Multilayered Bi-Directional Dual Band Frequency Selective Surface Design

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Abstract— The dissertation presented here designs a dual band (band-pass) frequency selective surface (FSS) that passes microwave frequencies of 8.5 GHz and 14 GHz. It is a bi-directional FSS that works the same from both the sides. It is a multi-layer FSS where a circular slot is sandwiched between two circular patches. Two layers of substrate are used (Rogers Ultralam 1250) with εr=2.5. Outer sides of these substrates contain circular patches of copper and inner side contain copper plane with a slot of same size as the circular patches. This works only designs one unit cell and analyzes its behavior. For more than four decades, FSSs have attracted much attention because of their comprehensive applications, such as polarisers, filters, sub-reflectors, and band-pass hybrid radomes. In some applications, multiband FSSs are needed for the design of dual-reflector antennas. Frequency selective surface find their application as band pass and band stop filter over other electromagnetic structures. Simulation is done on EM-CAD tool HFSS 11.1.

Keywords: Frequency selective surface, transmission coefficient, reflection coefficient, unit cell, radome

I. INTRODUCTION

Frequency Selective Surfaces (FSS) are being widely used as filters for microwaves and optical signals. In recent years they have been the subject of extensive research. An FSS basically consists of periodic arrays of elements printed on a dielectric substrate. The prime feature of an FSS is the dependence of the transmission coefficients on the frequency of the incident wave. At certain frequencies, they are transparent to electromagnetic waves while at others they are strongly reflective.

A. *Periodic Surface:*

A periodic surface is basically an assembly of identical elements arranged in a one or two-dimensional infinite array. An example is shown in FIG 1, where simple "dipoles" loaded at their centers with a load impedance ZL have been arranged in a rectangular array with inter-element spacings Dx and Dz.

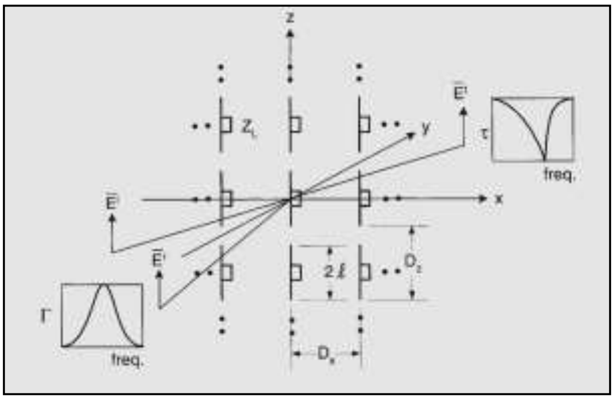


Fig. 1: Passive Periodic Surface

B. *Passive VS Active Array:*

Fundamentally, any periodic array can be excited in two ways: by an incident plane wave Ei, as shown in FIG 1 (passive array), or by individual generators connected to each element, as shown in FIG 2 (active array). In the latter case, the voltage generators must have the same amplitude and a linear phase variation across the active array in order for it to qualify as a periodic surface. (This constraint produces one or more radiated plane waves.)

In the passive array case, the incident plane wave will be partly transmitted in the forward direction (Et) and partly reflected in the specific direction. Under resonant condition and for no grating the amplitude of the reflected signal may equal Ei while Et = 0. It is customary to define the specular reflection coefficient as

$$\Gamma = E^r/E^i$$

C. *Frequency Selective Surfaces:*

When designing either a band-pass or band-stop FSS, the choice of the proper element may be of utmost importance. Some elements are inherently more broadbanded or more narrow-banded than others, while some can be varied considerably by design. When judging an element type, one might be tempted 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, at least for mechanical reasons, all FSS eventually must be supported by a substantial assembly of dielectric slabs. These can have a profound effect on the bandwidth variation with angle of incidence. Bandwidth of any FSS can in general be varied significantly by variation of the inter-element spacings Dx and Dy: A larger spacing will in general produce a narrower bandwidth, and vice versa. However, two things must in this case be watched closely: earlier onset of grating lobes and greater variation of the first resonant frequency with angle of incidence and polarization.

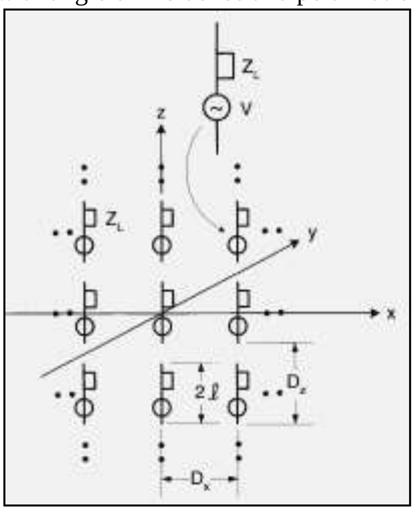
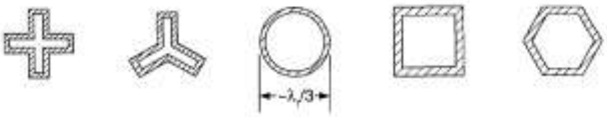


Fig. 2: Active Periodic Surface

The elements are arranged into four groups:

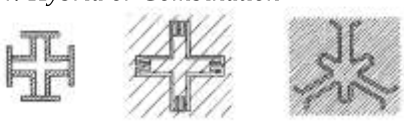
1) *Group 1: Center Connected or N-Poles*

2) *Group 2: Loop Type*



3) *Group 3: Solid Interior or Plate Type*

4) *Group 4: Hybrid or Combination*



D. Floquet Port in HFSS:

The Floquet port in HFSS is used exclusively with planar-periodic structures. Chief examples are planar phased arrays and frequency selective surfaces when these may be idealized as infinitely large. The analysis of the infinite structure is then accomplished by analyzing a unit cell. Linked boundaries most often form the side walls of a unit cell, but in addition, a boundary condition is required to account for the infinite space above. The Floquet port is designed for this purpose. The Floquet port is closely related to a Wave port in that a set of modes ("Floquet modes") represents the fields on the port boundary. Fundamentally, Floquet modes are plane waves with propagation direction set by the frequency, phasing, and geometry of the periodic structure. Just like Wave modes, Floquet modes too have propagation constants and experience cut-off at low frequency. When a Floquet port is present, the HFSS solution includes a modal decomposition that gives additional information on the performance of the radiating structure. As in the case of a Wave port, this information is cast in the form of an S-matrix inter-relating the Floquet modes. In fact, if Floquet ports and Wave ports are simultaneously present, the S-matrix will inter-relate all Wave modes and all Floquet modes in the project. For the current version, the following restrictions apply:

– Currently, only modal projects may contain Floquet ports.
– Boundaries that are adjacent to a Floquet port must be linked boundaries.
– Fast frequency sweep is not supported. (Discrete and interpolating sweep are supported.)

E. Multilayered Frequency Selective Surface:

The current trend in satellite communication systems indicates increased use of antenna systems such as FSS employing multiple frequency channels operating simultaneously. Over the last few decades a number of analytical and numerical techniques have been developed for designing a variety of frequency selective surfaces. However, due to the increase in complexity of the specifications for the frequency response characteristic of these surfaces, many designers have been led to investigate novel FSS configurations.

FSS designs require properties meeting a range of specific characteristics that can be achieved flexibly using more than one layer of element, where they may have different shapes and lattices. These properties include multiresonant, very close, or very wide frequency band spacing ratios, with wide or narrow bandwidths. The bandwidth of the response curve in the reflection band for example, is defined as the percentage ratio of the difference between the frequencies at the -10 dB point, to the reflection band centre (i.e. the reflection resonance) frequency. In other words, ($BW\% = \Delta f/f_R$, where Δf is the difference between the -10 dB points). Also the frequency band spacing or the band separation ratio is defined as the ratio between the transmission band centre (f_T) and the reflection band centre (f_R) frequencies. A sharper transition from the upper edge of the transmission band to the lower edge of the reflection band would normally be desired, enabling a close band spacing ratio to be achieved. The breadth of achieving such diverse properties is dominated by the choice of element and lattice geometries in each layer without neglecting the interaction region between the arrays.

II. FSS GEOMETRY

The proposed FSS consist of two boards of Rogers Ultralam 1250 (with permittivity of 2.5 and loss tangent 0.0015). The thickness of the substrate is 0.254 mm. Size of the square shaped board is 12.77×12.77 mm. The FSS contain 3 metallic layers in between two slabs of substrate. Top and bottom layers of metal are same. They have a circular patch of metal with radius 3.556 mm. The metal sheet in between two dielectrics contains a circular slot of the same radius as the patch on top and bottom layer. FIG 3 shows a three dimensional view of the frequency selective surface unit cell. The combination of circular patch and loop gives dual band pass operation at X band and Ku band. Symmetrical circular patches on top and bottom makes the shape a bidirectional filter. FIG 4 shows the top view of the unit cell and FIG 5 shows the side view of the unit cell.

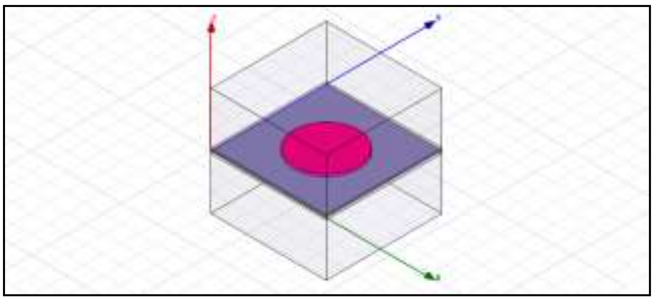


Fig. 3: UNIT CELL OF DESIGNED FSS

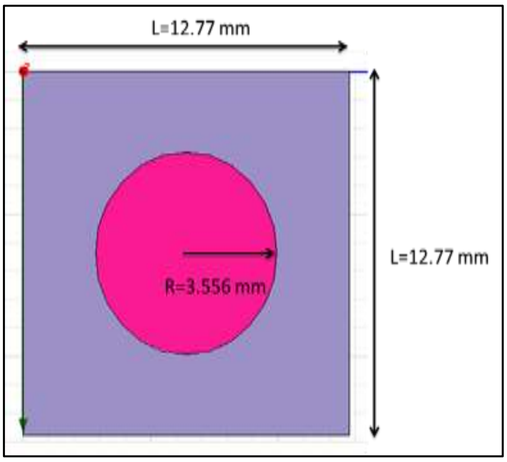


Fig. 4: FOOT PRINT (TOP VIEW) OF THE UNIT CELL

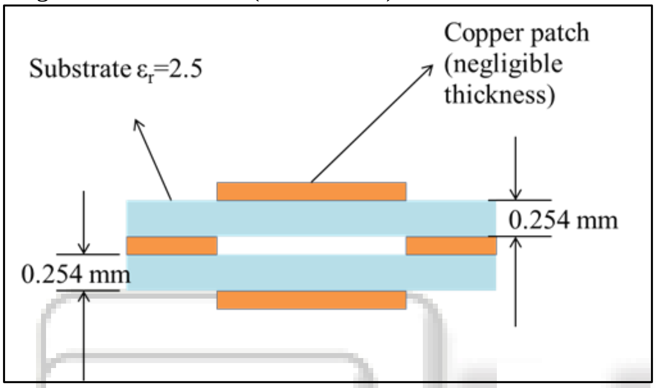


Fig. 5: SIDE VIEW OF THE UNIT CELL

III. SIMULATION RESULTS

Transmission and Reflection coefficient of the frequency selective surface is given at Incident Angle $=0^0$, Thickness of substrate: 0.254 mm, Permittivity of Substrate: 2.5 (Fig 6 and Fig 7)

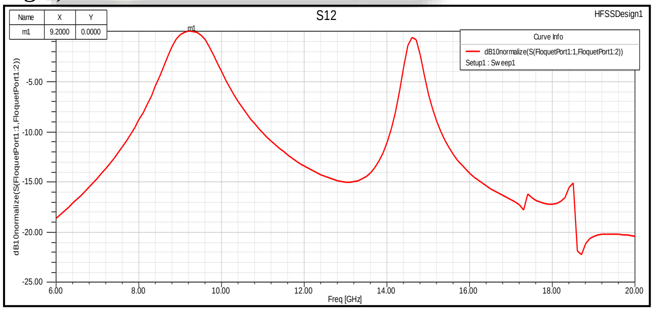


Fig. 5: TRANSMISSION COEFFICIENT

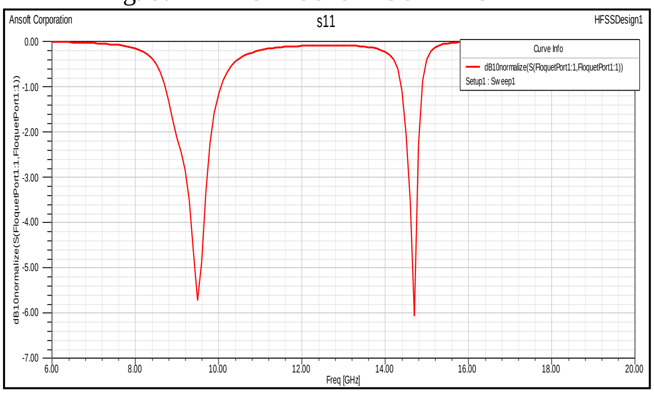


Fig. 6: REFLECTION COEFFICIENT

The designed FSS achieves -10 dB pass band at X band for the range of frequencies between 8 GHz and 11 GHz and at Ku band for the frequencies between 14 GHz to 15.5 GHz. Also S12 and S21 responses are same showing that the FSS is bidirectional.

IV. CONCLUSION

The dissertation successfully designs a multilayered bidirectional frequency selective surface that works at both X band and Ku band. The transmission coefficient of the FSS shows that it passes both X-band and Ku-band frequencies. This behavior is test at different angle of incidences. The FSS is also analyzed with variable substrate thickness and different dielectric material. When the angle of incidence is changed from normal the FSS does not work as expected.

V. FUTURE SCOPE

The FSS of various complex shapes can be made. More sophisticated FSS have better angle of incidence, polarization insensitivity. To increase the bandwidth of the pass band more layer can be introduced. Plate type and slot type designs are combined to get dual band operation. Tripole, dipole and Jerusalem Cross structures can also be employed to get some more variety in the FSS behavior.

After designing the unit cell there is another challenge of placing them in a grid. If the placing is not done correctly desired responses are not obtained. When used along with another electromagnetic structure one might face the problem of orientation and placement. Also it can change the behavior of host design. The design of the FSS grid will be taken up as a future task.

VI. APPLICATION

As the designed FSS passes Ku band, it can be placed in front of a horn antenna with the aim of increasing its directivity and gain. A radar absorbing material can be designed using this FSS. A radome (which is a combination of radar and dome) is a structural, weatherproof enclosure that protects radar antenna. The radome is constructed of material that minimally attenuates the electromagnetic signal transmitted or received by the antenna, effectively transparent to radio waves. Radomes protect the antenna from weather and conceal antenna electronic equipment from public view. They also protect nearby personnel from being accidentally struck by quickly rotating antennas.

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