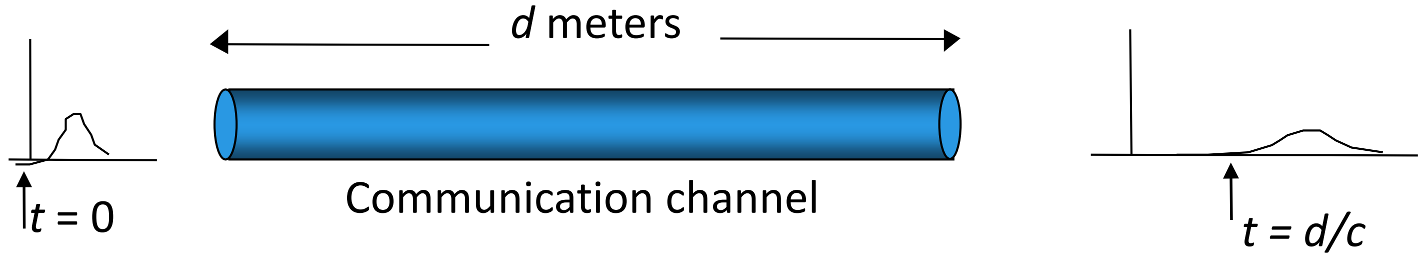
Transmission Mediums & Multiplexing

A/PROF. DUY NGO

Fundamental Issues in Transmission Media

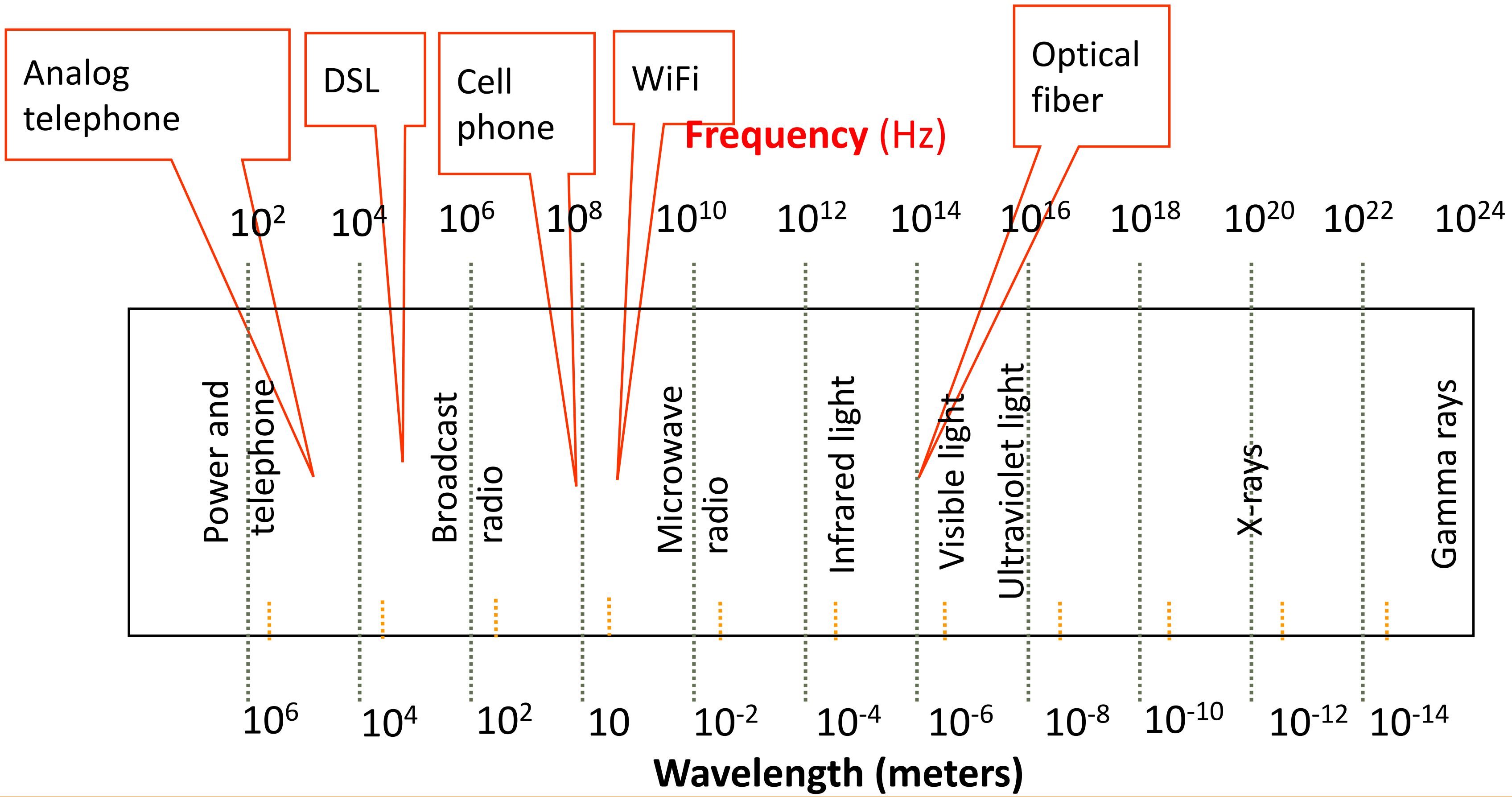


- Information bearing capacity
  - Amplitude response & bandwidth
    - Dependence on distance
  - Susceptibility to noise & interference
    - Error rates & SNRs

- Propagation speed of signal
  - c = 3 x 10^8 meters/second in vacuum
  - c_e = c/√ε speed of light in medium where ε>1 is the dielectric constant of the medium
  - c_e = 2.3 x 10^8 m/sec in copper wire; c_e = 2.0 x 10^8 m/sec in optical fiber

Communications systems & Electromagnetic Spectrum

- Frequency of communications signals



Wireless & Wired Media

Wireless media

- Signal energy propagates in space, limited directionality
- Interference possible, so spectrum regulated
- Limited bandwidth
- Simple infrastructure: antennas & transmitters
- No physical connection between network & user
- Users can move

Wired media

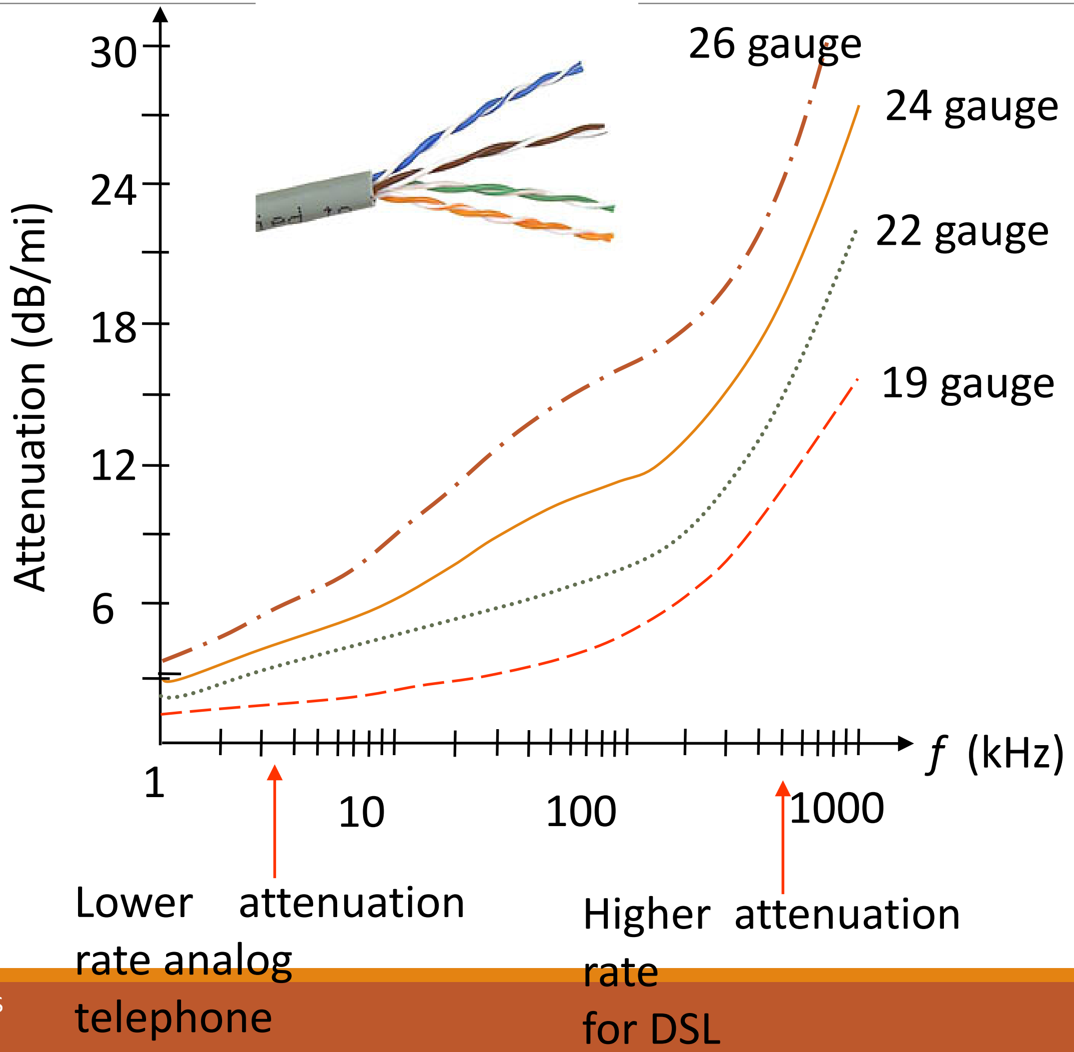
- Signal energy contained & guided within medium
- Spectrum can be re-used in separate media (wires or cables), more scalable
- Extremely high bandwidth
- Complex infrastructure: ducts, conduits, poles, right-of-way

Attenuation/Loss

- Attenuation varies with media
  - Dependence on distance of central importance
- Wired media has exponential dependence
  - Received power at d meters proportional to 10^{-kd}
  - Attenuation in decibel dB = $k*d$, where k is dB/meter
- Wireless media has logarithmic dependence
  - Received power at d meters proportional to d^{-n}
  - Attenuation in dB = $n \log d$, where n is path loss exponent; $n=2$ in free space
  - Signal level maintained for much longer distances
  - Space communications possible

Twisted Pair

- Twisted pair
- Two insulated copper wires arranged in a regular spiral pattern to minimize interference
- Various thicknesses, e.g. 0.016 inch (24 gauge)
- Low cost
- Telephone subscriber loop from customer to a switch or a node
- Intra-building telephone from wiring closet to desktop
- Twisted pair with coil loading has transmission bandwidth from 0 to 3.5 kHz with typical delay of 50 μs/km



Twisted Pair for Data Transmission

- Electronic industries association published standard ANSI/EIA/TIA-568 commercial building telecommunications cabling standard which specifies the use of voice and data grade UTP (unshielded twisted pair) and F/S/UTP (foil/shielded)
- Several cabling standard exists for the industry:
  - ANSI/TIA-568-c.0 generic telecommunications cabling for customer premises
  - ANSI/TIA-56-c.1 commercial building telecommunications cabling standard
  - ANSI/TIA-56-c.2 balanced twisted pair telecommunications cabling and components standard
  - ANSI/TIA-568-c.3 optical fibre cabling components standard
- Since 2000 twisted pair categories have started to make significant impact on data communications
- Cat 5, 6, 7 cables have gradually emerged with increasing data rates and lower losses

ANSI: American National Standards Institute, EIA: Electronic Industries Alliance, TIA: Telecommunications Industries Alliance

Twisted Pair Categories and Classes

Parameters	Cat5- Class D	Cat 6 – Class E	Cat 6A – Class E_A	Cat 7 Class F	Cat 7_A Class F_A
Bandwidth	100 MHz	250 MHz	500 MHz	600 MHz	1 GHz
Cable type	UTP	UTP/FTP	UTP/FTP	S/FTP	S/FTP
Data rate	1 Gbps	1 Gbps	10 Gbps	10 Gbps	>10 Gbps
Insertion loss (dB)	24	21.3	20.9	20.8	20.3
NEXT loss (dB)	30.1	39.9	39.9	62.9	65
ACR	6.1	18.6	19	42.1	44.1
Applications	Ethernet	Ethernet	Ethernet	Ethernet	Ethernet+CATV

UTP: Unshielded Twisted Pair, STP: Shielded Twisted Pair, FTP: Foil Shielded Twisted Pair

Twisted Pair: Losses

- **Insertion loss**: this loss refers to attenuation caused by the medium. This loss limits the transmission distance, where P_t and P_r are the transmitted and received power respectively.

$$A_{dB} = 10log_{10}\frac{P_t}{P_r}$$

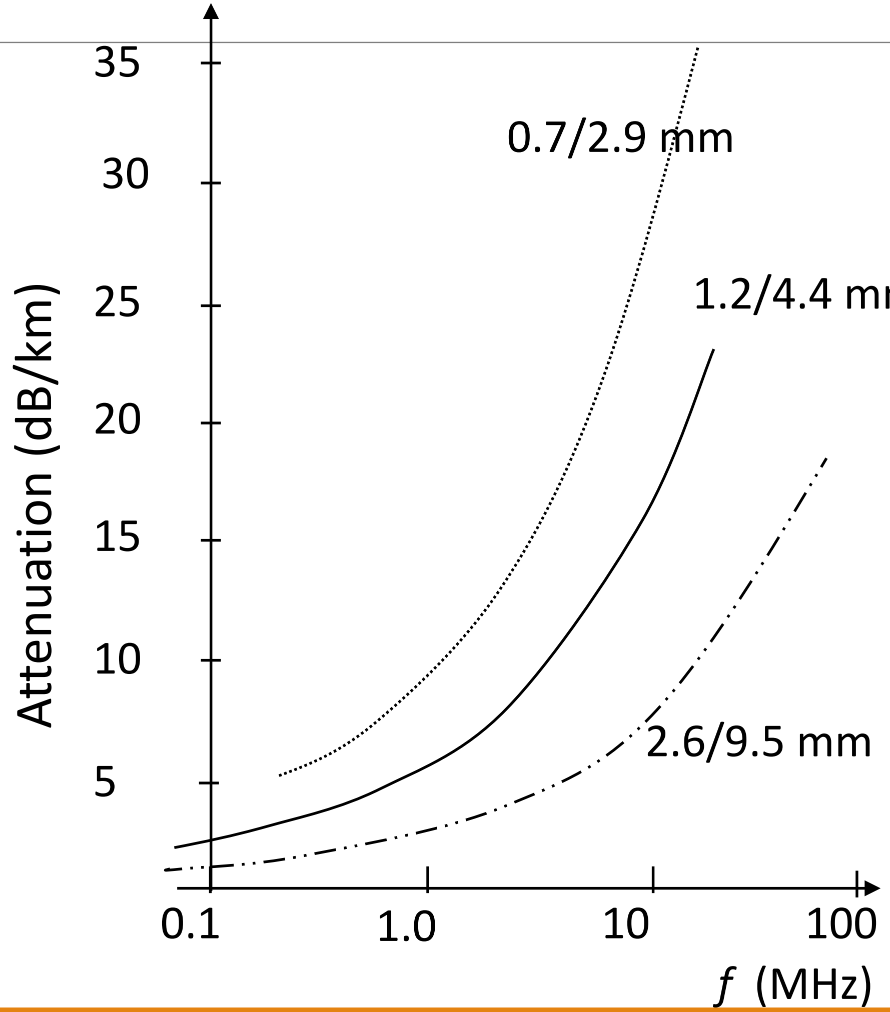
- **NEXT (near-end crosstalk)**: this loss applies to twisted pair wiring systems coupling of the signal from one pair of conductors to another pair. This figure shows how a transmitted signal is interfered by a received signal when the ports are close to each other, P_c is the coupling power

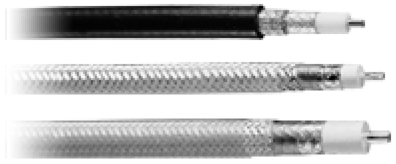
$$NEXT_{dB} = 10log_{10}\frac{P_t}{P_c}$$

- **ACR (attenuation-to-crosstalk)**: $ACR_{dB} = NEXT_{dB} - A_{dB}$
- ACR is a measure of how much larger the received signal strength is compared to crosstalk on the same pair

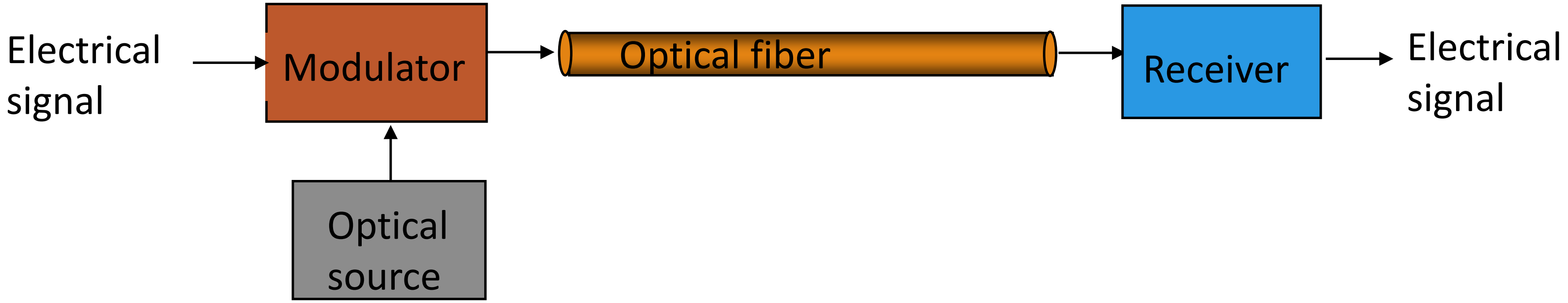
Coaxial Cable

- Twisted pair
- Cylindrical braided outer conductor surrounds insulated inner wire conductor
- High interference immunity
- Higher bandwidth than twisted pair
- Hundreds of MHz
- Cable TV distribution
- Long distance telephone transmission
- Original Ethernet LAN medium





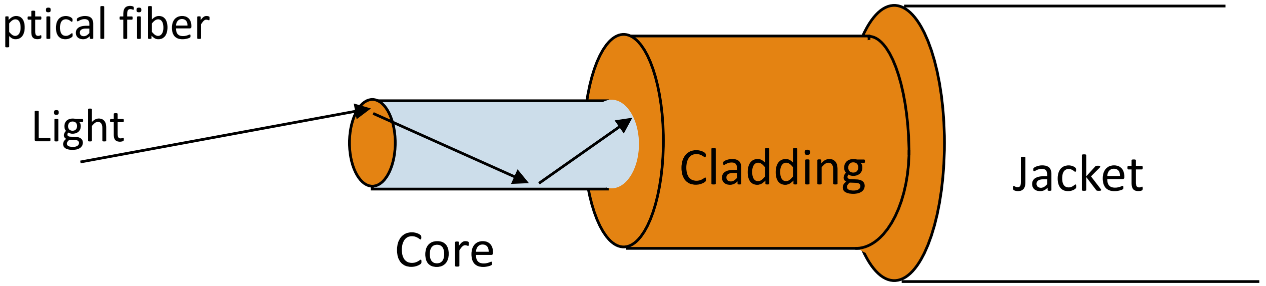
Optical Fiber



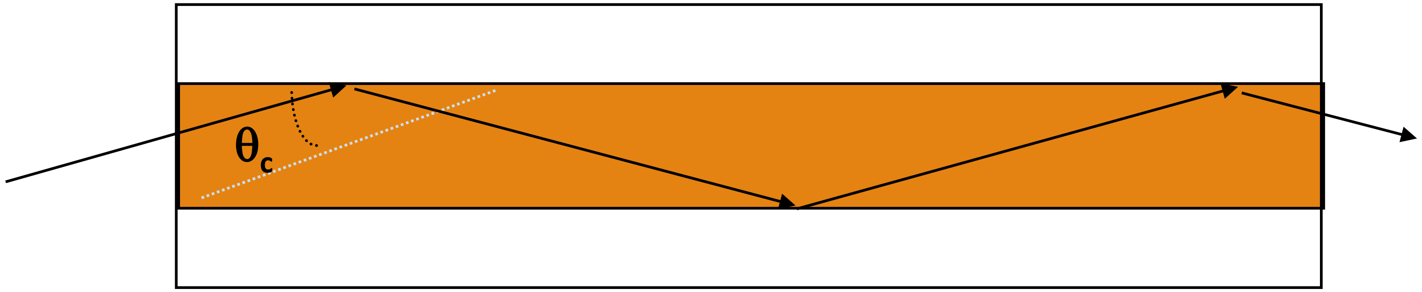
- Light sources (lasers, LEDs) generate pulses of light that are transmitted on optical fiber
  - Very long distances (>1000 km)
  - Very high speeds (>40 Gbps/wavelength)
  - Nearly error-free (BER (Bit Error Rate) of 10^{-15})
- Profound influence on network architecture
  - Dominates long distance transmission
  - Distance less of a cost factor in communications
  - Plentiful bandwidth for new services
  - Transmission bandwidth= $f_1 - f_2 = \frac{c}{\lambda_1} - \frac{c}{\lambda_2}$

Transmission in Optical Fiber

Geometry of optical fiber

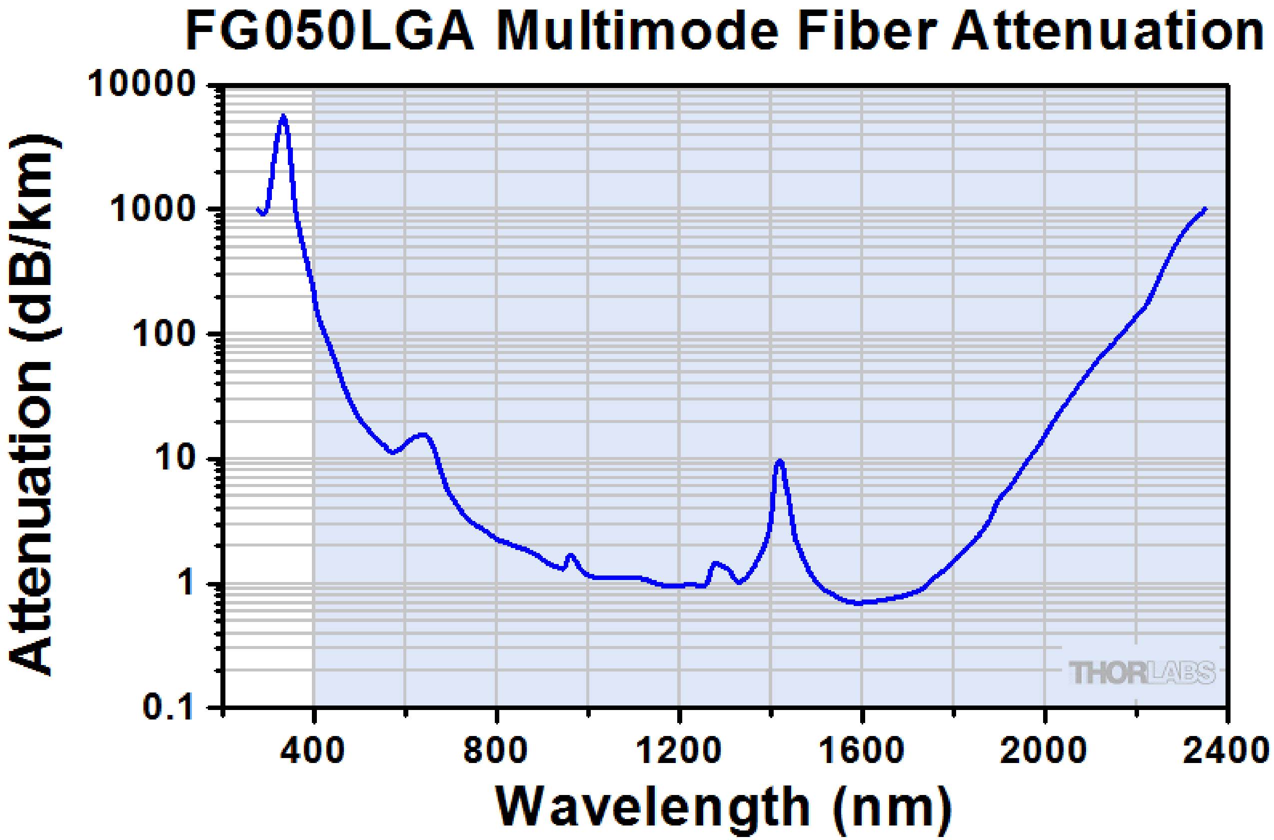


Total Internal Reflection in optical fiber



- Very fine glass cylindrical core surrounded by concentric layer of glass (cladding)
- Core has higher index of refraction than cladding
- Light rays incident at less than critical angle θ_c is completely reflected back into the core

Optical Fiber Loss



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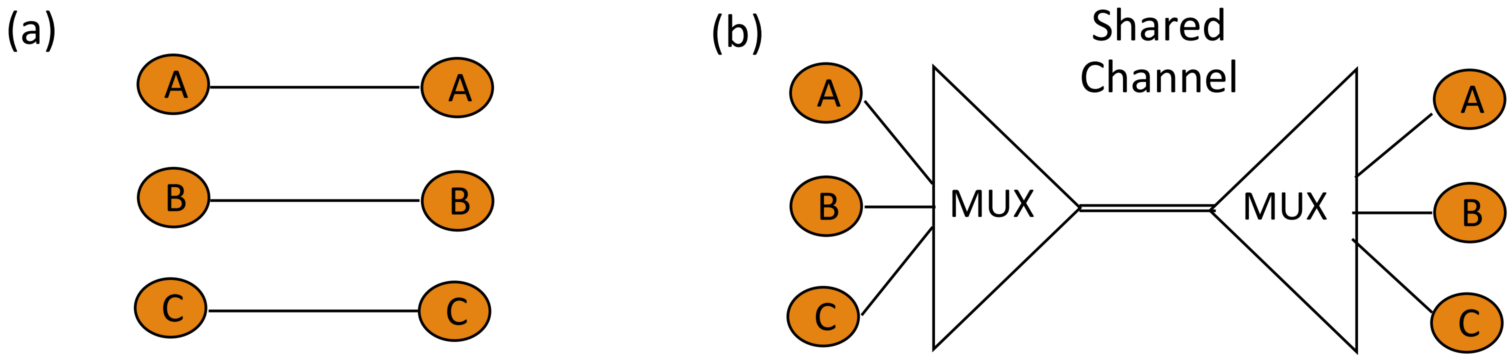
Multiplexing

- Transmission resources of a communication system is one of the most expensive component of a system
- Transmission links generally can accommodate a large number of baseband signals but those signals needs to be separated by using a multiplexing technique
- Five physical parameters can be utilised to implement multiplexing functionalities on a transmission link
- Multiplexing techniques used on transmission links are:
  - Frequency Division Multiplexing (FDM)
  - Time Division Multiplexing (TDM)
  - Code Division Multiplexing (CDM)
  - Space Division Multiplexing (SDM)
  - Wavelength Division Multiplexing (WDM)
  - Orthogonal Frequency Division Multiplexing (OFDM)

Multiplexing

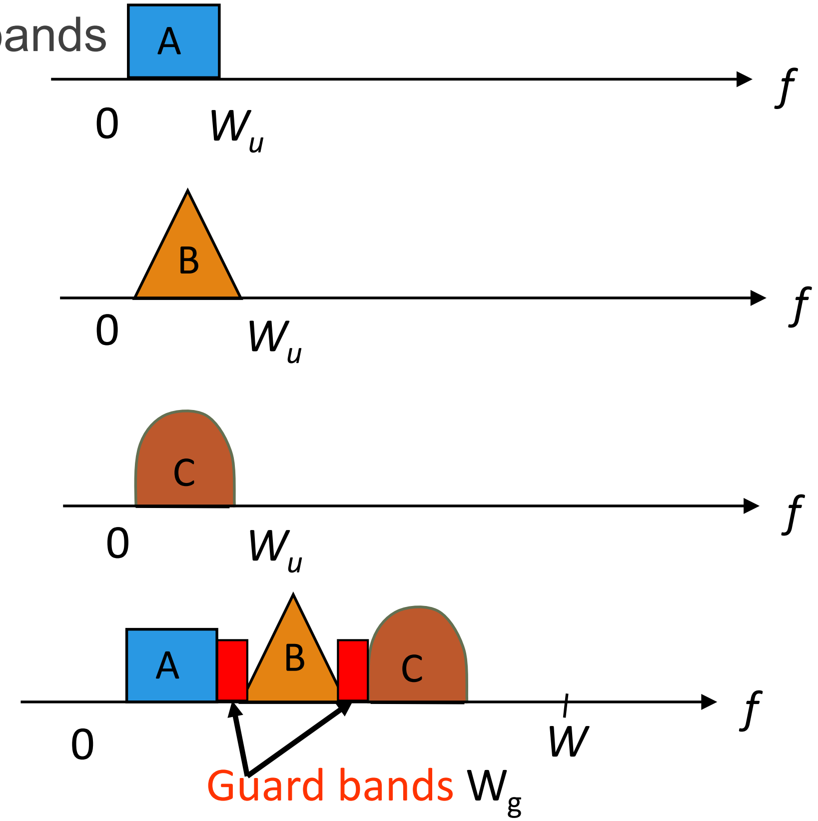
- Multiplexing involves the sharing of a transmission channel (resource) by several connections or information flows
  - Channel = 1 wire, 1 optical fiber, or 1 frequency band
- Significant economies of scale can be achieved by combining many signals into one
  - Fewer wires/pole; fiber replaces thousands of cables
- Implicit or explicit information is required to demultiplex the information flows.



Frequency-Division Multiplexing

- Channel divided into frequency bands

(a) Individual signals occupy W_u Hz



(b) Combined signal fits into channel bandwidth

- Guard bands required
- AM or FM radio stations
- TV stations in air or cable
- Satellite communication
- Mobile communication

FDM: Calculations

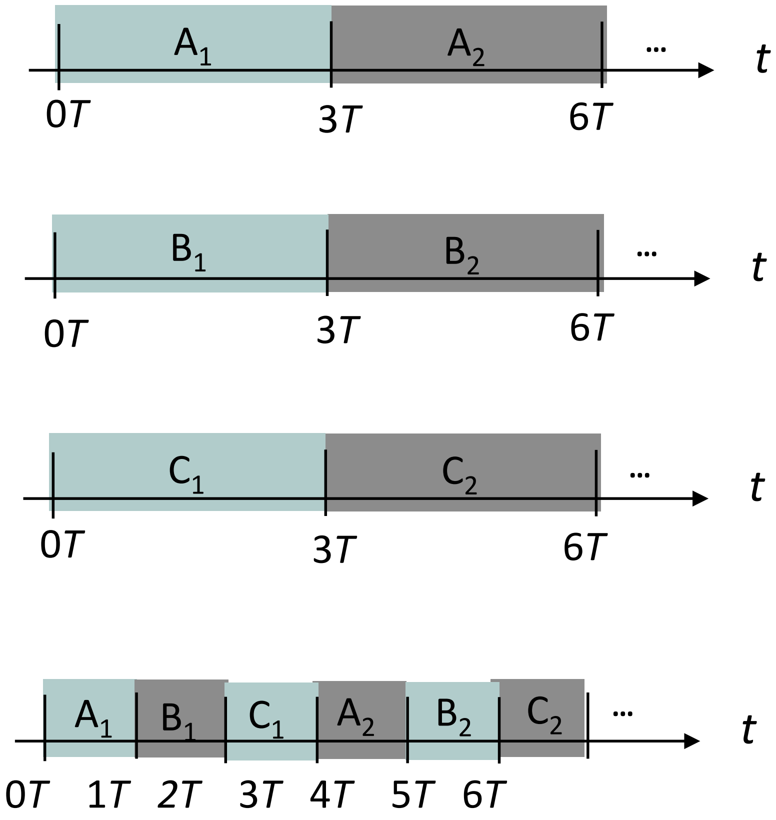
- Let *N* be the number of frequency bands. Value of *N* can be calculated using the following equation:
- $N = \left\lceil \frac{W-(N-1)W_g}{W_u} \right\rceil$
- The width of guard band will depend on the roll off characteristics of the filter used to avoid channel interference
- FDM channels can transmit both analog and digital signals
- End-to-end delay is controlled by the transmission and propagation delays
- FDM is hardly used in current fixed telecommunication networks

Time-Division Multiplexing

- High-speed digital channel divided into time slots

(a) Each signal transmits 1 unit every 3T seconds

(b) Combined signal transmits 1 unit every T seconds



- Framing required
- Telephone digital transmission
- Digital transmission in backbone network

TDM Calculations

- TDM connection allows only one user to use the transmission link for a time slot duration.
- Let's assume t_f and t_s are time frame and slot duration respectively represented in bits. Let's assume *R* is the transmission rate of the channel in bits/sec. Also, assume that *r* is the slot capacity in bits.
- No. of bits per TDM frame is r_f and *n* is the number of slots per frame are given by following equations:
- $R_f = R * T_f$
- $n = \frac{R*T_f}{r}$
- End to end delay is mostly controlled by the frame delay

Code Division Multiplexing

- Using the CDM technique each transmission medium can transmit data from multiple sources using the orthogonal codes
- Orthogonal codes have the following main property
  - Orthogonal codes have zero cross correlation
  - Assume three channels are transmitting data streams A, B and C using $a_1, a_2\ and\ a_3$orthogonal codes
  - For above codes following conditions will be true:
  - $a_1 * a_1 = 1, a_1 * a_2 = 0$, similarly others
  - Transmitted signal on a channel is represented by $T = a_1 * A + a_2 * B + a_3 * C$
  - If a data receiver wants to receive signal from channel C then the received data stream needs to multiplied by $a_3$as shown below.
  - $R = T * a_3 = a_3(a_1 * A + a_2 * B + a_3 * C) = a_3 * a_1 * A + a_3 * a_2 * B + a_3 * a_3 * C = 0 + 0 + C = C$