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Duobinary Modulation Format for Optical System- A Review

Rupinder Kaur [1], Sanjeev Dewra[2]

Dept. of ECE, Shaheed Bhagat Singh State Technical Campus, Ferozepur, Punjab, India[1]

Dept. of ECE, Shaheed Bhagat Singh State Technical Campus, Ferozepur, Punjab, India[2]

ABSTRACT: In metropolitan optical networks, with the increasing growth and demand for capability, high bit rate transmission has recently become an important part of communication. Duobinary modulation is more efficient format for transmitting high speed optical signals over bandwidth limited channel. The duobinary modulation format for long haul and WDM transmission links is the one that has a narrow spectral width, low susceptibility to fiber nonlinearity, large dispersion tolerance and good transmission performance and has a simple and cost-effective configuration.

KEYWORDS: Amplitude Shift Keying (ASK), Duobinary Modulation (DM), Mach Zender Modulator (MZM), Non-Return-to-Zero (NRZ), Phase-shift Keying (PSK), Return-to-Zero (RZ).

I.INTRODUCTION

Optical duobinary format has attracted much attention in latest years, since optical duobinary signals have a higher spectral efficiency and better tolerance of chromatic dispersion than the standard non-return-to-zero (NRZ) signals due to the narrower spectral bandwidth [1]. Optical duobinary is a proficient modulation format which is known to increase the spectral efficiency [2]. Duobinary modulation format have been proposed to increase the transmission capacity by improving the bandwidth efficiency of the limited amplifier bandwidth to reduce channel spacing with the narrow spectral width of modulated signals in DWDM systems [3]. The high dispersion tolerance of this modulation scheme can eliminate the accurate dispersion compensation [4]. Due to its large dispersion tolerance, the duobinary modulation is appropriate for optical metro area networks (MANs) [5]. Its simple implementation, high chromatic dispersion tolerance and enhanced spectral efficiency are all attractive characteristics for wavelength-division-multiplexed transmission systems [6]. Duobinary modulation is an attractive candidate because it is spectrally efficient (~0.8 b/s/Hz) [7]. Compared with the standard non-return-to-zero (NRZ) format, optical duobinary modulation also has higher threshold for the onset of Stimulated Brillouin Scattering (SBS) [8]. To improve the transmission capacity, the duobinary modulation format has been very attractive due to a narrow spectral width and a high tolerance to the chromatic dispersion [9].

Lender el at. [10] demonstrated a new approach to digital data transmission, termed duobinary and correlative, substantially increases speed over any band-limited media owing to correlation between signal states. Specific codes are used with or without carrier modulation. In the error detection process, it has been observed that with this type of system it is unnecessary to introduce redundant digits into the original data stream. Price and Mercier el at. [11] analysed a reduced bandwidth optical digital intensity modulation with improved chromatic dispersion tolerance. In this a simple optical modulation scheme using a lithium niobate MZ modulator driven by a three level drive waveform is proposed. The two-level intensity modulated optical signal obtained possesses a smaller optical bandwidth and thus greater chromatic dispersion tolerance compared with existing two-level IM methods used for high data rate transmission. Yonenaga and Shibata el at. [12] experimentally analysed an optical duobinary transmission system with no receiver sensitivity degradation .In this a novel optical duobinary transmission system with no receiver sensitivity degradation is proposed. The transmitter yields a narrowband optical signal and the receiver configuration is as simple as a binary intensity-modulation and direct-detection receiver. The feasibility of the proposed system is experimentally confirmed at 2.5,5 and 10 Gb/s. Jansen, Spalter, Weiske, and Escobar el at. [13] demonstrated and experimentally analysed comparison between NRZ and duobinary modulation at 43 Gb/s for midlink spectral Inversion -Based and DCF-based transmission systems. The performance of midlink spectral Inversion is compared with the performance of conventional dispersion compensation fiber -based transmission for two data formats: 43-Gb/s ON–OFF keying

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nonreturn-to-zero and 43-Gb/s duobinary is analysed. In the MLSI-based system, a polarization-diverse subsystem was used for spectral inversion employing magnesium-oxide-doped periodically poled lithium niobate waveguide technology. The transmission link consists of 8 × 100 km standard single-mode fiber using erbium doped fiber amplifiers for amplification. It was concluded that Compared to the DCF-based system, it was seen that the MLSI-based configuration enhances the dispersion tolerance for both the NRZ and the duobinary modulation formats.

Ono, Yano, Fukichi and Emura el at. [14] demonstrated the characteristics of optical duobinary signals in Terabit/s capacity, high-spectral efficiency WDM systems.

II. DUOBINARY SIGNALLING

An optical duobinary is a modulation format that provides high spectral efficiency and high tolerance to chromatic dispersion. Duobinary modulation can be described as a combination of a conventional ASK-based modulation and phase shift keying (PSK). Depending on the realization, optical duobinary transmission can be understood as a multi-level transmission with phase encoded bits and a reduced spectral width. Duobinary transmission technology was introduced for the first time by A. Lender in the 1960s as a mean of transmitting binary data over an electrical cable with high-frequency cut-off characteristics. Recently, duobinary modulation [15] has been applied to high-speed optical transmission systems with a channel data rate of 10 Gb/s in order to improve their dispersion tolerance. In the duobinary modulation format, the optical phases of “1” bits which are separated by an odd number of “0s” differ by π radians as shown in figure 1.

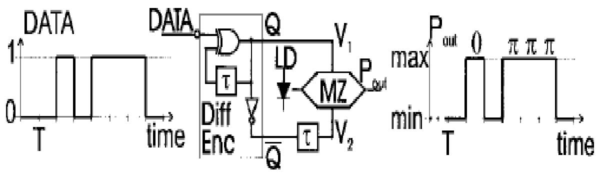

Fig. 1 Principle of duobinary modulation

The Duobinary modulation is an amplitude modulation where the bit stream is manipulated to reduce the bandwidth and certain phenomena that lead to ISI (Inter Symbol Interference).Previous implementations of duobinary transmitters had been based on the three-level electrical signals. The generation of the three-level signals requires electrical devices such as electrical low-pass filters [16]. It is reported that the three level signals give rise to the system performance degradation depending on word length due to the imperfection of the electrical low-pass filters [17].

Duobinary modulation is a format for transmitting R bits/sec using less than R/2 Hz of bandwidth [18]. Duobinary signalling, also named as correlative coding, was initially developed in the period of electronic communications as an efficient means for reaching the Nyquist limit [19]. Duobinary modulation format is based on producing a relationship between the adjacent bits at the transmitter. The main element in this process is duobinary generating filter, preferably composed of a simple feed-forward filter with a bit period delay in one arm followed by a sharp LPF having a cut off at B/2 [20]. The two main advantages attributed to this modulation format are increased tolerance to the effects of chromatic dispersion and an improved spectral efficiency. The first advantage enables transmission over longer spans of fiber without the need for dispersion compensation [21]. The second is assumed to enable closer spectral packing of channels in a wavelength-division-multiplexed (WDM) system [22]. Both these advantages are frequently attributed to the fact that the duobinary coding reduces the optical bandwidth of a full duty cycle near rectangular signal by a factor of 2 [23].

III. DUOBINARY TRANSMISSION BASED FIBER OPTIC COMMUNICATION SYSTEM

Duobinary transmission technology was studied by Lender in the 1960’s as a means of transmitting binary data into an electrical cable with high frequency cut off characteristic [10]. Recently, the technology has been applied to high speed optical transmission systems to avoid the waveform distortion due to chromatic dispersion. The optical signals have a narrower spectrum bandwidth than conventional IM signals and higher tolerance against fiber chromatic dispersion [11], [12].

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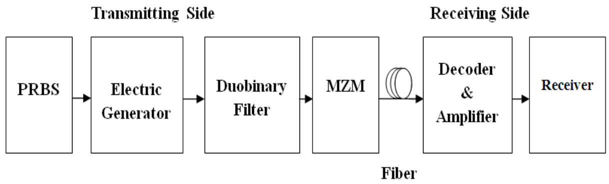

Fig. 2 General block diagram of duobinary filter in duobinary transmission system

The block diagram of a duobinary filter based duobinary fiber optic communication systems is shown in figure 2. In this case message means an electrical or another form of signal. This message is transmitted by a transmitter and passed via a fiber. It is detected and converted to the required form by the receiver. The electrical part of the duobinary transmitter comprises a data generator, a duobinary encoder and a Low Pass Filter (LPF). For transmission, the data generator is mainly a pseudo-random bit sequence that has properties of arbitrary data. To the transmitting side, the major purpose of the precoder is to generate the error-free duobinary signal. The encoder encoded the duobinary signal with the duobinary filter. In fiber optic communication system, light emitting diode (LED) or laser are used as an optical oscillator or a carrier signal. The function of low pass Bessel Thompson filter is to produce the three levels duobinary electrical signal and then the signal is modulated by MZ Modulator. To travel long distance, they produce signal frequency with sufficient power. The amount of power radiation is proportional to the output current of the modulator. This modulated signal is transmitted via proper channel means fiber optic cable. It may be guided or unguided. This signal is demodulated to the receiving end, decoded and filtered. Receiver detects, amplifies and converts the signal to appropriate form [24].

A. Pseudo Random Binary Sequence (PRBS)

Pseudo-random data generator has three properties that reflect the data’s randomness. Firstly, the number of marks and spaces (or “0s” and “1s”) in a sequence differ by 1. Secondly, the probability of a continuous string of marks or spaces is inversely proportional to the length of the string. This means that among the number of runs of marks of spaces in the Pseudo-random binary sequence (PRBS), one-half the funds of each kind are of length one, one-fourth are length two, one-eighth are length three and so on. At last, the autocorrelation of the Pseudo Random Binary Sequence is approximately zero everywhere except at the origin. The production of a Pseudo Random Binary Sequence is implemented by using a shift register with feedback has three properties that reflect the data’s randomness [25].

B. Duobinary Filter

Duobinary filter is a process of producing encoded duobinary signal. Duobinary filter is a fifth order Bessel filter called electrical analog low pass filter or Thomson filter [26]. A LPF is a filter that passes low-frequency signal but reduces the amplitude of signals with frequencies higher than the cut off frequency. In audio applications, it is also known as treble cut filter or high-cut filter. A Low Pass Filter is an alternative of a high-pass filter (HPF) and a band-pass filter (BPF) is a combination of a low-pass and a high-pass.

C. Mach Zender Modulator (MZM)

The Duobinary electrical signal drives the MZ Modulator to generate optical Duobinary signal. A Mach-Zender modulator is proficient of modulating both the amplitude and phase. A continuous wave or pulsed light wave generated by a laser diode is modulated by an external Mach-Zender modulator. The two arms of the Mach-Zender (MZ) modulator are driven by two electrical signals in push-pull fashion. The laser diode and the Mach-Zender (MZ) modulator make up the optical section of the duobinary transmitter means optical duobinary signal.

IV. OPTICAL DUOBINARY SIGNAL FROM BINARY BIT

Duobinary data can be achieved from binary data by adding the binary bits and shifting the bit stream to itself. For example, the sequence of binary bit is 10110010.The shifted first bit will be 0. The transfer function of duobinary encoder is $H(z) = 1 + z^{-1}$. To the decoder side, the inverse transfer function will be $H(z)\,G(z) = 1$or $G(z) = 1 / (1+z^{-1})$ that is described in figure 3.

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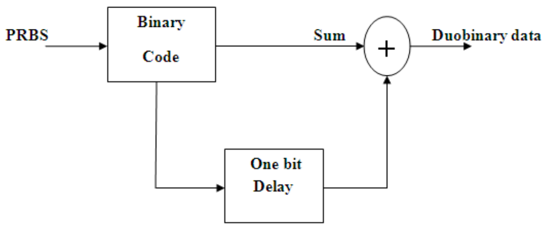

Fig. 3 Block diagram of converting duobinary code from binary

V. GENERATION OF OPTICAL DUOBINARY SIGNAL

The schematic diagram of the transmitter for the optical duobinary signal format is shown in Fig. 4. However, the signal that drives the data modulator is not the original NRZ data, but the duobinary-encoded data sequence [27]. Each step in the encoding process is illustrated as shown in Table 1. The first step in the process is to feed the original NRZ

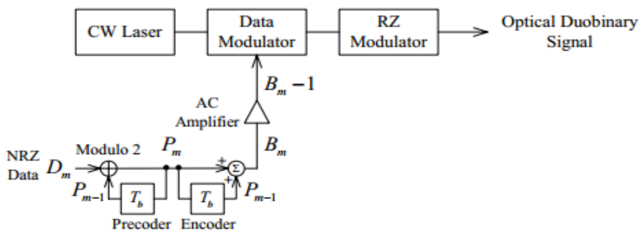

Fig. 4 Optical duobinary signal generation

data sequence D_m to the differential precoder in order to avoid error propagation at the receiver caused by the preceding received data not being recovered correctly [28], [29]. The precoded data sequence P_m is then passed through the delay-and-add circuit (encoder). The data sequence output from the encoder is denoted by B_m in Table 1. It is clearly seen that an original data bit 0 results in the B_m being either 0 or 2 whereas an original data bit 1 corresponds to $B_m = 1$. If the encoded data sequence B_m is used to directly drive the data modulator, the suppression of a spurious pulse caused by the overlap between two pulses cannot be achieved since the sign of B_m is always positive, hence the sign of the transmitted pulses will always be the same. In practice, the encoded data B_m is fed to an electrical amplifier before driving the data modulator. The role of the electrical amplifier is to amplify the signal to the desired level and to remove the DC component of the signal (the amplifier is AC coupled). Thus, the encoded sequence that drives the data modulator is B_m-1. As seen from Table 1, an original data bit 0 ($D_m = 0$) corresponds to $B_m-1 = \pm1$ while an original data bit 1 ($D_m = 1$) causes B_m-1 to take the value of 0 regardless of their positions. The NRZ optical duobinary signal is then converted to RZ optical duobinary by the RZ modulator. At the receiver, the square-law detector neglects the phase of a received pulse therefore, the received data sequence is the absolute value of the transmitted data sequence B_m-1. The received data sequence B_m-1 has to be inverted to recover the original data sequence D_m. It should be noted that if the original data sequence D_m is inverted before being fed to the precoder at the transmitter, the received data sequence B_m-1 is D_m.

Table 1: Illustration of duobinary precoding and encoding processes.

D_m		0	0	1	1	1	1	1	0	1	1	0	1	1	0	1	0
P_m	0	0	0	1	0	1	0	1	1	0	1	1	0	1	1	0	0
B_m		0	0	1	1	1	1	1	2	1	1	2	1	1	2	1	0
B_m-1		-1	-1	0	0	0	0	0	+1	0	0	+1	0	0	+1	0	-1
$\|B_m-1\|$		1	1	0	0	0	0	0	1	0	0	1	0	0	1	0	1
$\overline{\|B_m-1\|}$		0	0	1	1	1	1	1	0	1	1	0	1	1	0	1	0

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VI. COMPARISON OF DUOBINARY WITH DIFFERENT FORMAT

A. Non-return-to-zero (NRZ) Modulation format

The simplest modulation format is a NRZ, where the pulse is on for the entire bit period. Most commercial systems use the non-return-to-zero modulation format [30]. The NRZ has been the most leading modulation format in intensity modulated-direct detection fiber-optical communication systems for the previous years. The reasons for using non-return-to-zero in the early days of fiber-optical communication as it is not perceptive to laser phase noise, needs a moderately low electrical bandwidth for transmitter and receivers in comparison of RZ and the simplest configuration of transmitter and receiver. NRZ pulses have a narrow optical spectrum. This reduced spectrum width improves the dispersion tolerance but it has the effect of ISI between the pulses. This modulation format is not suitable when high bit rates and distance are considered. The narrow spectrum of NRZ pulses yields an improved realization of dense channel spacing in Dense Wavelength Division Multiplexing systems.

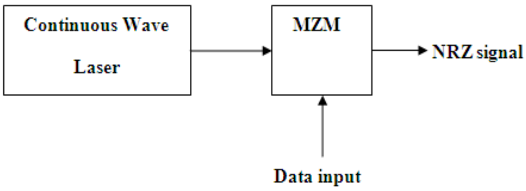

Fig. 5 NRZ Transmitter

B. Return-to-zero (RZ) modulation format

In RZ modulation format, power is transmitted only for a fraction of the bit period. A return-to-zero signal with the same average power of a non-return-to-zero signal has a spectrum peak-power twice larger than the NRZ pulse. The most important feature of RZ modulated signals is a moderately broad optical spectrum. The large spectral width results in a reduced spectral efficiency and reduced dispersion tolerance of RZ-based Wavelength Division Multiplexing systems. The return-to-zero pulse shape enables an increased robustness to fiber nonlinear effects and to the effects of polarization mode dispersion (PMD) [31]. The RZ system implementation improves the system receiver sensitivity up to 3 dB [32]. Due to its broader spectrum, RZ pulse has a reduced dispersion tolerance and spectral efficiency. The duty cycle of RZ pulse is less than unity. The reduced pulse width implies a broader signal spectrum making this technique less interesting for the implementation in DWDM systems. Higher optical powers per channel can be tolerated in a RZ-based WDM system, resulting in an improved maximum transmission length. The RZ modulation format is used for long haul optical communication systems working at higher bit rates.

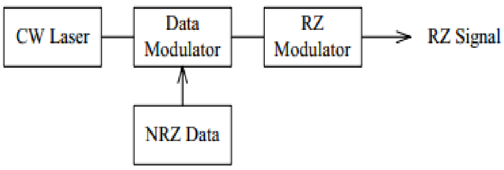

Fig. 6 RZ Transmitter

The above figure shows the block diagram of the RZ transmitter which is basically an NRZ transmitter with an extra external modulator driven by an electrical clock that can be achieved by a sinusoidal signal at the half data rate.

C. Doubinary modulation format

The optical duobinary signal has two intensity levels "on" and "off." The "on" state signal can have one of the two optical phases 0 and π. The two "on" states correspond to the logic states "1" and "-1" of the duobinary encoded signal and the "off" state corresponds to the logic state "0" of the duobinary encoded signal. According to the duobinary encoding rule, the logic states "-1," "0," and "1" of the duobinary encoded signal correspond to the logic states "0,"

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"1," and "0" of the original binary signal, respectively. Therefore, the original signal can be recovered by inverting the directly detected signal. The schematic diagram of the transmitter for the optical duobinary signal format is shown in fig. 7. The transmitter configuration of the optical duobinary signal format is identical to that of the RZ signal format.

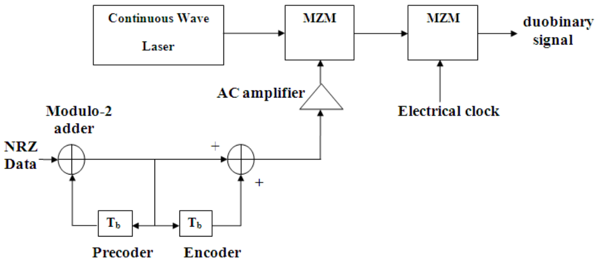

Fig. 7 Doubinary Transmitter

The optical spectrum of the duobinary signal is very compressed in comparison of other binary formats. Since in the optical duobinary spectrum, the carrier is effectively suppressed, duobinary modulation is also used for the suppression of SBS-effect. The spectral width of the signal is reduced twice compared to a conventional NRZ signal. The reduction of the spectral width of the optical duobinary signal is the reason for its better dispersion tolerance compared to NRZ signals and enables an improved spectral efficiency in WDM systems.

VII. ADVANTAGES OF DUOBINARY MODULATION

Duobinary Modulation is an effective method in high speed optical transmission systems to improve spectral efficiency, to increase dispersion tolerance and to reduce the sensitivity to nonlinear effects. Optical duobinary coding also helps to increase the threshold for the onset of Simulated Brillouin Scattering. DM is a better choice for uncompensated single mode fiber, since it is more resilient to dispersion. The duo binary modulation format can be suggested for long distance communication systems at high bit rates.

VIII. CONCLUSION

Duobinary modulation is the better choice for uncompensated single mode fiber, since it is more resilient to dispersion. It is concluded that the duobinay modulation format is better for the long distance optical communication system due to its low value of bit error rate and dispersion tolerance at high bit rates. It has high spectral efficiency and is also used for long haul high speed communication system. The use of the duobinary signal format generally results in better performance than non-return-to-zero (NRZ) for transmission in nonlinear dispersive fiber. By imposing some special characteristic onto the duobinary signal, system performance can be greatly improved.

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BIOGRAPHY

Rupinder Kaur was born in Ferozepur, Punjab, India, on 1 August, 1991. She obtained her Bachelor's degree in Electronics and Communication Engineering from Ferozepur College of Engineering & Technology, Ferozepur, Punjab, India. She is currently a M.Tech scholar in Electronics and Communication Engineering Department at Shaheed Bhagat Singh State Technical Campus Ferozepur, Punjab, India. Her research mainly focuses on Optical Fiber Communication.

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Sanjeev Dewra was born in Panagarh (West Bengal), India, on October 22, 1971. He received a B.E (Electronics & Telecomm.) degree from Mahatma Gandhi Missions College of engineering & technology, Marathwada University, Aurangabad (M.S) in 1993 and a M.E. degree from GNDEC, Ludhiana in 2002.He is currently working toward his Ph.D. degree at Thapar University, Patiala (Punjab). His field of interest is optical add drop multiplexer & optical cross connect for optical communication systems. He has published various research papers in international journals & conferences. Mr. Dewra is a life member of the Indian Society for Technical Education, Institution of Engineers (India). He has over 20 years of Education Experience. He served as lecturer in Saint Kabir Institute of Pharmaceutical & Technical Education, Fazilka from 1994 to 1998. He then joined Lala Lajpat Rai Institute of Engineering & Technology, Moga as a lecturer in 1999. In 2000, he joined Giani Zail Singh College of Engineering & Technology, Bathinda (Punjab) as Lecturer in the Department of Electronics and Communication Engineering and continued till 2003. In 2003, he joined as a Lecturer in the Electronics and Communication Engineering Department in Shaheed Bhagat Singh College of Engineering and Technology, Ferozepur (Punjab) & became a senior Lecturer in 2005. Presently he is working as an Assistant Professor & Head of ECE Department in the same college.