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Optical Trends in Premises Networks

Peter Ronco
Corning Optical Fiber
Global Product Line Manager
Premises and Single-mode Fibers
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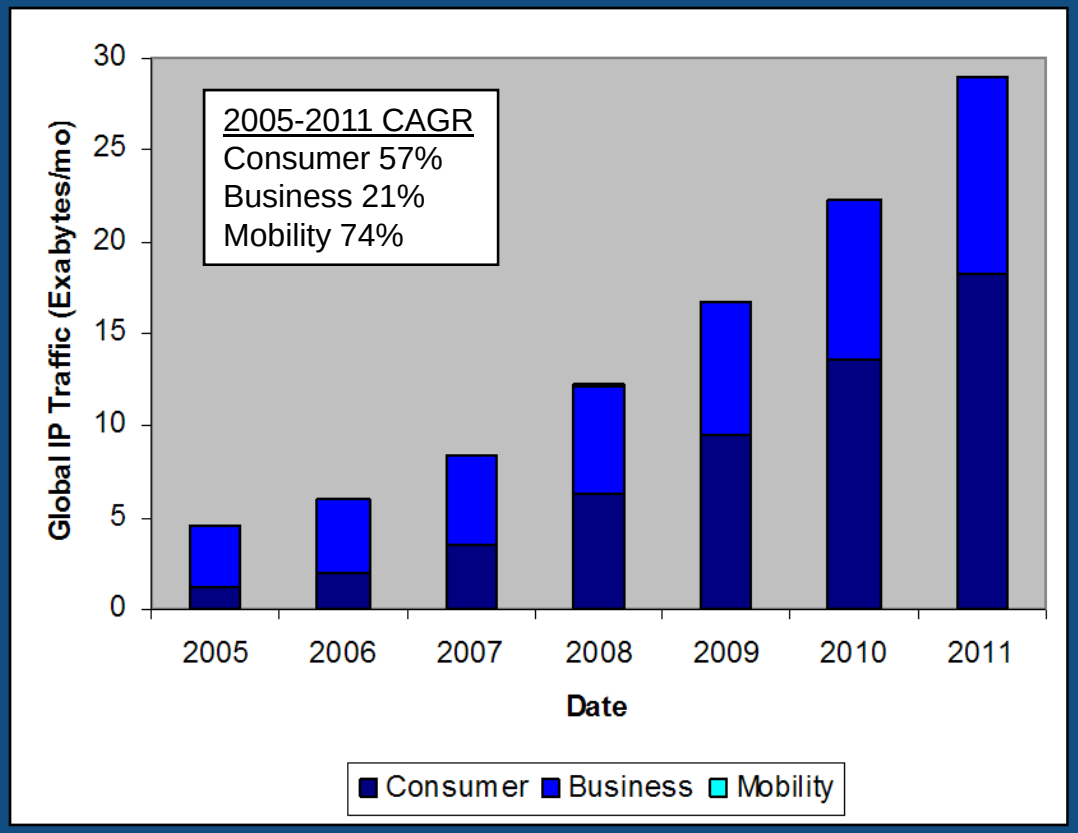
Agenda

- Traffic demand continues to grow
- Market trend from LEDs to lasers
- Trends in lasers
- The need for advanced fibers
  - OM3, OM4
- Copper still dominates
- Trends in connectivity
- What's next in fiber development?
  - Next generation speeds
  - Bendable fibers

Bandwidth Demand is Growing: Global Internet Traffic Expected to Grow



Source: Cisco Systems (2007), 1 Exabyte = 1000 Petabytes = 10^{18} bytes

Financial reporting:

Increasing data management as more sophisticated tools come to market, high cost of downtime, back-up systems

On-line business activity:

Internally, connecting remote/global locations. Externally, connecting customers with suppliers to drive supply chain efficiency. Multi-site software development.

Consumer entertainment:

HDTV, VOD, gaming, music downloads

Others:

Digital media and document/medical imagery, growth of WiMAX deployment in laptops

Consumer includes fixed IP traffic generated by households, universities, and internet cafes
Business includes all fixed IP WAN or internet traffic generated by organizations and governments
Mobility includes mobile data and internet traffic generated by handsets, notebook cards, and Wi-Fi hotspots

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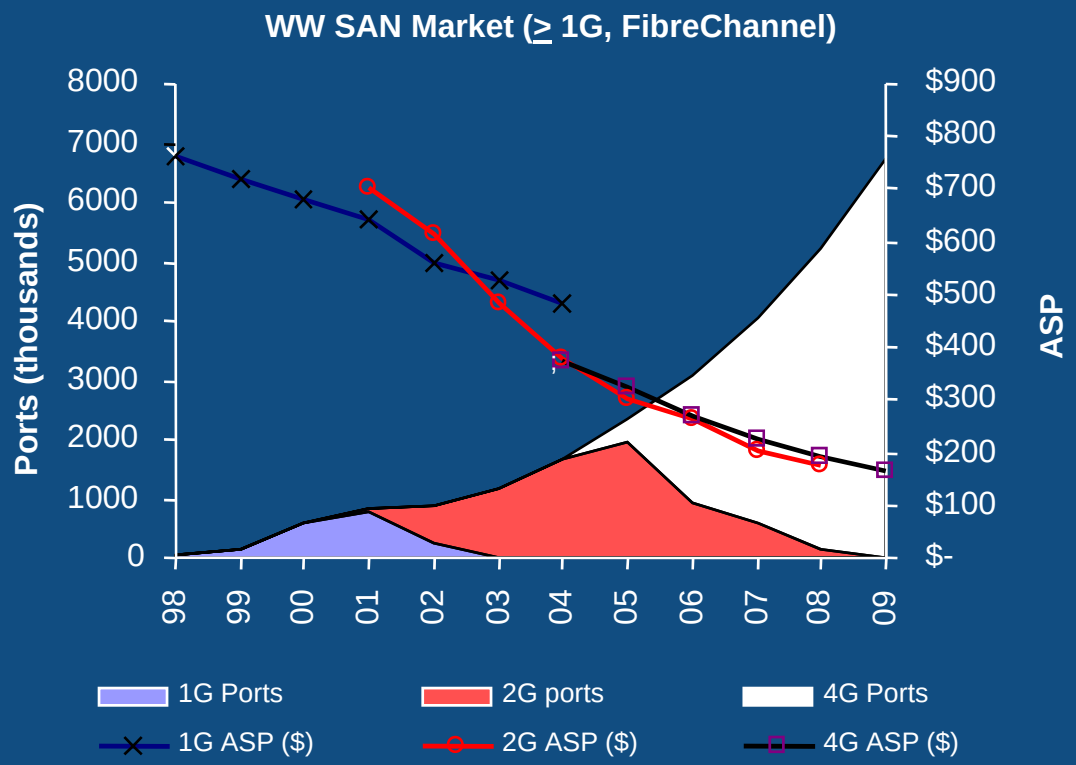
Deployment speeds continue to grow; 1G is the standard



- Sales of lower data rate ports continue to decrease
  - CIR projects 10GbE and 8GbFC port sales of 30-50MM in 2011
- 1G almost at price parity with 100Mb/s, especially in copper
- Move to optical 1G requires market shift from LEDs to lasers
- Growth in 8G/10G links drives interest and awareness for next generation speeds (16G, 40G, 100G)

Source: Dell'Oro

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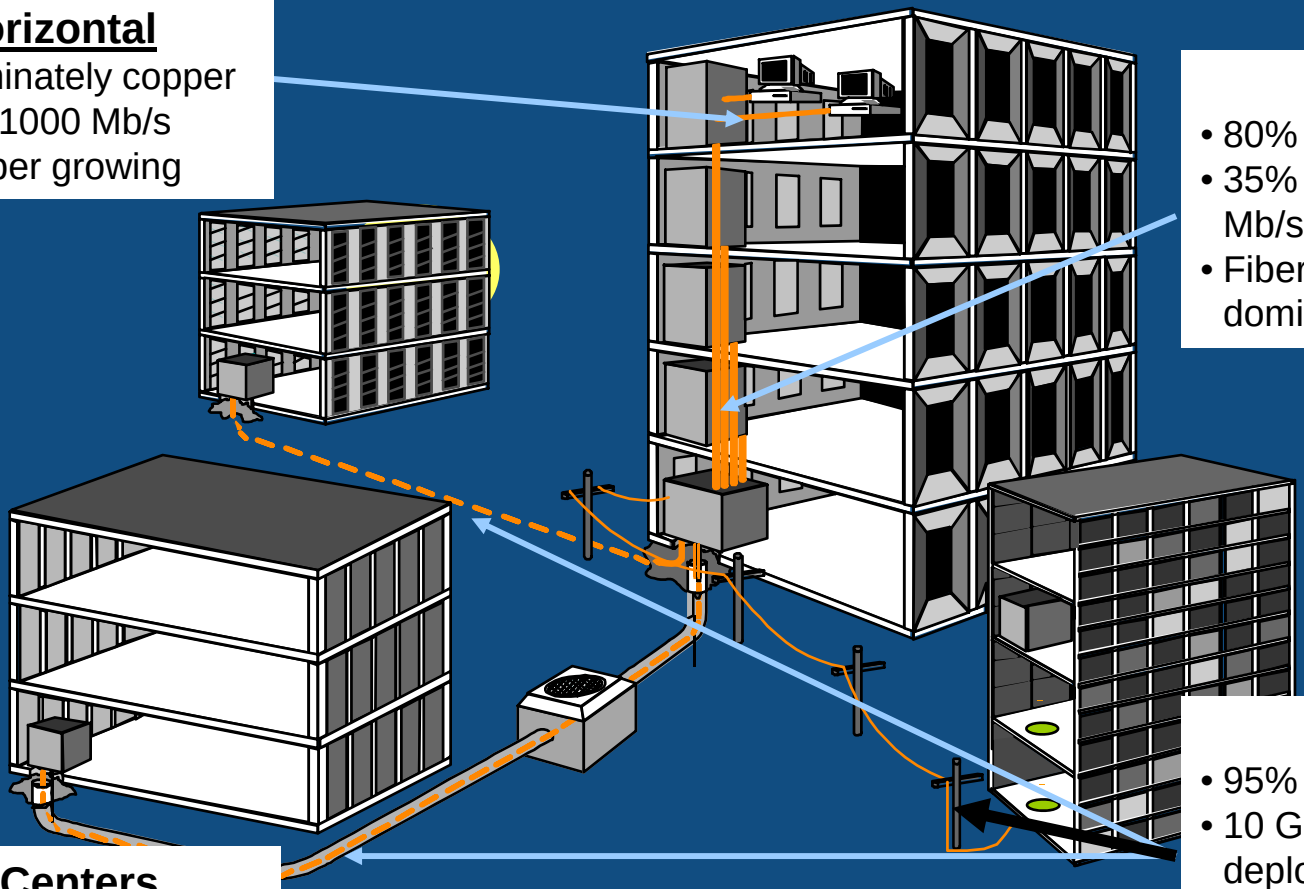
Fiber preferred everywhere except horizontal; single-mode fiber slowly taking share

Horizontal
- Predominately copper
- 10/100/1000 Mb/s
- Zone fiber growing



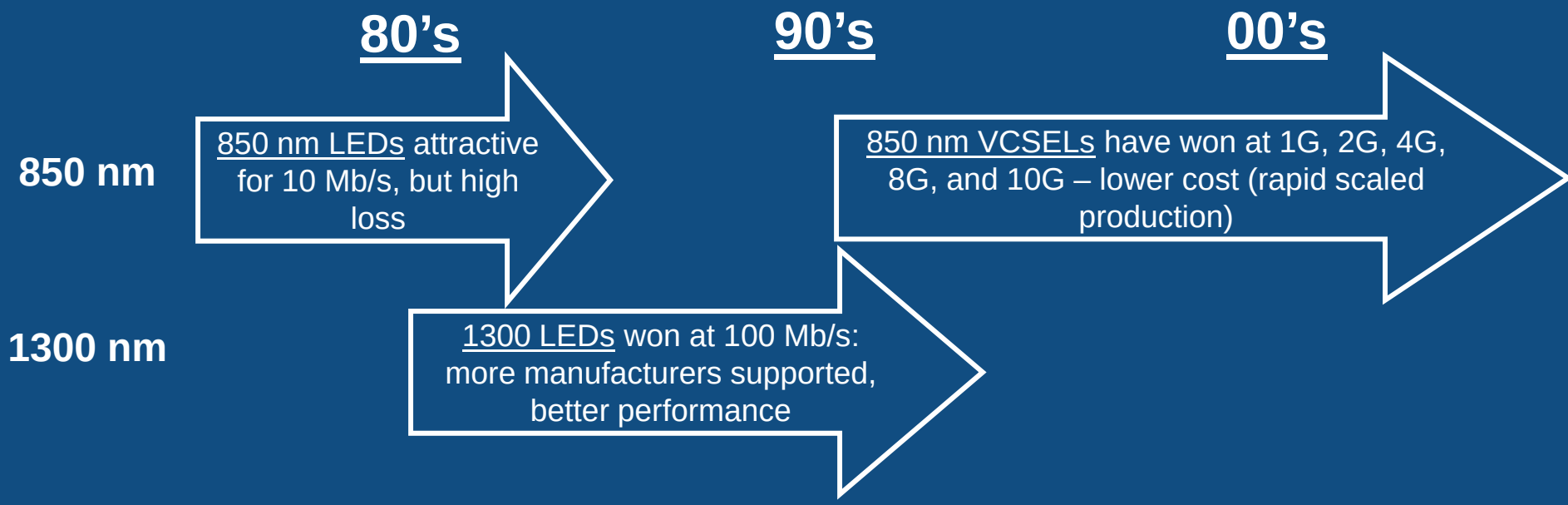
Riser
- 80% fiber and increasing
- 35% 1Gb/s - 65% 100 Mb/s
- Fiber has won, MMF dominates, OM3 preferred

Interbuilding
- 95% fiber and increasing
- 10 Gb/s initial deployments
- 70% 1G/25% 100M
- Fiber preferred, single-mode continues to gain

Data Centers
- 60% fiber and increasing
- 1, 2, 4 and 10 Gb/s
- MMF preferred – OM3

Souce: Corning Optical Fiber/Corning Cable Systems Analysis

In optical premises: 850 nm VCSELs dominate at 1G, harder challenges at 10G



- 1G, then-current generation of fibers able to support
  - 10G required new fiber attributes (specifications and measurements)
- OM3 fiber developed for 10G 850 nm
  - Some competing Ethernet technologies for installed base focus on 1300 nm

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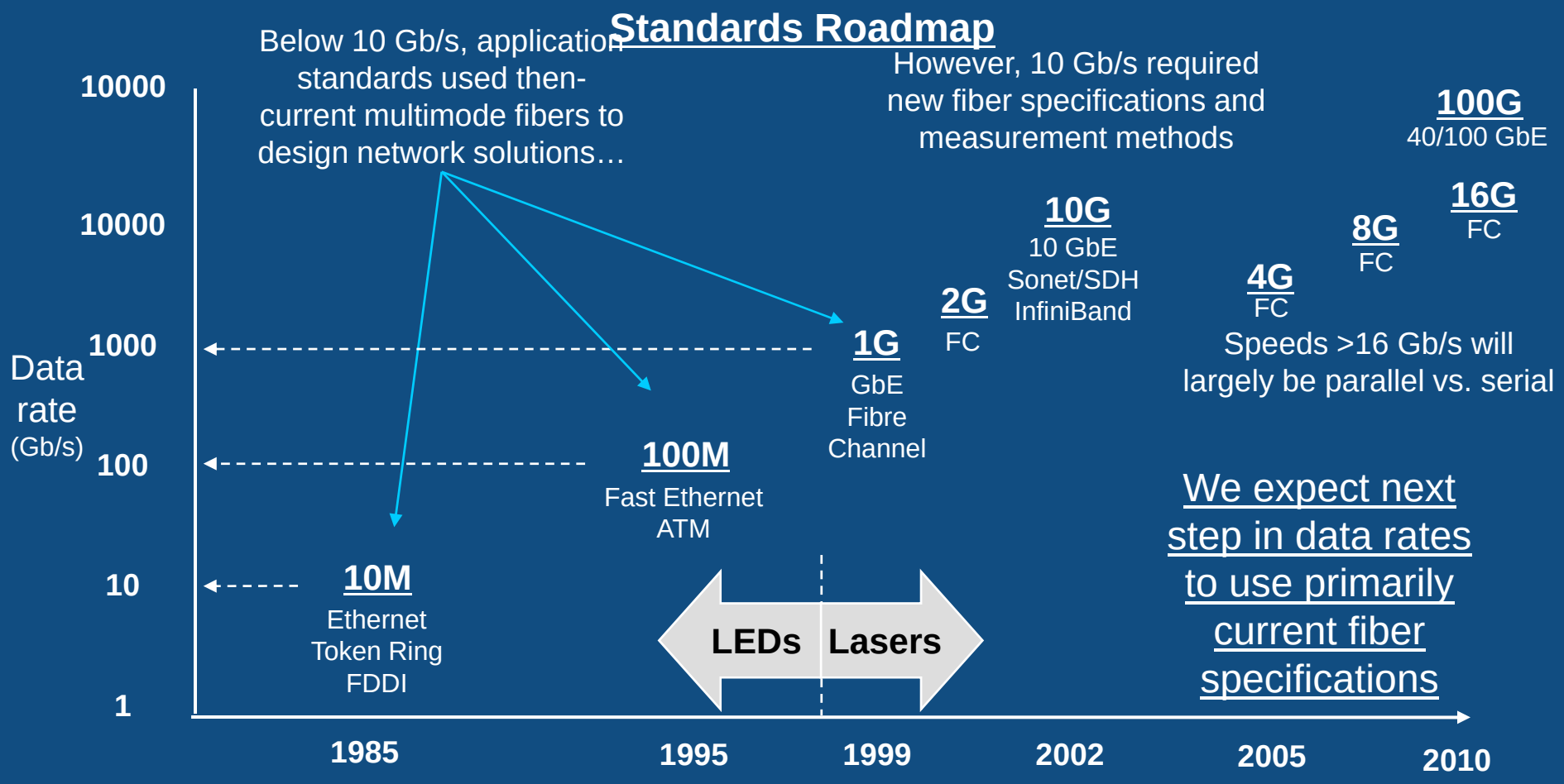
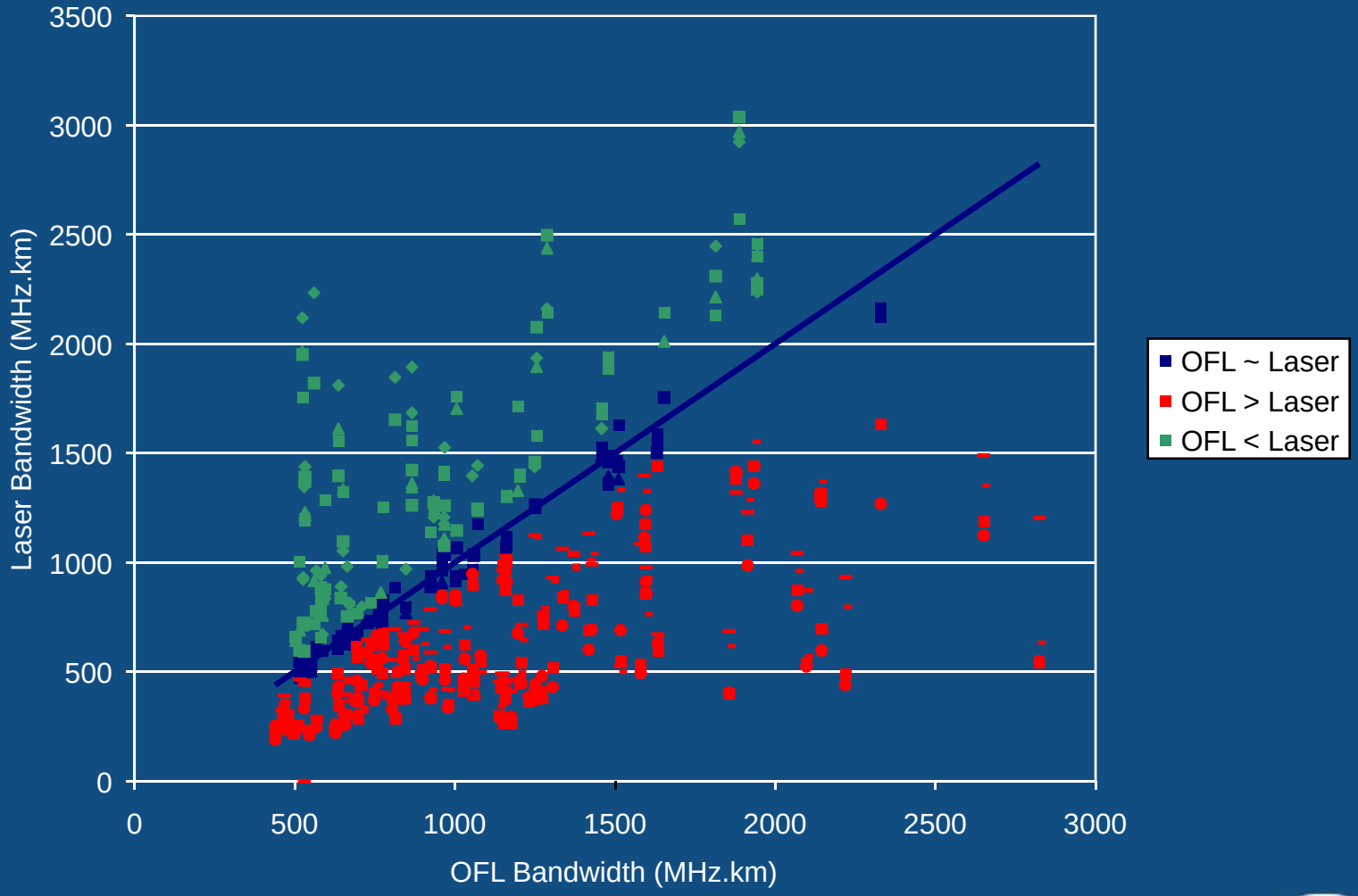
10G was the first time fiber and application standards were co-developed



Legacy bandwidth measurements cannot predict laser performance



Source: TIA FO-2.2.1 Round Robin

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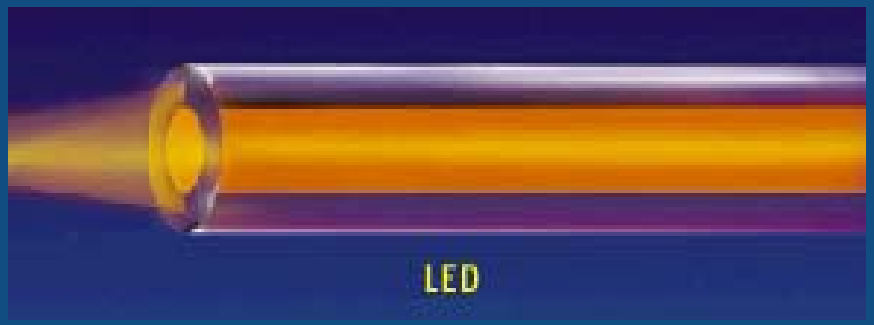
Move from LEDs to lasers required new bandwidth measurement systems

Light Sources



(Typically 10 and 100 Mb/s)

(1, 2, 4, 8, 10 Gb/s and higher)

Bandwidth Measurement

OFL (Overfilled-Launch)

- Designed to predict performance of low-speed LEDs, not lasers
- Power distributed in 100% of the fiber core, like LEDs
- Perturbations in index profile undetected

Laser-Based Measurements

- RML (Restricted Mode Launch) or DMD (Differential Mode Delay), minEMBc (minimum Effective Modal Bandwidth)
- Power distributed in a narrow region
- Simulates an actual laser launch
- More accurate indication of performance in high-speed laser-based systems

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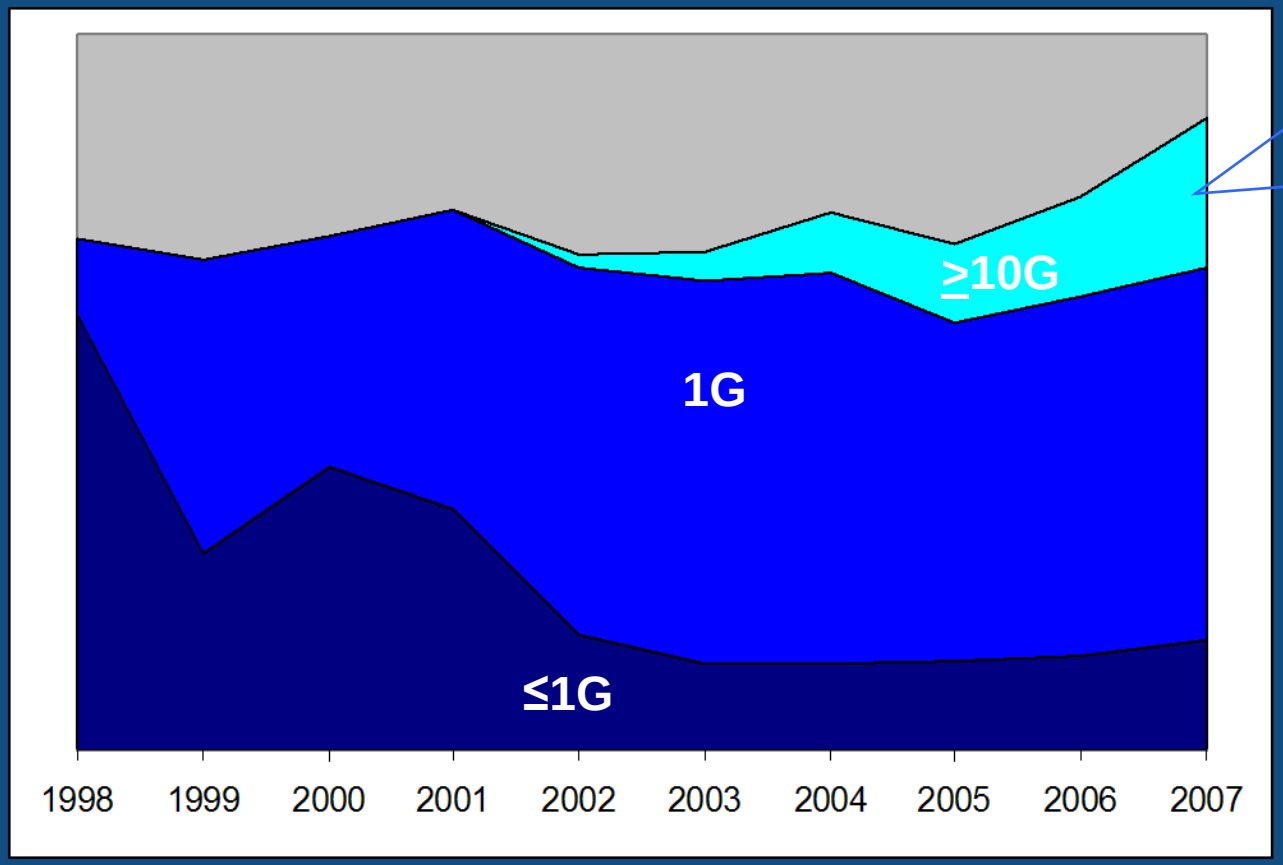
Dramatic increase in capability of MMF; 10G fibers growing the fastest

WW MMF Demand by Supported Data Rate



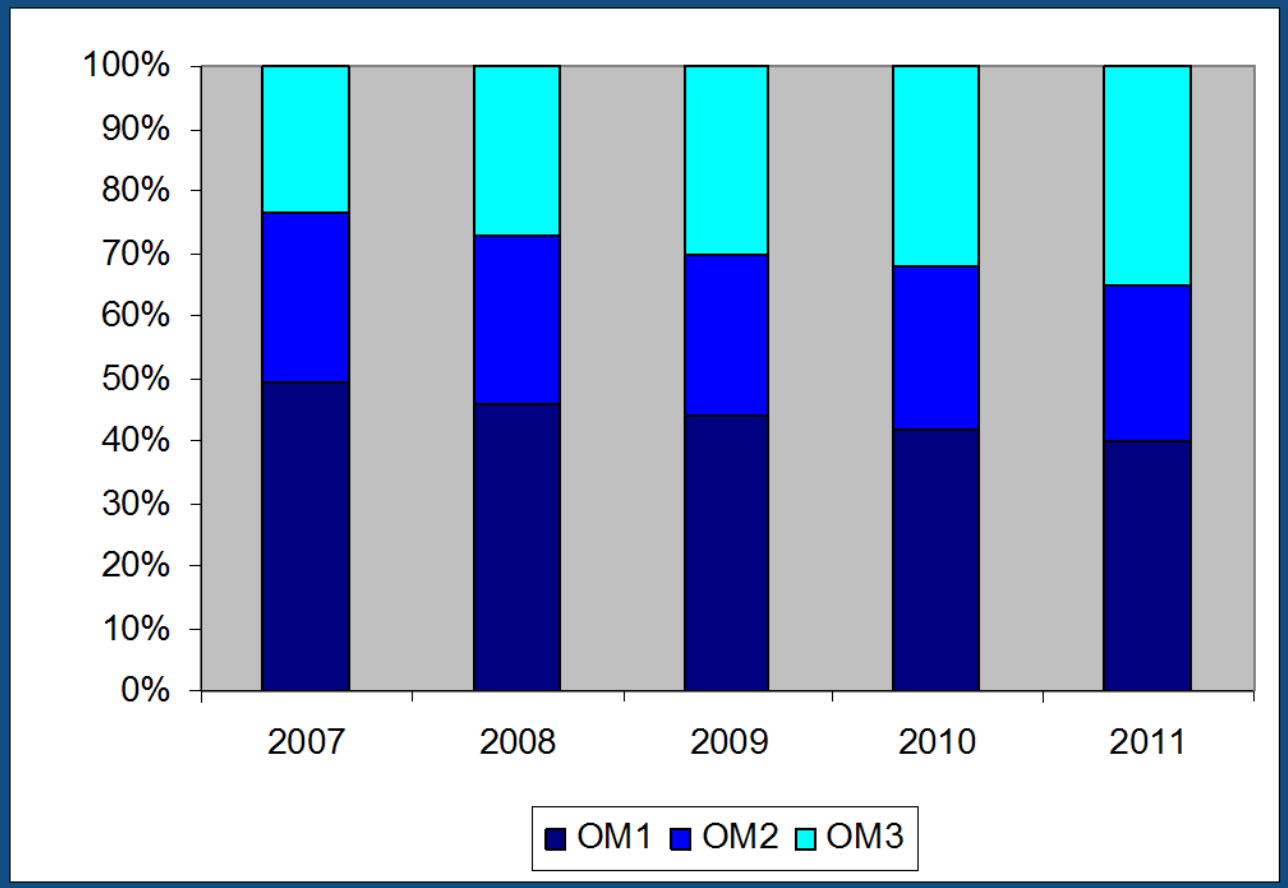
OM3 fiber has grown at over 60% CAGR since 2002 standard

	1998	2007E
Other	85%	17%
1 Gb/s	15%	59%
10 Gb/s	0%	24%

Source: Corning analysis

50 µm will continue to grow; 10G OM3 fibers the fastest

WW MMF Demand

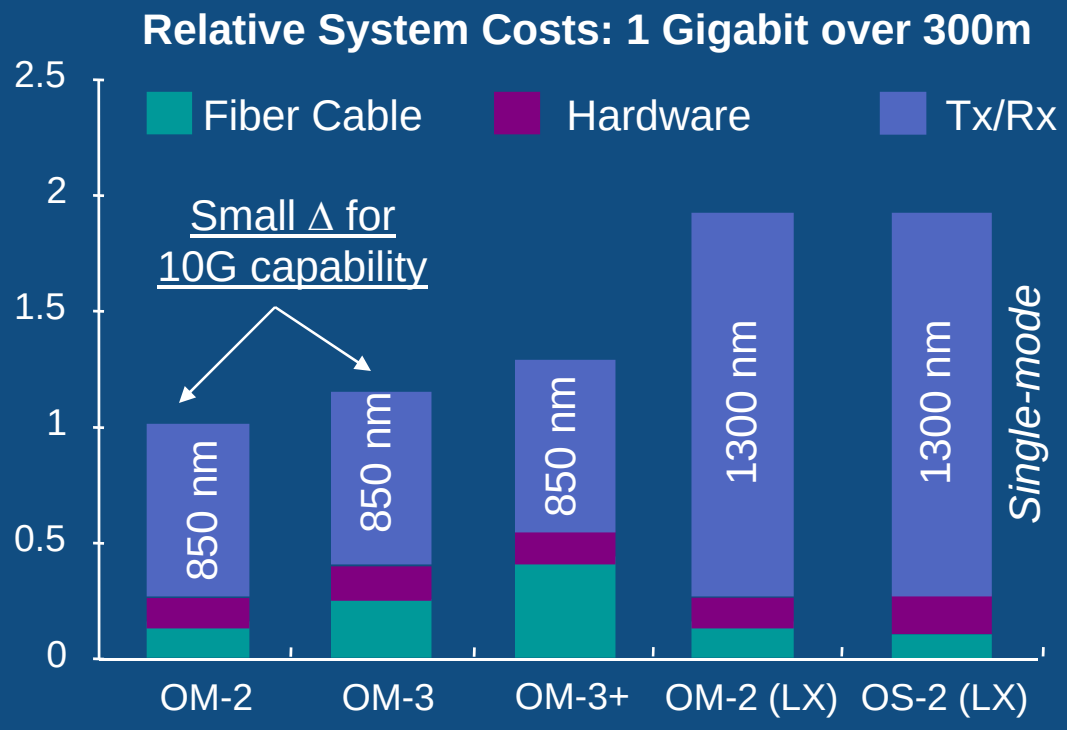


CAGR '07-'11	
62.5µ	0%
50µ (Other)	3%
50µ (10G)	16%

Source: Corning Analysis

SX (850 nm) lower-cost than LX (1300 nm)

- Assumptions
  - 300 m, 24F count cable, 24F Passive Interconnect (x2), 18x 1 Gb/s Transceivers
- Key findings:
  - Cable is a very small portion of link costs
  - SX (MMF) solutions always lower cost
- OM3 fiber
  - Supports 10 Gb/s over 300m
  - Lowest cost upgrade path to 10 Gb/s

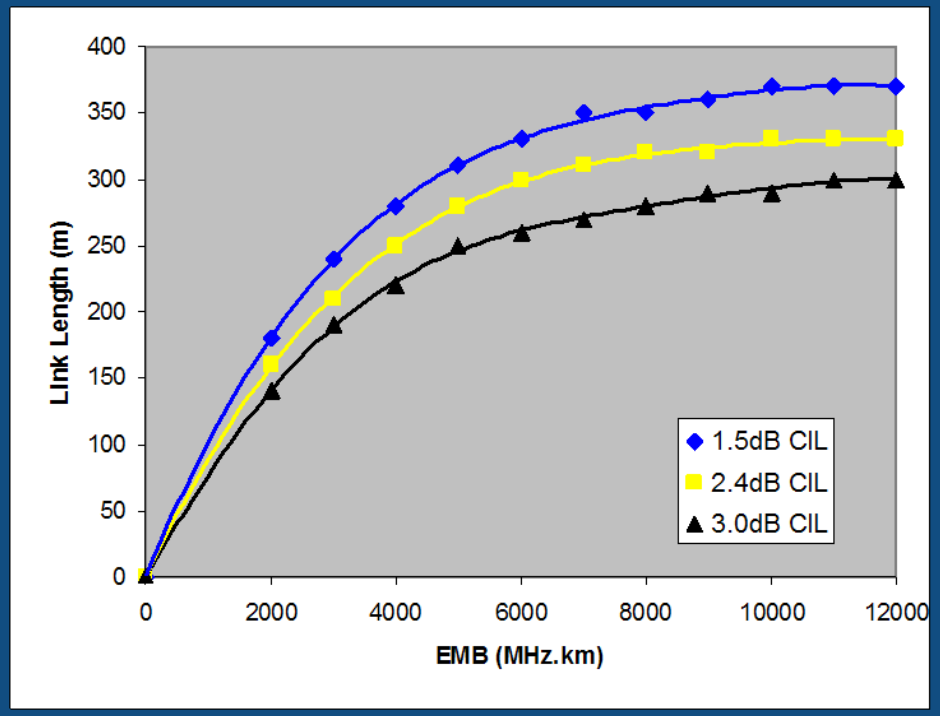


SX solution saves ~50% over LX

What is an OM4 fiber?
Why consider installing it?

- An OM4 fiber is a 50 μm MMF with higher effective modal bandwidth (e.g. 4700 MHz.km)
- There is currently not an OM4 standard although there is much discussion within the industry of developing a standard
- The extra bandwidth can be used for a variety of benefits
  - Higher serial bit rates
  - Longer link lengths
  - Increased margin for more connectivity
  - Lower cost electronics
- OM4 provides some additional benefit for 8GbFC and 10GbE but primary beneficiary appears to be 16GbFC
  - 300m with OM4 vs. 150m with OM3 and modest connector allocation

Multimode Reach in Support of Serial 16GbFC



Assumes 0.25nm spectral width, 25ps risetime, -3.8 dB Tx OMA, and 3.0 dB/km cable attenuation, limiting receiver

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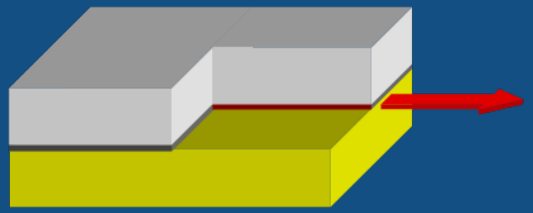
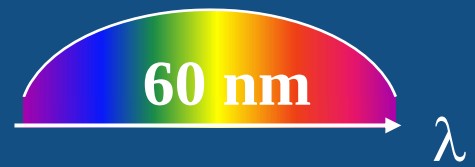
Device cost typically determines application segment

Low cost 850 VCSELs dominate the price sensitive Premises market

Comparison: Spectral Characteristics

LED
$





Fabry-Perot Laser
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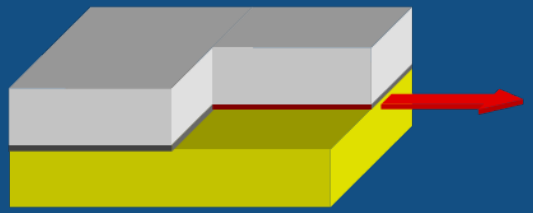

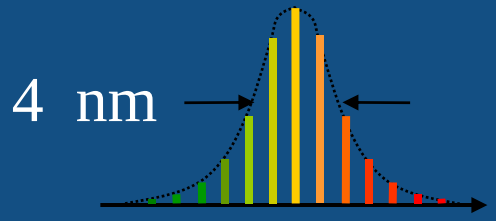

VCSEL
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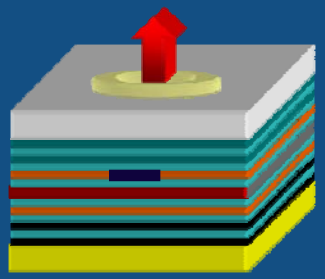
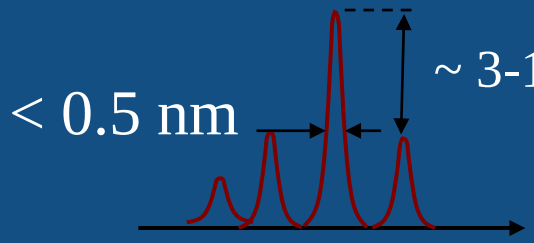
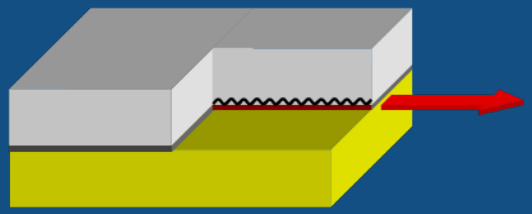
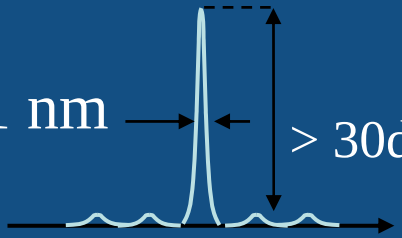
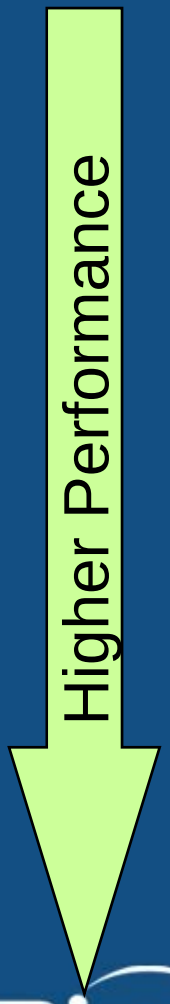




DFB laser
$$$$$







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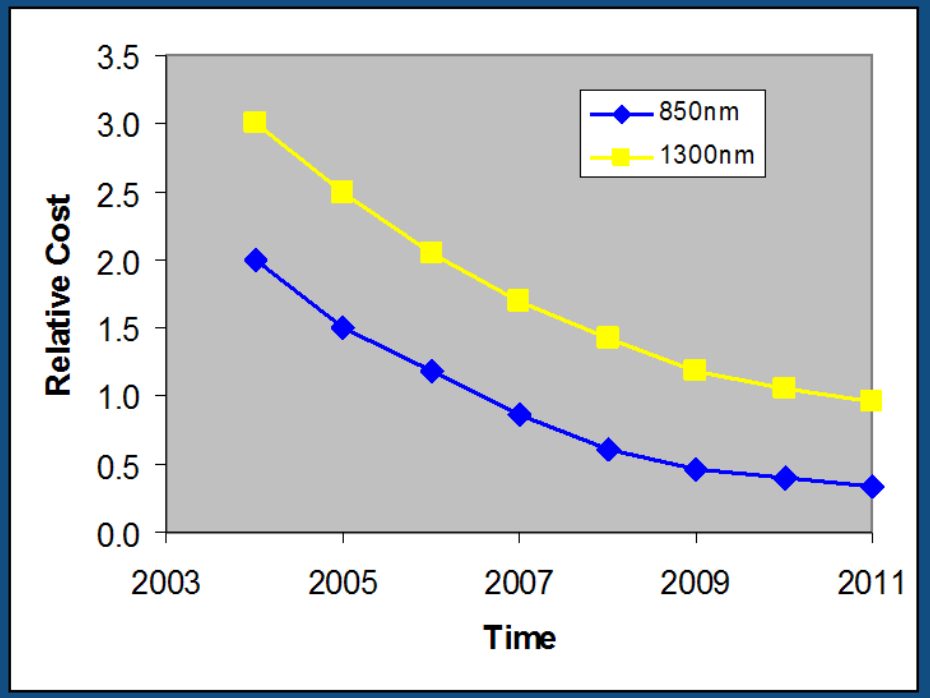
We expect lower-cost solutions in premises networks will be at 850 nm

- 850 nm VCSELs are ~90% of the 1G premises market
- 850 nm VCSELs just entering high-volume manufacturing cycle
  - Continues to be low-cost solution for 10G
  - Low-cot solutions have been identified for 100G
- LR (1300 nm) solutions may capture some market share in premises

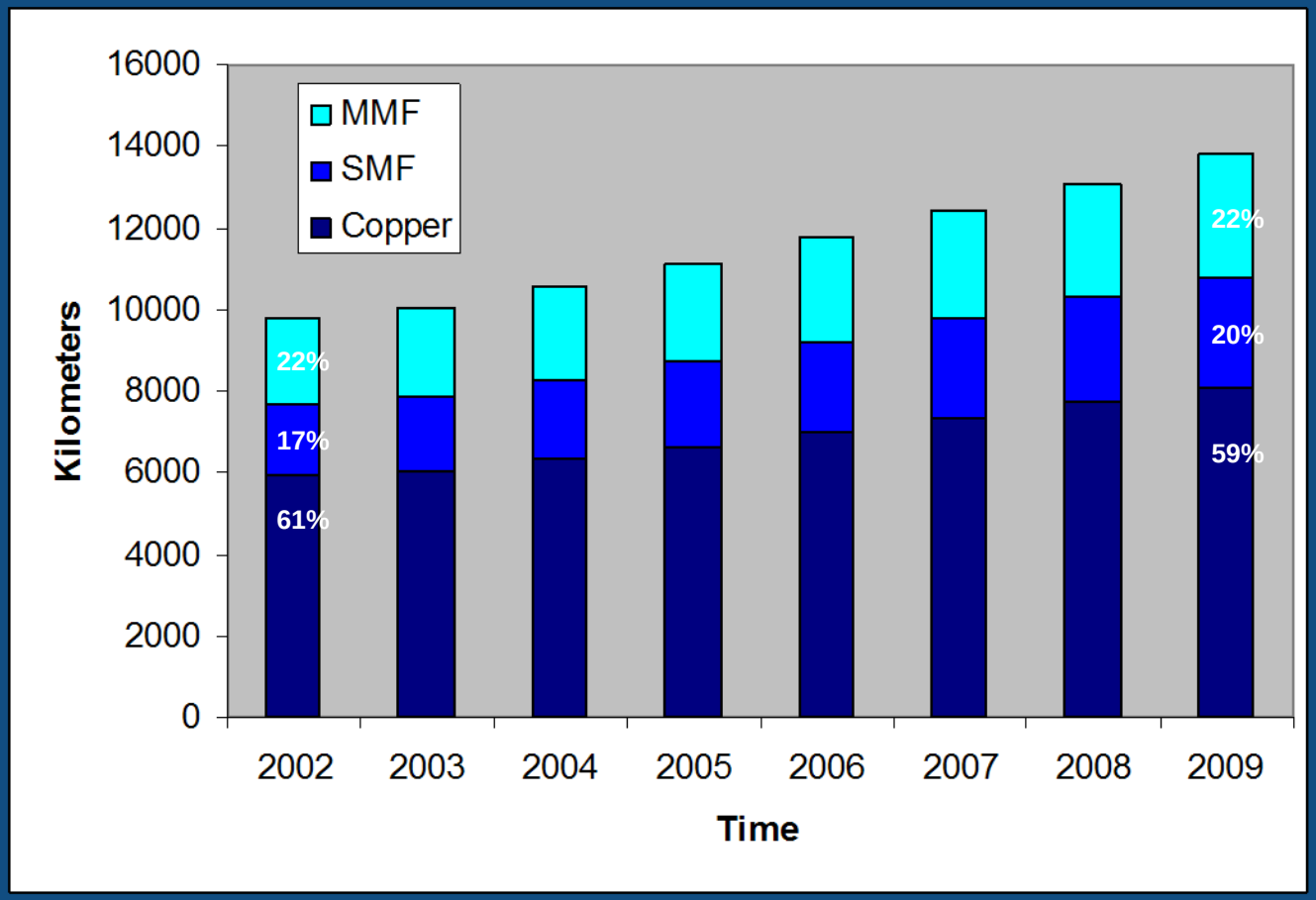
10G Transceivers



Source: Corning estimates

Copper continues to dominate premises; single-mode fiber gaining optical share

Worldwide Premises Cabling



Challenges for MMF

- Copper/Horizontal
  - Electronics Cost
  - Powering
  - Interfaces
- Single-mode fiber
  - "Futureproof"
  - Simplicity
  - Electronics mfgs' influence

Source: Corning, CRU

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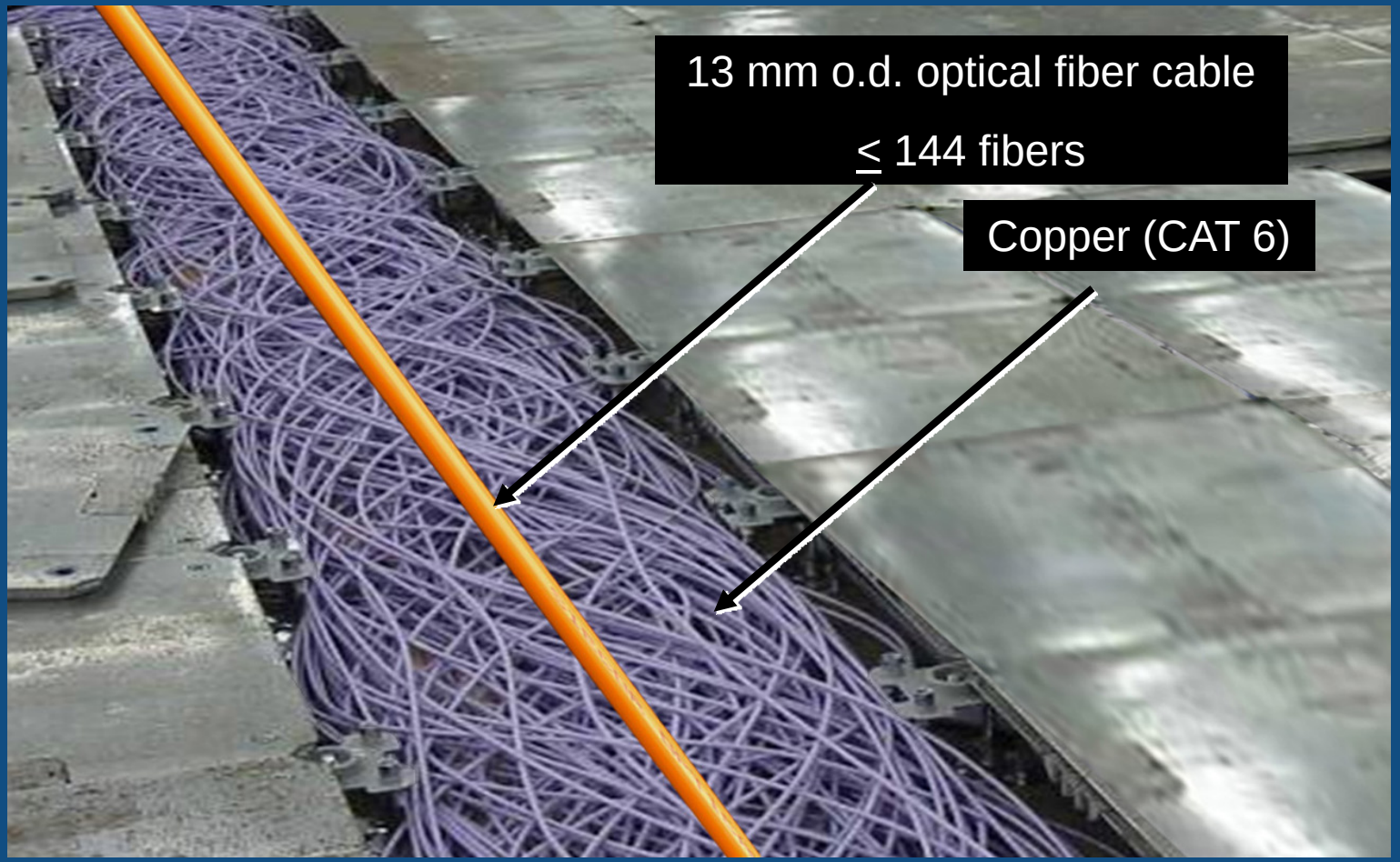
Why Fiber?

- Higher data rates and longer link lengths
- Flexible, reliable networks with low latency
- Unparalleled network security
- Immune to EMI, RFI and cross-talk
- Small lightweight cables – maximizes pathway and space utilization and minimizes cable fuel load
- Higher port density
- Easier installation, handling and termination
- Simplified field testing (e.g. 10G)
- Longer cable life cycle
- Lower power consumption, decreased cooling requirements, less expensive to operate

Why Fiber?



Fiber Connectivity Trends

- Pre-terminated solutions – 75% faster installations than traditional cabling solutions
- Modular component design – facilitates moves, adds and changes
- Small-form-factor products (LC, MT-RJ) – reduce space needed under floor, overhead and in racks/cabinets
- Clean – less mess for data center electronics that can be damaged by poor cleanliness and dust created by cable cutting and termination preparation

Market Interest in Next Generation Speeds

- An IEEE High Speed Study Group was formed in 2006 to develop the next Ethernet Standard
- Internet exchanges in Amsterdam and Tokyo already have 100 Gb/s traffic on their backbones
- Multiple end-users such as Google, Yahoo! and NYSE all spoke about the need for 100 Gb/s speeds today in their networks at the March 2007 IEEE HSSG meeting
- Other end-users such as Sun Microsystems, Intel, and Broadcom are touting the need for 40 Gb/s server interconnects
- 100 Gb/s over parallel multimode fibers demonstrated at OFC 2003 by IBM and Picolight
- MMF capability for 40 Gb/s performance using EDC/FEC demonstrated at OFC 2006

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IEEE HSSG Standards Development
Potential High Speed Ethernet Applications

- Data Center
  - Zone-to-zone
  - Rack-to-rack
- High Performance Computing Centers
  - CPU-CPU interconnect
  - I/O links
- In-building Backbone
  - Main distribution frame to intermediate distribution frame
  - Intermediate distribution frame to intermediate distribution frame
- IEEE HSSG has approved objectives for both 40 GbE and 100 GbE based on different requirements for computing and core networking applications

OM3 multimode fiber preferred for distances of 100-300m

Port density drives need for VCSEL arrays and MTP/MPO connectivity

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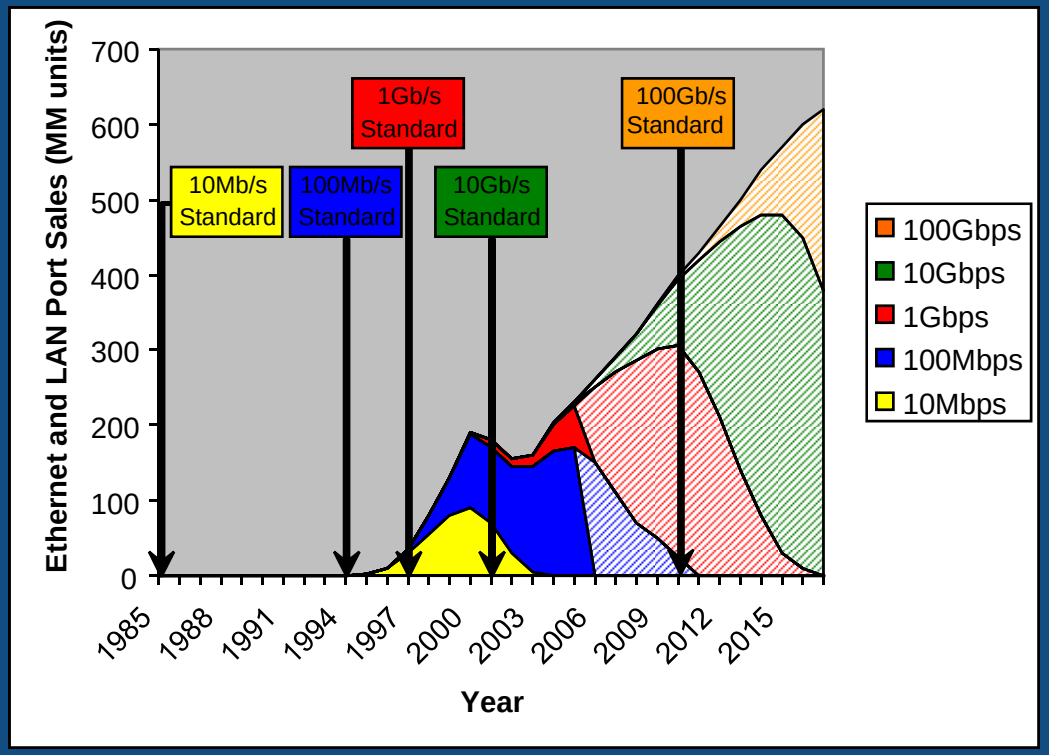
IEEE HSSG Standards Development
Need to Prepare for Next Generation Networks Now

- Recent history suggests that standards (and initial fiber sales) will lead actual port sales by ~3 years
- Given port sale historical trends, we can project initial applications ~2012
  - Most applications not expected until >2013



10Mb-10Gb data from Dell'Oro

IEEE HSSG Standards Development Approved Objectives

- Support a data rate of 40 Gb/s
  - Provide specifications which support 40 Gb/s operation over:
    - At least 100m on OM3 MMF
    - At least 10m over a copper cable assembly
    - At least 1m over a backplane
- Support a data rate of 100 Gb/s
  - Provide specifications which support 100 Gb/s operation over:
    - At least 40km on SMF
    - At least 10km on SMF
    - At least 100m on OM3 MMF
    - At least 10m over a copper cable assembly

Key Notes:

- Preliminary modeling suggests that 200 m is achievable on OM3 at 100 Gb/s with <10GbE source specifications
  - > 95% of data center link lengths
- Modeling further suggests that OM4 MMF could extend reach to 250 m with <10GbE source specifications
  - ~ 99% of data center link lengths
- **New IEEE work does not include a solution with OM1 or OM2**

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Next Generation Speeds Summary

- Bandwidth demand and data rates continue to grow
  - 1, 2, and 4 Gb/s most popular today, 8 and 10 Gb/s growing rapidly, 16, 40, and 100 Gb/s are on the horizon
- OM3, 8G and 10G solution remains less expensive than OM2 or single-mode fiber solutions for typical optical premises links
- Next generation standards work has started on 16GbFC and 40GbE and 100GbE
  - There will clearly be an OM3 multimode solution
  - There may be an OM4 multimode solution
  - There will not be an OM1 or OM2 solution for 40GbE and 100GbE
  - Transmitter and receiver array technology will likely be required to support parallel transmission architectures in premises networks

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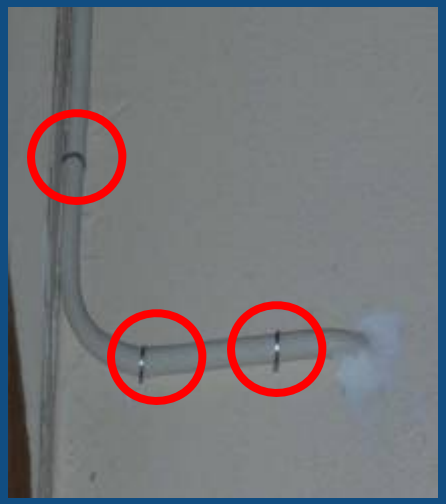
There is a need for bendable fibers

Deployment of fiber into premises networks and multiple dwelling units presents unique access, distribution, and routing challenges:

Tight Bends

Staples

Cable Tension



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Primary Drivers of Interest in Bend-Performance in FTTH

Goals	Why?	How?
Lower costs 	• Improve financial returns	• Reduce costs of "protecting" the fiber • Reduce labor time • Reduce labor rates…less specialized procedures • Reduce impact of mishandling performance
Increase speed/ ease of installation 	• Reduces initial costs • Efficient use of labor/capital • Rapidly add customers	• Eliminate need for installation of "protection" measures • Fiber cable with handling properties like copper solutions
Reduce aesthetic impact 	• Ease negotiations with building owners/ landlords/ tenants	• Reduce size passive components • Ensure small cables can bend around tight corners • Ability to "hide" excess cable in tight spaces

…all while protecting the optical power budget!!

Bend insensitive fiber functional to smaller bend radius

Small, tough cables that can be handled like copper

Smaller equipment that maintains flexibility, scalability, and ease of moves/adds/changes

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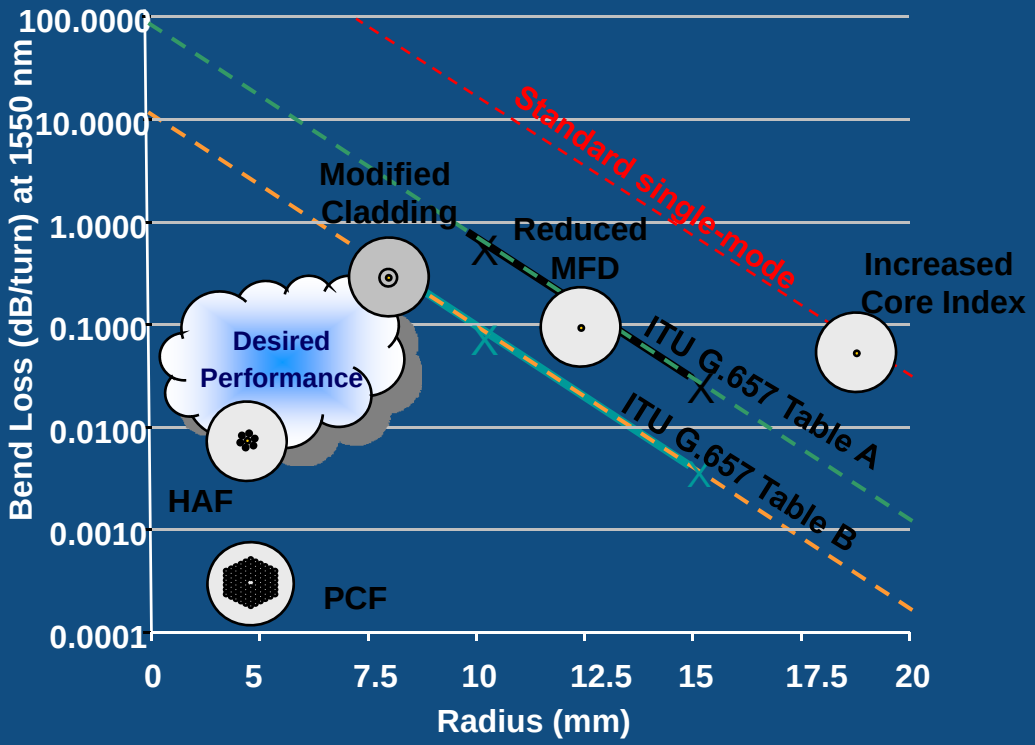
ITU G.657 Established to Address Macrobending Performance Requirements for FTTx

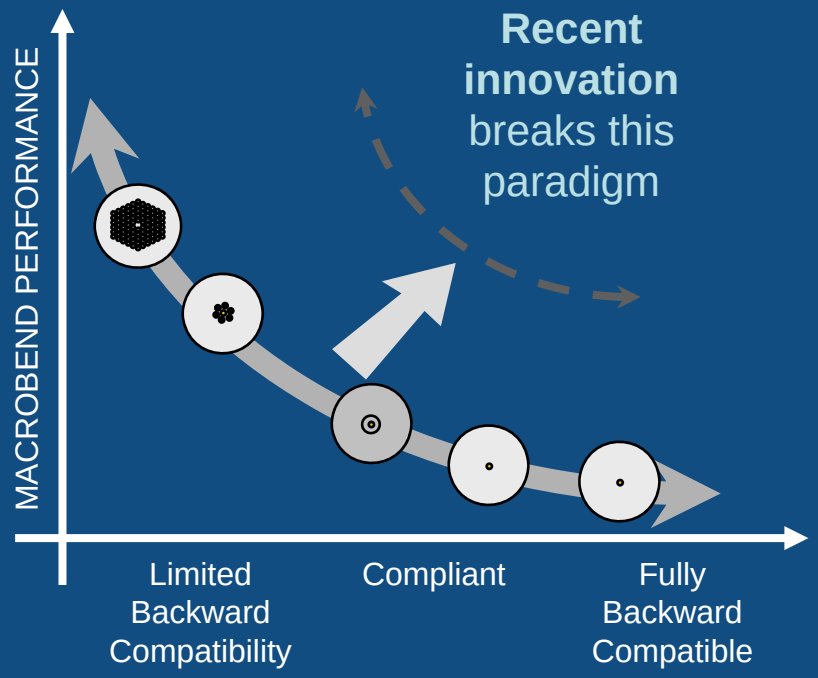
- Define and standardize two classes of single-mode fibers with different levels of enhanced bend performance

- Recommendation G.657.A “bend-improved” fibers
  - Prioritizes backward compatibility over bend enhancement
    - Slightly improved performance compared with legacy single-mode fibers
  - Specified to radii as low as 10 mm
  - Must also be compatible with ITU-T G.652.D “Low Water Peak”
  - Have enabled incremental improvements in legacy equipment designs

- Recommendation G.657.B “bend-tolerant” fibers
  - Prioritizes bend enhancement over backward compatibility
    - Opens the possibility for unconventional fiber designs
  - Performance specified to radii as low as 7.5 mm

New Solutions Required to Break the Inherent Bend-Performance/Compatibility Trade-off





There are technical solutions that meet/exceed the bend loss requirements

But there are compatibility tradeoffs inherent with current fiber design options

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Bendable Single-mode Fibers Summary

- Primary drivers of interest in bend: cost savings, decreased deployment times, and reduced aesthetic impact
- Fiber deployment closer to the end user is creating new demands on optical fiber, cable and hardware solutions
- Maximizing bend performance in fiber usually requires backward compatibility tradeoffs
  - Exciting innovations are changing this

Summary

- Bandwidth demand continues to grow, driven by both business and consumer requirements
- 850 nm VCSELs are the low-cost, high-performance sources of choice for high speed premises networks
- OM3 fiber is designed to enable the use of 850 nm VCSELs and drive high speed premises systems
- Copper is still the dominant cabling medium in the horizontal, where there is less bandwidth demand
- Next generation premises network transmission standards are being developed using high-performance OM3 and potentially OM4 fibers
- Bendable fibers are already being used in FTTH systems and could be useful in premises networks in the not-so-distant future

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