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Performance analysis of Radio over Fiber system using Direct and External Modulation Schemes

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Abstract— In this paper, the performance of eight dense wavelength division multiplexing optical data channels has been analyzed by employing direct and external intensity modulation schemes. These modulation techniques has been modeled using OptiSystem software(version 14.0). The various performance metrics such as Q-factor, BER, Eye height, Threshold and Eye opening have been evaluated w.r.t wavelength, bit rate and fiber length. Based on the simulation result obtained, it has been observed that external modulation is giving better Q-factor and minimum BER as compared to the direct modulation scheme.

Index Terms— Radio over Fiber, Direct Modulation, External Modulation, Dense Wavelength Division Multiplexing

1. INTRODUCTION

WITH the advancement in the communication systems, there is a need for large bandwidth to send more data at higher speed. Wireless network based on RoF technologies have been proposed as a promising cost-effective solution to meet ever increasing user bandwidth & wireless demands. RoF techniques are expected to form the backbone of the future 5G generation of wireless networks. Radio over Fiber Technology, the integration of microwave and optical networks is a potential solution for increasing capacity and mobility as well as decreasing costs in the access network [1]. Radio over Fiber is actually an analog optical link which transmits modulated RF signals. It transmits RF signal downlink and uplink, to and from control station (CS) and to base station (BS) (also known as remote access unit(RAU)). The main requirements of a RoF link architecture are duplex operation (downlink-uplink), reasonable length and high performance optical components. RoF systems have enhanced cellular coverage, lower attenuation losses, higher capacity, larger bandwidth and immunity to radio frequency interference. A general RoF architecture is shown in Fig.1. In this, RoF link consists of all the hardware required to impose an RF signal on an optical carrier, the fiber optic link and the hardware required to recover the RF signal from the carrier. At the optical transmitter, the RF signal can be imposed on the optical carrier by using direct or external modulation of the laser light. In the downlink transmission from the CS to the BS, the information from the internet or from the other CS is fed into a modulator in the CS. The RF signal modulates optical signal from laser diode. The modulated optical signal is transmitted to the BS via optical fiber. At the BS, the RF signal is recovered to detect the modulated optical signal by using a Photodiode. The recovered signal is transmitted to the Mobile Unit (MU) via antennas of the BS. In the uplink transmission from the Mobile Unit to the control station, the signal received at the BS are amplified and directly transmitted to the CS by modulating an optical signal from a laser diode. For utilizing the higher band width of optical systems, multiplexed systems are preferred for transmitting huge information on to a single fiber [2].Since RoF involves analog modulation, and detection of light, it is fundamentally an analog transmission system. Therefore, signal impairments such as noise and distortion, which are important in analog communication systems, are important in RoF systems as well. These impairments tend to limit the Noise Figure (NF) and Dynamic Range (DR) of the RoF links. DR is a very important parameter for mobile (cellular) communication systems because the power received at the BS from the MUs varies widely i.e. the RF power received from a MU which is close to the BS can be much higher than the RF power received from a MU which is several kilometers away, but within the same cell.

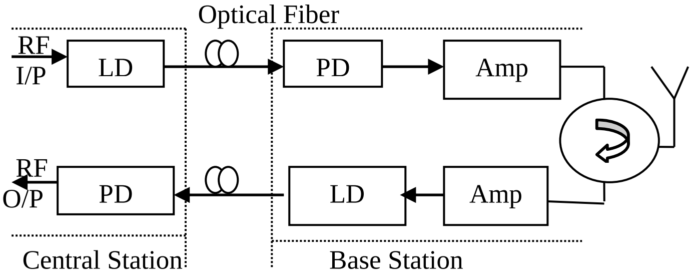

Fig.1 General RoF Architecture
(LD: Laser Diode; PD: Photo Diode; Amp.: Amplifier)

The remainder of the paper is organized as follows. Section 2 reviews background & related work. The operation of the proposed RoF has been discussed in Section 3. Section 4 analyzes the system performance and discusses the results extracted from simulations. Finally, Section 5 summarizes the main conclusion of the paper.

2. BACKGROUND AND RELATED WORK

Electrical to Optical conversion is performed by optical modulation. Modulation of the optical carrier can be achieved by either directly modulating the optical source or by using a separate optical modulator. These two techniques are typically referred to as direct modulation and external modulation respectively. The most straightforward method for modulation is to directly modulate the laser source. Due to the requirements of bandwidth and efficiency, only semiconductor lasers are of practical interest for direct modulation [3]. A unique feature of semiconductor lasers is that semiconductor lasers can be modulated directly by modulating the excitation current.

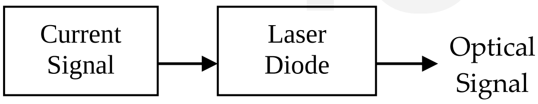

Fig.2 Direct Modulation Scheme

External modulation has higher performance for wide bandwidth optical fiber communication; by using high linearity $LiNbO_3$ external modulation to modulate signal. However the potential disadvantage is adding system complexity and high cost.

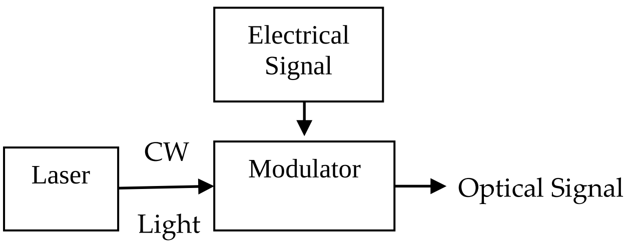

Fig.3 External Modulation Scheme

A typical RoF system consists of a laser source employing direct or external modulation, an optical fiber, and broadband photodetectors (PDs) [4]. External modulation is used when the transmission rate and bandwidth of the directly modulated lasers are not enough [5].The following types of the external modulators are used: (i) a Mach-Zehnder modulator (MZM) based on a Mach-Zehnder interferometer made of electro-optic materials of the $LiNbO_3$ type; (ii) an electroabsorption modulator (EAM) based on the Franz-Keldysh effect, *i.e.* the decrease of a semiconductor bandgap under the electric field applied; (iii) EAM based on the multiquantum well (MQW) structure using the quantum confined Stark effect (QCSE) [4]. EAM is characterized by a low cost, operates at lower voltage as compared to MZM, and can be monolithically integrated with a laser diode [5]. A GaAs EAM transferred to SiO_2 substrate has been demonstrated with a responsivity of 0.15 A/W for a downlink operation and a 2.5 dB ON/OFF ratio for an uplink [6]. EAM designed to operate both as modulator and as PD and having two separate radio frequencies (RF) ports for the modulation and photo detection had been developed [7]. Such a device called electroabsorption transceiver (EAT) can effectively operate at 60 GHz band and can be used for full-duplex RoF system [7]. RoF systems are successfully used in order to transmit RF modulated optical signals from a control station (CS) to remote access units (RAUs) which must be simple, small, easy to install, and low cost, while the signal processing, resources allocation and the system complexity should be transferred to CS [8].

3. PROPOSED MODEL

A DWDM Optical Communication System for eight channels by direct detection method as well as external intensity modulation has been modeled using OptiSystem(14.0). The simulation setup is shown in the Fig.4 and Fig 5. For transmitting the optical data channels, continuous wave semiconductor laser is used. In a direct detection method, a 1Gb/s NRZ signal is modulated by optoelectronic modulator whereas Mach-Zender modulator is used in external intensity modulation. In a external intensity method, the output of CW laser is again modulated by Mach-Zender modulator.

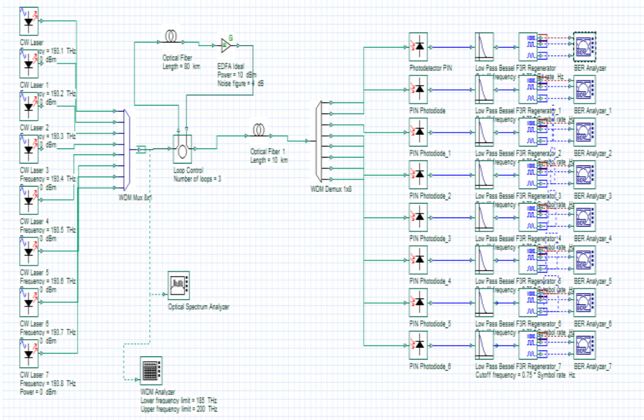

Fig.4. Direct Modulation of Eight Optical Data Channels

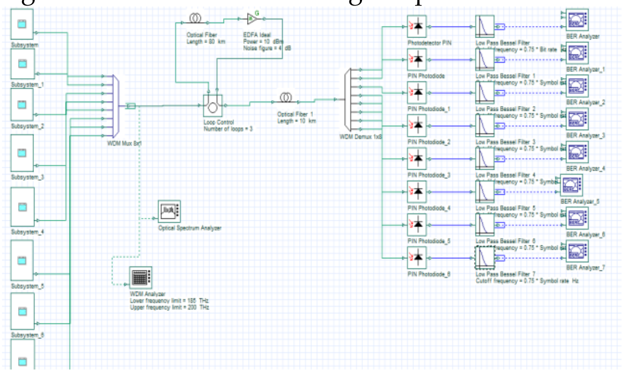

Fig.5. External Modulation of Eight Optical Data Channels

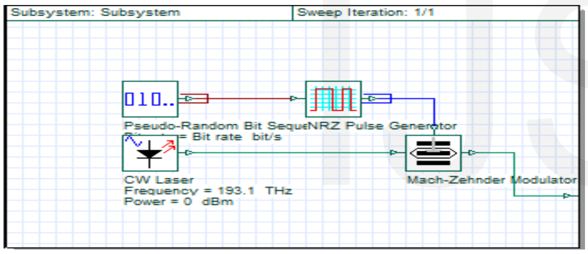

Fig.6. Subsystem of external modulator.

The output of the modulators are fed to single mode fiber and then amplified by inline Erbium Doped Fiber Amplifier. The centre frequency of first laser is taken as 193.1THz with the channel spacing of 0.1THz. At the receiver, Photodiode is employed to recover the original electrical signal back and the recovered signal is fed to the low pass filter. The BER analyzer at the receiving end estimates the BER, Q-factor, Eye height, Threshold and Eye opening.

4. RESULTS AND DISCUSSION

The OptiSystem software is used to simulate the optical communication experiments. The system performance is presented through visualizing tools, such as optical spectrum analyzer, WDM analyzer, and BER analyzer, which are used to display the spectrum at the output of the circuit components. The performance of external intensity modulation and direct modulation has been investigated in terms of Bit error rate, Q-factor and eye diagrams.

4.1 Bit Error Rate

In digital transmission the number of bit errors is the number of received bits of a data stream over a communication that have been altered due to noise, interference distortion bit or synchronization errors. The bit error rate or bit error ratio (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval [9].

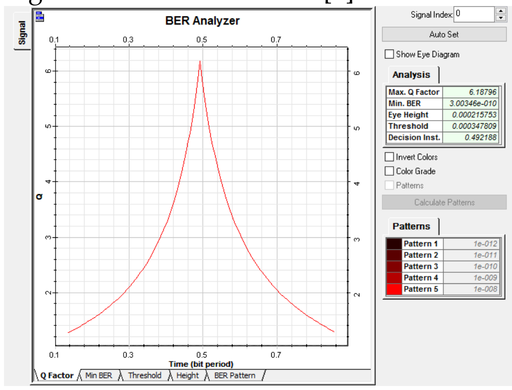

Fig.7 BER analyzer of Direct Modulation for 1GHz RF signal.

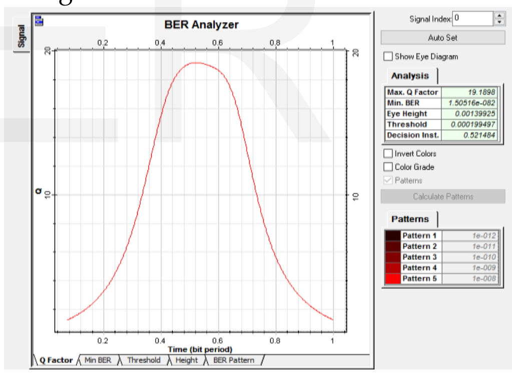

Fig.8 BER analyzer of External Modulation for 1GHz RF signal.

4.2 Eye Diagram Analyzer

The Eye Diagram Analyzer block of the OptiSystem software displays multiple traces of a modulated signal to produce an eye diagram. In telecommunication, an eye pattern, also known as an eye diagram, is an oscilloscope display in which a digital data signal from a receiver is repetitively sampled and applied to the vertical input, while the data rate is used to trigger the horizontal sweep. It is so called because, for several types of coding, the pattern looks like a series of eyes between a pair of rails [10].An open eye pattern corresponds to a minimal signal distortion. Distortion of the signal waveform due to intersymbol interference (ISI) and noise appears as a closure of the eye diagram. Fig.9 and Fig.10 shows the eye diagram of the Direct and External Modulation for 1GHz RF signal.

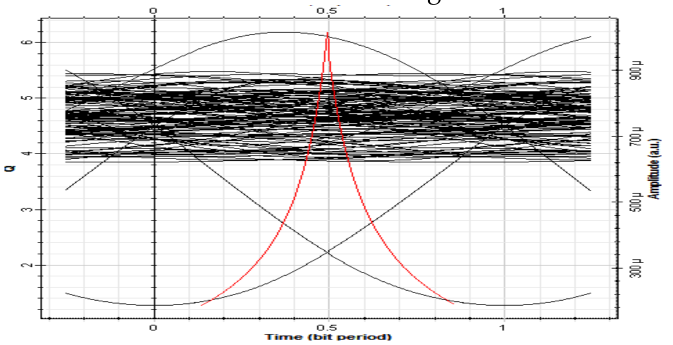

Fig.9 Eye Diagram for Direct Modulation

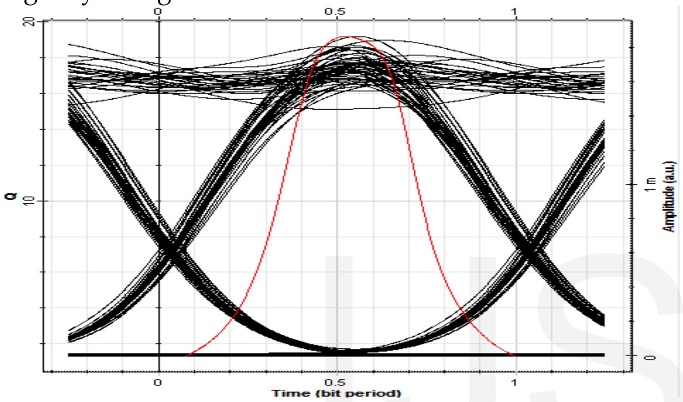

Fig.10 Eye Diagram for External Modulation

Table 1 shows the Q values, BER values for direct modulation and external intensity modulation respectively.

Modulation Techniques	Q-factor	BER	Eye Threshold
Direct Modulation	6.187	$3.003e^{-10}$	0.0003
External Modulation	19.189	$1.505e^{-82}$	0.001399

Comparing the characteristics of the system by using direct modulation and external intensity modulation it has been seen that external intensity modulation have better Q-factor and BER.

5. CONCLUSION

The direct and external intensity modulations in RoF systems have been presented and compared. It has been concluded that for the downstream architecture, direct modulation method can be employed since it operate at a higher RF input power and external modulation is desirable for the upstream architecture since it needs a higher optical power. The external modulation method exhibits better performance and produces a stable spectrum. The Q-factor, BER, Eye height values of the direct and external modulations have been obtained and compared. These values show that a much better modulation performance is produced by the external modulator than the direct modulation. The external modulation also has a better linearity than the direct modulation, because it has a wider dynamic range.

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