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Gain and Bandwidth Enhancement of Circularly Polarized MSA using RIS and FPC Resonator

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Abstract: *This paper presents high gain wide bandwidth circularly polarized (CP) microstrip antenna using reactive impedance surface (RIS) and Fabry Perot Cavity (FPC) resonator. A suspended CP microstrip antenna (MSA) is fabricated on FR4 substrate and placed 1.5 mm above ground plane. A RIS consisting of 7×7 array of 4 mm square patches with inter-element spacing of 1 mm is fabricated on the bottom side of FR4 substrate. RIS backed substrate improves impedance matching, bandwidth, gain and efficiency of antenna. This CP MSA is placed in a FPC resonator to enhance the gain of the antenna. 1×1 to 5×5 array of square parasitic patches are fabricated on a FR4 superstrate to form the partially reflecting surface (PRS) of FPC. The PRS is placed at about $\lambda_0/2$ from ground plane. MSA is fed by a 50 Ω coaxial probe. Axial ratio < 3 dB is obtained over 5.725 - 5.875 GHz ISM WLAN frequency band. The antenna with 5×5 square parasitic patches provides 15.6 dBi gain. The gain variation is less than 2 dB over the entire band. The antenna also provides SLL and cross polarization < -15 dB, front to back lobe ratio > 20 dB with > 70 % antenna efficiency. The antenna structure is fabricated. The measured results agree with the simulation results. The antenna can be a suitable candidate for WLAN access point in communication system.*

Keywords: *High Gain, Circular Polarization, MSA, PRS, Reactive Impedance Surface, Directive Antenna*

I. Introduction

Todays modern wireless communication industry, MSA antennas are the most important components required to create a communication link. Microstrip antenna (MSA) structures are used as they can be easily integrated with microwave monolithic integrated circuits (MMICs) used in radar, satellite, and other microwave communication systems.Linear Polarized Microstrip antennas (MSA) have low profile, less cost, easy to fabricate and integrated with monolithic microwave integrated circuits, but these have the drawbacks terms of gain, narrow bandwidth, low efficiency but circular Polarized Microstrip antennas can be designed in a variety of shapes to perform different functions and can be altered to enhance gain, bandwidth and high efficiency.[1]

circularly polarized waves when two orthogonal field components with equal amplitude but in phase quadrature are radiated. It produces an electromagnetic wave that propagates in two planes which creat circular effect making one complete revolution in a single wavelength timeframe.CP MSA bandwidth can be improved by low dielectric constant substrate. .[1-3]

Reactive impedance Surface (RIS) which is also known as meta-surface or artificial magnetic surface is used to enhance the performance of low profile CPMSA.[14].RIS consists of closely spaced array of square patches on a dielectric substrate. In RIS periodicity of patches is smaller than that of PRS. The periodicity of patches is much smaller than a wavelength in RIS. RIS suppress the surface waves and reduces the coupling between ground and patch. RIS improves the band width, radiating performance and also miniaturize the size of antenna [12-13].The one probe-fed circularly polarized (CP) microstrip patch antenna is placed at the center as the driven antenna and is gapped coupled to the remaining elements and performance of the patch can be proved by properly arranging these parasitic elements.[7]A circularly polarized array antenna on a curved surface with high gain is reported. The array, which can perform circular polarization operation, is constructed on a curved plane. The measured 3dB AR bandwidth is 53%. The proposed antenna has wide bandwidth and high-gain. The antenna gain is significantly enhanced to 20 dBi by the introducing of the multiple arrays. The structure is designed for WLAN band [8].

A small sized, low-profile, UHF antenna on RIS with high radiation efficiency which is achieved over 420–450 MHz is reported. RIS has the ability to reflect total power like perfect electric or magnetic conductors (PEC or PMC) surfaces as well as stores magnetic or electric energy. Miniaturization is obtained by combining the reactive characteristic of the RIS with the capacitive or inductive input impedance of antenna and hence the antenna resonates at lower frequency [6] Fabry-Perot cavity (FPC) resonator is enhanced to increase broad side directivity. FPC consists of a partially reflecting surface (PRS) and ground plane. PRS is formed by single or multiple dielectric layers. Air is used as a dielectric medium between superstrate and feed patch to obtain better efficiency. The structure is fed by an antenna. The overall bandwidth of such antenna depends on the reflection coefficient of PRS [9-11].

In this paper, a CP MSA with RIS is used to enhance the gain and bandwidth of the antenna. RIS is segregate the surface waves and coupling between the ground plane and MSA. FPC resonator improved the Gain of antenna. Rectangular MSA with RIS layer and 5x5 parasitic patch array on a superstrate layer offers 14.6 dBi gain with < 2 dB gain variation over 5.725 – 5.875 GHz ISM band. The antenna provides SLL and cross polarization < -20 dB with antenna efficiency > 70% and > 20 dB front to back lobe ratio. The following sections presents the antenna geometry and design theory, simulation results, fabrication and measurement results.

II. Antenna Geometry And Design Theory

A FPC consists of a perfectly reflecting ground plane and a PRS and fed by an antenna. Partially transmitted waves in phase results in directive radiation pattern. Assuming $\rho\, e^{j\psi}$ and f (α) are reflection coefficient of PRS and normalized field pattern of feed antenna respectively, then power (S) variation with angle α to the normal are given as [9]

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

Where, ϕ is the phase difference between the 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 [9]

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

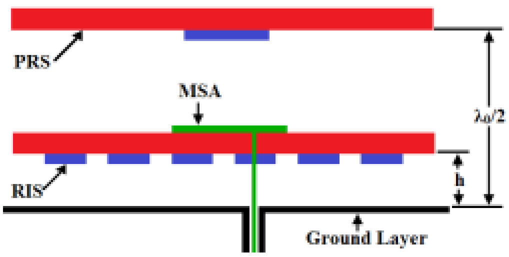
Where ψ_0 is phase angle of reflection coefficient of the PRS in degree and N=0, 1, 2, 3 etc. Gain and bandwidth of such antenna is given by,

$$G = 1 + \rho / 1 - \rho, \quad BW = \frac{\Delta f_{1/2}}{f_0} = \frac{\lambda}{2\pi L_r}\frac{1-\rho}{\sqrt{\rho}} \qquad (3)$$

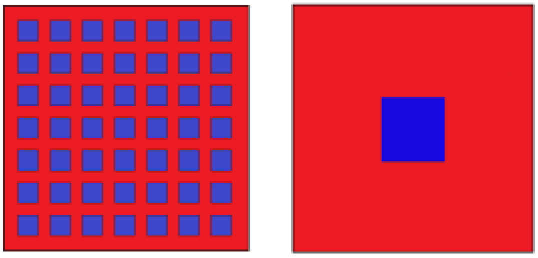
Gain can be increased by increasing the reflection coefficient of PRS. However, as gain increases bandwidth of antenna decreases. As metallic patches are good reflector of microwave frequencies, therefore, gain can be increased by using array of parasitic elements on a superstrate layer. Dimensions and spacing between parasitic patches are to be optimized to obtain high gain. Since the parasitic patches are positioned at different location and at different distance from feed patch. Hence feed to each element involves amplitude tapering. Amplitude tapering in feed reduces SLL.

For better the gain and bandwidth, a Circular MSA is fabricated on top side of a dielectric substrate and a RIS consisting of an 7×7 array of 4 mm square patches and inter-element spacing of 1mm with a periodicity < 0.1 λ_0, is fabricated on the bottom side of substrate and is used to feed a FPC resonator. Here λ_0 is the wavelength in air at the central operating frequency of antenna. RIS is an inductive layer and thus reduces the resonant frequency and therefore, miniaturises the size of antenna. RIS layer improves efficiency due to decrease in interaction between antenna and substrate resulting in decrease in surface waves and dielectric loss. RIS also improves impedance matching. As a result, printed antenna on RIS can provide wideband with compact size.

The geometry of the antenna structure is shown in Fig. 1(a). The Rectangular MSA fabricated on top side of FR4 substrate is placed at height of 1.5 mm from metal plated ground plane. A RIS, as shown in Fig. 1(c), consisting array of square patches of side 4 mm with inter-element spacing of 1 mm is fabricated on other side of FR4 substrate. The antenna structure is fed through a coaxial probe of 50 Ω. simulated on finite ground plane using method of moment based IE3D 14.0 simulator.



(a) Geometry of proposed antenna



(c) Reactive Impedance Surface (d) 1×1 square parasitic patches

Figure 1. Geometry of antenna structure

III. Analysis on Ground Plane

The suspended MSA structure with RIS layer on 60 mm square ground plane is designed and optimised. The structure termed as CPMSA has dimensions of 12.9 x15.0 mm and fed diagonally to provide circular polarization. 3 dB axial ratio (AR) bandwidth of 214 MHz (5.676-5.890 GHz) and 7.9 dBi gain with gain variation < 1 dB over 5.676-5.890 GHz is obtained. Its return loss, S_{11}< -10dB is obtained over 5.5 - 6.0 GHz. Now 1.6 mm FR4 superstrate layer is placed at about 0.5 λ_0 above the ground plane and structure termed as MSA-0 is optimised. MSA-0 provides 8.3 dBi gain while its axial ratio, AR< 3 dB is obtained over 5.706-5.950 GHz. Since RIS reduces the interaction between ground plane and substrate one need to modify the feed position to obtain the optimum impedance bandwidth and gain. RIS layer also miniaturises the dimensions of MSA patch.

Now a square patch or 1×1 to 6×6 arrays of square parasitic patches are fabricated on the superstrate to enhance the gain of antenna. CPMSA-1×1 on 80 mm square ground plane provide gain of 11.2 dBi with gain variation is < 0.5 dB. AR < 3 dB is obtained over the 5.72-5.885 GHz. CPMSA-2×2 on 100 mm square ground plane provide gain of 13.4 dBi with gain variation is < 1 dB. AR < 3 dB over the 5.724-5.904 GHz. Ground plane is increased by $\lambda_0/2$ (25 mm) with increase in the array size forming PRS. MSA-3×3 provide gain of 14.1 dBi with gain variation is < 1 dB. AR < 3 dB over the 5.693-5.937 GHz. MSA-4×4 provide gain of 14.6 dBi with gain variation is < 1 dB. AR < 3 dB over the 5.696-5.978 GHz. MSA-5×5 provide gain of 14.6 dBi with gain variation is < 1 dB. AR < 3 dB over the 5.708-5.990 GHz. MSA-6×6 provide gain of 14.1 dBi with gain variation is < 1 dB. AR < 3 dB over the 5.704-5.961 GHz Return loss of these structures are shown in Fig. 2, while Axial ratio and gain variation of these structures are shown in Fig. 3.

The impedance bandwidth and gain of the antenna depend on height of the superstrate layer, dimensions of the parasitic patches and the spacing between the parasitic patches. Dimensions of MSA patch are also optimised as reflections from PRS affect the impedance of MSA patch forming the feed array. SLL and cross polarization also depend on the dimensions of feed patch array and parasitic patch array. Impedance of structures with finite ground plane becomes more inductive as compared to structures with infinite ground plane. Therefore air gap between the FR4 substrate and ground plane is reduced to obtain the desired impedance bandwidth and gain

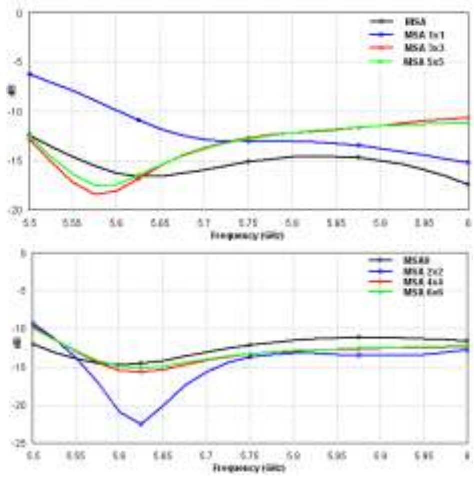


Figure 2. Return loss of structures

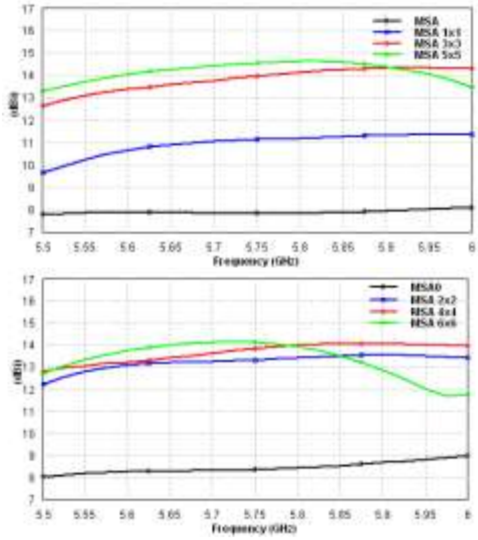
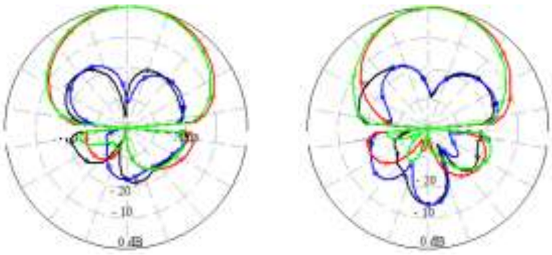
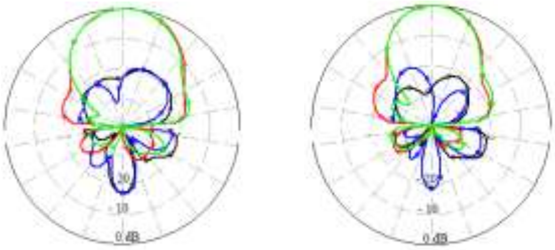


Figure 3. Gain variation of structures on finite ground plane

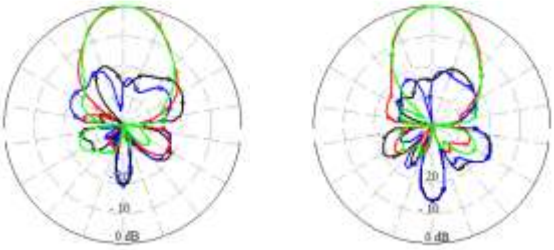
Radiation patterns at 5.8 GHz is shown in Fig. 4. Radiation patterns of MSA-6x6 has SLL < -20 dB and cross polarization < -20 dB and F/B lobe ratio > 20 dB. Radiation parameters of structures at 5.8 GHz is tabulated in Table 1 and Antenna Efficiency shown in fig. 5.



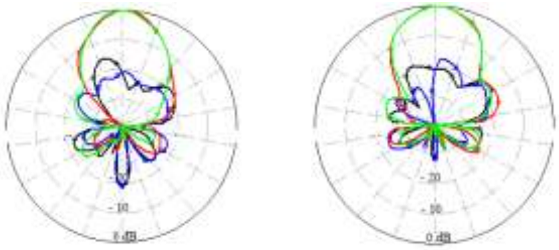
(i) MSA (ii) MSA0



(iii) MSA-1×1 (iv) MSA-2×2



(v) MSA-3×3 (vi) MSA-4×4



(v) MSA-5×5 (vi) MSA-6×6

(a) 5.8 GHz

Figure 4. Radiation pattern of structures on finite ground at 5.8 GHz

(— E_θ — E_φ at $\varphi = 0°$ and — E_θ — E_φ at $\varphi = 90°$)

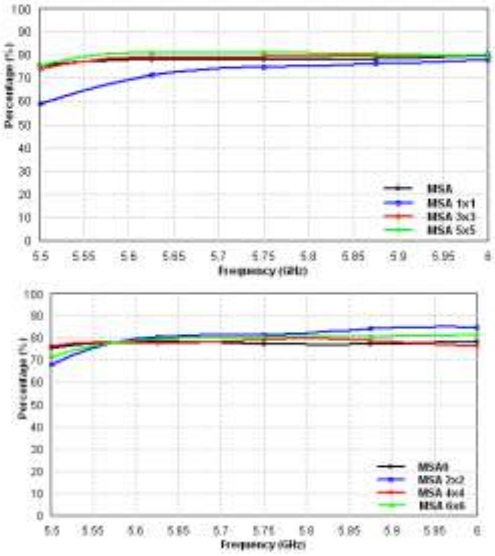


Figure 5.Efficency of structures on finite ground plane

Table 1: Radiation parameter of structures on finite ground at 5.8 GHz

S. No	Structure	Gain dBi	SLL dB	Cross Pol dB	F/B lobe ratio
1	MSA	7.9	-21.3	-24.5	21.4
2	MSA-1×1	11.2	-20.1	-21.4	18.7
3	MSA-3×3	14.1	-19.7	-18.5	20.1
4	MSA-5×5	14.6	-22.8	-16.6	21.2
5	MSA0	8.3	-23.4	-18.8	13.3
6	MSA-2×2	13.4	-19.6	-19.8	21.5
7	MSA-4×4	14.6	-14.8	-19.6	14.7
8	MSA-6×6	14.1	-24.4	-18.9	27.8

IV. Fabrication And Measurement Results

A prototype structure of MSA with RIS and 1x1 parasitic patch array as shown in Fig. 9 is fabricated and tested. Return loss is measured using Agilent 9916 A network analyzer. The measured and simulated results are shown in Fig. 10. The measured results agree with the stimulation results. The variation in measured and simulation results may be due to fabrication error, error in feed position and alignment error in substrate and superstrate layer.

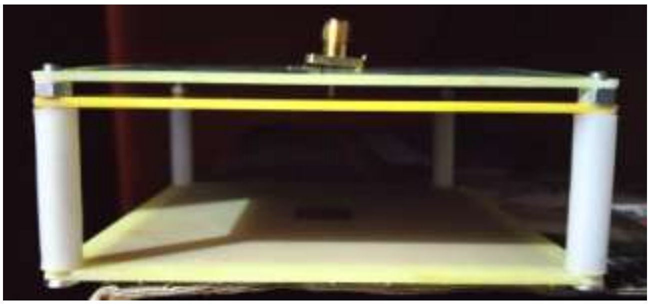


Figure 6. Photograph Side view of structure

V. Conclusion

High gain wide band antenna structures using a CP MSA with RIS in a Fabry perot cavity are designed. The MSA structures with square parasitic patches on FR4 superstrate layer offers gain of 14.6 dBi with gain variation < 2 dB over 5.696-5.978 GHz frequency band. The antenna offers SLL and cross polarization < -20dB and F/B lobe ratio > 20 dB and antenna efficiency > 70%. The structures can be a good candidate for long distance communication systems.

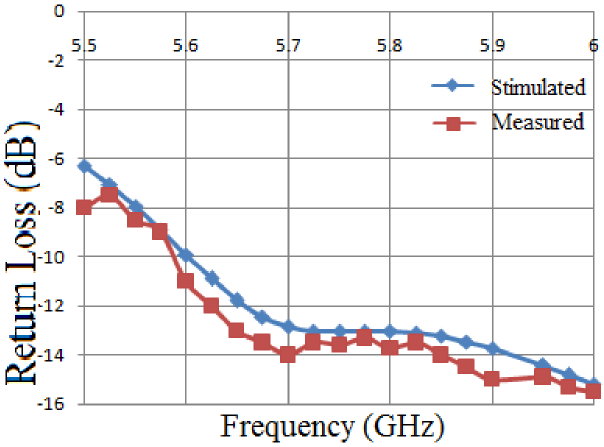


Figure7. Measured return loss of prototype 1×1-RIS structure

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