International Journal of Microwave and Wireless Technologies, 2016, 8(2), 301–307. © Cambridge University Press and the European Microwave Association, 2015
doi:10.1017/S1759078714001597

RESEARCH PAPER

Bandwidth enhancement of capacitive fed monopole antenna using parasitic patches

KAMALAVENI AYYADURAI AND GANESH MADHAN MUTHU

This paper proposed a compact planar monopole antenna operating at 5 GHz (5.180–5.825 GHz) industrial, scientific and medical (ISM) radio band. The antenna constructed with 20 mm × 12 mm radiating element and 25 mm square of the ground plane in FR4 substrate provided −10 dB bandwidth of 1 GHz (5.4–6.4 GHz). To improve the bandwidth, parasitic elements are added with the monopole antenna. A capacitive feed is also incorporated in the design. It observed that the proposed antenna with parasitic elements provides a larger impedance bandwidth of about 3 GHz (5.1–8.1 GHz), which is threefold improvements over the one without parasitic patches. The prototype of the antenna that operates at 5.8 GHz frequency range is fabricated and characterized using a near-field measurement system. A good agreement is found between the simulation and measured results.

Keywords: Antenna design, Modeling and measurements, Antennas and propagation for wireless systems

Received 21 August 2014; Revised 27 November 2014; Accepted 08 December 2014; first published online 9 January 2015

I. INTRODUCTION

Certain communication applications require antennas with omnidirectional radiation patterns, larger bandwidth, and non-dispersive behavior, low cost and also must be compact. One of the widely used antennas which present appealing physical features is the monopole antenna. Compared with traditional wire monopole antennas, printed monopole antennas have many advantages that include planar structure, and light weight which are suitable for compact receiver applications. Recently, various types of printed monopole antennas have been studied for high efficiency, broadband, and multiband requirements [1–4].

As the conventional monopole has a larger height and narrow bandwidth, planar elements with various shapes have introduced, which increases the surface area of the monopole, thereby increasing its bandwidth. These types of structures lengthen the current path thus reducing the physical height of the antenna [5–7].

A significant improvement in impedance bandwidth is also achieved by introducing parasitic element in printed antennas. In this scheme, rectangular parasitic patches are introduced at the bottom of the antenna, thus reducing the antenna dimensions for the same frequency [8]. The effective aperture area increases, and the surface wave decreases when the parasitic patches are used along with the antenna, which improves the bandwidth [9]. Parasitic elements used in the form of printed strips and placed in the radiating aperture of the planar antenna at the top and bottom suppresses the radiation at certain frequencies within an ultra-wide frequency band [10, 11]. Different types of parasitic elements have been used to improve the antenna performances. Antennas combined with spiral wire parasitic element achieve a circularly polarized wave and also provides a low return loss [12]. A parasitic patch antenna mounted above another driven patch, resonates at a slightly lower frequency than the original element. However, the main effect is to increase the impedance bandwidth of the antenna significantly. In some cases, the bandwidth can be increased by a factor of 10. A microstrip patch antenna with U-shaped parasitic elements stacked with rectangular patches on a separate layer was proposed for wide band applications [13, 14]. Beam steering can be achieved when parasitic elements are used in conjunction with reconfigurable antennas [15]. When these parasitic elements are used in multilayer antenna design, they improve the gain of the antenna [16, 17].

In recent days, antennas with parasitic elements are widely used in mobile phones and laptops for better isolation from another internal circuitry [18–20]. Many of the monopole antennas reported in literature have either larger physical dimensions or do not have sufficient impedance bandwidth. In this paper, a compact vertical monopole antenna incorporating parasitic patches is proposed. Considering the features of printed monopoles, parasitic patches are investigated and better impedance matching, wider bandwidth is achieved, when compared to other techniques. A capacitive feed is also incorporated in the design. This paper is organized as follows. First section deals with the design of rectangular closed ring monopole antenna for 5.8 GHz band. Analysis of parasitic elements in the designed monopole is then presented. The practical realization of the proposed antenna and the measurement results described in the subsequent section.

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https://doi.org/10.1017/S1759078714001597 Published online by Cambridge University Press

II. RECTANGULAR RING MONOPOLE ANTENNA

The width and length of the conventional patch is mentioned as W_{patch} (15.74 mm) and L_{patch} (15 mm), respectively. The antenna size was reduced by choosing the new width as $W_1 = W_{patch}/4$ and optimized length as L_1, respectively. The rectangular ring formed when a rectangular slot is cut in the centre of the rectangular microstrip patch. Figure 1 illustrates the proposed ring antenna design. According to the slot dimensions, the thickness of the loop (Wr) gets altered. Figure 2 shows the impact of the thickness of the loop (different slot dimensions) on the resonant frequency. Hence the size of the antenna ($W_1 = 4.5$ mm, $L_1 = 10$ mm with a uniform thickness $wr = 0.35$ mm) is reduced correspondingly, compared to the microstrip patch antenna, where the loop has larger electrical length required to achieve the same resonant frequency.

A capacitive coupled 50 Ω microstrip strip which is fed by a co-axial probe was introduced in this design. Impedance

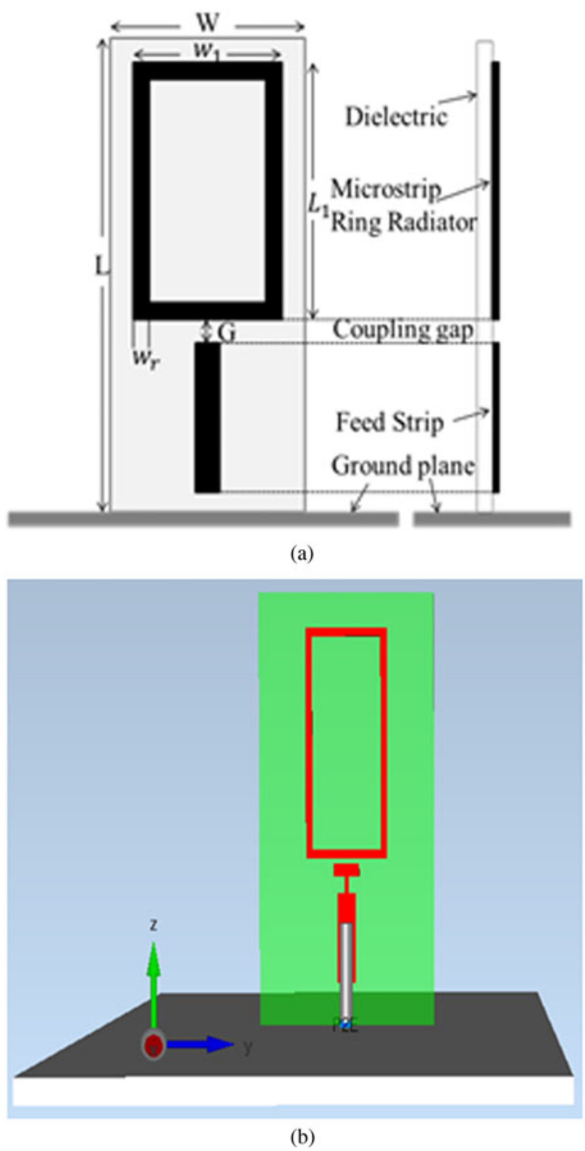

Fig. 1. A closed loop planar monopole antenna: (a) geometric view, (b) 3D view.

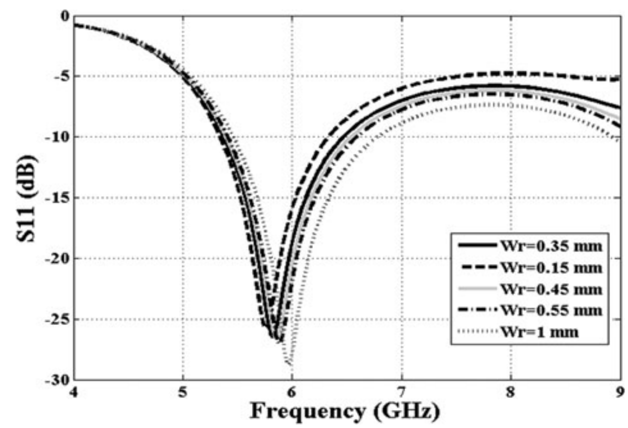

Fig. 2. Study on the effect of different thickness (W_r) of the loop characteristics.

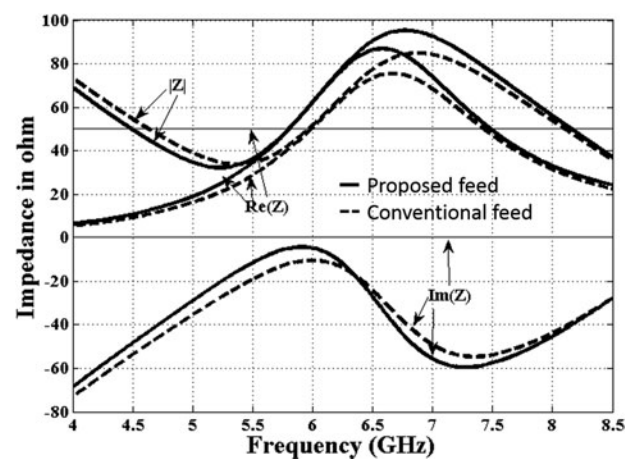

Fig. 3. Impedance characteristics of the antenna with proposed feed.

characteristics of the rectangular loop radiator with the proposed feed are illustrated in Fig. 3. It can be noted that significant improvement can be achieved from the proposed feed strip. The radiator and the coupled feed strip are printed on the same side of FR4 substrate ($W = 12$ mm, $L = 20$ mm) with the relative permittivity of 4.4 and a thickness of 0.762 mm. This radiator is placed vertically above the finite ground plane (25×25 mm^2) to obtain the desired band of

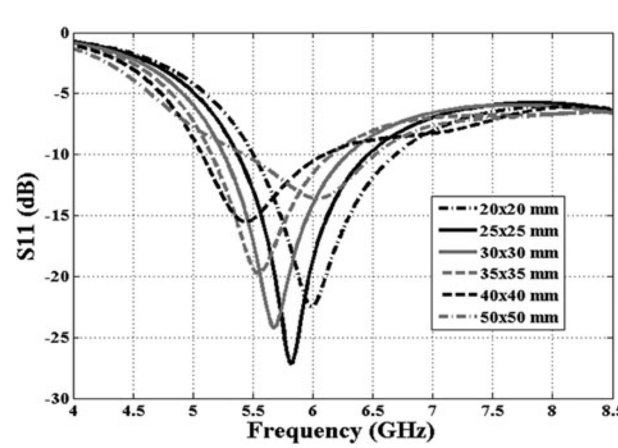

Fig. 4. Effect of size of ground plane on the resonant frequency.

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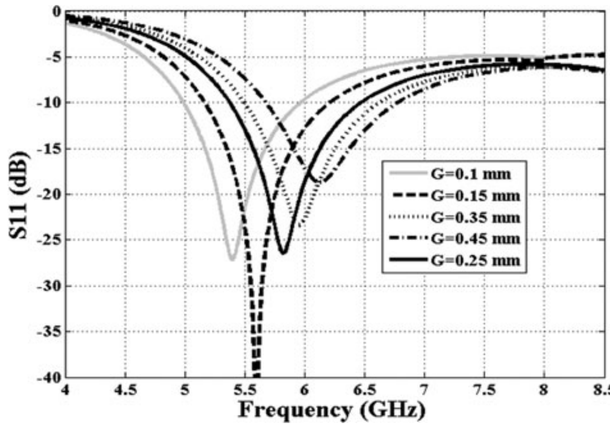

Fig. 5. Return loss with different values of *G*.

frequency. The designed antenna had been simulated using full wave three-dimensional (3D) simulation based on FDTD modeling technique (using EMPIRE ECcel). The effect of the ground plane is depicted in Fig. 4. This microstrip ring structure resonates when its electrical length is about an integral multiple of wavelength. The coupling gap (*G*) between the radiator and the feed strip determines the

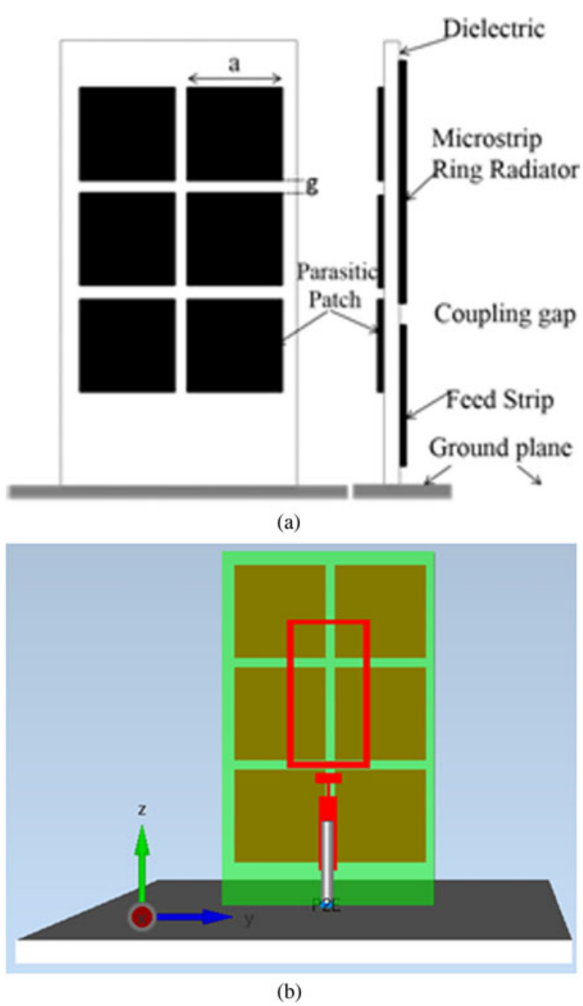

Fig. 6. Planar ring monopole with parasitic patch: (a) geometric view, (b) 3D view.

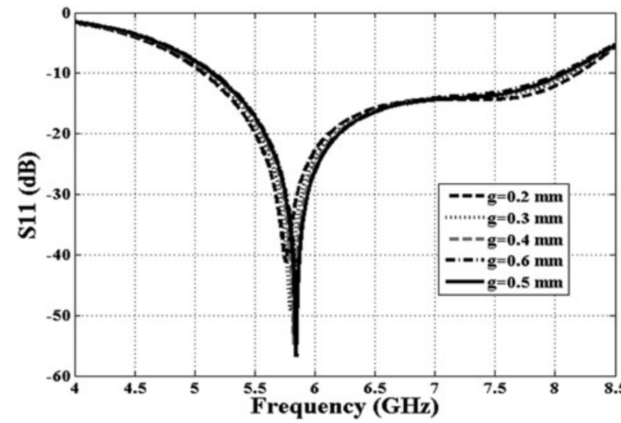

Fig. 7. Gap variations between the parasitic elements (*g*).

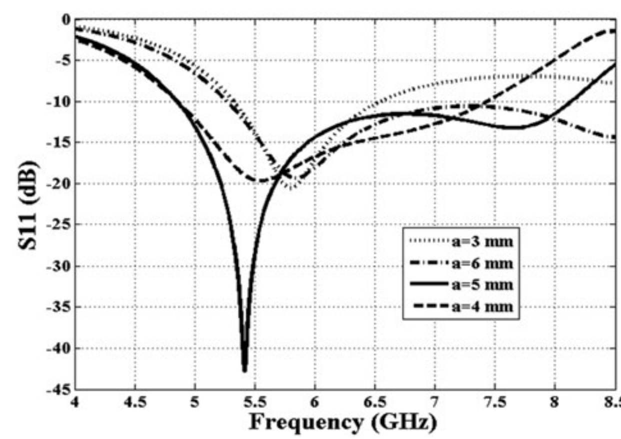

Fig. 8. Study of different patch size (a) at $g = 0.5$ mm.

desired frequency with impedance matching. Figure 5 shows the return loss for different coupling gaps between the feed strip and the radiating loop. For the prototype antenna, *G* is chosen as 0.25 mm, which provides a return loss of −27 dB at 5.8 GHz. The 10 dB bandwidth of the rectangular ring monopole antenna is found to be 1 GHz with the resonant

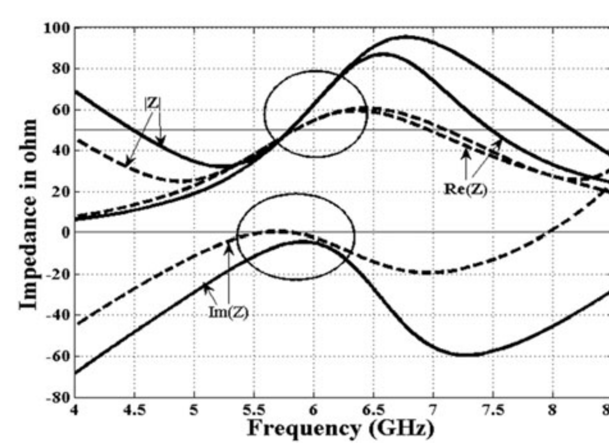

Fig. 9. Effect of parasitic elements on the impedance characteristics for loop (solid line) and loop with patches (dotted line).

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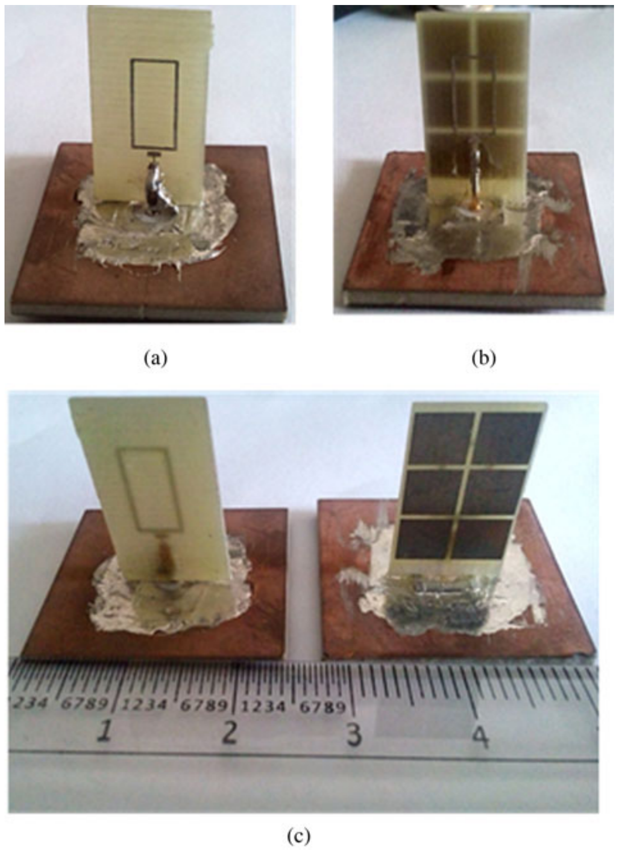

Fig. 10. Fabricated monopole antennas: (a) loop alone (front view), (b) loop with parasitic patch (front view), (c) loop alone (back view), and (d) loop with parasitic patch (back view).

frequency of 5.8 GHz. However, it covers the 5 GHz (5.725–5.875 GHz) industrial, scientific and medical (ISM) band partially.

III. ANALYSIS OF PARASITIC ELEMENTS WITH RING MONOPOLE

The bandwidth of the antenna is enhanced by introducing parasitic elements so that the complete ISM band (5 and

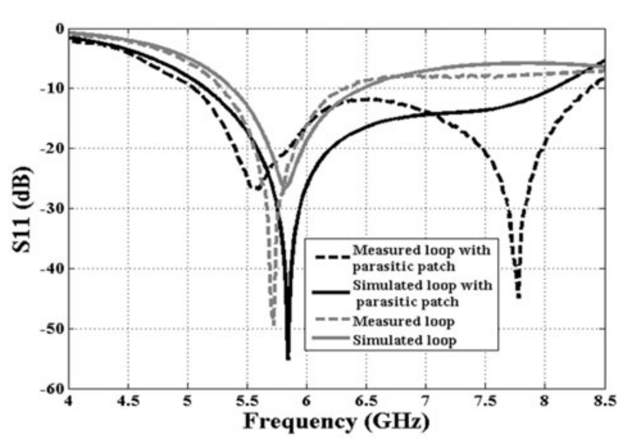

Fig. 11. Return loss comparison of the monopole antenna with and without parasitic patch (Network Analyzer).

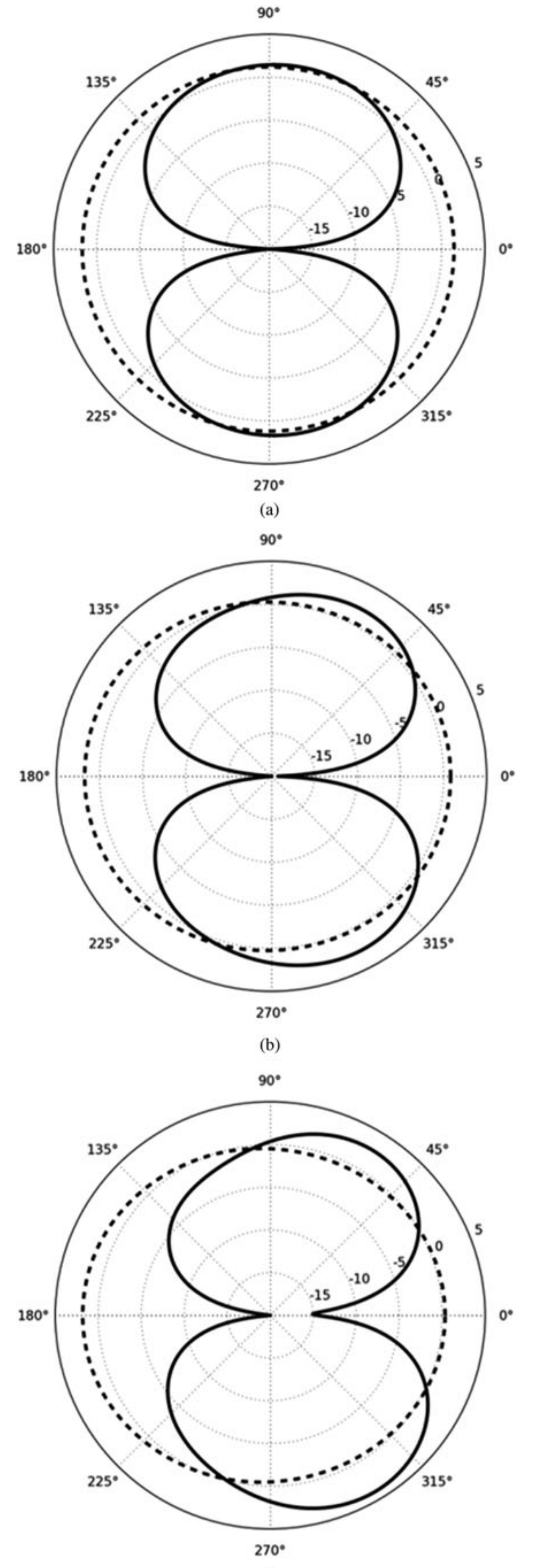

Fig. 12. Simulated radiation pattern for frequencies: (a) 5.2 GHz, (b) 7 GHz, and (c) 8 GHz.

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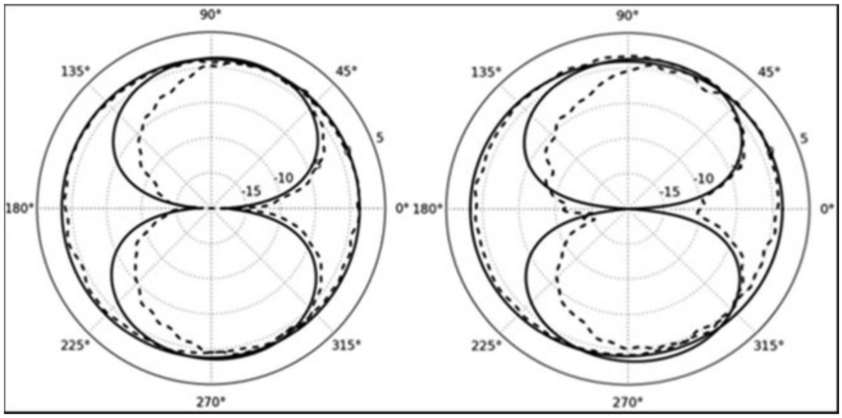

Fig. 13. Simulated (solid) and measured (dotted) radiation patterns at 5.8 GHz: (a) loop, (b) loop with parasitic patch.

5.8 GHz) could realize. A schematic diagram of the modified ring monopole antenna with square parasitic patches is shown in Fig. 6. The dimensions of the parasitic patches are chosen based upon the parametric study. Analysis has been performed for patch size (a) and the gap between the patches (g) to obtain a miniaturized design. A 2×3 array of patches has chosen, such that it encompasses the main radiating loop. Figure 7 shows that the return loss characteristics for different "g" values. The gap variation between the patches results in a small frequency shift in the resonant frequency; however, there is no variation in the bandwidth. A gap (g) of 0.5 mm between the patches has been chosen based upon the resonant frequency. A study on the effect of patch size at $g = 0.5$ mm is shown in Fig. 8. A maximum bandwidth is realized for a patch size of 5 mm. It observed that the optimized patch size (a) and gap (g) of the metal patch are 5 and 0.5 mm, respectively.

In the case of a rectangular loop monopole, the bandwidth enhancement due to impedance match is limited by its structure. To obtain a better impedance match, the reactance value should be close to zero, at the same time the real impedance value should be equal to the source impedance. Adding parasitic patches behind the loop leads to better impedance match which results in improved bandwidth. The impedance characteristics illustrated in Fig. 9.

IV. EXPERIMENTAL RESULTS

The measured bandwidth of the proposed antennas are determined using Agilent 8722ES (50 MHz to 20 GHz) Network Analyzer. The photographs of the fabricated ring monopole without and with parasitic patch are shown in Fig. 10. The simulated and measured return loss for both antennas is reported in Fig. 11. In the case of loop with parasitic elements, the second resonance is clearly visible in the measurement result compared to simulation. This is due to the manufacturing tolerance of the PCB and the manual assembly error which is difficult to incorporate in simulation. It found that the bandwidth (at -10 dB) of the proposed antenna is 3.2 GHz (5–8.3 GHz), which is a threefold improvement when compared with simple planar rectangular ring antenna.

The designed antenna was characterized for its radiation properties and gain in a SATIMO SG64 near field probing chamber (0.4–6 GHz). Due to the measurement limitations, the gain and efficiency are shown for the ISM band (5–5.9 GHz) considered in this study. Simulation results show the omni directional pattern at all frequencies, in the range of operation which is depicted in Figs 12(a)–12(c). The radiation performances of the ring antenna without and with parasitic patch displayed in terms of E-plane and H-plane, at 5.8 GHz are illustrated in Figs 13(a) and 13(b), respectively. The simulated and measured radiation patterns of the antennas agree well, and it also observed that the impact of the parasitic patches on the radiation pattern is not significant.

The gain and efficiency of the antenna has been obtained from the radiation pattern measurement carried out in Star Gate 64 probing chamber in spherical coordinates. The designed antenna is placed in the centre of an arch having 64 computer-switched probes, to measure one axis and two polarization vectors. The antenna will be rotated for 180°, by a motorized pole. For every one degree, the measurement has been obtained to generate a full 3D radiation pattern. The peak value point has been observed and the gain for this proposed antenna in both phi and theta cut is evaluated. The simulated and measured gains of both the antennas are shown in Fig. 14. A gain of 2.4 dB obtained, which is reasonable for broadband antennas. Over the band of interest (5.1–8.1 GHz) the efficiency remains above 80%, as shown in Fig. 15.

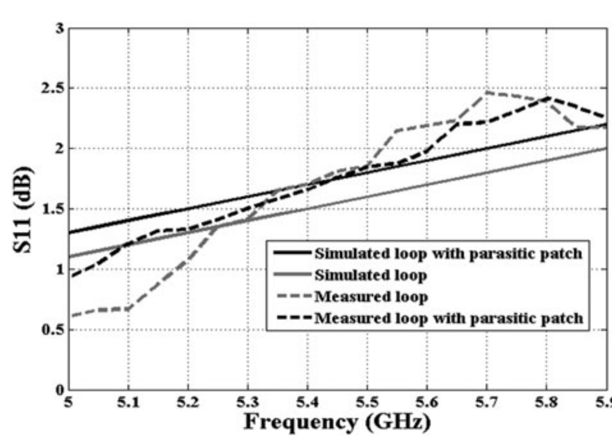

Fig. 14. Comparison of gain of the antennas (antenna in chamber).

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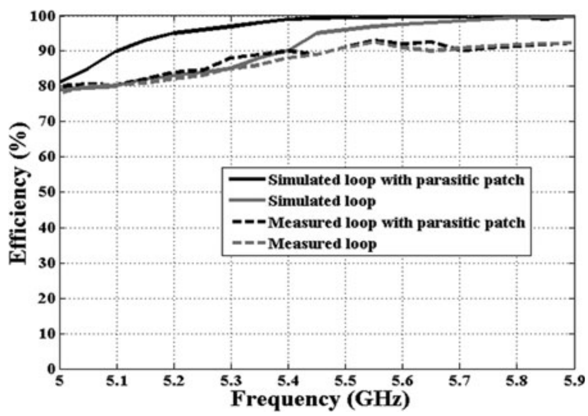

Fig. 15. Comparison of efficiency of the antennas.

V. CONCLUSION

A planar monopole rectangular ring antenna with parasitic patches using a finite sized ground plane is designed, analyzed and fabricated for 5 GHz ISM band applications. By introducing parasitic patches the impedance bandwidth of the proposed ring antenna can be significantly enhanced (threefold increase) with radiation efficiency and gain of 85% and 2.4 dB, respectively. The proposed design in this paper emphasizes on the bandwidth improvement. The work can be enhanced by improving the structure for multiband and ultra-wideband applications. Further investigations can be carried out for making the antenna still compact. This approach can also extend for low frequency bands.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Ganesh Balasubramanian, Amphenol Omni Connect India Pvt. Ltd. for providing measurement setup and support throughout this work.

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