Analytical Modeling and Simulation of SAW Filter Using Concave

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Abstract

A Simple novel tool has been developed to model and simulate SAW filter devices. GNU Concave; Freeware tool with open source coding has been used to specify a basic model for SAW delay lines and filters. This paper presents a way for obtaining the essential parameters of design and development of SAW devices as insertion loss. Other parameters were also predicted by within the reseach work like the radiation conductance, susceptance, Impedance, Admetance and the Frequency Response. They all calculated and plotted using Mathmatical equations drived from an equivalent model used to simulate our target. A comparision between the simulated device and an experimental puplished one has been achieved.

Keywords: SAW, model, simulation and filters

1. Introduction

Surface Acoustic Wave (SAW) were dicoverd and discussed the surface acoustic mode of propagation, also predicted its properties in 1885, by **Lord Rayleigh**. **White** and **Voltmer** proposed that surface wave can be excited and detected easily by depositing electrodes on the surface of a piezoelectric material [1]. Recently, SAW devices were designed and developed to be used in generation, detection, and amplifying the waves. Delay lines, stores, oscillators, filters, resonators and sensors are basic and familiar types for SAW devices. Most popular applications for using SAW devices found in TVs, radar, sonar, satellites, and Mobile communication systems. They can be used within the frequency range 10MHz to multiple GHz. In the last decade most research has developed in the area of surface acoustic wave filters and sensors [2]. The operation of the SAW device is based on acoustic wave propagation near the surface of a piezoelectric solid material like ST-Quartz, lithium tantalate (**LiTaO$_3$**), lithium niobate (**LiNbO$_3$**) and **GaAs Z**; etc. They have different piezoelectric coupling coefficients (**K^2**) and temperature sensitivities. **ST quartz** is our choice in the modeling and simulation work for the reason that it is used for most temperature stable devices. This indicates that the wave can be reformed while propagating. The surface wave can be excited electrically by means of an interdigital transducer (IDT). A basic SAW device consists of couple IDTs on a piezoelectric substrate as indicated in Figure 1. The input IDT generates and the output IDT receives the waves. The IDT has many identical electrodes connect consecutively to couple of metal busbars, When an electrical signal is applied to the input IDT, it is converted to SAW which cause a voltage to be monitored at the output after a delay determined by the space between the transducers and also by surface wave velocity. The input and output transducers may be equal or different. It depends upon the function which the SAW device has to perform. The magnitude of the output voltage decays as the frequency shifts from the central frequency. It means that SAW device is like bandpass filter [3]. The area between the input and output transducers may be a sensing element to detect signals and convert the device into sensor type.
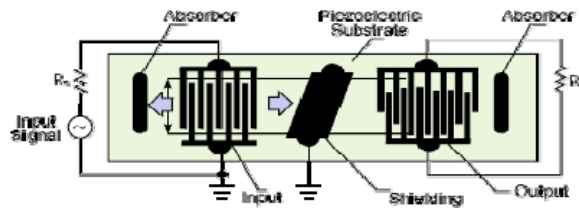
Figure 1. Surface Acoustic Wave Device Structure

The research work based upon model and simulation for the basic configuration of SAW delay line and filters using first order modeling known as impulse response model. Impulse response modeling is the simplest method to calculate ans plot basic parameters of the equivalent circuit for SAW sensor represented by cross field model, shown in Figure 2. Insertion loss is the main goal to be expected from the model, it is calculated as the logarithmic ratio of the power delivered to the load impedance before the SAW device is inserted to the power delivered to the load impedance after it is inserted. Some previous studies have studied frequency domain analysis of SAW devices [4-7] and time domain analysis [8]. Many other recent researches in SAW devices from 1985 up to 2013 introduced and compared by haresh pandya [9]. A propsed solution for simply obtaining the basic parameters of SAW device is presented via this research work with a novel simulation tool.
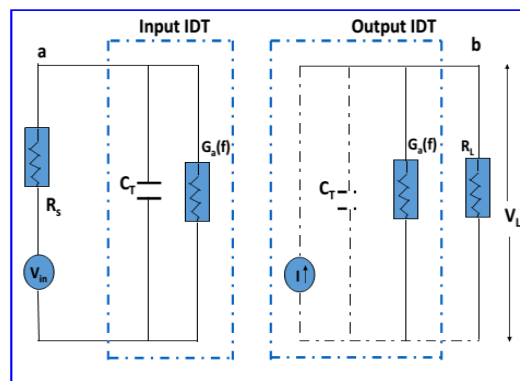

Figure 2. Cross field model for SAW devices [9]

2. SAW Device Modeling

The objective of SAW devices modeling is to realize spread, generation and recognition of acoustic waves upon piezoelectric materials and to design geomertry such as IDTs, delay lines, amplifiers, filters, correlators and resonators to achieve the frequency domain responses.

Various modeling techniques are used with SAW devices such as Impulse Response Model, equivalent circuit model, coupling of modes model and transmission matrix model.

Using both impulse response modeling and equivalent circuit modeling are the main contribution that introduced by this research work to introduce a first order analytical modeling technique for SAW sensor device and perform the simulation by using Concave tool ver. (4).

The model based on two conditions, the first one that one or both IDTs must be uniform apodized while the other criteria is to make the finger width constant and equal to each other. To represent surface acoustic waves, the SAW frequency f_o is related to the periodicity of the IDTs (λ) and to the acoustic velocity V_s.

$$f_o = \frac{v_s}{\lambda}$$
(1)

With aid of Mason equivalent circuit of an IDT, shown in figure (2), the model composed of three components: the total capacitance C_T, the acoustic susceptance B_a (f) and the radiation conductance G_a (f).

Starting with the time response of SAW IDT to obtain the required components where f_o is the synchronous frequency, K^2 is the piezoelectric coupling coefficient, D is the delay between two IDTs (in wavelengths), Cs is the capacitance for a finger pair per unit length, W_a is the finger overlap, Rin =Rg is the input or matched impedance and Np is the number of finger pairs.

$$h(t)\alpha 4\sqrt{K^2 C_s} f_o^{3/2}(t)sin(2\pi f_o t) \tag{2}$$

The Fourier transform of the impulse response:

$$H(f) = 4K^2 C_s W_a f_o N_p^2 \left(\frac{\sin X}{X}\right)^2 e^{-i\left(\frac{N+D}{f_o}\right)} \tag{3}$$

$$X = N_p \pi \left[\left(\frac{f-f_o}{f_o}\right)\right] \tag{4}$$

The number of fingers (Np) may be calculated as a function of designed center frequency and Null Bandwidth. Wa is also obtained using the following relation:

$$W_{a=}\frac{1}{R_{in}}\left(\frac{1}{2f_o C_s N_p}\right)\left\{\frac{4K^2 N_p}{\left(4K^2 N_p\right)^2+\pi^2}\right\} \tag{5}$$

The radiation conductance G_a (f) is the real part of the input admittance and is equal to the twice the magnitude of the frequency response.

$$G_a(f) = 2|H(f)| = 8K^2 C_s W_a f_o N_p^2 \left(\frac{\sin X}{X}\right)^2 \tag{6}$$

The acoustic susceptance is the imaginary part of the input admittance and derived from taking the Hibert transform of the radiation conductance.

$$B_a(f) = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{G_a(f')}{f'-f}df' \tag{7}$$

After integration, the expression become in the following form:

$$B_a(f) = \frac{G_a(f_o)\sin(2X)-2X}{2X^2} \tag{8}$$

The normalization of $G_a(f)$ and $B_a(f)$ have been included in the software tool as the ratio of $G_a(f)$ divided by its maximum value and $B_a(f)$ divided by the maximum value for $G_a(f)$ respectively.

The last component of the model is C_T and it is calculated by multiplying the number of fingers (Np), the finger overlap (W_a) and the capacitance for a finger pair per unit length Cs.

$$C_T = C_s W_a N_p \tag{9}$$

The previous parameters used to drive the total admittance and impedance of IDT respectively.

$$Y(f) = G_a(f) + j(2\pi C_{T+} B_a(f)) \tag{10}$$

$$Z(f) = \frac{1}{Y(f)} \tag{11}$$

Finally, the insertion loss that is the most important parameter to measure the performance of the SAW filter is written as:

$$IL(f) = -10log\left\{\frac{2G_a(f)R_{in}}{(1+G_a(f)R_{in})^2 + \left(R_{in}(2\pi f C_T + B_a(f))\right)^2}\right\} \qquad (12)$$

The total response of the SAW filter is also easy to be driven by multiplying the absolute value of frequency response for the first IDT by the absolute value of conjugate of the second IDT frequency response.

3. S/W Tool Implementation

Software tool is required to perform and procedure the mathmatical equations and plot the results. A code was written with GNU Octave software, Figure 3 which like Matlab but without graphical user interface. Octave is a high-level interpreted language which is basically used for numerical computations. The numerical solution of linear and nonlinear problems, performing other numerical experiments and providing extensive graphics capabilities for data visualization and manipulation is easy to be proceeded with octave. A portable source of software tool is used here and linked with matlab to generate a GUI interface for the Software code, Figure 4.

The code is devided into segments, a part of definition the parameters of the piezoelectric material used (ST-Quartz), another segment is for the geometry design and the third for the previous mathematical equations (1-12) that calculated the required parameters.

C++ is used to compile the written code and GUI interface and generate a self-executable tool to be used anwhere.

We can summarize the steps for writing the code to mode and simulate the SAW filter in the following simple steps:

1) Congiguration for the input parameters f_o, Vs, Cs, Np, Rg, Wa, Delay and K^2.
2) Building the equations (1-12) in the form of Concave tool.
3) Calculating and Plotting the required Parameters, Ga (f), Ba (f), H (f) and IL (f).
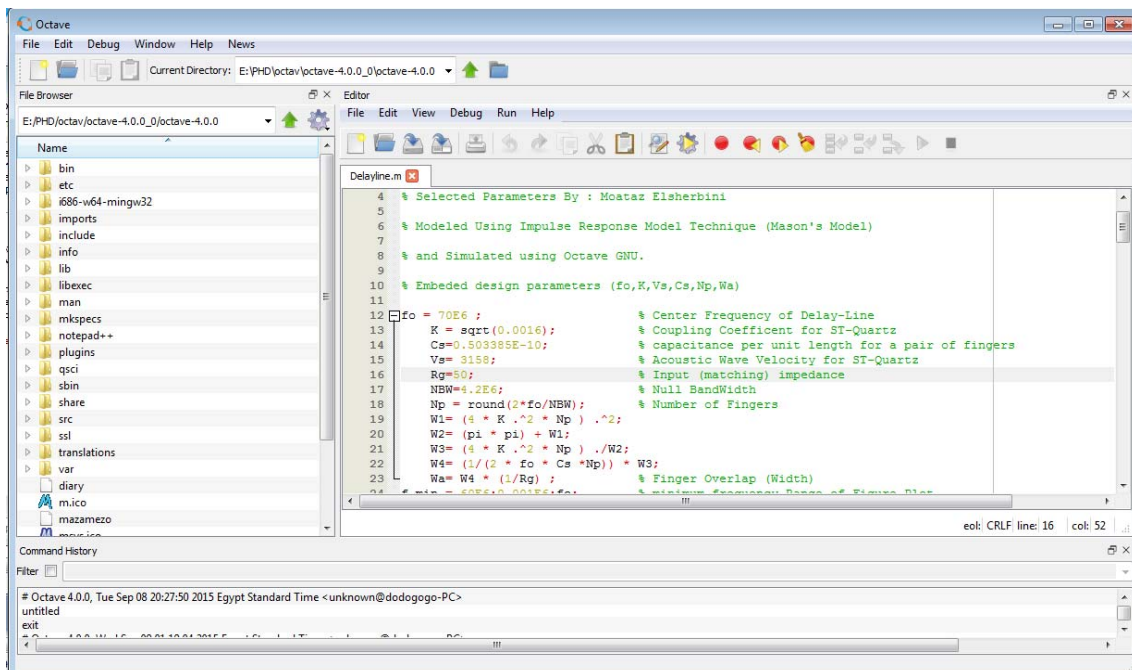4) Building a GUI interface using Matlab.
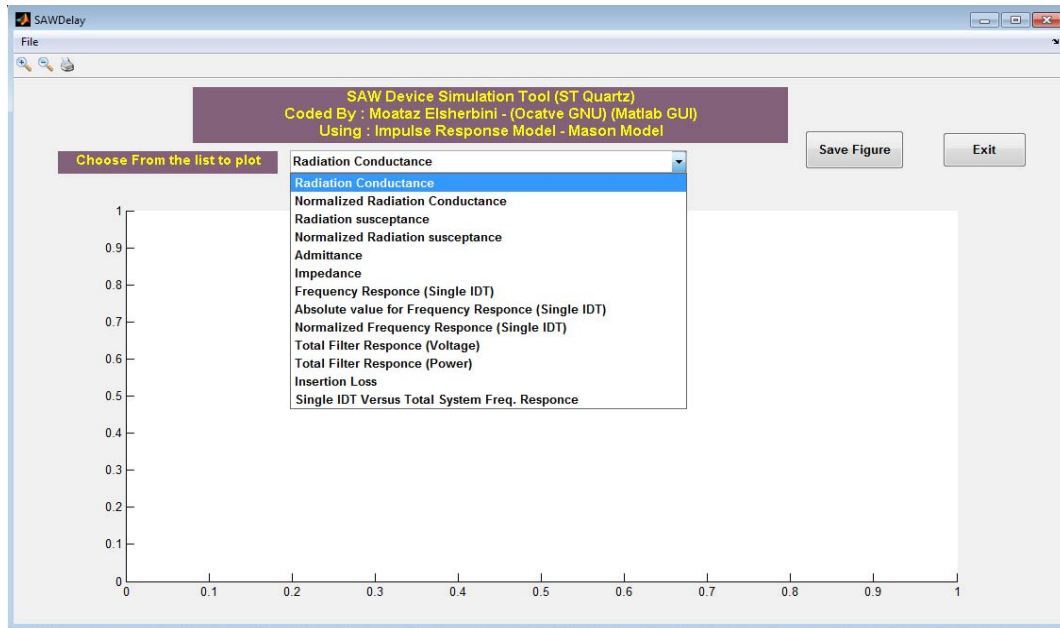

Figure 3. GNU Octave interface

Figure 4. GUI Matlab interface for the designed tool

4.   Simulation Results

The response comparison of SAW device, operating at 70 MHz and number of fingers of 33 has been done, The substrate is ST cut Quartz. The Null Bandwidth (NBW) is 4.3 MHz. the delay is 5λ and both input and matched resistances is 50Ω. The Coupling Coefficent for ST-Quartz is 0.04 and the capacitance per unit length for a pair of fingers is Cs=0.503385 pf/cm. the acoustic velocity, v= 3158 m/s and the finger overlap is 1831.99 um. From the model, the IDT Resistance at fo is 780.511Ω.

The comparison between the radiation conductance and susceptance has been visualized at Figure 5. Figure 6 and 7 introduce the admittance and impedance of equivalent circuit model. Figure 8 show the comparison the frequency response of i/p or o/p IDT compared with the total frequency response due to both of them. Figure 9 indicates the insertion loss of the device; its max value is approximately -20dB.
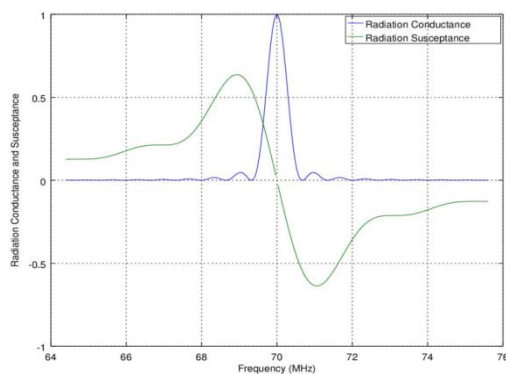

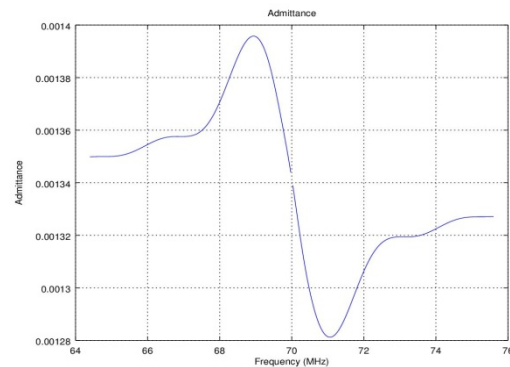Figure 5. The radiation conductance and susceptance of SAW device

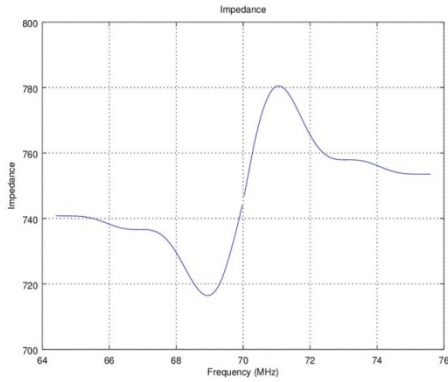Figure 6. Admittance (Y) of equivalent circuit model

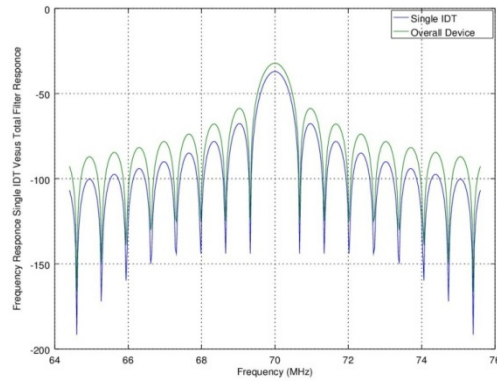Figure 7. Total Impedance (Z) of equivalent circuit model

Figure 8. Frequency response of single IDT compared with the total frequency response of the SAW device
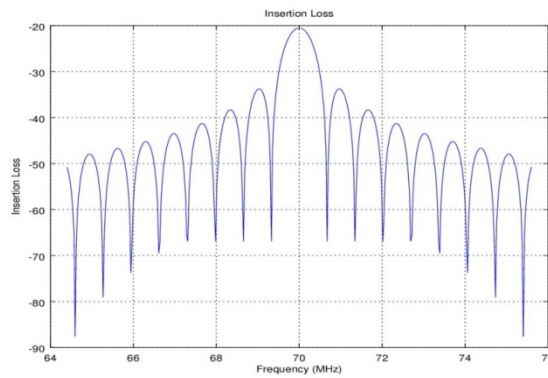

Figure 9. Insertion loss of the SAW device

Comparing obtained data from our simulation with commercial SAW filter (820-IF70.0M-F), shown in Figure 10 from Oscilent Corporation Company, we noticed that at -1dB the typical value of insertion loss for the commercial device is -22.5dB, while the simulated result is -20.5dB. This result supports the designed tool effectiveness.
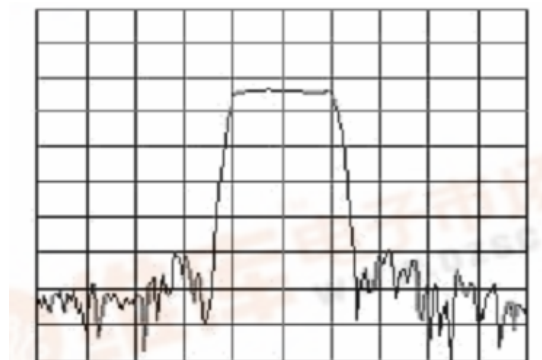

Figure 10. 820-IF70.0M-F commercial device with IL=22.5dB [11]

5. Conclusion

A simple tool for modeling and simulation SAW filter device has been developed using Concave software. The model can be used for other SAW delay line based applications. All required parameters like conductance, susceptance, impedance, admittance, frequency response and insertion loss have been modelled and predicted.

A comparison between the simulated Insertion loss and the measured has been demonstrated. The simulation and experiment results are relatively the same and the difference error is quite small. The results are useful to recognize parameters effect. Insertion loss, f_o, Np and substrate material which are important parameters in SAW devices design.

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