An equivalent circuit for simulating love mode acoustic wave transducers: Comparison of simulation and experimental results

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Abstract- A simulation was performed using the equivalent circuit previously developed for a Love mode surface acoustic wave transducer. The present model is based on the Mason equivalent circuit for inter-digital fingers. A Love mode SiO_2/ST-cut quartz transducer with operating frequency at 96 MHz was fabricated and the transfer function and input impedance were measured. Simulation results were compared with the experimental measurements. They showed close agreement.

A. Introduction

The previously suggested equivalent circuits for SAW (Surface Acoustic Wave) transducers were only based on blank uncoated transducers [1,4]. In this paper, simulation results of a Love mode model developed by the authors [5] will be compared with experimental measurements. A Love mode SAW transducer is a device with layers of different materials in which the propagation speed of the shear acoustic waves in the layers is smaller than that of the substrate.

A SiO_2/ST-cut quartz structure was fabricated. The ST-cut quartz crystal was used as the piezoelectric substrate and SiO_2 was deposited using r.f. magnetron sputtering as the guiding layer.

B. Theory

In the equivalent circuit for inter-digital fingers, the non-piezoelectric layers were modelled by wave-guide components with no electrical coupling [5]. The Mason equivalent circuit were used for modelling the piezoelectric substrate (Fig. 1). A scattering parameter (S-parameter) matrix denotes the division of acoustic energy between wave-guide components and the Mason circuit. The model was implemented using the computer aided engineering tool, Libra from HP-EEsof for the analysis of the equivalent circuit. The acoustic wave propagation simulator in the layered media, developed at McGill University, Canada by E.L. Adler [6], was used both for the calculation of particle movements and the propagation speed of the acoustic wave for each inter-digital finger section. Acoustic wave energy in the inter-digital finger sections were calculated using particle displacement magnitudes to acquire coefficients of the S-parameter matrix.

For the Love mode acoustic wave propagation, the In-Field model [4] was used due to the direction of movement of particles. In the In-field model, the applied electric field is normal to the acoustic wave propagation direction, which is in accordance with the characteristics of Love mode acoustic waves.

The acoustic energy is split and then added between the waveguide and the Mason circuit using scattering matrices. The scattering parameter matrix relates the amplitude of the incident waves on the port to those reflected from the ports. Two scattering parameter matrices were used in the input and outputs of each vertical section, respectively. A 3-port network was used in the input (shown in Fig. 2(a)).

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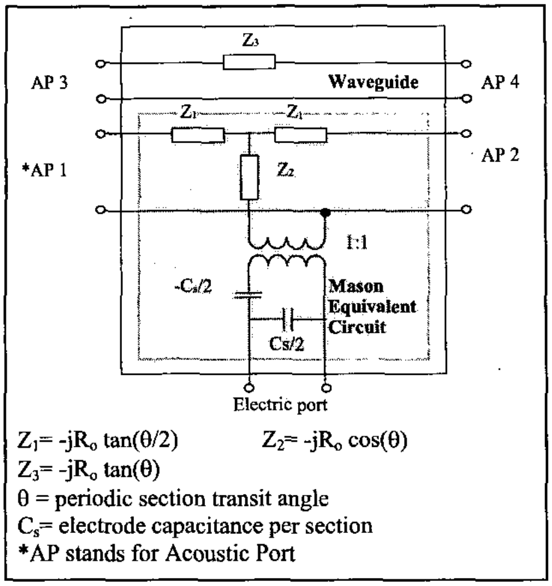

Fig. 1 Equivalent circuit model for each inter-digital finger.

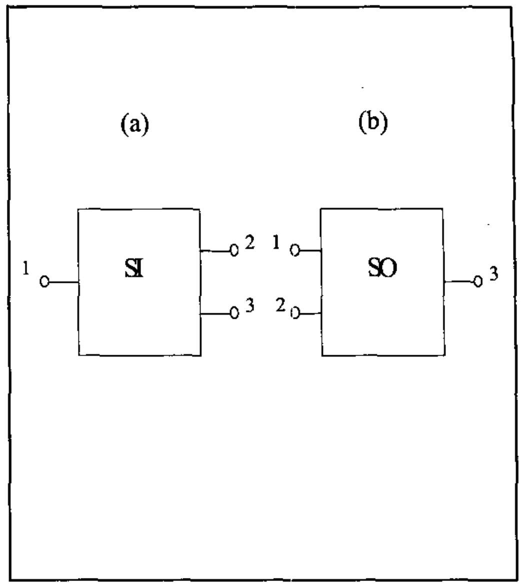

Fig. 2 Scattering parameter network blocks.

In this network, the scattering matrix is defined as the matrix [SI], which relates vectors $[A^+]$ and $[A^-]$. Elements of these vectors are A_j^+; the amplitude of the acoustic wave incident on port j and A_i^-; the amplitude of the acoustic wave reflected from port i:

$$\begin{bmatrix} A_1^- \\ A_2^- \\ A_3^- \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ S_{21} & 0 & 0 \\ S_{31} & 0 & 0 \end{bmatrix} \begin{bmatrix} A_1^+ \\ A_2^+ \\ A_3^+ \end{bmatrix} \quad (1)$$

in which a specific element of the matrix is determined as:

$$S_{ij} = \left. \frac{A_i^-}{A_j^+} \right|_{A_k^+ \text{ for } k \neq j} \quad (2)$$

In Love mode acoustic wave, movement of particles is transversal to the direction of the propagation of the wave and is parallel to the surface of the transducer. Considering this fact, S_{ij} parameters were computed with the help of the acoustic wave propagation simulator [5]. Using the electric displacement, which also can be computed by this software package, acoustic energy in each layer and substrate can be obtained. With the assumption that the magnitude of the particle movement at each point is proportional to the electric displacement at that point, energy can be calculated in each layer, which is proportional to the integral of square magnitude of particle movements.

The second scattering parameter matrix is located in the output of each vertical section where energies must be added again (Figure 2 (b)). The matrix [SO] with the elements of zeros and ones, relates the incident and reflected vectors as:

$$\begin{bmatrix} A_1^- \\ A_2^- \\ A_3^- \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} A_1^+ \\ A_2^+ \\ A_3^+ \end{bmatrix} \quad (3)$$

For transducers with more than one layer, the Mason equivalent circuit or waveguide line can be used to model the layers and the substrate depending on whether they are piezoelectric or non-piezoelectric. Dimensions of scattering parameter matrix increase with the number of layers.

C. Comparison of simulation and measurements

Simulation was performed for a SiO_2/ST-cut quartz crystal transducer with the direction propagation of acoustic waves normal to the x-axis. Thickness of SiO_2 was 0.95 μm. Figure 3 shows the simulation and measurement graphs of the S_{12} parameter when the transducer is connected to 50Ω transmission lines. In the magnitude graphs, simulation follows the measurement. Peaks and troughs happen almost at the same frequencies. Simulation and measurement both show a minimum in the centre of the pass-band region, although the measurement shows extra ripples at both ends of the pass-band region. Also, measurement shows an insertion loss of approximately 2 dB smaller than that of the simulation result, which may be due to a higher electro-mechanical coupling coefficient for the transducer than that used in the simulation parameters. Measurement also shows an increase of 5 dB in the insertion loss of the side lobes that may be due to a higher input capacitance.

The simulation and the measurement graphs for the phase are shown in figure 3 (b). They follow each other around the centre frequency. But they show less correlation in other frequencies, which is obviously as a result of higher capacitance of the fabricated transducer compared to the magnitude taken into consideration for the simulation.

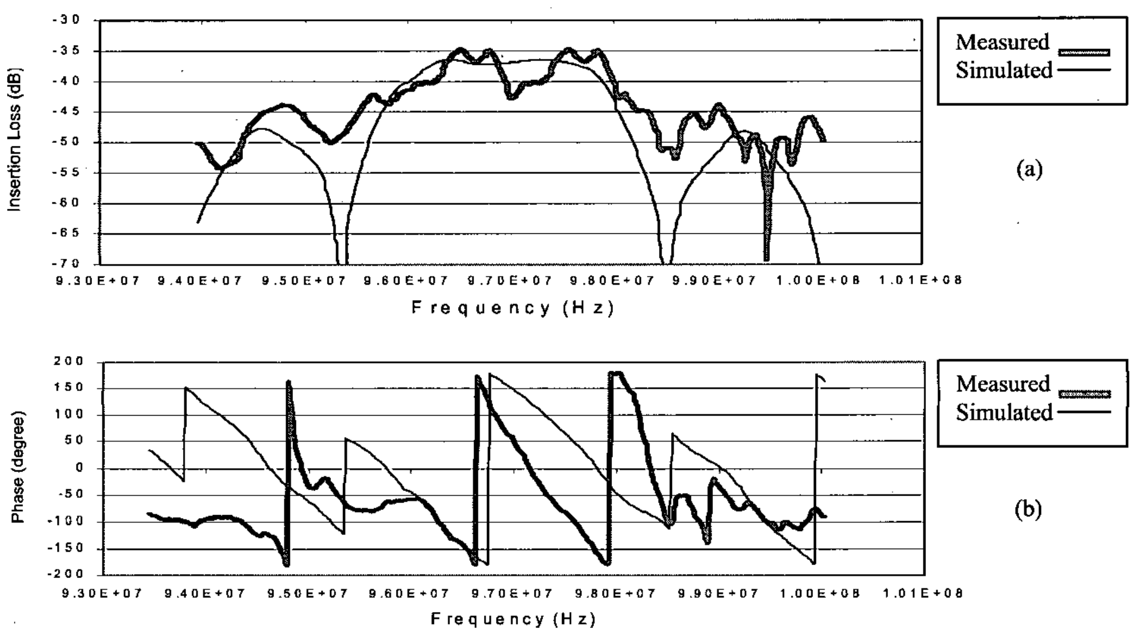

Fig 3 Simulation and experimental results for the insertion loss: a) magnitude and b) phase.

Figure 4 shows the absolute value magnitude of the admittance for the input with 64 IDTs. Both measurement and simulation were performed with 50Ω transmission lines. This resulted in a base value of $0.02\Omega^{-1}$ for both of them.

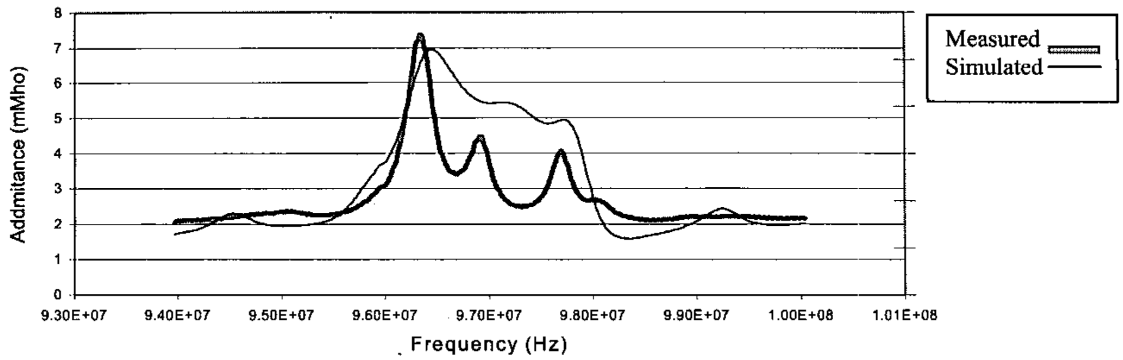

Fig. 4 The absolute value magnitude of the admittance for the input with 64 IDTs.

Both measurement and simulation have 3 peaks. The measurement shows sharper decreases and increases around the peaks. Both have almost the same value of $0.007\Omega^{-1}$ around 97 MHz.

D. Conclusion

In the present work the simulation results using a Love mode equivalent circuit (previously developed by the authors) have been compared with the experimental measurements. Measurements and simulation results closely track each other. Further work is to be carried out in order to include second order effects, which may cause the extra ripples in the frequency response of the transducer.

Acknowledgment

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