An Efficient HTS Filter Design Method Applying Parameter Extraction and Optimization

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An efficient design procedure for HTS coupled microstrip resonator filters is presented in this paper. Based on the relationship between the coupling matrix M and the frequency response of a filter, we made a program to get a response from a known M matrix and to achieve a better result by optimization of the M matrix. Using its optimization recursively, we can easily find the optimal filter configuration with a desired filter performance. A design example is given to demonstrate its feasibility. This computer-aided design method is very useful for HTS filter design and tuning.

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I. INTRODUCTION

High-temperature superconductor (HTS) filters have many dramatic advantages such as the very low passband insertion loss, high selectivity and large out-of-band rejection compared with the conventional filters. With the rapid growth of the mobile communications industry in these recent years, there will be an increasing demand for HTS filters to resolve the difficulties in expanding the capacity, eliminating the coverage gaps and reducing the interference [1]. There have been many publications concerning the design of high-performance HTS filters [2–5].

In the determination of the initial filter parameters such as the spacings between the resonators from Chebyshev prototype element values, we are unable to consider the non-adjacent couplings, which always exist in a compact microstrip filter. And thus we usually have to spend a lot of time in adjusting the spacings to get a desired response. To make design more efficient, a lot of researches have been done on computer-aided coupling matrix synthesis techniques [6–9].

This paper aims at solving the difficulties of adjusting the spacings in our HTS filter design and tuning. Based on the design technique of our laboratory [10] and the relationship between the coupling matrix M and the frequency response, we made a program to get a response from a known M matrix and to achieve a desired response by optimization of the M matrix. Combined with the EM simulator, the computer-aided coupling matrix extraction and optimization is a very efficient way to get a desired response. It also can be applied to filter tuning.

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Fig. 1 shows a general cross-coupled prototype bandpass network consisting of \( n \) coupled resonators. The source and load impedances \( R_1 \) and \( R_n \) in Fig. 1 may be normalized to unity by the inclusion of transformers at the input and output of the network. The total capacitance and the total inductance of each resonator may also be normalized to “inner” general cross-coupled prototype bandpass network (Fig. 2) by changing the values of \( M \) parameters [11]. Referring to the “inner” cross-coupled network, the loop equations may be represented in matrix form [12]

\[
\begin{align*}
[\omega' U - jR + M][I] &= [A][I] = -j[e], \quad j^2 = -1, \quad \omega' = \omega - \frac{1}{\omega}, \\
[e] &= e_1[1, 0, \Lambda, 0]^t, \quad [I] = [I_1, I_2, \Lambda, I_n]^t,
\end{align*}
\]

where \( R \) is an \( n \times n \) matrix with all entries zero, except \( R_{11} = R_1 \) and \( R_{nn} = R_n \), \( M \) is the \( n \times n \) coupling matrix and \( U \) is the identity matrix. If we relate the equation above with the equation in Ref. [13], we can get the transmission coefficient \( S_{21} \) of a coupled resonators
filter as follows.

\[ S_{21} = 2 \sqrt{\frac{R_1}{R_n} \frac{I_n R_n}{e_1}} = 2 \sqrt{\frac{R_1 R_n I_n}{e_1}} = -2j \sqrt{R_1 R_n [A^{-1}]_{n1}}. \]  \hspace{1cm} (2)

We can determine \( M_{ij}, R_1 \) and \( R_n \) by relating Fig. 2 to Chebyshev prototype circuit.

III. PARAMETER EXTRACTION AND OPTIMIZATION

The parameter extraction and optimization procedure can be summarized as follows:

1. Choose a resonator structure and determine the initial parameter values such as the spacings between each pair of resonators by an EM simulation software [10]. As a result, we get an initial filter configuration whose simulation result is usually far away from the desired performance because of not considering the cross-couplings between the nonadjacent resonators in determination of the initial values.

2. Extract an initial \( M \) matrix including all the nonadjacent couplings from the initial filter configuration using an EM simulator.

3. Put all of the initial values in our program as the starting point and use its optimization function to find a better one for a desired response. Considering its feasibility, we only optimize the adjacent coupling while fixing the cross-couplings. When the optimization result is much close to the desired one, modify the spacings between resonators using the optimized \( M \) matrix and a better response is achieved.

4. Repeat all the steps above and carry out this extraction and optimization recurrence until the desired response is obtained.

IV. DESIGN EXAMPLE

For HTS applications in a mobile communications base-station, the above method was applied to design a 12-pole microstrip filter with 10 MHz bandwidth centered at 1940 MHz on a sapphire substrate with a 0.425 mm thickness and a comparatively low relative dielectric constant \( \varepsilon_r = 9.99 \). We used the Sonnet software as the EM simulator.

A double-folded microstrip line resonator structure was developed by ourselves to realize the filter. After the determination of the initial parameter values [10] we obtained an initial response by Sonnet as shown in Fig. 3. After applying the above parameter extraction method, we got an initial \( M \) matrix including all the cross-coupling coefficients as listed in Table I. Considering the filter’s symmetric feature, here only the elements in top-left quarter entries of the matrix were presented.

Fig. 3 shows a comparison of the performance obtained from the extracted parameters and Sonnet. They are very matched.
TABLE I: Coupling Matrix After Parameter Extraction

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<td>0</td>
<td>-0.0081</td>
<td>0.53</td>
<td>0</td>
</tr>
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</table>

FIG. 3: Comparison of the performance obtained from the extracted parameters and Sonnet.

After the parameter optimization, we got the first optimized coupling matrix. Comparing it with the initial one, $M_{23}$ was changed from 0.6099 to 0.6301 and the other entries were unchanged. Then we calculated its performance by Sonnet again (Fig. 4) and found that the reflection coefficient $S_{11}$ of the filter had an improvement from a minimum 13.2 dB to a minimum 14.5 dB. Through several recurrences of the parameter extraction and optimization procedure, we achieved the final $M$ matrix listed in Table II. The final simulation result are shown in Fig. 4 with $S_{11}$ in passband better than 17.3 dB and it perfectly fulfills our demands.

V. CONCLUSION

We have described a computer-aided parameter extraction and optimization method for HTS filter design. It is simple and straightforward and can solve the problems in the
AN EFFICIENT HTS FILTER DESIGN METHOD . . .

FIG. 4: Performance comparision between the first optimized coupling matrix and the final one.

TABLE II: Final Coupling Matrix After Parameter Extraction

<table>
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<th>R1=Rn=1.16</th>
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<tr>
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</table>

filter parameter adjusting resulted from ignoring the nonadjacent couplings. This new method has been used to design a 12-pole HTS microstrip filter with a 10 MHz bandwidth centered at 1940 MHz and the results are satisfying.

Acknowledgments

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References

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