Combined Optimization For The SAW Filter Design

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Abstract.

A two-dimensional synthesis of filter characteristics considering an external circuit influence (50Ohm load), when the insertion loss is one of the goal parameters, is presented. The problem is formalized as a non-linear programming problem.

Introduction.

The SAW design is considered as a triple problem: optimization, implementation and prediction. That means the implementation with the predictable characteristics is a criterion of the combined optimization procedure. So, the optimization procedure

- tries to reduce the amount of small overlaps with behavior that is hard to predict. Such effects as diffraction and distortions around apodization gaps along electrodes might be ignored, when there are few small overlaps in the apodized inter-digital transducers (IDT).
- corrects the electrostatic end-effect, especially for the tilted topology, constructing the non-symmetric geometry of guard electrodes;
- chooses an appropriate (i.e. the most predictable and physically feasible) pair of functions for IDT-1 and IDT-2 for the goal frequency characteristics decomposition;
- takes into account a behavior of the IDT complex acoustic conductivity and an external circuit influence (for example, 50 Ohm load); the insertion loss is one of the goal parameters.

The apodization functions and apertures of IDT-1 and IDT-2 are the output parameters of the optimization procedure. In order to ignore the SAW velocity dispersion, an appropriate electrode thickness is chosen.

Goal Function.

The goal function for the main signal of desired insertion loss is used for the combined optimization procedure. It takes into consideration the external circuit influence. The goal frequency spectrum ***A(ω)*** of the SAW filter loaded with external circuits, is written in form [1]:

$$A(\omega) = \frac{-H_{sc} \cdot Y_c}{(Y_1 + Y_{c1})(Y_2 + Y_{c2})} \qquad (1)$$

Where

- the function H_{sc} is a short-circuit response defined as[1]

$$H_{sc} = H_1(\omega)H_2(\omega)S_{14}\exp(\omega T_{12}) \quad (2)$$

$H_1(\omega)$ and $H_2(\omega)$ are the transform functions of the IDT-1 and IDT-2 respectively;
S_{14} is the multi-strip coupler (MSC) characteristics;
T_{12} is the SAW delay between IDT-1 and IDT-2;

- Functions Y_1 and Y_2 are the complex acoustical conductivity of the IDT-1 and IDT-2 respectively,

$$Y_1 = G_{a1}(\omega) + j(B_{a1}(\omega) + \omega C_1)$$

$$Y_2 = G_{a2}(\omega) + j(B_{a2}(\omega) + \omega C_2)$$

C_1 and C_2 are the static capacities of the IDT-1 and IDT-2 respectively;

- Functions Y_{c1} and Y_{c2} are the complex conductivities of the external circuits connected to IDT-1 and IDT-2 respectively.

Optimal Decomposition.

If the transition band and near stop band are the most critical areas to predict, we need to design both IDT characteristics having the same pass bands and the same transition bands. I.e., for example, to obtain the stop band of 15.00MHz on the level 50dB, both of IDT-1 & IDT-2's stop bands of 15.00MHz on the level 25dB should be built. In this case the transition area characteristics are the most predicted.

Topology Implementation.

It is assumed, that the goal topology structure meets the following conditions.

- The filter consists of two IDTs and MSC.
- Both of IDT are of apodized structures.
- Apodization functions have few small overlaps, so the diffraction and distortions along electrodes might be ignored.
- In order to reduce RF leakage, the apodization functions have a big number of long grounded electrodes near the MSC.
- The tilted topologies have the benefit property. They have a smoothed acoustical conductivity. However, this feature is not a criterion of the synthesis. The desired smoothing of the acoustical conductivity is achieved by enlarging of the electrode overlaps. Moreover, the criterion of smooth multiplication $(Y_1+Y_{c1})(Y_2+Y_{c2})$ is used in the design.
- If we consider the anti- symmetrical structures, the big number of long hot electrodes is placed on the opposite side of each IDT. It may lead to big parasitic charge distribution end-effect. In order to reduce this unwanted effect, the IDT topology function has a non-symmetric component that enlarges length of grounded electrodes in both sides of the IDT.

Figure-1 shows schematically the topology implementation of SAW filter built utilizing a multi-string coupler (MSC).

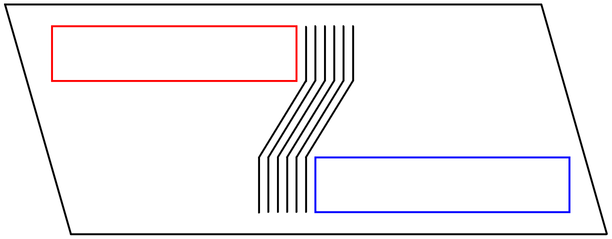

Figure 1. Schematic SAW filter topology designed using two apodized transducers and MSC.

The apodization functions for IDT-1 and IDT-2 implementations are performed in **Figure-2.** Special apodization for electrodes, which are coated by damper-glue, is applied in order to reduce an electrostatic end-effect.

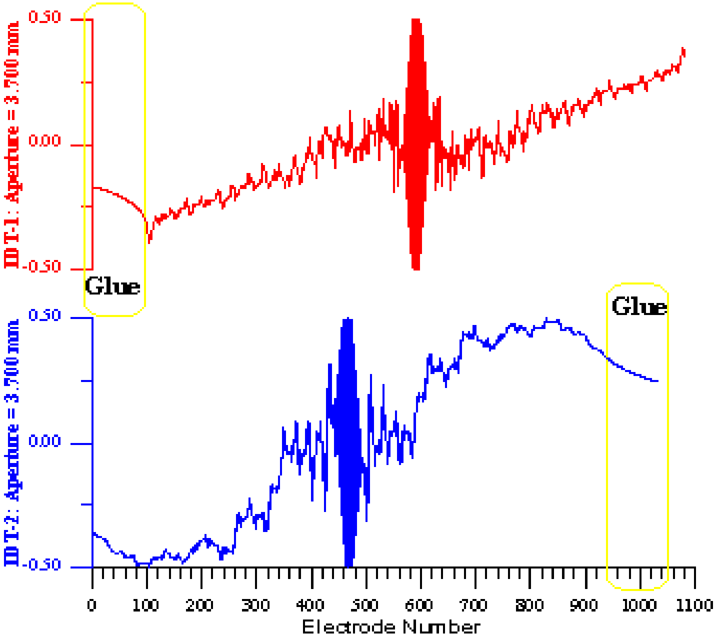

Figure 2. Apodization functions for IDT-1 and IDT-2 implementation.

SAW velocity.

The additional problem of the development of the vestigial transition-area band-pass filters, which are built with optimal decomposition, is the SAW velocity dispersion. Analysis model is in need of account a dependency of SAW velocity on electrical load (i.e. on apodization function) and frequency. This effect becomes essential for narrow transition zones and band pass more than 15% of the center frequency. This effect might be ignored when both of the apodization functions have few small overlaps and thickness of electrodes is chosen so that the SAW velocity is not changed in the pass band frequency area.

Step by Step Algorithm.

The step-by-step algorithm may be separated conditionally on the stages of following meaning.

- The two-dimensional synthesis (or weighting with decomposed weighting function)[2] is used. This optimization is based on the criterion of the IDT characteristics predictability (i.e. optimal decomposition and topology implementation conditions).
- The two-dimensional synthesis for $(Y_1+Y_{c1})(Y_2+Y_{c2})$ is used (in particular case, $Y_{c1}=Y_{c2}=1/R$, $R=50$ Ohm).

The procedure, that takes into consideration the external circuit influence (***50*** Ohm loading), where insertion loss also is one of goal parameters, finds optimal aperture and corrects the apodization function**.**

Results.

One of the principal benefits of using of the combined optimization procedure is the fact, the desired frequency characteristics may be reached without additional tuning. And if, nevertheless, we would like to use external circuit tuning, the pulsation in the frequency characteristics band pass is not increased dramatically because the acoustic conductivity as well as multiplication $(Y_1+Y_{c1})(Y_2+Y_{c2})$ is smoothed.

The SAW filter with the relative pass-band ***B*****(-3dB)/*****Fo*** of about **14.5%** and insertion loss of **24.5dB** was accomplished using this technique. The frequency characteristics shape factor ***B*****(-40dB)/*****B*****(-3)** equals **1.065**, peak-to-peak pass band pulsation is of **0.7dB** and delay variation is of **30nsec**, stop band attenuation is of **56dB**. The pulse characteristics is predicted down to **-60dB** level. (All the measurements were performed without additional circuits tuning.) The calculated frequency characteristics of this SAW filter are performed on the figure-3, figure-4, figure-5, figure-6, and figure-7. The group delay variation and the amplitude pulsation in pass band are shown on Figure-4. Big unwanted signal in the far zone from the pass band (Figure-5) is the result of the overlaps enlarging procedure. So, the overlaps enlarging is limited with specified requirements in the far frequency area. Detailed shape form is shown on Figure-6. Figure-7 demonstrates the result of the two-dimensional optimization of the multiplication $(Y_1+Y_{c1})(Y_2+Y_{c2})$**,** where the criterion of this optimization was the smoothing of the pulsation in the pass band. This is a principal feature of the combined optimization procedure.

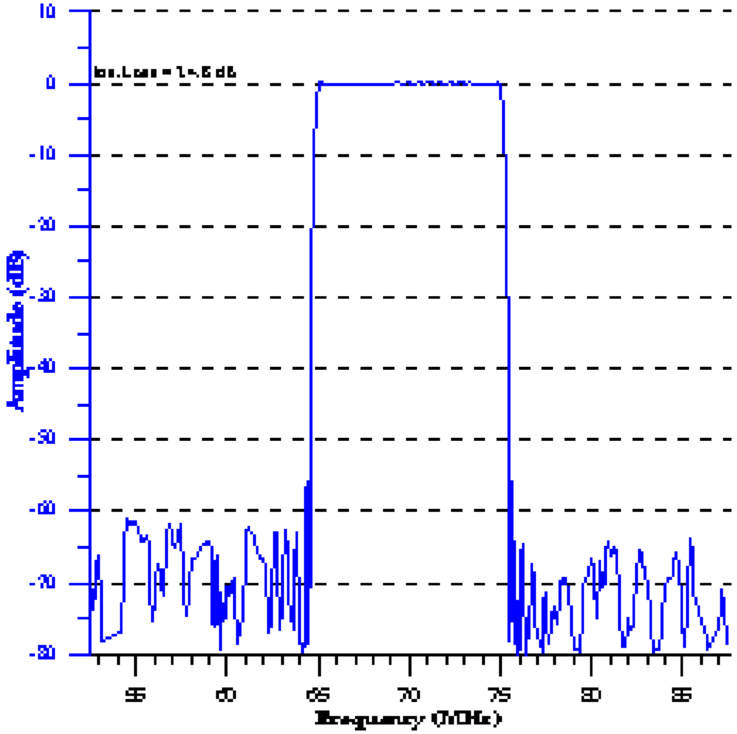

Figure 3. SAW Filter characteristics in the 50% area span.

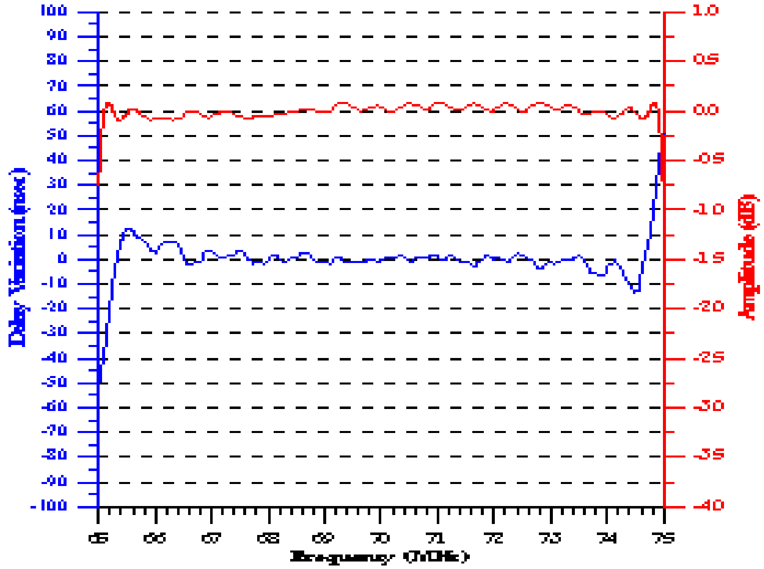

Figure 4. The delay variation and amplitude pulsation in the pass band.

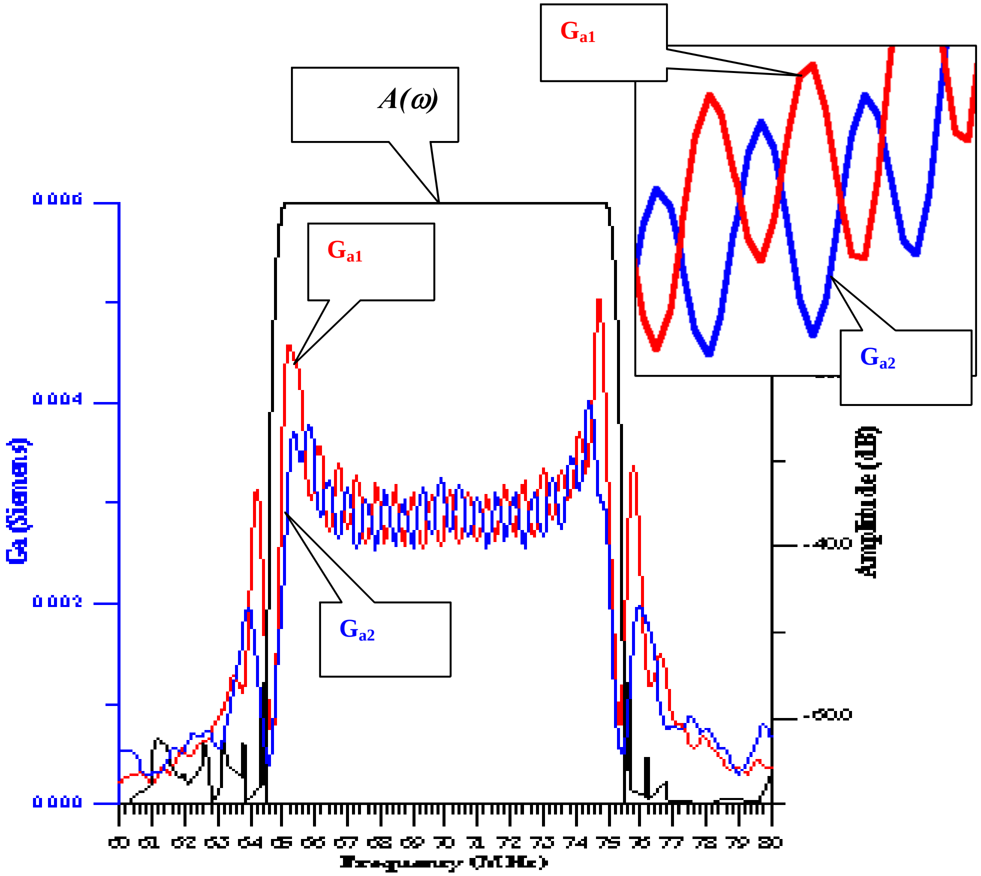

Figure-7. $\mathbf{G_{a1}}$ and $\mathbf{G_{a2}}$ are the real parts of acoustical conductivities for IDT-1 and IDT-2. ***A(ω)*** is the frequency spectrum of the SAW filter loaded with external resistance of 50 Ohm. Inter-behavior of $\mathbf{G_{a1}}$ and $\mathbf{G_{a2}}$ is the result of the two-dimensional optimization procedure using the band pass pulsation smoothing as a criterion to approach.

Conclusions.

This optimization procedure is a step-by-step algorithm of sequential approach to the goal function. Usually these calculations take about 500 hours (i.e. three weeks) running on PC based on the Intel Pentium-III 450MHz processor. So, this technique may be successfully applied for commercial design of SAW filters with high requirements to the shape factor, pass band, delay variation and stop-band attenuation.

Acknowledges.

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2. **C.Ruppel, W.Ehrmann-Falkernau, H.R.Stocker and W.Mader,** *A Design for SAW Filters with Multi-Strip Couplers* – IEEE Ultrason. Symposium – 1984, pp.13-17.