

Design of 64 Gbaud 16QAM Coherent Transmitter IC with Asynchronous Feed-Forward Equalizer

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Abstract— We demonstrate a 64 Gbaud 16-QAM coherent transmitter IC in CMOS SOI process with an asynchronous feed-forward equalizer (FFE) driver based on passive coplanar waveguide and Si Mach-Zehnder modulator, achieving a 3-dB bandwidth of 26GHz and 3 Vppd output swing.

Keywords— CMOS, Coherent, optical transmitter, integration, Feed-Forward Equalizer

I. INTRODUCTION

As hyperscale datacenters span short- to long-reach links and line rates continue to rise, interest in coherent optical links grows because of their high spectral efficiency and long-reach capability. Compared to an IMDD transmitter based on an MZM, a coherent transmitter using an IQ-MZM removes the key TX bottlenecks as lane rates scale. PAM4 over IMDD must linearize three eyes through the MZM's cosine transfer, which drives up Vppd and power, and its residual chirp couples with chromatic dispersion, forcing pre-emphasis that reduces OMA. In contrast, an IQ-MZM operated near quadrature enables low-swing, nearly chirp-free field modulation; higher spectral efficiency (e.g., DP-QPSK/16QAM) allows the same throughput at a lower baud per channel; and dispersion/PMD are digitally equalized at the receiver, easing TX ER/OMA and pre-distortion requirements. Practically, this is why coherent scales better in TX power, linearity, and packaging as we push beyond 100 Gb/s-per-lane.

Recent studies report InP photonic integrated circuits (PICs) achieving high extinction ratio and low $V\pi$ [1], as well as BiCMOS electronic ICs that are higher-speed and more breakdown-robust than CMOS [2]. However, heterogeneous integration between the PIC and the BiCMOS electronics increases packaging complexity, cost, and parasitics, making these approaches less attractive. Silicon photonics (SiPh) offers an attractive alternative to these limitations. However, the primary challenge for Si-based Mach-Zehnder modulator and its driver are higher $V\pi$, limited electro-optic bandwidth, and lower breakdown voltage. Moreover, in prevailing MZM-PAM4 transmitters the driver-side back-termination ($\approx 50 \Omega$ per arm) effectively halves the voltage delivered to the electrodes; restoring the target swing requires roughly doubling the output current, which inflates both termination and driver power dissipation. In addition, the lack of monolithic integration leaves a long, discontinuous electrical path (pads/ESD/wire-bonds or interposer traces) whose

inductive and capacitive parasitics degrade signal integrity—lowering return loss and inducing peaking/ringing and group-delay ripple—thereby further squeezing the PAM4 eye.

In this paper, we present a coherent transmitter based on a coplanar-waveguide-based analog feed-forward equalizer (CPW-FFE), achieving 3-dB bandwidth of 26 GHz and 3 Vpp differential output swing. This work demonstrates 64 Gbaud 16-QAM at 1310nm O-Band.

II. PROPOSED MONOLITHIC COHERENT TRANSMITTER

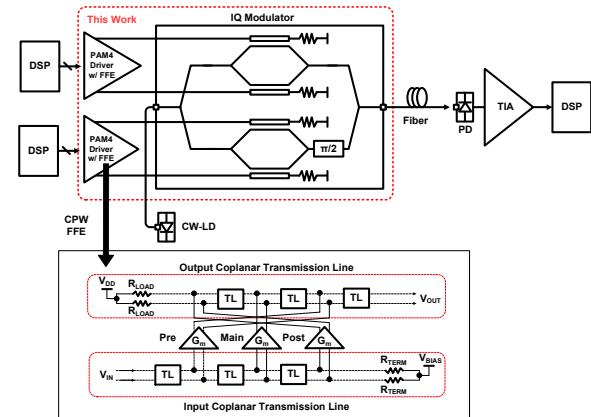


Figure 1. Block diagram of the transmitter with on-chip CPW-FFE.

Figure 1 depicts a monolithically integrated optical transmitter that combines a coplanar-waveguide feed-forward equalizer (CPW-FFE) with a silicon IQ modulator implemented as a nested Mach-Zehnder (MZM) structure. The electrical front end is a traveling-wave FFE formed by distributed driver slices that inject weighted versions of the data onto a 50- Ω CPW co-designed with the modulator electrodes. The line provides a per-tap propagation delay of $\Delta t \approx 26$ ps; at 28-GBaud (1 UI ≈ 35.7 ps) this corresponds to $\Delta t \approx 0.73$ UI, enabling fractional pre-emphasis that places spectral zeros between Nyquist lobes and compensates the mid-band roll-off of the package-plus-modulator channel. Tap weights are analog-controlled and selected to minimize inter-symbol interference by fitting the measured small-signal channel response; end-termination is matched to suppress reflections and maintain a unidirectional traveling wave.

The optical IQ stage adopts a nested MZM: two inner push-pull phase shifters realize the I and Q branches, which

are combined by a 2×2 coupler while a thermo-optic phase shifter enforces a 90° quadrature offset. Bias controllers hold each inner MZM at quadrature to achieve near-linear field modulation with low residual chirp. Sharing the same traveling-wave electrode geometry between the CPW-FFE and the modulator minimizes discontinuities and wire-bond parasitics, allowing modest-swing differential drive while preserving extinction and bandwidth. This co-design yields a compact transmitter that achieves the required pre-emphasis in the electrical domain and linear, chirp-controlled modulation in the optical domain—well suited for QPSK/16QAM operation at 28-GBaud and beyond.

The 3-tap CPW-FFE's transfer function is as follows:

$$H(j\omega) = b_0 + b_1 e^{-j\omega\tau} + b_2 e^{-j2\omega\tau} \quad (1)$$

$$|H(j\omega)| = \sqrt{(1 + b_1^2 + b_2^2 + 2(b_1 + b_1 b_2)\cos(\omega\tau) + 2b_2\cos(2\omega\tau))} \quad (2)$$

with the frequency domain transfer function given by (1) and its magnitude is expressed in (2). With a per-tap delay of 26 ps corresponds to ≈ 0.73 UI at 28 GBaud. Thus, network operates in a fractional-UI regime that produces intentional peaking near the Nyquist region, thereby extending electrical bandwidth more effectively than UI-spaced FFE. Per-tap transconductance coefficients (gm) are tuned by adjusting bias currents.

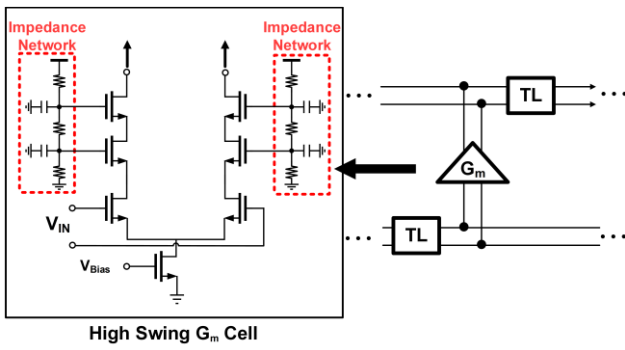


Figure 2. Schematic of FFE Gm cells.

In Figure 2, high-swing transconductance (Gm) cells are used in the proposed driver, which employs an external gate impedance network to mitigate transistor overstress. By adopting RC network at the gate node of cascode transistor, the voltage swing at the Gm cell output is evenly divided across each transistor [3].

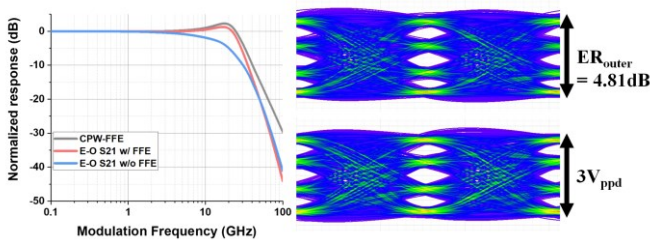


Figure 3. Simulated frequency response and 56Gb/s PAM-4 eye diagram.

The small signal responses for the photonic and electronic circuits are shown in Figure 3. The electrical 3 dB bandwidth is 13 GHz without the CPW-FFE and 28 GHz with the embedded CPW-FFE. A per-tap delay of 26 ps places the designed peaking near 13 GHz for effective bandwidth extension. The driver integrated with 2-mm-arm silicon modulator, achieves an electro-optic (E-O) bandwidth of 26 GHz and 12 dB gain by using distributed amplifying architecture [4]. Simulated eye diagram for proposed optical transmitter is indicated in Fig. 2(c). An outer ER of 4.81 dB is achieved at 56 Gb/s PAM-4, and each driver delivers up to 3 Vpp swing to the modulator through a 50Ω coplanar interface.

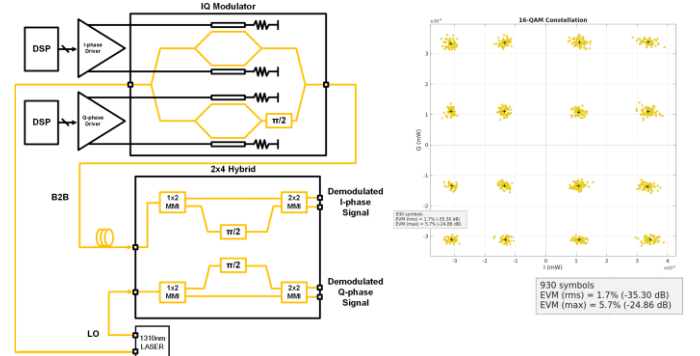


Figure 4. Block diagram of the transmitter characterization setup and 112Gbps unsampled constellation.

The optical simulation setup and resulting 16-QAM constellation are shown in Fig. 3. The stressed input signal, distorted by parasitics and further amplified in each driver, is captured using a 2×4 optical hybrid in a back-to-back configuration. 64 Gbaud 16-QAM constellation exhibits well-defined 16-QAM symbols with an EVM of 5.7% and pre-FEC BER below 3×10^{-3} .

III.CONCLUSION

We present a monolithic 16-QAM optical transmitter with an on-chip CPW-based analog FFE, which extends the bandwidth to 26 GHz and delivers 3 Vpp output swing. This architecture can be readily extended to dual polarization (DP) coherent systems by duplicating the I/Q-MZM branch and adding a polarization multiplexer using the same CPW-FFE network per polarization preserves high-frequency boosting, enabling 224 Gb/s DP-16-QAM.

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