International Journal of Modern Engineering Research (IJMER)

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1231-1236 ISSN: 2249-6645

Design of Frequency Selective Surface Radome over a Frequency Range

K. Renu[1], K.V. V. Prasad[2], S. Saradha Rani[3], A. Gayatri[4]

[1, 3, 4] *(Department of ECE, GITAM University, India)*

[2] *(Department of EEE, MVGR College of Engineering, India)*

ABSTRACT: A Frequency Selective Surface (FSS) is a metallic screen with frequency selective properties which are used as filters through which electromagnetic energy within a specific frequency range may be propagated. In Radar & Communication Systems, it is always required to filter the frequency of the plane waves. Due to its frequency selective property, Frequency Selective Surface is widely used for these applications. Frequency selective surfaces generally consist of an electrically conductive layer usually supported by a dielectric substrate. A common class of FSS can be constructed by placing periodic array of conducting elements on a dielectric substrate or slots in a conducting surface respectively. Multiple layers of such an FSS may be cascaded for greater effect. Depending upon design, it may below low-pass, high-pass, band-pass or band-stop FSS. One of the important applications is the band-pass radome antenna system. A one- or two- dimensional periodic array of resonant structures on a backing material, either apertures in a metallic sheet or metallic patches on a substrate, acts as a filter for a plane wave arriving from any angle of incidence. The primary objective of the paper is to study different approaches of the FSS radome design by using the basic concepts and the simulations. In this paper, slot element and ring element with different thickness are designed and the transmission and reflection properties of the designed elements are analyzed using the CST MICROWAVE STUDIO.

Keywords: Transmission, Reflection and Polarization

1. INTRODUCTION

Design of a band pass or band-stop FSS mostly depends on the choice of the proper element. Some elements are inherently more broad-banded or more narrow-banded than others, while some can be varied considerably by design. In this paper the typical behavior of the most common element types available to the FSS design are observed. All the curves are shown at 45°angle of incidence for orthogonal as well as parllel polarization with the resonant frequency around 10GHz. Further the FSS have 20mil e=2.2 dielectric slab placed on both sides.When judging an element type one might be tempeted to prefer an element where the bandwidth around the first resonance varies as little as possible with polarization. However it should be kept in mind that in general atleast for mechanical reasons, all FSS eventually must be supported by substantial assembly of dielectric slabs which have a profound effect on the bandwidth variation with angle of incidence.Or more to the point ,what is most stable without a substantial dielectric slab may not be the proper choice in the final FSS design. Also the bandwidth of any FSS can in general be varied significantly by variation of the interelement spacings Dx and Dz : A larger spacing will in general produce a narrowerbandwidth, and vice versa.

The curves presented in the following are mostly for small inter-element spacings resulting in a rather large bandwidth and stable resonant frequency with respect to angle of incidence. The plane wave of incidence and direction of incidence are indicated in fig.1.

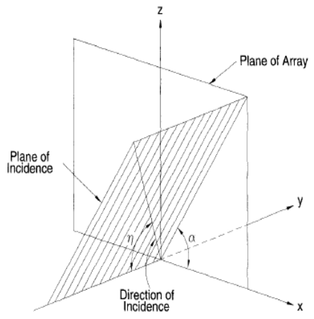


Fig. 1 The plane of incidence determined by αand the direction of incidence by η

All the cases presented in the following have been computed by using the program called "**Periodic Moment Method**"(PMM)[2,3]. It is considered to be one of the most reliable programs available which is being able to handle elements of arbitary shapes, slots as well as dipole arrays mixed together in an arbitary dielectric profile that may include loss.

2. GROUPS OF ELEMENTS

Frequency selective surfaces are used as filters through which electromagnetic energy within a specific frequency range may be propagated. Frequency selective surfaces generally consist of an electrically conductive layer usually supported by a dielectric substrate. The shapes of the apertures may include rings, crosses, slots, Jerusalem crosses. Here we use a dielectric substrate with thickness of 0.125, 0.5, 1.5, 3.2mm with a material of Rogers

RTduriod5880 (lossy metal) with dielectric constant 2.2 and the metal (copper) with 0.035mm thickness, with dielectric constant 5.8e+007.

The elements are arranged into two groups:

Group1: The center connected or N-poles, such as the simple straight element (slot), the Jerusalem crosses.

Group2: The loop types such as the four legged elements (cross), circular loops.

Group 1: The center connected or N-poles elements such as the simple straight element, three-legged element, anchor elements, Jerusalem cross and square spiral as shown in fig.2.

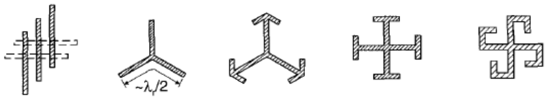


Fig. 2 Group I: The center connected or N-poles

Group 2: The loop types elements such as the three- and four-legged loaded elements, circular loops, square and hexagonal loops as shown in fig.3.

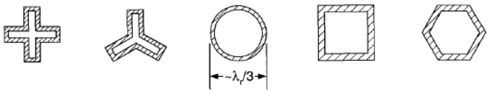


Fig.3 Group II: Loop Types

2.1 SLOT ELEMENT:

A basic slot is a radiating element which has a length of $\lambda/2$ and its width is much less than $\lambda/2$.When a high frequency field exists across a thin slot in a conducting plane, it radiates. A horizontal slot with such an excitation produces vertical polarization and vice-versa. In fact, slot radiates from both sides and it can be excited either by a coaxial cable or through waveguide.

Here $\lambda = C/F$,
Where $C=3*10^8$m/s, F=10GHz.

Basically it consists of simple straight dipole arrayed in a fashion. Here we show a simple rectangular grid having a single slot. Take a dielectric slab with a material Rogers RTduriod5880 (lossy metal) with dielectric constant 2.2 and its thickness is 0.125mm. To the edge of the dielectric slab copper metal with the thickness of 0.035mm is placed. A piece of slot with length of 15mm and width of 0.3mm is cut from the copper metal. It is clear that the length of the dipole elements becomes larger; that is, the fundamental resonance becomes lower with increasing n. In the figure rectangular grid we have only one dipole for which we get broadband width. As per the waveguide the dielectric slab length is 22.86mm and its width is 10.16mm, for metal (copper) the length and the width are same.

The tangential electric and magnetic fields are matched by the boundary conditions at every boundary surface of the structure in order to obtain S-parameters.

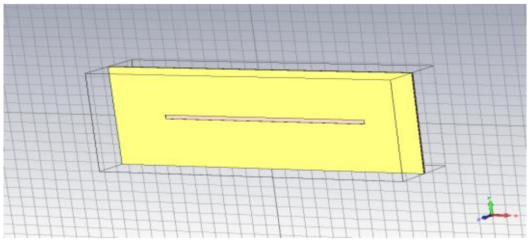


Fig.4 Single slot element with dielectric thickness of 0.125mm

As mentioned above here also same procedure is followed only by changing the dielectric substrate with a thickness of 0.5mm and a piece of slot element is cut with a length of 13mm and width of 0.4mm.

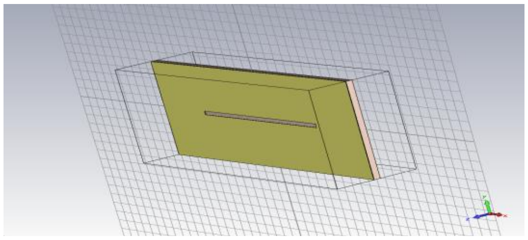


Fig.5 Single slot element with dielectric thickness of 0.5mm

2.2 RING ELEMENT:

It is only necessary to construct a single ring on its backing substrate. Construction of the geometry itself is simple: a substrate is defined using a brick primitive object, and then a hollow cylinder can be used to create the ring. The development of this element is quite instructive. Here we show a simple rectangular grid having a single ring element. Take a dielectric slab with a material Rogers RT5880 (lossy metal) with dielectric constant 2.2and its thickness is 0.125mm. To the edge of the dielectric slab place a metal copper with the thickness of 0.035mm.

A piece of ring element is cut with outer radius of 4.6, inner radius of 4.2 and width of 0.4mm from the metal copper. As per the waveguide the dielectric slab length is 22.86mm and its width is 10.16mm, for metal (copper) the length and the width are same. Both transmission and reflection are represented in terms of S-parameters.

Development of surfaces of single ring element is shown below.

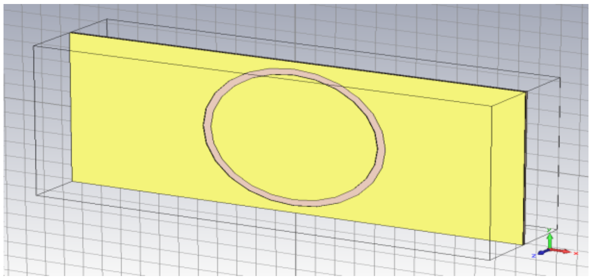


Fig.6 Single ring element with dielectric thickness of 0.125mm

As mentioned above here also same procedure is followed only by changing the dielectric substrate with a thickness of 0.5mm and a piece of ring element is cut with a outer radius of 4.6,inner radius of 4.2 and width of 0.4mm.

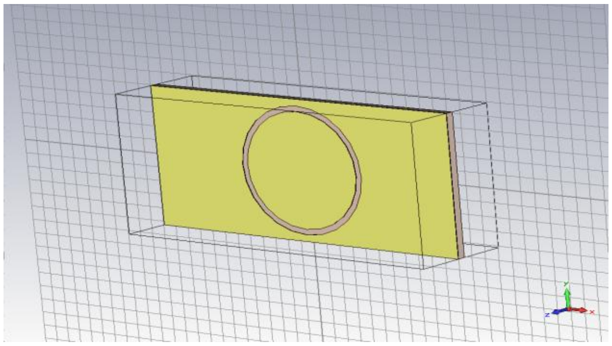


Fig.7 Single ring element with dielectric thickness of 0.5mm

3. SIMULATION

In this paper a software has been used called Computer Simulation Technology (CST) for the simulation of various elements. CST MICROWAVE STUDIO® is a fully featured software package for electromagnetic analysis and design in the high frequency range. It simplifies the process of inputting the structure by providing a powerful solid modeling front end which is based on the ACIS modeling kernel. Strong graphic feedback simplifies the definition of your device even further. After the component has been modeled, a fully automatic meshing procedure is applied before a simulation engine is started. A key feature of CST MICROWAVE STUDIO® is the *Method on Demand* approach which allows using the simulator or mesh type that is best suited to a particular problem.

All simulators support hexahedral grids in combination with the Perfect Boundary Approximation (PBA method). Some solvers also feature the Thin Sheet Technique (TST) extension. Applying these highly advanced techniques normally increases the accuracy of the simulation substantially in comparison to conventional simulators. Since no method works equally well in all application domains, the software contains four different simulation techniques they are transient solver, frequency domain solver, integral equation solver, Eigen mode solver to best fit for their particular applications. The frequency domain solver also contains specialized methods for analyzing highly resonant structures such as filters. Furthermore, the frequency domain solver supports both hexahedral and tetrahedral mesh types. The most flexible tool is the transient solver, which can obtain the entire broadband frequency behavior of the simulated device from only one calculation run in contrast to the frequency step approach of many other simulators. This solver is remarkably efficient for most kinds of high frequency applications such as connectors, transmission lines, filters, antenna etc.

The transient solver is less efficient for electrically small structures that are much smaller than the shortest wavelength. In these cases it is advantageous to solve the problem by using the frequency domain solver. The frequency domain solver may also be the method of choice for narrow band problems such as filters or when the usage of tetrahedral grids is advantageous. Besides the general purpose solver that supports hexahedral and tetrahedral grids, the frequency domain solver also contains fast alternatives for the calculation of S-parameters for strongly resonating structures. These solvers are currently available for hexahedral grids only.

Important features of Frequency domain solver are:

a) Efficient calculation for loss-free and lossy structures
Including lossy waveguide Ports b)
b) General purpose solver supports both hexahedral and tetrahedral meshes.
c) High performance radiating/absorbing boundary conditions.
d) Continuation of the solver run with additional frequency samples
e) Conducting wall boundary conditions (tetrahedral mesh only)
f) Automatic fast broadband adaptive frequency sweep
g) User defined frequency sweeps
h) Adaptive mesh refinement in 3D
i) Antenna far field calculation (including gain, beam direction, side lobe suppression, etc.) with and without far field approximation
j) Calculation of various electromagnetic quantities such as electric, magnetic fields, surface currents, power flows, current densities, power loss densities, Electric energy densities, magnetic energy densities.
k) Plane wave excitation with linear, circular or elliptical polarization (tetrahedral mesh only)
l) High performance radiating/absorbing boundary conditions.

m) Network distributed computing for optimizations and parameter sweeps
n) Antenna array far field calculation
o) RCS calculation (tetrahedral mesh only)
p) Besides the general purpose solver, the frequency domain solver also contains two solvers specialized on strongly resonant structures (hexahedral meshes only).The first of these solvers calculates S-parameters only whereas the second also calculates fields with some additional calculation time, of course.

Important features of transient simulators are:

a) Efficient calculation for loss-free and lossy structures
b) Broadband calculation of S-parameters from one single calculation run by applying DFTs to time signals
c) Calculation of field distributions as a function of time or at multiple selected frequencies from one simulation runs.
d) Frequency dependent material properties
e) Surface impedance model for good conductors
f) Automatic waveguide port mesh adaptation
g) User defined excitation signals and signal database.
h) Automatic parameter studies using built-in parameter sweep tool.

i) Frequency dependent material properties with arbitrary order for permittivity.

j) Multipin ports for TEM mode ports with multiple conductors
k) Plane wave excitation (linear, circular or elliptical polarization)
l) S-parameter symmetry option to decrease solve time for many structures
m) Auto-regressive filtering for efficient treatment of strongly resonating structures
n) Re-normalization of S-parameters for specified port impedances
o) Phase de-embedding of S-parameters
p) Full de-embedding feature for highly accurate S-parameter results
q) Single-ended S-parameter calculation
r) Excitation of external field sources imported from CST MICROWAVE STUDIO or Sigrity.
s) High performance radiating/absorbing boundary conditions
t) Calculation of various electromagnetic quantities such as electric fields, magnetic fields, surface currents, power flows, current densities, power loss densities, electric energy densities, magnetic energy densities, voltages in time frequency domain.

4. RESULTS

Using CST MICROWAVE STUDIO® software, different elements such as single ring element, single slot element, single Tripole element are simulated. Transmission and reflection curves of single slot element are presented with different element thickness. It is observed that beam width and frequency of the transmission and refection curves are changing with thickness of the element.

Fig.8 represents the transmission and reflection curves of single slot element with thickness of 0.125mm.

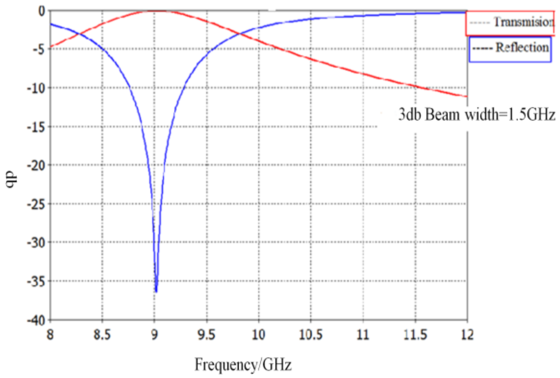


Fig. 8 transmission and reflection curves of single slot element with thickness of 0.125mm

From Fig.8 it is observed that the 3db beam width of the single slot element of thickness 0.125 mm is 1.5GHz and the centre frequency is 9.024GHz.

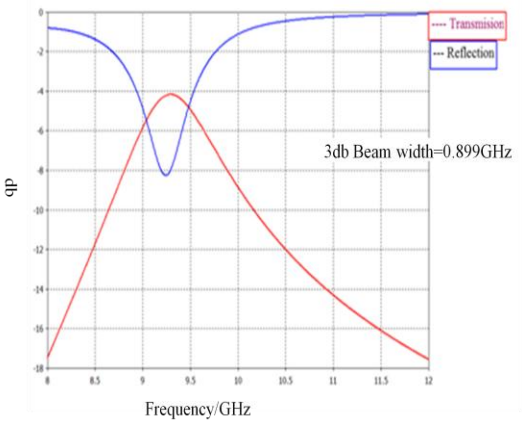


Fig. 9 transmission and reflection curves of single ring element with thickness of 0.125mm

From Fig.9 it is observed that the 3db beam width of the single ring element of thickness 0.125 mm is 0.899 GHz and the centre frequency is 9.29GHz

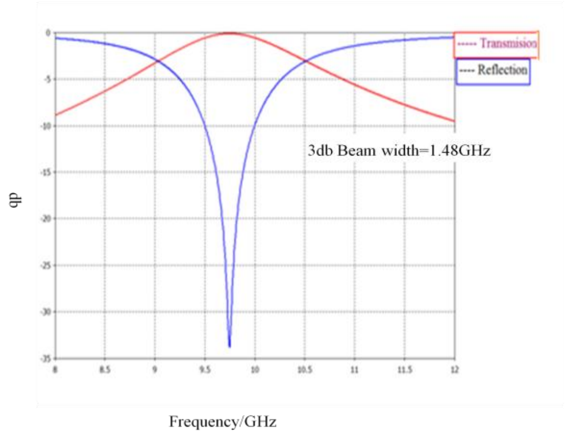


Fig.10 transmission and reflection curves of single slot element with thickness of 0.5mm

Fig.10 shows the transmission and reflection curves of single slot element with thickness of 0.5mm

From Fig.10**,** the 3db beam width of the single ring element of thickness 0.5 mm is 1.48GHz and the centre frequency is 9.75GHz.

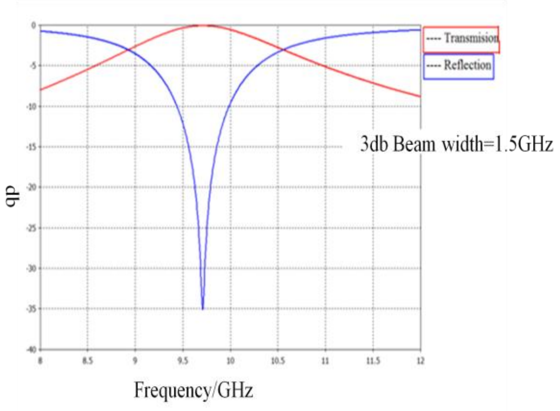


Fig.11 transmission and reflection curves of single ring element with thickness of 0.5mm

From Fig.11**,** the 3db beam width of the single ring element of thickness 0.5 mm is 1.5GHz and the centre frequency is 9.71GHz

All the results are calibrated using network analyzer. As an illustration Fig.12 and Fig.13 shows the comparison of simulated results with calibrated results for single slot of thickness 1.5mm and also single ring of thickness 1.5mm. Also the simulated and calibrated results are compared for single ring elements for thickness of 3.2 mm. The results are comparable and are encouraging.

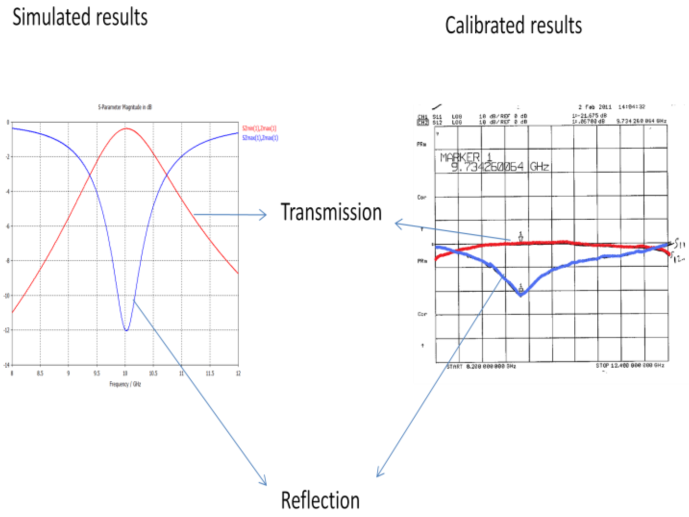
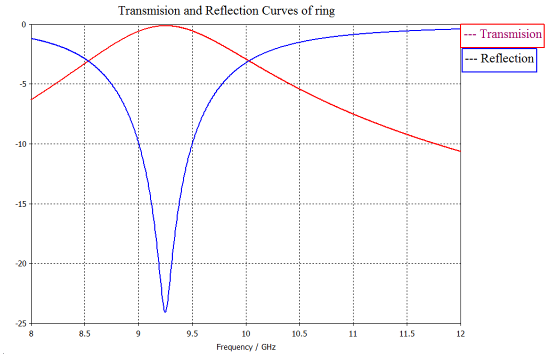


Fig.12 comparison of transmission and reflection curves of single slot element with thickness of 1.5mm

With the calibration of single slot element using network analyser, the transmission and reflection curves resonate at 9.73 GHz where as the simulation result is at 10 GHz. The phase shift observed is due to the manual cutting of slot element.

Below the results of single ring element with a thickness of 1.5mm is compared.

Simulated results



Calibrated results

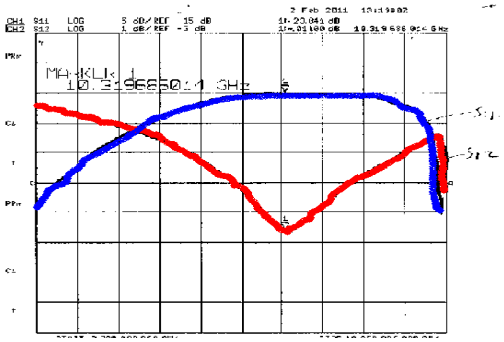
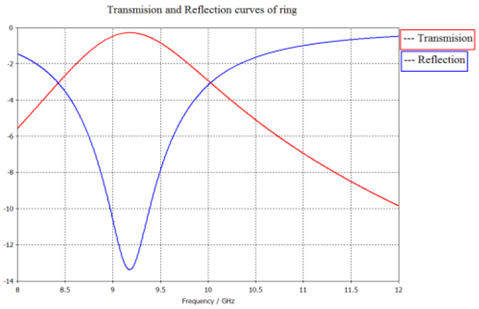


Fig.13 comparison of transmission and reflection curves of single ring element with thickness of 1.5mm

From the above figure it is observed that transmission and reflection curves resonate at 9.3GHz with simulation where as the calibrated value is resonating at 10.32GHz which is comparable.

Below the results of single ring element with a thickness of 3.2mm is compared.

Simulated results



Calibrated results

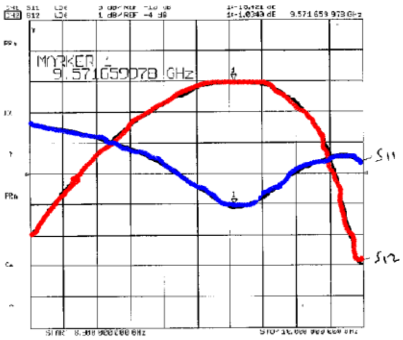


Fig.14 comparison of transmission and reflection curves of single slot element with thickness of 1.5mm

By using ring element of thickness it is observed that transmission and reflection curves resonate at 9.178GHz with simulation where as the calibrated value is resonating at 9.57 GHz which is comparable.The difference in resonating frequency between simulated results and calibrated results are mainly due to the manual cutting of the ring elements.

5. CONCLUSION

Using CST microwave studio, the transmission and reflection propoerties of a slot element(single) and ring element (single) designed for a frequency of 10GHz , with thickness of 0.125mm and 0.5 mm are analysed.Using the Network Analyzer, the transmission and reflection propoerties of a slot element(single) and ring element (single) are calibrated . The simulated results obtained using CST microwave studio are compared with the calibrated values and minimum deviation(0.27GHz) is observed.This work can be further extended to analyse transmission and reflection properties of different elements like cross and tripole elements, which are also used in designing of a Radome.As these elements are having the property to allow the particular frequency(10GHz) and attenuates the other frequencies, detection of the signals by the enemy is difficult.

6. REFERENCES

[1] B. A. Munk and R. D. Fulton, “Transmission through a Bi-Planar Slot Array Sandwiched Between Three Dielectric Layers, March 1973-Nov. 1975,” Tech. Rept. 3622-7, Ohio State Univ. ElectroScience Lab., Dept. of Electrical Eng., Columbus, Feb. 1976.

[2] L. W. Henderson, “The Scattering of Planar Arrays of Arbitrary Shaped Slot and/or Wire Elements in a Stratified Dielectric Medium,” Ph.D. Dissertation, Ohio State Univ., Dept. of Electrical Eng., Columbus, 1983.

[3] L. W. Henderson, “Introduction to PMM,” Tech. Rept. 715582-5, Ohio State Univ.

[4] B. A. Munk and G. A. Burrell, “Plane Wave Expansion for Arrays of Arbitrarily Oriented Piecewise Linear Elements and Its Application in Determining the Impedance of a Single Linear Antenna in a Lossy Half-Space,’’ *IEEE Trans. on Antennas and Propagation,* ***AP- 34(3),*** 331-343, May 1979.

[5] . B. A. Munk, G. A. Burrell, and T. W. Kornbau, “A General Theory of Periodic Surfaces in Stratified Media,” Tech. Rept. 784346-1, Ohio State Univ. ElectroScience Lab., Dept. of Electrical Eng., prepared under contract AFAL-TR-77-2 19, Nov. 1977.

[6] T. W. Kornbau, “Analysis of Periodic Arrays of Rotated Linear Dipoles, Rotated Crossed Dipoles, and of Biplanar Dipole Arrays in Dielectric,” Ph.D. Dissertation, Ohio State Univ., Dept. of Electrical Eng., Columbus, 1984.

[7] **S.** W. Schneider, “On the Scattering Properties of Super Dense Periodic Surfaces,” Ph.D. Dissertation, Ohio State Univ., Dept. of Electrical Eng., Columbus, 1992.

[8] B. A. Munk, United States Patent 3,789,404, Periodic surface for large scan angles, Jan. 29, 1974.

[9] E. L. Pelton and B. A. Munk, United States Patent 3,975,738, Periodic antenna surface of tripole slot elements, Aug. 17, 1976.