Improving the Bandwidth of High Gain Fabry-Perot Antenna Using FSS Substrate

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Abstract—In this paper presents a novel design of a Fabry-Perot (FP) resonator high gain antenna with improved bandwidth in X band. FP Resonator antenna generally consists of primary radiator backed with a metal ground plane and a partially reflective surface (PRS). We designed and simulated a highly gain and improved bandwidth antenna by the structure of Frequency Selective Surface (FSS). FP cavities are mainly used as energy-focusing elements to enhance the antenna directivity but at the same time leads to bandwidth reduction. This reduction of bandwidth in FP antenna is compensated by the use of EBG substrate. The proposed structure consists of Frequency selective surface array that is implemented as a PRS and an EBG substrate. The final design of antenna, which made of patch microstrip as the main radiator and the structure of the Frequency Selective Surface (FSS) as the upper layer of antenna also we have new method for enhanced the band width. We use Frequency Selective Surface on substrate the Antenna for enhancement band width. This Antenna is designed to operate at a frequency around 10 GHz. The structure increases the gain from 5.1 dB up to about 10.5 dB or more and improves the bandwidth 2.9%. For validation of purposes, the antenna is designed and simulated through using of two different 3D full-wave electromagnetic simulation tools; CST Microwave Studio and Ansoft's High Frequency Structure Simulator (HFSS).

Keywords—High-Gain Antenna; Electromagnetic Band Gap (EBG); Microstrip Antenna; Frequency Selective Surface (FSS); Fabry-Perot (FP); partially reflective surface (PRS).

I. INTRODUCTION (HEADING 1)

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 design high gain FP antenna used periodic dielectric structure. These surfaces are known as FSS. The FSS structure is used to design different types of FP and EBG antenna with directive [6], [7], sectoral [8], [9], and omnidirectional [10], [11] radiation patterns. The use of the FSS in the FP 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] enhanced the antenna 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]. The creation method of this paper to enhancement of bandwidth use FSS structure on substrate of antenna. 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. In this paper we used two FSS layer, one of the FSS layer is used superstrate to increase the gain. And the second FSS layer printed on the antenna substrate is used to improve the antenna bandwidth. These FSS structures printed on the antenna substrate were aimed at suppressing surface waves in the antenna operation frequency, so that improved the antenna bandwidth. The FSS superstrate layer enhanced directivity of antenna. So that superstrate FSS structure is enhanced antenna total gain. 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], [19], [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. In this paper we concluded this improvement for the antenna in X-band. One of the advantages of the proposed method is that we can design the final working frequency of the antenna in

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each desirable band by regulating the parameters that are related to the structure of the FSS and patch microstrip.

II. METHODS

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:

\[
\Delta \theta = \theta_p - \pi - \frac{2\pi}{\lambda} 2d = 2N\pi
\]  

(1)

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

\[
D = \frac{1 - R^2}{1 + R^2 - 2R \cos(\Delta \theta)}
\]  

(2)

Where \( R \) is reflection coefficient. If \( \Delta \theta \) is equal to pair coefficients of \( \pi \), maximum directivity is depend on (3):

\[
D_{\text{max}} = \frac{1 + R}{1 - R}
\]  

(3)

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

\[
BW = \frac{f_{\text{BW}}}{f_0} = \frac{(\lambda/2\pi a)}{\sqrt{R}}
\]  

(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:

\[
d \approx \frac{\lambda}{2}
\]  

(5)

According to (1), if \( \Delta \theta \) is equal to pair coefficients of \( \pi \), the high of FSS superstrate for frequency center of 10.57GHz becomes 14.2 mm. In the following section we present the design of patch antenna.

III. DESIGN OF FSS STRUCTURE

Is used the FSS superstrate to enhanced the Antenna gain. According with previous descriptions appropriate height for placing superstrate is obtained of (1).to design the FSS with above specification has been suggested a FSS unit cell dimensions in Fig. 3. Further to this unit cell will be presented the details. To increase the bandwidth of the antenna has been suggested a unit cell dimensions in Fig. 4. After placing FSS layers as shown in Fig. 5, the antenna gain is improved. By several simulations is presented The Optimized FSS structures for enhanced bandwidth. Using FSS on the antenna substrate is one of the benefits of this antenna. This has increased antenna bandwidth, and it can be manufactured easily.

Superstrate and lower layer printed on substrate are a Frequency Selective Surface (FSS) realized by a periodic distribution of metallic elements printed on a dielectric slab. The FSS superstrate layer can entirely reflect almost incident waves. By insertion of a source (a patch antenna) between the ground plane and the Superstrate, a high directive antenna can be obtained. So First, we design a unit cell of the FSS structure in HFSS and CST software. Each unit cell has one square loops and one square patches printed on the FR4 epoxy dielectric layer. The Unit Cell has a thickness \( h_2 \)=1.6 mm and a permittivity \( \varepsilon_r=4.4 \),the dimension of the unit cell is 10×10 mm and the dimension of frequency selective surface structure is 100×100 mm.
Figure 3. Geometry of the FSS Unit cell printed on the substrate.

Figure 4. Geometry of the complete antenna structure.

IV. RESULTS AND DISCUSSION

Figure 6 shows the phase curve versus frequency has a positive slope in the range of 10.3–13 GHz, which is expected to satisfy the relationship of (1). There is no special requirement for the exact reflection phase values. Even though the reflection phase is fixed, another parameter, namely the cavity height, can be adjusted for a required resonant frequency, as indicated in (1). Fig. 7 shows that the reflection magnitude is larger than 0.5, with the minimum value occurring at 10.1 GHz. Fig. 7 shows the range that magnitude of reflection coefficient is larger than 0.5, this is indicated by the red line, this range is 10.3GHz to 12.9GHz. Fig. 8 shows the reflection phase of FSS unit cell printed on the antenna substrate. It shows that the reflection phase of FSS layer printed on the antenna substrate between 10.3GHz to 11GHz is zero. That is operating frequency range of antenna. So that Elements FSS structures printed on the antenna substrate suppressing surface waves Propagation in operating frequency range of antenna [21].

Figure 7. Reflection Phase of the FSS layer structure printed on the antenna substrate.

Figure 9 shows the simulated return loss of the proposed FP antenna structure that consists of a superstrate FSS layer and an FSS layer printed on substrate. The simulated return loss bandwidth from 10.68 to 11 GHz is about 2.9%. It can be found that the operating band slightly shifts forward after covered by the FSS layer. Fig. 10 shows the results of the parameter study of d. With d increasing from 13mm to 14.5 mm, the impedance matching of the antenna becomes better, and the directivity slightly rises in the lower band but drops obviously in the higher band, which is more sensitive to d in the higher band. So the height of superstrate FSS layer is selected d=14.5mm. Fig. 11 shows the antenna radiation patterns of gain at the center frequency of 10.6 GHz at E-plane. The maximal gain has a value of 10.5dB, so the gain from 5.1 dB up to about 10.5dB. Fig. 12 shows the antenna...
radiation patterns of gain at the center frequency of 10.6 GHz at H-plane. The Gain curves of the antenna and the FP resonator are plotted in Fig. 13.

![Figure 8](image1.png)

Figure 8. Reflection coefficients of the patch antenna and the FP resonator antenna without lower FSS layer printed on substrate and FP resonator antenna with lower FSS layer printed on substrate.

![Figure 9](image2.png)

Figure 9. Reflection coefficients from parameter study of the distance $d$ between the ground plane and the superstrate FSS layer.

![Figure 10](image3.png)

Figure 10. Simulated E-Plane radiation pattern of antenna without FSS layers and proposed FP antenna with FSS layer printed on substrate.

![Figure 11](image4.png)

Figure 11. Simulated H-Plane radiation pattern of antenna without FSS layers and proposed FP antenna with FSS layer printed on substrate.

![Figure 12](image5.png)

Figure 12. Simulated the gain of antenna without FSS layers and proposed FP antenna with FSS layer printed on substrate.

V. CONCLUSIONS

The use of a planar FSS printed on the dielectric substrate to improve the bandwidth of patch antenna. And the FSS structure is used on superstrate of patch antenna to enhance the directivity on antenna. These planar FSS structures printed on the antenna substrate were aimed at suppressing surface waves in the antenna operation frequency, so that improved the antenna bandwidth. The FSS superstrate layer enhanced directivity of antenna. The maximal gain has a value of 10.5dB, so the gain from 5.1 dB up to about 10.5 dB, and improves the bandwidth 2.9%.

REFERENCES


