Optics Communications 387 (2017) 30–36

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

NRZ versus RZ over Absolute Added Correlative coding in optical metro-access networks

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ARTICLE INFO

Keywords:
Absolute Added Correlative Coding
Modulation formats
Optical metro-access networks
Pulse shape
Partial-response signaling
Direct detection

ABSTRACT

This paper comparatively investigates the transmission performance of absolute added correlative coding (AACC) using non-return-to-zero (NRZ) and return-to-zero (RZ) pulse shapes with a binary intensity modulation direct detection receiver in 40 Gb/s optical metro-access networks operating at 1550 nm. It is shown that, for AACC transmission, the NRZ impulse shaping is superior in comparison to RZ in spectral efficiency, dispersion tolerance, residual dispersion and self-phase modulation (SPM) tolerance. However, RZ-AACC experiences a ~1–2 dB advantage in receiver sensitivity over NRZ-AACC for back-to-back configuration as well as after 300-km single-mode fiber delivery.

1. Introduction

The explosive growth of high bandwidth applications/services, such as Internet Protocol Television (IP-TV), video calling and cloud computing have led to a remarkable change in the area of high-speed optical metro-access networks and its wavelength division multiplexing (WDM) technology in recent years [1–3]. Over the past several years, lots of techniques such as the new implementation of advanced modulation, coding, fiber types and electronic equalization have been investigated to improve the WDM transmission performance. Among these techniques, the employment of multilevel signaling has been outlined as the most favorable solution delivering a trade-off cost effective and higher capacity solution [1,4–8].

It is obvious that for any optical modulation format, one of the decisive dependent parameters in system design and performance optimization is the pulse coding format. For practical reasons, this choice is often between return-to-zero (RZ) and non-return-to-zero (NRZ) impulse shaping, with possible variations in duty cycle [9]. In the last decades, many reports have continuously centered on the comparative study of impulse shaping of NRZ and RZ for binary schemes e.g. on-off-keying (OOK) [10,11], differential phase-shift-keying (DPSK) [10,12] and duobinary [9,13] whereas the multilevel signaling such as 4-ary pulse amplitude modulation (4-PAM) [14,15] and differential quadrature phase-shift-keying (DQPSK) [16] has recently received considerable attention. Such researches have yielded critical conclusions. In specific that modulation formats with RZ impulse shaping are more similar to a soliton transmission, having a ~2 dB advantage in performance over NRZ pulse in amplified spontaneous emission (ASE) noise-limited systems. This is because of an inherent tolerance to intersymbol interference (ISI) of the RZ pulse shape.

We have recently introduced a novel higher-order intensity signaling christened absolute added correlative coding (AACC) which is the modulation with memory that has been presented as an alternative to 4-PAM scheme and applicable to optical interconnects applications and optical metro-access networks [5,17]. Although AACC has been studied extensively but there is a deficiency of results on a direct comparison between NRZ and RZ impulse coding in AACC transmission. We will address this issue by conducting a numerical analysis of externally-modulated direct-detection on NRZ-AACC and RZ-AACC systems in dispersive transmission medium with different conditions. Moreover for the first time the impact of self-phase modulation (SPM) on the performance of AACC is also investigated in this paper.

Section II of this manuscript, explains the working principle of AACC modulation formats. In Section III, the tolerance of the chromatic dispersion residual dispersion and SPM effects of NRZ- and RZ-AACC transmission systems is mainly investigated using a simulation analysis. BER computation method is also demonstrated in this

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http://dx.doi.org/10.1016/j.optcom.2016.11.017
Received 23 August 2016; Received in revised form 8 November 2016; Accepted 9 November 2016
Available online 18 November 2016
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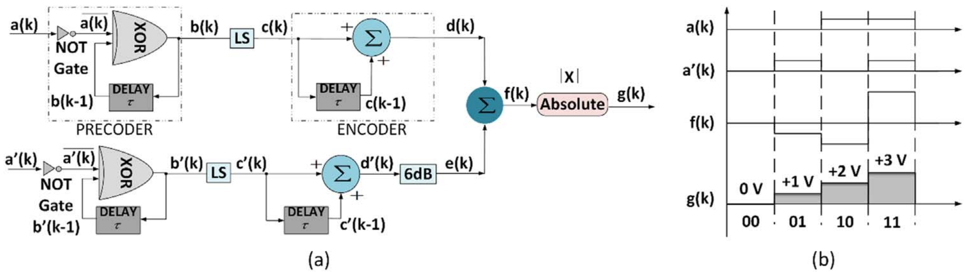

Fig. 1. (a) Electrical AACC transmitter. (b) AACC symbols..

section. Section IV presents the conclusions.

2. Review of AACC format

Fig. 1 shows the schematic diagram of the AACC transmitter. This proposed 2-bit/symbol partial-response signaling was achieved by combining two unequal-amplitude duobinary signals via a power combiner producing a multilevel bipolar signal. The signal is symmetrical with reference to zero amplitude. An electronic absolute device was exploited to gain a unique positive polarity symbol from the generated multilevel bipolar signal as shown in Fig. 1(b). With regards to clock recovery, Fig. 2 shows the electrical spectrum of AACC transmission at 20 Gbaud/s has a line at every 20 GHz, which then making the clock extraction from the high-speed serial data stream possible. A conventional direct detection technique can be utilized at the receiver (Rx). Original data can be then recovered by using three independent decision circuits as reported in [5].

The transmitter consists of two duobinary data inputs. The first path contains a pre-coder, a Level-Shifter (LS) and an encoder. The pre-coder typically is a differential encoder which is also employed for a differential phase-shift keying (DPSK) transmission [10]. It comprises a logic NOT gate, a logic XOR gate with an electrical delay-and-add filter, which acts as a correlative coding approach to avoid recursive decoding in the receiver. It therefore eludes error propagation and eases hardware complexity. The precoding function can be expressed as

$$b(k) = \overline{a(k)} \oplus b(k-1) \tag{1}$$

We have $b(k) = 1$ *if either* $\overline{a(k)}$ *or* $b(k-1)$ *is* 1
and $b(k) = 0$ *otherwise*

where $a(k)$ is the transmitted binary data sequence and $b(k)$ is the pre-coded binary sequence and ⊕ is the logic XOR gate.

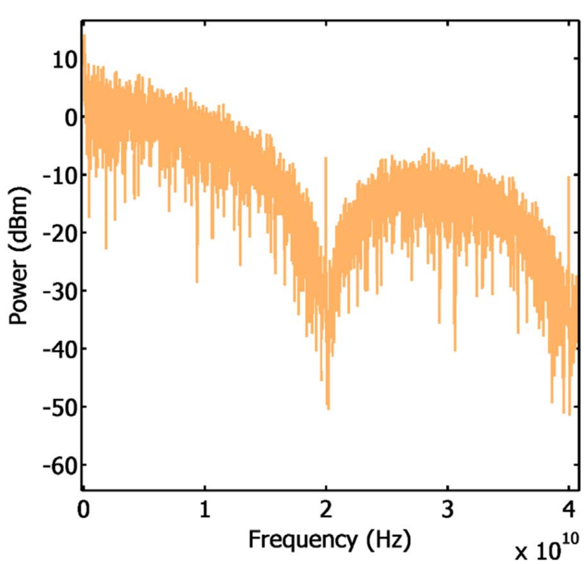

Fig. 2. Transitions at every 20 GHz which was utilized as frequency reference for clock recovery.

The sequence $b(k)$ is applied to the LS. The LS output, $c(k)$ is bipolar. The sequence $c(k)$ is subsequently passed to an encoder which operates as an electrical one-bit delay/feedback loop in order to convert a random binary signal to a normalized three-level electrical signal. The value of $d(k)=0$ if $a(k)=0$ and $d(k)=\pm 2$ if $a(k)=1$. In other words, by implementing the addition of the current bit to the previous bit will result in an electrical ternary voltage signals {−2 V, 0 V, 2 V}. This relation is found as

$$d(k) = c(k) + c(k-1) \tag{2}$$

where $d(k)$ is the encoded 3-level signal and $c(k)$ is the level-shifted binary stream.

A similar procedure is for the second path, but inserting a 6-dB electrical attenuator to reduce its power by half in order to achieve an equidistant 4-level signaling.

Table 1 distinctly clarifies the transmitted and received bit pattern of AACC generation. Specifically, it describes the operation of how a binary sequence {0 V, 1 V} is converted to ternary-levels {−2 V, 0 V, 2 V} and {−1 V, 0 V, 1 V} and then to quaternary-level signal {0 V, 1 V, 2 V, 3 V}. The intensity levels are equally-spaced and nonnegative, which are favorable in intensity-modulated direct-detection links [4,18]. It is worth noting that for differential precoding and encoding, a reference bit is essential to initiate the process. This reference bit could be arbitrarily set to either logic “1” or logic “0”. In Table 1 the reference bit $b(k)$ and $b'(k)$ at time instant $k=-1$ were set to logic “0”.

It is worth noting that the NRZ impulse shaping applied in the AACC transmission analysis is Gaussian, which is represented as

$$E_{NRZ}(t) = \begin{cases} e^{-(t/c_r)^2} & , \ 0 \le t \le t_1 \\ 1 & , \ t_1 \le t \le t_2 \\ e^{-(t/c_f)^2} & , \ t_2 \le t \le T \end{cases} \tag{3}$$

where c_r and c_f are the rise time coefficient and the fall time coefficient respectively. The parameters t_1 and t_2, together with c_r and c_f, are numerically determined so that pulses with the exact values of the rise time and fall time can be generated, and T is the bit period.

The four-level electrical signal was subsequently externally-modu-

Table 1
Transmitted and received bit stream for AACC modulation.

k	−1	0	1	2	3	4	5	6	7
a(k)		0	1	0	1	1	0	0	1
$\overline{a(k)}$		1	0	1	0	0	1	1	0
b(k)	0	1	1	0	0	0	1	0	0
c(k)	−1	1	1	−1	−1	−1	1	−1	−1
d(k)		0	2	0	−2	−2	0	0	−2
a’(k)		0	1	0	1	0	0	1	1
$\overline{a'(k)}$		1	0	1	0	1	1	0	0
b’(k)	0	1	1	0	0	1	0	0	0
c’(k)	−1	1	1	−1	−1	1	−1	−1	−1
d’(k)		0	2	0	−2	0	0	−2	−2
e(k)		0	1	0	−1	0	0	−1	−1
f(k)		0	3	0	−3	−2	0	−1	−3
g(k)		0	3	0	3	2	0	1	3