A computer Simulation for The Response of an Apodized SAW Filter

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Abstract—*in this paper, an algorithm suitable for the computer aided design (CAD) has been developed to estimate and model the main characteristic parameters of an apodized SAW filter. The design of SAW filters on different substrates consisting of two apodized interdigital transducers (IDTs) without using multistrip coupler is presented. The analytical model is described using REMEZ algorithm. The design criteria for an apodized SAW filter components are discussed in terms of number of fingers, minimum stopband attenuation, maximum passband ripples, and design frequency range requirements. In other words, the upper and lower hermitian frequency response, impulse response/apodization, and phase response are demonstrated with aid of the computer algorithm. The technique has been applied to the design of multiband linear phase SAW filters. The uses Hermitian function relations can be applied to realize an even or odd number of up to fifteen passbands with equal or unequal widths, as required. The results obtained in this work, provide an adequate basis for understanding the parameters effects, and optimization processes of an apodized SAW filter. A comparison between the obtained results and the experimental published results shows a good agreement.*

Index Terms—SAW, Apodized, Filter.

1. INTRODUCTION

In this paper, an algorithm suitable for the computer aided design (CAD) has been developed to estimate and model the main characteristic parameters of an apodized SAW filter. The design of SAW filters on different substrates consisting of two apodized interdigital transducers (IDTs) without using multistrip coupler or one apodized transducer and the other unapodized [1] is presented. The analytical model is described using REMEZ algorithm. The design criteria for an apodized SAW filter components are discussed in terms of number of fingers, minimum stopband attenuation, maximum passband ripples, and design frequency range requirements. In other words, the upper and lower hermitian frequency response, impulse response/apodization, and phase response are demonstrated with aid of the computer algorithm. The technique has been applied to the design of multiband linear phase SAW filters. The uses Hermitian function relations can be applied to realize an even or odd number of up to fifteen passbands with equal or unequal widths, as required. The results obtained in this work, provide an adequate basis for understanding the parameters effects, and optimization processes of an apodized SAW filter.

1.1. SAW FILTERS FUNDAMENTALS

SAW devices consist of two transducers with interdigital transducers of thin metal electrodes deposited on a piezoelectric substrate such as quartz or lithium tantalite. One of these acts as the device input and converts signal voltage variations into mechanical surface acoustic waves. The other IDT is used as an output receiver to convert mechanical SAW vibrations back into output voltages. Such energy conversions require the Interdigital transducers to be used in conjunction with elastic surfaces that are also piezoelectric ones [2].

1.2. APODIZED SAW FILTERS

Apodization is the most commonly used weighting technique for defining the impulse response of SAW filters [3]. It is a technique for modifying the response of a surface acoustic wave filter by varying the overlap between adjacent electrodes of the interdigital transducer.

In other words Apodization is a weighting produced by the change of finger overlap over the length of the IDT.

A standard design principle is the usage of SAW filters consisting of one apodized and one unapodized IDT. The apodized IDT provides the main contribution to the overall frequency response. But the application of two apodized IDTs (Figure 1) has the advantages of that Both IDTs provides similar contributions to the filter response.
The admittances of both IDTs are similar. The optimization of the filter design has additional variables. For highly coupling materials a multistrip coupler (MSC) can be used between both apodized IDTs [4].

The trade off here, of course, is in the increased substrate size required to accommodate the MSC. A design method for doubly apodized SAW filter without MSC has been published by Motsoela. [5].
The delta function model is one scheme, which provides basic information on the transfer function response of linear matched SAW filters. It can only yield a relative insertion loss as a function of frequency. When the voltage is applied at the electrodes of an IDT structure, it produces an electric field in the gaps between electrodes. At any instant, adjacent electrodes have opposite voltage polarity and opposite charges that accumulate at the edges of the IDT fingers. The resultant charge distribution can be modeled as delta function sources of electric field intensity at the finger edges. The summation of these delta sources can be used to simulate the resultant electric field intensity, and yield the frequency response H (f) [3].

One of the first applications of SAW Bandpass filters in communications was in television receivers as MF filters. They are still used in all TV systems (PAL, SECAM, NTSC), as well as in satellite, cable TV and HDTV systems. SAW Bandpass filters are used in space communications, digital optical communications, and GPS receivers in L band, mobile telephony, and digital Europe GSM network. Modern SAW filters have central frequencies in the range of 10 MHz to 4.4 GHz, passbands from 50 kHz to 70% of the central frequency.

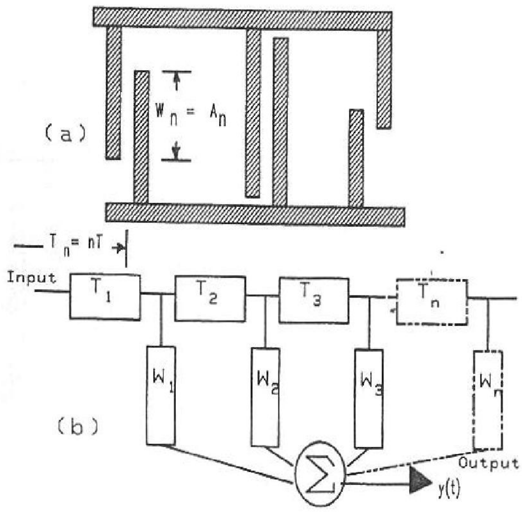

Figure 1: (a) Apodized transducer, and (b) delta function – model representation.

Many other various schemes exist for producing multiple passbands using surface acoustic wave (SAW) filters, other than simply tying the inputs of several interdigital transducers (IDT's) together. The basic IDT patterns are multiplied by a square wave. This modulation will produce a theoretically infinite number of passbands which are amplitude modulated by a (sinx)/x function. This technique has the disadvantage; however, that these have amplitude weighting that is dependent on frequency.
Another method that has been employed for realizing multiple passbands uses cosine or sine function modulation of the basic IDT pattern [6].
Time domain multiplication of the basic IDT pattern with that of the modulating function then yields convolution of the responses in the frequency domain. This method would appear to be restricted to the attainment of an even number of passbands, however, for other than single passband response.

1.3. USING REMEZ ALGORITHM

The SAW filter considered here consists of two apodized transducers, the input transducer and the output transducer. The design of this filter requires highly accurate simulation to compensate for second-order or more effects. The computer design technique devised for realizing optimum filter responses is based around the use of an optimum weighted Chebyshev approximation to the desired filter amplitude response. This optimum response is generated using the REMEZ exchange algorithm [7], [8].

This results in a unique best-weighted approximation to the desired amplitude response D (f). If the approximation achieved is D (f) + E (f), the REMEZ algorithm will minimize the weighted error W (f) ⎢E (f) ⎢, where W (f) is a positive error-

Weighting function that is applied to each of the passbands and stopbands under consideration.

The effect of increasing W (f) in a stopband specification would be to increase the degree of resultant stopband suppression, while an increase in the W (f) parameter for a given passband would serve to decrease the resultant amplitude ripple over the passband. The computer program output yields a discrete set of impulse response values associated with a given filter amplitude response specification. The delay time between impulse response samples is taken to be 1 sec. Under this normalization, therefore, the frequency response spectrum that results will repeat at 1 Hz intervals. The baseband response specification is for the baseband frequency range from 0Hz to +0.5Hz. For SAW filter realization, we must also consider the baseband Hermitian conjugate response (i.e. symmetric magnitude and ant symmetric phase response) over the negative frequency range from 0 Hz to -0.5 Hz. This response will be included when the baseband response is transformed to the operating frequency specification for the SAW filter. Figure 2 demonstrates a three-passband SAW filter response that will result when the baseband specification over 0 Hz to +0.5 Hz is transformed by IDT finger sampling. It may be noted that within the baseband range 0 Hz to +0.5 Hz the passband and stopband widths need not be equal.

About the transformed "centre" frequency +fo, however, the magnitude response will be symmetric as required by the Hermitian specifications. In physical terms, this specification simply ensures that the impulse response will be real, so that the placement of the uniformly spaced IDT fingers, commensurate with the sampled response, can be at physically real points on the SAW substrate.

The optimization program allows for up to fifteen SAW filter passbands, result when the Hermitian function relations are included. A total fractional bandwidth of 100% is also available for this maximum number of passbands.

1.4. MODELING OF APODIZED SAW FILTER

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 IDTs or with two IDTs and a multistrip coupler between them. In the first case one IDT is unapodized with a small number of electrodes, and the second one is apodized accordingly to the desired transfer function. In the second case both transducers are apodized, but only lithium niobate can be used. Bandpass filters are

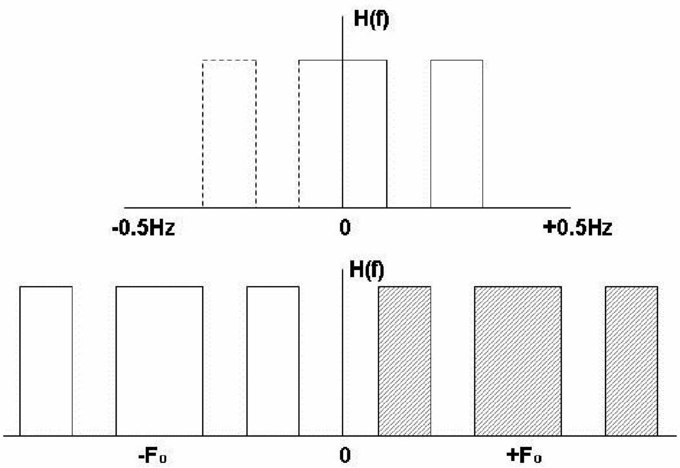

Figure 2: Baseband response (upper) and bandpass response (lower) of a 3-passband SAW filter.

designed using the known methods of FIR digital filters design.

Generally the finite impulse response of Apodized transducer can be modeled to be as shown in figure (3).

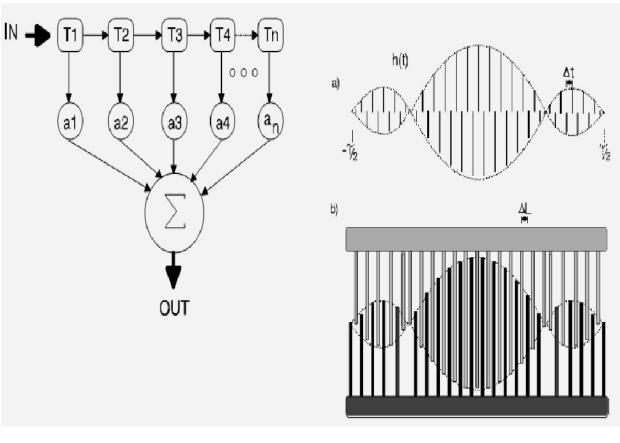

Figure 3: Schematic of a Finite Impulse Response (FIR) Filter.

The resultant frequency response is given by

$$h(t) = \sum_{i=1}^{I} h_i(t) \qquad \textbf{(4.1)}$$

SAW transducer impulse response is given by

$$H(\omega) = \sum_{i=1}^{I} H_i(\omega) = \sum_{i=1}^{I} \{ \int_{-\tau/2}^{\tau/2} h_i(t) e^{-j\omega t} dt \} \qquad \textbf{(4.2)}$$

It can be rewritten for (one transducer) as

$$\boldsymbol{H_1(f) = \sum_{n=-(N-1)/2}^{(N-1)/2} (-1)^n A_n e^{-j\beta x_n}} \qquad \textbf{(4.3)}$$

$\beta = 2\pi/\lambda = 2\pi f/v$ In terms of SAW velocity v.

$$H_1(f) = \sum_{n=-(N-1)/2}^{(N-1)/2} (-1)^n A_n e^{-j\omega x_n/v} \qquad \textbf{(4.4)}$$

Where the term $(-1)^n$ relates the alternating electrode polarity, while A, is an amplitude parameter proportional to the finger apodization overlap. This may be normalized to $\boldsymbol{A_n = 1}$ for the uniformly apodized IDT.
The total amplitude response is

$$H(f) = H_1(f).H_2^*(f) \qquad \textbf{(4.5)}$$

$$|H(f)| = |H_1(f)|.|H_2(f)| \qquad \textbf{(4.6)}$$

$$H(f) = \left[\sum_{n=1}^{N} A_n e^{j\omega x_n/v} \right] \left[\sum_{m=1}^{M} A_m e^{j\omega x_m/v} e^{j\omega t} \right] \qquad \textbf{(4.7)}$$

$e^{-j\omega t}$ Shift in time domain and translated to the frequency domain.
For both Apodized transducers, with N fingers in the input and M finger pairs in the output IDT, the frequency response of a "shared" (N, M) electrode pair will take the form

$$\boldsymbol{A_n A_m e^{j\omega(x_n - x_m)/v} x(a \ weighting \ factor \ C_{nm})}$$

So, The filter transfer function H(f) will be constrained as

$$\boldsymbol{H(f) = \sum_{n=1}^{N} \sum_{m=1}^{M} C_{nm} A_n A_m e^{j\omega x(x_n - x_m)/V}} \qquad \textbf{(4.8)}$$

Where, binding term $\boldsymbol{C_{nm}}$ cannot be split into two separate summations that represent the individual frequency response of input and output IDTs.

1.5. DESIGN OF AN APODIZED SAW FILTERS

Design of SAW devices as a SAW filter is very complex so that it could not be done without a computer. Generally the design procedure consists of the following steps [9]:

- Choice of the substrate and the types of IDTs,
- Determination of the coefficients of the impulse response of the apodized IDT,
- Determination of the apodization law,
- Determination of the matching network and the absolute apodization function,
- Determination of the geometries of the IDTs and the whole filter.
- Verification through characteristics calculation.

The choice of the substrate and the type of IDTs depends upon the type of device and its requirements. Mainly the lithium niobate and ST-cut quartz substrates are used. The lithium niobate has a higher electromechanical coupling coefficient and therefore is preferred for low insertion loss and wide band filters and delay lines. ST quartz has a lower coupling coefficient but has substantial advantages in respect to the influence of the second order effects, e.g. lower bulk wave generation, lower acoustic reflections and better temperature stability. There are many types of SAW transversal devices; one of them is bandpass filters.

1.6. RESULTS AND DISCUSSION

The algorithm is constructed with taking into consideration some parameters such as synchronous frequency, total number of bands, number of fingers, minimum stopband attenuation, and maximum passband ripples. Figures 4, 5 show effect of changing number of fingers for YZ LiNbO3 substrate from 64 to 100 upon the frequency, phase, and impulse response of the filter. Figures described at synchronous frequency of 80MHz, design range (upper hermitian frequency range) is 80-120MHz, total number of bands is 3 (80-92.5, 95-105, and 107.5-120) MHz, minimum stopband attenuation is 30db, and max passband ripples is 0.5db. it is noticed that while increasing number of fingers the phase difference increases and stop attenuation increases. While figure 6 shows the change in maximum passband ripples from 0.5db to 1db at the same substrate and same other parameters of figures 4, and 5.

It is noticed that phase difference decreases and the minimum required number of fingers decreases too. Now any decrease in passband ripples faces increase in phase difference and the minimum required number of fingers increased.

Figure 7 describes the change of minimum stopband attenuation value, when attenuation changed from 30db to 20db. It is noticed that any decrease in minimum stopband attenuation faces decrease in phase difference and the minimum required number of fingers increased and vice versa. Figure 8 describes the effect of changing the number of bands to four bands instead of three (as example) without changing other parameters (80-90, 91-100,101-110,111-120) MHz. It is noticed that phase difference decreases and vice versa for decreasing number of bands the phase difference increases and also minimum required number of fingers. Now to compare our algorithm with an experimental published one [10], describe the response of the filter simulated with our simulation program for typically losses, in the range of 3 to 20 dB, and out of band signal rejection of 60 dB. The phase error is ±2 °, and the passband loss variation 0.05 to 0.5 dB. We note that for a frequency band around 20-60MHz, the response of simulated program exhibit a better measurements than that obtained from experimental one.

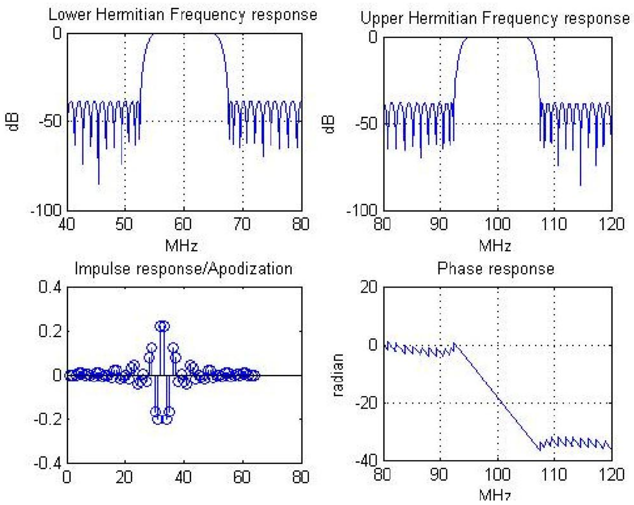

Figure 4: different responses of an apodized SAW filter of YZ LiNbO3 substrate, no. of fingers=64, 0.5db passband ripples, and min. stopband=30db.

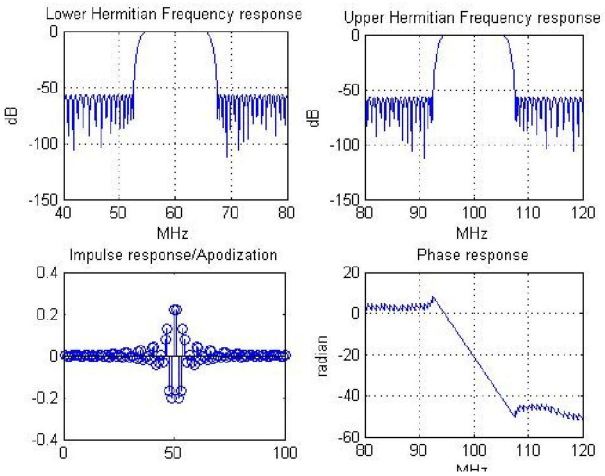

Figure 5: affect of changing number of fingers for YZ LiNbO3 substrate from 64 to 100 with the same other previous parameters.

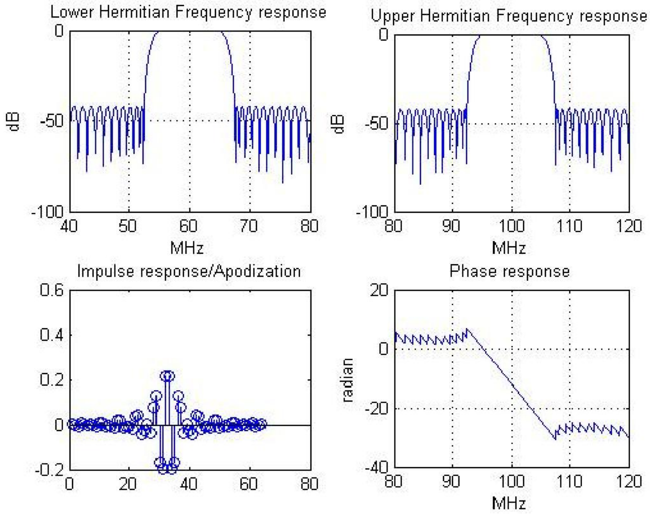

Figure 6: effect of the change in maximum passband ripples from 0.5db to 1db at the same substrate and same other parameters of figures 3, and 4.

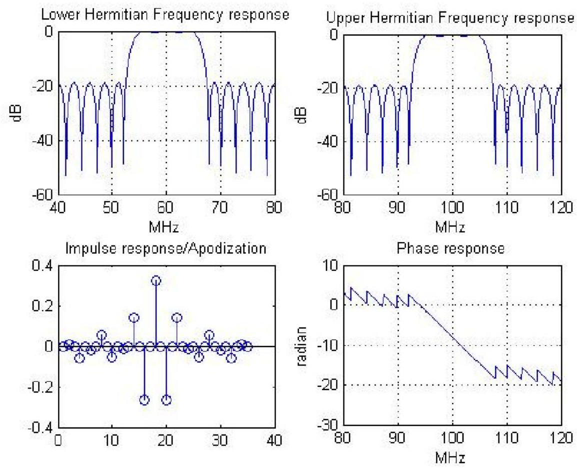

Figure 7: effect of the change of minimum stopband attenuation value, when attenuation changed from 30db to 20db.

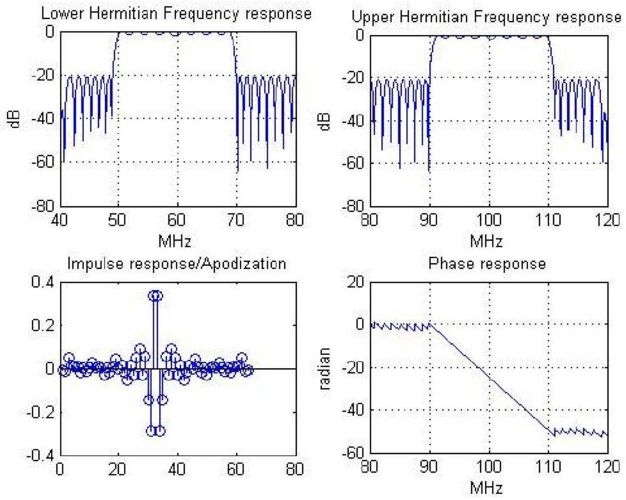

Figure 8: describes the effect of changing the number of bands to four bands instead of three without changing other parameters.

1.7. CONCLUSION

In this chapter our objective has been to develop a method of analyzing the behavior of an apodized SAW filter which leads to useful design criteria [11-13]. A simple computer algorithm has been constructed as a tool to achieve this design. The ability to produce high performance apodized SAW filter with optimum frequency and impulse response, achieved with our simulation program. Some parameters like number of fingers, minimum stopband attenuation, maximum passband ripples, and design frequency range requirements, are discussed.

The upper hermitian frequency response, lower hermitian frequency response, impulse response/apodization, and phase response are demonstrated with aid of the computer algorithm.

This constructed program simulates quickly, but does not include sufficient information detail for SAW filter design. Finally, this model relies on simplistic approximations although it is incapable of considering some other parameters such as diffraction and reflections.

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