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THE INVESTIGATION OF SUITABILITY OF VARIOUS LINE CODING TECHNIQUES FOR FIBER-OPTIC COMMUNICATION

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ABSTRACT

Fiber-optic communication is a way of transmitting information from one place to another by sending pulses of light through an optical fiber (usually made of glass or plastic), and has formed an integral part of the core network across many countries. Line coding deals with various techniques involved in representing digital signal transmission over an analog channel. This paper investigates the performances of recent line coding techniques when used across a fiber optic channel through the representation of the digital signal to be transported over the fiber channel and the effect of the drawbacks involved, such as the inability of the long distance communication owing to DC components when using this technique.

Keywords: fiber-optic, coding, channel, analog, digital, DC components.

INTRODUCTION

Digital Transmission is faster, has high resistance to noise, easier to calibrate and adjust and assumed to be error-free. Optical fiber remains the most common type of channel used in optical section of telecommunication and has the main advantages of having less attenuation and dispersion.

Line coding over a fiber-optic communication depicts the methodology by which digital signal, represented by the amplitude and time discrete signal is optimally tuned for transportation over the fiber optic channel. Its basic forms are Unipolar, Polar, Bipolar, and each of these forms can be encompassed into different types such as Return-to-Zero (RZ), Non-Return-to-Zero (NRZ) and the Manchester encoding to provide various advantages and cater for the main problem associated with the line coding for long distance application, The DC component. Worthy of mention, is another entirely type of line coding in optics that can provide a numerous combination is encoding m binary bits into n binary symbol pattern, the Block Coding (mBnB). It has the theoretical primary advantages of having no DC components; since long strings of ones and zeros are eliminated plus adequate time and error monitoring information [1]. This type is beyond the scope of this work.

The DC component, similar to the electrical signal, is the shift of the transmitted center level created by the average time the signal is on until the time is off. This leads to distortion in the receiver's eye pattern, jitter in decoded data and extra useless energy among others [1]. One of the common type of line coding used to cater for this and other problems in fiber optic communication line coding, is a variant form of Return-to-Zero line coding technique, the Carrier-Suppressed Return-to-Zero (CSRZ).

The main difference between the RZ format and the CSRZ format is *pi* phase shift between adjacent bit, and because of that phase alternation; there is a zero mean optical field envelope leading to theoretically the absence of DC component and carrier component for CSRZ in the spectrum and therefore providing improved spectral efficiency and reduced inter symbol interference due to the alternating optical phase of successive bits [2].

This study will look at three latest types of modification (all in this millennium) made to CSRZ format such as modification of continuous wave (CW), combination with pair wise or pulse-to-pulse alternate polarization (Apol) and Single-sideband differential phase-shift keying with asynchronous CSRZ. Each of these modifications is first introduced, their transmitter block diagram presented, implementation and results discussed, analysis of findings and individual conclusion drawn out for them. Finally, in the last section, a conclusion is drawn out.

THE CONTINUOUS WAVE-SQUARE WAVE CARRIER-SUPPRESSED RETURN-TO-ZERO (CWSW- CSRZ) [3]

It has already been mentioned that the CSRZ requires a baseband power spectrum that does not have a DC component. This can be accomplished with polar signaling in which pulse *s* (*t*) represents a binary 1, and pulse -*s*(*t*) represents a binary 0. The continuous-wave square-wave (CWSW) is achieved by combination of phase modulation and filtering, which result in amplitude modulation, and an RZ pulse train can be generated by square-wave phase modulation and filtering a continuous-wave (CW) signal. Its transmitter diagram is shown in Figure-1. The CW laser is phase-modulated with a square wave phase characteristic having a frequency of half the bit rate and amplitude of $\pi/2$, This is followed by an optical filter that performs phase-to-amplitude conversion, which results in the generation of an alternate-sign RZ pulse train at the filter output. The square-wave phase modulation removes the original carrier component (CW signal) and generates sidebands at odd multiples of half the bit rate from the carrier frequency. The resultant signal

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has a constant magnitude, but alternating with higher order sidebands. The shape of these pulses is determined by the transfer function of the filter, but the square-wave phase characteristic (no chirp) is essentially preserved. The pulse train is then gated on and off according to the data sequence prior to launch into an optical fiber.

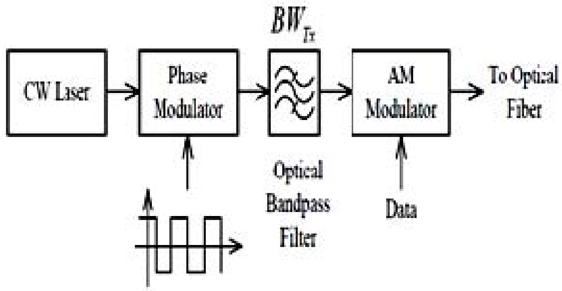

Figure-1. Transmitter block diagram of CWSW.

The RZ pulse generated by this technique has steep edges that result in an initial peak intensity enhancement (PIE) when propagating in a dispersive medium as a function of normalized transmission distance z_n (Figure-2). In digital systems, there is a possibility of the PIE counterbalancing the deleterious effect of the pedestal. In addition, the signs of adjacent pulses alternate, which makes the CWSW signal robust to intrachannel and interchannel impairments. The CWSW signal format also has implementation advantages. Generally, alternate signs between adjacent pulses in CS-RZ signal formats is accomplished by employing a push-pull type Mach-Zehnder (MZ) modulator that requires two opposite-sign (180° out-of-phase) sinusoidal clock signals, each driving one arm of the MZ modulator, but for a practical MZ modulator both arms are not identical; hence, the amplitudes of both driving signals have to be optimally adjusted to minimize the residual chirp [4]. Also, for CWSW a single drive phase modulator and an optical filter are used for the generation of alternate-sign RZ pulse train.

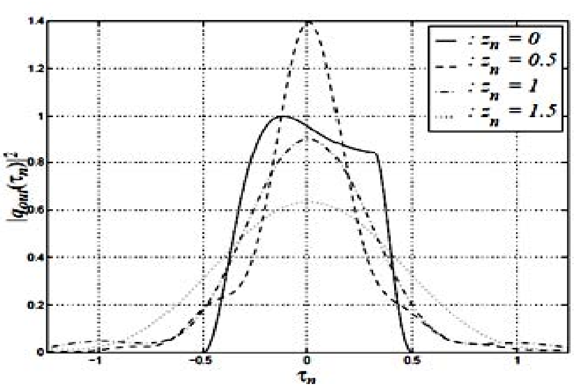

Figure-2. CWSW pulse evolution in a linear lossless fiber.

IMPLEMENTATION AND RESULTS

This format uses a 40Gbits/s single-channel system employing an optical preamplifier receiver (Noise figure=6dB, Bandwith=80GHz). Fifth order Butterworth filters are used to model optical bandpass filters at the transmitter and at the preamplifier output. The gain of the preamplifier is assumed to be sufficiently high that receiver thermal and shot noise are negligible compared with the amplified spontaneous emission (ASE) noise from the preamplifier. The receiver photodetector has a quantum efficiency of 0.7, and a 3rd order Butterworth filter having a bandwidth of 30 GHz is used to model the electrical lowpass filter following the photodetector. The effect of transmission through a fiber is numerically simulated by the split-step Fourier method21 using a pseudo random data sequence of length 128 to determine eye diagrams. The threshold value for Q is taken to be equal to 6 (15.6 dB), which corresponds to the probability of bit error of 10^{-9}. The average transmitted power P_{avg} and normalized transmitter filter bandwidth BW_{Tx} are optimized to maximize the transmission distance z. The range of BW_{Tx} considered is from 1 to 4; values less than 1 would result in excessive signal loss and distortion, and values in excess of 4 is essentially no filtering. The two tables below show various parameters gotten from using CSRZ modulated with CWSW to analysis.

Table-1. Relationship between optimum system parameters and transmission distance z, when d = +0.5ps/(km.nm) for CWSW.

z(km)	100	120	130	140	150
P$_{avg, opt}$ (dbm)	10	10	10	10	10
BW$_{tx}$	4	4	4	4	4
Q (dB)	38.6	34.1	31.8	29.4	26.8
z(km)	160	170	180	190	200
P$_{avg, opt}$ (dbm)	10	10	10	10	10
BW$_{tx}$	4	4	4	4	4
Q (dB)	24.1	21.8	19.4	16.9	14.3

Table-2. Relationship between optimum system parameters and transmission distance z, when D = -0.5ps/(km.nm) for CWSW.

z(km)	100	120	130	140	150
P$_{avg, opt}$ (dbm)	10	9	9	8	8
BW$_{tx}$	4	4	4	4	4
Q (dB)	35.4	29.4	26.3	23.2	19.9
z(km)	160	170	180	190	200
P$_{avg, opt}$ (dbm)	7	7	-	-	-
BW$_{tx}$	4	4	-	-	-
Q (dB)	16.5	12.9	-	-	-

Analysis of findings

It is seen from Tables-1 and 2 that $P_{avg, Opt}$ for CWSW is high and resistant to dispersion. For the systems employing DSF, CWSW significantly outperforms its

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counterpart AMI in term of the eye profile and the maximum transmission distance. The PIE as well as alternate signs between adjacent pulses is the key factor that makes CWSW robust to fiber dispersion and nonlinearity. The maximum transmission distances that can be achieved by employing the CWSW signal format are 195 km when D = +0.5 ps/(km.nm) and 162 km when D = −0.5 ps/(km.nm). However, CWSW has a considerably narrower bandwidth and higher advantage in WDM Systems. Its transmitter configuration is simple despite its encoder requirement.

CSRZ-OOK WITH PAIRWISE OR PULSE-TO-PULSE ALTERNATE POLARIZATION (APOL) [5]

This modification once again uses the main advantage of CSRZ, phase shift of π between adjacent pulses without requiring an additional phase modulator, using either a pairwise or a pulse-to-pulse alternate polarization to achieve a reduction of intrachannel nonlinear distortion with a low-complexity, low-cost transmitter. A schematic of the transmitter is shown in Figure-3. First, conventional CSRZ with a duty cycle of 67% is generated by two Mach–Zehnder interferometers (MZI) in push–pull configuration. The MZIs are followed by a polarization modulator, which consists of a polarization controller (PC), a polarization- beam splitter (PBS), a phase modulator (PM), and a polarization-beam combiner (PBC).

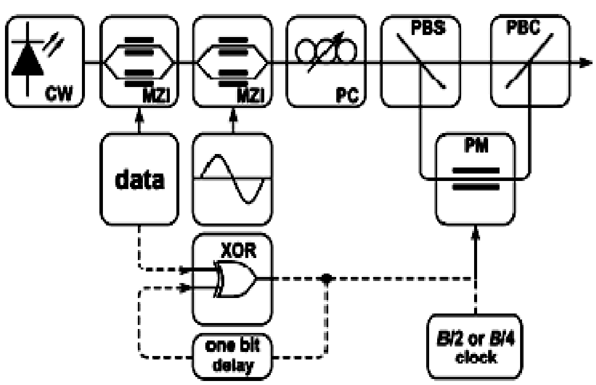

Figure-3. Transmitter schematic of APol CSRZ.

IMPLEMENTATION & RESULTS

For all simulations, the PM is driven by a filtered rectangular clock signal with a rise time of a quarter of the bit period. 40-Gb/s single-channel transmission over 4 80 km Single Mode Fiber (SMF) with full in-line dispersion compensation per span is simulated, the transmitted data is a de Bruijn binary sequence (DBBS) of length 2. Second-order modelling of Optical filters at the transmitter and receiver as Gaussian with a 3-dB bandwidth of 80 GHz. The electrical post-detection filter is a fifth-order Bessel low-pass filter with a cutoff frequency of 28 GHz. The bit-error rate (BER) is estimated with a semianalytic method based on a Karhunen–Loève expansion [6].

ANALYSIS OF RESULT

In Figure-4, the required OSNR to achieve a BER of 10 is plotted against launch power. Since CSRZ is well suited for WDM long-haul transmission with a spectral efficiency of 0.8 bit/s/Hz [7], the performance of the proposed formats was evaluated in the presence of narrowband optical filtering and coherent crosstalk.

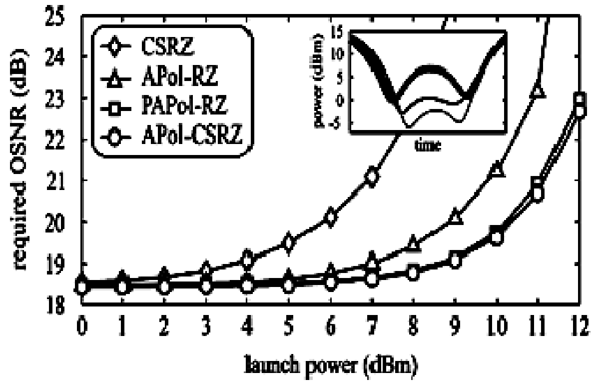

Figure-4. Required OSNR for a BER of 10 versus launch power after transmission over 4_80 km SSMF.

In Figure-5 the required back-to-back OSNR for a mean BER of 10 is plotted versus the demultiplexer filter bandwidth. The main drawback of APol-modulation formats is their reduced tolerance to Polarized Mode Dispersion (PMD).

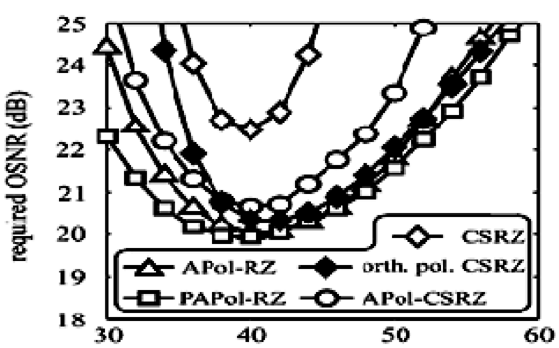

Figure-5. Back-to-back required OSNR versus demultiplexer filter bandwidth for optimized multiplexer filter bandwidth, 3WDM system, 50Hz.

The performance of CSRZ with pairwise or pulse-to-pulse alternate polarization in the presence of linear and nonlinear degrading effects is evaluated. Due to additional suppression of IFWM-induced ghost pulses, the nonlinear threshold is increased by 4.6 and 1.6 dB, compared to conventional CSRZ and APol-RZ, respectively. The PAPol-RZ format shows the best overall performance, especially in ultradense WDM systems with narrowband optical filtering, however requires some additional electrical components.

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SINGLE-SIDEBAND DIFFERENTIAL PHASE-SHIFT KEYING ASYNCHRONOUS CARRIER-SUPPRESSED RETURN- TO-ZERO (SSB-DPSK-ACS-RZ) [8]

In Ultradense Wavelength-Division Multiplexing (UDWDM) systems, linear crosstalk is an important impairment due to the small channel spacing (50 GHz for the bit rate of 43 Gbit/s) [9]. To mitigate this in the long haul and high capacity transmission, the novel DPSK ACS-RZ format plus SSB for small channel spacing required by UDWDM systems is used. The system setup is shown in Figure-6, where T_b is the bit period, R_b is the bit rate, and f_c is the 3 dB electrical transmitter filter bandwidth. T_k is the relative delay between the DPSK and the clock signal.

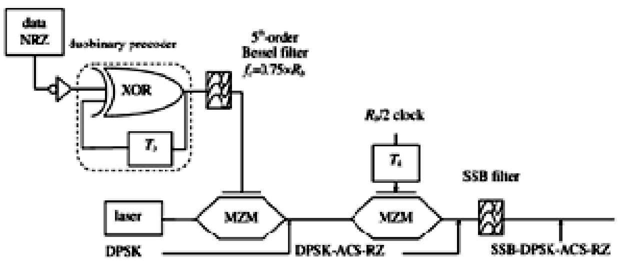

Figure-6. Generation scheme of novel SSB-DPSK-ACS-RZ signaling format.

IMPLEMENTATION AND RESULTS

Optimized SSB-DPSK-ACS-RZ format was obtained by numerical simulation of electrical transmitter bandwidth, relative time delay between the signals from the two MZMs, and optical filter bandwidth and detuning of MUX and DEMUX. The MUX and DEMUX were modelled by second-order super-Gaussian transfer functions. The BER is averaged over 100 realizations. From the realization to realization, the phase and time shifts are randomly varied between central and neighbouring channels. The time waveforms of SSB-DPSK-ACS-RZ and DPSK-ACS-RZ signals with optimized relative time delay, as well as off the clock and DPSK signals are presented in a diagrammatic format (Figure-7) below. It can be seen that the SSB-DPSK-ACS-RZ signal has the phase variation always at the bit-slot centers of zero bits, which is important for good group velocity dispersion (GVD) tolerance, as for duobinary format.

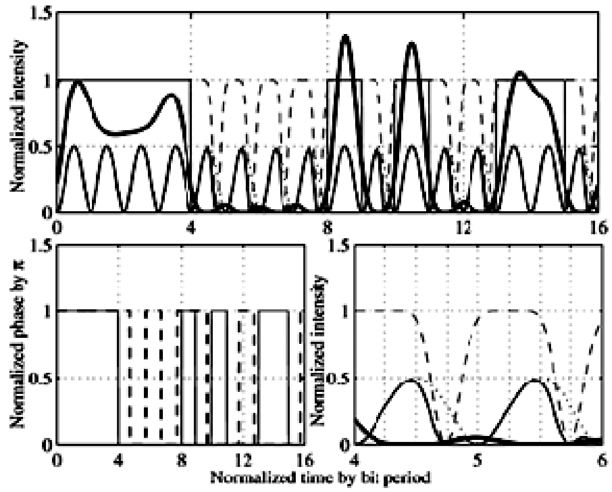

Figure-7. Time waveforms of (top) intensity of SSB-DPSK-ACS-RZ signal (solid thick line) and of DPSK-ACS-RZ (solid line) with optimized relative time delay between DPSK (dashed line) and the clock signal (dotted line); (bottom—left-hand side) normalized phase by π of DPSK signal (dashed line); (bottom—right-hand side) enlarged “00” detail of the top plot. The solid thin line represents the *deBruijn* binary sequence

Analysis of findings

The SSB-DPSK-ACS-RZ obtained a high bandwidth for 3-dB and 20-dB signal bandwidths obtained at the mux output and OSNR penalty of 1.65-dB for BER of 10^{-12} than its duo-binary counterpart signals. It also had lower total residual dispersion and similar Q-factor. For a comprehensive and thorough result, see the main paper [8]. This format also presents better tolerance to intrachannel nonlinear fiber effects but poorer tolerance to (GVD) than the corresponding ones of the bandwidth-limited duobinary format [10]. Also there is misalignment between DPSK and clock signals in generation scheme of SSB-DPSK-ACS-RZ causes the increase of amplitude variations of zero and one bits.

CONCLUSIONS

The recently proposed CSRZ signal, generated by filtering a CW signal that is square wave phase modulated (CWSW), performs comparably or better than its counterpart AMI techniques. CWSW achieves better performance in systems with small dispersion with simpler transmitter, but slightly poorer performance in systems with larger dispersion and dispersion compensation.

On the other hand, the 40-Gb/s carrier-suppressed return-to-zero On–Off keying (CSRZ-OOK) combined with either a pairwise or a pulse-to-pulse alternate polarization (APol), offer a loftier suppression of intrachannel four-wave mixing compared to conventional APol-formats, tolerant to narrowband optical filtering and thus suitable for ultradense wavelength-division multiplexing (UDWDM) systems with a spectral efficiency of 0.8 bit/s/Hz, but less tolerant to PMD and requires extra electrical components.

The novel single-sideband differential phase-shift keying asynchronous carrier-suppressed return-to-zero (SSB-DPSK-ACS-RZ) format, proposed for long-haul ultradense wavelength-division multiplexing (UDWDM) systems with 43 Gbit/s channel and 50 GHz of channel spacing combined with some optimization allows the using of a lower-cost direct-detection receiver and improved its spectral efficiency. It has significant total residual dispersion tolerance improvement achievement and high Q-factor for long-haul UDWDM transmission but performance remains the same with its counterparts in ultra-long-haul UDWDM system and less tolerant to GVD, an important dispersion parameter in duobinary formats.

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