dr inż. Piotr Górniak
prof. dr hab. inż. Wojciech Bandurski
Wydział Elektroniki i Telekomunikacji
Politechnika Poznańska
ul. Polanka 3, 60-965 Poznań

System Fidelity Factor for Testing the Quality of UWB signal reception

Key Words: Ultra-WideBand (UWB), System Fidelity Factor, wireless channel, convex obstacle

ABSTRACT

In the paper there are presented the results of the analysis of the quality of UWB pulse transmission in the channel containing convex obstacle. The convex ovstacle is a cylinder, which is widely used in simulation tools as a model of the human, whose presence in UWB channel have to be taken into consideration. The analysis are made with the usage of measurement results. The measurements were performed in an anachoic chamber. We use System Fidelity Factor (SFF) as a measure of the quality of the received UWB pulse.

1. INTRODUCTION

The UWB communication has received a great deal of attention in recent years, e.g. [2, 4]. The large bandwidth of UWB signals offers rapid increase in data transmission speed on the one hand, and greater accuracy of positioning and objects detection on the other hand. However, this large bandwidth of UWB signals introduces some problems nonexistent or negligible in narrowband data transmission. The distortion of an UWB pulse is one such problem. Since the propagation loss is frequency dependent, the frequency spectrum of the transmitted UWB signal is significantly changed during propagation. This phenomenon has been discussed in a number of papers, e.g. [1, 5]. This feature of UWB channel can provide degradation of the UWB correlation receiver operation. Pulse distortion is mainly caused by scattering objects such as walls, edges and rounded (convex) surfaces. We focus on convex object (cylinder). One of the most important applications of such objects in the area of UWB channel modelling is the modelling of the real obstacles in UWB channel, especially human being.

The paper is organized as follows. In Section 2 we describe the measurement setup. In Section 3 we show the measurement results processing procedure. Section 4 gives the results of channel quality analysis. We make conclusions in Section 5.

2. THE MEASUREMENT SETUP

The scenario of our measurements was as follows. The EM wave was propagating between two antennas which were shadowed by one cylinder, which was a paper muff coated by a silver foil. We made the measurements in an anechoic chamber. In order to make the measurements we collected all necessary aparature. We used two horn antennas. The signal were created by a sinusoidal generator, which swept UWB frequency band. The amplitude of each sinusoidal signal was the same. The frequencies of the signal was distributed between 1.00-3.00 GHz with a step 0.100 GHz. The amplitude of a received signal was measured by a power meter while signal phase was measured with the usage of a network analyzer. The measurements were taken in two scenarios. In the first the symmetry axis of a cylinder and

the symmetry axes of antennas were collinear. In the second scenario the cylinder was moved so that the symmetry axes of antennas were tangential to the cylinder. The measurement scenarios are presented in Fig. 1.

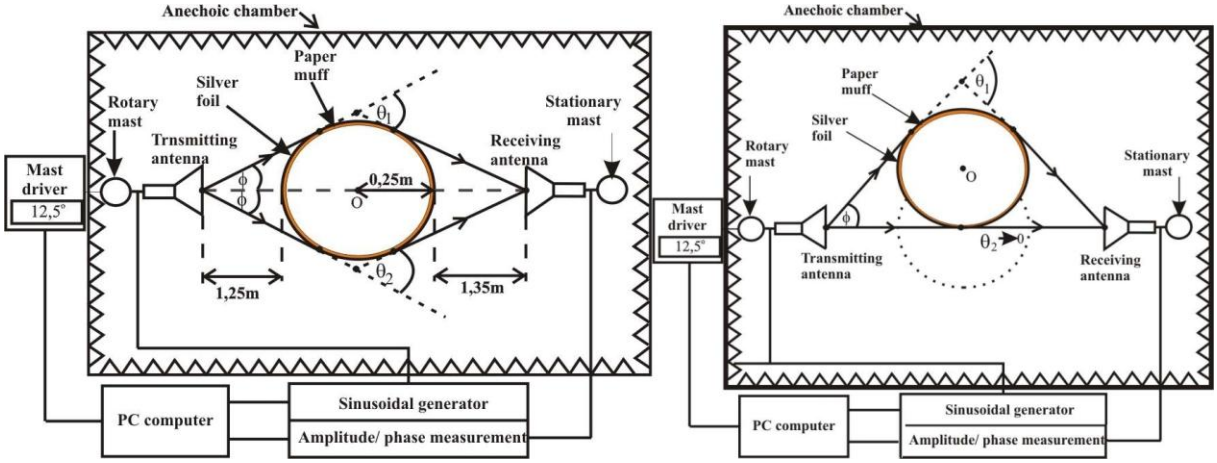

Fig. 1. The measurement scenario with the cylinder in central position (on the left side) and with cylinder in the tangential position (on the right side)

The radius of the cylinder was 0.25 m. The transmitting antenna was mounted on a rotary mast while receiving antenna was mounted on a stationary mast. The rotary mast was driven by a mast driver. The heights of the transmitting and receiving antenna were the same, to ensure the 2D propagation case. The transmitting antenna was rotating during measurements within the azimuth angle limits $\varphi \in <-60°, 0°>$

Although the transmitting antenna transmits the sinusoidal signals one after antother we can take the advantage of the linearity of the channel and analyze the distorion of an UWB signal created by the sum of sinusoidal signals. It can be prooved that the sum of periodic signals is a periodic signal with the period equal the least common multiple of all periods. The UWB signal which is analyzed in the paper is desribed by formula (1) and its two periods with the related Fourier series showed in Fig. 2. The period of the UWB signal is 3.(3) ns.

$$u_{IN}(t) = \sum_{k=0}^{6} \cos\left[\left(2\pi \cdot 1.2 \cdot 10^{9} + k \cdot 0.3 \cdot 10^{9}\right) \cdot t\right] \tag{1}$$

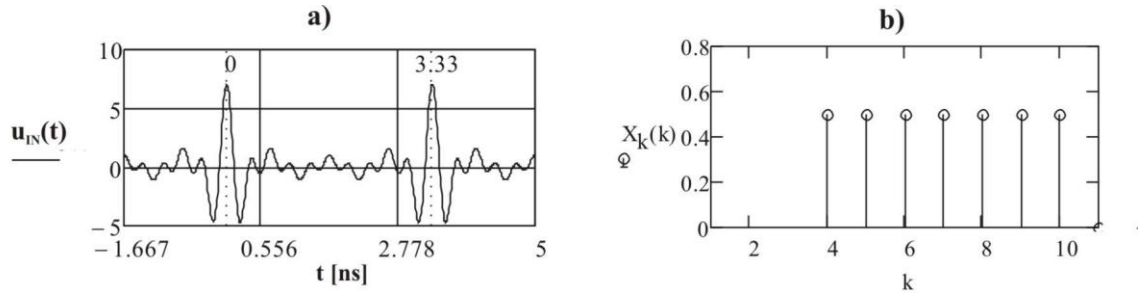

Fig. 2. Generated UWB signal in a) time-domain and b) frequency-domain

3. CROSS-CORRELATION COEFFICIENT AND SYSTEM FIDELITY FACTOR

In order to classify the distortion of the received UWB pulse we use cross-correlation coefficient which is a well known function in signal processing area e.g. [3]. Definition of cross-correlation coefficient for real valued periodic signals is following [3]:

$$\rho_{x,y}(t) = \frac{1}{T}\int_0^T x(t+\tau)y(\tau)d\tau \tag{2}$$

Assuming that signals x(t) and y(t) have Fourier series representation:

$$x(t) = \sum_{k=-\infty}^{\infty} X_k e^{jk\omega_0 t}, \quad y(t) = \sum_{k=-\infty}^{\infty} Y_k e^{jk\omega_0 t}, \tag{3}$$

we can define the normalized cross-correlation coefficient as:

$$\rho_{x,y}^N(t) = \frac{\sum_{k=-\infty}^{\infty} X_k Y_k^* e^{jk\omega_0 t}}{\sqrt{\sum_{k=-\infty}^{\infty}|X_k|^2}\sqrt{\sum_{k=-\infty}^{\infty}|Y_k|^2}}. \tag{4}$$

Now we can introduce, as in [6], System Fidelity Factor (SFF) by

$$SFF = \max_n\left[\rho_{x,y}^N(t_n)\right], \quad t_0\, t_1,....t_n \in T_o. \tag{5}$$

If H(ω) stand for the transfer function of the measured channel and antennas (amplitudes and phases of the received sinusoidal signals) we can finally define SFF in the following form ($k \in \{-10, -9, \ldots 0,1,2,\ldots,10\}$ in our case):

$$SFF = \max_n\left[\frac{\sum_{k=-\infty}^{\infty}|X_k|^2 H_k^* e^{jk\omega_0 t}}{\sqrt{\sum_{k=-\infty}^{\infty}|X_k|^2}\sqrt{\sum_{k=-\infty}^{\infty}|X_k|^2|H_k|^2}}\right]. \tag{6}$$

4. MEASUREMENT RESULTS

We collected the measurement results in two groups. In the first (Fig. 3, 4 and 5) we give the results of the System Fidelity Factor as a function of the transmitting antenna azimuth angle (Fig. 3) and the results of the normalized cross-correlation coefficient (Fig. 4 and 5). In the second group (Fig. 6 and 7) we compare the tramsitted and received UWB pulse shapes. In the both groups we include the results for the central position of the cylinder, as well as for the tangential position of the cylinder.

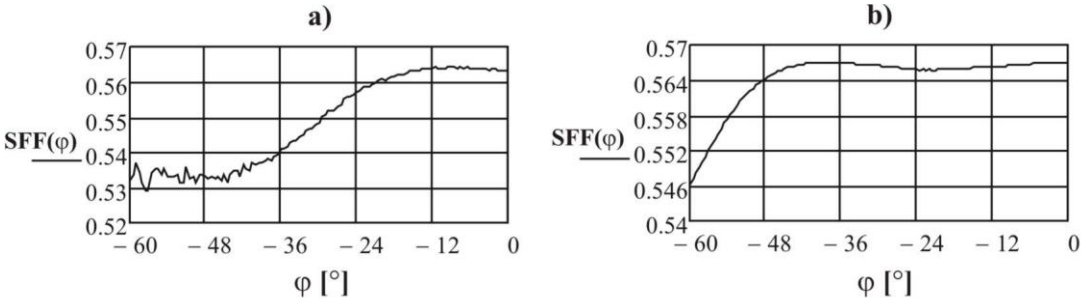

Fig. 3. The function of System Fidelity Factor with respect to the angle of transmitting antenna azimuth for a) central and b) tangential position of the cylinder

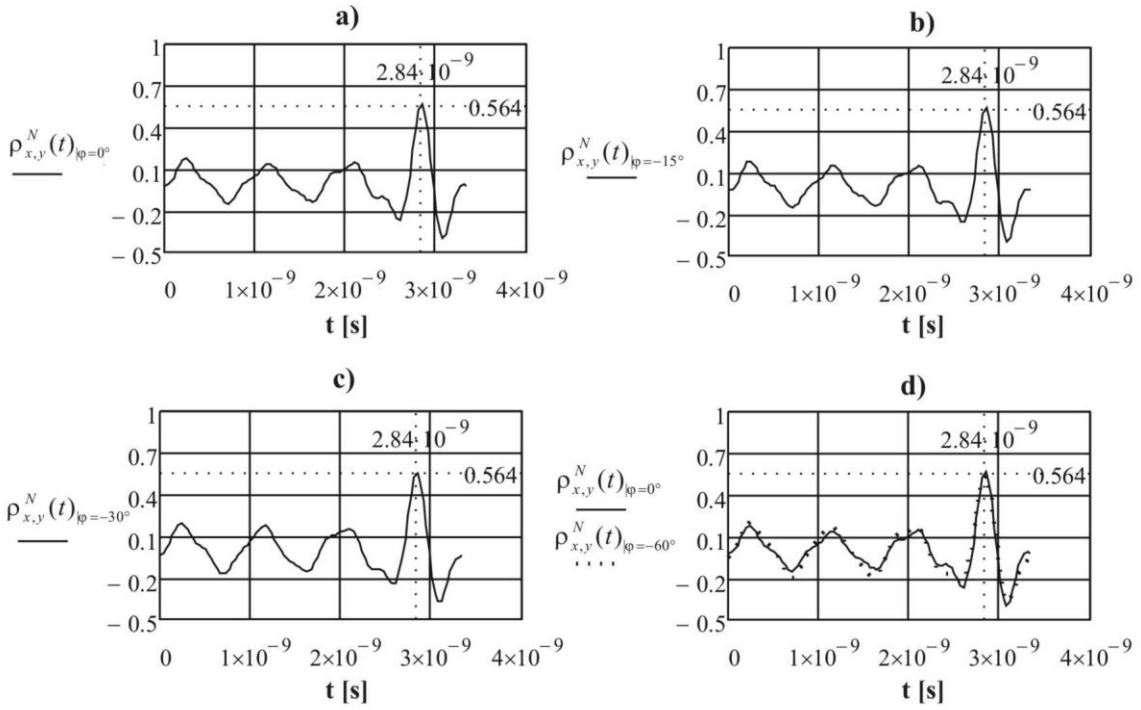

Fig. 4. The normalized cross-correlation results for central position of the cylinder for the azimuth angle a) φ=0°, b) φ=-15°, c) φ=-30°, d) φ=0° compared with the results for φ=-60°

Comparing the results of SFF for the central position of the cylinder with those for the tangential position of the cylinder we can see that in terms of their values they are close to each other, comprising in the limits 0.530 – 0.564 for the central position case and 0.546 – 0.567 for tangential position case (Fig. 3). Although we can deduce from Fig. 5 and 6 that a small margin between the SFF values for the analyzed UWB scenarios can provide visible difference in the degree of pulse distortion. The distortion of UWB pulse is stronger for the central position case. For the sake of comparing the shapes of the generated and received UWB pulses the latter are multipled by a constant factor. The factors are 10 and 5 for the case of the cylinder in the central and tangential position respetively (in the latter case the pulse is less attenuated by the channel). Considering the degree of distortion of the received UWB pulses from Fig. 5 and 6 we can classify the measured channel for the generated UWB pulse as a good quality channel, to which relate the values of SFF given above. These results are in good agreement with those from [6] where only UWB antenna quality were analyzed. Alhough for the case of more obstacles on the UWB pulse propagation path the SFF factor value will be smaller. Then the threshold value of SFF should be established so as to be able to make decisions if the channel can signifficantly degrade the data trasmission quality or not. According to [6] this value can be about 0.5. The question can be how fast the insreasing number of obstacles on the UWB pulse path will desrease the SFF value towards the threshold value. Therefore appropriate measurements and simulations should be made. For the cases of worse quality channels the additional signal processing is needed.

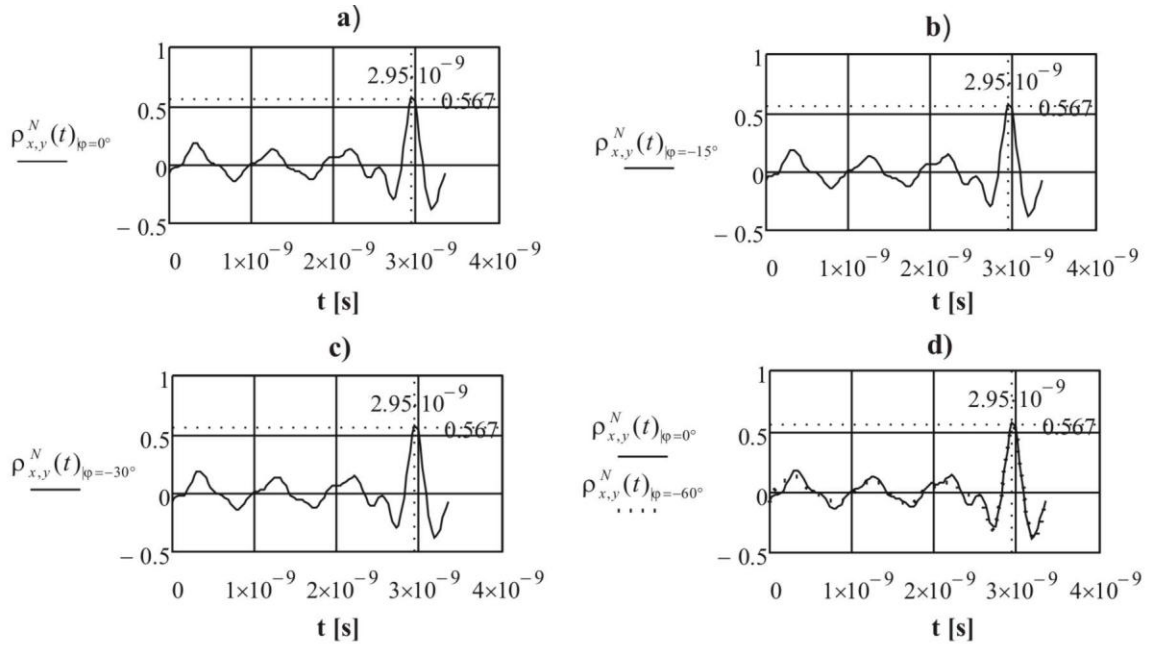

Fig. 5. The normalized cross-correlation results for tangential position of the cylinder for the azimuth angle a) φ=0°, b) φ=-15°, c) φ=-30°, d) φ=0° compared with the results for φ=-60°

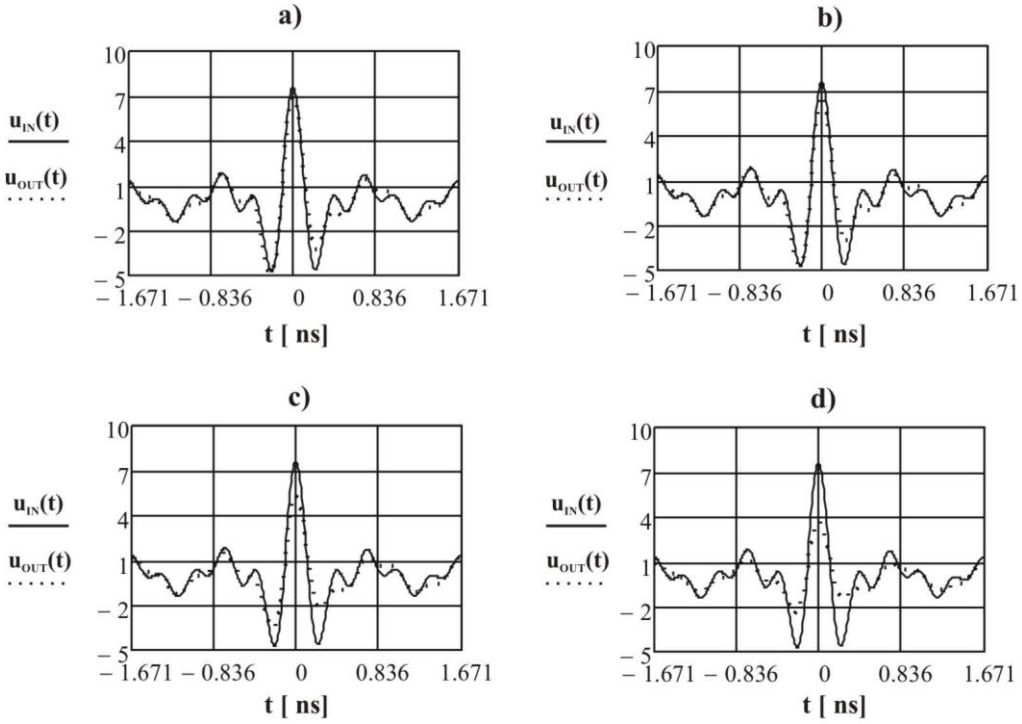

Fig. 6. The incident and distorted (received) pulse shapes for central position of the cylinder (the time argument is scaled in ns); the distorted pulse is delayed by 2.84 ns (Fig. 4) and multipled by 10; the transmitting antenna azimuth angle are: a) – φ=0°, b) – φ=-15°, c) – φ=-30°, b) – φ=-45°

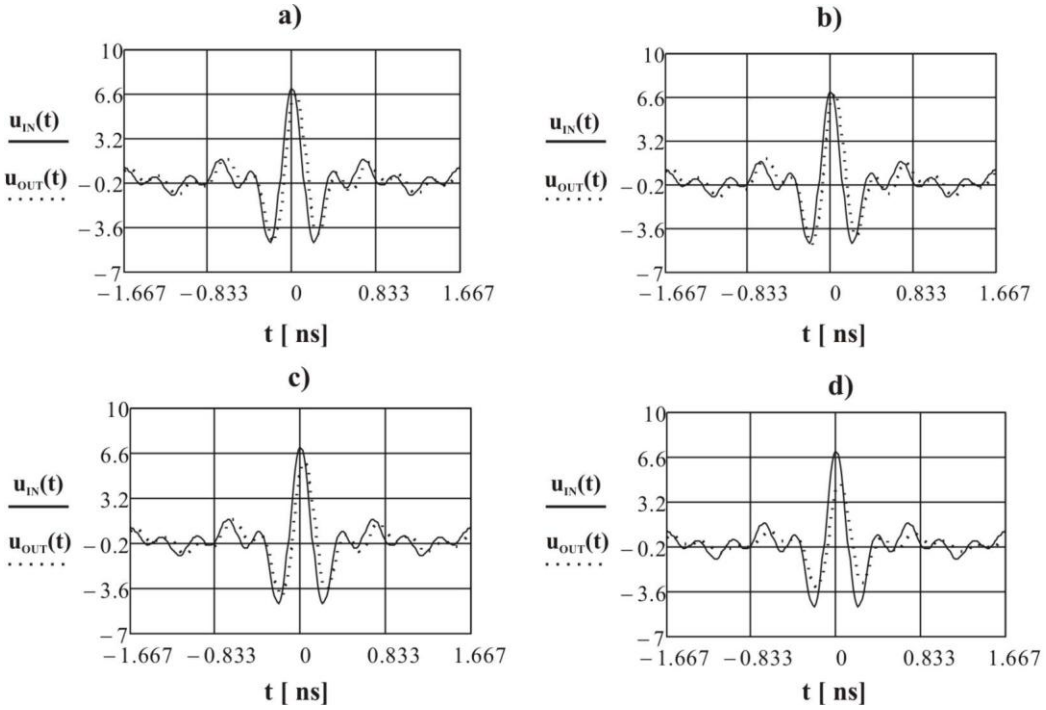

Fig. 7. The incident and distorted (received) pulse shapes for tangential position of the cylinder (the time argument is scaled in ns); the distorted pulse is delayed by 2.95 ns (Fig. 5) and multipled by 10; the transmitting antenna azimuth angle are: a) – φ=0°, b) – φ=-15°, c) – φ=-30°, b) – φ=-45°

5. CONCLUSIONS

We presented in the paper the usage of SFF as a very comfortable way for measuring the quality, as a function of different parameters (e.g. azimuth angle), of a distorted UWB pulse without the need of watching and comparing every ditorted (by the channel) pulse with the trasmitted one. Basing on the measurements performed in real scenario we can characterize channel quality. We presented the results of such analysis for a spesific UWB channel on the basis of SFF. The channel containing one convex obstacle introduce non signifficant distortions of UWB pulse. In this case channel can be classified as non signifficantly distorting good quality channel. Although further analysis of this kind of channels with more obcstacles in it must me made. More obastacles on the UWB signal path may couse a signifficant degradation of the received UWB pulse quality.

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Współczynnik dokładności systemu jako narzędzie do testowania jakości odbioru sygnału UWB

Słowa kluczowe: ultra-szerokopasmowy (ang. UWB), współczynnik dokładności systemu (ang. SFF), kanał bezprzewodowy, przeszkoda wypukła

STRESZCZENIE

W artykule zamieszczono wyniki analizy jakości transmisji UWB w kanle zawierającym przeszkodę wypukłą. Przeszkodą wypukłą jest obiekt cylindryczny, który jest szeroko stosowany w oprogramowaniu do symulacji propagacji fali EM jako model człowieka, którego obecność w kanale UWB musi by uwzględniana. Analizy przeprowadzone są z wykorzystaniem wyników pomiarów. Pomiary zostały wykonane w komorze bezodbiciowej. Jako miarę jakości odbieranego sygnału UWB wykorzystujemy współczynnik dokładności systemu (ang. SFF – *System Fidelity Factor*)