Finisar®

Fiber Optic Solutions
for High-Speed Networks

Finisar Presents:
Optics, Optical Fibers, and Transceivers

Optics 101

March 2011

Optics, Optical Fiber, & Transceivers

- Part 1 – Optics
  - Reflection & Refraction
  - Index of refraction
- Part 2 – Optical Fiber
  - Fiber construction
  - Multi mode fiber
  - Single Mode fiber

Optics, Optical Fiber, & Transceivers

- Part 3 - Optical Transceiver
  - Transceiver module architecture & construction
  - Transmitter
  - Receiver
  - Optical sub-assemblies (OSA)
  - Tx / Rx performance figures of merit

Optics, Optical Fiber, & Transceivers

- Part 4 –Power Budget, References
  - Power (link) budgets
  - References

Why Fiber Optics?

- Bandwidth is a compelling reason

1970's – Copper cable, 672 simultaneous data streams, with 2 km spacing between amplification points

Today – With a single fiber, in excess of 130,000 simultaneous data streams, with 60 km spacing between amplification points

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Why fiber optics?

- Low loss - Flat attenuation (loss) across frequency
- Electromagnetic immunity - No radiation or absorption of electromagnetic energy
- Light weight - Copper co-ax cable can weigh 9 times as much as fiber cable
- Small size - A smaller diameter fiber cable provides more bandwidth than a larger copper cable
- Safety - No electrical hazard, no spark potential
- Security - Extremely difficult to “fiber tap”

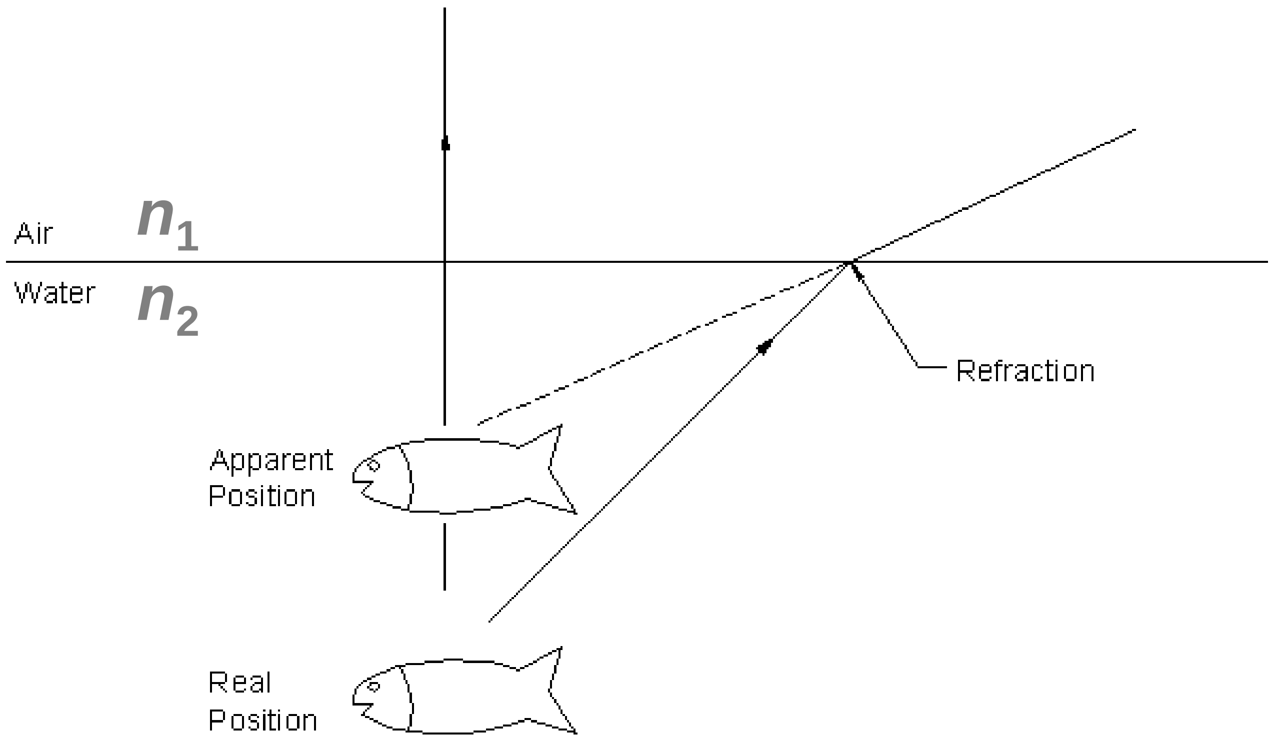
Part 1 – Optics

- Reflection and Refraction

Optics - Reflection & Refraction

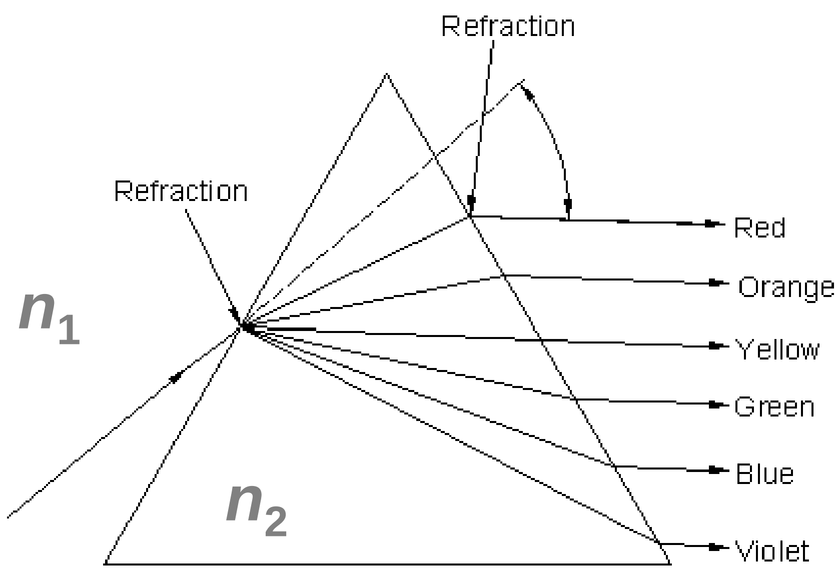
- "Speed of light" = 3 x 10^5 km/sec (186,000 miles per second) in a vacuum
- Light travels at different speeds in different materials; *speed is material dependent*
- Different wavelengths of light travel at different speeds in the same material; *speed is wavelength dependent*
- Light traveling at an angle from one material to a different material changes direction
- This change of direction is known as refraction

Optics - Refraction



Light traveling at an angle from one material to a different material changes direction

Optics - Refraction



- Light traveling at an angle from one material to a different material changes direction
- For a given material, different wavelengths of light travel at different speeds; speed is wavelength dependent

Optics - Index of Refraction

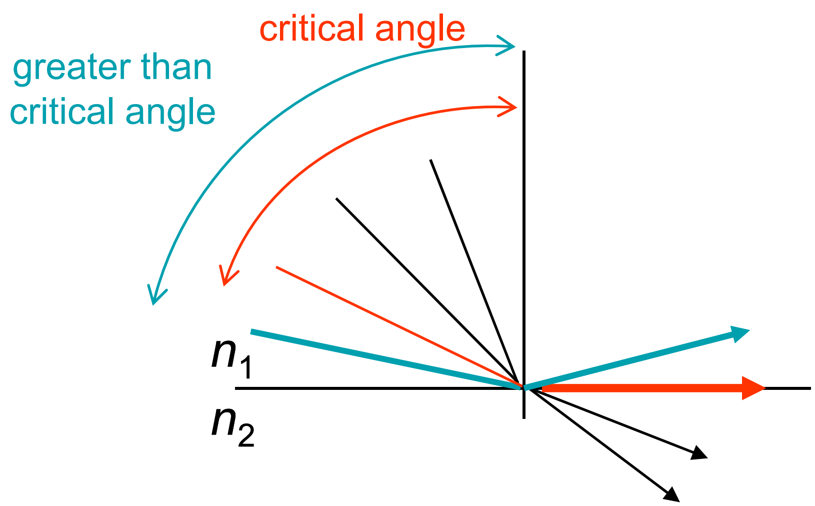
- Index of refraction *n*, *n* = c/v, where:
  - c = velocity of light in free space
  - v = velocity of light in a specific material

- Index of refraction for selected media:

Material	Index (*n*)	Light Velocity (km/s)
Vacuum	1.0	300,000
Air	1.0003	300,000
Water	1.33	225,000
Fused Quartz	1.46	205,000
Glass	1.5	200,000
Silica	1.52	198,000

Optics – Refraction and Reflection

- For n1 greater than n2:
- Incident light at the critical angle is not refracted into material n2
- Incident light greater than the critical angle does not pass into material n2, but is reflected within material n1



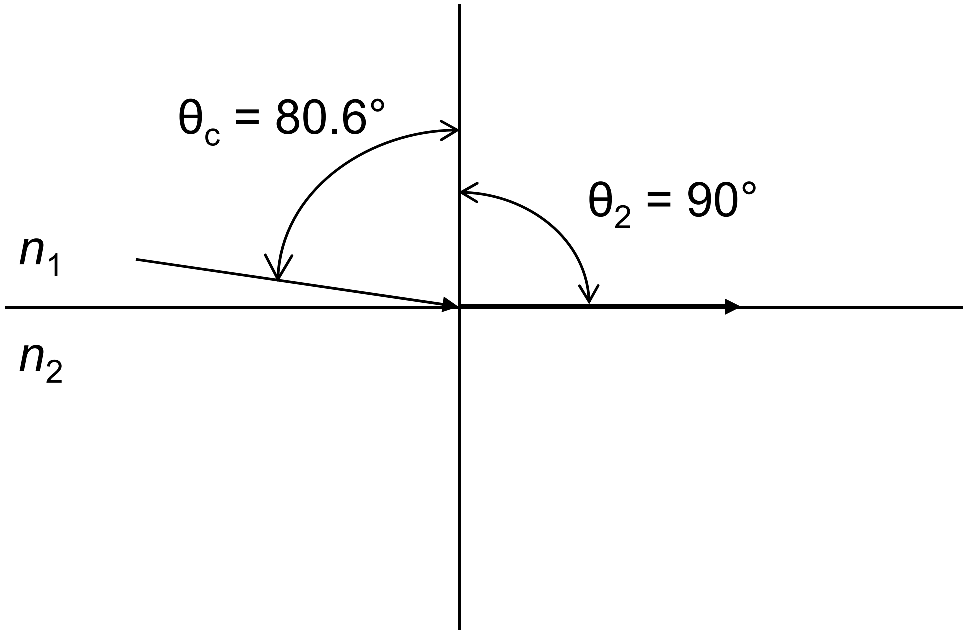
Optics - Reflection

Example:

n_1 = 1.48, n_2 = 1.46

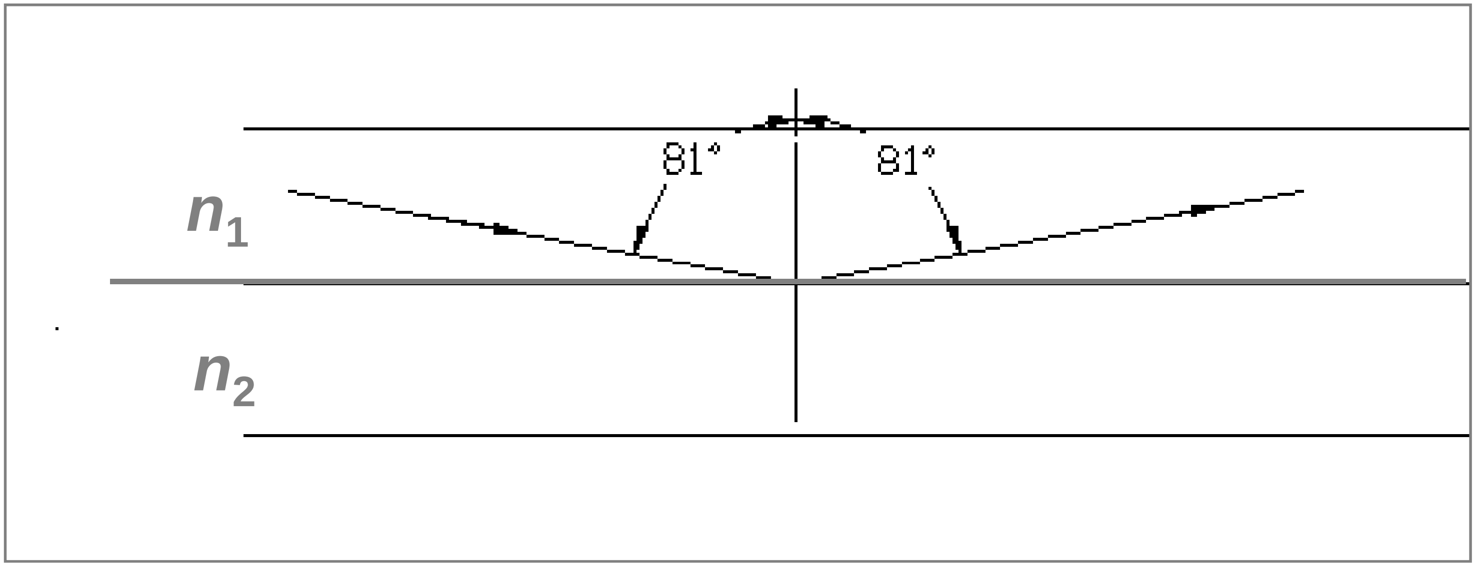
$\theta_c = \arcsin(1.48 / 1.46)$

$\theta_c = 80.6°$



Optics - Reflection

- Where index of refraction n_1 is greater than n_2, total internal reflection will occur if θ is greater that the "critical angle"



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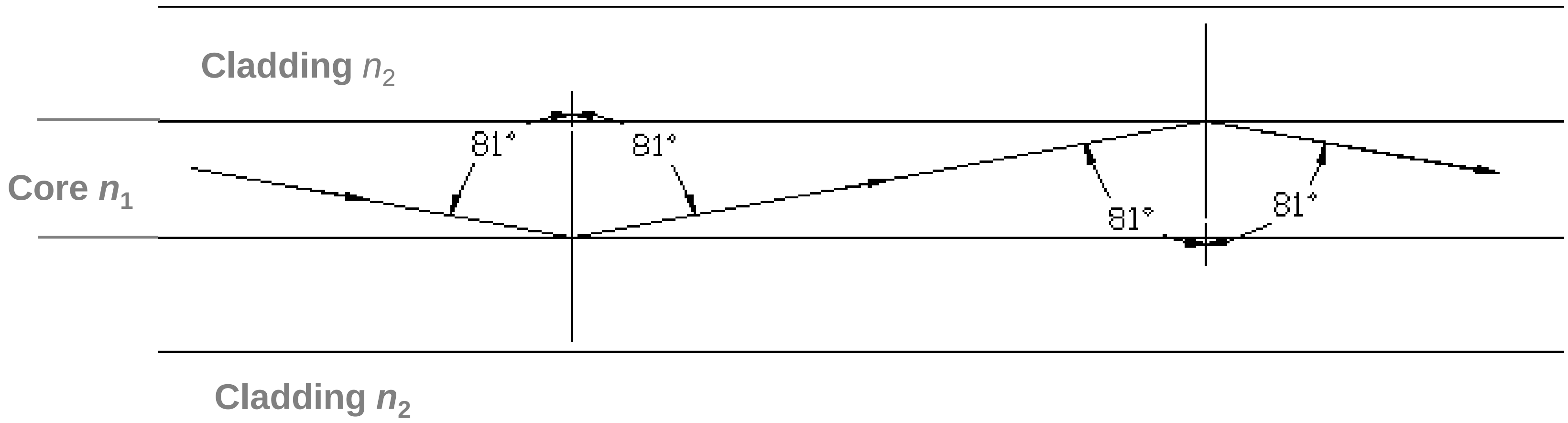
Optics - Reflection Example



Part 1 – Q&A

Q: Why is fiber so attractive?

A: Bandwidth

Q: Name one advantage of fiber over copper, besides bandwidth

A: Low loss, EM immunity, light weigh, small size, no electrical hazard, secure

Q: What is the speed of light in a vacuum?

A: 300,000 km/hr or 186,000 miles per second

Q: Light traveling thru material n_1, which is greater than n_2, does not refract from n_1 into n_2, but reflects back into n_1. What is this called?

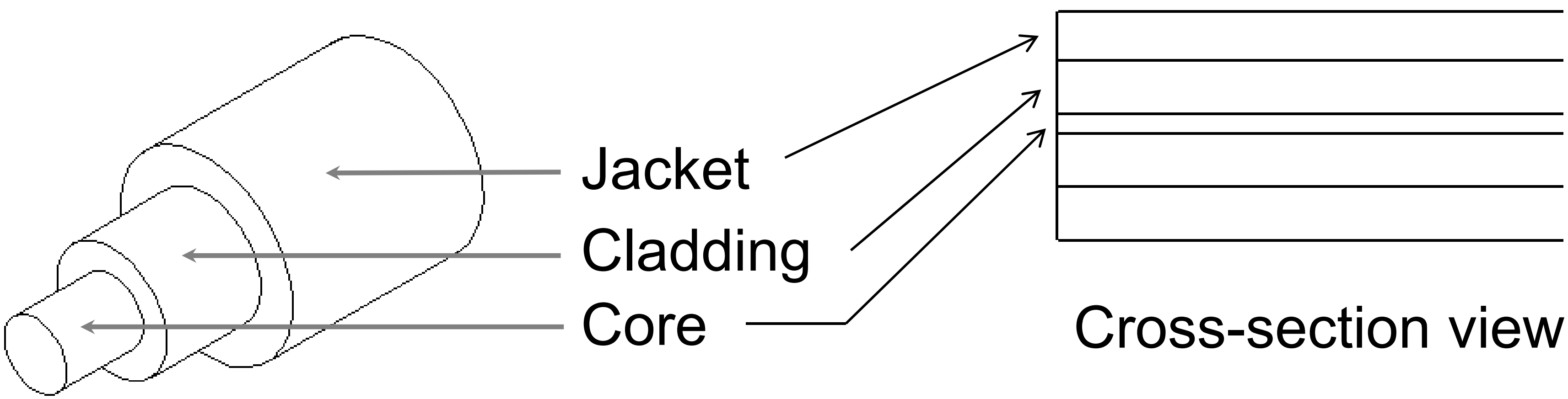
A: Total internal reflection

Part 2 – Optical Fiber

- Fiber construction
- Multi mode fiber
- Single mode fiber

Optical Fiber

- Concentric layers
  - Core
  - Cladding
  - Jacket
- The index of refraction, n, of the core (n1) is greater than the cladding (n2)

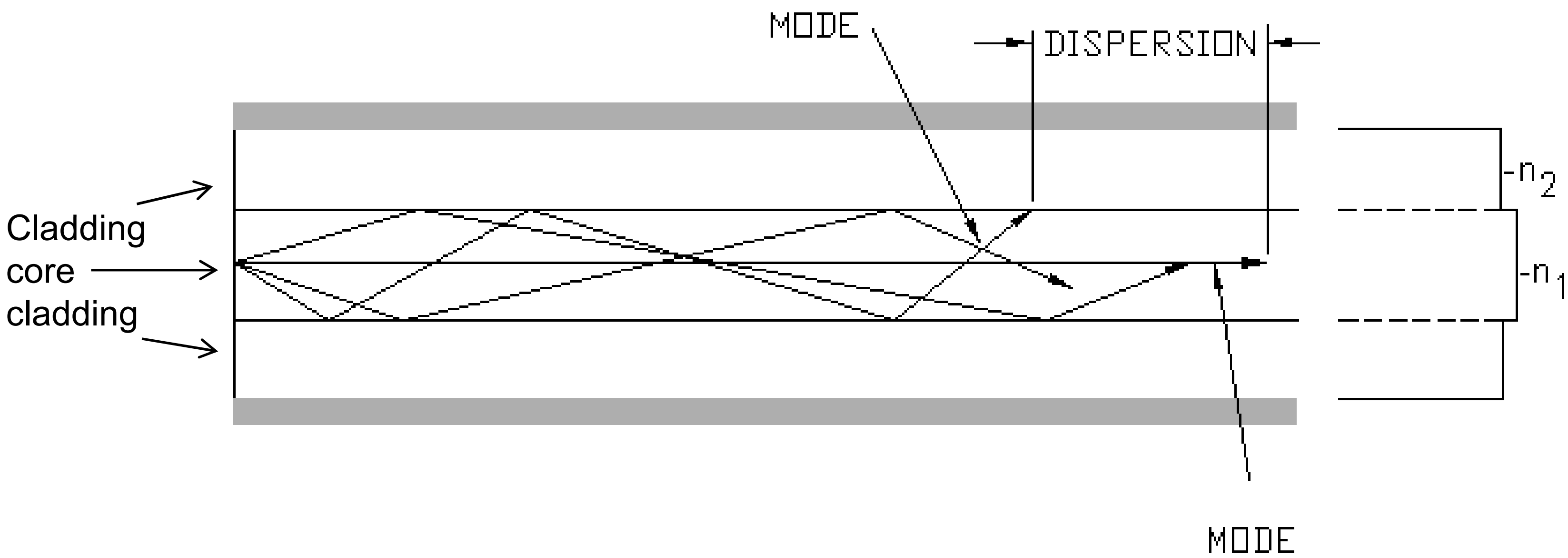


Optical Fiber

- Two primary types of fiber
  - Multi mode fiber
  - Single mode fiber

Multi mode fiber

- Core is 50 µm to 62.5 µm, cladding is 125 µm (point of reference: human hair is about 100 µm)
- Multiple light modes propagate thru the fiber. Different modes travel different paths, some longer than others, resulting in a spreading of the light pulse - modal dispersion



- Modal dispersion is a performance limiting factor in multi mode fiber

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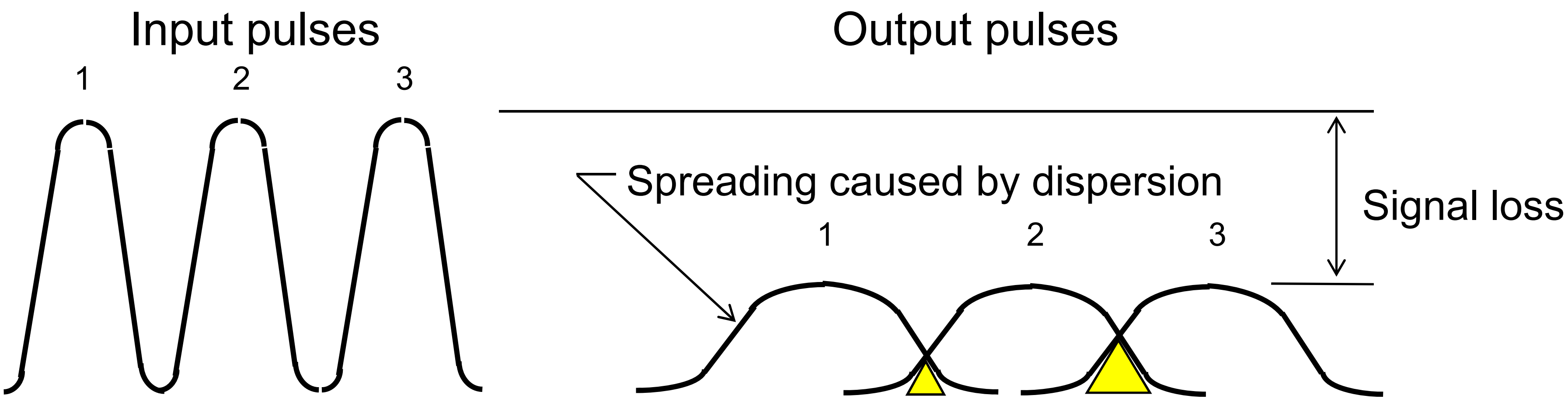
Dispersion – pulse spreading

- Input pulses are separate and distinct
- Output pulses exhibit pulse spreading, leading to pulse overlapping; pulses become indistinguishable from each other
- Bandwidth of the fiber decreases as dispersion increases



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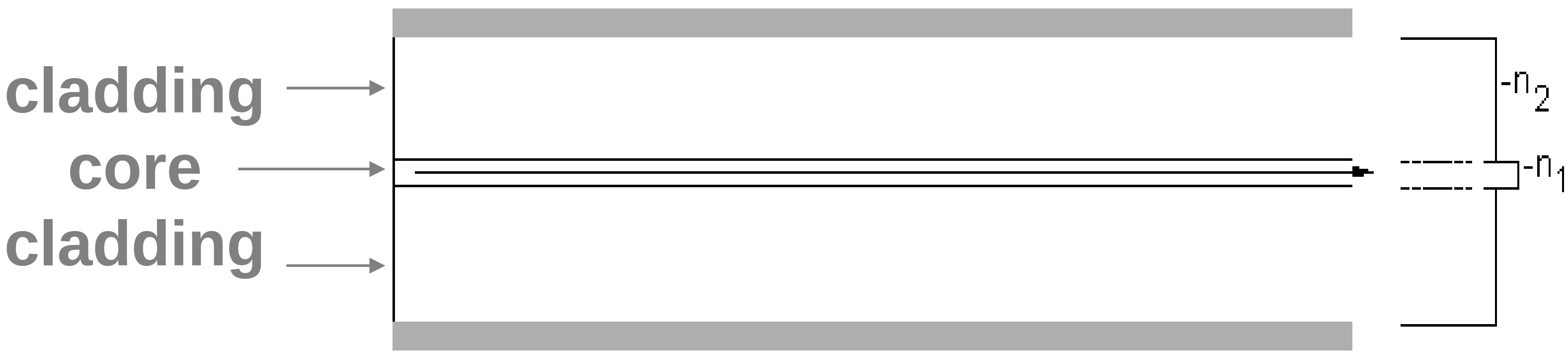
Single mode fiber

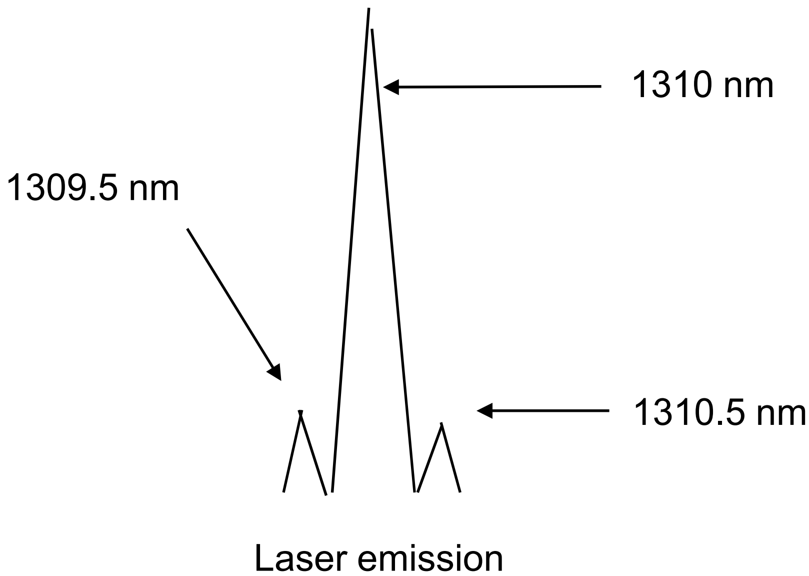
- Core is approx. 9 µm, cladding is 125 µm
- Core is sized proportionately (9 µm) to the wavelength (1100 nm and above) as to only propagate one mode efficiently



- Modal dispersion does not exist in single mode fiber

Dispersion in single mode fiber

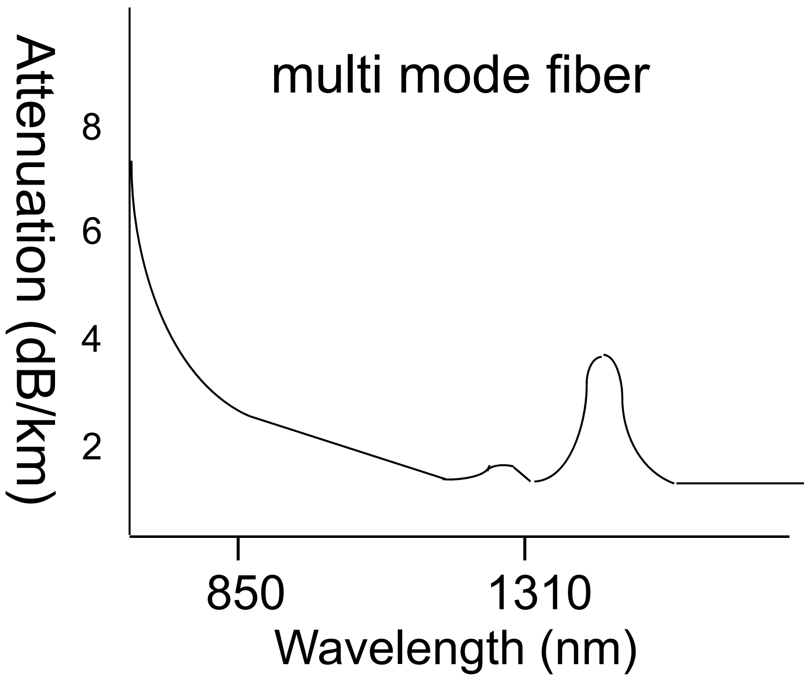
- Chromatic (material) dispersion
  - Chromatic dispersion is the result of different wavelengths traveling at different speeds

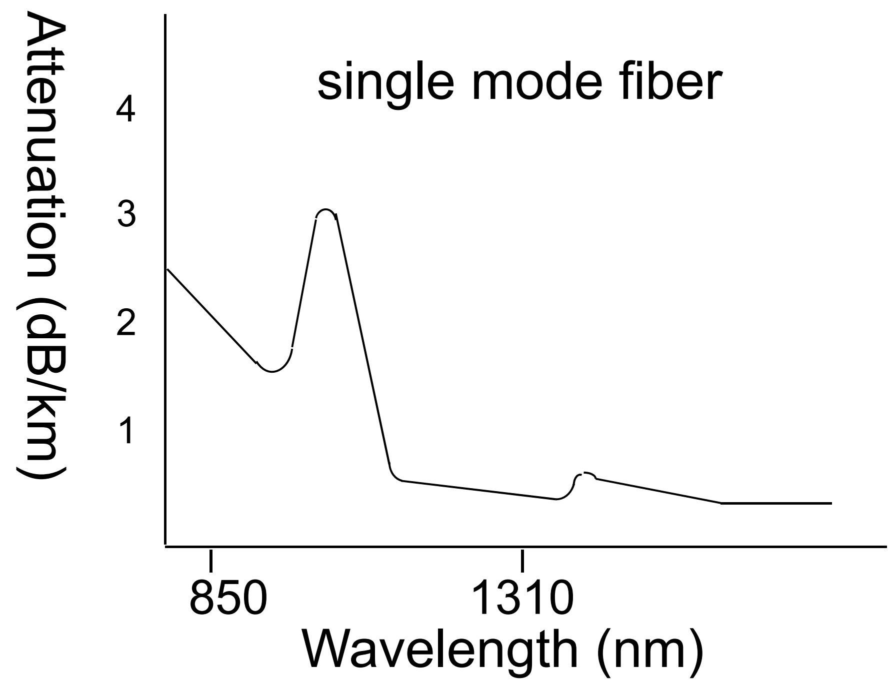


Chromatic (material) dispersion is a performance limiting factor in single mode fiber

Attenuation

- Attenuation is the loss of optical power as light travels thru the fiber
  - Varies with wavelength
  - Constant across frequency (unlike copper cable)
  - To minimize attenuation, use a source (laser) that emits in the low-loss region of the fiber





Attenuation – two primary contributors

- Scattering
  - Loss of optical energy due to imperfections in fiber
  - Light becomes multi-directional
- Absorption
  - Impurities in the fiber absorb optical energy

Summary – fiber, dispersion, and attenuation

- Multi mode fiber
  - Modal dispersion is the performance limiting factor
  - Chromatic (material) dispersion exists, but is not significant
  - Multi mode fiber is used for short distance links (up to 500 meters at 850 nm and Gigabit frequencies) due to bandwidth limitation caused by modal dispersion
- Single mode fiber
  - Modal dispersion does not exist
  - Chromatic (material) dispersion is a performance limiting factor
  - Single mode fiber is used for long distance links (up to 80+ km), at 1310 nm and 1550 nm
- Multi mode and single mode fibers and transceivers are generally not interchangeable

Part 2 – Q&A

Q: What are the two primary types of optical fiber?

A: Multi mode and single mode

Q: What color is the jacket of single mode fiber?

A: Yellow

Q: How many modes propagate thru a single mode fiber?

A: One

Q: In what fiber does modal dispersion become a performance limiting factor?

A: Multi mode fiber

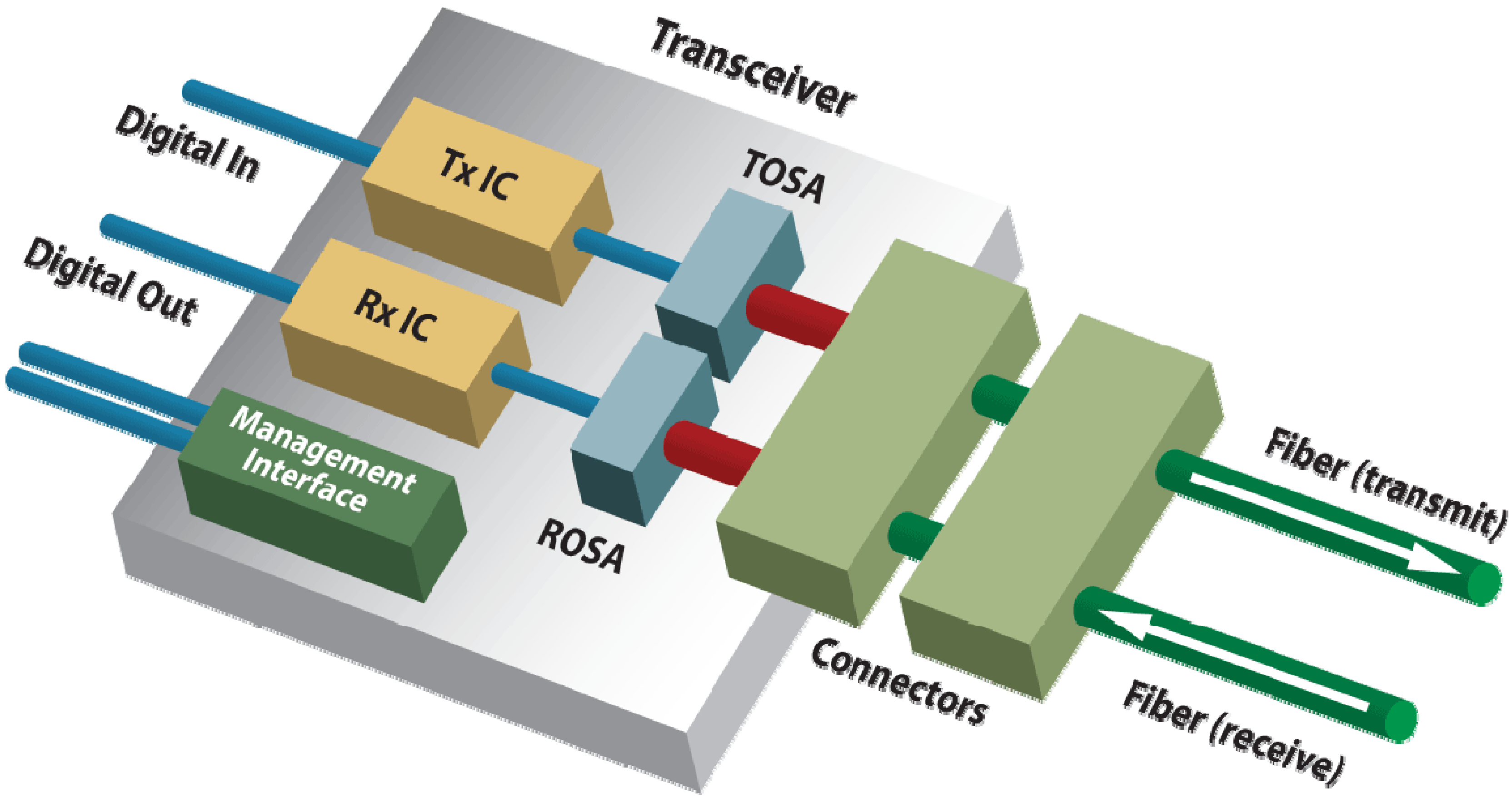
Q: What happens if n1 is LESS THAN n2?

A: The light refracts into the cladding, and does not propagate thru the core

Part 3 – Optical Transceivers

- Module architecture
- Transmitter
- Optical sub assemblies
- Transmitter characteristics
- Transmitter eye pattern
- Receiver
- Receiver characteristics & eye pattern

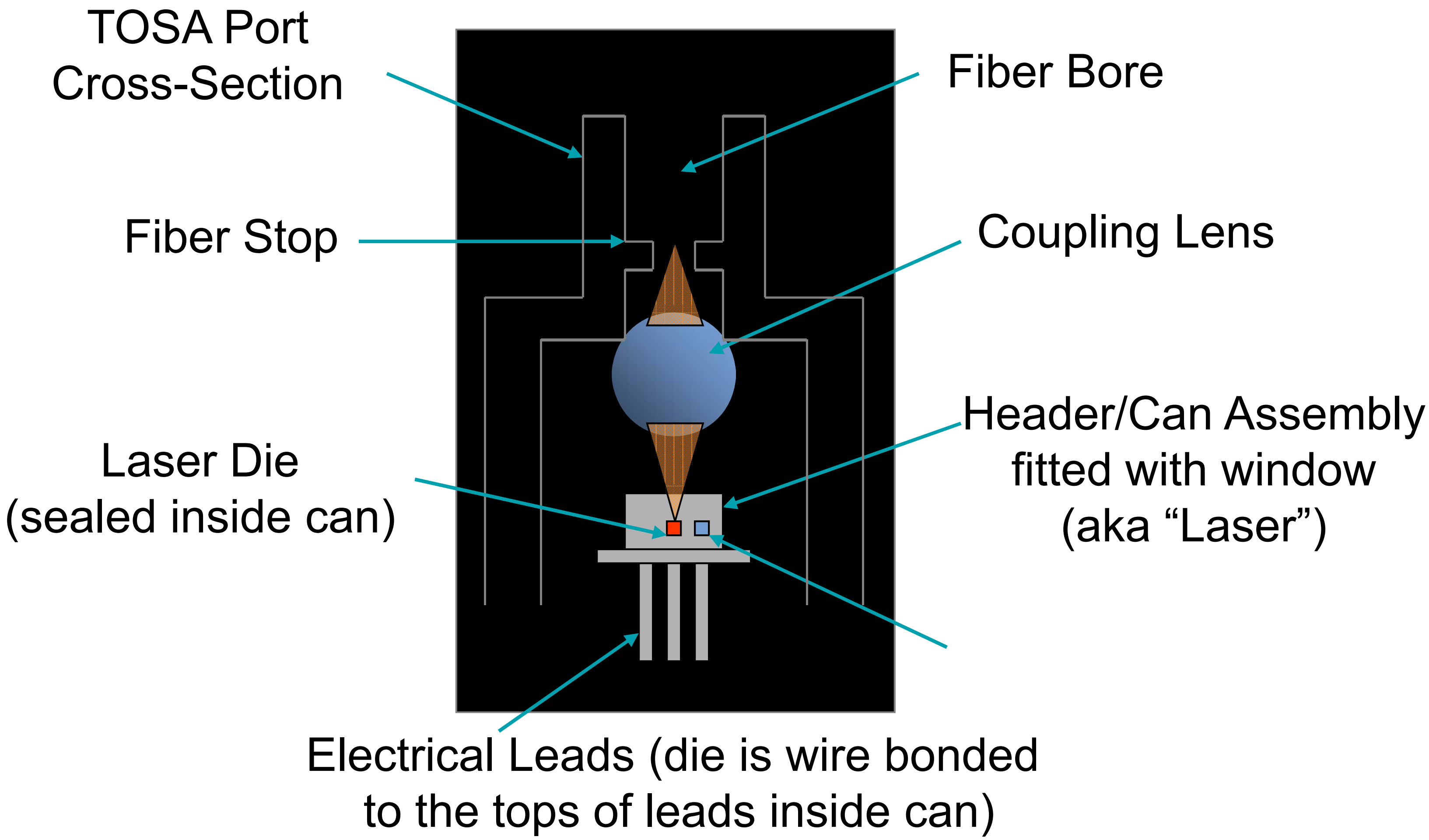
Basic Module Architecture



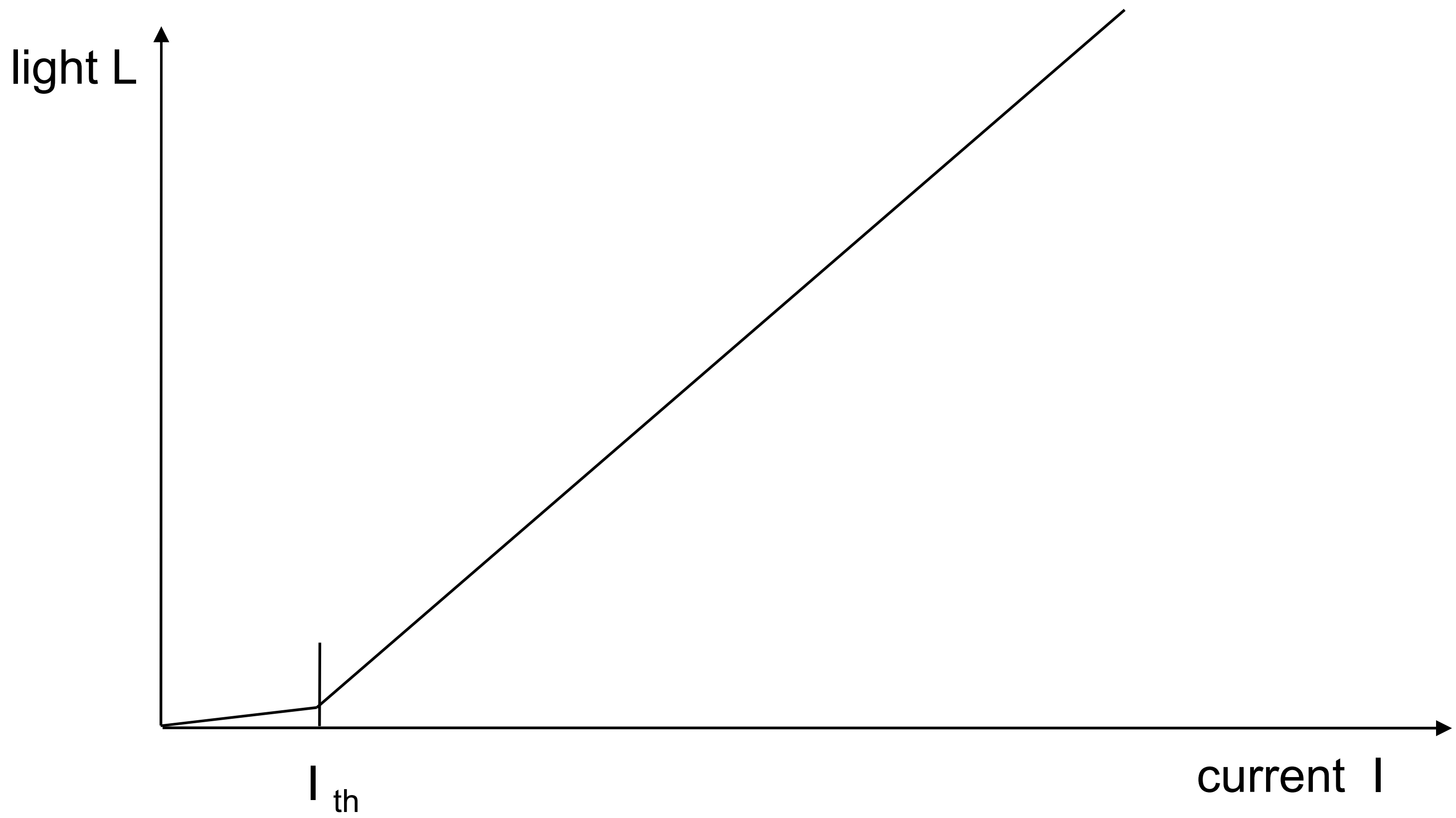
Transceiver Architecture

- Differential signaling used to minimize EM emissions to prevent:
  - Crosstalk – coupling of (e.g.) Tx signal to Rx circuit in module, which reduces sensitivity of receiver
  - EMI – electromagnetic interference affecting the customer's box; undesirably high emissions from the transceiver
- Laser Driver IC converts differential input signal into a current capable of driving the laser
- TOSA converts electrical signal to light (laser) and couples the light into optical fiber via lens

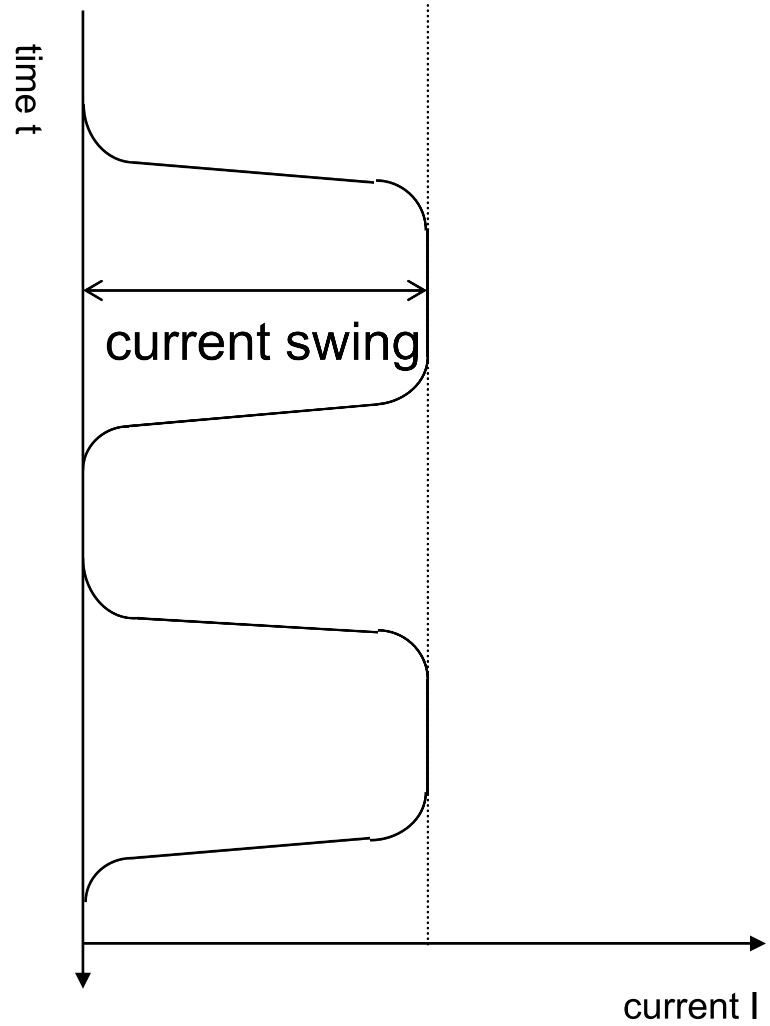
TOSA Architecture



Laser characteristics



Laser driver output current



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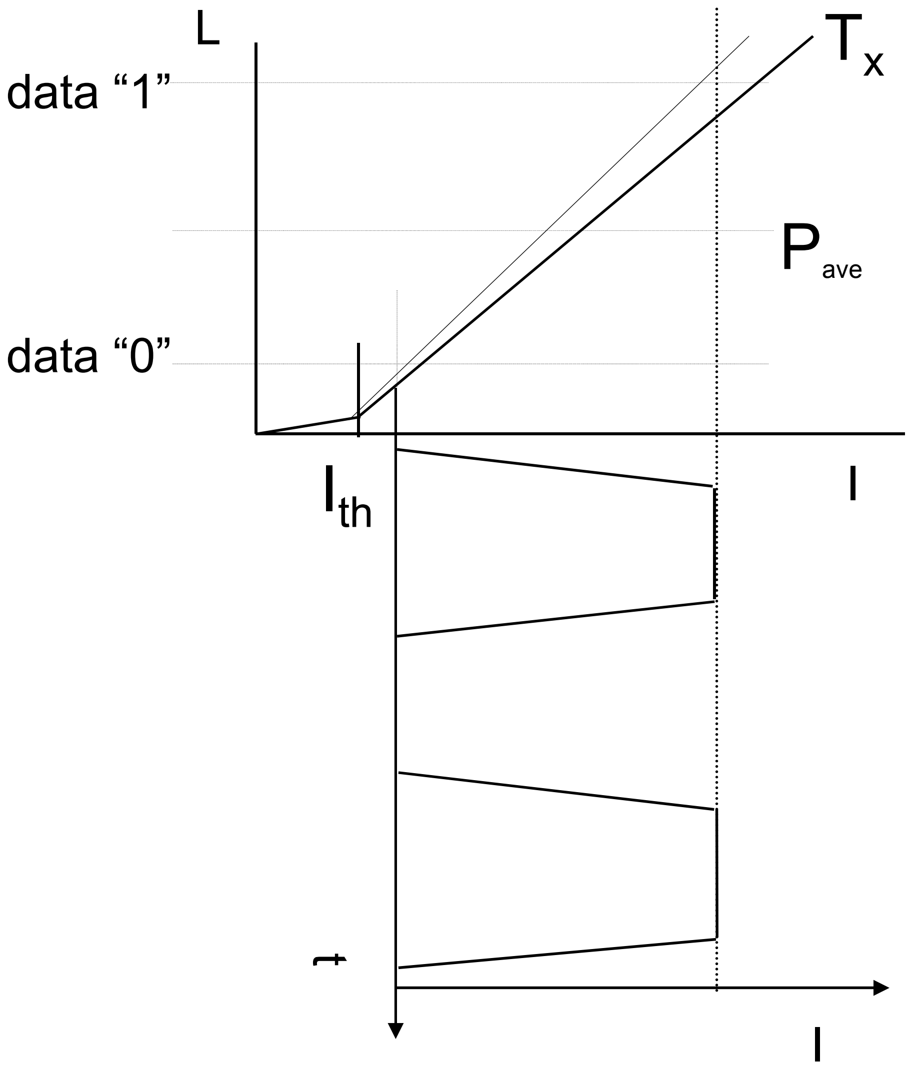
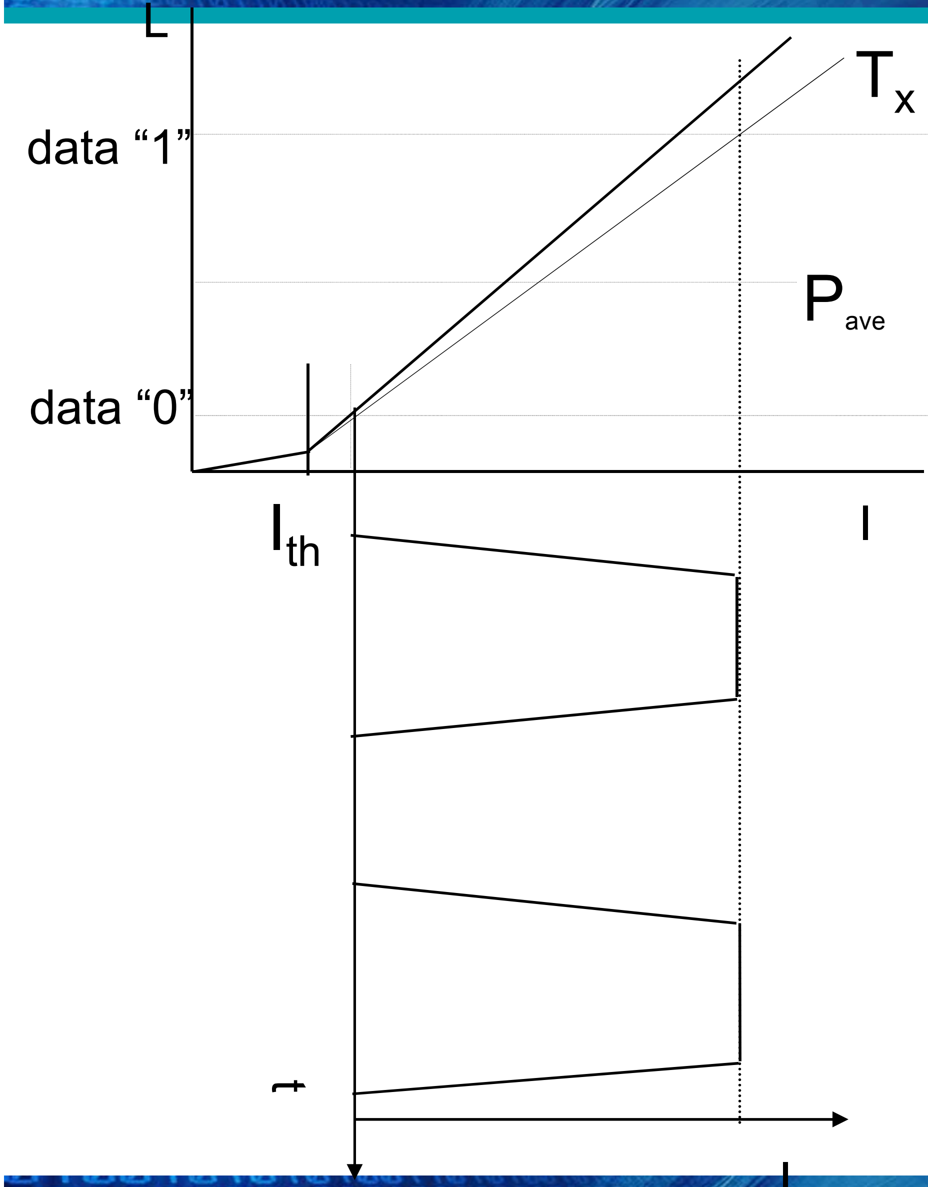
Laser driver and laser performance

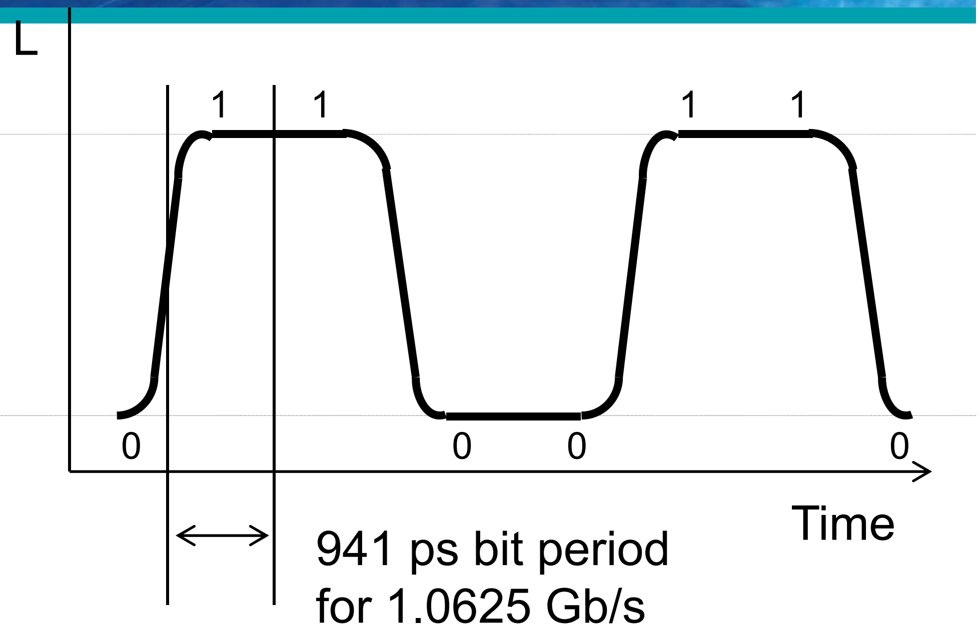


T_x = fiber-coupled optical power

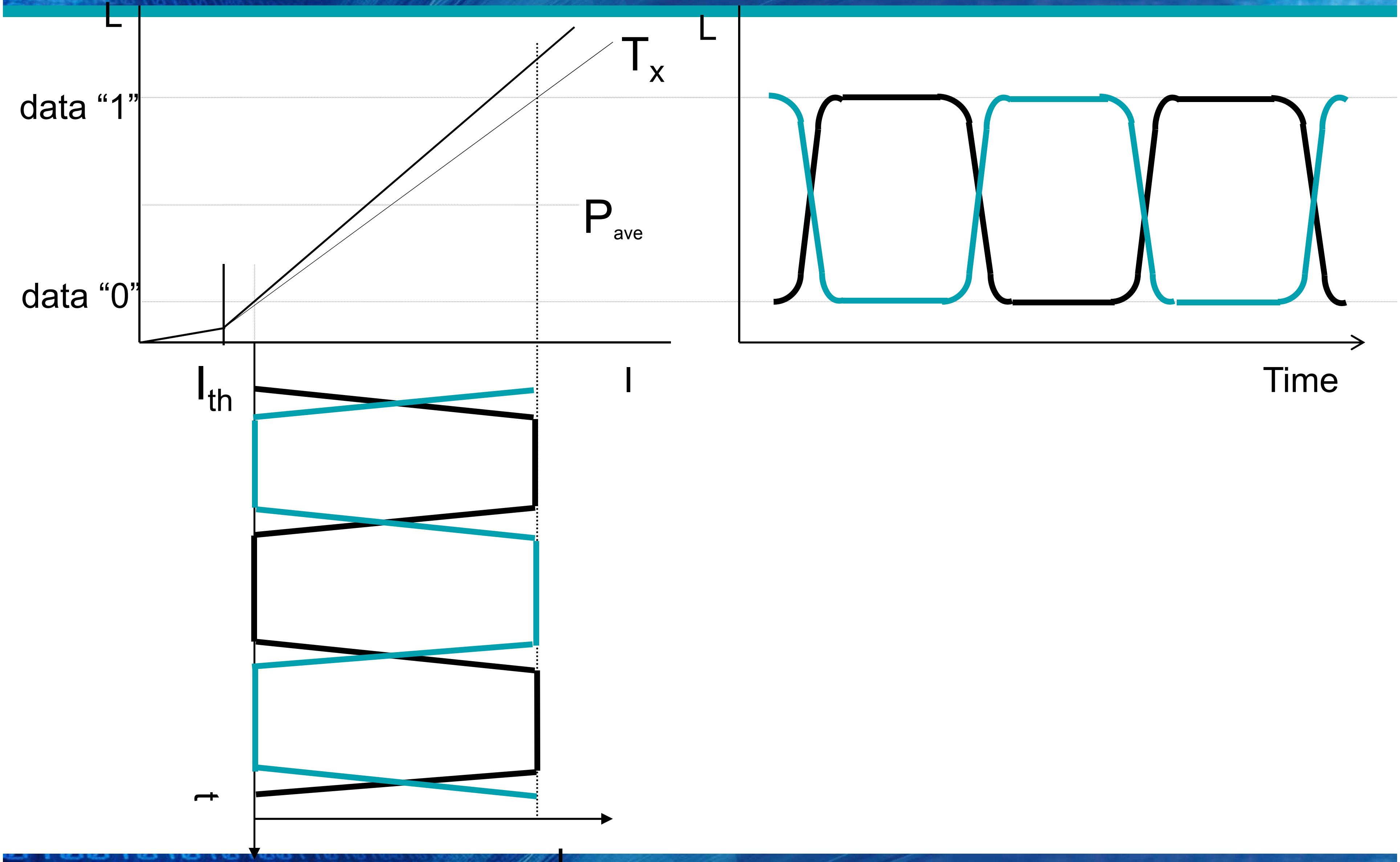
P_{ave} = average optical power

Laser output as digital optical signal

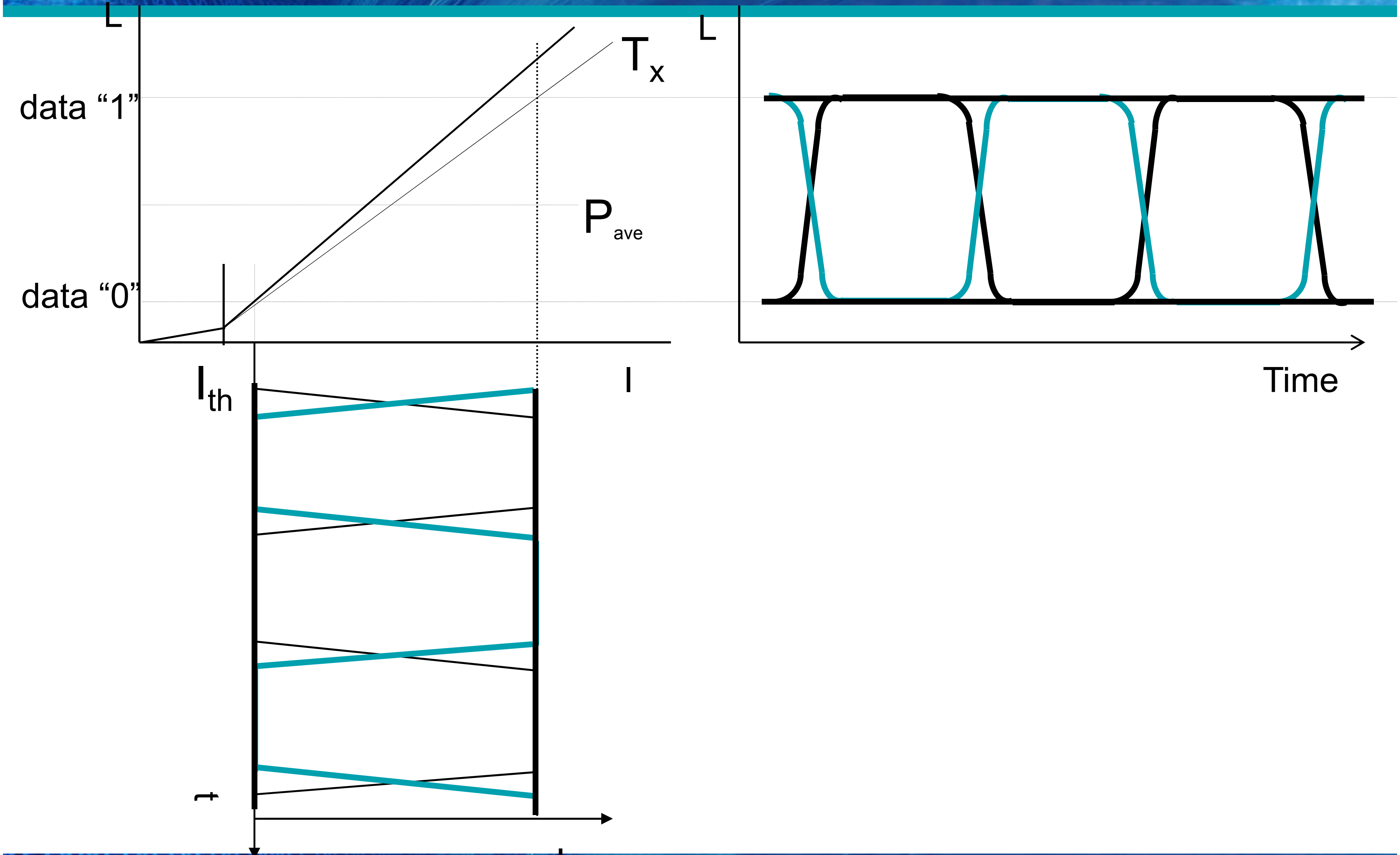




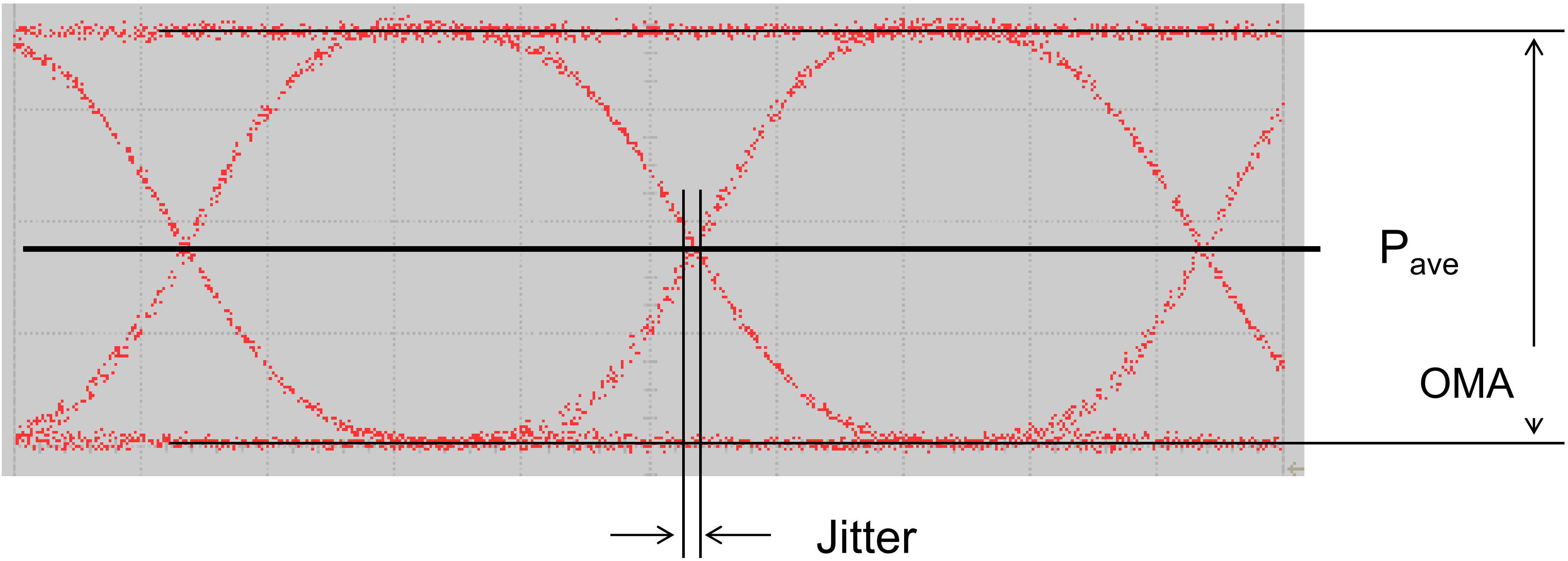
Building an eye pattern



Building an eye pattern



Transmitter eye pattern



- Average power (Pave)
- Optical modulation amplitude (OMA, in µW)
- Jitter (in ps)

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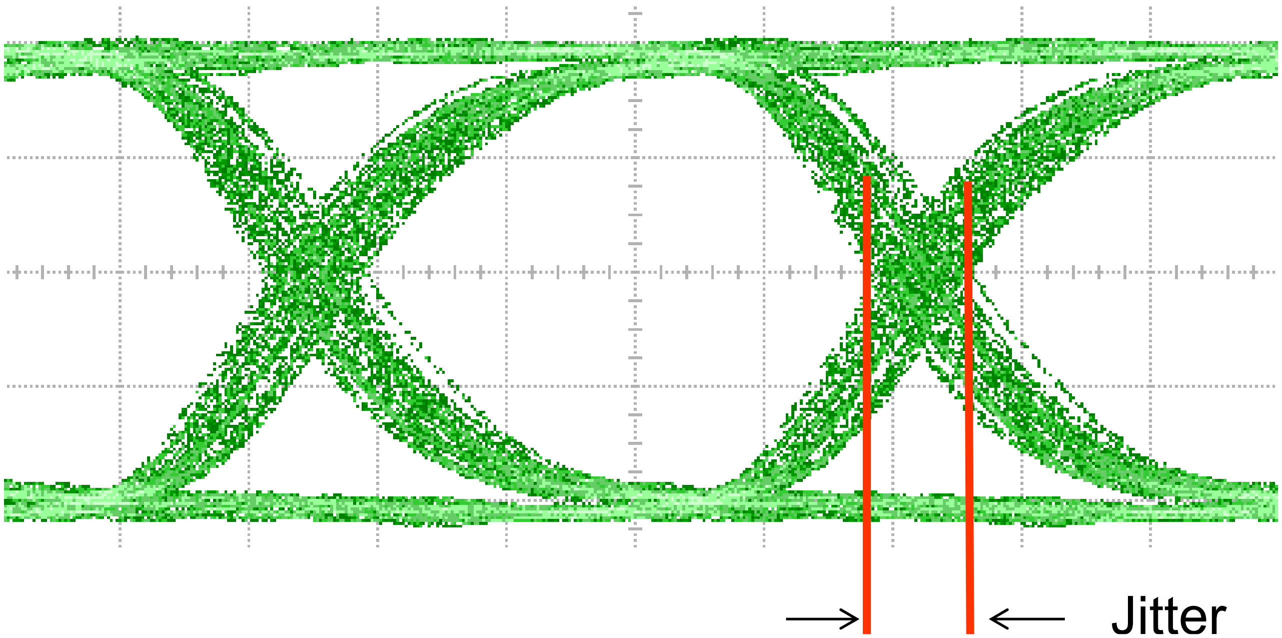
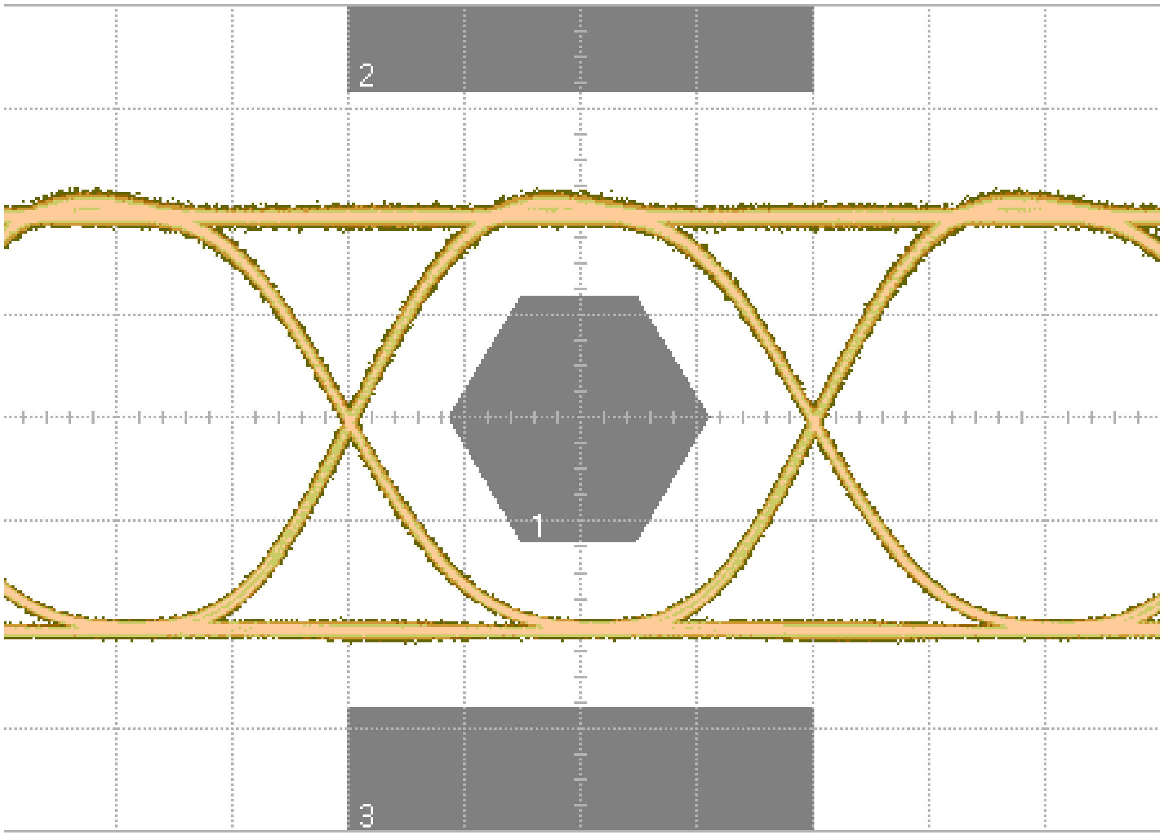
Transmitter eye pattern



- Jitter
  - Deterministic jitter– caused by dispersion in fiber, and inadequate bandwidth of transceiver components
  - Random jitter– caused by thermal noise, shot noise in components

Transmitter eye pattern - mask



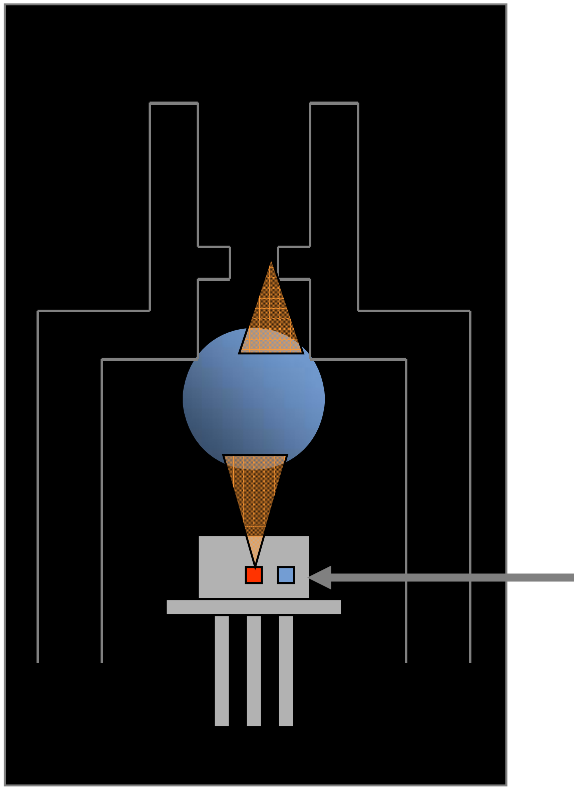
- Objective – no “mask hits”

Transmitter Characteristics

- Tx Power = fiber-coupled optical power
- Optical Modulation Amplitude (OMA) = difference in power between “1” and “0” bits
- “Eye Diagram” = useful mathematical construct for assessing digital signal quality, comprising 1000s (or more) of bits overlapped in time to one bit period
- Jitter = “thickness” of 0-to-1 and 1-to-0 transitions in eye diagram; an indication of instability in the bit period
- Eye Mask = keep out zone in eye diagram for error free transmission

ROSA Architecture

- Optical signal from fiber enters ROSA
- Lens couples light to photodiode (detector)



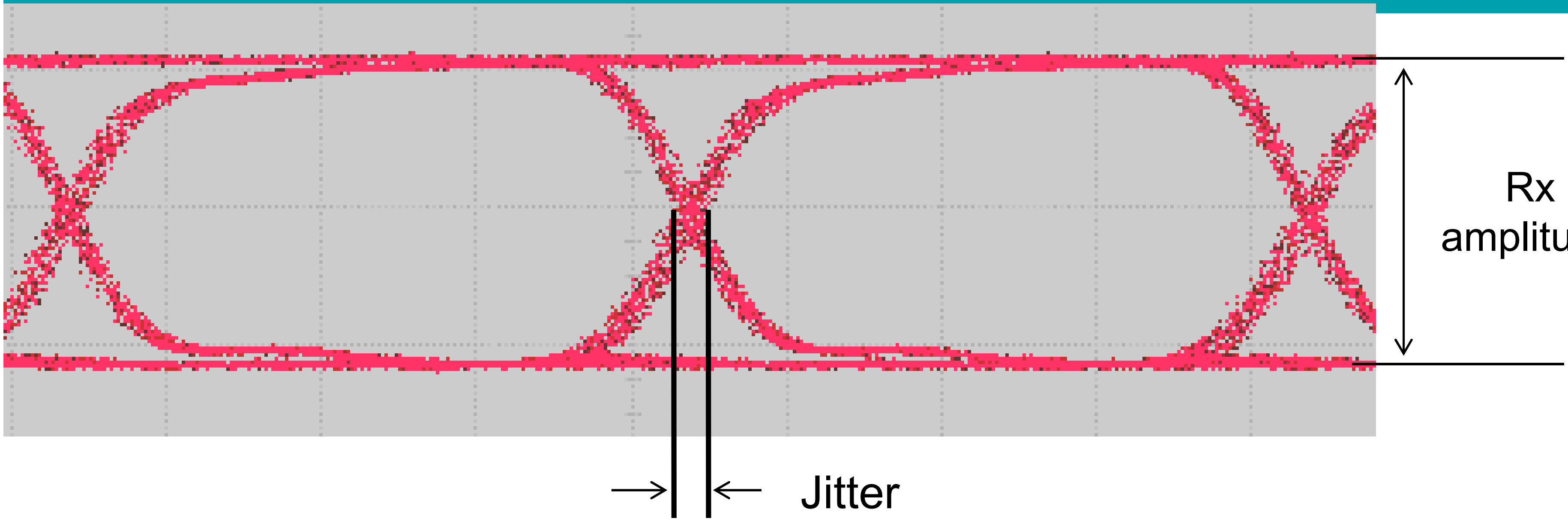
- Pre-Amp IC (TIA) boosts signal from detector

- Post amp IC (on the pcba) further boosts signal and provides host device with the differential output voltage signal

Receiver Characteristics

- Rx Amplitude – peak to peak voltage output
- Rx Jitter – analogous to Tx jitter
- Signal Detect / Loss of Signal (SD / LOS)
- BER (Bit Error Rate) = # bits in error per # bits transmitted. E.g., 1 error in 10^12 bits means BER = 10^-12
- Sensitivity = minimum received optical power that yields BER required by application

Receiver electrical eye pattern



- Rx amplitude (mV)
- Rx jitter (ps)

Part 3 – Q&A

Q: The transceiver has two interfaces – what are they?

A: Electrical and optical

Q: True or false - the OSA's contain a telescoping lens

A: False – they contain a ball lens

Q: True or false – the laser is "always on"

A: True. The low signal point has the laser operating above I_{th}.

Q: T or F -The optical output signal is the inverse of the laser driver output signal

A: False

Q: How much jitter is enough?

A: Jitter is a detrimental attribute – the less, the better

Part 4 –Power Budget, References

- Power budget
- References

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Power budget

- The difference between minimum transmitter output and minimum receiver sensitivity

Tx output power:	Rx sensitivity:
Max = -4 dBm	Max = 0 dBm
Min = -9.5 dBm	Min = -18 dBm

- Transceiver power budget is -9.5 - (-18) = 8.5 dB

- From this we subtract all the link losses, and need to have margin remaining

Power budget

Bandwidth check: (using multi mode fiber @ 850 nm & 1 Gb/sec) – 500 MHz/km / 1000 Mhz = 500 m ; we're ok at 200 m

Losses:

Fiber: 2.4 dB/km; @ 200m =	.5 dB
Splice:	.3 dB
2 connectors @ .3 dB each =	.6 dB
Total =	1.4 dB

Conclusion: power budget of 8.5 dB leaves plenty of margin

Power budget

Bandwidth check: (using multi mode fiber @ 850 nm & 1 Gb/sec) – 500 MHz /1000 m x 1000 m = 1000 meters in example – link is bandwidth limited!! Max frequency is 500 MHz!

Losses:

Fiber: 2.4 dB/km; @ 500m =	1.2 dB
Splice:	.3 dB
2 connectors @ .3 dB each =	.6 dB
Total =	2.1 dB

Conclusion: Link is bandwidth limited; loss is irrelevant unless we operate the link at 500 M instead of 1Gig

Power budget

- To achieve longer links
  - Use single mode fiber – bandwidth is limited not by modal dispersion, but by chromatic dispersion
  - Use a laser with narrow spectral width, which results in low chromatic dispersion. Attenuation & power budget become the link limiting factors up to roughly 80km
  - Use a receiver having greater sensitivity

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Power budget

- Typical 850 nm multi mode transceiver specifications
  - Tx average power -7 dBm
  - Rx sensitivity -21dBm
  - Power budget (link budget) 14 dB

Loss (dB)	Power Remaining (%)
10	10.0
20	1.0
30	0.1

Power budget

- Longer link budget transceivers (using DFB lasers, APD detectors)
  - Tx average power 0 dBm
  - Rx sensitivity -30 dBm
  - Power budget (link budget) 30 dB

Loss (dB)	Power Remaining (%)
10	10.0
20	1.0
30	0.1

References

- Schelto's Physical Page www.schelto.com
- IEEE / Fibre Channel – Physical Interface Standard www.t11.org
- GBIC standard ftp://playground.sun.com/pub/OEmod/
- Tutorials, industry information www.lightreading.com search for "tutorials"
- Technician's Guide to Fiber Optics – Third Edition Donald J. Sterling, Jr., Delmar Publishers
- Finisar Corporation www.finisar.com

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Part 4 – Q&A

Q: What is the recommended maximum distance for a multi mode link operating at 850 nm and 1.0625 Gb/s?

A: 500 meters

Q: How much light (of the 100% optical signal output) does a fully utilized 30dB link budget use?

A: Close to 99.9%

Q: True or False: MAXIMUM receiver sensitivity is key to a greater power budget

A: False

Q: Where is a great place to shop for your optical transceiver needs?

A: Finisar

Q: Have you found this session informative?

A: You decide and let us know!