A LOW NOISE MULTIPLE OUTPUT PHASE LOCKED LOOP SYNTHESIZER FOR RADAR APPLICATIONS

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ABSTRACT

Performance test results for fixed frequency phase locked loop synthesizers will be presented. The parameters that will be characterized include, phase noise, thermal stability and warm-up. The fixed frequency synthesizer for which test data is presented utilizes a 10 MHz reference OCXO and a 100 MHz VCO.

1. INTRODUCTION

High stability frequency references with extremely low phase noise floor performance are required for advanced RADAR applications. Generally the frequency of references for such applications tend to be in the 100 MHz to 200 MHz range. Even after the challenge of noise floors in the region of -175 dBc/Hz at 10 kHz offset is attained, oscillators in this frequency range are not suitable for the necessary thermal stability, aging and warm-up performance specified by many requirements.

To overcome this deficiency, phase locked loops are utilized.

2. CONSTRUCTION

To obtain the desired performance characteristics, the phase locked loop utilizes a high stability oven controlled crystal oscillator (OCXO) and a low phase noise voltage controlled OCXO (VC-OCXO). (Hereafter the VC-OCXO will be referred to as the voltage controlled oscillator or VCO.) A block diagram of the phase locked loop is shown in Figure 1.

A low frequency SC cut OCXO is utilized as the reference oscillator to obtain superior thermal stability, aging, warm-up and supply voltage sensitivity performance. One reason for this is because the load sensitivity of quartz crystals decreases at lower frequencies. This is also true for SC cut quartz crystals over AT cuts.

An AT cut crystal is generally utilized for the VCO to provide a sufficiently wide tuning range in order to reduce the time it takes to lock to the reference OCXO. A tradeoff in using AT cut quartz crystal is that it typically exhibits poorer thermal stability and aging performance compared to SC cut quartz crystals. While a wider tuning range is available to compensate for the VCO drift over temperature and time, it may be necessary to generate a stability error budget to ensure that the VCO will remain locked over the product lifetime.

For purposes of frequency calibration, the reference OCXO is typically also able to be voltage controlled.

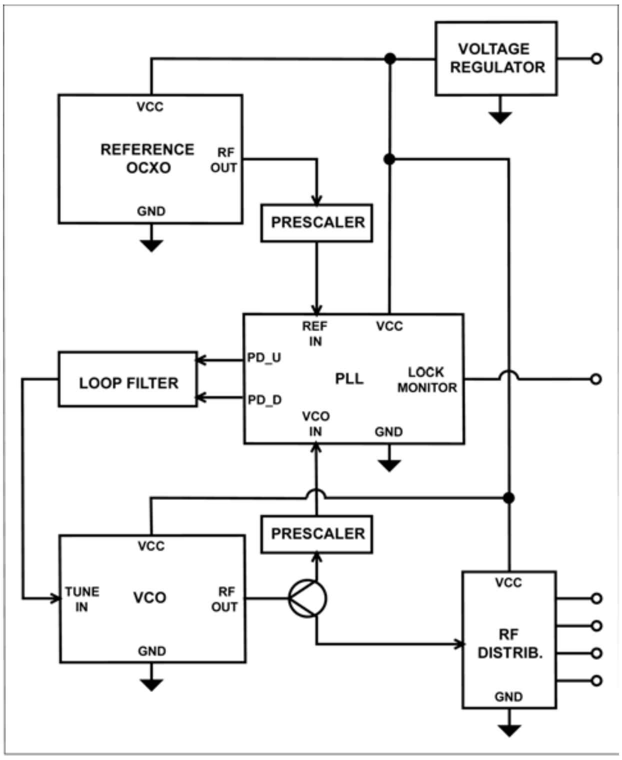

Figure 1

RF output signals from both the reference OCXO and the VCO are prescaled to a common comparison frequency as shown in Figure 1. This is then fed into the phase lock loop (PLL) circuit, which is primarily comprised of a phase detector and a charge pump. There are several integrated circuits available today that contain both these functions within the same device along with additional features such as built-in adjustable integer-N and/or fractional-N prescalars for both the reference OCXO and the VCO input signals, lock status monitors and digital programming capabilities.

The loop filter that follows the PLL circuit is used to shape the transient and steady-state response of the VCO output. The loop bandwidth of the filter may range from a few hertz to several kilohertz depending on the application requirements.

If a charge pump is not included within the PLL device, the phase detector output is directly fed into an active loop filter. Otherwise, the charge pump output may be fed into a passive loop filter. Nevertheless, it may be desirable to use an op-amp if the input tuning voltage range of the VCO exceeds the output swing range able to be obtained from the charge pump.

The output of the loop filter provides the tuning voltage necessary to steer the VCO and keep it phase locked to the reference OCXO.

The RF output of the VCO is split using a 2-way power splitter. One of the split signals is directed to the prescalar as described above and the other to the RF distribution circuitry for frequency synthesis. The latter may comprise of a combination of frequency multipliers, dividers and fan-out sub-circuits depending on the final frequencies and number of outputs required by the end-application.

The frequency stability characteristics of the RF outputs of the synthesizer are determined by the reference OCXO within the loop bandwidth and by the VCO outside the loop bandwidth.

3. PERFORMANCE TEST RESULTS

The fixed frequency synthesizer for which test results are presented in this paper utilized a 10 MHz SC cut quartz crystal for the reference OCXO and a 100 MHz AT cut quartz crystal for the VCO. The PLL integrated circuit employed did not contain a charge pump and required an active loop filter design. The loop bandwidth was set between 10 Hz and 12 Hz.

Parameter	10 MHz SC OCXO	100 MHz AT VCO
Thermal Stability [1]	1.5E-08	5.0E-07
Aging per Day	1.0E-09	4.0E-09
Phase Noise in dBc/Hz @ Offset		
1 Hz	-85	-60
10 Hz	-115	-90
100 Hz	-140	-120
1 kHz	-150	-150
10 kHz	-155	-172
100 kHz	-155	-172
STS @ 0.1 s	1.0E-11	1.0E-10
Warm-up Time in Minutes [2]	5.0	5.0
Warm-up df/f [2, 3]	5.0E-08	3.0E-07

Table 1

[1] From 0 °C to +70 °C.

[2] From 25 °C ambient.

[3] With respect to frequency at 60 minutes.

As a result, the short-term stability (STS) at times greater than the loop bandwidth as well as long-term stability (aging), thermal stability and warm-up performance the synthesizer are dependent on the performance of the 10 MHz SC cut reference OCXO for the same parameters. However, the STS at times less than the loop bandwidth is dependent on the performance of the 100 MHz AT cut VCO.

The performance specification for the stand-alone oscillators used in the synthesizer are summarized in Table 1.

3.1 Phase Noise

Two identical synthesizers were phase noised using a HP3048A Phase Noise Measurement System. All results shown have been corrected by 3 dB to account for equal power noise sources.

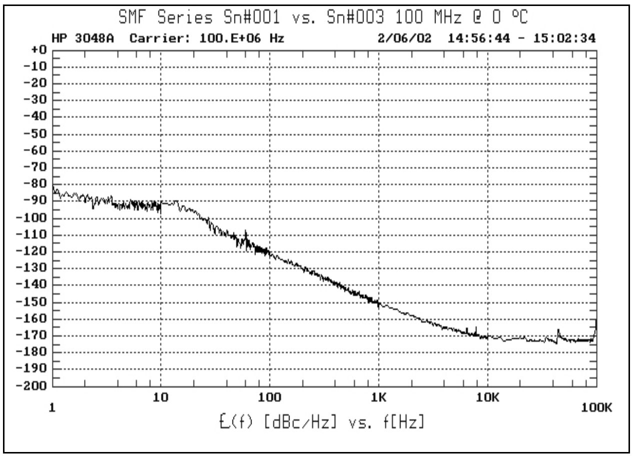

Figure 2

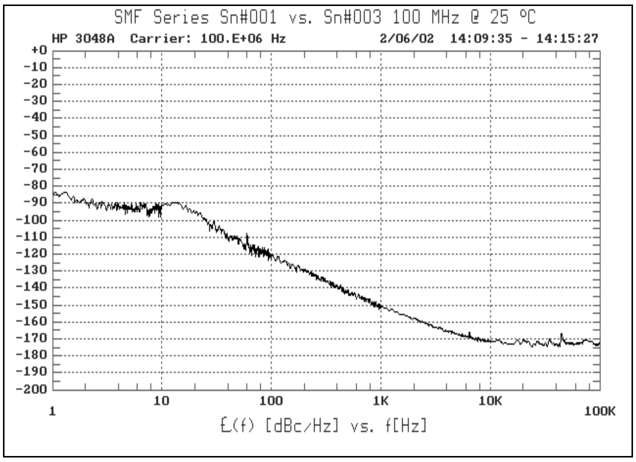

Figure 3

Phase noise measurements were performed at three different temperatures corresponding to the operating temperature extremes and at 25 °C ambient for each RF output. This was accomplished by placing both units inside an environmental chamber. Due to the mechanical vibrations from the fan motors and the chamber electronics interference affecting the measurement, the environmental chamber was powered down after allowing the units to soak for approximately 1 hour at the target temperature. As a result, the temperature within the chamber drifted by about 2.5 °C for the duration of the measurement.

Figures 2, 3 and 4 depict the phase noise performance of the 100 MHz output at 0 °C, 25 °C and 70 °C respectively.

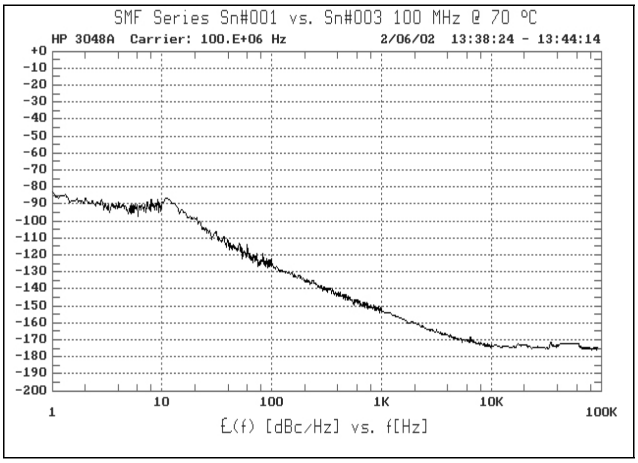

Figure 4

The loop bandwidth of approximately 11 Hz is clearly evident in the phase noise test results. At frequencies below 11 Hz offset from the carrier, the phase noise performance is that of the 10 MHz reference OCXO scaled to 100 MHz. This would imply that an average performance of -85 dBc/Hz at 1 Hz offset from the 100 MHz carrier represents -105 dBc/Hz performance of the 10 MHz reference OCXO. This is verified by the phase noise result of the 10 MHz output at 1 Hz offset shown in Figure 5.

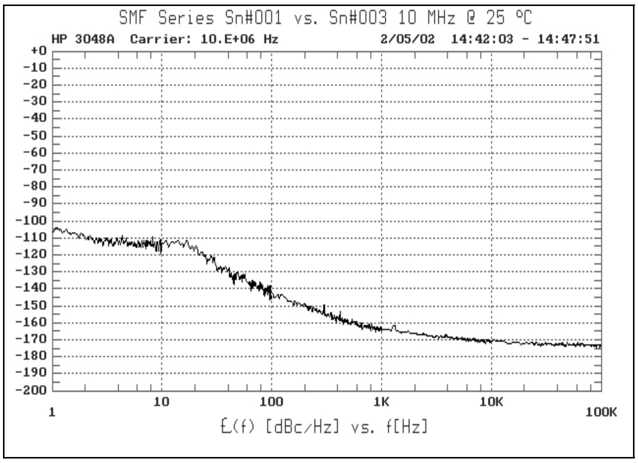

Figure 5

Figures 5, 6, 7 and 8 show the phase noise performance of the 10 MHz, 20 MHz, 50 MHz and 200 MHz outputs respectively at 25 °C ambient temperature.

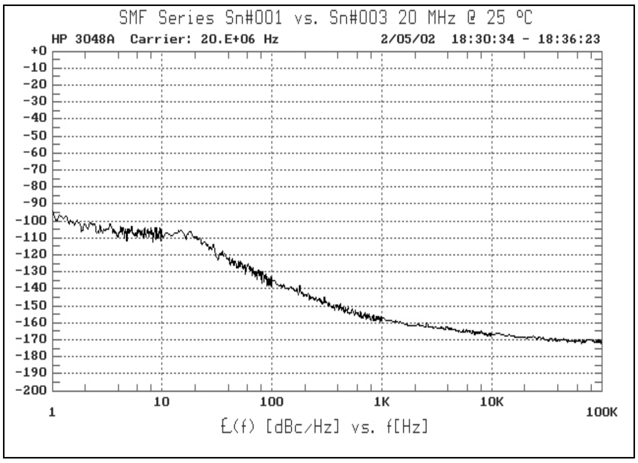

Figure 6

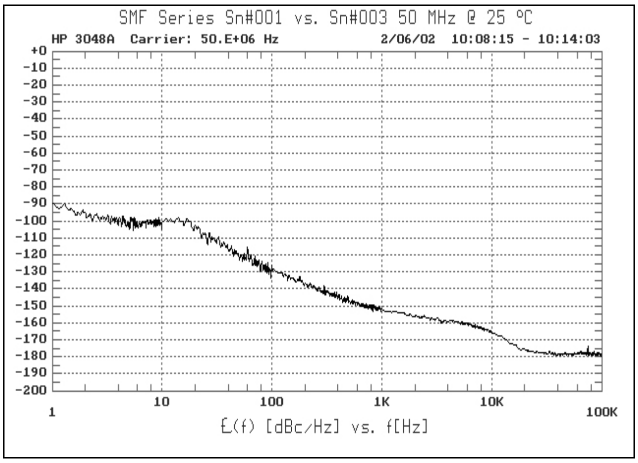

Figure 7

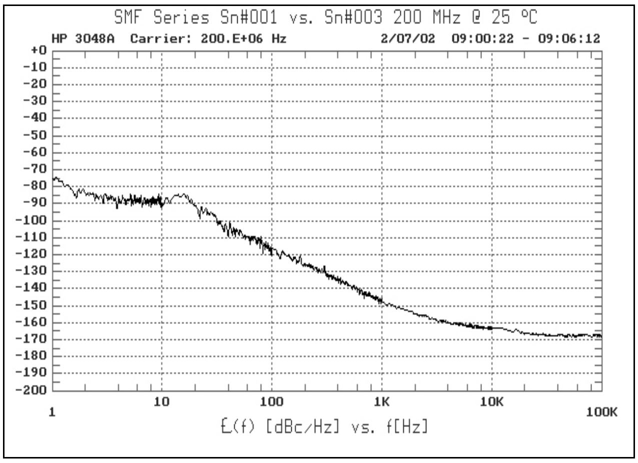

Figure 8

It can be seen from the results shown at each output frequency that the phase noise performance below approximately 10 kHz offset from the carrier is scaled by the output frequency. The scale factor between the phase noise levels of two outputs at different frequencies is given (in dB) by [1]:

$$20\bullet\log(f_2/f_1)$$

Equation 1

Where, f_1 and f_2 are the output frequencies.

This is because the RF output at each frequency is derived from the same 100 MHz signal source.

The phase noise floor results beyond approximately 10 kHz may not scale with the output frequency even though they are derived from the same 100 MHz VCO signal, since the phase noise performance in this region may be limited by the noise in the RF distribution circuit elements.

3.2 Thermal Stability

Thermal stability test on the synthesizer was performed by measuring the frequency using a counter set to a 1 second gate interval as the ambient temperature was ramped from 0 °C to 70 °C and back to 0 °C in 10 °C steps. The frequency was also observed at 25 °C prior to and at the end of the ramp cycle. This was done for the purpose of correcting for frequency drift that may have occurred during the test.

The thermal stability result for the 100 MHz output and the ambient temperature profile are presented in Figure 9.

By locking the 100 MHz AT cut VCO to the reference OCXO, the thermal stability performance of the 100 MHz output is identical to the 10 MHz SC cut reference OCXO.

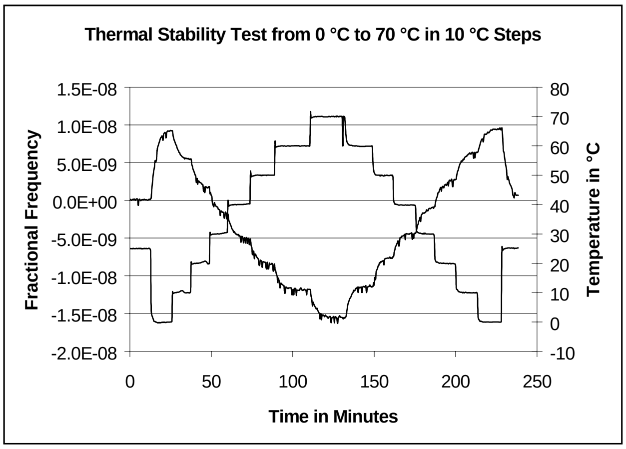

Figure 9

3.3 Warm-up

Figure 10 shows the warm-up performance of the 100 MHz output and the lock monitor status during the initial 5 minutes from application of power to the synthesizer. The test was performed in stirred air at 25 °C ambient temperature. The unit was powered off and allowed to soak at 25 °C ambient for approximately 24 hrs prior to application of power.

A logic high on the lock monitor indicates a locked status. Prior to attaining lock at approximately 2 minutes, the lock monitor was oscillating between logic levels at the beat frequency of the reference OCXO and the VCO. This is greater than the measurement bandwidth capability of the digital multi-meter used in the test setup. As a result, the lock monitor level data is recorded as the average DC level.

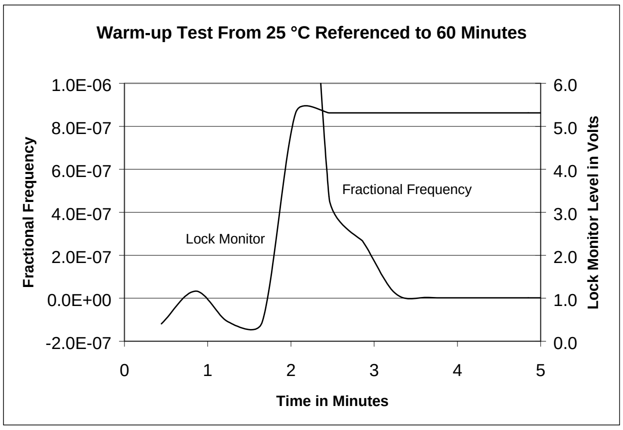

Figure 10

From Table 1, we expect the warm-up performance of the 100 MHz AT cut VCO to be worse than that of the 10 MHz SC cut reference OCXO. However, the wide tuning range of the 100 MHz AT cut VCO allows it to rapidly lock to the reference OCXO and track its warm-up performance. As a result, the 100 MHz output signal is able to reach 5×10^{-08} (with respect to the frequency at 60 minutes) in just over 3 minutes.

4. SUMMARY

The frequency stability characteristics of a VCO output in a phase locked loop are determined by the reference OCXO to which it is locked, within the loop bandwidth and by the VCO outside the loop bandwidth. By this method, references at frequencies as high as 200 MHz with phase noise floors of -168 dBc/Hz at 100 kHz offset in conjunction with high frequency stability performance matching that of low frequency SC cut quartz oscillators are able to be obtained.

Work is underway to further reduce the phase noise of the 200 MHz output to -175 dBc/Hz at 100 kHz offset from the carrier.

5. REFERENCES

[1] D. B. Leeson, *A Simple Model of Feedback Oscillator Noise Model*, Proc. IEEE L., vol. 54, pp. 329-330, February 1966.