8×10 Gb/s transmission system over 2015 km with dispersion compensation by fiber Bragg Grating*

CHEN Yong, CAO Ji-hong, TAN Zhong-wei, LIU Yan, CHEN Ting, MA Lina, CHANG De-yuan, NING Ti-gang, PEI Li, and JIAN Shui-sheng**

Institute of Lightwave Technology, Beijing Jiaotong University, Beijing, China, 100044

(Received 7 April 2005)

The cascaded chirp fiber Bragg gratings(CFBGs) with ITU-T standard wavelengths and wavelength grid are applied to compensate the dispersion of 8×10 Gb/s WDM system. The ASE of the EDFA could be reduced, the OSNR of the transmitted signal can be increased and the fluctuation of the EDFA gain can be restrained in a certain scope by the CFBG employed in the system. Experiment of error-free 8×10 Gb/s 2015 km transmission without FEC and electric regeneration is demonstrated in this paper. In this system, only EDFA is used as amplifier, and no other form of dispersion compensator is adopted except CFBG. The experimental result showed that after 2015 km transmission, the consistency of the dispersion compensating for each channel is perfect.

CLC number: TN913.7 **Document code:** A **Article ID:** 1673-1905(2005)01-0049-04

Long haul wavelength division multiplexing (WDM) has transformed the transmission technology and also the economics of optical network, and there is no electronics regeneration in the system so as to break the limit of the "electronics bottleneck". In order to improve the transmission performance and prolong the error-free transmitted distance without electronic relay, much work have been done to develop this technology which can be summarized in two following ways. First by means of power control, some systems use Erbium-Doped Fiber Amplifier (EDFA)[1] or Fiber Raman Amplifier (FRA)[2] as the solo amplifying method, and Raman EDFA hybrid amplifier was adopted in some other systems[3]. Second, by means of dispersion compensation, dispersion compensating fiber (DCF) was used to compensate the chromic dispersion in most system[1,4], chirped fiber grating was used as the solo dispensator in a few system[5], and DCF/CFBG hybrid compensator was also utilized[6]. Recent years, fiber Bragg grating (FBG) is a very popular device employed in many application fields, but FBG was doubted of its temperature and stress sensitivity. Some experiment results have proved that CFBG can used as a dispersion compensator well in the long haul transmission system if it is packaged by special materials to reduce the temperature and stress sensitivity[7]. It has been reported[5] that using EDFA and CFBG in a system resulted error-free transmission distance of 1000 km or so.

But most of the research results have shown that because of the signal distortion brought about by the group dispersion ripple (GDR) of the grating and the ASE by the EDFA, it's difficult to achieve error-free transmission distance over 1000 km without electronic regeneration[5]. An experiment of error-free 8×10 Gb/s 2015 km transmission without FEC and electronics regeneration is demonstrated in this paper. The cascaded CFBGs, with ITU-T standard wavelengths and wavelength grid are applied to compensate the dispersion in this experiment. In the transmission, EDFA+CFBG are adopted and the experimental result showed that after 2015 km transmission, the consistency of the dispersion compensating for each channel is perfect. It's the first time, to the best of our knowledge, that there was no similar transmission results reported with the same scheme.

The transmission loss has been solved because of the invention of EDFA, and the nonlinear effect can also be conquered effectively by power control and dispersion. The CFBG is a kind of feasible dispersion compensator for the high speed transmission. On the contrast to the disadvantage of the DCF, CFBG has some prominent advantages: It can be mass-produced presently and is low-cost. If the grating is designed accurately it can compensate not only the accumulated dispersion but also the dispersion slope. The all-fiber structure of the grating means that it can be coupled to SMF easily with less insert loss. Meanwhile, the CFBG can be used in the existing system and upgrade the system conveniently. In addition, the cascades of EDFAs in the transmission system and the accumulated ASE will impair the SNR. As the result, in the 10 Gb/s system if the DCF is the solo dispersion technique, the maximum transmission distance would be no more than several hundred kilometers[8]. However, the CFBG can filter the signal distribu-

* Supported by the National 863 Project(No. 2001AA122012) and the NSFC(No. 60337010)

** E-mail: chenyongxmu@163.com

ting out-of-band effectively which profits from the band-pass-filter character. Therefore, it can decrease the SNR impairment furthest and extend the error-free transmission distance without electronics regeneration.

Three factors must be considered for the gratings employed in the 10 Gbps system, that is, the ripple coefficient of time delay, the polarization mode dispersion PMD affection and the temperature instability of CFBG. In order to reduce system loss and increase bandwidth, high grating reflectivity is desirable. However, when the reflectivity is high, multiple reflections occur within the grating, leading to an increased number of ripples and worse bit-pattern dependency. Amplitude apodization is used to decrease the strength of the end reflection so as to suppress the ripple. Now, we can manufacture the FBG with temperature coefficient less than 0. 000 2 nm/℃, which insures that grating can meet the practical demand[8]. PMD of all the gratings measured with Jones Matrix Method by HP 8059B Polarization Analyzer is less than 1 ps.

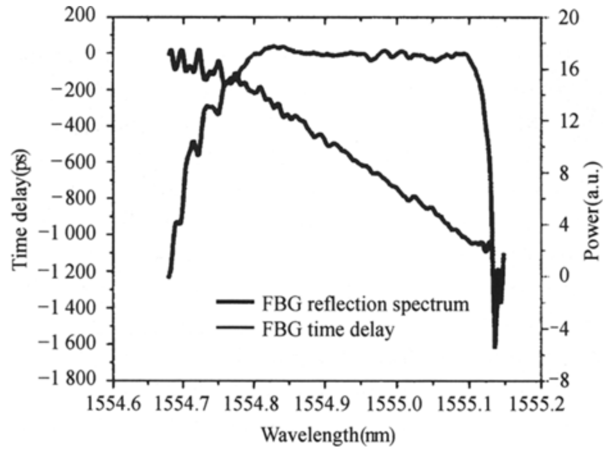


Fig. 1 The reflectivity and time delay of CFBG

Fig. 1 shows the reflectivity and time delay of one of the CFBGs measured by EG&G CD400 laser chromatic dispersion measurement system. The 3 dB bandwide of the grating is about 0. 34 nm and the dispersion of the grating within the passband is −2 632 ps/nm. The dispersion coefficient of the SMF is about 16. 5 ps/km • nm and so the CFBG can compensate about 155. 5 km SMF dispersion theoretically. Time delay ripple of FBG is showed in Fig. 2 and the maximum delay ripple is less than 17. 8 ps. Low ripple will help to improve the system stability and maintain the consistency of the dispersion compensating for each channel.

Fig. 3 indicates the optical spectrum of the DCM constructed from 8-channel CFBG cascades, and the center wavelengths of the eight channels are 1 554. 94 nm, 1 555. 75nm, 1 556. 55nm, 1 557. 36nm, 1 558. 17nm, 1 558. 98nm, 1 559. 79nm and 1 560. 61 nm, respectively. The frequency space is 100 GHz and the wavelength fits the ITU-T wavelength recommended. Fig. 3 shows all the spectra of the DCM used in the system from which some information can be acquired: the 3 dB bandwide of the grating ranged from 0. 32 nm to 0. 45 nm, the isolated bandwide at -20 dB to the peak of the grating is more than 0. 35 nm which will reduce impairment of ASE from EDFA, and the reflectivity ripple of all eight channels is less than 0. 3 dB that keeps the power consistency for each channel.

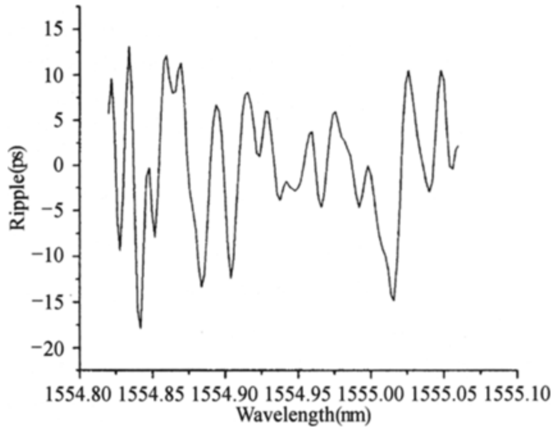


Fig. 2 The time delay ripple of FBG

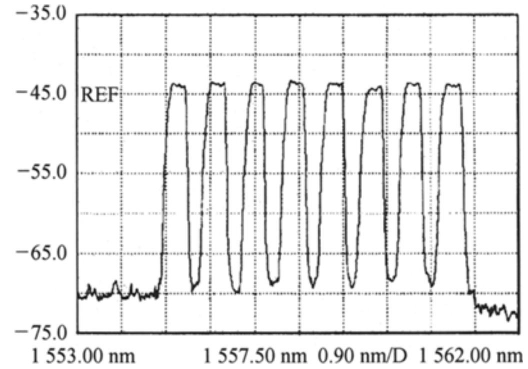
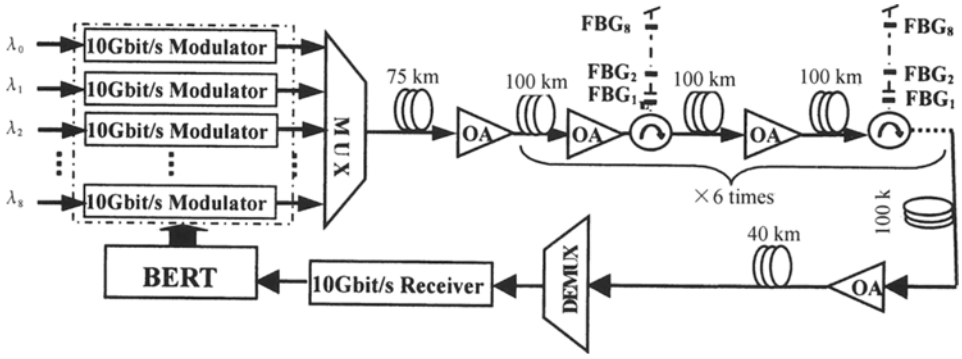


Fig. 3 The optical spectrum of the DCM Constructed from CFBG cascades

The experimental diagram for this 8×10 Gb/s WDM transmitting over 2 015 km of conventional SMF is shown in Fig. 4. Eight wavelengths with nominal spacing of 100G are modulated with 2^{23}-1 pseudorandom bit sequence (PRBS) 10 Gb/s NRZ data and then transmitted over nineteen 21 SMF spans. The loss for each 100-kilometer-span fiber is about 21 dB. The dispersion for each grating in the DCM mentioned above is about −2 650 ps/nm and it can compensate the dispersion accumulated from 160 km SMF, so thirteen DCMs are required to compensate the dispersion. The final 40 km of SMF is added for optimum eye shape, bringing the total transmission distance to 2 015 km. The transmission dispersion map is shown in Fig. 5, and here only channel 8 is presented as evidence. The accumulated dispersion of whole transmitted link fluctuates around zero and the absolute accumulated dispersion is comparatively minor.

High launch power will increase the OSNR of the signal, while induces nonlinear effect, and so appropriate adjustment on power should be done to equipoise the high OSNR and low signal nonlinear distort. In this way, the launch power for the span without prepositive grating can be operated at 3 dBm or so. More power up to 7 dBm is needed for the grating because the loss of the dispersion compensating grating inserted between stages of EDFAs. The nonlinear effect for the grating is



OA: Optical Amplifier BERT: Bit-error-rate tester PRBS: Pseudo Random Bit sequence

Fig. 4 Transmission system of 8×10 Gb/s over 2 015 km with dispersion compensation

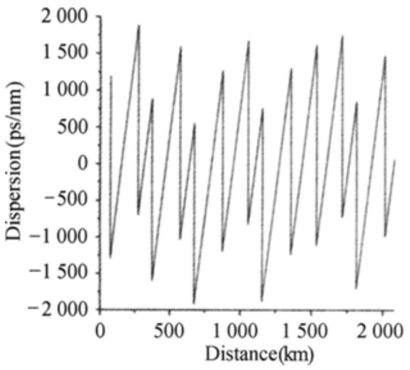


Fig. 5 Dispersion map for transmission distance of 2 015 km

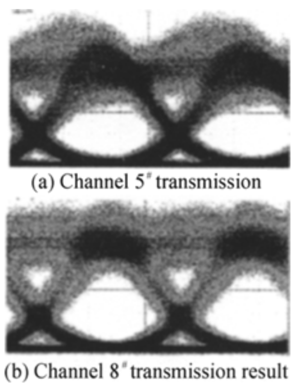


Fig. 6 The eye-diagrams after transmission and compensation in 2 015 km G. 652 fiber

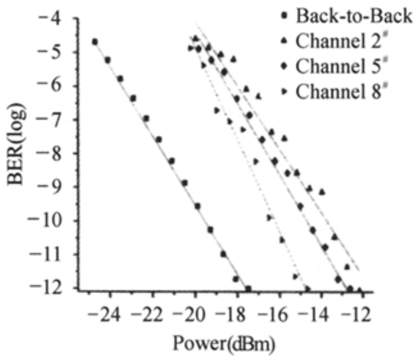


Fig. 7 The BER of 2 015 km FBG dispersion

so low that signal distort caused by nonlinear effect with 7 dBm input power to grating can be ignored. Thus the saturation output power should be 16 dBm and the gain of the amplifier should be 25 dB. The saturation output power of the EDFA is more than 18 dBm. The EDFA noise factor is no more than 5. 5 dB and its gain exceeds 27 dB. The performance of the amplifier can satisfy the demand of the experiment. Fine adjustments of some signal wavelengths are required for optimizing the performance. In addition, the reflectivity and the dispersion of the grating for all the channels should be consistent so that the transmitted performance of each channel can be uniform.

Two representative eye-diagrams seen at the 2 015 km transmission system output (chs. 5 and 8) are shown in Fig. 6. The eye-diagrams of all other channels are the same as these two channels approximately. Seen from the eye-diagrams, the shape of the pulse is recovered and the degree of the eye open is retained well. After 2 015 km transmission, we measured the bit-error-rate (BER) of each channel and got the BER curves terminated at the BER of 10^{-12}. The BER curves of the channels 2 #, 5 # and 8 # are shown in Fig. 7.

Experiment of error-free 8×10 Gb/s over 2 015 km transmission without FEC and electric regeneration is demonstrated. The experiment result has showed that after 2 015 km transmission, the consistency of the dispersion compensating in each channel is perfect and the

CFBGs decrease the transmitted signal OSNR distortion enormously. And the system is economized because of the EDFA + CFBG design. The gratings compensating dispersion for each wavelength overcome the accumulated dispersion discrepancy of different channels and no more other compensators are needed. The experiment proved that group-delay ripple (GDR) limits the CFBG to be put into use in practice mostly. GDR is generated by the interference between the light reflected from the grating and the small broadband reflection from the ends of the grating. Due to the existence of GDR, the different frequency components have some small different time delaies, which create echo pulses centered about the original input pulses. The main effects of the GDR on optical pulses lead to OSNR or eye-opening degradation. Two potential solutions for the problem have been proposed. One is that the grating fabrication should be further improved, and the other is that some novel modulation formats with more dispersion and nonlinear tolerance can be applied in this system to prolong the error-free transmission length.

References

[1] S. Bigo, A. Bertaina, and M. W. Chbat. *IEEE Photonics Technology Letters*, **10**(1998), 1045.

[2] D. F. Grosz and A. Agarwal. *Journal of Lightwave Technology*, **22**(2004), 423.

[3] D. G. Foursa and C. R. Davidson. *OFC* 2002 *Postdeadline Paper*, 2002, FC-1.

[4] Zou Mingyuan and Dong Yi. *Journal of Optoelectronics · Laser*, **14**(2003), 505. (in Chinese)

[5] Tan Zhong-wei and Jian Shui-sheng. *Microwave and Optical Technology Letters*, **42**(2004): 199.

[6] A. B. Grudinim and M. Durkin. *Electronics Letters*, **33**(1997), 1572.

[7] Pei Li and Jian Shui-sheng. *Optical Communications*, **222** (2003), 169.

[8] ZHANG Xuan and YANG Zhu. *Study on Optical Communications*, **98**(2000), 1. (in Chinese)