Enhancement of gain and efficiency of a wideband microstrip antenna (MSA)

Miss. Paurnima M. Vadak
Electronics and Telecommunication
K.C.College of Engineering
Thane, India
pornimavadak@yahoo.com

Dr. R.K.Gupta
Electronics and Telecommunication
Terna Engineering College
Nerul, India
rajivgupta@ternaenn.ac.in

***Abstract*—This article reviews the design and analysis of various antenna structures providing high gain and efficiency in different frequency bands according to the required area of application. The wideband microstrip antenna (MSA) is used in most of the structure obtained by using the principle of stacking i.e. multilayer structure. By using the parasitic patches the gain and efficiency of the MSA are increased. The antenna with 5 X 5 array of square parasitic patches provides a gain of 18.0 dB with 92% efficiency, SLL of -18.4 dB, and front to back lobe ratio of more than 20dB in 5.725–5.875 GHz frequency band. The similar another structure with some modifications provides a gain of 22.7 dB with 92% efficiency, SLL of -22.3 dB and front to back lobe ratio of more than 20 dB in the similar frequency band. The antenna providing 17.8dB gain with gain variation of <1.5 dB over 5.725-5.875GHz is also studied. The antenna structure also provides more than 80% efficiency, SLL < -18 dB and front to back lobe ratio > 22 dB. In the frequency range of 5.725-6.4GHz an antenna structure providing an antenna efficiency of 76.93% and gain of 16.54dBi is analyzed**.

Keywords— Broadband antennas, Fabry Perot Cavity (FPC), Parasitic patches, Superstrate, stacked MSA, ISM band, IE3D software

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I. INTRODUCTION

The numerous advantages of MSAs 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 have made them extensively popular in the wireless communication systems. However low gain, narrow bandwidth, low efficiency, and low power handling capability are the factors limiting its performance [1].

The gain and directivity of the MSA can be improved using line fed arrays but they suffer from low efficiency due to line losses and higher cross-polar radiation. Reflectarrays avoid the feed-line network and can be made flat or conformal. But, reflectarrays suffer from aperture blockage as feed antenna is located in its radiation aperture. Also, its efficiency is low due to dielectric losses [2-4].

Microstrip antenna performance is affected by the patch geometry; substrate properties and feed techniques [5].The use of high dielectric substrates with higher loss provide low gain but broad bandwidth and smaller dimensions [6]. Gain enhancement techniques based on Fabry-Perot cavity (FPC) has been considered to increase broad side directivity. A partially reflecting sheet (PRS) formed by single or multiple dielectric layers or a periodic screen at ~λ/2 above a ground plane is used to increase directivity. The gain of PRS antenna depends on the reflection coefficient of PRS and that of feed antenna [6-9]. The technique for improving the gain, bandwidth, and radiation efficiency by arranging parasitic elements above the feeding MSA is investigated. 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 [10-11]. The parasitic patches being a good reflector of microwave frequencies; results in improvement in antenna gain and the reflection coefficient.

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 broadside directive radiation pattern results when the distance between the ground plane and PRS causes the waves emanating from PRS in phase in normal direction. The structure can be formed by a half wavelength cavity consisting of a ground plane and a partially reflecting surface (PRS). Boresight gain and bandwidth are function of reflection coefficient

$$G = 1 + R/1 - R \qquad (1)$$

$$BW = \Delta f / f_0 = (\lambda / 2\pi Lr).(1 - R/R^{0.5}) \qquad (2)$$

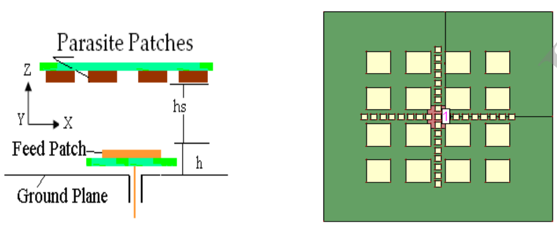
Where R is the reflection coefficient of PRS and Lr is the resonant length—distance between ground plane and PRS.

High gain phenomenon is also explained on the basis of increase in the effective aperture area. It is observed that superstrate layers have a focusing effect. The phase distributions of the fields with a superstrate are observed to be more uniform than one without the superstrate leading to an increase in effective aperture area and gain [12]. The focusing effect or phase smoothening and hence gain increases with increase in dielectric constant and thickness of superstrate. It is also observed that parasitic patch dimensions and spacing between patches decreases with higher dielectric superstrate.

III. ANTENNA GEOMETRY

The first antenna structure reviewed is as follows and 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 λ0 / (2√ εeff). 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 [13].

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.



(a) Side view (b) top view

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

The antenna structure same as the previous structure but with 3x3 array of parasitic patches on the superstrate is analysed. The height of the parasitic patches from the ground plane is optimized to 28mm.The 3x3 array of circular ptches of radius 8mm on superstrate is also analysed. The above structure provides the gain of 14.5dB and 12.9dB respectively [14].

This concept of parasitic patches and superstrates when applied to the multilayered structure improved the performance further. The structure can be considered as a multi-cavity resonator with multiple FSS or PRS. The structure is an extension of a half wavelength FPC consisting of a ground plane and a PRS, which results in multiple reflections between PRS and ground plane. A broadside directive radiation pattern results if the distance between the ground plane and PRS is such that it causes the waves emanating from PRS to be in phase in normal direction.

The FP is a metallic patch of 0.7-mm thickness placed at a height h = 2 mm from the ground plane. The PPs are fabricated on superstrate layers at height 'hs1,' 'hs2,' and 'hs3' from the ground plane and fabricated on the bottom side of 1.59-mm thick FR4 superstrate so that superstrate also acts as a radome to the antenna. The other conditions like thickness, dielectric constant, loss tangent of FR4 been same as that of previous structures [15].

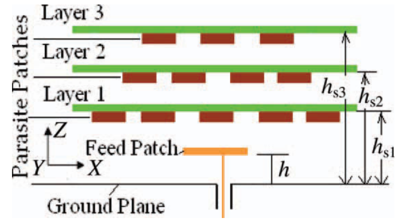


Fig. 2 Geometry of antenna structure (side view). The structure is termed as 5x5-4x4-3x3 antenna as it has 5x5, 4x4 and 3x3 PP array on superstrate layers 1, 2, and 3, respectively.

IV. ANTENNA PERFORMANCE ANALYSIS

The performance of the wideband high gain antennas obtained by the implementation of FPC structure and parasitic patches is regulated by parameters such as height of the superstrate layer, number of parasitic patches, shape and size of the array of parasitic patches. The analysis of the effects of this parameters is done here.

A. *Effect of size of array of parasitic patches*

MSA using a metallic patch of 0.7-mm thickness at a height h=2 mm from the infinite ground plane is designed and then a superstrate layer of FR4 at 0.5 λ_0 height is placed. The structures are optimized to operate over 5.725–5.875-GHz. MSA provides a gain of 9.4 dB, which increases to 11.6 dB when FR4 superstrate of 1.59 mm is placed above MSA. Thereafter, a single square parasitic patch (SSPP) is placed at the bottom of a FR4 and its dimensions are optimized to achieve maximum gain. Then, square PPs are placed at the bottom of a superstrate layer to form an even and odd array. As the size of the array increases the gain and directivity of the structure goes on increasing as shown below

TABLE I. GAIN AND DIRECTIVITY OF SPPA WITH DIFFERENT ARRAY SIZES

Size of an array	Gain (dB)	Directivity(dB)
1x1	13.4	13.0
2x2	15.9	14.9
3x3	17.3	16.4
4x4	16.9	16.2
5x5	18.0	17.3
6x6	17.0	16.3
7x7	18.6	18.1
8x8	18.3	17.9
9x9	19.5	19.0

B. *Effect of height of superstrate layer*

The various antenna structures considered for the gain enhancement consists of parasitic patches placed on or at the bottom of the superstrate layer. The height of the superstrate layer has following effect. For the antenna structure discussed in the previous section, Structures with 1 x 1 (SSPP) to 9 x 9 SPPA are optimized at 0.5, 1.0, and 1.5 λ_0 superstrate height.Thegain increases with increase in superstrate height but at the cost of higher SLL particularly in small size array.

C. *Effect of number of superstrate layers*

The multilayer structures not only increase the gain but also improve SLL. Radiation pattern of multilayer structures can be analyzed by considering top layer acting as a PRS while the structure below it as a feed antenna with field pattern f(a). In a multilayer structure, since the field pattern of feed antenna which consists of MSA and SPPA on a superstrate layer at 0.5 λ_0 has a narrower beam width and higher gain as compared with MSA, radiation pattern of multilayer structures are expected to have lower SLL as compared with those structures with SPPA on single superstrate layer placed at higher superstrate height and fed by MSA.

The structure can be also be analyzed as a multicavity resonator with multiple FSS or PRS. Each FSS layer acts as a filter or a lens and therefore has a focusing effect. Multiple reflections and field distribution take place at each PRS and therefore radiation pattern of such structures depend on two frequency sensitive processes—one is the interference of waves reflected from different PRS and other is the resonant interaction of waves with metallic patches [16]. Multiple reflections between different layers and also between different layers and ground plane add constructively in broadside direction and destructively in other directions and thus, results in high gain associated with low SLL. Multilayer structure provides additional design flexibility due to various parameters such as different combination of SPPA on different layers, spacing and dimensions of PPs on different layers, superstrate layer thickness, and superstrate material. Therefore, desired gain with low SLL can be obtained by using different combination of SPPA on different superstrate layers.

D. *Effect of material of superstrate layer*

Effect of superstrate material on a high-gain antenna using array of PPs has been analyzed. As superstrate with high dielectric constant has more focusing or phase smoothening effect, PP dimensions and spacing between PPs decrease with dielectric constant as well as thickness of superstrate.

For the SPPA antenna structure discussed in the previous section a gain of 17.5 dB on infinite ground plane can be realized with 5 x 5 array of square parasitic patches on ceramic superstrate that has about half the array size dimensions as compared to the structure on FR4 superstrate. Antenna with ceramic superstrate on finite ground requires 25% less ground plane size as compared to FR4. Beside this SLL in ceramic superstrate is about 5 dB less as compared to FR4 superstrate. The array has a flat, conformal profile, and can be conveniently embedded into the host vehicle [17].

E. *Effect of shape of parasitic patches*

The antenna performance is regulated by the shape of parasitic patches used. The MSA is fabricated on FR4 and placed at 1 mm from ground. The square parasitic patches are located at a height 'hs' from the feed patch and fabricated on the bottom side of FR4 superstrate of thickness 1.59 mm. Relative permittivity and loss tangent of FR4 is 4.4 and 0.02 respectively. The FR4 layer also acts as a radome to the antenna. Air is used as a dielectric medium between superstrate and feed patch to achieve high efficiency. MSA is fed through a coaxial probe of 50 Ω. The structure is designed to operate over 5.725 – 5.875 GHz band. Here the square and circular parasitic patches are placed on the FR4 layer.

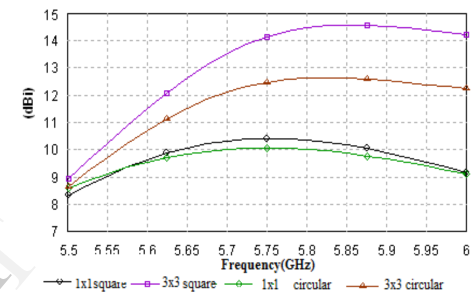


Fig. 3 Gain variations vs. frequency

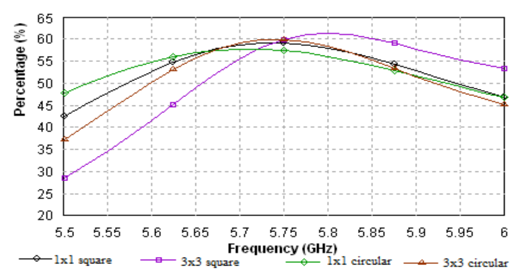


Fig. 4 Antenna efficiency vs. frequency

The effect of square and circular parasitic patches on MSA fed high gain antenna is seen. It shows that as compared to circular the square parasitic patches provides more gain, low SLL and less cross polarization [18] .

V. CONCLUSION

An efficient, high gain, easy-to-fabricate printed MSA fed antenna having low SLL and high gain is proposed. MSA antenna is placed in a FPC to enhance gain. The MSA dimension, parasitic patch dimensions and spacing between parasitic patches, MSA height and FPC height are the determining factor in improving gain of antenna. The effects of these factors is reviewed in this article.

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