Performance Assessment of Dispersion Supported Transmission Followed by Wavelength Conversion Based on Cross Gain Modulation at 20 Gbit/s

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Abstract
In this paper we demonstrate, by simulation, the compatibility between the technique of dispersion supported transmission (DST) and the technique of wavelength conversion based on cross gain modulation (XGM). A performance assessment is presented of dispersion supported transmission at 20 Gbit/s followed by wavelength conversion for link lengths ranging from 0 up to 68 km.

I. INTRODUCTION
Cross gain modulation (XGM) [1]-[3] in semiconductor optical amplifiers (SOAs) is a very attractive way for the realisation of wavelength conversion, but this technique, as other cross-modulated techniques, is not transparent to the modulation format, i.e., only converts intensity modulated signals from one wavelength at the input to another wavelength at the output of the converter. In this paper, we investigate the compatibility of wavelength conversion based on XGM with the technique of dispersion supported transmission (DST). In the DST technique [4], the laser is directly modulated in FSK. A dispersive fibre is used to convert this frequency modulation into a four-level amplitude modulation, and the original signal is recovered at the receiver by low pass filtering. So, we will study dispersion supported transmission systems followed by wavelength conversion (DST-WC). Although the emission of a laser directly modulated in FSK is also accompanied by ASK modulation, wavelength conversion before DST is not considered in this paper.

The remainder of this paper is organised as follows. Section II describes the modelling and simulation methodology and section III describes the performance assessment of dispersion supported transmission systems followed by wavelength conversion based on cross-gain modulation. Main conclusions are presented in section IV.

II. MODELLING AND SIMULATION METHODOLOGY
The block diagram of the simulated DST system with XGM-based wavelength conversion (DST-WC system) at 20 Gbit/s is shown in Figure 1. The system model of the DST system without wavelength conversion has been described in [5]. The pseudo-pattern generator (PPG) provides a pseudo-random binary sequence (PRBS) with 2^{31}-1 bits. The model of the wavelength converter is given in [6]. We have found by simulation that the converter parameters given in [6] are inadequate for simulation at 20 Gbit/s. To overcome this problem we have considered two SOAs placed in a cascade configuration, since this leads to an increase of the conversion bandwidth [7]. To reject the intense signal channel, used as a pump in the wavelength conversion process, the following types of optical filters have been considered: single (SCF) and double-cavity (DCF) Fabry-Perot filters [8], three-mirror Fabry-Perot filters (TMFs) [9], interference filters (IF) [10], and arrayed waveguide gratings with (PF-AWG) or without (AWG) passband flattened [11].

Fig. 1. Block diagram of the DST system with wavelength conversion based on cross-gain modulation (λₐ: emission wavelength of laser i, i=1,2).

For performance assessment, a pure semi-analytical method has been used, which combines noiseless signal transmission simulation with noise analysis in optical transmission systems using directly modulated MQW lasers and optically preamplified direct-detection receivers. Using that method with the Gaussian approximation, the average error probability has been estimated as in [5].

III. PERFORMANCE ASSESSMENT

Simulation results presented here were obtained considering $\lambda_1=1550$ nm as the wavelength of the signal channel and $\lambda_2=\lambda_1+\Delta\lambda$ as the wavelength of the probe channel, where $\Delta\lambda$ is the wavelength channel spacing, which is associated with the frequency channel spacing, $\Delta f_c$, by:

$$\Delta\lambda = -\Delta f_c \lambda_1^2 / c ,$$

where $c$ is the speed of light in vacuum.

A. Wavelength conversion at 0 km

Figure 2 illustrates the wavelength conversion process at 20 Gbit/s for 0 km (without optical fibre). The XGM-based wavelength converter copies the inverse sequence, regarding to the one carried by the signal channel at the wavelength $\lambda_1=1550$ nm, to the probe at the wavelength $\lambda_2 = \lambda_1 + \Delta f_c$. In this figure, we have set $\Delta f_c = 100$ GHz ($\lambda_2=1549.2$ nm). The signal, which works as a pump, must be intense enough to cause significant gain compression. Thus, the probe gain is low when the pump power level is high (symbols 1), but the probe gain increases considerably when the pump power levels are low (symbols 0).

![Fig. 2. Optical powers of the signal at the laser output and of the probe at the converter output. Average signal power at the converter input: 2.567 dBm; average probe power at the converter input: -13.01 dBm; sequence before conversion: 101001111100010111.](image)

Figure 3 shows the bit error probability (BER) at 20 Gbit/s, for 0 km and for a frequency shift $\Delta f_c = 100$ GHz ($\lambda_2=1549.2$ nm) or a frequency shift $\Delta f_c = -100$ GHz ($\lambda_2=1550.8$ nm). To reject the signal channel at the converter output, an interference filter (IF), with a full width at half maximum (FWHM) of 55 GHz, has been used. As can be seen in this figure, the receiver sensitivity degradation due to wavelength conversion when the signal is downconverted (to 1549.2 nm) is about 3.69 dB. When the signal is upconverted, there is an additional degradation of 0.32 dB, regarding to the case of downconversion.

![Fig. 3. Bit error rate at 0 km. Average signal power at the converter input: 2.567 dBm for $\Delta f_c = 100$ GHz, and 3.536 dBm for $\Delta f_c = -100$ GHz; average probe power at the converter input: -13.01 dBm in both cases.](image)

B. Wavelength conversion after DST over 50 km of SMF

In this subsection we consider the case of DST over 50 km of SMF followed by wavelength conversion. The system parameters have been optimised with the interference filters. The simulation results presented for other filter types have been obtained using the above referred set of system parameters, excepted the FWHM of each filter, which was again optimised.

Figure 4 shows estimates of the normalised optical power spectrum at the converter input, converter output, and at the optical filter output. These power spectrum estimates were obtained using the periodogram with a rectangular window. Figure 4.a shows the spectrum of the signal at 20 Gbit/s after DST via 50 km of SMF and the spectrum of the probe (CW), with a channel spacing of 100 GHz, at the converter input. Figure 4.b shows the spectra of probe and signal at the converter output. After wavelength conversion, the intense signal channel must be rejected. This situation is illustrated in Figure 4.c, where an interference filter with a FWHM of 50 GHz has been used. The corresponding eye diagram is shown in Figure 5, jointly with the eye diagram for the case of DST over 50 km of SMF without wavelength conversion.

Figure 6 shows the bit error rate after DST via 50 km followed by wavelength conversion, for several kinds of
optical filters. Wavelength was downconverted to $\lambda_2 = 1549.2$ nm ($\Delta \nu_c = 100$ GHz). For comparison purposes, the bit error rate of the DST system without wavelength conversion is also shown. As can be seen in this figure, the sensitivity degradation, due to wavelength conversion and due to crosstalk arising from the imperfect rejection of the signal channel used as a pump, is the following: 4.73 dB, 4.89 dB, 4.97 dB, 5.34 dB and 6.63 dB, for the following filter types: (their FWHM is indicated within brackets): IF (50 GHz), PF-AWG (44 GHz), TMF (40 GHz), AWG (60 GHz) c DCF (30 GHz), respectively. From this figure, we may conclude that the system performance is very similar when interference filters, PF-AWG filters, or TMFs are used.

Fig. 4. Normalised optical power spectrum estimates at:
a) converter input; b) converter output; c) optical filter output.

Fig. 5. Normalised eye diagrams at the low pass filter output, after DST at 20 Gbit/s over 50 km of SMF:
a) DST system without wavelength conversion;
b) DST system with wavelength conversion at the input of the optical receiver.

Figure 7 shows the bit error rate after DST via 50 km followed by wavelength conversion to $\lambda_2 = 1550.8$ nm ($\Delta \nu_c = -100$ GHz). In this case, the sensitivity degradation due to wavelength conversion and due to crosstalk arising from the imperfect rejection of the signal channel, is the following: 4.75 dB, 4.90 dB, 5.18 dB, 5.40 dB e 6.43 dB, for the following filter types: (with FWHM indicated within
brackets): IF (50 GHz), PF-AWG (55 GHz), TMF (40 GHz), AWG (60 GHz) and DCF (30 GHz), respectively. These results show that the sensitivity degradation is similar in both cases: when the wavelength is upconverted to $\lambda_2$=1550.8 nm or downconverted to $\lambda_2$=1549.2 nm.

![Graph 1](image1.png)

**Fig. 6.** Bit error rate after 50 km of SMF for DST and DST-WC systems with $\Delta_f$=100 GHz. Average signal power at the converter input: -2.70 dBm; average probe power at the converter input: -6.9897 dBm.

![Graph 2](image2.png)

**Fig. 7.** Bit error rate after 50 km of SMF for DST and DST-WC systems with $\Delta_f$=-100 GHz. Average signal power at the converter input: -2.8145 dBm; average probe power at the converter input: -10.0 dBm.

Figure 8 shows the BER after 50 km followed by wavelength conversion to $\lambda_2$=1548.4 nm ($\Delta_f$=200 GHz). As can be seen, the sensitivity degradation due to wavelength conversion and crosstalk is: 4.34 dB, 4.47 dB, 4.64 dB, 4.84 dB, 5.15 dB e 6.77 dB, for the following filter types: (with FWHM indicated within brackets): IF (60 GHz), PF-AWG (44 GHz), TMF (40 GHz), AWG (110 GHz), DCF (50 GHz) and SCF (35 GHz), respectively. In this case, a similar performance is obtained when the following filter types are used: interference filters, AWG filters with or without passband flattening and TMFs. Moreover, the sensitivity difference due to the use of a double cavity FPF instead of an interference filter is of about 0.816 dB.

![Graph 3](image3.png)

**Fig. 8.** Bit error rate after 50 km of SMF for DST and DST-WC systems with $\Delta_f$=200 GHz. Average signal power at the converter input: -1.9 dBm; average probe power at the converter input: -5.85 dBm.

### C. Wavelength conversion after DST via different fibre lengths

In the following, we analyse the performance of DST-WC systems with different fibre lengths. For each fibre length, the system parameters, namely the laser bias current, the modulation current, the optical powers of signal and probe at the converter input, the full width at half maximum (FWHM) of the optical filter, and the receiver cut-off frequency, have been adjusted in order to minimise the input mean optical power of the EDFA preamplifier for an average error probability (BER) of $10^{-9}$ (receiver sensitivity).

Figure 9 shows the receiver sensitivity of the DST-WC system for channel spacings of $\Delta_f$=100 GHz ($\lambda_2$=1549.2 nm) and of $\Delta_f$= - 100 GHz ($\lambda_2$=1550.8 nm). After wavelength conversion, the original signal channel is assumed to be rejected by a multilayer thin film interference filter (IF). In this Figure, in the region dominated by intensity modulation (up to about 10 km), we may observe high sensitivity degradations due to wavelength conversion: from 3.69 dB to 8.42 dB between 0 and 8 km for $\Delta_f$=100 GHz, and from 4.01 dB to 5.89 dB between 0 and 8 km for $\Delta_f$= - 100 GHz. However, a small improvement on the system performance due to wavelength conversion is observed in the transition between the region dominated by intensity modulation and the region of dispersion supported transmission: between 12.5 km and 15 km for $\Delta_f$=100 GHz, and between 12.5 and 17.5 km for $\Delta_f$= -100 GHz. For 20 km, the sensitivity degradation is of about 0.42 dB for $\Delta_f$=100
GHz and of about 0.02 dB for $\Delta f_c = -100$ GHz. After 20 km and up to 65 km, the receiver sensitivity degrades almost linearly with fibre length. After 30 km this sensitivity degradation is high: between 2.23 dB at 30 km and 6.87 dB at 65 km, for $\Delta f_c = 100$ GHz, and between 2.05 dB at 30 km and 6.66 dB at 65 km, for $\Delta f_c = -100$ GHz. Figure 10 shows the optimised optical power of signal and probe channels at the input of the wavelength converter.

![Receiver sensitivity of DST and DST-WC systems](image)

**Fig. 9.** Receiver sensitivity of DST and DST-WC systems with $\Delta f_c = 100$ GHz or $\Delta f_c = -100$ GHz.

![Optimised optical powers of signal and probe channels](image)

**Fig. 10.** Optimised optical powers of signal and probe channels at the input of wavelength converter for DST-WC systems with $\Delta f_c = 100$ GHz or $\Delta f_c = -100$ GHz.

IV. CONCLUSIONS

We have analysed the performance of DST-WC systems at 20 Gbit/s for link lengths ranging from 0 to 68 km of SMF. Detailed BER characteristics have been presented for 0 km and 50 km. For the case of the link length of 50 km, we have considered different types of optical filters used to reject, after conversion, the intense signal channel used as a pump. In this case, wavelength upconversion to 1550.8 nm and downconversion to 1549.2 nm and to 1548.4 nm was considered. For the case of link lengths ranging from 0 to 68 km, we have presented an assessment of the system performance with wavelength downconversion from 1550 nm to 1549.2 nm ($\Delta f_c = 100$ GHz) or with wavelength upconversion from 1550 nm to 1550.8 nm ($\Delta f_c = -100$ GHz).

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REFERENCES


