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Multilevel signalling in multimode fibre links

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The possibility of upgrading transmission capability of multimode fibre links by applying multilevel signalling is estimated in this paper. First, the simulation method is briefly presented. Next, the comparison between binary and multilevel signalling is undertaken. It is found in which link variant and in which aspects multilevel signalling shows advantages over binary one. Finally some experimental results are presented.

Keywords: multilevel signalling, fibreoptic transmission, fibreoptic link modelling

1. Introduction

In LED-multimode fibre based links their relatively low bandwidth limits transmission rate in case of binary signalling [1]. The main feature of multilevel signalling is that transmitted symbol rate is by $\log_2 M$ factor smaller then the bit rate (M is the number of signal levels) [2]. It means that multilevel signalling is more bandwidth efficient than binary one, and seems to be reasonable way to increase transmission capability of the link. Moreover, multilevel signalling offers possibility of redundant coding and/or channel multiplexing without increase in the transmission rate [3]. But on the other hand multilevel transmission suffers from intersymbol interference and any other signal distortions more than binary one, so the practical gain of multilevel signalling needs examination.

In this paper efficiency of high-speed multilevel transmission in short- and medium-haul multimode fibre optic (F/O) links operating in the first and second transmission window is examined.

2. Modelling of signal transmission in the fibre optic link

Adequate simulation of multilevel transmission needs much more precise modelling than usually used for binary one. In particular it was found that the signal distortion caused by the chromatic dispersion cannot be precisely modelled as fibre low-pass filtering, especially when the LED spectral distribution varies according to currently emitted optical power. To overcome this difficulty the new simulation approach was applied. The main idea of the reported method (see Fig. 1) is to discretise an optical spectrum emitted by the LED into a proper set of elements and to a partition transmitted signal into its spectral components. This allows taking into account real spectral characteristic of particular LED and an effect of its signal-caused variation and spectral dependence of any other link component parameters. It is worth to mention that in such approach the effect of signal chromatic dispersion is modelled directly by inequality of propagation delay of signal spectral components.

The applied LED model consists of three main parts: non-linear $P_\lambda(I)$ model, non-linear dynamic model, and signal-dependent spectral distribution model. The fibre model takes into account chromatic dispersion, modal dispersion, and wavelength-dependent attenuation. The photodiode model respects its wavelength-dependent sensitivity and parasitic capacitance. All model parameters was determined using where possible producer's data and (mainly) in experimental way. That was done for a set of link elements: five LEDs (1A194, 1A239, 1A255, 1A300 and 1A381 types by HAFO), two fibres (50/125 µm 0.5 km and 62.5/125 3 km pieces) and five photodiodes (1A211, 1A326, 1A354, 1A358 by HAFO and

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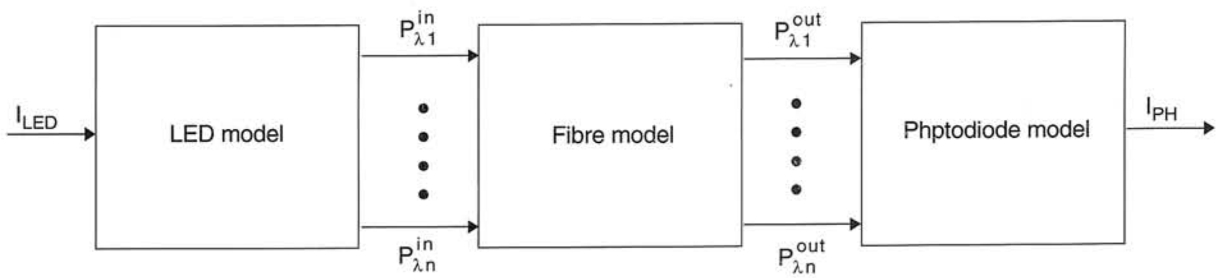

Fig. 1. Optical spectrum split F/O transmission modelling.

PD1002 by Mitsubishi). The overall link model accuracy was tested for various element combinations and input pulses and it was found as being in a range of 3% of full scale of a signal.

3. Comparison of binary and multilevel transmission capabilities

The comparison of binary and multilevel signalling efficiency presented in that section is based on some signal parameter estimation. In general, signal received from F/O link can be correctly recognised when it has sufficient amplitude and timing information. Amplitude quality estimation is based on two eye diagram parameters: the absolute and relative eye opening (H and h, respectively) (see Fig. 2). The absolute eye opening informs about a noise immunity of the received signal. Relative eye opening informs about an amount of intersymbol interference: h = 1 means no intersymbol interference, h = 0 means amount of intersymbol interference making correct signal recognition impossible. Timing information estimation will be provided by the clock frequency content in the signal frequency spectrum. All analysed signals are RZ (Return to Zero) shaped. That choice comes from RZ signalling efficiency in case of dispersion dominated transmission [4].

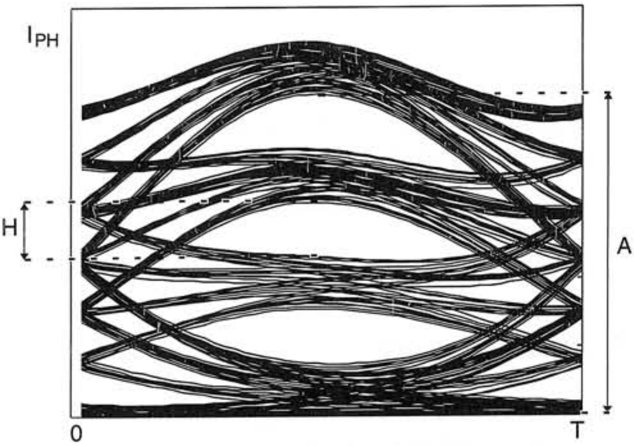

Fig. 2. Eye opening parameters.

Figures 3(a) and 3(b) show relative and absolute eye opening of photodiode current signals versus transmission bit rate for the 1st window 3-km long link. It can be noticed that for high bit rates four-level

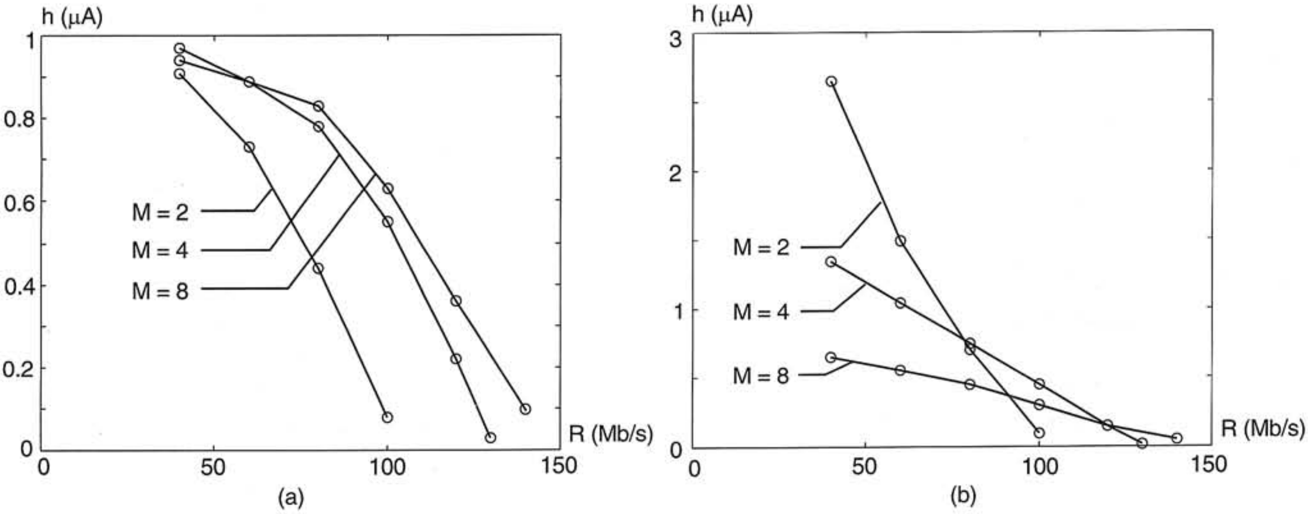

Fig. 3. Relative (a) and absolute (b) eye opening vs bit rate. 1st window 3-km link.

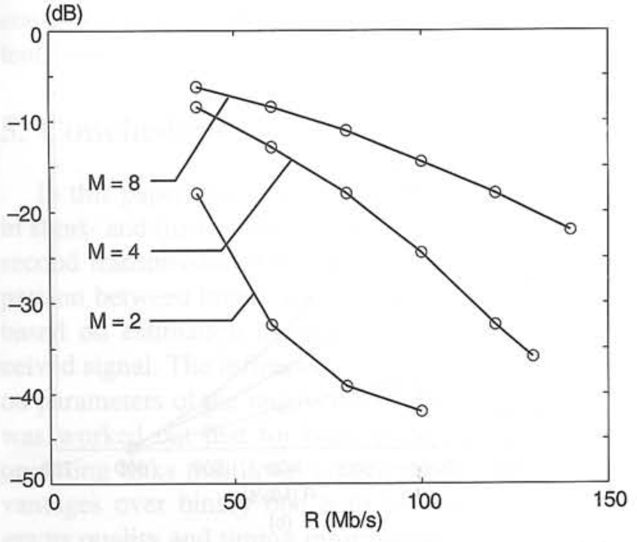

Fig. 4. Clock frequency content vs bit rate. 1st window 3-km link.

(M = 4) and eight-level (M = 8) signalling show significant advantage over the binary (M = 2) one. Taking h = 0.5 as a reference value the resulting maximum bit rate is 40% – 45% greater in the case of multilevel signalling. Also the clock frequency content is much greater for multilevel transmissions (see Fig. 4). Similar multilevel signalling advantages were observed for 0.5-km length link. In Fig. 5 the examples of 100 Mb/s eye diagrams are presented.

The results presented above concern the link applying an LED with negligible signal-caused spectral characteristic variation. However, in some LEDs full width at half maximum (FWHM) variation may be of the order of 30% of its mean value. If such LED is used some additional signal distortions will occur in case of high-speed multilevel signalling. The "eyes" are not equally opened and spaced, and slightly shifted in time domain (see Fig. 6). Eye opening and clock frequency content for 2nd window 3-km length link is shown in Figs. 7 and 8. In this case there is no advantage when using multilevel signalling in terms of eye opening, but still it is serious advantage in clock frequency content. Similar results were observed for 0.5-km length link.

That was found that different comparison results observed for the 1st and 2nd window links originate from some differences in intersymbol interference shape caused by signal chromatic dispersion in that windows. In the 1st window chromatic dispersion parameter has nearly constant value, when in the 2nd window it crosses the zero-dispersion point and changes its sign.

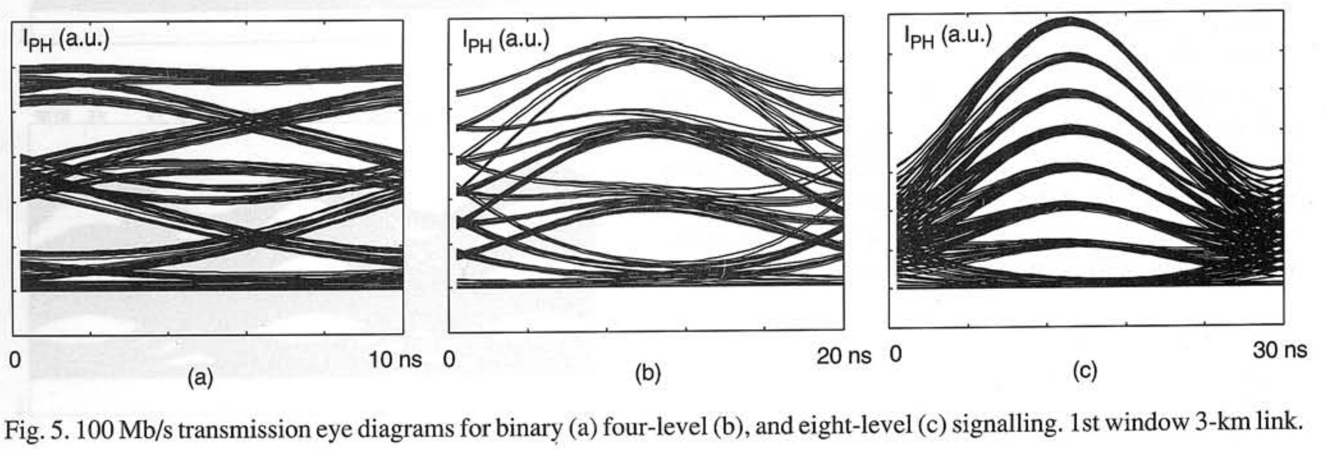

Fig. 5. 100 Mb/s transmission eye diagrams for binary (a) four-level (b), and eight-level (c) signalling. 1st window 3-km link.

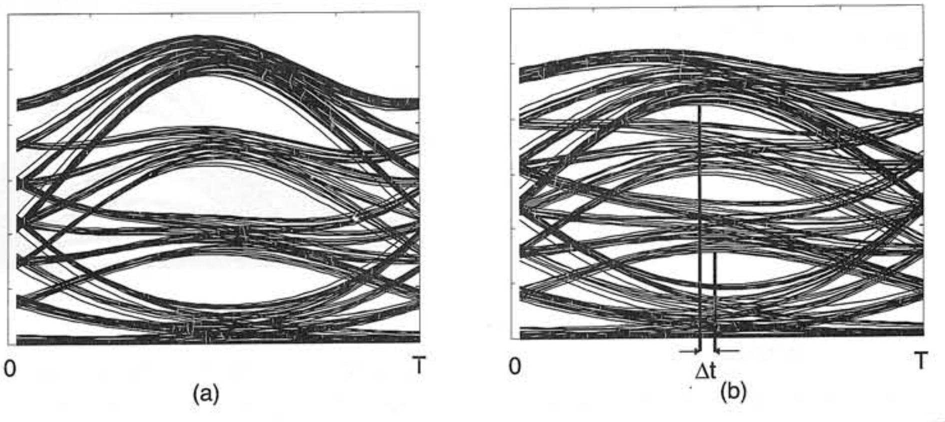

Fig. 6. FWHM variation influence on eye diagram (a) constant (mean) FWHM, (b) signal dependent FWHM.

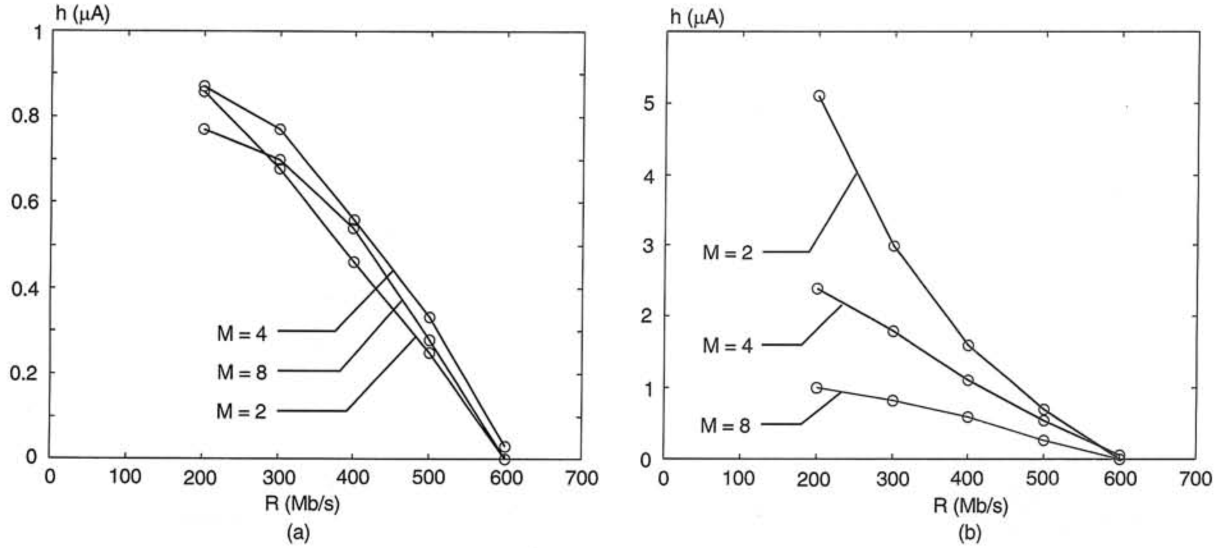

Fig. 7. Relative (a) and absolute (b) eye opening vs bit rate. 2nd window 3-km link.

4. Experimental results

To confirm the analysis presented above an experimental set was built. The pseudorandom sequence generator, binary/four-level/eight-level RZ encoder and D/A converter was used at link input. The transmission link consisted of LED (1A255 type), 3 km of 62.5/125 μm fibre and PD1002 photodiode. Photodiode current was amplified by a low-noise, high-bandwidth transimpedance preamplifier. The outcoming signal was recorded by digital scope in form of eye diagram. Additionally, the signal spectrum was measured at spectrum analyser. The eye diagrams measured for 100 Mb/s binary, four- and eight-level signalling are presented in. Fig. 9. Relative eye opening obtained from simulation and measurement were

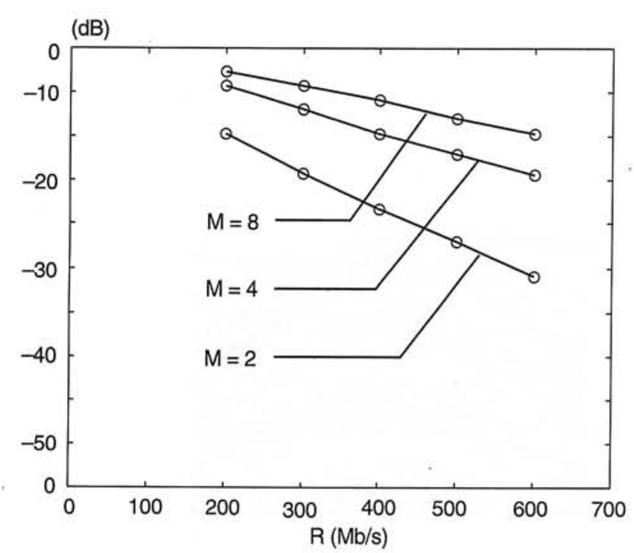

Fig. 8. Clock frequency content vs bit rate. 2nd window 3-km link.

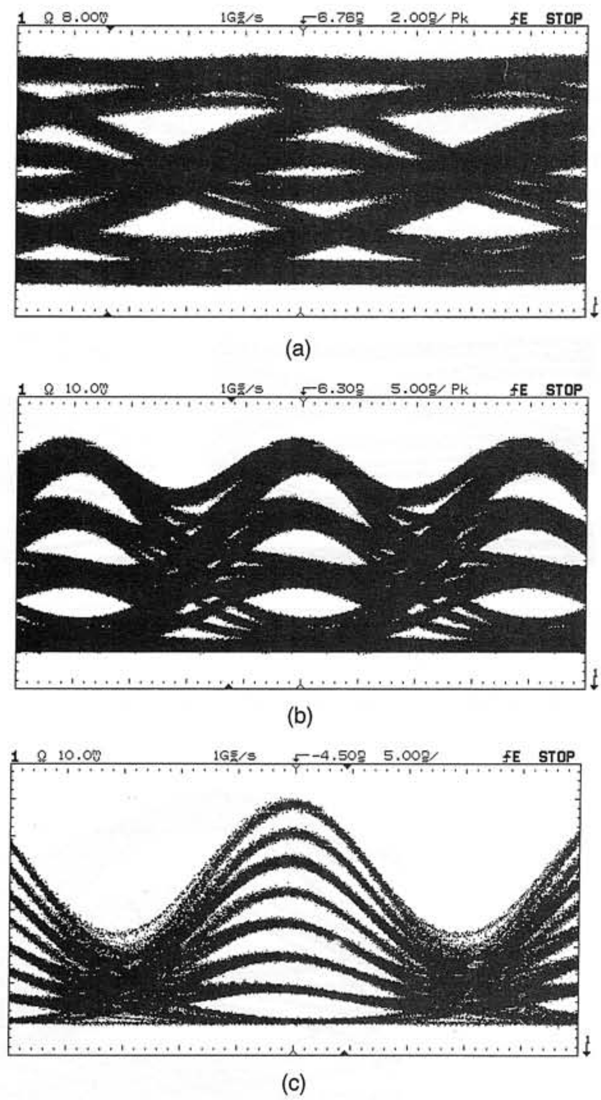

Fig. 9. Measured 100 Mb/s transmission eye diagrams for (a) binary (b) four-level, and (c) eight-level signalling. 1st window 3-km link.

consistent within 5% accuracy, clock frequency contents within 2 dB accuracy.

5. Conclusions

In this paper efficiency of multilevel transmission in short- and medium-haul links operating in first and second transmission window was examined. A comparison between binary and multilevel signalling was based on estimation of some parameters of the received signal. The influence of LED FWHM variation on parameters of the received signal was presented. It was worked out that for high-speed the 1st window operating links multilevel signalling shows some advantages over binary one both in terms of eye diagrams quality and timing information content, but for the 2nd window links in terms of timing information content only. Finally some experimental results are presented.

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