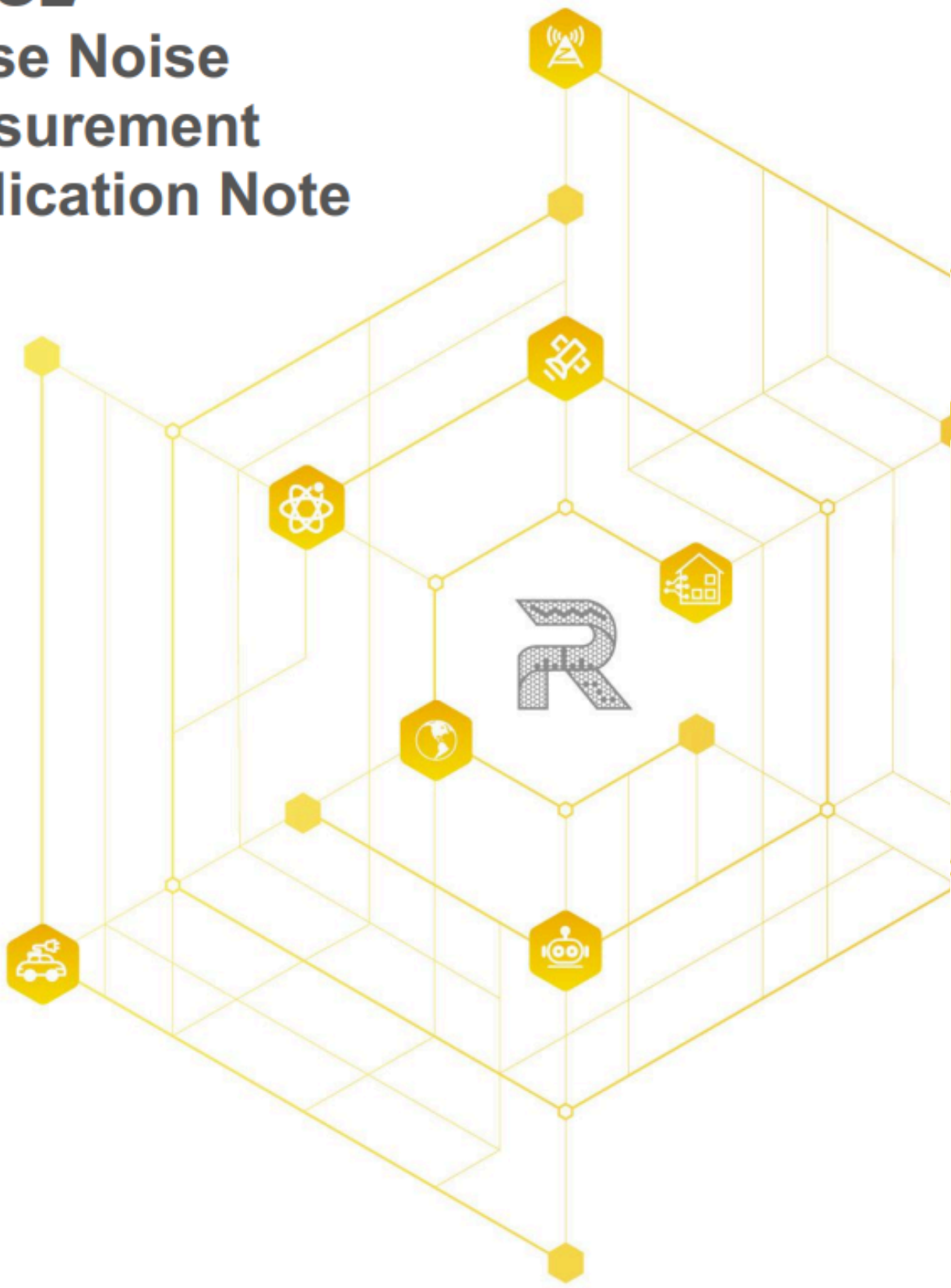
RIGOL
Phase Noise Measurement Application Note



ANW01000-1220-0048

1 Document description

1.1 Content in this guide

The purpose of this application guide is to describe the following:

- Explain the safety precautions when using the RSA6000 series spectrum analyzers for phase noise measurements
- Introduce the basic concepts and measurement principles of phase noise
- Explain the method of automated phase noise measurements using the RSA6000 PNOISE (Phase Noise Measurement) option
- Describe the key parameters that affect measurement accuracy and their optimization strategies
- Demonstrate the complete test process and interpretation of results through typical scenarios

1.2 Applicable instrument and software version

Category	Product information
Spectrum analyzers	RSA6000 series real-time spectrum analyzers
Analysis software options	Phase Noise Option (PMA)
Downloader software version	Refer to the software installation package release notes
Instrument firmware version	Refer to the firmware release notes in the corresponding product manual

Note: Before using this software option, make sure that the instrument has correctly activated the corresponding authorization. Please refer to the RSA6000 product brochure or visit the RIGOL website for information on how to activate the license.

2 Introduction to phase noise measurement

Phase noise is the core indicator of short-term frequency stability of the characterization oscillator, frequency synthesizer and signal source, directly affecting the error rate of the communication system, detection sensitivity of the radar, and clock jitter of the high-speed digital system.

With the PNOISE (Phase Noise Measurement) feature of the RSA6000 Series Spectrum Analyzers, the following objectives are achieved:

- Automated measurement of the SSB phase noise L(f) curve (logarithmic coordinates), covering a typical offset range of 100 Hz to 10 MHz
- Get a bias-free noise estimate on average with RMS power domains
- Extend the dynamic range of measurements by subtracting the spectrometer's own background with noise cancellation
- Automatically identifies and displays stray signals
- Calculates integral noise parameters (residual phase modulation, frequency modulation, jitter) within specified bandwidth

3 Description of the phase noise measurement software functions

The RSA6000 series of real-time spectrum analyzers from RIGOL, equipped with the PNOISE phase noise measurement option (RSA6000-PNM), enable users to efficiently analyze phase noise characteristics of oscillators, PLL frequency synthesizers and signal sources. This option offers complete capabilities such as automated scanning, smoothing, noise cancellation, stray detection and integration.

To ensure that the user can perform the test smoothly, the instrument provides an intuitive operator interface and a complete display of the measurement results for phase noise measurements.

3.1 Introduction to how it works

The function uses the **Direct Spectrum Method** for phase noise measurements.

Noise power is measured at different frequencies off the carrier, normalized to 1 Hz bandwidth and SSB phase noise is calculated:

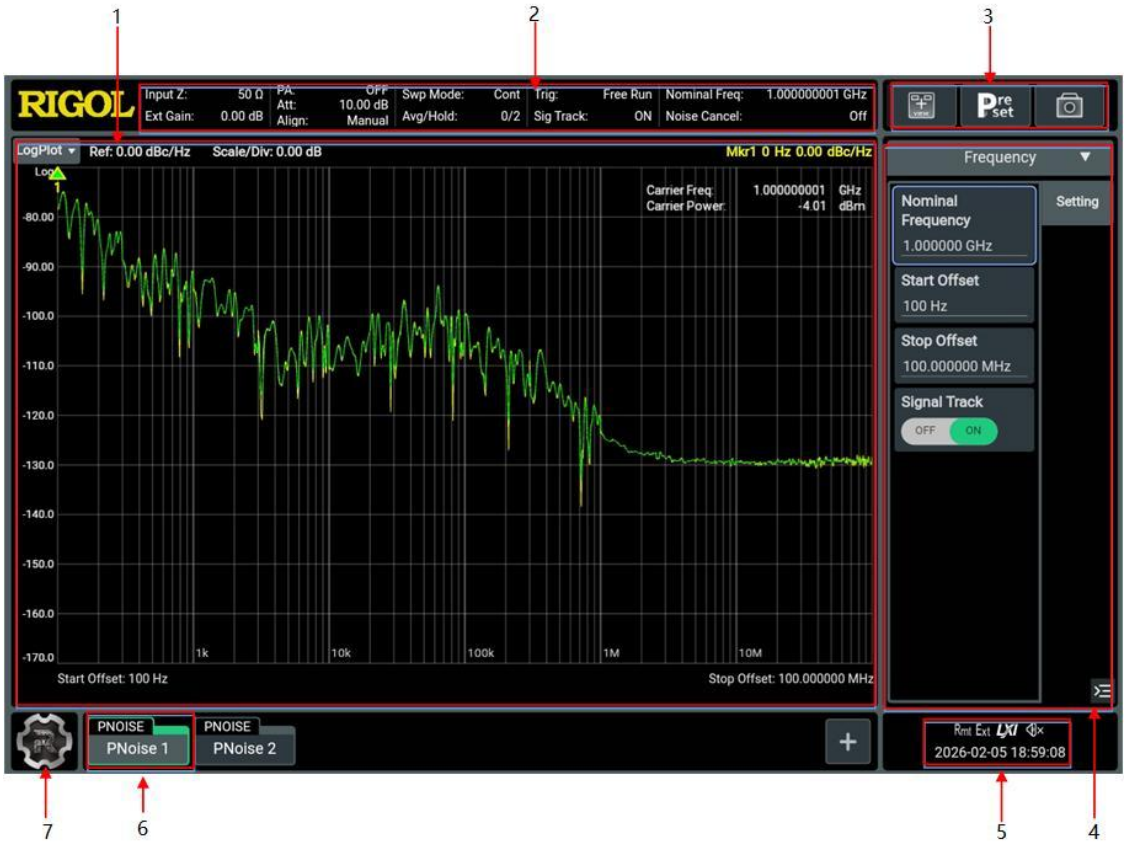
$$L(f_m) = P_n(f_m, 1\text{Hz}) - P_c$$

Where P_n is the noise power $\left(\frac{\text{dBm}}{\text{Hz}}\right)$ within 1 Hz bandwidth and P_c is the carrier power (dBm).

The PNOISE mode does the following automatically:

- Automatically selects the appropriate resolution bandwidth in different offset frequency bands (RBW)
- Normalization of noise bandwidth and filter shape factor correction is done automatically
- Splice each band data into a complete $L(f)$curve
- Improve the readability of measurements with smoothing algorithms and stray recognition

3.2 Feature configuration



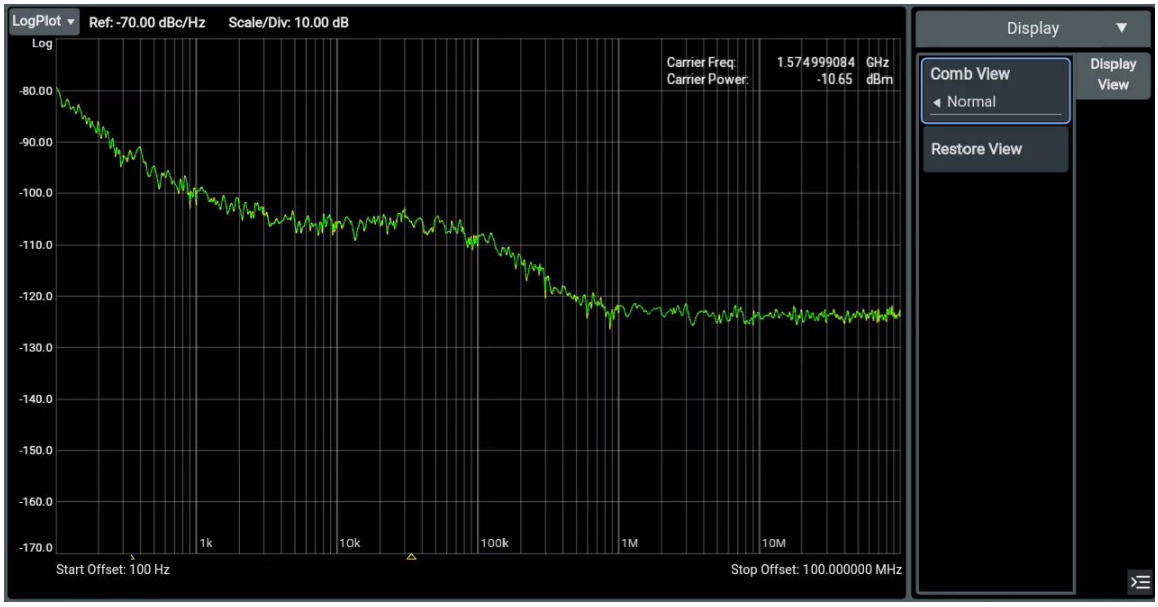
Number	Name	Description
1	Window display area	Displays different views.
2	Status display bar	Displays nominal frequency, noise cancellation, scan pattern, trigger measurements, and more.
3	Frequently used shortcut menus	Displays frequently used shortcut menus
4	Menu control area	You can set parameters of the measurement menu such as measurement settings, frequency, scan, trace, Display, Cursor, etc.
5	Notification area	Displays the USB drive icon, the LAN interface connection icon, the sound icon, the remote control icon, and the time. Tap this area to open the System Setup menu.
6	Operating mode	Displays the currently selected operating mode such as GPSA, RTSA, VSA, EMI, ADM, PNOISE, etc.
7	Feature navigation	Tap the icon to open the function navigation menu, and in the function navigation menu, tap the individual function keys to enter the function menu for function configuration. 

The PNOISE mode supports the following combinations of views:

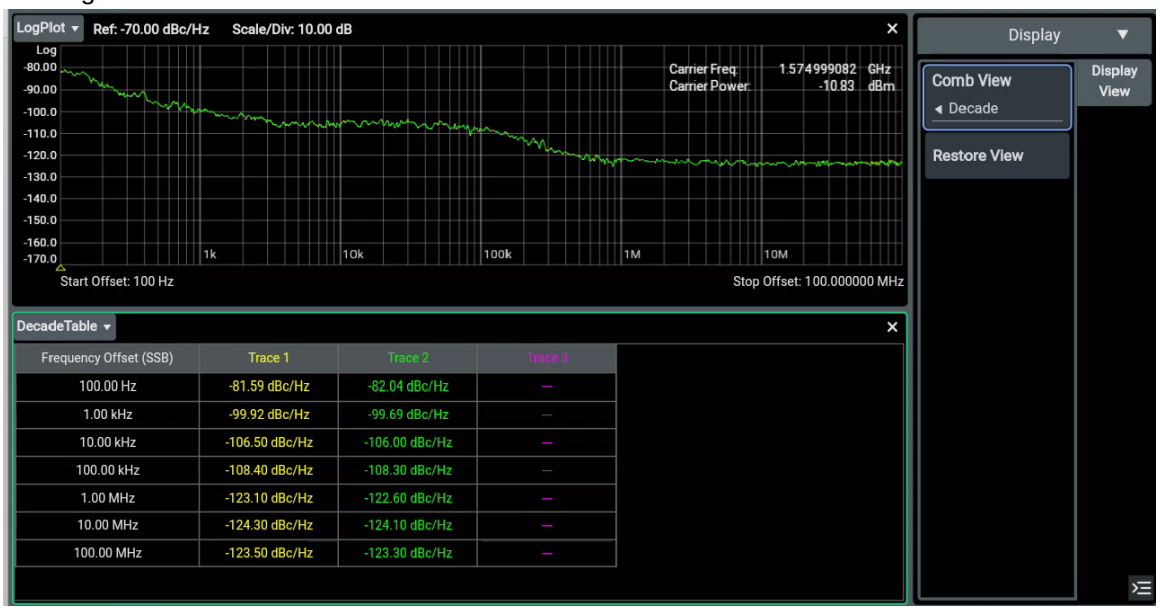
View type	Description
General view	Logarithmic view only, showing the $L(f)$ ~offset frequency curve
Ten-fold range view	Logarithmic View + Decimal Frequency Range Table showing values per 10 octave range boundary
Stray view	Logarithmic View + Stray Table, a list of all identified stray signals

Supports simultaneous display of up to 3 traces: Raw trace (Raw), smooth trace (Smooth), and reference trace (for noise cancellation).

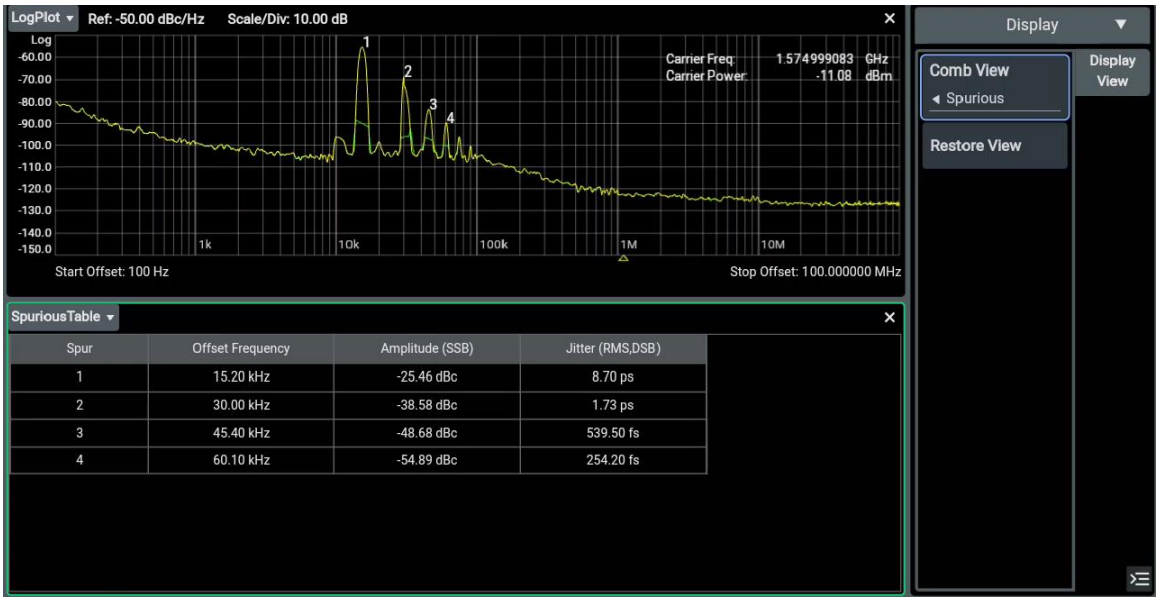
General view:



Ten-fold range view:



Stray view:



4 Pre-test preparation

4.1 Option confirmation

The PNOISE phase noise measurement feature requires the installation of option RSA6000-PNM. Please confirm before use:

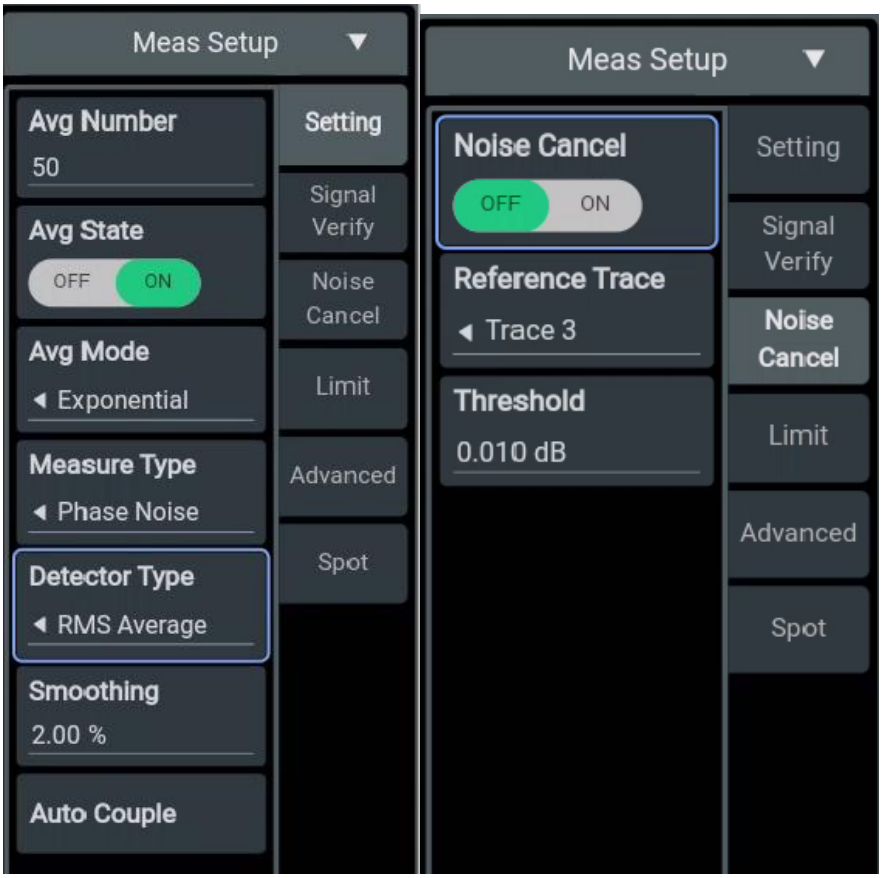
1 Option has been successfully purchased and an authorization code has been obtained
2 Option installation has been completed via SCPI commands or the Instrument menu
3 Verify that "RSA6000-PNM" is displayed in the System → Options list

4.2 Instrument configuration

Configuration item	Recommended configuration	Description
Warm-up time	≥ 60 minutes	The present vibration and OCXO achieve thermal stability
Self Calibration	Weekly/temperature change > 5°C.	Amplitude accuracy guaranteed
Attenuator	Automatic	Automatically optimizes the signal-to-noise ratio
Preamplifier	On demand	On with weak signal (gain ~20 dB)
Reference level	DUT power + 5 dB	Y axis reference value

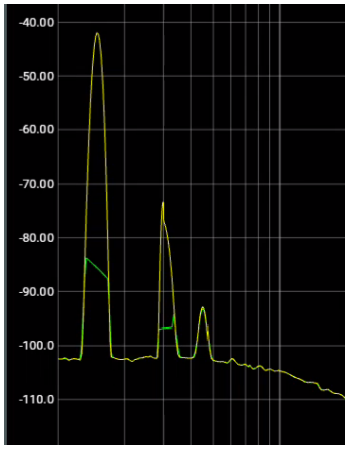
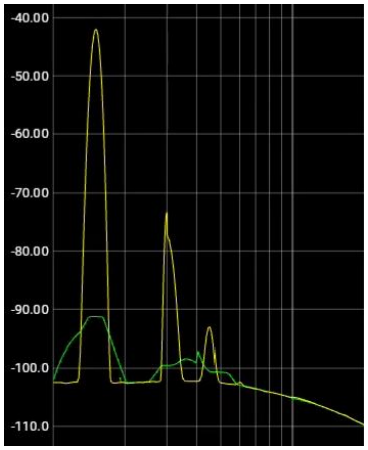
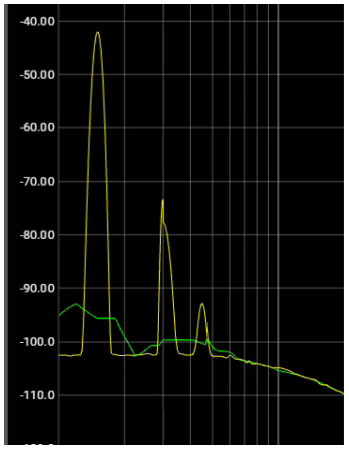
4.3 Key measurement recommendations

Parameters	Precision measurement	Quick assessment	Description
Average number of times	50	10	PNOISE defaults to 10
Type of detector	RMS Average	Average voltage	RMS is an unbiased estimate of the power domain
Smoothing percentage	2%	2%	PNOISE default
Noise cancellation	It is recommended to turn on	Close	Used to deduct the base of the spectrometer



RMS is averaged in the power domain and is a standard practice for phase noise measurements. The average voltage produces a system deviation of approximately 1.05 dB, and the logarithmic average produces a deviation of approximately 2.51 dB. **It is recommended to switch to RMS mean for precision measurements**.

Contrast the effect of percent smoothing on the trace (2%, 30%, 50%)

Smoothing percentage 2%	Smoothing percentage 30%	Smoothing percentage 50%
		

5 Typical application testing

This document describes the following 3 phase noise test scenarios. The required test tools are as follows:

Test the equipment	Description
Spectrum analyzers	Supports PNOISE function, recommended RSA6000 series (RSA6085/RSA6140/RSA6265)
RF cable	High quality coaxial cable, SMA or N-type connector
Signal source (optional)	Reference source for known phase noise characteristics for system verification

5.1 PLL frequency synthesizer phase noise evaluation

Analyze phase noise characteristics of general purpose RF signal sources for performance evaluation of oscillators, signal generators, etc.

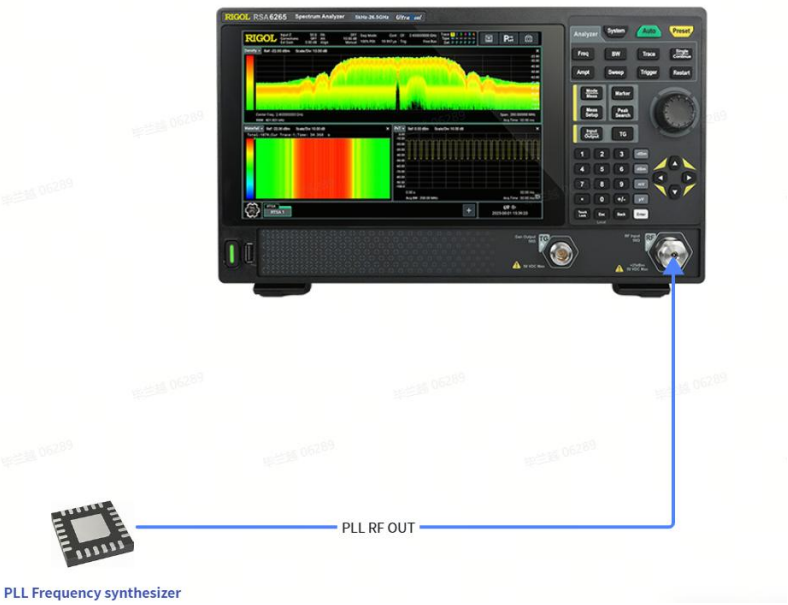
5.1.1 PLL phase noise composition

PLL output phase noise is superimposed by three parts:

- Reference source noise (low pass characteristic): Multiply the loop bandwidth by the split ratio N to dominate the in-band noise.
- VCO Free Oscillation Noise (High-Pass feature): Dominates outside of loop bandwidth.
- Phaser/charge pump noise: Superimposed in band.

Near the loop bandwidth, the output noise may be slightly higher than VCO free-oscillation noise (noise peak), reflecting the phase margin of PLL.

5.1.2 Test the connection diagram



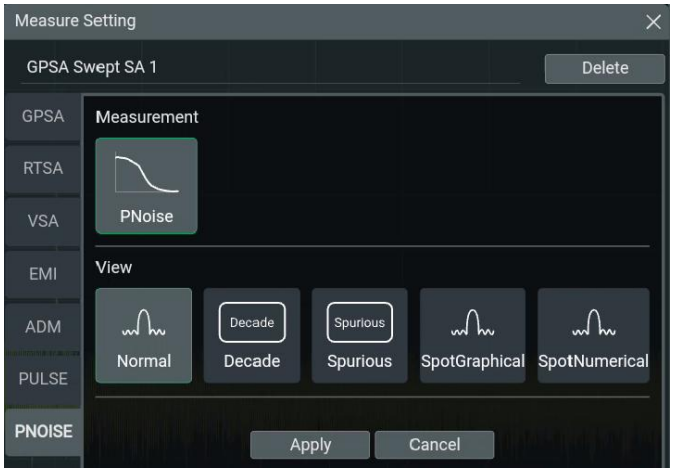
The source of the signal under test (RF Input) RSA6000

5.1.3 Test procedure

1 Verify that the instrument has been warmed up for ≥ 60 minutes.

2 Connect the source under test to the RF Input port of the RSA6000 via a coaxial cable, wired according to the test connection diagram of 6.1.1.

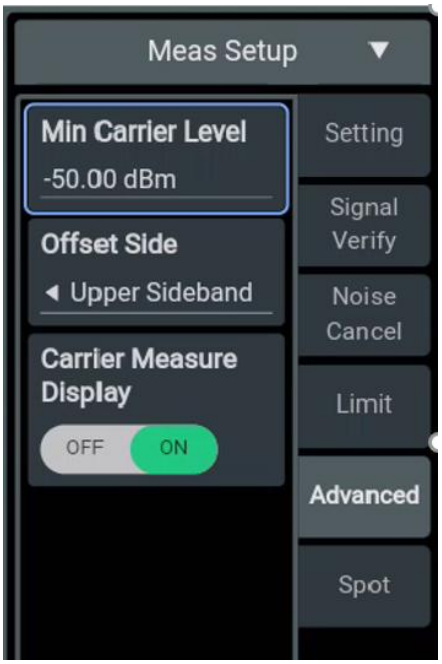
3 Press the Mode key to select PNOISE to enter the phase noise measurement mode.



4 Press the Preset key to restore the PNOISE defaults.

5 Carrier Related Settings: Sets the center frequency to the carrier frequency of the signal being measured (e.g. 1 GHz).

6 Set the minimum carrier level in Measure Setup - Advanced Settings to ensure that the carrier level of the signal being measured is greater than the minimum carrier level.



7 Configured in the measurement settings: Average status = ON, Average number of times = 50, Detector = RMS Average, Smoothing percentage = 2%.

8 To deduct the spectrometer′ s own background, switch the measurement mode to DANL when the input signal carrier is measured, and measure and save the background trace when the averaging is complete. Switch the measurement mode back to PhaseNoise and go to DUT to switch on noise cancellation.

9 Wait for the measurement to complete and read the phase noise value from the smooth trace (Trace 2).

10 Use the cursor or the cursor table to record the L(f) value at each offset frequency

5.1.4 Measurement results

Look at the slope variation of the noise curve near the loop bandwidth (typically 1 kHz to 100 kHz):

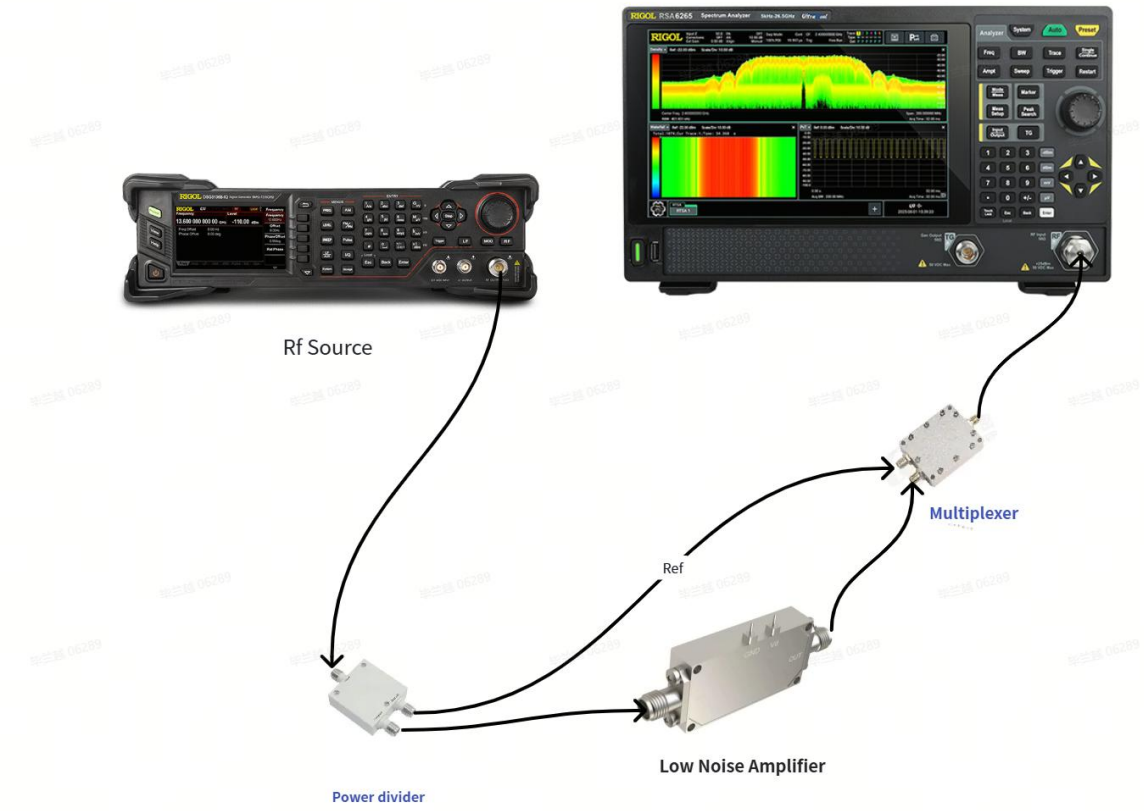
- In Band: Noise is flat

- Near loop bandwidth: Peak onset may occur
- Out-of-band: Noise continuously decreases

5.2 Amplifier additional noise estimate

Evaluate additional phase noise introduced by RF amplifiers for noise performance verification of low noise amplifiers (LNA), drive amplifiers, etc.

5.2.1 Test the connection diagram

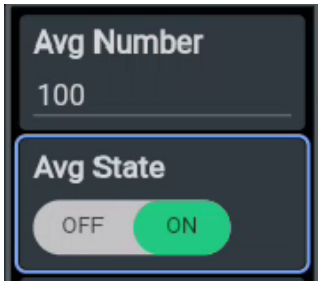


This architecture utilizes the phase of two signals to offset the additional noise of the extraction amplifier. The phase noise of the signal source is related on both paths and is canceled out in the combiner, leaving only non-related noise introduced by the amplifier.

5.2.2 Test procedure

1. Select a source with known phase noise characteristics that is greater than or equal to 10 dB below the expected amplifier additional noise.
2. Build the test system according to the connection diagram to ensure that the two-way cable lengths match.
3. Sets the RSA6000 PNOISE mode to the operating frequency of the amplifier under test. The frequency offset is set to 10~100MHz.

4. It is recommended to use a higher average number (100) and turn on noise cancellation for optimal sensitivity. Noise Cancellation Applications Reference Section 6.1.2 for instructions on noise cancellation.



5.2.3 Test results

Read low frequency bias region at 1 Hz to 10 kHz (or 100 kHz) proximal. The standard scintillation phase noise increases with frequency deviation and decreases at a slope of -10 dB per ten octaves. If the slope becomes steeper, it may mean that the measuring system is not calibrated or there is a slow phase drift/thermal effect.

Read a flat area, typically at over 10MHz,$L(f)_{floor}$ at the far end, determined by the thermal noise and the noise figure (NF) of the amplifier, where the relationship between the measured floor noise and the input power should be:

$$L(f)_{floor} \approx -177\ dBm/Hz + NF - P_{in}$$

6 Summary

6.1 Summary of Phase Noise Measurement Function

The RIGOL RSA6000 series of real-time spectrum analyzers support the PNOISE phase noise measurement function (option RSA6000-PNM), providing engineers with an automated, highly reliable phase noise measurement solution. This feature provides the following benefits:

- **Automated measurements**: One-touch curve scan of$L(f)$ an offset range from 100 Hz to 10 MHz (or wider)
- **Accurate noise estimation**: Bias-free phase noise measurements averaged over RMS power domains
- **Powerful data processing**: Smooth trace, noise cancellation, stray detection, integral noise calculation

Intuitive operator interface: Free combination of logarithmic view, decoupled scale table, stray table multi-view

6.2 Links to related products and resources

To get the latest firmware updates, complete user manuals or for professional technical support, please visit the official RIGOL channel:

- Official website: www.rigol.com
- RSA6000 Product Page: Search the "RSA6000" product flyer, data sheet, and list of the latest options.
- Technical Support & Service: If you have any questions regarding instrument usage or the automated test code (SCPI) writing process, please contact your local RIGOL sales engineer or call the official technical support line.

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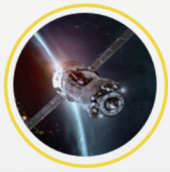

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