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PULSE PRESERVING CAPABILITIES OF PRINTED CIRCULAR DISK MONOPOLE ANTENNAS WITH DIFFERENT SUBSTRATES

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Abstract—This paper presents a theoretical investigation on the pulse preserving capabilities of the CPW-fed circular disk monopole antennas at the assistance of correlation factors. The distortions of the radiated signals, which are mainly caused by the bandwidth mismatch between the antennas and the source pulse, are alleviated by using suitable source pulse. The ringing and pulse-width spreading of the radiated signals caused by the energy-storage effects of the dielectric substrate are discussed in detail. Possible improvement solutions and an example are provided. The improvement of the correlation factors introduced by selecting suitable substrate parameters is about 7% on an average. With the physical insight and design example, the proposed solutions are expected to find applications in the design of printed UWB monopole antennas for better pulse preserving capabilities.

1. INTRODUCTION

Ultra-wideband (UWB) technology has been widely used in various radars, and attracted much attention recently for communication systems [1]. In these systems, a UWB antenna directly transmits narrow pulses instead of a continuous wave carrier to deliver information, thus it acts as a "wideband band-pass filter" rather than a "spot-frequency filter" as the resonate antennas. Furthermore, successful signal transmission and reception in UWB systems need minimized ringing, spreading and distortion [2, 15]. In order to characterize the time domain performance of a UWB antenna, some parameters such as antenna transfer function, pulse energy spread and correlation factor have been introduced. Apparently, the characteristics of a UWB antenna both in frequency domain and time domain should be investigated and optimized for better performance in UWB systems.

Planar monopole antennas have been widely used and studied for a long time due to their attractive merits such as wide impedance bandwidth, simple structure and nearly omni-directional radiation patterns [3–5, 16–19]. In addition, printed CPW-fed monopole antennas have been introduced for their compact size, low cost and ease to integrate with microwave circuits [6–8]. However, the distortion, ringing and spreading of an input pulse signal caused by a printed disk monopole antenna would greatly impair the communication quality of UWB systems [9, 13, 14]. Obviously, a printed monopole antenna with improved pulse preserving capabilities is urgently demanded and would become an indispensable part of UWB communication systems.

In this paper, the pulse preserving capabilities of the CPW-fed circular disk monopole antennas have been studied and optimized at the assistance of correlation factors. Detailed parameters study is presented. The ringing and pulse-width spreading of the radiated signals caused by the energy-storage effects of the dielectric substrate are discussed in detail. Possible improvement solutions and an example are also provided.

2. THE PROTOTYPE ANTENNA

The CPW-fed circular disk monopole antenna proposed in [10] is considered firstly. This printed antenna, shown in Fig. 1, has wide impedance bandwidth and nearly omni-directional radiation patterns, which's an attractive candidate for UWB communications. This prototype antenna, composed of a circular disk monopole with radius $R = 12.5\,\mathrm{mm}$ and a $50\,\Omega$-CPW feeding line (with $W = 4\,\mathrm{mm}$ and $G = 0.33\,\mathrm{mm}$), is printed on the same side of a dielectric substrate. The feed gap H and the length the CPW ground is respectively 0.3 mm and 10 mm for all the monopoles in this paper. The thickness t and relative permittivity εr of the dielectric substrate is 1.6 mm and 3.0, respectively. Other parameters and characteristics can be found in [9, 10]. It should be pointed out that we have modified the antenna dimension for a more compact size.

The time domain characteristics of the monopole antennas in this paper were calculated by using full-wave simulation software CST Microwave Studio. By placing some virtual probes which were located at a distance of 200 mm from the feeding point of the monopole antennas, the corresponding $E\theta$ components of electric field intensity signals $S_2(t)$ could be readily obtained. Thus we could calculate the correlation between the time-domain input pulse signal $S_1(t)$ and the

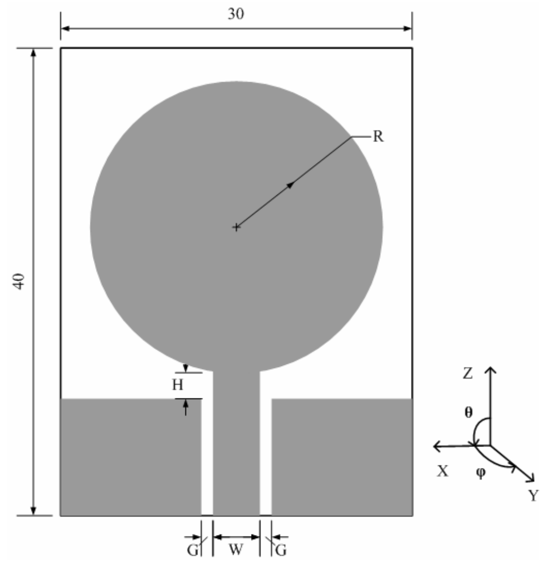


Figure 1. Geometry of prototype antenna and the coordinate system (dimensions in mm).

electric field intensity signals $S_2(t)$ seen by these probes to evaluate the signal preserving capabilities of these antennas. The definition of the correlation factor is given by

$$\rho = \max_{\tau} \left\{ \frac{\int s_1(t) s_2(t-\tau) dt}{\sqrt{\int s_1^2(t) dt} \sqrt{s_2^2(t) dt}} \right\} \tag{1}$$

where τ is delay which is varied to make ρ in (1) a maximum.

In order to alleviate the signal distortions caused by the bandwidth mismatch between the monopole antennas and the input source pulse [13], a UWB signal introduced in [11, 12] is assumed to excite these monopole antennas. This UWB signal is the 5th-derivative of the Gaussian pulse and is given by

$$s_1(t) = GM_5(t) = C\left(-\frac{t^5}{\sqrt{2\pi}\sigma^{11}} + \frac{10t^3}{\sqrt{2\pi}\sigma^9} - \frac{15t}{\sqrt{2\pi}\sigma^7}\right) \times \exp\left(-\frac{t^2}{2\sigma^2}\right) \tag{2}$$

C is a constant which can be chosen to comply with peak power spectral density that the FCC suggests and σ has to be 51 ps to ensure that the shape of the spectrum complies with the FCC spectral mask. Fig. 2 illustrates this pulse signal in time domain and frequency domain. It

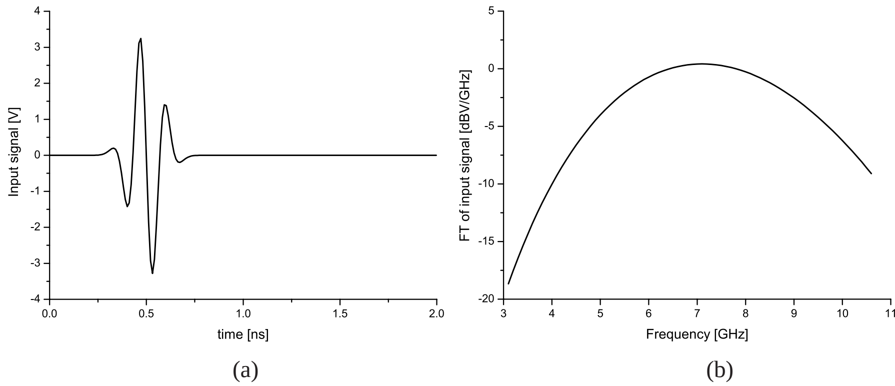


Figure 2. Antenna input signal: (a) time domain, (b) frequency domain.

could be observed that the 10-dB bandwidth of the input signal is from 4.1 GHz to 10.6 GHz, which lies in the impedance bandwidth of these monopole antennas as Fig. 6 shows.

The correlation factors of the prototype antenna and the received signals of the virtual probes are summarized in Table 1 and Fig. 3, respectively. The distortions of the received signals have been alleviated a little compared with the results in [13], and severe ringing and spreading of the received signals could be observed, which are similar as results in [9, 13, 14]. The transmitted signals with severe ringing and pulse-width spreading may be caused by the energy-storage effects of the dielectric substrate when the prototype antenna was transmitting pulse signals, which would be discussed in the next section.

Table 1. Correlation factors of the prototype antenna for various virtual probes positions.

Probe position	ρ
$\theta = 90^\circ,\ \varphi = 0^\circ$	0.7495
$\theta = 60^\circ,\ \varphi = 0^\circ$	0.9186
$\theta = 30^\circ,\ \varphi = 0^\circ$	0.8763
$\theta = 90^\circ,\ \varphi = 90^\circ$	0.9103
$\theta = 90^\circ,\ \varphi = 60^\circ$	0.7928
$\theta = 90^\circ,\ \varphi = 30^\circ$	0.7545

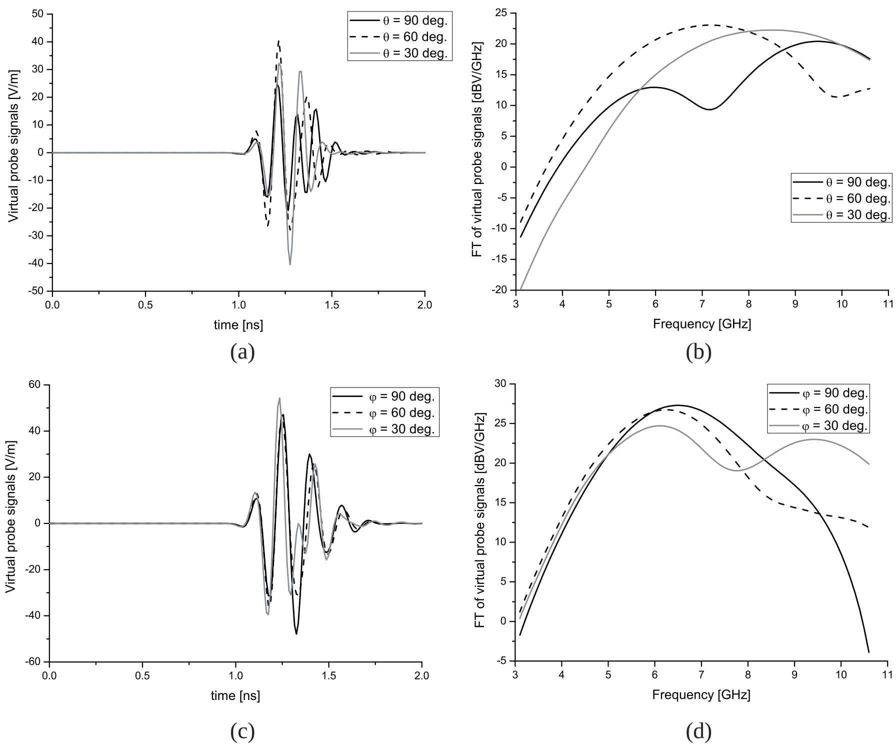


Figure 3. The received signals by the virtual probes of the prototype antenna: (a) time domain (X-Z plane), (b) frequency domain (X-Z plane), (c) time domain (X-Y plane), (d) frequency domain (X-Y plane).

3. A STUDY OF THE PARAMETERS

As mentioned above, the energy-storage effects of the dielectric substrate could add severe ringing and pulse-width spreading to the radiated pulse signals of a printed UWB monopole, which leads to poor correlation factors in most directions. Thus in this section, we'll investigate the influence of the dielectric substrates with different thicknesses and permittivity on the correlation factors of the printed circular disk monopole antennas.

Table 2 demonstrates the correlation factors of the monopoles with different substrate thicknesses and Fig. 4 shows the received signals of the virtual probes. It could be observed that the received signals almost have the same waveform as the input signal in the first time range of 1.0 ns to 1.3 ns, after the first time range, the received signals

Table 2. Correlation factors of the circular disk monopole antennas with different substrate thicknesses at the probe position $\theta = 90°$, $\varphi = 0°$ (substrate permittivity as 3.0).

Substrate thickness t	ρ
0.4 mm	0.8587
0.8 mm	0.8145
1.2 mm	0.7752
1.6 mm	0.7495
2.0 mm	0.7354

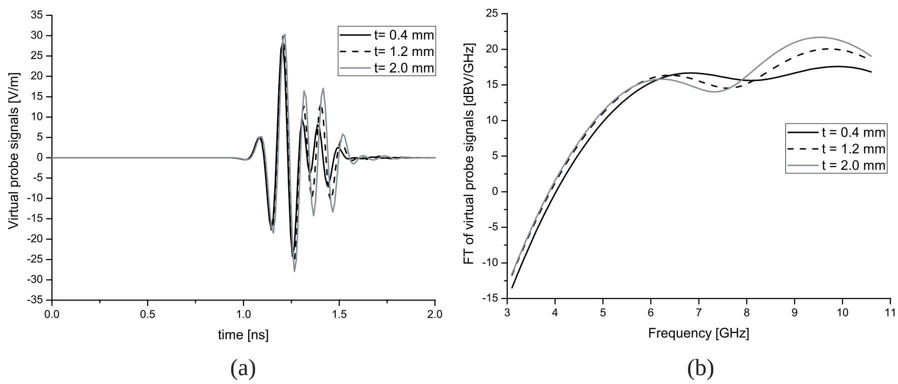


Figure 4. The signals received by the virtual probes at $\theta = 90°$, $\varphi = 0°$ (substrate permittivity as 3.0): (a) time domain, (b) Frequency domain.

show great ringing up to 1.6 ns, thus the pulse-width spreading is about 0.1 ns or 20% of the input pulse width. Besides, the ringing amplitude is much higher with larger substrate thickness because the thicker substrate would store more energy in the first time range of 1.0 ns to 1.3 ns and its contributed radiation is much stronger after that, which results in a worse correlation factor. It should be pointed out that we only give the received signals of probes which are located at $\theta = 90°$, $\varphi = 0°$ because the results of other probes with different locations are similar.

The correlation factors of the monopoles with different substrate permittivity and the received signals of the virtual probes are shown in Table 3 and Fig. 5, respectively. These results show that the substrate with larger permittivity could store more energy in the first time range and then contribute greater radiation after it. Moreover, when the permittivity of the substrate reaches 9.9, the pulse-width spreading is about 0.2 ns or 40% of the input pulse width, which could greatly obstruct the use of high permittivity substrate in UWB systems although it could enable a smaller antenna and higher directivity gain.

Table 3. Correlation factors of the circular disk monopole antennas with different substrate permittivity at the probe position $\theta = 90^\circ$, $\varphi = 0^\circ$ (substrate thickness as 0.4 mm).

Relative permittivity	ρ
1.0	0.8722
2.08	0.8696
3	0.8587
6.15	0.8169
9.9	0.7841

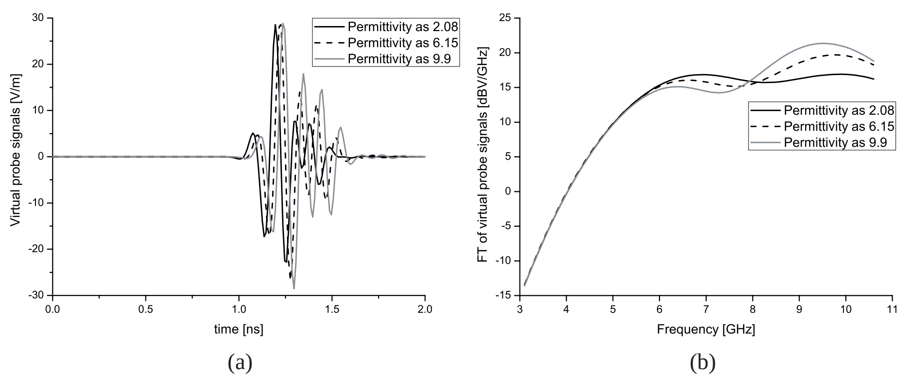


Figure 5. The signals received by the virtual probes at $\theta = 90^\circ$, $\varphi = 0^\circ$ (substrate thickness as 0.4 mm): (a) time domain, (b) Frequency domain.

It's also interesting to notice that the ringing and pulse-width spreading of the received signals in the time-domain mainly influence the higher frequency band from about 8 GHz to 10.6 GHz in the frequency-domain; and for the substrate with large thickness or permittivity, the influenced frequency band may be as low as 6 GHz. The main reason for that is that the electric size of a dielectric substrate could be much larger in the higher frequency domain and more energy could be stored in the substrate. Therefore, a thin substrate with low permittivity is highly recommended in printed UWB antenna design at the consideration of higher pulse preserving performance.

4. RESULTS AND DISCUSSION

The example monopole antenna has a circular element with radius $R = 12.5\,\mathrm{mm}$ and a $50\,\Omega$-CPW feeding line (with $W = 4\,\mathrm{mm}$ and $G = 0.2\,\mathrm{mm}$), the thickness and permittivity of the dielectric substrate is 0.4 mm and 2.08, respectively. It should be pointed out that we don't choose a substrate with decreased thickness or lower permittivity for the considerations of mechanic strength, fabrication complexity and cost. The simulated return loss of the prototype antenna and the optimized one is shown in Fig. 6, and we can see that both of them are well impedance matched in the frequency range of 3.1 GHz to 10.6 GHz.

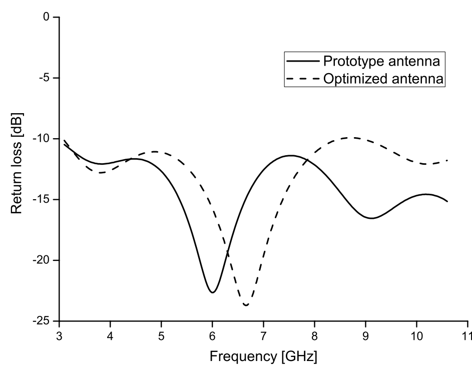
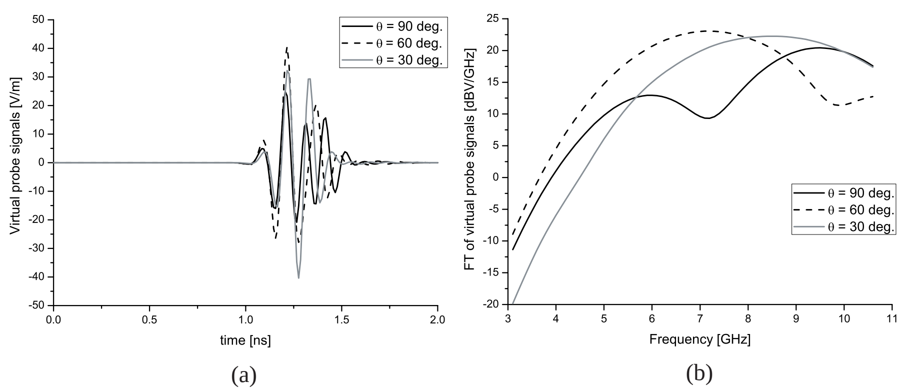
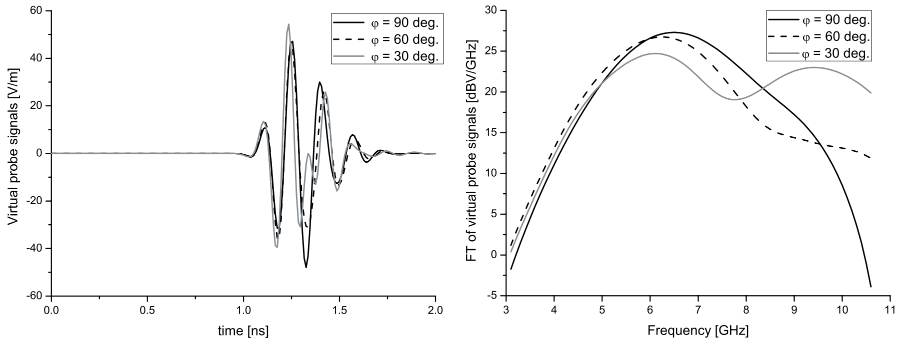


Figure 6. Simulated return loss of the prototype antenna and the optimized antenna.

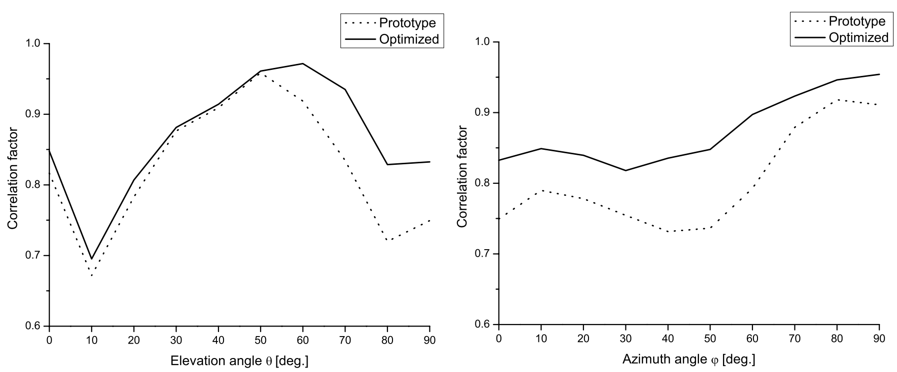




(c) (d)

Figure 7. The received signals by the virtual probes of the optimized antenna: (a) time domain (X-Z plane), (b) frequency domain (X-Z plane), (c) time domain (X-Y plane), (d) frequency domain (X-Y plane).

The received signals seen by the virtual probes of the prototype and optimized monopole antennas are demonstrated in Fig. 3 and Fig. 7, respectively. It could be observed that the received signals of the optimized antenna have very similar shape as the input signal, and the ringing amplitudes are much smaller than the prototype antenna. Therefore, the correlation factors have been greatly improved, on an average, by 7% as Fig. 8 shows.



(a) (b)

Figure 8. Correlation factors of the prototype antenna and optimized antenna: (a) X-Z plane, (b) X-Y plane.

Although in Section 3 only some pairs of the permittivity and thickness have been analyzed and discussed, the results and conclusions should be convinced because the time-domain performance of the printed UWB monopoles would not vary significantly within the gap of the substrate thickness and permittivity. More importantly, the energy-store effects of the antenna substrates and its deleterious effects on the time domain performance of printed monopoles always exist regardless of the monopole type. Therefore, the proposed solutions are expected to perform well in the design of printed UWB monopole antennas for better pulse preserving capabilities.

5. CONCLUSION

In this paper, the pulse preserving capabilities of the CPW-fed disk monopole antenna have been studied and optimized at the assistance of correlation factors. By using 5th-derivative of the Gaussian pulse as the source pulse, the distortions of the radiated signal have been partly alleviated. The ringing and pulse-width spreading of the radiated signals caused by the energy-storage effects of the dielectric substrate have been discussed in detail. Possible improvement solutions and an optimized example have been provided. The improvement of the correlation factors is about 7% on an average. With the physical insight and design example, the proposed solutions are expected to find applications in the design of printed UWB monopole antennas for better pulse preserving capabilities.

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