Design of a PAM-4 Driver Circuit for MZI Optical Moduators using eSim and Skywater 130 PDK

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***Abstract*— This paper presents the design of a driver circuit for generating a four-level Pulse Amplitude Modulation (PAM-4) format in Mach-Zehnder Interferometer (MZI) optical modulators. Higher-level modulation formats are inevitable for enhancing spectral efficiency and achieving high data rates in silicon-on-insulator (SOI) optical modulators, meeting the demands of AI-driven data centers. The design and verification of the proposed driver circuit are conducted using open-source simulation software, eSim, with the Skywater 130 PDK. These methodologies and results aim to advance India's semiconductor mission (ISM) by accelerating efforts in indigenous chip design.**

Keywords—PAM-4, Mach-Zehnder Modulator, eSim, Skywater 130, CMOS

I. INTRODUCTION

High-speed driver circuits are essential for achieving efficient switching in silicon photonics-based optical modulators. As data communication demands surge, increasing spectral efficiency and enabling high data rate modulation on a single optical carrier have become essential to support next-generation AI-driven data centers and optical computing. Advanced modulation formats, such as Quadrature Amplitude Modulation (QAM), Quadrature Phase Shift Keying (QPSK), and Pulse Amplitude Modulation (PAM), offer potential solutions to meet these demands. In this study, we propose a driver circuit that generates a four-level PAM (PAM-4) signal to drive a Mach-Zehnder Interferometer (MZI) optical modulator, leveraging open-source eSim and Skywater 130 PDK for design validation.

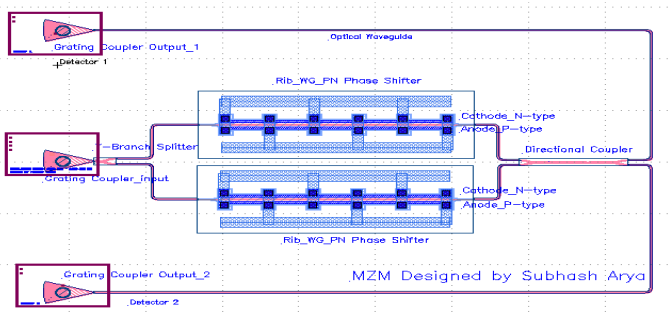

Fig. 1. GDS-II Layout of MZM using SIEPIC-pdk and tool

Figure 1 illustrates the GDS-II layout of the Mach-Zehnder Modulator (MZM), designed using the SiEPIC PDK and tools on the KLayout open-source platform. In this layout, the PAM-4 driver circuit is connected to the PN junction of the optical modulator. The four-level PAM-4 signal, generated from binary information bits, modulates the optical carrier at a wavelength of 1550 nm, selected due to its minimal optical loss, making it suitable for long-haul optical transmission. This design demonstrates the integration of multi-level signaling with silicon photonic modulators for efficient data transmission.

II. MODULATOR DRIVER BLOCK DIAGRAM

Figure 2 presents the block diagram of the proposed PAM-4 driver circuit designed to drive the Mach-Zehnder Modulator (MZM). The design employs a 2-bit synchronous counter that generates four binary states: 00, 01, 10, and 11. These states are converted into Gray code (00, 01, 11, 10) to ensure that only one-bit changes between adjacent states, thereby minimizing transition errors and enhancing signal stability.

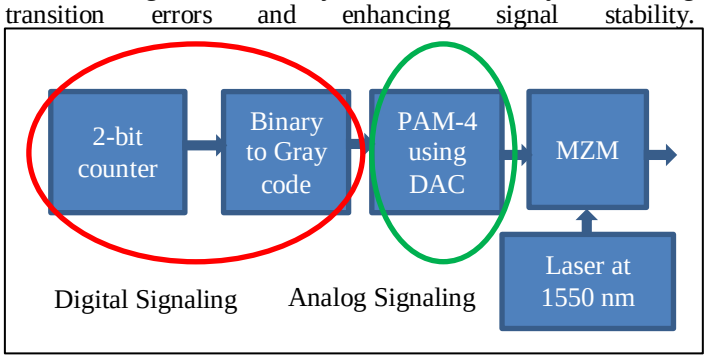

Fig. 2. Block diagram of designing PAM-4 driver

The Gray-coded output is then fed into a 2-bit Digital-to-Analog Converter (DAC) circuit, which produces a four-level PAM-4 signal. This signal drives the PN junction in the MZM, operating under reverse bias to achieve effective modulation of the 1550 nm optical carrier.

III. SIMULATION RESULTS AND DISCUSSION

Figutre. 3 shows the expected waveform output. The non-return-to-zero (NRZ) signal will be generated using a counter, and then binary to Gray code will assign the reference voltages to DAC to give PAM-4 signal.

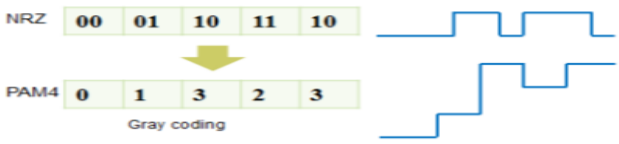

Fig. 3. The PAM-4 signal as per NRZ and Gray code (left its weight and right its waveshape at 4 voltage levels) [2]

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