

Letter

Impact of Double Cavity FP Demultiplexers on the Performance of WDM Dispersion Supported Transmission

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Abstract. This paper discusses the impact of double cavity Fabry-Perot demultiplexers on the performance of wavelength division multiplexing (WDM) systems with dispersion supported transmission (DST) of three 10 Gbit/s channels separated 1 nm. For performance assessment, a suitable simulation methodology has been used which combines signal simulation with noise analysis in optically amplified multichannel direct detection systems. Simulation results show an improved system performance if a double cavity Fabry-Perot filter is used as demultiplexer, resulting in WDM transmission with a crosstalk penalty less than 1 dB in the region of small linear increase of dispersion penalty of the DST method. The robustness of the multichannel DST method against data pattern dependencies is investigated.

1. INTRODUCTION

The method of dispersion supported transmission (DST) has shown to be very powerful for transmission of high bit rate signals over dispersive fibres [1]. However, it has used only a small fraction of the large bandwidth available in the low-loss region of the fibre. While the modulation bandwidth is in the order of tens of GHz, the available bandwidth in the 1550 nm window of singlemode fibres is about 12.5 THz [2]. The limitation on the increase of the bit rate is due to the insufficient bandwidth of electronic and optoelectronic devices, and to the fibre chromatic dispersion. One way to overcome this limitation is to transmit simultaneously many optical channels with slightly different wavelengths from each other. With this technique, known as wavelength division multiplexing (WDM), the transmission capacity for a system with N channels is increased to $B \cdot N$, where B is the bit rate in each channel [3].

In [4] we have assessed the performance of two-channel dispersion supported transmission systems using single and double cavity Fabry-Perot (FP) demultiplexers. In this paper we discuss the impact of double cavity FP demultiplexers on the performance of optical communication systems with dispersion supported transmission of three channels operated at 10 Gbit/s and wavelength division multiplexed with 1 nm of channel spacing.

2. SYSTEM MODEL AND PERFORMANCE ANALYSIS

Fig. 1 shows a schematic diagram of a wavelength division multiplexing system with dispersion supported transmission (WDM-DST) of three channels. A brief description of the system model follows. Each pseudo pattern generator (PPG) provides a pseudo random binary sequence (PRBS) with $2^7 - 1$ bits at 10 Gbit/s. Each one of the three optical transmitters consists of a laser driver and a multi-quantum-well distributed feedback (MQW-DFB) laser. Each MQW-DFB laser is assumed to be directly modulated and the quantum-well laser dynamics has been modelled using the rate equation model proposed in [5]. The emission wavelengths of lasers 1, 2, and 3 were 1533 nm (channel 1), 1532 nm (channel 2), and 1531 nm (channel 3), respectively. At the WDM optical multiplexer output, the total electric field is the sum of the input electric fields. Channel 2 was represented by its equivalent lowpass (signal channel), and channels 1 and 3 were frequency juxtaposed (interfering channels) with a separation of about 127.8 GHz (1 nm). Synchronous data patterns are assumed to be transmitted in all channels, since this is the worst case for crosstalk [6]. For this situation, the complex envelope of the multiplexed electric field in the frequency domain is given by [4]:

$$E_{\max}(\omega) = \sum_{i=1}^N E_i [\omega - (i - nsc)\Delta\omega] \quad (1)$$

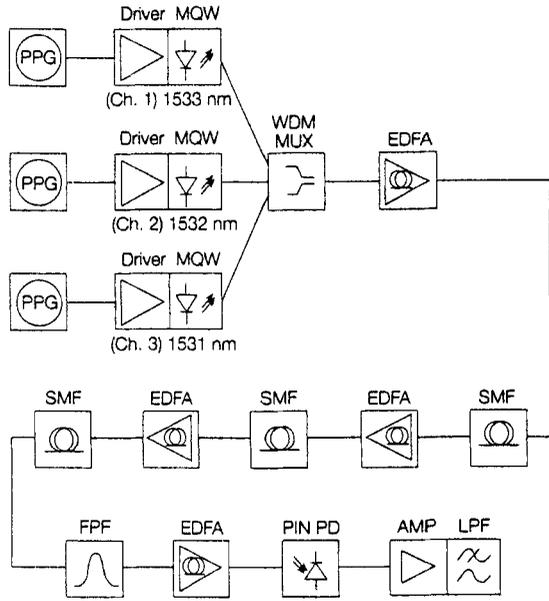


Fig. 1 - Block diagram of the simulated WDM-DST system with three 10 Gbit/s channels.

where $E_i(\omega)$ is the complex envelope of the input electric field for channel i , $\Delta\omega$ is the angular frequency channel spacing, nsc takes into account the location of the signal channel ($nsc = 2$), and N is the number of channels ($N = 3$).

The optical amplifiers (EDFAs) have been considered as linear, with a noise equivalent bandwidth of 1.25 THz and a spontaneous emission parameter of 0.3 dB. They are assumed to be used in the configurations of booster, in-line, and preamplifier, as in reported DST experiments [1]. The standard singlemode fibre (SMF) was modelled using the lowpass transfer function given in [7], just taking into account the first order dispersion term with $D = 16.2$ ps/(nm.km) at 1532 nm. An optical Fabry-Perot filter (FPF) [6] is assumed to be used to select channel 2 at the output of the fibre. In this study, we compare the system performance using single cavity (SC) or double cavity (DC) FPF. The finesse of the SC-FPF is 150, and the finesse of each cavity for DC-FPF is also 150. A PIN photodiode, with a 3 dB cutoff frequency of 9.35 GHz, is assumed to be used to convert the optical signal into an electrical signal. The receiver main amplifier (AMP) and the lowpass filter (LPF) have been jointly modelled as a RC lowpass filter with the 3 dB bandwidth required by the DST method.

For performance evaluation, a semi-analytical method [8] has been used, employing the Gaussian approximation. With this method, signal simulation was combined with noise analysis to evaluate the average error probability, which may be estimated by [4]:

$$P_e = \frac{1}{L} \sum_{i=1}^L Q \left[\frac{|V(\tau_k) - V_{th}|}{\sigma(\tau_k)} \right] \quad (2)$$

where L is the length of the PRBS used, $V(\tau_k)$ is the value of the signal waveform at the sampling instant τ_k ,

V_{th} is the decision threshold level, $\sigma(\tau_k)$ is the standard deviation of the noise at the sampling instant, and Q is the well known Q function [6].

After direct detection with a PIN photodiode, the variances of the signal-ASE, ASE-ASE, and crosstalk-ASE beat noise currents are given by [4]:

$$\sigma_{s-sp}^2 = B_e \left(\frac{\eta q}{h\nu} \right)^2 4 G P L_a^2 n_{sp} (G - 1) h\nu \quad (3)$$

$$\sigma_{sp-sp}^2 = B_e \left(\frac{\eta q}{h\nu} \right)^2 4 L_a^2 n_{sp}^2 (G - 1)^2 (h\nu)^2 B_o \quad (4)$$

$$\sigma_{r-sp}^2 = \sum_{\substack{i=1 \\ i \neq nsc}}^N \frac{B_e \left(\frac{\eta q}{h\nu} \right)^2 4 G P_{Ri} L_a^2 n_{sp}^2 (G - 1) h\nu}{\left\{ 1 + \left(\frac{2F}{\pi} \right)^2 \sin^2 \left[\frac{\pi(i - nsc) \Delta f}{FSR} \right] \right\}^k} \quad (5)$$

where B_e is the electrical bandwidth, B_o is the optical bandwidth, η is the quantum efficiency of the PIN photodiode, q is the electronic charge, h is Plank's constant, ν is the optical frequency, G is the optical preamplifier gain, P is the FPF mean input power for the signal channel (channel 2), P_{Ri} is the FPF mean input power for the interfering channel i , L_a is the loss between the optical preamplifier output and the photodetector input, n_{sp} is the spontaneous emission factor of the EDFA, Δf is the channel spacing, F is the finesse and FSR is the free spectral range of the FPF. The integer k is 1 for SC-FPF and 2 for DC-FPF.

3. SYSTEM PERFORMANCE IMPLICATIONS

The performance assessment was focused on channel 2. For each fibre length, the system parameters, namely the laser bias current, the modulation current, the FWHM bandwidth of the FPF and the receiver cutoff frequency, have been adjusted in order to minimize the EDFA preamplifier input mean optical power for an average error probability of 10^{-9} . This optimization was made for the case of transmission of the same PRBS in all channels. The same values of system parameters referred above have been used when the complementary PRBS was considered for optical transmission in the interfering channels.

In the following, optical transmission via 204 km of SMF is considered in Figs. 2, 3, and 4, and optical transmission via different fibre lengths is considered in Figs. 5 and 6.

Fig. 2 shows the optical spectrum estimate at optical multiplexer output for three 10 Gbit/s WDM channels separated 1 nm, and Fig. 3 shows the optical spectrum estimate at the double cavity FPF output, after selection of channel 2 with a FWHM of 50 GHz. These estimates were obtained using the periodogram with a rectangular window. As can be seen in Fig. 3, crosstalk levels are about 20 dB bellow the signal level for a double cavity FPF. If a single cavity FPF is used with a FWHM = 40

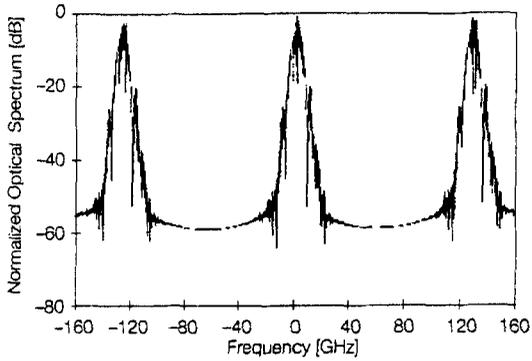


Fig. 2 - Optical spectrum estimate at optical multiplexer output, for three 10 Gbit/s WDM channels separated 1 nm.

GHz (optimum), the rejection of the interfering channels is about 16 dB. As a consequence, crosstalk penalties of about 0.35 and 0.92 dB have been estimated for double cavity and single cavity FPF, respectively. For the conditions of Fig. 3, the corresponding eye diagram at the lowpass filter output is shown in Fig. 4. This eye diagram is similar to the one obtained by Wedding *et al.* [1] with reduced receiver bandwidth.

The receiver sensitivity for channel 2 versus fibre length is displayed in Figs. 5 and 6, assuming that a single cavity (SC) or a double cavity (DC) FPF is used as demultiplexer, respectively. For comparison, the receiver sensitivity of a single channel DST system is also

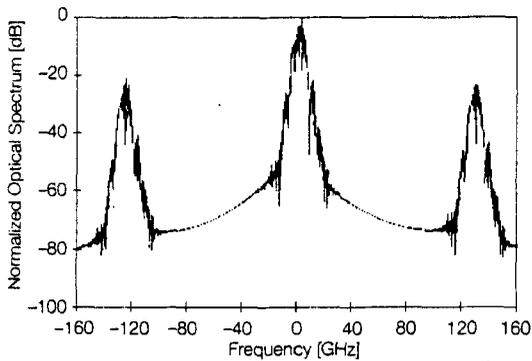


Fig. 3 - Optical spectrum estimate at double cavity FPF output, with FWHM = 50 GHz.

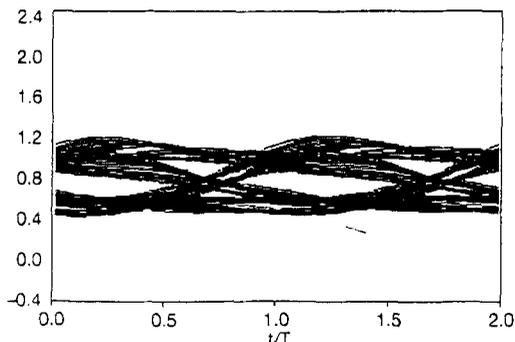


Fig. 4 - Eye diagram at lowpass filter output, after transmission via 204 km SMF of three 10 Gbit/s WDM channels separated 1 nm, and selection of channel 2 with a double cavity FPF with FWHM = 50 GHz.

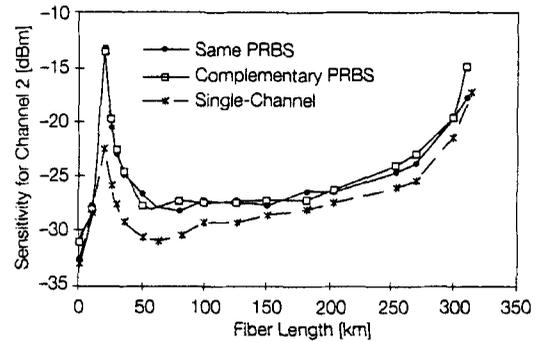


Fig. 5 - Receiver sensitivity for channel 2 versus fibre length. A single cavity (SC) FPF is assumed to be used as demultiplexer to select channel 2, after transmission of three WDM channels separated 1 nm. For comparison, the receiver sensitivity for the single channel DST system is also displayed.

displayed. In order to investigate the robustness against pattern dependencies, the same and the complementary PRBS, with respect to signal channel, have been considered in the interfering channels (ch. 1 and ch. 3). As can be seen in these figures, in the region of small linear increase of dispersion penalty of the DST method (80-270 km), the differences in power penalty, using the same and the complementary PRBS, are less than 1.0 and 0.4 dB for single and double cavity FPF, respectively. However, for distances ranging from 62.5 to 204 km, these differences are less or equal than 0.2 dB, if a double cavity FPF is used. These small differences follow the small crosstalk penalties which occur in this region.

As can be seen in these figures, in the region of small linear increase of dispersion penalty of the DST method (80-270 km), and considering the same PRBS for all channels, the power penalty for transmission of three 10 Gbit/s WDM channels separated 1 nm, relatively to the single channel DST, is less than:

- i) 2.5 dB, if a single cavity FPF is used as demultiplexer;
- ii) 1 dB, if a double cavity FPF is used as demultiplexer.

If a double cavity FPF is used as demultiplexer (Fig. 6), the simulations show that is possible to transmit

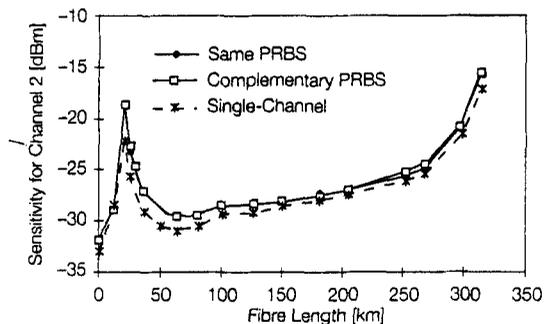


Fig. 6 - Receiver sensitivity for channel 2 versus fibre length. A double cavity (DC) FPF is assumed to be used as demultiplexer to select channel 2, after transmission of three WDM channels separated 1 nm. For comparison, the receiver sensitivity for the single channel DST system is also displayed.

three 10 Gbit/s WDM channels, separated 1 nm, with less than 1 dB power penalty, relatively to the single channel DST, in the region of small linear increase of dispersion penalty of the DST method:

- i) from 80 to 300 km, if the same PRBS is considered in the interfering channels;
- ii) from 100 km to 270 km, if the complementary PRBS is considered in the interfering channels.

These results indicate that double cavity FPFs may be preferable for dense WDM-DST systems, in spite of the additional losses due to the need of some form of isolation between the two filter sections, to avoid unwanted resonances [6].

4. CONCLUSIONS

Using a suitable methodology for simulation of optically amplified multichannel communication systems, we have assessed the performance of a WDM system with dispersion supported transmission of three channels. The simulation results show that it is possible to transmit three 10 Gbit/s channels, separated 1 nm, with a crosstalk penalty less than 1 dB in the region of small linear increase of dispersion penalty of the DST method, if a double cavity FPF is used as demultiplexer. These results suggest the feasibility of high density WDM-DST systems.

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