Optical & Photonic Manifesto

Enabling Breakthroughs in Optical Bandwidth Density

MACOM™

Partners from RF to Light

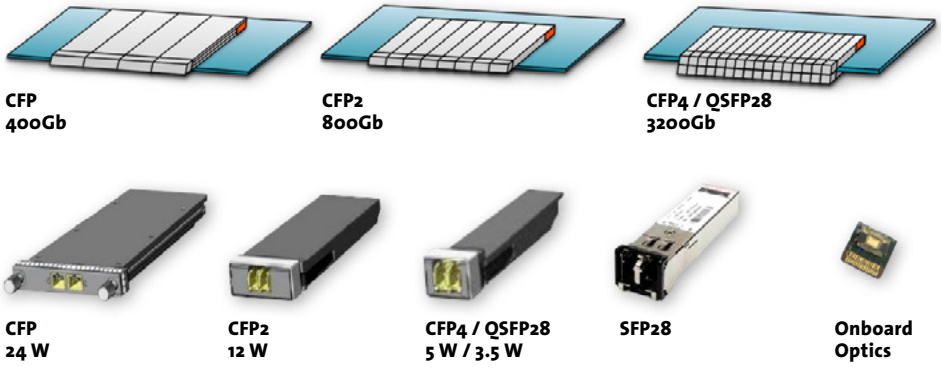
With the insatiable demand for higher throughput and increased connectivity, the estimated TAM for physical layer interconnect component solutions represents a $1B opportunity for MACOM[1]. In our Cloud connected, apps driven economy delivering services for the forecasted 3.9 billion global internet users in 2019[2], MACOM's high performance analog and photonic solutions products are delivering breakthrough gains in bandwidth density that help service providers and Cloud Data Centers enable a more connected world.

The Long Haul & Metro Successes

Today's service providers are challenged to maximize their bandwidth by leveraging existing fiber installations, and increasing throughput-per-fiber rates to improve overall spectral efficiency. The transition to 100G has been enabled by coherent technology and continued evolutions in dense wavelength division multiplexing (DWDM) that provide the pathway to 200G, 400G and beyond.

In parallel, service providers are deploying increasingly compact and thermally optimized optical transceiver modules to accommodate their rack space and power constraints, moving beyond the legacy CFP form factor toward today's CFP2 and future CFP4 form factors that are ½ and ¼ the size of CFP modules, respectively. Continued improvements in spectral efficiency and reductions in transceiver module size are enabling service providers to maximize their bandwidth density, measured in bit rate per available space and power budget.

Enabling continued improvements in spectral efficiency and reductions in transceiver module size.



The ability to deploy optical modules within strict size and power constraints is heavily defined by the analog and photonic technology within the modules. Over the last few years, MACOM has established a leading market position in long haul and metro networks, by its own estimates securing over 50% market share for coherent modulator drivers by providing the requisite breakthroughs in integration and power efficiency that are enabling denser module form factors.

In long haul, MACOM's breakthrough market penetration commenced with the introduction of our MAOM-003405 driver, the industry's first quad channel surface mount driver for 100G coherent applications. The space and power savings provided by this product

enabled the transition to smaller form factor transponders and higher density line cards, enabling service providers to achieve significant gains in bandwidth density. MACOM has continued building on the success of our long haul driver portfolio and today estimates that it holds over 50% share in this market.

In metro, MACOM's MAOM-03409B modulator driver was the first in the industry to meet the size and power consumption requirements of the CFP2 analog coherent optical (CFP2-ACO) module specification, today's de-facto standard for metro systems. Our breakthrough SMD packaging integration and first-to-market CFP2-ACO support has enabled significantly lower cost-per-bit ratios in metro applications, where lower power and smaller size ensure higher port densities that conserve valuable rack real estate. Providing a comprehensive range of limiting and linear drivers for QPSK and 16QAM modulation formats, MACOM estimates that it is positioned with over 75% design-win share in this segment, and we expect metro to continue to drive growth over the next several years.

The MAOM-00340: The industry's first quad channel surface mount driver for 100G coherent applications.

Looking ahead to future deployments, MACOM is sustaining and extending our market leadership with breakthrough products like the MAOM-006428, the industry's first 64 Gbaud linear modulator driver which enables data-rates up to 600G. By increasing the data rate on a single wavelength from 100G to 600G – up to 6X increase in throughput – service providers can dramatically increase their bandwidth density and reduce their cost-per-bit. Leveraging the combined strengths of our analog and photonics technology portfolios, we predict that the opportunity for MACOM in long haul and metro networks can surpass $1B over the next 5 of years.

Data Centers: Riding the Tsunami

The continuous explosion of video and mobile traffic drove 4.7 zettabytes, or almost five trillion gigabytes of Data Center traffic in 2015, per Cisco's Global Cloud Index . Every kilobyte of external traffic entering the Data Center generates approximately 930 kilobytes of internal traffic, and almost 80% of that traffic is East-West or remains within the Data Center, subject to the risk of bandwidth bottlenecks.

Cloud Data Centers: 10x - 100x larger opportunity than service providers.

To handle this tsunami of data traffic, Cloud Data Center operators such as Amazon, Microsoft, Google and Facebook are rapidly building out their Data Centers and simultaneously boosting connectivity by extending data delivery speeds to 100G and 400G and beyond. Space savings, power consumption and cost efficiencies are the critical considerations guiding Data Center operators' infrastructure build-out strategies as they seek to lower their average per-bit delivery costs.

It is therefore imperative that they maximize the data throughput per faceplate in their Data Center switches at the lowest possible cost, resulting in maximized bandwidth density in Cloud Data Centers, it is essential to improve the integration of analog and photonic content within the module, be it a CFP, CFP2, CFP4, QSFP28, OSFP or QSFP-DD form factor.

In parallel, as is the case with network service providers, Cloud Data Centers need to maximize the data throughput over their installed fiber in a cost efficient manner. Advanced modulation schemes that are efficient to implement in Silicon such as PAM4 increase the amount of data transmitted over each existing fiber connection while reducing the cost per bit significantly, hence the importance of PAM4 as a key technology in next generation Data Centers.

[1] MACOM Internal Estimates.
[2, 3] "Global Cloud Index (GCI)." Cisco. Accessed April 25, 2016.

Flagship Products

M02180
10G SiGe laser driver for PON
> Integrated CDR, APD DC-DC controller, EEPROM and DDMI
> Industry's lowest power

M02027
2.5G TIA for GPON ONU
> Best-in-class sensitivity and overload performance
> Industry's lowest power

131D-02E-VCT11-501
2.5G 1310mm DFB Laser for GPON
> Indium Phosphide
> Etch Facet Technology (EFT)

131F-10I-LT5K1C-S
2.5G 1310mm DFB Laser for GPON
> Indium Phosphide
> Etch Facet Technology (EFT)

MACOM's flagship high performance analog product offering.

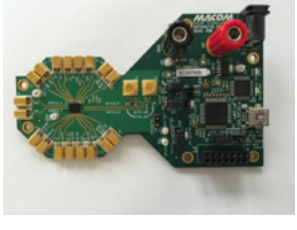
Individual Cloud Data Centers also need to be connected to each other at high bandwidth speeds to meet resiliency and data redundancy requirements, spanning distances up to 100km. Data Center interconnects (DCIs) are therefore rapidly transitioning to 100G and 400G, driving a tremendous demand for high-speed metro optical links, where MACOM holds leading market positions in product categories, including laser drivers, transimpedance amplifiers and clock an data recovery integrated circuits.

As of fiscal year 2016 MACOM enabled over a million 100G modules going into Data Center and Enterprise applications. This number is beyond even the largest TAM reported by any of the market analysts to date, and includes leadership positions in long reach and short reach laser and VCSEL drivers, CDRs and TIAs. What's even more exciting is that we believe this is just the beginning of a ramp that will see demand for 100G connectivity within Data Centers triple over the next four years.[4]

MACOM believes it has achieved over 60 percent share of the high-performance analog content going into these applications. Moving into the second half of 2017 we expect to more than double port shipments into these applications. We expect that 100G optical market growth will continue to exceed current analyst forecasts over the next two to three years, primarily driven by Cloud Data Center demand for high bandwidth connectivity.

Building on top of this strong foundation of high-performance analog content and leveraging our advanced Etched Facet Technology (EFT), MACOM is optimally positioned to capitalize on the 100G opportunity in Cloud Data Centers, replicating the breakthrough cost structure reductions that we previously achieved in passive optical networks (PON) – the world's largest unit volume and cost sensitive Indium Phosphide (InP)-based laser market, where we estimate we've claimed over 70% market share.

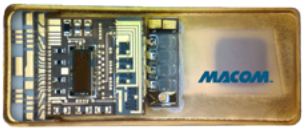
The inherent benefits of EFT are embodied in MACOM's portfolio of 25G lasers for 100G Cloud Data Center applications. Leveraging our in-house, wafer-scale InP manufacturing, our 25G laser portfolio reflects MACOM's cost and capacity advantages over incumbent laser suppliers, and solidifies our industry leadership in enabling the explosive growth of Cloud Data Centers.



The M37046: Industry Leading Four channel 25G / 28G CDR with Integrated Limiting Amplifier.

Building on our success with EFT lasers, MACOM has moved quickly to exploit EFT to enable the seamless integration of optical devices spanning lasers, modulators and multiplexers onto a single chip, yielding the industry's first silicon photonic integrated circuit (PIC) integrated with lasers (L-PIC™) for 100G. By solving the key challenge of aligning lasers to the silicon PIC with high yield and high coupling efficiency, MACOM is making the adoption of silicon PICs a reality for high speed, high density optical interconnects in Cloud Data Centers.

With the recent definitive agreement to acquire AppliedMicro, MACOM plans to solidify its technology leadership by marrying APM's PAM4 100G Single-lambda PHY technology that increases bandwidth density by 4X with MACOM's L-PIC, and combined with the PHY will enable a highly streamlined 400G transceiver that will quadruple the data throughput over existing fiber infrastructure. The completion of the portfolio on the PAM4, analog and photonic side positions us ideally for PAM4 adoption not just at 100G, but more importantly at 400G. Within the Data Centers, there are two standards – to date everything has been NRZ, which uses MACOM 25G lasers, 100G laser drivers, VCSEL drivers and CDRs. The second is PAM4 modulation, a key element moving to 400G. MACOM estimates more than half of the industry will be moving forward with PAM4 within Data Centers at 100G. The future integration of AppliedMicro and MACOM will combine our analog and photonic content for the complete front end capability, combined with the DSP in the PHY with SerDes as well as data converters.

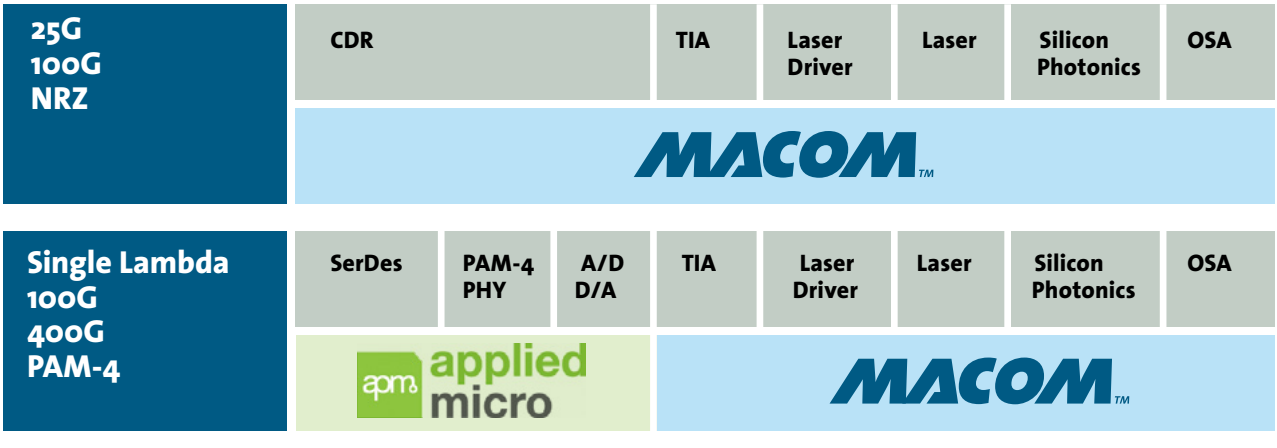


TOSAs & ROSAs optimize chip level semiconductor integration.

The wisdom of this approach was recently ratified by the IEEE, who announced standardization around the proposal which was championed by AppliedMicro and Cisco to implement single lambda PAM4 as the industry standard again for both 100G and 400G.

The continued strategic expansion of MACOM's product portfolio for Cloud Data Centers will encompass key protocols and span all formats, giving MACOM the agility to respond quickly to evolving market dynamics. Our flagship products are technology agnostic, and can be readily deployed to meet the unique needs of our tier-one customers.

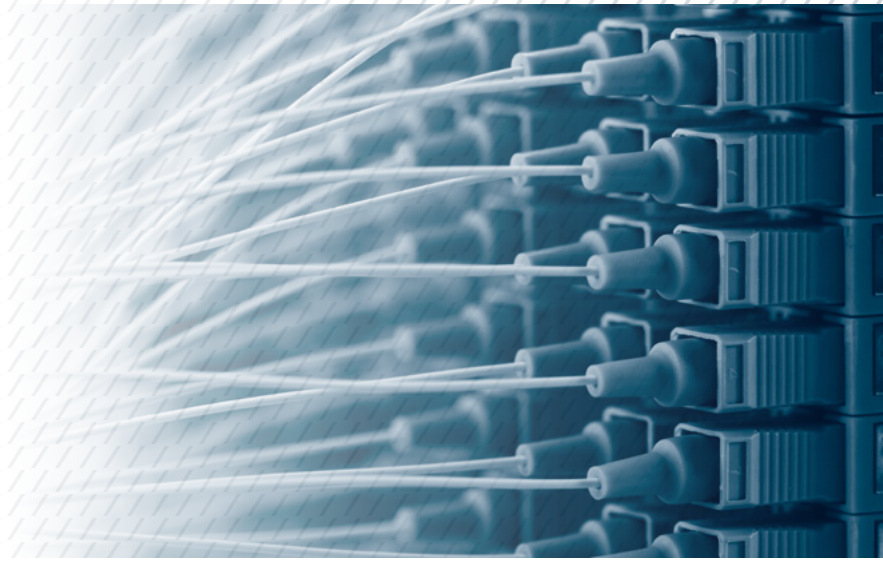
MACOM's competencies in Cloud Data Center connectivity culminate in our unique ability to provide customers with the entire optical subassembly, leveraging our portfolio of transmit optical subassemblies (TOSAs) and receive optical subassemblies (ROSAs) to optimize and validate chip-level semiconductor integration and packaging. For customers who may not have in-house optical packaging expertise, MACOM can provide the subassembly and/or reference designs that enable them to take advantage of our advanced optical components to speed the development of next generation optical transceivers.



The full portfolio from Switch to Fiber.

Applying our unique combination of expertise in the analog and photonics technology disciplines, MACOM is unrivaled in our ability to provide the seamlessly integrated content required for cost optimized optical components that light the path from 100G to 400G in long haul, metro and Cloud Data Centers. We deliver the enabling technologies that allow our customers to lead the industry with breakthrough advancements in bandwidth density, innovating next-generation network infrastructure that transforms global connectivity.

[4] Infonetics



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