53.2 Gb/s NRZ Transmission Over 10 km Using High Speed EML for 400GbE

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***Abstract*—10 km transmission with 53.2 Gb/s NRZ format was demonstrated using 1310 nm high speed EML device. Evaluated dispersion penalty and receiver sensitivity show enough capability of NRZ format for 400 Gb/s Ethernet applications up to 10 km link.**

***Keywords*—400GbE, EML, NRZ, 802.3bs, high speed**

I. INTRODUCTION

Demand of the high speed Ethernet module is rapidly increasing for telecom and inter- and intra-datacenter applications to provide cloud service or video streaming service [1]. This trend results in an intensive effort for 100 Gb/s optical modules using integrated 4:1 optical multiplexing/demultiplexing (MUX/DEMUX) technology [2-8] for CFP4 or QSFP28 platform [9, 10]. In May 2014, IEEE P802.3bs 400GbE Task Force was formed to publish 400GbE standard in 2017 as next generation Ethernet module employed in both data center and telecom applications up to 10km [11]. Regarding the serial data rate for 400GbE, two candidates of 100 Gb/s × 4λ and 50 Gb/s × 8λ are proposed. In terms of modulation format, one approach is improving frequency usage efficiency for suppressing Baud rate and wavelength number. 4-level Pulse-amplitude-modulation (PAM4) format is actively studied for both 100 Gb/s × 4λ and 50 Gb/s × 8λ systems over the years, which doubles the frequency usage efficiency avoiding Baud rate increase [12-14]. Another technology is a Discrete-Multi-Tone (DMT) format which demonstrated 100 Gb/s transmission with one wavelength [15]. These modulation formats, which are commonly used for electrical communication systems, have enough capability for over 100 Gb/s transmission. However, penalties caused by total harmonic distortion (THD), multipath interference (MPI) and non-linearity of the modulator have not been clarified yet. In addition, these technologies needs complicated digital signal processing (DSP) which increases cost and power consumption. Non-return-to-zero (NRZ) format, which has been employed in many standards at baud rates of 10/25/40 Gb/s, is a well-understood technology [16]. Just like in previous examples, 50 Gb/s NRZ format is the most promising candidate for the next generation serial rate. Potential applications is not only 400GbE, but also 50GbE (50 Gb/s × 1λ) or 200GbE (50 Gb/s × 4λ) [17]. Aiming for 400GbE systems, some demonstrations have been reported by 50 Gb/s × 8λ NRZ modulation format [18-22]. In this paper, using a 1.3 µm wavelength electro-absorption modulator laser (EML), we experimentally demonstrated 10 km transmission performance of 53.2 Gb/s NRZ and its dispersion penalty based on the blue-band extension of 100GBASE-LR4 wavelength allocation for 400 Gb/s system.

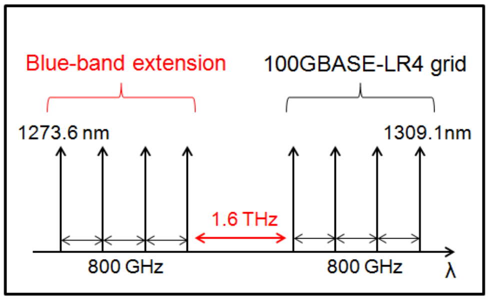


Fig. 1 Assumed wavelength allocation

II. MEASUREMENT SETUP

For 50 Gb/s × 8λ NRZ transmission, the wider wavelength range is needed than that of 100GBASE LR4 (25 Gb/s × 4λ NRZ) . Fig. 1 shows one example of the wavelength allocation with blue-band wavelength extension [23]. This wavelength allocation supports zero chirp and positive chirp modulators for standardized single mode fiber (SMF) with zero-dispersion wavelength of in range of 1300 nm and 1324 nm. A 1.6 THz spacing in the middle allows usage of two pair of 4-wavelength integrated TOSA/ROSAs, which enables a reuse of the same optics as 100GBASE LR4 modules, with external optical multiplexer/de-multiplexer [23]. With this wavelength allocation, we estimated the worst case dispersion value of -50.8 ps/nm for negative dispersion and +9.4 ps/nm for positive dispersion for 10 km link over 100GBASE LR4 compliant SMF [24]. In the measurement, 1310 nm wavelength EML and p-i-n photodiode (pin-PD) were used as the transmitter and the receiver, respectively. They were assembled into the butterfly package as shown in Fig. 2. Here, an EML driver IC was also integrated into the package. Operation bandwidth of transmitter and receiver were $f_{3\mathrm{dB}}$ = 38 GHz and $f_{3\mathrm{dB}}$ = 30 GHz, respectively. PD responsibility was 0.7 A/W. Fig. 3 shows the measurement setup of the transmission test. The bitrate was 53.2 Gb/s. To cover the wide wavelength range shown in Fig. 1, we prepared three kinds of SMFs with chromatic dispersion

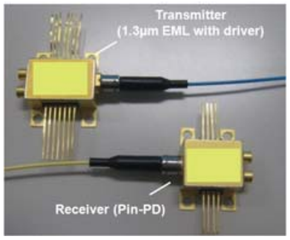


Fig. 2 Photograph of transmitter and receiver

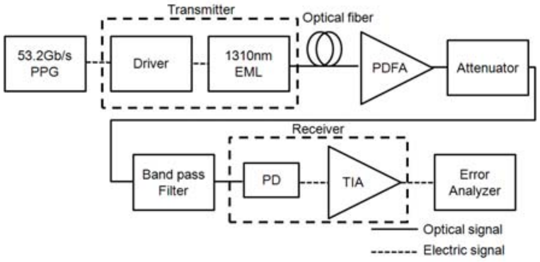
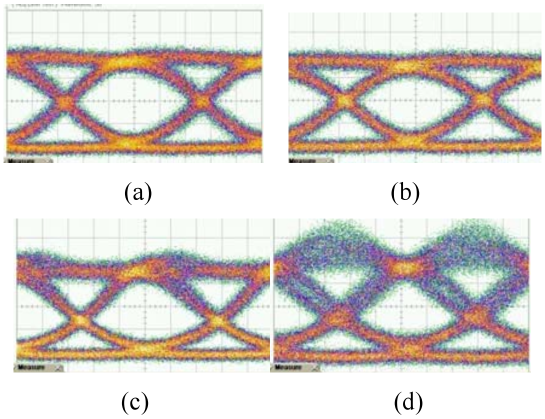


Fig. 3 Measurement setup


(a) (b)

(c) (d)

Fig. 4 53.2 Gb/s optical waveform of (a) Back-to-back, (b) +15 ps/nm, (c) -47 ps/nm and (d) -80 ps/nm.

values of -80 ps/nm, -47 ps/nm and +15 ps/nm at 1310 nm. Here, 10 km TrueWave RS-Fiber (-8.0 ps/nm-km at 1310 nm), 2.25 km Corning dispersion shifted fiber (-20.1 ps/nm-km), and 10 km Furukawa SMF (+1.5 ps/nm-km) were used for -80 ps/nm, -49 ps/nm and +15 ps/nm dispersion, respectively. Optical waveforms were measured just after the band pass filter using Keysight 86116C 65 GHz optical receiver without any Bessel filter.

III. MEASUREMENT RESULTS AND DISCUSSION

Fig. 4 shows the optical waveforms of before and after transmission. In all cases covering a full dispersion range for 10 km link from -50.8 ps/nm to +9.4 ps/nm, clear optical waveforms were observed. The extinction ratio of back-to-back condition was 6.7dB. It means a 43 Gb/s class EML has enough potential for 53.2 Gb/s NRZ application. From BER measurement, we estimated high minimum receiver sensitivity in average power of -14.1 dBm at BER = 2×10^{-4}, which corresponding to -13.0 dBm in optical modulation amplitude (OMA) as shown in Fig. 5. In IEEE 400Gb/s Ethernet Task Force, Forward Error Correction (FEC) is commonly believed to be a requirement [11]. Therefore, we assumed KP4 FEC, which has a pre-FEC BER threshold of 2×10^{-4} for a post-FEC BER of 2×10^{-15}. When the 8:1 optical Demux loss of 3dB for 400GbE (50 Gb/s × 8λ) is taken into account, Rx sensitivity in OMA is estimated at -10.0 dBm, which satisfied with the proposed specification value of -9.0 dBm [25]. From this result, 53.2 Gb/s NRZ is feasible technology thanks to its high receiver sensitivity. Ideally, bandwidth over 40 GHz is needed for 53.2 Gb/s operation. Further improvement of

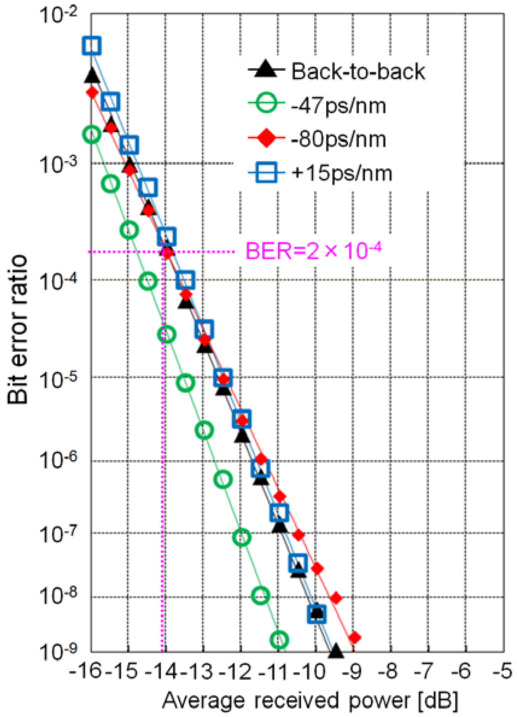


Fig. 5 Bit error ratio performance

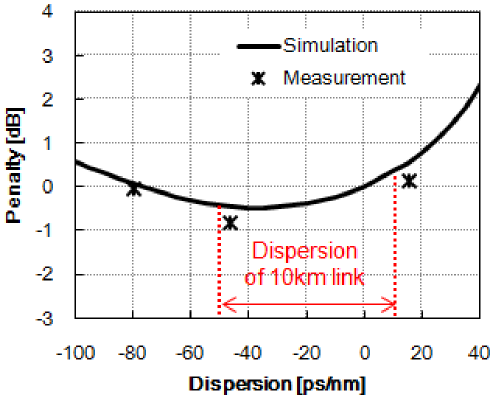


Fig. 6 Simulation and measurement results of path penalty at 53.2 Gb/s.

minimum receiver sensitivity may be possible with sufficient $f_{3\text{dB}}$ for both transmitter and receiver. No major degradation on BER curve was observed for all dispersion cases. Negative dispersion penalty at -47 ps/nm is due to a positive chirp of the EML and negative dispersion of the fiber. The simulated dispersion penalty is shown in Fig. 6. Here, actual measured EML chirp parameter curve as a function of EML reversal voltage was used in the simulation. The Simulation result indicates that the dispersion penalty for 10 km SMF link is less than 0.5 dB with wavelength allocation in Fig. 1, and less than 1 dB for 20km SMF link. Measured dispersion penalty was estimated at BER = 2×10^{-4} from Fig. 5. The measurement results show good agreement with simulation result and maximum dispersion penalty was only 0.3 dB at dispersion of +15 ps/nm. These results indicate that the distance is currently limited by the receiver sensitivity, and not dispersion. If a high speed APD [22] or a semiconductor optical amplifier is used, then transmission distance beyond 20km is expected.

IV. CONCLUSION

In this report, we discussed and demonstrated 53.2 Gb/s NRZ transmission performance for 400GbE 10km link. Receiver sensitivity of -14.0 dBm was experimentally demonstrated using 43 Gb/s devices. A very low dispersion penalty of less than 0.3dB was estimated assuming worst case dispersion for 50 Gb/s × 8λ system. Thanks to the high receiver sensitivity and low dispersion penalty of 53.2 Gb/s NRZ, 50 Gb/s × 8λ is clearly a very strong candidate for the 400GbE application.

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