Contributed paper

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Four-level signalling in fiber optic transmission of two different bit rates data streams

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In the paper an unisochronous four-level signalling is proposed as a method of two different bit rate data multiplexing in standard single mode, intensity modulation fiber optic transmission system. The method is described and its main limitation – some inherent jitter – is pointed out and estimated. After a brief discussion about transmitter (multiplexer) and receiver (demultiplexer) solution, an experimental transmission system is presented. In the system, the 155 Mb/s and 50 Mb/s data streams were successfully multiplexed. Measured systems sensitivity predisposes it to be used in short and medium haul links.

Keywords: data multiplexing, fiberoptic transmission, four-level signalling.

1. Introduction

In many practical cases the lack of free fibers in the transmission network leads to the need of not provided data multiplexing. The proposed method is based on continuous time (i.e. not sampled) mapping of two binary strings into a four-level signal (Fig. 1). Unlike in an ordinary four-level signalling, the outgoing signal is unisochronous (i.e. has no uniform time base), and should be continuously slicing in the receiver for data demultiplexing.

Fig. 1. Unisochronous four-level signalling scheme.

As it will be discussed in the next section, the demultiplexed binary signals are in some way distorted due to limited transmission medium bandwidth. This distortion could be acceptable small, when the medium bandwidth is relatively high in respect to the data bit rates. Thus, the proposed method seems to be specially useful in fiber optic transmission systems, where the available bandwidth can easily reach few GHz [1], and transmitted data rates are frequently limited up to few hundreds Mb/s.

The described method may be taken into account as a cost-effective alternative to usually used Wavelength Division Multiplexing (WDM) or Time Division Multiplexing (TDM), or as a next multiplexing level. In comparison to TDM multiplexing of different rates data the presented method shows some advantages: is relatively simple, is "transparent" (i.e. not restricted to particular data rates), and do not introduce any delay (do not need buffering of data blocks).

2. Jitter considerations

As it was mentioned above, the proposed multiplexing method is based on continuous time four-level mapping of incoming binary streams in the transmitter, and continuous time slicing in the receiver decision circuit (see Fig. 2). Taking into account an ideally shaped (i.e. having zero rise and fall time) signal at the input of the slicer [Fig. 2(b)], the restored binary signals on its output should be undistorted.

However, taking real bandlimited signal having some rise and fall time [Fig. 2(c)] it could be noticed that restored binary signals [Fig. 2(d)] are someway distorted. The delay between the original binary signal D_1 and restored D_1^R [t_A and t_B in Fig. 2(c)] depends on actual value of the second signal D_2. This means that D_1^R is disturbed by the jitter equal to $t_B - t_A$. Signal D_2^R is distorted by the "spikes" [marked by the circles in Fig. 2(d)] occurring during the change of D_1. These spurious events in the restored signal are time limited, and so can be removed by the circuit which ignores short spikes in the processed signal. The idea of such a circuit is shown in Fig. 3. From the detailed timing considerations it can be derived that spurious spikes can be properly eliminated when

$$t_S < t < \frac{1}{3} T_1 \tag{1}$$

where t_S means the spike duration, τ is the delay in the circuit from Fig. 3, and T_1 is the clock period of data D_1 (what

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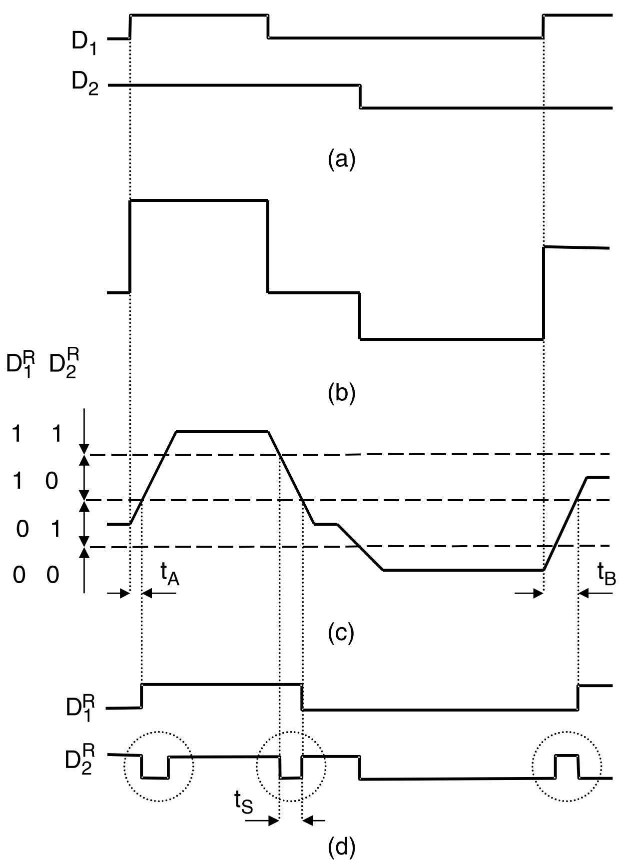

Fig. 2. Time diagrams of multiplexed and demultiplexed signals.

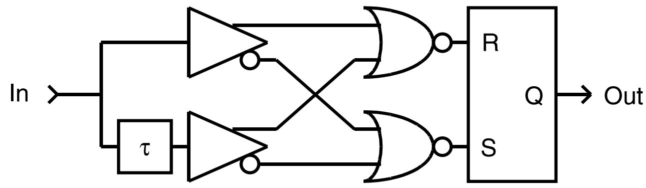

Fig. 3. Spike eliminating circuit.

is the possible spike repetition interval). However, the signal delay introduced by spike eliminator may vary in the range 0 ... $\tau + t_S$, depending on actual time relation between the neighbour D_1 and D_1 transitions, what means the spike elimination is paid by some jitter in corrected signal D_2^R.

The estimation of the jitters can be derived basing on the notice that the values of $t_B - t_A$ and t_S are equal to 25% to 75% rise/fall time of the 4-ary signal at the slicer input (additionally it should be observed that only the signal slopes caused by D_1 transitions are responsible for jitter inducted to both restored binary signals). Therefore the peak-peak jitter of D_1^R can be directly written as

$$t_{j1_{p-p}} = t_{25\% - 75\%}, \qquad (2)$$

where $t_{25\% - 75\%}$ is the mentioned above rise/fall time. Taking an assumption that the delay used in spike elimination circuit is only a bit greater than t_S [compare the condition (1)], the peak-peak jitter of D_2^R can be, with some underestimation (in practice the value of τ should be taken with some excess to ensure robust operation) written as

$$t_{j2_{p-p}} \approx 2t_{25\% - 75\%}. \qquad (3)$$

It may be more useful to express the jitters in terms of transmission system bandwidth. In general, the relationship between the bandwidth and the rise/fall time depends on particular system transfer function (or equivalently the impulse response), but in practice an estimated relationship (derived for Gaussian transfer function) can be used

$$t_{25\% - 75\%} \approx 0.18 \frac{1}{f_{-3dB}}, \qquad (4)$$

where f_{-3dB} is the –3 dB cut-off frequency. Taking for example f_{-3dB} = 500 MHz, what is value easy to maintain in nowadays fiber optic systems, the jitters can be estimated as 0.36 ns and 0.72 ns for D_1^R and D_2^R, respectively.

Therefore it may be concluded that proposed multiplexing/demultiplexing scheme introduces some inherent jitter to both transmitted signals. Anyway the jitters are in theirs pick-pick value limited and, when necessary, can be reduced by ordinary clock recovery and data retiming circuit.

3. Transmitter and receiver solutions

3.1. Transmitter

In general, a four-level signal can be generated in electrical or optical domain. It may be obtained by driving a laser by four-level current signal [see Fig. 4(a)], or by summing the optical signals from two binary driven lasers, using 66%/33% fibre coupler [see Fig. 4(b)]. It is worth mentioned that a special care should be taking for precise signal shaping: not only the rise/fall time should be minimise, but any tailing or ringing should be avoided to obtain good overall system performance. When using the idea shown in Fig. 4(b), more care should be taken of the laser transmitter associated with D_1 signal.

3.2. Receiver

A basic receiver structure is shown in Fig. 5. The most characteristic problem in the receiver design is to determine threshold levels for signal slicing. The thresholds should be adjusted to actual received signal amplitude, or alternatively the fixed thresholds and precise automatic gain control before slicing may be applied. Both solutions need peak-peak detectors for signal amplitude measuring or controlling.

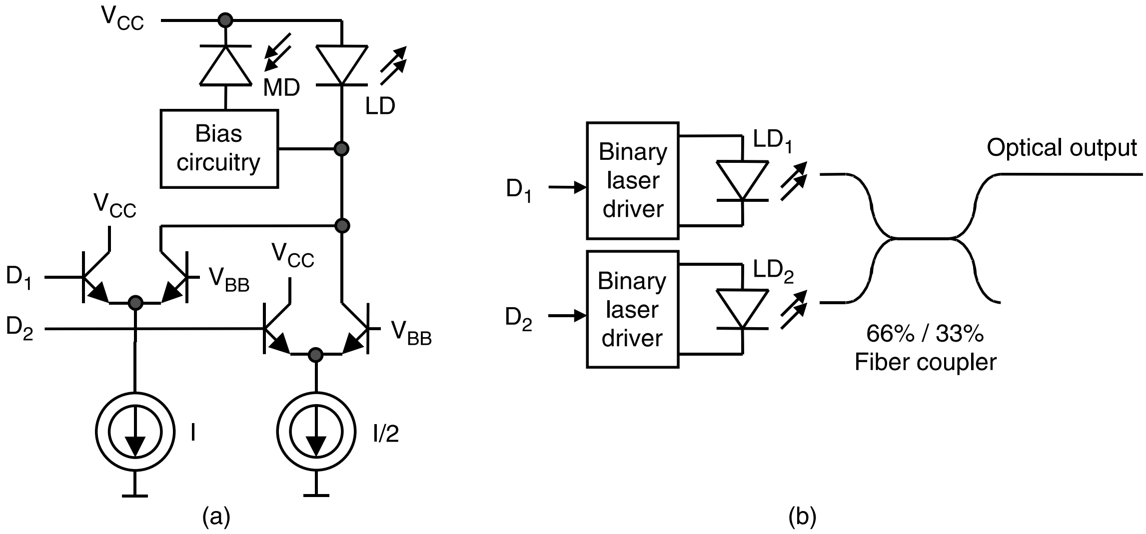

Fig. 4. Transmitter structures with electrical (a) and optical (b) 4-ary signal construction.

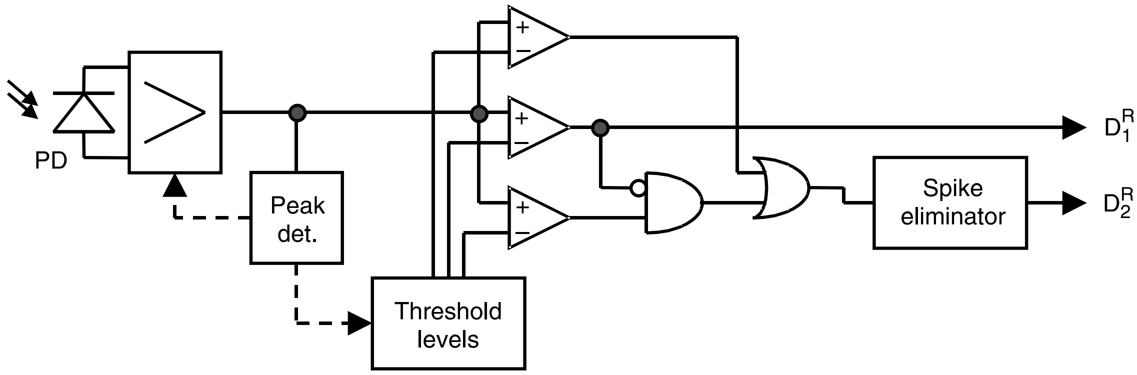

Fig. 5. Basic receiver structure.

It may be noticed that reconstruction of D_1 from 4-ary signal needs only a simple comparison with mean value that makes limiting amplifier or comparator in any ordinary binary receiver. The idea of using the integrated binary receiver for D_1 signal will be discussed in the next section.

4. Experimental results

The first experimental transmission system (see Fig. 6) consisted of four-level laser driver based on idea shown in Fig. 4(a), a 1310 nm FP laser, fiber with optical attenuation, PIN photodiode, transimpedance preamplifier and second stage voltage amplifier, demultiplexer (i.e. peak-peak detector, slicer and decoding logic), and spike eliminator. No data retiming was used. The multiplexed data were 155 Mb/s (D_1) and 50 Mb/s (D_2).

In Fig. 7, operation of spike eliminator is illustrated. The outgoing signals eye patterns are presented in Figs. 8(a) and 8(b). It can be seen that the received data were properly demultiplexed, however, some jitter was introduced, as it had been suspected. The measured pick-pick jitters were 1.2 ns and 4.5 ns for D_1 and D_2 data streams, respectively. The jitters were practically independent on the signal strength when varying from sensitivity level to the maximum value. The obtained receiver sensitivity was –24 dBm for BER equal to 10^{-9}.

Practically, the obtained jitters were a bit greater than it can be suspected from the estimations presented in Sec. 3 when taking $t_{25\% - 75\%}$ value at the output of receiver preamplifier (0.8 ns). Two reasons should be pointed out:

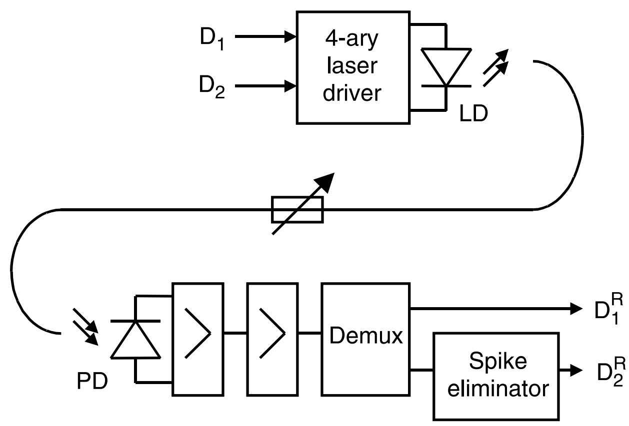

Fig. 6. Experimental transmission system.

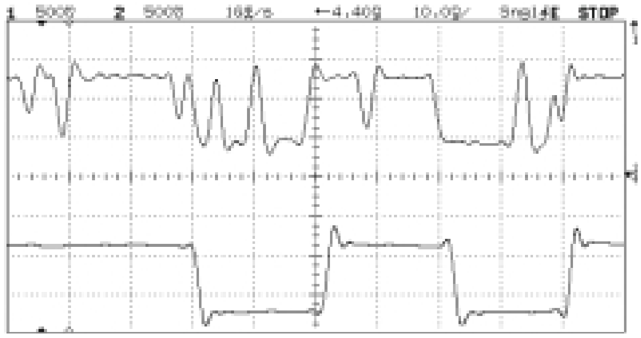

Fig. 7. The signal D_2 at the output of demultiplexer (upper trace) and after spike eliminator (lower trace).

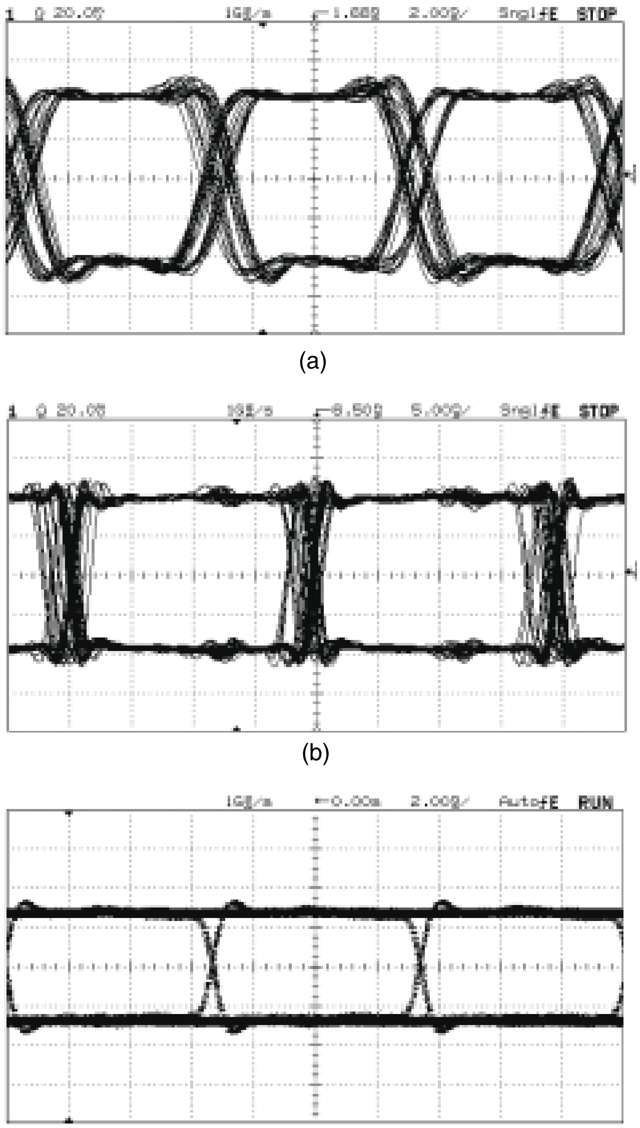

Fig. 8. Eye patterns of the demultiplexed data D_1 path (a), D_2 path (b), and D_1 path (c) after modification.

the limited analogue bandwidth of comparators used in the demultiplexer reduces the signal bandwidth and also increases equivalent signal rise/fall time. Additionally, dynamic imperfection of the decoding and spike eliminating logic circuits causes further signal degradation. Taking into account that state of the art, ultra fast comparators and ECL logic was used, no significant advantage can be obtained without integrating all the receivers in custom-design circuit.

However, serious reduction of jitters reduction was obtained using the concept shown in Fig. 9. In this structure, additional binary receiver was used in D_1 path to avoid dynamic limitations of 4-ary receiver and also binary drivers were used in transmitter for better signal shaping. Widely available 2.5 Gb/s integrated driver and receiver by Maxim were used. The modifications resulted in dramatic reduction of D_1^R jitter – down to 0.2 ns pick-pick [see Fig. 8(c)], and some reduction of D_2^R jitter – down to 3 ns pick-pick. In this solution, the distinction between faster (main) and slower (additional) channel is very clear.

Taking the idea of two separate receivers the next modification of the system structure can be made. Instead of use of one photodiode that drives both receivers, the fiber power splitter and separate photodiodes may be used. In this situation, both transmitters and receivers may be spatially separated, and only a part of fiber link is common for both channels.

5. Conclusions

The unisochronous four-level signalling as the method of two different bit rate data streams was presented. The pre-

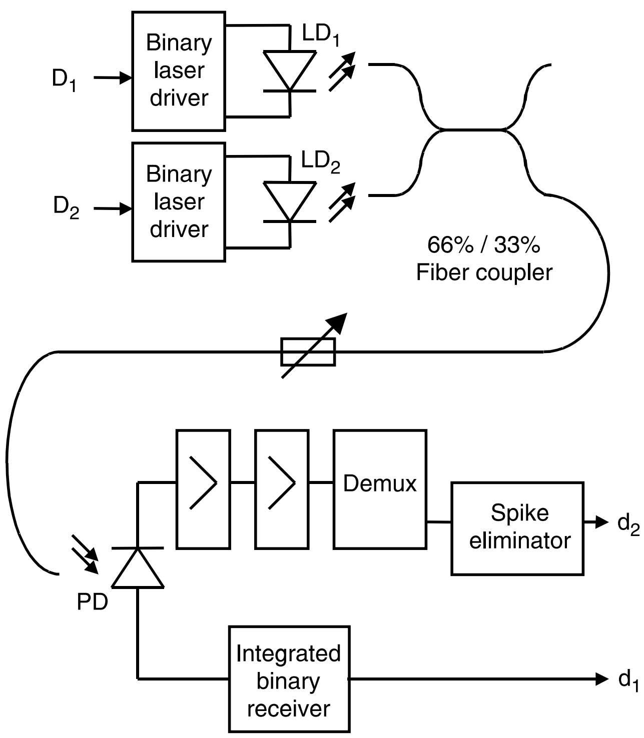

Fig. 9. Modified transmission system.

sented solution leads to some jitter in restored data but it should be emphasised that this jitter is peak-peak limited and therefore may be reduced by ordinary data retiming. The inherent feature of the proposed multiplexing scheme is some asymmetry between two available data channels; one has better timing performance and so is predisposes to carry higher bit rate data. The experimental fiber optic transmission system shows practical multiplexing possibility for data rates in the range of some hundreds of Mb/s. The system simplicity and flexibility make it an alternative to widely used TDM or WDM multiplexing methods.

Acknowledgement

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References

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International Exhibition of Electrical and Electric Equipment MATELEC 2002

The Association of Polish Electrical Engineers (SEP) has the pleasure to inform that an *International Exhibition of Electrical and Electric Equipment – MATELEC 2002* will take place in Madrid (Spain) on 8–12 October 2002.

MATELEC is based on a unique concept, it brings together complementary trade sectors at the same time and the same place: electrical installation, electronics, telecommunications, lighting, etc. Each individual sector is represented at highest level. This integrated presentation concept is guarantee to synergies and interdisciplinary solutions.

The exhibition has its well founded tradition of over ten years and is the first port of call for industry professionals from all over the world, especially for those interested in the Latin American growing markets. The presence in its last edition of 1400 exhibiting companies from 90 countries and over 55 000 visitors underlines the importance of the fair.

The interesting programme and scope of the event has led the Association of Polish Electrical Engineers (SEP) to participate in the promotion of Polish enterprises in the exhibition.