Electromagnetic Optimization Using Taguchi’s Method:
A Case Study of Band Pass Filter Design

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1. Introduction
This study presents a global electromagnetic optimization technique using Taguchi’s method [1] and its applications in microstrip filter designs. Microwave filters are widely used in telecommunication equipments. Although filters built with lumped elements can realize the desired frequency response, it is difficult to control the lumped elements’ properties in the microwave band. Therefore passive planar printed types of filters are usually used for microwave applications. These planar filters need to be accurately modeled due to the high frequency effects such as dispersion and dielectric/conduct loss. Therefore, a global optimization technique and a full wave EM simulator are necessary tools for an optimum design of such filters. In this study, a full wave commercial simulator IE3D [2] along with our external Taguchi’s based optimizer [3] are used to optimize a microstrip band pass filter (BPF) presented in [4] and shown in Fig. 1. The desired frequency responses of the band pass filters are successfully achieved with only few numbers of iterations.

2. Integration of Taguchi’s Method with IE3D
Taguchi’s method has been applied in many fields. In electromagnetic area, our previous works [3] show that Taguchi’s method successfully reaches the desired patterns in linear antenna array synthesis in less number of iterations. Using the concept of the orthogonal array (OA), the optimization is performed using an iterative procedure to reach the optimum solution. The optimization procedure starts with the problem initialization, which includes an appropriate design of the fitness function, and the selection of a proper OA. Each iteration consists of designing input parameters, conducting experiments, identifying optimal level values through a response table, and performing confirmation experiment. If the results of the current iteration do not meet the termination criteria, the process is repeated in the next iteration. More detailed information of Taguchi’s method for electromagnetic applications can be found in [3]. The same optimization procedure is applied in this study for the filter optimization. The initial dimensions of the filter reported in [4] are used as a starting point in the optimization process. IE3D is utilized to obtain the S parameters of the filter. Taguchi’s method is applied as the external optimizer to drive the IE3D engine as shown in Fig. 2. In IE3D, an EM problem is analyzed according to the *.sim and *.geo input files, which contain the simulation information and the dimensions of...
optimized parameters, and the simulation results are stored in *.sp output file. Our optimization code is developed such that it can change contents of the *.sim file in order to control IE3D simulation, and can read the output S parameter from *.sp file, which is used to calculate the fitness value. During each iteration the dimensions of the filter are determined by Taguchi’s method. If results do not meet the termination criteria, the dimensions of the BPF are modified for the next iteration process.

3. Design of a Band Pass Filter

The dimensions of a six pole edge-coupled microstrip band pass filter (BPF) is shown in Fig. 1, where the width \( W \) of coupled lines \( L_1 \) to \( L_3 \) and resonant lines \( L_4 \) and \( L_5 \) is fixed to 0.26 mm. The width \( W_{50} \) and length \( L_{50} \) of the 50 \( \Omega \) microstrip lines, which connect the input and output ports, are also fixed to 0.567 mm and 10.0 mm, respectively. The BPF is designed on a substrate with a thickness of 0.64 mm, a dielectric constant of 10.2, and a dielectric loss tangent of 0.0023 according to the manufacture specifications. The design objective illustrated by the dotted line in Fig. 3 is the same as reported in [4], i.e.

\[
|S_{11}| < -15 \text{ dB, for } 4\text{GHz} < f < 5\text{GHz}, \quad (1)
\]

\[
|S_{21}| < -35 \text{ dB, for } f < 3.5\text{GHz} \text{ and } f > 5.5\text{GHz}. \quad (2)
\]

The initial length of the coupled lines \( L_1 \sim L_3 \) and resonant lines \( L_4 + L_5 \) is set to 6.2 mm, which is around quarter wavelength at 4.5 GHz. The initial spacing between coupled lines \( S_1 \sim S_3 \) can be obtained by the parallel-coupled line formulas [4]. The initial dimensions of the BPF are shown in Table I.

Since there are eight parameters \( L_1 \sim L_5, S_1 \sim S_3 \) that need to be optimized to achieve the design specifications of the BPF, an orthogonal array OA(27, 8, 3, 2) is adopted in the BPF optimization [5]. The selected optimization ranges of the eight parameters are also shown in Table I. The following fitness function is proposed and used in the optimization process:

\[
\text{Fitness} = w_1 \left[ \int_{4.0}^{5.0} (S_{11} - S_{11,d}) \, db \, df \right], \quad \text{if} \quad |S_{11}| > |S_{11,d}| \\
+ w_2 \left[ \int_{3.0}^{5.5} (S_{21} - S_{21,d}) \, db \, df + \int_{5.5}^{6.0} (S_{21} - S_{21,d}) \, db \, df \right], \quad \text{if} \quad |S_{21}| > |S_{21,d}|,
\]

where, \( w_1 \) and \( w_2 \) are weighting coefficients that are identical in this optimization. The unit of frequency is GHz, and \( df \) is the frequency interval which is set to 0.03 GHz. The fitness value can be seen as the error between design specifications and obtained S parameters. Therefore, a smaller fitness value reflects a better filter design. The converged rate is set to 0.05, and the reduce rate is set to 0.8.

4. Numerical Results

After 9 iterations, the fitness value approaches zero, and the optimization process ends due to the fact that the design goals are achieved. The convergence curve of
the fitness value is presented in Fig. 4, which demonstrates the efficiency of the proposed optimization method. The optimized dimensions are listed in Table I. The $|S_{11}|$ and $|S_{21}|$ of the optimized BPF are shown in Fig. 3 and the desired frequency responses of the S parameters are achieved.

5. Conclusion

A global electromagnetic optimization approach using Taguchi’s method is linked with the IE3D simulator to design a microstrip band pass filter (BPF). Obtained results show that the desired frequency responses of the microstrip filters are successfully achieved, which demonstrates the validity and efficiency of the presented technique.

References


Fig. 1. Geometry of the six pole edge-couple microstrip band pass filter.
Table I. Optimization Parameters of the Band Pass Filter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
<th>$L_5$</th>
<th>$S_1$</th>
<th>$S_2$</th>
<th>$S_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial</strong></td>
<td>6.2</td>
<td>6.2</td>
<td>6.2</td>
<td>2.1</td>
<td>4.1</td>
<td>0.254</td>
<td>0.413</td>
<td>0.432</td>
</tr>
<tr>
<td><strong>Optimization</strong></td>
<td>5.7~6.7</td>
<td>5.7~6.7</td>
<td>5.2~7.2</td>
<td>1.1~3.1</td>
<td>2.6~5.6</td>
<td>0.204~0.304</td>
<td>0.313~0.513</td>
<td>0.332~0.532</td>
</tr>
<tr>
<td><strong>Optimized</strong></td>
<td>6.364</td>
<td>6.452</td>
<td>6.200</td>
<td>1.609</td>
<td>3.577</td>
<td>0.263</td>
<td>0.376</td>
<td>0.378</td>
</tr>
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</table>

Fig. 2. Flow chart of the filter optimization procedure.

Fig. 3. Optimized S parameters of the band pass filter.

Fig. 4. Convergence curve of the fitness value of the BPF design.