surface wave conversion process, and vice versa, associated with interdigital transducers on piezoelectric materials. Surface wave delay lines can now be designed with insertion loss <10 dB and delay >10 \( \mu s \) using single coil inductor matching on input and output. A unique feature of the surface wave is that acoustic energy can be tapped at any desired plane between the input and the output transducers using weakly coupled interdigital transducers.

The feasibility of using a multiple tapped surface wave delay line for analog matched filter applications (biphase correlator) has been investigated with excellent results. Fig. 1 shows two tapped delay lines fabricated on Y-cut X-oriented crystalline quartz plates 1.5 inches long. The upper line [Fig. 1(a)] has 11 taps spaced at 1 \( \mu s \) intervals. Input and output transducers contain 25 finger pairs with a 6-MHz, 3-dB bandwidth centered at 150 MHz, and are normally untuned with a series inductor for minimum conversion loss. The tap transducers are three-finger-pair structures and are normally untuned for minimum interference with the main signal.

The response of the 11-tap line (with all 11 taps connected together) to an RF pulse of two different lengths is shown in Fig. 2. In Fig. 2(a) the pulse length is 200 ns and in Fig. 2(b) it is 14 \( \mu s \). These show the individual tap contributions and the coherent summation, respectively. The loss on coherent summation (vector addition) compared with the sum of the individual taps (scalar addition) is <0.5 dB which is within the uncertainty of the measurement equipment. Coherent summation is observed at frequency intervals of 1 MHz corresponding to the reciprocal of the time delay between taps. Spurious echo rejection under coherent summation exceeds 30 dB. The absolute positions of the taps are determined by the mask fabrication precision and are located within \( \pm 1 \mu m \) of the required position giving all taps with \( < \pm 17^\circ \) phase variation from mean.

A 50-tap line [Fig. 1(b)] was designed for biphase correlator investigations. This 50-tap line has 200-ns spacing between taps; input/output transducers are centered at 120 MHz (4.8-MHz bandwidth) and the taps are three-finger-pair interdigital transducers. Fig. 3 shows the line in a 1\( \frac{1}{2} \) inch by 1\( \frac{1}{2} \) inch package with the 50 taps connected by wire bonds to sum lines on a thin-film substrate. Tap connections are made and sum lines externally connected to form the first 50 bits of a 63-bit maximal length biphase code. Fig. 4(a) shows the performance of this tapped delay line correlator. The upper trace is the 63-bit digital signal driving a biphase modulator. The lower trace of Fig. 4(a) shows the output of the tapped delay line, while Fig. 4(b) shows the correlation peak expanded to 200 ns per division.

The main correlation peaks are well defined and occur at the correct time slots, that is, when the first 50 bits of the biphase code coincide with the fixed biphase coding of the 50 delay line taps. The minor peaks are exactly as predicted, within experimental error, with respect to times of occurrence and amplitudes compared with the correlation peak. The carrier frequency for optimum correlation is sensitive to temperature changes of the delay medium. The center frequency has been experimentally determined to vary by 30 parts per million per °C over the temperature range 20 to 60°C.

The tapped surface wave delay line approach to analog matched filter implementation has considerable application potential. Examples include communications systems employing synchronous code detection, data demodulation, or variable data detection. Inherent advantages of this approach over digital matched filters are absence of Kirchhoff adder, invulnerability to CW interference, and operation at high speed with no dc power. Practical factors which will determine the utilization of the tapped surface wave delay line such as maximum frequency, maximum bit rates, maximum number of taps, cost, and reliability are under investigation.

**Acknowledgment**

The authors wish to thank J. H. Collins and B. L. Elvig for their contributions to this study.

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S. T. COSTANZA

P. J. HAGON

L. A. MACNEVEN

Autonetics Division

North American

Rockwell Corp.

Anaheim, Calif. 92803

**Dispersive Rayleigh Wave Delay Line Utilizing Gold on Lithium Niobate**

**Abstract**—The dispersion characteristics have been obtained for a gold film overlay on lithium niobate into which Rayleigh waves around 100 MHz are injected. Phase and attenuation measurements are conducted continuously as the gold film is deposited under vacuum conditions. Linear increase of delay with frequency is observed for a gold thickness approximating 5000 \( \AA \).

Measurements at frequencies around 100 MHz on dispersive Rayleigh wave propagation are reported here for propagation on a piezoelectric, lithium niobate delay line that is coated with a layer of gold of thickness...
much less than an acoustic wavelength. These measurements complement previously published data [1] on shear-type Love waves at UHF frequencies obtained using oriented cadmium sulphide depositions on yttrium aluminum garnet. In both cases the overlay material has lower acoustic velocity than the substrate material. Measurements of both phase velocity and attenuation have been made under vacuum conditions as the gold thickness is continuously varied. The data presented here should prove significant in the design of acoustic surface waveguides and the realization of pulse compression filters where the factors of small size, low cost, and batch fabrication predominate.

The experimental configuration is shown in Fig. 1. The lithium niobate delay line is Z-cut with acoustic propagation along the X-axis (Z-X orientation), and the electro-acoustic transducers are of the interdigital type, five periods in length, with a synchronous frequency of 117 MHz. A gold film, 1.9 cm in length, is vacuum deposited in the region between the transducers; the acoustic beam extends from the film surface through the film and a few microns into the substrate. The thickness of the film tapers within 250 μm of the ends to ensure a reflectionless transition between the coated and the uncoated regions. This is accomplished by evaporating through a mask spaced approximately 0.6 cm off the substrate so that the taper represents the geometrical shadow of the evaporation source.

Phase velocity in the coated region is determined from CW monitoring of the phase angle between the voltages at the input and output transducers. For this purpose we find it convenient to use the AD-YU type 406 H phase meter on the low frequency (~100 kHz) sampling outputs of a Hewlett-Packard type 158B oscilloscope, which samples directly the voltages at the two transducers. A sealed RF feedthrough system enables the phase measurement to be carried out while the delay line is undergoing film deposition in the vacuum. The film thickness is simultaneously monitored by means of a crystal resonator thickness monitor.

Fig. 2 shows the continuously measured phase velocity for the layered region versus normalized gold film thickness, the frequency being held constant at 116 MHz. The phase velocity is \( v_{p} = 3.74 \text{ km/s} \) at zero film thickness, and decreases approximately linearly to \( v_{p} = 3.21 \text{ km/s} \) at a final film thickness of 500 Å ± 50 Å. The velocity-thickness characteristic is in good agreement with approximate theory [2] which assumes an elastically isotropic film and substrate.

A second effect causing a decrease in velocity is due to the short-circuiting of the electric field parallel to the interface. This is given by Campbell and Jones [3] as \( \Delta v / v = -0.0025 \) and is quite small in comparison with the elastic dispersive effect.

Phase measurements were also made by varying frequency on the delay line with the final 5000 Å film. In this measurement an initial frequency of 98.3223 MHz was chosen, and 216 frequencies ranging to 120.5120 MHz were recorded, each corresponding to an increment of 2 GHz in the phase angle of the line. The resultant data are described by the quadratic least squares fit

\[
\omega_{n} = \frac{a}{2n} + bn + c
\]

where

\[
\omega_{n} = 98.3223 \text{ MHz}
\]

and \( n = 0, \ldots, 216 \) is the index of that frequency corresponding to a 2π increment of phase angle. The coefficients are given by

\[
a = -43.56 \text{ s}^{-1}
\]

\[
b = 6.554 \times 10^{8} \text{ s}^{-2}
\]

\[
c = 6.171 \times 10^{8} \text{ s}^{-3}
\]

the fit being sufficiently good to assign uncertainty less than 0.1 percent to each coefficient.

The delay corresponding to the associated group velocity of a pulse may be computed from the above as

\[
\tau(\omega) = \frac{\omega}{\omega_{n}} = \frac{2\pi}{2\omega_{n} + b}
\]

Fig. 3 presents a plot of this delay together with the measured insertion loss. Note the observed linear variation of delay over the operating frequency band, suggesting pulse compression filter application.

The insertion loss has a minimum of 15 dB at 109 MHz, the resonant frequency of the transducers as tuned by fixed series inductors. Of this loss, 16 dB represents the increase in propagation loss resulting from the introduction of the relatively lossy gold film. The 3 dB bandwidth is 7 MHz, or fractionally 0.064, with the fixed inductors. With fixed inductors, the insertion loss is controlled by the electrical Q, which is about 15 because of the relatively low coupling factor of the Z-X lithium niobate orientation [5]. However, the transducers could be retuned at each measurement frequency to give a 3 dB fractional bandwidth of 0.2.

The principal reason for choosing the Z-X configuration in this experiment is the high (greater than 25 dB) triple transit echo suppression required for the CW phase measurement. When high triple transit suppression is less critical, Y-cut, Z-propagating lithium niobate might be used. It has been shown [4], [5] that such a line with five-period transducers will have a 3 dB fractional bandwidth of 0.24 and triple transit suppression of 12 dB when fixed series inductive tuning is used.

ACKNOWLEDGMENT

The authors are grateful to D. K. Winslow for his technical guidance, and wish to acknowledge the technical contribution of D. J. Walsh in the film fabrication.

REFERENCES


