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DESIGNING A COMPACT MONOPOLE MICROSTRIP ANTENNA OPERATING AT ULTRA-WIDE BAND FOR MICROWAVE IMAGING APPLICATIONS

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ABSTRACT

In this paper, a novel design of a microstrip-fed compact monopole microstrip antenna with asymmetrically modified ground plane operating at ultra-wide band (UWB) frequency range is presented for microwave imaging applications. The performance characteristics of the proposed antenna in terms of impedance bandwidth and return loss meet the ultra-wide band requirements. The design and simulation procedures of the proposed antenna are carried out using an electromagnetic simulation software based on the characteristic impedance for the transmission line model. The proposed antenna, with small size of $32 \times 42 \times 1.55$ mm^3 on an FR4 epoxy substrate with permittivity (ε_r) 4.4, is fabricated and validated through the simulations and measurements. It is demonstrated that the measured -10 dB bandwidth for return loss is from 2.08 to 7.4 GHz but after this frequency, the antenna operates with minimum 87.4% efficiency up to 10.6 GHz. The antenna exhibits acceptable UWB characteristics and the results show that the designed antenna is suitable for various microwave imaging applications operating at UWB.

Keywords: *Microstrip, Antenna, Monopole, UWB, Imaging*

1. INTRODUCTION

In the last decades, the interest in microstrip antennas (MA) has increased with the development of technology and the miniaturization of wireless communication devices. Due to their attractive features such as simple structure, low profile, low cost, planar configuration, conformal shaping, ease in fabrication and integration with microwave integrated circuits and solid-state devices, microstrip antennas have been widely implemented with the development of ultra-wide band (UWB) applications such as mobile phones, personal communication systems (PCS), mobile satellite communications (MSC), direct broadcast satellite (DBS), wireless local area networks (WLAN) and other wireless and mobile devices that demand small sized antennas (Balanis, 2005). Besides, MA's are also preferred in applications such as ground penetrating radar, parking radars, indoor positioning, military applications and medical imaging.

Since 2002, Federal Communication Commission (FCC) of United States authorized the use of the frequency range from 3.1 GHz to 10.6 GHz for unlicensed use for UWB based on wideband to transmit data at very low power and the researchers have been focused on the design, research and development of UWB antennas to achieve the UWB technology requirements. UWB is defined as a technology that requires either a bandwidth of 500 MHz or fractional bandwidth equal to or greater than 20%.

Because of the ease in analysis and design, a significant part of the studies on patch antennas presented in the literature have concentrated on conventional MA geometries such as rectangular, triangular and circular. However, conventional shaped MAs have some drawbacks such as narrow impedance bandwidth, low efficiency, low gain and low power handling. Also, regularly shaped MAs are larger in size for lower frequencies. To overcome these disadvantages, compact microstrip antennas (CMAs) are proposed by modifying the MAs having conventional geometries mentioned above.

There are various techniques such as modifying the ground plane, slot loading on the ground and radiating patch, changing feeding techniques and using parasitic elements with stacked superstrates to achieve enhanced bandwidth and provide a reduction in antenna size. Due to their regular geometries, the transmission line model (Bhattacharyya et. al., 1985) and cavity model (Richards et. al., 1981) are utilized in the analysis of the conventional shaped MAs. On the other hand, the irregular structures of CMAs lead to difficulty and complexity in theoretical calculations. To overcome this problem, electromagnetic methods covering proper mathematical expressions with considerable numerical procedures such as finite difference time domain (FDTD) method (Taflove, 2005), finite element method (FEM) (Arora et. al., 2013) and method of moment (MoM) (Harrington, 1993) are extensively employed.

In the literature, various studies on CMA designs for microwave imaging applications operating at UWB are available and they can be used with their own benefits and limitations. Ghassemi et al. (2008) proposed a microstrip antenna design using two slots operating from 9.8 GHz to 19 GHz with a simulated gain of 5 dB. Compact microstrip patch antenna for UWB applications operating between 3 GHz and 10.26 GHz frequency band is designed by Mazhar et al. (2013) and measurement results are presented. Popovic and Kanj (2008) designed a new design of an ultra-compact broadband antenna for microwave breast tumor detection with -10 dB return loss bandwidth from 2 GHz to 35 GHz band. Another miniaturized microstrip antenna having T-slot operating between 2.85 GHz and 13.21 GHz frequency band for microwave imaging is proposed by Karli et al. (2014).

In this paper, a new design of a microstrip-fed compact monopole microstrip antenna with asymmetrically modified ground plane operating at ultra-wide band (UWB) frequency range is proposed. The asymmetric radiating element geometry provides 10 dB bandwidth between 2.08 GHz and 7.4 GHz and 9 dB bandwidth between 2 GHz and 8.5 GHz according to measurement results. The designed antenna with small size of 32 × 42 × 1.55 mm^3 on an FR4 epoxy substrate with permittivity (ε_r) 4.4 is fabricated. The simulation and measurement results show that the proposed antenna is a suitable choice for microwave imaging applications because of its small structure and low power handling performance.

2. ANTENNA DESIGN

The configuration of the designed antenna structure for microwave imaging applications, shown in Fig. 1, has a microstrip-fed asymmetric radiating patch with 18 nodes and an asymmetric ground plane.

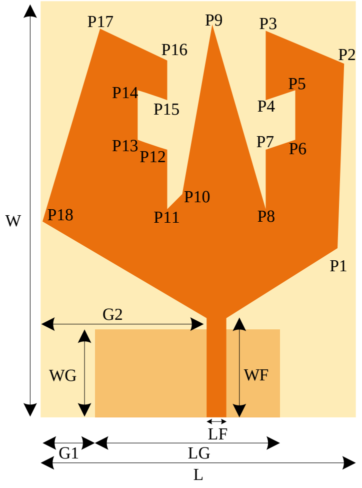


Fig. 1. The proposed antenna.

The width and length of the substrate and initial design are chosen to obtain minimum resonance frequency and tapered parts are used to maximize the impedance matching possibility. The ground plane is modified by reducing size and shifting to left to achieve UWB bandwidth requirements. The ground plane parameters and nodes of the radiating element are chosen to be optimized with the use of Particle Swarm Optimization (PSO) algorithm (Minasian et. al., 2013) to provide best impedance bandwidth. The physical parameters obtained by optimizing the structure of the designed antenna are given in Table 1.

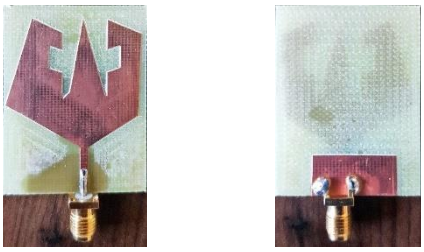
Table 1. Physical parameters of the proposed antenna

Parameter	Value
L	32 mm
W	42 mm
LF	2 mm
WF	8.79 mm
LG	16.99 mm
WG	8.03 mm
G1	4.11 mm
G2	14 mm
P1	(31.33 mm, 16.31 mm)
P2	(31.25 mm, 37.06 mm)
P3	(23 mm, 39 mm)
P4	(23 mm, 32 mm)
P5	(26 mm, 33 mm)
P6	(26 mm, 28 mm)
P7	(23 mm, 27 mm)
P8	(23.58 mm, 19.32 mm)
P9	(18.23 mm, 31.51 mm)
P10	(13.65 mm, 40.18 mm)
P11	(12.82 mm, 22.89 mm)
P12	(13 mm, 27 mm)
P13	(10 mm, 28 mm)
P14	(10 mm, 33 mm)
P15	(13 mm, 32 mm)
P16	(13 mm, 36 mm)
P17	(1.41 mm, 36.84)
P18	(0.68 mm, 17.22 mm)

The proposed antenna has three irregular-shaped branch strips to shape return loss results for UWB frequency range. The antenna is fed by a microstrip line of width WF = 8.79 mm and length LF = 2 mm. The ground plane is placed asymmetrically on the other side of the FR4 epoxy substrate with permittivity of 4.4 and thickness of 1.55 mm. The outer dimensions of the substrate are chosen as 32 × 42 mm^2. The feed structure of the proposed antenna is chosen as microstrip-fed and the feed line is formed to match characteristics impedance of 50 Ω.

3. NUMERICAL RESULTS

The photograph of the fabricated antenna is given in Fig. 2. The antenna is fabricated by scraping the copper planes to form the designed geometries of the radiating element and ground element on an FR4 epoxy substrate using LPKF E33 PCB prototyping machine. The return loss results of the fabricated antenna are measured by Agilent E5071B ENA Series RF Network Analyzer. The measured results of the antenna are limited to the lower and upper frequencies of 2 GHz and 8.5 GHz, respectively, because the network analyzer can measure up to 8.5 GHz frequency.



(a) (b)

Fig. 2. (a) Top view and (b) bottom view of the fabricated antenna.

The comparison of the simulated and measured return loss of the fabricated antenna is given in Fig. 3.

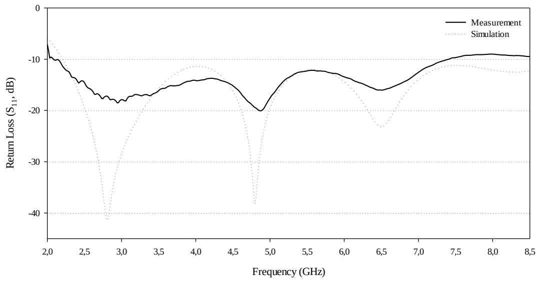
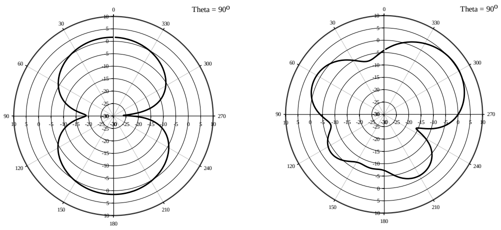


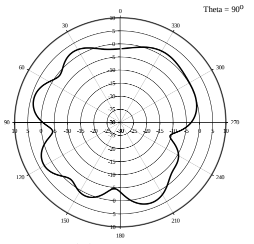
Fig. 3. Comparison of the simulated and measured return loss of the proposed antenna

It can be seen from the Fig. 3 that the simulation and measurement results are in a good agreement in overall frequency regions and the measured results are below -10 dB between 2.08 GHz and 7.4 GHz. Since the return loss represents the ratio of the reflected power to the transmitted power, the antenna can operate with lower efficiencies above -10 dB reference. The calculated efficiency using measured return loss is minimum 87.4%.

The simulated radiation pattern of the designed antenna is given in Fig. 4.

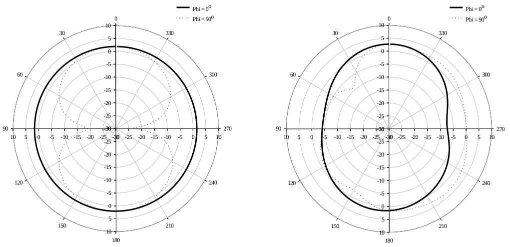


(a) 2 GHz (b) 6.5 GHz

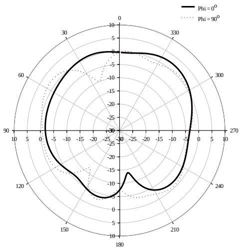


(c) 11 GHz

Fig. 4. The simulated radiation patterns for $\theta = 90^\circ$ at (a) 2 GHz, (b) 6.5 GHz and (c) 11 GHz.



(a) 2 GHz (b) 6.5 GHz



(c) 11 GHz

Fig. 5. The simulated radiation patterns for $\phi = 0^\circ$ (solid) and $\phi = 90^\circ$ (dashed) at (a) 2 GHz, (b) 6.5 GHz and (c) 11 GHz.

It can be seen from the Fig. 4 that the radiation pattern of the proposed antenna has a 3D donut shape and approximately bi-directional in the lower range of the UWB band. The change in the radiation diagram in the x-y plane and the appearance of side lobes with the increase in frequency are shown in Fig. 4 (b) and (c). Besides, the radiation characteristics of the proposed antenna in the y-z plane are nearly bi-directional whole UWB band.

5. CONCLUSION

A novel and compact monopole microstrip antenna with asymmetrically modified ground plane and microstrip-fed operating at UWB range for microwave imaging applications is presented. The designed antenna is fabricated on an FR4 epoxy substrate with permittivity (ε_r) of 4.4 and size of $32 \times 42 \times 1.55$ mm^3. The experimental results are compared with the simulated ones and it is seen that simulation and experimental results are in a good agreement. It is concluded that the proposed design is useful for microwave imaging applications and may be useful for microstrip antenna designers for specific fields and microwave imaging researchers.

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