5 Gb/s Laser-Driver GaAs IC

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Abstract

This paper presents the design of a 5 Gb/s laser-driver GaAs IC employing a novel high-speed, low-power, 50 Ω impedance matched output driver. Eye-diagrams with good eye openings, clean wave forms with insignificant ringing and output reflection coefficients of less than -8 dB for frequencies up to 10 GHz are demonstrated over the full 10-40 mA output current tuning range. An optical-fibre transmission experiment using an electro-optic modulator driven by the presented laser-driver has been conducted showing an optical extinction ratio of 11.4 dB.

Introduction

For the last decade ever faster laser-drivers have been reported meeting the ever increasing speed requirements of high-speed optical-fibre communication systems. From an electrical point of view the solitary laser diode is a current controlled low impedance device. Thus open-drain and open-collector type laser-drivers are widely applied [1][2] due to their high output impedance and high speed potential when used in conjunction with current mode logic (ECL, SCFL). Upgrading systems to multi gigabit per second bit rates will however require some kind of impedance matching between driver and laser diode to minimise reflections. Commercial laser diodes applicable at multi gigabit per second data rates are often attempted matched to 50 Ω. However, transitions from chip to package and package to board may still corrupt the pulse fidelity using high output impedance laser-drivers. In this paper a 5 Gb/s 50 Ω matched laser-driver IC with a 10-40 mA adjustable output current amplitude is presented.

Circuit design

A. Output driver

The laser-driver design presented in this paper includes four cascaded differential amplifiers and an output driver. Output matching accomplished by adding a resistor (>50 Ω) on-chip at the output of a simple differential amplifier type output driver is previously reported in literature [3][4]. This approach will, however, almost double the power dissipation and size of the output driver compared to the unmatched driver. Instead we propose the use of a differential super-buffer type output driver [5] as shown in Fig.1, which to the best of the authors knowledge has not previously been published as applied as a laser-driver.

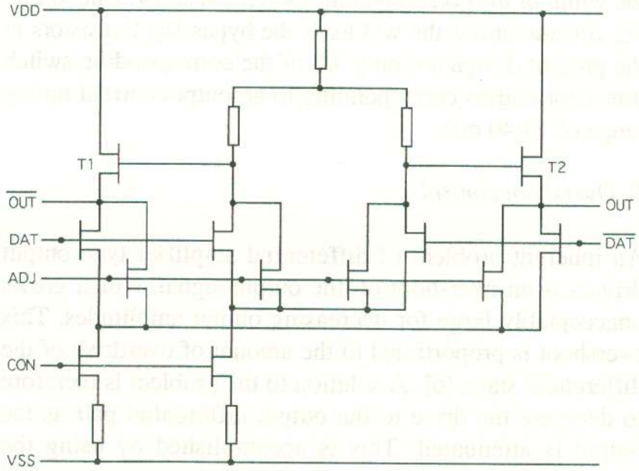

Fig.1. Circuit diagram of differential super buffer output driver.

The super-buffer and differential operation are circuit techniques well known to individually enhance high-speed operation, and the combination hereof certainly yields a high-speed output driver. The power dissipation of the output driver itself in the present design is reduced by more than 40% compared to that of the above mentioned simple differential amplifier type output driver assuming ac-coupled operation. Including the power dissipation of the source followers preceding the output driver the power dissipation advantage of the super-buffer output driver would be even more pronounced.

The output impedance of the differential super-buffer output driver shown in Fig.1 is to a first order approximation given as the inverse of the transconductances g_m of T_1 and T_2. Thus for a constant drain-to-source current and gate-to-source voltage of T_1 and T_2 the output impedance is constant except for a small g_m dependence on V_{ds}. Proper biasing is achieved by making the voltage swing at the gates of T_1 and T_2 equal to the output voltage swing and by keeping T_1 and T_2 in saturation over the full range of output voltages using an on-chip low power control circuit not described in this paper. The present laser-driver is designed for ac-coupled operation. Thus ideally a constant current of 20 mA will flow through both T_1 and T_2.

In the simple differential output driver mentioned above the modulation current amplitude can easily be adjusted by simply controlling the current through the current source. This will not significantly change the output impedance.

The output impedance of the differential super-buffer type output driver does indeed depend on the drain-to-source current through T_1 and T_2 as discussed previously. Thus the output amplitude is instead adjusted by by-passing the current through the switch transistors using the control signal ADJ as shown in Fig.1. In that manner the bias current through T_1 and T_2 and thus the output impedance remain constant almost independently of output amplitude. If the output voltage swing was to be adjusted to zero, the width of each by-passing transistor should be equal to half the width of the corresponding switch transistor. Due to layout considerations the widths of the bypassing transistors in the present design are only 3/8 of the corresponding switch transistor widths corresponding to an output current tuning range of 10-40 mA.

B. Overshoot control

An inherent problem of differential amplifier type output drivers is an overshoot on the output signal, which grows unacceptably large for decreasing output amplitudes. This overshoot is proportional to the amount of overdrive of the differential stage [6]. A solution to the problem is therefore to decrease the drive to the output differential pair as the output is attenuated. This is accomplished by using the modified inverter shown in Fig.2. If using a conventional inverter the topmost transistor of the source follower is pushed out of saturation for decreasing drive to the output driver thereby reducing the drive capability of the source follower. This problem is overcome by instead adjusting the output driver drive amplitude by the modified inverter ODC control signal thus maintaining a constant drain-to-gate voltage of the topmost transistor of the source followers independently of the drive applied to the output driver.

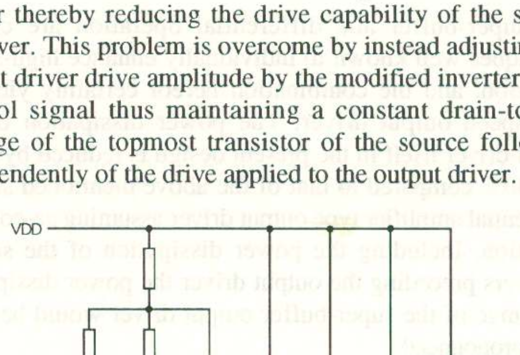

Fig.2. Circuit diagram of modified inverter used for controlling the overdrive of the output driver input.

C. Process

The presented laser driver is processed in TriQuints 0.5 µm gate length (F_t=20 GHz) GaAs MESFET HA process. In this process only depletion MESFETs are available. The threshold voltage is V_t=-1.7 V, and the knee voltage is approximately 1.7 V, which dictate a high internal logic swing in excess of 2 V and the use of a large power supply voltage span, V_{DD}=-V_{SS}=5 V. The rf transconductance is g_{mac}=160 S/m and I_{dss}=157 A/m. For a width of 125 µm of T_1 and T_2 in the above described super-buffer output driver this corresponds to an output impedance of 50 Ω at I_{ds}=20 mA at V_{gs}=0 V. Based on SPICE simulations T_1 and T_2 are made 120 µm wide. A micro photograph of the presented laser-driver IC is shown in Fig.3.

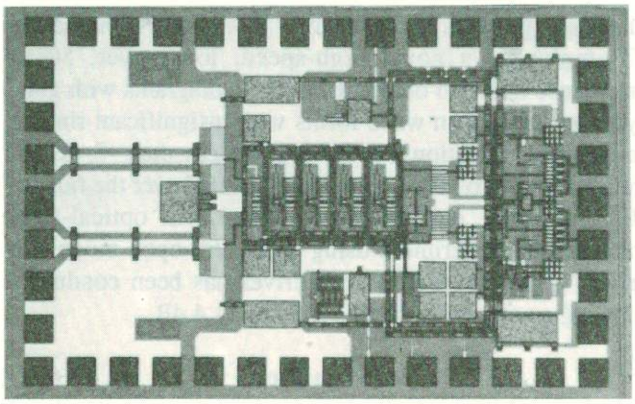

Fig.3. Micro photograph of the presented laser driver GaAs IC.

Measured performance

A. On-wafer measurements

The laser-driver chips were initially tested using wafer probing. By applying a differential PRBS data signal with 1 V amplitude to the data inputs and monitoring the output on a sampling oscilloscope clean wave-forms with only insignificant overshoot and eye-diagrams with good eye openings are observed at bit rates exceeding 5 Gb/s over a 10-40 mA range of modulation current amplitudes, Fig.4-6. In fact fully open eyes are obtained even at 6 Gb/s. The output reflection coefficients corresponding to the highest, lowest and the cross-over level have been measured to be less than -6 dB at frequencies up to 10 GHz, see Fig.7.

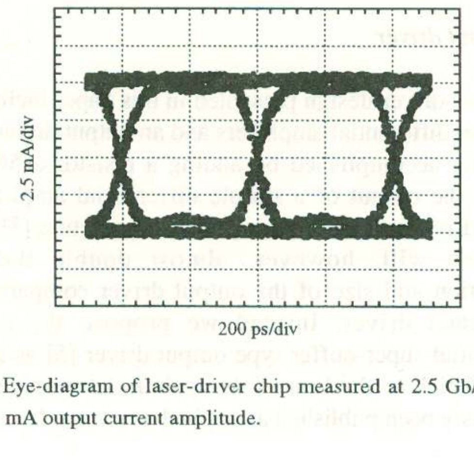

Fig.4. Eye-diagram of laser-driver chip measured at 2.5 Gb/s and 10 mA output current amplitude.

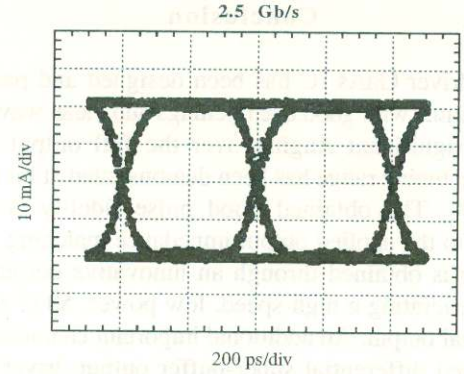

Fig.5. Eye-diagram of laser-driver chip measured at 2.5 Gb/s and 40 mA output current amplitude.

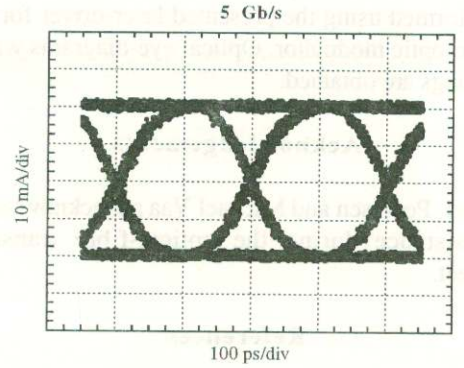

Fig.6. Eye-diagram of laser-driver chip measured at 5 Gb/s and 40 mA output current amplitude.

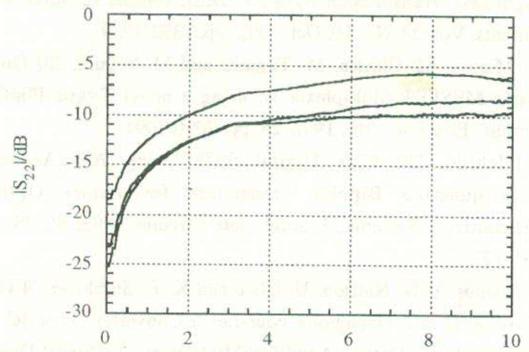

Fig.7. Output reflection coefficient measured on-chip at maximum, minimum and cross-over output voltage.

B. Measurements on packaged devices

A few samples of the laser-driver are mounted in standard TriQuint MLC20/8L ceramic packages and tested in a TriQuint EFT-9000 test fixture. In addition to the chip 1 nF dicaps are mounted inside the package for decoupling of power supplies and dc control signals. The applied package provides 8 pins, which is unfortunately one to few.

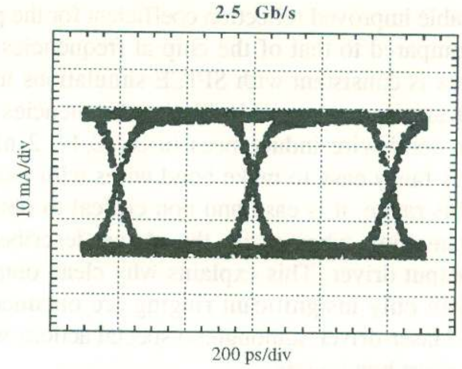

Fig.8. Eye-diagram of packaged laser-driver measured at 2.5 Gb/s and 36 mA output current amplitude.

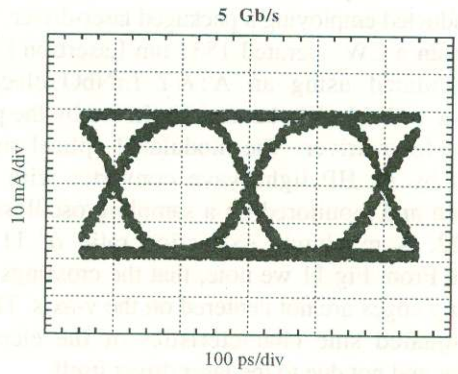

Fig.9. Eye-diagram of packaged laser-driver measured at 5 Gb/s and 36 mA output current amplitude.

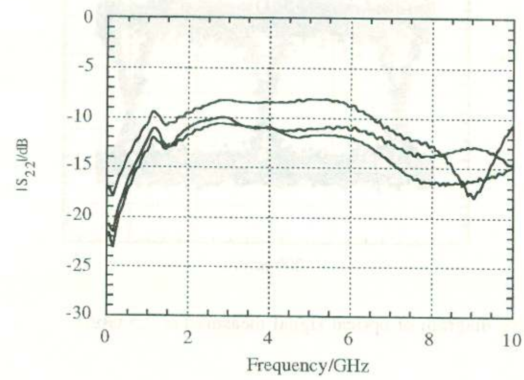

Fig.10. Output reflection coefficient of packaged laser-driver measured at maximum, minimum and cross-over output voltage.

Therefore the maximum obtainable modulation current is limited to 36 mA for the measurements shown above for the packaged devices. From Fig.8-9 we note the absence of ringing on the output signal, which is otherwise often seen after packaging due to bond wire inductances and package imperfections. The measured output reflection coefficients of the packaged laser-driver are shown in Fig.10. We note a considerable improved reflection coefficient for the packaged driver compared to that of the chip at frequencies above 5 GHz. This is consistent with SPICE simulations indicating a significant improvement in $|S_{22}|$ at frequencies above 5 GHz for bond wire inductances in the 0.4-1.2 nH range. Since it is fairly easy to make bond wires with inductances within this range, it is easy and non critical to obtain good output matching when using the above described super-buffer output driver. This explains why clean output wave forms with only insignificant ringing are obtained for the packaged laser-driver, although no special actions was taken to make short bond wires.

C. Optical measurements

A back-to-back optical-fibre transmission experiment has been conducted employing a packaged laser-driver. The light output from a CW operated 1531 nm Lasertron DFB laser was modulated using an AT&T LiNbO electro-optic modulator with 15 GHz bandwidth driven by the presented packaged laser-driver. The modulated optical signal was received by an HP light-wave converter with 11 GHz bandwidth and monitored on a sampling oscilloscope, see Fig.11-12. A maximum extinction ratio of 11.4 dB is obtained. From Fig.11 we note, that the crossings of rising and falling edges are not centered on the y-axis. This is due to the squared sine characteristics of the electro-optic modulator and not due to the laser driver itself.

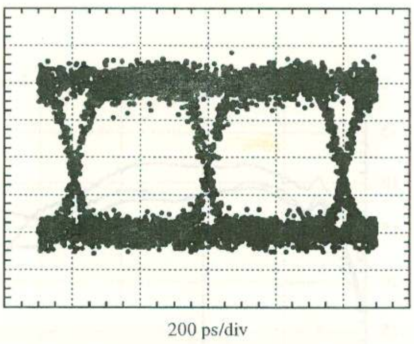

Fig.11. Eye-diagram of optical signal measured at 2.5 Gb/s.

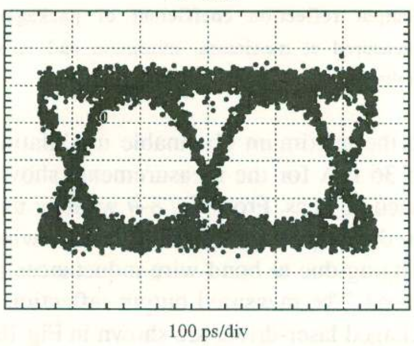

Fig.12. Eye-diagram of optical signal measured at 5 Gb/s.

Conclusion

A laser-driver GaAs IC has been designed and packaged. Eye-diagrams with good eye openings and clean wave forms without significant ringing over the full output current amplitude tuning range has been demonstrated at bit rates up to 5 Gb/s. The obtained good pulse fidelity is mainly ascribed to the applied output impedance matching. Output matching is obtained through an innovative output driver design generating a high-speed, low power, 50 Ω matched differential output. An additional important characteristic of the applied differential super-buffer output driver is, that bond wire inductances in the 0.4-1.2 nH range will improve the output matching thereby making it relatively easy to obtain good output matching and clean wave forms for packaged devices. An optical transmission experiment has been performed using the presented laser-driver for driving an electro-optic modulator. Optical eye-diagrams with good eye openings are obtained.

Acknowledgements

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References

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