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RESEARCH ARTICLE

Generation and transmission of dispersion tolerant 10-Gbps RZ-OOK signal for radio over fiber link

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Abstract We proposed and demonstrated the generation and transmission of 10-Gbps return-to-zero ON/OFF keying (RZ-OOK) signal using a new technique without pulse carving at transmitter. The new technique is characterized by a 3 dB built-in gain with better tolerance for chromatic dispersion in standard single mode fiber (SSMF). Fiber Bragg grating (FBG) is used as chromatic dispersion compensating device to investigate the tolerance of the proposed scheme. The simulation model of wavelength division multiplexing (WDM) based on OptiSystem.v.8.0 is presented. Simulation results show that there are error free transmission performance in a distance of 600 km with negligible power penalty and improved receiver sensitivity compared to conventional pulse carving approach.

Keywords modulation, pulse carver, chromatic dispersion, fiber Bragg gratings, radio over fiber (RoF)

1 Introduction

In recent years, rapid growth in broadband services has increased the demand for transmission capacity and bandwidth. Traditional network cannot meet this continuous growing demand for high data rate and bandwidth. Optical fiber is becoming the most favorable delivering media due to its huge bandwidth and excellent transmission performance [1]. The main goal of communication systems is to increase the transmission distance. However, dispersion poses a serious problem in optical communication, which severely limits either bit-rate or transmission distance. Dispersion is a phenomenon where the light pulse is broadened, as it travels along the fiber cable. This broadening of pulse has a destructive effect on sequential pulses. Recently, several techniques of dispersion compensating have been reported to mitigate the dispersion effects in fiber at the transmitter side, on the fiber as well as at the receiver side [2]. Transmitter side techniques include various modulation formats with different coding scheme to generate mm-wave. Dispersion compensating techniques, such as dispersion compensating fiber (DCF) and fiber Bragg grating (FBG), are widely used as on line compensating techniques [3]. In recent years, FBG has been identified as viable alternative to DCF as a means of mitigating the effects of chromatic dispersion [4]. In addition, techniques based on Pre, Post and symmetric compensation techniques were also investigated using both FBG and DCF [5]. However, these schemes used complex modulation formats, needed extra circuits and devices or faced with issues like bandwidth limitations, non linearity at high bit rate and practical realization [6]. Fiber chromatic dispersion leads to fading affects and time shifting of codes, therefore signals are highly degraded [7]. However, the signal generated by single side band (SSB) modulation is more immune to fading affects as compared to double side band (DSB) modulation [8].

In this paper we propose and demonstrate a new technique to generate 10-Gbps return-to-zero ON/OFF keying (RZ-OOK) signal without using pulse carving. Tolerance against the chromatic dispersion in a radio over fiber (RoF) link was also analyzed using FBG for the proposed technique. Compared to prior schemes, the RZ-OOK signal is generated without pulse carving to alleviate the transmitter complexity and cost.

In this study, we used electro absorption modulator (EAM), as it is a useful device for data modulation and pulse carving. Furthermore it is potentially cheaper than $LiNbO_3$ Mach-Zehnder modulators and requires a lower driving voltage for data modulation [9]. A higher frequency optical mm-wave can be generated by an EAM because of their higher frequency response. The rest of the paper is divided in four sections. Section 2 describes the theory and dispersion compensation principle, Section 3 describes network architecture and

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operation, Section 4 discusses the transmission performance and analysis and finally Section 5 summarizes the paper with conclusions.

2 Theory and principle for dispersion management in fiber

A dispersion management scheme attempts to solve the problem of chromatic dispersion along standard single mode fiber (SSMF). The basic idea behind such scheme is quite simple and can be understood by using the pulse–propagation equation [10].

$$\frac{\partial A}{\partial z}+\frac{\mathrm{i}}{2}\beta_2\frac{\partial^2 A}{\partial t^2}-\frac{\beta_3}{6}\frac{\partial^3 A}{\partial t^3}+\frac{\alpha}{2}A=\mathrm{i}\gamma|A|^2A, \quad (1)$$

where A is the pulse-envelop amplitude, α is the fiber loss coefficient and γ is the non linear parameter of the fiber. β_2 and β_3 are the second and third order dispersion coefficient. β_3 can be neglected when β_2 exceeds 0.1 ps^2/km. Equation (1) can be solved by using Fourier transform [5]. For specific case of $\beta_3=0$, the solution becomes

$$A(z,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{A}(0,\omega)\exp\left(\frac{\mathrm{i}}{2}\beta_2 z\omega^2-\mathrm{i}\omega t\right)\mathrm{d}\omega. \quad (2)$$

Dispersion-induced degradation of the optical signal is caused by the phase factor $\exp(\mathrm{i}\beta_2 z\omega^2/2)$, acquired by spectral components of the pulse during its propagation in the fiber. All dispersion-management schemes attempt to cancel this phase factor, so that the input signal can be restored. Actual implementation can be carried out at the transmitter, at the receiver, or along the fiber link. A special kind of fiber, known as the DCF, has been widely used for this purpose [11]. The use of DCF provides all-optical technique that is capable of compensating the fiber group velocity dispersion (GVD) completely. It is possible only if the average optical power is kept low enough so that the non linear effects inside optical fiber are negligible. It takes advantage of the linear nature of Eq. (1).

To illustrate the physics behind this dispersion-management technique, consider the situation in which each optical pulse propagates through two fiber segments, the second of which is the DCF. Using Eq. (2) for each fiber section consecutively, we obtain

$$A(L,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{A}(0,\omega)\times\exp\left(\frac{\mathrm{i}}{2}\omega^2(\beta_{21}L_{\mathrm{SMF}}+\beta_{22}L_{\mathrm{DCF}})-\mathrm{i}\omega t\right)\mathrm{d}\omega, \quad (3)$$

whereas $L=L_{\mathrm{SMF}}+L_{\mathrm{DCF}}$ and β_{2j} is the GVD parameter for the fiber segment of length L_j (j = 1, 2). If DCF is chosen such that the ω^2 phase term vanished, then pulse will recover its original shape at the end of DCF. The condition for perfect dispersion compensation is thus

$$\beta_{21}L_{\mathrm{SMF}}+\beta_{22}L_{\mathrm{DCF}}=0. \quad (4)$$

An FBG acts as an optical filter because of the existence of a stop band, the frequency region in which most of the incident light is reflected back. The stop band is centered at the Bragg wavelength $\lambda_{\mathrm{B}}=2\bar{n}\Lambda$, where Λ is the grating period and $\bar{n}$ is the average mode index. The periodic nature of index variations couples the forward and backward propagating waves at wavelengths close to the Bragg wavelength and, consequently provides frequency-dependent reflectivity to the incident signal over a bandwidth determined by the grating strength. In essence, a fiber grating acts as a reflection filter.

Chirped fiber gratings have a relatively broad stop band, and they were proposed for dispersion compensation [12]. In essence, the stop band of a chirped fiber grating results from overlapping of many mini stop bands, each shifted as the Bragg wavelength shifts along the grating. The condition for perfect dispersion compensation is thus;

$$D_{\mathrm{SMF}}(\lambda_{\mathrm{S}})L+D_{\mathrm{FBG}}(\lambda_{\mathrm{S}})=0, \quad (5)$$

whereas $D_{\mathrm{SMF}}(\lambda_{\mathrm{S}})$ is the dispersion coefficient of conventional single mode fiber in the work, wavelength (λ_{S}) and $D_{\mathrm{FBG}}(\lambda_{\mathrm{S}})$ is the dispersion compensation amount of FBG. L is the length of SSMF.

3 Network architecture and operation

The simulation and experimental setup for the proposed system is shown in Fig. 1. The transmitter composed of four 10-Gbps RZ-OOK WDM signals using ITU Grid-100 GHz channel spacing which are generated by DFB laser sources, ranging from 1550.11 to 1552.52 nm. The simulation module consists of a combiner, who combines data with clock before it gets modulated by EAM, hence eliminates the requirement of the pulse carver. The transmission link composed of 12 × 50 km SSMF with FBG used to achieve dispersion compensation. The receiver module includes photo detector PIN, low pass Bessel filters and a 3R generator.

Figure 2 shows a comparison of our proposed transmitter to generate 10-Gbps RZ-OOK signal with conventional approach of generating RZ-OOK signal. Compared to prior scheme, the RZ-OOK signal is generated without pulse carving to alleviate the transmitter complexity, component counts and deployment cost.

The simulation models of OptiSystem.v.8.0 are used to verify the performance of our proposed scheme. And it is compared to the conventional scheme of $LiNbO_3$-Mach Zehnder modulator with pulse carver. The parameters used in simulation model are listed in Table 1. The performances of these models are monitored by quality factor (Q-factor) bit error rate (BER) and eye diagram.

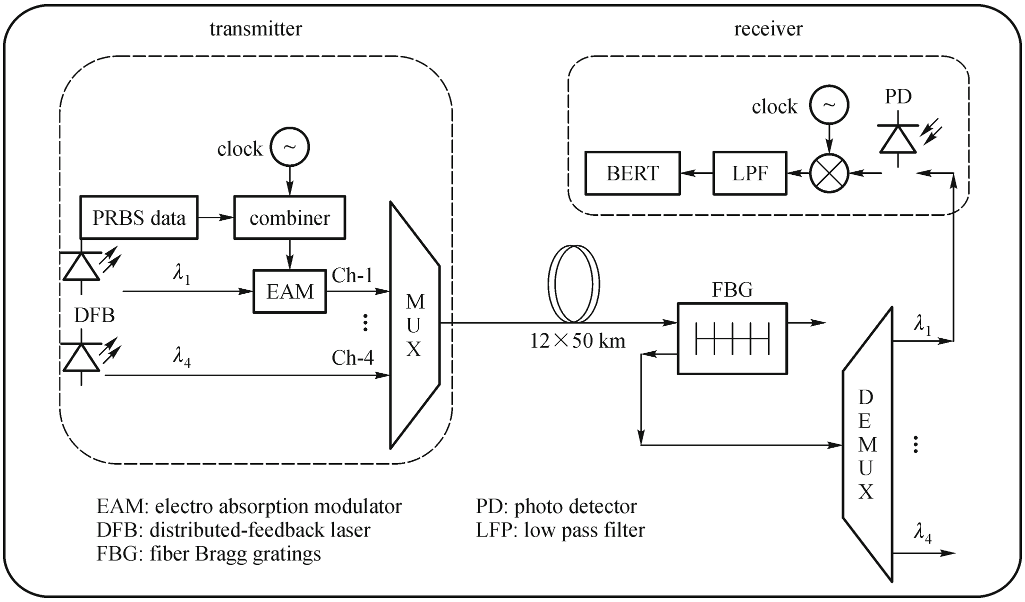

Fig. 1 Simulation and experimental setup of proposed RoF scheme

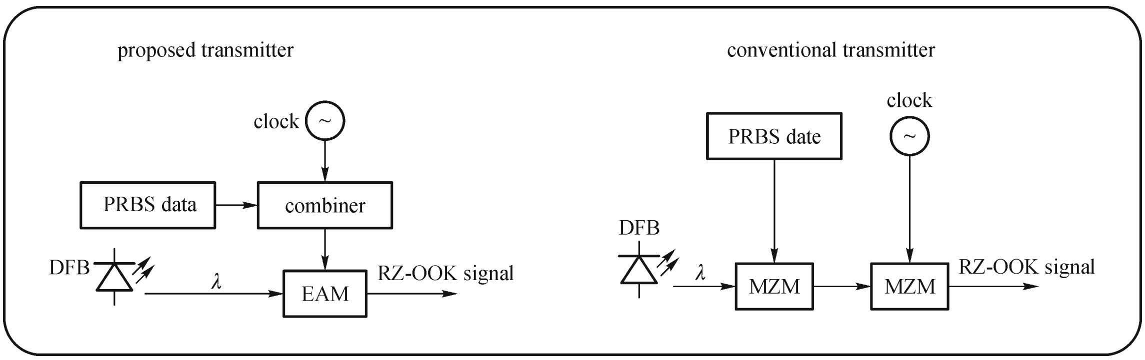

Fig. 2 Comparison of proposed and conventional transmitters

Table 1 Parameters used for simulation

parameters	values
dispersion parameter of SMF	17 ps/nm/km
dispersion slope of SMF	0.075 ps/nm^2/km
attenuation coefficient of SMF	0.2 dB/km
effective core area of SMF	80 um^2
non linear index-coefficient of SMF	2.6×10^{-20}
responsibility of photo detector	10 nA
dispersion compensation of FBG	–850 nm

4 Transmission performance and analysis

For simplicity we take one of the four inputs of 10-Gbps RZ-OOK signals for evaluation after transmission of 600 km. The fiber span include 12 transmission loops each having 50 km SSMF followed by FBG compensator. BER is analyzed against received optical power for ITU grid-100 GHz channel spacing. The comparison of BER as a function of launch power between proposed scheme and conventional scheme is given as in Fig. 3. The results show that there is an improvement in BER with increase in launch power, but it gets deteriorate when non linear impairment come into effect with increase in launch power. Our proposed scheme is shown that there is 2 dB improvement at BER = 1.0E–9 as compared to conventional scheme.

Figure 4 shows the respective performance of two schemes in term of Q-factor when launch power varied from –6 to 6 dBm. The proposed scheme has higher quality factor than that of conventional schemes. The maximum quality is recorded for launch power of 0 dBm before it gets degraded due to non linear factors at higher launch power.

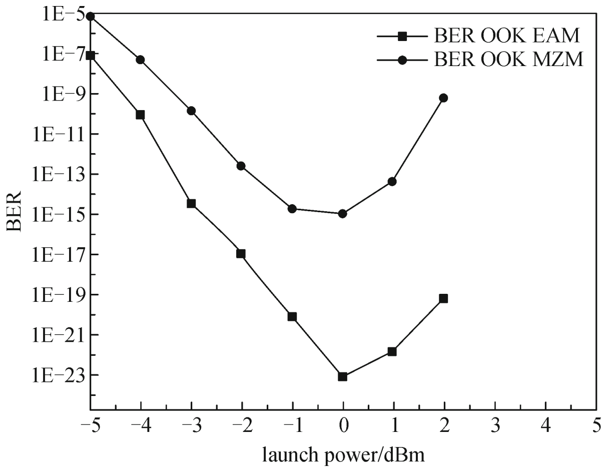

Fig. 3 Comparison of proposed and conventional schemes in term of BER vs. launch power

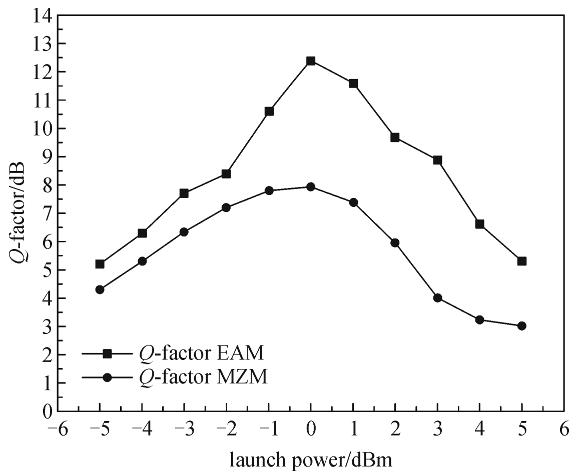

Fig. 4 Comparison of proposed and conventional schemes in term of Q-factor vs. launch power

Figure 5 depicts the BER for the two schemes against received optical power. The proposed system in this study presents better BER against the received optical power as compared to the conventional scheme which can improve receiver sensitivity. The eye diagram for the proposed and conventional scheme with FBG as compensator at 600 km is respectively shown as in Figs. 6(a) and.6(b).

5 Conclusions

We proposed and demonstrated the generation and transmission of 10-Gbps RZ-OOK data signal using a new technique without pulse carving at the transmitter. Error free transmission of 4×10-Gbps RZ-OOK WDM signals over 600 km SSMF was demonstrated with high

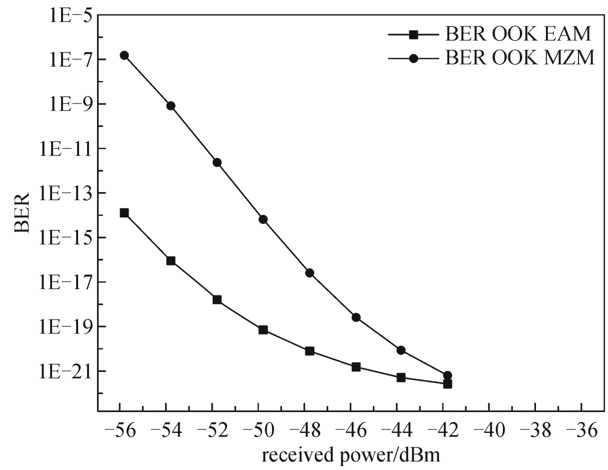

Fig. 5 Comparison of proposed and conventional schemes in term of BER vs. received optical power

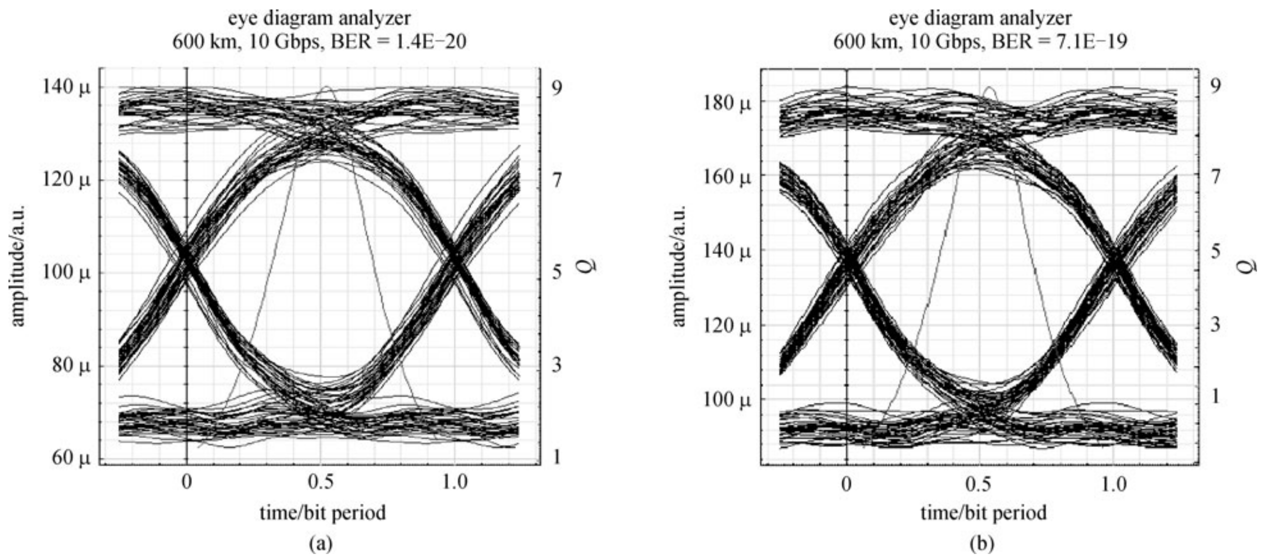

Fig. 6 Eye diagram for (a) proposed scheme and (b) conventional scheme after 600 km transmission

Q-factor and improved receiver sensitivity. The chromatic dispersion was effectively compensated with FBG compensator. The adoption of the proposed scheme will be helpful for reducing the deployment cost of RoF link as compared to conventional pulse carving approach.

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