THE MICROWAVE REALIZATION OF A SIMPLE SURFACE WAVE FILTER FUNCTION*

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Abstract

Surface wave acoustic device technology continues to generate new ideas, analyses and potential applications at an impressive rate. Concomitant introduction of some specific low-frequency prototypes into systems design and subsequently hardware is witness to the growing acceptance of this technology by the systems community. The demand for specific filter functions at steadily increasing frequencies is a natural consequence of this trend. Therefore, second order as well as high frequency effects must be understood in detail, if the desired filter properties are to be realized. In this paper the authors discuss the design and fabrication of a microwave delay line with a precisely specified bandpass characteristic and center frequency. The filter design required a parabolic form factor (to within ±0.3 dB) and essentially ripple free (<0.1 dB) in-band response between 3 dB points. The filter was fabricated using three-period tuned interdigital transducers produced by electron beam microfabrication. The emphasis of this paper will be on interaction of the various effects, such as electrical load and acoustic mass loading, frequency dependent propagation loss and matching element parasitics which, particularly at microwave frequencies, render the achievement of the desired pass band properties more difficult. In addition, the accuracy and stability requirements of the electron beam microfabrication of micron-sized electrode geometry will be discussed. The sources and control of spurious response ripples which degrade the otherwise smooth transfer function are also discussed.

Surface wave acoustic device technology, now in its eighth year,** continues to generate new ideas, analyses and potential applications at a seemingly undiminishing rate. Concomitant introduction of some specific low-frequency prototypes into systems design and subsequently hardware is witness to the growing acceptance of this technology by the systems community. The demand for specific filter functions at steadily increasing frequencies is a natural consequence of this trend and, therefore, second order as well as high frequency effects must be understood in detail, if the desired filter properties are to be realized. In this paper the authors discuss the realization of a microwave delay line with a precisely specified band pass characteristic and center frequency. The objective specifications for this delay line, to be developed on y-z $LiNbO_3$† are listed in Table I. The filter was fabricated using tuned interdigital transducers of seven periodically spaced electrodes produced by electron beam microfabrication. The emphasis of this paper will be on interaction of the various effects, such as electrical load and acoustic mass loading, frequency dependent propagation loss and matching element parasitics which, particularly at microwave frequencies, impede the achievement of the desired pass band properties. In addition, the accuracy and stability requirements of the electron beam microfabrication of micron-sized electrode geometry will be mentioned. The sources and control of spurious response ripples which degrade the otherwide smooth transfer function are also discussed.

TABLE I. Filter Specification

Frequency, f_o	837 MHz
Form factor	Parabolic in dB about f_o
Deviation	< ±0.3 dB
Ripple (pulsed signals)	< 0.1 dB
Insertion loss	< 25 dB at f_o
Bandwidth	Maximum, consistent with above
Delay	8.6 microseconds

Factors that Affect Pass Band Symmetry and Bandwidth

The synthesis of a symmetrical pass band surface wave filter using periodic transducer arrays utilizes the crossed field transducer model[1] as a starting point.[2,3] In its simplest form, a symmetrical pass band centered on f_o (837 MHz, in the present case) is predicted when an ideal inductor is used for a series tuning, while the slope of the frequency response depends on the degree of coupling between source impedance R_g and effective transducer series radiation resistance R_a. The frequency response shape required here demands less than critical coupling $R_a > R_g$, as otherwise a flat topped or double-humped pass band would result. Methods of achieving controlled coupling in a singly tuned

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**In the authors' time table it began with the discovery of the present interdigital transducer by R. M. White, F. W. Voltmer in 1965 Appl. Phys. Letters Vol. 7, p. 314, Dec. 1965. Prior work existed in Great Britain, apparently as early as 1962, of which the authors became only recently aware, W. S. Mortley, Proc. IEEE. Vol. 6, No. 1, p. 133, Jan. 1973.

†Polished substrate, of LINOBATE grade, furnished by AFCRL.

transducer, as seen with reference to our complete circuit model shown in Fig. 1, are either to increase R_a through decrease of the transducer aperture (reduction of C_T in transducer block diagram) or the reduction of the number of electrodes, or alternatively to increase the shunt capacitance C_e, external to the transducer.[3] The latter method leaves a greater degree of freedom, since shunt capacitance (part of inductance L) control is more readily accomplished and altered.

A second factor that affects the pass band shape is the frequency dependent propagation loss of the acoustic substrate itself[4] which tends to introduce a negative slope in the pass band. An excellent approximation in the frequency range and for the delay distance of interest is the expression shown in that figure, where f_0 = 837 MHz, L_0 = 3.36 dB, and x = 1.83, provided that the polished surface is scratch and defect free.

Electrical shorting of the electrode metal, as well as its mechanical loading, further distort the transducer pass band symmetry.[3,5] For purposes of this analysis, the two effects may be lumped together and are designated by the parameter τ, as shown in Fig. 1. At microwave frequencies and for a given metal film thickness, the mechanical loading (impedance discontinuity) accounts for an appreciable fraction of the total value of τ and, therefore, the film thickness becomes an important design parameter, as can be seen from an inspection of Fig. 2.

Partial compensation for these effects may be accomplished by choosing the proper inductance[3] to "detune" the transducers on the low side of the synchronous frequency of the array, not necessarily equal to f_0. Figure 2 shows the results of calculations that include all these effects except that due to the decoupling arising from the parasitic shunt capacitor C_e associated with the tuning inductor L. It can be seen that the combined effects seriously degrade the desired symmetrical response for the two chosen tuning conditions, whereas fairly symmetrical pass band shape results if the acoustic loading effects (acoustic impedance discontinuity ratio τ) are neglected.

Experimental Results

Two methods lend themselves to the reduction of these effects. First, the introduction of the shunt capacitance will decouple the total transducer acoustic radiation impedance and, therefore, the loading effects just described. Thus, a two-fold benefit accrues from a careful control of that circuit element although a compromise may be called for if both effects are not simultaneously realized. The second approach is to use a doublet electrode configuration[5-8] for which it has been shown that the in-band asymmetry is reduced. The experimentally determined frequency response[9] obtained under pulsed conditions, following the former approach, is shown in Fig. 3, superimposed on parabolic curves of best fit and ± 0.1 and ± 0.3 dB excursions. Electron-beam-fabricated patterns of the delay line (a portion of which is shown in Fig. 4) contained 3-1/2 period single electrode transducers of 1600 A Aluminum film thickness using a titanium interface adhesion layer of 200 A thick. Special planar spiral, low parasitic tuning inductors were developed for this work. It is seen that the desired parabolic frequency response was nearly achieved. However, spurious ripples not predicted by our analysis are evident in the passband.

Extensive trade-off calculations that account for the effects of the external capacitance on midband insertion loss, bandwidth, and deviation from symmetry, both for single as well as doublet electrodes have been carried out and will be compared with experimental results on such structures. The origin of spurious ripples in the pass band that may arise from substrate surface defects as well as bulk wave generation in the interdigital array and their reduction are treated.

Acknowledgement

Acknowledgements are gratefully accorded to W. E. Perkins for electron beam fabrication of the transducer patterns, to R. Dimon for delay line assembly and packaging, to W. R. Smith for technical discussions in connection with the use of his interdigital transducer computer program, and to Daniel Anderson who carried out the filter response calculations.

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(9) Measured data points were obtained from A. J. Slobodnik, Jr., AFCRL.

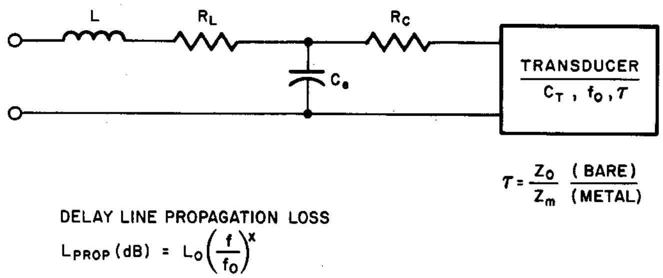

FIG. 1 Equivalent circuit used in the computation of passband characteristics. The transducer box contains the 3-port crossed-field circuit model that allows the inclusion of the acoustic impedance ratio τ. The capacitance C_e may include parasitics contributed by the tuning indicator L. The approximation to the frequency dependent propagation loss used in the computation is also shown.

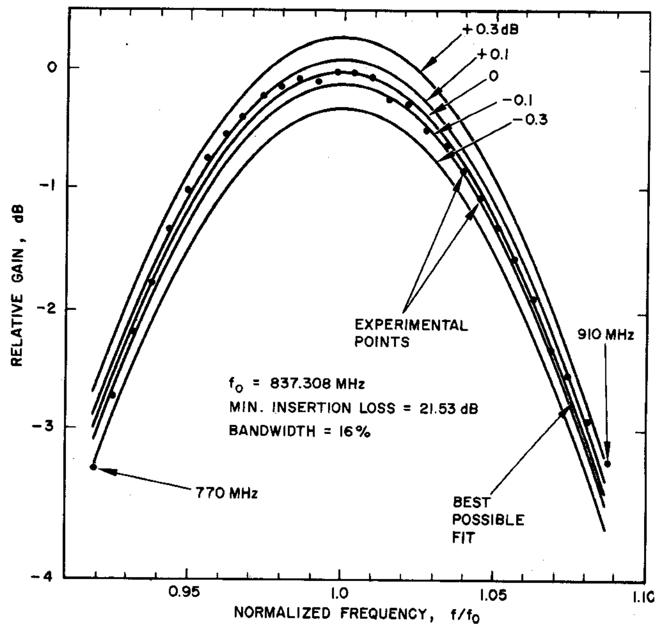

FIG. 3. Experimental frequency response of one electron-beam-fabricated transducer delay line. Each transducer contains 7 electrodes synchronous at 880 MHz, and is series tuned using a planar, spiral, copper inductor on a fused quartz substrate.

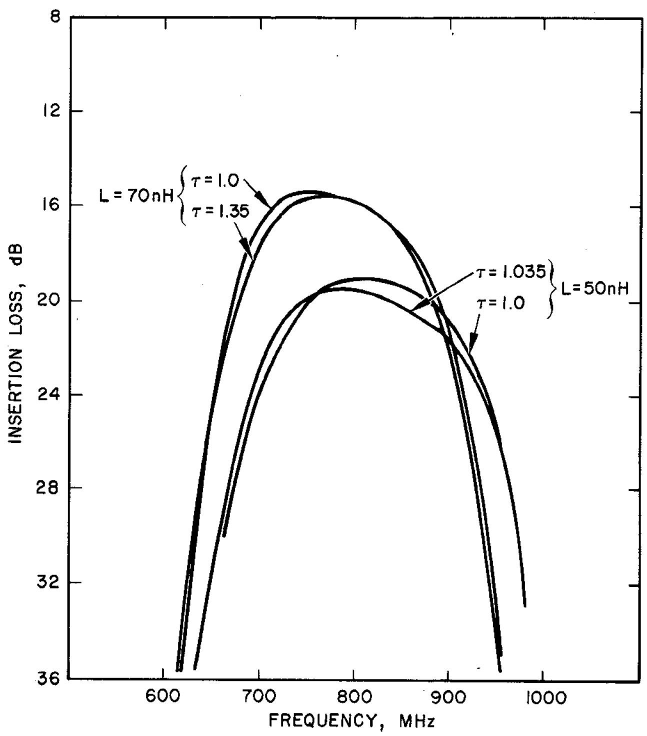

FIG. 2 Computed frequency response curves for two tuning conditions showing the effects of including the total acoustic impedance discontinuity.

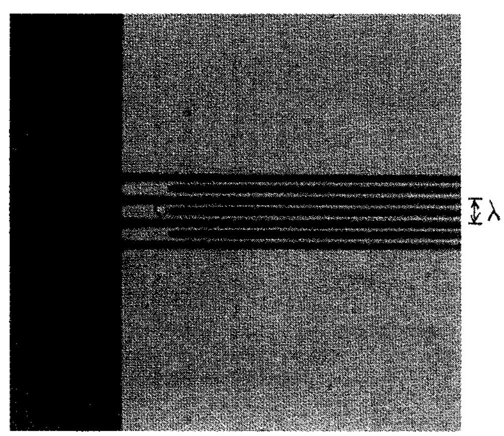

FIG. 4 Photomicrograph of the transducer electrode structure. Picture taken in transmission; original magnification was 1000 X (λ = 4.15 μm).