Omnidirectional Antenna with Multi-Resonance Performance for Microwave Imaging Systems

N. Ojaroudi, M. Ojaroudi, F. Geran, and Sh. Amiri

Abstract — **In this paper, a novel ultra-wideband printed monopole antenna (PMA) for microwave imaging systems is presented. The proposed antenna provides a wide usable fractional bandwidth of more than 160% (2.12-17.87 GHz). The 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.**

Keywords — **Microstrip-fed antenna, microwave imaging systems, multi-resonance performance.**

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 omnidirectional radiation patterns and large bandwidth [1]–[3]. The majority of the compact ultra-wideband (UWB) antennas presented in the literature exhibit omnidirectional radiation patterns with relatively low gain and an impulse response with observable distortion. These types of UWB antennas are suitable for the short-range indoor and outdoor communication. However, for radar systems, such as a UWB microwave imaging system for detection of tumor in woman's breast, a moderate gain directional antenna is advantageous. In addition to an UWB impedance bandwidth, as defined by the minimum return loss of the 10 dB, antenna is required to support a very short pulse transmission with negligible distortion. This is necessary to achieve precision imaging without ghost targets.

The unipolar and antipodal Vivaldi antennas presented in the literature [4]-[5] satisfy the requirements for imaging systems in terms of bandwidth, gain, and impulse response. However, the achieved performance is at the expense of a significant size, which has a length of several wavelengths. Therefore, the challenge is to reduce their physical dimensions such that it can be incorporated in a compact microwave imaging detection system while maintaining its broadband, high-gain, and distortionless performance. Several UWB antenna designs with compact size and low distortion have been proposed for use in the medical imaging systems [6]–[8]. Each has its own merits and drawbacks. Some of the proposed antennas have a no planar structure, whereas others have low-gain and/or low radiation efficiency.

A simple method for designing a novel and compact microstrip-fed monopole antenna with a multi resonances characteristic for microwave imaging system applications has been presented. In this paper, based on defected structures (DS), for bandwidth enhancement we use an I-shaped slot on the feed-line and a pair of S-shaped slots in the ground plane. By using these slots, the usable upper frequency of the monopole is extended from 10.3 GHz to 17.87 GHz. Unlike other antennas reported in the literature to date [9]-[11], this antenna provides a wide usable fractional bandwidth of more than 160% .

II. Antenna Design

The proposed monopole antenna fed by a microstrip line is shown in Fig 1, which is printed on a FR4 substrate of thickness 1.6 mm. The proposed antenna is connected to a 50Ω SMA connector for signal transmission.

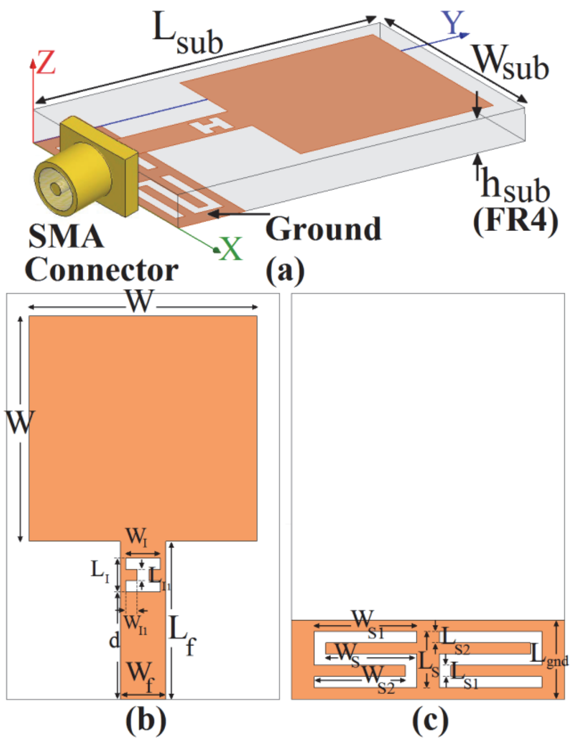

Fig. 1. Geometry of the proposed antenna, (a) side view, (b) top layer, and (c) bottom layer.

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In the presented structure, creating slots in the ground plane and feed-line provide an additional current path. Moreover, these structures change the inductance and capacitance of the input impedance, which in turn leads to change of the bandwidth. The DS applied to a microstrip line causes a resonant character of the structure transmission with a resonant frequency controllable by changing the shape and size of the slot [8]. Therefore, by using these slots and carefully adjusting its parameters, much enhanced impedance bandwidth may be achieved. Final values of the presented antenna design parameters are specified in Table. 1.

TABLE 1: THE FINAL DIMENSIONS OF THE DESIGNED ANTENNA.

Param.	***mm***	***Param.***	***mm***	***Param.***	***mm***
W_{Sub}	12	L_{Sub}	18	h_{sub}	1.6
L_f	7	W_f	2	W	10
L_I	1.5	W_I	1.5	L_{I1}	0.5
W_{I1}	0.5	W_S	4	L_S	2.5
W_{S1}	4.5	L_{S1}	0.5	W_{S2}	4.2
L_{S2}	0.5	d	4.75	L_{gnd}	3.5

In this work, the final step in the design is to choose the length of the I-shaped slot and S-shaped slots resonators. A good starting point is to choose it to be equal to $\lambda_m/4$, where λ_m is the guided wavelength in the microstrip line. In this design, the optimized length $L_{resonance}$ is set to resonate at $0.25\lambda_{resonance}$,

where

$L_{resonance1} = W_I + L_I + 2W_{I1}$,

$L_{resonance4} = 2W_{S1} + W_S + L_S$

and

$L_{resonance5} = W_{S2} + L_{S1}$

$\lambda_{resonance1}$, $\lambda_{resonance4}$ and $\lambda_{resonance5}$ correspond to the I-shaped slot resonance frequency (3.55 GHz) and the S-shaped slots resonance frequencies (13.4 GHz and 16.2 GHz, respectively).

III. RESULT AND DISCUSSION

In this section, microstrip monopole antennas with various design parameters were constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. Ansoft HFSS simulations are used to optimize the design and agreement between the simulation and measurement is obtained [12].

The structures of the various antennas used for simulation studies are shown in Figs 2. VSWR characteristics for ordinary square monopole antenna, with an I-shaped slot in the feed-line and also for the antenna with an I-shaped slot in the feed-line and a pair of rectangular slots in the ground plane, and the proposed antenna 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 and 8 GHz, respectively, in the absence of the I-shaped and S-shaped slots. The upper frequency bandwidth is significantly affected by using these slots. This behaviour is mainly due to creating slots that provide additional current paths. It is observed that by using these modified elements including I-shaped and S-shaped slots, additional first (3.55 GHz), fourth (13.4 GHz) and fifth (16.2 GHz) resonances are excited respectively, and hence the bandwidth is increased**.** Moreover, the input impedance of the presented monopole antenna structure on a Smith Chart is shown in Fig. 4.

In order to know the phenomenon behind these triple additional resonances performance, the simulated current distributions on the feed line and the ground plane patch for the proposed antenna at 3.55 GHz, 13.4 GHz and 16.2 GHz are presented in Fig. 5. It can be observed in Fig. 5 (a), that the current is concentrated on the edges of the interior and exterior of the I-shaped slot at 3.55 GHz. As shown in Fig. 5 (b) and (c), at the fourth and fifth resonance frequencies the current flows are more dominant around the S-shaped slots [13]-[14].

The proposed antenna has a slightly higher efficiency than the ordinary square antenna throughout the entire radiating band, which is mainly due to the new resonant properties. Results of the calculations using the software HFSS indicate that the proposed antenna features a good efficiency, being greater than 82% across the entire radiating band.

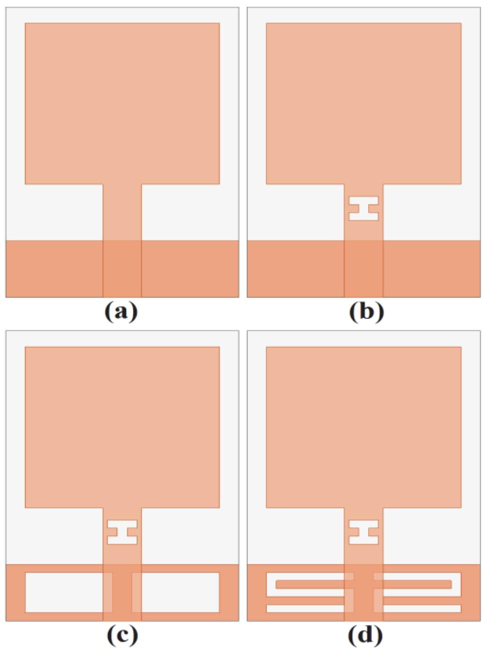

Fig. 2. (a) Ordinary square monopole antenna, (b) square antenna with an I-shaped slot in the feed-line, (c) antenna with an I-shaped slot in the feed-line and a pair of rectangular slots in the ground plane, and (d) the proposed antenna structure

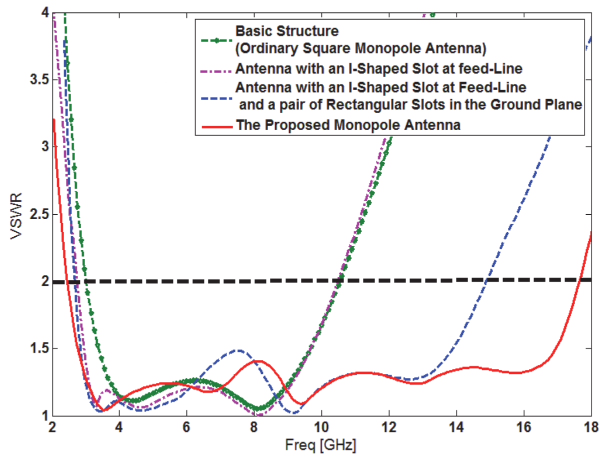

Fig. 3. Simulated VSWR characteristics for the various monopole antenna structures.

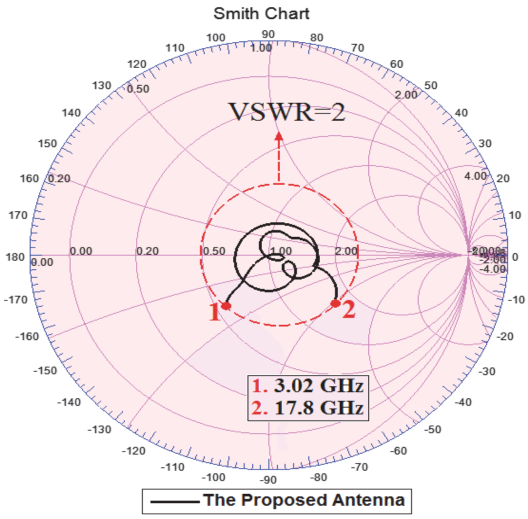

Fig. 4. Simulated input impedance on a Smith chart for the proposed monopole antenna.

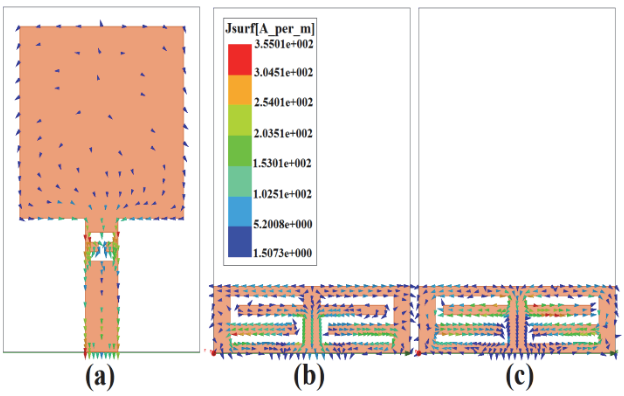

Fig. 5. Simulated surface current distributions for proposed antenna (a) on the feed-line at the first resonance frequency (3.55 GHz), (b) on the ground plane at the fourth resonance frequency (13.4 GHz), and (c) at the fifth resonance frequency (16.2 GHz).

The proposed antenna with a final design as shown in Fig. 6 was built and tested. The measured and simulated VSWR characteristics of the proposed antenna are shown in Fig .7.

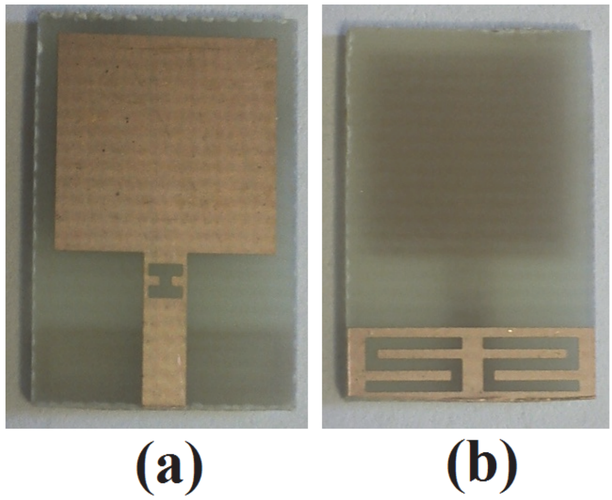

Fig. 6. Photograph of the proposed monopole antenna, (a) top view, and (b) bottom view.

The fabricated antenna has the frequency band of 2.12 to over 17.87 GHz. As shown in Fig. 7, there exists a discrepancy between measured data and the simulated results. This could be due to the effect of the SMA port, and also the accuracy of the simulation due to the wide range of simulation frequencies. In a physical network analyzer measurement, the feeding mechanism of the proposed antenna is composed of a SMA connector and a microstrip line (the microstrip feed line is excited by an SMA connector) whereas the simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS), that in HFSS by default, the antenna excited by wave port that it is renormalized to a 50 Ohm full port impedance, therefore this discrepancy between measured data and the simulated results could be due to the effect of the SMA port [8]. In order to confirm the accurate VSWR characteristics for the designed antenna, it is recommended that the manufacturing and measurement process be performed carefully. In conclusion, as the monopole is a short radiator, the SMA connector can modify its impedance matching.

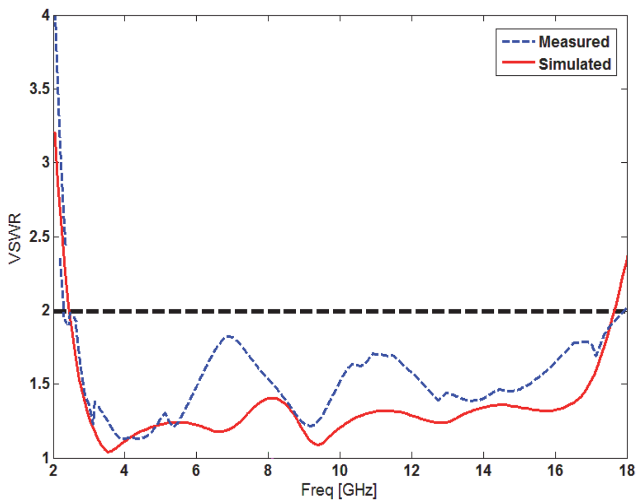

Fig. 7. Measured and simulated VSWR for the proposed antenna.

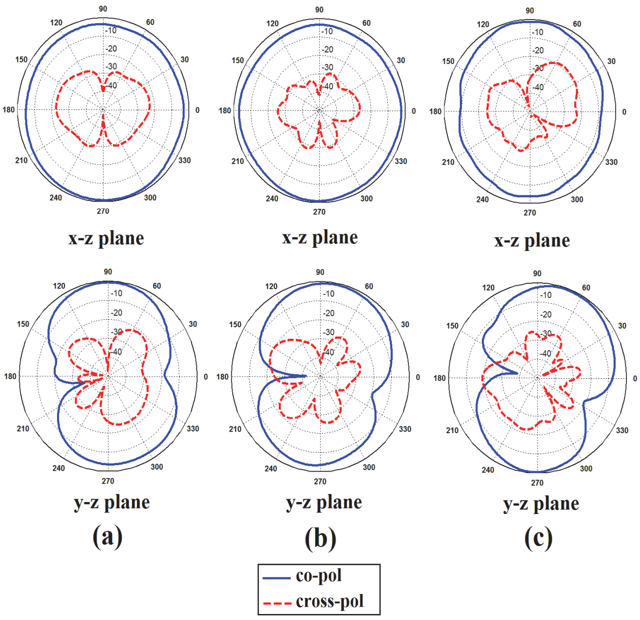

Fig. 8. Measured radiation patterns of the proposed antenna, (a) first resonance frequency (3.5GHz), (b) fourth resonance frequency (13.4GHz), and (c) fifth resonance frequency (16.2GHz).

Fig. 8 shows the measured radiation patterns at resonance frequencies including the co-polarization and cross polarization 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 for the four frequencies.

IV. Conclusion

In this paper, a novel and compact printed monopole antenna (PMA) with multi-resonance characteristics has been proposed for use in microwave imaging system applications. The fabricated antenna satisfies the VSWR<2 requirement from 2.12 to 17.87 GHz. In order to enhance bandwidth, we use an I-shaped slot on the feed-line and a pair of S-shaped slots in the ground plane and hence a much wider impedance bandwidth can be produced, especially at the higher band. The designed antenna has a simple configuration with an 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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