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Transmission (2Gbps) over optical fiber cable by using radio over fiber and wavelength division multiplexing techniques

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ABSTRACT

In recent years, there has been a growing and continuous demand for great (data rates) beyond existing wired and wireless networks. Radio-over-Fiber technology is considered as an efficient and practical solution for providing broadband wireless. In this paper, many techniques are used to implement a system that has the capability to provide a great bit rate, broadband bandwidth, and minimum cost. So Radio-over-Fiber technology was used to modulate the light with radio-signal and transmission the signals through an optical fiber cable. Wavelength-Division-Multiplexing technique was used to send many signals through the same link, and Subcarrier Multiplexing-Amplitude Shift keying as a modulation format. 2Gbps separate on two channels was transmitted on Single-Mode Fiber. The average results obtained from our experience was as follows: maximum Q factor average = 4.9712925, minimum BER average = 3.63×10^{-7} , total power average (dBm) = -51.1502, the OSNR average (dB) = 52.085 for channel_1. The results of channel_2 were: maximum Q factor average = 5.5901325, minimum BER average = 1.26×10^{-8} , total power average (dBm) = -46.60135, the average of optical signal-to-noise ratio (dB) = 54.65. All the average result that has from our simulation was very good and acceptable. The simulation and performance test of our experience was done using Optisystem 7.0.

I. Introduction

Optical communication is a style of communication that uses the light as a transmission medium. The radio frequency (RF) spectrum is crowded, and the providing of broadband services in new bands has become increasingly difficult. (RoF) is a representative optical link for the transmission of information via optical fibers by sending (RF) signals from and to the central station to the base station [1]. Nowadays, due to the different requirements of users of the system, the data capacity of wireless communication has been completely widened from simple sounds and messages to multimedia with evolutionary future services. RoF technique can be the solution to many of the urgent needs of telecommunication networks, as they can provide the bandwidth required for the transfer of broadband data to end users, and other advantages are low attenuation loss and immunity to radio-frequency-interference [2, 3]. In the RoF system, most signals processing processes ('including encryption', 'multiplexing' and 'RF' generation and modulation) is performed by the

central-office (CO), making the base-station (BS) cost-effective. Therefore, RoF will become a key and important technology in the next and future generation of mobile communications system [4].

The goal of this work is to enhance the performance of RoF technology. our work is going to design and test of RoF based on continues wave laser (CW) as a light source with WDM technique to exploit the existing optical fiber link via sending many signals on the same link. Also, the broadband system will be increased by overcoming on many problems that directly effect on the efficiency of system performance, like nonlinear problems and to do the system flexible via using a few components.

Many researchers were studied RoF and WDM like Peter and Renè [5] have been studied formats of the advanced optical modulation that have become a key component for the recent wavelength-division-multiplexing design WDM which is optically transported the networks. The researchers R. Avo and et.al. [6] have been studied millimeter-wave (mm-

wave) systems and networks operating in the 60 GHz region, they considered the optical transmission limitations of digitally modulated 60 GHz carriers, and considering different optical modulation techniques. The authors S. Revathi and G. Aarthi, [7] have been increased performance of the optical fiber transmission systems by employing systems of the multi-channel optic that has a large bandwidth possible in the fiber optics. The high-speed signals have been relating with many sequences of the low-speed signals. Today, many limited individual applications are utilizing the high bandwidth. These lower-speed channels have been multiplexing together with the higher-speed channels. There are multiple procedures such as the WDM, subcarrier multiplexing SCM that has been developing for increasing the transmission systems performance. Also, the authors Varghese and et. al., [8] have been provided a simple review of RoF algorithm. In addition, they are discussed in detail the designing of the RoF approaches to enhance the performance of the negotiable systems. They conclude that the costs of RoF system installations are reduced by decreasing the number of the RoF methods. The authors Simarpreet and et. al.,[9] have been described the Wireless network procedures that are associated with the Radio over Fiber technology. The previous technology is offered suitable methods to decrease the cost of growing user bandwidth and wireless. They have been applied it on mobile cellular that represented the high-performance system.

II. Methodology

In this section, some techniques that used to design our system like are being presented like WDM, and RoF.

2.1 Wavelength-Division-Multiplexing

Wavelength-Division-Multiplexing (WDM) is a passive device that combines light signals of various wavelengths, coming from various fibers, onto one fiber. These include DWDM Dense-Wavelength-Division-Multiplexers (DWDM) devices, which use optical (analog) multiplexing techniques to growing the fiber network capacity beyond the levels achievable through Time-Division-Multiplexing (TDM). The use of WDM for the distribution of RoF signals as shown in Fig-1 has recently gained importance. WDM can effectively exploit the bandwidth of the fiber network. These systems could realize capacities more than (1TB / s) on one fiber. At the same time, single-channel bit rates have increased to (10Gb/s) and systems that operate on (40 Gigabit/s) are commercially available. The Channel

spacing in WDM can be reduced to (50GHz) or even (25GHz), so hundreds of channels can be used. However, if channel spacing has been dropped to (50GHz) instead of (100GHz), it will be very difficult to upgrade systems to operate at (40Gb/s) due to (nonlinear effects), [10]. The WDM technique is shown in Fig (1).

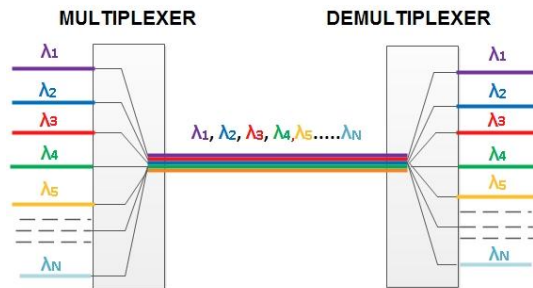


Fig (1): Wavelength-Division-Multiplexing (WDM) technique

2.2 Radio-over-fiber technology

RoF has been referring for a technology which is using light for modulate electrical-signal (radio-signal) and transmitting it through optical-fiber link for distributing radio signals from central location (Headend) to remote-antenna-unit (RAU) [11]. RoF is considered an integration of wireless and fiber-optic networks, is a key technology for providing unmetered access to broadband wireless communications in a range of applications counting the last mile solutions, extension of current wireless coverage and capacity [12]. RoF is typically used for wireless access. RoF networks operate primarily in the (mm-wave) bands, which require additional attenuation, particularly around (193.1THz) because the transmission range is restricted via oxygen absorbing in external environments. Compared with microwave bands like (2.4 or 5 GHz), that which require different (BSs) according to support a wide service area, the (mm-wave) band needs to (small cells). Networks that work with a large number of small cells have to deal with issues of cost-effectiveness and mobility management [13]. RoF offers many benefits, such as huge bandwidth and less attenuation [13].

III. System design

In our system design, the experiment has been proposed for RoF architecture based on the subcarrier of ASK and WDM. Table 1 shows the most important components to design our system.

Table (1): The most important components in proposal architecture

Transmitter Side Components			
No	Components	Values	Cause of use
1	Wave generator	Frequencies (10-50) GHz	Used for generate radio signals
2	Carrier Modulator	Frequencies= (50-100) GHz	Used for generate carrier signals
3	Continuous Wave	Frequency=(193.1 and 193.2) THz	Used for generate optical signal
4	Pseudo-Random Binary Sequence Generator	Bit Rate=1 GHz	Used for generate series of random bits
5	Electrical Amplitude Modulator	Frequency=1.7 GHz	Used for modulate electrical signal
6	Erbium doped fiber amplifier (EDFA)	Power=10 dBm, Noise figure=5 dB	Used for amplifying the signals
Transmission Link Components			
No	Components	Values	Cause of use
1	Multiplexer (WDM)	Depth=100 dB	Used to send tow signal over single fiber cable
2	Optical filter	Length=50 Km	Used for transmit the signal
3	Demultiplexer (WDM)	Depth=100 dB	Used to separate the single signal to two signals
Receiver Side Components			
No	Components	Values	Cause of use
1	Photodetector	Sample rate=1.6*10 ¹¹ Hz	Used to convert the optical signal to electrical signal
2	3R Generator	Bit Rate=1 GHz	Used for reshape and regenerate the signals
3	Monitors (BER) analyzer	Used for monitor the output signals	

The system consists of many devices that influence and influenced by the network behaviors. The main layout comprise from three main parts (*i.* optical transmitter, *ii.* optical transmission link, and *iii.* optical receiver). The first one is begin with continues wave (CW) laser with frequency of (193.1THz) to generate an optical signal with power of (6dBm) as showing in Equation (1).

The sine generator used to generate the electrical signal with four frequencies (10, 19, 31, and 50GHz). The carrier generator produces four carriers (50, 54, 60, and 70GHz). These values are optimized as RF Table (2), and the mathematical model shown in Equations (2 and 3). The series of random bits are generated by the Pseudo-Random Binary Sequence Generator (PRBSG), the electrical pulse signal as modulation formats coding obtains from Non-return-to-zero (NRZ) components, to modulate them in other techniques. The amplitude modulator (AM) is used for modulating the electrical signal as Equation (4), then the output from AM are added to the carrier signals by the electrical adder. The output from this component goes to the 90-degree hybrid coupler for coupling the RF signal generated by the sine generator. The output of the hybrid coupler take two output signals then goes to the input MZ modulator to modulate them with an optical signal that will be ready to launched to optical fiber showing in Fig (2). The second transmitter consists of the same components except changing values like this (CW₂ with 193.2THz, and power (6dBm), the carrier₂ generator with the frequencies (72, 76, 87, and

100GHz) illustrated in Fig (3). The outputs of these two channels connected to two (erbium-doped fiber amplifier (EDFA) with power=10dBm, and NF=5dB). The outputs of amplifiers go to the (WDM (2×1) with its properties (bandwidth=10GHz, depth=100dB, filter type of Bessel, and filter order equal to 2). Then the output of this components launched to the part two of the system SSMF with 50Km. The mathematical system of the signal behavior is shown in the Schrödinger Equation (5) and illustrated in Fig (4).

The third part of the system is the optical receiver that is consist of PIN photodiode, the fork, bandpass filter, electrical amplifier (Gain=15dB), AM demodulator to give us the output signal, 3R regenerator to reshape signal, and the BER analyzer to monitor the output signals as showing in Fig (5 and 6).

The bitrate of the main layout is (1Gbps), the time window is (1.28*10⁻⁷ s), the sample rate is (32 GHz), sequence length (128Bits), sample per bit (32), finally, the number of samples is (4096).

$$f(\Delta\varphi) = \frac{1}{2\pi\sqrt{\Delta f dt}} \cdot e^{-\frac{\Delta\varphi^2}{4\pi\Delta f dt}} \dots(1)$$

Equation (1) is known as CW Laser, [14].

Where $\Delta\varphi$ is the phase difference between two successive time instants, dt is the time discretization. A Gaussian random variable for the phase difference between two successive time instants with zero mean and a variance equal to $2\pi\sqrt{\Delta f}$ has been assumed, Δf as the laser Linewidth.

$$v_{out} = \sum_{i=1}^N v_i(t) + v_{bias} \dots(2)$$

$$v_i = A \sin(2\pi f_i + \phi_i) \dots(3)$$

Equations (2) and (3) are known as Carrier Generator, [14].

Where v_i is the signal for each carrier, N is the parameter Number of channels, v_{bias} is the parameter Bias and f_i is the frequency of each carrier.

$$v_{out}(t) = Gv_{in}(t) \cos(2\pi f_c t + \phi_c) + b \dots (4)$$

Equation (4) is known as Amplitude Modulator (AM), [14].

Where v_{in} is the input electrical signal, G is the parameter gain, b is the bias, f_c is the carrier frequency, ϕ_c is the phase of the carrier.

$$\frac{\partial E}{\partial z} + \alpha E + i\beta_2(w_0) \frac{\partial^2 E}{\partial T^2} - \frac{\beta_3(w_0)}{6} \frac{\partial^3 E}{\partial T^3} = i\gamma (|E|^2 E + \frac{i}{w_0} \frac{\partial}{\partial T} (|E|^2 E) - \rho_{R1} E \frac{\partial |E|^2}{\partial T}) \dots (5)$$

Equation (5) is known as Nonlinear Schrödinger (NLS), [14].

Where $E = E(z, T)$, is the electric field envelope. A frame moving at the group velocity ($T = t - \frac{z}{v_g} \equiv t - \beta_1 z$) is assumed, β_2 and β_3 are the first and the second group velocity dispersion (GVD) parameters, respectively, w_0 is the reference frequency of the signal related to the parameter "Reference wavelength" ("Main" category of the components tool-box) through $w_0 = \frac{2\pi c}{\lambda_0}$ with c being the light speed in vacuum.

Table (2): Optimization parameters values

	Sine Generator_1	Carrier Generator_1	Sine Generator_1	Carrier Generator_2
Sweeps	Frequency(GHz)	Frequency(MHz)	Frequency(GHz)	Frequency(MHz)
1	10.00000012448	50.00000006224	10.00000012448	72.00000008713
2	19.46469948953	54.73234974477	19.46469948953	78.62528964267
3	31.88670306118	60.94335153058	31.88670306118	87.32069214281
4	50	70	50	100

In this experiment, as shown in the Table (2), Optimized the Sine Generator and Carrier Generator. For the first channel, Optimize the Sine Generator from (10 to 50) and the Carrier Generator from (50 to

70) are done. While for the second channel the values of the Sine Generator are same as the first channel, but the Carrier Generator values are between (72 to 100).

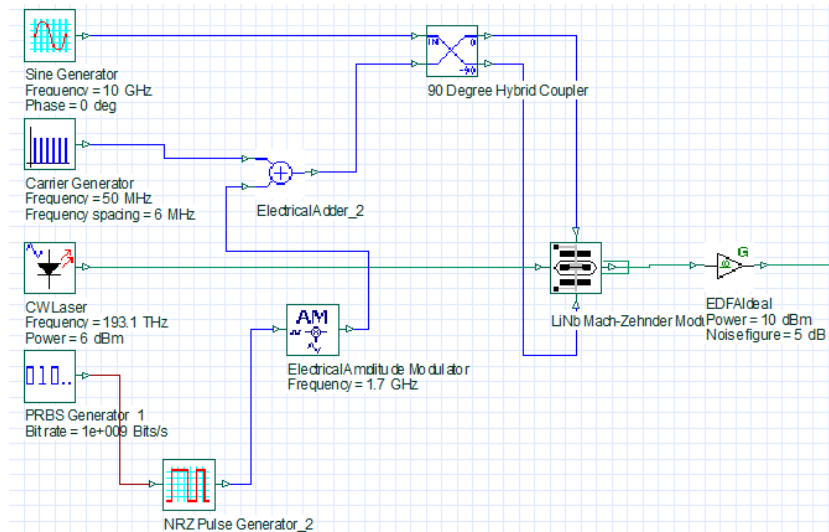


Fig (2): Transmitter_1 with its components

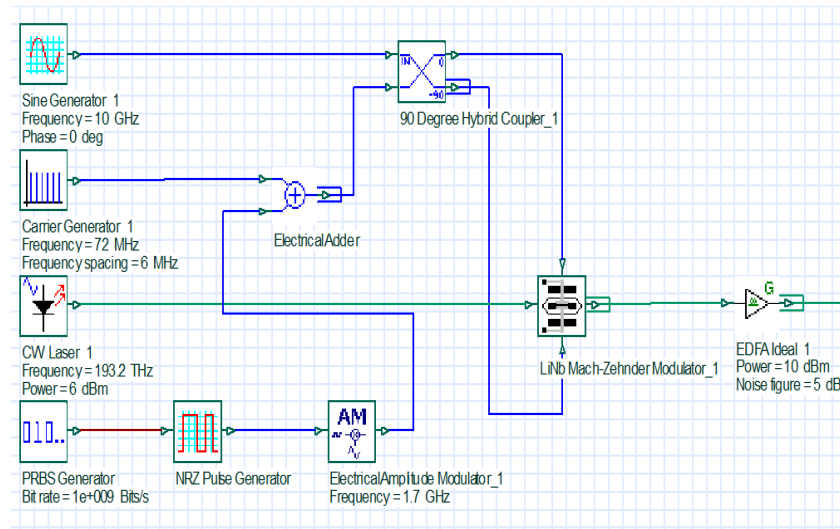


Fig (3): Transmitter_2 with its components

From previous Fig (2 and 3) shown the component parameters of the two channels. The first one begins with Continuous Wave (CW) laser with a frequency of (193.1THz) to generate an optical signal with power of (6dBm), the sine generator used to generate the electrical signal with four frequencies (10, 19, 31, and 50GHz). The carrier generator produces four carriers (50, 54, 60, and 70GHz). The series of random bits are generated by the Pseudo-Random Binary Sequence Generator (PRBSG), the electrical pulse signal as modulation formats coding obtains from Non-Return to Zero (NRZ) components, to modulate them in other techniques. The amplitude modulator (AM) is used for modulating the electrical

signal, then the output from AM are added to the carrier signals by the electrical adder. The output from this component goes to the 90-degree hybrid coupler for coupling with the RF signal generated by the sine generator. The output of the hybrid coupler take two output signals then goes to the input Mach Zehnder (MZ) modulator to modulate them with an optical signal that will be ready to launch to an optical fiber. The second transmitter consists of the same components except changing values like this (CW_2 with 193.2THz, power (6dBm), and the Values of carrier_2 generator are (72, 76, 87, and 100GHz).

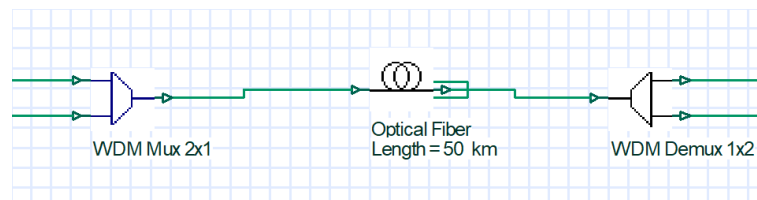


Fig (4): transmission link with WDM

Fig (4) as seen above, it is considered as a connector part between transmitter and receiver. The outputs from the two transmitter channels connected to two EDFA. and after that reach to the first part in the transmission link, it is (WDM), this component has 2

input with 1 output. Then the output of this components launched to the part two of the system SSMF with 50Km. finally, by third part the signal will be separated via the demultiplexer WDM (1x2).

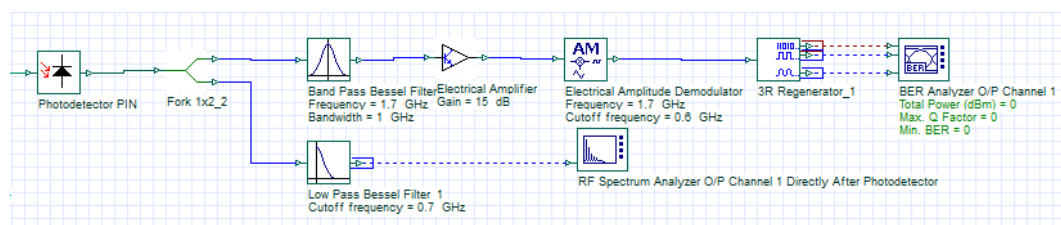


Fig (5): Optical receiver for channel_1.

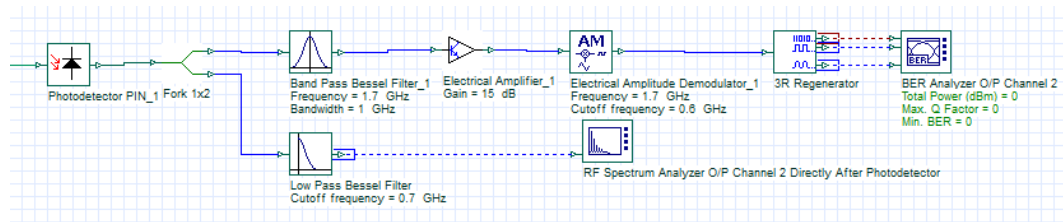


Fig (6): Optical receiver for channel_2.

The two previous Fig (5 and 6) are considered as a third part of the system, they are the optical receivers, our system consist on two optical receivers, both of them having the same components. Each optical receiver consists from PIN photodiode, the fork, bandpass filter, electrical amplifier, AM demodulator to give us the output signal, 3R regenerator to reshape signal, and the BER analyzer to monitor the output signals.

IV. Experiment Results

Here, will show The results that obtained depending on the software simulation which is used in many iterations and optimizations. In this experiment, there are some techniques and approaches are used and entries in the software simulation by using different parameters and components. Some of these are Sine generator and carrier generator, Pseudo-Random Binary Sequence Generator (PRBSG), amplitude modulation, continues wave leaser. The results in the output explained in Fig from fig (7) to Fig (11), and all the values that get in from our simulation are shown in Table (3).

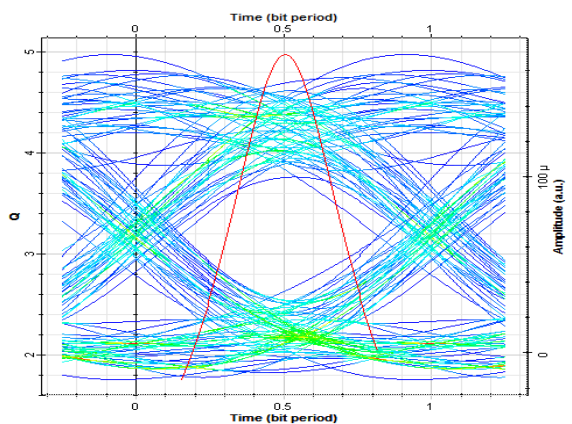


Fig (7): demonstrates the Q-Factor vs. Time vs. Amplitude for the output of channel_1@50Km of SSMF, 1x2GHz of Bandwidth, 2-WDM.

The good eye opening shows in Fig 7 for a data rate of 1 Gb/s over optical fiber length equal 50km, the received signals at the received side for the first channel is well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), The bit time refers to ellipse time to one bit to be out from the network, while the amplitude measures the change over the single carrier, and the Q indicates the value Q-factor the high peak in the red color curve show the Q-Factor at this iteration.

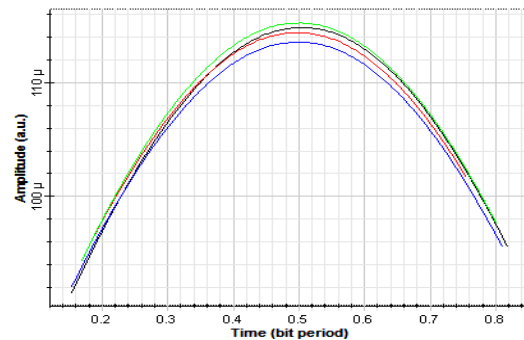


Fig (8): showing the eye amplitude vs. Time for four iterations at the optical receiver side @50Km of SSMF, 1x2GHz of Bandwidth, 2-WDM.

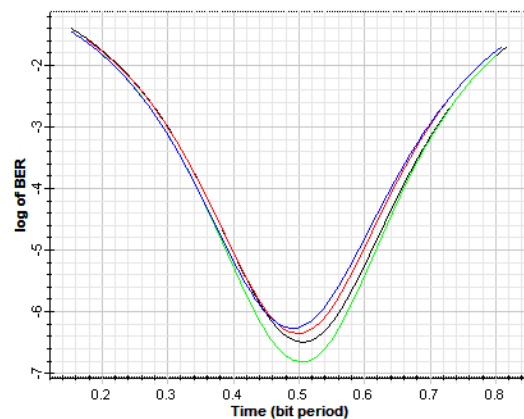


Fig (9): Show the log of BER and time of four iterations at the optical receiver side @50Km of SSMF, 1x2GHz of Bandwidth, 2-WDM.

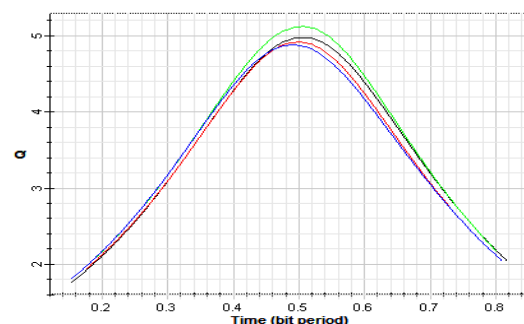


Fig (10): Illustrates the Q-Factors and time of all four iterations @50Km of SSMF, 1x2GHz of Bandwidth, 2-WDM.

The last three Fig (8-10) are shows the all iterations at the same figure, each iteration has a different color. In Fig (8) as shown on the eye Amplitude versus time for all iterations, for the second figure the log of BER

versus Time is showing for all iterations. While at last figure the Q-factor is clear for all of the iterations.

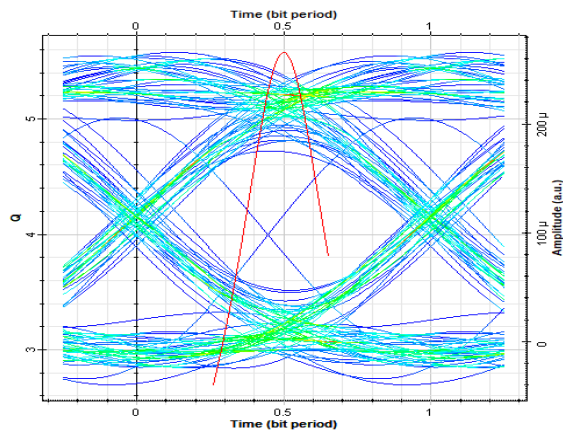


Fig (11): showing the Q-Factor vs. Time for the output channel (193.2THz), at 50Km of SSF, 1×2GHz of Bandwidth, 2-WDM.

Table (3): Summarize Results Obtain from the subcarrier multiplexing – RoF Systems

Iteration	Total Output Power (dBm) Channel_1	Total Output Power (dBm) Channel_2	Max Q-Factor Channel_1	Max Q-Factor Channel_2	Minimum BER Channel_1	Minimum BER Channel_2	OSNR (dB) Channel_1	OSNR (dB) Channel_2
1	-51.1273	-46.591	4.97632	5.57697	3.20E-07	1.21E-08	52.07	54.64
2	-51.1568	-46.6225	4.91348	5.73472	4.43E-07	4.81E-09	52.08	54.64
3	-51.1437	-46.5923	5.11961	5.49297	1.51E-07	1.97E-08	52.11	54.68
4	-51.173	-46.5996	4.87576	5.55587	5.40E-07	1.36E-08	52.08	54.64
AVERAGE	-51.1502	-46.60135	4.9712925	5.5901325	3.63E-07	1.26E-08	52.085	54.65

From the Fig from (7) through (11), the RoF system is consisting of the subcarrier with NRZ modulation format, 1×2Gb/s, 50Km SSF, and 2-WDM. The following results will be gotten: the OSNR average of the first channel at all iterations (52.085dB), the OSNR average of the second channel at all iterations (54.65dB), the average of total power in the output at first and second channels are (-51.1502dBm) and (-46.60135dBm) respectively, the maximum average of Q-factor at the first and the second channels are (4.9712925) and (5.5901325) respectively, the minimum average of the BER at first channel is (3.63×10^{-7}) and minimum average of the BER at second channel is (1.26×10^{-8}). At the receiver side, the outputs are very acceptable compared with the works of the many pieces of research because of selecting convince parameters, little components, and doing different optimizations for the generators of sine and carrier signals to get the optimum result.

Table (4): The Comparison between previous works and our work

Works	Modulation type	Bandwidth (bitrate)	BER	References
Previous work	OCS	1 Gbps	10^{-2}	[6]
Our work	SCM	2 Gbps	10^{-7}	Our Results

Table (4) shows the comparison between the previous researcher works and our work as see above, our result shows an attractive result compared with other researchers, this is due to selecting good components (active/passive) and good values and properties for parameters, also use multiple users by WDM without

The good eye opening shows in Fig 11 when the data rate equal 1 Gb/s over optical fiber length equal 50km, the received signals at the received side for second channel is well and demonstrate there are no ISI, and no crosstalk. The x-axis shows the values of the bit period (the intervals between transmitted bit), The bit time refers to ellipse time to one bit to be out from the network, while the amplitude measures the change over the single carrier, and the Q indicates the value Q-factor the high peak in the red color curve show the Q-Factor at this iteration.

need to changing the exiting the infrastructure (transmission link).

The Bit Error Rate (BER) is an indicator is affected by the bandwidth. The increasing or decreasing is influenced by the components used in the design and vary from design to another. In our design the BER was very acceptable according to the components and bandwidth that was used.

V. Conclusion

Nowadays, RoF communication system has drawn much attention. The architecture of RoF has various components (active component and passive component). The optimization on sine generator and carrier generator also were be done by using the simulation of the Optisystem application which is provided by the Canadian company. In this paper, the architecture that offers a good BER with few components are provided, that will increase the reliability of the system and reduce the operational expenditure. So a RoF system have been proposed based on Subcarrier Multiplexer- amplitude shift keying with WDM on standard single mode fiber (SSMF). In this work, the oscilloscope and bit error rate (BER) analyzer are used to monitor the behavior of the signal. The experience works divided into two stages (the first and second signals), send (1Gbps) over each signal are be done, so the cumulative bandwidth is (2Gbps) over single fiber. In the first signal, the result was as the following: total power average was (-51.1502dBm), maximum Q factor average was (4.9712925), minimum BER average was (3.63×10^{-7}), and the OSNR average was

(52.085dB). In the second signal, the result was as the following: total power average of the output was (-46.60135dBm), maximum Q factor average was (5.5901325), minimum BER average was (1.26×10^{-7}), and the OSNR average was (54.65dB). There is some Intersymbol interference ISI appears in the previous architecture because of the nonlinearities properties in

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the fiber phenomena and the second reason is the distance of the fiber span is very long.

All the average values are good and acceptable, was obtained on it according to using an attractive component and there is compatibility between all components. The simulation and performance test of RoF was done using Optisystem 7.0.

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إرسال (2Gbps) عبر كابل الألياف الضوئية باستخدام تقنيات الراديو عبر الألياف ومضاعفة تقسيم الطول الموجي

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الملخص

في السنوات الأخيرة، كان هناك طلب متزايد ومستمر لمعدلات بيانات كبيرة تتجاوز الشبكات السلكية واللاسلكية القائمة. تعتبر تقنية الراديو عبر الألياف حلاً فعالاً وعملياً لتوفير اتصال لاسلكي واسع النطاق. في هذه الورقة، يتم استخدام العديد من التقنيات لتنفيذ نظام لديه القدرة على توفير معدل بت كبير، وعرض نطاق عريض النطاق، وبأقل تكلفة. تم استخدام تقنية لتعديل الضوء مع الإشارة اللاسلكية ونقل الإشارات عبر كابل الألياف الضوئية. كما استخدمت تقنية مضاعفة تقسيم الطول الموجي لإرسال العديد من الإشارات عبر نفس الوصلة، تعدد الإرسال الفرعي - تضمين إزاحة السعة استخدم كنسق تشكيل. تم نقل (2Gpbs) منفصلة على قناتين عبر الألياف أحادية النمط. كان متوسط النتائج التي تم الحصول عليها من تجربتنا كما يلي: كان متوسط إجمالي الطاقة الخارجة -51.1502 (dBm)، وكان الحد الأقصى لمتوسط عامل الجودة 4.9712925، وكان متوسط BER الأدنى (3.63×10^{-7})، وكان متوسط OSNR 52.085 (dB). في الإشارة الثانية، كانت النتيجة كما يلي: كان متوسط إجمالي الطاقة الخارجة -46.60135 (dBm)، والحد الأقصى لمتوسط عامل الجودة 5.5901325، وكان متوسط BER الأدنى (1.26×10^{-8})، ومتوسط OSNR كان 54.65 (dB). كل النتائج المتوسطة التي حصلنا عليها من المحاكاة جيدة جدًا ومقبولة. تم إجراء اختبار المحاكاة والأداء على تجربتنا باستخدام برنامج Optisystem 7.0.