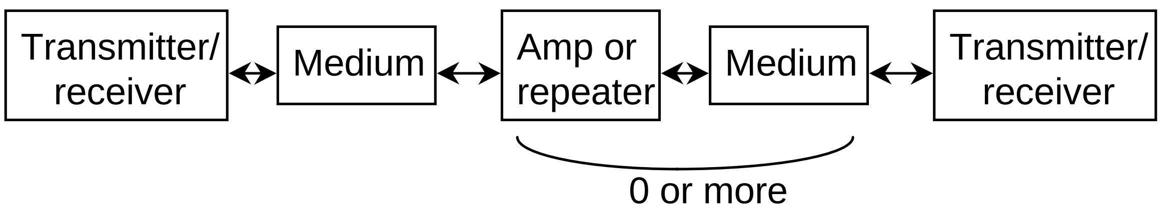
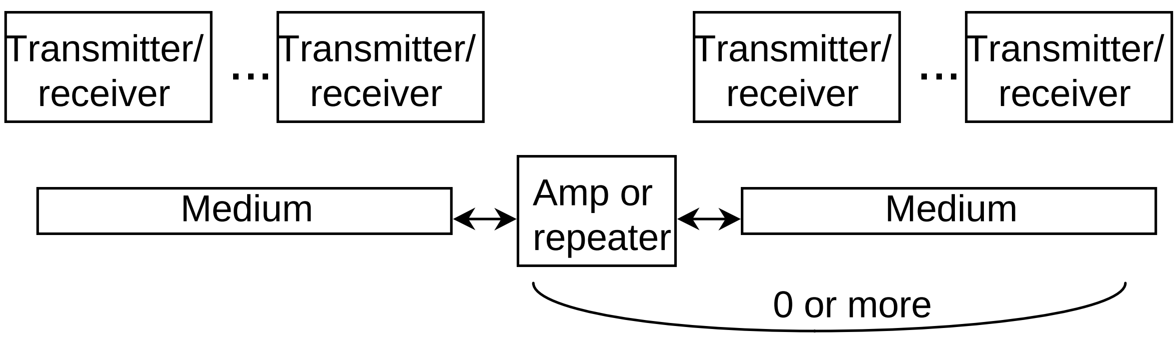
1. Concepts and Terminology

Transmission media

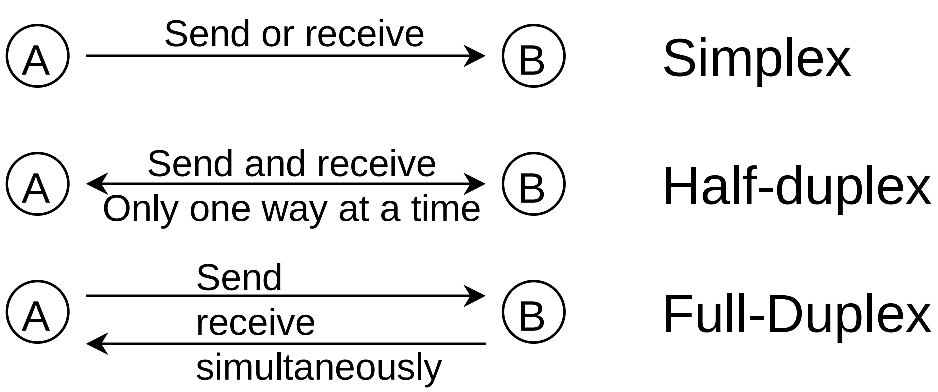
- Guided media - twisted pair, coaxial cable, optical fiber
- Unguided media - air, vacuum, sea water

Point-to-point vs. Multipoint

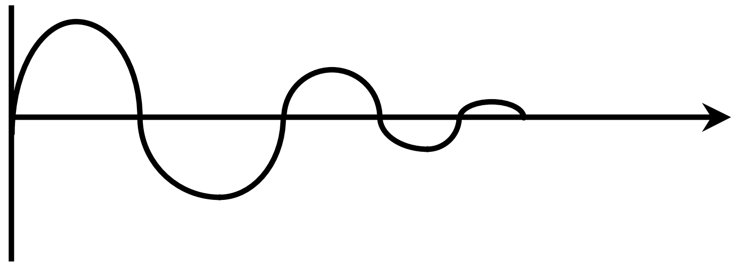




Simplex vs. Duplex

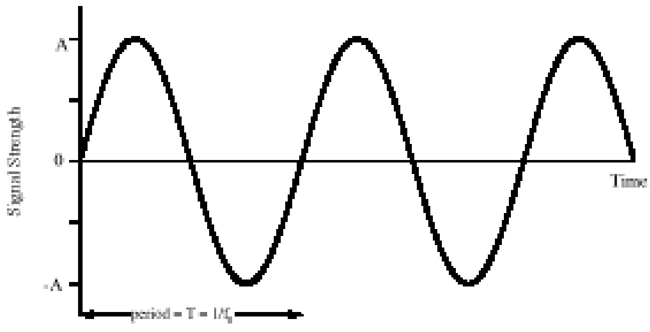


- Signals can be described:
  - – in the time domain
  - – in the frequency domain
- Time-Domain Characterization

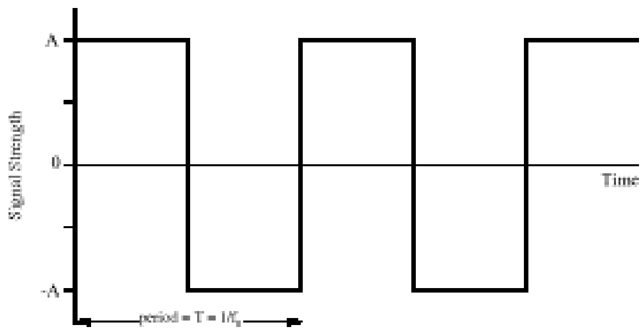


- Continuous
- Discrete
- Periodic
- Aperiodic

- Periodic Signal



(a) Sine Wave

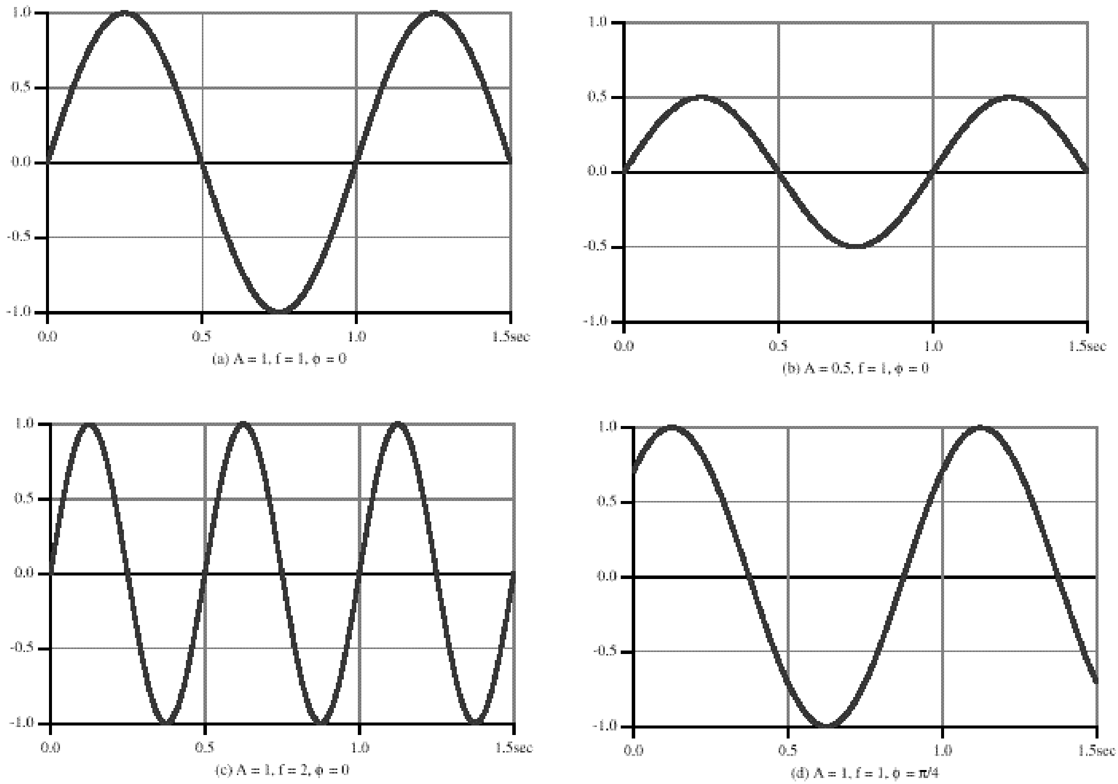


(b) Square Wave

- Sinusoidal signal

$$s(t) = A \sin(2\pi f t + \theta)$$

- A → amplitude
- f → Frequency = 1 / period (T)
- θ → phase



- Frequency Domain Concepts
  - Any periodic signal can be decomposed into a sum of sinusoidal signals using a Fourier series expansion

$$x(t) = C_0 + \sum_{n=1}^{\infty} C_n \cos(2\pi n f_0 t + \theta_n), \qquad f_0 = \frac{1}{T}$$

  - The component sinusoids are at frequencies that are <u>multiples</u> of the <u>basic frequency</u> of periodicity

multiples → harmonics; basic frequency → Fundamental frequency

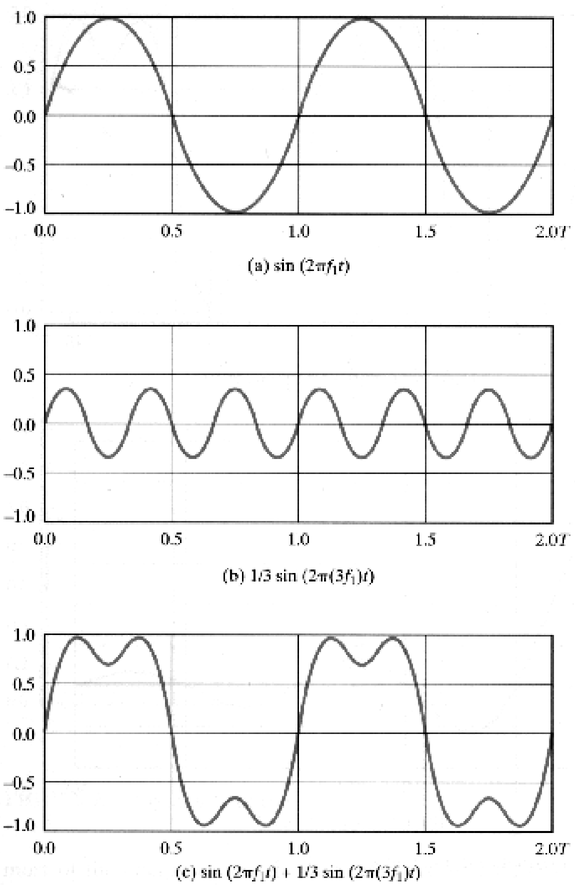


FIGURE 2.5 Addition of frequency components ($T = 1/f_1$).

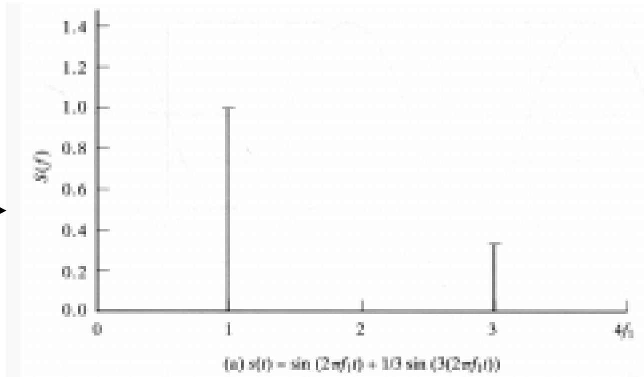
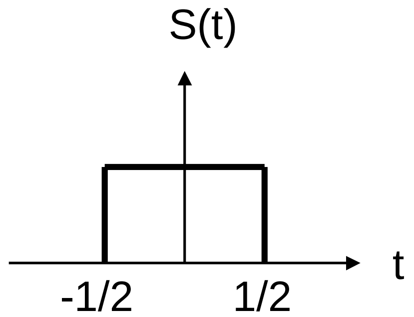


FIGURE 2.6 Frequency-domain representations.

– Even non-periodic signals can be characterized in the frequency domain using a continuous spectrum of frequency components

$$S(f) = \int_{-\infty}^{\infty} s(t)\, e^{-j2\pi ft} dt$$



$$\frac{\sin \pi f}{\pi f}$$

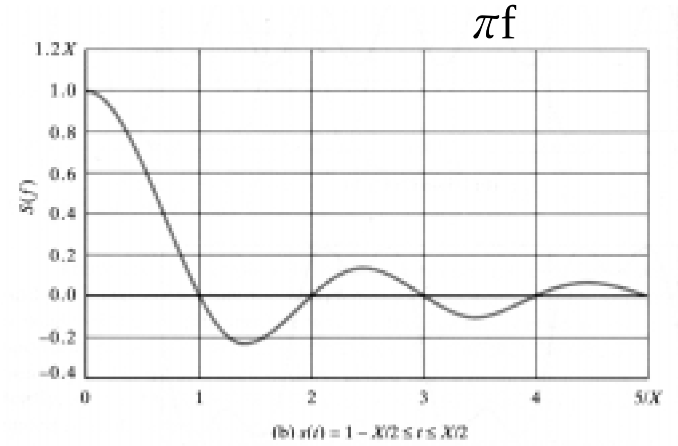
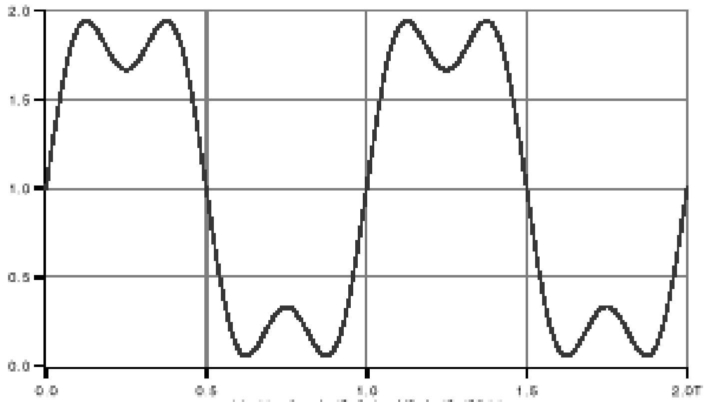


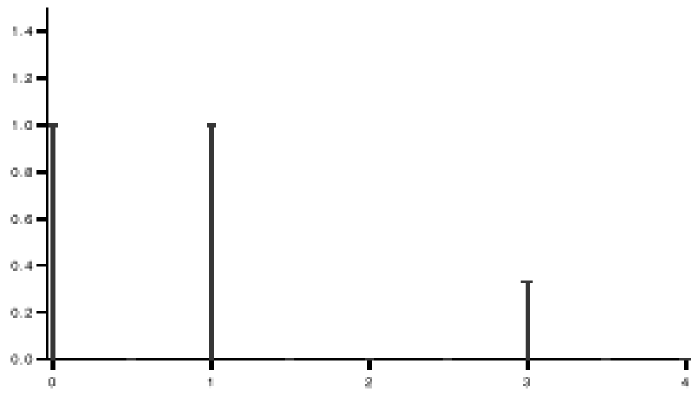
FIGURE 2.6 Frequency-domain representations.

– **Spectrum** of a signal - the range of frequencies it contains
– **Absolute bandwidth** - the width of the spectrum
– **Effective bandwidth** or just bandwidth - the band of frequencies which contains most of the energy of the signal - half-power bandwidth
– **dc component** - when the signal contains zero frequency

Signal with dc component



(a) $s(t) = 1 + \sin(2\pi f_1 t) + 1/3 \sin(2\pi(3f_1)t)$



(b) $S(f)$

- Relationship Between Data Rate and Bandwidth

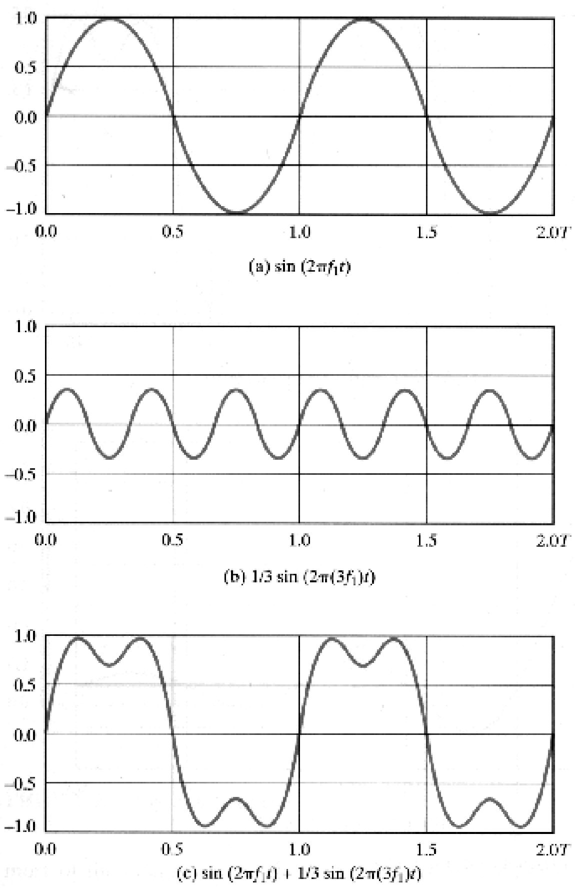


FIGURE 2.5 Addition of frequency components ($T = 1/f_1$).

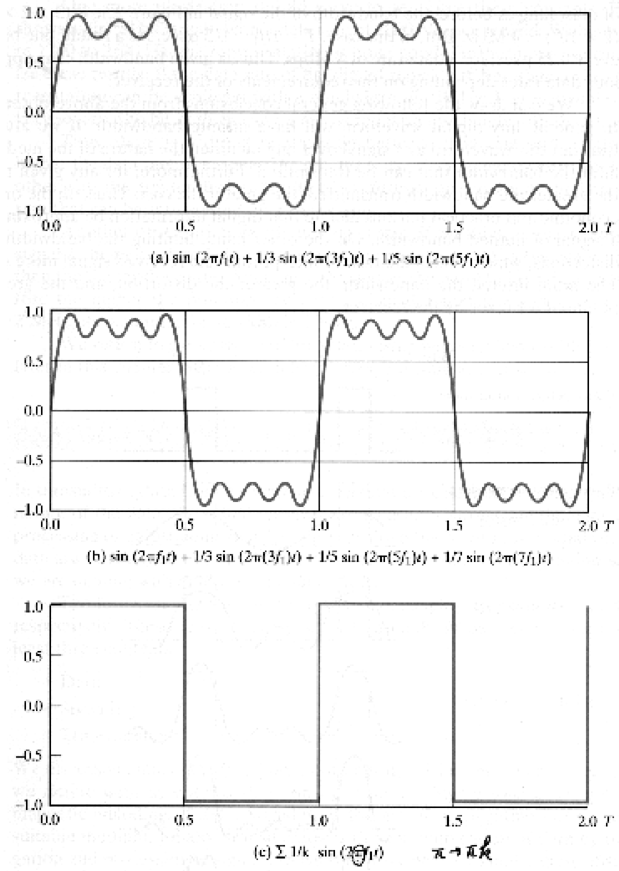


FIGURE 2.8 Frequency components of a square wave ($T = 1/f_1$).

$$s(t) = \sum_{k=1}^{\infty} \frac{1}{k} \sin(2\pi k f_1 t), \ \ \mathrm{k} = 1,3,5,\ldots$$

  – Consider the case binary data is encoded into digital signal, and to be transmitted by a transmission medium
  – Digital signal contains an infinite bandwidth, but a real transmission medium has a finite bandwidth, which can limit the data rate that can be carried on the transmission medium

- Limited bandwidth creates distortions of the input signal,which makes the task of interpreting the received signal more difficult
- The more limited bandwidth, the greater the distortion, and the greater the potential for error by the receiver
- The high the data rate of a signal, the greater is its effective bandwidth
- The grater the bandwidth of a transmission system, the higher is the data rate that can be transmitted

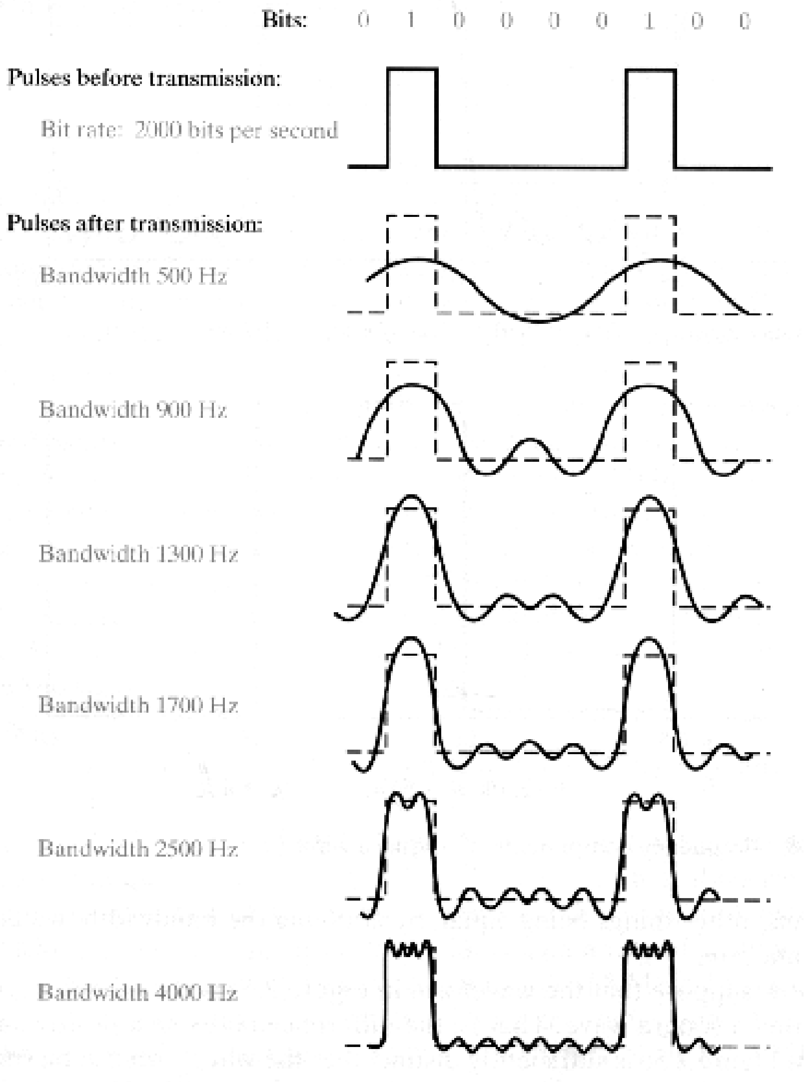
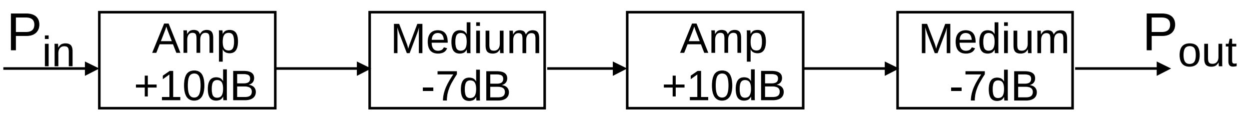


FIGURE 2.9 Effect of bandwidth on a digital signal.

- Signal Strength
  - Signal amplification / attenuation are expresses in logarithmic unit, decibel

  - Gain (amplification) / loss (attenuation) of a system is expressed as $N_{dB} = 10\log_{10}\left(\frac{Power_{out}}{Power_{in}}\right)$
    - e.g. Pin = 10 watts, Pout = 100 watts,
      N_{dB} = 10 log (100/10) = 10 dB
      Pin = 100 watts, Pout = 10 watts
      N_{dB} = 10 log (10/100) = -10 dB



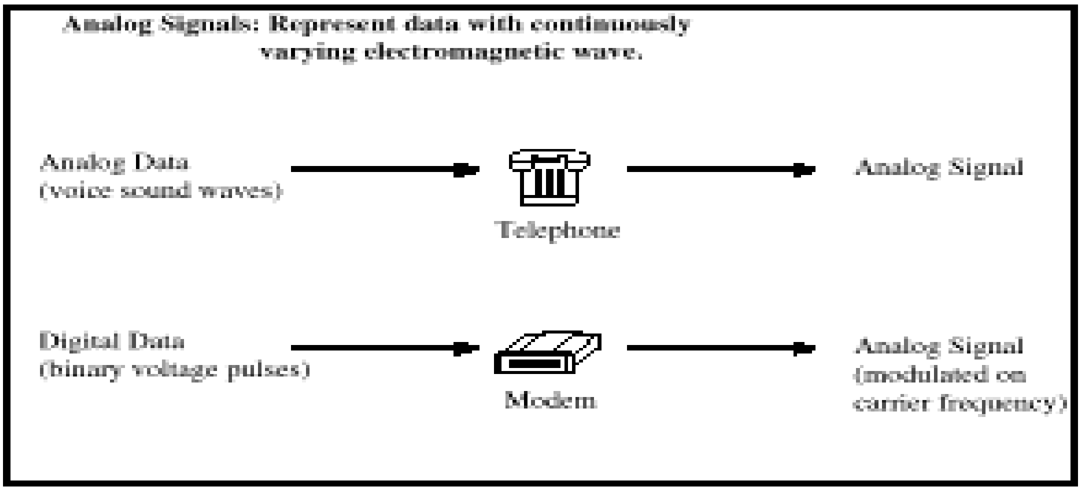
N_{dB} = 10 log (P_{out}/P_{in}) = +10 -7 +10 -3 = +10 dB
P_{out} = 10 P_{in}

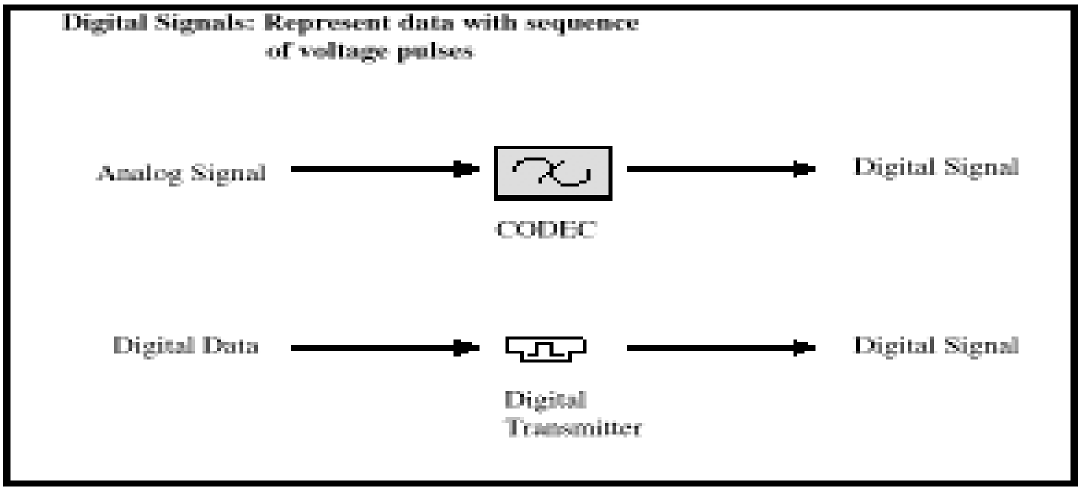
  - The decibel is also used to measure the difference in voltage

$$N_{dB} = 10\log\frac{P_{out}}{P_{in}} = 20\log\frac{V_{out}}{V_{in}}$$

2. Analog and Digital Data Transmission

- Data: Entity that conveys meaning
- Signal: Electric/Electromagnetic encoding (representation) of data
- Signaling: Act of propagating the signal along a suitable medium
- Transmission: Communication of data by the propagation and processing of signals





	Analog Data	Digital Data
Analog Signal	e.g. telephone	Modem (ASK, FSK, PSK)
Digital Signal	CODEC	Usually binary (NRZ, Manchester)

- Transmission techniques can be analog or digital
- With analog transmission, signals are transmitted without regard to content; with digital transmission, the content of message could be interpreted to aid in faithful transmission
- Important distinction is in the manner signal attenuation is handled at repeater / amplifiers
- Analog - Attenuated signal is amplified and retransmitted
- Digital - Data encoded in attenuated signal is recovered, a new signal is generated encoding that data, and retransmitted
- Digital signals always digitally transmitted, but analog signals can be transmitted either way (assuming the signal carries digital data)

Table 2.3 Analog and Digital Transmission

(a) Data and Signals

	Analog Signal	Digital Signal
Analog Data	Two alternatives: (1) signal occupies the same spectrum as the analog data; (2) analog data are encoded to occupy a different portion of spectrum.	Analog data are encoded using a codec to produce a digital bit stream.
Digital Data	Digital data are encoded using a modem to produce analog signal.	Two alternatives: (1) signal consists of a two voltage levels to represent the two binary values; (2) digital data are encoded to produce a digital signal with desired properties.

(b) Treatment of Signals

	Analog Transmission	Digital Transmission
Analog Signal	Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.	Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data is recovered from inbound signal and used to generate a new analog outbound signal.
Digital Signal	Not used	Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 1s and 0s is recovered from inbound signal and used to generate a new digital outbound signal.

3. Transmission Impairments

(Signal corruption during transmission)

- Attenuation
  - the strength of a signal falls off with distance
  - varies as a function of frequency
- Delay distortion
  - the velocity of propagation of a signal through a guided medium varies with frequency
- Noise
  - Thermal noise
    - white noise
  - Intermodulation noise
    - when two signals at different frequencies are mixed in the same medium, sum or difference of original frequencies or multiples of those frequencies can be produced, which can interfere with the intended signal
    - occurs when there is some nonlinearity in the system
  - Crosstalk
    - when there is an unwanted coupling between signal paths
  - Impulse noise

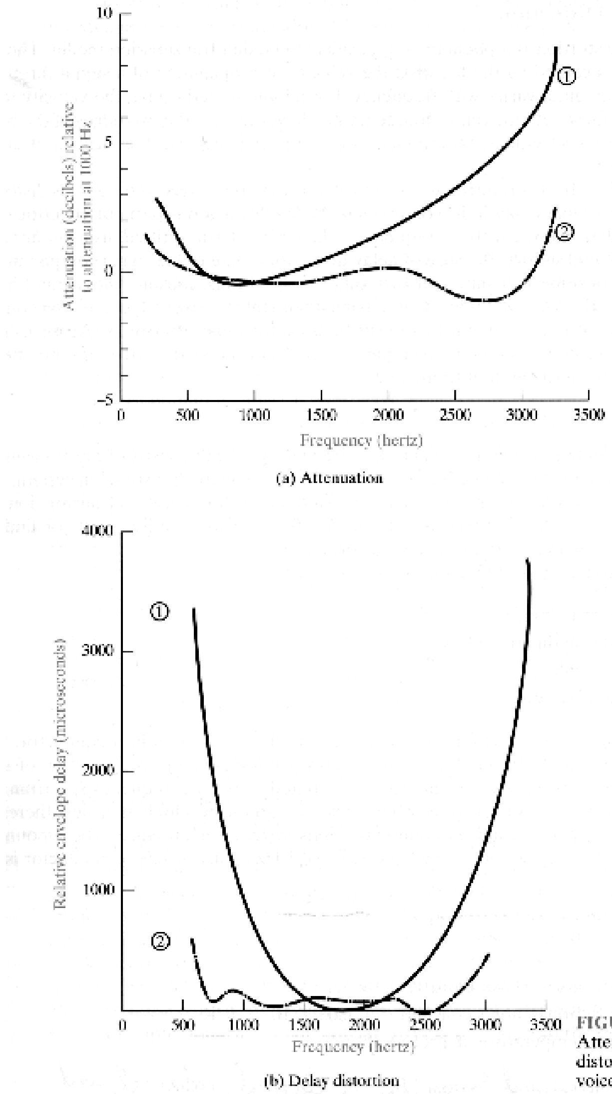
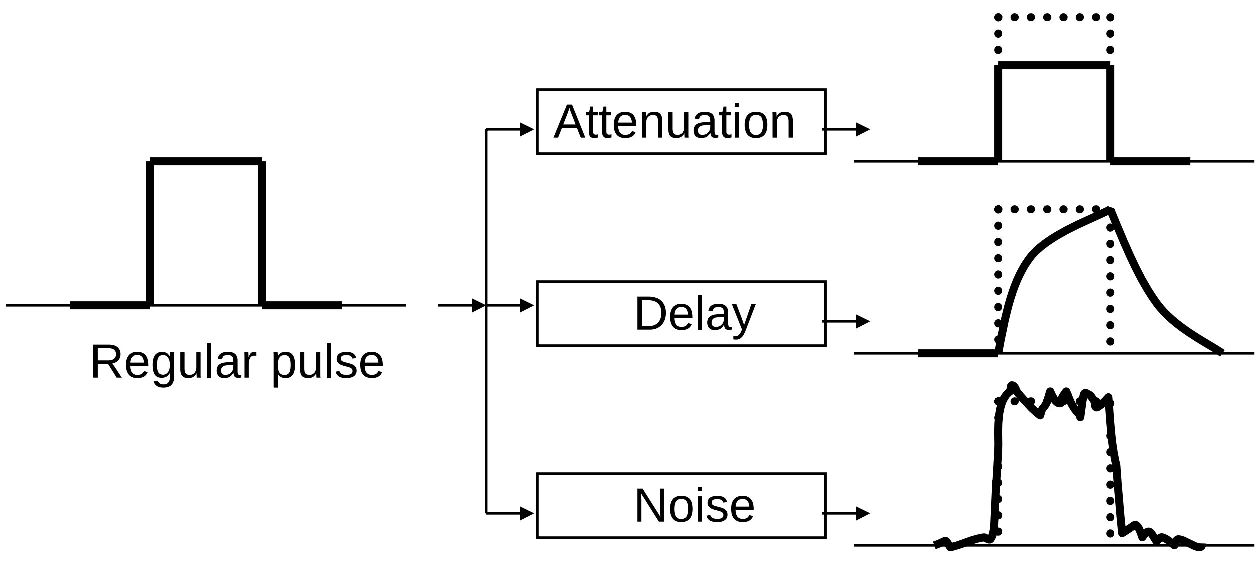


FIGURE 2.14
Attenuation and delay distortion curves for a voice channel.

Attenuation and delay
as a function of frequency



- Effect of noise on a digital signal

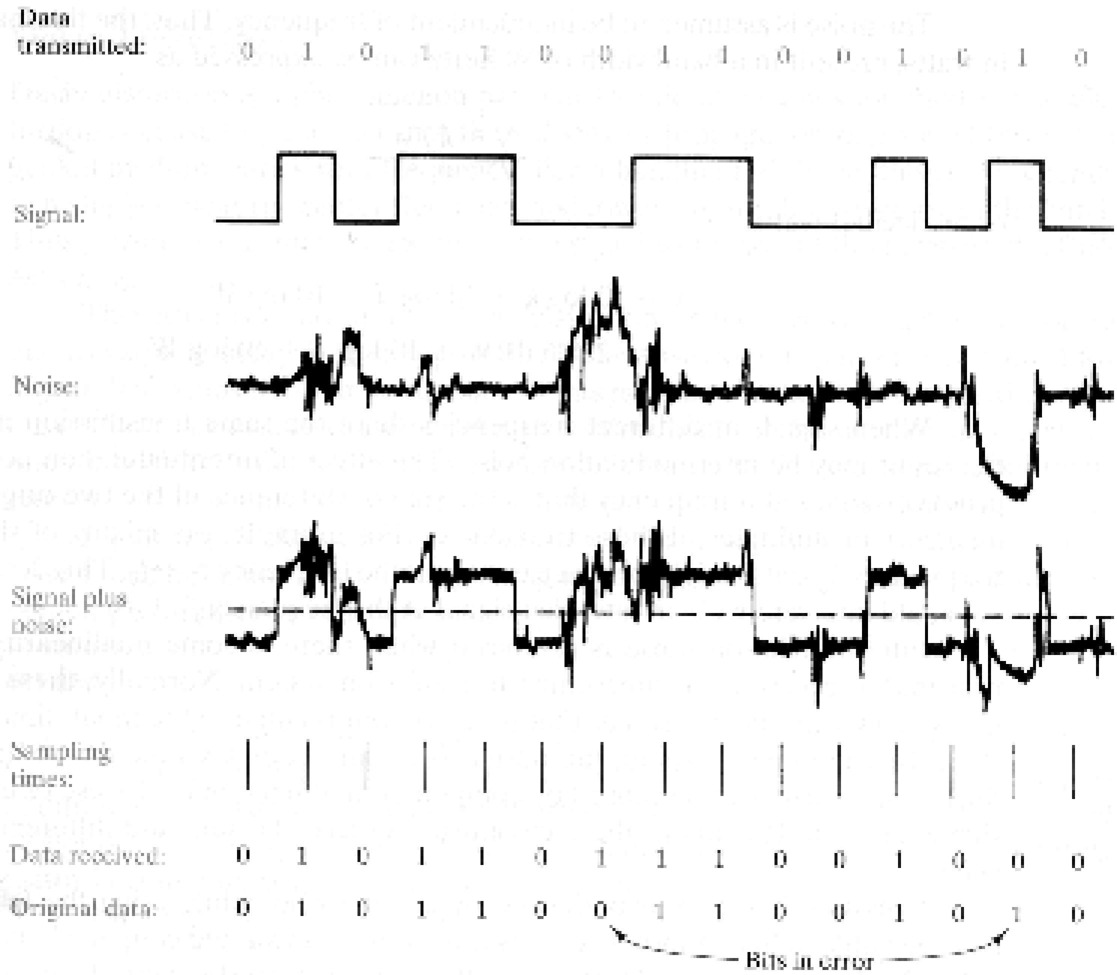


FIGURE 2.15 Effect of noise on a digital signal.

- Channel Capacity
  - The rate at which digital data can be transmitted over a given communication channel
  - **Nyquist** limit (In a noise-free environment)

$$C = 2\,W \log_2 M$$

Channel capacity in bits/second (C)

Bandwidth of physical channel (medium) (W)

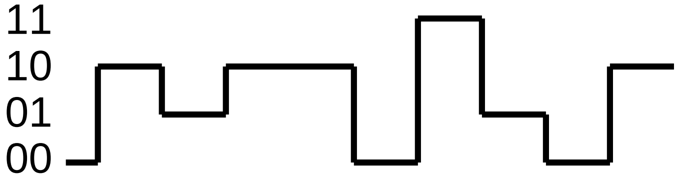
# of levels used in signaling (M)

  - Ex: Transmitted sequence

1 0 0 1 1 0 1 0 0 0 1 1 0 1 0 0 1 0

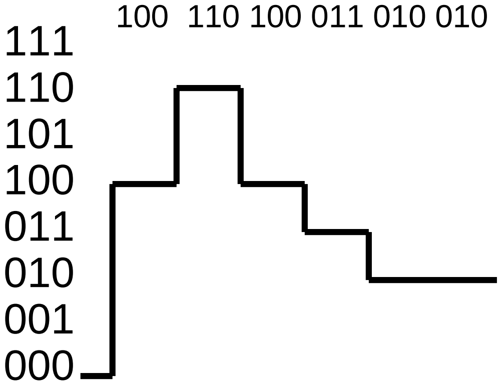
2-level encoding, W = 1/2T, C= 1/T

10 01 10 10 00 11 01 00 10



C= 2/T

100 110 100 011 010 010



C= 3/T

- Channel Capacity
  - Shannon's law

$$C = W \log_2\left(1 + \frac{S}{N}\right)$$

    - considers the noise
    - key parameter is signal-to-noise ratio (S/N, or SNR), which is the ratio of the power in a signal to the power contained in the noise, typically measured at the receiver
    - often expressed in decibels

$$(S/N)_{dB} = 10 \log \frac{\text{signal power}}{\text{noise power}}$$