


Circularly Polarized Electromagnetic Band Gap Patch-Slot Antenna with Circular Offset Slot

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Abstract

This paper reveals the impact of the insertion of electromagnetic band gap (EBG) structures on the performance of circularly polarized (CP) patch-slot antenna with offset slot. Several optimizations are necessary to precise physical parameters in the aim to fix the resonance frequency at 3.2 GHz. The proposed antenna possesses lightweight, simplicity, low cost, and circular polarization ensured by two feeding sources to permit right-hand and left-hand circular polarization process (RHCP and LHCP). The measured results compared with simulation results of the proposed circularly polarized EBG antenna with offset slot show good band operations with -10 dB impedance bandwidths of 9.1% and 36.2% centered at 3.2 GHz, which cover weather radar, surface ship radar, and some communications satellites bands. Our investigation will confirm the simulation and experimental results of the EBG antenna involving new EBG structures.

Index Terms: Circular microstrip patch-slot antenna, Circular polarization, Electromagnetic band gap (EBG) resonator, Microstrip antenna with an offset circular slot, RHCP and LHCP polarization

I. INTRODUCTION

Antennas analysis and conception have been the core of researches during the last decades. Great investigations were piercing to circularly polarized (CP) antennas, recognized as master key for various wireless and mobile communications systems, sensors in the aim to enhance various output parameters (gain, bandwidth, etc.) [1]. In addition, electromagnetic band gap (EBG) substrates, known as artificial periodic (or sometimes non-periodic) objects that manage electromagnetic waves in a specified frequency band, are attractive features to permit new functionality of these kind of antennas [2] and will provide solutions to numerous engineering problems [3].

A new concept of circularly polarized EBG antenna will be examined.

In the final attained antenna design, two orthogonal polarizations [4] with a low cross-polarization level < -40 dB, a return loss better than -10 dB at 3.2 GHz are reached. In the suggested design, provided with dual-sources [5], we have included slots, one on the edge to ensure circular polarization and one as an offset circular slot (Fig. 1), and inserted EBG structures above the antenna. This new shape has permitted better performances in the output parameters such as bandwidth, gain and radiation efficiency.

Our analysis will take into account the comparison of proposed circularly polarized EBG patch antenna design, including the EBG structures, with conventional circular antenna with the same radius and slits.

First section will include detailed design and analysis of EBG resonator antenna and the simulation results at 3.2195 GHz. The second section will cover the analysis of the

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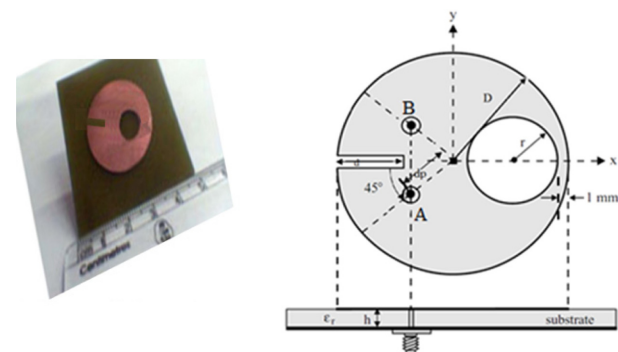


Fig. 1. Circularly polarized (CP) antenna with an offset circular slot.

antennas array based on the proposed single CP EBG patch-slot antenna with circular offset slot.

II. CIRCULAR PATCH-SLOT ANTENNA WITH CIRCULAR OFFSET

In our proposal, substrate of the patch antenna has been chosen as: microstrip circular patch antenna radius $D = 19$ mm, dielectric constant $\epsilon_r = 4.6$ and dielectric loss tangent is equal to 0.009 [6].

The conventional resonance frequency is obtained by using the cavity model [6-8]. Here, magnetic lateral walls of the cavity are chosen as cited in [9] and the circular patch resonant frequency is calculated by:

$$f_0 = \frac{c \cdot J_{mn}}{2\pi D \sqrt{\epsilon_r}}, \quad (1)$$

where c is the velocity of electromagnetic waves in free space and J_{mn} is n order derivative Bessel function of the m -th zero: for the TM₁₁ dominant mode, $J_{mn} = 1.84118$ [9] which is widely used in all microstrip antennas.

The compact CP patch-slot antenna with an offset slot, shown in Fig. 1, has $D = 19$ mm, and two slots: one as an offset circular slot is about 0.38–0.62 times the radius, D , of the circular patch placed at 1 mm from the edge. The other

slot, destined to ensure circular polarization by using two coaxial feedings, is inserted. First two resonant frequencies have orthogonal polarization planes and a low common frequency ratio of 1.15–1.18 than their fundamental resonant frequencies if considered separately.

For the offset circular slot, there is not good output parameters until the radius is greater than 5 mm (about $0.18D$). After that, and within the range 5–10 mm (about $0.62D$), good excitation of two separate resonant modes is achieved. The frequency ratio is within the range of about 1.15–1.18 in dependence of the slot radius. Feeds positions depend on the slot radius: they are moved toward patch center if the slot radius increases. In this sense, good impedance matching is realized only when the slot radius is between 5 mm and 10 mm.

Tuning the length of the slot length (as depicted in Fig. 1) can fix the antenna resonance in the 3.21 GHz band. Whereas tuning the offset circular slot aims to improve the performances of the proposed antenna in terms of achieving satisfactory output parameters. We have used a commercially available simulation software, so-called Computer Simulation Technology (CST) 2014 for the numerical analysis to acquire optimized proper geometrical parameters

Hence, when the ratio of the total slot length is properly chosen, the two near-excited resonance modes, using two feeds of equal amplitudes and 90° phase difference, circular polarization radiation is achieved.

In Fig. 1, r is the offset slot radius, dp is the position of the two feeds with angular angle of 90° , d is the length of rectangular slot from the edge of circular patch with width $w = 2$ mm, and h is the thickness of the substrate.

A comparative analysis shows that, only for the length of rectangular slot $d = 5$ mm there is good impedance matching and suitable output parameters (S_{11} , SWR, gain, and directivity). Table 1 presents a global overview of the output parameters in function of the length of slot d after a carefully fine sweeping on the parameter d while using the CST 2014 software.

Fig. 2 shows radiation pattern of CP patch slot in case of $h = 1.6$ mm, $\epsilon_r = 4.6$, $w = 1$ mm, $D = 19$ mm, $r = 5$ mm, and $d = 5$ mm.

The reflection coefficient is achieved at 3.21 GHz. Good matching impedance, peak value of the radiation power and

Table 1. Units for magnetic properties

Parameter	Length of the slot d		
	3 mm	5 mm	10 mm
S_{11}	−18 dB at 3.29 GHz	−31.29 dB at 3.219 GHz	−19.7 dB at 2.766 GHz
SWR	1.58	1.26	1.46
Gain (dB)	3.963	4.097	3.307
Directivity (dBi)	4.758	4.980	5.065
Radiated power, Pmax (W/m ²)	0.05173	0.09677	0.04619
Radiation efficiency	0.8457	0.8057	0.6673
Total radiation efficiency	0.2310	0.3866	0.1808

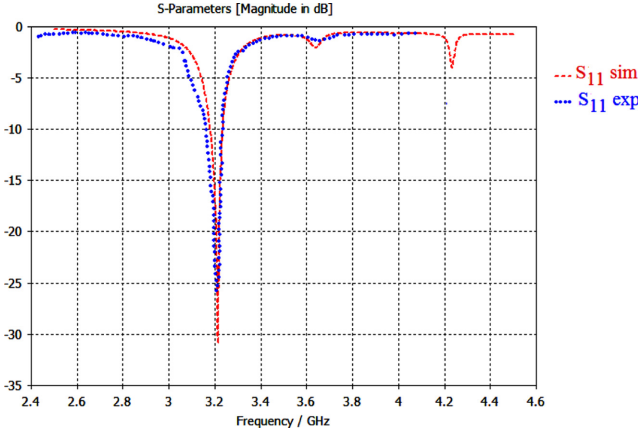


Fig. 2. Radiation pattern S_{11} (simulation versus experimental values) of CP patch-slot antenna.

Table 2. Output parameters of CP patch-slot antenna: simulation versus experimental results

	Simulation result	Experimental result
f (GHz)	3.2	3.195
S_{11} (dB)	-31.29	-26.7
Gain (dB)	8.112	7.98
Realized gain (dB)	0.584	0.544
Directivity (dBi)	10.32	9.89
Radiation efficiency	0.601	0.598

Total radiation efficiency are achieved at resonant frequency. It presents a reflection coefficient less than -10 dB and bandwidth equal to 54 MHz.

As a consequence of the comparison design given in Table 1 and based on modification of different geometric parameters, we have adjusted geometric parameters of the conventional antenna to be as follow: $h = 1.6$ mm, $d = 5$ mm, $D = 19$ mm, and $r = 5$ mm.

Table 2 shows the comparison between experimental and simulated results by using the CST software 2014 based on the adopted geometric dimensions of the proposed antenna.

An optimization of the two feeding sources is necessary to ensure good circular polarization performance of the antenna. The radiation pattern of the antenna, presented in the Fig. 3, shows the circularly polarized antenna. Moreover, the cross-polarization level in the E and H plane cuts is below -40 dB.

III. CIRCULAR PATCH-SLOT EBG ANTENNA WITH CIRCULAR OFFSET SLOT

The circularly polarized antenna with an offset circular slot geometry, studied in the first section, has been improved by the addition of new EBG materials [10]. Here, we will check the influence of number of EBG structures (chosen as

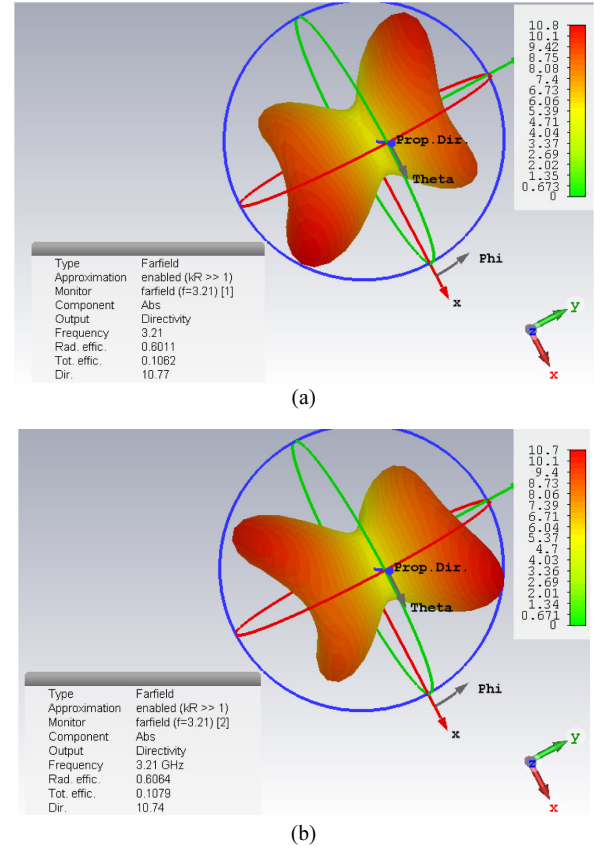


Fig. 3. Three-dimensional (3D) radiation pattern of the CP patch-slot antenna with circular offset slot. (a) Right-hand circular polarization. (b) Left-hand circular polarization.

Plexiglas layers) on the performance of the studied antenna while maintaining the same geometric parameters as adopted before. Since our study concern a single antenna, the electromagnetic lateral walls will be chosen magnetic.

EBG substrates, such presented in Fig. 4, are included overhead the predesigned antenna. Their dielectric permittivity is chosen $\epsilon_r = 4.6$ (Plexiglas). The distance between the patch and the first dielectric layer is fixed $\lambda_0/2$, otherwise distance between consecutive EBG layers is fixed to $\lambda_0/4$, thickness of EBG layers is $\lambda_g/4$. In our case, $\lambda_0 = 95.84$ mm and $\lambda_g/4 = 44.68$ mm.

Fig. 5 shows the impact of EBG layers numbers on the return loss S_{11} of the proposed CP-EBG antenna.

From Fig. 6, the reflection coefficient reaches $S_{11} = -44$ dB since the insertion of first Plexiglas layer above the CP antenna. As we increase the number of EBG layers, the impact of these EBG structures will appear and the output parameters will be better and the 3D radiation pattern shows a longer range of transmission.

In Fig. 5, the opening angle passes from 45.7° in case of CP antenna with offset circular slot, for each source to around 20.6° in case of CP-EBG antenna with a preferred

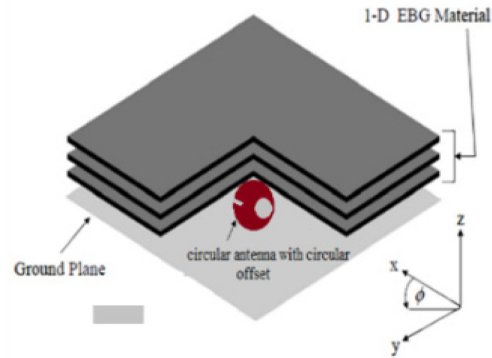


Fig. 4. Circularly polarized EBG antenna with circular offset.

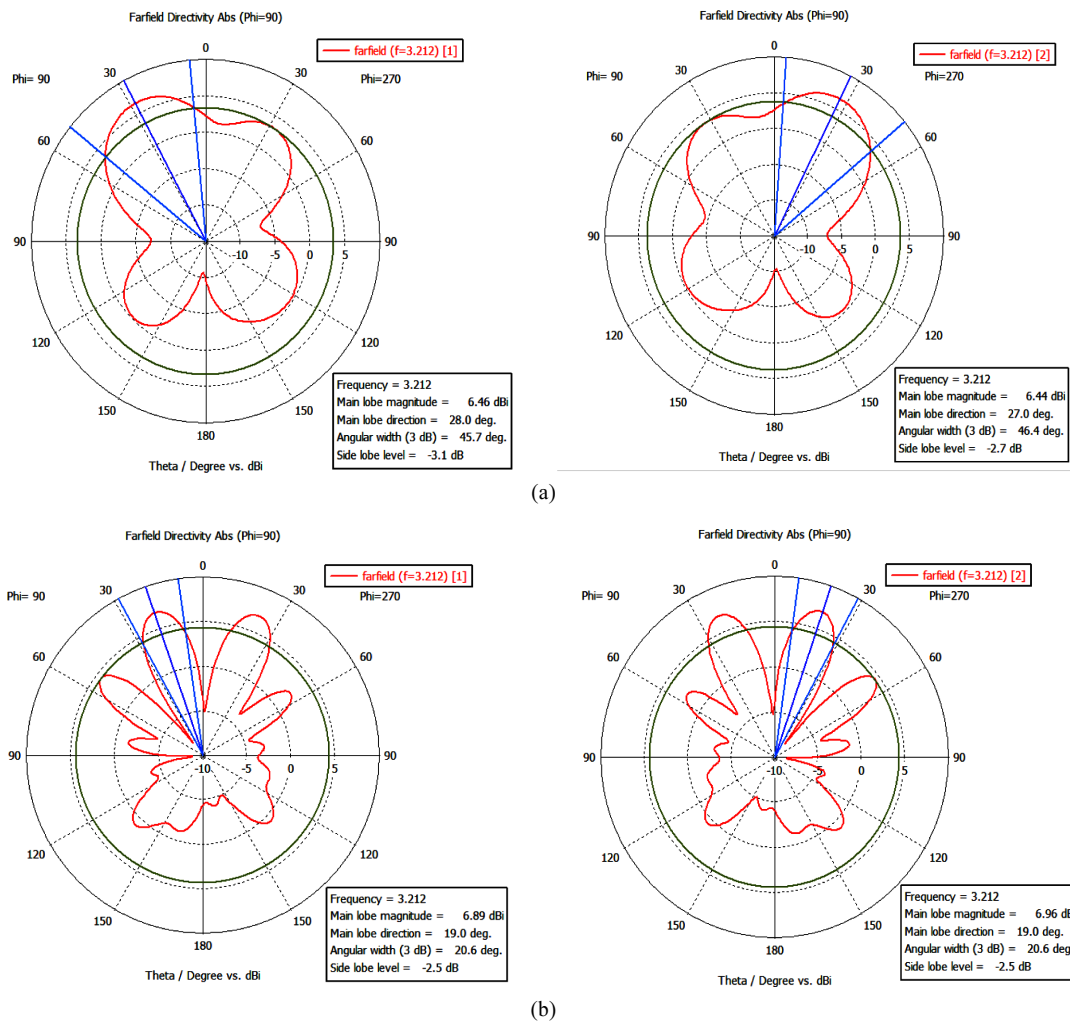


Fig. 5. Polar plot of radiation pattern of the CP-EBG antenna with an offset circular slot using EBG structures within a Plexiglas layer plane E for each radiation source (left and right) from 1-layer (a) to 5-layers (b).

direction of propagation along the z axis. This confirms our approach about control of transmission bandwidth of the CP antenna by using these EBG structures and their role in improving directivity gain and radiation efficiency. Table 3

explains in details comparison of output parameters (S_{11} , gain, directivity, radiation efficiency, etc.) depending on the number of EBG layers.

In comparison with the conventional CP antenna studied in

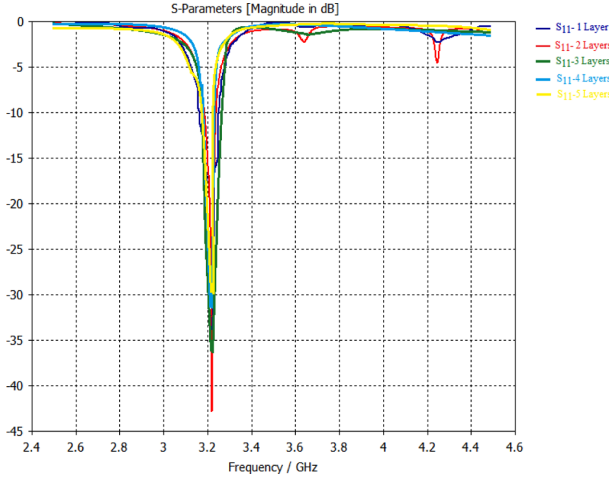


Fig. 6. Improvement of return loss S_{11} of CP-EBG antenna in function of the number of included EBG structures with 1-layer, 2-layers, 3-layers, 4-layers, and 5-layers.

Table 3. Output parameters of CP patch-slot antenna: simulation versus experimental results

Parameter		Number of EBG layers			
		1	2	3	4
f (GHz)		3.220	3.219	3.220	3.218
S_{11} (dB)	Simulation	-34.07	-43.89	-36.66	-29.54
	Experimental	-32.10	-42.16	-36.08	-23.87
Gain (dB)	Simulation	9.47	15.93	18.69	19.64
	Experimental	9.20	14.06	17.89	16.66
Directivity (dBi)	Simulation	12.06	18.8	21.9	25.96
	Experimental	11.89	17.89	20.88	24.36
Radiation efficiency	Simulation	0.651	0.613	0.574	0.333
	Experimental	0.589	0.604	0.545	0.289

the first part of this section, the insertion of EBG layers will play a very important role in the improvement of gain and directivity that will increase linearly with the number of inserted EBG layers according to the preferred propagation direction. However, this does not directly affect the bandwidth. At the resonance frequency 3.21 GHz, the antenna radiation pattern in x - y plane in the axial ratio band is more than 9 dB what means good cross-polarization discrimination (XPD).

IV. CONCLUSION

Comparative analysis of CP antenna including an offset circular slot as a fundamental structure and CP-EBG antenna including an offset circular slot was achieved by including new EBG structures above the original CP antenna. The final goal is to improve the electromagnetic

output parameters (directivity, gain, bandwidth, radiation efficiency, etc.). We have also tested these performances by varying the substrate thickness in the aim to find the ideal compromise between thickness and efficiency. Variation of number of EBG layers above the antenna have deeply changed its performances. The optimization of the new CP-EBG antenna shows that the number of included EBG Layers should be limited to three layers. Moreover, when length of the slot d , permitting LHCP and RHCP, increases from 3 to 10 mm for the CP antenna with an offset circular slot, performances (peak gain and peak directivity) are increasing first and then decreasing after the third EBG layer. Furthermore, the stability, while performing these characteristics, is proven with certain limits compared to the classic approach based on the CP antenna with offset slot especially when trying new structures with high permittivity values beside Plexiglas as EBG layers. In this case, improvement of major electromagnetic parameters should be re-analyzed to examine its performances in comparison with adopted one.

REFERENCES

- [1] X. Chen, L. Yang, J. Y. Zhao, and G. Fu, "High-efficiency compact circularly polarized microstrip antenna with wide beamwidth for airborne communication," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1518-1521, 2016. DOI: 10.1109/LAWP.2016.2517068.
- [2] M. Mavridou, A. P. Feresidis, and P. Gardner, "Tunable double-layer EBG structures and application to antenna isolation," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 1, pp. 70-79, 2016. DOI: 10.1109/TAP.2015.2496619.
- [3] S. S. Pawar, M. Shandilya, and V. Chaurasia, "Parametric evaluation of microstrip log periodic dipole array antenna using transmission line equivalent circuit," *Engineering Science and Technology, an International Journal*, vol. 20, no. 4, pp. 1260-1274, 2017. DOI: 10.1016/j.jestech.2017.09.002.
- [4] L. Sun, G. X. Zhang, and B. H. Sun, "Slim planar composite antenna with two orthogonal polarisations for WLAN router applications," *Electronics Letters*, vol. 51, no. 18, pp. 1392-1394, 2015. DOI: 10.1049/el.2015.1601.
- [5] T. N. Chang, J. M. Lin, and Y. G. Chen, "A circularly polarized ring-antenna fed by a serially coupled square slot-ring," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 2, pp. 1132-1135, 2012. DOI: 10.1109/TAP.2011.2173138.
- [6] D. M. Pozar and D. H. Schaubert, *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays*. New York, NY: John Wiley & Sons, 1995.
- [7] Z. N. Chen and K. M. Luk, *Antennas for Base Stations in Wireless Communications*. New York, NY: McGraw-Hill, 2009.
- [8] K. F. Lee and W. Chen, *Advances in Microstrip and Printed Antennas*. New York, NY: John Wiley & Sons, 1997.
- [9] S. Chandran, *Adaptive Antenna Arrays: Trends and Applications*. Heidelberg: Springer, 2004.
- [10] R. Sauleau, "Fabry-Perot resonators," in *Encyclopedia of RF and Microwave Engineering*. Hoboken, NJ: Wiley-Interscience, 2005. DOI: 10.1002/0471654507.emel05.



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