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Towards a Simple Model for SAW Delayline Using CAD

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Abstract

Due to further applications of Surface acoustic wave (SAW) devices in many applicable electronics and communications fields, modeling and simulation for these devices become more urgent in recent years. SAW devices can found in frequency range from 10 MHz to several GHz. It can found in RF, IF, stages of mobile. SAW devices convert mechanical waves to electrical and vice versa through IDT. This paper introduces a simplified tool for modeling and simulation of SAW delay line with uniform length transducers. Mason's equivalent circuit of SAW delayline is my selected technique of this research, and PTC software Tool is the simulation tool of the delayline. SAW delayline device operating at 70 MHz frequency to be used in IF stages in mobile communication circuits and systems. The results obtained in this work provide an adequate basis for understanding the parameters effects and to aid in the optimization processes of delay lines based upon these effects.

Keywords

Impulse Response, SAW, Modeling, Delay Line and IF BPF

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1. Introduction

A surface wave is a mechanical displacement, stress, and strain traveled along the surface of a solid material. It decays into the depth of the material with a characteristic length comparable to the wavelength [1]. Acoustic wave is a physical phenomenon which transmits the power from one point to another point through a medium and has speed, frequency, and wavelength. For surface acoustic wave, a propagating surface wave is accompanied by an electric field localized at the surface, and this enable the wave to be generated by applying a voltage to an array of metal electrodes on the surface. The electrode array is known as IDT (interdigital transducer). The operation of this transducer is dependent upon the substrate on which it is deposited being piezoelectric or if on non-piezoelectric material having a piezoelectric film deposited under or over the metal structure. The transducer has a set of identical electrodes connect alternately to two metal bus-bars, When an oscillatory voltage (electrical signal) is applied to the input transducer, it is converted to a corresponding surface wave which cause a voltage to appear on the output after a delay determined by the transducer separation and surface wave velocity. The wave types propagating on piezoelectric substrate materials show velocities, between

3000 to 5000 m/s, which are slower by a factor of 105 when compared to those of guided electromagnetic waves, e.g., waves guided by microstrip transmission lines.

Thus, devices operating in the VHF/ UHF frequency region can be fabricated with strip widths of the order of some microns or below, which can be produced very accurately and reproducibly using optical-projection printing techniques [2]. There are numerous methods of generating and detecting SAW electrically but of these we shall consider here the interdigital transducer which has become the pre-eminent transducer for SAW devices. Figure (1) shows a simple delay

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line with interdigital transducer. A SAW Delay Line is one in which SAW travels along the surface of a piezoelectric substrate and produce a time delay between the two Interdigital Transducers (IDTs) which designed to lunch straight-crested waves with the same vector perpendicular to the transducer fingers. As shows the transducer is symmetrical and waves are lunched in two opposite directions. Thus the transducer is a 3-port element two acoustic and one electric. The travel length between receiver and transmitter IDT is called as Delay Time. IDTs have a comb-like structure, where the distance between the fingers in the IDT determines the frequency of the waves propagating over the substrate. The study of these waves is useful in seismology and other areas.

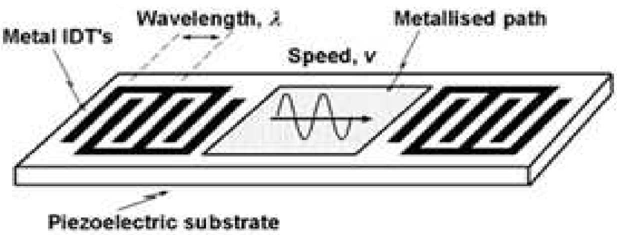

Figure (1). SAW delay line [3].

The operation of the transducer is dependent upon the substrate, on which it is deposited. Because of the anisotropic properties of the piezoelectric substrate the choice of plane and orientation of the transducer on that plane is vitally important for an efficient transducer. A voltage applied to the transducer set up spatial alternating electric fields that have the same periodicity as the transducer. These fields produce a spatial periodic distortion of the crystal. Now if the voltage is suddenly removed, the distortion will relax by all possible means, for e.g. radiation of bulk and surface acoustic waves from the transducer structure. If an alternating voltage is applied, a buildup of amplitude of a given mode can be made to occur simply by ensuring that constructive interface occurs for that mode. This is achieved for the surface wave when the period of the alternating signal T, is equal to the time for the wave to propagate from one finger pair to the next in the periodic structure, i.e.

$$(1/T) = f = \nu c / \lambda \text{ or } \lambda = d$$

Where:

f: The frequency

λ: The SAW wave length

νc: The velocity of SAW

d: The period length of the transducer

If the ratio of the finger width to gap is unity, the finger is width equal to λ/4.

Surface acoustic wave delay line often includes simple matching networks, as indicated in Figure (2) to reduce the insertion loss. The piezoelectric coupling parameter K2=Δv/v is very important for matched and unmatched transducers. Δv/v has an important influence on the transducer conversion loss, which decreases as Δv/v increases. SAW delay line is very important because it is the most obvious application of a SAW device which upgraded to be sensors, filters, and correlators.

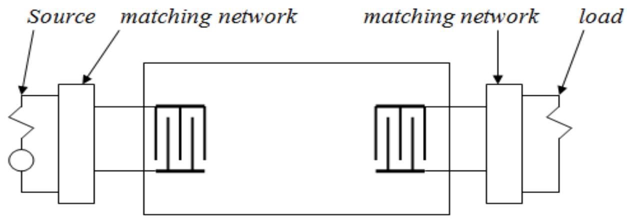

Figure (2). Delay line with matching network.

The purpose of this paper is to introduce a simple simulation tool for SAW devices. SAW delayline modeled with a simple equivalent Mason's circuit. The contribution of this work is to model and simulate delayline with PTC CAD software and extract all requires parameters (response, susceptance, admittance and Insertion Loss) with high accuracy from the simulation process on the same time and without need of high performance PCs specifications.

2. A Simple Model for SAW Devices

The simplified method for modeling SAW devices is through the Impulse Response Model. This model was firstly presented by Hartmann in 1973 [4]. It is used as the baseline for modeling the SAW device. This method is valid only for transducers where at least one of the two Inter-Digitated Transducers (IDTs) has a constant aperture or finger overlap [5]. Nowadays, the impulse response model is operating at several hundred MHz frequencies using piezoelectric substrate material as ST-X Quartz crystal [6] [7]. Using Impulse response model, the frequency response, the insertion loss of the system, the admittance Y, and other parameters can be calculated like radiation conductance G(f), acoustic susceptance B (f) and impedance Z (f). This model assumes equal spacing and finger widths, so a constant metallization ratio, usually 0.5 [8]. Figure (3) shows Mason circuit model that predicts the behavior of a sensing or IDT. CT represents the total capacitance of the IDT, Ga (f) the radiation conductance and Ba (f) is the susceptance [9].

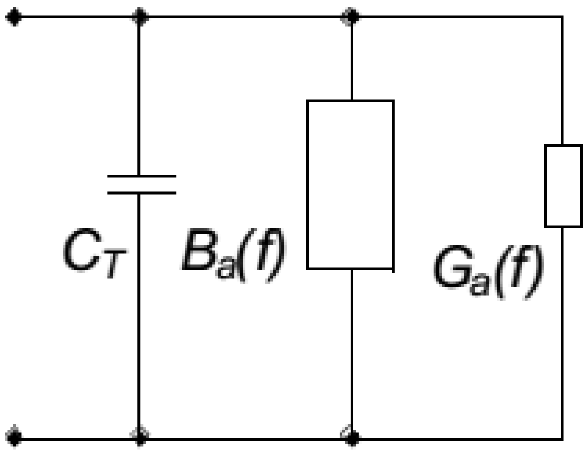

Figure (3). Mason equivalent circuit of IDT used in Impulse response model.

3. Modeling Steps

Five main parameters required to be calculated by PTC Mathematics computer aided design software using the impulse response model of SAW delay line. Radiation conductance, acoustic susceptance, admittance and impedance, frequency response, and aperture height are the main parameters that are required to be calculated to confirm the simulation [10].

The main parameters should be defined or determined before simulation is the synchronous (center) (instantaneous) frequency (fo), the acoustic velocity in the media, the coupling coefficient K2 which determined according to the type of selected piezoelectric material, the delay and the capacitance per unit length for a pair of fingers (Cs) [11].

3.1. Selction of Piezoelectric Substrate

Quartz-crystal cuts show excellent temperature stability, expressed by their temperature coefficients of delay, however, their coupling coefficients, k2, are low, which limits the relative bandwidth that can be electrically matched at low losses. Therefore, quartz-crystal cuts are mainly used for narrowband SAW devices, with relative bandwidths. SAW devices fabricated from quartz substrates are used in the IF stages of mobile phones, for resonators or delay lines for local-oscillator use, and for dispersive delay lines used in radar applications [12].

Table 1. shows Properties of some ST-Quartz material.

Material	Orientation		U [m/s]	K2	[ppm/oC]	Applications
	Cut	Prop				
QuartZ	ST	X	3158	0.0016	0	IF stage in Mobile Phone

3.2. Parameters Calculations

1. *Wavelength* = Acoustic velocity / synchronous frequency.

2. *Number of fingers* =

$$N_P = round\left(\frac{2f_o}{NBW}\right)$$

Where NBW is null bandwidth

3. *The time response* h(t) of SAW IDT is given by

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

4. *The frequency response* obtained by taking fast Fourier transform of time response

$$H(f) = 20log\left|\left\{4K^2C_sW_af_oN_p{}^2\left(\frac{\sin X}{X}\right)^2 e^{-i\left(\frac{N+D}{f_o}\right)}\right\}\right|$$

Where D is the delay length in wavelength between the IDTs, Wa is the Aperture height (finger overlap).

5. The Variable

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

6. *The aperture* (finger overlap) is dedicated from

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

Where, R_{in} is source resistance.

7. *The radiation conductance* derived from

$$G_a(f) = 8K^2C_sW_af_oN_p{}^2\left(\frac{\sin X}{X}\right)^2$$

8. The acoustic susceptance derived from taking the Hibert transform of the radiation conductance.

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

9. The total static capacitance

$$C_T = C_sW_aN_p$$

10. The total admittance is

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

11. The system impedance is

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

12. The insertion loss is

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

13. In order to obtain the frequency response of the system (sensors, filters, etc.), Combining the frequency response of each IDT is achieved. Identical IDTs have been selected with the same number of fingers and finger overlap.

$$H_T(f) = H_1(f) * H_2(f)$$

14. Sometimes, the normalization of $G_a(f)$, $B_a(f)$ and $H_a(f)$ required to rescale the amplitude of different response at maximum of 1.

4. Simulation Steps

The main steps for simulation can be described through the following flowchart shown in figure (4)

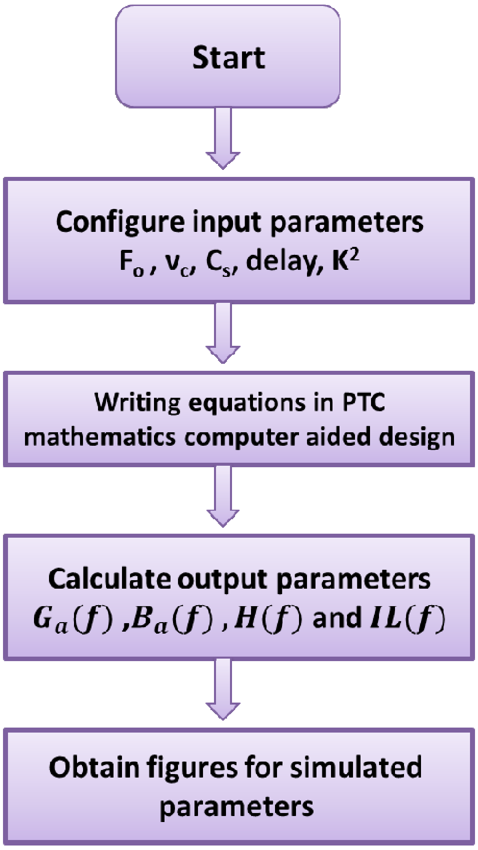

Figure (4). Flowchart of the simulation Program.

Using newer version; Mathcad 15, which is simple in entering data and equations, provides a GUI for displaying multiple responses at the time without exhaust more from RAM and Processor, and fast operation. ST-Quartz piezoelectric substrate of 0.0016 coupling coefficient (K2), Cs of 0.503385 pf/cm and 3158m/s acoustic velocity was selected. Also, 70MHz synchronous frequencies, 50Ω input resistance, 4 MHz for null Bandwidth, and delay between 2 IDTs of 5 have been selected.

5. Results

We can spot on some results from simulation as: Np: 33, λ=45.11µm, Wa= 1.832mm and CT=3.04pf.

The simulation results obtained and are shown from figure (5) up to figure (10), showing responses for Ga (f), Ba (f), H (f), their normalized values, total response of the system, effect of total impedance and admittance with frequency change and insertion loss.

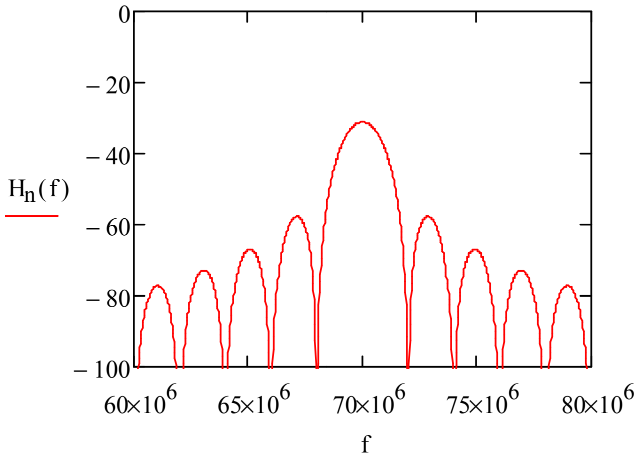

Figure (5). Simulated response of delay line.

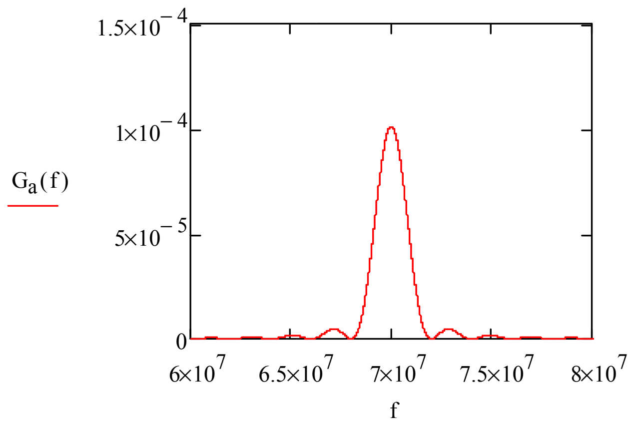

Figure (6). Simulated response for radiation conductance.

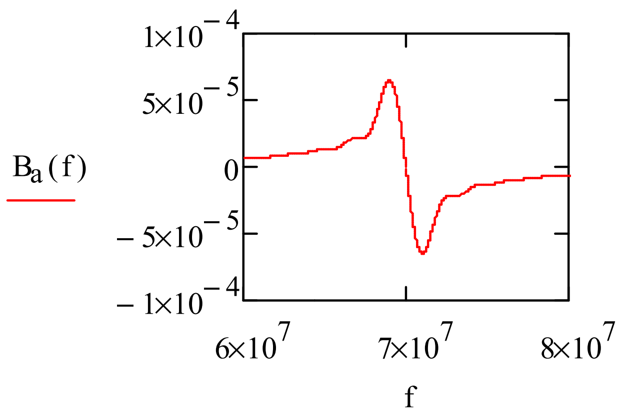

Figure (7). Acoustic susceptance against frequency.

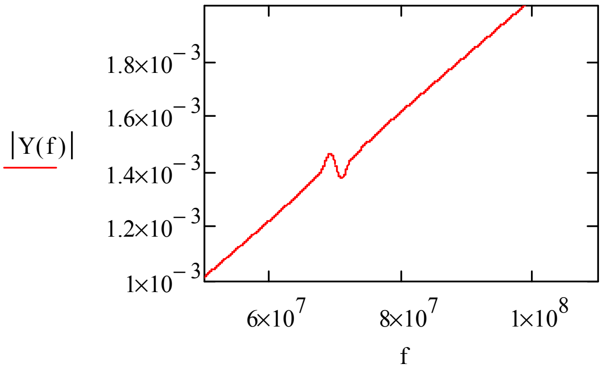

Figure (8). The absolute value of total admittance against frequency.

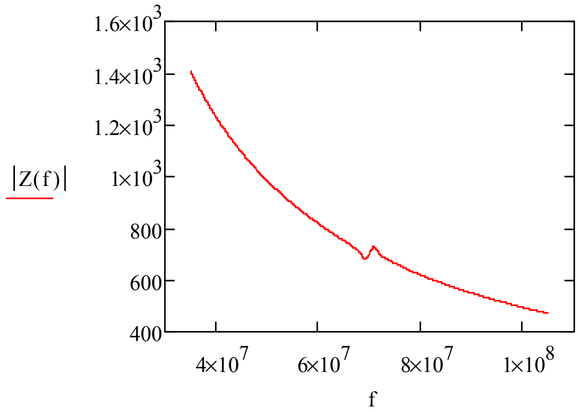

Figure (9). The absolute value of total impedance against frequency.

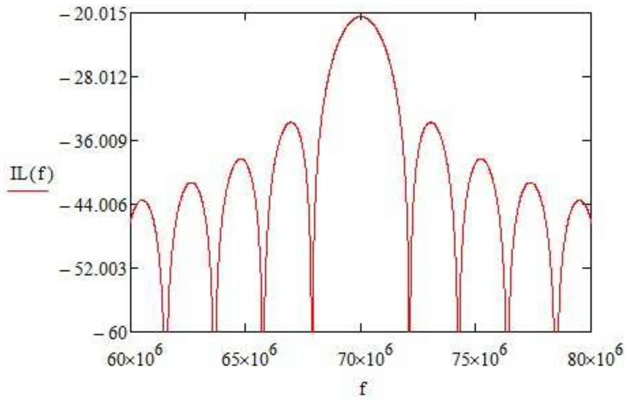

Figure (10). Insertion loss for delayline, using Mathcad

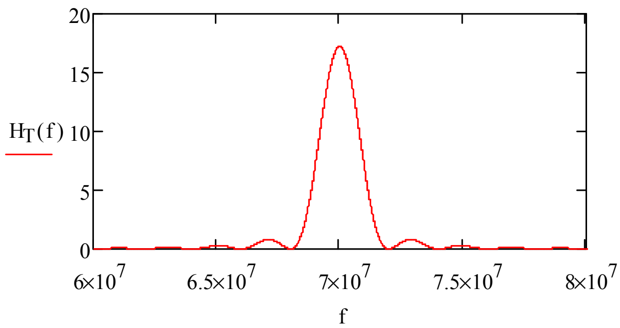

Figure (11). The total response of the two port SAW device.

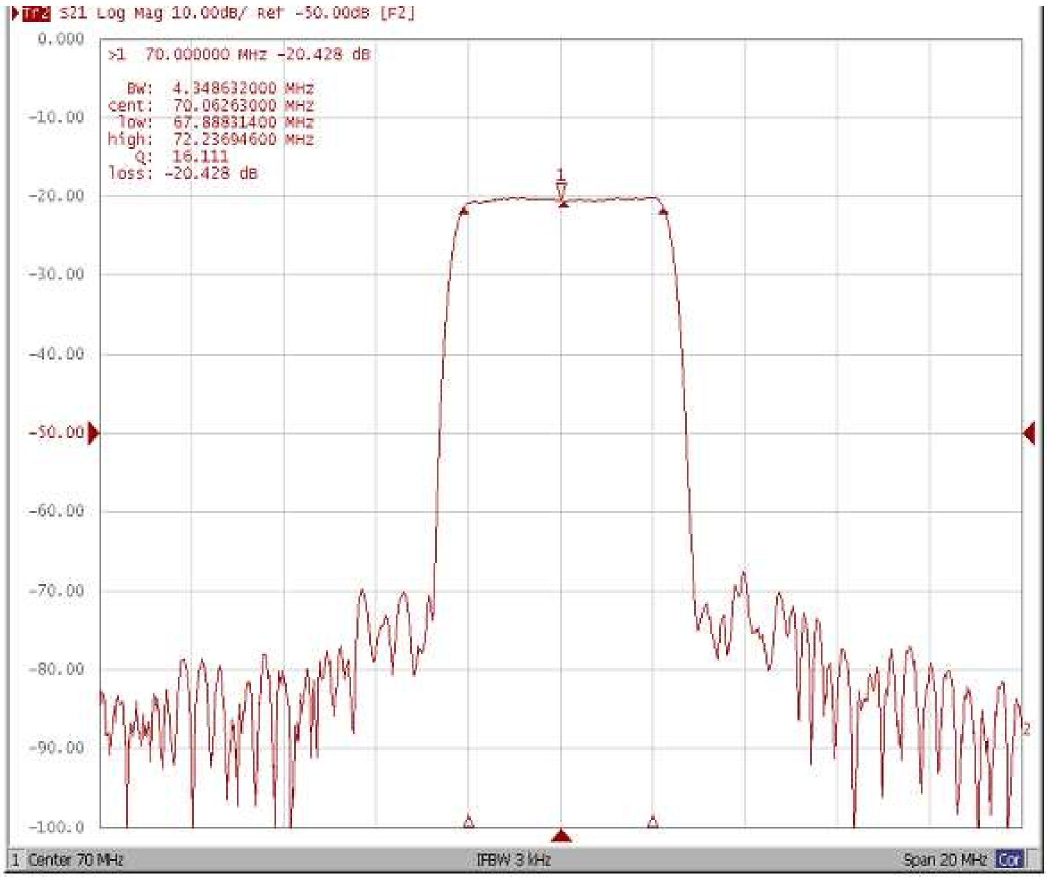

Figure (12). Insertion loss of 820-IF70.0M-S model [14].

Now, upgrading the design to be two port (pair of fingers) with the same previous modelling steps. It is easily to be created by combining the responses of IDTs to obtain the total response of the system, shown in figure (11).

The results compared with a commercial one with the same parameters specifications but changing the substrate from LiNabO3 to ST-Quartz, to provide an acceptable insertion loss. The comparison between the insertion loss obtained from a Commercial model 820-IF70.0M-S made by "Oscilent Corporation" company, it provides a quite good agreement using our program structure. Results and comparison are shown in figures (12, 13) and table (2).

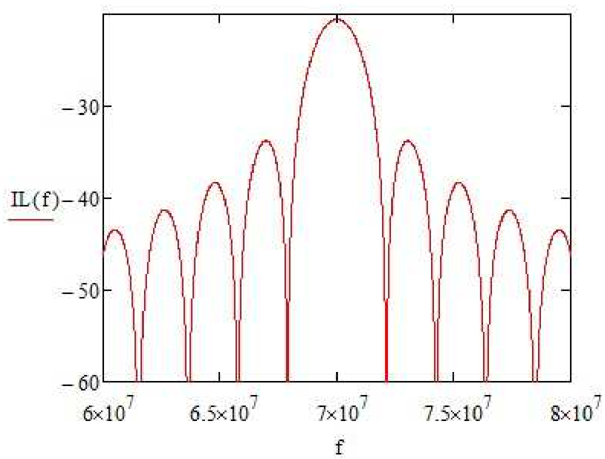

Figure (13). Insertion loss of 70MHz IF SAW, BW of 4.3MHz, using CAD software.

Table 2. Results comparison between commercial (data sheet) and simulated device [13].

parameter	Commercial (typical)	Simulated
f_o	70MHz	70MHz
NBW	4.3 MHz	4.3MHz
IL	20.5 dB	20.517 dB
substrate material	ST-Quartz	ST-Quartz

6. Conclusion

The impulse response model of delay line with 70MHz synchronous frequency has been achieved. Simulation was done by Mathcad for mathematics computer aided design that is considered simple and fast in operation. It provides multiple responses in the same time within the same GUI page. It allows to obtain time and frequency response for SAW devices. Other parameters can be achieved like insertion loss, impedance, admittance, susceptance and conductance. This model considered as first order model that doesn't take into consideration the effect of triple transient effect eco and ripples, but the model can be extended to include that effect. By using CAD structure to compare the simulated response of 70MHz delayline with two different commercial devices, the agreement between figures has a quite good.

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Biography

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