Laser Transmitters for Fiberoptics Communications

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- **Introduction**
- Laser Transmitters
- Seed Laser
- Optical Amplifiers
- Modulation
- Packaging
Motivation Behind Fiberoptic Proliferation

The Internet
Internet Traffic Growth

The graph illustrates the growth of US data network traffic from 1995 to 2010. The traffic has increased significantly, with a 2 dB/year rate (58% per year) as per R.W. Tkach and BLTJ in 2010. The traffic levels are marked at 100 Tb/s, 10 Tb/s, 100 Gb/s, and 10 Gb/s.
Continually evolving technologies to achieve higher data-rates

- WDM Evolution
- TDM Evolution

Coherent Evolution

- Coherent OFDM
- Stronger FEC
- Hybrid Raman/EDFA
- Multi-Core Fiber
- Multi-Mode Transmission

EDFAs
- Novel Fibers
- Dispersion Control
- Non-linearity Control

- Novel Mod. Format
- Coherent Receiver
- High Speed ADC/DSP
- WSS/ROADMs for Efficient BW usage

Reference: NTT Electronics
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Semiconductor Lasers
(also known as diode lasers or laser diodes)

- Typically a double heterodyne junction structure
- Laterally, the light is guided by total internal reflection
- Cavity is formed by cleaving the end facets, and placing dielectric coating on the backside
## Comparison of Light Sources

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>LED</th>
<th>Multi-Mode Diode Laser</th>
<th>Single-Mode Diode Laser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral width (nm)</td>
<td>20 - 100</td>
<td>~5</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Rise-time</td>
<td>2 - 250</td>
<td>0.1 - 1</td>
<td>0.05 - 1</td>
</tr>
<tr>
<td>Modulation Bandwidth (GHz)</td>
<td>&lt;0.3</td>
<td>20</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Fiber coupling efficiency</td>
<td>Very low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Temperature sensitivity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Communication distance</td>
<td>Moderate</td>
<td>Long</td>
<td>Longest</td>
</tr>
<tr>
<td>Communications data-rate</td>
<td>Moderate</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>Lifetime (hours)</td>
<td>1E5 to 1E11</td>
<td>1E6</td>
<td>1E6</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>High</td>
<td>Highest</td>
</tr>
</tbody>
</table>
Laser Wavelength Driven by Optical Attenuation in Fiber

- Loss due to absorption by impurities:
  - 1400nm peak due to OH ions

- Specified in loss per kilometer (dB/km):
  - 0.40 dB/km at 1310nm
  - 0.25 dB/km at 1550nm

- Optical amplifiers available in 1550nm window
Master Oscillator Power-Amplifier (MOPA)
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Comparison of Single Mode Lasers

Multi-Mode

Single-Mode
Distributed FeedBack (DFB)
Diode Laser Temperature and Current Dependence

Temperature dependence
~0.3nm shift/°C

Spectrum variation based on current variations
Diode Laser Intensity Noise

- **Relative Intensity Noise (RIN)**
  - Output power fluctuations

- **Back-reflection Noise**
  - Noise generated from perturbation of lasing modes

- **Modal Noise (Speckle)**
  - Noise due to energy distribution variation. Occurs in multi-mode fiber

- **Mode-Partition Noise**
  - Due to fluctuations in the longitudinal modes of the laser
Tunable Laser Transmitters

Tunable transmitter modules now commercially available

• Example: tuned via fiber Bragg grating

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Optical Amplifiers

An optical amplifier is a device which amplifies the optical signal directly without ever converting it to electricity.

Reasons to use the optical amplifiers:

- Reliability
- Flexibility
- Duplication is perfect; photons are cloned
- Delivery of 100’s of Gb/s data-arte at 10’s of Watt power

Variety of optical amplifier types exists, including:
Optical Amplifier Types

- **EDFA** (Erbium-doped fiber amplifier) DOMINANT type uses doped fiber
  - Most commonly used in C-band (1530 - 1565 nm)
  - Also available in L-band and S-Band

- **Raman Amplifier** adds performance or more wavelength range, can use any type of fiber, any wavelength possible, now of interest for C, L, and S-band

- **SOA** (Semiconductor Optical Amplifier) also entering market, similar to EDFA but Er is in a planar waveguide, compact, C and L band

- **EDWA** (Erbium-Doped Waveguide Amplifier) also entering market, similar to EDFA but Er is in a **planar waveguide**, compact, C and L band

- **TDFA, PDFA...** doped fiber amplifiers like EDFA using other dopants to allow gain at other wavelength, i.e., Thulium TDFA for S-band
**Fiber Amplifier Schematic (example)**

- **Input**
  - 1480 or 980 nm Pump Laser
- **Coupler**
- **Isolator**
- **Output**
- **Erbium Doped Fiber**
Operation of an EDFA

Power interchange between pump and data signals

980 nm signal 1550 nm data signal

980 nm signal 1550 nm data signal
Typical EDFA Schematic

High Power EDFA

Low Power EDFA

High Power EDFA
**Semiconductor Optical Amplifier (SOA)**

- SOA is essentially a laser diode without a cavity (feedback)
- SOAs optically amplify an input signal
- SOAs are much more compact than EDFAs, but cannot deliver as much output power
Amplifier Noise Mechanisms

- Signal heterodynes with amplified-spontaneous-emission (ASE)
- Amplified spontaneous emission (ASE) heterodynes with itself
- Amplified signal shot noise (negligible)
- Kerr Effects
  - Self phase modulation
  - Cross phase modulation
  - Four-wave mixing
- Scattering Effects
  - Stimulated Raman
  - Stimulated Brillouin
Output Spectra Example

Amplified signal spectrum (input signal saturates the optical amplifier)

ASE spectrum when no input signal is present

+10 dBm
-40 dBm
1525 nm 1575 nm
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Multiplexing & Modulation

- Wavelength Division Multiplexing (WDM)
- Polarization Multiplexing (PM)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)
- Quadrature Amplitude Modulation (QAM)
- Space (not implemented yet)

Reference: Alcatel / Lucent
Optical Modulators

- **Direct modulation**
  - Directly modulate the drive current of a semiconductor laser (slowest of the three)

- **Absorption modulation**
  - Modulate the absorption spectrum of reverse-biased diode placed in front of the laser
  - Faster and more linear than direct modulation (60 GHz)

- **The Mach-Zehnder (MZ) modulator**
  - Modulation by adding phase shifted signals (fastest)
Indirect Modulators

Mach-Zehnder Modulator
Polarization sensitive, need correct launch

Electro-Absorptive Modulator
DFB laser with external on-chip modulator
Laser section
Modulation section
Future Direction: Integration of Modulator with the Seed Laser

Reference: NTT Electronics
# Laser Transmitter Characterization

<table>
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<tr>
<th>PARAMETER</th>
<th>MEASURING INSTRUMENT</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>Power meter</td>
<td>pW, nW, uW</td>
</tr>
<tr>
<td>Wavelength</td>
<td>Optical spectrum analyzer</td>
<td>±15pm</td>
</tr>
<tr>
<td></td>
<td>Interferometric-based</td>
<td>±5 pm</td>
</tr>
<tr>
<td>Linewidth, chirp, modulation effects</td>
<td>High resolution spectrometer</td>
<td>±15 pm</td>
</tr>
<tr>
<td>Relative intensity noise, ASE noise...</td>
<td>Signal analyzer (optical)</td>
<td></td>
</tr>
<tr>
<td>Modulation bandwidth (EO response)</td>
<td>Component analyzer (optical)</td>
<td></td>
</tr>
</tbody>
</table>

Reference: Agilent Technologies
Measurement of Communications Quality

• An open Eye Diagram is indicative of low BER (bit error rate)
  • Eye-diagram is super-imposition of bit sequences

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Fiber Amplifier’s Interior

Fiber coupler

Pump laser

(Nd, Yb, Er… ion) doped fiber loop

Fiber input/output
Pluggable Modulatable Seed Lasers

For 10Gbit Ethernet and other Fiberoptic Transmission/reception Applications

Reference: Finisar
TAKE AWAY

- Only certain semiconductor lasers, and the fiber amplifiers are the practical lasers for fiberoptic communications.

- Master-Oscillator, Power-Amplifier (MOPA) is a common approach for providing a modulated transmitter.

- Current push is for cost-effective 100 Gb/s coherent laser transmitters.

- Fiber amplifiers provide high power levels, wide spectral bandwidth, extremely high modulation rate, and the reliability needed for most demanding fiberoptic comm applications.

- External modulation provides cleaner, higher extinction ratio pulses relative to direct modulation.

- Design of high power amplifiers should avoid noise and nonlinear effects.

- Future direction points towards miniaturization and integration.
QUESTIONS