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Editorial

Mails

Sometimes I wonder how I managed to deal with all the letters and manuscripts in paper form in former (?) times. This was a tremendous effort – and also costly, because most of the correspondence was with Asia and America and therefore I had to spend some money on the postage.

Today is everything is digital and can be sent without too much costs and efforts over the whole world. You may send one information to a lot of addresses – it does not cost more and it does not take more time.

So everything seems to be perfect – seems! Especially in Asia we have a problem which makes it even worse than before with all the paper work: I receive a manuscript by mail and answer the mail to acknowledge that we have received the paper: The mail comes back, because the mail adress is invalid or does not work. What to do? Sometimes we have several mail addresses or I have an address of somebody who may work close to the authors. But this is an additional effort. And if this does not work, we have to mail a conventional letter and ask for a valid and working email-address. There are three choices for the answer:

1. There is no answer.
2. The new mail address does not work either.
3. The new address is ok.

These answers are equally distributed.

Sincerely yours

Ralf Th Kersten

Editor-in-chief

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Chirped NRZ Modulation Format for High Speed Transmission*

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Summary

Novel modulation format using single push-pull Mach-Zehnder (MZ) modulator for high-speed transmission is proposed. Better or comparable performance with carrier-suppressed RZ is found. The simultaneous intensity modulation and differential phase-shift keying scheme using single MZ modulator is proposed too.

1 Introduction

D~nse wavelength division multiplexing (DWDM) fiber optics communication becomes the predominant transport mechanism for local, metropolitan, wide area networks (WAN) and long-haul transmission. The technologies enabling 40 Gbit/s/ch WDM transmission have been recently extensively studied. However, before the 40 Gbit/s/ch WDM systems become reality a number of problems to be overcome: increased sensitivity to accumulated chromatic dispersion, dispersion slope, PMD, increased sensitivity to fiber nonlinearities (XPM, FWM, SPM, SRS), ASE noise accumulation, double Rayleigh back-scattering in Raman amplifier applications, etc.

The main approach applied in long-haul communications is to reduce and tolerate the fiber nonlinearities, so that the system operates in so called quasi-linear regime. For such applications, the role of proper modulation scheme, proper dispersion map and proper forward error correction schemes to maintain the acceptable transmission system performance is becoming increasingly important.

A number of different return-to-zero (RZ) modulation formats were proposed recently [1–5]. The most popular among them are chirped RZ (CRZ) and carrier suppressed RZ (CSRZ). CRZ [5] is generated using bit-synchronous phase modulation of the RZ signal. Though highly tolerant to fiber nonlinearities, its spectrum is much broader than conventional RZ. On the other hand, narrower spectrum RZ formats, like CSRZ, are required for higher immunity to residual dispersion. The phase modulation can also be used for high-order dispersion compensation [1]. Recently proposed duobinary RZ (D-RZ) and modified duobinary RZ (MD-RZ) formats [2] are able to significantly suppress the discrete components, responsible for creation of ghost pulses arising from four-wave-mixing (FWM).

Unfortunately, different RZ modulation format employs two Mach-Zehnder (MZ) modulators and for duobinary transmission a pre-coder and an encoder must be also employed. We propose an alternative modulation format, named here as chirped-NRZ (due to its resemblance to CRZ [5]), by introducing the controlled phase modulation using single push-pull MZ modulator for both amplitude and phase modulations. Two parameters, the modulation depth and the phase modulation index, may be used to control the spectrum shape. Better or comparable performance with CSRZ modulation format is found. Using the similar idea the principle of ASK-DPSK with single MZ modulator is proposed too.

2 Proposed modulation format

Using elementary directional coupler theory the push-pull MZ modulator can be mathematically modeled as

$$\overline{E}_o = j\overline{E}_i \sin\left[\frac{\varphi_1 - \varphi_2}{2}\right]\exp\left[j\frac{\varphi_1 + \varphi_2}{2}\right], \tag{1}$$

where $\overline{E}_i$ and $\overline{E}_0$ denote the input and output electrical fields, whereas ϕ_1 and ϕ_2 represent the phases of two modulator arms. If the arms of the MZ modulator are driven by

$$\varphi_1(t) = \frac{\pi}{2}\frac{V_m}{V_\pi}m(t) + \frac{\pi}{2}\frac{V_s}{V_\pi}\sin(2\pi f_0 t)$$
$$\varphi_2(t) = -\frac{\pi}{2}\frac{V_m}{V_\pi}m(t) + \frac{\pi}{2}\frac{V_s}{V_\pi}\sin(2\pi f_0 t), \tag{2}$$

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where m(t) is NRZ coder output ($m \in \{0, 1\}$), V_m is the modulating signal amplitude, and V_s is the amplitude of a sine-wave signal of half-bit-rate frequency $f_0 = R_b/2$. (V_π is voltage required to introduce π rad phase shift.) After substitution of (2) in (1), the MZ output field becomes

$$\overline{E}_o = j\overline{E}_i \sin\left[\frac{\pi}{2}\frac{V_m}{V_\pi} m(t)\right] \exp\left[j\frac{\pi}{2}\frac{V_s}{V_\pi}\sin(2\pi f_0 t)\right] \quad (3)$$

Therefore, the phase change during the bit period follows the sinusoid of amplitude $\pi/2$. Two parameters, the modulation depth $a = V_m/V_\pi$ and the phase modulation index $b = V_s/V_\pi$, may be used to control the modulated signal spectrum. The spectrum of the proposed modulation format, for $a = b = 1$, is shown in Fig. 1, against the NRZ, RZ and CSRZ signals (at 40 Gbit/s). The spectrum is wider that in NRZ case and as such is expected to demonstrate high immunity to fiber nonlinearities and residual dispersion. The larger the phase modulation index is, the wider the spectrum is. Notice that just single push-pull MZ modulator is used as both modulator and spectrum shaper. To generate RZ or CSRZ signals two MZ modulators are required.

To simulate N × 40 Gbit/s WDM system the influence of four neighboring channels on observed channel is taken into consideration [3]. The transmission system consists of ten spans of SMF (every 80 km long), each followed by corresponding DCF section to compensate both dispersion and dispersion slope. Two EDFAs are put after SMF and DCF sections to compensate the fiber loss of previous sections.

The proposed modulation format demonstrates superiority over CSRZ in both single-channel and WDM environment, Fig. 2, for averaged lunch power per channel smaller than 4 mW. The channel spacing was 0.8 nm and the optical filter bandwidth 60 GHZ, and $a = b = 1$. (Notice that non-optimal dispersion map is considered and the power at DCF section input is kept strong to demonstrate superiority of the proposed modulation format in the presence of chromatic dispersion, fiber nonlinearities and linear crosstalk over CSRZ.) Results of simulations were obtained using commercially available tool – VPItransmission maker 4.5.

The system performance can be further improved by proper choice of the modulation depth and phase the modulation index, as illustrated in Fig. 3. Notice that optimum values for amplitude depth and phase modulation index are different for single channel and WDM transmission.

If the arms of the MZ modulator are driven as

$$\varphi_1(t) = \frac{\pi}{2}\frac{V_m}{V_\pi} m(t) + \frac{\pi}{2}\frac{V_s}{V_\pi} d(t)$$

$$\varphi_2(t) = -\frac{\pi}{2}\frac{V_m}{V_\pi} m(t) + \frac{\pi}{2}\frac{V_s}{V_\pi} d(t), \quad (4)$$

where m(t) is NRZ coder output ($m \in \{0, 1\}$), and d(t) ($d \in \{0, 1\}$) is the differentially encoded signal; the simultaneous amplitude and differential phase-shift keying is possible. The demodulation and performance are iden-

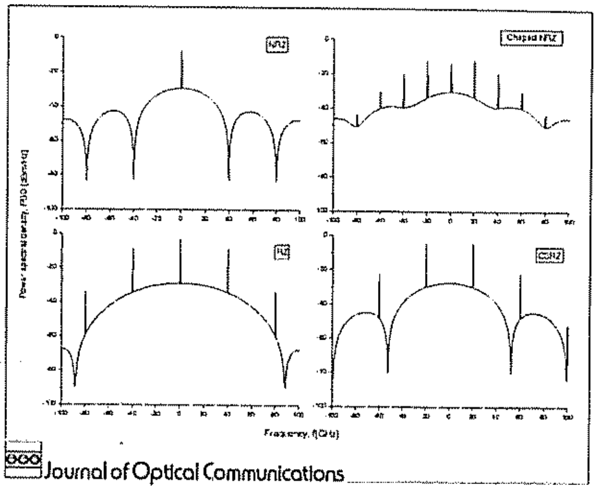

Fig. 1: Power spectral density of chirped NRZ signal

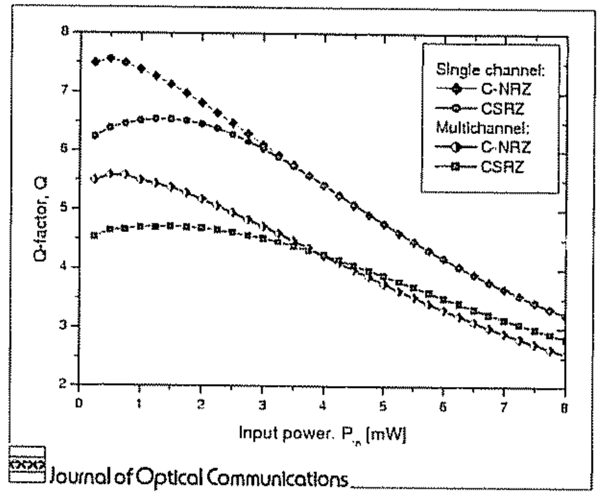

Fig. 2: Chirped NRZ versus CSRZ

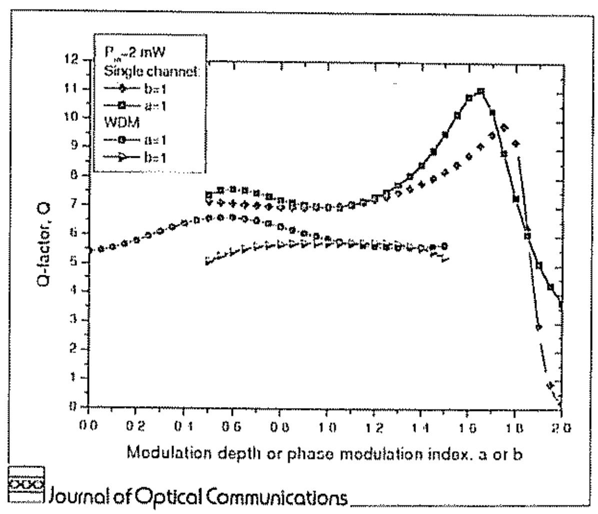

Fig. 3: Q-factor versus modulation depth/phase modulation index

tical to recently proposed quaternary ASK-DPSK direct detection scheme [7]

3 Conclusion

Novel modulation format for high-speed transmission employing single push-pull Mach-Zehnder modulator giving comparable or better performance to carrier-suppressed RZ is proposed. The proper choice of the amplitude depth and phase modulation index allows further performance improvement. The single MZ modulator based scheme for quaternary ASK-DPSK transmission is proposed too

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