Debugging the PAM4 Optical Core Router



Overview

Analyzing 26-53 GBaud PAM4 Optical and Electrical SignalsTo perform accurate debug and compliance tests of optical transceivers you need a high performance.

Key Takeaways

Debugging a PAM4 optical core router requires careful analysis of signal integrity, BER/SER measurements, and systematic diagnostic testing to identify and resolve errors in high-speed optical links. Understanding PAM4 SignalsPAM4 (4-level pulse amplitude modulation) encodes two bits per symbol, effectively doubling data throughput compared to NRZ while using half the bandwidth. Each symbol corresponds to one of four voltage or optical power levels (S0, S1, S2, S3), and errors in a single symbol can result in one or two bit errors.

Gray coding is often used to reduce the impact of symbol errors on bit error rate (BER) and to help the symbol error rate (SER) converge toward BER. PAM4 signals are more susceptible to signal-to-noise ratio (SNR) degradation, inter-symbol interference (ISI), and crosstalk due to the closer spacing of amplitude levels. Forward error correction (FEC) is commonly employed to compensate for the SNR drop, allowing raw BERs as high as 2.

4E-4 while maintaining reliable communication.

Key Debugging Techniques

Start with Simple Conditions Begin testing with a single channel and minimal stress to ensure the basic functionality of the transceiver. Gradually introduce additional channels, crosstalk, and stress patterns to isolate the source of errors.

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BER and SE

R Analysis Measure bit error rate (BER) to quantify the receiver's overall performance and symbol error rate (SER) to identify which PAM4 symbols are prone to errors.

Detailed SE

R analysis helps pinpoint whether errors are concentrated in specific amplitude levels, which can indicate issues like amplitude imbalance or timing skew. Eye Diagram Inspection Use high-speed oscilloscopes with precision optical-to-electrical (O/E) converters to visualize the eye diagrams of PAM4 signals. Inspect the low, middle, and upper eyes for closure or distortion, which can indicate ISI, jitter, or amplitude mismatches.

Compliance vs.

Diagnostic Testing

Compliance testing evaluates the transceiver under standardized stress conditions to ensure interoperability. Diagnostic testing isolates faults by testing under controlled, simplified conditions before gradually introducing stressors. This approach helps identify the root cause of failures, such as chromatic dispersion, modal dispersion, or electrical channel loss.

Simulation and Modeling Tools like Ansys INTERCONNECT can simulate PAM4 optical links, allowing you to model transmitter and receiver behavior, phase shifts, and coupling effects. This helps predict potential issues before physical testing.

Practical Test Setup

Optical Path: Transmit the PAM4 signal through a fiber that introduces chromatic dispersion (CD) and analyze it with an oscilloscope equipped with a precision O/E converter. Electrical Path: Send the signal through a test board that introduces ISI and loss to challenge transmitter equalization. Use a test fixture to deliver the signal to the oscilloscope.

Summary

Effective debugging of PAM4 optical core routers involves a combination of systematic diagnostic testing, BER/SER analysis, eye diagram inspection, and simulation tools. By starting with simple conditions and progressively introducing stress, engineers can isolate and correct issues related to amplitude levels, timing, crosstalk, and channel impairments, ensuring reliable high-speed optical communication.

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Article Content

Analyzing 26-53 GBaud PAM4 Optical and Electrical Signals

To perform accurate debug and compliance tests of optical transceivers you need a high performance, wide bandwidth oscilloscope equipped with an optical to electrical, O/E, convertor with great linearity

QSFP28 PAM4 DWDM: High-Capacity 100G/400G Optical

Explore QSFP28 PAM4 DWDM transceivers for high-speed 100G/400G networks. Learn how PAM4 modulation and DWDM enable long-reach, energy-efficient, and cost-effective optical

Debugging the 1 6T Optical Module PAM4

Ara, the industry"s first 3nm 1.6Tbps PAM4 optical DSP, is enabling the lowest-power 1.6T optical modules and advancing interconnect technology for next-generation AI and cloud data center networks.

Optical PAM4 transceiver

There are three steps associated with the whole process. Signal integrity analysis is done by special elements, the analyzers. Analyzers allows for post-processing of data stored in monitors. The results

50G PAM4 Technical White Paper

The optical components and chips of PAM4 modules are very different from those of NRZ modules. The following table lists the differences between 50G QSFP28 LR and 25G SFP28 LR.

AN 835: PAM4 Signaling Fundamentals

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

DesignCon 2002

With the introduction of PAM4, new methods have been introduced to handle the extra complexity of PAM4 encoding and to better measure jitter parameters of interest.

N19306B PAM-4 analysis | Keysight

Learn to make advanced measurements and how to model differential devices. Correctly measure non-linear differential circuits using single-ended techniques. Want help or have questions?

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PAM4 Analysis Software Instruction Manual

Select each part of the PAM4 signal you wish to display and measure: Full signal, Upper crossing, Middle crossing, and Lower crossing. All your PAM4 configurations will apply to this selection. Begin

PAM4 Signaling in High Speed Serial Technology: Test, Analysis, and Debug

Since fiber optic systems can operate above 25 Gbd with PAM2-NRZ the switch is less urgent—and this fact is reflected in the decreased rate of optical PAM4 development. For optical systems, the

PAM4 Signaling in High Speed Serial Technology: Test, Analysis, and Debug

Learn valuable information on testing PAM4 technology and approaches for validating PAM4 signals. This application note describes: PAM4 technology for 50-400G applications Provides details of PAM4

Coherent vs PAM4 Modulation: Optical Transceiver Guide

Compare Coherent and PAM4 modulation for optical transceivers. Learn differences, applications, costs, and when to choose each for 400G networks.

Debugging the 1 6T Optical Module PAM4

Marvell is honored to receive the Leading EDGE 2025 Award Ara, the industry"s first 3nm 1.6Tbps PAM4 optical DSP, is enabling the lowest-power 1.6T optical modules and advancing interconnect

PAM4 Optical Modulation: Meeting the Demands of Increasing

Consequently, the industry has turned to PAM4 modulation to realize ultra-high-bandwidth network architectures. PAM4 is an optical modulation technique that allows for higher data rates and

How are NRZ and PAM different in an eye diagram?

When three or more levels are used in an eye diagram, then the format can be PAM3, PAM4, and so on, depending on the number of levels. For

PAM4 Technology: Revolutionizing Optical Transceiver and ...

Introduction In the rapidly-evolving world of optical communication, PAM4 technology has emerged as a game-changer. PAM4 stands for Pulse Amplitude Modulation with 4 levels, and it

Multilevel Pulse Amplitude Modulation Transmissions for Data Center ...

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Four-level pulse amplitude modulation (PAM4) is appearing as an important option for many applications that require optical communications at high data rate for short distances and/or

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

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This document is for preliminary research. Verify specifications against current standards, product documentation and project requirements.

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