Miniaturization and Gain Enhancement of Microstrip Patch Antenna Using Defected Ground with EBG

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Abstract —In this research work, we have proposed an inset feed rectangular microstrip patch antenna operating at 2.45 GHz in the Industrial, Scientific and Medical (*ISM*) band for wireless communication. This conventional design of antenna has been modified with defected ground (*DG*) plane. When this is optimized back to 2.45 GHz, a miniaturization of 37.9 % of patch size has been achieved along with the enhancement in radiation performance. This design is then modified and loaded with mushroom-type Electronic Band-Gap (*EBG*) structure on the top of dielectric FR-4 substrates. This creates a band-gap region that suppresses the surface waves considerably, thus improves the overall performance and functionality of the proposed antenna. Radiation characteristics such as S-parameters, directivity, gain, efficiency, bandwidth, *VSWR* and Z_{11} of microstrip antenna have been performed and compared. The simulated results show that the antenna gain has been increased throughout the entire bandgap of *EBG* operating in 2.25 to 4.25 GHz. Moreover, rest of radiation performances remain highly preserved.

Index Terms—Dispersion, Electronic band-gap (*EBG*), Frequency selective surface (*FSS*), Metamaterial absorber (*MMA*), Radar Cross Section (*RCS*)

I. INTRODUCTION

The recent technological advancement and the latest research in metamaterials have pioneered the door to tremendous innovative antenna applications. A novel metamaterial structure efficiently manipulates the reflection and transmission of the impinging electromagnetic (*EM*) wave. By changing the physical and geometrical construction of metamaterial, one can demonstrate a pass-band and stop-band filter behavior. Some worthy of notice amelioration that can be impute to periodic metamaterial structures in antenna designing covers surface waves suppression [1]-[3], antenna size reduction [4], [5], enhancement of antenna efficiency [6], [7], mutual coupling reduction among exiting elements in antenna arrays [8], [9] and enhancement of stealth capability of antenna by lowering of radar cross section (*RCS*) [10]-[12].

A metamaterial absorber (*MMA*) periodic structure has been utilized efficiently to enhance the in-band stealth capability of the antenna by reducing its *RCS* [13]-[16].

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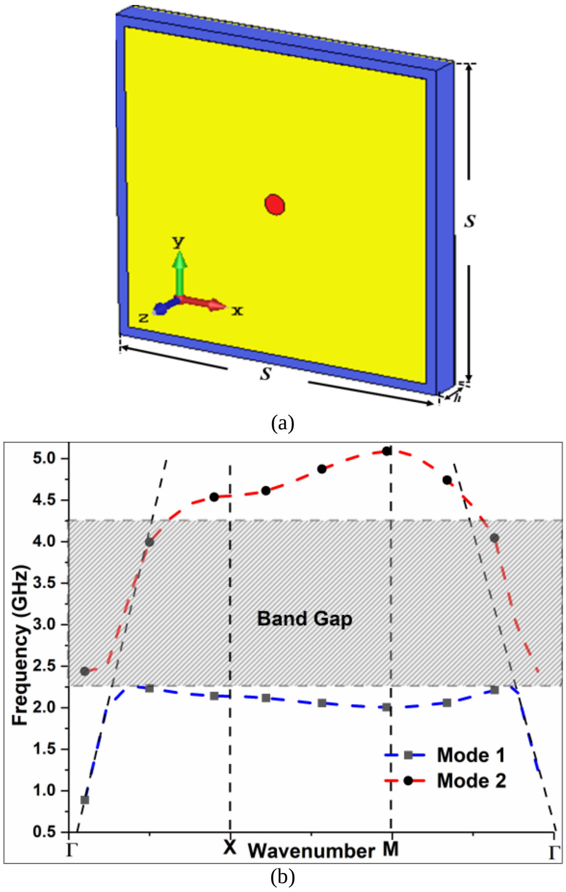


Fig. 1. The geometry of EBG unit cell. (a) perspective view and (b) Dispersion curve with dimensions: S= 16 mm, g= 1 mm, h=1.5 mm, t= 0.035mm and via= 0.5 mm.

On the other hand, it marginally degrades and affects the antenna radiation performance [17-18]. Similarly, a frequency selective surface (*FSS*) can act as a band-pass or band-stop filter in antenna radomes, artificial magnetic conductor (*AMC*) and find applications in lowering antenna's *RCS* [19]-[22]. However, it also deteriorates antenna radiation performance [23]. Contrary to this defected ground structure (*DGS*) has been widely used for different applications such as radiation properties enhancement [24], bandwidth [25], mutual coupling reduction in antenna arrays [26] and antenna size reduction [27]. The *DG* plane is realized by etching off a shape in the ground plane. Depending on the geometry and dimensions of the defective shape, the impedance and surface current distribution get perturbed and this further modifies the associated capacitance and the inductance. Thus, results in a controlled propagation and excitation of the *EM* waves through the dielectric substrate.

Similarly, *EBG* structures are also widely used because of its unique properties and *EM* features such as electromagnetic band-gap and in-phase reflection to heighten antenna performance [28]-[31]. Making these considerations in this research work, we have designed a traditional microstrip patch antenna operating at 2.45 GHz resonant frequency. Then this antenna is modified by the defected ground structure. Once again antenna structure is altered and loaded with *EBG* structure. The *EBG* structure is designed and optimized such that resonance peak of antenna lies within its forbidden band-gap so that the surface wave excited by this patch antenna could be suppressed and prevent propagation.

The remaining research work has been organized as follows: *section II* describes the designing process of *EBG* structure, while proposed patch antenna designing with *DG* plane and *EBG* structure together with radiation performance analysis has been given in *section III*. Finally, *section IV* concludes the work and recommends future direction.

II. Designing of Mushroom-Type EBG

Electronic band-gap structures are usually compact and lightweight, low fabrication cost, minor losses and can be easily integrated into antennas design without degrading performance. *EBG* structures possess interesting and unique properties such as it behaves like high impedance surface in the certain frequency band and behaves like a pass-band filter in others. Using these properties one can solve problems that arise when antenna's exiting source mount close to a ground plane. Another scenario exists when several exiting sources etched close to each other conducting planes. This would result in mutual coupling and lead to degradation of antenna performance. *EBG* structures are used in this scenario to minimize coupling by creating a band-gap region, where surface waves get suppressed. Thus, enhances the efficiency of the antenna by re-reflecting back *EM* radiations in phase with respect to forwarding *EM* radiations. On the other hand, *EM* signals remain unperturbed for out-band frequency region.

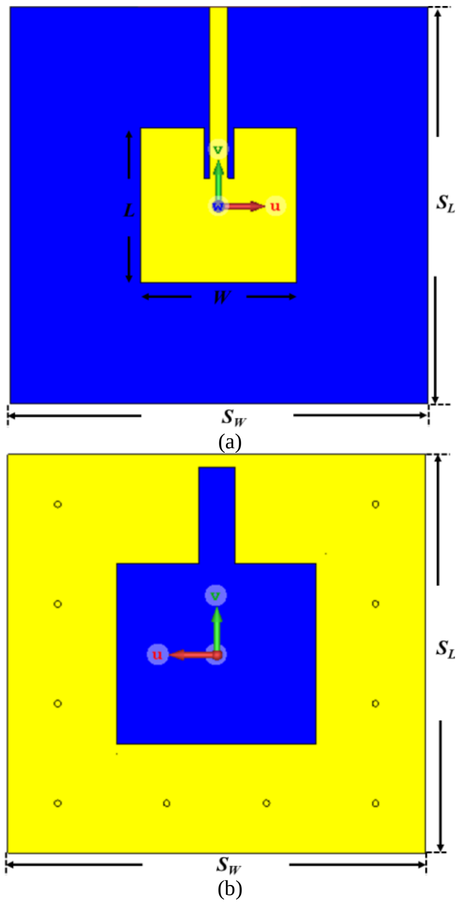
For the fast and accurate analysis of periodic *EBG* structures, a single *EBG* unit cell behavior could be considered and studied with appropriate boundary conditions. The periodicity (*S*) of a single unit cell of *EBG* is 16 mm. A copper patch of 15 mm x 15 mm has been directly printed on *FR-4* substrate material of thickness 1.5 mm with relative permittivity (ε_r) 4.3 and tangent loss (δ) 0.025. A via of diameter 0.5 mm connecting the metal patch to the ground plane has been chosen and shown in Fig. 1(a).

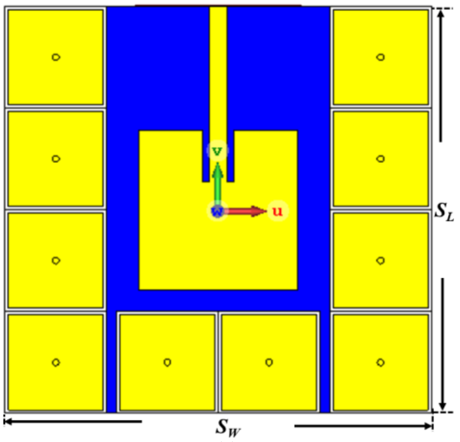
In an *EBG* equivalent frequency tuned circuit, the inductance is represented by via, while capacitance is governed by the gap (*g*) 1 mm between the patches. A dispersion diagram of a unit cell of the mushroom-type *EBG* structure has been plotted and depicted in Fig. 1(b).

The frequency band-gap of the *EBG* structure has been adjusted between 2.25 to 4.25 GHz using parameter sensitivity analysis. Parameter sensitivity is the deviation in frequency response with the variation of parameters. So, the parameters like periodicity (*S*), gap width (*g*), a substrate thickness (*h*), and dielectric constant (ε_r) of the *EBG* have been varied and tuned along with via diameter as it also has a trivial effect. All parameters are optimized to cover the operating frequency of 2.45 GHz.

III. Patch Antenna Designing with Defected Ground Plane and EBG

The basic geometry of a conventional microstrip patch antenna designed with inset feed has been shown in Fig. 2(a). The top layer is the radiating rectangular patch (copper), backed by most popular and readily available flame retarded (*FR-4*) substrate of height h = 1.5 mm. The substrate is grounded using a copper layer. The dimensions of the antenna are as follow: periodic length $S_L = 64$ mm, periodic width $S_W = 67$ mm of the substrate with length L = 28.88 mm, and width W = 35 mm of the radiating patch. A standard thickness of 35 µm has been considered which is compatible with *PCB* fabrication technology. The antenna is operational at 2.45 GHz of *ISM* band.





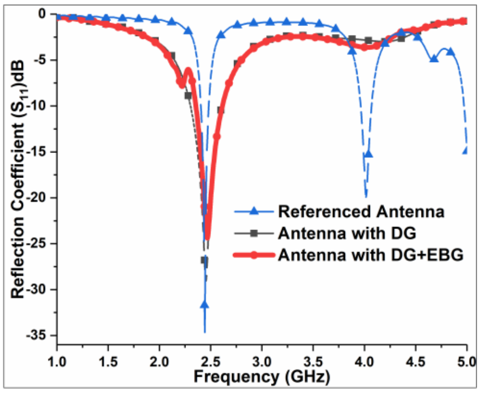
(c)

Fig. 2. Microstrip patch antenna (a) referenced antenna (b) antenna with the defected ground plane and (c) modified antenna (DG+ EBG).

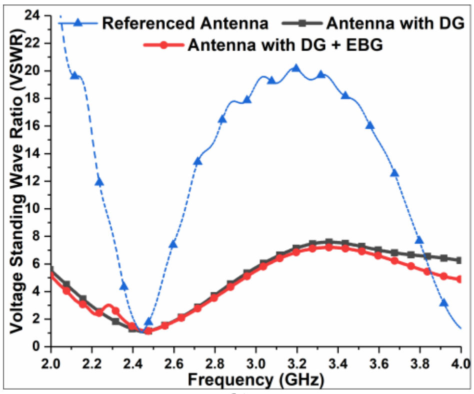
This referenced antenna is then modified with the defected ground plane as shown in Fig. 2(b). Which result in modification of resonant frequency and it gets shifted to the lower-band. So, when the antenna is optimized back to 2.45 GHz resonant frequency, the exiting patch dimensions get modified and become equals to L=25.1mm, and W = 25mm, respectively. This indicates a miniaturization to 37.9 % of patch size when get modified with *DG* plane. Finally, this antenna structure has been further modified with periodic mushroom-typed EBG to study the effect of EBG on overall antenna radiation performance and depicted in Fig. 2(c).

TABLE I: ANTENNA RADIATION PERFORMANCE COMPARISON

Structure/Performance Parameters	Referenced Antenna	Antenna with DG	Antenna with DG +EBG
Frequency (f_0) GHz	2.45	2.45	2.47
Return Loss (S_{11}) dB	-34.65	-29.02	-24.40
Bandwidth (-10 dB) MHz	72	304	256
VSWR	1.04	1.07	1.13
Impedance (Z_{11}) Ω	50.87	47.14	46.83
Radiation Efficiency (η)	35.1 %	85.06 %	83.97 %
Directivity (dBi)	6.68	4.48	4.68
Gain (dB)	2.12	3.77	3.84



(a)



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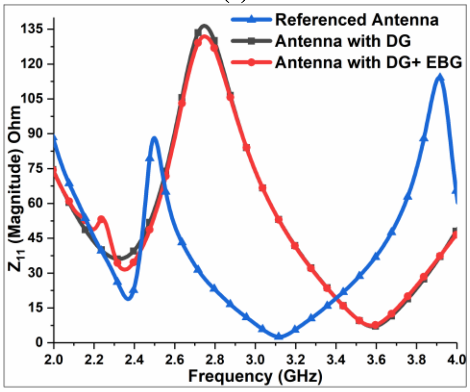

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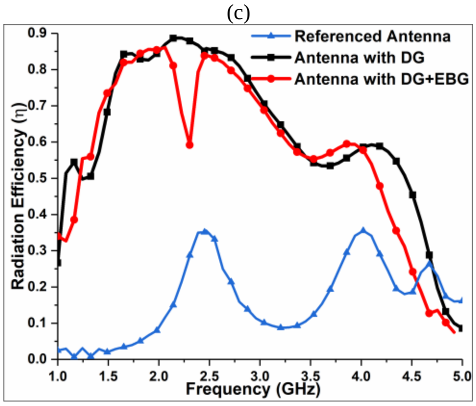


(d)

Fig. 3. Comparisons of antenna radiation performances (a) scattering coefficient (S_{11}) (b) VSWR (c) Z_{11} (magnitude) and (d) radiation efficiency (η).

A comparison of antenna radiation performances has been made and shown in Fig. 3. For the referenced antenna, the value of the S_{11} parameter has been observed at 2.45 GHz and equal to -34.65 dB. The antenna is then modified with *DG* plane with resonant frequency peak adjusted to 2.45 GHz with -29.02 dB. Finally, this structure has been modified by loading with EBG structure and which results in a slight shift of resonance frequency to 2.47 GHz with S_{11} approaches to -24.40 dB and shown in Fig. 3(a). For the referenced antenna, the value of *-10 dB* bandwidth is very small and equal to 72 MHz, whereas after modifying it with *DG* plane it effectively enhances to 304 MHz. But after loading of *EBG* structure slightly reduces the bandwidth to 256 MHz that is still larger than the referenced antenna.

To further analyze the behavior of proposed patch antenna on antenna radiation performances, an analysis of voltage standing wave ratio (*VSWR*), impedance (Z_{11}) and radiation efficiency (η) have been made. The results show that for reference antenna, the value for *VSWR* comes out 1.04 and 1.07 for an antenna with *DG* plane, whereas for a proposed model with *DG* and *EBG* it comes out to be 1.13 as shown in Fig. 3(b). All values of *VSWR* remain within the acceptable range of 1 to 1.5.

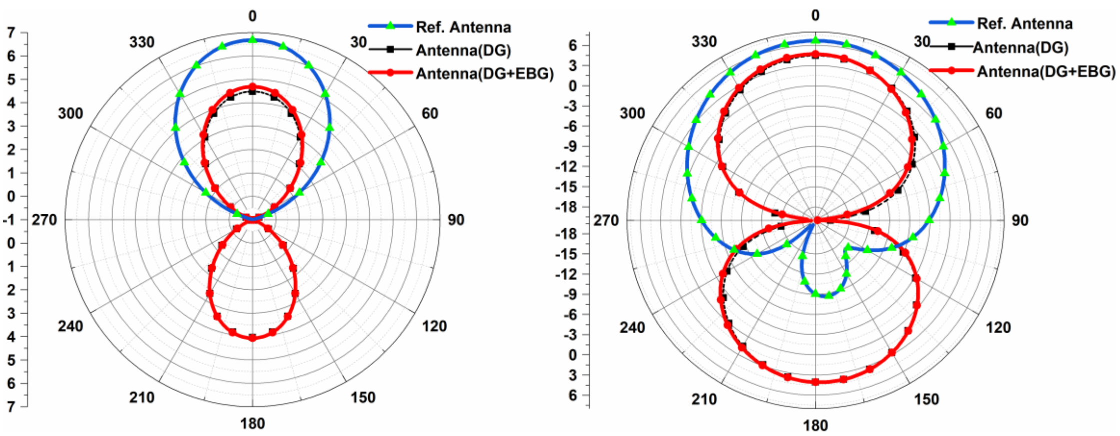
The value for Z_{11} (magnitude) for referenced antenna observed of 50.87 Ω and 47.14 Ω for an antenna with *DG* plane at 2.45 GHz, whereas for proposed model the value of Z_{11} reduces to 46.83 Ω at 2.47 GHz as shown in Fig. 3(c). All these values are approximated to 50Ω matching impedance.

Similarly, for reference antenna, the value of radiation efficiency (η) is very less and is equal to 35.1%. But when it modified with *DG* plane it effectively enhances to 85.06 %. For the proposed model with *DG* plane and *EBG*, the value of η marginally reduces to 83.97 % and depicted in Fig. 3(d). For better clarification and understanding, a comparison of antenna radiation performance has been given and tabularized in Table I.

A polar plot comparison for antenna directivity has been given in Fig. 4. The results indicate that for *E-Plane*, the referenced patch antenna main lobe magnitude is 6.68 dBi with 3 dB angular width is 87^0 and for an antenna with *DG* plane it reduces to 4.48 dBi with 3 dB angular width is 92.3^0. For the proposed model with *DG* and *EBG* structure, the value of main lobe magnitude is 4.68 dBi with 3 dB angular width is 89.2^0 as depicted in Fig. 4(a).

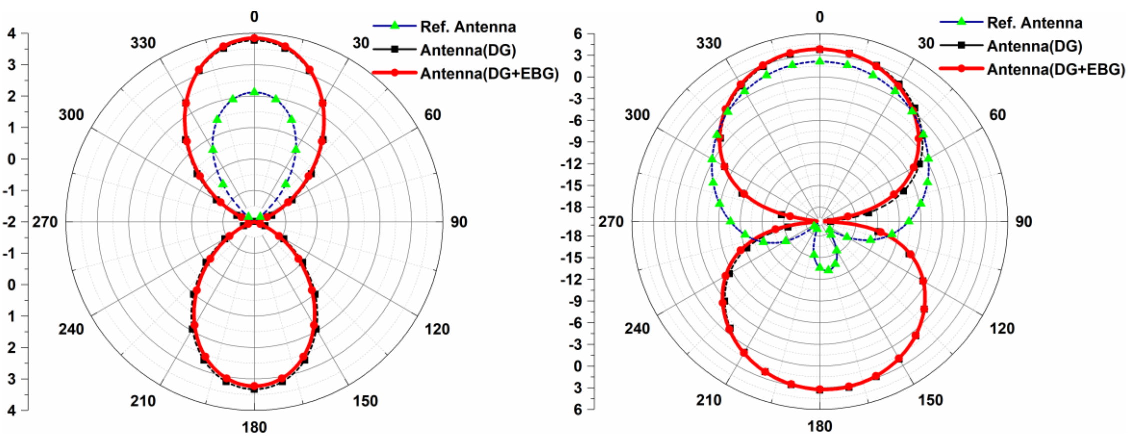
For *H-Plane*, the reference patch main lobe magnitude is 6.68 dBi with 3 dB angular width is 92.3^0 and for an antenna with *DG* plane it reduces to 4.48 dBi with 3 dB angular width is 74^0. For the proposed model with *DG* and *EBG* structure, the value of main lobe magnitude is 4.69 dBi with 3dB angular width is 72.2^0 as depicted in Fig. 4(b).

A polar plot comparison for antenna gain has been given in Fig. 5. The results indicate that for *E-Plane*, the reference patched antenna main lobe magnitude is 2.12 dB with beamwidth is 87^0 and for an antenna with *DG* plane it increases to 3.77 dB with beamwidth is 92.3^0. For the proposed model with *DG* and *EBG* structure, the value of main lobe magnitude further enhances to 3.84 dB with beamwidth is 89.2^0 as depicted in Fig. 5(a).



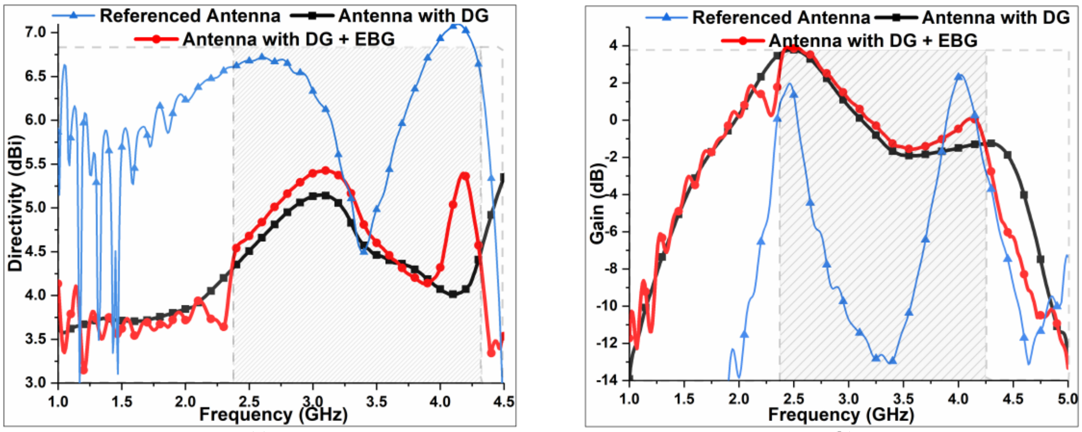
(a) (b)

Fig. 4. Polar plot comparisons of antenna directivity for (a) E-Plane and (b) H-Plane.



(a) (b)

Fig. 5. Polar plot comparisons of antenna gain for (a) E-Plane and (b) H-Plane.



(a) (b)

Fig. 6. Two-dimensional comparisons for (a) directivity and (b) gain.

For *H-Plane*, the reference patch main lobe magnitude is 2.12 dB with beamwidth is 92.3^0 and for an antenna with *DG* plane it increases to 3.77 dB with beamwidth is 74^0. For the proposed model with *DG* and *EBG* structure, the value of main lobe magnitude further enhances to 3.85 dB with beamwidth is 72.2^0 as depicted in Fig. 5(b).

This concludes that when the referenced antenna is modified with *DG* plane and *EBG*, its antenna gain enhances to 81.1%. So, the proposed antenna would require less power in the line of sight transmission and therefore would lead to a reduction in hardware cost as the number of repeaters required reduces. The beamwidth has been also reducing in the proposed antenna as compared to the conventional antenna. This would lead to a concentrate and focus power in the line of sight transmission for long distance transmission.

In Fig. 6, the two-dimensional comparisons of antenna's directivity and gain have been made between 1 to 5 GHz of the frequency band. The analysis indicates that when the antenna is loaded with *DG* and *EBG* structure, the value of directivity remains high for the entire band-gap of *EBG* structure that lies between 2.37 to 4.31 GHz and shown in Fig. 6(a). However, a minor fluctuation is observed between 3.67 to 3.92 GHz, where antenna with *DG* plane value slightly increases. On the other hand, the value of gain remains high for the entire bandgap of *EBG* structure that lies between 2.41 to 4.24 GHz and shown in Fig. 6(b).

IV. Conclusions and Future Remarks

In this research work, we have proposed an inset feed microstrip antenna operating at 2.45 GHz of *ISM* band. Its behavior has been analyzed after modifying it with the defected ground plane and then loading it with mushroom-typed *EBG* structure. It has been observed that when the antenna is modified with *DG* structure, it doesn't only miniaturize the exited patch but also enhances the bandwidth, gain and radiation efficiency. Furthermore, when the antenna is loaded with *EBG* structure, it enhances antenna directivity and gains. On the other hand, bandwidth and radiation efficiency are marginally affected. It has been also observed that the antenna directivity and gain increase throughout the band-gap of *EBG*. Whereas, the rest of parameters remain highly preserved. This structure finds its applications in antenna designing and reduction of monostatic and bistatic *RCS* in military and stealth platform for lower detectable objects.

References

[1] B. I. Wu, H. Chen, J. A. Kong, and T. M. Grzegorczyk, "Surface wave suppression in antenna systems using magnetic metamaterial," *Journal of Applied Physics*, vol. 101, no. 11, pp. 131-134, April 2007.

[2] A. Kumar, J. Mohan, and H. Gupta, "Surface wave suppression of microstrip antenna using different EBG designs," in *Proc. IEEE International Conference on Signal Processing and Communication*, Noida, India, March 16-18, 2015.

[3] S. Mirhadi and M. K. Hessari, "Surface waves suppression in a biaxially anisotropic metamaterial grounded slab," in *Proc. Progress in Electromagnetics Research Symposium Proceedings*, Moscow, Russia, August 18-21, 2009.

[4] D. Nashaat, H. A. Elsadek, E. Abdallah, H. Elhenawy, and M. F. Iskander, "Multiband and miniaturized inset feed microstrip patch antenna using multiple spiral-shaped defect ground structure (DGS)," in *Proc. IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting (APSURSI)*, Charleston, USA, June 1-5, 2009.

[5] P. K. Panda and D. Ghosh, "Mushroom-like EBG structures for reducing RCS of patch antenna arrays," in *Proc. IEEE International Conference on Microwave and Photonics*, Dhanbad, India, December 13-15, 2013.

[6] H. A. Majid, M. K. A. Rahim, and T. Masri, "Microstrip antenna's gain enhancement using left-handed metamaterial structure," *Progress in Electromagnetics Research M*, vol. 8, pp. 235-247, 2009.

[7] L. Leger, T. Monediere, and B. Jecko, "Enhancement of gain and radiation bandwidth for a planar 1-D EBG antenna," *IEEE Microwave and Wireless Components Letters*, vol. 15, no. 9, pp. 573-575, September 2005.

[8] Q. L. Zhang, Y. T. Jin, J. Q. Feng, X. Lv, and L. M. Si, "Mutual coupling reduction of microstrip antenna array using metamaterial absorber," *IEEE MTT-S International Microwave Workshop-Advanced Materials and Processes for RF and THz Applications*, Suzhou, China, July 1-3, 2015.

[9] H. T. Hui, M. E. Bialkowski, and H. S. Lui, "Mutual coupling in antenna arrays," *International Journal of Antennas and Propagation*, vol. 2010, pp. 1-2, April 2010.

[10] Y. Zhou, X. Cao, and J. Gao, "A novel wideband metamaterial absorber for antenna RCS reduction," in *Proc. International Applied Computational Electromagnetics Society Symposium (ACES)*, Suzhou, China, 1-4 August 2017, pp. 1-2.

[11] Y. Liu, Y. Hao, H. Wang, K. Li, and S. Gong, "Low RCS microstrip patch antenna using frequency-selective surface and microstrip resonator," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1290-1293, June 2015.

[12] W. T. Wang, S. X. Gong, X. Wang, H. W. Yuan, J. Ling, and T. T. Wan, "RCS reduction of array antenna by using bandstop FSS reflector," *Journal of Electromagnetic Waves and Applications*, vol. 23, no. 11-12, pp. 1505-1514, April 2012.

[13] D. Singh and V. M. Srivastava, "Dual resonances shorted stub circular rings metamaterial absorber," *AEU-International Journal of Electronics and Communication*, vol. 83, pp. 58-66, January 2018.

[14] D. Singh and V. M. Srivastava, "Triple band regular decagon shaped metamaterial absorber for X-band applications," in *Proc. IEEE International Conference on Computer Communication and Informatics*, Coimbatore, India, 5-7 January 2017, pp. 411-415.

[15] D. Singh and V. M. Srivastava, "Low Radar Cross Section of Patch Antenna using Shorted Stubs Metamaterial Absorber," *International Journal of Microwave and Optical Technology*, vol. 13, no. 3, pp. 194-202, May 2018.

[16] D. Singh and V. M. Srivastava, "An Analysis of RCS for Dual-Band Slotted Patch antenna with a thin dielectric using Shorted Stubs Metamaterial Absorber," *AEU-Journal of Electronics and Communication*, vol. 90, pp. 53-62, June 2018.

[17] Y. Liu and X. Zhao, "Perfect absorber metamaterial for designing low-RCS patch antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1473-1476, August 2014.

[18] Z.-X. Zhang and J. C. Zhang, "RCS reduction for patch antenna based on metamaterial absorber," *Progress in Electromagnetic Research Symposium (PIERS)*, Shanghai, China, 8-11 August 2016, pp. 364-368.

[19] N. Xu, J. Gao, J. Zhao, and X. Feng, "A novel wideband, low-profile and second-order miniaturized band-pass frequency selective surfaces," *AIP Advances*, vol. 5, no. 7, pp. 571-576, July 2015.

[20] S. Narayan, B. Sangeetha, T. V. Sruthi, V. Shambulingappa, and R. U. Nair, "Design of low observable antenna using active hybrid-element FSS structure for stealth applications," *AEU-International Journal of Electronics and Communications*, vol. 80, pp. 137-143, October 2017.

[21] D. Singh and V. M. Srivastava, "3-D Cylindrical shaped frequency selective surface," in *Proc. IEEE 4th International Conference on Advanced Computing and Communication Systems (ICACCS-2017),* Coimbatore, India, 6-7 January 2017, pp. 1-6.

[22] D. Singh and V. M. Srivastava, "Polarization insensitive cylindrical shaped frequency selective surface," in *Proc. IEEE 10th International Conference on Development in esystem Engineering (DeSe2017),* Paris, France, 14-16 June 2017, pp. 1-6.

[23] N. Kushwaha, and R. Kumar, "Design of a wideband high gain antenna using FSS for circularly polarized applications," *AEU - International Journal of Electronics and Communications*, vol. 70, no. 9, pp. 1156-1163, September 2016.

[24] A. Arya, M. V. Kartikeyan, and A. Patnaik, "Efficiency enhancement of microstrip patch antenna with defected ground structure," *IEEE Proceeding of International Conference on the Microwave,* Jaipur, India, November 21-24, 2008.

[25] N. Ripin, S. N. C. Yusoff, A. A. Sulaiman, N. E. A. Rashid, and M. F. Hussin, "Enhancement of bandwidth through I-shaped defected ground structure," *IEEE International RF and Microwave Conference (RFM2013),* Penang, Malaysia, 9-11 December 2013.

[26] F. Y. Zulkifli, E. T. Rahardjo, and D. Hartanto, "Mutual coupling reduction using dumbbell defected ground structure for multiband microstrip antenna array," *Progress in Electromagnetics Research Letters,* vol. 13, pp. 29-40, 2010.

[27] D. Fistum, D. Mali, and M. Ismail, "Bandwidth enhancement of rectangular microstrip patch antenna using defected ground structure," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 3, no. 2, pp. 428-434, August 2016.

[28] V. Ekke and P. Zade, "Implementation of EBG configuration for asymmetric microstrip antenna to improve radiation properties," *Journal of Telecommunication, Electronic and Computer Engineering*, vol. 9, no. 1, pp. 61-66, March 2017.

[29] S. Gnanasundar and K. U. Kiran., "Study of electromagnetic bandgap structures for antenna application," in *Proc. IEEE 3rd International Conference on Signal Processing, Communication and Networking (ICSCN),* Chennai, India, 26-28 March 2015.

[30] C. Neo and Y. H. Lee, "Patch antenna enhancement using a Mushroom-like EBG structure," *IEEE Antennas and Propagation Society International Symposium (APSURSI),* Orlando, USA, 7-13 July 2013.

[31] D. N. Elsheakh, H. A. Elsadek, E. A. Abdallah, H. Elhenawy, and M. F. Iskander, "Enhancement of microstrip monopole antenna bandwidth by using EBG structures," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 959-962, September 2009.

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