Improvement in Gain of MSA Fed Circular Polarized Antenna using Array of Parasitic Patches

Pratima Nirmal and Dr. Rajiv Kumar Gupta

Abstract: These paper present circular polarized microstrip antenna using array of parasitic patches on superstrate layer. parasitic patches are good reflector of microwave frequency hence it is used to enhanced the gain of antenna. The antenna structure consists of a microstrip antenna fabricated on FR4 substrate and placed at 1mm from ground. Circular polarization is obtained by diagonal feeding of microstrip antenna and using two shorting pins. In this paper we have presented improvement on gain of circular polarized antenna by using 1x1, 2x2, 3x3.4x4,5x5 array of parasitic patches fabricated on low cost FR4 superstrate. The printed MSA is fed by a 50 Ω coaxial probe. The VSWR is < 2 and axial ratio <3 over 5.725 – 5.875 GHz, ISM frequency band. The antenna provides increase in gain from 6 dB to 14 dB gain as we increase the array of parasitic patches from MSA 0 to MSA 5x5 over 5.725-5.875 GHz. The antenna structure also provides more than 70 % efficiency.

Keywords: Circularly Polarized antenna, Multilayer, High gain, MSA, PRS, Directive antenna.

1. INTRODUCTION :

An antenna has circular polarization if the field vector for the transmitted wave of the antenna has two orthogonal linear components with the same magnitude and phase difference between this is odd multiples of 90 degree. It produces an electromagnetic wave propagates in two planes creating a circular effect making one complete revolution in a single wavelength timeframe. It radiates both in horizontal as well as vertical direction.

In circularly polarized radiation the rotational orientations of the transmitter and the receiver antennas are unimportant in relation to the received signal strength. Also in CP, after reflection from metallic objects, the sense of polarization reverses from left-hand CP (LHCP) to right hand CP (RHCP) and vice versa to produce predominantly orthogonal polarization. The system then tends to discriminate the reception of such reflected signals from other signals arising from direct paths. Circular polarized antenna has a lot of advantage over linear polarized antenna such as :reflectivity , phasing issues ,multi-path , inclement weather , line of sight Therefore, CP is useful for a number of applications, such as radar, communication, and navigational systems.

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A Circularly polarized antenna can receive a horizontally polarized, vertically polarized or skew polarized signal at any angle at 3 dB loss compared to matched polarization. Circular polarization are of two types :Right hand polarized and Left hand polarized .If the rotation is clockwise looking in the direction of propagation, then antenna is called right-hand-circular antenna (RHC).If the rotation is counterclockwise, then antenna is called left-hand-circular antenna(LHC)..

Microstrip antennas (MSA) are one of the most useful antennas at microwave frequencies. These antennas have low profile, ease of fabrication, low cost, planar structure and ease of integration with monolithic microwave integrated circuits. It is used to generate both linear and circular polarization.MSA can also be modified to provide circular polarization.

Circularly polarized MSA (CPMSA) is obtained by using dual feed using a external two way 0˚ and 90˚ power divider . Circular polarization is also obtained by using a 3 dB two branch line coupler or by using an offset feed that provides a phase shift of 90˚ to two orthogonal modes. CPMSA is designed by using a single feed and modifying square MSA. These modifications involves using a nearly square, using stub, notches at two opposite edges of MSA, slots in MSA, trimming corners of MSA. However this antenna offers narrow axial ratio (AR) bandwidth and low gain.[1]

A suspended broadband CPMSA is reported [2]. The antenna provides 7.1% AR bandwidth, but the antenna provides 6.1 dB gain. A broadband high gain CPMSA is discussed in [3], The antenna provides 11% AR with 9.65 dB gain but the antenna requires a feed network. A novel 2 × 2 array antenna design with broadband and circularly-polarized (CP) operation is proposed [4].

A simple series-fed network is used to increase the CP bandwidth. AR bandwidth of 10% and 12 dBi gain are obtained. The antenna elements are fed by aperture feed and a feed line network. A novel circularly polarized microstrip antenna fed by coupled microstrip lines provides 10dBi gain but less than 2% AR bandwidth [5].

Gain enhancement techniques based on Fabry-Perot Cavity (FPC) have been considered to increase broad side directivity. A partially reflecting surface (PRS) formed by single or multiple dielectric layers or a periodic screen at integral multiple of λ/2 above a ground plane is used to increase directivity. The gain of PRS antenna depends on the reflection coefficient of PRS and feed antenna [6-10].

High gain microstrip array using a superstrate layer is proposed but it has the disadvantage of large inter-element spacing and low side lobe level (SLL) [11]. Three dimensional efficient directive antenna arrays fed in space using a single feed patch is proposed in [12]. The resulting array is planar and since the feed antenna is located behind the array, there is no aperture blockage but the structure has large thickness, more inter-element spacing and low SLL for small size arrays.

Metal plated MSA fed high gain antennas using parasitic patches on a superstrate offer high efficiency, low side lobe level and avoid feed network, but these antennas have to be fabricated mechanically [13-14]. High gain broadband antennas using stacked, multilayer or Fabry- Perot resonator structure are reported [14-18]. These structures provide high gain but linear polarization.

In this paper, circularly polarized microstrip antenna using an array of square parasitic patches on a superstrate layer is proposed. This paper present the antenna geometry and simulation results of an array of circular patches.

2. ANTENNA GEOMETRY AND DESIGN THEORY:

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. If reflection coefficient of the PRS is $\rho e^{j\psi}$ and f (α) is the normalized field pattern of feed antenna, then normalized electric field E and power S at an angle α to the normal are given by [2]

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

(1)

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

(2)

Where, ϕ is the phase difference between waves emanating from PRS. For the waves emanating from PRS to be in phase in normal direction, resonant distance L between ground plane and PRS is given by [2]

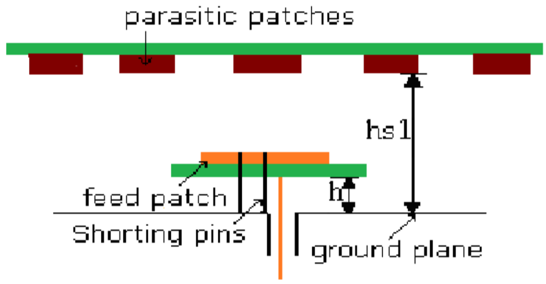
$$L_r = \left(\frac{\psi_0}{360} - 0.5\right)\frac{\lambda}{2} + N\frac{\lambda}{2}$$

(3)

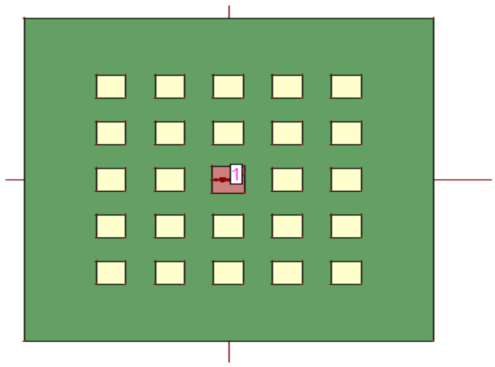
Where ψ0 is phase angle of reflection coefficient of the PRS in degree and N=0, 1, 2, 3 etc.

Gain can be increased by using array of parasitic elements on a superstrate layer. High gain broadside radiation can be achieved if the elements are fed in phase. The parasitic elements in an array are fed from the radiating field of microstrip antenna [12-13]. Dimensions of different parasitic patch are to be optimised to achieve high gain. Since the parasitic patches are positioned at different location and at different distance from feed patch. Hence feed to each element involves (a) amplitude tapering and (b) phase delay

Beside the amplitude tapering due to distance, there is additional amplitude tapering due to the radiation pattern of microstrip antenna. The amplitude tapering results in decrease in gain but it improves side lobe level. The phase delay in feed to different elements located at different position is compensated by detuning or decreasing the length of an element corresponding to the feed delay so that parasitic elements radiate in phase resulting in directive broadside radiation pattern. However, parasitic patches in the array, which are far from feed patch, receive less feed amplitude. Due to this mutual coupling effect of these elements decreases and they contribute less in radiation. Therefore, gain improvement decreases with increase in array size.



(a) Side view



b) Top view

Fig. 1 Geometry of antenna structure

The geometry of the proposed antenna structure is shown in Fig. 1. The MSA is fabricated on FR4 and placed at 1 mm from ground. The square parasitic patches are located at a height 'hs1' from the ground plane and fabricated on the bottom side of FR4 superstrate of thickness 1.59 mm. Relative permittivity and loss tangent of this superstrate is 4.4 and 0.02 respectively. The superstrate also acts as a radome to the antenna. To achieve high efficiency air is used as a dielectric medium between superstrate and feed patch. MSA is fed through a coaxial probe of 50 Ω. MSA is fed diagonally and two shorting pins along X axis on both side of the centre of MSA are used to generate circular polarization. The antenna is designed to operate over 5.725 – 5.875 GHz ISM band. All dimensions mentioned here are in mm only.

3. ANALYSIS ON INFINTE GROUND PLANE:

MSA is fabricated on infinite ground plane at an height of 1mm from the ground plane. The ground plane is perfectly reflecting plane. MSA dimensions are 14.5x15.1 and the feed patch is fed diagonally at (3.0 , 3.0) from the center of patch. Then two shorting pins are placed along X axis on both side of centre of MSA. Shorting pins are used to suppress the modes with no of variations and improve the quality of circular polarization thus produced. The superstrate layer is placed at an distance of λo/2 above it. An array of parasitc patches are placed below the superstrate layer to increase the gain of overall antenna structure. The MSA dimension, parasitic patch dimensions and spacing between parasitic patches, MSA height and FPC height are optimised in order to improve the gain of antenna.

Gain variation of MSA0, 1x1, 2x2, 3x3, 4x4 structures is shown in Fig. 2 (a) and 2(b). Axial Ratio variation and VSWR variation of 3x3, 4x4 and 5x5 is shown in Fig 3 and 4 respectively.

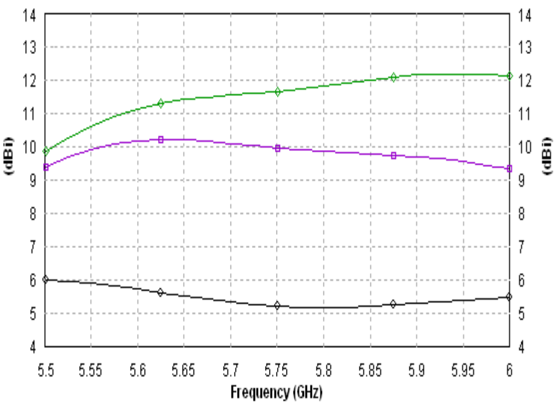


Fig 2 (a) Gain variations vs. frequency (— MSA0, — MSA 1x1, — MSA 2x2)

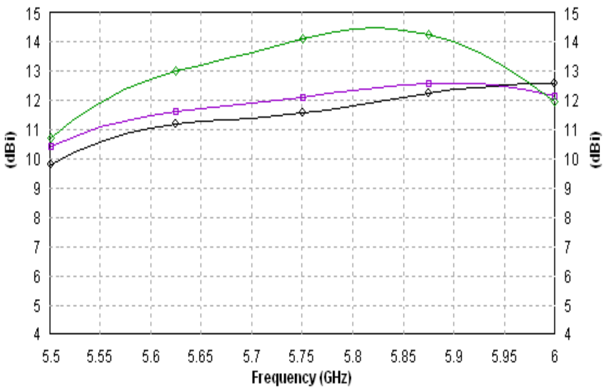


Fig.2 (b) Gain variation vs. .frequency (— MSA 3x3 —MSA 4x4, — MSA 5X5)

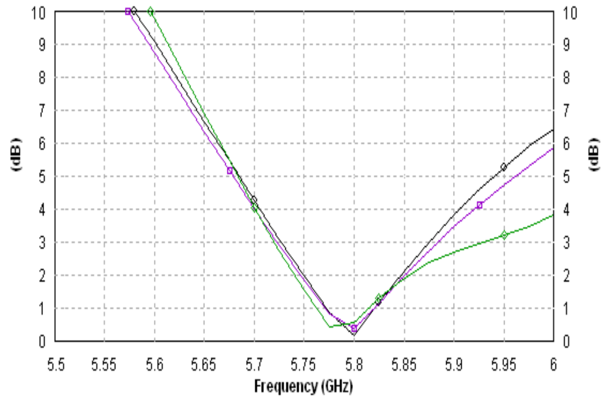


Fig.3 Axial ratio vs. .frequency (— MSA 3x3 —MSA 4x4, — MSA 5X5)

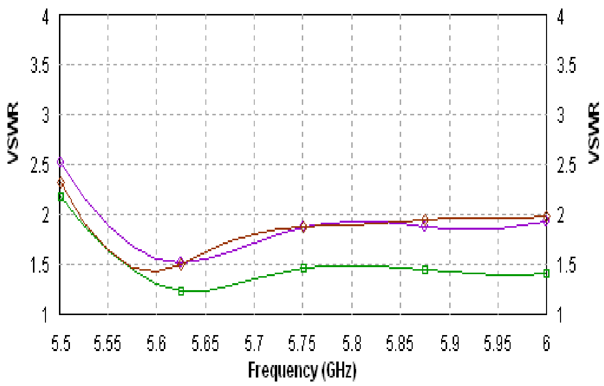
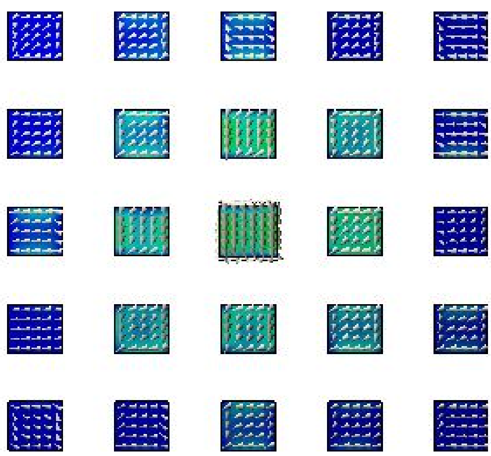
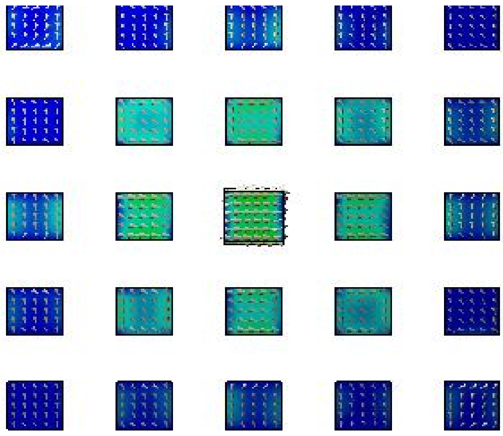


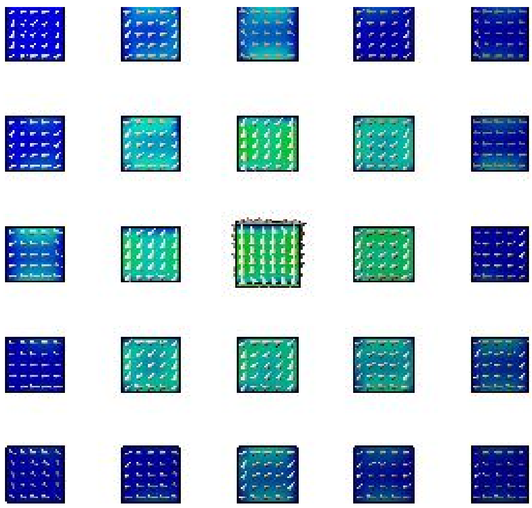
Fig.4 VSWR ratio vs. frequency (—MSA 3x3, — MSA 4x4 , — MSA 5x5)



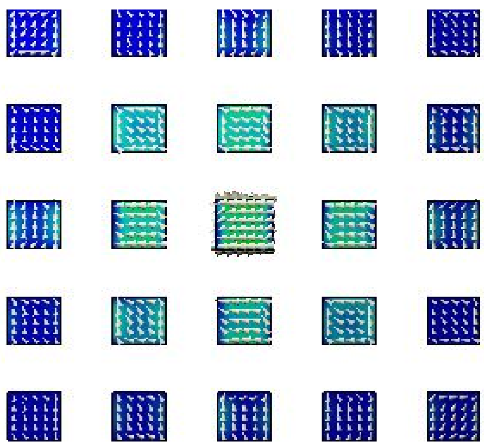
(a) t = 0



(b) t =0.25T



(c) t =0.5T



(d) t =0.75T

Fig. 5. Current distribution of 5x5 structure at 5.8 GHz

Fig. 5 shows average and vector current distribution at the feed and parasitic patches at 5.8 GHz at different time at t=0, 0.25T, 0.5 T and 0.75T, where T is time period of the wave at central operating frequency of 5.8 GHz. The current distribution shows that the fields rotates circularly and rotate clockwise by 90˚ to produce right hand circularly polarized waves. The current distribution shows that the amplitude of current induced in parasitic patches are nearly in phase and decrease as its distance from feed element increases.

4. CONCLUSION :

High gain Circular polarized antenna is proposed here. MSA antenna is placed in a Fabry perot cavity to enhance gain due to multiple reflection between ground plane and PRS. 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. There is increase in gain as we increase array of parasitic patches in superstrate layer .The proposed structure is suitable for satellite as well as terrestrial communications .

5. REFERENCES :

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

[2] V. G. Kasabegoudar and K. J. Vinoy, “A broadband suspended microstrip antenna for circular polarization”, Progress in Electromagnetic Research, vol. 90, pp. 353-368, 1990.

[3] P. Wang, G. Wen, J. Li, Y. Huang, L. Yang, and Q. Zhang, “Wideband circularly polarized UHF RFID reader antenna with high gain and wide axial ratio beamwidths, Progress in Electromagnetic Research, vol. 129, pp. 365-385, 2012.

[4] Tuan-Yung Han, “Series-Fed Microstrip Array Antenna with Circular Polarization”, International journal of Antenna and Propagation, vol 2012 pp. 1-5, 2012.

[5] YANG Xue-Xia and JIANG Chao, “Circularly Polarized Microstrip Antenna with High Gain and Low Profile”, IEEE International Symposium on Antenna and Propagation APSURSI, pp. 3106-3108, 2011.

[6] G. V. Trentini, Partially reflecting sheet arrays, *IRE Trans. Antennas Propag.* 4, 1956, pp. 666–671.

[7] A. P. Feresidis and J. C. Vardaxoglou, High gain planar antenna using optimized partially reflective surfaces, *IEE Proc. Microw. Antennas Propag* 148, 2001, pp. 345–350.

[8] Renato Gardelli, Matteo Albani, and Filippo Capolino, Array thinning by using antennas in a Fabry–Perot Cavity for gain enhancement, *IEEE Trans. Antennas Propag* AP- 54, 2006, pp. 1979–1990.

[9] Antonije R. Djordjević and Alenka G. Zajić, Optimization of resonant cavity antenna, European Conference on Antennas and Propagation, 2006.

[10] E.A. Parker, “The gentleman’s guide to frequency selective surfaces”, *17th Q.M.W. Antenna Symposium*, London, April 1991.

[11] W. Choi, Y.H. Cho, C. Pyo and J. Choi, High Gain Microstrip Patch Array Antenna using a Superstrate Layer, ETRI journal,Vol. 25, no.5, Oct. 2003.

[12] P.N.Chine and Girish Kumar, “Three Dimensional, Efficient, Directive Microstrip Antenna Arrays,” IEEE *Int. Symposium Antenna and Propagation.* Washington DC., July 2005.

[13] 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.

[14] 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.

[15] 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.
[16] H. Legay and L. Shafai, A new stacked microstrip antenna with large bandwidth and high gain, *Proc. IEEE AP-S Int. Symp.*, 1993, pp. 948–951.
[17] Egashira S., Nishiyama E., Stacked microstrip antenna with wide bandwidth and high gain, *IEEE Trans. Antennas Propag,* 44, 1996, pp. 1533-1534.
[18] Lee R.Q., Lee K.F., Experimental study of two layer electromagnetically coupled rectangular patch antenna, *IEEE Trans. Antennas Propag.*, 38, 1990, pp. 1298-1302.
[19] IE3D release 12.0, Zeland software Inc., Fremont, CA.,USA,2006

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