1995 IEEE INTERNATIONAL FREQUENCY CONTROL SYMPOSIUM

EXPERIMENTAL STUDIES OF SAW AND STW ACCELERATION SENSITIVITY

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Abstract: Comparative studies of the normal acceleration sensitivities of 360 MHz SAW and STW two-port resonators have been performed. The resonators were fabricated on the same ST-cut wafer to insure the clearest comparison. The results show that the normal acceleration sensitivities of both types of devices can easily be improved one order magnitude by selecting the appropriate aspect-ratio of the device substrate and/or mounting system. Based on these results, the normal acceleration sensitivities of the STW resonators have been further improved through modifications to the existing resonators, resulting in normal acceleration sensitivity as low as 2.93×10^{-10}/g. The measured values of the STW normal acceleration sensitivities are compared to that calculated for the case of simple supports along rectangular edges.

Introduction

Surface transverse wave (STW) resonators are currently being proposed as the basis for high performance oscillators in a variety of military electronic systems. In these applications, phase noise under vibration, and hence acceleration sensitivity, are critical parameters. Unlike the SAW case for which a significant body of literature exists, little has been published to date on the acceleration sensitivity of STW resonators. As a consequence, comparative studies of the normal acceleration sensitivities of 360 MHz SAW and STW two-port resonators have been performed. The primary focus of the studies has been to determine whether SAW or STW has an intrinsic advantage over the other in regard to acceleration sensitivity, and to evaluate the use of aspect-ratio compensation for reducing the normal acceleration sensitivity of STW resonators.

Experimental Procedure

Two-Port Resonators

The two-port SAW and STW resonators used in the comparative studies were designed and fabricated at the U.S. Army Research Laboratory's Physical Sciences Directorate facility located at Fort Monmouth, New Jersey. All of the devices were fabricated on ST-cut (θ=42.75°) quartz using three inch diameter, 20 mil (0.508 mm) thick wafers, taking care to avoid the seed region. For this study, two wafers were processed containing a total of eight devices.

To insure the clearest comparison, both SAW and STW resonators were fabricated on each wafer. All of the devices were designed for a 360 MHz nominal center frequency. Using ST-cut quartz, the SAW devices were temperature compensated while the STW devices were not. The thickness of the Al metallization (1400 Å) was chosen as a compromise between the desired 1% metallization for SAW and the desired 2% metallization for STW. Again, to insure the clearest comparison, the wafers were diced such that the substrates for both SAW and STW resonators were 20 mm x 20 mm squares.

The two-port SAW resonators were driven and sampled by 70½ finger pair transducers spaced approximately 100λ apart. The reflective gratings consisted of 1000 shorted metal strips with a period of 4.36µm and an acoustic aperture of 100λ. The reflective gratings were left floating.

The design of the two-port STW resonators was as close as possible to that of the SAW resonators. The STW resonators were driven and sampled by 70½ finger pair transducers spaced 100λ apart. The reflective gratings consisted of 1000 shorted metal strips with a period of 7.00 µm and an acoustic aperture of 100λ. The reflective gratings were left floating. An inter-transducer grating with a period of 6.80 µm was used to trap the wave in the cavity.

Test Oscillator

A basic feedback loop oscillator circuit compatible with both resonator types was developed for the comparative studies. The oscillator circuit consists of, in order, the acoustic resonator, a multistage electronic phase shifter, a single op amp, and a 20 dB output coupler. The physical implementation of the oscillator is shown in Figure 1. The oscillator circuit was implemented in microstrip using a 0.254 mm thick Duroid board with 1/2 oz. of rolled copper on the top surface. The 9.8 cm x 8.3 cm circuit board was rigidly attached to a 6.35 mm thick aluminum backing on the bottom surface. For the vibration tests, the oscillator was operated at the frequency of minimum insertion loss of the resonator being tested.

<u>Resonator Mounting System</u>

In order to facilitate the comparative studies, a simple, interchangeable resonator mounting system was developed. The mounting system consisted of a set of "picture frames" (see Figure 2) which were attached

TABLE I
SUPPORT FRAME INNER DIMENSIONS

Frame Number	Inner Length	Inner Width	Aspect-Ratio
1	0.000 mm	14.000 mm	0
2	4.666 mm	14.000 mm	1:3
3	5.600 mm	14.000 mm	2:5
4	7.000 mm	14.000 mm	1:2
5	9.333 mm	14.000 mm	2:3
6	14.000 mm	14.000 mm	1:1
5	14.000 mm	9.333 mm	3:2
4	14.000 mm	7.000 mm	2:1
3	14.000 mm	5.600 mm	5:2
2	14.000 mm	4.666 mm	3:1
1	14.000 mm	0.000 mm	∞

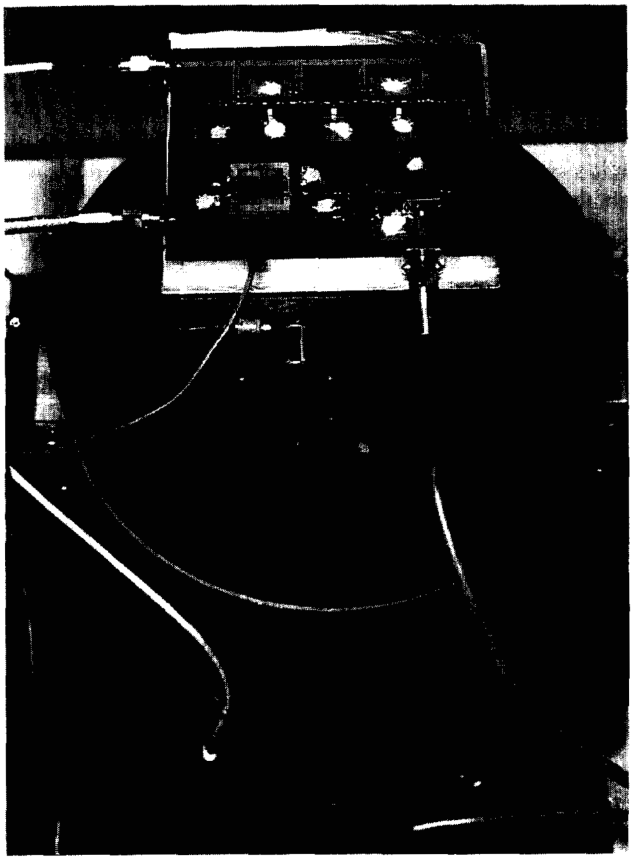

Figure 1. Test oscillator and shake-table apparatus. An STW resonator is mounted in the test oscillator.

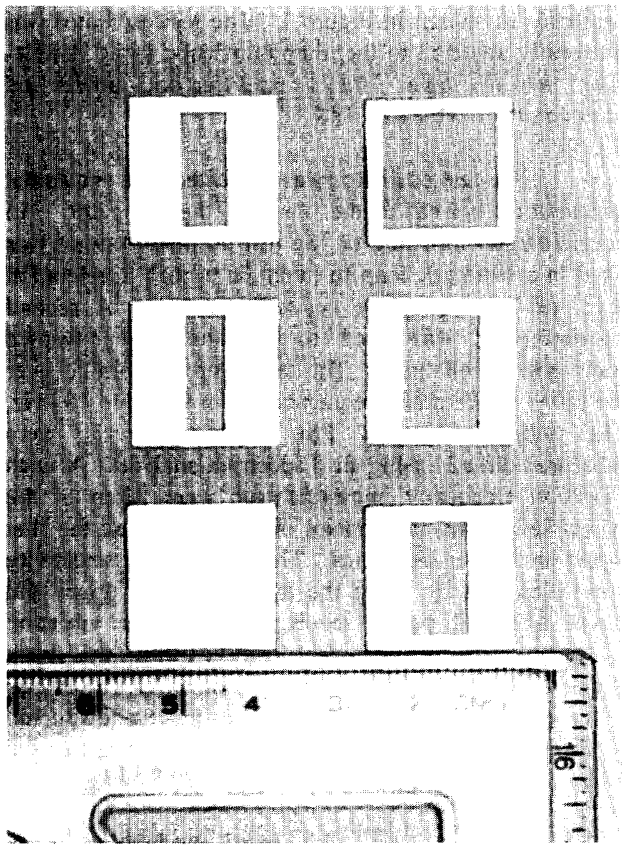

Figure 2. Support frames for mounting the resonators.

between the oscillator circuit board and the acoustic resonator using a double-sided adhesive tape. The support frames were sheared and machined from a sheet of 0.508 mm thick molybdenum material. The outer dimensions of all of the support frames were fixed at 18 mm x 18 mm. The inner width dimension of each frame was cut and machined to 14 mm, while the inner length dimensions of the frames were cut and machined to yield a variety of aspect-ratios as listed in Table I. The inverse of the intended aspect-ratios were obtained by rotating each frame by 90°, and taking the inner length to be fixed. A solid plate (no inner opening) was used for the limiting aspect-ratio values of zero and infinity.

Shake Table Test System

The normal acceleration sensitivities of the various SAW and STW resonators were measured using a shake table test system described in detail elsewhere [1]. A four inch aluminum cube was bolted directly to the shake table, and served as the support for the test oscillator as shown in Figure 1. The test oscillator was uniformly attached to the aluminum cube using double-sided adhesive tape. The dc lines for both power and tuning voltage were shielded.

The test oscillator was subjected to a sinusoidal acceleration normal to the plane of the resonator. An accelerometer mounted on the test oscillator circuit was used in a feedback loop to maintain a peak acceleration level of 1 g along the desired test axis. A second accelerometer was used to monitor any unwanted transverse acceleration. The tests were performed over the range of vibration frequencies from 90 Hz to 10 kHz. The vibration-induced FM sideband levels were measured directly using an rf spectrum analyzer. At each vibration frequency, measurements were taken of the power levels and frequencies of the carrier and the first upper and lower sidebands. The acceleration sensitivity was calculated by using the average of the upper and lower sideband power levels, the applied vibration frequency, the carrier frequency, and the peak acceleration along the desired vibration axis. The effects of temperature-induced frequency drift were overcome by using a single sweep mode to record the measurement at each vibration frequency.

In most cases, the small modulation index approximation of Filler [2] was used to interpret the measured data. For certain aspect-ratios using both SAW and STW resonators, the first sideband-to-carrier power level ratio $\pounds^{1}_{v}(f)$ exceeded -26 dBc, resulting in a modulation index greater than 0.1. Under these conditions, the "moderate" modulation index approximation was utilized to accurately calculate the acceleration sensitivity [1].

Experimental Results

SAW Resonators

The measured normal acceleration sensitivities of the SAW resonators tested are plotted as a function of aspect-ratio in Figure 3. The acceleration sensitivity data are presented in terms of the maximum and minimum normal acceleration sensitivities observed over the range of vibration frequencies from 90 Hz to 990 Hz. Note that the SAW devices are taken to be of length 2a along the X_1 axis and width 2b along the X_3 axis, in which case the aspect-ratio a/b corresponds to that defined by Tiersten [3]. For graphical purposes, the normal acceleration sensitivities measured using the solid plate configuration (aspect-ratios of zero and infinity) are plotted as aspect-ratios of zero and four.

The largest acceleration sensitivities are obtained using the support frame with an aspect-ratio of 1:1, while the smallest acceleration sensitivities are obtained using the solid plate configuration. A local minimum appears to be indicated at an aspect-ratio of 2.5:1.

STW Resonators

The measured normal acceleration sensitivities of the STW resonators tested are plotted as a function of aspect-ratio in Figure 4. The acceleration sensitivity data are presented in terms of the maximum and minimum normal acceleration sensitivities observed over the range of vibration frequencies from 90 Hz to 990 Hz. Note that, for consistency with the analytical results of [4], the STW device is taken to be of width 2a along the X_1 axis and length 2b along the X_3 axis, i.e., the dimensions a and b are assigned to the X_1 and X_3 axes respectively and not to the length and width directions. For graphical purposes, the normal acceleration sensitivities measured using the solid plate configuration (aspect-ratios of zero and infinity) are plotted as aspect-ratios of zero and four.

The largest acceleration sensitivities are obtained using the support frame with an aspect-ratio of 1:1, while the smallest acceleration sensitivities are obtained using the solid plate configuration. The presence of any local minima are not clearly indicated.

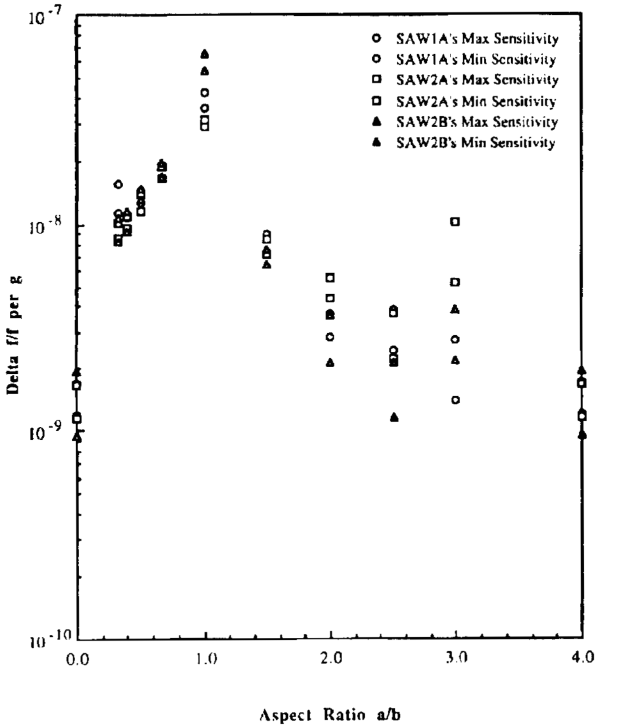

Figure 3. Measured SAW resonator normal acceleration sensitivity versus aspect-ratio.

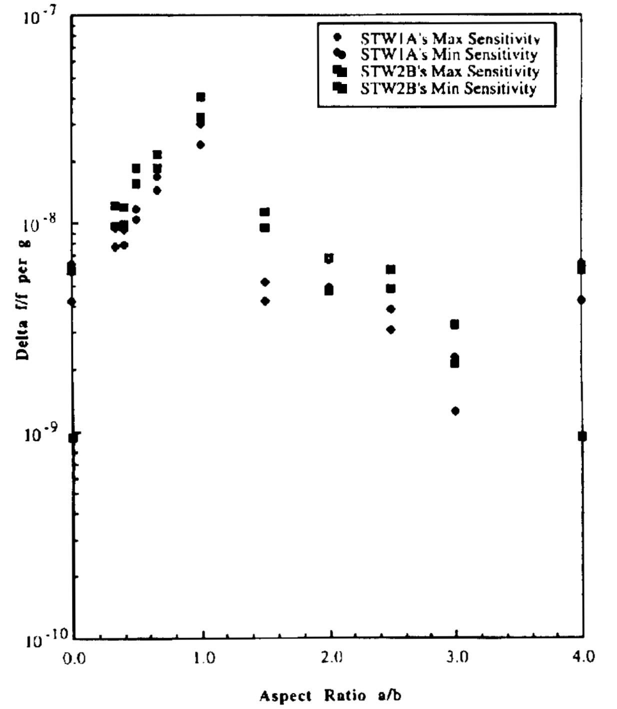

Figure 4. Measured STW resonator normal acceleration sensitivity versus aspect-ratio.

Discussion

The solid plate mounting configuration yields the lowest normal acceleration sensitivities for both SAW and STW resonators. For the SAW resonators, the measured data using the solid plate mount ranged from $9.57 \times 10^{-10}/g$ to $1.94 \times 10^{-9}/g$, while for the similarly mounted STW resonators the data ranged from $9.34 \times 10^{-10}/g$ to $5.99 \times 10^{-9}/g$. The data indicated essentially identical best case performance for the two types of devices. The smaller scatter in the SAW data using the solid plate mount are attributed to a somewhat more uniform adhesion of the double-sided tape achieved by pressing with a pair of tweezers in the inter-transducer gap when mounting the devices. The same could not be done with the STW devices due to the inter-transducer grating.

Using the 1:1 aspect-ratio support frame mounting, the STW resonators performed marginally better than the SAW resonators. The apparent local minimum at or near an aspect-ratio of 2.5:1 for the SAW case is in general agreement with the value of 1.8:1 reported in [5].

In Figure 5, the measured data for the STW resonators are compared with an analytic calculation of the normal acceleration sensitivities of comparable STW resonators simply supported along rectangular edges with the support dimensions corresponding to the inner dimensions of the mounting support frames for the various cases considered. The calculation appears to provide a reasonable estimate of the minimum observed normal acceleration sensitivity data. This is consistent with the lessons of practical experience that acceleration sensitivity is readily made worse but rarely, if ever, made better by accident. The calculation anticipates an aspect-ratio compensation of the normal acceleration sensitivity for an aspect-ratio of 1.8:1. The data may indicate a local minimum near 1.5:1, however additional measurements with finer aspect-ratio resolution will be required to provide a definitive answer.

After completing the comparative studies, the STW devices were subjected to a series of modifications (different modifications for each device) to further verify the understanding gained from the experimental and analytical studies. The results to date are shown in Figure 6. The normal acceleration sensitivities of the 360 MHz STW resonators were reduced to as low as $2.93 \times 10^{-10}/g$ after the series of modifications.

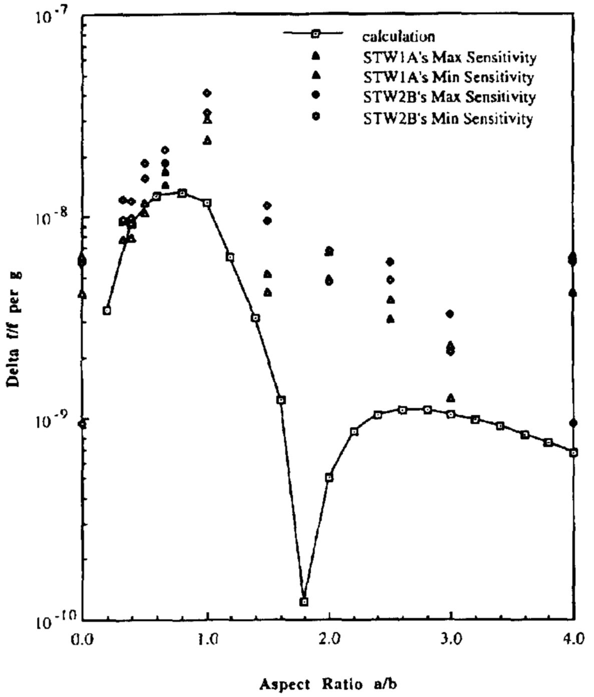

Figure 5. Comparison of measured and calculated STW normal acceleration sensitivity.

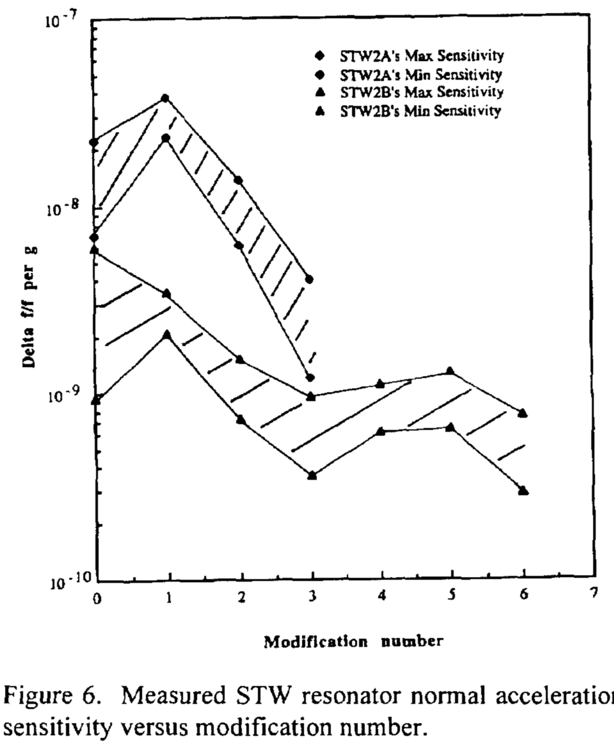

Figure 6. Measured STW resonator normal acceleration sensitivity versus modification number.

Conclusion

Comparative studies of the acceleration sensitivities of 360 MHz SAW and STW two-port resonators have been performed. Neither SAW nor STW exhibited any significant advantage over the other in regard to normal acceleration sensitivity.

Acknowledgment

The authors wish to thank Sally Laffey of Vitronics, Inc. for assistance with the resonator mounting/demounting and cleaning procedures, and Frank McBride of CECOM for assistance in developing the support frame mounting structure.

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