Performance of Microstrip Antenna Arrays Using Patch Type Electromagnetic Band Gap Structures

K. Prahlada Rao, P.V. Hunagund & Vani R.M

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ABSTRACT

The paper explains the improvement in the performance of microstrip antenna arrays using fork shape patch type electromagnetic band gap structure. The two element modified microstrip antenna array is giving enhanced gain and bandwidth equal to 22.72 dB and 156.4 % compared to 5.069 dB and 2.35 % of two element conventional microstrip antenna array. The four element modified microstrip antenna array is producing increased gain and bandwidth equal to 26.92 dB and 182.3 % compared to 6.81 dB and 4.89 % of four element conventional microstrip antenna array. The eight element modified microstrip antenna array is producing higher gain and bandwidth equal to 31.31 dB and 211.2 % compared to 7.44 dB and 4.98 % of eight element conventional microstrip antenna array. All the modified antenna arrays are showing good reduction in mutual coupling and appreciable radiation characteristics. Corporate feeding technique is employed to feed the microstrip antenna arrays. The antenna arrays are designed using Mentor Graphics IE3D software.

Keywords: corporate feeding technique; electromagnetic band gap structure; gain; micro strip antenna array; return loss.

Classification: FOR Code: 100501

Language: English

London Journals Press

LJP Copyright ID: 392834
Print ISSN: 2631-8474
Online ISSN: 2631-8482

London Journal of Engineering Research

Volume 19 | Issue 1 | Compilation 1.0

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ABSTRACT

The paper explains the improvement in the performance of microstrip antenna arrays using fork shape patch type electromagnetic band gap structure. The two element modified microstrip antenna array is giving enhanced gain and bandwidth equal to 22.72 dB and 156.4 % compared to 5.069 dB and 2.35 % of two element conventional microstrip antenna array. The four element modified microstrip antenna array is producing increased gain and bandwidth equal to 26.92 dB and 182.3 % compared to 6.81 dB and 4.89 % of four element conventional microstrip antenna array. The eight element modified microstrip antenna array is producing higher gain and bandwidth equal to 31.31 dB and 211.2 % compared to 7.44 dB and 4.98 % of eight element conventional microstrip antenna array. All the modified antenna arrays are showing good reduction in mutual coupling and appreciable radiation characteristics. Corporate feeding technique is employed to feed the microstrip antenna arrays. The antenna arrays are designed using Mentor Graphics IE3D software.

Keywords: corporate feeding technique; electromagnetic band gap structure; gain; micro strip antenna array; return loss.

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I. INTRODUCTION (*HEADING 1*)

An antenna is defined as a radiator by which electromagnetic waves are conducted and received. The IEEE definition of antenna is "a means for radiating and receiving radio waves". Antennas are basic electromagnetic devices. Antennas are available in various shapes, sizes and configurations. In recent years many types of antennas have been designed. One of the antennas which have gained high level of appreciation and importance are microstrip antennas. These antennas have radiating patch and ground plane on either side of dielectric substrate. [1-6]. Electromagnetic band gap (EBG) structures have gained huge prominence and high demand because of their distinguished features. These are the structures that form a periodic arrangement of unit cells that object or assist in the propagation of electromagnetic waves for all incident angles and polarization states in one, two or three dimensions. In the past these structures have been proved to produce promising results to overcome the limitations of microstrip antennas and arrays particularly to improve the bandwidth and suppress surface waves. The characterization, contribution and applications have become the central focus of research. [7-14].

II. CONVENTIONAL MICROSTRIP ANTENNA ARRAY

In this paper three conventional microstrip antenna arrays are designed. They consist of two, four and eight elements respectively. The antenna arrays are designed using Mentor Graphics IE3D software. The dielectric substrate employed is FR-4 glass epoxy. The substrate has dielectric constant and loss tangent equal to 4.2 and 0.0245. The height of the substrate is 1.6 mm. The design frequency of the antenna arrays is equal to 6 GHz. The two element conventional microstrip antenna array (TECMAA) is made of two identical rectangular radiating elements. The two radiating elements of TECMAA are separated by a distance of $\lambda/4$, where λ is the wavelength calculated at the design frequency of 6 GHz. The dimensions of each of the radiating elements are 15.73 mm × 11.76 mm respectively. Corporate feeding technique is employed to feed TECMAA. The schematic of TECMAA is depicted in Fig.1. The dimensions of all the parts of TECMAA are shown in Table 1.

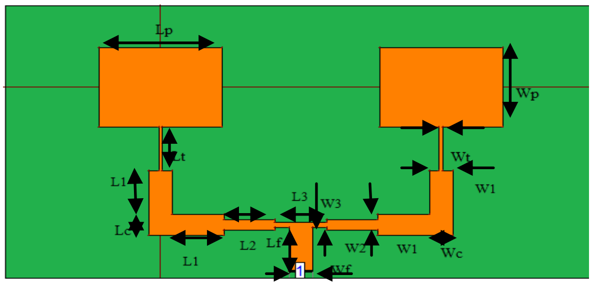


Fig.1: Schematic of TECMAA.

Table I. Parameter values of conventional two element antenna array.

Parameter	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	3.05
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
Width of the 100Ω line (W3)	0.70
Length of the feed line (Lf)	6.52
Width of the feed line (Wf)	3.05

To determine the mutual coupling between the two antenna elements of TECMAA, the elements are fed independently as depicted in Fig.2.

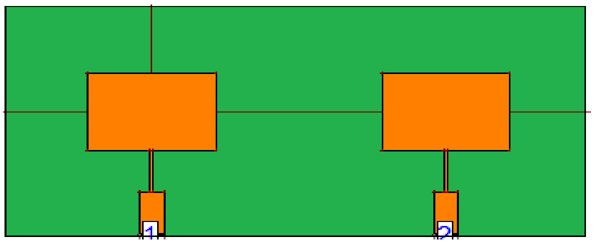


Fig.2: Schematic of setup of TCMAA for mutual coupling measurement.

Fig.2 the two antenna elements are separated by the same distance as that in Fig.1.

Fig.3 depicts the schematic of four element conventional microstrip antenna array (FECMAA). It has four identical rectangular radiating patches. The distance between the four elements of FECMAA is same as that in TECMAA. All the dimensions of FECMAA are same as that of TECMAA.

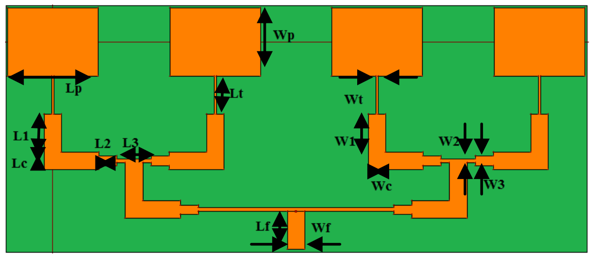


Fig.3: Schematic of FECMAA.

To determine the mutual coupling between the adjacent antenna elements of FECMAA, the four radiating elements are excited separately as shown in Fig. 4. The distance between the antenna elements is maintained constant.

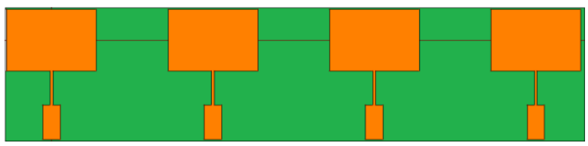


Fig.4: Schematic of setup of FECMAA for mutual coupling measurement.

Fig.5 depicts the schematic of eight element conventional microstrip antenna array (EECMAA). It has eight identical rectangular radiating patches. The distance between the eight elements of EECMAA is same as that in TECMAA and FECMAA. All the dimensions of EECMAA are same as that of TECMAA.

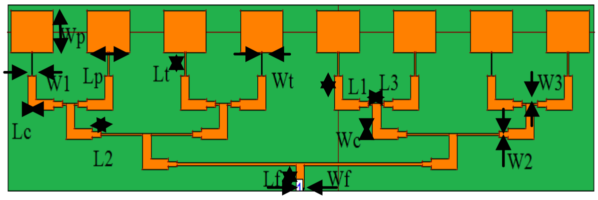


Fig.5: Schematic of EECMAA.

To determine the mutual coupling coefficients between the elements of EECMAA, all the eight elements are fed independently as shown in Fig.6. The distance between the antenna elements is maintained constant.

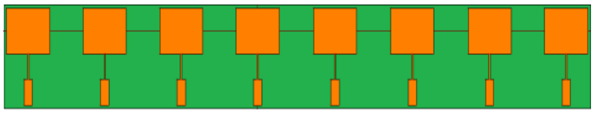


Fig.6: Schematic of setup of EECMAA for mutual coupling measurement.

III. PROPOSED MICROSTRIP ANTENNA ARRAYS

The proposed microstrip antenna arrays are designed by loading the EBG patch type structure on the surface of conventional microstrip antenna arrays. The EBG structure used is fork shape patch type EBG structure. The unit cell and the fork shape patch type EBG structure are depicted in Figs. 7 and 8.

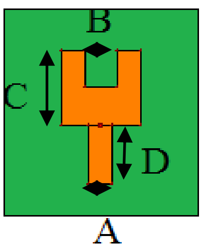


Fig.7: Schematic of unit cell of fork shape patch type EBG structure.

In Fig.7, A = 1.5 mm, B = 2 mm, C = 5 mm and D = 4 mm respectively.

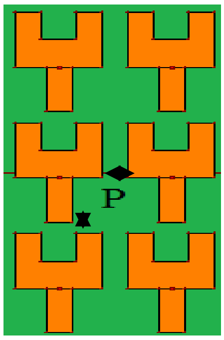


Fig.8: Schematic of fork shape patch type EBG structure.

In Fig.8, the periodicity of the unit cells of the EBG structure is equal to P = 1.5 mm along the x-axis and y-axis.

The two element modified microstrip antenna array (TEMMAA) is obtained by placing the EBG structure shown in Fig.8 on the surface of TECMAA. The EBG structure is placed in between the two radiating elements of TEMMAA. The schematic of TEMMAA is depicted in Fig. 9.

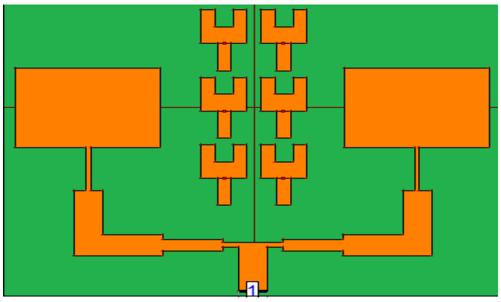


Fig.9: Schematic of TEMMAA.

To measure the mutual coupling of TEMMAA, the EBG structure shown in Fig. 8 is placed on the surface and in between the radiating elements of the schematic depicted in Fig.2. The schematic employed to estimate the mutual coupling of TEMMAA is shown in Fig.10.

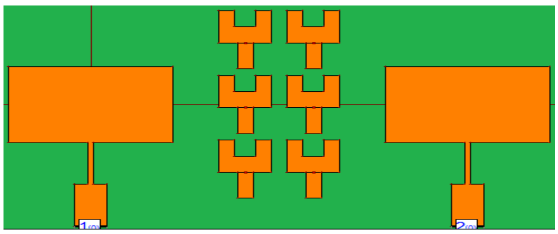


Fig.10: Schematic of setup of TEMMAA for mutual coupling measurement.

The four element modified microstrip antenna array (FEMMAA) is obtained by placing the EBG structure shown in Fig.8 on the surface of FECMAA. The EBG structure is placed in between the adjacent radiating elements of FEMMAA. The schematic of FEMMAA is depicted in Fig. 9.

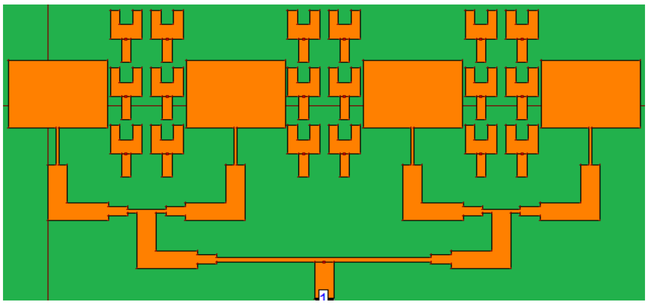


Fig.11: Schematic of FEMMAA.

To measure the mutual coupling between the radiating elements of FEMMAA, the EBG structure shown in Fig. 8 is placed on the surface and in between the radiating elements of the schematic depicted in Fig.2. The schematic employed to estimate the mutual coupling of FEMMAA is shown in Fig.12.

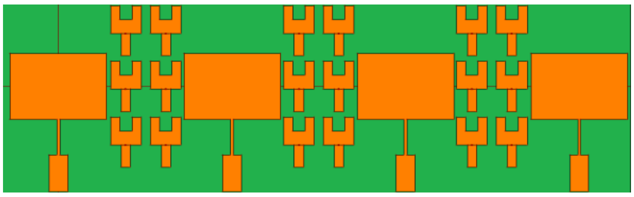


Fig.12: Schematic of setup of FEMMAA for mutual coupling measurement.

The eight element modified microstrip antenna array (EEMMAA) is obtained by placing the EBG structure shown in Fig.8 on the surface of EECMAA. The EBG structure is placed in between the adjacent radiating elements of EEMMAA. The schematic of EEMMAA is depicted in Fig. 13.

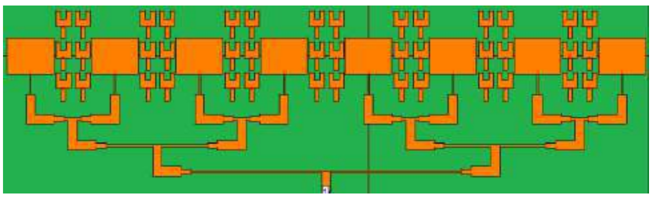


Fig.13: Schematic of EEMMAA.

To measure the mutual coupling between the radiating elements of EEMMAA, the EBG structure shown in Fig. 8 is placed on the surface and in between the radiating elements of the schematic depicted in Fig.2. The schematic employed to determine the mutual coupling between the elements of FEMMAA is shown in Fig.14.

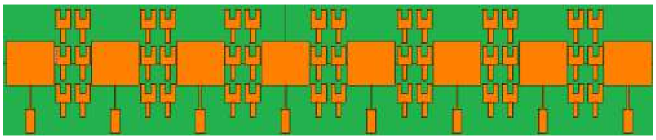
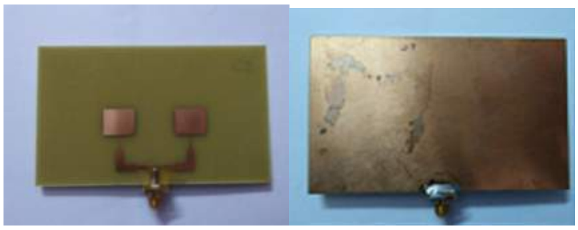


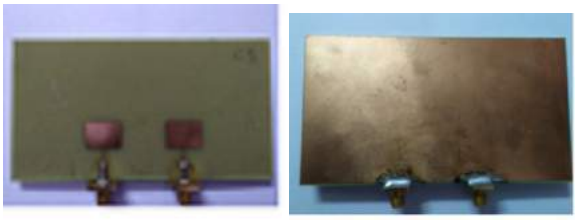
Fig.14: Schematic of setup of EEMMAA for mutual coupling measurement.

Figs. 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 and 26 depict the photographs of the fabricated antenna arrays.



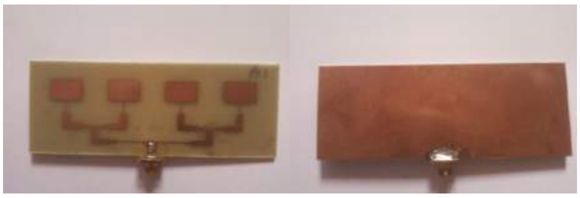
(a) Front view (b) Back view.

Fig. 15: Photograph of TECMAA.



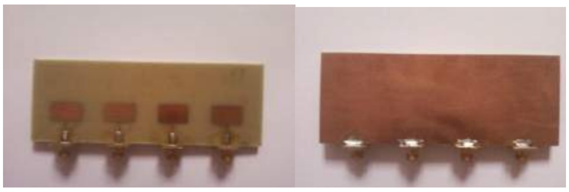
(a) Front view (b) Back view.

Fig.16: Photograph of setup of TECMAA for mutual coupling measurement.



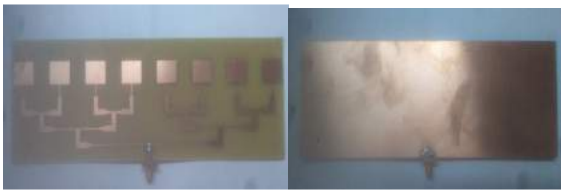
(a) Front view (b) Back view

Fig.17: Photograph of FECMAA.



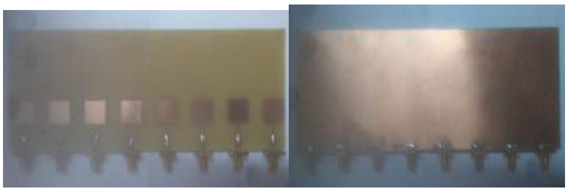
(a) Front view (b) Back view

Fig.18: Photograph of setup of FECMAA for mutual coupling measurement.



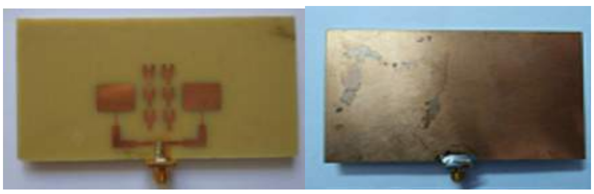
(a) Front view (b) Back view

Fig.19. Photograph of EECMAA.



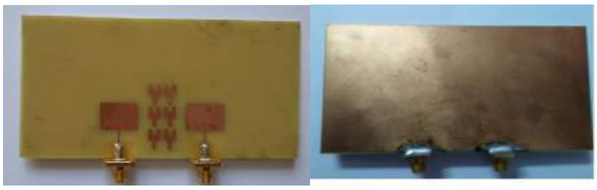
(a) Front view (b) Back view

Fig.20: Photograph of setup of EECMAA for mutual coupling measurement.



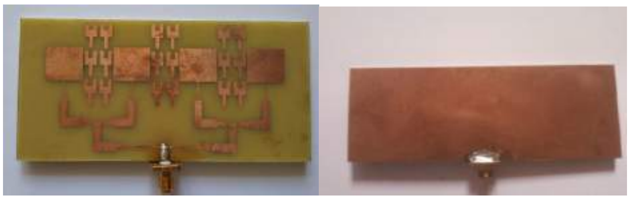
(a) Front view (b) Back view

Fig.21: Photograph of TEMMAA.



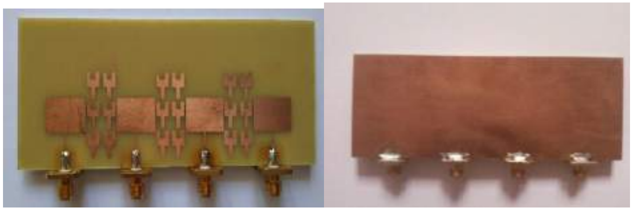
(a) Front view (b) Back view

Fig.22: Photograph of setup of TEMMAA for mutual coupling measurement.



(a) Front view (b) Back view

Fig.23: Photograph of FEMMAA.



(a) Front view (b) Back view

Fig.24: Photograph of setup of FEMMAA for mutual coupling measurement.

(a) Front view (b) Back view

Fig.25: Photograph of EEMMAA.

(a) Front view (b) Back view

Fig.26: Photograph of setup of EEMMAA for mutual coupling measurement.

IV. MEASURED RESULTS

The measured results of conventional and proposed microstrip antenna arrays are obtained using vector network analyzer. Fig. 27 depicts the graph of return loss and mutual coupling versus frequency of TECMAA.

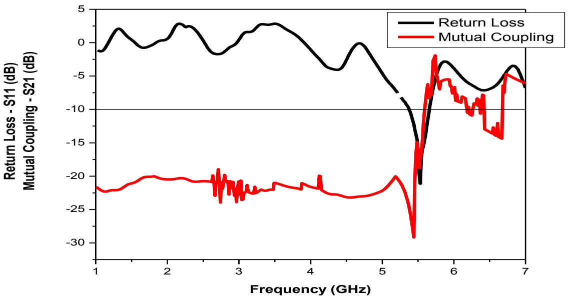


Fig.27: Plot of return loss and mutual coupling – S21 versus frequency of TECMAA.

Fig.27 shows that the resonant frequency of TECMAA is equal to 5.53 GHz with a return loss of -21.23 dB. The other parameter that can be calculated from Fig.27 is bandwidth. Bandwidth is equal to subtracting the lower frequency from the upper frequency where the return loss is equal to -10 dB value. Therefore the bandwidth of TECMAA is equal to 130 MHz. The bandwidth (%) is determined by using equation (1) 0 %. (1)

$$\frac{Bandwidth}{Resonant\ frequency} \times 10 \qquad \frac{Bandwidth}{Resonant\ frequency} \times 10 \qquad (1)$$

The bandwidth (%) of TECMAA is equal to 2.35%. Information about another important parameter mutual coupling is obtained from Fig.28. The S-parameter S21 is used to measure the mutual coupling of TECMAA. The value of mutual coupling obtained at the resonant frequency of 5.53 GHz is equal to -17.83 dB. The value of mutual coupling is considered to be high and can cause serious problems that can be harmful for the proper operation of TECMAA. From Fig.27 we also see that the graphs of return loss and mutual coupling of TECMAA are overlapping each other at the resonant frequency of 5.53 GHz, indicating that there is disturbance of electromagnetic signals between the transmitting element 1 and the receiving element 2. This implies that there is interference between the two radiating patches.

Figs. 28, 29 and 30 show the graphs of return loss and mutual coupling versus frequency of FECMAA.

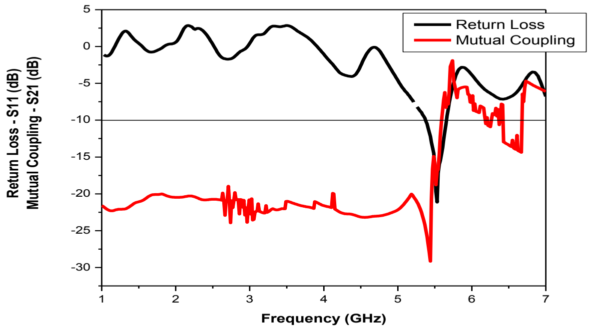


Fig.28: Plot of return loss and mutual coupling – S21 versus frequency of FECMAA.

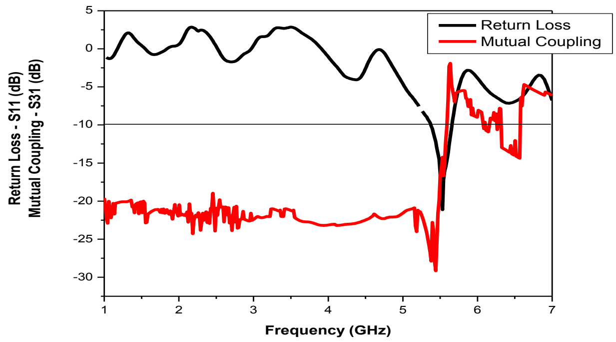


Fig.29: Plot of return loss and mutual coupling – S31 versus frequency of FECMAA.

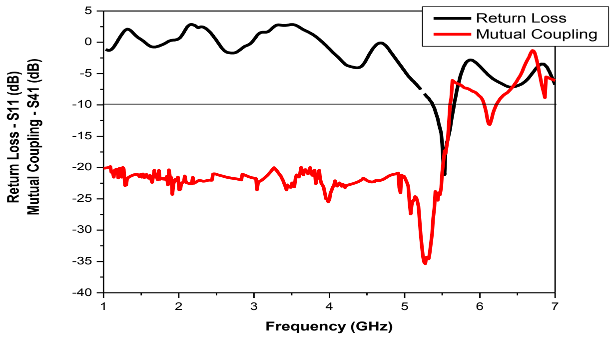


Fig.30: Plot of return loss and mutual coupling – S41 versus frequency of FECMAA.

From Figs. 29, 30 and 31 we see that FECMAA is resonating at 5.53 GHz with a return loss of -21.06 dB. FECMAA is producing a bandwidth of 273 MHz. Using equation (1) the bandwidth (%) of FECMAA is equal to 4.89 %. The mutual coupling between the elements of FECMAA is measured by the S-parameters S21, S31 and S41 respectively. The values of these S-parameters measured at the resonant frequency of 5.53 GHz are S21 = -16.95 dB, S31 = -14.22dB and S41 = -17.30 dB respectively. The values of mutual coupling coefficients are very high and need to be decreased. Additional information that is obtained from Figs. 28, 29 and 30 is the graphs of return loss and mutual coupling are overlapping with each other at the resonant frequency of 5.53 GHz. This is an indication towards high and severe level of interference between the transmitting element 1 and the receiving elements 2, 3 and 4 respectively. Hence transmission and reception of electromagnetic signals is not proper between the transmitting and receiving elements of FECMAA.

Figs. 31, 32, 33, 34, 35, 36 and 37 depict the graphs of return loss and mutual coupling versus frequency of EECMAA.

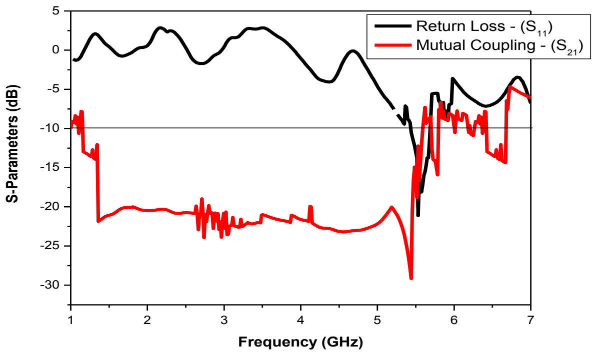


Fig.31: Plot of return loss and mutual coupling – S21 versus frequency of EECMAA.

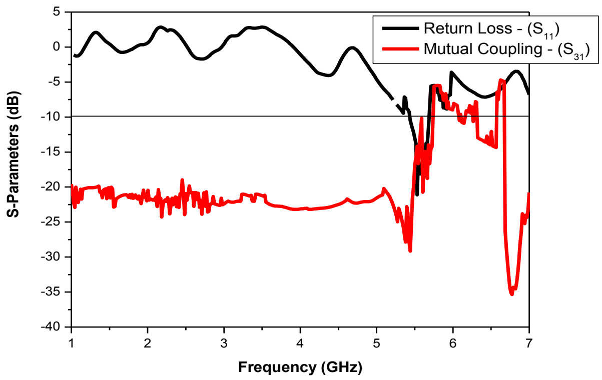


Fig.32: Plot of return loss and mutual coupling – S31 versus frequency of EECMAA

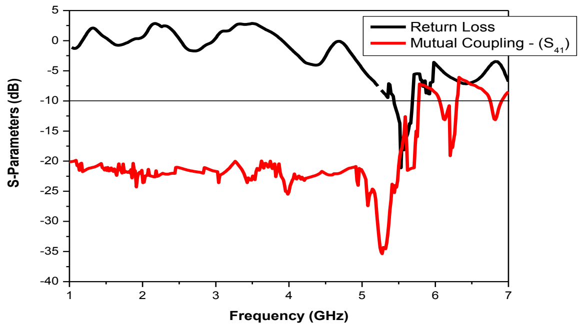


Fig.33: Plot of return loss and mutual coupling – S41 versus frequency of EECMAA

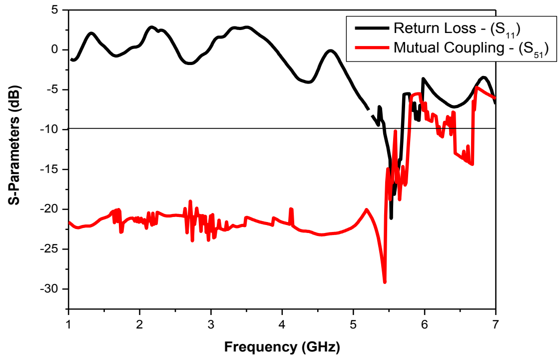


Fig.34: Plot of return loss and mutual coupling – S51 versus frequency of EECMAA

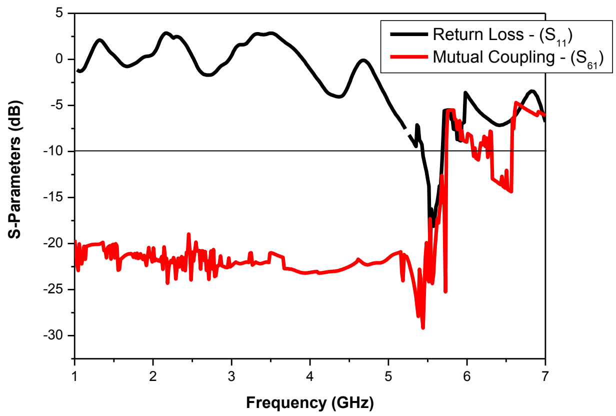


Fig.35: Plot of return loss and mutual coupling – S61 versus frequency of EECMAA

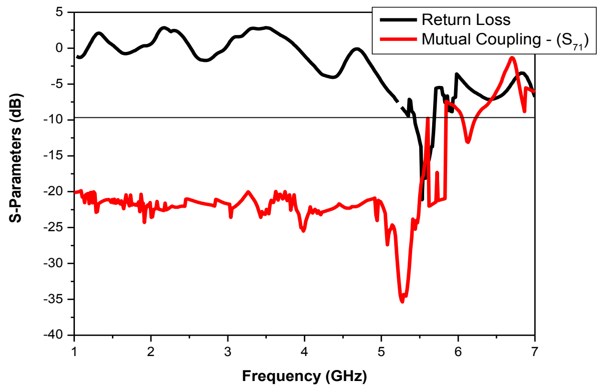


Fig.36: Plot of return loss and mutual coupling – S71 versus frequency of EECMAA

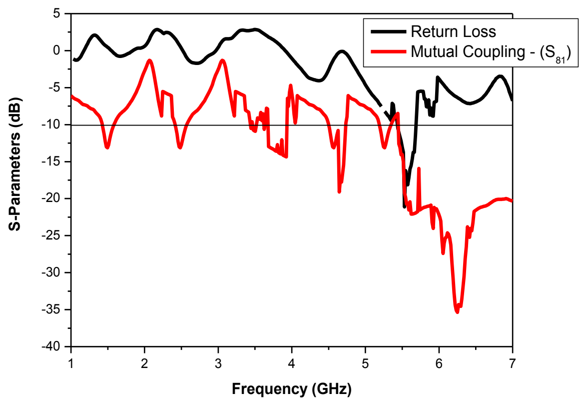


Fig.37: Plot of return loss and mutual coupling – S81 versus frequency of EECMAA

The graphs depicted in Figs. 31, 32, 33, 34, 35, 36 and 37 show that EECMAA is resonating at the fundamental frequency of 5.53 GHz with a return loss of -21.12 dB. The calculated value of bandwidth of EECMAA is equal to 275 MHz. In terms of bandwidth (%), it is equal to 4.98 %. The mutual coupling between the elements of EECMAA is measured with the S-parameters S11, S21, S31, S41, S51, S61, S71 and S81 respectively. From Figs. 31, 32, 33, 34, 35, 36 and 37, the values of mutual coupling measured at the resonant frequency of 5.53 GHz are equal to S21 = -12.22 dB, S31 = - 14.18 dB, S41 = -18.23 dB, S51 = -16.45 dB, S61 = -17.31 dB, S71 = -18.09 dB and S81 = -19.23 dB respectively. The mutual coupling values of EECMAA are high. Figs. 31, 32, 33, 34, 35, 36 and 37 depict that the graphs of return loss and mutual coupling are crossing each other at the resonant frequency of 5.53 GHz. This overlapping nature leads to improper transfer of information between the transmitting antenna 1 and the receiving antennas 2, 3, 4, 5, 6, 7 and 8 respectively and deteriorates the performance of EECMAA. Fig. 38 depicts the graph of return loss and mutual coupling versus frequency of TEMMAA.

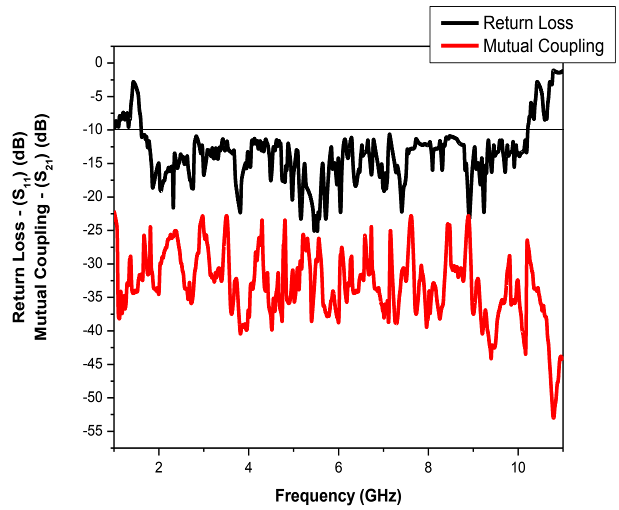


Fig.38: Plot of return loss and mutual coupling – S21 versus frequency of TEMMAA.

From Fig. 38 we see that TEMMAA is having a fundamental resonant frequency of 5.53 GHz. The return loss at this resonant frequency is equal to -26.54 dB. The bandwidth calculated at the resonant frequency of 5.53 GHz is equal to 8.64 GHz. Therefore the bandwidth (%) of TEMMAA is equal to 156.4 %. Hence bandwidth (%) of TEMMAA is greater than the bandwidth (%) of its counterpart i.e. TECMAA. Therefore TEMMAA is a better antenna than TECMAA in terms of bandwidth (%).

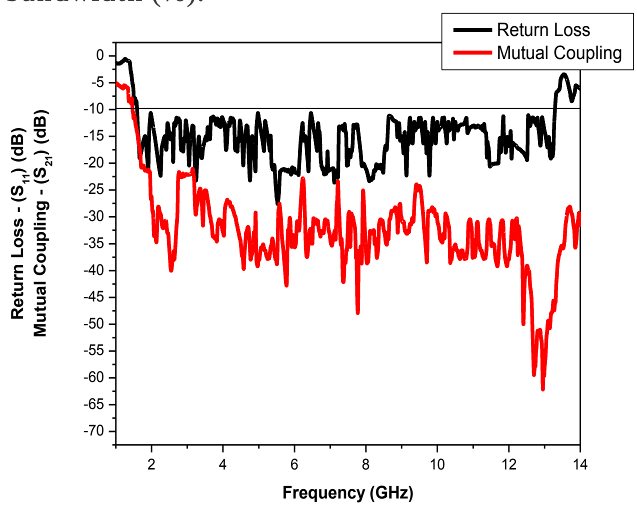


Fig.42: Plot of return loss and mutual coupling – S21 versus frequency of EEMMAA.

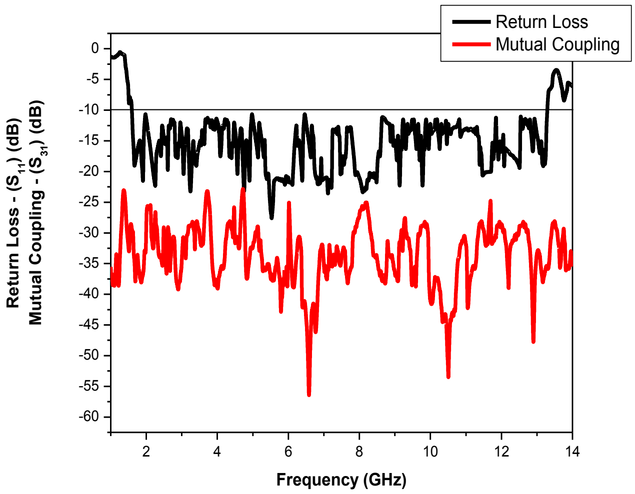


Fig.43: Plot of return loss and mutual coupling – S31 versus frequency of EEMMAA.

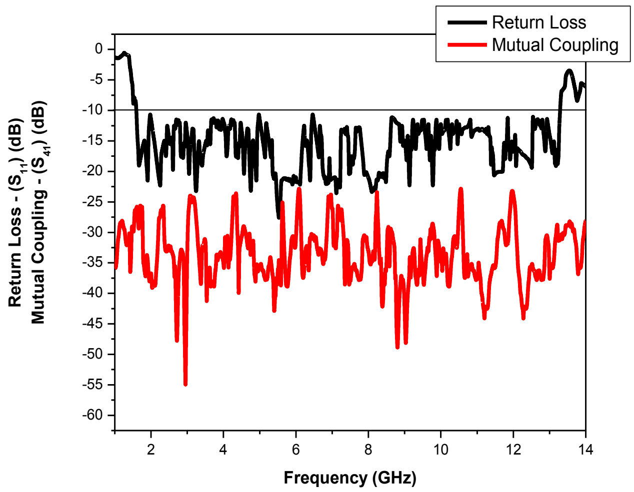


Fig.44: Plot of return loss and mutual coupling – S41 versus frequency of EEMMAA.

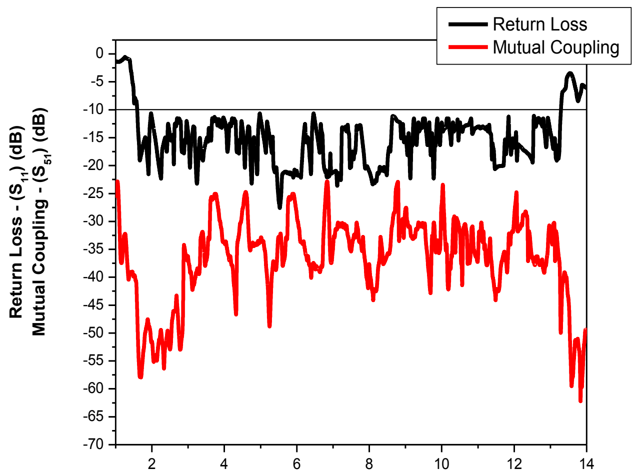


Fig.45: Plot of return loss and mutual coupling – S51 versus frequency of EEMMAA.

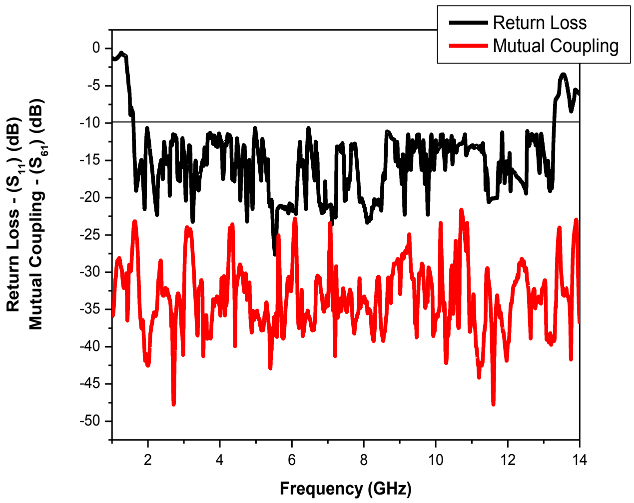


Fig.46: Plot of return loss and mutual coupling – S61 versus frequency of EEMMAA.

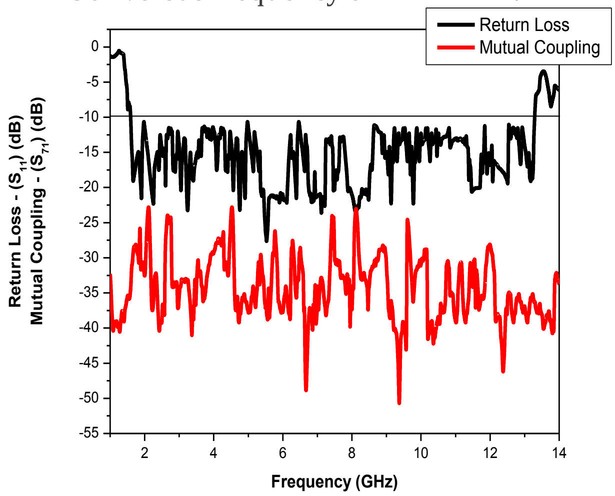


Fig.47: Plot of return loss and mutual coupling – S71 versus frequency of EEMMAA.

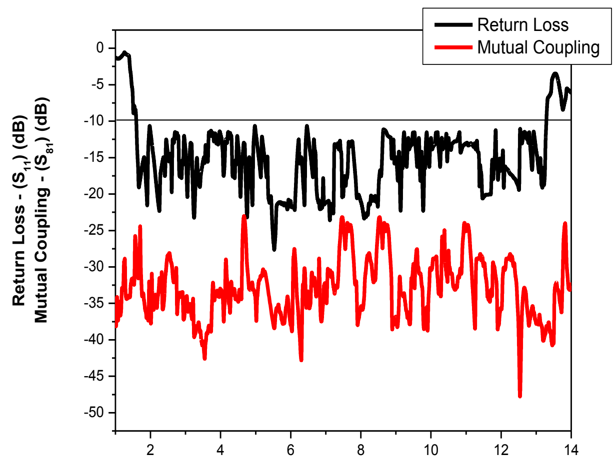


Fig.48: Plot of return loss and mutual coupling – S81 versus frequency of EEMMAA.

Fig.48. Plot of return loss and mutual coupling – S81 versus frequency of EEMMAA. Figs. 42, 43, 44, 45, 46, 47 and 48 depict that EEMMAA is resonating at the fundamental frequency of 5.53 GHz with return loss equal to -28.2 dB. The bandwidth of FEMMAA at the resonant frequency of 5.53 GHz is 11.67 GHz. The calculated value of bandwidth (%) of EEMMAA is equal to 211.2 %. The bandwidth (%) of EEMMAA is greater than that produced by EECMAA. Hence EEMMAA is a better antenna than EECMAA in terms of bandwidth (%). In terms of mutual coupling, Figs. 42, 43, 44, 45, 46, 47 and 48 depict that the values of mutual coupling at the resonant frequency of 5.53 GHz are equal to S21 = -35.87, S31 = -36.14, S41 = -33.17, S51 = -34.56, S61 = -37.13, S71 = -38.19 and S81 = -39.19 dB respectively. Comparing the results of mutual coupling of EEMMAA and EECMAA we see that the mutual coupling values of EEMMAA are decreased compared to that of EECMAA. Moreover, the graphs of return loss and mutual coupling versus frequency of EEMMAA are not overlapping with each other at the resonant frequency of 5.53 GHz. This implies that the interference level between the transmitting element 1 and the receiving elements 2, 3, 4, 5, 6, 7 and 8 in EEMMAA is less compared to that in EECMAA. Therefore EEMMAA is a better antenna than EECMAA in terms of mutual coupling.

The parameter Gain is calculated by using the formula

$$G = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\frac{Pr}{Pt} - Gt \quad (2)$$

where,
Pt is the transmitted power.
Pr is the received power.
R is the distance between the transmitting and the receiving antennas.
λ is the wavelength at the resonant freq uenc of 5.53 GHz. Gt is the gain of the transmitting antenna.
Gt is given by the formula

$$Gt = 10\log_{10} Gs \quad (3)$$

$$Gs = \frac{2\pi ab}{\lambda^2} \quad (4)$$

where a and b are the length and width of the standard pyramidal horn antenna used as the transmitting antenna. The dimensions a and b are equal to 24 and 14 cm respectively. The distance between the transmitting antenna (standard pyramidal horn antenna) and the receiving antenna (antenna under test) is given by the formula

$$R \geq \frac{2D^2}{\lambda} \quad (5)$$

D is the larger dimension of the transmitting antenna and λ is the wavelength calculated at the resonant frequency of 5.53 GHz. Hence the value of R is equal to 71.86m.

Considering TECMAA and TEMMAA as receiving antennas, the transmitted and received powers in the case of TECMAA are equal to 8.7 µW and 8.8 nW respectively. TEMMAA is producing transmitted and received powers equal to 8.7 µW and 0.49 µW. Hence substituting the relevant parameters in equation (2), the calculated values of gain of TECMAA and TEMMAA are equal to 5.069 and 22.72 dB respectively. TEMMAA is having better gain than TECMAA. Therefore TEMMAA is a better antenna than TECMAA in terms of gain.

Considering FECMAA and FEMMAA as receiving antennas, FECMAA is producing transmitted and received powers equal to 8.7 µW and 12.4 nW respectively. On the other hand FEMMAA is producing transmitted and received powers equal to 8.7 µW and 1.273 µW. Hence substituting the relevant parameters in equation (2), the calculated gains of FECMAA and FEMMAA are equal to 6.81 and 26.92 dB respectively. The gain of EEMMAA is greater than that of EECMAA. Hence EEMMAA is a better antenna than EECMAA in terms of gain.

Considering EECMAA and EEMMAA as receiving antennas, FECMAA is producing transmitted and received powers equal to 8.7 µW and 14.35 nW respectively. The corresponding transmitted and received powers produced by EEMMAA On the other hand FEMMAA is producing transmitted and received powers equal to 8.7 µW and 3.467

μW. Hence substituting the relevant parameters in equation (2), the calculated gains of EECMAA and EEMMAA are equal to 7.44 and 31.31 dB respectively.

Fig. 49 depicts the radiation patterns of TECMAA and TEMMAA.

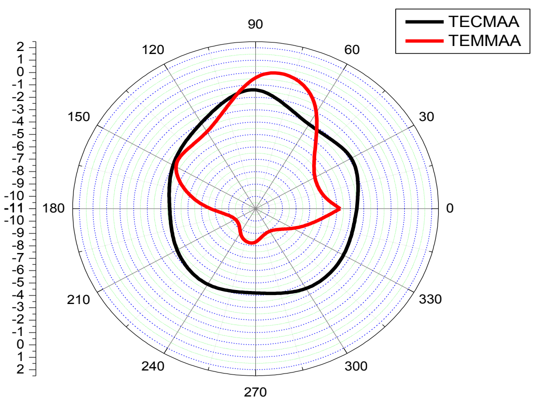


Fig.49: Plot of radiation patterns of TECMAA and TEMMAA.

The forward and backward powers are measured with the help of radiation pattern. These powers are measured at the angles of 900 and 2700 respectively. From Fig. 49, the forward and backward powers produced by TECMAA and TEMMAA are -1.31 and -0.75 dB respectively. The corresponding backward powers are equal to -4.18 and -9 dB respectively. Comparing the forward and backward powers of TECMAA and TEMMAA, TEMMAA is radiating more forward power and less backward power than TECMAA. Hence TEMMAA is a better antenna than TECMAA 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 FBR values of TECMAA and TEMMAA are equal to 2.87 and 8.25 dB respectively. As TEMMAA is having greater value of FBR than TECMAA, TEMMAA is radiating more effectively in forward and backward directions than TECMAA. Hence TEMMAA is a better antenna than TECMAA in terms of FBR parameter.

Fig. 50 depicts the radiation patterns of FECMAA and FEMMAA.

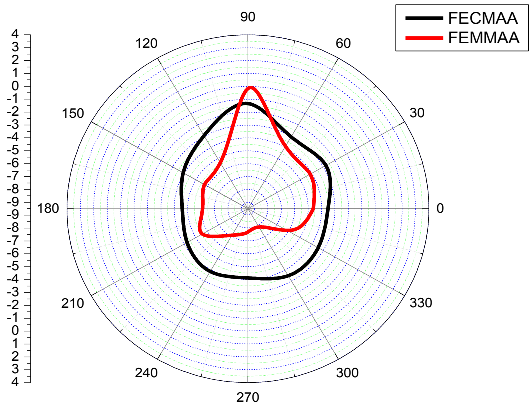


Fig.50: Plot of radiation patterns of FECMAA and FEMMAA.

From Fig.50 we see that the forward and backward powers radiated by FECMAA are -2 and -4.5 dB respectively. FEMMAA is producing forward and backward powers equal to 0 and -8 dB respectively. Comparing the forward powers of FECMAA and FEMMAA, FEMMAA is producing more forward power than its competitor i.e. FECMAA. As far as backward power or back lobe radiation is concerned, FEMMAA is producing reduced power in the backward direction than FECMAA. Hence FEMMAA is a better antenna than FECMAA in terms of forward and backward powers. The calculated values of FBR of FECMAA and FEMMAA are 2.5 and 8 dB respectively. Thus the FBR value of FEMMAA is greater than that of FECMAA. Hence FEMMAA is a better radiator than FECMAA.

Fig.51 depicts the radiation patterns of EECMAA and EEMMAA.

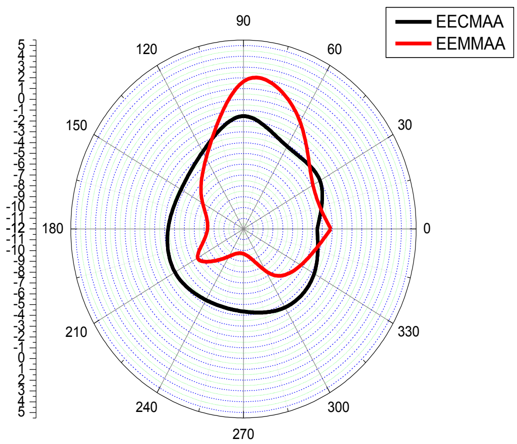


Fig.51. Plot of radiation patterns of EECMAA and EEMMAA.

Fig.51 shows that the powers produced by EECMAA in the forward and backward directions are equal to -3 and -4.5 dB respectively. As far as EEMMAA is concerned the corresponding forward and backward powers are equal to 2 and -9.75 dB respectively. Hence EEMMAA is producing increased power in the forward direction than EECMAA. In the case of backward power, EEMMAA is radiating less power in the backward direction compared to EECMAA. Therefore EEMMAA is a better antenna in terms of forward and backward powers. The FBR values of EEMMAA and EEMMAA are calculated as equal to 1.5 and 11.75 dB respectively. As FBR of EEMMAA is more than that of EECMAA, EEMMAA is a better antenna than EECMAA.

Tables II, III and IV summarize the measured results of conventional and proposed microstrip antenna arrays.

Table II: Measured results of TECMAA and TEMMAA.

Type of Antenna	Resonant Frequency (GHz)	Return Loss (dB)	Band Width (MHz)	Band Width (%)	Gain (dB)
TECMAA	5.53	-21.23	130	2.35	5.069
TEMMAA	5.53	-26.54	8640	156.4	22.72

Table III: Measured results of FECMAA and FEMMAA.

Type of Antenna	Resonant Frequency (GHz)	Return Loss (dB)	Band Width (MHz)	Band Width (%)	Gain (dB)
FECMAA	5.53	-21.06	273	4.89	6.81
FEMMAA	5.53	-28.54	10080	182.3	26.92

Table IV: Measured results of EECMAA and EEMMAA.

Type of Antenna	Resonant Frequency (GHz)	Return Loss (dB)	Band Width (MHz)	Band Width (%)	Gain (dB)
EECMAA	5.53	-21.12	275	4.98	7.44
EEMMAA	5.53	-28.54	11670	211.2	31.31

Considering the performances of TEMMAA, FEMMAA and EEMMAA, EEMMAA is the best antenna. The bandwidth (%) and gain of EEMMAA is highest compared to TEMMAA and FEMMAA. We notice that as the number of elements of the designed antenna array is increasing, bandwidth (%) and gain is increasing. Also appreciable reduction in mutual coupling and good radiation characteristics are also obtained.

V. CONCLUSION

The two, four and eight element conventional and the proposed microstrip antenna arrays are designed, fabricated and tested experimentally. Fork shape patch type EBG structure has played a pivotal role in enhancing the performance of microstrip antenna arrays. Increase in bandwidth and gain coupled with good radiation characteristics have been the main features of proposed microstrip antenna arrays. Additionally it has also been proved that increase in the number of elements of microstrip antenna arrays, performance becomes better.

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