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MULTI-RESONANCE SQUARE MONOPOLE ANTENNA FOR ULTRA-WIDEBAND APPLICATIONS

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Abstract—In this paper, a modified square monopole antenna with multi-resonance performance, for UWB applications is proposed. The proposed antenna consists of a square radiating patch with a pair of T-shaped slots and a ground plane with a pair of rectangular sleeve and a T-shaped resonator which provides a wide usable fractional bandwidth of more than 125% (3.05–13.57 GHz). By optimizing dimension of rectangular sleeves, T-shaped slots and resonator, the total bandwidth of the antenna is greatly improved. The designed antenna has a small size of 14×22 mm^2. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and experimental results are presented to demonstrate the performance of a suggested antenna.

1. INTRODUCTION

Commercial UWB systems require small low-cost antennas with omnidirectional radiation patterns and large bandwidth [1]. It is a well-known fact that printed monopole antennas present really appealing physical features, such as simple structure, small size and low cost. Due to all these interesting characteristics, planar monopoles are extremely attractive to be used in emerging UWB applications, and growing research activity is being focused on them.

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In UWB communication systems, one of key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band. Consequently, number of microstrip monopole antenna with different geometries have been experimentally characterized [2–4] and automatic design methods have been developed to achieve the optimum planar shape [5, 6]. Moreover, other strategies to improve the impedance bandwidth which do not involve a modification of the geometry of the planar antenna have been investigated [7, 8].

In this paper, we propose a novel modified square monopole antenna with increased impedance bandwidth, for UWB applications. At first, by optimizing the dimension of a rectangular sleeve, the total bandwidth of the antenna is greatly improved. Moreover, by optimizing the dimension of the T-shaped resonator and T-shaped slots on radiating patch, much wider impedance bandwidth can be produced.

The proposed antenna has a novel structure and a small area of $14 \times 22\,\text{mm}^2$ and offers a wide usable fractional bandwidth with multi resonance performance of more than 125% (3.05–13.57 GHz) for ($S_{11} < -10\,\text{dB}$), which has a frequency bandwidth increment of 20% with respect to the previous similar antenna as was shown in Refs. [7–10], and an area reduction of 25% with respect to the previous antenna as was shown in Ref. [11], and also the proposed antenna displays a good omni-directional radiation pattern even at higher frequencies. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and experimental results are presented to demonstrate the performance of a suggested antenna.

2. ANTENNA DESIGN

The proposed square monopole antenna fed by a microstrip line is shown in Figure 1, which is printed on a FR4 substrate of thickness 1.6 mm, and permittivity 4.4. The width W_f of the microstrip feedline is fixed at 2 mm. The basic antenna structure consists of a square radiating patch, a feedline, and a ground plane. The patch is connected to a feed line of width W_f and length L_f, as shown in Figure 1. On the other side of the substrate, a conducting ground plane of width W_{sub} and length L_{gnd} is placed. The proposed antenna is connected to a $50\,\Omega$ SMA connector for signal transmission.

To design a novel antenna, the square antenna with a pair of rectangular sleeves, T-shaped slots and T-shaped conductor-backed

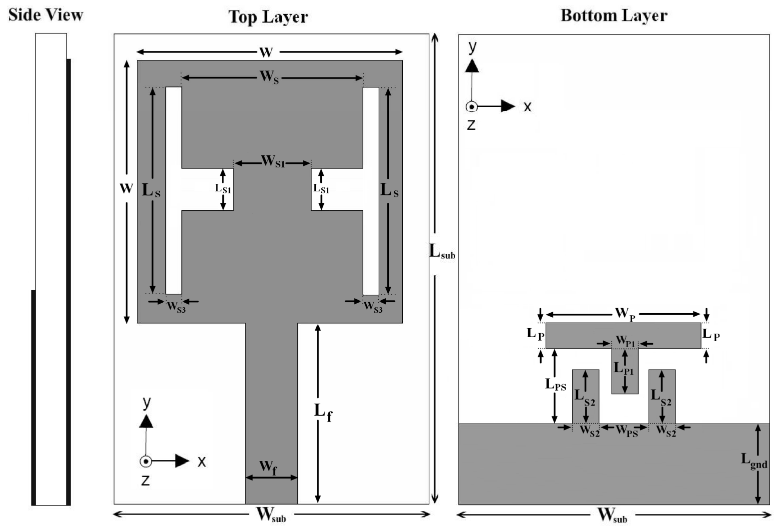


Figure 1. Geometry of proposed antenna.

plane is proposed. Based on the analysis of current distribution in UWB frequency band, it is observed that the currents at low frequency are distributed on the vertical plane at the monopole's bottom edge but the currents at high frequency are distributed on the horizontal plane [9]. By cutting the T-shaped slots of suitable dimensions at the square radiating patch, it is found that much enhanced impedance bandwidth can be achieved for the proposed antenna.

In addition, the conductor-backed plane is playing an important role in the broadband characteristics of this antenna, because it can adjust the electromagnetic coupling effects between the patch and the ground plane, and improves its impedance bandwidth without any cost of size or expense [9–11]. This phenomenon occurs because, with the use of a conductor-backed plane structure in air gap distance, additional coupling is introduced between the bottom edge of the square patch and the ground plane [12]. In this structure, T-shaped resonator and T-shaped conductor-backed plane are the same.

3. RESULTS AND DISCUSSIONS

In this section, the microstrip square monopole antenna with various design parameters were constructed, and the numerical and experimental results of the input impedance and radiation

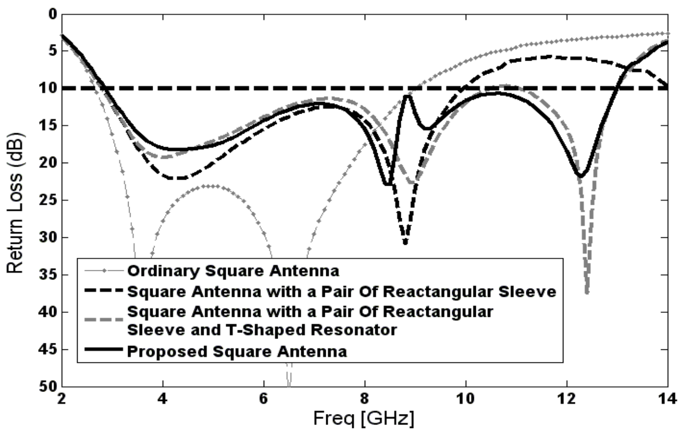


Figure 2. Simulated return loss characteristics for the various square monopole antenna structures.

characteristics are presented and discussed. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [13].

The optimal dimensions of the designed antenna are as follows: $W_{sub} = 14\,\mathrm{mm}$, $L_{sub} = 22\,\mathrm{mm}$, $W = 12\,\mathrm{mm}$, $W_f = 2\,\mathrm{mm}$, $L_f = 9\,\mathrm{mm}$, $W_S = 8\,\mathrm{mm}$, $L_S = 10\,\mathrm{mm}$, $W_{S1} = 4\,\mathrm{mm}$, $L_{S1} = 2\,\mathrm{mm}$, $W_{S3} = 1\,\mathrm{mm}$, $W_P = 6\,\mathrm{mm}$, $L_P = 1\,\mathrm{mm}$, $W_{P1} = 1\,\mathrm{mm}$, $L_{P1} = 2\,\mathrm{mm}$, $W_{PS} = 2\,\mathrm{mm}$, $L_{PS} = 3\,\mathrm{mm}$, $W_{S2} = 1\,\mathrm{mm}$, $L_{S2} = 2\,\mathrm{mm}$, and $L_{gnd} = 5\,\mathrm{mm}$.

Figure 2 shows the effect of various square monopole antenna structures on impedance bandwidth. It is seen that the upper frequency bandwidth is affected by using the rectangular sleeves in the ground plane, and as shown in Figure 2, it is observed that by using modified elements including a pair of T-shaped slots cut in the radiating patch and T-shaped conductor-backed plane inserted on the other side of substrate, additional third and fourth resonances are excited respectively, and hence the bandwidth is increased.

To understand the phenomenon behind this multi resonance performance, the input impedance of the various square monopole antenna structures that studied on Figure 2, on a Smith Chart is shown in Figure 3.

As shown in Figure 3, the upper frequency bandwidth is affected by using modified elements including the rectangular sleeves in the ground plane, and a pair of T-shaped slots cut in the radiating patch and T-shaped conductor-backed plane inserted on the other side of substrate.

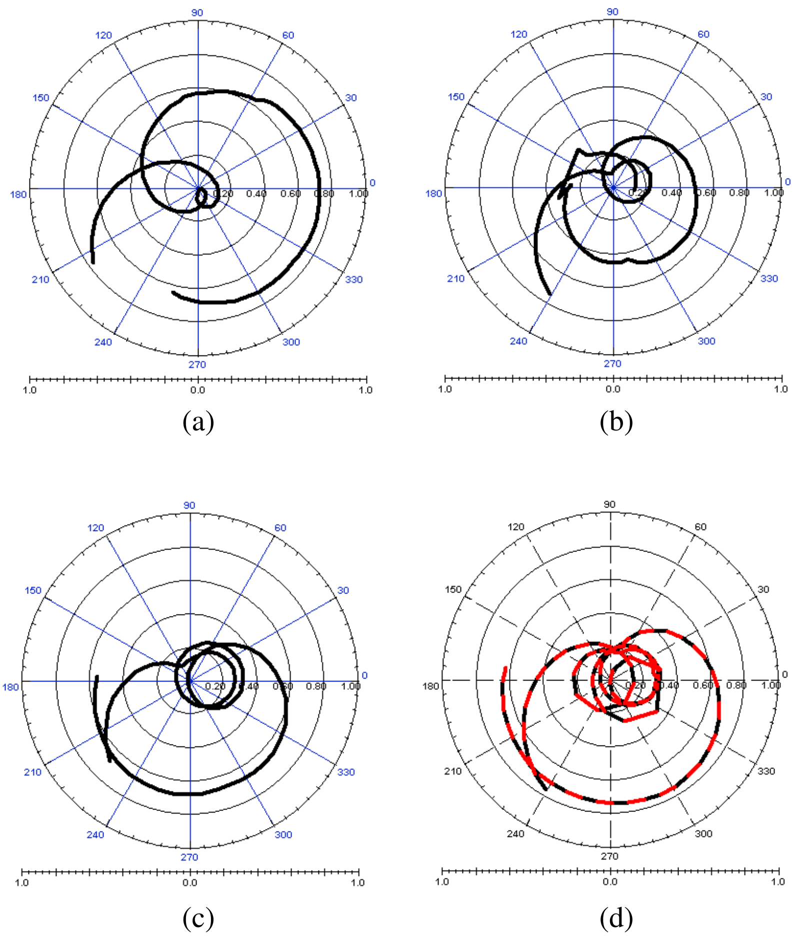
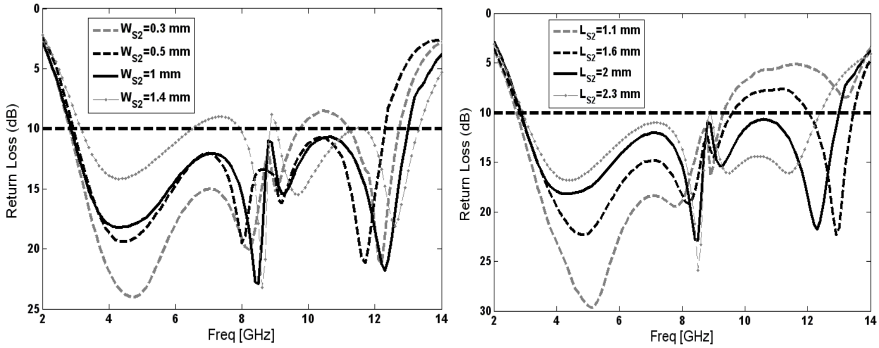


Figure 3. Simulated smith chart characteristics for the, (a) ordinary square antenna, (b) square antenna with a pair of rectangular sleeve, (c) square antenna with a pair of rectangular sleeve and T-shaped resonator, and (d) proposed antenna.

To increase the upper frequency bandwidth of the square antenna and, a rectangular sleeve is introduced into ground plane to alter the input impedance characteristics [9]. Figure 4 shows the return loss curves for different cases of the length and width dimension of the rectangular sleeve (W_{S2} and L_{S2}). As shown in Figure 4(a), it is



(a) (b)

Figure 4. Simulated return loss characteristics for the proposed antenna, (a) With different values of W_{S2} (L_{S2} is fixed at 2 mm), (b) With different values of L_{S2} (W_{S2} is fixed at 1 mm).

found out that the upper-edge frequency of the impedance bandwidth is increased with increasing W_{S2}, but the matching became poor for larger values. Therefore the optimized W_{S2} is 1 mm. From the result in Figure 4(b), it is also observed that the sleeve length also influences the bandwidth of the antenna. The length of the sleeve can be used to extend the upper edge frequency of the impedance bandwidth. The optimized sleeve length L_{S2} was found to be 2 mm, which provides a very wide bandwidth.

Another important element of this structure is the T-shaped resonator on the ground plane. Using a T-shaped resonator increases the upper-edge frequency, and by adjusting W_{P1} and L_{P1}, the electromagnetic coupling between the rectangular sleeve and the T-shaped resonator can be properly controlled [10]. Figures 5(a) and (b) show the return loss characteristics simulated for different values of W_{P1} and L_{P1}. It is seen that the forth resonance frequency is affected and therefore the upper-edge frequency of the impedance bandwidth is reduced with variation W_{P1} and L_{P1}. As shown in Figure 5(c) by adjusting the upper edge width of T-shaped resonator W_P, it is possible to control upper-edge frequency of the impedance bandwidth. Therefore the W_P is another important factor in determining frequency bandwidth and impedance matching.

In this study, in order to enhance the impedance bandwidth characteristic two T-shaped slots are inserted in the radiating patch of the proposed antenna as displayed in Figure 1. These slots are placed to create additional path for the surface current, which produce an additional resonance, as a result, increase the bandwidth [8, 9].

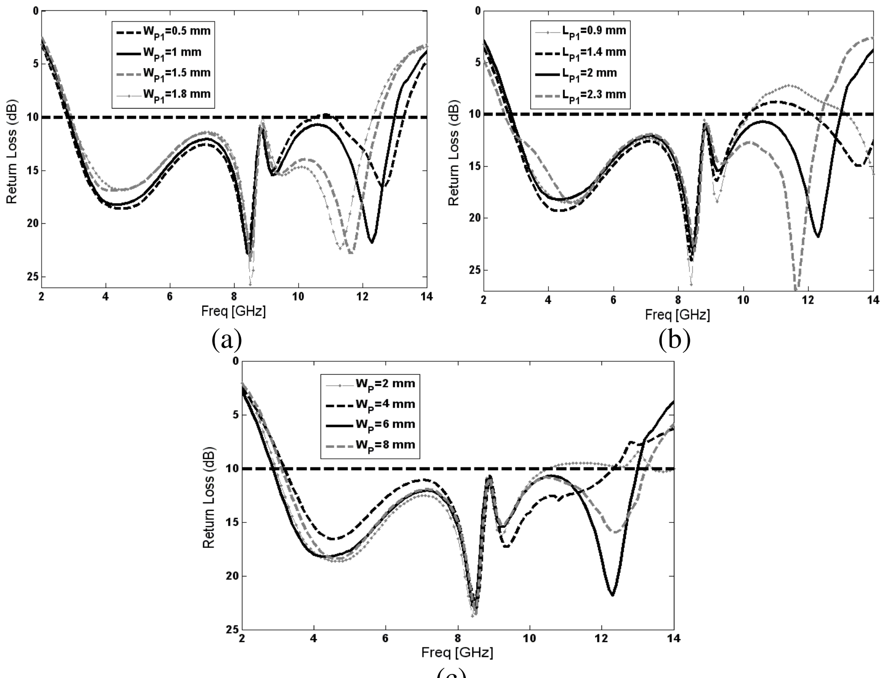


Figure 5. Simulated return loss characteristics for the proposed antenna. (a) With different values of W_{P1}. (b) With different values of L_{P1}. and (c) With different values of W_P.

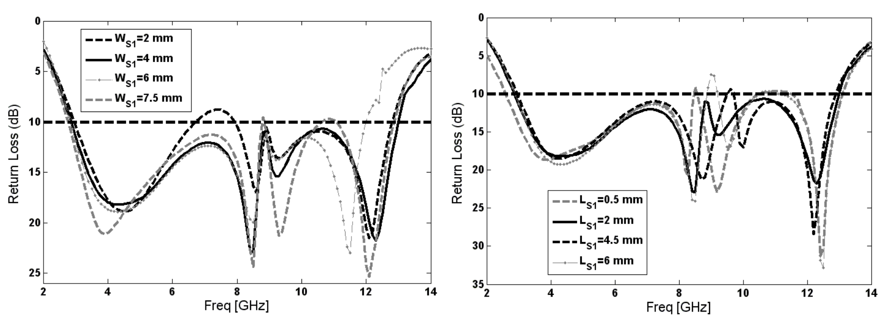
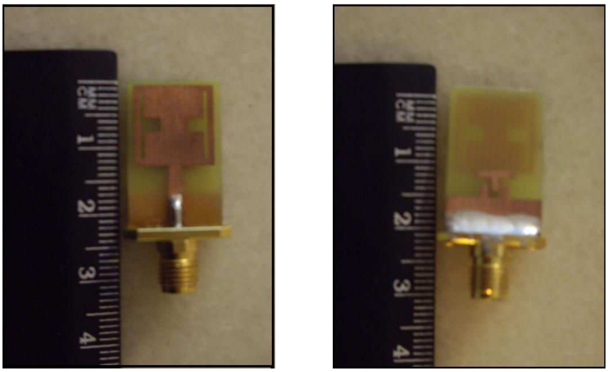


Figure 6. Simulated return loss characteristics for the proposed antenna. (a) With different values of W_{S1} (L_{S1} is fixed at 2 mm). (b) With different values of L_{S1} (W_{S1} is fixed at 4 mm).

Figure 6 shows the effects of two T-shaped slots on the impedance matching. It is found out that by using these slots the third resonance occur at around 9.5 GHz in the simulation.

The proposed antenna with optimal design, as shown in Figure 7, was fabricated and tested in the Antenna Measurement Laboratory at Iran Telecommunication Research Center (ITRC). Figure 8 shows the measured and simulated return loss characteristics of the proposed antenna. The fabricated antenna has the frequency band of 3.05 to



(a) (b)

Figure 7. Photograph of the realized antenna, (a) top view, (b) bottom view.

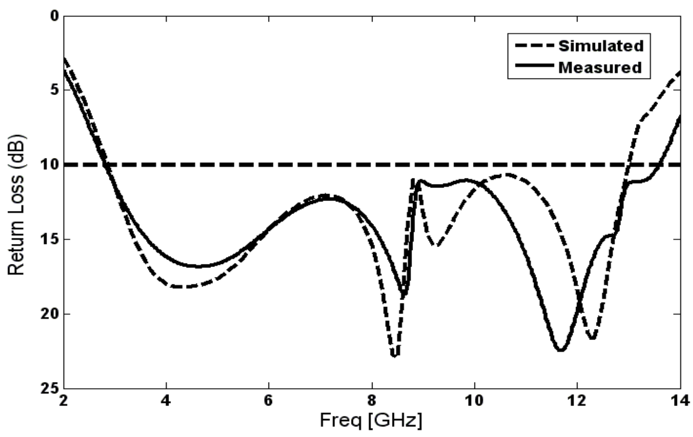


Figure 8. Measured and simulated return loss characteristics for the proposed antenna.

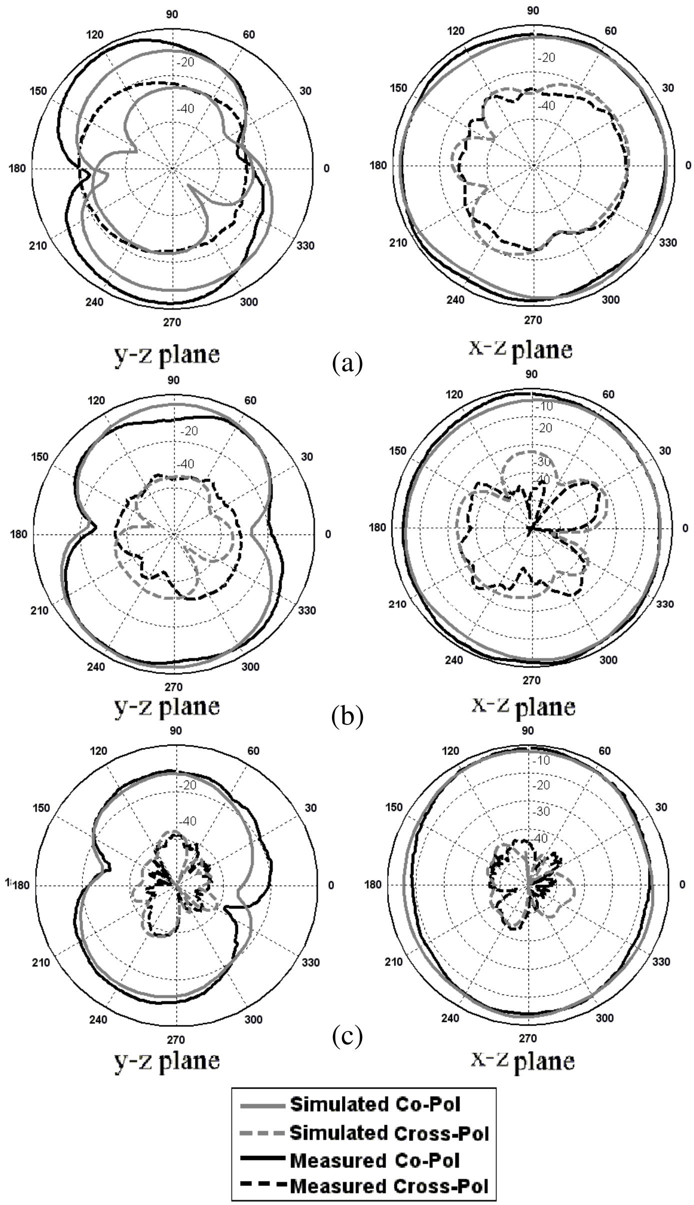


Figure 9. Measured radiation patterns of the proposed antenna. (a) 4 GHz, (b) 8 GHz, (c) 12 GHz.

over 13.57 GHz. As shown in Figure 8, there exists a discrepancy between measured data and the simulated results this could be due to the effect of the SMA port. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully.

Figure 9 shows the measured and simulated radiation patterns including the co-polarization and cross-polarization in the H-plane (x-z plane) and E-plane (y-z plane). It can be seen that the radiation patterns in x-z plane are nearly omnidirectional for the three frequencies.

4. CONCLUSION

In this paper, a novel printed monopole antenna with multi-resonance performance and wide bandwidth capability for UWB applications is proposed. In this design, the proposed antenna can operate from 3.05 to 13.57 GHz with $S_{11} < -10$ dB and displays a good omni-directional radiation pattern even at higher frequencies. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB application.

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