Transmission Fiber Chromatic Dispersion Dependence on Temperature: Implications on 40 Gb/s Performance

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ABSTRACT—In this letter, we will evaluate the performance degradation of a 40 km high-speed (40 Gb/s) optical system, induced by optical fiber variations of the chromatic dispersion induced by temperature changes. The chromatic dispersion temperature sensitivity will be estimated based on the signal quality parameters.

Keywords—Optical fiber chromatic dispersion, temperature, optical communications.

I. Introduction

The continuous increase in traffic demand has imposed 40 Gb/s as a suitable bitrate for implementation in commercial transmission systems. A critical performance-limiting factor for these networks is optical fiber chromatic dispersion.

Chromatic dispersion in standard optical fibers (SMF) is temperature dependent, which results in a dependence of the residual dispersion for a fully compensated link as the temperature of the transport fiber changes [1]. Even buried optical cables are subject to seasonal temperature variations larger than 40ºC [2], which combined with the long link extensions is responsible for a high value of the fluctuation of residual chromatic dispersion [3].

Manuscript received Aug. 12, 2005; revised Jan. 09, 2006.

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We have investigated the dominant contributions to the chromatic dispersion dependence on temperature [4], which results from electronic effects, in particular temperature variations of the electronic absorption ascribed to the material energy band gap (E_g). Recently, we have shown that by monitoring the 4.3 eV Si-Si absorption band, it was possible to predict the first and second chromatic dispersion values at 1550 nm [5].

Such temperature effects on the performance of high speed systems have attracted the attention of several research groups, through simulation [6] and experimental [7] analyses.

In this letter, we demonstrate the temperature effects on the performance of 40 Gb/s optical systems, due to optical fiber chromatic dispersion dependence, and estimate its dependence on temperature from system power penalty measurements. This type of experimental analysis is reported here for the first time for high speed transmission systems.

II. Results and Discussion

To investigate the thermal effects on transmission performance, we have implemented a single wavelength transmission system operating at 40 Gb/s over standard single mode fiber (SMF), according to the scheme in Fig. 1.

The optical signal from an external cavity laser emitting at 1550 nm, with a continuous wave linewidth smaller than 10 kHz, was externally modulated with a Sumitomo Lithium Niobate modulator (model T.DEH1.5-40-ADC) in a Mach-Zehnder configuration with a 40 Gb/s 2^{23}-1 pseudo random bit sequence. The average output power was 3 dBm, which is sufficiently low

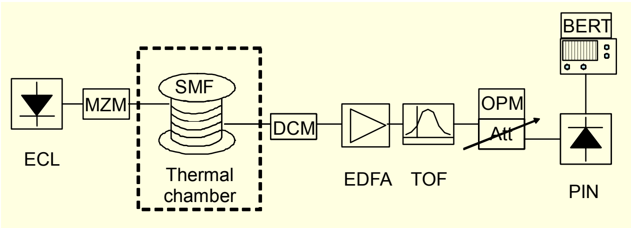

Fig. 1. Implemented experimental scheme. ECL: external cavity laser; MZM: Mach-Zehnder modulator; SMF: standard single mode fibre, DCM: dispersion compensation module, EDFA: Erbium doped fibre amplifier; TOP: tuneable optical filter; OPM: optical power meter; Att: attenuator; PIN: photodiode, and BERT: bit error rate tester.

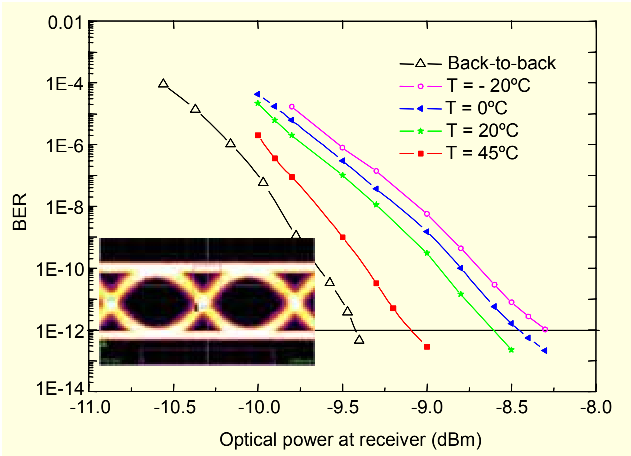

Fig. 2. BER versus the optical power at the receiver as a function of the SMF fibre temperature. The inset shows the eye diagram for a 10^{-12} BER at the receiver.

to avoid the excitation of nonlinear effects on the transmission fiber, which was a single reel with 40 km of SMF, manufactured by Corning with a 1550 nm attenuation and chromatic dispersion of 0.19 dB/km and 16.1 ps/nm/km. This setup is followed by a dispersion compensation module (DCM) from Sumitomo (model N-DCFN-40) based on a dispersion compensation fiber (DCF), with 1550 nm first- and second-order chromatic dispersions of –640 ps/nm and 1.56 ps/nm^2, respectively. The optical power injected on the DCM was 7 dBm, which is believed to be sufficiently low to avoid the excitation of nonlinear effects on the DCF fiber. At the receiver, there is an optical pre-amplifier with automatic gain control (EDFA), followed by a Santec optical tuneable filter (model OTF-920) to remove the out-of-band amplified spontaneous emission noise, and an attenuator/power meter. Finally, the signal is converted to the electrical domain using a 45 GHz bandwidth PIN (Discovery model DSC10H), with a responsivity of 0.60 A/W @ 1550 nm.

The SMF was placed in an environmental chamber with a stability of better than 0.01ºC. Prior to the measurements, the chamber temperature was stabilized for one hour to ensure temperature stabilization on the fiber. The effect of the Silica thermal expansion on the fiber chromatic dispersion is accounted on its thermal sensitivity coefficient. On the other hand, it is believed that the fiber being in a spool is not limitative, since the effect of traction due to mechanical expansion of the reel should be analogue to the traction due to expansion of the optical cable when deployed on the field. The DCF module was kept at a constant temperature along all the measurements in order to avoid the dispersion fluctuations in this module.

Then, the signal quality at the receiver was measured for different values of SMF temperature, through bit-error rate (BER) analysis, performed over 5 min, and is presented in Fig. 2. The BER tester was an Agilent ParBERT 81250, and the BER values were estimated directly for the optimum decision level. At the chosen bitrate, the acquisition time used is large enough to ensure the attaining of a number of samples statistically significant even for the lower BER values. The inset in Fig. 2 shows the signal eye diagram at the receiver when the BER was 10^{-12}.

The DCM was designed to compensate the dispersion for a SMF length of 40 km, although a total link residual dispersion value different from zero and being positive is expected. The increase on the transmission fiber temperature results in a decrease of the chromatic dispersion value and a correspondent reduction of the link residual dispersion. For this reason, it is an expectable improvement on the system transmission performance.

The power penalty for a 10^{-12} BER is shown in Fig. 3. The dispersion-induced power penalty can be obtained using expression 1, where we implicitly introduced the fiber chromatic dispersion variation with temperature and the DCM dispersion value [4], [8].

$$P_P = 5\log\left(1+\left(4BL\Delta\lambda\left(D_{SMF}+\frac{dD}{dT}\Delta T\right)-D_{DCM}\right)^2\right), \quad (1)$$

where B is the bitrate, L is the link length, D_{SMF} stands for the chromatic dispersion coefficient, dD/dT represents the chromatic dispersion thermal sensitivity, D_{DCM} is the total dispersion of the DCM, $\Delta\lambda$ stands for the signal line width, and ΔT represents the temperature variation relative to a reference value.

The fit of expression 1 to the data in Fig. 3, using a Nelder-Mead nonlinear minimization, allows us to obtain the chromatic dispersion thermal sensitivity, around -1.26×10^{-3} ps/nm/km/ºC, with an error smaller than 5%. This estimated value is comparable with that previously reported (-1.4×10^{-3} ps/nm/km/ºC) [4].

From these results, we can conclude that the main source of signal degradation is the chromatic dispersion fluctuation induced by the thermal effects on the transport fiber. Therefore,

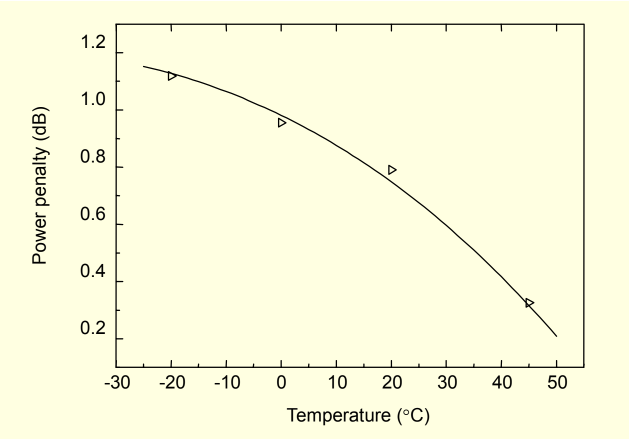

Fig. 3. Power penalty in reference to the back-to-back situation at a BER of 10^{-12}. The points represent experimental data and line fitting to expression 1.

an adaptive dispersion compensation scheme is mandatory for these high speed optical transmission systems [9].

III. Conclusions

We experimentally evaluated the effect of the residual dispersion caused by temperature-dependent changes in the chromatic dispersion of an optical fiber on a 40 km 40 Gb/s optical link. From the power penalty, we could estimate a chromatic dispersion thermal sensitivity of around -1.26×10^{-3} ps/nm/km with an error smaller than 5%. This value agrees well with previous reported values for the chromatic dispersion thermal sensitivity. The high value estimated for the chromatic dispersion thermal sensitivity indicates that this factor can be the main degradation factor of the system's overall performance. Due to the good agreement between the experimental estimated chromatic dispersion thermal sensitivity value and those previously calculated through theoretical simulations, it is our belief that the reported procedure can be used to design dynamic dispersion compensation devices specially configured for the compensation of the residual dispersion.

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