MODIFIED EQUIVALENT CIRCUIT MODEL FOR ULTRASONIC SURFACE WAVE INTERDIGITAL TRANSDUCERS

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Summary

An equivalent circuit model has been modified to include interelectrode reflections. Using this extended model, the second order effects observed experimentally for 13-bit PSK filters on YZ $LiNbO_3$ can be qualitatively predicted.

Introduction

An equivalent circuit model of interdigital surface wave transducers based on Mason's[1] bulk mode models has been previously reported in the literature.[2] This model inherently approximates such second order effects as electro-acoustic regeneration and triple transit between output and input transducers, but, as formulated, does not include the effects of the discrete metal fingers themselves in terms of surface wave reflections, scattering of surface modes into bulk modes, or direct bulk mode generation.

Development of the Model

The discrete metal fingers on the surface of the propagation substrate effect the boundary conditions in three ways: first, due to the electrical shorting at the surface; second, due to the mass loading; and, third, due to the finite thickness of the metal film (causing dispersion). It is postulated that the first two effects can be simulated by separating the propagation medium into sections with or without a metal overlayer and assigning different characteristic impedances to these sections in the equivalent circuit model. The third effect is small for thicknesses appreciably less than a wavelength as in the case of practical, nondispersive devices. It should be noted that bulk mode generation is not included in the modified model. The equivalent circuit model of a 4-interdigital finger device is shown in Fig. 1. The "crossed field" case is considered here since a YZ lithium niobate substrate is assumed for the calculation. The driven electrical equivalent T network is centered directly under each metal finger, while the passive T network is located directly between two metal fingers. To maintain the center frequency coupling at the value given in Ref. 2, the turns ratio has to be increased by $\sqrt{2}$ as shown. The end effects are approximately modeled by halving the turns ratio for the end electrodes.

Analysis

The equivalent circuit model was set up for the 13-bit Barker coded device. The impedance mismatch between sections on lithium niobate with 1000 Å of aluminum metallization is predominantly due to the shorting effect, and a reduction of characteristic impedance under the metal fingers of approximately 2% is expected.[2,4] Actually, several values including 1, 2, and 5% have been investigated in this study.

Because of the different velocities between the bulk modes and surface mode of propagation, it was decided that less ambiguous results would be obtained experimentally in the time domain. Accordingly, the circuit was computer-analyzed to provide sufficient frequency data points for an accurate Fast Fourier Transform to be taken. The resulting impulse response of this circuit was obtained in both directions by modeling an output transducer having three interdigital pairs at either end, as was used in practice.

Results

Theoretical results are shown in Fig. 2 for a 2% impedance mismatch. The results clearly predict that more trailing energy is present (after the time duration T of the actual code) in one direction than the other. This asymmetry was not observed theoretically when the acoustic mismatch was set to zero. Also, Fig. 3 shows the theoretical compressed pulse using a perfect time reversed code incident on Port 2. Distortion of the trailing sidelobes is predicted as shown. Experimental results were taken of the impulse response of several devices and typical results are shown in Fig. 4. The shape and magnitude of this trailing energy in both directions show good agreement between theory and experiment for the 2% mismatch as expected. Applying an electronically generated code into Port 2 of the device gave the compressed pulse shown in Fig. 5 which exhibits distortion in the trailing sidelobes very close to that predicted theoretically.

Improved Device Design

One way to reduce the effects of electrode acoustic mismatch is to reduce the number of electrodes in the code. For the case of a single sampled code having a 1-bit long input transducer, the compressed pulse using an electronic code generator is shown in Fig. 6. The trailing sidelobes are seen to be considerably improved.

Conclusions

A model to include the effects of acoustic mismatch at the metal electrodes has been developed and a device has been theoretically characterized in the time and frequency domain. The model has been experimentally verified in the time domain using the impulse responses and correlation output of 13-bit Barker codes at 30 MHz on lithium niobate with very good agreement. The model is also most useful in predicting the effects of acoustic mismatch in the frequency domain, where high frequency roll-off is predicted in the bandpass response, as is observed in practice in many cases.

Since the frequency response of an individual T section is a sine function, it represents two impulses in the time domain at the edges of the metal electrodes. Hence, this extended model is closely related to the impulse model recently proposed,[5] but, in addition, retains the interaction between the various electrodes which is lost in the simple impulse model analysis.

References

1. Mason, W. P., "Electromechanical Transducers and Wave Filters," 2nd Ed., Princeton, N.J., Van Nostrand (1948).
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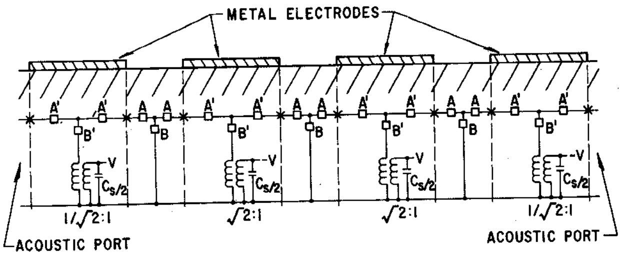
3. Jones, W. S., Hartmann, C. S., and Claiborne, L.T., "Evaluation of Digitally-Coded Acoustic Surface Wave Matched Filters," IEEE Trans. on Sonics and Ultrasonics, SU-18, 1, January 1971.
4. Campbell, J.J., and Jones, W.R., "A Method for Estimating Optimal Crystal Cuts and Propagation Directions for Excitation of Piezoelectric Surface Waves," IEEE Trans. on Sonics and Ultrasonics, SU-15, October 1968.
5. Tancrell, R.H., "Surface Wave Filters," presented at the 1970 IEEE Ultrasonics Symposium, San Francisco, Oct. 21-23, Paper M-1.

Fig. 1. Equivalent Circuit Including Mechanical Mismatch



$A' = jR' \tan \theta/8$ $\quad B' = -jR' \csc \theta/4$

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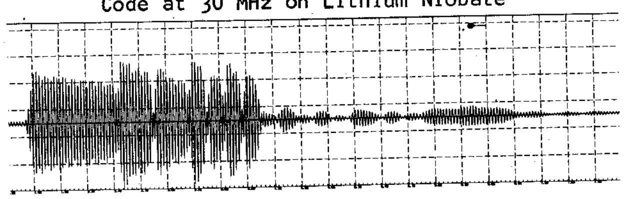
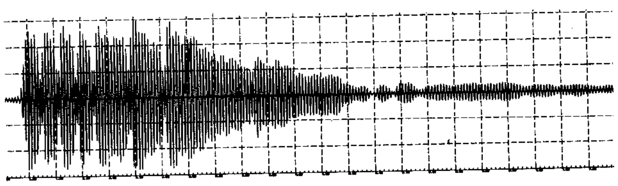
Fig. 2. Theoretical Results for 13-Bit Barker Code at 30 MHz on Lithium Niobate



(a) Impulse Response-Direction 1



(b) Impulse Response-Direction 2

Fig. 3. Compressed Pulse Using Perfect Input Signal

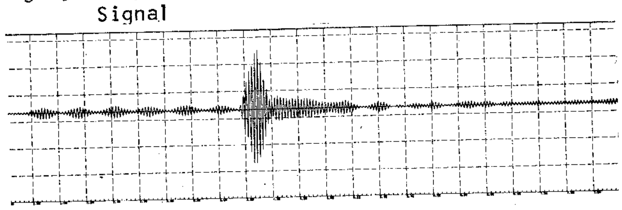
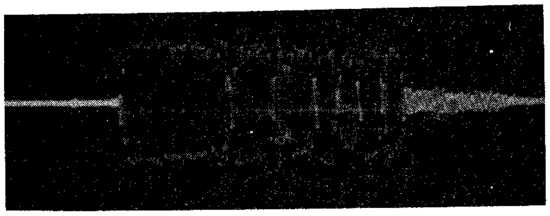
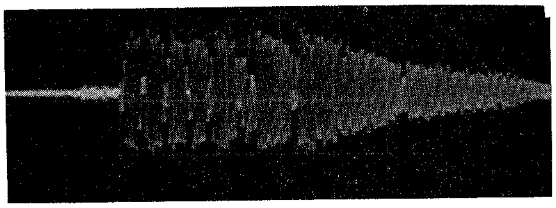


Fig. 4. Experimental Results



(a) Impulse Response-Direction 1



(b) Impulse Response-Direction 2

Fig. 5. Compressed Pulse Using Electronic Generator into No. 2 Port

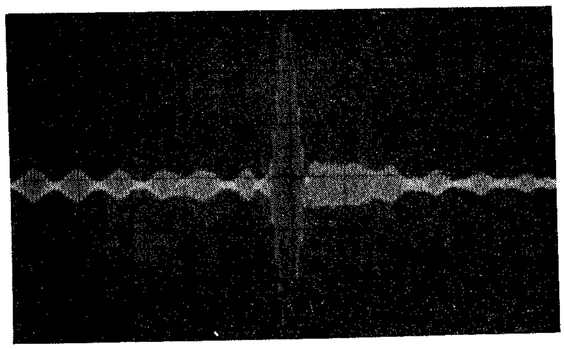


Fig. 6. Compressed Pulse of Single Sampled Barker Device