ACCELERATION SENSITIVITY STUDY FOR COMMERCIALLY AVAILABLE SAW OSCILLATORS

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ABSTRACT

SAW stabilized oscillators are currently being considered for use in many future military systems. In operation, these devices will be subjected to harsh environmental conditions including temperature, humidity and vibration. This study was initially devised to accomplish two objectives. The primary objective was to determine the feasibility of using commercially available SAW oscillators to meet the stringent acceleration sensitivity requirement of 10^{-11}/g needed for state-of-the-art military applications. The second objective was to establish a performance baseline of acceleration sensitivity since there was very little preexisting data for use by system developers. However, when the acceleration sensitivity data collected for the various oscillators was correlated with the physical attributes of the oscillator circuits and SAW resonators, more general design guidelines could be inferred from the data for the production of vibration insensitive oscillators.

INTRODUCTION

The severe military operation environment under which modern Army weapons systems must operate produces a set of demanding performance requirements on the components that make up the system. This is particularly true when the equipment is mounted on mobile military system platforms which include fixed wing, rotary wing and wheeled or tracked vehicles which produce severe vibrations for on-board electronics. These induced conditions not only introduce mechanical failures into equipment due to stress and fatigue, but also cause degradation in the electronic performance which is less widely understood.

Among the various electronic performance parameters, the acceleration sensitivity of the crystal oscillators has for some time been recognized as one of the limiting factors in the ultimate performance of military equipment. The improved system performance which can be achieved by reducing the vibration sensitivity of crystal oscillators can often be dramatic. A 12 dB improvement in oscillator phase noise under vibration can either double the detection range of a radar system for a constant target size, or reduce the required target cross section for detectability by a factor of 16 for constant range.

Oscillators tested in this study have exhibited acceleration sensitivities ranging from 2×10^{-10} to 4×10^{-8}/g. The range of responses exhibited by the oscillators was as myriad as the number of oscillators tested and several informative results were observed from the test data.

TEST SYSTEM AND PROCEDURE

A computer-controlled shake table system was employed to test each SAW oscillator, details are described in Reference 1. During testing, each device was subjected to a sinusoidal acceleration of 2 g's. Two accelerometers were mounted on the test fixture. One was used in a feedback loop to maintain a peak acceleration level of 2 g's along the desired test axis, while the other was used to measure any unwanted transverse acceleration. The vibration frequency was swept from 90 Hz to 9990 Hz during testing. If the device was a VCO, tuning voltage was also varied. At each vibration frequency (and each tuning voltage, where applicable), measurements are taken of the power levels and frequencies of the carrier, the first upper sideband and lower sideband. The acceleration sensitivity is calculated by the computer software using the average of the first sideband power levels, the vibration frequency, the carrier frequency, and the peak acceleration along the test axis.

Acceleration sensitivity was measured along three orthogonal directions using the axial convention indicated in Figure 1. The three components of the acceleration sensitivity vector Γ are denoted by Γ_x, Γ_y and Γ_z.

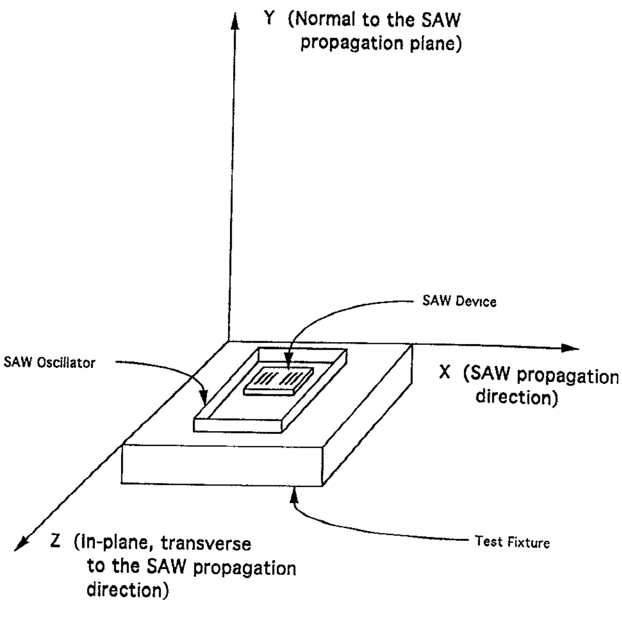

Figure 1 Axial Convention for Vibration Study

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For SAW oscillators, the first sideband-to-carrier power level ratio $\pounds_v^1(f)$ often exceeds -26 dBc, resulting in a modulation index, ß, which is greater than 0.1. In order to accurately calculate the acceleration sensitivity under these conditions, the "moderate" modulation index approximation is utilized [2].

Limitations in the measurement system have been discussed previously [3]. Errors arise from the measurements of four quantities: vibration frequency, peak acceleration, carrier frequency and sideband-to-carrier power level ratio. However, the dominant source of error is the sideband power ratio measurement, which introduces an error in $|\Gamma|$ ranging from +19% to -16%.

TEST RESULTS & CONCLUSIONS

The complete data set resulting from the shake table tests is far more comprehensive than the information provided by a manufacturer. Typically, the manufacturer will only provide the total acceleration sensitivity of a device, if any information on $|\Gamma|$ is given at all. This masks the fact that acceleration sensitivity is a function of vibration frequency and in the case of a VCO, it may also be a function of tuning voltage. It is interesting to note that the VCOs tested here, when subjected to low frequency vibrations ($\leq$300 Hz), exhibit as much as an order of magnitude change in their acceleration sensitivity as the tuning voltage is varied.

Figure 2 summarizes the results of all the SAW oscillators tested. It shows the magnitude of the total acceleration sensitivity vector $|\Gamma|$ for each device output measured, i.e., it is the root-sum-squared of the three orthogonal components. Table 1 serves as a key for the various venders and oscillator types represented in Figure 2. The magnitudes of the acceleration sensitivity vector components ranged from 10^{-10} to 4.4×10^{-8}/g. The military requirement of 10^{-11} is an order of magnitude lower than the best oscillator tested in the study.

Table 2 summarizes the acceleration sensitivity for each output of the 22 devices tested. The data presented in this table includes the device number, where the letters **A, B, C or D** after the device number denotes multiple outputs from the same device. Column 2 identifies the vender of a particular device. The next three columns provide the magnitude of the three acceleration sensitivity vector components. Column 6 gives the magnitude of the total acceleration sensitivity vector.

More interesting than the absolute results of the study is the correlation of the measured acceleration sensitivities with the physical attributes of the various oscillators. One of the more prominent results to come out of this study is the superior acceleration performance achieved with a symmetric crystal mount as compared to an asymmetric mounting scheme. Devices 1-7, in Figure 2, are nominally symmetrically mounted devices (attached to the substrate in the center of the crystal) which have an average acceleration sensitivity of 5.6×10^{-9}/g. Devices 12-21 are asymmetrically mounted devices (cantilevered structure, attached to the substrate at one end) which have an average acceleration sensitivity of 28×10^{-9}/g. Comparing the two mounting configurations for this limited selection of devices, a factor of 5 enhancement was observed by going from a cantilevered mount to a symmetric mount.

Devices 8-11 illustrate the potential advantages of symmetry and miniaturization for low acceleration sensitivity. The average $|\Gamma|$ of devices 8-9, (240 MHz VCOs), is 33.5×10^{-9}/g, while $|\Gamma_{avg}|$ for devices 10-11, (400 MHz VCO), is 23.6×10^{-9}. In both cases the quartz substrates are the same size, however, the metallized region of the 240 MHz device is 1.5 times wider than the metallized region of the 400 MHz device. Assuming that the resonator mountings are not perfectly symmetric, theory predicts that, for a fixed biasing deformation, the shift in the eigenfrequency of the piezoelectric resonator subjected to a biasing condition (deformation) will decrease as the active area decreases. In this particular example , the plate thicknesses are identical, therefore, the stresses induced in both types of devices are similar. This example would seem to indicate that improved acceleration sensitivity can be achieved by device miniaturization.

Several devices also illustrated that improved $|\Gamma|$ can be achieved by minimizing the deformation of the resonator. In general, the acceleration sensitivity of a device degraded as the length of the quartz substrate increased. We interpret this result as follows: since there was no special precautions taken to minimize resonator deformation, in the samples tested here, as the length increased, so did the acceleration induced deformation which led to greater frequency shifts. Table 3 shows the average $|\Gamma|$ vs. resonator length, L. It is also interesting to note the correlation between the carrier frequency and $|\Gamma_{avg}|$.

Viewing the crystal oscillator as an electronic circuit, two examples show strong evidence the acceleration-induced phase perturbations in loop components (other than the resonator) arise primarily from changes in lead inductance as loop components shift and leads deform in the response to the applied acceleration [4]. Devices 8-11 are the worst symmetrically mounted resonators. An inspection of the loop components reveals several large hand-wound air-core inductors in the oscillator loop. In this case, it can be easily argued that not only is the increased $|\Gamma|$ a function of the acceleration induced changes in lead inductance, (based on the well-defined grouping of the two mounting configurations, in Figure 2), but also the wide variations in the response of the two oscillators is a function of the variability in the construction and mounting of the individual inductors. Similarly, devices 6 and 7, in Figure 2, reveal a considerable difference in the $|\Gamma|$ for the two devices. Upon a visual inspection, the most noticeable physical difference between the two devices was that the wirebonds on device 6 were longer than those on device 7, indicating that an acceleration induced transimpedance change on the longer leads in device 6 might be the source of the increased acceleration sensitivity.

Although the market survey on acceleration sensitivity of SAW stabilized oscillators provides a baseline of acceleration performance for these devices, it is far more useful when combined with the theoretical work of Kosinski and Ballato [4], as a design guide for low acceleration sensitivity. The combination of $|\Gamma|$ data with the observations of the physical construction of these devices provided information consistent with the concept that low acceleration sensitivity can be achieved by minimizing resonator deformation, using symmetric mounting and eliminating motion-sensitive components. Most of the illustrative examples examined proved concepts by antithesis, however, the strongest evidence validating these design criteria is the superior performance of device 22 which employs many of these criteria.

ACKNOWLEDGEMENT

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REFERENCES

[1] J. Himmel, R. McGowan, J. Kosinski and T. Lukaszek, "Market Survey of Acceleration-Insensitive SAW Oscillators", Proc. 46th Annual Frequency Control Symposium, pp. 849-860, May 1992.

[2] J. Kosinski and A. Ballato, "Advances in Acceleration Sensitivity Measurement and Modeling", Proc. 46th Annual Frequency Control Symposium, pp. 838-848, May 1992.

[3] J. Kosinski, A. Ballato and T. Lukaszek, "Measurements of Acceleration-Induced Phase Noise in Surface Acoustic Wave Devices", Proc. 44th Annual Frequency Control Symposium, pp. 488-492, May 1990.

[4] J. Kosinski and A. Ballato, "Designing for Low Acceleration Sensitivity", Proc. 14th Piezoelectric Devices Conference 1992, vol. 1, pp. 1-8.

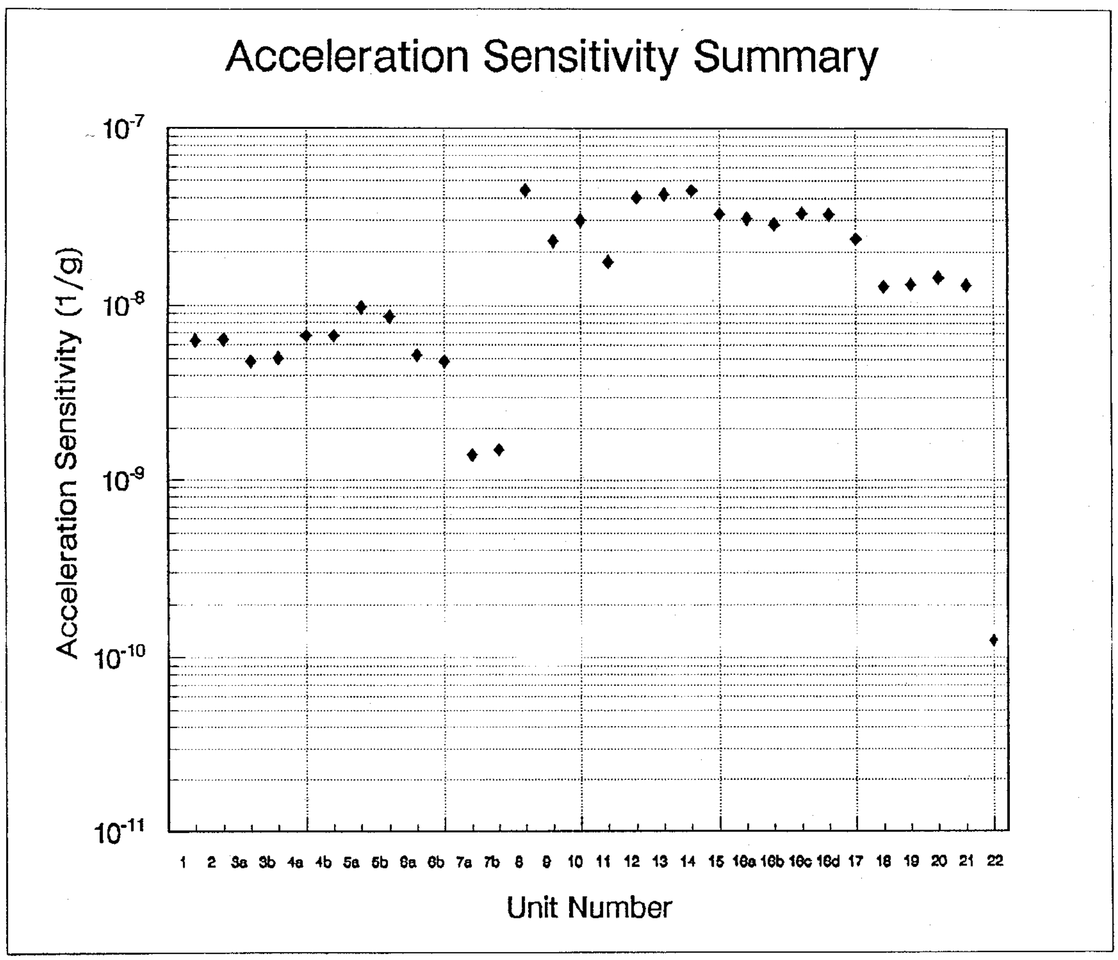

Figure 2 Summary of the Acceleration Sensitivity Vector

Table 1 Vender Key

Unit #	Vender	Oscillator Description
1-2	A	Fixed Frequency; 500 MHz
3a	B	VCO; 701 MHz; 1x Output
3b	B	VCO; 1403 MHz; 2x Output
4-5	B	Fixed Frequency; 225 MHz Complementary ECL Output
6-7	B	Fixed Frequency; 357 MHz Complementary ECL Output
8-9	C	VCO; 240 MHz
10-11	C	VCO; 400 MHz
12-15	D	VCO; 622 MHz
16	E	Fixed Frequency; 250 MHz Two Pairs of Differential ECL Outputs
17-21	F	VCO; 600 MHz
22	G	VCO; 450 MHz, All Quartz Package

Table 3 Comparison of Resonator Lengths

Vender	$\|\Gamma\|_{avg}$*	f_o (MHz)	L (mm)
B3	4.8	701	2.78
F	13 0	600	5.79
C2	23.6	400	7 40
C1	33.5	240	7.40
D	39.5	622	8.56

Note: *- Unit for Γ is $x10^{-9}/g$
All devices are VCOs

Table 2 Summary of Acceleration Sensitivity

DUT	Vender	$\|\Gamma_x\|$	$\|\Gamma_z\|$	$\|\Gamma_y\|$	$\|\Gamma\|$
1	A	≤2.00	0.40	6.00	6.30
2	A	≤2.00	≤1.00	6.00	≤6.40
3A	B3	0.20	0.20	4 80	4.80
3B	B3	0.30	0.10	5 00	5 00
4A	B1	2.10	1.00	6.30	6 70
4B	B1	1.90	1.00	6.30	6.70
5A	B1	3.30	1.20	9.00	9.70
5B	B1	3.10	1.30	7.90	8 60
6A	B2	3.30	2.30	3.30	5 20
6B	B2	3.60	0.87	2.90	4.80
7A	B2	1.10	0.61	0 66	1 40
7B	B2	1.30	0.44	0.57	1.50
8	C1	≤25.4	≤7.97	35.2	≤44.1
9	C1	1.31	≤2.48	22.7	≤22.9
10	C2	≤9.31	≤3.42*	≤28 1*	≤29.8
11	C2	≤5 99*	≤14.9*	≤7.00*	≤17.5
12	D	≤6.02	≤1.36*	39.5	≤40 0
13	D	≤7.51	≤10.9	≤39.0	≤41.9
14	D	≤15.5	≤16 0	≤37 9	≤44 0
15	D	≤9.25	2.23	31.0	≤32.4
16A	E	≤3.37	3.12	30.2	30.5
16B	E	≤2 26	≤2 01	28 3	28.5
16C	E	≤1 77	≤1 36	32.6	32 7
16D	E	≤2.05	≤1.00	32.2	32 3
17	F	14.5*	1.44*	18.4*	23.5
18	F	2.71*	5.22	11.4	12.8
19	F	≤0.20	≤0 20	13 1	13 1
20	F	0.78	≤0 40	14 4	14 4
21	F	0.74	≤0.20	13.0	13 0
22	G	0.096	0.046	0.066	0.125

Note. Unit for Γ is $x10^{-9}/g$
*- Γ varied substantially with tuning voltage