Mushroom-like EBG structure for Enhancement of Circular Polarization Array Antenna Performances

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Abstract: In this paper a microstrip array antenna with 4 truncated corner square patches surrounded with mushroom-like EBG structures have been widely developed in 2.48 GHz frequency. If the stop band of EBG structure is in the operational frequency of electromagnetic propagation wave with circularly polarized antenna, it can improve antenna applications. Results show that, these techniques cause axial ratio bandwidth (polarization quality) enhancement and gain improvement, also it decrease side lobe levels (SLL). In this paper we used HFSS 13 simulator to report antennas outputs with and without EBG surfaces.

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1. Introduction

Local Area Network (LAN) allows users to access network services without using wired infrastructure. In point to point communication it is necessary to have light weight, low cost and small system designs. So WLAN applications have become more popular. One of the most important parameter should consider in antenna installation is polarization. Polarization is an expression of electric flux lines orientation in electromagnetic field (EM). It can be constant in a particular direction over all times, or it can rotate left-hand or right-hand in with each wave cycle. For effective communication, physical orientation of antenna must be harmonious with transmitted or received radio waves. It means a transmitter antenna needs a receiving antenna with the same polarization for optimum operation. Over long distance, the atmosphere can change the polarization. Thus the distance between source and destination is a significant factor shall consider. Besides, a large number of applications, including satellite communication, have trouble with polarization, because the orientation of the antenna is variable and unknown. In a circular polarized antenna, it radiates its energy in both vertical and horizontal planes, so the electric field varies in two orthogonal directions (x and y) with same magnitude and a 90^0 phase difference.

The result for circular polarization antenna is two modes, the TM10 mode (a mode vary in the x direction) and TM01 (a mode vary in the y direction). One of the modes is excited with 90° phase delay with respect to the other mode [1]. Circular polarized microstrip antennas have been used in widely used in many applications because of all their advantages. But these structures have been suffered from their narrow bandwidth and low power capability. Typically they have only 10% and less in s11 impedance bandwidth and 2% and less in axial ratio bandwidth.

Many techniques have been employed to improve these bandwidths, such as stack patches with truncated opposite corner [10] and L-shaped probe with impedance matching networks [2]. But large antenna height and difficulty in impedance matching networks make it complicated to design and develop in the printed antenna [2].

Some disadvantages will appear in presence of electronic conductors which adversely affect the performance of electromagnetic devices. They work as reflector, but they reverse the phase of reflector waves. They also support propagating surface waves which can have deleterious effects on antenna performance.

Surface waves can occur on the interface between two dissimilar materials, such as metal and free space. They are bound to the interface, and decay exponentially into the surrounding space, and they are often best described as surface currents. They can be modeled from the viewpoint of an effective dielectric constant, or an effective surface impedance [12,13].

Various structures of electromagnetic band gap have been presented to improve microstrip performances [3]. EBG structures include periodic metal elements. Unlike normal conductors, EBG surface does not support propagating surface waves, and its image currents are not phase reversal. In the conductive surface, the image currents cancel the currents of original current, resulting in poor radiation efficiency. In contrast, the EBG surface is capable of providing a constructive image current within a certain frequency band, resulting in good radiation efficiency.

A mushroom-like EBG surface because of its simple design and construction is used more than the other shapes. In this paper bandwidth was improved to 0.94% by using mushroom-like EBG surface.

Also EBG structures are capable to reduce side lobe levels (SLL), back lobes and coupling. Besides they increase gain of an antenna and its results of pass-band and stop-band frequency. EBG structure prevents the surface waves propagate in operation frequency.

Worked on cp microstrip array antenna with EBG, have been limited until now and it is just developed on single microstrip. So in this paper mushroom-like EBG has been used to improve the result of bandwidth, gain and SLL of circular polarization array antenna with 4 elements.

2. Single feed circularly polarized antenna

Many types of circular polarized antenna have been studied so far with several feeding techniques [7].

In order to get circular polarization, these conditions are essential to do, 1- Split signal in two equal parts, 2- Feed one signal to a horizontal radiator and the other to a vertical radiator, 3- Change the phase of one signal by 90^0 in compare with to the other signal.

In this paper truncated corner square patch antenna is used. Accordingly, the operational principle of this antenna is based on the fact that the generated mode can be separated in to two orthogonal modes 1 and 2 by the effect of perturbation segment. In actually, perturbation creates two new modes. Another approach is to see the patch as a parallel RLC resonance circuit. Amplitude and phase diagrams of this antenna are shown in [7].

With accurate adjustment in patch and perturbation dimensions two resonances, f_1 and f_2 (two modes) have happened. When the corresponding resonance frequencies are slightly different, there is small frequency band where the phase difference of the two RLC circuits is 90^0. Figure 1 indicates a single feed corner truncated square patch antenna. The equation of this antenna is expressed as follows [7]:

$$\Delta s = 1/2Q \qquad (1)$$

Where, Δs is the area of the perturbation with Δa length and Q is the quality factor for a square patch with a width. f_1 and f_2 are resonances frequencies of two RLC circuits

$$f_1 = f_0\,(1- (2\Delta s/s)) \qquad (2)$$

$$f_2 = f_0$$

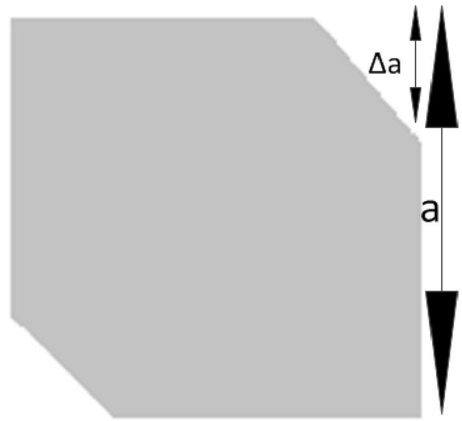


Figure 1. corner truncated patch for circular polarization

Where, f_0 is a resonant frequency of original square patch with area of s and the circular polarization frequency f_{cp} happens between two resonant frequencies of orthogonal modes. So f_{cp} = 2.48 GHz was used for WLAN applications.

3. EBG Description

Generally speaking, electromagnetic band gap structures are defined as artificial periodic (or sometimes no-periodic) objects that prevent the propagation of electromagnetic waves in a particular band of frequency for all incident angles and all polarization states [3].

2-D EBG surfaces such as a mushroom-like surface, which have the advantages of low profile, light weight, and low fabrication cost, are widely studied in antenna engineering.

There are three analysis methods for EBG structures [7], that Lumped element model as a simple design for LC resonance circuit description, was shown in figure 2. A voltage applied parallel to the surface cause's charges to build up on the ends of the top metal plates. This can be definition of capacitance. As the charges slosh back and forth, in response to radio-frequency field, they flow around a long path through the vias and the bottom ground plane, and thus an inductance.

The resonance frequency of mushroom-like surface is calculated as following

$$w_0 = \frac{1}{\sqrt{LC}} \qquad (3)$$

The edge capacitance for narrow gap is given by the following equation

$$C = \frac{w\varepsilon_r(1+\varepsilon_r)}{\pi}\cos^{-1}\left(\frac{w+g}{g}\right) \quad (4)$$

From the stored magnetic energy and the excited energy the equivalent inductance has been computed. The inductance is expressed as bellow

$$L = \mu h \quad (5)$$

LC model is a simple equivalent model, but the static field approximation limits its accuracy.

4. Antenna design and configuration with EBG surfaces

A 2×2 CP microstrip array antenna with single feed network on the conventional ground plane has been designed and

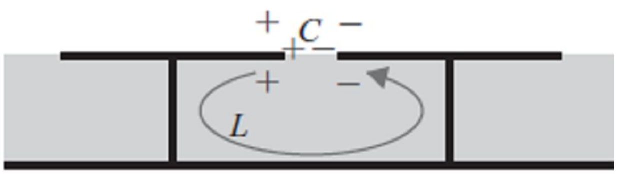


Figure 2. Lumped LC model for EBG

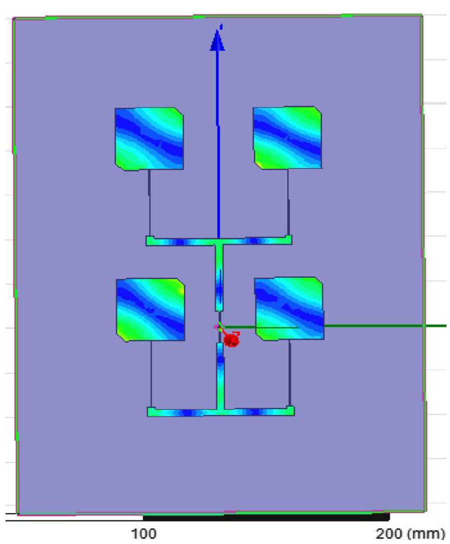


Figure 3. 2×2 Circular polarized antenna simulated using finite-element based HFSS to work at 2.48 GHz as shown in figure 3.

From equation (1) and (2) corner truncated square patch dimensions were calculated width a =28 mm and perturbation segment is Δa=3.2mm.

The distance between patches is almost half of wavelength free space. Substrate height is h=1.6 mm and ground dimensions are 168×224 mm^2. FR4/epoxy was used as material substrate with ε_r =4.4 dielectric constant.

From equation (3), (4), (5) EBG width=17 mm and gap distance =0.01mm.

5. Simulation results

CP microstrip array antenna was simulated with Hfss 13. In this section we want to embed EBG structures with various shapes in designed antenna to find optimum and maximum ARBW and gain. First of all one row of these patches with various distances have been located in right and left sides of antenna. Figure 4 shows a 4 elements CP array antenna with one row of mushroom-like EBG surfaces in left and right side. Total results of this structure were presented in table 1.

From table 1 the maximum axial ratio bandwidth (ARBW) and gain have been achieved from the nearest distance.

Maximum ARBW has been illustrated in figure 5. Simulation result shows that in the best conditions ARBW (for AR<6 dB) have been increased from 1.25% (2.38-2.41 GHz) for CPAA without EBG to 2.19% (2.47-2.52 GHz) with EBG. Also axial ratio was shifted from 2.4 GHz to the operational frequency 2.48 GHz.

Besides side lobe level has been decreased from -15.42 to -17.28. The summary of these changes was reported in table 2. Radiation pattern in $\varphi=0^{\circ}$ and $\varphi=90^{\circ}$ have been shown in figure 6 (a & b).

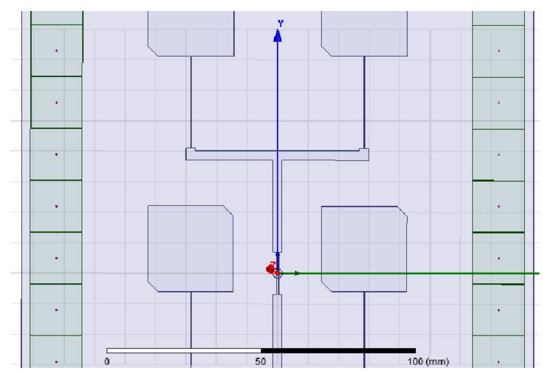


Figure 4. 2×2 Circular polarized antenna with one EBG row

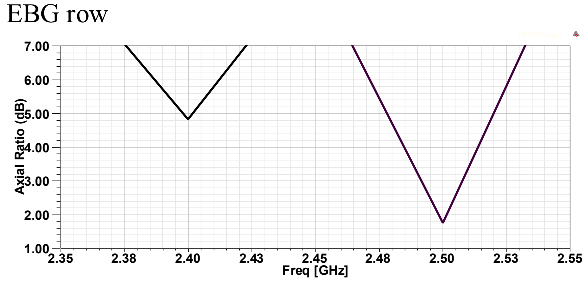


Figure 5. Axial ratio for CP array antenna with (dash line)and without EBG (solid line)

Table 1. output values for one row EBG in right and left side of CPAA with different distances between patch center and EBG patch center

Distance between patch center and EBG center	f_r (min) dB	CPBW (MHz)	Gain (dB)
0.7912 λ_0	3.7717	34	7.0773
0.7660 λ_0	1.7983	54	6.875
0.7251 λ_0	3.7832	34	7.053
0.6837 λ_0	1.8991	53	6.9121
0.4357 λ_0	1.977	51	6.8938
0.3632 λ_0	1.75	54	7.12

Table 2. Output values for CPAA with and without EBG

	Gain (dB)	CPBW (MHz)%	Min (AR)	SLL (dB)
Without EBG	5.73	30 1.25%	4.82	-15.42
With EBG	7.12	54 2.19%	1.75	-17.23

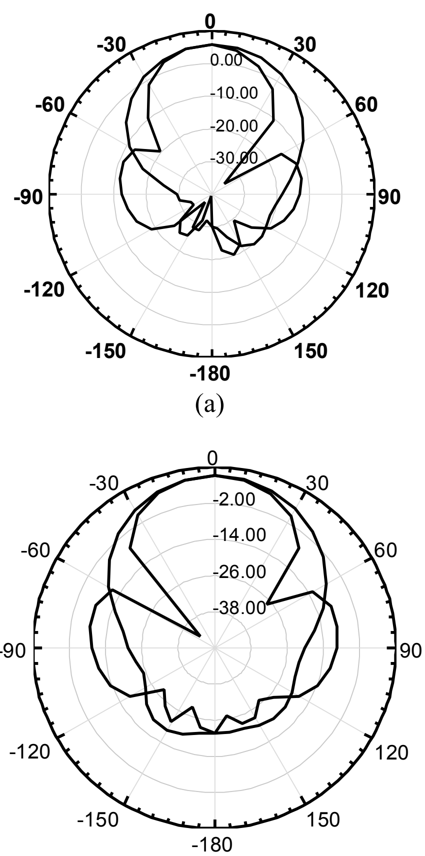


Figure 6. Radiation pattern of E plane (solid line) and H plane (dash line) 2×2 Circular polarized a) array antenna, b) array antenna with EBG

In the second step CPAA with two and three rows of designed EBG will be compared with different distances, and summary of results have been presented in table 3 and 4. Figure 7 illustrates CPAA with three rows of EBG. In the third step CPAA with a ring of EBG will be considered. Output values have been summarized in table 5. Also figure 8 (a and b) show radiation patterns for two distances in $\varphi=0^{\circ}$ and $\varphi=90^{\circ}$. At last the effects of EBG rows on up and down will be considered. Output values have been presented in table 6.

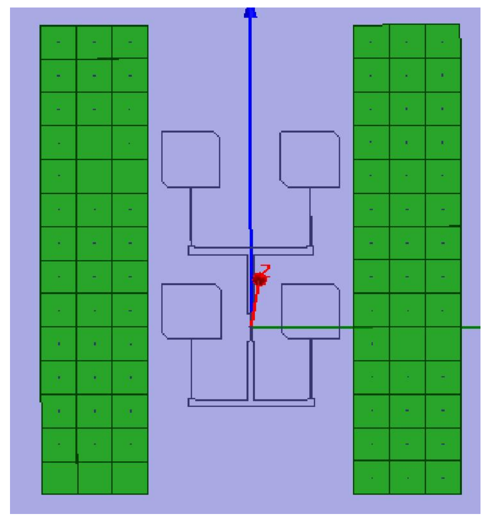


Figure 7. 2×2 Circular polarized antenna with three EBG rows

Table 3. Output values for two rows EBG in right and left side of CPAA with different distances between patch center and EBG patch center

Distance between patch center and EBG center	f_r (min)dB	CPBW (MHz)	Gain (dB)
0.7912 λ_0	2.0196	50	7.0678
0.7251 λ_0	1.0704	52	7.0286
0.4357 λ_0	2.37	51	6.65
0.3632 λ_0	1.9087	50	7.0792

Table 4. Output values for three row EBG in right and left side of CPAA with different distances between patch center and EBG patch center

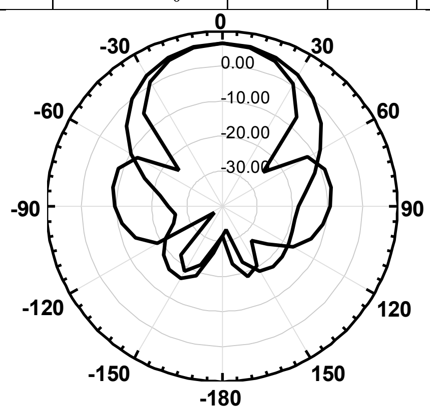
Distance between patch center and EBG center	fr(min) dB	CPBW (MHz)	Gain (dB)
0.7912 λ_0	2.0021	51	6.9406
0.4357 λ_0	1.77	53	6.8454

Table 5. output values for a ring of EBG around CPAA with different distances between patch center and EBG patch center

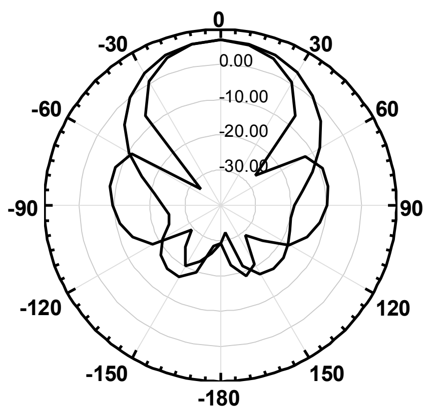
Distance between patch center and EBG center		fr (min) dB	CPBW (MHz)	Gain (dB)
Right & left	0.4357 λ_0	2.688	46	6.9369
Up & down	0.5376 λ_0			
Right & left	0.0739 λ_0	1.4408	56	6.49
Up & down	0.4963 λ_0			

Table 6. output values for one & two rows of EBG in up and down side of CPAA with different distances between patch center and EBG patch center

Distance between patch center and EBG center		f_r (min) dB	CPBW (MHz)	Gain (dB)
Two rows	0.5376 λ_0	2.93	42	7.071
One row	0.4417 λ_0	2.87	44	7.0277



(a)



(b)

Figure 8. Radiation pattern of E plane (dash line) and H plane(solid line) for 2×2 Circular polarized antenna with a ring of EBG a) near distance, b) far distance

6. Conclusion

A new type of metallic electromagnetic surface has been used to improve 2×2 CP microstrip array antenna applications. It made from periodic metal surfaces conduct DC currents, but does not conduct AC current in a forbidden frequency band. So it removes the adversely surface currents and its effects. Typically truncated corner patch, have a narrow axial ratio bandwidth (without considering substrate thickness and impedance bandwidth) about ARBW<1%. By embedding EBG surfaces around antenna in left and right side in the nearest distance between patch center and EBG center, ARBW has been increased to 0.94% it means from 30 MHz to 54 MHz besides minimum frequency have been shifted from 2.4 GHz to operational frequency. In this manner mushroom-like patches cause 1.39 dB increments in gain and improvement in SLL.

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