Fiberoptics in 1GbE and 10GbE

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Outline

- Gigabit Ethernet
- Bandwidth of MM fibers
- Differential Mode Delay
- 10 Gigabit Ethernet
- 50/125 fiber for 10GbE

Ethernet (IEEE 802.3) Over Fibers

✓10 MB/s	10BASE-FL	LED
✓100 MB/s	100BASE-FX	LED
	100BASE-SX (TIA/EIA-785)	LED
✓1000 MB/s = GbE (802.3z)	1000BASE-SX	LD
	1000BASE-LX	LD
✓10GB/s (draft) (802.3ae)	10GBASE-LX4	LD
	10GBASE-SR, SW	LD
	10GBASE-LR, LW	LD
	10GBASE-ER, EW	LD

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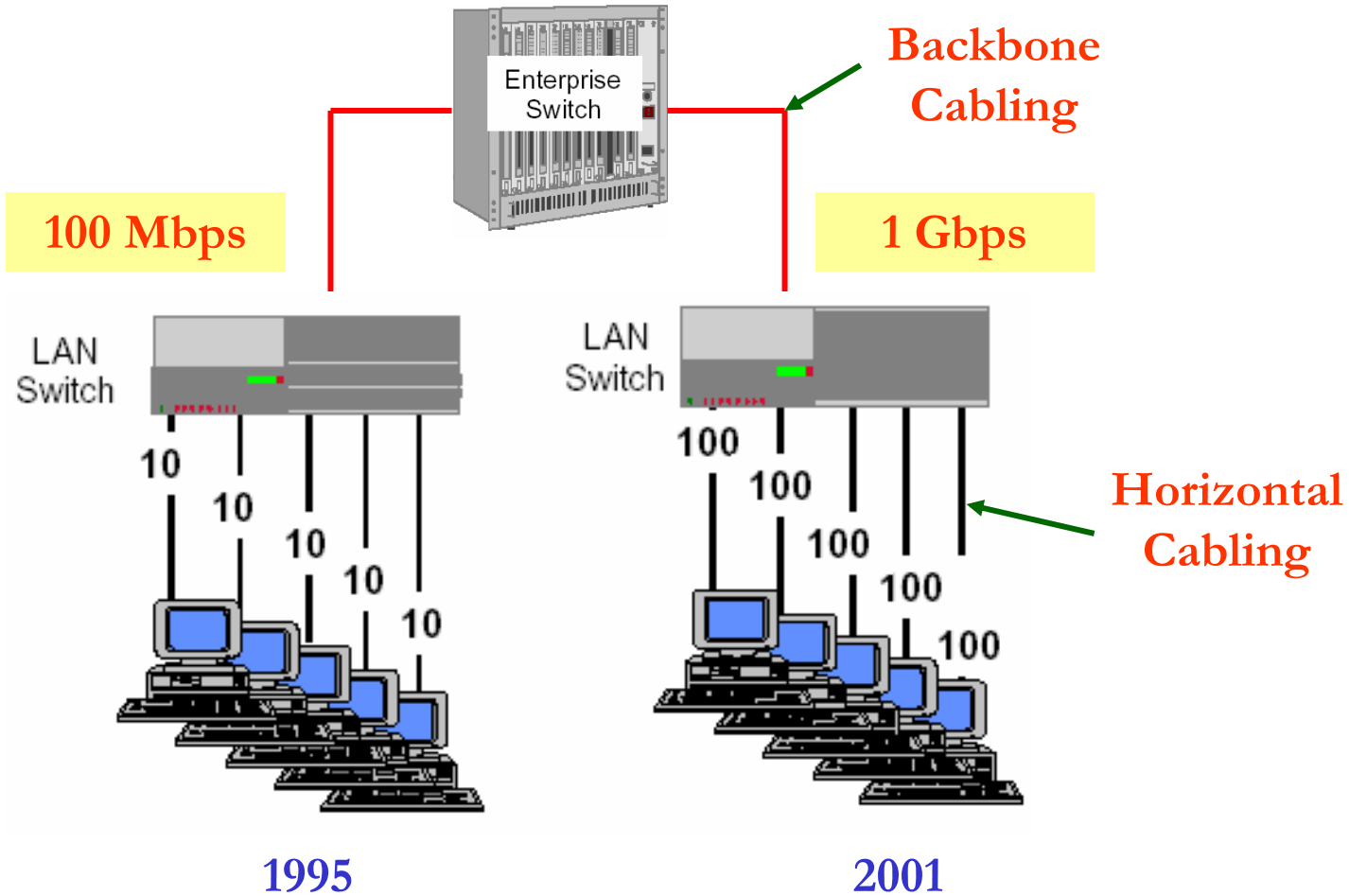
Present Day Implementation of GbE



Gigabit Ethernet (GbE) - 1

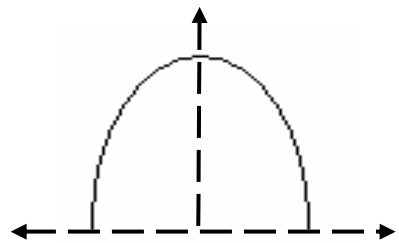
- Latest addition to the IEEE 802.3 (Ethernet) family of standards (June 1998)
- Effective bit rate of 1 Gbps – 1000 Mbps
- 8B/10B encoding – real rate is 1.25 Gbps
- Backward compatibility ⇒ legacy MM fibers the main media.
- Use of MM fibers considerably limits link length
- Standard SM fiber also recognized (for new installations)

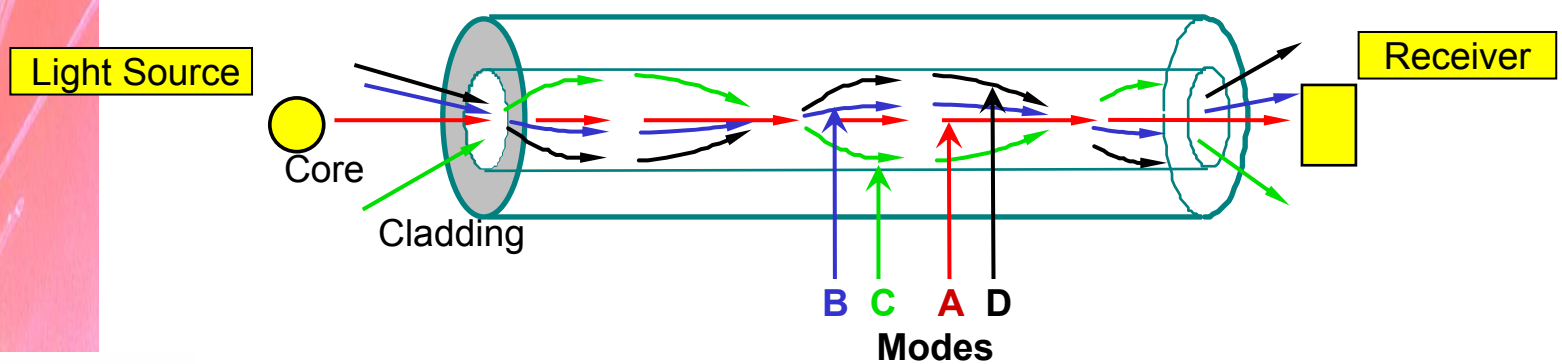
Gigabit Ethernet (GbE) - 2

- Light sources are Laser Diodes (LEDs are too slow)
  - At 850 nm – VCSEL (Vertical Cavity Surface Emitting Laser)
  - At 1300 nm – standard Fabry-Perot (F-P) LD
- Use of LD with MM fibers at high bit rate present problems never before encountered in F/O systems
- GbE can be implemented also over copper (Cat 5e / 6 / 7 cabling)

Multi-Mode Fiber Bandwidth - 1

- MM fiber bandwidth is determined by modal dispersion: group velocity varies by mode number
- All MM fibers in use are graded-index – the refractive index (n) is graded so as to minimize the group velocity variation among the modes

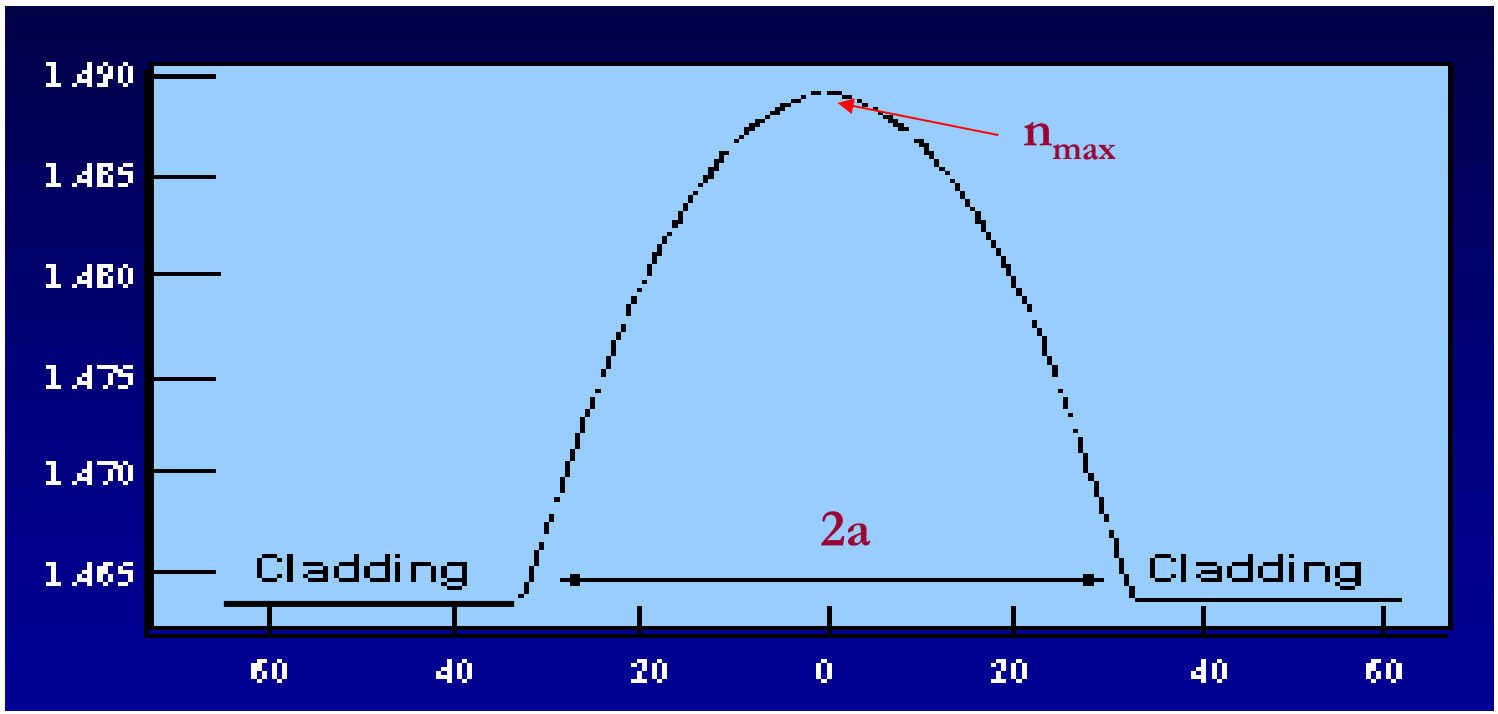




Multi-Mode Fiber Bandwidth - 2

- The bandwidth is determined by the arrival delay difference between the slowest and fastest mode
- Therefore the fiber bandwidth depends on the number of modes propagating in the fiber
- Chromatic dispersion may decrease the fiber bandwidth – depending on wavelength and source spectral width

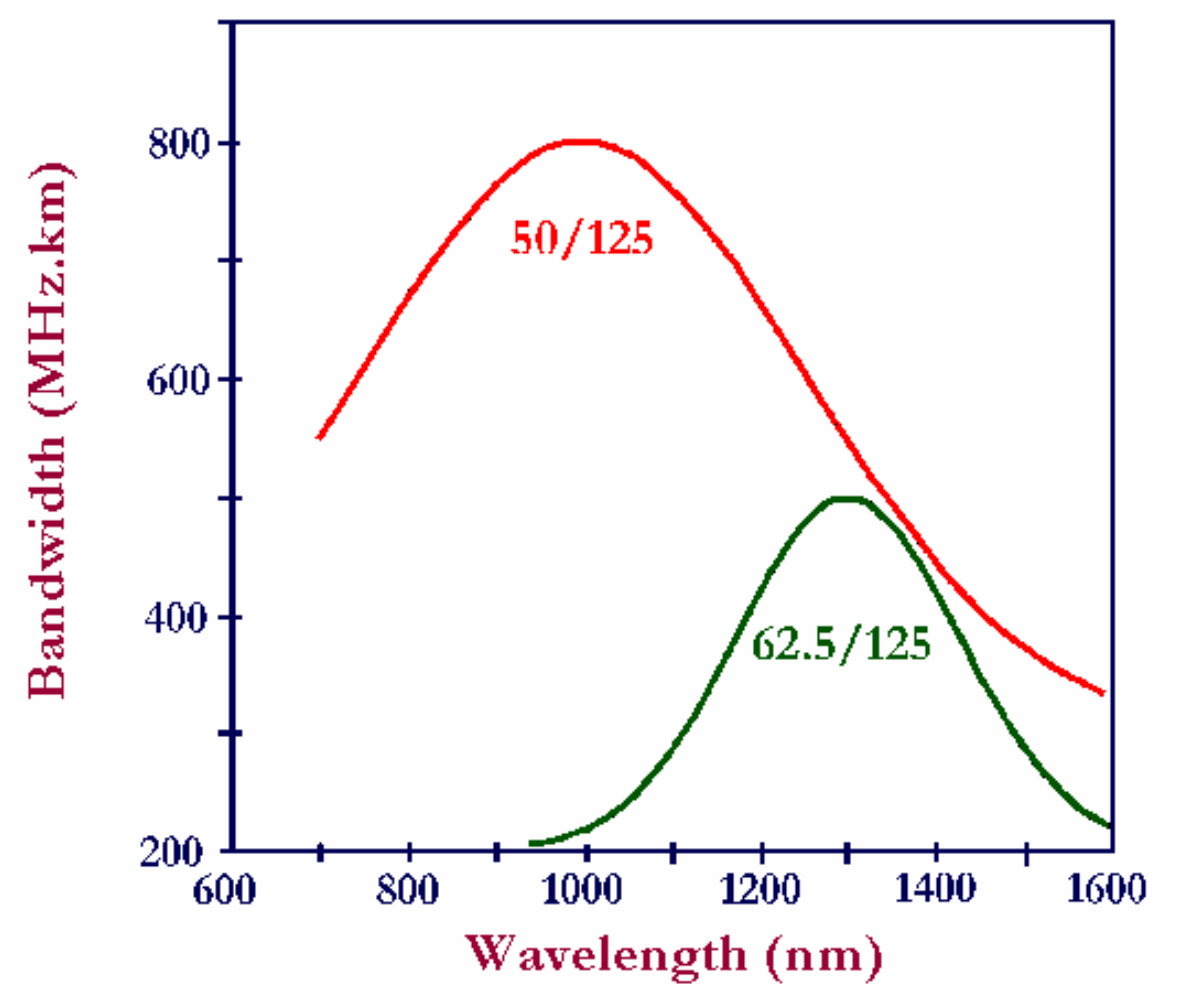
Ideal Graded Index Profile



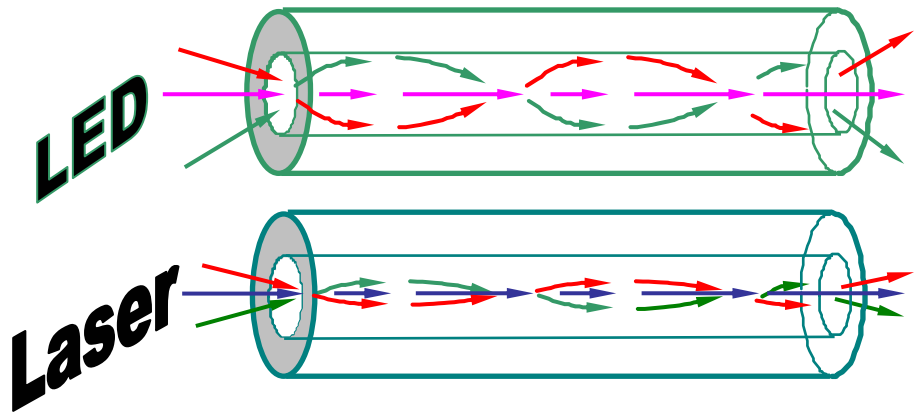
To achieve best bandwidth, profile should be:

$$n = n_{\max}\left[1 - \Delta\left(\frac{r}{a}\right)^{g}\right]$$

Bandwidth vs. Wavelength



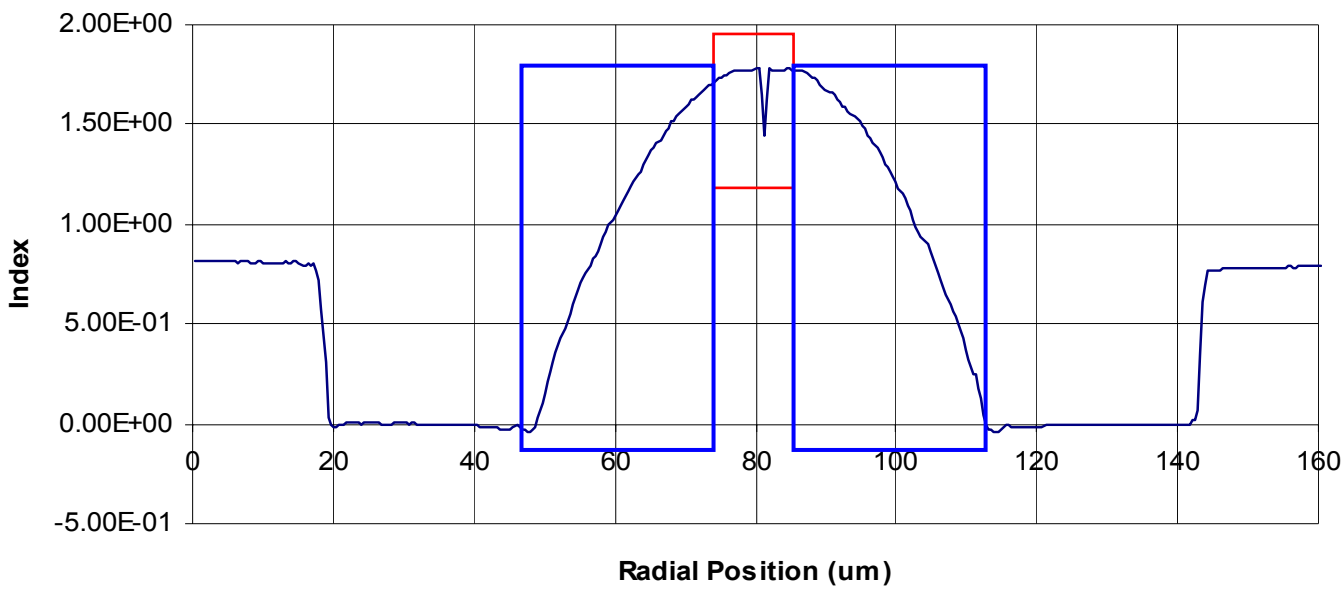
Mode Excitation with LED and LD



- LED launching excites all the modes
- BW Measurement method simulates LED launching – Overfill Launch (OFL)
- Laser Diode (LD) launching excites only some of the modes

A Standard MM Fiber

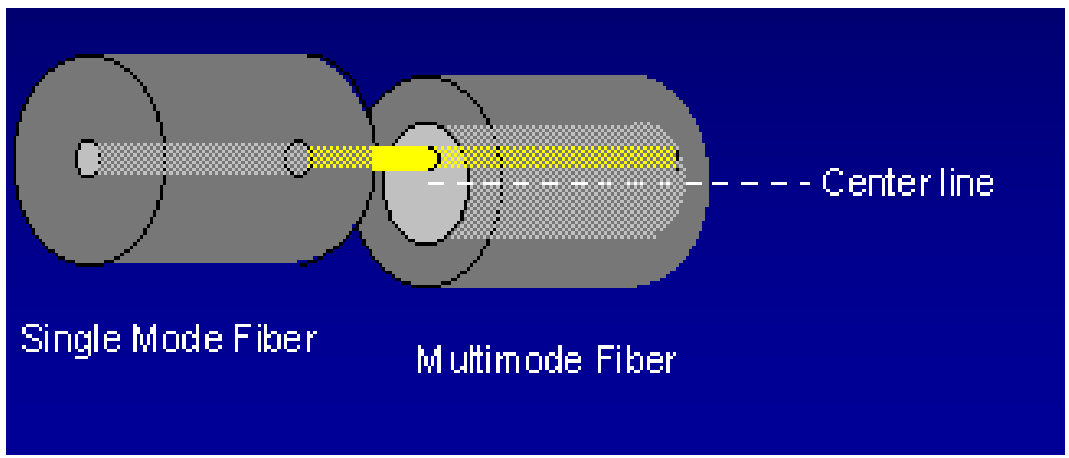
A "Real World" profile



- Modes excited by LD travel in the red area
- Modes excited by LED travel also in the blue area – the red area is negligible

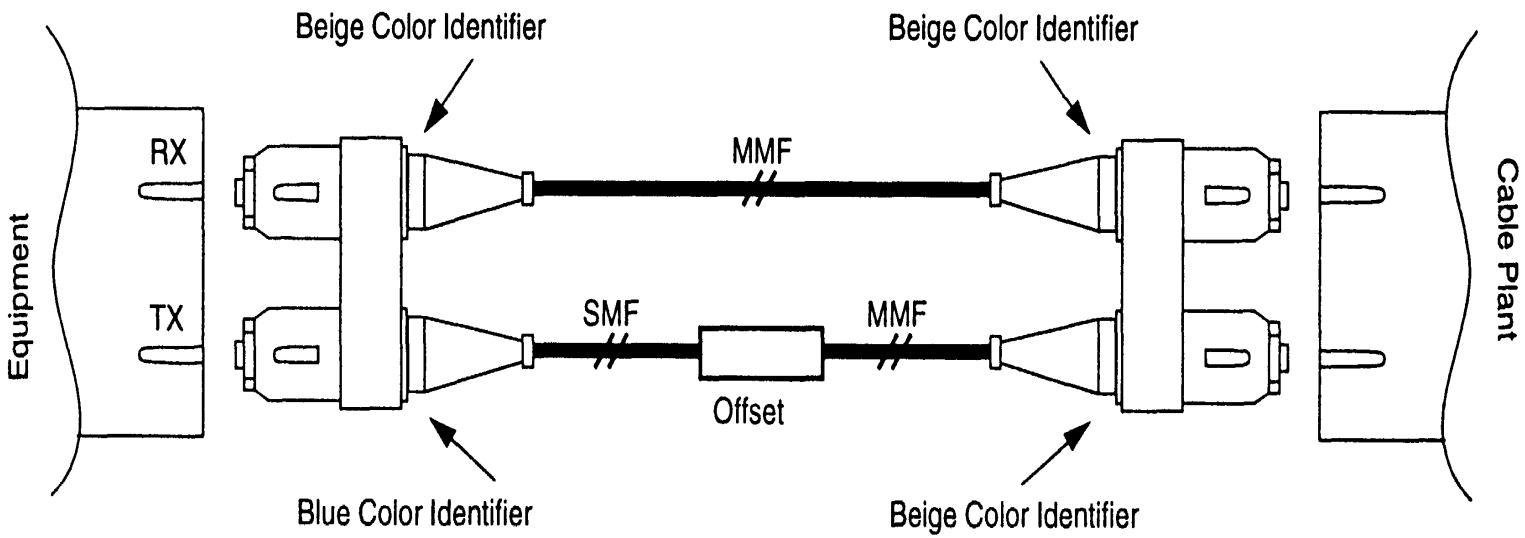
Mode Conditioning Patch Cord

- To avoid launching power to fiber center – use a Mode Conditioning Patch Cord (IEEE 802.3z)
- Use only at 1300 nm where F-P LD beam is very narrow



- Offset: for 50/125 – 10-16 μm
  for 62.5/125 – 17-23 μm

Offset Launch Mode Conditioning Patch Cord

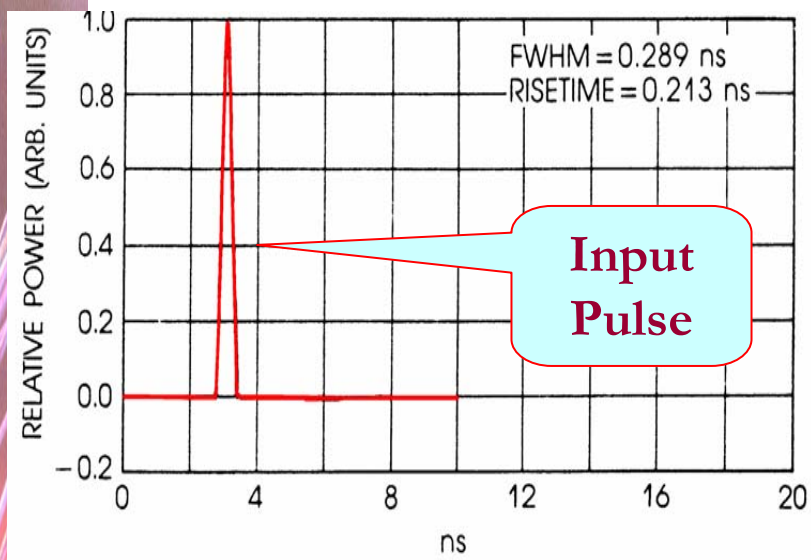


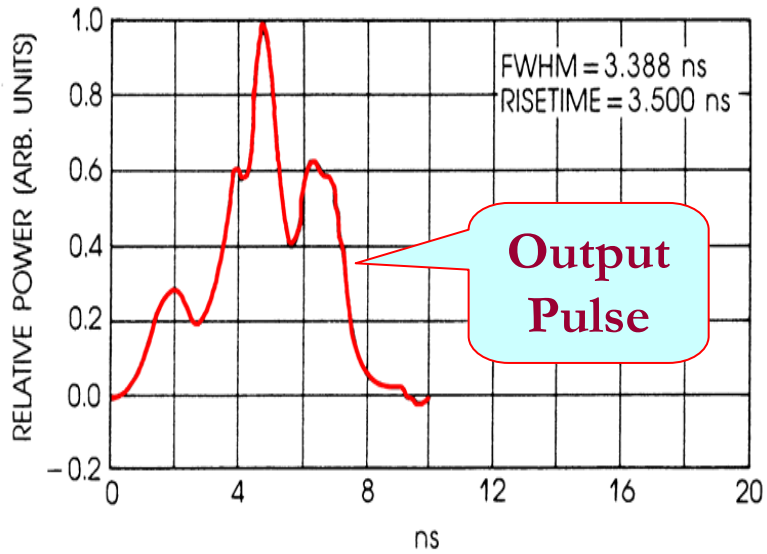
IEEE 802.3z GbE Distances per Fiber Type

Fiber Type	At 850 nm 1000BASE-SX		At 1300 nm 1000BASE-LX	
	Modal Bandwidth (*)	Minimum Range	Modal Bandwidth (*)	Minimum Range
62.5/125	160 MHz.km	220 m	500 MHz.km	550 m
62.5/125	200 MHz.km	275 m		
50/125	400 MHz.km	500 m	400 MHz.km	550 m
50/125	500 MHz.km	550 m	500 MHz.km	550 m
SM (G.652)	---	---	---	5,000 m

(*) Bandwidth measured in OFL method.

Bandwidth Measurement
(Time Domain)

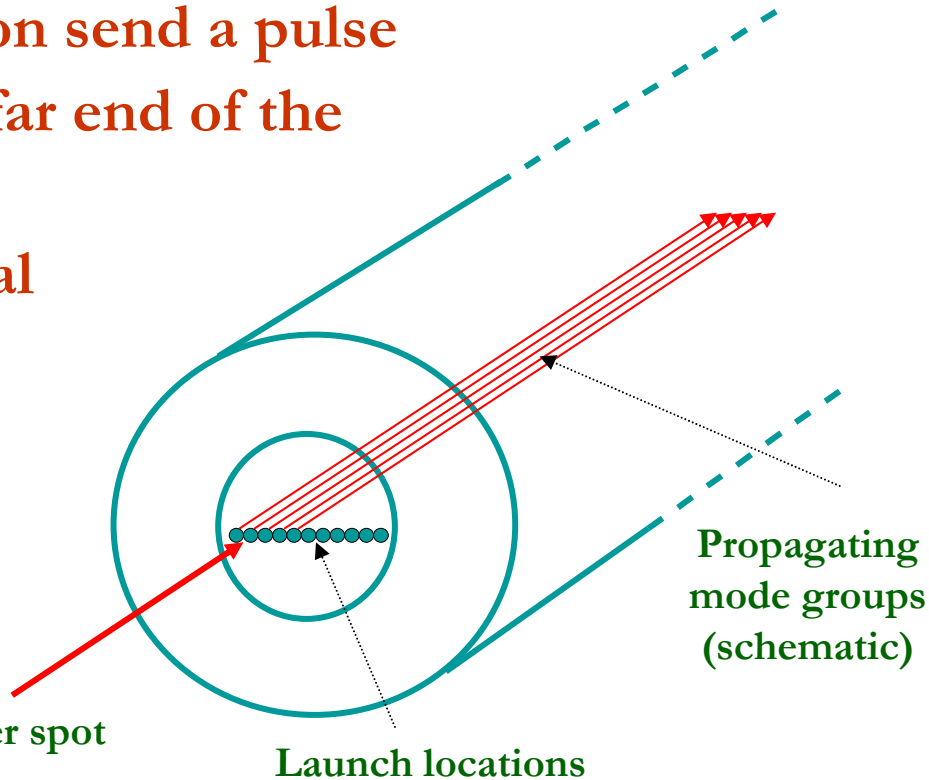




- Pulse broadening reflects modal dispersion
- Bandwidth is calculated by Fourier transforming the time-domain data to the frequency domain
- To achieve reproducibility, overfill launch (OFL) is used

Differential Mode Delay

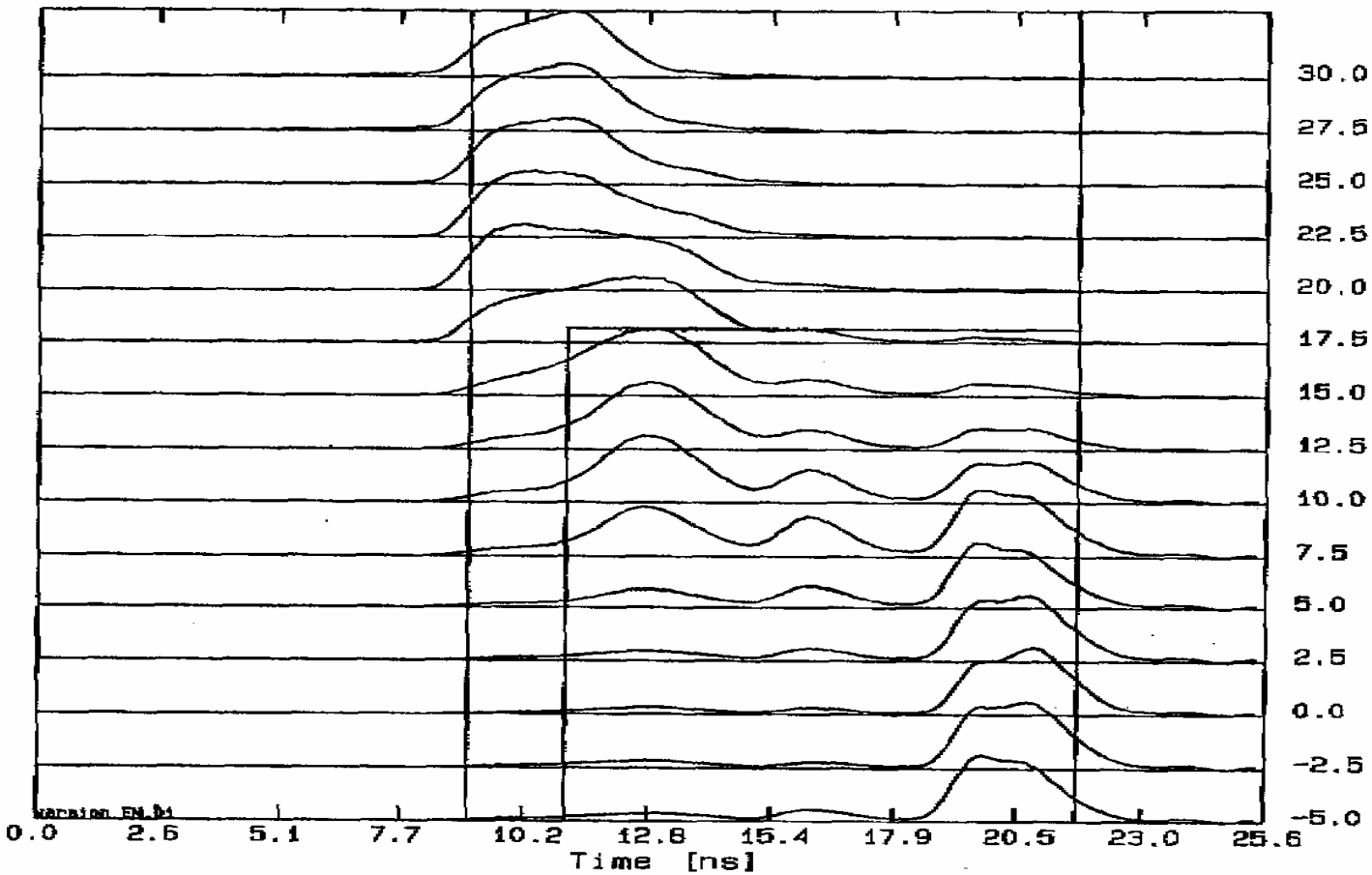
- Excite different mode groups by scanning a light spot across core surface
- At each launch location send a pulse
- Monitor the pulse at far end of the fiber vs. launch spot
- The overall differential arrival time delay + pulse broadening is a measure of the fiber modal dispersion



DMD Measurement

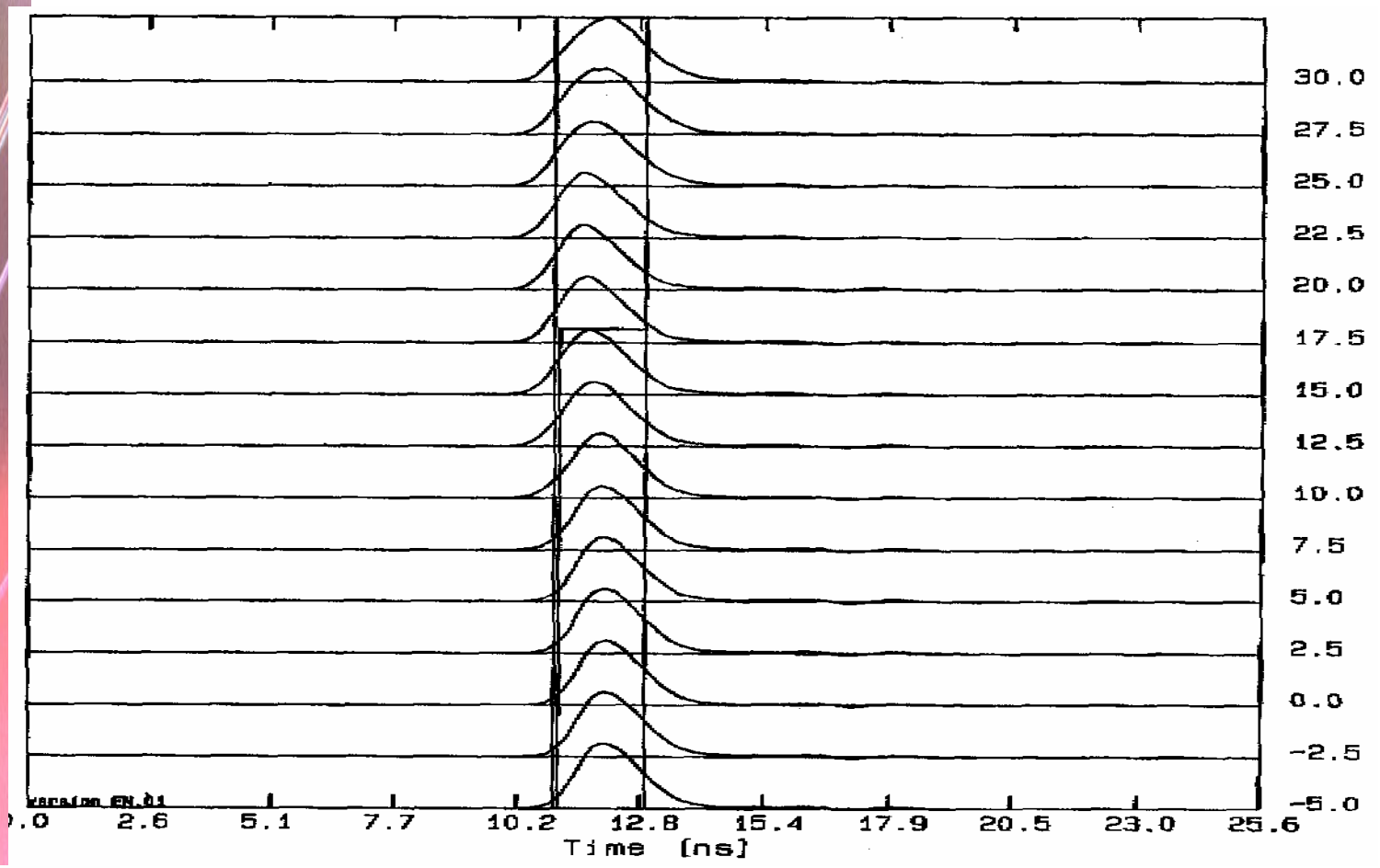
- Defined in TIA/EIA FOTP-220 (last draft 4.1 dated August 2001)
- Light spot is generated by a SM fiber (at the measurement wavelength)
- Use appropriately short pulses
- Scan measured fiber endface in intervals of 5 μm
- Differential Mode Delay is the overall time delay between leading edge of the slowest pulse to the the trailing edge of the fastest pulse

Differential Mode Delay (DMD)
Standard 62.5/125 fiber



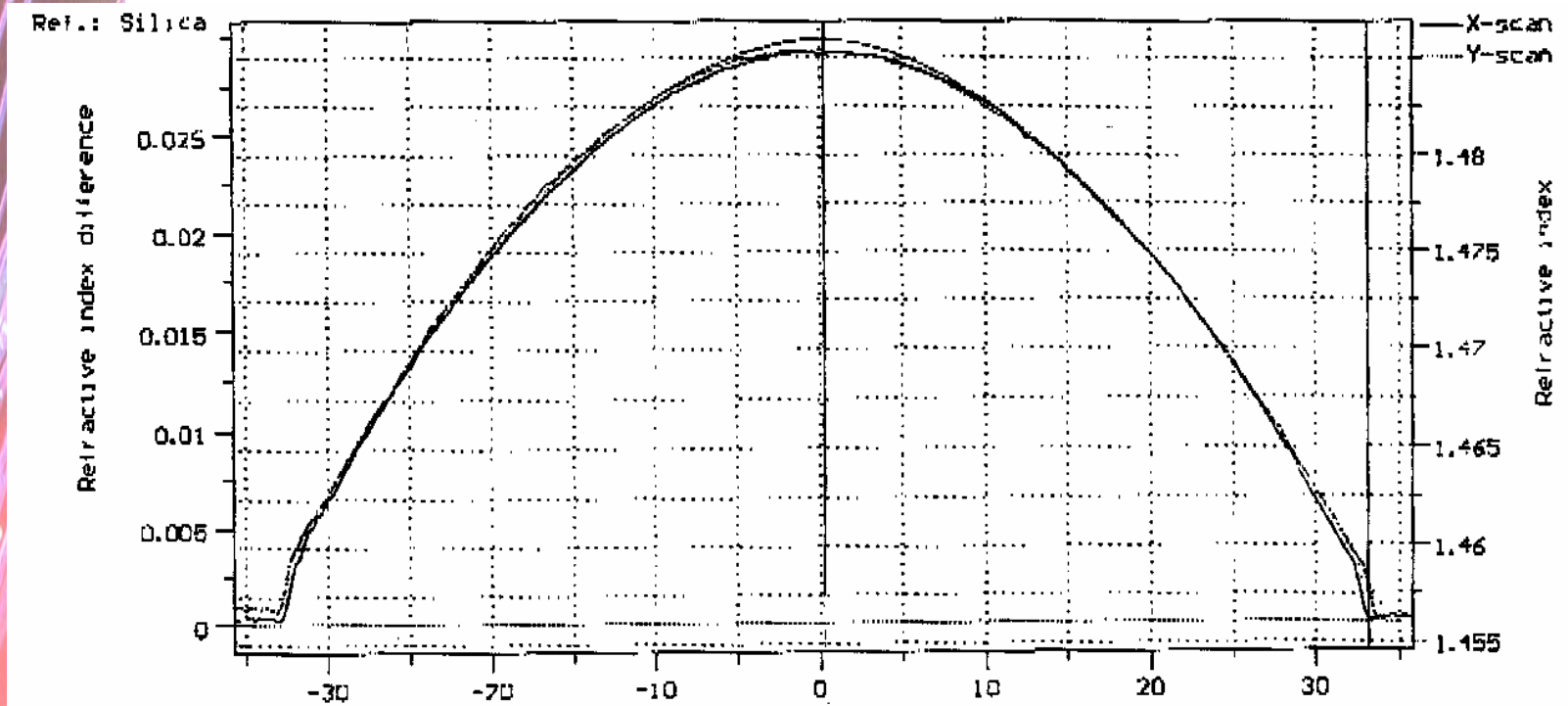
Source: YOFC

Differential Mode Delay (DMD)
HiBand 62.5/125 Fiber



Source: YOFC

Refractive Index Profile
62.5/125 HiBand Fiber



X and Y scans showing very good cylindrical symmetry, smooth profile, absence of index "dip"

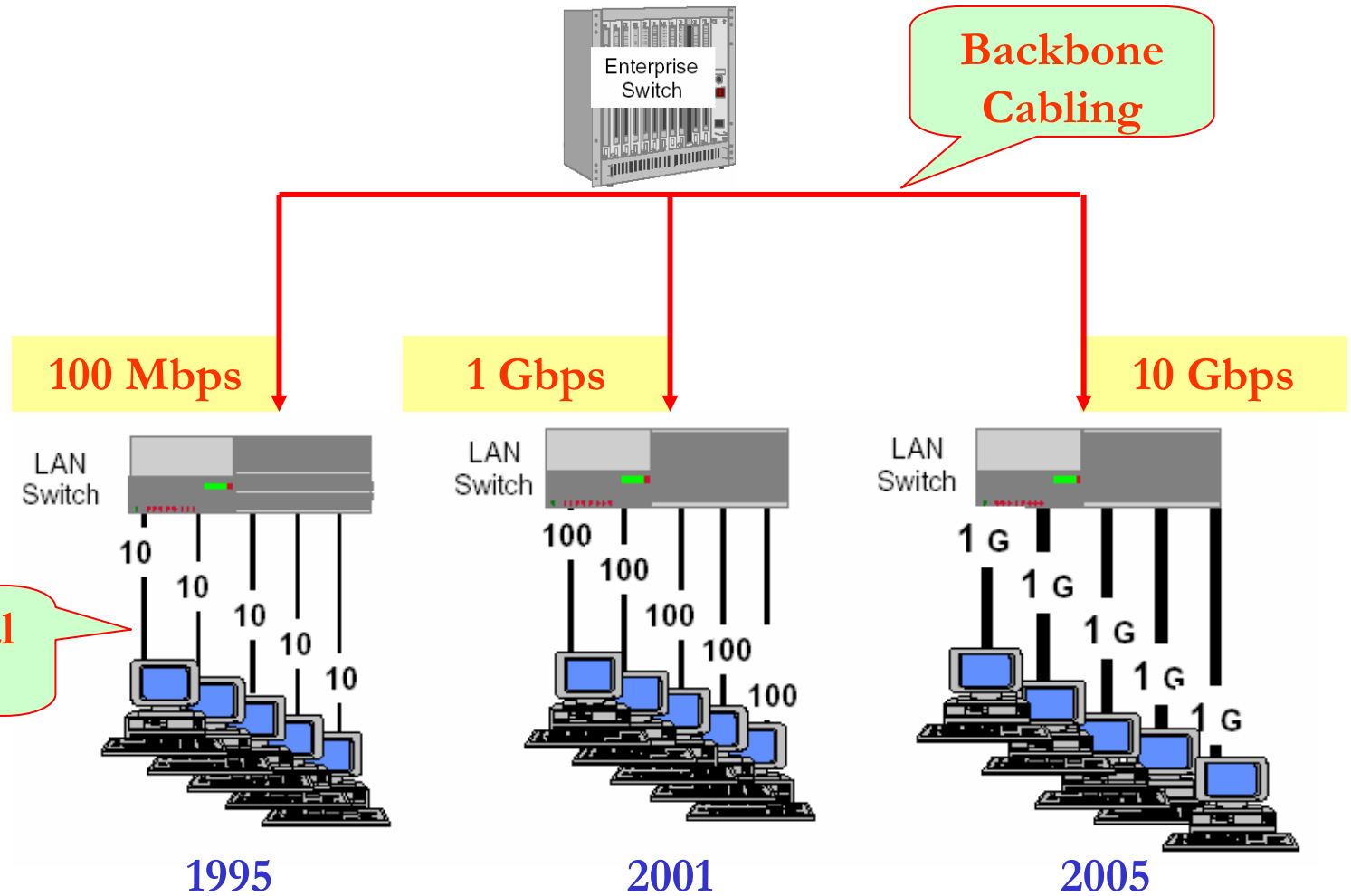
New Fibers DMD-Optimized for GbE

- Fibers optimized for GbE are:
  - DMD tested to assure low profile distortion
  - Tested with actual GbE systems
- Link length for GbE is assured by fiber manufacturer and cable manufacturer
- No need to use Mode Conditioning Patch-cord
- Cable prices are only slightly higher than standard cables
- Available now

Available GbE Fibers

	SX (850 nm)	LX (1300 nm)
62.5/125	300 - 500 m	550 – 1000 m
50/125	600 – 750 m	600 – 2000 m

10GbE Implementation in LAN



10GbE – IEEE 802.3ae

- Extends Ethernet onto the Wide Area Network (WAN) – defined up to 40 km
- Supports traditional LAN applications (mostly backbone) and SAN (Storage Area Network)
- Compatible with all previous Ethernet implementations – 10, 100, 1000 Mbps
- Maintains backwards compatibility to existing infrastructure – MM fibers
- Due to be completed this year

Physical Layer Media in 10GbE

(Draft March 2001)

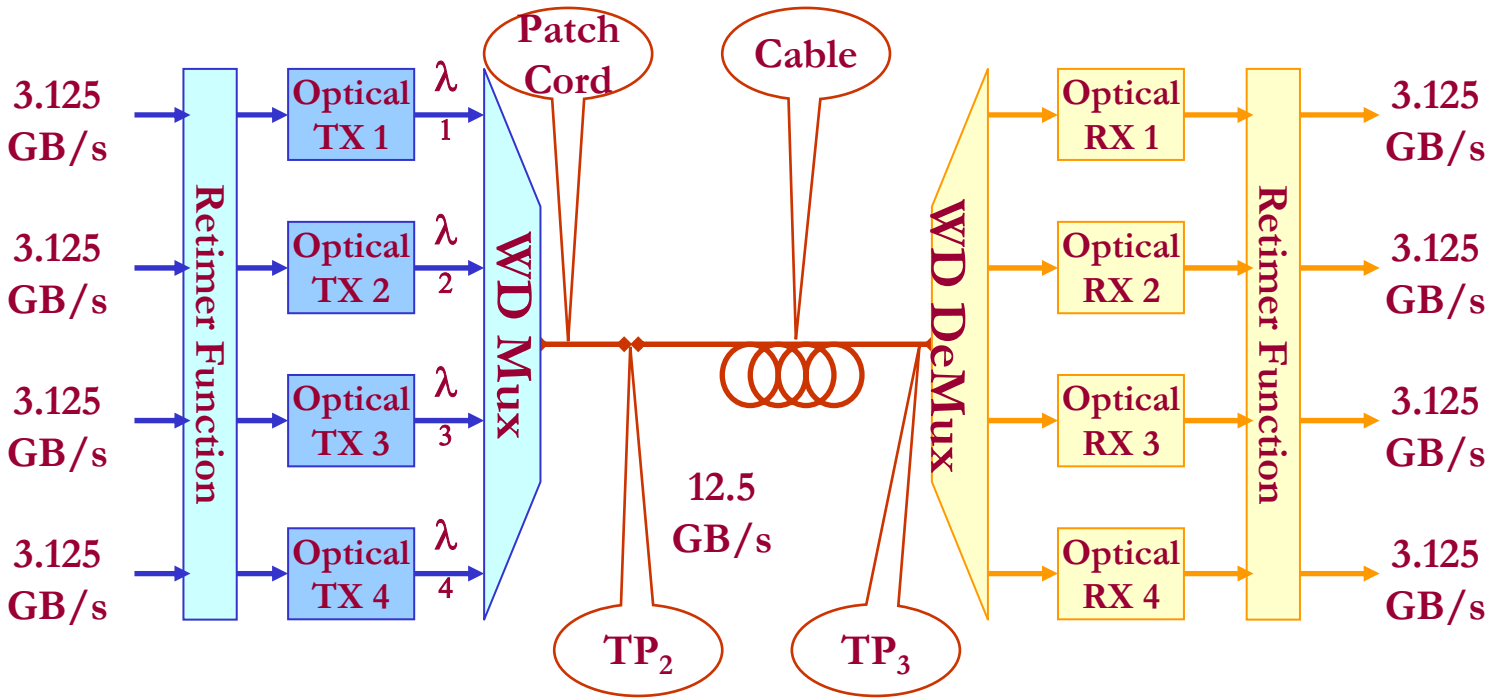
Code	Data Coding	Effective Bit Rate (GB/s)	Type	Wave-Length
10GBASE-LX4	8B/10B	12.5	WWDM	~ 1300 nm
10GBASE-SR	64B/66B	10.3125	Serial	850 nm
10GBASE-LR				1310 nm
10GBASE-ER				1550 nm
10GBASE-SW		9.95 (SDH)		850 nm
10GBASE-LW				1310 nm
10GBASE-EW				1550 nm

10GB Ethernet Distances

(Draft March 2001)

Fiber	Bandwidth (MHz.km)	Link Length (m) @ 10GBASE-			
		LX4 (~ 1300 nm)	SR/SW (850 nm)	LR/LW (1310 nm)	ER/EW (1550 nm)
62.5/125	160/500	300	26	---	---
62.5/125	200/500		33	---	---
50/125	400/500	240	66	---	---
50/125	500/500	300	82	---	---
50/125	2000 Laser optimized fiber (OM-3)	---	300	---	---
G.652 SM	---	10 km	---	10 km	40 km

WWDM PMD (10GBASE-LX4)



- Wavelength Centers~1275, 1300, 1324, 1349 nm

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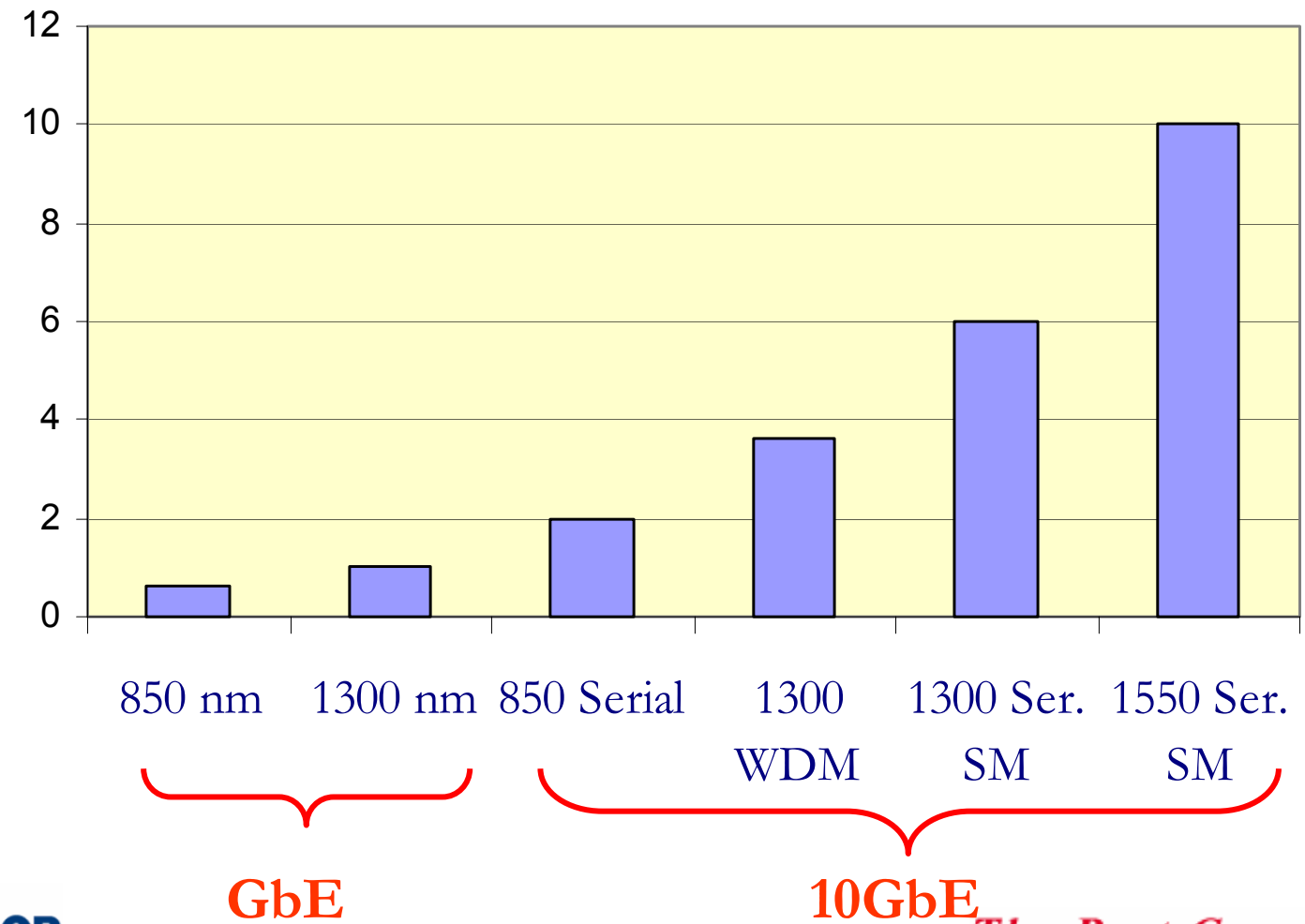
OM-3 – Fibers Optimized for Operation with a 850 nm VCSEL

- Use only 50/125 fiber
- Profile optimized for 850 nm
- The laser (VCSEL) spot size is defined:
  - ≤ 30% of flux encircled by a 4.5 μm radius
  - ≥ 86% of flux encircled by a 19 μm radius
- DMD is used to characterize modal dispersion in the MM fiber
- Allowed DMD is defined (see below)
- A minimum OFL bandwidth is required

The Standards

- Laser Spot size measurement: defined in FOTP 203 (TIA/EIA-455-203 published in June 2001),
- DMD test method defined in FOTP-220 (draft) and in IEC 60793-1-49 (draft)
- Activity by the TIA FO-2.2.1 committee
- The term OM-3 is to be introduced to ISO/IEC 11801 2nd Edition
- The fiber is added in a an Addendum to TIA 568B.3
- Submitted also to IEC 86A to specify a new fiber type (in IEC 60793-2)

Port Cost Comparison



OM-3 Fibers Now

- The least expensive implementation of 10GbE in LAN – up to 300 m
- Compatible with present GbE links W/O Mode Conditioning patch cord
- Allows extended length for GbE systems:

	Link Length 10GbE @850 nm	Link Length GbE @ 850 nm	Link Length GbE @ 1300 nm
MaxCap 300	300 m	1000 m	550 m (*)
MaxCap 150	150 m	750 m	550 m (*)

(*) No need for a Mode Conditioning Patch cord

Summary

- Demand for bandwidth will continue to increase – 100 Mbps ⇒1Gbps ⇒ 10Gbps
- Gigabit Ethernet systems in LAN are based on MM fibers.
- Improved MM fibers are available for links beyond the length defined in IEEE 802.3z
- In 10Gbps, the most cost effective LAN implementation is over OM-3 multimode fibers
- Such fibers are available now!!