

Band Stop optimization of Frequency Selective Surfaces Using the Transmission Line Modeling Method

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Abstract— Optimization is applied to Transmission Line Method (TLM) modeling of a Double Square Loop Frequency Selective Surface for electromagnetic shielding in the 900MHz and 1800MHz bands. The objective function to be optimized is based on the transmission coefficients at frequencies in the stop-bands. In this work the use of GG_TLM inside an optimization process is demonstrated. It is the purpose of optimization to find the set of parameter values which best minimizes the objective function. At least 20dB return loss is required. Combining the TLM solution with an optimization technique reduces the human input required in searching for the optimal set of parameters for the dual band frequency selective surface (FSS). A good agreement is found between simulation and experimental work.

Keywords— Frequency Selective Surface, shielding, Transmission line modeling, optimize

I. INTRODUCTION

The Transmission Line Modelling (TLM) technique is a time domain numerical method that is often used to solve the differential form of Maxwell's equations. Electromagnetic modeling techniques are employed for analyses and designs using electrical component analogy [1]. In addition to this we may use GGI_TLM to optimize designs so as to achieve or optimize a specified performance criterion. In this work the use of GG_TLM inside an optimization process is demonstrated. A specified number of parameters together with a figure of merit (objective function) for the design which is intended to minimize is chosen. It is the purpose of optimization to find the set of parameter values which best minimizes the objective function.

Frequency selective surfaces (FSS) have found widespread application from antennas to filters at microwave frequencies [2-5]. FSS are either patches or apertures arranged in a periodic fashion in a conducting surface for frequency filtering. The frequency behavior of the FSS is determined completely by the dimensions of the surface in one period or unit cell. The Transmission Line Method (TLM) [6] is used in the modeling analysis and

design of the Double Square Loop. The TLM electromagnetic solver enables losses in the dielectric substrates and the finite conductivity of the printed patches of the FSS to be accounted for. Finally, optimization is applied in the TLM using the multidimensional generalization of the bisection method for the design of Double Square Loop Frequency Selective Surface. The objective function to be optimized (minimized in this case) is based on the transmission coefficients in two stop frequency bands of (900 and 1800MHz). A return loss of at least 20dB is sought.

The paper is organized as follows: section I is the introduction, while section II presents the TLM modelling technique. Section III is the optimization scheme applied in the TLM and section IV shows the experimental setup and measurements with section V been the conclusion.

II. THE TLM METHOD

The TLM modeling technique is an explicit numerical method that is founded on the equivalence between voltages and currents on a transmission line network and electric and magnetic fields in 3D space. The 3D time domain Electromagnetic field solver creates and solves problems on a structured cubic mesh [6].

The boundary description of symmetrical condensed node is easy to work with since all the six filed components can be defined at a single point in space [7]. The waves are characterized by voltage and current and their associated Electric and Magnetic fields. The Electric and Magnetic fields are orthogonal to each other and to the direction of propagation. For example a z directed transmission line polarized in the x direction is associated with the fields E_x and H_y .

The TLM simulation involves filling the computational space with symmetrical condensed node meshes [8-9]. A schematically arrangement of the transmission line in the 3D space is shown in Fig. 1.

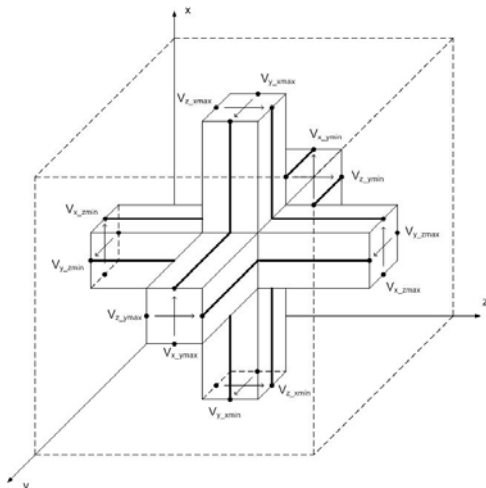


Figure 1. Symmetrical condensed node (SCN).

The problem space is discretised into cubic cells where the cell size is significantly smaller than the shortest wavelength of interest in the analysis. Each cell face has two orthogonal TEM transmission lines (link lines) with associated Electric and Magnetic field components tangential to the cell face. The transmission lines incident from each face intersect at the cell centre forming a junction.

The link transmission lines have distributed capacitance and inductance representing the permittivity and permeability of a vacuum. For materials other than free space, the permittivity or permeability may be augmented by the addition of suitably defined stub transmission lines.

A voltage impulse incident on the cell centre junction from one of the link lines scatters back into the link lines, this process is described by a scattering matrix. The scattering matrix is defined such that the transmission line network models Maxwell's equations. The scattered voltage pulses reach the cell faces half a time-step later and connect to adjacent cells. The TLM algorithm can be considered as a discrete version of Huygen's principle [6].

The propagation delay on every transmission line in the network (the simulation time-step) is chosen to be the same. This property of the network provides discretisation in time and ensures time synchronization of the scatter and connect processes in the network.

The structure of the cell is such that all 3 components of both electric and magnetic field are evaluated at the cell centre during the scattering process and tangential Electric and Magnetic field components are calculated half a time-step later at the cell faces during the connect process.

Boundary conditions are applied on the outer surfaces of the problem space as required for the scenario under study. Boundary conditions may represent perfectly conducting surfaces or implement an absorbing boundary condition for example.

The open source TLM code GGI_TLM [10] is applied to the modeling of the dual band stop FSS. The GGI_TLM code allows the imposition of a 'wrapping boundary condition' [11], allowing the simulation of an infinite periodic array of elements with a model of a single cell of the FSS structure. The GGI_TLM code is a time domain method, frequency domain results are obtained by the Fourier Transform thus GGI_TLM predicts the response of the FSS over the entire frequency range of interest.

The square loops of the FSS are modeled as perfect electrical conductors. Wrapping boundary conditions are placed on the $\pm x$ and $\pm y$ boundaries. An absorbing boundary condition is imposed on the $\pm z$ boundaries to absorb the scattered field. In the TLM model a Gaussian pulse plane wave whose width is chosen to cover the frequency band of interest is launched towards the FSS sheet. Time domain fields are recorded on both the reflection and transmission side of the FSS until all the significant electromagnetic interactions have taken place. This is followed by a post processing procedure which involves Fourier transformation to obtain the reflection and transmission coefficient characteristic of the design at the desired frequencies.

In this paper a double square loop FSS designed to block the GSM900 and GSM1800 frequencies is studied. The Fig.2 shows the relative spacing of elements of the double square loop FSS where Dim1 – Dim4 are the optimization parameter values.

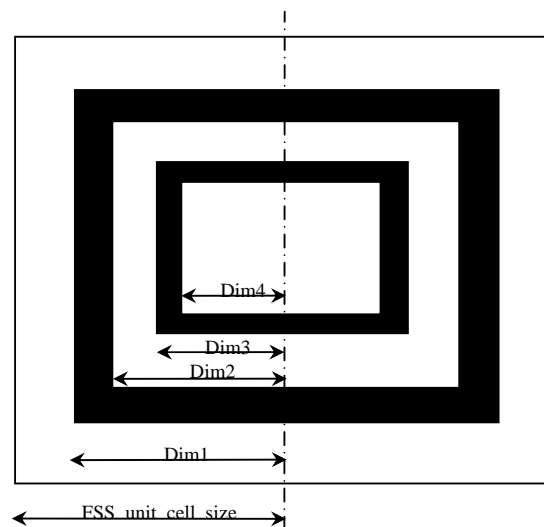


Fig.2 Double square loop optimization parameters (Dim1-4) of a unit cell

The initial value of these dimension were 50mm and evaluation steps of 2.5 mm.

III. Optimization of the FSS

The purpose of optimization is to find the set of the dimensions of the FSS geometric structure which best minimizes the objective function to achieve the specified performance criterion (the stop band transmission). The multi-dimensional optimization of the bisection method is explored by evaluating the objective function at various points surrounding a central point. The initial central point and separation of the surrounding points are specified, 880MHz and 920MHz then 1780MHz and 1820MHz at 20dB. At each stage of the optimization process a new point or set of points is derived based on the values of the objective function at the points already evaluated. The objective function is carefully chosen to achieve the desired performance. While the desirable features are promoted, the undesirable features of response are penalized [11].

The optimization is based on a multi-dimensional generalization of the bisection method. The multi-dimensional optimization space is explored by evaluating the objective function at various points surrounding a central point. The initial central point and separation of the surrounding points must be specified by the user. At each stage of the optimization process a new point or set of points is derived based on the values of the objective function at the points already evaluated. The Figures 3 and 4 illustrate the basic operation of the bisection method in a 2D optimization space. In handling more function evaluations, the bisection method may be more efficient, and more robust in some circumstances as compared to the simplex method of optimization [10].

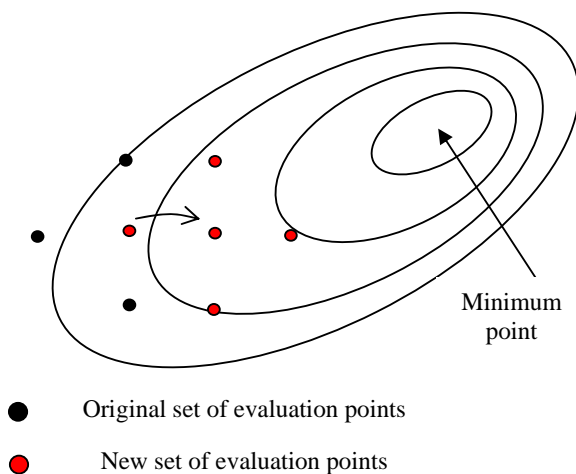


Fig. 3 2D optimization space

The starting point for the optimization is taken at a point from which the optimum point may be reached

by a downhill search method. Optimization of geometry: geometry definition is continuous however the resulting mesh is discrete therefore the objective function will exhibit a step-like form as a function of geometric parameters. Meshed parameters cannot be optimized beyond the mesh resolution [11].

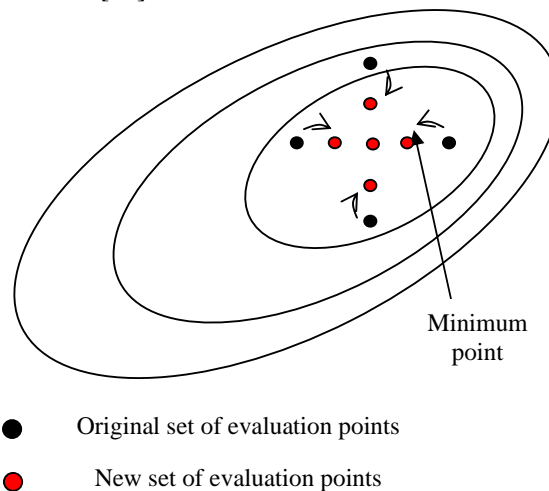


Fig.4 convergence state

In this optimization of the dual band FSS it is required to minimize the transmission of the surface in the bands 880MHz to 920MHz and 1780MHz and 1820MHz. Some experience of working with shell scripts and Fortran programming is employed in order to achieve the optimization of parameterized models. A subroutine for the optimization code is included at the end of the paper.

Some considerations in optimisation of GGI_TLM models [10]:

The objective function should be chosen carefully so that the desired performance is achieved. It may be that undesirable features of response should be penalized as well as desirable features being promoted.

The starting point for the optimization should be at a point from which the optimum point may be reached by a downhill search method.

That the process will find local minima of the objective function is no guarantee that this will be the global minimum. It may be useful to restart the optimization from different points so as to establish the robustness of the minimization.

Optimization of geometry: geometry definition is continuous however the resulting mesh is discrete therefore the objective function will exhibit a step-like form as a function of geometric parameters. Meshed parameters cannot be optimized beyond the mesh resolution.

The most efficient optimization sequence may be a multi-stage process in which a coarse mesh is optimized first then moving on to a refined mesh once the optimum parameters on the coarse mesh is found.

Care must be taken that every choice of trial parameters will lead to a valid geometry and cause no errors. This may be achieved by appropriate parameterization of the model.

The effectiveness of the parameterization can affect the efficiency of the optimization. A smooth objective function with a well defined minimum is desirable.

The most efficient optimization sequence may be a multi-stage process in which a coarse mesh is optimized first then moving on to a refined mesh once the optimum parameters on the coarse mesh is found.

IV. MEASUREMENTS

The Double Square loop FSS was made by placing copper tape of paper substrate. The sample FSS sheet consists of a 5 by 5 matrix.

To conduct measurements, the FSS sheet is situated between the transmitting and receiving antennas in an anechoic chamber. The antennas are then connected to Vector Network Analyzer (VNA) E8362B model as shown in Fig.5. Calibration was done without the FSS sheet in place, and subsequently measurements were taken with the FSS sheet. The sides are completely shielded with the conical absorbers.

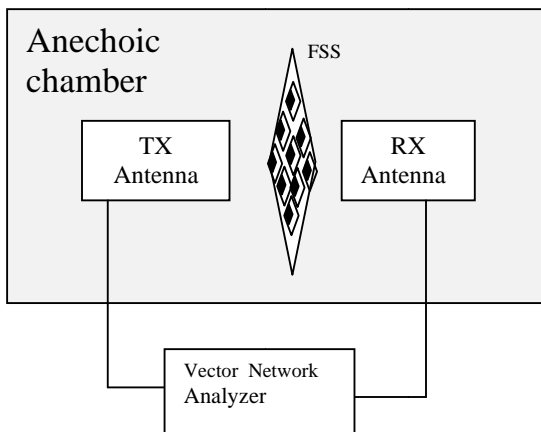


Fig.5. S21 measurement setup in Anechoic Chamber.

A trial simulation at the onset of optimization and the plot is shown in Fig. 6. The improvement can be seen when compared with that obtained at the end of the optimization process.

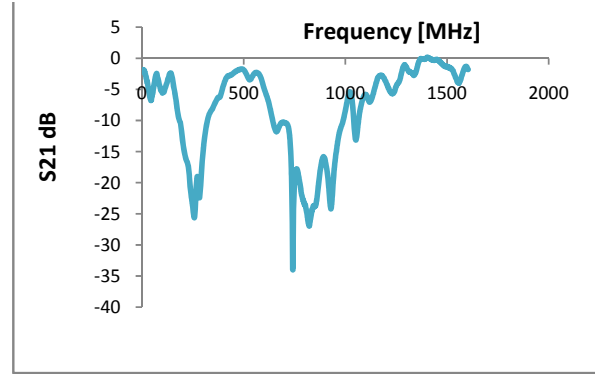


Fig. 6 TLM simulation with initial optimization parameters

Fig. 7 shows a plot of the magnitude of the transmission coefficient in dB versus frequency for using GG_TLM at the end of optimization and that obtained with measurements.

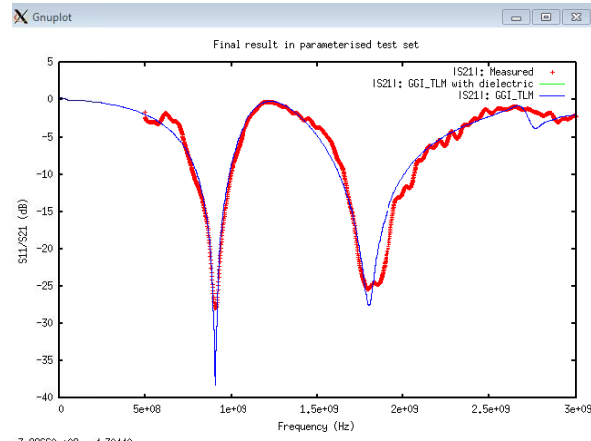


Fig.7. S21 for optimized FSS in GG1_TLM and Measurements

Overall there is reasonable agreement in the results between the modeling with GG_TLM method and measurements. The first transmission band centered on f_1 (904.6MHz) for optimized GG_TLM and measurements. We observe from simulations with the GG_TLM method that this resonance is less dependent on the inner square side length than on its width. There is however some difference seen in the frequency of the second resonance at f_2 (1.7812GHz) between the GG1_TLM and measurements. This second resonance is determined mainly by the dimensions of the inner square.

However, the optimization method employed is inefficient when compared to other techniques especially for well behaved objective functions and some effort could usefully be put into improving the efficiency of the optimization method as the evaluation of the objective functions using

GGI_TLM may be very time consuming. The method used here is only suitable for problems which can be simulated in a matter of minutes or at most hours.

V. CONCLUSION

It is demonstrated in this work that optimization can be applied in GGI_TLM for optimum designs of frequency selective surfaces. The shielding effectiveness of the double square loop achieved in this study is in excess of 25dB at 900MHz and at 1,800MHz. The good agreement between the simulated and experimental results shows that GG_TLM can be used to model FSSs with double square loop patch elements for shielding. Optimization applied in the GG_TLM provides a robust means of arriving at the premium set of parameters for the design.

```

OPTIMIZATION SUBROUTINE
IMPLICIT NONE
real*8 :: value
real*8 :: cell_size,dim1,dim2,dim3,dim4
real*8 :: t1,t2,t3,t4
real*8 :: r(9)
integer :: i,ii
integer :: nvalues

! START
! set the FSS dimensions from the parameter
! values

t1=4e-2*parameters(1)
t2=1e-2*parameters(2)
t3=2e-2*parameters(3)
t4=2e-2*parameters(4)

dim4=t1
dim3=t1+t2
dim2=t1+t2+t3
dim1=t1+t2+t3+t4
cell_size=t1+t2+t3+t4+2e-2*parameters(5)

! evaluate the function to minimize

! First write the dimensions to a file
open(unit=50,file='FSS_dimensions')

write(50,8000)cell_size,dim1,dim2,dim3,dim4
8000 format(5E16.6)
close(unit=50)

! Run the script which runs and post processes
the TLM solution
CALL system("run_GGI_TLM_FSS_solution_run_seq
OPTIMIZE_FSS")

! Calculate the objective function to optimise
from the output result(s)

value=0d0

open(unit=50,file='S21.fout')
! read header line
read(50,*)
! read the data file
nvalues=0
1000 CONTINUE
read(50,*,end=1010)(r(ii),ii=1,9)

```

```

if ( (r(1).GE.880E6).AND.(r(1).LE.920E6) )
then
value=value+r(9) ! sum the transmission
coefficient in dB
nvalues=nvalues+1
else if (
(r(1).GE.1780E6).AND.(r(1).LE.1820E6) ) then
value=value+r(9) ! sum the transmission
coefficient in dB
nvalues=nvalues+1
end if
GOTO 1000

1010 CONTINUE

if (nvalues.EQ.0) then
value=large
else
value=value/nvalues
end if

close(unit=50)

END SUBROUTINE calculate_function

```

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