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Printed MSA fed High Gain Wide band Antenna using Fabry Perot Cavity Resonator

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ABSTRACT

A low cost, printed high gain and wideband antenna using Fabry Perot cavity resonator for wireless applications is proposed. The antenna structure consists of a suspended microstrip antenna fabricated on FR4 substrate and placed at 1 mm from ground. MSA feeds 4 X 4 array of square parasitic patches fabricated on 1.6 mm thick FR4 dielectric layer. This superstrate layer is suspended in air at λo/2. Closely spaced square patches with less than 0.1λ x 0.1λ are fabricated near MSA to provide an inductive surface and to reduce gain variation. The VSWR of proposed antenna is < 2 over 5.725 – 6.4 GHz frequency band. The antenna provides 16.0 dB gain with less than 2.5 dB gain variation over 5.725-6.4 GHz, covering WLAN band and uplink C-band for satellite communication. There is small but acceptable radiation pattern variation over the 5.725-6.4 GHz band. The antenna structure also offer < -16 dB SLL and cross polarization with more than 20 dB front to back lobe ratio. The proposed structure is suitable for terrestrial and satellite communication.

Keywords: Broadband, Directive antenna, Fabry Perot Cavity antenna, High gain, MSA, PRS, , Radiating Systems, Wireless Communication .

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1. INTRODUCTION

Microstrip antennas (MSA) are widely used due to its attractive features such as light weight, small size, ease of fabrication and integration with Microwave Integrated Circuits (MIC) and conformal to host surface. However, it also has disadvantages of low gain, low efficiency, low power handling capability and narrow bandwidth. Various bandwidth improvement techniques using electromagnetic coupling or stacking the patches have been reported [1].

High gain antennas are designed using line fed MSA antenna arrays [2]. Line-fed microstrip antenna arrays are planar but suffer from low efficiency due to feed line and dielectric losses and high cross-polarization due to radiation from the feed-line network. Reflectarray antennas have been proposed [2-3]. Reflectarrays do not require the feed-line network and are conformal. However they suffer from aperture blockage as feed antenna is located in its radiation aperture and low efficiency due to dielectric losses.

Gain enhancement techniques based on Fabry-Perot Cavity (FPC) have been considered to increase broad side directivity. 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 λ/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 [4-8].

High gain microstrip array using a superstrate layer is proposed but it has the disadvantages of large size and high side lobe level (SLL) [9]. An efficient space fed directive antenna arrays using a single feed patch is proposed in [10]. The resulting structure is planar and there is no aperture blockage as feed antenna is located behind the array but the structure has large size 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 electromagnetic coupling techniques for

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improving the gain and bandwidth by arranging parasitic elements above the feeding MSA are investigated [13-14].

Here gain and bandwidth improvement using an array of parasitic patches at 0.5λ0 is proposed. The proposed antenna consists of a suspended microstrip antenna fabricated on FR4 substrate and placed at 1 mm from ground. Closely spaced square patches with less than 0.1λ x 0.1λ are fabricated near MSA to provide an inductive surface and to reduce gain variation. The MSA feeds an array of square parasitic patches printed on a FR4 superstrate and positioned at λ0/2 from the microstrip antenna. The antenna with 4 X 4 square parasitic patch on finite ground provides side lobe level and cross polarization <-16 dB and front to back lobe ratio of more than 20 dB with an associated gain of 16.0 dB. The VSWR is < 2 over 5.74 – 6.5 GHz frequency band. The gain variation is less than 2.5 dB over 5.725-6.4 GHz covering both WLAN band (5.725-5.875 GHz) and uplink C-band (5.9-6.4 GHz) for satellite communication.

The following sections deal with the antenna geometry, design theory and simulation results. Radiation pattern and impedance variation of antenna structures on infinite and finite ground plane are also described.

This article demonstrates gain and bandwidth improvement using Fabry-Perot Cavity without compromising on cross-polarization and F/B ratio. Gain as well as bandwidth is improved by resonating the MSA, parasitic patches and FPC at different but nearby frequencies. The different element of a structure resonating at different close by frequencies results in gain and bandwidth improvement. The antenna design and optimization have been carried out using commercial IE3D software [15].

2. ANTENNA GEOMETRY AND DESIGN THEORY

Bandwidth and gain improvement can be achieved using patches on a multilayer superstrate. Bandwidth enhancement is obtained using multi-resonator concept when the patches on multilayer superstrate are separated by about 0.1λ. Increase in gain is observed when the separation between patches exceeds 0.3 λ. The electric field at parasitic and feed patch are observed to be 180˚ out of phase when the separation between patches is approximately half a wavelength. Also it results in high gain broadside radiation pattern as the radiation from feed and parasitic patch are in phase as the patches are separated by λ/2.

A broadside directive radiation pattern results when the distance between the ground plane and PRS causes the waves emanating from PRS in phase in broadside direction. If the PRS reflection coefficient is ρejψ and normalized field pattern of feed antenna is f (α), then normalized electric field E and power S at an angle α to the broadside direction are given by [2]

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

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

Here, ϕ is the phase difference between adjacent waves emanating from PRS. Resonant distance Lr between ground plane and PRS for the waves emanating from PRS to be in phase in broadside direction is given by [2]

$$L_r = \left(\frac{\psi_0}{360} - 0.5\right)\frac{\lambda}{2} + N\frac{\lambda}{2} \tag{3}$$

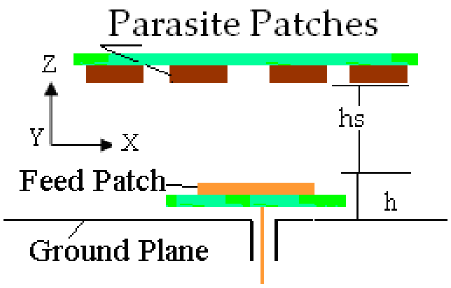
Here ψ0 is PRS reflection coefficient phase angle in degree and N=0, 1, 2, 3 etc.

Gain can be increased by increasing reflection coefficient. Since metallic patches are good reflector of microwave, therefore array of parasitic patches on a dielectric layer is used for gain improvement. High gain broadside radiation can be achieved if these patches are fed in phase. These parasitic patches are fed from the radiating field of microstrip antenna as shown in Fig.1. However, feed to each patch involves amplitude tapering as well as phase delay as the patches in an array are located at different distance from feed patch.

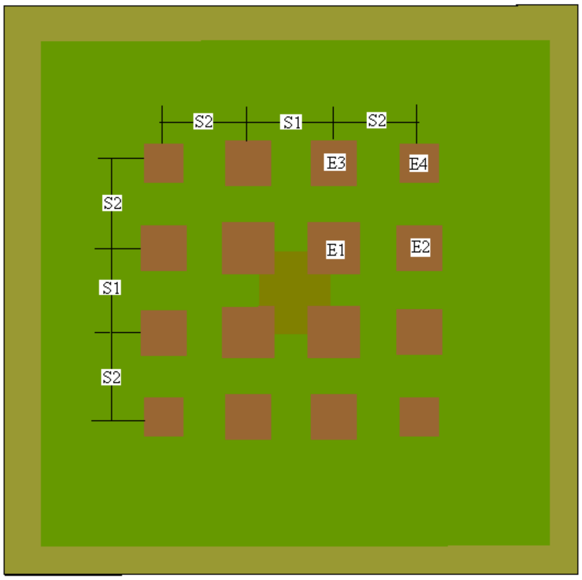
There is amplitude tapering due distance and the radiation pattern of microstrip antenna which feed the parasitic patches. Gain decreases due to amplitude tapering but it results in improvement in side lobe level.

The phase delay in feed to different elements located at different position is compensated by decreasing the length of an element corresponding to the feed delay so that parasitic elements radiate in phase resulting in directive broadside radiation pattern. The parasitic elements in an array are fed by the radiating field of feed patch as well as from the neighbouring elements. If the distance between parasitic patches is λ, then constructive mutual coupling between the patches results in high gain broadside radiation.

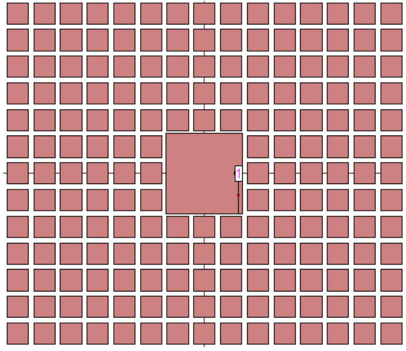
Now if we optimize MSA height, FPC height, inter-element spacing and parasitic patches dimensions so that different elements resonant at different frequencies close to central frequency. It results in broad impedance and gain bandwidth. Also reflection coefficient decrease which result in decrease in gain but increase in bandwidth.



(a) Side view



(b) Top view



(c) Top View of MSA with closely spaced patches

Fig. 1: Geometry of antenna structures

The geometry of the proposed antenna structure is shown in Fig. 1. The feed patch (FP) is fabricated on FR4 substrate and placed at 1.0 mm from the ground plane. Closely spaced square patches with less than 0.1λ x 0.1λ are fabricated near MSA to provide an inductive surface and to reduce gain variation. The square parasitic patches are located at a height 'hs' from the feed patch and fabricated on the bottom side of FR4 dielectric. The thickness, Relative permittivity and loss tangent of FR4 dielectric are 1.59mm, 4.4 and 0.02 respectively. This FR4 layer also acts as a radome to the antenna. To achieve high efficiency and wide bandwidth MSA is suspended in air. Air is also used as a dielectric medium between superstrate and feed patch. Feed patch is fed using a 50 Ω coaxial probe. The antenna is designed to operate over 5.725 – 6.4 GHz band. All dimensions mentioned here are in mm only. The structure is symmetrical and parasitic patches at same distance from the centre have same dimension in E or H plane.

3. ANTENNA DESIGN ON INFINITE GROUND

Initially, a suspended MSA on infinite ground plane with air spacing of 1 mm on a FR4 substrate is designed to operate over 5.725-6.4 GHz band. MSA provides gain of 6.4 dB. Then 2x2 square parasitic patch array (SPPA) are fabricated on 1.6 mm FR4 superstrate layer placed at about $\lambda_o/2$ above feed patch. The patch dimensions, spacing between the patches, feed patch dimensions and cavity height are optimised to obtain impedance bandwidth (VSWR< 2) of 5.725-6.4 GHz. Gain improves to 11.4 dB. The optimum dimensions are hs=25.3, h=2.6, E1=16 and S1=29.9. Also gain variation of less than 2 dB is obtained. Now 4x4 square parasitic patches are placed on the superstrate layer and the structure is optimized to obtain impedance bandwidth (VSWR< 2) of 5.725-6.4 GHz. antenna gain of 14.9 dB is obtained. The optimum dimensions are hs=2.2, h=26, E1=15, E2 = E3 =14, E4 =14, S1=30.0 and S2=26.9.The structure is modified and 4x4 mm square patches at 1 mm spacing are fabricated near MSA to provide an inductive surface and to reduce gain variation. Impedance variation of 2x2, 4x4 SPPA and modified 4x4 SPPA are shown in Fig. 2. Gain variation in modified 4x4 SPPA decreases as shown in Fig. 3.

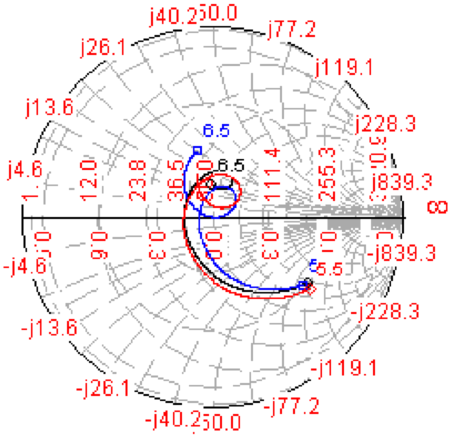


Fig. 2: Impedance variations vs. frequency
(—◆—2x2,—▫— 4x4, —◇— modified 4x4SPPA structures)

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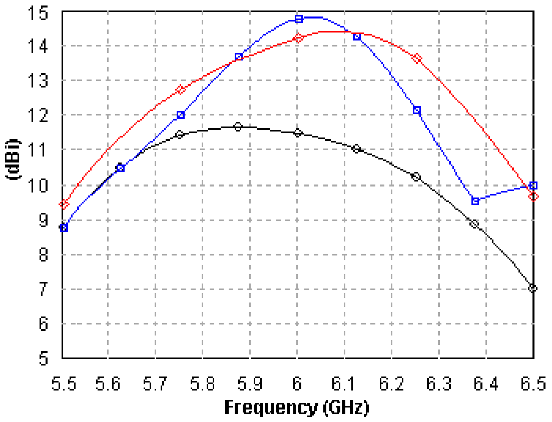
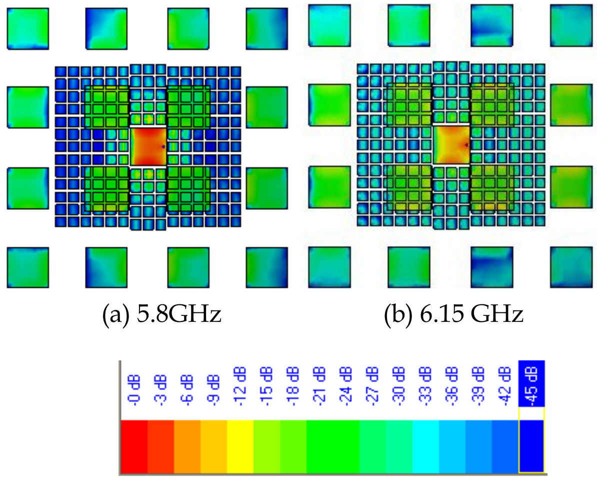


Fig. 3: Gain variations vs. frequency (—◆—2x2, —□—4x4, —◇— modified 4x4 structures)

Average current distribution at the feed and parasitic patches at 5.8 and 6.15 GHz frequency is shown in Fig. 4. The current distribution shows that the amplitude of current induced in parasitic patches decrease as its distance from feed element increases. 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, thus increases the effective aperture area, resulting in gain improvement [11-12].

4. ANTENNA DESIGN ON FINITE GROUND

The modified 4x4 SPPA structure is redesigned on finite ground plane of size 150mm x 150 mm. VSWR is < 2 is obtained over 5.725 – 6.5 GHz frequency band as shown in Fig. 5 The antenna provides 16.0 dB gain with less than 2.5 dB gain variation over 5.725-6.4 GHz covering WLAN band (5.725-5.875 GHz) and uplink C-band (5.9-6.4 GHz) for satellite communication. There is acceptable small radiation pattern variation over the entire 5.725-6.4 GHz band. Gain variations of structures on finite and infinite ground are shown in Fig. 6. It is observed that gain increases slightly with finite ground and HPBW decreases. It is due to constructive interference between radiated and reflected waves at particular dimensions of finite ground. Fig. 8 shows the radiation patterns on infinite and finite ground. Broadside radiation patterns are symmetrical with < -16 dB SLL, < -16 dB cross polarization and F/B ratio of about 20 dB.



(a) 5.8GHz (b) 6.15 GHz

Fig. 4: Current distribution of modified 4x4 SPPA

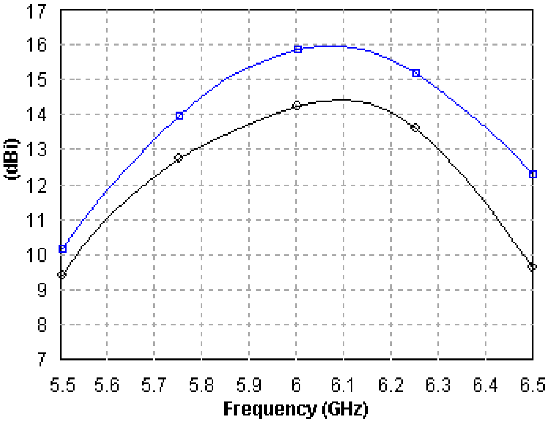


Fig. 5: Gain vs. frequency of 4x4 SPPA

(—◇— Infinite, —□—Finite Ground)

5. CONCLUSION

A low cost, high gain, wide band, easy-to-fabricate MSA fed antenna having low SLL and high F/B is proposed. MSA is placed in a FPC to enhance impedance and gain bandwidths. The MSA, parasitic patch dimensions, inter-element spacing, feed patch height and FPC height are the determining factor in improving gain and bandwidth of antenna. Beside this gain variation is reduced by fabricating an inductive surface near the MSA which compensate the phase change due to capacitive surface of superstrate. Resonating different elements of structures at different near resonance frequencies leads to an improvement in impedance as well as gain bandwidth. The proposed structure is a suitable candidate for satellite and terrestrial communications and can be embedded into the host vehicle.

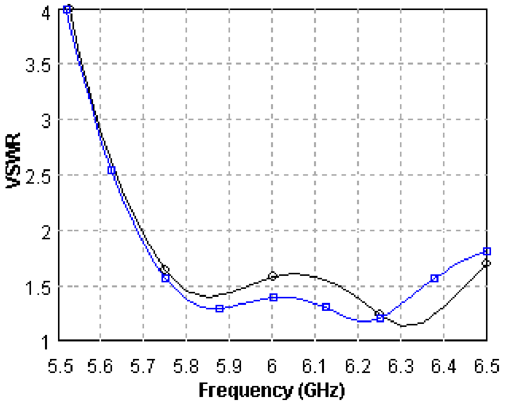
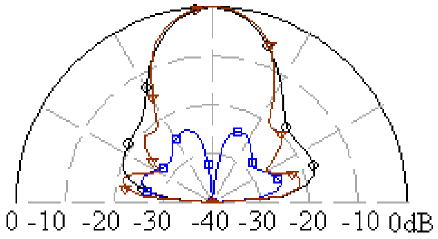
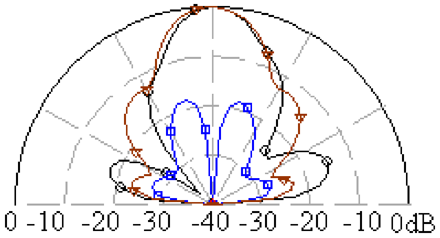


Fig. 6: VSWR vs. frequency

(—◇— Infinite, —□—Finite Ground)

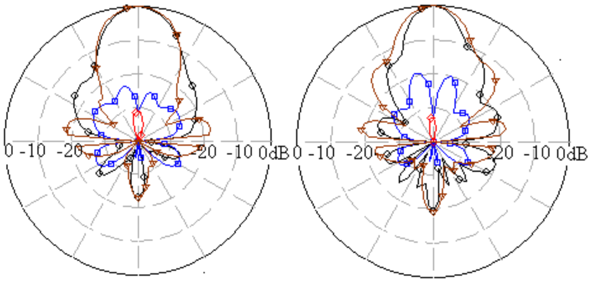


(i) 5.8 GHz



(ii) 6.15 GHz

(a) Infinite ground plane



(i) 5.8 GHz (ii) 6.15 GHz

(b) Finite ground plane (—◇— Eθ —◇— EΦ at Φ = 0°,—□—Eθ —▽— EΦ at Φ = 90°)

Fig. 7: Radiation patterns of modified 4x4 SPPA antenna

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