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# ENHANCEMENT OF RADIATION PROPERTIES OF MICROSTRIP ANTENNA ARRAY

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In this paper, reduction of mutual coupling and miniaturization of four element microstrip antenna array is achieved by loading the ground plane of the conventional four element microstrip antenna array with hexagon shaped slot type electromagnetic band gap structure. FR-4 glass epoxy substrate is employed as dielectric substrate. The conventional antenna array is resonating at a fundamental frequency of 5.53 GHz with a return loss of -21.06 dB. The proposed microstrip antenna array is resonating at 2.92 and 5.53 GHz respectively. The virtual size reduction obtained is 47.19 %. The mutual couplings of the proposed antenna array are reduced to -27.45, -24.76 and -25.98 dB respectively. The antennas have been designed using Mentor Graphics IE3D simulation software and measured results have been taken using vector network analyzer. The antenna finds application in the C- band of the microwave frequency range.

*Index Terms* — Bandwidth, corporate feeding, electromagnetic band gap structure, return loss.

## I. Introduction

Microstrip antennas and arrays play a pivotal role in various applications ranging from GPS to radar systems. Microstrip antennas can be easily fabricated and integrated with other active and passive devices. The design of multi element antenna arrays is gaining widespread importance and usage. However, the major drawback of antenna arrays is the high value of mutual coupling between the antenna elements. Reduction of mutual coupling between the array elements has become one of the major challenges faced by the researchers in recent years. A high value of mutual coupling (> -20dB) leads to degradation of performance of antenna arrays in terms of decrease of output power, gain, efficiency and deterioration of radiation properties. Hence a low value of mutual coupling is very much desired leading to less interference between the transmitting and receiving antennas. [1-3].

Recently there has been a great interest in the study of microstrip array antennas with various periodic structures including electromagnetic band gap (EBG) structures, photonic band gap structures etc. Electromagnetic band gap structures have emerged as the foremost candidates in minimizing the demerits of microstrip antenna arrays. The major disadvantage of microstrip antenna arrays is the excitation of surface waves in the substrate. The surface waves are undesired because when a radiating patch radiates, a portion of the total radiated power is trapped in the substrate. This reduces the amount of power radiated into free space. These surface waves have a significant impact on the mutual coupling between the array elements. EBG structures can be employed in the ground plane or in between the radiating patches. [4-5].

In [6], Fan Yang *et al* have utilized mushroom like EBG structure to decrease the effect of surface waves. The results of E – plane coupled microstrip antennas depict that bandwidth increases with increasing thickness and decreases with increasing permittivity. The mutual coupling increases with increasing substrate thickness and permittivity. With 2, 3 and 4 mm EBG cases, the mutual coupling values are -15.85, -25.03 and -16.27 dB respectively. In [7], Halim Boutayeb *et al* have improved the performance of circular microstrip antenna using cylindrical EBG structure to increase the antenna gain. The cylindrical EBG structure is made of two periodic structures with different periods. One structure is made of metallic rings and the other of grounding vias. The conventional antenna is resonating at 2.6 GHz and producing a gain of 6 dB. The proposed antenna is producing a better gain of 9.33 dB at the same resonant frequency. Bandwidth of 3 5 % is also obtained. The E and H plane radiation patterns show that there is reduced power along the dielectric substrate and improved front to back ratio. In [8], 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 performances 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 [9], Mohamed I. Ahmed *et al* have designed novel single and two elements KSA (kingdom of Saudi Arabia) sign shape slot microstrip antennas with KSA shape EBG embedded on the surface and in between them. In the case of single element antenna, ultra wide band of 7.7 GHz (2.3 – 10 GHz) is obtained. Gains of 2.9 and 4.6 dB are obtained at the two resonant frequencies 2.8 and 8.6 GHz respectively. High amount of radiation and antenna efficiencies of 94, 87, 93 and 84 % are obtained. In the case of two element antenna array, bandwidths of 37 and 58 % are obtained at the two resonant frequencies 2.8 and 8.6 GHz respectively. Enhanced gains of 3.2 and 5.5 dB are obtained at the corresponding resonant frequencies. Mutual coupling is reduced from -11.5 and -13.2 to -14.6 and -20.2 dB respectively at the two resonant frequencies. Radiation and antenna efficiencies are increased to 98, 78, 95 and

77 % respectively. The designed antennas are employed in soldier belts for military applications. 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. Hence surface waves are best suppressed using proposed structure using vias. In [12], 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 [13], 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 [14], 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 [15], 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. In [16], Nilima A. Bodhaye *et al* have demonstrated the improvement in the performance of microstrip patch antenna array using double I shaped slot DGS. The single element antenna with DGS is resonating at 2.4, 3.58 and 5.5 GHz respectively. The bandwidths produced at the three resonant frequencies are 60, 130 and 70 MHz respectively with a gain of 3.3 dB. By incorporating DGS in the two element microstrip antenna array, four resonant frequencies i.e. 2.48, 3.29, 3.57 and 5.51 GHz respectively are yielded. Improved bandwidths of 80, 90, 110 and 180 MHz are produced. The proposed antenna array is useful for wireless applications. In [17], Ahmed Ghaloua *et al* have proposed a highly miniaturized microstrip antenna array for small wireless device. Miniaturization of 78.63 % is achieved at 2.45 GHz using a new type of DGS. The resonant frequency of the antenna array is shifted from 5.8 to 2.45 GHz. However the bandwidth of the proposed array is decreased to 157.5 MHz which covers the operating frequency of Industrial Scientific Medical (ISM) band. It is also clearly observed that a maximum current is shown around the feed network and the extremities of the radiating patch at 5.8 GHz. In the presence of DGS, the density of current is concentrating around DGS slots. In [18], Mohssine El Ouahabi *et al* have demonstrated the filtering characteristics of a compact triple band stop filter based on complementary split ring resonator. The complementary split ring resonator is implemented on the extended microstrip line

and in the ground plane. It is characterized by dual and single bands. The dual band bandstop filter is suppressing bands corresponding to 2.4 and 3.5 GHz (WLAN/WiMax applications) respectively. The single band bandstop filter is suppressing 5.2 GHz band (WLAN application).

The problem statement of the present research work is that conventional microstrip antenna arrays possess narrow bandwidth and high levels of mutual coupling. There is necessity to enhance the performance of such microstrip antenna arrays. The objective of the present research work is to enhance the performance of four element microstrip antenna array. The novelty in the present research work is achievement of individual bandwidth of 2.15 GHz and bandwidth (%) of 85.74 % compared to the previous published research work.

## II. Design of Microstrip Antenna Arrays

The conventional four element microstrip array antenna (CFMAA) consists of four identical rectangular radiating patches. CFMAA is energized by corporate feeding method. The dimensions of each radiating patch are 15.73 mm×11.76 mm. The dimensions of the quarter wave transformer are 6.47mm×0.47mm. The quarter wave transformer is used to match the impedance of the radiating patch and the feed. The feed used is a 50Ω transmission line. The dimensions of the feed used are 6.52mm ×3.05mm. The distance between the two adjacent antenna array elements of CFMAA is λ/4, where λ is the wavelength calculated at the design frequency of 6 GHz. The dielectric material used is FR-4 glass epoxy substrate with a dielectric constant of 4.2 and loss tangent of 0.0245. The schematic of CFMAA is depicted in Fig. 1. The schematic in Fig. 1 is employed to determine the return loss characteristics of CFMAA.

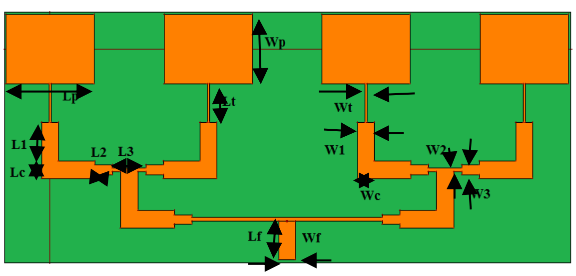


Fig. 1. Schematic of CFMAA

By maintaining the same distance between the two adjacent antenna elements as λ/4, the parameter mutual coupling can be measured by exciting the four antenna elements separately as shown in Fig. 2.

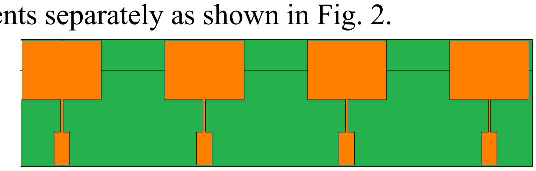


Fig. 2. Schematic of setup of CFMAA for mutual coupling measurement

All the four antenna elements are assumed to be fed with the same amount of power.

Table 1 shows the dimension values of different parts of CFMAA.

The proposed four element microstrip array antenna (PFMAA) is designed by loading hexagon shaped slot type EBG structure in the ground plane of CFMAA. The EBG structure used consists of a matrix of 4 rows and 9 columns of hexagon-shape slot unit cells. The schematic of the unit cell of the EBG structure employed is shown in Fig. 3. Each side of the hexagon slot unit cell is equal to 4.2mm.

TABLE I
DIMENSIONS AND VALUES OF CFMAA

| Dimension | Value (mm) |
|---|---|
| Length of the patch (Lp) | 15.73 |
| Width of the patch (Wp) | 11.76 |
| Length of the quarter wave transformer (Lt) | 6.47 |
| Width of the quarter wave transformer (Wt) | 0.47 |
| Length of the 50Ω line (L1) | 6.52 |
| Width of the 50Ω line (W1) | 3.05 |
| Length of the coupler (Lc) | 3.05 |
| Width of the coupler (Wc) | 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 |
| Width of the 100Ω line (W3) | 0.70 |
| Length of the feed line (Lf) | 6.52 |
| Width of the feed line (Wf) | 3.05 |


Fig. 3. Schematic of unit cell of EBG structure

The schematic of hexagon slot type EBG structure is depicted in Fig. 4. The periodicity of unit cells of EBG structure is 5 mm along x-axis and y-axis.

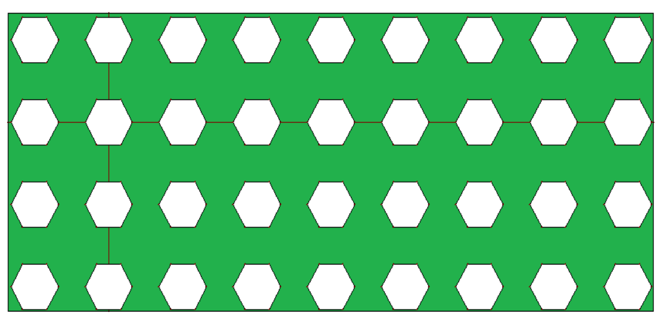


Fig. 4. Schematic of hexagon slot type EBG structure

The schematic of PFMAA is depicted in Fig. 5 and is employed to determine the return loss characteristics of PFMAA.

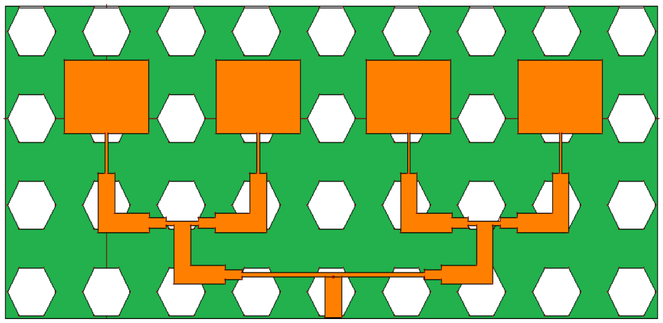


Fig. 5. Schematic of PFMAA

The setup of elements of PFMAA depicted in Fig. 6 is used to measure the mutual coupling of PFMAA. Fig. 6 consists of hexagon slot type EBG structure loaded in the ground plane of schematic shown in Fig. 2.

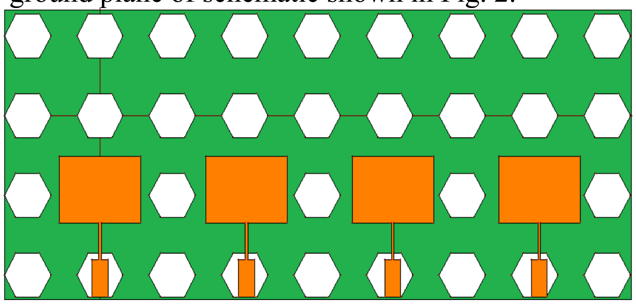
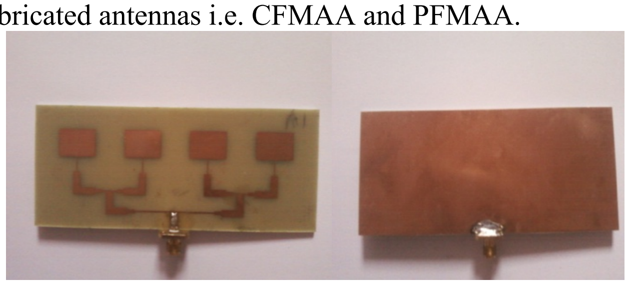


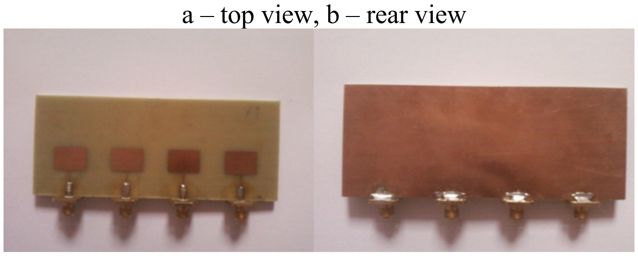
Fig. 6. Schematic of setup of PFMAA for mutual coupling measurement

Figs. 7, 8, 9 and 10 depict the photographs of the fabricated antennas i.e. CFMAA and PFMAA.



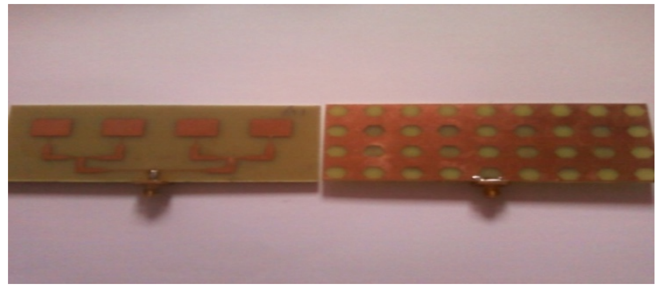
a b

Fig. 7. Photograph of fabricated CFMAA: a – top view, b – rear view



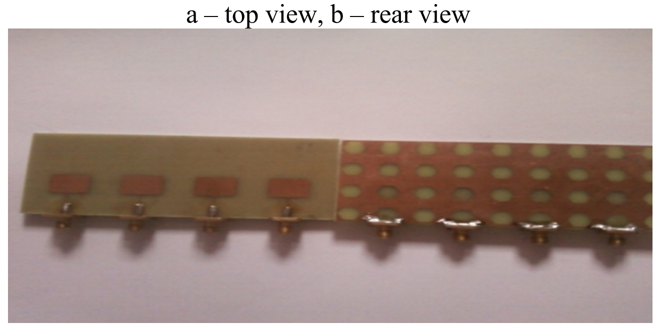
a b

Fig. 8. Photograph of fabricated setup of CFMAA for mutual coupling measurement: a – top view, b – rear view



a b

Fig. 9. Photograph of fabricated PFMAA: a – top view, b – rear view



a b

Fig. 10. Photograph of fabricated PFMAA: a – top view, b – rear view

## III. MEASURED RESULTS AND DISCUSSION

The measured results of the fabricated microstrip antenna arrays are obtained using vector network analyzer. Figs. 11, 12 and 13 depict the graphs of measured return loss and mutual coupling characteristics versus frequency of CFMAA. The return loss is designated by the S-parameter S11 and mutual coupling parameters are designated by the S-parameters S21, S31 and S41 respectively.

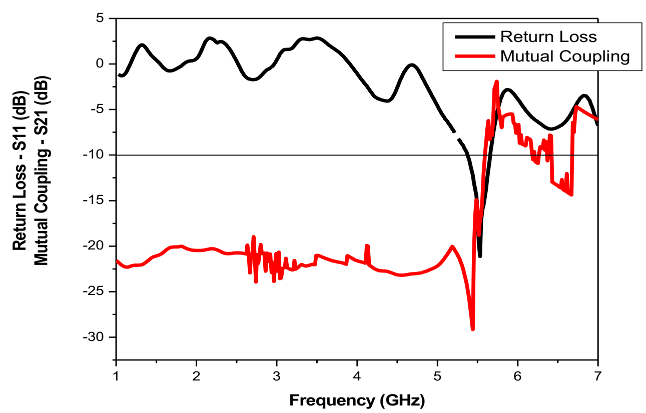



Fig.11. Plot of return loss and mutual coupling ($S_{21}$) versus frequency of CFMAA.

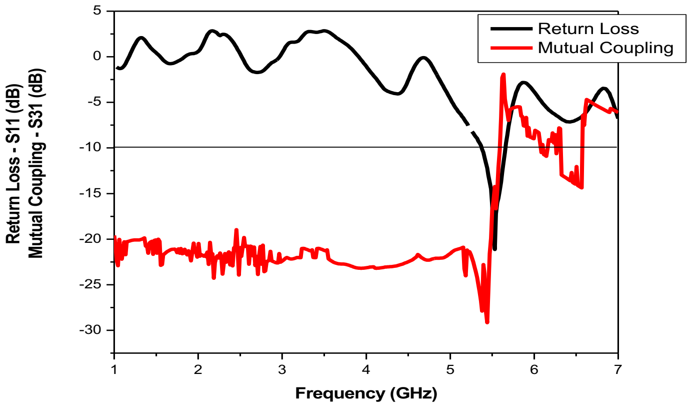



Fig. 12. Plot of return loss and mutual coupling ($S_{31}$) versus frequency of CFMAA

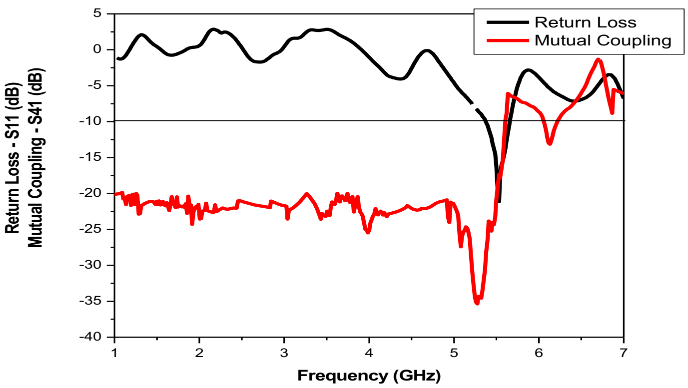



Fig.13. Plot of return loss and mutual coupling ($S_{41}$) versus frequency of CFMAA

Figs. 11, 12 and 13 show that CFMAA is resonating at the fundamental frequency of 5.53 GHz. The return loss produced at the resonant frequency of 5.53 GHz is equal to -21.12 dB. From the return loss graph the parameter bandwidth is calculated. The lower frequency is subtracted from upper frequency where the return loss is equal to – 10 dB to calculate the bandwidth. The lower and upper frequencies are located on either side of the resonant frequency. Therefore, the bandwidth of conventional microstrip antenna array is equal to 273 MHz. The bandwidth (%) is determined by using “(1)”.

$$Bandwidth(\%) = \left( \frac{Bandwidth}{\mathrm{Re}\,sonantFrequency} \right) \times 100 \quad (1)$$

Hence CFMAA is producing bandwidth of 4.89 %. As the bandwidth of CFMAA is very narrow it is very much required to enhance it.

From Figs. 11, 12 and 13 we see that the measured values of mutual coupling (S21, S31 and S41) of CFMAA are -16.95, -14.22 and -17.30 dB respectively. The values of mutual coupling are very high, severe and harmful and need to be decreased. Additionally, we can see that the graphs of return loss and mutual coupling versus frequency of CFMAA are crossing each other at the resonant frequency of 5.53 GHz. This means that there is interference between the transmitting element 1 and the receiving elements 2, 3 and 4 respectively of CFMAA. Hence there is no proper transmission and reception of information between the transmitting element 1 and the receiving elements 2, 3 and 4 of CFMAA. Figs. 14, 15 and 16 depict the graphs of measured return loss and mutual coupling characteristics versus frequency of PFMAA.

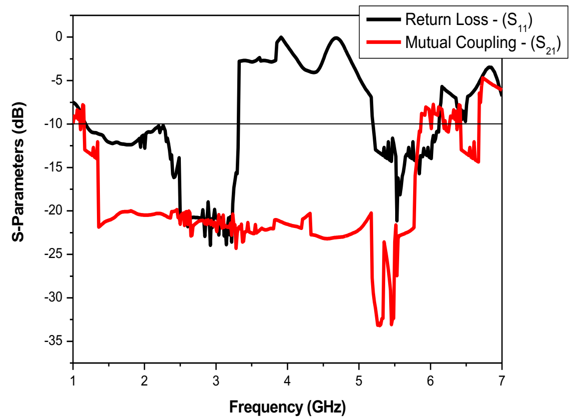



Fig. 14. Plot of return loss and mutual coupling ($S_{21}$) versus frequency of PFMAA

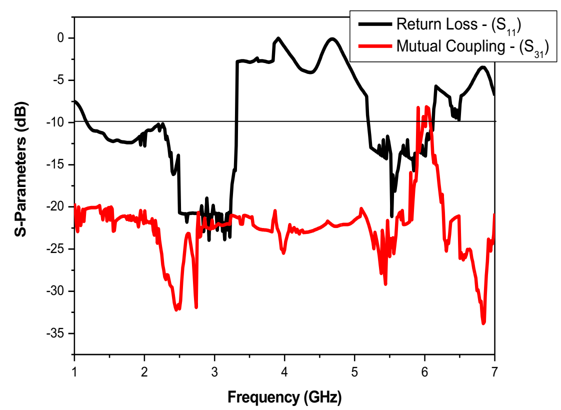



Fig. 15. Plot of return loss and mutual coupling ($S_{31}$) versus frequency of PFMAA

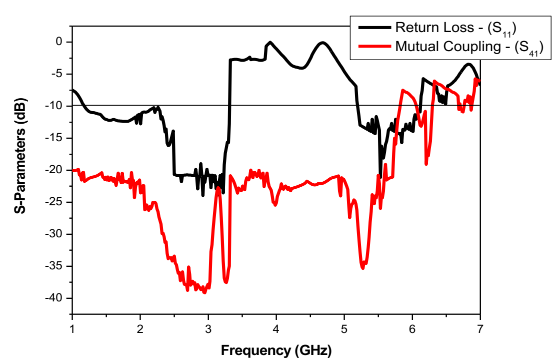



Fig.16. Plot of return loss and mutual coupling ($S_{41}$) versus frequency of PFMAA

From Figs. 14, 15 and 16 the return loss plot shows that PFMAA is resonating at a fundamental frequency of 2.92 GHz. The return loss is equal to -23.98 dB. It is also resonating at 5.53 GHz. The bandwidths produced at these resonant frequencies are 2150 and 950 MHz. Therefore, the overall bandwidth of PFMAA is equal to 85.74 %. As the overall bandwidth (%) of PFMAA is greater than that of CFMAA, PFMAA is a better antenna than CFMAA in terms of bandwidth. The values of mutual coupling - $S_{21}$, $S_{31}$ and $S_{41}$ measured at the resonant frequency of 5.53 GHz are equal to -27.45, -24.76, and -25.98 dB as depicted in Figs. 14, 15 and 16. These values of mutual coupling are lesser than that obtained by CFMAA. Moreover, the plots of mutual coupling and return loss of PFMAA are not overlapping at the resonant frequency of 5.53 GHz. This means the transmission of information between the transmitting element 1 and the receiving elements 2, 3 and 4 is better in PFMAA as compared to that in CFMAA. Hence PFMAA is a better antenna than CFMAA in terms of mutual coupling.

From Figs. 11 and 14 we see that the fundamental resonant frequency of CFMAA is equal to 5.53 GHz as against 2.92 GHz of PFMAA. The lower resonant frequency of PFMAA than that of CFMAA corresponds to virtual size reduction. The virtual size reduction (%) is determined by using “(2)”.

$$\left(\frac{f1-f2}{f1}\right)\times 100 \qquad (2)$$

In “(2)”, f1 and f2 are the fundamental resonant frequencies of CFMAA and PFMAA equal to 5.53 and 2.92 GHz respectively. Hence the virtual size reduction produced by PFMAA is 47.19 %.

Fig. 17 shows the radiation plot of CFMAA and PFMAA.

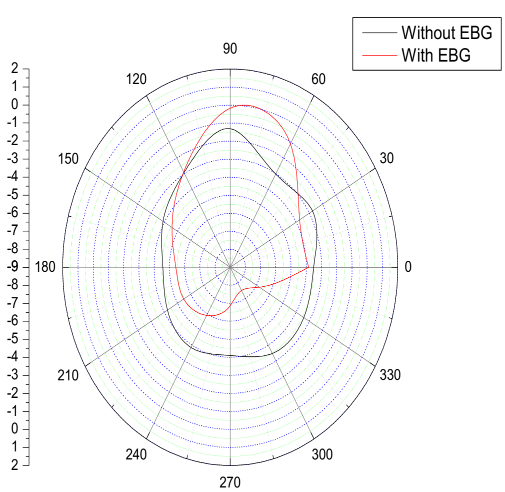



Fig. 17. Plot of radiation patterns of CFMAA and PFMAA

The radiation patterns of CFMAA and PFMAA are plotted at the resonant frequency of 5.53 GHz. The amount of forward power radiated is measured at the angle of $90^0$ and the backward power radiated at the angle of $270^0$ as shown in Fig.17. The plot in black depicts the radiation pattern of CFMAA and that in red that of PFMAA. The amount of back lobe radiation has been reduced substantially with the introduction of EBG structure. The amount of power radiated in the backward direction of CFMAA is equal to -4 dB. With the introduction of hexagon shape slot EBG structure the backward power is decreased to -7 dB. The measured values of forward power of CFMAA and PFMAA are -1.5 and 0 dB respectively. PFMAA is radiating more power in the forward direction compared to CFMAA. Hence PFMAA is a better candidate than CFMAA in terms of forward and backward powers.

The parameter front to back ratio (FBR) is calculated by subtracting the backward power from the forward power. Hence the FBR values of CFMAA and PFMAA are equal to 2.5 and 7 dB respectively. As FBR of PFMAA is greater than CFMAA, PFMAA is a better radiator than CFMAA.

With enhanced bandwidth and healthy reduction in mutual coupling, PFMAA is a better antenna than its opponent i.e. CFMAA. In addition, with decreased back lobe radiation and increase in forward power, PFMAA has proved its superiority over its counterpart i.e. CFMAA.

## IV. Conclusion

This paper demonstrates the usefulness and capability of electromagnetic band gap structures towards the better performance of four element microstrip array antenna. The hexagon shape slot type electromagnetic band gap structure etched in the ground plane has considerably improved the performance parameters. A good percentage of miniaturization has been achieved with the lowering of the resonant frequency of the conventional array antenna. The mutual coupling parameters have also been reduced to a good extent. With the introduction of electromagnetic band gap structure, the bandwidth is increased to 85.74 %. The back lobe reduction in the radiation pattern confirms the better radiation characteristics of the array antenna.

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