Basic Concepts in Data Transmission

EE450: Introduction to Computer Networks

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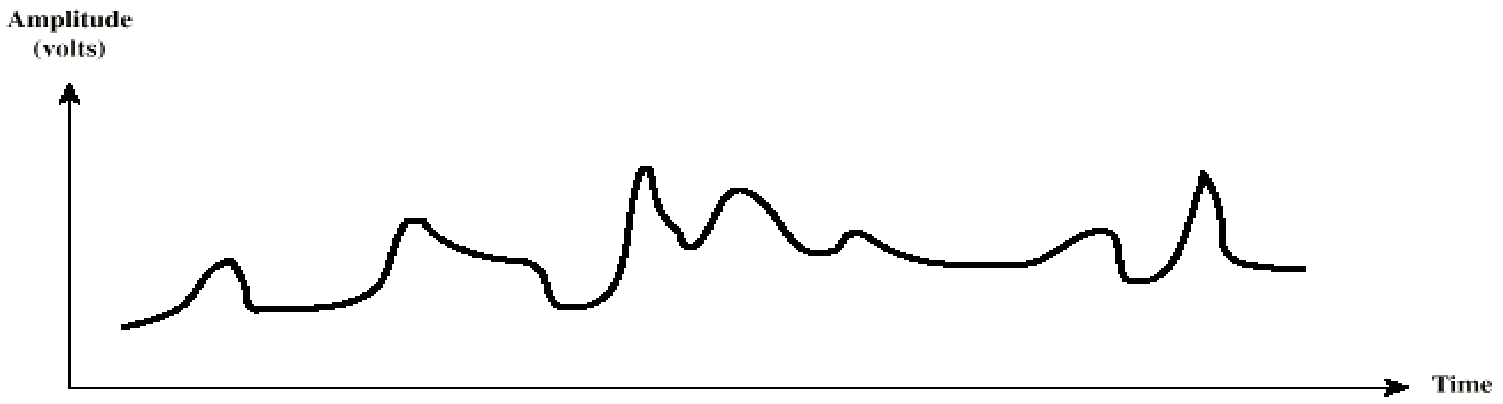
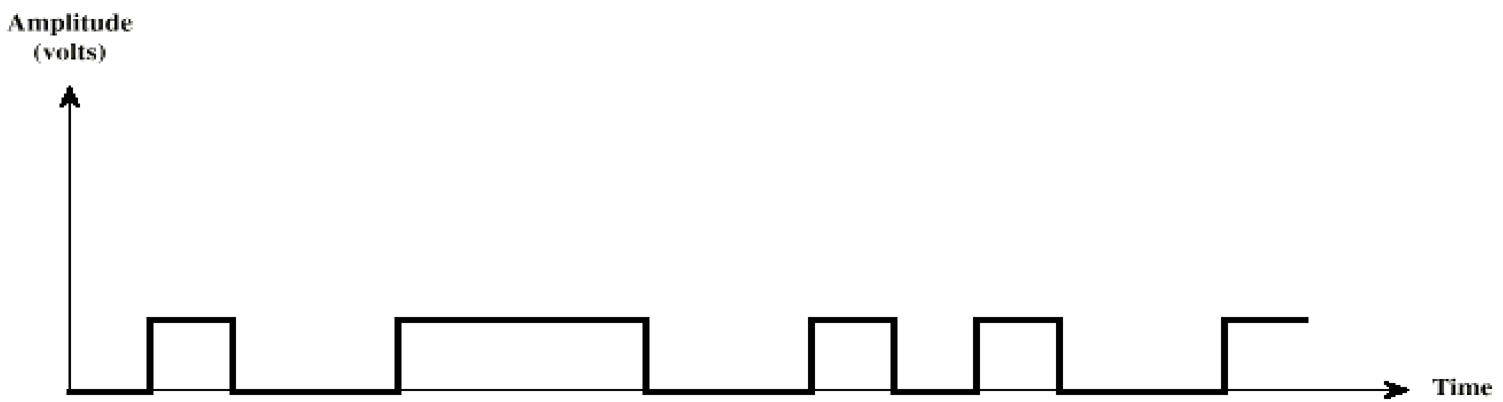
Data and Signals

- Data is an entity that convey information
  - *Analog*
    - Continuous values within some interval
    - e.g. sound, video
  - *Digital*
    - Discrete values
    - e.g. text, integers
- Signals are electrical or electromagnetic or optical representations of data

Analog vs. Digital Signals



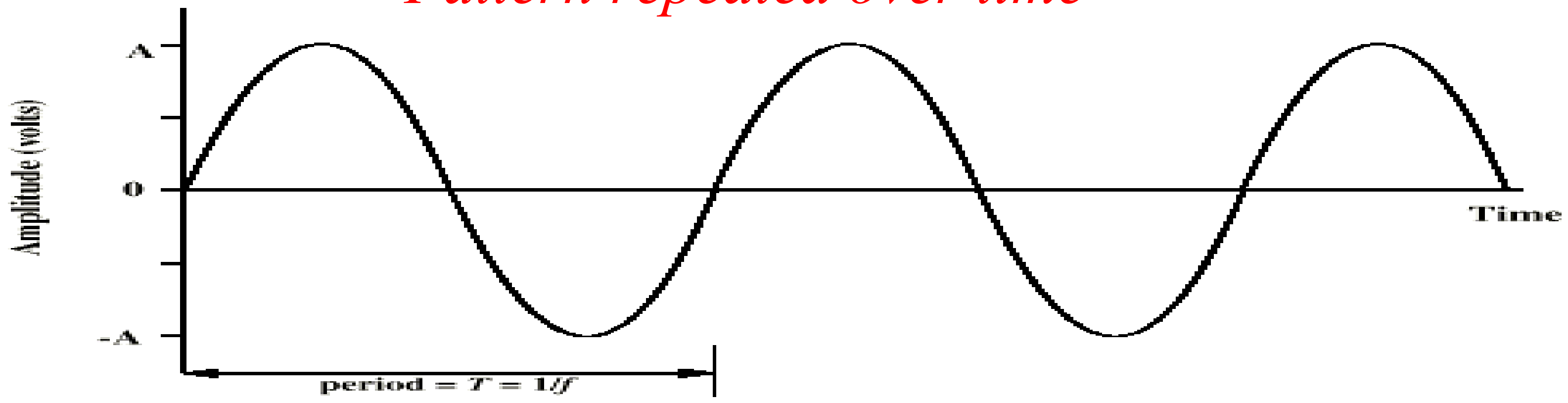
(a) Continuous



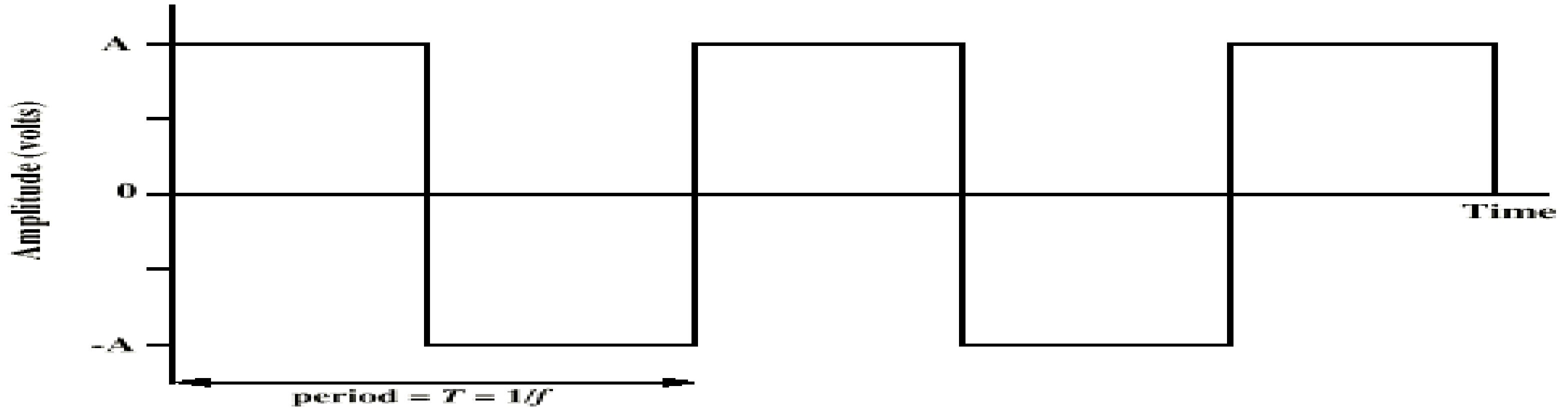
(b) Discrete

Periodic Signals

"Pattern repeated over time"



(a) Sine wave

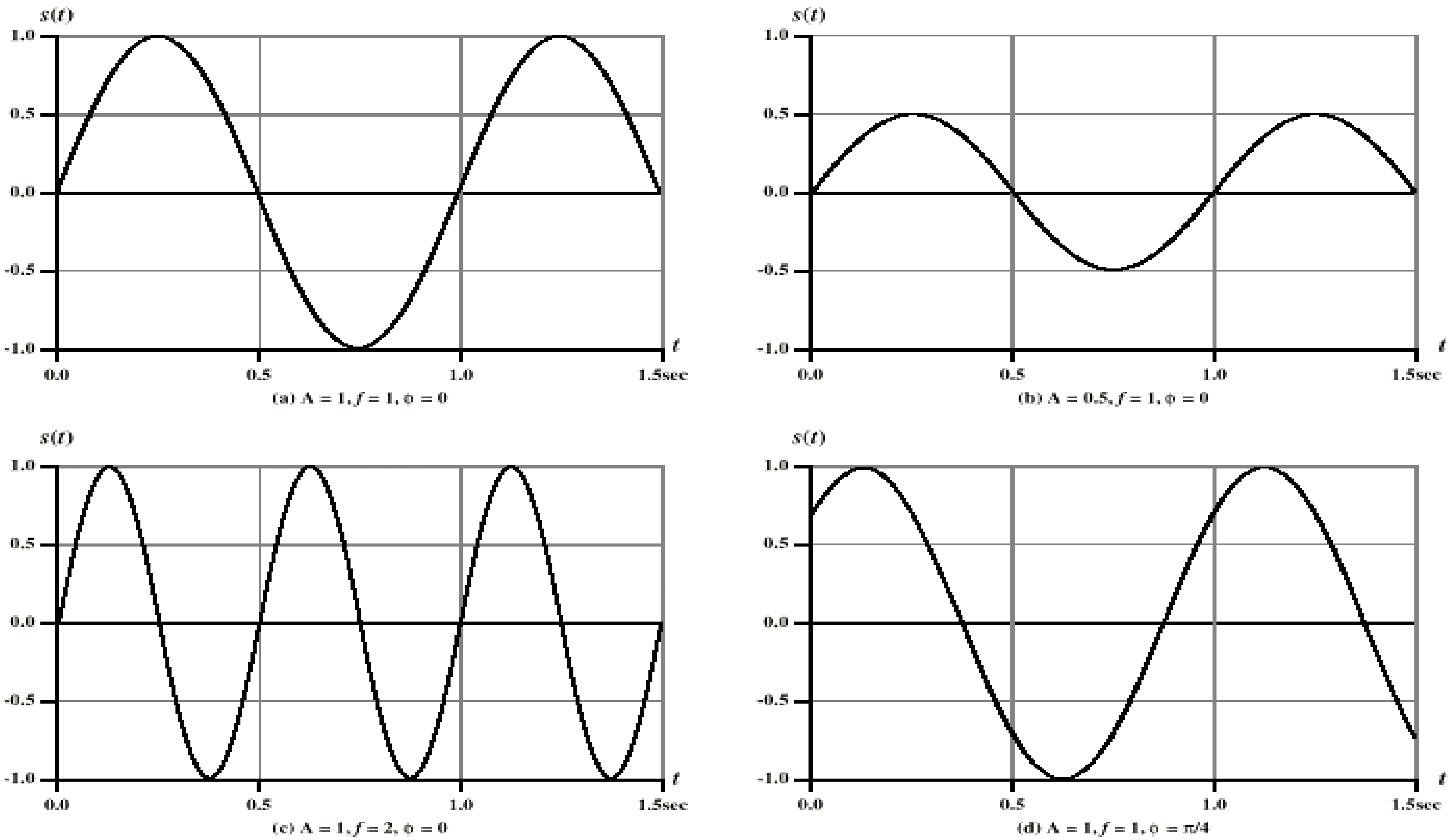


(b) Square wave

Parameters of a Sinusoid

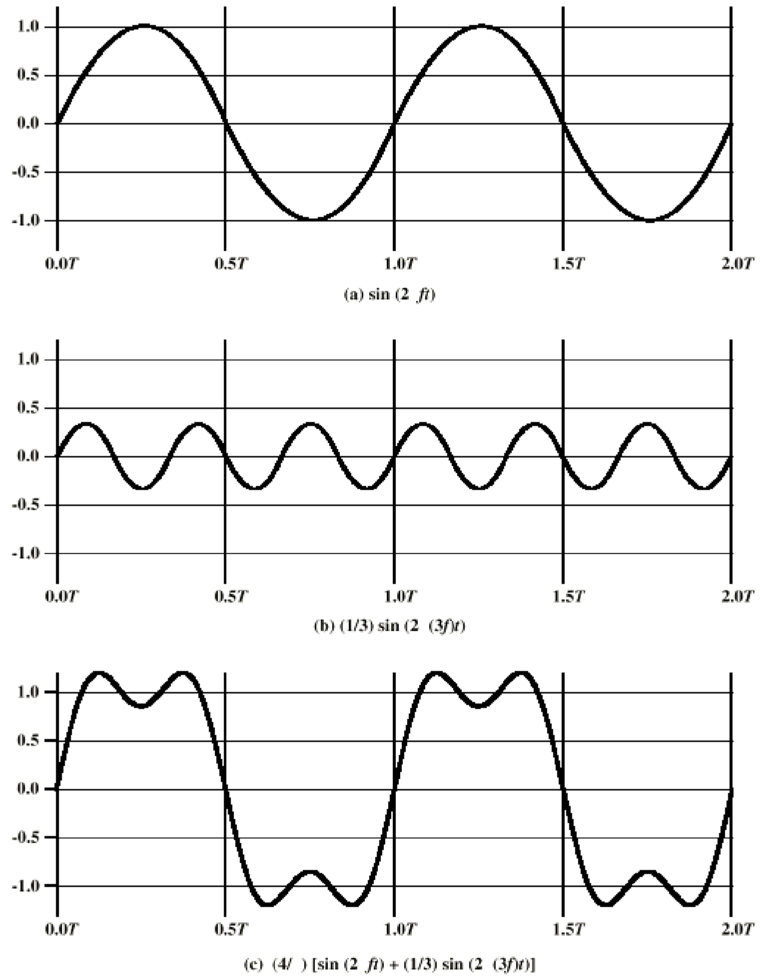
- Peak Amplitude (A)
  - Maximum strength of signal
  - Measured in volts or amps
- Frequency (f)
  - Rate of change of signal
  - Measured in Hertz (Hz) or cycles per second
  - The Period of a periodic signal, $T = 1/f$
- Phase (ϕ)
  - Relative position in time
  - Measured in Degrees (or Radians)

Varying Sine waves
$s(t) = A\sin(2\pi f t + \phi)$

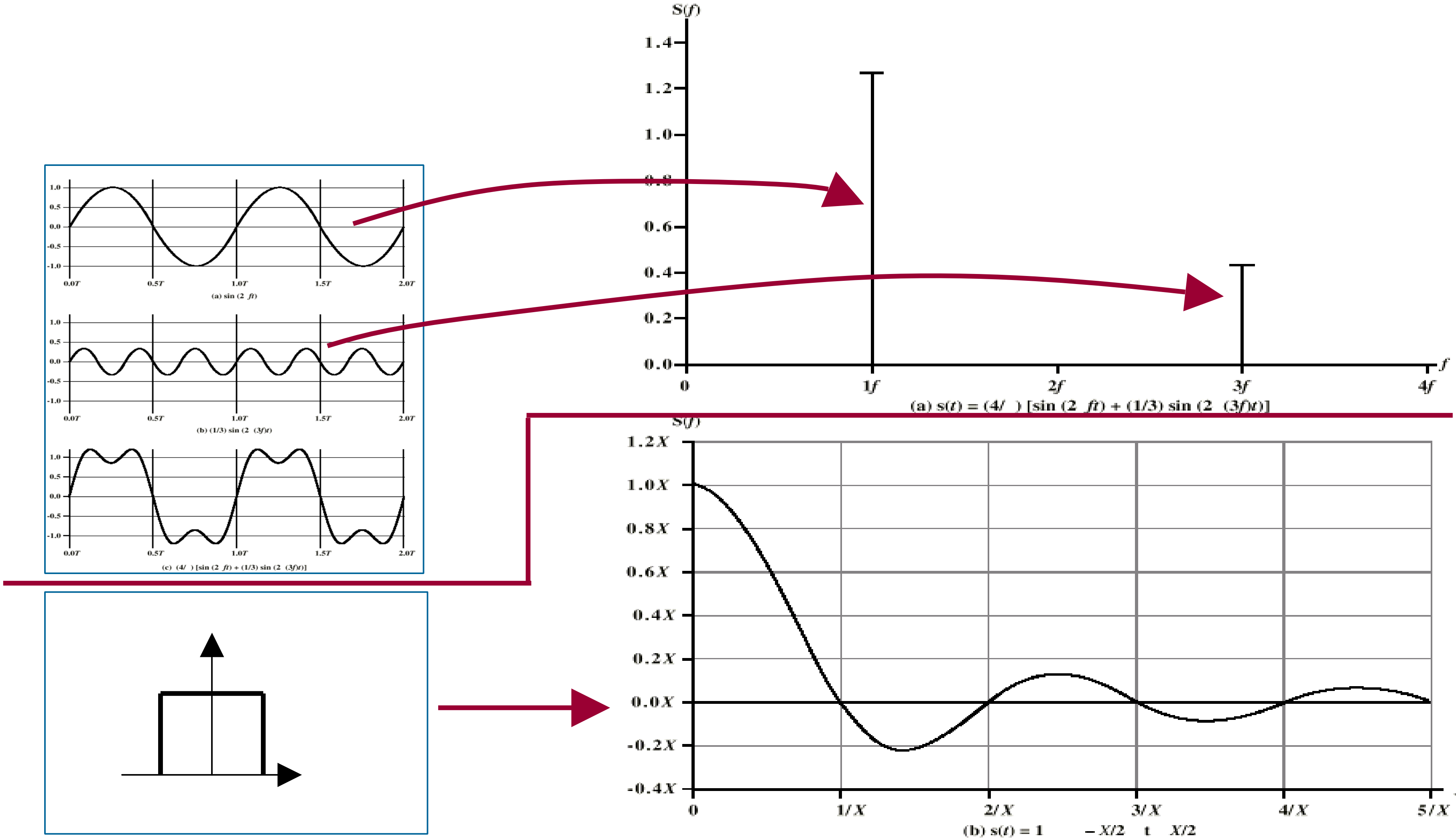


Frequency Domain Concepts

- Any arbitrary signal can be thought as a combination of many (may be infinite) components with each component being a sinusoidal waveform of given amplitude, frequency and phase
- Example shows the addition of two sinusoids



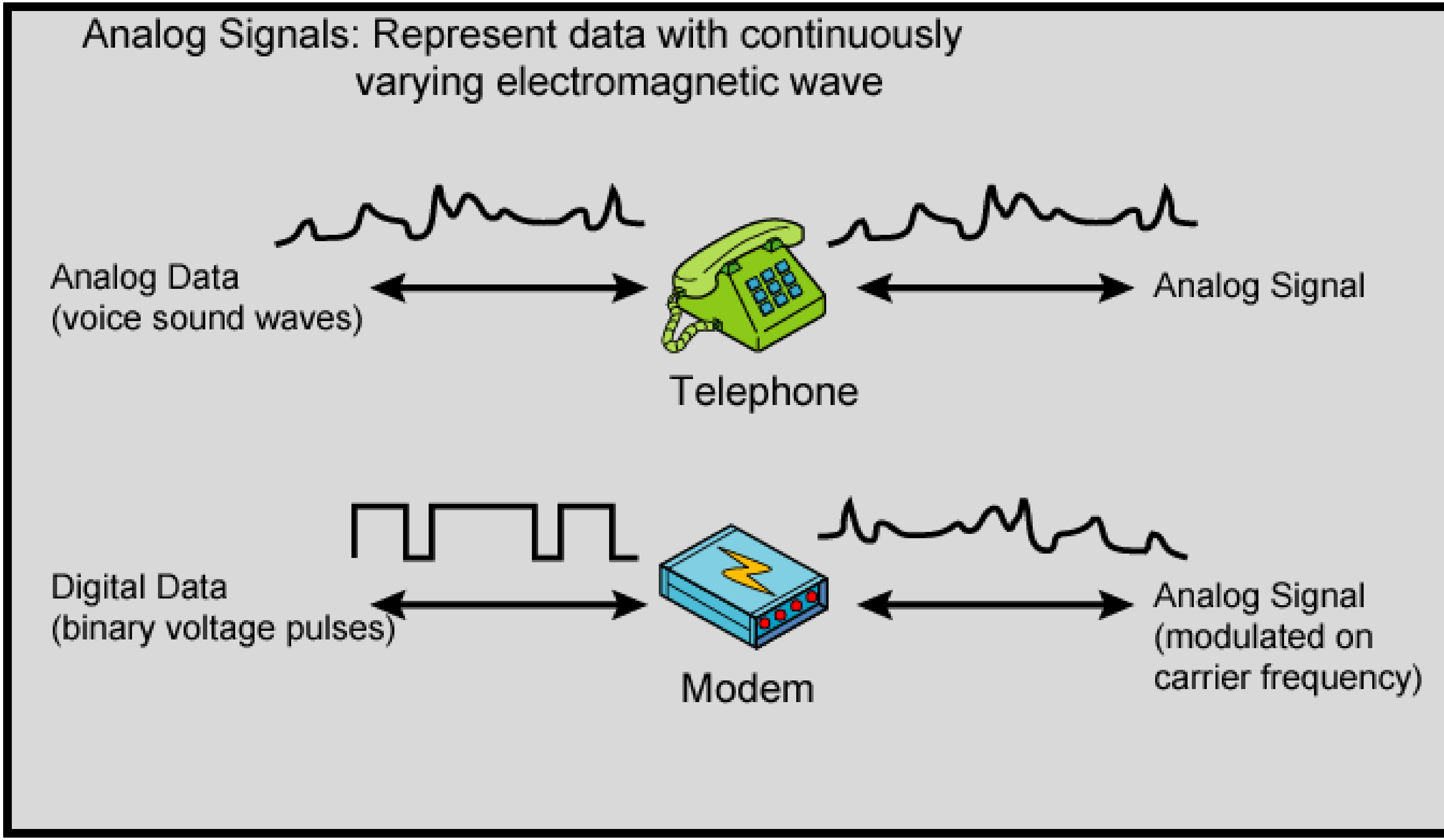
Time vs. Frequency Domains



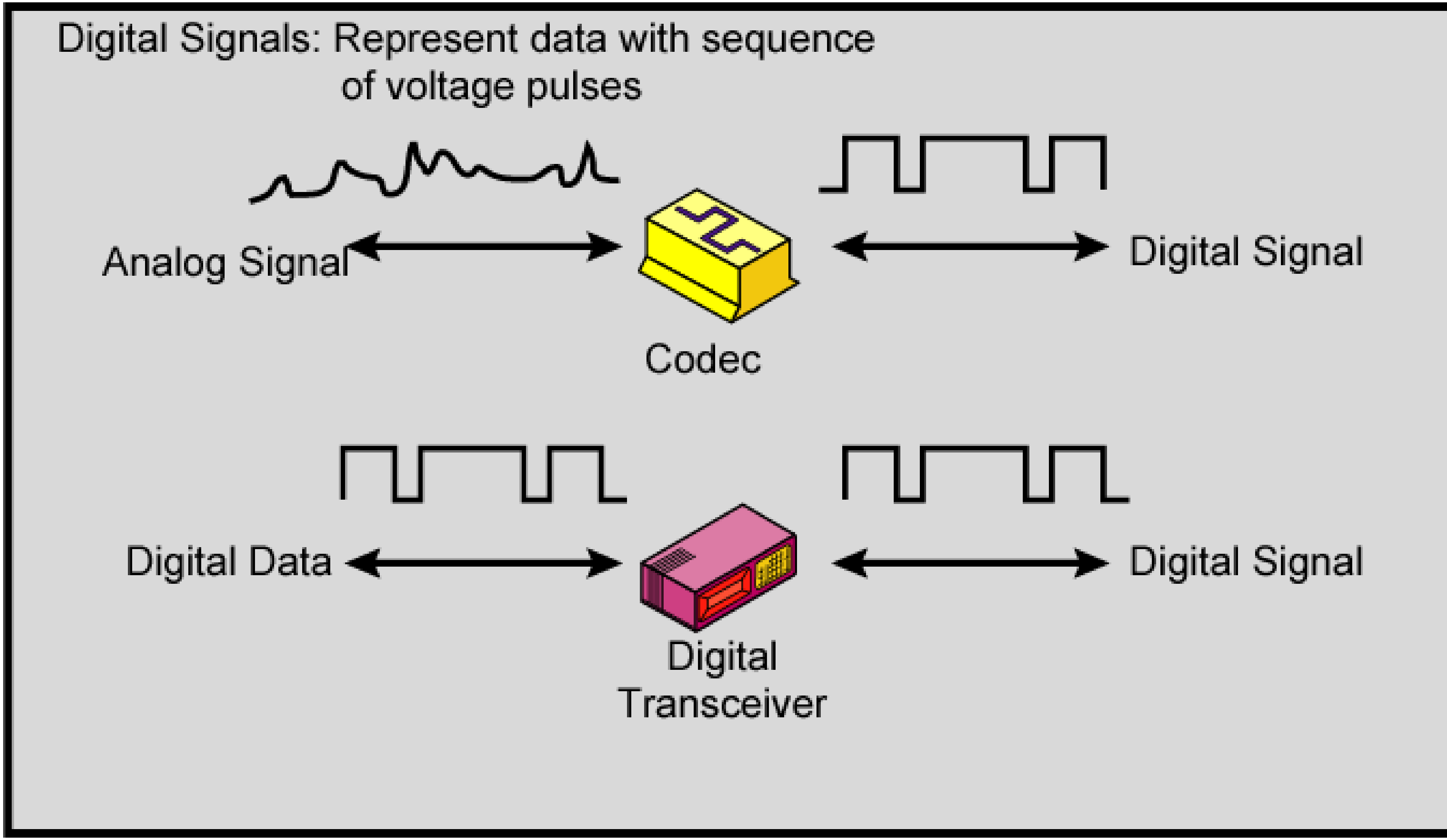
Spectrum and Bandwidth

- Spectrum of the Signal
  - range of frequencies contained in signal
- Bandwidth of the Signal
  - width of spectrum
  - Telephony (Voice) bandwidth 300Hz~ 3400Hz
  - Video bandwidth 4~6 MHz
- Bandwidth of Transmission System
  - Range of frequencies that will pass through the system without much degradation

Analog Signals representing Analog/Digital Data



Digital Signals representing Analog/Digital Data



Advantages of Digital Transmission

- Digital Technology
  - Low cost VLSI technology
- Data Integrity
  - Longer distances over lower quality lines
- Capacity Utilization
  - High bandwidth links economical
  - High degree of multiplexing easier with digital techniques
- Security & Privacy
  - Encryption
- Integration of Services
  - Can treat analog and digital data similarly

Transmission Impairments

- Signal received differ from signal transmitted
  - Analog - degradation of signal quality
    - Performance Measure : SNR
  - Digital - bit errors
    - Performance Measure: Bit Error Rate
- Reasons
  - Attenuation (amplitude distortion)
  - Delay distortion (pulse smearing!)
  - Noise: Thermal, Crosstalk, Impulse, etc…
  - Interference (intentional or un-intentional)

Channel Capacity (Shannon Theorem)

- The presence of noise can corrupt one or more bits
- Assume that the bandwidth of the medium is B (Hz) and the signal-to-noise ratio is SNR (usually given in *decibels*)
- The capacity of the channel (in bps) is the maximum transmission bit rate possible with negligible bit error rates (i.e. reliable transmission)
- $R_b \leq C = B \log_2 (1 + SNR)$
    - Note that to increase the capacity, we need either to increase the bandwidth, increase the signal power or reduce the noise power

Quick Review of decibels

$$N_{dB} = 10 \log_{10} \frac{P_2}{P_1}$$

P_1 = input power level

P_2 = output power level

N_{dB} = number of decibels

$\log_{10}$ = logarithm to the base 10

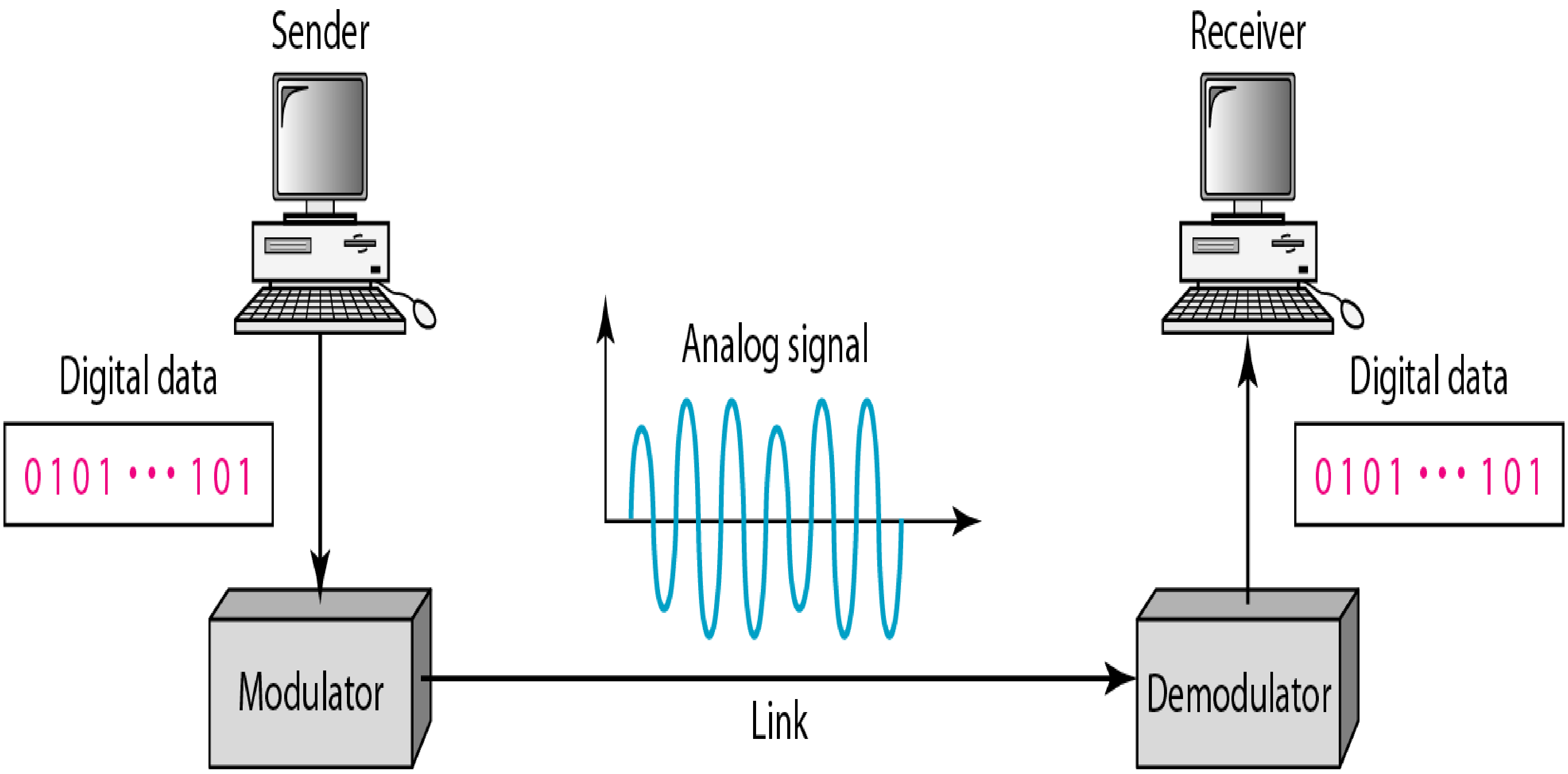
<u>Example</u>: If the input power level to a transmission system is 10mW and the measured output is 5mW, the power loss in dB is

$$N_{dB} = 10 \log (5/10) = 10 (-0.3) = -3 \text{ dB}$$

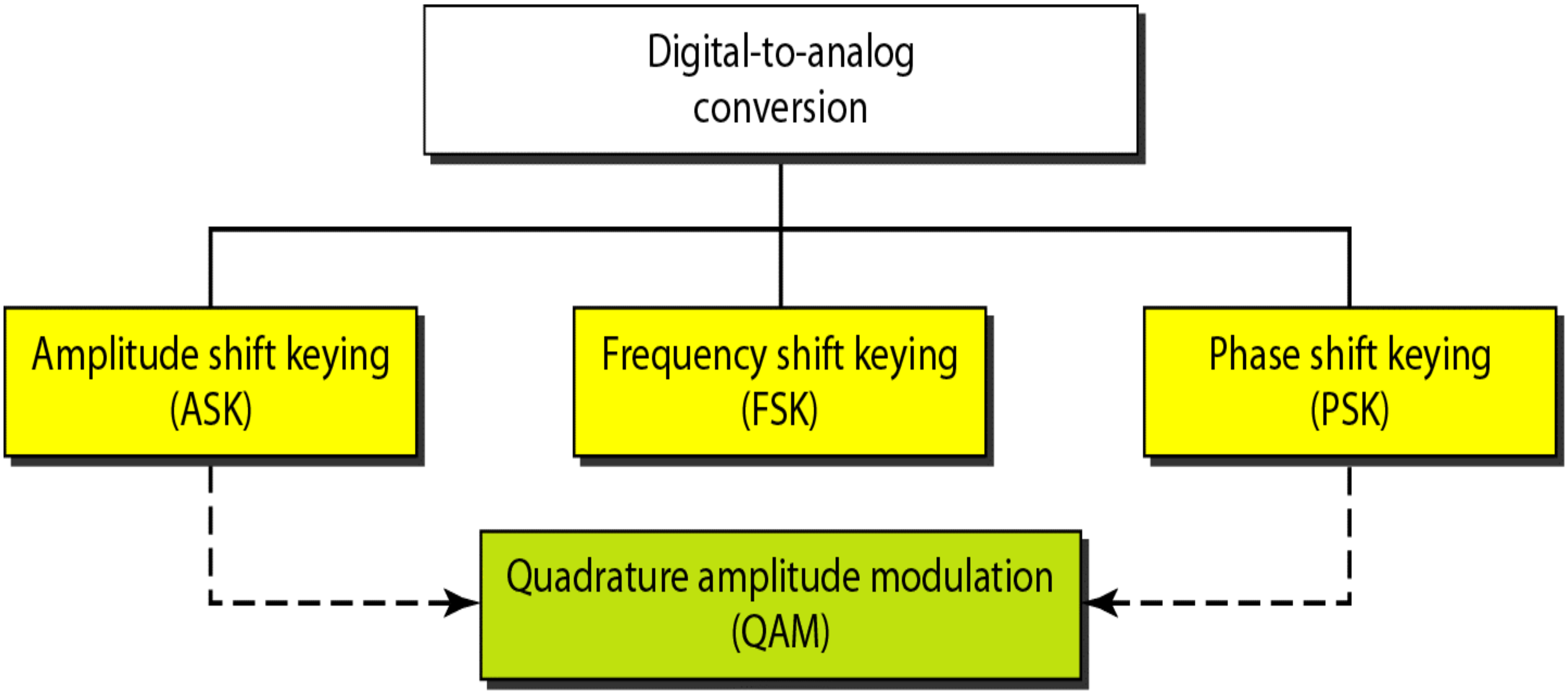
Modulation/Demodulation (Modems)

- Modulation is the process of varying one or more parameters of a carrier signal (Amplitude, Frequency or Phase) in accordance to an information signal
- Binary Modems: One bit goes-in, one signal goes-out $\Rightarrow$ Signaling (Baud) Rate = Bit Rate
- Multi-level Modems: "k" bits go-in, one signal goes-out $\Rightarrow$ $R_s = R_b/k$

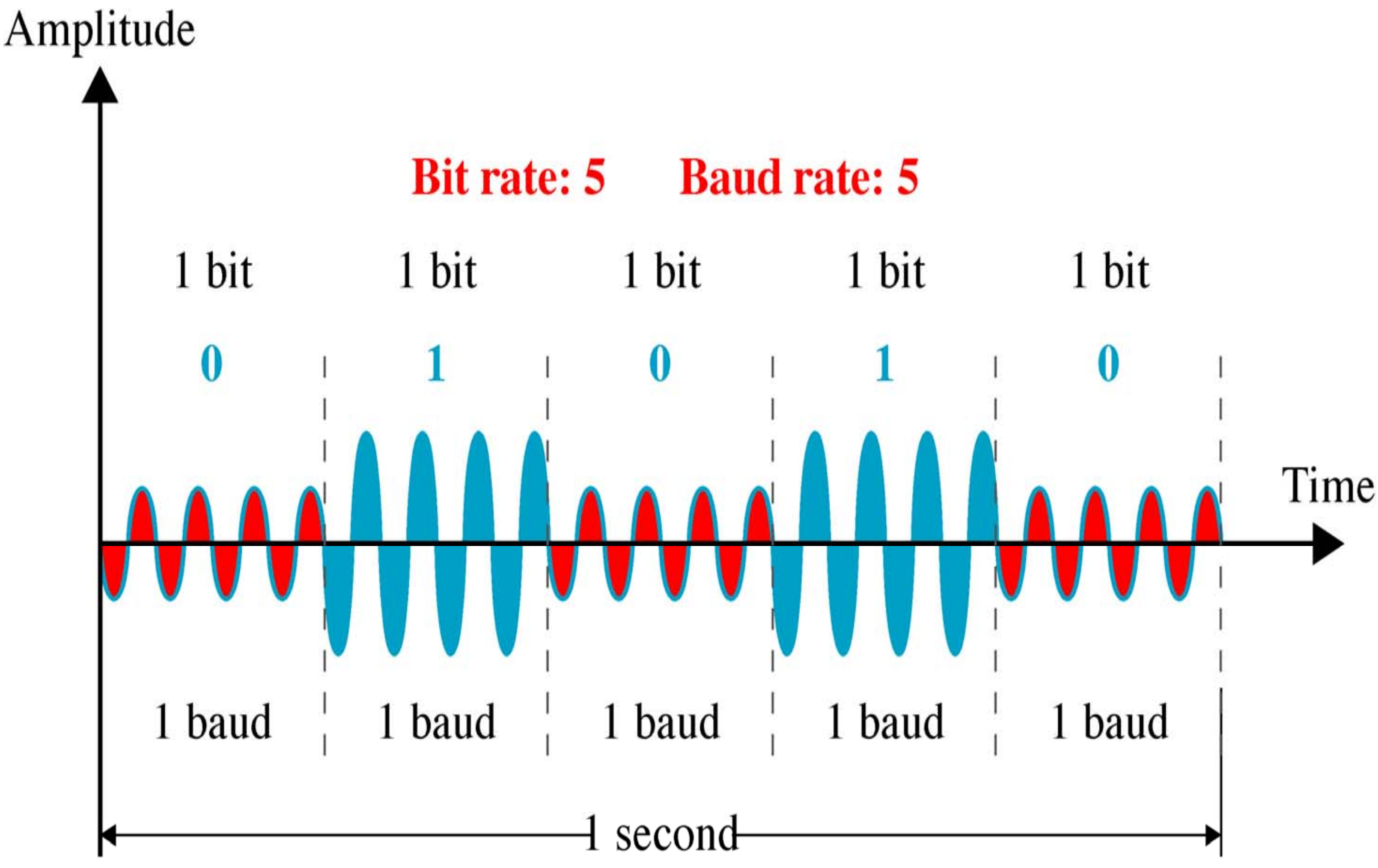
Modems (Continued)



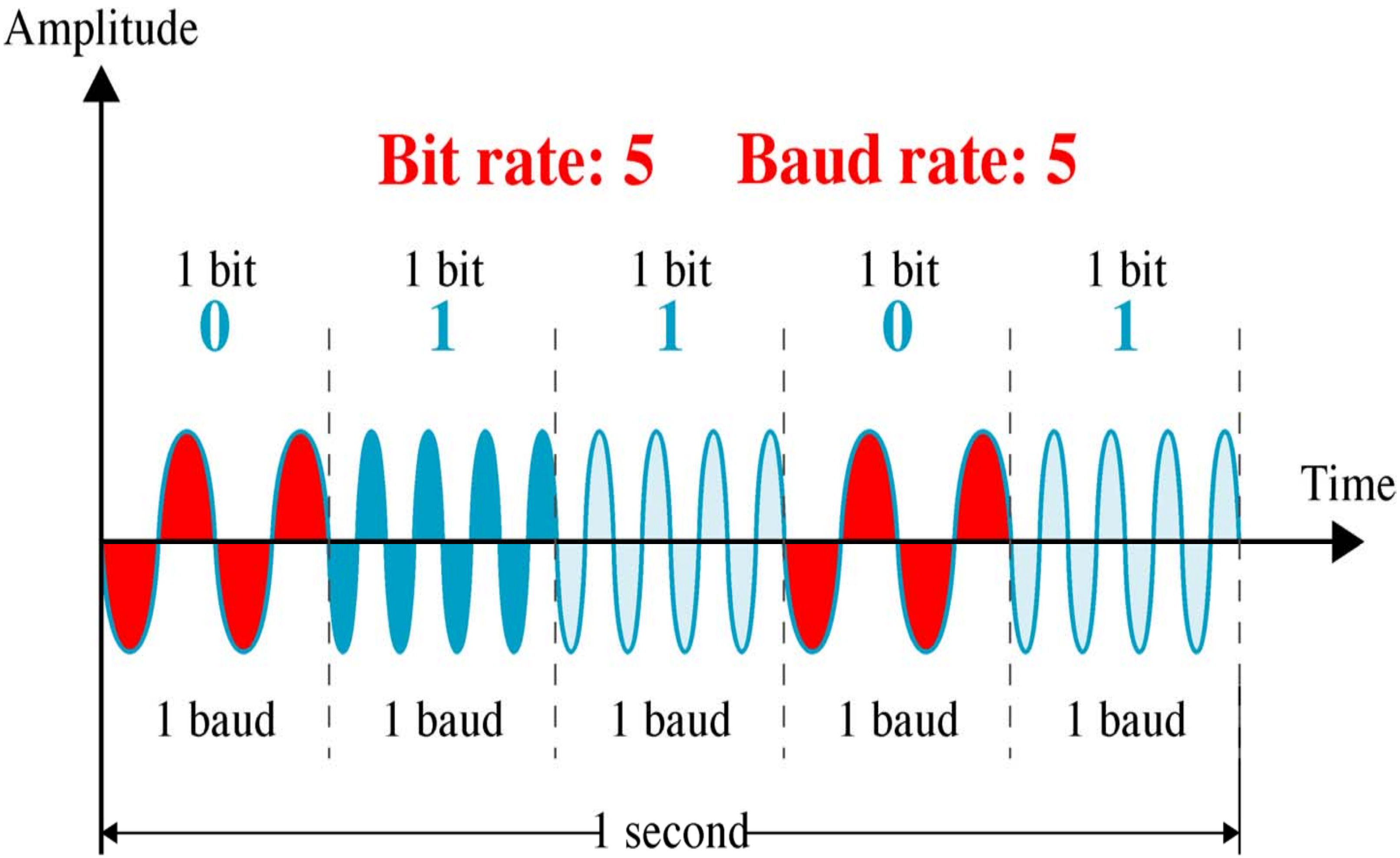
Types of Modulation



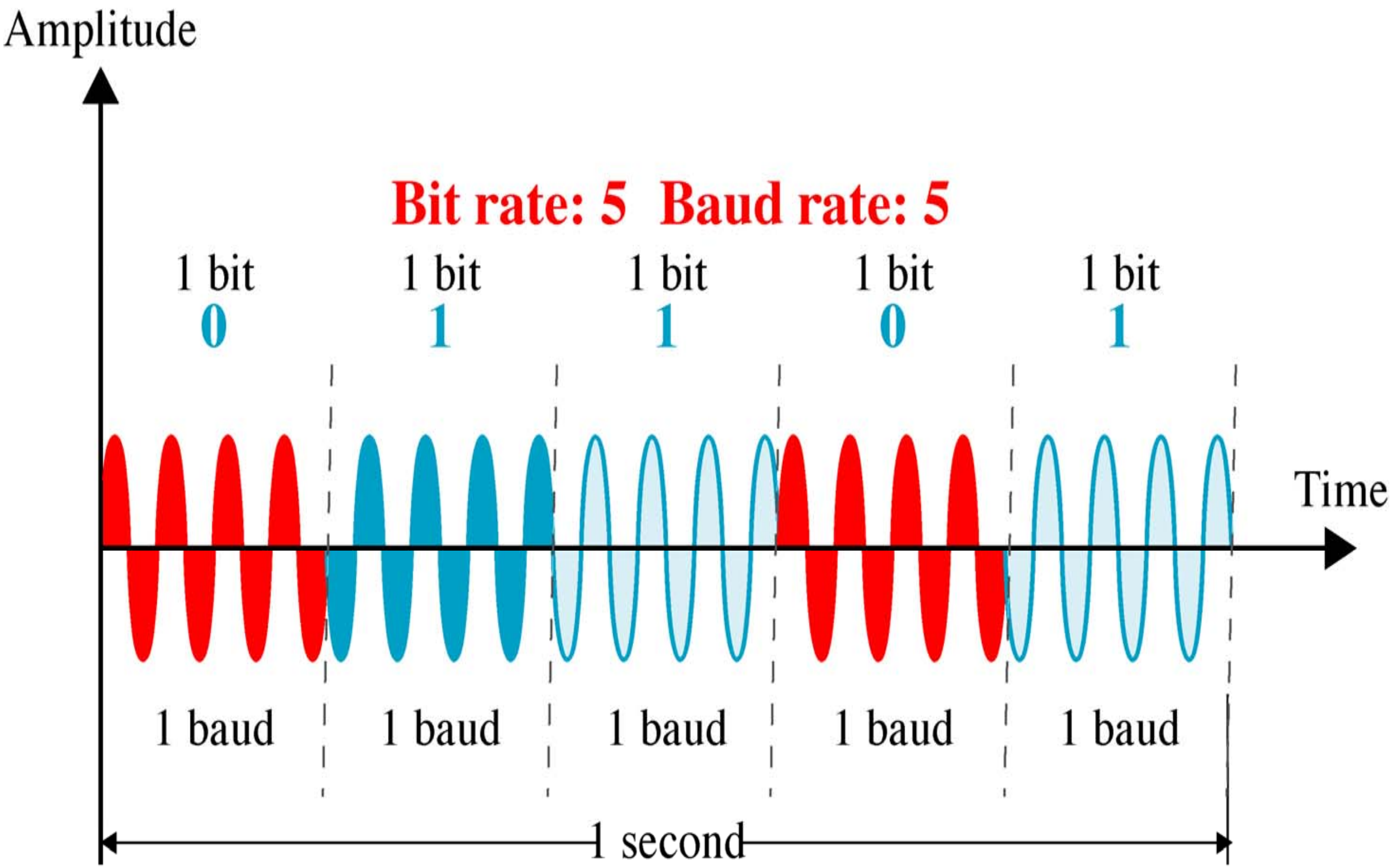
Binary Amplitude Shift Keying



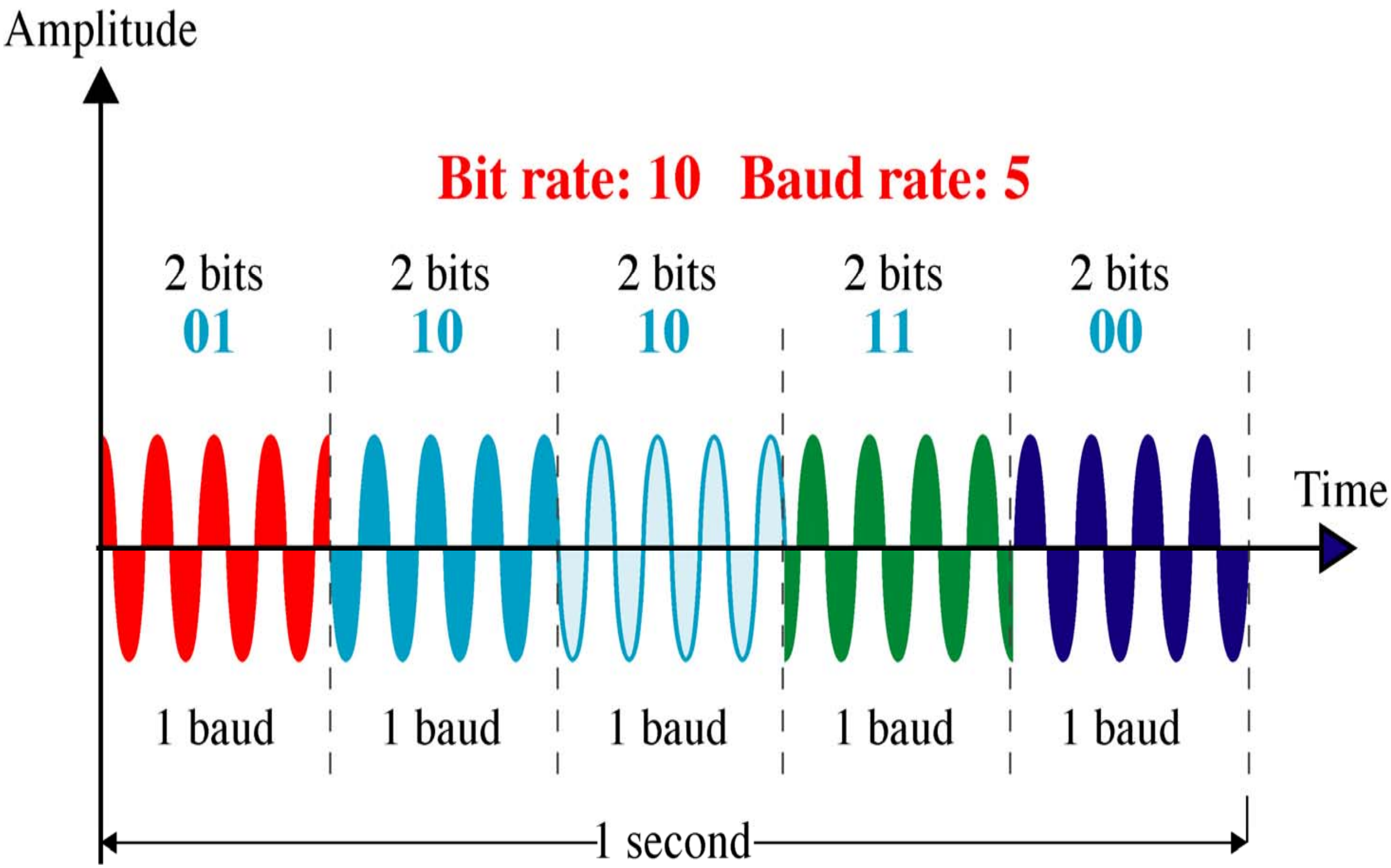
Binary Frequency Shift Keying



Binary Phase Shift Keying



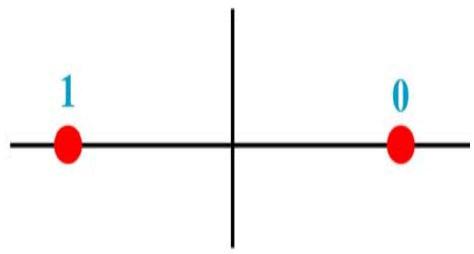
Quadrature Phase Shift Keying (QPSK)



Example: Phase Constellations

Bit	Phase
0	0
1	180

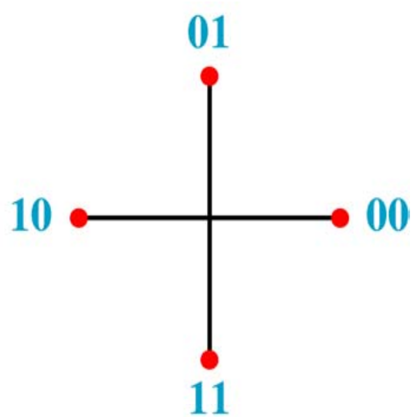
Bits



Constellation diagram

Dibit	Phase
00	0
01	90
10	180
11	270

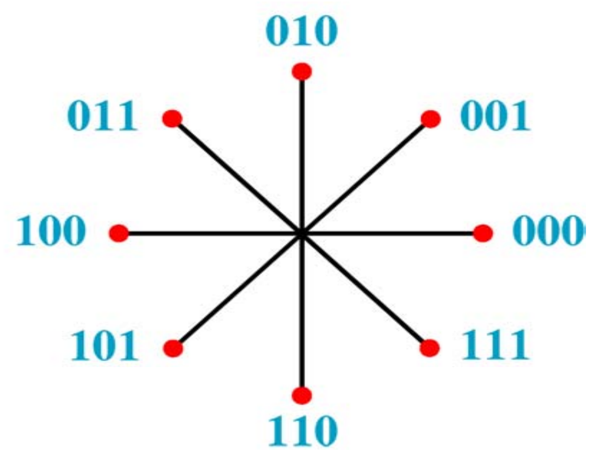
Dibit
(2 bits)



Constellation diagram

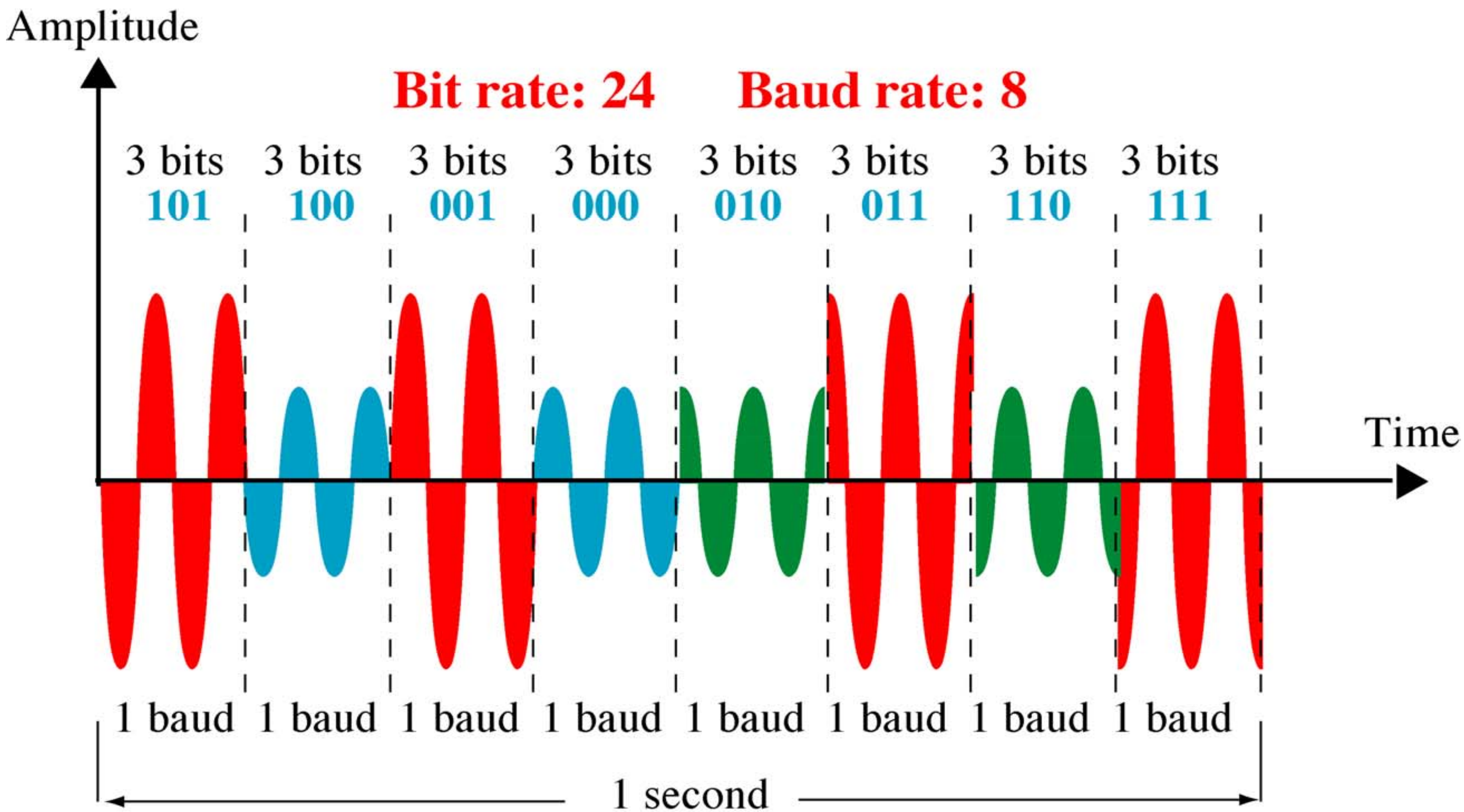
Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

Tribits
(3 bits)



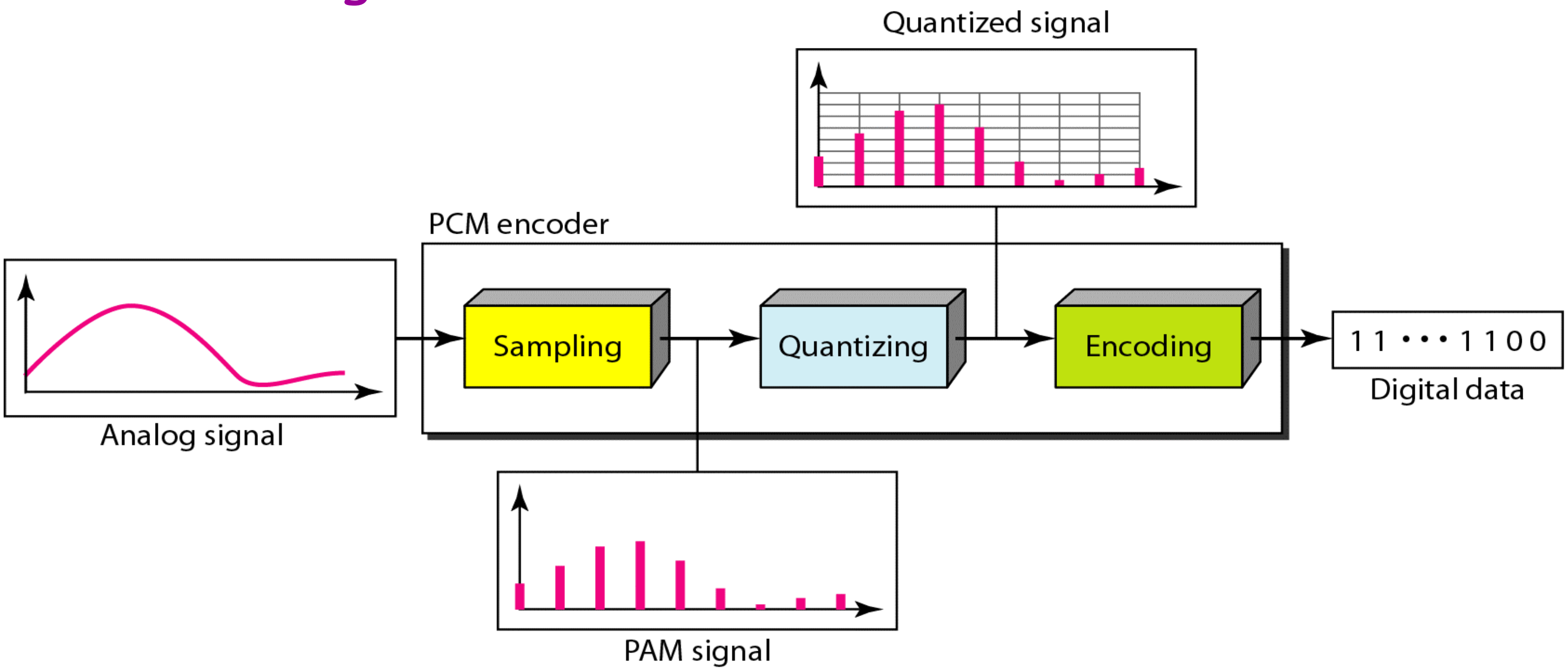
Constellation diagram

Quadrature Amplitude Modulation



Analog/Digital Conversion (A/D)

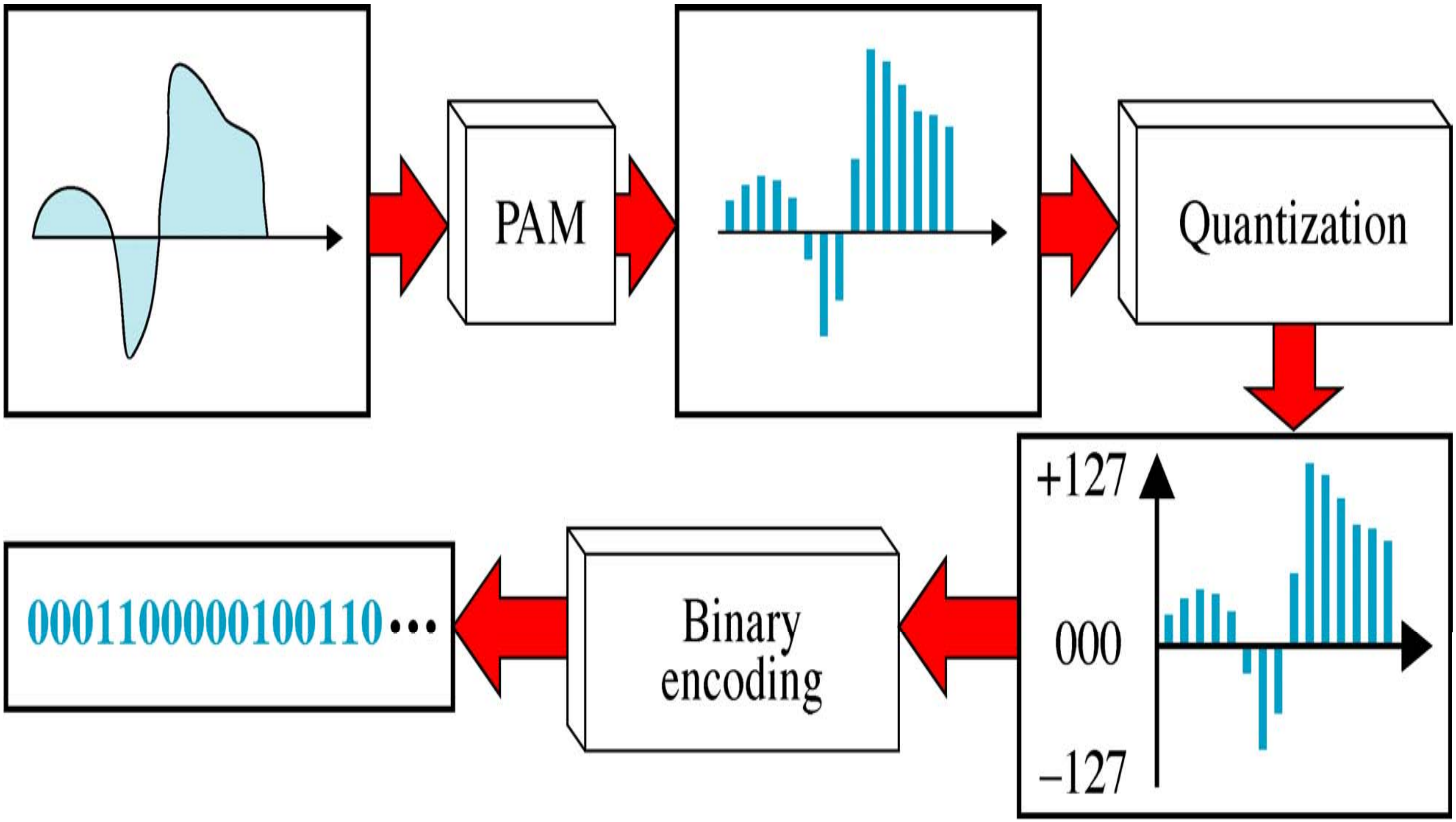
- Digitization consists of 3 processes
  - Sampling
  - Quantization
  - Encoding



Sampling/Quantization/Encoding

- If a signal is sampled at regular intervals at a rate higher than **twice** the highest signal frequency, the samples contain all the information of the original signal
- Voice signals are limited to below 4000Hz $\Rightarrow$ Require **8000** sample per second
- The result, which is 8000 analog samples/sec are quantized to certain number of **allowable** levels. In practice, for telephony, 256 allowable levels
- Each quantized sample is encoded into 8 bits resulting in a **digital signal** of rate 64 Kbps

Analog/Digital Conversion (Cont.)

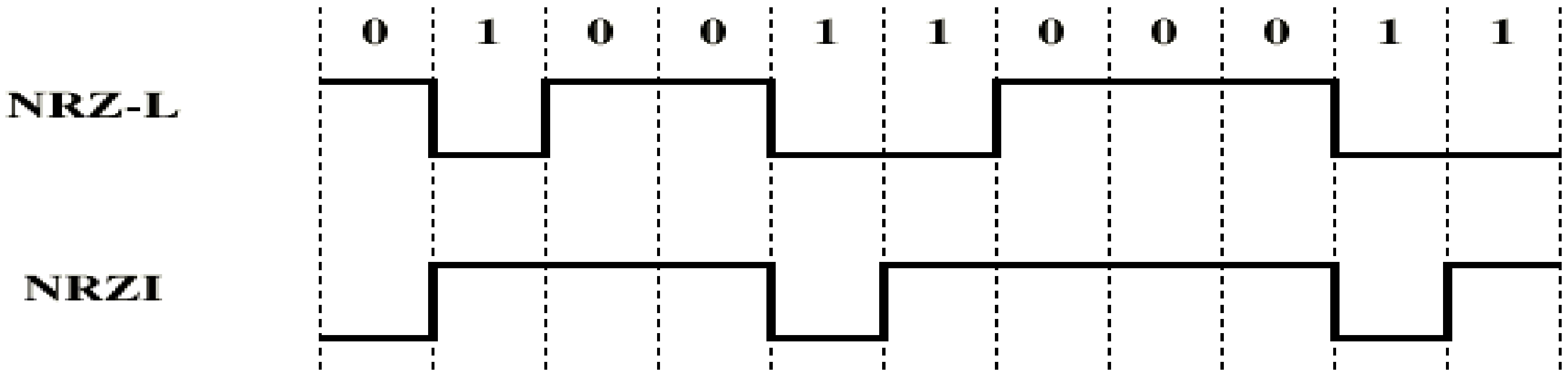


Digital Data/Digital Signals (Line Coding)

- Line coding is the process of encoding the binary string of bits by a digital/discrete-level signal suitable for transmission over the line
- Examples include:
  - NRZ-L : Non-Return-to-Zero Level
  - NRZ-I : Non-Return-to-Zero Inverted
  - Manchester/ Differential Manchester Coding
  - Many others…

NRZ & NRZI

- NRZ: Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
- e.g. Absence of voltage for zero, constant positive voltage for one. More often, negative voltage for one value and positive for the other
- NRZI: Non-return to zero inverted on ones

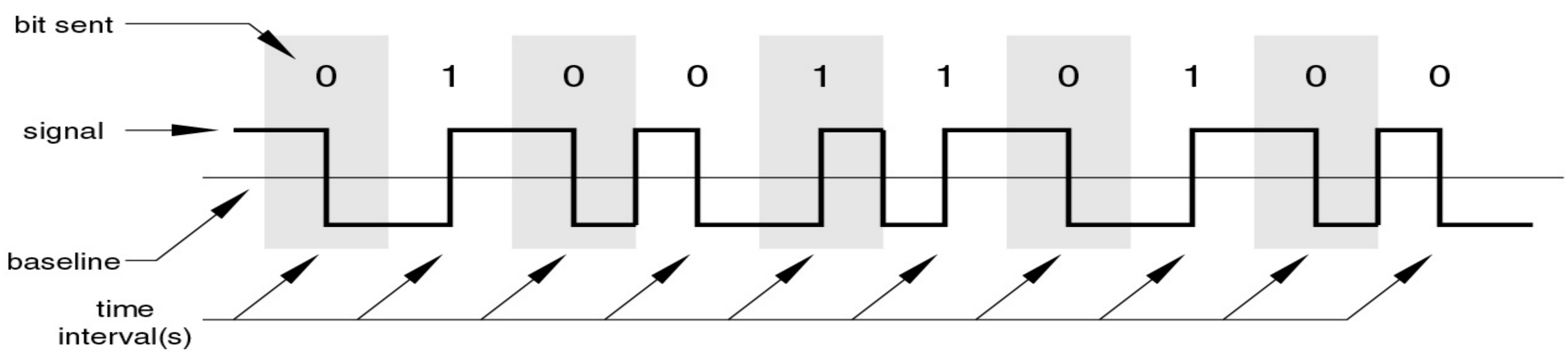


Manchester/Differential Manchester

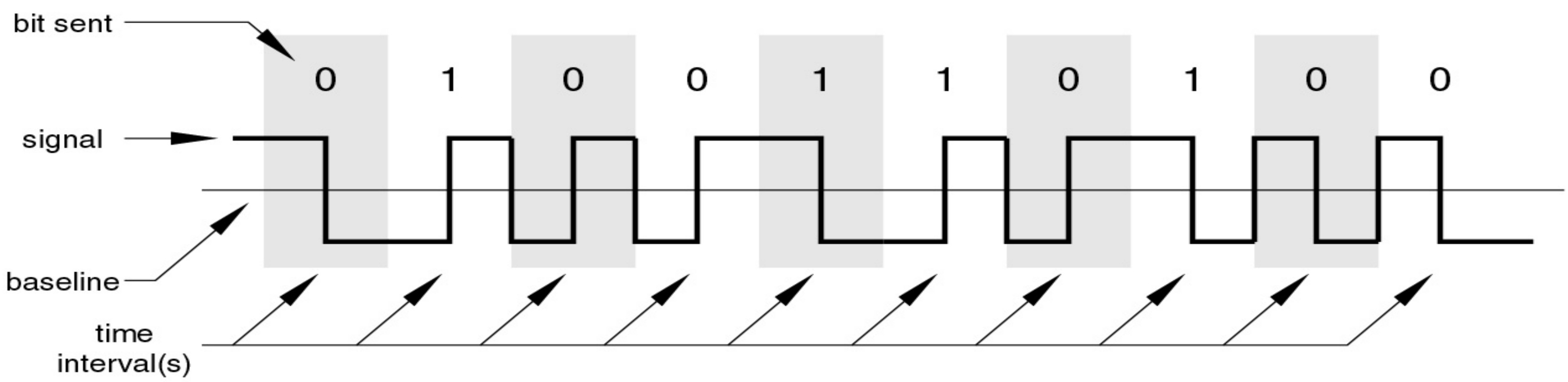
- Manchester
  - Transition in middle of each bit period
  - Transition serves as clock and data
  - Low to high represents one
  - High to low represents zero
  - Used by IEEE 802.3
- Differential Manchester
  - Mid-bit transition is clocking only
  - Transition at start of a bit period represents zero
  - No transition at start of a bit period represents one
  - Note: this is a differential encoding scheme
  - Used by IEEE 802.5

Manchester/Differential Manchester

Manchester Encoding



Differential Manchester Encoding



Trade-offs in choice of Line Coding

- Signal Spectrum
  - Lack of high frequencies reduce required BW
  - Lack of dc component allows ac coupling, providing isolation
- Clocking
  - Synchronizing transmitter and receiver
  - External clock or Sync based on signal
- Immunity to Interference and Noise
- Error Detection
- Cost and Complexity