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Theoretical and Experimental Investigation on a Slot Loaded Compact Multi-band Frequency Selective Surface

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ABSTRACT
This paper presents the effects of slots cut on the patches of a single substrate layer Frequency Selective Surface (FSS) in the aspect of multiband characteristics enabling applications in different fields like Wi-Fi, WiMAX, RADAR etc with reduced resonating frequency. Each FSS periodic cell consists of a metallic square patch loaded with two back to back slots of seven variable length strips. This designed FSS provides total seven reflection bands along with reduced patch size. The proposed design has been investigated both theoretically using ANSOFT® software and practically. In comparison to the conventional square patch Frequency Selective Surface (FSS) without slot, this slotted square patch FSS can provide reduction in resonant frequency resulting in size reduction up to 94%. The structure acts like a band reject filter with seven bands having resonant frequencies of 5.1 GHz, 7.06 GHz, 11.87 GHz, 14.55 GHz, 17.89 GHz, 19.65 GHz and 22.77 GHz.

Index Terms
Frequency Selective Surface, Method of Moments, Slot, Bandwidth, Size reduction.

1. INTRODUCTION
A Frequency Selective Surface (FSS) or dichrohic is a periodic array consisting of conducting patch or aperture elements. Similar to the frequency filters in traditional radio frequency (RF) circuit, the FSS may have band-pass or band-stop spectral behaviour depending upon the array element type (i.e. aperture or patch). The patch type FSS is used where transmission is minimum at resonating frequency i.e. reflection is maximum. Below and above the resonating frequency, transmission gradually increases and finally reaches its maximum value. Reverse situation arises for aperture type frequency selective surfaces. Here transmission is maximum at resonating frequency i.e. reflection is minimum. Below and above the resonating frequency, transmitted electric field gradually decreases and finally becomes zero. The FSS structure has a phenomenon with high impedance surface that reflects the plane wave in-phase and suppresses surface wave [6]. FSS are used as space filters in both commercial and military sectors for various applications, such as reflector antenna system of a communication satellite, deep space exploration vehicle for multi frequency operations, band pass radomes for missiles etc [1-3].To analyse different types of FSS structures theoretically, basically three methods are used – Finite Difference Time Domain (FDTD) method, Finite Element Method (FEM) and the Method of Moment (MoM). Among these three, Method of Moment is the most complicated but its accuracy is the best. Different softwares are available for theoretical analysis by different methods. Here we have used the software based on Method of Moment. However the application of FSS may be extensive in Radio astronomy [4-5].

2. DESIGN OF THE FSS
In designing the patch type FSS, a two dimensional array of a square shaped patch of size (12 mm × 12 mm) is used. The metallic patches are considered to be present on one side of a thin dielectric slab and the copper coating on the other side of the slab is completely removed.

On each metallic patch, two back to back slots with variable length strips of 8.5mm and 10mm length and 1mm width spaced at a distance of 2mm to each other are cut. The dielectric constant used for the PTFE substrate is 2.4. The periodicity of two adjacent patches the FSS structure is 10.5 mm both in the horizontal and vertical directions. All the dimensions of a single square patch with the slots inside it have been indicated in Fig. 1. The spacing between two adjacent patches is shown in Fig. 2. The practical implementation of the FSS is shown in the Figure 3.

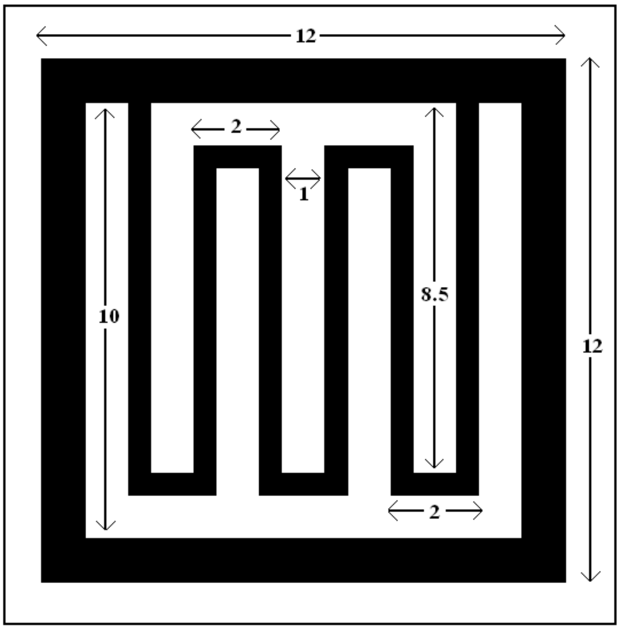

Fig.1 Single Slot loaded Square Patch. (All dimensions are in mm)

For the practically designed FSS structure glass-epoxy substrate may also be used in place of PTFE substrate.

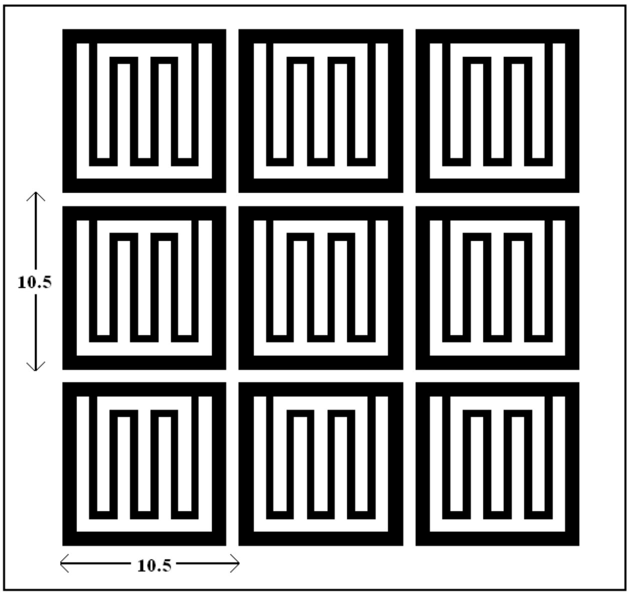

Fig.2 Spacing between adjacent patches with slots in the FSS.

(All dimensions are in mm)

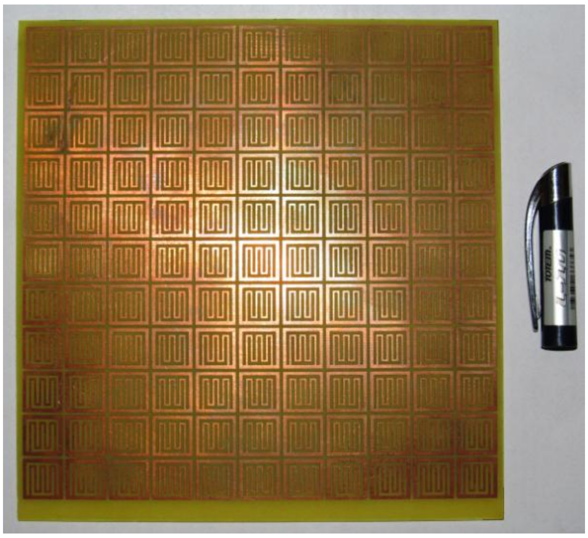

Fig. 3 Practical implementation of the Slot loaded FSS

3. RESULTS

Transmitted electric field for the FSS structure has been investigated both theoretically as well as practically. When no slot is cut on the on the square patches of the FSS, it resonates at 21.12 GHz with the periodicity of 10.5mm both in the horizontal and vertical direction, as shown in the Fig. 4.

Solid lines in the Fig. 5 shows the simulated result as calculated by Ansoft® software in the frequency range of 4 GHz. to 24 GHz for the FSS structure with slots cut on the patches and with the periodicity similar to that in the FSS without slots. The result shows seven reflection bands with resonating frequencies of 5.1 GHz, 7.06 GHz, 11.87 GHz, 14.55 GHz, 17.89 GHz, 19.65 GHz and 22.77 GHz. In the same figure the dotted lines represent the experimental results for the slotted patch FSS.

Transmission test for the FSS structure has been performed using standard microwave test bench. The transmitting horn antenna is connected to a variable R.F. oscillator (Marconi Microwave Source, Model No. 6058B) and the receiving horn antenna to the Agilent Power meter (Model No. E4418B) with power sensor (Model No. E4412A).

The proposed FSS as shown in the Fig. 3 is kept on a wooden frame stand at far field distance of the transmitting horn antenna.

The R.F. oscillator radiates power which is fully reflected at seven different frequencies of 5.1 GHz, 7.1 GHz, 12 GHz, 15 GHz, 18 GHz, 20 GHz and 23 GHz respectively which are indicated from the readings of the power meter in dBm and these values were normalized to plot in the graph of measured normalized transmitted electric field vs. Frequency as shown by the dotted lines in the Fig. 5.

Both the simulated and measured results with band separation of respective reflection bands are shown in the Table I.

Table I
Simulated and Experimental Results for the Slotted Patch FSS

Band	Resonant Frequency (GHz)		-10 dB Bandwidth (GHz)		Percentage Bandwidth (%)		Band Separation (dB)	
	Simulated	Experimental	Simulated	Experimental	Simulated	Experimental	Simulated	Experimental
1st	5.1	5.1	0.71	1.1	14	21.6	-22	-18
2nd	7.06	7.1	0.31	0.4	4.4	5.6	-15	-12
3rd	11.87	12	1.01	2.5	8.6	21	-41	-32
4th	14.55	15	1.08	2.1	7.4	14	-36	-30
5th	17.89	18	0.7	1.5	4	8.3	-31	-28
6th	19.65	20	3.09	2.7	15.4	13.5	-35	-25
7th	22.77	23	0.66	1.01	2.9	4.4	-22	-18

Here the parameter percentage bandwidth denotes the ratio of the factor -10dB bandwidth and the resonant frequency of that corresponding band.

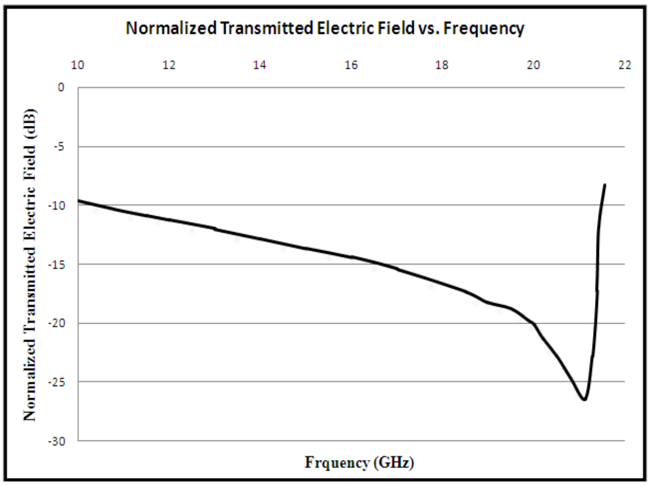

Fig.4 Study of Transmitted Electric-field Vs. Frequency (Without slot)

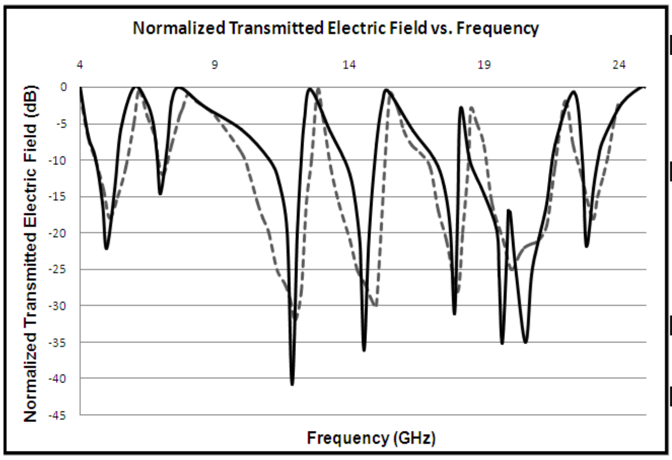

Fig.5 Study of Transmitted Electric-field Vs. Frequency for FSS (With slot)

4. CONCLUSIONS

It is seen from both the theoretical and experimental analysis that, with the introduction of multiple strip shaped slots of variable lengths of strips in the metallic patches of the FSS, it acts like a band reject filter which resonates at seven different frequencies at which the FSS shows maximum reflection of the R.F. wave incident on it with considerable band separation as shown in the Fig. 5. It can also be observed that results of simulation using ANSOFT® designer and experimental results are almost same in terms of resonating frequencies but a little different in terms of percentage bandwidth (-10dB Bandwidth/resonating frequency) having a higher value for experimental results of each reflection bands.

Another important observation may be noted here with respect to the slot loaded patch type FSS. As the FSS resonates at 21.12 GHz for the square patch size of (12mm ×12mm) and periodicity of 10.5mm both in the horizontal and vertical direction, as shown in the graph of Fig.4 when no slot is drawn, so if we want to design a FSS structure with square patches to resonate at 5.1 GHz (lowest resonating frequency of the slot loaded patch type FSS for reflection of -22 dB band separation), the area of the square patch should be 2470 mm2. So the size reduction of the square patch is calculated as [{(2470-122)/2470}*100] i.e. 94% (approx).

Considering -10 dB bandwidth for the FSS, the maximum reflection bandwidth for the 6th band is 3.7 GHz with a percentage bandwidth of 15.4% and a large band separation of -35dB.

The proposed structure has a number of applications in different fields. The 1st band with a resonating frequency of 5.1 GHz can be used for IEEE 802.11a, Wi-Fi, ISM, UNII, WiMAX, FWA etc. The 2nd band with 7 GHz is applicable in the field of RADAR. The 5th band with 17.89 GHz as the resonating frequency has its application for passive microwave sensors where by NASA the band of 17.7-17.9 GHz is allocated as passive band for use in microwave sensors.

With a detail observation it can be concluded that the total number of consecutive strips and the total number of consecutive reflection bands are equal, so in future with the increment of number of strips, the number of reflection bands can be achieved.

5. REFERENCES

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