40 Gbit/s optical receiver module with high conversion gain and sensitivity

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An optical receiver for 40 Gbit/s communication systems with 8274 V/W conversion gain and 950 mV_{p-p} limiting differential output is reported. A back-to-back sensitivity of −9.4 dBm at a bit error rate of 10^{-12} was observed for a $2^{31}-1$ pseudorandom binary sequence. The receiver incorporates an InP based *pin* diode, a transimpedance amplifier and a limiting amplifier. This is the largest conversion gain with high sensitivity reported for 40 Gbit/s receivers without optical amplification.

Introduction: Large-scale commercial deployment of 40 Gbit/s systems will be economically feasible if low-cost integrated solutions are available, and will enable transponder manufacturers to meet cost, performance, power and size constraints. Optical receivers used at the transponder front-ends greatly influence the cost and performance of the entire link. High conversion gain with limiting output from the receiver can eliminate the need for additional gain elements or amplitude gain control (AGC) blocks. High receiver sensitivity allows for larger repeater spacing in the system, and relaxes the performance requirements on optical amplifiers within the link. High conversion gain and sensitivity can be obtained in receivers by using optical amplification before the signal undergoes an optical to electrical (O–E) conversion [1–3]. However it adds to system size, cost and complexity. We have earlier reported a high sensitivity wide dynamic range 40 Gbit/s receiver composed of an InP based *pin* photodiode (PD) and an InP HBT transimpedance amplifier (TIA), that achieved 550 V/W conversion gain without using optical amplification [4]. In this Letter, we report a receiver module that also incorporates an InP HBT limiting amplifier (LA) to achieve >8274 V/W conversion gain and 950 mV_{p-p} limiting differential output. The receiver also obtained −9.4 dBm back-to-back sensitivity at a bit error rate (BER) of 10^{-12} with a wide dynamic range of 12.6 dB, for a non-return-to-zero (NRZ) $2^{31}-1$ pseudorandom binary sequence (PRBS).

Device technology: InAlAs/InGaAs/InP DHBT technology with a carbon-doped base for improved reliability at high current density is used for the TIA and LA. The smallest devices with $1 \times 3\ \mu m^2$ emitter area exhibit a typical current gain of 40 with 8 V breakdown (V_{br}), 140 GHz f_t and 160 GHz f_{max}. Commercial 4 inch GaAs HBT wafer processing techniques were used for the two layers of interconnect metal with polyimide dielectric, 0.36 $fF/\mu m^2$ Si_3N_4 metal-insulator-metal (MIM) capacitors, 50 Ω/sq resistivity NiCr resistors and co-planar waveguide (CPW) wiring environment.

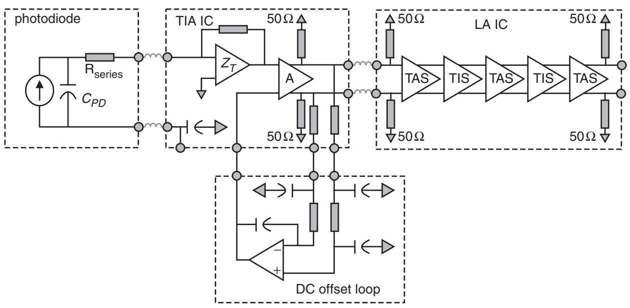

Fig. 1 *Schematic block diagram of 40 Gbit/s receiver module showing photodiode, transimpedance amplifier, limiting amplifier and DC offset loop*

Circuit design: The receiver (Fig. 1) incorporates an InP HBT LA in addition to the PD and TIA reported earlier [4]. To obtain high linear gain over wide bandwidth the LA uses alternating differential trans-admittance (TAS) and transimpedance (TIS) stages (Fig. 1). Low inter-stage impedance provided by this architecture [5] greatly extends the bandwidth. The five-stage LA has current-mode-logic (CML) interfaces with 50 Ω terminations, input threshold control and output offset adjust features. Harmonic balance simulations showed that about 3 dB of gain peaking at 40 GHz obtained a flat response under limiting operation, and was incorporated in the design.

Results: The LA was installed along with the PD and TIA in the receiver module. The photodiode has a responsivity of 0.76 A/W at 1550 nm wavelength. The TIA IC has a differential transimpedance of 750 Ω with 37 GHz bandwidth and ±10 ps group delay variation. The LA IC has 24 dB differential gain with 46 GHz bandwidth and 16 mV input sensitivity. A DC offset restoration loop is also included within the receiver [4], which supplies a reference signal that is dependent on the magnitude of the input photo-signal, to balance the differential output of the TIA. The receiver operates from +5, +3.3 and −5 V supplies, consuming 1.1 W.

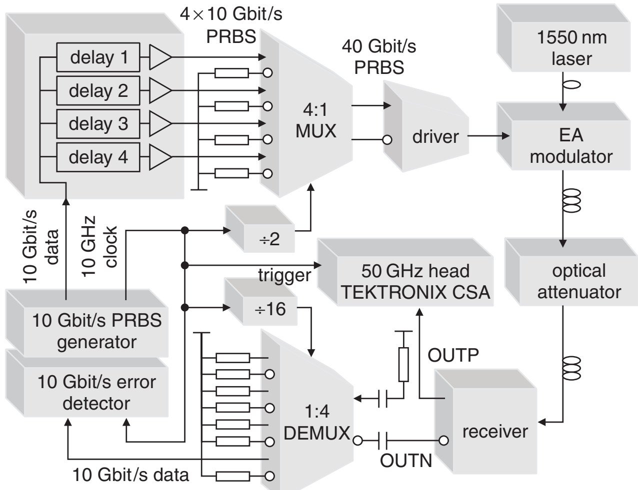

Fig. 2 *Test setup used to measure 40 Gbit/s eye pattern and BER*

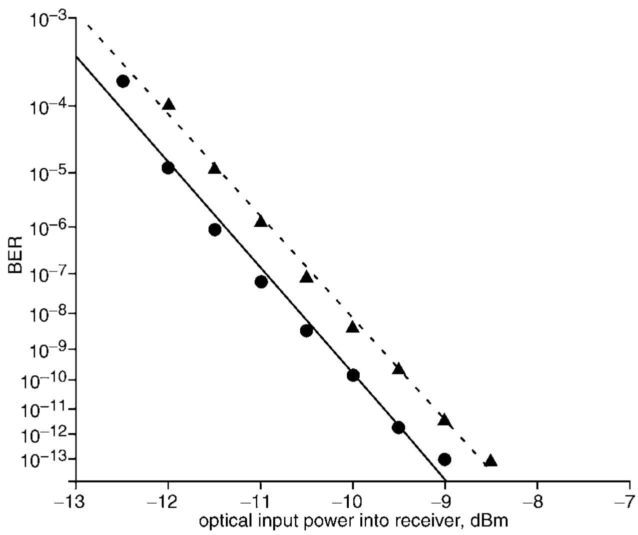

Fig. 3 *BER measurement result of link, showing sensitivity of −9.4 dBm, and dispersion penalty of 0.6 dB for 40 Gbit/s NRZ, $2^{31}-1$ PRBS data*

—●— input after 0 km of fibre
---▲--- input after 2.26 km of fibre

The receiver was tested using a 40 Gbit/s NRZ PRBS data. Four channels of uncorrelated 10 Gbit/s PRBS data were multiplexed using a 4:1 multiplexer (MUX) (Fig. 2). A modulator driver drives an electro-absorption modulator (EAM) that modulates a 1550 nm CW laser. Attenuated optical output from the EAM feeds the receiver. One output of the receiver is demultiplexed into four channels of 10 Gbit/s data and sent to the error detector. A plot of BER against the input optical power into the receiver after 0 and 2.26 km of singlemode fibre (SMF) is shown in Fig. 3. A sensitivity of −9.4 dBm at a BER of 10^{-12} and an overload margin of 3.2 dBm was obtained, corresponding to a dynamic range of 12.6 dBm. A dispersion penalty of 0.6 dB was observed after transmission over 2.26 km of SMF. The other output of the receiver is monitored using a 50 GHz sampling oscilloscope. Measured single-ended output (Fig. 4) shows 475 mV_{p-p} swing, 20–80% rise/fall times of 7 ps, root-mean-square (rms) jitter of 1.8 ps/1.64 ps for a −9.4 dBm/0 dBm optical input, respectively. This limiting 0.95 V differential swing for a −9.4 dBm input power indicates a better than 8274 V/W differential conversion gain. Also, the measured rms jitter for the optical input was 1.8 ps, indicating that a precision time-base oscilloscope is required for accurate jitter measurements.

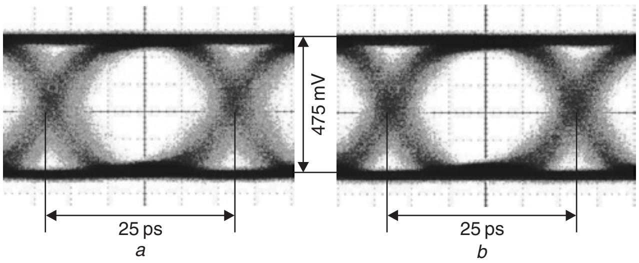

Fig. 4 *Non-return-to-zero eye diagram at output of receiver*

a Input optical power −9.4 dBm
b Input optical power 0 dBm

Conclusions: We have demonstrated a receiver module that includes a PD, TIA and LA integrated in a single package. It achieves a differential conversion gain of 8274 V/W, a limiting 950 mV_{p-p} differential output, a back-to-back sensitivity of −9.4 dBm at a BER of 10^{-12}, as well as a wide dynamic range of 12.6 dBm, when measured using a 40 Gbit/s, $2^{31}-1$, NRZ PRBS data. To the best of our knowledge, this represents the highest conversion gain with such high sensitivity [6, 7] for a 40 Gbit/s receiver without optical amplification.

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