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Corporate Feed, Compact 2X2 Array Antenna With Enhanced Radiation Characteristics using Metamaterial Structure

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Abstract**:** ***In current study, mushroom type metamaterial substrate is designed to operate at ISM band and is embedded in 2X2 array as a ground. Unique properties of mushroom type metamaterial substrate like as high impedance surface (HIS) helped in design of low aperture antenna, Artificial magnetic conductor (AMC) helps in enhancing the radiation characteristics and Forbidden band gap (FBG) helps in suppressing transverse electric (TE) and transverse magnetic (TM) wave propagation hence point of mutual coupling and side lobe levels are reduced. So, 2X2 array antenna with corporate feed resonating at 2.5GHz is embedded by array of mushroom type metamaterial unit cells is designed in HFSS and obtained results are compared with 2X2 array resonating at 2.5GHz on conventional conducting ground results. An enhancement in impedance band width of 2.47%, gain of 2.91dB and with lowered side lobe reduction of 3.74dB.***

Index Terms**:** ***metamaterial, high impedance surface, Artificial magnetic conductor, Forbidden band gap.***

I. INTRODUCTION

Two or more antenna elements arranged in some fashion and etched on common substrate is considered as an array. These array structures are used for high gain applications[1]. Along with advantages these structures also have some drawbacks majority of which is mutual coupling between elements, this occur due to surface waves, space waves and covering of close fields results poor performance of an array[2]. In array design the coupling is effected by permittivity and thickness of substrate, size of ground plane, type of excited modes and gap between elements etc. [3-5]. Numerous techniques were published in literature to minimize coupling such as: corrugations [6,7], split ring resonators[8,9] and Defected Ground Structures [10-12].

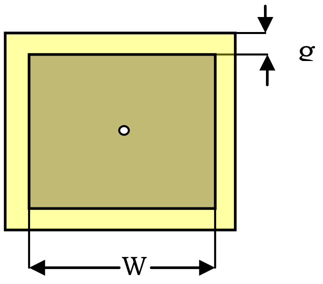
The target of this paper is to structure a minimized corporate feed 2X2 array antenna inserted by cluster of mushroom type metamaterial unit cells. Analyze its radiation characteristics such as return loss, gain, H plane radiation pattern and surface current distribution. So at first mushroom type metamaterial substrate is design to resonate at ISM band and its electromagnetic characteristics are determined later array of these structures are introduced in array antenna structure to achieve our object. To validate the obtained results, another corporate feed 2X2 array antenna on conventional conducting ground is design to operate at same frequency as proposed design is resonating and its obtained results are compared with proposed design results.

II. UNIT CELL DESIGN

The mushroom type metamaterial unit cell proposed is designed in simulation software with following dimensions. The area of metal patch is 0.14λX0.14λ (λ is operating wave length), stature of substrate is 0.027λ, radius of verticle metal stub is 0.475mm. Plan parameters and its relating vales are abridged in table I.

Table 1: Dimensions of mushroom type metamaterial UC model

Parameter Name	**Symbol**	**mushroom type metamaterial**
Metallic square patch	W X W	17.5X17.5mm^2
Gap between patches	g	1mm
Stub radius	r	0.475mm
Dielectric substrate height	h	1.6mm
Dielectric permittivity and loss tangent		4.4, 0.02 (FR4)



(a) Top view

(b) Side view

Figure 1: schematic of mushroom type metamaterial structure.

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III. ANALYSIS OF EBG STRUCTURES

Four important and most popular techniques are available to analyze mushroom type metamaterial electromagnetic properties [31]: They are 1)Lumped element circuit model, 2) Transmission line model, 3) Computational electromagnetic modeling and 4) Use of full wave solver. Fourth one is used in our study

A. Determination and Analysis of AMC property

To find AMC property of mushroom type metamaterial unit cell, In HFSS a finite element method (FEM) based simulator is used Bloch-Floquet theory. During simulation, mushroom type metamaterial unit cell is placed inside a rectangular box, whose four faces are alternately applied by perfect magnetic conductors (PMC) and perfect electric conductors (PEC) boundaries. A wave port is placed on top face to radiate and EM waves on to the mushroom type metamaterial unit cell and receive reflected ones so that coefficient of reflection phase can be determined. The complete setup is shown in Figure 2.

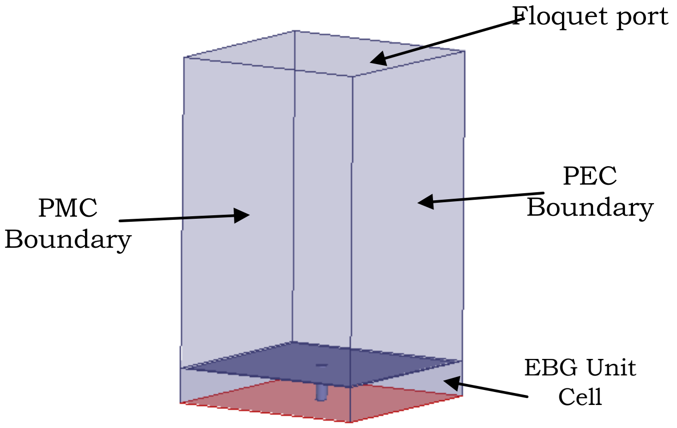
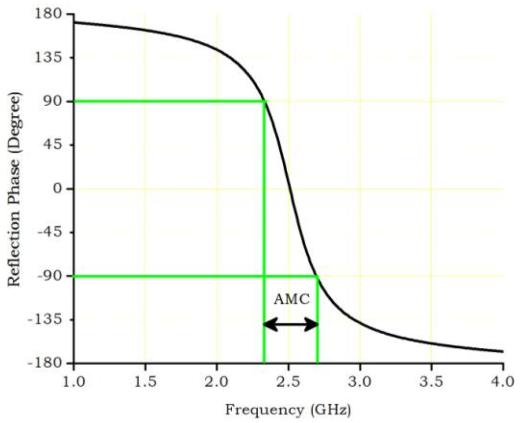
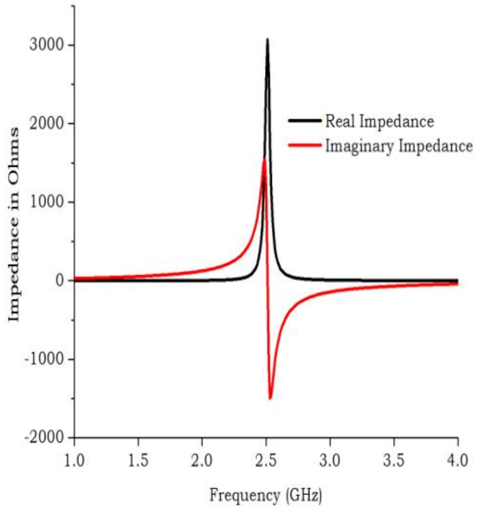


Figure 2: Simulation setup for measurement of reflection coefficient of mushroom type metamaterial unit cell.



(a) Reflection coefficient of mushroom type metamaterial



(b) HIS Region of mushroom type metamaterial.

In Figure 3(a), coefficient of reflection stage for ordinary occurrence plane EM waves is appeared and are constantly differing from +1800 to - 1800 concerning recurrence.The resonating frequency of mushroom type metamaterial unit cell can be determined using reflection coefficient graph that the reflection curve crosses the zero degree line corresponding frequency is treated as operating frequency. Current structure is resonating at 2.5GHz with AMC band gap of 404.2MHz (fractional band width of 16.17%). Here AMC band gap is the gap between $+90^0$ to - 90^0 during which the angle between reflected and incident waves is zero. igh impedance district can be characterized as a low misfortune receptive surface. At and around the reverberation recurrence, the impedance of mushroom type metamaterial surface is displaying high surface impedance that existing in AMC district as appeared in figure 3(b). This property helps being developed of low volume emanating reception apparatuses.

B. Analysis of FBG property

The complete behaviour of mushroom type metamaterial UC cannot be defined by AMC and HIS properties, under normal incidence. Hence forth FBG property need to be derived using dispersion diagram. During simulation mushroom type metamaterial UC is placed inside rectangular box. Its four sides are applied with periodic boundary conditions[48,49]. Top face of box contains perfect matched layer (PML) which imitate like intimate free space. The simulation setup is shown in figure 5. The dispersion diagram along □-*X* direction of propagation [32] is considered. It contains first scattering (mode 1 demonstrates the lower recurrence breaking point of band gap) and second scattering (mode 2). The crossing point of mode 2 with the light line decides the maximum furthest reaches of recurrence band hole. By looking at the territory between the lower and furthest cutoff points of band hole taboo band hole is gotten.

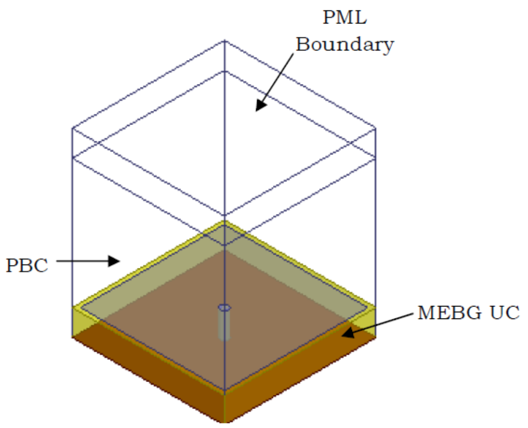


Figure 2:Reproduction setup for estimation of FBG of proposed UC connected with occasional limits bested PML.

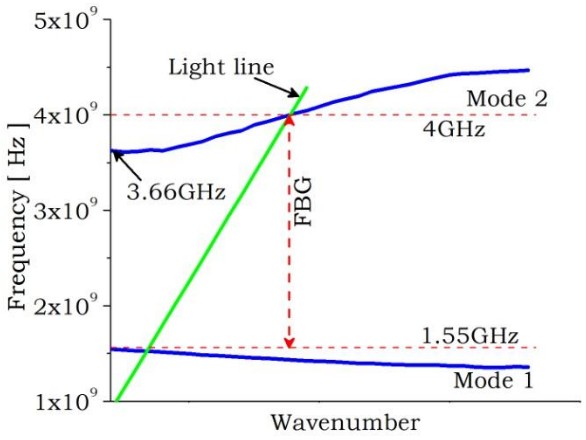
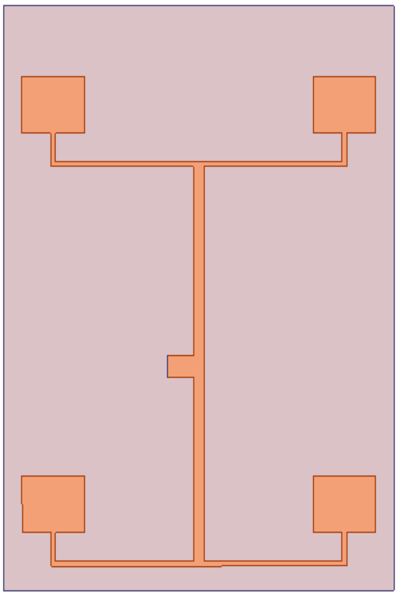


Figure 6: Dispersion diagram for mushroom type metamaterial model.

In Figure 6 pass band and stop band regions can be visualized hence surface wave propagation and forbidden regions can be understood. FBG gap of 2.45GHz (fractional FBG of 98%), ranging from 1.52GHz (TM mode edge) to 4GHz (TE mode edge). Above the light line, at and above 3.66GHz frequency, broken waves exist and can transmit proficiently into free space.

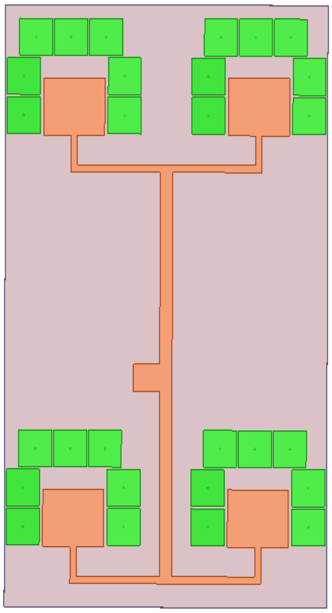
IV. COMPACT 2X2 ARRAY ANTENNA DESIGN

First of all, a 2X2 array antenna resonate at 2.5GHz over conventional electric conductor ground is designed. Where aperture of every patch is 33.3mmX27.6mm etched on top face of FR4 epoxy substrate of 1.6mm stature backed by conducting ground of 284.9mmX208mm. The impedance band width of 62.6MHz (fractional band width of 2.49%) and a gain of 6.29dB. The edge to edge gap between elements is 124.15mm to avoid mutual coupling, which increases size of array antenna as well as side lobes with a magnitude of 2.54dB. Next, 2X2 array antenna with corporate feed embedded by mushroom type metamaterial ground is designed on 1.6mm FR4 epoxy substrate. The aperture of every antenna is 32.4mmX27.2mm and ground is 171mmX284.9mm. This design is resonating at 2.5GHz with an impedance band width of 124.4MHz (fractional band width of 4.96%) and gain of 9.2dB. The edge to edge distance between elements is 65.2mm. The overall size of array antenna is scaled 39.9% along its length, 26.9% along its width when compared with conventional design. The magnitude of side lobes are -1.19dB. The reduction in side lobes are of 3.74dB when compared with conventional design. The simulated results at both the cases are presented in table VI. for comparative analysis.



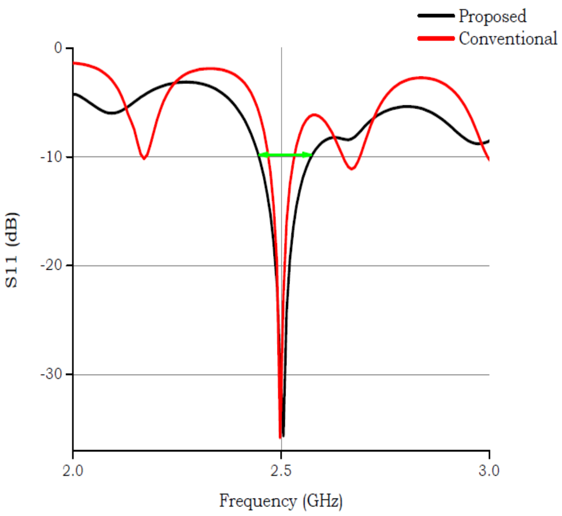
(a) Corporate feed 2X2 array antenna over conducting ground, resonating at 2.5GHz.

(b)

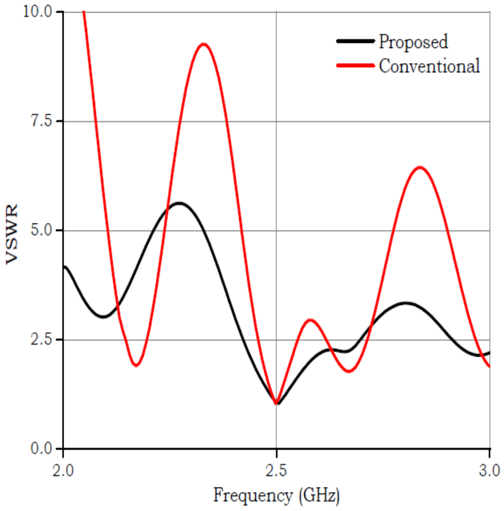


(c) Corporate feed 2X2 array antenna over mushroom type metamaterial, resonating at 2.5GHz.

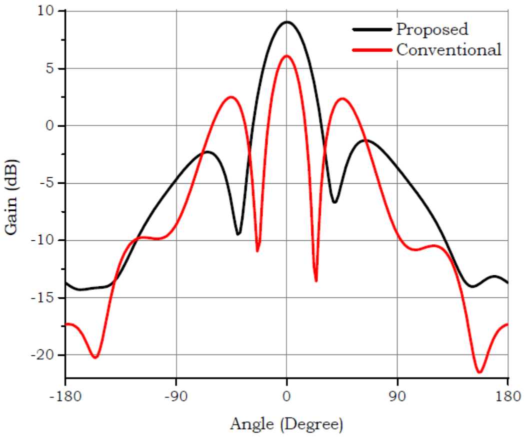
Fig. 15. Simulated models of conventional and proposed models



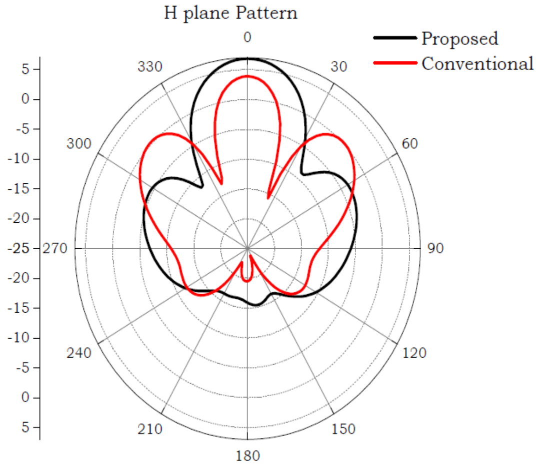
(a) Return Loss



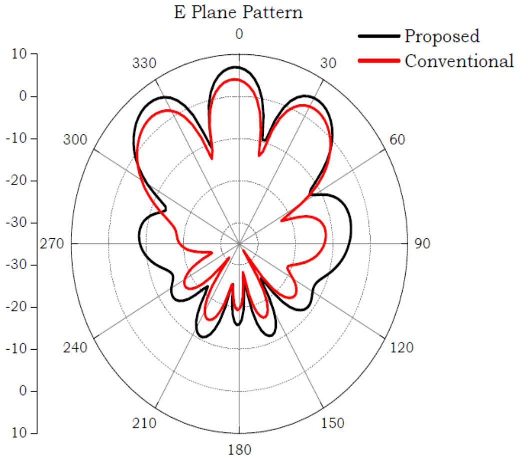
(b) VSWR



(c) Gain of an array antenna (H plane)

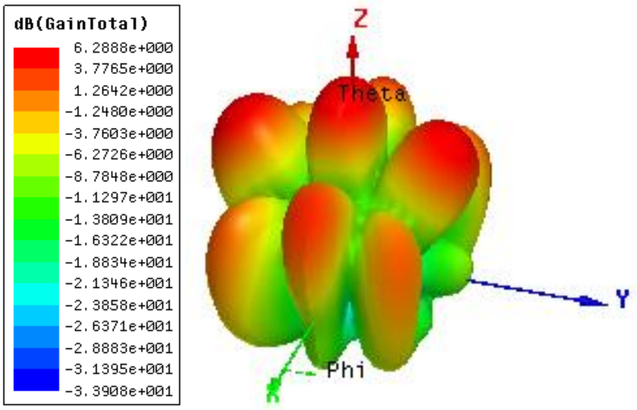


(d) H plane Radiation pattern

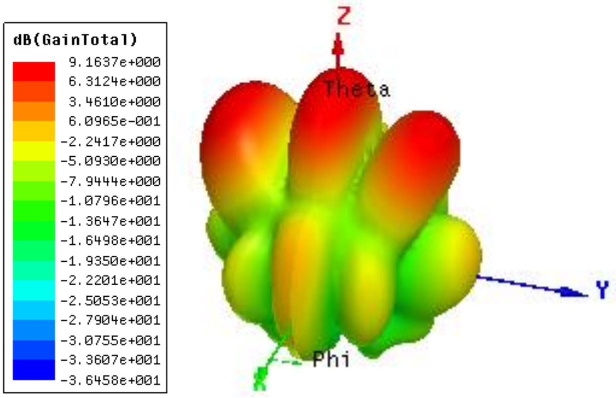


(e) E plane Radiation pattern

Radiated energy density from the antenna is represented in 3D polar plots. These are showing that maximum energy is radiated in intended direction. In proposed design the total gain is enhanced.



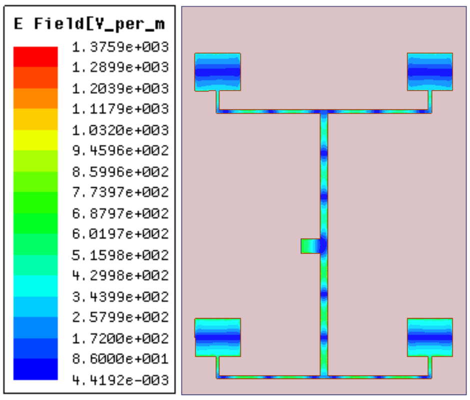
(f) Polar plot of conventional grounded 2X2 array antenna.

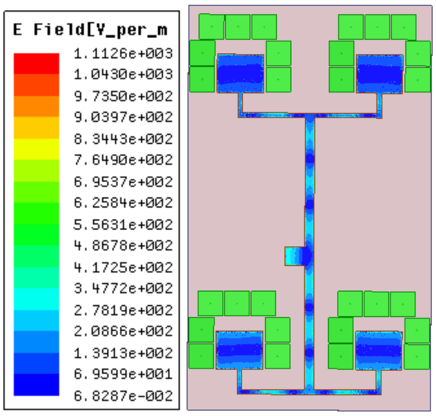


(g) Polar plot of metamaterial grounded 2X2 array antenna.

Fig. 16. Simulated results of conventional and metameterial grounded 2X2 array antenna with corporate feed.

E field distribution on the surface of conventional and proposed antenna is shown bellow. Maximum amount of RF energy is radiating from longer edges of antenna in both cases. In conventional design energy density at all the points throughout the longer edge is almost same. But due to existence of mushroom type metamaterial structures in the proposed design energy density is more at the center of longer edges and less at the corners, so the spreading of E field away from the antenna as a surface waves is minimized in proposed design.





The surface current distribution on the aperture of an antenna in both the cases is shown in bellow figure. In conventional design the current is distributed equally through out the the aperture of an antenna bu in proposeddesign concentration of surfcace current is more at the center of aperture of antenna this showing that the existance of mushroom type metamaterial structures arround the aperture of antenna is stopping the spread of H field away from antenna as a surfcae waves. If proposed design is used in array architecture the problem of mutual coupling can be minimized. Both model results are summarized in table VI.

Table VI: Comparison of simulated models of conventional and metamaterial grounded 2X2 array antenna.

Antenna Parameters	Conventional Ground	Mushroom type metamaterial Ground
Patch size	33.3X27.6mm^2	32.4X27.2mm^2
Edge to Edge space between patches	124.15mm	65.2mm
Ground size	284.9X208mm^2	117X284.9mm^2
Ground length miniaturization	Reference	39.9%
Ground width miniaturization	Reference	26.9%
Centre frequency	2.5GHz	2.5GHz
Peak directivity	15dB	16.85dB
Gain	6.2328dB	9.2dB
Radiation efficiency	27.91%	48.9%
Return loss	-35.8795dB	-35.67dB
Band width	62.6MHz	124.4MHz
VSWR	1.0327	1.0093
FBR	304.18	284.12
Magnitude of side lobes	2.4dB	-5.25dB

V. CONCLUSION

During current study of mushroom type metamaterial, it is concluded that compact, high gain and wide band corporate feed 2X2 array antenna resonating at 2.5GHz is possible to design by unique properties such as HIS, AMC and FBG. of mushroom type metamaterial.

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