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Design of a frequency selective surface with multiple four legged Slots

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ABSTRACT

A design is presented for a triple band frequency selective surface (FSS) with triple-four-legged loaded slots elements. The resonant element considered is four legged loaded slot (FLLS). The frequency response curve of the FSS varies with respect to the scaling factors of the slots. An optimal scaling factor has been proposed for the slots such that it provides wide and multiple bands. These kinds of reflectors make structures low profile by providing the flexibility in mounting them closer to antenna without disturbing the impedance bandwidth and providing a good gain control in the main beam direction. Its frequency performance is obtained by using numerical simulation software HFSS based on finite-element method (FEM).

***Keywords* – Frequency selective surface (FSS), four legged loaded slot (FLLS).**

I. INTRODUCTION

Frequency selective surfaces (FSSs) have been the subject of intensive investigation for their widespread applications as spatial microwave and optical filters for more than four decades Frequency selective surfaces (FSSs) are some periodic surfaces, which are basically assembly of identical elements arranged in one- or two-dimensional infinite arrays but finite arrays in practice [1]. They have often been considered for the reflector antenna applications [2]-[4]. Typically, an FSS is employed for the subreflector and the different frequency feeds are optimized independently and placed at the real and virtual foci of the subreflector. Hence, only one single main reflector is required for the multi frequency operation. For example, the Voyager FSS was designed to diplex S and X bands [2]. In that application the S-band feed is placed at the prime focus of the main reflector, and the X-band feed is placed at the Cassegrain focal point. Note that only one main reflector is required for this two band operation. Thus, tremendous reduction in mass, volume and, most important, the cost of the antenna system are achieved with the FSS sub reflector.

FSSs have gained more and more attention in telecommunications, antenna design, and electromagnetic compatibility (EMC) recently. They are widely used as spatial filters, subreflectors for multiband frequency antennas, polarizers and as radomes for radar cross section (RCS) controlling. These surfaces provide uninhibited transmission in specific frequency bands but suppress transmission in other bands. Multiband FSSs have been investigated by many researchers. In space missions such as Voyager, Galileo, and Cassini, the use of dual-reflector antennas with a subreflector made of an FSS has made it possible to share the main reflector among different frequency bands [5]-[8].

Many configurations of the frequency selective surface are possible like layered or stacked FSS, perturbed element FSS, Dual band resonators etc. One interesting property in these structures is the self-similarity property. In plain words self-similarity can be described as the replication of the geometry of the structure at a different scale within the same structure. Self-similarity of the structure results in a multiband behavior [9]. The applications of frequency selective surfaces are many and varied, and they range over much of the electromagnetic spectrum. In the microwave region, the frequency selective properties of periodic screens are exploited, for example, to make a more efficient use of reflector antennas [10].

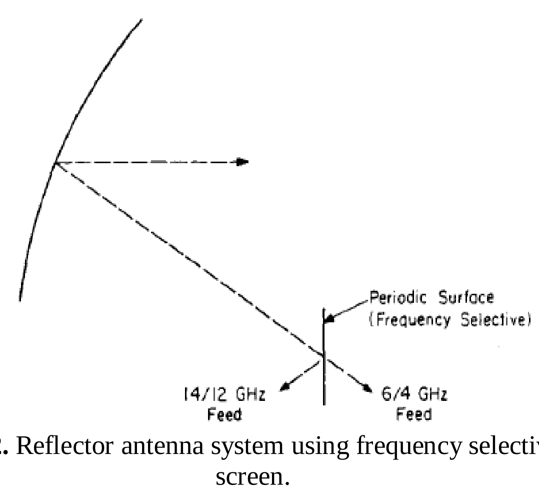

Fig 2. Reflector antenna system using frequency selective screen.

As shown in Fig. 2, a frequency selective surface is placed between two feeds, radiating at differing frequencies, and the main reflector. The screen is totally reflecting (or nearly so) over the operating band of feed one, and conversely, it is nearly totally transparent over the band of feed two. Hence, in this configuration, two independent feeds may share the same reflector antenna simultaneously, in a frequency reuse mode.
The main limitation to design a truly multiband FSS is the appearance of grating lobes. To avoid grating lobes the spacing between adjacent elements has to be smaller than the free-space wavelength; however, the elements cannot be brought closer than its own length.

II. DESIGN PROCEDURE

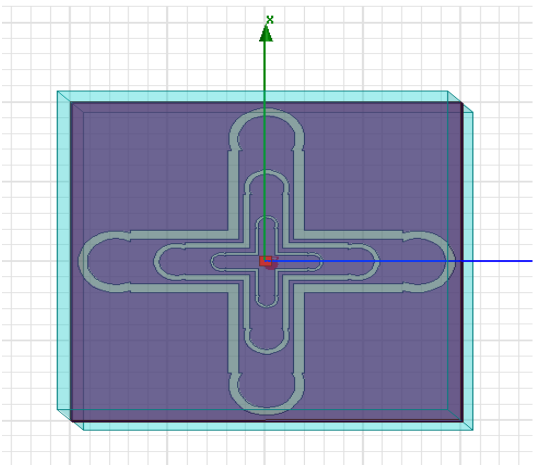

Fig 1. Proposed model of the FSS

The frequency response of an FSS is entirely described by the geometry of the structure in one period called a unit cell. Frequency selective surfaces are usually constructed from periodically arranged metallic patches of arbitrary geometries or their complimentary geometry having aperture elements similar to patches within a metallic screen. These surfaces exhibit total reflection or transmission, for the patches and apertures respectively, in the neighborhood of the element resonances. The most important step in the design process of a desired FSS is the proper choice of constituting elements for the array. The element type and geometry, the substrate parameters, the presence or absence of superstrates, and inter-element spacing generally determine the overall frequency response of the structure, such as its bandwidth, transfer function, and its dependence on the incidence angle and polarization. The resonant frequencies of a slot depend on the slots' width and length, but it is mainly controlled by the slot length. The first resonant frequency decreases with increase of a slot length and a slot width has little effect on the resonant frequency.

More recently, advanced methods based on method of moments (MoM), finite element method (FEM), and finite-difference time-domain (FDTD) with periodic boundary conditions have made the design process of FSSs substantially easier. Generally, for designing FSSs in HFSS, one can go with three options using perf E and perf H boundaries, using master/slave boundaries and PML setup and plane wave excitation or using floquet ports.

The FSS is designed first by creating a four legged loaded slot element (FLLS) with curved surface at the four corners. The measurements of the slot are specified in the table given below.

dimension	Measurement (units)
Length of outer leg (l_1)	1 mm
Length of outer leg (l_2)	1.2 mm
Width of outer leg (w_1)	0.5 mm
width of outer leg (w_2)	0.4 mm
Lengths of second leg	l_1/k_1, l_2/k_1 mm
Lengths of third leg	l_1/k_2, l_2/k_2 mm
Thickness of dielectric	1.2 mm

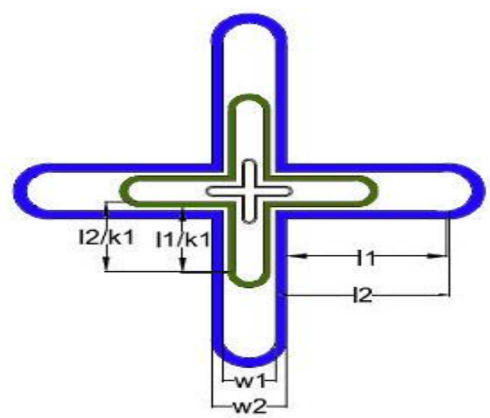

Fig2. Dimensions of the slotted element

TABLE 1
Geometrical specifications of the FSS

The other slot elements are made by scaling the first one with two scaling factors thus creating two slot elements and hence a triple four legged loaded slot element. 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. A dielectric material of permittivity $\varepsilon_r=2.2$ and thickness of 1.2mm is placed on either sides of the FSS. The resonance of FLLS occurs when the circumference of the four-legged element is a multiple of the wavelength. The resonant frequency can be changed by modifying the slot lengths.

However, the resonant frequency changes to somewhere between f_0 and $f_0/\sqrt{\varepsilon_r}$ when a dielectric slab is added next to a periodic structure. Furthermore, the size of the outer FLLS can be obtained by multiply scale factor *k* and the size of inner FLLS. The scale factor used for stage 2 and stage 3 is determined by the location of the next desired resonant point in relation to the resonant frequency of the fundamental element.

III. RESULTS AND DISCUSSIONS

Transmission coefficient equals incident voltage divided by the transmitted voltage.

$$\gamma = \frac{V_{\text{transmitted}}}{V_{\text{incident}}}$$

The scattering matrix relates the outgoing waves of a port to the incoming waves that are incident on a port. The matrix elements s11, s12, s21, s22 of the scattering matrix S are referred as scattering parameters. The parameters s11, s22 have the meaning of reflection coefficients and parameters s21, s12 the meaning of transmission coefficients. In a two port network S_{21} is described in dB as follows

$$S_{21} = 20 \log (\gamma)$$

Fig.3 shows the frequency response curve of the four legged loaded slotted FSS with scaling factors for the middle and outer slots as 1.67 and 2.6 respectively. As we can see that the bandwidth obtained for each band is narrow at these scaling factors. The resonant frequencies occur at 12GHz, 23GHz and 38GHz which represent three zeros and also represents that two poles occur at 20GHz and 33GHz.

From the frequency response it is clear that the FSS sufficiently reflects the S, K and Ku band frequencies thus making it useful in reflector applications where it reflects the S and Ku bands while transmitting X and Ka bands through it. Hence, only one single main reflector is required for the multi frequency operation. Thus the size, mass, volume and cost of the system can be greatly reduced. In the figure below the blue color graph indicates the return loss which shows a minimum value at the transmitting frequencies and the red color graph indicates the transmission coefficients S_{21}. The design is simulated for different scaling factors keeping the thickness of dielectric constant. In this case grating lobes appear at high frequencies. At low frequencies they can be neglected.

With proper values of scaling factors we can get a zero at around 25GHz also which comes in the k band of frequency range which is allocated by ITU to both near Earth and Deep Space services to enhance the downlink data rate. Given the new frequency allocation, the European Space Agency (ESA) now aims to upgrade its Deep Space Antennas (DSAs) so that this new band can be used. The DSAs are beam waveguide antennas that use frequency selective surfaces, also called dichroic mirrors, to separate the various frequency bands [14].

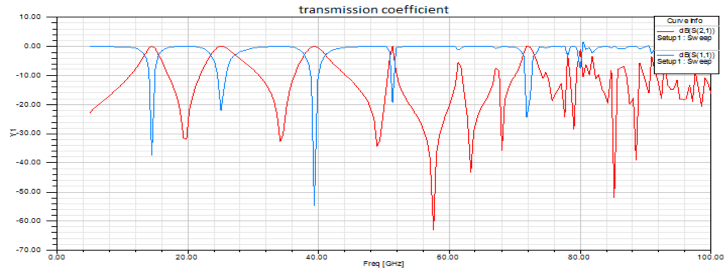

Fig 3. Frequency response curve for scaling factors of 1.67 and 2.6

Fig 4 represents frequency curve for scaling factors of 1.5 and 2.77 for the middle and outer slots respectively. As the scaling factor increases we observe that the bandwidth of the transmission band becomes wide and at the same time the number of transmission band tends to reduce.

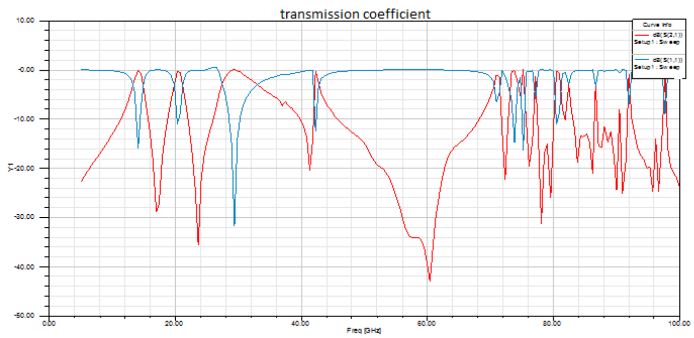

Fig 4. Frequency response curve for scaling factors of 1.5 and 2.77

Fig 5 shows the frequency response curve for scaling factors of the outer most slot changed to 3.3 than the previous case. In this case the outer most slot dimension becomes large and thus less surface is available at the centre inside the inner slot. Therefore the curve exhibits only few transmission bands than the previous case.

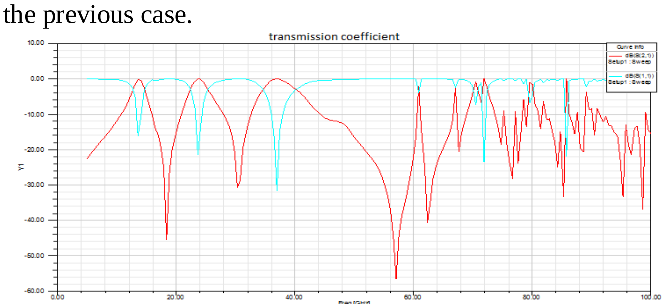

Fig 5. Frequency response curve for scaling factors of 1.67 and 3.3

Fig 6 shows the frequency response curve for scaling factors of slots as 2 and 5. Each part of the surface available on the FSS can be thought of acting at different resonant frequency. As the inner surface becomes smaller it cannot produce resonance. So only the outer slot elements can be able to produce resonance.

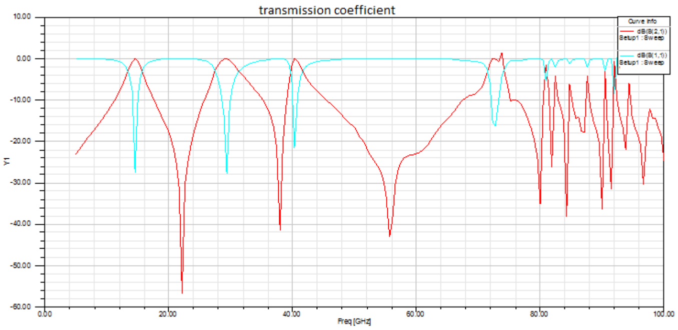

Fig 6 Frequency response curve for scaling factors of 2 and 5

Fig 7 shows the frequency response curve for a much scaled versions of the slots of 2.5 and 6.25. In this case the inner surface is very much reduced. So the bands are reduced to two. Also we can observe that the bands become more wide as the scaling factors are increased. This corresponds to the circular shapes for the four legged slots at the four corners as a result of which the circumference is increased and hence the frequency at which the resonance occurs is also increased. Hence a wide band is obtained for the same design just by changing the scaling factors for the slots.

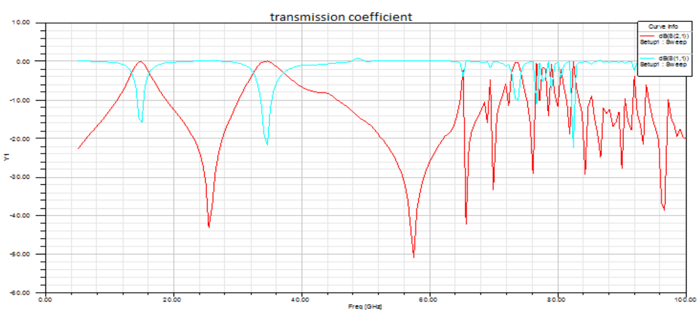

Fig 7 Frequency response curve for scaling factors of 2.5 and 6.25

IV. CONCLUSIONS

The performance of an FSS is often attributed entirely to the elements. The elements must also be arranged in the proper grid. The proposed design of the frequency selective surface has a triple band making it useful at various reflector applications in satellite subsystems. It has been observed that by changing the scaling factors for the four legged loaded slot the frequency response varies widely as the circumference is varied with scaling factors and hence the resonant frequency also changes. From the results obtained we can conclude that to get a better frequency response the scaling factors should not be too high because high scaling factors reduces the inner surfaces area thus making it less involve in its contribution. Changing the substrate dimensions also affects the frequency response. The optimum substrate thickness can be used is 1-2 mm. Some recent applications of FSS include RFID tags, Collision avoidance, RCS augmentation, Robotic guided paths, EMI protection, Photonic band gap structures, Waveguide or cavity controlled coupling, Low-probability of intercept systems (e.g. “stealth”).

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