Optimal Low Noise Floors Using External References

How voltage-tunable external reference oscillators lower the close-to-carrier floor of the 7000 Series and shorten a low-noise 10 MHz OCXO measurement from hours of correlations to minutes, with the connections, the supply and tuning calibration in the GUI, and the measured results.

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1 Optimal Low Noise Floors Using External References

Measuring the phase noise of very low noise reference sources can take hours on internal references alone. This note shows how the BNC 7000 Series signal source analyzer (referred to below as the PNT) uses external tunable references to reach lower instrument noise floors close to the carrier while cutting measurement time from hours to minutes.

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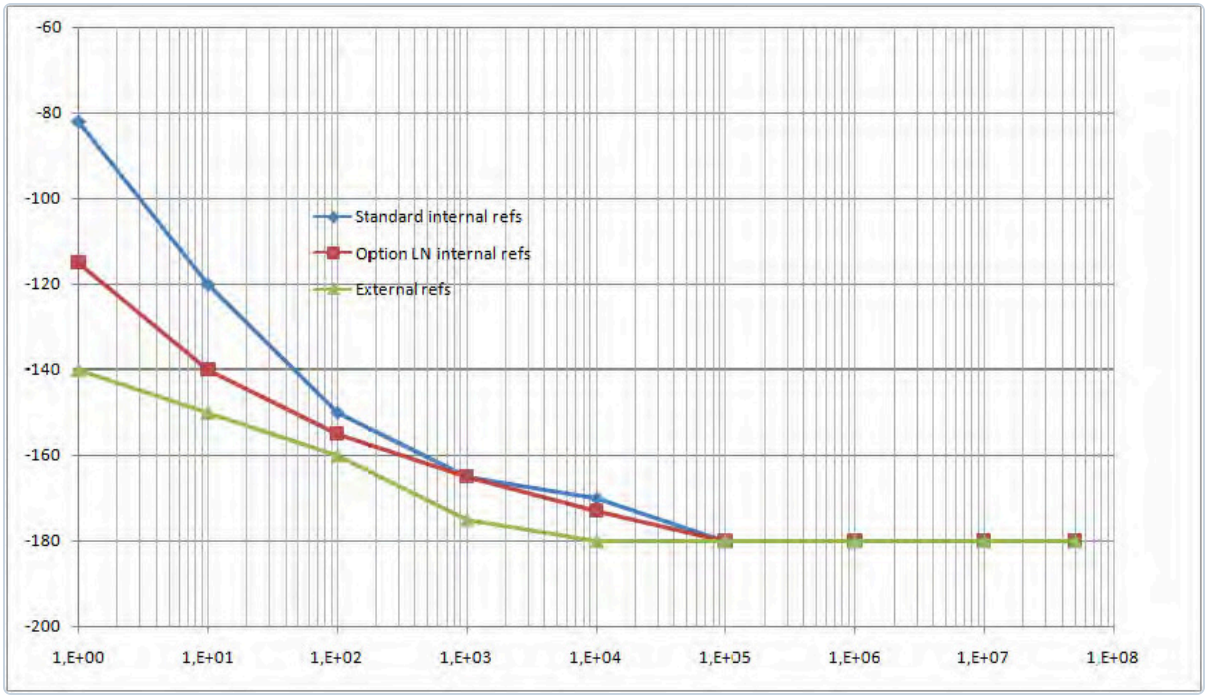
2 Introduction

Using the PNT with the cross-correlator and external references shortens the measurement of ultra-low single sideband (SSB) phase noise of devices under test (DUT). The 7000 Series offers three choices of reference:

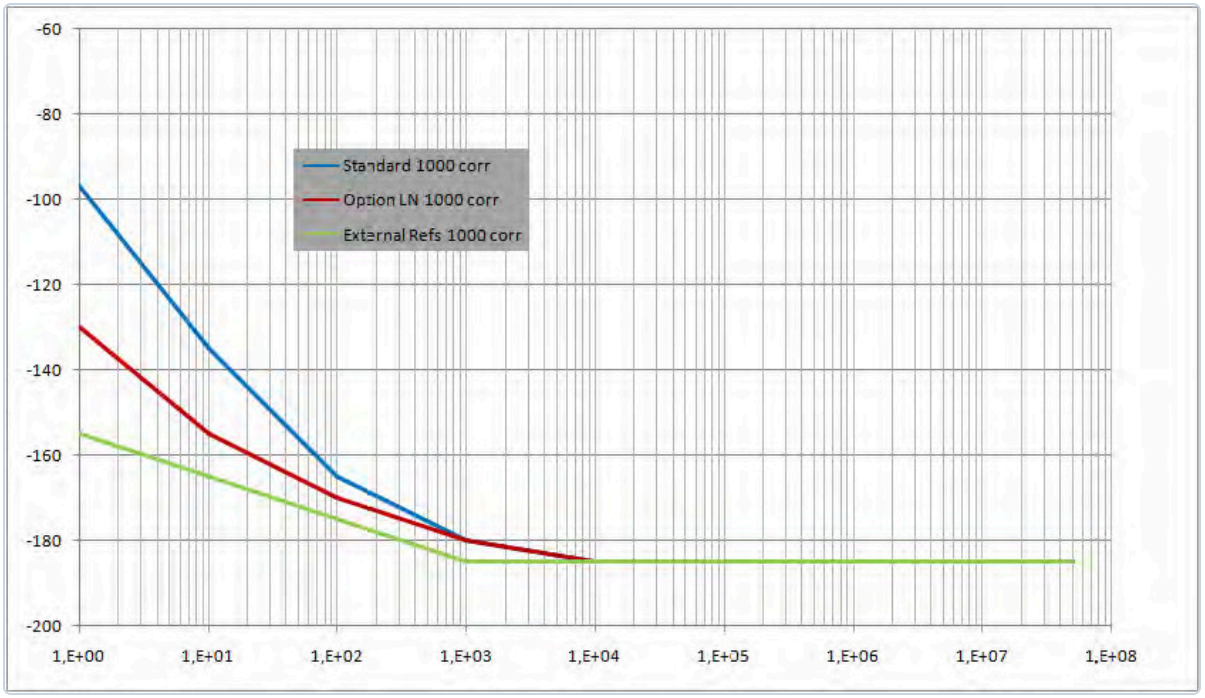
- **Standard internal references**
- **Option LN:** close to carrier ultra low noise internal references
- **Voltage tunable external references**

Figure 1 shows the phase noise sensitivity of the PNT for a single correlation (16 s measurement time) at a 10 MHz DUT frequency. The phase noise sensitivity is the lowest DUT phase noise, at a given offset from the carrier, that can be measured accurately. A DUT with phase noise below the sensitivity needs additional correlations, which lengthen the measurement, or cannot be measured.



DERIVED **Figure 1.** Phase noise sensitivity of the PNT at 10 MHz after 1 correlation (16 s measurement time), plotted from the published sensitivity figures for standard internal references (blue), Option LN internal references (red) and external references (green).

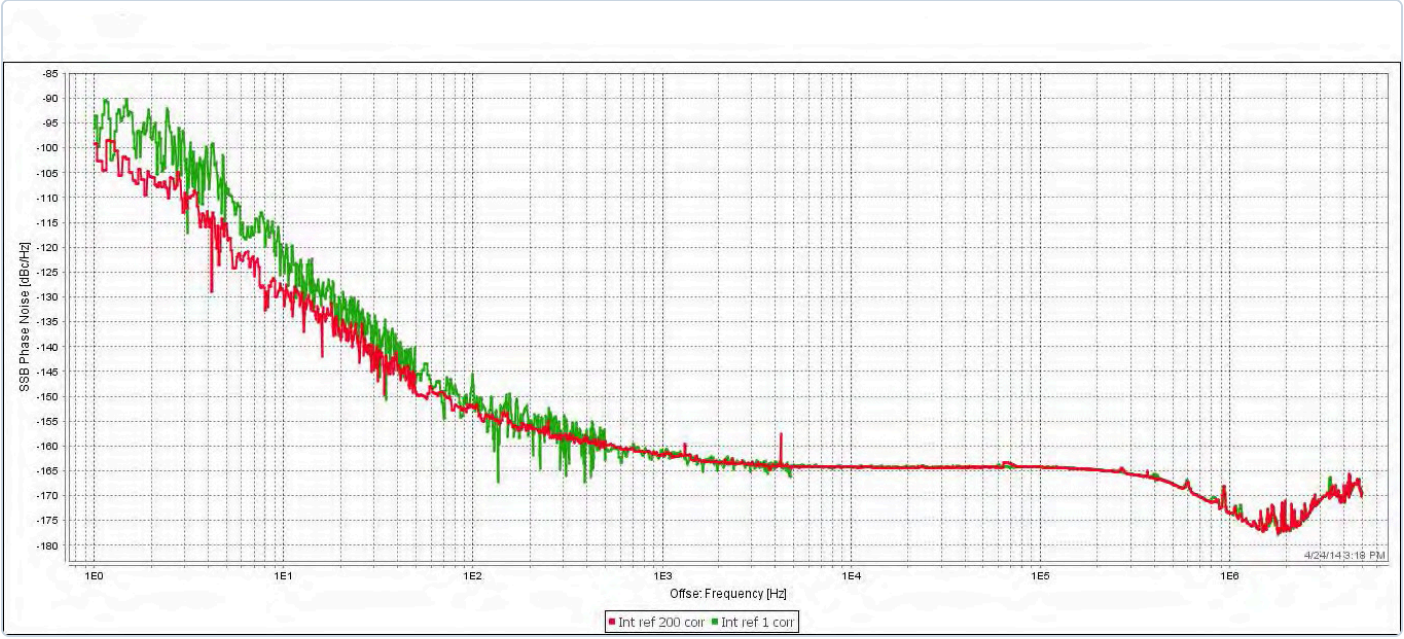
Figure 2 shows the phase noise sensitivity after 1000 correlations, about 4.5 hours of measurement time. In this example a 10 MHz low phase noise OCXO with an expected phase noise of around -105 dBc/Hz at 1 Hz offset is to be measured. Even after 1000 correlations, such a device cannot be measured at 1 Hz offset with the standard internal references.



DERIVED **Figure 2.** Phase noise sensitivity of the PNT at 10 MHz after 1000 correlations (about 4.5 hours), for standard internal references (blue), Option LN internal references (red) and external references (green).

3 The Limitations of Standard Internal References

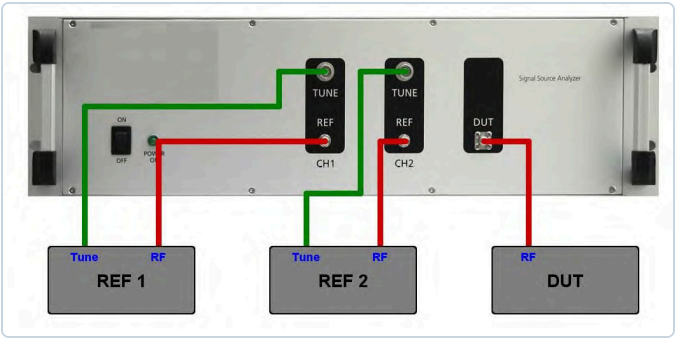
Figure 3 shows the corresponding results after 1 correlation (green trace) and 200 correlations (red trace). For offsets of 100 Hz and above the traces are identical. For offsets below 100 Hz the measurement is limited by the phase noise sensitivity of the PNT with standard internal references. Even after 200 correlations and 90 minutes of measurement time, the 1 Hz offset has not reached the expected value, and further hours of correlations would be needed to obtain the actual result.



MEASURED **Figure 3.** Phase noise of the low-noise 10 MHz OCXO with standard internal references. Green trace: 1 correlation. Red trace: 200 correlations, 90 minutes measurement time.

4 The Measurement Setup Using External References

Alternatively, external references give a substantially lower phase noise sensitivity at low offset frequencies. The block diagram of the measurement setup is shown in Figure 4. Two 10 MHz OCXOs are used as external tunable references. Both references are mounted on through-hole test fixtures and are powered from the two low-noise DC supplies of the PNT. Each reference OCXO output is connected to the REF port of one PNT channel, and each OCXO tuning port to the corresponding TUNE output of the PNT, so the external references are fully controlled (biased and tuned) by the PNT. The DUT signal is fed into the DUT port.



SCHEMATIC **Figure 4.** The connectivity block diagram drawn by the PNT GUI. The REF 1 and REF 2 external OCXOs connect to the TUNE and REF ports of CH1 and CH2, and the DUT connects to the DUT port.

The measurement setup is shown in the photograph of Figure 5.

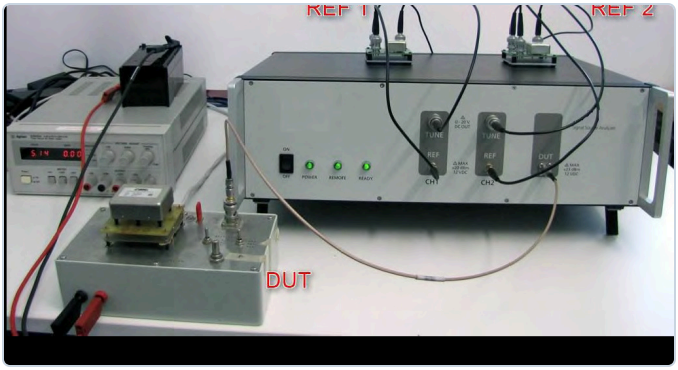
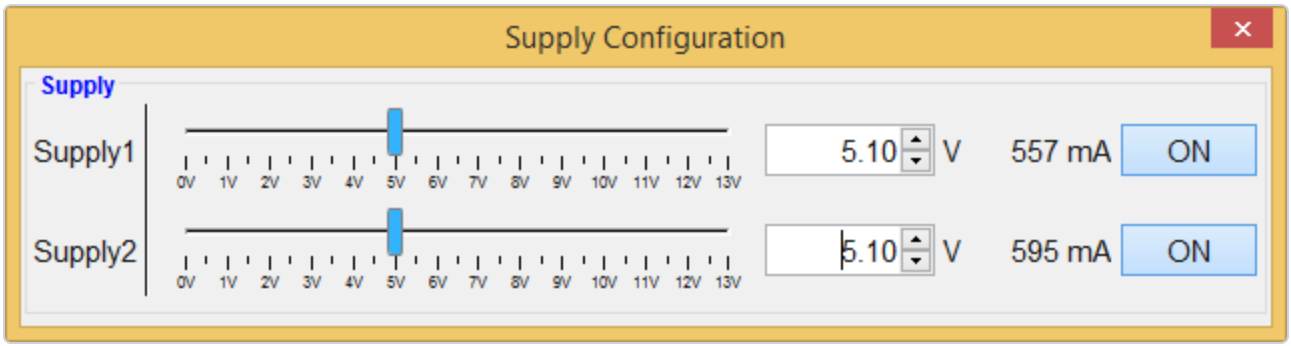


PHOTO **Figure 5.** The measurement setup, with the two reference OCXO fixtures on top of the analyzer, the DUT OCXO in its shielded enclosure, and a bench supply powering the DUT.

5 The GUI Setup

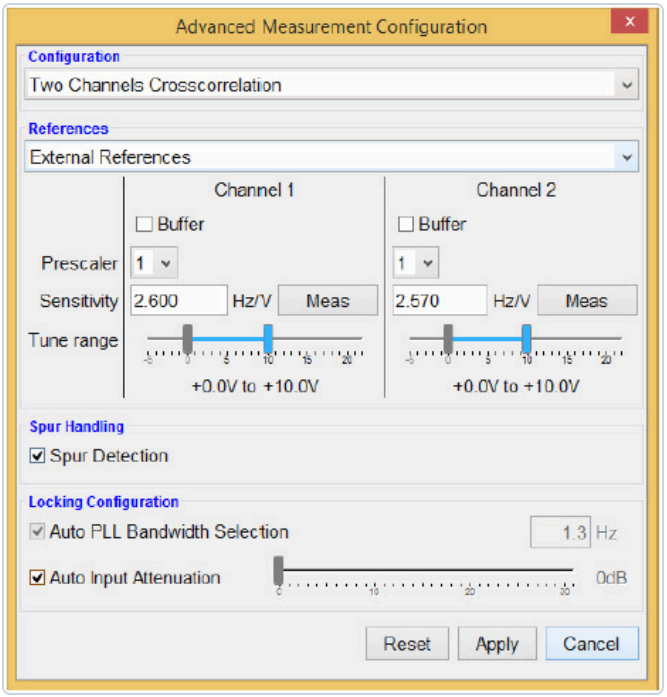
In the PNT GUI, first enable the low-noise internal power supplies if they are to power the external references. In the Supply Configuration menu of Figure 6 both supplies are enabled and set to 5.1 V; during OCXO warm-up the oven heaters draw the readings shown, 557 mA and 595 mA, and the current falls once the ovens reach temperature. The supplies are rated 550 mA per channel. Alternatively, the external references may be powered from external power supplies.



MEASURED **Figure 6.** The Supply Configuration menu with both supplies set to 5.10 V and ON, reading 557 mA and 595 mA during OCXO warm-up.

Next, the external references need a short calibration sequence to determine their tuning constants. In the Advanced Measurement Configuration menu, the tuning voltage range is set for each channel; here a tuning range from 0 to +10 V is used. The Meas button then executes the calibration measurement. In this example the calibration gives tuning sensitivities of 2.60 Hz/V and 2.57 Hz/V on the two channels.

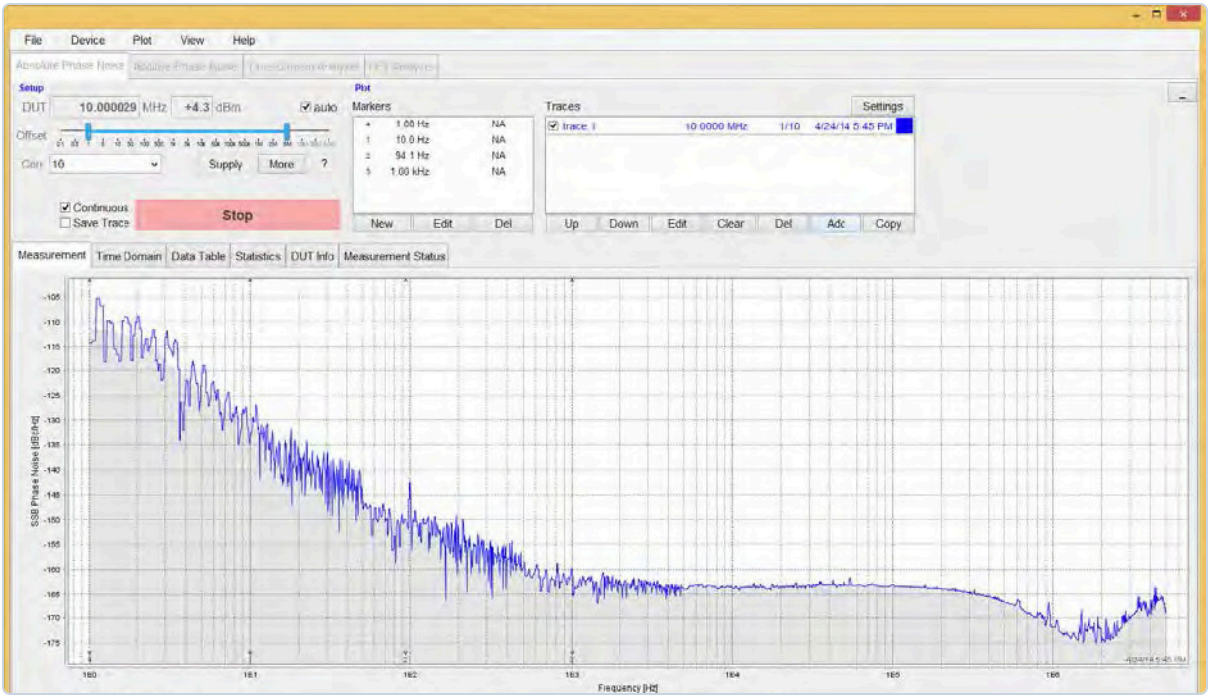
> **Note**
> This calibration must be performed only once during the setup. Only if a reference is replaced, the corresponding calibration step must be repeated.



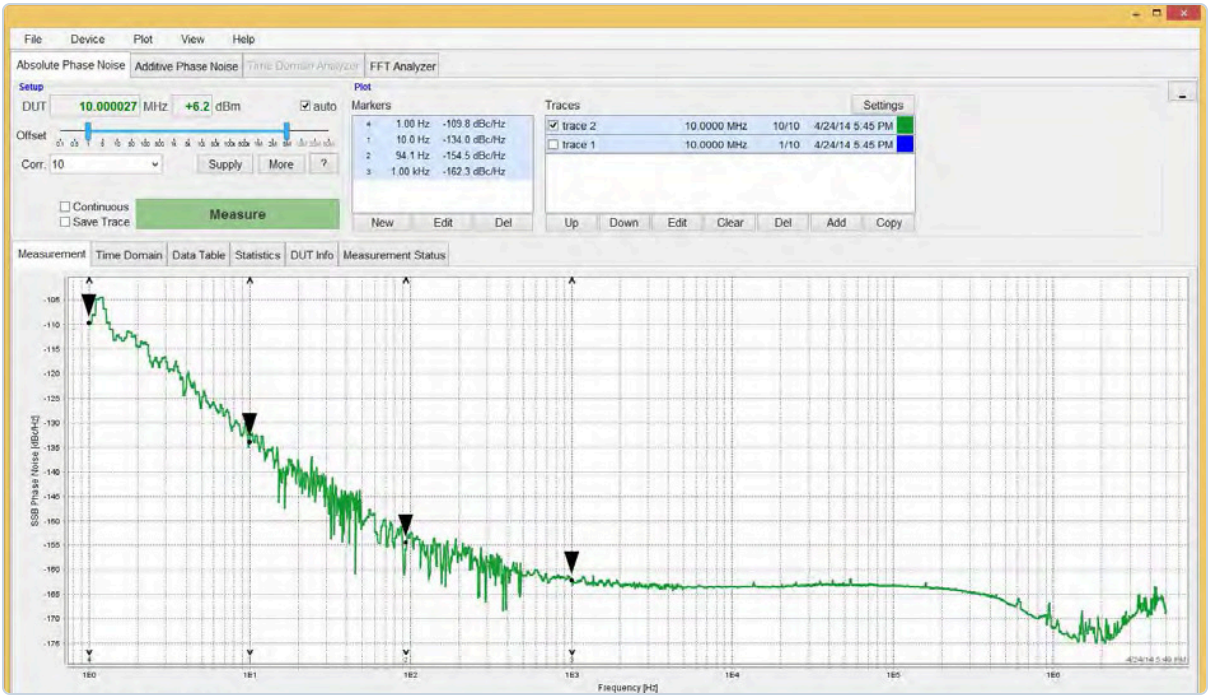
MEASURED **Figure 7.** The Advanced Measurement Configuration menu set to Two Channels Crosscorrelation with External References, tune range +0.0 V to +10.0 V on both channels, and calibrated sensitivities of 2.600 Hz/V and 2.570 Hz/V.

6 The Measurement Results

Once the calibration is complete, a click on the measurement button starts the measurement. In this example the offset range is set from 1.0 Hz to 5.0 MHz with a total of 10 correlations. Figure 8 shows the phase noise trace after the first correlation and Figure 9 the same measurement after 10 correlations. The results after 1 and 10 correlations agree closely; the longer measurement averages the trace.

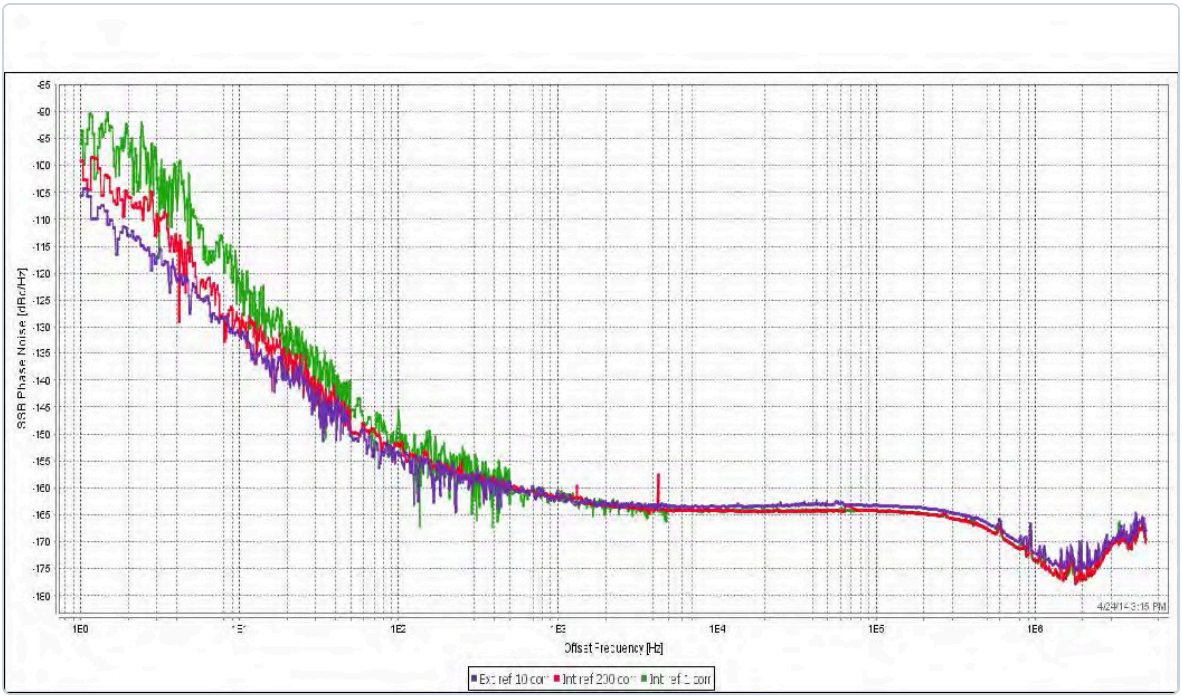


MEASURED **Figure 8.** The DUT phase noise trace after the first correlation (16 s measurement time), offset 1 Hz to 5 MHz, DUT 10.000029 MHz at +4.3 dBm.



MEASURED **Figure 9.** The final measurement after 10 correlations (160 s measurement time), with markers at 1 Hz, 10 Hz, 54 Hz and 1 kHz.

Finally, the measurements with internal and external references are compared in Figure 10. The internal reference measurements (green trace after the first correlation, red trace after 200 correlations) agree with the purple trace (external references, 10 correlations) for offsets above 100 Hz. For offsets below 100 Hz, the external references yield the correct result after 10 correlations.



MEASURED **Figure 10.** Phase noise of the low-noise 10 MHz OCXO with internal references (green, 1 correlation; red, 200 correlations) and with external references (purple, 10 correlations, 160 s measurement time).

7 Conclusion

The 7000 Series can be configured to the noise floor and measurement time a DUT requires.

For most phase noise measurements, the standard configuration with the internal references is the right choice.

For very low phase noise DUTs, especially close to the carrier below 10 Hz offset, the low-noise internal references (option LN) or external references give a lower instrument noise floor and a much shorter measurement: in this example, 10 correlations in 160 s with external references replaced more than 200 correlations and 90 minutes with the standard references.

The PNT GUI handles the supply, the tuning calibration and the configuration of the external references.

8 Talk to an application engineer

If you are measuring ultra-low phase noise sources and want the lowest instrument noise floor in the least measurement time, our engineers can help you choose the reference option for your DUT. Request a quote or a technical consultation and we will match a 7000 Series configuration to your requirement. 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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