

Fabrication of 53 Gb/s Optical Transceiver over 40-km transmission with PAM4 modulation

Sang-Moon Shin*, Hong-Beom Kim*, Jae-Woo Kim**

*R&D Department, ARTECH Co., Ltd., 147, 1Gongdan-Ro, Gumi, Republic of Korea

**ICT Center, University of Kumoh National Institute of Technology, Gumi, Republic of Korea

sangmoon.shin@artech200.com, hongbeom.kim@artech200.com, jaewookim@kumoh.ac.kr

Abstract— In this paper, we present a QSFP28 optical transceiver to transmit 53 Gb/s PAM-4 modulated signal over 40-km SMF(Single Mode Fiber) by applying EML TOSA and low cost PIN-PD ROSA combination. The Tx OMA power is 7.5 dBm at room temperature and the OMA receiver sensitivity is measured of -12.6 dBm. Fabricated transceiver reaches up to 55-km SMF with power consumption of less than 3.5W.

Keywords— PAM-4, PAM4, QSFP28, Extended Range, Optical transceiver

I. INTRODUCTION

The PAM4 signal is a modulation scheme that can transmit double rate to the same symbol compare than conventional NRZ, the efficiency of the signal is doubled, and the transmission cost can be reduced [1].

The IEEE802.3cd standard includes physical layers and management parameters for 50 Gb/s PAM4 optical transmitter and receiver characteristic for 50GBASE-FR (Far Reach, for 2-km) and LR (Long Reach, for 10-km) [2]. In the case of the specification for 40-km transmission of PAM4 modulated signal has not yet been standardized. Recently, several research groups reported experimental results for 40-km and 60-km transmission by applying APD(Avalanche photodiode detector)s [3],[4]. However, APD requires additional circuitry to handle it, and the price is also high. There are PIN-PDs (PIN Photo Diode) that are more economical than APDs, However, because the Rx sensitivity of the PIN-PD is lower than the Rx sensitivity of the APD, the PIN-PD is typically not used for 40 km transmissions without an external SOA (semiconductor optical amplifier).

In this paper, we designed a QSFP28 optical transceiver using only EML TOSA(Transmitter Optical Sub-Assembly) and a low cost PIN-PD ROSA(Receiver Optical Sub-Assembly) and successfully transmit PAM-4 signal over 55-km SMF without an SOA respectively.

We present that we can transmit over 40-km by increasing Tx output power and extinction ratio, while using a short-distance, low-cost PIN-PD ROSA.

II. DESIGN AND FABRICATION

To design the optical transceiver of QSFP28 form factor, QSFP multi-source agreement (MSA) and IEEE802.3cd

standard were observed[2],[6]. Items related to design are described below by distinguishing the block diagram and the fabrication as a QSFP28 transceiver.

Generally, when designing a 40-km optical transceiver, the Rx sensitivity is improved by using an external SOA or APD at a receiver.

The SOA module is applied to a large size transceiver form factor such as CFP or CFP2, and additional circuit is required to drive a SOA module and TEC simultaneously. Therefore, it can be a disadvantage that additional power is supplied to drive SOA and TEC[5].

In the case of APD, In order to implement an APD driver circuit to 40-km transmission, a DC/DC converter to apply a high reverse voltage to APD, is required. It is disadvantageous in design considering narrow and small PCB area with a small transceiver form factor like QSFP28.

On the other hand, when implemented with PIN-PD, the same voltage as the power supplied to the board can be applied without additional DC/DC converter. Therefore, it is possible to drive a PD even in a small PCB area.

A. Block diagram

Internal structure of QSFP28 optical transceiver is composed of PAM4 DSP, EML-TOSA, PIN-PD ROSA, Linear Driver, TEC Controller and MCU depicted in Figure 1.

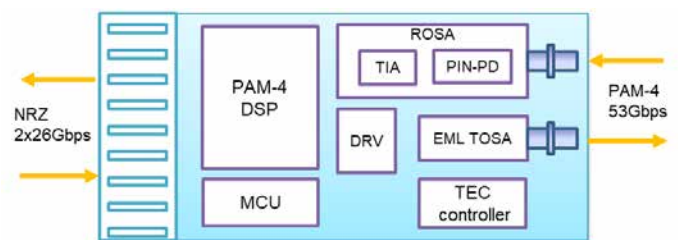


Figure 1. Block diagram of a PAM4 transceiver

A PAM4 DSP chip converts 2-channel 26 Gb/s NRZ signals into 1 x 53Gb/s PAM4 signals and also convert reverse direction.

The applied EML TOSA is a conventional 25G/28G single channel TOSA consists of an EA modulator integrated DFB-LD, a monitor photodiode, a built-in optical isolator and a TEC (thermo-electric cooler) in a package for the originally NRZ purpose, and is applied to PAM4 signal transmission in this study. The TEC controller IC is used to control the TEC temperature inside of the TOSA.

A linear PIN-PD ROSA for receiving PAM4 optical signal consists of a 25 GHz bandwidth photodiode and a linear TIA with up to 2.5 mA input power range and adjustable 3dB bandwidth from 31 to 37 GHz.

A MCU controls the ADC and DAC of the optical transceiver to set a laser diode, a linear driver and a linear TIA and drives a PAM4 DSP. It also controls the interface with host equipment.

B. Fabrication of QSFP28 transceiver

We designed NRZ electrical interface to be compliant with CEI-28G-VSR standards for LAUI-2 with 2 x 26 Gb/s high-speed CML, and PAM4 optical interface to be compliant with IEEE802.3cd, up to 40-km reach for 50GBASE-ER over SMF with industry standard duplex LC receptacle. Module dimension is compliant with QSFP28 MSA(Multi-Source Agreement), 18.35-mm x 72.4-mm x 8.5-mm as described in SFF-8661[7].

Also, we implemented a management interface, including I2C, low speed control and status pins according to SFF-8679[8].

EML TOSA, linear PIN-PD ROSA, PAM4 DSP, and various electrical parts were outsourced from each vendor respectively.

PCB is designed as a 10-layer substrate by mixing low dielectric constant and low dissipate factor material substrate for high speed transmission line and FR-4 substrate to reduce the cost. The fabricated PCB and assembled parts on are depicted in Figure 2.

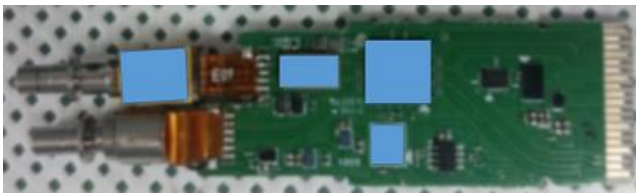


Figure 2. Fabricated PCB

III. EXPERIMENTAL SCHEME AND RESULTS

A. Experimental scheme

Experimental scheme is depicted in figure 3. ONT-603 (VIAVI solutions) is the 4 x 25G test equipment to test 100G Ethernet and PRBSn mode. The optical transceiver was tested by connecting it to an attenuator or spool after connecting it to the EV board. The figure 3. shows the transmission

experiment using the 55 km spool and the experiment using the attenuator is omitted in the figure.

The experimental set-up in the chamber for low temperature, room temperature and high temperature experiments is shown in Figure 4.

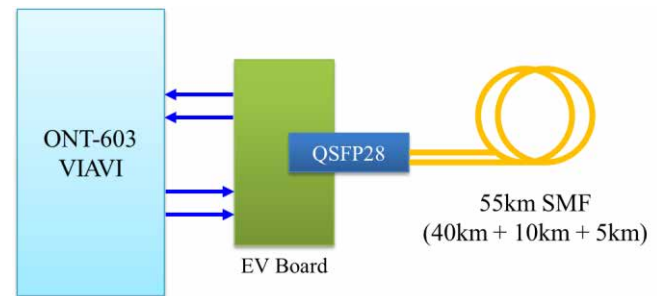


Figure 3. Experimental scheme

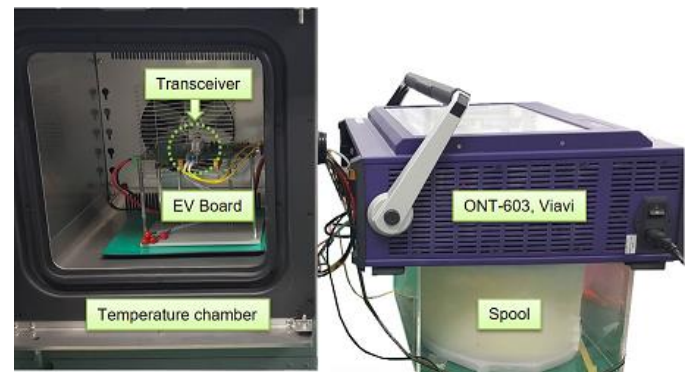


Figure 4. 53Gb/s PAM4 transceiver mounted an experimental fixture

B. Experimental Results

Measured optical PAM4 eye pattern on Tx port is depicted in figure 5.

Tx OMA output power of the transceiver is 7.3 dBm at 0 °C, 7.5 dBm at 25 °C and 7.5 dBm at 70 °C of case temperature respectively. The variation of ERouter at each temperature is about 1dB because of linear driver's variation characteristics according to temperature.

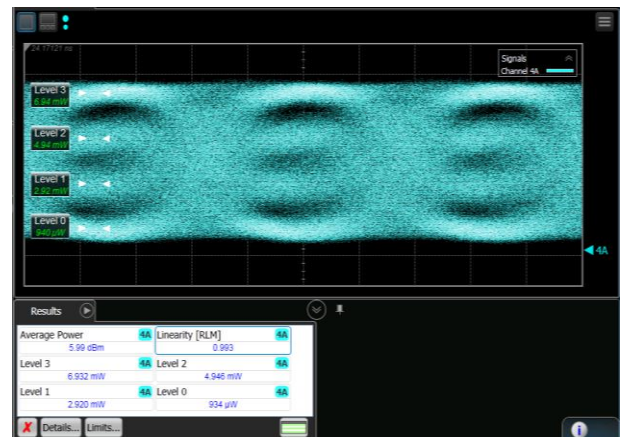


Figure 5. PAM4 TX optical eye pattern

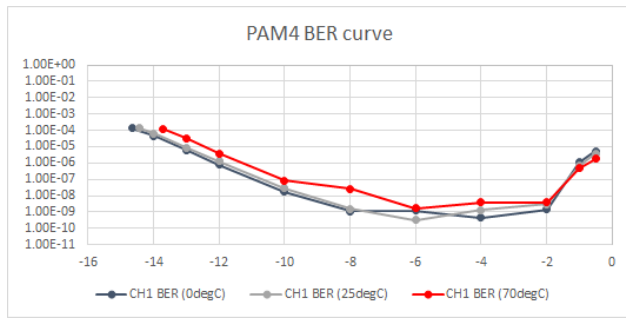


Figure 6. PAM4 BER characteristics

Summarized BER characteristics at 0 °C, 25 °C and 70 °C case temperature condition is depicted in figure 6. When an Rx received power is greater than -2 dBm, it can be seen that the Rx eye saturates at level 3 and the BER decreases.

The optical power applied to the Rx port after passing through the 55 km SMF spool was -13.99 dBm, and the Rx sensitivity was measured to be 8.6E-5.

One of the initial forecast of 50GBASE-ER requires 18dB insertion loss from Tx OMA power of +4.5 dBm to Rx OMA received power of -13.5 dBm when an APD ROSA was applied [1]. The experimental results show that even though Rx sensitivity of APD is not exactly satisfied, the insertion loss of 40 km can be satisfied even by using the PIN-PD.

The fabricated QSFP28 transceiver's experimental results are summarized in table 1.

TABLE 1. TRANSCEIVER FEATURES SUMMARY

list	unit	Case temperature		
		0°C	25°C	70°C
Wavelength	[nm]	1308.422	1308.408	1308.38
ERouter	[dB]	9.0552	8.7641	8.0731
Tx power OMAouter	[dBm]	7.2754	7.4896	7.4712
Rx sensitivity, OMA	[dBm]	-12.7350	-12.5811	-12.0845
Link Budget	[dB]	20.0104	20.0707	19.5556
Calculated transmission distance	[km]	57.1726	57.3450	55.8733
Power consumption	[W]	2.805	2.653	3.085

IV. CONCLUSIONS

In this paper, we demonstrated that the optical transceiver of QSFP28 form factor with EML-TOSA and PIN-PD can transmit 50 Gb/s PAM4 signal over 55 km SMF. The results of this study show that the link budget of 50GBASE-ER requirement can be satisfied by using PIN-PD, which is lower cost than applying an APD to increase Rx sensitivity and can simplify schematic design of an optical transceiver.

ACKNOWLEDGMENT

This work was supported by the ICT R&D program of MSIT/IITP(B0717-7-0041/Development of PAM-4 Optical Transceiver for Short-reach Ethernet Interface).

REFERENCES

- [1] 50G PAM4 technical white paper, The Huawei website. [Online]. Available: <https://carrier.huawei.com/en/technical-topics/fixed-network/huawei-released-50g-pam4-technical-white-paper>
- [2] Media Access Control Parameters for 50 Gb/s and Physical Layers (PHY) Specification, IEEE Std. 802.3cd, 2018.
- [3] Masahiro Nada, et al., "High-linearity Avalanche Photodiode for 40-km Transmission with 28-Gbaud PAM4", OSA Technical Digest, Optical Society of America, 2015, paper M3C.2
- [4] Kangping Zhong, et al., "Amplifier-Less Transmission of 56Gbit/s PAM4 over 60km Using 25Gbps EML and APD", OSA Technical Digest, Optical Society of America, 2017, paper Tu2D.1
- [5] Ryota TERANISHI, et al., "SOA Module for 100GBASE-ER4", SEI technical review, Number 78, April 2014, pp.55~57
- [6] SFF-8665, Specification for QSFP+ 28 Gb/s 4X Pluggable Transceiver Solution (QSFP28), Rev 1.9 June 29, 2015
- [7] SFF-8661, Specification for QSFP+ 4X Pluggable Module, Rev 2.3 September 13, 2014
- [8] SFF-8679, Specification for QSFP+ 4X Base Electrical Specification, Rev 1.7 August 12, 2014



Sang-Moon Shin was born in South Korea, He received the B.S., M.S., and Ph.D. degrees from the School of Electrical Engineering, University of Ulsan, Ulsan, Korea, in 2000, 2002, and 2014, respectively. He is currently in charge of development of optical transceivers on ARTECH Co. Ltd., Gumi, Korea. His research interests include various topics in optical transceivers, indoor air quality, sensor networks, microwave/millimeter-wave communication, high-voltage discharge, dielectric barrier discharge, ion generation, and lightning detection.



Hong-Beom Kim was born in South Korea, He received the B.E. degree from School of Electronic Engineering, University of Kumoh National Institute of Technology in 2017. He is currently a firmware engineer and researcher for ARTECH Co. Ltd., R&D department, Gumi, Korea. His research area is optical transceiver including IC algorithm optimization, firmware design and performance evaluation.



Jae-Woo Kim was born in South Korea, He received the Ph.D degree from the School of Computer Engineering, University of Kumoh National Institute of Technology. He worked at ARTECH Co. Ltd. from 2014. 5 to 2018, 7. He is currently working as a research professor at the ICT Center at Kumoh University in Korea. His major research areas are protocol engineering, mobile communication, optical communication, and firmware technology.