

DOI: 10.5281/zenodo.3591584  
CZU 621.396.67:537.8



## TWO ELEMENT MICROSTRIP ANTENNA ARRAY USING STAR SLOT ELECTROMAGNETIC BAND GAP STRUCTURE

K. Prahlada Rao<sup>1\*</sup>, ORCID: 0000-0002-1940-8941,  
Vani R. M.<sup>2</sup>, P. V. Hunagund<sup>1</sup>

<sup>1</sup>Gulbarga University, Dept. of PG Studies and Research in Applied Electronics, Gulbarga, India

<sup>2</sup>Gulbarga University, University Science Instrumentation Center, Gulbarga, India

\*Corresponding author: K. Prahlada Rao, pra\_kaluri@rediffmail.com

Received: 10. 02. 2019

Accepted: 12. 05. 2019

**Abstract.** This paper deals with the performance of two element antenna array without and with electromagnetic band gap structures. The antenna arrays are using Mentor Graphics IE3D software and measurements have been taken using vector network analyzer. The dielectric substrate used in the design and fabrication of antennas is FR-4 glass epoxy. The unit cell of the electromagnetic band gap structure is star slot structure. The electromagnetic band gap structure structures applied in the ground plane of the microstrip antenna array are resulting in a remarkable decrease in mutual coupling to – 35.05 dB from – 17.83 dB of the conventional array antenna. The proposed microstrip antenna array is producing bandwidth of 25.18 % as against 2.35 % of conventional microstrip antenna array. The antenna array with electromagnetic band gap structure is resonating at a fundamental frequency of 3.31 GHz; thereby achieving a virtual size reduction of 40.14 %. The proposed microstrip antenna array finds application in C band of the microwave frequency region.

**Keywords:** *bandwidth, dielectric substrate, mutual coupling, radiation pattern, resonant frequency, return loss, surface waves, virtual size reduction.*

### Introduction

An antenna is defined as an electrical device used to transmit and receive electromagnetic waves. An antenna array is a serial arrangement of antenna elements with proper spacing between the antenna elements. With the need to design compact size antennas, microstrip antennas and arrays have become the main area of interest among researchers in the field of antenna engineering. A microstrip antenna is made of a ground plane sandwiched between ground plane in the bottom and a radiating patch on the top. Microstrip antennas and arrays find applications in various fields – wireless communications, millimeter wave engineering, radar communications etc. These antennas can be fed using stripline feeding, proximity coupled feeding, probe feeding and aperture coupled feeding techniques. In the recent past researchers are showing great interest in these antennas as they can be easily integrated with other devices [1 - 3].

With the extensive growth in technology, electromagnetic band gap (EBG) structures have emerged as one of the most efficient and sought after structures in enhancing the performance of microstrip antenna arrays. Recently, there is an increasing interest in the use of EBG structures. When a microstrip antenna array radiates electromagnetic waves, a small amount of power is transmitted into free space and a majority of power is lost in the dielectric. The surface waves in the dielectric substrate have detrimental effect on the interference levels between the antenna elements of microstrip antenna array. There is a necessity to overcome this serious drawback of microstrip antenna arrays. EBG is a finite and periodic array of dielectric or magnetic cells. When these structures come in contact with electromagnetic waves, they possess distinctive pass and stop bands. Thus an EBG structure acts as a filter in suppressing certain frequencies and very much useful in suppressing the propagation of electromagnetic waves through the dielectric. Thus EBG structures aid in increasing the performance of the antenna array and thereby its efficiency [4].

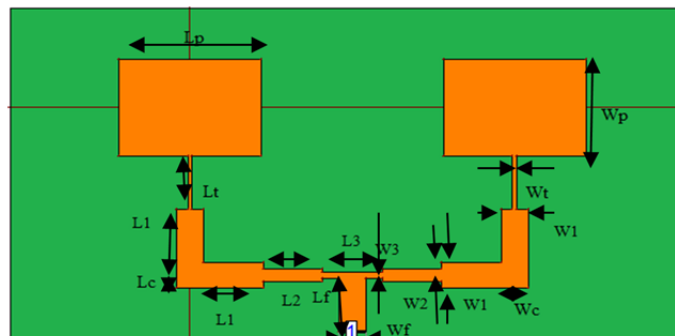
In [5], D. N. Elsheak *et al* have discussed the study of EBG structures loaded in the ground plane, their types, and their behaviour in enhancing the performance of two element microstrip patch antenna arrays. The EBG structures employed are of two dimensional in nature and corporate feeding technique is used to feed the antenna array. The performance of Square, Circular, Star, H and I shape EBG structures are compared. Highest bandwidth of 5.1 % has been achieved using H shape EBG structure. Least amount of mutual coupling ( $S_{21}$ ) of -30 dB and highest gain of 13.75 dB have been obtained in the case of Star EBG structure. In [6], Mohammad Naser - Moghadasi *et al* have designed  $2 \times 5$  EBG structure to reduce mutual coupling between patch antennas of MIMO array. Two microstrip patch antennas are designed for resonance at 5.28 GHz. The conventional MIMO array is fed by coaxial feed and bandwidth is equal to 3 %. The EBG structure is inserted between the two patch antennas and on the surface. Mutual coupling values without and with EBG structure are -22 and -43 dB respectively. By increasing the gap between the unit cells of EBG structure, the resonant frequency of proposed MIMO array is reduced. A gain value of 6.86 dBi is also produced. Moreover the EBG structure has reduced antenna current from 8.5 A/m to 3.9 A/m, so the coupling is reduced by 50 %. However the antenna efficiency is reduced from 65 to 53 %. In [7], H. C. Nagaraj *et al* have presented a novel structure suppressing the mutual coupling between nearby patches. The antenna array is fed by coaxial probe feeding method. It is observed that mutual coupling is reduced from -20.95 to -25.6 dB. Good improvement in VSWR and return loss are also noticed. However the gain of the antenna is reduced indicating radiation losses. The structure is dedicated to linear polarization. In [8], Niraj. R. Ada *et al* have proposed the design of  $2 \times 2$  microstrip patch array with  $2 \times 2$  EBG substrate with respect to the rectangular ground plane. The material used for the substrate is Rogers \_RO3010 with dielectric constant 10.2. The return losses of the antenna array with EBG are -48 and -42 dB at 3.5 and 7 GHz respectively. The overall bandwidth of the proposed antenna is 16 %, which is double that of bandwidth obtained for conventional antenna. The gain of the antenna in the presence of EBG is 8.45 dBi which is greater than without EBG equal to 1.96 dBi. In [9], F. Benikhlef *et al* have investigated the effects of two dimensional EBG structure (operating at 2.4 GHz) on the performance of microstrip antenna arrays. Taconic (tm) dielectric material is employed as patch substrate. The mutual couplings of the antennas without and with EBG structure are -38.4 and -40.2 dB respectively. The gain of the proposed antenna is 8 % more than the

conventional antenna. In [10], M. I. Ahmed *et al* have presented the design of single and two element eagle shaped microstrip antennas using a novel eagle shaped uniplanar EBG structure. The results depict 6 dB reduction in first band (1.71 – 2.98 GHz), 10 dB in second band (4.26 – 5.62 GHz) and 6 dB in third band (6.57 – 9.16 GHz) respectively. Highest gain of 6.09 dB is observed in the second band. Highest radiation and antenna efficiencies of 96 and 90 % are observed in the first band. The antennas are employed in soldier belts, a commodity for military application. In [11], F. Benykhlef *et al* have analyzed the isolation properties of different EBG structures and compared them in antenna arrays. Mushroom like EBG, fork shaped EBG and proposed structure with vias are designed and fabricated. With one row of mushroom like EBG structure, the mutual coupling is -22.5 dB. An approximately 4 dB reduction in mutual coupling is observed with fork shaped EBG structure. The EBG structure with vias is producing the best isolation of 6 dB. In [12], A. Rajasekhar *et al* have designed a miniaturized patch antenna array resonating at 5.8 GHz WLAN band. The novel mushroom like EBG structure is loaded in between the patches. The dimensions of the patches are 14 mm × 11.4 mm and the two patches are separated by 30 mm. Initially, the mutual coupling between the antenna elements is -19.97 dB. As the distance of separation is decreased, mutual coupling is increased and vice versa. After the introduction of array of 3 rows and 2 columns of EBG structure on the structure, the mutual coupling is equal to -35 dB. Using other methods like substrate removal and back cavity, the mutual coupling values are higher than that produced by EBG structure equal to -20 and -21 dB respectively. In [13], Duong Thi Thanh Tu *et al* have designed dual band MIMO antenna system with enhanced isolation. Using a double rectangular DGS, the antenna is resonating at 2.6 and 5.7 GHz with bandwidths of 5.7 and 4.3 % respectively. The proposed antenna is having high isolation which is stable and around -20 dB over all frequencies. At 2.6 GHz, gain and radiation efficiency are 2.63 dB and 59 %. The corresponding values at 5.7 GHz are 1.6 dB and 39.8 %. MIMO antenna with double side EBG structure is reducing mutual coupling from -20 to -40 dB. At 2.6 GHz the antenna gain and radiation efficiency are improved to 4.25 dB and 68.7 %. At 5.7 GHz, the antenna gain is increased to 1.76 dB and radiation efficiency to 39.8 %. In [14], M. K. Abdulhammed *et al* have performed a review of various EBG structures and the methods involved in improving the performance of microstrip antenna arrays. Electromagnetic characteristics of EBG structures are dictated by its physical measurements like patch width, gap width, substrate thickness, substrate permittivity and radius of via. One of the methods is surrounding the EBG structure around the antenna. Four rows of EBG patches are used to suppress the surface waves. Lowermost back lobe radiation of 15 dB lesser than other EBG structures is produced. After positive application of a single microstrip patch antenna with EBG structure, 8 dB reduction in mutual coupling is produced after inserting four columns of EBG patches in between the array elements. When a dumbbell EBG structure is used with 2×2 microstrip antenna array, mutual coupling is decreased by 4 dB. There is also a gain enhancement of 1.5 dB. In [15], Reefat Inum *et al* have proposed rectangular and circular EBG structures to investigate the antenna performance used in microwave brain imaging system. The return losses produced due to rectangular and circular EBG structures are -40.15 and -49.29 dB respectively. Using circular EBG is producing better bandwidth of 291.6 MHz compared to 275.5 MHz that due to rectangular EBG. Moreover gains of 6.7 and 6.06 dBi are obtained using circular and rectangular EBG. The specific absorption rates are equal to 0.922 and 0.695 W/Kg, which are lesser than maximum standard surface absorption rate limit of 1.6 and 2 W/kg, which

ensures the safety of the considered microwave brain imaging system. In [16], Xiaoyan Zhang *et al* have designed dual band circular patch MIMO antenna on an EBG surface. Defects are introduced in the rows and columns of the EBG cells. A healthy reduction in mutual coupling equal to 25 dB is generated between the antenna elements. The proposed antenna is operating in 5.71 – 5.97 GHz and 6.31 – 6.54 GHz respectively. The -10 dB impedance bandwidth is extended by 28.9 and 27.8 % at the low and high frequency band. Moreover the gains are enhanced by 5 and 6.9 dB and the back lobe radiations are decreased by 15 and 10.3 dB at the resonant frequencies of 5.75 and 6.44 GHz respectively.

### Design of Antenna Arrays

The conventional microstrip antenna array consists of two elements. The antenna array is designed at 6 GHz. The dielectric constant and loss tangent of the FR-4 glass epoxy substrate are 4.2 and 0.0245 respectively. The design frequency is selected as 6 GHz. The antenna array is fed using corporate feed technique. The length and width of the finite ground plane are equal to 115.8 and 62.7 mm. The length ( $L_p$ ) and width ( $W_p$ ) of each element of the antenna array are equal to 15.73 and 11.76mm. The antenna elements are excited by a feed of length ( $L_f$ ) and width ( $W_f$ ) equal to 6.52 and 3.05 mm. The distance between the two elements of the antenna array is equal to  $\lambda/4$ , where  $\lambda$  is the wavelength at the design frequency of 6 GHz. Figure 1 depicts the schematic of the conventional two element antenna array. The schematic in Figure 1 is employed to determine the return loss characteristics of conventional microstrip antenna array.



**Figure 1.** Schematic of conventional microstrip antenna array.

Table 1 summarizes the parameter values of conventional two element antenna array.

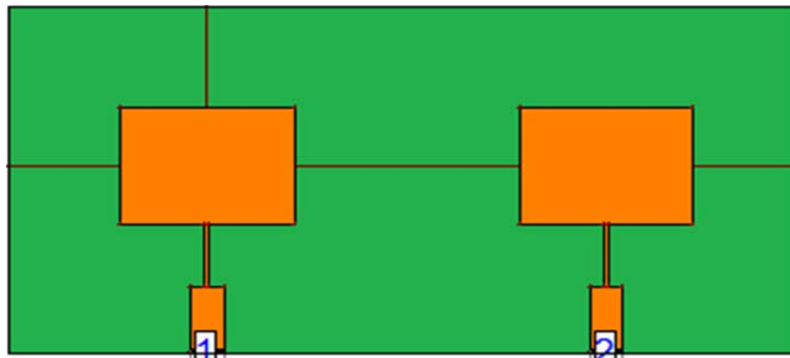
Table 1

Dimensions and values of conventional microstrip antenna array	
Dimension	Value (mm)
Length of the patch ( $L_p$ )	15.73
Width of the patch ( $W_p$ )	11.76
Length of the quarter wave transformer ( $L_t$ )	6.47
Width of the quarter wave transformer ( $W_t$ )	0.47
Length of the 50 $\Omega$ line ( $L_1$ )	6.52
Width of the 50 $\Omega$ line ( $W_1$ )	3.05
Length of the coupler	3.05

Continuation Table 1

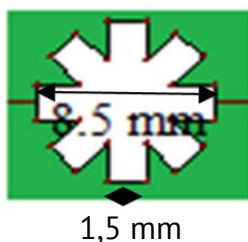
Width of the coupler	3.05
Length of the 70Ω line (L2)	6.54
Width of the 70Ω line (W2)	1.62
Length of the 100Ω line (L3)	6.56
Length of the patch (Lp)	15.73
Width of the patch (Wp)	11.76
Width of the 100Ω line (W3)	0.70
Length of the feed line (Lf)	6.52
Width of the feed line (Wf)	3.05

By maintaining the same distance between the two antenna elements, the parameter mutual coupling can be measured by exciting the two antenna elements separately as shown in Figure 2. It is assumed that same amount of power is given to the two feeds.

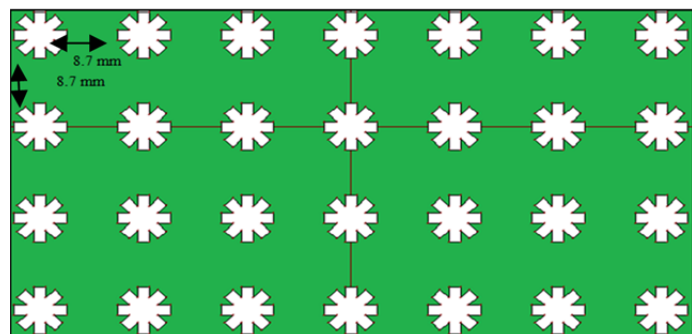


**Figure 2.** Schematic of setup of conventional microstrip antenna array for mutual coupling measurement.

The unit cell of the EBG structure is shown in Figure 3. Each star slot has eight identical rectangles. The length and width of each rectangle is 8.5 mm and 1.5 mm. The angle between two adjacent rectangles is  $45^\circ$ . The centers of all the eight rectangles are coinciding at the same point.



**Figure 3.** Schematic of unit cell of star slot EBG structure.

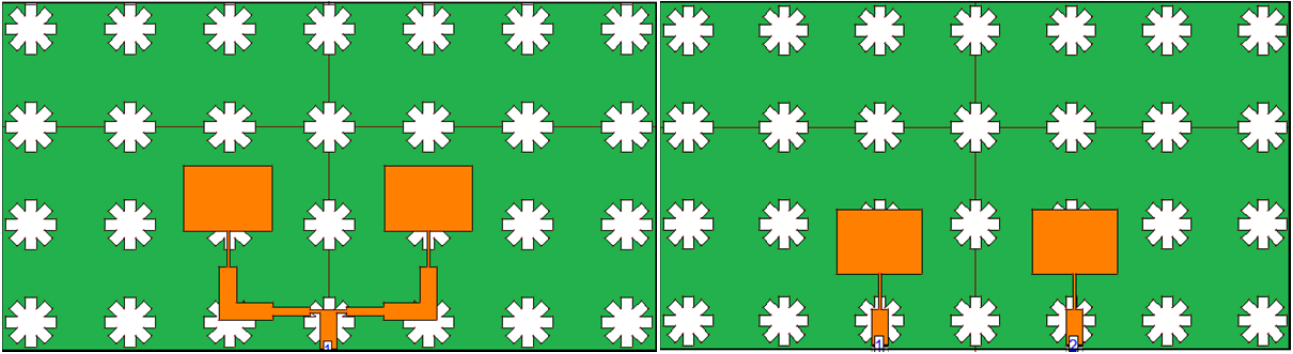


**Figure 4.** Schematic of star slot EBG structure.

The EBG structure used to modify the conventional two element antenna array consists of a matrix of 4 rows and 7 columns of star slots.

The periodicity of the cells of the EBG structure along the x-axis and y-axis is 8.7 mm. Figure 4 depicts the EBG structure employed in the antenna array design.

The finite ground of the two element conventional microstrip antenna array is replaced with the star slot EBG structure depicted in Figure 4. Figure 5 depicts the two element antenna array with star slot EBG structure loaded in the ground plane.

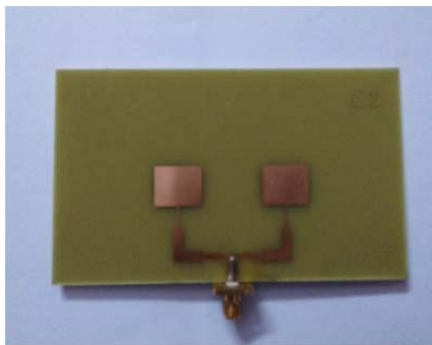


**Figure 5.** Schematic of microstrip antenna array with star slot EBG structure.

**Figure 6.** Schematic of setup of microstrip antenna array with star slot EBG structure for mutual coupling measurement.

To determine the effect of star slot EBG structure on mutual coupling, the EBG structure is incorporated in the finite ground plane of the two antennas fed separately as shown in Figure 6.

Figures 7, 8, 9 and 10 depict the photographs of the microstrip antenna arrays.

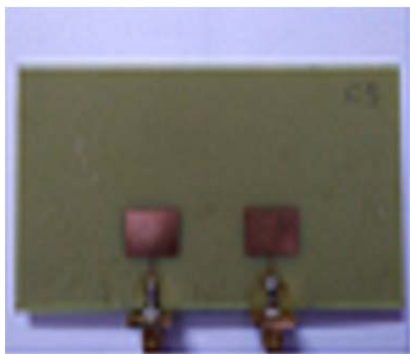


a)



b)

**Figure 7.** Photograph of conventional microstrip antenna array: a) front view; b) back view.

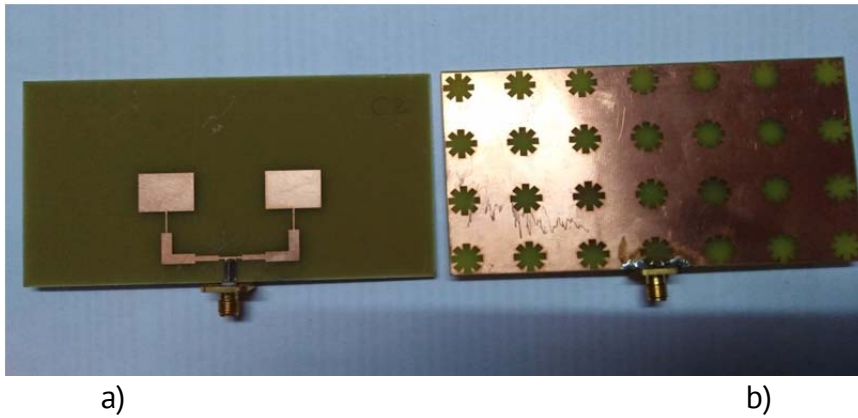


a)

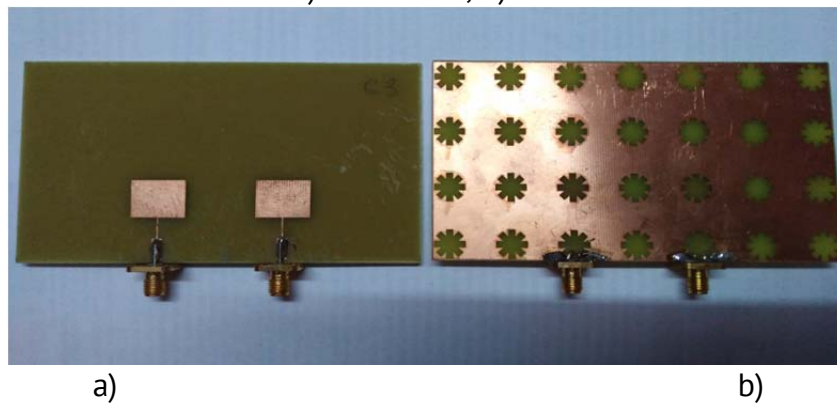


b)

**Figure 8.** Photograph of setup of conventional microstrip antenna array for mutual coupling measurement: a) front view; b) back view.



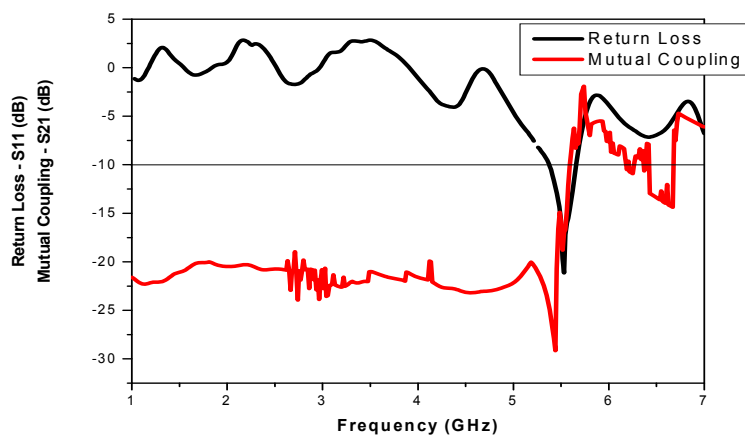
**Figure 9.** Photograph of microstrip antenna array with star slot EBG structure: a) front view; b) back view.



**Figure 10.** Photograph of setup of microstrip antenna array with star slot EBG structure for mutual coupling measurement: a) front view; b) back view.

### Results and Discussion

The performances of the two element microstrip antenna arrays without and with star slot EBG structure are compared in terms of return loss, bandwidth, virtual size reduction, mutual coupling, back lobe radiation and front to back ratio. Figure 11 shows the graph of return loss and mutual coupling versus frequency of conventional microstrip antenna array.



**Figure 11.** Graph of return loss and mutual coupling –  $S_{21}$  versus frequency of conventional microstrip antenna array.



Figure 11 depicts that the conventional microstrip antenna array is resonating at the fundamental frequency of 5.53 GHz with a return loss of -21.23 dB. It is producing bandwidth of 130 GHz. The bandwidth (%) is calculated by using Eq. (1).

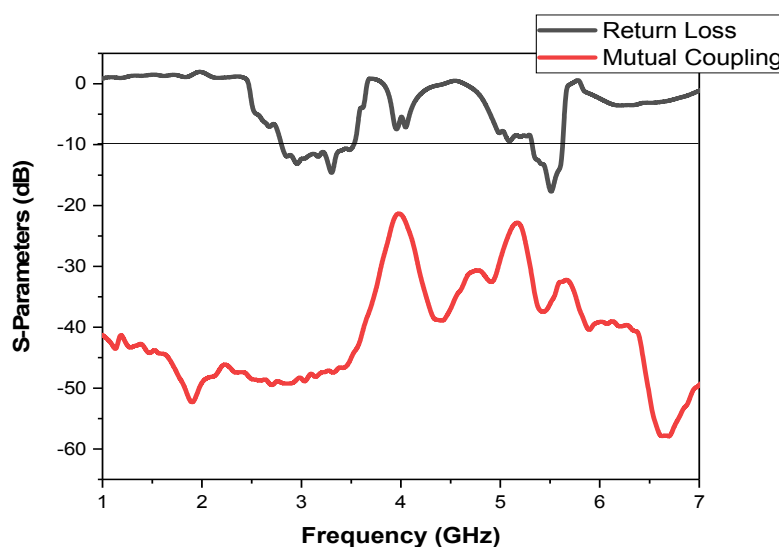
$$\frac{\text{Bandwidth}}{\text{Resonant frequency}} \times 100\% \quad (1)$$

Thus the bandwidth (%) of conventional microstrip antenna array is equal to 2.35 %. The mutual coupling parameter measured is  $S_{21}$ . From Figure 11 the value of mutual coupling at the resonant frequency of 5.53 GHz is -17.83 dB. The mutual coupling value is high as it is greater than -20 dB. Figure 11 also shows that the plots of return loss and mutual coupling are crossing each other at the resonant frequency of 5.53 GHz. This implies there is huge amount of interference between the transmitting element 1 and the receiving element 2 of conventional microstrip antenna array. Thus there is improper transfer of information between the transmitting element 1 and the receiving element 2 of conventional microstrip antenna array.

Figure 12 shows the graph of return loss and mutual coupling versus frequency of microstrip antenna array in the presence of star slot EBG structure.

Figure 12 shows that with the introduction of EBG structure in the ground plane the microstrip antenna array is resonating at the fundamental frequency of 3.31 GHz with a return loss of -14.66 dB.

Additional harmonic frequency is observed at 5.53 GHz. The bandwidths measured at the fundamental and harmonic frequencies are 760 and 320 MHz respectively. Hence the overall bandwidth (%) obtained is 25.18 %. As the bandwidth (%) of microstrip antenna array with EBG structure is greater than that of conventional microstrip antenna array, hence the microstrip antenna array with EBG structure is a better antenna than its opponent i.e. conventional microstrip antenna array in terms of bandwidth.



**Figure 12.** Graph of return loss and mutual coupling –  $S_{21}$  versus frequency of microstrip antenna array with star slot EBG structure.

From Figure 12 the mutual coupling measured at the resonant frequency of 5.53 GHz is equal to -35.05 dB. Thus mutual coupling is lowered with the introduction of star slot EBG structure. Moreover, the plots of return loss and mutual coupling are not overlapping at the resonant frequency of 5.53 GHz indicating there is no interference between the transmitting and receiving antennas. This implies there is better transmission and reception of electromagnetic signals in microstrip antenna array in the presence of EBG structure. Hence the microstrip antenna array with star slot EBG structure is a better antenna than conventional microstrip antenna array in terms of mutual coupling.



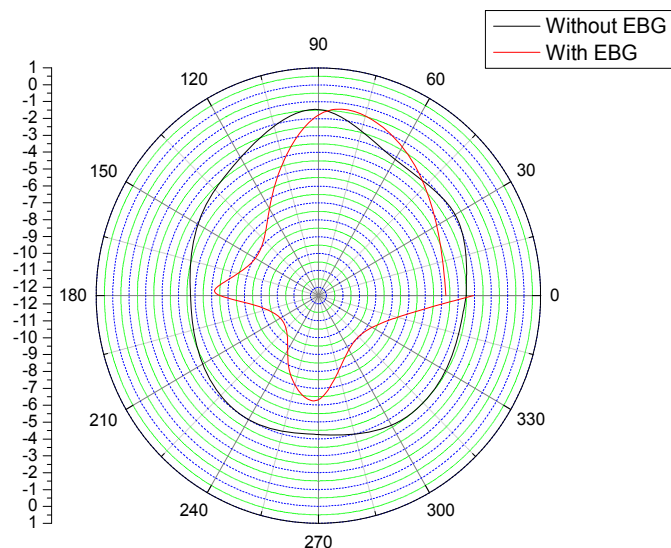
Moreover from Figures 11 and 12 we see that the microstrip antenna arrays in the absence and presence of star slot EBG structure are producing fundamental resonant frequencies of 5.53 and 3.31 GHz respectively. With the introduction of star slot EBG structure, the fundamental resonant frequency of conventional microstrip antenna array is decreased to a lower value of 3.31 GHz. This reduction in resonant frequency contributes to virtual size reduction. Virtual size reduction (%) is calculated by using Eq (2).

$$\left(\frac{f_1 - f_2}{f_1}\right) \times 100 \quad (2)$$

In Eq. (2)  $f_1$  and  $f_2$  are the fundamental resonant frequencies in the absence and presence of EBG structure. Hence the virtual size reduction (%) produced by microstrip antenna array with star slot EBG structure is 40.14 %.

The radiation plot also provides valuable information regarding the performance of a microstrip antenna array. The radiation pattern plots of the microstrip antenna arrays without and with star slot EBG structure are depicted in Figure 13.

The backward power is measured at the angle of  $270^\circ$  and forward power at the angle of  $90^\circ$ . The amounts of back powers radiated without and with star slot EBG structure are equal to -4.18 and -6 dB respectively. These values show that there is a considerable decrease in the back lobe radiation in the presence of EBG structure. The microstrip antenna arrays in the absence and presence of EBG structure are radiating almost equal powers of -1.31 dB in the forward direction.



**Figure 13.** Graph of radiation plots of microstrip antenna arrays without and with star slot EBG structure.

As the microstrip antenna array with EBG structure is producing lesser backward power compared to that without EBG structure, hence radiation characteristics of the microstrip antenna array are improved with the introduction of star slot EBG structure.

The parameter front to back ratio is calculated by subtracting the back lobe radiation from the forward power. Thus the front to back ratios of the microstrip antenna array in the absence and presence of star slot EBG structure are 2.87 and 4.69 dB respectively. As front to back ratio of microstrip antenna array in the presence of EBG structure is greater than that without EBG structure, the modified microstrip antenna is a better antenna that its counterpart in terms of front to back ratio.

## Conclusion

In this paper, the study of performance of two element antenna array without and with star slot EBG structure is performed. With the finite ground plane replaced with the

EBG structure, the two element antenna array has performed better compared to its counterpart in terms of various parameters. With the reduction in mutual coupling, there is a better isolation between the two antenna array elements. With the etching of EBG structures in the ground plane, the antenna array is resonating at dual frequencies with an overall bandwidth of 25.18 %. The decrease in the back lobe and greater value of front to back ratio confirm the better radiation characteristics of the antenna array with EBG. Therefore the microstrip antenna array with star slot EBG structure is a better candidate than conventional microstrip antenna array.

## References

1. Constantine A. Balanis. *Antenna Theory, Analysis and Design*. Berlin: John Wiley & Sons Inc, 1997.
2. Bahl I.J., Bhartia P. *Microstrip Antennas*. Artech House, 1980.
3. Reinhold Ludwig, Pavel Bretchko. *RF Circuit Design: Theory and Applications*. 2009.
4. Fan Yang, Yahya Rahmat-Samii. *Delectromagnetic Band Gap Strucures in Antenna Engineering*: Cambridge University Press, 1980.
5. Elsheakh D. N., Iskander M. F., Abdallah E. A., Elsadek H. A. Microstrip array antenna with new 2D – electromagnetic band gap structure shapes to reduce harmonics and mutual coupling. In: *Progress in Electromagnetic Research C*, 2010, 12, pp. 203-213.
6. Mohammad Naser – Moghadasi, Rahele Ahmadian, Zahra Mansouri, Ferdows B. Zarrabi, Maryam Rahimi. Compact EBG structures for reduction of mutual coupling in patch antenna MIMO arrays. In: *Progress in Electromagnetic Research C*, 2014, 53, pp. 145-154.
7. Nagaraj H. C., Rukmini T. S., Prasanna Paga, Kamal Lamichhane. Mutual coupling reduction between planar patch antennas by using electromagnetic band gap structures. In: *International Journal of Advanced Computing and Electronics Technology*, 2015, 2 (2), pp. 87-91.
8. Niraj R. ADA, Mayank A. Ardeshana. Electromagnetic band gap (EBG) structure antenna design for wide band applications. In: *International Journal of Advance Engineering and Research Development*, 2015, 2 (7), pp. 327-311.
9. Benikhlef F., N. Boukli-Hacen. Effets of two dimensional electromagnetic bandgap (EBG) structures on the performance of microstrip patch antenna arrays. In: *International Journal of Applied Engineering Research*, 2016, 11 (11), pp. 7472-7477.
10. Ahmed M. I., Abdallah E. A., Elhennawy H.M. Mutual coupling reduction in UWB slotted antenna array using UCEBG structures for wireless applications. In: *Proc. of Fourth International Japan-Egypt Conference on Electronics, Communications and Computers*, May 2016, pp. 67-70.
11. Benikhlef F., N. Boukli-Hacen. EBG structures for reduction of mutual coupling in patch antenna arrays In: *Journal of Communications Software and Systems*, 2017, 13 (1), pp. 9-14.
12. A. Rajasekhar A., Vara Prasad K. Mutual coupling reduction of microstrip antenna array by using electromagnetic band gap structures In: *International Research Journal of Engineering and Technology*, 2017, 4 (8), pp. 1988-1993.
13. Duong Thi Thanh Tu, Nguyen Van Hoc, Pham Dinh Son, Vu Van Yem. Design and implementation of dual-band MIMO antenna with low mutual coupling using electromagnetic band gap structures for portable equipments In: *International Journal of Engineering and Technology Innovation*, 2017, 7 (1), pp. 48–60.
14. Abdulhameed M. K., Isa M. S. M., Ibrahim I. M., Zin M. S. I. M., Zakaria Z., Mowafak K. Mohsin, Alrifai M. F. Review of radiation pattern control characteristics for the microstrip antenna based on electromagnetic band gap (EBG) In: *Journal of Telecommunications, Electronic and Computer Engineering*, 2018, 10 (3), pp. 129–140.
15. Reefat Inum, Md. Masud, Rana, Kamrun Nahar, Shushama, Md. Anwarul, Quader. EBG based microstrip patch antenna for brain tumor detection via scattering parameters in microwave imaging system. In: *International Journal of Biomedical Imaging*, 2018, 2018, pp. 1–13.
16. Xiaoyan Zhang, Yuting Chen, Haitao Ma, Lewei Li., Huihui Xu. Design of Defective EBG structures for dual-band circular patch MIMO antenna applications In: *A ECS Journal*, 2019, 34 (6), pp. 890–897.