Multi-Resonance Monopole Antenna with Inverted Y-Shaped Slit and Conductor-Backed Plane

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Abstract **─** This manuscript introduces a new design of multi-resonance monopole antenna for Ultra-Wideband (UWB) applications. The proposed antenna consists of an ordinary square radiating patch and a modified ground plane with inverted Y-shaped slit and conductor-backed plane, which provides a wide usable fractional bandwidth of more than 135%. By cutting an inverted Y-shaped slit in the ground plane and also by embedding an Inverted Y-shaped conductor-backed plane in the feed gap distance, additional (third and fourth) resonances are excited and hence much wider impedance bandwidth can be produced; especially at the higher band. By obtaining these resonances, the usable lower frequency is decreased from 3.12 to 2.9 GHz, and also the usable upper frequency of the presented monopole antenna is extended from 10.3 to 14.85 GHz. The measured results show that the proposed antenna can achieve the Voltage Standing Wave Ratio (VSWR) requirement of less than 2.0 in frequency range from 2.83 to 14.87 GHz, which is suitable for UWB systems.

Index Terms **─** Bandwidth enhancement, conductor-backed plane, DGS, UWB applications.

I. INTRODUCTION

After allocation of the frequency band from 3.1 to 10.6 GHz for the commercial use of Ultra-Wideband (UWB) systems by the Federal Communication Commission (FCC) [1], ultra-wideband systems have received phenomenal gravitation in wireless communication. Designing an antenna to operate in the UWB band is quite a challenge, because it has to satisfy the requirements such as ultra wide impedance bandwidth, omni-directional radiation pattern, constant gain, high radiation efficiency, constant group delay, low profile, easy manufacturing, etc. [2]. 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, a number of microstrip antennas with different geometries have been experimentally characterized [3-4]. Some methods are used to obtain the multi-resonance function in the literature [5-8].

In this paper, a new design is proposed to obtain the very wideband bandwidth for the compact monopole antenna. In the proposed antenna, to obtain the multi-resonance property, the inverted Y-shaped slit and conductor-backed plane are used in the ground plane, which provides a wide usable fractional bandwidth of more than 130%. Regarding Defected Ground Structures (DGS) theory, the creating slits in the ground plane provide additional current paths. Moreover, these structures change the inductance and capacitance of the input impedance, which in turn leads to change the bandwidth [9].

Therefore, by cutting an inverted Y-shaped slit in the ground plane, much enhanced impedance bandwidth may be achieved. In addition, based on Electromagnetic Coupling Theory (ECT), by adding an inverted Y-shaped conductor-backed plane in the air gap distance, additional coupling is introduced between the bottom edge of the square

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patch and the ground plane and its impedance bandwidth is improved without any cost of size or expense. The proposed antenna has an ordinary square radiating patch, therefore displays good omni-directional radiation patterns even at the higher frequencies.

II. MICROSTRIP ANTENNA DESIGN

The presented small monopole antenna fed by a microstrip line is shown in Fig. 1, which is printed on an FR4 substrate of thickness of 1.6 mm, permittivity of 4.4, and loss tangent 0.018.

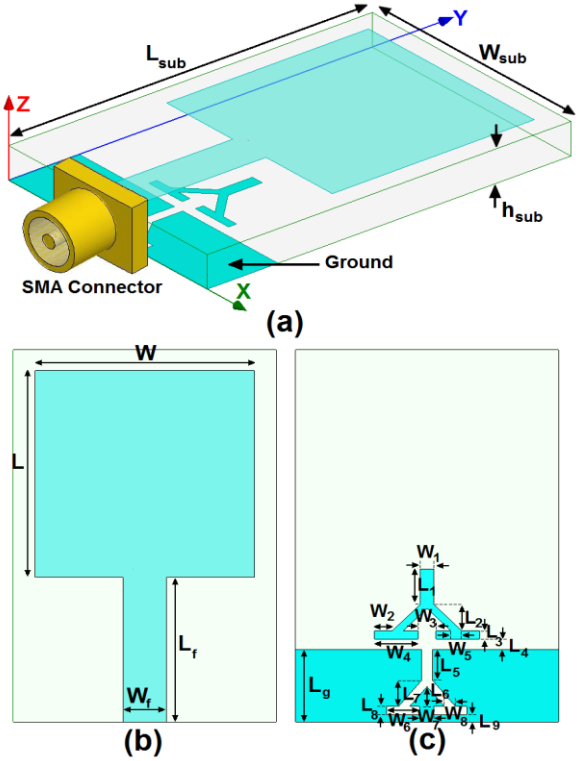

Fig. 1. Geometry of proposed monopole antenna: (a) side view, (b) top layer, and (c) bottom layer.

The basic monopole antenna structure consists of a square patch, a feed line and a ground plane. The square radiating patch has a width W. The patch is connected to a feed line of width W_f and length L_f. The width of the microstrip feed line is fixed at 2 mm, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane with two inverted fork-shaped slits and a pair of Γ-shaped parasitic structures is placed. The proposed antenna is connected to a 50-SMA connector for signal transmission.

The DGS applied to a ground plane causes a resonant character of the structure transmission with a resonant frequency controllable by changing the shape and size of the slits. In addition, based on ECT, by using a parasitic structure in the feed gap distance, the antenna impedance bandwidth is improved. The final dimensions of the designed antenna are specified in Table 1.

Table 1: Final dimensions of the antenna

Parameter	W_{sub}	L_{sub}	h_{sub}	W	L
Value (mm)	12	18	1.6	10	10
Parameter	W_1	L_1	W_2	L_2	W_3
Value (mm)	0.5	1.7	0.8	1.3	0.8
Parameter	L_3	W_f	L_f	W_4	L_4
Value (mm)	0.4	2	7	2	0.5
Parameter	W_5	L_5	W_6	L_6	W_7
Value (mm)	0.5	1.5	1.5	1	0.7
Parameter	L_7	W_8	L_8	L_9	L_g
Value (mm)	1.25	0.5	0.4	0.35	3.5

III. RESULTS AND DISCUSSIONS

The proposed microstrip monopole antenna with various design parameters was constructed and the numerical and experimental results of input impedance and radiation characteristics are presented and discussed. The analysis and performance of the proposed antenna is explored by using Ansoft simulation software High-Frequency Structure Simulator (HFSS) [10], for better impedance matching.

Figure 2 shows the configuration of the various antennas used for simulation studies. VSWR characteristics for ordinary monopole antenna (Fig. 2 (a)), the antenna with an inverted Y-shaped slits (Fig. 2 (b)), and the proposed antenna (Fig. 2 (c)) structures are compared in Fig. 3. As shown in Fig. 3, in the proposed antenna configuration, the ordinary square monopole can provide the fundamental and next higher resonant radiation band at 4.8 and 8.1 GHz, respectively, in the absence of the inverted Y-shaped slit and conductor-backed plane structures. It is observed that by using these modified elements, additional third (10.3 GHz) and fourth (14.4 GHz) resonances are excited, respectively, and hence, the bandwidth is increased. Also, the input impedance of the proposed antenna on a Smith Chart is shown in Fig. 4.

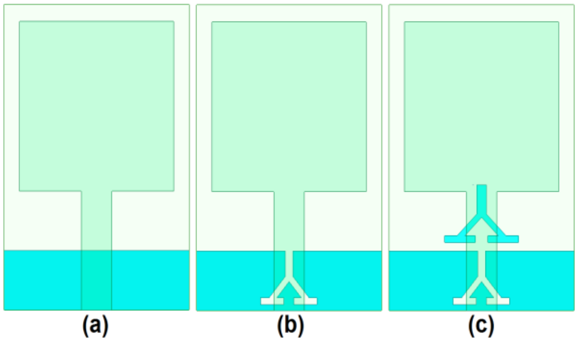

Fig. 2. (a) Ordinary square monopole antenna, (b) square antenna with an inverted Y-shaped slit in the ground plane, and (c) the proposed monopole antenna.

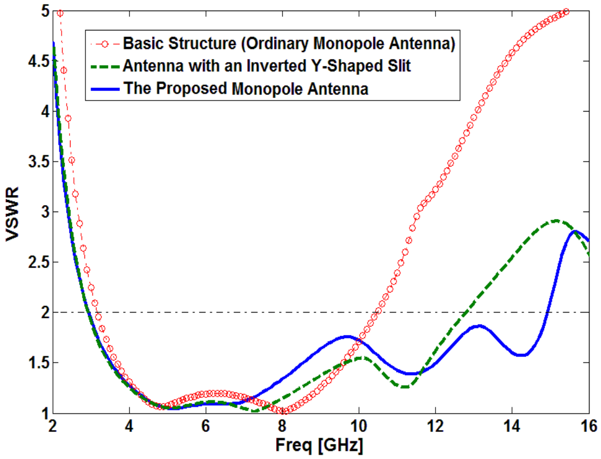

Fig. 3. Simulated VSWR characteristics for the various monopole antennas shown in Fig. 2.

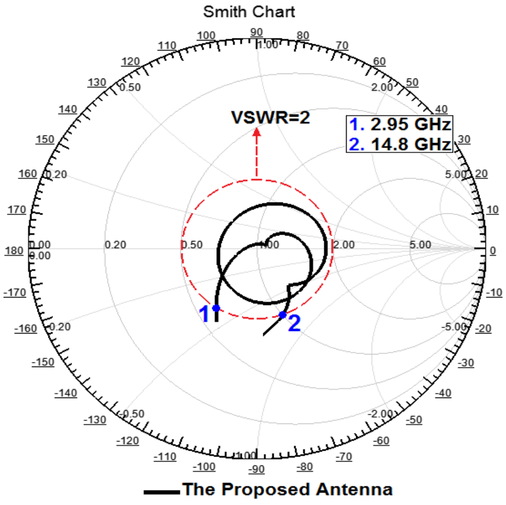

Fig. 4. Simulated input impedance on a Smith Chart for the proposed antenna.

In order to understand the phenomenon behind the multi-resonance performance of the proposed, the simulated current distributions on the ground plane for the proposed antenna at 5, 6.7, 11.3 and 14.4 GHz (resonance frequencies) are presented in Fig. 5. As illustrated in Figs. 5 (a) and 5 (b), at the lower frequencies it can be observed that the directions of surface currents at the ground plane are reversed in comparison with each other, which cause the antenna impedance changes at these frequencies. Also, as shown in Figs. 5(c) and 5 (d), at the additional resonances frequencies (third and fourth) the currents concentrated on the edges of the interior and exterior of the inverted Y-shaped slits and conductor-backed plane [11].

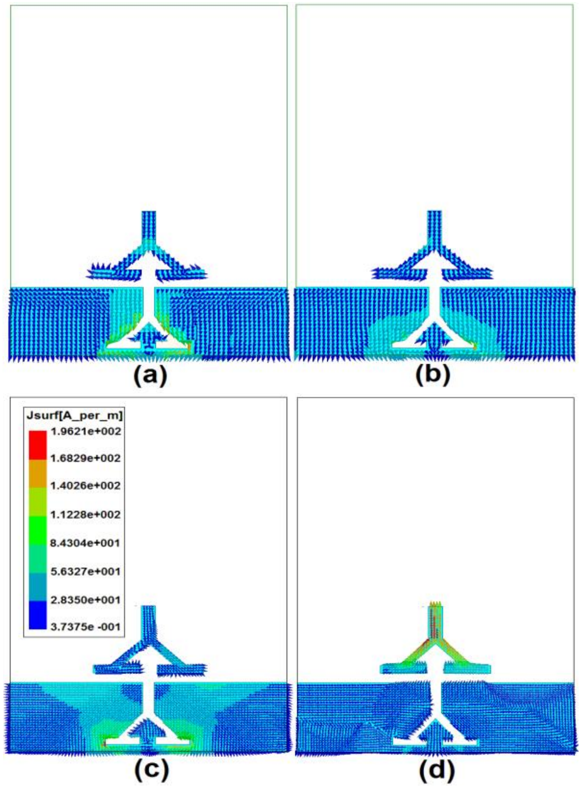

Fig. 5. Simulated surface current distributions on the ground plane for the proposed antenna at: (a) 5 GHz, (b) 6.7 GHz, (c) 11.3 GHz, and (d) 14.4 GHz.

The proposed antenna was fabricated and tested. Figure 6 shows the measured and simulated radiation patterns, including the co-polarization in the *H*-plane (*x-z* plane) and *E*-plane (*y-z* plane). The main purpose of the radiating patterns is to demonstrate that the antenna actually radiates over a wide frequency band. It can be seen that the radiation patterns in *x-z* plane are nearly omni-directional for the three frequencies. The radiation patterns on the y-z plane are like a small electric dipole leading to bidirectional patterns in a very wide frequency band. With the increase of frequency, the radiation patterns become worse, because of the increasing effects of the cross-polarization [12-13].

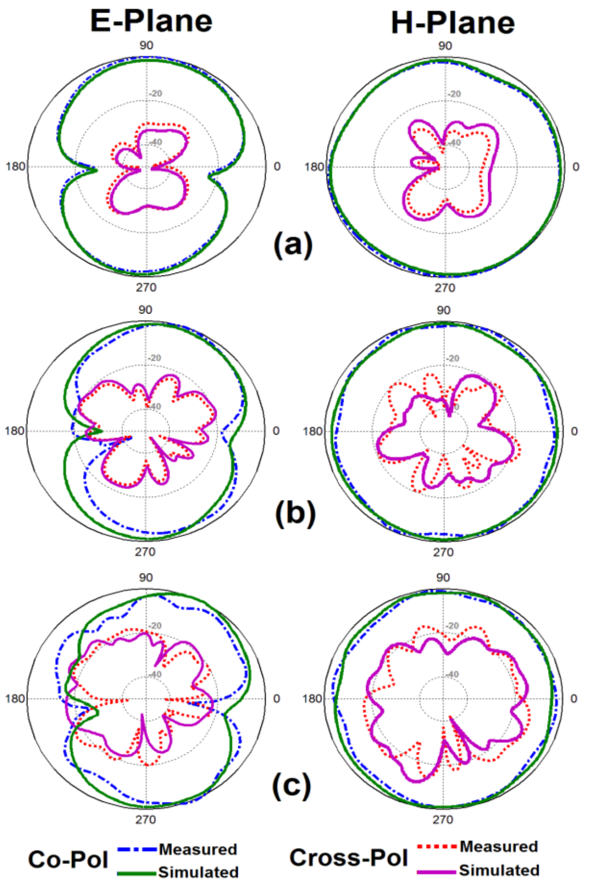

Fig. 6. Measured and simulated radiation patterns of the proposed antenna: (a) 5 GHz, (b) 9 GHz, and (c) 13 GHz.

Figures 7 and 8 show the measured and simulated VSWR and return loss characteristics of the proposed antenna. As seen, the fabricated antenna has the frequency band of 2.95 to 14.84 GHz.

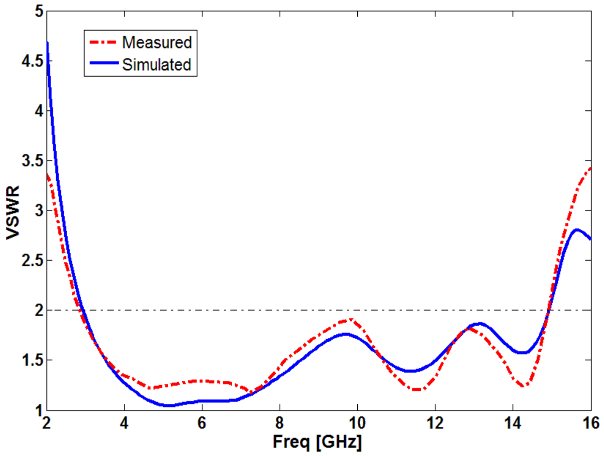

Fig. 7. Measured and simulated VSWR characteristics for the proposed antenna.

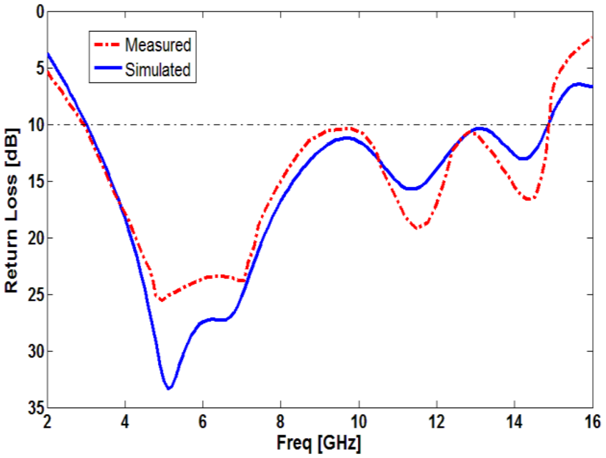

Fig. 8. Measured and simulated return loss characteristics for the proposed antenna.

The simulated radiation efficiency characteristic of the proposed antenna is shown in Fig. 9. Results of the calculations using the software HFSS, indicated that the proposed antenna features a good efficiency, being greater than 82% across the entire radiating band. In addition, the measured maximum gain of the antenna against frequency is illustrated in Fig. 9. The antenna gain has a flat property which increases by the frequency. As seen, the proposed antenna has sufficient and acceptable gain levels in the operation bands [14-15].

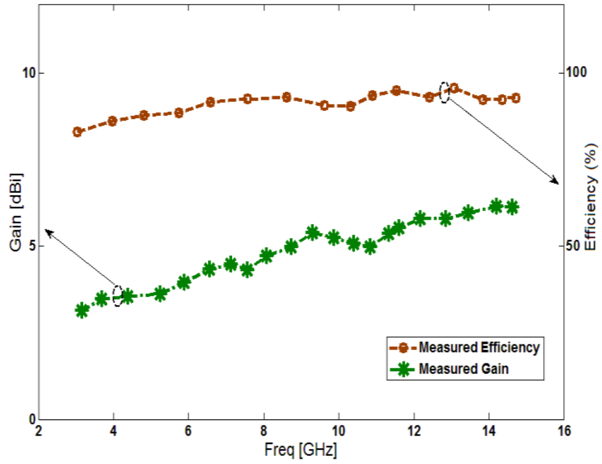

Fig. 9. Radiation efficiency (simulated) and gain (measured) characteristics of the antenna.

The radiating mechanism of the proposed antenna is more novel than was explained in previous works. The proposed structure is the combination of the monopole antenna with the dipole and slot antenna. In this study, the modified ground-plane structure is the combination of the monopole antenna and the slot antenna. By using the modified conductor-backed plane, the interaction of the two parts of the overall antenna is occurred. The embedding parasitic structure in the ground plane of the monopole antenna acts as a dipole antenna that can provide an additional current path. Also, the entire back conducting plane could be part of the radiator, especially when operating at lower frequencies [16].

Table 2 summarizes the proposed antenna and the previous designs [17-24]. As seen, the proposed antenna has a compact size with very wide bandwidth, in comparison with the pervious works. In addition, the proposed antenna has good omni-directional radiation patterns with low cross-polarization level, even at the higher and upper frequencies. As the proposed antenna has symmetrical structure and an ordinary square radiating patch without any slot and parasitic structures at top layer, in comparison with previous multi-resonance UWB antennas, the proposed antenna displays a good omni-directional radiation pattern even at lower and higher frequencies. Also, the proposed antenna has sufficient and acceptable radiation efficiency, group delay and antenna gain levels in the operation bands [25-28].

Table 2: Comparison of previous designs with the proposed antenna

Ref.	FBW (%)	Dimension (mm)	Gain (dBi)
[17]	47%	33×33	3.5~6
[18]	87%	22×24	1~5.5
[19]	87%	32×25	2~5.5
[20]	91%	26×26	3-7
[21]	112%	20×20	2~4.7
[22]	118%	40×10	2.3~6.3
[23]	130%	12×18	2.7-5.5
[24]	132%	25×26	not reported
This Work	*136%*	*12×18*	*3.2~6.3*

IV. CONCLUSION

In this manuscript, a compact Printed Monopole Antenna (PMA) with multi-resonance characteristic for UWB applications has been proposed. The fabricated antenna can operate from 2.95 to 14.84 GHz. In order to enhance the bandwidth, an inverted Y-shaped slit is inserted in the ground plane and also by adding an inverted Y-shaped conductor-backed plane structure, additional third and fourth resonances are excited, and hence much wider impedance bandwidth can be produced. The designed antenna has a simple configuration with small size of 12×18 mm^2. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB systems application.

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