making the connection, torque the connector to the proper value.

Proper Connector Torque

- Provides more accurate measurements
- Keeps moisture out of the connectors
- Eliminates radio frequency interference (RFI) from affecting your measurements

The torque required depends on the type of connector. Refer to **Table 19-1**. Do not overtighten the connector.

Never exceed the recommended torque when attaching cables.

Table 19-1 Proper Connector Torque

Connector	Torque cm-kg	Torque N-cm	Torque in-lbs	Wrench P/N
Type-N	52	508	45	hand tighten
3.5 mm	9.2	90	8	8710-1765

Connector Wear and Damage

Look for metal particles from the connector threads and other signs of wear (such as discoloration or roughness). Visible wear can affect measurement accuracy and repeatability. Discard or repair any device with a damaged connector. A bad connector can ruin a good connector on the first mating. A magnifying glass or jeweler's loupe is useful during inspection.

2.92 Connector Precautions

2.92 connectors are used on the front RF In connector on the test set. These connectors can be used with 2.92 mm and 3.5 mm connectors.

Cleaning Procedure

WARNING

To prevent electrical shock, disconnect the Keysight Technologies Model N5511A from mains before cleaning. Use a dry cloth or one slightly dampened with water to clean the external case parts. Do not attempt to clean internally.

1. Blow particulate matter from connectors using an environmentally-safe aerosol such as Aero-Duster. (This product is recommended by the United States Environmental Protection Agency and contains tetrafluoroethane. You can order this aerosol from Keysight (see [Table 19-2](#).)
2. Use alcohol and a lint-free cloth to wipe connector surfaces. Wet a small swab with a small quantity of alcohol and clean the connector with the swab.
3. Allow the alcohol to evaporate off of the connector before making connections.

CAUTION

Do not allow excessive alcohol to run into the connector. Excessive alcohol entering the connector collects in pockets in the connector's internal parts. The liquid will cause random changes in the connector's electrical performance. If excessive alcohol gets into a connector, lay it aside to allow the alcohol to evaporate. This may take up to three days. If you attach that connector to another device it can take much longer for trapped alcohol to evaporate.

Table 19-2 Cleaning Supplies Available from Keysight

Product	Part Number
Aero-Duster	8500-6460
Isopropyl alcohol	8500-5344
Lint-Free cloths	9310-0039
Small polyurethane swabs	9301-1243

WARNING

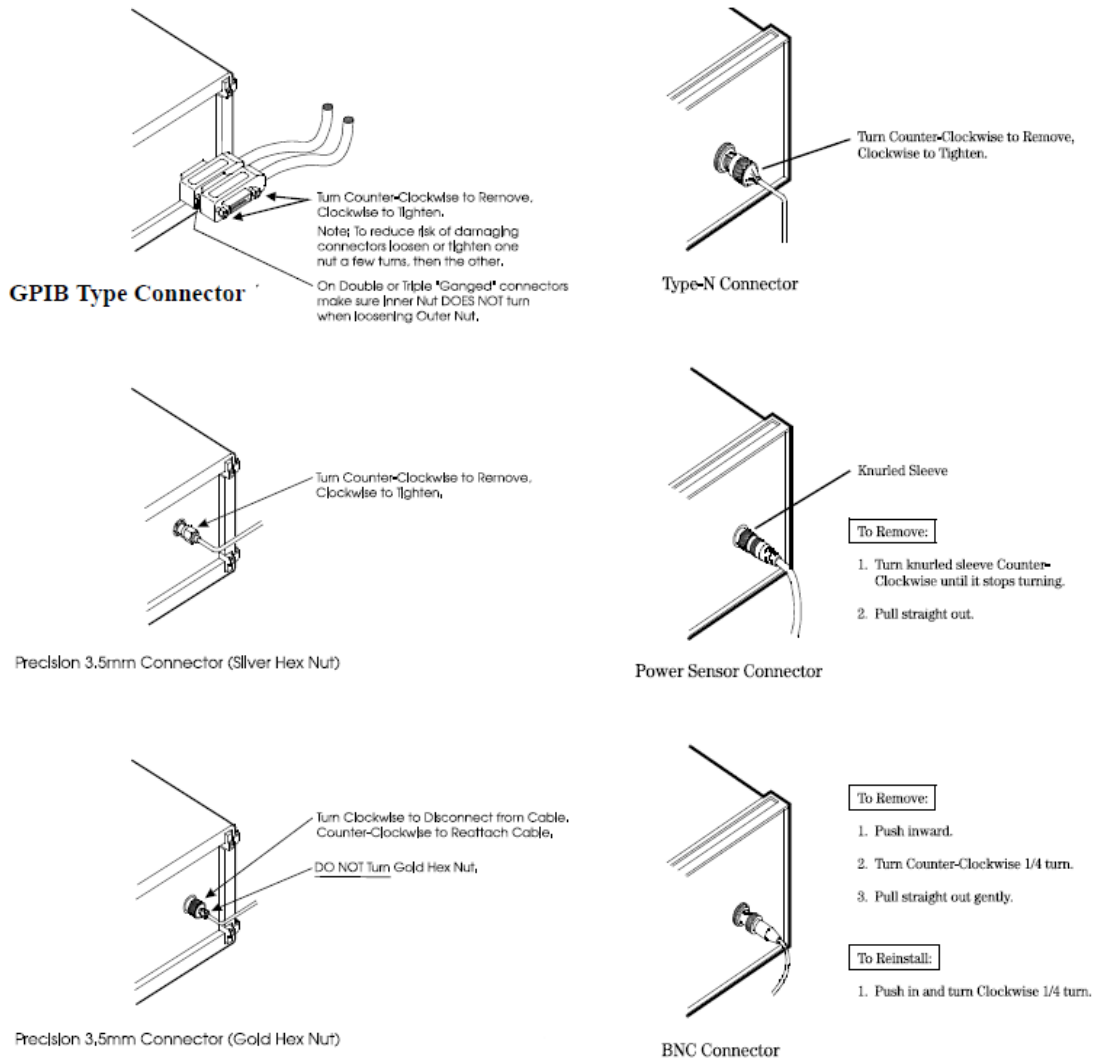
If flammable cleaning materials are used, the material should not be stored, or left open in the area of the equipment. Adequate ventilation should be assured to prevent the combustion of fumes, or vapors.

General Procedures and Techniques

This section introduces you to the various cable and connector types used in the system. Read this section before attempting to remove or install an instrument! Each connector type may have unique considerations.

Always use care when working with system cables and instruments.

Figure 19-1 GPIB, 3.5 mm, Type-N, power sensor, and BNC connectors



Connector Removal

GPIB Connectors

These are removed by two captured screws, one on each end of the connector; these usually can be turned by hand. Use a flathead screwdriver if necessary.

GPIB connectors often are stacked two or three deep. When you are removing multiple GPIB connectors, disconnect each connector one at a time. It is a good practice to connect them back together even if you have not yet replaced the instrument; this avoids confusion, especially if more than one instrument has been removed.

When putting GPIB connectors back on, you must again detach them from one another and put them on one at a time.

Precision 3.5 mm Connectors

These are precision connectors. Always use care when connecting or disconnecting this type of connector. When reconnecting, make sure you align the male connector properly. Carefully join the connectors, being careful not to cross-thread them.

Loosen precision 3.5 mm connectors on flexible cables by turning the connector nut counter-clockwise with a 5/16 inch wrench. Always reconnect using an 8 inch-lb torque wrench (Keysight part number 8720-1765). Semirigid cables are metal tubes, custom-formed for this system from semirigid coax cable stock.

3.5 mm Connectors with a gold hex nut

The semirigid cables that go to the RF outputs of some devices have a gold connector nut. These do not turn. Instead, the RF connector on the instrument has a cylindrical connector body that turns. To disconnect this type of connector, turn the connector body on the instrument clockwise. This action pushes the cable's connector out of the instrument connector.

To reconnect, align the cable with the connector on the instrument. Turn the connector body counterclockwise. You may have to move the cable slightly until alignment is correct for the connectors to mate. When the two connectors are properly aligned, turning the instrument's connector body will pull in the semirigid cable's connector. Tighten firmly by hand.

3.5 mm connectors with a silver hex nut

All other semirigid cable connectors use a silver-colored nut that can be turned. To remove this type of connector, turn the silver nut counter-clockwise with a 5/16 inch wrench.

When reconnecting this type of cable:

- Carefully insert the male connector center pin into the female connector. (Make sure the cable is aligned with the instrument connector properly before joining them.)
- Turn the silver nut clockwise by hand until it is snug, then tighten with an 8 inch-lb torque wrench (part number 8720-1765).

Bent Semirigid Cables

Semirigid cables are not intended to be bent outside of the factory. An accidental bend that is slight or gradual may be straightened carefully by hand. Semirigid cables that are crimped will affect system performance and must be replaced. Do not attempt to straighten a crimped semirigid cable.

Instrument Removal

To remove an instrument from the system, use one of the following procedures.

Required tools:

- #2 Phillips screwdriver
- #2 POZIDRIV screwdriver

Standard instrument

Table 19-3 To remove an instrument from a rack

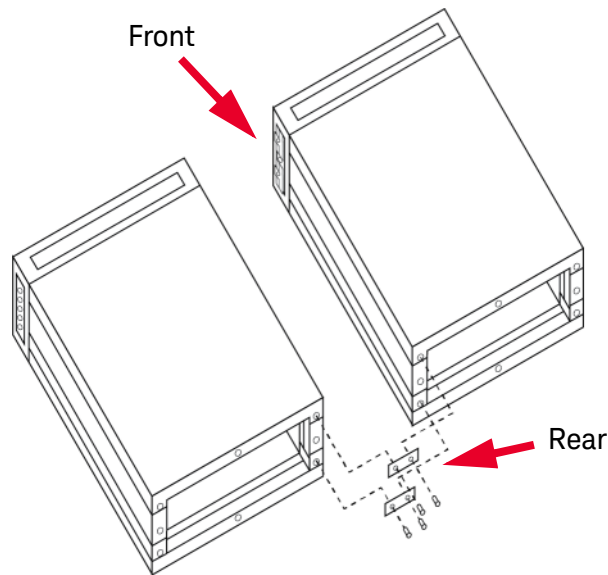
Step	Notes
1. Turn off system power, but leave the system computer turned on.	If you do plan to turn computer power off for any reason, have the computer system administrator: Shut down all running software. Shut down the computer.
2. Read “General Procedures and Techniques”, then disconnect all cables on the front and on the rear panel.	Most cables are fairly easy to remove and reconnect, and have no special considerations (besides making sure you put the cables back in the right place). Semirigid cables require more care, especially when reconnecting them. Make sure all semirigid cables, on the front and back of an instrument are fully disconnected before removing the unit.
3. When all cables are disconnected (including the power cord), remove the screws in the instrument’s rack “ears” that hold it in the rack.	
4. Slide the instrument out.	If you feel any resistance when attempting to pull the instrument out, STOP! Look inside the cabinet and carefully examine all surrounding cables. Make sure all cables are fully disconnected.

Half-Rack-Width Instrument

Table 19-4 To remove a half-width instrument from a system rack

Step	Notes
1. Power off the system.	For details see the system installation guide.
2. Remove the selected instrument's power cord from the power strip in the rack.	
3. The instrument is attached to the half-rack width instrument beside it; remove that instrument's power cord from the power strip also.	The instruments are secured together by lock links at the front and rear. The lock links at the rear attach with screws. The lock links at the front hook together.
4. Remove the power cord and other cables from the front and rear of both instruments.	Note the location of cables for re-installation.
5. Remove the four corner screws on the front of the rack panel that secures the instruments in place.	The screws are located near the corners of the face of the instrument. Use a #2 Phillips screwdriver.
6. Slide both instruments, as a single unit, out from the front of the rack and set them on a secure, flat surface.	
7. Detach the lock links that secure the rear of the instruments together by removing their screws.	Use a #2 POZIDRIV screwdriver. See Figure 19-2 .
8. Carefully and at the same time, push one instrument forward and pull the other back to unhook the lock links that secure the front of the instruments to each other.	
9. Store the "partner" instrument and lock links while the selected instrument is out of the rack.	Only install the instruments as a pair; individual installation is not secure.

Figure 19-2 Instrument lock links, front and rear



Benchtop Instrument

Table 19-5 To remove an instrument from a benchtop system

Step	Notes
1. Power off each instrument in the system.	
2. Unplug the selected instrument's power cord from the AC power supply.	
3. Remove the power cord and other cables from the front and rear of the instrument.	Note the location of cables for re-installation.

Instrument Installation

To install or re-install an instrument in a system, use one of the following procedures.

Required Tools

- #2 Phillips screwdriver
- #2 POZIDRIV screwdriver
- system installation guide

Standard rack instrument

Table 19-6 To install an instrument

Step	Notes
1. Slide the instrument gently into the rack.	
2. Insert the screws in the rack ears.	<p>Most cables are fairly easy to remove and reconnect and have no special considerations (besides making sure you put the cables back in the right place).</p> <p>Semirigid cables require more care, especially when reconnecting them. Make sure all semirigid cables, on the front and back of an instrument are fully disconnected before removing the unit.</p>
3. To reconnect the semirigid cables, carefully align them before you insert the male connector.	<p>Do not insert the male pin in at an angle or you will damage the female connector. RF connector center pins are very delicate, and if damaged must be replaced. System performance may be greatly impaired if there is a bad RF connector.</p>
4. Turn on system power and restart the system computer if necessary.	

Half-Rack-Width instrument

Table 19-7 To install the instrument in a rack

Step	Notes
1. Make sure the system is powered off.	
2. Re-attach the lock link that secures the front of the returned instrument to it's partner half-rack-width instrument.	Use a #2 POZIDRIV screwdriver. See Figure 19-2 .
3. Re-attach the lock link that secures the rear of the instruments together.	Use a #2 POZIDRIV screwdriver.
4. Insert the attached instruments in the same slot from which you removed them, sliding them along the support rails until they meet the rack-mount ears.	The rack-mount ears stop the instruments at the correct depth.
5. Replace the rack panel in front of the instruments and secure the four corner screws.	The screws are located near the corners of the face of the instrument. Use a #2 Phillips screwdriver.
6. Confirm that the instrument is turned off.	
7. Connect the appropriate cables to the instruments (front and rear), including the power cords.	
8. Power on the system.	

Benchtop instrument

Table 19-8 To install an instrument in a benchtop system

Step	Notes
1. Make sure the system is powered off.	
2. Connect all cables to the instrument (front and rear), including the power cord.	
3. Connect the power cord to the AC power source.	
4. Power on the system.	
5. Set the instrument GPIB address, if necessary.	

