Physical Layer

Signal Encoding

Data and Signals

Data = Something which carries meaning

Signals = Encoded data

- **Data**
  - Analog Data - takes on continuous values (e.g., audio)
  - Digital Data - takes on discrete values (e.g., text)

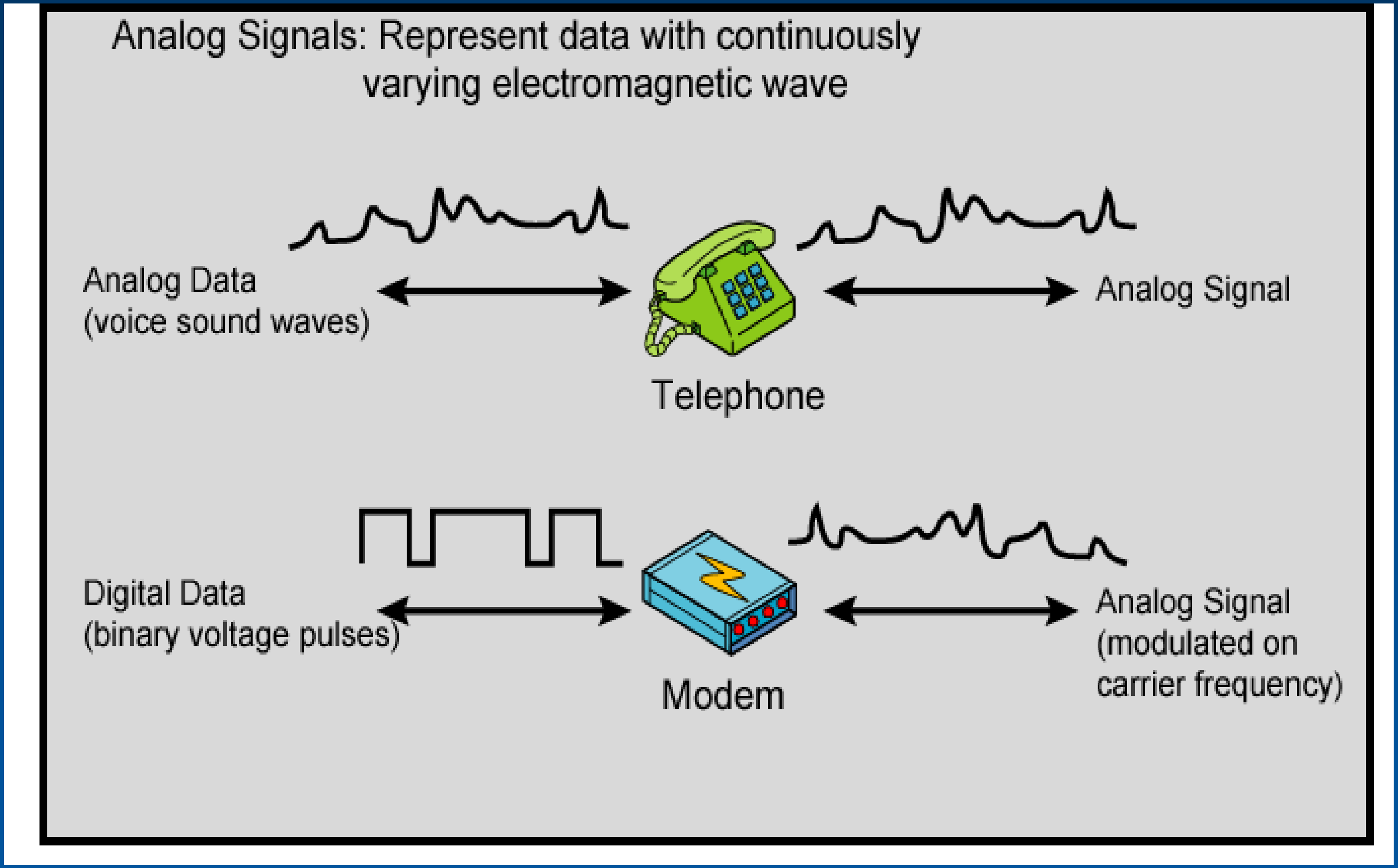
- **Signals:** All data are propagated by signals
  - Analog Signals - Represents data with continuously varying electromagnetic wave
  - Digital Signals - Represents data with a sequence of voltage pulses

Data Encoding

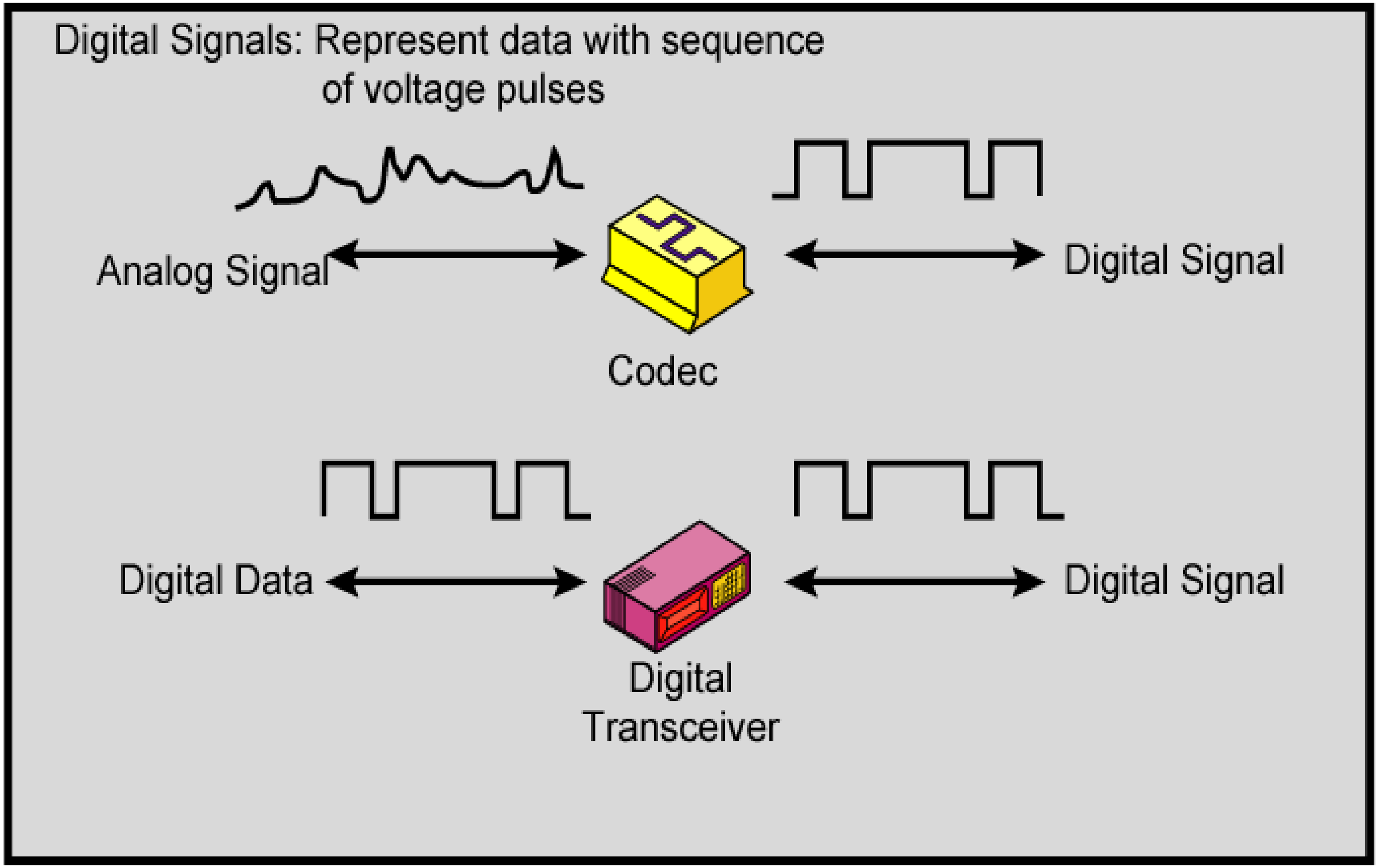
- All of the following combinations are used:

Digital Data Digital Signal	Digital Data Analog Signal
Analog Data Digital Signal	Analog Data Analog Signal

Analog vs. Digital Data/Signaling



Analog vs. Digital Data/Signaling



Analog Transmission

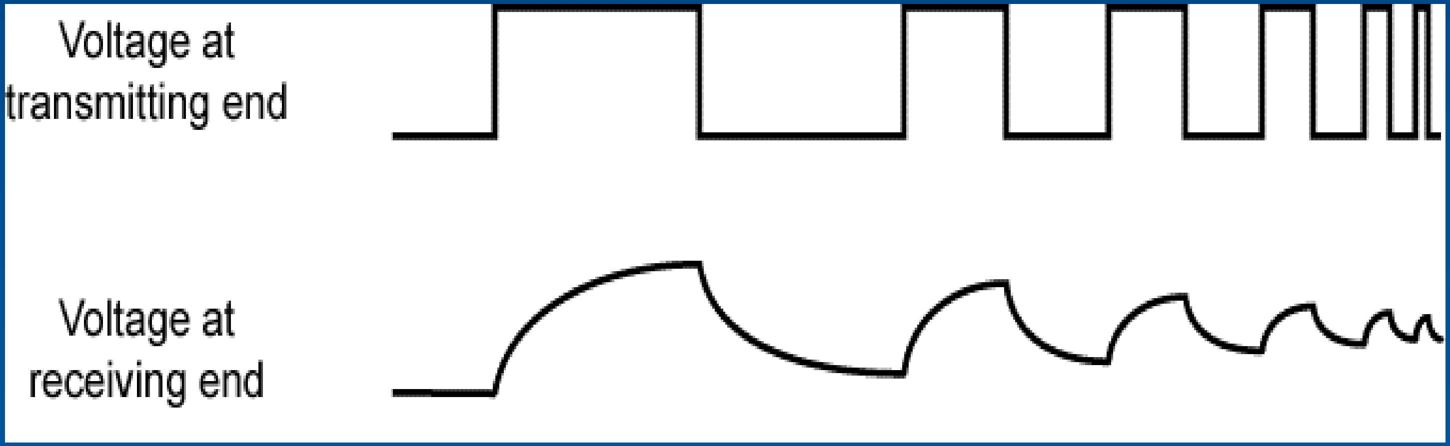
- May be analog or digital data
- Attenuated over distance
- Use amplifiers to boost signal
- Also amplifies noise

Digital Transmission

- Integrity endangered by noise, attenuation etc.
- Repeaters used
- Repeater receives signal
- Extracts bit pattern
- Retransmits
- Attenuation is overcome
- Noise is not amplified

Transmission Impairments

- Signal received may differ from signal transmitted
- Analog - degradation of signal quality
- Digital - bit errors
- Caused by
  - Attenuation and attenuation distortion
  - Delay distortion
  - Noise

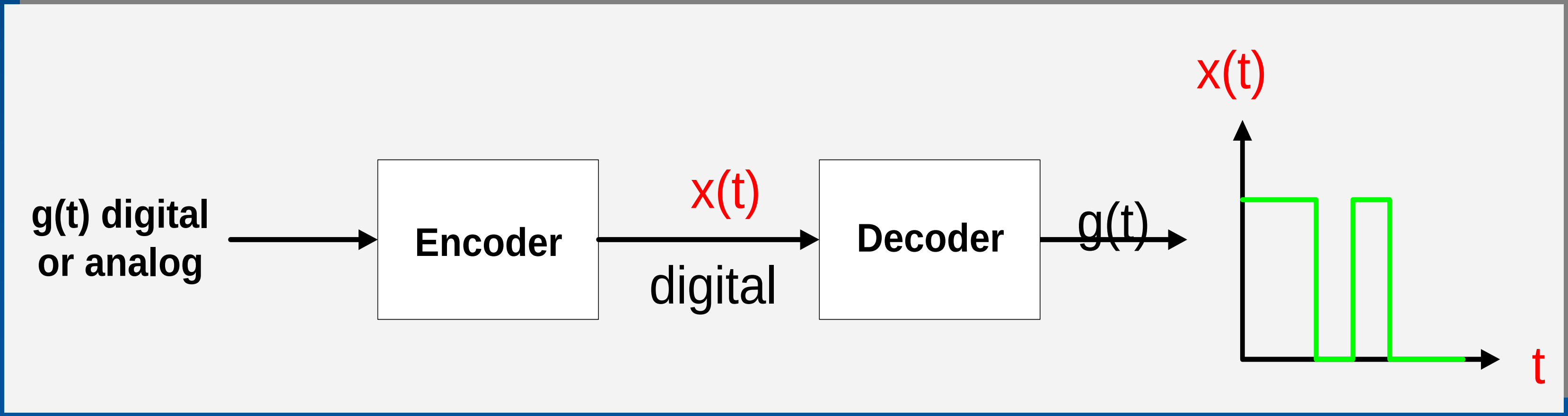


Attenuation of Digital Signals

Data Encoding

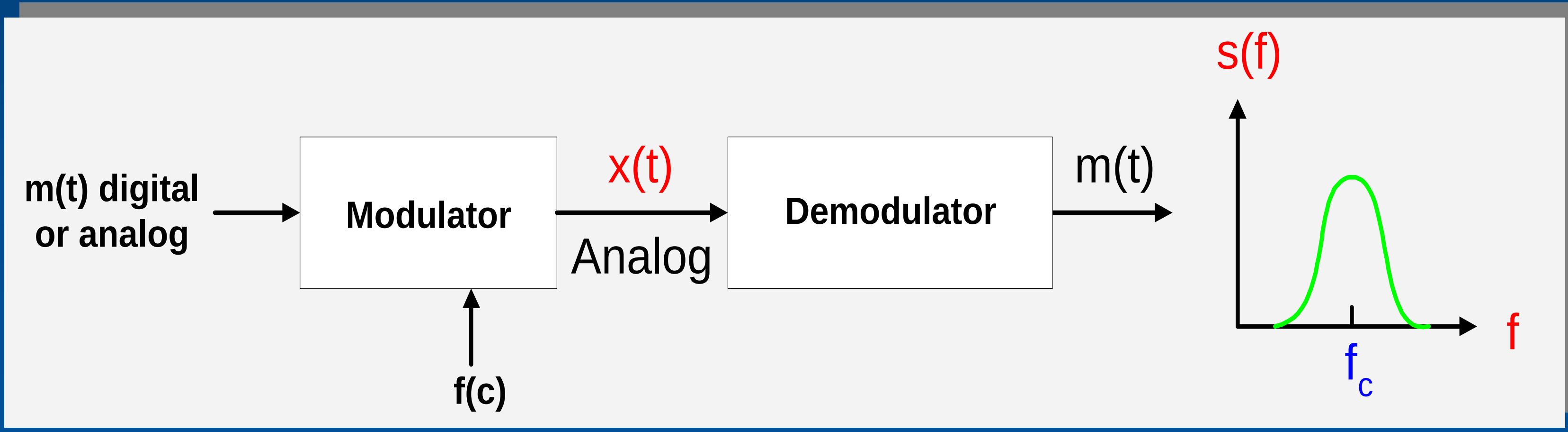
- Data encoding describes the techniques used to map data into signals

- With digital signals:
  - Data is encoded onto a digital signal.



Data Encoding

- With analog signals:
- Data is encoded onto a carrier signal with frequency f_c.This process is called Modulation.



Digital Data / Digital Signals

- Recall:
  - A digital signal is a discrete voltage pulse.
  - Each pulse represents one or several bits.
- Terminology
  - Data Rate. Rate at which data can be transmitted (measured in bps)
  - Bit Length. Time to transmit a bit.
  - Modulation Rate. Rate at which the signal is changed (measured in signal elements per second or baud)

Digital Data / Digital Signals

- A large number of digital data/digital signal encoding techniques are available. The criteria for selecting a scheme are:
  - Frequency Spectrum
  - Bit Timing (Clocking)
  - Error Detection
  - Immunity to interference.

Digital Data / Digital Signal

- **Encoding Schemes**

- NRZ-L (Nonreturn-to-zero-level)
  0 = high level   1 = low level
- NRZI (Nonreturn-to-zero-Inverted)
  0 = no transition at beginning of interval
  1 = transition at beginning of interval
- Bipolar-AMI
  0 = no line signal.
  1 = positive or negative level, alternating for successive ones

Digital Data / Digital Signal

- Pseudoternary

  0 = positive or negative level, alternating for successive zeros

  1 = no line signal

- Manchester

  0 = transition from high to low in middle of interval

  1 = transition from low to high in middle of interval

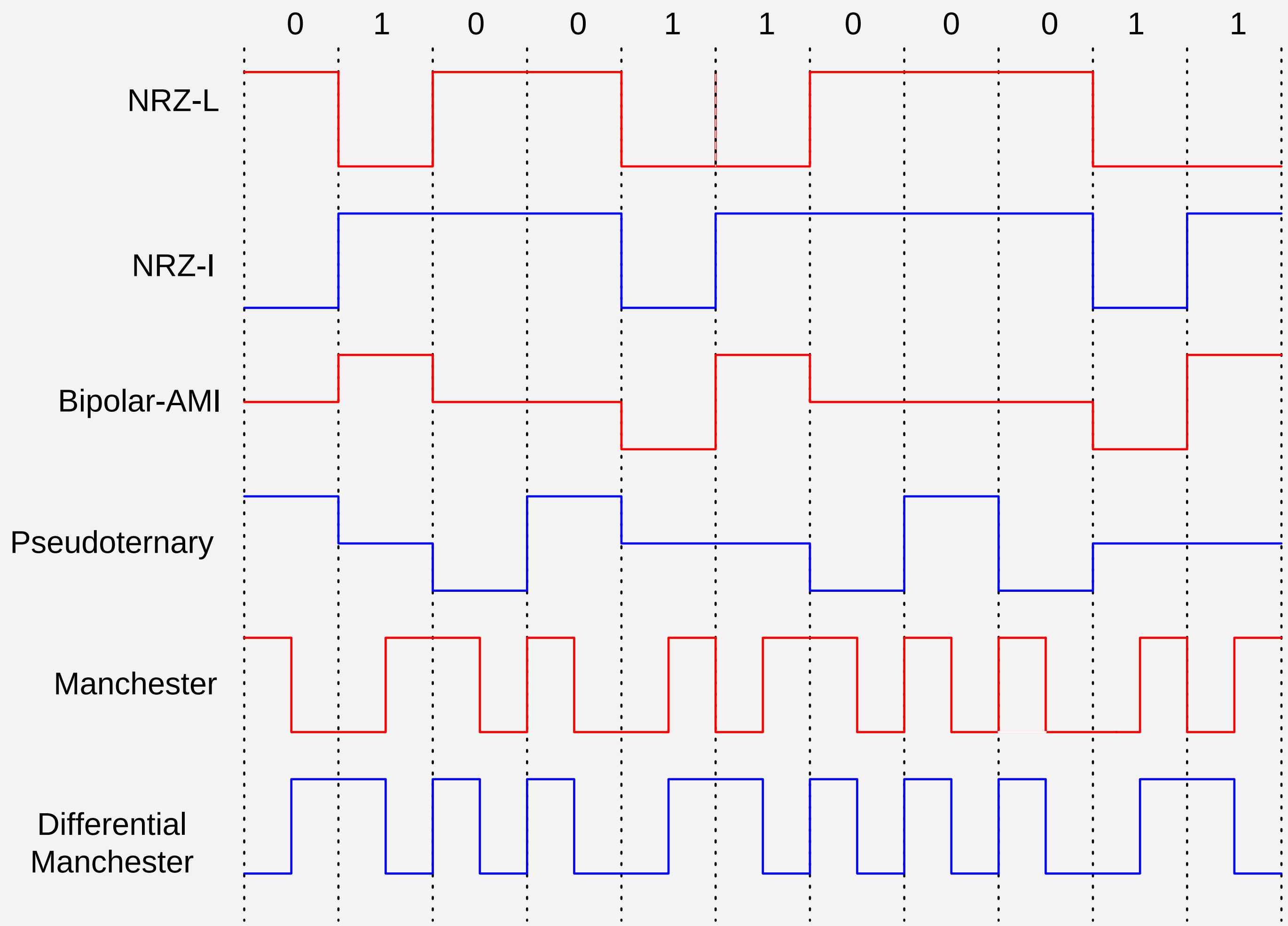
- Differential Manchester

  Always a transition in middle of interval

  0 = transition at beginning of interval

  1 = no transition at beginning of interval

Digital Data / Digital Signal



Digital Data / Analog Signal

- Familiar example:
  - Using a modem over the (analog) telephone network
- Recall:
  - Basis for analog signaling is carrier signal
  - Data are modulated onto carrier signal
- There are 3 encoding techniques for transforming digital data to analog signals:
  - Amplitude-shift keying
  - Frequency-shift keying
  - Phase-shift keying

Digital Data/Analog Signal

- Carrier Signal:

$$s(t) = A\cos(2\pi f_c t + \theta_c)$$

- Amplitude-shift keying (ASK)

$$s(t) = A\cos(2\pi f_c t + \theta_c) \quad \text{for binary } 1$$

$$s(t) = 0 \quad \text{for binary } 0$$

Digital Data/Analog Signal

- Frequency-shift keying (FSK)

$$s(t) = A\cos(2\pi f_1 t + \theta_c) \qquad \textit{for binary } 1$$

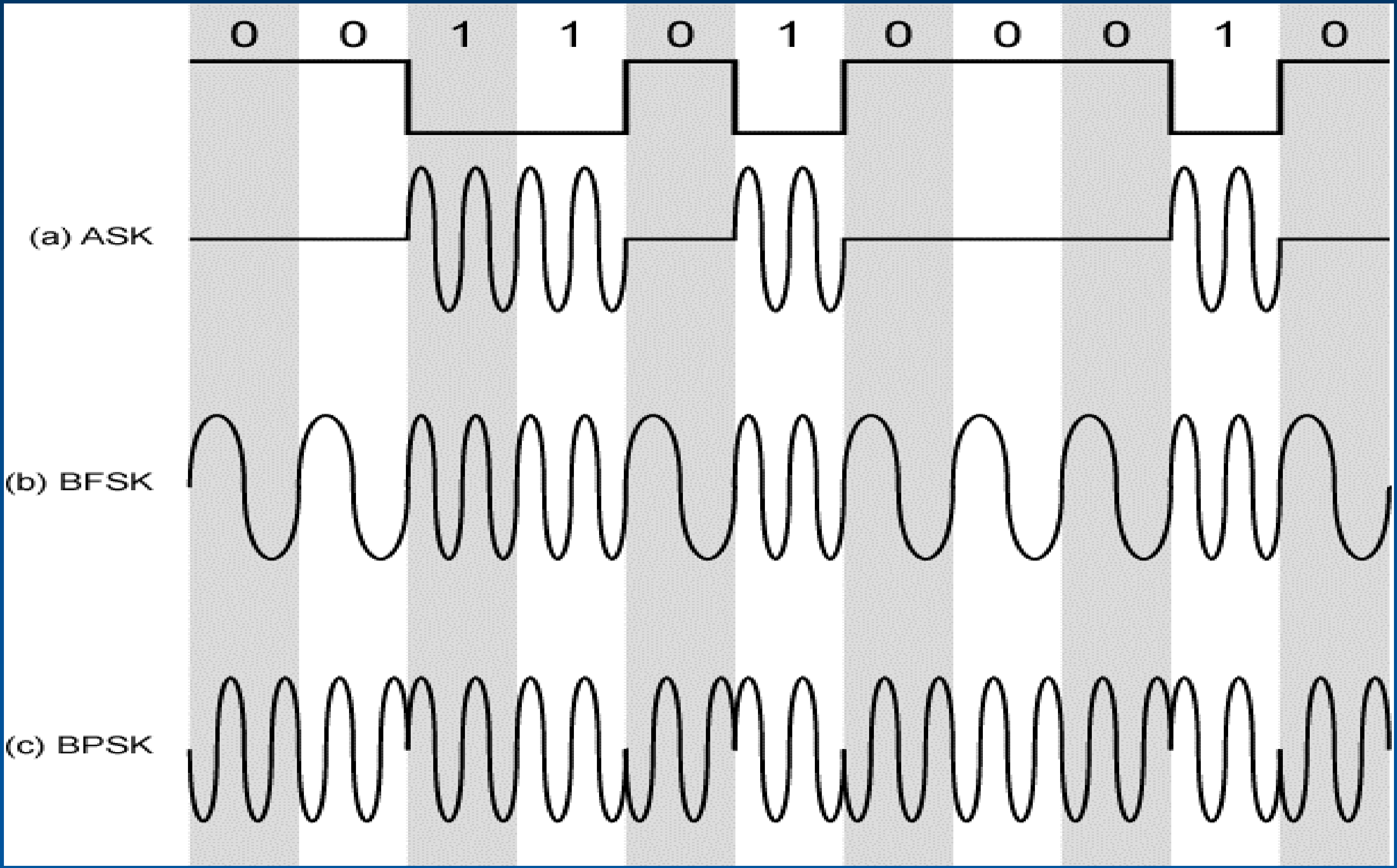
$$s(t) = A\cos(2\pi f_2 t + \theta_c) \qquad \textit{for binary } 0$$

- Phase-shift keying (PSK)

$$s(t) = A\cos(2\pi f_c t + \pi) \qquad \textit{for binary } 1$$

$$s(t) = A\cos(2\pi f_c t) \qquad \textit{for binary } 0$$

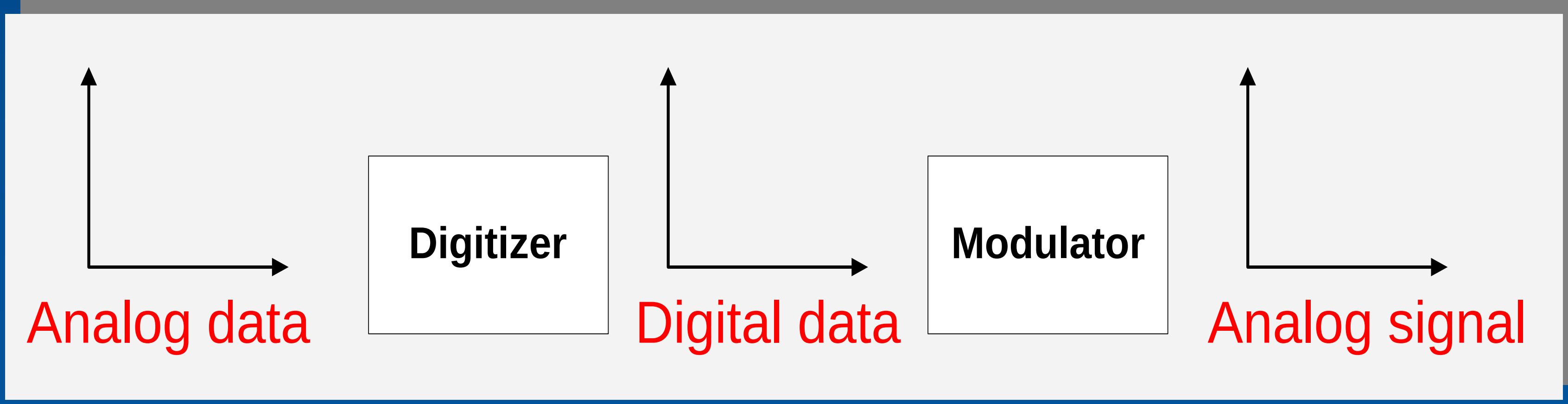
Digital Data/Analog Signal



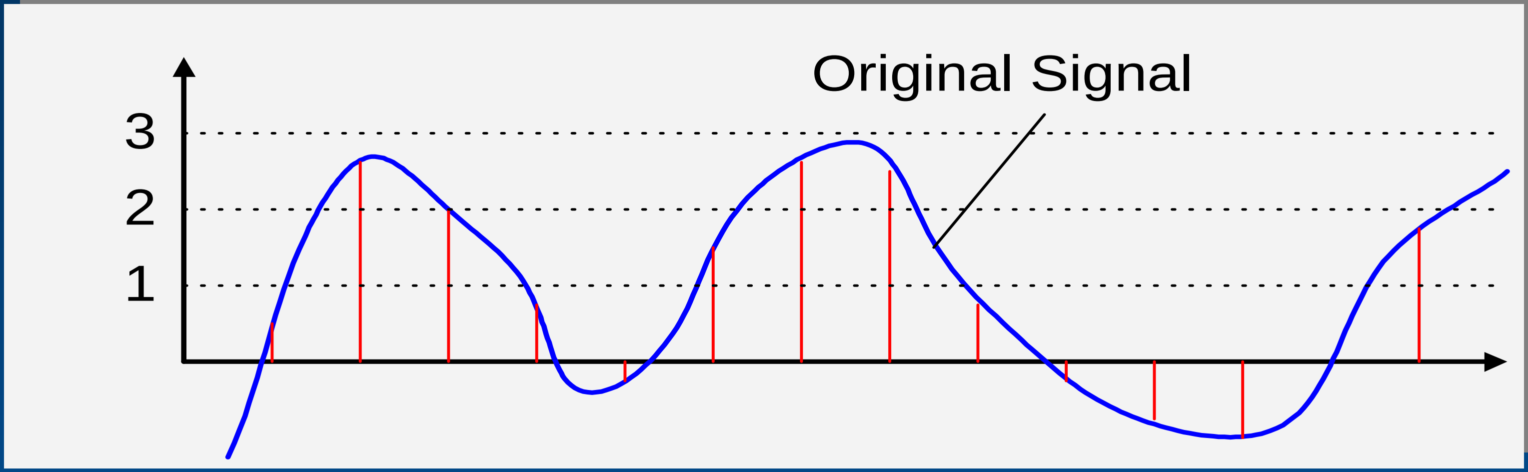
Analog Data/Digital Signal

- Transmission is accomplished in two steps:
  1. Conversion of analog data into digital data (Digitization)
  2. Digital data is converted into an analog signal (Modulation)

- Codec is a device for converting analog data into digital data (and vice versa).



Pulse Code Modulation (PCM)



- **Sampling Theorem (by Nyquist):**

  If a signal f(t) is sampled at regular intervals of time and at a rate higher than twice the highest significant signal frequency, then the samples contain all the information of the original signal. The function f(t) may be reconstructed from these samples by the use of a low pass filter.

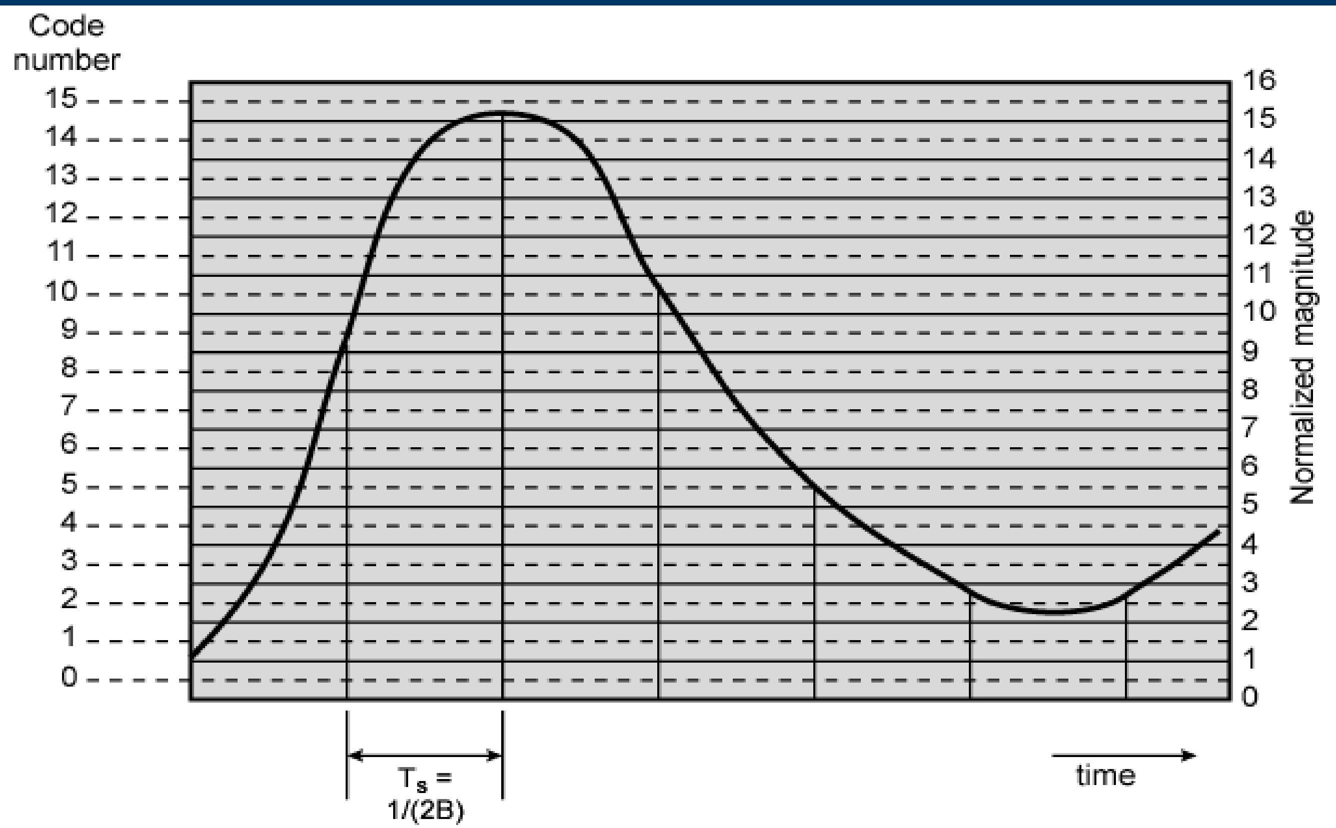
Pulse Code Modulation (PCM)

- Example: PCM encoding of voice data:
  - Voice has a bandwidth of about 4 kHz
  - Sampling rate must be 8000 samples/second

  - Typically, the sample size is 7-8 bits
  - Voice channel requires 56-64 kbps

  - PCM for voice is standardized as ITU-TS G.711
  - Note: ISDN B-channel has 64 kbps

PCM Example



PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

Analog Data/Analog Signal

- Why modulate analog signals?
  - Higher frequency can give more efficient transmission
  - Permits frequency division multiplexing (chapter 8)

- There are three types of modulation:
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)

Analog Modulation