Measuring Ultra Low Noise Metrological Reference

Very low noise signal sources such as masers have significantly improved their performance in the last few years. It has become increasingly challenging to measure their phase noise with standard equipment and even dedicated phase noise measurement systems. In this technical brief, we show a measurement setup that allows capturing phase noise below the specified noise floor of the measurement instrument by externally down converting a microwave signal to a low IF frequency.

Effect of Frequency Scaling on Phase Noise

Frequency dividers and multipliers scale both the frequency and phase with the same factor, therefore effectively changing the phase noise of the signal by the same factor. Given an ideal frequency scaling of $f_2 = n \cdot f_1$, the phase noise $L(f)\ dB$ is increased as following:

$$L_{f_2}(f)\ dB\ = L_{f_1}(f)\ dB + 20 \cdot log10(n)\ dB$$

Since this has implications on the phase noise of synthesizer outputs, it will also affect the performance (noise floor) of dedicated measurement systems that use internal references to measure phase noise. In general, the measurement noise floor of such instruments rises for higher frequencies.

Measurement Setup

Figure 1. Measuring the synthesizer output directly.

In this scenario, a low noise oscillator produces a 5 MHz signal that has phase noise below the measurement sensitivity of the signal source analyzer at offset frequencies below 10 Hz. Measuring the direct setup shown in Figure 1 would only reveal the noise floor of the signal source analyzer at those offsets or would require excessive correlations (increasing the measurement time significantly) to reach the DUT (device under test) phase noise levels.

To overcome this problem, a different setup is necessary. By using a PLL based multiplier, the initial frequency is increased to a higher frequency $f_1 = f_0 \cdot n$. Let's assume $n = 1000$ for the moment, which results in $f_1 = 5\ GHz$. At the same time, a second multiplier is used to create a second frequency $f_2 = 5.01\ GHz\ (n = 1002)$. Both signals have the same phase noise scaled up by the same factor (since $20 \cdot (log10(1002) - log10(1000)) < 0.02\ dB$) and can therefore assumed to be equal.

$$L_{f_1}(f)\ dB\ = L_{5\ MHz}(f)\ dB + 20 \cdot log10(n)\ dB \approx L_{f_2}(f)\ dB$$

The two frequencies are mixed together to create a signal at frequency $\Delta f\ = 10\ MHz$. The phase noise of this signal is

$$L_{\Delta f}(f)\ dB\ = L_{f_1}(f)\ dB + L_{f_2}(f)\ dB = L_{5\ MHz}(f)\ dB + 20 \cdot log10(n)\ dB + 3\ dB$$

The full setup can be seen in Figure 2.

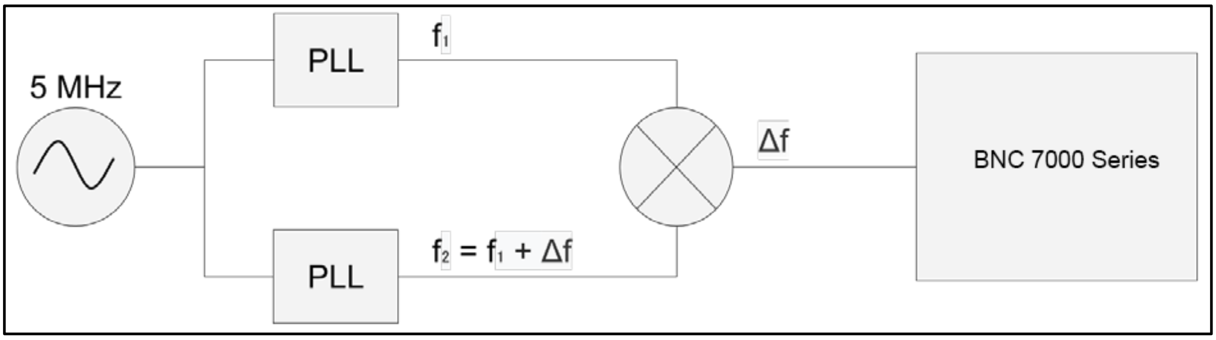

Figure 2. Measuring by downconversion to improve the phase noise sensitivity of the signal source analyzer.

In summary, we now have a signal at 10 MHz with a higher phase noise (about 63 dB). The noise floor of the signal source analyzer is no longer dominating the measurement. The phase noise of the original oscillator can be calculated from the result by subtracting the effect of the multiplication and the doubling of the phase noise in the mixer.

$$L_{5\ MHz}(f)\ dB\ = L_{\Delta f}(f)\ dB - 20 \cdot log10(n)\ dB - 3\ dB \approx L_{\Delta f}(f)\ dB - 63\ dB$$

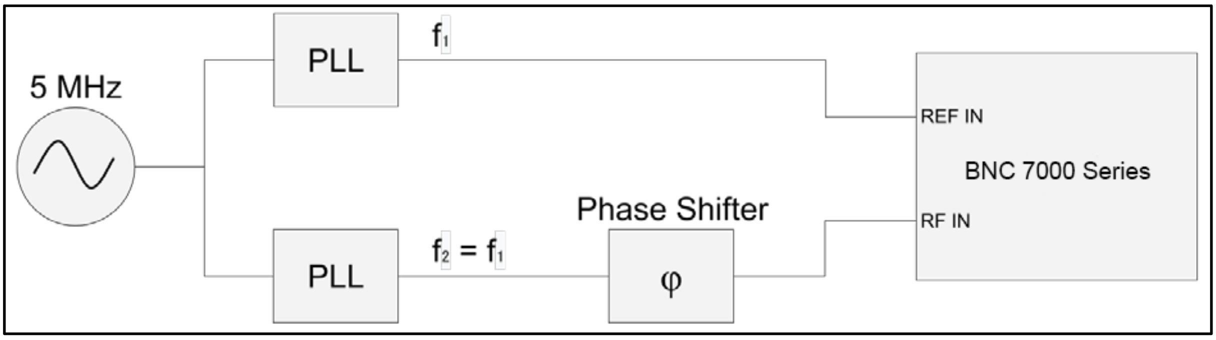

Figure 3. Testing the additive phase noise of the multipliers.

One of the assumptions taken with this approach is that the PLL multipliers and the mixer don't add significant phase noise. To test this, an additive phase noise measurement can be performed on the two signals at 5 GHz. Figure 3 shows the measurement setup that is used to confirm that the additive phase noise of the multipliers is below the phase noise of our DUT at the frequency offsets of interest (<100 Hz).

All measurement results are shown in Figure 4. The direct setup and the mixer setup are adjusted by the 63 dB calculated above. The additive phase noise of the PLL multipliers is adjusted to 5 MHz as well to make it comparable.

We can confirm that the PLL multipliers are not contributing to the phase noise of the mixer setup since there is a gap of more than 6 dB between the two measurements. And by using a diode-based double-balanced mixer, we can assume that the phase noise contribution of the mixer is also negligible.

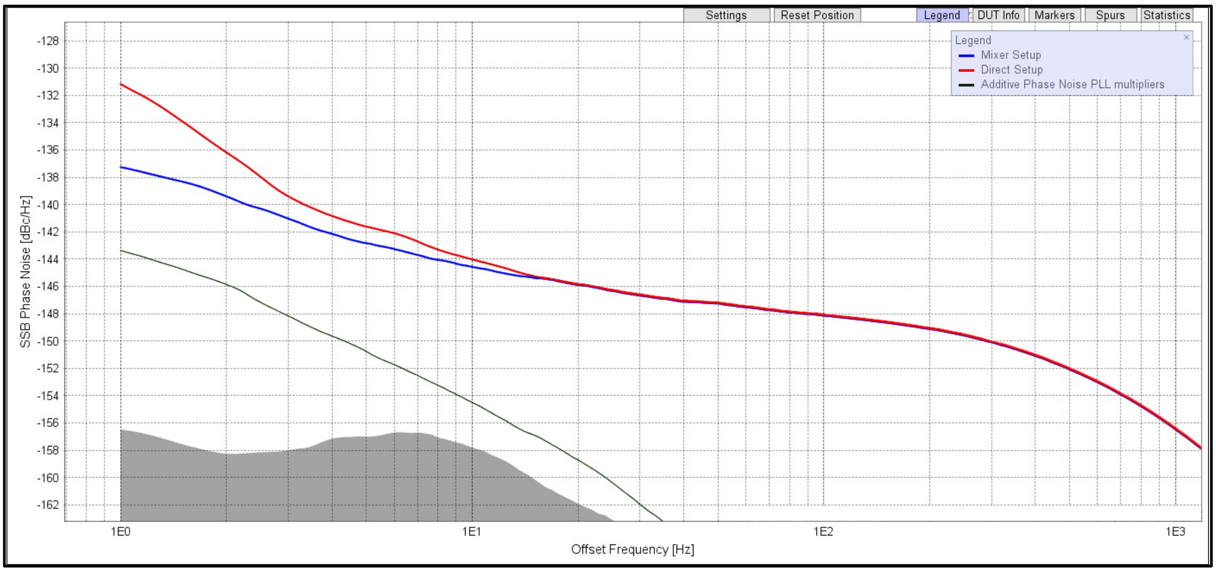

Figure 4. Comparing the 5 MHz DUT phase noise measurements of the direct setup (red) and the mixer setup (blue). The additive phase noise of the PLL multiplier (black) is below the other measurements and is therefore not contributing to the measurement.

The red trace (direct setup) took more than 30 minutes and over 300 correlations. The measured phase noise at 1 Hz offset of -131 dBc/Hz is an extremely good value to be measured at 5 MHz with this instrument. Nonetheless, it is still limited by the instrument noise. A longer measurement time could possibly improve this value, but it is doubtful that the real value of the DUT will be reached.

The blue trace on the other hand took only about 20 seconds and 10 correlations. The relative measurement noise floor of this measurement (shown in the plot in Figure 4 as gray area) is already far below the measurement itself and the phase noise value of -137 dBc/Hz at 1 Hz offset is the DUT phase noise.

Conclusion

Since the noise floor of common phase noise measurement equipment scales with frequency, it is sometimes possible to achieve a much better measurement result by multiplication and down conversion of the test signal. This technique improves measurement speed and noise floor of the measurement. The described method reaches a phase noise value of -137 dBc/Hz at 1 Hz offset for a 5 MHz signal. There is no commercially available device known that is able to measure these levels directly at 5 MHz.

When using this method, it is important to make sure that the added components do not contribute to the phase noise. Using the additive phase noise measurement capabilities of the 7000 Series Phase Noise Tester, it has been demonstrated how to check and confirm the initial assumptions as well as verify these test results.

BNC 7000 Series