

Development of Long-Distance Optical Modules



Overview

Long-haul large-capacity 400G optical transmission over 1,500 km is possible through advanced fibre-optic systems.

Key Takeaways

Long-distance optical modules are evolving through coherent optics, silicon photonics, and pluggable high-speed designs, enabling longer transmission distances, higher data rates, and lower power consumption.

Coherent Optical Modules: Coherent technology is central to long-distance, high-speed transmission, offering superior signal quality and extended reach. Modern pluggable coherent modules, such as 800G ZR/ZR+, can transmit over 1,000 km at 800 Gbps and up to 2,500 km at 400 Gbps using Probabilistic Constellation Shaping (PCS), approaching the Shannon limit for data transmission efficiency. These modules have largely closed the performance gap with traditional embedded DSP-based systems, enabling flexible deployment in metro and long-haul networks (Marvell) .

Silicon Photonics (SiPh): SiPh integrates optical components on silicon substrates using CMOS processes, providing high integration, cost efficiency, and scalability. It is particularly advantageous for data center interconnects (DCI) and coherent optics, supporting 400G and 800G modules while reducing power consumption and footprint .

Linear and Half-Retimed Optics (LPO/LRO): LPO modules simplify design by eliminating traditional DSP and CDR chips, retaining high-linearity drivers and trans-impedance amplifiers, reducing power consumption from over 13W to under 4W for 800G modules. LRO serves as a transitional technology, balancing performance and energy efficiency while maintaining interoperability .

Co-Packaged Optics (CPO): CPO tightly integrates switch ASICs and optical engines on the same board, reducing signal loss, power consumption, and cost. While still in early development, CPO is expected to become critical as data rates approach 1.6T, complementing silicon photonics and coherent solutions .

Transmission and Module Innovations

Pluggable Modules: Standardized pluggable form factors (QSFP-DD, OSFP) allow modular deployment, reducing cost, power, and space requirements. 100G BIDI modules achieve 80 km transmission using single-fiber bidirectional architecture, high-power DFB lasers, dispersion compensation, and low-noise APD detectors, optimizing cost-effectiveness for DCI and backbone networks .

WDM/DWDM and ROADM Technologies: Dense Wavelength Division Multiplexing (DWDM) and Reconfigurable Optical Add-Drop Multiplexers (ROADM) enable high-capacity, flexible long-distance transmission. Optical cross-connects (OXC) further allow large-scale signal routing without electrical conversion, supporting mesh core networks .

Market and Future Outlook

The global optical module market is projected to grow from \$11 billion in 2022 to over \$20 billion by 2027, driven by AI, 5G, and ultra-large-scale data centers. Emerging 1.6T and 3.2T modules, combining silicon photonics with thin-film lithium niobate modulation, are expected to support ultra-long-distance interconnects and next-generation AI computing clusters, with commercial availability anticipated after 2026 .

Summary

The development of long-distance optical modules is characterized by higher data rates, longer reach, lower power consumption, and modularity. Key enabling technologies include coherent optics, silicon photonics, LPO/LRO, CPO, and advanced WDM/DWDM systems. These innovations are driving the adoption of 400G, 800G, and future 1.6T+ modules for DCI, metro, and backbone networks, meeting the growing demands of AI, 5G, and global data center expansion.

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