Wideband Design of Circular Microstrip Patch Antenna using Rectangular Metal Sheet Superstrate for X-Band Applications

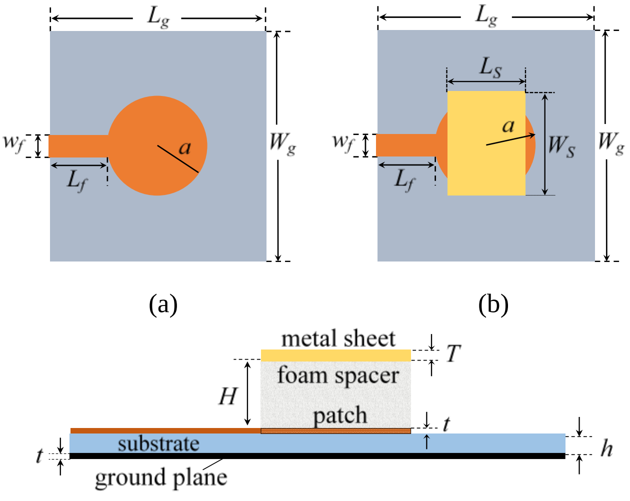
Chandrashekar K S, Chandramma S, Halappa Gajera, Koushik Dutta

Abstract**:** ***A wideband circular microstrip patch antenna (CMPA) has been presented employing a rectangular metal sheet superstrate. The proposed concept follows a unique, simple, and a flexible design approach to enhance the bandwidth of a circular patch. A simple change in the conventional antenna geometry has been suggested by adding a rectangular metal sheet superstrate, placed symmetrically above the patch. A cylindrical shaped foam spacer has been used to provide mechanical support to the optimized superstrate. The proposed antenna offers about 36% of impedance matching bandwidth ranging between 8.46 GHz to 12.06 GHz with a total bandwidth of 3.6 GHz. Whereas, a conventional circular patch, resonating at 9.96 GHz, hardly shows about 4.8% of impedance bandwidth (480 MHz) only. In addition to the enhanced bandwidth characteristics, the proposed antenna, also reveals a little increase in the gain throughout the operating frequency band. For the experimental validation, a set of antenna prototype has been fabricated using the commercially available dielectric substrate. The measured result is very closely agreed with the simulated predictions.***

Keywords**:** ***microstrip patch antenna, circular patch antenna, wideband antenna, wide bandwidth, superstrate.***

I. INTRODUCTION

The research and development in the field of microwave communication, biomedical engineering, space science, remote sensing, and radar technology need a huge demand on bandwidth [1–2]. Wideband antenna systems are therefore necessary for such applications. Microstrip patch antennas (MPAs) are being widely used by scientists for their advantageous features such as small size, lightweight, and low profile [3–4]. However, compared to other antennas, patch have some limitations such as narrow bandwidth, low gain, and low radiation efficiency. Among them, the narrowband feature of MPA primarily limits its practical use in wideband applications.



(a) (b)

(c)

Fig. 1. Schematic diagram of a strip-fed circular microstrip patch antenna (CMPA), (a) top view of the conventional circular patch, (b) top view of the proposed antenna, (c) side view of the proposed antenna. Parameters: L_g = 30.27, W_g = 33.06, a = 5.4, w_f = 1.2, L_f = 10.6, L_s = 9.06, W_s = 12, H = 2.54, h = 1.6, t = 0.03, T = 0.8, ε_r =2.2. (all dimensions are in mm)

In the last few decades, researchers are trying to increase the MPA bandwidth employing various antenna configurations. The patch antenna using a thicker substrate [5] with lower dielectric constant [6] was proposed as a wideband design approach. But such configuration possesses poor radiation efficiency. In addition to the primary radiating patch, various parasitic patch elements were used for multiple close resonances. Single-layer, multi-layer [7], and stacked configurations [8–9] are the most used designs using parasitic patches. Wideband performance of the patch antenna was also studied after employing electromagnetic bandgap structures [10–11], loading chip resistors [12], and split-ring resonators [13]. But, the performance of these antenna configurations [5–13] is not satisfactory in terms of their size, design complexity, gain over the bandwidth and cross-polarization purity. Various superstrate configurations were explored mainly to enhance the gain of a primary radiator such as patch [14], radiating-slot [15-16] and dielectric resonator antenna [17-19]. In addition to the gain enhancement, the antenna bandwidth has also been improved [17-19] significantly. But they are not attractive as their profiles are not very low.

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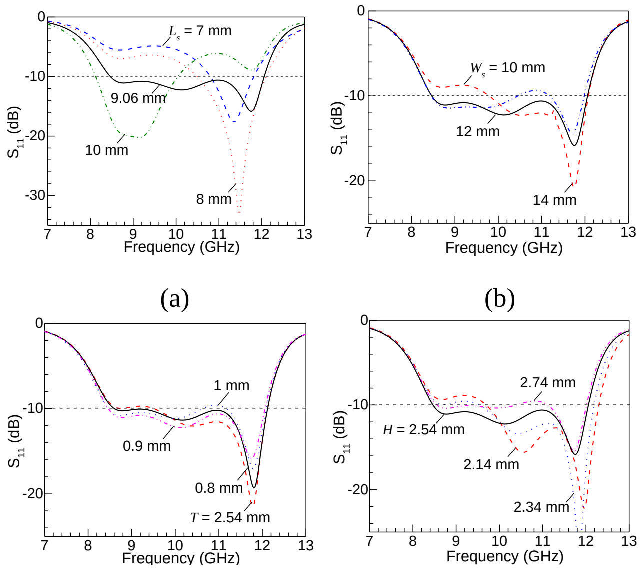


(a) (b)

(c) (d)

Fig. 2. 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). All other parameters are same as in Fig. 1.

In this paper, low-profile and wideband design of circular patch antenna (CMPA) has been proposed employing a rectangular metal sheet superstrate. A cylindrical dielectric post has been used to support the superstrate. The proposed design is very simple, cheap, and easy to fabricate. About 36% 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 [20]. The prototypes of the proposed antenna with and without metal sheet have been fabricated for experimental verification. The measured result is very close to the simulated data.

II. DESIGN PROCEDURE

A superstrate loaded circular microstrip patch has been designed following a systematic approach. Every design step has been thoroughly described below.

Table I 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	t	0.03
L_S	9.06	T	0.8
a	5.4	H	2.54

Methodology

Step-1:

The dimensions of a conventional circular patch are estimated following the cavity model analysis discussed in [1].

All design parameters are needed to be finalized using a commercial simulator [20].

Step-2:

A 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, and thickness of the metal sheet and its height from the ground plane are optimized.

Step-3:

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

Step-4:

Experimental and simulated results of conventional and proposed configurations are compared and validated.

B. Antenna Design and Configuration

Fig. 1(a) shows the microstrip-fed circular patch antenna designed following the guideline of [1]. 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].

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

where,

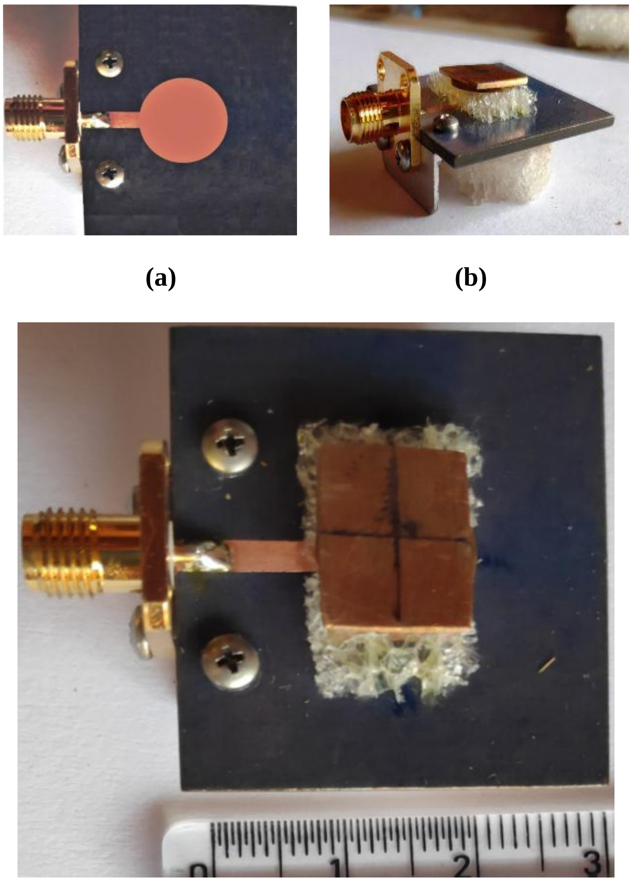
$$F=\frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \qquad (2)$$

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

This conventional CMPA has been treated as the reference antenna which is actually resonating at 9.96 GHz after being tested using simulator [20]. The proposed antenna has been realized by employing a rectangular metal sheet firmly placed above the conventional circular patch. The top and side view of the proposed MPA is as shown in Figs. 1(b) and (c) 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 of the metal sheet has been optimized using [20]. Optimization procedures are elaborately discussed in the section-III.

III. PARAMETRIC STUDIES

A series of simulation studies has been performed to optimized the length, width, thickness and height of the superstrate. All such parametric studies are presented in Fig.2 using simulated S_{11} characteristics of the proposed antenna.



(a) (b)

(c)

Fig. 3. Fabricated antenna prototypes. (a) top view of the conventional (reference) CMPA, (b) perspective view of the proposed antenna, (c) top view of the proposed antenna. Parameters as in Fig. 1.

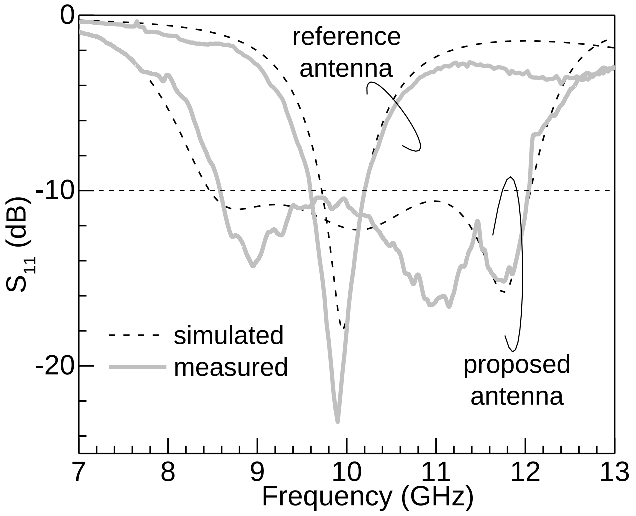
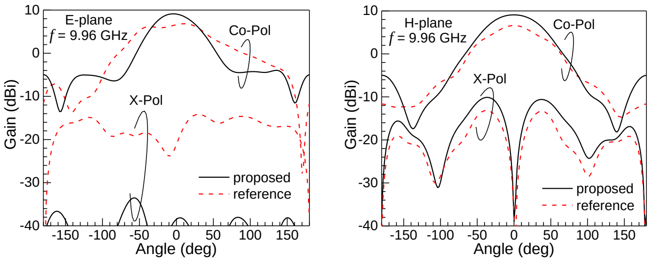


Fig. 4. Measured S_{11} characteristics of the fabricated antenna prototypes compared with the simulated prediction. All parameters as in Fig. 1.

Fig. 2(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. 2(b) keeping L_s=9.06 mm. W_s=12.0 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 Figs. 2(c) and (d) respectively. Optimized parameters are T=0.8 mm and H=2.54 mm. All optimized dimensions are shown in Table-I.



(a) (b)

Fig. 5. Comparison of simulated radiation patterns of the proposed antenna and the reference CMPA without metal-sheet superstrate at 9.96 GHz. (a) E-plane pattern and (b) H-plane patterns of the with their co-polarized (CoP) and cross-polarized (XP) components. Parameters as in Fig. 1.

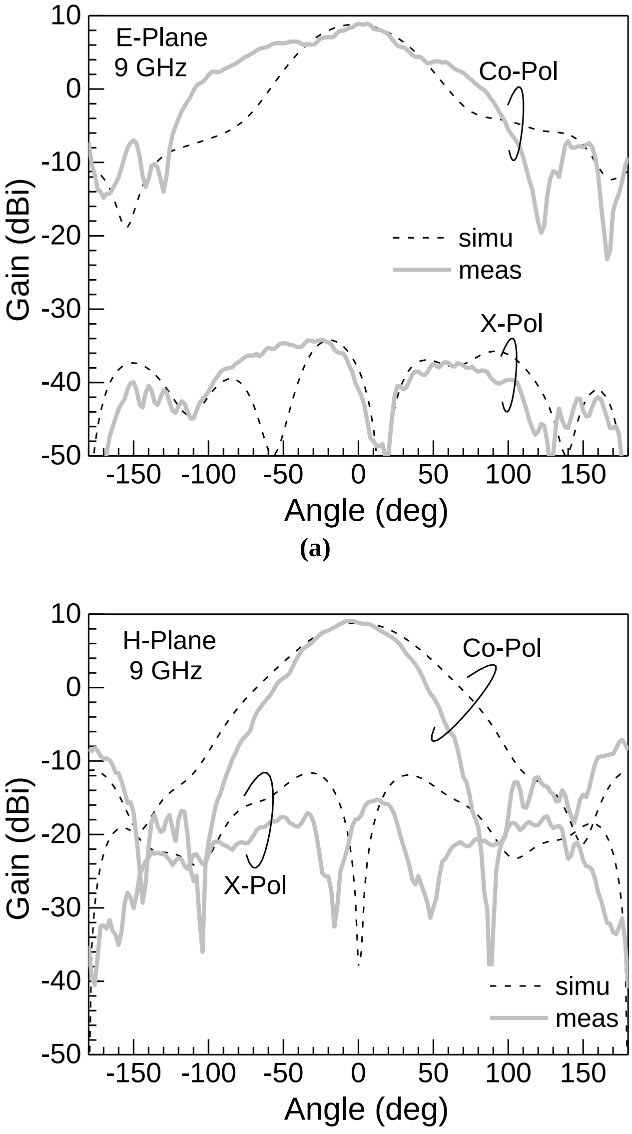
IV. EXPERIMENTAL VALIDATION

A set of antenna prototypes is fabricated for experimental validation as shown in Fig. 3. 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.

A. Simulated Prediction

Simulated S_{11} characteristics of the proposed and the reference (conventional) antenna are compared in Fig. 4. The reference antenna, resonating at 9.96 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 36% matching bandwidth (S_{11}≤–10 dB) ranging from 8.46 GHz to 12.06 GHz. The proposed antenna, therefore, shows about 3.6 GHz total bandwidth. The wide bandwidth characteristics 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 rectangular metal sheet and the cavity formed between the metal sheet and the ground plane. The metal superstrate is magnetically coupled (near field coupling) with the primary radiating patch. Overlapping of such multiple resonances leads to a wider bandwidth. However, impedance matching performance is not much satisfactory over the bandwidth.

Simulated E- and H-plane patterns of the reference and the proposed antenna are compared in Fig. 5 at 9.96 GHz. Co-polarized (CoP) and cross-polarized (XP) gain components have been considered in this comparison.



(a)

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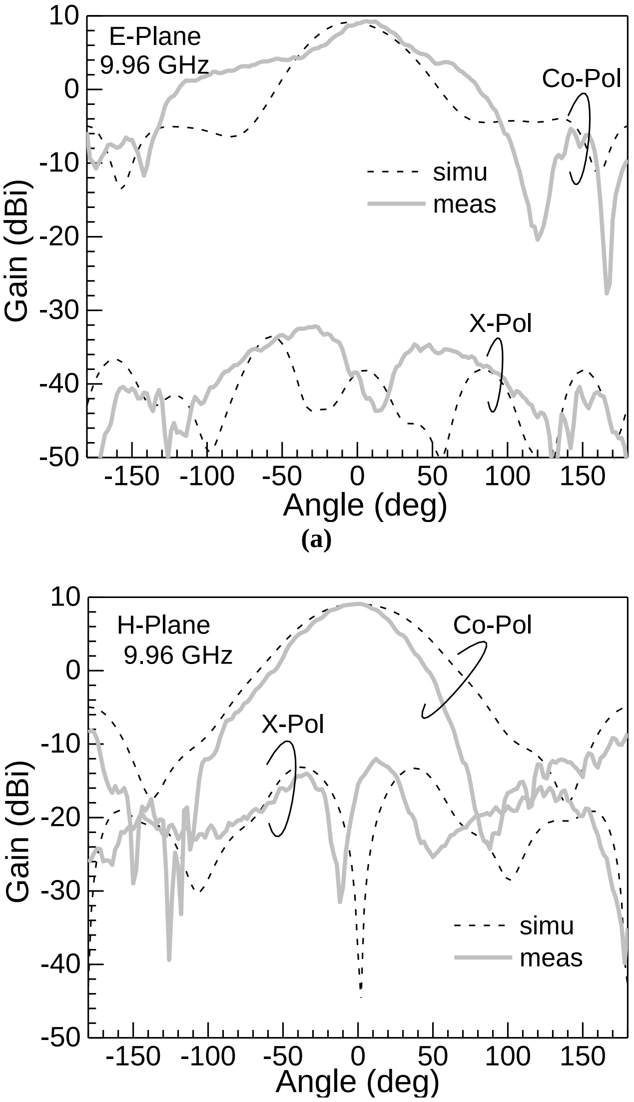
Fig. 6. Measured and simulated principal plane patterns of the proposed antenna at 9 GHz. (a) E-plane and (b) H-plane. Parameters as in Fig. 1.



(a)

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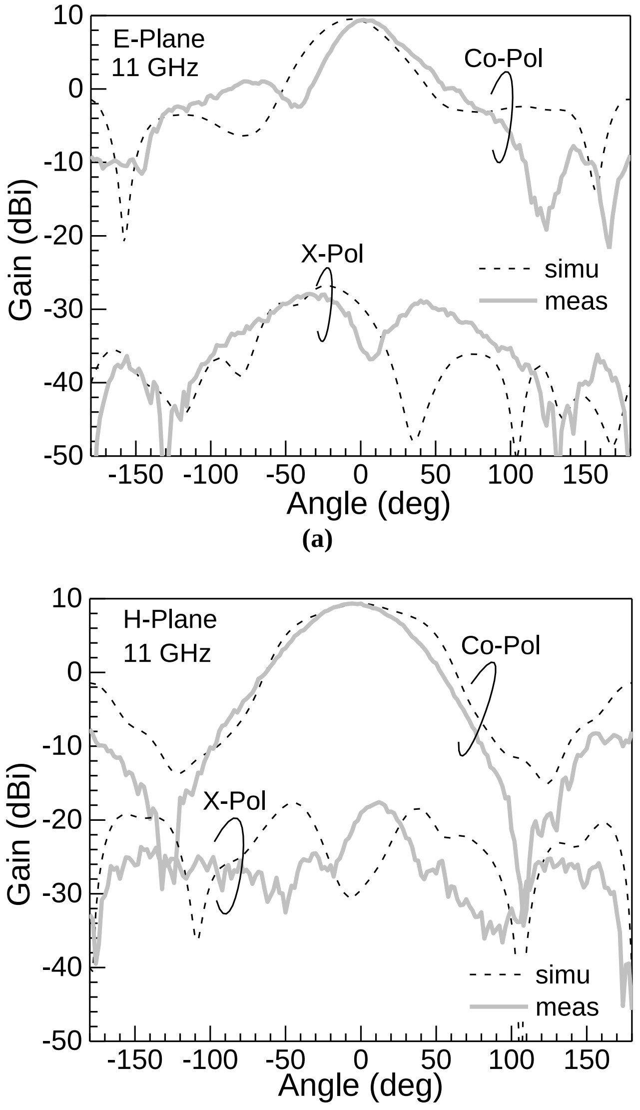
Fig. 7. Measured and simulated principal plane patterns of the proposed antenna at 9.96 GHz. (a) E-plane and (b) H-plane. Parameters as in Fig. 1.

The reference antenna is a broadside radiator with about 6.62 dBi peak-gain and about −18 dB XP level (co- to cross-polarized isolation). On the other hand, with respect to the reference antenna, the proposed antenna shows about 2.5 dB improvement in the peak-gain value along with a huge improvement in the broadside XP level (43 dB). This improved predominately in the E-plane where the XP level maintained below 45 dB 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.

B. Measured Result

The measured S_{11} characteristics of the antenna prototypes (reference and proposed) are also compared Fig. 4 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 9.95 GHz, 10.9 GHz, and 11.75 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 Figs. 6, 7, 8, 9 at four different frequency values (9 GHz, 9.96 GHz, 11GHz, and 12 GHz). E- 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 8.82 dBi, 9.08 dBi, 9.34 dBi, and 10.62 dBi 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 35 dB to 45 dB over the matching bandwidth. The performance degrades slightly near 11 GHz.



(a)

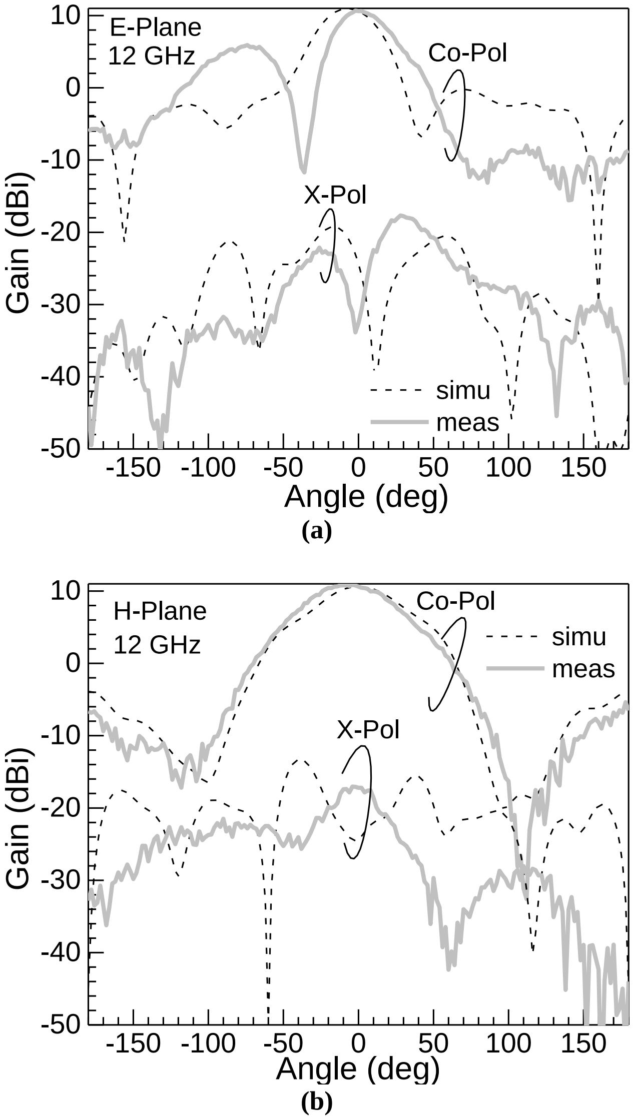
(b)

Fig. 8. Measured and simulated principal plane patterns of the proposed antenna at 11 GHz. (a) E-plane and (b) H-plane. Parameters as in Fig. 1.

The cross-polarized isolation for the H-plane is varying between 24 dB to 35 dB over the frequency.

V. CONCLUSION

A new bandwidth enhancement technique is presented. A significant improvement in antenna bandwidth has been successfully demonstrated by using a rectangular metal sheet superstrate. The proposed design appears to be very simple, cheap, and easy for fabrication compared to other wideband designs using a patch. The broadside gain, cross-polarization level and other radiation properties are satisfactory over the wide bandwidth. This antenna may be used for the wideband applications, especially in the X-band region. Poor impedance matching performance is the only drawback of such a wideband antenna. There is a potential scope of further improvement by exploring various patch and superstrate configurations.



(a)

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Fig. 9. Measured and simulated principal plane patterns of the proposed antenna at 12 GHz. (a) E-plane and (b) H-plane. Parameters as in Fig. 1.

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