Iterative design of SAW bandpass filters with arbitrary magnitude and phase specifications

A.S.Rukhlenko and V.S.Kiranov

Semiconductor Physics Dept, Belarusian State University
4, Fr. Skorina Ave., Minsk, 220050, Republic of Belarus

Abstract

The problem of approximating the desired (target) complex-valued SAW filter frequency response with arbitrary magnitude and phase specifications is considered in the paper. A new iterative design algorithm is proposed, with the design aim being not to accomplish the optimum fit to a design target but rather to fit with an acceptable accuracy within *arbitrary* magnitude and phase tolerances. However, the solution obtained is likely to be rather close to the optimum one. An advanced tolerance transformation scheme is proposed to transform the initial magnitude and phase tolerances to the auxiliary tolerances to the real and imaginary (quadrature) components to be optimized iteratively using linear optimization techniques, the Remez exchange algorithm for example. The algorithm is easy to programming and exhibits and excellent convergence. An illustrative design example is presented which confirms the accuracy and flexibility of the proposed algorithm.

1. Introduction

SAW filters with uniform finger spacing can have arbitrary magnitude and phase characteristics if a synchronous frequency is chosen outside a filter passband.[1] A complicated problem of approximating the desired (target) response

$$F_0(\omega)=R_0(\omega)e^{j\theta_0(\omega)} \tag{1}$$

with arbitrary magnitude and phase characteristics $R_0(\omega)$ and $\theta_0(\omega)$ by a SAW filter frequency response

$$F(\omega)=R(\omega)e^{j\theta(\omega)}=C(\omega)+jS(\omega) \tag{2}$$

within prescribed magnitude and phase error tolerances $\Delta R(\omega)$ and $\Delta\theta(\omega)$ (Fig.1) must be solved.

As the approximation problem is non-linear with respect to the filter coefficients general-purpose non-linear optimization techniques might be applied to adjusting the filter coefficients to fit the target response.[2,3] However, they are time consuming, capable to find the local maximum only, and impractible in many cases.

This virtually non-linear problem can be linearized by splitting the frequency response $F(\omega)$ into the real (cosine) and imaginary (sine) components $C(\omega)=R(\omega)\cos\theta(\omega)$ and $S(\omega)=R(\omega)\sin\theta(\omega)$ to be optimized separately by linear optimization techniques.[4-7] Unfortunately, the initial tolerance field $\Delta R(\omega)$ and $\Delta\theta(\omega)$ cannot be directly converted to the auxiliary tolerances $\Delta C(\omega)$ and $\Delta S(\omega)$. Therefore, approximate tolerance transformation schemes must be applied to linearize the problem.[4-7]

As a rule, the prescribed tolerances are assumed to have small values $\Delta R(\omega)$ $\Delta\theta(\omega)<<1$, and the magnitude error is minimized at the expense of the phase error or *vice versa*.[4,5]

Besides, under assumption of small tolerances a tolerance sector $\Delta R,\Delta\theta$ can be approximated by a rotated rectangle ΔR, $R\Delta\theta$. This enables for the linear programming techniques to be directly applied to optimizing the filter coefficients, with the Cartesian coordinates C, S appropriately rotated.[6,7]

However, the known tolerance transformation schemes suffer from the following drawbacks.

1) approximation errors are larger than optimum ones;
2) the approximation might fail for arbitrary tolerances $\Delta R(\omega)$, $\Delta\theta(\omega)$;
3) magnitude and phase errors cannot be independently weighted.

To overcome these difficulties a new iterative algorithm based on the advanced tolerance transformation scheme is proposed in the paper. The design aim is not to accomplish the best (optimum) fit to a design target but rather to approximate with an acceptable accuracy within arbitrary magnitude and phase specifications by using linear optimization techniques, the Remez exchange algorithm for example.

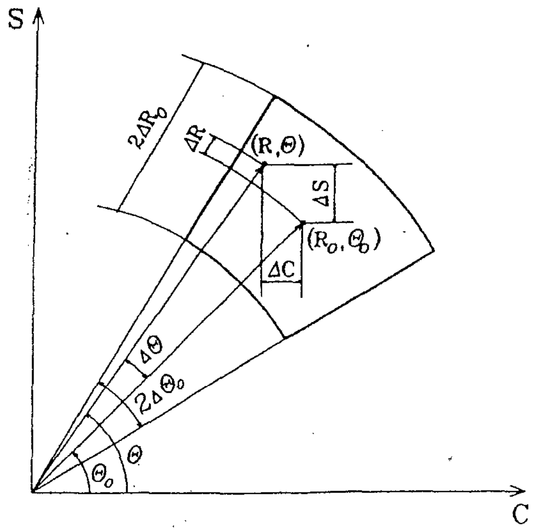
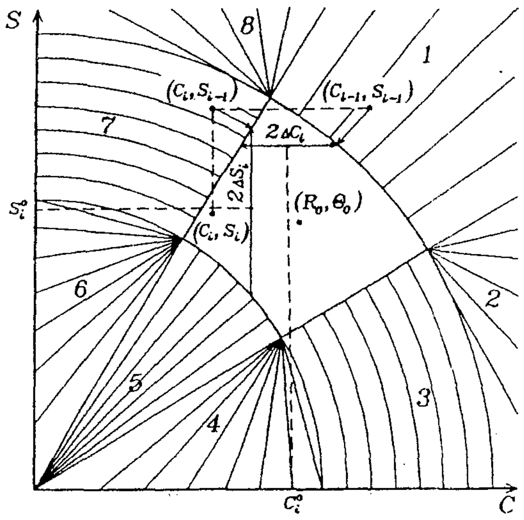


Fig. 1. Tolerance field and approximation error in the polar and Cartesian coordinates



1, 5 - radial projections;
3, 7 - azimuth (angle) projections;
2, 4, 6, 8 - combined (radial and azimuth) projections

Fig. 2. Projections field with respect to the tolerance sector

2. Tolerance transformation scheme and algorithm implementation

In the aforementioned tolerance transformation schemes the auxiliary tolerances $\Delta C(\omega)$ and $\Delta S(\omega)$ are evaluated separately and independently to each other. As the result, the initial tolerance sector ΔR, $\Delta\theta$ and the resulting rectangle ΔC, ΔS can appreciably differ that leads to the approximation accuracy sacrificing or to the filter length increasing. This principal drawback is eliminated due to the following features of the proposed algorithm:

1) an iterative optimization of the interrelated functions $C(\omega)$ and $S(\omega)$;

2) a dynamical redefining and reweighting of the optimized functions $C(\omega)$ and $S(\omega)$ to allow for the results of the previous iterations.

The algorithm works as follows.

Suppose we are to calculate the target functions $C_i^o(\omega)$ and $S_i^o(\omega)$ and their appropriate tolerances $\Delta C_i(\omega)$ and $\Delta S_i(\omega)$ at the ith iteration. To this end, the values $C_{i-1}(\omega)$ and $S_{i-1}(\omega)$ so far obtained are evaluated in the filter passband with respect to the initial tolerance sector $| R(\omega)-R_0(\omega) | \leq \Delta R(\omega)$ and $| \theta(\omega)-\theta_0(\omega) | \leq \Delta\theta(\omega)$. There are to possible cases.

1. The current point with Cartesian coordinates (C_{i-1}, S_{i-1}) is situated inside the tolerance sector $(\Delta R, \Delta\theta)$. The low and upper limits of the functions $C_i(\omega)$ or $S_i(\omega)$ to be optimized at the next iteration can be found by using the horizontal and vertical intersections of the tolerance sector in the point (C_{i-1}, S_{i-1}), with the desired (target) values $C_i^o(\omega)$ or $S_i^o(\omega)$ being the medium points of these intersections (Fig. 2).

2. The current point with Cartesian coordinates (C_{i-1}, S_{i-1}) is situated outside the tolerance sector $(\Delta R, \Delta\theta)$. The point is projected to the nearest bound of the of the tolerance sector according to the projections field shown in Fig. 2. The projection direction (radial, azimuth, or combined) depends on the relative position of the point with respect to the tolerance sector. The intersections needed are constructed for this projection point imposing the more stringent constraints to the functions $C_i(\omega)$ or $S_i(\omega)$ for the next iteration. Thus, outside points will tend to enter the tolerance field while optimizing.

If a new intermediate point with Cartesian coordinates (C_i, S_{i-1}) will be outside the tolerance sector it is projected again to the nearest bound and the vertical intersection is used to determine the tolerance $\Delta S_i(\omega)$ for the next iteration. If this point is inside the tolerance sector the vertical intersection is constructed directly through this point. This projection/intersection technique secures for the point with coordinates (C_i, S_i) to be finally allocated within specified tolerance sector if a sufficient filter length has been a priory provided for.

The same approach might be applied in a filter stopband where a tolerance sector degenerates into a circle. However, to simplify the algorithm the independent tolerances to the real and imaginary components may be imposed, with the 3 dB stopband attenuation surplus provided for.

The algorithm convergence is illustrated in Fig. 3. It is worthy to note that contrary to the "static" tolerance transformation scheme the entire area of the initial tolerance sector is accessible while optimizing due to the wandering and dynamical transforming of the virtual tolerance field (dashed in Fig. 3) from iteration to iteration.

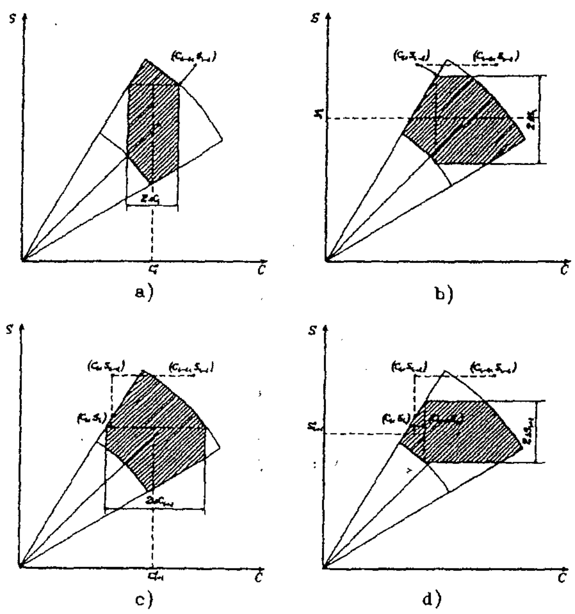


Fig.3. Illustration of the algorithm convergence and virtual tolerance field (dashed)

The algorithm is easy to programming and exhibits an excellent convergence. It takes generally no more than 3-5 iterations to obtain the solution rather close to the optimum non-linear one. Moreover, in many practical cases an accurate approximation may be obtained after the first iteration.

3. Design example

The design procedure is illustrated by the synthesis of a SAW TV filter with prescribed magnitude and group delay time specifications. The suboptimal synthesis technique[8] based on the Remez exchange algorithm has been used to optimize the real and imaginary components.

The design results of the first three iterations are shown in Fig.4. The synthesized magnitude and phase characteristics entirely satisfy the prescribed tolerances. After 3-4 iterations the solution behaviour becomes stable and further iterations do not amend it.

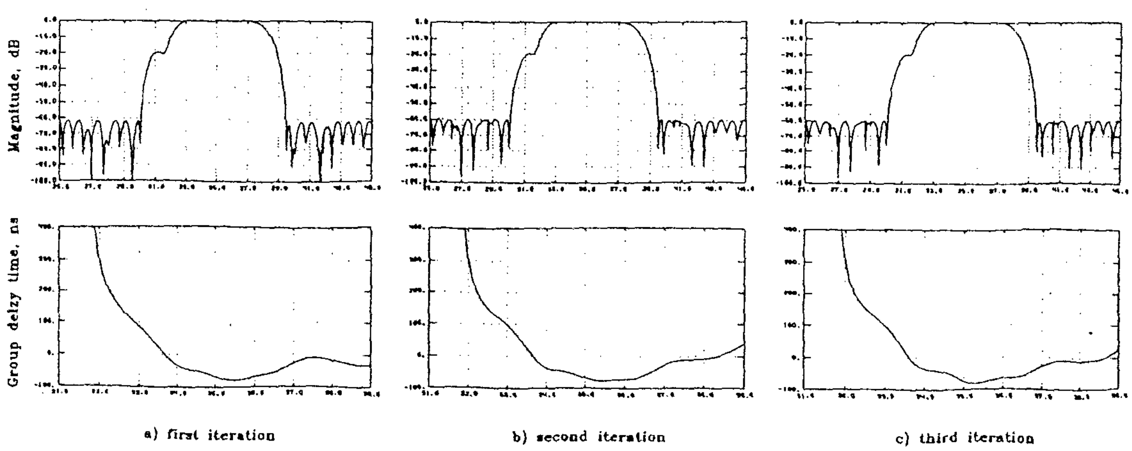


Fig. 4. SAW TV filter with prescribed magnitude and group delay time specifications

4. Conclusions

The approach presented in this paper gives a viable iterative technique for designing SAW bandpass filters with arbitrary prescribed magnitude and phase specifications. A feature of the algorithm is a dynamical redefining and reweighting of the interrelated optimized functions from iteration to iteration. This results in a more accurate and flexible approximation if compared to the other tolerance transformation techniques.

The algorithm was implemented in the SAW filters real-time computer-aided design based on the IBM PC/AT computers. The design experience confirmed accuracy, convergence, flexibility, and reliability of the present technique. Good agreement between design and experimental results has been observed within SAW model constraints applied.

References

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