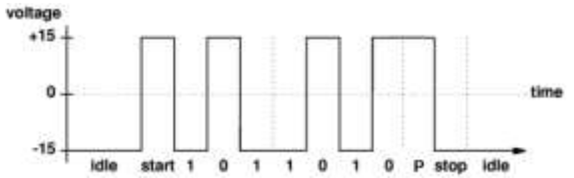
Modulation

COMP476
Networked Computer Systems

Digital Data Transmission

- Digital data is usually considered a series of binary digits.
- RS-232-C transmits data as square waves.



Analog and Digital Signals

- Data communications deals with two types of information:
  - analog
  - digital
- An analog signal is characterized by a continuous mathematical function
  - when the input changes from one value to the next, it does so by moving through all possible intermediate values
- A digital signal has a fixed set of valid levels
  - each change consists of an instantaneous move from one valid level to another

Analog and Digital Examples

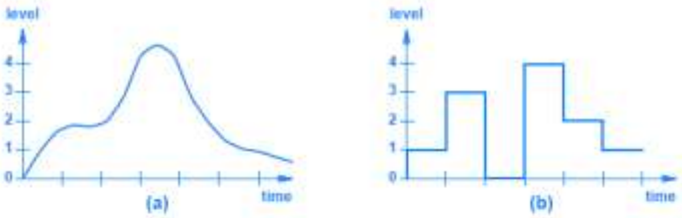
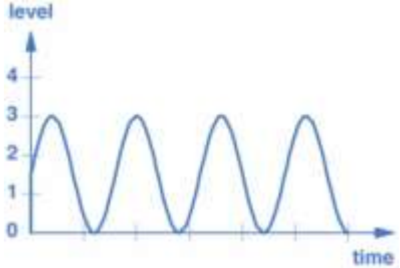


Figure 6.1 Illustration of (a) an analog signal, and (b) a digital signal.

Periodic and Aperiodic Signals

- Signals are broadly classified as
  - periodic
  - aperiodic (sometimes called nonperiodic)

classification depends on whether they repeat



Sine Waves and Signal Characteristics

- Much of the analysis in data communications involves the use of sinusoidal trigonometric functions
  - especially sine, which is usually abbreviated sin
- Sine waves are especially important in information sources
  - because natural phenomena produce sine waves
  - electromagnetic radiation can be represented as a sine wave
- We are interested in sine waves that correspond to a signal that oscillates in time

Sine Waves and Signal Characteristics

- Important characteristics of signals that relate to sine waves:
- Frequency: the number of oscillations per unit time (usually seconds) measured in Hertz (Hz)
- Amplitude: the difference between the maximum and minimum signal heights
- Phase: how far the start of the sine wave is shifted from a reference time
- Wavelength: the length of a cycle as a signal propagates
  - is determined by the speed with which a signal propagates
- These characteristics can be expressed mathematically

Sine Waves and Signal Characteristics

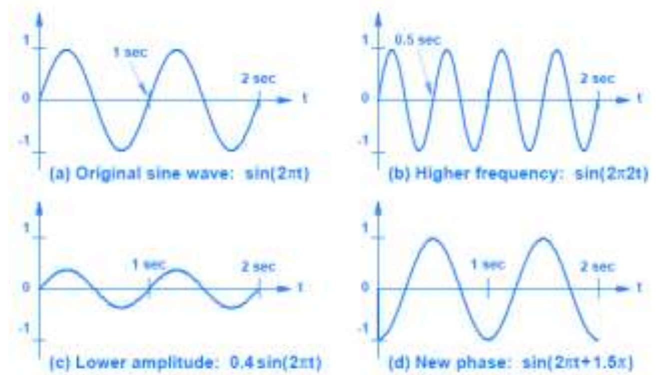
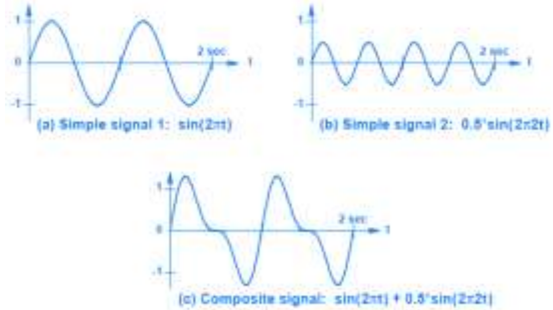


Figure 6.3 Illustration of frequency, amplitude, and phase characteristics.

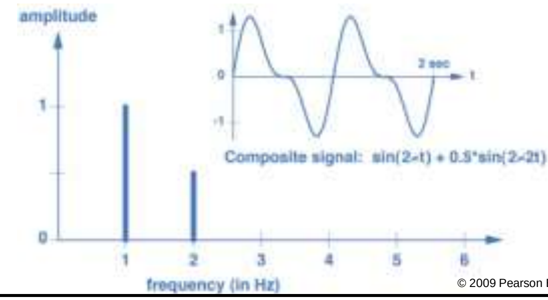
Composite Signals

- Some signals are simple because they consist of a single sine wave that cannot be decomposed further
- Most signals are classified as composite. The signal can be decomposed into a set of simple sine waves



Frequency Domain Representation

- A mathematician named Fourier discovered that it is possible to decompose a composite signal into its constituent parts, a set of sine functions, each with a frequency, amplitude, and phase
- The analysis by Fourier shows that if the composite signal is periodic, the constituent parts will also be periodic



Bandwidth of an Analog Signal

- We define the bandwidth of an analog signal to be the difference between the highest and lowest frequencies of the constituent parts (the highest and the lowest frequencies obtained by Fourier analysis)

Bandwidth of an Analog Signal

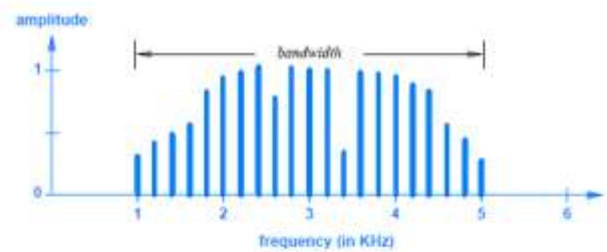


Figure 6.7 A frequency domain plot of an analog signal with a bandwidth of 4 KHz.

Sine Waves vs. Square Waves

- Sine waves propagate better than square waves
- A square wave with perfectly vertical sides is actually impossible
- An immediate voltage change in zero time requires and infinite amount of energy.

Fourier Series

- A square wave can be considered the infinite sum of sin * cos products.

$$\sum_{i}^{\infty} a_i \sin(t) * b_i \cos(t)$$

The square wave is built from many harmonics or sine waves at higher frequencies.

Harmonics

- You may be familiar with harmonics from the world of music.
- If a piano and a flute play the note B flat, it sounds different even though it is the same note.
- Each instrument has different intensities for the different harmonics.
- Music does not sound very good over a telephone line because it filters the higher harmonics.

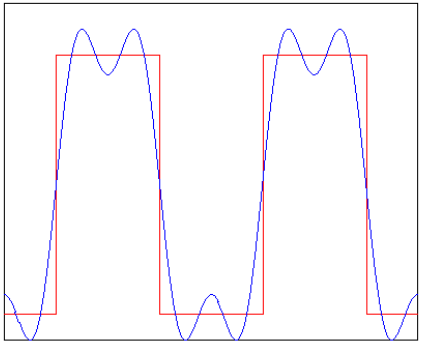
Sums of Harmonics

- A square wave is an infinite sum of sine and cosine wave harmonics.
- With unlimited bandwidth, you can transmit all of the harmonics for a square wave and it will appear square.
- A bandwidth limited channel (i.e. phone line) filters the higher frequencies or harmonics.
- Limited bandwidth distorts the wave.

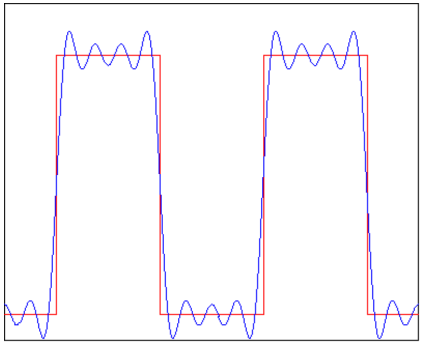
Square waves over bandwidth limited channels

- Without the higher frequencies, the wave no longer looks like a square wave.
- This makes it difficult for the receiver to determine the actual bit value.

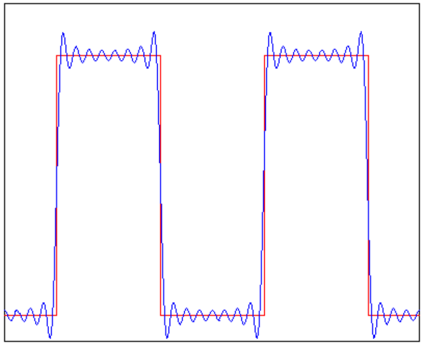
Square Wave with 4 Harmonics



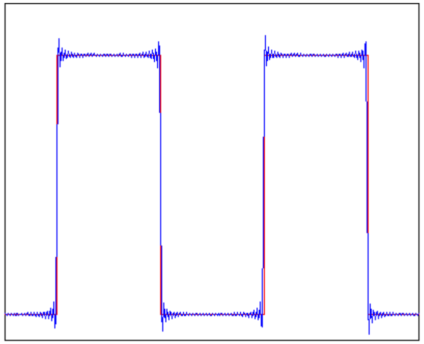
Square Wave with 8 Harmonics



Square Wave with 16 Harmonics



Square Wave with 64 Harmonics



Sine Wave Transmission

- To avoid the problems with square waves, sine waves can be used.
- Sine waves are the sum of only one harmonic.
- No higher frequencies need to be sent.
- Sine waves can be sent exactly over a limited bandwidth channel.

Modulating Sine Waves

- A sine wave's properties (such as amplitude, frequency or phase shift) can be varied or modulated to represent different values.
- A device that modulates and demodulates the transmitted sine wave is called a **mo**dulator-**dem**odulator or **modem**.
- There are different modulation techniques.

Waves are States

- The Nyquist formula uses the number of different states

  max data rate(bits/sec) = $2 * B * \log_2 V$
- A state can be any different signal
  - voltage
  - wave amplitude, frequency, phase
  - color

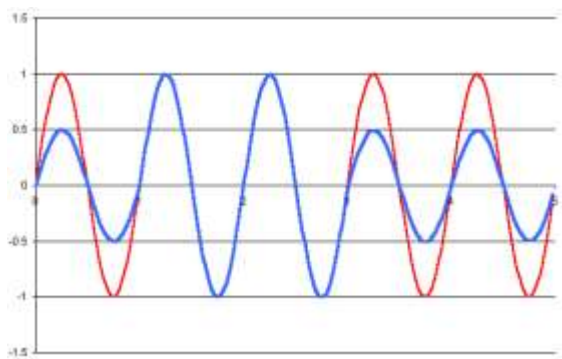
Modulation Examples

- In the following modulation diagrams, each represents the transmission of five values where a value is transmitted **during one wavelength**.
- Each diagram shows the transmission of **01100**
- The **red** waveform represents the unmodulated frequency while the **blue** waveform represents the wave that would actually be sent.

Amplitude Modulation

- Different values can be sent by varying the amplitude or energy level (loudness) of the sine wave.
- A 0 bit might be represented by a wave that has half the energy or height in the graph.
- A 1 bit might be represented by a full sized wave.

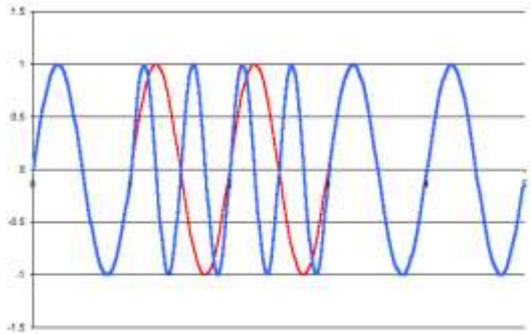
Amplitude Modulation



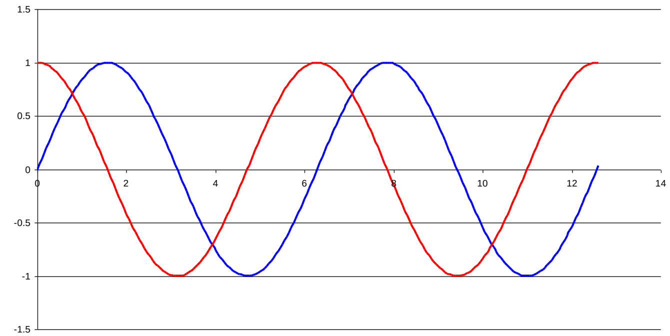
Frequency Modulation

- Different values can be sent by varying the frequency or pitch of the sine wave.
- A 0 bit might be represented by a low frequency wave.
- A 1 bit might be represented by a high frequency wave.

Frequency Modulation

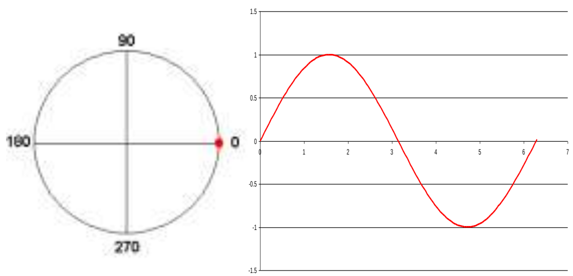


Wave Phase



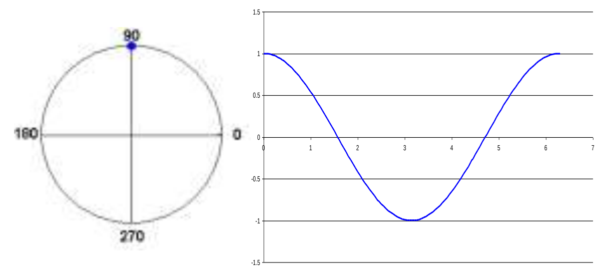
Both waves have the same amplitude and the same frequency, but different phases.

Wave Defined by Unit Circle



The sine wave is defined by the Y axis position of a point moving counterclockwise around a circle.

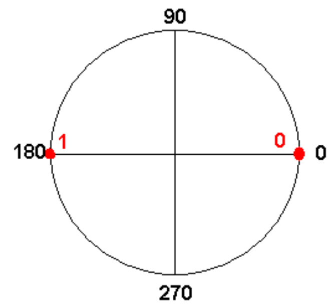
Wave From Different Start



Phase Shift Modulation

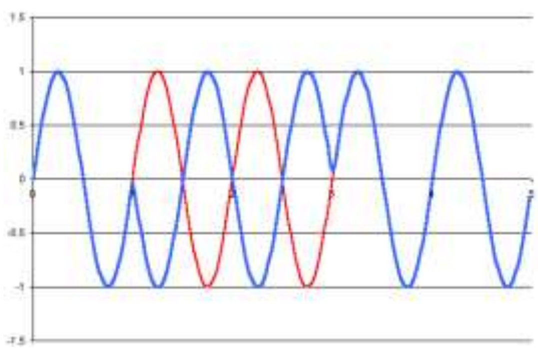
- Different values can be sent by varying the phase of the sine wave.
- The phase is determined by the starting position of the wave.
- A 0 bit might be represented by an unchanged wave.
- A 1 bit might be represented by a wave shifted by 180° (mirror image or original).

2 Value Phase Shift Modulation

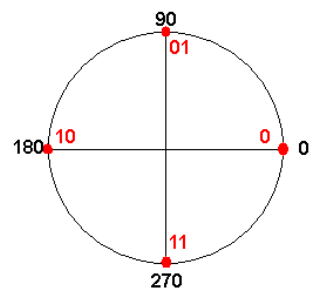


- Data values can be represented as points on a unit circle
- A 0 bit is shifted 0°
- A 1 bit is shifted 180°

Phase Shift Modulation



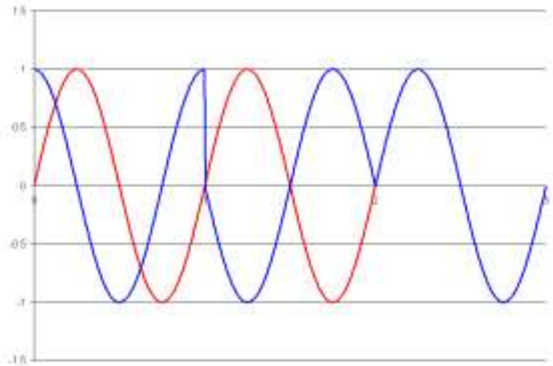
4 Value Phase Shift Modulation



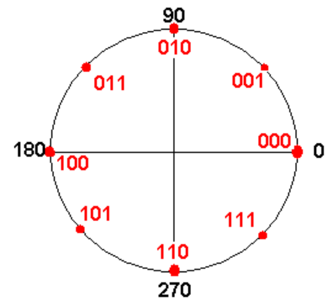
- Each signal represents 2 bits.
- 00 is shifted 0°
- 01 bit is shifted 90°
- 10 bit is shifted 180°
- 11 bit is shifted 270°

4 Value Phase Shift Modulation

01 10 00



8 Value Phase Shift Modulation

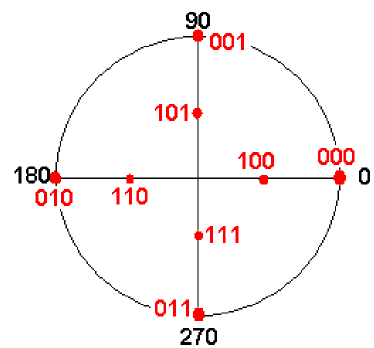


- Each signal represents 3 bits.

Quadrature Amplitude Modulation

- Different modulation techniques can be combined to generate more unique states.
- Quadrature Amplitude Modulation (QAM) combines amplitude and phase shift modulation.

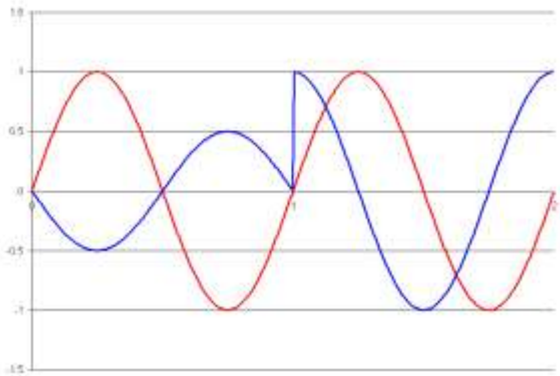
Quadrature Amplitude Modulation



- There are 4 frequencies and 2 amplitudes
- Points closer to the center have low amplitude.
- Outer points have high amplitude

Quadrature Amplitude Modulation

110 001



What bits are being sent?