Impact of Temperature and High Vibration in Ground, Shipboard and Aircraft Platforms on GPS-disciplined, Low Phase Noise, Time and Frequency References

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BIOGRAPHY

Timothy Tetreault is a Lead Engineer at Orolia Government Systems, Inc. His technical interests are focused on working closely with commercial and military customers to develop custom and COTS Timing & Frequency products. Tim is especially focused on improving phase noise and frequency stability of standard products under harsh vibration and temperature conditions. He has worked as an Engineer for over 30 years. He received his Bachelor of Science in Electrical Engineering Technology from the Rochester Institute of Technology.

Abstract

As more SIGINT and radar applications become reliant on GPS for timing and frequency, it is even more important to maintain accuracies in harsh environments such as vibrations and temperature. The systems designed to use GPS to generate time and frequency signals must be able to discipline the phase and frequencies while being exposed to vibration and varying temperature.

The sensitivity of oscillators to vibration, g-forces, and magnetic fields is often an overlooked factor, unnoticed until system-level or flight tests occur. Detection of this problem is difficult at the system level, since it will manifest in reduced receiver sensitivity or transmitter noise, making it difficult to isolate. It is best to consider this issue up front in the design process.

This paper describes products that Orolia has developed to address problems that can be seen on ground, ship, and aircraft platforms. Data such as phase noise plots will be presented to show the effects of vibration on standard products and products that have been designed to minimize these effects. We discuss the importance of working closely with end-users to understand the application, environmental challenges and the desired outcome.

We will also present how a combination of software, electrical, and mechanical modifications are required to meet the challenges seen in real-world applications.

INTRODUCTION

Timing and Frequency products are often subjected to different types of harsh environments, the most common being vibration and temperature. Some of the different environments that we have designed our products to deal with are:

- High/Low Frequency Vibrations
- Resonant Frequency in Chassis/System
- Temperate Change and System Response
- Effects of Magnetic Fields on Phase Noise

Each of these environments will affect phase noise in different ways and must be addressed differently, based on the customer's application and final expected results.

High and Low Frequency Vibrations

On ground, ship, and aircraft platforms, the causes of vibration can come from many sources. In the phase noise plot in Figure 1, a rack mount product was installed in a static environment. But when the phase noise was measured, a spike was found around 4KHz that caused the unit to fail its required specification.

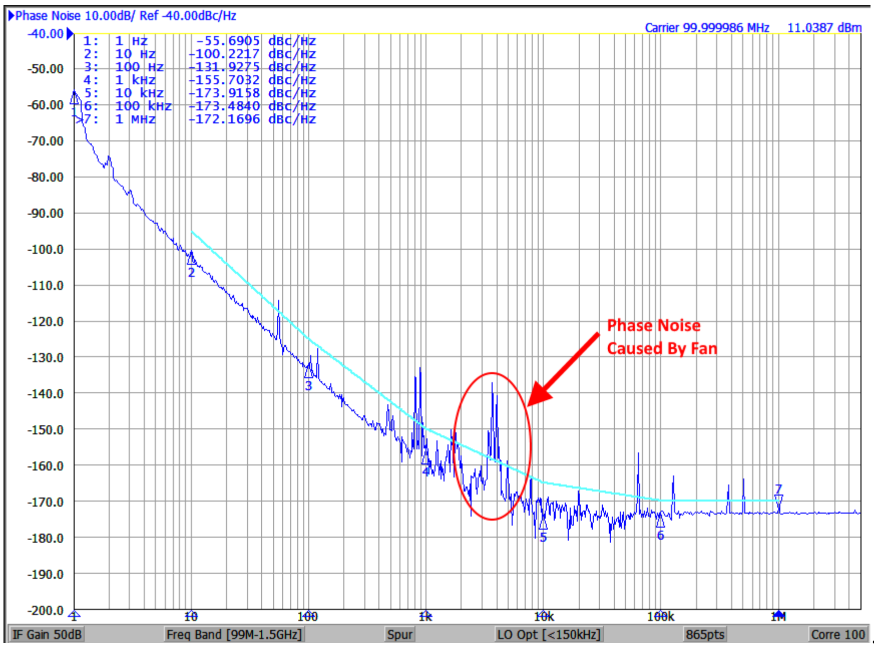

Figure 1

After additional testing, it was determined that the cause of the phase noise spike was the vibration of a cooling fan in the system. By working with our oscillator manufacture, we were able to replace the current 100MHz oscillator with a new one that had the same phase noise specifications, but also had a Low g-sensitivity of 0.01 g2/Hz (Figure 2, below). Vibrations that are higher than 100Hz to 200Hz can most often be addressed by combining a Low g-sensitivity oscillator with mechanical isolation such as cushions, springs, and stiffeners.

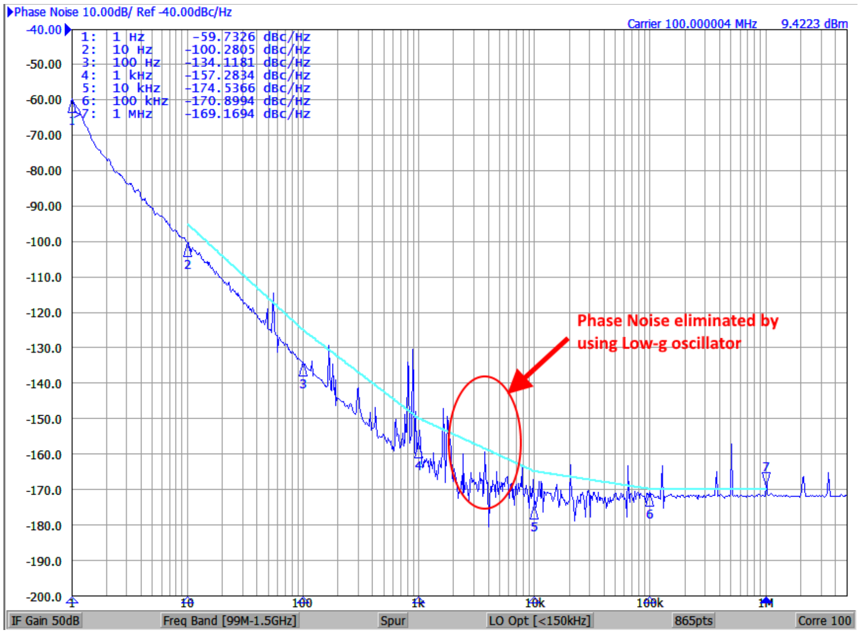

Figure 2

Dealing with Lower Frequency Vibrations

In many environments, such as shipboard applications, generated vibrations are much lower in frequency: usually, below 100Hz. With lower frequency vibrations, oscillators with only low g-sensitivity and mechanical damping will not be able to reduce the effects on phase noise. Often, mechanical solutions can cause harmonics on lower frequencies that can worsen phase noise. In these applications, it is important to minimize any mechanical harmonics that might be caused by the chassis or enclosure. Also, the use of an oscillator with electronic, active compensation is required to improve the phase noise.

Figure 3 (below) shows the phase noise for a 10Mhz output under a typical shipboard vibration profile. The configuration at this point is a standard chassis with a standard oscillator.

Figure 3

Phase noise measurement of standard product under low frequency random vibration.

Measurements made using an Agilent E5052B, Signal Source Analyzer.

Figure 4 shows the phase noise for a 10Mhz output under the same shipboard vibration profile. The configuration for this test has changed by using a ruggedized chassis with minimal harmonics and an oscillator with a Low g-sensitivity of 1ppb/g. There is an improvement in the phase noise of roughly 20dBc.

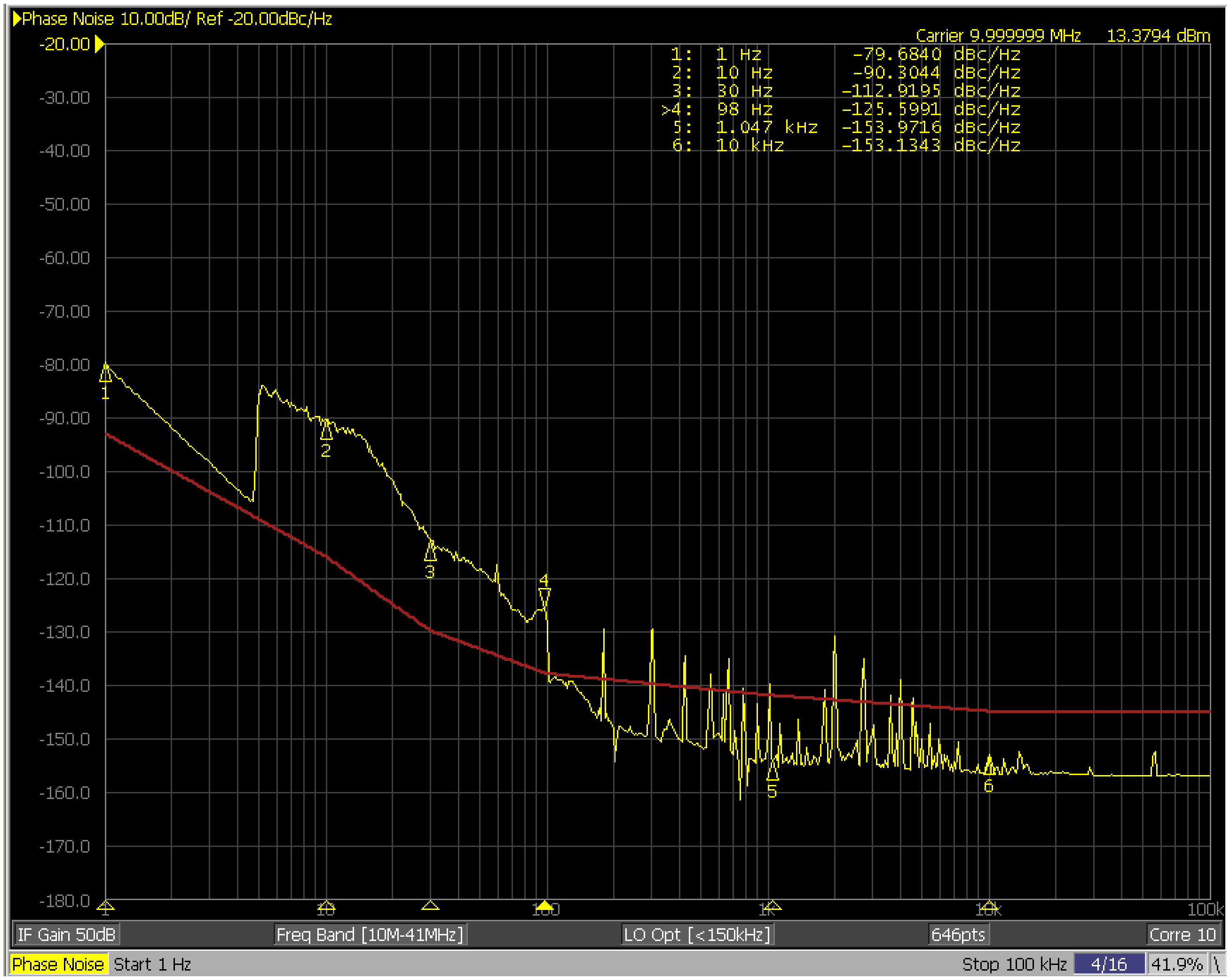

Figure 4

Phase noise measurement of 10MHz output with ruggedized chassis and low-g oscillator configuration

Figure 5 shows the phase noise for a 10Mhz output under the same shipboard vibration profile. The configuration for this test was changed by using a ruggedized chassis with minimal harmonics and an oscillator with mechanical and electronic damping.

By working closely with the customer to understand the application, we were able to develop a rugged chassis that either moved or minimized any harmonics from the operational vibration range. Also, by working closely with the oscillator manufacturer, we were able to design a custom configuration to meet the customer's phase noise requirements.

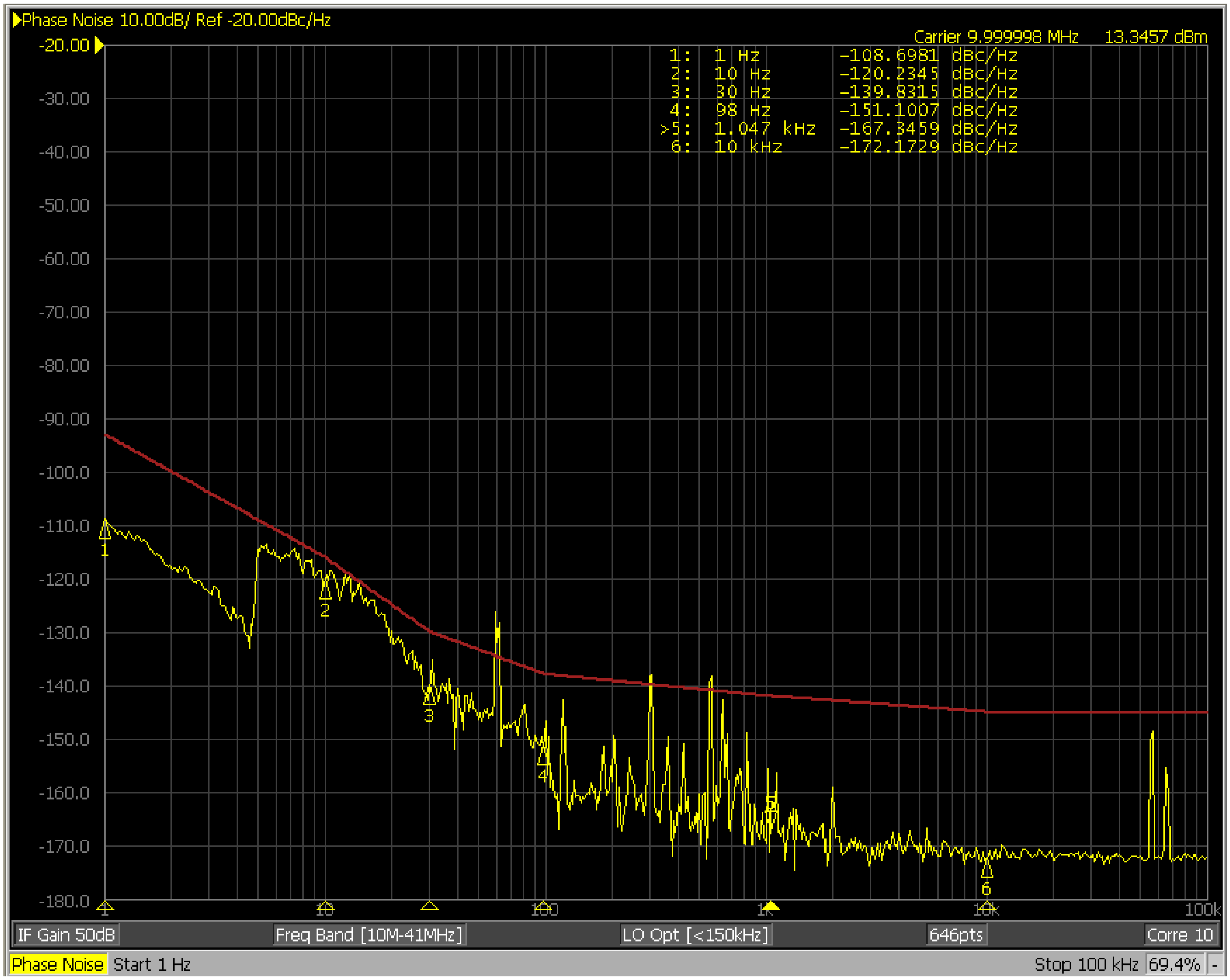

Figure 5

Phase noise measurement of 10MHz output with ruggedized chassis and hybrid oscillator with low-g sensitivity and mechanical and electronic damping.

Resonant Frequency in Chassis/System

The time and frequency systems of today are more accurate than ever. Oscillators are designed to provide better temperature stability and better phase noise response while under vibration. Large amounts of time and resources are spent to design oscillators that will meet exposure to harsh environments. But if the entire system is not designed to meet the vibration exposure, all the time and money spent on the oscillator will be wasted.

Figure 6 (below) shows a resonant frequency sweep of a standard 1U chassis. You can see that there is a large resonant frequency around 66Hz. In applications where the chassis is not exposed to vibrations, the chassis will provide a stable platform for the oscillator without any degradation to its performance.

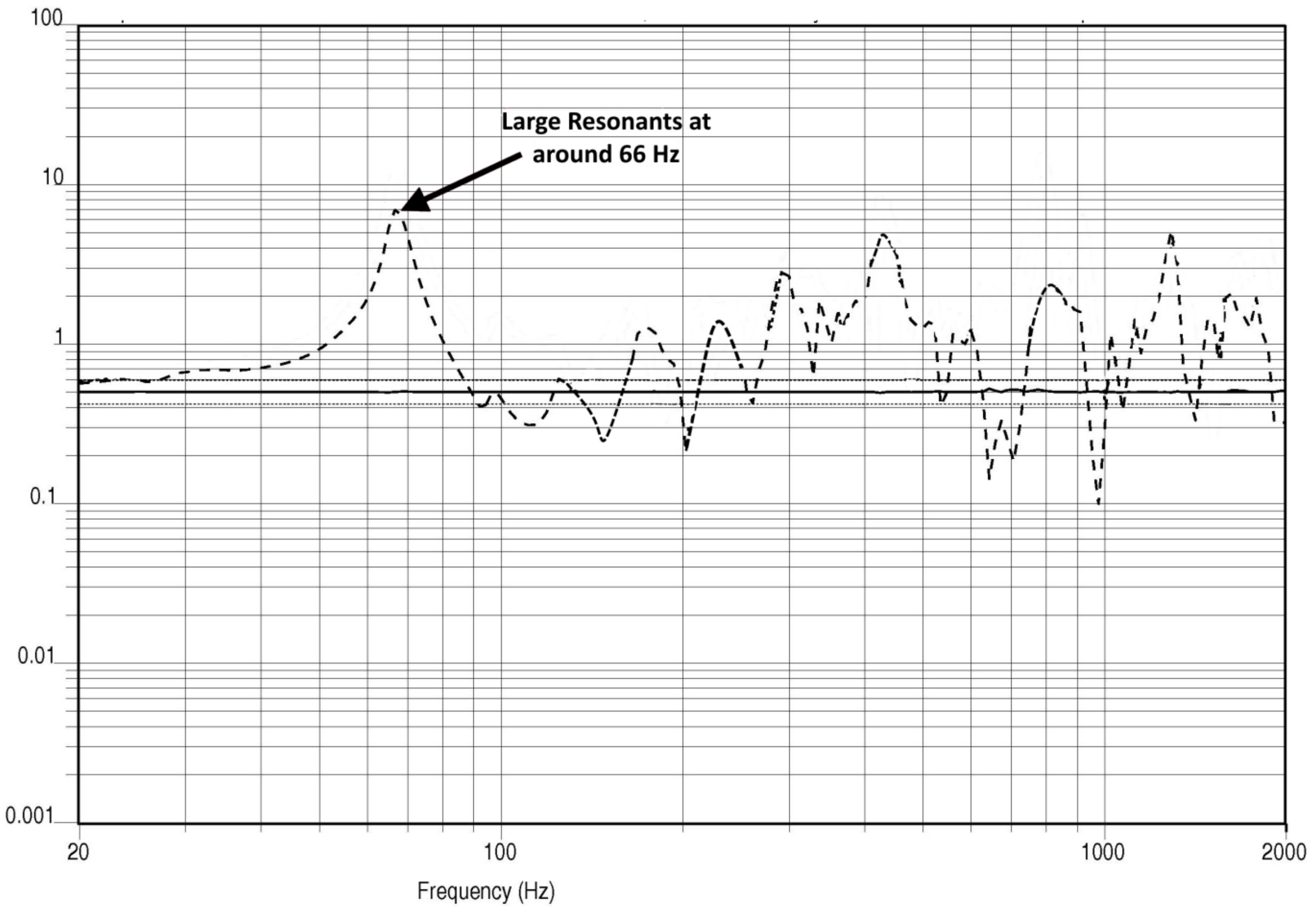

Figure 6

Resonant Frequency sweep of a standard 1U chassis

Figure 7 below shows the same resonant sweep of a standard 1U chassis but overlaid with a typical vibration profile of a Turboprop Aircraft. In an application with this vibration profile, the mechanical resonance seen around 66 Hz would substantially amplify vibrations seen by the oscillator. The performance expected by the oscillator would never be reached.

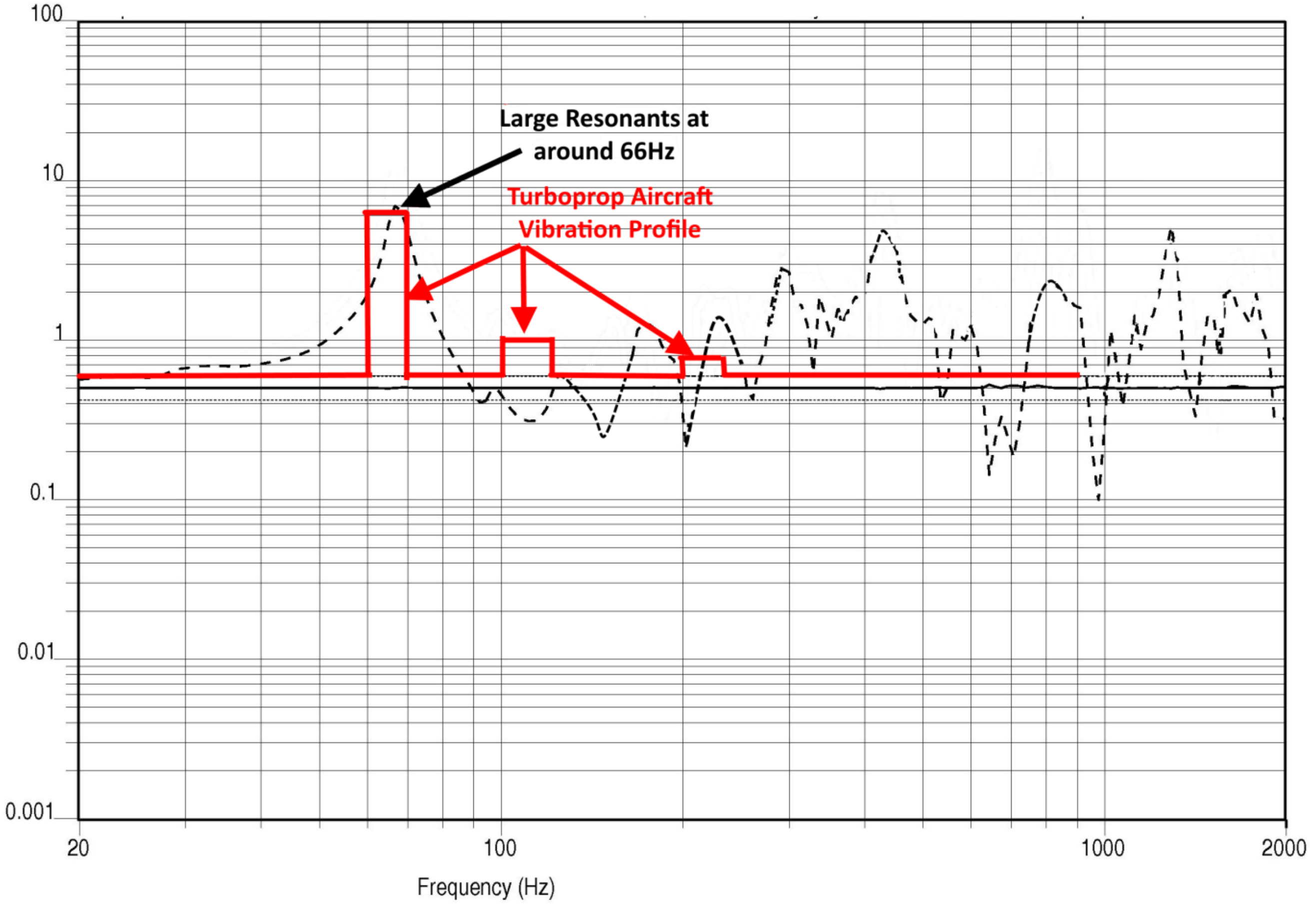

Figure 7

Resonant Frequency sweep of a standard 1U chassis with Turboprop Aircraft Vibration Profile

To minimize any mechanical resonances that may be caused by the enclosure, Orolia designed several custom chassis (Figure 8 & 9). All products are run through a resonate sweep to create models for each chassis (Figure 10 & 11).

These models are matched up to each customer's environmental conditions so that any mechanical resonates will be minimized or outside the vibration frequency range.

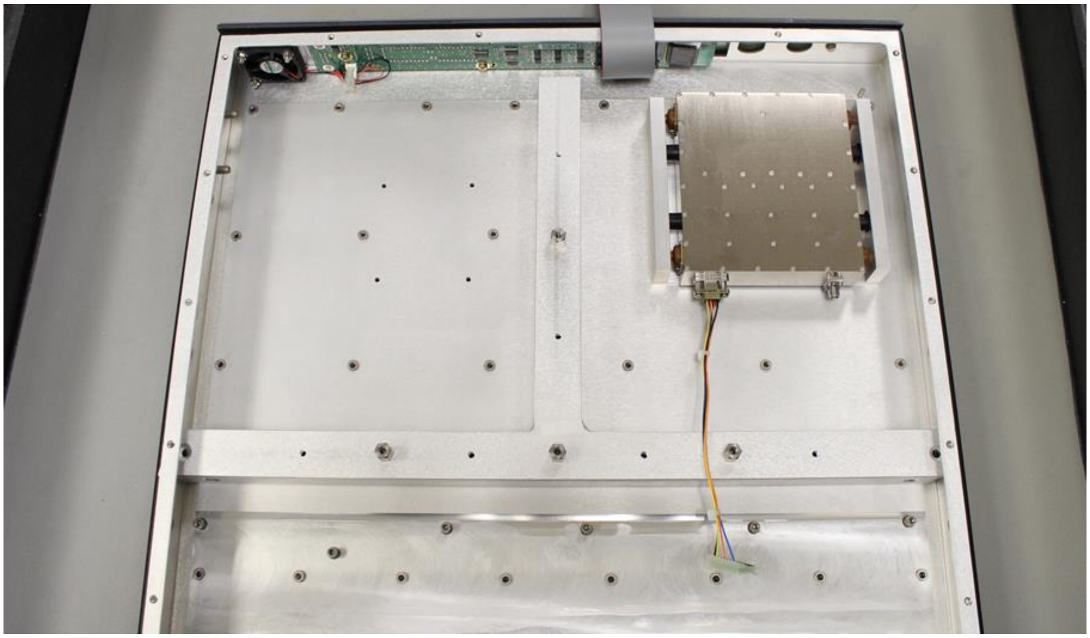

Figure 8

Custom Ruggedized 1U Chassis with stiffing plate and support

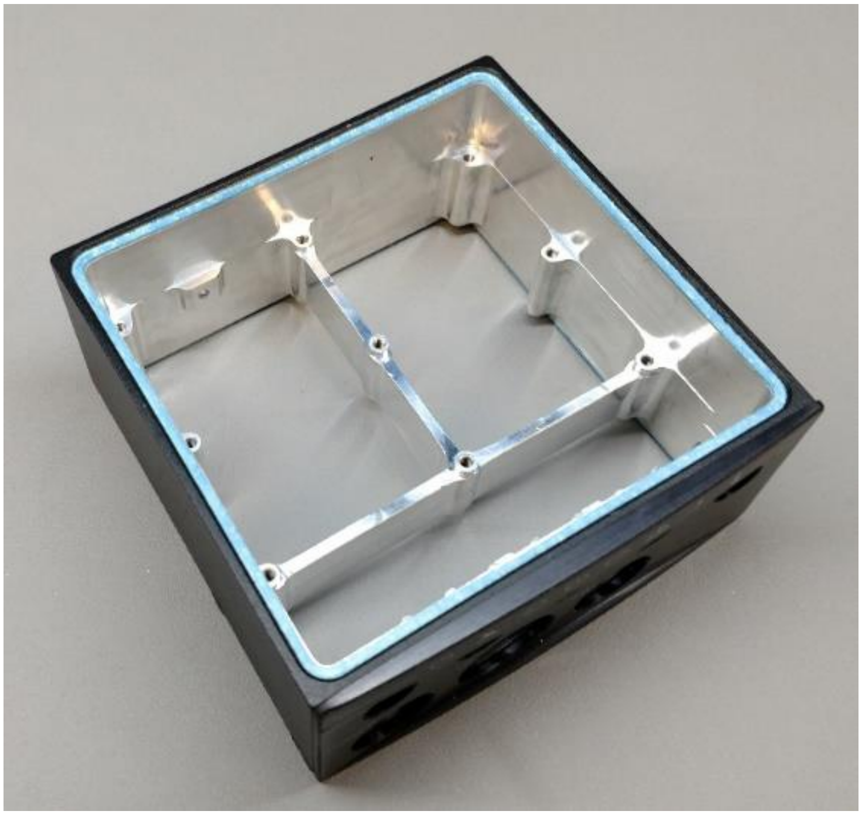

Figure 9

Custom Ruggedized Mobile Chassis with PCB supports

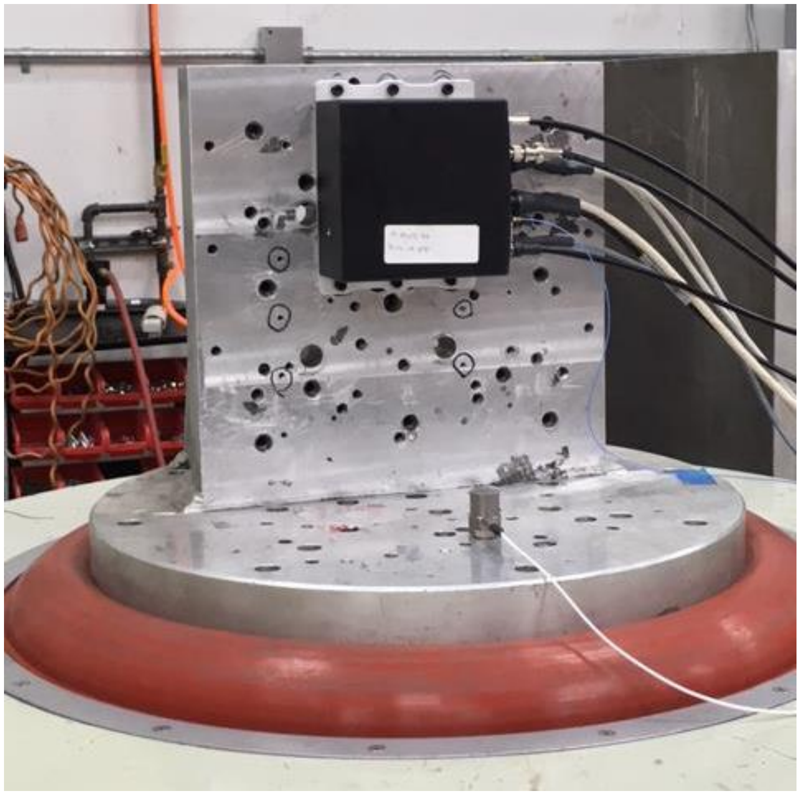

Figure 10

Custom Ruggedized Mobile Chassis undergoing a resonance sweep on an electrodynamic table

Figure 11

Custom 2U Ruggedized Chassis undergoing a resonance sweep on an electrodynamic table

Temperature Change and System Response

In most time and frequency systems, selection of the oscillator is critical to having successful results. To specify an oscillator for a system, there are several important factors that contribute to its stability. Two of the most common environmental factors that affect the performance of an oscillator are temperature and vibration. When designing a system to address these environments, it may be necessary to optimize for one while compromising on the other due to cost, size or schedule limitations.

For these reasons, at Orolia we focus on understanding the customer's application. This is critical for a successful product that meets the customer's requirements. The following is an example of one such design.

A customer approached Orolia with requirements for a Mobile PNT product that required very specific phase noise performance while under a defined vibration profile. The customer was currently using a product from a competitor that had very good stability specifications but did not meet the phase noise requirements for the 10MHz output, which was critical for their application. Using a clean-up oscillator was not an option since size and space were very limited.

After working closely with an oscillator manufacturer, we were able to come up with a solution that met the phase noise requirements while under the specific vibration profile. The new oscillator met the phase noise requirements but didn't have the same temperature stability as the customer's previous oscillator.

Below is a phase error plot of the new oscillator. T1 is the change in phase to a temperature change. T2 is the system's response to the change in phase, by disciplining the oscillator back to the GPS reference.

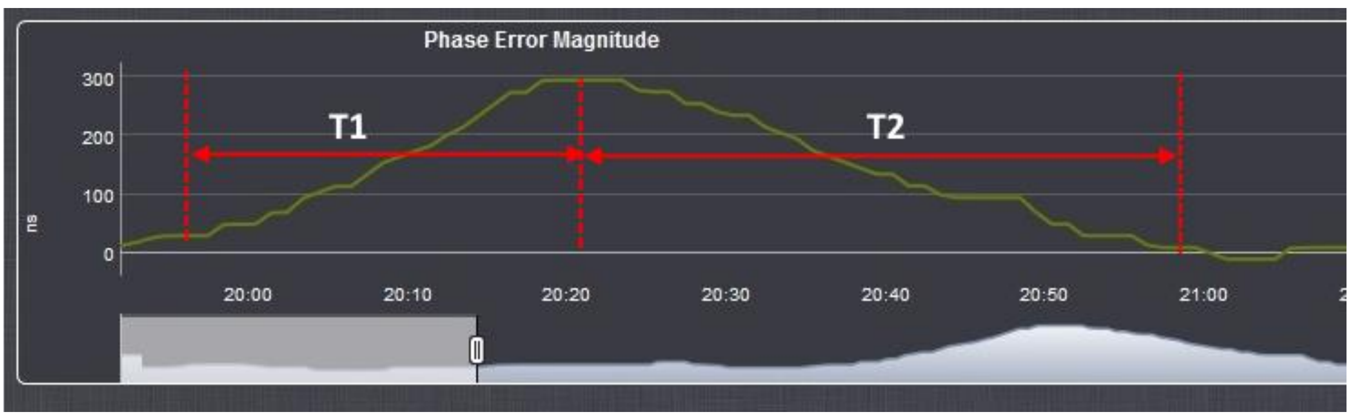

Figure 12

Recorded Phase Error caused by sudden temperature change and system response

Initially, we had the configured the disciplining to have a more aggressive, faster response to changes in phase. However, this caused two issues. The first was that the customer was phase locking a 10MHz output to their system clock. When large changes were made to the 10Mhz signal to correct for phase drift, it caused the phase lock loops to go out of lock. The second problem that was created was phase noise. Figure 13 shows the phase noise from one of Orolia's SecureSyncs. The **BLUE** plot is the phase noise from the 10 MHz output in a static state with no environmental changes occurring. The **RED** line shows the jump in the phase noise from 1 to 10Hz range when a large adjustment is made to the tuning voltage of the oscillator. The large adjustment was made to show what effect it can have on phase noise. But even small adjustment can affect the phase noise. This will show up as noise at the low frequencies between 1 and 10Hz.

Our team at Orolia was able to come up with a solution where the disciplining software was modified so that the phase lock loop in the customer's system was stable and so the phase noise of the 10Mhz output was kept below the customer requirements.

We also developed a way to pass the phase error directly from our unit to the customers system. By passing a serial message indicating the real time phase error, they were able to compensate for the drift at the system level. These kinds of solutions are only possible when both our team and the customer work closely to understand the application and the desired results.

Figure 13

Phase Noise of 10MHz output showing the effect of a large change to the oscillator's tuning voltage

Effects of Magnetic Fields on Phase Noise

When a product needs to operate in an environment with vibrations, it is common to use an electrodynamic shaker table to simulate the random vibration profiles. These tests are run along a single axis at a time, using the specific vibration profile that the Unit Under Test (UUT) will be exposed to in the field. The shaker table is also what is used to run resonant sweeps to identify potential mechanical harmonics. While these tools are invaluable for testing and verifying a product, it is important to understand the effects that the magnetic field can sometimes have on the UUT.

An example of these effects was validation testing we were doing on a new product we developed for a customer. The customer required our product meet specific phase noise specs of the 10MHz output while operating under the customers vibration profile. The product would be receiving and locked into a GNSS reference. While running the vibration profile on each axis, the phase noise results were not as expected. The test setup was inspected to check for bad cabling, loose connectors, or internal parts. The accelerometers were also inspected to ensure the vibration profile was at the correct levels.

Once all those potential problems were eliminated, we became suspicious that the issue could be related to the magnetics of the shaker table. A reason for our suspicions was that we had mounted the UUT at different positions on the table and saw different phase noise results.

To verify that magnetics were the cause of the phase noise, we developed a test using a cart that would support the unit above the table while the table ran the vibration profile. Figure 14 shows the test setup.

Figure 14

Test setup for measuring the effect of magnetic field on phase noise

We first ran the UUT with the table turned off so that we could measure the phase noise and create a base line plot (see Figure 15). We then made the same phase noise measurement with the shaker table running the profile while the UUT was held, floating above the table. The phase noise plot showed that even though the UUT was not attached to the table, the effects of the vibration profile were still affecting the 10MHz output. In further tests, we backed away the UUT by 12" at a time; the effect to the phase noise dropped with each move away from the magnetics. We repeated this test for each axis and had similar results.

After removing the effects of the magnetics on the phase noise from the testing, we found that the phase noise matched the expected phase noise as designed.

In the end, there were no requirements for environmental magnetic susceptibility, but it was important to understand the effects so that we could show the product had met its requirements. We also were able to apply what was learned to future testing and to better placement of the UUT as to minimize the magnetic effects.

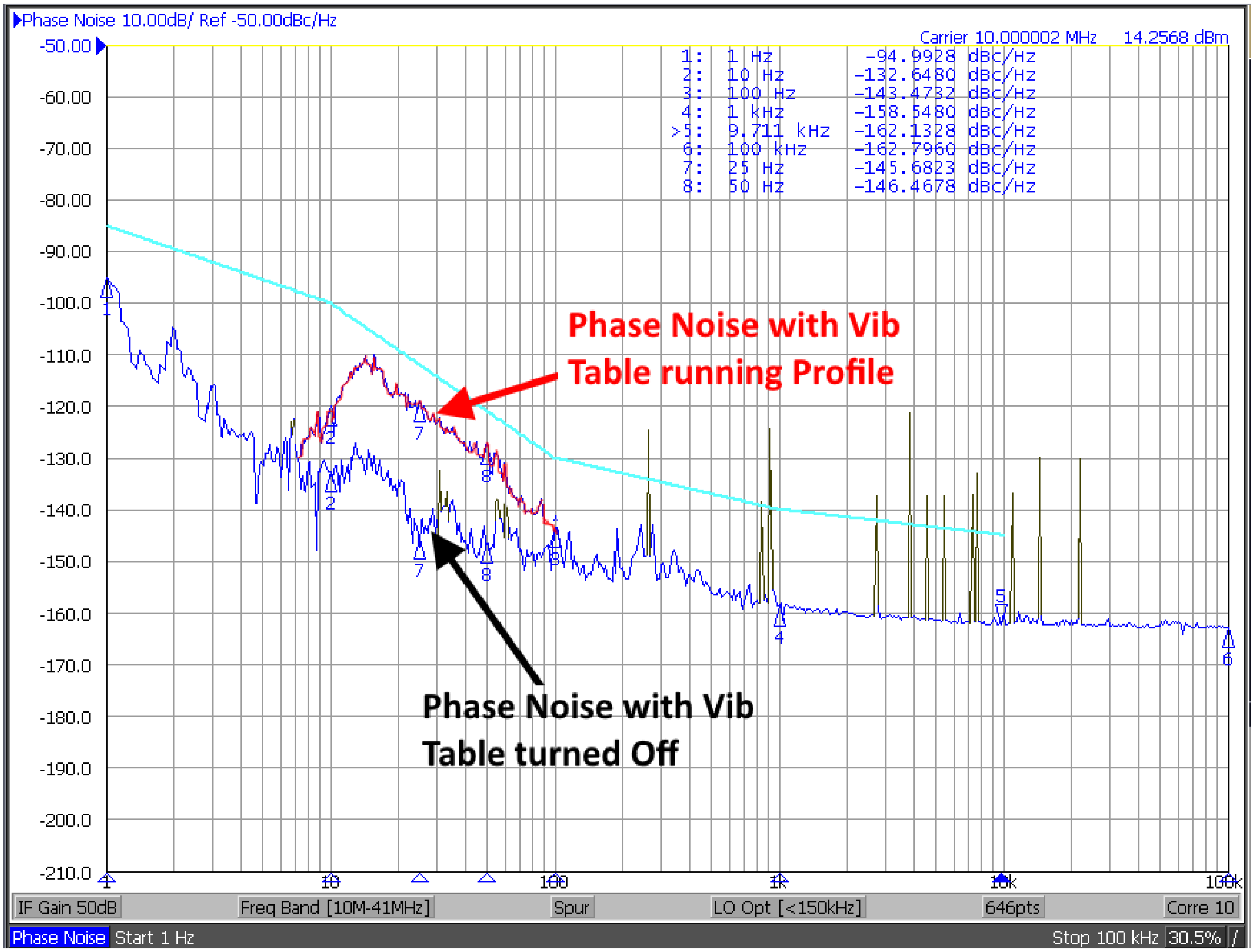

Figure 15

Phase Noise from a 10MHz output showing the effects of Magnetics from a Shaker Table

CONCLUSION

The understanding of a customer's application and required specifications are critical to a successful outcome. Spending the time at the proposal stage to fully understand the different environmental effects on the system will save time and money on a project.

It is important to have a group of people with experience in software, hardware and mechanical engineering to support all aspects of the challenging environments that Timing and Frequency systems are exposed to. We at Orolia have people with years of experience working with customers and partnering with venders to provide solutions for land, sea, or air applications.

STANDARDS

[1] MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests