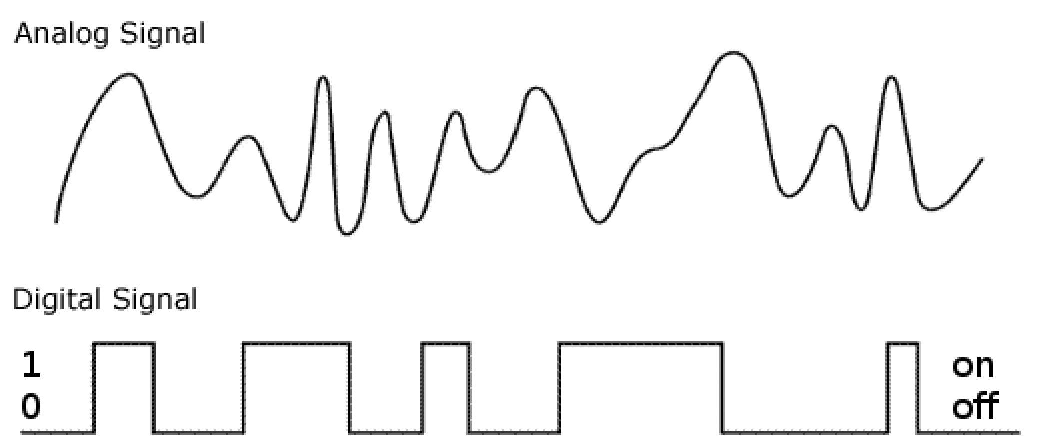
Physical Layer

서영주

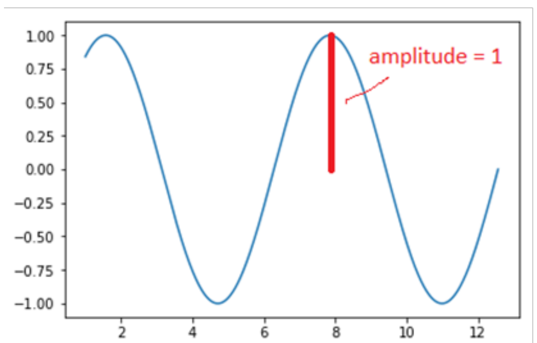
Data & Signal

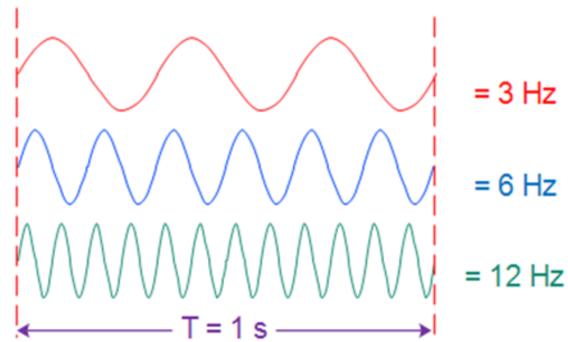
- Data - something that has meaning
  - Analog (continuous) data - audio, video
  - Digital (discrete) data - text
- Signal – electric or electromagnetic representations of data for transmission (encoded data)
  - Analog signal - represents data with continuously varying wave
  - Digital signal - represents data with sequence of voltage pulses

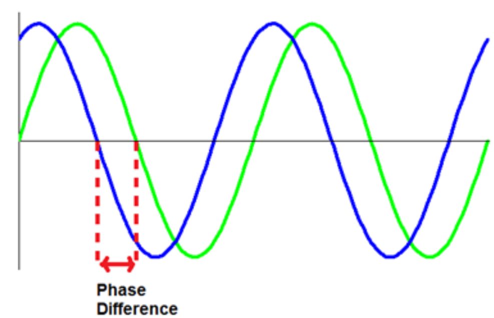


Time-Domain Representation of Signals

- Analog signals have three components
  - Amplitude: strength of signal (volts)
  - Frequency: rate of change of signal (Hz)
  - Phase: position of waveform relative to a given moment of time (degree)





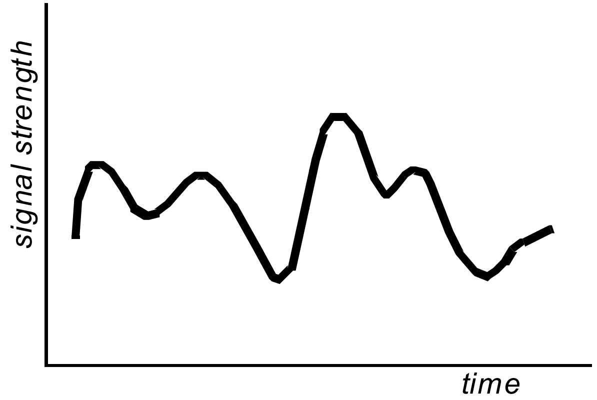


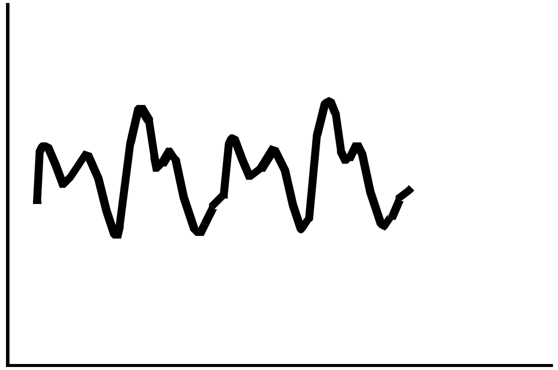
Ex: sinusoidal signal $s(t)=A\sin(2\pi ft+\theta)$

A: amplitude, f: frequency=1/T, θ: phase

Frequency-Domain Representation of Signals

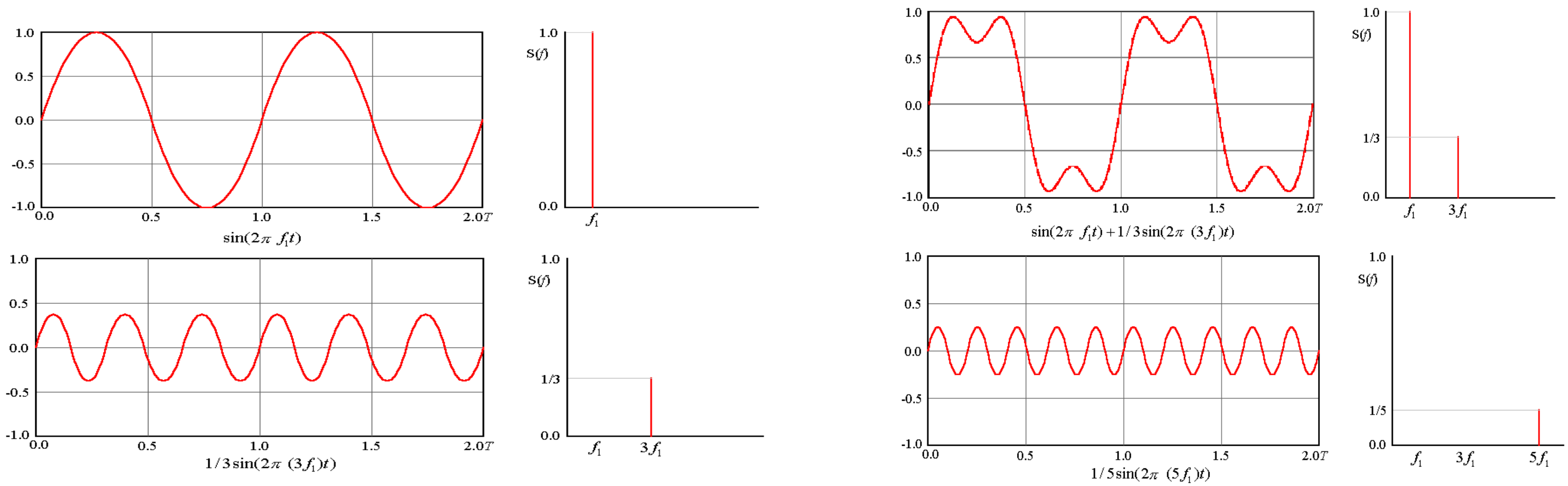
- Why freq-domain representation?

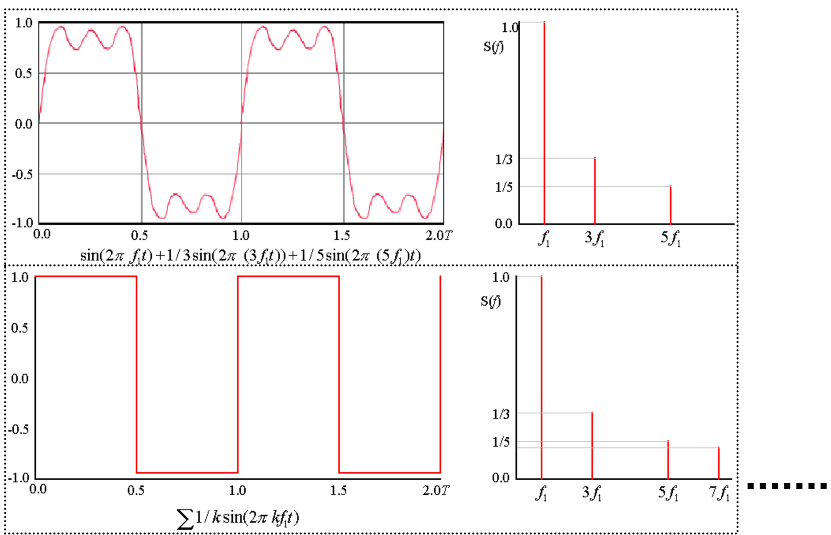




- Signal usually made up of many frequencies
- Components are sine waves
- Can be shown (Fourier analysis) that any signal is made up of component sine waves
- Can plot frequency domain functions

Example

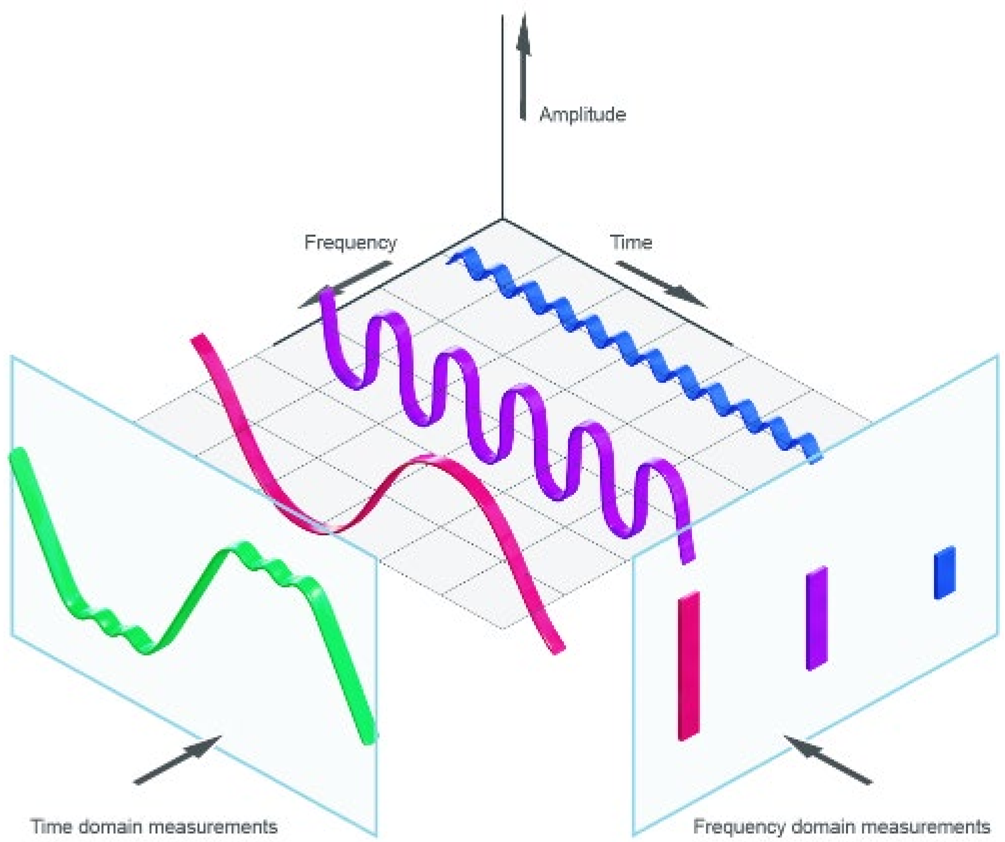




Fourier Analysis:

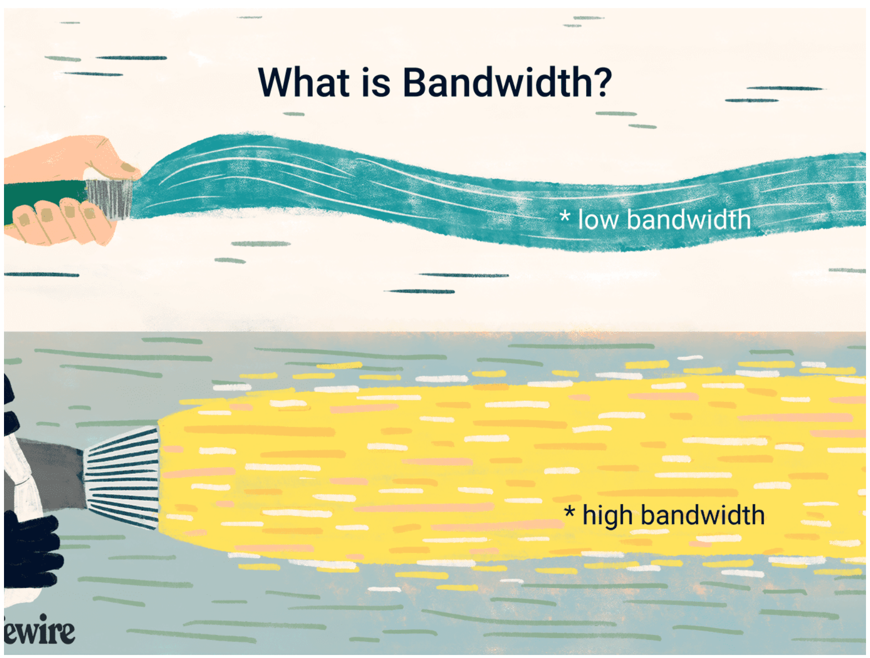
Any periodic signal can be decomposed into a (possibly infinite) series of sinusoidal signals.

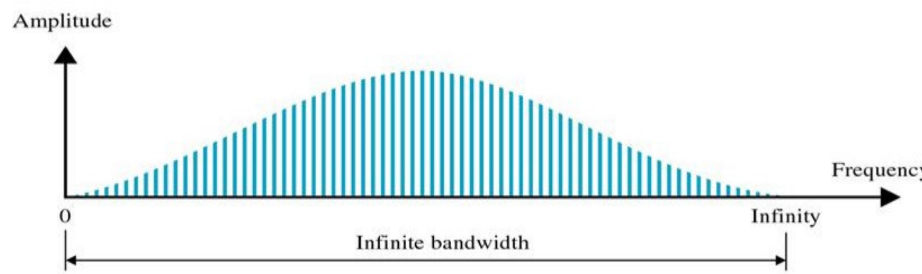
- Signal Spectrum
  - Describes a signal's characteristics as a function of frequency.



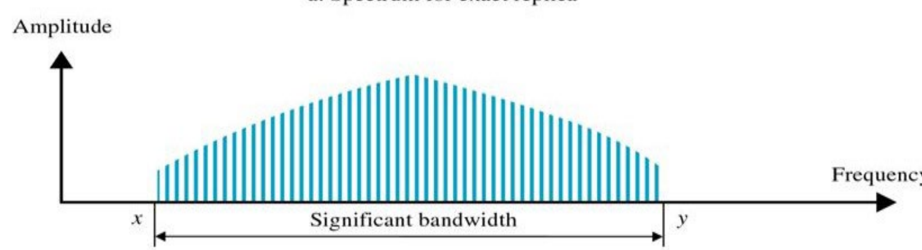
Spectrum and Bandwidth

- Bandwidth = BW
  - Maximum amount of data transmitted over an internet connection in a given amount of time.
  - The difference between the highest and the lowest frequencies contained in a signal





a. Spectrum for exact replica

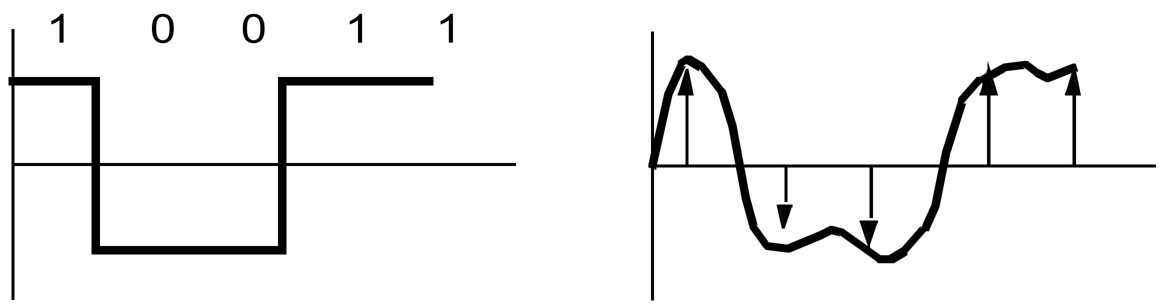


b. Significant spectrum

- Digital data is transmitted by a signal of limited bandwidth
  - Creates distortion to the signal
  - Makes interpreting of the received signal difficult
  - Increases errors in the receiver

[Remarks]

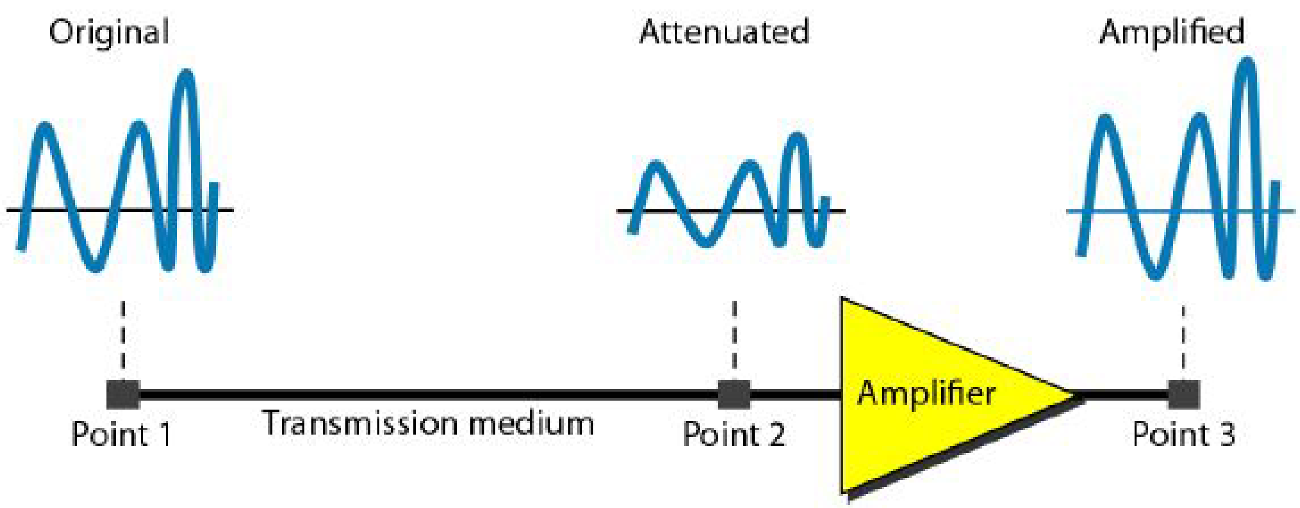
- The receiver samples the received signal at the center of each bit interval
- Exact shape of the signal outside the sampling instant is less important



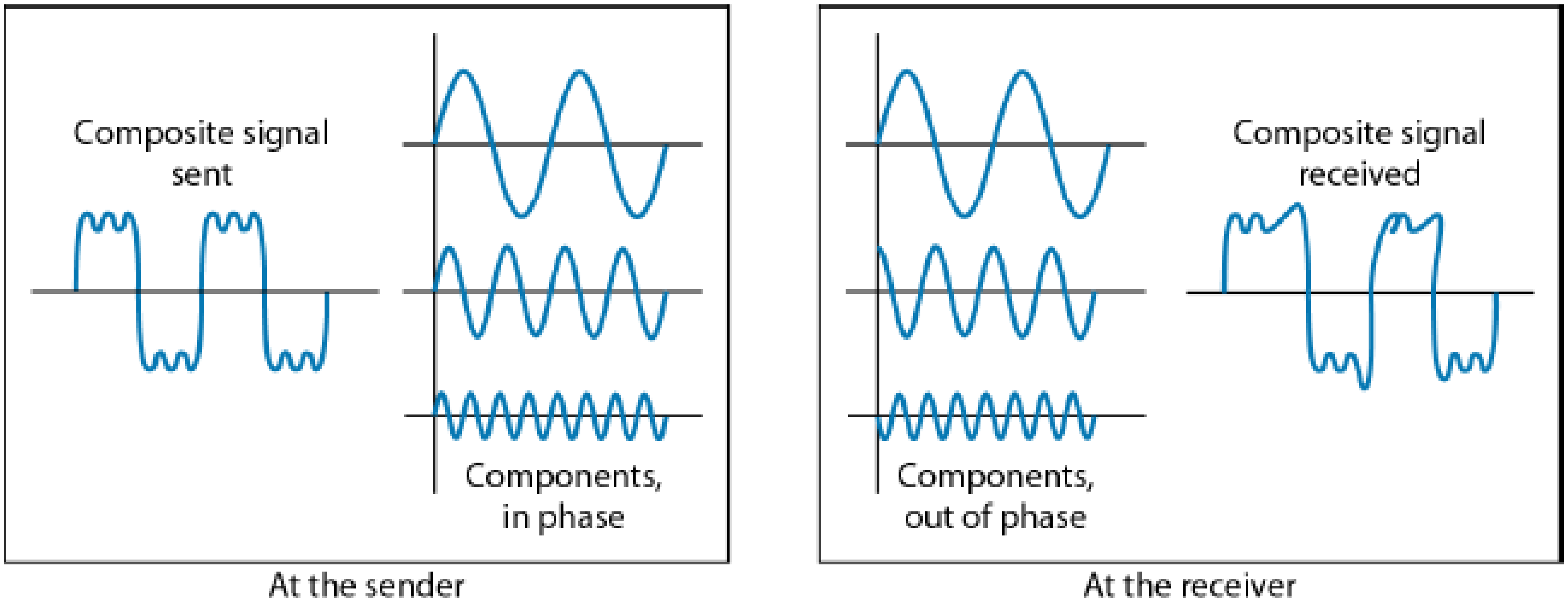
- Transmission Impairments
  - Effect of transmission impairments
    - distorts or changes the values of the original transmitted signal
    - make the signal more difficult to determine the exact form of the original signal
      - Analog - degradation of signal quality
      - Digital - bit errors

- Impairment sources
  - Attenuation
  - Delay distortion
  - Noise

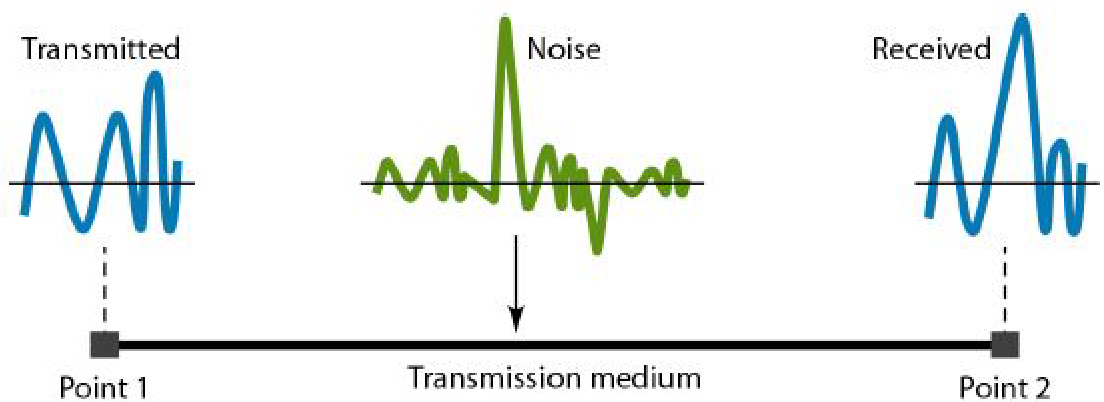
- Attenuation
  - With the increase in distance, energy of signal decreases
  - The energy loss is due to resistance of transmission wire which gets warm when signals are passed through them
  - Received signal strength must be enough to be detected
  - To re-boost the weak signal, amplifiers are used

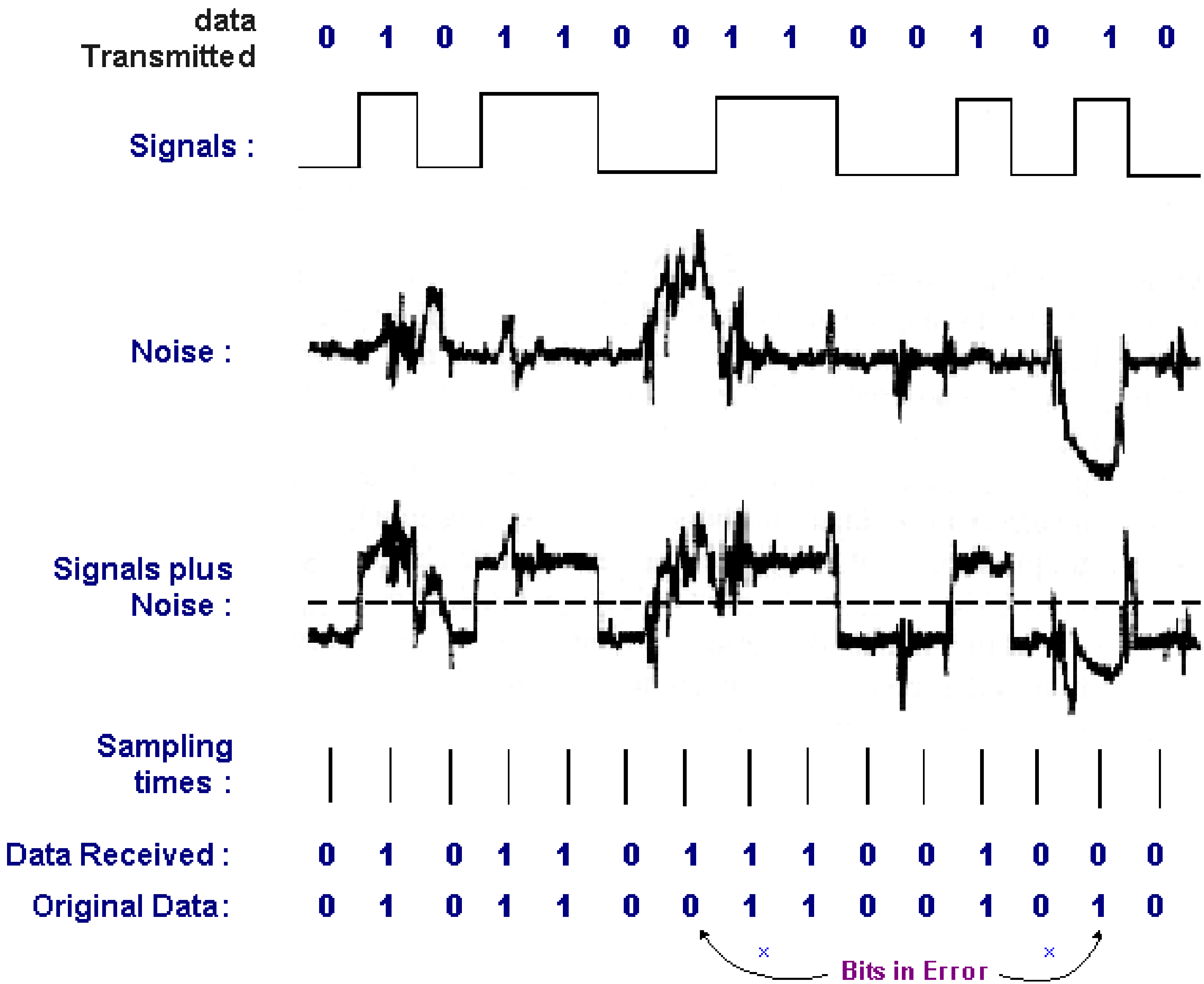


- Delay distortion
  - The velocity of propagation of a signal through a guided medium varies with frequency



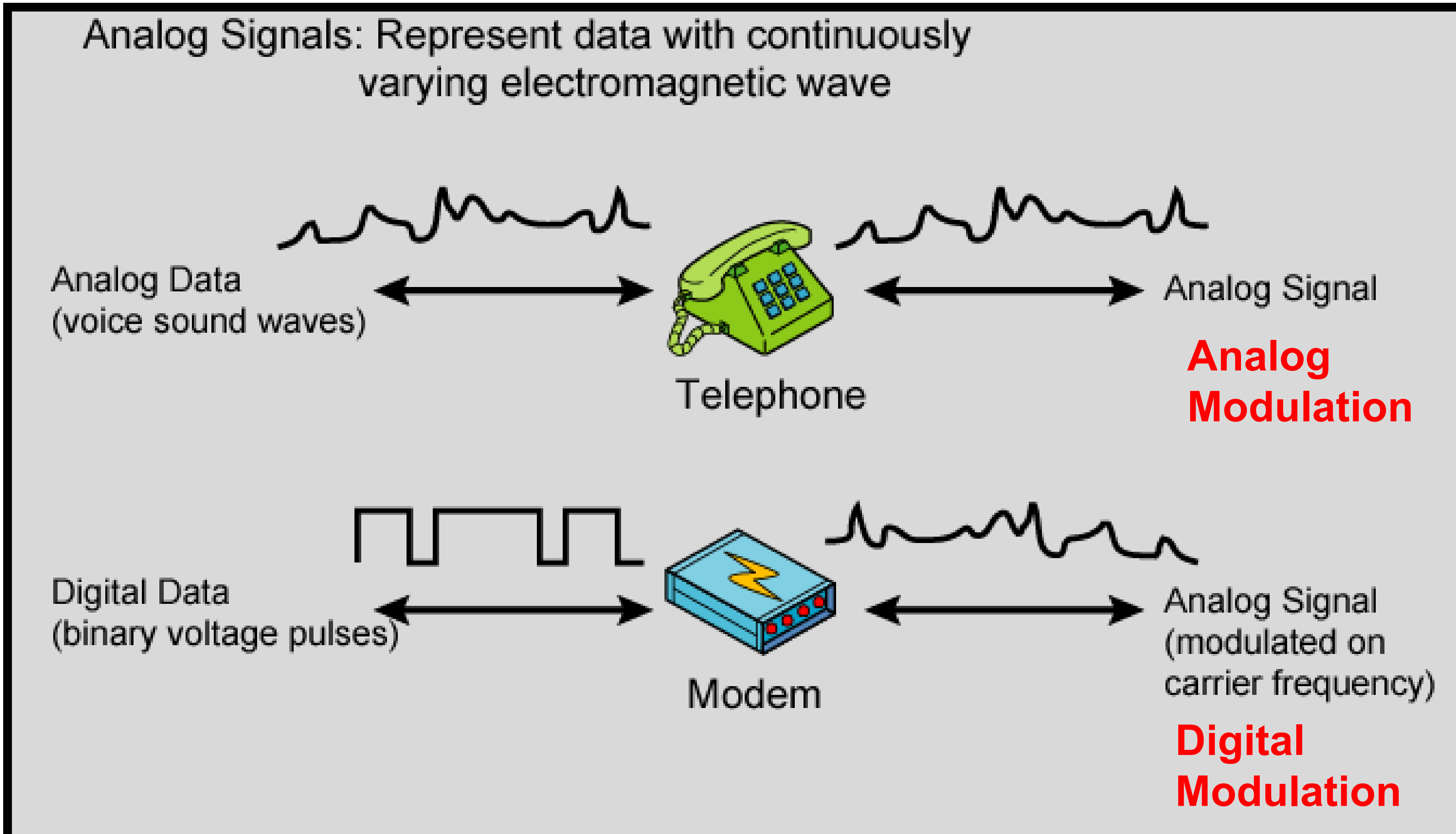
- Noise - a major limiting factor
  - unwanted signal inserted somewhere between transmission and reception
  - source of noise
    - thermal - caused by thermal agitation of electrons in a conductor
    - crosstalk - interference in a communication channel caused by a signals traveling in an adjacent channel
    - impulse - short external pulse, (ex) lightening

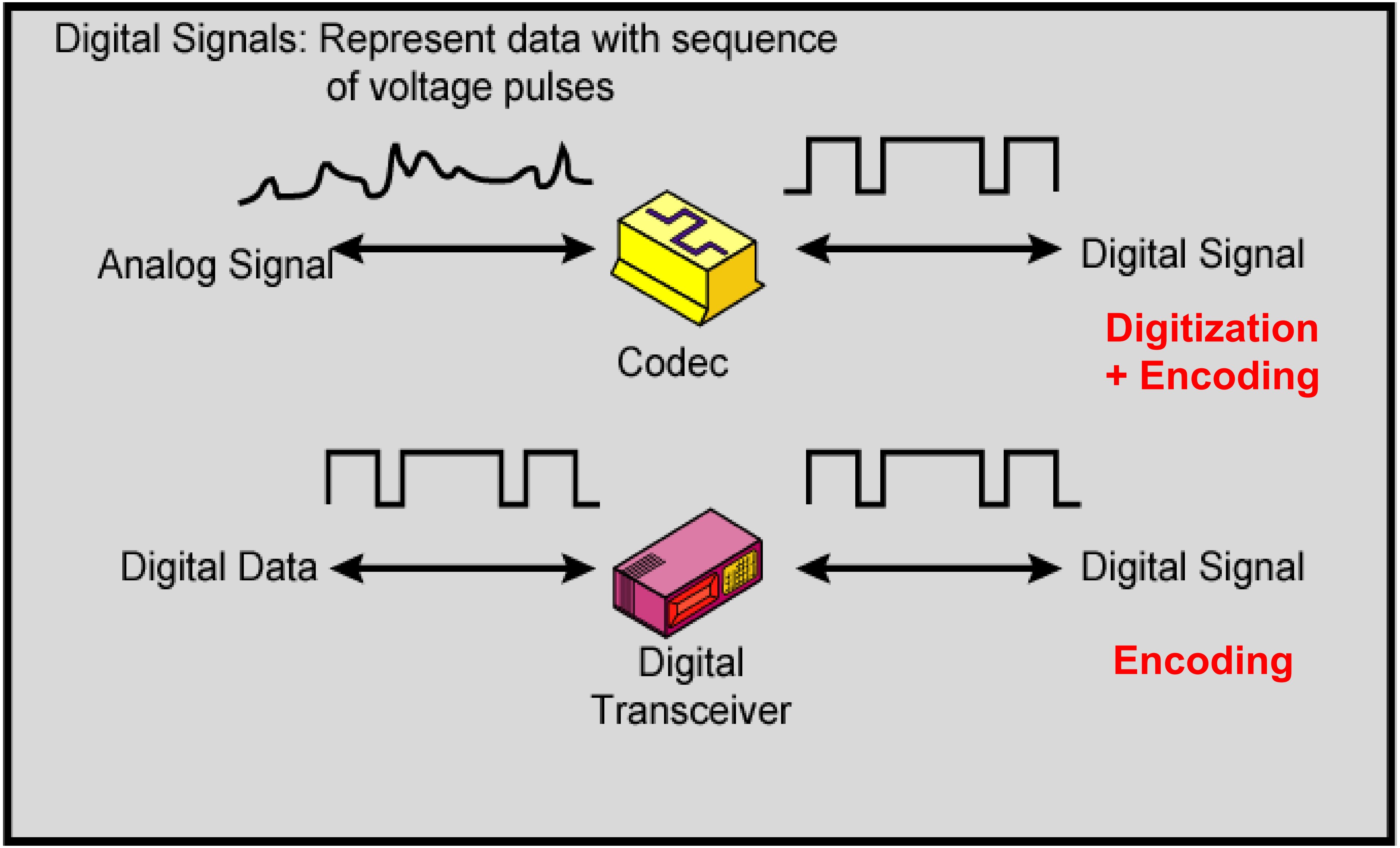



data
Transmitted
0 1 0 1 1 0 0 1 1 0 0 1 0 1 0
Signals :
Noise :
Signals plus
Noise :
Sampling
times :
Data Received : 0 1 0 1 1 0 1 1 1 0 0 1 0 0 0
Original Data : 0 1 0 1 1 0 0 1 1 0 0 1 0 1 0
x
x
Bits in Error

Data Encoding

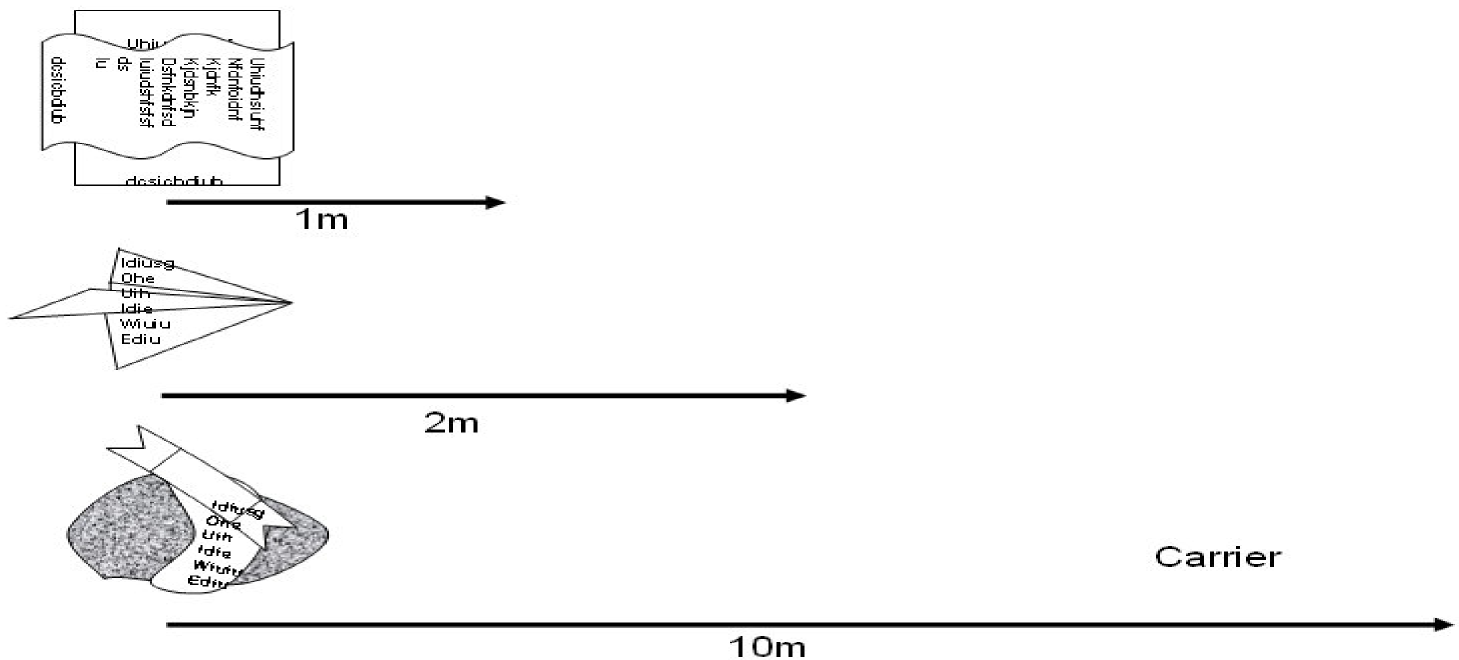
➔ Data are either analog or digital - converted into a signal for transmission





Digital Signals: Represent data with sequence of voltage pulses
Analog Signal
Codec
Digital Signal
Digitization + Encoding
Digital Data
Digital Transceiver
Digital Signal
Encoding

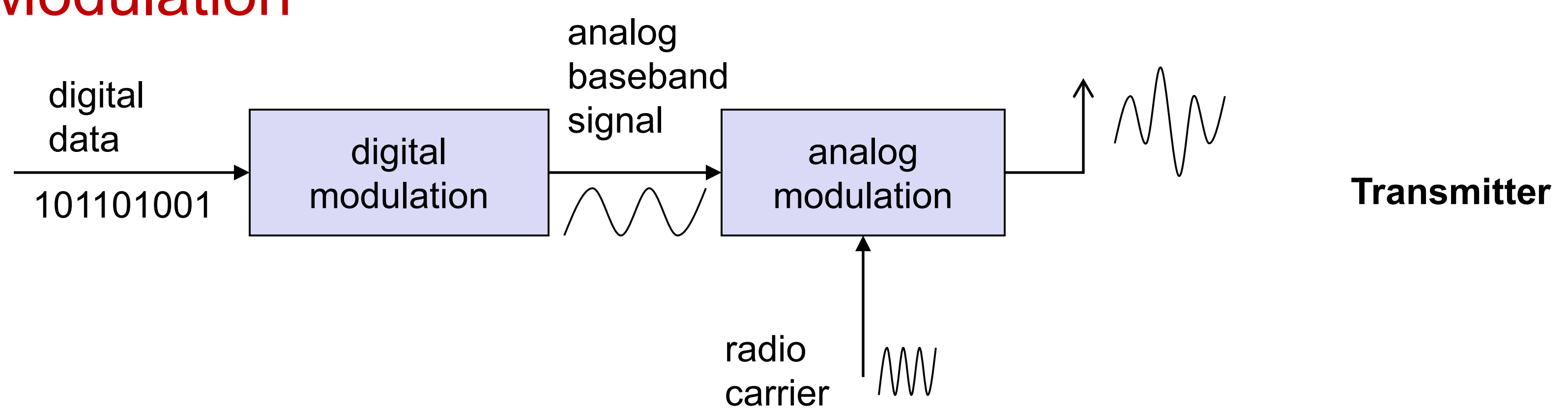
- Modulation – the process of translation of baseband signal to bandpass (modulated carrier) signal at frequencies that are very high compared to the baseband frequencies



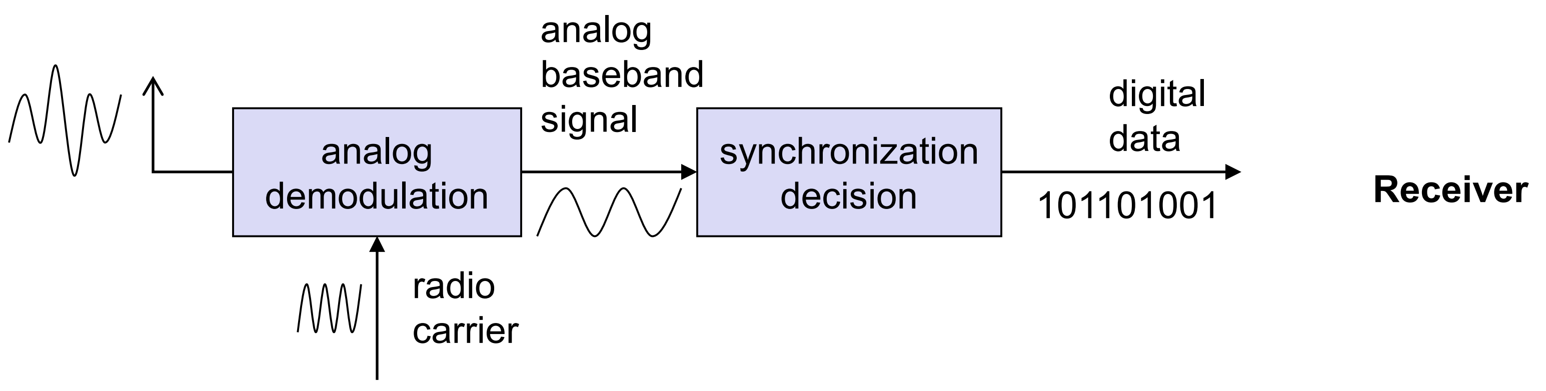
- Demodulation - process of extracting the baseband signal back from the modulated carrier.

- Analog data → Analog signals : (Analog) Modulation
  - The process of combining an input signal m(t) and a carrier c(t) at frequency f_c to produce a signal s(t) whose bandwidth is centered on f_c.
    - m(t) : modulating signal or baseband signal
    - c(t) : carrier signal
    - s(t) : modulated signal
  - Shifts center frequency of baseband signal up to the radio carrier
  - Why modulation?
    - Higher frequency can give more efficient transmission
    - For FDM (Frequency Division Multiplexing)
    - To adjust to medium characteristics

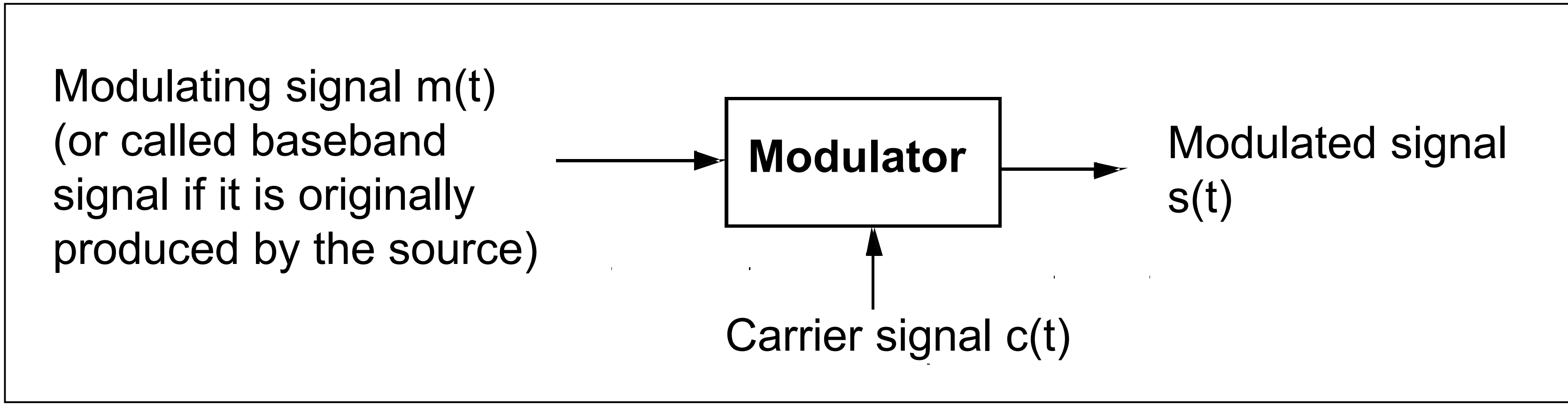
Modulation



Demodulation



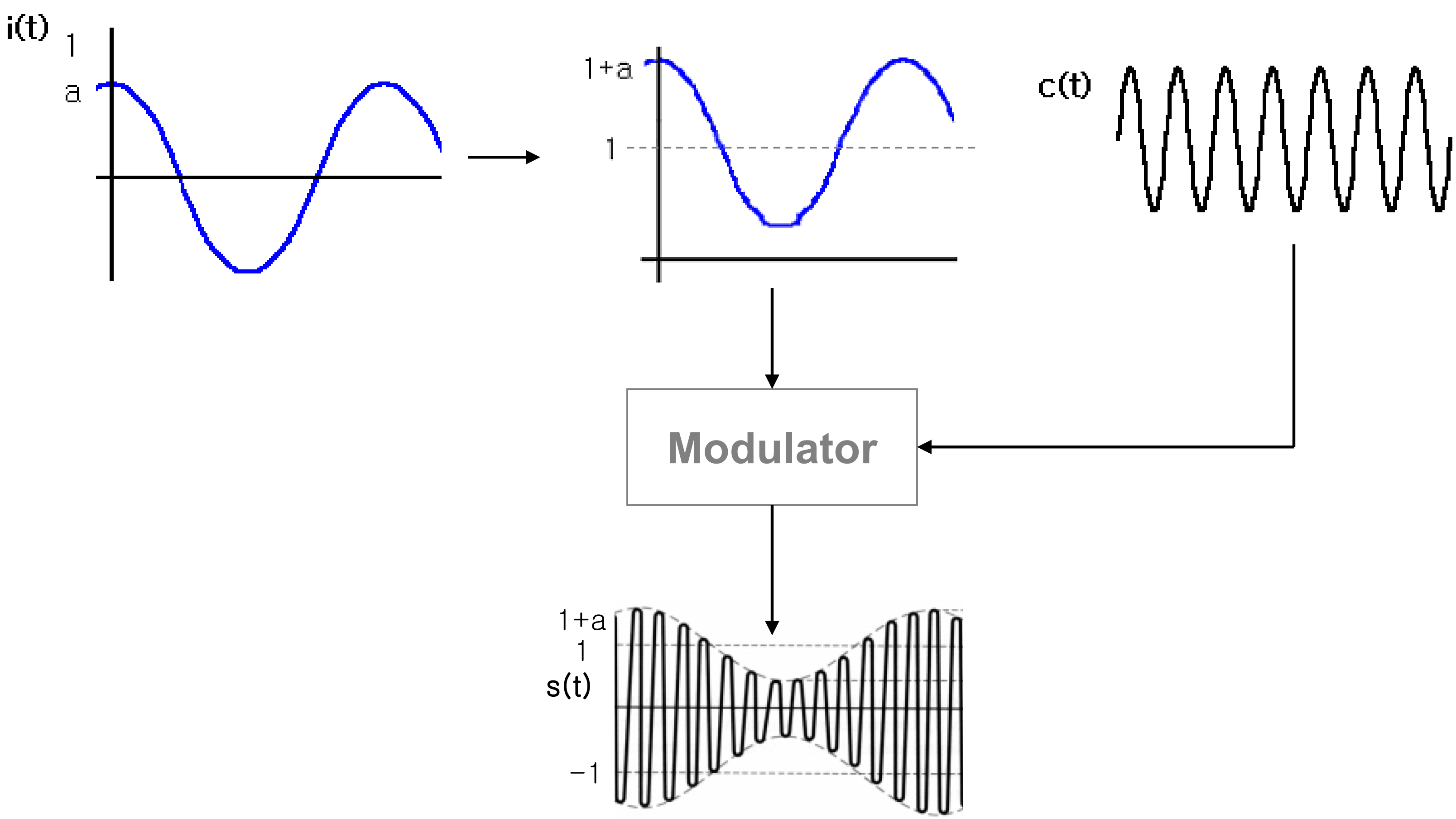
Modulation process



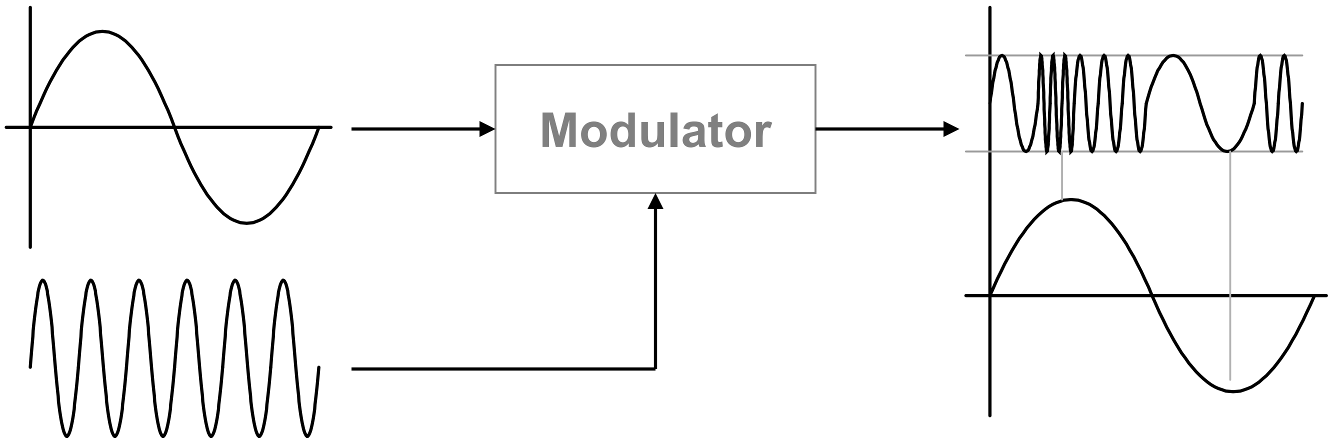
- Carrier signals have 3 basic characteristics : amplitude, frequency, phase
- Change any of these characteristics for modulation

- Amplitude Modulation (AM)

(ex1)



- Frequency Modulation (FM)



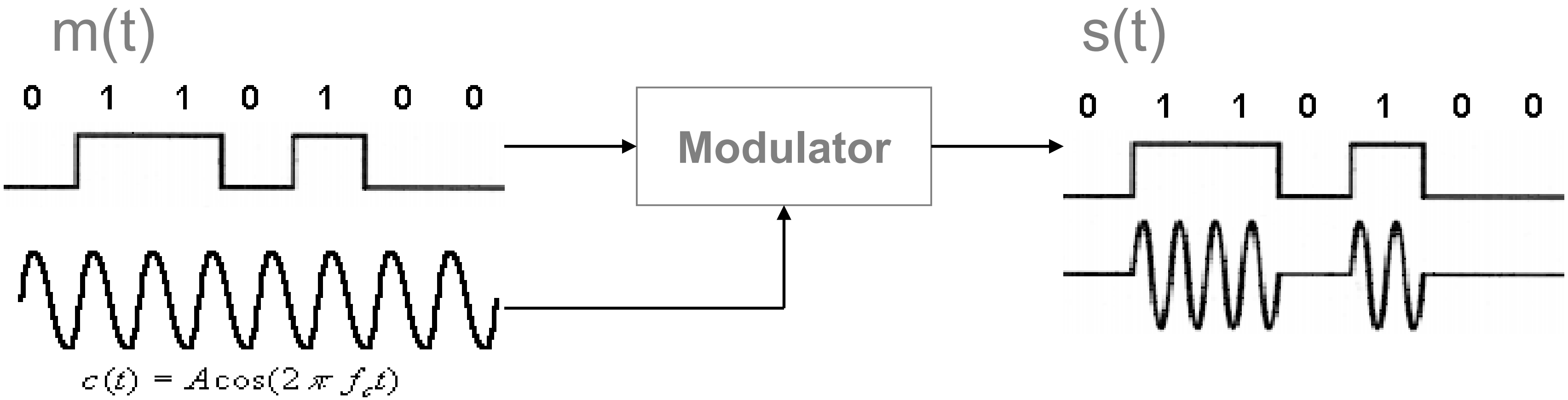
- Phase Modulation → change phase
    - If modulation signal is analog, the result is basically the same as (or similar to) FM.

- Digital Data → Analog Signals (Digital Modulation)
  - → Transmitting digital data through telephone network
  - → Use modem (modulator-demodulator)

- Modulation of digital signals is known as Shift Keying
- Basic modulation methods
  - Amplitude shift keying (ASK) - change $A(t)$
  - Frequency shift keying (FSK) - change w
  - Phase shift keying (PSK) - change θ
- Differences in spectral efficiency, power efficiency, robustness

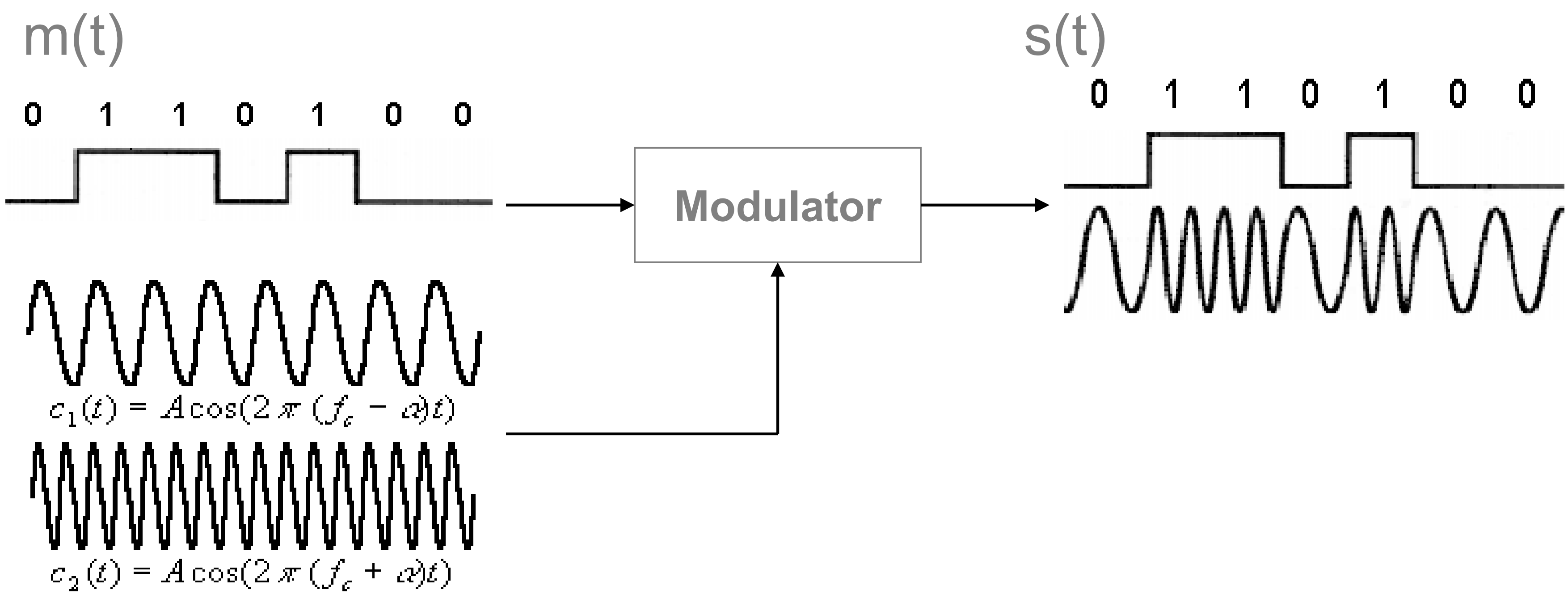
- Amplitude Shift Keying (ASK)
  - very simple
  - low bandwidth requirements
  - very susceptible to interference

$$S(t) = \begin{cases} A\cos 2\pi f_c t & binary\ 1 \\ 0 & binary\ 0 \end{cases}$$



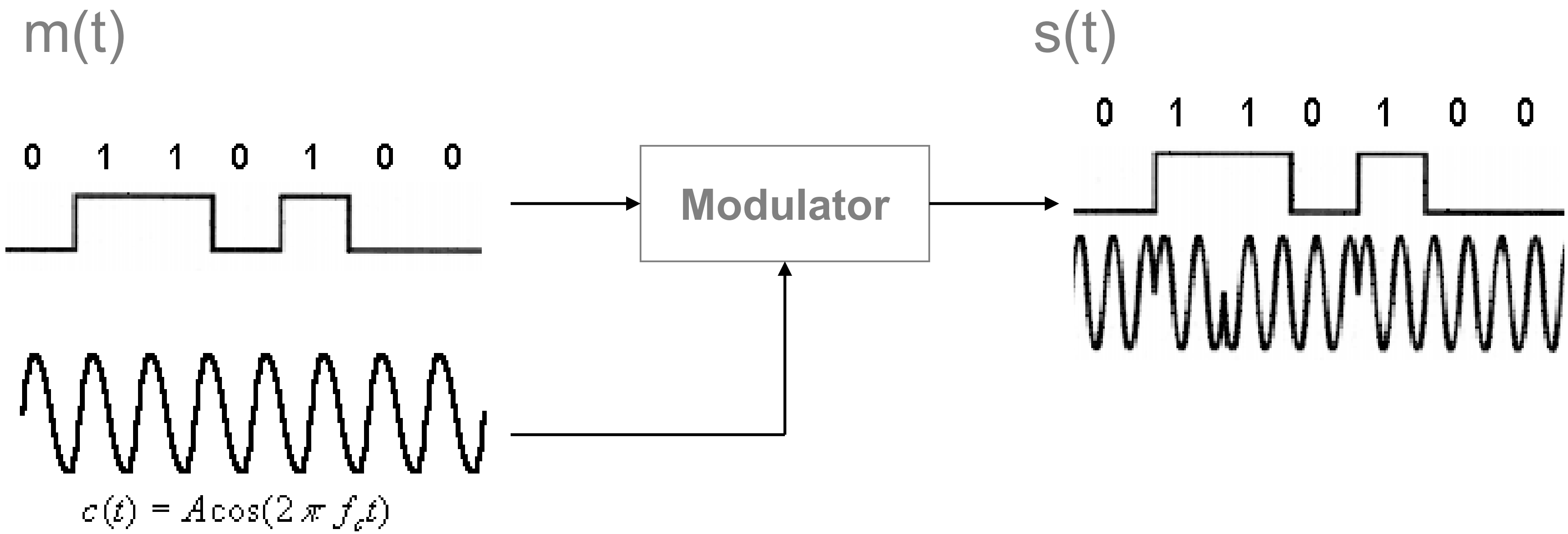
- Frequency Shift Keying (FSK)
  - needs larger bandwidth
  - less susceptible to errors than ASK

$$S(t) = \begin{cases} A\cos 2\pi f_1 t & binary\,1 \\ A\cos 2\pi f_2 t & binary\,0 \end{cases}$$

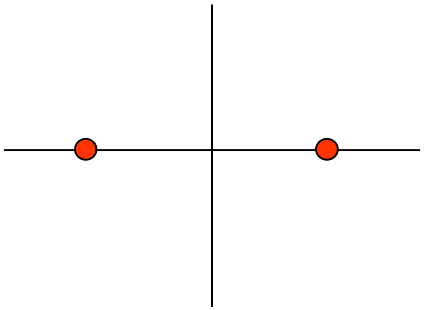


- Phase Shift Keying (PSK)
  - more complex
  - robust against interference

$$S(t)=\begin{cases} A\cos(2\pi f_c t+180°) & binary\,1 \\ A\cos 2\pi f_c t & binary\,0 \end{cases}$$

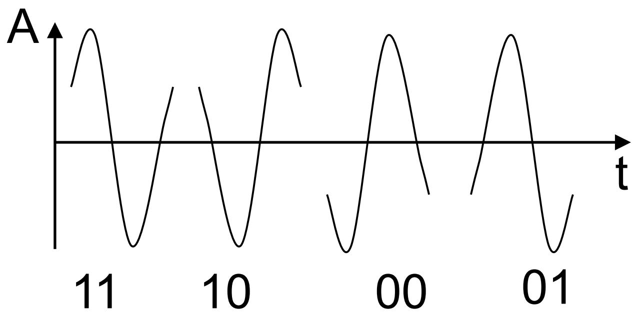


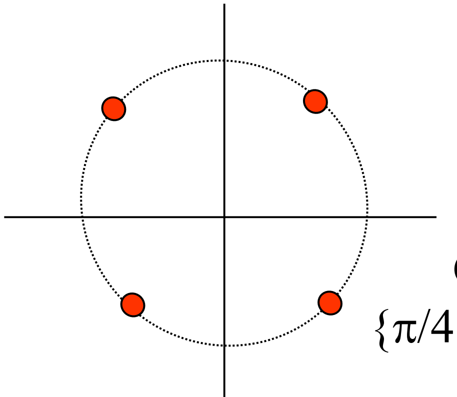
- BPSK (Binary Phase Shift Keying)
  - bit value 0: sine wave
  - bit value 1: inverted sine wave
  - very simple PSK
  - low spectral efficiency
  - Robust



Signal Constellation Diagram

- Quadrature Phase Shift Keying (QPSK)
  - 2 bits coded as one symbol
  - twice the bandwidth efficiency of BPSK since 2 bits are transmitted in a single modulation symbol
  - symbol determines phase shift relative to reference signal





Carrier phases
$\{\pi/4, 3\pi/4, 5\pi/4, 7\pi/4\}$

- Quadrature Amplitude Modulation (QAM)
  - Combines amplitude and phase modulation
  - Possible to code n bits using one symbol

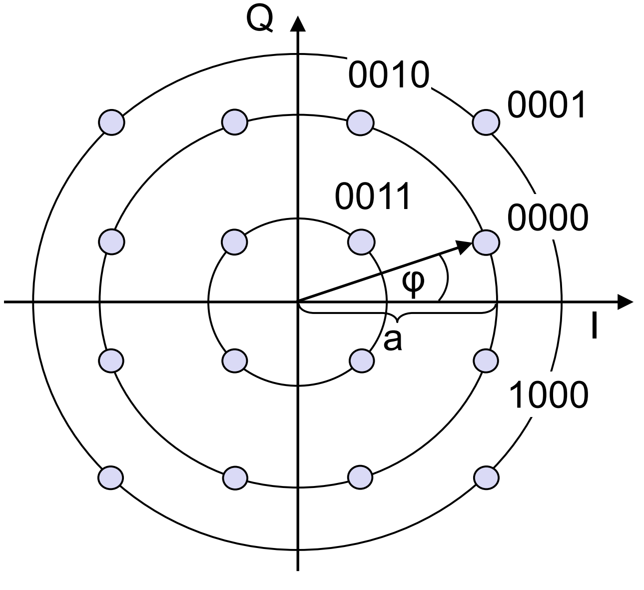
    → 2^n discrete levels; n=2 identical to QPSK
  - Bit error rate increases with n, but less errors compared to comparable PSK schemes

Example: 16-QAM (4 bits = 1 symbol)

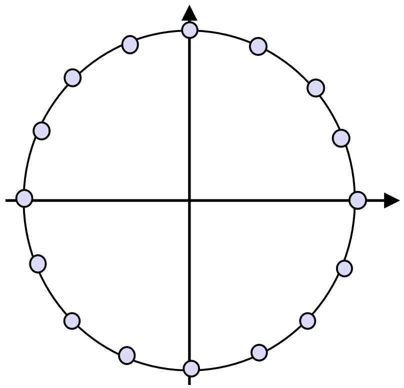
Symbols 0011 and 0001 have the same phase, but different amplitude.

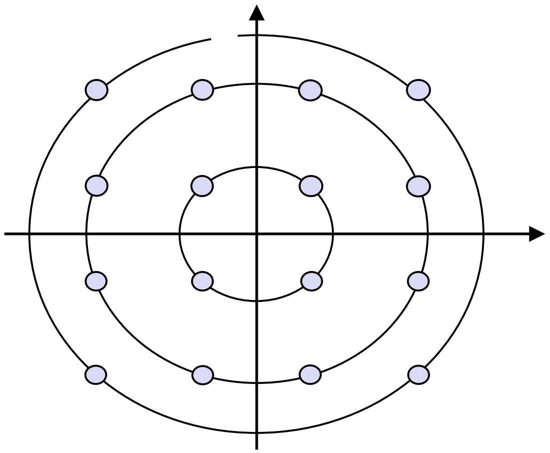
Symbols 0000 and 1000 have different phase, but same amplitude

→ used in standard 9600 bit/s modems

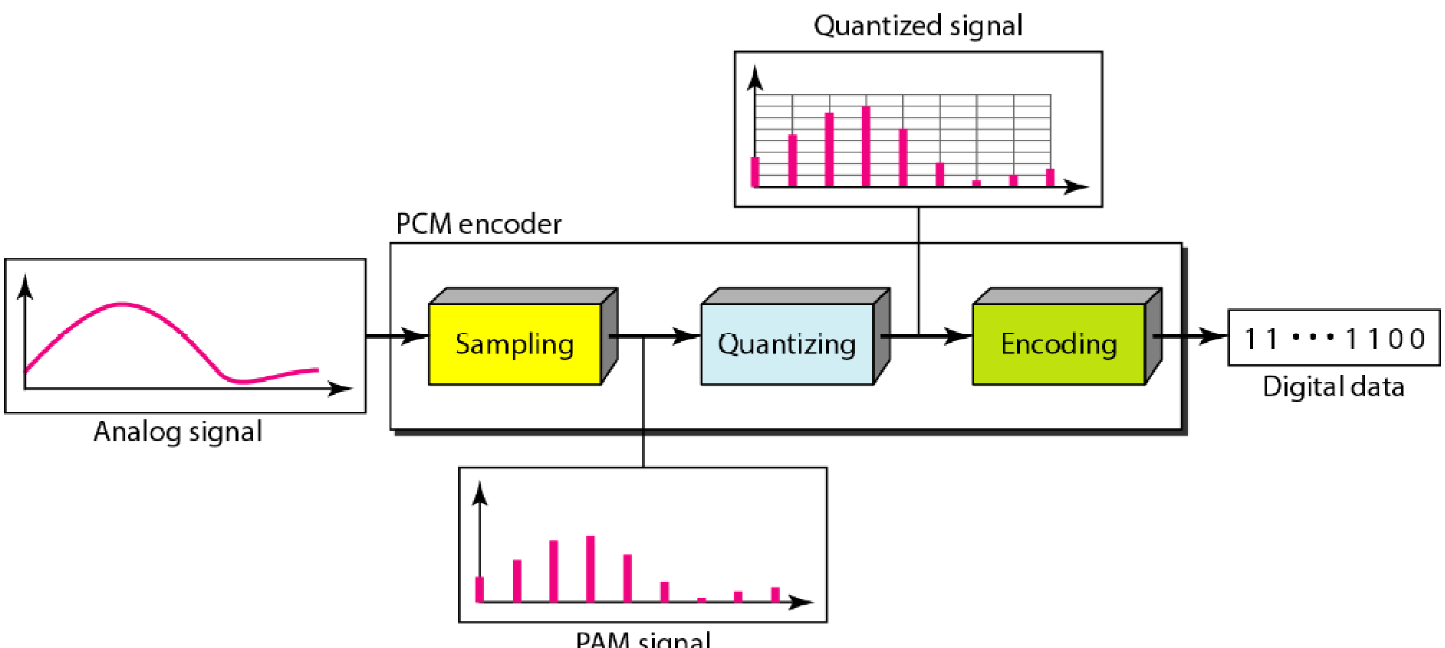


- QAM vs. PSK
  - 16QAM has larger distance between points, but requires very linear amplification.
  - 16PSK has less stringent linearity requirements, but has less spacing between constellation points, and is therefore more affected by noise.





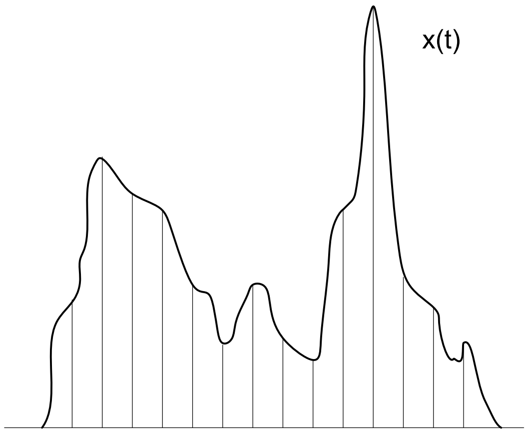
- Analog Data → Digital Signals (Digitization)
  - Steps
    - Sampling - taking finite samples in time
      - Samples are taken by measuring the value of the signal at regular time intervals
    - Quantizing - round off samples to take values of discrete values
    - Encoding - Use binary encoding to represent the different quantized values



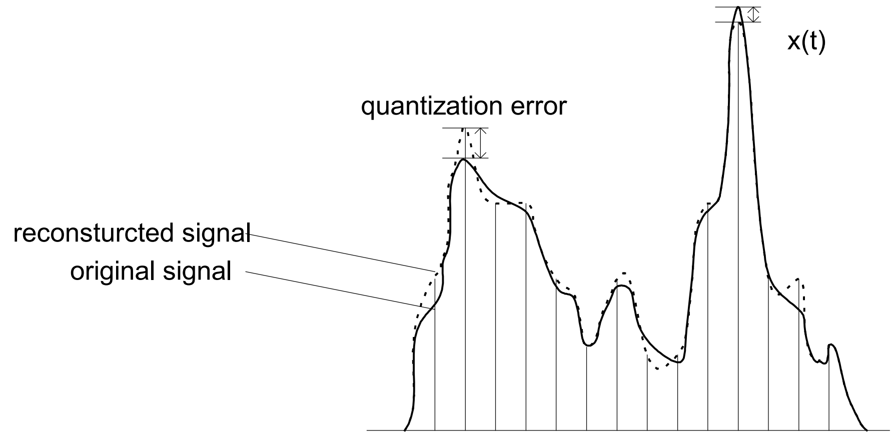
- Sampling theorem (by Nyquist 1933)
  - If a band-limited signal is sampled at a rate greater than twice the highest frequency present in the signal, it is possible to accurately and precisely reconstruct the original signal from the sample values.
- Voice data limited to below 4000Hz → Require 8000 sample per second
- Each sample assigned digital value
- n bit system gives 2^n levels
- Quantized → Pulse Code Modulation (PCM) pulses

- Standard Telephone Voice
  - Utilizes 256 levels ($256 = 2^8$) → 8 bit encoding
  - Voice signal bandwidth = 4000Hz
  - 8000 samples/sec (by sampling theorem) * bits/sample = 64Kbps

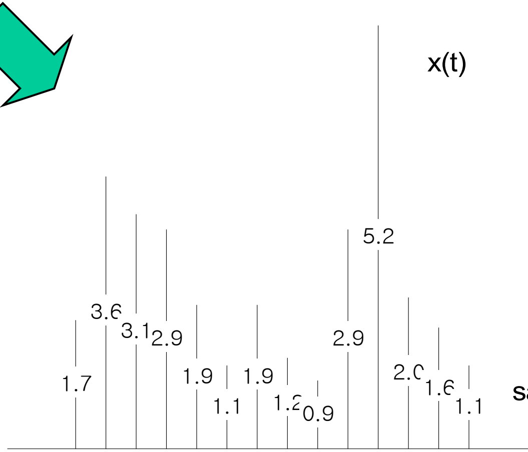
Digitizing the Sampled Signal → Quantizing



original signal

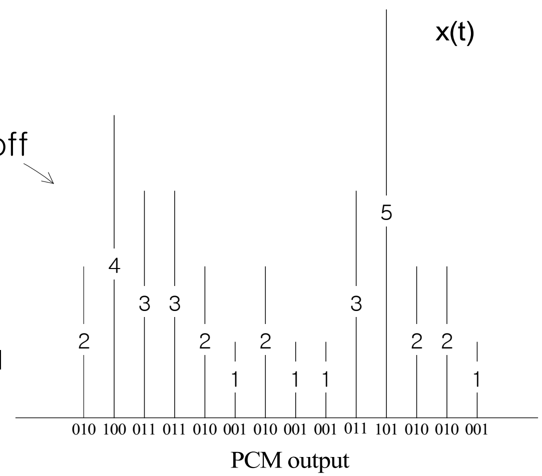


reconstructed signal



round off

sample signal



Pulse Amplitude Modulation (PAM) pulses

quantizing

Pulse Code Modulation (PCM) pulses

n-bit system gives 2^n levels

- Digital Data → Digital Signal
  - A large number of encoding techniques are available.
  - The criteria for selecting a scheme are:
    - Frequency spectrum
      - A lack of high frequency component → save bandwidth
      - A lack of dc-component → reduce interference
    - Clocking → synchronization
    - Error detection
    - Noise immunity
  - Encoding schemes
    - Non-Return to Zero (NRZ) Encoding
      - Nonreturn to Zero-Level (NRZ-L)
      - Nonreturn to Zero Inverted (NRZI)
    - Multilevel Binary Encoding
    - Biphase Encoding
      - Manchester
      - Differential Manchester

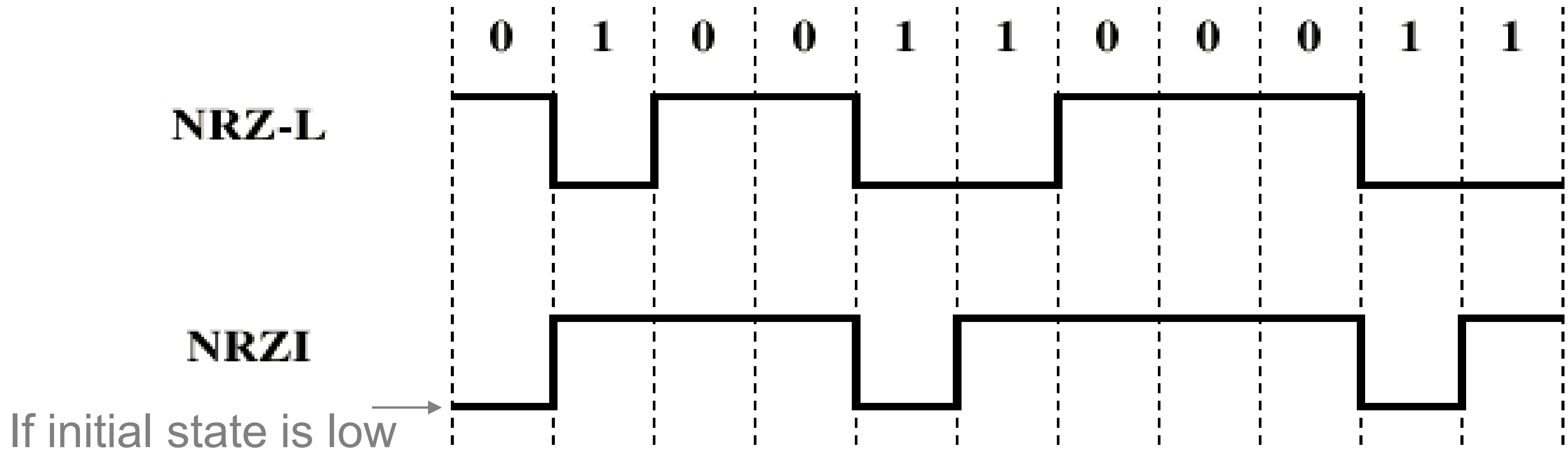
Non-Return to Zero (NRZ) Encoding

- Non-Return to Zero-Level (NRZ-L) Encoding
  - 0 = high level (high voltage)
  - 1 = low level (low voltage)

- Problem of NRZ-L: consecutive 0s and 1s
  - Receiver keeps average of signal it has seen so far
    - high if received signal is significantly higher than average
    - low if received signal is significantly lower than average
  - Too many consecutive 0s or 1s cause the average to change → difficult to detect signal
  - May cause clock drift problem

- Non-Return to Zero Inverted (NRZI) Encoding
  - 0 = No transition
  - 1 = Transition

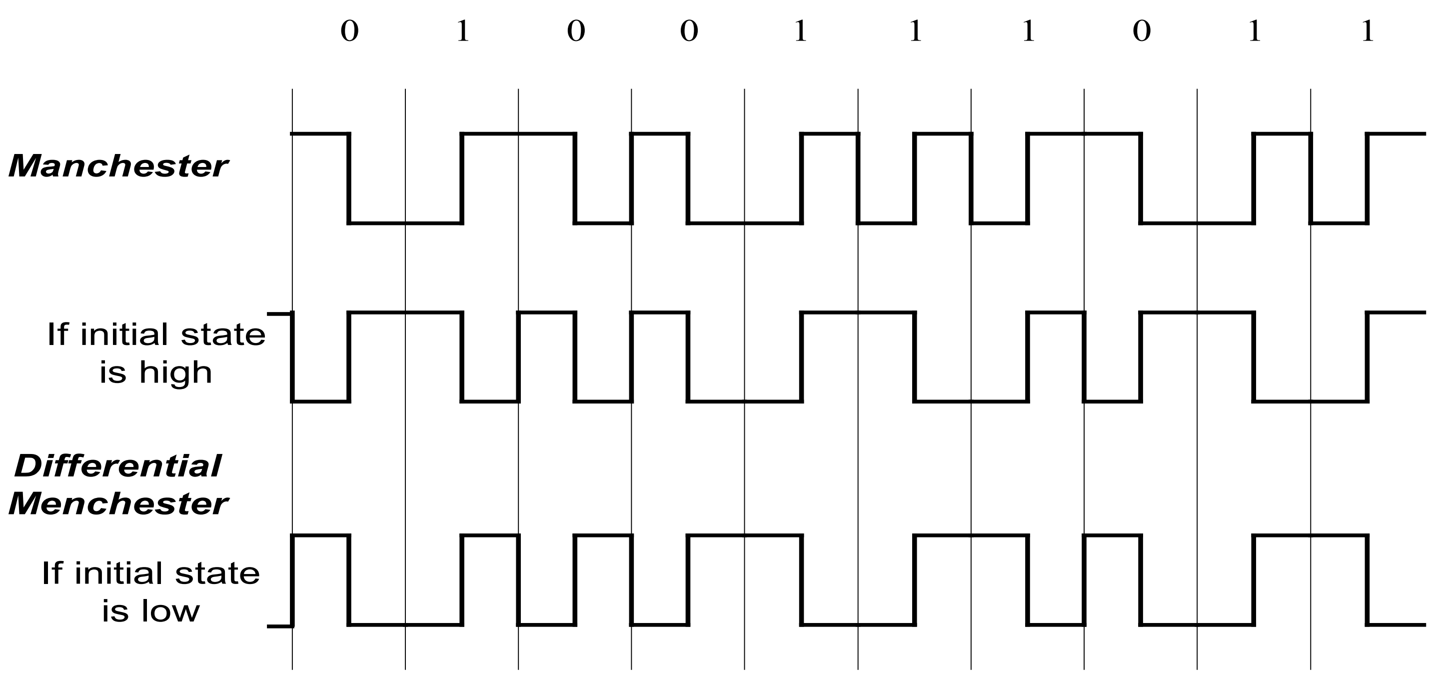
→ Solves the problem of consecutive 1s in NRZ-L, but does nothing for consecutive 0s



- Advantages of NRZ Encoding
  - Efficient use of bandwidth
  - Simple and easiest
- Disadvantages of NRZ Encoding
  - Consecutive 0s and/or 1s (dc component)
  - Lack of synchronization capability

(ex) a long string of 0's or 1's for NRZL or a long string of 0's for NRZI → Output of a constant voltage over a long period of time may result in a loss of synchronization

- Biphase Encoding → Transition in middle of each bit period
  - Manchester → IEEE 802.3 (Ethernet)
    - 0 = transition from high to low
    - 1 = transition from low to high
  - Differential Manchester → IEEE 802.5 (token ring)
    - 0 = transition at beginning of interval
    - 1 = no transition at beginning of interval



- Advantages of Biphase Encoding
  - Synchronization
  - No dc component
  - Error detection
- Disadvantages of Biphase Encoding
  - Requires more bandwidth
  - Maximum modulation rate is twice NRZ (efficiency=50%)

	Min	Max
NRZL	0 (000…) or (111…)	B (10101010…) or (01010101…)
NRZI	0 (000…)	B (111…)
Manchester	B (1010…) or (0101…)	2B (000…) or (111…)
Differential Manchester	B (111…)	2B (000…)