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GAIN AND BANDWIDTH ENHANCEMENT OF CIRCULAR MICROSTRIP PATCH ANTENNA USING A CIRCULAR GROOVE ETCHED RECTANGULAR METAL SHEET SUPERSTRATE

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Abstract

A design of gain and bandwidth enhancement of Circular Microstrip Patch Antenna (CMPA) has been presented employing a circular groove etched in a rectangular metal sheet used as superstrate. The proposed concept is unique, and simple as flexible approach to enhance the gain and bandwidth. A rectangular shaped foam spacer has been used to provide mechanical support to place an optimized groove etched rectangular metal sheet superstrate. The proposed antenna offers about 35.5% of impedance matching bandwidth ranging between 8.45 GHz to 12 GHz with a total bandwidth of 3.55 GHz, whereas a conventional circular patch, resonating at 9.95 GHz, hardly shows about 4.8% of impedance bandwidth (480 MHz) only with co-pol. peak gain of 7dBi. In addition to the enhanced bandwidth characteristics co-pol. peak gain of 10dBi is maintained throughout the operating frequency band. There is 3dBi gain enhancement is achieved when compared to conventional CMPA. For the experimental validation, a set of antenna prototype has been fabricated using the commercially available dielectric substrate. The measured result shows similar with the simulated predictions.

Keywords:

Bandwidth, Circular Patch Antenna, Circular Groove, Superstrate

1. INTRODUCTION

The rapid development in the field of microwave wireless communication systems, biomedical research, space science and radar technology needs a huge demand on the bandwidth [1]-[4]. Microstrip patch antennas (MPAs) are widely used because of its small size, light weight, and low profile [5]-[8]. However, MPAs also have some limitations compared to other conventional microwave antennas, such as narrow bandwidth, low gain, large ohmic loss in the array, and radiation of energy mostly to half space. Among them, main drawback is the narrow bandwidth, which limits the use of MPAs from many practical applications

In the last few years, the MPAs researchers trying to increase bandwidth using different techniques such as using parasitic patches in single layer, multilayer configurations [9]-[10], stacked and parasitic patches [11]-[15], increasing the thickness of the substrate [16], decreasing the substrate dielectric constant [17]-[19], employing electromagnetic band gap structures [20]-[21], loading chip resistor [22], metal sheet [23], using split ring resonator [24]. However, these proposed MPAs configurations are made by adding additional structure so that their structures become more complex. Still now the superstrate layer concept is applied for the enhancement gain in MPAs [25]. But they are not attractive as their profiles are not very low.

In this paper, low-profile wideband circular patch antenna (CMPA) has been proposed employing a circular groove etched rectangular metal sheet used as superstrate. Rectangular foam is fixed by rubber adhesive material to the patch and then the metal superstrate is also fixed on the other side of foam surface. It gives mechanical support hold the superstrate rigidly on the patch of CMPA. The proposed design is very simple, low cost and easy to fabricate. About 10dBi gain is revealed over entire band of frequencies with high co-pol. to cross-pol. and 35.5% impedance bandwidth has been revealed which is found to be much improved compared to a conventional CMPA without using superstrate (bandwidth~4.8%).

The performance of the conventional and the proposed antennas have been thoroughly studied [26]. The prototypes of the proposed antenna with and without circular groove rectangular metal sheet have been fabricated and measured. A close agreement between the simulated and measured data has also been revealed.

2. ANTENNA CONFIGURATION

A superstrate loaded circular microstrip patch has been designed and analysed systematically also every design step has been thoroughly described below.

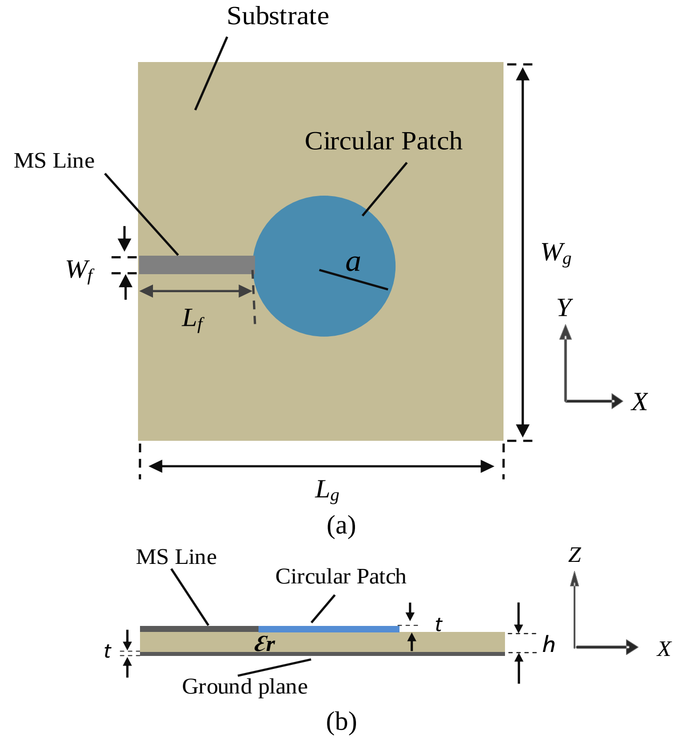


Fig.1. Schematic diagram of a strip-fed circular microstrip patch antenna (CMPA), (a) top view of the conventional CMPA, (b) side view of the conventional antenna

2.1 METHODOLOGY

Step 1: The dimension of a conventional circular microstrip patch antenna is estimated using the cavity model analysis discussed in [1]-[2]. All optimum design parameters are obtained by series of simulations using a commercial simulator [HFSS].

Step 2: A circular groove rectangular metal sheet is used as a superstrate and is symmetrically placed on the patch with some dielectric support made of foam material. The length, width, of the metal sheet is optimized using simulator. The circular groove radius, and thickness and its height from the ground plane are optimized based on its effect on CMPA.

Step 3: Prototypes are fabricated using RT-Duriod substrate with the latest PCB fabrication technique.

Step 4: Finally the simulation predictions are validated by a series of experiments in well-established EM laboratory

2.2 ANTENNA DESIGN AND CONFIGURATION

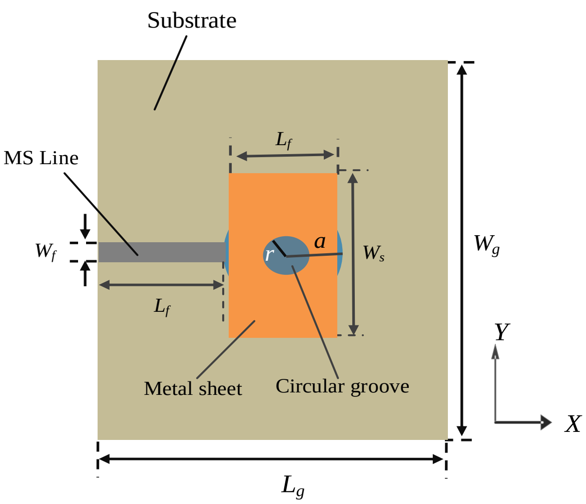
The Fig.1(a) and Fig.1(b) shows the microstrip-fed circular patch antenna designed following the guideline of [1]-[2]. The patch dimensions and dielectric substrate (RT-Duriod, ε_r = 2.2 and thickness h = 1.6 mm) are selected to resonate at 10 GHz. The circular patch radius (a) has been calculated using the approximate relation [1].

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{0.5}} \quad (1)$$

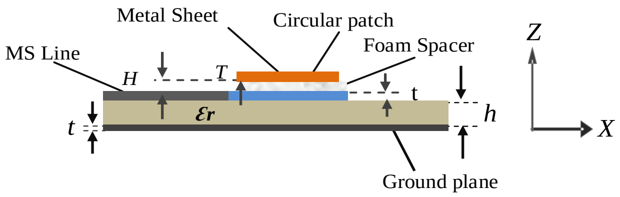
where,

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

where, f_r is the resonant frequency, ε_r is the dielectric constant of the substrate, and h is the substrate height.



(a)



(b)

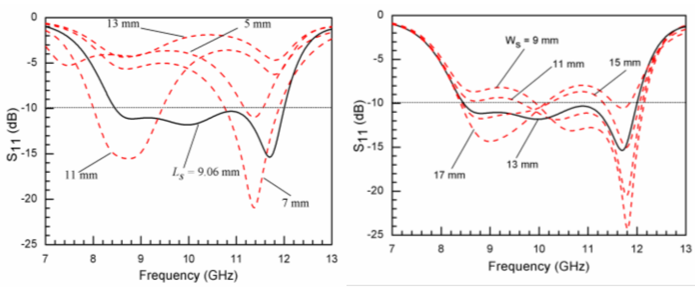
Fig.2. Schematic diagram of a strip-fed circular microstrip patch antenna (CMPA), (a) top view of the proposed CMPA, (b) side view of the proposed antenna

This conventional CMPA has been treated as the reference antenna which is actually resonating at 9.95 GHz after being tested using simulator [26].

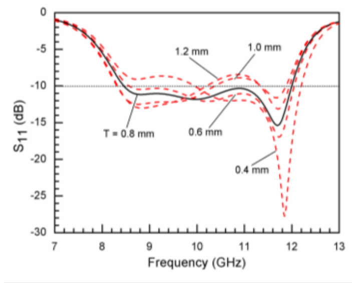
The proposed antenna has been realized by employing a circular groove etched rectangular metal sheet firmly placed above the conventional circular patch. The top and side view of the proposed MPA is as shown in Fig.2(a) and Fig.2(b) respectively. The superstrate is mechanically supported by a dielectric foam spacer with a gap (~λ/8) maintained between the patch and the ground plane. The length, width, position and thickness, circular groove of the metal sheet has been optimized using [26]. Optimization procedures are elaborately discussed in the section 2.3.

2.3 PARAMETRIC STUDIES

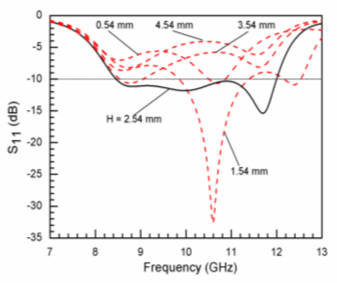
A series of simulation studies has been performed to optimize the length, width, thickness, circular groove, and height of the superstrate. All such parametric studies are presented in Fig.3 using simulated S_{11} characteristics of the proposed antenna. Fig.3(a) shows the effect of superstrate length (L_s) antenna bandwidth. L_s = 9.06 mm appears to be the optimum length of the superstrate to produce maximum antenna bandwidth. Similarly, parametric study for the superstrate width (W_s) has been studied in Fig.3(b) keeping L_s = 9.06 mm. W_s = 13 mm is found to be the optimum width of the superstrate. Similarly, superstrate height (H) and thickness (T) are optimized through S_{11} characteristics plotted in Fig.3(c) and Fig.3(d) respectively. Optimized parameters are T = 0.8 mm and H = 2.54 mm. The Fig.3(e) shows circular groove radius r = 0.9 mm. This optimization has been performed based on the All optimized dimensions are shown in Table.1.



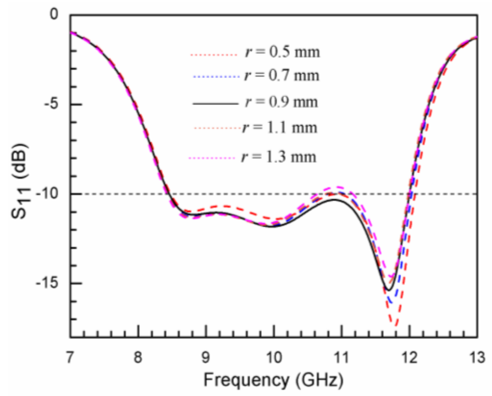
(a) (b)



(c)



(d)

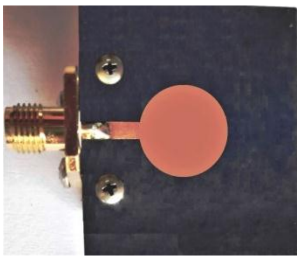


(e)

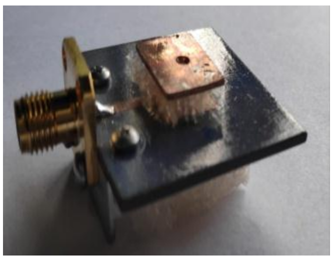
Fig.3. Comparison of simulated S_{11} properties of the antenna for the variation of different superstrate dimensions. Parametric studies for superstrate: (a) length (L_S), (b) width (W_S), (c) thickness (T), (d) height (H), (e) circular groove etched radius (r)

Table.1. Optimized Antenna Parameters

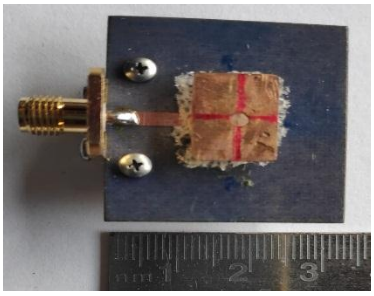
Parameters	**Optimized value (mm)**	**Parameters**	**Optimized value (mm)**
L_g	30.27	W_f	1.2
W_g	33.06	L_f	10.3
W_S	12.0	r	0.9
L_S	9.06	T	0.8
a	5.4	H	2.54
t	0.035	h	1.6



(a)



(b)



(e)

Fig.4. Fabricated antenna prototypes. (a) Top view of the conventional CMPA, (b) perspective view of the proposed antenna, (c) top view of the proposed antenna

3. EXPERIMENTAL DISCUSSIONS

A set of antenna prototypes is fabricated for experimental validation as shown in Fig.4. Commercially available RT-Duriod substrate with ε_r=2.2 has been used for the antenna fabrication. A dielectric foam spacer (relative permittivity~1.1) has been used to provide mechanical support to the superstrate. A gap (~λ/8) is maintained between the patch and the metal sheet. Some synthetic rubber-based adhesive has been used to fix the metal sheet firmly with the patch. Agilent's N5230A vector network analyzer has been used for S_{11} measurement. Antenna radiation pattern has been measured using an automated anechoic chamber.

3.1 SIMULATED PREDICTIONS

The simulated S_{11} characteristics of the proposed and the conventional antenna are compared in Fig.5. The conventional antenna, resonating at 9.95 GHz, shows very good impedance matching but, can only be able to offer about 4.8% antenna bandwidth (480 MHz). A huge improvement in antenna bandwidth has been revealed just by placing a simple metal sheet superstrate above the reference patch. This offers about 35.5% matching bandwidth (S_{11}≤–10dB) ranging from 8.45 GHz to 12 GHz.

The proposed antenna, therefore, shows about 3.55 GHz total bandwidth. The wide bandwidth characteristic is due to the multiple resonances developed between the patch and the superstrate. In addition to the radiating circular patch, close resonances are due to the circular groove rectangular metal sheet and the cavity formed between the metal sheet and the ground plane. The metal superstrate is near field coupling with the primary radiating patch. Overlapping of such multiple resonances leads to a wider bandwidth with improved radiation characteristics. However, impedance matching performance is not much satisfactory over the bandwidth.

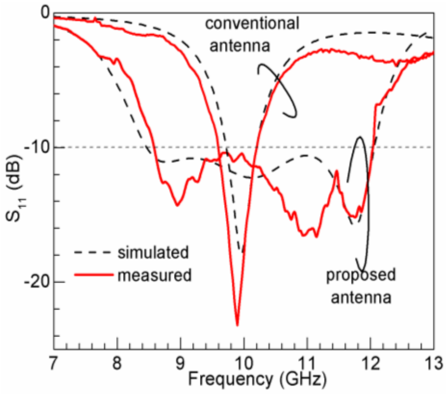
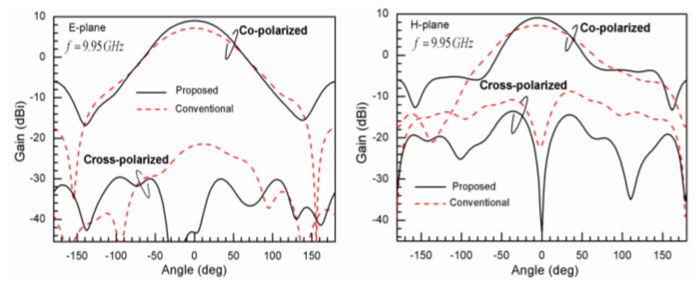


Fig.5. Measured S_{11} characteristics of the fabricated antenna prototypes compared with the simulated prediction



(a) (b)

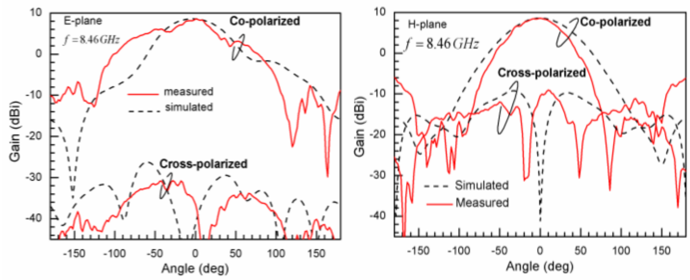
Fig.6. Comparison of simulated radiation patterns of the proposed antenna and the conventional CMPA at 9.95 GHz. (a) E-plane pattern and (b) H-plane patterns of the with their co-polarized and cross-polarized components

Simulated E- and H-plane patterns of the conventional and the proposed antenna are compared in Fig.6 at 9.95 GHz. Co-polarized (CoP) and cross-polarized (XP) gain components have been considered in this comparison. The reference antenna is a broadside radiator with about 7.01dBi peak-gain and about –19dB XP level (co- to cross-polarized isolation). On the other hand, with respect to the reference antenna, the proposed antenna shows about 3dB improvement in the peak-gain value along with a huge improvement in the broadside XP level (30dB). This improved predominately in the E-plane where the XP level maintained below 40dB over the angle of radiation. The radiation patterns of the proposed wideband antenna at different frequency values have been discussed in the next section through comparison with the measured data.

3.2 MEASURED RESULTS

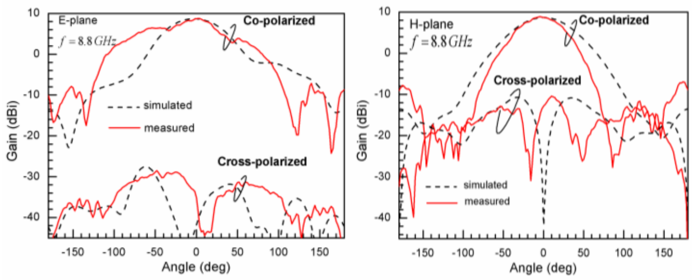
The measured S_{11} characteristics of the antenna prototypes (reference and proposed) are also compared in Fig.5 with the simulated data. The measured result shows a marginal improvement in impedance matching relative to the simulated data for both the prototypes. S_{11} minima of the proposed antenna observed around 8.8 GHz, 10 GHz, and 11.7 GHz indicates three close resonances due to the superstrate (L_s), the patch (a), and the cavity (H) respectively. However, the experimental data show a big shift in the second resonance towards the higher side. This may be due to some additional loading arises from the probe connected to the antenna.

The measured radiation patterns of the proposed antenna with their simulated results are also compared in Fig.7 - Fig.11 at five different frequency values (8.46 GHz, 8.8 GHz, 10 GHz, 11.7 GHz, and 12 GHz). E- plane and H-plane patterns are considered in this comparison with their co-polarized and cross-polarized components. Measured results are closely corroborated with the simulated predictions. The antenna maintains its broadside pattern with a co-polarized peak gain of 8.6dBi, 8.8dBi, 9.0dBi, 10.7dBi and 10.3dBi respectively at these four frequencies. As predicted, the cross-polarized radiations in H-plane are relatively higher than its value in E-plane. The E-plane cross-polarized isolation between Co-Pol and X-Pol is ranging between 35dB to 45dB over the matching bandwidth. The performance degrades slightly near 11.7 GHz and 12 GHz. The cross-polarized isolation for the H-plane is varying between 24dB to 35dB over the frequency. But radiation pattern of H- plane for over the entire frequency band at an angle 0^0 is lower about -50dBi.



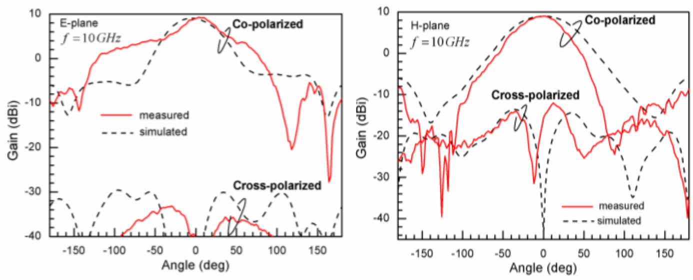
(a) (b)

Fig.7. Measured and simulated principal plane patterns of the proposed antenna at 8.46 GHz. (a) E-plane and (b) H-plane



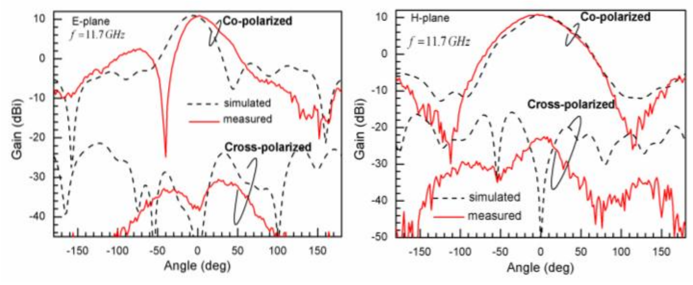
(a) (b)

Fig.8. Measured and simulated principal plane patterns of the proposed antenna at 8.8 GHz. (a) E-plane and (b) H-plane



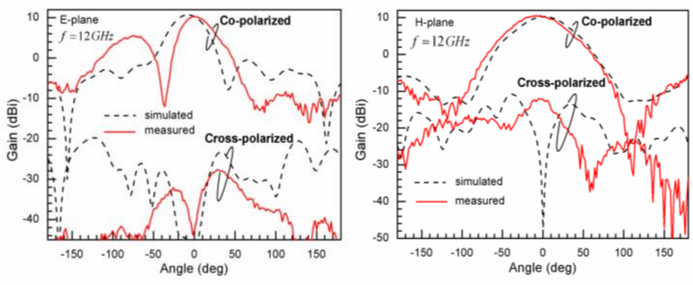
(a) (b)

Fig.9. Measured and simulated principal plane patterns of the proposed antenna at 10 GHz. (a) E-plane and (b) H-plane



(a) (b)

Fig.10. Measured and simulated principal plane patterns of the proposed antenna at 11.7 GHz. (a) E-plane and (b) H-plane



(a) (b)

Fig.11. Measured and simulated principal plane patterns of the proposed antenna at 12 GHz (a) E-plane and (b) H-plane

4. CONCLUSION

A new gain and bandwidth enhancement technique has been presented. A significant improvement in antenna bandwidth with improved cross pol radiations is successfully demonstrated by using a circular groove etched rectangular metal sheet superstrate. The proposed design appears to be very simple, low cost and easy for fabrication compared to other wideband designs using a patch. The broadside gain, low cross-polarization level and broadside radiation properties are satisfactory over the wide bandwidth. This antenna can be used for the wideband applications, especially in the X-band region. There is a potential scope to reduce the cross polarised radiations.

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