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Wide Band and Enhanced Gain Microstrip Antenna Array for WiMax Applications

K. Prahlada Rao[1], Vani R.M[2], P.V.Hunagund[3]
Dept. of PG Studies and Research in Applied Electronics[1,3],Gulbarga University[1,3]
University Science Instrumentation Center[2],Gulbarga University[2]
Email: pra_kaluri@rediffmail.com

Abstract- This paper demonstrates the improved performance of microstrip antenna array consisting of two elements. The design frequency of the antenna arrays is 6 GHz. The conventional microstrip antenna array is resonating at 5.53 GHz with a bandwidth of 2.35%. At the resonant frequency of 5.53 GHz, the mutual coupling and gain are equal to -17.83 dB and 5.06 dB respectively. With the incorporation of h-shape slot Electromagnetic Band Gap structure in the ground plane and meandering patch Electromagnetic Band Gap structure on the surface of the conventional antenna array, the proposed antenna array is producing an increased bandwidth of 37.50%. The mutual coupling and gain of the proposed antenna array at the resonant frequency of 5.53 GHz are -29.37 dB and 7.84 dB respectively. The proposed antenna array is producing a virtual size reduction of 34.80%. Additionally, the proposed antenna array is also producing good reduction in back lobe radiation and increase in front to back ratio. The proposed antenna array is useful in the radar band of 5.25 – 5.925 GHz. This frequency range is the C band. It is also useful for WiMax (upper band) applications, whose frequency range is 5.2-5.8 GHz.

Index Terms- Bandwidth; Gain; Microstrip Antenna Array; Mutual Coupling; Return Loss.

1. INTRODUCTION

The term "microwave" refers to those electromagnetic signals whose frequency lies between 300MHz and 300 GHz. They are so called because of their tiny wavelength. The microwave system is an arrangement of various active and passive devices. Some of the prominent examples of such systems are microwave communication systems and microwave radar systems. In a microwave system, the antenna is one of the most important components. Wireless and radio communications are used to transmit information over longer distances. Antennas are circuits by means of which wireless and radio communication is possible. Antennas are nothing but modified form of transmission lines. [1-5].

A microstrip antenna consists of a radiating patch which is supported on a dielectric substrate while the lower surface consists of a finite ground plane. By using microstrip antenna arrays the performance of communication systems can be enhanced in terms of gain, bandwidth and other vital parameters. Microstrip antenna arrays are used in a number of applications ranging from radars to millimetre wave engineering. Many researchers are concentrating in developing and designing microstrip antenna arrays for high gain and reduced mutual coupling applications. Careful selection and analysis of input parameters of these antenna arrays shall serve the purposes and objectives to be fulfilled. [6-10].

The structures employed in the design are called as the Electromagnetic Band Gap (EBG) structures. These structures are defined as artificial, uniform and periodic arrangement of metal patches either loaded in the ground plane or on the surface of the microstrip antennas and arrays to block or assist the propagation of electromagnetic waves in specified band of frequencies. During the past one or two decades, these structures have become very prominent. They are also used in sensors for the measurement of electromagnetic radiation and to decrease noise and losses in transmission. They can be one, two or three dimensional with the researchers mainly employing the former two types. These structures are also called as photonic Band Gap structures. [11-17].

2. DESIGN OF CONVENTIONAL MICROSTRIP ANTENNA ARRAY

The Mentor Graphics IE3D simulation software is used to design the antenna arrays. In the design of conventional microstrip antenna array (CMA), two identical radiating patches are fed using corporate feeding technique. The radiating patches are rectangular in shape. The dimensions of the finite ground plane on which CMA is placed are 115.6 mm×62.7 mm. The substrate employed as part of the design is FR-4 glass epoxy. This substrate has a dielectric constant of 4.2 and loss tangent of 0.0245. The height of the substrate is 1.6 mm. The schematic of CMA is depicted in Fig.1 and dimensions of CMA are shown in Table 1. The distance between the two patches of CMA is equal to 20.81 mm. The feed line is a 50Ω transmission line which is used to excite the antenna array. The radiating patches are responsible for transmission and reception of electromagnetic

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waves. The quarter wave transformer is a matching device used to match the impedance of the radiating patch and the feed line.

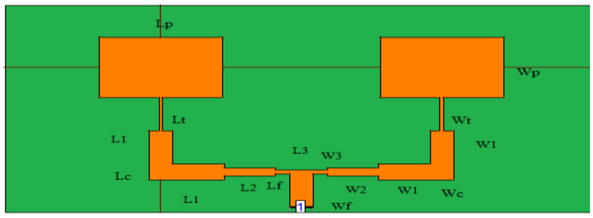

Fig.1. Schematic of conventional microstrip antenna array.

Table 1. Dimensions of conventional microstrip 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 (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

In order to measure the parameter mutual coupling between the two antenna elements, the two antenna elements of CMA are driven separately as shown in Fig.2. The parameter mutual coupling is designated by the S-parameter S_{21}, where the first digit is the output port and the second digit is the input port. The distance between the two radiating patches is same as that maintained in Fig.1. All the dimensions of CMA are maintained constant.

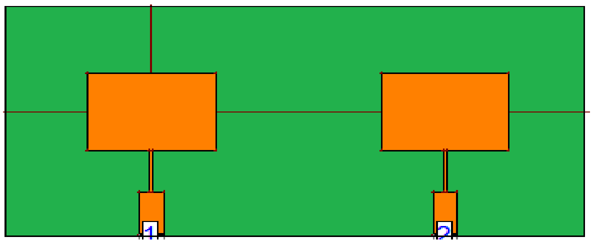

Fig.2. Schematic of conventional microstrip antenna array for mutual coupling measurement.

3. DESIGN OF EBG STRUCTURE

To enhance the performance of CMA, it is modified by loading the EBG structures in the ground plane and on the surface. The EBG structure present in the ground plane of CMA consists of 4 rows and 7 columns of h-shape slot type structure and the EBG structure present on the surface of CMA consists of 5 rows and 3 columns of meandering patch type structure. The unit cells of the EBG structures employed are shown in Fig.3 and the EBG structures are depicted in Figs .4 and 5 respectively.

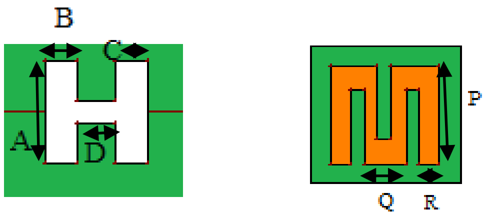

Fig. 3. Unit cells of EBG structures employed in the ground plane and on the surface of conventional microstrip antenna array.

A = 9mm, B= 2.7mm, C=3.5mm and D=3.6mm are applicable to unit cell of EBG structure placed in the ground plane of CMA. P = 4mm, Q = 1.5 mm and R = 0.75 mm are applicable to unit cell of EBG structure placed on the surface of CMA. The schematics of the EBG structures are depicted in Figs. 4 and 5.

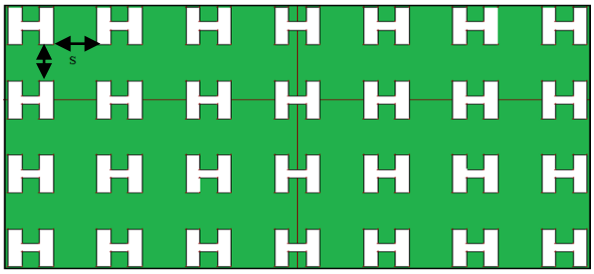

Fig.4.Schematic of EBG structure employed in the ground plane of conventional microstrip antenna array.

In Fig.4, the unit cells of the EBG structure are repeated after every s = 8.7 mm along the x-axis and y-axis.

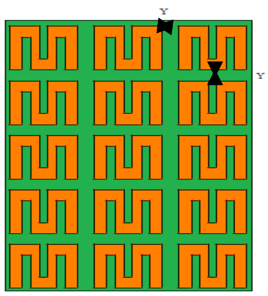

Fig.5.Schematic of EBG structure employed on the surface of conventional microstrip antenna array.

In Fig.5, the periodicity of the unit cells of the EBG structure is Y = 1 mm along the x-axis and y-axis.

4. DESIGN OF PROPOSED MICROSTRIP ANTENNA ARRAY

In order to observe the variation in the performance of CMA, the proposed microstrip antenna array is designed by placing the EBG structures mentioned in section III in the ground plane and on the surface of CMA as depicted in Fig. 6. The EBG structure used on the surface is placed in between the two radiating patches.

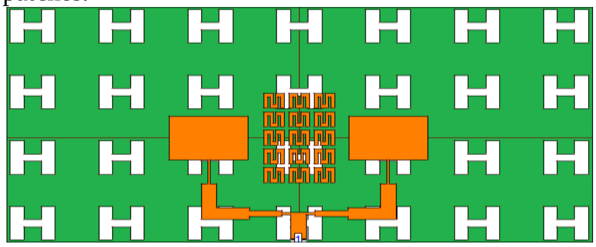

Fig.6. Schematic of proposed microstrip antenna array.

The change in the value of mutual coupling is measured by etching the EBG structures mentioned in Section III in the ground plane and on the surface of the schematic depicted in Fig.2.The proposed microstrip antenna array for the measurement of mutual coupling is shown in Fig. 7.

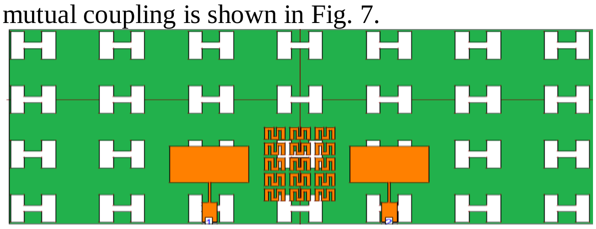

Fig.7. Schematic of proposed microstrip antenna array for mutual coupling measurement.

5. PHOTOS OF FABRICATED ANTENNAS

The photographs of the fabricated antenna arrays are shown in Figs. 8, 9, 10 and 11 respectively.

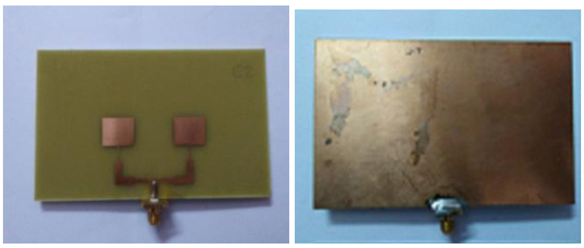

Fig.8. Photograph of CMA.
(a) Front view (b) Back view.

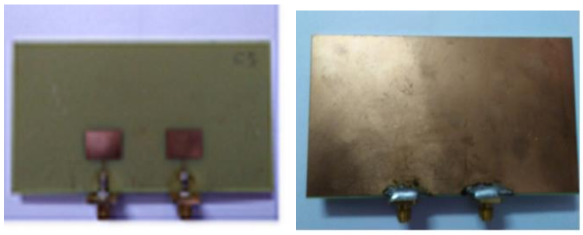

Fig.9. Photograph of CMA arrangement for mutual coupling measurement.
(a) Front view (b) Back view

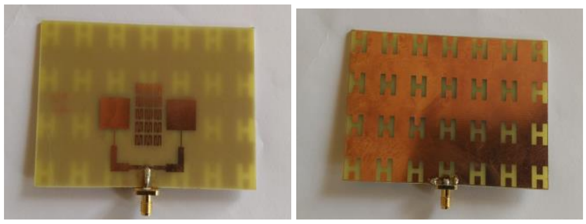

Fig.10. Photograph of proposed Microstrip antenna array.
(a) Front view (b) Back view

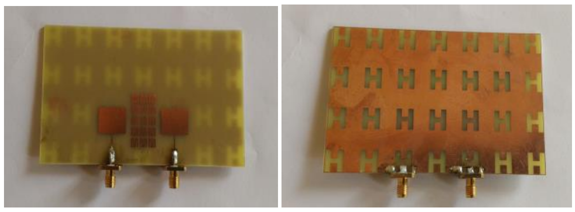

Fig.11. Photograph of proposed microstrip antenna array arrangement for mutual coupling measurement.
(a) Front view (b) Back view

6. MEASURED RESULTS

The CMA and the proposed microstrip antenna array are compared in terms of return loss, bandwidth, virtual size reduction, mutual coupling, gain, back lobe power and front to back ratio. The measured results are obtained using vector network analyzer. The graph of return loss versus frequency of CMA is depicted in Fig. 12.

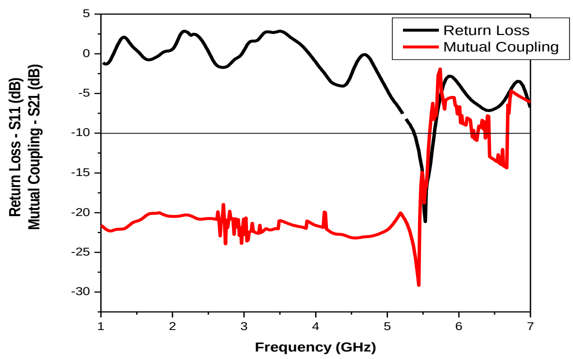

Fig.12. Plot of Return Loss and Mutual Coupling versus Frequency of CMA.

The parameter Return Loss is designated by the S-parameter S_{11} and is measured in dB. The resonant frequency of a microstrip antenna is determined as the frequency where the antenna experiences least return loss between the two points where the return loss is crossing the -10 dB line. From Fig.12 the CMA is resonating at 5.53 GHz with a good return loss of -21.23 dB. The parameter bandwidth is calculated by subtracting the lower frequency from the upper frequency where the return is equal to -10 dB. Hence the bandwidth of CMA is equal to 130 MHz. The bandwidth (%) is determined by using the formula.

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

The bandwidth (%) of CMA is equal to 2.35%. From Fig.12 the value of mutual coupling at the resonant frequency of 5.53 GHz is -17.83 dB. We also observe that the return loss and mutual coupling plots are overlapping at the resonant frequency of 5.53 GHz. This implies that there is interference between the two radiating patches. Moreover, the -17.83 dB of mutual coupling is a high value and needs to be decreased. The graph of return loss versus frequency of proposed microstrip antenna array is shown in Fig. 13.

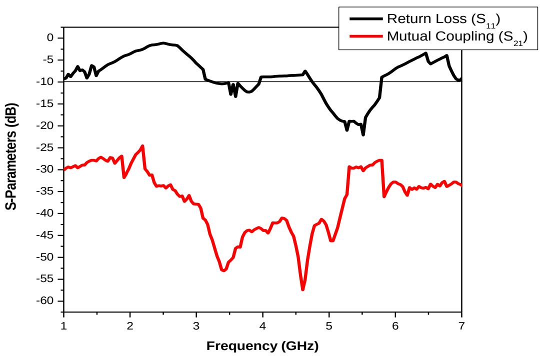

Fig.13. Plot of Return Loss and Mutual Coupling versus Frequency of Proposed Microstrip Antenna Array.

The proposed microstrip antenna array is resonating at a fundamental frequency of 3.60 GHz. Additionally, it is also resonating at 5.53 GHz with a return loss of -22.13 dB. The range of frequencies where the return loss ≤ -10 dB are from 3.27 to 3.95 GHz and 4.75 to 5.78 GHz. Hence the bandwidths are 680 and 1030 MHz respectively. Hence the bandwidth (%) of the proposed microstrip antenna array is 37.50 %. The proposed microstrip antenna array is producing a reduced mutual coupling of -29.37 dB at the resonant frequency of 5.53 GHz. Moreover, the return loss and mutual coupling plots are not overlapping, implying the interference between the two antenna elements is minimized.

Hence the proposed microstrip antenna array is performing better than CMA in terms of bandwidth (%) and mutual coupling.

The gains of CMA and the proposed microstrip antenna array are calculated by using the formula

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

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 frequency of 5.53 GHz.
Gt is the gain of the transmitting antenna.
Gt is given by the formula

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

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

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 horn antenna) and the receiving antenna (antenna under test) is given by the formula

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

where D is the larger dimension of the transmitting antenna equal to 24cm. The value of R = 71.86m. Gain is measured in the far field limit because in the far field the variation of power does not change significantly no matter what distance you measure at. However, when measured in the near field region the gain changes with range.

For the conventional antenna array the transmitted and received powers are equal to 8.7 µW and 8.8 nW respectively. Substituting all the parameter values in equation 1) the value of gain for the conventional antenna array is equal to 5.069 dB.

For the proposed antenna array the transmitted and received powers are equal to 8.7 µW and 15.78 nW respectively. Substituting all the parameter values in equation 2) the value of gain for the proposed microstrip antenna array is equal to 7.84 dB.

As per the above discussion, with the introduction of EBG structures the gain of the proposed microstrip antenna array is equal to 7.84 dB. Hence the proposed antenna array is performing better compared to its counterpart in terms of gain, where the gain of CMA is equal to 5.069 dB.

The radiation pattern of an antenna is plotted by measuring the electromagnetic power from 0^0 to 360^0. It provides the information about the distribution of power at different orientations of antenna. The radiation plots of the antenna arrays without and with EBG structures is depicted in Fig. 14.

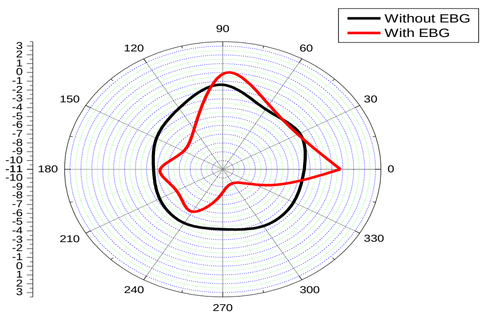

Fig. 14. Plot of radiation pattern of antenna arrays without and with EBG.

The forward power is measured at the angle of 90^0 and backward power at the angle of 360^0. The radiation patterns of CMA and the proposed antenna array are plotted at 5.53 GHz, where both the antenna arrays are resonating. From Fig.14, the forward and backward power (back lobe power) radiated by CMA are -1.31 and -4.18 dB respectively. With the introduction of EBG structures, the modified antenna i.e. the proposed microstrip antenna array is radiating a forward power of 0.1 and -8.9 dB respectively. The parameter Front to Back Ratio (FBR) is calculated by subtracting the backward power radiated from the forward power radiated. Hence the calculated FBR values of CMA and proposed microstrip antenna array are 2.87 and 9 dB respectively. From the above discussion the proposed antenna array is radaiating more power in the forward direction and less power in the backward direction. The EBG structures are aiding the CMA in effectively decreasing the back lobe radiation and enhancing the forward power and thereby increasing the FBR value. The proposed microstrip antenna array is radiating more power in the desired direction (forward direction) and less power in the undesired direction (backward direction).

From Figs.12 and 13, the CMA and the proposed microstrip antenna array are resonating at the fundamental frequencies of 5.53 and 3.60 GHz respectively. This means the proposed microstrip antenna array is resonating at a lesser fundamental frequency compared to its counterpart. With the help of EBG structures in the ground plane and on the surface of CMA, the proposed microstrip antenna array is producing virtual size reduction. The virtual size reduction (%) is determined by using the formula

$$\left(\frac{f1-f2}{f1}\right) \times 100 \qquad (6)$$

where, f1 and f2 are the fundamental resonant frequencies of CMA and the proposed microstrip antenna array. f1 = 5.53 GHz and f2 = 3.60 GHz. Hence the value of virtual size reduction (%) produced by the proposed microstrip antenna array is 34.80%. Tables II and III depict the comparison of measured results of CMA and proposed microstrip antenna array.

As the modified antenna array is having improved performance in terms of various parameters as discussed above at the resonant frequency of 5.53 GHz, it is useful in the radar band of 5.25 – 5.925 GHz. This band of frequency range is the C band. The C-band radar is confined within the above mentioned frequency range. Hence the modified antenna array designed can be employed to design radars in the C band of the microwave frequency region. These radars are employed in battlefield surveillance, missile control, ground surveillance and other defense applications with short and medium range. This frequency band is also predetermined for most types of weather radars used to locate precipitation in temperate zone in Europe. It can also be used for WiMax application (upper band). WiMax has three frequency bands 2.5-2.69 GHz (lower band), 3.2 – 3.6 GHz (middle band) and 5.2 – 5.8 GHz (upper band).

Type of Antenna	**Resonant Frequency (GHz)**	**Return Loss (dB)**	**Band Width (MHz)**	**Band Width (%)**	**Mutual Coupling (dB)**
CMA	5.53	-21.23	130	2.35	-17.83
ProposedAntenna Array	3.60 5.53	-13.54 -22.13	680 1030	37.50	-29.37

Table 2. Summarized Measured Results.

Type of Antenna	**Forward Power (dB)**	**Back Lobe Power (dB)**	**Front to Back Ratio**	**Gain (dB)**
CMA	-1.31	-4.18	2.87	5.069
Proposed Antenna Array	0.1	-8.9	9.00	7.84

Table 3. Summarized Measured Results.

7. CONCLUSION

The CMA and the proposed microstrip antenna arrays are successfully designed and fabricated. The performance of both the antenna arrays is compared in terms of various parameters over the frequency range 1-7 GHz. The EBG structures employed have efficiently enhanced the performance of CMA. The mutual coupling of the proposed microstrip antenna array is decreased to a lesser value by 11.54 dB. With the incorporation of EBG structures, there is a good increase in the value of gain to 7.84 dB as compared to 5.069 dB of CMA. Moreover, the proposed microstrip antenna array is showing better radiation characteristics compared to its counterpart in terms of decrease of back lobe radiation and increase of FBR value. The results demonstrate the enhancing capability of EBG structures in improving the performance of microstrip antenna array.

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