Generation of 40 Gbps Duobinary Signals Using an Integrated Laser—Mach-Zehnder Modulator

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Abstract: Generation of 40 Gbps duobinary signals is demonstrated using the intrinsic EO response of an Mach-Zehnder modulator integrated with a widely tunable laser over a wavelength range of 1537nm – 1569nm.

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1. Introduction

To meet growing transmission demand, 40 Gbps optical channel rate is proving increasingly attractive. This requires the development of low-cost optical transmitters. For short-distance interconnects, directly modulated VCSELs is emerging as an attractive potential source [1]. More complex modulation formats with high tolerance to fiber non-linearities such as RZ-DQPSK [2] is attractive for long-haul transmission. For intermediate reach, where linear chromatic fiber dispersion is the dominant impairment, optical duobinary (ODB) is attractive for increased reach, compact channel width and direct detection.

ODB using $LiNbO_3$ modulators have been demonstrated up to 107 Gbps [3]. Semiconductor modulators are a more attractive option because of its potentially lower drive voltage, integration with lasers and compatibility with compact, low-cost packaging. 40 Gbps semiconductor Mach-Zehnder (MZ) modulators have been demonstrated both discrete [4] and integrated to a laser [5].

In this work we demonstrate an integrated 40Gbps duobinary transmitter consisting of a MZ modulator integrated with a widely tunable Sampled-Grating DBR laser. Unlike previous results where 10Gbps duobinary modulation was generated and transmitted using this type of device [6], this demonstration does not require a low-pass filter for the drive signal. Instead, the electro-optic (EO) response of the MZ modulator is designed such that a good return loss over a broad frequency band, and a sharp EO roll-off of ~50dB/decade, is used to form the duobinary optical signal when driven directly by binary drive signal.

2. Device and Experiment

The device used in this work consists of a sampled-grating DBR laser integrated to an SOA and a dual-drive MZ modulator. All sections of the device are integrated onto one single Indium-Phosphide chip. The sampled-grating DBR laser can be tuned throughout the C-band and the integrated SOA provides power leveling over this wavelength range and compensates for cavity and modulator losses. The MZ modulator consist of two optical waveguide segments with RF electrodes situated in-between two multimode interference (MMI) couplers. More details of this type of device can be found in [7].

In order to generate the 3 level electrical drive signals for the MZ modulator through Inter-Symbol-Interference (ISI), a low-pass electrical filter is normally used. This low-pass filter has a 3dB bandwidth of approximately 0.25xBitRate and with a 40-50dB/decade filter roll-off after the 3dB cut-off. Typically this is accomplished by a Bessel Thompson filter employing absorptive filter design, giving good S11 performance and simultaneously achieving a steep filter roll-off at ~40-50dB/decade. For our 40Gbps optical duobinary transmitter, we design the MZ modulator such that its EO response has a 3dB bandwidth of 10GHz, has a 40-50dB/decade roll-off after the 3dB cut-off, and is broadband impedance matched such that reflection of the 40Gbps input drive is minimized. This design approach eliminates the need for additional sharp electrical low-pass filter as generation of the ISI drive is performed by the modulator itself.

To achieve the design objectives mentioned above, both the EO response and return loss performance of our modulator need to be improved. Broadband impedance matching is necessary because of the relatively low modulator impedance of ~26-29Ω resulting from our fabrication process. In addition, RC time-constant limited EO response usually gives a 20dB/decade roll-off after the 3dB cut-off, hence sharper roll-off in the response will be needed in order to be used in a 40Gbps duobinary application. We achieved these objectives by using a distributed electrode design such that on-chip matching elements are introduced in the modulator electrodes. This increases the input impedance of the modulator to ~37Ω, and at the same time, slows the electrical phase velocity such that a huge velocity mismatch now exists between the electrical signal and the optical wave. Velocities mismatch in electrical and optical domain then results in the required bandwidth, and increases the roll-off of the response after the 3dB cut-off.

To determine the suitability of the modulator for 40Gbps duobinary applications, frequency domain characterization is performed whereby the chip-on-carrier return loss S11 and electro-optic (EO) response are measured using a network analyzer. Fig.1 shows the experimental setup for time domain characterization of the Integrated-Laser-Mach-Zehnder (ILMZ) chip-on-carrier. The output of the pseudo-random pattern generator is used to drive a matched pair of 40Gbps drivers. Two phase tuners are used to equalize the delays of the RF signal paths from pattern generator to the probes tips. No low-pass filters are used for our experiments as the required duobinary signal is generated by the EO response of the MZ modulator itself. Without a 40Gbps differential encoder at our disposal, time-domain characterizations include eye diagram measurements at 0km (BTB), 10km and 12.5km of single-mode fiber across the 1537-1569nm tuning range.

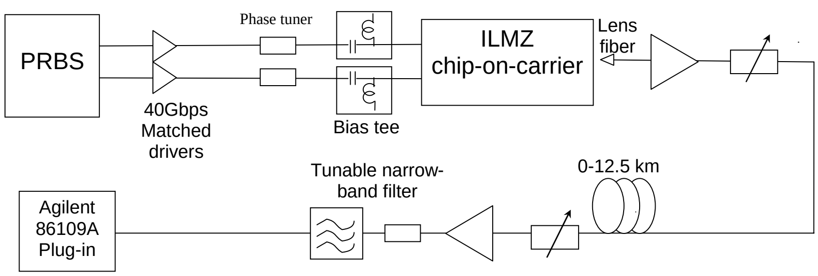

Fig. 1. Schematic of experimental arrangement used to generate 40 Gbps duobinary modulation using the integrated SGDBR laser – Mach-Zehnder modulator. Intrinsic MZ modulator EO response is used to generate the 40Gbps duobinary modulations.

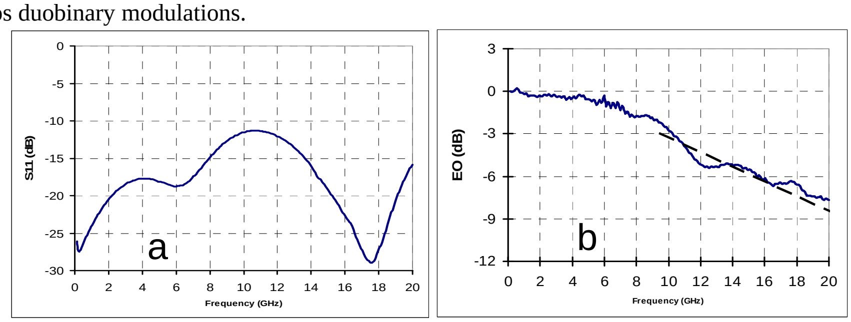

Fig. 2a: Return loss S11 of chip-on-carrier with a 750µm long modulator. Fig. 2b: Electro-optical response of chip-on-carrier with a 750µm long modulator.

3. Results

In Fig. 2a, the return loss S11 of the chip-on-carrier with a 750µm long modulator biased at -1.5V is plotted. The S11 plot shows that the return loss is below -15dB for most of the 20GHz band measured, indicating an excellent impedance matching. Broadband impedance matching beyond the 0.25xBitRate band is desirable in our case as the input signal is a 40Gbps Non-Return-to-Zero signal. The small-signal EO response is measured with the MZ modulator bias at -1.5V and is shown in Fig. 2. The 750µm long MZ modulator gives a 3dB bandwidth 10.4GHz. A ~50dB/decade roll-off of the modulator is obtained by fitting a line at the EO response as shown in Fig. 2. The high roll-off of the EO response is due to velocities mismatch of the electrical and optical signals as indicated previously. With good return loss, a bandwidth of 0.25xBitRate and a sharp roll-off, the MZ modulator is suitable for 40Gbps duobinary transmitter application without additional electrical low-pass filter.

Fig. 3 plots the optical eye diagrams for transmit wavelengths of 1537nm, 1542nm, 1555nm and 1569nm, after transmission of 0km, 10km and 12.5km of fiber, using a PRBS word length of $2^{\wedge 31}$-1. RF drive voltages of the modulator are 3.5Vpp, 3.95Vpp, 4.3Vpp and 4.3Vpp for wavelength channels of 1537nm, 1542nm, 1555nm and 1569nm respectively. The back-to-back eye diagrams show that the MZ modulator, with its sharp EO response roll-off, functions as a 40Gbps duobinary transmitter according to expectations. The device used in this experiment has input MMI that is input power dependent such that at short wavelength, the optical splitting ratio is severely unbalanced. Unequal splitting ratio results in residual chirp at short wavelength channels such that an “open” optical eye is not possible after fiber transmission. Nonetheless, for wavelength channels that do no suffer from this artifact, “open” optical eye diagrams are obtained after transmission of 10-12.5km of fiber.

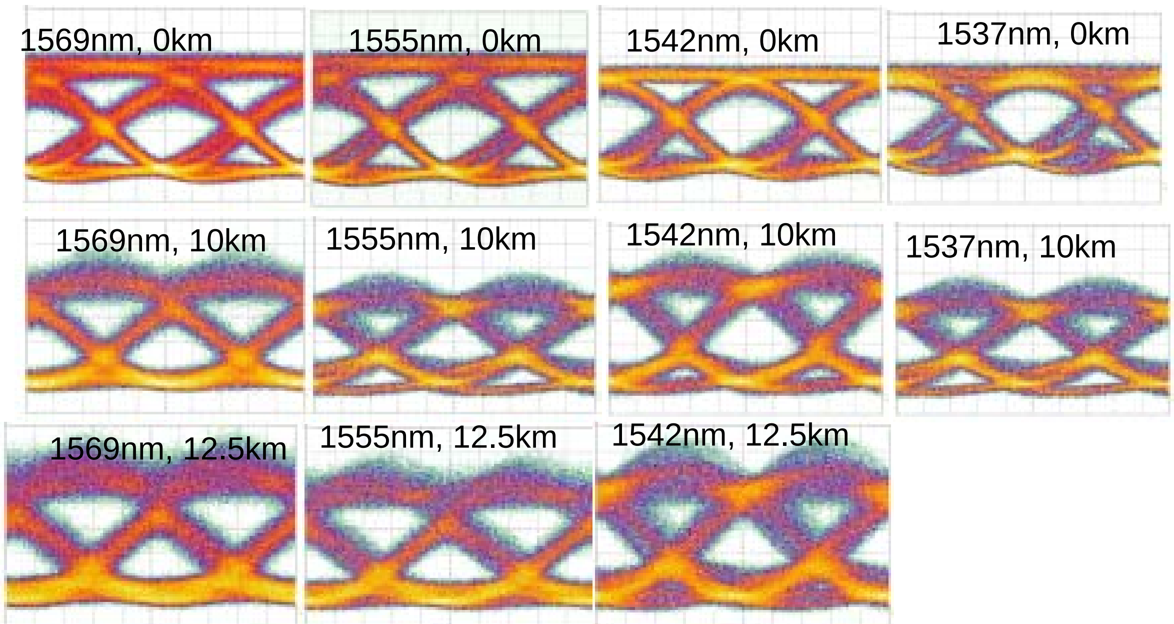

Fig. 3: Received optical eye diagrams at 1569nm, 1555nm, 1542nm, 1537nm after transmission through 0km, 10km and 12.5km fiber, respectively.

4. Conclusion

We demonstrate, for the first time, a 40Gbps duobinary transmitter using an integrated widely-tunable SGDBR laser and a Mach-Zehnder modulator. 40Gbps ODB eye diagrams are obtained for wavelength channels from 1537nm to 1569nm, using the intrinsic EO response of the modulator. This eliminates the need for an additional electrical low-pass filter. The modulator uses on-chip matching in the modulator electrodes to achieve good return loss over a 20GHz frequency band and a sharp 50dB/decade EO response roll-off. “Open” eye diagrams are obtained indicating a good potential for high transmission performance.

5. References

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