EE 443 Optical Fiber Communications
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http://www.wiretechworld.com/the-future-of-optical-fibres/
Optical Communications

Definition - What does *Optical Communication* mean?

Optical communication is any type of communication where light is used to carry the signal to its destination, instead of an electrical voltage of current. Optical communication relies upon optical fibers acting as waveguides to carry such signals.

Primary Driving Force for Optical Fiber Communications

Telecommunication’s purpose is to carry digitized signals around the World.

“The primary driving force behind the widespread use of fiber is the large and rapidly increasing consumer and commercial demand for more telecommunications capacity and Internet access. Fiber optic technology provides the capability to expand and meet this expanded information capacity (Note: It is far greater than copper and wireless connections).”

Single Optical Fiber Has More Capacity than a Bulk Copper Cable

https://fiberu.org/OSP/LP1.html
Keck’s Law

\[ y = 0.196x - 380.9 \]

\[ R^2 = 0.971 \]

\[ y = \log \text{(data rate)}, \ \text{and} \ x = \text{years (Y)} \]

https://www.semanticscholar.org/paper/Latching-on-to-Keck's-law-%3A-Maintaining-the-high-in-Routray-Javali/2fd9aa141650703b76fb02bd3256e66f2b1552a8
The Electromagnetic Spectrum & Selected Applications


SI Units

- peta – $10^{15}$
- tera – $10^{12}$
- giga -- $10^9$
Optical Fiber Wavelengths

The three primary wavelengths for fiber optics, 850, 1300 and 1550 nm drive much of what we use in OFC. NIST (the US National Institute of Standards and Technology) provides power meter calibration at these three wavelengths for fiber optics. Multimode fiber is designed to operate at 850 nm and 1300 nm, while singlemode fiber is optimized for 1310 nm and 1550 nm. The difference between 1300 nm and 1310 nm is simply a matter of convention, harking back to the days when AT&T dictated most fiber optic jargon. Lasers at 1310 nm and LEDs at 1300 nm were used in singlemode and multimode fiber, respectively.

<table>
<thead>
<tr>
<th>Plastic Optical Fiber (POF)</th>
<th>Multimode Graded Index Optical Fiber</th>
<th>Singlemode Optical Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>650 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>850 nm</td>
<td>850 nm</td>
<td></td>
</tr>
<tr>
<td>1300 nm</td>
<td>1310 nm</td>
<td>1490 to 1625 nm</td>
</tr>
</tbody>
</table>

Approximate wavelength windows.

https://www.thefoa.org/tech/wavelength.htm
Bit Rate × Distance Product Versus Technology Class

http://www.alanptlau.com/Research.html
Comparing Wireline to Optical Channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisted-pair wire</td>
<td>Inexpensive \n Widely available \n Easy to work with</td>
<td>Slow (low bandwidth) \n Subject to interference \n Easily tapped (low security)</td>
</tr>
<tr>
<td>Coaxial cable</td>
<td>Higher bandwidth than twisted-pair \n Less susceptible to electromagnetic interference</td>
<td>Relatively expensive and inflexible \n Easily tapped (low-to-medium security) \n Somewhat difficult to work with</td>
</tr>
<tr>
<td>Fiber-optic cable</td>
<td>Very high bandwidth \n Relatively inexpensive \n Difficult to tap (good security)</td>
<td>Difficult to work with (difficult to splice)</td>
</tr>
</tbody>
</table>

https://bndsbon.wordpress.com/2016/11/01/transmission-media/
Twisted Pair Wire

Flexible Coaxial Cable

- 50-Ohm RG-7 or RG-11: used with thick Ethernet.
- 50-Ohm RG-58: used with thin Ethernet
- 75-Ohm RG-59: used with cable television
- 93-Ohm RG-62: used with ARCNET

https://networksmania.wordpress.com/topics/transmission-media-2/coaxial-cable/
### Flexible Coaxial Cable Attenuation

#### 100 Series
- **Nominal Attenuation**

<table>
<thead>
<tr>
<th>MHz</th>
<th>900</th>
<th>1800</th>
<th>2500</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>db/100ft</strong></td>
<td>22.8</td>
<td>23.2</td>
<td>39.8</td>
</tr>
<tr>
<td><strong>db/100m</strong></td>
<td>74.8</td>
<td>108.8</td>
<td>130.6</td>
</tr>
</tbody>
</table>

**Example**
- 0.105 inch
- 39.8 dB/100 feet @ 2.5 GHz

#### 195 Series
- **Nominal Attenuation**

<table>
<thead>
<tr>
<th>MHz</th>
<th>900</th>
<th>1800</th>
<th>2500</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Ohm Impedance</td>
<td>11.1</td>
<td>16.0</td>
<td>19.0</td>
</tr>
<tr>
<td><strong>db/100ft</strong></td>
<td>36.5</td>
<td>52.5</td>
<td>62.4</td>
</tr>
</tbody>
</table>

**Example**
- 0.240 inch
- 12.9 dB/100 feet @ 2.5 GHz

#### 200 Series
- **Nominal Attenuation**

<table>
<thead>
<tr>
<th>MHz</th>
<th>900</th>
<th>1800</th>
<th>2500</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Ohm Impedance</td>
<td>9.9</td>
<td>14.2</td>
<td>16.9</td>
</tr>
<tr>
<td><strong>db/100ft</strong></td>
<td>32.6</td>
<td>46.6</td>
<td>55.4</td>
</tr>
</tbody>
</table>

#### 240 Series
- **Nominal Attenuation**

<table>
<thead>
<tr>
<th>MHz</th>
<th>900</th>
<th>1800</th>
<th>2500</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Ohm Impedance</td>
<td>7.6</td>
<td>10.9</td>
<td>12.9</td>
</tr>
<tr>
<td><strong>db/100ft</strong></td>
<td>24.8</td>
<td>35.6</td>
<td>45.4</td>
</tr>
</tbody>
</table>

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Rectangular Waveguide


https://www.oc2me.com/products/rf-solutions/microwave-waveguides/
Electric and Magnetic Fields in Rectangular Waveguide

Field Lines in Rectangular Waveguide Showing Different Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>TE_{10}</th>
<th>TE_{11}</th>
<th>TE_{21}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>![Diagram TE_{10}]</td>
<td>![Diagram TE_{11}]</td>
<td>![Diagram TE_{21}]</td>
</tr>
<tr>
<td>2</td>
<td>![Diagram TE_{10}]</td>
<td>![Diagram TE_{11}]</td>
<td>![Diagram TE_{21}]</td>
</tr>
<tr>
<td>3</td>
<td>![Diagram TE_{10}]</td>
<td>![Diagram TE_{11}]</td>
<td>![Diagram TE_{21}]</td>
</tr>
</tbody>
</table>

Cylindrical Waveguide

Electric and Magnetic Fields in Cylindrical Waveguide

Cylindrical Waveguide Modes

Cutoff frequencies TE_{11}

https://csttutorial.blogspot.com/2016/06/circular-waveguide-we-simulated-and.html
Dielectric Rod Waveguide and Dielectric Resonators

https://www.globalspec.com/reference/58526/203279/chapter-3-dielectric-rod-waveguides

Dielectric Resonator Electrical Model

https://www.everythingrf.com/community/what-is-a-dro-dielectric-resonator-oscillator
Dielectric Waveguides in Many Shapes

Optical Fiber for Lightwave Communications

https://media.springernature.com/original/springer-static/image/chp%3A10.1007%2F978-3-319-31903-2_8/MediaObjects/370011_1_En_8_Fig4_HTML.gif
Advantages for Optical Communications Over Fiber (1)

- Extremely high information \((i.e.,\ data)\) transmission capacity. *Example*: 1550 nm wavelength = 193.4 THz (terahertz) = \(1.943 \times 10^{14}\) hertz; If we assume that 1\% of 193.4 THz may be used for channel bandwidth, the communication bandwidth is approximately 2 THz (about \(2 \times 10^{12}\) hertz).

- Very low attenuation per kilometer with optical fiber. *Example*: A typical fiber attenuation is about 0.4 dB/km. For comparison, a coaxial cable (say RG-19U) is about 23 dB/km.

- Optical fiber (both glass and plastic) are excellent insulators thus providing for high electrical isolation.
Advantages for Optical Communications Over Fiber (2)

- Absence of “cross-talk” between fibers.
  The optical signal within the fiber itself does not leak out, thus, interference from “cross-talk” is zero.
- Immunity to RFI and EMI.
  Exceptional rejection of external radio frequency interference (RFI) from radio/microwave signals. Fibers reject electromagnetic interference (EMI) from electrical sparking, lightning, etc.
- Optical fiber offer exceptional data security because fibers do not externally radiate optical signals and there is no “cross talk.”
Advantages for Optical Communications Over Fiber (3)

- Small temperature sensitivity. Glass fibers can withstand extremely high temperatures before deteriorating.
- Resistance to water and many chemicals leading to negligible corrosion. Copper can have significant corrosion issues (as compared to glass or plastic).
- Fiber is smaller size and much lower in weight compared to copper wire. Example: A typical optical fiber of diameter of 0.125 mm and weights approximately 6 kg/km; RG-19/U coaxial cable has an outer diameter of 28 mm and weights about 1,100 kg/km.
- Fiber itself has a long lifetime (> 100 years).
Disadvantages of Using Optical Fiber

- Optical fibers are more expensive to install, and must be installed by specialists using special equipment.
- Optical fibers are more fragile than copper. They are susceptible to being cut or damaged during installation or during construction activities.
- The optical fibers are difficult to splice. They have a limited safe physical arc from bending – excessive bending can break a fiber or degrade its performance.
- Optical fiber requires more protection around the fiber cable as compared to copper wire.
- More difficult to add nodes after the initial installation.
Ask a Question