# Data and Computer Communications

Tenth Edition

by William Stallings

# CHAPTER 3

## Data Transmission

*"I have been trying to prove the following theorem: for any operators T,R the length of an arbitrary message f1 multiplied by its essential spectrum and divided by the distortion of the system is less than a certain constant times the time of transmission of F multiplied by its essential spectrum width or—roughly speaking—it is impossible to reduce bandwidth times transmission time for a given distortion.*

*This seems to be true although I do not have a general proof as yet."*

**—Letter to Vannevar Bush,**
**February 16, 1939,**
**from Claude Shannon**

# Transmission Terminology

**Data transmission occurs between transmitter and receiver over some transmission medium**

**Communication is in the form of electromagnetic waves**

**Guided media**

- Twisted pair, coaxial cable, optical fiber

**Unguided media (wireless)**

- Propagation through air, vacuum, and seawater

# Transmission Terminology

**Direct link**

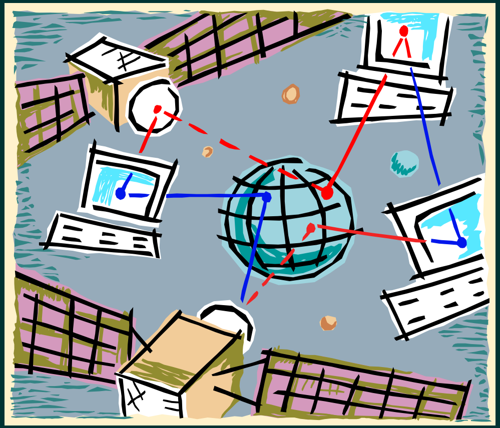
- No intermediate devices other than amplifiers or repeaters used to increase signal strength

**Point-to-point**

- Direct link between two devices
- Are the only 2 devices sharing medium

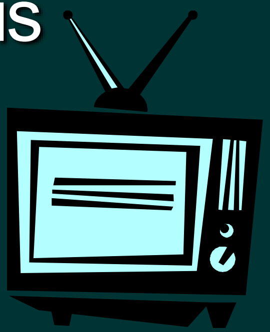
**Multi-point**

- More than two devices share the same medium

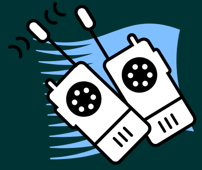


# TransmissionTerminology

- **Simplex**
  - Signals are transmitted in only one direction
  - One station is transmitter and the other is receiver



- **Half duplex**
  - Both stations transmit, but only one at a time



- **Full duplex**
  - Both stations may transmit simultaneously
  - The medium is carrying signals in both directions at the same time

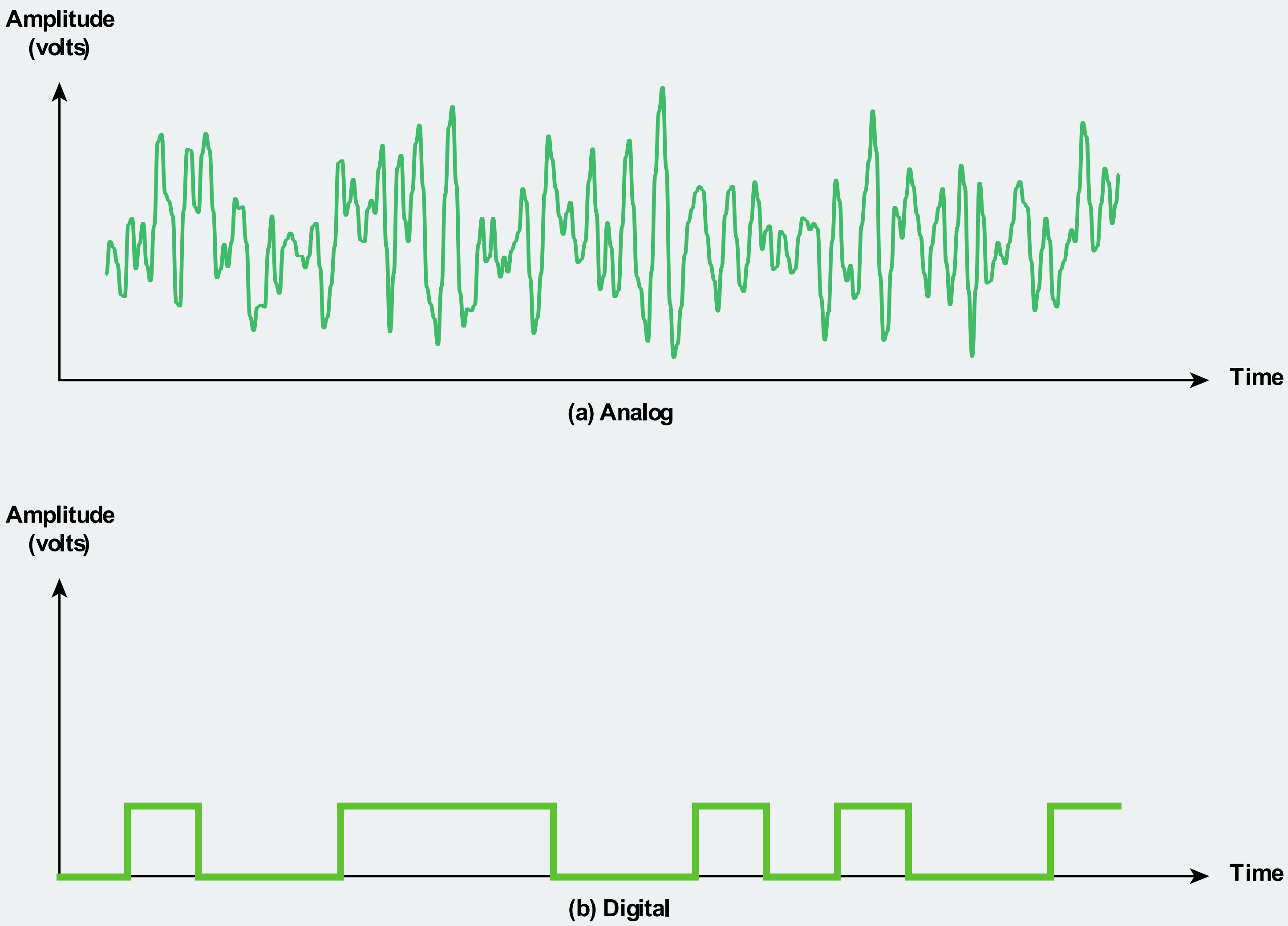
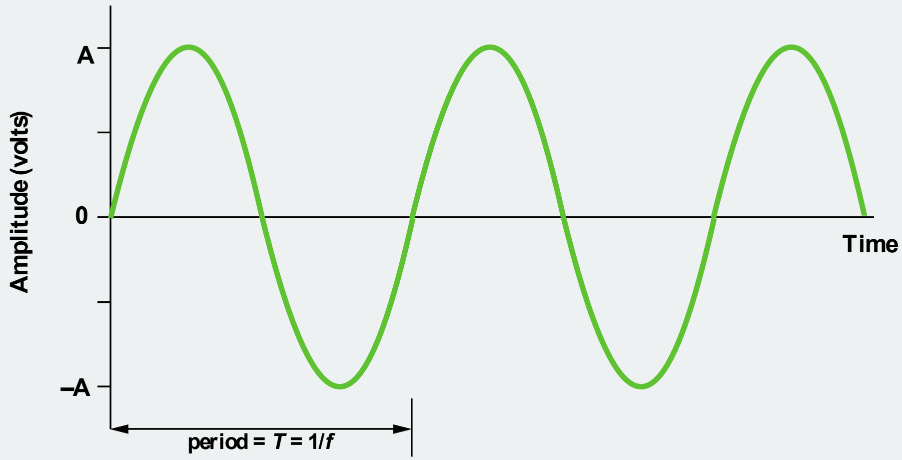
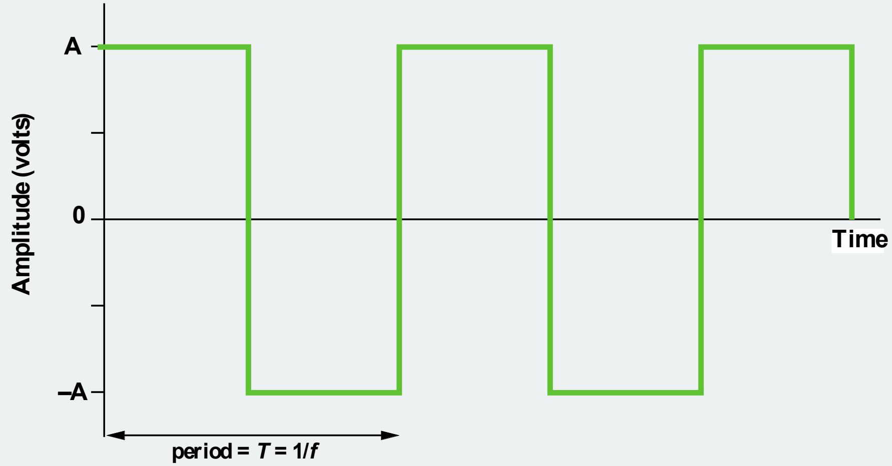



**Figure 3.1 Analog and Digital Waveforms**




(a) Sine wave




(b) Square wave

**Figure 3.2 Examples of Periodic Signals**

# Sine Wave

- **Is the fundamental periodic signal**
- **Can be represented by three parameters**
  - **Peak amplitude (*A*)**
    - Maximum value or strength of the signal over time
    - Typically measured in volts
  - **Frequency (*f*)**
    - Rate at which the signal repeats
    - Hertz (Hz) or cycles per second
    - Period ($T$) is the amount of time for one repetition
    - $T = 1/f$
  - **Phase ($\phi$)**
    - Relative position in time within a single period of signal

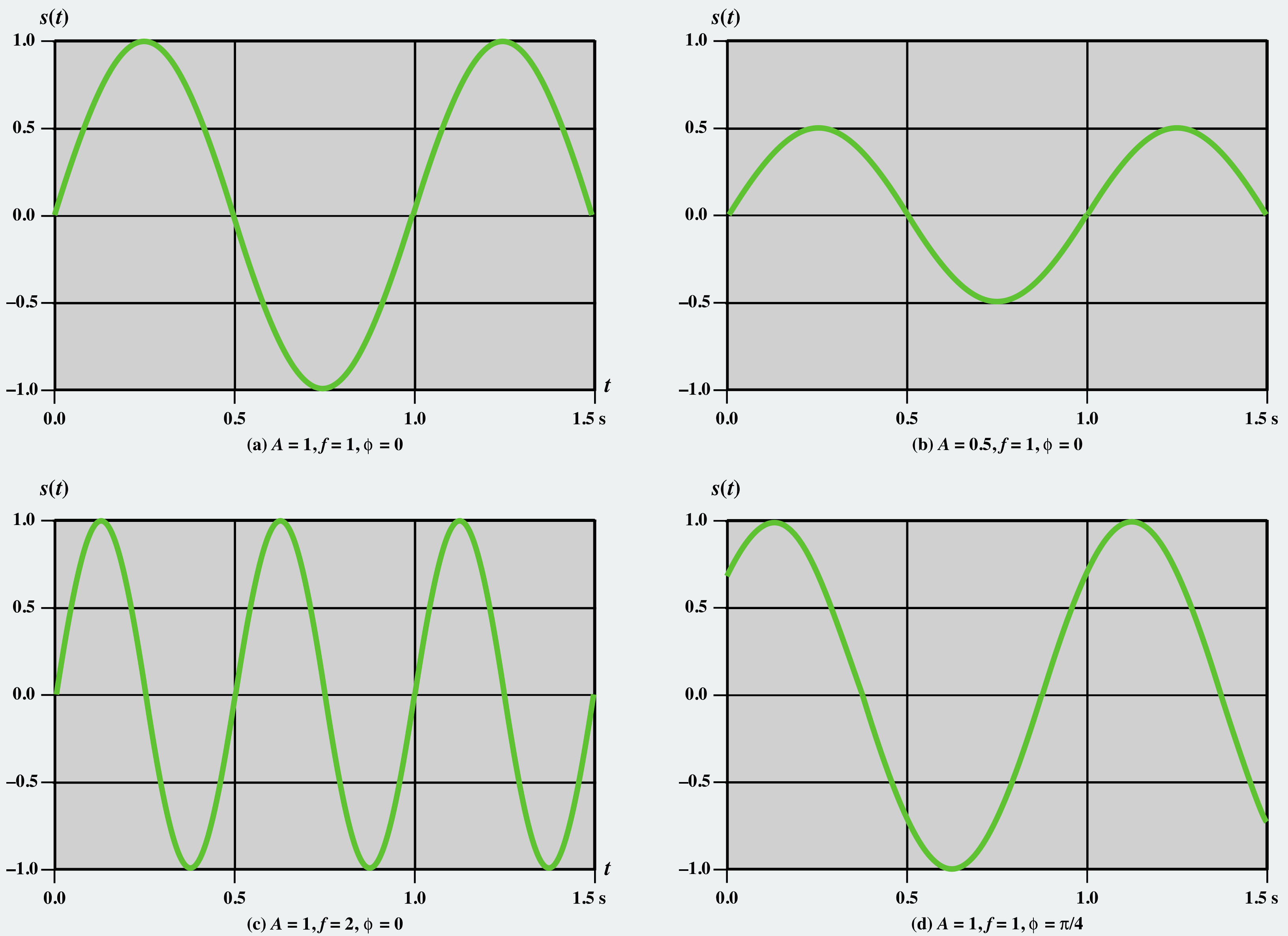



**Figure 3.3** $s(t) = A \sin(2\pi f t + \phi)$

# Wavelength ($\lambda$)

The wavelength of a signal is the distance occupied by a single cycle

Can also be stated as the distance between two points of corresponding phase of two consecutive cycles

Assuming signal velocity $v$, then the wavelength is related to the period as $\lambda = vT$

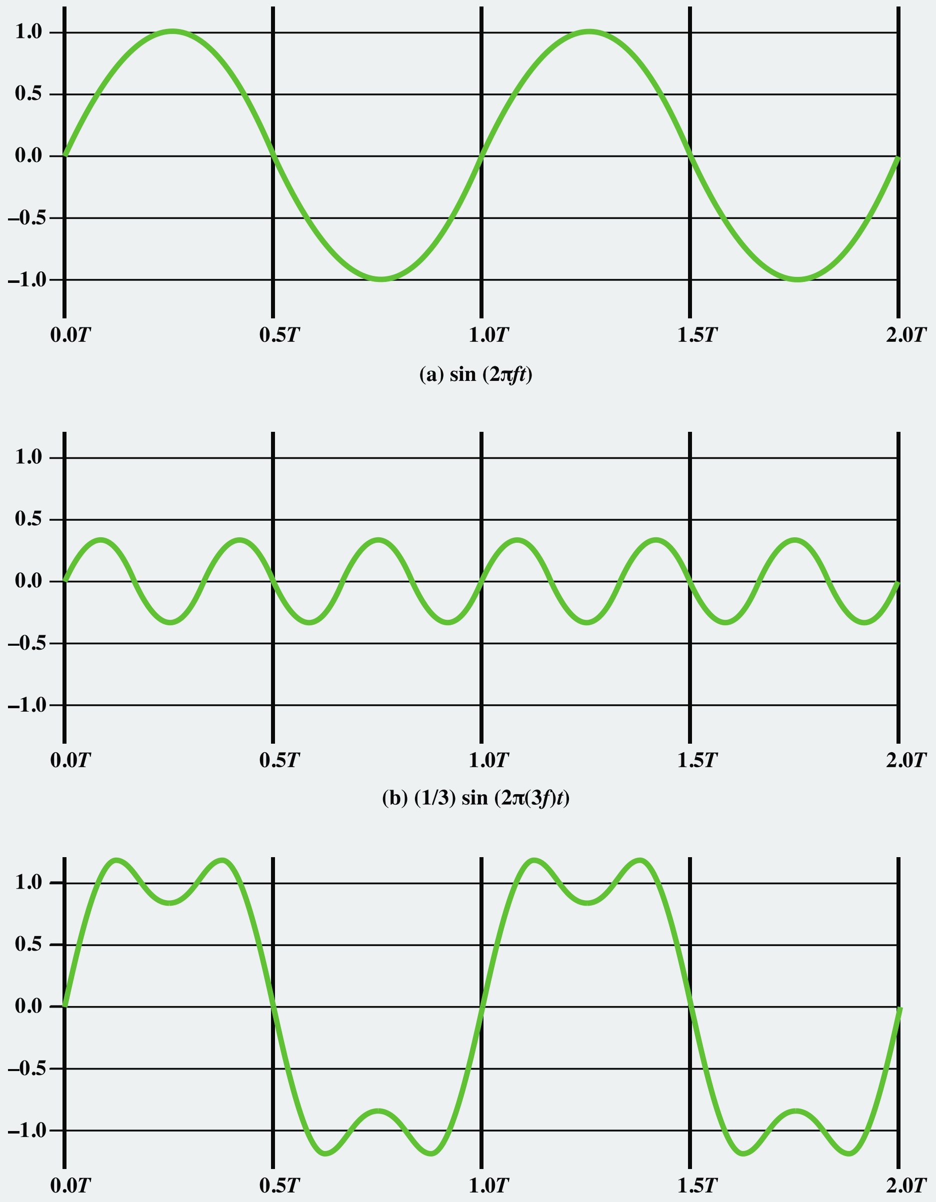
Or equivalently $\lambda f = v$

Especially when $v=c$

$c = 3*10^8$ m/s (speed of light in free space)

# Frequency Domain Concepts

- Signals are made up of many frequencies
- Components are sine waves
- Fourier analysis can show that any signal is made up of components at various frequencies, in which each component is a sinusoid
- Can plot frequency domain functions




(a) sin (2π*ft*)

(b) (1/3) sin (2π(3*f*)*t*)

(c) (4/π) [sin (2π*ft*) + (1/3) sin (2π(3*f*)*t*)]

**Figure 3.4 Addition of Frequency Components ($T = 1/f$)**

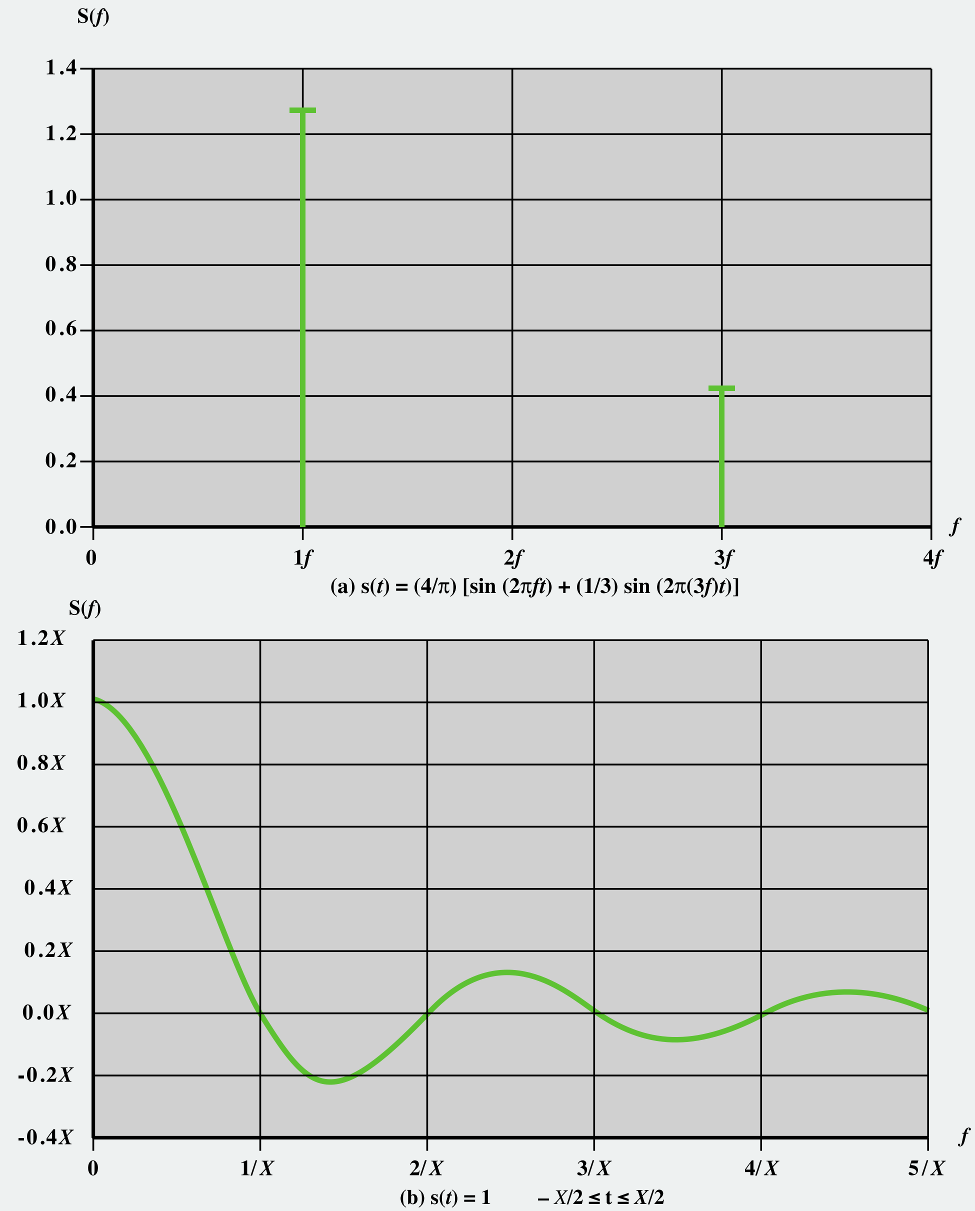



**Figure 3.5 Frequency-Domain Representations**

# Spectrum and Bandwidth

**Spectrum**

- *Range of frequencies contained in signal*

**Absolute bandwidth**

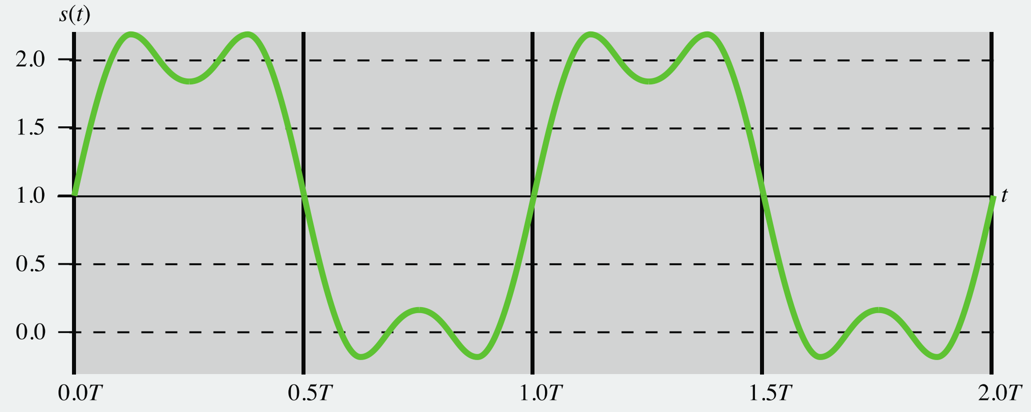
- *Width of spectrum*

**Effective bandwidth (or just *bandwidth*)**

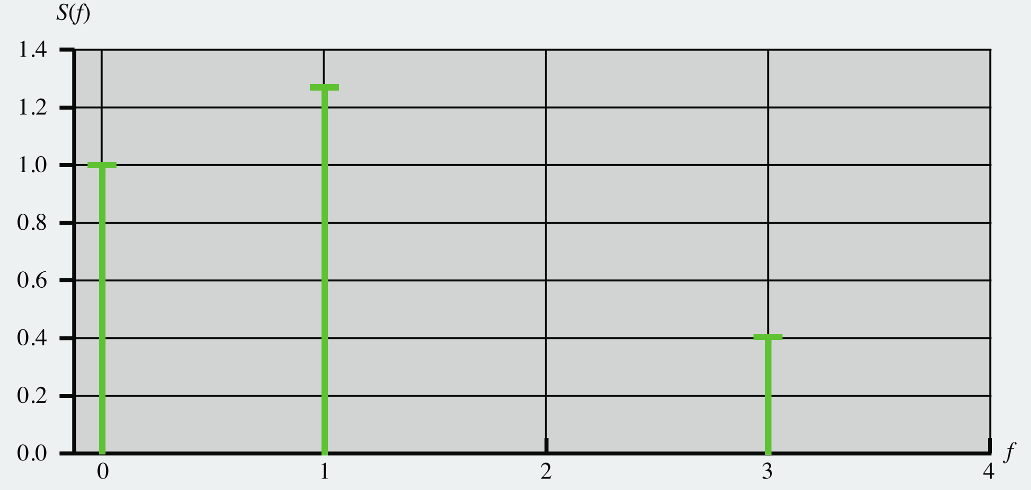
- *Narrow band of frequencies containing most energy*

**Dc component**

- *Component of zero frequency*




**(a) s($t$) = 1 + (4/π) [sin (2π$ft$) + (1/3) sin (2π(3$f$)$t$)]**




**(b) S($f$)**

**Figure 3.6  Signal with dc Component**

# Data Rate and Bandwidth

Any transmission system has a limited band of frequencies

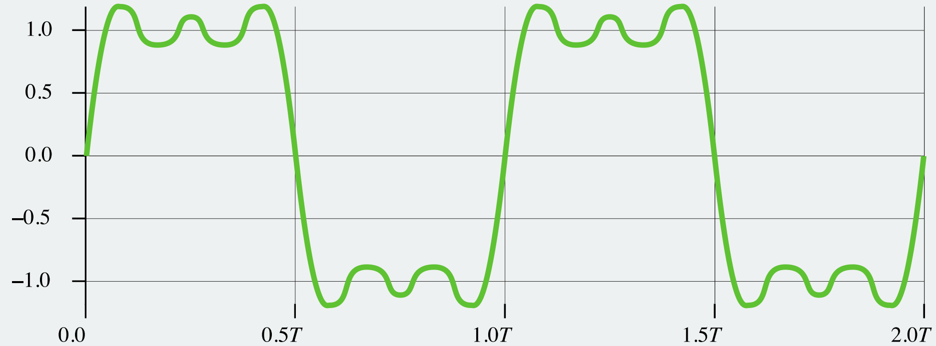
This limits the data rate that can be carried on the transmission medium

Square waves have infinite components and hence an infinite bandwidth

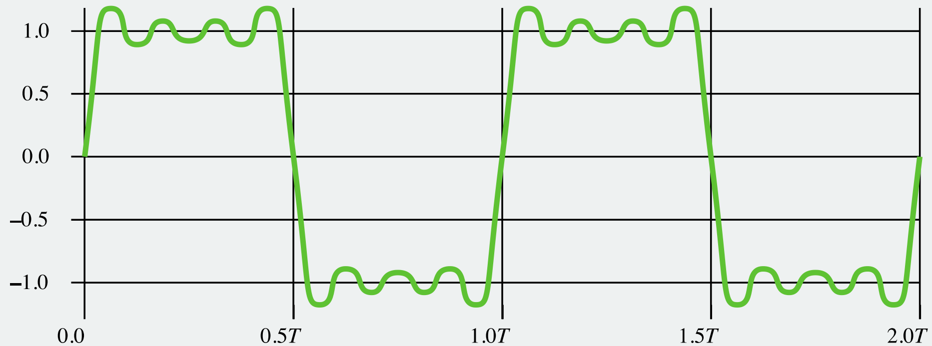
Most energy in first few components

Limiting bandwidth creates distortions

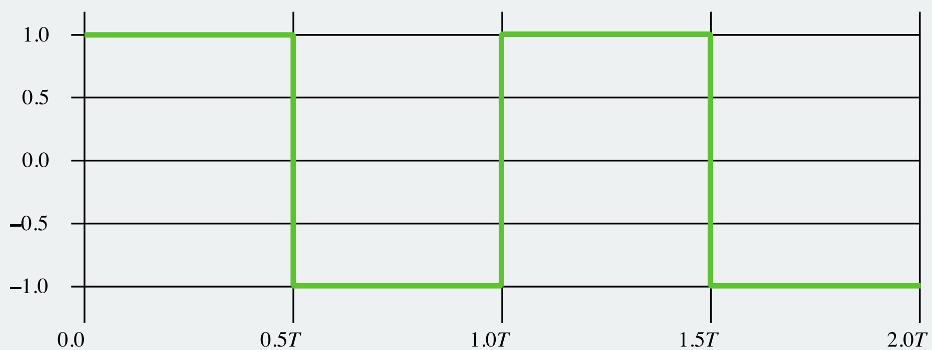
**There is a direct relationship between data rate and bandwidth**




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

**Figure 3.7 Frequency Components of Square Wave ($T = 1/f$)**

# Analog and Digital Data Transmission

| Data | Signals | Signaling | Transmission |
|---|---|---|---|
| Entities that convey information | Electric or electromagnetic representations of data | Physical propagation of the signal along a suitable medium | Communication of data by the propagation and processing of signals |

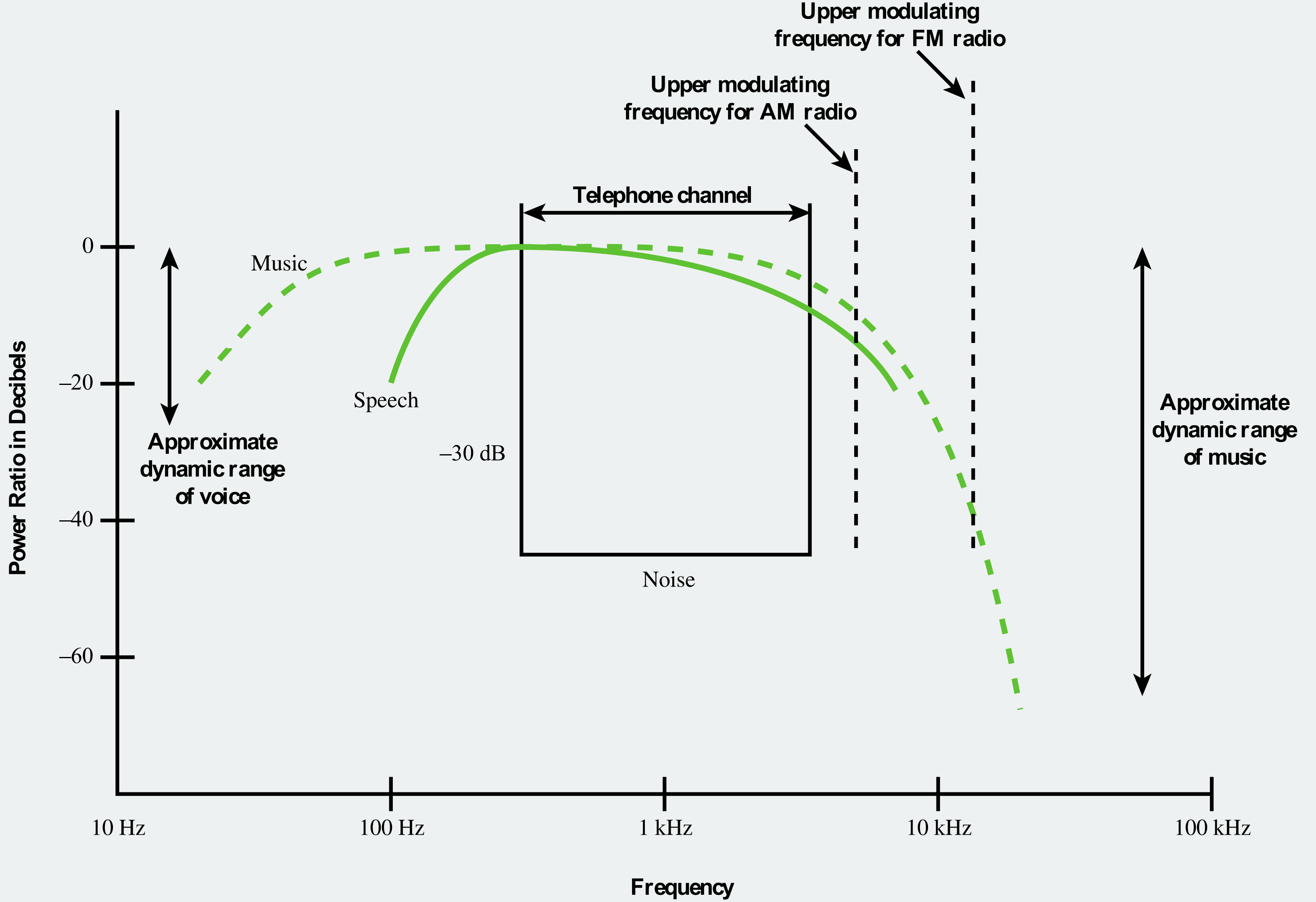
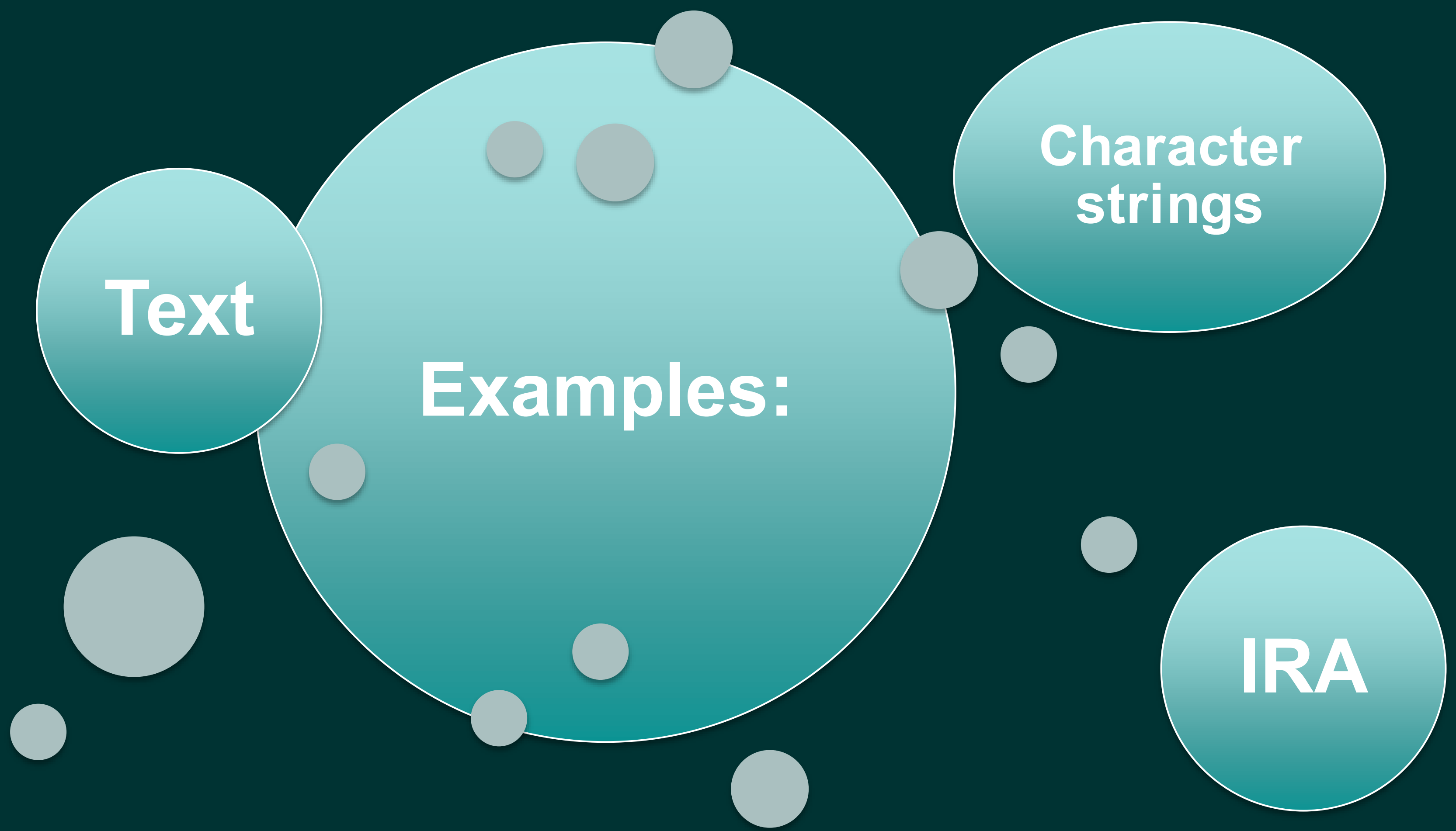



**Figure 3.9 Acoustic Spectrum of Speech and Music [CARN99]**

# Digital Data



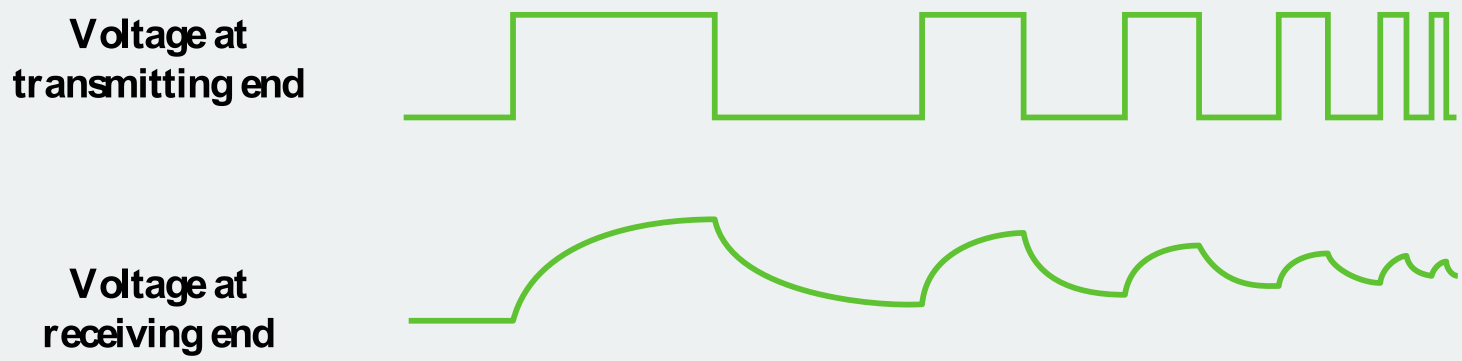


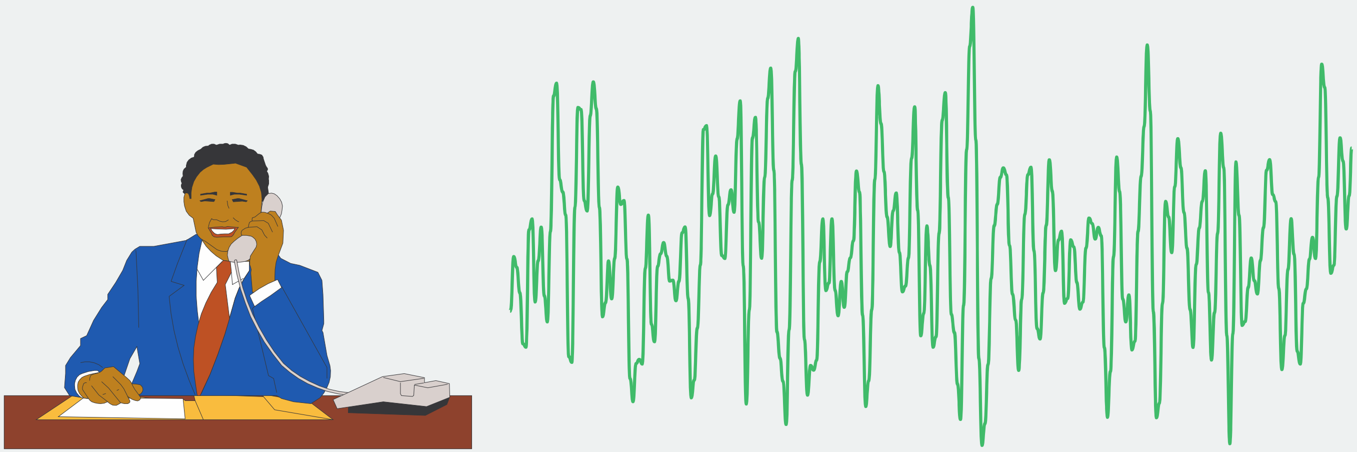

Figure 3.10 Attenuation of Digital Signals

# Advantages and Disadvantages of Digital Signals

Generally cheaper

Less susceptible to noise interference

Suffer more from attenuation

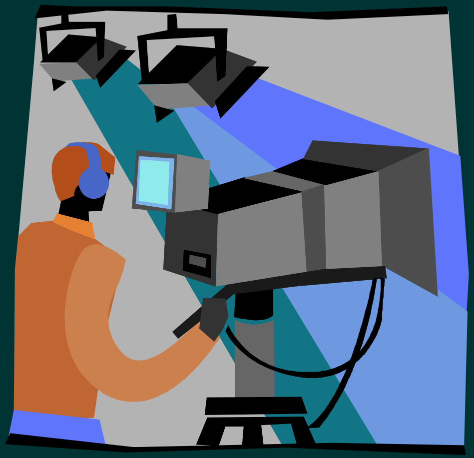


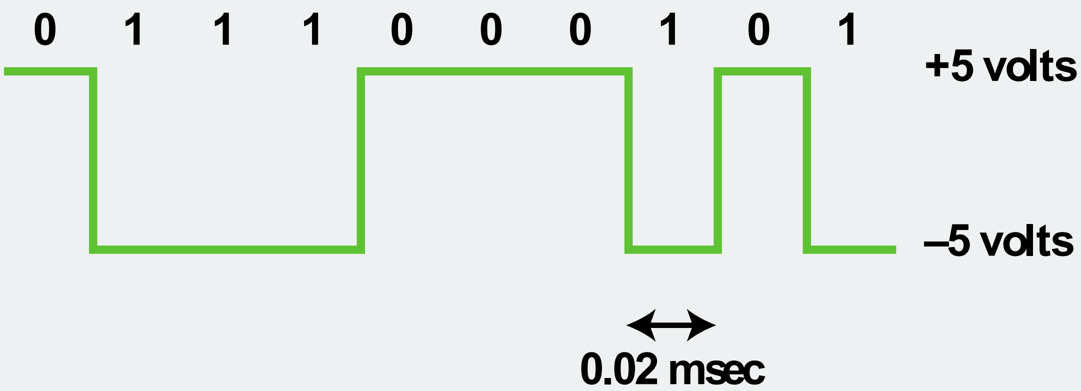
In this graph of a typical analog voice signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

**Figure 3.11 Conversion of Voice Input to Analog Signal**

# Video Signals

- To produce a video signal a TV camera is used
- USA standard is 483 lines per frame, at a rate of 30 complete frames per second
  - Actual standard is 525 lines but about 42 are lost during vertical retrace
- Horizontal scanning frequency is 525 lines x 30 scans = 15750 lines per second
- Max frequency if line alternates between black and white as rapidly as possible






User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by –5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

**Figure 3.12 Conversion of PC Input to Digital Signal**

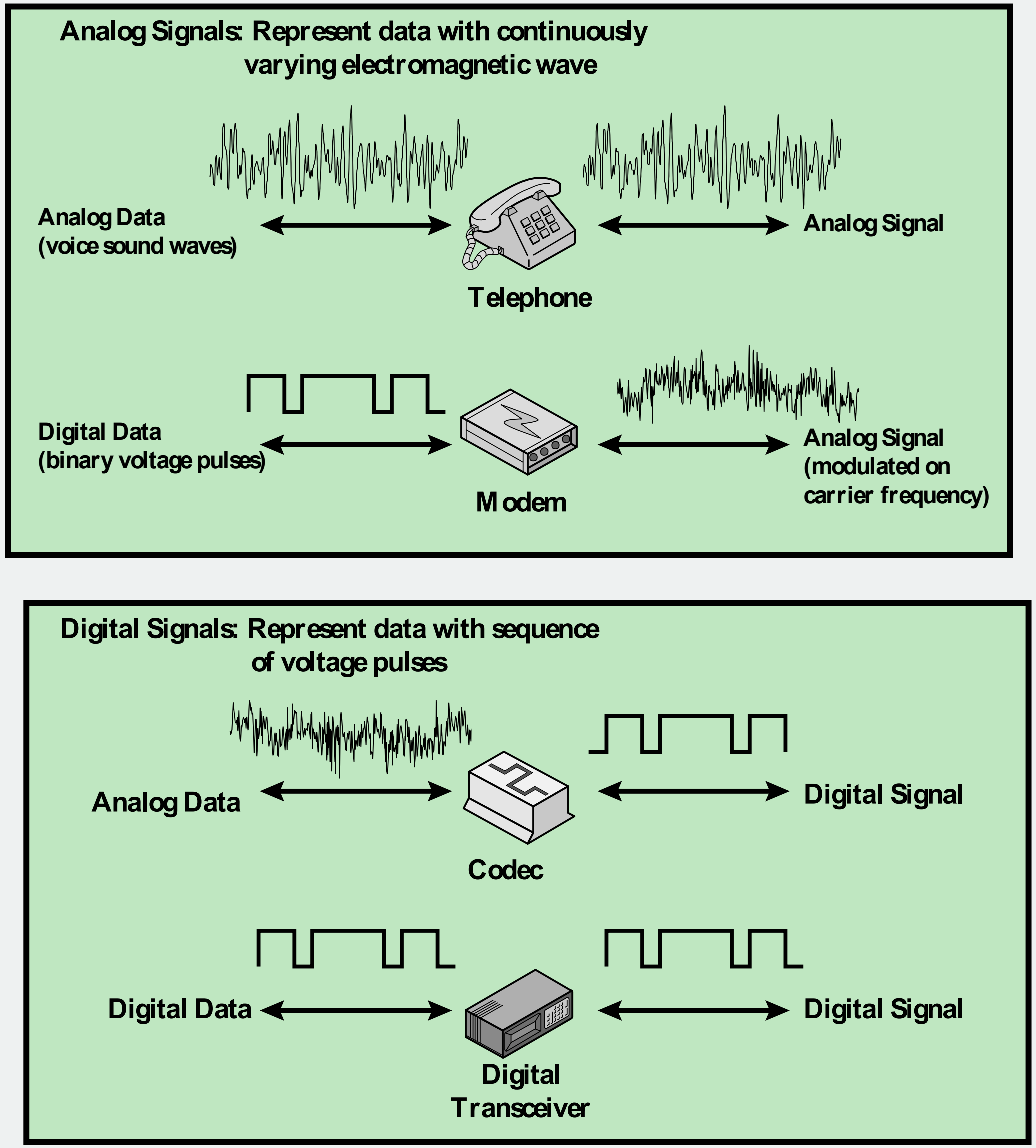



Figure 3.13 Analog and Digital Signaling of Analog and Digital Data

# Table 3.1

# 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 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 are 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. |

# Move to Digital

- Digital technology
  - LSI and VLSI technology has caused a continuing drop in the cost and size of digital circuitry
- Data integrity
  - The use of repeaters has made it possible to transmit data longer distances over lower quality lines while maintaining the integrity of the data
- Capacity utilization
  - It has become economical to build transmission links of very high bandwidth, including satellite channels and optical fiber, and a high degree of multiplexing is needed to utilize such capacity effectively
- Security and privacy
  - Encryption techniques can be readily applied to digital data and to analog data that have been digitized
- Integration
  - Economies of scale and convenience can be achieved by integrating voice, video, and digital data

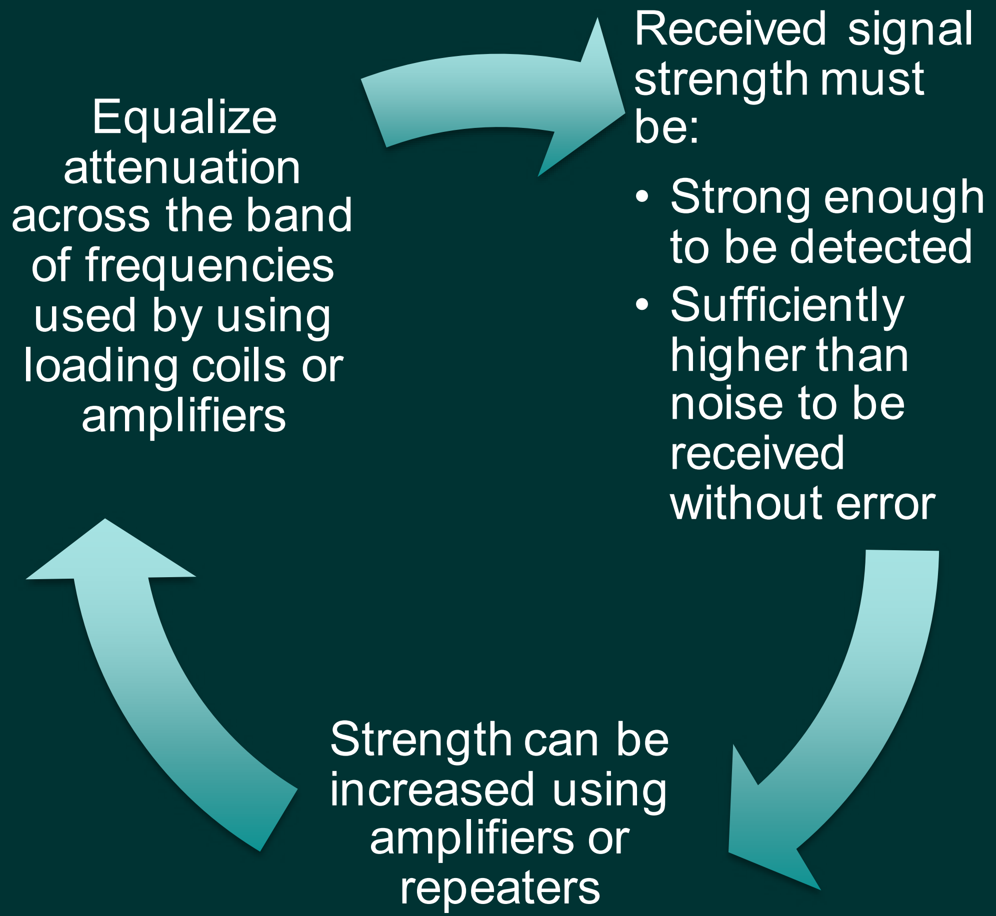
# Asynchronous and Synchronous Transmission

- Asynchronous
  - Strategy is to avoid the timing problem by not sending long, uninterrupted streams of bits
  - Data are transmitted one character at a time, where each character is 5 to 8 bits in length
  - Timing or synchronization must only be maintained within each character
  - The receiver has the opportunity to resynchronize at the beginning of each new character

- Synchronous
  - A block of bits is transmitted in a steady stream without start and stop codes
  - Block may be many bits in length
  - To prevent timing drift between transmitter and receiver, their clocks must somehow be synchronized
    - Provide a separate clock line between transmitter and receiver
    - Embed the clocking information in the data signal
  - Frame
    - Data plus preamble, postamble, and control information

# Transmission Impairments

- Signal received may differ from signal transmitted causing:
  - Analog - degradation of signal quality
  - Digital - bit errors
- Most significant impairments are
  - Attenuation and attenuation distortion
  - Delay distortion
  - Noise




# ATTENUATION

- Signal strength falls off with distance over any transmission medium
- Varies with frequency

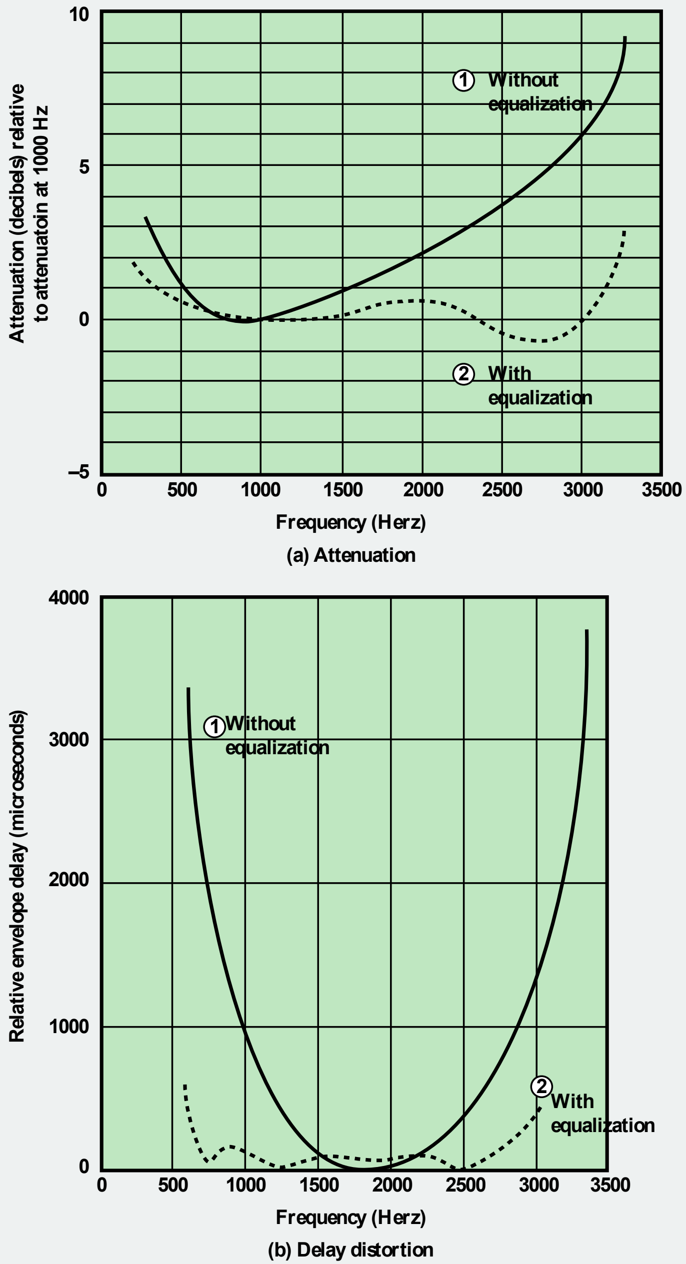



**Figure 3.14 Attenuation and Delay Distortion Curves for a Voice Channel**

# Delay Distortion

- Occurs in transmission cables such as twisted pair, coaxial cable, and optical fiber
  - Does not occur when signals are transmitted through the air by means of antennas
- Occurs because propagation velocity of a signal through a guided medium varies with frequency
- Various frequency components arrive at different times resulting in phase shifts between the frequencies
- Particularly critical for digital data since parts of one bit spill over into others causing intersymbol interference

# Noise

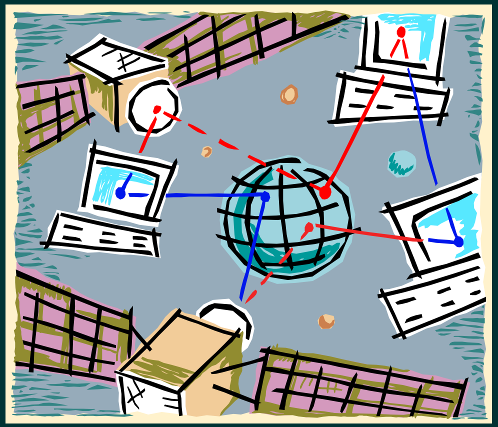
Unwanted signals inserted between transmitter and receiver

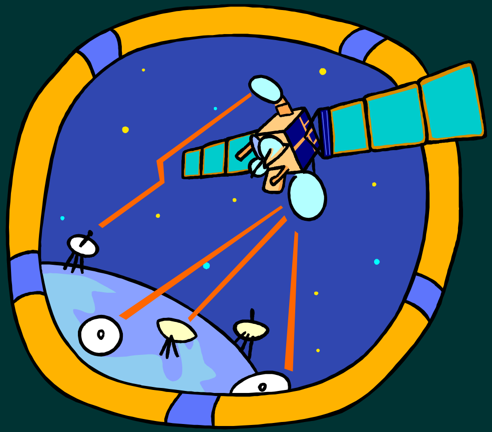
Is the major limiting factor in communications system performance

# Categories of Noise

**Thermal noise**

- Due to thermal agitation of electrons
- Uniformly distributed across bandwidths
- Referred to as white noise





**Intermodulation noise**

- Produced by nonlinearities in the transmitter, receiver, and/or intervening transmission medium
- Effect is to produce signals at a frequency that is the sum or difference of the two original frequencies

# Categories of Noise

## Impulse Noise:

- Caused by external electromagnetic interferences
- Noncontinuous, consisting of irregular pulses or spikes
- Short duration and high amplitude
- Minor annoyance for analog signals but a major source of error in digital data

## Crosstalk:

- A signal from one line is picked up by another
- Can occur by electrical coupling between nearby twisted pairs or when microwave antennas pick up unwanted signals

# Channel Capacity

**Maximum rate at which data can be transmitted over a given communications channel under given conditions**

| Data rate | Bandwidth | Noise | Error rate | | |
|---|---|---|---|---|---|
| The rate, in bits per second (bps) at which data can be communicated | The bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or hertz | The average level of noise over the communications path | The rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted | The greater the bandwidth of a facility, the greater the cost | The main constraint on achieving efficiency is noise |

# Nyquist Bandwidth

In the case of a channel that is noise free:

- The limitation of data rate is simply the bandwidth of the signal
  - If the rate of signal transmission is $2B$ then a signal with frequencies no greater than $B$ is sufficient to carry the signal rate
  - Given a bandwidth of $B$, the highest signal rate that can be carried is $2B$
- For binary signals, the data rate that can be supported by $B$ Hz is $2B$ bps
- With multilevel signaling, the Nyquist formula becomes: $C = 2B \log_2 M$
- Data rate can be increased by increasing the number of different signal elements
  - This increases burden on receiver
  - Noise and other impairments limit the practical value of $M$

# Shannon Capacity Formula

- Considering the relation of data rate, noise and error rate:
  - Faster data rate shortens each bit so bursts of noise corrupts more bits
  - Given noise level, higher rates mean higher errors
- Shannon developed formula relating these to signal to noise ratio (in decibels)
- $SNR_{db}$=10 $\log_{10}$ (signal/noise)
- Capacity $C = B \log_2(1+SNR)$
  - Theoretical maximumcapacity
  - Get much lower rates in practice

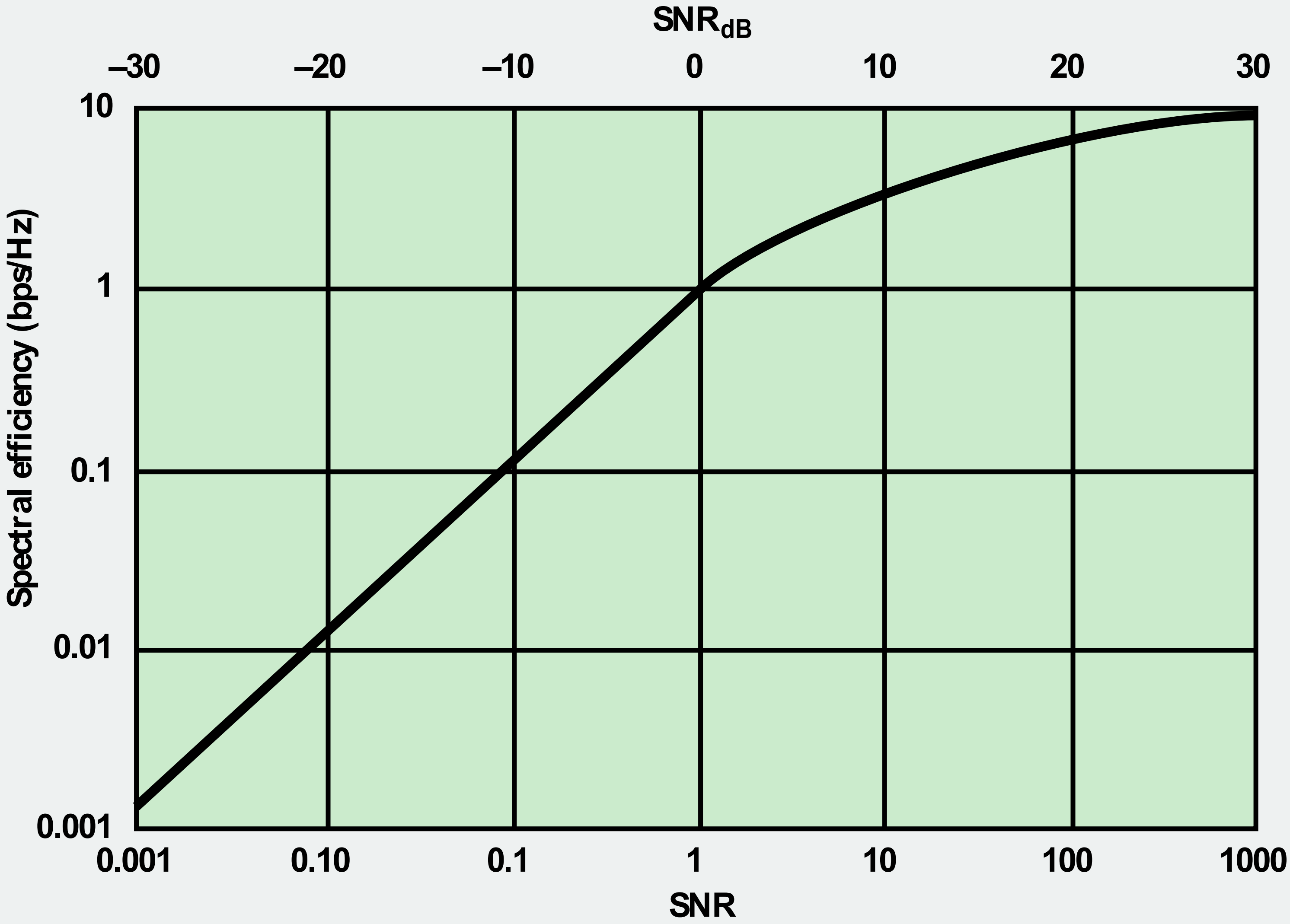



Figure 3.16 Spectral Efficiency versus SNR

# Summary

- Transmission terminology
- Frequency, spectrum, and bandwidth
- Analog and digital data transmission
  - Analog and digital data
  - Analog and digital signals
  - Analog and digital transmission
  - Asynchronous and synchronous transmission
- Transmission impairments
  - Attenuation
  - Delay distortion
  - Noise
- Channel capacity
  - Nyquist bandwidth
  - Shannon capacity formula
  - The expression $E_b/N_o$