# Phase Noise Measurement with a Computer Sound Card

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## Introduction

Phase noise adversely effects high dynamic range receivers, digital modulation that employs small phase shifts and microwave systems that operate into the 100 GHz region and beyond.

A technique for measuring phase noise was published in DUBUS **[1]** and in QEX **[2]**.  These papers cover the theory and practice of phase noise measurement and their review is recommended for those who wish to do phase noise measurement.  However, the described technique depends on test equipment that may be difficult or expensive to obtain.  After the DUBUS publication, Harke Smits PA0HRK suggested using the Focusrite Scarlett Solo **[3]** sound card with DG8SAQ's AudioMeter software **[4]** to measure phase noise.  This paper outlines using the Focusrite sound card and AudioMeter to do phase noise measurement.

## A Brief Introduction to Phase Noise Measurement

**Figure 1** is a representation of a signal with and without phase noise.

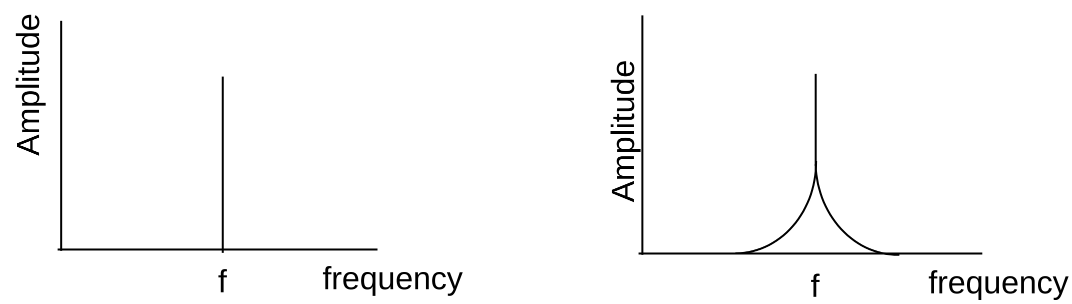



**Figure 1:** Signal without Phase Noise with Phase Noise

Phase noise is specified by the ratio $\mathscr{L}(f)$.  It is the noise power of one sideband in a one Hz bandwidth (power spectral density: W/Hz) offset from a carrier by a frequency, f, divided by the carrier power.  The units are dB with respect to the carrier or dBc:

$$L(f) \;=\; 10\log\left(\frac{P_{ssb}\ \text{f from carrier in}\,1\,Hz\,BW}{P_{carrier}}\right)\ dBc$$

**Figure 2** is the block diagram of the measurement system that uses a phase locked loop (PLL) with a phase detector and a low frequency spectrum analyzer.  The PLL translates the carrier frequency down to zero frequency.  The phase noise spectrum is translated down to baseband where it can be measured with a low frequency spectrum analyzer.  **Figure 3** is the output of the phase detector.  The Focusrite Solo and AudioMeter act as the low frequency spectrum analyzer.  Notice the similarity to a direct conversion receiver.

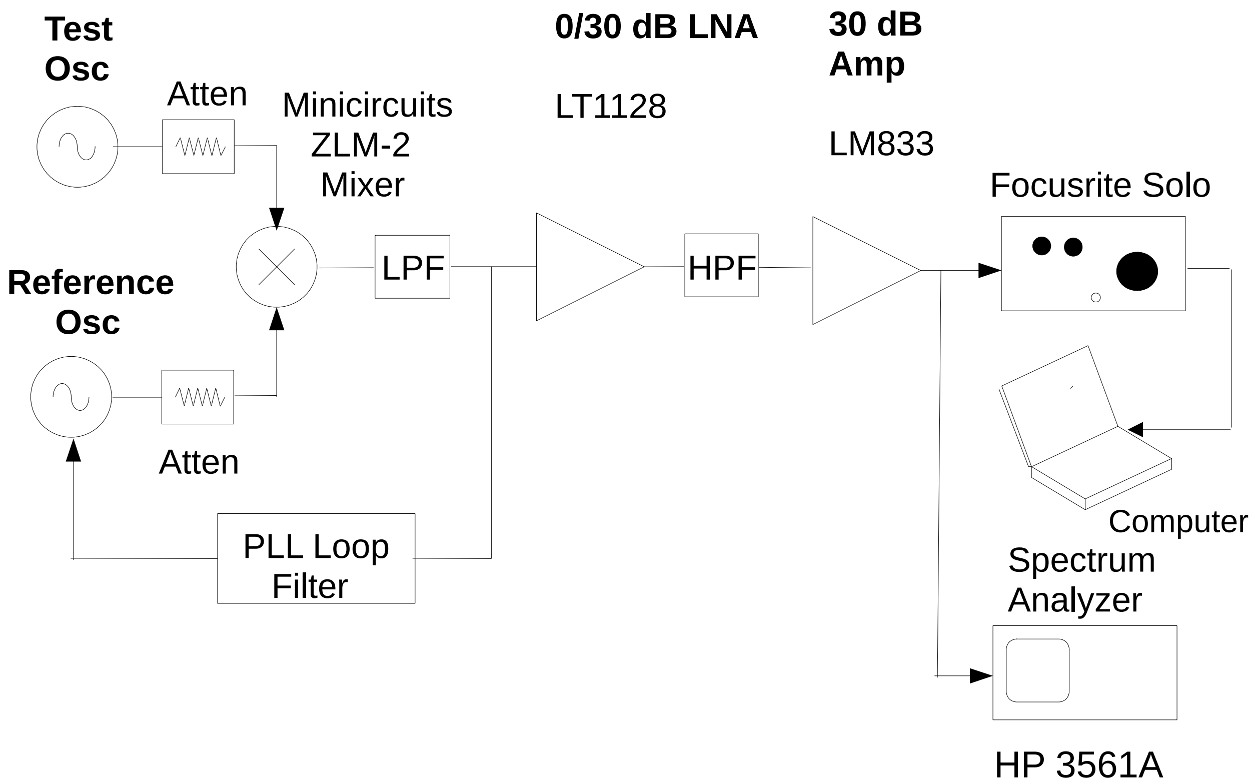



**Figure 2:** PLL phase noise measurement system. LPF: low pass filter. HPF: hi pass filter. The low noise amplifier (LNA) uses an ultra low noise LT1128 op amp. See the DUBUS/QEX papers for circuit details.

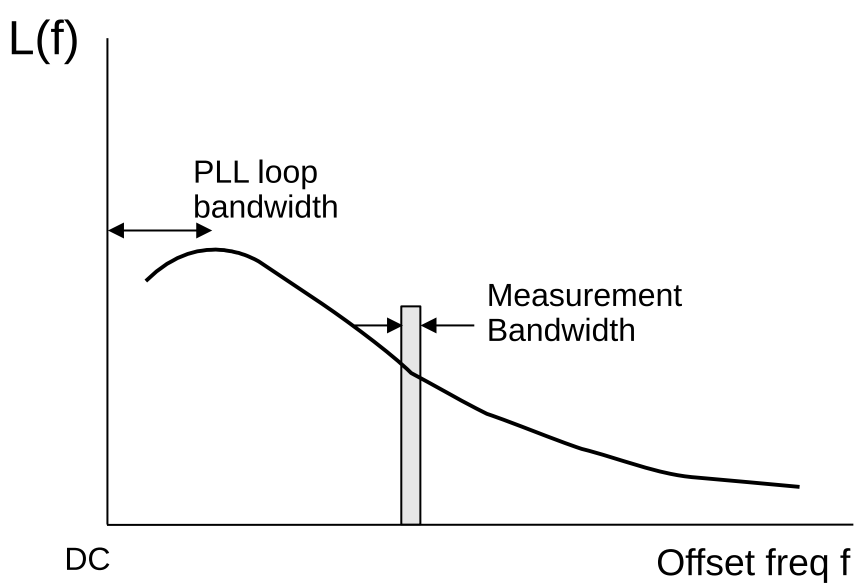



**Figure 3:** The spectrum of $\mathscr{L}$(f) at the output of the phase detector.

Phase noise measurement can be a challenge because the signal level is extremely low and the needed dynamic range may exceed 100 dB. To minimize the effect of ground loops, power supply noise and power mains induced spurious, the phase noise measurement circuity was built into a shielded enclosure and powered by batteries. Connectorized phase detectors and high quality double shielded cables are desirable as well.

**Focusrite Scarlett Solo Sound Interface**

The Focusrite Solo is a high performance USB audio sound interface intended for musicians. It will do up to 196 ksps with 24 bit resolution. A Solo third generation was obtained for about $140 from Crutchfield's **[5]**, an audio supply house. A 4$^{th}$ generation Solo is now available.

Windows drivers for the Solo are available from Focusrite **[3]**. Once the drivers are installed, the Focusrite should appear as a sound card option in the Windows "Device Manager" and in AudioMeter as shown in **Figure 4**.

The Solo has three inputs. One input is for a microphone with a XLR connector and it has an optional microphone power supply. A line level input and an instrument input are available through a ¼" phone jack. A button on the front panel selects one of these two inputs. Either can be configured as a balanced (T/R) or as a single ended (T/S) input. There is a gain control for each input.

The line input in the unbalanced (T/S) mode was used. The gain in phase noise measurement system shown in **Figure 2** can be set for 0 dB, 30 dB or 60 dB. To calibrate the Focusrite gain, the PLL is unlocked and the test and reference oscillators are offset a few hundred hertz apart. The resulting beat note in 0 dB gain mode is applied to the Focusrite line input. As the Focusrite line gain control is advanced, the LED ring around it lights green, then amber and finally red indicating ADC clipping. Set the gain below the clipping level for the greatest dynamic range. Review the Focusrite documentation for details on the inputs.

**AudioMeter**

AudioMeter is a Windows-based audio analysis program by DG8SAQ. While dated, Windows 7 was the newest version of Windows that was available. AudioMeter and the Focusrite Solo operate properly under Windows 7. Drivers for newer versions of Windows and for the 4$^{th}$ generation Solo are available from Focusrite. AudioMeter should run under newer versions of Windows.

AudioMeter can be configured to calculate noise power which makes it ideal for phase noise measurement. When mated with the Focusrite, 110 dB of dynamic range has been observed.

**AudioMeter Setup**

Using **Figure 4** as a guide, choose "ADC Sample Rate" as 96 or 192 ksps and "ADC Resolution" as 16 bits or 24 bits. Due to sampling theory and the anti-aliasing filters in the Focusrite, 96 ksps will allow phase noise to be measured to an offset of about 35 kHz from the carrier. For a given sampling rate, increasing the "Sample Length" reduces the width of the frequency bins in the Fast Fourier Transform (FFT) of AudioMeter. Think of the FFT as a bank of narrow band filters (frequency bins) spread over a specified bandwidth. Increasing the sample length improves the frequency resolution but increases computation time. It also effects how AudioMeter reports power spectral density. This will be explained later. A 16k or 32k Sample Length appears as a reasonable trade off.

**Analysis for the Focusrite and AudioMeter**

In order to use the Focusrite and AudioMeter to display phase noise, the analysis from the original DUBUS/QEX paper needs to be adapted. The original analysis for $\mathscr{L}$(f) is:

$$L(f) = \frac{V_{orms}^2(f)}{4\,V_{brms}^2\,BW} \tag{1}$$

$V_{orms}$(f) is the noise voltage measurement at the desired offset frequency in the measurement bandwidth, BW, and $V_{brms}$ is phase detector beat frequency calibration voltage. Each of these voltages is measured as rms and squared so they represent a power.

In terms of dB:

$$L(f) = 20\log\left(V_{orms}(f)\right) - 20\log\left(V_{brms}\right) - 10\log\left(BW\right) - 6 \pm \mathit{Corrections} \quad dBc/Hz \tag{2}$$

See the original DUBUS/QEX papers for the needed corrections. This analysis assumes the availability of the measurement noise bandwidth. The AudioMeter noise bandwidth is not directly available but a workable estimate can be calculated from the sample rate, sample length and window type chosen for the FFT.

After the Focusrite gain is set, the AudioMeter must be calibrated with the phase detector beat note voltage. So that AudioMeter reports results as a power rather than a voltage choose “Display dB” in **Figure 5**. Its measurement is done as rms. Choose “Signal” from the meters tab and “Flat Top” from the Windows tab under “Spectrum” in **Figure 6**.

If a 632.46 mV p-p (223.6 mV rms) signal is applied to AudioMeter as the calibration signal, then 0 dB will be 0 dBm. AudioMeter assumes a 50 ohm impedance. However, AudioMeter can be calibrated to other values by using the “Reset Level Cal” followed by the “Calibrate Level” buttons on the Measure tab as shown in **Figure 5**. AudioMeter is calibrated with the phase detector beat note voltage at 0 dB gain as the reference. This signal will still appear as “0 dBm” but it is actually 0 dB with respect to the phase detector output power. If the calibration is correct, the AudioMeter “S” (signal) meter should read “0 dBm” with the phase detector beat frequency voltage as shown in **Figure 6**. The Input Cut-on and Input Cut-off frequencies in **Figure 5** need to encompasses the beat note signal frequency.

**Configuration to Display dBc**

While AudioMeter can be set up to display power spectral density within its spectrum analysis window defined by the Cut-on and Cut-off frequencies, its marker function and its spectrum plot are ideally suited to display phase noise. They can be configured to display dBc directly. However, using the markers and the amplitude offset within AudioMeter to plot phase noise in dBc requires some understanding of the FFT process in AudioMeter.

First activate the markers for the desired offset frequencies under the “Spec. Markers and Annotation” tab shown in **Figure 7**. The noise power reported for each marker is related to the power in the FFT frequency bins nearest the specified marker frequency. However, the noise power in each FFT bin is a function of the sampling rate, the sample length and the equivalent noise bandwidth of the chosen FFT window function. Windowing controls the effective filter bandwidth. This is outlined in **[5][6]**. Changing any of these parameters will change the reported noise power. However, it is possible to calculate an effective noise bandwidth (ENBW) that can be used in Eq (2) above. It is given by:

$$\frac{(Sample\,rate)}{(FFT\ length)}(NENBW) = ENBW \qquad (3)$$

Due to the windowing, the ENBW is wider than the bandwidth of a single FFT bin. The NENBW (Normalized Effective Noise Bandwidth) is the correction factor defined in terms of the number of FFT bins for the chosen window. An example for 96 ksps with a 32768 sample length is given in Eq (4) below. The 3.77 factor is the Flat Top window NENBW from **[5]**.

$$\frac{(96\,ksps)}{32768}\,3.77 = 11.04\,Hz\ ENBW \qquad (4)$$

The 11.04 Hz result becomes the bandwidth parameter in Eq (2) above. This value is used to normalize Eq (2) to the required 1 Hz. It is important to note that other combinations of sample rate and FFT length can produce the same ENBW:

$$\frac{(48\,ksps)}{16384}\,3.77 = 11.04\,Hz\ ENBW \qquad (5)$$

$$\frac{(24\,ksps)}{8192}\,3.77 = 11.04\,Hz\ ENBW$$

The Flat Top window function was chosen for its amplitude accuracy, required for the amplitude calibration, and for its spurious side lobe suppression, necessary so the window’s spurious side lobes don’t contaminate the noise measurement. The trade off is that the Flat Top window has a fairly wide ENBW. The resulting noise bandwidth from Eq (4) or (5) using the Flat Top window is probably adequate for offset frequencies of a 100 Hz or greater. A window with a narrower ENBW may be better for closer in offsets.

The results from Eq (2) are used to scale the AudioMeter display directly in dBc.  This can be done in the “Settings” window as shown in **Figure 8** using the “Y Offset” parameter:

$$Y\,Offset \;=\; -10\log\left(ENBW\right)-6-Corrections \;=\; -10.4\,dBHz-6-3-60 \;=\; -79.4\,dB \quad (6)$$

“Y maximum” is set for -40 so the top of the plot will be -40 dBc.  The bottom is set to -170 dBc using the “Y span” parameter.  With this scaling, the markers and the plot will display phase noise from -40 dBc down to -170 dBc.  Different values for Y maximum and Y span will produce a different plot range.  The 3 dB correction assumes that the two oscillators are identical and 60 dB is the correction for the gain used in the phase noise measurement.

As a footnote, **[6]** suggests that there are a number of different implementations of the so called Flat Top window.  However, they aren’t all exactly the same.  While the NENBW factors for the various Flat Top windows are fairly similar, their side lobe suppression can vary.  It is unknown what Flat Top algorithm was used in AudioMeter or in the HP3561A Dynamic Signal Analyzer (a FFT based low frequency spectrum analyzer) used in the original DUBUS/QEX papers.  It is possible that differences in these windows could introduce an error.  The consistency of the phase noise measurements suggest that this error is probably small.  The averaging used with the HP3561A measurement results in an approximately -1.3 dB, +1.8 dB error window.  Any measurement within that difference range between AudioMeter and the HP3561A was considered to be consistent.  Measurements with AudioMeter and the HP3561A made at the same time often agreed within 1-2 dB.

In **Figure 8,** the “Screenshot” function allows saving the Spectrum plot.  Choose “Screenshot size.”  A standard screen resolution works well. <^S> will save the Spectrum plot to the computer’s Clipboard and <^V> will paste the result into a document or other graphic editor. The “Spec. Smoothing” tab in **Figure 8** brings up another window that allows for smoothing. Increasing the “Meter Time Constant” results in time averaging but it slows the amplitude response.  The result is that it may take a number of seconds for the measurement to stabilize.  In addition, “Data Reduction/Smoothing” reduces the large number of FFT bins to a manageable number for the display and marker functions.  Set “Data Reduction/Smoothing” to “Smooth power to” and a number of points.  A power of 2 such as 2048 seems to work well.

## Measurement

The Focusrite/AudioMeter system was used to measure the phase noise of the 100 MHz Bliley NV26R891 OCXOs that were used as the example in the original DUBUS/QEX papers. **Figure 9** is the phase noise of the Bliley OCXOs measured with AudioMeter and **Figure 10** compares the phase noise of the Bliley OCXOs using AudioMeter with the phase noise measured using the HP3561A.

## Conclusion

This paper covers the basics of using the Focusrite Solo sound card and AudioMeter software to measure phase noise.  **Figure 11** is a picture of the system using the Focusrite, a laptop computer running AudioMeter and the phase noise box described in the original DUBUS/QEX papers.  They form a phase noise measurement system that offers high performance at relatively low cost with components that are readily available to amateurs.

Jim Davey, K8RZ, was coauthor on the DUBUS paper that described this system **[8]**.  Jim reproduced the DUBUS phase noise measurement hardware and together we did a lot of "button pushing" with AudioMeter in order to get consistent phase noise measurements.  He was also helpful in understanding the FFT in AudioMeter.

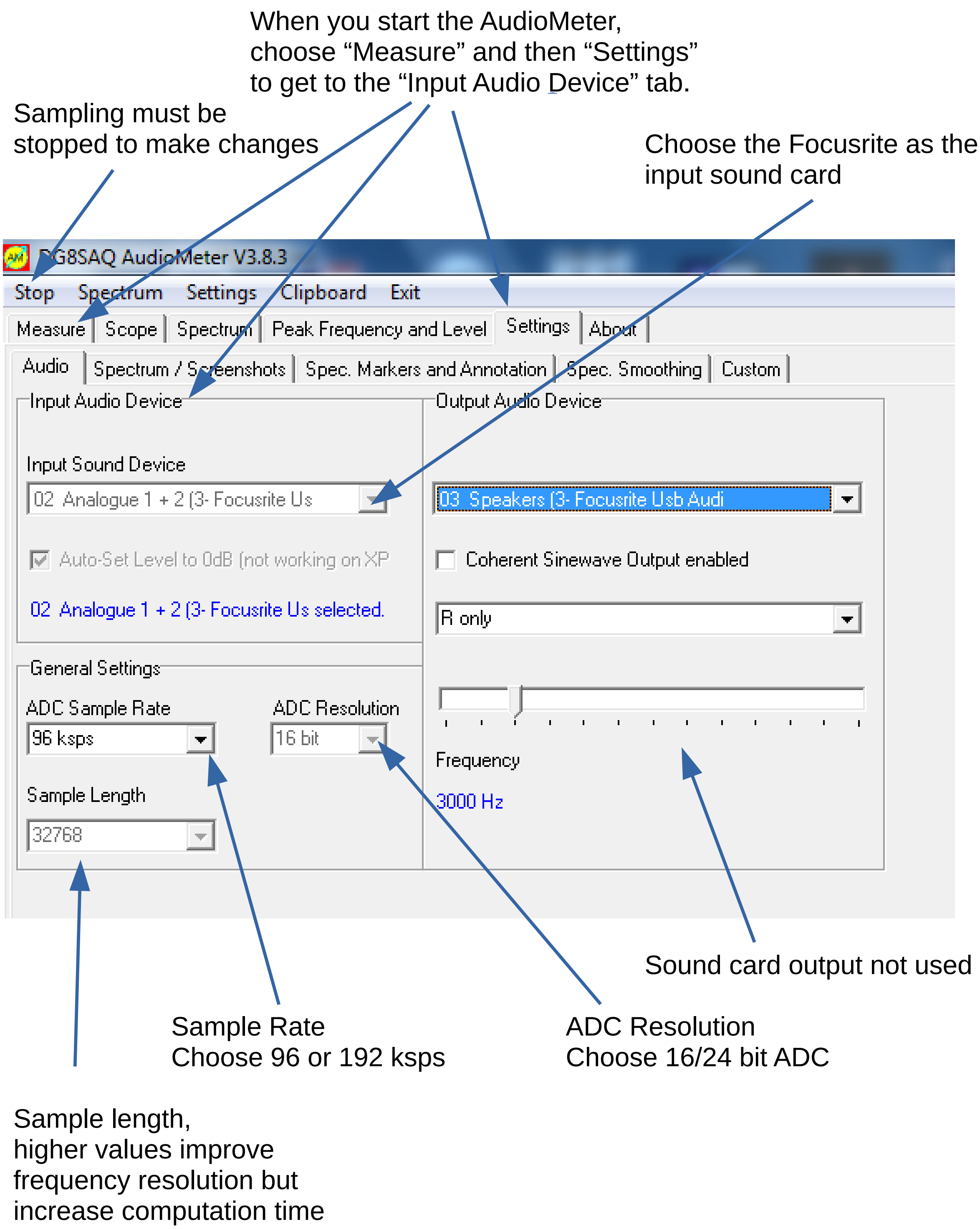



**Figure 4:** AudioMeter Setup

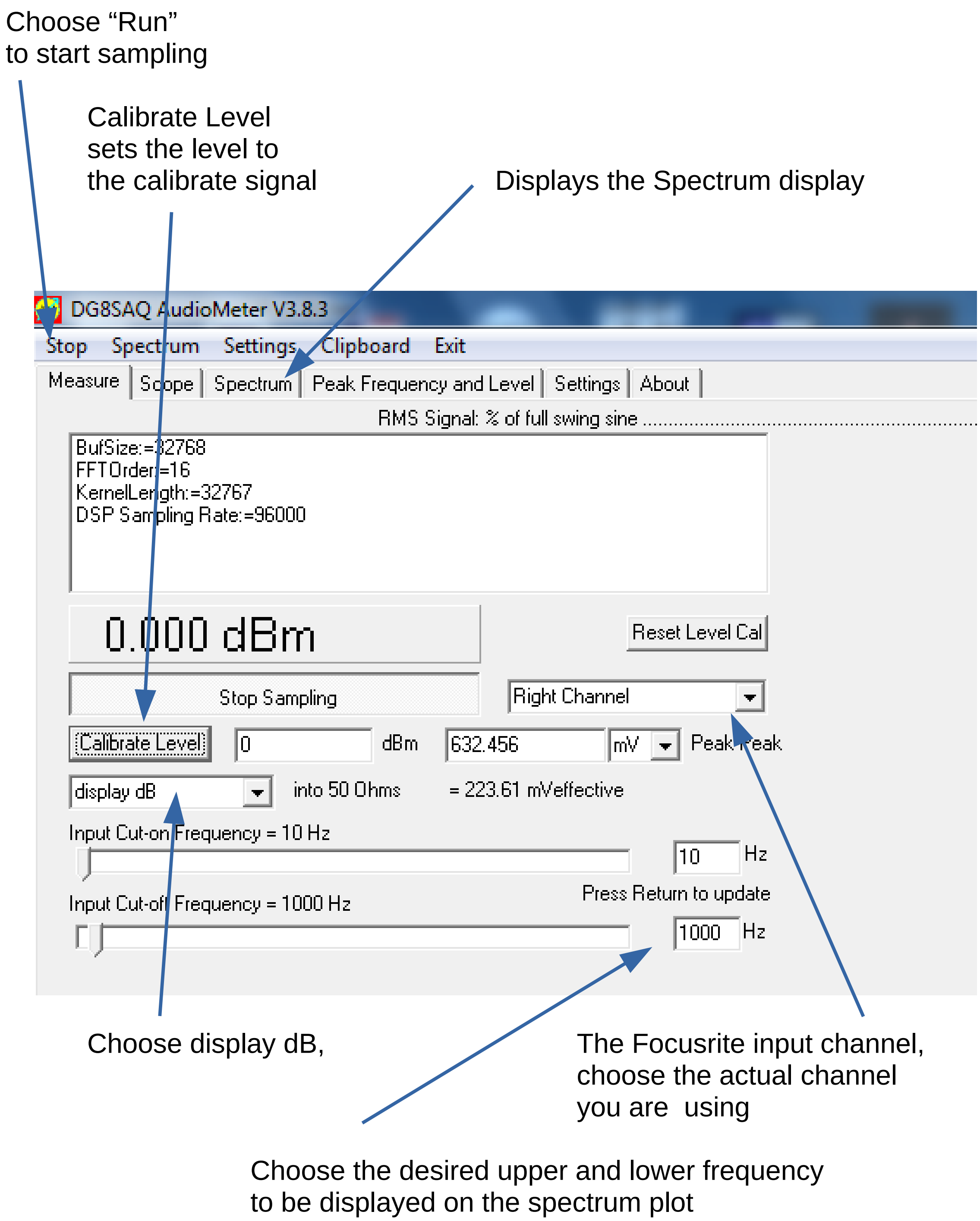



**Figure 5:** The AudioMeter 0 dB level must be calibrated. For phase noise measurement, 0 dB can be calibrated with respect to the phase detector beat frequency output voltage.

Under this tab choose: Window Type: “Flat Top”
and under Meters choose: “Signal” which will display
the level with respect to the calibration.

If the calibration is correct and things
are properly set up, the amplitude
will read 0 dB (dBm).

Choose “Spectrum” to display the
phase detector beat signal

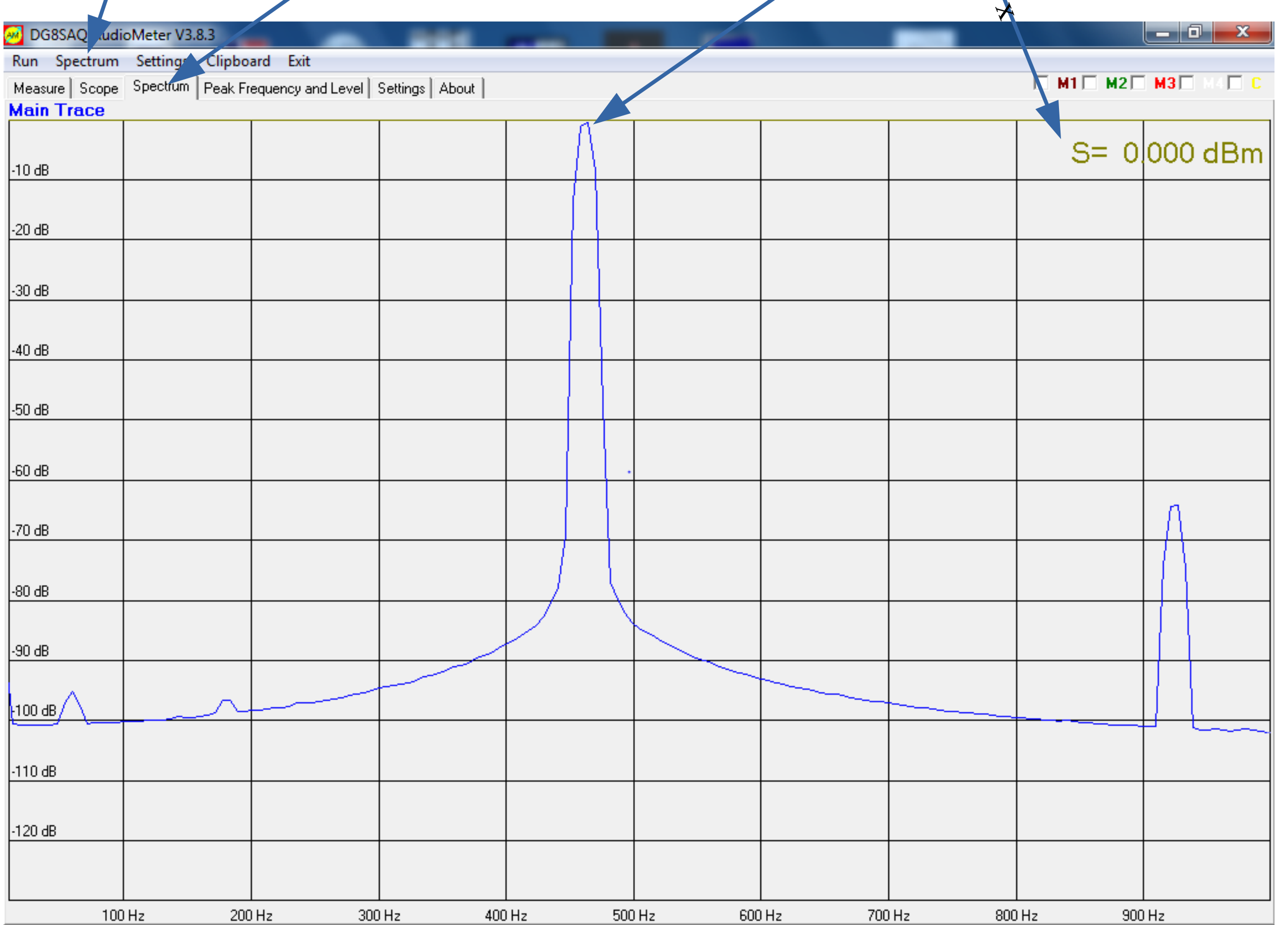



**Figure 6:** Calibrated Signal Display. Beat note measurement with the PLL unlocked, 0 dB gain. This plot is similar to **Figure 10** in the DUBUS paper.

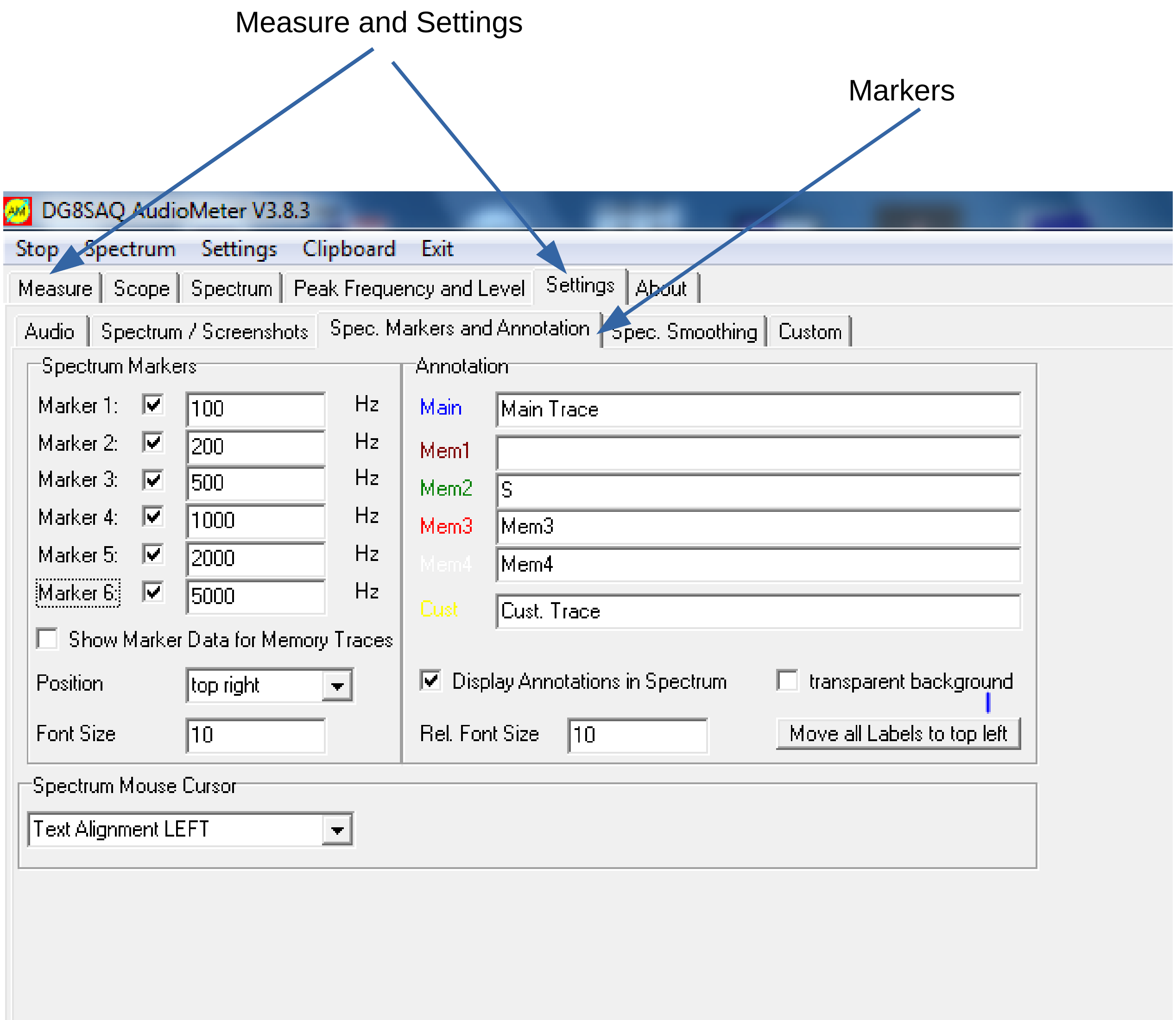


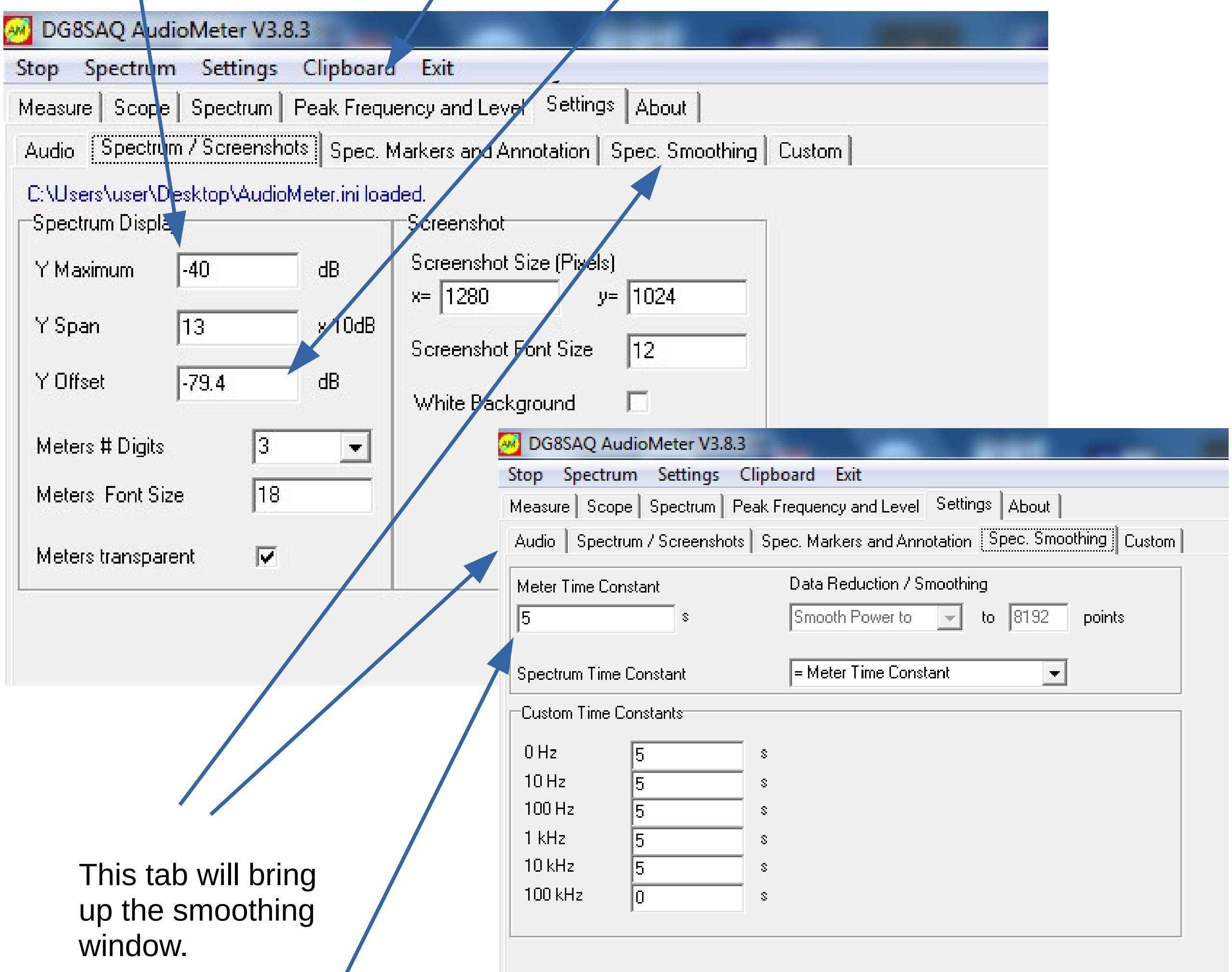

**Figure 7:** Markers set under the “Spec. Markers and Annotation” tab.

This window is accessed through the “Measure” and “Settings” tabs as described in **Figure 1**.  Choose the “Spectrum/Screenshots” tab.

The Y Offset is set to accommodate the phase noise box gain, 60 dB for the LNA, the 6 dB constant, 3 dB for identical oscillators and 10.4 dBHz for the ENBW correction.  Since the top of the plot was calibrated for 0 dB for beat note output, the Spectrum plot will now read directly in dBc for phase noise.

Set to -40 dB to raise the plot

<^S> will copy the spectrum plot to the clipboard, <^V> will paste it into a document.




This tab will bring up the smoothing window.

Increase “Meter Time Constant” for additional smoothing.

**Figure 8:**  Spectrum Display Normalization

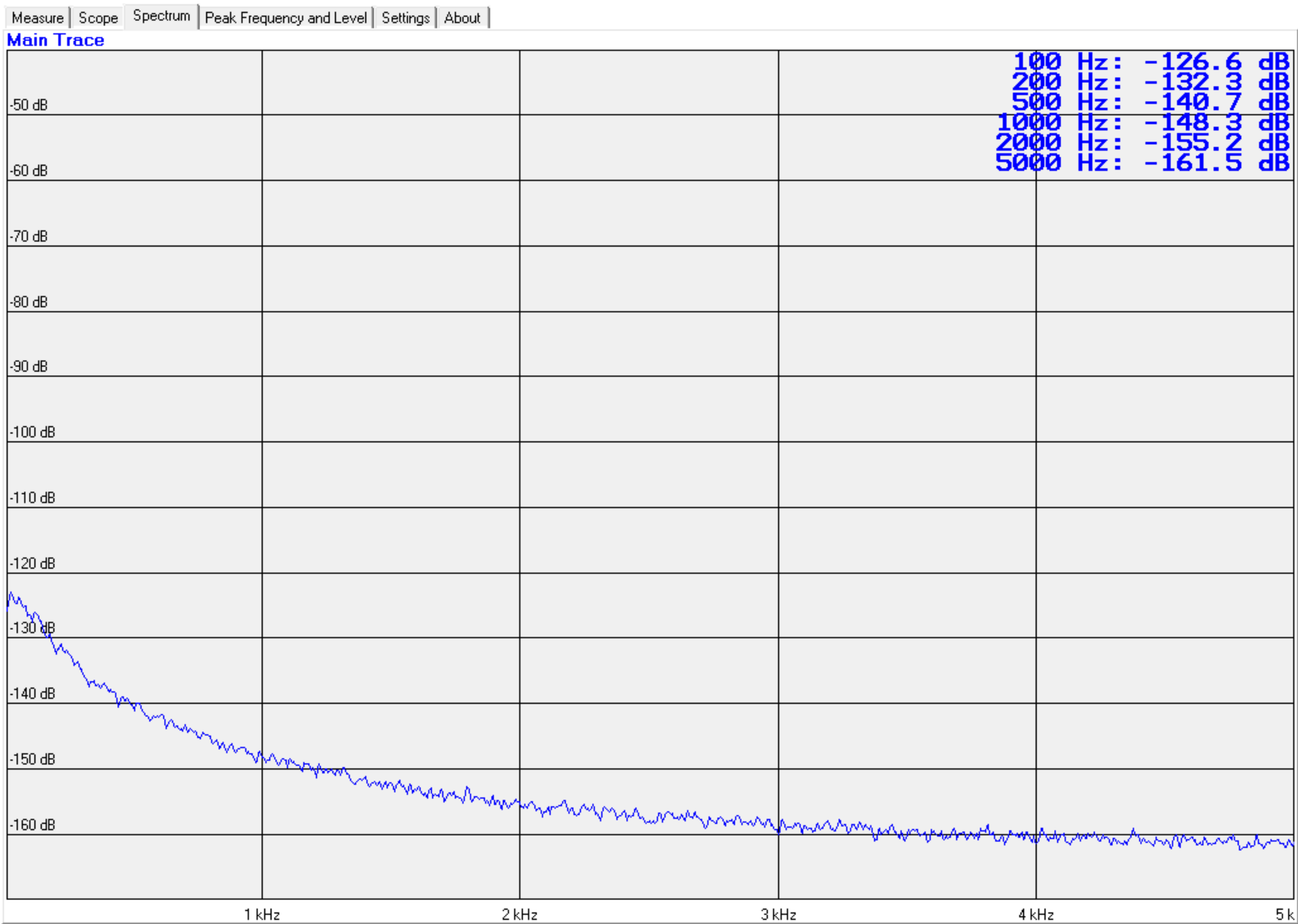



**Figure 9**: Phase Noise Measurement after phase lock of a 100 MHz Bliley NV26R891 OCXO. Gain is 60 dB. This plot is dBc after corrections with respect to the phase detector output at 0 dB. The Y Offset = -79.4 dB. The displayed spectrum is 10 Hz to 5005 Hz. The system noise floor is approximately -161 dBc. Note that the values for the phase noise at various offsets can be read directly from the markers in the upper right.

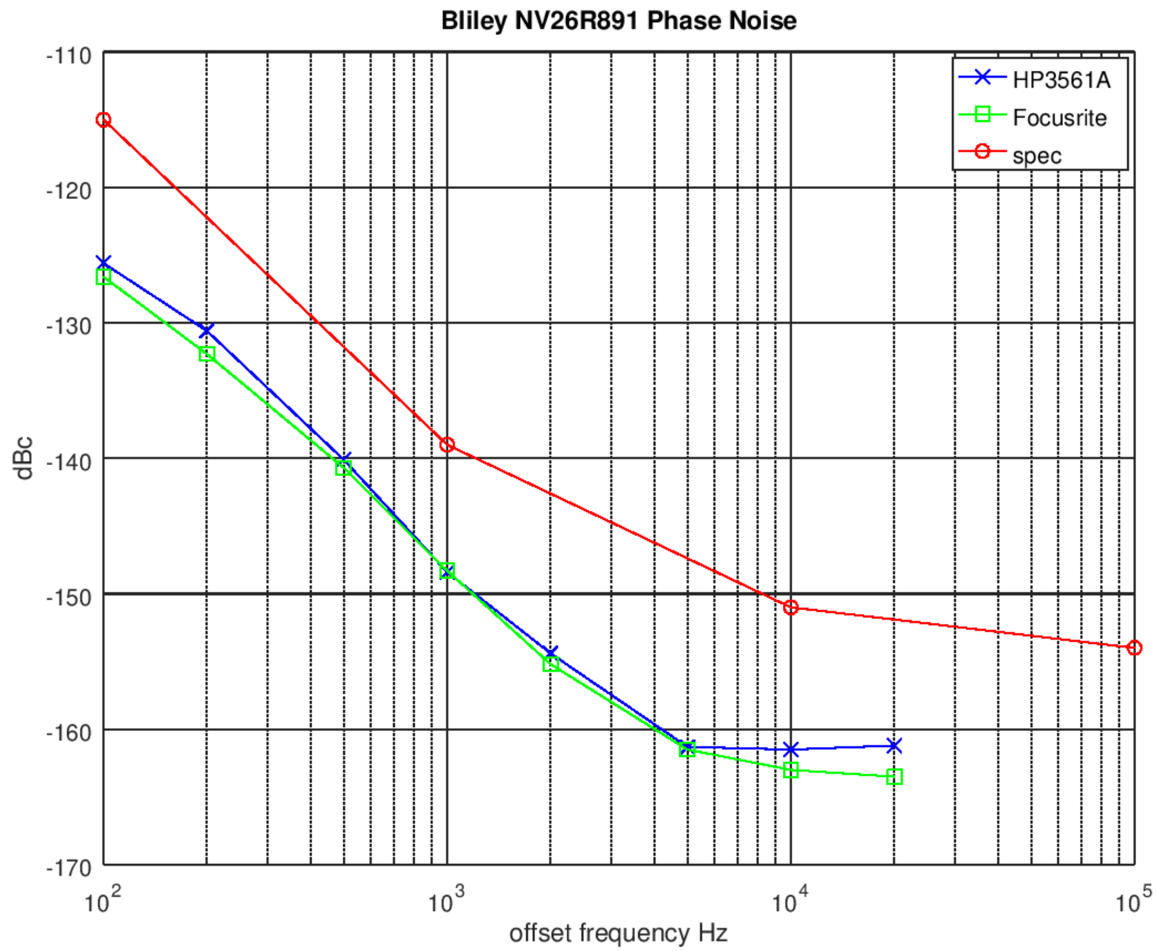



**Figure 10:** Comparison of the simultaneous Focusrite/AudioMeter and HP3561A phase noise measurement of the 100 MHz Bliley NV26R891 oscillators.

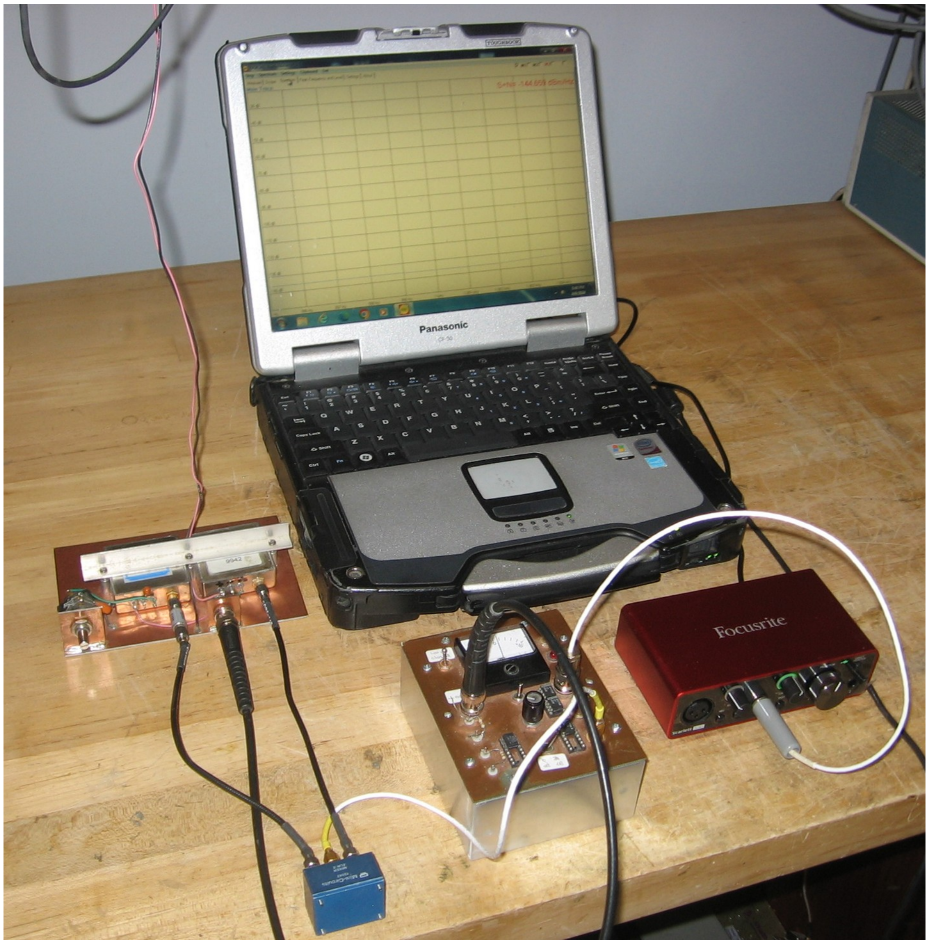



**Figure 11:** Phase noise measurement system with the Focusrite Solo and a laptop running AudioMeter. The 100 MHz Bliley NV26R891 test oscillators are to the left of center. The ZLW-2 phase detector, phase noise box and the Focusrite are lower left to right. The phase noise box and the phase detector are described in the original DUBUS/QEX papers.

**References**

**[1]** Dennis G. Sweeney, WA4LPR, Phase Noise Measurement Revisited, DUBUS, Vol. 52, 3/2023, pp. 93-117.
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**[3]** https://focusrite.com/
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**[5]** www.crutchfield.com
**[5]** Michael Cerna and Audrey F. Harvey, The Fundamentals of FFT-Based Signal Analysis and Measurement, National Instruments, Application Note 041, July 2000.
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**[7]** Dennis G. Sweeney, WA4LPR, and Jim Davey, K8RZ, Phase Noise Measurement Revisited: Revisited, DUBUS, Vol. 53, 3/2024, pp. 26-35.