was achieved at room temperature. No penalty was observed after transmission over 10km of standard singlemode fibre.

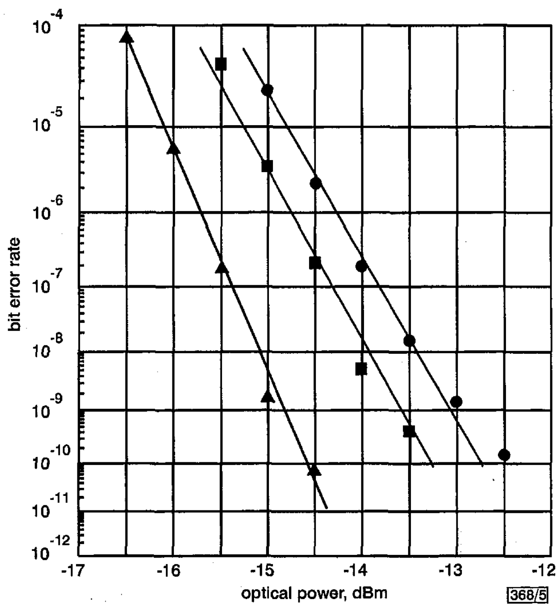

Fig. 5 *BER measurement*

▲ back to back at room temperature
■ back to back at T = 65°C
● over 4km of singlemode fibre at T = 65°C

To investigate the effects of temperature, transmission experiments at a transmitter case temperature of 65°C were performed. Fig. 5 shows the measured bit error rate performance at room temperature, and at 65°C for a back-to-back configuration and over 4km of singlemode fibre, respectively. The increase in temperature results in a power penalty of ~1.2dB, while transmission over 4km of standard singlemode fibre at 650°C yields another penalty of ~0.5dB. The 1dB difference in sensitivity at room temperature compared to Fig. 4 is due to the use of a different receiver module with a reduced fibre-to-chip coupling efficiency in this transmission experiment.

Conclusions: We have presented a 10Gbit/s transmission system using an uncooled MQW ridge waveguide laser as a transmitter. We achieved a sensitivity of -13.0dBm at a transmitter case temperature of 65°C over 4km of standard singlemode fibre. Using standard T046 packages for the transmitter and receiver offers low cost potential, which is essential for future high-speed datacommunications applications.

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120Gbit/s OTDM system using electroabsorption transmitter and demultiplexer operating at 30GHz

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The authors describe a 120 Gbit/s (4 × 30Gbit/s) OTDM system in which the transmitter and the receiver are based on electroabsorption modulators operating at 30GHz. Error-free operation with an average 120Gbit/s sensitivity of -22.6dBm is achieved.

Introduction: Sinusoidally driven electroabsorption (EA) modulators have recently attracted much attention in high-speed optical time division multiplexed (OTDM) systems as optical short pulse generators and optical demultiplexers [1, 2]. An 80Gbit/s OTDM data stream (with 10Gbit/s base rate) was realised by short pulses generated from EA modulators without using any nonlinear pulse compression [1]. Conversely, a 160Gbit/s optically multiplexed data stream was demultiplexed to 10Gbit/s using two concatenated EA modulators [2]. Owing to advances in high-speed electrical TDM, it is inevitable that next generation OTDM systems will operate at a base rate of 40Gbit/s, with optical multiplexing to 160Gbit/s or more [3, 4]. The increase of the base rate and the consequent reduction in the number of optical channels should allow for more robust and stable high-speed OTDM systems [5].

Recently, we demonstrated sub-4ps pulse generation using a single EA modulator at modulation frequencies ≥ 30GHz [6] as well as integrated tandem EA modulators for > 100Gbit/s optical demultiplexing [7]. In this Letter, we demonstrate a 120Gbit/s (4 × 30Gbit/s) OTDM system based on 30GHz modulation of these devices. We believe that this is the first demonstration of the feasibility of using EA modulators in conjunction with high-speed (> 20Gbit/s) electrical multiplexing and demultiplexing for > 100Gbit/s OTDM systems.

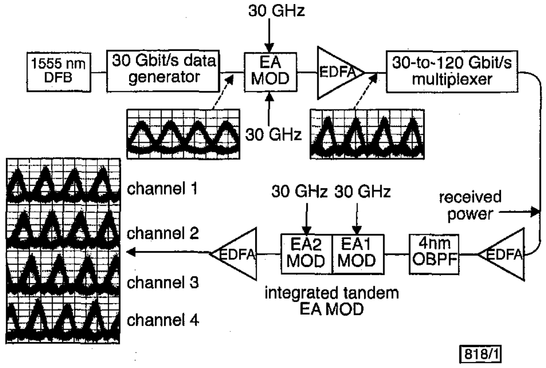

Fig. 1 *Experimental setup for 120Gbit/s OTDM system*
Eye diagrams - 13.3ps/div

Experimental setup and results: The experimental setup for the 120Gbit/s OTDM system is shown in Fig. 1. The base rate of 30Gbit/s was generated by electrically multiplexing two 7.5Gbit/s channels with pattern lengths of 2^{31}–1, followed by optical multiplexing to 30Gbit/s. The 30Gbit/s optical signal of 2dBm was then coupled into the dual-drive EA modulator [6], which has a maximum extinction ratio of 40.3dB and a bandwidth of 26GHz. The modulator was reverse biased at –6V and driven by two 30GHz RF amplifiers (7V_{pp}) which were synchronised to the 30Gbit/s data stream by electrical delay lines. Transform-limited 4ps pulses were generated and external compression was not employed after the modulator. The 30Gbit/s signal was then passively multiplexed (with 200 bits of delay between channels) to generate the 120Gbit/s OTDM data stream. Both time and polarisation multiplexing were employed at the last stage of the multiplexer to minimise coherent interference between adjacent channels. Fig. 2 shows the two 60Gbit/s optical channels measured using a 30GHz photodiode.

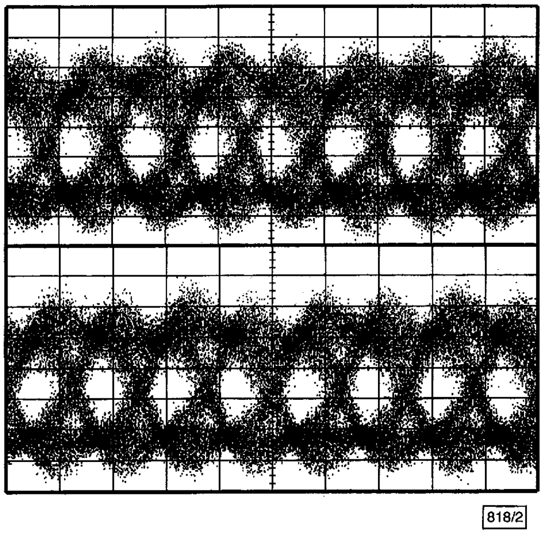

Fig. 2 *Two 60Gbit/s channels measured with 30GHz photodiode*
13.3ps/div

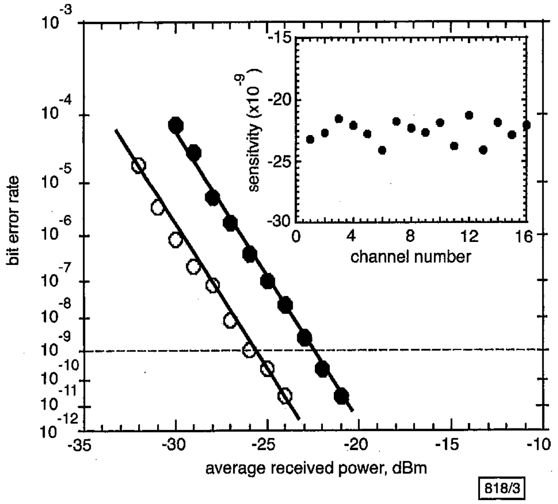

Fig. 3 *BER measurements*
● 120Gbit/s
○ 60Gbit/s
Inset: Receiver sensitivity at 10^{-9} for all 16 channels

In the receiver, the 120Gbit/s data stream was optically preamplified and fed into the optical demultiplexer which consisted of integrated tandem EA modulators [7]. The two modulators (EA1 and EA2) are 300µm and 400µm long, respectively, and are separated by a 20µm long optical waveguide region. H$^+$ ion-implantation was used between the modulators to reduce electrical crosstalk and capacitance. The insertion loss of the device was 14.2dB while the maximum extinction ratio was ~50dB. Both modulators were driven by 30GHz RF signals and a switching window of 5 to 6ps was achieved over a wide range of reverse biases. The output in Fig. 1 shows the four demultiplexed 30Gbit/s optical channels. A polarisation sensitivity of ~2dB was observed which had a minimal impact on the 30Gbit/s eye opening. The received 30Gbit/s eye diagrams also indicate that further high-speed electrical demultiplexing is feasible. It should also be noted that a similar dual-drive EA modulator used in the transmitter could have been employed as the optical demultiplexer.

To simplify bit error rate (BER) measurements, EA2 was only driven by a 7.5GHz RF signal and the 120Gbit/s data stream was directly demultiplexed to 7.5Gbit/s. Fig. 3 shows the 120Gbit/s and 60Gbit/s BER measurements for an arbitrarily selected channel. Error-free operation with a 120Gbit/s receiver sensitivity of –22.2dBm was achieved. The inset to Fig. 3 shows the sensitivities of all 16 channels for a BER of 10^{-9} (mean of –22.6dBm) while Fig. 4 shows all the demultiplexed channels.

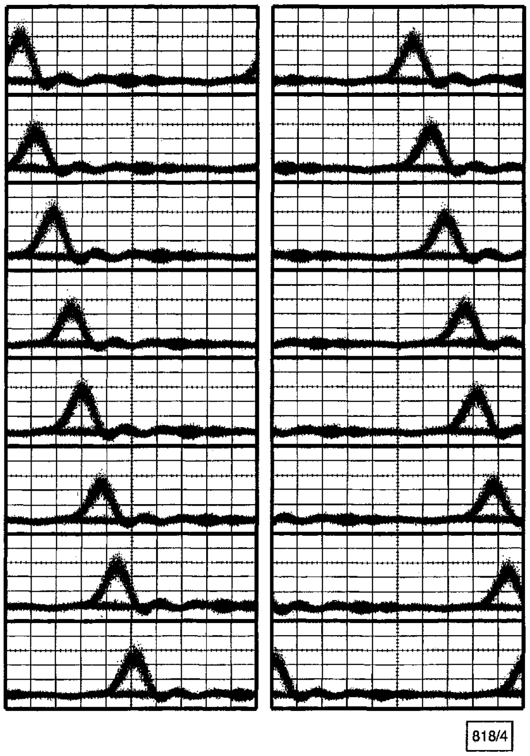

Fig. 4 *Eye diagrams for all 16 demultiplexed channels*
13.3ps/div

Summary: We have successfully demonstrated a four-channel 120Gbit/s OTDM system that reduces the number of optical channels by increasing the base rate to 30Gbit/s. This is achieved by employing electroabsorption modulators operating at 30GHz for pulse generation and optical demultiplexing. Further operation at a base rate of 40Gbit/s for an aggregate data rate of 160Gbit/s should be feasible with these devices.

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8 × 40Gbit/s transmission over 640km of large-effective-area nonzero-dispersion shifted fibre with an input power tolerance greater than 7dB

H. Murai, H.T. Yamada, A.R. Pratt and Y. Ozeki

40Gbit/s transmission is reported over 640km of large-effective-area nonzero dispersion shifted fibre for eight wavelength division multiplexed channels with a channel spacing of 100GHz and an input power tolerance greater than 7dB.

Introduction: Reducing nonlinear effects in high-speed, dense wavelength division multiplexing (DWDM) transmission systems has become increasingly more important as bit rates evolve to keep pace with bandwidth demand. Whereas the dispersion of the transmission fibre can be compensated for using standard dispersion compensating techniques [1], fibre nonlinearity increases proportionally with bit rate and represents the ultimate limit to system performance. Large-effective-area nonzero-dispersion shifted (NZDS) fibre has an increased light-carrying cross-section and can potentially support higher input powers, while at the same time suppressing four wave mixing (FWM), cross-phase modulation (XPM) and pulse distortion due to self-phase modulation (SPM) [2]. Reducing the fibre nonlinearity facilitates linear-like transmission at higher bit rates. This improves the transmission characteristics since the fibre dispersion can be almost completely compensated using the appropriate length of dispersion compensating fibre (DCF). In this Letter we demonstrate for the first time the feasibility of transmitting a 40Gbit/s return-to-zero (RZ) signal over eight 80km spans of large-effective-area nonzero-dispersion shifted fibre. Eight multiplexed wavelength channels, with a channel spacing of 100GHz, have been successfully transmitted, error free, over a total transmission distance of 640km with an input power tolerance greater than 7dB.

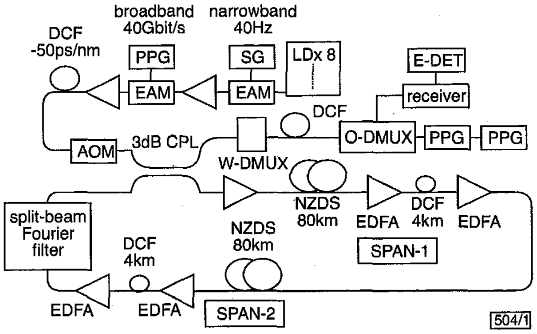

Fig. 1 *Recirculating loop experiment*

Experiment: Fig. 1 shows the experimental setup. Eight 100GHz-spaced wavelength channels, ranging from 1547.0nm to 1552.6nm, were combined and modulated using two high-speed InGaAsP-based multiple quantum well electroabsorption (EA) modulators [3, 4], to generate a 40Gbit/s optical pulse stream. Data encoding at 40 GBit/s, with a $2^{15} - 1$ pseudorandom binary sequence (PRBS) was performed using the second EA modulator. Four 10Gbit/s signals, each encoded with $2^{15} - 1$ PRBS, were electrically multiplexed to generate the $3.0V_{pp}$ 40Gbit/s modulation signal. The 40Gbit/s RZ signal was amplified and the wavelength channels decorrelated using 0.75km of DCF (–50ps/nm), which also introduced pre-chirp prior to transmission. The recirculating loop experiment consisted of two amplifier spans, comprising 80km of NZDS fibre with an effective area of $75\mu m^2$ and an average dispersion of 3.8ps/nm/km (at 1549nm). An additional amplifier was included in each span to prevent signal-to-noise ratio (SNR) degradation and to maintain a power level of ~–5dBm before launching into the dispersion compensating fibre (DCF). 4km of DCF, with a typical average dispersion of –80ps/nm/km, was inserted at the end of each span. The wavelength corresponding to zero average dispersion was set to 1549.1nm. After transmission, each wavelength channel was demultiplexed using a tunable optical bandpass filter with a 3dB bandwidth of ~60GHz (0.5nm). A length of DCF was also adjusted outside the loop to individually compensate the accumulated dispersion at each wavelength. The transmission of the individual channels was evaluated by optically demultiplexing the 40Gbit/s data stream to 10Gbit/s using two 20Gbit/s EA modulators. An electronic phase-locked loop (PLL) clock recovery setup was used to drive the EA modulators and act as a trigger for the bit error rate (BER) measurements.

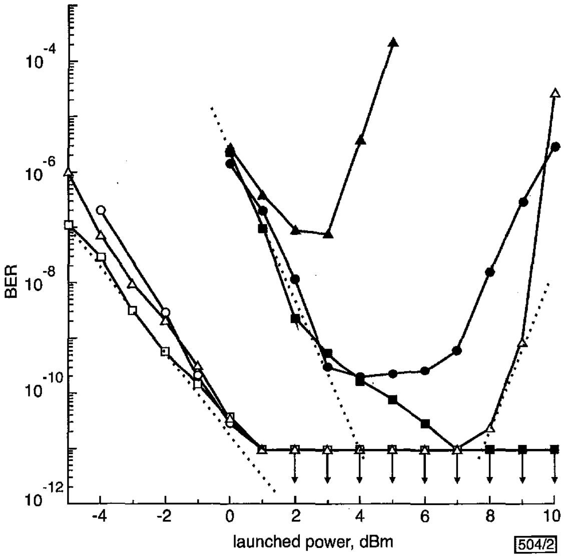

Fig. 2 *Single-channel, 40Gbit/s transmission*

Wavelength
□ 1549.4nm (640km)
△ 1552.6nm (640km)
○ 1547.0nm (640km)
■ 1549.5nm (1120km)
▲ 1552.6nm (1120km)
● 1547.0nm (1120km)

Results and discussions: Fig. 2 shows the BER characteristics for single-channel 40Gbit/s RZ transmission at three wavelengths of 1547.0nm, 1549.4nm and 1552.6nm. The results clearly demonstrate that error-free transmission (corresponding to a BER < 10^{-9}) was achieved after a total transmission distance of 1120km (equivalent to fourteen 80km spans of NZDS fibre) for all but the longest wavelength channel. Owing to the relatively large dispersion slope of the NZDS fibre (~$0.1 ps/nm^2/km$), the accumulated dispersion was largest at 1552.6nm, and the transmission at this wavelength was limited by nonlinear effects. The launch power per channel was also varied to determine the input power tolerance afforded by the large-effective-area fibre. Close to the zero-dispersion wavelength, the eye patterns showed clear openings over an input range of 10dBm, indicating that nonlinear effects did not limit the transmission. At a transmission distance of 640km, error-free transmission was achieved at all three wavelengths with a similar input power tolerance of 10dB. It is worth noting that the EA