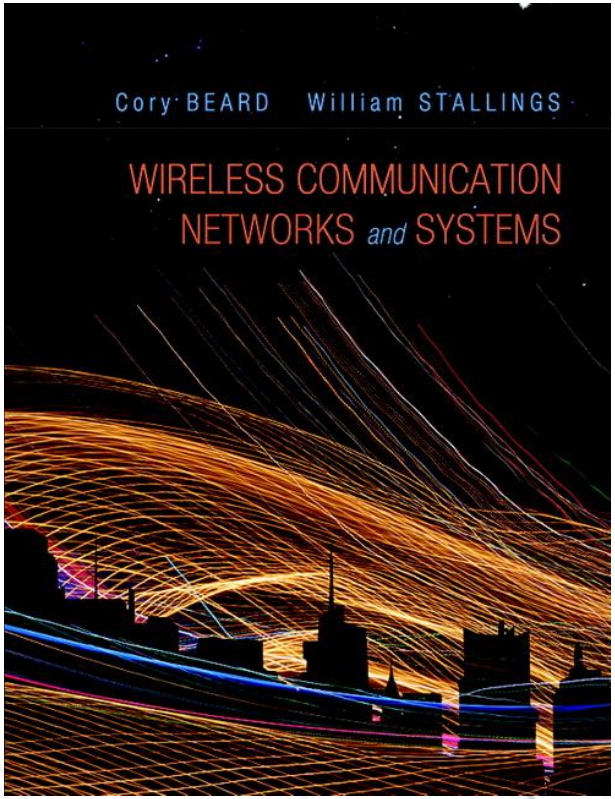
Fundamentals of Digital Communication

Network Infrastructures

A.A. 2018/19

CHAPTER 2 TRANSMISSION FUNDAMENTALS

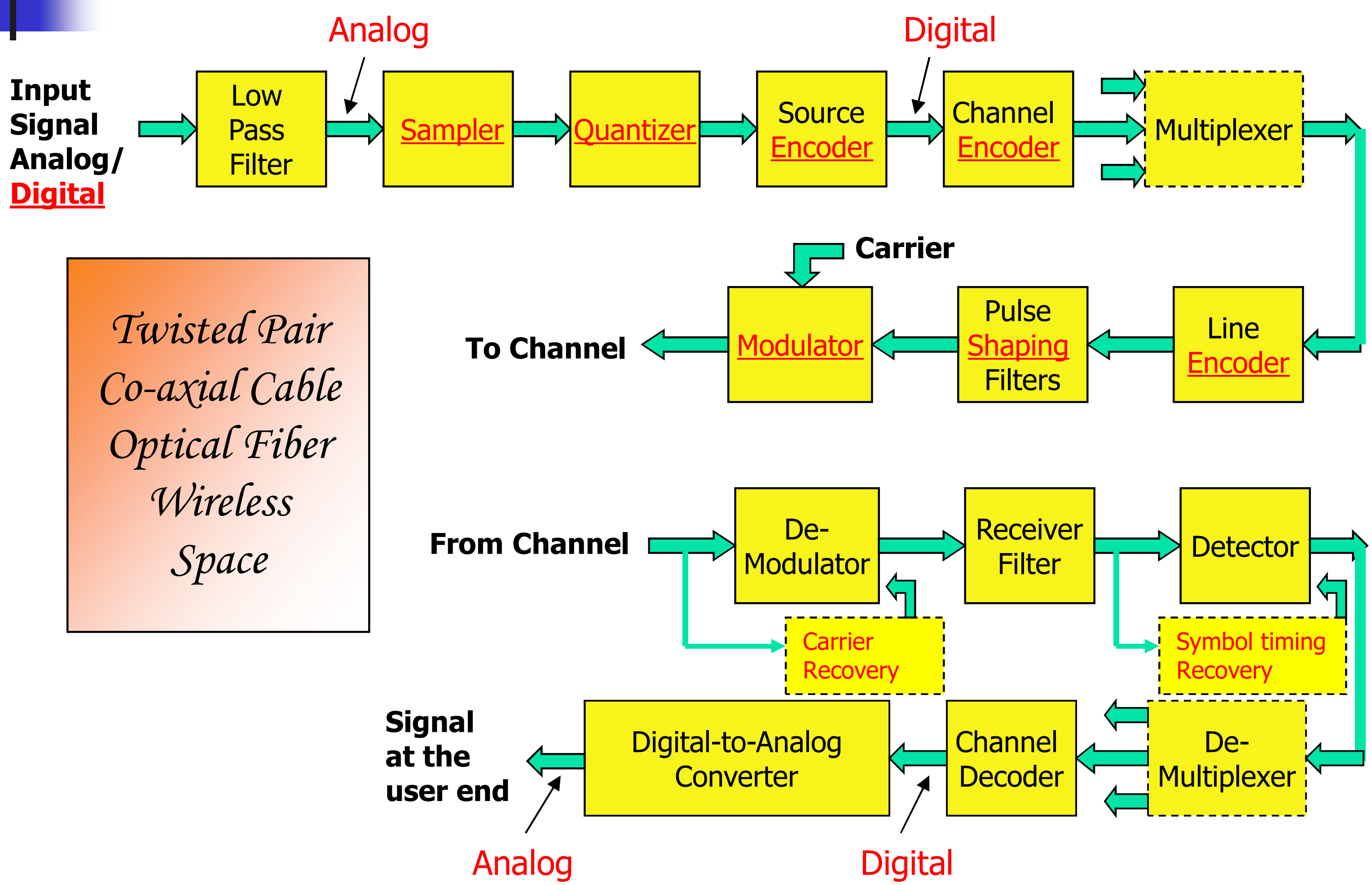


Wireless Communication Networks and Systems

1st edition

Cory Beard, William Stallings

Digital communication system



ELECTROMAGNETIC SIGNAL

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

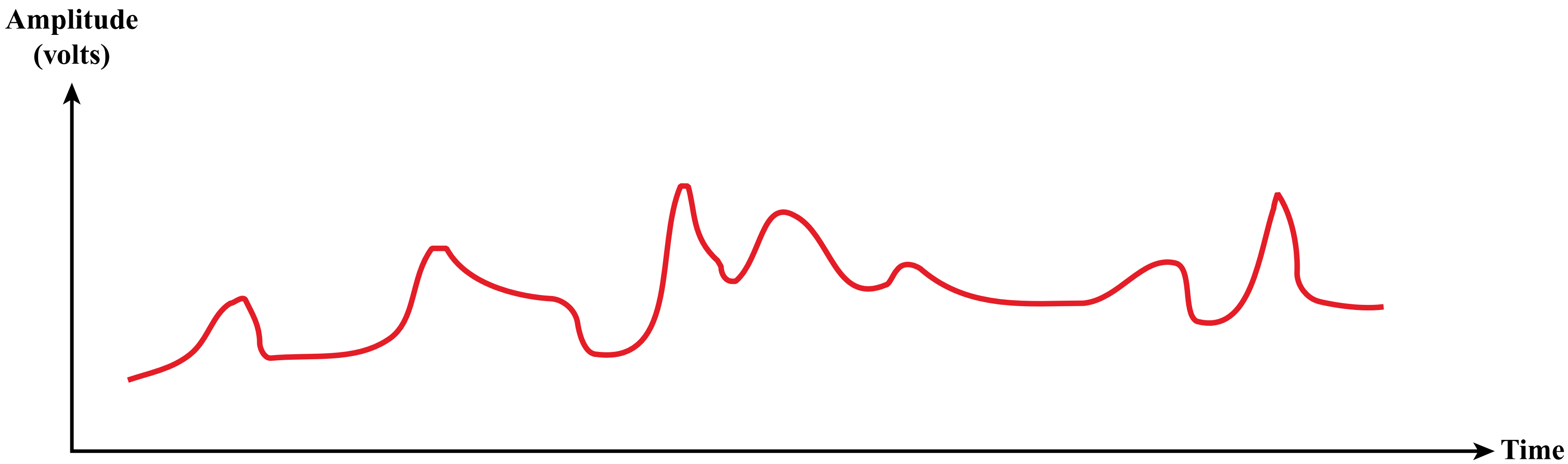
$$s(t) = A_t \sin(2 \pi f_t t + \varphi_t)$$

TIME-DOMAIN CONCEPTS

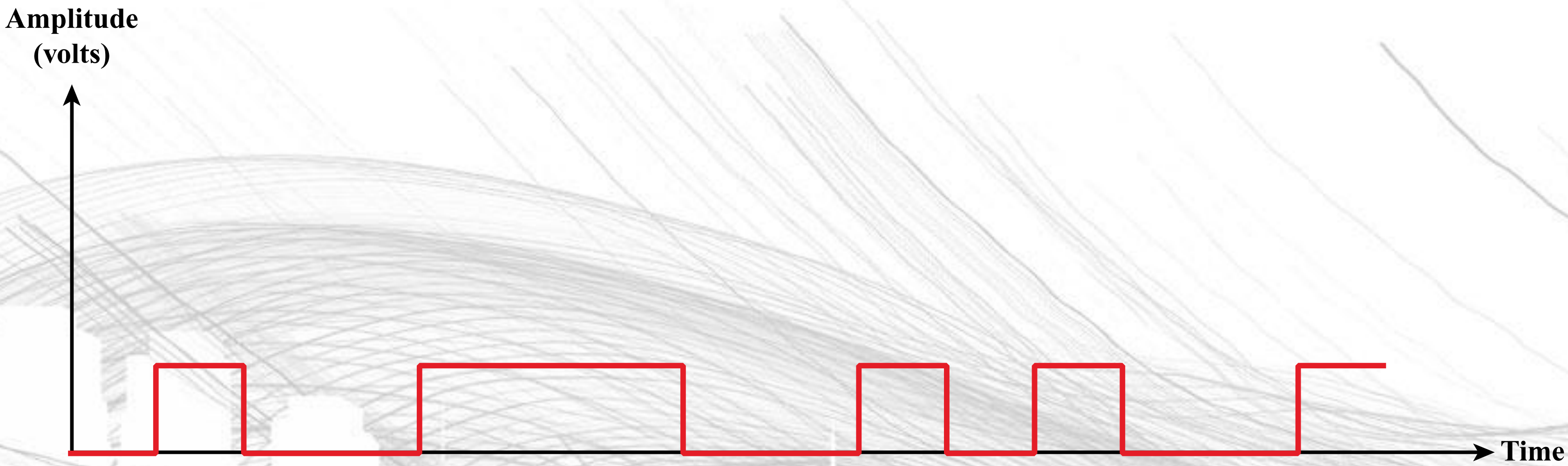
- Analog signal - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
- Digital signal - signal intensity maintains a constant level for some period of time and then changes to another constant level
- Periodic signal - analog or digital signal pattern that repeats over time

$$s(t+T) = s(t) \quad -\infty < t < +\infty$$

  - where T is the period of the signal



(a) Analog



(b) Digital

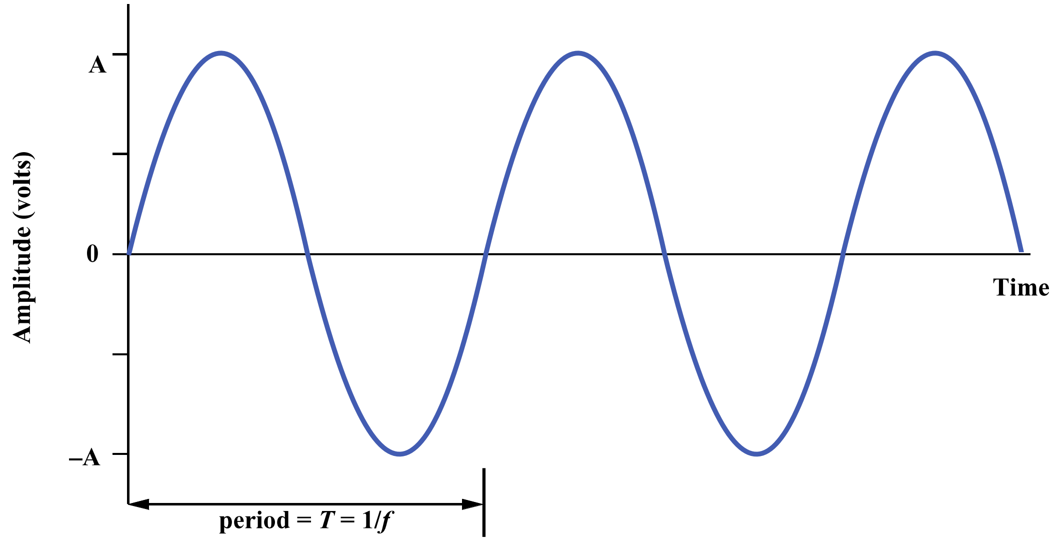
2.1 ANALOG AND DIGITAL WAVEFORMS

TIME-DOMAIN CONCEPTS

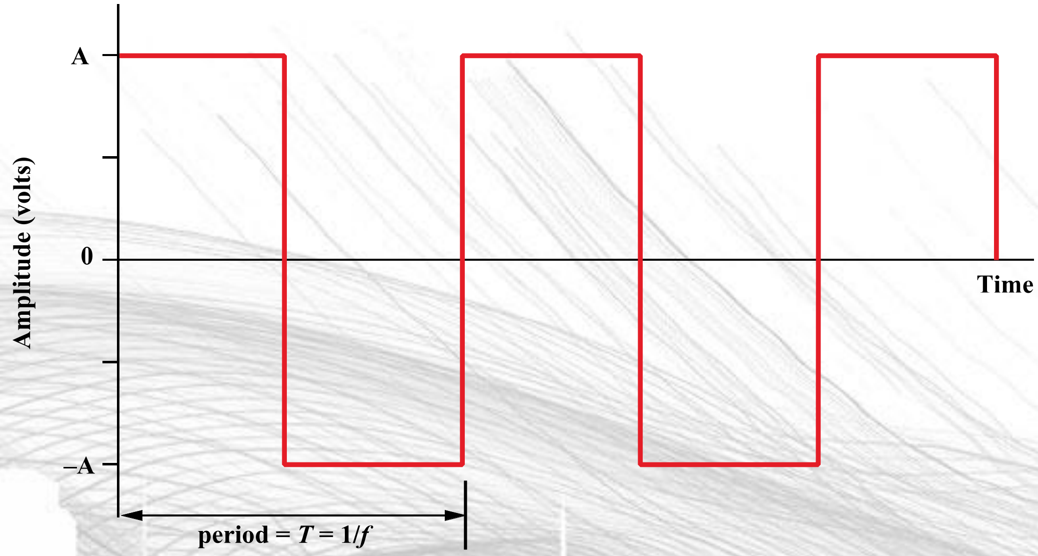
- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time
- Periodic Signal - analog or digital signal pattern that repeats over time
- Peak amplitude (*A*) - maximum value or strength of the signal over time; typically measured in volts
- Frequency (*f*)
  - Rate, in cycles 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
  - $\lambda = vT = v/f$



(a) Sine wave

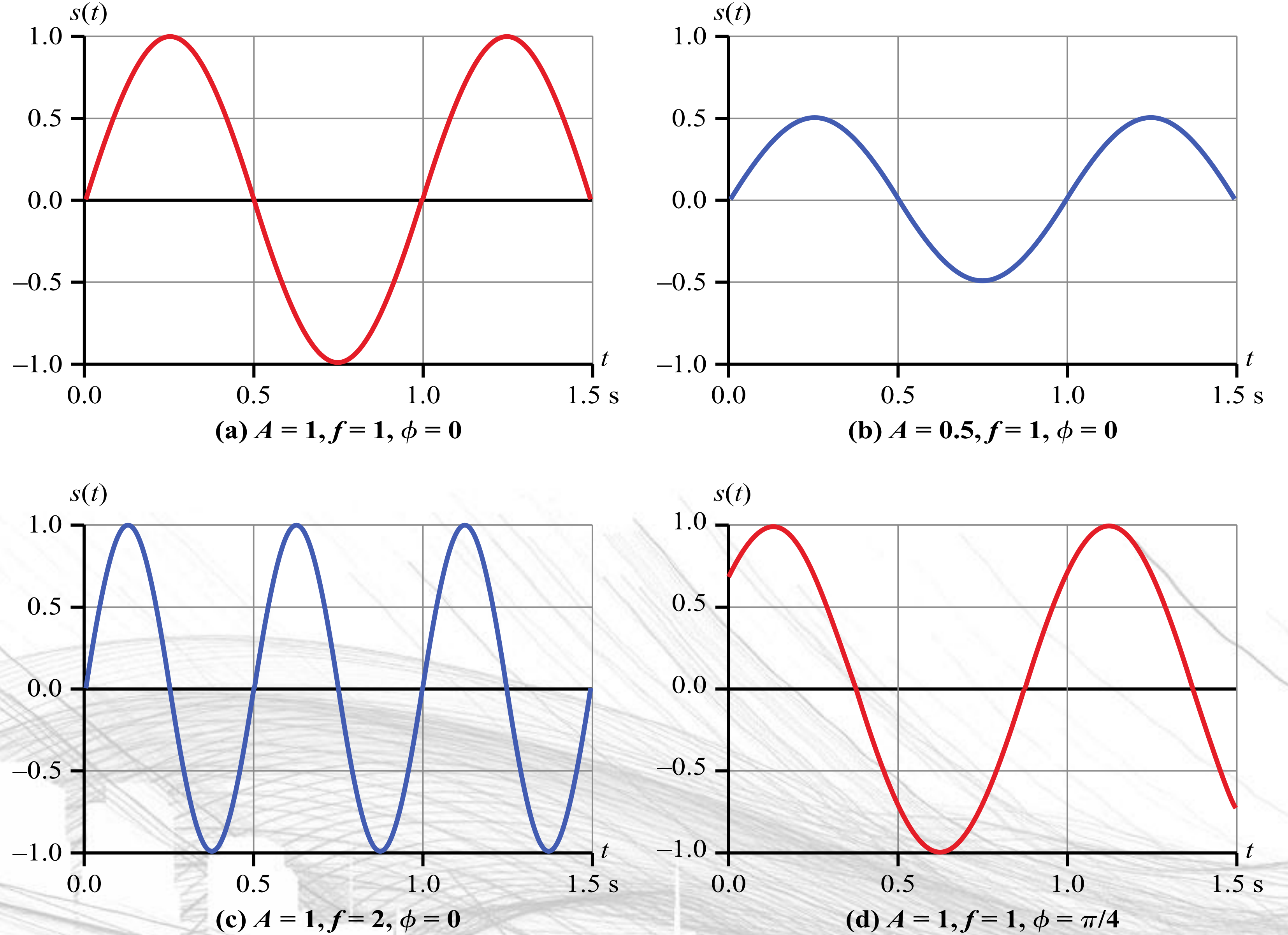


(b) Square wave

2.2 EXAMPLES OF PERIODIC SIGNALS

SINE WAVE PARAMETERS

- General sine wave
  - $s(t) = A \sin(2\pi ft + \phi)$
- 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 $T = ½$
  - (d) Phase shift; $\phi = \pi/4$ radians (45 degrees)
- Note: 2π radians = 360° = 1 period



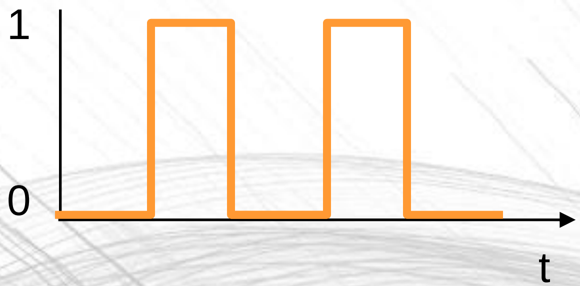
2.3 $s(t) = A \sin(2\pi f t + \phi)$

TIME VS. DISTANCE

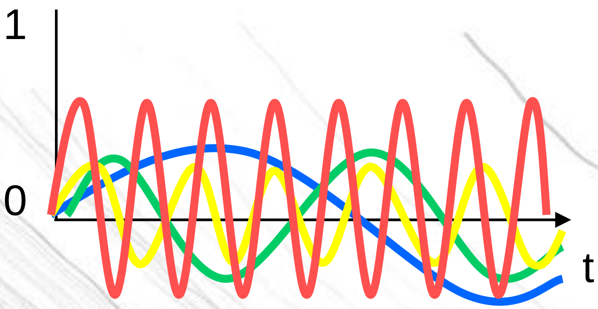
- When the horizontal axis is *time*, as in Figure 2.3, graphs display the value of a signal at a given point in *space* as a function of *time*
- With the horizontal axis in *space*, graphs display the value of a signal at a given point in *time* as a function of *distance*
  - At a particular instant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

COMPOSITION OF PERIODIC SIGNALS

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



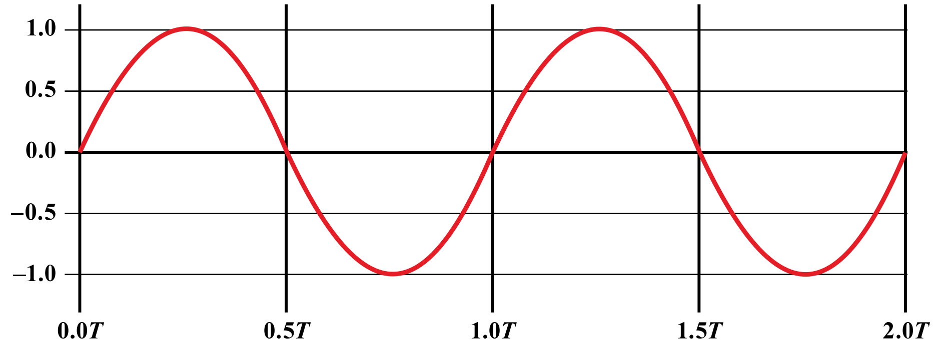
ideal periodic signal



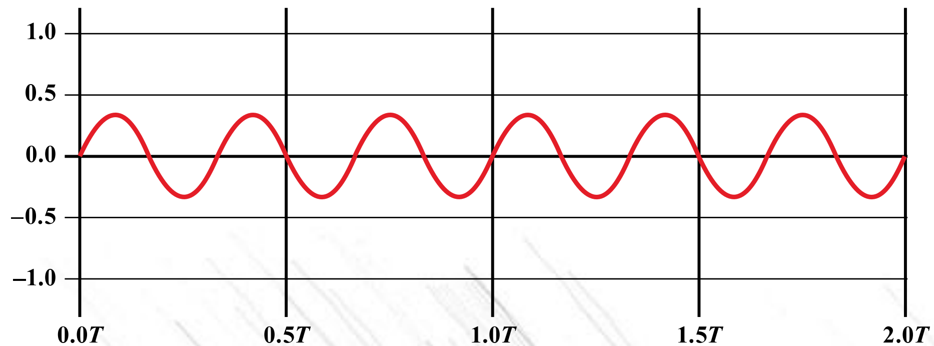
real composition
(based on harmonics)

FREQUENCY-DOMAIN CONCEPTS

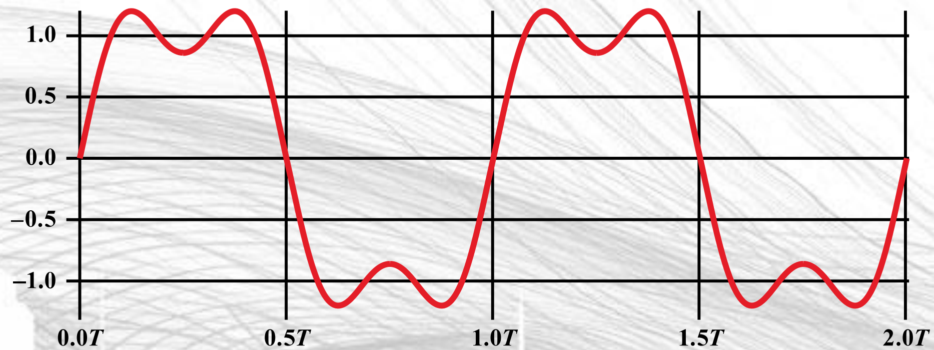
- Fundamental frequency - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency
- Spectrum - range of frequencies that a signal contains
- Absolute bandwidth - width of the spectrum of a signal
- Effective bandwidth (or just bandwidth)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



(a) $\sin(2\phi f t)$



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

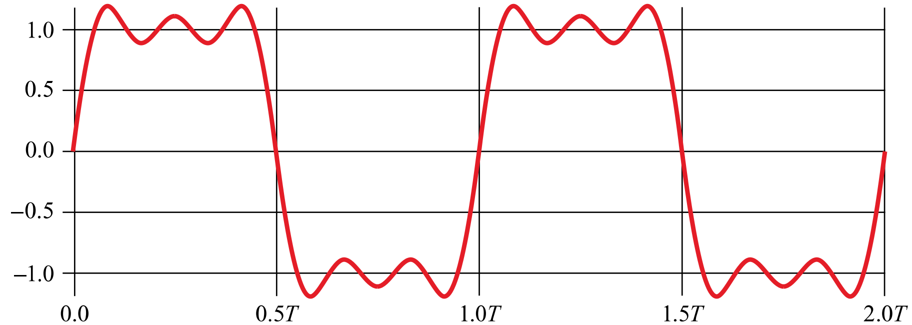


(c) $(4/\phi)\,[\sin(2\phi f t) + (1/3)\sin(2\phi(3f)t)]$

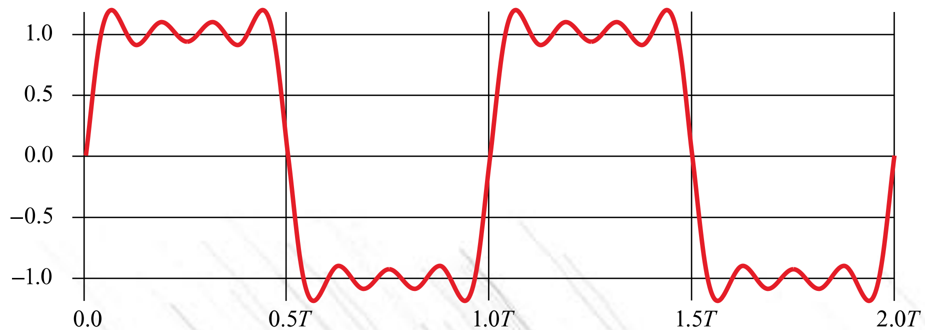
2.4 ADDITION OF FREQUENCY COMPONENTS($T = 1/f$)

FREQUENCY-DOMAIN CONCEPTS

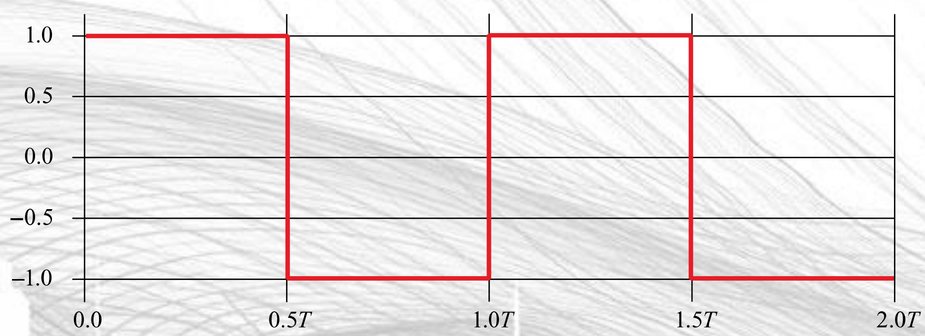
- Any electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases
- The period of the total signal is equal to the period of the fundamental frequency



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

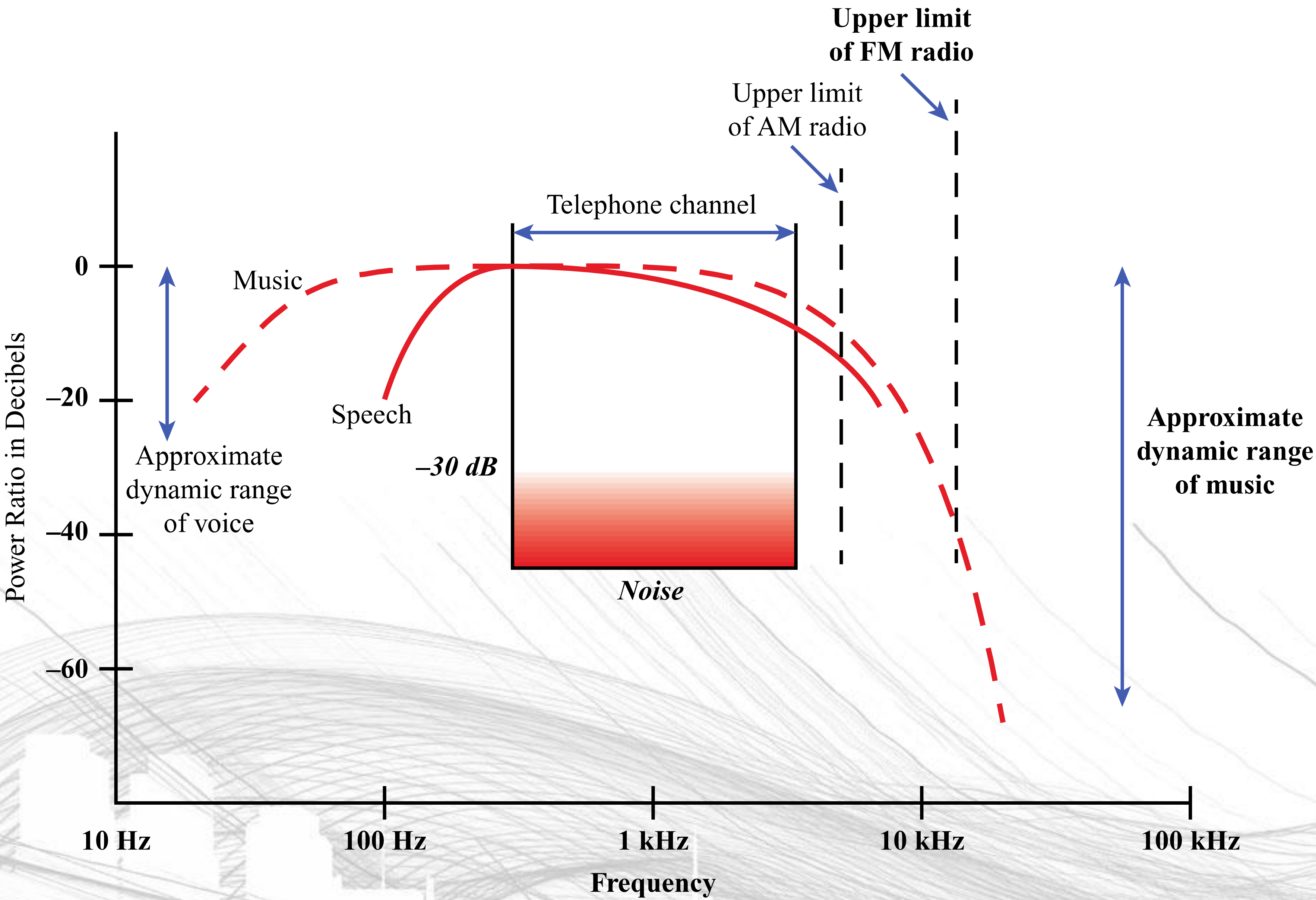


(b) $(4/\phi)\,[\sin(2\phi ft) + (1/3)\sin(2\phi(3f)t) + (1/5)\sin(2\phi(5f)t) + (1/7)\sin(2\phi(7f)t)]$



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

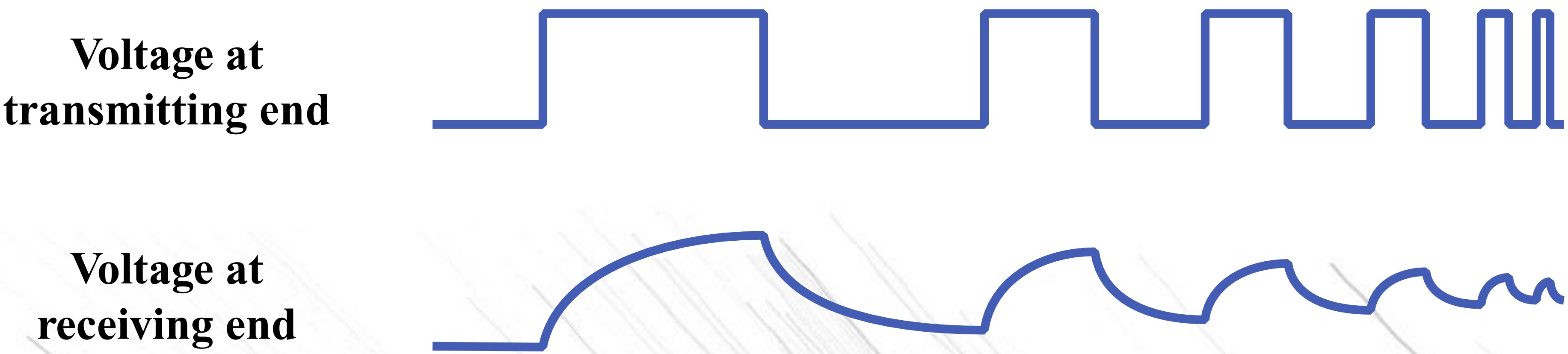
2.5 FREQUENCY COMPONENTS OF SQUARE WAVE



2.6 ACOUSTIC SPECTRUM OF SPEECH AND MUSIC

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



2.7 ATTENUATION OF DIGITAL SIGNALS

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

EXAMPLES OF ANALOG AND DIGITAL DATA

- Analog
  - Video
  - Audio
- Digital
  - Text
  - Integers
  - Digital Video
  - Digital Audio

ANALOG SIGNALS

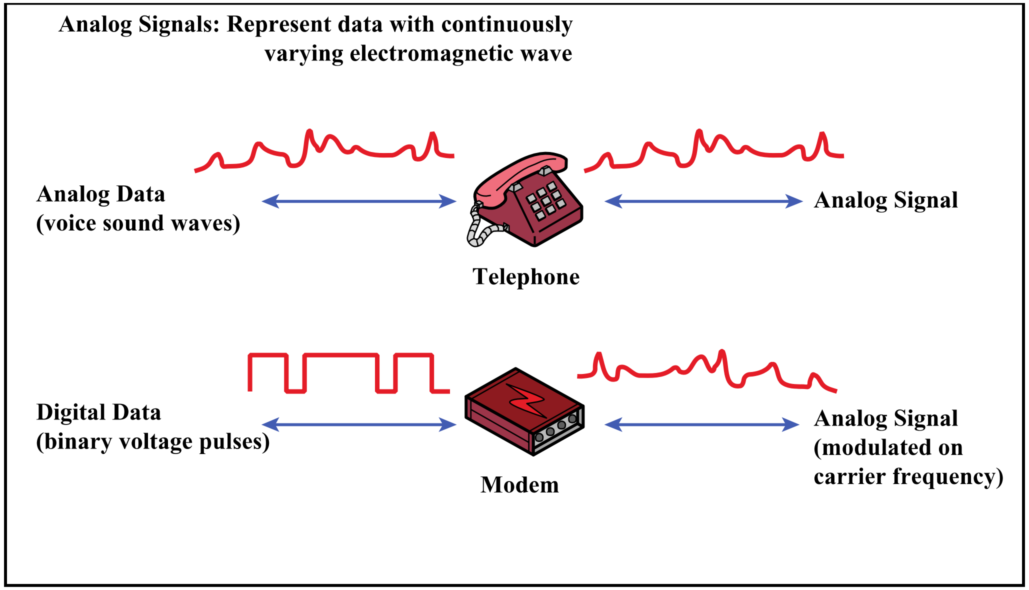
- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency
- Examples of media:
  - Copper wire media (twisted pair and coaxial cable)
  - Fiber optic cable
  - Atmosphere or space propagation
- Analog signals can propagate analog and digital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

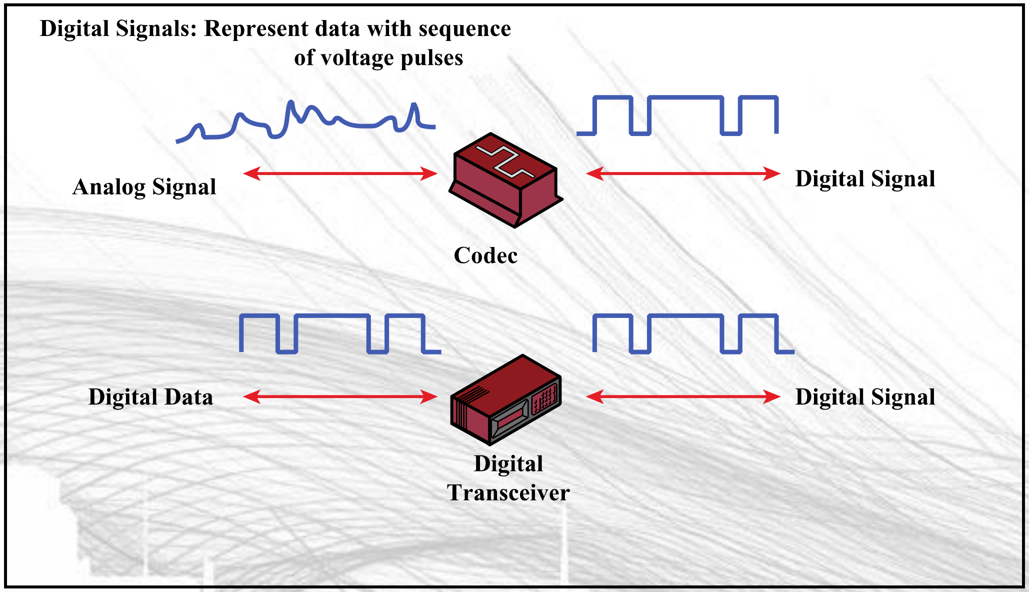
DIGITAL SIGNALS

- 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

REASONS FOR CHOOSING DATA AND SIGNAL COMBINATIONS

- Digital data, digital signal
  - Equipment for encoding is less expensive than digital-to-analog equipment
- Analog data, digital signal
  - Conversion permits use of modern digital transmission and switching equipment
- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - Examples include optical fiber and satellite
- Analog data, analog signal
  - Analog data easily converted to analog signal





2.8 ANALOG AND DIGITAL SIGNALING OF ANALOG AND DIGITAL DATA

ANALOG TRANSMISSION

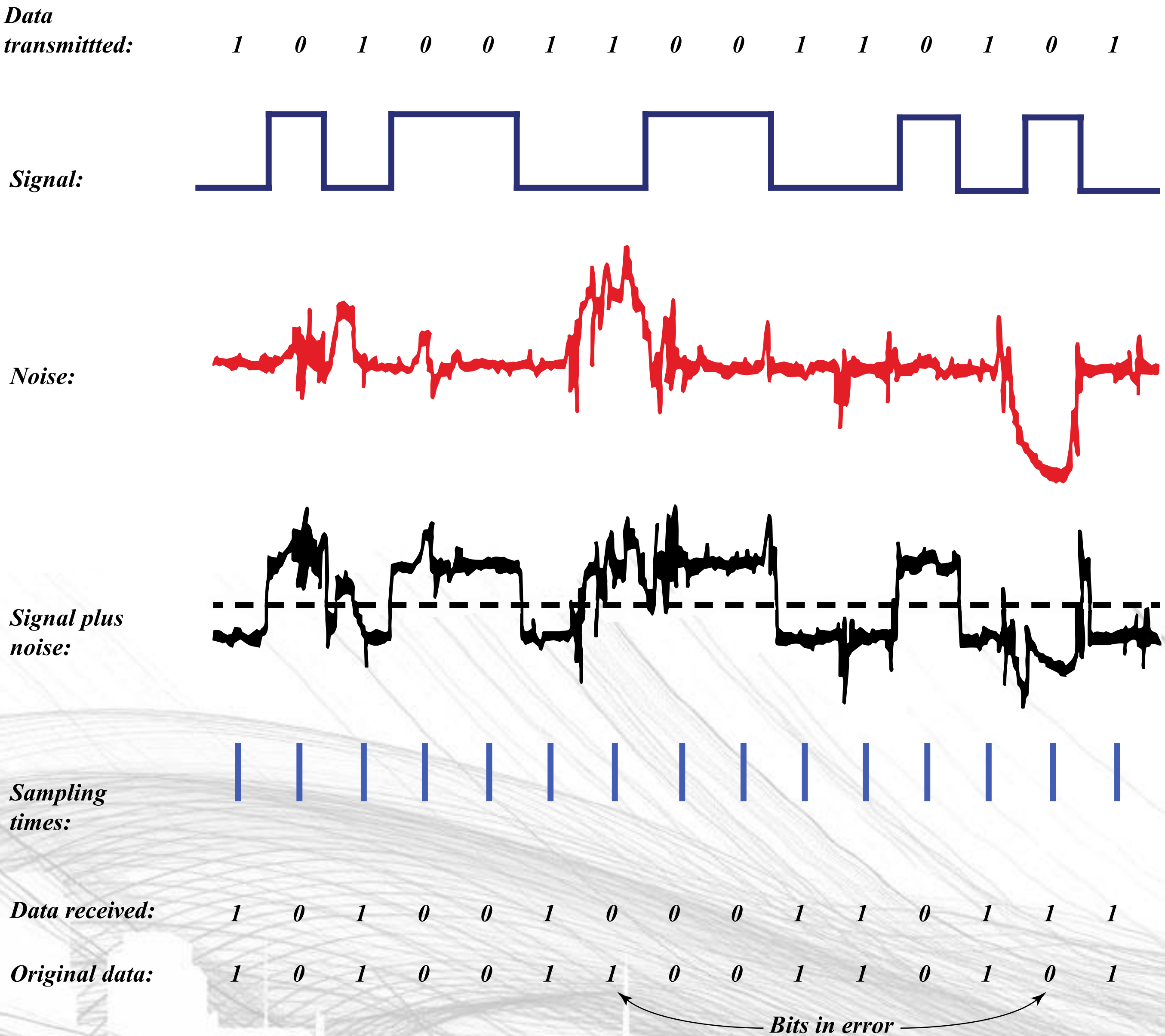
- Transmit analog signals without regard to content
- Attenuation limits length of transmission link
- Cascaded amplifiers boost signal's energy for longer distances but cause distortion
  - Analog data can tolerate distortion
  - Introduces errors in digital data

DIGITAL TRANSMISSION

- Concerned with the content of the signal
- Attenuation endangers integrity of data
- Digital Signal
  – Repeaters achieve greater distance
  – Repeaters recover the signal and retransmit
- Analog signal carrying digital data
  – Retransmission device recovers the digital data from analog signal
  – Generates new, clean analog 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



2.9 EFFECT OF NOISE ON DIGITAL SIGNAL

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

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?

$$C = 2B \log_2 M$$

$$8 \times 10^6 = 2 \times \left(10^6\right) \times \log_2 M$$

$$4 = \log_2 M$$

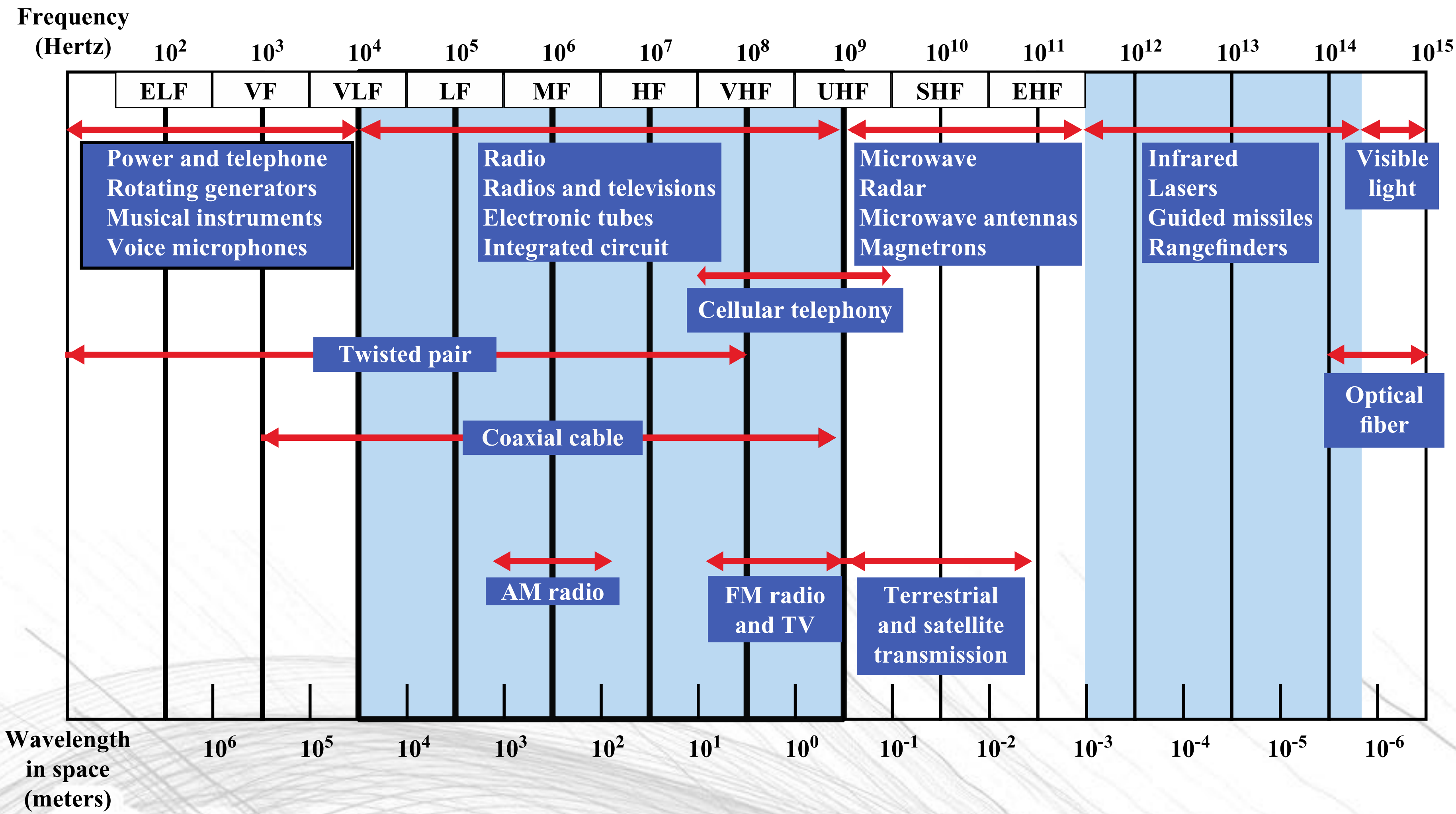
$$M = 16$$

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



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency

MF = Medium frequency
HF = High frequency
VHF = Very high frequency

UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

2.10 ELECTROMAGNETIC SPECTRUM OF TELECOMMUNICATIONS

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, $3x10^{11}$ to $2x10^{14}$ 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

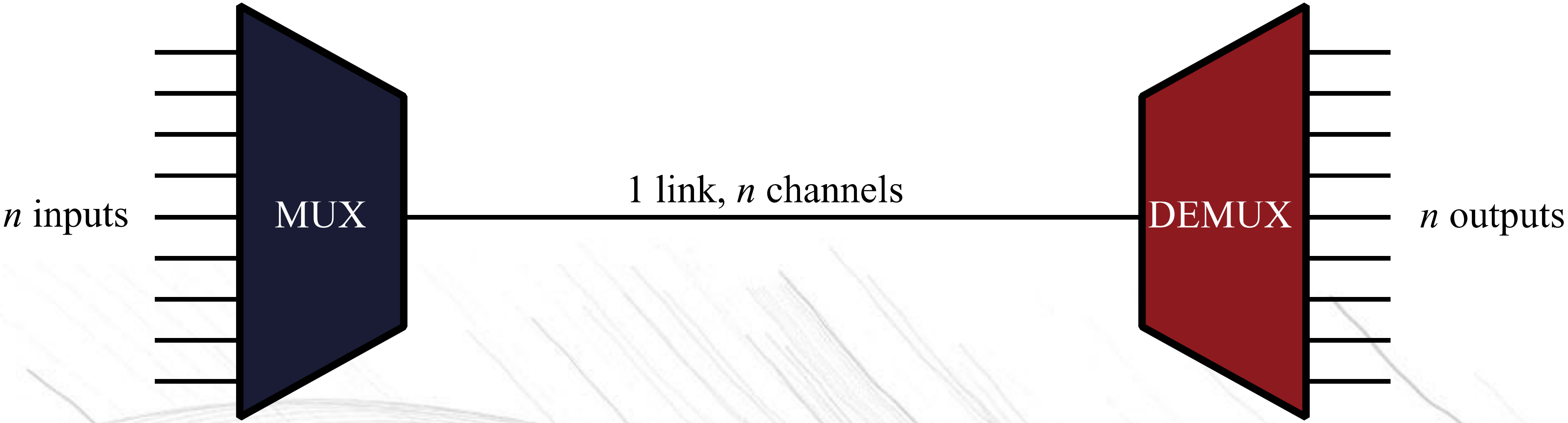
- Description of communication satellite
  - Microwave relay station
  - Used to link two or more ground-based microwave transmitter/receivers
  - Receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink)
- Applications
 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



2.11 MULTIPLEXING

REASONS FOR WIDESPREAD USE OF MULTIPLEXING

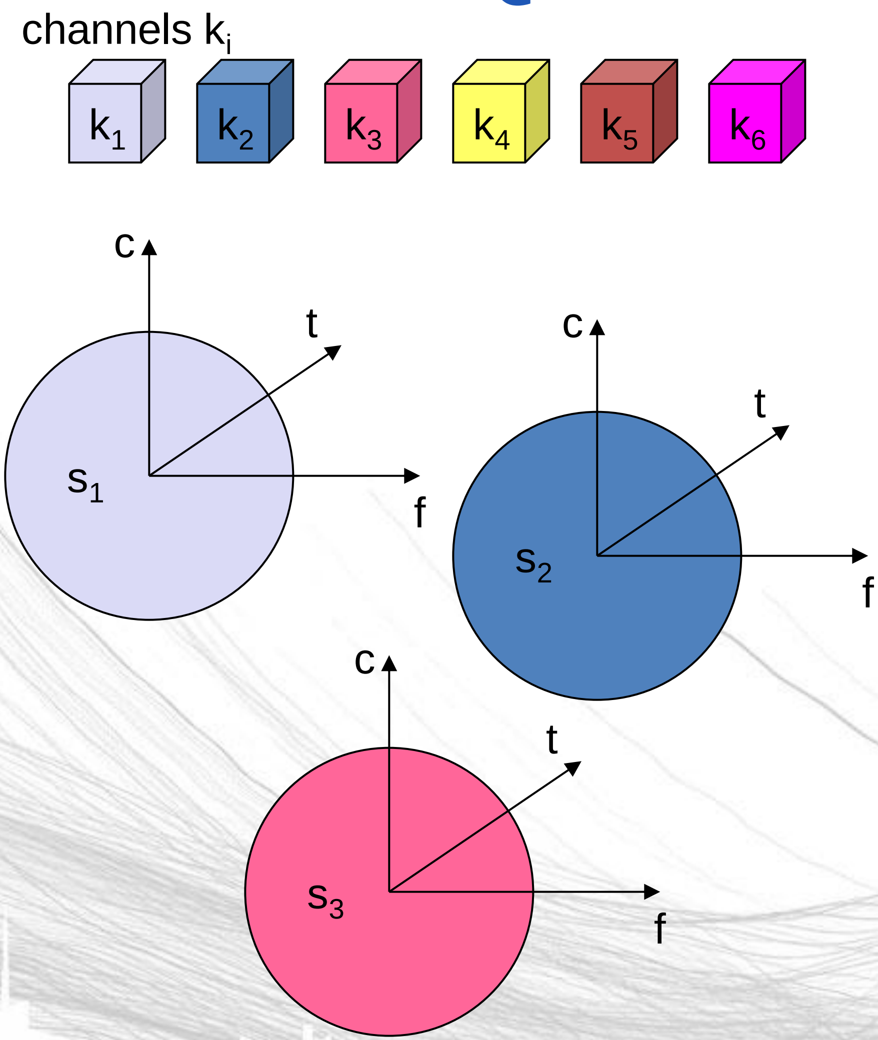
- Cost per kbps of transmission facility declines with an increase in the data rate
- Cost of transmission and receiving equipment declines with increased data rate
- Most individual data communicating devices require relatively modest data rate support

MULTIPLEXING TECHNIQUES

- Multiplexing in 4 dimensions
  - space (s_i)
  - time (t)
  - frequency (f)
  - code (c)

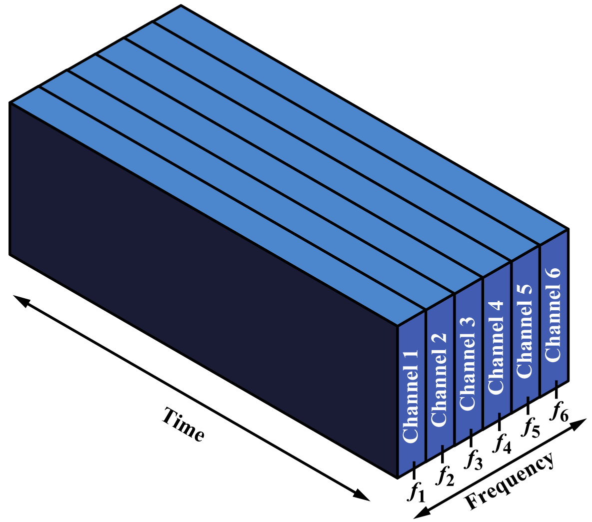
- Goal: multiple use of a shared medium

- Important: guard spaces needed!

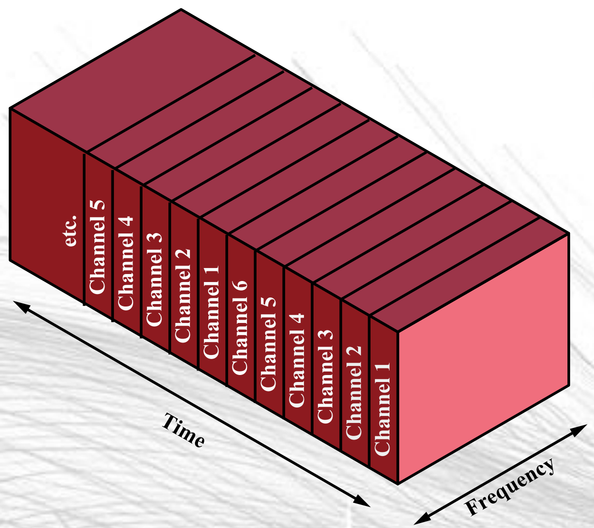


MULTIPLEXING TECHNIQUES

- 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

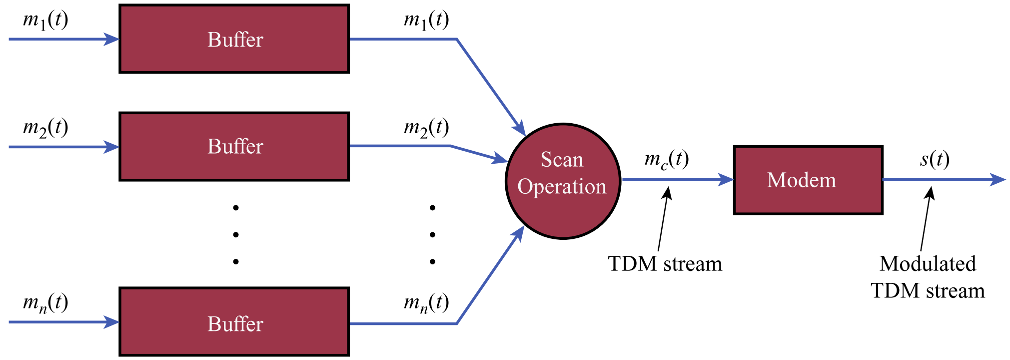


(a) Frequency division multiplexing

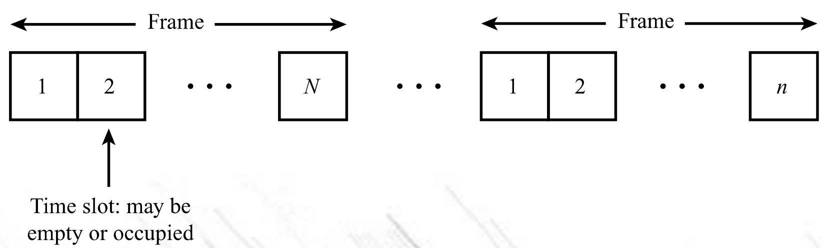


(b) Time division multiplexing

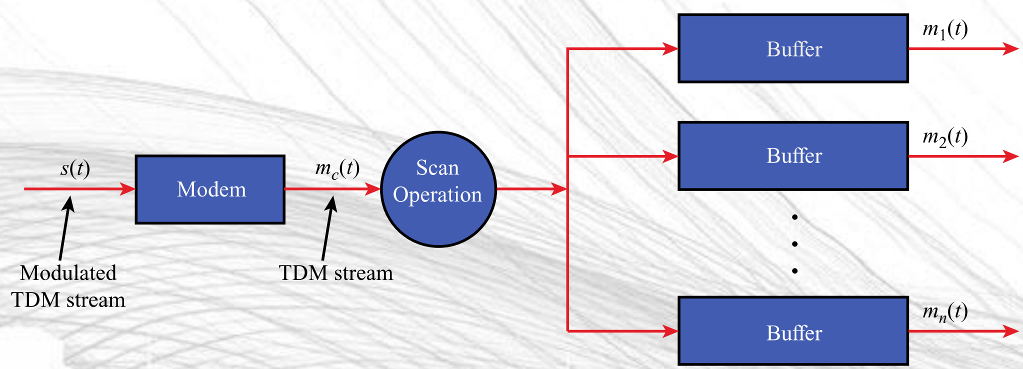
2.12 FDM AND TDM



(a) Transmitter



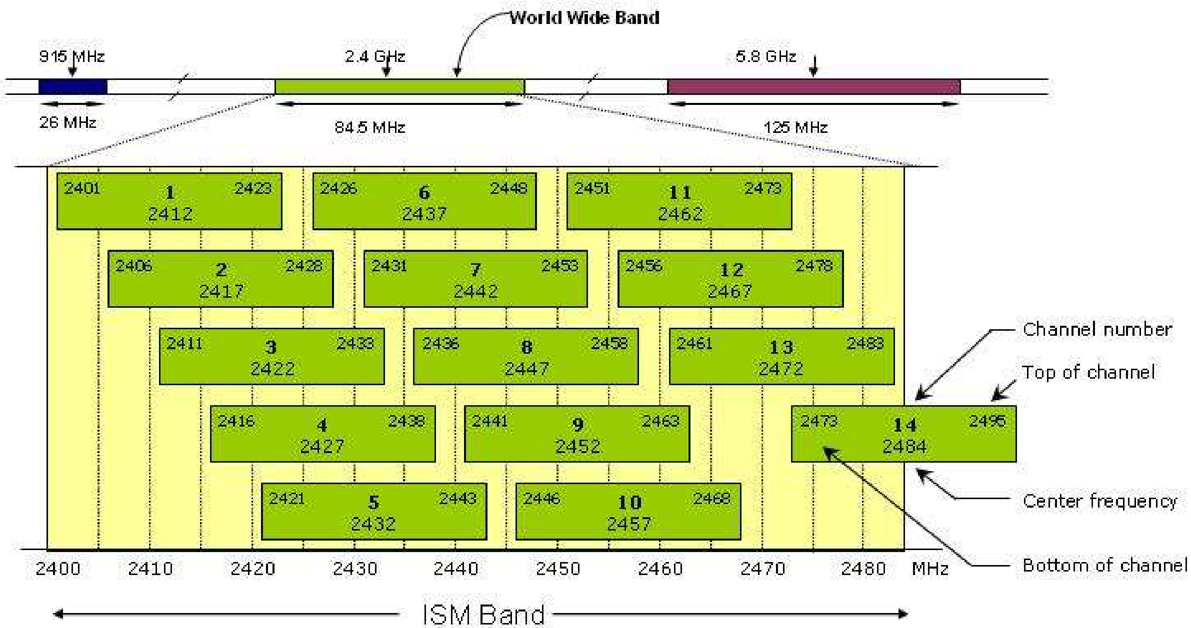
(b) TDM Frames



(c) Receiver

2.13 SYNCHRONOUS TDM SYSTEM

Wi-Fi channles



FCC spectrum occupation