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Modelling of SAW Devices for Gas Sensing Applications – A Comparison

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Abstract

SAW technology based devices are being widely used as gas sensors. This paper reports the modeling of SAW devices by comparing the results obtained using two different models. The devices were modeled for their responses in frequency & time domain. The results were used to calculate the insertion loss and bandwidth of SAW delay line at 400 MHz. The modeling study was carried out using MATLAB simulation tool and the results were used to design a photomask for device fabrication.

Keywords: *Delay line; Equivalent Circuit; Impulse Response Modelling; SAW.*

1.INTRODUCTION

SAW Technology is fast emerging as gas sensors. The salient feature of SAW device based sensor is its capability to detect gases at low concentration (low ppb). The modeling of SAW device is essential to study its characteristics and subsequently fabricate the device for sensor applications. The device was modelled for Quartz substrate at centre frequency (*f*) of 400 MHz as the sensitivity of SAW devices increases by a factor of f^2. The device may be used for various field applications such as Chemical Sensor Biological Sensor, Gas Sensors, Pressure Sensor, Temperature Sensor, Strain Sensor, Proximity Sensor, Nano technologies etc (Haresh M. Pandya *et al*. 2012, 2013). This paper describes and compares the results obtained using two different types of SAW device modeling.

2. MODELS USED

Modelling of SAW devices is carried out using different types of models each having its own limitations. The impulse response model & equivalent circuit model are widely used for modeling. A comparative study of the two is described below.

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2.1 Impulse Response Method

The first Impulse response method presented by Hartmann *et al*. in 1973 used the delta function with non-dispersive transducer (Hartmann *et al*. 1973). The Impulse response model utilizes the operating frequency and the mechanical & electrical behavior of SAW device on piezoelectric substrate. It is primarily a first order model. This model is based on Hilbert transform, which is used to calculate the total energy transfer, radiation Conductance G(f) and susceptance B(f) of SAW device.

This paper details the Impulse response model from Mason equivalent circuit,as shown in figure 2. The model assumes constant finger overlap or constant aperture (A) and finger spacing (W) between adjacent electrodes to calculate the frequency response H(f), the insertion loss (IL). The equations are as follows (Venkatesan *et al*.2013):

A Frequency Response H(f) can be calculated in equation 1.

$$H(f) = 20\log\left[\left[4K^2 C_s W f_0 N p^2 \left(\frac{\sin(X)}{X}\right)^2 \exp(-jy)\right]\right] \quad ....1$$

Where, Np is number of fingers pairs in input and output IDT

$$Np = M = N \qquad ...2$$

$$X = Np\,\pi\left(\frac{f - f_0}{f_0}\right) \qquad ....3$$

$$y = \left(\frac{Np + D}{f_0}\right) \qquad ....4$$

The Radiation conductance can be calculated from equation 5.

$$G(f) = 8K^2 C_s W\, f_0 Np^2 \left|\frac{\sin(X)}{X}\right|^2 \qquad ....5$$

The acoustics susceptanceB(f) can be calculated from equation 6.

$$B(f) = G(f_0)\left[\frac{\sin(2X) - 2X}{2X^2}\right] \qquad ....6$$

The Insertion Loss IL(f) can be calculated from equation 7.

$$IL(f) = -10\,\log\left[\frac{2\,G(f)\,R}{(1+G(f)R)^2 + [R\,(2\,\pi\,f\,C_t + B(f))]}\right] \qquad ....7$$

The above equations are used in MATLAB simulation tool to generate the program code and obtained results are displayed in graphical form.

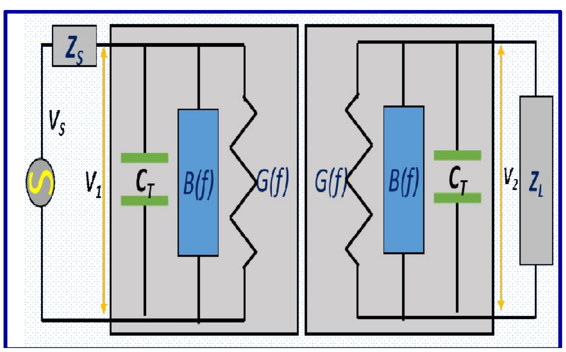

Fig. 2: Mason Equivalent Circuit for Impulse Response model

2.2 Crossed-field Equivalent Circuit Model (ECM):

An equivalent circuit model is considered in this case. This model is a second order model. The advantage of ECM model is straight forward execution of circuit in MATLAB. In crossed-field circuit model the distribution of electric field under the electrodes of IDT is normal to the piezoelectric substrate andis similar to the electric fielddistribution of a parallel plate capacitor as shown in figure 3 (Smith *et al.* 1969).

ECM model may be considered as modified Mason model. In ECM model voltage is applied to the electrode of IDT in order to calculate the frequency response H(f), admittance of device, the Effective Transmission Loss (ETL) by improved Impulse response model. The corresponding equations are as follows:

$$H(f) = \frac{y_{ab}R_L}{(1 + y_{aa}R_L)(1 + y_{bb}R_L) - y_{ab}^2 R_s R_L} \qquad ....8$$

$$ETL = 20\log_{10}\left|\frac{\left[(1+y_{aa}R_s) + (1+y_{bb}R_L) - y_{ab}^2 R_s R_L\right]\sqrt{R_L/R_s}}{2R_L y_{ab}}\right| \qquad ....9$$

Where y_{aa} is input admittance, y_{bb} is output admittance and y_{ab} is total transfer admittance. R_S and $R_L$are source and load resistance (Devries,1677).

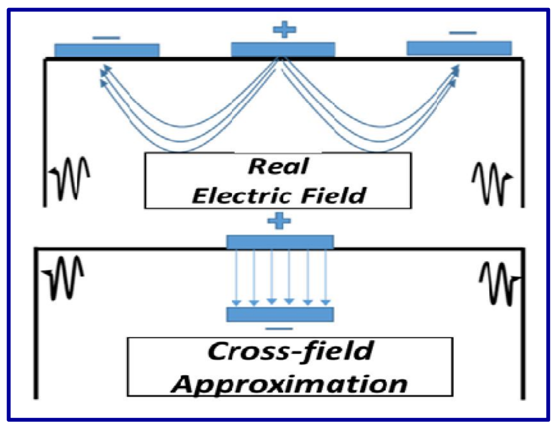

Fig. 3: Crossed-field ECM for Electric field Direction

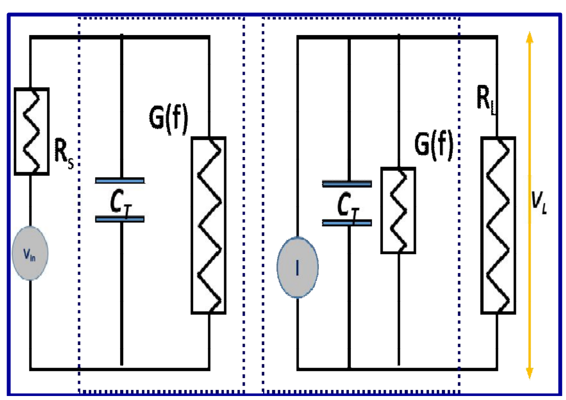

Fig. 4: Equivalent Circuit for ECM

3. MODELLING OF SAW DEVICE

The basic parameters considered in present study are tabulated in table 1. The MATLAB code for the above mentioned two models has been developed as per the flow chart shown in figure 5.

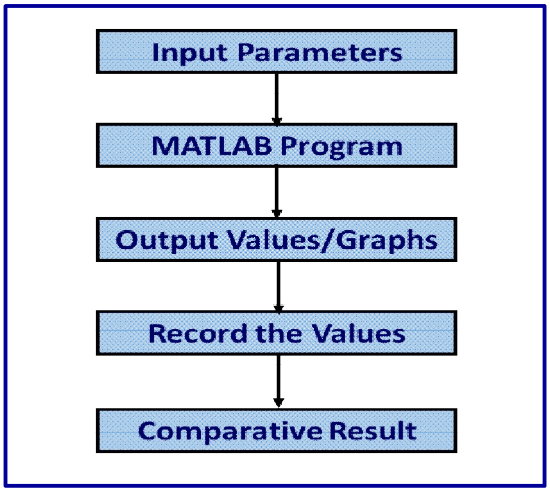

Fig. 5: Flow chart for modelling process

Table 1. Basic parameters for SAW device

S.No	Parameter(symbol)	Values
1	Coupling Coefficient (K^2)	0.0016(Quartz)
2	SAW velocity(V)	3153.5 m/s
3	Center Frequency (f_0)	400 MHz
4	IDT Geometry	Split Geometry
5	Finger width	0.98547 X 10^{-8}m
6	Number of fingers pairs(N)	40
7	Load Resistance(R_L)	50Ω
8	Source Resistance (R_S)	50Ω

The end result of both the models, i.e. Impulse response model and Crossed-field Equivalent circuit model depends on delay of SAW device. The SAW device was modelled with the help of above mentioned models and results were compared. The operating frequency of SAW device was 400 MHz.

4. RESULT & DISCUSSION

The response comparison of SAW device, operating at 400 MHz, has been done, where basic parameters for IDT finger width is taken from Table1, and the number of input and output IDT electrode pairs are 40 respectively. In the first order model the achieved insertion loss is -24.7317dB and band width is 6.3665MHz as shown in figure 6.

The second order model i.e. ECM yields the output value of insertion loss as -28.2436dB and band width as 6.4749MHz as shown in figure 7.

The graphical analysis of the above obtained results clearly indicates that the difference in insertion loss value is 3.5119dB and that for bandwidth value is 0.1084MHz as shown in figure 8. If a common factor of 1.1420 is added into equation 7, of impulse response model, the Insertion loss value using both the model will become equal but at the same time there will be a decrease in bandwidth in Impulse responsemodel as compared to ECM model, as shown in figure 9. This modelling study was of an ideal device response. ECM model is very perfect model for modelling 400MHz SAW device with 40 electrode IDT pairs.

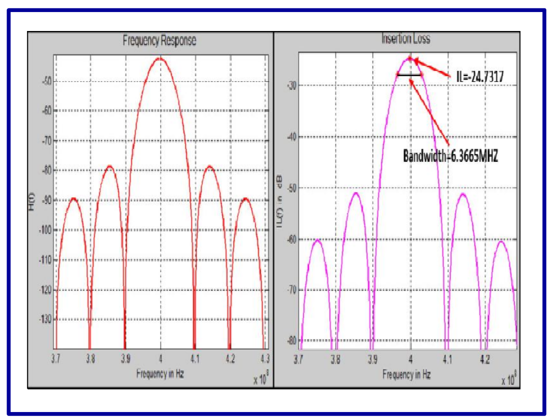

Fig. 6: Impulse Response Model output graphs at 400MHz

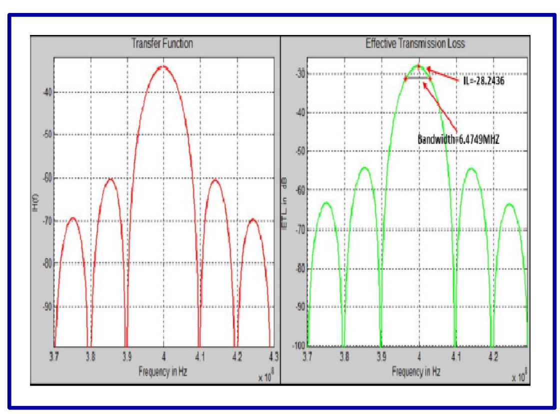

Fig. 7: Equivalent Circuit Model output graphs at 400MHz

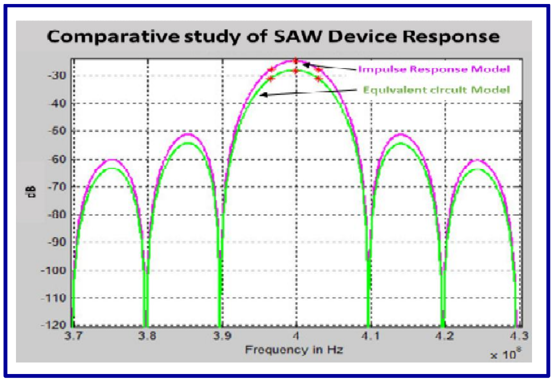

Fig. 8: Comparative of SAW device Response

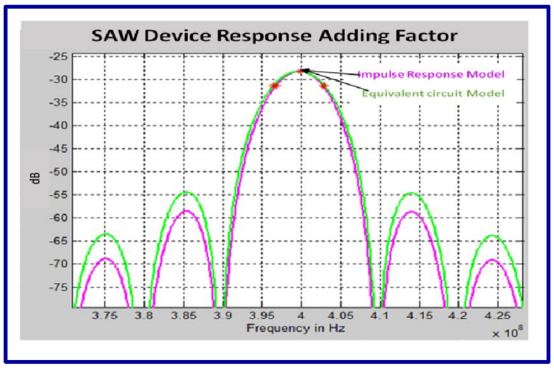

Fig. 9: Comparison of SAW device Response Adding Factor

Table 2. Comparison of Impulse response and ECM model

	Impulse Response Model	Equivalent Circuit Model
Insertion Loss	-24.7317dB	-28.2436dB
Bandwidth	6.3665MHz	6.4749MHz
Adding Factor		
Insertion Loss	-28.2436	-28.2436
Bandwidth	**5.9708 MHz**	**6.8956MHz**

It is evident from table2 that ECM model is best suited model while modeling a SAW device, to be used in communication purpose, due to its low loss and higher bandwidth (Donald C. Malocha *et al*. 2013). Finally the ECM model has been used for modelling purpose which is compatible with MATLAB simulation tool. The simulation results are in sync with the experimental results.

5. CONCLUSION

The SAW device was modelled using both Impulse Response and Crossed Field Equivalent circuit model at center frequency of 400MHz, 40 input and output IDTs finger pairs are used respectively. The graphical results are used for comparative study of models. The MATLAB simulation tool was convenient for comparative study of the two models.

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