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Modeling and simulation of unapodized surface acoustic wave filter

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ABSTRACT

In this paper, the study for influence of using different substrate types, number of finger pairs, and finger overlap distance on the response of unapodized surface acoustic wave (SAW) filter, is given. Within this study, a computer algorithm has been developed to estimate and model the main characteristic parameters of unapodized SAW filter. The detailed parameters of unapodized SAW filter such as increasing or decreasing the finger overlap in cm in either input or output inter-digital transducer (IDT) or both, also increasing or decreasing number of finger pairs in either input or output IDT, or both are described with aid of the computer algorithm. The results obtained in this work provide an adequate basis for understanding the parameters effects, and to aid in the optimization processes of unapodized SAW filter based upon these effects.

Keywords: Surface acoustic wave, filter, inter-digital transducer.

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INTRODUCTION

The main advantage of surface acoustic wave (SAW) filters is that they are a more compact and also narrower band than the conventional strip line. Figure 1 shows the basic filter fabricated on a piezoelectric substrate. Many other advantages may be taken into consideration such as reduced size and weight, high reliability and ruggedness, no tuning or readjustment, and mass production capable.

The fundamentals of SAW filter can be described briefly as two transducers with interdigital transducers of thin metal electrodes deposited on a piezoelectric substrate such as quartz. It converts signal voltage variations into mechanical surface acoustic waves. On the other hand, IDT is used as an output receiver to convert mechanical SAW vibrations back into output voltages. Such energy conversions require the inter-digital transducers to be used in conjunction with elastic surfaces that are also piezoelectric ones. As a result, the mechanical energy is transformed back into an electrical signal (Yuen, 2005). In SAW bandpass filters, IDTs have uniformly spaced electrodes and the desired characteristic is tailored by apodization. Bandpass filters IDTs can be designed only with two uniformed IDTs or with two IDTs (one or both is non-uniform apodization) and a multistrip coupler between them. In this paper, we study the first model of SAW filter with uniform weighted/apodization IDTs.

MODELING OF UNAPODIZED SAW FILTER

Unapodized SAW filter can be designed to operate very efficiently in harmonic modes up to the ninth harmonic frequency. There is uniform overlap in input and output IDTs (input and/or output IDTs are apodized, apodization pattern is symmetric about the IDT central axis).

It will give a linear-phase response because phase angle varies linearly with frequency. The desired amount of filter time delay, or phase shift at a given frequency, is then simply achieved by selecting the spacing between IDTs.

Unapodized filters mean that the electrode lengths are equal or uniform amplitude (Figure 2a). Both windowing function and delta function model provide basic information on the transfer function of linear matched

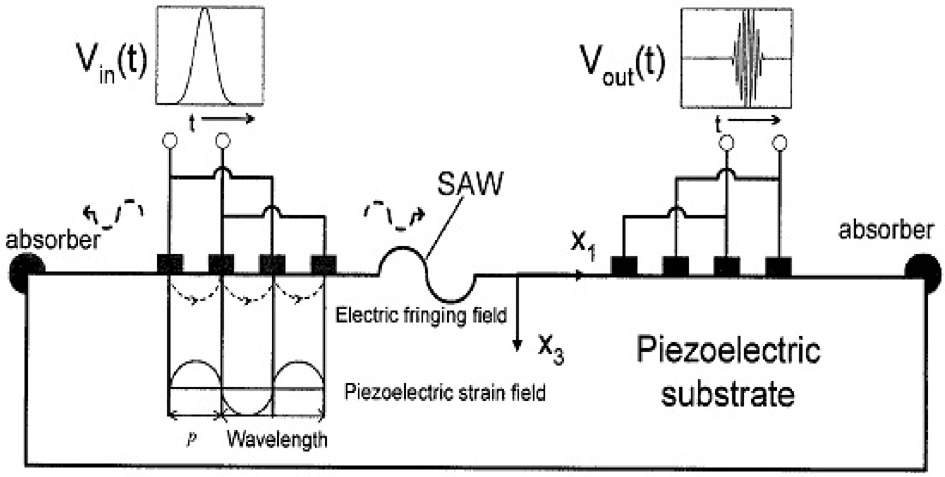
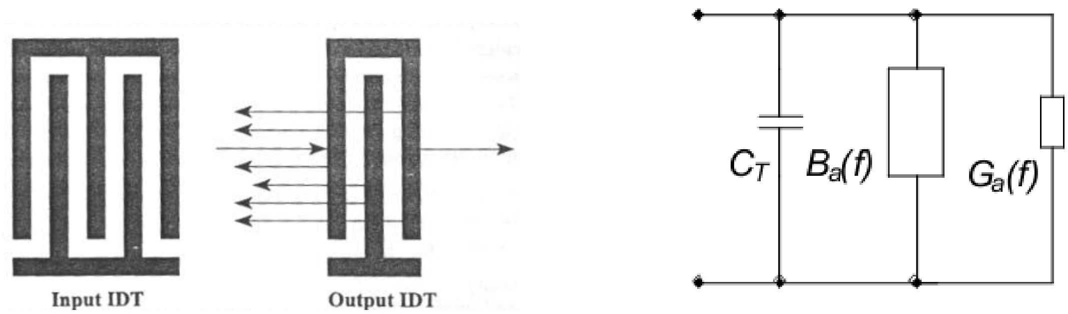


Figure 1. Cross section of basic SAW filter fabricated on a piezoelectric substrate (Yuen, 2005).



(a) (b)

Figure 2. (a) SAW filter with unapodized transducer; (b) Equivalent circuit of unapodized transducer.

SAW filters. It can only yield a relative insertion loss as a function of frequency (Issa, 2010).

In order to be able to predict the behavior of a sensing or ID system based on SAWs, a suitable model must be available, along with adequate software tools. Fortunately, the behavior and modeling of typical SAWs is a task that has been under investigation for a long time, and there are excellent texts on the subject. Several models have been developed, but the most useful one, from an electronic designer's point of view is the so-called crossfield model, where the IDT can be modeled by the circuit.

In Figure 2b, CT represents the total capacitance of the IDT, Ga (f) the radiation conductance and Ba (f) the acoustic radiation susceptance. With such a simple model, there is no need to implement specific software for the simulation. The simulation technique consists basically of the implementation of the equations in Matlab. The IDT frequency response is given by Mendes and Santos (2012):

$$\left|H(f)\right| = 2\,k\,\sqrt{C_S f_o}\,N_P\,\frac{\sin X}{X}\exp\left(\frac{\omega j\,2\,\pi f N_P}{2\,f_o}\right) \quad (1)$$

Where: f_0 is the center frequency; Np is the number of finger pairs; k is the piezoelectric coupling coefficient; C_s is the capacitance of (per) a finger pair per unit length, and

$$X = N_P \,.\, \pi \,.\, \frac{f - f_o}{f_o} \quad (2)$$

Now the global IDT response is given by the product of the transfer functions of both IDTs:

HT = H1 (f). H2 (f) (3)

The real part of the input admittance (radiation conductance) is given by:

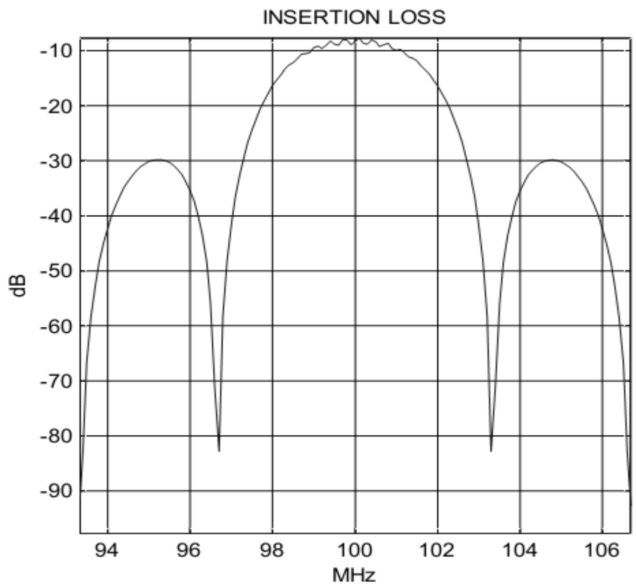


Figure 3. Unapodized SAW filter analysis using $LiNaBO_3$ YZ substrate.

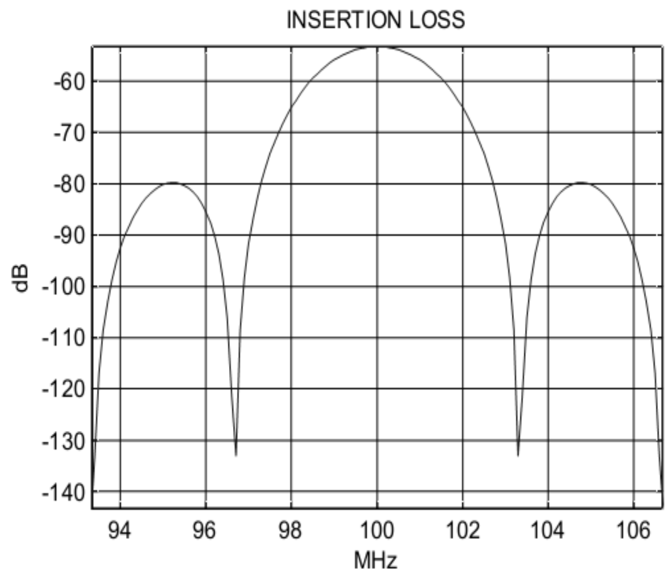


Figure 4. Unapodized SAW filter analysis using quartz substrate.

$$G_a(f) = 8k^2.C_S.W_a.f_o.N_P^2.\left|\frac{\sin X}{X}\right|^2 \quad (4)$$

And the insertion loss is

$$IL(f) = -10\log\left\{\frac{2G_a(f)R_g}{(1+G_a(f)R_g)^2+(R_g.(2\pi.f.C_T+B_a(f)))^2}\right\} \quad (5)$$

$$B_a(f) = \frac{8N^2G_o[\sin(2X)-2X]}{2X^2} \quad , X = N\pi(f-f_o)/f_o \quad (6)$$

For an optimum design, the effective finger width (acoustic aperture) must be adjusted to:

$$W_a = \frac{1}{R_{in}}.\left(\frac{1}{2f_o.C_S.N_P}\right).\frac{4k^2.N_P}{(4k^2.N_P)^2+\pi^2} \quad (7)$$

The transducer electrode capacitance is given as:

$$CT = C_s W_a N_p \quad (8)$$

SIMULATIONS AND RESULTS

The insertion loss of SAW filter is measured with respect to bandwidth frequency of the filtered signal by using the computer algorithm. A small code is estimated to achieve this measurement. There are some main parameters included within the simulation program as different substrates, number of finger pairs of input or output interdigital transducers, and finger overlap in cm. This beside other parameters as source and load resistances, center to center distance between IDTs in cm, and center frequency in MHz. The simulation program records the relation between the insertion loss and frequency according to including parameters effects into consideration. So in this paper, we may study different parameters effects.

Different substrates

We studied two different substrates $LiNaBO_3$ YZ (Lithium Niobate), and quartz with same fixed common parameters (Figures 3 and 4). It is noticed that the response for the two different substrates differ in insertion loss, increased in value for $LiNaBO_3$ than quartz. The response measured at 30 input and output number of fingers, 0.05 cm finger overlap, and 50 Ω source and load resistance.

Changing number of finger pairs for input or output IDTs

We select quartz substrate as a reference substrate to study effect of number of fingers for input and output IDTs. While decreasing number of fingers of input IDT than output IDT, e.g. 20 for inputs and 30 for outputs, we notice that number of side bands increased within the same frequency range, also insertion loss decreased, than when number of fingers at both input and output IDTS are the same. Now while increasing number of fingers of input

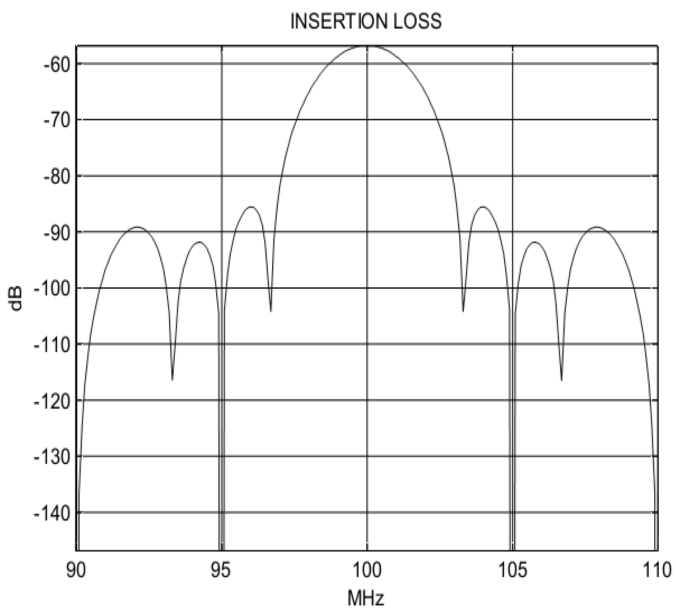


Figure 5. Unapodized SAW filter analysis with quartz substrate, at lower number of fingers at output IDT than input IDT.

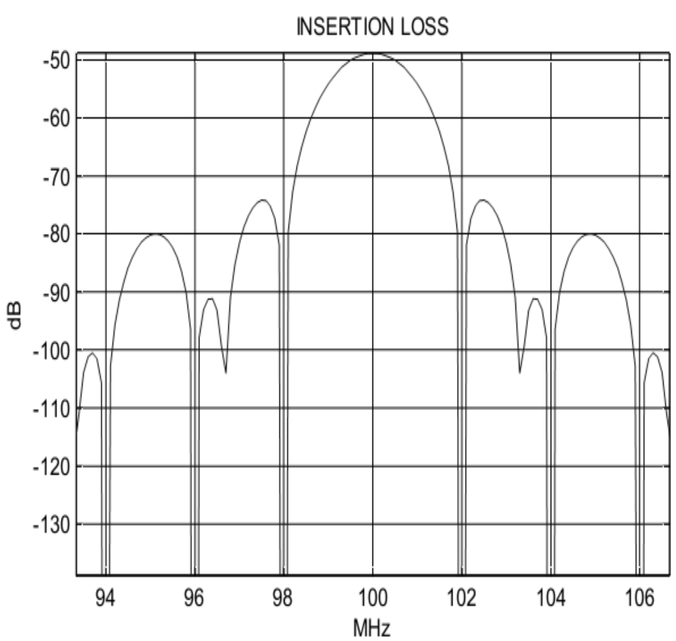


Figure 6. Unapodized SAW filter analysis with quartz substrate, at lower number of fingers at input IDT than output IDT.

IDT than output IDT, e.g. 30 for inputs and 20 for outputs, we notice that number of side bands decreased within the same frequency range, also insertion loss increased in both two previous cases, than when number of fingers at both input and output IDTS are the same, and it is may be avoided, because we need to lower the insertion loss as possible (Figures 5 and 6).

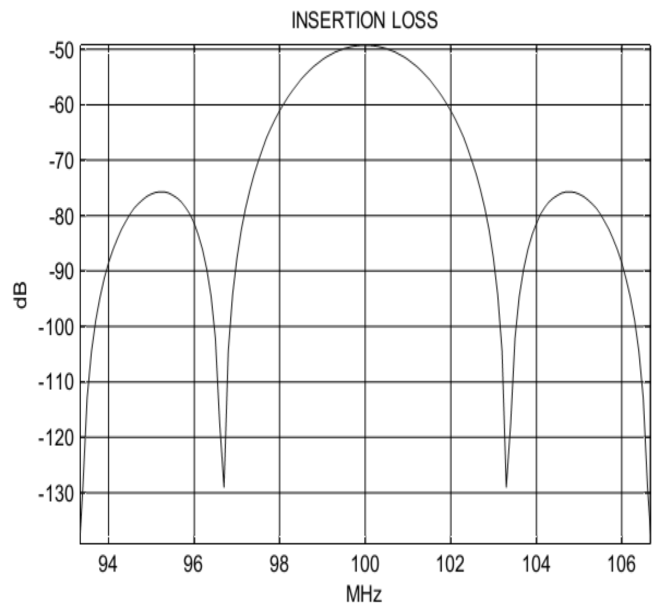


Figure 7. Unapodized SAW filter analysis with quartz substrate, at increasing finger overlap of input IDT than output IDT.

Changing finger overlap in cm of input or output IDT

We select quartz substrate as a reference substrate to study effect of finger overlap in cm for input and output IDTs regardless of the number of finger pairs at input and output IDTs.

While decreasing finger overlap of input IDT than output IDT (e.g. 0.02 cm for input and 0.05 cm for output), the insertion loss decreases and vice versa (e.g. 0.08 cm for input and 0.05 cm for output) (Figures 7 and 8).

RECENT APPLICATIONS OF SAW FILTERS

SAW filters have been largely used in RF and IF filters of mobile phone because of their small size, high reliability, and the capability to be mass produced. Because the acoustic wave propagates on the substrate surface, the package must protect the die surface from damage and contamination (Wang and Zhan, 2006).

CONCLUSION

In this paper, an influence of three main different parameters on the response of unapodized SAW filters has been discussed (Elkordy et al., 2012). Different substrates, number of finger pairs of input or output interdigital transducers, and finger overlap in cm are the main parameters studied. A simple computer algorithm has been constructed to characterize the insertion loss of unapodized SAW filter through these parameters. This constructed program simulates quickly, but does not include sufficient information detail for SAW filter design. The ability to produce high performance SAW devices with low insertion loss at low cost may be achieved with our simulation program. Finally, this model relies on simplistic approximations, although it is incapable of considering some other parameters. This paper is considered as a parallel work for analysis of frequency response of a SAW filter that is discussed by Wu et al. but by using a uniform apodization IDTs (Wu et al., 2002).

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