On the Use of Optimization Techniques in the Design of FSS

PAVEL TOMASEK
Tomas Bata University in Zlin
Department of Electronics and Measurements
Nad Stranemi 4511, 760 05 Zlin
THE CZECH REPUBLIC
tomasek@fai.utb.cz

Abstract: Work presented in this paper aims at description of the optimization process of frequency selective surfaces with an example of a Wi-Fi band-stop filter. In this work the method of moments is used to analyse a planar periodic structure. The approach allows to automate the whole process of the filter design and frees the users from the detailed knowledge of the filter design theory. For the practical part of the paper, the algorithm of Levenberg-Marquardt is chosen as a local optimisation method. Whole process of automation is implemented in Matlab. An optimisation of a band-stop filter for Wi-Fi signals serves as a practical example. S-parameters of the final filters are presented in the paper. This work also compares two possible geometries made of simple elements, rectangles. It is a simple cross and a Jerusalem-cross. There is also an interesting note about the quality of these filters using different number of layers.

Key–Words: frequency selective surface, band-stop filter, local optimisation, planar periodic structures, method of moments, Wi-Fi signal, 802.11

1 Introduction

Frequency Selective Surfaces (FSSs) are important spatial filters which can efficiently filter desired band of frequencies. Therefore these can play a significant role in electromagnetic related problems.

To briefly sketch the history, the beginning of FSS relates to Ben A. Munk which was the guru of this approach [1]. In the last decade, the idea of FSS has spread out into many applications. Example of a band-pass FSS is in [2,3] where the goal was to transmit GSM signals through energy efficient windows. The first FSS absorber was presented by Salisbury and Jaumann [4,5]. Ghaffer et. al., [6] and Umair et. al., [7] proposed a novel and compact design to obtain stable frequency response by absorbing 5 GHz signals.

In this paper there are several aims. The first one is to describe the possibility of filtering of 2.4 GHz Wi-Fi signal (approach presented in [8]). The second aim is to examine two different FSS geometries. And the last goal is to figure the influence of the number of layers of the FSS filters.

2 Statement of the Problem

Assume that there is a need to prevent transmission of Wi-Fi signal so that it cannot spread out of a given room.

A Wi-Fi device communicating under standard 802.11b or 802.11g uses a specific channel which has frequency between 2.412 and 2.484 GHz [8]. Therefore the goal is to design a band-stop filter (ideally a wallpaper) which does not transmit mentioned band of frequencies.

3 Design of an Appropriate FSS

In this paper two geometries are examined. It is a simple cross and a Jerusalem-cross. Initially, these schemes are double-layer to provide a more narrow band-stop filter. The schema is presented in Fig. 1. Theoretically, the second geometry may have better reflection in comparison with a simple cross. Both models consist of simple rectangular elements. In Fig. 1, a represents the width and height of a cell (a cell is just one element of the whole FSS), l is the total width and height of the cross, w is the width of an arm and lej represents the length of the bar connected to the end of an arm of the Jerusalem-cross.

The electrical conductivity of the metallization is 56 MS/m and the thickness is 17 µm. The relative permittivity of the dielectric layer (between conductive layers) is 1.0 and the thickness is 1.57 mm.
4 Optimization

A frequency range, an initial geometry with design variables (e.g. width and height of the arms of the cross) and optimization goals must be set before performing the optimization of an FSS filter.

The transmission coefficient depends on frequency and other parameters forming the parameter vector of the filter which specifies the geometry (defined by design variables). An optimization method searches for the set of parameters which satisfies the given objectives, at least approximately, being thus in a certain sense optimal.

An optimization goal is defined by a frequency range where the transmission coefficient must be lower or greater than a threshold value set by the user.

In our experiment three optimization goals were modelled (also presented in Fig. 2 and Fig. 3 together with results of the initial configuration):

1. To pass frequencies from 1.0 to 2.2032 GHz (threshold: -2.5 dB)

2. To stop frequencies from 2.3256 to 2.5704 GHz (this range relates to the Q factor equal to 10, threshold: -20.0 dB)

3. To pass frequencies from 2.6928 to 5.0 GHz (threshold: -2.5 dB)

The initial values of design parameters with lower and upper bounds are mentioned in Table 1 where \( l = ka \), \( l_j = k_{1j}a_j \) and \( l_{ej} = k_{2j}l_j \).

In our work, optimization was performed numerically using an implementation of local optimizer Levenberg-Marquardt (a possible alternative is fmincon [14] or fminsearchbnd [13] which can be directly used in Matlab or it can also be an evolutionary algorithm).

The settings of the optimization process:

- Optimization technique: Levenberg-Marquardt
- FunTol = \( 10^{-3} \), this represents the threshold tolerance
- MaxIter = 100, this constant is the maximal number of iterations
- NormStep = 0.06, this is the constraint on maximal norm of a step
- Constraints on design variables \( a, w, k, a_j, w_j, k_{1j} \) and \( k_{2j} \) respect the lower and upper bounds mentioned in table 1

The initial configuration of the simple cross (on the left) and the Jerusalem-cross (on the right)

Figure 1: Schema of a cell containing the simple cross (on the left) and the Jerusalem-cross (on the right)

Figure 2: Transmission coefficients of the initial simple cross FSS Wi-Fi filter (to be optimized)

Figure 3: Transmission coefficients of the initial Jerusalem-cross FSS Wi-Fi filter (to be optimized)
### Table 1: Description of design parameters related to the simple cross and Jerusalem-cross FSS filters (see Fig. 1; index $j$ relates to the Jerusalem-cross geometry)

<table>
<thead>
<tr>
<th>Param. Description</th>
<th>Initial Value</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>0.06</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>$w$</td>
<td>0.003</td>
<td>0.001</td>
<td>0.006</td>
</tr>
<tr>
<td>$k$</td>
<td>0.8</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>$a_j$</td>
<td>0.05</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>$w_j$</td>
<td>0.002</td>
<td>0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>$k_{1j}$</td>
<td>0.85</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>$k_{2j}$</td>
<td>0.35</td>
<td>0.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*Cost function used the method of moments [1,9,10,11] to analyse and estimate the FSS transmission coefficients*.

All computations by optimization were based on perpendicular angle of incidence only.

In this study, we used FSSMR software [12] which was developed at Tomas Bata University in Zlin and which analyses the planar periodic structures and tries to optimize them with respect to the optimization goals.

### 5 Results

The optimization procedure results in a filter which suppresses well the central channels of 2.4 GHz Wi-Fi. The first and the last channels are partially transmitted, the attenuation is around -15 dB for the Jerusalem cross filter what can be considered as not a perfect but still good filter. Perfect suppression of signals on these boundary frequencies can be processed in a further research. The final transmission coefficients are presented in Fig. 4 and Fig. 5. The process of optimization in Matlab took about 4 hours using an average computer (mainly depends on the number of tested frequency points and the density of mesh cells in computation).

The Jerusalem-cross FSS filter performs a little bit better in comparison with the simple cross filter. The optimized simple cross filter is a too narrow band-stop filter which does not reflect the lower channels of Wi-Fi signal well. There is also some kind of a low subsidiary attenuation between 4 and 6 GHz.

Also another result may be interesting. Considering the transmission coefficients of Jerusalem-cross FSS filter with simply increased number of metallic layers from two to three the results are not better (see Fig 6). To have a better shaped band-stop filter the whole process of optimization must be run again. Otherwise simple addition of some metallic layers seems to be worthless.

The optimized values of design parameters are presented in the list below:

- **Simple cross FSS filter**
  - $a = 0.072745 m$
  - $w = 0.005 m$
  - $k = 0.801129$

- **Jerusalem-cross FSS filter**
  - $a_j = 0.042554 m$
  - $w_j = 0.002991 m$
  - $k_{1j} = 0.900435$
  - $k_{2j} = 0.403906$

Furthermore, from the design parameters we can compute the lengths $l$, $l_j$ and $l_{ej}$ in the following way:

- **Simple cross FSS filter**
  - $l = ka; l = 0.038317111 m$ (the total width and height of the simple cross geometry)

- **Jerusalem-cross FSS filter**
  - $l_j = k_{1j}a_j; l_j = 0.038317111 m$ (the total width and height of the Jerusalem-cross)
  - $l_{ej} = k_{2j}l_j; l_{ej} = 0.015476511 m$ (the total length of an outer arm)

### 6 Conclusion

A method of optimization of an FSS filter was described and tested on a problem of filtering of 2.4 GHz Wi-Fi signal. Two possible relatively simple geometries (the simple cross and the Jerusalem-cross) of FSS filters were compared. The initial proposed solutions of both FSS filters were optimized and corresponding transmission coefficients of optimized filter were shown.
Moreover, the influence of number of metallic layers was discussed and estimated transmission coefficients of the Jerusalem-cross FSS filter consisting of three layers were also presented.

The results presented in this paper are quite promising. Presented method seems to be suitable in design of many band-stop or band-pass filters and could help to find solutions of other complicated electromagnetic problems. Anyway, further work in this direction should prove this theoretical study by results of real measurements.

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References:


[8] P. Tomasek, Automated Design of Frequency Selective Surfaces with the Application to Wi-Fi


