A Low-power, 128-Gbit/s, DC-coupled linear driver IC for Electro-absorption Modulated DFB Laser

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Abstract: We demonstrate a 128-Gbit/s/λ optical transmitter with newly developed DC-coupled linear driver IC for electro-absorption modulator. High-quality PAM-4 eye diagram with higher extinction ratio is obtained with low-power consumption, which is suitable for 100G-LR1/ER1 application. © 2022 The Author(s)

1. Introduction

Electro-absorption modulated DFB laser (EML) is a promising optical modulator device for high-speed optical communication thanks to its wide bandwidth. Therefore, EML is expected to use as a high-speed optical transmitter up to 40km transmission, and the multi-source agreement of single lane 100-Gbit/s transceiver has been standardized [1]. In a transceiver, an electrical PAM-4 signal from DSP is required to be amplified by a linear driver IC before driving an EA modulator. However, in general, since the power consumption of linear driver IC is high due to termination resistors, it is not suitable for high density applications such as data center. Therefore, low-power driver IC for EML with linear operation is strongly required to realize a high-speed multi-level modulation. In this study, we developed DC-coupled linear driver ICs for EML, and demonstrated high quality PAM-4 eye diagrams and higher extinction ratio (ER) with low-power consumption under 53 GBaud and 64 GBaud PAM-4 operation.

2. Driver IC design

Fig. 1 (a) and (b) show the block diagram of newly developed driver IC and the schematic of push-pull driver block, respectively. The driver IC is composed of a push-pull driver with EA bias control, a level-shifter to generate two differential signals with proper DC bias levels for both push and pull driver, and a preamp with 6dB gain. In the push-driver, an emitter follower Q1p pushes the charges of EA whose cathode is connected to power supply Vcc. While a cascode common emitter amplifier (Q2p and Q3p) pulls the charges from EA and assists the emitter follower especially in higher frequency. A damping resistor Routp is used to suppress frequency resonances due to parasitic inductances and inductive behavior of the emitter follower. The output resistance of the push-pull driver can be lower than that of conventional driver IC with terminations. Therefore, E-O bandwidth can be wider with low-power consumption. The push-pull driver is designed as differential circuit to reject a common mode with spiral inductors LEp and LEn. The dimension of the driver IC is 940 × 710 μm^2. EML can be directly mounted on the driver IC with 3D flip-chip bonding (hereafter FCB). Also, the other IC is prepared for wire-bonding (hereafter WB) connection to EML. These ICs are fabricated by using 130nm SiGe:C BiCMOS (ft/fmax =350/450 GHz).

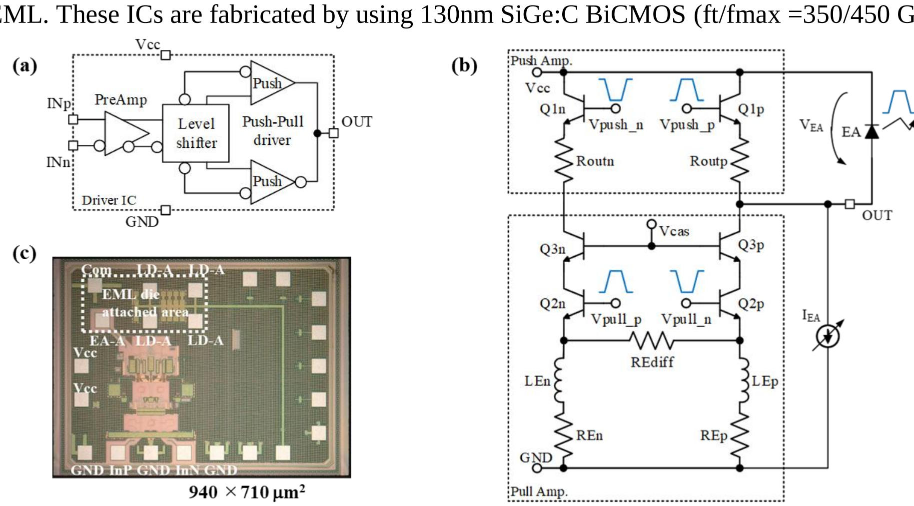

Fig. 1 . (a) Block diagram of the newly developed driver IC, (b) schematic of push-pull driver block, and (c) photograph of the driver IC.

3. Experimental results

A measurement setup for optical eye diagram is shown in Fig. 2 (a). An arbitrary waveform generator (AWG) was used to generate electrical differential signals up to 64 GBaud PAM-4. The electrical signals from AWG were reached to driver IC with coaxial cables (1m length) through a GSGSG probe. The RF loss and skew of long coaxial cables were automatically corrected by AWG. DC supply voltage for driver IC and laser bias current was applied to both driver IC and EML. The temperature of EML was controlled at 50 °C by using a thermo-electric cooler. An optical output of EML was coupled to a single mode fiber SMF through a lens, and then received by a digital communication analyzer (DCA) for eye measurement. Fig. 2 (b) shows test sample views of FCB and WB connections.

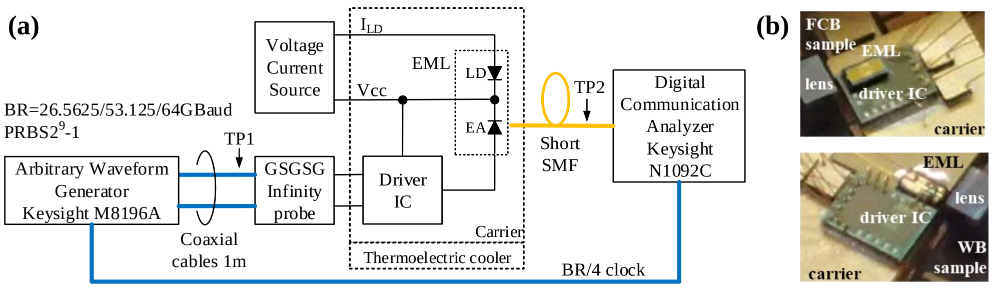

Fig. 2 (a) Measurement setup for optical eye diagram and (b) sample views.

Fig. 3 (a) shows DC response from input amplitude of the driver IC to the optical power at TP2. When 400mVppd as input amplitude is applied at TP1, 5.0 dB of DC ER can be expected. The power consumption of driver IC is 240 mW at room temperature. E-O responses for WB and FCB samples are shown in Fig. 3 (b). The 3dB-bandwidths are 48 GHz at FCB and 33 GHz at WB. These are sufficiently wide for 53 GBaud PAM-4 modulation.

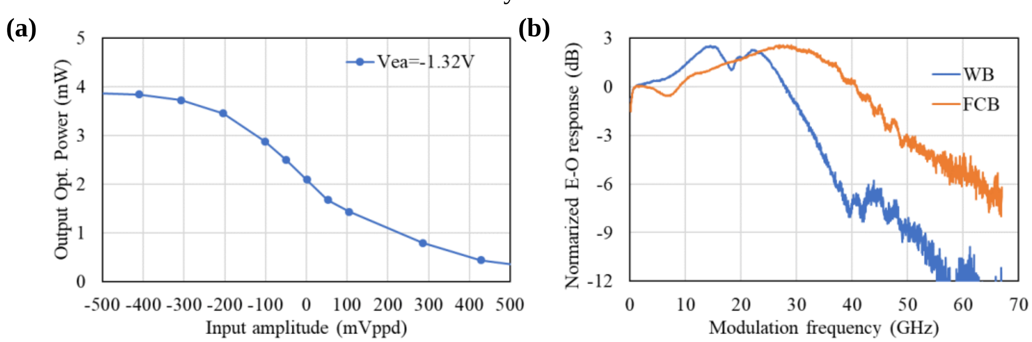

Fig. 3 (a) DC response from input differential amplitude to fiber output power and (b) normalized E-O responses.

Fig. 4 shows measured PAM-4 optical eye diagrams at TP2 when the input signals of 26.5625, 53.125 and 64 GBaud with PAM-4 PRBS2^9-1 pattern were supplied at TP1. Green and yellow PAM-4 eye diagrams were before (pre-) and after (post-) feed forward equalizer (FFE), respectively. FFE was defined as Transmitter and Dispersion Eye Closure Quaternary (TDECQ) equalizer [2] and installed in DCA. We obtained high outer ER greater than 5.0 dB and low TECQ [1] value less than 1.5 dB even with 530 mVppd of small input amplitude. At 64 GBaud signal, because of the limitation of the input amplitude from AWG due to RF cable losses, ER was lower compared to that of 53 GBaud. In spite of this limitation, good eye diagrams are confirmed even at 64 GBaud.

Fig. 5 (a) shows the input amplitude dependence of outer ER at 53 GBaud. EA bias (Vea) was adjusted by controlled circuit. Because of high outer ER with small input amplitude, this sample can be directly connected to DSP. The relationship between TECQ and outer ER is shown in Fig. 5 (b). The MSA specifications of 100G-LR1 and 100G-ER1 are also highlighted. These minimum ER and TECQ are 3.5 dB and 3.4 dB for 100G-LR1-20, and 5.0 dB and 3.9 dB for 100G-ER1-30/40. Both low TECQ less than 2.0 dB and high outer ER up to 6.0 dB are demonstrated. As shown in this figure, our driver IC can be used as 100G-ER1 application

Table. 1 compares the reported driver IC with other state-of-the-art driver ICs for EML. This work has the highest operation baud rate 128-Gbit/s and enough high ER for extended reach communication such as 100G-ER1-30/40. This driver also has good power efficiency even with the highest speed operation.

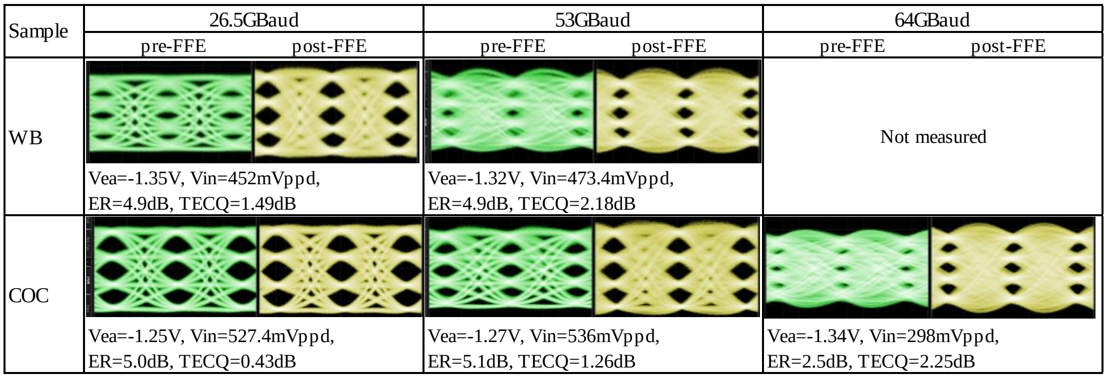

Fig. 4 Measured PAM-4 optical eye diagrams.

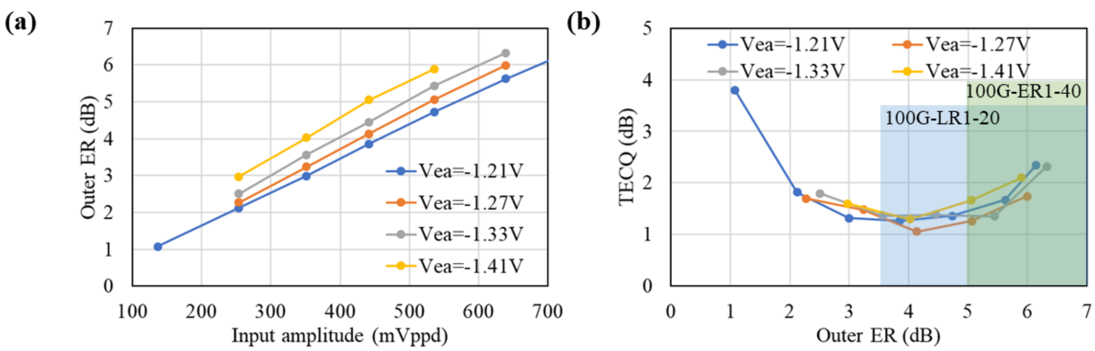

Fig. 5 (a) Input amplitude dependence of outer ER and (b) relationship between TECQ, outer ER and 100Glamda MSA specification.

Table. 1 Comparison of the state-of-the art driver IC for EML (Bit Rate > 50-Gbit/s)

Ref.	Speed (Gbit/s)	Power (mW)	Efficiency (pJ/bit)	Limit swing (Vpp)	ER (dB)	modulation format	Coupling	driving methode	Output circuit topology	Load	Chip Area (mm2)
[3]	56	84	1.50	1.3	5.4	PAM-4	DC	linear, single-ended	CML(TWA)	InP-EML//50Ω	2.52
[4]	56	61	1.09	1.3	5.0*	NRZ	DC	differential	CML	GeSi-EAM	0.37
	70		0.87	2.0							
[5]	106	159	1.50	-	4.5	PAM-4	DC	differential	CML(2b-DAC)	EAM	0.56
[6]	56	219	3.91	2.0	8.0*	PAM-4	DC	differential	CML	InP-EAM	0.044
This work	106	240	2.26	>1.2	6.0	PAM-4	DC	linear, single-ended	Push-pull	EAM	0.67
	128		1.88		2.5**						

* Estimated ER from output swing, ** limited by small input amplitude due to RF cable losses.

4. Conclusion

We have demonstrated 128-Gbit/s optical transmitter with newly developed DC-coupled linear driver IC for EML. The driver IC power consumption was 240 mW (1.88 pJ/bit) at room temperature. 3-dB E-O bandwidth was 48 GHz and TECQ was less than 2.0 dB when the outer ER was up to 6.0 dB. From these results, we conclude that our new driver IC is suitable for 100G-LR1 and 100G-ER1 optical transmitter.

5. References

[1] 100Glamda MSA, 100G-LR1-20, 100G-ER1-30 and 100G-ER1-40 Technical Specifications Rev 1.1.
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