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Research Article

Performance Evaluation of RoF System by using SAMZM and DAMZM in External Modulation

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Abstract

Radio over Fiber (RoF) system is defined as the technique to modulate the light by the Radio Frequency (RF)Signal and to transmit it over the optical fiber. But, RoF system becomes unfeasible if there is no way to deal with dispersion and nonlinear effects predominantly available in optical communication system. The use of Mach-Zehnder External Modulator, either Single Arm Mach-Zehnder Modulator (SAMZM) or Dual Arm Mach-Zehnder Modulator (DAMZM) is one of the solutions to efficiently design RoF system. This work focuses on the simulation comparison of external modulation using SAMZM and DAMZM in RoF system. After modulation, the signal is transmitted through the Standard Single Mode Fiber (SSMF) without dispersion compensation. The Erbium Doped Fiber Amplifier (EDFA) has been used to compensate the inline losses. The system performance is evaluated in terms of Bit Error Rate (BER), Q-Factor and Eye Diagram. The optical systems have been designed using Optsim, which is one of the most powerful optical simulation tools. The graphs have been plotted using Matlab software. All the reported results up to the distance of 50 km have shown that the RoF system using SAMZM is excellent as compared to the system using DAMZM.

Keywords:*RoF system, External modulation, SAMZM, DAMZM, EDFA, Eye Diagram, BER and Q-Factor.*

1. Introduction

Nowadays, RoF system has attracted much attention due to its advantages such as immunity to radio interference, security, high bandwidth (Green R.J., 2007), flexibility and low attenuation characteristics (El-Sayed A. El-Badawyl*et al*, 2011) as compared to traditional RF communication system. Thus, the signal can be transmitted with negligible attenuation as compared to other systems like wireless systems. In this way, it is of great importance to transmit the RF signal over the optical fiber, i.e., RoF system, in order to exploit the advantages of the fiber stated above. The transmission of RF signal over Fiber is known as RoF system.

With the increase in spectrum demand for mobile wireless networks, RoF system comes as a flexible and cost-effective choice (Wake D *et al*, 2010; Ajay Kumar Vyas *et al*, 2012;Yan Cui et al, 2012) since it allows to the microwave signal to utilize the huge bandwidth of the optical fiber by minimizing the degradation to the wireless range (Wake, D.*et al*, 2010). Hence, the signal fading frequently encountered in wireless communication due to three basic mechanisms of propagation (reflection, diffraction and scattering) can be counteracted at an appreciable level (Theodore S. Rappaport, 2010). Moreover, the communication security is increased with the RoF system as comparedto conventional wireless communication system since the optical fiber cannot be easily tapped. The RoF system is depicted in figure 1.

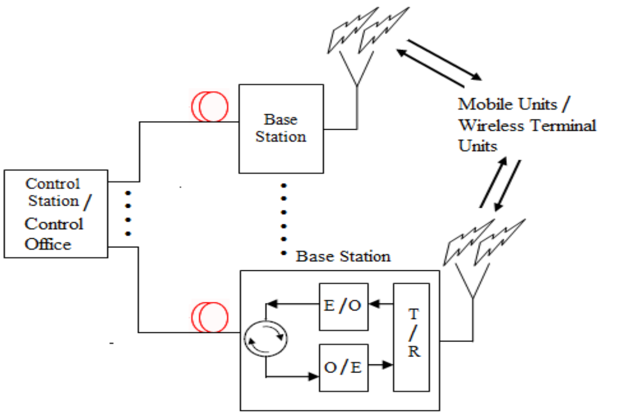

Figure 1: General RoF system

In RoF system, the signal is generated at the Central Office (CO), also called Control Station (CS), which is responsible of all switching activities. Likewise, the modulation processes as well as signal processing take place at the CO/CS in order to form the baseband signal suitable for transmission. Thereafter, the RF signal is transmitted over the fiber which is the backhaul of the wireless network connecting the CO/CS and the wireless front-end (Shaddad, R.Q.*et al*, 2013). The signal is transmitted with negligible attenuation (commonly known as signal fading in wireless communication). The low

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attenuation transmission is achieved by using the fiber with attenuation of 0.2 dB/km at the operating wavelength of 1550 nm. Fortunately, the commercial fibers offering this low attenuation are available in the market. The typical example is the corning SSMF which is one of the most deployed fibers. After transmission through the optical fiber, the signal is detected at the Base Station Unit (BSU) which comprises the optical detector as well as the filter in order to recover the transmitted signal. At the BSU, the Optical to Electrical (O/E) as well as Electrical to Optical (E/O) conversion is performed. From the BSU, the wireless transmission is performed to the specific user also known as Mobile Unit (MU) or Wireless Terminal Unit (WTU). All communication between the MU/WTU must go via the BSU (Geoff Sanders *et al*, 2003). Similarly, the MU/WTU can transmit the signal to the BSU in wireless fashion and later on, the BSU can communicate with the CS/CO by means of optical signal. The signal is transmitted and received by the antenna located at the BSU in Local Area Networks (LANs), mostly in cellular fashion as it happens in conventional wireless communication system. Due to the huge bandwidth of optical fiber, RoF system offers more advantages as compared to traditional wireless communication system. In fact, the cost of equipments (antenna and amplifiers) which are used to detect and re-radiated the RF signal is reduced. RoF system is more efficient than conventional wireless networks in terms of system resource management (Hong Bong Kim, 2005).

Many techniques for generating the RF signal over the fiber have been proposed. They are broadly classified into Direct and External modulation techniques. These two techniques differ in terms of the achievable receiver sensitivity, higher dynamic range as well as resilience to nonlinear effects.

With direct modulation techniques, it has been found that the system is much more dominated with nonlinear effects; thus making the RoF system design complicated. Many techniques which have been proposed to counteract the nonlinear effects along with direct modulation exhibit less efficiency. For example, low optical modulation indices, which were initially preferred, failed due to the predominance of optical carrier over optical sub-carrier. This has an effect of deteriorating the receiver sensitivity, thus compromising the signal power required to realize the intended BER. Therefore, we are prompted to use higher order modulation indices. However, this option is not helpful at all since higher order modulation indices increase nonlinear effects.

The option suitable for counteracting the nonlinear effects and achieve better receiver sensitivity, is to use external modulation. In external modulation, SAMZM and DAMZM have been proposed to be efficient in dealing with the problems like nonlinear effects, chromatic dispersion and receiver sensitivity. SAMZM and DAMZM are also known as singe-electrode Mach-Zehnder modulator (SEMZM) and Dual-electrode Mach-Zehnder modulator (DEMZM) respectively. The low order modulation indices are no longer a great hindrance since the Mach-Zehnder Modulators (MZMs) are built to with the capability to withstand nonlinear effects at a certain extent. In this paper, SAMZM and DAMZM have been implemented in order to transmit the RF signal. The booster or post-amplifier has been used to compensate the losses which have been encountered during modulation process. Likewise, the EDFA has been used at the end of the optical link in order to compensate the in-line losses. In external modulation, the EDFA has shown to improve the performance of RoF system (Vishal Sharma *et al*, 2011).

2. System Modeling

In communication system, it is impossible to transmit the signal to a long distance without modulation. Modulation is the process to form a baseband signal by varying the characteristics of the carrier. There are two major modulation schemes which have been described earlier: direct and external modulation. In this work we focus on external modulation by using SAMZM and DAMZM due to more benefits it provides. Generally, the Q-Factor and the BER are better in case of external modulation as compared to direct modulation (HimanshuRana*et al*, 2012). The block diagrams of external modulation using SAMZM and DAMZM are shown in figure 2 and 3 respectively.

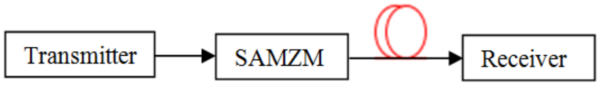

Figure 2: External modulation using SAMZM

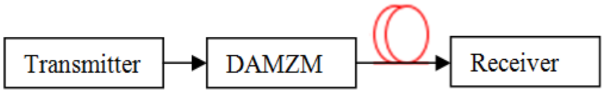

Figure 3: External modulation using DAMZM

In both figure 2 and 3, the transmitter unit is composed of Pulse/signal Generator, Pseudo Random Binary Sequence(PRBS) Generator, laser, modulator driver and SAMZM/DAMZM in order to generate the RoF signal and impose it to the optical carrier. The optical link is composed of the SSMF, booster as well as the pre-amplifier. The SSMF has been used without compensating dispersion in order to assess how much SSMF can withstand the effects of chromatic dispersion in RoF system. Chromatic dispersion or intramodal dispersion takes place in all types of fibers (John M. Senior, 2010) since it is wavelength dependent. At the receiving unit of both figures 2 and 3, the PIN photodetector is utilized to convert the optical signal into electrical signal. Thereafter, the signal is applied to the electrical filter before it is fed to the measurement component.

3. System Simulation Setup

A. *Single Arm Mach Zehnder Modulator (SAMZM)*

The system set up composed of SAMZM is depicted in figure 4. The bit rate of data source is set to 10 Gbps as the available electronic equipments comply with this data rate.

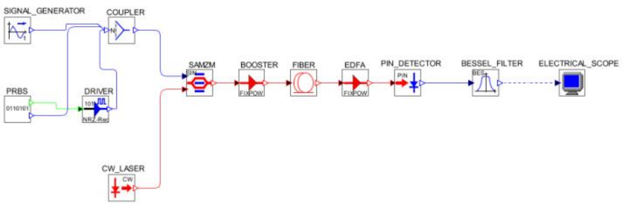

Figure 4: Simulation setup of External modulation using SAMZM.

The Continuous Wave (CW) laser operating at the wavelength of 1550 nm is used to generate the optical carrier of 9 MHz Full Width Half Maximum (FWHM), i.e., laser line-width, as it helps to avoid excessive chirps. The FWHM plays an important role in improving the RoF system performance (Vishal Sharma *et al*, 2011). As well, the chirp factor has been set to zero in case of SAMZM in order to serve the same purpose of minimizing the excessive chirp. The RF signal modulated at 20 GHz is generated. The laser power has been fixed to 1 mW in order to avoid any potential Cross Phase Modulation (XPM). The system performance has been evaluated for the distance up to 50 km. The Extinction ratio of the SAMZM is fixed to 20 dB in order to maintain the amplitude of the signal. Similarly, the offset voltage of 5V and Vpi of 5 V have been use in order to keep the modulator balanced. The signal is first amplified by using the booster whose gain is set to 35 dB. The output power of this amplifier has been set to 0.05 mW in order to avoid excessive Amplified Spontaneous Emission (ASE). The SSMF is used to transmit the modulated signal towards the receiver. This fiber has the loss of 0.2 dB/km, the dispersion coefficient (D) of 17 ps/(nm.km) and the core effective area (A_{eff}) of 85 µm^2 at reference frequency of 1550 nm. Thereafter, the signal is amplifier by the EDFA before being fed to the PIN detector. The gain of the EDFA is fixed to 35 dB too but the output power is lowered down to 0.01 mW in order to provide the power which will be easily handled by the electronic equipments at the receiver side. The EDFA improves the system performance by reducing the attenuation; thus increasing the signal range, i.e., length of link (Husam Abduldaem Mohammad, 2013). The PIN detector converts the optical signal into electrical one. The responsivity and the quantum efficiency of the PIN detector are set to 0.8751 A/W and 0.7 respectively in order to provide the proper signal recovery. After the signal is converted to electrical form, it is applied to electrical scope which provides the facility to evaluate the system performance. From the electrical scope, different parameters for performance evaluation are displayed. The parameters of our interest are BER, Q-Factor and eye diagram since they provide the clear picture of how much successful is our system.

B. Dual Arm Mach Zehnder Modulator (DAMZM)

The system set up composed of DAMZM is depicted in figure 5.

In figure 5, the generated single-tone RF signal as a product of the combination of data source and pulse generator, is electrically split into two parts. One part is shifted in phase by 90^o and applied to one electrode of the DAMZM whereas the other part is directly applied to the second electrode of DAMZM without phase shift.

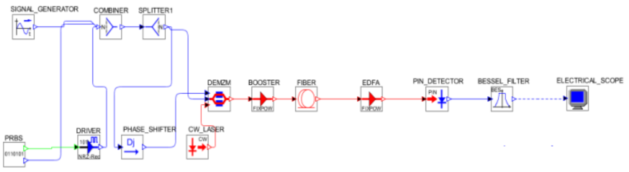

Figure 5: Simulation setup of External modulation using DAMZM.

The laser is connected to the DAMZM in order to provide the optical carrier. The CW laser whose FWHM is set to 9 MHz is used. Likewise, the laser power is set to 1 mW in order to avoid any potential XPM. The CW laser source wavelength has been set to 1550 nm as in case of SAMZM. The bit rate of 10 Gbps is used for data source. The offset voltage of 5V has been utilized to bias both electrodes of DAMZM. This is done in case of zero phase retardation when there is no electric field. The Vpi of 5 V have been use in order to keep the modulator balanced. , the chirp factor has been set to zero in case of DAMZM. The signal is amplified by the booster whose gain and output power are set to 35 dB and 0.05 mW respectively. The booster helps to counteract the losses which have taken place during modulation process. The RF signal modulated at 20 GHz is generated and transmitted through the optical fiber whose sensitive parameters are fiber loss of 0.2 dB/km, dispersion coefficient of 17 ps/(nm.km), and core effective area (A_{eff}) of 85 µm^2 at the reference frequency of 1550 nm. The EDFA whose output power is set to 0.01 mW is used to compensate the losses which have taken place during the transmission. As well the gain of EDFA is the same as the one used for SAMZM and it is fixed to 35 dB. At the receiving section, the PIN photodiode is employed. The quantum efficiency of the PIN diode is set to 0.7 while its responsivity is set to 0.8751A/W. The output data is detected by using the electrical scope which provides the facility to get the evaluation parameters.

C. Simulation Results for SAMZM and DAMZM

The system has been designed using Optsim, which is one of the powerful optical systems design tools. The system is evaluated in terms of eye diagram, BER and Q-Factor. The eye diagram has been obtained directly after simulation using Optsim whereas the BER and Q-Factor variation has been plotted using Matlab. The eye diagram gives good visual of timing and level errors; the BER helps us to know how many bits are erroneous while the Q-Factor provides the knowledge of how much the statistical noise has affected the signal.

- *Eye Diagram*

The eye opening is a good measure of different system impairments whichhave taken place during the transmission. The quality of the signal can be judged from the appearance of the eye diagram (Eduard Sackinger, 2005). The horizontal eye opening gives the idea of how the signal fits in its time slot, i.e., the time jitter is quantified. The vertical eye opening helps to measure the Inter-Symbol Interference (ISI) which might have taken place. With the increase of errors, the eye opening becomes narrower. This shows that the signal amplitude and the bit slot have drifted from their normal position. The eye diagram evaluation is performed with reference to the ideal eye diagrams obtained when the optical link (optical fiber, booster and EDFA) is removed, i.e., back-to-back set up. The ideal eye diagrams for externally modulated signal using SAMZM and DAMZM are depicted in figure 6.

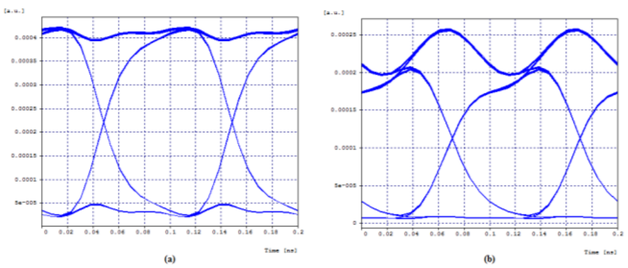

Figure 6: Ideal eye diagram of external modulation for (a) SAMZM (b) DAMZM.

The system has been evaluated for the distance of 10 km, 20 km, 30 km, 40 km and 50 km. The system evaluation based on eye diagram for both SAMZM and DAMZM at 10 km is depicted in figure 7.

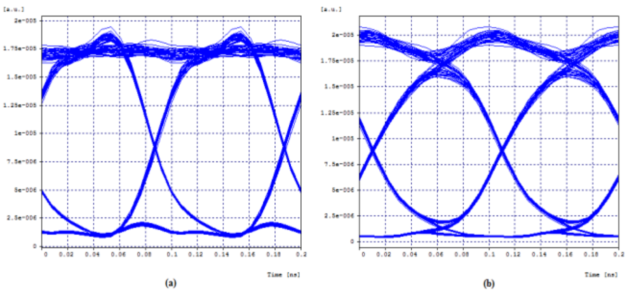

Figure 7: Eye diagram of external modulation for (a) SAMZM (b) DAMZM at 10 km.

As it can be observed from the figure 7, the vertical and horizontal eye openings for both SAMZM and DAMZM are satisfactory since they almost resemble to the ideal eye opening obtained when back-to-back system set up is performed. However, we notice that the eye opening for SAMZM is better that the one for DAMZM. The rising and the falling edges are more refined for SAMZM than DAMZM. Moreover, the overshoots are more for DAMZM than SAMZM. The ISI is very less as the vertical eye opening is appropriate for both SAMZM and DAMZM. Likewise, the information conveyed by the horizontal eye opening reveals very less time jitter; thus the signal will be properly sampled and recovered by the receiver.

The system evaluation based on eye diagram for both SAMZM and DAMZM at 20 km is depicted in figure 8.

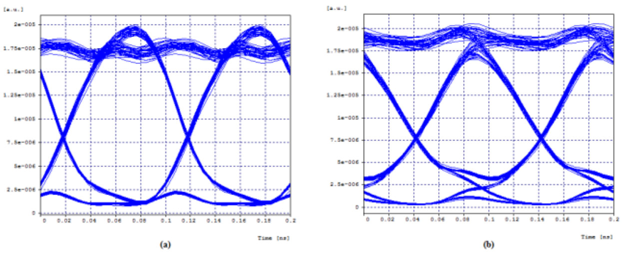

Figure 8: Eye diagram of external modulation for (a) SAMZM (b) DAMZM at 20 km.

The analysis of the figure 8 shows that the signal will be successfully transmitted to 20 km for both SAMZM and DAMZM. The comparison of figure 6 and figure 8 shows that the eye diagrams up to the distance of 20 km do not deviate much from the ideal eye diagrams for both SAMZM and DAMZM. Though, both horizontal and vertical eye openings are lesser as compared to figure 7, still they are in acceptable range. Notice that the overshoots are increasing when we increase the transmission distance up to 20 km. Thus we expect from the upcoming transmission distances to have more overshoots. After all, the SAMZM shows better performance as compared to DAMZM.

The system evaluation based on eye diagram for both SAMZM and DAMZM at 30 km is depicted in figure 9.

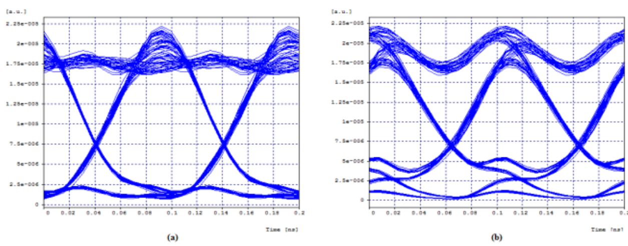

Figure 9: Eye diagram of external modulation for (a) SAMZM (b) DAMZM at 30 km.

The figure 9 shows that the eye opening is still excellent for SAMZM while the eye opening for DAMZM is getting rapidly distorted. The overshoots and undershoots are increasing at fast rate for DAMZM as compared to figure 8. However, the signal could be successfully transmitted to 30 km since the eye opening still more than the half of the ideal eye opening depicted in figure 6.

The system evaluation based on eye diagram for both SAMZM and DAMZM at 40 km is depicted in figure 10.

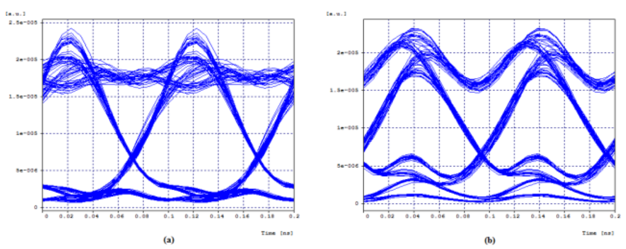

Figure 10: Eye diagram of external modulation for (a) SAMZM (b) DAMZM at 40 km.

The system performance up to the distance of 40 km shows that SAMZM is still more efficient than DAMZM.

It can be noticed from the figure 10 that the eye opening is much wider for SAMZM while it is narrower for DAMZM. Fortunately, the eye opening in case of DAMZM is still more than the half of the ideal eye opening depicted in figure 6. But, the under- and overshoots present in figure 10(b) show that the signal amplitude is affected by the noise. Nevertheless, the signal can be transmitted to 40 km with tolerable effects of statistical noise for both SAMZM and DAMZM irrespective of those under- and overshoots present in case of DAMZM.

The system evaluation based on eye diagram for both SAMZM and DAMZM at 50 km is depicted in figure 11.

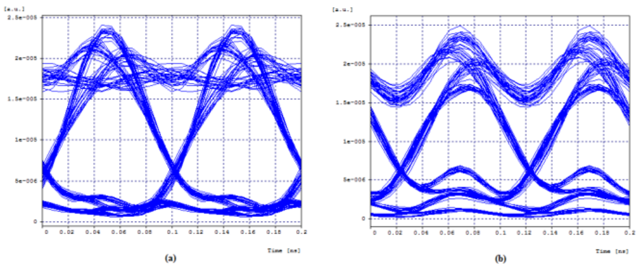

Figure 11: Eye diagram of external modulation for (a) SAMZM (b) DAMZM at 50 km.

The analysis of figure 11 shows that the eye diagram in case of DAMZM is distorted so that the signal could not be successfully transmitted to 50 km. The eye diagram for SAMZM is still having good appearance. Even though the overshoots are increased, the eye opening is more than the half of the ideal one depicted in figure 6. However, the eye opening for DAMZM is less than the half of the ideal one; thus compromising the recovery of the transmitted signal by the receiver.

- *Bit Error Rate (BER)*

The system performance is evaluated in terms of BER too. The BER- based system evaluation is illustrated in figure 12.

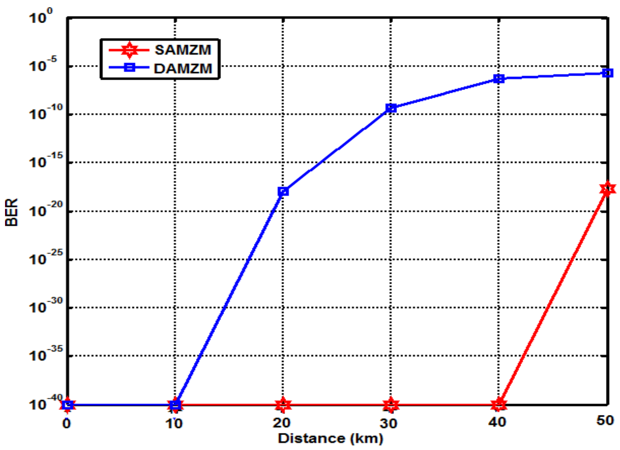

Figure 12: Illustration of the difference in BER performance of external modulation for SAMZM and DAMZM.

The BER is an important parameter of the system design and measure of success and performance (Irfan Ali, 2013). If the BER is too high, then the system performance degrades considerably (Harry J. R Dutton, 1998). The system has been evaluated for the distance of 10 km, 20 km, 30 km, 40 km and 50 km. For each transmission distance, the BER is evaluated with respect to the value of 10^{-09} as it is the threshold value for most of optical communication systems (Govind P. Agrawal, 2002). This means that the BER should be less than 10^{-09} in order to judge if the system is successful.

The figure 12 depicts the variation of BER with respect to distance in case of both SAMZM and DAMZM. The distance which has been taken into consideration starts from zero (back-to-back design) and it ends to 50 km. Notice that the BER is constant and it is the highest ever achievable up to 10 km for both SAMZM and DAMZM. The BER starts to increase in steeper manner beyond 10 km in case of DAMZM while it is still constant for SAMZM. The BER for SAMZM starts to increase after 40 km and it is still with the allowable margin even up to 50 km. The analysis of the figure 12 reveals that the RoF signal can be successfully transmitted to 50 km in case of SAMZM. Whereas, the RoF signal can only be transmitted up to 30 km with the BER of $5.058*10^{-10}$ in case of DAMZM. Moreover, the reported BER value of $5.066*10^{-07}$ at 40 km for DAMZM shows that the signal cannot be successfully transmitted to this distance since the BER is greater than 10^{-09}. Hence, the transmitted information could not be properly recovered by the receiver, thus compromising the integrity of the information. We would expect from the signal reach to improve by using dispersion compensation techniques. Likewise, the system performance can be improved by choosing the fibers which have very low dispersion coefficient. In our case, we have chosen the SSMF, irrespective of its high dispersion coefficient, due to the fact that it is one of the most deployed fibers. Thus, we have the flexibility to design our system without changing the deployed fiber.

- *Q-Factor*

The system evaluation is performed with the help of Q-Factor as well. The Q-factor comes to supplement other performance evaluation parameters which have been taken into account (eye diagram and BER). Moreover, the Q-Factor provides a cost-effective system performance evaluation since the BER is very slow or very costly (R. Bach *et al*, 2001). The Q-Factor helps us to evaluate the performance of the system without computing the Optical Signal-to-Noise Ratio (OSNR). If the Q-Factor is in the allowable margin (above 6), we simply conclude that the power requirements for proper system design have not been violated. A successful system has higher Q-Factor since the Q-Factor is inversely proportional to BER (A. K. Jaiswal *et al*, 2012). The Q-Factor based system evaluation is illustrated in figure 13.

The figure 13 depicts the variation of Q-Factor with respect to distance in case of both SAMZM and DAMZM. We are going to analyze our system performance based on the threshold Q-Factor of 6. This value corresponds to the BER of 10^{-09} andit implies that the received power is enough to realize the responsivity of thePIN detector required to successfully recover the transmitted signal.

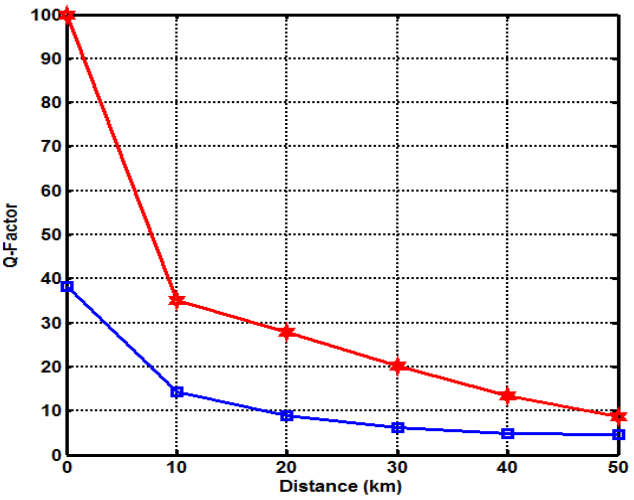

Figure 13: Illustration of the difference in Q-factor performance of external modulation for SAMZM and DAMZM.

The same distance used in case of BER evaluation is taken into consideration for Q-Factor evaluation too, i.e., distance from zero (back-to-back) to 50 km. The analysis of the figure 13 shows that the RoF signal can be successfully transmitted to 30 km and 50 km for DAMZM and SAMZM respectively. The SAMZM shows better performance in terms of Q-Factor as it is confirmed by the reported values of 8.746 and 4.672 for SAMZM and DAMZM respectively at the distance of 50 km. These results supplement the BER-based results in order to prove the excellence of SAMZM as compared to DAMZM. The difference between these two modulators is so pronounced at the extent that the Q-Factor for SAMZM is more than twice the Q-Factor for SAMZM along the whole transmission distance.

The performance evaluation of this system using EDFA based on BER and Q-Factor is depicted in table 1. The results have been obtained from the eye diagram after simulation using Optsim software.

Table 1: Simulation results for SAMZM and DAMZM.

Fiber Length (km)	SAMZM		DAMZM	
	BER	Q-Factor	BER	Q-Factor
0	10^{-40}	100	10^{-40}	38.234
10	10^{-40}	35	10^{-40}	14.334
20	10^{-40}	27.978	$1.275*10^{-18}$	8.813
30	10^{-40}	20.122	$5.058*10^{-10}$	6.155
40	10^{-40}	13.476	$5.066*10^{-7}$	4.917
50	$2.24*10^{-18}$	8.746	$1.934*10^{-6}$	4.672

The table 1 summarizes the performance evaluation of the system based on BER and Q-Factor. It is evident that the SAMZM is excellent to DAMZM throughout the whole transmission distance up to 50 km.

Conclusion

Nowadays, the high capacity demand of broadband wireless communication system has emerged as the key factor in designing and planning wireless systems. ROF technology seems to be the latest rising technology to cope with the high capacity requirement for better communication. External modulation using SAMZM and DAMZM has been gone through in this paper by using dispersion uncompensated SSMF. The EDFA has been chosen for RF signal amplification since it provides better compensation of losses as compared to other amplifiers at the operating wavelength of 1550 nm. The system performance has been evaluated for the distance up to 50 km. The system has been evaluated in terms of eye diagram, BER and Q-Factor. The reported results have shown that the RoF system is successful up to 30 km and 50 km for DAMZM and SAMZM respectively. All the results based on eye diagram, BER and Q-Factor prove that the noises as well as different impairments which take place in RoF system are tolerable up to 30 km and 50 km for DAMZM and SAMZM respectively. Hence, the RF signal will be properly recovered by the receiver without compromising the integrity of the transmitted information. After all, the external modulation by using SAMZM exhibits excellent performance as compared to DAMZM. It has been substantiated by the reported values in terms of eye diagram, BER and Q-Factor. The eye opening at 50 km is more than the half of the ideal one for SAMZM. Likewise, the values below 10^{-09} and above 6 are reported for BER and Q-Factor respectively in case of SAMZM whereas the RoF system is unsuccessful up to 50 km in case of DAMZM.

References

Green, R.J. (2007), Secure Communication: The Infrared Alternative, ICTON Mediterranean Winter Conference ICTON-MW, Sousse, pp. 1-4.

El-Sayed A. El-Badawy, Abd El-Naser A. Mohamed, Ahmed NabihZakiRashed, Mohamed S. F. Tabbour (2011), New Trends of Radio over Fiber Communication Systems for Ultra High Transmission Capacity, International Journal of Communication Networks and Information Security (IJCNIS),Vol. 3, pp. 217-225.

Wake, D., Nkansah, A, Gomes, N.J. (2010), Radio over Fiber Link Design for Next Generation Wireless Systems, IEEE, Journal of Lightwave Technology, Vol. 28, pp. 2456-2464.

Ajay Kumar Vyas, Navneet Agrawal (2012), Radio over Fiber: Future Technology of Communication, International Journal of Emerging Trends & Technology in Computer Science (IJETTCS), Vol. 1, pp. 223-237.

Yan Cui, Kun Xu, Jian Dai, Xiaoqiang Sun, Yitang Dai, Yuefeng Ji, Jintong Lin ((2012), “Overcoming Chromatic-Dispersion-Induced Power Fading in RoF Links Employing Parallel Modulators”, IEEE Photonics Technology Letters, Vol. 24, No. 14, pp. 1173-1175.

Wake, D., Nkansah, A., Assimakopolous, P., Gomes, N. (2010), Design and Performance of Radio over Fibre links for Next Generation Wireless Systems Using Distributed Antennas, Future trend and Mobile Summit Florence, pp 1-9.

Theodore S. Rappaport (2010), Wireless Communications, Principles and Practice, Prentice Hall, 2nd Ed., chap.4, pp. 113-138, India.

Shaddad, R.Q, Mohammad A.B., Al-Hetar A.M., Al-Gailani, S.A. (2013), Wireless Signal Transport Schemes in Fiber Wireless Systems, Photonics (ICP), IEEE 4th International Conference , pp.47-49.

Geoff Sanders, Lionel Thorens, Manfred Reisky, Olive Rulik, Stefan (2003), GPRS Networks, John Willey & Sons, Ltd, chap. 2, pp. 18-30.

Hong Bong kim (2005), Radio over Fiber Based network Architecture, Thesis, TechnischenUniveritat Berlin.

Vishal Sharma, Amarpal Singh, Ajay K. Sharma (2011), Simulative investigation the impact of optical amplification techniques on single- and dual-electrode MZM and direct modulator's in single-tone RoF system, Optik - International Journal for Light and Electron Optics, Vol. 122, pp. 371-374 .

HimanshuRana,Sushank, Chandika Mohan Babu (2012), Simulative Investigation of Performance of Direct Intensity Modulation and External Modulation in Optical Network, IRACST – International Journal of Computer Networks and Wireless Communications (IJCNWC), Vol.2, No.2, pp. 147-150.

John M. Senior (2010), Optical Fiber Communications, Principle and Practice, Pearson Education LimitedIndia, 3rd Ed., chap.3, pp. 109-113.

Vishal Sharma, Amarpal Singh, Ajay K. Sharma (2011), Analysis of Impact of P-Ratio on BER, Q-Factor and OSNR of Radio over Fiber (RoF) System, Optics and Photonics Journal, Vol. 1, pp. 179-188.

HusamAbduldaem Mohammed (2013), Performance Evaluation of DWDM for Radio over Fiber System with Dispersion Compensation and EDFA, International Journal of Computer Applications (0975-8887), Vol. 72, No. 10, pp 9-19.

Eduard Sackinger, (2005), Broadband circuits for Optical Fiber Communication, John Wiley & Sons, Inc., pp. 313-319.

Irfan Ali (2013), Bit-Error-Rate (BER) Simulation Using MATLAB, International Journal of Engineering Research and Applications (IJERA), Vol. 3, pp. 706-711.

Harry J. R Dutton (1998) Understanding Optical Communications, IBM Corporation, International Technical Support Organization, 1st Ed., chap. 7, pp. 327, New York.

Govind P. Agrawal (2002), Fiber-Optic Communication Systems, John Wiley & Sons, Inc., 3rd Ed., chap.1, pp. 16-19.

R. Bach, W. Moench, G. Strohmaier (2001), In-service Optical Performance Monitoring of High-speed transparent networks based on Q measurements, 3rd International Conference on Transparent Optical Networks (ICTON), Cracow, pp. 210–217.

A. K. Jaiswal, Anil Kumar, SantoshTripathi, Amarendra Kumar Chaudhary (2012), To study the Effect of BER and Q-Factor in Intersatellite Optical Wireless Communication System, IOSR Journal of Electronics and Communication Engineering (IOSR-JECE), Vol.3, pp 19-21.