trained weights are not as good at characterising the testing set. The outstanding ability of the STNN for feature finding can be further noted by comparing the initial and final traces, as shown in Fig. 2. The traces can evolve from the initial disorder (Fig. 2a) to obvious ordered structures (Fig. 2b). This property cannot be observed when only $R(t)$ is employed in learning. Hence, the importance of MEF can be validated as helping the self-clustering of classes.

Discussion and conclusion: Our STNN scheme is quite different from the optimal training signal mapping model presented by Wallis [3]. The STNN does not only show good invariance extraction on a small training set (short pattern sequences), as accomplished by Wallis's model, but also exhibits a good learning ability for a large training set in realistic tasks (long pattern sequences). For this purpose, a new energy function for self-organising the neural network feature extractor is presented. Extracting the invariance from input patterns is a self-organising minimisation process of such an energy function. Our simulation has shown inspiring, good results.

Acknowledgment: We would like to thank G. Wallis for providing some experimental data. This work is supported by a grant from NSF of China (No. 69501003) and a grant from Young Scientists Foundation of Jiangsu Province, China (No. BQ94003).

© IEE 1998
Electronics Letters Online No: 19980161
21 October 1997
Hai Chuan Peng, Lifueng Sha, Qiang Gan and Yu Wei (Department of Biomedical Engineering, Southeast University, Nanning 210696, People's Republic of China)
E-mail: phc@seu.edu.cn

References

Bidirectional transmission of 40 Gbit/s WDM signal over 100 km dispersion shifted fibre

Chang-Hee Lee, Sang-Soo Lee and Seo Yeon Park

The authors demonstrate bidirectional transmission of a 40 Gbit/s (4 × 10 Gbit/s) WDM signal over 100 km of dispersion shifted fibre (DSF) at ITU-T standard wavelengths. The cross-talk penalty induced by Rayleigh back-scattering and four-wave mixing are suppressed by using an arrayed-waveguide grating demultiplexer and channel allocation, respectively.

Introduction: Bidirectional transmission over a single fibre has been investigated for efficient use of optical fibre and for bidirectional optical networks. In bidirectional transmission systems, Rayleigh back-scattering and optical reflection degrade the system performance and induce an optical power penalty [1, 2]. The induced penalty was suppressed by using a fibre grating, and bidirectional transmission of a 10 Gbit/s signal over 240 km of DSF (dispersion shifted fibre) was demonstrated [3]. For a WDM signal, bidirectional transmission at 40 Gbit/s (4 × 10 Gbit/s) over 100 km of DSF was reported [4]. Two amplification bands of an EDFA were used, i.e. 1530 and 1550 nm bands, to reduce the induced penalty. In this Letter, we demonstrate bidirectional transmission of a 40 Gbit/s (4 × 10 Gbit/s) WDM signal over 100 km DSF at ITU-T standard wavelengths in the 1550 nm amplification band. The cross-talk induced by Rayleigh back-scattering and optical reflection is suppressed by using an AWG (arrayed-waveguide grating) demultiplexer. The four-wave mixing penalty is also minimised by channel allocation.

Fig. 1 Experimental setup for bidirectional transmission of 4 × 10 Gbit/s WDM signal over 100 km DSF
AWG: arrayed-waveguide grating; cir: circulator; MOD: modulator; ORX: optical receiver

Fig. 2 Channel allocation diagram

Fig. 3 Measured optical spectra
a Input spectrum of EDFA III
b Demultiplexed output spectrum for channel 7
Experimental results: The experimental setup for bidirectional transmission of a 40Gbit/s WDM signal is shown in Fig. 1. It consists of two $8 \times 1$ AWG multiplexers, two $1 \times 8$ AWG demultiplexers, two optical booster amplifiers, two optical preamplifiers, and a transmission fibre of 100km DSF. The loss of the transmission fibre is 23dB. The channel spacing of our system is 200GHz and each channel is assigned to a standard frequency proposed by ITU-T. Since the average zero dispersion wavelength of our DSF is 1554.4nm, we allocate channels 3 (1550.92nm) and 5 (1554.13nm) to the up stream signal, and channels 4 (1552.52nm) and 6 (1555.75nm) to the down stream signal, as shown in Fig. 2. By doing this, we minimised the four-wave mixing penalty.

The input spectrum of EDFA III shown in Fig. 3a shows the transmitted down stream signal (channels 4, 6, 7, and 8) and the Rayleigh back-scattered up stream signal (channels 1, 2, 3, and 5). These signals are demultiplexed by using AWG III after amplification. The output spectrum of the demultiplexer for channel 7 is shown in Fig. 3b. The amplitude of the cross-talk signals due to Rayleigh back-scattering and optical reflection is 30dB less than that of channel 7. It may be noted that the major cross-talk of $-22$dB at channel 6 arises from the down stream signal component. Thus, the power penalty induced by the Rayleigh back-scattering and the optical reflection is negligible [1, 5].

Discussion and conclusion: The maximum transmission loss of the bidirectional repeaterless transmission system is $C_{sys} - R_{sys}$, where $C_{sys}$ is the allowed cross-talk of the system minus the cross-talk of the AWG, and $R_{sys}$ is the back reflection coefficient including Rayleigh back-scattering. For our system, the back reflection coefficient and the cross-talk of the AWG are $-32$ and $-22$dB, respectively. Thus, the maximum transmission loss is 38dB, when the maximum allowed cross-talk is $-16$dB (giving a total cross-talk of $-10$dB for four transmission channels) [5]. Then, the sensitivity of the optical receiver determines the required output power of the transmitter or the optical booster amplifier. The required output power increases as we increase the transmission bit rate; it is 5dBm/channel, when the receiver sensitivity is $-33$dBm at 10Gbit/s. However, the maximum output power is limited by optical nonlinearity, e.g. four-wave mixing, of the dispersion shifted fibre.

In conclusion, we have demonstrated bidirectional transmission of a 40Gbit/s (4 x 10Gbit/s) WDM signal over 100km of dispersion shifted fibre at ITU-T standard wavelengths. The penalty due to the Rayleigh back-scattering and the four wave mixing are suppressed by an AWG demultiplexer and proper channel allocation, respectively. The experimental results show the possibility of the high capacity (≥ 80Gbit/s) bidirectional transmission. We can enhance the system capacity by using the periodic property of the AWG without changing the AWGs.

References

Fig. 4 Measured BER curves and measured power penalty at BER of 10^{-10}

We measured the BER (bit error rate) of the demultiplexed signals, and the results are shown in Fig. 4. The BER curves show no error-floor. The measured penalty at a BER of 10^{-10} for each channel is shown in Fig. 4b and the maximum value of 0.5dB was observed at channel 3. The difference in power penalty between unidirectional transmission and bidirectional transmission is within experimental error.

The four-wave mixing penalty for the down stream signal (channels 4, 5, 6 and 7) was measured without the up stream signal. The measured maximum power penalty at a BER of 10^{-10} was < 0.5dB, when the coupled power to the fibre is approximately 2dBm/channel. However, the maximum power penalty was increased to 3.2dB in unidirectional transmission of channels 4, 5, 6, and 7, although the coupled power is 0 dBm/channel. It may be noted that average zero dispersion wavelength of our DSF is 1554.4nm and it is located between channel 4 and channel 5. The experimental results show a suppression of the four-wave mixing penalty in bidirectional transmission with proper channel allocation.

Fig. 5 Measured BER curves and measured power penalty at BER of 10^{-10}

In conclusion, we have demonstrated bidirectional transmission of a 40Gbit/s (4 x 10Gbit/s) WDM signal over 100km of dispersion shifted fibre at ITU-T standard wavelengths. The penalty due to the Rayleigh back-scattering and the four wave mixing are suppressed by using an AWG demultiplexer and proper channel allocation, respectively. The experimental results show the possibility of the high capacity (≥ 80Gbit/s) bidirectional transmission. We can enhance the system capacity by using the periodic property of the AWG without changing the AWGs.

Passive all-optical clock signal extractor for non-return-to-zero signals

Chang-Hee Lee and Hak Kyu Lee

The authors propose and demonstrate a new all-optical clock signal extraction from non-return-to-zero signals for optical clock recovery. The signal extractor is a simple passive optical interferometer based on polarisation maintaining fibre.