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Design of Microstrip Patch Antenna for Dual-band Operation using Metal Ring Superstrate

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Abstract*: *In this paper, a dual-band generation in rectangular microstrip patch antenna (RMPA) using a superstrate metal ring has been proposed. In this configuration, a metal ring is placed above the rectangular patch with the support of two dielectric posts. The metal ring behaves as a superstrate layer and resonator for the lower band, the other band is generated by microstrip patch and hence the combined configuration metal ring and patch gives dual-band characteristics. The lower band resonates at 9 GHz with an impedance bandwidth of 6.8% and higher band at 11.35 GHz with impedance bandwidth of 3.1%. The co-polarized peak gain values at these frequencies are 8.2 dBi and 10.1 dBi respectively. This may be used in applications like airborne and naval-radar. The prototypes are fabricated using commercially available dielectric substrate (RT-Duriod ε_r = 2.2 and thickness h =1.6 mm). The measured results show good agreement with the simulated predictions.

Keywords*: *dual-band, microstrip patch antenna, metal ring, superstrate.

I. INTRODUCTION

Microstrip patch antenna (MPA) is popular because of its attractive characteristics such as lightweight, low profile, low cost, easy fabrication, compatibility to MMIC and broadside radiations [1-2]. The MPAs have been widely used for most of the wireless communication applications. Various superstrate geometries were reported in the literature for the enhancement of MPA characteristics, but their configurations are complex [5-17]. A circular MPA was designed with stubs to generate dual-band for L-band applications [5]. The circularly polarized S-shaped slotted patch antenna for dual-band is reported in GPS applications [6]. The technique of stacked-patch was also used for the generation of dual-band [7]. The compact single layer, dual-band microstrip antenna for satellite applications was reported in [8]. An electromagnetic bandgap (EBG) layer as superstrate was used to generate the dual-band with gain enhancement [9]. A high-gain microstrip patch antenna was proposed using EBG [10] for dual-band operation. Two spiral resonators were used for medical applications [11]. A dual-band circular-MPA with stubs was proposed for L-band applications [12]. Superstrate layers as a meta-resonator were demonstrated utilizing the stacking technique [13]. A dual-band design of circular patch with an annular ring was proposed for medical applications [14]. A spiral patch as an EBG superstrate was also discussed in [15]. The dual-band design was realized based on a different strategy where microstrip mode and annular slot mode are combined and used for GPS applications [16]. A coupled-fed stacked microstrip patch antenna was used for WLAN applications [17]. Most of these antenna configurations were complex due to some additional structures.

In this paper, a new and simple design of rectangular microstrip patch antenna (RMPA) is proposed for dual-band operation. A metal ring superstrate (diameter ~ λ/2) is placed above the patch supported by two dielectric posts using some rubber adhesive material. This proposed configuration is mechanically robust and perfect for X-band applications. Simulated results of the proposed antenna are presented using [4]. The prototypes of the proposed antenna with and without metal ring are fabricated and measured. The simulated and measured results are in good agreement.

II. DESIGN PROCEDURE

A. Methodology

1. A conventional rectangular microstrip patch antenna (RMPA) is designed using the transmission line model (TLM). The designed antenna is simulated using [4].
2. A circular metal ring placed on the patch with the support of dielectric posts and simulated using [4]. Metal ring dimensions such as inner radius, outer radius, thickness and height are optimized.
3. Prototypes are fabricated using RT-Duriod substrate with the latest PCB technique.
4. Experimental and simulated results of conventional and proposed configurations are compared and validated.

B. Antenna Design and Configuration

A conventional quarter-wave transformer-fed rectangular microstrip patch antenna (QWT-MPA) is designed using the guidelines of [1-2]. The conventional QWT-MPA is resonating at 9.7 GHz using a dielectric substrate

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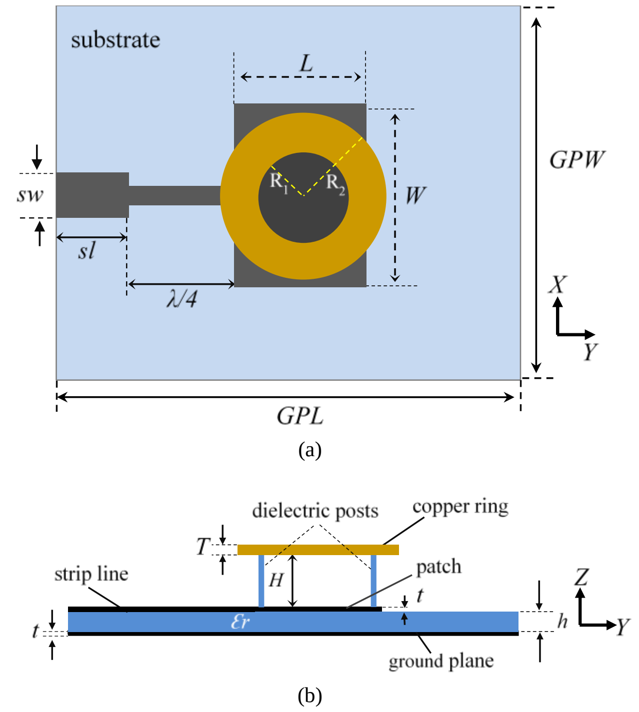


Fig. 1. Schematic diagram of the QWT fed rectangular microstrip patch antenna. (a) Top view of a proposed MPA, (b) side view of a proposed MPA Parameters: *GPL* = 30.26, *GPW* = 33.06, *W* = 11.85, *L* = 9.06, *sl* = 5.3, *sw* = 3.4, R_1 = 3, R_2 = 5.8, ε_r = 2.2, *h* = 1.6, *t* = 0.03, *H* = 0.74, *T* = 0.8, (all dimensions are in mm)

(RT-Duriod ε_r = 2.2 and thickness *h* =1.6 mm).

The length (*L*) and width (*W*) of the patch are calculated using the following relations [1-2]:

$$W = \frac{c}{2 f_r \sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2} \quad (2)$$

$$\Delta L = 0.412h\left[\left(\frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} - 0.258}\right)\left(\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8}\right)\right] \quad (3)$$

$$L = \frac{c}{2 f_r}\left(\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\sqrt{\left[1 + 12\frac{h}{W}\right]}\right)^{-\frac{1}{2}} - 2\Delta L \quad (4)$$

where *c* is the velocity of light, ε_r is the dielectric constant of the substrate, ΔL is the correction factor of effective length and ε_{reff} is effective dielectric constant.

The proposed configuration consists of a conventional QWT-MPA and a metal ring are firmly placed above the patch by cylindrical-shaped dielectric support. The dielectric posts are firmly fixed between the patch and the ring using some synthetic rubber-based adhesive material. The air gap of λ/8 is maintained between the patch and the metal ring.

TABLE I: PARAMETERS OF THE PROPOSED ANTENNA

Para-meters	Optimized value (mm)	Para-meters	Optimized value (mm)
GPL	30.26	R_2	5.8
GPW	33.06	***sl***	5.3
W	11.85	***sw***	3.4
L	9.06	***T***	0.8
R_1	3.0	***H***	0.74

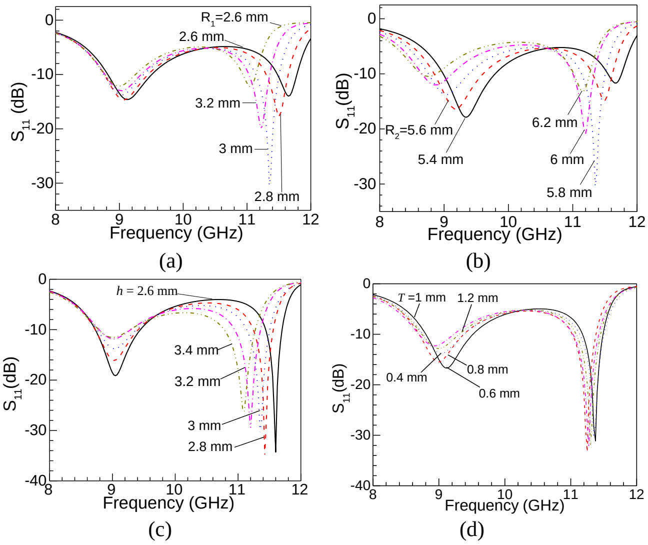


Fig.2. Simulated S_{11} characteristics of the antenna due to the variation of metal-ring dimensions: (a) Inner radius (R_1), (b) Outer radius (R_2), (c) Height (*H*), (d) Thickness (*T*). Other parameters are as in Fig. 1.

The top and side view of the proposed MPA is shown in Fig. 1(a) and (b) respectively. The radius, position, and thickness of the ring are finalized by optimization. The details of optimization procedures are discussed in the section-III. All dimensions of the proposed configurations are given in Table-I.

III. PARAMETRIC STUDIES

The effect of varying metal ring parameters such as inner radius, outer radius, thickness, and height of a proposed antenna has been investigated through the optimization process**.** Initially, a circular patch (radius ~ 6 mm) has been used as the superstrate and placed above the rectangular patch. But this cannot produce any dual-band characteristics. A dual-band behaviour has been realized using a ring-shaped superstrate only. This has been realized by reshaping the circular patch into a ring. The dimensions of the ring such as R_1, R_2, the thickness of the ring (*T*) and the position of the ring above the patch and the height (*H*) have been finalized by a series of simulation studies as shown in Fig 2. The optimized dimensions of the metal ring are found to be R_1=3 mm, R_2 = 5.8 mm, *H*= 0.74 mm, *T*= 0.8 mm.

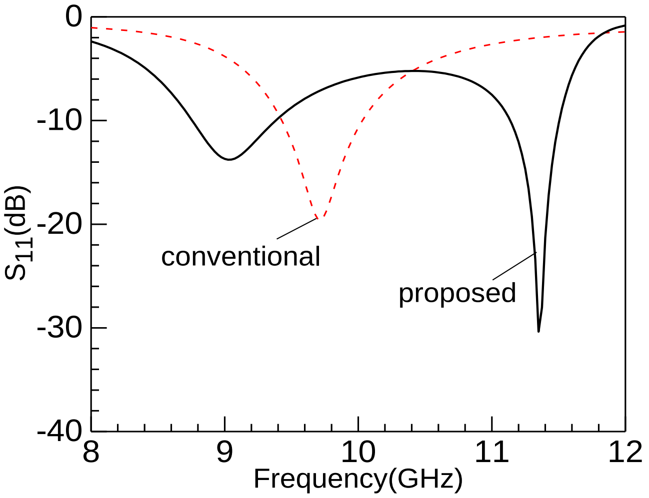


Fig. 3. Comparison of simulated reflection coefficient characteristics of the antenna for with and without the metal ring. Parameters are same as in Fig. 1.

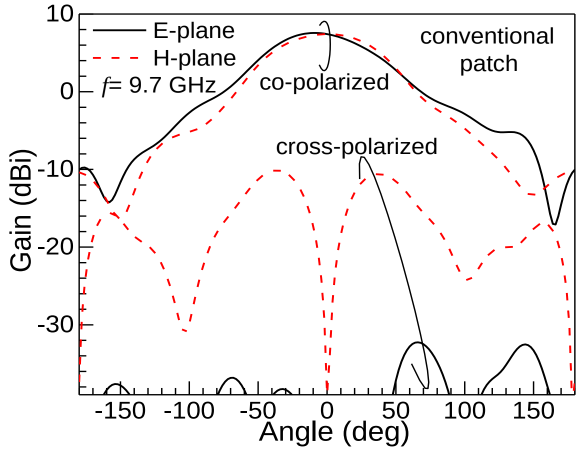
IV. SIMULATED RESULTS AND DISCUSSIONS

The simulated return loss characteristics of conventional and proposed QWT-MPA are compared in Fig. 3. The conventional antenna resonates at 9.7 GHz with good impedance matching. Whereas, the proposed antenna offers a dual-band characteristic as shown in Fig. 3. The lower band resonating at 9 GHz is mainly due to the radius of the circular superstrate (R_2) as estimated in [17]. The formula has been modified slightly to $f_{Ring} = \frac{c}{2\pi R_2}$, where c is the velocity of light and R_2 is the outer radius of the metal ring. There is no effect of the dielectric material because of air substrate. The higher band resonating at 11.35 GHz is due to the induced electric fields between the patch and the superstrate. The plot reveals the effect of capacitive loading which causes a shift in resonance towards the lower side of the frequency and hence a relative shift in S_{11} minima.

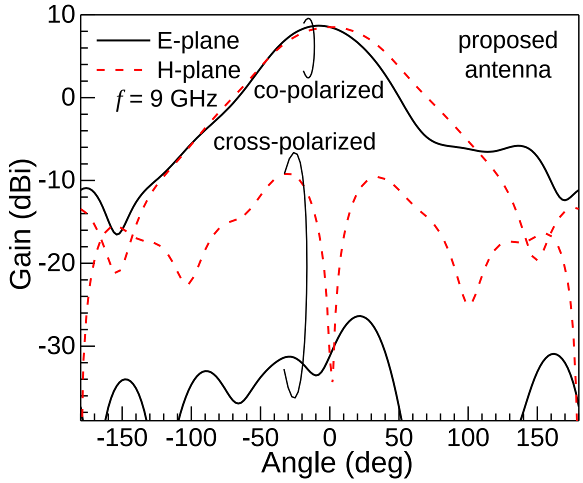
Fig. 4 shows the simulated co-polarized and cross-polarized radiations of the conventional and proposed configurations. Co-polarized radiation patterns for the E- and H-planes in Fig. 4(a) indicates about 7.4 dBi peak gain value along the broadside. Fig. 4(b) and 4(c) show the E- and H-plane patterns of the proposed antenna obtained at 9 GHz and 11.35 GHz respectively. About 8.2 dBi and 10.1 dBi peak-gain values are revealed with broadside radiations respectively.

V. EXPERIMENTAL RESULTS

The prototypes of conventional and proposed rectangular microstrip patch antennas are fabricated using commercially available RT-Duriod substrate with ε_r=2.2. The prototypes are measured using the Agilent's N5230A vector network analyzer and the automatic anechoic chamber. The prototypes of the conventional and the proposed antennas are depicted in Fig. 5(a) and (b) respectively. The metal ring and the experimental setup for S_{11} measurement are shown in Fig. 5 (c) and (d) respectively.



(a)



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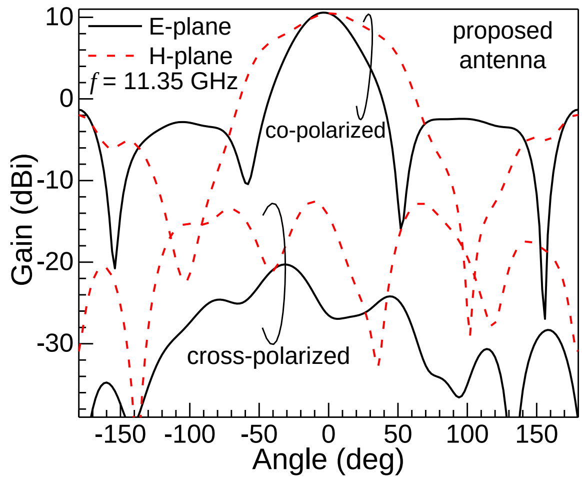

(c)

Fig. 4. Simulated E- and H- plane radiation characteristics: (a) the conventional antenna at 9.7 GHz, (b) the proposed antenna at 9 GHz, and (c) the proposed antenna at 11.35 GHz. Parameters are same as in Fig. 1.

The return loss characteristics of measured and simulated results of conventional and proposed configurations are compared in Fig. 6. Results are closely corroborated with the simulated predictions (as in Fig. 3).

The relative shift in S_{11} minima, as well as the impedance mismatch, is due to the feed network and the metal ring superstrate.

The measured radiation patterns over the principal planes are shown in Fig. 7. Simulated data are incorporated for comparison and revealed very close agreement. About 8.2 dBi co-polarized peak gain is observed at the first resonance with cross-polarized radiation maintained below −30 dB (Fig. 7 (a)). There is no change in co-polarized peak gain value in the H-plane. But this shows a degradation in cross-polarized radiations (−10 dB) as shown in Fig. 7 (b). About 10.1 dBi co-polarized peak-gain is

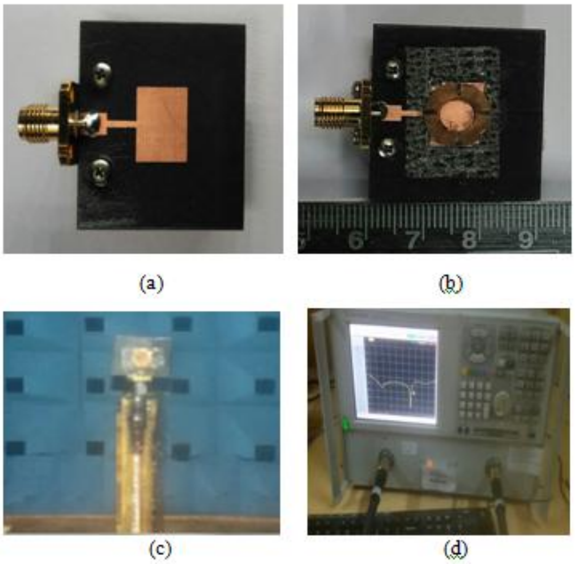

Fig. 5. Antenna prototypes and the experimental setup: (a) top view of conventional antenna, (b) top view of the proposed antenna, (c) radiation pattern measurement setup in anechoic chamber (d) S_{11} measurement setup. Parameters are same as in Fig. 1.

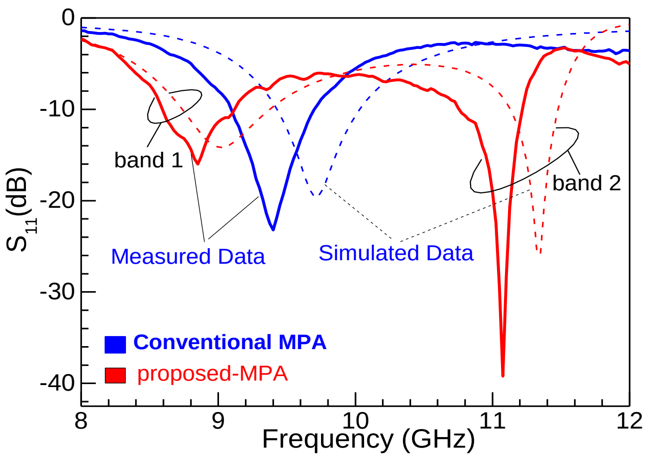

Fig. 6. Simulated and measured S_{11} characteristics of conventional and proposed MPA configurations. Parameters are same as in Fig. 1.

observed in the second resonance with higher cross-polarized radiation as shown in Fig. 7 (c). No change in co-polarized peak gain is observed in the H-plane, but this shows about −10 dB cross-polarized radiations (Fig.7 (d)).

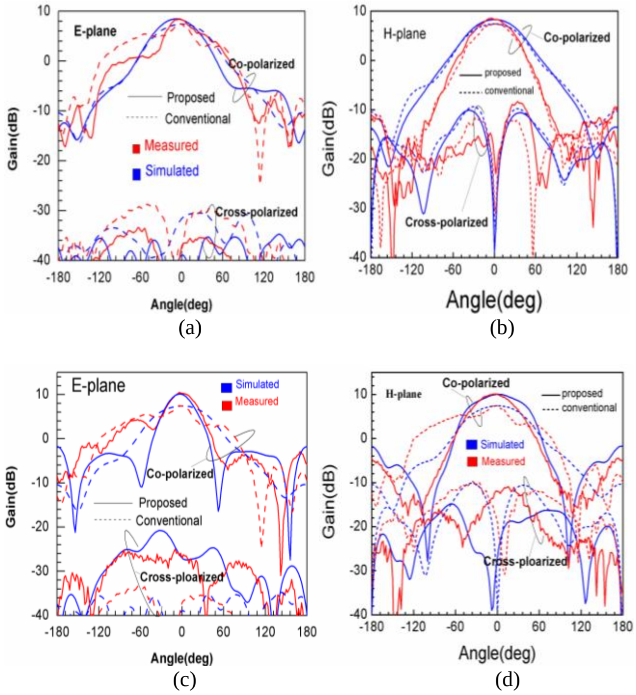

Fig.7. Simulated and measured radiation characteristics of conventional and proposed MPA configurations, (a) E-plane, (b) H-plane radiations at 9 GHz, (c) E-plane, (d) H-plane radiations at 11.35 GHz. Parameters are same as in Fig. 1.

VI. CONCLUSION

A simple design of a microstrip patch has been demonstrated for dual-band operations. A metal ring has been used as a superstrate layer. The proposed antenna shows very good impedance matching and broadside radiations with high gain in both the resonating bands. The first and second resonance frequencies are respectively 9GHz and 11.35 GHz with 8.2 dBi and 10.1 dBi peak gain values. This configuration is compact and useful for X-band applications.

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