UWB Square Monopole Antenna with Omni-Directional Radiation Patterns for Use in Circular Cylindrical Microwave Imaging Systems

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Abstract **─** In this paper, a novel ultra-wideband printed monopole antenna (PMA) for the use in a circular cylindrical microwave imaging system is presented. The proposed antenna consists of a square radiating patch and a ground plane with a pair of L-shaped slots and two L-shaped conductor back plane, which provides a wide usable fractional bandwidth of more than 130 % (3.02 GHz - 15.21 GHz). By cutting two modified L-shaped slots with variable dimensions on the ground plane corners and also by inserting two L-shaped conductor back plane on the other side of the substrate, additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the higher band. The proposed antenna has an ordinary square radiating patch, therefore displays a good omni-directional radiation pattern even at higher frequencies, and also its radiation efficiency is greater than 82% across the entire radiating band. The designed antenna has a small size of 12 × 18 mm^2. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for circular cylindrical microwave imaging system.

Index Terms **-** Circular cylindrical microwave imaging systems, L-shaped conductor back plane, L-shaped slot, square monopole antenna, and UWB antenna.

I. INTRODUCTION

In general, the microwave imaging system is formed by a circular cylindrical array antenna in order to detect cancerous tissue. In this approach, circular cylindrical microwave imaging systems require small antennas with omni-directional radiation patterns and large bandwidth [1-5]. Thus, in circular cylindrical microwave imaging system, one of the key issues is the design of a compact antenna while providing wideband characteristic over the whole operating bands. It is a well-known fact that planar 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 UWB applications, and growing research activity is being focused on them [6-11].

A simple method for designing a novel and compact microstrip-fed monopole antenna with multi resonances characteristic for microwave imaging system applications has been presented. In this paper, based on Defected Ground Structures (DGS), for bandwidth enhancement we use a pair of L-shaped slots in the ground plane. And based on the Electromagnetic Coupling Theory (ECT) [12], by using two L-shaped conductor back plane on the other side of the substrate, additional resonances are excited and hence much wider impedance bandwidth can be produced (unlike other monopole antennas

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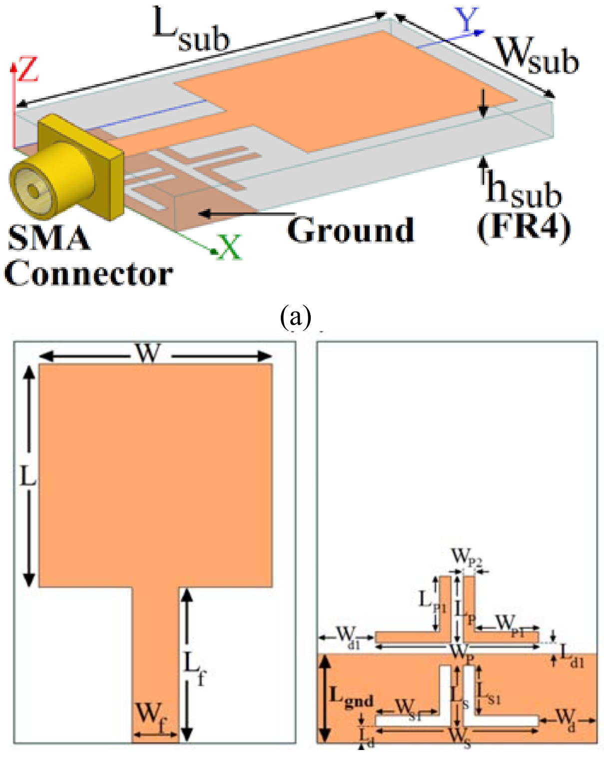
reported in the literature to date [6-11], this structure has an ordinary square radiating patch configuration). By obtaining these resonances, the usable upper frequency of the monopole is extended from 10.3 GHz to 15.21 GHz. The presented monopole antenna has a small size of 12×18 mm^2. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for circular cylindrical microwave imaging system applications.

II. ANTENNA DESIGN

The proposed monopole antenna fed by a microstrip line is shown in Fig. 1, which is printed on an FR4 substrate of thickness 1.6 mm. As shown in Fig. 1, the proposed antenna consists of a square radiating patch and a rectangular partially modified ground plane with two T-shaped parasitic structures. The basic antenna structure consists of a square patch, a feedline, and a ground plane. The square patch has a width W. The patch is connected to a feed line of width W_f and length L_f, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane of width W_{sub} and length L_{gnd} is placed. The width W_f of the microstrip feedline is fixed at 2 mm. The proposed antenna is connected to a 50 Ω SMA connector for signal transmission.

Regarding Defected Ground Structures (DGS), the created slots in the ground plane provide an additional current path. Moreover, this structure changes the inductance and capacitance of the input impedance, which in turn leads to changing the bandwidth. The DGS applied to a microstrip line causes a resonant character. This generated resonant frequency can be controlled by changing the shape and size of the slot [9]. Therefore, by cutting two L-shaped slots in the ground plane and carefully adjusting its parameters, much enhanced impedance bandwidth may be achieved. Also L-shaped conductor back plane plays an important role in the broadband characteristics of this antenna because they can achieve additional resonances and improve the bandwidth [10]. In other words, the impedance bandwidth is effectively improved at the upper frequency that can be considered as a parasitic resonator electrically to the square monopole.

In this work, we start by choosing the dimensions of the designed antenna. These parameters, including the substrate, is $L_{sub} \times W_{sub}$ = 12 mm × 18 mm, or about $0.15\,\lambda \times 0.25\,\lambda$ at 4.2 GHz (the first resonance frequency). We have a lot of flexibility in choosing the width of the radiating patch. This parameter mostly affects the antenna bandwidth.



(a) (b) (c)

Fig. 1. Geometry of the proposed microstrip-fed monopole antenna, (a) side view, (b) top view, and (c) bottom view.

As W decreases, so does the antenna bandwidth, and vice versa. Next step, we have to determine the length of the radiating patch L. This parameter is approximately λ_{lower} / 4, where λ_{lower} is the lower bandwidth frequency wavelength. λ_{lower} depends on a number of parameters such as the slot width as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated [11]. The last and final step in the design is to choose the length of the resonator structure. In this design, the optimized length $L_{resonance}$ is set to resonate at $0.25\,\lambda_{resonance}$, where $L_{resonance3} = 0.5\,W_S + L_S$, and $L_{resonance4} = W_{P1}$

+ L_{P1}. $\lambda_{resonance3}$ and $\lambda_{resonance4}$ correspond to new resonances frequencies at 11.7 GHz and 14.2 GHz, respectively. The final values of the presented slot antenna design parameters are specified in Table 1.

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Table 1: The final dimensions of the designed antenna.

Param.	mm	Param.	mm	Param.	mm
W_{Sub}	12	L_{Sub}	18	W	10
L_f	7	W_f	2	W_{S1}	2.75
W_S	7	L_S	2.25	L_d	1.5
L_{S1}	1.75	W_d	2.5	W_P	5
W_{d1}	3.5	L_{d1}	0.5	L_{P1}	3
L_P	3.5	W_{P1}	1.75	W_{P2}	0.5
L	10	h	1.6	L_{gnd}	3.5

III. RESULTS AND DISCUSSIONS

The proposed microstrip monopole antenna with various design parameters were constructed, and the numerical and experimental results of the input impedance and radiation characteristics were presented and discussed. Ansoft HFSS simulations are used to optimize the design and to show the agreement between the simulation and the measurement results [13].

Figure 2 shows the structure of various antennas used for simulation studies. VSWR characteristics for ordinary square monopole antenna (Fig. 2(a)), with two L-shaped slots with (Fig. 2(b)), and the proposed antenna (Fig. 2(c)) 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 GHz and 8.2 GHz, respectively, in the absence of the L-shaped slots and conductor back plane. The upper frequency bandwidth is significantly affected by using the L-shaped slots in the ground plane. This behavior is mainly due to the slots created in the ground plane, which provide an additional current path. Furthermore, by inserting two L-shaped conductor back plane on the ground plane the impedance bandwidth is effectively improved at the upper frequency [14-15]. It is observed that by using these modified elements, including two L-shaped slots and two L-shaped conductor back plane in the ground plane; an additional third (11.7 GHz) and fourth (14.2 GHz) resonances are excited respectively, and hence the bandwidth is increased**.** Moreover, the input impedance of the various monopole antenna structures that were shown in Fig. 2, is shown in Fig. 4 on a Smith Chart.

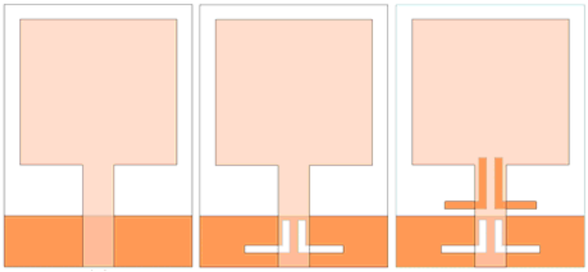

(a) (b) (c)

Fig. 2. **(**a) The basic structure (ordinary square monopole antenna), (b) antenna with two L-shaped slots in the ground plane, and (c) the proposed antenna.

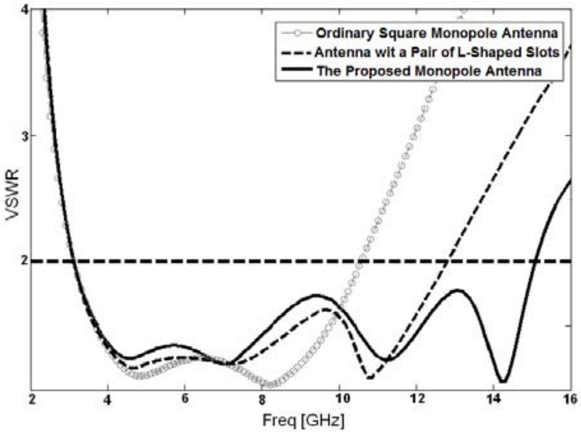


Fig. 3. Simulated VSWR characteristics for the various antenna structures shown in Fig. 2.

In order to know the phenomenon behind these additional resonances performance, the simulated current distributions on the ground plane patch for the ordinary square monopole antenna with two L-shaped slots on the ground plane at 11.7 GHz are presented in Fig. 5 (a). It can be observed in Fig. 5 (a), that the current is concentrated on the edges of the interior and exterior of the protruded L-shaped slots at 11.7 GHz. Other important design parameters of this structure are the L-shaped conductor back planes, used on the other side of the substrate. Figure 5 (b) presents the simulated current distributions on the ground plane at the forth resonance frequency (14.2 GHz). As shown in Fig. 5 (b), at the forth resonance frequency the current flows are more dominant around the L-shaped conductor back plane. The proposed antenna has a slightly higher efficiency rather than the ordinary square antenna throughout the entire radiating band, which is mainly owing to the new resonant properties. The HFSS results indicated that the proposed antenna features a good efficiency, being greater than 82 % across the entire radiating band.

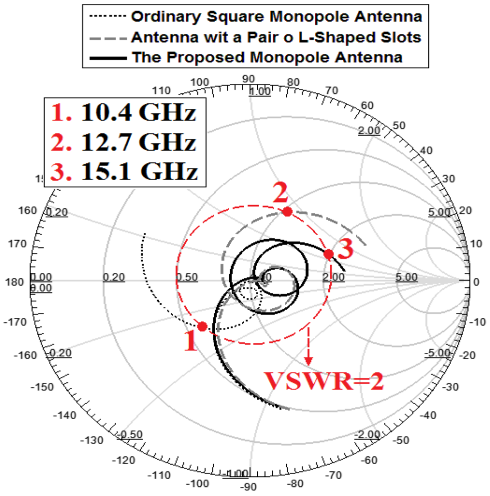
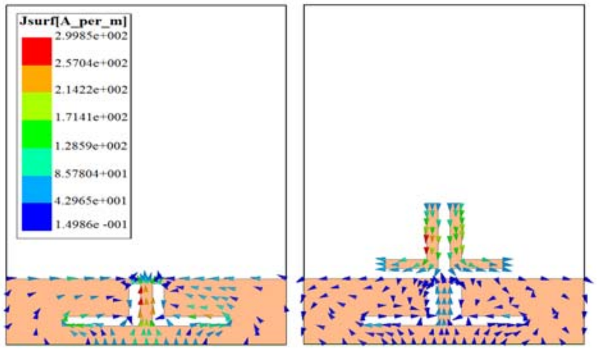


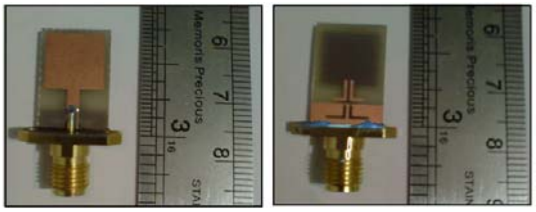
Fig. 4. Simulated input impedance on a Smith chart for the antenna structures shown in Fig. 2.



(a) (b)

Fig. 5. Simulated surface current distributions on the ground plane for, (a) the square monopole antenna with two L-shaped slots at the third resonance frequency (11.7 GHz), (b) the proposed antenna at the fourth resonance frequency (14.2 GHz).

The proposed antenna with optimal design, shown in Fig. 6, was built and tested. The measured and simulated VSWR and return loss characteristics of the proposed antenna are shown in Figs. 7 and 8, respectively. The fabricated antenna has the frequency band of 3.02 GHz to over 15.21 GHz. As shown in Fig. 7, there exists a discrepancy between the measured data and the simulated results. This could be due to the effect of the SMA port, in addition to the simulation accuracy due to the wide range of simulation frequencies. In a physical network analyzer measurement, the feeding mechanism of the proposed antenna is composed of an SMA connector and a microstrip line, whereas the simulated results are obtained using the HFSS. In HFSS by default, the antenna is excited by a wave port that it is renormalized to a 50 Ohm full port impedance, therefore this discrepancy between the measured data and the simulated results could be due to the effect of the SMA port [9]. In order to confirm the accurate VSWR characteristics of the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully. In conclusion, as the monopole is a short radiator, the SMA connector can modify its impedance matching.



(a) (b)

Fig. 6. Photograph of the printed monopole antenna, (a) top view and (b) bottom view.

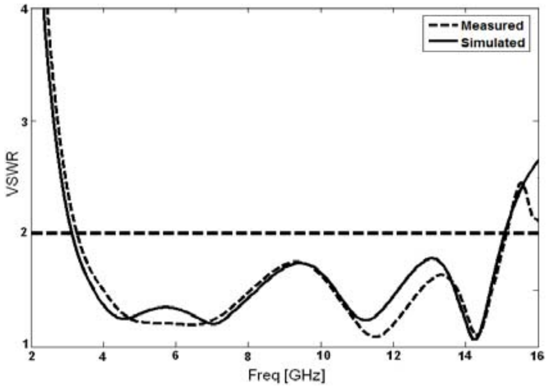


Fig. 7. Measured and simulated VSWR for the proposed antenna.

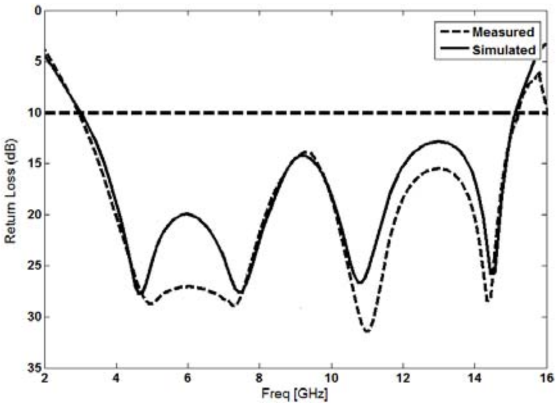
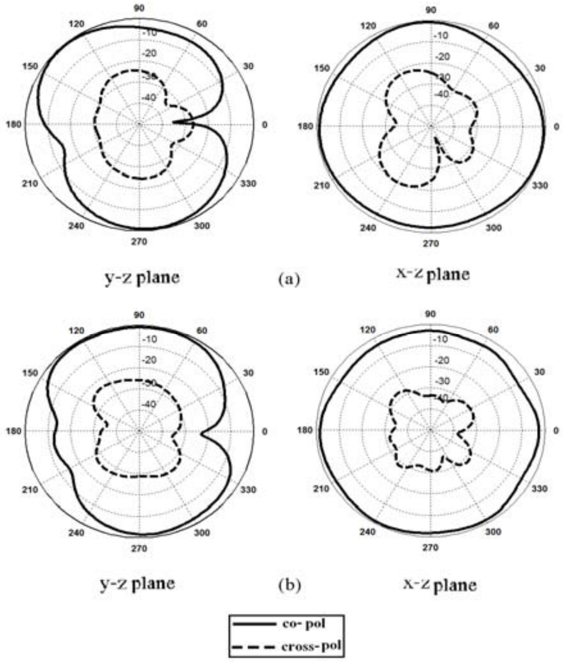


Fig. 8. Measured and simulated return loss for the proposed antenna.

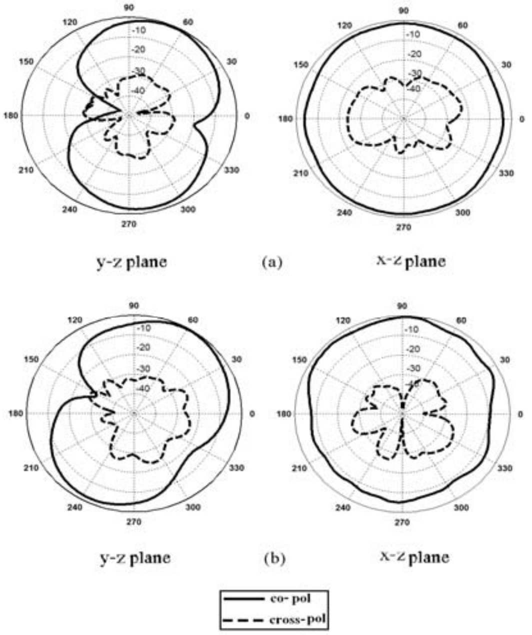
Figures 9 and 10 show the measured radiation patterns at resonance frequencies, which includes the co-polarized and cross-polarized in the E-plane (Y-Z plane) and H-plane (X-Z plane). The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide frequency band. It can be seen that the radiation patterns in X-Z plane are nearly omni-directional even at higher frequencies, and also the cross-polarization level is low at the four frequencies.



y-z plane (a) x-z plane

y-z plane (b) x-z plane

Fig. 9. Measured radiation patterns of the proposed antenna at the (a) first resonance frequency (4.2 GHz) and the (b) second resonance frequency (7.6 GHz).



y-z plane (a) x-z plane

y-z plane (b) x-z plane

Fig. 10. Measured radiation patterns of the proposed antenna at the (a) third resonance frequency (11.7 GHz) and (b) fourth resonance frequency (14.2 GHz).

V. CONCLUSION

In this paper, a novel compact Printed Monopole Antenna (PMA) with multi-resonance characteristics has been proposed for the use in circular cylindrical microwave imaging system applications. The fabricated antenna satisfies the VSWR < 2 requirement from 3.02 GHz to 15.21 GHz. In order to enhance bandwidth we insert two L-shaped slots in the ground plane, and also by using two L-shaped conductor back plane with variable dimensions on the ground plane; additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the higher band. The designed antenna has a simple configuration with ordinary square radiating patch and small size of 12×18 mm^2. Simulated and experimental results show that the proposed antenna could be a good candidate for circular cylindrical microwave imaging system applications.

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