Negative Dispersion Fibers for Uncompensated Metropolitan Networks

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Abstract: MetroCor™ fiber, a negative dispersion fiber, is demonstrated to enhance the transmission of directly modulated DFB lasers (DMLs) and DFB lasers integrated with electroabsorption modulators (DFB/EAs). Uncompensated reach of 300 km and 225 km, suited for metropolitan networks, were achieved with OC-48 DMLs and OC-192 DFB/EAs rated for <100 km of standard single mode fiber.

Introduction

There is growing interest in dense wavelength division multiplexing (DWDM) systems for metropolitan networks. The introduction of DMDM in metro networks will require the use of low cost devices, such as directly modulated lasers (DMLs). The transmission distance in metro networks possibly exceeds 200 km, driven by the cost savings of optical transparency. At such a distance, fiber dispersion is the major impairment, if low cost DMLs and standard single mode fibers (SSMFs) with positive dispersion are used. However, the use of dispersion compensating modules (DCMs) is not only cost prohibitive for metro systems but also causes network topology issues.

In this paper, we show that by using MetroCor fiber, a negative dispersion fiber (NDF) in the entire usable bandwidth (1280-1620 nm) with a zero dispersion wavelength beyond L-band, we can take advantage of the positive chirp characteristics of DMLs to enhance signal transmission. Experimental and theoretical results are presented to demonstrate how NDFs benefit the transmission with OC-48 DMLs. The upgrade path using OC-192 DFB/EAs is also presented. Uncompensated reach of 300 km and 225 km over NDFs is demonstrated experimentally with OC-48 DMLs and OC-192 DFB/EAs rated for a dispersion tolerance of +1800 ps/nm and +1400 ps/nm, respectively.

OC-48 Transmission with Directly Modulated Lasers

A 32-channel DWDM transmission experiment was conducted to verify that the NDFs enable longer uncompensated reach with DMLs /1/. The experiments were focused on the C-band where the NDFs have higher absolute value of dispersion. The channels are between 1533.5 nm and 1558.2 nm with 100 GHz spacing. The MetroCor fiber used in experiments has an average dispersion of about -3 ps/nm/km in the L-band and about -8 ps/nm/km in the C-band.

Figure 1 shows the comparison of the Q-factors after propagating 300 km of NDFs and SSMFs. As shown by the solid dots, all 32 channels have a Q higher than 9 dB, corresponding to a bit error rate (BER) lower than 10^{-15}, after transmitting over 300 km of NDF. In the contrast, all of the channels fail after propagating 300 km over SSMFs, as shown by the open circles. Obviously, the performance difference between NDF and SSMF is strongly device dependent, as shown by the Q variations of the same channel over two types of fibers.

The power penalty for achieving a BER of 10^{-10} was also measured. After 300 km of NDF, all 32 channels need less power than their back-to-back case for achieving the specified BER. The "negative power penalty" or performance enhancement ranges from 0.3 dB to about 1.5 dB. On the other hand, there is a large power penalty ranging from 4 dB to over 10 dB for these signals to propagate through 300 km of SSMF.

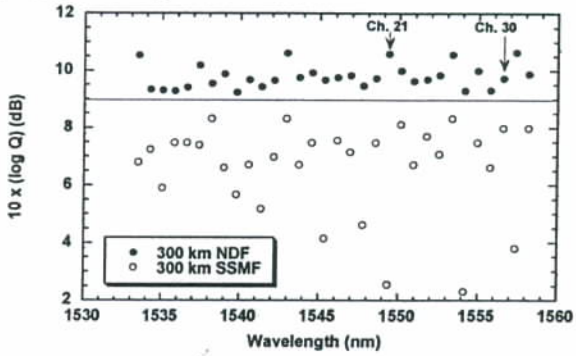

Fig. 1: Q-factor comparison of 32 DMLs over 300 km of MetroCor fiber and standard single mode fiber.

In order to characterize the different transmission performance of lasers across the channel plan, the power and chirp waveforms at the output of the DMLs were measured (Fig. 2 shows the results for ch.21 and ch.30). Clearly, the DML of ch.21 is transient chirp dominated while the one of ch.30 is adiabatic chirp dominated /2/.

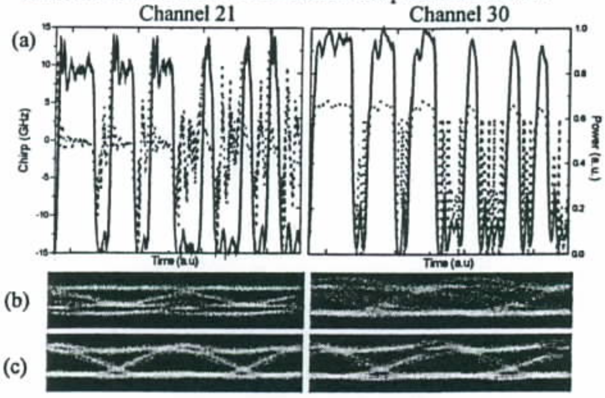

Figure 2: (a) Power (solid line) and chirp (dotted line) waveforms for ch. 21 and ch. 30. The received eye-patterns at the receiver are also shown for transmission over 300 km of (b) SSMFs and (c) NDFs.

In the case of ch.21, the blue shifted leading edge of the pulses advances relative to the main portion of the pulses for transmission over positive dispersion fiber (SSMF). This results in intersymbol interference and the eye in this case will be severely closed (Fig. 2b). On the other hand, the chirped leading edge will compress the pulses through transmission over NDFs and the eye will look perfectly open (Fig. 2c). In the case of ch.30 where the transient chirp has been completely "masked" by the adiabatic chirp, the shape of the received eyes can be described by considering the "self-steepening" effect /2/. In this case, the transmission performance is determined mainly by the absolute value of dispersion and not its sign. The eye corresponding to SSMF is more distorted than that of NDF (Fig. 2) mainly because of the larger absolute value of the dispersion. The different dispersion sign will affect the symmetry characteristics of the eye.

The above considerations are confirmed also by simulation. The DFB semiconductor laser is modeled by rate equations /2/. The seven most influential parameters of the DFB laser are varied around the values given by /3/ as shown in Table 1. Each range is sampled at the end points and the middle, yielding a population of 2,187 lasers. Thermal effects and laser parasitics are ignored.

Symbol	Units	Description	Range
tc	ns	Carrier lifetime	0.5-3.5
V	e-17 m^3	Active volume	2.0-10.0
a0xvg	e-12 m^3/s	Differential gainxgroup velocity	1.0-9.0
n0	e24 1/m^3	Carrier density at transparency	0.5-2.5
L	mm	Length	0.2-0.4
ε	e-23 m^3	Nonlinear gain compression factor	1.0-9.0
α		Linewidth enhancement factor	3.0-9.0

Table 1: Most influential DFB laser parameters

The modulating current is composed of 2.5 Gb/s raised-cosine current pulses with rise and fall times of 100 ps. Bias currents for the ones and zeros are chosen to achieve 1mW average optical power and 10 dB extinction ratio for each laser. Under these driving conditions, 11% of the generated laser population present power ringing that causes more than 1 dB eye closure back-to-back and they are rejected from the population. The rest of the laser waveforms are transmitted through the fiber.

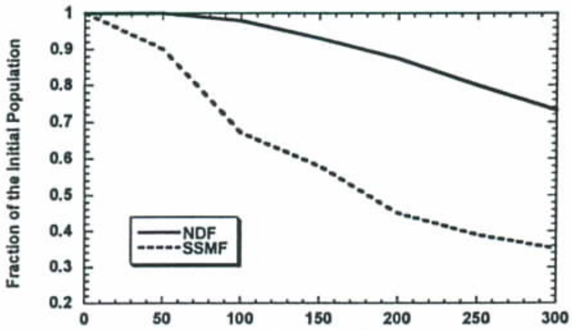

Figure 3: Simulated yield for DMLs to propagate through NDFs and SSMF.

The fiber is modeled as an all-pass filter with quadratic phase /1/. Non-linear effects are ignored due to the small transmitted powers and the short distances in typical metropolitan networks. The receiver optical filter is assumed third-order Butterworth filter. The photodiode is modeled as a square law detector followed by a 4-th order Bessel electric lowpass filter. The chirp-induced penalty is estimated by calculating the amount of eye degradation at the output of the receiver /1/.

Figure 3 shows the fraction of the initial acceptable laser population that has less than 2-dB dispersion induced penalty as a function of distance. The solid line corresponds to NDF and the broken line to SSMF. The transmission wavelength is chosen to be 1528.77 nm, which is the lower end of the C-band. This represents the worst case scenario for the NDF and the best case scenario for the SSMF. At least 73% of the lasers can go through 300 km of NDF where at most 35% of the remaining lasers can go through 300 km of SSMF. These numbers are based on the assumption that the probability of occurrence of each DFB semiconductor laser in the simulated population is the same.

OC-192 Transmission with DFB/EAs

Experiments were also carried out with OC-192 DFB/EAs over both SSMF and the NDF. The Q-factor, measured using an optically pre-amplified receiver, is shown in Fig. 4 as a function of distance for both types of fibers. The wavelength of the laser was 1556.56nm. Since the alpha parameter of an EA modulator is tunable, the modulator bias and peak-to-peak voltage swing were optimized for the each of the fiber types. The optimized extinction ratio for propagating through NDF and SSMF is 7.3 dB and 10.3 dB, respectively. As a result, at zero distance, the SSMF case has higher Q. It is shown that for SSMFs the transmission distance is limited to less than 80 km for Q>9 dB. On the other hand, using the MetroCor fiber, the transmission distance could be extended up to 225km with a Q of better than 9 dB.

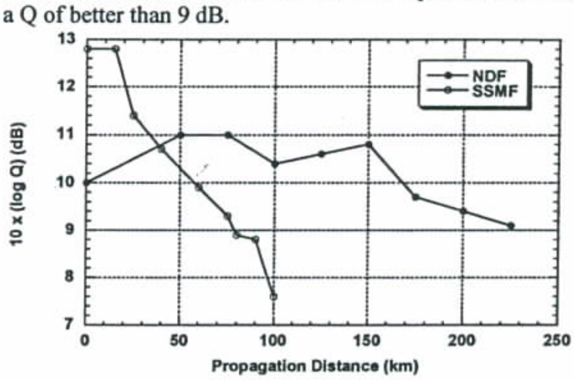

Figure 4: OC-192 transmitting with a DFB/EA

Summary

Uncompensated reach of 300 km with OC-48 DMLs and 225 km with OC-192 DFB/EAs are demonstrated using Corning ® MetroCor negative dispersion fiber. Chirp waveform measurements and computer simulations were used to explain transmission performance variations for transient- and adiabatic-chirp dominated DFBs.

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References

/1/ D. A. Atlas, A. F. Elrefaie, M. B. Romeiser, and D. G. Daut, Optics Letters, 13, p. 1035 (1988).

/2/ P. J. Corvini and T. L. Koch, J. Lightwave Tech., vol.5, p. 1591, (1987).

/3/ O.-K. Kwon and J.-I. Shim, IEEE J. Quantum Electron., Vol. 34, p. 225 (1998).