Demultiplexing 160 Gbit/s OTDM signal to 40 Gbit/s by FWM in SOA

DOI:
10.1049/el:20020684

Document status and date:
Published: 01/01/2002

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

cleaning before connection. This is because the connection characteristics deteriorate when the fibre endface is contaminated with dust. When a high-power light is incident on the endface, dust might cause fatal damage rather than simply performance degradation. Because dust would often be generated during mating operations, we performed a mating test to investigate the influence of dust adhering to the fibre endface when high-power optical light was launched into the fibre. We examined the mating characteristics of the connectors at an input optical power of 2 W. We used SMF and DSF as the optical fibres, MU-type plugs, and adaptors with a zirconia split alignment sleeve. We also used a commercially available dry-type optical connector cleaner. We performed 200 mating cycles with and without fibre endface cleaning. In the measurements, light was launched into the fibre only during the connected state, and the mating was undertaken without any input light.

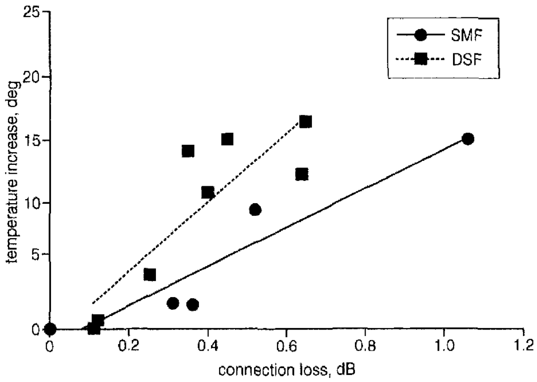

Fig. 1 *Experimental surface temperature measurements of split alignment sleeve at optical incidence of 2 W*

■ and ● measured value
--- and — linear fitting

Table 1: Influence of mating on fibre endface under high-power optical incidence (○ no damage observed, × fatal damage observed)

Cleaning	Fibres	
	SMF	DSF
Every mating	○	○
None	×	×

Table 1 summarises our experimental results. We observed no deterioration in either the SMF or DSF in the experiments with fibre endface cleaning, and no trouble occurred. By contrast, we observed fibre endface damage for both SMF and DSF before the completion of 200 mating cycles in the experiments without fibre endface cleaning. Furthermore, with DSF the fibre fuse phenomenon [6] sometimes occurred during the experiments. Since the optical power density of DSF is higher than that of SMF, we believe that the fibre fuse effect is generated more easily in DSF than SMF. Fig. 2 shows the monitored optical output power during a mating test using DSF with a 2 W optical input. When the ferrule endface cleaning was performed, as shown in Fig. 2, the output optical power maintained its initial value on completion of 200 mating cycles. However, the output optical power began to decrease at about 100 mating cycles without cleaning, and the fibre fuse phenomenon occurred at 160 mating cycles before any great deterioration in the optical characteristics. Thus, if the ferrule endface were left uncleaned, there would be the possibility of fibre fuse generation when a high-power system was in operation. Therefore, it is especially important to perform appropriate fibre endface cleaning in a high-power system.

Conclusion: We investigated the characteristics of the MU-type fibre-optic connector when a high-power optical signal was launched into a fibre. We observed that the connection point temperature increased with a high input power due to connection loss, and we showed that the maximum temperature increase would be 10° for a connection loss of 0.25 dB and a launched power of 1 W. Dust on the fibre endface is also a factor that has a detrimental effect on optical connector performance, and we performed 200-cycle mating tests with a 2 W optical input to investigate its influence. Fibre endface damage was observed for both SMF and DSF only when the fibre endfaces were not cleaned. With DSF the fibre fuse phenomenon was also observed before the optical characteristics had greatly deteriorated. Therefore, with high-power systems it is especially important to perform appropriate fibre endface cleaning on optical connectors before connection.

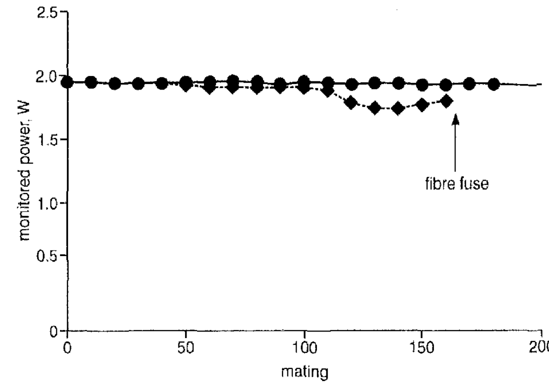

Fig. 2 *Monitored output optical power of mating tests with 2 W optical input*

● with fibre endface cleaning
◆ without fibre endface cleaning

Acknowledgments: The authors thank M. Koga, T. Morioka, Y. Tada, Y. Miyamoto, H. Takara and M. Tomizawa of NTT for their encouragement throughout this work.

23 May 2002
Electronics Letters Online No: 20020647
DOI: 10.1049/el:20020647

S. Yanagi, S. Asakawa and R. Nagase (*NTT Photonics Laboratories, Nippon Telegraph and Telephone Corporation, 3-1 Wakamiya Morinosato, Atsugi, Kanagawa 243-0198, Japan*)

E-mail: yanagis@aecl.ntt.co.jp

References

1 SUZUKI, H., KANI, J.I., MASUDA, H., TAKACHIO, N., IWATSUKI, K., TADA, Y., and SUMIDA, M.: '1-Tb/s (100 × 10 Gb/s) super-dense WDM transmission with 25-GHz channel spacing in the zero-dispersion region employing distributed Raman amplification technology', *IEEE Photonics Technol. Lett.*, 2000, **12**, (7), pp. 903–905

2 WATANABE, T., KANO, F., KUWANO, S., SUZUKI, H., and KOGA, M.: 'Scale expansion of transparent photonic transport network based on distributed Raman amplification', *IEEE Photonics Technol. Lett.*, 2000, **12**, (10), pp. 1420–1422

3 GARRERR, L.D., WAARTS, M., GILTNER, D., and TKACH, R.W.: 'Field demonstration of distributed Raman amplification with 3.8 dB Q-improvement for 5 × 120 km transmission'. OFC2000, Baltimore, MD, USA, Paper PD42

4 NAGASE, R., SUGITA, E., IWANO, S., KANAYAMA, K., and ANDO, Y.: 'Design for MU-type single-mode miniature optical connector', *IEICE Trans. Electron.*, 1998, **E81-C**, pp. 408–415

5 SHINTAKU, T., NAGASE, R., and SUGITA, E.: 'Connection mechanism of physical contact optical fiber connectors with spherical convex polished ends', *Appl. Opt.*, 1991, **30**, pp. 5260–5265

6 KASHYAP, R., and BLOW, K.J.: 'Observation of catastrophic self-propelled self-focusing in optical fibres', *Electron. Lett.*, 1988, **24**, (1), pp. 47–49

Demultiplexing 160 Gbit/s OTDM signal to 40 Gbit/s by FWM in SOA

S.L. Jansen, M. Heid, S. Spälter, E. Meissner, C.-J. Weiske, A. Schöpflin, D. Khoe and H. de Waardt

Error-free demultiplexing of 40 Gbit/s channels out of a 160 Gbit/s optical time-division signal is demonstrated using four-wave mixing in a semiconductor optical amplifier.

Introduction: In next generation communication systems optical time-division multiplexing (OTDM) will be a key technology to cope with the increasing demand for capacity. For OTDM signals several demultiplexing techniques have been reported so far [1, 2]. For system applications semiconductor optical amplifier (SOA)-based switches are particularly promising because they feature superior stability and low switching energies. Using four-wave mixing (FWM) in SOAs demultiplexing up to 200 Gbit/s (32 × 6.3 Gbit/s) has been reported by Morioka *et al.* [3]. The highest base rate reported to date is 20 Gbit/s [4]. In this Letter we demonstrate demultiplexing of a 40 Gbit/s channel out of a 160 Gbit/s OTDM signal.

Experimental setup: Fig. 1 shows the experimental setup. A 10.616 GHz clock was fed into two modelocked fibre lasers (MLFLs). The data laser (MLFL 1), which produced a 1.5 ps pulsewidth pulsetrain at 1547.2 nm, was first multiplexed to 42.464 GHz in a passive fibre delay line multiplexer and then modulated. The modulation signal was generated using electrical time-division multiplexing (16 × 2.654 Gbit/s channels). Each channel was generated using a $2^7 - 1$ pseudorandom bit sequence (PRBS). Subsequently the 169.856 Gbit/s OTDM signal was obtained by delaying and multiplexing 42.464 Gbit/s signal four times. The control laser (MLFL 2), which produced a 1.7 ps pulsewidth pulsetrain at 1538.3 nm, was multiplexed to the base rate of 42.464 GHz. The total power launched into the SOA was 13.2 dBm. The data signal comprised 3.2% (−1.7 dBm) of the SOA input. The SOA length was 500 μm and the current (I_{SOA}) was set to 200 mA. The FWM signal was filtered by an optical bandpass filter (FWHM = 11 nm). Finally the FWM signal was detected using a 42.464 to 2.654 Gbit/s ETDM demultiplexer followed by a 2.654 Gbit/s bit error rate (BER) detector.

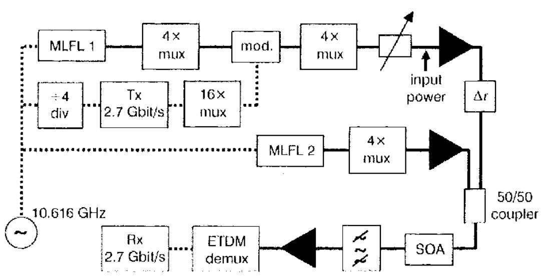

Fig. 1 *Experimental setup for demultiplexing 160 to 40 Gbit/s*

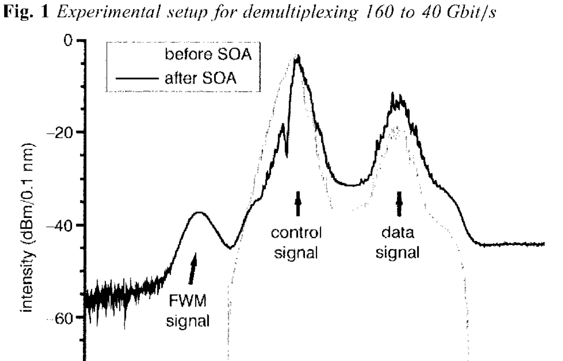

Fig. 2 *Optical spectrum at SOA input and output*

Results: Fig. 2 shows the optical input and output spectrum of the SOA with a spectral resolution of 0.1 nm. While the data signal experienced some amplification, the control signal had significantly less energy at the output compared to the input and was shifted to longer wavelengths. This was mainly due to self-phase modulation caused by gain saturation produced by the control pulse [5]. Clearly a FWM product was present at about 1530 nm. The FWM efficiency, defined as the output FWM power devided by the input power of the data, was 2.4% in this setup.

Fig. 3 shows the BER performance for the four demultiplexed base rate channels. Error-free operation (BER $< 10^{-10}$) was obtained for all channels. The sensitivities (the input power for a BER of 1×10^{-9}) of the best and the worst demultiplexed channel were −20.8 and −20.3 dBm, respectively. The 0.5 dB power penalty for the worst channel was mainly caused by an imperfect alignment of amplitude and delay in the multiplexers.

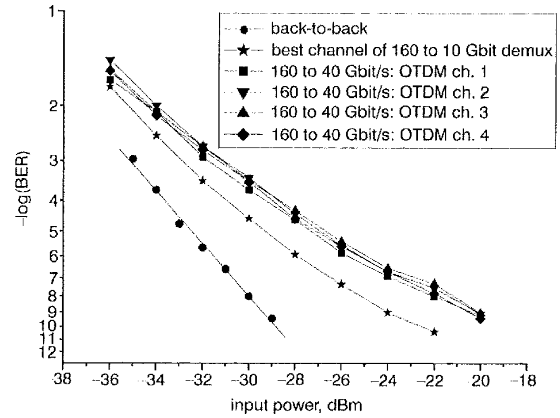

Fig. 3 *Bit error rate measurements of 160 to 40 Gbit/s demultiplexing*

Fig. 4 shows the clear and open demultiplexed eye diagram that was obtained. The eye diagram clearly shows that more noise is present on the '1' bit than on the '0' bit. This is due to a residual bit pattern dependency, i.e. a dependency of the switching gate extinction ratio on the bit sequence.

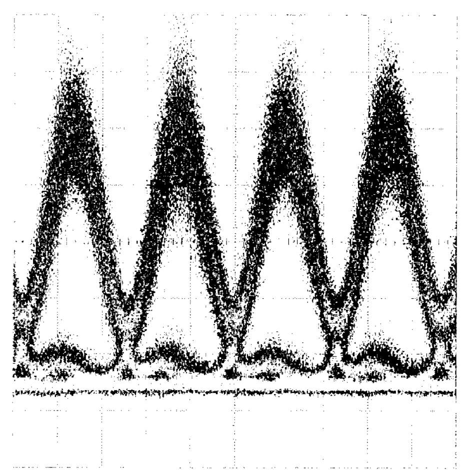

Fig. 4 *40 Gbit/s demultiplexed eye diagram*

Conclusion: The results of this experiment have successfully demonstrated error-free demultiplexing of a 160 Gbit/s signal to a base rate of 40 Gbit/s by employing FWM in a SOA. This technique has proven to be more stable than interferometric SOA-based switches. Also the alignment of the setup was less critical.

Acknowledgment: The work reported was conducted within the framework of the IST project FASHION (IST-2000-28765).

11 June 2002
Electronics Letters Online No: 20020684
DOI: 10.1049/el:20020684

S.L. Jansen, D. Khoe and H. de Waardt (*COBRA Institute, University of Technology Eindhoven, Department of Electrical Engineering, Den Dolech 2, 5612 AZ, Eindhoven, The Netherlands*)

E-mail: s.l.jansen@student.tue.nl

M. Heid, S. Spälter, E. Meissner, C.-J. Weiske and A. Schöpflin (*SIEMENS AG, Optical Networks, Advanced Technology, Hofmannstr. 51, D-81359 Munich, Germany*)

References

1 LUDWIG, R., FEISTE, U., SCHMIDT, C., SCHUBERT, C., BERGER, J., HILLIGER, E., KROH, M., YAMAMOTO, T., WEINERT, C.M., and WEBER, H.G.: 'Enabling transmission at 160 Gbit/s'. OFC, Anaheim, CA, USA , 2002, TuA1

2 SPÄLTER, S., HEID, M., JANSEN, S.L., LEHMANN, G., MEISSNER, E., and LANKL, B.: '160-Gbit/s demultiplexing based on a monolithically integrated Mach-Zehnder interferometer'. ECOC'02, Copenhagen, Denmark, 2002 (to be presented as an invited paper)

3 MORIOKA, T., TAKARA, H., KAWANISHI, S., UCHIYAMA, K., and SARUWATARI, M.: 'Polarisation-independent all-optical demultiplexing up to 200 Gbit/s using four-wave mixing in a semiconductor laser amplifier', *Electron. Lett.*, 1996, **32**, pp. 840–841

4 SHAKE, I., TAKARA, H., UCHIYAMA, K., OGAWA, I., KITOH, T., KITAGAWA, T., OKAMOTO, M., MAGARI, K., SUZUKI, Y., and MORIOKA, T.: '160 Gbit/s full optical time-division demultiplexing using FWM of SOA-array integrated on PIC', *Electron. Lett.*, 2002, **38**, pp. 37–38

5 DAS, N.K., KAWAZOE, T., YAMAYOSHI, Y., and KAWAGUCHI, H.: 'Analysis of optical phase-conjugate characteristics of picosecond four-wave mixing signals in semiconductor optical amplifiers', *IEEE J. Quantum Electron.*, 2001, **37**, pp. 55–62

Differential detection of single modulation sideband for ultra-dense optical frequency-division multiplexed systems

K. Kikuchi and K. Katoh

Differential detection of the single modulation sideband of the binary phase-shift-keying (BPSK) signal is demonstrated. Using single-sideband differential detection at the intermediate frequency stage, it is possible to demodulate 2.5 Gbit/s BPSK-modulated optical channels with spacing as narrow as 2.5 GHz. Even though the spectra of the two channels are overlapped, error-free operation is maintained in each channel.

Introduction: The communication theory shows us that the single sideband (SSB) of a modulated signal carries full information. Since the carrier component and one of the sidebands are eliminated, SSB transmission can minimise the optical power and the occupied bandwidth; therefore, it is very attractive for future ultra-dense frequency-division multiplexed (FDM) systems.

The SSB modulator made of an $LiNbO_3$ waveguide device [1] and the SSB optical filter [2] have been developed to generate the SSB signal. However, it has been believed that the complicated carrier-recovery circuit such as a phase-locked loop (PLL) is necessary for demodulation of the SSB signal, which makes the SSB scheme impractical. So far, the vestigial-sideband (VSB) demodulation, where the SSB is directly detected by beating with the remaining carrier, has been proposed to avoid this difficulty [3].

In this Letter, we demonstrate, for the first time to our knowledge, differential detection of the single sideband of the binary phase-shift-keying (BPSK) signal, using neither a remaining carrier nor a carrier-recovery circuit. The differential detection has been employed to demodulate the double-sideband (DSB) BPSK signal both at the optical stage and the intermediate frequency (IF) stage [4], and can easily be implemented in the SSB system.

Using the optical heterodyne receiver with high frequency resolution [5] and the SSB differential detector at the IF stage, we demodulate any one of two 2.5 Gbit/s DSB BPSK channels with a channel spacing as narrow as 2.5 GHz. The channel spacing is so narrow that the upper sideband of the low frequency channel and the lower sideband of the high frequency channel are overlapped entirely. However, by detecting only the other modulation sideband of each channel, we can achieve error-free operation with a small power penalty. This channel spacing is halved compared to that of the DSB modulation scheme [5].

Experimental setup: Fig. 1 shows a comparison of the phasor diagram between the DSB-BPSK and SSB-BPSK modulation. In the case of the DSB-BPSK modulation, the phasor moves between two phase angles of 0 [rad] and π [rad] via the upper or lower half of the circle. Conversely, in the case of the SSB-BPSK modulation, the phasor rotates on the circle clockwise or counter-clockwise. The only difference between them is the direction of rotation of the phasor, and it is obvious that the differential coding and differential detection can be applied to both cases.

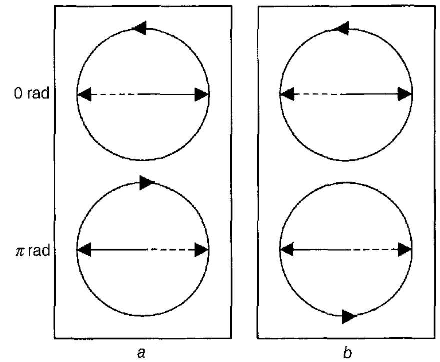

Fig. 1 *Comparison of phasor diagram between DSB-BPSK and SSB-BPSK modulation*

a Double sideband BPSK modulation *b* Single sideband BPSK modulation

Fig. 2 shows the experimental setup of the SSB differential detection system, which consists of three parts surrounded by broken lines. In the transmitter, we used two 1550 nm DFB lasers, LD1 and LD2, the 3 dB spectral widths of which were 50 kHz. The laser temperature and bias current were highly stabilised to realise the long-term frequency drift below 10 MHz. The channel spacing was adjusted by slightly changing the laser temperature. LD1 and LD2 were phase-modulated by $LiNbO_3$ Mach-Zehnder modulators at 2.5 Gbit/s using differentially coded NRZ pseudorandom bit sequences. The transmission loss was simulated by a variable optical attenuator (VOA).

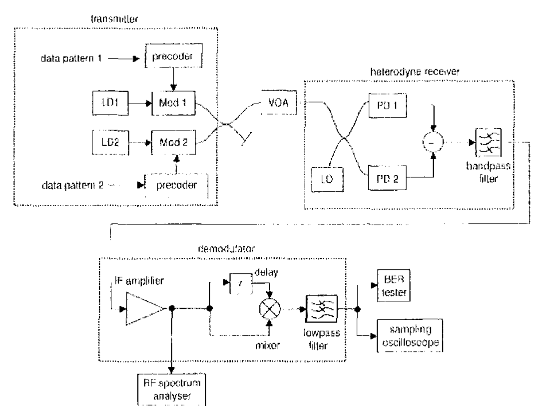

Fig. 2 *Experimental setup for SSB demodulation*

We constructed a heterodyne receiver consisting of a local oscillator (LO), an optical double-balanced receiver having a 20 GHz bandwidth, and a bandpass filter [5]. Fig. 3 shows the transmission characteristics of the filter. The centre frequency and 0.5 dB bandwidth of the filter are 9.7 and 3.2 GHz, respectively. The LO was a DFB laser the specifications of which were the same as those of the transmitter lasers. The LO frequency was tuned with temperature, and the polarisation state of LO was controlled so that it was matched with those of the transmitted signals.

Tuning the LO frequency, we could filter out only the single sideband of each 2.5 Gbit/s DSB-PSK signal. The single-sideband intermediate-frequency (IF) signal thus obtained was demodulated by a differential detector consisting of a low-noise IF amplifier, a one-bit delay line, an electrical double-balanced mixer, and a Bessel filter with a cutoff frequency of 1.866 GHz. The IF spectrum was monitored by an RF spectrum analyser. The demodulator output was led to a bit error rate (BER) tester measuring the BER and to a sampling oscilloscope monitoring the waveform.