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10 Gbit/s WDM-PON using downstream FSK coded by polarization modulation and upstream IRZ re-modulation

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In this paper, a centralized-light source-passive optical network (CLS-PON) structure with downstream 10Gbit/s frequency shift keying (FSK) signal generated by polarization modulation and upstream 10Gbit/s inverse-return-to-zero (IRZ) signal has been demonstrated by simulation. The bit error rate (BER) of downstream and upstream signals has been investigated in the case of back-to-back and the transmission of 20-km single-mode fiber (SMF) with no dispersion compensation, showing a potential transmission performance. Besides, the influence of FSK frequency spacing of 20GHz and 30GHz on the downstream and upstream signal has also been discussed. Moreover, the good dispersion tolerance of IRZ upstream is compared with ASK upstream.

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Keywords: Frequency shift keying (FSK), Inverse-return-to-zero (IRZ), Passive optical network (PON)

1. Introduction

Due to the broad bandwidth and better flexibility, the wavelength division multiplexing passive optical network (WDM-PON) has been considered as the best choice for next-generation access networks [1-4]. In order to reduce the fabrication and management cost, re-modulation of downstream signal has been used to generate upstream signal directly without additional light source. There have been several re-modulation schemes, such as differential phase shift keying (DPSK) and on-off keying (OOK) in upstream [5], downstream inverted return-to-zero and upstream OOK [6], down stream polarization shift keying (PolSK) and upstream amplitude shift keying (ASK) [7], downstream Manchester signal and upstream OOK signal [9] and etc.

Frequency shift keying (FSK) has been paid much attention owing to its constant intensity and lowest sensitivity with respect to fiber non-linearity impairment. FSK modulation has been combined with orthogonal modulations and adopted in optical labelling [10-13]. In previous reports, the FSK signal is obtained by directly modulating the bias current of a DFB laser [10] or a grating-assisted co-directional coupler with sampled grating reflector (GCSR) laser [11]. However, the bit rate of FSK label in this scheme is limited due to the low frequency modulation response of laser. In [12], a specially designed LiNbO3 external FSK modulator is reported, while it is very complicated in manufacturing and integrating. In [13], an optical FSK transmitter is reported based on polarization which is transparent to data rate and can be continuously tuned with the frequency spacing.

An inverse-return-to-zero (IRZ) signal is formed by inverting the intensity level of a conventional RZ signal, thus it carries optical power at both the mark levels and space levels in each bit period. After the re-modulation of downstream data, the amplitude change of downstream is not too sharp, so that the upstream IRZ data possesses a good tolerance of fiber dispersion. In this paper, A centralized-light source-passive optical network (CLS-PON) structure with downstream 10Gbit/s FSK signal and upstream10Gbit/s IRZ signal has been demonstrated by simulation. Bidirectional transmission is demonstrated at with little power penalty for downstream FSK signal and of 0.5dB for upstream IRZ signal. No CD compensation is used in our proposed 20 km-reach 10Gbit/s WDM-PON.

2. Principle of the FSK signal and IRZ signal

Fig. 1 illustrates the configuration and operation principle of the proposed OFSK transmitter. The polarization states of two continuous wave (CW) light beams (λ_1 and λ_2) are adjusted by polarization controller (PC) to make sure that they are linearly polarized and are 45° relative to the principal axes of the phase modulator (PM). The polarization states of these two light beams are shown in Fig. 2 A and B, respectively. The two light beams are combined and fed into a polarization beam splitter (PBS) which makes the light beam split into two parts with two orthogonal polarization states, shown in Fig.2 C and D. In the D branch, the light is polarization-modulated by a PM. There is no phase shift of the light beam when the signal “0” is carried on PM; while there will be π phase shift of the light beam when the signal “1” is carried on the PM. Therefore, the polarization state of light in this branch is varied with the signal which is shown in Fig.2 E. After a polarization beam combiner (PBC), the lights with orthogonal polarization states are combined shown in Fig.2 F. Thus after a polarizer whose polarization state with 45° polarization angle, the signal becomes an OFSK signal with constant intensity shown in Fig. 2G.

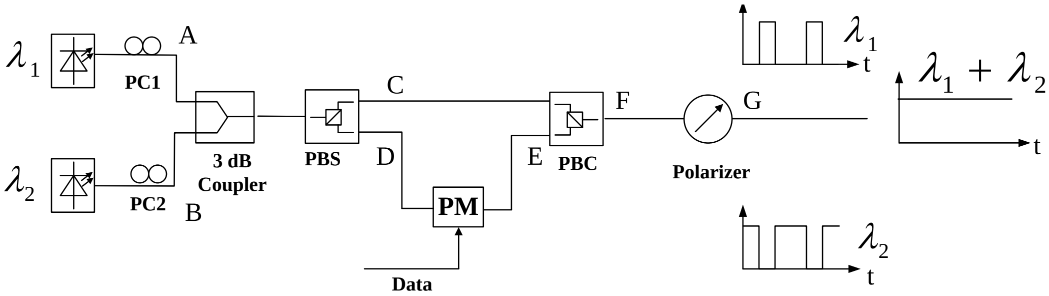

Fig. 1 Principle of optical FSK transmitter based on polarization modulation.

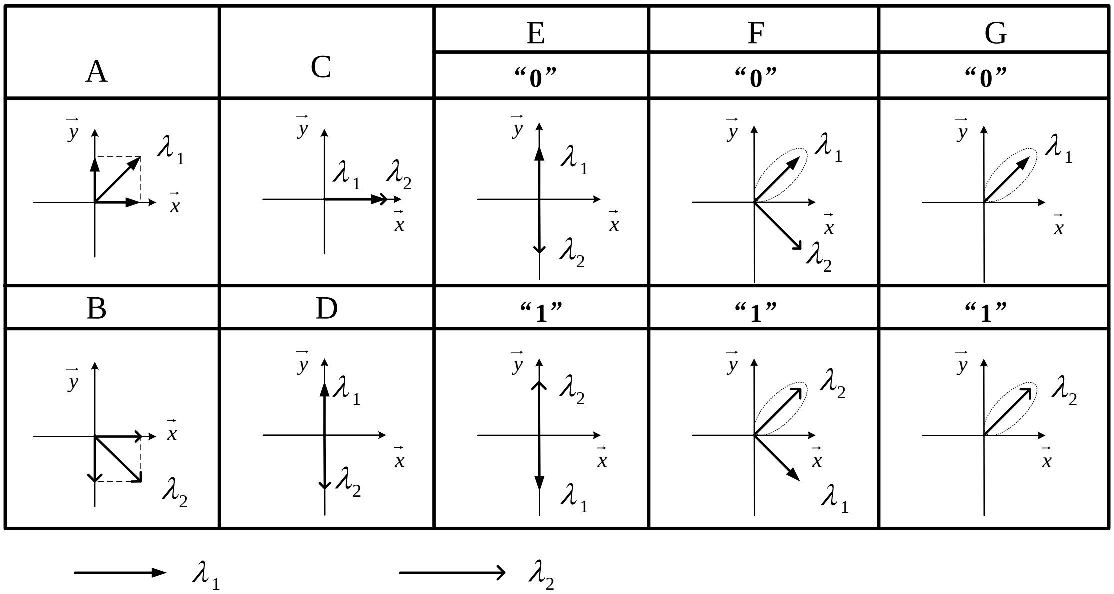

Fig. 2 Schematic of the polarization states at different points in Fig. 1.

Fig.3 shows the principle for generating an IRZ pulse. Fig.1 (a) illustrates the transmission characteristics of the Mach-Zenhder modulator (MZM). The electrical driving signal is an electrical return zero (RZ) signal which is obtained by a logic AND operation between a driving radio frequency (RF) clock and non-return zero (NRZ) RF signal. By adjusting the direct current (DC) bias of MZM, the electrical signal “0” modulates the optical signal as the mark level, while the electrical signal “1” as an inversed-pulse waveform as the space level. Therefore it carries optical power at both the mark level and the space levels in each bit period. The duty cycle of the IRZ signal is inversely proportional to that of the RF signal, and is also affected by the modulator’s response.

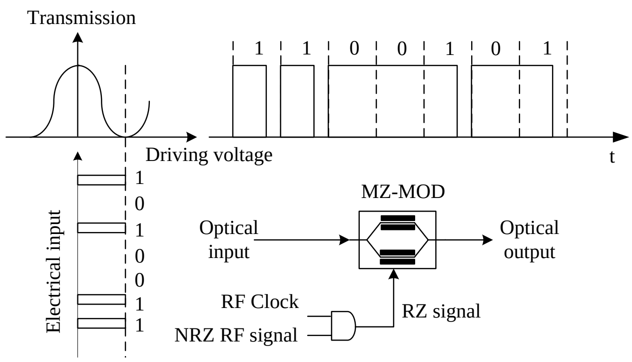

Fig.3 The principle for generating an IRZ pulse

3. WDM-PON Architecture with FSK downstream and IRZ upstream

Fig. 4 shows the proposed WDM-PON architecture utilizing FSK as downstream modulation format and IRZ as upstream modulation format. Downstream traffics are routed from the optical line terminal (OLT) by one or more multiplexers at the remote node (RN) to different optical network units (ONU). At the OLT, a FSK signal is obtained based on polarization modulation. At the ONU, a portion of received downstream signal power is fed into a photodiode for detection, while the remaining power is fed into a MZM driven by a RZ-shaped RF signal for upstream data re-modulation. The constant power of downstream IRZ signal provides the light source for upstream data.

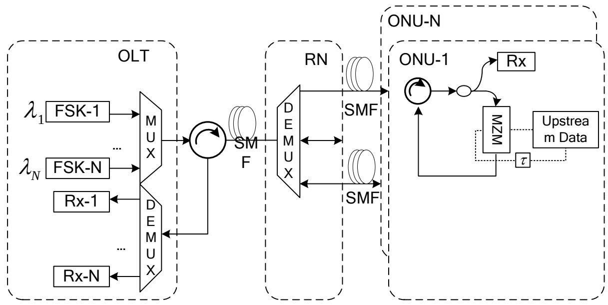

Fig. 4 The proposed WDM-PON architecture with FSK downstream and IRZ upstream

4. Simulation setup of PON system with FSK downstream and IRZ upstream

The experimental setup is shown in Fig.5. At the OLT, two CW lights at frequency 193.51 THz and 193.56 THz with the power of 1 mW are combined by a 3-dB coupler and split by a PBS. The polarization states of two light beams are adjusted by respective PC before fed into the PM. It is required that the polarization states of two lights are linearly polarized 45° relative to the principal axed of the PM and orthogonal with each other. One of the split lights after PBS is modulated in PM with 10Gbit/s pseudorandom bit sequence1 (PRBS) of length 2^7-1 to generate a polarization-modulated signal. The polarization-modulated signal and another split lights are combined by PBC. After the polarizer with 45 ° polarization angle, the FSK label with constant intensity is achieved, whose waveform and optical spectrum are shown in Fig.5(i) and (ii). Due to the above principle, the downstream signal is FSK modulated and then amplified by an erbium doped fiber amplifier (EDFA) to be transmitted in 20 km SMF. The dispersion coefficient and dispersion slope of SMF are 16ps/nm/km and 0.08ps/nm^2/km.

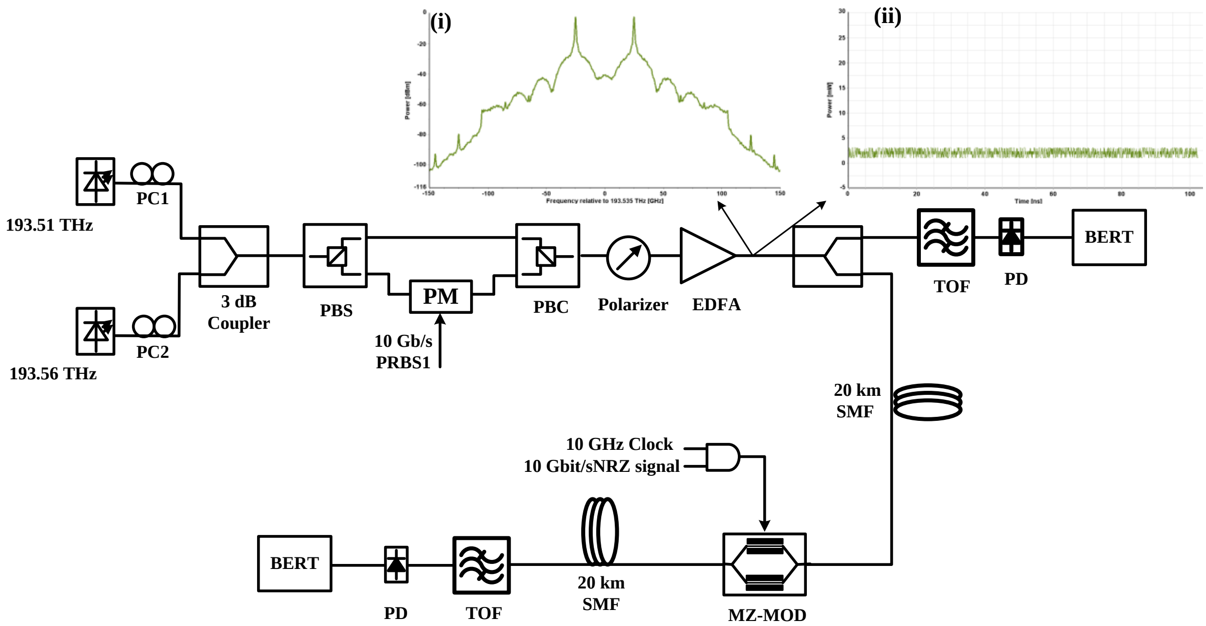

Fig.5 Simulation setup.

At the ONU, the signal is divided into two parts by a 50/50 coupler. One part of the FSK downstream signal is detected by PD after the tunable optical filter (TOF) with bandwidth of 12 GHz.

The other part is re-modulated by a MZM, driven by an RZ pulse-shaped 10Gbit/s PRBS2 data with length of 2^7-1, which is generated by the logic AND operation between a 10Gbit/s NRZ signal and 10Gbit/s clock. The upstream IRZ signal is sent over a 20 km SMF back to the OLT, where it is detected by a 10GHz PD.

5. Simulation, results and analysis

Fig.6 shows the BER curves of the downstream 10Gbit/s FSK signal. The power penalty of the 20km SMF transmission is neglectable at BER of 10^{-9}, compared with the back-to-back measurement. The typical received eye diagrams of back-to-back and 20km SMF transmission are shown in the inset of Fig.6(i) and (ii), respectively, and clearly indicates the good quality of the FSK signal after 20km transmission. To evaluate the power penalty owing to the re-modulation of FSK signal, BER measurements for the re-modulated IRZ signals are performed, as shown in Fig.7. The eye diagrams of IRZ with and without 20km SMF are presented in Fig.7 (i) and (ii), respectively. The back-to-back receiver sensitivity of the re-modulated upstream IRZ signal at ONU is around -21.5dBm, as shown in Fig.7. After upstream 20km SMF transmission, the upstream IRZ signal at OLT suffers from 0.5dB power penalty, which is an acceptable value

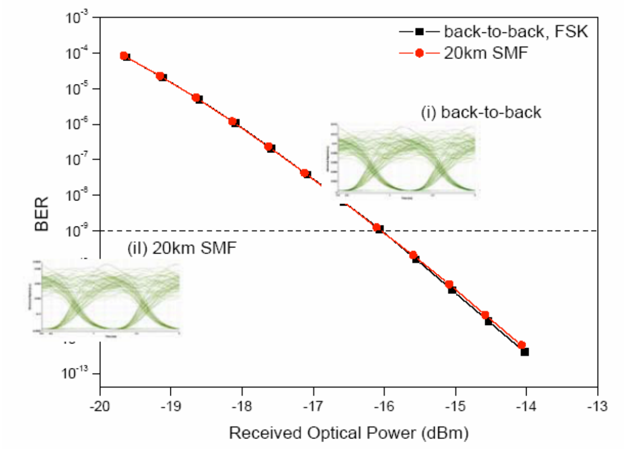

Fig.6 BER and eye diagrams of FSK downstream in the back-to-back (B2B) case and after transmission over 20-km SMF

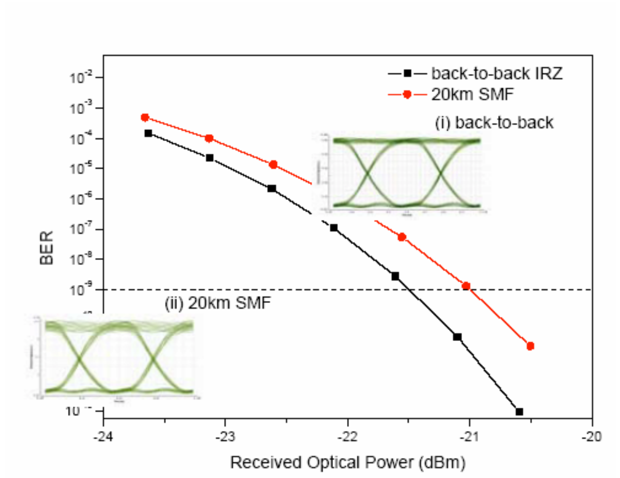

Fig.7 BER and eye diagrams of IRZ upstream in the back-to-back (B2B) case and after transmission over 20-km SMF

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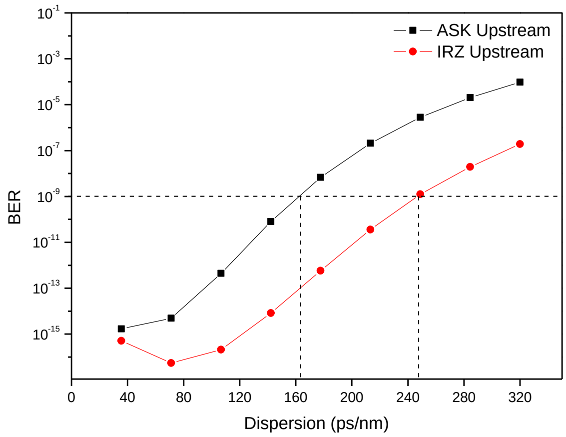

Fig.8 BER vs dispersion for ASK upstream and IRZ upstream in the WDM-PON system

Due to the orthogonal modulation adopted in the WDM-PON system, it is necessary to investigate the dispersion tolerance of the upstream signal. Fig.8 shows the BER curves of dispersion for ASK upstream and IRZ upstream with the SMF length of 20km. It is shown that the dispersion of ASK signal and IRZ signal with the same bit rate is ~160ps/nm and ~250ps/nm. Thus, the dispersion tolerance of IRZ signal presents a better dispersion tolerance than ASK signal. This is because the IRZ signal carries optical power at both the mark levels and space levels in each bit period. After the re-modulation of downstream data, the amplitude change of downstream is not too sharp, so that the upstream IRZ data possesses a good tolerance of fiber dispersion.

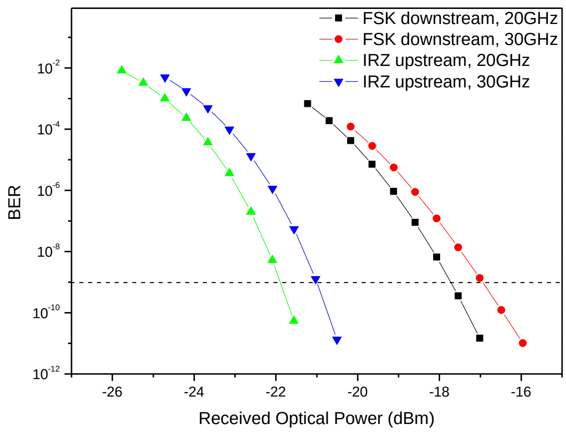

Fig.9 Transmission performance of FSK downstream and IRZ upstream with FSK frequency spacing of 20GHz and 30GHz.

Additionally, the influence of frequency spacing of FSK label on the WDM-PON system has been investigated, as shown in Fig.9. The frequency spacing of FSK label is set to 20GHz and 30GHz by adjusting the center frequency of the two lasers. From Fig.9, it can be observed that the enlarged frequency spacing deteriorates the BER of downstream signal and upstream signal. The receiver sensitivities of FSK downstream and IRZ upstream with frequency spacing of 20GHz are both ~1dB lower than that of 30GHz. For FSK, varying frequency spacing has little influence on the FSK label because only one FSK tone is needed to be detected at the receiver. However, the reduced receiver sensitivity is mainly caused by the dispersion of SMF without dispersion compensation. For IRZ upstream signal, the power penalty for different frequency spacing arises due to the increased dispersion resulted by the broadened optical spectrum.

5. Conclusion

A novel carrier-reuse 10Gbit/s WDM-PON using downstream FSK and upstream IRZ re-modulation signal scheme has been demonstrated. The FSK downstream is generated based on polarization modulation with the advantages of transparency of data rate and continuously tuned frequency spacing. IRZ signal is used for upstream as its good tolerance of chromatic dispersion. A 20km-reach WDM-PON without chromatic dispersion compensation has been realized and a 0.5dB power penalty has been added after the re-modulated and transmission. The proposed scheme using the FSK downstream and IRZ upstream is shown to be a potential candidate for the next-generation wavelength re-modulation WDM-PON.

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