POWER FLOW ANGLE AND PRESSURE DEPENDENCE
OF SAW PROPAGATION CHARACTERISTICS IN QUARTZ

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ABSTRACT

Surface acoustic wave propagation on doubly rotated cuts of quartz is considered. Sample static frequency-temperature results are given corresponding to regions where the second order temperature coefficient is small, and these are compared to singly rotated cuts. The force-frequency effect is measured, as is power flow angle, for sample cuts, and it is shown how the static frequency-temperature curve may be compensated using the power flow variation with temperature. The anisotropy ratio is tabulated for a number of doubly rotated cuts.

INTRODUCTION

The evolution of bulk acoustic wave (BAW) resonators from single rotated types to doubly rotated cuts[1] led to a number of improvements, despite the greater difficulty of manufacture. Almost certainly the most significant advance has been the development of the SC cut.[2] It is in the spirit of these BAW developments that doubly rotated SAW cuts have been investigated.[3] We report here on a number of aspects of this investigation.

FREQUENCY-TEMPERATURE

The static frequency-temperature (f-T) behavior of a resonator is represented by the cubic relation $\Delta f/f = a\Delta T + b\Delta T^2 + c\Delta T^3$, with $\Delta T = T - T_o$. T is the temperature variable, and $T_o = 25^oC$ is the reference temperature. Table 1 lists the nominal values for the coefficients b and c (in units of $10^{-9}/K^2$ and $10^{-12}/K^3$, respectively) for the single rotated AT and BT BAW cuts, the SC doubly rotated BAW cut, and the ST and SST[4] singly rotated SAW cuts. The "a" coefficient is zero; the reference temperature is 25^{o}C.

Table 1. Temperature Coefficients

CUT	b	c
AT	- 0.5	+109.
BT	-40.	-128.
SC	-12.	+ 58.
ST	-34.	- 18.
SST	-20.	+ 96.

Table 2 gives a number of doubly rotated orientations with parabola constants (b values) for SAW propagation that are representative of the best determined in this study. An experimental f-T curve is shown in Fig. 1.

Table 2. Superior TCF of Doubly Rotated SAW Cuts.

(YXwlt) $\Phi/\Theta/\Psi$ (DEGREES)	TCF (1) ($10^{-6}/K$)	TCF (2) ($10^{-9}/K^2$)	TCF (3) ($10^{-12}/K^3$)	VELOCITY (M/S)	K^2 (%)	PFA (DEGREES)
12.01/31.21/39.8	0.06	-11.9	45	3243	0.101	-4.1
15.13/31.13/37.33	0.11	-11.8	25.3	3245	0.098	-4.6
14.31/41.07/40.56	0.37	-13	51	3315	0.094	-8.6
-1.05/28.07/136.5	---	-11	73	3259	0.11	+1.5

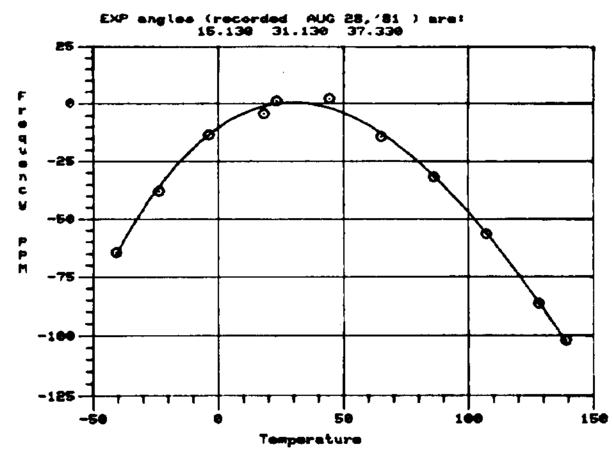

Fig. 1. Frequency-Temperature Plot of SAW on Doubly Rotated Quartz Plate.

Shown in Fig. 2 is a comparison of the singly rotated ST and SST cuts with one of the best doubly rotated cuts. It is seen that the doubly rotated (dr) cut is slightly better than the SST cut, particularly at higher temperatures. In Fig. 3 is seen the effect of small changes in the

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angle ψ (see the diagram inset in Fig. 2). For this cut $\partial a/\partial\psi$ is approximately $+2.7 \times 10^{-6}/K,^{o}\psi$.

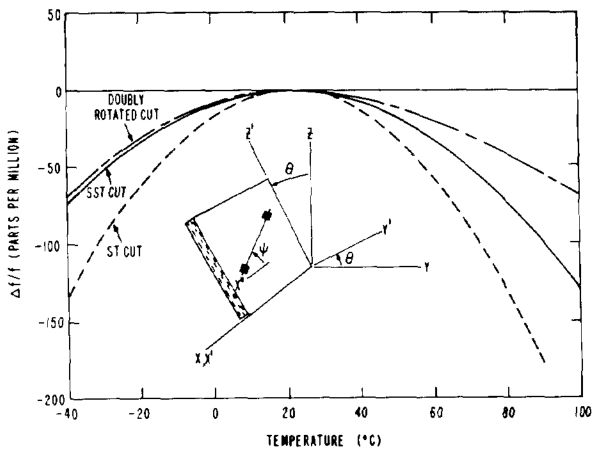

Fig. 2. Frequency-Temperature Behavior Comparison of Select Orientations.

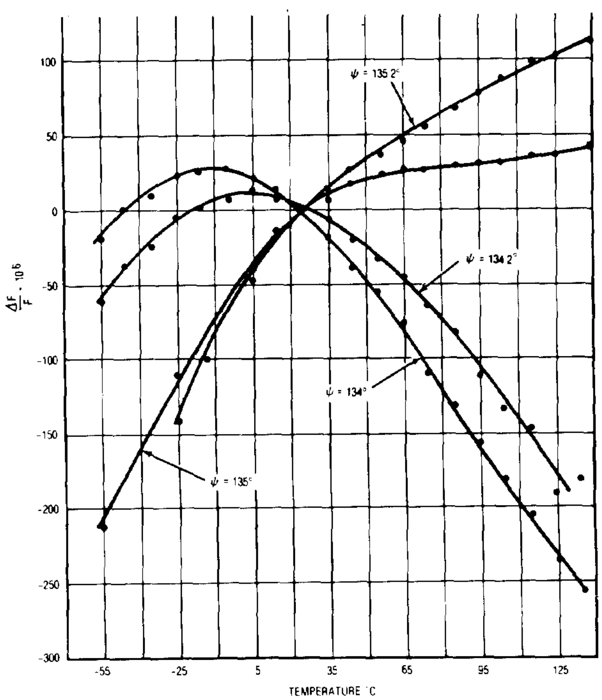

Fig. 3. Frequency-Temperature Dependence on ψ.

FORCE-FREQUENCY

The force-frequency effect was measured with the apparatus shown in Fig. 4. The SAW plates were rounded and subjected to in-plane, diametric force pairs. The phase change upon force application was translated into a normalized frequency shift $\Delta f/f$. This shift, divided by the magnitude of the force applied and multiplied by the disc cross-sectional area, $\phi_a \cdot t_a$, defines the coefficient $\overline{K}_f$ chosen to characterize the effect. Figure 5 is a plot of phase and impedance of a dr SAW device measured as a two-port delay line. The device dimensions are ϕ_a = 11 mm, t_a = 0.9 mm, a = 166λ, b = 140λ, and c = 1 mm. (Cf. Fig. 7 for definitions).

In Fig. 6 is shown $\overline{K}_f$ measured for an ST cut disc as function of force azimuth Ψ. The symmetry of the ST about the X (Ψ = 0°) and Z' (Ψ = 90°) axes is apparent. Figure 7 shows the corresponding curve of $\overline{K}_f$ for a representative dr cut. The curve is unsymmetric and larger in magnitude.

Fig. 4. Force-Frequency Apparatus and Measurement Instrumentation.

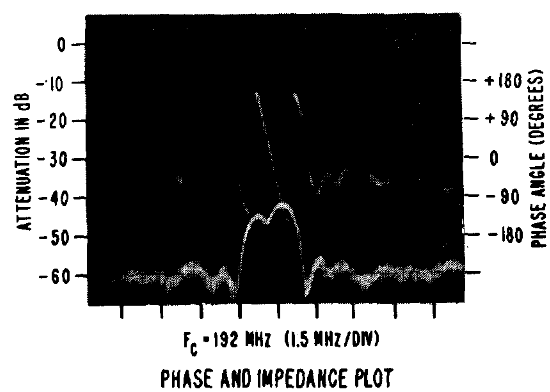

Fig. 5. Phase and Impedance Response of Doubly Rotated Crystal (Unmatched).

POWER FLOW ANGLE

Power flow angle (pfa) is the angle between phase and group velocity vectors, as depicted in Fig. 8. This angle is a function of temperature as seen in Fig. 9 for a dr cut. Table 3 provides measured values of pfa for a variety of cuts at three temperatures. The sensitivity to temperature of the pfa may be applied to compensate for

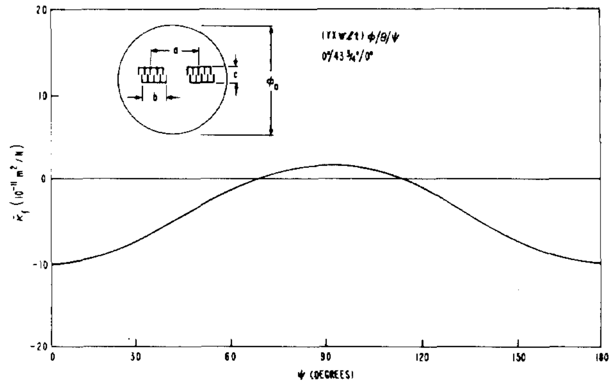

Fig. 6. Force-Frequency Azimuth Curve for ST Cut.

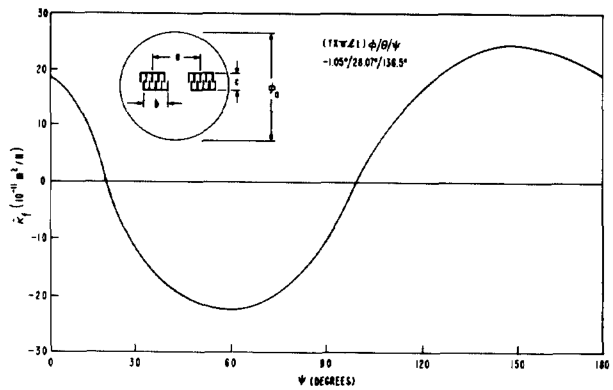

Fig. 7. Force-Frequency Azimuth Curve for Doubly Rotated Quartz Cut.

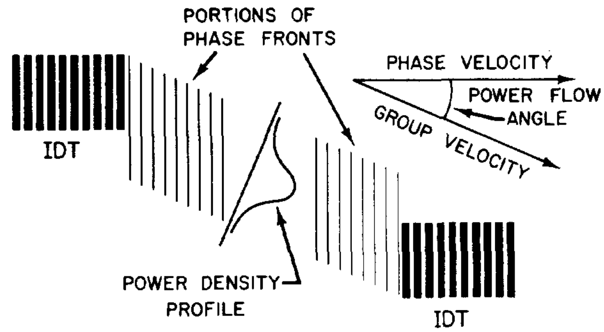

Fig. 8. Schematic of Power Flow Angle

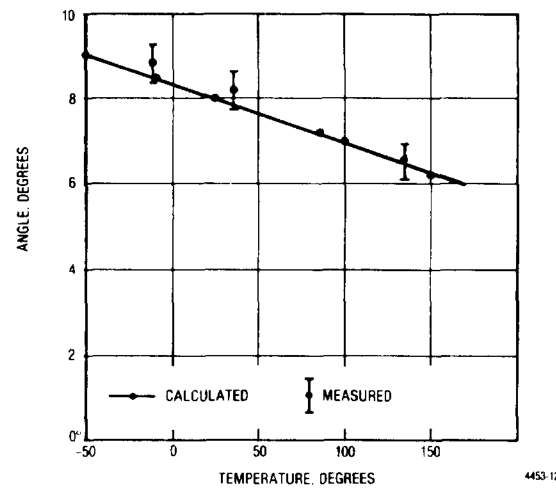

Fig. 9. Power Flow Angle vs. Temperature for (YXwℓt) 14.283/39.117/40.6 Plate.

the static f-T behavior of the SAW device. This is accomplished[5] by employing small-aperture auxiliary IDT transducers to sense the changing pfa with temperature. Combining the outputs of these auxiliary transducers with that of the main transducer produces a phase correction with temperature to correct frequency. Figure 10 shows an example of the technique.

The power flow angle is related to the incremental slope of the inverse velocity surface. It is characterized by the anisotropy ratio γ.[5,6] The temperature dependence of γ is given for a number of SAW singly and doubly rotated orientations in Table 4.

CONCLUSION

Doubly rotated SAW cuts exist that are superior to singly rotated cuts in f-T behavior. Because of the asymmetry of these cuts and of the phase propagation angle necessary to produce small "a" values, the pfa values are not zero, and the curves for such effects as force-frequency are unsymmetrical. Notwithstanding these complications, dr SAW plates have certain attractive features, such as the ability to be temperature compensated over wide ranges, and, for some orientations, a high force sensitivity. In addition, cuts that are compensated for various nonlinearities (as is the SC BAW cut) remains an intriguing possibility.

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Table 3. TEMPERATURE DEPENDENCE OF THE POWER FLOW ANGLE ON DOUBLY ROTATED CUTS AT ORIENTATIONS (YX WLT) PHI/THETA/PSI

Orientation			Power Flow Angle		
PHI	THETA	PSI	T = 25°C	T = 150°C	T = −50°C
−1.330	28.100	137.692	+1.2	−0.1	+1.8
−1.050	28.067	136.534	+2.5	+1.0	+3.2
−0.967	26.233	138.449	+1.1	−0.2	+1.8
−0.33	26.700	138.859	+0.5	−0.7	+1.1
0.633	26.150	137.016	+1.4	+0.1	+2.1
5.583	27.833	135.194	+0.3	−0.9	+1.0
5.583	27.833	134.940	+0.5	+0.1	+1.1
5.583	27.833	134.994	+0.4	−0.8	+1.1
6.000	26.967	135.812	−0.1	−1.2	+0.5
6.067	25.933	133.099	+1.7	+0.3	+2.4
6.567	26.883	134.925	+0.1	−1.0	+0.7
7.410	27.380	134.2	+0.1	−1.0	+0.8
8.033	26,967	134.618	−0.3	−1.4	−0.3
8.05	25.900	135.71	−0.7	−1.6	−0.1
14.283	39.117	40.627	−8.1	−6.2	−9.0
15.300	40.683	40.031	−8.6	−6.8	−9.6
16.117	41.267	37.309	−7.2	−5.5	−8.1

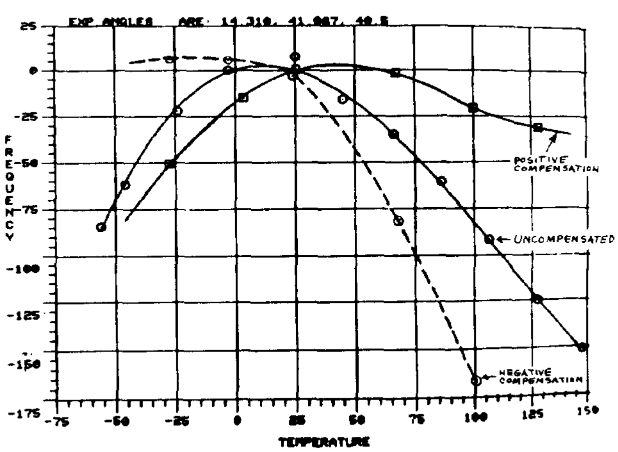

Fig. 10. Frequency-Temperature Compensation Employing PFA Correction.

Table 4. Temperature Dependence of γ.

ORIENTATION			ANISOTROPY PARAMETER γ		
PHI	THETA	PSI	T = -50°C	T = 25°C	T = 150°C
0	42.5	0	0.369	0.375	0.369
0	27.0	137.72	0.669	0.616	0.669
7	27.0	135.64	0.444	0.379	0.444
12.5	35.0	130.62	0.704	0.645	0.704
14.3	39.1	40.6	0.625	0.614	0.625
15.0	32.5	38.55	0.775	0.756	0.775
15.0	40.0	40.0	0.637	0.621	0.637

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