WDM-DPSK detection by means of frequency-periodic Gaussian filtering

A. D'Errico, R. Proietti, L. Giorgi, G. Contestabile and E. Ciaramella

A single frequency-periodic narrow filter converts DPSK to intensity modulation in a high number of WDM channels. It also strongly enhances their tolerance to chromatic dispersion and is exploited in a 16×10 Gbit/s transmission over 240 km G.652 fibre with no chromatic dispersion compensation.

Introduction: Differential phase shift keying (DPSK) is an attractive modulation format because of its high robustness to nonlinear propagation [1]. Various solutions were proposed for detecting optical DPSK. Among them, probably the most popular is the delay Mach-Zehnder interferometer (MZI) [2, 3], which converts DPSK into an intensity modulated (IM) signal. Using MZIs could require introducing into WDM systems a number of additional bulky components, one for each WDM channel. As recently proposed, a single MZI could also be used to demodulate any ITU DPSK channel, but here the two interferometer arms should be carefully designed and highly stabilised to get a frequency-periodic filtering effect [4, 5].

An alternative solution to the MZI was theoretically proposed in [6]. It is based on narrow optical filtering of a DPSK signal and moreover could strongly enhance the signal tolerance to chromatic dispersion [7]. Unfortunately, owing to the criticality of realising a suitable filter (e.g. Fabry-Perot filters would not work [7]), only very preliminary experimental results on this scheme were presented, all limited to a single channel [8, 9]. Therefore, one can expect that, using this technique, many components might be needed for WDM applications.

Here we experimentally assess the feasibility and the potential benefits of this approach in a 16×10 Gbit/s WDM-DPSK transmission. Principally, we introduce a single component that acts as a periodic narrowband Gaussian filter in the frequency domain (see Fig. 1), thus converting the DPSK modulation into IM in all WDM channels simultaneously. This effectively reduces the component count and implements the solution proposed in [6] extending it into the WDM domain. Furthermore, this scheme enhances so strongly the tolerance to chromatic dispersion that we transmit 10 Gbit/s DPSK signals with no dispersion compensation over 240 km G.652 fibre, a distance approximately three times higher than usual.

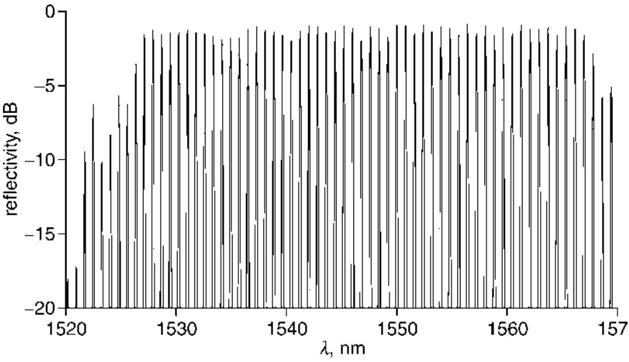

Fig. 1 *Reflectivity profile of FBG array*

Experiment: The component used for the experiments is a custom-made array of unchirped fibre Bragg gratings (FBGs), all written in the same piece of fibre. It works together with an optical circulator as the FBGs act as selective reflecting filters. The spectral behaviour of the component reflectivity is reported in Fig. 1. On each WDM channel of the ITU-T 100 GHz grid, we get a reflectivity profile having around 6 GHz full width at half maximum.

As indicated in [7], the reflectivity has approximately a Gaussian shape. The gratings are chirp-free, with almost flat phase response (i.e. they have no chromatic dispersion), as it is confirmed by the operation in the back-to-back configuration. The insertion loss at the various carrier wavelengths ranges between −4.0 and −5.5 dB, mainly due to coupling losses.

We used this device in the experimental setup shown in Fig. 2. We had 16 CW optical carriers produced by DFB lasers combined by an arrayed waveguide router (AWG1, 32 channels, 100 GHz spacing) and modulated by a $LiNbO_3$ phase modulator at 9.953 Gbit/s (PRBS: $2^{31}-1$). Note that we take advantage of the PRBS property to avoid any electronic differential encoder (the coded sequence is the original one, shifted by some bits). Polarisation controllers (PC) are used to match the polarisation of the optical carriers to the transverse electric (TE) mode of the modulator, to produce the maximum phase modulation depth. The DPSK signals are then transmitted along a three-span line. Each span is made of an erbium-doped fibre amplifier (EDFA), with $\simeq$15 dBm output power, and 80 km of G.652 singlemode fibre ($D = 16.4$ ps/nm/km). No dispersion compensation is used.

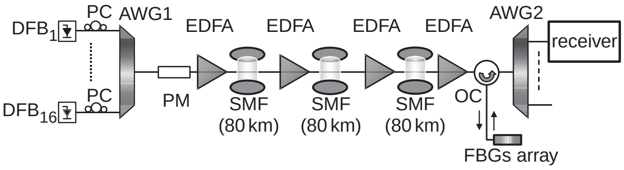

Fig. 2 *Experimental setup*

DFB: CW lasers; PC: polarisation controllers; AWGs: WDM (de)multiplexer; PM: phase modulator. FBG array: array of unchirped FBGs (bandwidth: 6 GHz on each WDM channel)

We outline that, according to the original theoretical proposal, in the linear regime the FBG array could be positioned either at the receiver or at the transmitter with the same practical performance. However, in a real link including nonlinear propagation effects, we found it highly preferable to use it at the link end, to maintain the DPSK higher robustness to nonlinear effects (namely owing to the constant envelope). After demodulation, all channels are demultiplexed by means of another AWG (AWG2), and then received using an APD-based receiver with variable threshold.

Figs. 3*a* and *b* show typical eye diagrams in back-to-back configuration and after 3×80 km spans, respectively, taken at one of the AWG2 output pigtails. In Fig. 3*b*, despite the high accumulated dispersion, the eye is quite open. Still some intersymbol interference (ISI) is present, partly owing to non-ideal behaviour of the filter and, mostly, owing to the high accumulated dispersion (around 4000 ps/nm). All the WDM channels were successfully transmitted over 240 km. Fig. 3*c* presents the optical spectrum at the output of the line. As can be seen, the optical signal-to-noise ratio (OSNR) values are quite good and range between 30 and 32 dB for all channels.

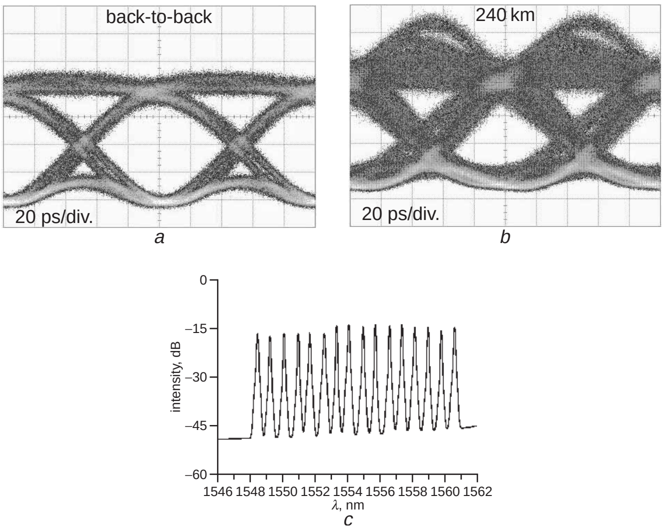

Fig. 3 *Eye diagrams and optical spectra*

a Typical eye diagram at receiver in back-to-back configuration
b After 240 km G.652 fibre
c Optical spectra taken at the line output (resolution bandwidth: 0.1 nm)

We measured the bit error rate (BER) for these channels after each span and found that the penalty increases at any span up to around 2.5 dB, showing indeed quite higher tolerance to chromatic dispersion than in usual DPSK-detection techniques, as predicted in [7]. Fig. 4*a* shows the BER curves taken for the worst-case channel (at 1551.72 nm) in the back-to-back condition, and after 80, 160 and 240 km, respectively. We report the final power penalty at BER $= 10^{-9}$ for all WDM channels in Fig. 4*b*. The channels do not have exactly the same performance, mainly because of the non-ideal response of the filters (slight deviations from the Gaussian amplitude response and residual phase ripples). These measurements confirm that the filter can be effectively used in a WDM environment.

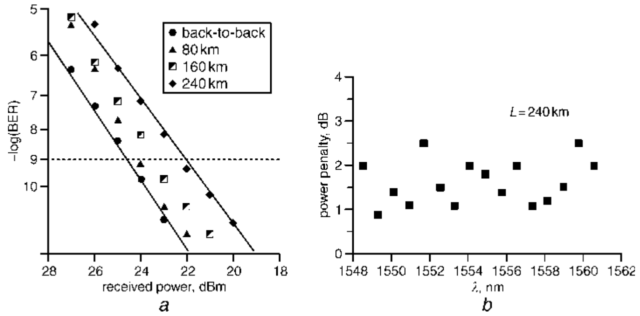

Fig. 4 *BER and power penalty*

a BER measurements for worst-case channel ($\lambda = 1551.7$ nm) in back-to-back and after 80 km, 160 km and 240 km
b Power penalty (at BER $= 10^{-9}$) for 16 DPSK channels after uncompensated transmission over 240 km G.652 fibre

Conclusions: We have demonstrated the feasibility of an FBG-based component capable of simultaneous demodulating a high number of WDM-DPSK channels, furthermore increasing the system tolerance to chromatic dispersion. We tested it in a system experiment demonstrating transmission over 240 km of G.652 fibre ($\simeq$4000 ps/nm accumulated dispersion) with no chromatic dispersion compensation. Good system performance was obtained on all 16 channels. Owing to the spectral filtering shape of the component it could be also used for a quite higher number of WDM channels (up to 50). We note that although the system demonstration was carried out using 10 Gbit/s DPSK signals, it could be directly extended to 40 Gbit/s signals. In that case, one should properly redesign the filter (and, clearly, the dispersion tolerances should be lower, although higher by around a factor of 3 than in MZI-detected 40 Gbit/s DPSK).

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A. D'Errico, R. Proietti, L. Giorgi, G. Contestabile and E. Ciaramella (*Scuola Superiore Sant'Anna, Via G. Moruzzi 1, 56124 Pisa, Italy*)

E-mail: antonio.derrico@sssup.it

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