Development of Electro-Absorption Modulator Driver ICs for 25G/40G Transmission

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The authors have developed new EA (electro-absorption modulator) driver ICs for both 25 Gbit/s and 40 Gbit/s transmission. These ICs achieve low power dissipation and high bit-rate operation characteristics by adopting the InP D-HBT (double-heterojunction bipolar transistor) process and optimizing the circuit configurations for each bit rate. In addition, the authors have successfully reduced the size of optical transmitter modules by mounting the EA driver ICs and the DFB (distributed feedback laser) chips in the same packages. This paper outlines the development of the EA driver ICs and evaluates the performance of the optical transmitter modules in accordance with SDH (Synchronous Digital Hierarchy) and 100G Ethernet standards.

Keywords: electro-absorption modulator driver, InP D-HBT process, optical transmitter module, IEEE802.3ba

1. Introduction

As Internet traffic increases, large communication capacity is required in optical communication systems. For the client side of DWDM [*1] (dense wavelength division multiplexing) systems, the baud rate of current optical communication is mainly 10 Gbit/s, which has already been used in 10G Ethernet. However, these systems will be insufficient for the accelerated traffic increase expected in the next few years. Therefore, a 100G Ethernet system using the LAN-WDM [(1)] technique has been standardized by the IEEE (Institute of Electrical and Electronics Engineers). In this standard, 4-lane wavelength division multiplex with 800 GHz spacing from 1296 to 1309 nm is employed. In addition, as part of the OTN (optical transport network) standardization, OTU4 (optical-channel transport unit 4; 112 Gbit/s), which is more compatible with 100G Ethernet, was proposed in ITU-T (International Telecommunication Union Telecommunication Standardization Sector. The baud rate of the 100G Ethernet system and OTU4 are 25 Gbit/s and 28 Gbit/s, respectively. On the other hand, STM-256, a well-known standard of ITU-T, has a baud rate of 39.8 Gbit/s. In addition, demand is increasing for OTU3 (43.0 Gbit/s), a new standard compliant with 40G Ethernet. In the latest system, low power dissipation is essential. More particularly, CFP (centum gigabit form factor pluggable)[*2 (2)] a widely-used MSA (Multi-Source Agreement) transceiver, requires to have low power consumption and fit in a small outline package for optical transmitter modules.

We have already developed an optical transmitter module and a driver IC for high-speed optical communication systems up to 10 Gbit/s. As for 40G and 25G transmitters, electro-absorption modulators integrated with DFB laser (EA-DFB[*3]) are suitable for high-optical transmitter sources.

In this paper, we outline newly developed EA modulator driver ICs for both 25G and 40G transmission. These ICs have low power dissipation and high-speed drivability, and are fabricated by an in-house InP D-HBT process (ft/fmax = 150/250 GHz). To minimize power dissipation for each bit rate, the circuit topology was optimized. These ICs have a built-in optical transmitter module to provide the best performance. This paper describes an overview of EA modulator driver ICs and their evaluation results. The performances of the optical transmitter modules, compliant with SDH, OTN and 100G Ethernet standards, are also reported.

2. Specifications

Table 1 shows the specifications of EA driver ICs.

For the 40G EA driver IC, a maximum operation bit rate of 43.0 Gbit/s (OTU3) is required. To fulfill an optical extinction ratio of not less than 9.0 dB, the output amplitude needs to be more than 1.9 Vpp. Maximum power consumption is 1.8 W.

For the 25G EA driver IC, a maximum operation bit rate of 28.0 Gbit/s (OTU4) is required. In the 100G CFP

Table 1. Specifications for 25G/40G EA driver ICs

25G EA driver IC	
Operation Temperature	-5 to 85˚C
Supply Voltage	-5.2V
Output Amplitude	1.8 Vpp Min.
Operation Bit Rate	24.7 to 28.0Gbit/s
Power Consumption	1.25W Max.
40G EA driver IC	
Operation Temperature	-5 to 85˚C
Supply Voltage	-5.2V
Output Amplitude	1.9 Vpp Min.
Operation Bit Rate	39.8 to 43.0Gbit/s
Power Consumption	1.8W Max.

light transceiver, four optical transmitter modules with different wavelengths are mounted, and accordingly, reduction in the power consumption of a module makes a great difference. For this reason, maximum power consumption is set to 1.25 W for each EA driver IC. As an optical extinction ratio of more than 7.0 dB is required for the transmitter module, an output amplitude of 1.8 Vpp is essential for the driver IC.

3. Development of the 40G EA Driver IC

3-1 Structure of the 40G optical transmitter module

First, we describe the optical transmitter module with a built-in 40G EA driver IC. **Photo 1** shows the appearance of the transmitter module. This module has a ceramic package of 12 x 18 x 9 mm^3, two small coaxial connectors for differential RF signal inputs and 14 DC pins for power supply and control. The dimensions and physical interface of this transmitter module are fully compliant with XLMD-MSA (40 Gbit/s Miniature Device Multi-Source Agreement [(3)]), an industry standard for optical modules. A block diagram of the transmitter module is shown in **Fig. 1**, which is composed of an EA driver IC, a 50 Ω termination resistor, and an EA-DFB laser. For stabilizing the optical output power, the EA-DFB laser chip and termination resistor are mounted on a thermoelectric cooler (TEC [*4]). To suppress heat generation on the TEC, the EA driver IC is not mounted directly on the TEC but is connected to the EA-DFB laser by a 50 Ω transmission line. In this module structure, to achieve 43 Gbit/s operation with a good optical waveform, it is important to suppress signal reflection between the laser and the IC. Therefore, the EA driver IC must fulfill not only high-speed operation but also low output return loss (S_{22}) in the high frequency domain up to about 50 GHz.

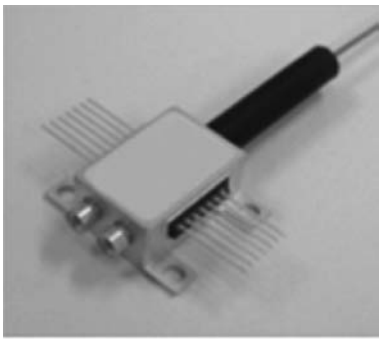


Photo 1. Appearance of the 40G transmitter module

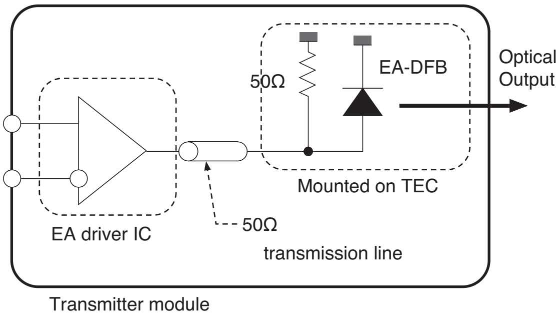


Fig. 1. Block diagram of the 40G transmitter module

3-2 Design and characteristics of the 40G EA driver IC

Figure 2 shows a block diagram of the 40G EA driver IC. Here, we used a TWA [*5] output stage to achieve high-speed operation and lower return loss. The TWA output stage consists of eight distributed amplifier unit cells connected by coplanar line on the IC surface. The TWA output stage constitutes a 50 Ω output transmission line consisting of a coplanar line and output capacitance of the unit cells. Theoretically, the TWA topology enables high-speed operation and low return loss, and some driver ICs using the TWA have been reported [(4)]. In the conventional lumped element circuit, the output capacitance of the amplifier that constitutes an output stage is an aggravating factor for return loss in the high-frequency domain. In a TWA circuit, the amplifier is divided into unit small cells, and then divided small output capacitance is included in a part of distributed capacitance in TL1. Therefore, the return loss of the TWA can be minimized.

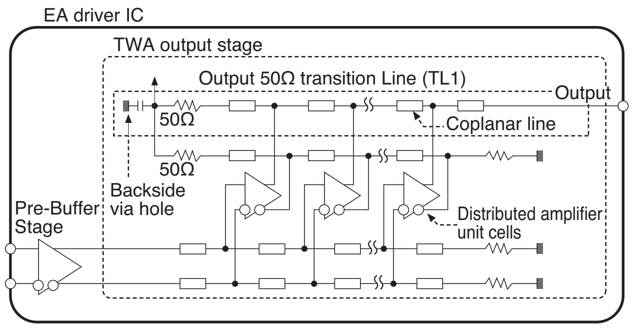
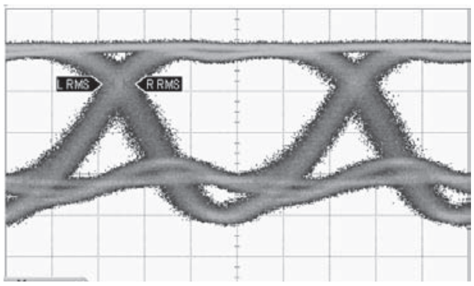


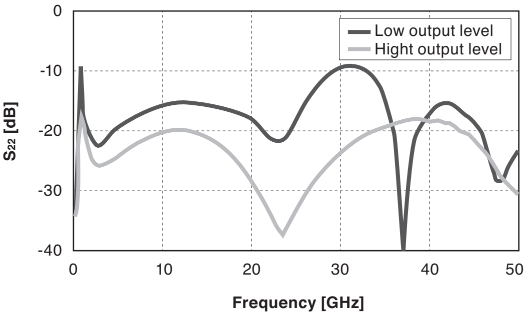
Fig. 2. Block diagram of the 40G EA driver IC

In this TWA circuit, the design of the characteristic impedance of TL1 is important to reduce return loss. We use cascode output transistors in distributed amplifier unit cells. This design stabilizes the characteristic impedance of TL1 as the output capacitance value of the unit cells are not affected by the state of the unit cells. Additionally, we use backside via holes to improve frequency dependence of the characteristic impedance. These via holes are installed between GND planes of the coplanar line and the IC backside GND to improve frequency characteristics of the coplanar line, and accordingly, the characteristic impedance of TL1. Measurement results for the EA driver IC are shown in **Fig. 3**. **Figure 3(a)** shows an electrical output eye diagram with 39.8 Gbit/s PRBS (pseudorandom binary sequence) 2^{31}-1. The output amplitude is 1.8 Vpp. Both the rise time and fall time are 7.0 ps. **Figure 3(b)** shows the output return loss (S_{22}) at a low output level and high output level. It shows a positive result of -10 dB or less in a 50 GHz broadband except for a few domains. These results indicate



5 ps/div Bit rate: 39.8 Gbit/s PRBS 2^{31}-1 0.5 V/div

(a) Electrical output eye diagram



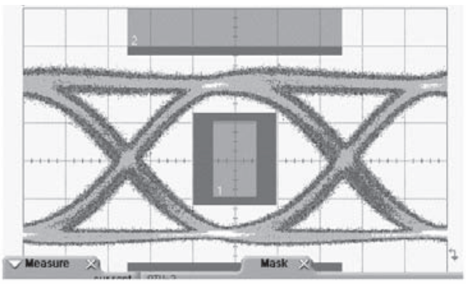
(b) Output return loss (S_{22})

Fig. 3. Measurement results for the 40G EA driver IC

that the IC has desirable characteristics for 43 Gbit/s operation.

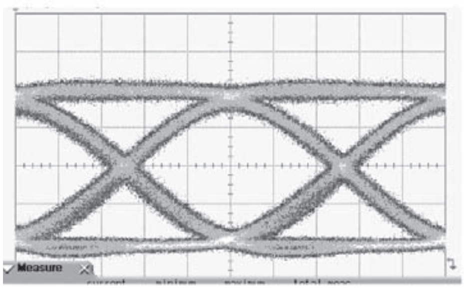
3-3 Module performance

Figure 4 shows optical output eye diagrams for the 40G transmitter module that incorporates the newly developed EA driver IC. **Figure 4(a)** shows the waveform before transition, and **Fig. 4(b)** shows the waveform after 2 km SMF transmission. The wavelength of the EA-DFB laser, a module that aims to VSR (very short reach[*6]) applications, is 1.55 μm. The bit rate is 43.018 Gbit/s, and the signal pattern is PRBS 2^{31}-1. These eye diagrams were obtained after passing through the Bessel-Thomson filter built as an optical plug-in in the oscilloscope. Before transmission, the extinction ratio is 10.0 dB, and the mask margin is more than 20% of the OTU3 requirement. The waveform after transmission also shows a promising result.



Extinction ratio = 10.0dB, Mask margin = 23%

(a) Before transmission



(b) After transmission (2 km)

Bit rate 43.018Gbit/s PRBS 2^{31}-1

Fig. 4. Optical output eye diagrams

4. Development of the 25G EA driver IC

4-1 Design and characteristics of the 25G EA driver IC

Photo 2 shows a small-sized transmitter optical module for 25G operation. The package size, except the connector sleeve and pins, is 5.8 x 13 x 5.6 mm^3. The block diagram of this module is the same as that of the 40G optical module shown in **Fig. 1**. As stated earlier, in the development of the 25G EA driver IC, it is important to achieve low power consumption. The TWA circuit used for the 40G EA driver IC has excellent characteristics in high-speed operation and low return loss, however, it is not suitable for reducing power consumption because each distributed amplifier unit cell requires a certain amount of power. Therefore, we used a lumped element circuit, which is advantageous for low power consumption. A block diagram of the 25G EA driver IC is shown in **Fig. 5**, and a micropho-

Photo 2. Appearance of small-sized transmitter optical module for 25G

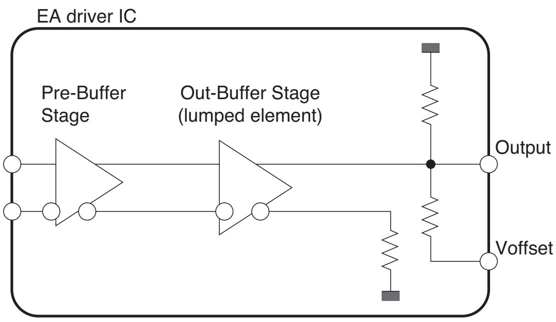


Fig. 5. Block diagram of 25G EA driver IC

tograph of the driver IC is shown in **Fig. 6**.

Although a lumped element circuit is inferior to a TWA circuit in high-speed operating characteristics, 28 Gbit/s operation is realized by adding a boost function of a high-frequency component to the output stage. Regarding influence of the return loss, we suppressed the influence on the optical output waveform to the tolerance level by optimizing the impedance of the output stage to EA-DFB.

Figure 7 shows an electrical output eye diagram of the newly developed 25G driver IC. The bit rate is 28.0 Gbit/s, and signal pattern is PRBS 2^{31}-1. The output amplitude was set to 1.8 Vpp, and rise and fall times were 14 ps and 12 ps, respectively.

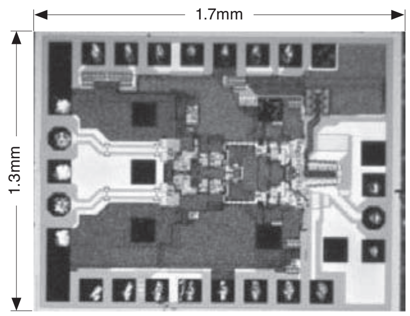


Fig. 6. Microphotograph of 25G driver IC

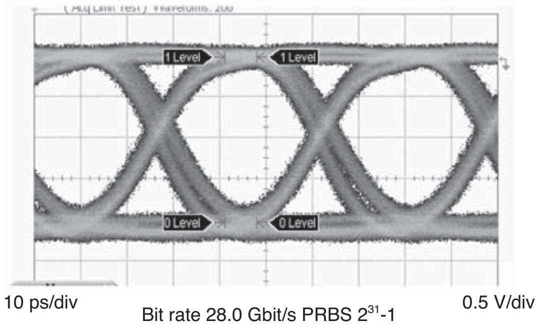


Fig. 7. Electrical output eye diagram

4-2 Module performance

Figure 8 shows optical output eye diagrams of the transmitter module mounted with the newly developed EA driver IC. Before transmission, the bit rate is 27.94 Gbit/s and signal pattern is PRBS 2^{31}-1. The waveforms are measured after passing through the Bessel-Thomson filter. The optical wavelength corresponds to the LAN-WDM standard specified by 100G Ethernet. The optical extinction ratio is 7.7 dB and the mask margin is more than 30% of the mask requirement specified by OTU4.

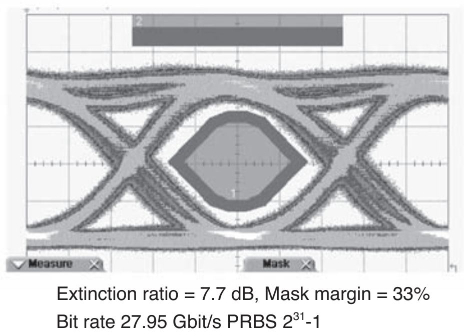


Fig. 8. Optical output eye diagram

4-3 Power consumption

Figure 9 shows the frequency distribution of the maximum power consumption of the newly developed 25G EA driver IC. From this result, it was confirmed that there is a margin sufficient for the specification value (1.25 W).

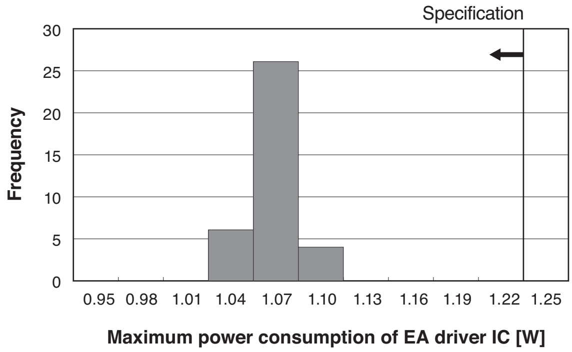


Fig. 9. Frequency distribution of the maximum power consumption of the driver IC

5. Conclusion

We have developed EA driver ICs for 25G and 40G operation, and conducted demonstration tests of optical transmitters with these ICs. By selecting a suitable circuit topology for each transmitter rate, advanced specifications required for an optical transceiver module are satisfied. These driver ICs can contribute to improvement in the performance of optical communication systems.

Technical Term

*1 WDM (wavelength division multiplexing): WDM is technology that enables multiplex transmission with a single optical fiber by using different wavelengths.

*2 CFP (centum gigabit form factor pluggable): CFP is a Multi-Source Agreement for hot-pluggable optical transceivers that enables 40 Gbit/s and 100 Gbit/s applications.

*3 EA-DFB (distributed feedback) laser: EA-DFB is a semiconductor laser chip that integrates an EA (elector-absorption modulator) and DFB.

*4 TEC (thermoelectric cooler): A TEC is a small cooling device using a peltier element.

*5 TWA (traveling waveform amplifier): TWA is a distributed constant circuit that excels at high-speed operation and impedance matching.

*6 VSR (very short reach): VSR is an ITU-T standard for 2 km optical data transmission.

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