ECE 466/566
Advanced Computer Networks

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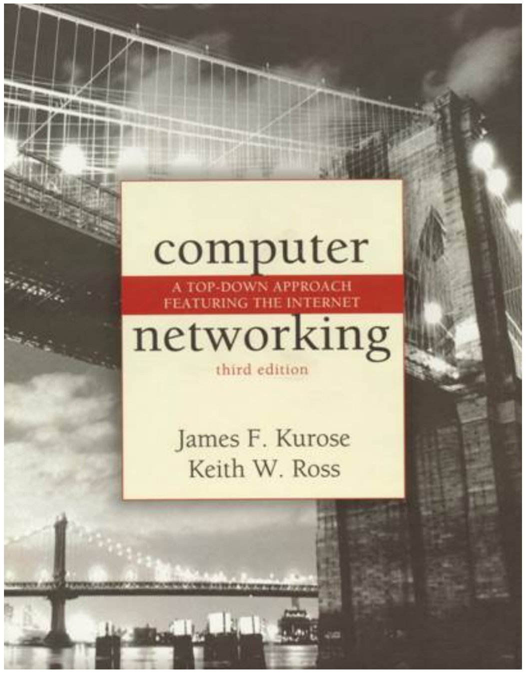
Office hours

- My office hours: T: 9:00-:11AM, Kelley Engineering Center 3115

Class homepage

- http://www.eecs.orst.edu/~thinhq/teaching/ece466/winter07/winter07.html

Text



Computer Networking: A Top Down Approach Featuring the Internet,
3rd edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2004.

Other necessary materials will be handed out in the class.

Course Objectives

- Deepen your computer networking knowledge
- Be familiar with current research directions in computer networks.
- Be work-ready in telecommunication industry
- Have fun while learning

Class Outline

- Physical Layer (1 1/2 weeks)
- Issues in Multimedia Networking (wired/wireless) (3 weeks)
  - Network architecture for multimedia
  - Multimedia protocols
  - Multimedia coding for networks
  - Multimedia communication systems
- P2P Networking
- Issues in Network Securities (wired/wireless) (1 1/2 weeks)
  - Privacy, Authentication
  - Intrusion detection
  - SSL
  - IPSec
- Network Management (1/2 week)
  - SNMP
- Trends in Wireless Networking (1 1/2 weeks)
  - WiMax
  - Mesh Networks
  - Mobile Ad-hoc Networks
  - Sensor Networks

Detail Syllabus

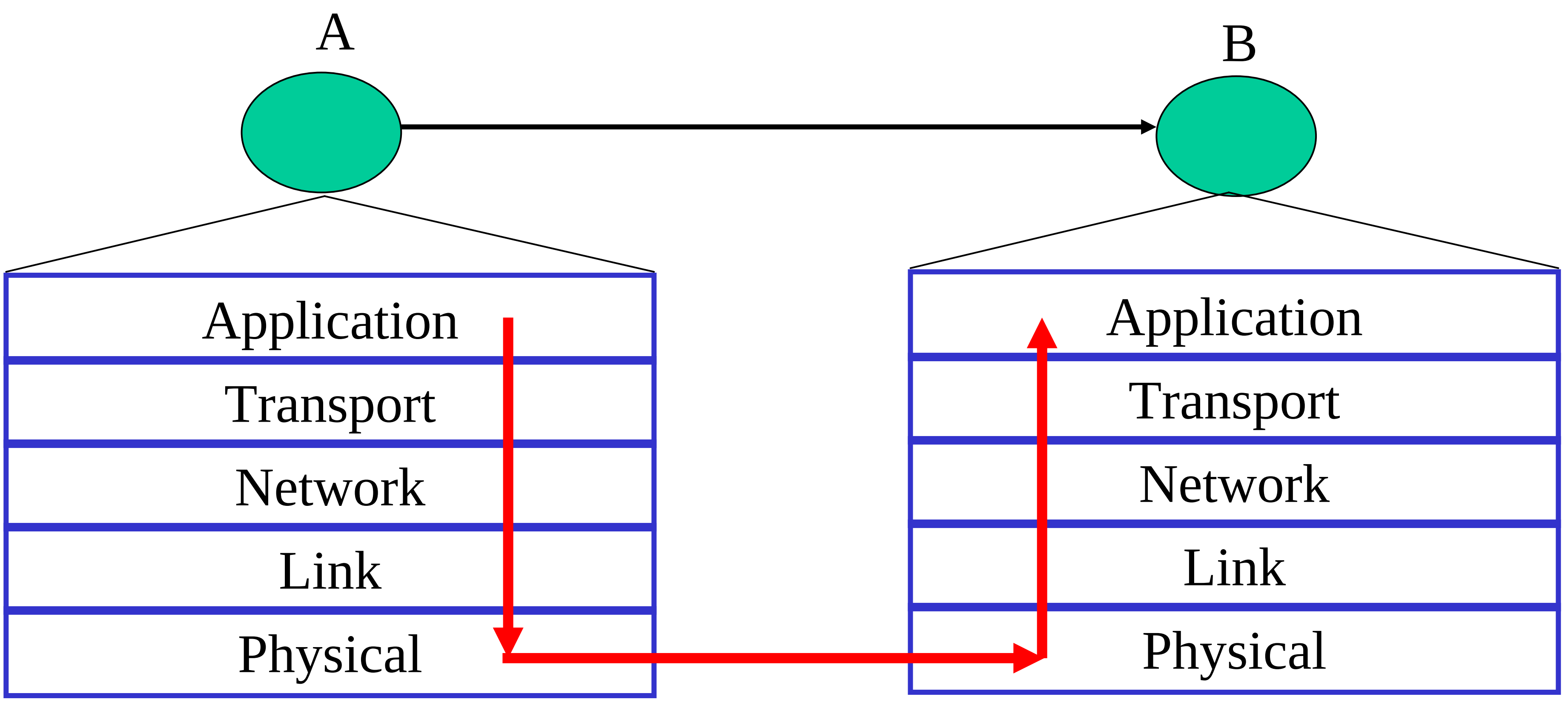
- http://www.eecs.orst.edu/~thinhq/teaching/ece466/winter07/syllabus.pdf

Pre-requisites

- ECE465 – with B- or better.
- Strong programming skills, C++
- Project based class

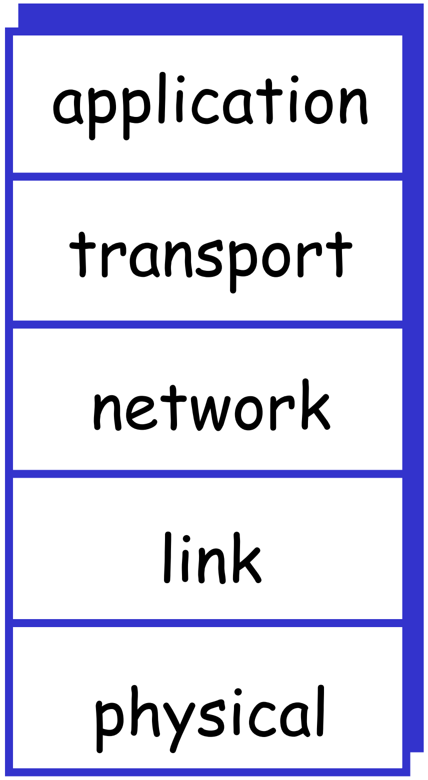
Review: Networking Basics

Network Layer

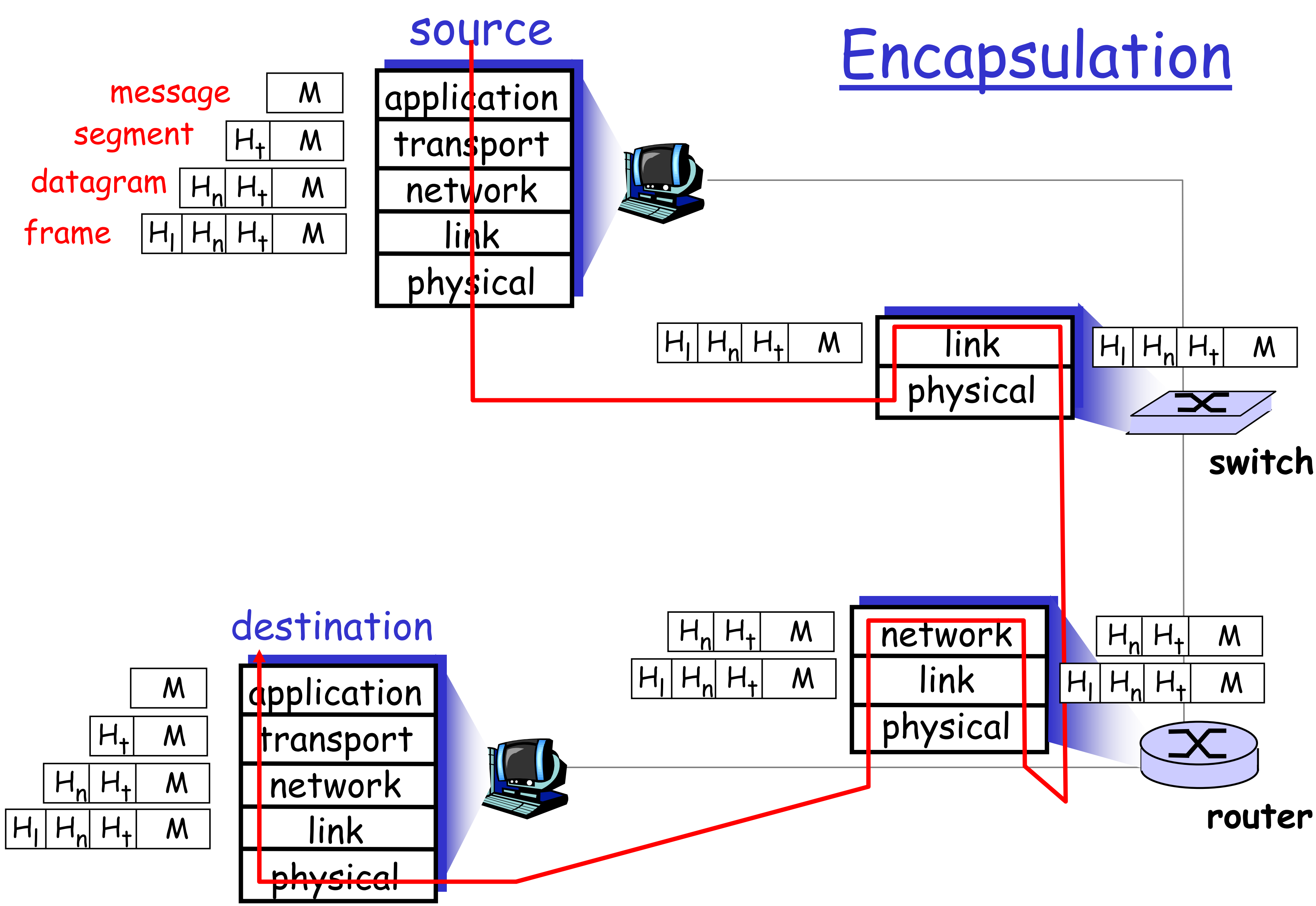


Internet protocol stack

- application: supporting network applications
  - FTP, SMTP, STTP
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits “on the wire”



Encapsulation



Physical Layer

- Communication Links
  - Digital Link
  - Frequency and Propagation
  - Limitations
    - Attenuation
    - Distortion
    - Dispersion
    - Noise
  - Converting between Bits and Signals
    - Asynchronous and Synchronous Transmission
- Optical Links
  - End-to-End Characteristics
  - Dispersion Limit
  - Fiber Types
  - Light Sources
  - Light Detector
  - Free-space Infrared
- Copper Lines
- Modulation
  - Multiplexing
  - Modems
  - CATV and Video-onDemand Systems
- Radio Links
- Case Studies:
  - SONNET
  - ADSL
  - RS-232

Communication Links

- Digital Links
  - Consider only electromagnetic links
  - Convert bits into signals that propagate through a channel
  - Signals: guided and unguided electromagnetic waves.
    - Optical fiber, wires, radio waves
  - Bit rates and the transmitting distance is inversely proportional.

Communication Links

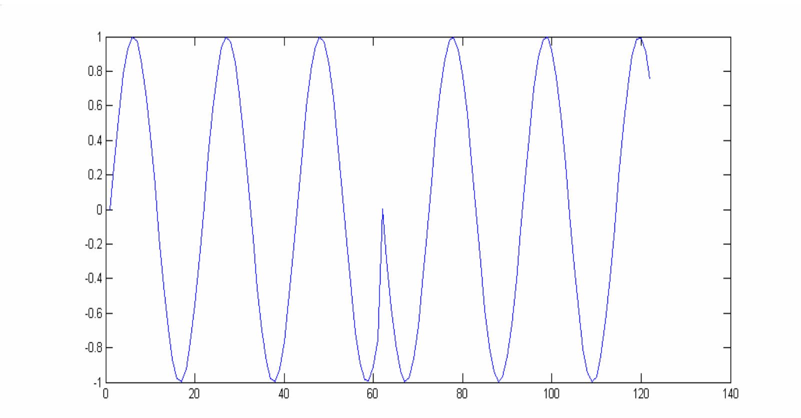
Transmitted bits

01 → Modulation → Channel → Demodulation →

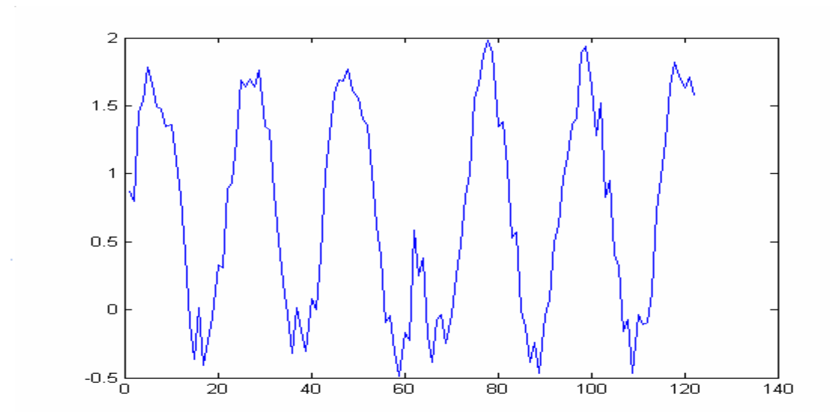
Hopefully, no errors

Detected bits

01



Transmitted Signals



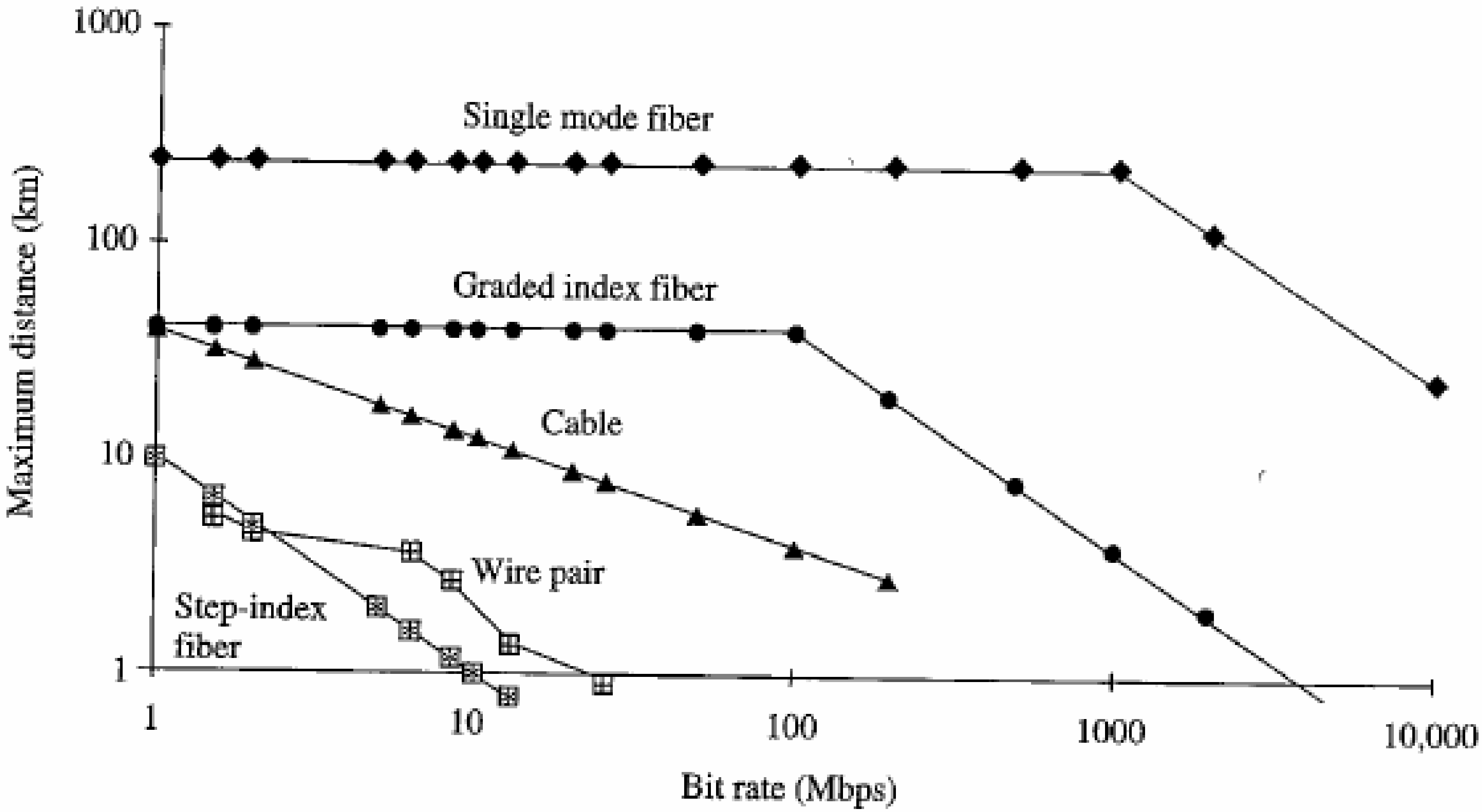
Received Signals

Noise + other corruption

Free space, copper wires, or optical fiber

Bit Rate vs Distance

Achievable distance as a function of the bit rate for optical links, wire pairs, and cable. (*The graphs are approximate.*)



Frequency and Propagation

- Signal propagation carry energy from one place to another.
- Maxwell equation describes the interaction of electrical and magnetic fields.
- Electromagnetic wave propagation is caused by the interactions of an oscillating eletrical field and and oscillating magnetic field pushing one another through empty space.
- Examples of electromagnetic waves:
  - Light, radio waves

Frequency and Propagation

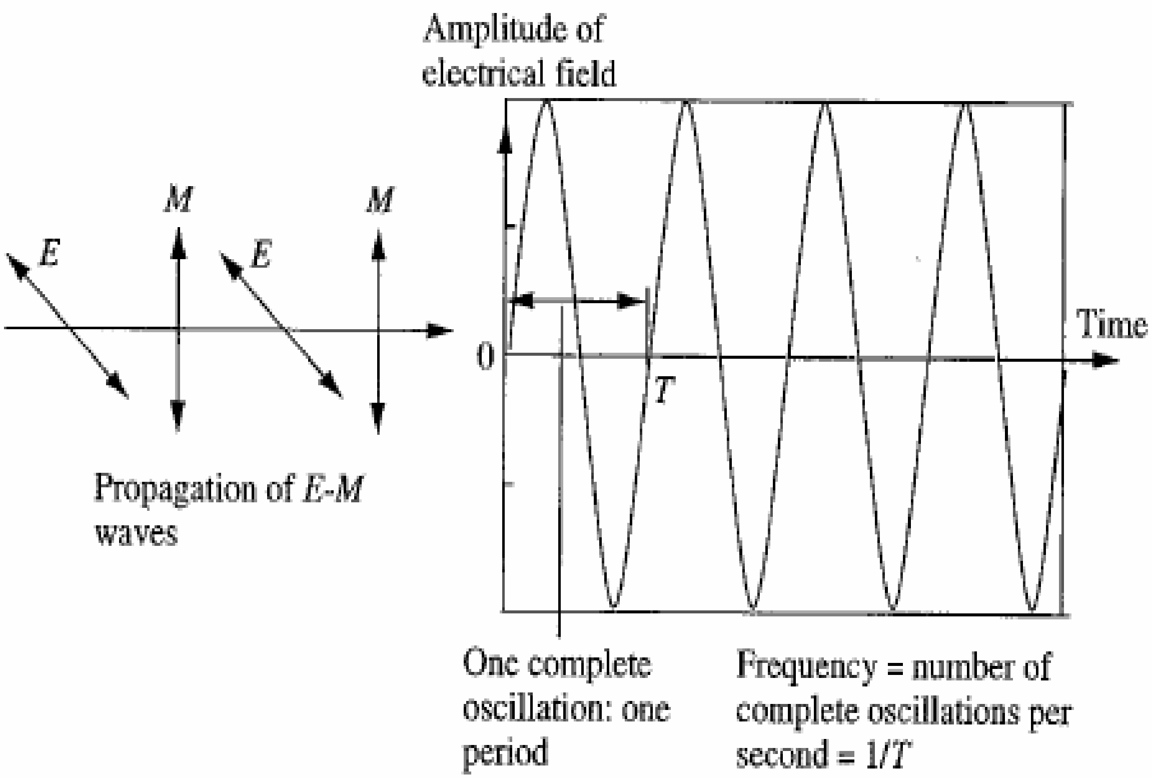
- Frequency = number of osscilations of the electric and magnetic fields in one second

- Propagation speed of an electromagenic waves in *a vacuum is*

$3x10^{8}$ meter per second

Eletromagnetic waves

Electromagnetic waves: Their propagation (left), frequency (center), and typical frequency ranges (right).



Frequency ranges:

Twisted pairs: 0–a few 100 kHz
Coaxial cable: a few 100 kHz–1 GHz
Waveguide: 1 GHz–a few hundred GHz
Optical fiber: ≈ 100 THz (10^{14} Hz)
AM radio: ≈ 1 MHz
VHF TV: 20 MHz–80 MHz
FM radio: 88 MHz–108 MHz
UHF TV: 300 MHz–600 MHz
Cellular phones: 850 MHz, 1.2 GHz, . . .
Satellite: 1 GHz–100 GHz

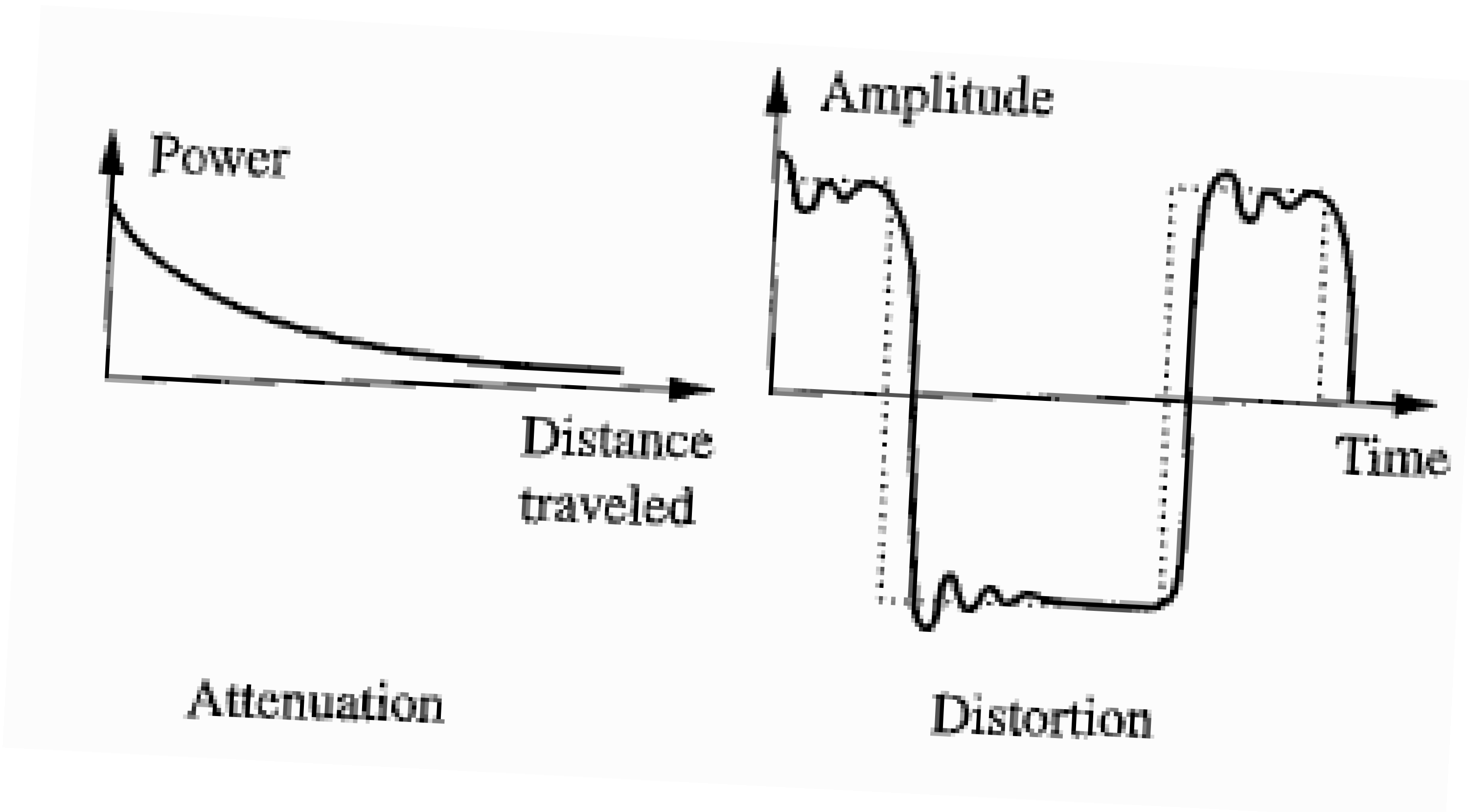
Sources of Signal Degradation

- There are 4 sources that contribute to signal degradation in electromagnetic wave transmission.
  - Attenuation
    - The loss of energy per area of the wave as it propagates
    - Energy being absorbed by surrounding
  - Distortion
    - Frequency of the wave remains constant.
    - Propagation in a transmission link or fiber attenuates and delays differently for different frequencies.
    - Hence, the shape of a signal consisting of different waves will be distorted at the receiver.

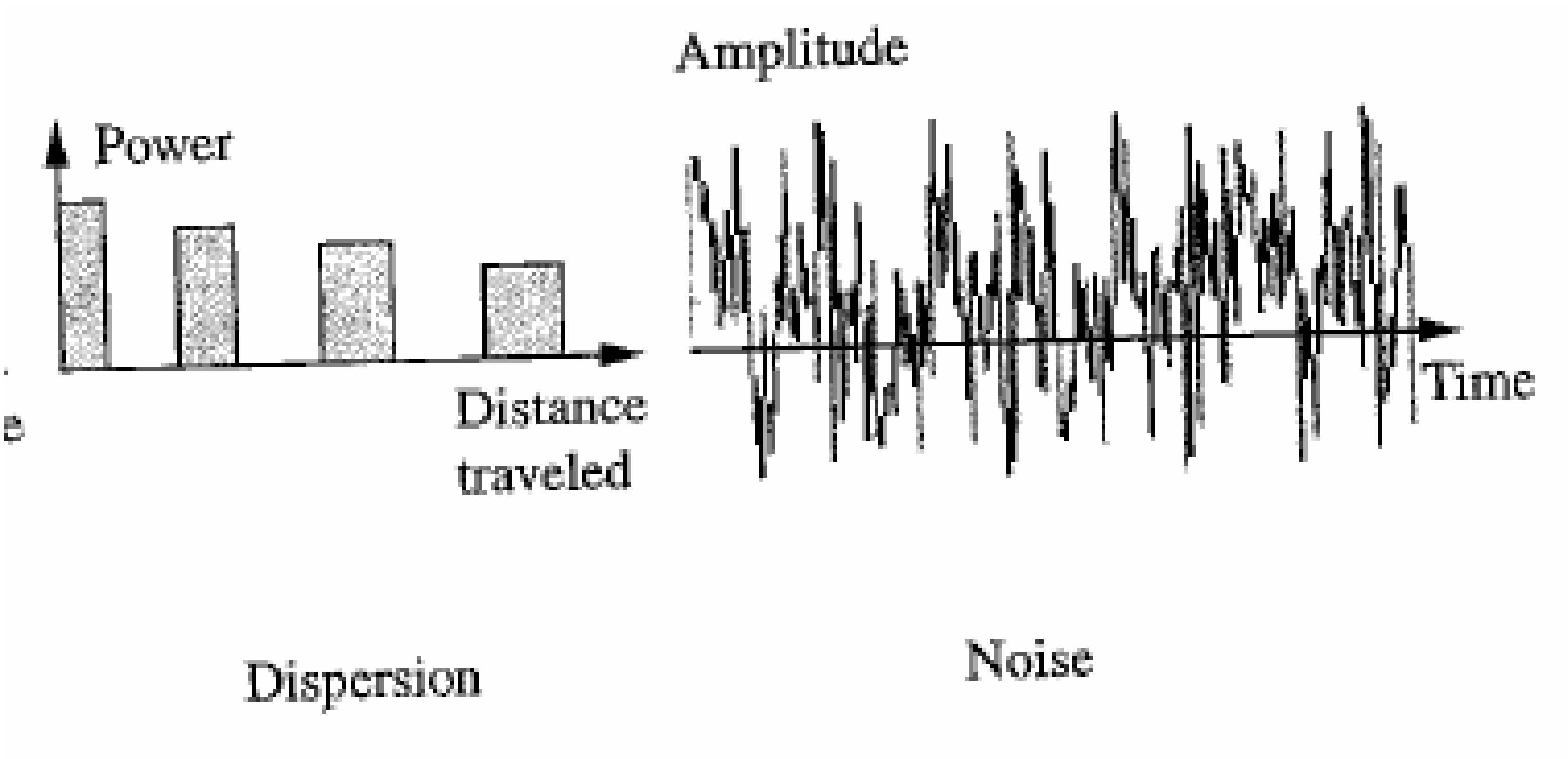
Sources of Signal Degradation

- Dispersion
  - Burst of eletromagnetic energy that a transmitter sends in a cable wire or optical fiber spreads as it propagates.
- Noise
  - Unpredictable variation in the signal that reaches the receiver.
  - Thermal agitation of electrons in conductors
  - Uncertainty in the number of photons that a light source generates.
  - Electromagnetic waves from other sources

Sources of Signal Degradation



Sources of Signal Degradation



Can one transmit arbitrarily large amount of information in a short time?

Is there any wrong with this argument?

- Example:

Transmit a 10 Tera bit file: 1010001000 …….. 101

(bit string length: 10^{13})

1) Transmitter sends a pulse with voltage V down the transmission line:

$$V = b1*10^{13} + b2*10^{12} + \dots\ b13$$

2) Receiver detects the value of V, and uses V to obtain the bit patterns.

The pulse travels at approximately the speed of light. One can achieve inifinite bandwidth!!!???

Channel Capacities

- Signal degradation (from four sources) prevents the receiver from detecting an accurate value of V.

- Signal degradation also results in transmission errors or commonly known as bit error rate.

  - Optical Fiber: 10^{-12}
  - Copper lines: 10^{-7}
  - Wireless link: 10^{-3}

Channel Capacities

- Signal degradation (from four sources) prevents the receiver from detecting an accurate value of V.
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  - Optical Fiber: 10^{-12} → Dispersion
  - Copper lines: 10^{-7} → Attenuation (heat)
  - Wireless link: 10^{-3} → Fading – superimposition of reflected waves

Converting Bits and Signals

- Transmitter converts bits to signals, often called modulation.
- Receiver performs the reverse conversion: demodulation from signals to bits.

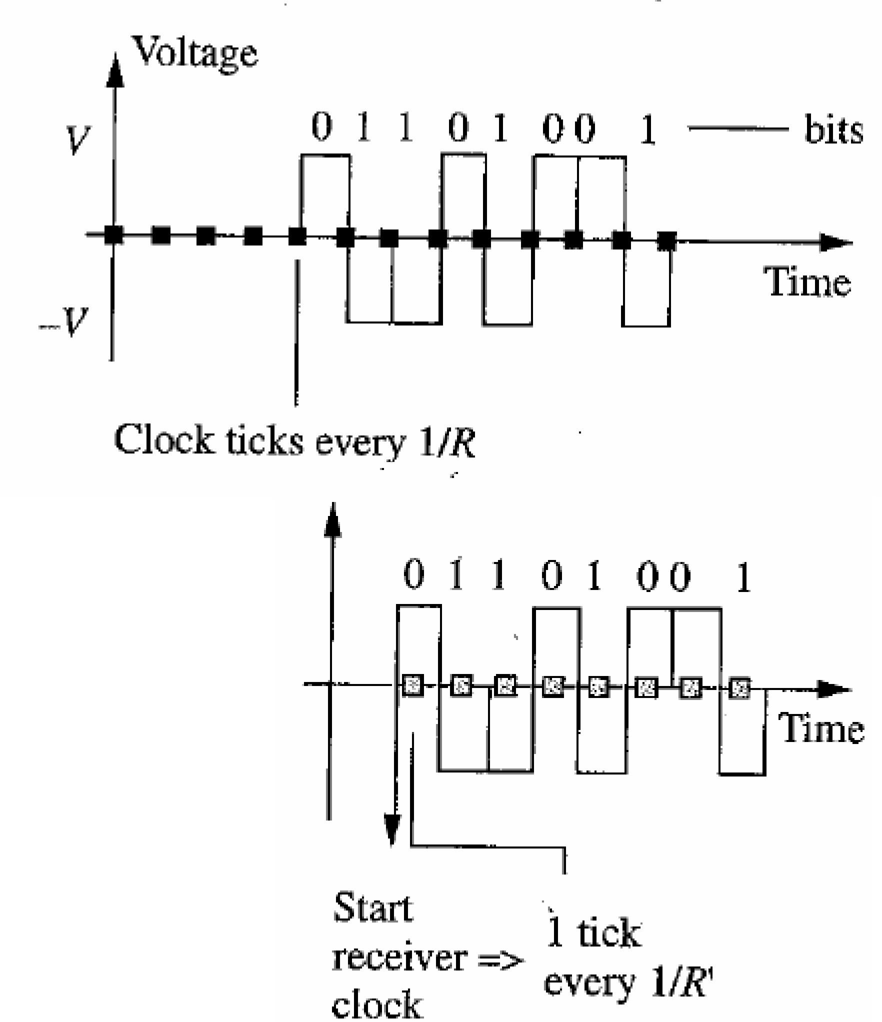
- Modem (Modulator-Demodulator)

Asynchronous Baseband Transmission

Bipolar modulation

1. Transmitter and receiver each have a clock with approximately the same rate (Hz).
2. Transmitter first groups the bits into short words of K bits.
3. Initally the transmitter sets the voltage at its end of the transmission line to 0 volt.
4. To send the first word, the transmitter, using its clock, sets the voltate successively to V volts during T = 1/R seconds for each bit 0 in the word and to –V volts for each bit 1.

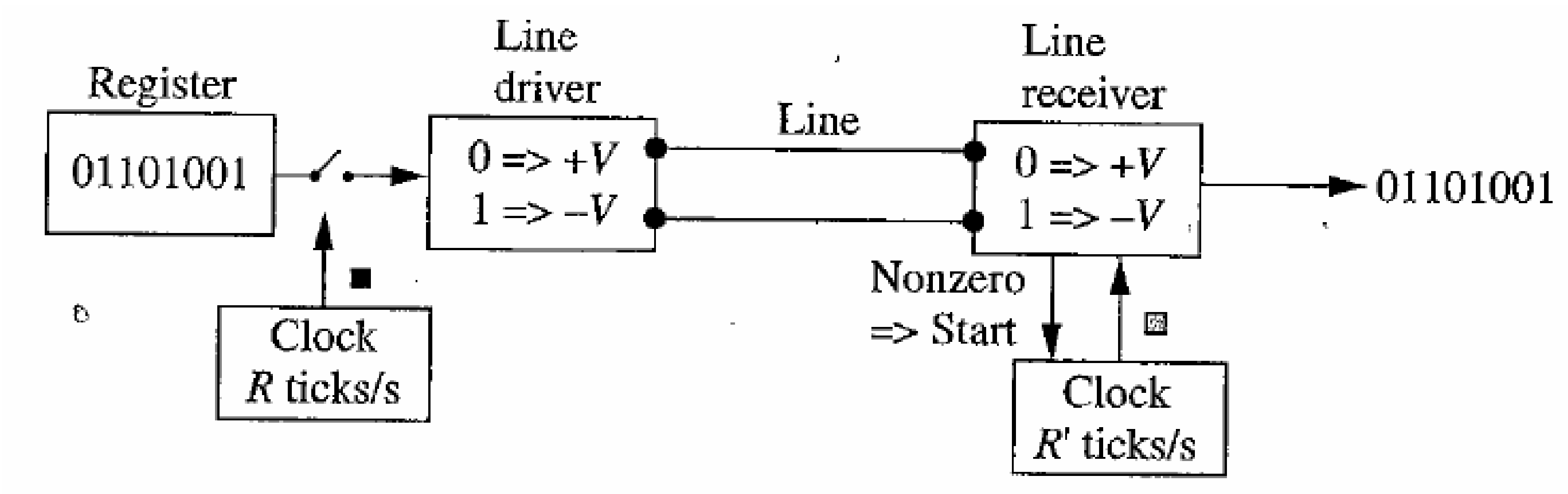
Bipolar Modulation



Sender

Receiver

Bipolar Modulation



Asynchronous baseband transmission: Transmission of words of K bits can occur at arbitary times. (when the voltage jumps away from zero)

The timing of the asynchronous transmission method limits the size of K of the words and the bit rate R to small values

Asynchronous Optical Transmission

- Similar to asynchronous baseband transmission
- The transmitter sends words of K bits by switching the light source ON for each bit 1 and OFF for each bit 0, in each case for T seconds.
- Commonly known as ON-OFF keying (OOK)
- The infrared remote control uses this transmission procedure.

Asynchronous Broadband Transmission

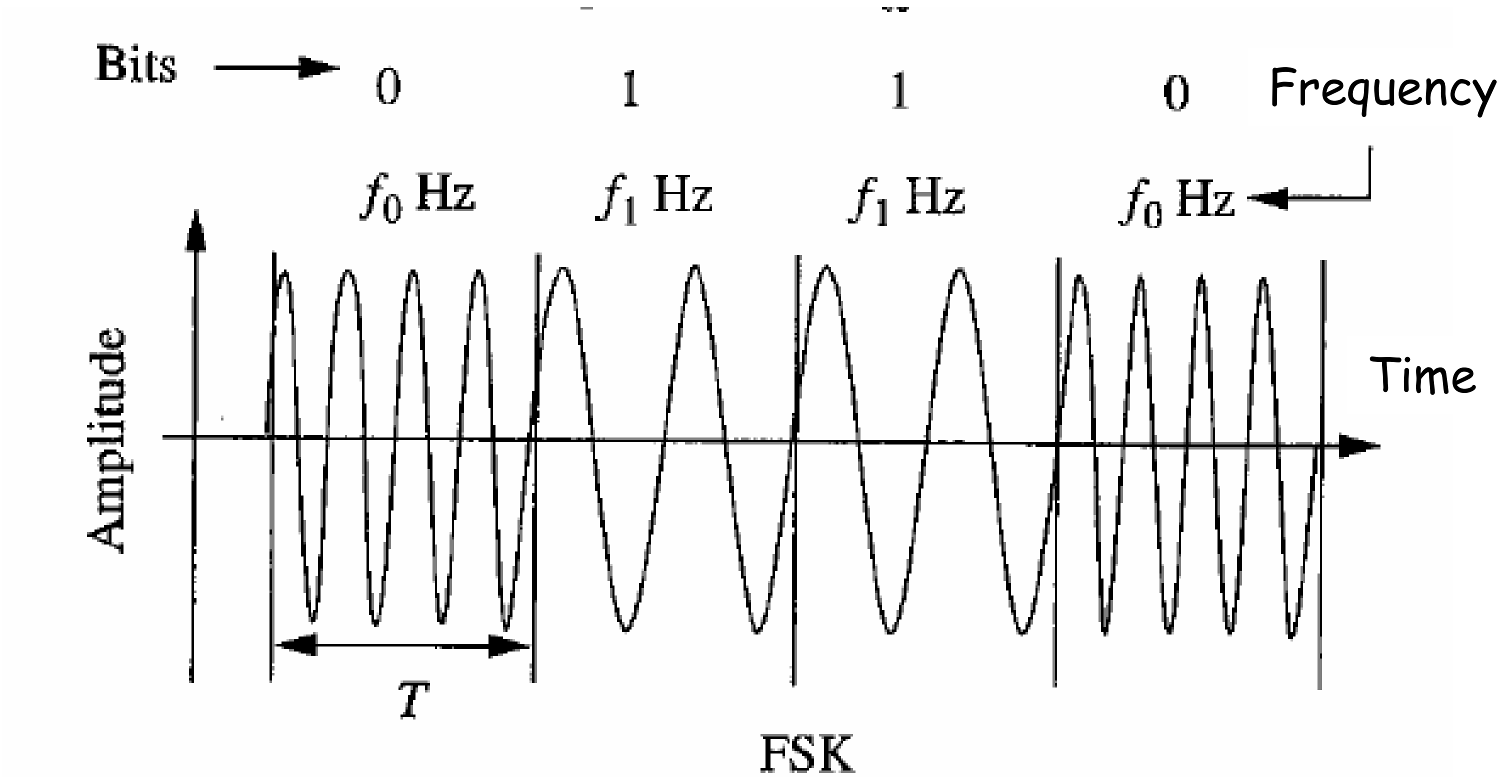
- Broadband: the signal is modulated (multiplied) by a signal at higher frequency.

- When using Frequency Shift Keying (FSK)

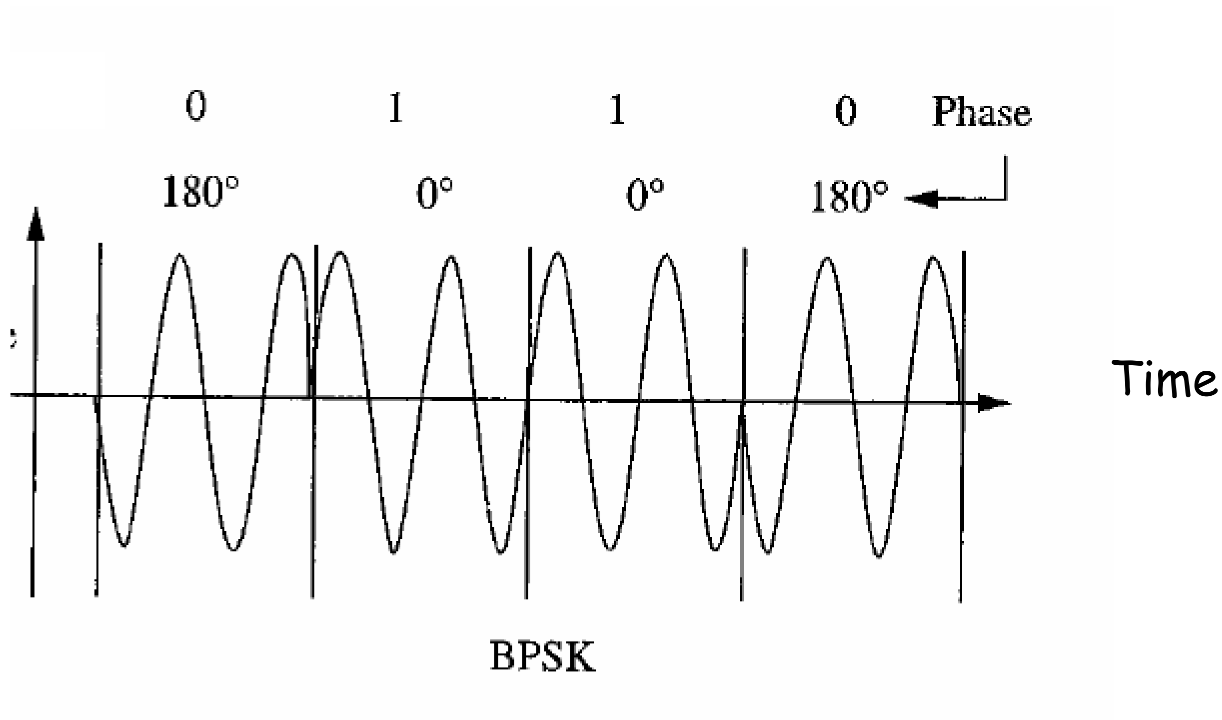
  - The transmitter sends a 0 by transmitting a sine wave of frequency f_0 and a 1 by transmitting a sine wave of frequency f_1, each during T seconds.

- When using Binary Phase Shift Keying (BPSK)
  - The transmitter sends a 0 by transmitting a sine wave of frequency f_0 and a 1 by transmitting a sine wave of the same frequency but whose phase differ by 180^0

Frequency Shift Keying

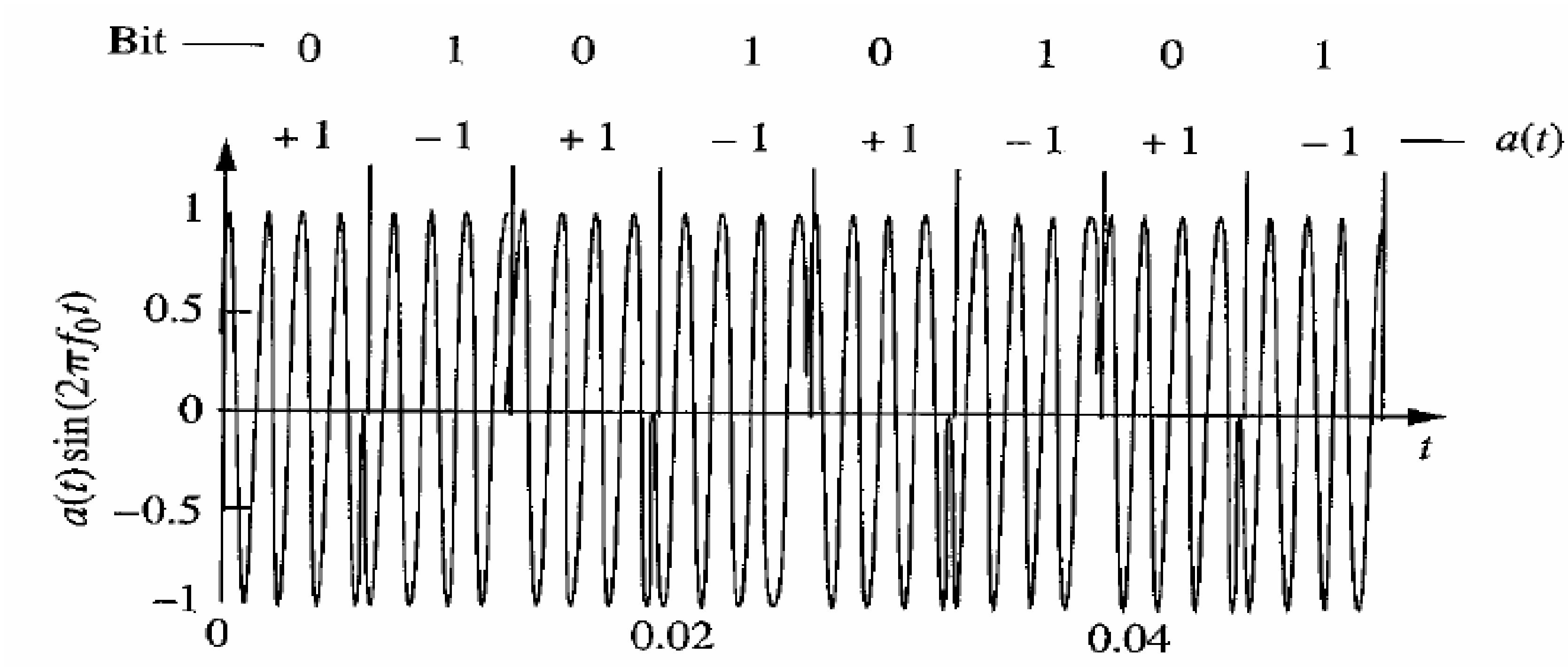


Binary Phase Shift Keying



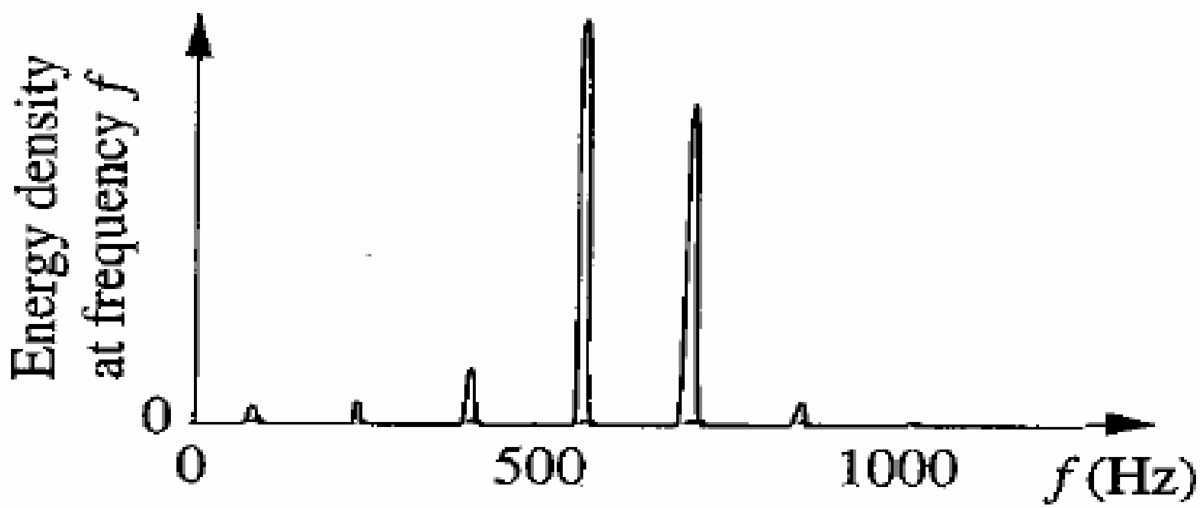
Binary Phase Shift Keying

- Example:
  - A modem is transmiting a bit stream with rate 150 bits per second using BPSK with frequency f = 600 Hz.



Binary Phase Shift Keying

Energy distribution in different frequency



Most energies are in the range (525 Hz, 675 Hz).

Bandwidth = 150 Hz.

Signal Spectrum

$$X_n = \sum_{k=0}^{N-1} x_k e^{-2\pi ikn/N}$$

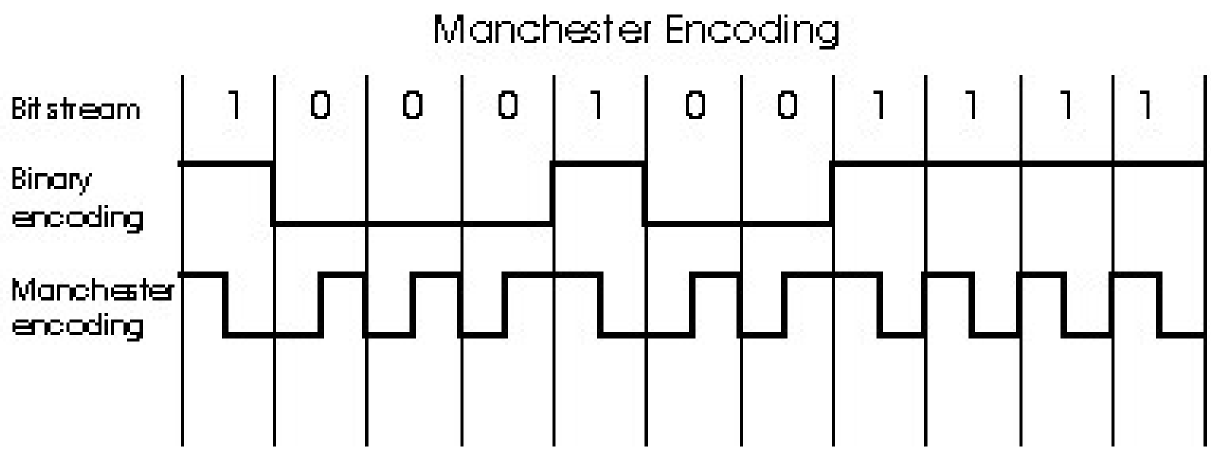
$$x_k = \frac{1}{N} \sum_{n=0}^{N-1} X_n e^{2\pi ikn/N}$$

$$Spectrum = |X_n|^2$$

Synchronous Baseband Transmission

- Use different time mechanism than asynchronous methods.
- Keep the receiver synchronized to the incoming bits, even after thousands of bits, the synchronous methods use a self-synchronizing code, i.e. a code that contains the timing information in addition to the transmitted bits.
- Manchester coding

Manchester encoding



- Used in 10BaseT
- Each bit has a transition
- Allows clocks in sending and receiving nodes to synchronize to each other by sending a premable 101010101 … pattern (using phase-locked loop circuit)
  - no need for a centralized, global clock among nodes!
- Useful bandwidth reduces by two

Optical Links

- Lowest signal losses are for ultrapure fused silica – but this is hard to manufacture.
- and part of the infrared spectrum.
- Three standard wavelengths : 850 nanometers (nm.), 1300 nm, 1500 nm.
- *First-generation optical fiber* : 850 nm, 10's Mbps using LED (light-emitting diode) sources.
- *Second and third generation optical fiber* :: 1300 and 1500 nm using ILD (injection laser diode) sources, gigabits/sec.

Optical Links

- End-to-End characteristics
  - Capacity is limited by dispersion
  - 10 Gbps over more 100 km
  - Bit error rate $< 10^{-12}$
- Dispersion Limit

Dispersion limits the product :

RxL

where R is the bit rate and L is the transmitting distance.

Longer the distance leads to smaller the bandwidth!

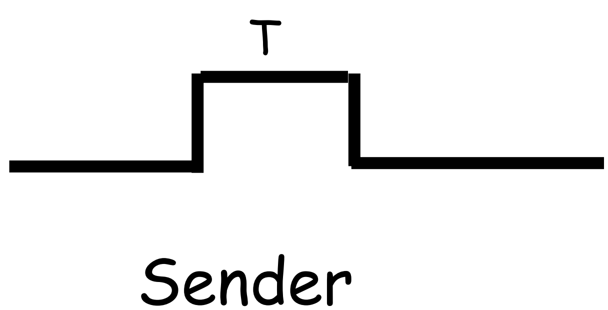
Optical Links

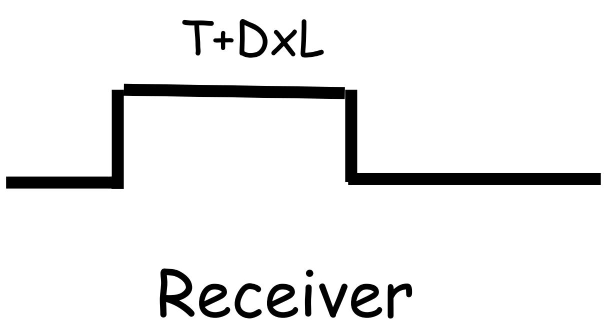
- Suppose a light pulse propagates in a fiber.

- Laws of propagation implies that different fractions of the energy in that pulse travel at different speeds a long the fiber.

Optical Links

- Suppose the lowest fraction of the energy takes D seconds more to cover 1 km of the fiber than the fastest fraction of that energy.
- If the pulse travels across L km of fiber, then the slowest fraction of energy reaches the end DxL seconds later than the fastest fraction.
- Consequently, if the transmitter injects a pulse with a duration of T seconds, then that pulse has a duration of T + DxL seconds after L km of fiber.





Optical Links

- Consider sending a sequence of bits 101010101 … modulated by OOK into a light wave.
- Bits are sent at R bps, i.e. $T = 1/R$.
- Accordingly, after L km, the gaps between the pulses (bits 1) are equal to $T - DxL$.
- If the gap is small, the receiver cannot detect it, e.g. if they are less $\frac{1}{2}$ T.
- Thus the maximum value of L is such that

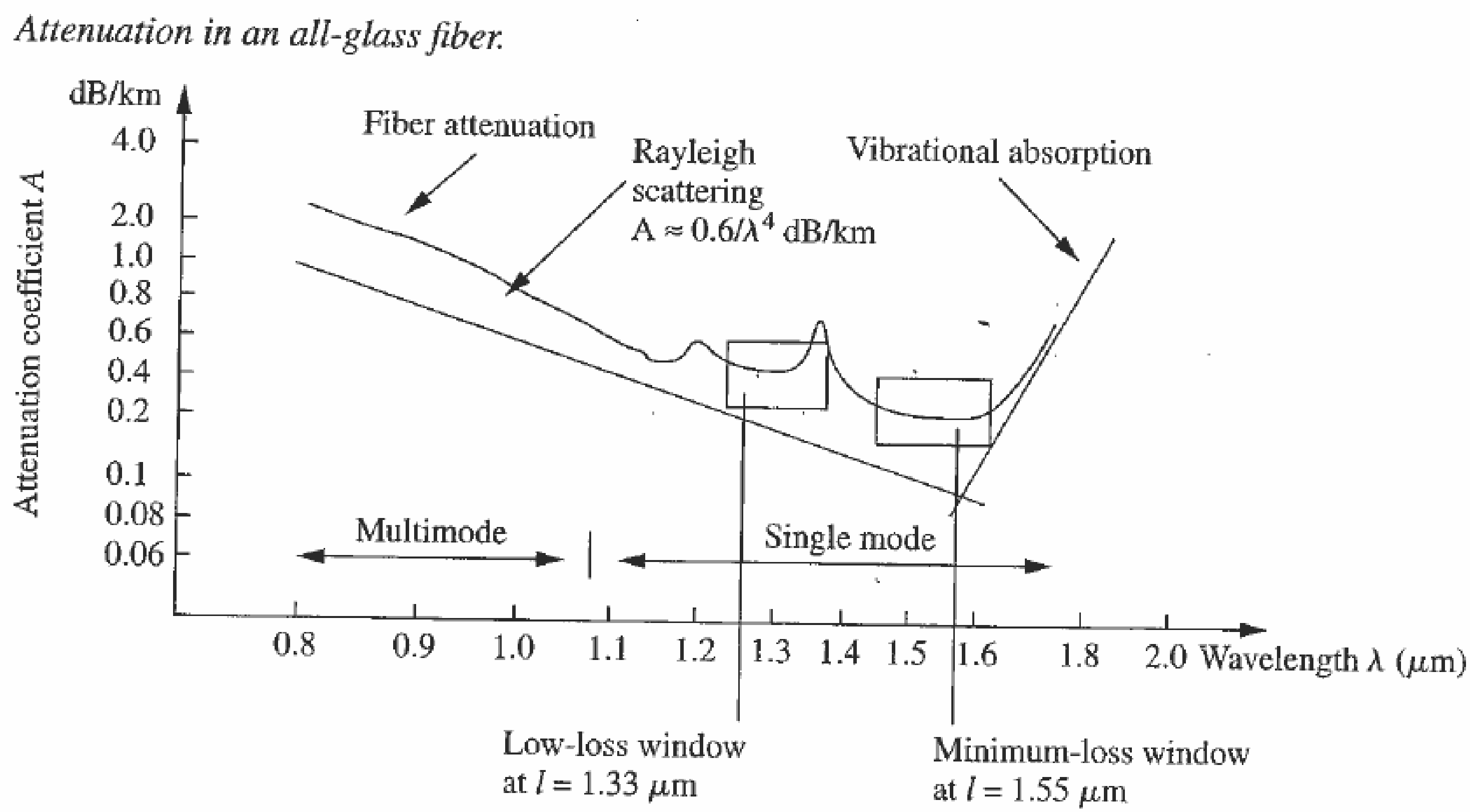
$$DxL < T/2 \text{ or}$$

$$RXL < 1/2D$$

Optical Links

- Attenuation of an all glass fiber as function of the wavelength.

$$P(L) = P(0)x\ 10^{-AL/10} \quad \text{and} \quad 10\log_{10}\{P(0)/(P(L)\} = AL\ \text{dB}$$

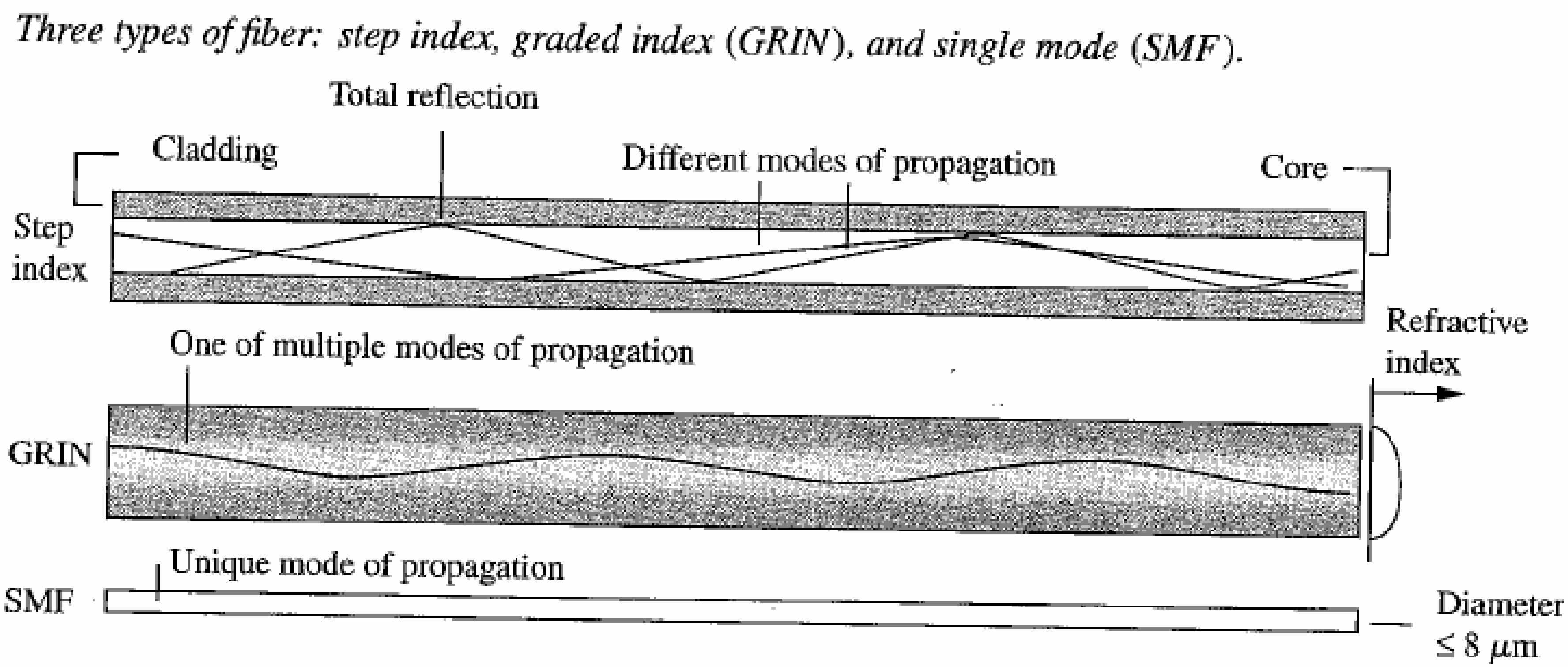


Fiber Types

- Optical fiber is a long cylinder made of plastic or glass.
- Three types of fibers: step index, grade index, and single mode.

Step-index fiber:	RxL < 10 Mbps x km
Graded-index fiber:	RxL < 1 Gbps x km
Single-mode fiber:	RxL < 200 Gbps x km

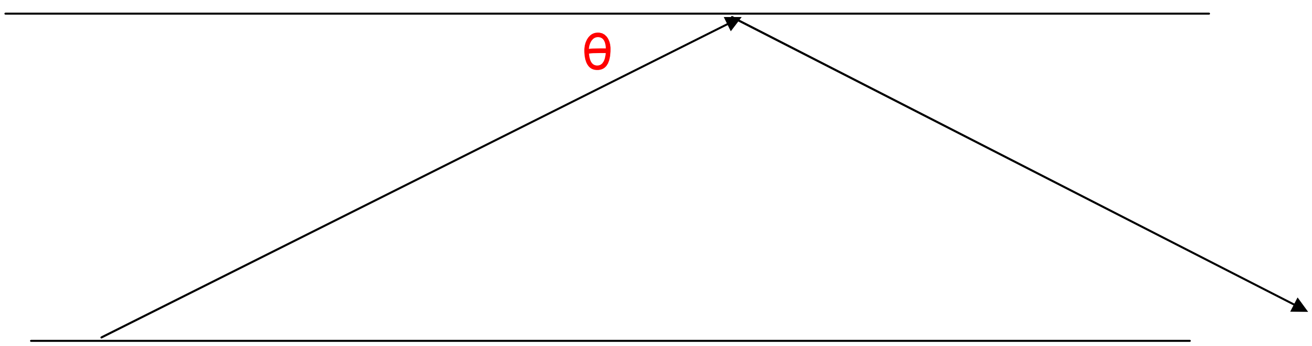
Fiber Types



Three types of fiber: step index, graded index (GRIN), and single mode (SMF).
Total reflection
Cladding
Different modes of propagation
Core
Step index
Refractive index
One of multiple modes of propagation
GRIN
Unique mode of propagation
SMF
Diameter ≤ 8 μm

Propagation in Fibers

- Step-index fiber
  - A step-index optical fiber is a cylindrical core or plastic refractive index n that is rounded by a tube of glass or plastic with slightly smaller refractive index v.



Critical Angle θ: cos θ = v/n : light cannot escapes

Light travels at velocity c/n.

Different distances that different modes cover results in different travel times, which corresponds to some dispersion rate D

Propagation in Fibers

Velocity = c/n

- Ray parallel to the fiber have travel time equal to

  $T1 = 1/Velocity = n/c$ per km of the fiber

- Ray with maximum relfected angle θ covers a maximum distance of $1/\cos\theta$. Hence, the travel time of this ray is

$$T2 = T1/\cos\theta = T1x(n/v).$$

$$D = T2 - T1 = (n/c)(n/v - 1)$$

$$D \approx (n-v)/c$$

$$RxL < c/[2(n-v)]$$

Propagation in Fibers

- GRIN Fiber (graded index fiber)
  - The GRIN fiber is manufactured such that the refractive index of the core of a GRIN fiber decreases with the distance from the fiber axis.
  - Rays are subject to continuous refraction and propagate along oscillatory paths.
  - The rays that travel longer distances go through regions of the fiber where the refraction index is smaller and, therfore where the propagation speed is larger. Thus, remarkably, longer distance are compenstated by larger average speeds.
  - The propgation time of the longer rays is similar to the rays which travel closer to the center of the fiber.

  - $RxL < 2cn1/(n1-n2)^2$

n1, n2 are refractive index at the center of the fiber and at the periphery of the fiber.

Propagation in Fibers

- Single-Mode Fiber
  - Radius is small -> multimode transmission is not possible.
  - However, SMF still suffers from material dispersion.
  - Material dispersion is caused by the differences of the refractive index at different wavelengths, which results in different veocity of different wavelengths.
  - A light source emits light consisting of different wavelengths (or frequencies)

$$R \times L < 1/(4\Phi\sigma)$$

σ is the spectral with of the light source.

$\Phi = d^2n(\varepsilon_0)/d\varepsilon^2$: Second derivaties of the refractive index as a function of wavelength ε

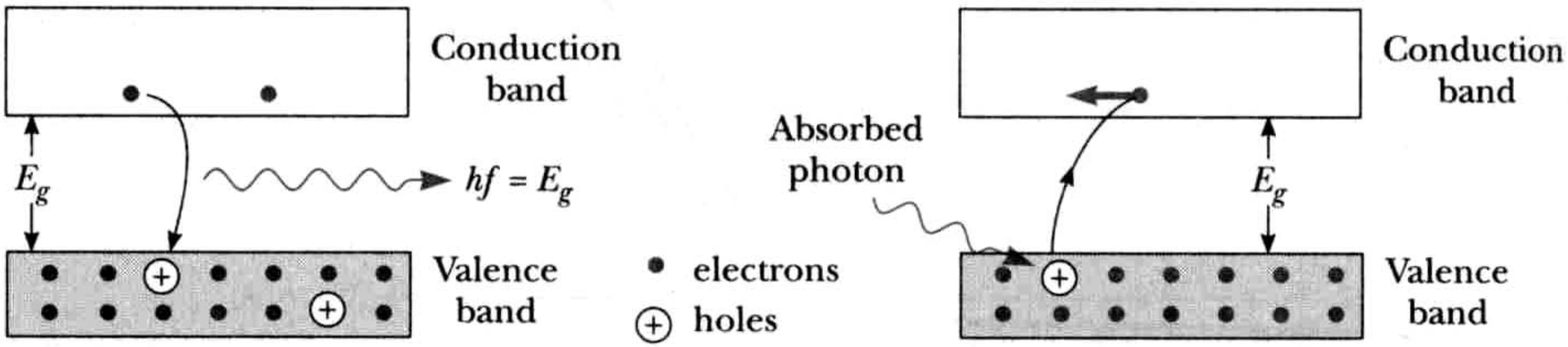
Light Source/Detector

- Optical links use two types of light source: light-emitting diodes (LEDs) and laser diodes (LDs)
- LED: is a PN semiconductor junction.
  - When a LED is connected to a constant current, it produces a light beam with an intensity proportional to the current.
  - Injected electrons cause the recombination of hole-electrons, release energy in the form of light.
  - Few milliwatts of optical power when about 50 mA are injected
  - Electron-hole pairs take sometime to recombine. Limit the modulation rate: 1 to 100 MHz.
- LD:
  - Modulate up to 11 Gbps.
  - Temperature-sensitive.

Light Source/Detector

LED

PN Photodiode



(a) Light emission

(b) Light absorption

Free Space Infrared

- Standardized mainly for computer peripheral connections: keyboard, printer, ...
- Bit rates: 2400 bps, 115 kbps, 1.152 Mbps, 4 Mbps.
- Use OOK (on-off keying)
- Wavelength: 0.86 μm

Copper Line

- Twisted pair: Ethernet, telephone line
- Coaxial cable: cable modem
- Copper line guides eletromagnetic waves, inducing varying currents in the wire.

Twisted Pair

- Two insulated wires arranged in a spiral pattern.
- Copper or steel coated with copper.
- The signal is transmitted through one wire and a ground reference is transmitted in the other wire.
- Typically twisted pair is installed in building telephone wiring.
- Local loop connection to central telephone exchange is twisted pair.

Twisted Pair

- Limited in distance, bandwidth and data rate due to problems with attenuation, interference and noise.

  - Attenuation: At high frequencies, resistivity is high in the line – electrons are pushed toward the peripheral of the conductin materials. Hence, very small current is actually inside the conductor.

  - Cross-talk: due to interference from other signals.

    - "shielding" wire (shielded twisted pair (STP)) with metallic braid or sheathing reduces interference.
    - "twisting" reduces low-frequency interference and crosstalk.

Twisted Pair

UTP ≡ UNSHIELDED TWISTED PAIR

Category Specifications

EIA/TIA Category Specification provide for the following cable transmission speeds with specifications (Note prior to Jan94 UL and Anixter developed a LEVEL system which has been dropped or harmonized with the CATEGORY system);

Category 1 = No performance criteria
Category 2 = Rated to 1 MHz (used for telephone wiring)
Category 3 = Rated to 16 MHz (used for Ethernet 10Base-T)
Category 4 = Rated to 20 MHz (used for Token-Ring, 10Base-T)
Category 5 = Rated to 100 MHz (used for 100Base-T, 10Base-T)

UL LAN Cable Certification Program - Underwriters Laboratories publication 200-120 30M/3/92, 1992 [characteristics of Cat 3-5 UTP]

voice grade

Category 3 corresponds to ordinary voice-grade twisted pair found in abundance in most office buildings.
Category 5 (used for Fast Ethernet) is much more tightly twisted.

EIA/TIA 568 and ISO/IEC 11801 Wiring Grades

Grade 1 - Unshielded Untwisted wiring.
Commonly called inside wire by the Telco community.

Grade 2 - Unshielded twisted pair (UTP) derived from IBM Type 3 spec.

Category 3 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to **16 MHz.** May be used with 10Base-T, 100Base-T4, and 100Base-T2 Ethernet. (Obsolete)

Category 4 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to **20 MHz.** May be used with 10Base-T, 100Base-T4, and 100Base-T2 Ethernet. (Obsolete)

Category 5 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to **100 MHz.** May be used with 10Base-T, 100Base-T4, 100Base-T2, and 100Base-TX Ethernet.

EIA/TIA 568 and ISO/IEC 11801 Wiring Grades

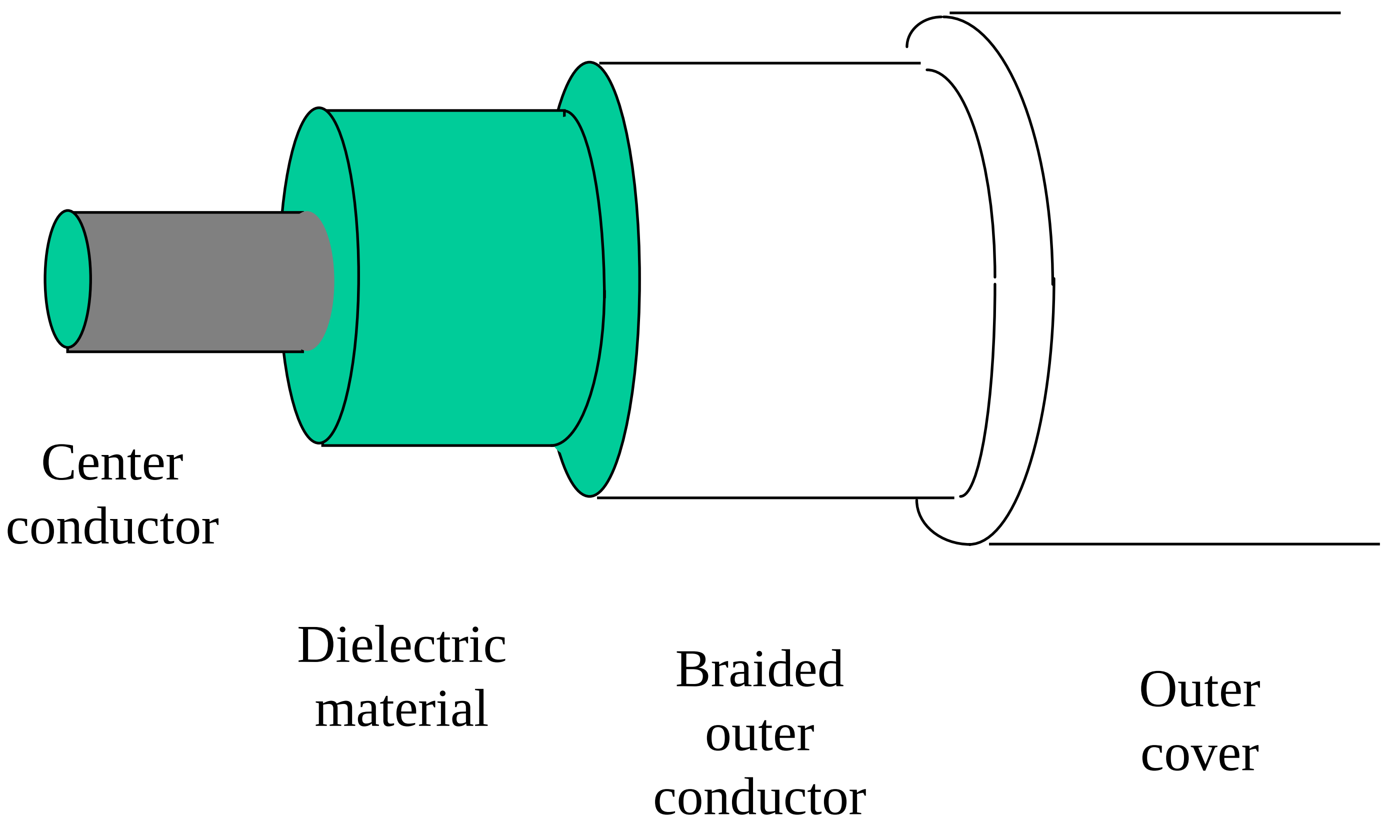
Category 5e - "Enhanced Cat 5" exceeds Cat 5 performance. Very similar to Cat 5, it has improved specifications for NEXT (Near End Cross Talk), PSELFEXT (Power Sum Equal Level Far End Cross Talk), and Attenuation. May be used for 10Base-T, 100Base-T4, 100Base-T2, 100BaseTX and 1000Base-T Ethernet. (Minimum acceptable wiring grade)

Category 6 - In June 2002 TIA approved specification for Cat 6 doubling Cat 5 bandwidth to **250 MHz.** Cat 6 is backward compatible with lower Category grades and supports the same Ethernet standards as Cat 5e. A Cat 6 whitepaper is available from TIA. Currently there are no Ethernet standards that take advantage of Cat 6. ANSI/TIA854 is working on 1000Base-TX. When complete this standard will use two pair in each direction as opposed to all four for 1000Base-T over Cat 5e. This is expected to reduce the cost of Gigabit Ethernet implementations. 1000Base-TX will only operate over Cat6.

Category 7 - Proposed standard to support transmission at frequencies up to

600 MHz over 100 ohm twisted pair.

Coaxial Cable



Coaxial Cable

- Two basic categories for coax used in LANs:
  - 50-ohm cable [**baseband**]
    - Widely used with radio transmitter applications.
  - 75-ohm cable [**broadband or single channel baseband**]
    - 75 ohms: The characteristic impedance 75 ohms is an international standard, based on optimizing the design of long distance coaxial cables. 75 ohms video cable is the coaxial cable type widely used in video, audio and telecommunications applications.
  - Coaxial cable provides much higher bandwidth than twisted pair.
- However, the cable is 'bulky'.
- A bit of impedance at high frequencies.

  - Z = Voltage of the signal/current.
  - Source impedance must be equal to the load impedance in order to achieve maximum power transfer and minimum signal reflection at the destination.
  - In real world case this generally means that the source impedance is the same as cable impedance and the value of the receiver in another end of the cable has also the same impedance.

Notes on Impedance

- Impedance only makes any difference when the length of the cable is a large fraction of a wavelength long for the particular frequency it is carrying.

- An audio frequency of 20,000 Hz has a wavelength of 9,750 meters, so a cable would have to be four or five *kilometers* long before it even began to have an effect on an audio frequency.

- Normal video signal rarely exceed 10 MHz. That's about 20 meters for a wavelength. High resolution computer video signals and fast digita signals easily exceed 100 MHz so the proper impedance matching is needed even in short cable runs.

Baseband Coaxial Cable

- 50-ohm cable is used exclusively for digital transmissions.
- Uses Manchester encoding, geographical limit is a few kilometers.

10Base5 ***Thick Ethernet*** :: thick (10 mm) coax

10 Mbps, 500 m. max segment length, 100 devices/segment, awkward to handle and install.

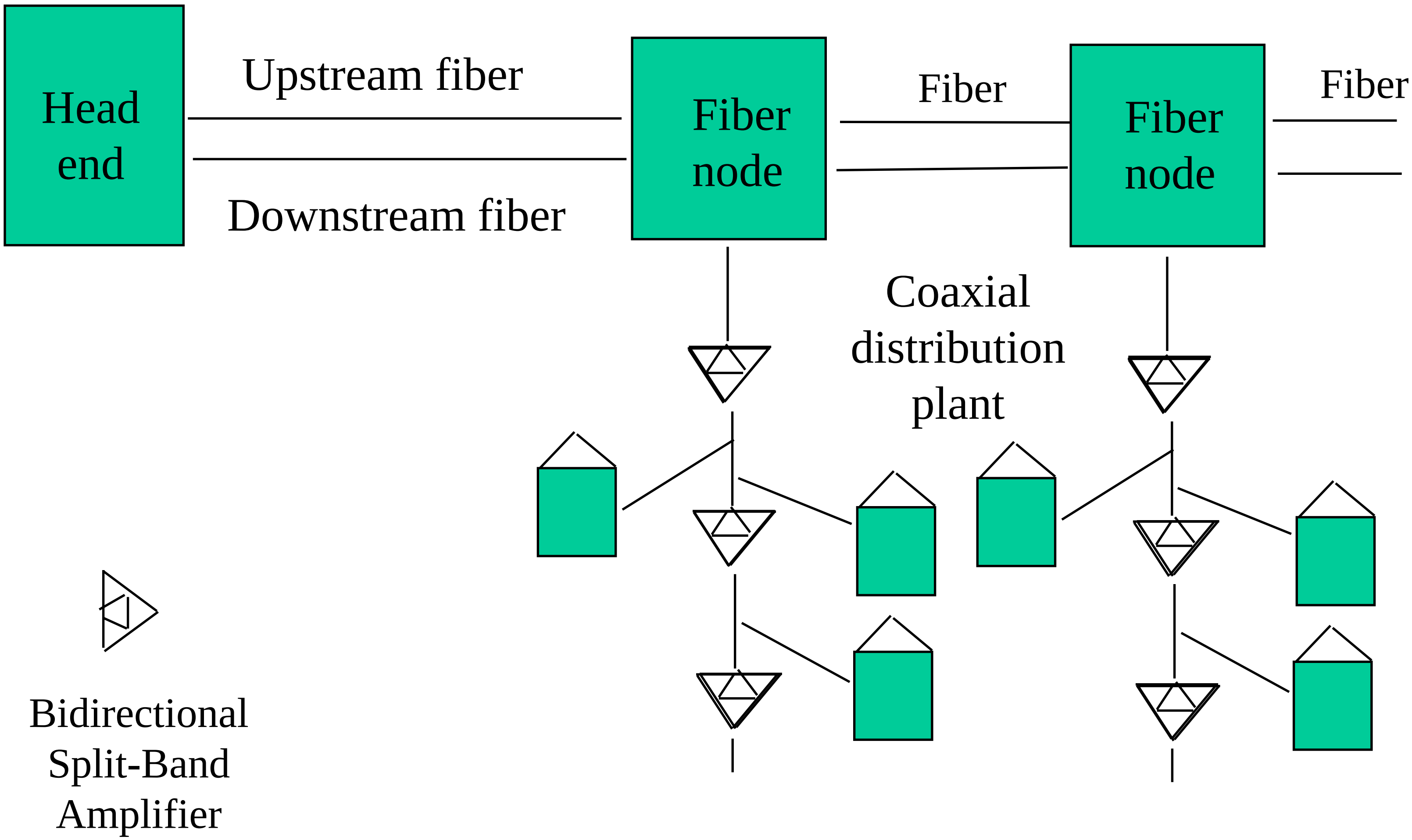
10Base2 ***Thin Ethernet*** :: thin (5 mm) coax

10 Mbps, 185 m. max segment length, 30 devices/segment, easier to handle, uses T-shaped connectors.

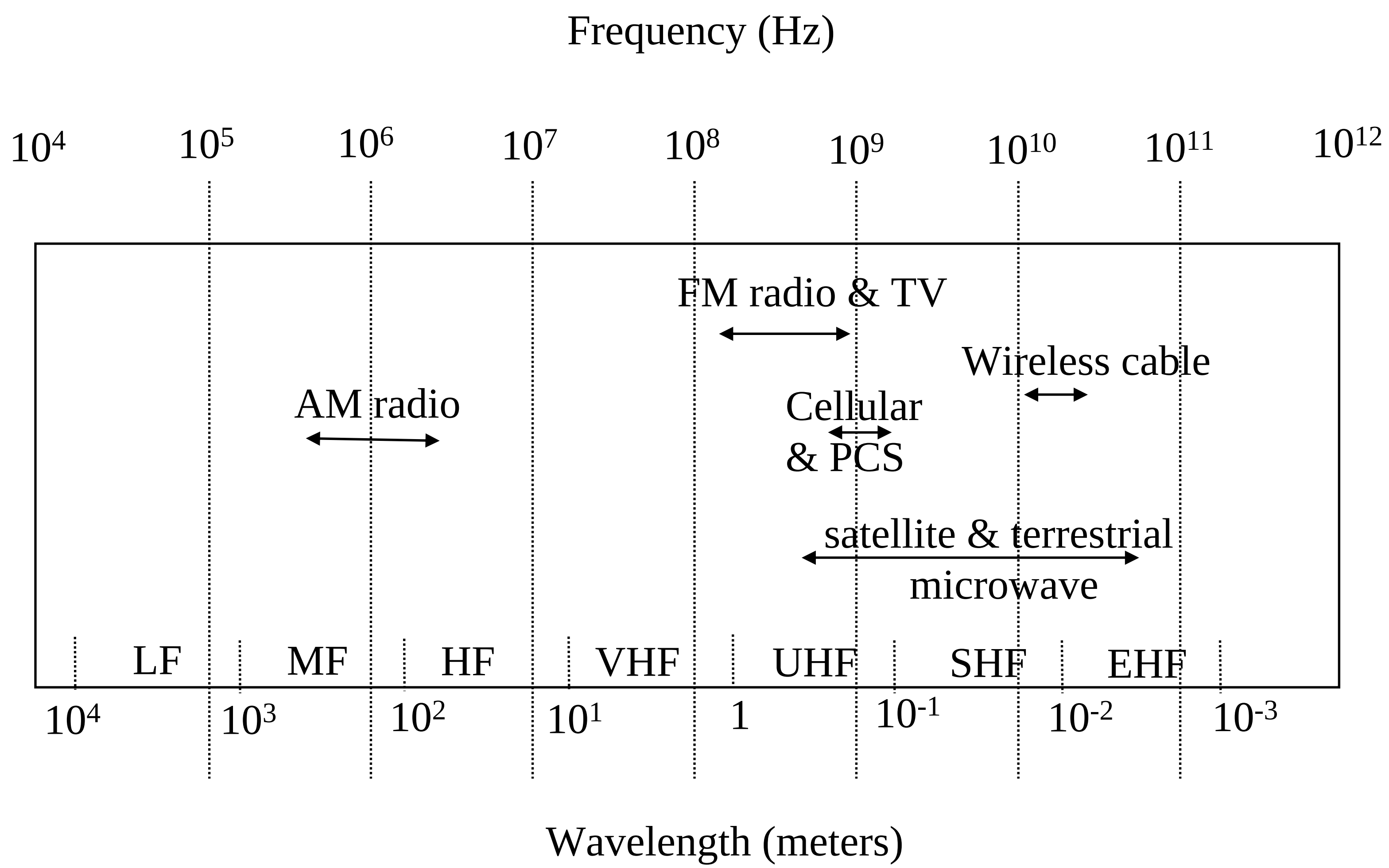
Broadband Coaxial Cable

- 75-ohm cable (CATV system standard).
- Used for both analog and digital signaling.
- Analog signaling – frequencies up to 500 MHZ are possible.
- When FDM used, referred to as ***broadband.***
- For long-distance transmission of analog signals, amplifiers are needed every few kilometers.

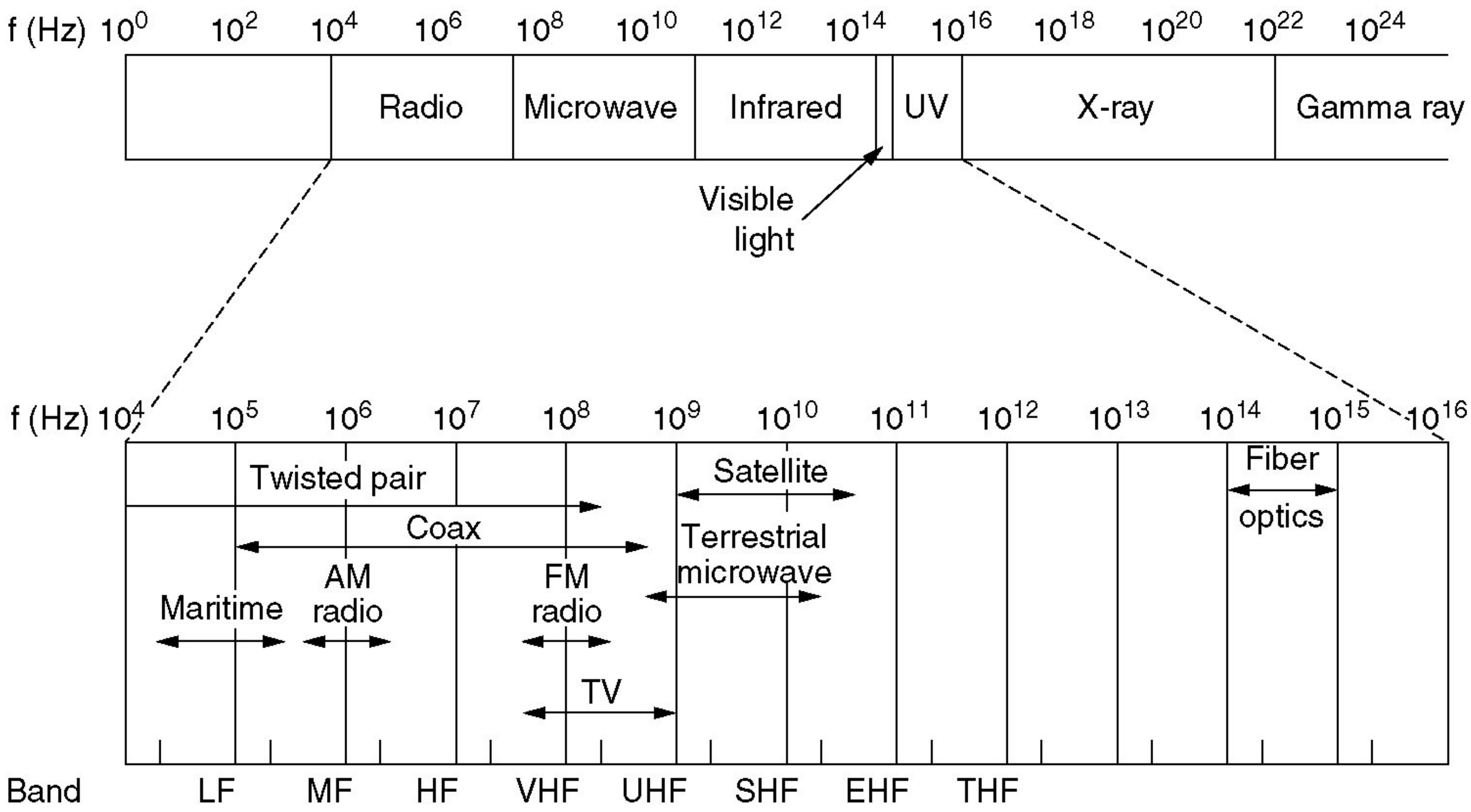
Broadband Coaxial Cable



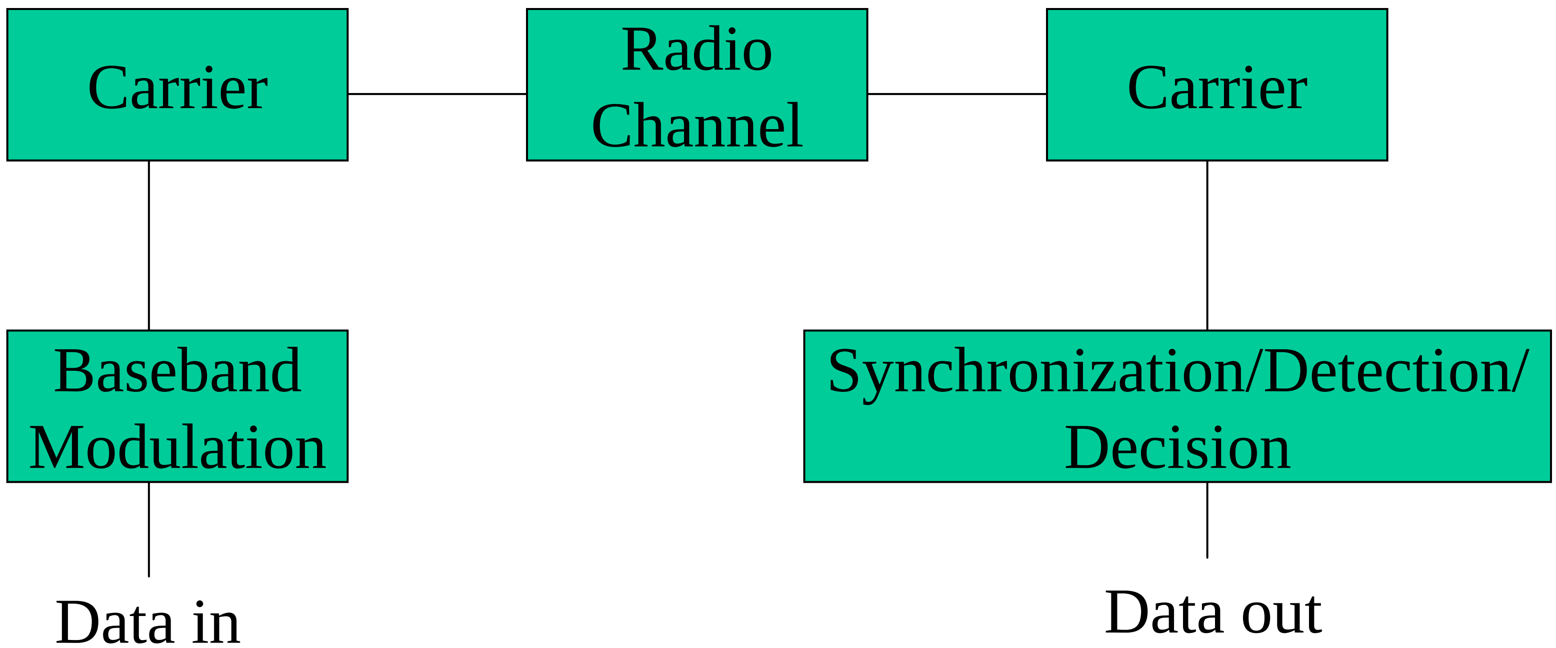
Unguided Electromagnetic Waves



Unguided Electromagnetic Waves



Modulation and Demodulation in Depth



Modulation

- Modulation - process (or result of the process) of translation the baseband message signal to bandpass (modulated carrier) signal at frequencies that are very high compared to the baseband frequencies.

- Demodulation is the process of extracting the baseband message back the modulated carrier.

- An information-bearing signal is non-deterministic, i.e. it changes in an unpredictable manner.

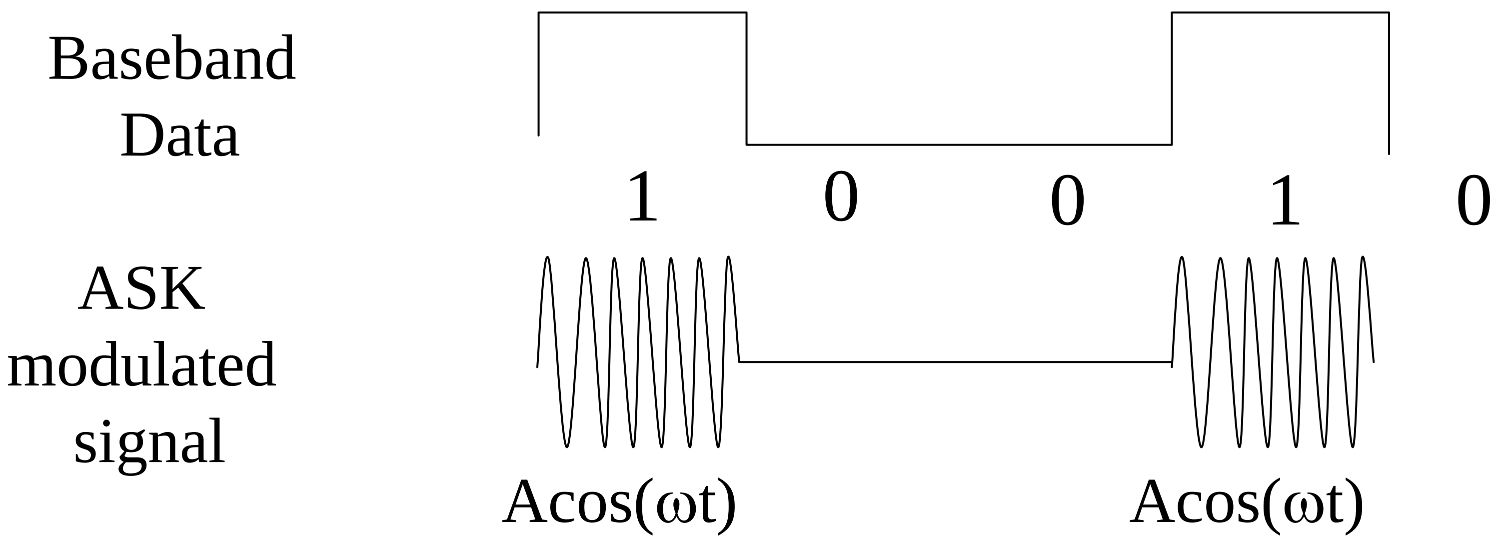
Why Carrier?

- Effective radiation of EM waves requires antenna dimensions comparable with the wavelength:
  - Antenna for 3 kHz would be ~100 km long
  - Antenna for 3 GHz carrier is 10 cm long
- Sharing the access to the telecommunication channel resources

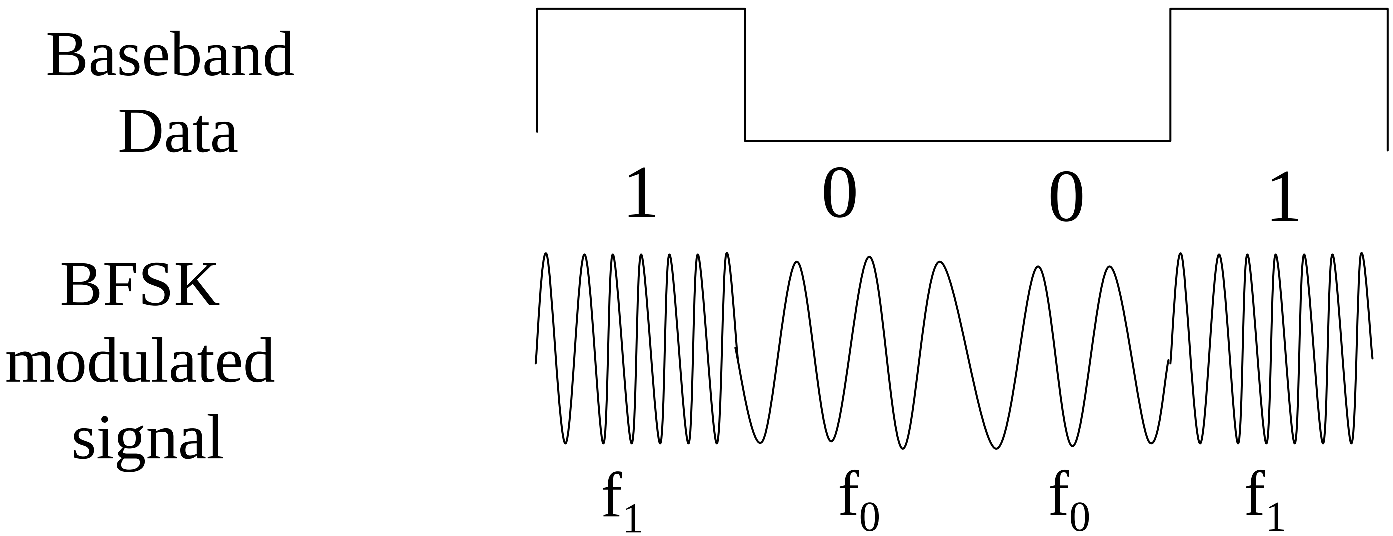
Continuous Carrier

- Carrier: $A \sin[\omega t + \varphi]$
  - A = const
  - ω = const
  - φ = const
- Amplitude modulation (AM)
  - $A = A(t)$ – carries information
  - ω = const
  - φ = const
- Frequency modulation (FM)
  - A = const
  - $\omega = \omega(t)$– carries information
  - φ = const
- Phase modulation (PM)
  - A = const
  - ω = const
  - $\varphi = \varphi(t)$ – carries information

Amplitude Shift Keying (ASK)



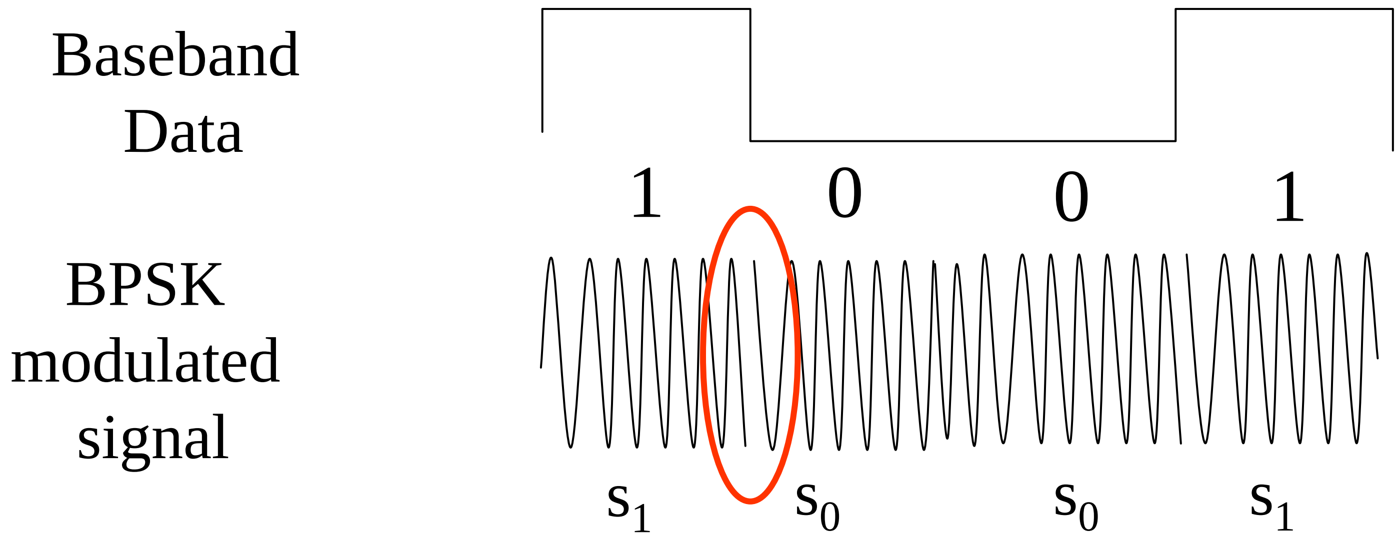
Frequency Shift Keying (FSK)



where $f_0 = A\cos(\omega_c - \Delta\omega)t$ and $f_1 = A\cos(\omega_c + \Delta\omega)t$

- Example: The ITU-T V.21 modem standard uses FSK
- FSK can be expanded to a M-ary scheme, employing multiple frequencies as different states

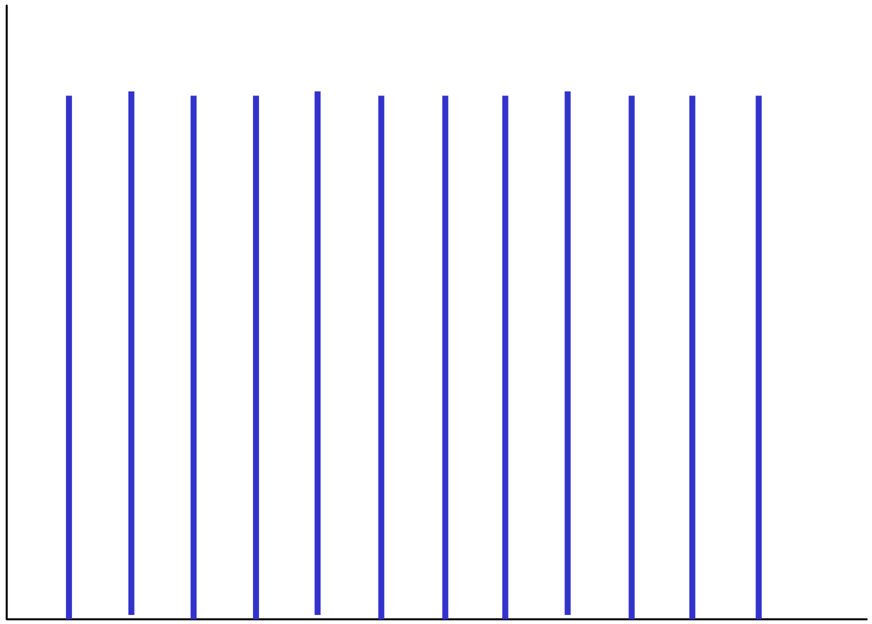
Phase Shift Keying (PSK)



where $s_0 = -A\cos(\omega_c t)$ and $s_1 = A\cos(\omega_c t)$

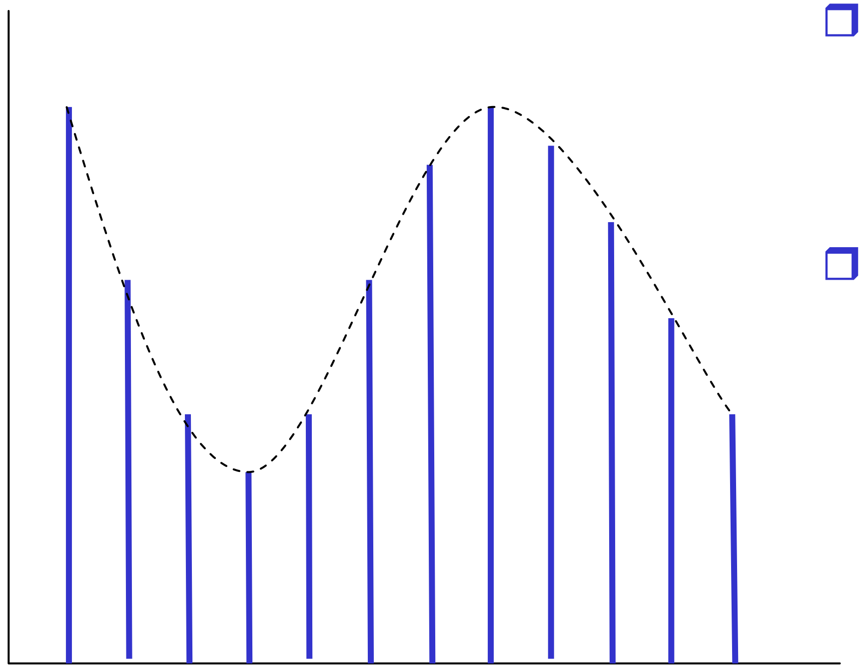
- Major drawback – rapid amplitude change between symbols due to phase discontinuity, which requires infinite bandwidth.
- BPSK can be expanded to a M-ary scheme, employing multiple phases and amplitudes as different states

Pulse Carrier



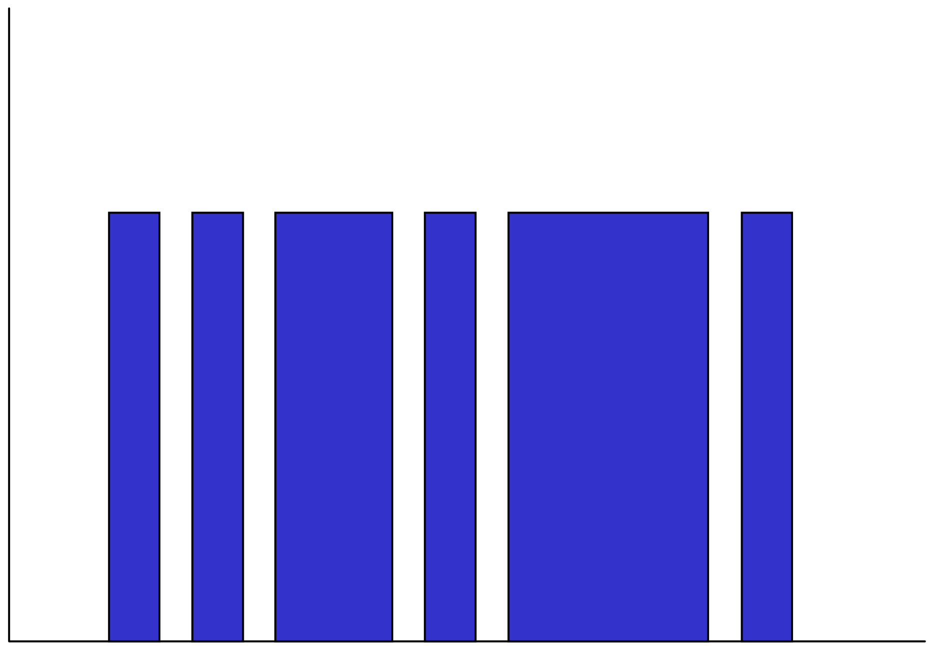
- Carrier:
  A train of identical pulses regularly spaced in time

Pulse-Amplitude Modulation (PAM)



- Modulation in which the amplitude of pulses is varied in accordance with the modulating signal.
- Used e.g. in telephone switching equipment such as a private branch exchange (PBX)

Pulse-Duration Modulation (PDM)

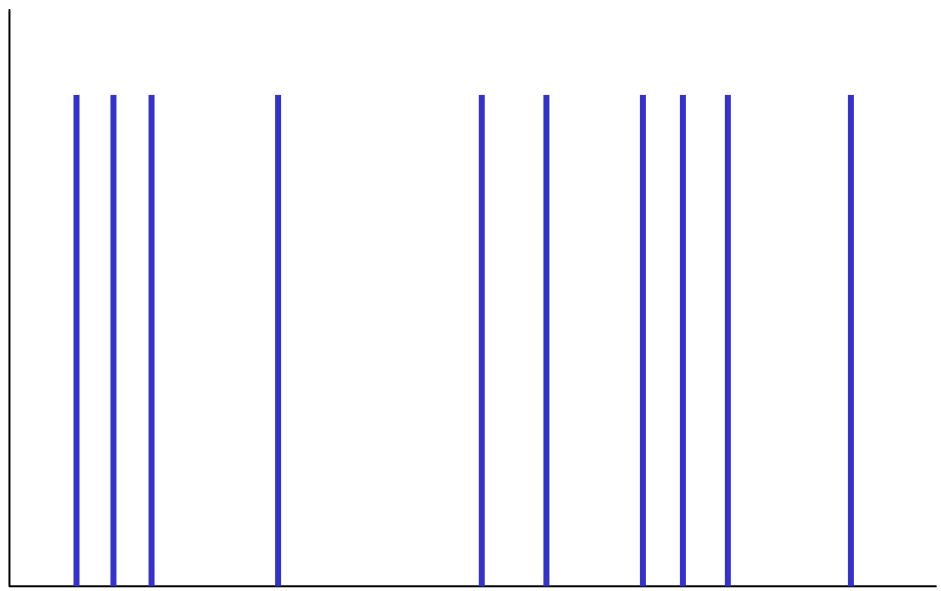


Used e.g. in telephone switching equipment such as a private branch exchange (PBX)

Modulation in which the duration of pulses is varied in accordance with the modulating signal.

Deprecated synonyms: pulse-length modulation, pulse-width modulation.

Pulse-Position Modulation (PPM)



- Modulation in which the temporal positions of the pulses are varied in accordance with some characteristic of the modulating signal.

Ultra-Wideband (UWB) Systems

- Radio or wireless devices where the occupied bandwidth is greater than 25% of the center frequency or greater than 1.5 GHz.

- Radio or wireless systems that use narrow pulses (on the order of 1 to 10 nanoseconds), also called carrierless or impulse systems, for communications and sensing (short-range radar).

- Radio or wireless systems that use time-domain modulation methods (*e.g.,* pulse-position modulation) for communications applications, or time-domain processing for sensing applications.

Demodulation & Detection

- Demodulation
  - Is process of removing the carrier signal to obtain the original signal waveform
- Detection – extracts the symbols from the waveform
  - Coherent detection
  - Non-coherent detection

Coherent Detection

- An estimate of the channel phase and attenuation is recovered. It is then possible to reproduce the transmitted signal and demodulate.
- Requires a replica carrier wave of the same frequency and phase at the receiver.
- The received signal and replica carrier are cross-correlated using information contained in their amplitudes and phases.
- Also known as synchronous detection

Coherent Detection

- Carrier recovery methods include
  - Pilot Tone (such as Transparent Tone in Band)
    - Less power in the information bearing signal, High peak-to-mean power ratio
  - Carrier recovery from the information signal
    - E.g. Costas loop
- Applicable to
  - Phase Shift Keying (PSK)
  - Frequency Shift Keying (FSK)
  - Amplitude Shift Keying (ASK)

Non-Coherent Detection

- Requires no reference wave; does not exploit phase reference information (envelope detection)
  - Frequency Shift Keying (FSK)
  - Amplitude Shift Keying (ASK)
  - Non coherent detection is less complex than coherent detection (easier to implement), but has worse performance.

Geometric Representation

- Digital modulation involves choosing a particular signal $s_i(t)$ form a finite set S of possible signals.
- For binary modulation schemes a binary information bit is mapped directly to a signal and S contains only 2 signals, representing 0 and 1.
- For M-ary keying S contains more than 2 signals and each represents more than a single bit of information. With a signal set of size M, it is possible to transmit up to $log_2 M$ bits per signal.

Example: BPSK

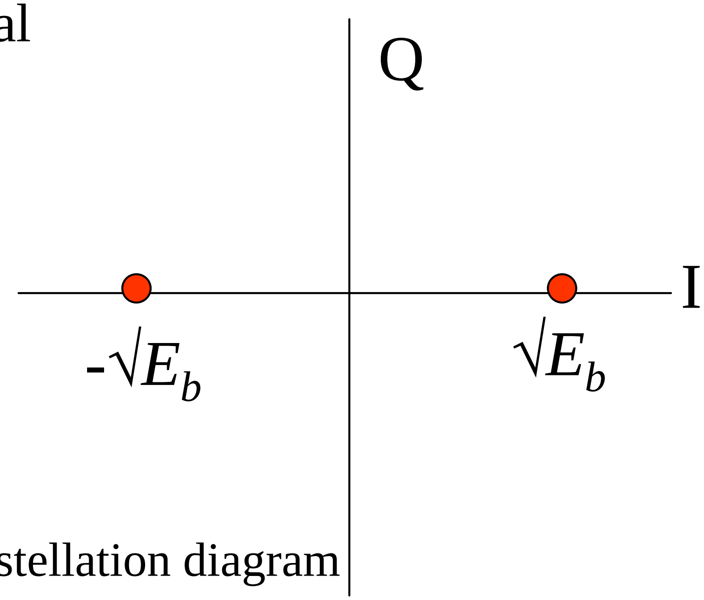
$$S_{BPSK} = \left\{ \left[s_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \right], \left[s_2(t) = -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t); \right] \right\}; \quad 0 \le t \le T_b$$

$E_b =$ energy per bit; $T_b =$ bit period

For this signal set, there is a single basic signal

$$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos(2\pi f_c t); \quad 0 \le t \le T_b$$

$$S_{BPSK} = \left\{ \left[\sqrt{E_b}\,\phi_1(t) \right], \left[-\sqrt{E_b}\,\phi_1(t) \right] \right\}$$

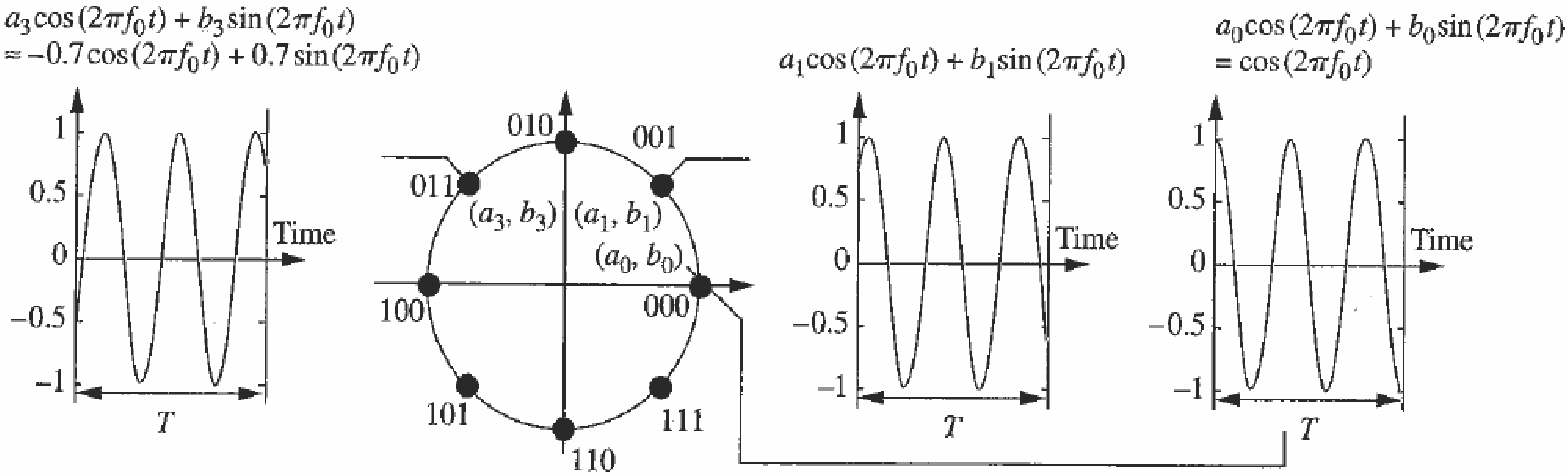


Constellation diagram

Example: QPSK

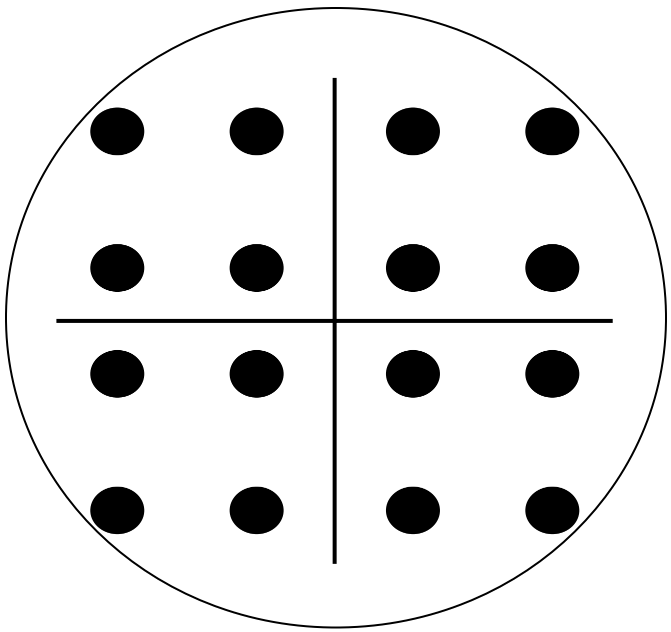
1. Transmitter groups the bits 3 by 3.
2. Each of the 8 possible groups of 3 bits, the transmitter select a pair of number (a_n, b_n) equallly spaced on the unit circle
3. Transmitter then sends the signal $a_n \sin(2\pi f_0 t) + b_n \cos(2\pi f_0 t)$ for T seconds.

QPSK. The transmitter groups the bits 3 by 3. To transmit a 3-bit group, the transmitter sends $a_n \cos(2\pi f_0 t) + b_n \sin(2\pi f_0 t)$ *for T seconds, where the coefficients* (a_n, b_n) *correspond to the group.*



Example: QAM

1. Choose any 2^k points (a_n,b_n) on and inside the unit circle.
2. Each of the coefficients (a_n,b_n) represents a k-bit word.
3. Hence, signal bandwidth is R/k Hz. Reduce the frequency needed!



16 QAM

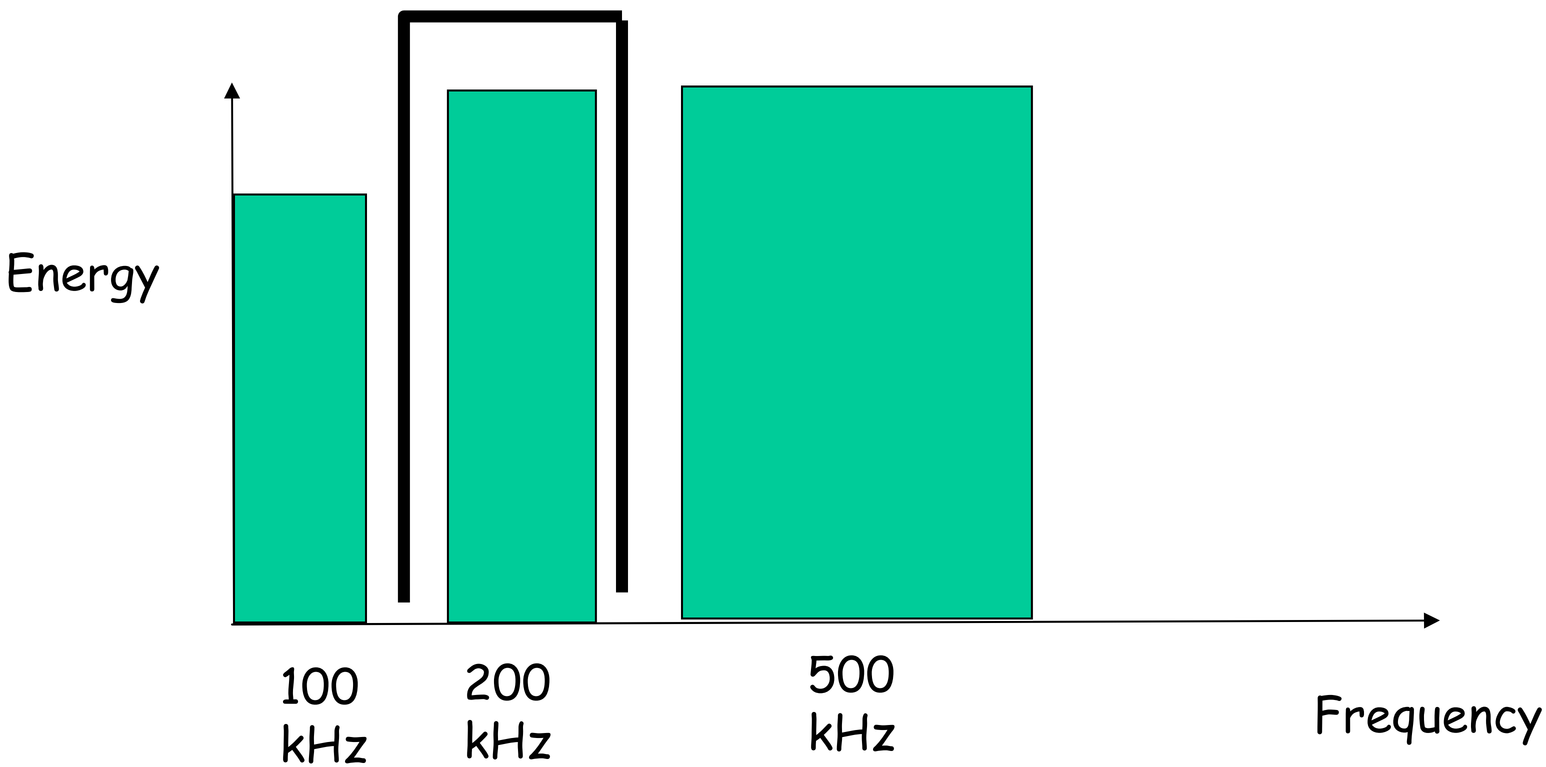
Detecting Received Signal

1. Higher k for QPSK or QAM -> larger bandwidth

2. However, it's not free. It's hard to detect the signal accurately.

Multiplexing

- Different carrier frequencies enables the receiver to select different signals.
- If the signal bandwidth is not overlapped, the selected signal can be recoverred.



Modulation real-life examples

- Telephone Modems:
  - 9.6 kbps (V.32) : QAM 32 points
  - 14.4 kbps (V.332 bis) : QAM 64 points
  - 28.8 kbps: QAM 960 points
  - 33.3 kbps: QAM 1664 points
- Cable modems:
  - Use QPSK

Digital Subscriber Line (DSL) [LG&W p.137]

Telphone companies originally transmitted within the 0 to 4K HZ range to reduce crosstalk. ***Loading coils*** *were added within the subscriber loop to provide a flatter transfer function to further improve voice transmission within the 3K HZ band while increasing attenuation at the higher frequencies.*

ADSL (Asymmetric Digital Subscriber Line)

- Uses existing twisted pair lines to provide higher bit rates that are possible with ***unloaded*** *twisted pairs* (i.e., there are no **loading coils** on the subscriber loop.)

ADSL

the network transmits downstream at speeds ranging from 1.536 Mbps to 6.144Mbps

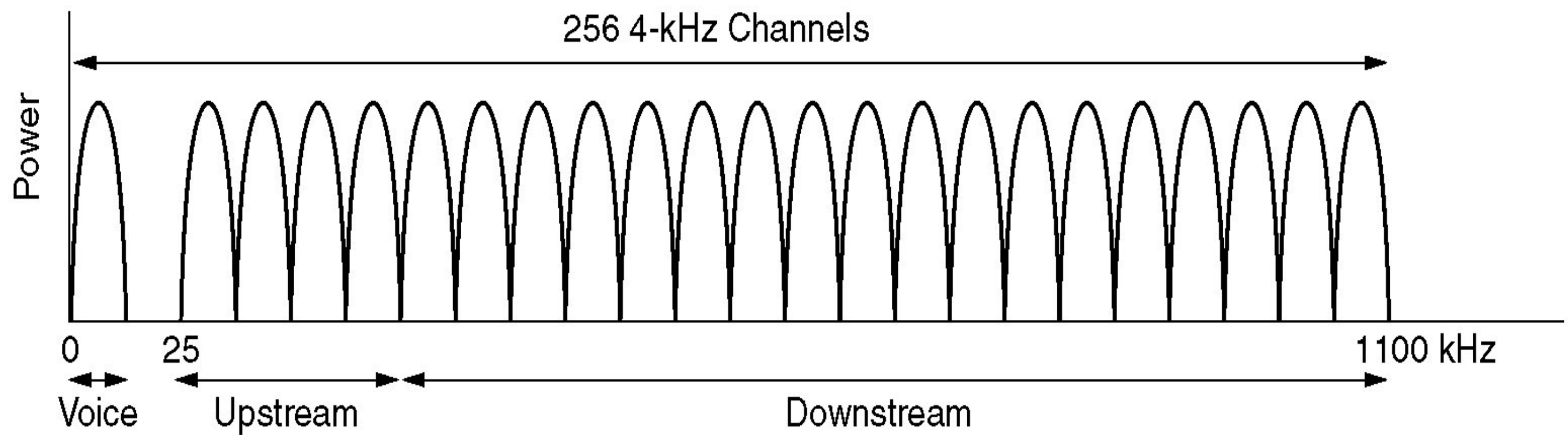
asymmetric
bidirectional
digital transmissions

users transmit upstream at speeds ranging from 64 kbps to 640 kbps

[higher frequencies]

0 to 4K HZ used for conventional analog telephone signals

Asymmetric Digital Subscriber Lines



Operation of ADSL using discrete multitone modulation.
A QAM pulse represents 11 bits is sent per channel.
If the channel is bad, fewer bits can be sent.