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UWB RADAR MULTIPATH PROPAGATION EFFECTS

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Katedra elektrotechniky, elektroniky a zabezpečovací techniky
[*/] ÚFA AV ČR

1. Introduction

The UWB concept is very useful for radars and communications [1], [2]. UWB is defined by FCC as any radio technology having a spectrum that occupies a bandwidth greater than 20 percent of the center frequency or a bandwidth of at least 500 MHz. UWB radar output signals are formed both with transmitters and antennas. Therefore UWB antenna should be considered as an integral part of the whole system. A UWB engineer needs to be familiar in both the time domain and frequency domain, able to switch seamlessly from one domain to the other as the nature of problem demands. In many situations, harmonic functions offer a potentially misleading situation. For instance, any attempt to model an ideal step function using superposition of harmonic functions yields overshoot and ringing. Therefore, the utilization of Fourier transform (especially FFT, when aliasing can occur) should be considered very carefully. The output transmitted signal is usually formed according to UWB system requirements. That is why propagation analyses should be done for very wide frequency spectrum and simultaneously, the effect of various transmitted signal shapes (e.g. pulses) should be considered. The effect of various antenna receiving and transmitting responses as well as UWB signals (pulses) are analyzed in [3] - [5]. Various combinations of signals, transmitting or receiving antennas (small and aperture antennas) and wall structures as well as multipath propagation have been calculated and compared. Some of these results can only be shown here. The papers [3] - [5] mostly studies spectra and UWB signal propagation through walls. This paper is dealing with multipath effects in time domain signal representation.

2. Propagation through Walls

Antenna receiving and transmitting responses as well as UWB signals (pulses) are analyzed in [3], where spectra and their UWB signals are studied for several pulses, aperture and small antennas, both for transmitting and receiving antennas. Of course, the real antennas cannot work from DC to infinity and therefore, they form band-pass filter. Therefore, the real antennas do not exactly perform differentiation or integration and their responses are causal. The considered wall parameters are given [3] both for brick and concrete walls for various wall thickness t with wall electrical properties according to [6] and [7]. The calculations of parameters s_{11} and s_{21} for various cases of propagations through walls are shown in [3]. If parameter S_{21} is known (calculated), it is possible to obtain the output signal spectrum b_2 (Θ_0) for any point (Θ_0 is incident angle) both for TE and TM waves

$$b_2(\theta_0) = S_{21}(\theta_0)a_1(\theta_0) \ , \qquad (1)$$

where $a_1(\Theta_0)$ is the input signal spectrum. The output signal spectra are not too illustrative (but they are certainly very important for various purposes such as EMC analyses). Therefore, it is much more convenient to use inverse Fourier transform (IFFT) and analyze the signal responses in the time domain. Several cases of propagation through walls have been analyzed. Some of them can be found in [3] - [5].

3. Multipath Effects

The multipath effects should be considered for UWB systems. The most common case is given in Fig. 1 where direct and reflected signals are shown. Usually, it is not possible to consider one reflection only and the other reflections from a ground, walls and nearby objects should be taken into account. Using the program [3] this case can be easily calculated. Both direct and reflected signals propagate through wall and they can be calculated directly by that program. The spectrum of reflected signal is modified (multiplied) by the reflection coefficient of ground (or possibly of another object)

$$b_{2r}(\theta_r) = S_{21}(\theta_r)a_1(\theta_r)\,\rho_S(\alpha) \qquad (2)$$

where $\rho_S(\alpha)$ is the reflection coefficient at the given surface, which can be calculated as a reflection from a dielectric layer. Of course, surface properties at the related angle α should be considered. The other parameters are the same as for (1) but for the angle of θ_r. The reflection coefficient can be obtained by program [3], too. It is possible to use inverse Fourier transform (IFFT) and analyze the signal responses in the time domain. In this case, the delay between direct and reflected signals can be clearly seen. Various cases have been numerically simulated. Direct and reflected signals for small transmitting antenna and propagation through wall with ε_r = 5.1– j0.46 and thickness t=0.19 m are shown for TE waves in Fig. 2 to 10. The ground with ε_r = 5.1– j0.46 and t=0.19 m has been considered. Various heights h_1 and h_2 and distances r have been analyzed. The special shaped pulses have been analyzed in [3]

$$s_n(t) = a_n(t)\cos\omega_0 t \qquad (3)$$

where $\omega_0 = 2\pi f_0$ and f_0 is frequency. The following pulse has been only chosen for this paper

$$a_3(t) = \cos^2\left(\frac{\pi}{4}\frac{t}{\tau_0}\right) \quad for \;\; t \in \langle -2\tau_0, +2\tau_0 \rangle$$
$$0 \qquad\qquad for \;\; t \notin \langle -2\tau_0, +2\tau_0 \rangle \qquad (4)$$

where f_0 = 1.5 GHz and τ_0 = 1 ns.

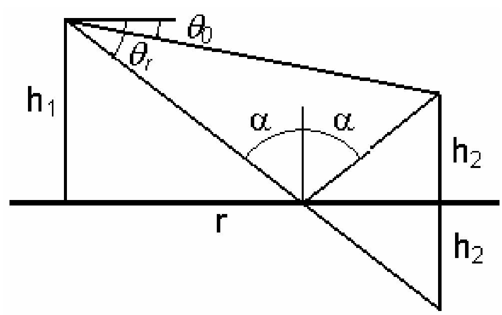

Fig. 1 Direct and reflected rays

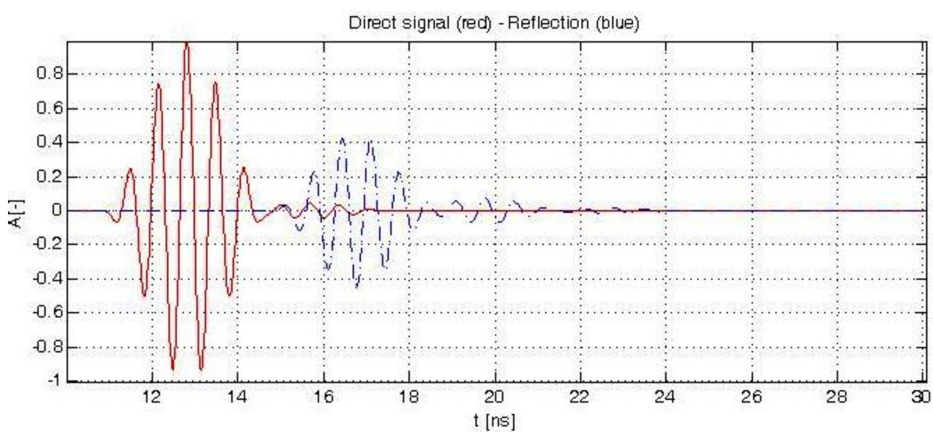

Fig. 2 Direct (solid line) and reflected signals for small transmitting antenna, h1 = 1.5m, h2 = 1.5m and r = 3 m

Various delays (due to propagation through wall and various paths of direct and reflected rays) and the ringing (similar to UWB propagation through wall) can be clearly seen. Certainly, these phenomena are much more pronounced for reflected rays. On the other hand, the interference effects of multiple reflections and multipath effects are much smaller for UWB signals than for CW narrow-band applications as interference minima and maxima do not occur for the same frequencies. Moreover for very short pulses, the individual pulses are received at various times and can be distinguished more easily. Using *Fig. 2* to 10 time delays between direct and reflected signals can be derived. That is shown in Fig. 10 for small transmitting antenna with h_1 = 1.5m, h_2 = 1.5m (solid line) and h_1 = 1.5m, h_2 = 0.4m.

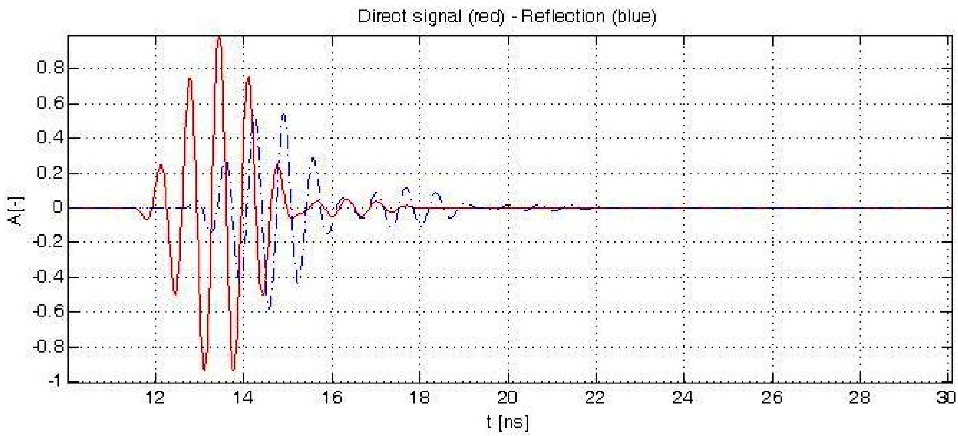

Fig. 3 Direct (solid line) and reflected signals for small transmitting antenna, h_1 = 1.5m, h_2 = 0.4m and r = 3m

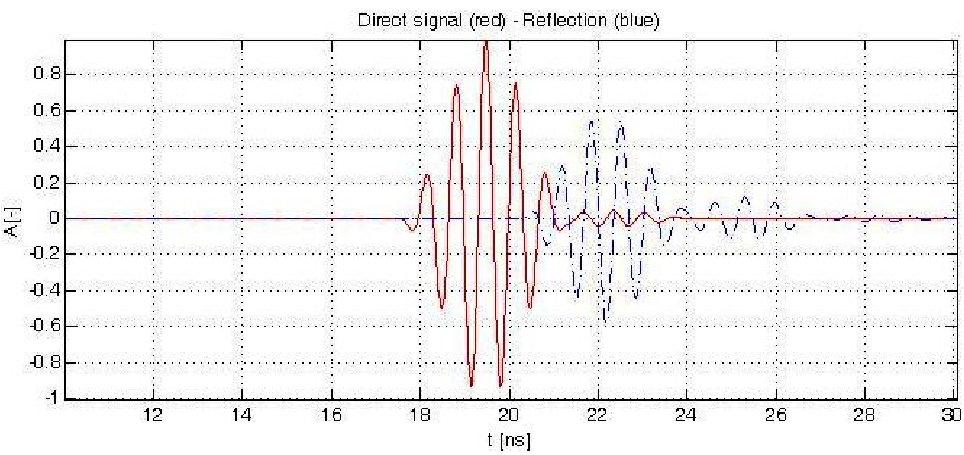

Fig. 4 Direct (solid line) and reflected signals for small transmitting antenna, h_1 = 1.5m, h_2 = 1.5m and r = 5m

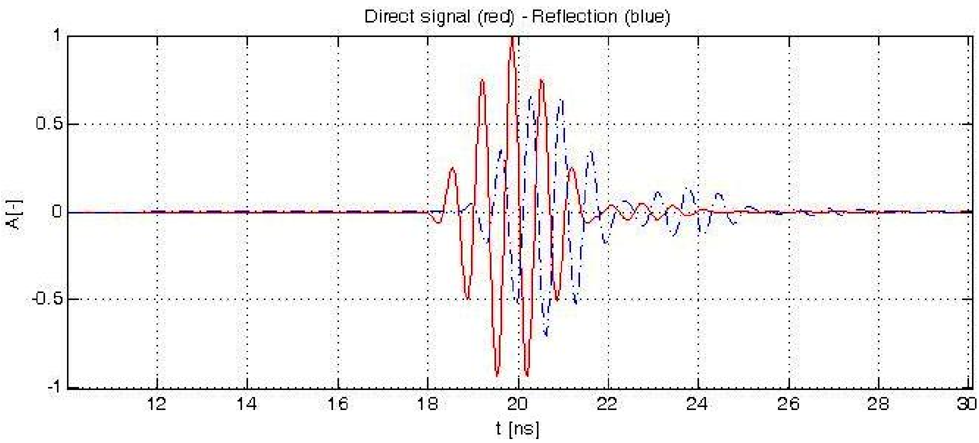

Fig. 5 Direct (solid line) and reflected signals for small transmitting antenna, h_1 = 1.5m, h_2 = 0.4m and r = 5m

4. Conclusions

Several combinations of receiving and transmitting antennas and input signals have been calculated and compared (see [3] - [5]). It can be concluded that UWB radar output transmitted signals are formed both with transmitters and antennas. The transmitting transient responses of an ideal antenna are proportional to the time derivatives of the receiving transient responses of the same antenna. Therefore, UWB antennas should be considered as an integral part of the whole systems. Moreover, the output transmitted signals should be formed according to UWB system demands. That means that analyses should be done for very wide frequency spectrum and simultaneously, the effect of input signals (e.g. special shaped pulses) should be considered both for transmitting and receiving antennas.

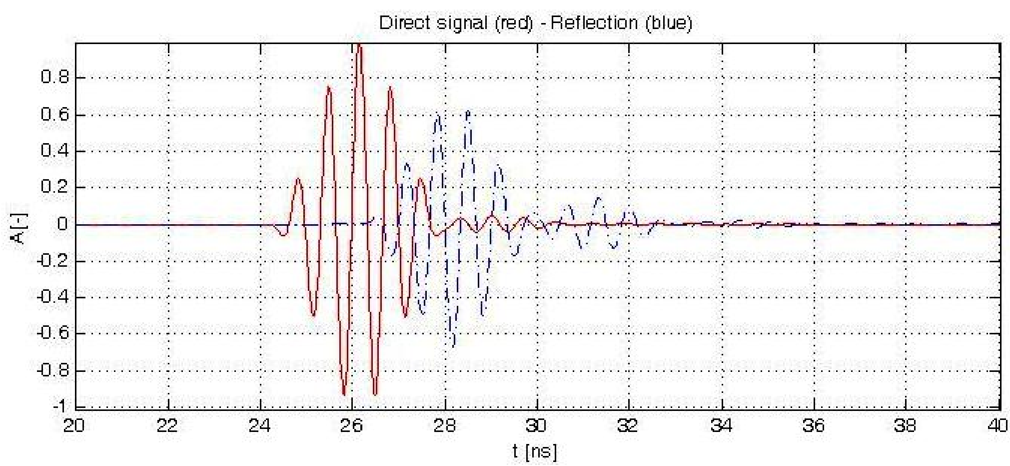

Fig. 6 Direct (solid line) and reflected signals for small transmitting antenna, h_1 = 1.5m, h_2 = 1.5m and r = 7m

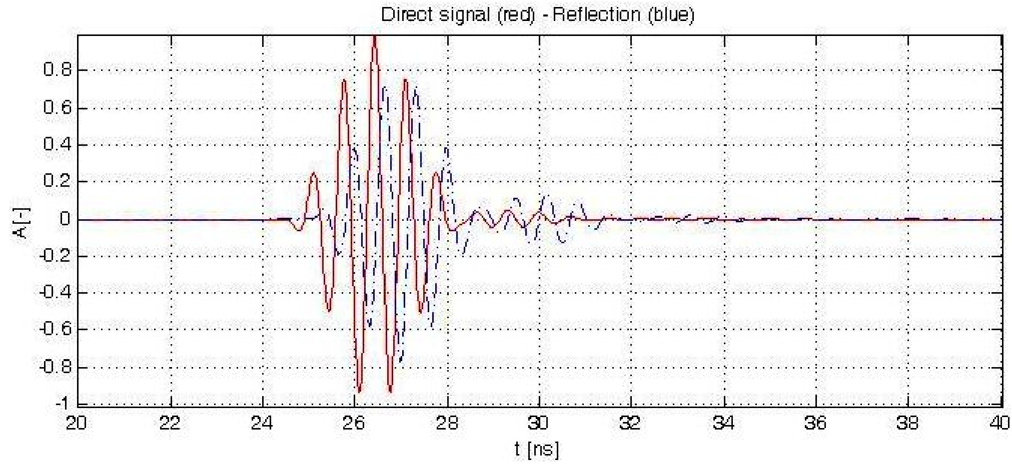

Fig. 7 Direct (solid line) and reflected signals for small transmitting antenna, h_1 = 1.5m, h_2 = 0.4m and r = 7m

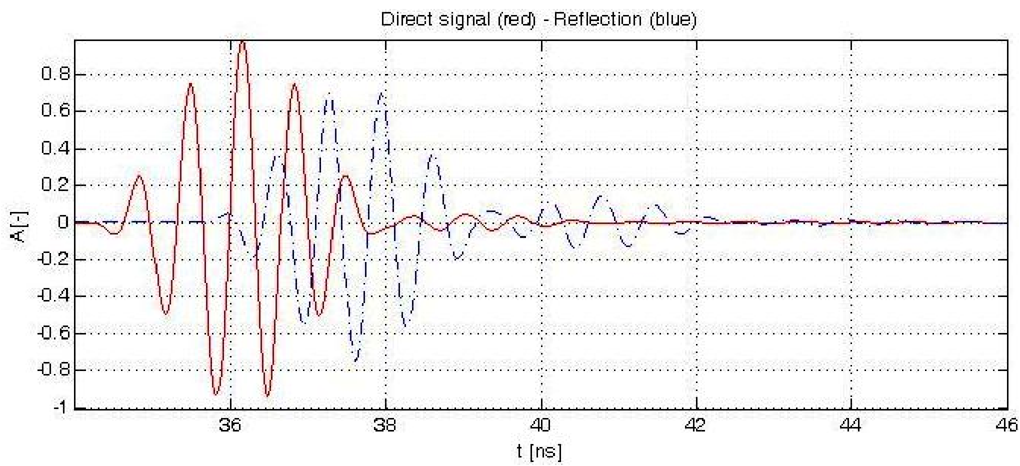

Fig. 8 Direct (solid line) and reflected signals for small transmitting antenna, h_1 = 1.5m, h_2 = 1.5m and r = 10m

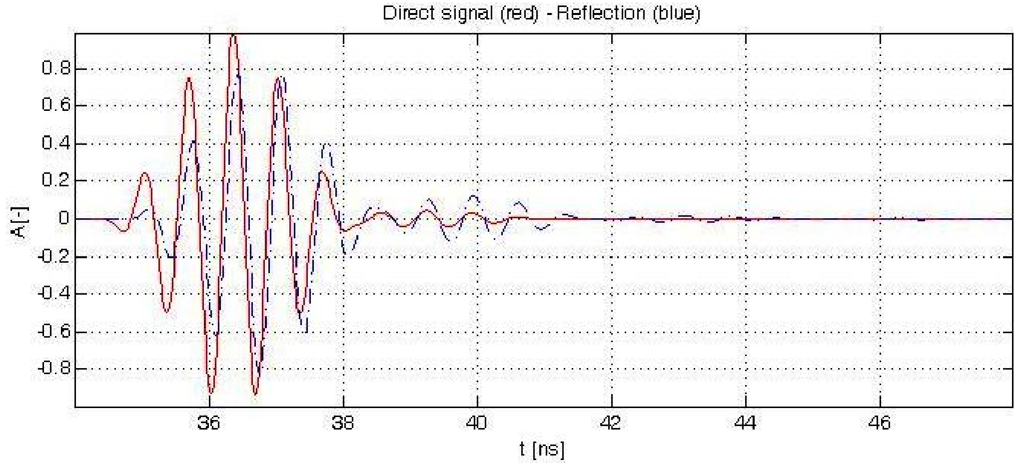

Fig. 9 Direct (solid line) and reflected signals for small transmitting antenna, h_1 = 1.5m, h_2 = 0.4m and r = 10m

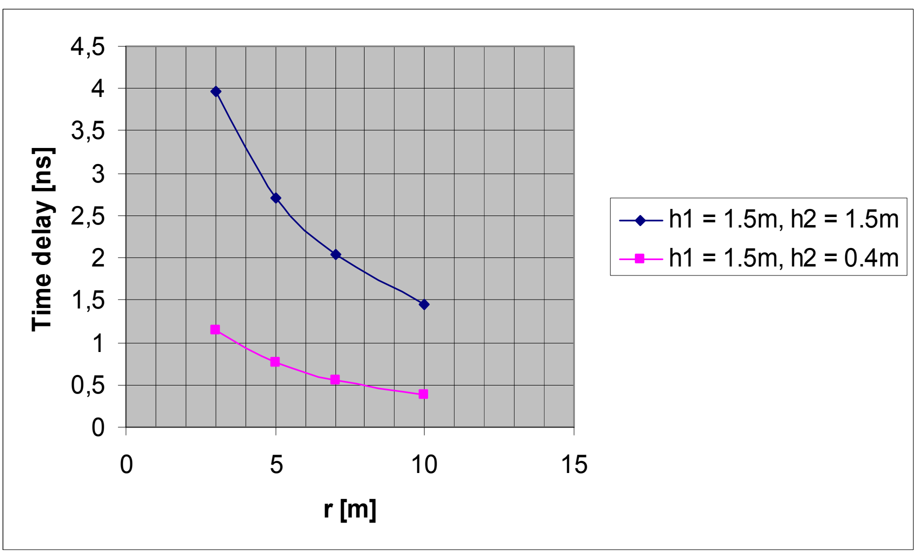

Fig. 10 Time delay between direct and reflected signals for small transmitting antenna with h_1 = 1.5m, h_2 = 1.5m (solid line) and h_1 = 1.5m, h_2 = 0.4m

The propagations of electromagnetic waves through obstacles have been analyzed [3] - [5], where wall parameters are given both for brick and concrete walls with various thicknesses, where s_{11} and s_{21} can be found for these cases. The responses (input and output signals calculated using IFFT) have been extensively analyzed as well. The ringing (due to boundary multiple reflections) can be clearly observed. Naturally, the interference (disturbing) of multiple reflections is much smaller for very short pulses than for CW and narrow-band applications.

The method [3] can be used for analyses of multipath propagation due to reflections (such as ground or wall reflections). Various cases show delays (due to propagation through wall and various paths of direct and reflected rays) and the ringing (similar to UWB propagation through wall). Certainly, these phenomena are much more pronounced for reflected rays. On the other hand, the interference effects of multiple reflections and multipath effects are much smaller for UWB signals than for CW narrow-band applications as interference minima and maxima do not occur for the same frequencies. Moreover for very short pulses, the individual pulses are received at various times and can be distinguished more easily. Time delays between direct and reflected signals for small transmitting antenna with h_1 = 1.5m, h_2 = 1.5m (solid line) and h_1 = 1.5m, h_2 = 0.4m are shown in *Fig. 10*.

Acknowledgements

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Resumé

MNOHOCESTNÉ ŠÍŘENÍ RADIOVÝCH VLN V TECHNICE UWB RADARŮ

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Příspěvek se zabývá UWB technikou aplikovanou v radarové i komunikační oblasti. Zejména se soustředí na řešení mnohocestného šíření, které je analyzované v časové oblasti a mělo by být uvažováno při uvažování UWB systémů. To je případ, kdy je příjímán současně přímý a jeden nebo více odražených paprsků od Země nebo okolních objektů.

Byl vytvořen program, který modeluje mnohocestné šíření. Používá inverzní Fourierovu transformaci (IFFT) k analýze odezev signálu v časové oblasti. Jsou ukázány zpoždění mezi přímým a odraženým paprskem.

Příspěvek dospívá k názoru, že mnohonásobné odrazy a efekty mnohocestného šíření jsou v případě UWB signálů mohem menší než pro CW úzkopásmový signál. Je to tím, že se interferenční minima a maxima nevyskytují vlivem různých kmitočtů UWB signálu současně.

Summary

UWB RADAR MULTIPATH PROPAGATION EFFECTS

Dusan CERMAK, Vladimir SCHEJBAL, Zdenek NEMEC, Pavel BEZOUSEK, Ondrej FISER

The paper is dealing with the UWB technology in the radar technique and communications. Special attention is given to the multipath effects in the time domain signal representation, which should be considered for the UWB systems. This is the case when both direct and (multiply) reflected signals are received. The reflections are due to ground, wall and nearby objects.

A program was created to model this multipath propagation. The inverse Fourier transform (IFFT) to analyze the signal responses in the time domain was also used and the delay between direct and reflected signals was shown.

It is concluded that multiple reflections and multipath effects are much smaller for UWB signals than for CW narrow-band applications as interference minima and maxima do not occur for the same frequencies.

Zusammenfassung

MEHRWEGEFFEKTE BEI DER WELLENAUSBREITUNG VON UWB-RADARS

Dusan CERMAK, Vladimir SCHEJBAL, Zdenek NEMEC, Pavel BEZOUSEK, Ondrej FISER

Der Beitrag befasst sich mit der UWB-Technologie in der Radar- und Kommunikationstechnik. Besondere Aufmerksamkeit wird der Mehrwegausbreitung in der Zeitdomaene-Signal-Repraesentation, die für UWB-Systeme berücksichtigt werden sollte, gegeben.

Dies ist der Fall wenn sowohl direkte als auch (mehrfach) reflektierte Signale empfangen werden. Reflektionen koennen von der Erde oder von naeheren Objekten verursacht werden.

Ein Programm zur Modellierung der Mehrweg-Ausbreitung wurde erstellt. Es benutzt die Inverse Fouriertransformation (IFFT), um die Reaktion des Signals in der Zeitdomaene zu analysieren. Die Verzoegerung zwischen direktem und reflektiertem Signal wurde gezeigt.

Es wird geschlossen, dass Mehrfachreflektionen und Mehrwegeffekte fuer UWB Signale viel schwaecher sind als fuer schmalbandige CW-Signale, weil die Interferenzminima und -maxima nicht fuer die gleichen Frequenzen auftreten.