

How to Measure Additive (Residual) Phase Noise of Amplifiers

A single-channel additive phase noise measurement of an RF amplifier on the 7000 Series with option APN: the hardware setup, the automated phase detector calibration and quadrature adjustment, and how to read the result against the setup noise floor.

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1 How to Measure Additive (Residual) Phase Noise of Amplifiers

Additive phase noise is the phase noise a component adds to a signal that passes through it, and it is the quantity a system noise budget needs for each two-port stage. This note walks through a single-channel additive phase noise measurement of an RF amplifier on the BNC 7000 Series with option APN, from the hardware setup through calibration to reading the final plot.

[Download the full note \(PDF\)](#)

2 What additive (residual) phase noise is

Additive phase noise, also known as residual phase noise, is the self phase noise of a component that adds to an existing signal as the signal passes through it. Hence, the additive (residual) phase noise measurement is a valuable technique used to identify the phase noise contribution of a single component as part of a system design. This application note focuses on the single-channel additive phase noise measurement of an RF amplifier.

3 Introduction

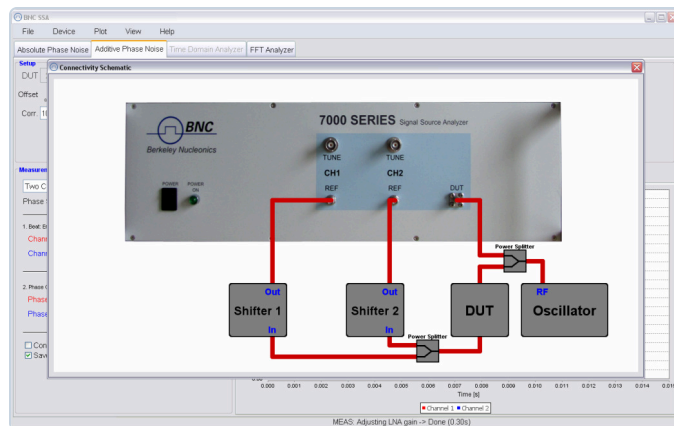
The 7000 Series measures the additive phase noise (also known as residual phase noise) of non-oscillating devices under test (DUT) such as amplifiers, transmitters, mixers or prescalers. The measurement requires option APN; option LO adds access to the internal reference as the stimulus source. The measurement can be made on a single channel, as in this note, and a two-channel cross-correlation measurement reaches the lowest floor.

4 Theory

The single-channel additive phase noise measurement works as shown in the schematic of Figure 1, which is drawn for the two-channel case; the single-channel measurement uses one phase shifter and the REF and DUT inputs of one channel. A stimulus source is set to the desired frequency. The signal is split into two paths. One path is fed into the DUT input and the other path into the REF input. In one signal path a phase shifter is inserted to allow phase adjustments between the REF and DUT ports. The 7000 Series compares the phase of the DUT and REF paths using a low noise phase detector. Using the phase shifter, the two signal paths are set to phase quadrature (90 degrees apart) at the phase detector. It can be shown that under perfect quadrature the correlated noise in the two signal paths (in particular phase noise from the stimulus source) is cancelled out.

Without any DUT, this measurement can be used to determine the setup phase noise floor. Adding the DUT into one signal path will add the DUT's phase noise and will be detected by the phase detector as deviation from quadrature (because it is only appearing in one signal path).

Note that in a single channel measurement, the phase shifter and the DUT can be located in either the DUT or REF signal paths. This gives some additional flexibility in the measurement setup.



SCHEMATIC Figure 1. The two-channel cross-correlation additive phase noise setup as drawn by the GUI connectivity schematic. The stimulus oscillator is split through two power splitters into Shifter 1 and Shifter 2, the DUT, and the REF and DUT inputs of channels 1 and 2 of the 7000 Series.

5 Measurement setup and procedure

Additive noise measurements are made at a lower noise level than absolute phase noise measurements and need careful setup and calibration. The setup is conventional microwave cabling; the calibration is where a manual procedure costs time and introduces error, and the 7000 Series automates it.

The hardware setup is shown in Figure 2. In addition to the 7000 Series, a low phase noise signal source (here a Model 845-20 Signal Generator), a power splitter and an electrically tunable or mechanical phase shifter are required. BNC offers the PS06 (1 to 6 GHz) and PS18 (6 to 18 GHz) mechanical phase shifters as accessories for this measurement.

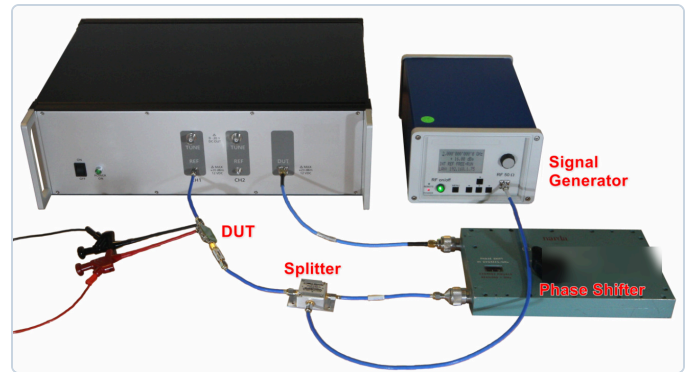


PHOTO Figure 2. The test setup. The 7000 Series analyzer with its CH1 REF, CH2 REF and DUT inputs, the Model 845-20 Signal Generator, a power splitter, a mechanical phase shifter and the DUT amplifier cabled in place.

6 The GUI setup

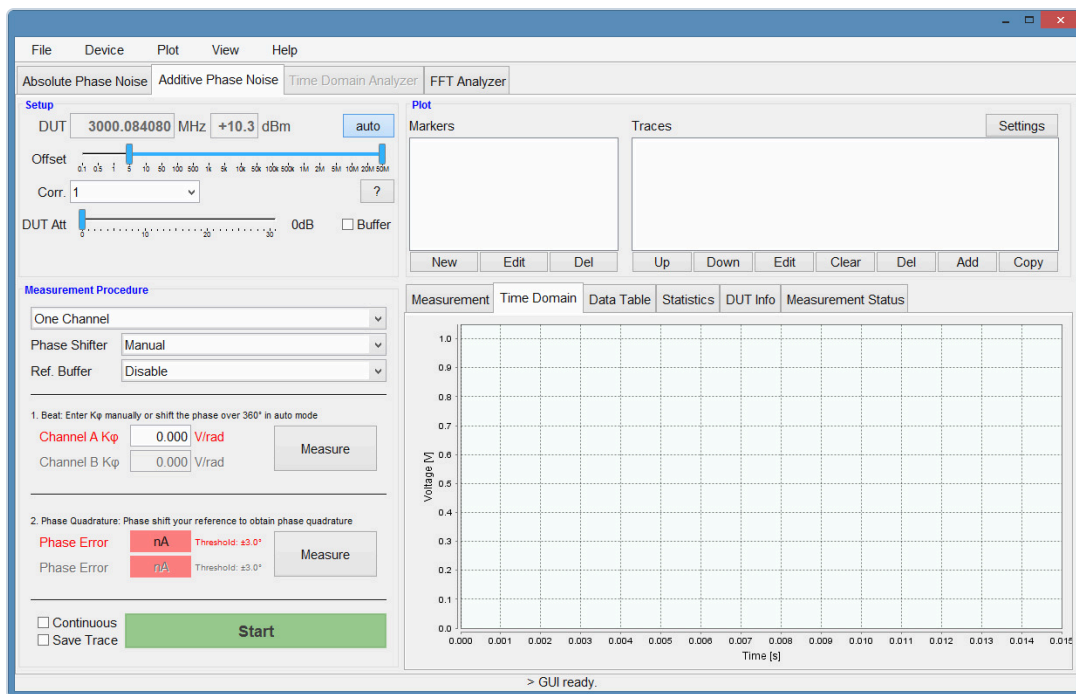
The measurement procedure can be split into two steps:

- **A.** Determine the measurement noise floor
- **B.** Perform the actual measurement on DUT

Determining the setup noise floor (step A) is especially important to ensure that the DUT noise is properly defined and is not influenced by other noise contributors. This step may be omitted if instrument noise floor is already known for the particular setup.

In step B, the DUT is added into one signal path and the measurement is repeated this time including the DUT.

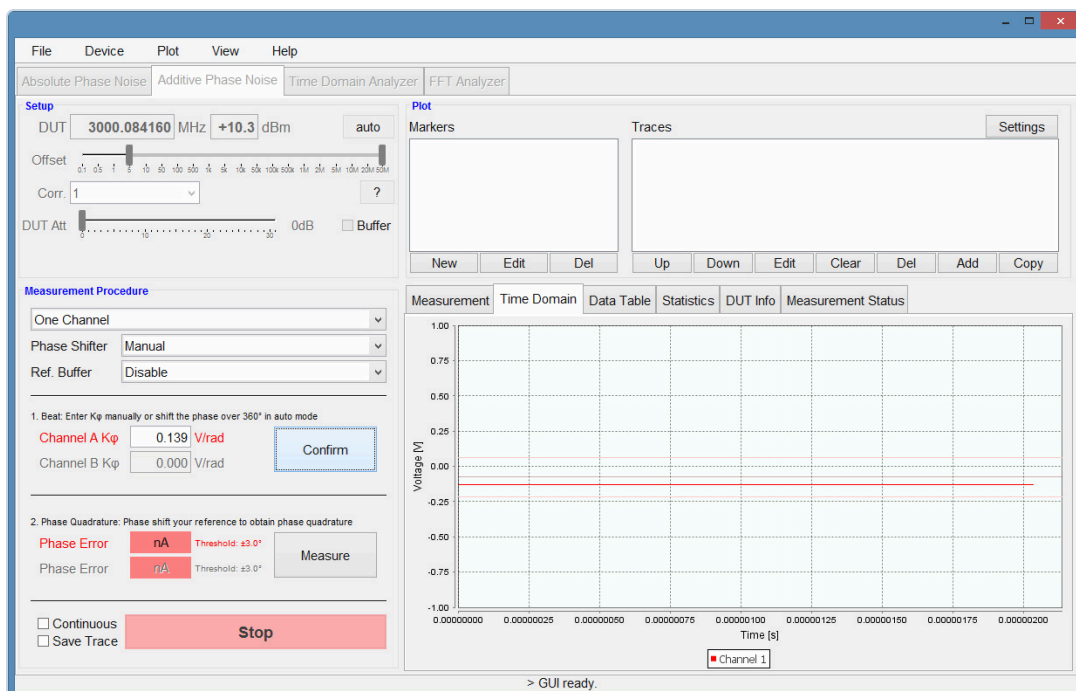
Both steps require a full measurement to be performed; the only difference is that the DUT is replaced with a cable to measure the noise floor.



■ **MEASURED** **Figure 3.** The Additive Phase Noise tab of the GUI before calibration. The setup panel reads DUT 3000.084080 MHz at +10.3 dBm, 1 correlation and 0 dB DUT attenuation; the Measurement Procedure panel has One Channel selected with a manual phase shifter.

After starting the GUI, the connection to the 7000 Series is established and the Additive Phase Noise tab is selected (Figure 3). The next steps are:

1. **Select offset range and number of correlations.** As in the absolute phase noise tab, select offset range and number of correlations. If additional signal attenuation or amplification is desired, then use the input attenuator/low noise amplifier stage.



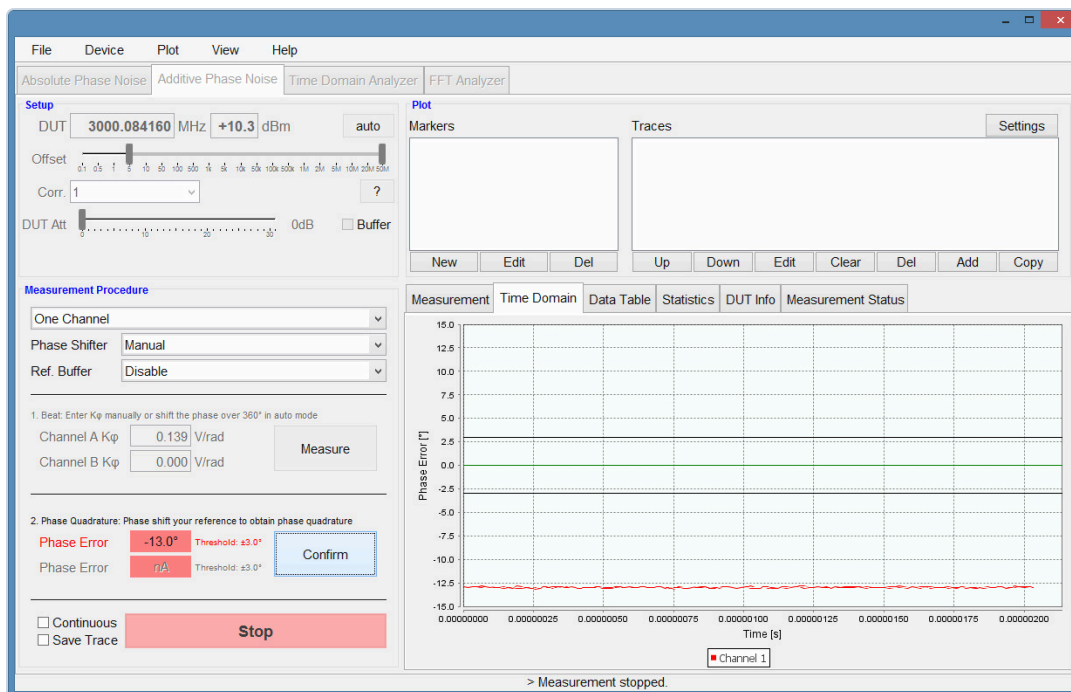
■ **MEASURED** **Figure 4.** Rotating the phase at the phase detector with the phase shifter determines the phase detector constant of the setup. Channel A K ϕ reads 0.139 V/rad and the Confirm button completes the beat calibration step.

Note

Care must be taken, that the DUT and the REF ports are operated at appropriate power levels:

- The **DUT input** accepts +3 to +23 dBm (option APN). Above +10 dBm, adjust the DUT input attenuator. Below +3 dBm, the input low noise amplifier may improve the measurement noise floor.
- The **REF input** should be operated between +13 and +20 dBm. Below +13 dBm the REF input low noise amplifier may be switched in to improve the noise floor.
- It is recommended to adjust the measurement setup if possible before using the buffer or attenuation options. For instance, the DUT can be placed either on the DUT or on the REF side, which changes the power levels at the DUT and REF inputs.
- To measure the input power of the signals, use the DUT input and press the "auto" button to start the frequency and power measurement of the attached signal.

2. **Select the "One Channel" measurement.** The phase shifter can be a manually controlled phase shifter (as in this example) or a voltage controlled phase shifter driven from the 7000 Series tuning port.



- **MEASURED** **Figure 5.** Adjusting to phase quadrature with the phase shifter. The Phase Error field reads -13.0° against a $\pm 3.0^\circ$ threshold before the reference is shifted into quadrature.

3. **Start the calibration.** Once the setup is completed, the calibration procedure is started by clicking on the first "Measure" button. Using the phase shifter, the phase is

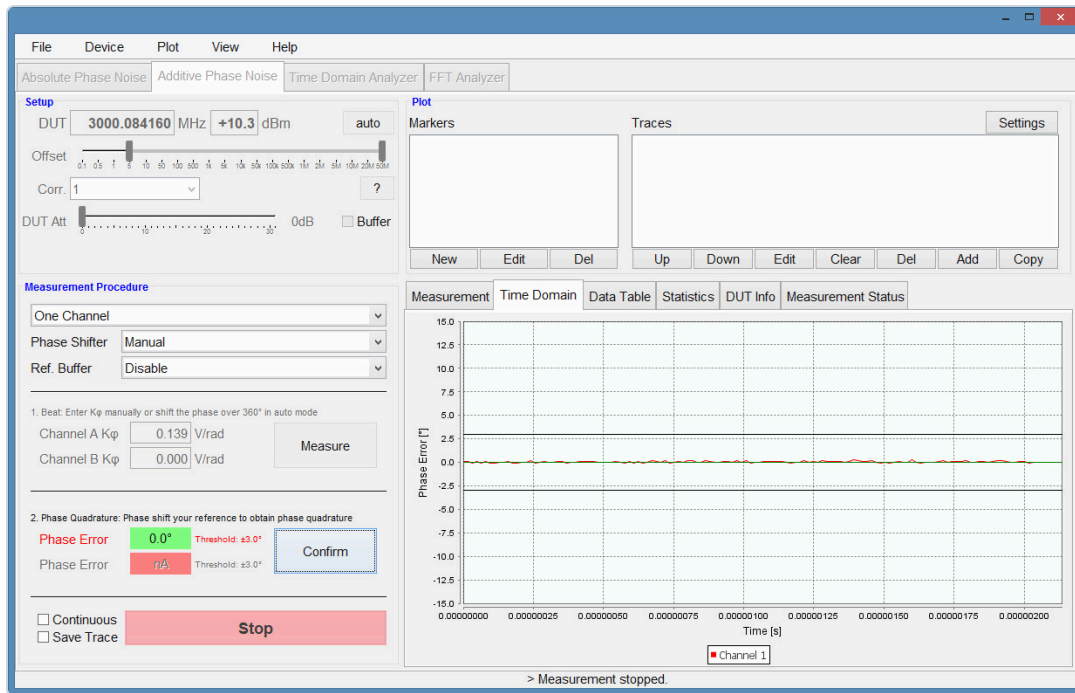
now rotated continuously over 360 degrees to determine the phase detector constant (see Figure 4). Complete

the calibration step by clicking on the corresponding "Confirm" button.

4. **Adjust to quadrature.** In a next step, the signals at the phase detector are adjusted to quadrature (90° phase shifted in respect to each other) using the phase shifter (refer to Figure 5 above and Figure 6 below). Clicking on the second "Measure" button will continuously show the current phase error which has to be reduced to 0° by phase shifting the reference. Once the phase error is

minimized, complete the calibration step by clicking on the second "Confirm" button.

5. **Start the measurement.** Once the phase detector has near quadrature phases and is confirmed by the user, the "Start" button is enabled and the actual measurement can be performed by clicking on the green "Start" button. The GUI will automatically switch to the phase noise plot and show the result after the measurement is finished.

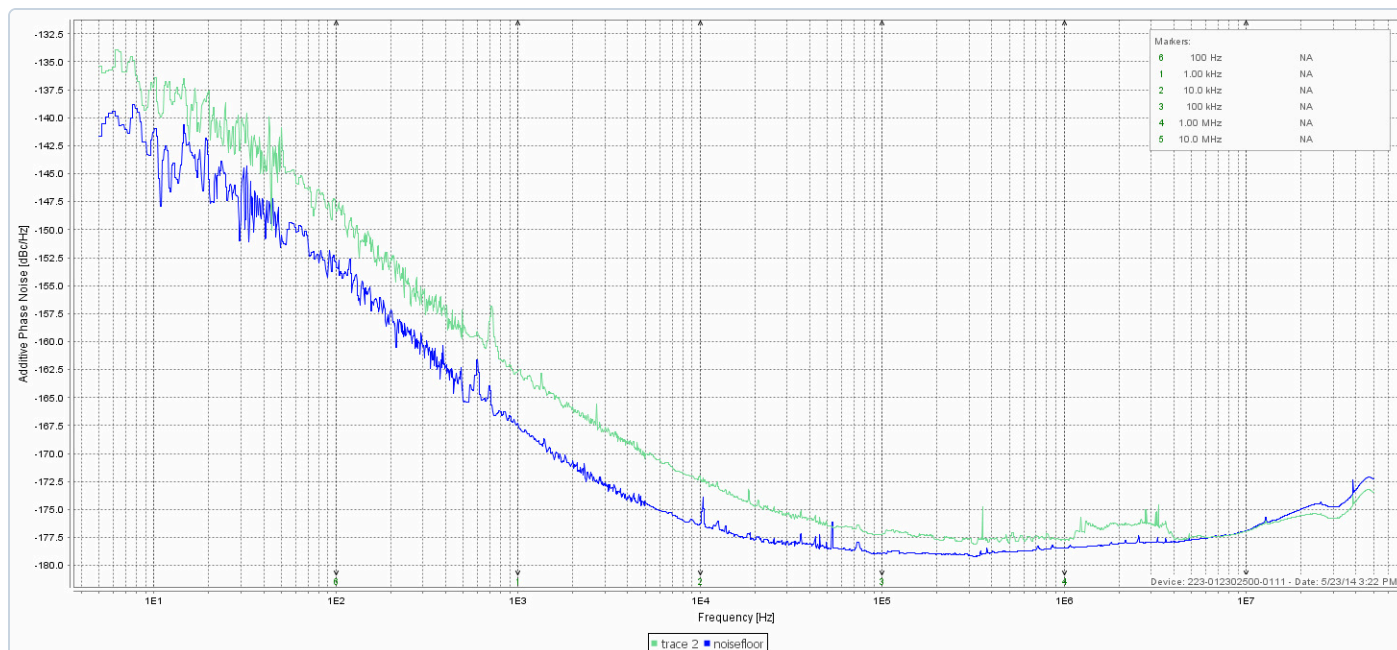


- **MEASURED** **Figure 6.** Quadrature reached within the accepted tolerance. The Phase Error field reads 0.0° (green) against the $\pm 3.0^\circ$ threshold, and the measurement is enabled.

7 Analyzing the result

Figure 7 shows the setup noise floor measured in step A as the blue curve. With a stimulus of +16 dBm at 2 GHz, the setup noise floor is below -175 dBc/Hz for offsets above 10 kHz and below -140 dBc/Hz at 10 Hz offset. Two-channel cross-correlation lowers the floor further by about 5 dB for every tenfold increase in the number of correlations (7000 Series datasheet, additive phase noise sensitivity).

The measurement including the DUT amplifier is shown as the green curve.



■ **MEASURED** **Figure 7.** Additive phase noise in dBc/Hz against offset frequency. The blue trace labeled noise floor is the setup noise floor and the green trace labeled trace 2 is the measurement including the DUT amplifier; the two meet near 4 MHz offset.

For offsets up to 4 MHz the DUT phase noise is above the setup noise floor, so the measurement is dominated by the DUT. At higher offsets the green trace reaches the setup noise floor, and only a cross-correlation measurement can resolve lower levels there.

8 Conclusion

The procedure in this note measures amplifier additive phase noise down to the single-channel setup floor, below -175 dBc/Hz above 10 kHz offset in this example. For lower floors, the setup is duplicated on the second measurement channel and cross-correlation is applied.

9 Talk to an application engineer

If you are budgeting the additive phase noise of an amplifier, mixer, or other two-port device, our engineers can help you match a 7000 Series configuration to your frequency, power, and noise-floor targets. Request a quote or a demo and we will follow up with a setup tailored to your device under test. You can also reach us at info@berkeleynucleonics.com or 800-234-7858.

Ask now →

Chat with our assistant and get an answer in seconds.

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