# Direct Differential Drive of a Conventional 53-Gbaud EA-DFB using Commercially Available DSP

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**Abstract** DSP-direct differential drive of an EA-DFB without an external/integrated driver amplifier was demonstrated for the first time. A 53.125-Gbaud PAM4 eye waveform was confirmed with outer ER of 3.5 dB and TDECQ of 2.7 dB by differential drive with 630 $mV_{ppd}$ directly supplied from the DSP.

## Introduction

Increasing data transmission capacity in data centres (DCs) is being demanded for successful operation of modern internet services. To address this issue, 400-Gb/s optical transceivers (TRVs) are being developed actively. One of the intrinsic features of 400-Gb/s TRVs is adopting four-level pulse amplitude modulation (PAM4) instead of non-return-to-zero (NRZ) format used in conventional 100-Gb/s TRVs. For example, data rate of 106.25 Gb/s/lambda achieved by 53.125-Gbaud PAM4 has been standardized for 400G-FR4[1].

For handling PAM4 signals, a digital signal processer (DSP) is generally built into a 400-Gb/s TRV, and its transmitter typically consists of the DSP, a driver amplifier (DRV), and laser diodes (LDs)[2]. The DSP is generally equipped with a differential output with a pair of signal lines. Since the peak-to-peak amplitude of the modulation voltage ($V_{mod}$) from the DSP of each line is small-insufficient to drive the LD (e.g., around 500 $mV_{pp}$), the driver amplifier is necessary to compensate $V_{mod}$ (i.e., the driver amplifier converts the differential output from the DSP to a single-ended one or simply amplifies one output of the differential pair.).

However, it is favorable not to use the driver amplifier to reduce the number of components and power consumption. Additionally, removing the driver amplifier is expected to improve signal integrity inside the TRV, since the bandwidth degradation caused by implementing it can be suppressed. DSP-direct drive of LDs is thus one of key issues concerning TRVs using PAM4.

An electro-absorption modulator integrated DFB laser (EA-DFB) is one of the leading LDs for the 400-Gbps TRVs thanks to its large bandwidth and high extinction ratio (ER). In terms of using an EA-DFB for DSP-direct drive, mainly three approaches are taken. One is to develop a low-voltage drive EA-DFB[3]. A technical challenge concerning this approach is keeping both high ER with good linearity and high-enough output power at low $V_{mod}$. The second approach is using a DRV-integrated type DSP, which enables the same $V_{mod}$ as when using an external DRV. This approach is stable, at least for 400-Gb/s TRV, since such a DSP has been developed recently[4].

The third approach is differential drive of the EA-DFB. The advantage of this approach is that $V_{mod}$ is doubled as compared to the single-ended drive. A DRV-less TRV can thus be considered possible. Although $V_{mod}$ from the one signal line of the DSP is small, total $V_{mod}$ applied to the EA-DFB is doubled if the differential drive can be utilized. It is therefore possible to achieve large-enough ER for practical use without a DRV. Moreover, this approach is one of the promising candidates to attain high-enough ER in the case of the next-generation higher-speed TRVs (i.e., 800 Gb/s or more), whose $V_{mod}$ would be extremely small because of the resulting high-frequency loss. Even in such a case, differential drive with a DRV-integrated type DSP would surely supply enough $V_{mod}$ to drive LDs.

We previously demonstrated the differential drive of a conventional EA-DFB with a passive impedance-control circuit[5]. That is, we used a pulse-pattern generator (PPG) as a signal source for differential output, and successfully achieved 53.125-Gbaud PAM4 optical waveform with outer ER of 4.1 dB and TDECQ of 1.63 dB with 0.57 $V_{pp}$ /lane.

In this study, we demonstrated DSP-direct differential drive of a conventional EA-DFB without any external / integrated driver amplifier for the first time. One of issues concerning differential drive is common-mode noise rejection, since the output signal from a DSP of each signal line is not always so symmetrical, which is often degraded by common-mode noise. We evaluated the common-mode rejection ratio (CMRR) of a fabricated transmitter optical sub assembly (TOSA), and confirmed CMRR of more than 20 dB up to 30 GHz. Using commercially available DSP, we then demonstrated 53.125-Gbaud PAM4 differential drive, and confirmed optical waveform with outer ER of 3.5 dB and TDECQ of 2.7 dB, which are compliant with 400G-FR4 specification, under 630 $mV_{ppd}$ directly supplied from the DSP.

## Design and small-signal characteristics

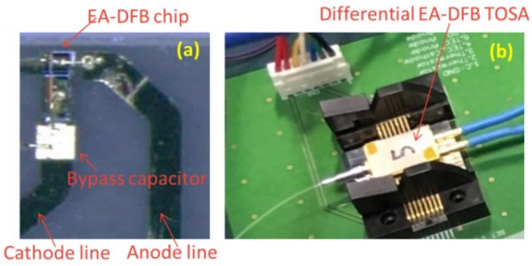


**Fig. 1:** Photograph of (a) EA-DFB on carrier developed for differential drive and (b) fabricated differential EA-DFB TOSA using the EA-DFB on carrier.

Photographs of a fabricated EA-DFB on carrier and a TOSA for differential drive are shown in Figs. 1(a) and (b), respectively. The EA-DFB chip and the carrier used in this study is almost the same as that used in our previous work[6,7]. The carrier consists of anode and cathode high-frequency lines for applying the differential signal to the EA-DFB chip. To eliminate unwanted additional modulation of the DFB laser by the cathode signal of the differential pair, a bypass capacitor is connected in parallel to the DFB laser[8].

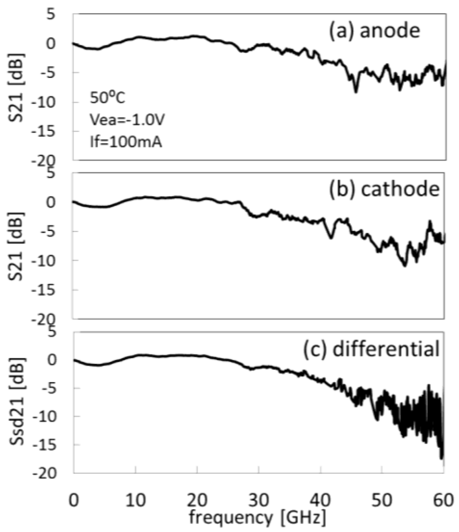


**Fig. 2:** Frequency response of (a) anode, (b) cathode, and (c) differential-drive conditions.

The TOSA shown in Fig. 1(b) consists of the EA-DFB chip on carrier, a lens, a thermo-electric cooler, and an intermediate substrate. Note that an active IC is not included in the TOSA.

The measured frequency responses (S21) of the TOSA in the anode and cathode drive are shown in Figs. 2(a) and (b), respectively, under applied DC bias voltage to the EAM ($V_{ea}$) of -1.0 V and forward DC current to the DFB (If) of 100 mA at 50ºC. As for the differential drive, a pair of RF signals with their phase shifted by π is used, and each signal is input into the anode and the cathode line, respectively. Therefore, S21 under each drive condition has to be the same. As shown in Figs. 2(a) and (b), almost the same S21 responses under anode and cathode drive conditions were obtained with large 3-dB bandwidth of around 37 GHz by the carefully optimized high-frequency carrier design. Moreover, frequency response under the differential-drive condition (Ssd21) was evaluated as shown in Fig. 2(c). Reflecting the large bandwidth of S21 under both the anode and cathode drive conditions, Ssd21 shows a superior 3-dB bandwidth of 38 GHz.

## Experimental setup for DSP-direct drive

The experimental setup for DSP-direct differential drive is shown in Fig. 3(a). We used a commercially available DSP in this study. A DSP is directly connected to the differential-EA/DFB TOSA via a BiasTees for DC ($V_{ea}$) supply.

Optical output from the TOSA was detected by a digital communication analyzer (DCA, (Keysight N1092C)). Intrinsic electrical output from the DSP was firstly evaluated by using the setup shown in Fig. 3(b). The DCA was equipped with a pair of differential electrical input ports. Measured electrical eye waveforms of 53.125-Gbaud PAM4 from the DSP and its inversion without any equalizing are shown in Figs. 4(a) and (b).

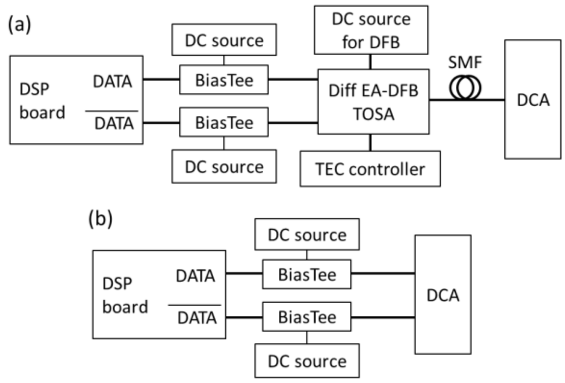


**Fig. 3:** Experimental setup for (a) DSP-direct differential drive of the fabricated differential EA-DFB TOSA and (b) measurement of intrinsic output from the DSP IC.

As shown in these figures, the eye waveforms are almost the same, but both waveforms are equally asymmetric with respect to the vertical axis. This asymmetricity indicates that common-mode noise is included in each signal from the DSP. On the other hand, the eye waveform of the differential signal shown in Fig. 4(c) is symmetrical. In the case of measurement equipment like a DCA, a pair of input ports for the differential signal is precisely designed to have equal impedances, namely, very high

CMRR. Accordingly a symmetrical differential eye waveform can be obtained since the common-mode noise can be clearly suppressed.

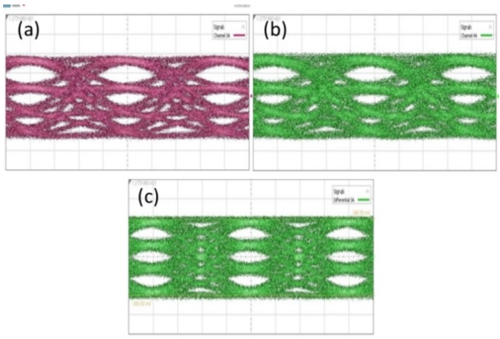


**Fig. 4:** 53.125-Gbaud electrical eye waveforms from DSP w/o equalizing: (a) anode, (b) cathode, and (c) differential signal.

## Results

CMRR of the differential EA-DFB TOSA was firstly evaluated. CMRR is usually defined as the difference between transmission-frequency characteristics in differential and common modes. Ssc21 (which corresponds to the transmission characteristic in common mode) was thus evaluated, and then subtracted from Ssd21 (shown in Section 2). Measured CMRR, shown in Fig. 5, is over 20 dB up to around 30 GHz. This result is almost the same as CMRR of a commercially available packaged electrical linear amplifier equipped with differential input and single-ended output[9]. In other word, our differential EA-DFB TOSA is expected to have superior common-mode noise-rejection capability.

A 53.125-Gbaud PAM4 (106.25-Gbps) DSP-direct differential drive with the fabricated EA-DFB TOSA was also evaluated. The experimental setup is shown in the previous section [Fig. 3(a)].

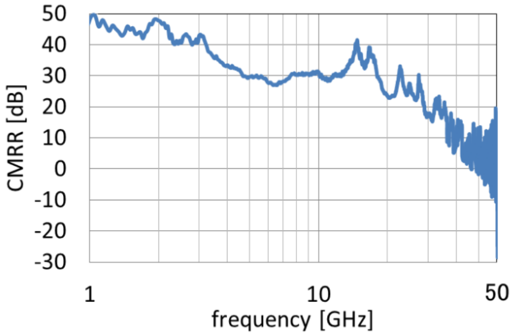


**Fig. 5:** Measured CMRR of differential EA-DFB TOSA.

Measured optical eye waveforms under $V_{ea}$ of -1.2 V and If of 100 mA at 50ºC with pseudo-random bit sequence (PRBS) of $2^{15}$-1 are shown in Fig. 6. Peak-to-peak $V_{mod}$ of the differential signal applied to the TOSA from the DSP is 630 $mV_{ppd}$, which indicates that $V_{mod}$ in anode and cathode lanes are both 315 $mV_{pp}$.

A symmetrical waveform, even with raw data, was obtained, reflecting the good CMRR of the TOSA, and a clear eye waveform with outer ER of 3.5 dB with FFE of 3 Taps is confirmed. Moreover, measured TDECQ with a $4^{th}$-order Bessel-Thomson filter (26.6GHz) was 2.7 dB. These results are compliant with the 400G-FR4 specification, and it is concluded that a practical optical eye waveform can be obtained by DSP-direct differential drive without a driver amplifier.

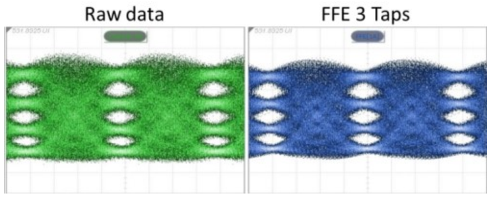


**Fig. 6:** Measured 53.125-Gbaud optical eye waveforms of raw data and with FFE of 3 taps with Vea of -1.2 V and If of 100 mA at 50ºC.

## Conclusions

DSP direct differential drive of a conventional EA-DFB without an external/integrated driver amplifier was demonstrated for the first time. The fabricated differential-EA-DFB TOSA showed very high CMRR of 20 dB up to around 30 GHz. Reflecting that superior CMRR, a symmetrical 53.125-Gbaud PAM4 optical eye waveform was confirmed by DSP-direct differential drive with outer ER of 3.5dB and TDECQ of 2.7 dB, which is compliant with the 400G-FR specification, by supplying modulation voltage of 630 $mV_{ppd}$ directly from the DSP.

## References

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