

Laser-Optimized Multimode Fiber: What Is It? How Do I Use It In My Network?

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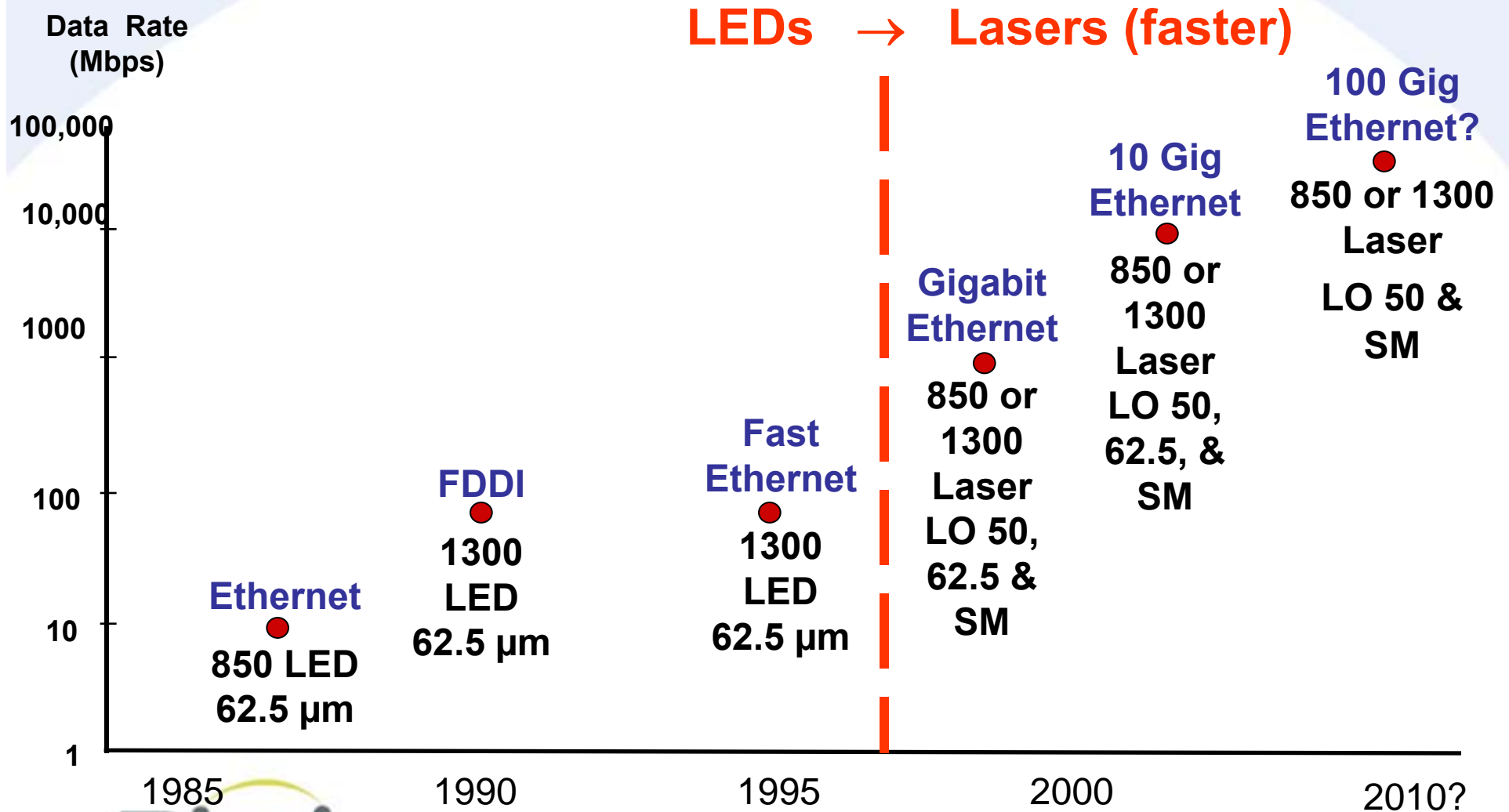
Goals & Outline

- Answer key questions:
 - What is laser-optimized fiber?
 - Does it cover all types of fiber?
 - How is the right fiber selected for an application?
 - How is bandwidth determined for laser-optimized fiber?
- Evolution of LAN transmission speeds
- Developments in light sources: VCSELs & LEDs
- Laser-optimized fiber design and performance
- Fiber types, applications and standards
- Bandwidth measurement techniques



Evolution of LAN Ethernet Technology

Lasers & laser-optimized fibers necessary for Gigabit speeds



Optical Sources, Fiber Specifications and Measurement Techniques

	LED System	Laser System
Speed/ Distance	10 Mb/s – 622 Mb/s ≤ 2000 meters	1000 Mb/s – 10,000 MB/s (1 Gb/s) (10 Gb/s) ≤ 550 meters
Design Drivers	Low Cable Loss High Coupling Efficiency (Low insertion loss)	High Bandwidth
Fiber Type	LED-optimized (50µm → 62.5 µm)	Laser-optimized (62.5 µm → 50 µm)
BW Measurement	Overfilled (OFL) BW	-Differential Mode Delay -Effective Modal Bandwidth -Restricted Modal BW



LEDs vs.. Lasers in Communications Systems

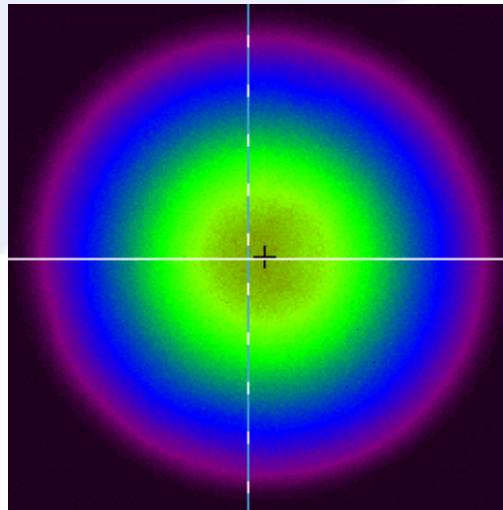
LED

- Light Emitting Diode
- Wide spot size
- 850 nm and 1300 nm available
- Applications up to 622 Mb/s
- 10 and 100 Mb/s Ethernet, 155 and 622 Mb/s ATM

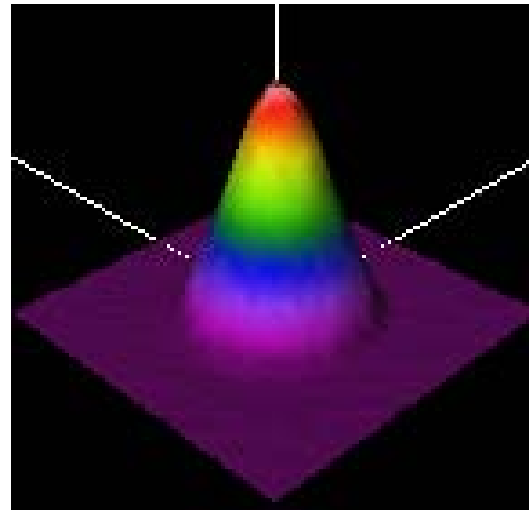
Laser

- Light Amplification by Stimulated Emission of Radiation
- Narrow spot size
- Several different types – DFB, FP, VCSEL, etc.
 - Low cost 850 nm versions are VCSELs
 - High cost 1300 & 1550nm versions are DFB and FP types
- 1 Gb/s through 40 Gb/s.
- 1 and 10 Gb/s Ethernet, 40 Gb/s SONET, 2.5 Gb/s 12 wide arrays, etc.

LEDs vs. Vertical Cavity Surface Emitting Lasers



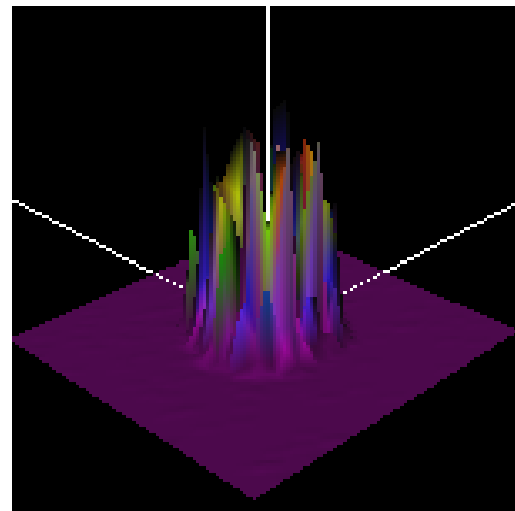
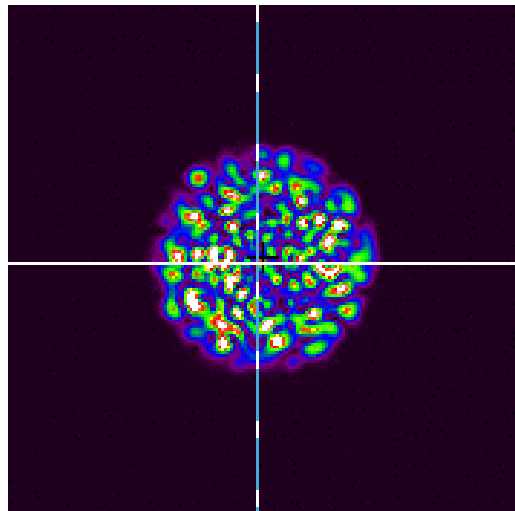
Encircled Power



3D Power map

LED (up to 622 Mbps)

- Overfills core (large spot size)
 - Excites all modes.
- Bandwidth performance dependant on all modes.
- Uniform, consistent power profile. Repeatable.

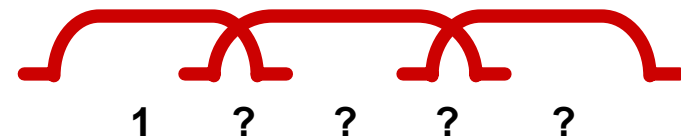
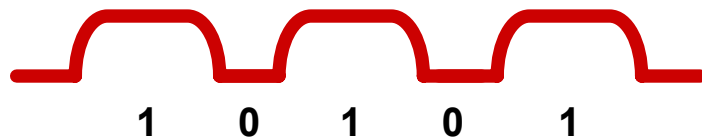
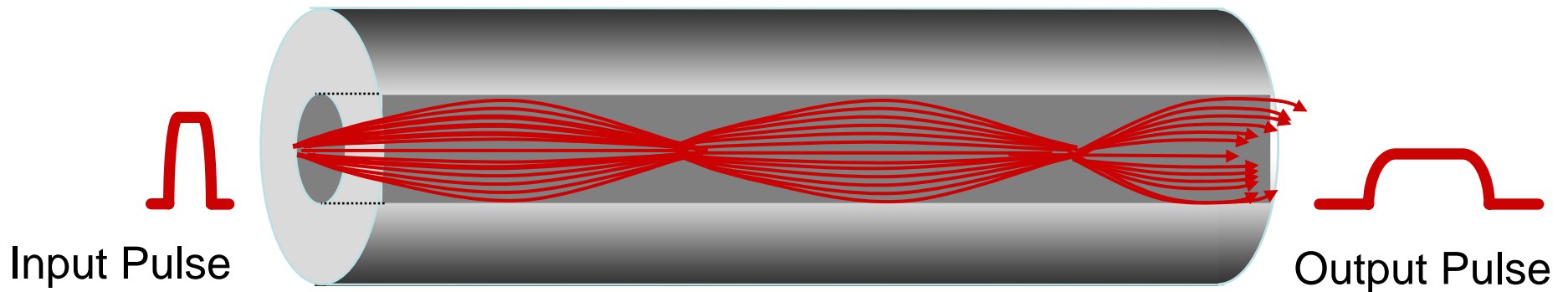


VCSEL (1 or 10 Gbps)

- Underfills core (small spot size)
 - Excites fewer modes
- Bandwidth dependant on which modes happen to carry power.
- Non-uniform, fluctuating, non-repeatable power profile.

Multimode Fiber

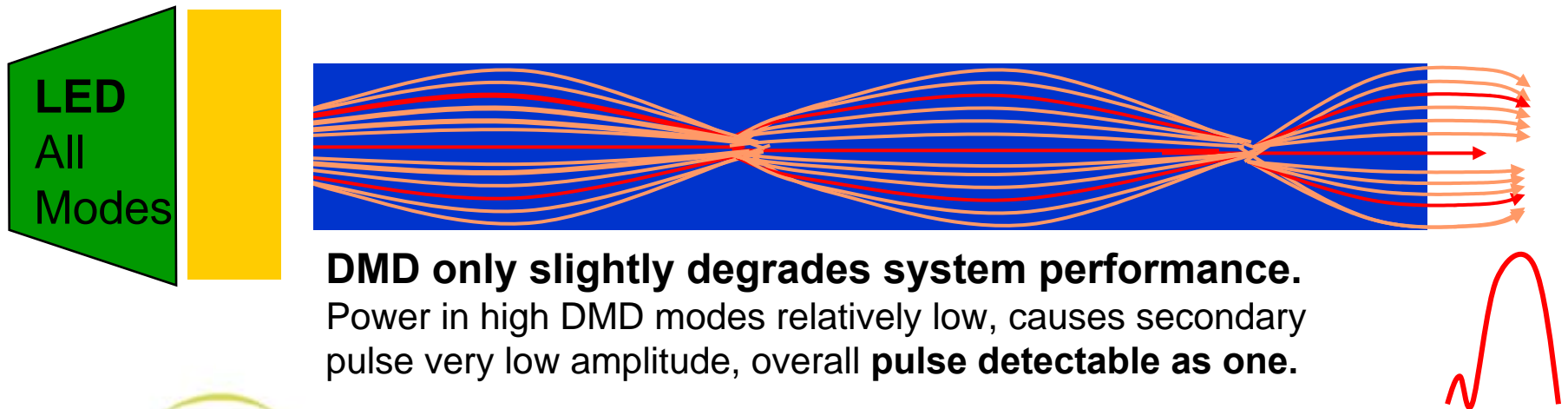
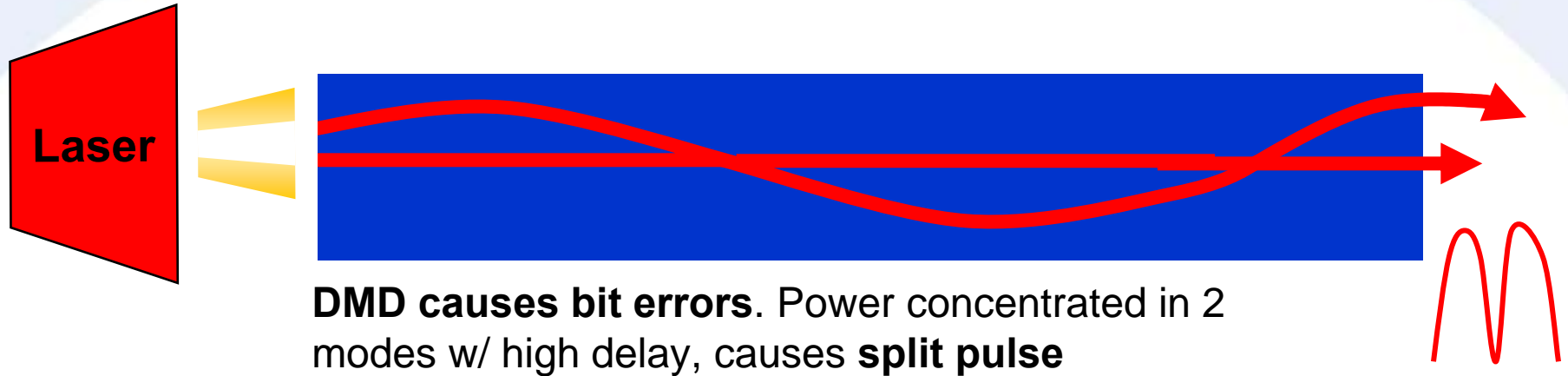
- Light Signal (*pulse*) travels along many modes, or paths.
- Pulse spreading occurs due to **Inter-Modal Dispersion**, or **DMD** (*Differential Mode Delay*)
- Pulse spreading limits **Bandwidth** (*transmission carrying capacity*)



**Excessive Pulse Spreading =
Intersymbol Interference (ISI) =
Bit Errors**

Impact of Light Source on Bandwidth

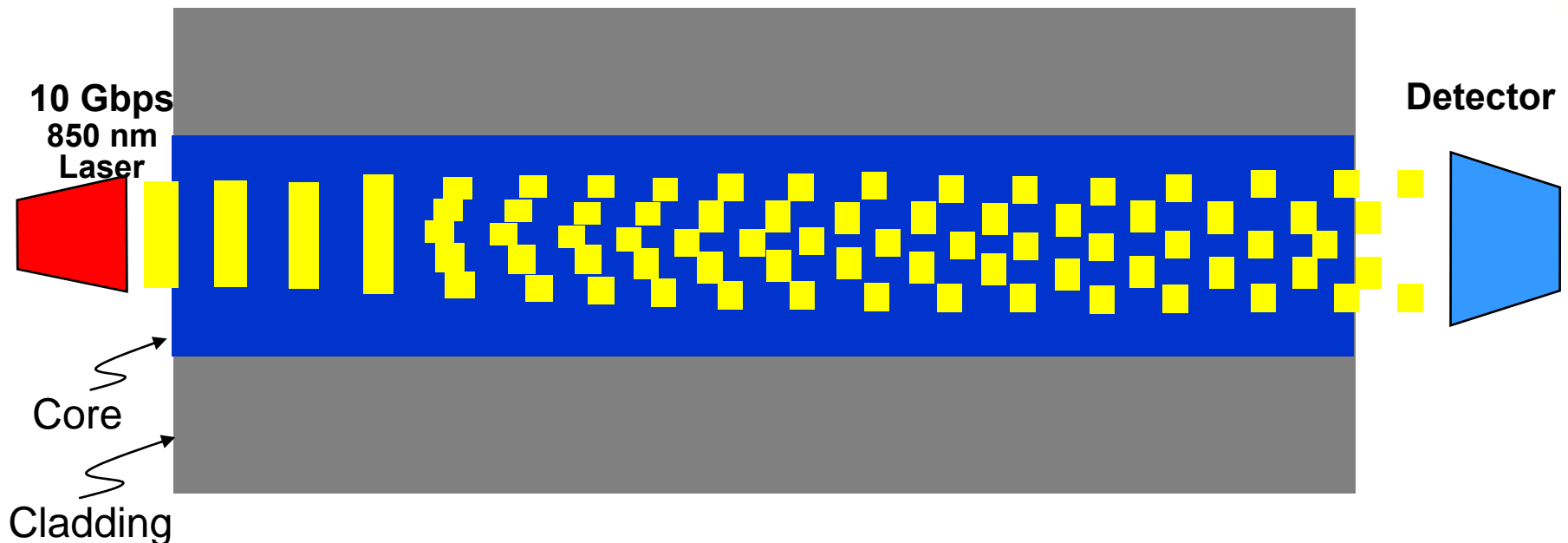
- On a conventional fiber with high DMD between 2 modes
- DMD reduces laser system bandwidth, minimal impact w/LED



Conventional Multimode Fiber

Excessive **DMD** limits use
to impractical distances for 10 Gb/s applications

1 0 1 0 1 0 1 0 1 0 1 ?

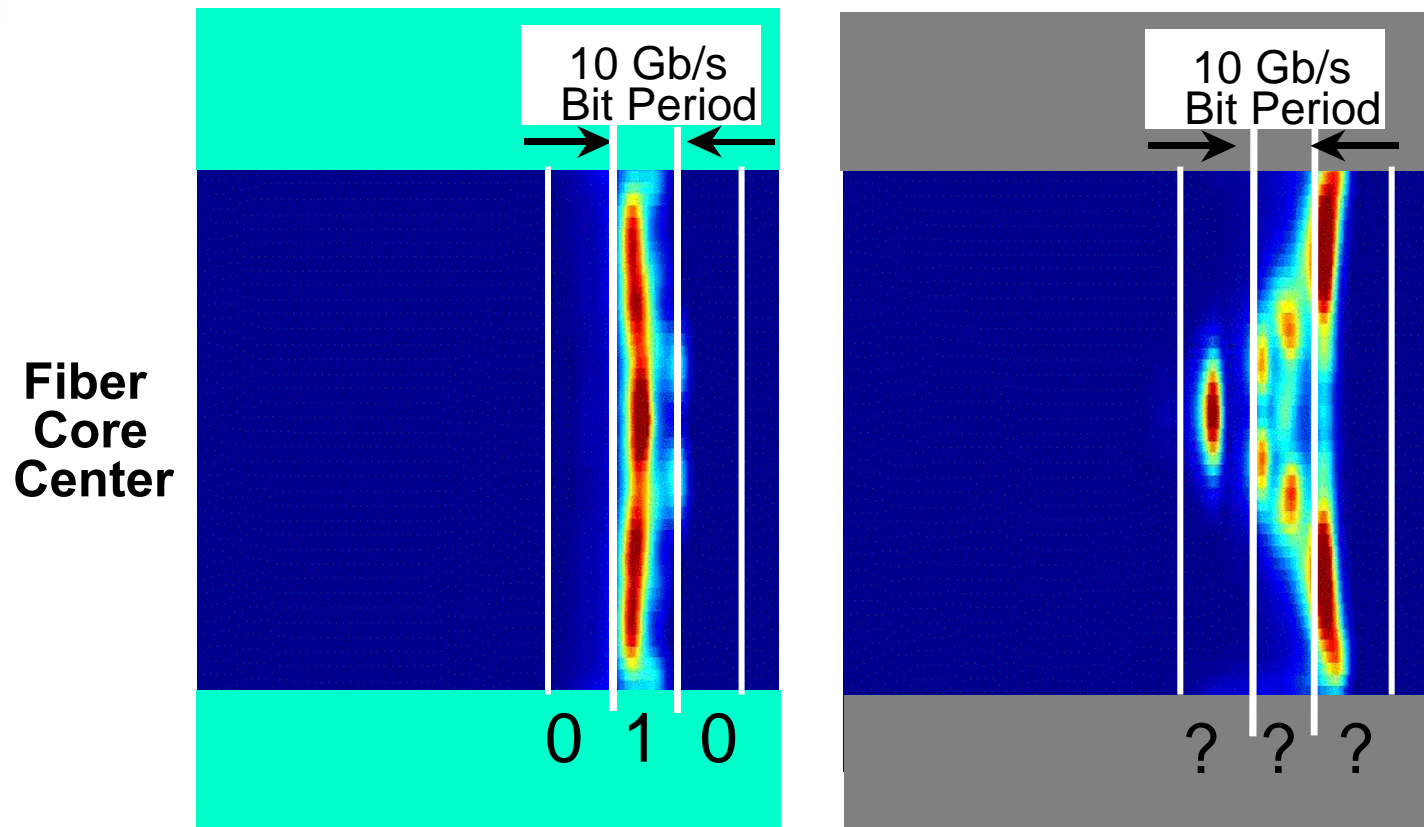


Conventional Fiber - 50 or 62.5 micron
Supports only 25 - 82 meters at 10 Gb/s



DMD Controlled and Measured Fiber Essential for high-speed Laser-based systems

Bit Period Window decreases as Transmission Rate Increases



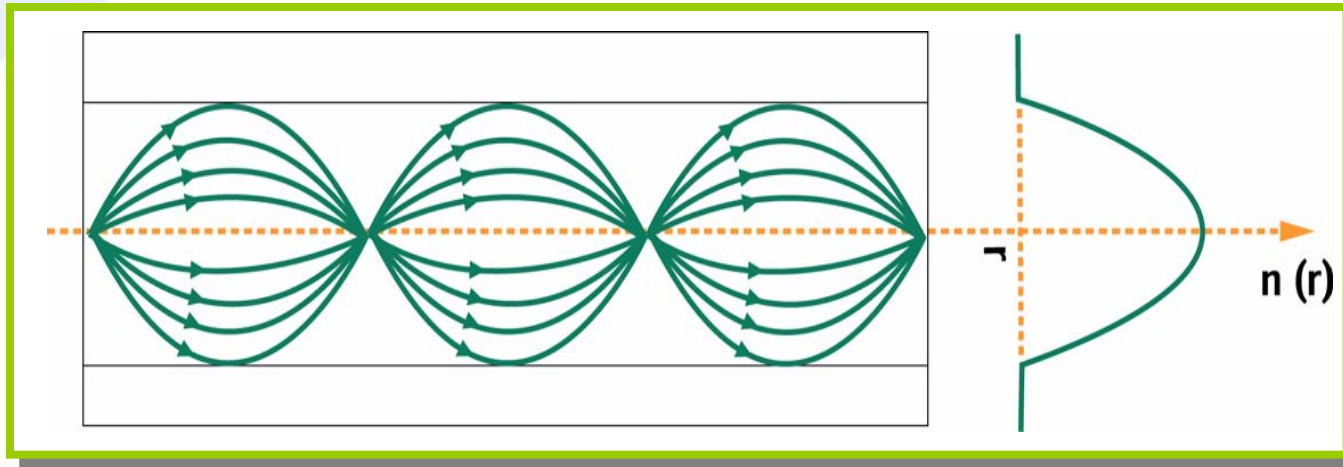
OM3 Fiber

Conventional MMF

Received pulse at 10Gb/s over 300 meters



Solution: Graded Index Profile

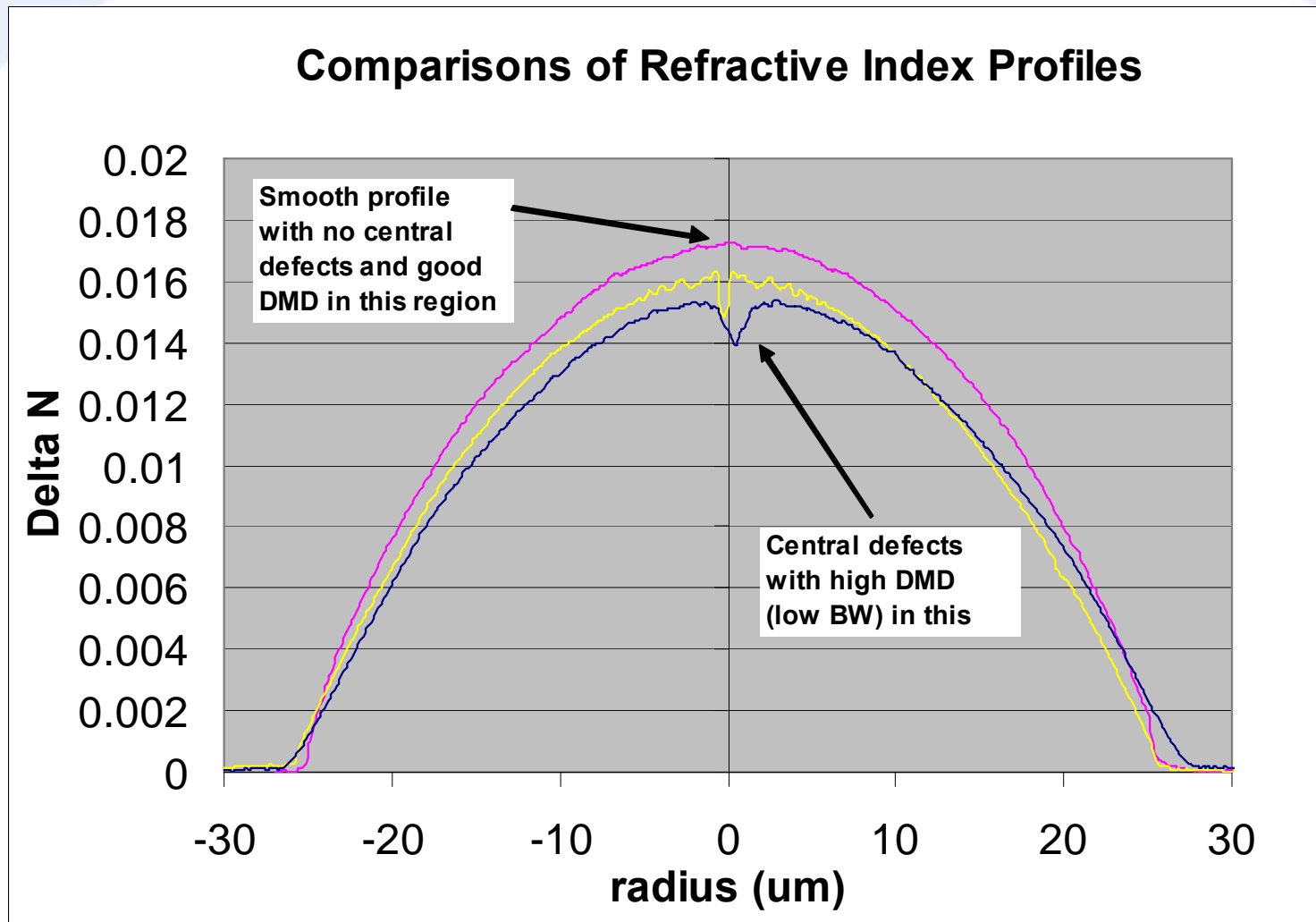


- By using a graded index profile, DMD is minimized by speeding up modes that travel long distances, and slowing down modes that travel short distances
- The speed is a function of the refractive index: $n(r)$

In reality, the profile may contain enough imperfections to limit bandwidth and transmission rate

Laser Optimized Multimode Fiber

Refractive Index Profile *optimized* for use with VCSELs



Industry Standard Multimode Fiber Sub-types

Fiber type	Wavelength (nm)	Max Loss (dB/km)	Min Bandwidth (MHz·km)		1 Gb/s Reach (meters)	10 Gb/s Reach (meters)
			OFL	EMB		
62.5 μm (OM1)	850	3.5	200	n.s.	275	33
	1300	1.5	500	n.s.	550	300
50 μm (OM2)	850	3.5	500	n.s.	550	82
	1300	1.5	500	n.s.	550	300
850-nm 10G Laser-Optimized 50 μm (OM3)	850	3.5	1500	2000	1000	300
	1300	1.5	500	n.s.	600	300

OM1, OM2, OM3 =
ISO/IEC 11801 designations

OFL = Overfilled Launch
EMB = Effective Modal Bandwidth
(also known as “Laser” BW)

EMB met by meeting a) DMD specifications, or b) EMBc, as outlined in TIA 492 AAAC-A



Other Multimode Fiber Sub-Types

Fiber Type	Wavelength (nm)	Max Loss (dB/km)	Min Bandwidth (MHz·km)		1 Gb/s Reach (meters)	10 Gb/s Reach (meters)
			OFL	EMB		
50 μm (OM2+)	850	3.5	700	950	750	150
	1300	1.5	500	n.s.	600	300
50 μm (OM3+)	850	3.5	3500	4700	1040	550
	1300	1.5	500	n.s.	600	300

DMD specifications determined by scaling rules outlined in TIA 492 AAAC-A

OFL = Overfilled Launch

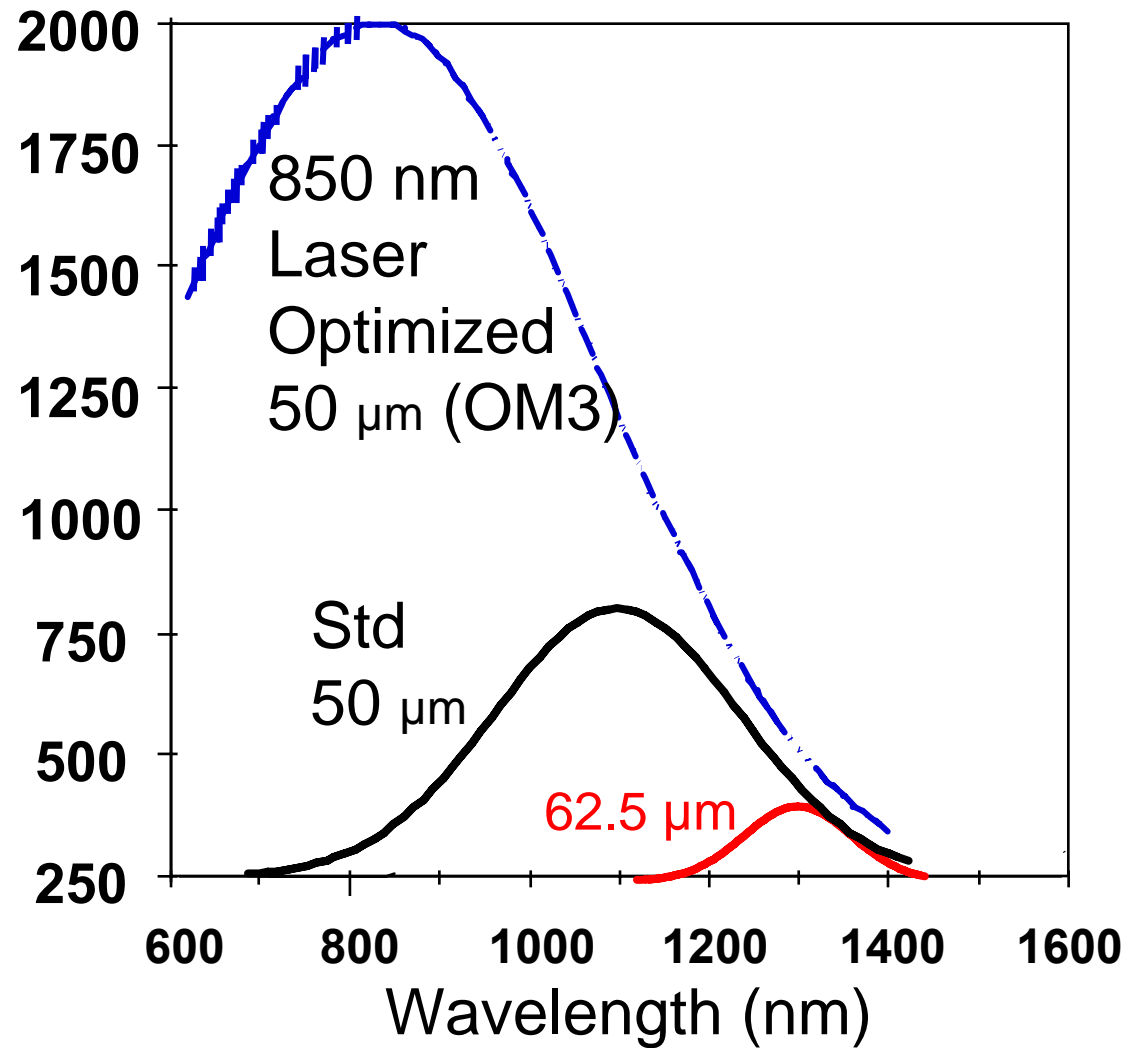
EMB = Effective Modal Bandwidth
(also known as "Laser" BW)



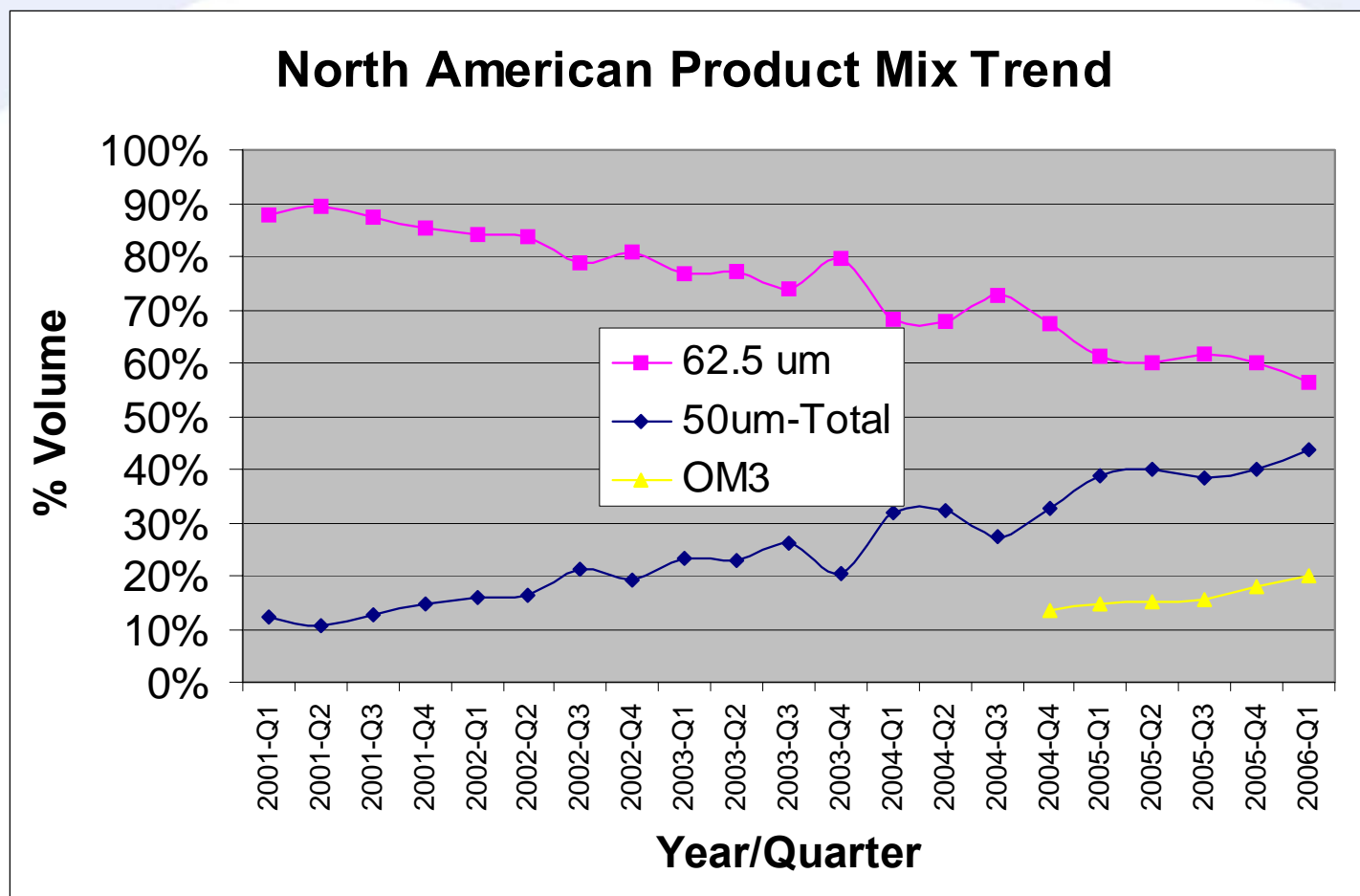
Multimode Fiber Types

Optimized for low cost 850 nm operation

**Minimum
Effective
Modal
Bandwidth**
MHz.km



Shift to 50um and OM-3 MMF is Happening



- NAR 50um Mix quadrupled in five + years!
- 10Gb/s MM fiber ~ 20% of total and ~45% of all 50um

• Source: Burroughs MM Report, Q2 2006



Caution!!!!

Laser-optimized or OM3 10Gb/s fiber?

- “Laser-optimized multimode fiber” (**adjective**)
 - Optimized for use with laser sources
 - Does not imply a specific specification of bandwidth or link length
 - Can be either 62.5 or 50 um
 - Typically referring to a 1Gb/s fiber
 - May be measured by OFL, RML or DMD?
- “850nm-Laser Optimized 50um Fiber” (**noun**)
 - Specific fiber type referenced by TIA-492AAAC-A
 - Also know as OM3 by ISO 11801 2nd Ed.
 - 50um Fiber with 1,500 MHz-km OFL-BW **and** 2,000 MHz-km EMB
 - Optimized for 850nm 10Gb/s VCSEL
 - Rated to 300 meters using a 10GBase-SR port



1 and 10 Gb/s Optical Modules vs. Fiber Type vs. Reach (meters)

10 Gb/s Transceiver Designation	Wavelength	62.5 um (OM1)	Std 50 um (OM2)	LO 50 um (OM3)	SM (OS1)
1000Base-SX	850 nm Serial VCSEL	275	550	1,000	NA
1000Base-LX	1300 nm Serial Laser	550 ¹	550 ¹	600	10,000
10GBase-SR	850 nm Serial VCSEL	33	82	300	NA
10GBase-LX4	1300 nm CWDM Laser	300 ¹	300 ¹	300	10,000
10GBase-LR	1300 nm Serial Laser	NA	NA	NA	10,000
10GBase-LRM	1300 nm serial Laser/EDC	220 ¹	220 ¹	220	NA



¹Mode Conditioning Patch-cords required

New Ethernet Standard

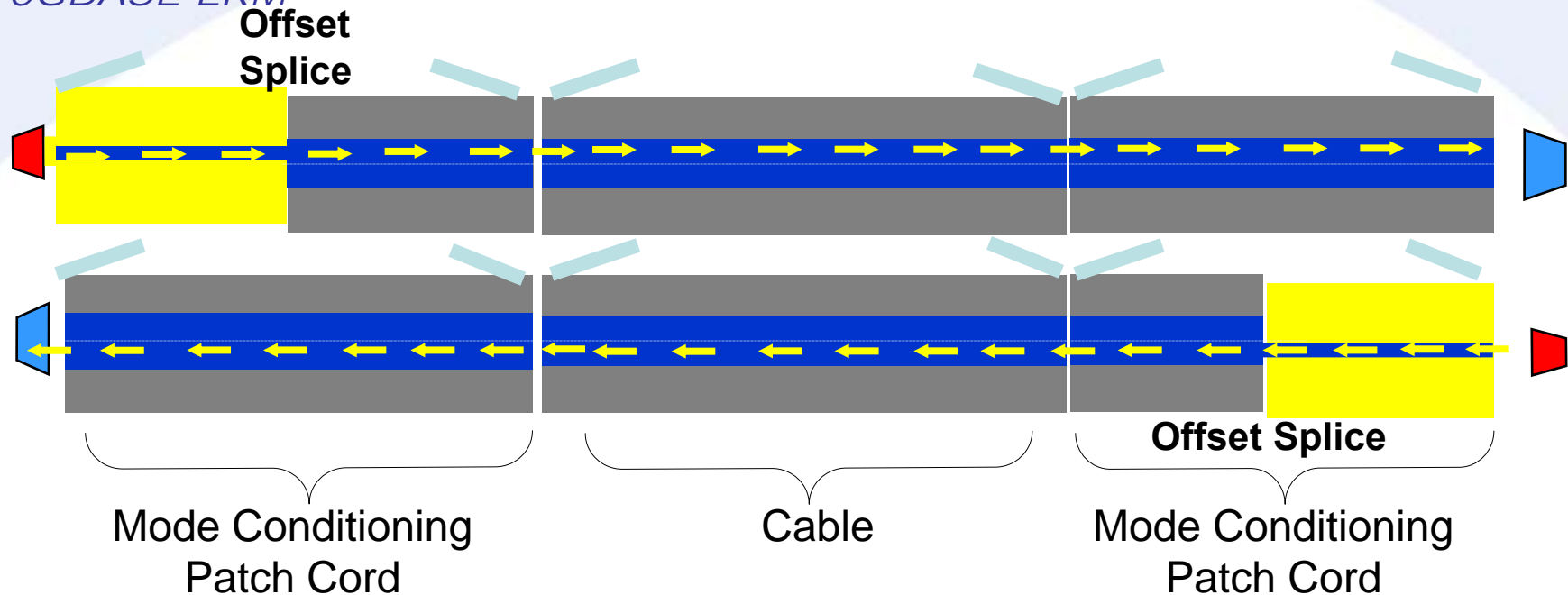
10GBASE-LRM (IEEE 802.3aq task force)

- **What is it?**
 - 10GBASE-LRM is a new Ethernet standard to support the installed base of Multimode fibers for 10 Gb/s applications
 - An alternative to 10GBASE-LX4 in order to support small form factors using serial transmission
 - Utilizes EDC (Electronic Dispersion Compensation) at 1310 nm
- **10 GbE Reach Support:**
 - 220 meters for “installed” 500MHz-km MMFs (62.5 & 50 um, 1980s - present)
 - 220 meters for OM3 MM fibers
- **Likely cost about equal to 10GBASE-LR (singlemode 10G port)**
 - Single-mode 1310nm lasers and packaging & EDC chip cost
- **Mode Conditioning patch cords?**
 - *May be Required* for conventional 50 and 62.5 micron
 - Not required for OM3 50um



Mode Conditioning Patch Cords

Required for 1000BASE-LX, 10GBASE-LX4 MMF per IEEE 802.3, 10G FC and 10GBASE-LRM



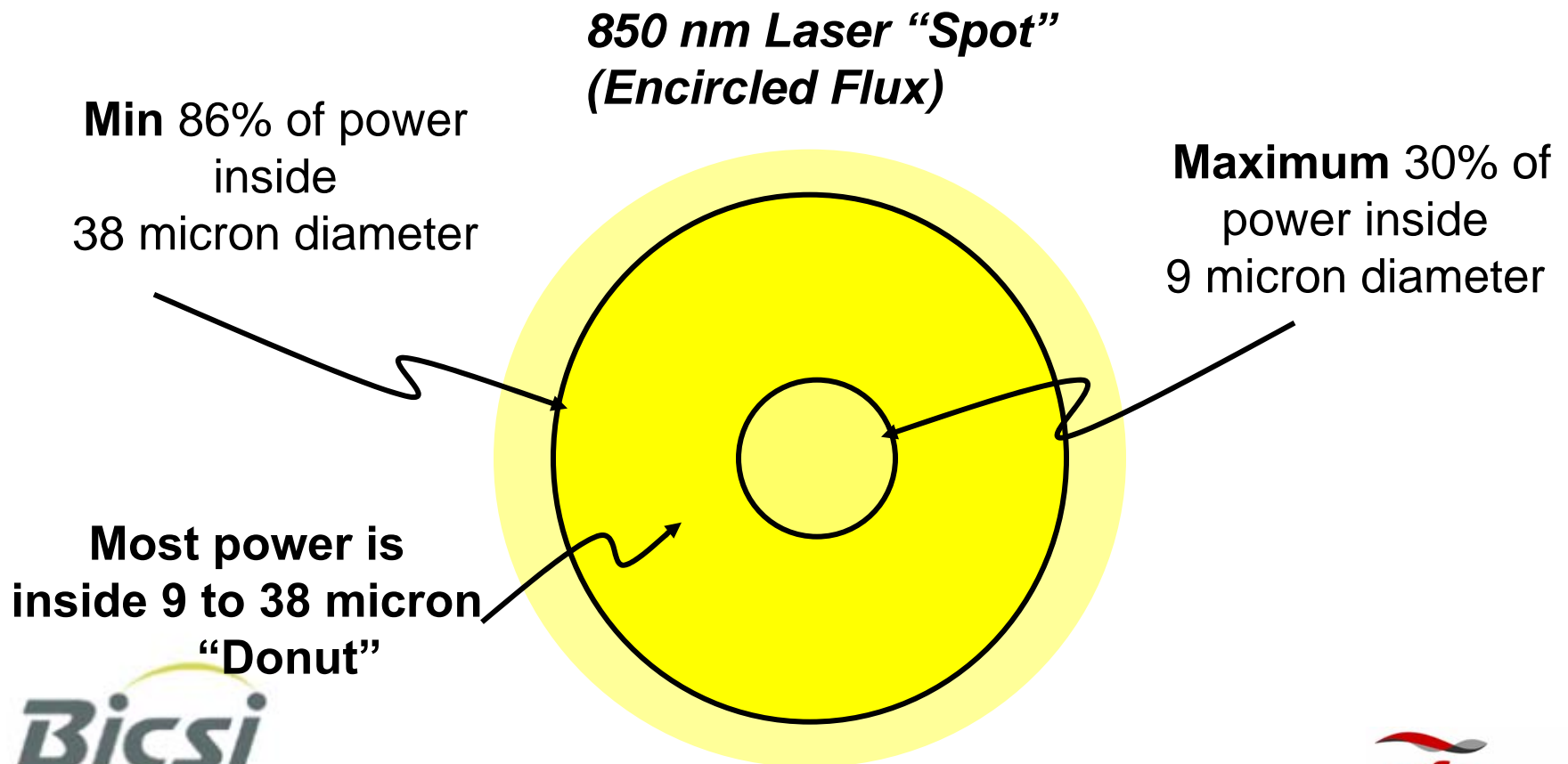
- **Offsets launch to avoid center core defect present in conventional MMF**
- **Different cords for 50 and 62.5 micron**
 - 50 micron – 10 to 16 micron offset
 - 62.5 micron – 17 to 23 micron offset
- **About \$300 each**
- **Inventory management issues**

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850nm 10 Gb/s Source Restricts Power in Center

Transceiver specifications: (IEEE 10 G Ethernet Std)

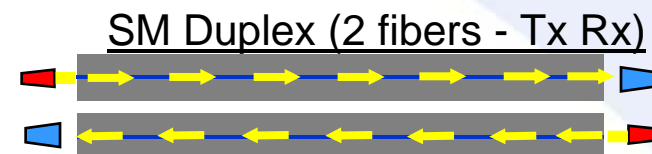
- Work with fiber DMD specifications to assure rated distance
- Enable low cost packaging



Serial Transmission Singlemode Fiber

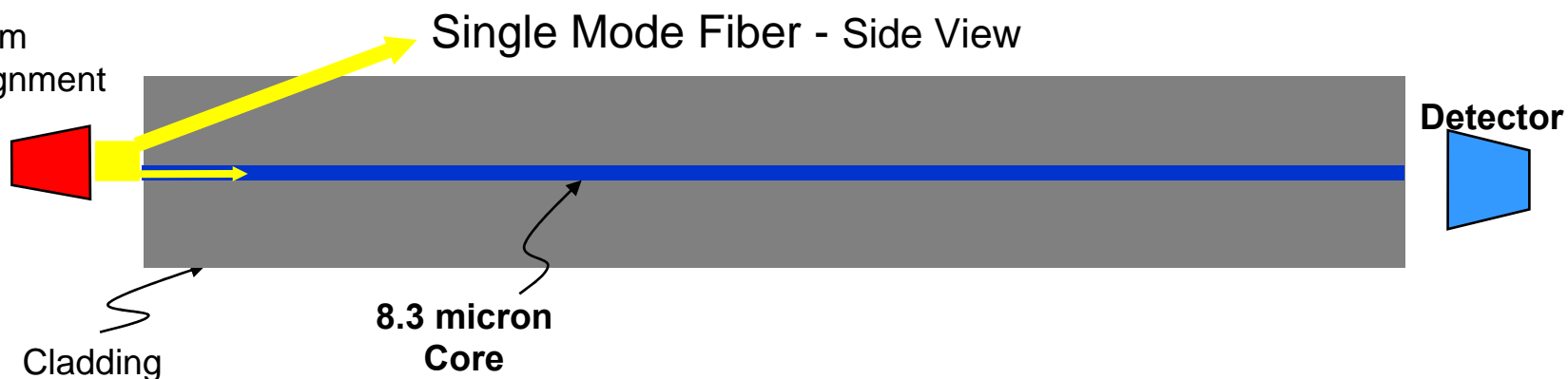
1G Ethernet	1310 nm:	1000BASE-LX	10 KM
	1550 nm	1000BASE-ZX*	70 KM
10G Ethernet	1310 nm	10GBASE-LR	10 KM
	1550 nm	10GBASE-ER	40 KM

* Not a standard.



Laser

2 - 3 um
misalignment



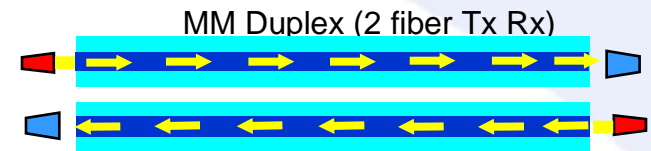
Expensive Laser to Core Alignment = **+/- 1 micron**

- Costly materials and alignment during packaging
- Hermetically sealed package
- Expensive single mode connectors and cabling installation

850 nm Serial over Laser Optimized MMF (OM3)

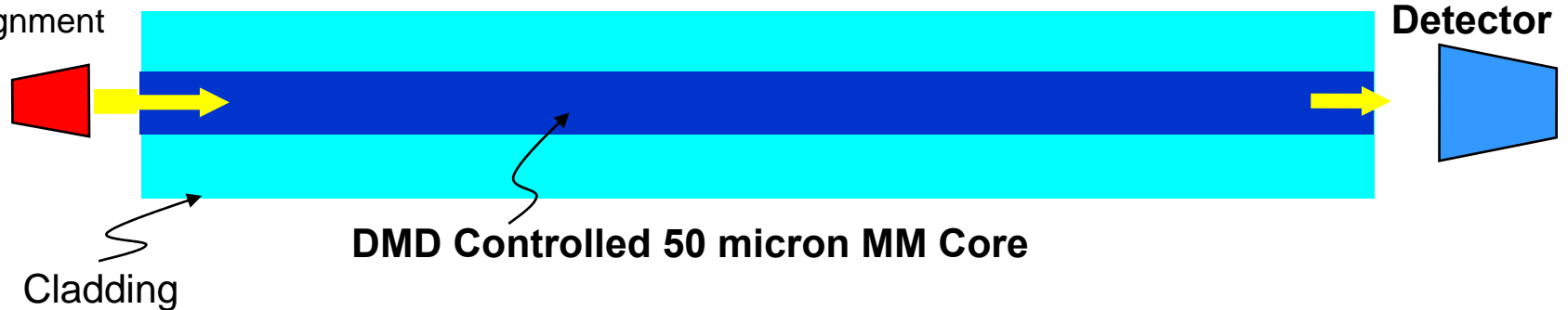
1G Ethernet 850 nm:
1000BASE-SX: up to 1000 meters

10G Ethernet 850nm:
10GBASE-SR up to 550 meters



Laser

10 um
misalignment



Relaxes tolerances for Laser to Core (10 times easier than SM)

- Enables lowest cost optics, packaging, and connectors

Leverages existing 1G Ethernet manufacturing capacity (>10M/yr)

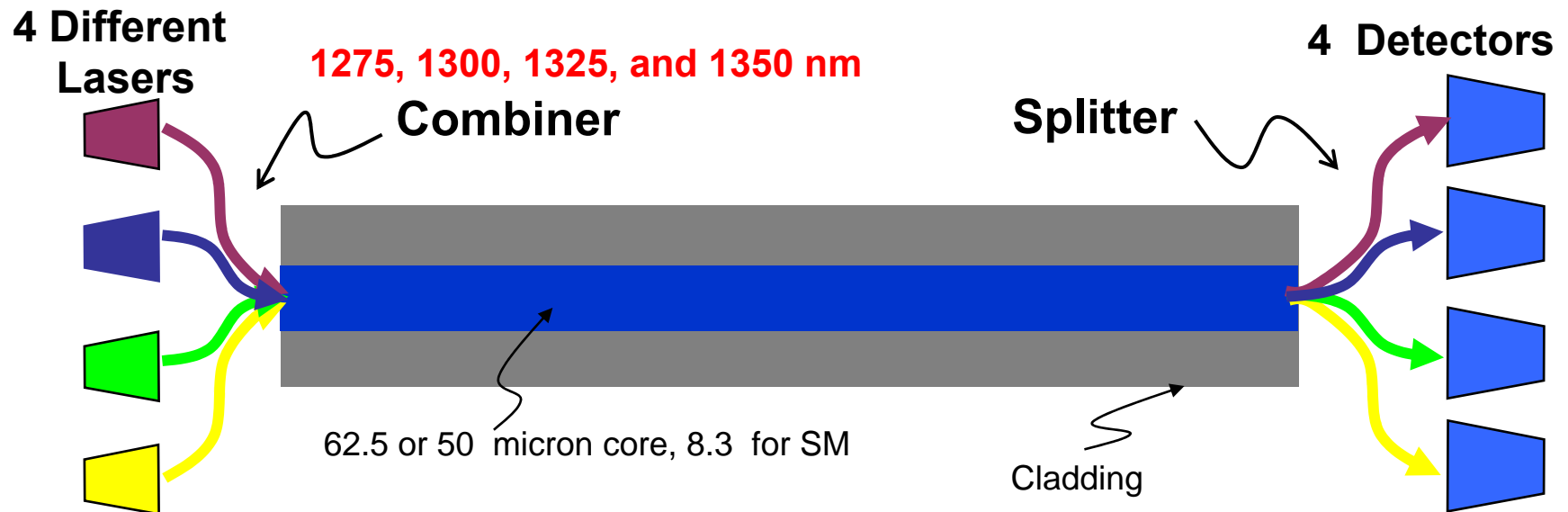
- 80 - 90% of Gigabit Ethernet optical ports are 850 nm

Same connectors and installation as conventional multimode fiber

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CWDM (Coarse Wavelength Division Multiplexing)

10G Ethernet 1310 nm 10GBASE-LX4 10 KM SM fiber
300m MM fiber



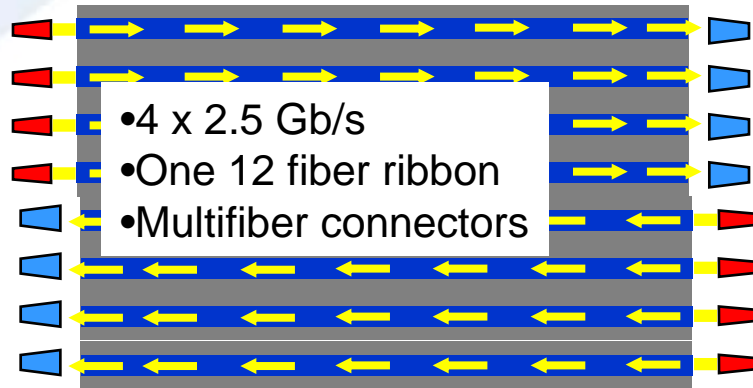
- High cost SM packaging, plus more parts and complexity
- Requires “mode conditioning patch cord” if used with conventional MMF
- 850nm alternatives should be less expensive

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Parallel

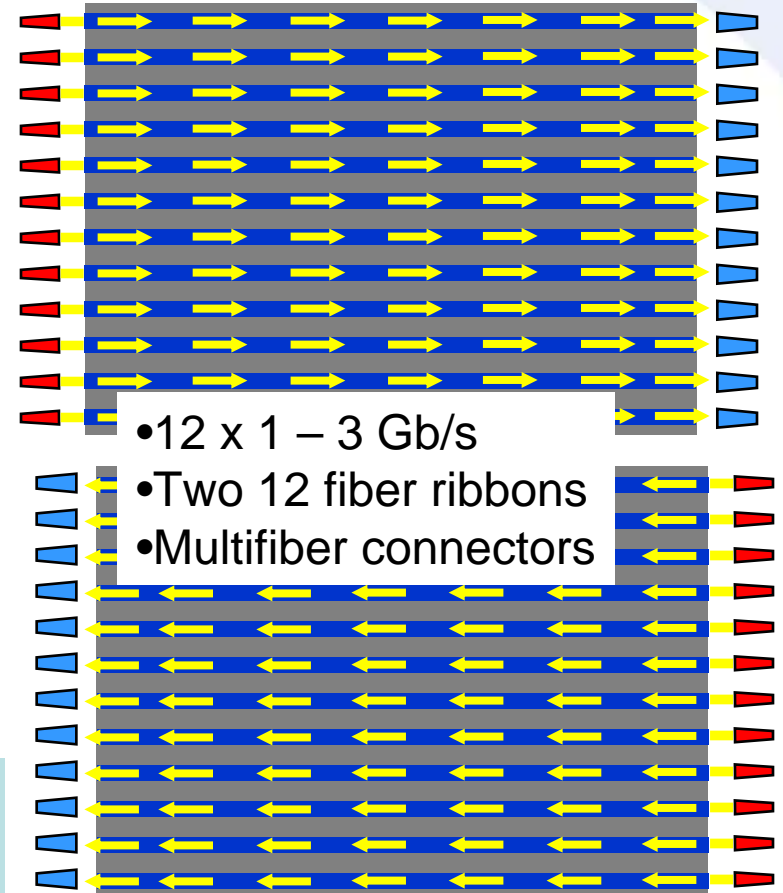
Using 850 nm VCSEL arrays 10GFC, OIF, & Future Speeds

4 Channel Duplex



- 50 or 62.5 micron multimode
- Ribbon cable
- MTP Connectors
- Very high density

12 Channel Duplex



Makes sense to increase density in Data Center applications.



What's Next?

Higher Ethernet Transmission Rates

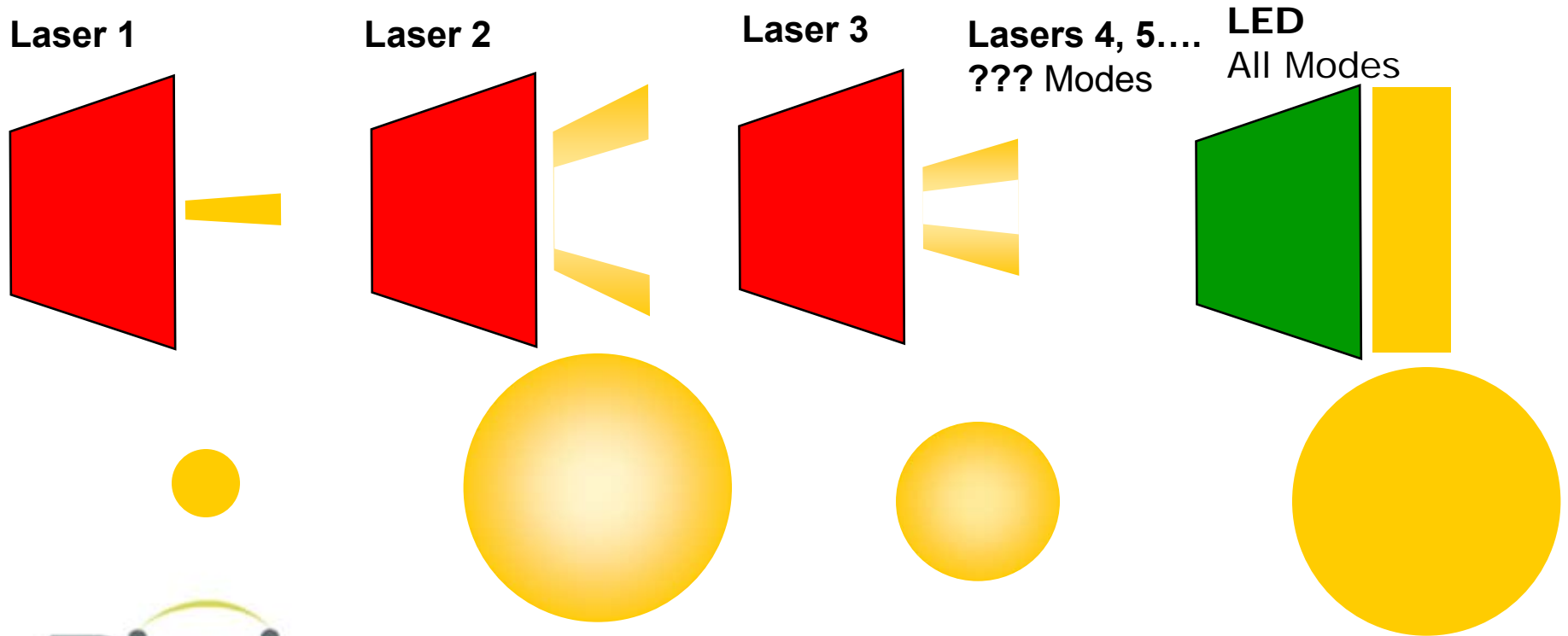
- IEEE could begin writing 100G std in ~2006 – 2007
- High Speed Study Group formed to investigate next Ethernet speed
- Likely 100 Gb/s
- Will leverage existing fiber and transceiver technologies
 - Parallel and/or CWDM Transceivers
 - OM3 fibers (allows lowest cost and greatest expansion) → 850nm range
 - 10 X 10 Gb/s Parallel (at 850nm) promoted by IBM
 - 4 x 12.5 Gb/s CWDM (at short wavelengths) over 2 fiber Parallel??
 - OM1 and OM2 (to support the installed base) → 1300nm range,
 - If possible, limited to short distances
 - Singlemode for long distances → 1300nm range

Laser Bandwidth (Fiber EMB with Lasers)

Does overfilled bandwidth predict Laser bandwidth? - NO

Different lasers at the same speed and wavelength:

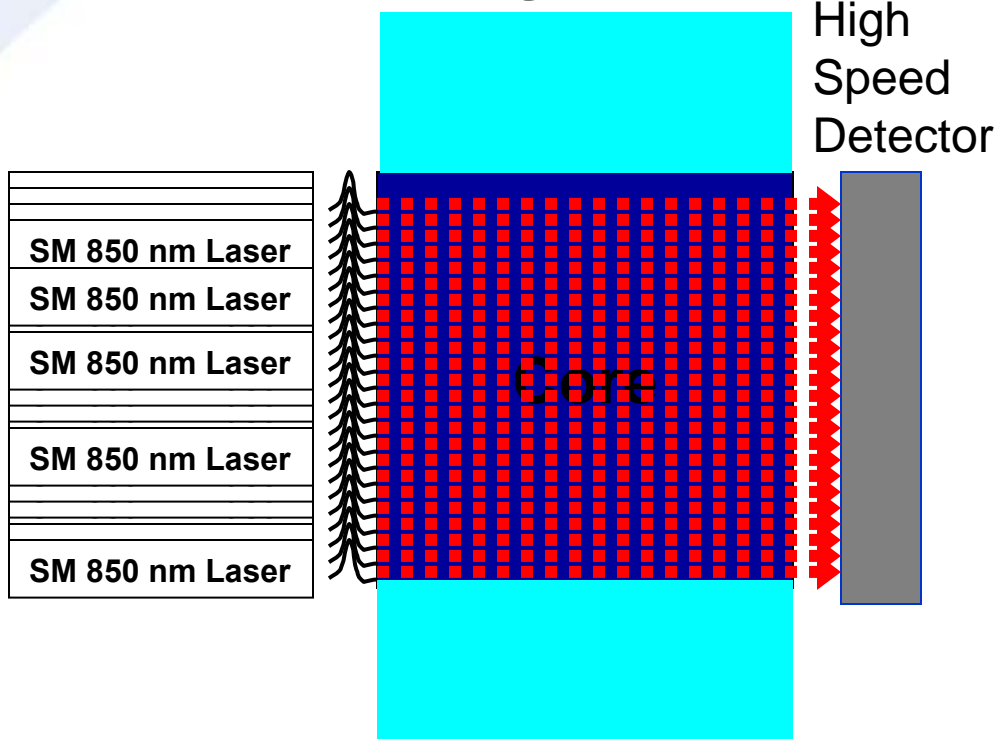
- Have different power output profiles (Encircled flux)
- Fill a subset of the hundreds of modes in MMF
- Each fills **different subsets** of modes
- **Will produce different bandwidths on the same fiber**



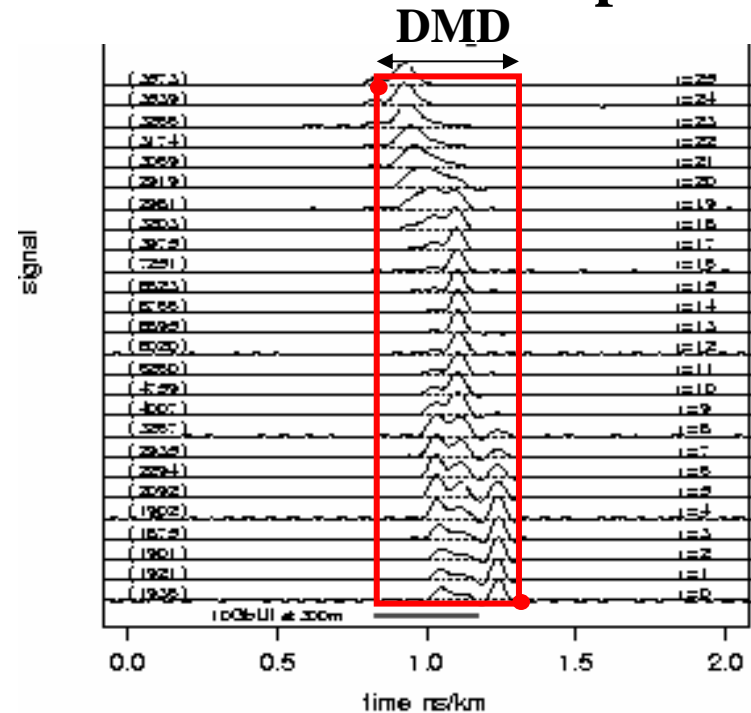
DMD Measurement Provides a Means to Assess Bandwidth for Specific Modes

(per IEEE 802.3ae, TIA FOTP-220 and TIA492-AAAC-A)

DMD Scanning Process



DMD Scan Example



DMD = Difference in delay between the earliest and latest arriving pulses

a.j.ritger 22Jan00



DMD Templates (TIA-492AAAC-A, IEC 60793-2-10)

2000 MHz- Effective Modal Bandwidth (EMB) 10G MMF

EMB is assured

- Based on 40,000 VCSEL/Fiber combinations
- Validated by TIA round robin testing

DMD Scan compared to 6 DMD templates

- Fiber must meet at least one template
- Each template has inner and outer mask
- Inner mask floats temporally in outer mask

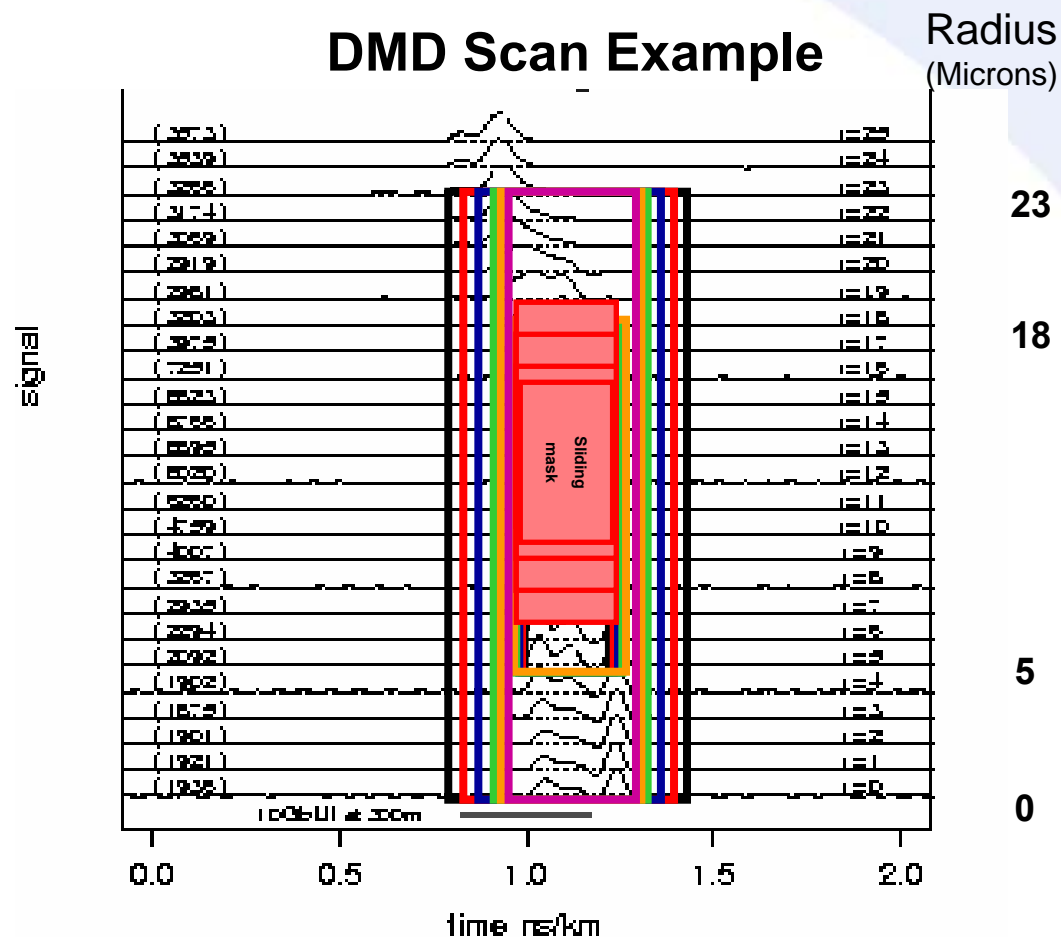
Additional “sliding mask” DMD requirement

- Slightly improves system reliability
- “Smooth” DMD in critical region 7-19 microns
- Assured by sliding DMD mask
- DMD < 0.25 ps/m over any 6 micron radius

- TIA-492AAAC-A templates
- 1 —
 - 2 —
 - 3 —
 - 4 —
 - 5 —
 - 6 —



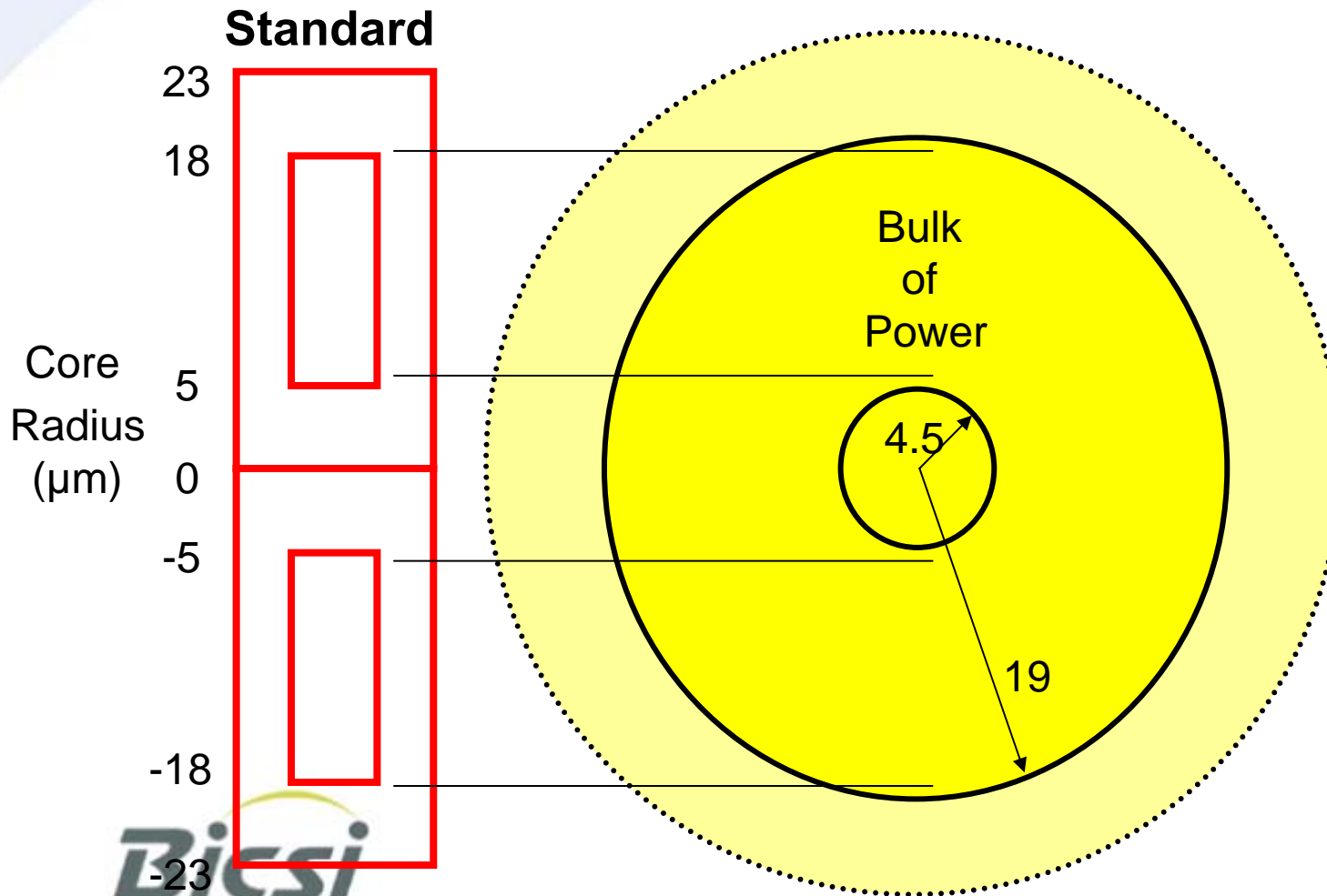
DMD Scan Example



This fiber meets templates 3, 4, and 5 and meets the sliding mask specification

DMD to Encircled Flux Correspondence

- Tight inner mask matches region carrying bulk of power

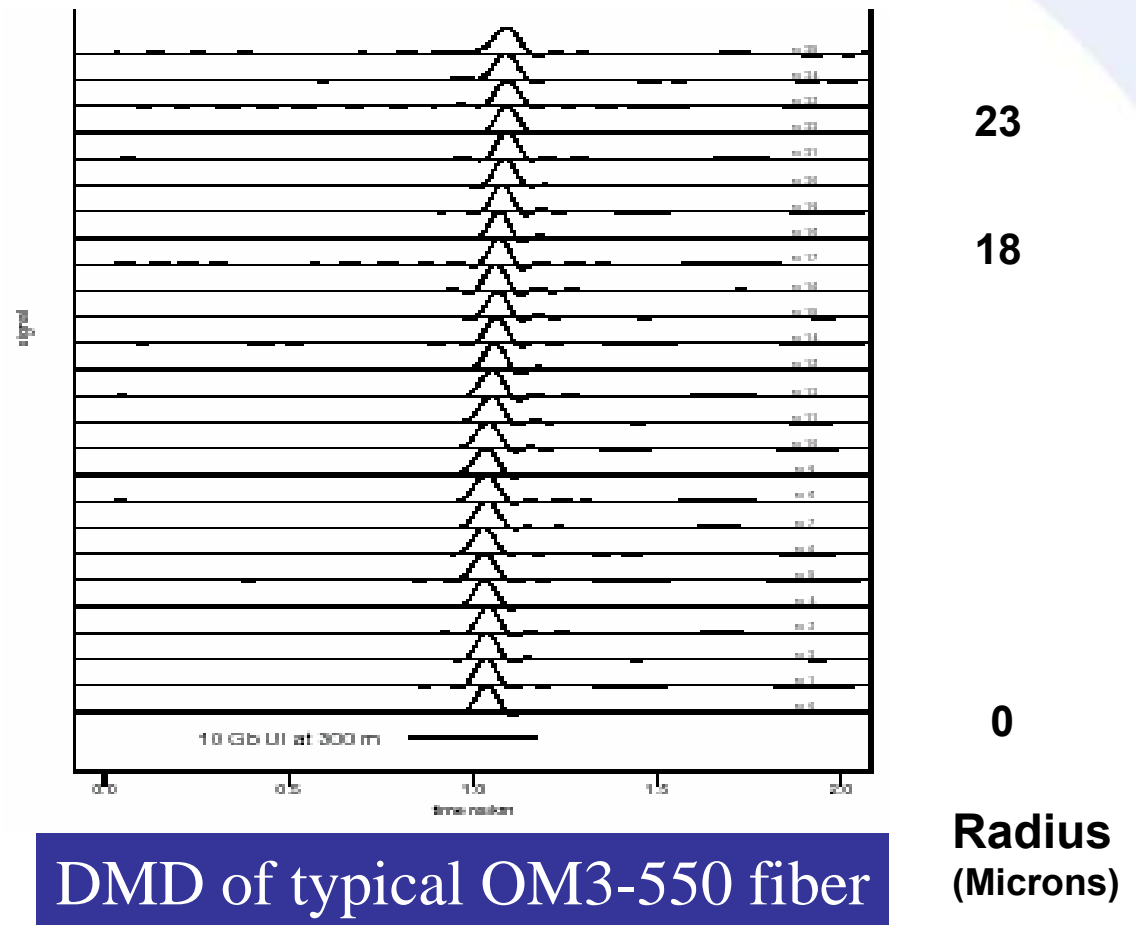


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OM-3 Laser Optimized 50 Micron Fiber

Ideal DMD Profile

- All pulses aligned in time
- Nearly zero DMD
- >4700 MHz-km of Laser bandwidth
- Assured by smooth, defect free refractive index profile



EMB_c (TIA-492AAAC-A, IEC 60793-2-10)

2000 MHz- Effective Modal Bandwidth (EMB) 10G MMF

Calculated based on DMD

- DMD of fiber measured per TIA FOTP-220
- Calculated from interaction of the DMD with 10 simulated VCSELs
- 10 VCSELs meant to represent a broad range of compliant VCSEL specifications
- The lowest of the 10 bandwidths is EMB_c
- Intended to be equivalent to the TIA DMD mask method of assuring EMB



Summary

- Increasing data rates have necessitated the use of laser sources and laser-optimized multimode fibers
 - Prepare now for 10 Gb/s capability in LANs, SANs, Data Centers
- Not all “laser-optimized” fibers are alike
 - Specify 850nm Laser-Optimized 50um fiber (OM3) per TIA492-AAAC-A
- To avoid confusion, pay attention to bandwidth specifications and measurement methods
 - EMB, DMD, EMBc measurements and specifications required for OM3
- 10G LO 50um OM3 and OM3+ fibers recommended for future speeds
 - Provides upgrade path to higher speeds, at lowest system cost
 - Provides headroom for increasing channel insertion loss & improving reliability

To learn more about optical fiber, subscribe to our free email newsletter, [Fiber Topics](http://www.ofsoptics.com), by visiting www.ofsoptics.com



Thank you.....



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