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An Elliptical Ring FSS Antenna excited with Microstrip Feed for Satellite Application

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ABSTRACT

A novel light weight FSS antenna is designed and discussed in this paper.FR4 epoxy is used as the substrate with relative permittivity 4.4 and dielectric loss tangent 0.02.The dimensions of the substrate is 150mm × 150mm with height 1.6mm.The shape of the patch used is elliptical ring which is in 3×4 array. The elliptical patches are interconnected to achieve better antenna characteristics. Microstrip line feeding technique is used for feeding the antenna. The design is proposed for satellite applications. HFSS software is used to simulate the antenna and study the antenna parameters.

Keywords : FSS (Frequency selective surface), Micro Strip Line Feeding, FR4 epoxy, HFSS

I. INTRODUCTION

FSS is a periodic array structure which consist of radiating or non-radiating elements which make them act as band pass or band stop filters.[1]FSS is a function of both frequency and angle of incidence. FSS can act as a barrier for unwanted signal and hence we can use it as spatial filters. FSS is used to enhance antenna performance as a reflector. [1]-[2]For wearable antennas, FSS is employed as sub reflector. In any planar or irregular structure, FSS can be employed as EMI shield.

Cross polar radiation components are reduced by using polarisation dependent frequency selective surfaces. Circular polarisation is generated itself by FSS. [3] For satellite communication, the necessary requirements are wide bandwidth, high gain and circular polarisation. Patch array antenna are better option for increasing gain. Designing multiple feeds is difficult in FSS. [4]- [5] Side lobes and back radiations are reduced by circular polarisation. Microstrip antenna with circular polarisations finds its application in satellite communication, radar and mobile communication because of its compact size and low profile. Circularly polarised antennas are superior in performance than linearly polarised antennas. [6]These antennas reduces Faraday rotation effect and multi path interference. Achieving 3dB axial ratio bandwidth is critical for circular polarised antenna. To realize wideband impedance bandwidth and 3dB axial ratio bandwidth of circular polarised antenna various steps can be taken. Lower the dielectric constant of substrate, higher the antenna efficiency but size of the antenna will be more.[7] Thicker substrate gives wider impedance bandwidth. Impedance bandwidth can be improved by employing proximity coupled feeding [8].

Thickness and type of substrate used has a major impact on gain improvement. If the eccentricity of the ellipse is small in a narrow frequency band, the radiation can either right hand or left hand circularly polarised [9]. Use of multiple feeds results in circular polarisation. But for exciting circularly polarised antenna only one feed point is required.

II. ANTENNA DESIGN

The proposed design is a periodic array of elliptical ring with interconnections. The dimension of proposed antenna is 150mm×150mm. The substrate used is FR4 epoxy with relative permittivity 4.4, relative permeability 1, dielectric loss tangent 0.02 and magnetic loss tangent 0.The height of the substrate is 1.6mm.Ground lies below substrate which is of negligible thickness. Above the substrate patches are designed. The antenna design consist of 3×4 array. It consist of 12 periodic elliptical ring patches. Elliptical ring consist of two ellipses, one outer ellipse and one inner ellipse. The desired design of the patch is obtained by subtracting one ellipse from another. The outer ellipse has a major radius of 10mm and ratio is 2.The inner ellipse has a major radius of 5mm and ratio of 3. Micro strip line feeding technique is used for the antenna. The material of the radiation box is air contains the antenna setup. The antenna is simulated and results are obtained in C band. Figure 1 illustrates the proposed antenna design.

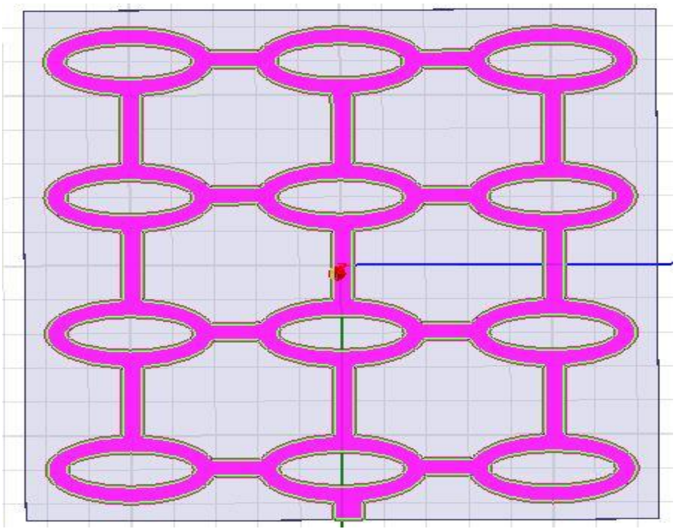

Figure 1. Proposed antenna design

Patch and feeding technique used is fabricated in the dielectric substrate. Patches are interconnected so that equal surface current distribution is there throughout radiating patches. If the patches are not interconnected, there are mutually coupled but the characteristic parameters varies. Design flexibility is provided by elliptical ring patch as the dimensions can be altered. Circular polarisation can be obtained by using single feed point on the elliptical ring patch.

The geometrical shape of elliptical patch allows to perform rigorous theoretical analysis in a standard co-ordinate system. x-y coordinates are replaced by elliptical coordinates u and v.

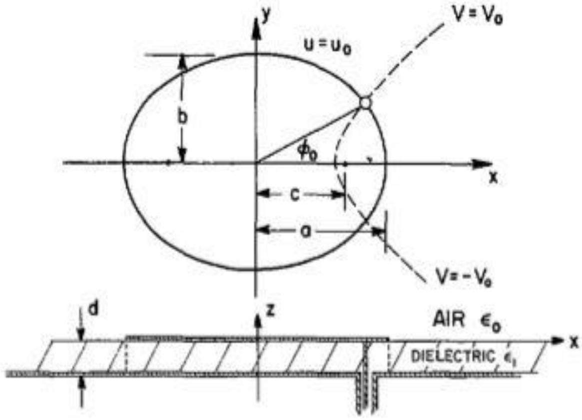

Figure 2. Ellipse with elliptical coordinates

Figure2 illustrates ellipse with elliptical coordinates

Ellipse is defined by :

u = ln $(\frac{a+b}{c})$ where

semi major axis is designated by a, semi minor axis is designated by b and foci is designated by c.

Ellipse eccentricity is given by :

$e = \frac{c}{a}$

The Maxwell's equations reduces to the following set of equations when thickness of dielectric substrate is smaller than wavelength :

$$\frac{\partial^2 E_z}{\partial u^2} + \frac{\partial^2 E_z}{\partial v^2} + {k_1}^2 c^2 (cosh^2 u - cos^2 v) E_z = 0$$

$$H_u = \frac{j}{\mu\omega c\sqrt{cosh^2 u - cos^2 v}} \frac{\partial E_Z}{\partial v}$$

$$H_v = \frac{-j}{\mu\omega c\sqrt{cosh^2 u - cos^2 v}} \frac{\partial E_Z}{\partial u}$$

$H_z = 0 \quad E_z = 0 \quad E_z = 0$

$k_1 = \omega\sqrt{\mu_0 \varepsilon}$

Maximum directivity can be calculated by :

$D = \frac{1+|r|}{1-|r|}$ where reflection coefficient is designated by r

For a particular frequency, maximum power in boresight direction($\theta = 0$) is obtained when resonant length is given by:

$l = \frac{N\lambda}{2} + (\frac{\phi_r+\varphi_g}{\pi})\frac{\lambda}{2}$ where N is integer number (=1)

Reflection coefficient phase of FSS unit cell is designated by $\emptyset_r$

Reflection coefficient phase of substrate with ground plane is designated by φ_g

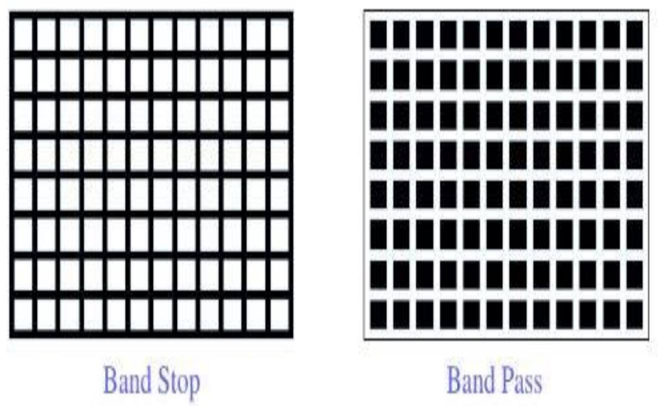

Figure 3. Characteristics of FSS

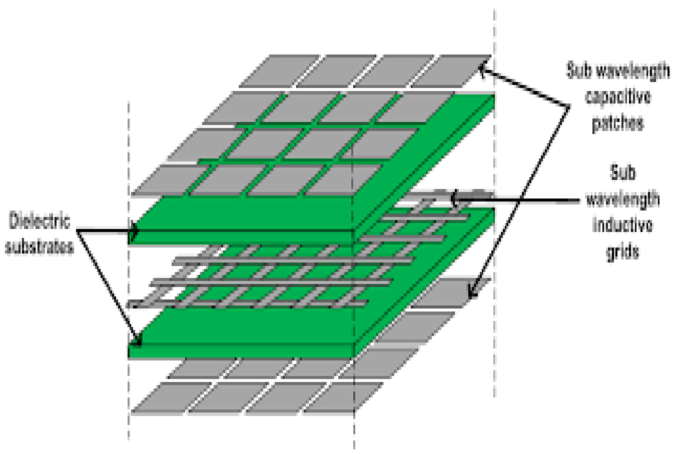

Figure 4. Structure of FSS

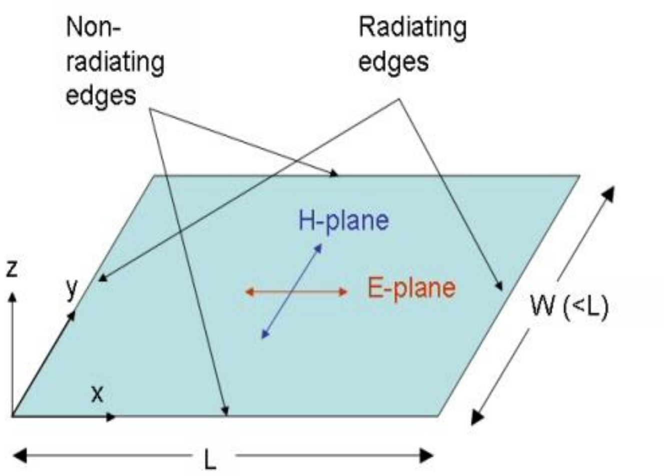

Figure 5. Patch edges

Figure3 shows characteristics of FSS. Figure 4 gives the structure of FSS. Figure 5 shows Patch edges.

III. SIMULATION RESULTS AND DISCUSSIONS

Based on transmission line model, antenna parameters are calculated. Generally elliptical antenna has elliptical polarised radiation but it is circular polarised when antenna is fed under specified condition. By limiting eccentricity of the ellipse to a range of 10 to 20 percent desired circular polarisation can be achieved.

S parameters are scattering parameters which are vector entities. They are popularly used in microwave circuit design and testing. At high frequencies, measurement of Y, H or Z parameters are difficult. Vector network analyser is used to measure S parameters. There are four scattering parameters for two port device. S_{11} and S_{22} are forward and reverse reflection coefficients respectively. When it is ideal short, S_{11}= -1 and for ideal termination S_{11}=0. S_{11} is measured below -10dB and is minimised at the resonating frequencies.Figure6 shows the S_{11} parameter graph. There are two resonating frequencies. The resonating frequencies of the proposed antenna design are 4.08 GHz and 5.45 GHz.

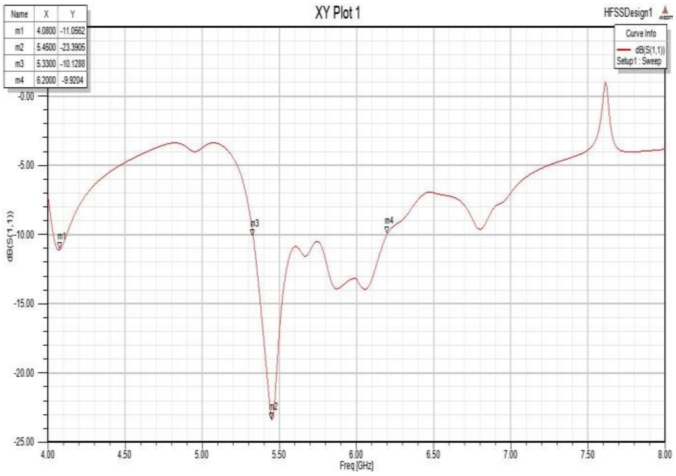

Figure 6. S_{11} parameter graph

VSWR indicates the mismatch between antenna and the feed lines connected to it. VSWR for a ideal system is 1 but practically it is below 2.When the VSWR graph is below 2, it means impedance is matched properly and reflections are less. If the antenna is poorly matched then VSWR value exceeds 2.Reflections are caused by mismatched impedances. For proper matching, the load impedance should be equal to characteristic impedance of the transmission line. The load must not have any reactance elements. Figure 7 shows VSWR graph. It is observed that at the resonating frequencies the VSWR value is below 2.The VSWR is 1.78 and 1.14 at the respective resonating frequencies.

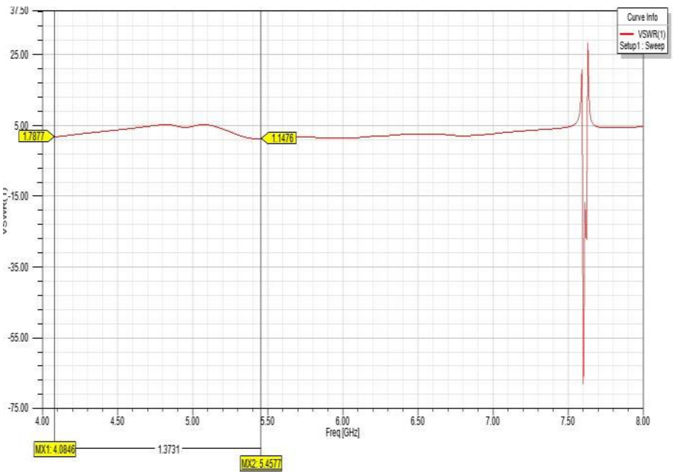

Figure 7. VSWR graph

Radiation is not uniform for all antennas in all directions. Radiation pattern is plotted in azimuth or E plane and elevation or H plane respectively.

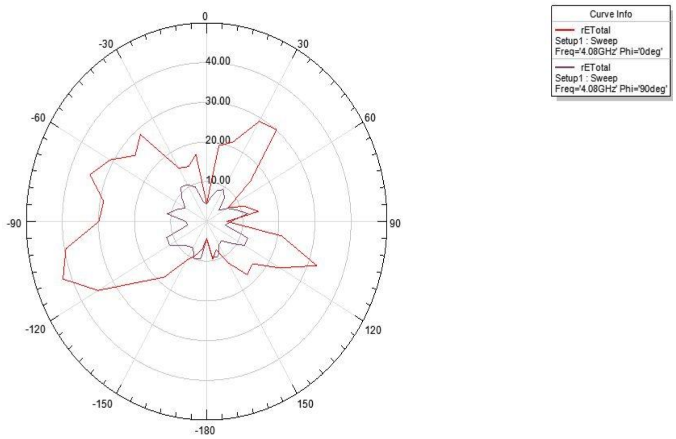

Figure 8. Radiation pattern at resonating frequency 4.08 GHz for $\varphi = 0^0$ and $\varphi = 90^0$

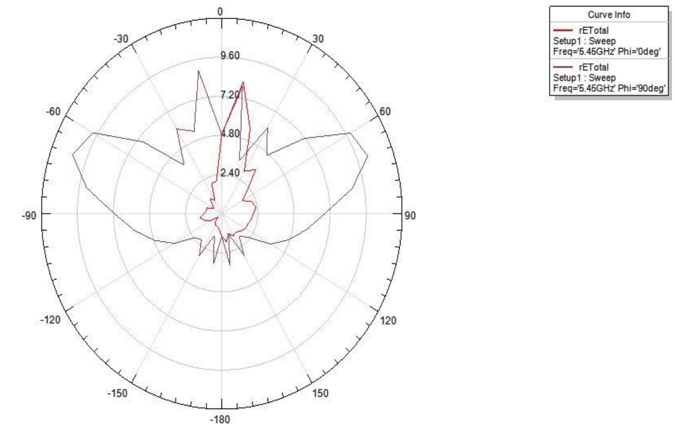

Figure 9. Radiation pattern at resonating frequency 5.45 GHz for $\varphi = 0^0$ and $\varphi = 90^0$

Figure 8 shows the radiation pattern at resonating frequency 4.08 GHz for $\varphi = 0^0$ and $\varphi = 90^0$ respectively. Figure 9 shows the radiation pattern at resonating frequency 5.45 GHz for $\varphi = 0^0$ and $\varphi = 90^0$ respectively.

Gain of an antenna is measured in dBi or dBd. Direction of maximum radiation is referred as gain. It can be discussed as a function of angle. Figure10 shows 3D polar plot of gain at 4.08 GHz resonating frequency. Figure11 gives 3D polar plot of gain at 5.45 GHz resonating frequency.

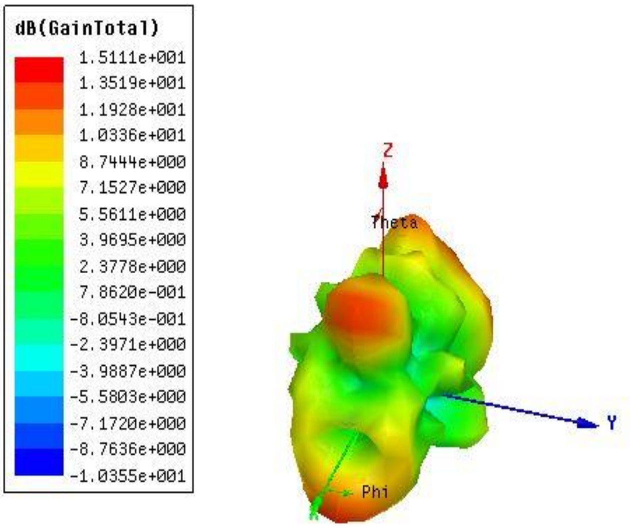

Figure 10. 3D polar plot of gain at 4.08 GHz

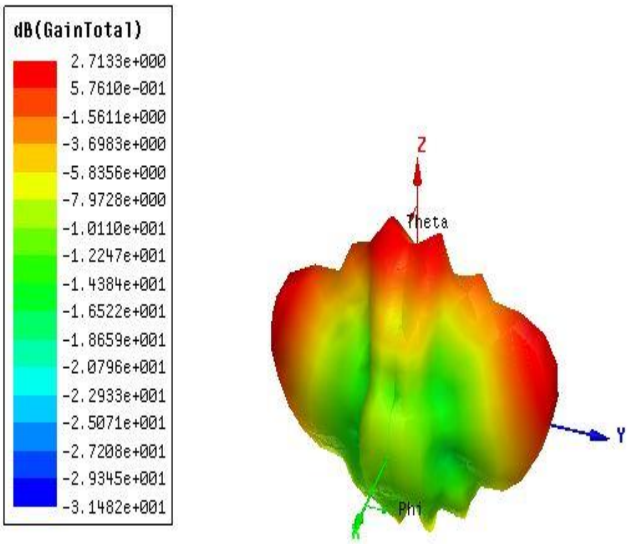

Figure11. 3D polar plot of gain at 5.45 GHz

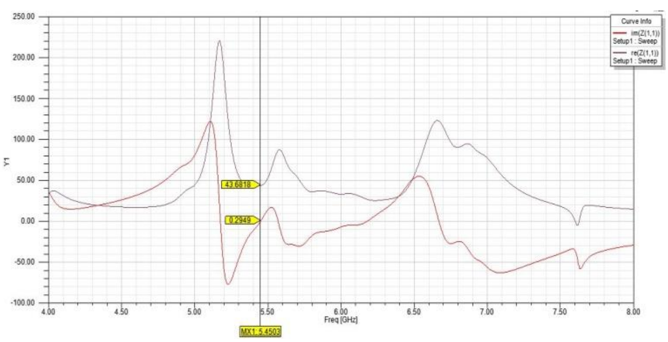

Figure 12. Input impedance Vs frequency graph

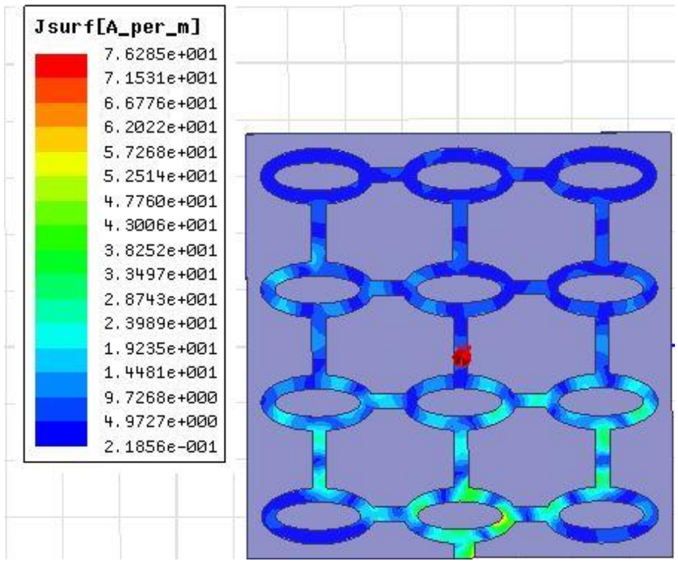

Figure 13. Current distribution of proposed antenna

Figure 12 shows input impedance Vs frequency graph. Figure 13 illustrates current distribution of proposed antenna.

Methods using current distribution curve are used to calculate antenna impedance, resistance, radiation resistance, reactance, radiation pattern etc.

IV. CONCLUSION

An interconnected elliptical ring patch FSS antenna is designed. It consist of periodic 3×4 array of twelve patches. The substrate is FR4 epoxy with dimension 150mm×150mm×1.6mm.The resonating frequencies of the proposed antenna are 4.08 GHz and 5.45 GHz. The antenna utilizes low power. Desired gain and bandwidth is achieved. The antenna finds its application in satellite communication. The results are obtained in C band using HFSS.

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