International Journal of Engineering Sciences & Emerging Technologies, Feb. 2013.
ISSN: 2231 – 6604 Volume 4, Issue 2, pp: 1-12 ©IJESET

A NOVEL HIGH DIRECTIVE EBG STRUCTURE AND METAMATERIAL SUPERSTRATE FOR MICROSTRIP ANTENNA

R.A. Sadeghzadeh[1], Reza Khajehmohammadlou[2], Mahdi Jalali[3]

[1]Department of Electrical Engineering, Khaje-Nasir Toosi University, Tehran, Iran
sadeghz@eetd.kntu.ac.ir
[2]Department of Electrical Engineering, Miandoab Branch, Islamic Azad University, Miandoab, Iran
reza.mohammadlou63@gmail.com
[3]Department of Electrical Engineering, Naghadeh Branch, Islamic Azad University, Naghadeh, Iran
Jalali.mahdi@gmail.com

ABSTRACT

In this paper a high gain and directive microstrip antenna made from metamatrial superstrate and an electromagnetic band-gap (EBG) substrate has been investigated. EBG structures have two main configurations, first EBG substrate and second EBG superstrate. In first case, the patch of antenna is surrounded with EBG structure that suppress the propagation of surface wave and in second case, layer of EBG structure that call EBG superstrate or metamaterial superstrate set above the patch of antenna. The layers of EBG superstrate have near zero refraction index that concentrate radiation energy normal to superstrate. A patch antenna surrounded with novel EBG structure is used for radiation. By choosing appropriate geometrical parameters of the structures we can obtain suitable impedance matching and negative refraction. The results show that the gain of the antenna with one layer of H-Doubled split ring EBG superstrate increase up to 16dB at 14.3 GHz. In addition, pattern of microstrip antenna with EBG superstrate is more narrower than simple microstrip antenna.

KEYWORDS: negative refraction; return loss; gain; H-double split rings.

I. INTRODUCTION

Microstrip antennas are widely used in various applications because of low profile, low cost, lightweight and conveniently to be integrated with RF devices. However, microstrip antennas have also disadvantages. The main disadvantages are the excitation of surface waves that occurs in the substrate layer and radiation of electromagnetic energy in different directions from radiation source (i.e. patch). Surface waves are undesired because when a patch antenna radiates, a portion of total available radiated power becomes trapped along the surface of the substrate. Therefore, surface wave can reduce the antenna efficiency, gain and bandwidth. In other hand, radiation in different directions cause the electromagnetic energy duo to the patch and feed of microstrip antenna, divide in all direction in the space that it results to reduce directivity, gain and wide radiation beam [1].
One solution to reduce above disadvantages is using EBG structure [2, 3]. EBG structures are periodic structures that are composed of dielectric, metal or metallo-dielectric materials. These structures can prevent or assist wave propagation in special directions and frequencies therefore they can be used as spatial and frequency filters [4]. The 2-D EBG surfaces, have the advantages of low profile, light weight, and low fabrication cost, and are widely considered in antenna engineering. Two popular kind of 2-D EBG are mushroom-like EBG surface and Uniplanar EBG surface [5, 6]. An important feature in the uniplanar EBG design is the removal of vertical vias. Thus, it simplifies the fabrication process and is compatible with microwave and millimeter wave circuits. There are several configurations of EBG structures according to their application in antenna. Two main configurations are [7]:

a) EBG structures place on antenna substrate that by creation band gap in certain frequency range Suppress from propagation of surface wave. This configuration is defined as EBG substrate. In this configuration both of mushroom-like EBG and uniplanar EBG is used [8].
b) EBG structure place at certain distance above radiation source of antenna i.e. patch and by creation ultra refraction phenomenon, concentrate radiation in various direction normal to EBG structure. This configuration is defined as EBG superstrate or Metamaterial superstrate and only the uniplanar EBG is used in this one [9].
In this paper, simple square patch microstrip antenna with coaxial feed is used for analysis and simulation the effect of two configurations of EBG structures. The reason of this choice is that high directive and wideband antenna with more compact structure and simple feeding is of great interest in recent years [10].
The frequency is selected between 12 GHz to 19 GHz in Ku band. The reason of this selection is that nowadays the most of lower bands is occupied and Ku band have lots of applications in satellite communication. The simulation results show that the characteristics of microstrip antenna with EBG structure are improved.
The article is organized as following sections. Section 2 describes the EBG design and analysis for antenna substrate. This section divide to three subsection section 2.1 and 2.2 relate to design mushroom like and Uniplanner EBG in Ku-band and section 2.3 shows design of antenna with theses loaded EBG structures on substrate. Section 3 presents the design and simulation results of antenna with EBG superstrate. In this section introduce square unipalnnaer EBG superstrate and simulated it and proposed H-double splite ring EBG superstrate. Section 4 summarizes the study

II. DESIGN AND ANALYSES EBG FOR ANTENNA SUBSTRATE

2.1. Mushroom-like EBG structure for substrate

The mushroom-like EBG structure consists of four parts, which are: 1) a ground plane, 2) a dielectric substrate, 3) square metal patches, 4) connecting via that is shown in Figure-1. The frequency band-gap is determined by the patch width w, the gap size g, the substrate thickness t and the substrate dielectric constant ε_r. When the periodicity ($w + g$) is small compared to the operating wavelength, the operation mechanism of this EBG structure can be explained using an effective medium model with equivalent lumped LC elements [11]. The capacitor results from the gap between the patches and the inductor results from the current along adjacent patches. The method of calculating the transmission coefficient is introduced to identify the bandgap, as shown in Figure-1. A 4×13 units of EBG structure is inserted between the two 50 Ω open-ended microstrip-line. One of the microstrip-line is used to excite the surface wave and another is acted as the detector of the electromagnetic field intensity.
The EBG structures are simulated on Roger RT/duroid 5880 substrate which its permittivity is 2.2 and thickness is 1.575 mm. They have the following geometrical parameters: w=0.12λ, g=0.02λ, where λ is the free space wavelength at resonance frequency of patch antenna [4]. The radius of vias is 0.3 mm. With the transmission line method, the optimized parameters of EBG structure are w=2.5 mm and g=0.5 mm and the results are shown in Figure-2. From the simulation results, it can be seen that due to the existence of EBG structures between the two microstrip-lines, the magnitude of S_{21} decreases greatly within the range of 12 GHz–18 GHz. It means that the propagation of surface wave is successfully suppressed. The designed EBG structures can satisfy the requirements of the patch radiation.

2.2. Uniplanner EBG design for substrate

One of the most important features in the uni-planar EBG design is removal of vertical vias. Similar to the mushroom-like EBG surface, the operational mechanism of the uniplanar EBG surface can be explained by the lumped LC model. The capacitance *C* also comes from the edge coupling between adjacent patches. Instead of using vertical vias to provide an inductance *L*, a thin microstrip line on the same layer of the patches is used to connect them together. The main parameters of uniplanar EBG are shown in Figure-3. For frequency bandgap of uniplanar EBG be similar as mushroom-like EBG, the dimensions of uniplanar EBG must be greater than mushroom-like EBG. Therefore

dimension of parameters are: a =0.3λ, b=0.26λ, s=0.14 λ, t=g=0.04 λ [4]. The method of calculating the transmission coefficient is used to identify the bandgap of uniplanar EBG, too. The EBG structures are simulated on same substrate as mushroom-like EBG that is shown in Fig. 3. By using the transmission line method, the optimized parameters of EBG structure are a=5.9 mm, b=5.1mm and s=2.8mm and t=g=0.8 mm and the results are shown in Figure-4. Compared with mushroom-like EBG, uniplanar EBG suppress surface wave less than mushroom-like EBG and has multi narrower frequency band-gaps.

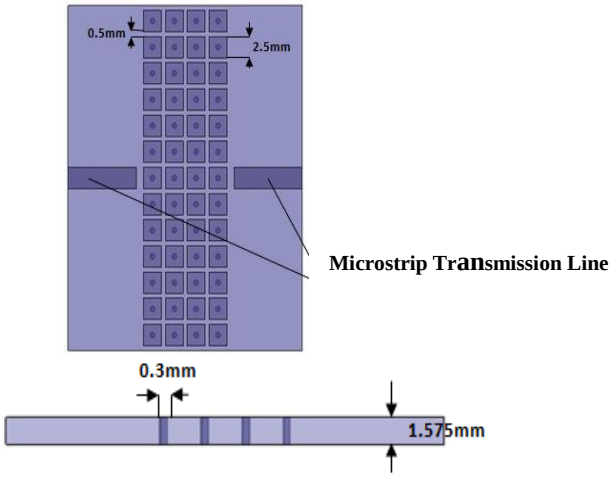


Figure-1: Configuration of 4×13 EBG structures that feed with two microstrip lines

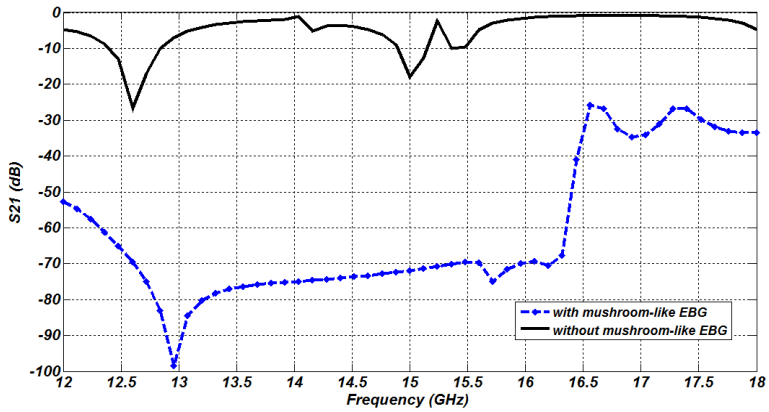


Figure-2: Simulation result of transmission coefficient between the two microstrip-line

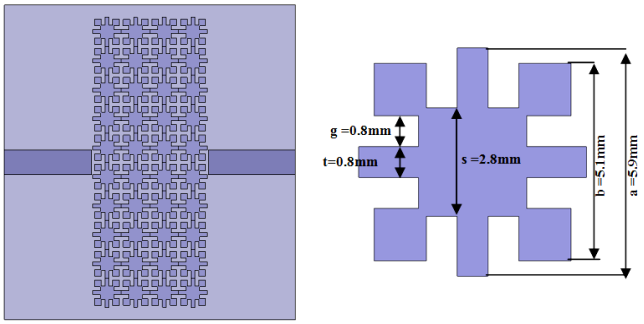


Figure-3: Configuration of 4×10 uni-planer EBG structures that feed with two microstrip lines

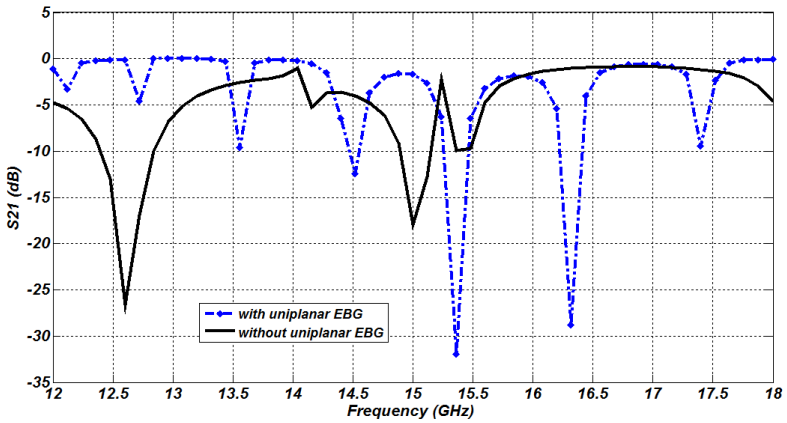
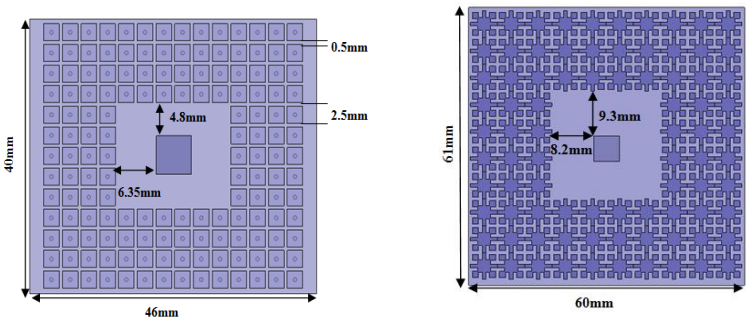


Figure-4: Simulation result of transmission coefficient between the two microstrip-lines

2.3.Antenna with EBG substrate

A simple probe-fed microstrip antenna is used for simulation. Square patch with dimension 5.6mm×5.6mm use as radiation source on the Roger RT/duroid substrate with permittivity 2.2 and height 1.575mm. Square patch feed by 50Ω coaxial probe is positioned 1.3mm off-center. The operation frequency of antenna is 15.23 GHz.Microstrip patch antenna with 4×13 units of mashroom-like EBG structures and with 3×10 units of uniplanar EBG are shown in Figure-5. EBG structure surrounded the patch of antenna. We observe from Figure-2 and Figure-4, these structure have frequency bandgap at the operation frequency of probe-fed microstrip antenna. Therefore, these structures prevent from propagation of surface wave to the edge of substrate. In this work, Ansoft HFSS is used for simulation of parameters of microstrip antennas. Figure-6 shows return loss of antenna with and without EBG structures. Maximum return loss obtained with mushroom-like EBG about -26dB at 15.23 GHz. Gain of antenna are shown in Figure-7 for all frequencies in Ku-band. Maximum gain obtained with uniplanar EBG about 11dB at 15.23GHz. Radition pattern of antenna are shown at operation frequency 15.23GHz in Figure-8 for φ=0 and 90 degree. From results are absorved that by using EBG structures back lobe of antenna is reduced.



(a) (b)

Figure-5: probe-fedmicrostrip antenna with (a) mushroom-like EBG structure (b) uniplanar EBG sturucture

III. DESIGN AND ANALYSES ANTENNA WITH EBG SUPERSTRATE

3.1 Method of EBG superstrate analysis

Figure-9 shows the basic geometries that we consider in analyzing the antenna. These geometries consist of two ideal plates with special reflection, transmission and refraction coefficients and a primary radiation source [7]. To determine the characteristics of the superstratelayer we consider it and its image in the ground plane as depicted in Figure-9. By considering the transmission matrix of each layer we can obtain the transmission matrix of whole structure. Consequently total transmission and reflection coefficients become:

$$T = \frac{t^2 e^{-j\varphi}}{1-r^2 e^{-j2\varphi}} \quad (1)$$

$$R = \frac{r(1+(t^2+r^2)e^{-j2\varphi}}{1-r^2 e^{-j2\varphi}} \quad (2)$$

Which t and r are transmission and reflection coefficient of each superstrate layer and $\varphi=k_0 d$ which d is distance of superstrate layer from radiation source.It can be seen that the total transmission of the structure depends on the distance of the layers and also the transmission and reflection coefficients of each layer.

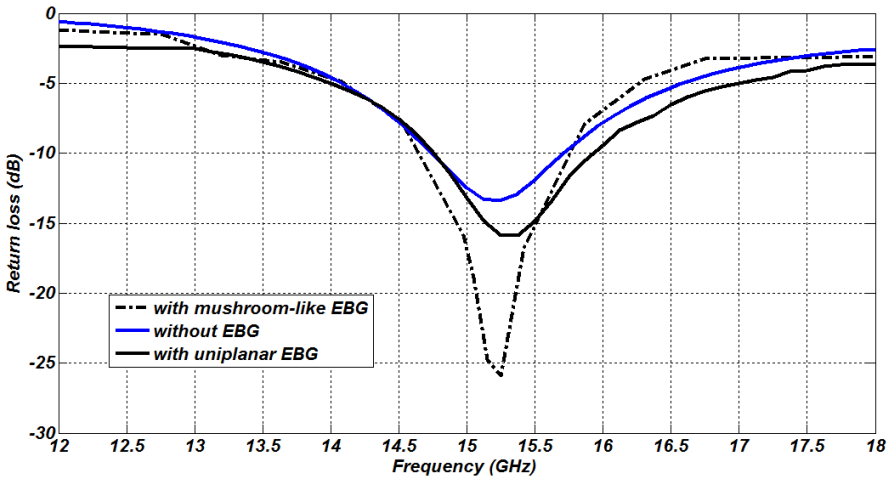


Figure-6: Comparison returns loss of microstrip antenna with and without EBG structures

To obtain refraction index of EBG superstrate, we use parallel-plate waveguide structure filled with EBG superstrate material and extract scattering parameters. With scattering parameters, transmission and reflection coefficients, we can retrieve relative permittivity and permeability of EBG superstrare, refraction index of EBG superstrate obtain as follow:

$$n = \sqrt{\varepsilon_r \mu_r} = k/k_0$$

k is wave number and k_0 is wave number of free space.

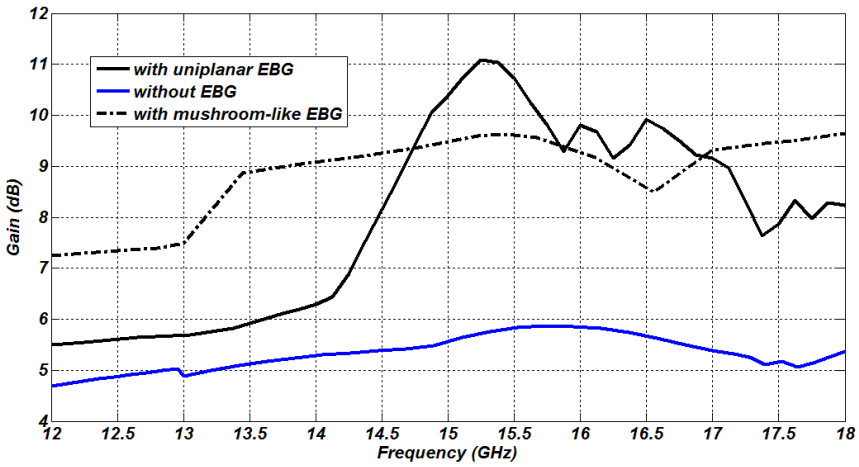
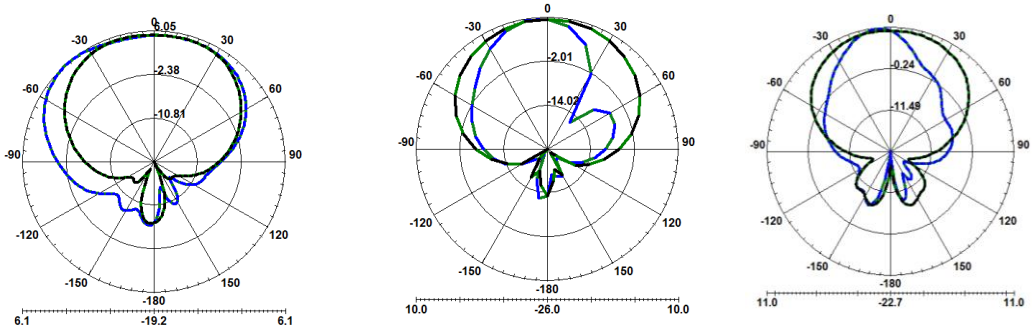


Figure-7: Comparison gain of microstrip antenna with and without EBG structures in Ku-band



(a) (b) (c)

Figure-8: Radiation pattern of microstrip antenna (a) without EBG (b) with mushroom-like EBG (c) with uniplanar EBG

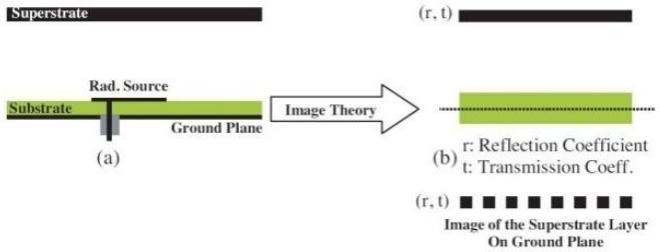


Figure-9: Configuration of antenna with superstrate layer using by Image theory

3.2 Design EBG superstrate

The EBG superstrate used in our simulation is composed of one-layer and two-layer Square uniplaner EBG structure. The unit cell for the square unipalaner EBG structure medium is shown in Figure-10. To obtain unit cell refraction index, a unit cell is identified from the full size structure and placed in a waveguide to collect the S-parameters. The top and bottom surface has PEC boundary conditions, whereas the left and right have perfect magnetic conductor (PMC) boundary conditions and front and back as open boundary condition. A waveguide port is placed at the open boundaries [12, 13]. With the S-parameter data from the waveguide, we can retrieve the refraction index at all frequencies. The refection index of unit cell is shown in Figure-11 (a). Using the same method we obtain refraction index for 7×8 array of the Square uniplaner EBG structure that is shown in Figure-11 (b). From the Figure-11 (b), it is observed the refraction index is near the zero in the frequency range 12-18GHz. Then, it is expected the ultra refraction phenomenon in this range. The radiated energy will be concentrated in a direction close to the normal of the EBG superstrate.

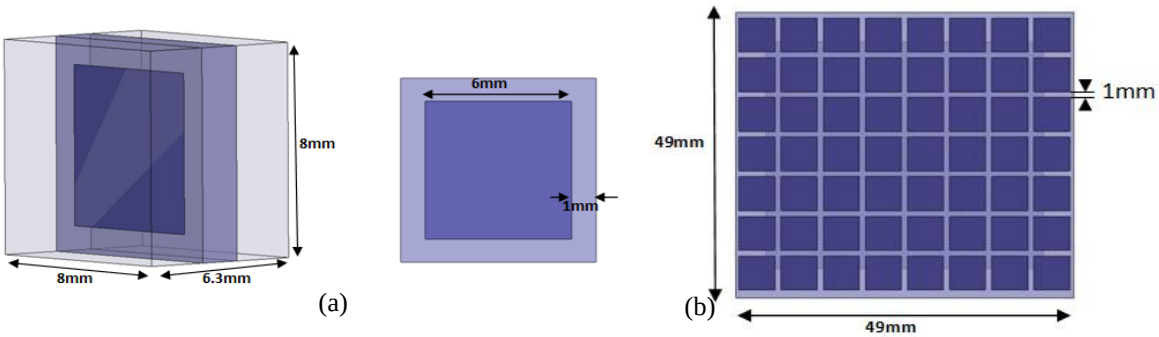


Figure-10: Configuration of Square uni planer for superstrate layer (a) unit cell (b) 7×8 array superstrate layer

3.3 . Antenna with square uni planar EBG superstrate

The schematic view of the antenna is presented in Figure-12. EBG superstrate is placed above the

simple microstrip antenna with same characteristics as mentioned before. Adjustment of first superstrate layer is the most important stage in antenna design and it is about one third of operation wavelength (λ/3) above ground plane which cause to gain increase. The second layer, improve beam shaping and bandwidth. The distance of second layer from first layer is between λ/3 to λ/2 [10].
Figure-13 shows the Return loss of the one-layer, two layer, and probe-fed microstrip antenna. The first layer is about 9.225mm above the ground plane and the distance of second layer is between 10.5mm up to 11.75mm. From diagram is observed, the second layer cause to frequency operation of Antenna move down to lower frequencies. Also bandwidth (S11≤-10dB) of antenna with two layer increases effectively, that is about 1.3 GHz. Figure-14 shows the gain of one layer and two layer superstrate antenna and simple microstrip antenna in the range of 12-18GHz. It is observed the gain of antenna is improved about 11dB with both one layer and two layer Square uniplaner EBG superstrate. Furthermore Figure-15 shows radiation pattern at 15.23GHz for One layer and 14 GHz for two layer EBG superstrate which Gain is maximum in these frequencies. It is apparent directivity of the probe-fed microstrip antenna with EBG superstrate is increased.

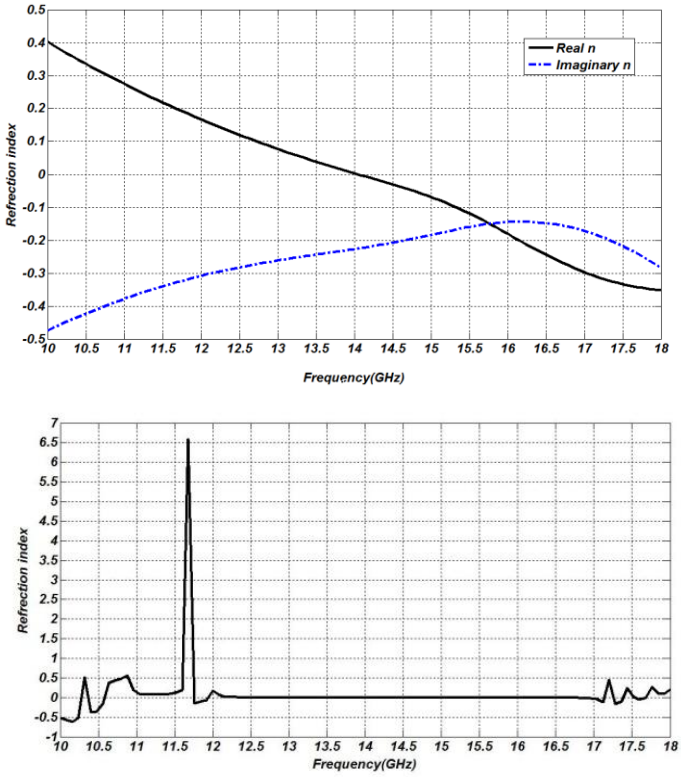


Figure-11: Refraction index of Square uniplaner EBG superstrare layer (a) unit cell (b) 7×8 array

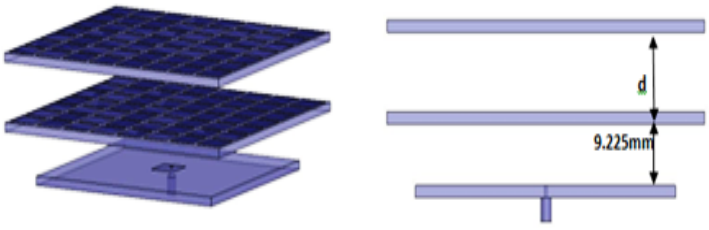


Figure-12: Configuration of microstrip antenna with Square uni planer EBG superstrate

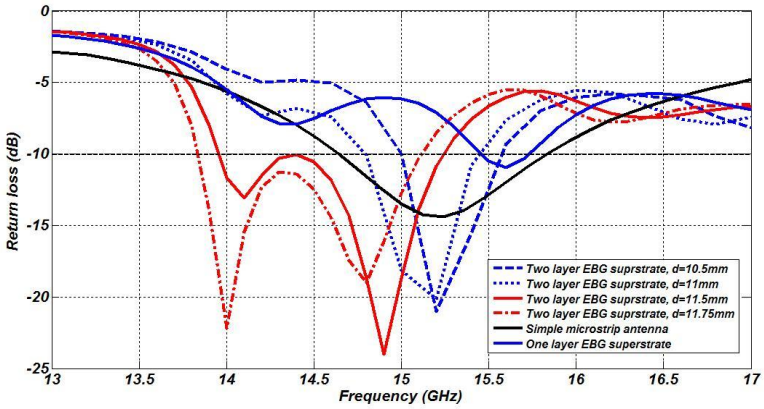


Figure-13: Comparison of return loss of microstrip antenna with and without superstrate layer and with different distance of second layer

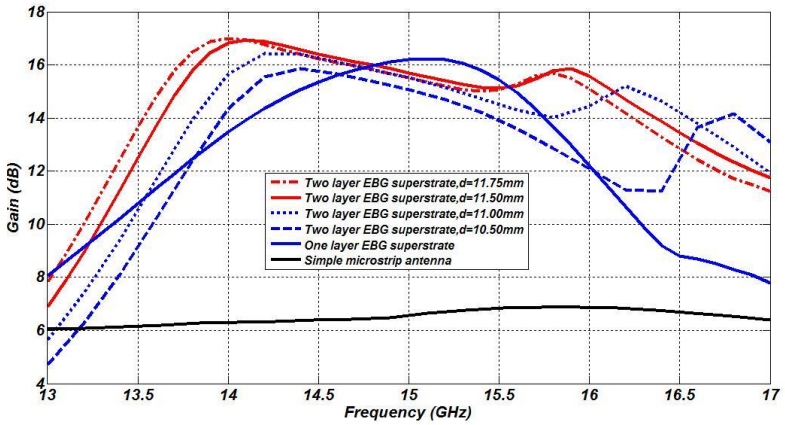
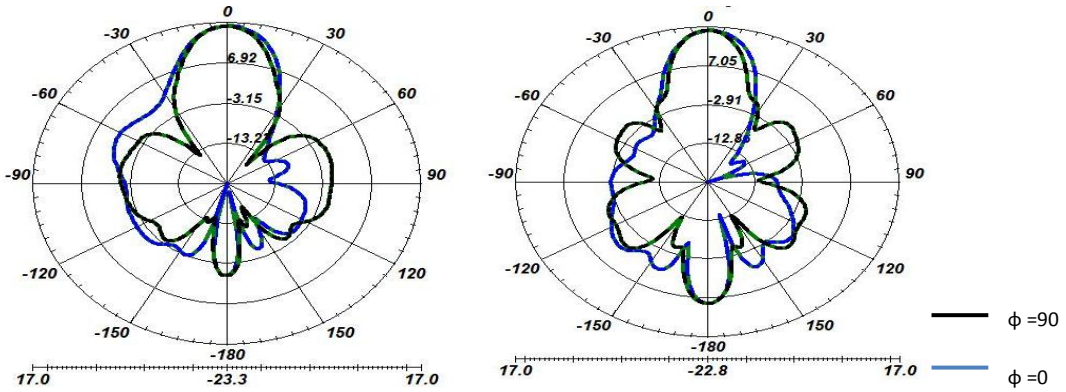


Figure-14: Comparison of Gain of microstrip antenna with and without superstrate layer and with different distance of second layer



(a) (b)

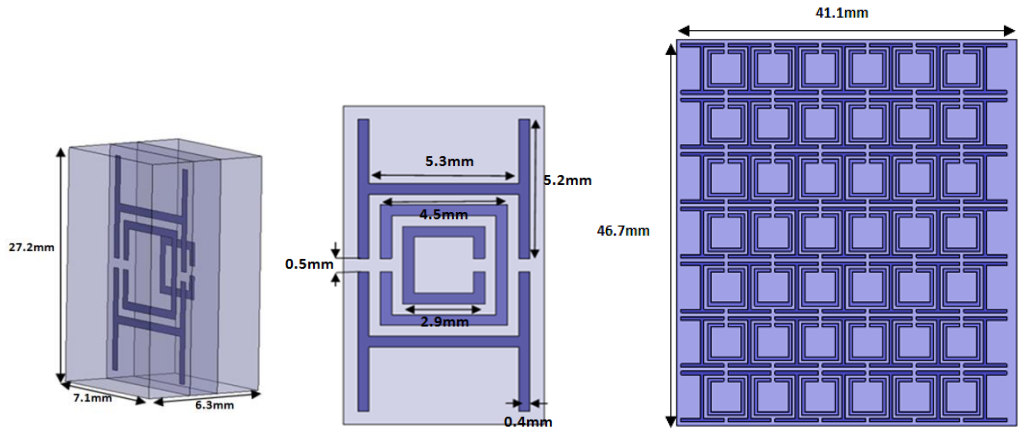
Figure-15: Gain pattern of microstrip antenna (a) one layer Square uni planer EBG superstrate at 15.35 GHz (b) two layer Square uniplaner EBG superstrate at 14 GHz

3.4 Improved EBG superstrate design

From the result of section 3.3, is completely clear that second layer affect the bandwidth and beam shaping. But, antenna with two superstarte layer has its complications. Also, it is caused the thickness of whole Antenna is increased. Therefore, it is logical to overcome these problems, we design improved EBG superstrate layer with H-double splite ring EBG structures. The refraction index of

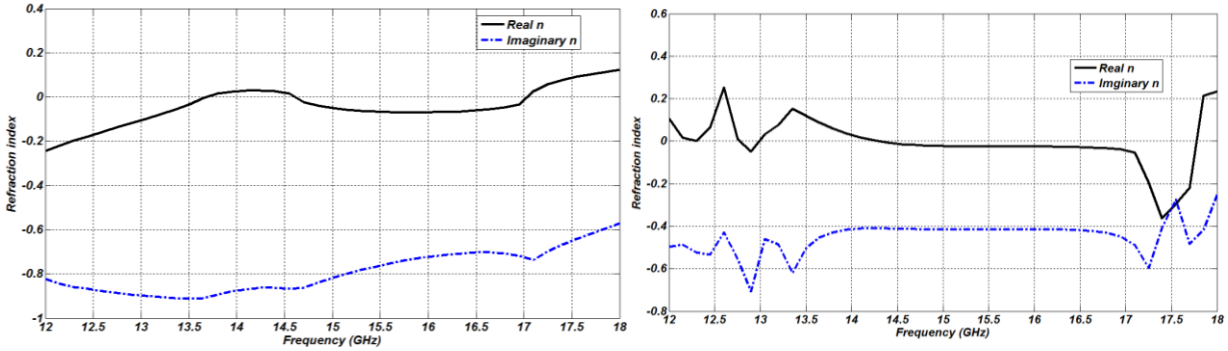
layer is obtained with same method as used in section 3.2. Figure-16 shows the structure of single unit cell and array 6×7 elements of this structure. Also, refraction index of them have shown in Figure-17. From this Figure, we observe that near zero refraction index at Ku-band.

Figure-18 shows microstrip antenna with one layer H-double split rings. Return loss of antenna is shown in Figure-19. It is observed the bandwidth of antenna has increased with one layer compared with antenna with two layer square EBG structure. Figure-20 shows the gain of antenna in 13 GHz to 17 GHz and Figure-21 shows gain pattern of antenna. Although the bandwidth of antenna with this type of superstrate layer increase about 2 GHz just with one layer and whole thickness of antenna is reduced, the gain of antenna slightly reduced and beam of antenna at 14.3 GHz, that it has maximum Gain, as it is observed in Figure-21, it is wider than antenna with two layer square EBG superstrate.



(a) (b)

Figure-16: Configuration of H-Double split ring EBG (a) unit cell (b) 6×7 array



(a) (b)

Figure-17: Refraction index of H-Double split ring EBG superstrate (a) unit cell (b) 6×7 array

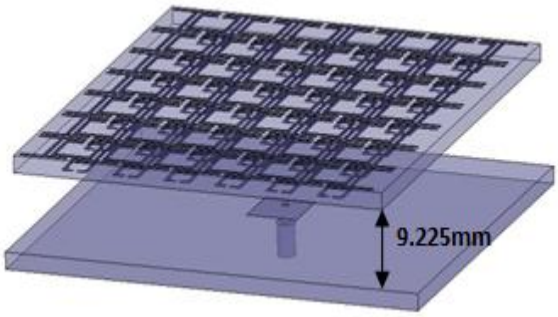


Figure-18: Configuration of microstrip antenna with one layer H-Double split ring EBG superstar

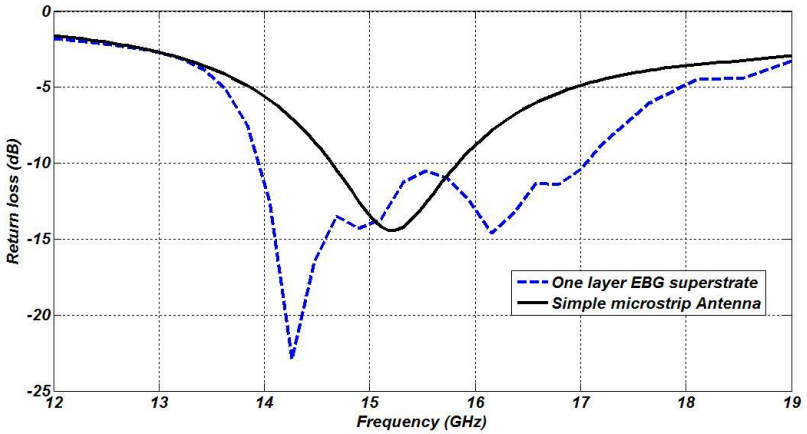


Figure-19: Comparison of return loss of microstrip antenna with H-Double split ring and without superstrate layer

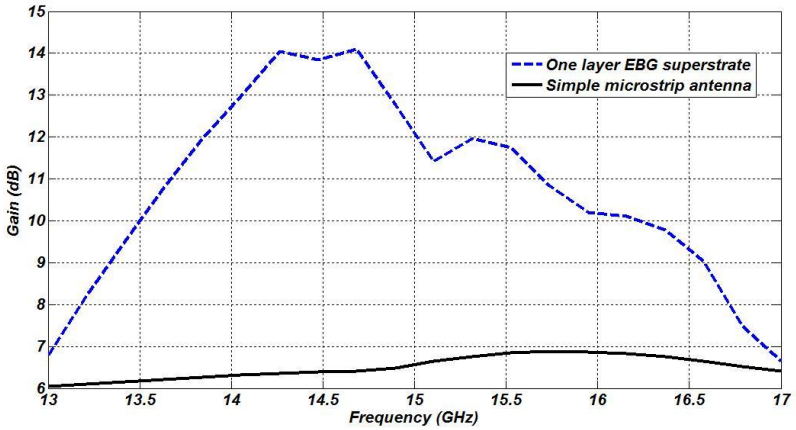
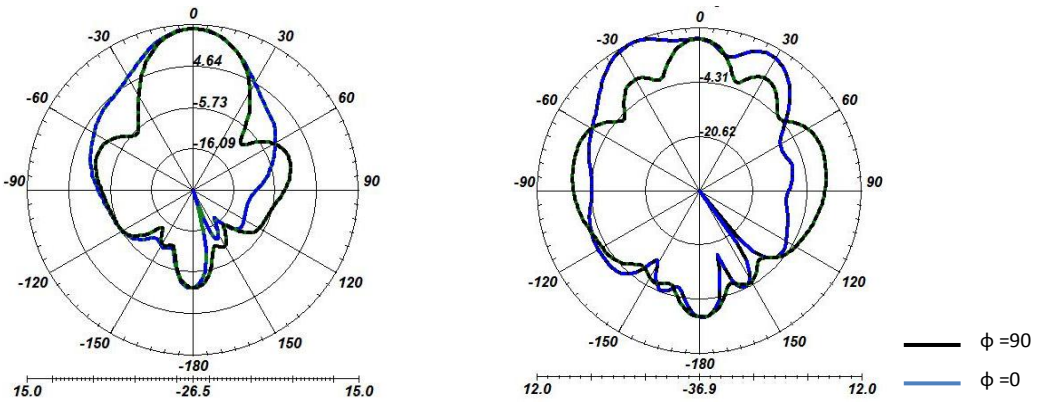


Figure-20: Comparison of Gain of microstrip antenna with H-Double split ring and without superstrate layer



(a) (b)

Figure-21: Gain pattern of microstrip antenna with one layer H-Double spliring EBG superstrate at (a) 14.3GHz (b) 15.23 GHz

IV. CONCLUSION

In conclusion, EBG structures improve return loss, gain and beam shaping of microstrip antenna. When EBG structures are used as substrate, they assist to reduce surface waves. Maximum return loss obtained with mushroom-like EBG about -26dB at 15.23 GHz that return loss has been improved about -14dB. But, vias of Mushroom like EBG complicate process of fabrication, therefore, uniplaner

EBG structures are used. Although uniplaner EBG eases the fabrication, reduce return loss less than Mushroom-like EBG. When EBG structures are used as superstrate, they help to improve the return loss, Gain and beam shaping of microstrip antenna. Square uniplaner EBG superstrate increase gain of microstrip antenna up to 17dB. Also the bandwidth of microstrip antenna with two layers square uniplaner EBG superstrate improves about 1.3 GHz. But with H-Doubled split ring EBG superstrate with only one layer, the bandwidth of antenna increases about 2GHz and gain of it increase up to 16dB at 14.3 GHz. In addition, gain pattern of microstrip antenna with EBG superstrate is more narrower than simple microstrip antenna.

REFERENCES

[1] R. Garg, "Microstrip Antenna Design Handbook", Artech House, London, 2001.

[2] N. Llombart, A.Neto, G.Gerini, and P. de Maagt, "Planar Circularly Symmetric EBG Structures for Reducing Surface Waves in Printed Antennas", IEEE transactions on antennas and propagation, vol. 53, pages 3210 - 3218 (2005)

[3] Reducing Surface Waves in Printed AntennasF. Yang and Y. Rahmat-Samii, "Microstrip antennas integrated with electromagnetic band-gap (EBG) structures: A low mutual coupling design for array applications," *IEEE Trans. Antennas Propagation*, vol. 51, pp. 2936–2946, Oct. 2003.

[4] F. Yang, " Electromagnetic Band Gap Structures in Antenna Engineering", Cambridge Universuty press, 2009

[5] M. N. Md. Tan, T. A Rahman, S. K. A. Rahim, M. T Ali, and M. F Jamlos, "antenna array enhancement using mushroom-like electromagnetic band gap (ebg)", EuCAP conferance page 1-5 (2010)

[6] W. H. Chen, H. Zhang, and J. Wang, "a new uniplanar electromagnetic bandgap power plane with broadband suppression of simultaneously switching noise", progress in electromagnetics research, vol. 1, pages 95–99 (2008)

[7] A. Pirhadi, F. Keshmiri, M. Hakkak and M. Tayarani, "Analysis and design of dual band high directivity ebg resonator antenna using square loop fss as superstrate layer", Progress In Electromagnetics Research, progress in electromagnetics research, vol. 70, pages 1-20, (2007)

[8] sh. zhu, and R. Langley, "Dual band Wearable Textile Antenna on an EBG Substrate ", IEEE transaction on antenna and propagation, Vol. 57, pages 926-935 (2009)

[9] Dalin Jin, Bing Li , And Jingsong Hong, "gain improvement of a microstrip patch antenna using metamaterial superstrate with the zero refractive index", Microwave and Millimeter Wave Technology conferece (ICMMT), page 1-3 (2012)

[10] HuiliangXu, Zeyu Zhao, YueguangLv, Chunlei Du and XiangangLuo, "metamaterialsuperstrate and electromagnetic band-gap substrate for high directive antenna", International journal of Infrared and Millimeter Waves, Vol. 29, pages 493-498 (2008)

[11] H. H. Xie, Y.C. Jiao, K. Song, and B. Yang, "Miniature electromagnetic bandgap structure using spiral ground plane", Progress In Electromagnetics Research Letters, Vol. 17, pages 163-170 (2010)

[12] U. C. Hasar, and J. J. Barroso, "Retrieval approach for determination of forward and backward wave impedances of bianisotropic metamaterials", Progress In Electromagnetics Research, Vol. 112, pages 109-124 (2011)

[13] Xudong Chen, Tomasz M. Grzegorczyk, Bae-Ian Wu, Joe Pacheco, Jr., and Jin Au Kong, "Robust method to retrieve the constitutive effective parameters of metamaterials", PHysical Review E 70 (2004)

Authors

R.A Sadeghzadeh received his B.Sc. in 1984 in telecommunication engineering from the K.N. Toosi, University of Technology, Tehran Iran and M.Sc. in digital Communications Engineering from the University of Bradford and UMIST (University of Manchester Institute of Science and Technology), UK as a joint program in 1987. He received his Ph.D. in electromagnetic and antenna from the University of Bradford, UK in 1990. He worked as a Post-Doctoral Research assistant in the field of propagation, electromagnetic, antenna, Bio-Medical, and Wireless communications from 1990 till 1997. From 1984 to 1985 he was with Telecommunication Company of Iran (TCI) working on Networking. Since 1997 He is with K.N. Toosi

University of Technology working with Telecommunications Dept. at faculty of Electrical and Computer Engineering. He has published more than 75 referable papers in international journals and conferences. Dr. Sadeghzadeh current interests are numerical techniques in electromagnetic, antenna, propagation, radio networks, wireless communications, nano-antennas and radar systems.

Reza khajeh Mohamadlou received the B.S. degree in telecommunication engineering from IAU university, Urmia Iran in 2007, and M.S. degree in electrical engineering from Islamic Azad University- south Tehran branch, Iran in 2009. He is working in Azad University Miandoab Branch as a member of faculty of electrical engineering from 2011 and now is a student of Ph.D. in telecommunication engineering in SRBIAU university from 2012. His research works about antenna, propagation, metamatrial and telecommunication.

Mahdi Jalali received the B.S. degree in telecommunication engineering from IAU University, Urmia, Iran in 2003, and M.S. degree in electrical engineering from Islamic Azad University-south Tehran branch, Iran in 2006. He is working in Azad University Naghadeh Branch as a member of faculty of electrical engineering from 2010. And now is a student of Ph.D. in telecommunication engineering in SRBIAU university from 2012. His research works about antenna, propagation, electromagnetic, metamatrial and wireless communications.