BANDWIDTH ENHANCEMENT OF HIGH GAIN ANTENNA USING CIRCULAR ARRAY OF SQUARE PARASITIC PATCHES

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ABSTRACT

This paper presents the design of Microstrip Antenna (MSA) with circular array of square parasitic patches (CASPPs) on a superstrate layer for bandwidth enhancement. The antenna structure consists of a MSA, which feeds circular array of 36 parasitic patches (PPs) printed below a FR4 superstrate and positioned at about 0.5λ₀ height from the ground plane. The antenna structure provides peak gain of 17.15 dBi with impedance bandwidth of 950 MHz (16.6%) which covers 5.25-5.875 GHz ISM frequency band and 5.9-6.2 GHz up-link C-band for satellite communication. High-gain and broadband performance is obtained by resonating MSA and PPs at different frequencies in 5.25-6.2GHz band. Results obtained verify that the proposed antenna structure is attractive solution for several wireless communication systems, such as satellite systems, base station cellular systems, and point-to-point links.

KEYWORDS: High gain wideband antenna, directive antenna, multilayer, stacked antenna, ISM, Fabry-Perot Cavity.

1. INTRODUCTION

MSA is one of the most usable antennas at frequencies greater than 1GHz. MSA has several advantages like low profile, low cost, easy to fabricate, easy to feed etc. Beside all these advantages MSA suffers from disadvantages like low gain, low bandwidth, low efficiency etc. [1].

Gain enhancement techniques based on Fabry-Perot cavity (FPC) where a partially reflecting surface (PRS) formed by a dielectric layer or a periodic screen at approximately 0.5λ above a ground plane is used. The reflection coefficient of PRS and radiation characteristic of feed antenna affects the gain of PRS antenna [2-5]. High gain antennas with artificial magnetic conductors based on FPC model have been proposed [6]. High gain antennas using a frequency selective surface, electromagnetic band gap resonator [7-8].

High gain antennas using PPs on a superstrate have been reported. Such
antennas offer high efficiency, low side lobe level and avoid feed network but suffer from narrow bandwidth [9-10]. These antennas exhibit high gain but the bandwidth performance is poor. The techniques for improving the gain and bandwidth by arranging parasitic elements above the feeding MSA are investigated [11-14]. A high gain and wideband FPC antenna with CASPPs on a superstrate layer have been proposed [15].

In this paper, antenna structure for high gain and wide bandwidth applications is investigated and designed using CASPPs at about 0.5λ₀ height. The antenna structure consist of a MSA, which feeds circular array of 36 square PPs printed below a FR4 superstrate and positioned at about 0.5λ₀ from the ground plane. The antenna structure is designed to operate over 5.25-6.2 GHz band, which covers 5.25-5.875 GHz ISM band and 5.9-6.2 GHz up-link C-band for satellite communication. Here, the feed-line network is completely avoided so antenna structure is easy to design and fabricate. By resonating the MSA, PPs and FPC at different nearby frequencies, gain as well as bandwidth is improved. The different element of a structure resonating at different close by frequencies results in gain and bandwidth improvement. The antenna design and optimization is carried out using commercial method-of-moment based IE3D software [16]. The following sections deal with the antenna geometry, design theory, simulation results. Radiation pattern and impedance variation of antenna structure is also described.

2. ANTENNA DESIGN METHODOLOGY AND GEOMETRY

In this section, antenna design methodology and antenna geometry is described. The side view of the circular array of 36 square PPs below superstrate layer antenna structure is shown in Fig-1. The Feed Patch (FP) is a metallic MSA of 0.5 mm thickness. It is placed at a height h = 3mm from the ground plane. The PPs are fabricated at bottom side of FR4 superstrate layer at about hs = 0.5λ₀ height, where λ₀ is the free space wavelength corresponding to central frequency 5.7 GHz. Relative permittivity and loss tangent of FR4 superstrate is 4.4 and 0.02 respectively. Air is used between FP and ground plane, superstrate layer and FP as a dielectric medium to achieve higher efficiency. A 50 Ω coaxial probe is used to feed the FP. The antenna is designed to operate over 5.25-6.2 GHz frequency band. Geometry of CASPPs (top view) is shown in Fig-2.

![Figure 1: Geometry of antenna structure (side view)](image-url)
The antenna structure can be considered as a cavity resonator with FSS or superstrate. The antenna structure is an extension of a half wavelength FPC consisting of a ground plane and a partially reflecting surface which results in multiple reflections between superstrate and ground plane. A broadside directive radiation pattern results if the distance between the ground plane and superstrate is such that it causes the waves emanating from superstrate to be in phase in normal direction. If reflection coefficient of the superstrate is $\rho \exp(i\psi)$ and $f(\alpha)$ is the normalized field pattern of feed antenna, then normalized electric field $E$ and power $S$ at an angle $\alpha$ to the normal is derived in [2]

$$|E| = \sqrt{\frac{1-\rho^2}{1+\rho^2-2\rho\cos\phi}} f(\alpha)$$  \hspace{1cm} (1)

$$S = \frac{1-\rho^2}{1+\rho^2-2\rho\cos\phi} f^2(\alpha)$$  \hspace{1cm} (2)

Here, $\phi$ is the phase difference between waves emanating from superstrate. Boresight gain ($\phi = 0^\circ$) and bandwidth are function of reflection coefficient [2-3]

$$G = 1 + \rho / 1 - \rho$$  \hspace{1cm} (3)

$$BW = \Delta f / f_c = (L/2\pi\lambda_c)(1-\rho) / \rho^{1.5}$$  \hspace{1cm} (4)

Resonant distance $L_r$ between ground plane and superstrate is given by

$$L_r = \left(\frac{\psi_0}{360} - 0.5\right)\frac{\lambda}{2} + N\frac{\lambda}{2}$$  \hspace{1cm} (5)

Here $\psi_0$ is expressed in degree and $N = 0, 1, 2, 3$ etc.

When a MSA feeds CASPPs on a superstrate layer, high gain broadside radiation can be achieved if the PPs are fed in phase and current induced at patches are in phase. Since the PPs are positioned at different location and at different distance from FP, therefore, feed to each element involves amplitude tapering and phase delay. Beside the amplitude tapering due to distance, there is additional amplitude tapering due to the radiation pattern of MSA. The amplitude tapering results in decrease in gain but it improves bandwidth and side lobe level. There is little phase delay in feed to different PPs, which leads to bandwidth improvement. Hence, high gain wide band array antenna with a low SLL can be achieved.
Gain and bandwidth of such structure depends on the reflection coefficient of superstrate. The gain increases but the bandwidth decreases with reflection coefficient of superstrate. Therefore, PPs on a dielectric layer are fabricated to enhance the reflection coefficient and the gain. As the waves emanating from the superstrate must be cophasal, the gain of the antenna depends on the spacing between patches and their dimensions. Identical size of PPs leads to different close resonant frequencies resulting into wide bandwidth.

3. ANALYSIS ON INFINITE GROUND PLANE

MSA using a metallic patch of 0.5 mm thickness at a height $h = 2$ mm from the infinite ground plane is designed and then a superstrate layer of FR4 at $hs = 0.5\lambda_0$ height is placed and the structure is optimized. MSA provides a gain of 8 dBi, which increases to 10.5 dBi when FR4 superstrate of 1.59 mm is placed above MSA. Placing superstrate above MSA results into increase in capacitive impedance. To compensate it, $h$ is increased to 3 mm and $hs$ is optimized to 30.9 mm. As a result, impedance bandwidth is improved and VSWR less than 2 is obtained over 5.15-5.875 GHz.

Inner CASPPs consisting of 6 PPs of size $16 \times 16$ mm is placed above superstrate and structure is optimized which provides VSWR less than 2 over 5.15-5.875 GHz frequency band and 12.5 dBi gain. Then another circular array consisting 12 square PPs is placed below the superstrate layer and the structure is optimized. The structure provides gain of 15 dBi with impedance bandwidth of 13.8%, which covers 5.25-5.875 GHz ISM bands. Square PPs is of $16 \times 16$ mm each. Distance between PPs is optimized to obtain desired bandwidth performance.

Outer CASPPs of 18 elements of size $15 \times 15$ mm is placed below the superstrate layer in addition to two inner arrays and structure is optimized. The size of PPs in outer array is slightly less than that of inner arrays which compensates the amplitude tapering and these PPs resonate at higher frequency than inner arrays resulting into wideband performance. The structure provides peak gain of 16.5 dBi with impedance bandwidth of 16.6% which covers 5.25-5.875 GHz ISM band and 5.9-6.2 GHz up-link C-band for satellite communication. Radial distance between PPs is optimized to obtain desired gain bandwidth performance. The radial distance between PPs is kept close to $\lambda$, where $\lambda$ is the wavelength in FR4 dielectric. The optimum dimensions are $h = 3$ mm, $hs = 30.9$ mm, whereas square PPs in inner two arrays are of $16 \times 16$ mm each and PPs in outer circular array are of $15 \times 15$ mm each.

VSWR vs frequency of the final antenna structure on infinite ground is shown in Fig-3, which shows the operating frequency band of the designed structure. Vector current distribution at the FP and PPs at 5.5 GHz and 6.1 GHz is shown in Fig-4. The superstrate affects the phase and amplitude distribution of fields. The phase distributions of the
fields with a superstrate are observed to be more uniform than one without the superstrate. The superstrate has a focusing or phase smoothening effect and thus increases the effective aperture area, resulting in gain improvement [4-5]. The gain vs frequency plot is shown in fig-5. The proposed antenna structure provides peak gain of 16.5 dBi on infinite ground.

Figure 3: VSWR vs. frequency on infinite ground

Figure 4: Current distribution in CASPPs

Figure 5: Gain vs. frequency on infinite ground plane

4. ANTENNA REALIZATION ON FINITE GROUND

The antenna structure with 36 PPs is redesigned on square finite ground plane of size $4\lambda_0 \times 4\lambda_0$. Structure offers 950MHz (16.6%) impedance bandwidth and maximum gain of 17.15 dBi. Gain
variation of structure on finite ground is shown in Fig-6. Gain increases slightly with finite ground. This may be due to constructive interference between radiated and reflected waves at particular dimensions of finite ground. This antenna structure offers antenna efficiency more than 85% and radiation efficiency more than 90% as shown in Fig-7. VSWR vs frequency plot is shown in Fig-8. Radiation pattern on finite ground at 5.5 GHz is shown in Fig-9. Cross polarization is less than -20 dB, SLL is less than -18 dB with F/B ratio more than 25, which is appreciable for high gain wideband antennas. Radiation pattern is directive and symmetrical in broadside direction which confirms the usability of the antenna for wideband applications.

![Figure 6: Gain vs. frequency on finite ground plane](image6)

![Figure 7: Efficiency vs. frequency on finite ground plane](image7)

![Figure 8: VSWR vs frequency on finite ground plane](image8)

![Figure 9: Radiation pattern at 5.5 GHz on finite ground plane](image9)

5. CONCLUSION

A high gain and wideband FPC antenna with circular array of square parasitic patches is investigated and presented. The antenna structure is designed on low cost easily available FR4 superstrate. Impedance and radiation pattern bandwidth characteristics are observed which cover 5.25–6.2GHz frequency band. The structure provides peak gain of 17.15 dBi with impedance bandwidth of 16.6%. The results indicate that the proposed antenna is capable of generating efficient directive
radiation patterns in the desired frequency band. The structure has a flat, conformal profile, and can be embedded into the host vehicle.

REFERENCES


