PHASE NOISE PERFORMANCE OF SAPPHIRE MICROWAVE OSCILLATORS IN AIRBORNE RADAR SYSTEMS

T. Wallin, L. Josefsson, B. Lofter

Ericsson Microwave Systems AB, SE-431 84 Mölndal, Sweden
e-mail: thomas.wallin@ericsson.com, lars.josefsson@ericsson.com, bjorn.lofter@ericsson.com
Tel: +46 31 747 00 00, Fax: +46 31 747 11 54

Abstract

One performance limiting factor in many Radar Systems is the phase noise of the frequency reference source. Oscillators based on sapphire loaded cavity resonators with their extremely low phase noise are good candidates as frequency sources in future Radar Systems. A vibration sensitivity of $5x10^{-10}$ per g for this type of oscillator has been reported.

Phase noise performance of a compact sapphire microwave oscillator measured under realistic vibration conditions, however, has not been published. We will present results measured during random vibration corresponding to two different airborne radar applications. During the measurements the oscillator was mounted with anti-vibration suspension.

Introduction

One important property of modern Radar Systems is the ability to detect low target signatures in clutter and hostile jamming environments. The performance is dependent on the quality of the transmitted signal, the receiver, and the data processing. In many Radar Systems today, one major limiting factor for better performance is the phase noise from the High Frequency Generator, see figure 1. Due to the phase noise, weak targets can be hidden by strong unwanted echoes, even if they are separated by doppler shifts. Figure 2 illustrates a weak radar echo close to a phase noise modulated strong ground return. This is particularly critical for low target speeds (small doppler shifts). To meet future radar requirements a microwave source with a high degree of spectral purity is absolutely essential.

One of the more interesting stable frequency sources is based on a sapphire loaded cavity resonator. Extremely low noise levels have been reported in bench tests, e.g. -140 dB/Hz at 1 kHz for X-band in [1]. That is superior to what can be achieved with conventional frequency sources. Figure 3 shows a comparison between the phase noise of a sapphire microwave oscillator and a multiplied crystal oscillator. The difference is substantial.

However, the same performance in a realistic environment is not easily achieved. For the practical implementation in a system one has to consider performance under vibration. A vibration sensitivity of $5x10^{-10}$ per g for a sapphire microwave oscillator is reported in [2]. We have verified that result with the oscillator development model, shown in figure 4, also based on a sapphire loaded cavity resonator. The oscillator was subjected to random vibration and similar result as in [2] was achieved.

Vibration sensitivity is not the only parameter that determines phase noise performance in the final application. Just as important is the vibration energy spectrum and how the oscillator is mounted. The test described below aimed to show the actual performance in two different radar applications when the oscillator is mounted with anti-vibration suspension.

When using anti-vibration suspensions, it is appropriate to use an oscillator that has the mass concentrated to the physical center and also as low weight as possible. A compact design has also less mechanical resonances that can cause problems in vibration. For that reason, a rugged and compact sapphire microwave oscillator from PSI [3] was used in this test.

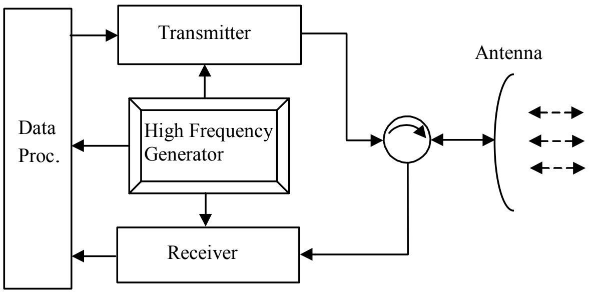

Figure 1 Simple block schematic of a radar system.

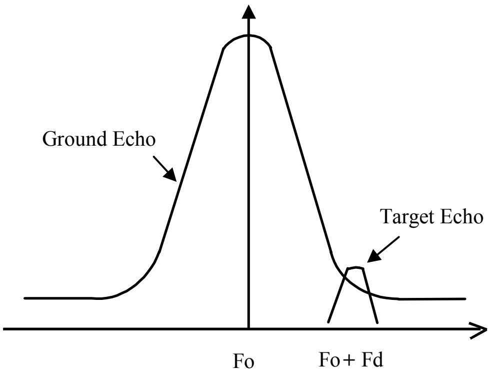

Figure 2 Received radar echo.

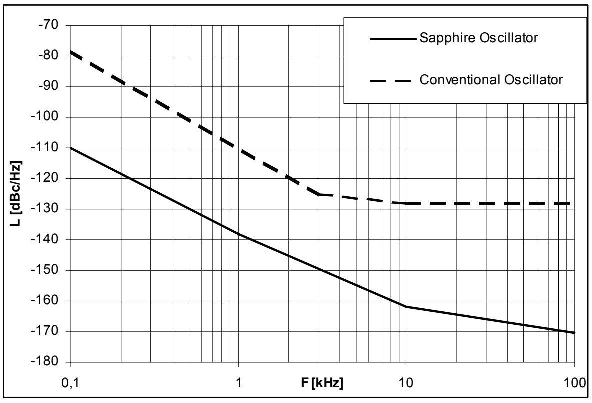

Figure 3 Comparison between a sapphire microwave oscillator and a frequency multiplied crystal oscillator, both oscillators at 9 GHz.

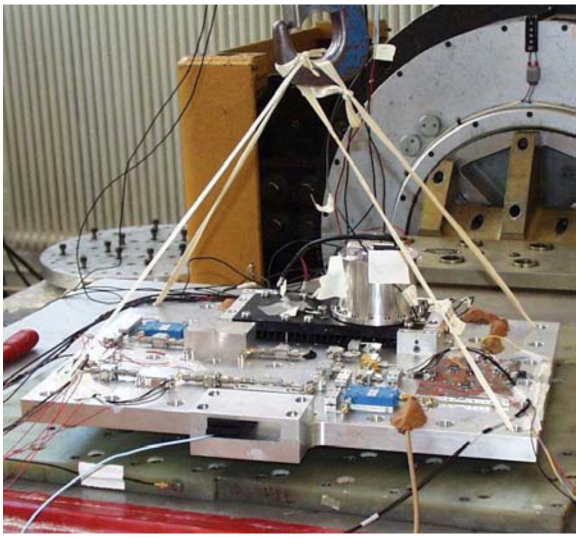

Figure 4 The oscillator development model and parts of the vibration test system facilities.

Measurement Procedure

The vibration test system used was from Ling Dynamics System model V964LS and can vibrate large and heavy objects and subject them to random vibration up to 5 kHz.

Several accelerometers were used. One of them was placed on the vibration table and was used by the vibration test system, which uses a servo loop to get the desired vibration spectrum on the table. The other accelerometers were placed on the oscillator and were used to monitor the vibration at different places.

The oscillator was mounted with vibration absorbers from Barry Controls of model GE2102-5 at each corner. The absorbers attenuate the vibration energy at relatively high frequencies but at the expense of a gain at lower vibration frequencies.

The phase noise measurement setup is shown in figure 5. A rack mount sapphire oscillator from PSI was used as reference.

The center frequency of the oscillator was 9 GHz.

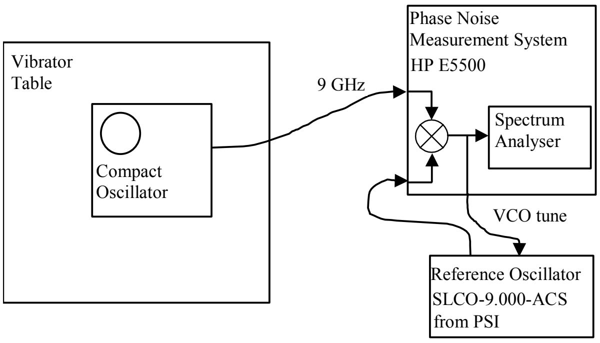

Figure 5 Measurement setup.

Phase Noise in airborne radar applications

Two measurements representing two different airborne radar applications are described below.

One of the tested vibration spectra corresponds to the level in the cabin of a commercial jet aircraft. The vibration is of random type and the level is shown in figure 6, where also the level measured on the oscillator mounted with vibration absorbers is shown. As can be seen in figure 6, the vibration absorbers attenuate the vibration energy well for vibration frequencies above about 100 Hz. This is done at the expense of a broad resonance peak around 30 Hz. The vibration table is vibrated only in one direction, but some vibration energy is transferred into the other two directions. That level is about 20 dB lower than in the primary direction.

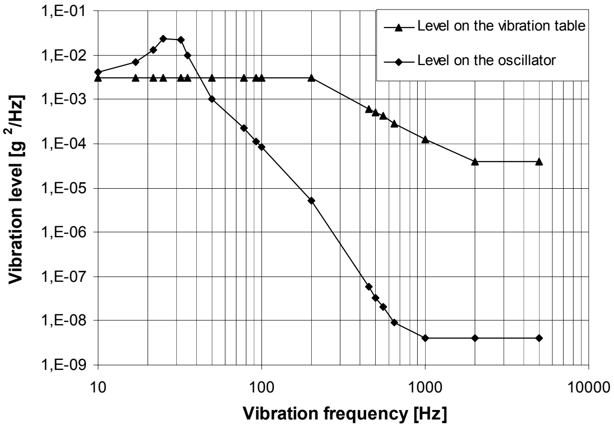

Figure 6 Vibration level in the cabin of a commercial jet-aircraft and on the oscillator.

The phase noise measured during the vibration specified in figure 6 is shown in figure 7. For frequencies above 800 Hz the measured phase noise is the same as the noise from the reference oscillator. The measured oscillator itself, on bench, has about –140 dBc/Hz at 1 kHz offset and about –160 dBc/Hz at 10 kHz,(thus, we see that the reference did not perform to this level during the test situation).

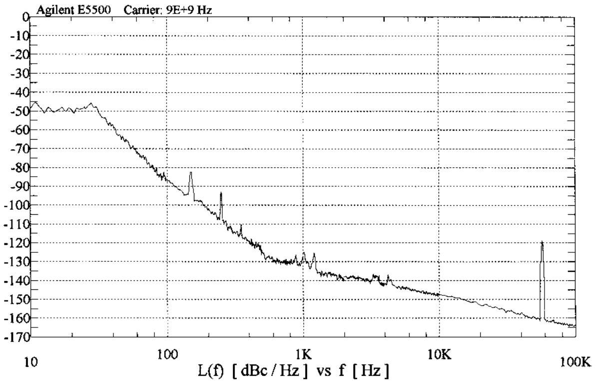

Figure 7 Phase noise of the oscillator when vibrated with the level in figure 6.

An other application is that in a fighter aircraft. One of the curves in figure 8 shows the vibration level in a fighter aircraft, but adjusted to correspond to suspension in one stage. That curve is applied to the vibration table. The other curve in figure 8 is the level measured on the oscillator. In this way the level on the oscillator correspond to what could be expected on an oscillator in a fighter aircraft, mounted with anti-vibration suspension in two stages. Suspension in two stages is most often needed in a fighter aircraft due to the relatively high vibration levels.

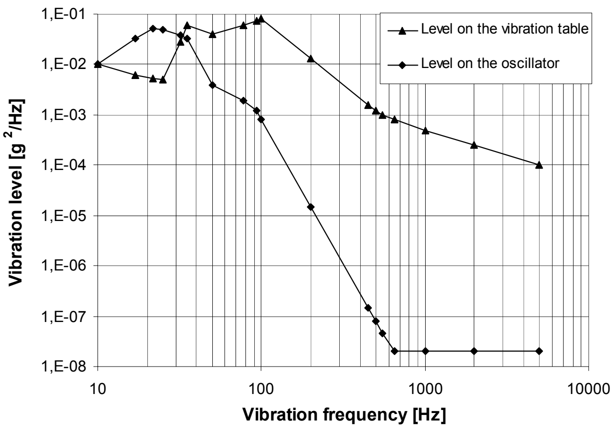

Figure 8 Vibration levels applicable for fighter aircraft.

The phase noise measured during the vibration specified in figure 8 is shown in figure 9. For frequencies above 4 kHz the measured phase noise is the same as the noise from the reference oscillator. The discrete steps in the phase noise curve are due to push type connectors inside the oscillator. New versions of the oscillator do not use these connectors.

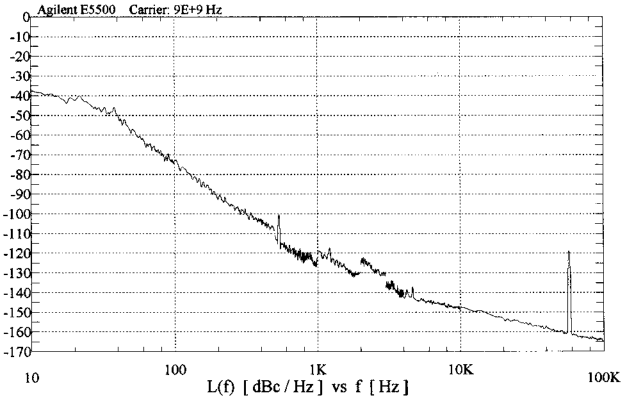

Figure 9 Phase noise of the oscillator when vibrated with the level in figure 8.

Conclusion

Phase noise measurements on an oscillator based on a sapphire loaded cavity resonator have been made under random vibration. The vibration levels represent two airborne radar applications. The measured phase noise in figure 7 and figure 9 can be compared with the curves in figure 3. We find that at offset frequencies higher than 100 to 200 Hz, the measured phase noise under vibration for the two cases is significantly lower than that of a conventional frequency multiplied source on bench (no vibration).

This means that better radar performance, in particular better ability to detect low signature targets is possible if today's sapphire microwave oscillator technology is used. Furthermore, the oscillator manufacturer has indicated that a reduction of vibration sensitivity by a factor of 2 to 5 is possible in the near future. That improvement implies an even lower phase noise (about 6 to 14 dB lower).

References

[1] C. McNeilage, J.H. Searls, P.R. Stockwell, E.N. Ivanov, M.E. Tobar, and R.A. Woode, "Advanced Phase Detection Technique for the Real Time Measurement and Reduction of Noise in Components & Oscillators*", Proc. 1997 IEEE Int. Freq. Cont. Symp.*, pp. 509-514.

[2] P. Stockwell, C.McNeilage, M.Mossammaparast, D.M.Green, J.H.Searls, "3-axis Vibration Performance of a Compact Sapphire Microwave Oscillator" *IEEE International Frequency Control Symposium, June 2001*

[3] Poseidon Scientific Instruments, see http://www.psi.com.au (date:2003-02-27)