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Transient Analysis for 70MHz $LiNaBo_3$ SAW delayline

Moataz Mostafa Elsherbini[1*], Mohamed Fahim Elkordy[2], Aly Mohamed Gomaa[1*]

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This paper provides a simple new method for study the time domain analysis of SAW delay line for IF mobile stage with 70MHz center frequency. Finite element Method (FEM) analysis of SAW delay line in 3D geometry form has been achieved using the basic information of Stress and strain equations for linear elastic piezoelectric materials. . A 3 cycles of electric potential at output port of the device has been visualized. Displacement along wave direction and thickness were simulated. FFT of output wave has been monitored. Simulation results were done with minimum PC specifications possible.

Introduction

Surface acoustic wave (SAW) are found now in the main parts of the radio frequency (RF) and (IF) stages of many electronic systems, such as television, touch screen monitors, mobiles and tablets, satellite receivers, remote control units, and mobile phones [1]. Surface acoustic wave propagate with velocity around 105 times less than Electromagnetic waves. They occupy a wide frequency range approximately from 10 MHz to several GHz [2]. SAW devices are found in several applications as delay lines, filters, resonators, and more popular as sensors [3]. SAW delay line shown in figure (1) consists of three ports element two of them are acoustic (one Input and the other is for output) and the third is for electric port. Each port of two acoustics is consists of IDT structure with many fingers spaced as a function of wavelength, one acts as a transmitter (input port) that converts electrical signal into electromechanical wave propagates on the surface of piezoelectric material. The other employs as a receiver (output port) that recover the original electric signal from the acoustic energy. The phase difference between the signals from input and output ports depends on the elastic material properties of the piezoelectric substrate and also the horizontal and vertical gap between the ports. The time taken by SAW to propagate between two IDTs is equivalent to the delay. The delay time of SAW delay is less than 50 µsec. SAW delay line is developed to perform sensing operations, correlations [4], filters (uniform apodized or Apodized) [5,6] and many other applications. Surface acoustic wave delay line often includes A simple matching network of impedance usually 50Ω is inserted between the generator and transmitting port, also between the receiving port and the load to reduce the insertion loss. Both matched and unmatched transducers depend on piezoelectric coupling parameter (K), which varies according to the type of selected piezoelectric material. The delay time of SAW delayline can be expressed in from t = d/v where d correspond to the propagation speed of SAW and d is the horizontal spacing between the transmitting and receiving IDTs.

Some previous studies in SAW delay line to measure frequency domain parameters like the radiation conductance, the acoustic susceptance, total admittance and insertion loss with different simulation tools [7,8]. More results obtained for calculation of temperature coefficient of delay and frequency, suppressing the triple Transit Signals, Measuring Liquid Viscosity and Conductivity and more parameters are discussed in a comparative study prepared by Haresh [9].

Theoretical Model Design

From the basics of SAW, it is known that SAW propagation in a piezoelectric substrate is controlled through both stress and strain equation (electromechanical) of motion [11].

T = CE*S- eT *E (1)

D =e*S +εs*E (2)

T is the stress matrix, S is the strain tensors, E is the electric potential field and D is the displacement vector. Parameters CE, εs and e are for the elasticity matrix, permittivity matrix and coupling matrix of the piezoelectric substrate respectively. Matrices C, e and ε have the following forms:

$$C = \begin{pmatrix} C_{11} & C_{12} & C_{13} & C_{14} & 0 & 0 \\ C_{12} & C_{11} & C_{13} & -C_{14} & 0 & 0 \\ C_{13} & C_{13} & C_{33} & 0 & 0 & 0 \\ C_{14} & -C_{14} & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & C_{14} \\ 0 & 0 & 0 & 0 & C_{14} & (C11- \quad 12)/2 \end{pmatrix} \quad (3)$$

$$e = \begin{pmatrix} 0 & 0 & 0 & 0 & e_{15} & -e_{22} \\ -e_{22} & e_{22} & 0 & e_{15} & 0 & 0 \\ e_{31} & e_{31} & e_{33} & 0 & 0 & 0 \end{pmatrix} \quad (4)$$

$$\varepsilon = \begin{pmatrix} \varepsilon_{11} & 0 & 0 \\ 0 & \varepsilon_{11} & 0 \\ 0 & & \varepsilon_{33} \end{pmatrix} \quad (5)$$

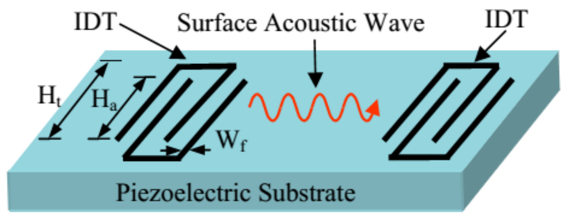

Fig.1. Basic SAW delay line [**10**].

For Lithium Niobate (LiNaBo3) piezoelectric substrate, elements of matrices substituted according to following values

For Relative permittivity ε and Density

Description	Value
(ε)	{{43.6, 0, 0}, {0, 43.6, 0}, {0, 0, 29.16}}
Density (ρ)	4700[kg/m^3]

For Coupling Matrix (e)

Description	Value
Coupling matrix (e) Mechanical properties.	{{0, 0, 0, 0, 3.69594, -2.53764}, {-2.53764, 2.53764, 0, 3.69594, 0, 0}, {0.193644, 0.193644, 1.30863, 0, 0, 0}}

For Elasticity Matrix (e)

Description	Value
Elasticity matrix (piezoelectric properties)	{{2.02897e+011, 5.29177e+010, 7.49098e+010, 8.99874e+009, 0, 0}, {5.29177e+010, 2.02897e+011, 7.49098e+010, -8.99874e+009, 0, 0}, {7.49098e+010, 7.49098e+010, 2.43075e+011, 0, 0, 0}, {8.99874e+009, -8.99874e+009, 0, 5.99034e+010, 0, 0}, {0, 0, 0, 0, 5.99018e+010, 8.98526e+009}, {0, 0, 0, 0, 8.98526e+009, 7.48772e+010}}

The transformed matrices eT obtained from the Crystal Rotation Calculator. It is available online at www.zephrasoft.com.

3D Model Analysis and simulation steps

A simple model of 3D SAW delay line was built using FEM simulation COMSOL tool [12] to describe the time domain analysis of Raleigh wave on SAW device. Lithium Niobate (LiNbO3) substrate is the piezoelectric material selected with 128 YX cut orientation due to its wide uses like in mobile telephones, optical modulators, laser frequency doubling, optical parametric oscillators, anti-aliasing filters, optical switches for very high frequencies and optical waveguides [13]. Inter-digital Transducers (IDTs) for both input and output ports are considered as pure conductors.

Some parameters of the model have been selected to give the best results and computation efficiency. Depth of substrate (Thickness) is one of main important parameters in which the surface acoustic waves assumed not to penetrate more than assumed value for the thickness (3/4λ) or around 80µm. Thickness of IDT is assumed to be very thin compared with thickness of piezoelectric substrate so Stiffness dynamics and Mass effect of IDT on SAW delay line may be neglected. A 70MHz center frequency is adjusted to be used in IF stages of mobile set. Four identical and unapodized electrodes in both input and output port are assumed to give fast solution. The electrode width is designed as a λ/4; while the electrode length is four times the wavelength. Horizontal and vertical gap between the two acoustic ports is selected as twice wavelength and λ respectively. Electrode pitch selected as four times the electrode width. The overall design is shown in Fig. 2.

Density, Elasticity matrix, Coupling matrix and relative permittivity and material contents of LiNaBo3 piezoelectric substrate that describes the strain and stress charge form are the main four properties which their values mentioned in the previous item.

Finite Element Method (FEM) with boundary conditions is the best choice of simulation method for SAW delay line over Coupling of Modes (COM) because several features of FEM (MESH) method such as it can be used can be used to reliably simulate non-periodical devices. FEM gives accepted and accurate results for short structures and extremely accurate in the simulation of wide-band devices and in the simulation of device operation over a wide frequency range. In general, FEM is fast and computationally efficient [14]. Boundary conditions applied to both input and output ports to set the terminal voltage at input port (Sine Wave) and to make the output voltage to be an open circuit by setting the charge to zero. Also; boundaries selected to the ground terminals of electrodes at input and output ports.

MESH customized by controlling the element size, Figure (3). The best choice according to the PC specifications used in simulation of 4GB RAM and Core I5 processor was to let the COMSOL as one of their predefined values (finer) (around λ for maximum size of MESH). To obtain a better resolve, increasing MESH segments is required but it exhausts more physical memory RAM and High processor is needed.

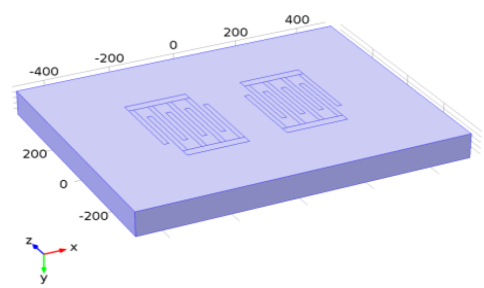

Fig. 2 Geometry of SAW delay line.

The optimum Mesh segments to resolve SAW in space is obtained with mesh size less than λ (around λ/5 or less) done with at least dual processor PC with physical memory more than 12GB RAM. Surface acoustic wave resolved in time by using the condition of courant Friedrich lewy (CFL=0.2) to obtain a time step of CFL*max. MESH size/VSAW.

A numerical noise may be found in High frequency is suppressed by amplification for high frequency by a factor of 0.6. A time dependent solver is the choice from Simulation tool to record the transient of SAW, Displacement along thickness and Displacement along wave direction.

Results

A small geometry of 3D Model SAW delay line is shown in Fig. 4. Essentially parameters has been defined to introduce the model like number of electrodes, electrode length and width, pitch, gap between the two acoustic ports, etc.

The obtained signal from output port (IDT) in Fig. 5 is recorded with amplitude less than the applied Sine Wave signal to the input port (IDT) due to theory of amplitude decay with substrate depth and due to the loss of energy in the formation of volume waves and by reflected surface wave interference. The frequency spectrum of the visualized output has been recorded in Fig. 6.

Displacement of surface acoustic wave along wave direction has been captured in Fig. 7, while Displacement along thickness was recorded to agree with assumed 3/4λ thickness or nearly 80μm. Figure 8 indicates that SAW doesn't penetrate more than the thickness of piezoelectric substrate. The determined time delay of the SAW device is equal to 4.2857E-8 sec.

Additional math operations may be applied to the input and output visualized signal like Fast Fourier Transform shown in figure (9). It is used to discover noise in high frequencies; it is suppressed by setting the magnification factor to 0.6 through time dependent solver.

Number of degrees of freedom solved for more than 70789 segments. Complete mesh consists of 13386 domain elements, 3286 boundary elements, and 592 edge elements.

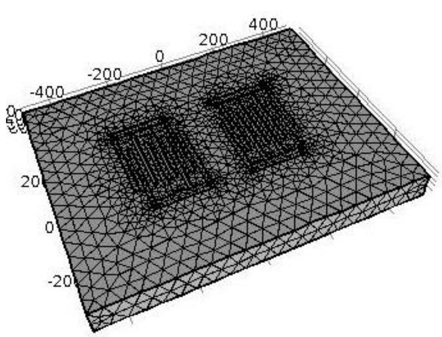

Fig. 3 Customize MESH for time solving.

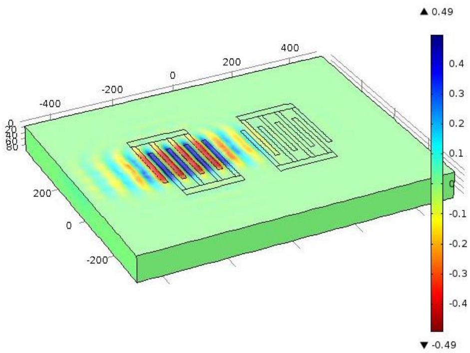

Fig. 4 Surface displacement field

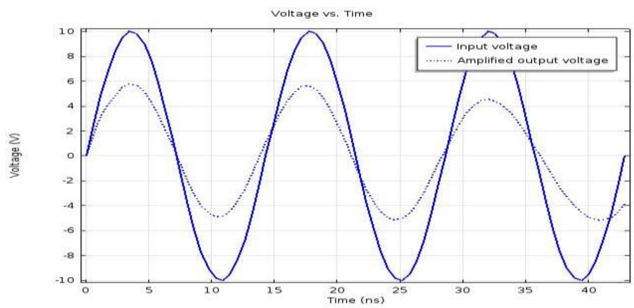

Fig. 5 Applied signal to input IDT versus recorded output potential via output IDT

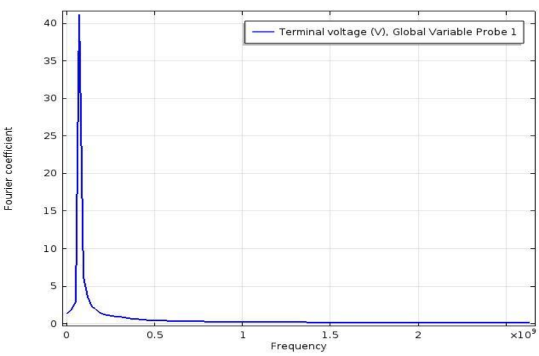

Fig. 6 Frequency spectrum of output

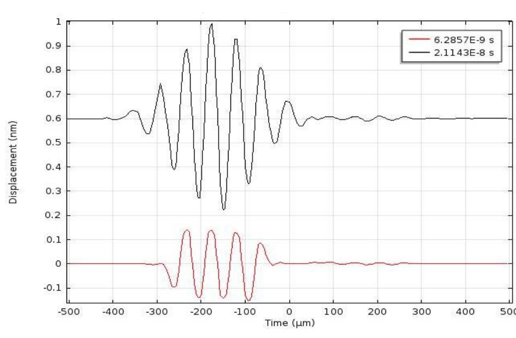

Fig. 7 Displacement along wave direction

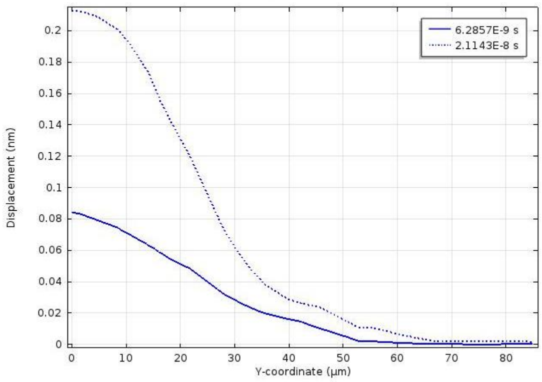

Fig. 8 Displacement along thickness

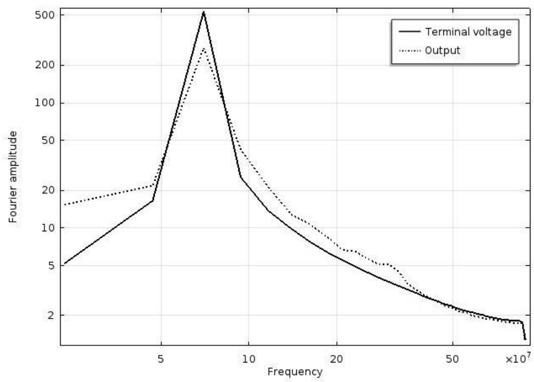

Fig. 9 FFT of applied input voltage and recorded output voltage.

Conclusion

A complete design for 3D Model of SAW delay line has been built. FEM simulation of LiNaBo3 based SAW delay line is performed. A Transient analysis, where 3D model is presented, is used to investigate propagation of SAW upon surface of piezoelectric substrate. The response of the SAW devices under alternating-current excitation measured at the transmitting and receiving IDTs electrodes for 4.2857E-8 s duration of the time domain analysis. This paper presented an effective method of investigating the SAW propagation in SAW delay line.

Notes and References

[1]*Dept. of Electrical Engineering, Shoubra Faculty of Engineering, Benha University, Egypt.*
[2]*Dept. of communications, Faculty of Electronic Engineering, Menoufia University, Egypt.*
**Corresponding author, E-mail: motaz.ali@feng.bu.edu.eg*

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