Photoneco white papers:

Single-modulator RZ-DQPSK transmitter

Description of the prior art

Optical fiber systems in their infancy used to waste bandwidth both in the optical and in the electrical domain since there was no need to increase efficiency being transmission line impairments sufficiently low. Those systems, with no exception, used only binary NRZ (Non-Return-to-Zero) and RZ (Return-to-Zero) formats. In NRZ the mark was transmitted through a substantially constant optical signal over the whole bit time slot, and the space through a reduced or absent optical power over the whole bit slot. In the common RZ modulation format, the mark corresponds to the presence of an optical pulse with proper optical power and duration shorter than the bit period, the space corresponds to the absence of pulses, or to a pulse with reduced power. The outcome was a very cheap implementation of such systems with 2.5 Gbit/s off-the-shelf transceivers now sold at around 1000 USD.

When bit rate became equal or higher than 10 Gbit/s a series of system impairments showed up so that research labs started the quest for advanced optical modulation formats, other than NRZ/RZ, able to offer improved performance and tolerance to optical linear and nonlinear detrimental physical effects.

Key features for the success of advanced modulation technologies are the tolerances to linear and to nonlinear optical effects, the receiver sensitivity, the reachable signal extinction ratio, the number of modulators required at the transmitter, the electronics bandwidth as well as the maximum spectral efficiency in the wavelength division multiplexing (WDM) transmission. Local and Metropolitan optical networks require modulation formats with large tolerances to chromatic dispersion, and low-cost transmitter/receiver devices.

Moreover, next generation WDM channels are planned to transmit at bit rates of R = 40, 80 and 160 Gbit/s and the feasibility of commercial NRZ or RZ transmitters at those bit rates is not obvious, because the required bandwidth for the electronics and opto-electronics is comparable to R. The development of stable 40 GHz electronics has emerged in the last few years, and is still characterized by high production costs, whereas the development of electronics with cut-off frequency approaching to 80 or 160 GHz is still far to come.

In the above context, the transmission of optical advanced modulation formats with multi-level signals permits to reduce the transmitter/receiver electrical and optical bandwidth, as well as the optical pulse repetition rate, increasing the tolerances to chromatic dispersion.

In the last years, several multilevel optical modulation formats and new transmitter/receiver schemes have been proposed in the literature: Low-Pass Filter (LPF) duobinary, Dark-pulse and Bright-pulse PhIM (pulsed phase and intensity modulation), RZ-DQPSK (differential quadrature phase shift key), RZ-DPSK.

The modulation formats and transmitter/receiver schemes proposed above require one or two external optical phase modulators to generate the optical signal, and one to $N=\log_2 M$ phase modulators for a M-ary signal. For all the transmitter schemes presented in the prior art, a further optical intensity modulator is required to shape the optical pulses in the form of a pulse train (RZ-DPSK, RZ-DQPSK etc.). The complexity of the proposed transmitters, and the high costs for each optical modulator reduce their applicability to metropolitan and local area networks, where cost-effective devices are a primary requisite.

The proposed transmitter

Photoneco Ltd developed two new, patent pending transmitter schemes implementing new multilevel optical signal transmission (Patent No. US 7398022 B2 of Jul. 8, 2008)

The purpose of the invention is the simplification of the transmitter scheme using a single Mach-Zehnder optical modulator. Electronics bandwidth at the transmitter and the receiver is considerably reduced with respect to the prior art, permitting the transmission of high bit rates using components with relatively modest bandwidth. A purpose is also the increase of the transmission distance, of the bit rate and the spectral efficiency [bit/s/Hz] in long-haul and in metropolitan optical transmission systems.

The transmitter scheme according to the proposal is illustrated in figure 1 (proposal with 2 optical modulators); it includes an electrical signal pre-encoder (Fig. 2) having at input four or more binary signals (electrical NRZ) at bit rate R, and a clock at half frequency R/2, and generating two couples of output multilevel electrical signals at baud rate R (V_1 .. V_4), used to drive two optical modulators. A diode laser generates a substantially continuous flow of optical radiation, which is modulated by the said optical modulators in the proposed format. The proposal also includes the use of a transmitter with a single modulator and two or more input binary signals.

Figure 3 shows an example of transmission impairments vs. the optical fiber length in a typical metropolitan transmission system. The proposed advanced modulation formats in the prior art (LPF duobinary, Bright pulse PhIM, RZ-DQPSK, RZ-DPSK) are able to transmit over fiber distances not overcoming 80-160 km. On the contrary, the two proposed transmitters with one and two optical modulators, and using two and four input binary signals, extend the transmission distances to 150 and 300 km respectively.

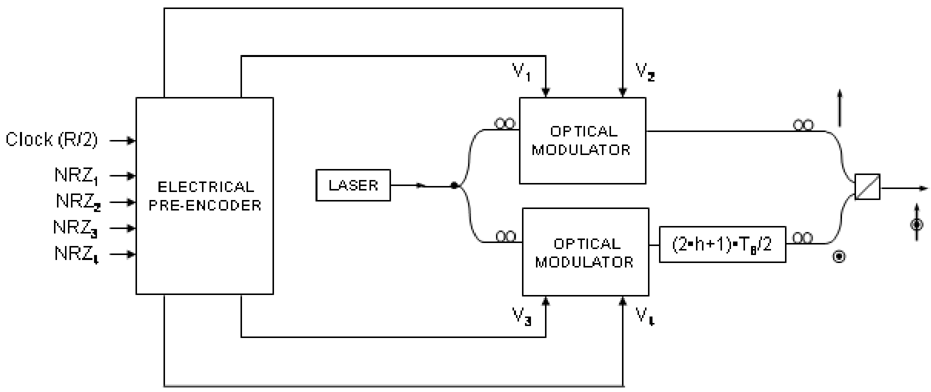

Fig. 1 – Photoneco's polarization-multiplexed RZ-DQPSK

Figure 3 shows the performance of a 10 Gbit/s system operating on a standard single mode fiber in terms of optical signal-to-noise ratio. Since a value of OSNR=20 is a reasonable line engineering choice, the proposed transmitter design by far outperforms the best system manufactured nowadays for example by Nortel/Bookham Technologies (green curve).

Actually, whereas the transmitter and receiver are standard layouts, inventor's patent covers the mixed design IC shown in Fig. 1, whose inputs are the four data streams at 2.5 Gbit/s and the clock at 1.25 Gbit/s. The four outputs V_i are analog signals in the range -6 to 6 Volts loaded by a 50 Ohms modulator input impedance. The analog functions inside the IC are amplification and signal summing.

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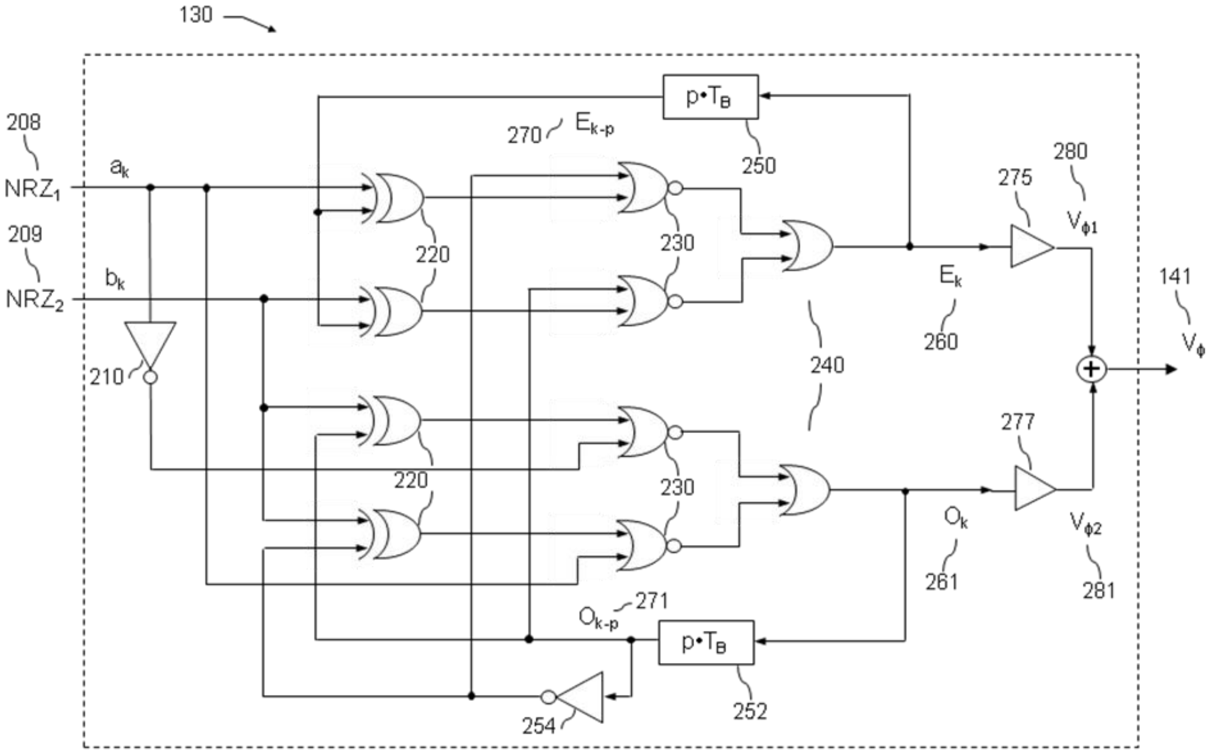

FIG. 2

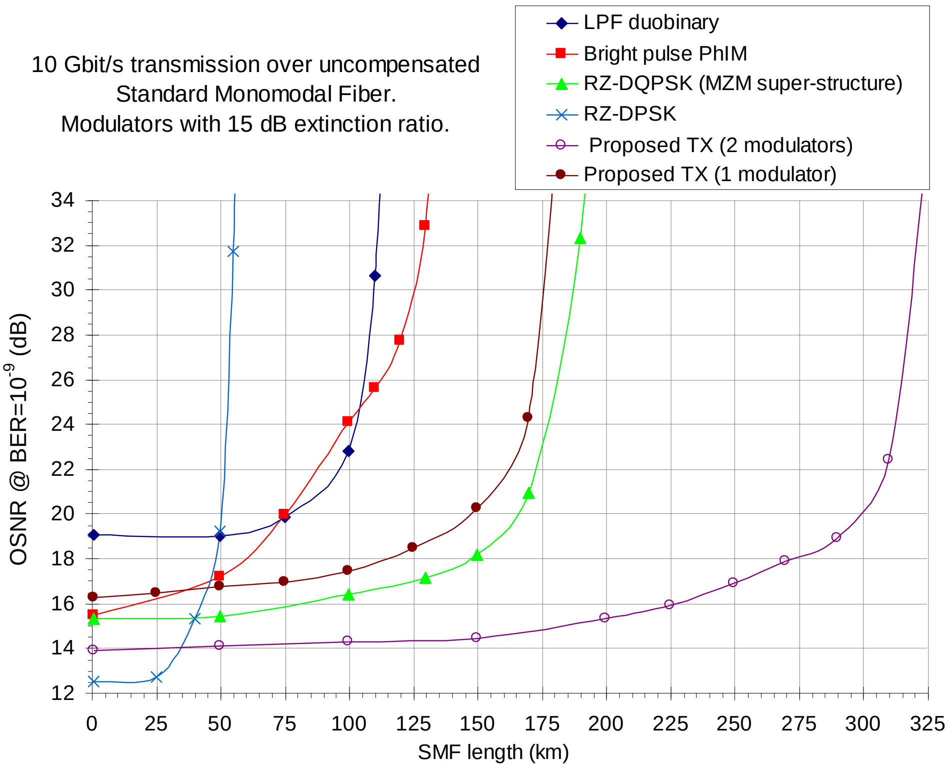

Fig. 3 – Transmission impairments

Note 1: The referenced DQPSK transmitter developed by Nortel/Bookham is described by Griffin's patent shown in Fig. 4. A Mach-Zehnder super-structure is used to generate a multilevel phase signal. RZ-DQPSK requires the use of 2 phase modulators and a shaper intensity modulator.

Fig. 4

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(12) **Patent Application Publication** (10) **Pub. No.: US 2005/0074245 A1**

Griffin (43) **Pub. Date: Apr. 7, 2005**

(54) **DIFFERENTIAL ENCODER FOR AN OPTICAL DQPSK MODULATOR**

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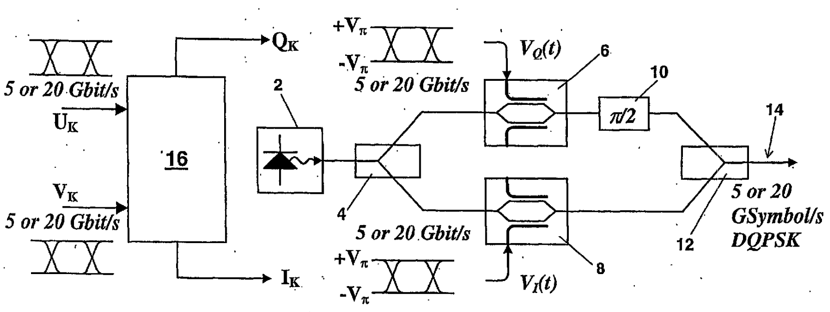
(52) **U.S. Cl.** **398/188**

(57) **ABSTRACT**

A modulator arrangement adapted to use a differential quadrature phase shift key for use in an optical wavelength division multiplex (WDM) optical communications system, comprising a precoder **(16)**, which is adapted to generate drive voltages for first and second phrase modulators **(6, 8)** in dependence upon first and second data streams. The respective drive voltages for the first and second modulators **(6, 8)** are fed back to the precoder inputs with a delay related to the line speed of the data system, wherein the length of the delay corresponds to n bits.



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Note 2: the referenced PhIM modulation format uses opto-electronics with halved bandwidth respect to the common NRZ transmitter/receiver, and is described in [M. Zitelli, Opt. Expr. 13, pp. 1215-1220 (2005)] or by the patent application US 10/732404 (publication 20050002676) shown in Fig. 5.

Fig. 5

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(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2005/0002676 A1**

Zitelli (43) **Pub. Date: Jan. 6, 2005**

(54) **OPTICAL PHASE AND INTENSITY MODULATION WITH IMPROVED TRANSMITTERS**

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(57) **ABSTRACT**

An apparatus for transmitting at least a digital optical signal with a simultaneous modulation of the amplitude and the phase, the said encoded optical signal having improved spectral efficiency and performances, and being generated by transmitters with simplified scheme; an optical communication system comprising the said apparatus, a transmission line and an apparatus to receive the said optical signal.