Introduction to Optical Fiber Communication

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Communication System

Transmission Media:

- **Cu-wire**: kHz
- **Coaxial Cable**: MHz
- **Microwave Link**: MHz – GHz
- **Satellite Channel**: GHz
- **Optical Fiber**: THz

**Carrier frequency for Microwave Communication ~ 1 GHz (Typical)**

**for Optical fiber Communication ~ 100 THz (10^{14} Hz), 10^5 times larger than that of Microwave Communication**
EM Spectrum for Fiber-Optic Communication

Fig. 1.1 Electromagnetic spectrum
Figure 1.1 The electromagnetic spectrum showing the region used for optical fiber communications
Background

**Historical Perspective**

Early civilizations have used mirrors, fire beacons or smoke signals for communication (to convey a single information, mainly warning purpose). Up to 18\textsuperscript{th} century (even today): signaling lamps (traffic control, naval vessel, airport control tower), flags and different other semaphore devices.

The Term “fiber optics” was first introduced by N.S. Kapany at London during developing “flexible fiberscope” in 1956 (claim). Charles Kao and Charles Hockham at Standard Terleocom Lab in England proposed optical fiber as comm channel in 1966. At that time fiber loss was found as 20 dB/km.
Emergence of new technology

In 1830s – Telegraphy, Light is replaced by Electricity
Use: Morse Code, dot-dash (Digital), 10bps

In 1876 – Telephone is invented
Analog Electrical Signal
Electrical Comm System

In 1966 – Optical Fiber
Initially fiber loss 1000 dB/km
Gradually: 20 dB/km
0.2 dB/km
Evolution of Lightwave System

1st Generation Lightwave System:

- Operated near ~ 0.8 μm
- Attenuation (fiber loss) ~ (≤) 1.0 dB/km
- Bit Rate ~ 45 Mb/s
- Repeater spacing ~ 10 km
- GaAs Semiconductor Laser Diode was used

2nd Generation Lightwave System:

- Became available commercially in 1980s
- Operated near ~ 1.3 μm
- Attenuation (fiber loss) ~ 0.5 dB/km
- Bit Rate < 100 Mb/s (MMF), increased (up to GB/s) by SMF
- Repeater spacing ~ 50 km (SMF)
- InGaAsP Semiconductor Laser Diode was used
Evolution of Lightwave System

3rd Generation Lightwave System:
- Became available commercially in 1990
- Operated near ~ 1.55 μm, Fiber Dispersion is high at this range for SMF
- Attenuation (fiber loss) ~ 0.2 dB/km
- Bit Rate ~ 2.5 Gb/s
- Repeater spacing ~ 60 km, Electronic Repeaters (so coherent receivers used to increase bit rate)

4th Generation Lightwave System:
- Became available after 1990 (around 1992)
- Operated near ~ 1.55 μm
- Attenuation (fiber loss) ~ 0.2 dB/km
- Bit Rate ~ 10 Gb/s, Optical Amplification + WDM Technology = System capacity is enhanced much
- Repeater spacing: 60~ 80 km
- By 1996, large number of submarine lightwave systems were deployed using that technology
5th Generation Lightwave System:

Starting from 2000
Operated near ~ 1.55 μm, (covering S, C, L bands: extended the wavelength range of WDM system)
Attenuation (fiber loss) ~ (≤) 0.2 dB/km, Dry fiber can be used:
   Low loss over 1.3 μm to 1.65 μm wavelength range
Bit Rate ~ 10 Gb/s, 40 Gb/s, 1000s of WDM channels are possible, Total capacity 100 Tb/s or more
EDFA, and Raman Amplifier can be used
Repeater spacing ≥ 60 km,

Fiber-optic communication technology is around 35 years old. Started from around 1975, It has advanced rapidly. 1st generation started with capacity of 45 Mb/s, after 35 years the capacity has jumped by a factor of more than 10,000
Table 1.2  Different wavelength bands in optical fiber. The ranges are approximate and have not yet been standardized.

<table>
<thead>
<tr>
<th>Band</th>
<th>Descriptor</th>
<th>Wavelength range (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-band</td>
<td>Original</td>
<td>1260 to 1360</td>
</tr>
<tr>
<td>E-band</td>
<td>Extended</td>
<td>1360 to 1460</td>
</tr>
<tr>
<td>S-band</td>
<td>Short</td>
<td>1460 to 1530</td>
</tr>
<tr>
<td>C-band</td>
<td>Conventional</td>
<td>1530 to 1565</td>
</tr>
<tr>
<td>L-band</td>
<td>Long</td>
<td>1565 to 1625</td>
</tr>
<tr>
<td>U-band</td>
<td>Ultra-long</td>
<td>1625 to 1675</td>
</tr>
</tbody>
</table>
Low loss window for lightwave system at different stages
Evolution of Lightwave System

Increase of bit-rate distance product with time
Non-electrical signal is converted into electrical signal by transducer and the transmitter (modulator) converts it into proper form.

**OE Source**
E/O Converter: LED or LASER (for high speed)

**OE Detector**
O/E Converter: Optoelectronic detector PIN photodiode or APD (for high speed)

**Receiver**
Filter + Amplifier, for Digital: Decision circuit
A Typical Optical Fiber Communication System

- **Message Source**
  - **Modulator**
    - **Optical Source**
    - **LED or LASER drive circuit**
    - **LED/LASER**
    - **Fiber cable**
    - **p-i-n photodiode/APD**
    - **Amplifier and Equalizer**
- **Reconstructed signal at Destination**
Advantages and Disadvantages of OFC

Advantages:

- **Huge Potential BW**: $10^{13}$ to $10^{16}$ Hz
- **Small Size and Weight**: very small core dia < 10 μm (SMF), (less than human hair, 20 to 180 μm), 50 μm (MMF)
- **Electrical isolation**: glass or plastic (no earth loop, no spark or short ckt)
- **Immunity to interference and crosstalk**: dielectric WG (no EMI, no RFI, no transient, not susceptible to lightning strikes)
- **Signal Security**: no significant radiation, not broadcasting like wireless
- **Low loss**: ≤ 0.2 dB/km, wide repeater spacing
- **Robustness & flexibility**: fiber cables have high tensile strength, compact, small bend radii
- **System Reliability and ease of maintenance**: life time 20-30yrs etc.

Disadvantages:

- Huge Installation Cost but cost/capacity decreases