2nd International Conference on Engineering Optimization
September 6 - 9, 2010, Lisbon, Portugal

A New Equivalent Circuit Based FSS Design Method by Using Genetic Algorithm

E. Fuad Kent[1], Bora Döken[2], Mesut Kartal[3]

[1] Department of Mechanical Engineering, ITU, Istanbul, Turkey, kente@itu.edu.tr
[2] Vocational School, ITU, Istanbul, Turkey, dokenb@itu.edu.tr
[3] Department of Electonics&Communication, ITU, Istanbul, Turkey, kartalme@itu.edu.tr

Abstract
This project is proposed to optimize Frequency Selective Surface parameters for the desired transmission response or a reflection response effectively. Square Loop FSS is chosen as a sample FSS to examine. For simulation and optimization purposes High frequency simulation software (HFSS) and its Genetic Algorithm module are used. The fitness function of GA is defined with the help of equivalent circuit model. Satisfying optimization is achieved in a short simulation time than the fitness function without having the equivalent circuit model expressions.
Keywords: Equivalent Circuit Model, Frequency Selective Surfaces, FSS, Genetic Algorithm, Periodic Structures, Optimization.

1. Introduction

Frequency selective surfaces (FSS) are periodic structures which have low pass, high pass, band pass and band stop filter characteristics when interacting with electromagnetic waves [1]. They have been widely used in broadband communications, radar systems, and antenna technology [1 pp. 14-20]. For analyzing the electromagnetic behavior of FSS, finite element method, finite difference method or dedicated MoM methods are commonly employed [2, 3]. Despite their accuracy in analysis, these techniques require time consuming simulations and do not allow the designer to have a good insight into the physics behind the structures. Equivalent circuit representations are useful for quickly predicting the performance of FSS and allow performing a very simple model able to describe every kind of shape after a full-wave computer simulation [4, 5]. These equivalent circuit models also provide useful physical insight into the performance of the FSS. The equivalent circuit model can also be employed in the design of the multilayered FSS.

During the last years, several approaches that combine heuristic optimization methods with numerical analysis techniques have been proposed in the literature to carry out the optimization of Frequency Selective Surfaces (FSS) [6].

Genetic algorithm (GA) is essentially a search algorithm based on the mechanics of nature and natural genetics. It combines solution evaluation with randomized and structural exchanges of information among solutions to obtain optimization. GA is considered to be a robust method because no restrictions on the solution space are made during the process and have a wide range of applications in the design of electromagnetic systems [7]. The power of this algorithm comes from its ability to exploit historical information structures from previous solution guesses in an attempt to increase the performance of future solution structures. The Genetic Algorithms are a versatile tool which can be applied as a global optimization method to the electromagnetic engineering problems, since it is both easy to implement and performs well on non-differentiable functions and discrete search spaces. Generic design methodology is able to give a reliable method to obtain the geometric and physical parameters from the equivalent lumped circuit design and HFSS simulation results.

2. Equivalent circuit model

In contrast to the computationally intensive numerical approaches, the Equivalent Circuit Model offers a simple alternative method in FSS analyses which are useful for quickly predicting the performance of FSS and allow performing a very simple model able to describe every kind of shape after a full-wave computer simulation. Based on a transmission line analogy the interaction of incident waves with an FSS is represented as a wave travelling down a transmission line, with shunt lumped circuit impedances. The modeling technique is based on equations given by Marcuvitz [8], who developed the initial expression for the periodic gratings. These equations can only be applied at oblique angles of incidence to an inductive component illuminated by a TE-incident wave or a capacitive component illuminated by a TM-incident wave. Modified equations are derived by Lee [5] for the other two cases that are inductive TM-incidence and capacitive TE-incidence.

For an infinite array of thin, perfectly conducting narrow strips the shunt impedance is either inductive or capacitive, as shown in Figures 1-(a) and 1-(b), depending on whether the incident wave is polarized parallel or perpendicular to the strips [9].

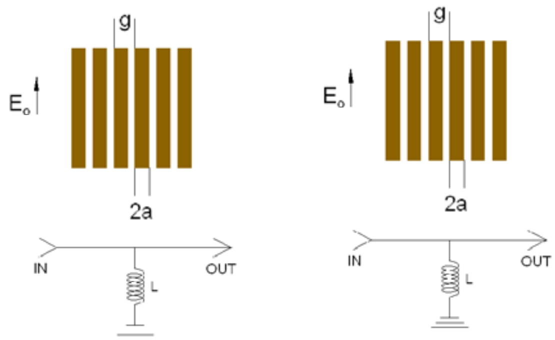


Figure 1: (a) Inductive strip grating, (b) Capacitive strip grating

The normalized shunt inductive reactance expression of the inductive strip grating was given by Marcuvitz as [8]:

$$X_{TE} = {}^{w.L}/_{Z_0} = \frac{p.\cos(\theta)}{\lambda} . (\ln(cosec(\pi w/2p)) + G(p, w, \lambda, \theta)) \tag{1}$$

The normalized shunt susceptance expression of the capacitive strip grating was given by Lee as [5]:

$$B_{TE} = {}^{w.C}/_{Y_0} = \frac{4.p.sec(\theta)}{\lambda} . (\ln(cosec(\pi g/2p)) + G(p, w, \lambda, \theta)) \tag{2}$$

where G is the correction term given as:

$$G(p,w,\lambda,\theta) = \frac{0.5(1-\beta^2)^2\left[\left(1-\frac{\beta^2}{4}\right)(A_{1+}+A_{1-})+4\beta^2 A_{1+}A_{1-}\right]}{\left(1-\frac{\beta^2}{4}\right)+\beta^2\left(1+\frac{\beta^2}{2}-\frac{\beta^4}{8}\right)(A_{1+}+A_{1-})+2\beta^6 A_{1+}A_{1-}}$$

$$A_{1\pm} = \frac{1}{\sqrt{\left(\frac{p\sin\theta}{\lambda}\pm 1\right)^2 - \frac{p^2}{\lambda^2}}} - 1$$

$$\beta = \sin(0.5\pi w/p) \tag{3}$$

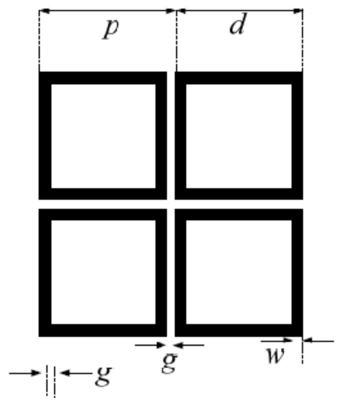
These equations are valid at frequencies below the onset of the first grating lobe. The criterion for grating lobe suppression needs to be considered. The criterion for grating lobe suppression is $p.(1 + \sin\theta) < \lambda$ where p is the element repeating period, θ is the incident angle and λ is the wavelength [1, p24].

3. Equivalent circuit model of Square Loop FSS

The frequency characteristic of Square Loop FSS's has a single reflection band and a lower-frequency transmission band which can be approximately represented with resonant circuits consisting of inductances and capacitances via the Equivalent Circuit Model [4]. As is shown in Figure 2, square loop FSS can be represented by a single series LC circuit shunted across a transmission line of impedance Z_o. Z_o is the characteristic impedance of free space.

For constructing the Equivalent Circuit Model the square loop FSS can be separated into vertical and horizontal conducting strips virtually depicted in Figure 3. For modeling the vertical strips, the equivalent inductive impedance, two adjacent strips are approximated as one strip with width equal to 2w. Values for L and C can be determined as follows: The normalized shunt inductive reactance expression of the square loop FSS

$$X_{TE} = {}^{w.L}/_{Z_0} = \frac{p.\cos(\theta)}{\lambda} . (\ln(cosec(\pi 2w/2p)) + G(p, w, \lambda, \theta)) \tag{4}$$



(a) (b)

Figure 2: (a) Square loop FSS, (b) Equivalent circuit model

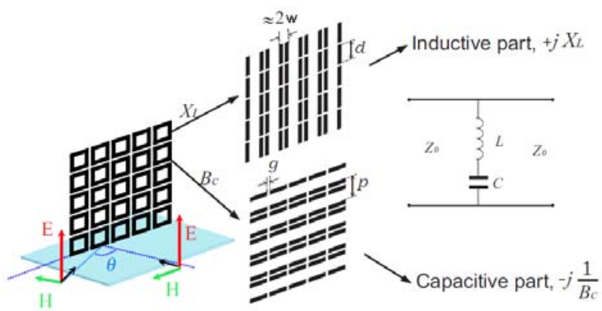


Figure 3: Square loop FSS and its equivalent circuit

the normalized shunt susceptance expression of the capacitive strip grating

$$B_{TE} = {w.C}/{Y_0} = \frac{4.p.sec\,(\theta)}{\lambda} \,.\, (\ln\,(cosec(\pi g/2p)) + G(p, w, \lambda, \theta)) \tag{5}$$

$$Z = jwL + \frac{1}{jwC} = j(wL - \frac{1}{wC}) \tag{6}$$

and the reflection coefficient

$$s_{11} = \frac{-1}{2.\frac{Z}{Z_0}+1} \tag{7}$$

4. Solution procedure

The solution procedure includes two processes: one is to simulate the FSS structure and the other is to optimize the structure's parameters according to the data returned from simulation. The two processes are being run alternately until a satisfying optimization is obtained.

High Frequency Simulation Software (HFSS) is a software package for calculating electromagnetic behavior of a structure and includes a powerful Genetic Algorithm module. HFSS simulates each structure and returns the results of simulation to GA module, and GA module optimizes the structure's parameters continually according to the data returned from HFSS.

The design problem is described as a multi-dimensional continuous optimization problem, where the number of dimensions is determined by the number of design parameters to be adjusted as illustrated in Fig.2.
The Equivalent Circuit Method gives reasonable results compared to numerical methods and do not need time consuming simulations. The transmission coefficients calculated with Equivalent Circuit Method can lead the HFSS GA optimizer module to obtain a satisfying solution in a short time.
Two optimizations and two fitness functions were defined and run simultaneously by a HFSS macro language and in the genetic algorithm module, the population size and the number of generations were equal to 10 and 80, respectively, in both of the optimizations.
The fitness functions which are defined from Equivalent Circuit Model are given by

$FF1 = |Z/Z_0|$ frequency = 2.4 GHz

$FF2 = 20 \log_{10}|s_{11}\_HFSS\_TE|$ frequency = 2.4GHz

where $|Z/Z_0|$ (TE polarization) and s_{11}_HFSS_TE (TE polarization) are normalized impedances, calculated by the Equivalent Circuit Model of FSS reflection coefficient and by HFSS software, respectively.

5. Conclusion

In this project a robust GA optimization approach has been introduced for the FSS design. Satisfying optimization is achieved in a short simulation time than the fitness function without having the Equivalent Circuit Model expressions. FSS parameters have been optimized, and the results of the current optimization show that this approach is effective and offer beneficial reference for the FSS design.

References

[1] Munk, B.A. *Frequency Selective Surfaces -Theory and Design.* New York: John Wiley and Sons. Inc., 2000.

[2] Mittra, R., Chan, C. H. and Cwik, T., Techniques for analyzing frequency selective surfaces a review. *Proc. IEEE*, 76 (12), 1593-1615, 1988.

[3] Bardi, I., Remski, R., Perry, D. and Cendes, Z. Plane wave scattering from frequency-selective surfaces by the finite-element method. *IEEE Trans. Magnetics,* 38 (2), 641-644, 2002.

[4] Langley, R. J. and Parker, E. A. Equivalent circuit model for arrays of square loops. *Electronics Letters,* 18 (7), 294–296, 1982.

[5] Lee, C. K. and Langley, R. J. Equivalent-circuit models for frequency selective surfaces at oblique angles of incidence. *IEE Proceedings H - Microwaves Optics and Antennas,* 132, 395–399, 1985.

[6] Li, Z., Papalambros, P.Y. and Volakis, J.L., Frequency selective surface design by integrating optimization algorithms with fast full wave numerical methods. *IEE Proc. Microw. Antennas Propag.,* 149 (3), 175–180, 2002.

[7] Rahmat-Samii, Y., *Electromagnetic Optimization by Genetic Algorithms.* Wiley Series in Microwave and Optical Engineering, 1999.

[8] Marcuwitz, N. *Waveguide Handbook*. 1st edition, New York: McGraw-Hill, 1951.

[9] Hooberman, B, Everything You Ever Wanted to Know About Frequency-Selective Surface Filters but Were Afraid to Ask, http://calvin.phys.columbia.edu/group_web/filter_development/download/filter.pdf, 2005.