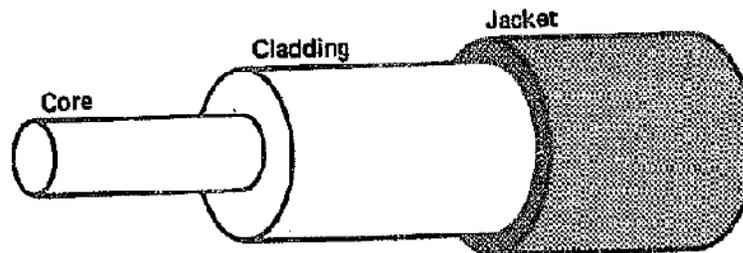# FIBER OPTIC COMMUNICATIONS

Optical Fibers

❑ Fiber optics (optical fibers) are long, thin strands of very pure glass about the size of a human hair. They are arranged in bundles called optical cables and used to transmit signals over long distances.

Fiber Optic Data Transmission Systems

❑ Fiber optic data transmission systems send information over fiber by turning electronic signals into light.

❑ Light refers to more than the portion of the electromagnetic spectrum that is near to what is visible to the human eye.

❑ The electromagnetic spectrum is composed of visible and near-infrared light like that transmitted by fiber, and all other wavelengths used to transmit signals such as AM and FM radio and television.

❑ The electromagnetic spectrum.

❑ Only a very small part of it is perceived by the human eye as light.

Fiber Optics Transmission

❑ Low Attenuation

❑ Very High Bandwidth (THz)

❑ Small Size and Low Weight

❑ No Electromagnetic Interference

❑ Low Security Risk

❑ Elements of Optical Transmission

    ❑ Electrical-to-optical Transducers

    ❑ Optical Media

    ❑ Optical-to-electrical Transducers

    ❑ Digital Signal Processing, repeaters and clock recovery.

Types of Optical Fiber

❑ Multi Mode :

(a) Step-index – Core and Cladding material has uniform but different refractive index.

(b) Graded Index – Core material has variable index as a function of the radial distance from the center.

❑ Single Mode – The core diameter is almost equal to the wave length of the emitted light so that it propagates along a single path.
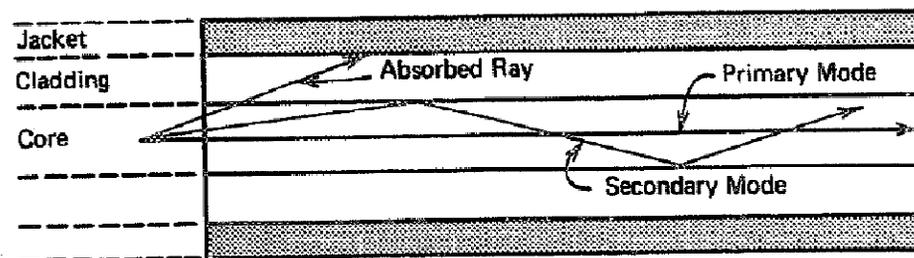
Transducers

❑ Electrical-to-Optical Transducers

  ❑ LED - Light Emitting Diode is inexpensive, reliable but can support only lower bandwidth.

  ❑ LD – Laser Diode provides high bandwidth and narrow spectrum.

❑ Optical-to-Electrical Transducers

  ❑ PIN Diode - Silicone or InGaAs based p-i-n Diode operates well at low bandwidth.

  ❑ Avalanche Diode – Silicone or InGaAs Diode with internal gain can work with high data rate.

```
Electrical        Electrical                        Optical          Electrical        Electrical
                     to                                to            RX Signal
TX Data           Optical          Fiber            Electrical       Processing         RX Data
```

BW Capacity of Fiber Optics

❑ To give perspective to the incredible capacity that fibers are moving toward, a10-Gbps signal has the ability to transmit any of the following per second:

❑ 1000 books

❑ 130,000 voice channels

❑ 16 high-definition TV (HDTV)channels or 100 HDTV channels using compression techniques. (an HDTV channel requires a much higher bandwidth than today's standard television).

Transmission Limitations

❑ Transmission over fiber is limited by the attenuation and dispersion.

❑ Multimode fibers may experience

   ❑ Multimode dispersion: The delayed rays cause pulse spreading

   ❑ Chromatic dispersion: Individual wavelengths may travel at different speeds.

❑ Dispersion creates an inherent operational limit defined as a bandwidth-distance product (BDP).

Bandwidth-Distance Factor & Dispersion

❑ Bandwidth-Distance Factor (BDP) & Dispersion

$$DL\Delta\lambda \leq 0.25T$$

$$NRZ\text{-}BDP = BL \leq \frac{250}{D\Delta\lambda}\ Gbps\text{-}km$$

$$RZ\text{-}BDP \leq \frac{500}{D\Delta\lambda}\ Gbps\text{-}km$$

Acceptable
dispersion

where D = Dispersion coefficient
(psec/km-nm)
L = Distance (km)
T = bit interval (psec)

$\Delta\lambda$ = Spectrum width (nm)

Optical Source and Detectors' Sensitivity

❑ The spectral width of an optical source is commonly specified as the fullwidth at half-maximum (FWHM) which represents the spread between the wavelength at which the spectrum is at half the magnitude of the peak.

❑ The receiver sensitivity decreases with data rate.

❑ Change in Sensitivity

$$\Delta R = 10 \log_{10} (R_0/R)$$

where R = new data rate
R$_0$ = reference data rate

$$\text{Sensitivity } R = \text{Sensitivity } R_0 + 10\log_{10}\left(\frac{R}{R_0}\right)$$

Optical Transmission System Design

❑ Transducers

❑ Electrical-to-optical

Device Type	Wavelength (nm)	Launched Output Power (dBm)	FWHM Spectrum Width (nm)
Si LED	850	−16	50
Ge LED	1300	−19	70
InGaAsP LED	1300	−10	120
DFB LD	1300	−5	1.0
DFB LD	1550	−5	0.4
IL/DFB LD	1550	+2	0.8

❑ Spectral with of an optical source is commonly specified as the full width at half-maximum (FWHM)

❑ Optical-to-Electrical

Device Type	Wavelength (nm)	Receive Power (dBm)	Data Rate (Mbps)
Si p-i-n	850	−48.0	50
Si APD	850	−58.0	50
InGaAs p-i-n	1310	−35.0	420
InGaAs APD	1310	−43.0	420
InGaAs APD	1310	−26.0	8000
InGaAs APD	1550	−37.5	678
InGaAs p-i-n	1550	−37.0	1200
InGaAs APD	1550	−33.0	4000

Line Coding in Optical Transmission

❑ Some fiber systems use the line codes described for wireline transmission that we studied previously.

❑ A few line codes are specifically developed for fiber applications.

❑ Note that optical sources and detectors are primarily used in nonlinear modes of operation with significant gain and threshold variations.

  ❑ They are best suited for on or off.

❑ On-off keying is most natural for optical transmissions

mBnB Line Codes

❑ mBnB – codes m binary bits into n bits (m<n)

  ❑ Example: if m=4 and n=5, sixteen data codes must be chosen from the set of thirty-two 5-bit line codes.

  ❑ This is 4B5B line code. The code space is used for control as well as data.

  ❑ When transmitting data, the minimum pulse density is 40% and there can never be more than three intervals without a pulse

❑ 8B10B coding is used for fiber optics transmission

  ❑ Each input byte is separated into a 5-bit filed and a 3-bit field that respectively encoded using a 5B6B and 3B4B algorithm.

Other Line Code Examples

❑ Digital Biphase (Manchester) 1B2B line code

Decimal	Binary	Functional Assignment
0	00	Disallowed
1	01	Data symbol 0
2	10	Data symbol 1
3	11	Disallowed

❑ Coded Mark Inversion (CMI) 1B2B Line Code

| Decimal	Binary	Functional Assignment
0	00	Data symbol 1 (if 11 previously sent)
1	01	Data symbol 0
2	10	Disallowed
3	11	Data symbol 1 (if 00 previously sent)

❑ Bit Insertion Codes

❑ mB1P code inserts an odd parity every m bits of input

❑ mB1C inserts a bit after every m source bits, complementary to preceding pulse value. Performance cannot be monitored.

WDM

❑ Achieved through refraction and diffraction technique for combining and separating optical signals of different wave lengths.

❑ Dense Wave Division Multiplexing
  ❑ Closely spaced wavelengths are used.
  ❑ The current methods are:
  ❑ Thin-film filters
  ❑ Arrayed Wavelengths
  ❑ Diffraction Grating
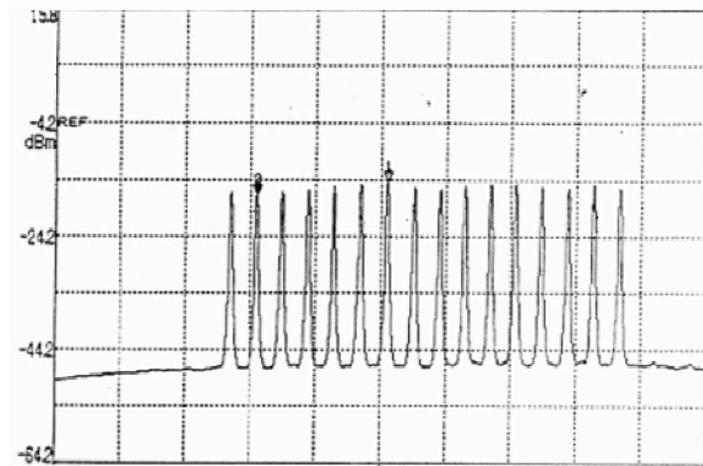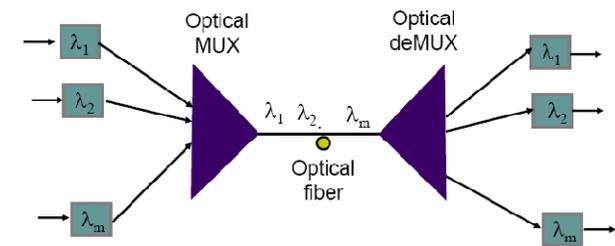
WDM

❑ WDM is fundamentally identical to frequency division multiplexing as used on electrical or radio transmission systems. In fact, using the following relationship allows wavelengths to be related to frequency

$$v = f\lambda$$

v=velocity of light=3×10^8 m/sec
f=frequency (Hz)
λ=wavelength (m)

❑ Example: Determine the difference in wavelegth of two optical signals separated by 2 GHz and centered at 1500 nm.

f=c/λ=200,000 GHz

Fiber Connectors

❑ A **fiber optic splice** establishes an optical connection between two individual optical fibers.

❑ It may be required to fix broken fiber connection or to tap the fiber for additional connections
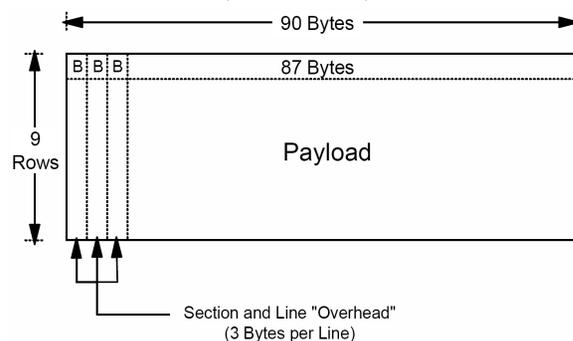
SONET

❑ SONET (Synchronous Optical Network) is a US standard for the internal operation of telephone company optical networks.

❑ It is closely related to a system called SDH (Synchronous Digital Hierarchy) adopted by the CCITT (now the ITU-T) as a recommendation for the internal operation of carrier (PTT) optical networks worldwide.

❑ Despite the name SONET is not an optical networking system. It is an electronic networking system designed to use optical link connections.

Importance of SONET

❑ SONET and SDH are of immense importance for two reasons:

❑ They offer vast cost savings in public communications networks by redefining the system of channel multiplexing. This is achieved through time division multiplexing of user data channels throughout the network. SONET/SDH offers a significantly better method of doing this.

❑ Management of the cable plant. Within a typical telephone company there are many end-user service offerings. Each of these is a network in its own rite (including and especially the telephone network). Each of these networks needs link connections of various speeds connecting nodes (central offices) at arbitrary points around the country. However the company wants to manage and share its cable plant as a single entity.

SONET Protocol Structure

❑ The basic structure in SONET is a frame of 810 bytes which is sent every 125 μsec. This allows a single byte within a frame to be part of a 64 kbps digital voice channel. Since the minimum frame size is 810 bytes then the minimum speed at which SONET will operate is 51.84 megabits per second.

   ❑ 810 bytes × 8000 frames/sec × 8 (bits) = 51.84 megabits/sec.

   ❑ This basic frame is called the Synchronous Transport Signal level 1 (STS-1), which is an electrical signal.

The diagrammatic representation of the frame as a square is done for ease of understanding. The 810 bytes are transmitted row by row starting from the top left of the diagram. One frame is transmitted every 125 μsec.

Sonet STS-1 Frame Structure.

Optical Carrier (OC) Levels

❑ SONET defines optical carrier (OC) levels and electrically equivalent synchronous transport signals (STSs) for the fiber-optic–based transmission hierarchy.

| Signal Level	Bit Rate	DS-0s	DS-1s	DS-3s
STS-1 and OC-1	51.84 Mbps	672	28	1
STS-3 and OC-3 (STM-1)	155.52 Mbps	2,016	84	3
STS-9 and OC-9	466.56 Mbps	6,048	252	9
STS-12 and OC-12 (STM-4)	622.08 Mbps	8,064	336	12
STS-18 and OC-18	933.12 Mbps	12,096	504	18
STS-24 and OC-24	1244.16 Mbps	16,128	672	24
STS-36 and OC-36	1866.24 Mbps	24,192	1008	36
STS-48 and OC-48 (STM-16)	2488.32 Mbps	32,256	1344	48
STS-n and OC-n (STM-n/3)	n * 51.84 Mbps	n * 672	n * 28	n

The SDH (ITU standard) refers to synchronous transfer module-n (STM-n) signals.

SONET RINGS

❑ In long distance wide area applications, SONET networks may (and usually are) installed using a traditional nodal network structure.

❑ However, SONET was designed to be operated using a "Ring" structure. Two basic types of self-healing rings are
   ❑ Unidirectional ring
   ❑ Bidirectional ring

❑ The ring structure allows for very fast and automatic service restoration in the case of a cable breakage.

❑ Commercially available SONET equipment is usually able to restore service after a cable breakage in a time of between 20 ms and 40 ms.
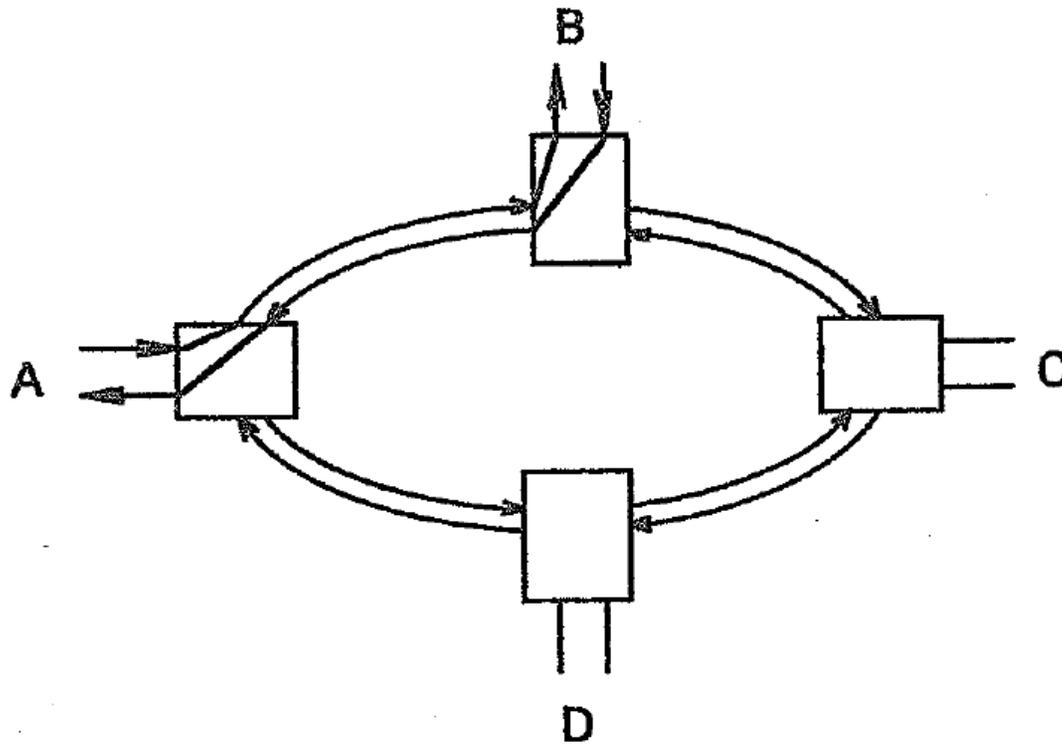
Unidirectional Ring

❑ Unidirectional path switch ring (UPSR) transmit the same information from A to B in both directions around the ring. Normally, only the working path is accessed by the receiving node: if a failure occurs, a node can select the data on the protection channel.
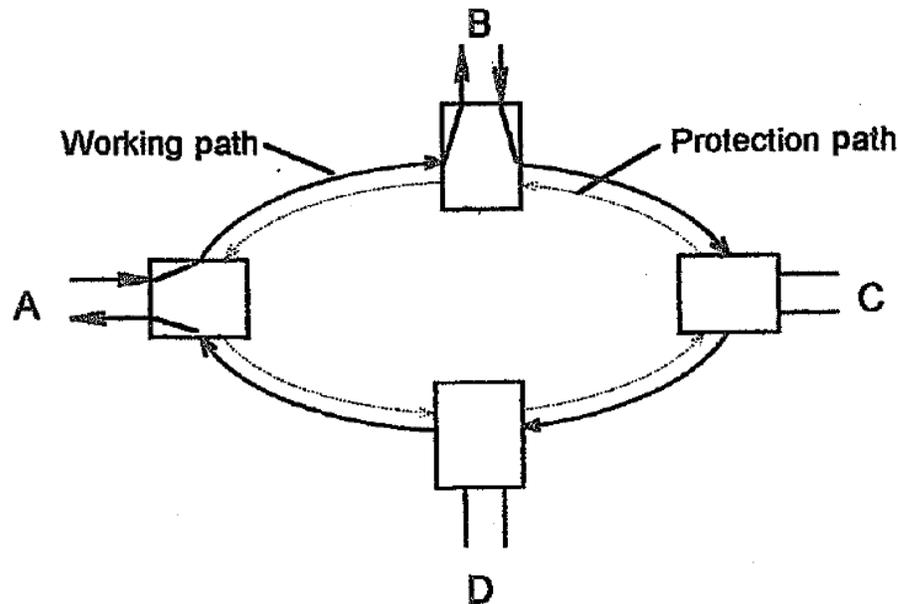
Bidirectional Ring

❑ Bidirectional Line-Switched Ring

Tributaries

❏ Within each payload, slower-speed channels (called tributaries) may be carried.
  ❏ Tributaries normally occupy a number of consecutive columns within a payload.
❏ A US T-1 payload (1.544 Mbps) occupies three columns, a European E-1 payload (2.048 Mbps) occupies four columns. Notice that there is some wasted bandwidth here.
  ❏ A T-1 really only requires 24 slots and three columns gives it 27.
❏ An E-1 requires 32 slots and is given 36. This "wastage" is a very small price to pay for the enormous benefit to be achieved by being able to demultiplex a single tributary stream from within the multiplexed structure without having to demultiplex the whole stream.
❏ The tributaries may be fixed within their virtual containers or they may float, similar to the way a virtual container floats within the physical frame.
❏ Pointers within the overhead are used to locate each virtual tributary stream.