Electromagnetic Band Gap (EBG) Superstrate Resonator Antenna Design for Monopulse Radiation Pattern

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Abstract **─** A high directive electromagnetic bandgap (EBG) antenna operating in a wide frequency band is used to design a monopulse radiation pattern. Four aperture coupled microstrip antennas (ACMA) are used as feeding sources in this EBG antenna, and a frequency selective surface (FSS) is used as a superstrate layer. By suitable design of a wideband feeding network, it is possible to obtain a monopulse radiation pattern in E&H-Planes simultaneously. In this antenna, using the superstrate layer and the ACMA simultaneously, leads to produce a wide frequency band for the antenna reflection coefficient. Also, high directivity is achieved only by using the superstrate layer that has been made by the FSS layer with square loop elements. At first, a wideband ACMA is designed to operate in x-band. Secondly, after the design of optimum superstrate layer by the FSS structure, it is added to the four ACMA in order to increase both bandwidth and directivity. Finally, a wideband feeding network which operates in X-Band is designed to produce monopulse radiation pattern. The EBG antenna operates in three different modes including one sum radiation pattern and two difference radiation patterns in E&H-Planes simultaneously.

Index Terms **─** Aperture coupled microstrip antennas (ACMA), electromagnetic bandgap (EBG), and monopulse radiation pattern.

I. INTRODUCTION

Electromagnetic bandgap structures are periodic structures that can be used to control and manipulate the propagation of electromagnetic waves. The high directive resonator antenna is an example of antenna application of EBG structures which is also called the EBG antenna [2-4]. The EBG antenna consists of a feeding source and some superstrate layers. By suitable design of the superstrate layers it is possible to obtain a high directive antenna. There are several configurations for the design of the superstrate layer. In low profile antenna applications this layer must be compact, easy to fabricate and commercially available [5-8]. To this purpose, frequency selective surfaces (FSS) can be good candidates. Various configurations such as ring, patch, square loop, strip and slot shapes have been used to design FSS superstrate layer [9-11]. By using the FSS superstrate layer singularly, or combination of the FSS layer and reactive surface, the bandwidth, polarization and radiation pattern characterizations such as side lobe level (SLL) can be controlled [12-16]. Beside the enhancement of directivity, the FSS superstrate layer can be used as a polarizer. In this case, it is possible to obtain circular polarization by using a single source [17, 18].One of the most important challenges in the design of the EBG antenna is its frequency bandwidth for the reflection coefficient and maximum directivity. These characteristics depend on the FSS superstrate layer and feed source [19-20]. Among various feeding sources that have been used, microstrip antennas, because of their low profile and easy construction are very desirable. The authors in [21], beside the enhancement of directivity, have studied the effect of the FSS

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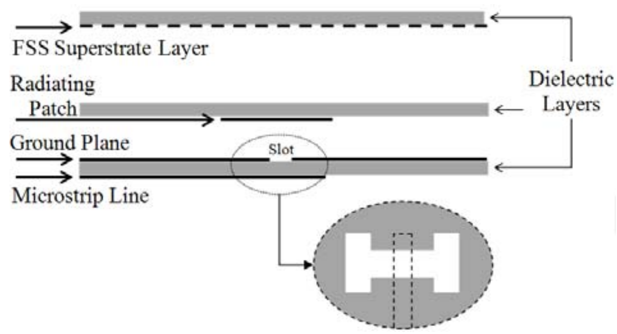
superstrate layer on the reflection coefficient of a probe-fed microstrip antenna.

In this paper, using an ACMA as the feeding source and an FSS layer as the superstrate, the EBG antenna will be studied. The reflection coefficient of the ACMA has the widest frequency bandwidth among the single fed microstrip antennas. This phenomenon is obtained by suitable design of coupling aperture configuration, but the directivity of the antenna decreases in the 10dB return loss (RL) bandwidth. The FSS superstrate layer is used to solve this problem. In addition, beside the directivity, a wide frequency band for the reflection coefficient by a suitable design of the FSS superstrate layer is obtained. Compared to monopulse slotted waveguide array antennas, it operates in a wider frequency bandwidth. A typical 10dB RL bandwidth of monopulse slotted waveguide array is less than 10% [1-chapt.46, 28]. Also, compared to monopulse microstrip array antennas, it has a simpler feeding network and therefore a little loss of power in the feeding network. It must be noticed that in the microstrip array antennas the microstrip feeding network is distributed for all elements and some of the power is dissipated as undesirable radiation power in the feeding network.

In Section II, the FSS superstrate layer and the ACMA are designed separately and in Section III, the combination of ACMA and FSS superstrate layer are studied. In this section, the most effective parts that influence the radiation characteristics and the bandwidth of the antenna are examined parametrically. In Section IV, to design the monopulse antenna four ACMA are used as the feeds of the EBG antenna. By suitable excitation of these four antennas, it is possible to obtain different radiation patterns including two difference radiation patterns and a sum radiation pattern. Also, in this section a suitable wideband feeding network which produces such excitations of the antennas, is designed. All simulations have been done by high frequency structure simulator (HFSS) based on finite element method (FEM).

II. DESCRIPTION OF THE ANTENNA CONFIGURATION

The antenna structure is composed of three sections including coupling aperture, radiating patch and the FSS superstrate layer (Fig. 1a). The antenna configuration to design monopulse antenna is depicted in the Fig. 1b.



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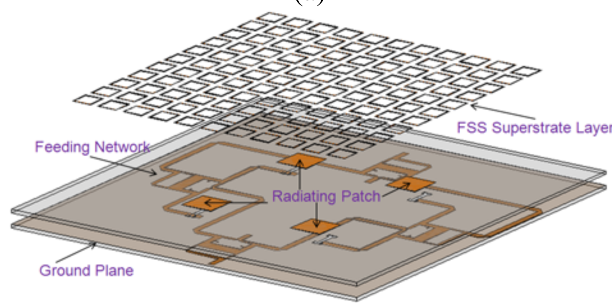


(b)

Fig. 1. (a) Geometry of EBG antenna fed by a single aperture coupled microstrip patch. (b) Geometry of EBG antenna fed by four apertures coupled microstrip antennas to design monopulse antenna.

A. Design of the FSS Superstrate Layer

There are different configurations and methods to design the superstrate layer. In fact, this layer acts as a partially reflecting surface. Near its resonance frequency where the reflection coefficient of surface is about unity, radiating source, and the superstrate layer produce resonance condition. In this case, the directivity of antenna increases considerably [7, 11]. The resonance frequency of the FSS superstrate layer has to coincide with a desired operating frequency. In this paper the square loop elements have been used to design the FSS superstrate layer. The square loop has symmetrical geometry and can be used in dual polarize and dual band applications. Also, compared with the patch element it has a more compact size and a more controllable resonance frequency. Figure 2 shows the amplitude and phase of reflection coefficient of the FSS superstrate layer. Because of the periodicity of the FSS superstrate layer, to determine its reflection coefficient of the FSS, it is enough to analyze just one cell.

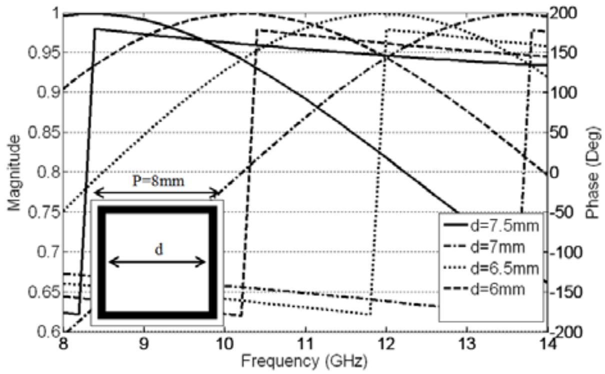
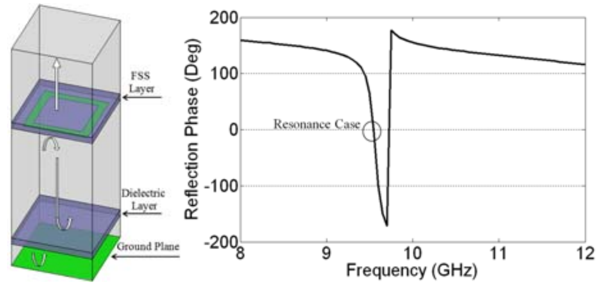


Fig. 2. Magnitude and phase of reflection coefficient of FSS.

Figure 3 shows how the FSS superstrate layer in combination with an aperture coupled microstrip antenna is used to produce resonance condition. In this configuration, there are three layers that are important in producing resonance condition. These layers are the ground plane in which the coupling aperture of ACMA has been placed, the dielectric layer in which the patch has been placed, and the FSS superstrate layer. The reflection coefficient of ground plane for horizontal electric fields is (-1). The dielectric layer reflects and transmits the EM fields with coefficients proportional to the thickness and dielectric properties of layer and the FSS layer reflects and transmits the EM fields according to the Fig. 2. Among these layers, only the FSS layer can be adjusted. This layer must be adjusted so that all of the EM fields in outer region of the structure are added constructively. In this case, the reflection coefficient phase of the whole structure in Fig. 3 is 2nπ and the resonance condition takes place [22].

After determining the primary values of the FSS superstrate parameters, its combination with ACMA will be studied to obtain the optimum values of the EBG antenna. The most important parameters to adjust the resonance frequency are the height of the FSS layer, periodicity of the FSS elements, and dimensions of the FSS elements. In the EBG antenna because the antenna equivalent aperture increases, the directivity increases in the frequency band about the resonance frequency.



(a) (b)

Fig. 3. (a) Unit cell of the whole structure, (b) phase of the reflection coefficient for the resonance condition of unit cell.

B. Design of Wideband Aperture Coupled Microstrip Antenna

The configuration of ACMA is shown in Figure 4. Many useful features of this type of antenna attract designers to use it for various applications [23-25].

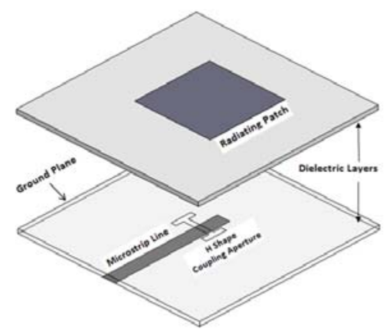


Fig. 4. Configuration of ACMA.

The capability of this antenna is obtaining wide bandwidth for 10dB RL bandwidth by suitable design of its coupling aperture. This phenomenon is obtained by using a cross-shaped coupling slot, two orthogonal offset slots and so on. In this paper the H shape slot is used [26]. By using this structure, two resonance frequencies due to the patch and slot are adjusted to obtain the wide frequency band for reflection coefficient. Figure 5 shows the directivity and reflection coefficient of the ACMA feeding by H shape slot. The ACMA antenna and the FSS superstrate layer are designed on PCB microwave board (Rogers RO3003) with a relative dielectric constant of ε_r=3.38, a dielectric loss tangent=.0027 and thickness=.782mm. By using the H shape slot, the resonance frequency of the coupling aperture moves next to the resonance frequency of patch.

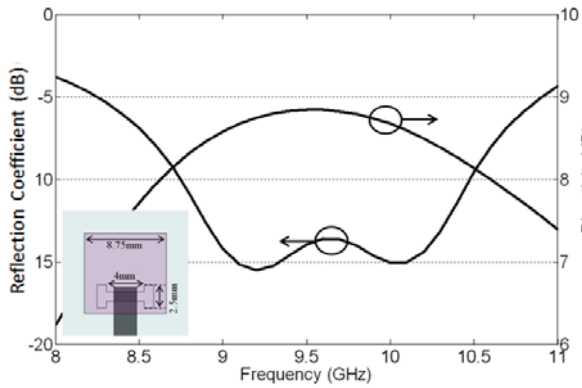


Fig. 5. Reflection coefficient and directivity of ACMA fed by H shape slot and dielectric height=3mm.

III. PARAMETRIC STUDY OF ANTENNA THE WIDEBAND HIGH DIRECTIVE ACMA

In this section, the effects of important parameters such as the height and dimensions of the FSS layer on both the reflection coefficient and the directivity of the antenna are studied. By varying the height of the FSS, the resonance frequency of the EBG antenna is displaced. Moreover, to keep the resonating condition in the EBG antenna, it is necessary to modify the dimensions of the FSS elements. This modification for large variations of the height of the FSS is considerable but for small variations it is negligible. In the Fig. 6, the effects of the height of FSS superstrate layer on the reflection coefficient and the directivity of antenna has been shown. To this purpose, the EBG antenna has been simulated for the different values of the FSS superstrate layer heights. Figure 6a depicts that increasing the height of the FSS leads to the movement of the 2nd resonance frequency toward a lower frequency. Also, it is observed form the Fig. 6-b that the maximum directivity of the antenna moves to the lower bound of the frequency bandwidth.

Another important parameter in the design of the EBG antenna is the FSS dimensions. In this case, the antenna is considered as a leaky wave antenna (LWA). The leaky waves propagate toward the edges of FSS and produce radiating current distribution on the FSS layer. Increasing the dimensions of FSS layer, leads to the increase of the radiating aperture of the antenna.

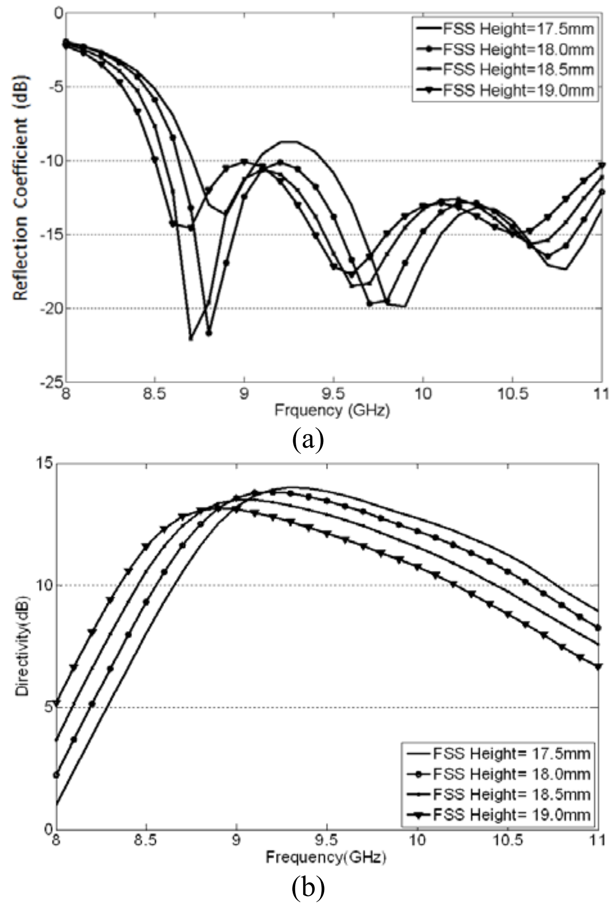
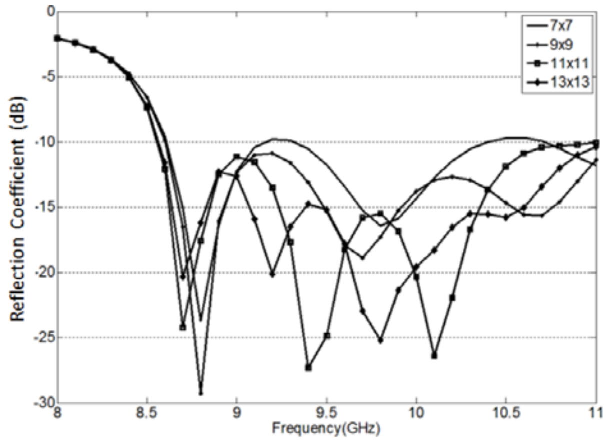


Fig. 6. Effect of FSS height (a) directivity of EBG antenna; (b) reflection coefficient of EBG antenna.

In the 2-D LWAs which are constructed using FSS surface, the leakage current is tapered toward the edges of the FSS [22, 27]. Therefore, the dimensions of the FSS superstrate layer must be chosen such that, the reflected wave from the edges of FSS can be neglected. To examine the effects of the FSS dimensions, the FSS superstrate layer is studied with different number of cells. Figure 7 depicts the reflection coefficient and the directivity of the antenna for the FSS with different number of cells. Simulation results show that enhancing the dimension of the FSS more than 11×11 elements, has a little effect on the 10dB RL bandwidth.



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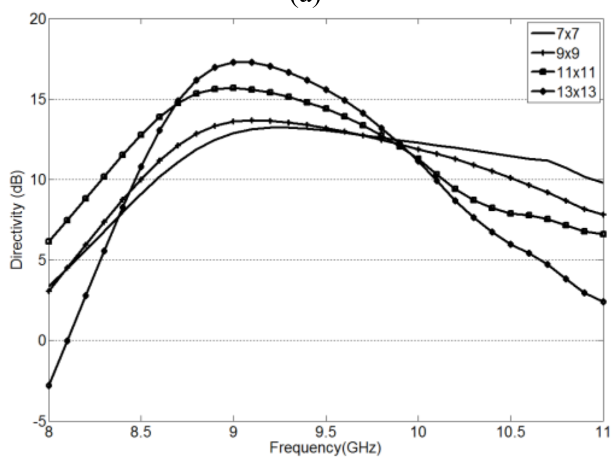

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Fig. 7. Effect of the FSS with different cell number. (a) reflection coefficient of EBG antenna. (b) Directivity of EBG antenna.

The above mentioned parameters are important in the design of the EBG antenna with a single feed. Another important parameter which must be investigated in the design of the EBG antenna to achieve the monopulse radiation pattern is the distance of the feeding sources from each other. This parameter affects the aperture current distribution of the EBG antenna in operating modes. The effect of this parameter on the directivity of the EBG antenna in the sum mode is depicted in the Fig. 8. Increasing the distance of the feeding sources leads to the reduction of mutual coupling and therefore, the reduction of reflection coefficient of the EBG antenna in different operating modes.

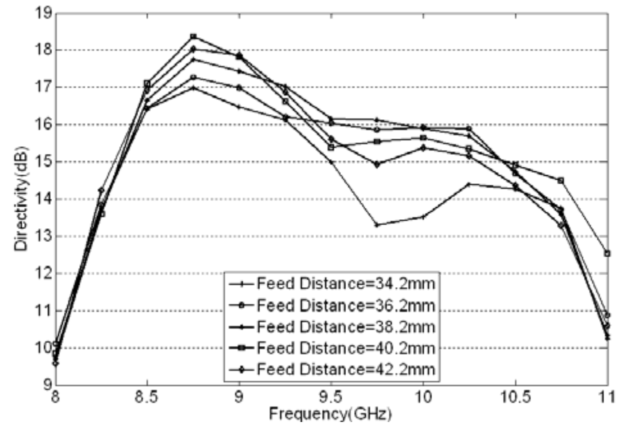
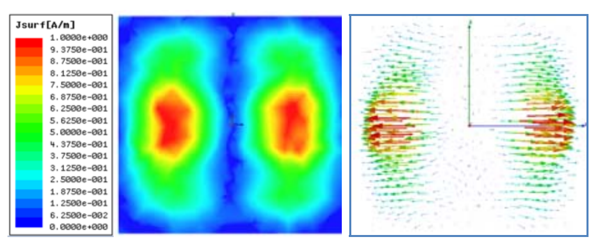


Fig. 8. Effect of the distance of feeding sources.

IV. DESIGN OF MONOPULSE ANTENNA AND EXPERIMENTAL RESULTS

A. Monopulse Radiation Patterns and Feeding Network

To design a monopulse antenna, it is necessary to have four feeds in the EBG antenna. By suitable excitation of the feeds and adjusting their distances, it is possible to obtain different current distributions on the FSS. These currents produce the various operating modes of the monopulse antenna in E and H planes. The combination of the feeds and the FSS layer is depicted in Fig. 1. Also, the current distributions on the FSS layer for various operating modes are depicted in the Fig. 9. In the difference modes as shown in the Fig. 9, the surface currents of the radiating aperture are such that the antenna produces the radiation patterns with the null in E & H planes (Fig. 14).



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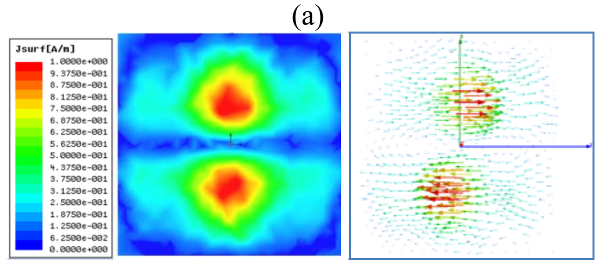

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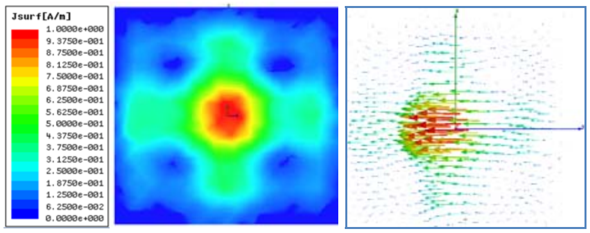

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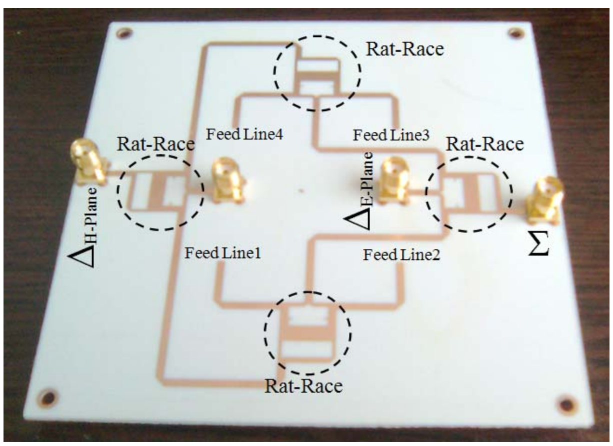
Fig. 9. Current distribution on the FSS surface at f=9.5GHz. (a) Difference mode in E-plane. (b) Difference mode in H-plane. (c) Sum mode.

The feeding network is necessary to produce the various excitations for the feeds. To design the feeding network four rat-races are necessary. The most important challenge in the design of the feeding network is its wideband operating frequency in which it is necessary to use wide band rat-race. The designed feeding network has been shown in Fig. 10.



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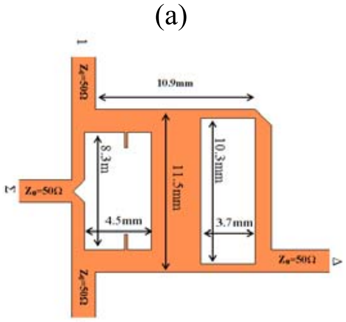

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Fig. 10. (a) Fabricated feeding network for the monopulse EBG antenna; (b) wideband rat-race.

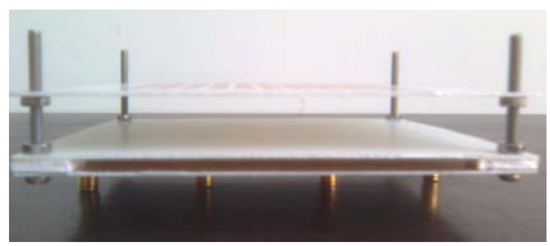
The feeding network has four ports including two difference ports and one sum port. The fourth port is terminated with the 50Ω matched load. Table 1 shows the excitations of four ACMA when the different ports are exited. It must be noticed that the antennas 1 and 2 are symmetrically mirrored respect to antennas 3 and 4. Therefore, in the Table 1, π degree phase shift has to be added to antennas 3 and 4.

Table 1: Excitation of ACMA when the different ports are excited

Input Port	*Antenna 1*	*Antenna 2*	*Antenna 3*	*Antenna 4*
Σ	$1e^{j0}$	$1e^{j0}$	$1e^{j\pi}$	$1e^{j\pi}$
$\Delta_{\text{-E}}$	$1e^{j0}$	$1e^{j0}$	$1e^{j0}$	$1e^{j0}$
$\Delta_{\text{-H}}$	$1e^{j\pi}$	$1e^{j0}$	$1e^{j\pi}$	$1e^{j0}$

B. Experimental Results

The Fig. 11 shows the fabricated EBG antenna. In the final design, the air gap between the substrates of the slots and radiating patches is 3.5mm and the distance of the substrate of FSS from the patch is 14.75mm. Also, the periodicity of FSS elements is 7mm and the width of square loops of the FSS is 5mm with 0.2mm thickness. The distance between the feeding sources of antenna is 36.2mm.



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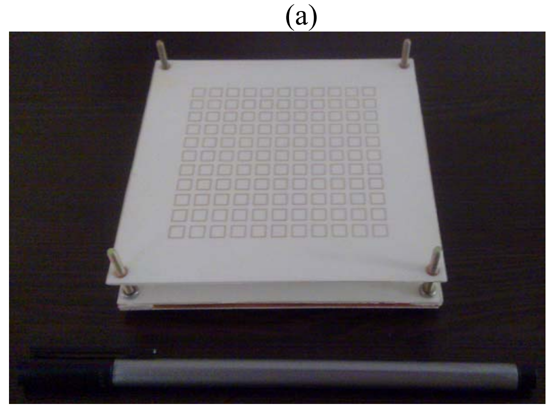

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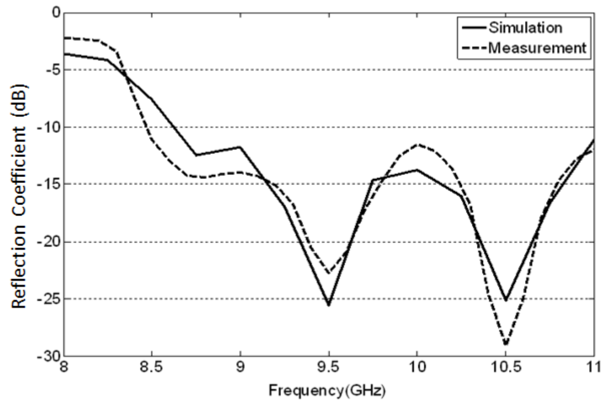
Fig. 11. The fabricated monopulse EBG antenna (a) side view; (b) top view.

The reflection coefficient of antenna for different ports has been shown in Fig. 12.



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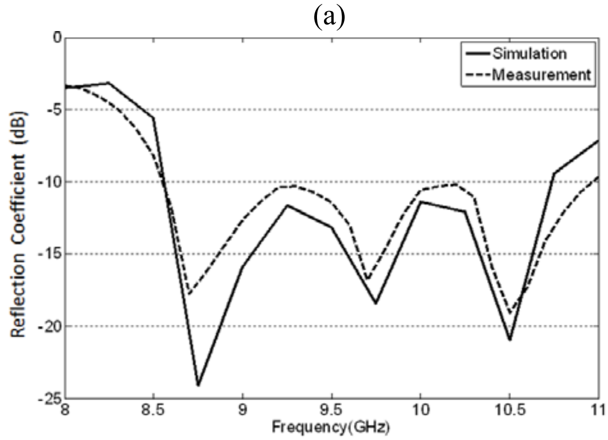

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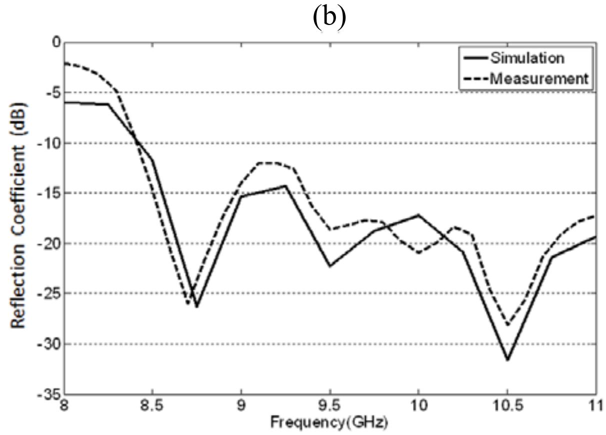


(c)

Fig. 12. Reflection coefficient of ACMA in the presence of the FSS layer (a) sum mode, (b) difference mode in E-plane, (c) difference mode in H-plane.

The antenna gain in the sum operating mode has been depicted in Fig. 13.

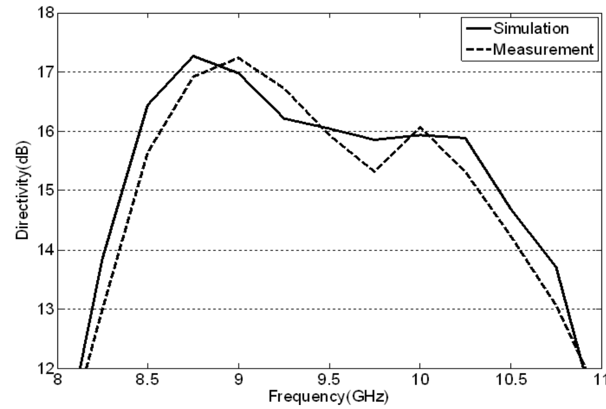
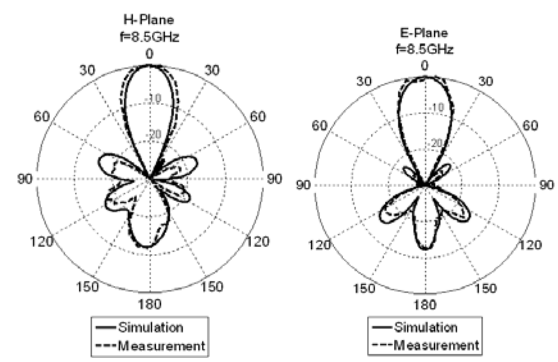


Fig. 13. Directivity of ACMA in the presence of FSS layer in the sum mode.

The radiation patterns of the monopulse EBG antenna for 8.5GHz and 10.5GHz in (E & H) planes for different operating modes are shown in the Fig. 14. By increasing the operating frequency, the relative spaces (respect to λ) between the feeds of the EBG antenna will increase. Therefore, the grating lobes in the sum mode will appear in the upper frequencies. The back lobe of the antenna is due to coupling aperture of ACMA. To reduce the back lobe level especially in the sum mode, the conducting plate or absorbing material can be placed behind the antenna.



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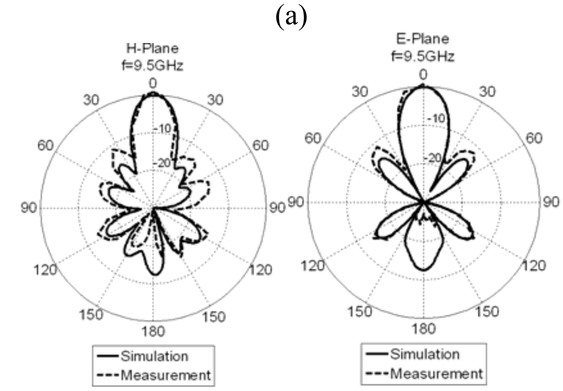

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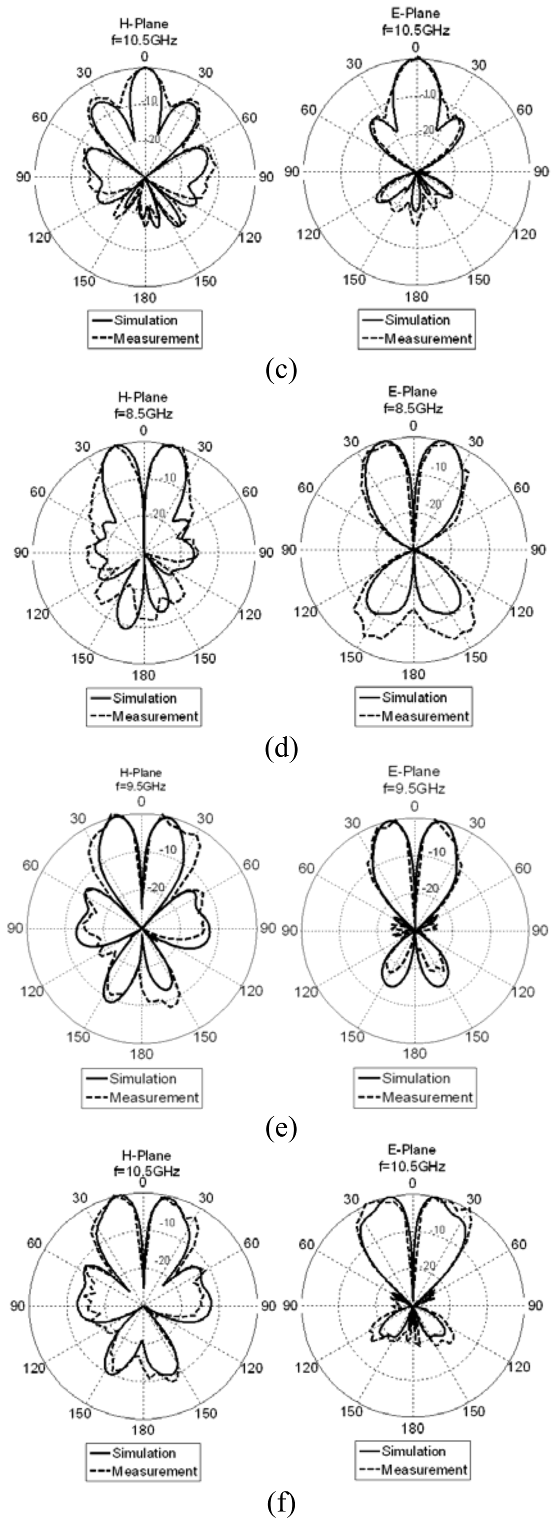

Fig. 14. Measurement and simulation results of normalized electric field radiation patterns of antenna for E&H-planes. (a) Sum mode at f=8.5GHz; (b) sum mode at f=9.5GHz; (c) sum mode at f=10.5GHz; (d) difference mode at f=8.5GHz; (e) difference mode at f=9.5GHz; (f) difference mode at f=10.5GHz.

VI. CONCLUSION

In this paper, the monopulse antenna has been designed using the EBG antenna. The bandwidth of the EBG antenna with ACMA feed for both directivity and reflection coefficient is about 20% at center frequency 9.5GHz. Based on this characteristic it is possible to design a wideband monopulse antenna with the EBG antennas with four ACMA feeds. This type of monopulse antenna has wide bandwidth and also a simple feeding network. In the future, by using the different combinations of the feeds it is possible to obtain shaped beam radiation pattern with the EBG antenna.

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