PAM4 Optical Module Principle



Overview

Optical PAM4 transceiver Pulse amplitude modulation builds upon this concept by encoding data across multiple voltage levels. PAM4 uses four levels. A PAM4.

Key Takeaways

PAM4 optical modules transmit data using four distinct amplitude levels per clock cycle, effectively doubling the bit rate compared to traditional NRZ encoding. Basic Principle of PAM4PAM4 (Pulse Amplitude Modulation with 4 levels) is a multi-level modulation technique used in high-speed optical communication. Unlike traditional NRZ (Non-Return-to-Zero) signals, which encode one bit per clock cycle using two voltage levels (0 and 1), PAM4 uses four distinct amplitude levels to encode two bits per clock cycle (00, 01, 10, 11).

This allows PAM4 to double the data rate without increasing the baud rate, improving bandwidth utilization and reducing transmission costs.

Optical Implementation

In optical modules, PAM4 signals are typically generated using Mach-Zehnder modulators (MZMs).

The MZ

M converts electrical PAM4 signals into optical intensity variations. Traditional designs use a digital-to-analog converter (DAC) to drive the MZM, but advanced designs employ segmented-electrode MZMs, which can implement PAM4 without a separate DAC by using binary-weighted phase shifters. Each segment modulates a portion of the optical signal corresponding to the most- and least-significant bits, allowing precise control of the four amplitude levels.

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Signal CharacteristicsPAM4 signals have three eye openings in the eye diagram, compared to a single eye for NRZ signals. Each eye represents a voltage transition between two adjacent levels, and the signal-to-noise ratio (SNR) requirements are higher because the voltage difference between levels is smaller. Proper timing and phase alignment are critical to maintain signal integrity, especially at high data rates like 50 Gbps per lane used in 400GE and 200GE interfaces.

Advantages

Higher spectral efficiency: Transmits two bits per symbol, doubling the bit rate at the same baud rate. Reduced cost per bit: Achieves higher throughput without increasing channel bandwidth. Compatibility with high-speed interfaces: Adopted in IEEE 802.3 standards for 50GE, 200GE, and 400GE.

SummaryPAM4 optical modules leverage four-level amplitude modulation to increase data throughput efficiently. By using MZMs with segmented electrodes or DAC-driven modulators, they convert electrical PAM4 signals into optical signals suitable for high-speed fiber-optic communication. The design requires careful attention to eye diagram quality, SNR, and timing alignment to ensure reliable transmission at high data rates.

Article Content

Optical PAM4 transceiver

Pulse amplitude modulation builds upon this concept by encoding data across multiple voltage levels. PAM4 uses four levels. A PAM4 signal can appear as one of four voltages during

PAM-4 Transmitter PIC Design Using Segmented-Electrode Mach

Figure 1 shows an OptSim Circuit schematic of a PAM-4 transmitter using an SE-MZM made from discrete PIC elements. The topology comprises bidirectional PIC elements such as an optical splitter

What is PAM4 Modulation and How is it Transforming

What is PAM4 Modulation and How is it Transforming Optical Networking? In this blog, we take a higher-level look at PAM4, the modulation scheme that makes

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This Pulse-Amplitude Modulation 4-Level (PAM4) application note explains PAM4 theory and operation while introducing the Intel® Stratix® 10 TX device capability and the realization of 57.8 Gbps data

PAM4 Modulation for High-Speed Optical Interconnects

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By 2022, IEEE 802.3ck had extended the principle to 100 Gbps per lane using 53.125 GBaud PAM4, enabling single-lane 100G transceivers and 800G modules with eight electrical lanes.

A 100-Gb/s PAM4 Optical Transmitter in a 3-D-Integrated SiPh-CMOS ...

Abstract—This article presents a 100-Gb/s four-level pulse-amplitude modulation (PAM4) optical transmitter system implemented in a 3-D-integrated silicon photonics-CMOS platform.

PAM4 for 400G Optical Interfaces and Beyond (Part 1)

How PAM4 works and why it relieves bandwidth requirements. Instead of sending binary 1''s and 0''s, PAM4 presents 4 levels, which are generated by combing two bits into a single symbol

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In this blog, we take a higher-level look at PAM4, the modulation scheme that makes short distance 400G networking possible, and discuss how this technology has enabled big leaps in optical

Understanding PAM4 Signaling: A Beginner Guide

Its extra voltage level requires reduced level spacing, resulting in a higher signal-to-noise ratio, which is why PAM4 works best in short-range optical systems. PAM4 is generally only suitable

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PAM4 technology offers several advantages for optical transceiver modules. Firstly, PAM4 allows for a higher data rate to be transmitted over the same bandwidth as NRZ.

What Is PAM4? What Are the Advantages of PAM4?

Four-level pulse amplitude modulation (PAM4) uses four different signal levels for signal transmission, doubling the signal transmission efficiency compared with the traditional non-return-to

AN 835: PAM4 Signaling Fundamentals

This application note explains PAM4 theory and its operation. It describes NRZ and PAM4 fundamentals, standards using PAM4 coding schemes, and CEI-56G Interconnect reaches and

Design and Implementation Scheme of QSFP28 Optical Transceiver

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The rest of the paper is organized as follows: In Section 2, the principle of the PAM4 method and the relevant standard are analyzed for the design of the QSFP28 optical transceiver.

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Introduction to PAM4

PAM4 Standards Optical Internetworking Forum (OIF) outlines a few standards using PAM4 scheme The one that is relevant for FPGA to optical module communication is CEI-56G-VSR (very short

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Discover the benefits, features, and applications of 100G PAM4 DWDM optical modules, and learn how they compare with coherent optics for modern network deployment.

6 PAM4 Signaling and its Applications

6 PAM4 Signaling and its Applications Abstract: In recent years, investments by cloud companies in mega data centers and associated network infrastructure has created a very active and dynamic

Open the Door to PAM4 Modulation

By leveraging PAM4, the module effectively doubles the bit rate compared to traditional NRZ-based solutions, making it ideal for cost-effective, high-performance, and long-distance optical

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