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Design of a Rectangular Metallic Monopole Antenna with Protruding Normal Plates for Applications in UWB Communication

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Abstract—In this paper, a rectangular metallic monopole antenna with normal rectangular stubs is presented for application in ultra wideband communication systems. It is shown by computer simulations (HFSS and CST) and actual fabrication and measurement that the addition of protruding normal metallic stubs leads to the increase of impedance bandwidth. The optimum design of geometrical dimensions of the antenna (consisting of the monopole plate and stubs) achieves up to 10 dB return loss in the UWB (3.1–10.6 GHz) frequency range. The radiation efficiency of antenna is better than 95%. Furthermore, the antenna provides linear polarization, with quite low cross-polarization levels.

1. INTRODUCTION

Recently ultra-wideband antennas have been of interest in many systems, such as wireless communication systems, high data rate systems, position detection and tracking, remote sensing, imaging and indoor radar systems. Monopole metallic plate antennas are attractive choices because of their wideband impedance characteristics, omnidirectional horizontal radiation patterns, linear polarization, simple structure and ease of fabrication. Rectangular metallic shapes are preferable to circular and elliptical plates. The circular plates provide wider impedance bandwidths than the rectangular plates, because the periphery of circular plate does not have any corners and its geometry bends gradually. On the other hand, the radiation patterns of the rectangular plate exhibit much less variation with frequency and are more stable, because the current distribution on the plate surface remains uniform due to its rectangular periphery [1]; furthermore, it gives linear polarization. The bandwidth of such monopole antennas may be enhanced by beveling and shorting techniques [2–5].

In this paper, a novel rectangular metallic monopole antenna with protruding normal rectangular plates is introduced. The proposed antenna has y-directed as well as x-directed current distribution. Thus the antenna's radiated fields in the x and y directions are expected to be identical, thereby causing much improved omnidirectional radiation characteristics in the azimuthal plane for higher operating bandwidth. Antenna structure provides several parameters (such as widths and heights of normal sub plates) that give some degrees of freedom to improve the antenna impedance bandwidth by employing optimization softwares, such as CST and Ansoft® HFSS. The proposed antenna configuration leads to the decrease of antenna height and ground plane radius (R), and gives better matching than those in [2, 6].

In addition, the antenna gives a wider impedance bandwidth than a simple monopole plate antenna, although it may have a 3-D structure. A simple monopole antenna has a bandwidth of 3–7 GHz [7], whereas the proposed antenna has an ultra-wideband 3.1–10.6 GHz.

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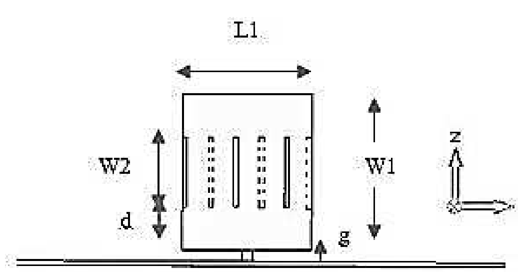
2. ANTENNA DESIGN

The proposed antenna configuration, consisting of a rectangular metallic monopole plate (with dimensions $L_1 \times W_1$) having protruding normal plates (with dimensions $L_2 \times W_2$) over a circular ground plate of radius R, is shown in Fig. 1 by front and top views. The spacing of protruding plates is S. The feeding system of antenna is by SMA connector with center conductor (diameter 1.3 mm) passing through a via-hole in the ground plane along a gap (g) to be connected to the center of the plate. The value of parameter g may be obtained by formulas in [7]. Note that the cross-sectional area of the antenna has two side lengths of $2L_2$ and L_1 in the x and y directions, respectively. By comparing the simple monopole antenna to the proposed antenna, the current distribution is in x-direction as well as y-direction. The antenna's radiated fields in the x and y directions are expected to have about the same amplitude, thereby causing much improved omnidirectional radiation characteristics in the azimuthal plane for higher operating bandwidth [8]. The other parameters of antenna geometry are determined by parametric study with CST simulations to realize the radiation specifications (such as return loss of 10 dB). The ultra-wideband frequency interval 3.1 to 10.6 GHz is selected for antenna design. The minimum number of normal plates is selected equal to 6, in order to achieve the required ultra-wide bandwidth (3.1–10.6 GHz). Lower number of normal plates tends to decrease the bandwidth. "The use of these plates adds modes of higher resonances, causing an increase in the impedance bandwidth compared to a simple monopole." [6]. The positions of normal stubs are determined by computer simulation.

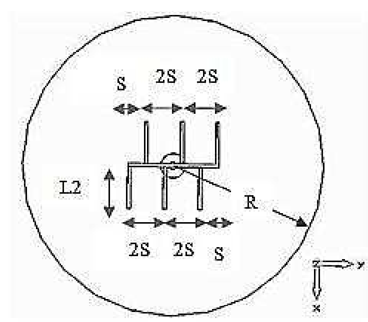
3. SIMULATION RESULTS

The waveguide port of CST software is used for the antenna excitation. The selected plates are made of Bronze sheets with tin plating of thickness 0.5 mm. The optimum geometrical dimension of antenna according to Fig. 1 is given in Table 1.

The diameter of center conductor of SMA is 1.3 mm. Fig. 2 shows the return loss as a function of frequency for the simple rectangular metallic plate without normal protruding stubs with the radius of ground plane $R = 70$ mm for several values of L_1 and W_1. The dimensions L_1 and W_1 affect the impedance bandwidth. Actually, the impedance bandwidth depends on the variation of L_1 and W_1 [7]. The parametric study in Fig. 2 is done as follows. First, W_1 is fixed at 18 mm, and L_1 is selected equal to 20, 18 and 15 mm. Then, L_1 is fixed at 15 mm, and W_1 is taken as for 20 and 15 mm. Then the



(a)



(b)

Figure 1. Geometrical configuration of the proposed rectangular metallic monopole antenna with protruding plates. (a) Front view. (b) Top view.

Table 1. optimum values of geometrical dimensions of proposed antenna.

W_1	L_1	W_2	L_2	S	d	g	R
18 mm	15 mm	8 mm	7 mm	5 mm	5 mm	1 mm	70 mm

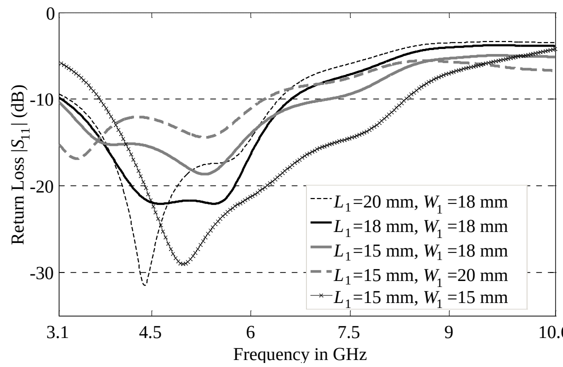


Figure 2. Return loss of the simple rectangular metallic monopole antenna without normal stubs for various values of dimensions of L_1 and W_1 with the radius plane equal to $R = 70\,\text{mm}$.

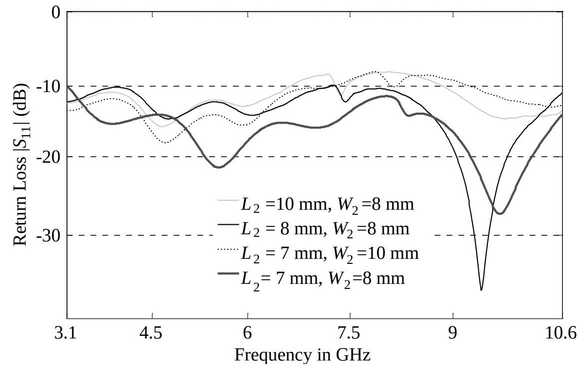


Figure 3. Return loss of the proposed antenna for various geometrical values of stubs (L_2 and W_2) with $L_1 = 15\,\text{mm}$, $W_1 = 18\,\text{mm}$, $g = 1\,\text{mm}$, $S = 5\,\text{mm}$, $d = 5\,\text{mm}$ and $R = 70\,\text{mm}$.

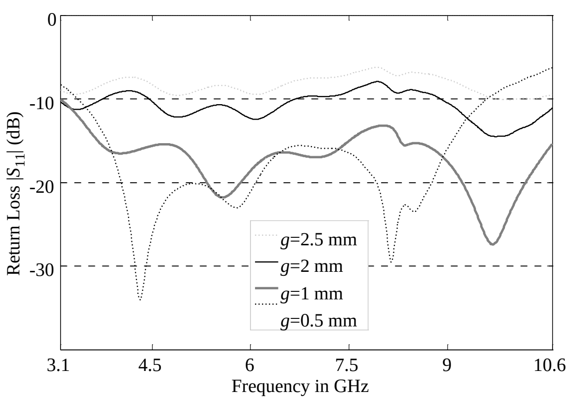


Figure 4. Return loss of proposed antenna for various values of antenna height g with $L_1 = 15\,\text{mm}$, $W_1 = 18\,\text{mm}$, $L_2 = 7\,\text{mm}$, $W_2 = 8\,\text{mm}$, $S = 5\,\text{mm}$ and $d = 5\,\text{mm}$

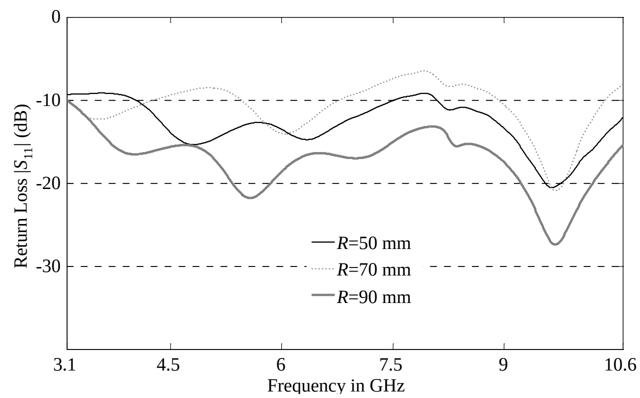


Figure 5. Return loss of proposed antenna for various values of ground plane with $L_1 = 15\,\text{mm}$, $W_1 = 18\,\text{mm}$, $L_2 = 7\,\text{mm}$, W_2=8 mm, $S = 5\,\text{mm}$, $d = 5\,\text{mm}$ and $g = 1\,\text{mm}$.

dimensions of main plate (W_1, L_1) is fixed; the dimensions of normal stubs (W_2, L_2), gap length (g) and radius of ground plane (R) are varied; the reflection coefficient (S_{11}) is obtained versus frequency. These frequency responses are drawn in Figs. 3, 4 and 5. Fig. 3 shows that dimensions L_2 and W_2 affect the higher frequency limit of bandwidth. The parametric study in Fig. 3 is done as follows. First, W_2 is fixed at 8 mm, and L_2 is taken equal to 8 and 10 mm. Then, L_2 is fixed at 7 mm, and W_2 is taken as 8 and 10 mm. Fig. 4 shows that decreasing the size of g leads to the increase of $|S_{11}|$. The lowest value obtained for g by CST software and formulas is about 1 mm. Fig. 5 shows that the lowest acceptable value of radius of ground plane is 70 mm. For R less than 70 mm, the return loss deteriorates. The dimensions of various parts of antenna are obtained by the procedure in [7] and by CST.

The current distributions on the simple monopole plate antenna and proposed antenna with stubs are shown in Fig. 6, for comparison. Observe that the surface current distribution on the main plate is concentrated at its edges at the lower frequencies and moves toward the center of plate as frequency increases.

In this way the current will change from y-direction in the main plate to x-directed current on protruding plates. Compared with current distribution of the simple monopole antenna, the x-directed current causes radiation in x direction. So the antenna's radiated fields in the x and y directions will be equal; radiation characteristics in the azimuthal plane will be more omnidirectional for higher operating bandwidth. We may then conclude that the placement of normal protruding plates at the edges and

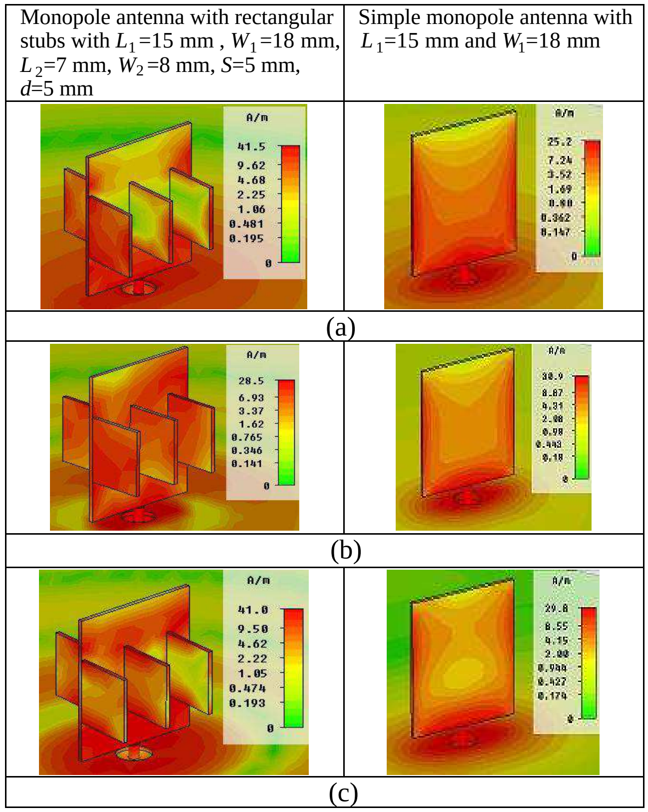


Figure 6. Current distributions on the antenna at various frequencies, (a) 4 GHz, (b) 7 GHz, (c) 9.5 GHz.

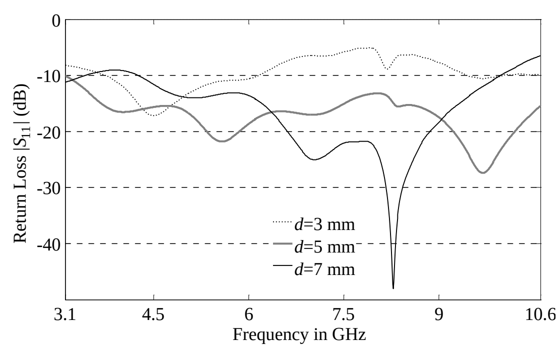


Figure 7. Return loss of antenna for various values of stub heights (d) with $L_1 = 15$ mm, $W_1 = 18$ mm, $L_2 = 7$ mm, $W_2 = 8$ mm, $S = 5$ mm, $g = 1$ mm and $R = 70$ mm.

center of the main plate may increase the bandwidth of antenna. The reflection coefficient S_{11} of the proposed antenna for various values of d is shown in Fig. 7. Its optimum value is $d = 5$ mm, with other values of parameters as given in Table 1. The directivities of proposed antenna (at three frequencies) are shown in Fig. 8 in three coordinate planes ($\varphi = 0°$, $\varphi = 90°$ and $\theta = 90°$).

The maximum gain of the proposed antenna versus frequency is drawn in Fig. 9, which increases with frequency. The radiation and total efficiencies of the proposed antenna are shown in Fig. 10. Its average radiation efficiency is about 97%, and total efficiency is better than 90% for UWB.

The E-plane (yz plane) and H-plane (xy plane) co-polar radiation patterns of antenna are drawn in Fig. 11 at frequency 7 GHz. The discrepancy between the CST software results and measurement data may be attributable to experimental errors.

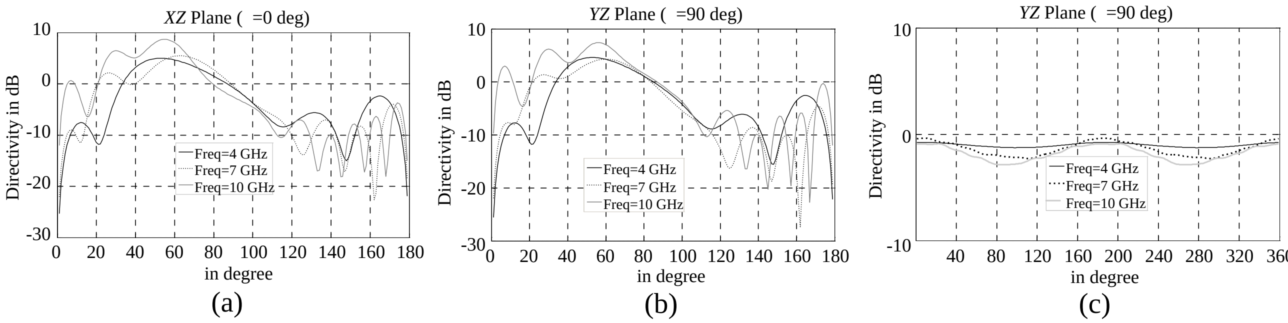


Figure 8. Rectangular radiation pattern of proposed antenna at three frequencies on three cross sections, (a) phi $= 0°$, (b) phi $= 90°$, (c) theta $= 60°$ with $L_1 = 15\,\text{mm}$, $W_1 = 18\,\text{mm}$, $L_2 = 7\,\text{mm}$, $W_2 = 8\,\text{mm}$, $S = 5\,\text{mm}$, $d = 5\,\text{mm}$, $g = 1\,\text{mm}$ and $R = 70\,\text{mm}$.

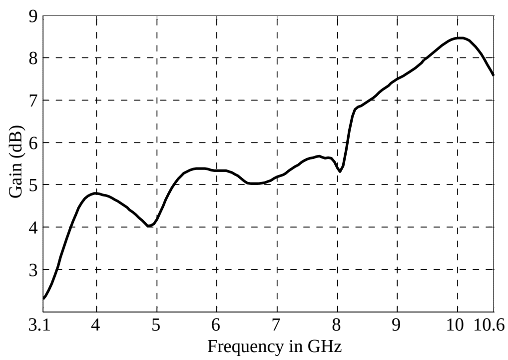


Figure 9. Gain-vs-frequency curve of proposed antenna.

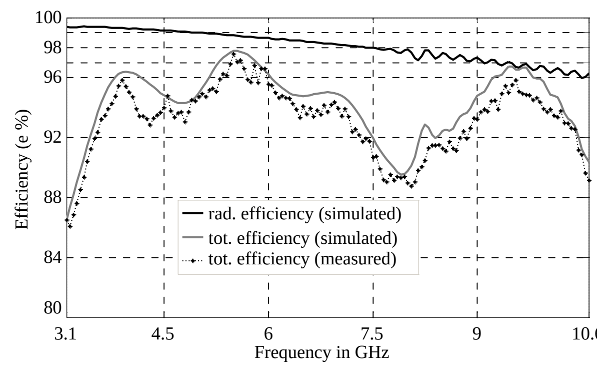


Figure 10. Radiation efficiency and total efficiency of antenna.

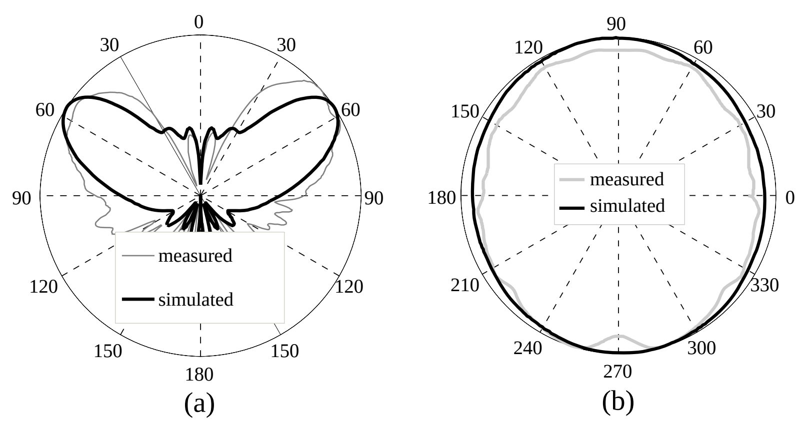


Figure 11. The radiation patterns of antenna at $f = 7\,\text{GHz}$, (a) E-plane in yz-plane, (b) H-plane in xy-plane.

In order to compute the phase of scattering parameter S_{21}, two identical designed antennas are placed face-to-face in their far-field regions. Their phases are drawn in Fig. 12. The variation of phase is shown in Fig. 12(a) as saw-tooth discontinuous curve from 180° to −180°. The variation of phase as a continuous linear function of frequency is shown in Fig. 12(b). The phase of S_{21} is identical to that of S_{12} by reciprocity. Observe that the group delay is constant, which shows that the proposed antenna is appropriate for UWB applications.

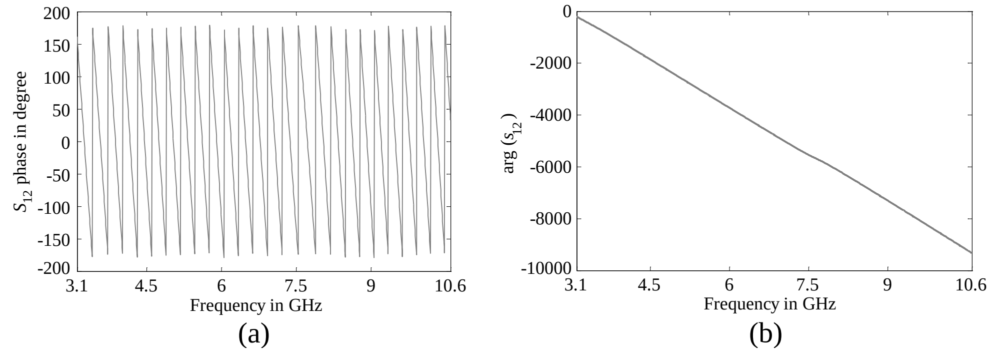


Figure 12. Frequency response of phase of S_{21}, (a) saw-tooth discrete response, (b) continuous response.

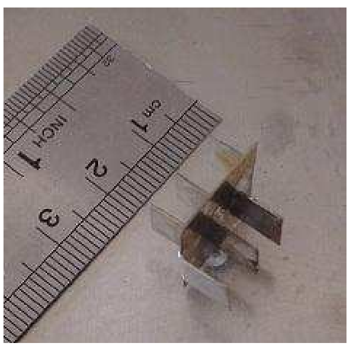


Figure 13. A photograph of fabricated antenna and measured.

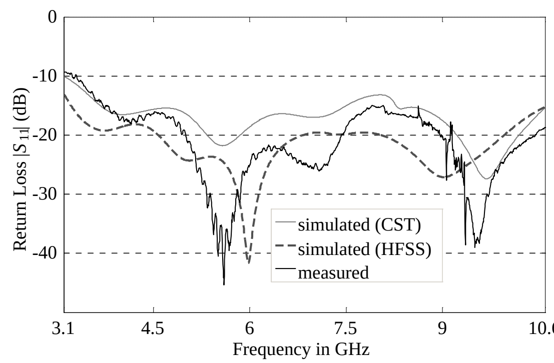


Figure 14. Return loss of antenna as obtained by simulation.

4. MEASURED RESULT

A prototype antenna with the optimized geometrical dimensions given in Table 1 is fabricated. Its photograph is shown in Fig. 13. The measured values of reflection coefficient of antenna are reported in Fig. 14, which are compared with those of computer simulated ones. Simulated and measured results are shown in Figs. 10 and 11; good agreement between them shows that our proposed antenna has a better omnidirectional pattern and radiation efficiency than a simple planar monopole antenna. Return loss of the antenna presented in Fig. 14 shows that this antenna has better matching and wider bandwidth than a simple planar monopole antenna.

5. CONCLUSIONS

In this paper, a novel antenna configuration is presented, which consists of a rectangular metallic plate with perpendicular stubs placed over a suitable circular ground plane. Its linear polarization covers the entire UWB band (3.1–10.6 GHz).The addition of protruding vertical plates causes the current distribution to appear in two orthogonal directions which leads to ground radius reduction, improved omnidirectional pattern, increased impedance bandwidth increment, and better matching with the source.

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