THE ROLE OF ACOUSTIC SURFACE WAVES IN SIGNAL PROCESSING

by

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On Fig. 1 is shown an actual plot of wavecrests on the surface of crystal. Notice that these wavecrests are not regular, they appear to be relatively flat within the beam then they appear to fall back rapidly away from the beam center. That is because lithium niobate crystal is highly anisotropic, and the waves moving slightly off the beam direction tend to move more slowly than waves directly on the beam direction. The straight-crested surface wave is generated on lithium niobate with a transducer shown in Fig. 2. The position of the fingers in the transducer matches the position of the crests and troughs of Fig. 1, and if an electrical signal at the appropriate frequency is applied to the transducer then a surface acoustic wave beam radiates from these transducers. The transducer is relatively efficient--a bit less than half the available electrical energy is put into the desired acoustic wave with this particular design.

In addition to generating acoustic waves on the surfaces of crystals it is also possible to guide them, to amplify them, to switch them, and to manipulate them in other ways; in short it is possible to manipulate surface waves in as many ways as electronic current and voltage waves.

It is possible to substantially contain acoustic waves in the waveguide structure in Fig.3, which is a photograph of soft ribbon-like overlayer of gelatin of rectangualr cross-section on top of a stiff and hard substrate of aluminum. Virtually all the acoustic energy is contained inside the overlayer ribbon and very little energy travels beneath the overlayer and in the substrate. The surface displacement of the fundamental mode is visible in the photograph. The particle displacements are similar to theoretical expectations(1).

If a short electrical impulse is applied to a transducer, the transducer will radiate a characteristic signal which is a function of the particular electrode pattern. It is possible to configure very complicated and intricate acoustic (or electrical) signals by impulsing a complicated pattern on the surface of a piezoelectric material. Such signal generators are likely to be more reliable and less expensive than active electronic devices.

An acoustic disturbance which propagates in a piezoelectric crystal has associated with that disturbance an electrostatic field. If the acoustic disturbance propagates on the surface of the crystal, part of the electrostatic field extends out of the surface. If we bring into the ambiance of the electrostatic field drifting carriers, then it becomes possible to transfer energy from a dc source to the acoustic wave to effect acoustic amplification. In Fig. 4 is shown a photograph of such an amplifier, and in Fig. 5 is a plot of the noise figure and gain of this acoustic amplifier. Notice the noise figure is comparable to the performance of solid state electronic amplifiers using transistor circuits.

An acoustic wave in a piezoelectric material has a mechanical and electrical component of energy. If the electrical component is removed, less energy is stored in the material and the acoustic velocity increases. It is possible to remove a portion of the electrical energy by shorting out the electrostatic field. In Fig. 6 are shown the effects which are obtained when the carriers are brought close to a piezoelectric surface and when they are removed from that surface in a semiconductor by applying a transverse electrostatic field. Notice a substantial phase change can be obtained by these means.

The velocity of the surface waves is independent of frequency on the surface of homogenous solids. However, dispersion can be obtained if a film a large fraction of an acoustic wavelength thick is deposited on a substrate. An increasing portion of the wave energy resides in the film as the wavelength gets shorter, and the velocity of the wave changes from that in the substrate to that in the overlayer with increasing frequency. In Fig. 7 is plotted the delay as a function of frequency for various film thicknesses. Notice that the thicker the overlayer the more pronounced the change of delay with frequency. Another method for achieving dispersion is to place a transducer grating with variable spacing on the

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surface of a piezoelectric crystal. The grating strongly radiates a signal from a portion in which the acoustic wavelength matches that of the distance between fingers. Consequently short wavelengths,or high frequencies are radiated by closely spaced fingers, and low frequencies are radiated by fingers which are further apart. In this way the path length and in consequence the delay can be varied by design.

Applications

The means have been acquired to transduce surface waves to generate them in response to electrical impulses, to disperse them in time and in space, to switch them, amplify them, and guide them. Just how well these components perform in relation to competitive techniques is the subject of the remainder of this talk.

A figure will be shown on which is plotted with logarithmic scales, the bandwidth in megahertz and the dispersion in microseconds of the capacities of available devices and the capacities of two kinds of surface wave dispersive devices. The potential bandwidth of the dispersive surface wave device exceeds conventional devices by approximately 1/2 an order of magnitude. There are some military applications which could make use of these increased capacities. Furthermore, the surface wave compressors are simpler than their conventional counterparts, and substantial savings in cost and space are anticipated. Simularly, a figure will be shown of the nondispersive delay capacities of conventional devices and the capacities of surface wave devices. Again the surface wave devices show promise of delivering capacities well in excess of conventional devices. An additional advantage of surface wave delay lines is the ease with which taps are applied, and it is likely that surface wave lines will be used when multiple taps are desired.

If the number of fingers is varied and if the length of fingers is varied along an interdigital transducer then the response as a function of frequency can be modified greatly. Special surface wave filters with moderate pass bands have been fabricated for IF strips, TV tuners, and communications equipment . A number of commercial firms are attempting to exploit this technique because it shows promise of replacing coils in filters because surface wave devices are fabricated with a method which is compatible with conventional planar techniques for microminiature circuits. Filters of this sort have been incorporated in pre-production devices and they are currently under intensive development at several commercial laboratories.

Up to now the discussion was limited to applications which are based on existing technology. In the long run, it may become possible to employ surface acoustic wave techniques for special digital memory applications, especially for applications where high data rates and relatively slow access times on the order of a microsecond are acceptable. A stack of surface wave tapped digital delay lines could replace disc and drum memories in certain computers which require higher data rates. The acoustic memory could have bit rates as large as 10^8 per second, a storage density on the order of 10^4 per square centimeter, plate sizes on the order of 20 centimeters, at a substrate cost of about \$10 per cm^2.

Another future application might be the utilization of waveguides to fashion a phased array on a crystal surface. The far distribution of the array corresponds to the Fourier transform of the amplitude distribution of the phased array. This device may find considerable application in instrumentation devices, in radar signal processing devices, and in image recognition devices.

Conclusions

There are two principal advantages of acoutic waves over electromagnetic waves: The acoustic waves travel 5 orders of magnitude more slowly than electromagnetic waves. Therefore it is possible to contain in an inch of crystal a signal that ordinarily fills a mile of coaxial cable. The second advantage is that the attenuation of an acoustic wave is substantially less than the attenuation of an electromagnetic wave. In other words perhaps 1/10 of the input energy emerges at the output of the inch long acoustic crystal, whereas less than 1/10,000 of the input energy emerges at the end of the coaxial cable. Surface acoustic waves have the additional advantage because they can be fabricated by planar techniques of the sort that are much in fashion for the fabrication of microminiature electronic circuits. Surface acoustic wave devices therefore are particularly well suited for mass production procedures. Surface wave devices are likely to be used instead of certain bulk acoustic delay lines, and electronic filters. There is a possibility that they may become useful for applications where a large amount of storage and relatively limited access is permissible, and they may replace certain digital components such as shift registers, disc and drum memories, and delay lines.

References

1. R. A. Waldron, "Mode Spectrum of a Microsound Waveguide Consisting of an Isotropic Rectangular Overlay on a Perfectly Rigid Substrate", IEEE Trans. on Sonics and Ultrasonics, Vol. SU-18, #1, p. 8, January 1971.

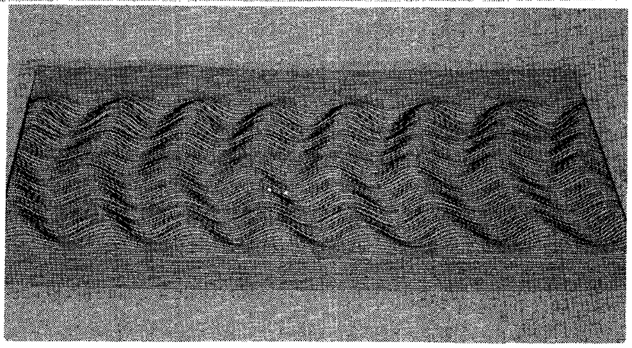

Figure 1. A three dimensional view of a UHF surface wave on lithium niobate.

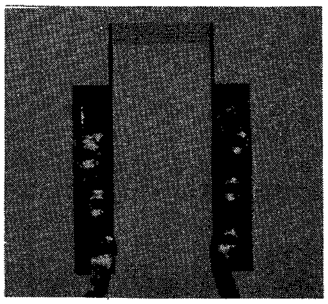

Figure 2. Surface Wave Transducer.

Figure 3. Gelatin Waveguide on Aluminum Plate.

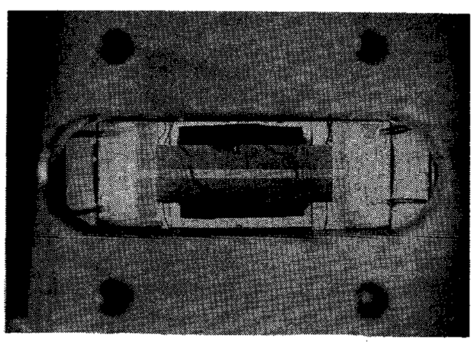

Figure 4. A photograph of an accumulation layer amplifier. The amplifier consists of a clear lithium niobate crystal on which 500 Å thick spacer rails were deposited. A thin silicon wafer with an accumulation layer is placed on top of the spacer rails.

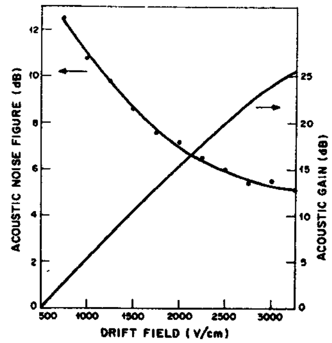

Figure 5. Acoustic noise figure and acoustic gain vs drift field at 167 MHz of the accumulation layer amplifier.

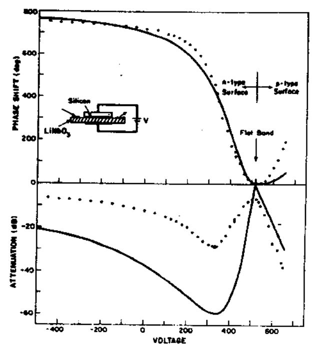

Figure 6. Phase shift and attenuation as a function of transverse voltage in a gapped accumulation layer amplifier structure. The dots are experimental and the solid lines are theoretical results.

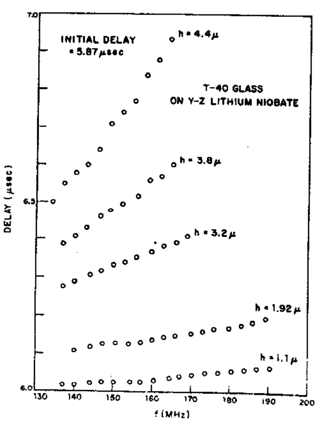

Figure 7. The dispersion obtained with a leaded glass film on a lithium niobate substrate for various glass film thicknesses.

Notes