IMPLICATIONS OF TEMPERATURE IN THE CHROMATIC DISPERSION: CONSEQUENCES ON HIGH SPEED OPTICAL NETWORKS PERFORMANCE

P. S. André (1), A. N. Pinto (2)
1 : Instituto de Telecomunicações (IT), Universidade de Aveiro (UA), 3810-193 Aveiro, Portugal, pandre@av.it.pt
2 : Instituto de Telecomunicações (IT), Universidade de Aveiro (UA), 3810-193 Aveiro, Portugal, anp@det.ua.pt

Abstract *We derive an expression for the dispersion slope variation with temperature, and verify that the effect of temperature cannot be ignored in the design of dispersion compensation devices for high debit systems.*

Introduction

Actually, the transport in high transmission rate WDM systems is realized over standard single mode fibers (SSMF). In order to cope with the restrictions imposed by the chromatic dispersion of the SSMF fibers it is necessary to use dispersion compensation devices, especially for high bit rates signals where the dispersion tolerances are tight (≥ 40 Gbit/s). These devices should accurately manage the dispersion, compensating the residual dispersion and equalizing the dispersion slope. Since the chromatic dispersion of the deployed optical fibers depend on temperature, it is important to know the relation between dispersion and dispersion slope with temperature, in order to enable the full dispersion compensation for a width temperature range.

The previous studies of optical fibers chromatic dispersion temperature dependence, have been focused on the variations of slope dispersion at zero dispersion wavelength [1-3]. *Hamp et* al [4] have shown that the dispersion variation with temperature is related with the zero dispersion wavelength and with the dispersion slope at the zero dispersion wavelength, and that this second term cannot be ignored in general as suggested by *Kato* et *al* [2]. For the studied fibers *Hamp* showed that this second term contribute with around 2.5% - 16.7% to the variations of the dispersion with temperature.

We derive an expression for the variation of the dispersion slope of SSMF, at the 3rd transmission window wavelengths, with temperature. By this expression we verified that the contribution of the slope variation with temperature at the zero dispersion wavelength contributed with around 54 % for the total slope variation.

Chromatic dispersion

The refractive index of any optical material can be interpolated by the *Sellmeier* formula. The thermo-optic coefficient, $\partial n/\partial T$, which describes the refractive index variation with respect to temperature, contains the electronic and optical phonons contribution. The electronic effects in particular the temperature variations of the electronic absorption peak energy gap have the dominant contribution. Therefore it can be described in terms of the linear expansion coefficient α and of the temperature variation of the energy gap $(\partial E_g/\partial T)$ [5].

$$2\cdot n\cdot\left(\frac{\partial n}{\partial T}\right)=\left(-3\cdot\alpha\cdot\left(n_1{}^2-1\right)\right)\cdot\left(\frac{\lambda^2}{\lambda^2-\lambda_g{}^2}\right)+\left(-\frac{2}{E_g}\cdot\frac{\partial E_g}{\partial T}\cdot\left(n_1{}^2-1\right)\right)\cdot\left(\frac{\lambda^2}{\lambda^2-\lambda_g{}^2}\right)^2 \tag{1}$$

where E_g is the band gap energy, λ_g the wavelength correspondent to the energy gap and n_1 is the less dispersive refractive index.

The total chromatic dispersion, given by the sum of the material and waveguide contributions, is usually modeled by following expression [4]:

$$D(\lambda)=\frac{S_0}{4}\left(\lambda-\frac{\lambda_0{}^4}{\lambda^3}\right) \tag{2}$$

where λ_0 is the zero dispersion wavelength and S_0 is the dispersion slope at λ_0. For dispersion compensated spans, more important than S_0 is the dispersion slope at the transmission wavelength, $\partial D/\partial\lambda$.

$$\frac{\partial D}{\partial \lambda}=\frac{S_0}{4}\cdot\left(1+3\cdot\frac{\lambda_0{}^4}{\lambda^4}\right) \tag{3}$$

which have a temperature dependence given by:

$$\frac{\partial}{\partial T}\frac{\partial D}{\partial \lambda}=\frac{1}{4}\cdot\left(1+3\cdot\frac{\lambda_0{}^4}{\lambda^4}\right)\cdot\frac{\partial S_0}{\partial T}+3\cdot S_0\cdot\frac{\lambda_0{}^4}{\lambda^4}\cdot\frac{\partial \lambda_0}{\partial T} \tag{4}$$

While S_0 varies negatively with temperature the dispersion at the C band wavelength have a positive variation with temperature. Considering the mean values presented in [4] for $\partial S_0/\partial T$ and $\partial\lambda_0/\partial T$ of -2.46×10^{-6} ps/nm/km/°C and 0.026 nm/°C, respectively, and assuming S_0 = 9.352 × 10^{-2} ps/nm/km, λ_0 = 1319.30 nm, we observe that the first term of expression (4) will contribute with 54.3 % for the dispersion slope variation with temperature, which have a value of 1.323 × 10^{-6} ps/nm^2/km/°C at 1550 nm.

From the values of λ_0 and S_0 reported by *Hamp et al* for a SSMF, we have calculated the dispersion and dispersion slope at 1550 nm as functions of temperature through expression (2) and (3), respectively. These values are shown in the figure 1 with the respective errors bars and linear fit along with the results obtained from a numerical model. The *numerical model calculates the total dispersion from the* material and the waveguide dispersion. The material dispersion was computed from the refractive index which have a temperature dependence given by (1).

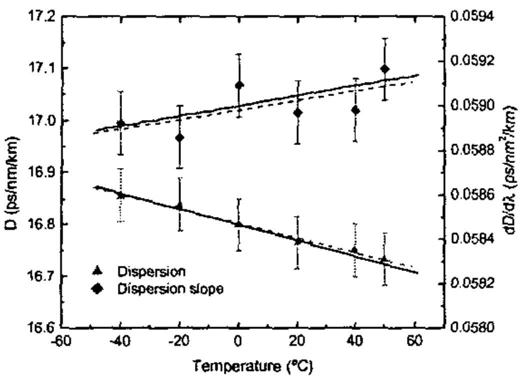

Fig. 1 – Theoretical (solid) and experimental (dashed) values of dispersion and dispersion slope versus temperature at 1550 nm. The experimental values were obtained from [4] and calculated through expressions (2) and (3).

It can been seen that the model of *Ghosh* can be used to calculate the variation of dispersion slope with temperature and the obtained values matches the values of dispersion and dispersion slope for a 100 °C interval calculated from the values of *Hamp* [4] with our expressions.

Implication in 40 and 80 Gbit/s systems

We implement a 40 Gbit/s - 500 km transmission scheme with all-at-the-end dispersion compensation, as describe in [6].

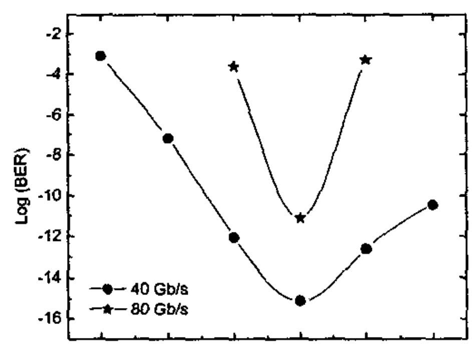

Fig. 2 – BER versus temperature of the transmission fiber for 40 Gbit/s and 80 Gbit/s. The system have a full compensation for the 20° C temperature. The line is a guide to the eyes.

The used input impulses have a Gaussian shape with a full width half maximum (FWHM) of 5 ps and an average power of 0 dBm. The system performance is evaluated in terms of BER, obtained by solving *numerically* the *generalized Schrodinger* equation with a split-step method [6]. We consider an exact loss compensation and a full compensation of the G.652 fiber, β_2 and β_3 coefficients, obtained from the values of figure 1 for a temperature of 20° C. Then the β_2 and β_3 coefficients were changed to reflect the effect of temperature, between – 40 ° C and 60 °C. Figure 2 displays the BER of the signals for several temperatures. The system was initially optimized for 20 ° C. The results considering a 80 Gbit/s bitrate are also presented. Figure 3 reports the eye diagrams corresponding to the system of 40 Gbit/s - 500 km for a pseudo random bit sequence (PRBS) sequence of 512 bits. The eye diagram on the top left and right are ascribed to the temperatures of – 20 °C and 60 ° C, respectively, while the center eye diagram is for a temperature of 20 ° C.

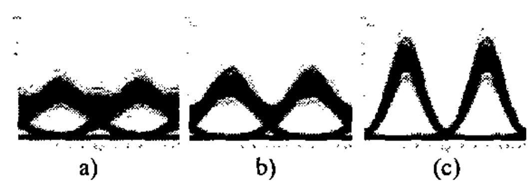

Fig. 3 – Eye diagram after 500 km of propagation: (a) – 20 °C, (b) 60 °C and (c) 20 °C.

Conclusions

The presented results indicate that change of dispersion and dispersion slope in SSMF is dominated by the material dispersion variation and this is related *with the temperature induced refractive index* variations.

The simulation results show that the temperature of the fiber has a high contribution in the performance of 40 Gbit/s systems.

References

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