40 Gb/s Differential Traveling Wave Modulator Driver

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***Abstract*—In this letter a MMIC differential traveling wave driver for 40 Gb/s electro-absorption modulation driver is presented. The driver delivers 2.7 Vp-p or 2.4 V eye amplitude at each output into 50 Ω load. The driver has high gain (> 20 dB), a 3 dB bandwidth of 45 GHz, and rise/fall times of only 10/9 ps, respectively. The circuit uses a single -5.0 V power supply and consumes 1.8 W of dc power. The driver also features cross-point control and output amplitude control functions.**

***Index Terms*—Amplifiers, fiber optics, MMICs, modulator driver.**

I. Introduction

THE driver for the electro-absorption modulator (EAM) remains one of the most challenging physical layer ICs in 40 Gb/s systems. The driver requirements are demanding: speed of 40 Gb/s, high single-ended output swing, short rise /fall times and low power to name the few. A differential configuration is preferred, since it can support functions such as cross-point and duty cycle control. To achieve desired speed and fast rise and fall times, wide bandwidth is needed. Traditional traveling wave amplifiers (TWA) have demonstrated ultra wide bandwidths [1]–[3], but they suffer from low gain and need bias-tees and /or dc blocks, increasing size and cost. Therefore, combining differential configuration with distributed amplifier has potential to fulfill all the driver requirements.

The choice of technology is also important. GaAs PHEMT has a main advantage of high breakdown and therefore can deliver very high output voltage [1], [2], [4]. This makes it a perfect solution for $LiNbO_3$ modulators, which require > 5 V output swing. However, for EAM modulators this solution tends to consume too much dc power [4]. Low dc power is important to prevent excessive heating of the EAM modulator and therefore degrading performance. SiGe HBT has shown good results for 40 Gb/s ICs, but the driver still remains a challenging part primarily due to low breakdown of SiGe HBTs [5]. Therefore, InP-based HBTs or DHBTs seem to be the most promising technology for 40 Gb/s EAM modulator drivers due to their exceptional maximum oscillation frequency (fmax), current gain cut-off frequency f_T, and low power consumption [6].

In this letter, a fully differential traveling wave modulator driver using InP HBTs with fmax and f_T over 150 GHz [7], is presented. It delivers output eye amplitude (mean-to-mean) of 2.4 V across 50 Ω loads at each output. The rise/fall times are 10/9 ps respectively. It consumes 1.8 W dc power at maximum swing using a single -5.0 V power supply.

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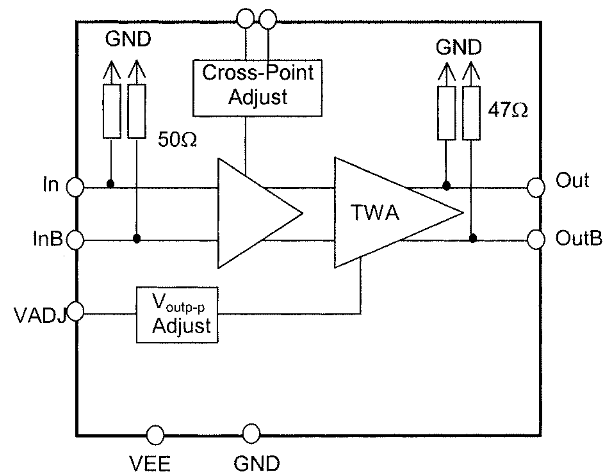

Fig. 1. Block diagram of the modulator driver.

II. Circuit Design

The modulator driver consists of a lumped-element differential predriver followed by a differential traveling wave amplifier [4], as shown in Fig. 1. The predriver is required because the differential TWA does not provide enough gain by itself. The circuit is dc coupled and no bias-tee or dc block is needed. The predriver consists of two emitter followers and one diode for level shifting and bandwidth improvement, and a cascode differential pair. The predriver input has on-chip 50 Ω resistors for input matching. The cross-point control feature is implemented in the predriver.

The traveling wave amplifier is realized using coupled microstrip lines. The inside cell has two emitter followers, each with one level shifting diode and a cascode pair. The TWA has four stages and the on-chip output matching resistor is 47 Ω.

The circuit was designed using Agilent's Advanced Design System (ADS). Frequency domain, small signal analysis was performed to determine the circuit S-parameters. This was followed by a time domain transient analysis to simulate the eye diagram and obtain important parameters such as output swing, rise and fall times and jitter. Both simulations are necessary to understand circuit behavior and improve design performance.

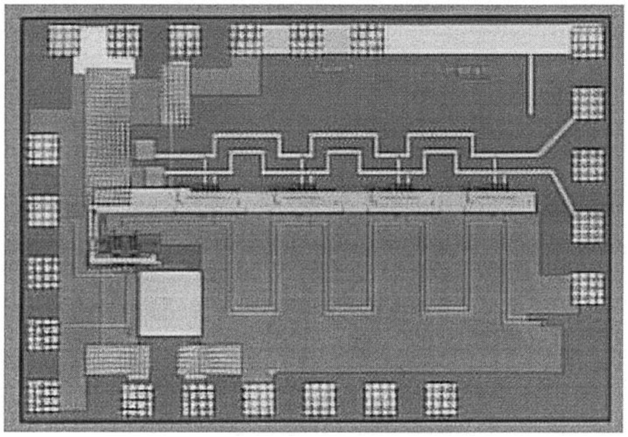

Fig. 2. Photograph of the differential modulator driver. The die size is 2.02 × 1.39 mm^2.

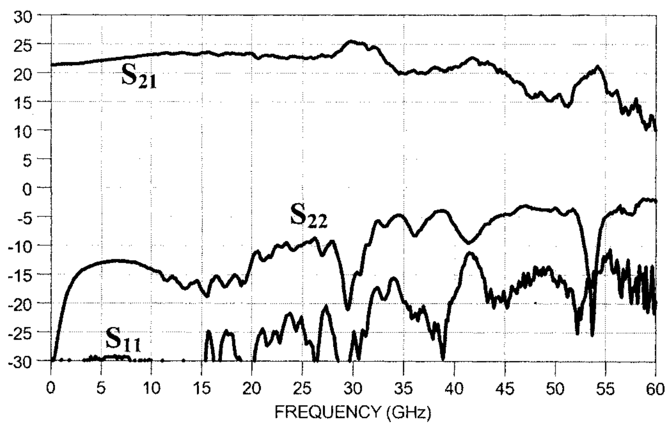

Fig. 3. Measured S-parameters of the modulator driver.

III. Fabrication

The modulator driver IC was fabricated by Global Communication Semiconductors, Inc. on a 4-inch wafer. This process offers three standard device sizes with beta > 30, and breakdown voltage > 3.5 V [7].

A photograph of the fabricated EAM driver is shown in Fig. 2. The die size is 2.02 × 1.39 mm^2.

IV. Measured Results

Small and large signal measurements were performed on a full thickness wafer (25 mils). First, the S-Parameters were measured from 45 MHz to 60 GHz using the Anritsu 37 397C vector network analyzer and differential probe station. The nondriven input and output were terminated with 50 Ω. Fig. 3 shows the measured single-ended small signal S-parameters. As seen in Fig. 3 this configuration gives superior gain of 21.4 dB compared to traditional TWAs [1], [2]. The 3 dB bandwidth is 45 GHz, which is sufficient for 40 Gb/s operation. The input return loss is excellent, better than 15 dB up to 40 GHz. The output return loss is good at low frequencies, better than 9 dB up to 20 GHz, but degrades approaching 40 GHz. This could be further improved, but is good performance for a first pass design.

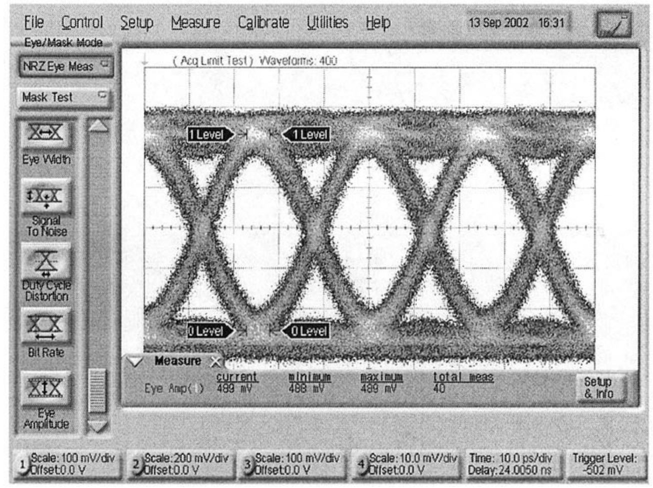

Fig. 4. 40 Gb/s eye diagram of the input signal. The eye amplitude is 0.5 V. $\mathrm{PRBS} = 2^{31} - 1$.

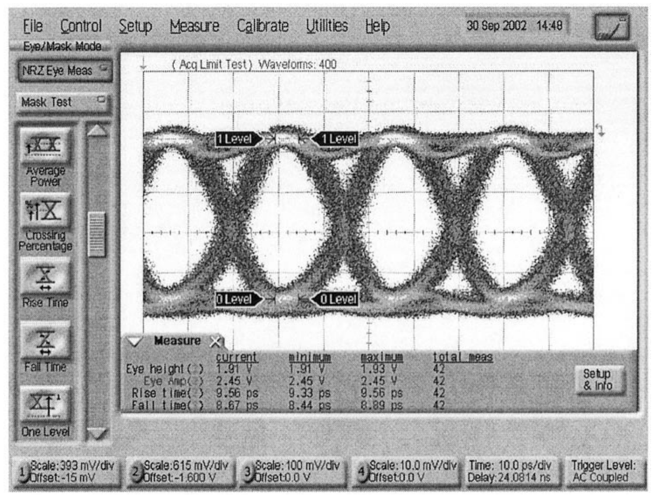

Fig. 5. 40 Gb/s eye diagram of the output signal. The eye amplitude is 2.4 V. $\mathrm{PRBS} = 2^{31} - 1$.

The 40 Gb/s eye diagram was measured with Agilent's Infinium DCA 86 100A wide-band oscilloscope using a 50 GHz Agilent 83 484A module. The input signal is $2^{31} - 1$ pseudo-random bit sequence (PRBS). Fig. 4 shows the eye diagram of the input signal. The input signal eye amplitude (measured from mean to mean) is 0.5 V and peak-to-peak amplitude is 0.6 V. The output eye diagram for one of the differential outputs is shown in Fig. 5. The eye amplitude is 2.4 V, peak-to-peak voltage is 2.7 Vp-p, and the eye height is 1.9 V. The wide bandwidth contributes to fast rise/fall times of 10/9 ps. The cross-point control feature range was also tested found to be from 30 to 70%. This eye diagram performance was achieved using a single -5.0 V power supply and consuming only 1.8 W of dc power.

V. Conclusion

A differential traveling wave driver for the electro-absorption modulator is presented. The circuit consists of a lumped-element predriver and a traveling wave amplifier. This configuration allows dc coupled operation and cross point control, which are difficult to achieve in a standard traveling wave amplifier. This one chip MMIC produces high gain and excellent bandwidth, which are difficult to achieve in pure lumped approach. The technology chosen is InP HBT with excellent fmax and f_T. The driver was carefully simulated using small signal, frequency domain and large signal, time domain analysis. This method yielded a first pass modulator driver with 2.7 Vp-p or 2.4 V eye amplitude, more than 20 dB of gain and 45 GHz bandwidth. These were achieved while consuming 1.8 W of dc power and operating out of single -5.0 V power supply.

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REFERENCES

[1] R. S. Virk, E. Camargo, R. Hajji, S. Parker, R. Benelbar, S. Notomi, and H. Ohnishi, "40-GHz MMIC's for optical modulator driver applications," in *IEEE Int. Microw. Symp. Dig.*, vol. 1, June 2002, pp. 91–94.

[2] H. Shigematsu, M. Sato, T. Hirose, and Y. Watanabe, "A distributed amplifier for 40 Gbps fiber-optics communication systems," *Microw. J.*, pp. 78–90, Apr. 2002.

[3] H. Suzuki, K. Watanabe, K. Ishikawa, and H. Masuda, "InP/InGaAs HBT IC's for 40 Gbit/s optical transmission systems," in *GaAs Symp. Tech. Dig.*, Oct. 1997, pp. 215–218.

[4] D. S. McPherson, F. Pera, M. Tazlauanu, and S. P. Voinigescu, "A 3-V fully differential distributed limiting driver for 40 Gb/s optical transmission systems," in *IEEE GaAs IC Symp. Dig.*, Oct. 2002, pp. 95–98.

[5] G. Freeman *et al.*, "40 Gbit/sec circuits built from a 120 GHz f_T SiGe technology," *IEEE J. Solid-State Circuits*, vol. 37, no. 9, pp. 1106–1114, Sept. 2002.

[6] Y. Baeyens *et al.*, "InP D-HBT IC's for 40-Gb/s and higher bitrate lightwave tranceivers," *IEEE J. Solid-State Circuits*, vol. 37, no. 9, pp. 1152–1159, Sept. 2002.

[7] N. X. Nguyen, J. Fierro, G. Peng, A. Ly, and C. Nguyen, "Manufacturable commercial 4-inch InP HBT device technology," *GaAs MANTECH Dig.*, pp. 26–29, Apr. 2002.