# Effect of dimensions and spacing of Parasitic Patches on Gain flattening of an Efficient, Wideband, High Gain MSA

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***Abstract***— This paper proposes the gain flattening of a stacked wideband antenna by varying the size and position of the parasitic patches in antenna structure with 4x4 array of parasitic patches. The 3 layered antenna structure consists of a microstrip antenna with probe feed to patch which feeds a parasitic patch on second layer and 4 X 4 array of square parasitic patches fabricated on a low cost FR4 superstrate suspended in air at λo/2 forming Fabry Perot Cavity (FPC) resonating structure. The VSWR is < 2 over 5.725 – 6.5 GHz frequency band. The antenna provides more than 89% antenna efficiency, 15.8 dB gain with less than 3 dB gain variation in the frequency range covering 5.725-5.875 GHz WLAN band and 5.9-6.4 GHz uplink C-band for satellite communication.

***Keywords***- *Fabry Perot Cavity, Broadband, MSA, PRS, superstrate layer*

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## I. INTRODUCTION

Microstrip patch antennas offer an attractive solution to compact and ease-low-cost design of modern wireless communication systems due to their many advantages as light weight and low volume, low profile, planar configuration which can be easily made conformal to host surface, low fabrication cost, and the capability of obtaining dual and triple frequency operations. When mounted on rigid surfaces microstrip patch antennas are mechanically robust and can be easily integrated with microwave integrated circuits (MICs). However, microstrip patch antennas suffer from a number of disadvantages as compared to conventional non-printed antennas. Some of their major drawbacks are the narrow bandwidth, low gain, and surface wave excitation that reduce radiation efficiency. Bandwidth increases with an increase in substrate thickness and decrease in the effective dielectric constant [1-3]. Variations in the feeding techniques, modifications in the substrates [4-5], modification in the ground plane [6], and introduction of a slot in the radiating patch are some of the techniques to enhance bandwidth of MSA [7-8]. Stacking of MSA's also enhances the bandwidth. The bandwidth of MSA is dependent on the electrical thickness and the effective dielectric constant of the substrate used.

The use of parasitic patches in the structure and Fabry Perot Cavity resonator structure helps in enhancement of gain. Gain enhancement techniques based on Fabry-Perot cavity (FPC) using a partial reflecting surface (PRS) formed by wire grid, metal strip on a dielectric layer and uniformly spaced thin dipoles and fed by waveguide has been reported. The gain of this antenna depends on the reflection coefficient of PRS and feed antenna [9-10].

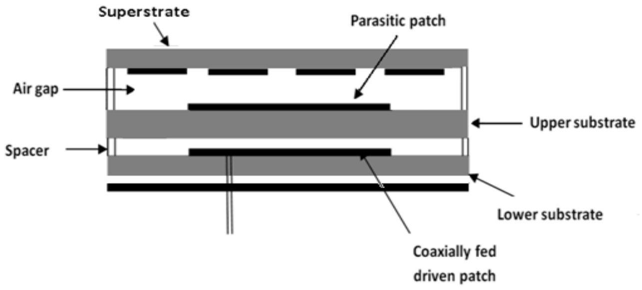
The improvement in the gain and bandwidth is achieved using electromagnetic coupling techniques by arranging parasitic elements above the feeding MSA are investigated [11-12].Here PRS is fed by single microstrip antenna to achieve high gain as well as wide bandwidth. The effect of multilayered substrate and superstrate thickness, dielectric material and patch dimensions are discussed [13-15]. By properly selecting the thicknesses of the substrate and the superstrate layers, a very large gain can be realized. The resonance gain method has been studied using moment method. More recently, the PRS have been regarded as frequency selective surface (FSS) or electromagnetic band gap (EBG) superstrates. Gain enhancement using EBG resonator antennas have similar characteristics to PRS antennas. However PRS antennas tend to have lower profiles than EBG antennas. An optimization of MSA height, FPC height, inter-element spacing and parasitic patches dimension to improve impedance and gain bandwidth is carried out that results in off resonance conditions such that different elements resonant at different frequencies close to central frequency. It results in decrease in reflection coefficient and increase in gain bandwidth.

## II. ANTENNA DESIGN THEORY

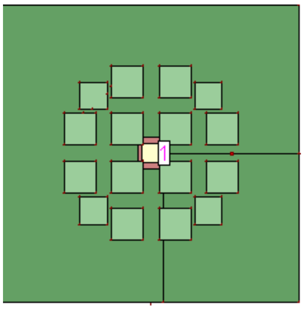
The stacked antenna structure with multiple resonators arranged vertically over each other being the basis of multiresonator concept, with the different patch sizes are optimized so that each one resonates at different but nearby frequencies which due to electromagnetic coupling provides a comparatively large bandwidth. The use of air as a dielectric between the ground plane and feed patch and patch and superstrate enhances bandwidth and efficiency. A cavity resonator consisting of single or multi dielectric layers to form a Fabry–Perot cavity (FPC) have been considered to enhance the directivity at broadside. This structure is mainly formed by a half wavelength chamber between a ground plane and a partially reflective surface (PRS) located on top of the cavity. By adding a partially reflecting sheet in front of the antenna and parallel to the reflecting screen, multiple reflections between the sheet and screen are obtained. The distance between the sheet and screen must be such that the partial rays projected through the sheet into space have equal phases in the normal direction. If the distance between the PRS and ground plane is such that the partial rays projected through the PRS into space have equal phases in the normal direction, it results in gain enhancement. Parasitic patches affect the field distribution, its amplitude and phase and hence affect the gain. The patches resonate at higher frequency with decrease in patch dimensions and spacing between the patches and thus the gain at higher frequency increases while the gain at lower frequency decrease. This results in gain flattening.

## III. ANTENNA GEOMETRY

The geometry of the proposed antenna structure is shown in Fig.1. The antenna consists of a feed patch, a parasitic patch near the fed MSA and a FR4 superstrate layer with parasitic patch array which acts as a partially reflecting surface. The feed patch of size 13.6x16 mm is designed on a 1.6 mm FR4 substrate of dielectric constant 4.4 and loss tangent of 0.02 which is suspended in air at 1mm from the ground plane. The parasitic patch is placed above this MSA and its dimensions are optimized to length and width of 10 mm respectively. The air gap and this parasitic patch help in achieving broad bandwidth from 5.725 to 6.4 GHz. The parasitic patch is also designed on the substrate having same specifications as that of lower substrate. The air gap of height 1mm is introduced between the two substrate layers.



(a) Side View



(b) Top View

Fig.1 Geometry of 4x4 MSA with variation in size & position of corner elements

Bandwidth enhancement is obtained using multi-resonator concept when the patches on multilayer superstrate are separated by about 0.1λ. The feed patch is fed using a coaxial probe with 50Ω impedance. The 4x4 square parasitic patch array of patch size 16 x 16 mm with spacing of 24 mm is place initially on a FR4 superstrate layer and placed at a height of 26 mm from the feed patch. The parasitic patches are fabricated on the bottom side of FR4 superstrate of thickness 1.6 mm, which acts as a radome to antenna. The superstrate layer is placed at about 0.5 $\lambda_0$ from the feed patch. Relative permittivity and loss tangent of this superstrate is 4.4 and 0.02 respectively. The top view of superstrate layer with parasitic patches is shown in Fig 1 (b).

To achieve high efficiency and wide bandwidth air is used as a dielectric between MSA and ground plane and between MSA and superstrate layer. Initially 4x4 array of square parasitic patches are fabricated with spacing greater than λo/2 at the bottom side of the superstrate layer placed at about λo /2 from the ground plane. The structure is initially optimized on infinite ground plane. The simulated results give gain of 16.6 dBi but with a gain variation of more than 4 dB. By decreasing the spacing and size of the corner elements the maximum gain obtained is 15.8 dB with a gain variation of < 3 dB thus leading to gain flattening. VSWR and return loss of 4x4 MSA and modified 4x4 MSA structures are shown in Fig. 2. The impedance variations of these structures are shown in Fig. 3. The radiation pattern of modified 4x4 MSA is shown in Fig. 4. It is observed that side lobe level (SLL) and cross polarization increases with increase in frequency. Further gain flattening results in increase in SLL and cross polarization. Thus one need to compromise between gain variation and SLL and cross polarization. Modified 4x4 MSA structure has -18 dB and -12 dB SLL at 5.8 GHz and 6.15 GHz respectively while cross polarization is -19 dB and -10 dB at 5.8 GHz and 6.15 GHz respectively.

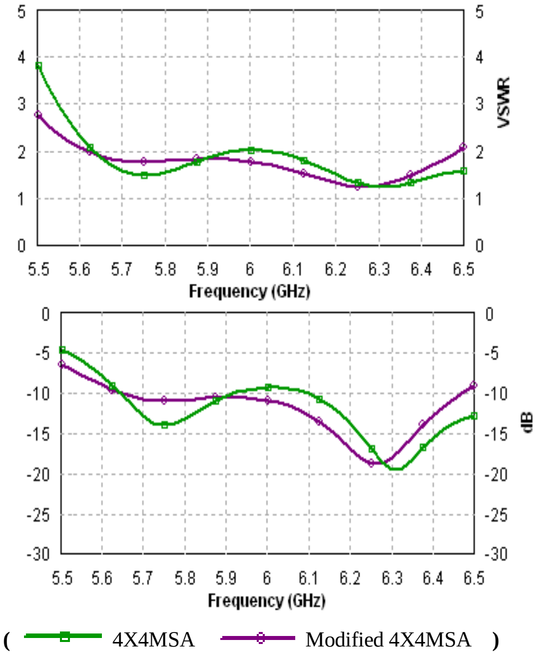
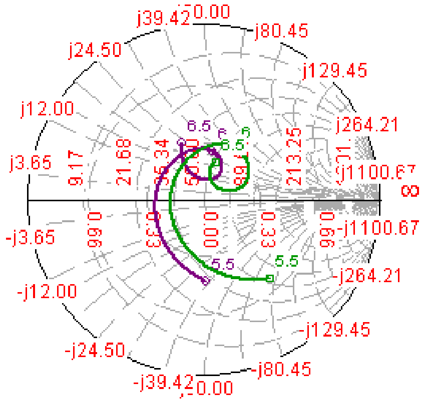
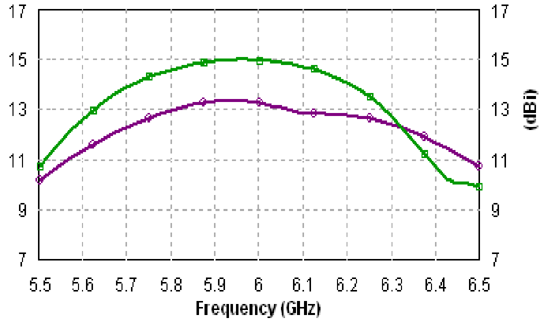


Fig.2 VSWR vs frequency & Return Loss vs frequency of 4X4 MSA and modified 4X4 MSA on infinite ground



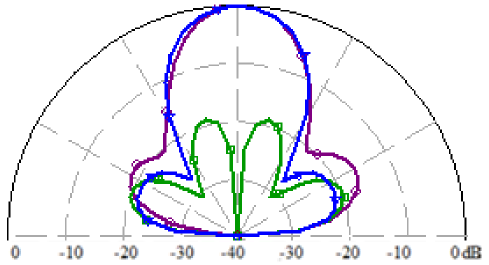
( 🟩 4X4MSA 🟪 Modified 4X4MSA )

Fig. 3 Impedance variation of 4X4 MSA and modified 4X4 MSA on infinite ground

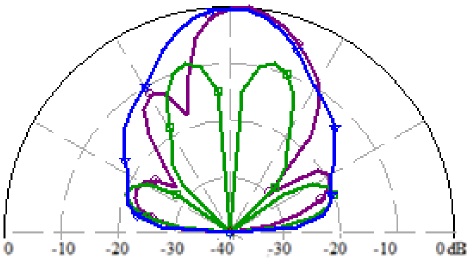


( 🟩 4X4MSA 🟪 Modified 4X4MSA )

Fig. 4 Gain variation of 4X4 MSA and modified 4X4 MSA on infinite ground



(a) 5.8 GHz



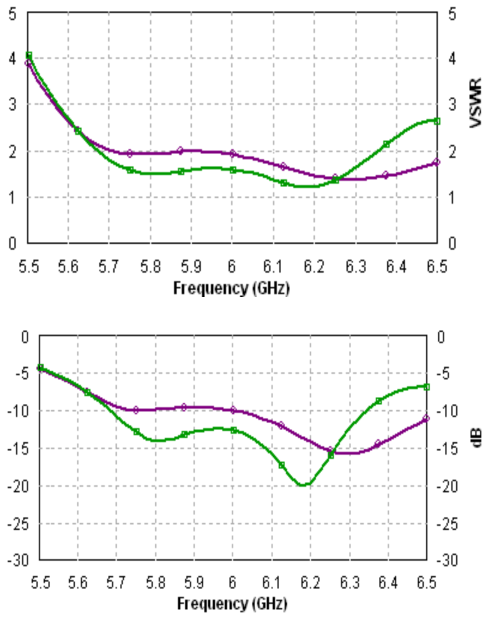
(b) 6.15 GHz

( 🟩 4X4MSA 🟪 Modified 4X4MSA )

Fig.5 Radiation pattern of 4X4 MSA and modified 4X4 MSA on infinite ground

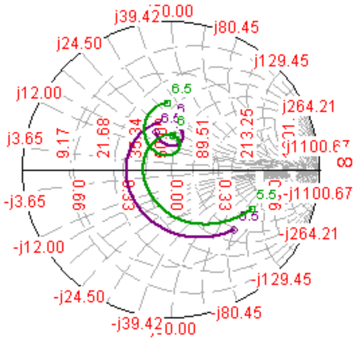
## IV. ANTENNA DESIGN ON FINITE GROUND PLANE

The structures are redesigned on 150x150 mm finite ground. The ground plane dimensions are optimized to have a Front to back lobe ratio ( F/B) of 20 dB. Smaller ground plane dimensions results in lower F/B ratio. VSWR and return loss of 4x4 MSA and modified 4x4 MSA structures are shown in Fig. 5. The impedance variations of these structures are shown in Fig. 6. The gain variation of 4x4 MSA and modified 4x4 MSA structures on finite ground is shown in Fig. 7. It is observed that by decreasing spacing between the parasitic elements and by decreasing the dimensions of parasitic patches. These patches resonate at higher frequency and thus gain at higher frequency increases but at the same time it decreases at lower frequencies resulting in gain flattening. The radiation pattern of modified 4x4 MSA is shown in Fig.7 SLL and cross polarization is -15 dB at 5.8 GHz which increases to about -11 dB at 6.15 GHz. F/B ratio is about 20 dB is obtained. The structure is fabricated. The photograph of the structure is shown in Fig. 10. The simulated and measured results are shown in Fig. 11. Measured results agree with the simulated results.



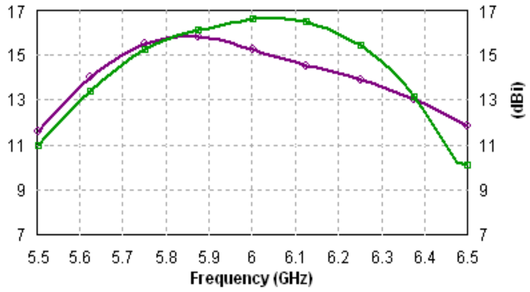
( 🟩 4X4 MSA 🟪 Modified 4X4 MSA )

Fig.6 VSWR Vs frequency & return loss Vs frequency of 4X4 MSA and modified 4X4 MSA on finite ground



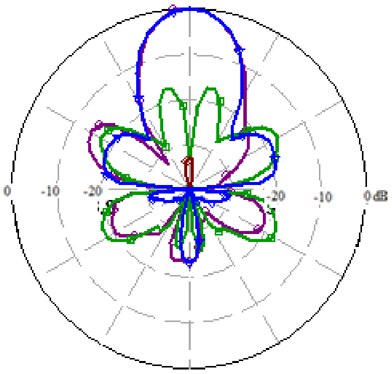
( 🟩 4X4 MSA 🟪 Modified 4X4 MSA )

Fig.7 Impedance variation of 4X4 MSA and modified 4X4 MSA on finite ground

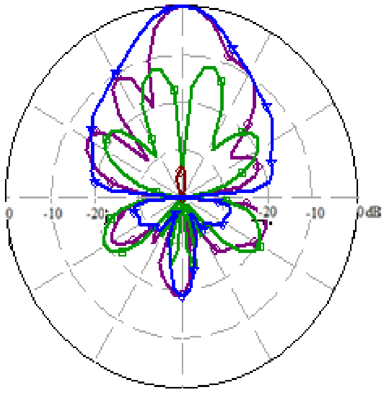


( 4X4 MSA Modified 4X4 MSA )

Fig.8 Gain variation of 4X4 MSA and modified 4X4 MSA on finite ground



(a) 5.8 GHz



(b) 6.15 GHz

( 4X4 MSA Modified 4X4 MSA )

Fig.9 Radiation pattern of 4X4 MSA and modified 4X4 MSA on infinite ground

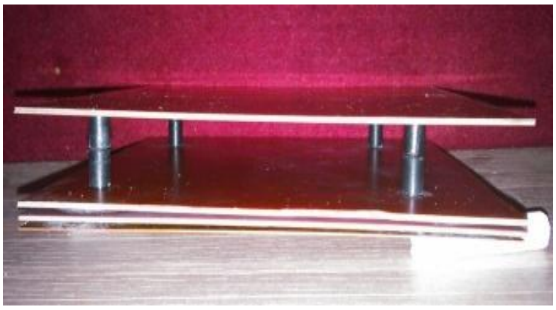


Fig.10 Antenna structure on finite ground

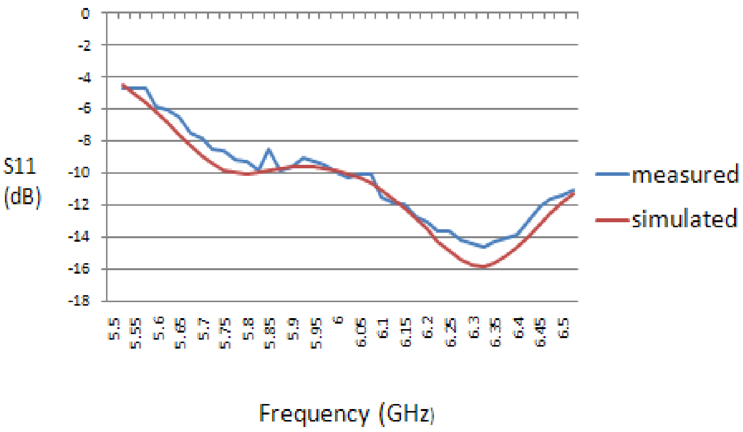


Fig.11 Comparison of measured & simulated values of S parameters Vs Frequency

## V. CONCLUSION

Gain variation in high gain wideband antenna using a Fabry Perot Cavity resonator can be decrease by decreasing the spacing between the parasitic elements and by decreasing the dimensions of parasitic patches. Gain variation of <3 dB is obtained over 5.725 – 6.4 GHz which covers 5.725-5.875 GHz ISM band and 5.9-6.4 GHz band used for WLAN and uplink C band satellite communication.

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