A novel architecture of hybrid Phase-Modulated Duobinary modulation format

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A novel architecture of Phase-Modulated Duobinary (PM-Duobinary) modulation format is proposed in this study. It is an enhanced modulation scheme to the conventional Duobinary modulation format. The proposed hybrid PM-Duobinary is an external modulation format, where the modulators are needed for the generation of the optical signal for transmission. In this paper, the performance comparison among PM-Duobinary modulation format, conventional Duobinary modulation format, and non-return-to-zero on-off keying (NRZ-OOK) modulation format is also investigated. The obtained results show that, the PM-Duobinary modulation format can significantly improve the transmission distance by 44.4% and 80.5% over the conventional Duobinary and the NRZ-OOK modulation format, respectively.

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1. Introduction

For decades, a number of simulations and experiments concerning transmission through the use of a variety modulation formats have been reported in [1-16]. The non-return-to-zero on-off keying (NRZ-OOK) intensity modulation has been used as the data format for the optical transmission systems. However, when channel data rates increase and system tolerances become more important, the use of alternative modulation formats can be beneficial. One of the most promising alternative modulation formats is the Duobinary format. Duobinary modulation turns out to be a much better choice since it is more resilient to dispersion and also reasonably simpler for implementation. Although Duobinary modulation format is superior compared to NRZ-OOK modulation format, however, there is still way to further improve its performance. Therefore, an enhanced modulation scheme is proposed in this study, known as Hybrid Phase-Modulated Duobinary (PM-Duobinary) modulation format through the implementation of a phase modulator with the existing conventional Duobinary modulation format, which has superior performance compared to the conventional Duobinary and thus, better than the NRZ modulation format. A better and more cost effective way is to develop a technology that enhances the network performance without having to replace the fiber cable. This can be achieved by developing a more efficient transmitter and receiver, such as the proposed PM-Duobinary modulation transceiver. Through the implementation of such modulation format, network performance can be increased without having to sacrifice the shared optical components, especially the fiber cables. Consequently, cost savings are realised.

The main objective of this study is to carry out research on PM-Duobinary modulation format for short haul (access network) communications. It looks into how and why PM-Duobinary modulation format could provide a better solution for the optical communication systems with the increasing demand in higher data rate and high reliability if compared to the conventional NRZ and conventional Duobinary modulation format. This study also aims to highlight the selection of the main components of an optical communication system, namely, optical source, optical fiber, and optical receiver; so as to minimize the cost for certain modulation format in such optical communication system. To verify the proposed solution, the above mentioned modulation format will be constructed and simulated using OptSim^{TM} (optical system simulator).

2. Proposed scheme and setup

Fig. 1 shows the schematic diagram of the proposed PM-Duobinary modulation format. In the PM-Duobinary system, the laser source is modulated by a phase modulator before it is sent to the Mach-Zehnder Modulator (MZM) for transmission as stated earlier. The precoder used in the PM-Duobinary system is similar to the conventional Duobinary precoder. The reason of using the same precoder is to show a fair comparison for the results analysis. The PM-Duobinary signal is transmitted afterward through the fiber. However, a conventional Intensity Modulated Direct Detection (IMDD) receiver cannot be used due to the involvement of phase modulation in the PM-Duobinary modulation format. A receiver that is capable of analysing the phase as well as intensity modulation is deployed in the receiver system. Thus, a balanced receiver is used as the detector in the proposed PM-Duobinary system.

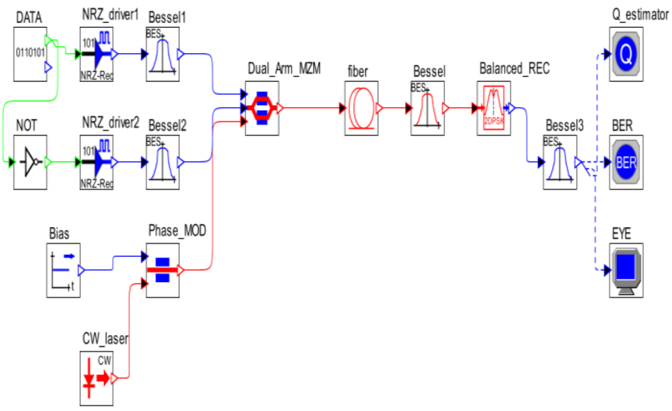


Fig. 1. Schematic setup for PM-Duobinary.

Since the above modulation format is meant for passive optical access network, thus, no optical amplifiers are needed in the transmission path. The wavelength of the modulated signals of the above schematic diagram is set to 1550 nm. The PM-Duobinary transmitters are driven by the pre-coded 10 Gbps pseudo-random bit sequence (PRBS) logical signals. The NRZ drivers are used to convert the binary pseudorandom signal into equivalent electrical signals to drive the MZMs. As stated, the launching optical power is set to 0 dBm for the maximum power transfer and for coupling into the fiber for the optimum transmission.

The role and principle of the phase modulator is stated in this section. Particularly, the timing and synchronization have been done by the bias voltage. As shown from Fig. 1, DC bias impresses the phase modulator. This will give the fixed phase rotation to the Continuous-wave Lorentzian (CW) light. The CW light is modulated by the phase modulator before it is fed to the Dual-Arm MZM. By changing the bias voltage, it also changes the output. In this study, the bias voltage is fixed at its optimum point; therefore, it will have a constructive matching of the PM light with the Dual-Arm MZM signals. In this modulation format, the matching of signals occurs when both correctly PM light signals are inputted to the Dual-Arm MZM to have a construction optical output from the modulator. For the SSMF model deployed in the above modulation format, dispersion (D), non-linear coefficient (n_2), and effective core area (A_{eff}) are set to 16ps/nm/km, 2.5×10^{-20} m^2/W, and 80 μm^2, respectively. The phase modulator that is used in the PM-Duobinary modulation format has set parameters to 5 V of π voltage and excess loss of 3 dB. It is biased with a voltage of 5 V through a bias wave generator. The output of the phase modulator is a PM laser source fed into the MZM. The data is encoded in this PM laser source where the output of the laser having a series of pulse pairs. Each pulse pair has a PM portion from the laser source, followed by a fixed phase portion from the MZM. The PM portions have a frequency shift, relative to a carrier frequency. The fixed phase portions have a phase difference, relative to a preceding pulse pair corresponding to the frequency shift of the PM portion. The fixed phase portions of the signal have a frequency, substantially equal to one another to the carrier frequency. Based on the degree of phase shift from the laser, light from two segments interferes at the recombining junction destructively or constructively before it is transmitted into the fiber. The high dispersion tolerance is due to phase-correlative modulation among the adjacent bits via precisely controlling the phase shift of the laser source through the phase modulator [17]. With proper controlling, the phase flip between 0 and π (in the middle of the space bit) can be realised that causes destructive or constructive interference between the energies on either side of the middle of the space after the dispersion introduced broad spectrum [17]. The π out of phase is the key to the dispersion tolerance. This resulting phase correlation is similar to that of the optical Duobinary modulation. The asynchronous data signal will be transmitted to the fiber by the MZM.

Since PM-Duobinary modulation system has phase signal in the transmission path, therefore, normal IMDD receiver cannot be deployed. For the balanced receiver used, it is composed of a tunable Mach-Zehnder interferometer, which has two optical output ports. In the interferometer, the optical paths differ by a delay τ, must be equal to the bit time duration, where τ is 1 bit or 100 ps in this setup. Each of the optical output is detected by a PIN photo-detector and the output electrical signal is the difference between the detected currents. The Bessel filter is employed after the receiver, which is low pass type with a number of poles of 5 and -3 dB of 10 GHz bandwidth. Table 1 shows the component parameters used in PM-Duobinary.

Table 1. Component parameters for PM-Duobinary.

Data Source	10 Gbps, with word length of PRBS of 2^7-1
NRZ precoder	Upper level: +5 V Lower level : -5 V
Electrical Bessel Filter	Number of poles: 5 -3 dB bandwidth: 10 GHz
Standard single-mode fiber (SSMF)	Attenuation: 0.2 dB/km Zero Dispersion Wavelength: 1391.5 nm Dispersion Slope at 1550 nm: 0.058 [ps/nm^2/km] Dispersion at 1550 nm: 17 ps/nm/km Reference Frequency: 193.4 THz
CW laser	Center emission wavelength: 1550 nm Optical launching power: 0 dBm

3. Results and discussion

The results obtained from the proposed PM-Duobinary modulation format are compared with the NRZ-OOK and the conventional Duobinary modulation formats. Thus, the results of NRZ-OOK and conventional Duobinary modulation formats are deemed to be a reference point for the performance comparison of the proposed PM-Duobinary modulation format. A simple thermal noise limited receiver and bit-error-rate (BER) tester are used to calculate the BER via standard quasi-analytical (QA) method, while a separate Karhunen-Loeve (K-L) BER estimator [5] is used to calculate the BER via more advanced K-L method. The BER measurements compare digital input and output signals to assess what fraction if the bits are received incorrectly. They offer a quantitative measurement of signal quality. In practice, a data-generator (PRBS) generates a randomised bit pattern, which is transmitted through the system. The total number of bits transmitted are counted and compared with the total number of bits received at the receiver end. The errors occur when the signal bit is interpreted by the receiver (does not match with the transmitted signal). The wrong bits can be obtained in some cases due to worse transmission quality.

The curve of BER versus distance transmitted of PM-Duobinary modulation format is plotted in Fig. 2. At the desired BER of 10^{-9}, it corresponds to 130 km of transmission. The transmission further than this distance will not comply with the communication link requirement. It is observed that, the proposed PM-Duobinary modulation format is capable of delivering signals up to distance of 130 km; thus, if the access network link that covers distance more than 100 km, the proposed PM-Duobinary modulation format can be taken into consideration.

The eye diagrams for the PM-Duobinary modulation format are shown in Fig. 3. Fig. 3 shows the received signal from the eye diagram of the PM-Duobinary modulation format at 10 km, 80 km, 120 km, and 150 km, respectively. At 10 km of transmission distance, the eye opening is wide and easy to distinguish. At 80 km, the eye diagram of this PM-Duobinary modulation format is still clearly depicted; however, noise is noticeable at the lower levels of the eye diagram. At 120 km, the eye diagram starts showing the indistinct pattern, where the lower level of the eye diagram starts accumulating higher level of noise; however, the eye opening still can be determined. At 150 km, the eye opening is severely distorted, where high noise level accumulating at the upper and lower part of the eye diagram.

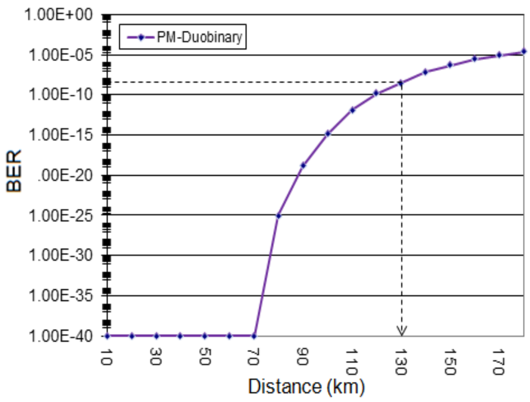
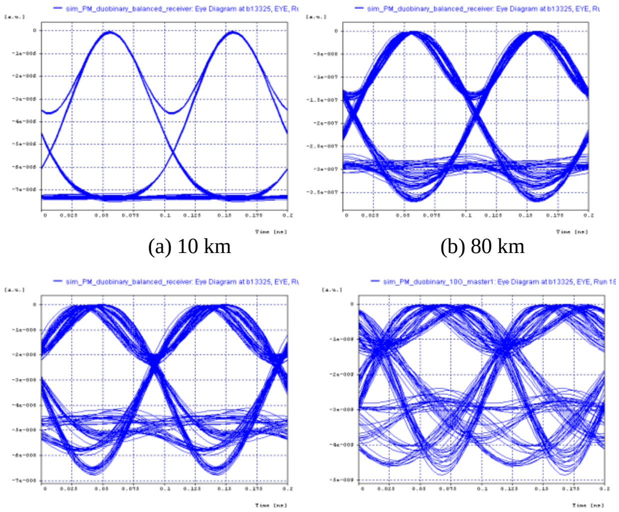


Fig. 2. BER versus distance (km) for PM-Duobinary modulation format.



(a) 10 km (b) 80 km

(c) 120 km (d) 150 km

Fig. 3. Eye diagram of PM-Duobinary modulation format at (a) 10 km; (b) 80 km; (c) 120 km; (d) 150 km.

Fig. 4 shows the performance comparison among NRZ-OOK, conventional Duobinary, and PM-Duobinary modulation format, in terms of BER versus transmission distance (km). From the results obtained from Fig. 4, it can be noticed that the maximum distance achieved by the proposed PM-Duobinary modulation format is 130 km. It is further observed that, the maximum transmission distance is limited to 90 km by the conventional Duobinary modulation format. While for the NRZ-OOK modulation format, it corresponds to a distance of 72 km. Hence, the proposed PM-Duobinary modulation format has shown improvement of 44.4% and 80.5% over the conventional Duobinary and the NRZ-OOK modulation format, respectively at a given BER = 1×10^{-9}. Therefore, by simply adding the phase modulator to the transmission system (without any modification to the existing fiber facilities), higher improvement is achieved in terms of transmission distance. Thus, the rural areas, which are located far away from the central offices, are still able to enjoy the high-speed broadband provided by the service providers through the improvement of transmission distance using the proposed PM-Duobinary modulation format.

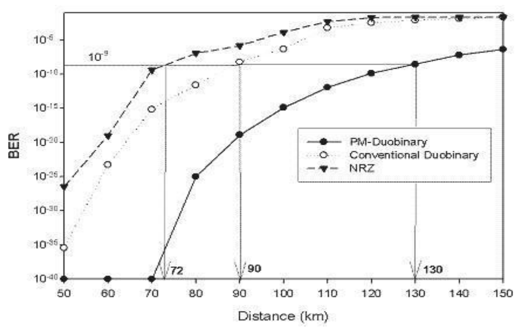


Fig. 4. BER versus transmission distance (km) with NRZ-OOK, conventional Duobinary, and PM-Duobinary modulation formats.

Fig. 5 shows performance comparison with respect to eye diagram (received signal) for NRZ-OOK, conventional Duobinary, and PM-Duobinary modulation format at transmission distance of 10 km and 80 km, respectively. The eye opening is wide and easy to distinguish in all three modulation formats at 10 km transmission distance. Beyond 80 km transmission distance, the eye diagram of the NRZ-OOK modulation format starts showing the indistinct pattern, where the eye opening is severely distorted and difficult to be distinguished. It is further observed, noise is noticeable at the upper and bottom levels of the eye diagram of the conventional Duobinary at 80 km transmission distance. The eye opening is, however, still clearly depicted. The PM-Duobinary modulation also experiences slight signal distortion at the bottom levels of the eye diagram at 80 km transmission distance; but, it has successfully demonstrated the clearest and the widest eye opening among all. It is interesting to note that, the eye diagrams in Figs. 5(b) and 5(c) are non-symmetrical. From the simulation results, it can be concluded that, the proposed PM-Duobinary can transmit signal without severe distortion up to a distance of 130 km through the standard single mode fiber (SSMF) in the transmission system.

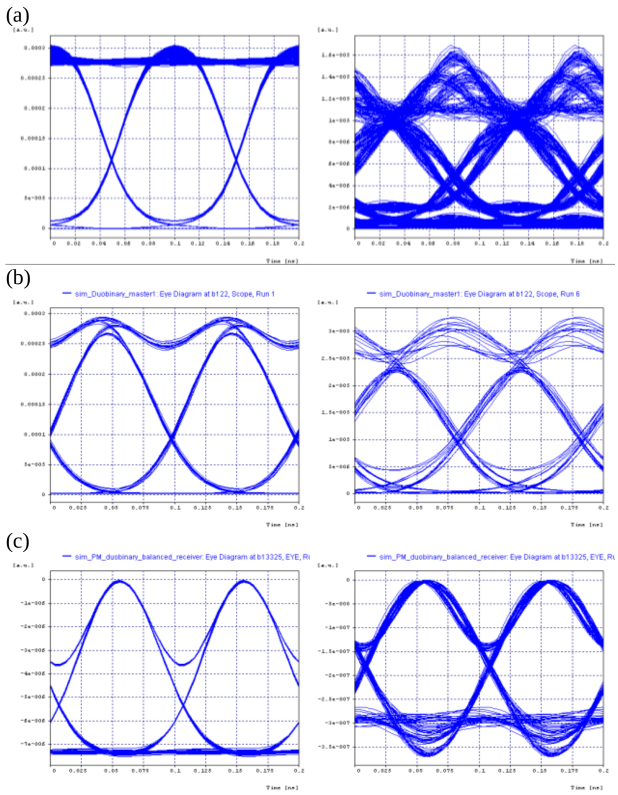


Fig. 5. Eye diagrams for (a) NRZ-OOK; (b) conventional Duobinary; (c) PM-Duobinary modulation format at 10 km and 80 km of transmission distances.

4. Conclusions

This study has successfully demonstrated that the proposed PM-Duobinary modulation format can achieve better performance as compared to the conventional Duobinary and the NRZ-OOK modulation formats in terms of transmission distance. The obtained results reveal that the proposed PM-Duobinary modulation format yields significant improvement of about 44.4% and 80.5%, respectively (with respect to the transmission distance) over the conventional Duobinary and the NRZ-OOK modulation formats at a given BER = 10^{-9}. For the PM-Duobinary modulation, less maintenance is required along its propagation path as no electrical power is needed, since there are no active components involved, such as amplifiers or regenerators. This study can assist the service providers to supply high-speed broadband services to the rural areas, which are located very far away from the central office.

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