Application Report
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Vibration and Shock Sensitivity: A Comparative Study of Oscillators

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ABSTRACT

When designing a system that incorporates a clock oscillator, the vibration sensitivity of the oscillator device is a specification that is easily overlooked. Sensitivity to vibration can have a detrimental impact on the overall system performance. Since crystal oscillators fundamentally rely on the vibration and mechanical resonance of a piezoelectric material, external disturbances can couple into the device and degrade its performance. These external disturbances can result in output frequency shifts, elevated phase noise and spurs. Mechanical shocks of sufficient magnitude can also cause irreversible frequency shifts at the output of the crystal oscillator.

In the tests outlined in this study, the TI oscillator exhibited an order of magnitude improved resilience to vibration versus two competitor offerings. It also had the least frequency perturbations in response to mechanical shock. Test procedure details and measured results are presented in the following sections.

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(1) "MIL-STD-883H, Test Method Standard, Microcircuits." Department of Defense. 26 February 2010.

1 Introduction

Table 1 below shows typical levels of acceleration that a device might experience in various operating environments. Sources of vibration are present anywhere from inside a moving vehicle or aircraft, to a handheld mobile device. Systems are also susceptible to vibrations from sources such as cooling fans in the equipment chassis. The performance of aircraft radar, for example, is directly related to the reference oscillator phase noise in the system. Vibration induced elevated phase noise translates to the blurring of targets and a decrease in accuracy of detection. Medical imaging and ultrasound applications are also quite sensitive to vibration. In these systems, the reference oscillator phase noise limits the maximum achievable resolution, so the system must be resilient to vibration to operate reliably.

Table 1. Typical Acceleration Levels in Various Environments(1)

ENVIRONMENT	TYPICAL ACCELERATION (G's)
Buildings, quiescent	0.02 rms
Tractor-trailer (3-80 Hz)	0.2 peak
Armored personnel carrier	0.5 to 3 rms
Ship - calm seas	0.02 to 0.1 peak
Ship - rough seas	0.8 peak
Railroads	0.1 to 1 peak
Propeller aircraft	0.3 to 5 rms
Helicopter	0.1 to 7 rms
Jet aircraft	0.02 to 2 rms
Missile - boost phase	15 peak

(1) John R. Vig, “Quartz Crystal Resonators and Oscillators,” US Army Communications-Electronics Research, Development & Engineering Center. January 2004.

The LMK6xxx family of high-performance fixed and programmable oscillators from Texas Instruments (TI) is resilient to the effects of vibration and mechanical shock. Integrated circuit (IC) packaging and layout techniques are optimized to minimize the coupling of external vibrations through the body of the device to the resonating element.

To test resilience to vibration, three tests were performed on the LMK61E2, the flagship oscillator from TI, and a similar PLL-based oscillator from another vendor. A surface acoustic wave (SAW) based oscillator from competition was also added to the test for vibration sensitivity to compare different oscillator technologies. The units were first subjected to sinusoidal vibration at various frequencies along x, y and z directions. The test was repeated a second time along each axis with random vibration profiles. The final test measured the transient frequency deviation of the units during operation in response to mechanical shock. Phase noise (including spurs) and frequency excursion data was recorded during the tests.

2 Test Setup and Procedure

2.1 General Setup

Table 2 lists the 3 devices tested as part of this comparative study. The TI LMK61E2 and Silicon Labs Si536 utilize a quartz resonator and an internal PLL to synthesize output frequencies (156.25 MHz for this study). The third device selected for the test was an Epson EG-2102CA 125 MHz fixed frequency SAW-based oscillator. The measured data for the Epson device was normalized with respect to frequency to give an accurate representation of relative performance.

Table 2. Devices Tested and Their Specifications

LABEL	MANUFACTURER	PART NUMBER	TECHNOLOGY	FREQUENCY	OUPUT
TI	Texas Instruments	LMK61E2-SIA	XO + PLL	156.25 MHz	LVPECL
SL	Silicon Labs	536AB156M250DG	XO + PLL	156.25 MHz	LVPECL
EP	Epson	EG-2102CA 125.0000M-PHPAL3	SAW	125 MHz	LVPECL

All devices were installed on identical boards for testing. The board was square shaped with the oscillator mounted in the center and standoffs at each corner so that when mounted to a test fixture, vibrations couple into the device uniformly. The board was also designed to minimize extraneous components that could affect the response of the measurement system to vibration, leading to incorrect conclusions. In addition to connectors for the output signal and power, the only other components on the boards were power supply filtering capacitors and LVPECL output passive termination components.

The test fixture for vibration and shock transmitted accelerations along one axis. To test the devices in all axes with minimum re-configuration, the three boards (one with each device under test, or DUT) were mounted to a metal plate. A fourth board for which data was not taken was added to each plate to even the weight distribution on the plate. Three of these plates were then prepared and mounted on different sides of a metal cube attached to the test fixture. The plates were oriented on the cube such that movement of the cube in one axis transmits accelerations in a different axis for each plate and set of devices. Figure 1 and Figure 2 depict the finished cube setup.

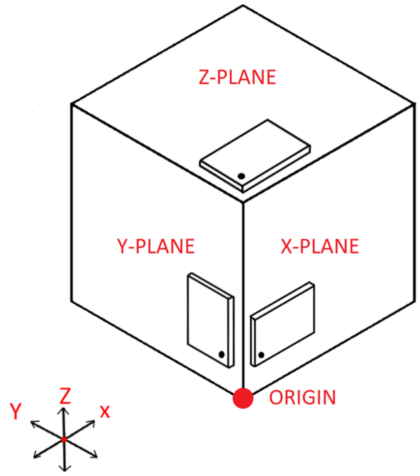

Figure 1. Orientation Of The Devices On The Cube With respect To Pin 1. Movement Of The Cube Is Along The Z Axis.

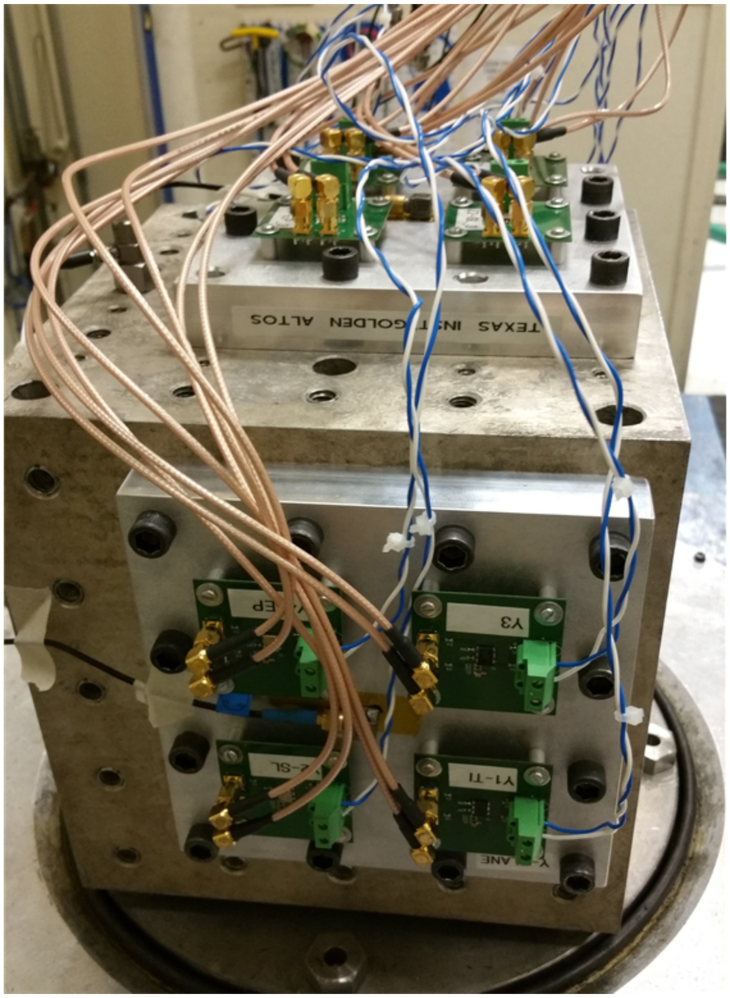

Figure 2. Photo of Vibration Test Equipment

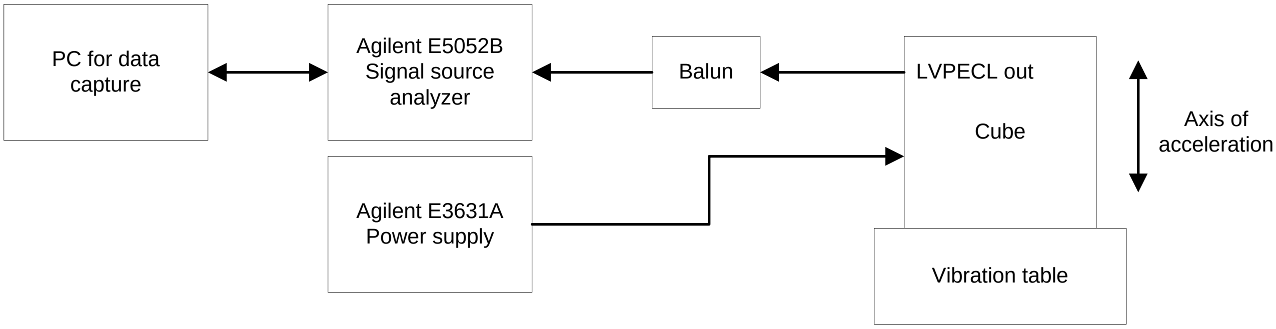

Figure 3. Sinusoidal and Random Vibration Test Setup Diagram

Figure 3 shows the sinusoidal and random vibration test setup. In this test, the cube was mounted on a vibration table which subjected the units under test to an acceleration of a specific magnitude along one axis. The DUTs were all powered by a bench power supply. LVPECL differential outputs from the DUTs were converted to single-ended waveforms before being measured by a signal source analyzer (SSA). The output clock phase noise and frequency data was then transmitted from the SSA to a PC.

2.1.1 Test 1: Sinusoidal Vibration

The vibration table was set for a peak acceleration of 4-g. A dwell time of 1 minute was allowed before taking data to rule out settling effects. The vibration frequencies selected for the test were: 15 Hz, 30 Hz, 60 Hz, 100 Hz, 300 Hz, 600 Hz, 1000 Hz, and 2000 Hz.

Vibrations at a specific frequency manifest as spurs on the output clock phase noise plot that occur at the corresponding offset from the carrier frequency. The magnitude of these spurs, in dBc, was recorded and converted into parts per billion (ppb) frequency shifts. Finally, the ppb value was normalized by the peak acceleration of 4-g to obtain a frequency shift per g of acceleration value (ppb/g), which is a measure of resilience to vibration for an oscillator.

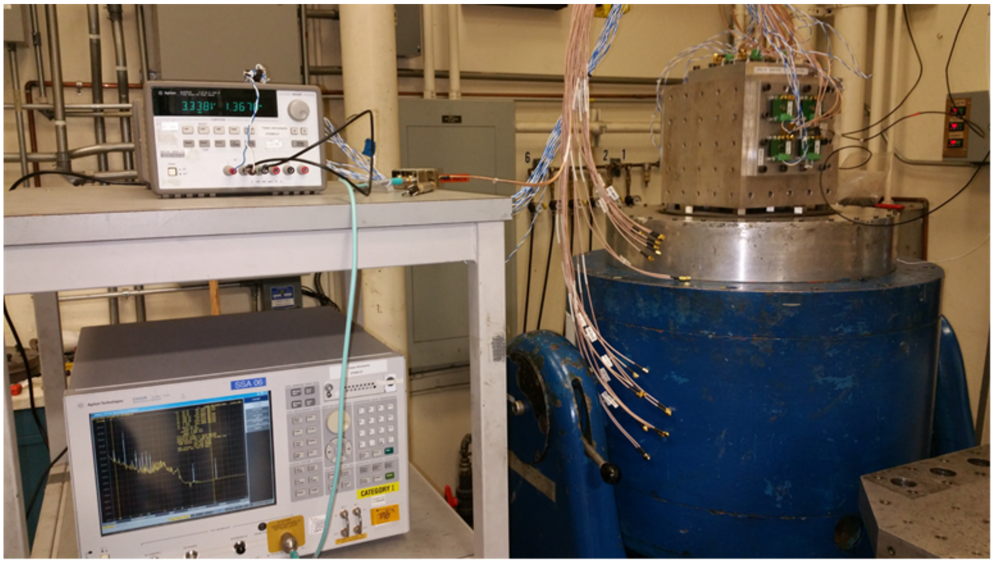

Figure 4. Vibration Test Setup Showing Cube On Vibration Table With The DUTs Connected To A Power Supply And Signal Source Analyzer

2.1.1.1 Random Vibration

In this test, the cube was subjected to accelerations with random frequency content that mimicked a real world application. The test setup was similar to the previous one where we measured the impact of sinusoidal vibration. For the random vibration test, the vibration table was set to generate an acceleration profile as defined by MIL-STD-883H, Method 2026, Condition B. (1) This profile subjects the DUTs to an acceleration of 7.5-g rms.

Random vibrations also increase oscillator phase noise. The test hardware generated random vibration over the specified frequency range, based on the power spectral density level as shown in Figure 5. Since the vibration was spread over a range of frequencies, there was an overall increase in the phase noise of the output clock from the DUT rather than just spurs at specific frequency offsets. The integrated RMS phase jitter values were measured over an integration band from 15 Hz to 10 kHz, which was approximately the range of vibration frequency content generated by the vibration table according to MIL-STD-883H. Measurements were taken with and without the vibrations present and the RMS jitter difference between the two cases was calculated to determine the jitter induced by the vibration for each DUT.

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(1) "MIL-STD-883H, Test Method Standard, Microcircuits." Department of Defense. 26 February 2010.

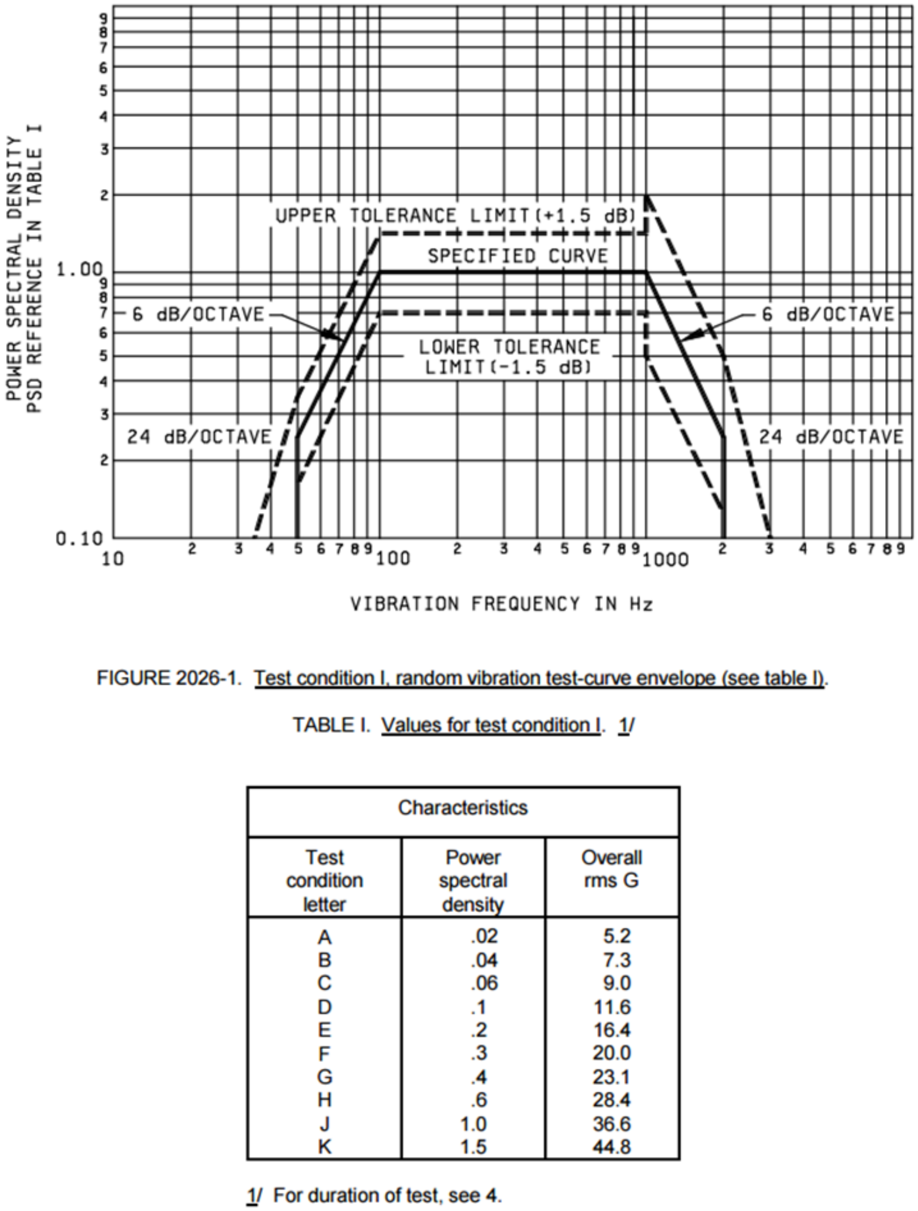

FIGURE 2026-1. Test condition I, random vibration test-curve envelope (see table I).

TABLE I. Values for test condition I. 1/

Characteristics		
Test condition letter	Power spectral density	Overall rms G
A	.02	5.2
B	.04	7.3
C	.06	9.0
D	.1	11.6
E	.2	16.4
F	.3	20.0
G	.4	23.1
H	.6	28.4
J	1.0	36.6
K	1.5	44.8

1/ For duration of test, see 4.

Figure 5. MIL-STD-883H, Method 2026: Random Vibration [2]

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[2] "MIL-STD-883H, Test Method Standard, Microcircuits." Department of Defense. 26 February 2010.

2.1.2 Test 3: Mechanical Shock

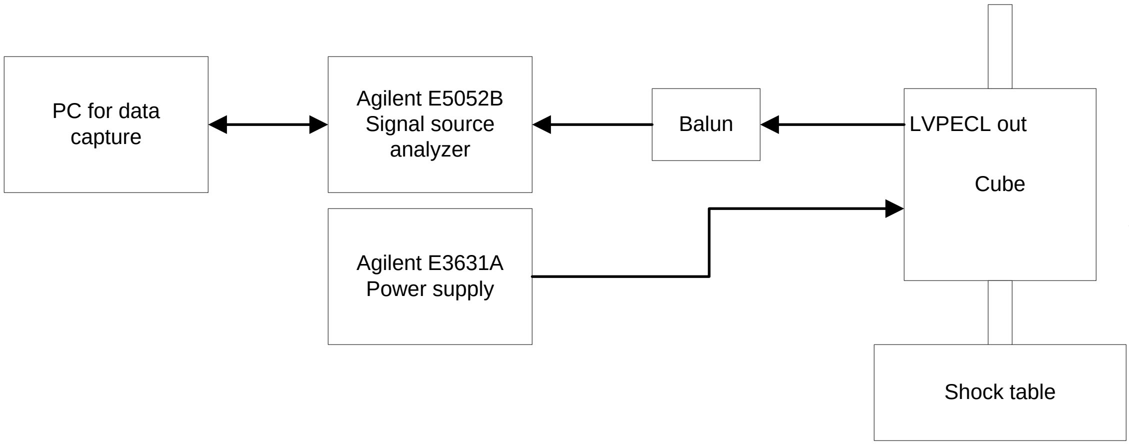

Figure 6. Shock Test Setup Diagram

In this test, the cube was subjected to an impulsive acceleration to determine the impact of shock on the DUT output frequency. Instead of the cube being mounted on a vibration table, it was attached to a guide rail on a shock table which allowed the cube to be lifted and then dropped in a controlled manner, resulting in mechanical shock when it hit the table. Also, only 1 DUT was attached to the cube at a time, to avoid causing damage to units not being tested. The shock applied is defined by MIL-STD-883H, Method 2002, Condition A. (3) This profile subjects the DUTs to a 1 ms half sine wave shock pulse with an acceleration of 500-g.

A shock impact could result in a momentary output frequency excursion or in extreme cases a permanent shift in the operating frequency. Data was measured using the transient mode of the signal source analyzer to record the output frequency every 100 μs for a 10 second duration surrounding the moment of impact. Three trials were run to account for any inaccuracy that may have resulted from the frequency excursion falling within the sampling interval. The worst case frequency deviation and any persistent frequency offset after the impulse was then used to compare the resilience of the DUTs to shock.

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(3) “MIL-STD-883H, Test Method Standard, Microcircuits.” Department of Defense. 26 February 2010.

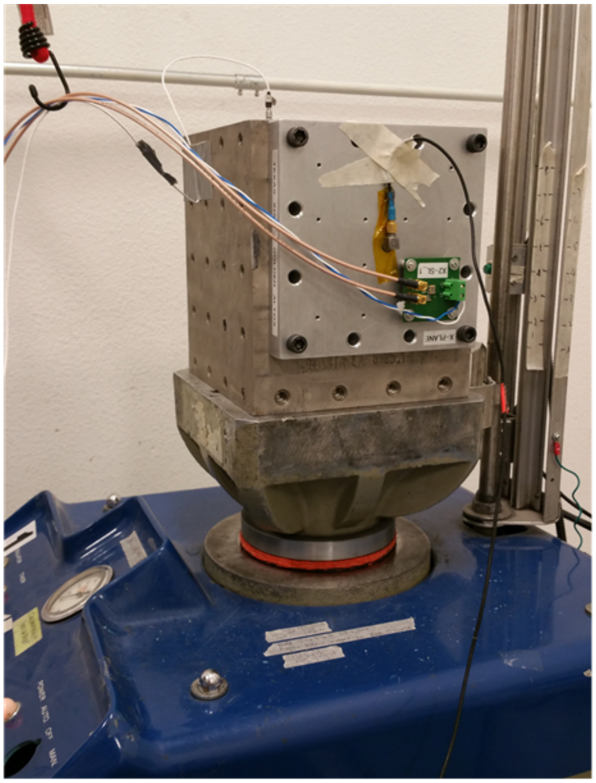

Figure 7. Shock Test Setup Showing Cube On Shock Table And Guide Rail. Only 1 Dut Is Attached At A Time To Avoid Causing Damage To The Others.

3 Data and Results

3.1 Test 1: Sinusoidal Vibration

The two PLL based oscillators showed roughly similar levels of sensitivity to sinusoidal vibration. The average frequency shift per ‘g’ of acceleration also did not change significantly as the frequency was varied for any of the devices. The TI oscillator showed less sensitivity than the other PLL based device at 1 kHz of vibration along the Y-axis, but in general, the devices had comparable performance. The Epson SAW oscillator was the most sensitive to sinusoidal vibration, exhibiting an order of magnitude more frequency shift along the X and Z axes.

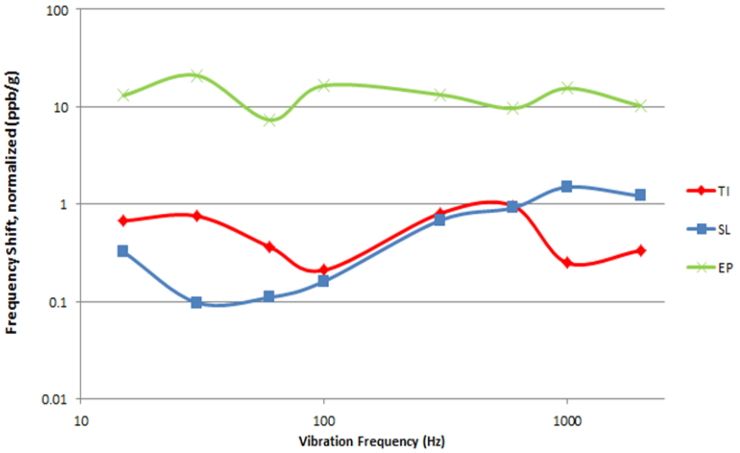

Figure 8. Sensitivity To X-axis Acceleration Over Frequency Of Vibration. Lower Is Better.

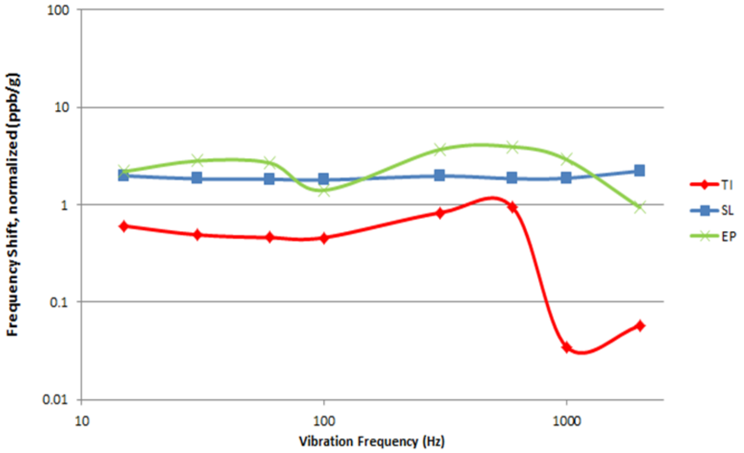

Figure 9. Sensitivity To Y-axis Acceleration Over Frequency Of Vibration. Lower Is Better.

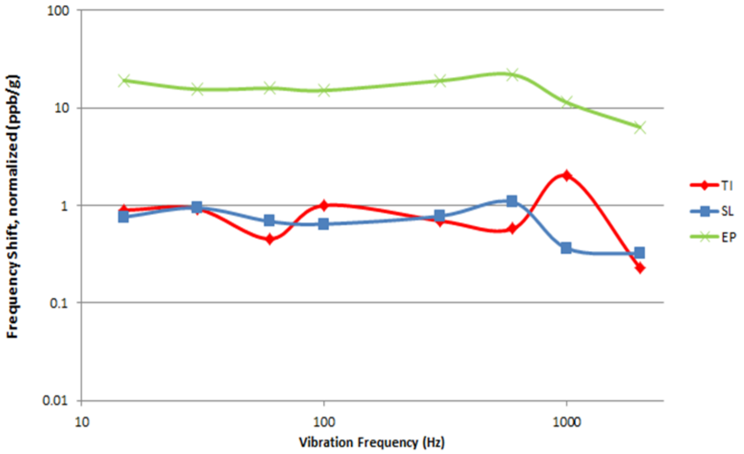

Figure 10. Sensitivity To Z-axis Acceleration Over Frequency Of Vibration. Lower Is Better.

3.2 Test 2: Random Vibration

The TI oscillator clearly stood out with superior vibration resistance when subjected to random vibration. It exhibited the lowest average induced phase jitter out of the devices tested. Its performance exceeds that of the Silicon Labs part along every axis of vibration, with about 25 times less induced jitter along the Z axis. The Epson SAW oscillator was again the most vibration susceptible device in the test group, with the worst average induced jitter. The fact that the induced jitter can sometimes exceed 100 ps RMS, which is significantly higher than baseline values, underscores the importance of considering vibration when designing an oscillator into a system.

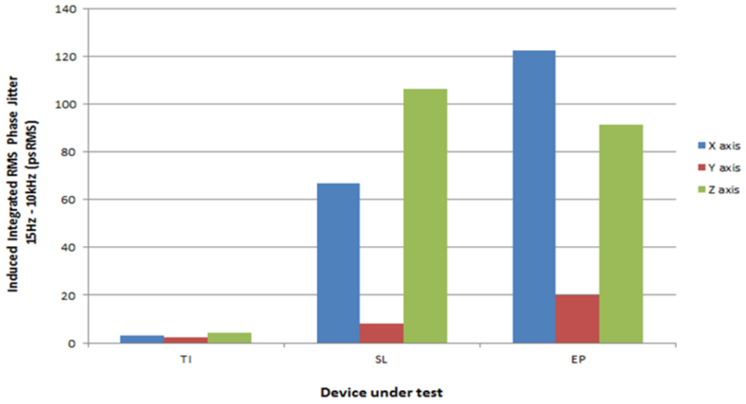

Figure 11. Phase Jitter Induced by Random Vibration. Lower Is Better.

3.3 Mechanical Shock

The shock test data was fairly consistent with the results of the random vibration test. The TI oscillator exhibited significantly less frequency shift compared to the device from Silicon Labs. Neither device showed a permanent shift in output frequency after the impulse was removed. However, the test was performed at the lowest acceleration level under the MIL-STD-883H. Increasing the shock to a high enough level could cause permanent damage, so applications wherein high shock impact is plausible, additional testing is recommended.

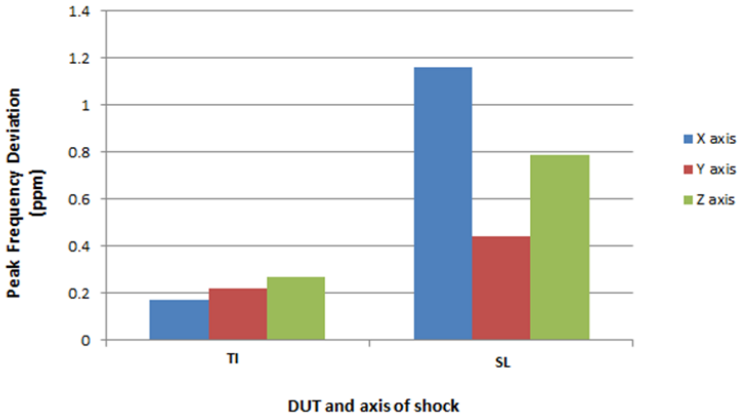

Figure 12. Frequency Deviation in ppm Under 500-g Shock. Lower Is Better.

4 Conclusion

When designing a clock oscillator into a system, the impact of vibration is often overlooked. However, as demonstrated above, oscillators with similar specifications can exhibit vastly different behaviors when subject to vibration or shock, possibly resulting in the addition of tens of picoseconds of jitter and violation of design requirements. TI's LMK61E2 and LMK6xxx family of oscillators are engineered with robustness in mind and the tests performed in this study demonstrate the effectiveness of their design. The vibration and shock resilience of TI oscillators complements their ultra-low phase noise, making Texas Instruments the optimal choice for current and next generation high performance systems

5 References

Vig, John R. "Quartz Crystal Resonators and Oscillators." US Army Communications-Electronics Research, Development & Engineering Center. January 2004.

"MIL-STD-883H, Test Method Standard, Microcircuits." Department of Defense. 26 February 2010.

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