# Effect of Small Patches on Gain of Stacked High Gain Wide Band Antenna

*Sonal A. Patil and Dr. R. K. Gupta*

*Abstract*: **This paper presents design of stacked high gain wide band antenna using printed MSA for gain flattening over the frequency range of 5.725GHz to 6.4GHz. The design adopts existing techniques, 4x4 arrays of square patches, probe feed to patch. The antenna structure consists of a suspended microstrip antenna fabricated on FR4 substrate layer. Fabry-Perot Cavity (FPC) consisting of a partially reflecting sheet (PRS) and a perfect reflecting ground plane has been considered for enhancing gain. The proposed antenna structure uses sub small array of square parasitic patches of dimension 4 mm on superstrate layer, results in gain flattening. The structure is optimized to provide VSWR less than 2 and return loss less than -9.5 dB over the frequency range of 5.725 – 6.4 GHz. The simulated results showed adequate performance with attainable impedance bandwidth of 675MHz, antenna efficiency of 76.93% and gain of 16.54dBi. The antenna exhibits stable radiation pattern. The proposed structure is suitable for ISM and Satellite C band.**

**General Terms**
Wireless Communication, Radiating Systems, Antennas.

**Keywords**
Fabry Perot Cavity antenna, Broadband, High gain, MSA, PRS.

## I.INTRODUCTION

It is important to design broadband and high gain antennas to cover a wide frequency range for the growth of wireless system and booming demand for a variety of new wireless application. Microstrip patch antennas have found extensive applications in wireless communication system owing to their advantages such as light weight, small size, low profile, ease of fabrication, ease of integration with microwave integrated circuits (MMICs ) and a planar structure that can be made conformal to host surface. However, MSA suffers from low directivity, narrow bandwidth typically 5% with respect to center frequency, low efficiency and low power handling capability, high cross polarization [1-4].

To increase the directivity of the antenna line fed antenna arrays have been reported. High Gain Line-fed microstrip antenna arrays are planar but they suffer from low efficiency due to line losses and higher cross-polar radiation due to the feed-line network. Reflectarrays avoid the feed-line network and can be made flat or conformal. The feed antenna of the reflectarray results into aperture blockage. Also, the design of the reflectarray is highly involved and its efficiency is low due to dielectric losses [1].

Sonal A. Patil and Dr. R. K. Gupta are with Terna Engineering College, Nerul, Navi Mumbai, Emails: sonal_deokar@yahoo.co.in, rajivgupta@ternaengg.ac.in

High gain antennas using parasitic patches on a superstrate offer high efficiency, low side lobe level and avoid feed network, but these antennas have narrow bandwidth [2]. The techniques for improving the gain and bandwidth by arranging parasitic elements above the feeding MSA are investigated [3, 7].

Microstrip antenna performance is affected by the patch geometry; substrate properties and feed techniques [4].The use of high dielectric substrates with higher loss provide low gain but broad bandwidth and smaller dimensions [5].
The structure of the Fabry–Perot resonator can be used to enhance the gain of printed antennas. FPC consists of a single or multiple dielectric layers or a periodic screen which functions as a partially reflecting surface (PRS) and a ground plane. PRS is placed at integral multiple of $\lambda/2$ above a ground plane and fed by an antenna to increase directivity and gain. The gain improvement of antenna depends on the reflection coefficient of PRS [4-9].
Three dimensional efficient directive antenna arrays using a single feed patch is proposed [8] but the structure has large thickness, more inter-element spacing and high SLL for small size arrays.
High gain antennas using parasitic patches on a superstrate have been reported. These antennas use a single feed and offer high efficiency and low side lobe level, but these antennas have narrow bandwidth [11-12]. The parasitic patches being a good reflector of microwave frequencies; results in improvement in antenna gain and the reflection coefficient.

The electromagnetic coupling techniques for improving the gain and bandwidth by arranging parasitic elements above the feeding MSA are investigated [13-14].Here PRS is fed by single microstrip antenna to achieve high gain as well as wide bandwidth. To improve impedance and gain bandwidth optimization of MSA height, FPC height, inter-element spacing and parasitic patches dimension is carried out it 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 bandwidth enhancement can be obtained by using multiple resonators. When the parasitic patch is close to the feed patch, the stacked antenna has two near-resonant frequencies and the resonant mode of the parasitic patch is almost the same as the primary mode of the feed patch, will result in bandwidth enhancement.

A partially reflecting sheet (PRS) placed above a ground plane at approximately $\lambda_0/2$ and fed by an antenna, causes multiple reflections between the ground plane and PRS. 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.

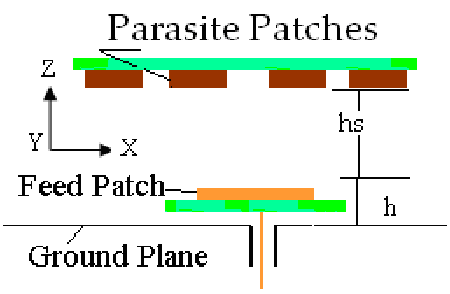
The sub small array (SSA) of patches between parasitic patches on superstrate layer formulates strong coupling, which grades in gain flattening. The structures are simulated with IE3D software for infinite as well as finite ground plane.

## III. ANTENNA GEOMETRY

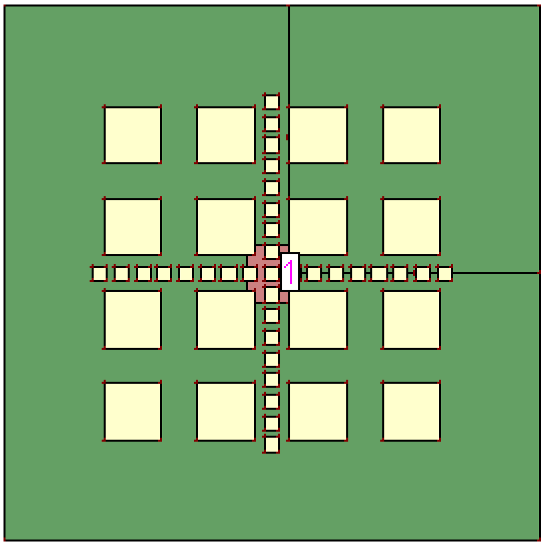
The impedance gain and bandwidth improvement using 4x4 array of parasitic patches is proposed. The proposed antenna structure consists of a suspended microstrip antenna fabricated on FR4 substrate and placed at 1 mm from ground. The thickness, relative permittivity and loss tangent of this substrate layer is 1.59mm, 4.4 and 0.02 respectively. The feed patch printed on FR4 substrate layer has dimensions of $\lambda_0 / (2\sqrt{\varepsilon_{eff}})$. The MSA is fed by single probe feed to patch at position L/6. The superstrate layer is fabricated above the ground plane at λo/2, forms an FPC. The thickness, relative permittivity and loss tangent of substrate and superstrate layer is 1.59mm, 4.4 and 0.02 respectively. Air is used as dielectric between the MSA and ground plane, also between feed patch and superstrate layer to increase the antenna efficiency.

Initially 4x4 array of square parasitic patches are fabricated at the bottom side of the superstrate layer of size λ/2 with spacing greater than λo/2. The structure is optimized on infinite and finite ground plane. The simulated results give gain of 16.4dBi. The structure is modified with sub small array (SSA) of parasitic patches of dimension less than 0.1 λ, which are fabricated at bottom side of superstrate layer, which improves in gain variations. The antenna structure with SSA is optimized on finite and infinite ground plane, obtains stable impedance gain of 16.53dBi over the frequency range of 5.725GHz to 6.4GHz. The modified geometry of antenna structure is shown in fig.1.

The all antenna structures are optimized with MSA height, FPC height, inter-element spacing and parasitic patches dimensions so that different elements resonant at different frequencies close to central frequency. It results in broad impedance and gain bandwidth. Also reflection coefficient decreases which result in decrease in gain but increase in bandwidth.




(a) Side View




(b) Top View

Fig.1Geometry of 4x4 MSA with sub small array structure

## IV. ANTNENNA DESIGN ON INFINITE GROUND PLANE

A suspended MSA is fabricated on FR4 substrate layer at 1mm from infinite ground plane. The thickness, permittivity and loss tangent of this FR4 substrate is 1.6mm, 4.4 and 0.02 respectively. The feed patch fabricated on substrate layer has optimized dimension of 14.2x16mm, and feed point at 4.8 mm. The FPC height is optimized to 25.3mm above the feed patch and square parasitic patches of 16mm are spaced at 25.9mm. The structure is modified by fabricating sub small array of square parasitic patches of 4mm between parasitic patches on superstrate layer as shown in fig. 1(b). The closely spaced square patch array reduces gain variations. The feed patch dimensions, feed position, parasitic patch dimensions, spacing between the patches, and cavity height are optimised to obtain impedance bandwidth of 5.725-6.4 GHz.

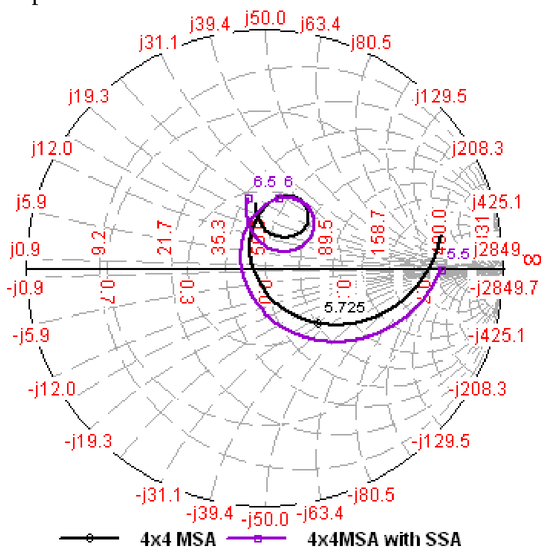



Fig.2 Impedance Variations

The impedance variations are shown in fig.2. It is observed that VSWR is less than 2 over the desired frequency range of 5.725 – 6.4GHz. Also the loop size of 4x4 MSA with SSA is increased which shows strong coupling. The structure is capacitive for lower frequencies while inductive at higher frequencies.

The antenna structure is optimized to obtain return loss less than -9.5dB over the frequency range of 5.725 – 6.4GHz as shown in fig.3.

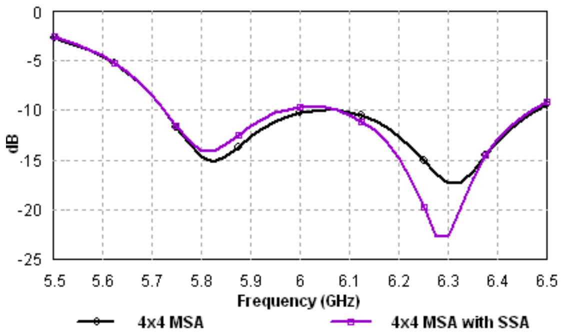



Fig.3 Return Loss

The total field gain Vs. frequency plot is shown in fig.4, gives maximum gain of 14.82dBi. It is observed that modified 4x4 MSA with SSA results in impedance gain flattening over the frequency range of 5.725 – 6.4GHz.

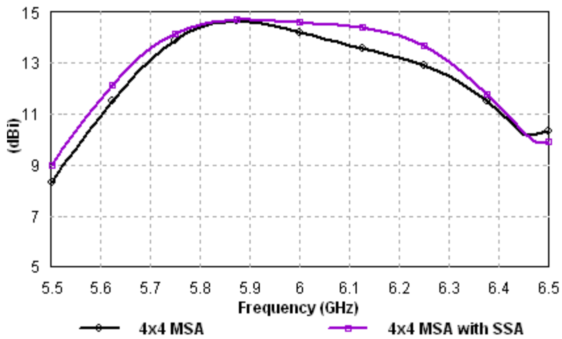



Fig.4 Total Field Gain Vs. Frequency

## V. ANTENNA DESIGN ON FINITE GROUND

The modified 4x4 MSA with SSA antenna structure is redesigned on finite ground plane with the size of ground plane designed as 3λ. The structure is optimized to obtain VSWR is < 2 over 5.725 – 6.5 GHz frequency band. The antenna provides 16.53 dBi gain with less than 3dB gain variations over 5.725 – 6.5 GHz. Gain variations of antenna structures are shown in Fig. 5. The optimized gain is 16.53dBi with finite ground plane. The increase in gain results because of constructive interference between radiated and reflected waves at particular dimensions of finite ground.

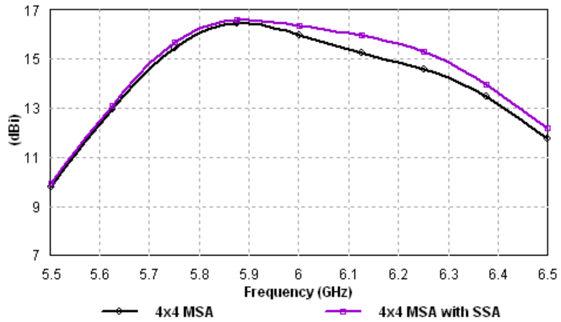



Fig. 5 Total Field Gain Vs. Frequency

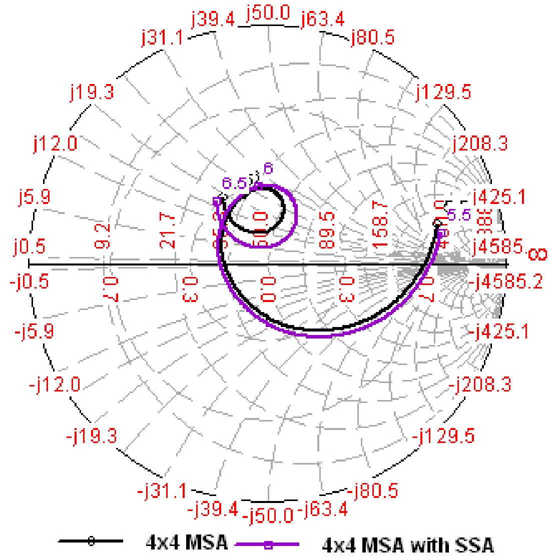



Fig.6 Impedance Variations

The impedance variations on finite ground plane are shown in fig.6. The antenna structures are optimized to obtain the VSWR is less than 2 and return loss is less than -9.5dB. The obtained antenna efficiency of 4x4 MSA with SSA on finite ground plane is 76.93% as shown in fig.7. To increase the efficiency MSA is suspended in air. It is observed that the antenna efficiency increases due to decrease in dielectric and conducting losses.

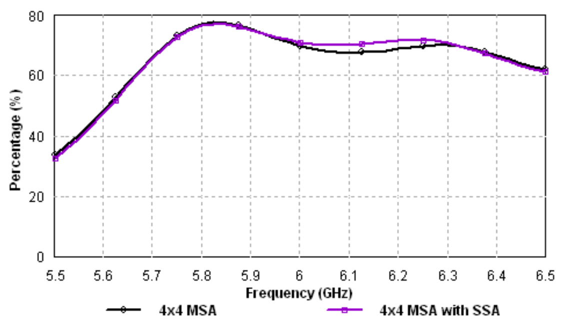
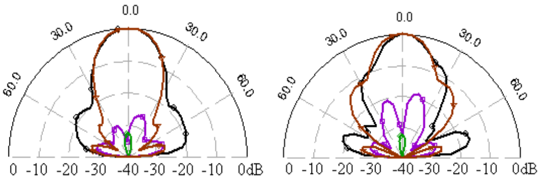


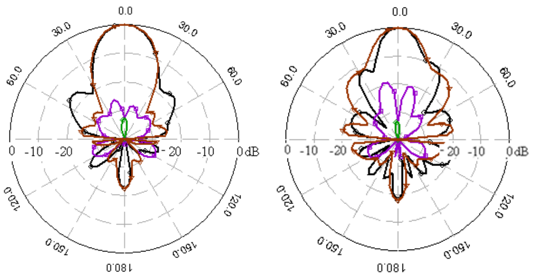

Fig.7 Antenna Efficiency Vs. Frequency

The radiation patterns of modified 4x4MSA with SSA on finite and infinite ground plane are shown in fig. 8 and 9 respectively. The broadside radiation patterns are symmetrical. The antenna exhibits stable radiation pattern over the operating frequency band. The optimized side lobe level (SSL) is less than -16dB, cross polarization is less than -16dB and front to back ratio about 20dB.




(a) 5.8GHz (b) 6.15GHz

Fig. 8 Infinite Ground Plane




(a) 5.8GHz (b) 6.15GHz

Fig. 9 Finite Ground Plane

## VI. CONCLUSION

The improvement in impedance as well as gain bandwidth is obtained by resonating different elements of structures at different near resonance frequencies. The parasitic patches being good reflector at microwave frequencies lead to increase in gain as well as antenna efficiency. Further the gain and bandwidth is improved by optimizing the MSA, parasitic patch dimensions, inter-element spacing, feed patch height and FPC height. The 4x4 MSA with SSA provides strong coupling between the patches which results in gain flattening. The proposed structure is a suitable candidate for ISM band and satellite C band.

## VII. REFERENCES

[1] R. D. Javor, X.D. Wu, and K. Chang, “Design and performance of a microstrip reflectarray antenna”, IEEE Trans. Antennas Propagat., Vol. AP- 43, pp. 932-939, 1995.

[2] A. P. Feresidis and J. C. Vardaxoglou, “High gain planar antenna using optimized partially reflective surfaces”, IEE Proc. Microw. Antennas Propagat., vol.148, pp. 345–350,2001.

[3] R. K. Gupta and J. Mukherjee, Low cost efficient high gain antenna using array of parasitic patches on a superstrate layer, Microw. Opt. Technol. Lett. 51, 2009, pp. 733– 739.

[4] X.H. Shen, G. A. E. Vandenbosch, “Aperture field analysis of gain enhancement method of microstrip antennas”, IEE Int. conference Antenna and Propagation, 1997.

[5] G. V. Trentini, “Partially reflecting sheet arrays”, IRE Trans. Antennas Propagat., vol.4, pp. 666–671, 1956

[6] H. Y. Yang and N. G. Alexopoulos, “Gain enhancement methods for printed circuit antennas through multiple substrates”, IEEE Trans. Antennas Propagat., vol. AP-35, pp. 860–863, 1987.

[7] Egashira S., Nishiyama E., “Stacked microstrip antenna with wide bandwidth and high gain”, IEEE Trans. Antennas Propag, vol. AP-44, pp. 1533-1534, 1996.

[8] P.N. Chine and Girish K umar, “Three dimensional, efficient, directive microstrip antenna arrays,” IEEE Int. symposium Antenna and Propagation, 2005 .

[9] G.Kumar and K.P.Ray, Broadband Microstrip Antennas, Norwood, MA Artech House,2003.

[10] D.M.Pozar, S.D.Targonski and H. Syrigos, Design of millimeter wave microstrip reflectarrays", IEEE Trans. Antennas Propagat., vol. AP-45 no.2, pp.287-295, Feb. 1997.

[11] R. K. Gupta and J. Mukherjee, Effect of superstrate material on a high gain antenna using array of parasitic patches, Microw. Opt. Technol. Lett. 52, 2010, pp. 82– 88.

[12] D. M. Pozar and D. H. Schaubert, *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays*, John Wiley and sons Inc. USA, 1995.

[13] Zhi-Chen Ge, Wen-Xun Zhang, Zhen-Guo Liu,Ying-Ying Gu, Broadband and High gain printed antennas constructed from Fabry- Perot resonator structure using EBG or FSS cover, Microw. Opt. Technol. Lett., 48, 2006, pp. 1272–1274.

[14] Egashira S., Nishiyama E., Stacked microstrip antenna with wide bandwidth and high gain, IEEE Trans. Antennas Propag, 44, 1996, pp. 1533-1534.

**First Author** Sonal Patil received her Bachelor degree from GSMCOE Pune, Maharashtra. She is per suing master degree from Terna Engineering College, Nerul, Navi Mumbai. Currently she is working as Professor in Electronics and Telecommunication Engineering Department at A. C. Patil College of Engineering, Kharghar, Navi Mumbai

**Second Author** Dr. R.K.Gupta received his Bachelor degree from NIT Kurukshetra, master degree from IIT Delhi and Ph.D from IIT Bombay. He has published more than 65 papers in national and internationals jornals and conference proceedings. He has 2 patents to his credit. He is a reviewer of many international and national journals.His research interest are antenna design: patch antenna, dual anfd multiband antennas, Ultra wide band antennas and high gain multilayer antennas.

Currently he is working as Professor in Electronics and Telecommunication Engineering Department at Terna Engineering College, Nerul, Navi Mumbai