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Improving the Bandwidth of High Gain Patch Antenna Using Frequency Selective Surface

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Abstract
This research work was devoted to design and simulated a highly gain Frequency Selective Surface (FSS). We enhanced the antenna bandwidth by using a patch microstrip as the main radiation and structure of the FSS on the upper layer of antenna. Many researches have designed the FSS on the antenna. However, the antenna gain and bandwidth were satisfactory. In our work we simulated this antenna using Ansoft HFSS Software and CST Software. The results indicate that the radiation pattern gain of antenna and band width vitally enhanced. In this case the gain increased by 3.3dB and band width increased 8.9%. However these change increase the height of antenna, when is one of the disadvantage of this microstrip patch antenna. In our method the antenna final working frequency in each desirable band can be regulated the parameters by the FSS and patch microstrip.

Keywords: High-Gain Antenna, Electromagnetic Band Gap (EBG), Microstrip Antenna, Frequency Selective Surface (FSS)

INTRODUCTION

In recent years, a new kind of highly directive and compact antennas has been realized using Electromagnetic Band Gap (EBG) materials [1-5]. More recently, many researchers proposed new surfaces to replace the EBG antenna upper interface usually conceived of periodic dielectric layers. These surfaces are known as Frequency Selective Surfaces (FSSs) and they have been used to design different types of EBG antennas with directive [6], [7], sectoral [8,9], and omnidirectional [10,11] radiation patterns. The use of the FSS in the EBG antenna has enabled the conception of many configurations like the dual band and the low profile designs. Moreover, these surfaces combined together allow, with respect to certain conditions [12], [13], the enhancement of the antenna radiation bandwidth. This last configuration with combined FSS is used to design a wide-band EBG antenna operating in the X-band. Many solutions have been proposed in the literature to improve antenna radiation bandwidths [14]. We utilized a FSS structure in ground of antenna to enhancement the antenna bandwidth. Therefore, we presented an ultra-wideband [15] and wideband [16] antenna with a novel multilayer FSS reflector on a microstrip which provides easy and inexpensive approach.

This microstrip patch antennas became very popular in mobile and radio wireless communication, due to ease of their analysis, fabrication, and attractive radiation characteristics. The use of microstrip antenna in wireless communication found advantageous compared to other types of antenna due to their low fabrication cost, small size, supporting character to linear as well as circular polarization, robustness when mounted on rigid surfaces. However, they have their own limitations due to low efficiency, narrow bandwidth, surface wave loss and low gain [17]. FSS, as superstrate overcomes the limitations of microstrip patch antenna. We simulated our design using High Frequency Structure Simulator (HFSS) tool [18-20]. We improved the gain and obtained some other frequency band for many application [17], [18]. For example X-band used in military application, for military application antenna should have high gain while patch antenna does not need this facilities. One of the advantages of the proposed method is that we are able to design the final working frequency of the antenna in each desirable band by regulating the parameters that are related to the structure of the FSS and patch microstrip. In the following section, we calculate the structure of this FSS design.

Structure of the FSS

Figure 1 shows radiation between the ground and the patch and FSS structure. This radiation increased the gain and reduced bandwidth of the antenna. A phase difference in the wave propagation is:

$$\Delta\theta = \theta_R - \pi - \frac{2\pi}{\lambda} 2d = 2N\pi \qquad (1)$$

Where $\Delta\vartheta$ is phase difference in the wave propagation, θ_R is reflection coefficient phase of the FSS superstate structure, and d is distance between FSS superstrate and patch. In equation (1) π is reflection coefficient phase of the ground, $(2\pi/\lambda)\times2\times d$ is the phase difference due to the distance between FSS and patch, N is integer, and λ is the wave length. If $\Delta\vartheta$ is equal to pair coefficients of π, maximized directivity. The directivity antenna (D) is:

$$D = \frac{1 - R^2}{1 + R^2 - 2R \times \cos(\Delta\theta)} \quad (2)$$

Where R is reflection coefficient. If $\Delta\vartheta$ is equal to pairs coefficients of π, maximum directivity is expend on (3):

$$D_{\max} = \frac{1 + R}{1 - R} \quad (3)$$

If the reflection coefficient is close to 1, D_{max} will be maximum directivity. Bandwidth (BW) is also (4):

$$BW = \frac{\Delta f}{f_0} = (\lambda / 2\pi L_r) \times \frac{(1 - R)}{\sqrt{R}} \quad (4)$$

Where f_0 is frequency of antenna. If the reflection coefficient is close to one, the bandwidth is reduced. Simplifying (1), the height of FSS structure becomes:

$$d \approx \frac{\lambda}{2} \quad (5)$$

According to (1), if $\Delta\vartheta$ is equal to pair coefficients of π, the high of FSS superstrate for frequency center of 10.7GHz becomes 13.7 mm. In the following section we present the design of patch antenna.

Design of Patch Antenna

The structure of microstrip antenna is usually consists of a pair of parallel conducting layers separating a dielectric medium, in this structure substrate is Arlon AD300A (tm). The source quality was a coaxial type the dimension of the rectangular patch antenna which is shown in Fig. 2. In this antenna, the substrate has a thickness h_1=1.6 mm and a permittivity ε_r=3. The length and width of patch are a=22 mm, b=21 mm respectively. The length and width of ground plane are L_g=W_g=40 mm. The antenna is also fed by a coaxial Probe. Feed point is located when 50 ohm resistance occurs [21]. The designed microstrip antenna has a fractional bandwidth (-10 dB) of 2.76%, which ranges from 10.7 GHz to 11 GHz maximum gain is 8.9 dB at the center frequency of 10.85 GHz. In the following section we present the design of FSS structure.

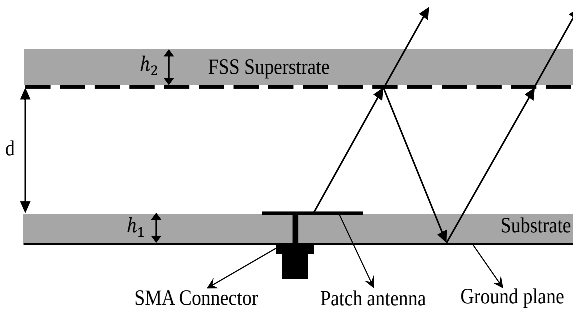

Figure 1. Radiation between resonator elements of antenna

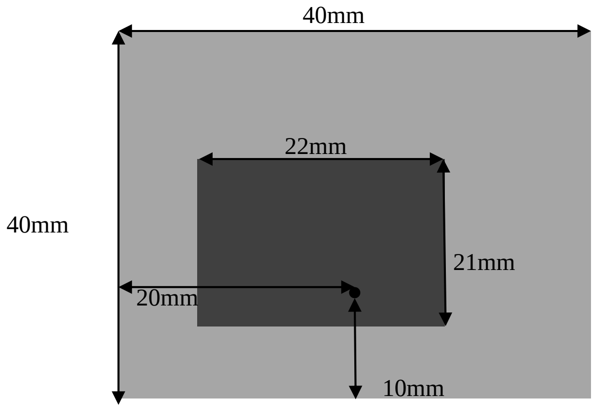

Figure 2. Dimension of the patch antenna

Design of FSS Structure

Superstrate is a FSS realized by a periodic distribution of metallic elements printed on a dielectric slab. It entirely reflects the incident waves. By insertion of a source (a patch antenna) between the ground plane and the superstrate, a high directive antenna can be obtained. We designed a unit cell of the FSS structure using HFSS and CST software. Boundary conditions master-slave are considered it periodically. This is a wave guide condition for the periodic structure that provided infinite condition. The results obtained for a single cell to the whole structure expands. Feeding (stimulation) of the wave plate was used floquet port that each cell gives the same radiation angle. Bandwidth and stability of resonant frequency with angle of incidence should be considered for the design of the unit cell [19]. Which is a square loop structure. Fig. 3 depicts the dimensions of the FSS unit cell. Each unit cell has three square loops, and four square patches printed on the FR4_epoxy dielectric layer. The unit cell has a thickness h_2=0.4 mm and a permittivity ε_r=4.4. The dimension of each unit cell and FSS structure is 10×10mm, and 40×40 mm respectively. Fig. 4 depicts the boundary conditions and excitation in the FSS unit cell. In the following section we present the result and discussion calculated in this study.

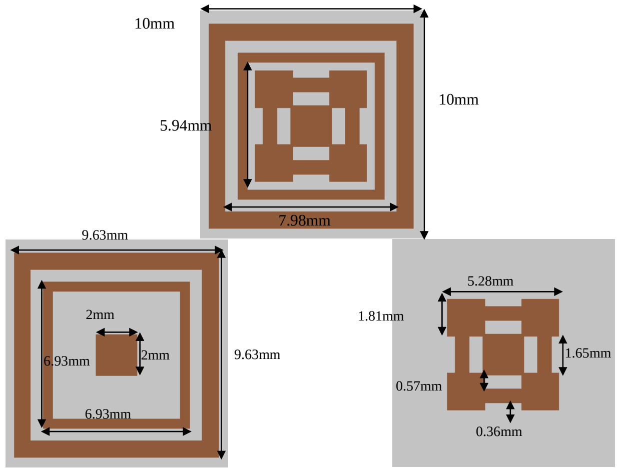

Figure 3. Dimension of the FSS unit cell

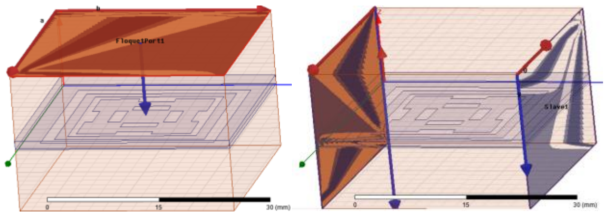

Figure 4. boundary conditions and excitation in the FSS unit cell

RESULTS and DISCUSSION

Three factors contribute to the amount of gain and return loss curve. First, it is the height of the FSS, which are also on the return loss and the gain curve. The second factor is the thickness of the FSS. Better results can be achieved by reducing the thickness. The results for the three values are given in Table 1. If the thickness of the structure increases, its impedance increases, resulting in reduced power transfer. The third factor is also the unit cell. The simulations shows minimum number of unit cells to obtain an acceptable answer is 4 rows. When the number of layers becomes greater than this value, no significant changes occurs. Most of the changes does not happen remarkably. Figure 5 shows the variations of return loss curve with respect to the FSS height variations. Figure 6 shows S-parameter curve antenna without the FSS superstrate and antenna with superstrate FSS and S11 of FSS structure. Figure 7 shows a plot of antenna gain without the FSS. Figure 8 shows a diagram of the antenna gain of the FSS structure as the layer's. Height is calculated from the equation (2) which is 13.7 mm.

TABLE 1.

Number of design	Gain Changes Depending on Thickness Variations Patch FSS Structure	
	Thickness(um)	***Gain(dB)***
1	Antenna without FSS superstrate	8.7dB
2	Sheet without thickness patch	12dB
3	17um	11.8dB
4	70um	11.3dB

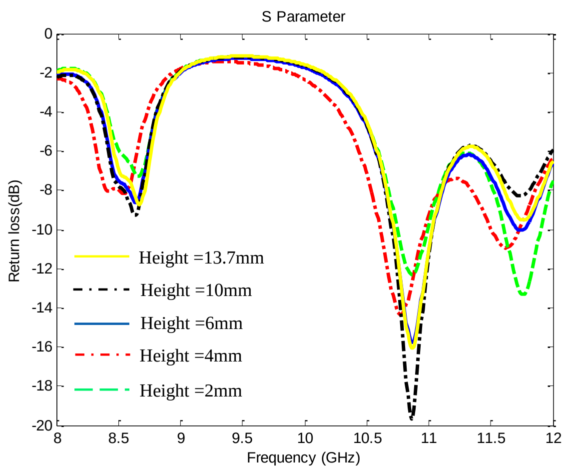

Figure 5. Changes to the return loss curve by the changes of FSS height

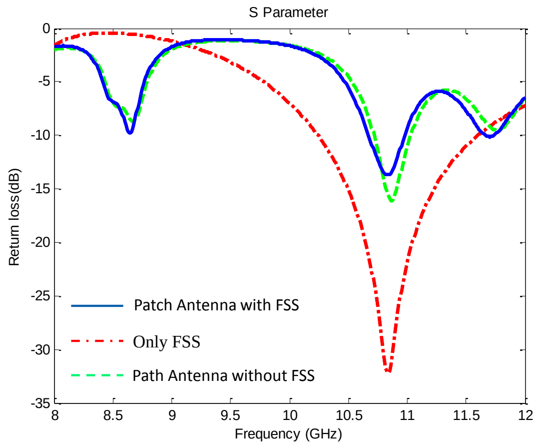

Figure 6. S Parameter curve of Antenna FSS structure

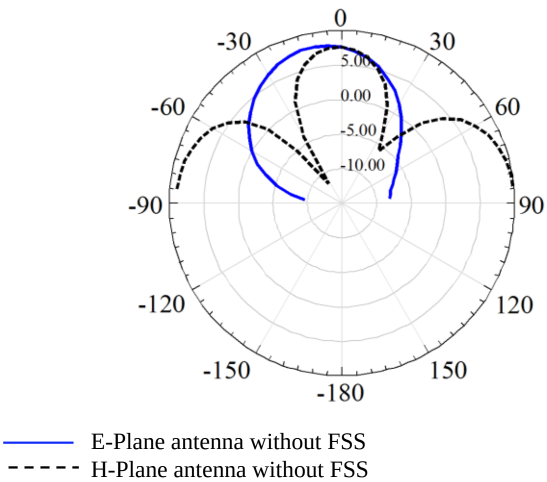

Figure 7. The gain pattern of antenna without the FSS

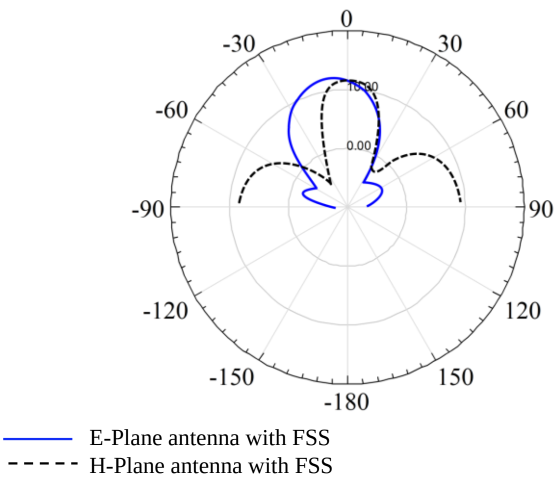

Figure 8. The gain pattern of antenna with the FSS superstrate

To improve the bandwidth, we used a FSS structure in ground of the antenna. This idea is similar to imperfect ground. By this way we get an enhancement bandwidth. Having the FSS structure in ground, the antenna enhanced 8.9% bandwidth. Fig. 9 shows the final schematic of FSS antenna. Figure10 shows the return loss parameter for antenna without FSS structure and return loss of antenna with superstrate FSS structure, and return loss of antenna with FSS superstrate and ground structure. Fig. 10 shows the improvement of the bandwidth of Micro strip patch antenna. This approach varies the frequency resonance a little amount. This little frequency shift shown in Fig. 10. Therefore we designed a high gain microstrip patch antenna by FSS structure that solve problem of microstrip patch antenna with a low gain.

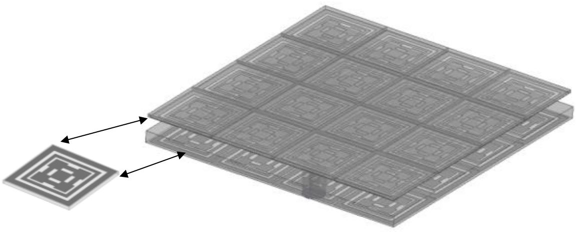

Figure 9. The final schematic of FSS antenna

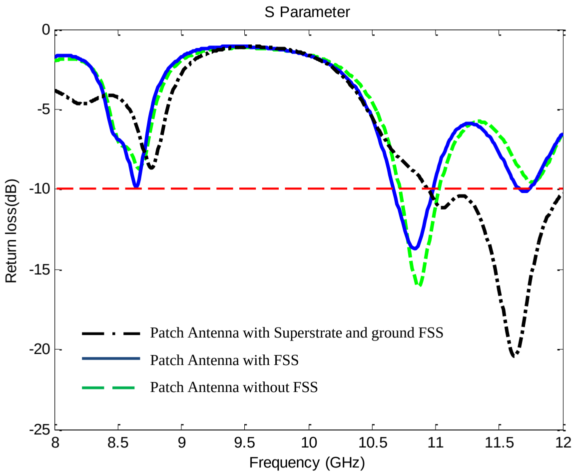

Figure 10. Return loss of FSS antenna by superstrate an ground FSS structere.

CONCLUSIONS

Integration of the FSS structure with the patch antenna improved the gain and bandwidth. By using the FSS structure, we used FSS structure in the superstrate and ground of antenna to improve bandwidth and gain of an antenna. The surface wave effect is reduced resulting to the improvement of the antenna performance which an advantage of the proposal method. Therefore, we are able to design the final working frequency of the antenna in each desirable band by regulating the parameters that are related to the structure of the FSS and patch antenna.

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