Design of Gain Enhanced Microstrip Patch Antenna Using Frequency Selective Surface

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***Abstract*: This paper designs a rectangular microstrip antenna with 9.5 dB gain at 9.5 GHz resonant frequency. For gain enhancement the antenna is backed with a frequency selective surface (FSS) made of 5x5 array of square loops. Square loop shaped unit cell of FSS is first designed with 6mm inner length and 6.5 mm outer length. Performance of unit cell Is analyzed using Floquet's port method in HFSS. Footprint of the final antenna is 37.5mm x 37.5mm after the FSS is placed. To design the base antenna standard formulae have been used. The antenna shows very prominent increase in gain as compared to the basic microstrip antenna.**

I. INTRODUCTION

There have been various researches in increasing the gain of a rectangular microstrip antenna. Many scholars have used various techniques to increase the gain of printed antennas such as EBG structures, adding superstrates, using better quality substrates and changing the shape of antenna. The gain enhancement techniques that involve either changing the shape of antenna or the ground plane may also result in including unwanted harmonics in the frequency response of the antenna. Very good quality substrates with good loss tangent are either very costly or not very easily available. This problem was greatly solved by the development of the metamaterial technology. In this the dielectric properties of traditional materials can be dramatically changed by synthesizing repetitive shapes on them. There are various literatures [1], [2], [3], [4] available on how to make these metamaterials.

There are another category of metameterials known as Frequency Selective Surface. These are periodic surfaces that have the capability to act as filters. FSS can be placed on the way of electromagnetic waves to pass some specific frequencies and block others. They have applications in Radomes, Filters, Subreflectors, absorbers and meanderline polarizers.

II. DESIGN OF 9.5 GHZ INSET FEED MICRSTRIP ANTENNA

This section shows the design procedure of a basic microstrip line fed patch antenna. This antenna uses inset feed to match the antenna impedance with impedance of the 50 ohms coaxial cable. Antenna is designed and simulated using HFSS – EM structure designing tool.

Design formula (equations 1-4) used to estimate the dimensions of a rectangle shaped antenna. Length and width that comes out of the formula for 9.5 GHz is 10 mm $\times$ 12 mm. To accommodate the above patch a substrate of 15 mm $\times$ 20 mm is selected. A substrate must have low loss tangent for better radiation performance. Roger RT/Duroid 5870 is chosen as the dielectric material with dielectric constant 2.33 and loss tangent 0.0012. Height of the substrate is taken as 1.5 mm.

RT/duroid® 5870 high frequency laminates are PTFE composites reinforced with glass microfibers. The randomly oriented microfibers result in exceptional dielectric constant uniformity.

The dielectric constant of these high frequency laminates is the lowest of all products, and low dielectric loss make them well suited for high frequency/ broad band applications where dispersion and losses need to be minimized. Because of its extremely low water absorption characteristics, RT/duroid 5870 laminates are ideal for applications in high moisture environments.

RT/duroid 5870 laminates are easily cut, sheared and machined to shape, and resistant to all solvents and reagents normally used in etching printed circuits or plating edges and holes. RT/duroid 5870 and 5880 laminates have the lowest electrical loss of any reinforced PTFE material, low moisture absorption, are isotropic, and have uniform electrical properties over frequency.

The antenna is fed through a microstrip line. Edge impedance of the patch is very high, so feeding the patch at the edge is never practical. An inset is made approximately at one third of the total length of the antenna and the feed is inserted. The patch impedance decreased as we go at the inner side of the patch and at about one-third length antenna impedance is approximately 50 ohms. Width of the microstrip line for 9.5 GHz is calculated using formula in [6] and it is computed as 4.5 mm. There are numerous other feeding techniques like probe feeding, proximity coupled feeding, aperture coupled feeding etc. [8].

To design a patch antenna one should decide the operating frequency f_r (in Hz), thickness of the substrate h and relative permittivity of the substrate ε_r.

Design formula used for the estimation of antenna geometry is as follows:

Width of the antenna is given by

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Effective Dielectric constant is given by (h/W<1)

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{2}$$

Actual Length of the patch is given by

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \quad (3)$$

Where,

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

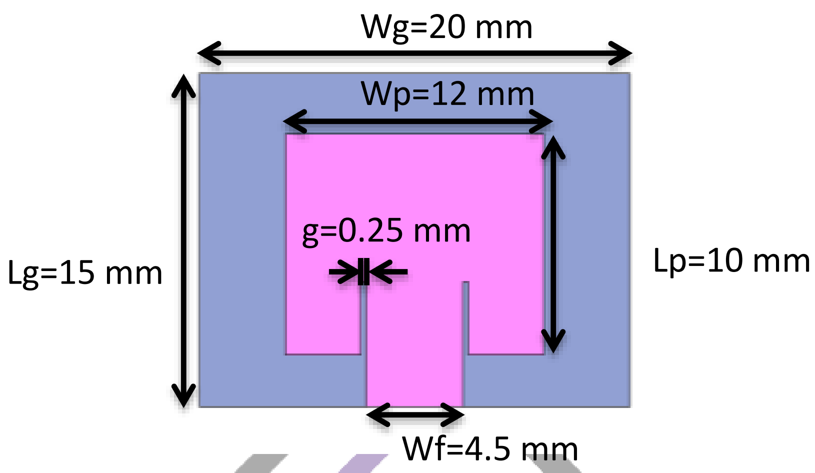


Figure 1 Dimensions of the designed antenna

Table 1 show the dimension of the patch antenna in tabular form.

TABLE 1 DIMENSION OF THE ANTENNA

Dimension	Value in mm
Width of the patch (Wp)	12
Length of the patch (Lp)	10
Width of the substrate (Wg)	20
Length of the substrate (Lg)	15
Inset feed gap (g)	0.25
Width of microstrip line	4.5

III. FREQUENCY SELECTIVE SURFACE

A. Design of a unit cell of FSS for 9.5 GHz

The proposed FSS consist of a board of Rogers RO3003 (with permittivity of 3 and loss tangent 0.0013). The thickness of the substrate is 0.782 mm. Size of the square shaped board is 7×7 mm. The FSS contain a square loop with inner length 6 mm and outer length of 6.5 mm on one side of the board. The loop lies on only lower side of the board (Side 2 shown in Fig 2). The mentioned dimension resonates at 9.5 GHz. For the sake of analysis the dimension of the square loop is varied keeping the thickness of the loop as 0.5 mm, resonance shifts elegantly as expected. Symmetrical circular patches on top and bottom makes the shape a bidirectional filter. Fig 3 shows the 3D view and Fig 3 shows the top view of the unit cell.

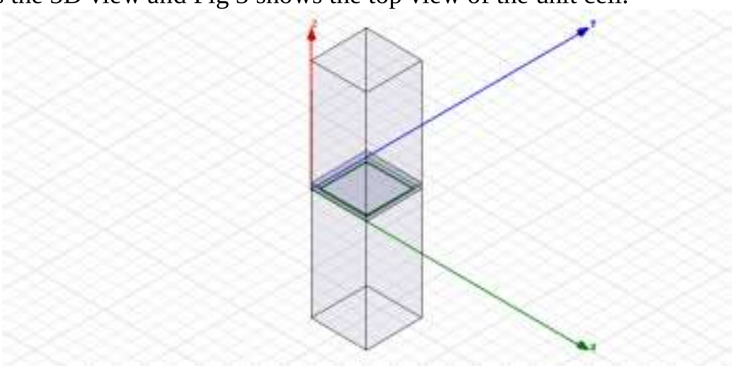


Figure 2 3D view of the designed unit cell

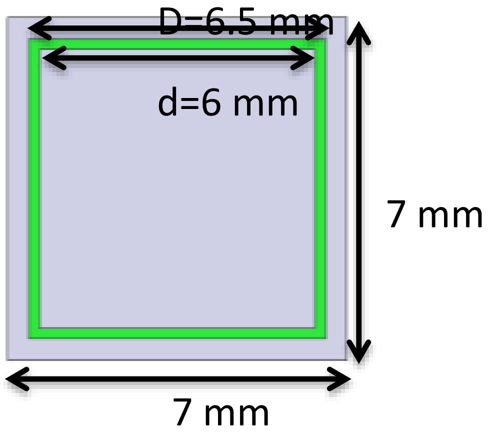


Figure 3 Top view of the unit cell

B. Behaviour of FSS unit cell

Reflection Coefficient

The reflection coefficient of a unit cell of FSS is shown in Fig 4. It shows that if an EM wave of 9.5 GHz enters from port 1 how much of it is reflected back. It can be seen that the designed cell reflects most of the energy at 9.5 GHz if the inner length (d) of the loop is 6 mm and outer length (D) is 6.5 mm. All other sizes of the loop show their responses at other frequencies.

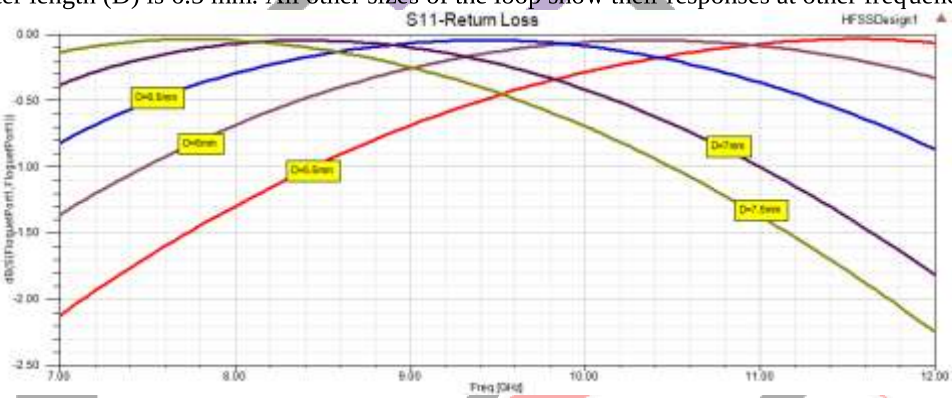


Figure 4 Reflection coefficient of Unit Cell for various loop dimensions

Transmission Coefficient

The transmission coefficient of the unit cell of FSS is shown in Fig 5. It shows that if an EM wave of 9.5 GHz enters from port 1 how much of it is transmitted to port 2. It can be seen that the designed cell does not allow frequencies at 9.5 GHz if the inner length (d) of the loop is 6 mm and outer length (D) is 6.5 mm. If the dimension of the loop is changed transmission coefficient curve is moved to other frequencies.

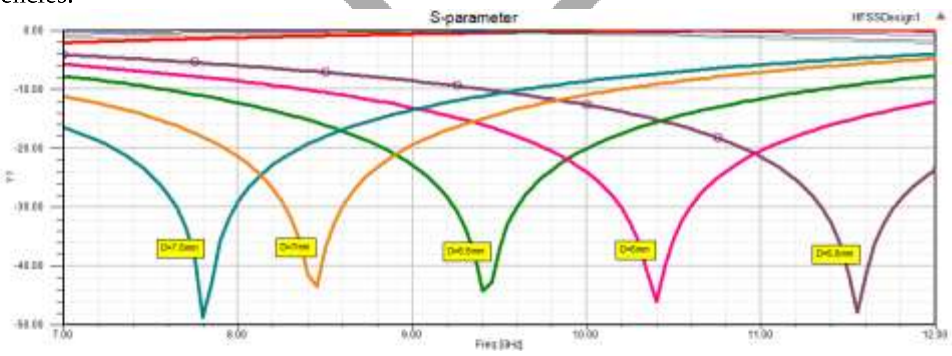


Figure 5 Transmission Coefficient of Unit Cell for Various Loop Dimensions

Above results show that if an array of above unit cell is designed, it will reflect 9.5 GHz. That is why the array of this FSS is placed behind the ground plane of the designed microstrip patch antenna.

IV. DESIGN OF GAIN ENHANCED MICROSTRIP PATCH ANTENNA

Fig 6 shows the final designed microstrip antenna. Patch antenna resonant at 9.5 GHz is backed with a 0.782 mm thickness substrate with square loops in an array of 5 × 5.

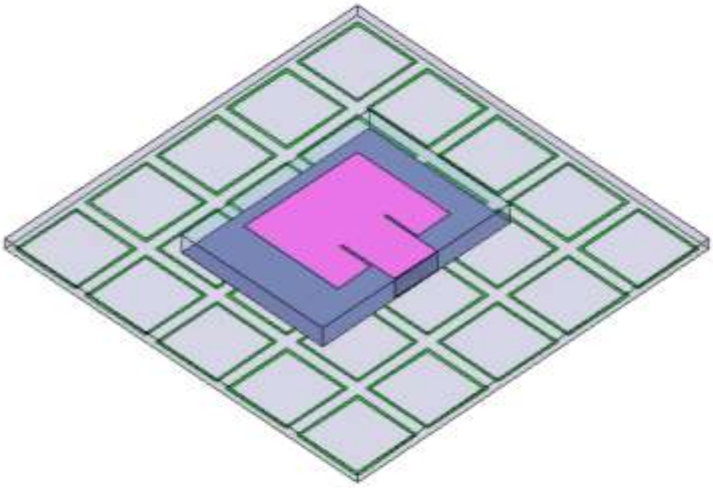
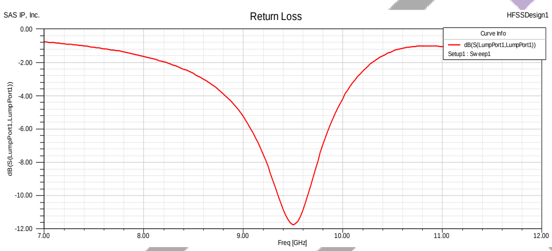
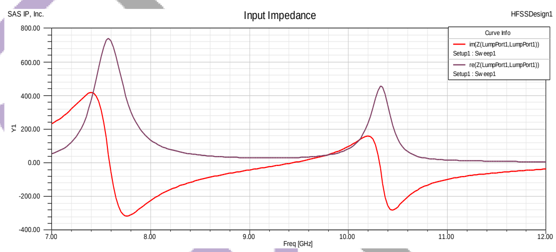


Figure 6 Microstrip Patch Antenna with FSS Substrate

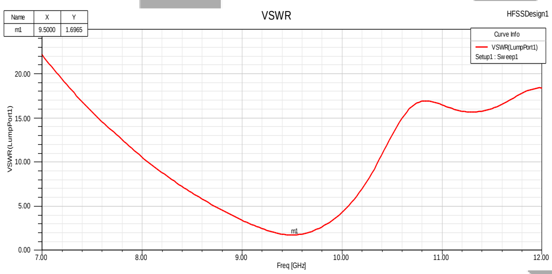
V. SIMULATION RESULTS OF ENHANCED GAIN ANTENNA



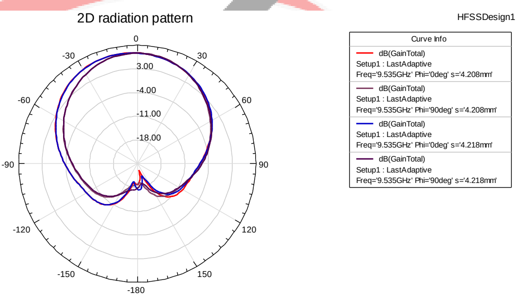
(a) Return loss of final Antenna



(b) Antenna impedance



(c) VSWR



(d) Radiation Pattern

Figure 7 Simulation Results

IV. CONCLUSION

Fig. 7 (a), (b), (c) and (d) show the return loss, antenna impedance, VSWR and radiation pattern respectively of the designed antenna. This is a good sign because theoretically the behavior of antenna changes when another structure is introduced in its vicinity. A substrate below the antenna in its invisible region is placed rather than putting a superstrate directly in its radiating region. This is the main reason that other than providing its reflection characteristics FSS is not changing the behavior of microstrip antenna. From Fig 7 (d), it can be seen the radiation pattern of microstrip antenna is also improved because of the FSS substrate. Gain of the simple microstrip antenna was around 6 dB. After using FSS the gain is increased upto 9.5 dB.

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