Transmission Fundamentals

Chapter 2

Electromagnetic Signal

- Function of time
- Can also be expressed as a function of frequency
  - Signal consists of components of different frequencies

Time-Domain Concepts

- Analog signal - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
- Digital signal - signal intensity maintains a constant level for some period of time and then changes to another constant level
- Periodic signal - analog or digital signal pattern that repeats over time
  - $s(t+T) = s(t) \qquad -\infty < t < +\infty$
    - where T is the period of the signal

Time-Domain Concepts

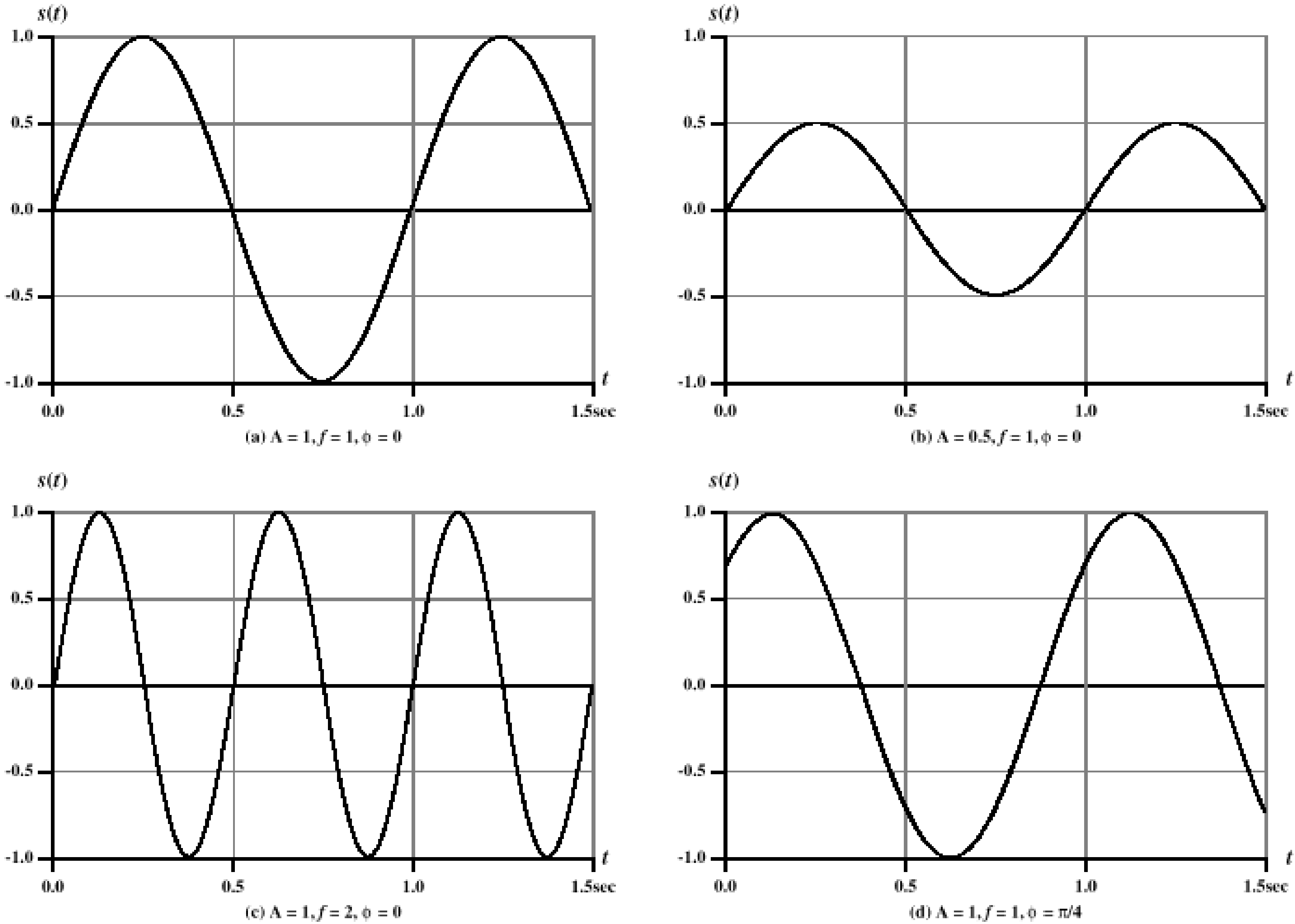
- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time
- Peak amplitude (A) - maximum value or strength of the signal over time; typically measured in volts
- Frequency (f)
  - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats

Time-Domain Concepts

- Period (T) - amount of time it takes for one repetition of the signal
  - $T = 1/f$
- Phase (ϕ) - measure of the relative position in time within a single period of a signal
- Wavelength (λ) - distance occupied by a single cycle of the signal
  - Or, the distance between two points of corresponding phase of two consecutive cycles
  - $\lambda = v \cdot T$

Sine Wave Parameters

- General sine wave:
  - $s(t) = A \sin(2\pi f t + \phi)$
- Figure 2.3 shows the effect of varying each of the three parameters:
  - (a) $A = 1$, $f = 1$ Hz, $\phi = 0$; thus $T = 1$s
  - (b) Reduced peak amplitude; $A=0.5$
  - (c) Increased frequency; $f = 2$, thus $T = 1/2$
  - (d) Phase shift; $\phi = \pi/4$ radians (45 degrees)
- note: 2π radians = 360° = 1 period



(a) $A = 1, f = 1, \phi = 0$

(b) $A = 0.5, f = 1, \phi = 0$

(c) $A = 1, f = 2, \phi = 0$

(d) $A = 1, f = 1, \phi = \pi/4$

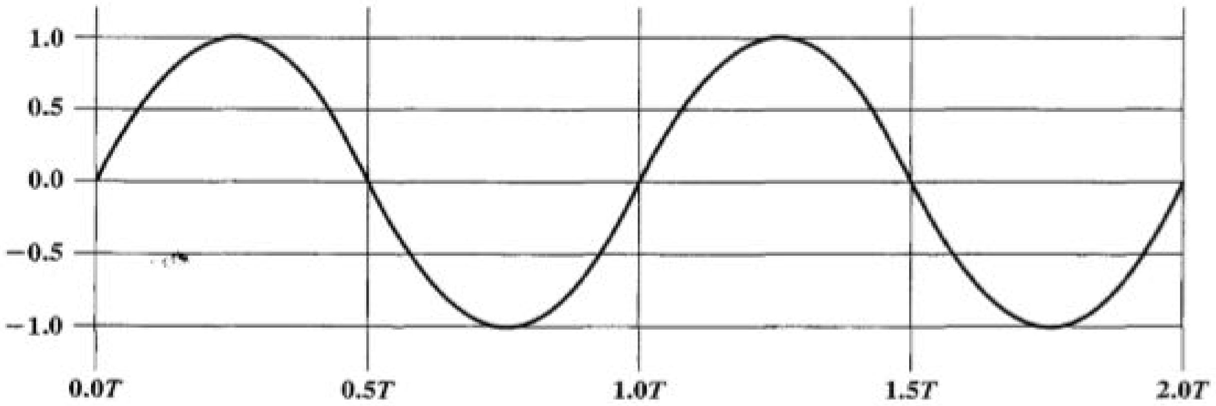
Figure 2.3 $s(t) = A \sin (2 \;\; ft + \phi)$

Time vs. Distance

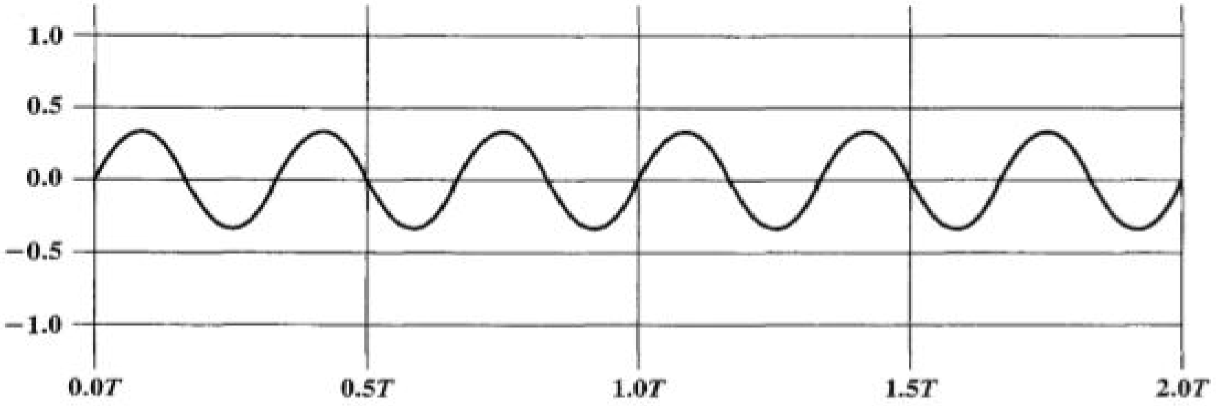
- When the horizontal axis is *time*, as in Figure 2.3, graphs display the value of a signal at a given point in *space* as a function of *time*
- With the horizontal axis in *space*, graphs display the value of a signal at a given point in *time* as a function of *distance*
  - At a particular instant of time, the intensity of the signal varies as a function of distance from the source

Frequency-Domain Concepts

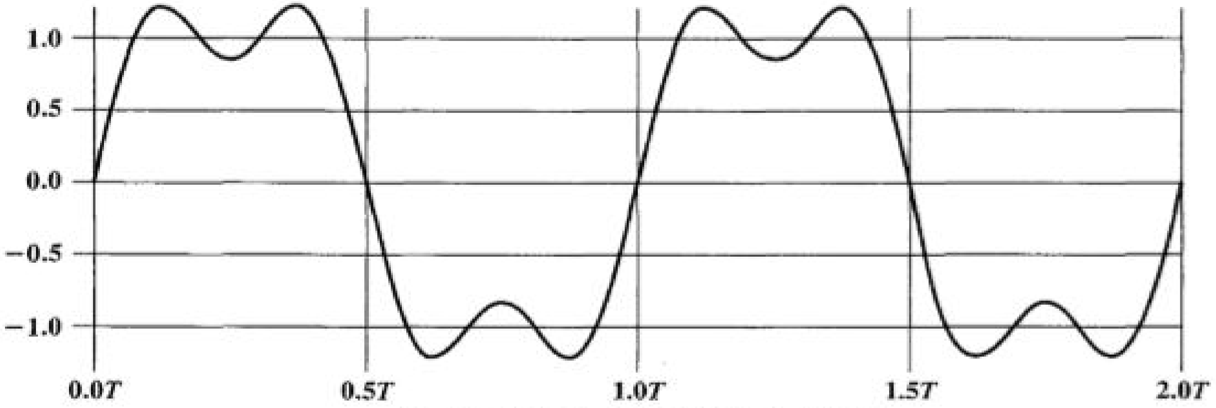
- Fundamental frequency - when all frequency components of a signal are integer multiples of one frequency, it’s referred to as the fundamental frequency
- Spectrum - range of frequencies that a signal contains
- Absolute bandwidth - width of the spectrum of a signal
- Effective bandwidth (or just bandwidth) - narrow band of frequencies that most of the signal’s energy is contained in



(a) $\sin(2\pi ft)$



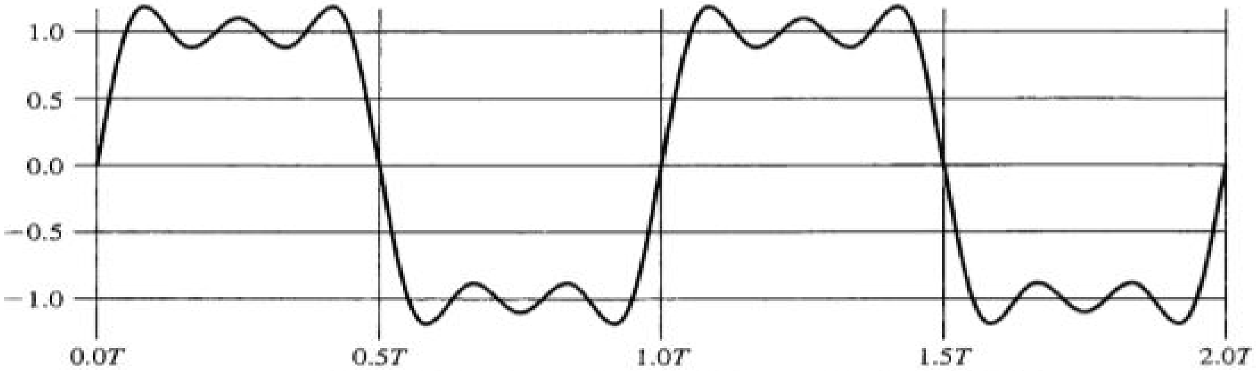
(b) $(1/3)\sin(2\pi(3f)t)$



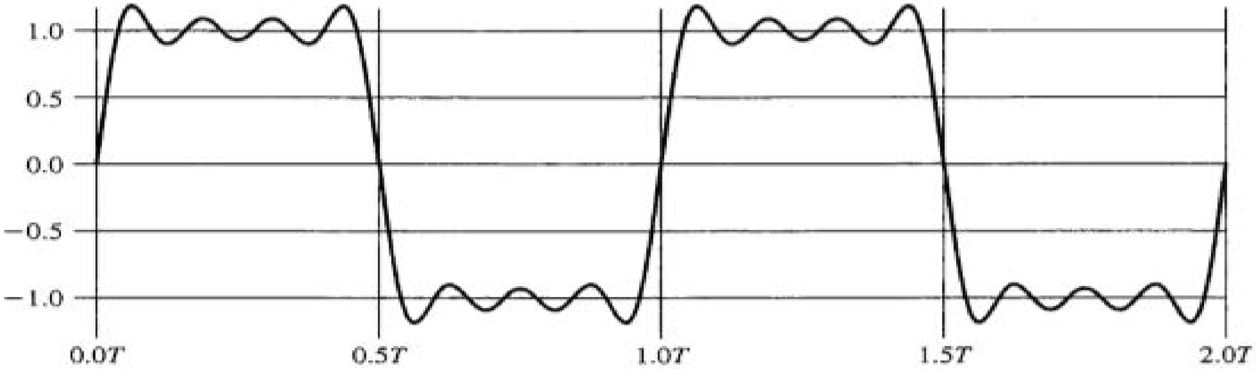
(c) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

Frequency-Domain Concepts

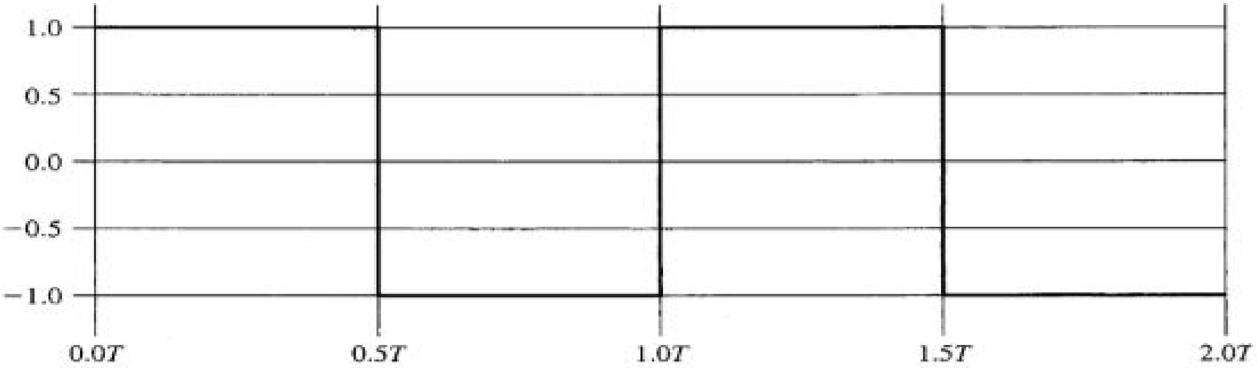
- Any electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases
- The period of the total signal is equal to the period of the fundamental frequency



(a) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$



(b) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$



(c) $(4/\pi)\,\Sigma\,(1/k)\sin(2\pi(kf)t)$, for k odd

Figure 2.5 Frequency Components of Square Wave ($T = 1/f$)

Relationship between Data Rate and Bandwidth

- The greater the bandwidth, the higher the information-carrying capacity
- Conclusions
    - Any digital waveform will have infinite bandwidth
    - BUT the transmission system will limit the bandwidth that can be transmitted
    - AND, for any given medium, the greater the bandwidth transmitted, the greater the cost
    - HOWEVER, limiting the bandwidth creates distortions

Data Communication Terms

- Data - entities that convey meaning, or information
- Signals - electric or electromagnetic representations of data
- Transmission - communication of data by the propagation and processing of signals

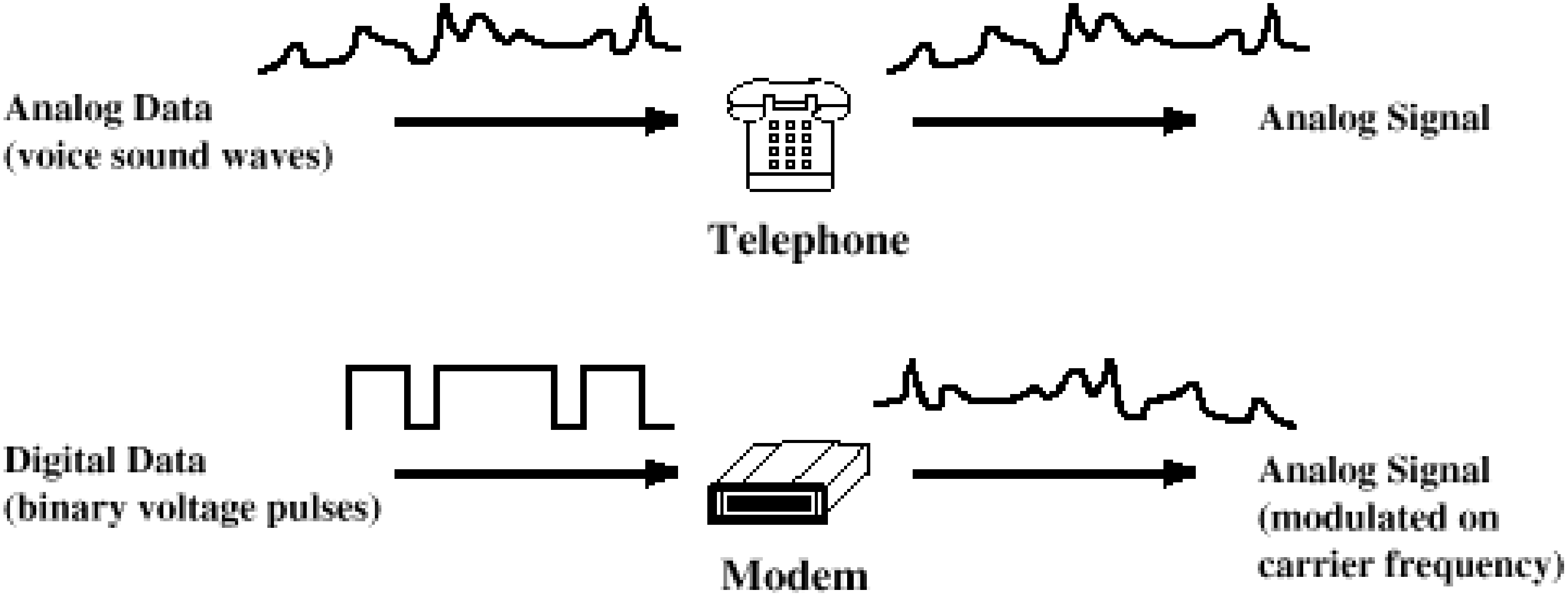
Analog Signals

- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency
- Examples of media:
  - Copper wire media (twisted pair and coaxial cable)
  - Fiber optic cable
  - Atmosphere or space propagation
- Analog signals can propagate analog and digital data

Digital Signals

- A sequence of voltage pulses that may be transmitted over a copper wire medium
- Generally cheaper than analog signaling
- Less susceptible to noise interference
- Suffer more from attenuation
- Digital signals can propagate analog and digital data

Analog Signals: Represent data with continuously varying electromagnetic wave



Analog Data
(voice sound waves)

Telephone

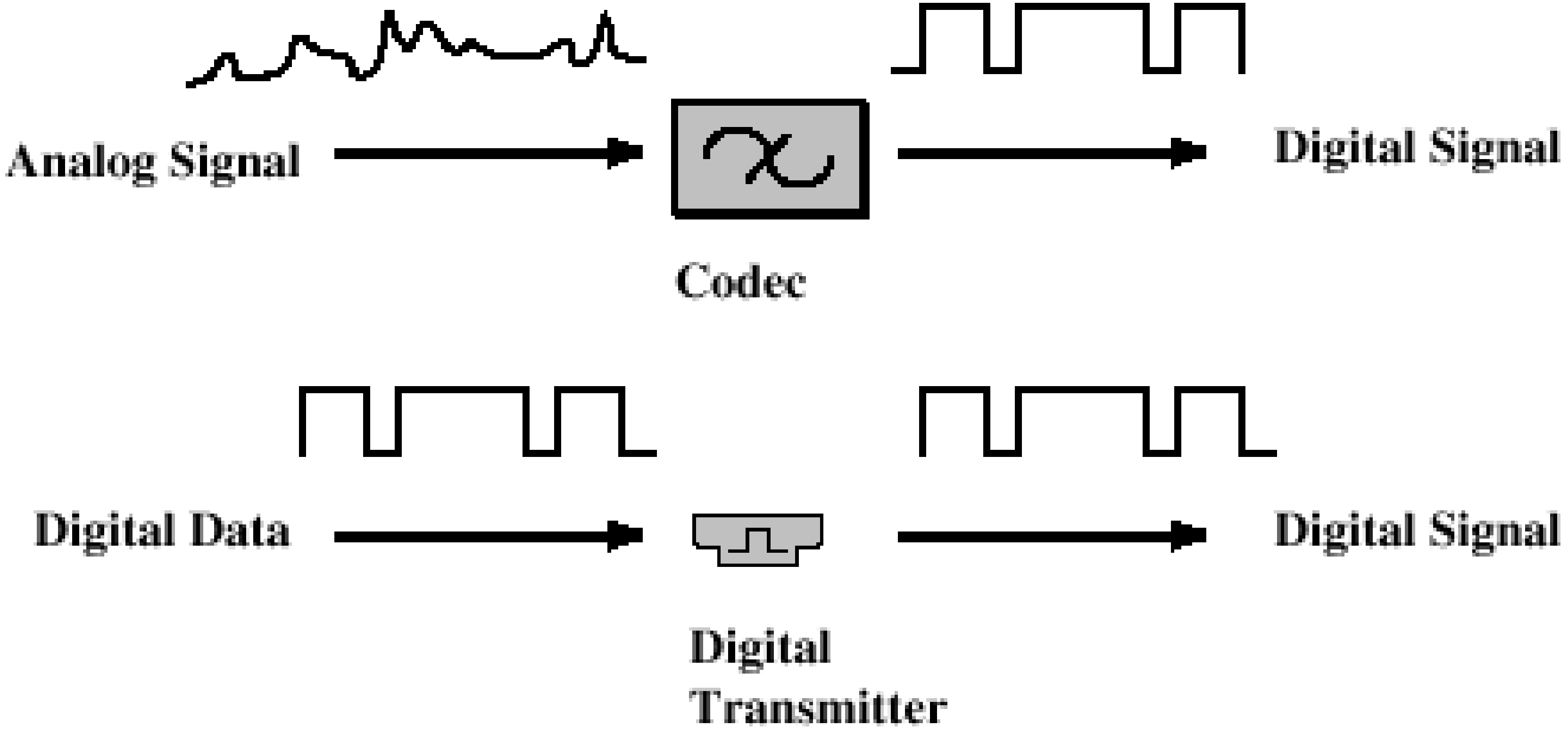
Analog Signal

Digital Data
(binary voltage pulses)

Modem

Analog Signal
(modulated on
carrier frequency)

Digital Signals: Represent data with sequence of voltage pulses



Analog Signal

Codec

Digital Signal

Digital Data

Digital Transmitter

Digital Signal

About Channel Capacity

- Impairments, such as noise, limit data rate that can be achieved
- For digital data, to what extent do impairments limit data rate?
- Channel Capacity – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions

Concepts Related to Channel Capacity

- Data rate - rate at which data can be communicated (bps)
- Bandwidth - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- Noise - average level of noise over the communications path
- Error rate - rate at which errors occur
  - Error = transmit 1 and receive 0; transmit 0 and receive 1

Nyquist Bandwidth

- For binary signals (two voltage levels)
  - $C = 2B$
- With multilevel signaling
  - $C = 2B \log_2 M$
    - M = number of discrete signal or voltage levels

Signal-to-Noise Ratio

- Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission
- Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

$$(SNR)_{\text{dB}} = 10\log_{10}\frac{\text{signal power}}{\text{noise power}}$$

- A high SNR means a high-quality signal, low number of required intermediate repeaters
- SNR sets upper bound on achievable data rate

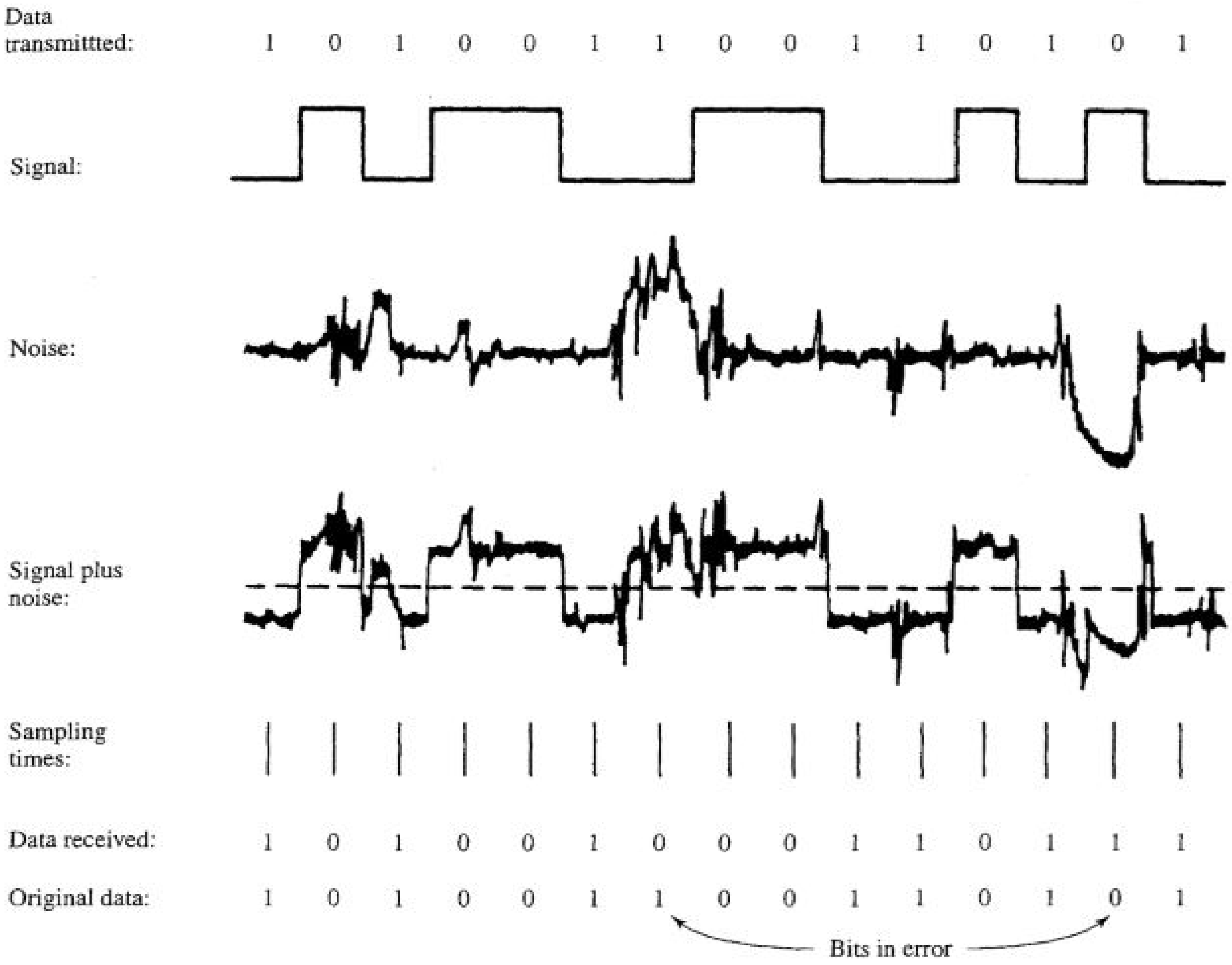


Figure 2.9 Effect of Noise on a Digital Signal

Shannon Capacity Formula

- Equation:

$$C = B\log_2\left(1 + \mathrm{SNR}\right)$$

- Represents theoretical maximum that can be achieved
- In practice, only much lower rates achieved:
  - Formula assumes white noise (thermal noise)
  - Impulse noise is not accounted for
  - Attenuation distortion or delay distortion not accounted for

Example of Nyquist and Shannon Formulations

- Spectrum of a channel between 3 MHz and 4 MHz ; $\mathrm{SNR}_{\mathrm{dB}} = 24$ dB

$$B = 4\,\mathrm{MHz} - 3\,\mathrm{MHz} = 1\,\mathrm{MHz}$$

$$\mathrm{SNR}_{\mathrm{dB}} = 24\,\mathrm{dB} = 10\log_{10}(\mathrm{SNR})$$

$$\mathrm{SNR} = 251$$

- Using Shannon’s formula

$$C = 10^6 \times \log_2(1+251) \approx 10^6 \times 8 = 8\mathrm{Mbps}$$

Example of Nyquist and Shannon Formulations

- How many signaling levels are required?

$$
\begin{aligned}
&C = 2B\log_2 M \\
&8\times10^6 = 2\times\left(10^6\right)\times\log_2 M \\
&4 = \log_2 M \\
&M = 16
\end{aligned}
$$

Classifications of Transmission Media

- Transmission Medium
  - Physical path between transmitter and receiver
- Guided Media
  - Waves are guided along a solid medium
  - E.g., copper twisted pair, copper coaxial cable, optical fiber
- Unguided Media
  - Provides means of transmission but does not guide electromagnetic signals
  - Usually referred to as wireless transmission
  - E.g., atmosphere, outer space

Unguided Media

- Transmission and reception are achieved by means of an antenna
- Configurations for wireless transmission:
  - Directional
  - Omnidirectional

General Frequency Ranges

- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Infrared frequency range
  - Roughly, 3×10^{11} to 2×10^{14} Hz
  - Useful in local point-to-point multipoint applications within confined areas

Terrestrial Microwave

- Description of common microwave antenna:
  - Parabolic "dish", 3 m in diameter
  - Fixed rigidly and focuses a narrow beam
  - Achieves line-of-sight transmission to receiving antenna
  - Located at substantial heights above ground level
- Applications:
  - Long haul telecommunications service
  - Short point-to-point links between buildings

Satellite Microwave

- Description of communication satellite:
  - Microwave relay station
  - Used to link two or more ground-based microwave transmitter/receivers
  - Receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink)
- Applications
  - Television distribution
  - Long-distance telephone transmission
  - Private business networks

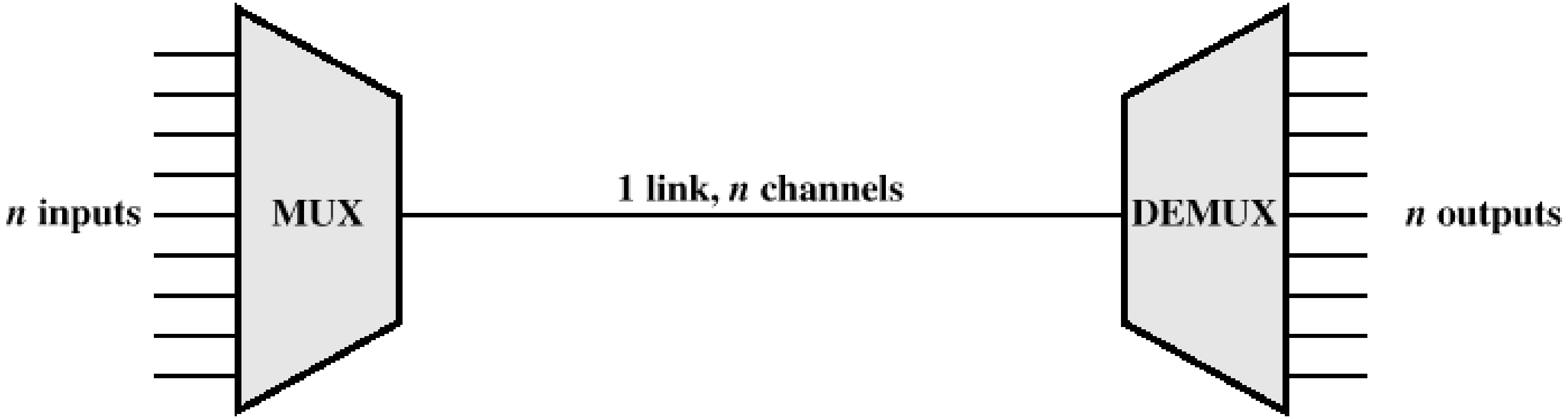
Broadcast Radio

- Description of broadcast radio antennas:
  - Omnidirectional
  - Antennas not required to be dish-shaped
  - Antennas need not be rigidly mounted to a precise alignment
- Applications:
  - Broadcast radio
    - VHF and part of the UHF band; 30 MHZ to 1GHz
    - Covers FM radio and UHF and VHF television

Multiplexing

- Capacity of transmission medium usually exceeds capacity required for transmission of a single signal
- Multiplexing - carrying multiple signals on a single medium
  - More efficient use of transmission medium

Multiplexing



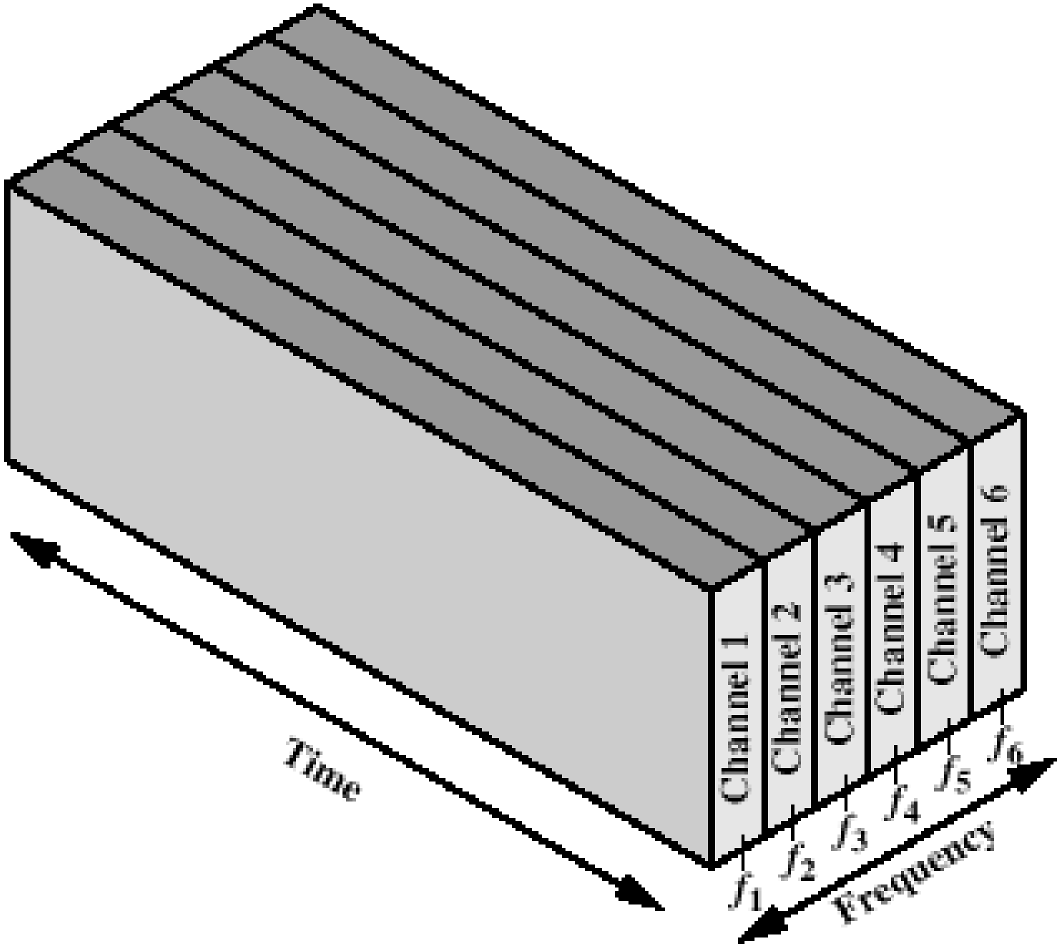
Reasons for Widespread Use of Multiplexing

- Cost per kbps of transmission facility declines with an increase in the data rate
- Cost of transmission and receiving equipment declines with increased data rate
- Most individual data communicating devices require relatively modest data rate support

Multiplexing Techniques

- Frequency-division multiplexing (FDM)
  - Takes advantage of the fact that the useful bandwidth of the medium exceeds the required bandwidth of a given signal
- Time-division multiplexing (TDM)
  - Takes advantage of the fact that the achievable bit rate of the medium exceeds the required data rate of a digital signal

Frequency-division Multiplexing



Time-division Multiplexing