bit pseudorandom sequence at 622Mbit/s using an $LiNbO_3$ intensity modulator, which also polarised the ASE. The receiver consisted of an APD-FET. The bit error rate (BER) was determined against received power at each wavelength. The results are shown in Fig. 5. The receiver sensitivities for transmission at the four wavelengths are very similar, as expected.

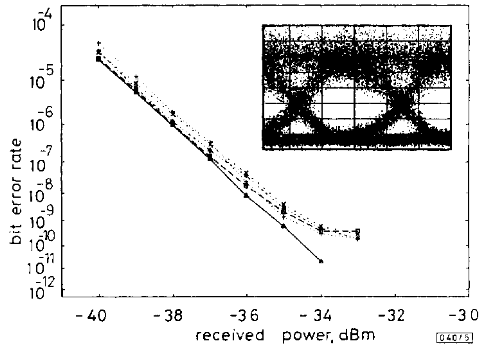

Fig. 5 *Measured bit error rates and eye diagram at 622Mbit/s*

◊ 1545nm
+ 1550nm
□ 1555nm
× 1560nm
Δ DFB LD

An error rate floor may be present in systems based on ASE sources if the ratio of the optical to electrical bandwidth of the sliced channel is not sufficiently large. This arises as a fundamental consequence of spontaneous-spontaneous beat signals which are converted to baseband intensity noise [3]. We observe an error-rate floor, as seen in Fig. 5, at $\sim 10^{-10}$. The corresponding eye diagram, shown in Fig. 5, clearly shows higher noise levels for a '1', as expected.

The BER measurements for spectrum-sliced channels are compared with the BER when the broadband source is replaced by a DFB laser transmitter and polarisation controller with the same power as the ASE source measured at the output of the modulator, also shown in Fig. 5. Data transmission using the ASE source has a power penalty of ~0.5 – 1dB at a BER of 10^{-9}, attributable to the error-rate floor.

Conclusions: We have demonstrated a 110mW broadband ASE source with a spectrum tailored to have excellent uniformity over 15nm and a 3dB bandwidth of 22nm. Such high power and spectral uniformity make the ASE source ideal for use in spectrum-sliced WDM systems. We have confirmed the excellent properties of the ASE source by demonstrating equal receiver sensitivities at 622Mbit/s for transmission of a single 0.23nm channel tuned over a 15nm band with a small observed penalty compared to a DFB laser transmitter of the same power. Considerable scope exists to further improve the characteristics of the ASE source.

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All-optical WDM to TDM transmultiplexer

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Indexing terms: Wavelength division multiplexing, Time division multiplexing, Optical communication, Semiconductor optical amplifiers, Optical frequency conversion

An all-optical WDM to TDM converter, or transmultiplexer, is described. The transmultiplexer is based on optical frequency conversion by gain compression in semiconductor optical amplifiers. Operation of the transmultiplexer is demonstrated experimentally, and bit error rate measurements are reported.

Introduction: Optical time-division multiplexing (TDM) and wavelength-division multiplexing (WDM) are well-established techniques for increasing the aggregate data rate in trunk communications links and multiuser systems. Future all-optical networks may use a variety of multiplexing techniques, in which case there will be a need for all-optical conversion of data between the WDM and TDM formats. We have recently demonstrated an all-optical TDM to WDM converter, or transmultiplexer, based on four-wave mixing in a semiconductor optical amplifier (SOA) [1]. In this Letter, we describe the first all-optical WDM to TDM transmultiplexer. The transmultiplexer uses optical frequency conversion by gain compression in SOAs [2]. We demonstrate operation of the WDM to TDM transmultiplexer, and report bit error rate measurements.

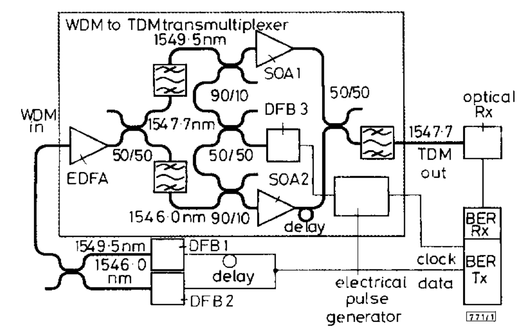

Fig. 1 *Experimental configuration*

——— optical paths
- - - - electrical paths

Experiment: The experimental configuration of the demonstration all-optical WDM to TDM transmultiplexer is shown in Fig. 1. Two distributed feedback (DFB) semiconductor lasers, *DFB*1 and *DFB* 2, operating at 1549.5 and 1546.0nm respectively, are directly modulated at 350Mbit/s nonreturn-to-zero (NRZ) by the transmitter of a bit-error rate (BER) test set. The data input to *DFB* 1 are delayed with respect to the data input to *DFB* 2, to mimic two separate data streams. The optical outputs of the two DFB lasers are combined to produce a WDM signal which is fed into the input of the transmultiplexer.

At the input to the transmultiplexer, an erbium-doped fibre amplifier (EDFA) boosts the power of the WDM signal. The amplified signal is then split by a 50/50 coupler and passed through 1nm dielectric bandpass filters to separate the two WDM channels. Each channel is passed to the input of a separate SOA. The WDM channel at 1549.5nm is fed into *SOA*1, and the WDM channel at 1546.0nm is fed in to *SOA* 2 (both BT&D SOA1100-1550/A2). A third DFB laser, *DFB*3, operating at 1547.7nm, is directly modulated by an electrical pulse generator synchronised to the 350MHz clock of the BER test set transmitter. The resulting optical pulses from *DFB* 3 are 730ps in duration. These pulses, the 'probe' pulses, are split by a 50/50 coupler, and are combined in 90/10 couplers with the amplified WDM channels at the inputs to *SOA* 1 and *SOA* 2. Optical and electrical delays in the system are adjusted to ensure that the probe pulses and data bits are aligned in time at the inputs to the SOAs. Polarisation controllers (not shown in Fig. 1) align the fields of the lasers with the TE mode of the SOA waveguides.

In each SOA, the input data on the WDM channel are transferred to the output optical frequency by gain compression [2]. A data bit of level '1' compresses the SOA gain available to the coincident probe pulse, while a probe pulse coincident with a data bit of level '0' is strongly amplified, so that the probe pulses leaving the SOAs are modulated with the complement of the WDM input data. The frequency conversion is therefore accompanied by a sampling process, in which the input NRZ format is converted to a pulsed return-to-zero (RZ) output.

The output of *SOA* 2 is delayed by one half of the bit period with respect to the output of *SOA* 1, and the two signals are combined in a 50/50 coupler to produce a bit interleaved RZ TDM signal. At the output of the transmultiplexer, a 0.2nm fibre Fabry-Perot filter rejects the original WDM signals. The output from the transmultiplexer is detected by an optical receiver and fed to a BER test set.

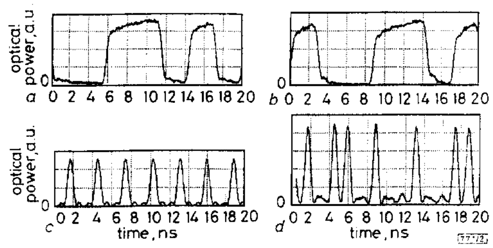

Fig. 2 *Signal waveforms*

a 350Mbit/s NRZ WDM input at 1549.5nm
b 350Mbit/s NRZ WDM input at 1546.0nm
c 350MHz probe pulses at 1547.7nm
d 700Mbit/s RZ TDM output at 1547.7 nm

Results: Fig. 2 shows optical inputs to the transmultiplexer, the probe pulse train, and the transmultiplexer output, all detected by a 1GHz receiver (New Focus 1611) and observed on a sampling oscilloscope. Fig. 2*a* shows the 350Mbit/s NRZ WDM input bit sequence 0011010 at 1549.5nm, and Fig. 2*b* shows the 350Mbit/s NRZ WDM input bit sequence 1001101 at 1546.0nm. Fig. 2*c* shows the 350MHz optical probe pulses at 1547.7nm. The output from the transmultiplexer is shown in Fig. 2*d*. The output is the 700Mbit/s TDM bit sequence 10110100100110, as expected, at a wavelength of 1547.7nm. The extinction ratio of this waveform is better than 8.8dB. The bias current, average input probe power, and average input data power at *SOA* 1 were 70mA, −19dBm, and −3dBm, respectively; and at *SOA* 2 were 80mA, −18dBm, and −5dBm, respectively.

Under the same conditions, the BER of data converted by the transmultiplexer was measured, with an input pseudorandom bit sequence of length $2^{23}-1$. Bit error rates better than 4×10^{-10} were measured for both channels. The bit rate of the present experiment was limited by the available error rate test set and associated electronics. With faster electronics, the single-channel bit rate would eventually be limited by the SOA carrier spontaneous lifetime [3, 4]. However, the transmultiplexing technique described here could be used at bit rates up to tens of gigabits per second in the TDM channel for systems with more than two multiplexed channels.

Conclusion: We have reported the first demonstration of an all-optical WDM to TDM transmultiplexer. Gain compression in SOAs was used to convert two 350Mbit/s WDM channels, spaced by 3.5nm, to a bit-interleaved 700Mbit/s TDM data stream at a third wavelength. BERs of less than 10^{-9} were observed on both output TDM channels.

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Eight-wavelength, densely-spaced coherent WDM recirculating-loop experiments at 2.5Gbit/s over 600km

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Indexing terms: Fibre amplifiers, Optical communication, Wavelength division multiplexing

Eight-wavelength, densely-spaced coherent CPFSK recirculating-loop experiments at 2.5Gbit/s have been demonstrated over 600km through 30 cascaded EDFAs. The WDM signals were densely packed in a bandwidth of only 1.4nm, indicating the effective use of optical frequency resources by coherent schemes.

Introduction: Increasing attention has recently been paid to wavelength-division-multiplexing (WDM) lightwave communication systems for expanding transmission capacity and for the construction of flexible transparent systems in future all-optical networks. Most of the WDM experiments have been carried out using intensity-modulation direct-detection (IM-DD) schemes [1, 2]. However, in WDM systems using IM-DD schemes, channel spacings between adjacent channels have to be set relatively large (typically 1 to 3nm) due to the practically available bandwidths of optical bandpass filters (BPFs) for receivers. Such large channel spacings result in an imbalance of signal-to-noise ratios between WDM carriers in in-line amplifier systems due to the accumulation of unflatness in the wavelength against gain characteristics of erbium-doped fibre amplifiers (EDFAs); some countermeasures against the problem have been proposed [1–4].

We have already shown that the problem can also be alleviated by coherent schemes with a densely-spaced carrier arrangement in 2.5Gbit/s, four-channel, 1200km CPFSK transmission experi-