ELECTRICAL BANDPASS CHARACTERISTICS OF MECHANICALLY TERMINATED LONG INTERDIGITAL TRANSDUCERS

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ABSTRACT

Frequency responses of N equal sections of surface acoustic wave interdigital transducers are presented. These are obtained through transmission matrices of crossed-field models and indicate the sharpness of insertion loss that can be obtained using a large number of equal sections.

INTRODUCTION

Surface Acoustic Wave (SAW) filters offer the advantages of small size and weight together with low cost and high reproducibility. Consequently there has been considerable interest in SAW filters, and they have been extensively studied in recent years.[1-5] Most of the studies have been based on the use of a small number of interdigital transducer (IDT) sections for converting electrical signals into surface acoustic waves, and reconverting back to the electrical signal, in order to obtain desired filter characteristics. A general mathematical expression for the admittance matrix for an N-section SAW transducer, characterized by either the crossed-field or the in-line model,[6-9] has been recently developed.

In the present paper, the admittance matrix for the N-section crossed-field model of the SAW transducer is used to derive the electrical admittance of a three-port long interdigital transducer mechanically terminated at its two acoustical ports. The real part of the electrical admittance is plotted, and seen to be of bandpass form. The responses of the real part of the electrical admittance, the phase and finally the insertion loss in dB are plotted as a function of frequency for different numbers of IDT sections. It is observed that the sharpness of response is improved tremendously with a large number of identical IDT sections.

A SAW resonator containing two reflective gratings and an IDT was previously simultated to show the nature of its bandpass filter response.[10] But the present analysis shows that a better response can be obtained with a larger number of IDT sections.

Mathematical Formulation

A general expression for the electrical admittance of an IDT can be derived in terms of its transmission matrix elements. In order to achieve a narrow bandpass filter response, a long IDT, consisting of a large number of identical electrode pairs, is utilized. The schematic representation of the filter using a long IDT is shown in Figure 1 where the Z_ℓ's symbolically represent

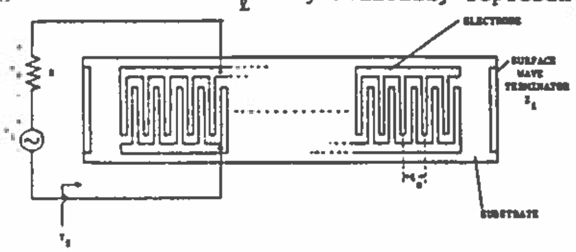


FIGURE 1: SCHEMATIC REPRESENTATION OF FILTER USING LONG IDT SECTIONS.

mechanical loading of the acoustical ports. We will be interested in taking the output across the resistor R in using the device as a reflection-type filter.

Assuming identical sections, each of which consists of one-half of an electrode of each polarity and the piezoelectric material between, the admittance matrix in the sinusoidal steady-state for the N-section crossed-field model of a SAW transducer is given by:[8]

$$\begin{bmatrix} V_1 \\ V_N \\ I_3 \end{bmatrix} = \begin{bmatrix} -\frac{j}{Z_0}\cot N\theta & \frac{j}{Z_0}\operatorname{cosec} N\theta & -\frac{j\phi}{Z_0}\tan\frac{\theta}{2} \\ \frac{j}{Z_0}\operatorname{cosec} N\theta & -\frac{j}{Z_0}\cot N\theta & (-1)^N \frac{j\phi}{Z_0}\tan\frac{\theta}{2} \\ -\frac{j\phi}{Z_0}\tan\frac{\theta}{2} & (-1)^N \frac{j\phi}{Z_0}\tan\frac{\theta}{2} & j\left(\omega C_T + \frac{2N\phi^2}{Z_0}\cdot\tan\frac{\theta}{2}\right) \end{bmatrix} \begin{bmatrix} F_1 \\ F_N \\ V_3 \end{bmatrix} \quad (1)$$

Where V_1, F_1 are the input variables and V_N, F_N are the output variables at the acoustic (unloaded mechanical) ports, and I_3, V_3 are used to denote current and voltage at the electric port of the three-port interdigital transducer. The variables V's and F's of the acoustic ports are the particle velocities and the forces applied, respectively, at the respective ports.

The other parameters of equation (1) are defined as follows:

$\theta = \frac{\ell_0}{V_0}\cdot\omega$, is the acoustic transit angle of the substrate

$\phi = \left(\frac{K^2 C_0 Z_0 V_0}{\ell_0}\right)^{1/2}$ is the transformer turns ratio.

$\omega = 2\pi f$, f=frequency. Z_0 = acoustic characteristic impedance, K^2 = piezoelectric coupling coefficient, C_0 = capacitance for the nth section, V_0 = velocity of the acoustic propagation, ℓ_0 = length of a single section, $C_T = NC_0$, N=number of sections in the IDT.

In order to find the input electrical admittance Y_E we use Figure 2, in which the interdigital

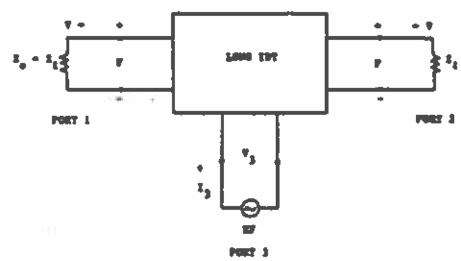


FIGURE 2: BLOCK DIAGRAM OF A 3-PORT IDT.

transducer is considered to be acoustically bidirectional and characteristically terminated by an impedance Z_ℓ at each acoustic port. Because of the bidirectional symmetry of the interdigital transducer, when an RF voltage is applied at port 3, the surface acoustic waves are generated and propagate symmetrically away from the transducer in both directions. Thus, the port 1 and port 2 velocities and forces are equal.

In terms of the variables used in Figure 2, a transmission matrix equation can be constructed with an explicit expansion of it in the following form

$$F_1 = T_{11}F_N + T_{12}V_N + T_{13}V_3 \quad (2)$$

$$V_1 = T_{21}F_N + T_{22}V_N + T_{23}V_3 \qquad (3)$$

$$I_3 = T_{31}F_N + T_{32}V_N + T_{33}V_3 \qquad (4)$$

The T_{ij}'s are found directly from equation (1). Thus, from the middle row of (1) we have

$$F_1 = \left(\frac{\cot N\theta}{\operatorname{cosec} N\theta}\right)F_N + \left(\frac{Z_0}{j}\sin N\theta\right)V_N + \left\{(-1)^{N+1}\emptyset \cdot \tan\frac{\theta}{2}\sin N\theta\right\}V_3$$

$$\text{or } F_1 = (\cos N\theta)F_N - (jZ_0 \sin N\theta)V_N + \left[(-1)^{N+1}\emptyset \cdot \sin N\theta \tan\frac{\theta}{2}\right]V_3 \qquad (5)$$

From the first row of (1) and using (5)

$$V_1 = \frac{1}{Z_0}\left[\operatorname{cosec} N\theta - \cot N\theta \cos N\theta\right]F_N - (\cos N\theta)V_N + \frac{j\emptyset}{Z_0}\tan\frac{\theta}{2}\left\{(-1)^{N+2}\cos N\theta - 1\right\}V_3$$

$$\text{or } V_1 = \left(\frac{1}{Z_0}\sin N\theta\right)F_N - (\cos N\theta)V_N + \left[\frac{j\emptyset}{Z_0}\tan\frac{\theta}{2} \cdot \left\{(-1)^{N+2}\cos N\theta - 1\right\}\right]V_3 \qquad (6)$$

Also from the third row of (1) and again using (5)

$$I_3 = \frac{j\emptyset}{Z_0}\tan\frac{\theta}{2}\left\{(-1)^N - \cos N\theta\right\}F_N - \left(\emptyset \sin N\theta \tan\frac{\theta}{2}\right)V_N + j\left[\omega C_T + \frac{2N\emptyset^2}{Z_0}\tan\frac{\theta}{2} + (-1)^{N+2}\frac{\emptyset^2}{Z_0}\sin N\theta \tan^2\frac{\theta}{2}\right]V_3 \qquad (7)$$

Consequently the explicit form of the elements T_{ij} are $T_{11} = -T_{22} = \cos N\theta$, $T_{12} = -jZ_\ell \sin N\theta$,

$T_{13} = (-1)^{N+1}\emptyset \sin N\theta \tan\frac{\theta}{2}$, $T_{21} = \frac{1}{Z_\ell}\sin N\theta$,

$T_{23} = j\left[\frac{\emptyset}{Z_\ell}\tan\frac{\theta}{2}\left\{(-1)^{N+2}\cos N\theta - 1\right\}\right]$,

$T_{31} = \frac{j\emptyset}{Z_\ell}\tan\frac{\theta}{2}\left\{(-1)^N - \cos N\theta\right\}$,

$T_{32} = -\emptyset \sin N\theta \tan\frac{\theta}{2}$,

$T_{33} = j\left[\omega C_T + \frac{2N\emptyset^2}{Z_\ell}\tan\frac{\theta}{2} + (-1)^{N+2}\frac{\emptyset^2}{Z_\ell}\sin N\theta \tan^2\frac{\theta}{2}\right]$.

Using $V = V_1 = V_N$ and $F = F_1 = F_N$, the load impedance Z_ℓ is given by $Z_\ell = -\frac{F}{V}$ (8)

Equations (2), (3) and (4) can now be utilized to obtain the following values of F and V.

$$F = \frac{T_{13}}{1 - T_{11} + \frac{T_{12}}{Z_\ell}} \cdot V_3 \qquad (9)$$

$$V = \frac{T_{23}}{1 + T_{21}Z_\ell - T_{22}} \cdot V_3 \qquad (10)$$

Direct substitution of equations (9) and (10) into equation (4) yields I_3 in terms of V_3 for the loaded network.

$$I_3 = \frac{T_{31}T_{13}}{1 - T_{11} + \frac{T_{12}}{Z_\ell}}V_3 + \frac{T_{32}T_{23}}{1 + T_{21}Z_\ell - T_{22}}V_3 + T_{33}V_3 \qquad (11)$$

The electrical admittance Y_E of the transducer can therefore be written in the form

$$Y_E = \frac{I_3}{V_3} = \frac{T_{31}T_{13}}{1 - T_{11} + \frac{T_{12}}{Z_\ell}} + \frac{T_{32}T_{23}}{1 + T_{21}Z_\ell - T_{22}} + T_{33} \qquad (12)$$

This expression of Y_E will be used to obtain the bandpass filter response of the reflection-type amplifier.

In terms of Y_E, the insertion loss in dB and phase are calculated, by reference to Fig. 1 with $G = \frac{1}{R}$, as follows:

$$\text{Insertion Loss} = 10\log_{10}\left|\frac{V_0}{V_i}\right|^2 = 20\log_{10}\left|\frac{Y_E}{G + Y_E}\right| \qquad (13)$$

and Phase $= \tan^{-1}\left(\frac{Y_I}{Y_R}\right)$ where Y_R and Y_I represent the real and imaginary components of Y_E, respectively.

PHYSICAL PARAMETERS

Using the above results, simulation was made for which the substrate material for the IDT was chosen to be Lithium niobate ($LiNbO_3$) along with aluminum metalization. The following list(4,11) shows the numerical values of all physical parameters used in the simulation, where the characteristic impedance and resistance R are normalized to unity:

Center frequency, fo = 100 MHz, Number of IDT sections, N=25,101, $V_0 = 1.37 \times 10^5$ in/s

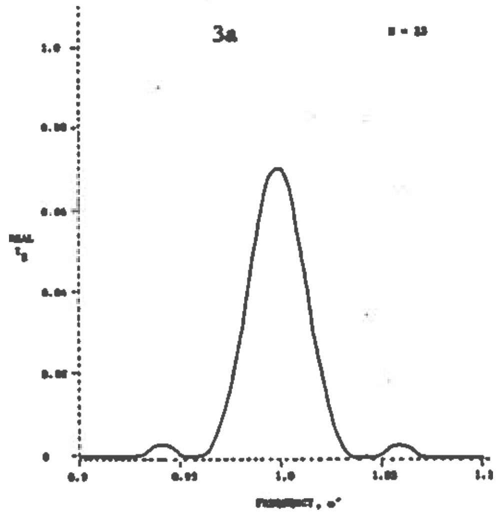
$C_0 = 0.635 \times 10^{-11}$ farads/in,

$\ell_0 = \frac{\lambda}{2} = 0.6850 \times 10^{-3}$in, $K^2 = 0.045$, $Z_\ell = Z_0 = 1.0$,

$\omega' = \frac{\omega}{\omega_0}$. Here ω' denotes the normalized frequency.

RESULTS AND CONCLUSION

The computer response of the real part of Y_E, phase and the insertion loss in dB are shown as a function of normalized frequency in figures 3 through 5 with N, the number of sections, varied



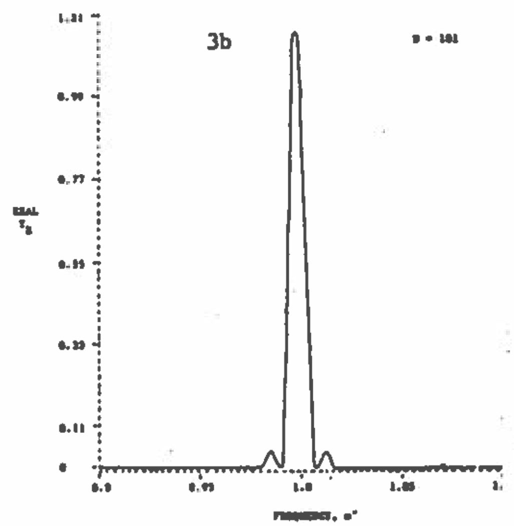
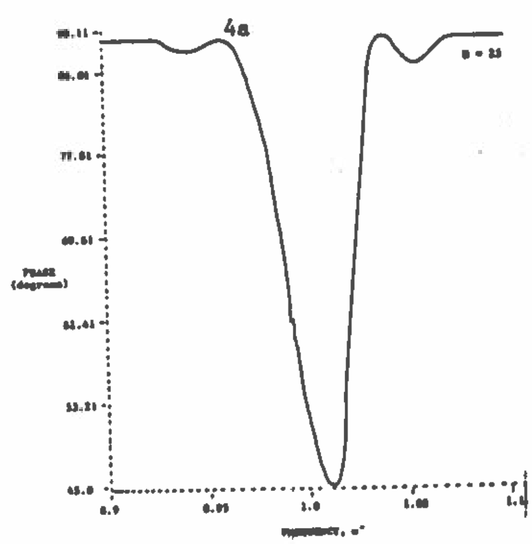


FIGURE 3: PLOT OF REAL Y_E VS. NORMALIZED FREQUENCY.



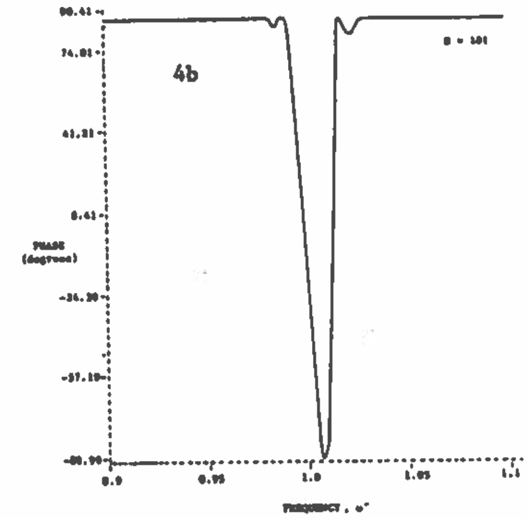
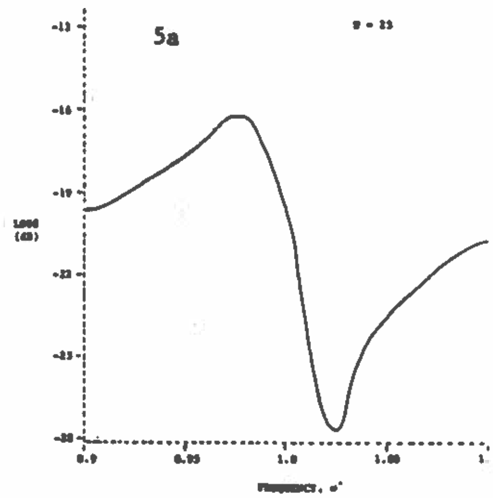


FIGURE 4: PLOT OF PHASE VS. NORMALIZED FREQUENCY.



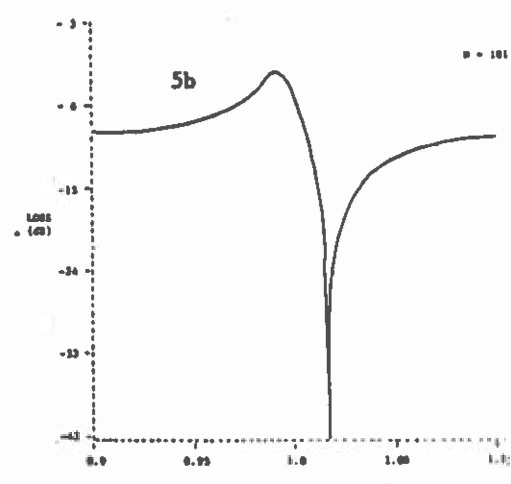


FIGURE 5: PLOT OF INSERTION LOSS VS. NORMALIZED FREQUENCY.

through the two values N=25, and N=101.

Therefore, an IDT with a large number of periodic sections is found to be appropriate for designing very narrow bandpass filters. Indeed, as per figure 5 and depending upon the sharpness required, over 100 sections may be necessary. It should be observed that equal sections, as opposed to variable finger structures, are of most convenience for design and construction. So the results indicate that large scale integrated SAW devices may be very practical.

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BIOGRAPHIES

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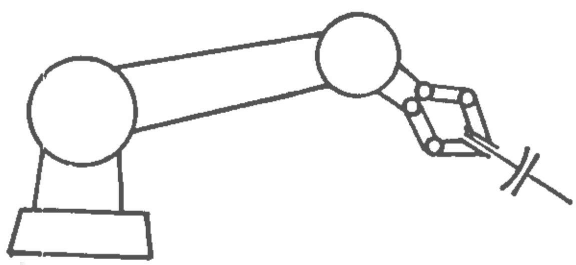

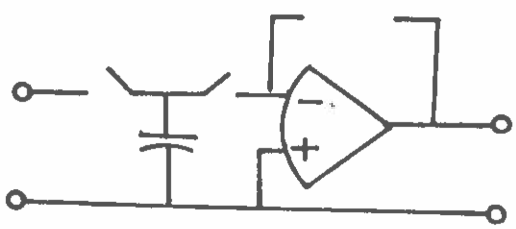

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