

Next Generation Fibers and Standards

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The Bicsi logo features the word "Bicsi" in a bold, italicized, sans-serif font. A thin, curved line arches over the letters "i" and "s".

Agenda

- Multimode fiber remains the most cost-effective choice for enterprise networks
- Enterprise and data center trends drive changes in fibers and standards
- Next generation fibers
- Next generation standards

Part I

- Multimode fiber remains the most cost-effective choice for enterprise networks
 - Multimode fiber primer
 - Advantages of multimode fiber over single-mode fiber
 - Advantages of fiber over copper

Multimode fiber types classified based on bandwidth values

“OM” Designation	Core Diameter (µm)	EMB (MHz.km)	OFL 850/1300 (MHz.km)	10G Link Length
OM1	62.5	-	200/500	33 m
OM2	50	-	500/500	82 m
OM3	50	2000	1500/500	300 m
OM4	50	4700	3500/500	550 m

- Optical Multimode (OM) designations are per ISO/IEC 11801
- EMB = Effective Modal Bandwidth (Laser BW)
- OFL = Overfilled Bandwidth (Legacy/LED BW)

Lasers require new bandwidth measurement systems

OFL (Overfilled Launch)

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

EMB (Effective Modal Bandwidth)

DMD (Differential Mode Delay) based measurement

minEMBc or DMD-mask

Power distributed in a narrow region

Simulates an actual laser launch

More accurate indication of performance in high-speed laser-based systems

Light Sources



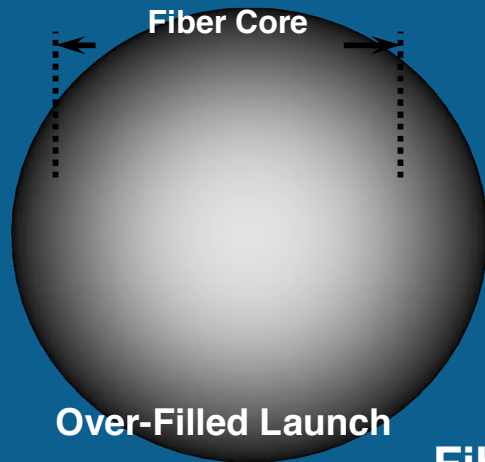
(Typically 10 and 100 Mb/s)



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

Characterization Methods

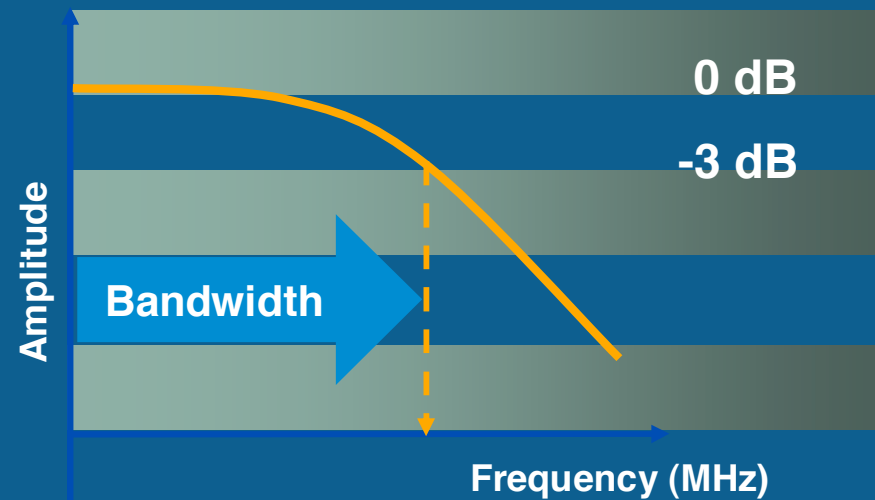
LED – Legacy Bandwidth



LED– Overfilled Launch Bandwidth
for legacy certification only
Not suitable for Laser Transceivers

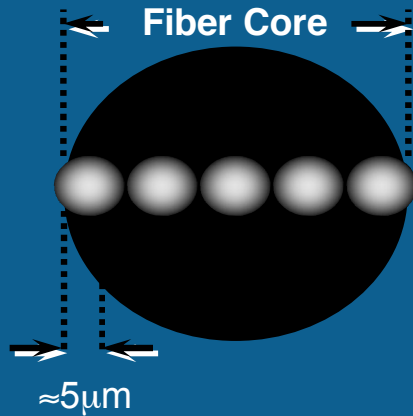


Measurement Output:
Frequency Domain Measurement



Characterization Methods

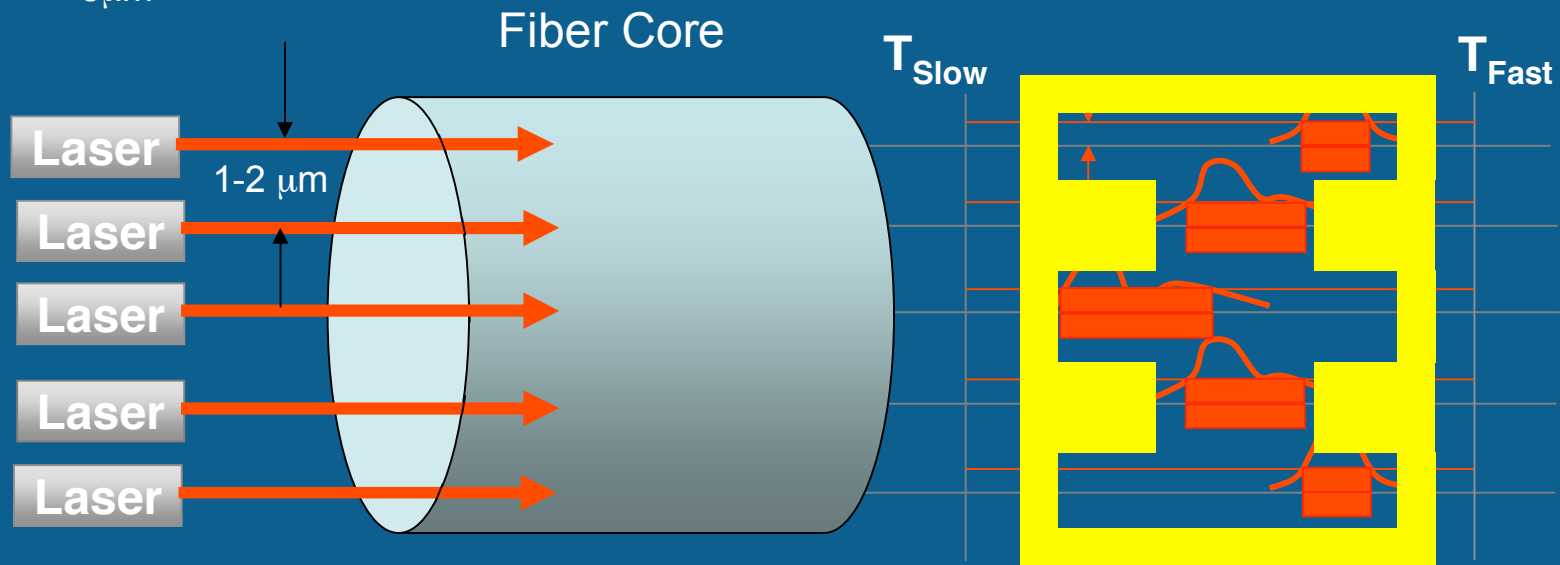
DMD (differential mode delay) Mask



1 of 2 DMD-based standards compliant measurements
 One laser type scanned across core
 BW defined by most delayed pulse

DMD output is "Normalized"

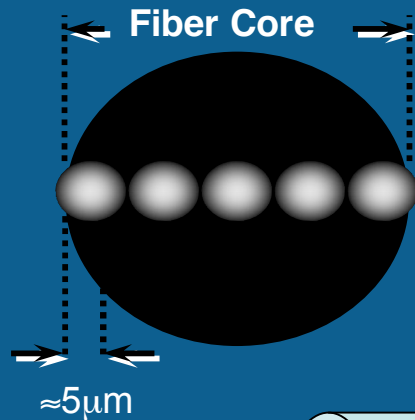
6 Masks Applied for OM3 (3 masks for OM4)
 Must only pass 1 mask to be OM3 (or OM4) compliant



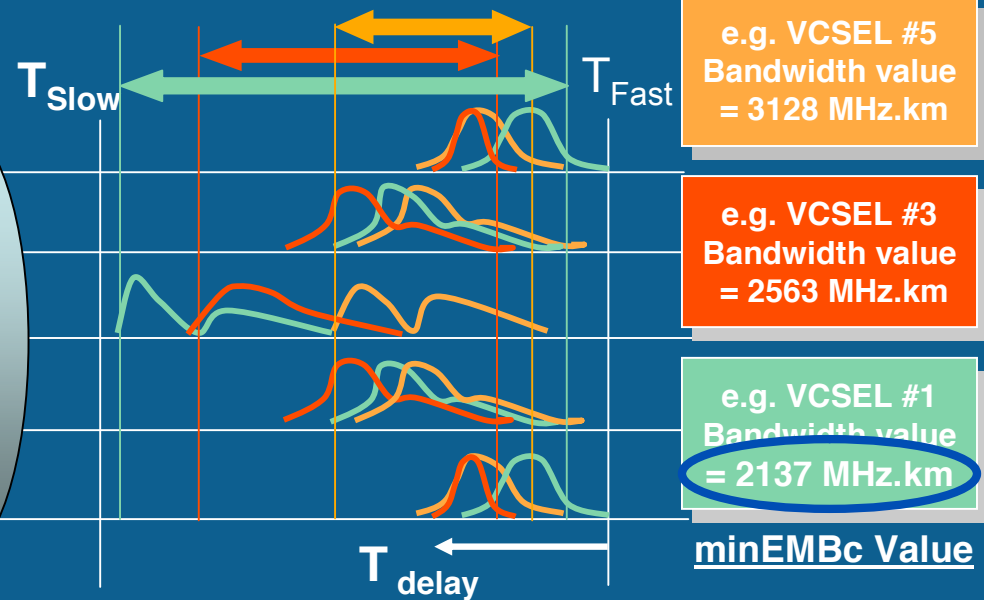
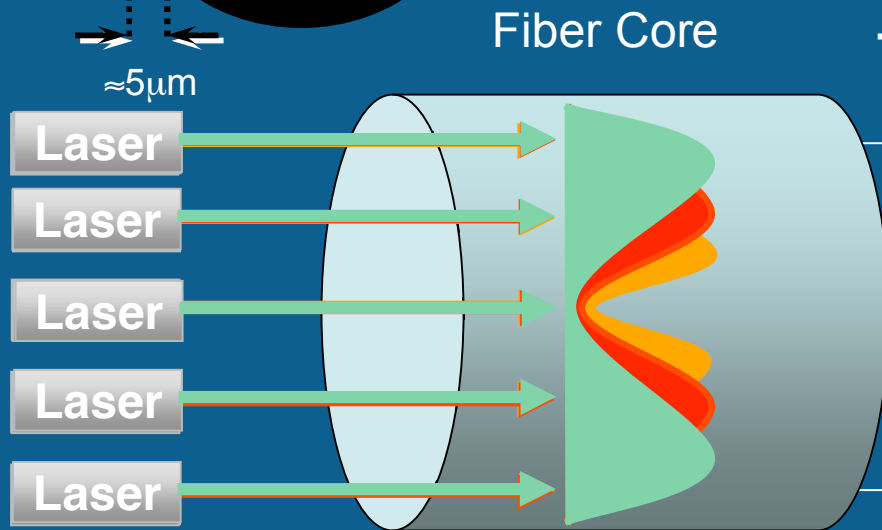
Pass = OM3 (2000 MHz.km EMB) or OM4 (4700 MHz.km EMB)
 Fail = OM2 (< 2000 MHz.km EMB)




Characterization Methods

minEMBc (min Effective Modal BW – calc)



1 of 2 DMD-based standards compliant measurements
 Simulates several laser types scanned across core
 BW defined by most delayed pulse



-  "Hot inside" laser
-  "Mid-range" laser
-  "Hot outside" laser

Different laser characteristics simulated

Note: BW values provided for illustrations purposes only, drawing not scale

Fiber preferred everywhere except the horizontal

Multimode fiber dominates in risers & data centers

Horizontal

- Predominately Copper
- 10/100/1000 Mb/s
- Zone (FTTE) fiber growing

In-Building Backbone

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

Campus Backbone

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

Data Centers

- 60% fiber and increasing
- 1, 2, 4, 8 and 10 Gb/s
- Fiber preferred, MMF dominates, OM3 strongly preferred

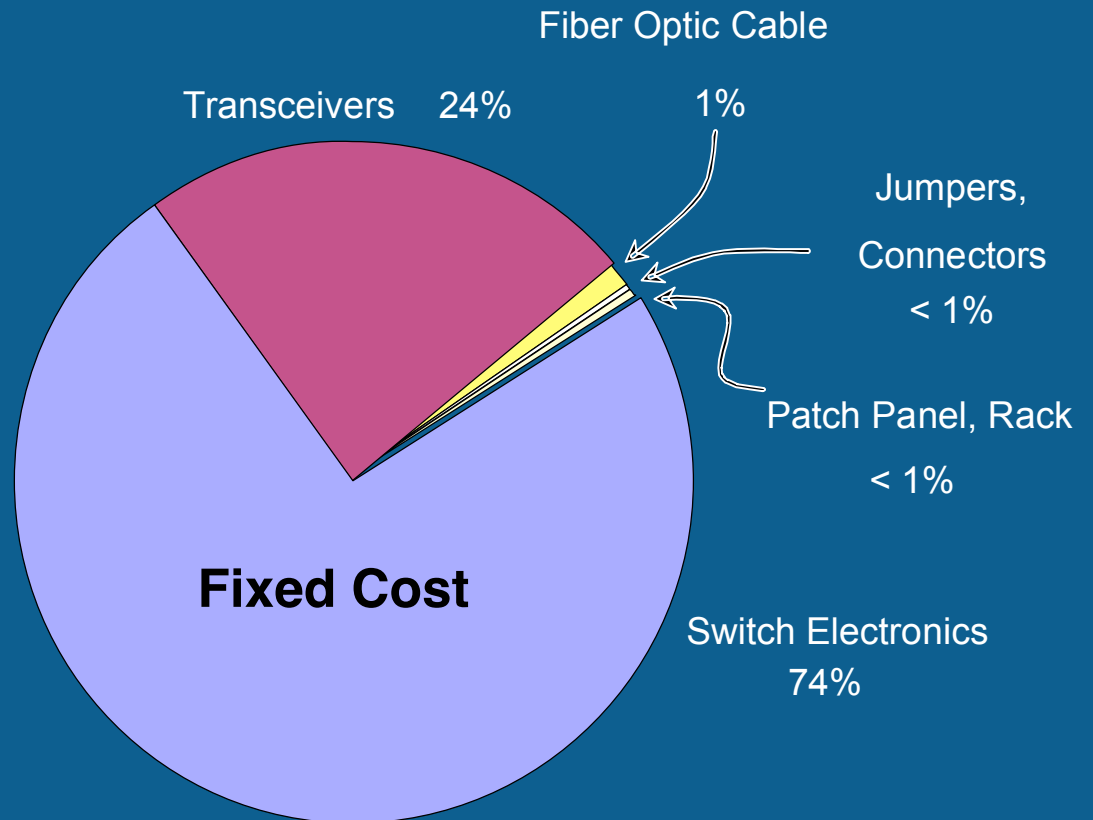
Source: Corning Analysis

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Active components costs dominate enterprise link economics

- Fixed costs ~ the same regardless of fiber choice
- Transceiver costs ~ 1/4 of total system costs
 - Key area for savings with multimode fiber
 - Greatly outweighs difference in single-mode versus multimode cable cost



Typical 300 meter backbone

Source: www.foundry.com, www.peppm.org, Corning analysis

Multimode fiber solution saves ~ 50% over single-mode fiber solution

- Assumptions

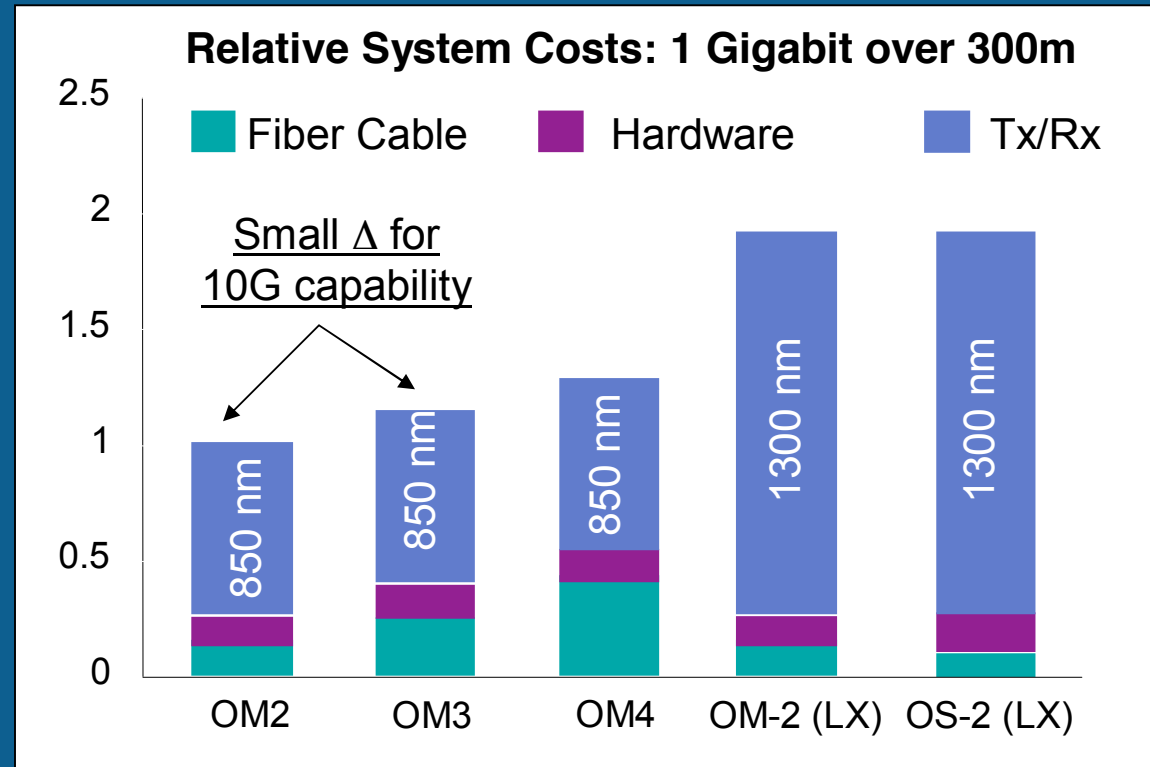
- 300 m, 24F count cable
- 24F Passive Interconnect (x2)
- 18x 1 Gb/s Transceivers

- Key findings:

- Cable very small portion of link costs
- MMF 850 nm (SX) solutions always lower cost

- OM3 fiber

- Supports 10 Gb/s over 300m
- Lowest cost upgrade path to 10G

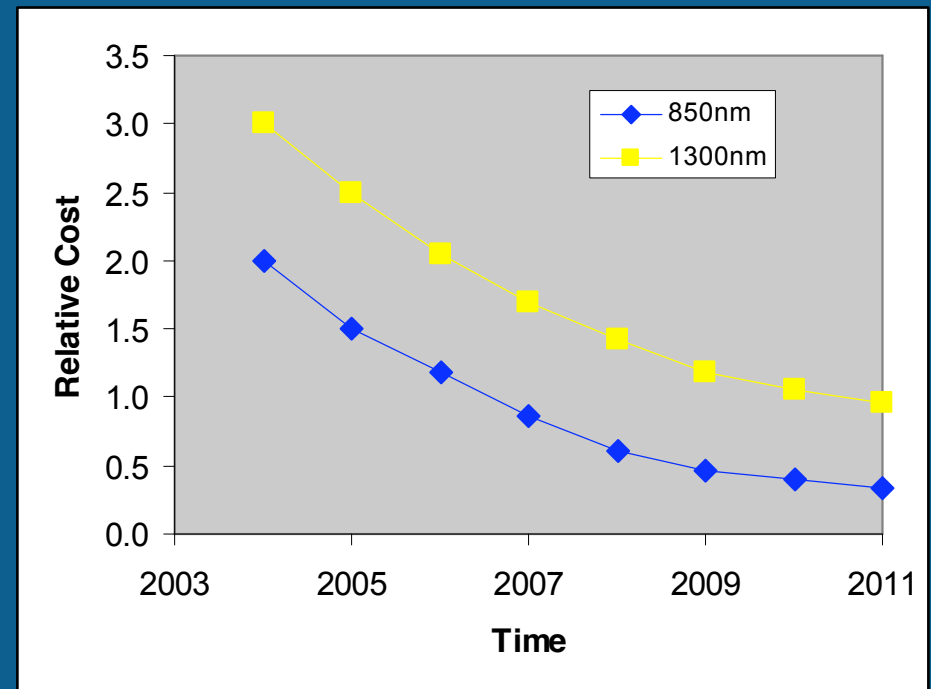


LX = Long Wavelength = 1300 nm

Technology – 850 nm provides cost benefit

- 850 nm VCSELs ~90% of optical 1G enterprise market
- 850 nm 10G VCSELs just entering high-volume manufacturing
 - 850 nm continues to be low-cost solution for 10 Gb/s
 - Low cost solutions for 100 Gb/s have been identified
 - SFP+ 850nm transceivers continue to drive price down
- LR (1300 nm) solutions may capture some market share in enterprise networks
 - Small percent of new installs

10 Gb/s Transceivers



Source: Corning estimates

Multimode fiber preferred for enterprise networks

	Single-mode	Multimode
Information carrying capacity	X	
Distance supported	X	
Fiber price	X	
Connector price		X
Transceiver price		X
Ease of handling (core size)		X

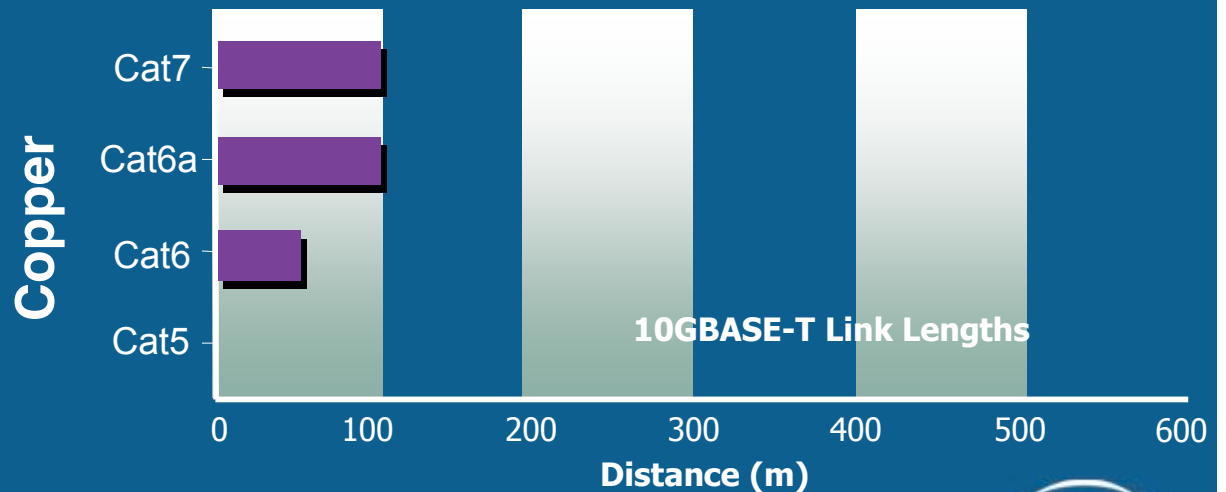
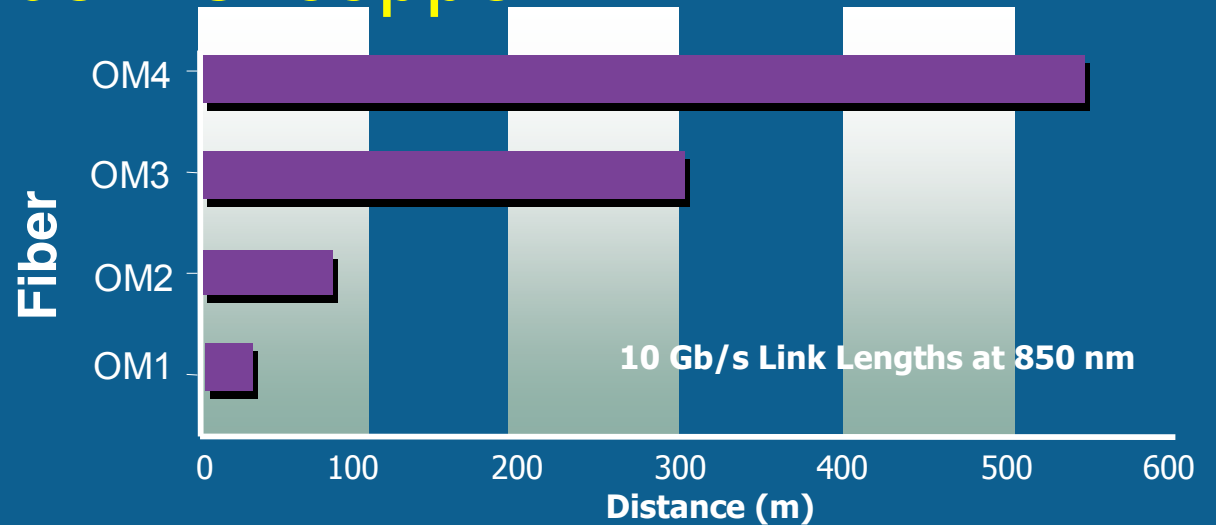
Multimode = Lowest price system for shorter links (10G to 600m) with many terminations

Single-mode = Best solution for high bandwidth longer links (10G > 600m)

TIA-942 recommends the use of laser-optimized 50 μ m multimode fiber for backbone cabling because of its capability of supporting higher network speeds over longer distances while being more cost-effective to implement than single-mode fiber.

Historically, there have been many benefits of fiber vs. copper

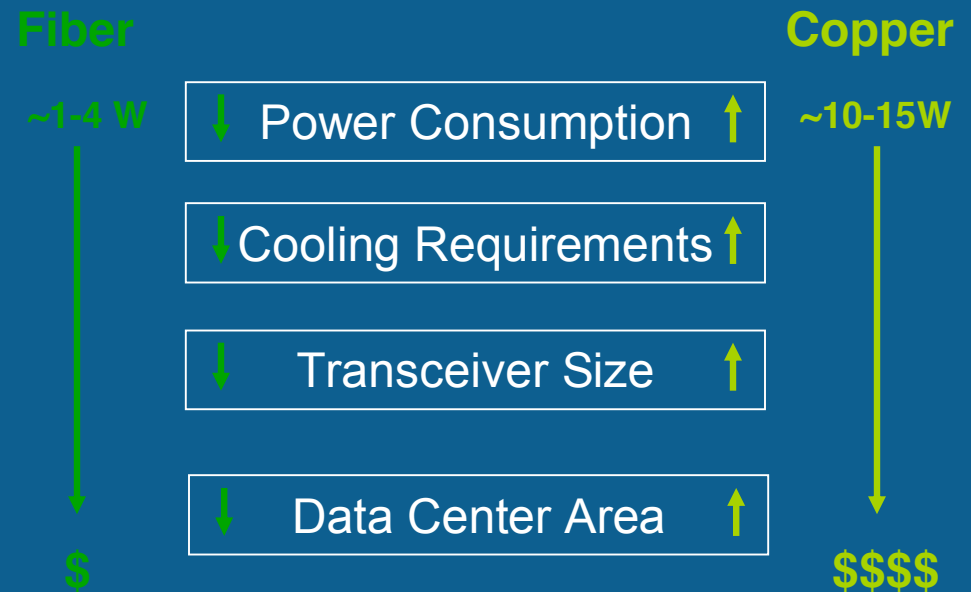
- Performance
 - Higher data rates/ longer link lengths
 - Low latency
 - Network security
 - Immune to EMI, RFI and cross-talk
 - Longer cable life
- Pathways and space
 - Smaller, lighter cables
 - Less cable fuel load
 - Easier installation



With 10G the list of benefits of fiber vs copper is growing

- Electronics port density, power and cooling efficiencies = GREEN
- Cost position changing with 10G
 - TIA Fiber Optic LAN Cost Model
 - Complexities of 10G copper testing

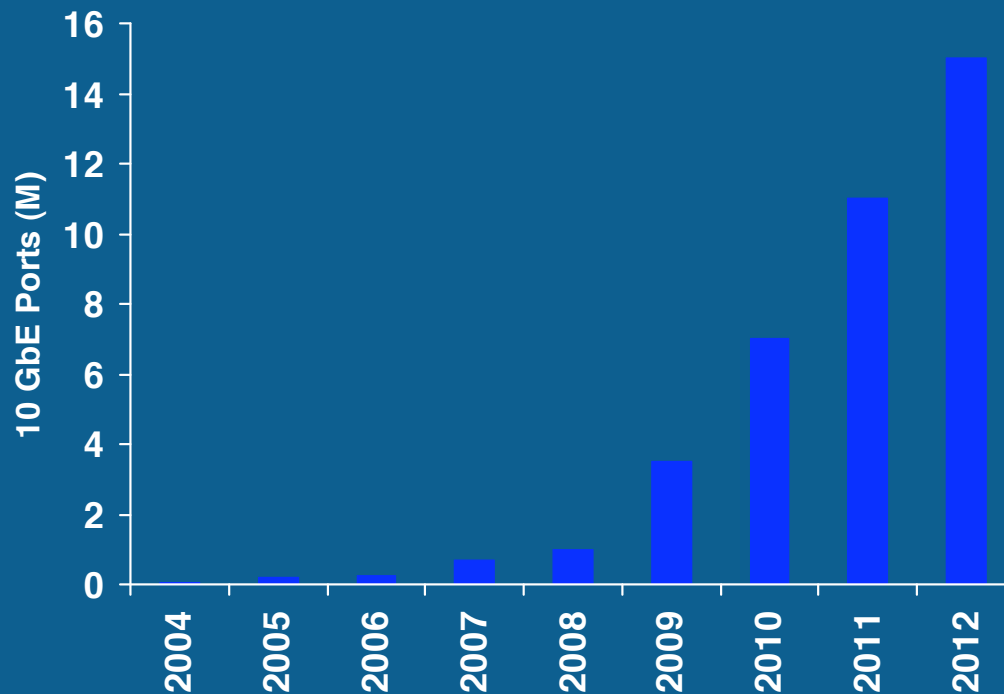
10 Gb/s Operating Cost Fiber v. Copper



Part II

- Enterprise and data center trends drive changes in fibers and standards
 - Increased speeds put pressure on enterprise networks
 - Market continues to shift to laser-optimized 50 μm fiber

Enterprise network data rates continue to increase; Drives interest in next generation speeds



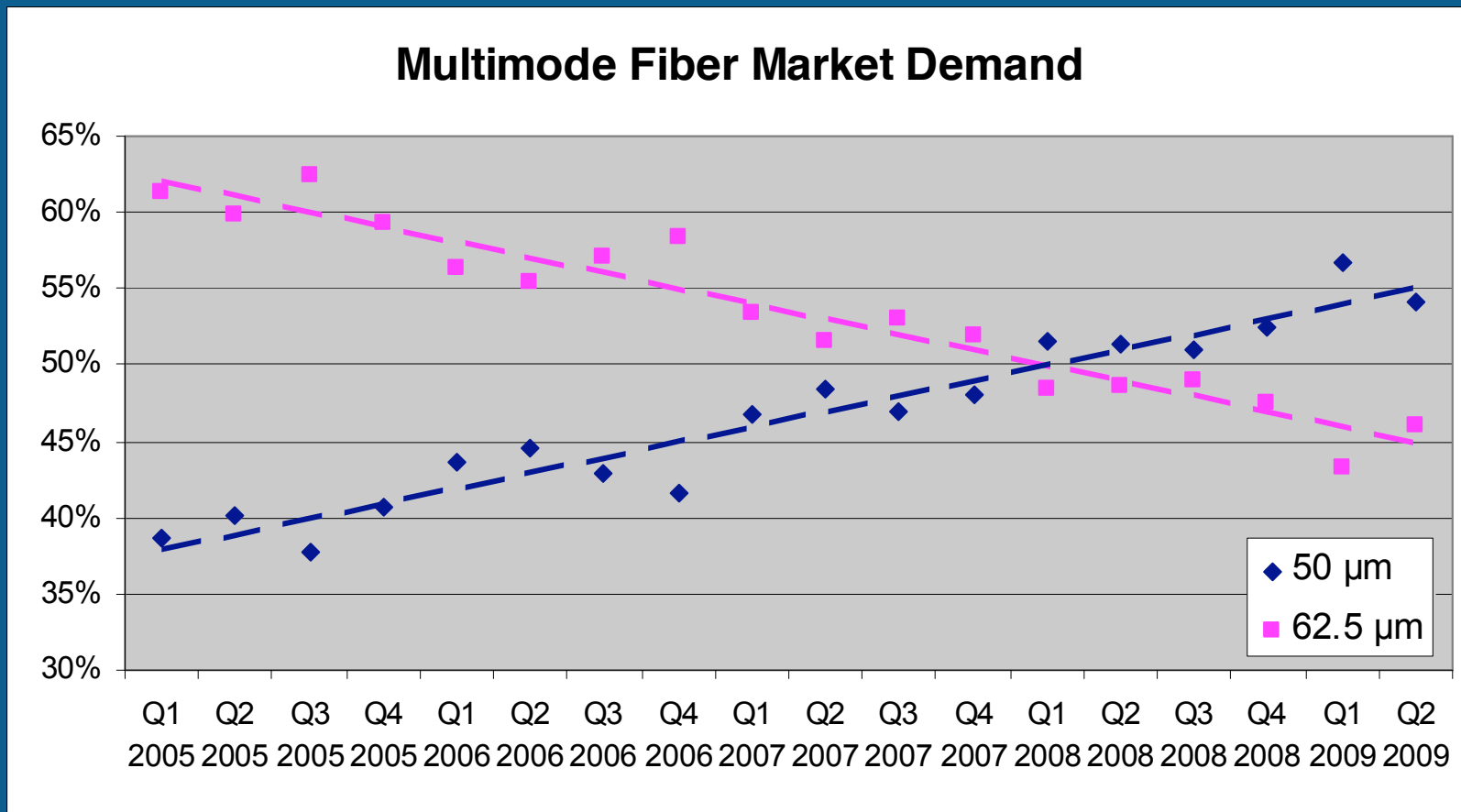
Source: Dell'Oro

- Sales of 10 GbE ports growing despite declining market
- Dell'Oro projects 10GbE port sales of 15M in 2012

Need for faster speeds already exists

- 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 now in their networks
- Other end-users such as Sun Microsystems, Intel and Broadcom are touting the need for 40 Gb/s server interconnects

North American market now majority 50 μm



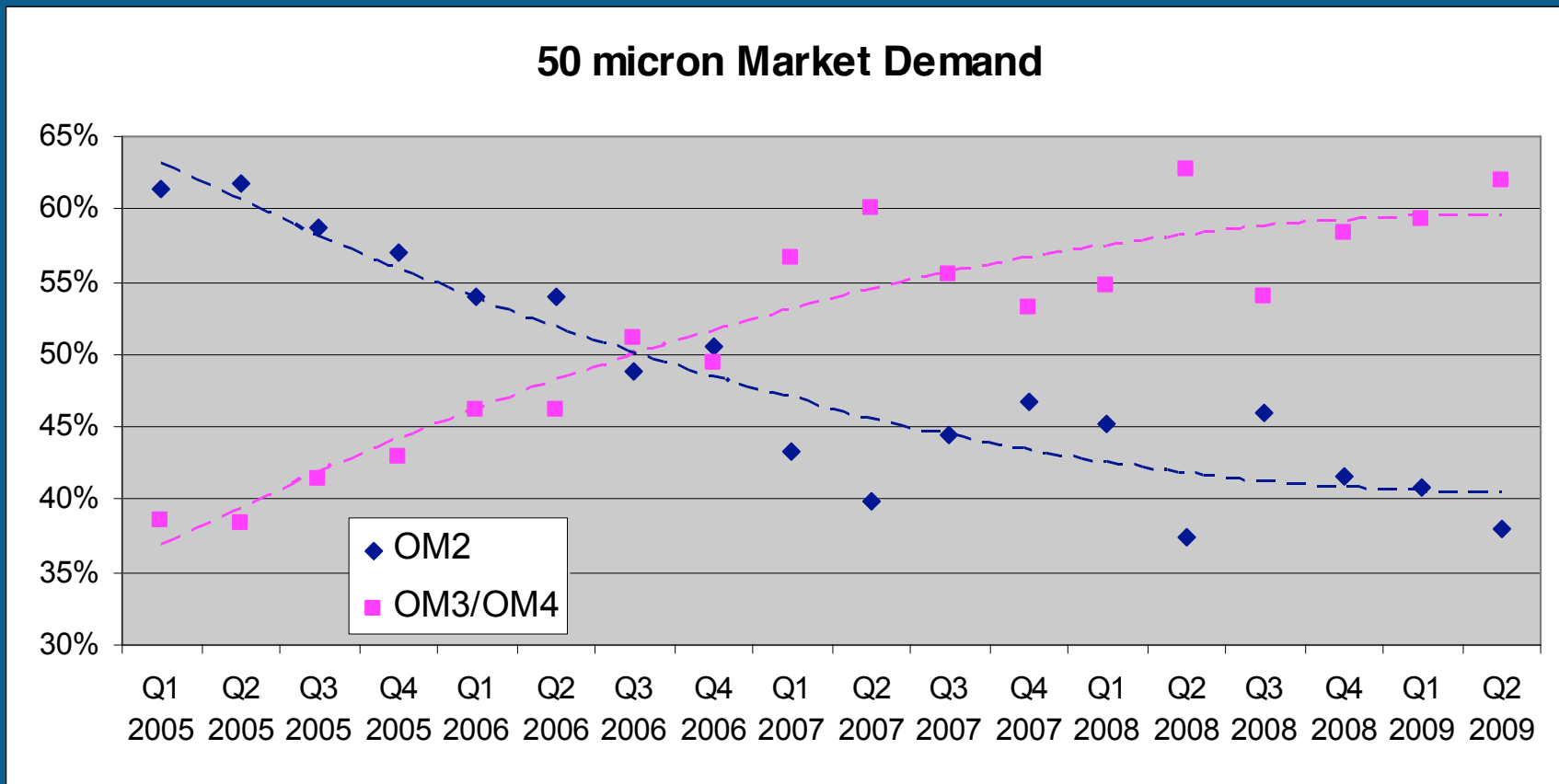
Source: Burroughs Report

More 50 μm sales than 62.5 μm sales since Q1 2008

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Laser-Optimized 50 μm continues to grow



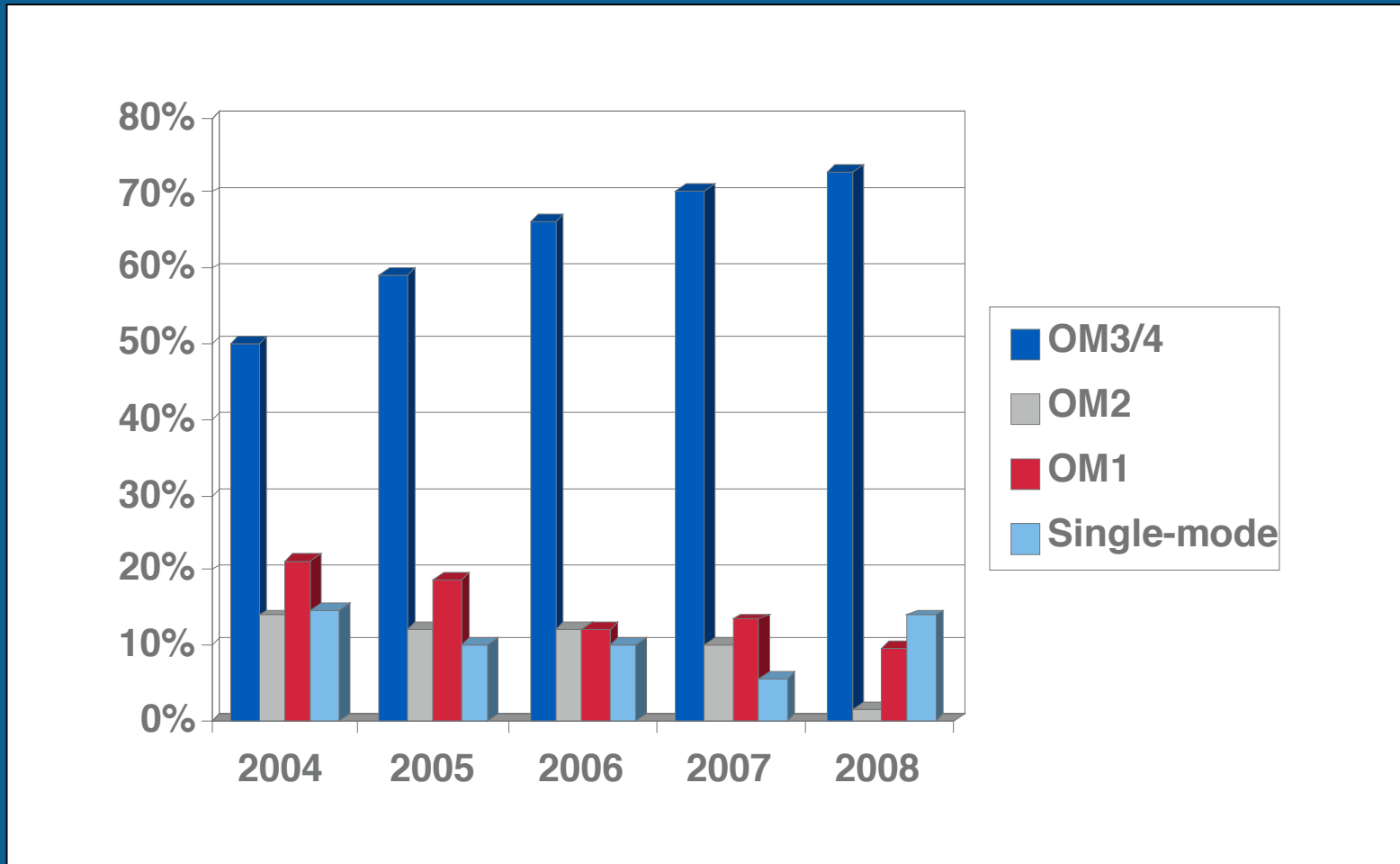
Source: Burroughs Report

OM3 has been majority of 50 μm since Q1 2007

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OM3/OM4 dominate data centers



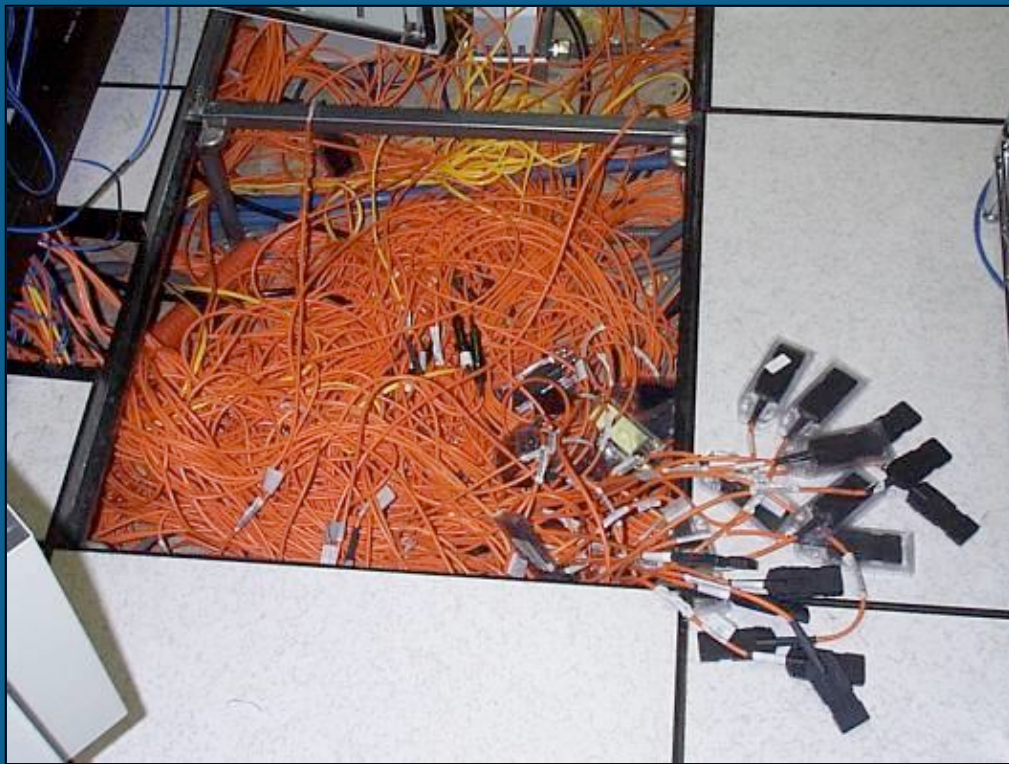
Source: Corning Cable Systems

Part III

- Next Generation Fibers
 - Bend-insensitive multimode fiber
 - OM4 fiber

Need for bend-insensitive multimode fiber

Over time moves, adds and changes (MACs) lead to mismanaged cabling

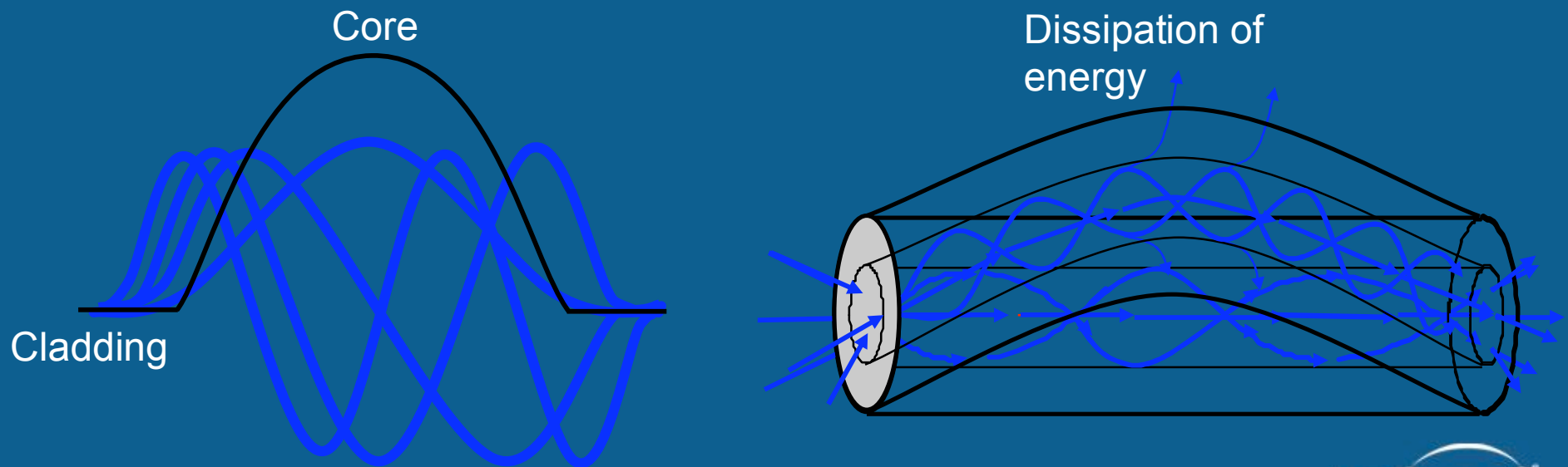


Mismanaged cabling results in:

- Congestion in sub-floor space
- Bend-induced attenuation
- Restricted air flow
- Negative impacts on cooling efficiency

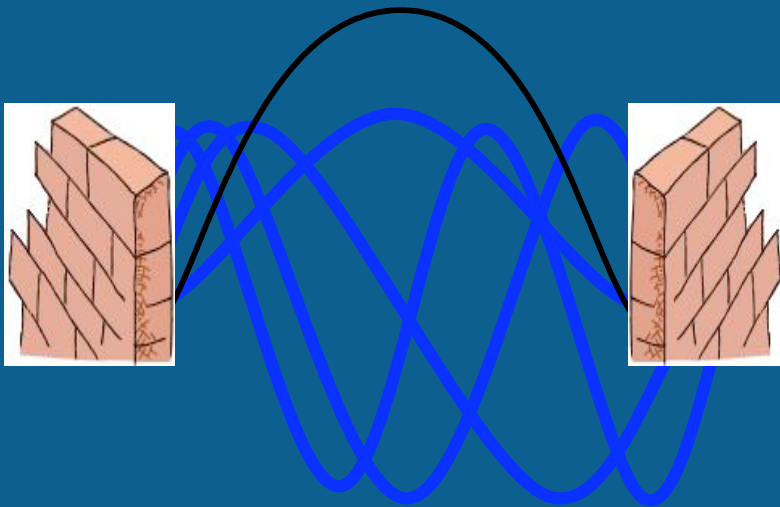
Fundamentals of macrobending in multimode fiber

- Multimode fiber has many modes of light traveling through the core
- As each of these modes moves closer to the edge of the core it is more likely to escape, especially if the fiber is bent
- In a traditional multimode fiber, as the bend radius is decreased, the amount of light that leaks out of the core increases

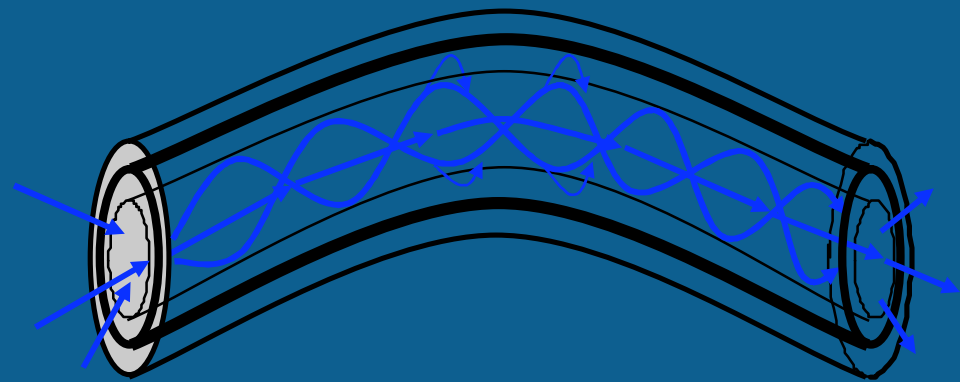


Bend-insensitive multimode fiber technology prevents light from escaping

- A specially engineered optical trench can be used to trap the energy in the many modes which propagate within the fiber core
- Keeping the light in the core, even in the most challenging bending scenarios, significantly reduces the bend-induced attenuation



Trench acts like barrier



Energy is confined inside the fiber

Existing MMF macrobend standards are not very challenging

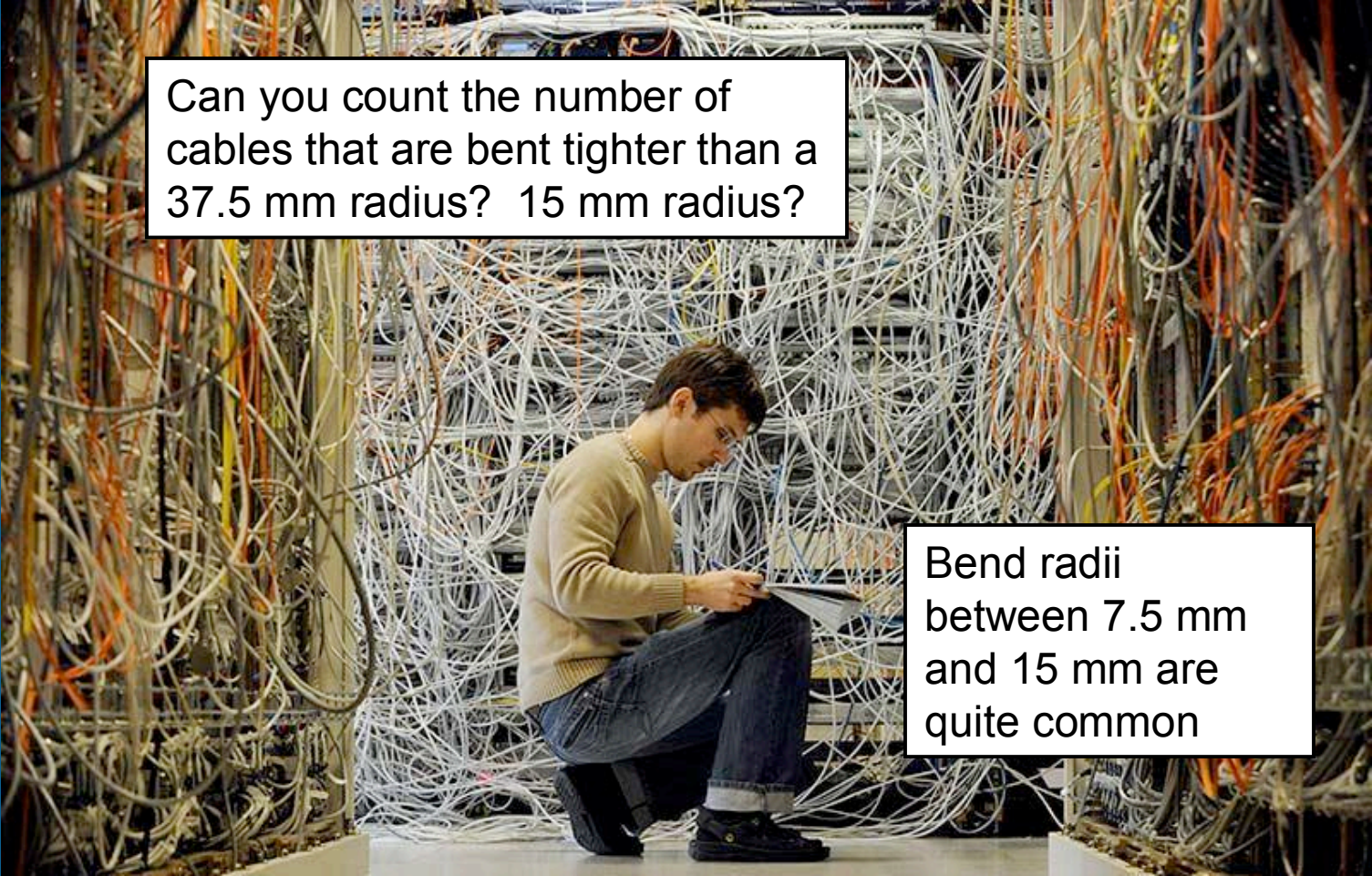
Multimode Std: IEC 60793-2-10

Bend Radius	37.5 mm
Number of Turns	100
Max Attn @ 850 nm	0.5 dB

Multimode Std: ITU - G.651.1

Bend Radius	15 mm
Number of Turns	2
Max Attn @ 850 nm	1 dB

Tighter bend radii are quite common Higher level of performance is required



Can you count the number of cables that are bent tighter than a 37.5 mm radius? 15 mm radius?

Bend radii between 7.5 mm and 15 mm are quite common

Comparison of standard OM3/OM4 versus bend-insensitive OM3/OM4

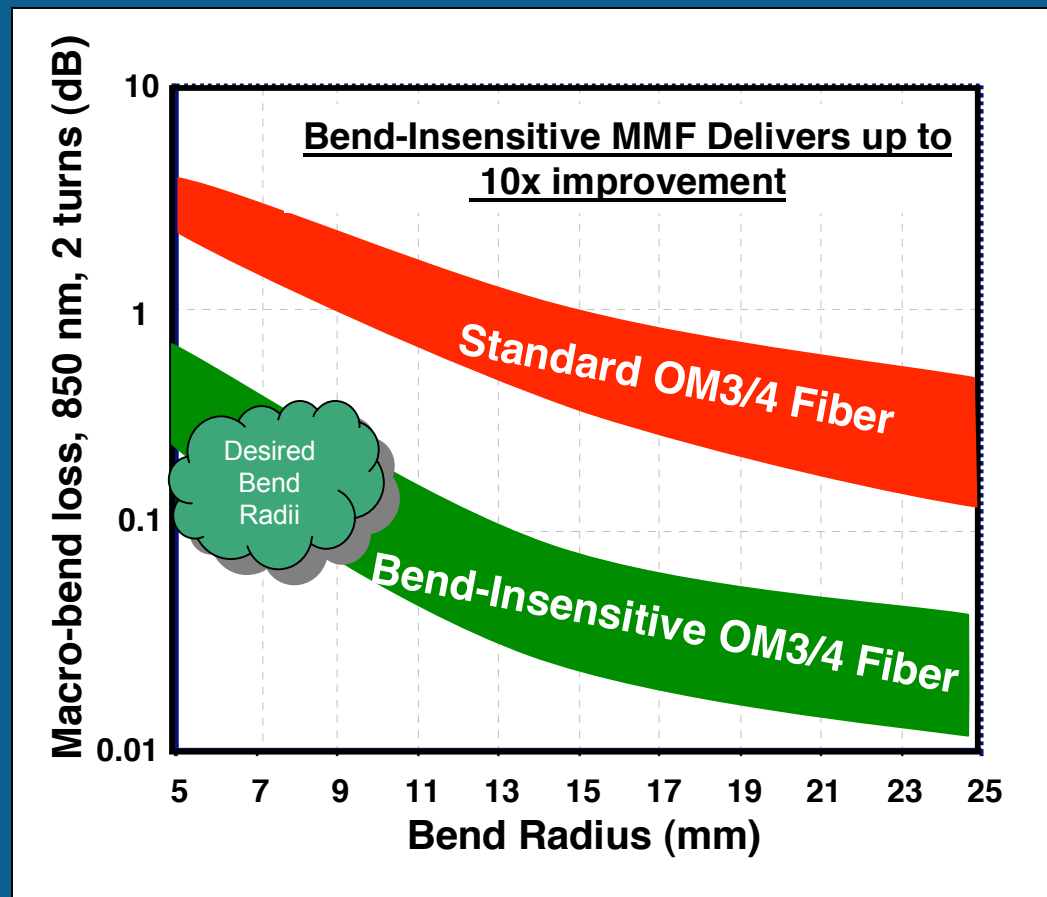
Up to 10x better bend performance than standard 50 μm fiber

High bandwidth OM3 and OM4 capability

Improved optical performance

Fully standards compliant;
Compatible with installed base

May be spliced/ connectorized
with commercially available
equipment



Bend-Insensitive multimode fiber addresses key concerns of enterprise network operators

Bend Loss
Reduced by up
To 90%

Better Optical
Performance

Enables smaller,
lighter more robust
Cable/H&E designs

**Bend-Insensitive
Multimode Fiber**

More reach & flexibility

More connectors,
moves, adds & changes

Lower maintenance cost

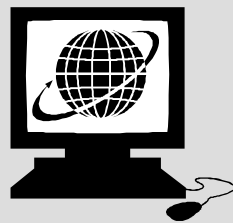
More future proof
optical cabling

Better cooling efficiency

Efficient use of space

Reduced cable fuel load

Network
Impacts



**Greater Network
Reliability:
reduced downtime**

A Future Proof System

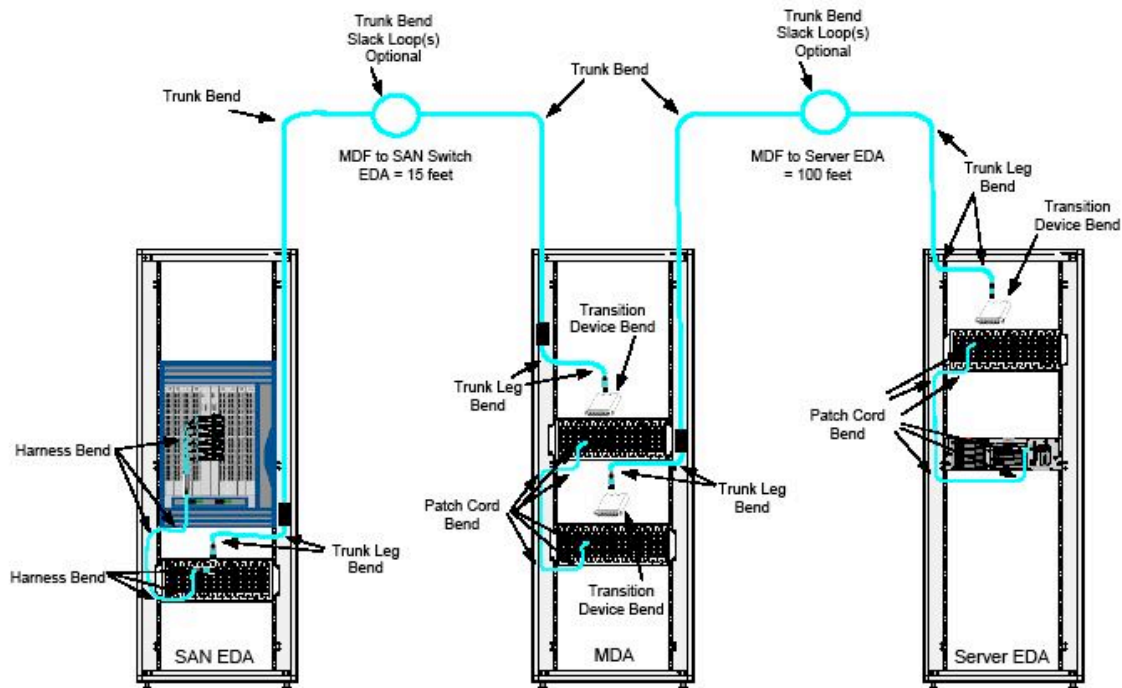
Reduced Operating Costs

**Faster & Lower
Cost Installation**

**Operators
Key
Concerns**



Typical Storage Area Network (SAN) link includes > 30 bends



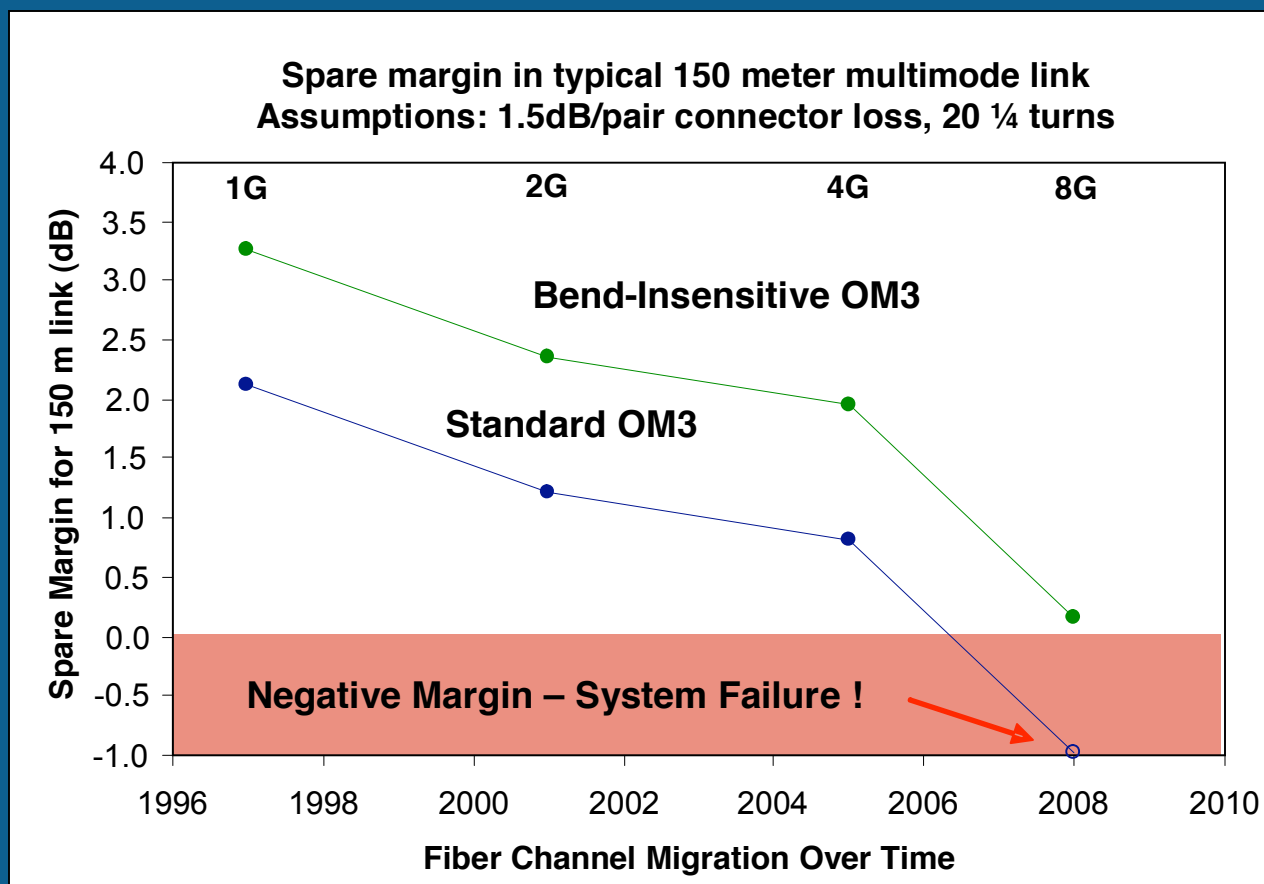
Total Harness Fiber Bends = 6
Total Trunk Fiber Bends = 14 (legs = 8; distribution cable = 6)
Total Patch Cord Fiber Bends = 12
Total Transition Device Fiber Bends = 3+
Total Fiber Bends in the Channel = 35

Plug & Play SAN Channel
through an MDA

Source: Corning Cable Systems

Lower bend loss = Greater system reliability

- Spare margin = power remaining after link component losses and power penalties
- As speeds increase power budgets see growing pressures
 - Bends in standard OM3 links can cause system failure
 - Bend-insensitive multimode fiber reduces bend-induced loss and increases system reliability



Benefits of increased spare margin

Increased spare margin allows:

- Greater reliability and less downtime
- More system flexibility
 - Longer link lengths
 - Additional connector pairs

Downtime is real dollars:

- “80 largest US companies experience enterprise network downtime costs equal to 3.6% of annual revenues”
- “Medium sized businesses lose an average of 1% of their annual revenues (\$867,000) in network downtime”

Source: Infonetics Research (2004, 2006)

Jumpers with ultra-bendable performance offer network insurance

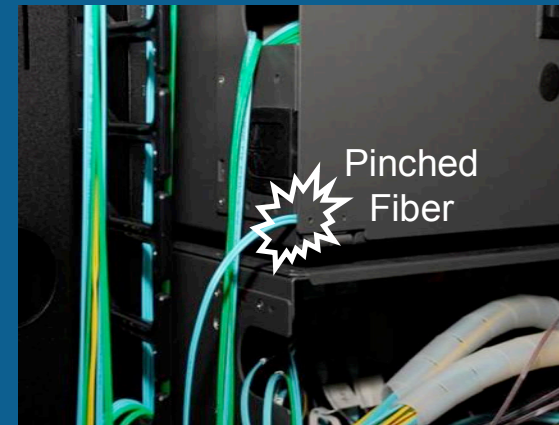
- Even when best practices are followed, **mistakes can occur** that result in **kinked and bent cables** beyond recommended minimum bend radius
- Jumpers with ultra-bendable fiber will **greatly reduce most outages and degradation** in a system caused by macro-bending

Standard 50 μm Jumper



Bit Error Rate = 10^{-6} ...Link Failure

Ultra-bendable 50 μm Jumper

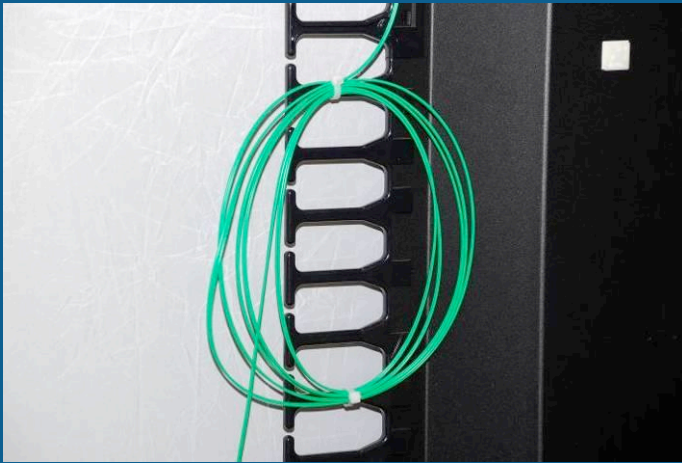


Bit Error Rate = 10^{-12} ...Link Unaffected

Source: Corning Cable Systems

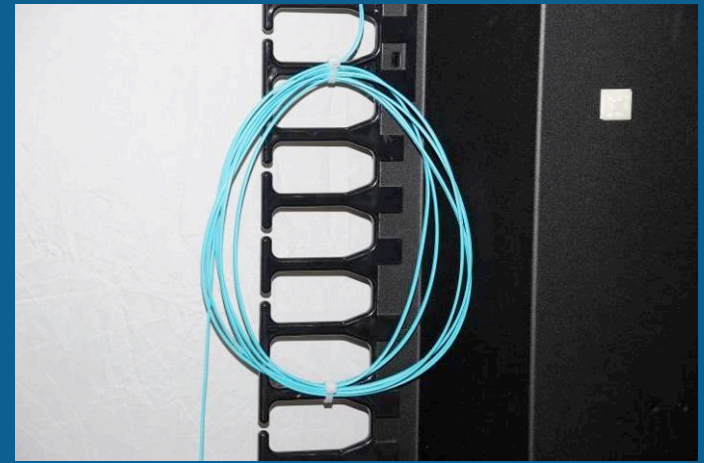
With ultra-bendable fiber, a tight loop can become a non-event

Standard 50 μm Jumper

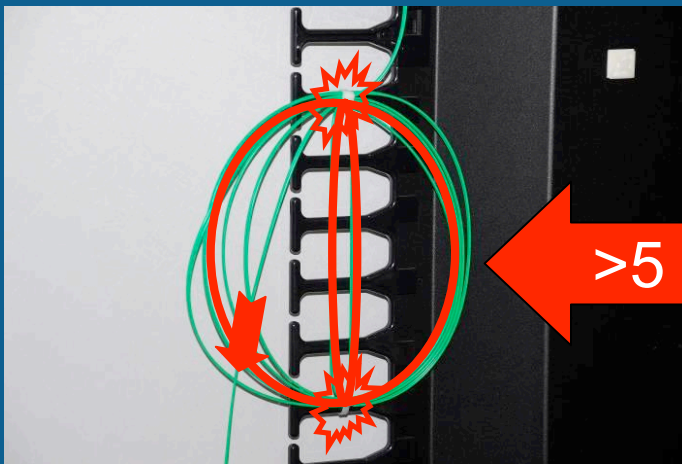


A common practice today is to store slack in a tie-wrapped loop

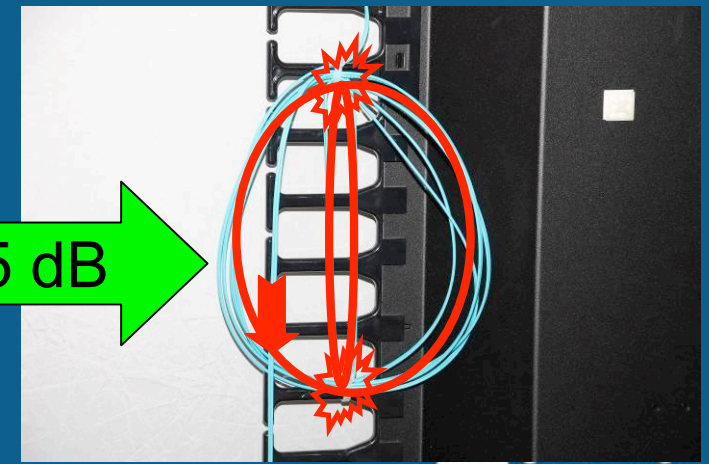
Ultra-bendable 50 μm Jumper



When a jumper is re-positioned, a tight loop can result...



>5 dB



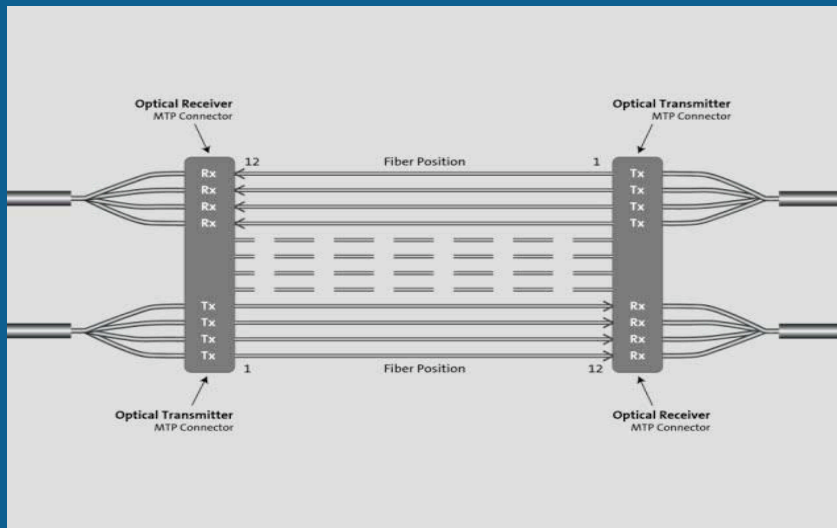
0.5 dB

OM4 standard approved by TIA in August

- OM4 is 50 μm fiber with higher effective modal bandwidth than OM3
 - Extra bandwidth can be used for higher bit rates, longer link lengths or increased margin for more connectivity
- Existing “OM” designations (per ISO/IEC 11801) are shown in the table below
- IEC proposal for OM4 has yet to be approved but highly likely it will be harmonized with TIA

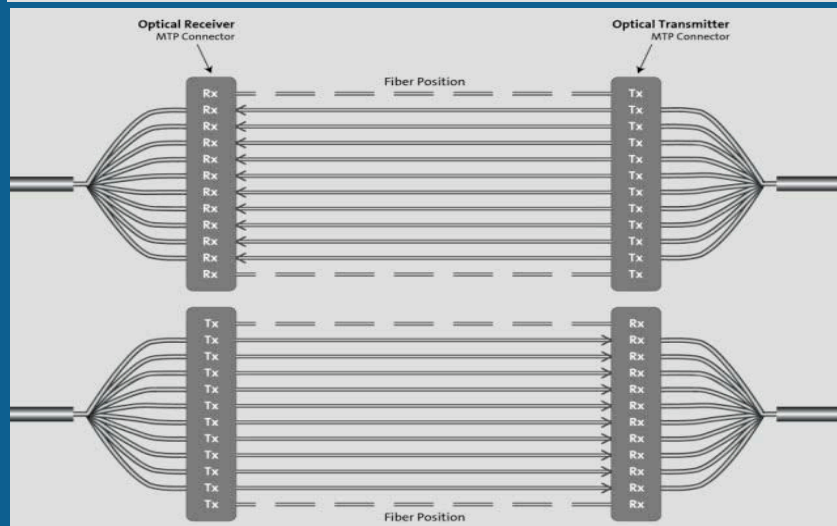
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OM2	50	-	500/500	82 m	-
OM3	50	2000	1500/500	300 m	100 m
OM4	50	4700	3500/500	550 m	125 m

Parallel optics are preferred for multimode fiber objectives



40 Gb/s

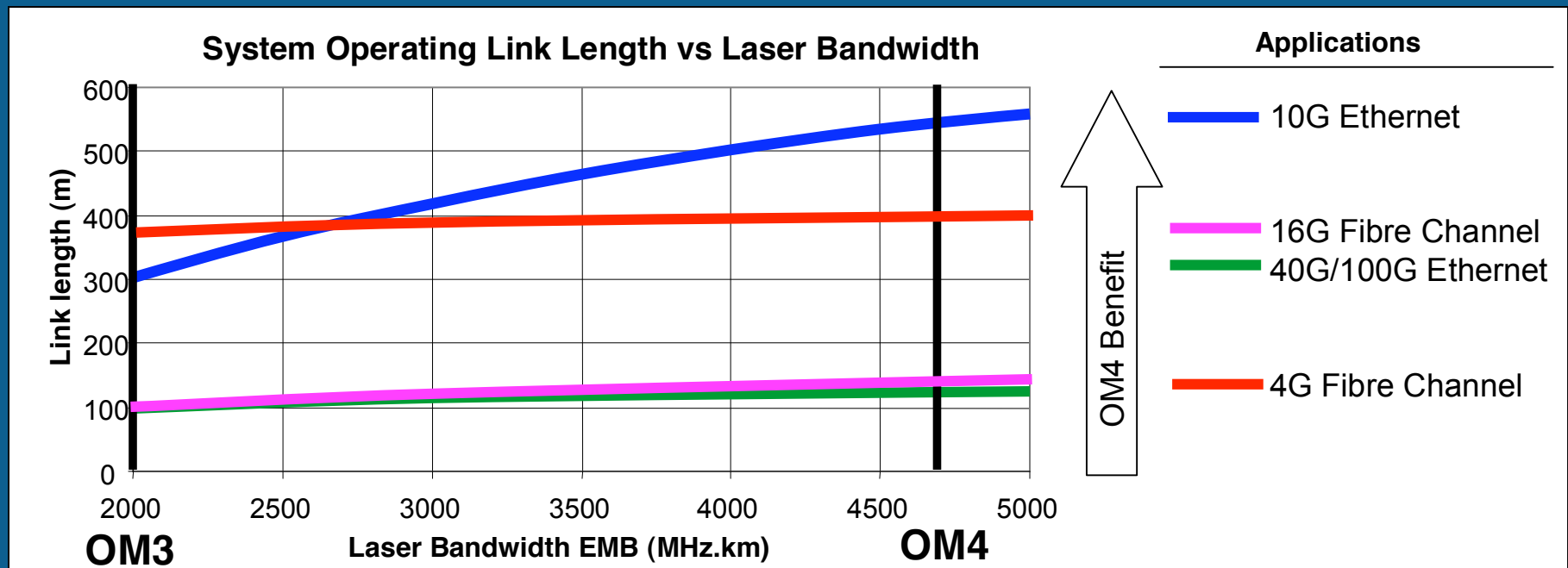
- 4 fibers x 10 Gb/s for transmit
- 4 fibers x 10 Gb/s for receive
- One 12F ribbon



100 Gb/s

- 10 fibers x 10 Gb/s for transmit
- 10 fibers x 10 Gb/s for receive
- Two 12F ribbons

Value prop for OM4 depends on application

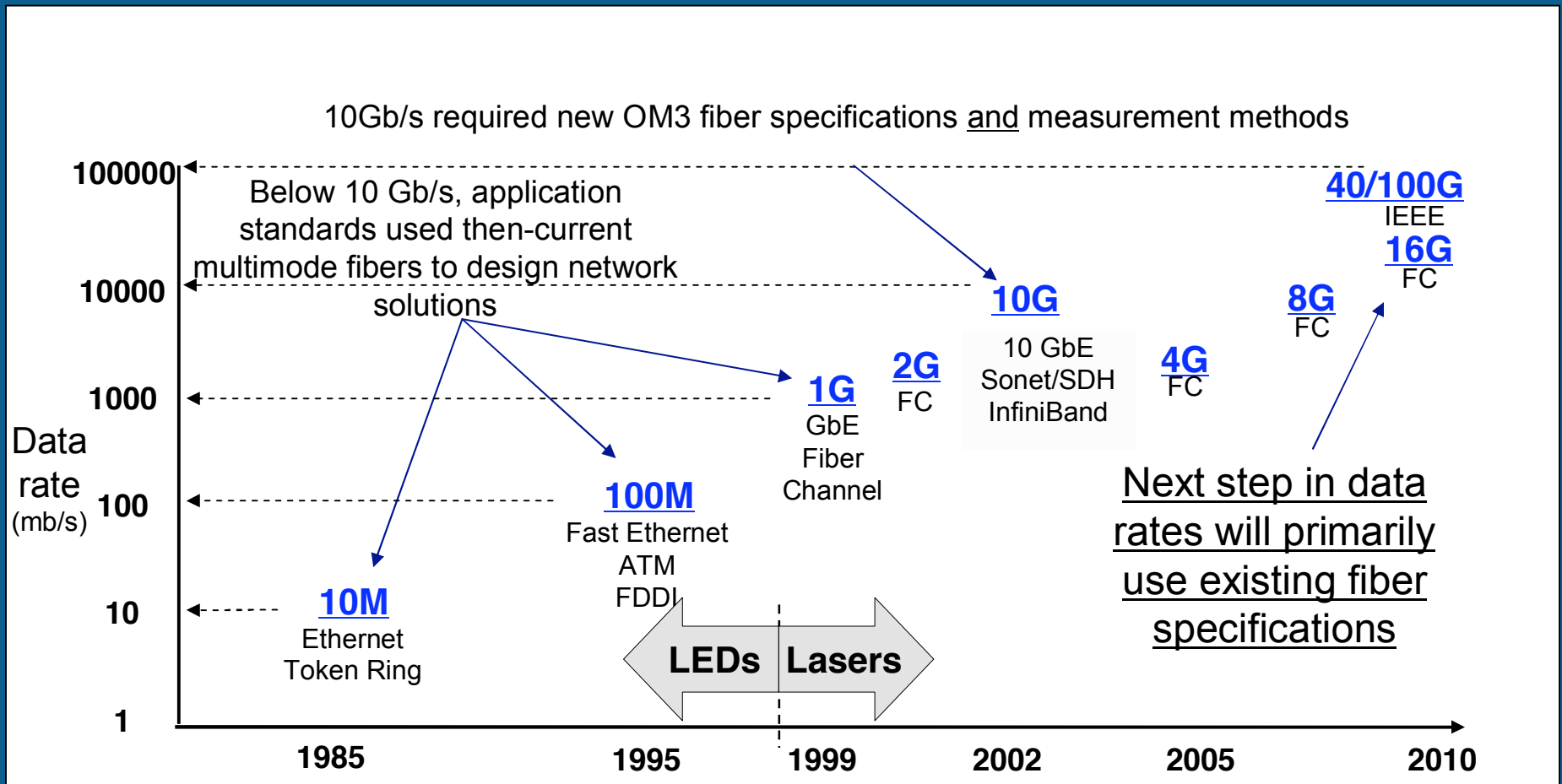


- Significant value for OM4 at 10G
- Little value for OM4 at 4G regardless of EMB value
 - Dispersion limited because of broad spectral width
- 16G has tighter spectral width than 4G so value increases
- Although 40G/100G is based on 10G arrays, looser specifications for 40G/100G transceiver arrays significantly reduce the value

Topic IV

- Next Generation Standards
 - 16 Gb/s Fibre Channel
 - 40 Gb/s and 100 Gb/s Ethernet

Next steps in data rates will use existing fiber types



Fibre Channel voted in June to include OM4

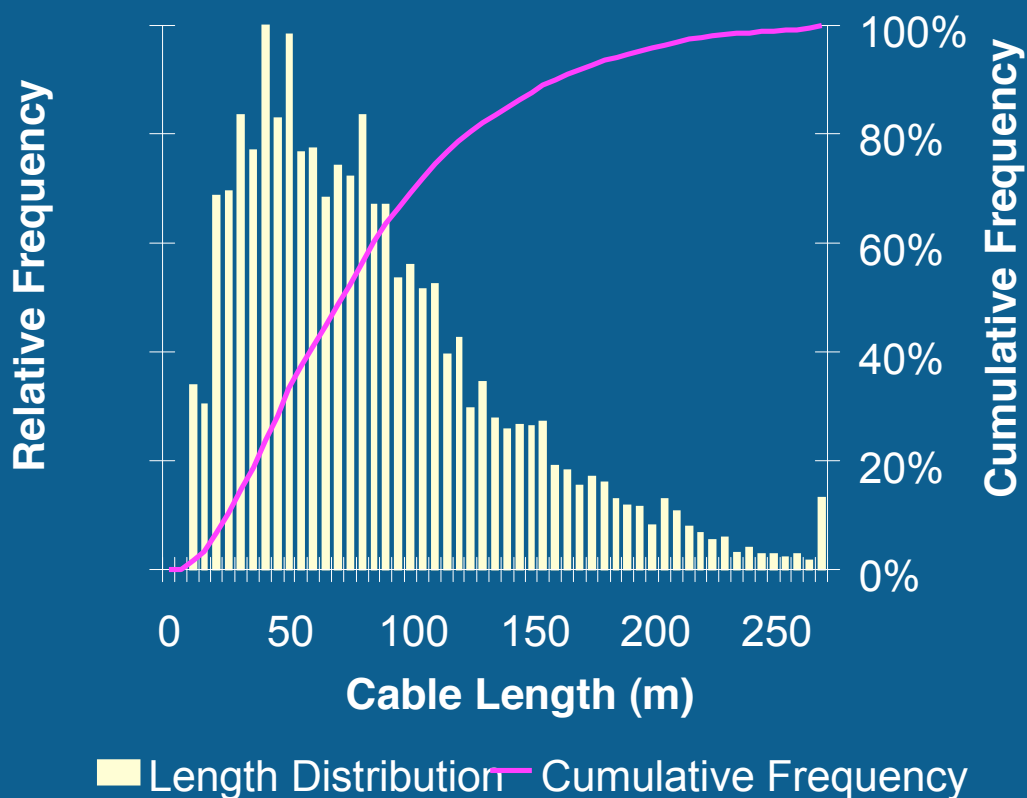
- Current proposal is for 130 m over OM4 for 16GFC
 - Ongoing debate about whether or not this can be extended
- Proposal also made to include OM4 in 4GFC and 8GFC

Fibre Channel Speed	OM3 Distance	OM4 Distance
4 Gb/s	380 m	400 m
8 Gb/s	150 m	200 m
16 Gb/s	100 m	130 m

IEEE 40G/100G Approved Objectives

- Provide specifications which support 40 Gb/s over:
 - At least 10km on single-mode fiber
 - **At least 100m on OM3 MMF**
 - **At least 125m on OM4 MMF**
 - At least 7m over a copper cable assembly
 - At least 1m over a backplane
- Provide specifications which support 100 Gb/s over:
 - At least 40km on single-mode fiber
 - At least 10km on single-mode fiber
 - **At least 100m on OM3 MMF**
 - **At least 125m on OM4 MMF**
 - At least 7m over a copper cable assembly

Including OM4 in 40G/100G standard makes cost effective MMF solution available to additional 10%



Source: Corning Cable Systems

- Objective of at least 100 m on OM3 covers ~ 70% of data center links
- Extending OM4 distance to 125 m with existing transceivers covers ~ 80% of data center links

OM3 and OM4 fibers can support even longer distances but transceiver change is required

- 40 Gb/s and 100 Gb/s transceivers based on parallel optics
 - Array of 10 Gb/s transceivers
- Current transceiver spec = lowest cost solution for up to 125 meters
- Want to also provide low cost MMF solution for > 125 m
 - Work presented during standards development showed several paths to get 150 – 250m
 - Proposals included CDR, EDC, FEC and tighter transceiver specifications
 - Proposals focused on 150m over OM3 and/or 250m over OM4
 - Corning testing with commercially available fiber, cable & transceivers achieved 250m over OM3 and 350m over OM4

Summary

- Multimode fiber remains the most cost-effective choice for enterprise networks
- Enterprise network and data center trends drive changes in fibers and standards
- Bend-insensitive multimode fibers can help solve key concerns of enterprise network operators
- OM4 fibers are now standardized and provide a path for extended distances for next generation speeds
- Next generation standards will use OM3 and OM4 fibers to provide low cost future-proof solutions for enterprise networks