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# Electroabsorption modulator laser for cost-effective 40 Gbit/s networks with low drive voltage, chirp and temperature dependence

G. Aubin, J. Seoane, K. Merghem, M.S. Berger, C.F. Jespersen, A. Garreau, F. Blache, C. Jany, J.-G. Provost, C. Kazmierski and P. Jeppesen

The performances of a novel low-chirp electroabsorption modulator laser module are presented. Transmission is analysed in standard singlemode fibre at 40 Gbit/s. Propagation without chromatic dispersion compensation up to 2 km exhibits a low penalty variation over a wide temperature range. A propagation scheme with compensation leads to negligible impairment at 88 km.

**Introduction:** Bandwidth projections of future computing network applications are expected to exhaust current 10G Ethernet interfaces. 40 Gbit/s Ethernet seems the upgrade of choice to meet this demand [1]. Electroabsorption modulator lasers (EMLs) have recently attracted much attention [2–6] as they combine the low-drive voltage characteristics of a directly modulated laser (DML) and the low-chirp features of lithium niobate modulators, which will minimise power consumption and footprint, while optimising cost.

In this Letter we report non-return-to-zero 40 Gbit/s feasibility of operation of a self-thermal compensated single active layer AlGaInAs EML as an actual promising device. We used a fully packaged version of the chip that has been described in [7]. We quantify the transmission quality robustness of that monolithically integrated source for the first time at that data rate. Results are presented for both compensated and uncompensated links. Low penalty variation is obtained over the range (20–60°C) in the latter ones. Negligible power penalties are measured up to 88 km in compensated systems.

**Short-reach uncompensated links experiment:** Commonly, computing networks are confined to corporate in-building or campus-like solutions, which require very short-reach transmission and best benefit from low-cost solutions. In addition to an EML's low drive voltage, use of legacy fibres, direct detection and uncooled operation are desirable. Here, we report uncompensated transmission results over SMF links using a novel EML, emphasising performance over a wide temperature range, therefore suggesting potential for the desired uncooled operation.

As far as long pattern effects mainly concern electronics behaviour, we performed measurements at 43 Gbit/s with a  $2^7 - 1$  PRBS. The signal was applied to the EML through a broadband bias T with a peak-to-peak amplitude of 2 V, which allowed control of the operation point within the transmission curve of the EML. The laser current was kept constant at 60 mA, optimising bandwidth-power and chirp trade-off, and the wavelength was 1545 nm. The link comprised 2 km of SMF.

Bit error ratio (BER) measurements against temperature are shown in Fig. 1. EAM bias,  $V_{DC}$ , was adjusted for each temperature following a simple linear law for optimum performance. As seen in Fig. 1, the back-to-back sensitivity of the EML remains weakly affected for 20 and 40°C operation, whereas 60°C performance achieves less than 1.5 dB sensitivity reduction. Transmission penalty is usually defined as the required power difference between back-to-back and after-fibre transmission in order to achieve a specific BER. For the lower temperatures, transmission penalty after 2 km of SMF for a BER of  $10^{-9}$  remains within 1.5 dB and it does not exceed 3 dB for high temperature operation. No error floor was observed under any of these operating conditions.

To minimise saturation effects in the EML, we operated with a lower laser current (30 mA) and used an optical preamplifier to compensate for the lower power. By measuring the sensitivity at the input of the preamplifier we even observed a transmission penalty of less than 2 dB at each temperature within the same range (20–60°C).

**Medium-reach compensated links experiment:** The implemented setup is depicted in Fig. 2. The EML's laser current is set to 50 mA at 25°C. The EAM bias ( $V_{DC}$ ) is  $-2.4$  V, and the peak-to-peak modulation amplitude of the PRBS electrical data is 2.25 V. The optical signal power into the transmission span can be controlled by means of a variable optical attenuator (VOA). BER measurements for the system are shown in Fig. 3. The reception chain is not the one used in the short reach configuration and the back-to-back sensitivity measurement for

the preamplified receiver is approximately  $-24.7$  dBm for a BER of  $10^{-9}$ .

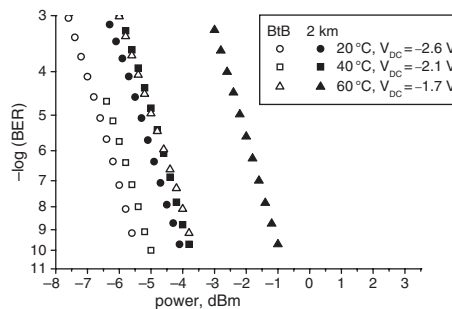


Fig. 1 BER dependence on temperature for uncompensated system

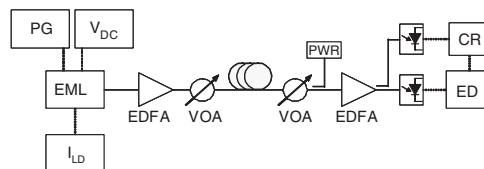


Fig. 2 Schematic for compensated transmission

PG: pattern generator; ED: error detector; VOA: variable optical attenuator; CR: clock recovery

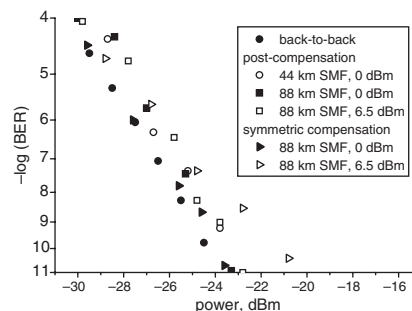


Fig. 3 BER against input power for compensated systems

Initially, 44 km of SMF together with its corresponding length of DCF was investigated. The dispersion compensation is very accurate, and the accumulated dispersion at the receiver is below 10 ps around 1550 nm. The injected average data power into the transmission span is 0 dBm. The measured sensitivity for a BER of  $10^{-9}$  in this configuration is  $-23.7$  dBm. Therefore, measured power penalty is roughly 1 dB.

Secondly, the transmission distance was extended to 88 km of SMF, using its corresponding DCF, in a so-called post-compensation scheme. The sensitivity value was found to be approximately the same as the previous one at  $-23.7$  dBm, therefore confirming that no more cumulative penalty appeared. In another dispersion map commonly known as symmetric compensation, the total length of DCF was sandwiched between two 44 km SMF spans. The performance remained similar with a sensitivity of approximately  $-24$  dBm, illustrating the quasi-linear dispersion compensation of the transmitted signal. Care had to be taken with regards to the optical power injected into the DCF as the latter configuration proved more sensitive to nonlinear effects, which can be seen in Fig. 3 when the power level reached 6.5 dBm into the first SMF.

**Conclusion:** EML transmitters have commonly suffered from a reduced electrical bandwidth and extinction ratio, and larger chirp and temperature drifts, compared to traditional lithium niobate modulators. Here it is proved that state-of-the-art EML designs can reduce EAM saturation effects detrimental to the bandwidth-power trade-off, while simultaneously offering low temperature dependence, reduced chirp and enlarged extinction ratios. It has been shown that such EML modules are suitable devices for 40 Gbit/s uncompensated ultra-short reach transmission systems by suffering only roughly 3 dB penalty at 2 km over the (20–60°C) operating range. In medium reach (80 km) systems, negligible penalty transmission was achieved aided by dispersion compensating modules and optical amplifiers. Temperature

robustness, low chirp and low consumption make the device promising for low cost targets as expected in short and medium reach systems.

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