Journal University of Kerbala , Vol. 16 No.1 Scientific . 2018

Transmission Performance Evaluation of Wireless Communication System Based on UWB Signals over Optical Fiber

تقييم أداء الأرسال لنظام اتصالات لاسلكي بالاعتماد على اشارات ذات طيف واسع عبر الألياف البصرية

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(بحث مستل)

Abstract

The aim of this paper is to assess the transmission performance of the Ultra Wideband (UWB) signals over fiber system that consists of Single Mode Fiber (SMF) and Dispersion Compensation Fiber (DCF). This investigation covers both electrical and optical generation of UWB signal. Simulation results are presented using both Gaussian monocycle and doublet pulse each operating with bit rate 1.25 Gbps and 10 Gb/s with ON-OFF Keying (OOK) modulation technique. The simulation results reveal that extending the coverage area for UWB signals towards 130 km in electrical generation and 230 km in the optical generation is possible for the UWB signals and modulation format adopted in this work.

Key Words: UWB, Monocycle pulse, Doublet pulse, OOK, Optical fiber.

الخلاصة

الهدف من هذا البحث هو تقييم اداء الارسال لإشارات ذات الطيف الواسع (UWB) عبر الالياف البصرية التي تتكون من ليف بصري احادي الصيغة (SMF) وليف بصري معالج التشتت (DCF). يشمل هذا التحقيق كلا من التوليد الكهربائي والضوئي لإشارة الطيف الواسع. تم الاعتماد على اشارة كاوس الاحادية والثنائية كل واحدة منها بمعدل ارسال 1.25 (كيكا بايت/ثانية) و10 (كيكا بايت/ثانية) وبنظام ترميز OOK للحصول على النتائج. تشير النتائج الى امكانية زيادة منطقة التغطية الى حوالي 130 كم في حالة التوليد الكهربائي و230 كم في حالة التوليد الضوئي لإشارات ذات الطيف الواسع وطريقة الترميز المستخدمة في هذا العمل.

1- Introduction

Ultra wideband (UWB) communication is considered as one of the most favorable schemes for next generation of indoor communications and short-range wireless systems. The field of UWB communication almost remained restricted and limited to military and government uses until onset of February 2002 in which the Federal Communications Commission (FCC) has allocated 7.5 GHz that spectrum (3.1 to 10.6) GHz for unlicensed use of UWB communication service, with a transmitted power spectral density (PSD) of less than -41.3 dBm/MHz for indoor application. The transmission range of UWB signals restricts to only a few or tens meter due to the low power spectrum density. Therefore, using optical link considered one possible means to overcome this restrict to extend UWB signals over long distances and this technology is called UWB over fiber [1, 2]. A communication system can be said to be UWB if the fractional bandwidth more than 20% of the central frequency or the instantaneous spectral occupies a -10dB bandwidth more than 500 MHZ. The Gaussian pulses are widely used in UWB communication systems due to them can be simply generated by pulse generator [3]. The current techniques for a generation the pulses in UWB over fiber communication systems can be classified into two methods: electrical and photonic [4]. The aim of this paper to compare the transmission performance of UWB signals that generated in electrical domain and optical domain over the optical link that consists SMF and DCF, and assess the best method to extend the coverage area with high bit rate. Simulation results are presented using optisystem version 14.1 software package.

This work has four section. Firstly, describe the generation technique of the UWB pulses. Then, description of the benefit of using optical fiber with this technique and show how can solve the problem of dispersion by using DCF. After that, simulation results of the UWB pulses over SMF and DCF are presented. Lastly, conclusions of this work that get it in this work.

2- Generation Techniques of UWB Pulse

UWB pulse can be generated by two methods; electrical and optical method, and there are various techniques of generation in each domain.

A. Pulse Generation in Electrical Domain

A normal signal that can be taken into account as a basic function for UWB transmission can be generated in the simplest method by a pulse generator is a Gaussian pulse. The first and the second derivative of Gaussian pulse represented the Gaussian monocycle and doublet pulse. The fundamental of Gaussian waveforms named electrical Gaussian pulse represented by $Y_{g1}(t)$ expressed as (1) [5]

$$Y_{g_1}(t) = K_1 \exp\left(-\frac{t^2}{\tau^2}\right) \qquad (1)$$

Where K_1 is a constant, τ represent the time delay difference, and $-\infty < t < \infty$. Additional waveforms can be generated by a sort of filtering of a Gaussian pulse. This filter works in a manner like to take the derivatives of equation (1). By taking the first derivative of Gaussian pulse, a Gaussian monocycle can be generated as in equation (2)

$$Y_{g_2}(t) = K_2 \frac{-2t}{\tau^2} . \exp\left(-\frac{t^2}{\tau^2}\right) \qquad (2)$$

Where $Y_{g_2}(t)$ represent Gaussian monocycle and K_2 is a constant. A Gaussian doublet pulse is obtained from the second derivative of equation (1)

$$Y_{g_3}(t) = K_3 \frac{-2}{\tau^2}\left(1 - \frac{2t^2}{\tau^2}\right) \exp\left(-\frac{t^2}{\tau^2}\right) \qquad (3)$$

Where Y_{g_3} a Gaussian doublet and K_3 is a constant. Figure (1) shows the generation of monocycle pulse or doublet pulse using a first or second order differentiator [6].

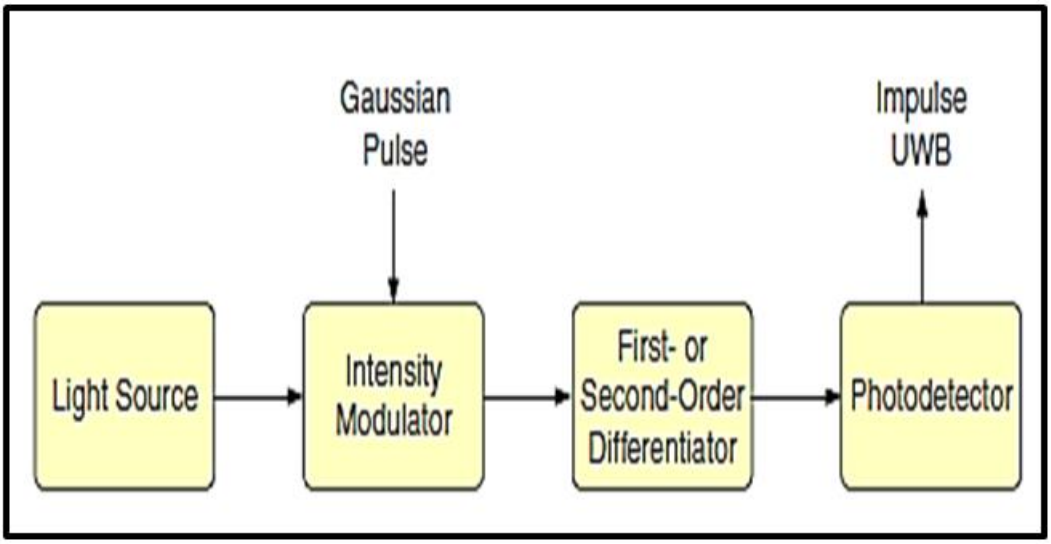


Fig. 1: Generation UWB monocycle or doublet pulse using first or second differentiator.

Electrical generation of UWB pulse is more advantage such as low cost, the possibility of integration on one chip, and back up many modulation formats. On the other side, there is the imperfection of this generation that the range of transmission UWB signals is very limited. Furthermore, generating the UWB pulse in electrical domain and converting it to optical domain requires an additional component that converts the electrical signal to optical domain (E/O) [7].

B. Pulse Generation in Optical Domain

Generation UWB signals optically are desirable since it directly generated without the need for additional electrical to optical conversion. Furthermore, using the optical method to generate UWB signals has numerous advantages like small size, lightweight, and immunity to interference electromagnetic [8, 9]. In this work, using a microwave delay line filter method to generate UWB signals, which attracts increasing attention due to different signaling formats can be obtained in the optical domain [10]. If a Gaussian pulse assumed $n(t)$ that is applied to a two taps microwave delay line filter with one positive coefficient and one negative coefficient of [1, -1], as illustrated in figure (2). The output of the filter $m(t)$ is given by [11, 12]

$$m(t) = n(t) - n(t - \tau) \qquad (4)$$

Where τ represent the difference of the time delay. For the two side of eq. (4) applying Fourier transform, gives

$$M(f) = N(f) - e^{-J2\pi f\tau}.N(f) \qquad (5)$$

Where $M(f)$ and $N(f)$ are Fourier transforms of $m(t)$ and $n(t)$, respectively. One can show that

$$M(f) = N(f) - e^{-J2\pi f\tau}.N(f)$$
$$= J2e^{-\frac{J2\pi f\tau}{2}}.\sin\left(\frac{2\pi f\tau}{2}\right).N(f)$$

Using the geometric identity $\sqrt{2}sin\theta = \sqrt{1 - cos2\theta}$ yields

$$M(f) = \left[J\sqrt{2}e^{-\frac{Jw\tau}{2}}\sqrt{1 - cos2\pi f\tau}\right].N(f)$$

The magnitude of frequency response of the filter is given by

$$|H(f)| = \left|\frac{M(f)}{N(f)}\right| = \sqrt{2 - 2\cos(2\pi f\tau)} \qquad (6)$$

To get a spectrum corresponding UWB monocycle pulse, frequency response with band pass filter can shape the spectrum of a Gaussian pulse input that can be obtained by properly choosing time delay difference τ.

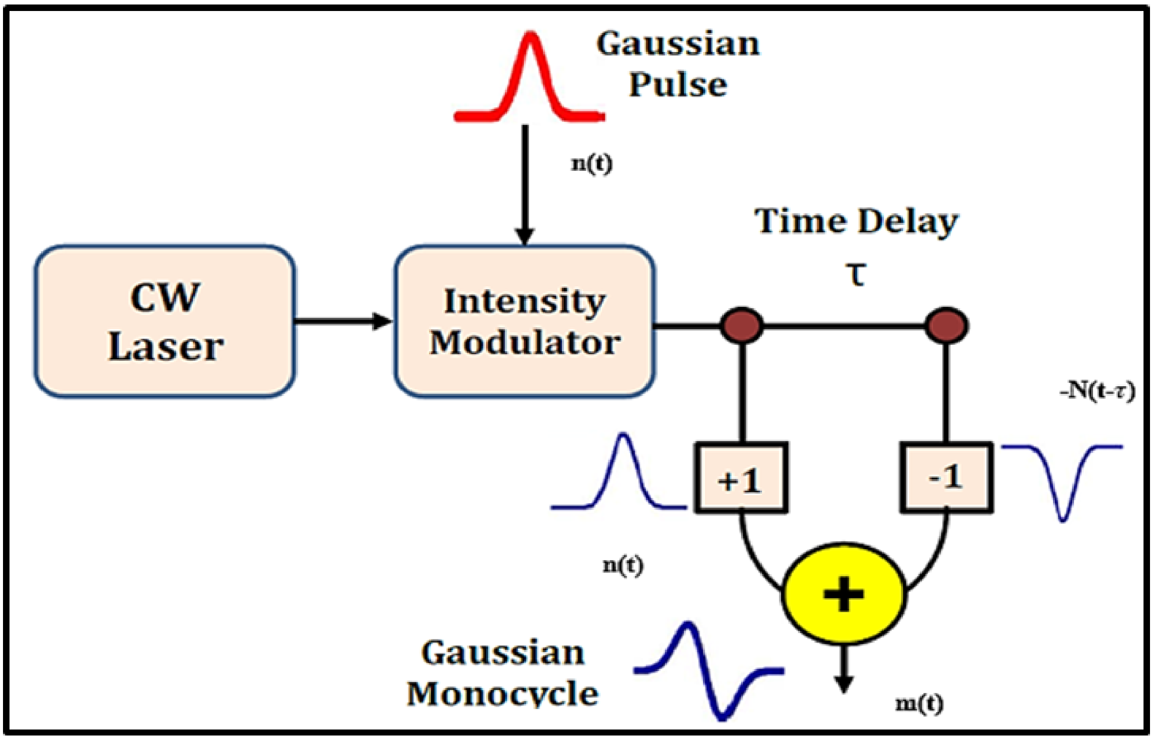


Fig. 2: Generation UWB pulse based on a two-tap microwave delay line filter

To generate UWB doublet signal, the second order derivative should be implemented to a Gaussian pulse that can be approximated by the second order difference as in equation (7) [11]

$$\begin{aligned} m(t) &= [n(t) - n(t-\tau)] - [n(t-\tau) - n(t-2\tau)] \\ &= n(t) - 2n(t-\tau) + n(t-2\tau) \qquad (7) \end{aligned}$$

Eq. (7) shows that an UWB doublet pulse can be generated using a microwave delay line filter with three taps with coefficients [1 -2 1] as illustrated in figure (3).

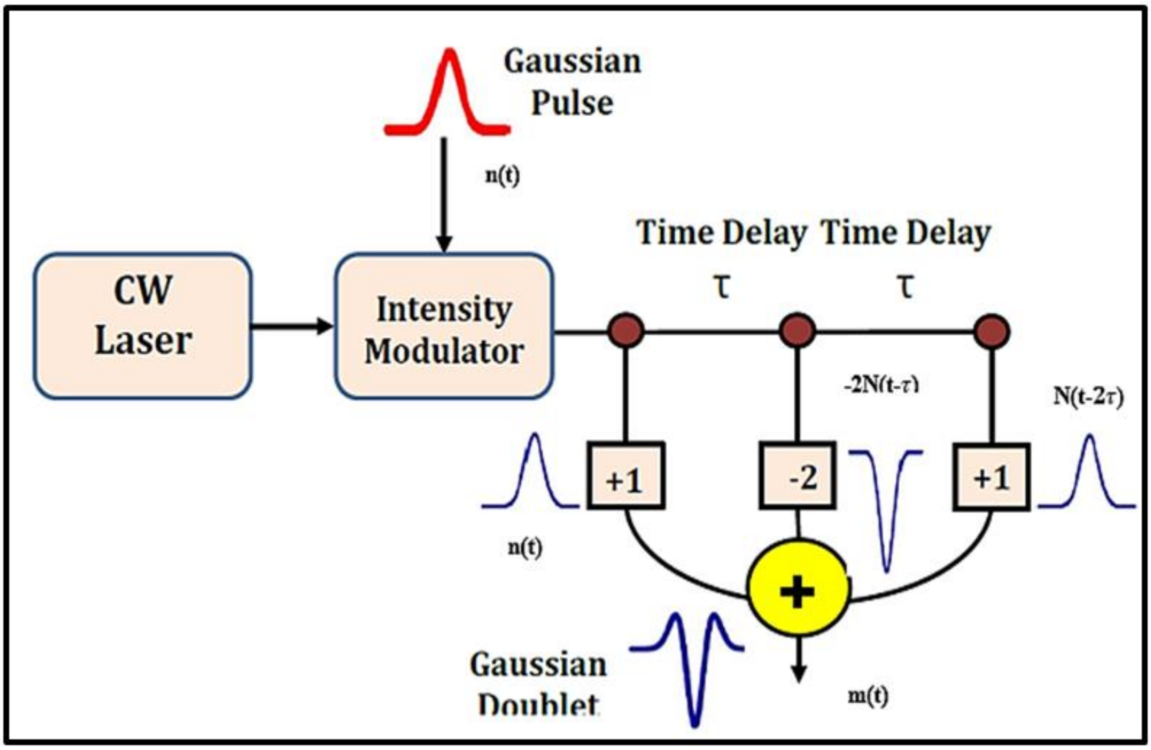


Fig. 3: Generation UWB doublet based on three-tap delay line filter

The frequency response of microwave delay line with three taps is given by

$$|H(f)| = \left|\frac{M(f)}{N(f)}\right| = 1 - 2e^{J2\pi f\tau} + e^{-J2\pi f\tau} \qquad (8)$$

Based on the cross gain modulation (XGM) in semiconductor optical amplifier (SOA), the negative coefficient can be generated as [13, 14].

3- Ultra Wideband (UWB) Over Fiber

One from the main aims of the communication system is to increase the transmission distance. Therefore, there has been increasing interest in transmitting UWB signals over a long distance of existing SMF transmission link. The performance of such transmission that designed to operate at 1550 nm wavelength is degraded mainly by chromatic dispersion that become the major factor that restricts the long distance fiber optic system. To improve installed links of standard single mode fiber, the use of dispersion compensation fiber is an efficient method. Conventional dispersion compensating fibers have a high negative dispersion (-70 to -90) ps/nm.km, therefore, used to compensate the positive value dispersion for the transmission fiber. There are three dispersion compensation schemes according to the relative position of single mode-fiber and DCF that is; (pre-compensation, post-compensation and mix compensation) [15]. In this paper, it assumed that DCF is used at the end of SMF section to compensate it dispersion.

DCF has become a most suitable method of dispersion compensation because are stable, more mature, no easily affected by temperature and wideband width. To compensate the losses, two optical amplifiers of gain G_1 and G_2 can be inserted and can be calculated as [16].

$$G = L.\alpha \qquad (9)$$

Where G the gain measured in dB, L is the length measured in km, and α is the loss measured in dB/km. If suppose the SMF and DCF be characterized by L_{SMF} and L_{DCF} respectively, the condition for perfect dispersion compensation is [17].

$$D_{SMF}.L_{SMF} + D_{DCF}.L_{DCF} = 0 \qquad (10)$$

That means the length of the DCF should be chosen to satisfy [17].

$$L_{DCF} = -\frac{D_{SMF}}{D_{DCF}} . L_{SMF} \qquad (11)$$

As shown in eq. (11), choose the length of DCF is to get a negative dispersion, which is equal in value to the positive dispersion of accumulated in the transmission of SMF, so that the net pulse broadening is close to zero [18]. The parameter values of the optical channel for both SMF and DCF are list in the table (1).

Table (1): parameters of single mode fiber and dispersion compensation fiber.

Parameter	SMF	DCF	Units
Length	Variable	Variable	Km
Attenuation	0.2	0.5	dB/km
Dispersion	17	-85	ps/nm/km
Dispersion slop	0.075	-0.3	$ps/nm^2/k$
PMD coefficient	0.2	0.2	ps/km
Effective	80	22	μm^2

4- Simulation Results

There has been increasing interest in using optical networks to distribute signals of UWB in order to increase the coverage zone. In this work, investigates the transmission performance of UWB signals over existing fiber links and address the possibility of increasing the coverage area beyond 35 km.

4.1 Performance Evaluation of UWB Signal in Electrical Domain

In this subsection, illustrate the transmission performance of UWB signal that generated electrically supported by DCF for perfect Group velocity Dispersion compensation for both Gaussian monocycle and doublet pulse, each operating with OOK with data rate 1.25 Gb/s. The value of BER corresponding to 10^{-9} of that consider for reference objective in this paper.

I. Gaussian Monocycle Pulse

Figure (4) show the variation of BER with transmission length for OOK before and after using DCF.

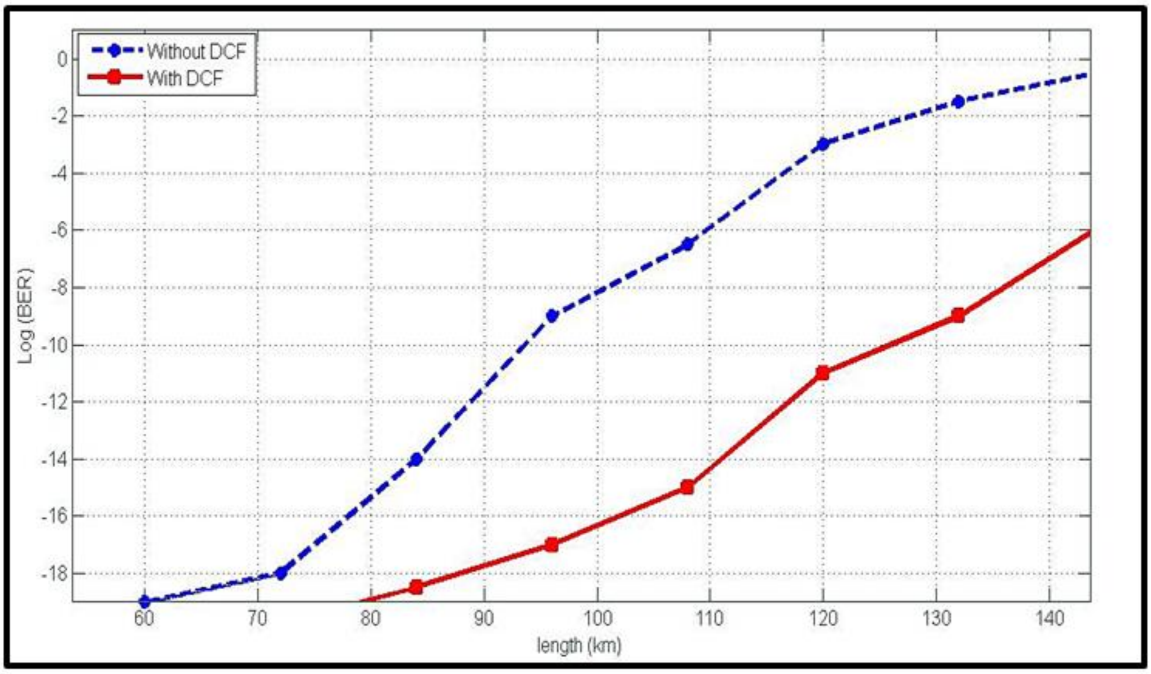


Fig. 4: BER for OOK as a function of fiber length with and without using DCF for monocycle pulse.

It can show that to achieve a BER of 10^{-9}, the transmission length of monocycle pulse without and with using DCF is (96 km) and (132 km), respectively.

Figure (5 a and b) shows the received eye diagram before and after use DCF for OOK modulation. The corresponding power spectrums of the transmitted RF signal after using DCF is shown in figure (5 c).

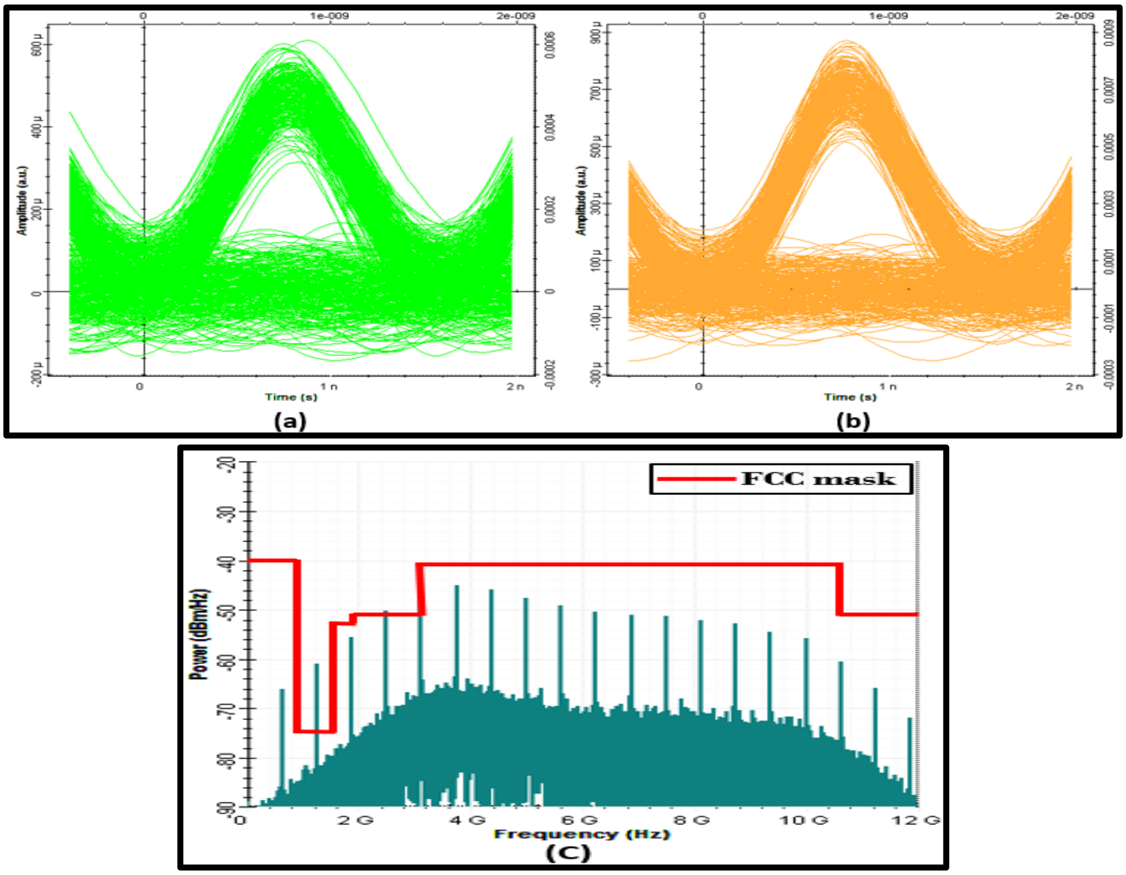


Fig. 5: Received signal characteristics after transmission through SMF over 96 km (a) Eye diagram before using DCF (b) Eye diagram after using DCF (c) RF spectrum of the signal when using DCF.

Two points can conclusion after insert DCF:

1- DCF will improve the eye opening and improve the BER characteristic.
2- The spectrum of the transmitted RF signal when DCF is used satisfy FCC generation.

II. Gaussian Doublet Pulses

Doublet pulse is achieved using the second derivative of the Gaussian signal. Figure (6) show the variation of BER with transmission length for OOK before and after using DCF.

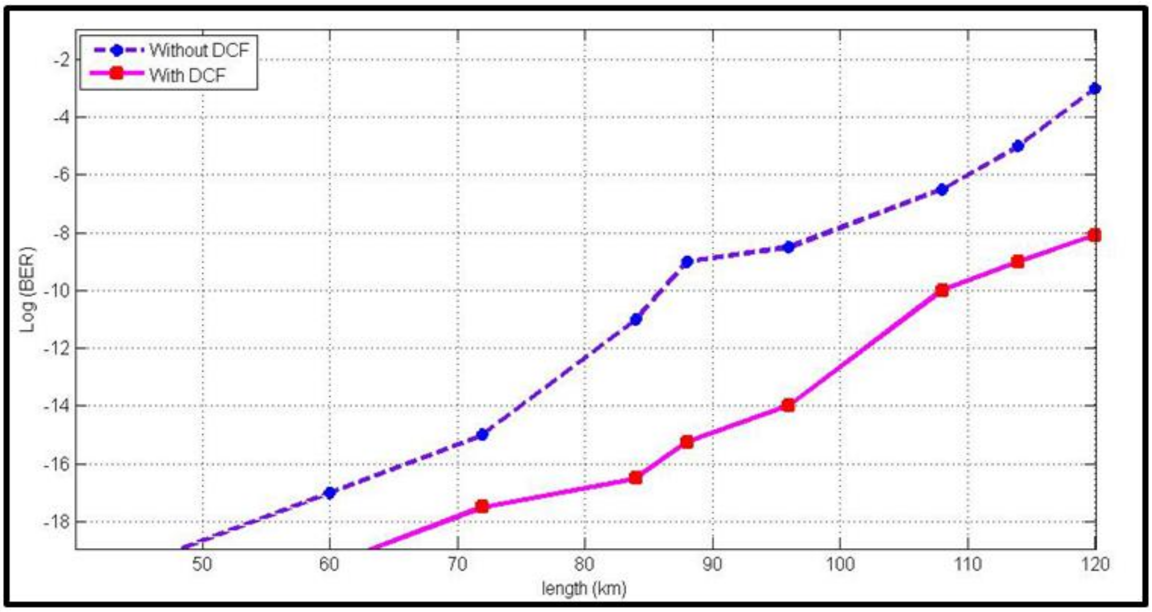


Fig. 6: BER for OOK as a function of fiber length without and with using DCF for doublet pulse.

The length of the fiber is (88) km and (114 km) to achieve BER = 10^{-9}. To show the received eye diagrams before and after using DCF with the power spectrum of the transmitted RF signal, it illustrates in figure (7) for OOK.

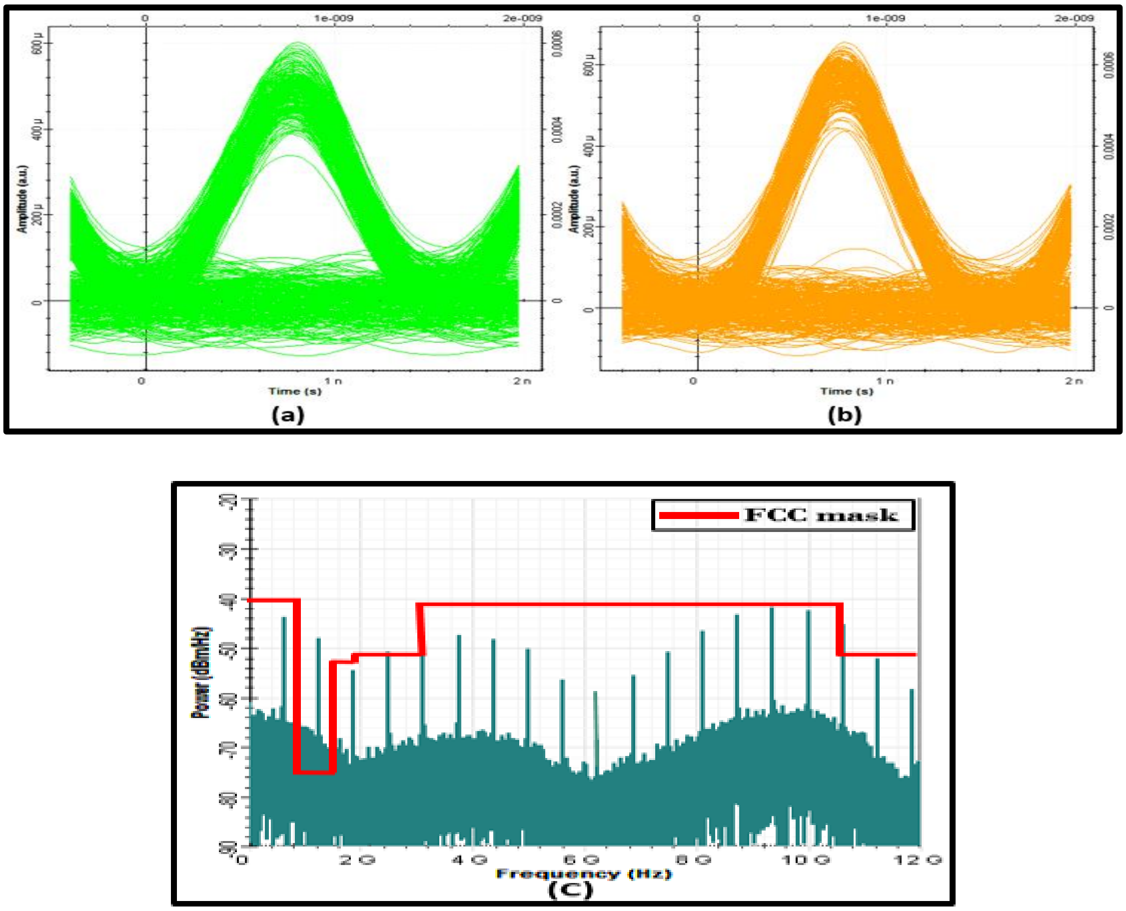


Fig. 7: Received signal characteristics for doublet pulse OOK system after transmission through SMF over 88 km (a) Eye diagram before using DCF (b) Eye diagram after using DCF (c) RF spectrum of the signal when using DCF.

The main conclusion drawn from these figures can be compared with the results of monocycle pulse that is the transmission link of monocycle pulse is longer than in doublet pulse and RF spectrum is more regular than doublet pulse.

Table (2) shows the maximum allowable transmission distance for both monocycle and doublet pulse.

Table (2): Summary of transmission link lengths for OOK modulation format before and after using DCF.

Pulse type	Length=L_{SMF} (km)	Length= L_T (km)
Monocycle	96	132
Doublet	88	114

From the table above, the maximum allowable length in OOK is reduced by 0.91when doublet Gaussian system are used to replace the monocycle system.

4.2 Performance Evaluation of UWB Signal in Optical Domain

In this subsection, the transmission performance of UWB signal generated optically is illustrated. Using OOK modulation, the transmission link contains SMF and DCF for two pulses of Gaussian that is monocycle and doublet with 10 Gb/s data rate.

I. Gaussian Monocycle Pulse

In the first step, transmission the signal of UWB optically through the optical fiber with SMF only, and then compared with the signal through optical fiber contains DCF. Figure (8) show the variation of BER with transmission length for monocycle pulse before and after using DCF.

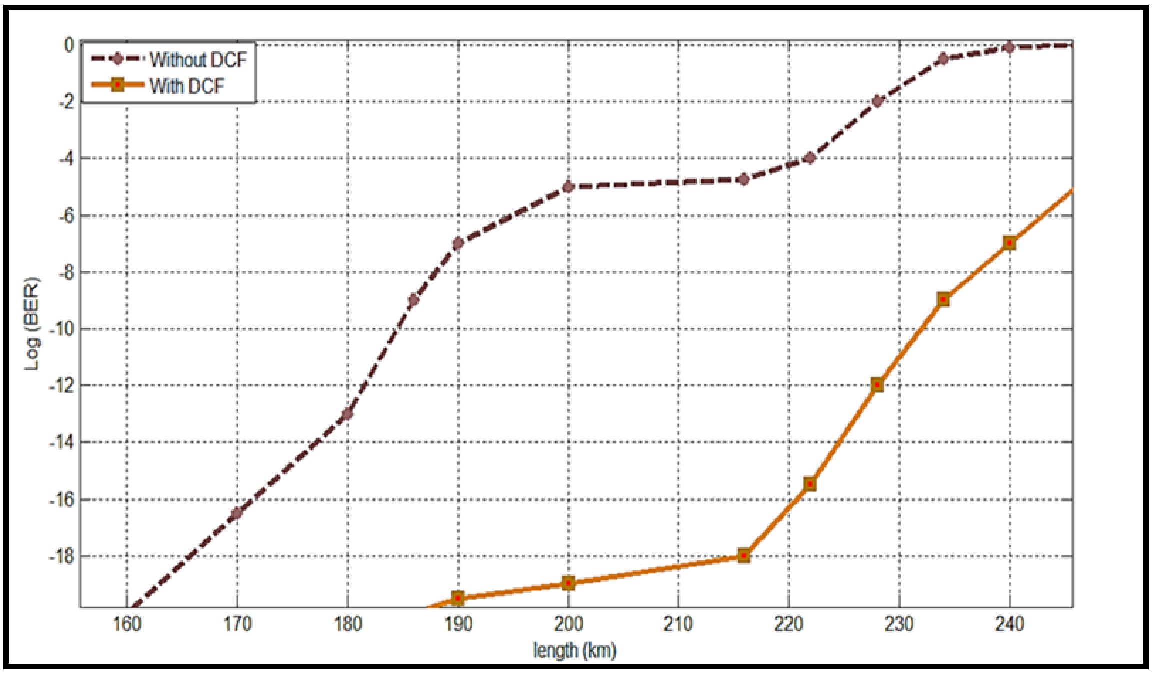


Fig. 8: BER for OOK as a function of fiber length with and without using DCF for monocycle pulse.

As shown in the figure above, the transmission length of monocycle pulse without and with using DCF is (186 km) and (233.1 km), respectively, to achieve BER=10^{-9}. That mean, the DCF improved the transmission link up to 47 km. The received eye diagram before and after using DCF is shown in figure (9 a and b), while the power spectrum of the transmitted UWB signal is shown in figure (9 c).

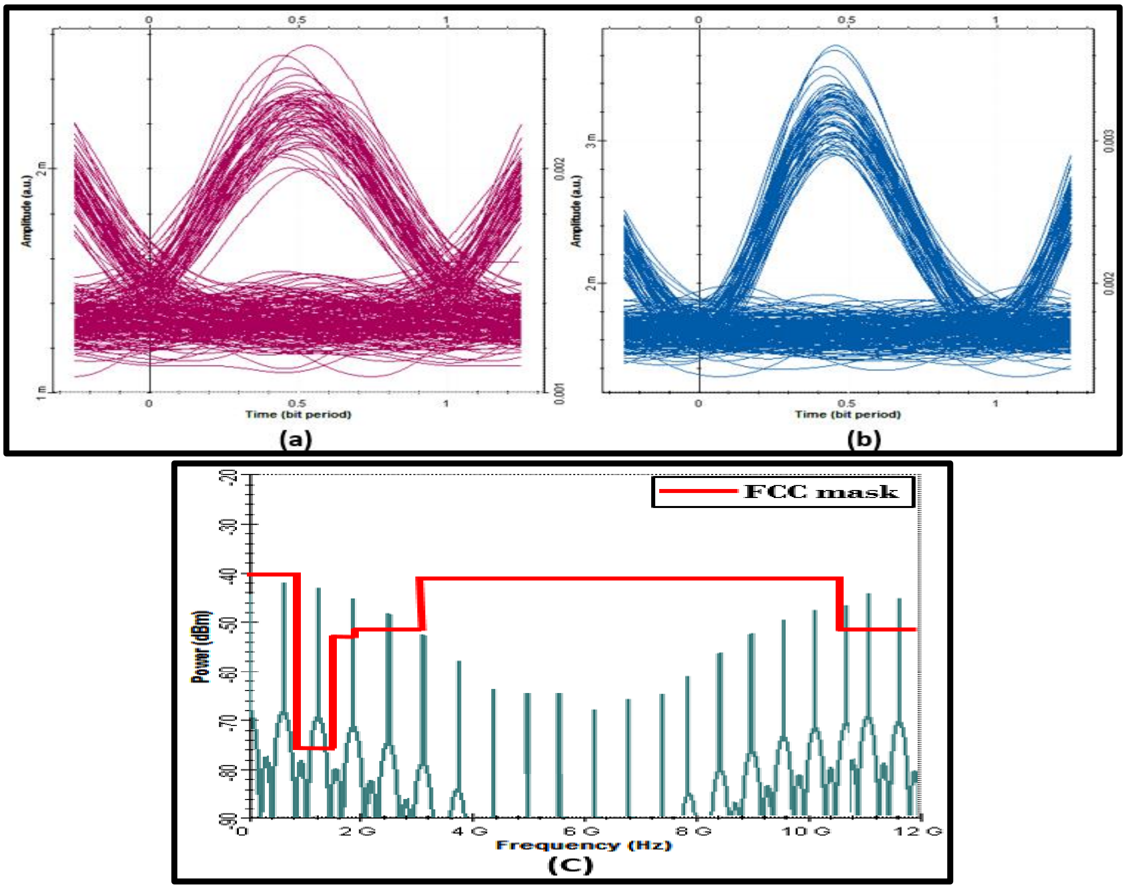


Fig. 9: Received signal characteristics for monocycle pulse OOK system after transmission through SMF over 186 km (a) Eye diagram before using DCF (b) Eye diagram after using DCF (c) RF spectrum of the signal when using DCF.

As shown in figure (9), the DCF is also improving the eye opening and in addition, the spectrum of the transmitted RF signal lies perfectly within FCC mask.

II. Gaussian Doublet Pulses

Figure (10) show the variation of BER for doublet pulse with and without using DCF.

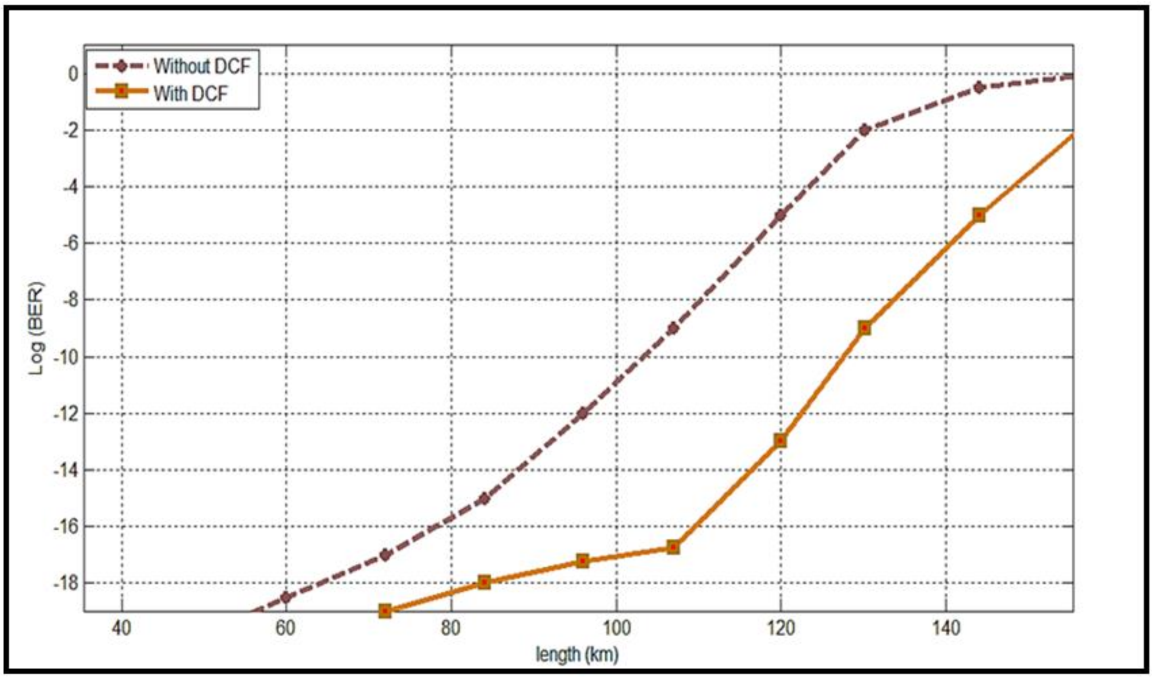
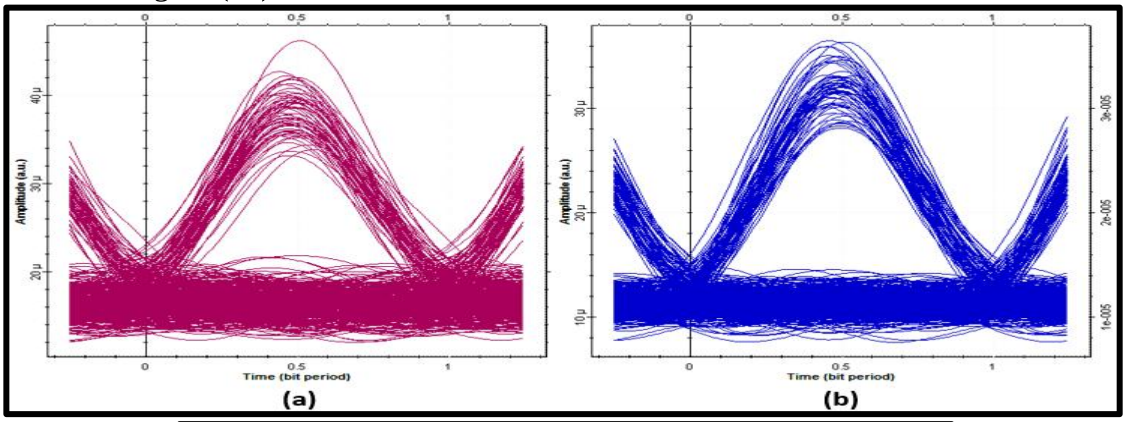


Fig. 10: BER for OOK as a function of fiber length with and without using DCF for doublet pulse.

As shown in the figure above, to achieve BER = 10^{-9}, the transmission length is (107 km) and (130.2 km) without and with using DCF, respectively. The received eye diagram of doublet pulse is demonstrated in figure (11).



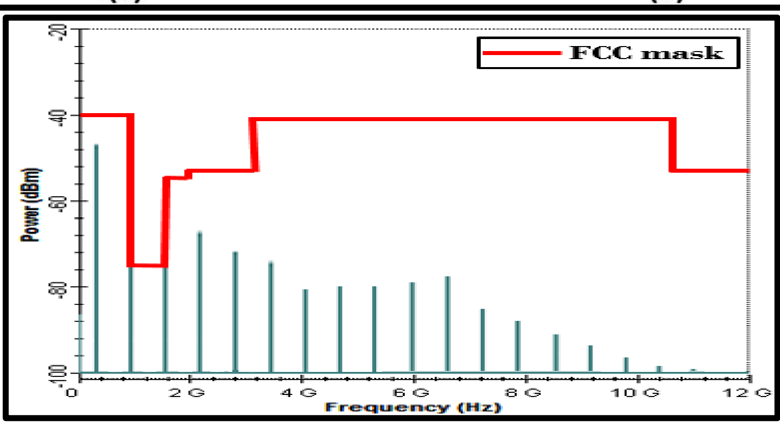


Fig. 11: Received signal characteristics for doublet pulse OOK system after transmission through SMF over 107 km (a) Eye diagram before using DCF (b) Eye diagram after using DCF (c) RF spectrum of the signal when using DCF.

Table (3) illustrate the maximum allowable transmission distance for OOK modulation formats for monocycle and doublet pulse in the electrical and optical domain.

Table (3): Transmission distance with a bit rate for two-generation type for monocycle and doublet pulses.

Generation type	Pulse type	Bit rate Gb/s	Length= L_{SMF}	Length=L_T
Electrical	Monocycle	1.25	96	132
	Doublet		88	114
Optical	Monocycle	10	186	233.1
	Doublet		107	130.2

From the table, it can conclude that the optical generation gives more benefit from electrical signal by increasing the data rate and increasing the distance of optical link.

5- Conclusion

The fiber transmission performance of different UWB signals has been investigated. In this work, using an electrical and optical method of generation UWB signals with OOK modulation format with 1.25 Gbps and 10 Gbps bit rate. In the electrical generation, the Gaussian monocycle system can support longer transmission link as compared with Gaussian doublet pulse. The maximum allowable transmission length is reduced by 0.91 when doublet pulse is used to replace the monocycle pulse. In the optical generation, the transmission link and bit rate are longer and bigger than the electrical domain. The transmission link for monocycle pulse is 96 km with bit rate 1.25 Gb/s in electrical generation, while in the optical generation at bit rate 10 Gb/s, the transmission link reach to 186 km to achieve BER=10^{-9} in both cases of generation without using dispersion compensation fiber.

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