Study of a Printed Circular Disc Monopole Antenna for UWB Systems

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***Abstract*—This paper presents a study of a novel monopole antenna for ultrawide-band (UWB) applications. Printed on a dielectric substrate and fed by a 50 Ω microstrip line, a planar circular disc monopole has been demonstrated to provide an ultra wide 10 dB return loss bandwidth with satisfactory radiation properties. The parameters which affect the performance of the antenna in terms of its frequency domain characteristics are investigated. A good agreement is achieved between the simulation and the experiment. In addition, the time domain performance of the proposed antenna is also evaluated in simulations.**

***Index Terms*—Circular disc monopole, microstripline-fed, printed antennas, ultrawideband (UWB).**

I. Introduction

With the definition and acceptance of the ultrawide-band (UWB) impulse radio technology in the USA [1], there has been considerable research effort put into UWB radio technology worldwide. However, the nondigital part of a UWB system, i.e., transmitting/receiving antennas, remains a particularly challenging topic.

A suitable UWB antenna should be capable of operating over an ultra wide bandwidth as allocated by the Federal Communications Commission. At the same time, reasonable efficiency and satisfactory radiation properties over the entire frequency range are also necessary. Another primary requirement of the UWB antenna is a good time domain performance, i.e., a good impulse response with minimal distortion [2].

Conventional UWB antennas in the geometry of either log periodic or spiral tend to be dispersive. They usually radiate different frequency components from different parts of the antenna, which distorts and stretches out the radiated waveform [3]. Recently, several broadband monopole configurations, such as circular, square, elliptical, pentagonal and hexagonal, have been proposed for UWB applications [4]–[7]. These broadband monopoles feature wide operating bandwidths, satisfactory radiation properties, simple structures and ease of fabrication. However, they are not planar structures because their ground planes are perpendicular to the radiators. As a result, they are not suitable for integration with a printed circuit board.

In this paper, a novel design of printed circular disc monopole fed by microstrip line is proposed and investigated based on our previous studies [8], [9]. The parameters which affect the operation of the antenna in terms of its frequency domain characteristics are analyzed both numerically and experimentally in order to understand the operation of the antenna. It has been demonstrated that the optimal design of this type of antenna can achieve an ultra wide bandwidth with satisfactory radiation properties. Furthermore, the simulations have also shown that the proposed monopole antenna is nondispersive, which is very important for UWB systems.

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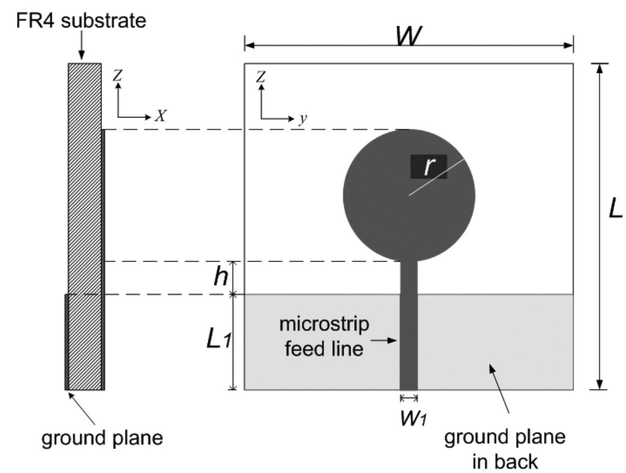


Fig. 1. Geometry of the printed circular disc monopole.

The paper is organized in the following sections. Section II describes the antenna design and the 10 dB return loss bandwidth obtained for an optimal design. Section III analyzes the characteristics of the antenna. Section IV presents the time domain performance of the antenna. Section V summarizes and concludes the study.

II. Antenna Design and Performance

The proposed monopole antenna is illustrated in Fig. 1.

A circular disc monopole with a radius of r and a 50 Ω microstrip feed line are printed on the same side of the dielectric substrate (in this study, the FR4 substrate of thickness 1.5 mm and relative permittivity 4.7 was used). L and W denote the length and the width of the dielectric substrate, respectively. The width of the microstrip feed line is fixed at $W_1 = 2.6$ mm to achieve 50 Ω impedance. On the other side of the substrate, the conducting ground plane with a length of $L_1 = 20$ mm only covers the section of the microstrip feed line. h is the height of the feed gap between the feed point and the ground plane.

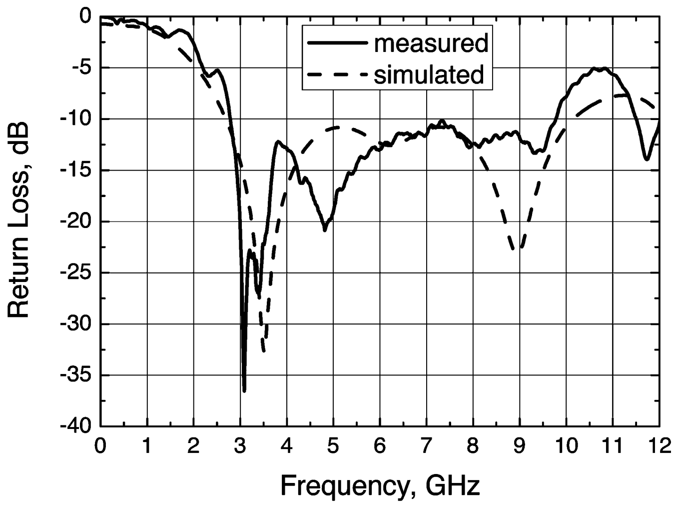


Fig. 2. Simulated and measured return loss curves with $r = 10$ mm, $W = 42$ mm, $L = 50$ mm, $L_1 = 20$ mm, and $h = 0.3$ mm.

The simulations are performed using the CST Microwave Studio package which utilizes the finite integration technique for electromagnetic computation [10].

A prototype of the proposed circular disc monopole antenna with optimal design, i.e., $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm, $L = 50$ mm and $L_1 = 20$ mm, as shown in Fig. 1, was fabricated and tested in the Antenna Laboratory at Queen Mary, University of London (QMUL), and the return losses were measured using a HP 8720ES network analyzer in an anechoic chamber.

Fig. 2 shows the simulated and the measured return loss curves. The measured 10 dB return loss bandwidth is from 2.78 to 9.78 GHz, while in simulation from 2.69 to 10.16 GHz. The measurement confirms the UWB characteristic of the proposed printed circular disc monopole, as predicted in the simulation.

III. Antenna Characteristics

For circular disc monopole, the ground plane serves as an impedance matching circuit. Consequently, it tunes the input impedance and hence the 10 dB return loss bandwidth by changing the feed gap h [10], [11].

Another two important design parameters that affect the antenna performance are the width of the ground plane W and the dimension of the disc. The effects of these two parameters can be well explained by investigating the current distributions of the antenna.

A. Current Distributions

The simulated current distributions at different frequencies for the optimal design with $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm, and $L = 50$ mm are presented in Fig. 3. Fig. 3(a) shows the current pattern near the first resonance at 3 GHz. The current pattern near the second resonance at 6.5 GHz is given in Fig. 3(b), indicating approximately a second order harmonic. Fig. 3(c) illustrates a more complicated current pattern at 9 GHz, corresponding to the third order harmonic.

As shown in Fig. 3, the current is mainly distributed along the edge of the disc, which indicates that the first resonant frequency

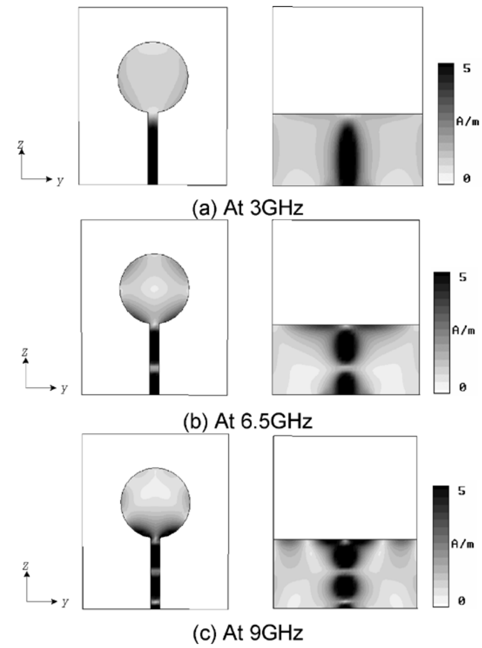


Fig. 3. Simulated current distributions on the disc monopole and the ground plane with $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm, and $L = 50$ mm. (a) At 3 GHz, (b) 6.5 GHz, (c) 9 GHz.

is associated with the dimension of the circular disc. This will be discussed in detail in next section.

On the ground plane, the current is mainly distributed on the upper edge along the y-direction. That means the portion of the ground plane close to the disc acts as the part of the radiating structure. Consequently, the performance of the antenna is critically dependent on the width of the ground plane W [8], [9]. However, it also leads to a disadvantage, i.e., when this type of antenna is integrated with printed circuit board, the RF circuitry can not be very close to the ground plane.

Simulations have shown that when the length L_1 of the ground plane is more than 14 mm, the performance of the antenna is almost independent of L_1.

B. The Effect of the Dimension of the Disc

Current distributions have indicated that the first resonant frequency is associated with the disc dimension. Actually, it is noticed in the simulations that the first resonance always occurs at around 3.5 GHz for different h and different W when r equals to 10 mm [9]. Furthermore, the diameter of the disc (i.e., 20 mm) is very close to the quarter wavelength at the first resonant frequency which is around 21 mm.

Fig. 4 presents the simulated return loss curves for different dimensions of the circular disc with their respective optimal designs ($r = 10$ mm with $h = 0.3$ mm, $W = 42$ mm and $L = 50$ mm; $r = 12.5$ mm with $h = 0.3$ mm, $W = 50$ mm and $L = 50$ mm; $r = 15$ mm with $h = 0.3$ mm, $W = 57$ mm and $L = 60$ mm; $r = 20$ mm with $h = 0.4$ mm, $W = 75$ mm and $L = 75$ mm).

It is seen in Fig. 4 that the first resonant frequency decreases with the increase of the diameter of the disc. The relationships between the diameters and the first resonances are tabulated in Table I.

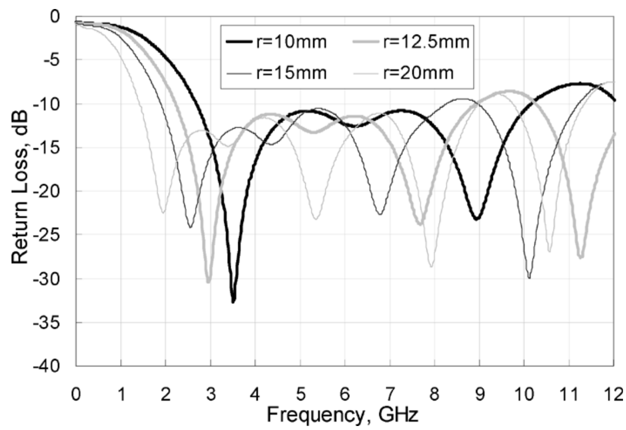


Fig. 4. Simulated return loss curves for different dimensions of the circular disc with the optimal designs.

TABLE I
RELATIONSHIPS BETWEEN THE DIAMETERS AND THE FIRST RESONANCES

Diameter $2r$ (mm)	First resonance f (GHz)	Wavelength λ at f (mm)	$2r$ / λ
20	3.51	85.5	0.23
25	2.96	101.4	0.25
30	2.56	117.2	0.26
40	1.95	153.8	0.26

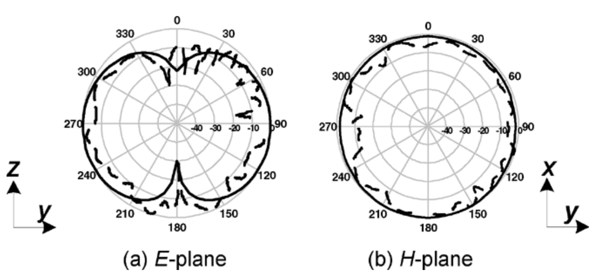


Fig. 5. Simulated (solid line) and measured (dotted line) radiation patterns with $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm, and $L = 50$ mm at 3 GHz (a) E-plane (b) H-plane.

Fig. 4 and Table I demonstrate that the first resonant frequency is determined by the diameter of the disc, which approximately corresponds to the quarter wavelength at this frequency. So the lower end frequency of the 10 dB return loss bandwidth of the antenna is directly related to the dimension of the disc.

C. Radiation Patterns and Gain

The radiation patterns have been calculated and also measured inside an anechoic chamber.

The measured and the simulated normalized radiation patterns at 3, 6.5, and 9 GHz are plotted in Figs. 5–7 respectively. The measured H-plane patterns are very close to those obtained in the simulation. It is noticed that the H-plane pattern is omnidirectional at lower frequency (3 GHz) and is near omni-directional at higher frequencies (6 and 9 GHz), where the gain reduces 8 dB in the x-direction at 9 GHz. In general, the shapes of the H-plane patterns correspond well to the current patterns on the disc, as shown in Fig. 3 at different frequencies, respectively.

The measured E-plane patterns follow the shapes of the simulated ones, though the agreement is not as good as the H-plane patterns. There are many ripples and distortions on the measured curves, which are caused by the feed connector and the coaxial cable. The simulated E-plane pattern is like a traditional monopole at 3 GHz. With the increase of frequency (6.5 and 9 GHz), it starts to form notches and get more directional at around $\pm 30^\circ$ from the z-direction.

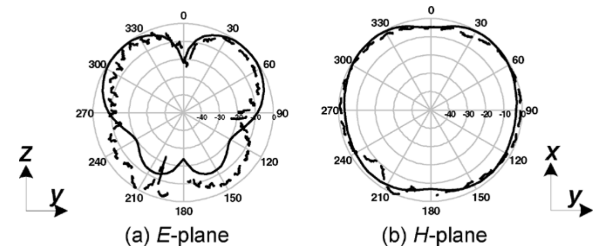


Fig. 6. Simulated (solid line) and measured (dotted line) radiation patterns with $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm, and $L = 50$ mm at 6.5 GHz (a) E-plane (b) H-plane.

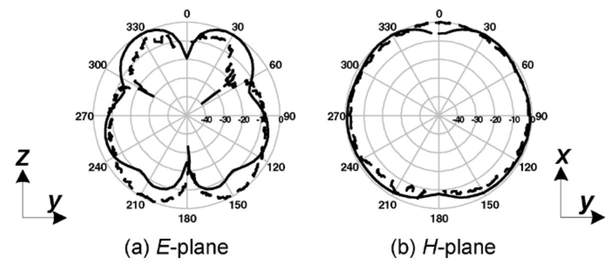


Fig. 7. Simulated (solid line) and measured (dotted line) radiation patterns with $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm and $L = 50$ mm at 9 GHz (a) E-plane (b) H-plane.

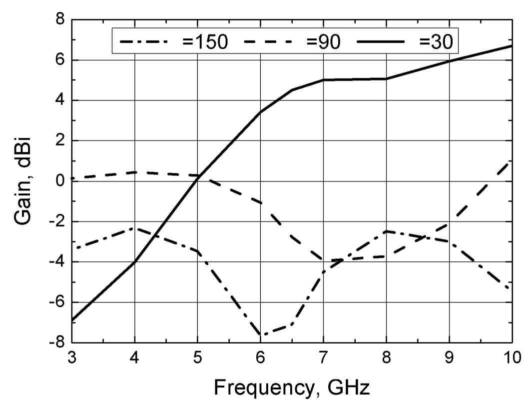
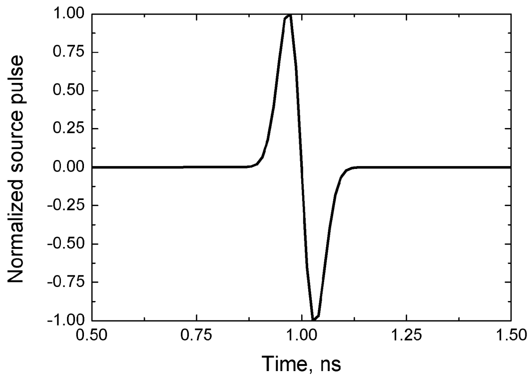


Fig. 8. Simulated theta-polarization gain in different directions in E plane with $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm, and $L = 50$ mm.

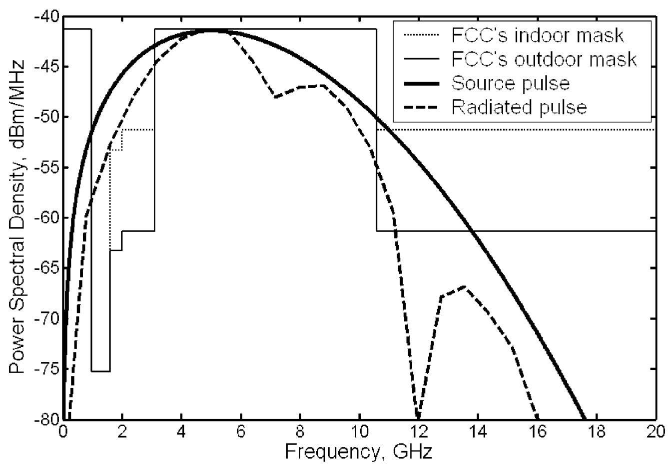
Fig. 8 illustrates the simulated gain of the proposed antenna in different directions in E plane with $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm and $L = 50$ mm. It is shown that the maximum gain occurs at the direction of $\theta = 90^\circ$ when the frequency is no more than 5 GHz; at higher frequencies (from 6 to 10 GHz), it shifts to the direction when $\theta = 30^\circ$ and ranges from 3.5 to 6.7 dBi due to the more directional radiation properties, as shown in Figs. 5–7.

IV. TIME DOMAIN PERFORMANCE OF THE ANTENNA

Apart from the consideration of the 10 dB return loss bandwidth and radiation pattern, as studied in the previous Section,



(a)



(b)

Fig. 9. (a) Source pulse waveform with $a = 45$ ps. (b) Spectral density shaping of radiated electrical fields.

a good impulse response, i.e., time domain characteristic, is an essential requirement for an UWB antenna. The printed circular disc monopole antenna has also been tested for its impulse response in the simulation.

In the modeling, the system is comprised of two identical disc monopoles with the optimal design parameters, i.e., $r = 10$ mm, $h = 0.3$ mm, $W = 42$ mm, and $L = 50$ mm. The transmitter and receiver are positioned in two scenarios, i.e., face to face and side by side, with a distance of 1.2 m. A first-order Rayleigh pulse, as presented in (1), is used as the source signal to drive the transmitter [11]

$$f(t) = \frac{-2(t-1)}{a^2} \exp\left(-\left(\frac{(t-1)}{a}\right)^2\right). \tag{1}$$

In this study, the pulse parameter a is fixed at 45 ps such that the pulse spectrum peaks at around 5 GHz as given in Fig. 9.

Fig. 9(b) illustrates the spectral density shaping of the source pulse and the radiated pulse by the disc monopole. It is noticed that the radiated spectrum can meet the FCC defined emission mask in the most part of the frequency range except at lower frequencies (less than 3.1 GHz) where the emission levels of the radiated pulse are higher than the FCC mask.

The simulated impulse responses for both scenarios are given in Fig. 10. It is shown the ringing effect is slightly less in the face to face case compared to the side by side case. However

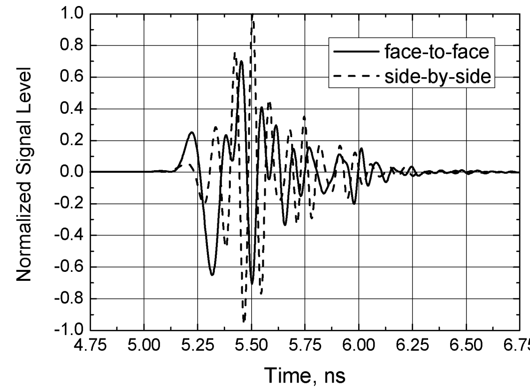


Fig. 10. Simulated impulse responses.

the maximum amplitude of the received waveform for the face to face case is about 30% lower than that of the side by side case. The signal distortions are mainly due to the bandwidth mismatch between the source pulse and the antenna. The 10 dB return loss bandwidth of the antenna ranges from 2.69 to 10.16 GHz, which is less than the 10 dB bandwidth of the source pulse, as shown in Fig. 9(b). As a result, some frequency components of the pulse can not be transmitted effectively by the monopole, leading to the distortions of the received signal.

V. Conlusion

The printed circular disc monopole antenna fed by microstrip line is investigated in this paper. It has been shown that the performance of the antenna in terms of its frequency domain characteristics is mostly dependent on the feed gap h, the width of the ground plane W and the dimension of the disc. The first resonant frequency is directly associated with the dimension of the circular disc because the current is mainly distributed along the edge of the disc. It is demonstrated numerically and experimentally that the proposed printed circular disc monopole can yield an ultra wide bandwidth, covering the FCC defined UWB frequency band. It is observed that the radiation patterns are nearly omni-directional over the entire 10 dB return loss bandwidth. Simulations have also indicated that the impulse response of the antenna has a slight ringing effect due to the mismatch between the antenna bandwidth and the pulse bandwidth, while the radiated spectrum can meet the FCC defined emission mask in the most part of the frequency range.

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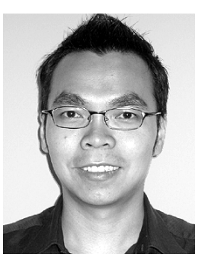

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