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***Research paper***

# BER Performance of Ultra-Wideband Signal in Optical Transmission Line

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## Abstract

The main interest of ultra-wideband (UWB) system is that it can coexist with the current radio system with minimal or no interference, which indeed benefits the radio service provider to avoid paying expensive spectrum licensing fees. However, UWB system has a limited propagation distance, typically up to 10 meters. Thus, optical UWB technology has been proposed recently to overcome this problem. In this paper, Matlab simulation has been done to study the performance of the UWB signal in the optical transmission line. Bit error rate (BER) performance has been compared using minimum mean square error (MMSE) equalizer with varying tap length. Results indicate that the distance of the UWB signal transmission can be extended using optical fibre as long as the sampling rate does not cause the optical multipath channel to generate too much interference.

***Keywords***: *Ultra-wideband; Optical; Multipath channel; Bit error rate.*

## 1. Introduction

In this era of globalization, the rapid growth in technology and the well-development of wireless communications are significantly affecting human's daily lives. As the client interest for higher capacity or higher information rate, faster service and the more secure wireless connections increases, all these new enhanced technologies have to find their position in the scarce and over-crowded radio frequency (RF) spectrum [1]. Ultra-wideband (UWB) technology provides solution to overcome the limited availability of the RF spectrum by allowing the new services to coexist with current radio systems with minimal or no interference [1]. With this coexistence, it benefits the providers of all other radio services to avoid the expensive spectrum licensing fees [2].
However, UWB wireless technology has short propagation distances (usually up to 10 meters) of electromagnetic waveforms. The reason that UWB system can only travel over a short distance is due to low power spectral density (PSD) [3]. Moreover, UWB signal suffers long symbol delay spread [4], which then creates long multipath effect [5], causing the limitation of transmitting signal over a distance no longer than 10 meters due to severe signal interferences such as inter-symbol interference (ISI) and multi-user access interference (MAI) [6]. In order to overcome this problem, optical technology can be integrated with the UWB technology as reported in [7] - [9].
Optical UWB system is the distribution of UWB signal over optical fibre, or called as UWB over fibre (UWBoF). UWBoF can increase the area of coverage to offer the availability of undisrupted service across the different networks [7]. One of the important advantages for UWBoF system is that without the requirement for extra electrical to optical conversion, where the UWB signal can be easily generated directly in the optical domain [8]. Such technique has been implemented in the UWB radio over fiber (UROOF) technology, which allows the signal transmission of UWBoF by superimposing the UWB RF signal of several Gigahertz on the optical continuous-wave (CW) carrier [9]. On the other hand, a free space optical UWB is also proposed in [10] without using the conventional optical fibre.
In this paper, the objective is to construct a basic optical UWB system, and then study the performance of UWB signal propagated via the existing optical transmission line. The proposed system model is shown in Figure 1. The optical integration has been done in [11], but we extend the work further by generating the multipath channels at different sampling rates and, then conduct the bit error rate (BER) performance of the UWB signal propagated via the optical transmission line at the receiver side. The performance comparisons have been made by varying the number of equalizer's tap length under each multipath channels.

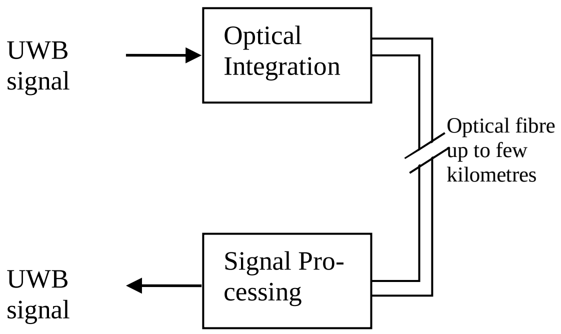


**Fig. 1:** Integration of UWB signal into optical fibre.

The paper is organized as following: Section 2 illustrates the system model of a basic optical UWB transmission. Section 3 includes the generation of the UWB optical channel multipaths and the performance analysis of the UWB transmitted signals over the optical channel. Section 4 concludes the research finding in this paper.

## 2. Methodology

In the proposed system model, binary phase shift keying (BPSK) modulation scheme is chosen to ease the process of integration of UWB signal to the optical transmission line as reported in [12]. The BPSK-UWB signal is given as following [2].

$$s(t) = \sum_{i=1}^{M} b_i p(t - t_p) \quad (1)$$

where $b_i$ is the random bit sequence generated in the form of +1 and -1 using BPSK modulation, $M$ is the total number of information bits, $p(t)$ is the UWB pulses, and $t_p$ is the period of the pulses.
After propagating through the optical transmission path, the UWB received signal is equal to:

$$y(t) = s(t) \otimes h(z,t) + n(t) \quad (2)$$

where $h(z,t)$ is the impulse response of the optical channel stated in [11], and $n(t)$ is the additive white Gaussian noise (AWGN) added to represent any noisy environment.
Since the transmission medium is an optical fibre, the multipath channel has an impulse response re-formulated as [11];

$$h(z,t) = \sum_{\mu} w_{\mu} e^{(-\gamma_{\mu} z)} \partial(t - \tau_{\mu} z) \quad (3)$$

where $w_\mu$ is the is the mode power distribution (MPD), $\gamma_\mu$ is the attenuation coefficient for mode μ, $z$ is the distance of the optical transmission path, and $\tau_\mu$ is the group delays per unit length, which is the inverses of the mode group velocities [11]. The estimated values of $w_\mu$ and $\tau_\mu$ can be found in [11].
In order to study the performance of the proposed system, the UWB received signal is then pass through the equalization process [13] for recovering the bit information from its error due to multipath channel effect.

## 3. Results and discussion

### 3.1. Parameters

In this paper, all of the result performance is obtained using Matlab simulation. The performance comparison has been made among three selected sampling rates of received signal: 10 picoseconds, 20 picoseconds and 30 picoseconds respectively. The sampling rates are chosen to show the effect of multipath at the fastest possible sampling rate that can be achieved without the loss of transmitted information. The transmitted bits are generated randomly with a size of 100,000 bits and are uniformly distributed. The UWB receiver has an equalizer using the most common minimum mean square error (MMSE) optimization criterion [13] for error recovery.
Throughout the simulation, the value for attenuation coefficient, $\gamma_\mu$ is set to 2.3 dB/kilometer, which is according to the standard of the multimode optical fibre [11]. The distance between transmitter and receiver, $z$ is chosen as 600 meters following the distance in [11]. The tap length of the equalizer is varied to compare the performance of the optical UWB system at each selected sampling rates

### 3.2. Sampling rate at 10 picoseconds

Figure 2 illustrates the optical channel multipaths generated with sampling rate at 10 picoseconds. Sampling rate is inversely proportional to the data rate. It can be observed that the channel has 8 multipath components, and all of the magnitudes are very small (less than 10% of the transmitted bit amplitude). The channel does not have the strongest multipath components in its propagation through the optical transmission line. Indeed, the multipath channel will cause a delay spread up to 8 information bits, which is expected to bring severe interference to any propagated signal.
Figure 3 presents the BER performance of the UWB received signal with sampling rate at 10 picoseconds. It is observed that the UWB signal does not achieved a good BER performance due to the significant loss of transmitted bit energy across the optical path. The performance of the MMSE equalizer does not converge to a BER of $10^{-5}$ for all simulated tap length, $k$ when $E_b/N_0 < 30$ dB since it is not able to mitigate the severe interference effect at a sampling rate of 10 picoseconds.

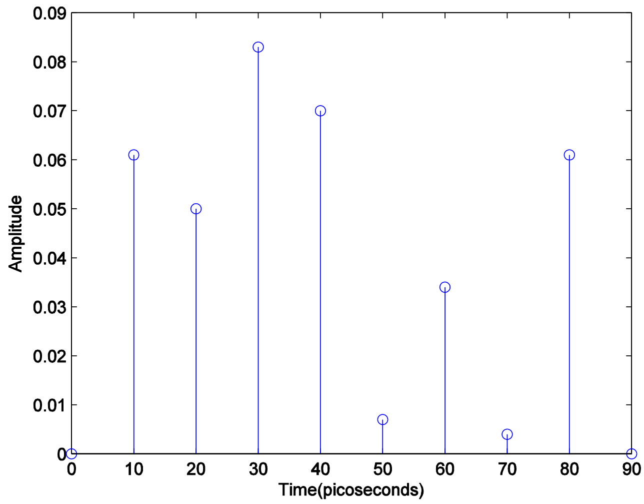


**Fig. 2:** Multipath channel with sampling rate at 10 picoseconds.

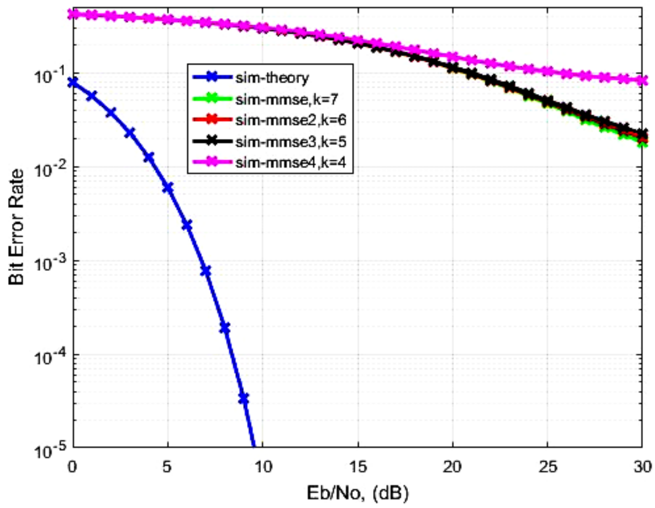


**Fig. 3:** BER vs $E_b/N_0$ graph with tap length, $k$ = 4, 5, 6 and 7 for first multipath channel.

### 3.3. Sampling rate at 20 picoseconds

Figure 4 illustrates the optical channel multipaths generated with sampling rate at 20 picoseconds. It can be observed that the channel has reduced its number of multipath components down to 4 only, and it has the strongest multipath components with magnitude more than 10% of its transmitted bit amplitude at the beginning of its propagation through the optical transmission line. Due to this characteristic, it is no doubt that the signal quality of the UWB under the second multipath channel will be expected to be better than the first multipath channel.
Figure 5 presents the BER performance of the UWB received signal with sampling rate at 20 picoseconds. In this case, the MMSE equalizer is able to achieve a BER of less than $10^{-5}$ for all simulated tap length, $k$ when $E_b/N_0 < 30$ dB. At a BER of $10^{-5}$, the MMSE equalizer with tap length, $k = 6$ and $k = 7$ gives a perfor-

mance gain of approximately 1 dB over the same equalizer with shorter tap length, $k = 4$ and $k = 5$ respectively.

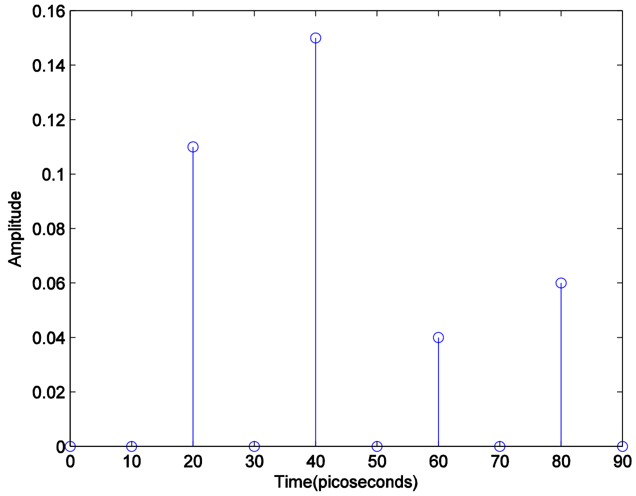


**Fig. 4:** Multipath channel with sampling rate at 20 picoseconds.

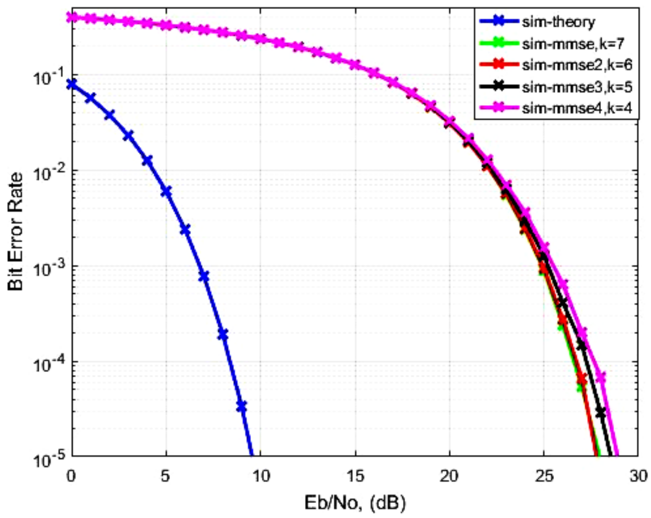


**Fig. 5:** BER vs $E_b/N_0$ graph with tap length, $k = 4, 5, 6$ and $7$ for second multipath channel.

### 3.4. Sampling rate at 30 picoseconds

Finally, Figure 6 illustrates the optical channel multipaths generated with sampling rate at 30 picoseconds. It can be observed that the channel has again reduced its multipath components down to 3 only, and it has the strongest multipath components with magnitude up to nearly 20% at the first multipath propagation.

Since the data rate is getting lesser and lesser, which lead to lesser interference, and thus, the BER will be reduced. To further verify the statement, Figure 7 presents the BER performance of the UWB received signal with sampling rate at 30 picoseconds. At a BER of $10^{-5}$, the MMSE equalizer with tap length, $k = 5$, $k = 6$ and $k = 7$ gives a performance gain of approximately 1 dB over the same equalizer with tap length, $k = 4$. Moreover, the MMSE equalizer is able to achieve the BER of $10^{-5}$ at $E_b/N_0 = 25$ dB, which is less than $E_b/N_0 = 27.5$ dB under the second multipath channel.

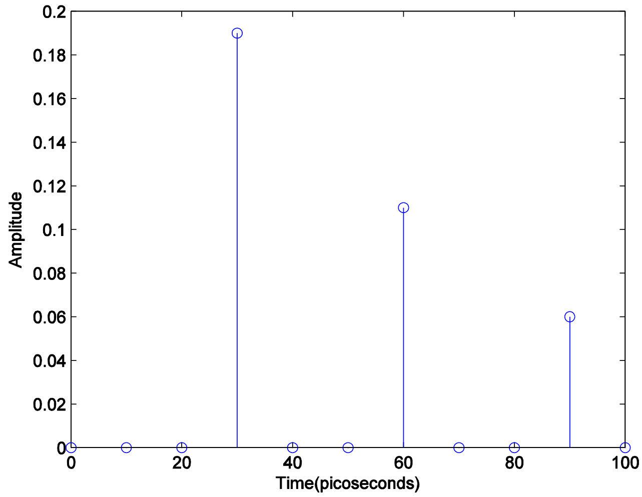


**Fig. 4:** Multipath channel with sampling rate at 30 picoseconds.

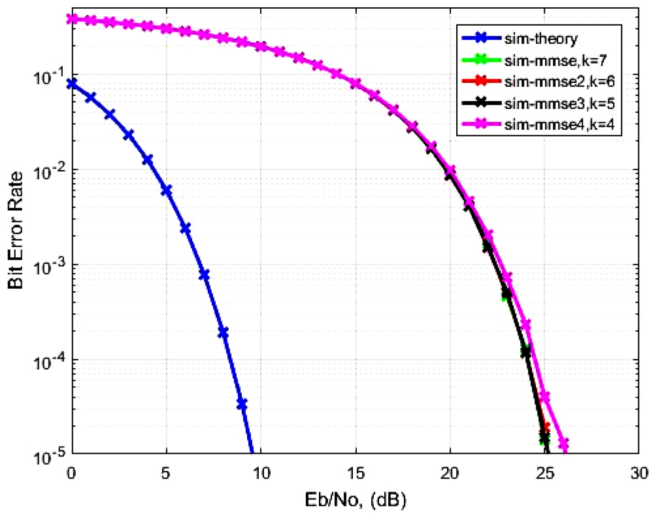


**Fig. 5:** BER vs $E_b/N_0$ graph with tap length, $k = 4, 5, 6$ and $7$ for third multipath channel.

Based on Figure 2 to Figure 7, when the sampling rate is increased, the size of the array for the multipath channel is decreased, but the amplitude of the multipath channel is increased. Therefore, the BER performance of the optical UWB signal with sampling rate at 30 picoseconds is better than the sampling rate at 20 picoseconds. Where else, when the sampling rate reduces to 10 picoseconds only, the optical UWB system cannot perform well unless additional signal processing needed to be included in the system model for error correction. Due to the same reason, the obtained BER performances in Figure 5 and Figure 7 will not approach the theoretical performance.

## 4. Conclusion

In this paper, a basic optical UWB system has been constructed, and the UWB signal is transmitted through a specific optical channel model. Simulation results show that the MMSE equalizer is able to recover the signal distortion due to optical channel multipath effect as long as the sampling rate is not less than 20 picoseconds. The optical UWB has the best BER performance at 30 picoseconds of sampling rate. Future work can be done by implementing better equalization at the receiver or minimizing the amplitude reduction of UWBoF signal using repeaters along the optical fibre.

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