Asian Journal of Convergence in Technology *Volume II, Issue III*
Issn No.:2350-1146, I.F-2.71

Compact Modified Ground Plane 1x2 Circular Patch Antenna

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***Abstract*–In this paper a 1x2 Compact Wide-band Circular Patch Antenna is proposed. The antennas are designed for the IEEE 802.16a (5GHz to 6GHz) and 802.16b (2GHz to 11GHz) frequency band. A modified ground plane is loaded at feeding point to introduce additional reactance which results in wideband response. Compact size is achieved by transforming dipole antenna to monopole antennas. The -10dB impedance bandwidth of antenna is 50%. To reduce the mutual coupling mushroom type Electronic Band-gap Structure (EBG) is designed and incorporated in between the two common ground plane circular patch. Antennas are placed four times closer than minimum required separation. The size reduction of the antenna is more than 80%. Proposed techniques are implemented on rectangular, circular and triangular shape patches. Proposed antenna is simulated using HFSS-13.**

***Index Terms* – Circular patch antenna; Compact Antenna; Electronic Band-gap Structure; Patch Antenna; Wideband Antenna;**

I. INTRODUCTION

Due to the emerging need mobile wireless devices has to provide faster access, brighter and higher resolution screens, additional connectivity all with compact size [1]. The size of devices can be reduced by using compact components. Antenna is one of the important components that must be considered for size reduction and other performance enhancement of the transmitting and receiving devices. In 4G communication systems, not one but two antennas are required each with specific requirements: Bandwidth, Mutual Coupling, Size and cost. Wide-band antennas are one of the important components of the wide-band communication systems. Different techniques have been implemented to achieve wideband response of antennas as: Fractal Microstrip antenna [2], Aperture coupled antennas [3], slotted antennas [4] and [5], Psi-shaped antennas [6], meta-material antennas [7], [8] and modified ground plane antenna [9].

The factors affecting the performance of MIMO antennas are categories in three main types: Antenna Size, device usage models and mutual coupling between a pair of antennas. The size of antenna is dependent on bandwidth of operation, frequency of operation and required operation of frequency. In 1x2 antennas both the antennas are placed on same longitudinal chassis, they will produce the same radiation pattern. Since both the antennas are coupled in the same mode, they experience mutual coupling. The power introduced into one antenna is partially coupled in second antenna source resistance, and is subsequently lost [1]. Various techniques have been deployed to minimize the mutual coupling in MIMO antennas as: placement of Electronic Band-gap Structures in between the two antennas[10], [11] and [12], slotted complementary split ring resonator [13], negative magnetic meta-material [14] and meta-material monopole antennas [15].

II. ANTENNA DESIGN AND STRUCTURE

The proposed antenna has been designed in four parts: The antennas are built on a FR4 Epoxy dielectric substrate with dielectric constant 4.4, dielectric loss tangent 0.02 and thickness 1.6mm. The antenna is designed for 50Ω microstrip feeding line.

A) *Design of conventional Patch Antennas:*

In conventional rectangular, triangular and circular patch micro-strip antenna at a particular instant of time, the underside of the patch is positively charged and ground plane is negatively charged. The attractive force between these sets of charges tends to hold a large percentage of the charge between the two surfaces. However, the repulsive force between positive charges on the patch pushes some of these charges towards the edges, resulting in large charge density at the edges. These charges are source of fringing fields and the associated radiation. The dimensions of conventional circular patch antenna are calculated from Equation 1 to Equation 4. The calculated dimensions of conventional circular patch antenna are a=3.49mm, W_g=17.6mm and L_g=19.6mm. The antenna is fed by a micro-strip line of dimensions W_f=0.4mm and L_f=9.3mm.Dimensions of circular patch antenna are depicted in Figure.1.

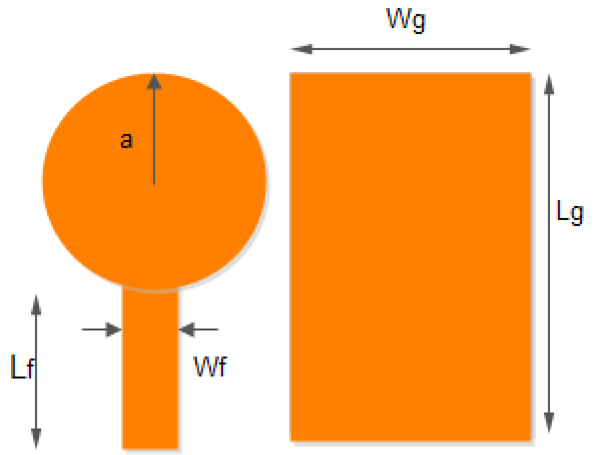

Fig.1 Conventional circular patch antenna (a=3.49mm, Wf= 0.4mm, L_f= 9.3mm, W_g=17.6mm and L_g=19.6mm)

$$f_{nm} = \frac{x_{nm} c}{2\pi a_e \sqrt{\varepsilon r}} \quad (1)$$

Table.1Values of x_{nm} for different propagation modes

Modes(n,m)	0,1	1,1	2,1	0,2	3,1
x_{nm}	0	1.84	3.05	3.83	4.20

$$a_e = a[1+\frac{2h}{\pi a \varepsilon r}\{\ln\frac{\pi a}{2h} + 1.7726\}]^{1/2} \quad (2)$$

$$L_g \leq a+6h \quad (3)$$

$$W_g \leq a+6h \quad (4)$$

B) Design of compact wideband patch antennas:

Single elements of compact wide-band antennas are illustrated in Figure.2.To achieve the compact size conventional dipole micro-strip antennas are transformed into monopole antennas. The ground plane of the dipole antennas is removed to transform it to monopole antennas. A partial ground plane is loaded at feeding point to introduce additional reactance which results in wideband response. The input impedances of rectangular, triangular and circular antennas are nearly same in monopole configuration, hence same micro-strip line (W_f=1.6mm and L_f=10mm) is used for rectangular, triangular and circular patch antennas. Dimensions of partial ground plane (L_{gm}= 6mm and W_{gm}=17.6mm) for all three antennas are calculated by Equation.5 and Equation.6. Equation.5 and Equation 6 works for all three rectangular, triangular and circular patch antennas. The dimensions of patches and substrate specifications are same as of conventional patch antennas.

$$W_{gm} = Wg \quad (5)$$

$$L_{gm} = \lambda_o/8.33 \quad (6)$$

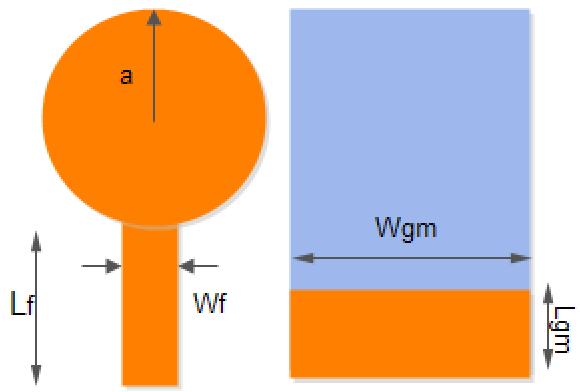

Fig.2. Partial ground circular patch antenna (a=3.49mm, Wf= 1.6mm, L_f=10mm, W_{gm}=17.6mm and L_{gm}=6mm)

Simulated results of conventional and monopole configurations of circular patch antenna without ground plane and with partial ground plane are depicted in Figure.3and Figure.4. Due to transformation of dipole antenna into monopole antenna the capacitive reactance of antenna reduces and hence operating frequency is shifted down to 2.3GHz from 12.08GHz. The dimensions of conventional rectangular patch for 2.3GHz are 39.69X30.75mm^2 which has been achieved by 8x5mm^2 patches. Hence approximately a size reduction of 97% has been achieved.

The partial ground plane introduces a parallel capacitive reactance in the monopole configuration antenna which results in second resonant frequency and hence the bandwidth of antenna is enhanced. Figure.4. depicts the radiation pattern of conventional, monopole and partial ground antennas. This can be observed that both monopole and partial ground plane antennas is poor radiator than conventional dipole antenna. Also the monopole configurations results in undesired back lobe and very poor front to back ratio and hence poor radiation efficiency and gain. To enhance the radiation efficiency and gain of antennas multiple antennas can be used. Multiple antennas will increase the overall size of antenna. So there is a tradeoff of Size, bandwidth and radiation efficiency in Single Input Single Output (SISO) systems but these antennas will be very effective for the Multiple Input Multiple Output (MIMO) systems. The circular patch antenna gives better results for monopole and partial ground plane configurations.

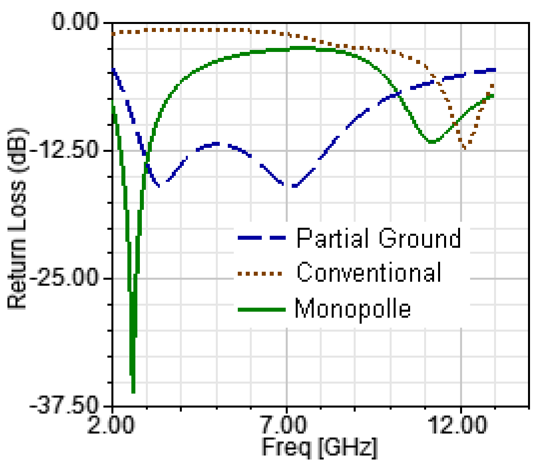

Fig.3. Return Loss of conventional, monopole and partial ground plane configurations.

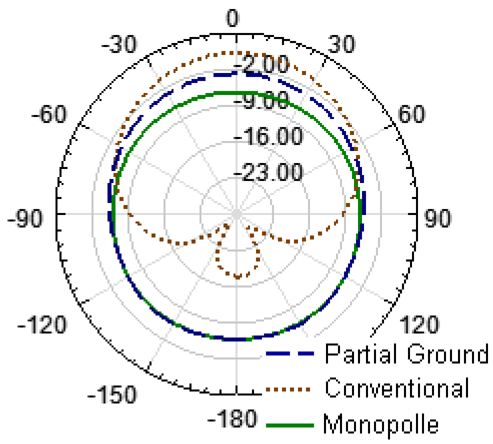

Fig.4. Radiation pattern conventional, monopole and partial ground plane configurations.

C)Design of Mushroom type EBG structure:

A simple mushroom type EBG structure has been designed that consist of periodic metallic patches connected to common ground through shorted stubs.

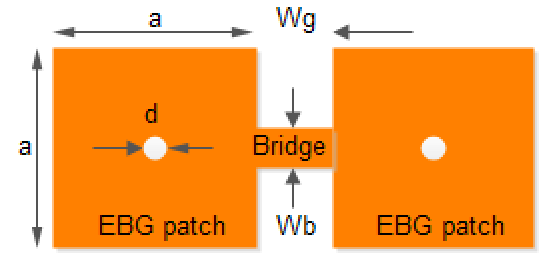

Fig.5. Bridge connection between two unit cells (a=4mm, Wg=1mm, d=0.2mm, Wb=0.25mm and d=0.2mm).

Fig.6.Ground plane of EBG structure

$$f_{Low}=\frac{1}{\pi\sqrt{Cp(Lp+Lg)}} \quad (7)$$

$$f_{high}=\frac{Co}{2b\sqrt{\varepsilon r}} \quad (8)$$

$$Lp=\mu_o t \quad (9)$$

$$Cp=\varepsilon_o\varepsilon_r b^2/t \quad (10)$$

$$Lg = K_1 W_g \ln\left(2\pi\frac{t}{Wb}\right) \quad (11)$$

$K_1= 2x10^{-7}$ H/m and $C_o=3x10^8$ m/s

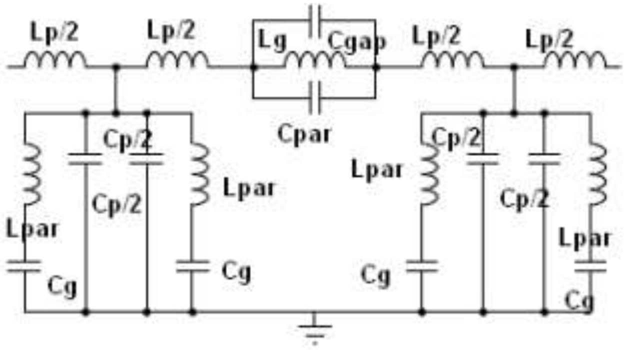

Fig.7. Equivalent circuit of two cascaded unit cells

The proposed EBG structure consists of four elements. All the elements are connected in series by a rectangular bridge. The dimension of bridge is $0.25x1mm^2$. Each element consist of a $4x4mm^2$ rectangular patch, a stub of radius 0.2mm, FR4 Epoxy substrate of thickness 1.6mm and ground plane of dimension $4x4mm^2$. For simplicity of design the thickness of substrate are chosen same for EBG structure and antenna elements.Figure.5, Figure.6 and Figure.7 shows the structure and equivalent circuit of two cascaded elements of EBG structure. The lower and higher cutoff frequencies of EBG structure are calculated by Equation.7 to Equation.11.

The effect of EBG structure on 1x2 circular patch antennas is illustrated in Figure.8, Figure.9 and Figure.10. The EBG structures are placed closely to the antennas which results in additional capacitive reactance on the patches. As the bandwidth of the parallel resonant circuits are inversely proportional to the capacitive reactance the bandwidth of the monopole circular patch antenna reduces. During experiments this is observed that the lower cutoff frequency decreases as EBG patch dimension is increased or bridge inductance is increased. The higher cut off frequency of proposed EBG structure depends only on the patch dimensions. The higher cutoff frequency is inversely proportional to the patch dimensions.

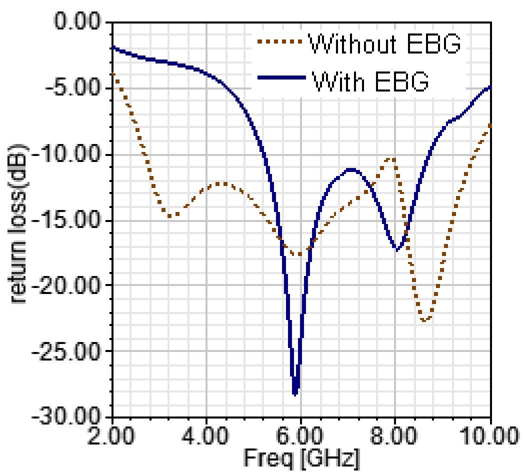

Fig.8. Return loss of 1x2 circular patch antenna with and without EBG structure

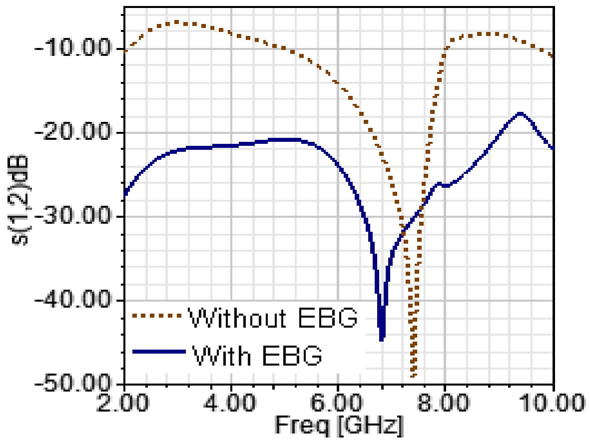

Fig.9. Mutual coupling of 1x2 circular patch antenna with and without EBG structure.

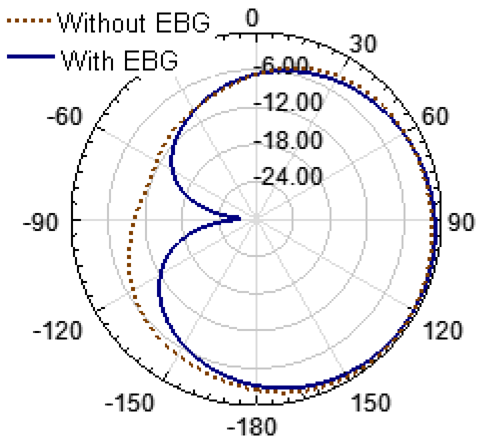

Fig.10. Radiation pattern of 1x2 circular patch antenna with and without EBG structure.

III. Results And Discussions

The conventional patch antennas behave like a series resonant circuits and have narrow frequency range. The operating frequency of series resonant circuits is inversely proportional to the inductive and capacitive reactance. The monopole antennas have very high inductive reactance with respect to dipole antennas hence results in low operating frequency with smaller size. The effect of transformation of dipole configuration to monopole configuration can be observed in Figure.3 and Figure.4. Due to the large inductive reactance a compact size is achieved but the radiation performances of the monopole antennas degraded. This can be seen in Figure.4. The partial ground plane antennas exhibits the properties of parallel resonant circuits. The quality factor of parallel resonate circuits are low hence a wideband response has been achieved. The effect of partial ground plane can be observed in Figure.3 and Figure.4.

IV. Conclusion

The monopole configurations of antennas are very compact but the radiation characteristics are very poor. So the monopole configuration of patch antennas is not suitable for the SISO systems. To enhance the bandwidth a partial ground plane is incorporated, that increases the capacitive reactance and decreases the quality factor of the patches. This results in wideband response. Multiple partial ground plane antennas can be used for SISO systems nut this will result in larger antenna size. As 4G communication systems usage 1x2 or 2x2 MIMO antennas, the partial ground plane antennas are a good choice. For further size reduction an EBG structure is placed in between the two patches. The EBG structures results in compact size as well as good radiation performances. A tradeoff between bandwidth and mutual coupling has been done. Because proposed EBG structure reduces the bandwidth of 1x2 antennas.

The partial ground plane and proposed EBG structure work for any shape of antennas. The triangular patch has least mutual coupling due to large overall edge separation but standing waves are more and bandwidth is less. The proposed antennas configurations are very simple and easy to fabricate. The results of proposed antennas are satisfactory and can be implemented for IEEE 802.16a and IEEE 802.16b standards.

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