SCTE
Greater Chicago Chapter

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Optical Network evolution
Fiber Optic Principals
Remember

Relax
Have Some Fun
Learn Something
Ask Questions
Enjoy Life
What Is Light?
Spectral Characteristics

- **Light:**
  - Ultra-Violet (UV)
  - Visible
  - Infrared (IR)

- **Communication Wavelengths:**
  - 850, 1310, 1550 nm
    - Low Loss Wavelengths

- **Specialty Wavelengths:**
  - 980, 1480, 1625 nm
Optics Fundamentals

Color

Like a Prism

- **Wavelength**: $\lambda$
  - Is measured in nanometers --
    - nano = billionth

- **Frequency**: $f$
  - Is measured in tera Hertz --
    - tera = trillion

Singlemode Fiber

Total Internal Reflection

Cross-Section

[Diagram showing singlemode fiber with core, cladding, and coating dimensions: 9µm core, 250µm total diameter]
Optics Fundamentals

**Reflection**
Light reflects *inside* medium

**Refraction**
Light passes *through* medium boundary;

- Light
- Air
- Glass

Light is refracted
Total Internal Reflection

Beyond some maximum incident angle the ray of light cannot pass through the boundary of the two materials and the ray is completely reflected.

When the angle of incidence exceeds the maximum angle or Critical Angle, we have Total Internal Reflection. Total Internal Reflection is the property that allows fiber optic communication to occur.

**Critical Angle**

\[
\sin \theta_c = \frac{n_2}{n_1}
\]
Refraction
Optical Fiber is a cylindrical waveguide made of a high purity fused silica.

The core has a refractive index slightly higher than the cladding which allows the propagation of light via total internal reflection.

A single-mode core diameter is typically 5-10 μm.

A multimode core diameter is typically over 100 μm.
Index of Refraction

The index of refraction (n) is the ratio of the speed of light in a vacuum (c) to the speed of light in the material (v). This is written as: 

\[ n = \frac{c}{v} \]

Simply, Index of Refraction is a relative measure of the propagation speed of the signal. 

For a vacuum: \( n = 1 \); Air: \( n = 1.0003 \); Water: \( n = 1.333 \)

Also, different wavelengths have different indices of refraction. This is why a prism divides the visible colors of the spectrum.

![Diagram of a prism separating white light into its constituent colors](image)
Fiber Attenuation

- Just like Coax, fiber has different loss characteristics at different frequencies
- Unlike Coax, the higher 1550 region optical signals have less attenuation than at the lower 1310 region
- 1310nm loss is .35db per km
- 1550nm loss is .25db per km
- Splice loss is typically engineered at ___db per fusion splice and ___db per mechanical splice
Fiber Attenuation – Standard SMF

**Attenuation:** The change in the optical power of a signal as it travels down a fiber.

- **Rayleigh Scattering**
- **Impurity**
- **Infrared Absorption**

Attenuation levels:
- 1310 nm
- 1550 nm

Wavelength (nm)

Attenuation (dB/km)

1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2
Dispersion

Chromatic Dispersion
Different wavelengths travel at different speeds
Causes spreading of the light pulse

Polarization Mode Dispersion
Single mode fiber supports two polarization states
Fast and Slow axes have different group velocities
Causes spreading of the light pulse
Impacts of Speed on Dispersion

2.5 Billion times a second

OC-48

10 Billion times a second

OC-192
Impacts of Dispersion

A normal undistorted pulse has a relatively well defined transition between high and low states, making it easy to determine a transition from one state to another. Once a pulse has encountered the effects of dispersion, the transition between high and low states becomes much less defined as shown above.

When viewed through a data analyzer, the pulse now appears to be “smeared” along the horizontal (time) axis.
The amount of transition edge “smearing” will be the same regardless of the data rate.

However, the resultant signal quality caused by dispersion varies greatly with data rate.

In the above example, the both 10Gb/s and 2.5Gb/s signals have propagated the same distance.

A transition between high and low states is still distinguishable on the 2.5Gb/s signal, but not on the 10Gb/s signal.
Effects of Fiber on Digital Signals

Attenuation: Power level erodes with distance

Dispersion: Clarity erodes with distance and speed

Combined effect:
Optical Line Amplification

1550 Region

Attenuated Channels

Amplified Channels

All Wavelengths Amplified with One Amplifier
**Optical Amplifier Architecture**

- **Erbium Doped Fiber**
- **1550 nm band signal input**
- **(980 and 1480 nm) pump signal input**
- **Spectrum of a typical EDFA**
- **1550 nm band signal output**
- **Pump signal output (980 and 1480 nm)**
- **dBm**
- **Wavelength**

The diagram illustrates the flow of signals through an erbium-doped fiber amplifier, showing the input and output bands, along with the spectrum of a typical EDFA, indicating the performance in terms of dBm versus wavelength.
Span Loss (Power Budget)

Transmitter power - Minus Fiber Loss = Equals Receiver Input
Optical Fiber - Construction

- **Core**
- **Cladding**
- **Coating**
Single Mode Step Index

Step
Core
Cladding
8.1 µm
125 µm

Tropic Networks Confidential & Proprietary
Types of Fibers

- **Single Mode Fiber**
  - Jacket: 125 um
  - Cladding: 250 um Diameter
  - Core: 8.5 to 10 um

- **Multi Mode Fiber**
  - Jacket: 125 um
  - Cladding: 250 um Diameter
  - Core: 50 to 62.5 um Typical
Multi Mode Fiber

Multimode - 850nm and 1300nm
  - Short haul - LAN, Low Speed Digital Networks
Single Mode Fiber

Singlemode - 1310nm and 1550nm
- Long haul - Telephone, CATV, High Speed Data Networks
Bends
Macro and Micro-bends

Macrobend refers to loss caused by bending the fiber beyond a minimum bend radius.
Microbend refers to small bends or minute deviations in the core/cladding interface
Attenuation

Scattering
Absorption
Microbends
**Attenuation**

**Scattering**

- Loss of energy due to imperfections in the fiber
- Rayleigh Scattering
- Theoretical lower limits of attenuation
  - 0.24 dB at 1300 nm
  - 0.012 dB at 1550 nm

**Engineering Rule for Attenuation:**

- 1310nm - .35/km
- 1550nm - .25/km
Scattering
Scattering
Attenuation

Absorption

- Impurities absorb optical energy and dissipate it as small amounts of heat
  - Hydroxyl molecule, ions of iron, copper, cobalt, vanadium and chromium
    - Concentration < 1 part per billion

Microbends

- Variation in core-to-cladding interface
Splicing

Fusion Splicing
- Fusing pieces of glass together
- Losses 0.02 typical

Mass Fusion Splicing
- Fusing 12 to 16 fibers at one time
- Losses 0.04 typical

Mechanical Splices
- CSL, RMS, others (vendor specific)
- Reflective & losses 0.1 typical
- Time consuming
Aerial Plant Splicing

Splice Enclosure stored on strand or in Storage Pedestal

- Always leave enough storage/slack to bring enclosure into splicing vehicle

Steel Riser

Straps and Spacers / Tie wraps
Underground Plant Splicing

Storage Pedestals or Storage Vaults

- Leave enough slack to move splice enclosure into vehicle
Record Keeping

Maps

Cable Routing
- Splice Locations
  - Color Codes
- Link Characteristics
  - Lengths & Losses

OTDR Traces

Special Forms
- Splicing form, Active fiber list, etc.
Documentation Flowchart

INSTALLATION

DOCUMENTATION

PREVENTATIVE MAINTENANCE  RESTORATION
Basics of Restoration

1) Documentation
2) Have a plan
3) Find what went wrong
4) Find the problem
5) Restoration
6) Permanent Repair Kit
7) Prepare for the next cut
Cleaning Connectors

Clean Every Time Exposed to Air

Cleaning Materials

- Lint Free Swab @ Alcohol
- Lens Tissue
- Special Cleaning Devices - Cartridge
Connectors and Splices

Core size Mismatch

Core Diameter Mismatch

Concentricity

Ellipticity (ovality)
Connectors and Splices

Four Main Causes of Loss in a Connector or Splice

Lateral Displacement

End Separation

Angular Misalignment

Surface Roughness
Splitter and combiner are the same device. They are wavelength agnostic. Any wavelength can go to any port and any port can be multi-wavelength. The power loss is the same whether it is used as a combiner or splitter.

- There is no such thing as wavelength agnostic and lossless combiner.
- Ideal loss 1/n. Add 0.5 dB insertion loss for connectors and splicing.
Wave Division Multiplexing
Dense Wave Division Multiplexing

OC3 POS
OC48
1 Gbe
10 Gbe

WDM MUX
Wavelengths of Light

• Light travels farther in fiber at certain wavelengths
• Those wavelengths are used for transmission systems

1310 nanometers
• Used extensively for metropolitan area systems and analog video transport

1550 nm Region
• Light travels farther than at 1310
• Components are more expensive
• Used mostly for long distance

• DWDM - Between 1530 and 1560
• Wavelengths must be very specific
• Extra components needed to “lock” wavelengths to specific color
Evolution of DWDM Systems

1. **Early WDM** – one 1310 and one 1550 channel

2. **2nd Generation** – 2-4 Windows, 400+ Ghz spacing with 1 carrier per window

3. **Dense WDM** – 20 - 40 Windows, 100-200 Ghz spacing with 1 carrier per window

4. **Next Gen DWDM** – Windows, 50 Ghz spacing with as many as 4 carriers per window
Wavelength MUX / DMUX

- Works like a prism
- Each port has an associated wavelength which is fixed.
- Same device can be both MUX/DMUX
- Theoretically can be lossless. In actuality, insertion loss increases with port count.
Wavelength Add/Drop Multiplexer

Drop

Can be cascaded, insertion loss increases with cascade.

Add
Wavelength Add/Drop Multiplexer

Typical OADM

Amplifier (optional)
- Same dropped wavelength can be added back to the system (i.e. reuse), except carrying a different traffic signal.
- A wavelength filter is the same as an add/drop multiplexer with only the input and drop ports.
What is a ROADM?

- Reconfigurable Optical Infrastructure Component
- Add / Drop / Pass / Null control of every lambda
- Power Level control of every lambda
- Optical Switching Fabric
- Eliminates stranded bandwidth (no optical banding at nodes)
**Key Functionality:**
- 8 colorless ports, without additional add/drop filtering
- Any wavelength or subset of wavelengths can be added/dropped to these ports
- Mesh capable via colorless add/drop ports
ROADM Metro Transport Network

- 4 node ROADM ring
- 40km between sites

Any to Any connectivity

10 x 1G Traffic - Unprotected
10 x 1G Traffic - Protected
“Mini ROADM” with Colorless Add/Drop
High Capacity ROADM

Typical High Capacity Add/Drop WSS ROADM
ROADM Degree 2 to 3 Expansion

- Simply add the components to terminate the additional fiber pair, and interconnect the WSS ports
- Any unused WSS ports can be used
- In-service upgrade; no existing services are disrupted as all wavelength power levels are nominally identical
ROADM Degree 2/3 to 4 Expansion

- Same process:
- Terminate the additional fiber pair(s)
- Interconnect the WSS ports
Layer 1 Optical Management

- Wavelength Tracker™
- Wavelength path trace
- Optical fiber view
- Fault sectionalization & isolation
- Remote optical power control
- Threshold alarming
- Automated fault correlation

Service-aware Optical Layer Management
Problem Resolution

Remotely Monitors, Controls & Alarms at Component Level

1. Fault location identified at Node E on EMS.
2. Power alarm raised for $\lambda_2$
3. Right-click takes you to the affected card or service(s)
4. Wavelength Tracker™ traces power along path of service to isolate spectral equalization problem at site C to single $\lambda$
5. Faulty power management module uniquely identified as root cause at site C
6. Eliminate BER’s and restore service on $\lambda_2$

Wavelength Tracker™ Locates the Exact Location of the Problem
Thank you

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