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10 GBPS Full Duplex Transmission Using Reed-Solomon Encoder and Decoder

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Abstract— We have proposed and demonstrated a novel architecture for a bidirectional wavelength division multiplexed passive optical network (WDM-PON) system based on forward channel coding (FEC) method by employing Reed-Solomon (RS) encoder and decoder in the configuration. We have used mutually injection locking technique by employing Fabry-Perot laser diode (FPLD) as the broadband light source (BLS). The remodulation technique has been used for the uplink transmission by deploying reflective semiconductor optical amplifier (RSOA) at the user end. The RS codec has enhanced the performance of the system as it can transmit 10 Gbps data rate in the downlink and the uplink as well. Among many types of RS codes we have preferred the RS (255, 223) for its effectiveness and the capacity of burst error correcting. The uplink and downlink transmission performances are checked by the impressive eye diagrams and the low bit error rate (BER), measured at BER tester or eye diagram analyzer. The results provide its utility as an effective and suitable WDM-PON system for next generation broadband communication.

Index Terms— WDM-PON, RS encoder and decoder, FPLD, RSOA

I. INTRODUCTION

WDM-PON has long been considered as the ultimate solution for the bandwidth hungry future communication world as it has many advantages like huge bandwidth, high capacity and secure transmission [1]-[5]. Most of the earlier works have emphasized on the cost-efficiency of the system. They have preferred injection locked FPLD as the BLS to the asynchronous spontaneous emission (ASE) light sources, the light emitting diode (LED), etc [6-7]. The injection locking technique was introduced in the classic paper of Van der Pol in 1927[8]. Adler has described it for the semiconductor devices [9]. Several approaches have been taken for applying the injection locking technique in the WDM-PON system [10-12]. Among them mutually injection locked FPLD has emerged as the most popularized cost-effective method for the optical wave transmission [13-14]. There are two FPLDs involved in this process. One is acting as the master laser and other one is acting as the slave laser. In the injection-locking technique the light wave from master laser has penetrated into the slave laser and enforced it to operate it in a specific wavelength. Direct modulation technique is preferred to the external modulation technique due to its cost-efficiency. The direct modulation in the FPLD is discussed briefly in [15-16]. The Remodulation technique is cost-effective measure which is widely accepted for the uplink transmission in the recent works on full duplex transmission in a WDM-PON [17].

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With the advent of RSOA the interest in remodulation technique has been increased. RSOA has huge bandwidth and capacity of operating in a low drive current [18-20]. For high data rate transmission, the FEC method is introduced in the system. The scheme of channel coding has corrected the errors and made the system more secure [21-23]. RS codes are suitable choice due to having capability of correcting burst error code. RS codes are expressed as RS (n, k), where ‘n’ is the codeword length and the ‘k’ is the un-coded data length. The number of error symbols can be corrected by the codec is‘t’ = (n-k)/2. The number of the bits in each symbol is ‘m’ where n = (2^m-1). RS codes have several advantages over other error correcting codes like turbo codes, LDPC codes, etc. The low power loss and high coding rate have made the RS codec appropriate for the next generation WDM-PON systems. Recently some works have been reported on the WDM-PON system, using FEC method by employing RS encoder and decoder in the design [22-24]. But these architectures are not cost-effective and therefore not apposite for the subscriber’s demand.

In this paper we have proposed a novel architecture, having capability of full duplex transmission of 10 Gbps data rate over a 50 km SMF. The mutual injection technique has been used for generating carrier wave by direct modulation method in the FPLD. The remodulation technique is used as the RSOA is deployed at the optical network unit (ONU) for uplink transmission of 10 Gbps data rate. We have applied the RS (255, 223) codec in the proposed architecture for the FEC method which has enhances the speed and the security of the system. The RS (255, 223) has greater capacity of correcting errors in the system. The RS (255, 223) encoder has encoded the massage signal at the transmitter end and the decoder has decoded the received signal by locating and correcting errors. If the modulation bandwidth is limited then the performance of the system is getting better by increasing the redundancy in the system. The encoder has added redundancy to the massage input. The redundancy has been detected by parity symbols. The noise or the error symbols have generated the syndromes in the syndrome calculator by operating with the parity. The syndromes have been removed by the decoder and a faster transmission of higher data rate is provided to the user end. The downlink and the uplink transmission performances have been checked by the BER and the eye diagrams at different lengths of SMF.

II. EXPERIMENTAL SETUP

Fig. 1 has shown the experimental set up for our proposed scheme, which is capable of transmitting 10 Gbps data rate at uplink and downlink. We have used mutually injection locked FPLD as the BLS, which is injection locked by the master FPLD at a wavelength of 193.1THz.

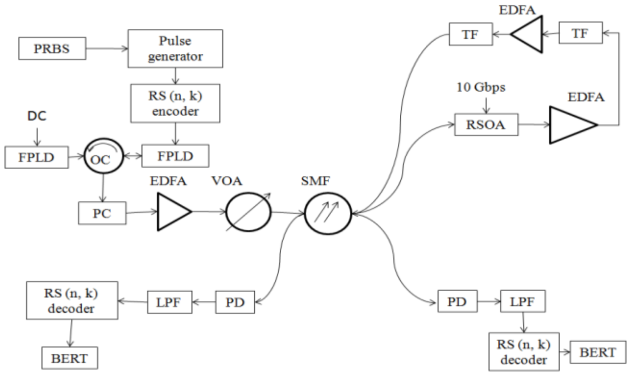


Fig.1. Block diagram of experimental set up

The carrier wave is directly modulated by the 10 Gbps encoded data-rate, generated by the pseudo random binary sequence (PRBS) generator of pattern length (2^{11}-1), the NRZ pulse generator and the RS (255, 223) encoder. Here 'n' is 255 and 'k' is 223. Parity symbols are introduced in the codeword by the RS (255, 223) encoder. Optical-circulator (OC) is used for the injection locking and transmitting the modulated carrier wave to the polarization controller, having symmetry factor of 10. Then the signal is passing through the erbium doped fiber amplifier (EDFA), having length of 5m and pumping power of 100 mw, and a variable optical attenuator (VOA) of 10 dB attenuation. After that the light wave is transmitted to the receiver end through the SMF, having dispersion of 16.75 ps/nm/km and attenuation of 0.2 dB/km. At the receiver end downlink signal is converted to electrical signal by the photo-diode PIN (PD) and then passed through the Bessel low pass filter (LPF). The filtered signal is decoded by the RS (255, 223) decoder and reached to the BER analyzer. At the analyzer the downlink transmission performance is checked by the clear eye diagrams and low BER for the different lengths of SMF (0km and 50km). The downlink transmission is received by the RSOA at the ONU also. The RSOA has the injection power at 12 dB and the injection current of 60 mA. The signal is remodulated at the RSOA by 10 Gbps data rate, generated by the PRBS of word length of (2^{11}-1) and encoded by the RS (255, 223) encoder. The remodulated signal is passed through the first order tunable filters, EDFA and fed into the SMF. After that the optical signal is converted to electrical one at the optical line terminal (OLT) by the PD and filtered by the Bessel LPF. The filtered signal is decoded by the RS (255, 223) decoder and the decoded signal is analyzed by the clear eye diagrams and the low BER measured by BER analyzer.

III. RESULTS & DISCUSSIONS

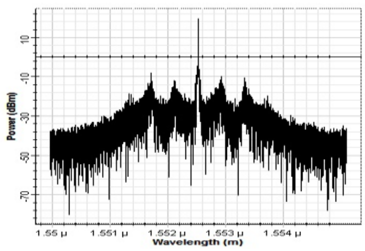


Fig. 2 spectrum after injection locking at FPLD

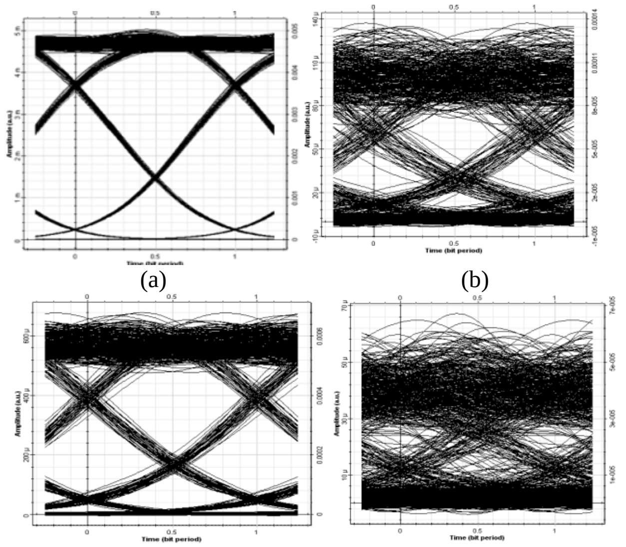
The information signal is encoded by the RS (255, 223) encoder. The performance of the encoder is depending upon the Galois field multiplier, based upon finite field elements. The generator polynomial is given by the following equation

$$g(x)=\prod_{i=1}^{i=32}(x+\alpha^{i}) \qquad (1)$$

The primitive polynomial is given as:

$$p(x)=\alpha^{8}+\alpha^{4}+\alpha^{3}+\alpha^{2}+1 \qquad (2)$$

Where α is the primitive polynomial in the GF (2^8) field. The number of parity symbols induced in the codeword is 16. The transmitted wave is carrying the parity symbols over the SMF to the ONU; where RSOA has received the signal and remodulated it by the 10 Gbps data rate. The RSOA is operating in the saturation gain region and has reduced the downlink residual signal and the Raleigh backscattering. Thus the noise has been reduced as it depends on the residue of the downlink signal, backreflection and the backscattering effect.



(a) (b)

(c) (d)

Fig. 3. Eye diagrams for downlink transmission for (a) b-t-b and (b) 50 km and eye diagrams for uplink transmission for (a) b-t-b and (b) 50 km

Fig.3 has shown the eye diagrams for the uplink and downlink signals for B-t-B and 50 km SMF transmission. The uplink signal shows more noise than the downlink signal due to the backscattering, dispersion, attenuation, etc. The noise effects are increasing as the transmission distance increases. The high data rate transmission also causes noise in the uplink broadcast.

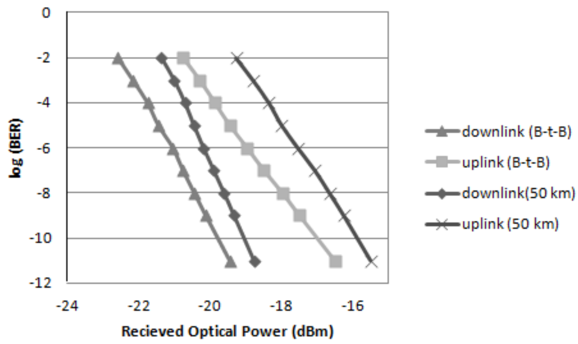


Fig.4. BER curves for uplink and downlink transmission over B-t-B and 50 km SMF

Fig. 4 has shown the BER curves for uplink and downlink transmission. The power penalty is recorded as 2 dB for the downlink and 3dB for the uplink transmission for the BER of 10^{-9} order. The increase in the noise in the uplink transmission due to backscattering, dispersion etc. has degraded the feat. The performance has been improved by the FEC method by deploying RS (255, 223) encoder and decoder in the proposed system. The transmission is getting faster and the capacity of the system has been increased. The coding gain of RS (255, 223) is 14.6 dB which is suitable for the system operation. The redundancy is 14.35 and the coding rate is 0.8745 of RS (255, 223) codec.

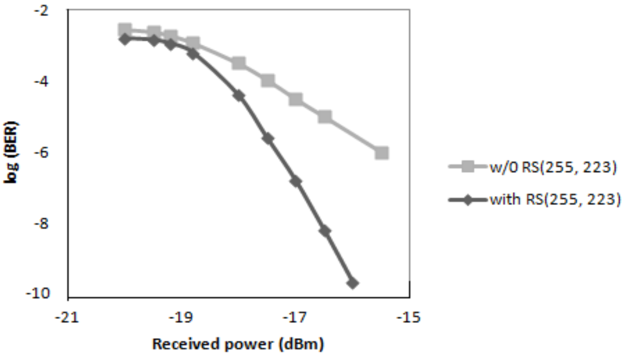


Fig.5 measured BER curve for the system with RS codec and without RS codec at the downlink.

Fig.5 has shown that the BER performance is getting better by applying the RS coder in the proposed scheme. The BER is related to the symbol error rate by the following expression:

$$BER = 1-(1-P_s)^{1/m} \quad (3)$$

P_s is the symbol error rate and m is the number of bits in each symbol. The plot in the fig.5 has justified the relation. The transmission performances in the uplink and the downlink have been improved by adding of redundancy by the RS codec.

IV. CONCLUSION

The uplink and downlink transmission performance of the proposed configuration is successfully analyzed for b-t-b and 50 km SMF. The low BER and clear eye diagrams have shown the long haul transmission capability of the design. The injection locking technique, the direct modulation by FPLD and the remodulation technique by RSOA have successfully executed in the proposed architecture. The FEC method has enhanced the capacity of the circuit. The fruitful execution of the scheme by employing RS (255, 223) codec in the system has made this configuration suitable for the next generation WDM-PON system.

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