

UWB Electric and Magnetic Monopole Antennas

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Abstract—This paper summarizes our recent advances in antenna designs for ultra wideband (UWB) applications. Two types of monopoles are studied and developed in our research group. The first type belongs to the electric monopole with a circular disc fed by three different feeding structures. The second type is the magnetic monopole with an elliptical slot. The performances of these two types of antennas are evaluated in both frequency and time domains. The important design parameters for achieving optimal operations are also analyzed. It is shown that both electric and magnetic monopoles can provide ultra wide bandwidth with nearly omni-directional radiation patterns over the entire frequency band. In addition, the impulse responses of the selected antennas are shown to correspond well to the frequency domain characteristics.

Index Terms—Ultra-wide-band (UWB), electric monopole, magnetic monopole, circular disc monopole, printed antenna, slot antenna, coplanar waveguide (CPW).

I. INTRODUCTION

ULTRA wideband (UWB) radio technology has been used in the areas of radar, sensing and military communications during the past 20 years. A substantial surge has occurred since February 2002, when the Federal Communications Commission (FCC) of America issued a ruling that UWB could be used for data communications as well as for radar and safety applications [1], [2]. Since then, UWB radio technology has been rapidly advancing as a promising wireless communications technology and attracting considerable research interest around the world.

A UWB system transmits short pulses rather than using a narrowband frequency carrier. Normally, the pulses have very short durations, typically a few nanoseconds, leading to an ultra-wideband spectrum. FCC also allocated a frequency band of 7.5GHz (from 3.1GHz to 10.6GHz) to UWB applications, by far the largest allocation of bandwidth to any commercial terrestrial system. However, such a huge frequency spectrum

also provides challenges to antenna designers.

A suitable UWB antenna should have an impedance bandwidth (-10dB) larger than the FCC defined frequency band. At the same time, an omni-directional radiation pattern over the entire frequency band is also desirable especially for high data-rate indoor wireless communication systems. Besides, a good time domain performance, i.e. a good impulse response with minimal distortion, is also a primary requirement for the UWB antenna [3] because the signal pulse is the carrier of useful information.

There are a range of classical broadband antennas that are under consideration for use in UWB systems. A straight wire monopole features a simple structure, but its bandwidth is only around 10%. A vivaldi antenna is a directional antenna and hence unsuitable for indoor systems and portable devices. A TEM horn has a big size which limits its application. Log periodic and spiral antennas tend to be dispersive and suffer severe ringing effect. The printed versions of biconical antennas, such as bow-tie-like and the disc dipole [4], [5], need a balanced feed which leads to further complications to the RF circuit. There is a growing demand for small and low cost UWB antennas. Therefore, significant research efforts have been put into the monopole type of UWB antennas by research groups worldwide, including that in our research group [6]–[10].

This paper summarizes our work on two types of UWB monopole antennas, i.e. electric circular disc and magnetic elliptical slot monopoles [6]–[10]. The performances of these two types of antennas are analyzed both numerically and experimentally. All of the simulations are performed by using CST Microwave Studio™ package which utilizes the Finite Integration Technique for electromagnetic computation [11].

The rest of the paper is structured as the following. Section II presents the electric type of monopole antennas. Section III describes the magnetic type of monopole antennas. Section IV touches on the time domain characteristics of the selected UWB monopoles. A brief conclusion is given in Section V.

II. ELECTRIC MONOPOLE ANTENNAS

Several broadband monopole configurations, such as circular, square, elliptical, pentagonal and hexagonal, have been proposed for UWB applications recently [12], [13]. Compared with other configurations, several research groups, including our group, have chosen a circular disc monopole as

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one of the favorite choices for a wider frequency bandwidth. The configuration of the circular disc monopoles has also evolved from a vertical disc to a printed disc on a PCB (Printed Circuit Board).

A. Performances of circular disc monopoles

The vertical disc monopole originates from the conventional straight wire monopole and is realized by replacing the wire element with a copper disc, as shown in Fig. 1. This antenna has the attractive features of ultra wide bandwidth, omni-directional radiation patterns, simple structure and ease of fabrication. However, it is non-planar structure because the ground plane is perpendicular to the disc. Although the ground plane can be narrowed substantially [6], it is still not suitable for integration with a printed circuit board.

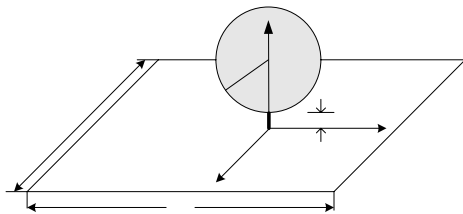


Fig. 1. Geometry of vertical disc monopole

To come up a planar version of UWB disc monopole, a printed feeding structure is required. There are two choices; one is microstrip line and the other CPW feeding structure. These two planar versions of UWB disc monopoles are illustrated in Fig. 2 (a) and Fig. 2 (b), respectively.

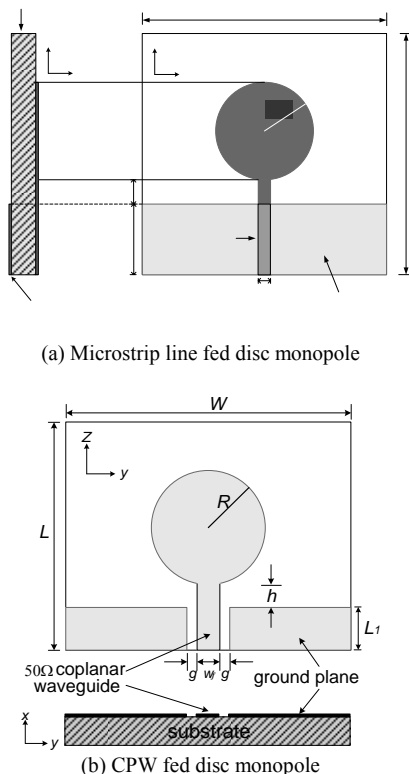


Fig. 2. Geometry of printed disc monopoles

The measured return loss curves for the three disc monopoles with their respective optimal designs (vertical disc monopole: $R=12.5\text{mm}$, $h=0.7\text{mm}$, $W=100\text{mm}$ and $L=10\text{mm}$; microstrip line fed disc: $R=10\text{mm}$, $h=0.3\text{mm}$, $W=42\text{mm}$ and $L=50\text{mm}$; CPW fed disc: $R=12.5\text{mm}$, $h=0.3\text{mm}$, $W=47\text{mm}$ and $L=50\text{mm}$) are plotted in Fig. 3.

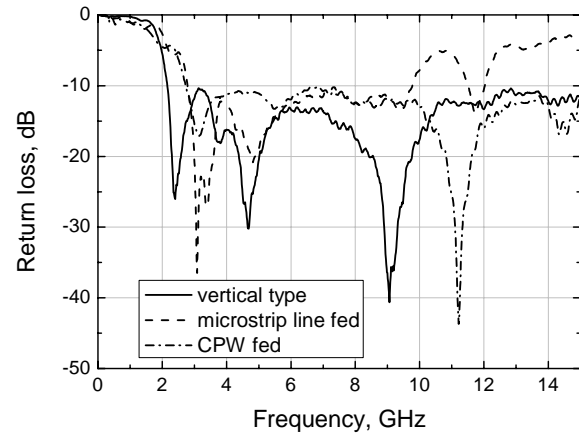


Fig. 3. Measured return loss curves of disc monopole antennas

It is noticed in Fig. 3 that the -10dB bandwidth of vertical disc monopole ranges from 2.16GHz to $>15\text{GHz}$, and that of CPW fed disc monopole from 2.73 to $>15\text{GHz}$. Both of them can operate across the whole FCC defined UWB frequency band. The bandwidth of microstrip line fed disc monopole spans from 2.78GHz to 9.78GHz , only slightly narrower than the FCC defined UWB band.

B. Characteristics of circular disc monopoles

For disc monopole antennas, the ground plane serves as an impedance matching circuit, and it tunes the input impedance by changing the feed gap h . So the operating bandwidth of the monopole is very sensitive to the variation of h .

Another two important design parameters that affect the antenna performance include 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.

Simulations have shown that disc monopoles with different feeding structures have similar current distributions. Fig. 4 presents the simulated current distributions of CPW fed disc monopole.

As shown in Fig. 4, the current is mainly distributed along the edge of the disc for different frequencies. This demonstrates a number of characteristics of the disc monopoles.

Firstly, the resonant frequency is associated with the dimension of the disc. The diameter of the disc corresponds to one quarter wavelength at the first resonance and hence determines the lower edge of the operating bandwidth.

Secondly, the disc monopole is capable of supporting multiple resonance modes, the higher order modes (f_2, f_3, \dots, f_n) being the harmonics of the fundamental mode of the disc. So the wavelengths of the higher order modes satisfy:

$$2R = n \lambda_n / 4 = \lambda_1 / 4 \quad (1)$$

where n is the mode number. In fact, Fig. 4 (a) shows the current pattern near the first resonance at 3GHz. The current pattern near the second resonance at 5.6GHz is given in Fig. 4(b), indicating approximately a second order harmonic. Fig. 4(c) illustrates a more complicated current pattern at 8.8GHz, corresponding to the third order harmonic. The overlapping of these higher order modes leads to the UWB characteristic, as shown in Fig. 5.

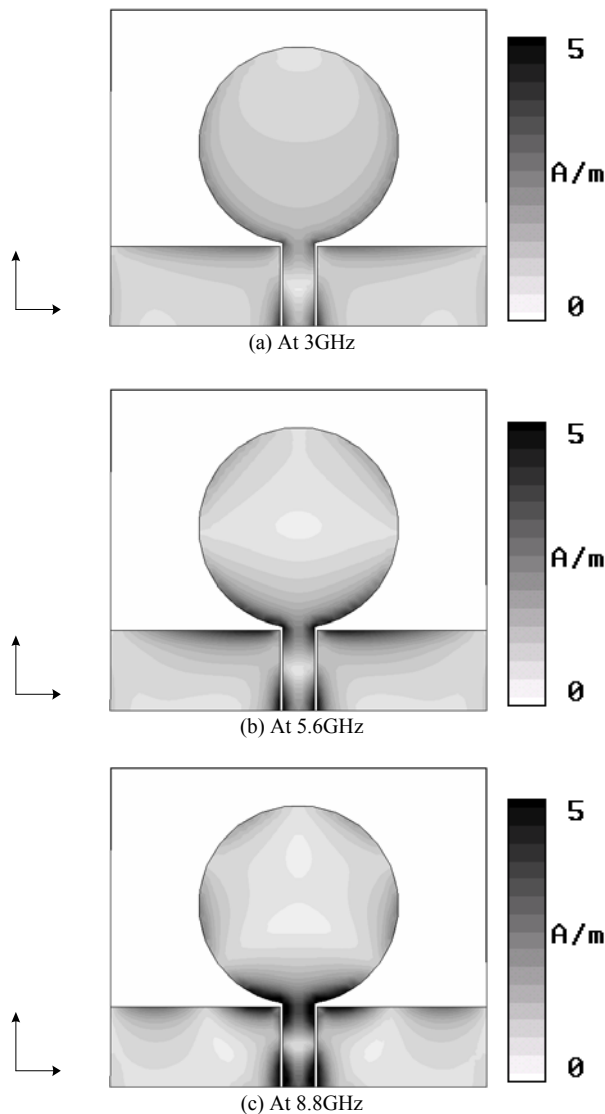


Fig. 4. Simulated current distributions of CPW fed disc monopole

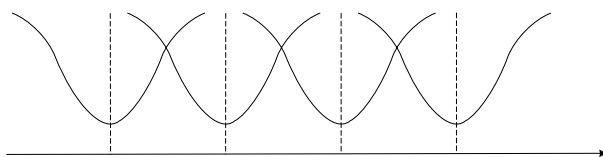


Fig. 5. Overlapping of the multiple resonance modes

Thirdly, cutting the central part of the disc to form a circular

ring monopole will not lead to any sacrifice of the bandwidth or serious distortion of the radiation patterns [14].

It is also observed in Fig. 4 that, on the ground plane, the current is mainly distributed on the upper edge along the y -direction. This indicates that the antenna performance is mainly dependent on the width of the ground plane W . So the length of the ground plane L can be much narrower than the width W whilst retaining the UWB characteristic. This is very encouraging for the miniaturization of the antenna.

C. Radiation patterns of circular disc monopoles

It has been demonstrated numerically and experimentally that all of the three disc monopoles can exhibit similar radiation properties.

Fig. 6 shows the radiation patterns of microstrip line fed disc monopole. It is noticed that the E -plane pattern is like a traditional monopole at 3GHz. With the increase of frequency, it starts to form notches and get more directional at around ± 30 degrees from the z -direction.

The H -plane pattern is omni-directional at lower frequency (3GHz) and is near omni-directional at higher frequencies (9GHz), where the gain reduces 8dB in the x -direction at 9GHz. So the disc monopole is generally omni-directional over the entire bandwidth.

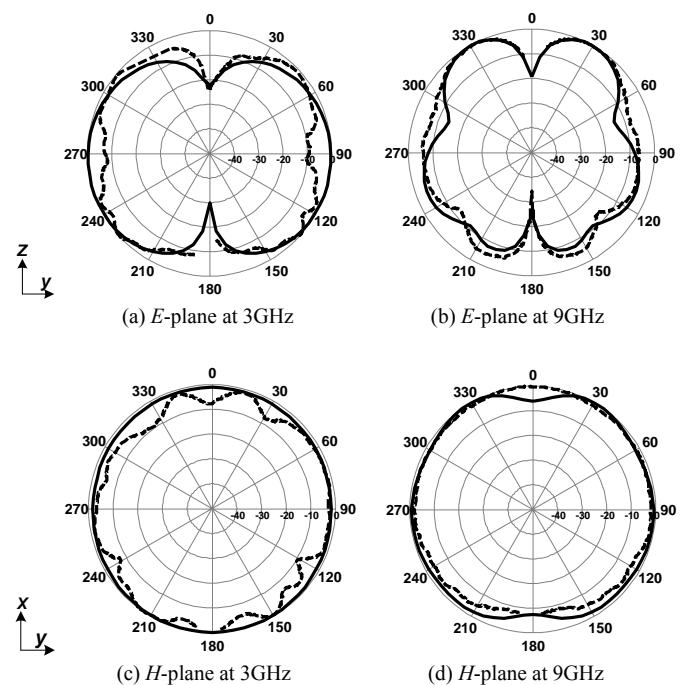


Fig. 6. Simulated (solid line) and measured (dotted line) radiation patterns of microstrip line fed disc monopole

III. MAGNETIC MONOPOLE ANTENNAS

In contrast to electric monopole antennas, wherein the copper disc serves as the radiator, magnetic monopoles use slot as the radiating element. In this section, elliptical slot antennas with two different feeding structures, i.e. microstrip line and CPW, are investigated.

A. Performances of elliptical slot antennas

The geometries of two printed elliptical slot antennas are illustrated in Fig. 7. For both of the antennas, the elliptical slot is etched from the ground plane. A U-shaped tuning stub is used to improve the coupling between the feed line and the slot. The tuning stub is all positioned within the elliptical slot region and symmetrically with respect to the short axis of the elliptical slot. Besides, an additional bandwidth enhancement can be achieved by tapering the feed line with a slant angle θ for a distance of H .

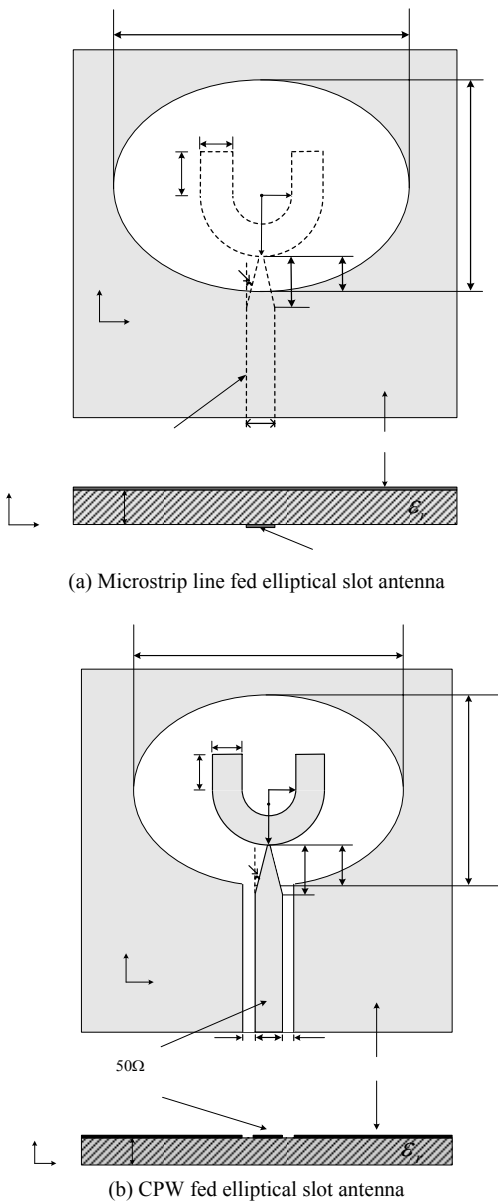


Fig. 7. Geometry of printed elliptical slot antennas

Measurements have shown that the optimal designs of both the two slot antennas (microstrip line fed slot antenna with $\theta=15^\circ$, $H=3\text{mm}$, $S=0.6\text{mm}$, $A=16\text{mm}$ and $B=11.5\text{mm}$; CPW fed slot antenna with $\theta=15^\circ$, $H=2.5\text{mm}$, $S=0.4\text{mm}$, $A=14.5\text{mm}$ and $B=10\text{mm}$) can achieve ultra wide bandwidths. As shown in Fig.

8, the measured -10dB bandwidth of microstrip line fed elliptical slot antenna is from 2.6GHz to 10.22GHz , and that of the CPW fed one from 3.1GHz to 10.55GHz .

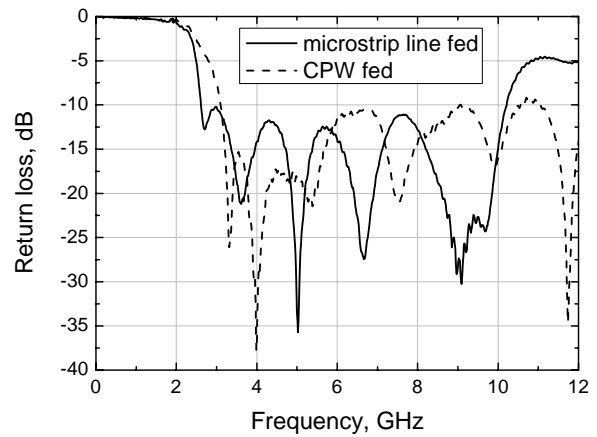


Fig. 8. Measured return loss curves of elliptical slot antennas

B. Design parameters of elliptical slot antennas

The simulations reveal that the ultra wide bandwidth of the slot antenna results from the multiple resonances introduced by the combination of the elliptical slot and U-shaped tuning stub. Consequently, the slant angle θ , the tapered length H , and the distance S between the stub and the bottom of slot are the most important parameters which affect the antenna performance. These parameters should be optimized for maximum bandwidth.

Moreover, the lower edge of -10dB bandwidth is directly associated to the dimension of the slot (A and B). An empirical equation is introduced to describe the relationship between the lower frequency edge f_i and the slot dimension, as given in (2).

$$f_i = \frac{30 \times 0.32}{2A + 0.25B} \quad (2)$$

where A, B in cm, and f_i in GHz.

The comparison between the calculated f_i and the measured one for different printed slot antennas are tabulated in Table 1. It shows a good agreement between the calculated and measured f_i .

Table 1. The calculated and measured lower edge of bandwidth

Elliptical slot antenna	A (mm)	B (mm)	Measured f_i (GHz)	Calculated f_i (GHz)
Microstrip line fed	16	11.5	2.6	2.74
Microstrip line fed	13.3	13.3	3.46	3.21
CPW fed	14.5	10	3.1	3.17
CPW fed	13.3	13.3	3.75	3.21

L

r

C. Radiation patterns of elliptical slot antennas

The radiation patterns of CPW fed elliptical slot antenna with the optimal design are illustrated in Fig. 9. It is noticed that the radiation properties of elliptical slot antenna are similar to those of disc monopole, i.e. the *E*-plane pattern is monopole-like and the *H*-plane pattern is nearly omni-directional over the entire bandwidth.

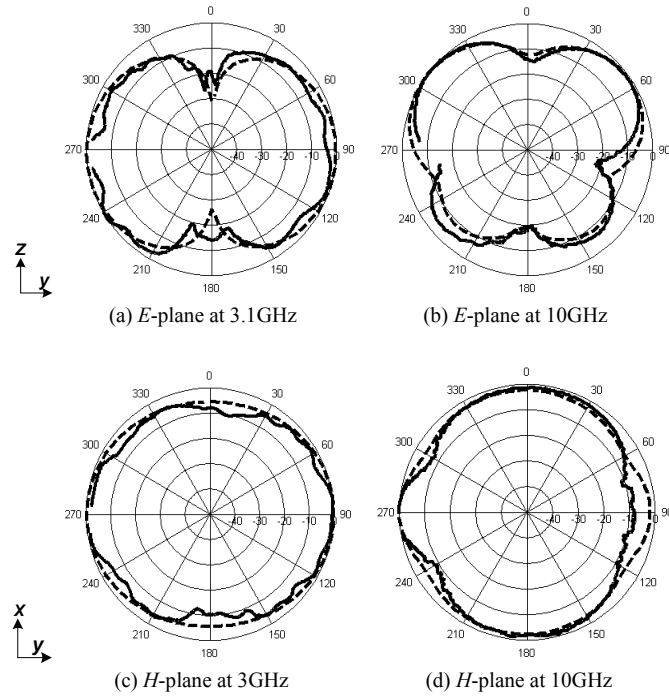


Fig. 9. Simulated (solid line) and measured (dotted line) radiation patterns of CPW fed elliptical slot antenna

IV. ANTENNA PERFORMANCE IN TIME DOMAIN

The time domain characteristics of vertical type and microstrip line fed disc monopoles are examined numerically. In the modelling, the antennas system comprises of two identical disc monopoles. The transmitter and receiver are positioned face to face with a distance of 1.2m. A first-order Rayleigh pulse, as presented in (3), is used as the source signal to drive the transmitter.

$$f(t) = \frac{-2(t-1)}{a^2} \exp\left(-\left(\frac{(t-1)}{a}\right)^2\right) \quad (3)$$

In this study, the pulse parameter a is fixed at 45ps such that the pulse spectrum peaks at around 5GHz, as given in Fig. 10. It is also noticed in Fig. 10 (b) that the pulse spectrum has a -10 dB bandwidth of 13.5GHz, from 0.3GHz to 13.8GHz. The lower edge of the pulse bandwidth is smaller than those of the two monopoles, while its upper edge is higher than microstrip line fed disc, but lower than the vertical one, as shown in Fig. 3.

The impulse response of vertical disc monopole is plotted in Fig. 11. The received signal waveform generally follows the source pulse, but has a slight ringing effect. This is mainly due

to the bandwidth mismatch between the source pulse and the antenna, as shown in Fig. 10 (b). Some low frequency components of the pulse can not be efficiently transmitted by the disc monopole.

The time domain performance of microstrip line fed disc monopole is inferior to vertical disc. Fig. 12 (a) illustrates that the received signal has more distortions. This is because of the narrower operating bandwidth of this type monopole. Compared with vertical disc, microstrip line fed disc monopole has filtered more pulse components, as shown in Fig. 10 (b). The results indicate that the impulse responses of the antennas correspond well to the frequency domain performances.

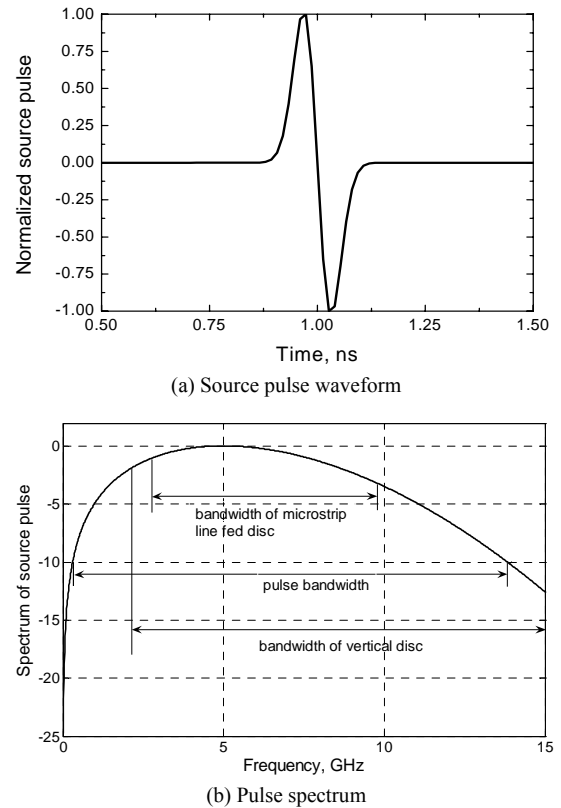
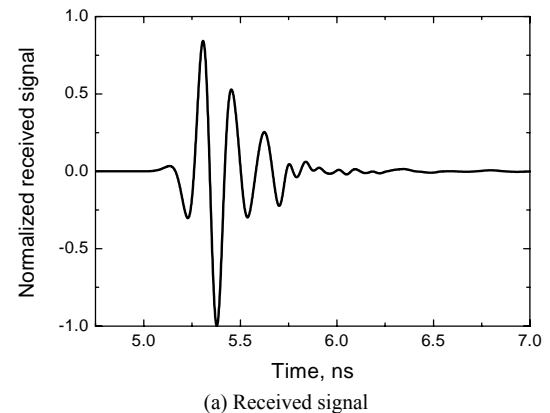


Fig. 10. First-order Rayleigh pulse



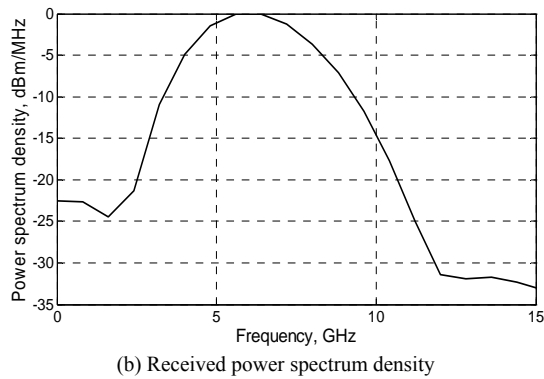


Fig. 11. Impulse response of vertical disc monopole

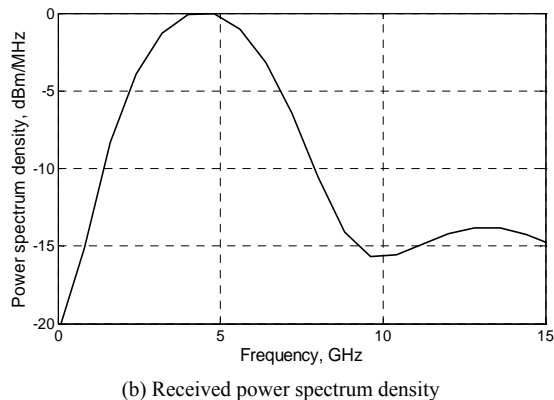
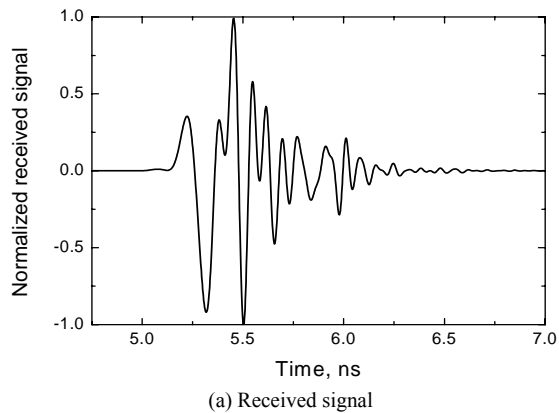


Fig. 12. Impulse response of Microstrip line fed disc monopole

V. CONCLUSION

This paper is a brief summary of our recent research work on UWB antennas. Two types of antennas, i.e. circular disc monopoles (electric monopoles) and elliptical slot antennas (magnetic monopoles) are investigated with an emphasis on the understandings of antenna operations. Studies have demonstrated that both of the two types of antennas can exhibit UWB characteristics with nearly omni-directional radiation patterns over the entire bandwidths. It is also shown that antenna characteristics in time domain correspond well to those in frequency domain. Moreover, planar versions of UWB antennas, fed by microstrip line or coplanar waveguide, feature low profile, small size and suitability for integration with printed circuit board, which make them promising for future

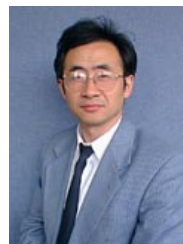
UWB applications.

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