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## TEMPERATURE VARIATION OF SAW POWER FLOW ANGLE

Indexing terms: SAW devices, Piezoelectrics

The power flow angle of surface acoustic waves in quartz not on a crystalline axis of symmetry is shown to vary rapidly with temperature. Experimental results and theoretical calculations are presented demonstrating the dependence of the acoustic power flow angle on a doubly rotated cut of quartz.

Surface acoustic wave (SAW) delay line oscillators are used for frequency sources and have several advantages over their bulk wave counterparts, because of their planar fabrication. Higher frequencies of operation are easily obtainable at harmonics of the fundamental. A simple one-step fabrication process is all that is necessary to produce inexpensive, highly reliable SAW delay lines. Long delay times are also easily achievable. Currently, almost all temperature stable SAW devices are fabricated on quartz and use the *ST*-cut,<sup>2</sup> which exhibits a parabolic frequency dependence in temperature too large for many applications. The object of this letter is to demonstrate how the SAW power flow angle<sup>1</sup> (PFA) affects device design and may be used to improve the temperature stability of the SAW delay lines which are commonly used as electronic frequency sources.

The power flow angle for a particular direction of propagation is an important parameter. While the phase fronts always remain parallel to the source transducer, the wave as a whole does not propagate perpendicular to the wavefronts. This is a characteristic of anisotropic substrates where the phase velocity is asymmetric about the propagation direction; i.e.  $v(\psi + \Delta\psi) \neq v(\psi - \Delta\psi)$ . The major problem which arises is that the acoustic beam may steer off the desired propagation track, missing the output transducer unless it is properly designed.

The power per unit width carried in a surface wave is found

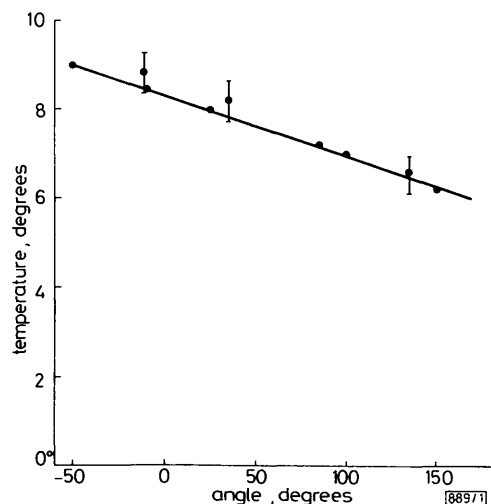


Fig. 1 Power flow angle against temperature for (YXwlt) 14-283/39-117/40-6

—●— Calculated      ● Measured

by integrating the mechanical and electrical Poynting vectors, to obtain

$$P_i = -\frac{1}{2} \operatorname{Re} \left\{ \int_{-\infty}^0 T_{ij} \mu_j^* dx_3 - i\omega \int_{-\infty}^{\infty} \phi D_i dx_3 \right\} \quad (i = 1, 2)$$

where  $\mu_j$  is the particle displacement,  $T_{ij}$  the stress tensor,  $\phi$  the electric potential and  $D_i$  the electric displacement.  $P_1$  and  $P_2$  give the power flow perpendicular and parallel to the wavefront, respectively.  $P_3 = 0$  for the Rayleigh wave which is confined to the surface. The power flow angle may be defined as  $\theta = \arctan (P_2/P_1)$ . Power flow angles as high as 20° are not uncommon on quartz.

Calculations<sup>3,4</sup> of the power flow angle at different temperatures for doubly rotated cuts of quartz have been performed. The cuts are designated by the 1949 IRE<sup>5</sup> standard. Fig. 1 illustrates the temperature variation of the power flow angle for the doubly rotated cut of quartz (YXwlt) 14-283/39-117/40-6. The important feature of this dependence is the large variation of the power flow angle over the temperature range shown.

Fig. 2 contains a pictorial representation of a device fabricated at (YXwlt) 14-3/39-1/40-6. The input transducer on the left generates an acoustic wave which only partially illuminates the output transducer on the right. Figs. 3a and 3b are photographs of the device response with a short gated RF pulse as

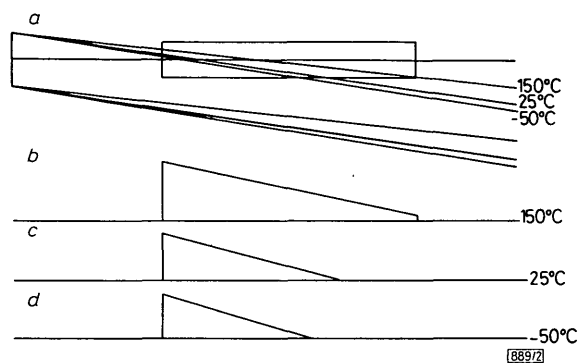


Fig. 2 Pictorial representation of device response

- a Device geometry
- b Impulse response at 150°C
- c Impulse response at 25°C
- d Impulse response at -50°C

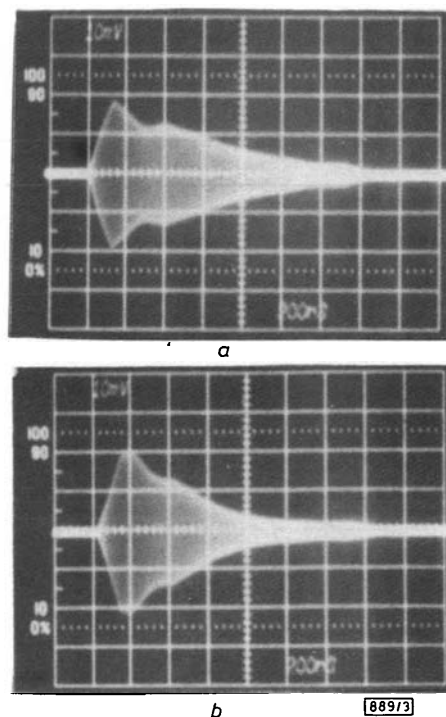


Fig. 3 Device response to short gated 270.4 MHz input pulse

- a At 131°C
- b At 34°C

the input, showing the response at 131°C and 34°C, respectively. The first notch is a result of missing finger pairs. The anisotropy parameter<sup>6</sup> was calculated to be 0.625 at -50°C, 0.614 at 25°C and 0.586 at 150°C. The transducer apertures are 34 mils and 24 mils, the length of the device is 260 mils and the acoustic wavelength is 0.48 mils. The temperature dependent effects of diffraction on the envelope were found to be negligible. The shortening of the device response is clearly evident from the photographs and is due to the rapidly decreasing power flow angle successively illuminating more of the output transducer as the temperature increases. The power flow angles estimated from these photographs are displayed in Fig. 1 alongside the theoretical results.

In designing filters and reflective array devices on rotated cuts of quartz, additional care must be taken to ensure that the temperature dependent power flow angle does not degrade device response. If improperly designed, device time delay, bandwidth and phase all become temperature dependent when fabricated on a rotated cut. These observations are especially important for reflective array devices in which rotated cuts of quartz are often used to achieve temperature compensation in two different propagation directions. Suitable device design can overcome these problems and result in temperature compensated delay lines useful for oscillator applications. The moving acoustic beam may be made to illuminate different parts of the output transducer at different temperatures in such a way as to maintain a steady phase over the entire temperature range. A design using the temperature dependent PFA is currently being fabricated in which a compensation signal maintains a relatively constant output phase despite the temperature dependent delay time. Input beam aperture compression may be used to achieve increasingly accurate adjustments of the output phase. Materials such as lithium niobate with higher coupling coefficients may be useful in this respect.

Rapid variation of the acoustic power flow angle with temperature has been demonstrated both theoretically and experimentally. New SAW filter and reflective array device design

considerations on rotated cuts were discussed. A method was proposed to obtain temperature compensated delay line oscillators by taking advantage of the temperature dependence of the power flow angle.

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## GUIDED-WAVE HOLOGRAPHIC GRATING BEAM EXPANDER—FABRICATION AND PERFORMANCE

*Indexing terms: Integrated optics, Diffraction, Holography*

A novel realisation is presented of an established optical component—a beam expander which diffracts guided optical waves using an ion-etched holographic grating.

**Introduction:** There has recently been considerable interest in integrated optic signal processing devices such as spectrum analysers, convolvers and correlators.<sup>1</sup> Beam expanders, collimators and Fourier transform lenses are important components in these devices. Geodesic,<sup>2</sup> Luneberg<sup>3</sup> and grating<sup>4</sup> lenses may fulfil these requirements.

Geodesic lenses are difficult to fabricate, as are short focal length Luneberg lenses; in both cases the lens index must be much larger than the guided mode index, and nonplanar processing steps are implied.

In this letter, we introduce the grating beam expander (Fig. 1) fabricated on an optical waveguide, such that guided light impinges on the grating at the Bragg angle and is slowly diffracted into a wider beam. We briefly discuss the theory and

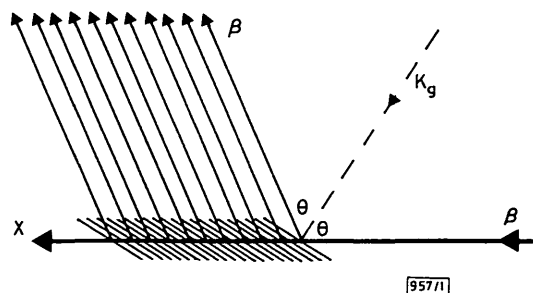


Fig. 1 Conceptual diffraction grating beam expander

Incident guided wave front enters the grating from rhs. Expanded beam vector has the same propagation constant but is angularly deflected by  $2\theta$ . Grating vector is  $k_g$  normal to corrugations

the techniques for fabricating the grating and experimental evidence of performance. We also suggest how the amplitude of the output beam can be weighted by depth-tapering the grating.

**Basic theory:** The narrow ( $< 1$  mm) beam of light in the waveguide is to be expanded into a much wider beam (5–10 mm). The condition for strong diffraction is that the incident beam interacts with the grating at the Bragg angle (Fig. 1) given by  $\cos \theta = k_g/2\beta$  where  $\beta$  is the propagation constant of the incident wave,  $k_g$  is the grating vector and  $\theta$  is the angle between the incident field and the grating vector. The propagation constant of the incident wave will be perturbed by the presence of the grating, and the effect of a small perturbation will be to replace the original value of  $\beta$  by

$$\beta_p = \beta + A \cos(k_g x \cos \theta)$$

assuming a sinusoidal grating profile, where the coupling coefficient  $A$  is a constant which depends only on the characteristics of the waveguide. The grating efficiency clearly depends on  $A$ , which is a function of the grating depth, the refractive index profile of the guide, and the excited mode. The diffraction efficiency can be enhanced by using shallow waveguides and by making the grating penetrate relatively deeply into the guide.<sup>5</sup>

**Fabrication technique:** We fabricated the grating beam expanders in soda-lime glass. The soda-lime glass substrates may be ion-exchanged before or after etching of the grating, to form the guiding layer. The ion exchange process is carried out by immersing the substrate in a melt of a monovalent metal salt.<sup>6</sup> These beam expanders were fabricated in prediffused caesium-doped waveguides. The sodium-caesium ion-exchange was carried out in a melt of caesium nitrate at 500°C for four to five hours; single mode waveguides were formed with normalised propagation constants varying from 1.512 (substrate value) to 1.53 at  $\lambda_{HeNe}$ .

A high resolution resist (Shipley AZ 1350J) was spun on the substrate to a thickness similar to that of the grating period