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Performance Evaluation of Radio Frequency Transmission over Fiber using Optical Amplifiers

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Abstract---The growth of mobile and wireless communication is increasing the demand for multimedia services with a guaranteed quality of service. This requires realization of broadband distribution and access networks. Radio over Fiber technology has various advantages when it applies to wireless systems, especially, mobile communication radio networks. Radio-over-Fiber (RoF) system mainly uses two modulation techniques ie; direct- and external-laser modulation. In RoF technology, the fiber dispersion and chirp parameters are the important parameters in degrading the performance of optical communication systems. External modulators of Mach-Zehnder type minimize the transmission power penalty due to fiber chromatic dispersion. So these modulators are also known as chirp-free modulators. Also, better suppression of nonlinear distortion is achieved by using Mach-Zehnder external modulator. Data is either externally modulated by using single-electrode (SEMZM) – and dual electrode (DEMZM) – Mach-Zehnder modulator. This work presents a simulation comparison of external modulation schemes using different optical amplifiers, comparison of received electric Rf power with different optical amplifiers and calculation of BER at received channel. Simulation of external modulation using EDFA and SOA are performed by using OPTSIM 5.3.

Keywords: Radio over fiber (RoF) system, External modulation, Dual-and single-electrode MZM, SOA, EDFA

I. INTRODUCTION

Radio-over-Fiber (RoF) techniques are attractive for realizing high-performance integrated networks. Nowadays, there is an increasing demand for broadband services which leads to ever-growing data traffic volumes over these services. This requires realization of broadband distribution and access networks. To meet the accelerating demands in communication systems, the integration of optical network and wireless radio is a promising solution. ROF means the optical signal is being modulated at radio frequencies and transmitted via the optical fiber. The RoF technology has various advantages when it applies to wireless systems, especially, mobile communication radio networks [2]. The central office handles call processing and switching, while the Base Stations (BS) act as the radio interfaces for the Mobile Units (MU) or Wireless Terminal Units (WTU). The BSs may be linked to the central office through either analogue microwave links or digital fiber optic links. Once the baseband signals are received at the BS, they are processed and modulated onto the appropriate carrier. The radius covered by the signal from the BS is the cell radius. All the MU/WTU within the cell, share the radio frequency spectrum. WLANs are configured in a similar fashion, with the radio interface called the Radio Access Point (RAP). Figure 1 illustrates the configuration of narrowband wireless access systems (e.g.GSM).

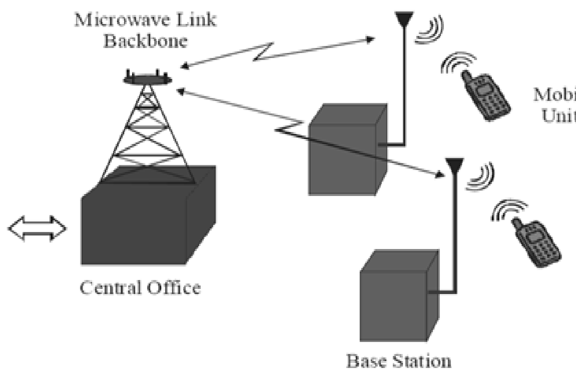

Fig. 1: Components of a Narrowband Wireless Access Network

A technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access is referred to as Radio over Fiber (RoF). Although radio transmission over fiber is used for multiple purposes, such as in cable television (CATV) networks and in satellite base stations, the term RoF is usually applied when this is done for wireless access. In RoF systems, wireless signals are transported in optical form between a central station and a set of base stations before being radiated through the air. Each base station is adapted to communicate over a radio link with at least one user's mobile station located within the radio range of the base station [3].Radio over fiber (RoF) technology has emerged as a cost effective approach for reducing radio system costs because it simplifies the remote antenna sites and enhances the sharing of expensive radio equipment located at appropriately sited switching centers (SC) or otherwise known as central sites/stations (CS).Radio-over-Fiber (RoF) technology entails the use of optical fiber links to distribute RF signals from a central location (head-end) to Remote Antenna Units (RAUs). In narrowband communication systems and WLANs, RF signal processing functions such as frequency up-conversion, carrier modulation, and multiplexing, are performed at the BS or the RAP, and immediately fed into the antenna. RoF makes it possible to centralize the RF signal processing functions in one shared location (head-end), and then to use optical fiber, which offers low signal loss (0.3 dB/km for 1550 nm, and 0.5 dB/km for 1310 nm wavelengths) to distribute the RF signals to the RAUs, as shown in Figure 2. By so doing, RAUs are simplified significantly, as they only need to perform optoelectronic conversion and amplification.

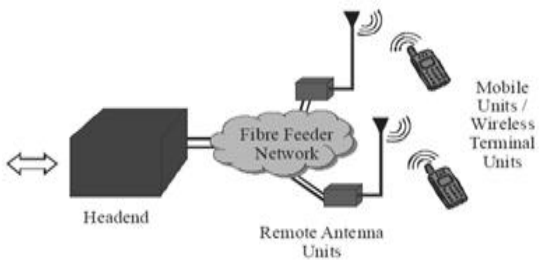

Fig. 2: Block diagram Radio over Fiber System

Several techniques for distributing and generating microwave signals via optical fiber exist. The techniques may be classified into two main categories namely Intensity Modulation- Direct Detection (IM-DD) and Remote Heterodyne Detection (RHD) techniques [3]. In such systems, it is desirable to achieve better receiver sensitivities, higher dynamic ranges, and lower nonlinear distortions. Techniques to reduce nonlinear distortions have been investigated extensively. A method for reducing nonlinear HDs and IMDs is to use the pre-distortion method [4], However, if EAMs are used, it was found that EAM modulation characteristics are not only dependent on wavelength, but also on input optical power [5]. Thus, different pre-distortions for different wavelengths and different power levels have to be used, making the radio over fiber (RoF) system design very complicated. In order to reduce nonlinear distortions, low optical modulation indexes or depths (the ratio of optical signal sub-carrier to optical carrier) were usually preferred. Unfortunately, in this case the optical carrier is dominant in comparison to the optical signal sub-carrier, which leads to reduced receiver sensitivity. So, higher modulation indexes are preferred, which lead to significant increases of nonlinear distortion. In [8], the better suppression of nonlinear distortions consist of harmonic distortions (HDs) and intermodulation distortions (IMDs), both of which come from the nonlinear modulation characteristics of the optical modulators, was achieved by using single electrode Mach-Zehnder external modulator (SEMZM) with EDFA in a single-tone RoF system. In this work, we have transmitted a single-tone channel of 20 GHz, modulated either by external modulation schemes consist of DEMZM, SEMZM or by direct modulation, with EDFA and SOA at an optical link of 20km and compared the received RF power of the transmitted single-tone channel for each case.

II. SYSTEM MODELLING

Modulation is a process by which some characteristics of carrier are varied in accordance with a modulating wave (signal). Radio-over-Fiber (RoF) system mainly uses two modulation techniques ie; direct- and external-laser modulation. In external modulation, Modulation and light generation are separated. In direct modulation, message signal is super imposed on a bias current which modulate laser. In case of external modulation, we use single and dual electrode Mach-Zehnder modulator. The transmitter section consists of Pseudo Random Binary Sequence Generator (PRBS**),** Pulse Generator, Single Mode Fiber and dispersion compensation fiber. A 10 Gbps data source is used. The modulated signal is transmitted through optical fiber of 20 km length. At the receiving section, signal is amplified by using EDFA and SOA and PIN photodiode is employed in order to convert optical signal to electrical form. The block diagram of external modulation using Dual electrode Mach-Zehnder modulator is shown in Figure 3.

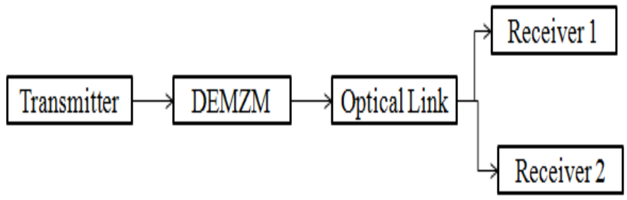

Fig. 3**:** Block Diagram External modulation using DEMZM

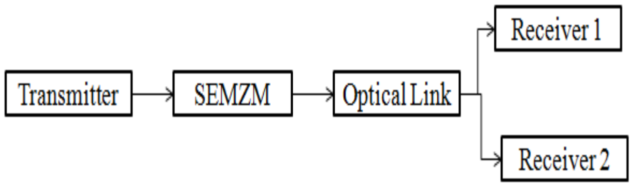

Fig. 4: Block Diagram External modulation using SEMZM

III. SIMULATION SETUP

In external modulation, the RF signal transmitted from transmitter and optical signal from a CW Laser fed to an external modulator (DEMZM, SEMZM) [1]. A 10 Gbps data source is used. Figure 5 shows External modulation by using SEMZM. The Single Mode Fiber (SMF) is used to transmit the modulated signal towards to the receiver. In the receiver section, the single-tone RF signal is splitted into two parts by using electrical splitter; one part with phase shift of 90° is applied to the first drive electrode while the second part is directly applied to the second drive electrode of DEMZM modulator. In the receiving section, the two channels are splitted, amplified either with an EDFA or SOA and detected by connecting narrow bandwidth electric power meters and eye-diagram analyzers to evaluate the performance of each channel signal. A 10 Gbps data source is used. The modulated signal is transmitted through optical fiber of 20 km length. At the receiving section, signal is amplified by using Erbium Doped Fiber Amplifier and SOA. The Eye Diagram is a timing analysis tool providing the user with a good visual of timing and level errors. In real life, errors like jitter are very difficult to quantify since they change so often and are so small. Therefore, an eye diagram is a very good tool for finding the maximum errors as well as voltage level errors. As these errors increase, the white space in the center of the eye diagram decreases. That space is defined by two characteristics; the eye width and the eye height. The width of the white space of the eye diagram is called, simply enough, the eye width.. The height of the white space of the eye diagram is called the eye height. An ideal eye opening measurement would be equal to the eye amplitude measurement. Power Meter can be used to measure the power of an electrical Signal. Radio over fiber transmission using Dual Electrode Mach–Zehnder modulator is simulated. Simulation layout is shown in Figure 5.

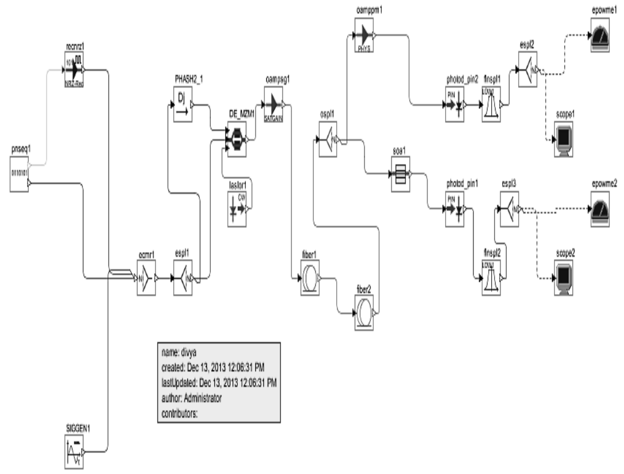

Fig. 5: Simulation setup of External modulation using DEMZM

In external modulation, the RF signal transmitted from transmitter and optical signal from a CW Laser fed to an external modulator (DEMZM, SEMZM). Simulation setup of External modulation using DEMZM is shown in Figure 5.4. In case of external modulation using DEMZM, the wavelength of continuous wave laser source is 1550.5nm of laser line width 10MHz with CW power of 10mW. A 10 Gbps data source is used. The single-tone RF signal and the data source is combined in a combiner and which is splitted into two parts by using electrical splitter; one part with phase shift of 90° is applied to the first drive electrode while the second part is directly applied to the second drive electrode of DEMZM modulator. The offset voltage corresponding to the zero phase retardation in absence of any electric field on both electrodes of DEMZM modulator is set at 5V. The chip factor is kept at zero in case of DEMZM. The Vpi voltage is fixed at 8.2V. The modulated signal is transmitted through the fiber at different length. At the receiving section, signal is splitted and amplified by using EDFA and SOA and PIN photodiode is employed. The quantum efficiency and responsivity of PIN diode is fixed at 0.7199 and 0.9A/W respectively. The output data is observed through an electroscope and power meter. Radio over fiber transmission using SEMZM simulation block is shown in Figure 6.

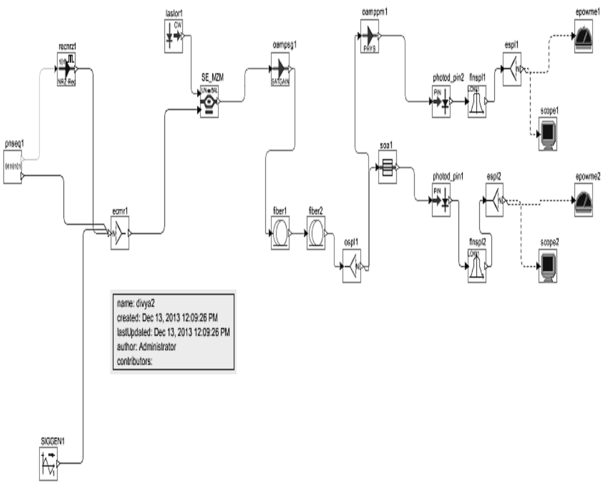

Fig. 6: Simulation setup of External modulation using SEMZM

The better quality the digital signal transmission, the more open white space there should be in the eye. Said differently, the eye width and eye height should be as large as possible

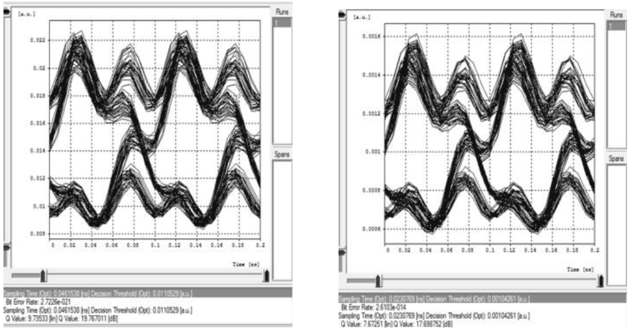

Fig. 7: Eye diagram of External Modulation Using DEMZM obtained from (a) EDFA (b) SOA at 20 Km

Figure7 shows the eye diagram of External modulation using DEMZM. At 20 Km, Q value and bit error rate of external modulation using DEMZM with EDFA is 19.7670 and $2.722*10^{-21}$ and in case of SOA which is 17.698 and $2.610*10^{-14}$. The signal to noise ratio of the high speed data signal is also directly indicated by the amount of eye closure.

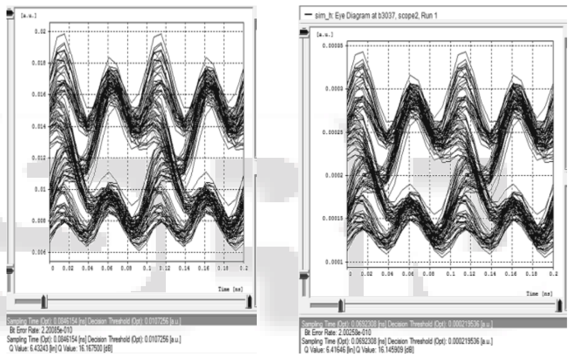

Fig. 8: Eye diagram of External Modulation Using DEMZM obtained from (a) EDFA (b) SOA at 30 Km

Eye height is a measure of the vertical opening of an eye diagram. Figure 8 shows the eye diagram of External modulation using DEMZM. At 30 Km, Q value and bit error rate with EDFA is 16.16 and $2.2*10^{-10}$. In case of SOA which is 16.14 and $2.00*10^{-10}$.

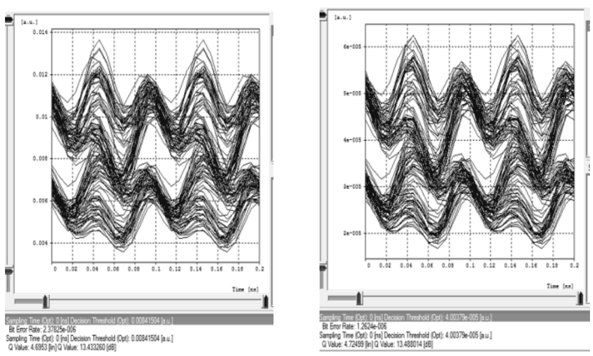

Fig. 9: Eye diagram of External Modulation Using DEMZM obtained from (a) EDFA (b) SOA at 40 Km

Figure 9 shows the eye diagram of External modulation using DEMZM. At 40 Km, Q value and bit error rate of external modulation with EDFA is 13.87 and $8.38*10^{-7}$. In case of SOA which is 13.41 and$1.26*10^{-6}$.

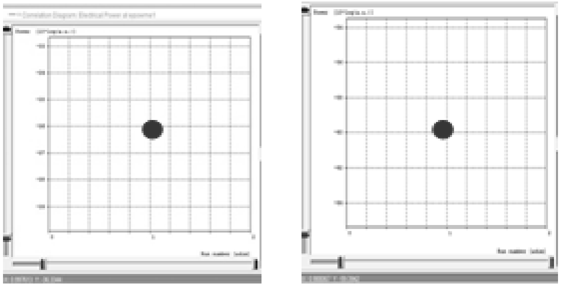

Fig. 10: RF Power of External Modulation Using DEMZM obtained from (a) EDFA (b)SOA at 20 Km

In case of external modulation, we can use dual electrode and single electrode MZM. Figure 10 shows the RF Power of External Modulation Using DEMZM. At 20 Km, the measurement of RF power with EDFA is -36.334dB and SOA which shows -59.3942dB.

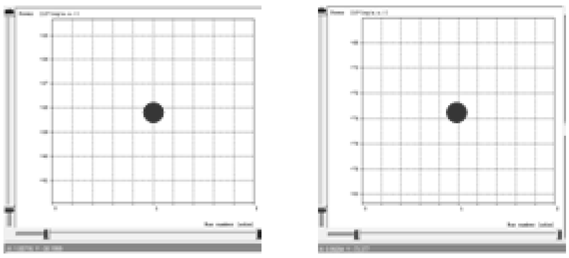

Fig. 11: RF Power of External Modulation Using DEMZM obtained from (a) EDFA (b) SOA at 30 Km

Figure 11 shows the RF Power of External modulation by using DEMZM with EDFA and SOA at 30 Km. Here, the RF Power of External modulation with EDFA is-38.19dB and in case of SOA which is -73.377dB.

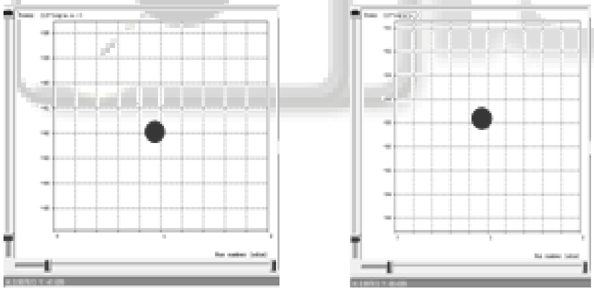

Fig. 12: RF Power of External Modulation Using DEMZM obtained from (a) EDFA(b) SOA at 40 Km.

Figure 12 shows RF Power of External modulation. At 40 Km, RF power DEMZM with EDFA is -41.699dB and the RF power DEMZM with SOA which is -88.438dB.

FIBER LENGTH (Km)	EDFA			SOA		
	QVALUE	BER	RF POWER (dB)	QVALUE	BER	RF POWER (dB)
20	19.7670	$2.722*10^{-21}$	-36.334	17.698	$2.610*10^{-14}$	-59.3942
30	16.167	$2.200*10^{-10}$	-38.199	16.14	$2.00*10^{-10}$	-73.377
40	13.871	$8.381*10^{-7}$	-41.699	13.4	$1.26*10^{-6}$	-88.438

Table. 2: Simulation results of DEMZM

In case of external modulation using SEMZM, the wavelength of continuous wave laser source is 1549.5nm of laser line width 10MHz with CW power of 10mW. A 10 Gbps data source is used. The single-tone RF signal and the data source are combined in a combiner and which is transmitted into the SEMZM modulator and the maximum transmitted offset voltage is set to zero. The chip factor is kept at zero in case of SEMZM. The Vpi voltage is fixed at 8V. The modulated signal is transmitted through optical fiber at different length. At the receiving section, signal is splitted and amplified by using EDFA and SOA and PIN photodiode is employed. PIN photodiode is used to convert optical signal to electrical signal. The quantum efficiency and responsivity of PIN diode is fixed at 0.7199 and 0.9A/W respectively. Radio over fiber transmission using SEMZM simulation setup is shown in Figure 13. The output data is observed through an electroscope and power meter.

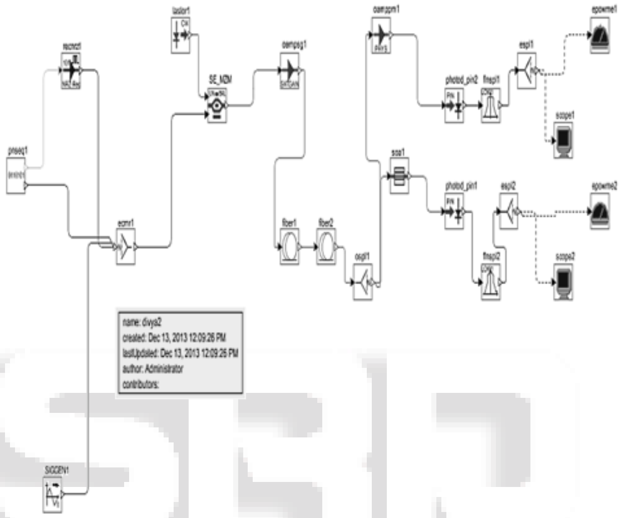

Fig. 13: Simulation setup of External modulation using SEMZM

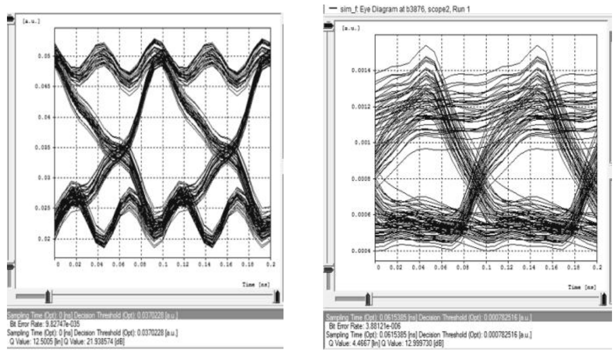

Fig. 14: Eye diagram of External Modulation Using SEMZM obtained from (a)EDFA (b) SOA at 20 Km

Figure 14 shows the eye diagram of External modulation using SEMZM. At 20 Km, Q value and bit error rate of external modulation with EDFA is 21.93 and $9.82*10^{-35}$. In case of SOA which is 12.99 and$3.88*10^{-6}$. The bit-error rate (BER) is defined as

$$BER = Errors/Total\ number\ of\ bits.$$

The Q-factor reduction due to inter symbol interference (ISI), exists due to receiver bandwidth limitation, nonlinearity of the active components, causes optical power penalty or error floor in an optical receiver design.

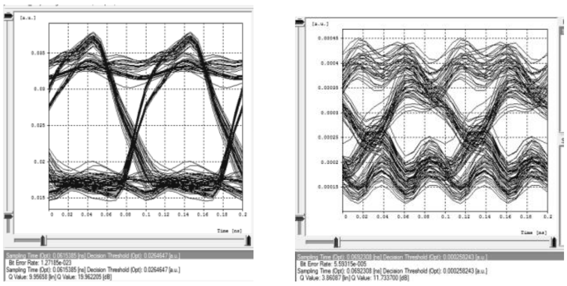

Fig. 15: Eye diagram of External Modulation Using SEMZM obtained from (a)EDFA (b) SOA at 30 Km

Figure 15 shows the eye diagram of External modulation using SEMZM. At 30 Km, Q value and bit error rate of external modulation with EDFA is 19.962 and $1.27*10^{-21}$. In case of SOA which is 11.733 and$5.59*10^{-5}$.

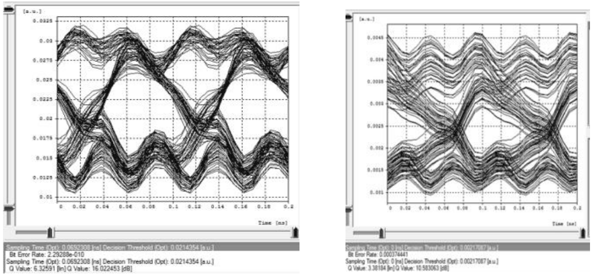

Fig. 16: Eye diagram of External Modulation Using SEMZM obtained from (a)EDFA (b)SOA at 40 Km

Figure 16 shows the eye diagram of External modulation using SEMZM. At 40 Km, Q value and bit error rate of external modulation with EDFA is16.02 and $2.292*10^{-10}$. In case of SOA which is 10.58 and $3.74*10^{-4}$.

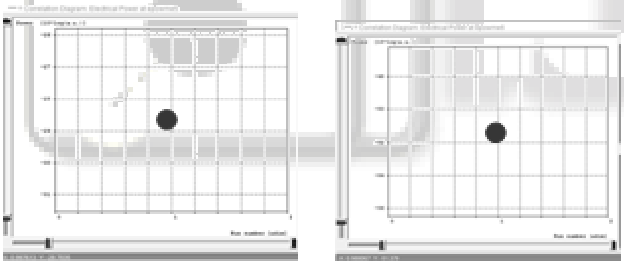

Fig. 17: RF Power of External Modulation Using SEMZM obtained from (a) EDFA (b) SOA at 20 Km

In SEMZM, which have only one electrode and RF signal apply in that electrode. Figure 17 shows the RF Power of External modulation using SEMZM with EDFA and SOA at 20 Km. Here, the RF Power of External modulation with EDFA is -28.70dB and in case of SOA which is -51.37dB.

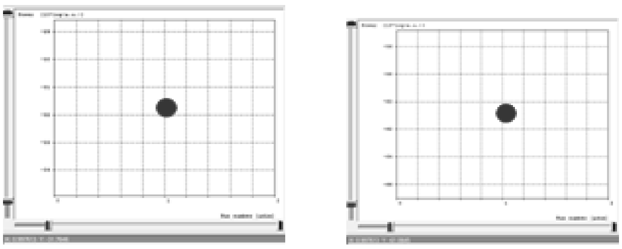

Fig. 18: RF Power of External Modulation Using SEMZM obtained from (a) EDFA (b) SOA at 30 Km.

Figure 18 shows the RF Power measurement of External modulation. At 30 Km, RF power SEMZM with EDFA is -31.764dB and RF power with SOA which is -61.06dB.

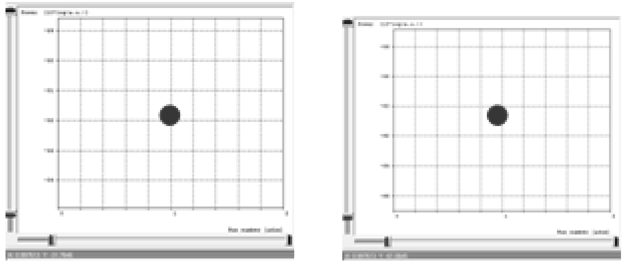

Fig. 19: RF Power of External Modulation Using SEMZM obtained from (a) EDFA (b) SOA at 40 Km

Figure 19 shows the RF Power of External Modulation Using SEMZM. At 40 Km, the measurement of RF power with EDFA is -33.20dB and SOA which shows -70.84dB.

FIBER LENGTH (Km)	EDFA			SOA		
	QVALUE	BER	RF POWER (dB)	QVALUE	BER	RF POWER (dB)
20	21.9385	$9.82*10^{-35}$	-28.703	12.999	$3.88*10^{-6}$	-51.379
30	19.962	$1.271*10^{-21}$	-31.764	11.733	$5.59*10^{-5}$	-61.06
40	16.02	$2.292*10^{-10}$	-33.20	10.583	$3.7441*10^{-4}$	-70.84

Table. 3: Simulation results of SEMZM

IV. CONCLUSION

The demands of broadband multimedia services for wireless users are increasing day by day. ROF (Radio Over Fiber) technology has become the latest emerging technology to meet with such demands. The radio over fiber system uses two types of modulation ie, direct and external modulation. The modulation techniques with different optical amplifiers using OptSim simulation are investigated. The comparisons of both modulation schemes are analyzed. It is found that the performance of External modulation using SEMZM modulator with EDFA amplifier is better than DEMZM in terms of Quality factor, BER and RF power measurement.

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