IF2230 Jaringan Komputer

Phycsical layer

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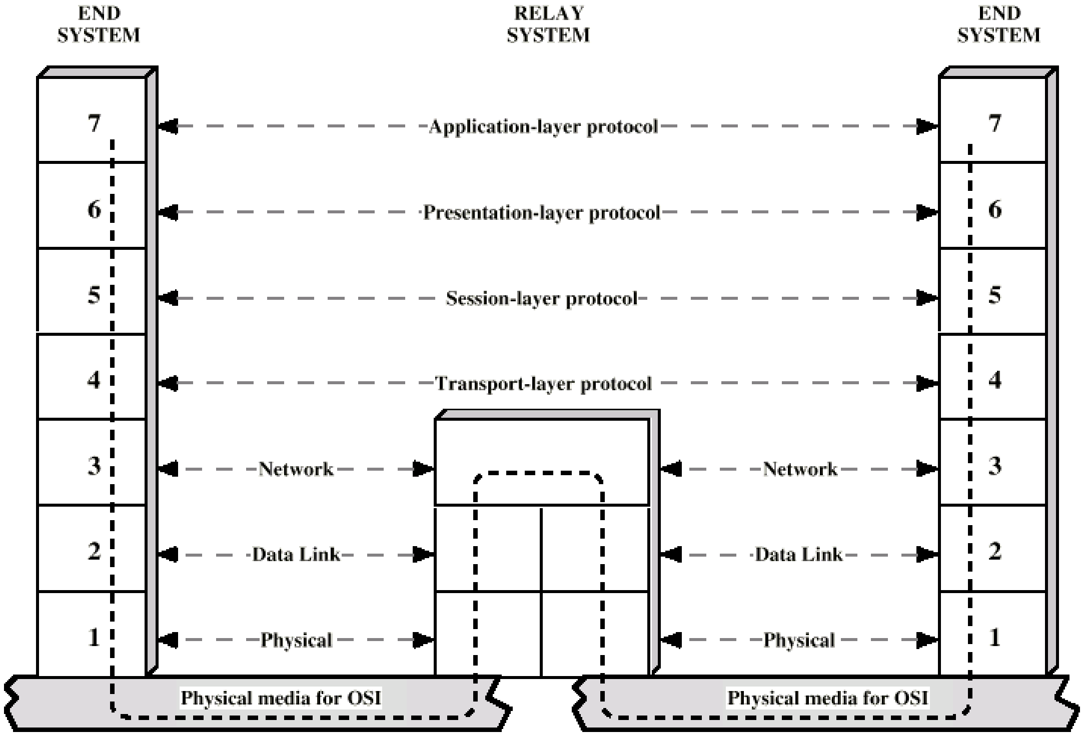
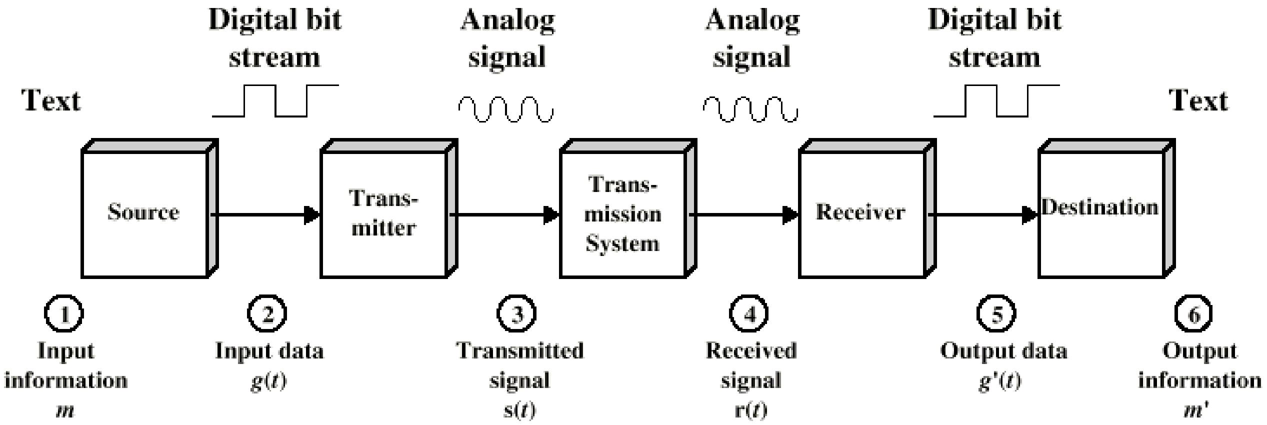
Today’s Lecture

- Dasar teori komunikasi data
- Jenis media transmisi
  - Media transmisi kabel
  - Media transmisi tanpa kabel
- Komunikasi satelit
- Contoh sistem komunikasi:
  - PSTN
  - Sistem telpon mobile
  - TV Kabel

Introduction



Physical layer



Physical Components of a Transmission System

- Transmitter
- Receiver
- Transmission media
  - Guided: cable, twisted pair, fiber
  - Unguided: wireless (radio, infrared)

A Transmission System

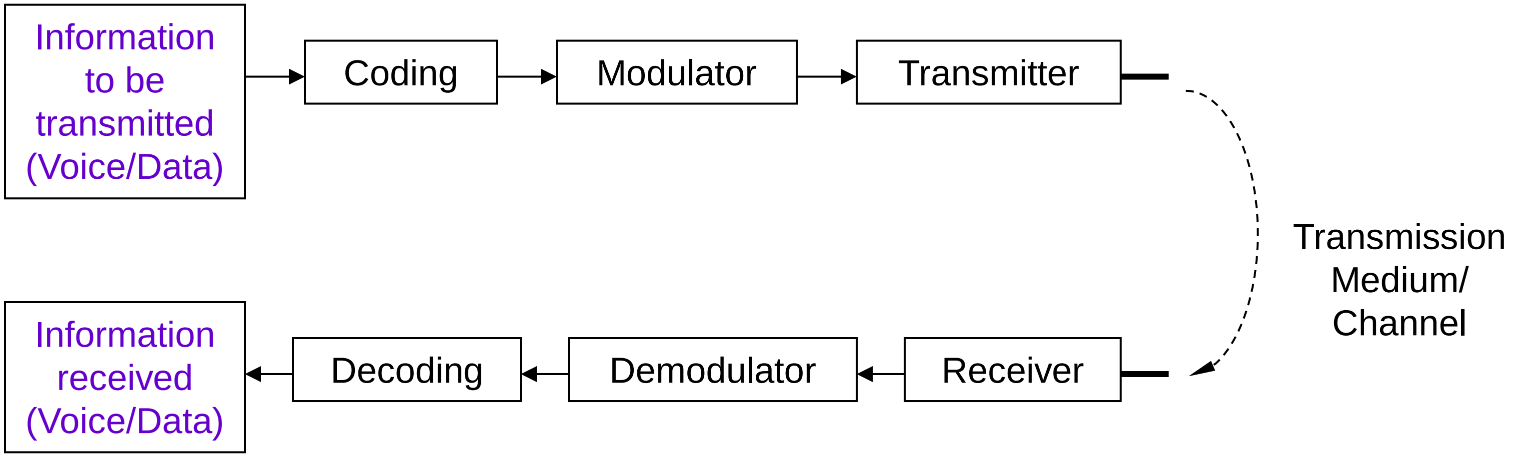
Transmitter

- Converts information into *signal* suitable for transmission
- Injects energy into communication medium or channel
  - Telephone converts voice into electric current
  - Modem converts bits into tones

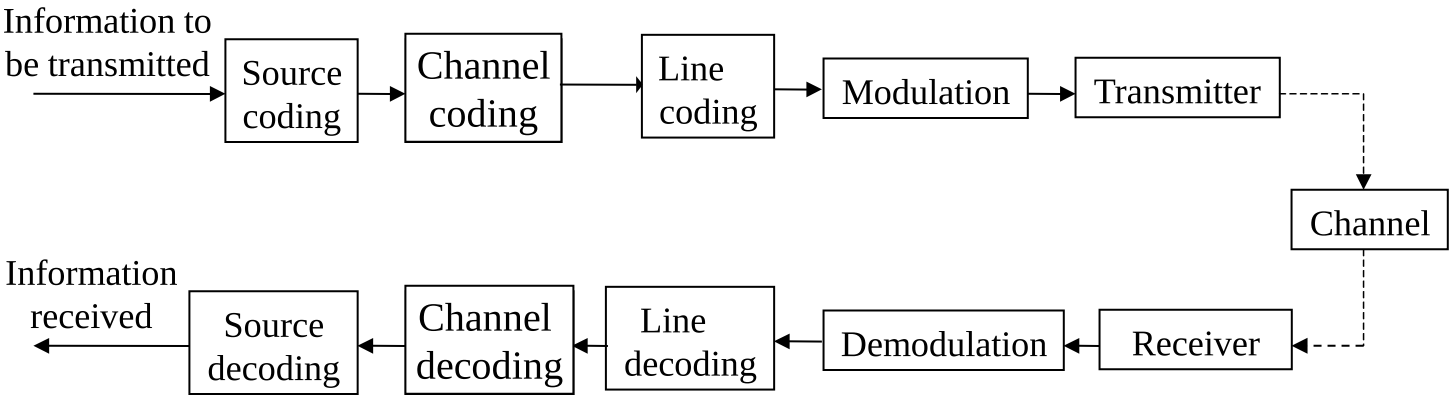
Receiver

- Receives energy from medium
- Converts received signal into a form suitable for delivery to users
  - Telephone converts current into voice
  - Modem converts tones into bits

A Simplified Communication System



What You Need for Better Understanding



Information

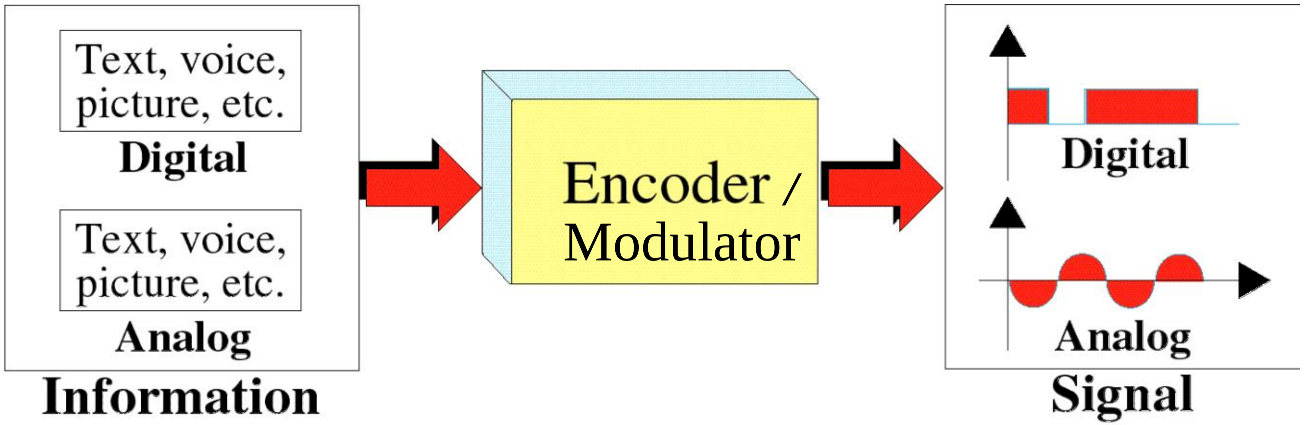
Data vs Signal

- Data:
  - Information units that can be stored in storage devices;
- Signals:
  - Transmission units that can be transmitted over transmission media.
- Data is converted to signal in physical layer.

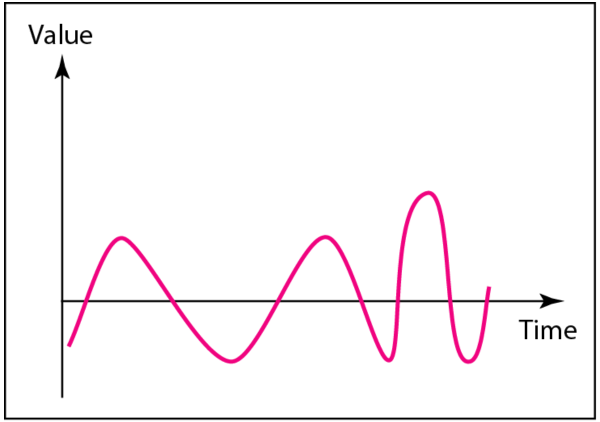
Analog and Digital

- Data can be analog or digital.
  Signals can also be analog or digital
- Analog is something that is continuous, can have infinite values in a range.
- Digital is something that is discrete, can have only a limited number of values.
- Hence, there are
  - Analog and Digital Data
  - Analog and Digital Signals
  - Periodic and Nonperiodic Signals

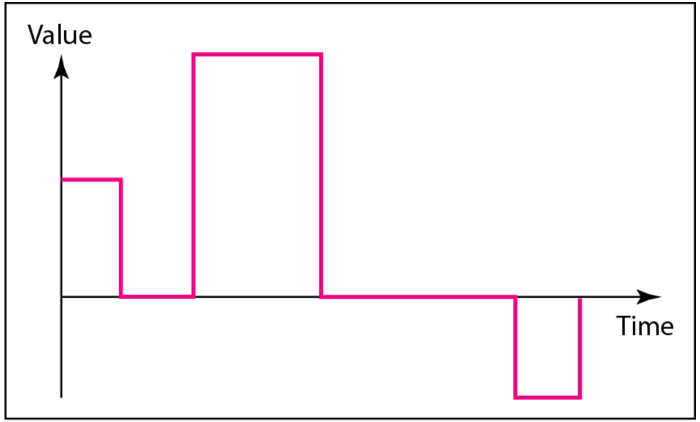
Data to Signal



Analog Signal and Digital Signal

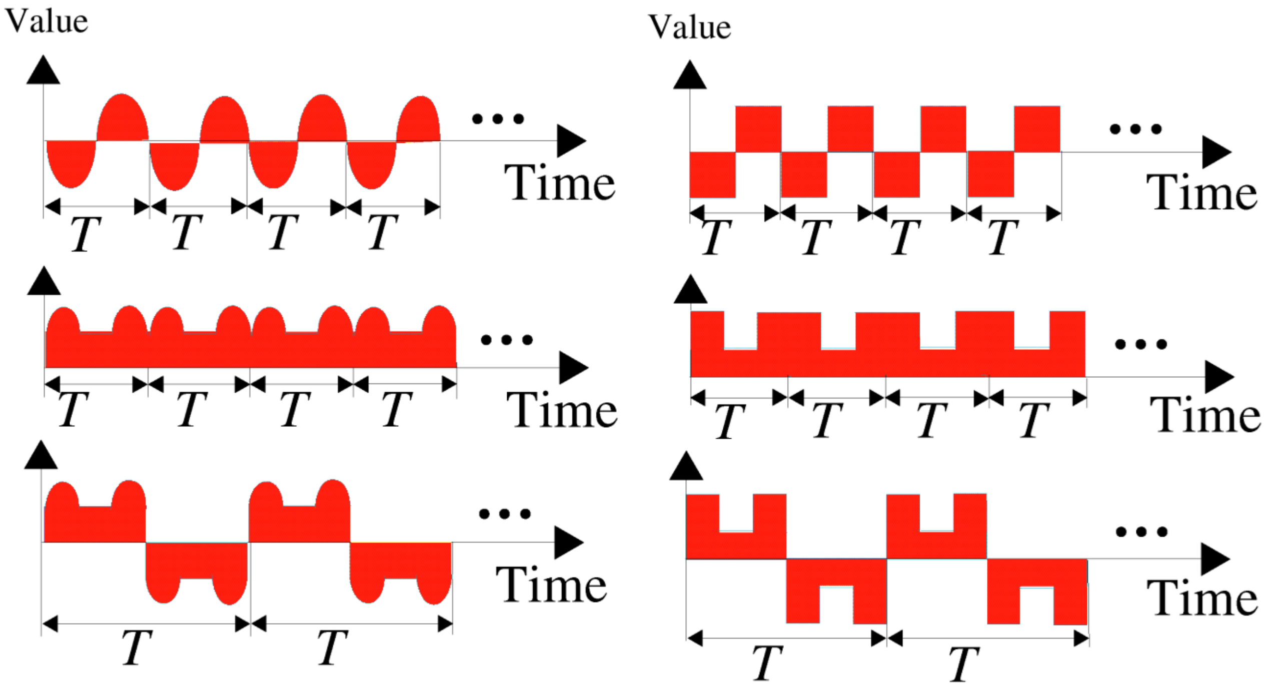


a. Analog signal



b. Digital signal

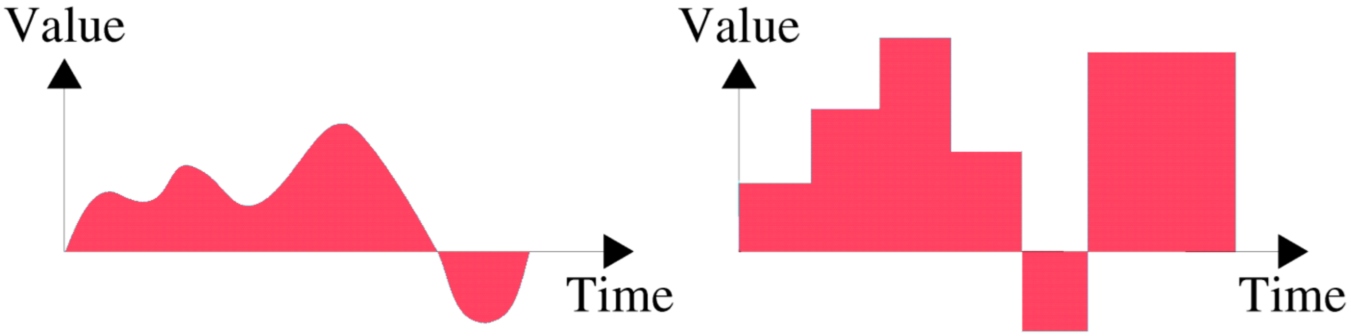
Periodic Signal



a. Analog

b. Digital

Aperiodic Signal



a. Analog

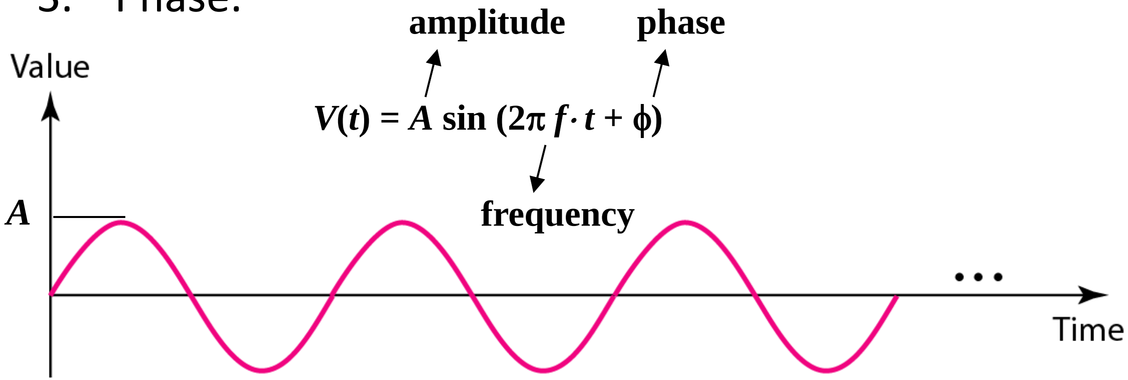
b. Digital

Periodic Analog Signals

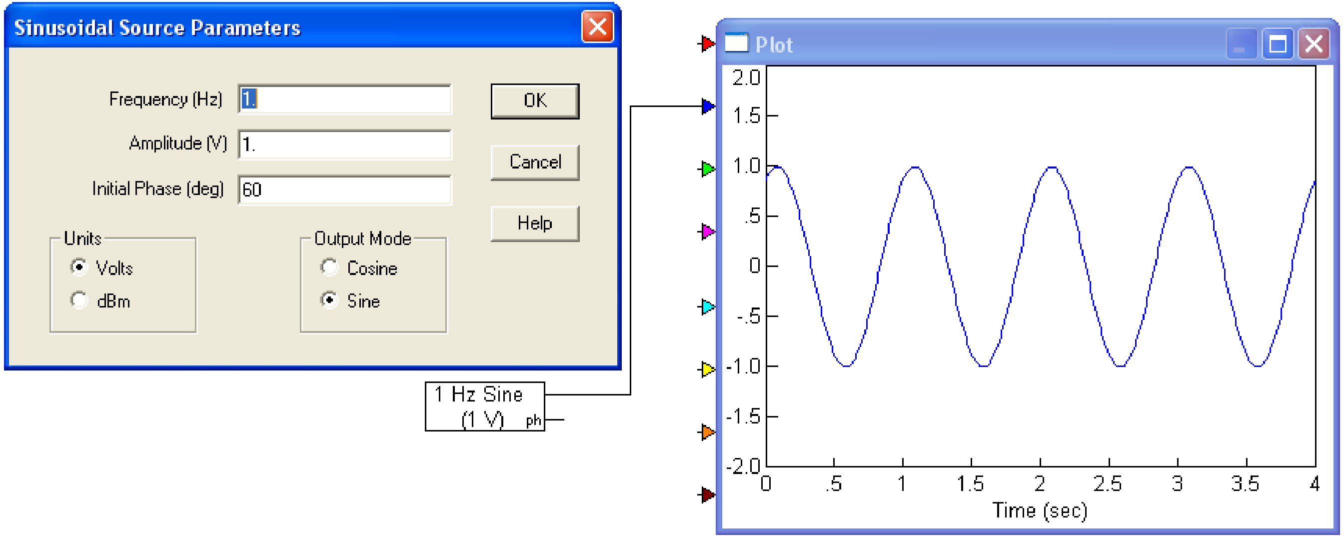
- Analog signals can be classified as simple or composite.
- A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- A composite periodic analog signal is composed of multiple sine waves.
  – Square wave, Triangular wave, Sawtooth wave
  – Fourier series, still remember

Analog Signals

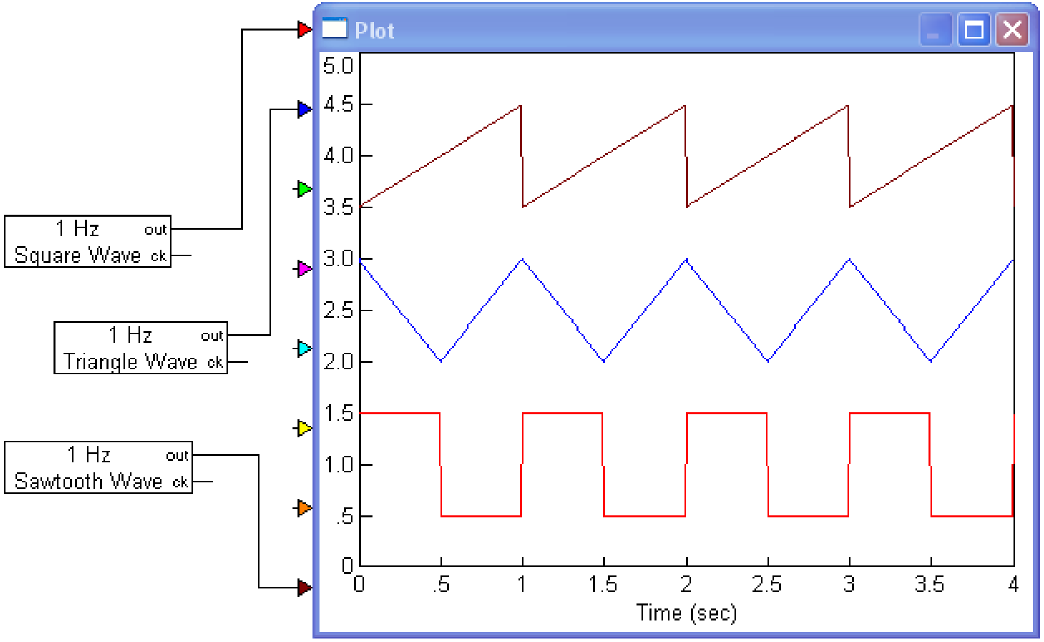
- The sine wave is the most fundamental form of a periodic analog signal.
- Sine waves can be fully described by three characteristics:
  1. Amplitude
  2. Frequency (which is equal to 1/Period)
  3. Phase.



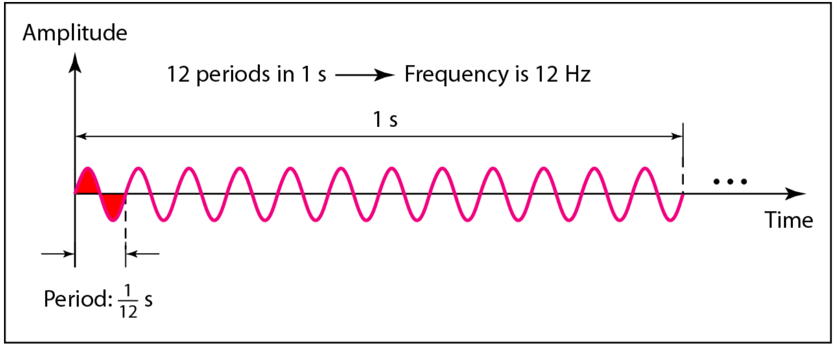
Commsim – Sine Wave



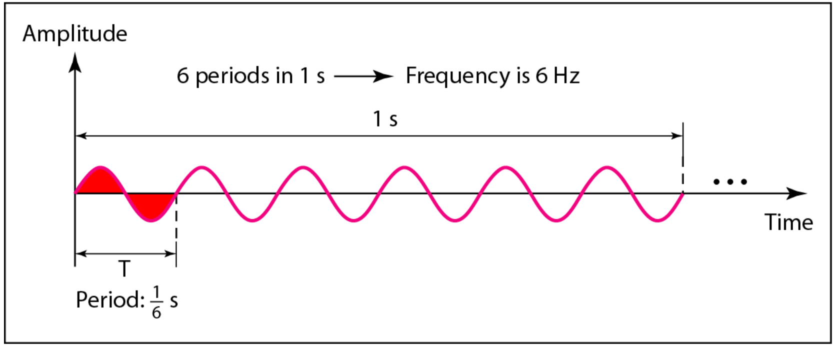
Composite Signals



Frequency and Period



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

$$\boxed{f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}}$$

Example

The power we use at home has a frequency of 60 Hz. The period of this sine wave can be determined as follows:

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166\ \text{s} = 0.0166 \times 10^{3}\ \text{ms} = 16.6\ \text{ms}$$

Example

The period of a signal is 100 ms. What is its frequency in kilohertz?

Solution

First we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz).

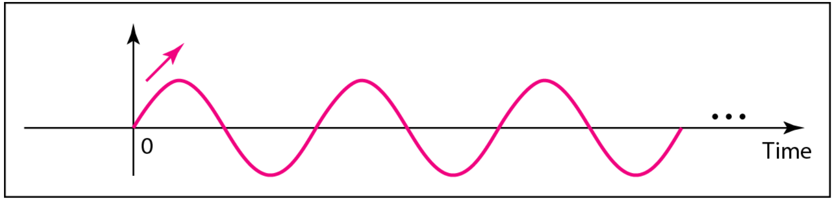
$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

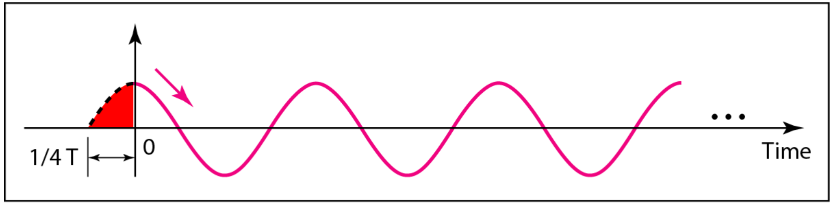
Notes on Frequency

- Frequency is the rate of change with respect to time.
- Change in a short span of time means high frequency.
- Change over a long span of time means low frequency
- If a signal does not change at all, its frequency is zero.
- If a signal changes instantaneously, its frequency is infinite.

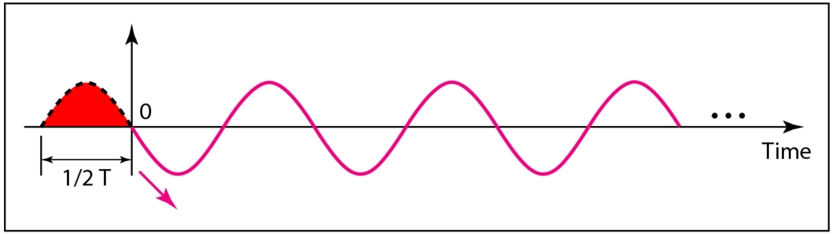
Phase



a. 0 degrees



b. 90 degrees



c. 180 degrees

Example

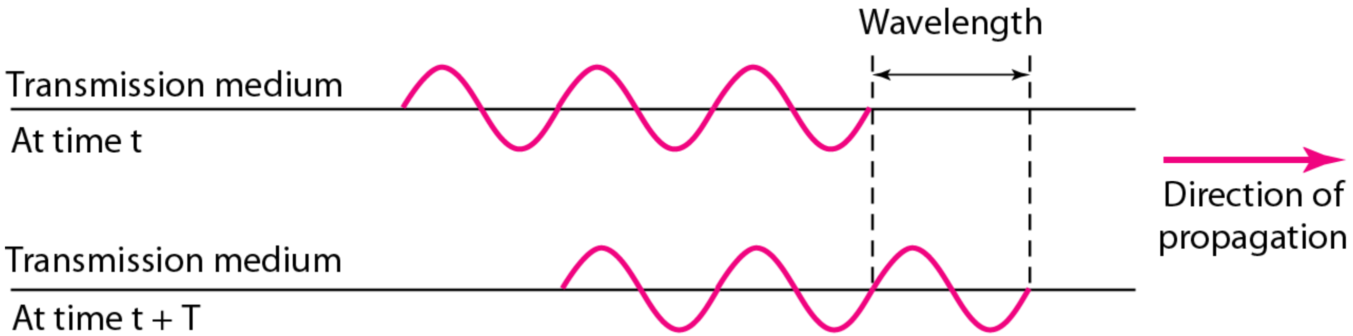
A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

Solution

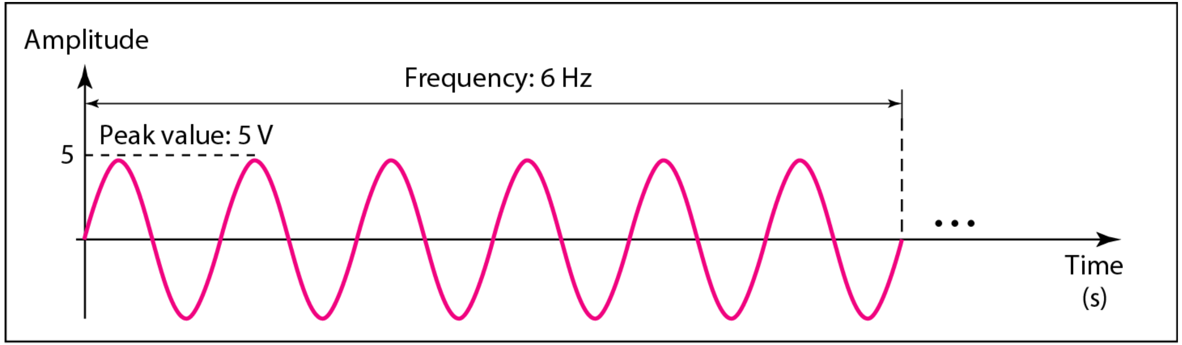
We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is

$$\frac{1}{6} \times 360 = 60^\circ = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}$$

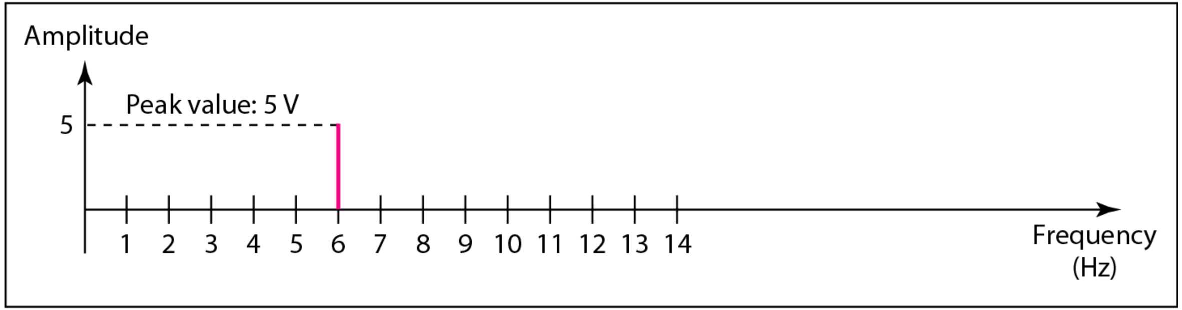
Wavelength and Period



Time & Frequency Domain

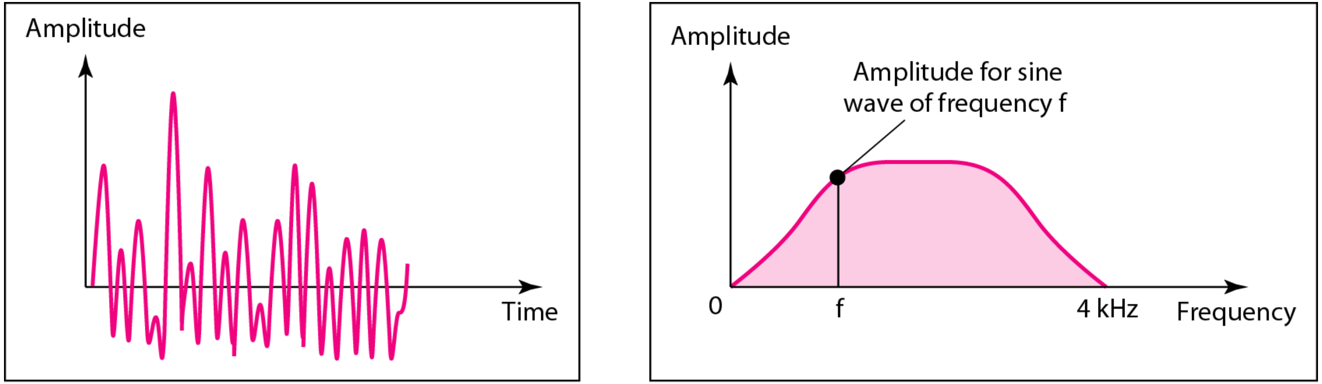


a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

Non-Periodic Signal



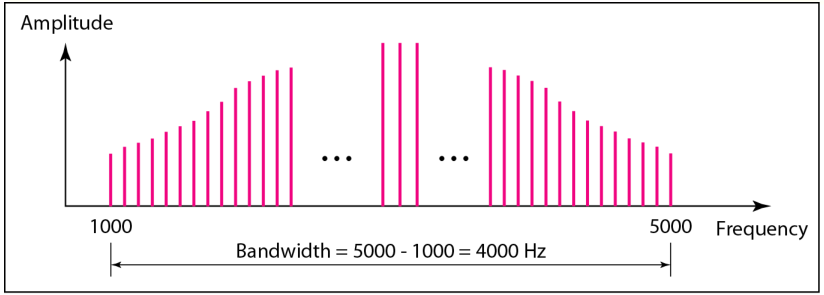
a. Time domain

b. Frequency domain

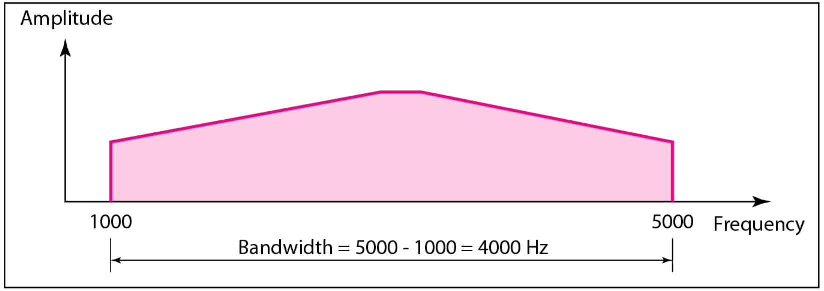
a nonperiodic composite signal. It can be the signal created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.

Bandwidth

- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

Example

If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$\boxed{B = f_h - f_l = 900 - 100 = 800 \text{ Hz}}$$

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz

Example

A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

Solution

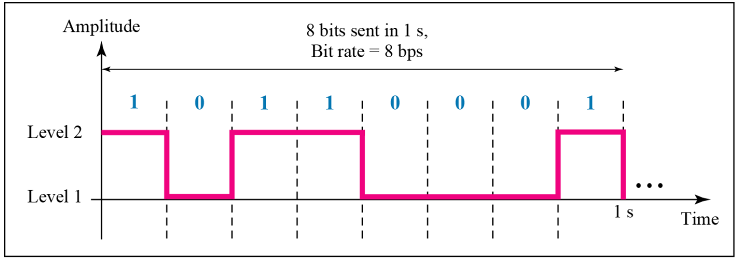
Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l \quad \Rightarrow \quad 20 = 60 - f_l \quad \Rightarrow \quad f_l = 60 - 20 = 40 \text{ Hz}$$

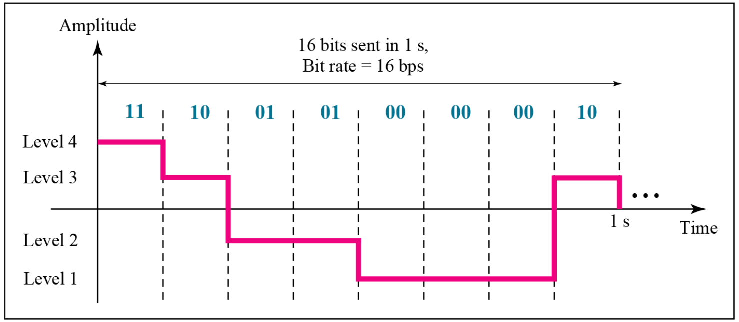
The spectrum contains all integer frequencies. We show this by a series of spikes.

Digital Signal

- In digital signal, a 1 can be encoded as a positive voltage and a 0 as zero voltage.
- A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.
- Bit rate is used to describe digital signals. The bit rate is the number of bits sent in one seconds, expressed in bits per second (bps).



a. A digital signal with two levels



b. A digital signal with four levels

Example

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

Each signal level is represented by 3 bits.

Example

Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel? Given that a page is an average of 24 lines with 80 characters in each line, and one character requires 8 bits.

Solution

$$\frac{100 \times 24 \times 80 \times 8}{60} = 25600 \text{ bps} = 25.6\text{kbps}$$

Example

A digitized voice channel, as we will see in Chapter 4, is made by digitizing an analog voice signal with spectrum from 0 Hz to 4-kHz. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

The bit rate can be calculated as

$$\boxed{2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}}$$

Example

What is the bit rate for high-definition TV (HDTV)?

Solution

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16 : 9. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel.

$$\boxed{1920 \times 1080 \times 30 \times 24 = 1{,}492{,}992{,}000 \text{ or } 1.5 \text{ Gbps}}$$

The TV stations reduce this rate to 20 to 40 Mbps through compression.

Other Definition

bit duration = time period for a bit
= 1 / bit rate

Example*: *A digitized voice channel has a bit rate of 64kbps. Then the duration of each bit is 1/64kbps = 0.000015625 s = 15.625 μs

bit length = distance a bit occupies the medium
= propagation speed $\times$ bit duration

Example*: *In the previous example, suppose that the signal propagation speed in the medium is 2×10^8 m/s, Then the bit length is
2×10^8 m/s $\times$ 0.000015625s = 3125 m = 3.125km

Data Rate Limits

- A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:
  - The bandwidth available
  - The level of the signals we use
  - The quality of the channel (the level of noise)

Nyquist Rate

- Nyquist bit rate defines the theoretical maximum bit rate:
  - Bit rate = 2 x bandwidth x $\log_2 L$,
  - bandwidth is the analog bandwidth, and, L is the signal level.
- Theoretically, if we can have infinitely many levels,
  then we can achieve infinite bit rate.
- But in reality, it can never be achieved because increasing the levels of a signal may reduce the reliability of the system as the noise may more easily corrupt the signals.

Example

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

Example

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

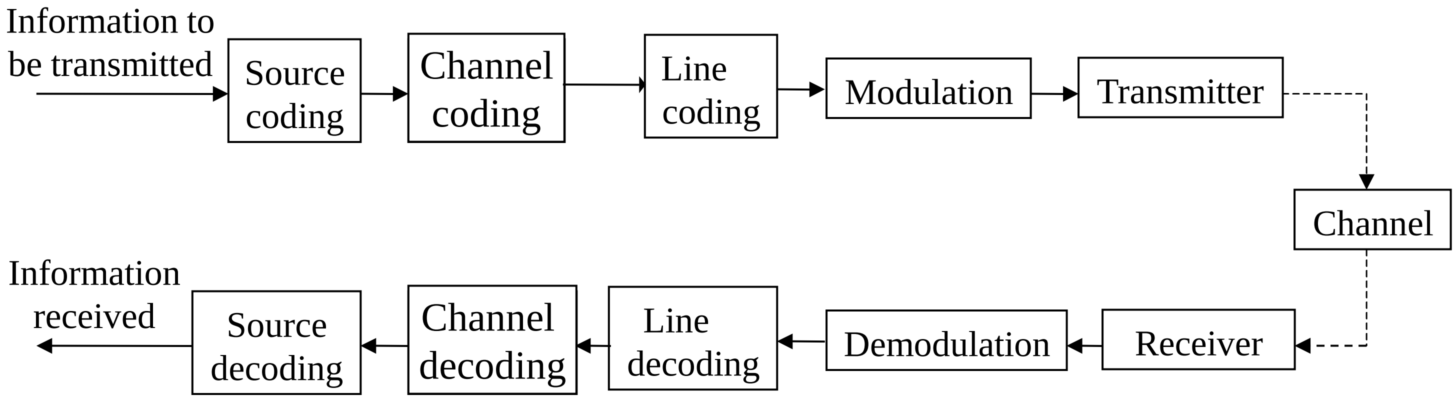
$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Encoding

What You Need for Better Understanding



Encoding

- The first step in turning nodes and links into usable building blocks is to
- understand how to connect them in such a way that bits can be transmitted from one node to the other.
- **Signals propagate over physical links**.
- The task, therefore, is to encode the binary data that the source node wants to send into the signals that the links are able to carry
- At the receiving node, it needs to decode the signal back into the corresponding binary data

Source Coding

- Networks are handling streams of 0’s and 1’
- Source Encoding: compression, according to statistics of 0’s and 1’s, map blocks of bits to more regular “shorter” blocks! Get rid of redundancy
- Source Decoding: inverse of source encoding

Channel Coding

- Channel Encoding: According to channel conditions, add redundancy for more reliable transmission
- Channel decoding: the inverse
- Observation: source encoding attempts to eliminate "useless information", while channel encoding add "useful information"; both deal with redundancies!

Modulation/Demodulation

- Modulation: maps blocks of bits to well-defined waveforms or symbols (a set of signals for better transmission), then shifts transmission to the carrier frequency band (the band you have right to transmit)
- Demodulation: the inverse of modulation
- Demodulation vs. Detection: Detection is to recover the modulated signal from the "distorted noisy" received signals

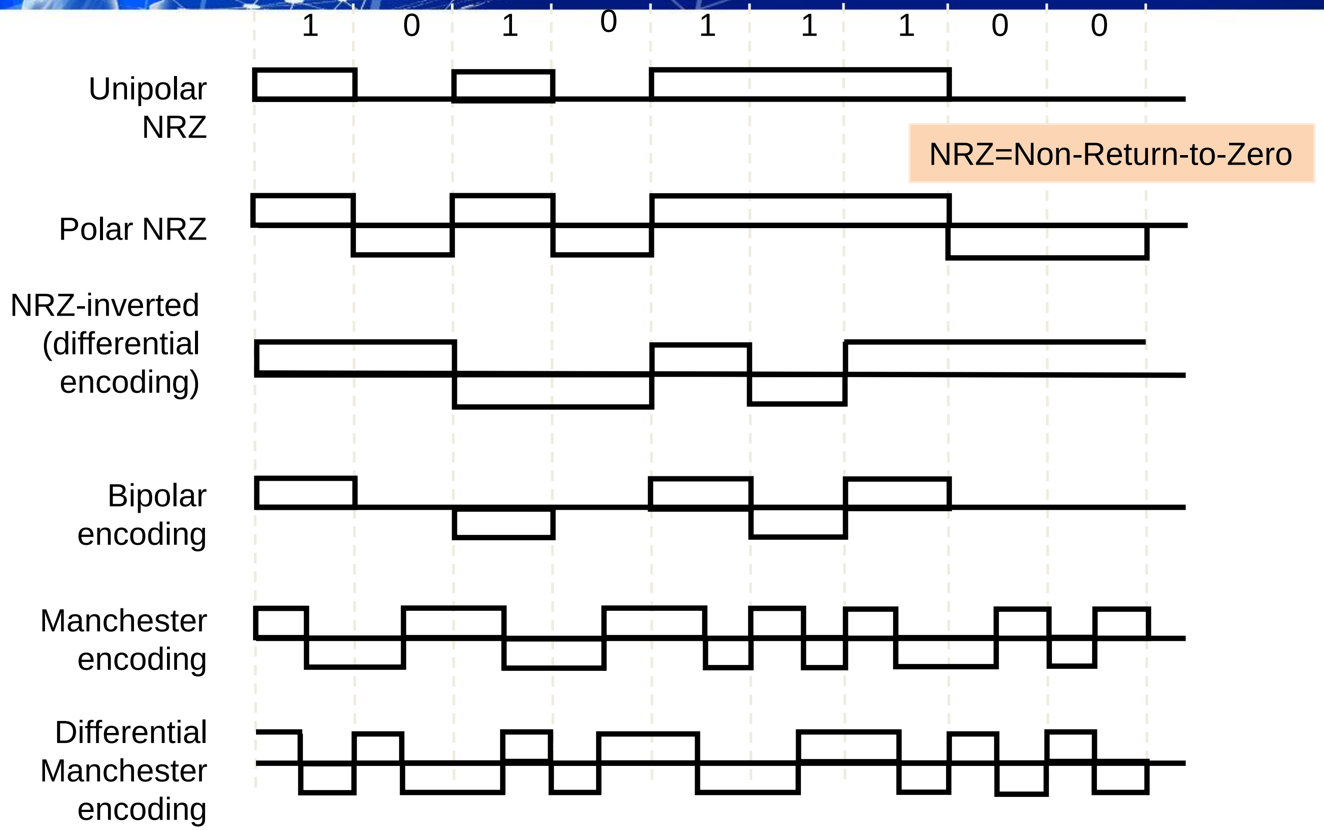
Source vs. Channel vs. Line Coding

- Source coding: eliminating redundancy in order to make efficient use of storage space and/or transmission channels
  - Huffman coding/ Morse code
- Channel coding: a pre-transmission mapping applied to a digital signal or file, usually designed to make error-correction possible
  - Parity check / Hamming code / Reed-Soloman code
- Line coding: performed to adapt the transmitted signal to the (electrical) characteristics of a transmission channel
- Order: source coding -> channel coding -> line coding

What is Line Coding?

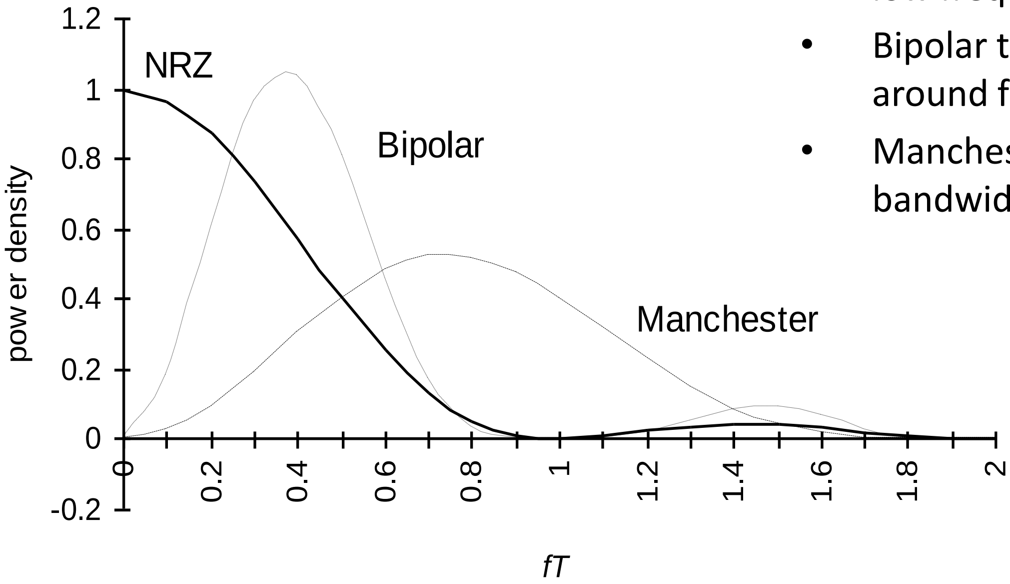
- Mapping of binary information sequence into the digital signal that enters the channel
  - Ex. "1" maps to +A square pulse; "0" to –A pulse
- Line code selected to meet system requirements:
  - *Transmitted power*: Power consumption = $
  - *Bit timing*: Transitions in signal help timing recovery
  - *Bandwidth efficiency*: Excessive transitions wastes bw
  - *Low frequency content*: Some channels block low frequencies
    - long periods of +A or of –A causes signal to "droop"
    - Waveform should not have low-frequency content
  - *Error detection*: Ability to detect errors helps
  - *Complexity/cost*: Is code implementable in chip at high speed?

Line coding examples



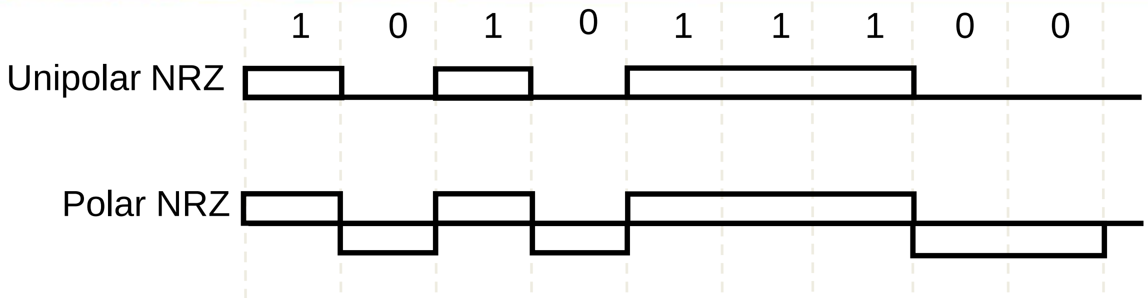
Spectrum of Line codes

- Assume 1s & 0s independent & equiprobable



- NRZ has high content at low frequencies
- Bipolar tightly packed around f=*1*/(2T) or 0.5/T
- Manchester wasteful of bandwidth

Unipolar & Polar Non-Return-to-Zero (NRZ)



Unipolar NRZ

- “1” maps to +A pulse
- “0” maps to no pulse
- High Average Power

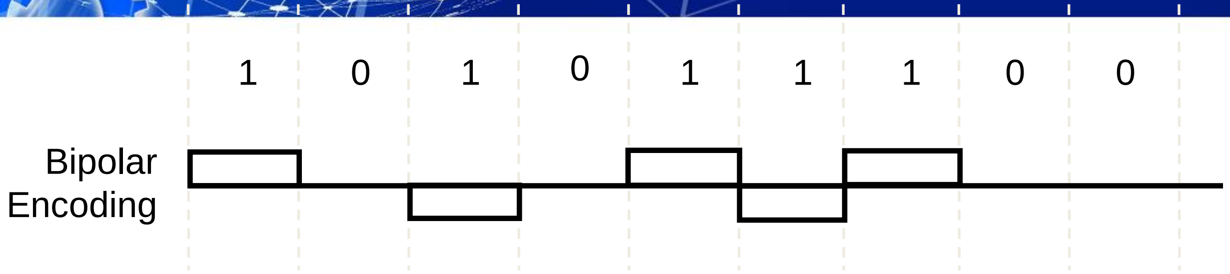
  $0.5*A^2 +0.5*0^2=A^2/2$
- Long strings of A or 0
  - Poor timing
  - Low-frequency content
- Simple

Polar NRZ

- “1” maps to +A/2 pulse
- “0” maps to –A/2 pulse
- Better Average Power

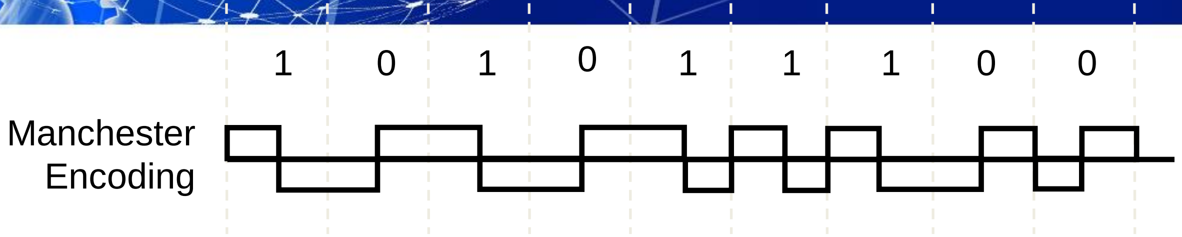
  $0.5*(A/2)^2 +0.5*(-A/2)^2=A^2/4$
- Long strings of +A/2 or –A/2
  - Poor timing
  - Low-frequency content
- Simple

Bipolar Code



- Three signal levels: {-A, 0, +A}
- “1” maps to +A or –A in alternation
- “0” maps to no pulse
  - Every +pulse matched by –pulse so little content at low frequencies
- String of 1s produces a square wave
  - Spectrum centered at around f=*1*/(2T) or 0.5/T
- Long string of 0s causes receiver to lose synchronization
- Zero-substitution codes are needed

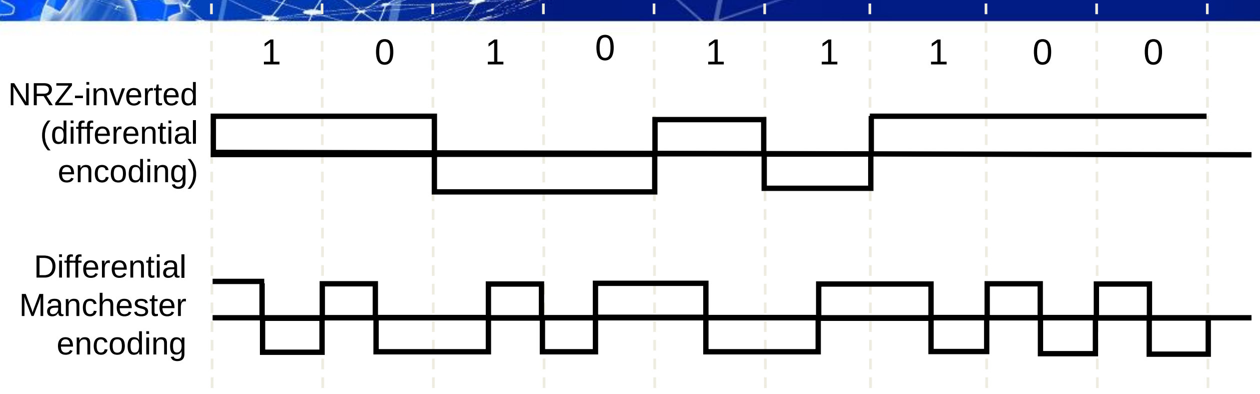
Manchester code & *m*B*n*B codes



- "1" maps into A/2 first *T*/2, -A/2 last T/2
- "0" maps into -A/2 first *T*/2, A/2 last *T*/2
- Every interval has transition in middle
  - Timing recovery easy
  - Uses double the minimum bandwidth
- Simple to implement
- Used in 10-Mbps Ethernet & other LAN standards

- *m*B*n*B line code
- Maps block of *m* bits into *n* bits
- Manchester code is 1B2B code
- 4B5B code used in FDDI LAN
- 8B10b code used in Gigabit Ethernet
- 64B66B code used in 10G Ethernet

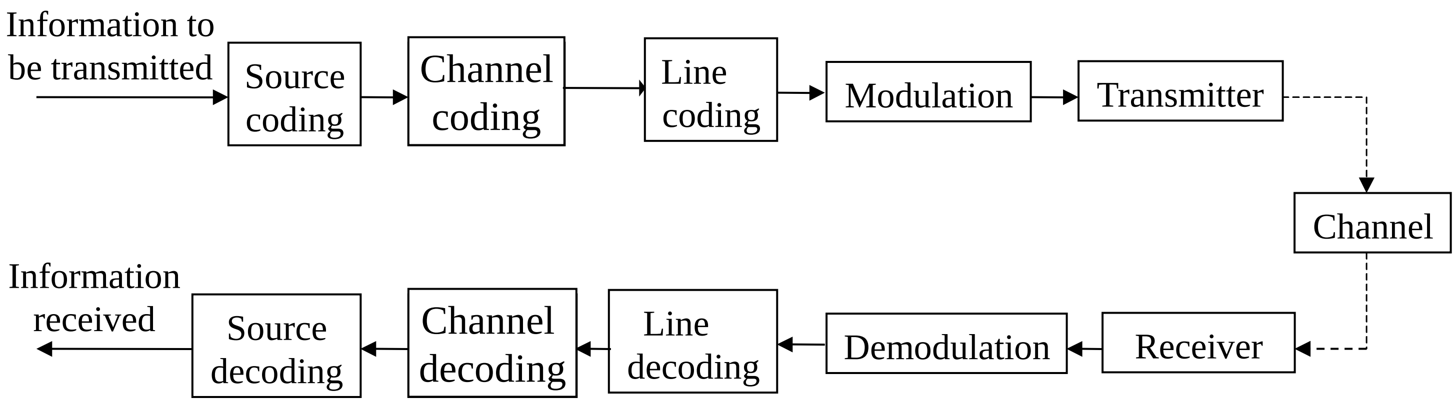
Differential Coding



- Errors in some systems cause transposition in polarity, +A become –A and vice versa
  - All subsequent bits in Polar NRZ coding would be in error
- Differential line coding provides robustness to this type of error
- "1" mapped into transition in signal level
- "0" mapped into no transition in signal level
- Also used along with Manchester coding

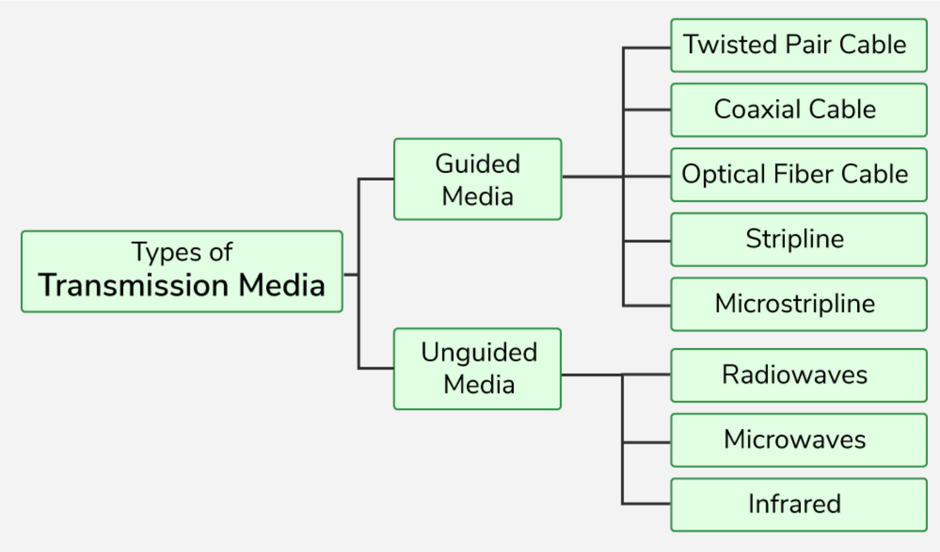
Transmission Medium

What You Need for Better Understanding



Transmission Medium

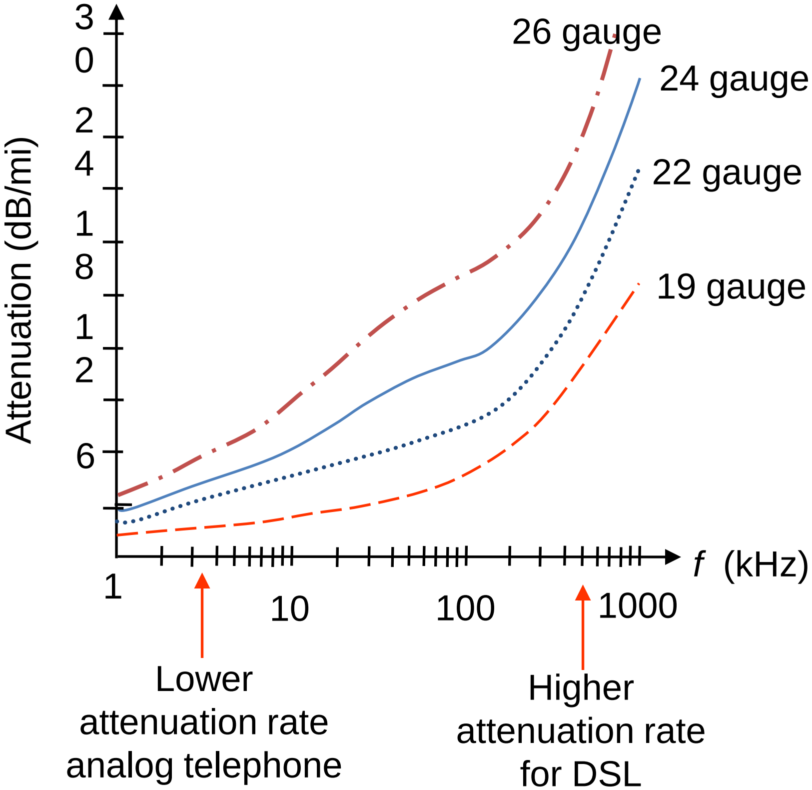
- A transmission medium is a physical path or a **communication channel** that carries the information from the sender to the receiver



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 CO
- Old trunk plant connecting telephone COs
- Intra-building telephone from wiring closet to desktop
- In old installations, loading coils added to improve quality in 3 kHz band, but more attenuation at higher frequencies



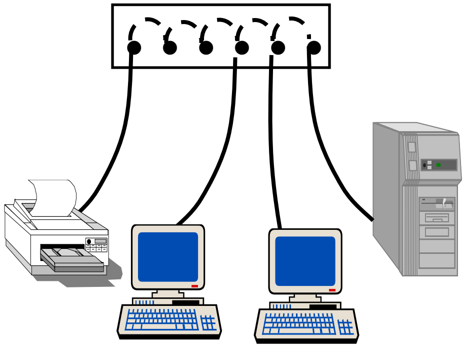
Twisted Pair Bit Rates

Data rates of 24-gauge twisted pair

Standard	Data Rate	Distance
T-1	1.544 Mbps	18,000 feet, 5.5 km
DS2	6.312 Mbps	12,000 feet, 3.7 km
1/4 STS-1	12.960 Mbps	4500 feet, 1.4 km
1/2 STS-1	25.920 Mbps	3000 feet, 0.9 km
STS-1	51.840 Mbps	1000 feet, 300 m

- Twisted pairs can provide high bit rates at short distances
- Asymmetric Digital Subscriber Loop (ADSL)
  - High-speed Internet Access
  - Lower 3 kHz for voice
  - Upper band for data
  - 64 kbps inbound
  - 640 kbps outbound
- Much higher rates possible at shorter distances
  - Strategy for telephone companies is to bring fiber close to home & then twisted pair
  - Higher-speed access + video

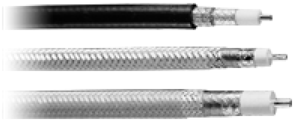
Ethernet LANs

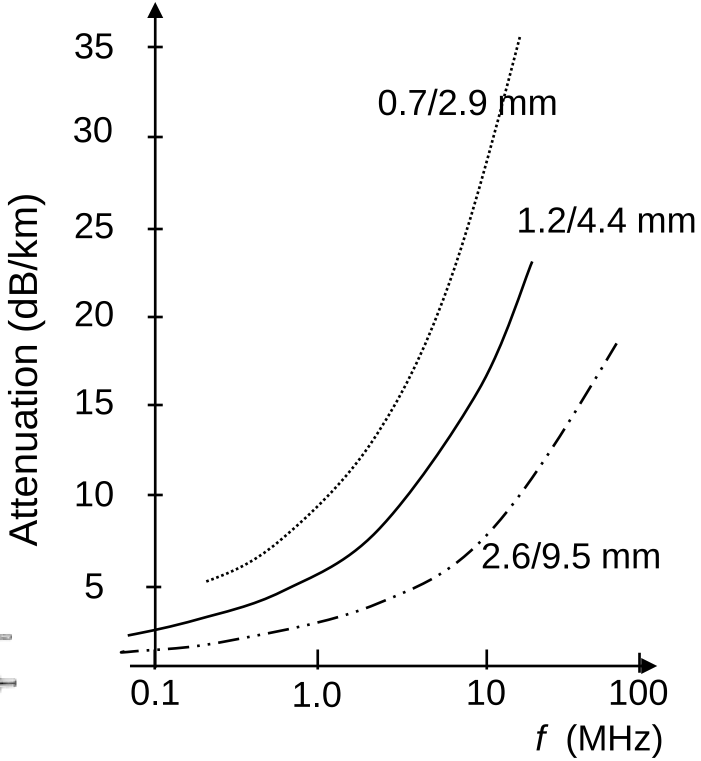


- Category 3 unshielded twisted pair (UTP): ordinary telephone wires
- Category 5 UTP: tighter twisting to improve signal quality
- Shielded twisted pair (STP): to minimize interference; costly
- 10BASE-T Ethernet
  - 10 Mbps, Baseband, Twisted pair
  - Two Category 3 UTPs
  - Manchester coding, 100 meters
- 100BASE-T4 *Fast* Ethernet
  - 100 Mbps, Baseband, Twisted pair
  - Four Category 3 UTPs
  - Three pairs for one direction at-a-time
  - 100/3 Mbps per pair;
  - Limited to100 meters
- Category 5 & STP provide other options

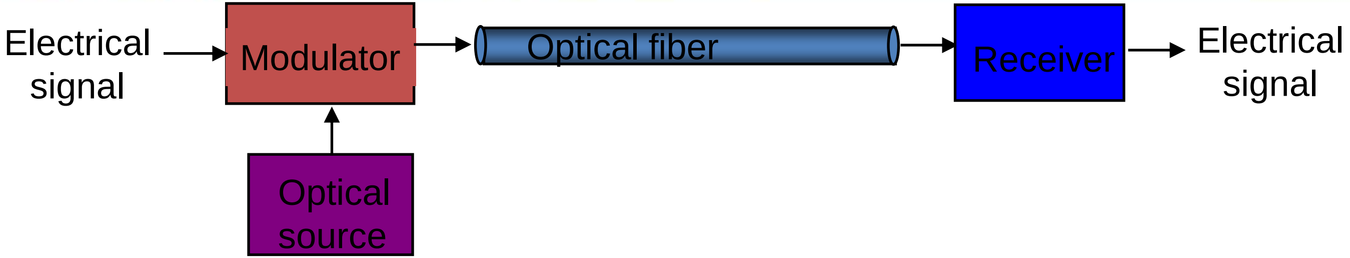
Coaxial Cable

- 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





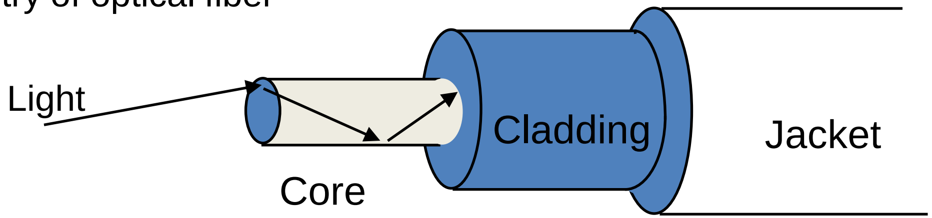
Optical Fiber



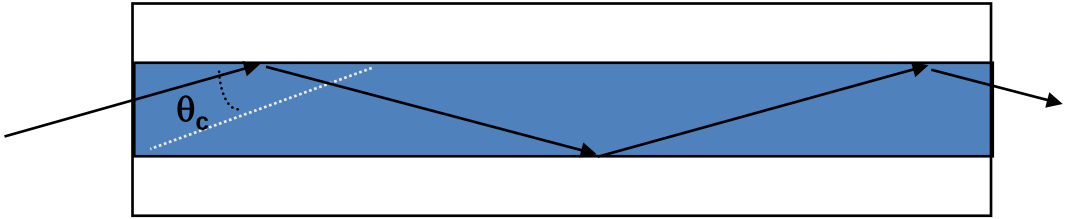
- Light sources (lasers, LEDs) generate pulses of light that are transmitted on optical fiber
  - Very long distances (>1000 km)
  - Very high speeds (>40 Gbps/wavelength)
  - Nearly error-free (BER of 10^{-15})
- Profound influence on network architecture
  - Dominates long distance transmission
  -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

Transmission in Optical Fiber

Geometry of optical fiber



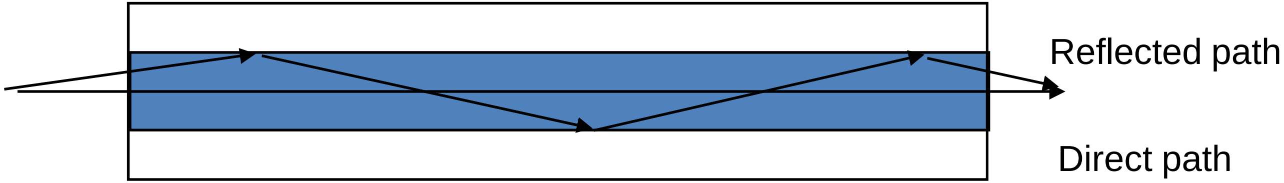
Total Internal Reflection in optical fiber



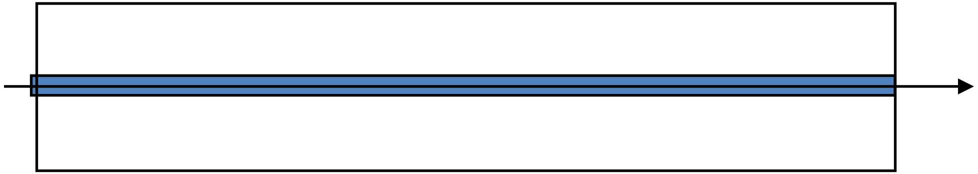
- Very fine glass cylindrical core surrounded by concentric layer of glass (cladding)
- Core has higher index of refraction than cladding
- Light rays incident at less than critical angle θ_c is completely reflected back into the core

Multimode & Single-mode Fiber

Multimode fiber: multiple rays follow different paths



Single-mode fiber: only direct path propagates in fiber



- Multimode: Thicker core, shorter reach
  - Rays on different paths interfere causing dispersion & limiting bit rate
- Single mode: Very thin core supports only one mode (path)
  - More expensive lasers, but achieves very high speeds

Optical Fiber Properties

Advantages

- ***Very low attenuation***
- ***Noise immunity***
- ***Extremely high bandwidth***
- Security: Very difficult to tap without breaking
- No corrosion
- More compact & lighter than copper wire

Disadvantages

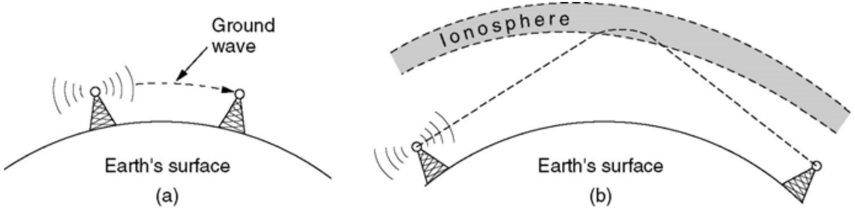
- New types of optical signal impairments & dispersion
  - Polarization dependence
  - Wavelength dependence
- Limited bend radius
  - If physical arc of cable too high, light lost or won’t reflect
  - Will break
- Difficult to splice
- Mechanical vibration becomes signal noise

Radio Transmission

Radio transmission sends information from one place to another through the air. The information is sent on radio waves

(a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.

(b) In the HF band, they bounce off the ionosphere



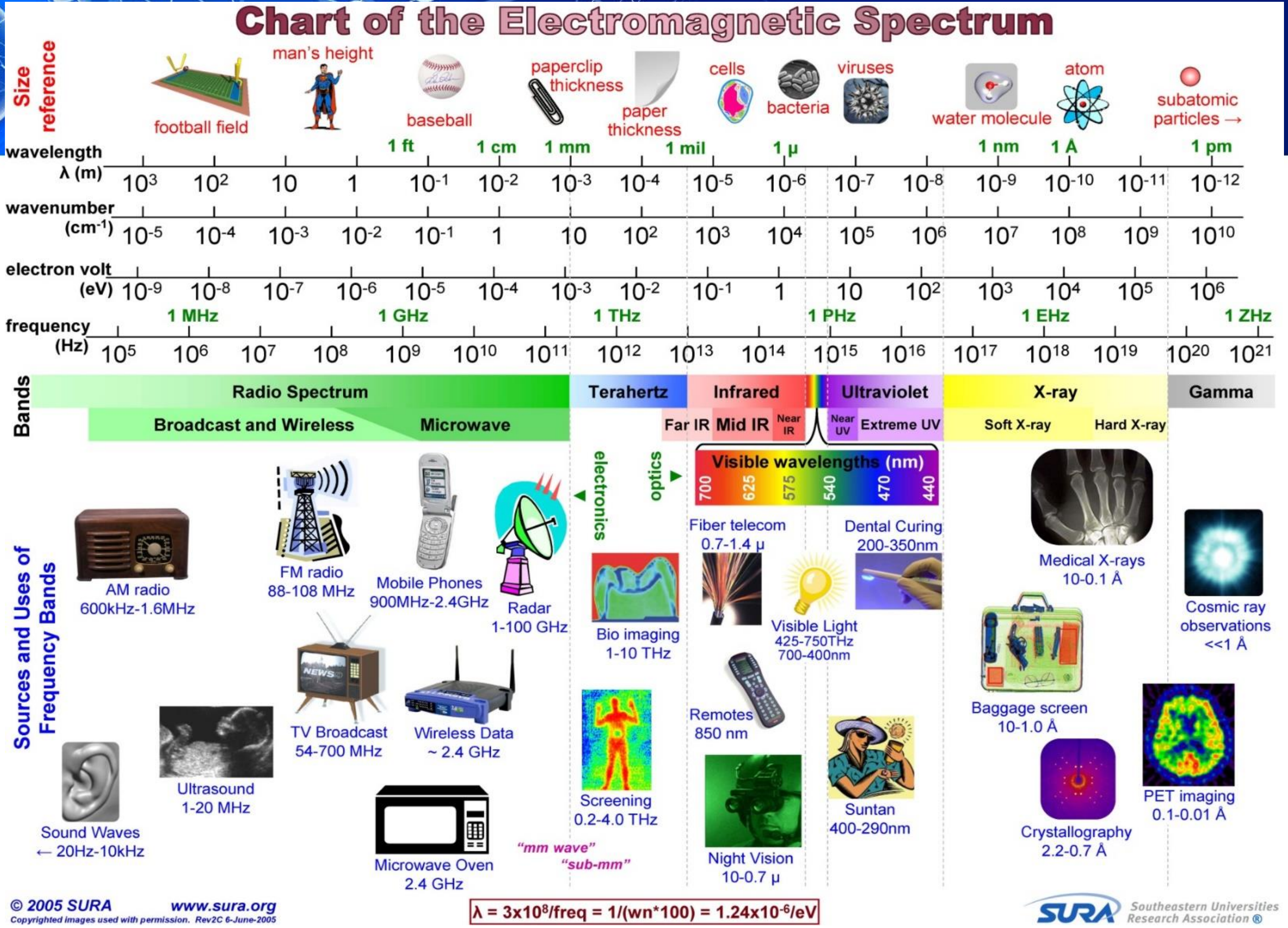


Chart of the Electromagnetic Spectrum
Size reference
football field
man's height
baseball
paperclip thickness
paper thickness
cells
bacteria
viruses
water molecule
atom
subatomic particles →
1 ft
1 cm
1 mm
1 mil
1 μ
1 nm
1 Å
1 pm
wavelength λ (m)
10³ 10² 10 1 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶ 10⁻⁷ 10⁻⁸ 10⁻⁹ 10⁻¹⁰ 10⁻¹¹ 10⁻¹²
wavenumber (cm⁻¹)
10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 1 10 10² 10³ 10⁴ 10⁵ 10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰
electron volt (eV)
10⁻⁹ 10⁻⁸ 10⁻⁷ 10⁻⁶ 10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 1 10 10² 10³ 10⁴ 10⁵ 10⁶
1 MHz
1 GHz
1 THz
1 PHz
1 EHz
1 ZHz
frequency (Hz)
10⁵ 10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰ 10¹¹ 10¹² 10¹³ 10¹⁴ 10¹⁵ 10¹⁶ 10¹⁷ 10¹⁸ 10¹⁹ 10²⁰ 10²¹
Bands
Radio Spectrum
Terahertz
Infrared
Ultraviolet
X-ray
Gamma
Broadcast and Wireless
Microwave
Far IR
Mid IR
Near IR
Near UV
Extreme UV
Soft X-ray
Hard X-ray
Visible wavelengths (nm)
700 625 575 540 470 440
electronics
optics
Sources and Uses of Frequency Bands
AM radio
600kHz-1.6MHz
FM radio
88-108 MHz
Mobile Phones
900MHz-2.4GHz
Radar
1-100 GHz
Bio imaging
1-10 THz
Fiber telecom
0.7-1.4 μ
Visible Light
425-750THz
700-400nm
Dental Curing
200-350nm
Medical X-rays
10-0.1 Å
Cosmic ray observations
<<1 Å
TV Broadcast
54-700 MHz
Wireless Data
~ 2.4 GHz
Remotes
850 nm
Baggage screen
10-1.0 Å
Ultrasound
1-20 MHz
Screening
0.2-4.0 THz
Suntan
400-290nm
PET imaging
0.1-0.01 Å
Sound Waves
← 20Hz-10kHz
Microwave Oven
2.4 GHz
"mm wave"
"sub-mm"
Night Vision
10-0.7 μ
Crystallography
2.2-0.7 Å
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λ = 3x10⁸/freq = 1/(wn*100) = 1.24x10⁻⁶/eV
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Performance

Performance

- Important metrics in networking
  - Bandwidth
  - Throughput
  - Latency (Delay)

Bandwidth (again)

- In networking, we use the term bandwidth in two contexts.
- The first, bandwidth in hertz (or, analog bandwidth), refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.
- The second, bandwidth in bps (or, digital bandwidth), refers to the speed of bit transmission in a channel or link.
- The bandwidth of a subscriber line is 4 kHz for voice or data. The bandwidth of this line for data transmission can be up to 56,000 bps using a sophisticated modem to change the digital signal to analog.

Throughput

- The throughput is a measure of how fast we can actually send data through a network. A link may have a bandwidth of B bps, but we can only send T bps, where $T \leq B$.
- For example, we may have a link with a bandwidth of 1Mbps, but the devices connected to the end of the link may handle only 200kbps.

Example

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}$$

The throughput is almost one-fifth of the bandwidth in this case.

Delay

- The latency or delay defines how long it takes for an entire message to arrive at the destination from the first bit is sent out from the source.
- It is basically made of four components.
- Latency = propagation time +
  transmission time +
  queueing time +
  processing delay