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RESEARCH PAPER

A compact broadband printed monopole antenna with U-shaped slit and rectangular parasitic patches for multiple applications

SUDEEP BAUDHA AND DINESH KUMAR VISHWAKARMA

This paper presents a compact broadband printed monopole antenna with U-shaped slit in the partial ground plane and rectangular parasitic patches adjacent to the microstrip line for multiple applications. The optimal dimensions of the proposed antenna are 35 × 25 × 1.5 mm^3 and is fabricated on commercially available low-cost FR4 substrate with $\varepsilon_r = 4.3$ and 0.025 loss tangent. Due to introduction of rectangular parasitic patches and U-shaped slit large bandwidth has been achieved. The impedance bandwidth (return loss, magnitude of $S_{11} < 10$ dB) of the proposed antenna is 139% (2.9–16.3 GHz). The proposed antenna covers ultra wide band applications, 5.2/5.8 GHz WLAN bands, 3.5/5.5 GHz WiMAX bands, X band (8–12 GHz), satellite communication, and other wireless communication services. The study shows that there is good agreement in simulated and measured results. Nearly stable radiation patterns have been obtained throughout the operating band. Antenna results and details are discussed and elaborated.

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

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I. INTRODUCTION

Due to rapid advancements in wireless communication, printed monopole broadband antenna has attracted attention of several researchers worldwide. Printed monopole antennas have high gain, high efficiency, large bandwidth, omnidirectional radiation patterns, etc. and they are easy to fabricate. Several techniques, such as cutting various types of slots have been suggested for attaining broadband characteristics in patch antennas [1]. Dual broadband characteristic has been achieved by adding a parasitic patch and slot in the ground plane [2]. Parasitic patch and slot provides better impedance matching at the second operating band without affecting the performance of the first operating band. Bandwidth enhancement of 26% has been reported due to introduction of the curved slot in the rectangular patch [3]. Bandwidth enhancement is obtained by excitation of higher-order resonating modes at the upper operating frequency band. A printed monopole antenna with fork-like tuning stub is proposed for bandwidth enhancement in [4]. By adding parasitic patch and rotating the slot, bandwidth enhancement has been reported [5–7]. A combination of T- and C-shaped slots has been used in partial ground plane monopole antenna to attain dual-band notch behavior along with bandwidth enhancement [8]. Band rejection behavior is proposed by inserting an inverted U-shaped slot in the radiating patch and a rectangular slot in the partial ground plane [9]. In [10] a CPW-fed monopole antenna with a square and a circular slot is demonstrated. Most of the above proposed antenna focuses on specific applications and moreover the size of such structures is large.

In this paper, a compact broadband printed monopole antenna with U-shaped slit in the partial ground plane and rectangular parasitic patches adjacent to the microstrip line is proposed. Higher-order resonances are created due to introduction of parasitic patches and U-shaped slit. It is studied that the performance of the proposed antenna is highly affected by size of the ground plane. The impedance bandwidth (return loss $S_{11} < 10$ dB) of the proposed antenna is 139% (2.9–16.3 GHz). The peak gain and radiation efficiency of the proposed antenna are 5.2 dB and 87%, respectively. The optimum overall size of the proposed antenna is 35 × 25 × 1.5 mm^3. The proposed antenna shows nearly stable radiation patterns throughout the operating frequency band.

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II. ANTENNA DESIGN

The geometrical configuration of the proposed antenna is shown in Fig. 1. The proposed antenna has overall dimension of 35 × 25 × 1.5 mm^3 and is fabricated on commercially available low-cost FR4 substrate with $\varepsilon_r = 4.3$ and 0.025 loss tangent. The exact dimensions of the various parameters of the proposed antenna are shown in Table 1. The proposed antenna is fed by a 50 Ω microstrip line of width 3 mm.

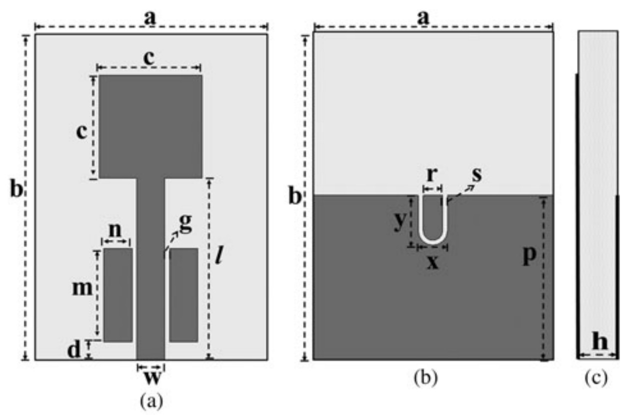

Fig. 1. The proposed antenna configuration: (a) top view, (b) bottom view, and (c) side view.

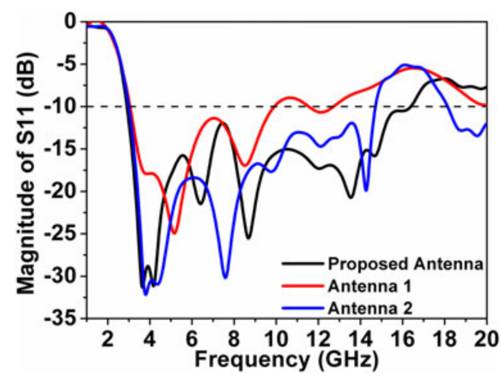

Fig. 2. Simulated return loss (magnitude of S_{11} (dB)) comparison of Antenna 1, Antenna 2, and the proposed antenna.

The top portion of the proposed antenna consists of the patch, microstrip line, and parasitic patches. Parasitic patches are situated adjacent to the microstrip line. The gap between the microstrip line and the parasitic patches is denoted by g and the overall dimensions of the parasitic patches are given by $n \times m$, whereas the length of the microstrip line is denoted by l. The bottom portion of the proposed antenna consists of partial ground plane and U-shaped slit. The width of the U-shaped slit is denoted by s, whereas the depth and the length of the slit is given y and x, respectively. Values of g and s are optimized for best possible impedance matching.

Computer simulation is carried out using CST simulation software, a finite integration technique-based commercial electromagnetic simulator. Bandwidth enhancement is achieved due to introduction of U-shaped slit and parasitic patches. Initially a U-shaped slit is etched out in the partial ground plane, which causes bandwidth enhancement then two rectangular parasitic patches are introduced adjacent to the microstrip line for further bandwidth enhancement due to better impedance matching at the higher operating frequencies. The gap (g) acts as an important factor in the performance of the antenna. Impedance bandwidth of 139% is obtained covering several applications.

III. PARAMETER STUDY

In this section, parameter study of various sections of the proposed antenna is carried out. The proposed antenna has been developed in three stages. Initially the antenna consists of simple patch with partial ground plane denoted by Antenna 1, then a U-shaped slit is itched out in the partial ground plane denoted as Antenna 2, finally two parasitic patches are introduced adjacent to microstrip line which is denoted as the proposed antenna. The return loss (magnitude of S_{11} (dB)) comparison of Antenna 1 (patch antenna without U-shaped slit and parasitic patches), Antenna 2 (patch antenna with only U-shaped slit) and the proposed antenna (patch antenna with U-shaped slit and parasitic patches) is shown in Fig. 2. The impedance bandwidth of Antenna 1 is 106% (3–9.9 GHz); Antenna 2 is 133% (2.9–14.5 GHz), whereas that of proposed antenna is 139% (2.9–16.3 GHz). Initially on introduction of U-shaped slit bandwidth has enhanced from 9.9 to 14.5 GHz and on introduction of two parasitic patches bandwidth has further enhanced from 14.5 to 16.3 GHz showing higher-order resonance at frequencies greater than 9.9 GHz. These higher orders of resonance have been resulted due to introduction of the U-shaped slit and parasitic patches. Simulated return loss (magnitude of S_{11} (dB)) comparison for different values of size of the ground plane (p) is shown in Fig. 3. Size of the ground plane drastically affects the performance of the proposed antenna. As the size of the ground plane is increased, initially there is impedance mismatch but as the value reaches to 17.5 mm broadband behavior is observed and there is further mismatch for the higher values of s.

Figures 4 and 5 show simulated return loss (magnitude of S_{11} (dB)) variation for different values of the width of the U-shaped slit (s) and the gap between parasitic patches and microstrip line (g). Reportedly as the width of the slit is increased beyond 0.5 mm, the higher-order resonating modes start decaying. The bandwidth starts decaying and

Table 1. Parameter value of different sections of the proposed antenna (in mm).

Parameters														
a	*b*	*c*	*d*	*g*	*h*	*l*	*m*	*n*	*p*	*r*	*s*	*w*	*x*	*y*
25	35	11	2	0.5	1.5	19.5	10	3	17.5	2	0.5	3	3	4.75

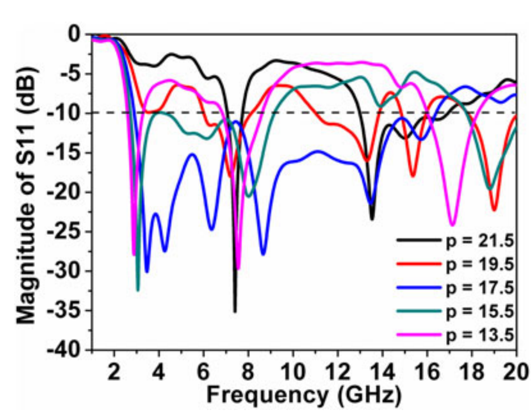

Fig. 3. Simulated return loss (magnitude of S_{11} (dB)) comparison of the proposed antenna with different values of p (all other parameters are fixed and have same values as in Table 1).

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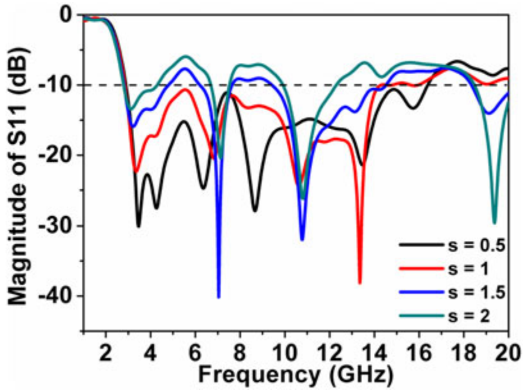

Fig. 4. Simulated return loss (magnitude of S_{11} (dB)) comparison of the proposed antenna with different values of s (all other parameters are fixed and have same values as in Table 1).

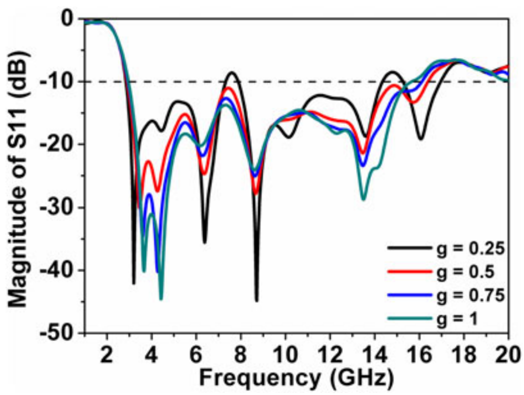

Fig. 5. Simulated return loss (magnitude of S_{11} (dB)) comparison of the proposed antenna with different values of g (all other parameters are fixed and have same values as in Table 1).

multi-band behavior have been observed due to impedance mismatching at different sections of the bandwidth. As observed from Fig. 5, the size of the gap (g) has more impact at frequency ranging from 14 to 16 GHz. The optimal dimension for g and s are set to be 0.5 mm. Variation of the length of the parasitic patches (m) is shown in Fig. 6. It is evident from the curves that as the length of the patches is enhanced the antenna starts resonating at frequencies greater than 14.5 GHz till the value reaches 10 mm; after this value the antenna performance starts decaying due to impedance mismatching. The length of the parasitic patches too has impact at frequency ranging from 14 to 16 GHz.

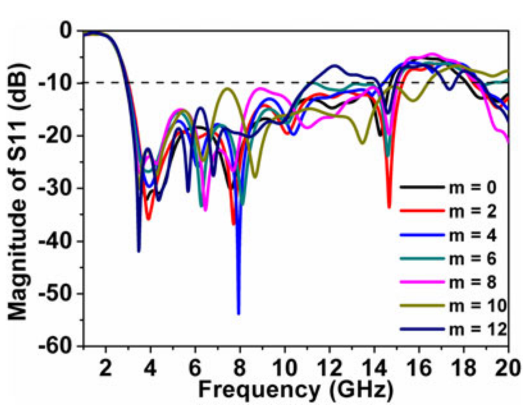

Fig. 6. Simulated return loss (magnitude of S_{11} (dB)) comparison of the proposed antenna with different values of m (all other parameters are fixed and have same values as in Table 1).

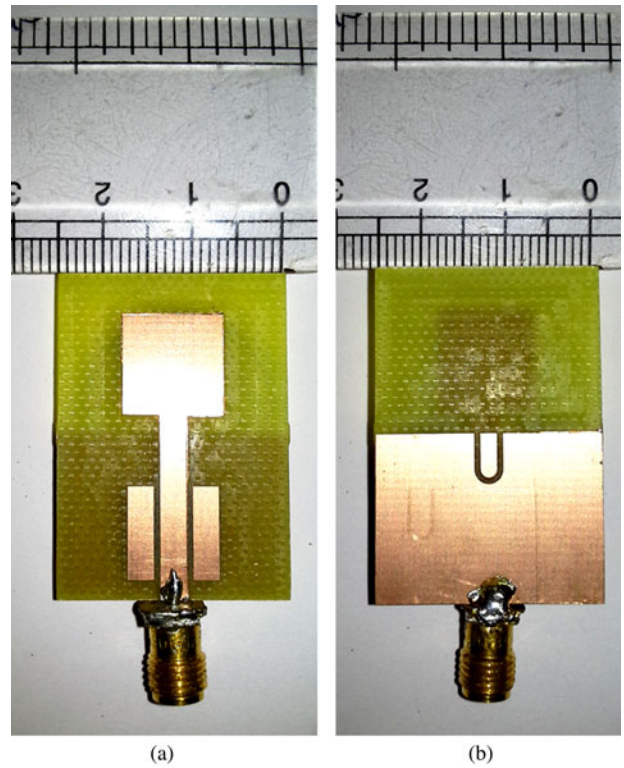

Fig. 7. Photograph (prototype) of the fabricated antenna: (a) top view and (b) bottom view.

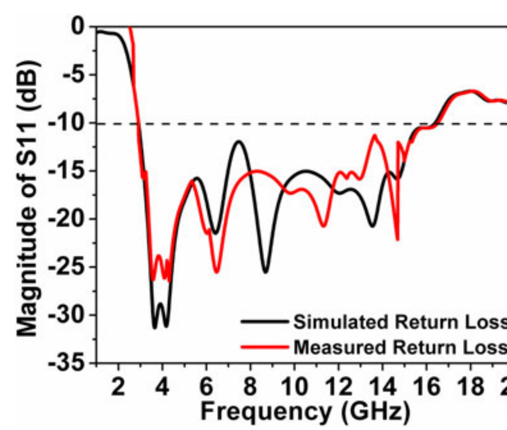

Fig. 8. Simulated and measured return loss (magnitude of S_{11} (dB)) of the proposed antenna.

IV. RESULTS

The prototype of the proposed antenna is fabricated on commercially available low-cost FR4 substrate with $\varepsilon_r = 4.3$ and 0.025 loss tangent using LPKF PCB prototyping machine as shown in Fig. 7. Testing and measurement have been carried out using Agilent Vector Network Analyzer.

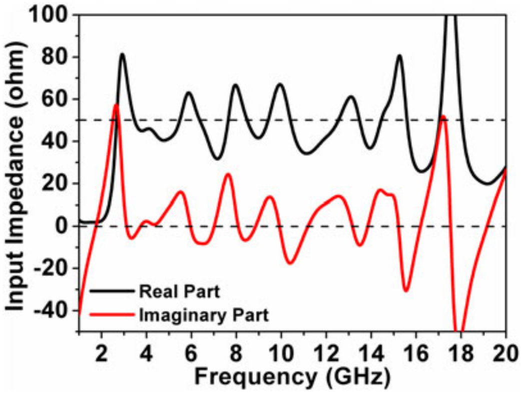

Fig. 9. Input impedance (real and imaginary parts) of the proposed antenna.

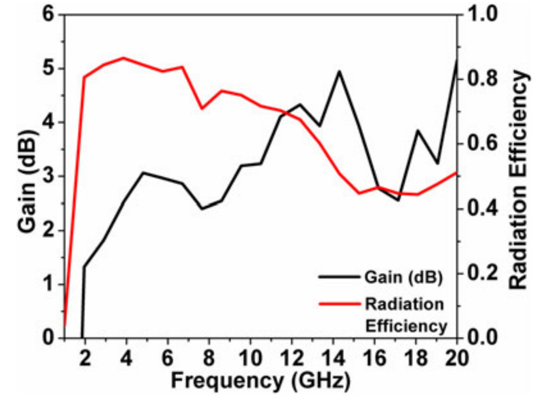

Fig. 10. Gain (dB) and radiation efficiency of the proposed antenna.

Simulated and measured return loss (magnitude of S_{11} (dB)) of the proposed antenna is shown in Fig. 8. It is observed that measured results are in good agreement with the simulated results except slight shift of the resonance in the range of 7–11 GHz. This shift in the resonance is due to the fabrication tolerance and considering the fact that the measurements have not been performed in anechoic chamber. The measured result justifies and validates the simulated ones and the attained impedance bandwidth of the proposed antenna is 138% (2.9–16.3 GHz). Input impedance curve of the proposed antenna is shown in Fig. 9. The real part of the input impedance curve depicts that the impedance is maintained to 50 Ω throughout the operating frequency band; specifically it is in the range of 35–75 Ω in the operating frequency band. It is evident from the imaginary part of the input impedance that for major part of the operating band, the behavior of

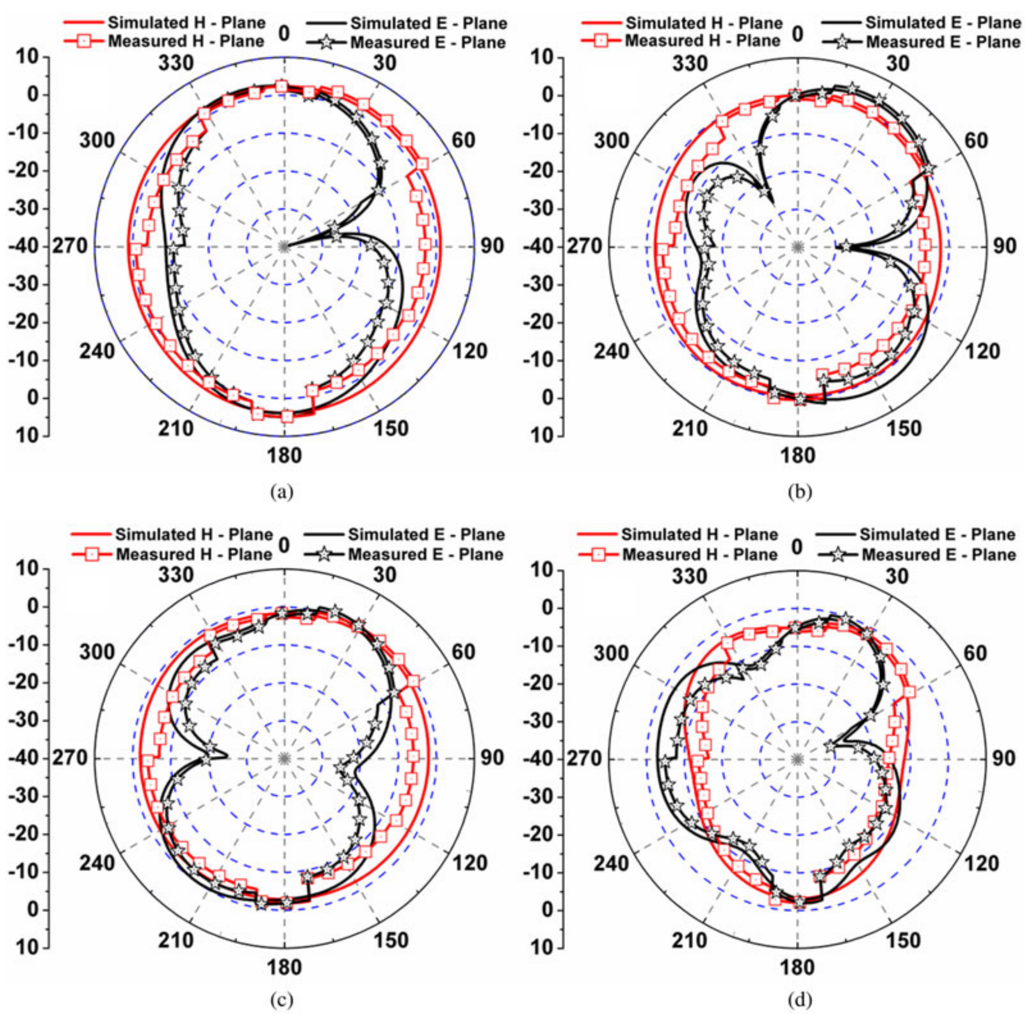

Fig. 11. Simulated and measured radiation patterns of the proposed antenna at (a) 3.7 GHz, (b) 6.3 GHz, (c) 8.7 GHz, and (d) 13.5 GHz.

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the proposed antenna is inductive whereas for some frequencies it is capacitive.

Simulated gain and radiation efficiency curves of the proposed antenna are shown in Fig. 10. The peak gain of the proposed antenna is 5.2 dB, whereas gain have been maintained from 2 to 5.2 dB and the peak radiation efficiency of the proposed antenna is 87%, whereas radiation efficiency has been maintained from 87 to 45% in the entire operating frequency band (2.9–16.3 GHz). As observed from Fig. 10, the gain of the proposed antenna in the low-frequency band is lower than one in the high-frequency band, but the radiation efficiency in the low-frequency band is higher than one in the high-frequency band. This is due to the reason that at higher frequencies focusing (directional) properties of antenna are increased due to larger electrical size giving rise to higher gain up to 14 GHz gain, beyond this it starts decaying due to higher-order modes, whereas efficiency depends on losses and the dielectric loss normally increases with frequency hence there is gradual decrease in antenna efficiency. Figure 11 shows simulated and measured radiation patterns of the proposed antenna at 3.7, 6.3, 8.7, and 13.5 GHz. Measured radiation patterns are in good agreement with the simulated ones and are nearly stable for the entire band of operation. As expected for monopole antennas, the proposed antenna is showing omnidirectional behavior for the *H*-plane radiation pattern and nearly bidirectional behavior for the *E*-plane radiation patterns for most of the frequencies at the operating frequency band.

V. CONCLUSION

In this paper, a compact broadband printed monopole antenna with U-shaped slit and rectangular parasitic patch for multiple applications is proposed. The combination of U-shaped slit and rectangular parasitic patches leads to better impedance matching and creation of higher-order resonance. U-shaped slit contributes from 9.9 to 14.5 GHz range, whereas rectangular parasitic patches contribute from 14.5 to 16.3 GHz range. In the proposed design, bandwidth has been enhanced in the upper frequency band due to excitation of additional resonance. The fractional bandwidth of the proposed antenna is 139% (2.9–16.3 GHz). The peak gain and radiation efficiency of the proposed design is 5.2 dB and 87%, respectively. The proposed antenna exhibits nearly stable radiation patterns at the entire operating frequency band. All these qualities of the proposed antenna make it a suitable candidate for ultra wide band applications, 5.2/5.8 GHz WLAN bands, 3.5/5.5 GHz WiMAX bands, X band (8–12 GHz), satellite communication, and other wireless communication services.

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