BLG 337E- Principles of Computer Communications

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-Physical Layer(2)-

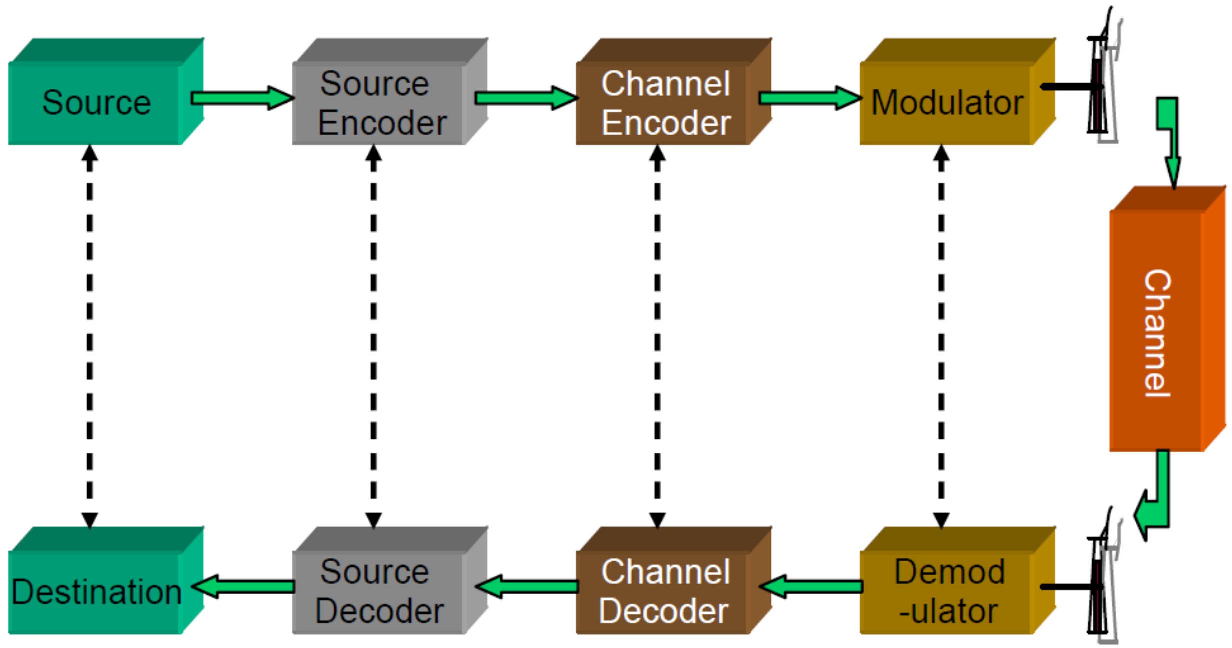
References:

Data and Computer Communications, William Stallings, Pearson-Prentice Hall, 9th Edition, 2010.

-*Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

-Google!

Modulation


Source
Source Encoder
Channel Encoder
Modulator
Channel
Demod -ulator
Channel Decoder
Source Decoder
Destination

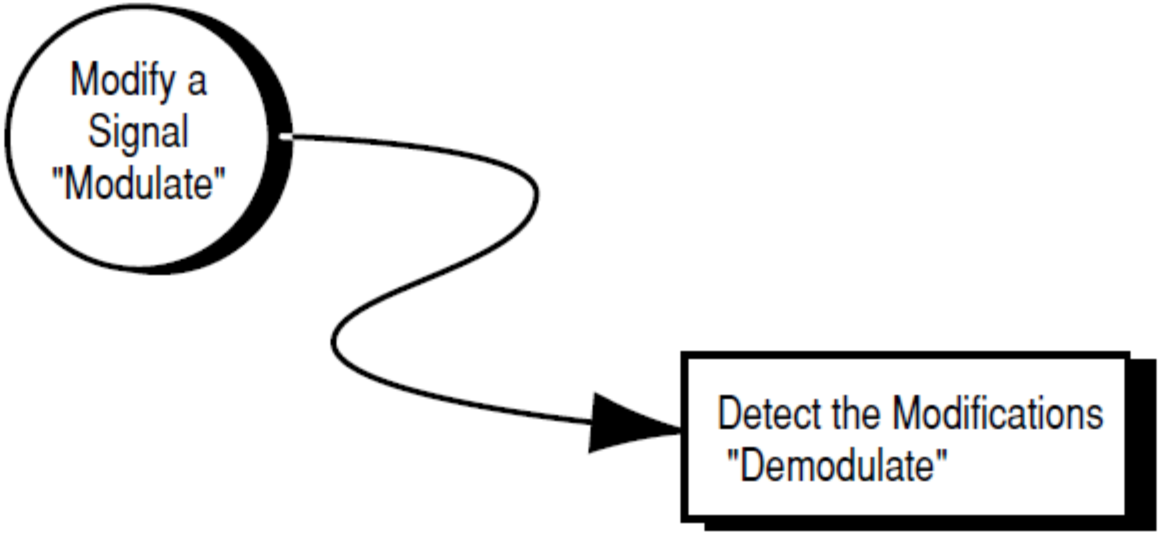
- Channel Capacity (C)
  - the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions
- Data rate (bps)
  - rate at which data can be communicated , impairments, such as noise, limit data rate that can be achieved
- Bandwidth (B)
  - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- Noise (N)
  - impairments on the communications path
- Error rate - rate at which errors occur (BER)
  - Error = transmit 1 and receive 0; transmit 0 and receive 1

Reasons for choosing encoding techniques

- Digital data, digital signal
  - Equipment less complex and expensive than digital-to-analog modulation equipment
- Analog data, digital signal
  - Permits use of modern digital transmission and switching equipment
- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - E.g., unguided media (air)
- Analog data, analog signal
  - Analog data in electrical form can be transmitted easily and cheaply
  - E.g., AM Radio

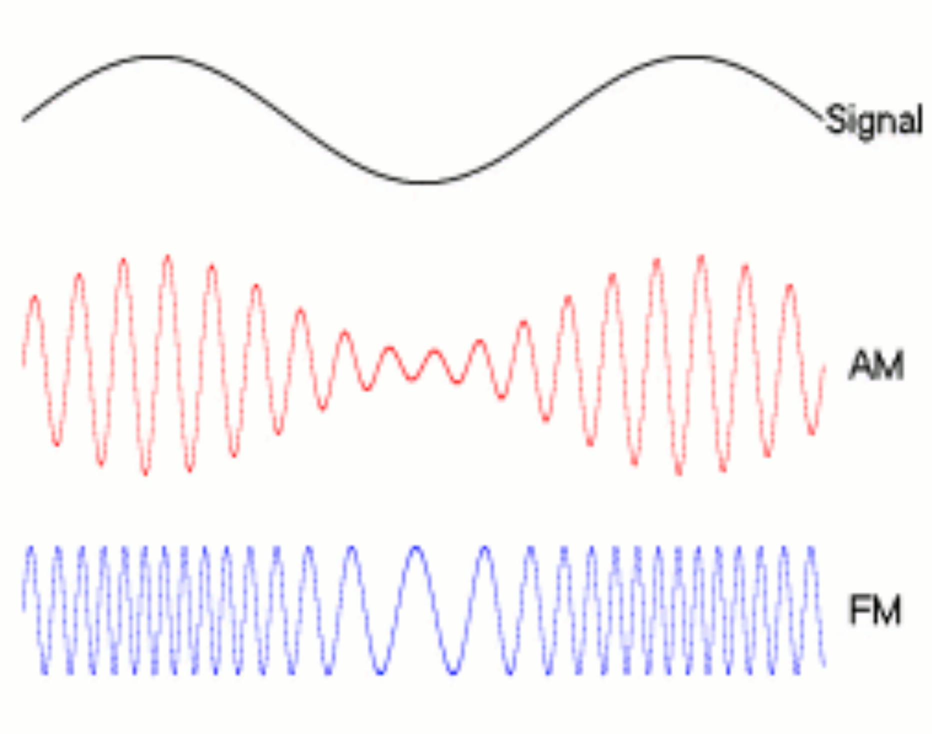
What is modulation ?

- Modulation = Adding information to a carrier signal
- The sine wave on which the characteristics of the information signal are modulated is called a carrier signal

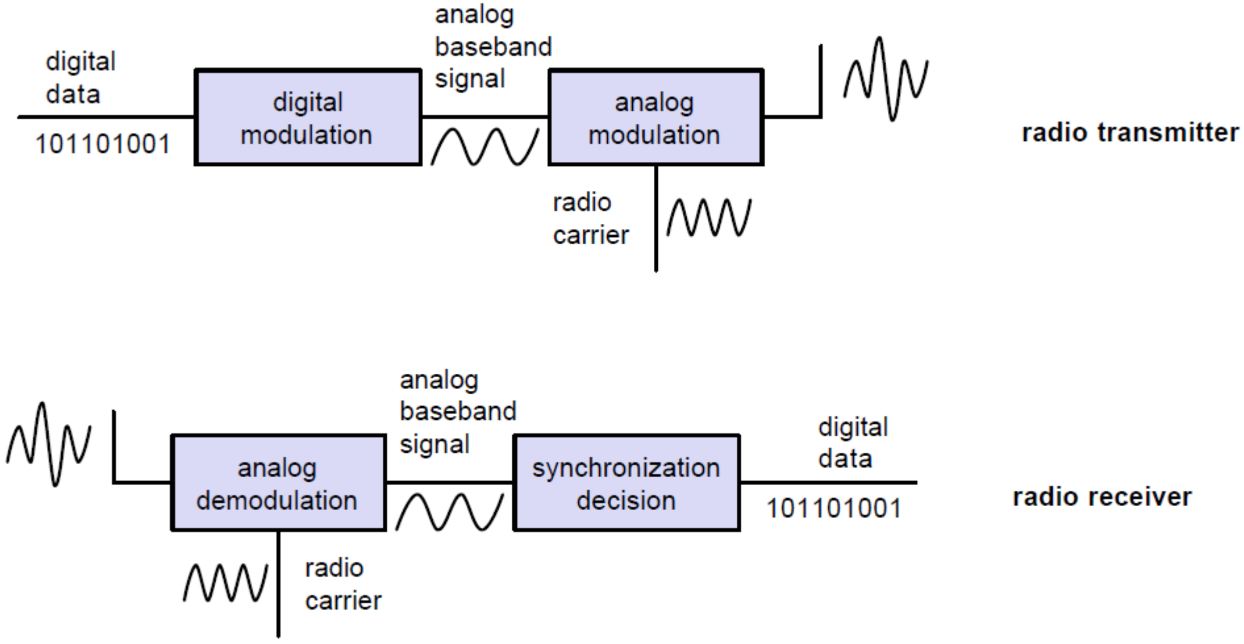


Any reliably detectable change in signal characteristics can carry information

Analog modulation



Digital modulation and demodulation



Baseband Transmission

Digital transmission is the transmission of electrical pulses. Digital information is binary in nature in that it has only two possible states 1 or 0. Sequences of bits encode data (e.g., text characters).

Digital signals are commonly referred to as <u>baseband signals</u>.

In order to successfully send and receive a message, both the sender and receiver have to agree how often the sender can transmit data (<u>data rate</u>).

<u>Data rate</u> often called <u>bandwidth</u> – but there is a different definition of bandwidth referring to the frequency range of a signal!

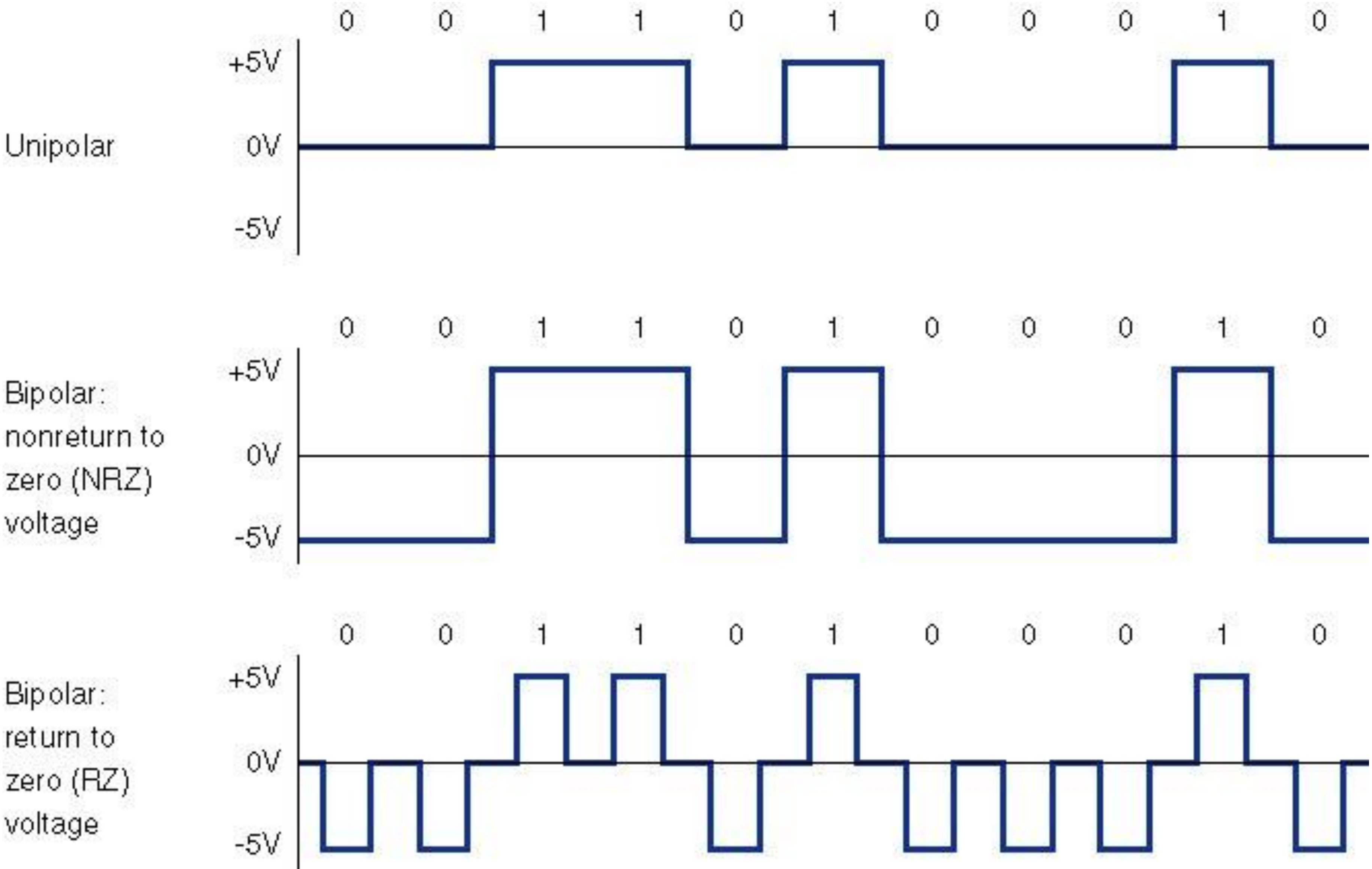
Baseband Transmission

With unipolar signaling techniques, the voltage is always positive or negative (like a dc current).

In bipolar signaling, the 1's and 0's vary from a plus voltage to a minus voltage (like an ac current).

In general, bipolar signaling experiences fewer errors than unipolar signaling because the signals are more distinct.

Baseband Transmission

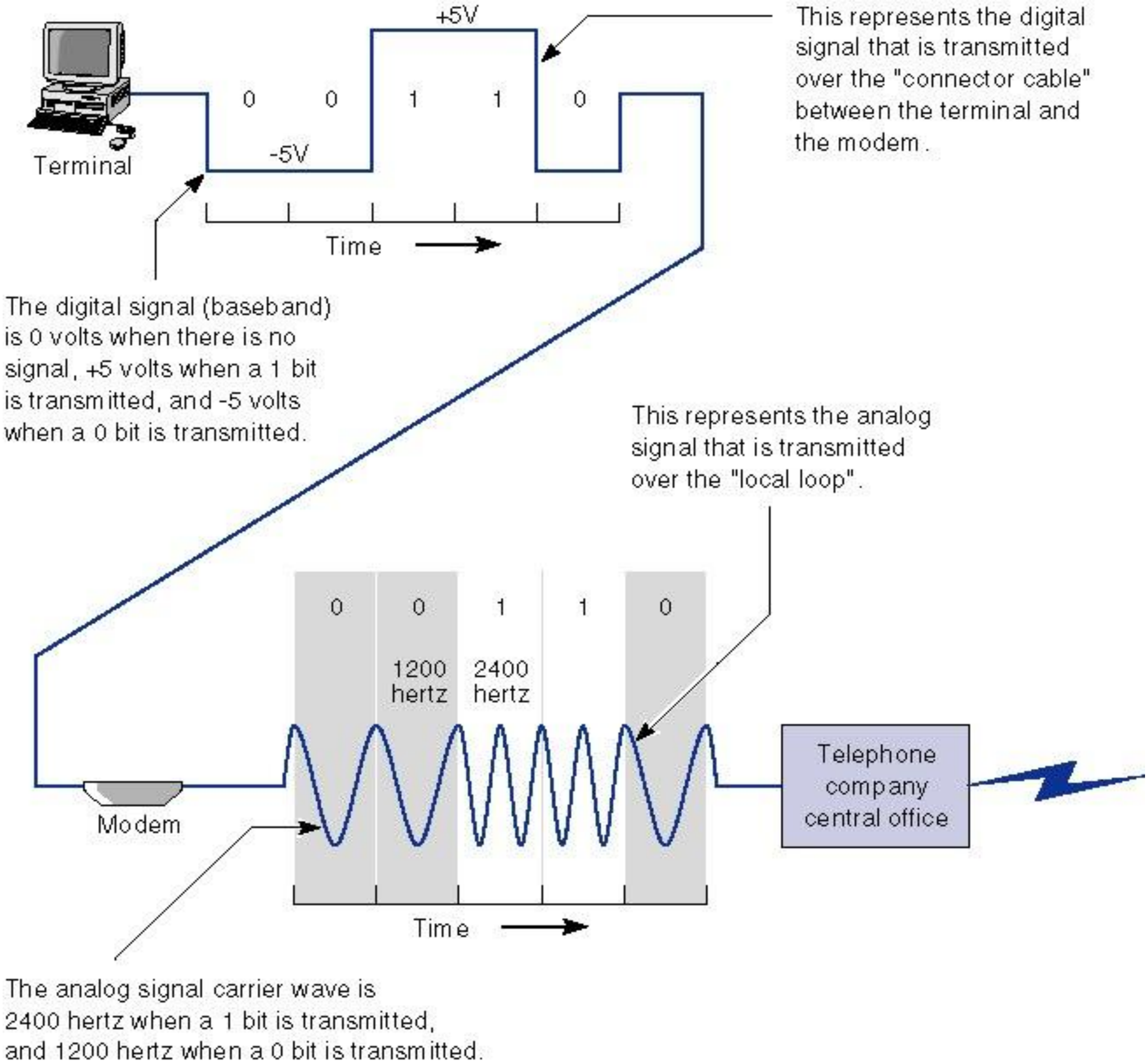


ANALOG TRANSMISSION OF DIGITAL DATA

Analog Transmission occurs when the signal sent over the transmission media continuously varies from one state to another in a wave-like pattern.

e.g. telephone networks, originally built for human speech rather than data.

Advantage for long distance communications: much less attenuation for analog carrier than digital

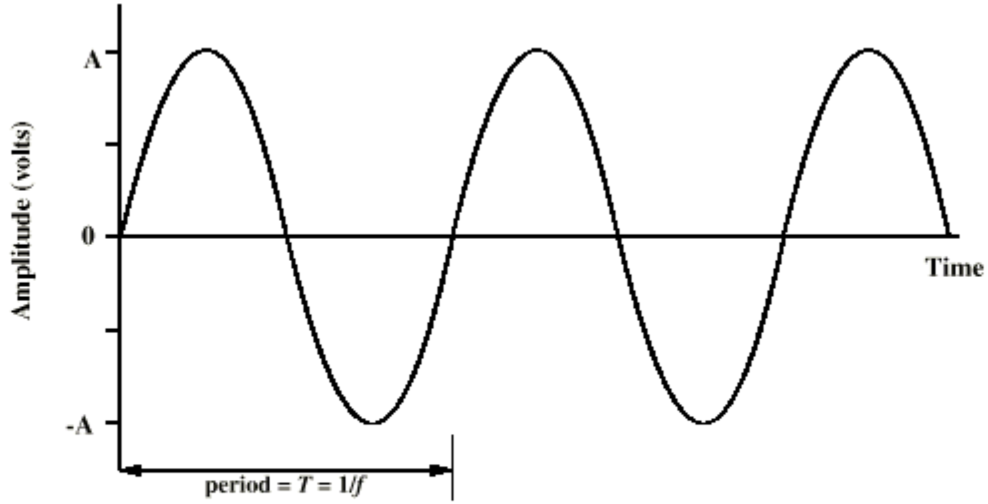


+5V
This represents the digital signal that is transmitted over the "connector cable" between the terminal and the modem.
0
0
1
1
0
-5V
Terminal
Time
The digital signal (baseband) is 0 volts when there is no signal, +5 volts when a 1 bit is transmitted, and -5 volts when a 0 bit is transmitted.
This represents the analog signal that is transmitted over the "local loop".
0
0
1
1
0
1200 hertz
2400 hertz
Telephone company central office
Modem
Time
The analog signal carrier wave is 2400 hertz when a 1 bit is transmitted, and 1200 hertz when a 0 bit is transmitted.

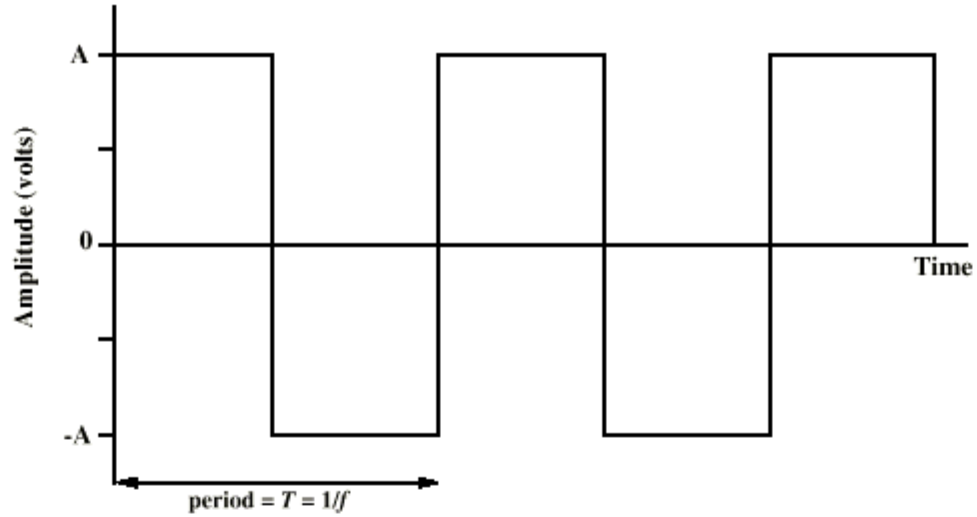
Digital Data to Analog Transmission

Before we get further into Analog to Digital, we need to understand various characteristics of analog transmission.

Periodic Signals



(a) Sine wave



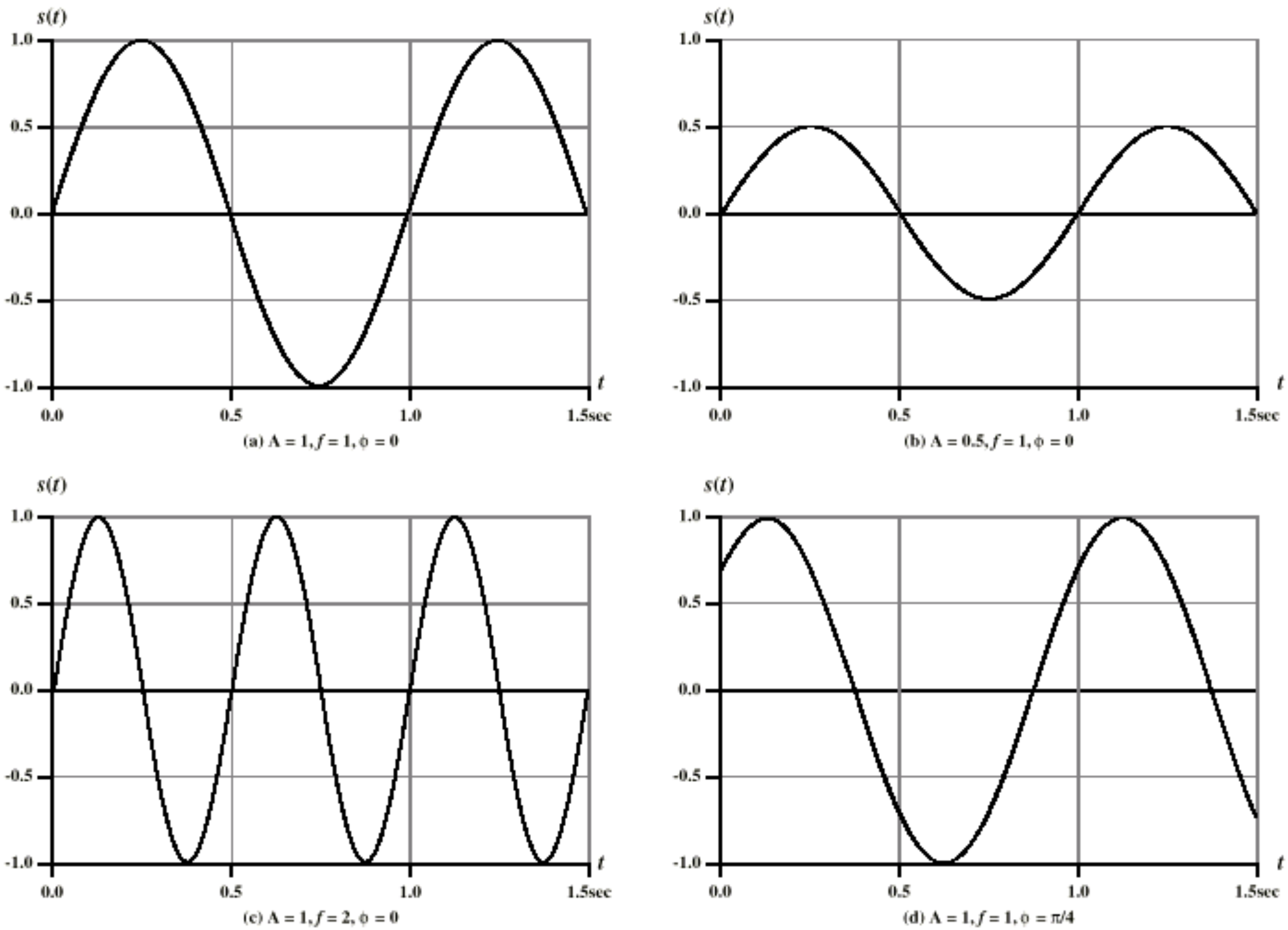
(b) Square wave

Sine Wave

- Peak Amplitude (A)
  - maximum strength of signal
  - volts
- Frequency (f)
  - Rate of change of signal
  - Hertz (Hz) or cycles per second
  - Period = time for one repetition (T)
  - T = 1/f
- Phase (ϕ)
  - Relative position in time, from 0-2*pi
- General Sine wave

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

Varying Sine Waves



Wavelength

- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
- λ = Wavelength
- Assuming signal velocity *v*
  - $\lambda = vT$
  - $\lambda f = v$
  - $c = 3*10^8\ ms^{-1}$ (speed of light in free space)

Frequency Domain Concepts

- Signal usually made up of many frequencies
- Components are sine (or cosine) waves
- Can be shown (Fourier analysis) that any continuous signal is made up of component sine waves
- Can plot frequency domain functions

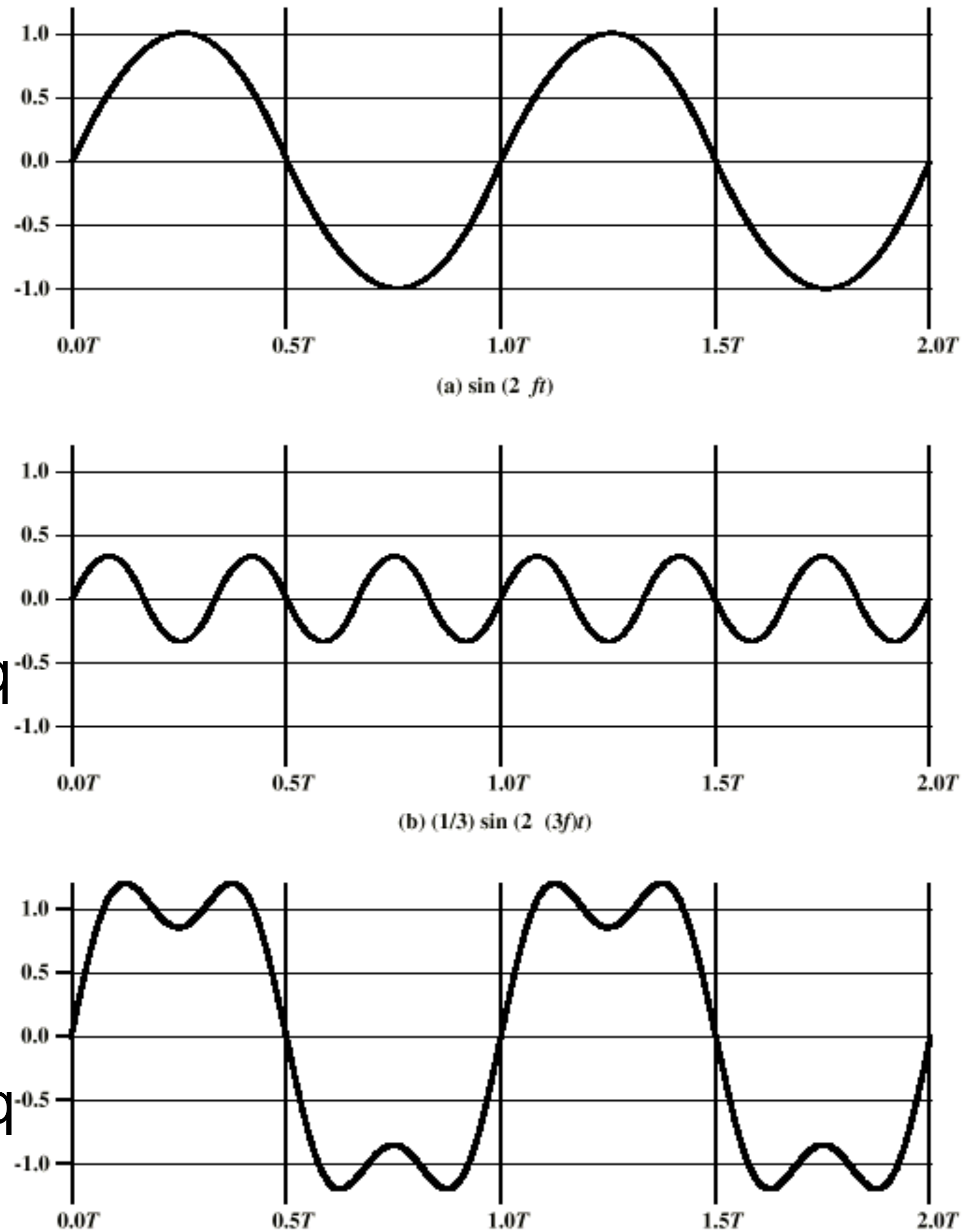
Addition of Frequency Components

Notes:

2nd freq a multiple of 1st
1st called fundamental freq
Others called harmonics

Period of combined =
Period of the fundamental

Fundamental = carrier freq



(a) sin (2 ft)

(b) (1/3) sin (2 (3f)t)

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

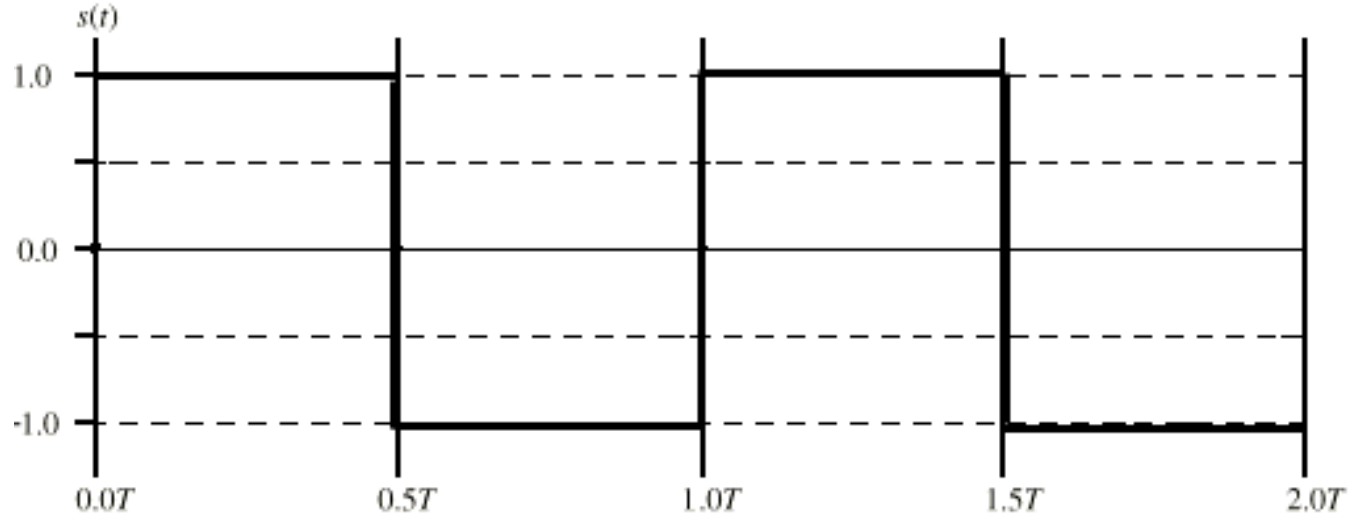
Data Rate and Bandwidth

- Any transmission system has a limited band of frequencies
- This limits the data rate that can be carried

- Spectrum
  - range of frequencies contained in signal
- Absolute bandwidth
  - width of spectrum
- Effective bandwidth
  - Often just *bandwidth*
  - Narrow band of frequencies containing most of the energy

Example of Data Rate/Bandwidth

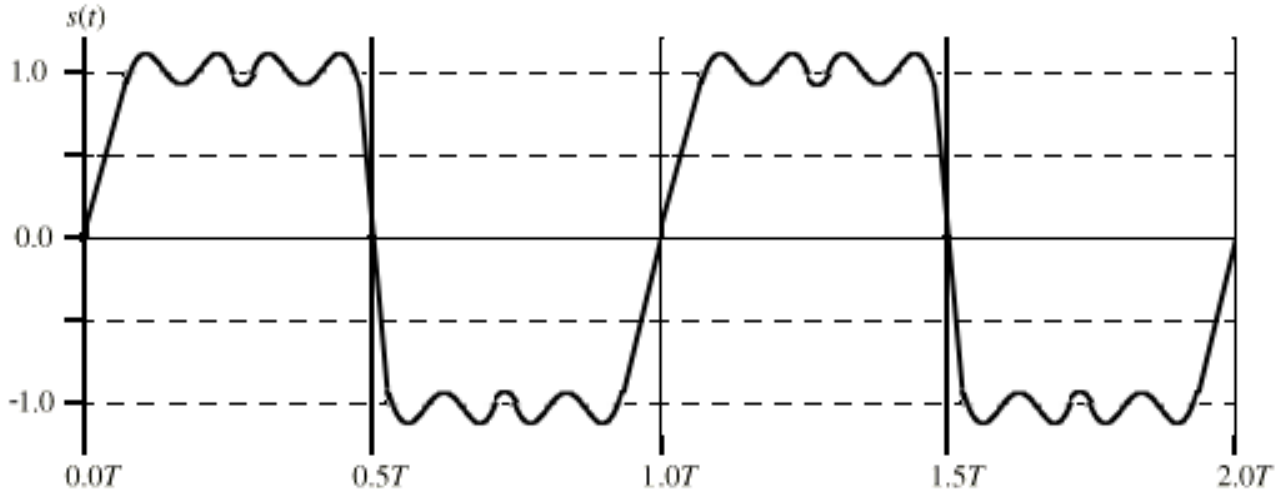
Want to transmit:



Let's say that f=1Mhz or 10^6 cycles/second, so T= 1microsecond

Let's approximate the square wave with a few sine waves:

Ex(1): Sine Wave 1

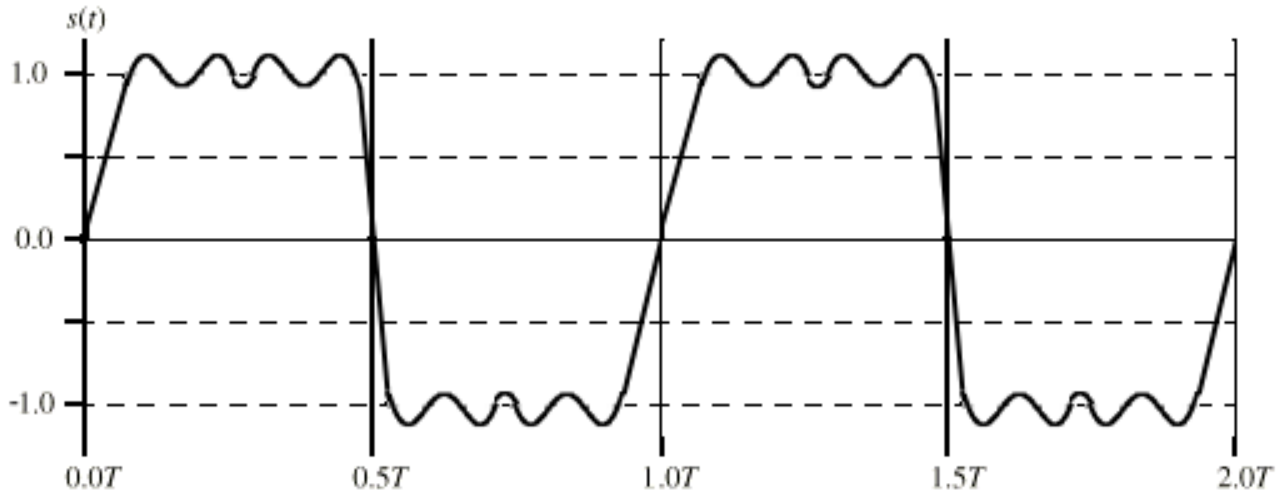


$$s(t) = 4/\pi[\sin(2\pi ft) + 1/3\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$$

Bandwidth=5f-f =4f
If f=1Mhz, then the bandwidth = 4Mhz

T=1 microsecond; we can send two bits per microsecond so the data rate = $2 * 10^6$ = 2Mbps

Ex(2): Sine Wave 1, Higher freq



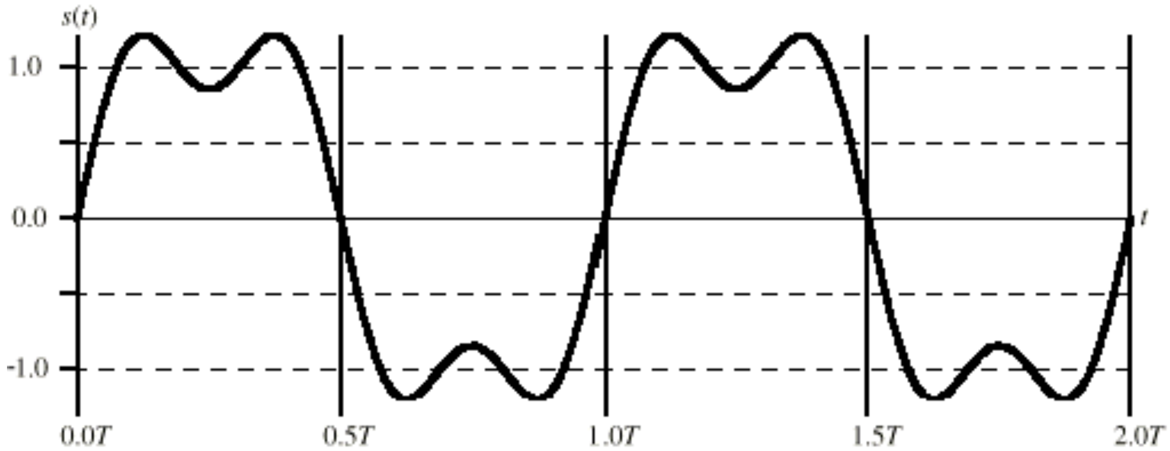
$$s(t) = 4/\pi[\sin(2\pi ft) + 1/3\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$$

Bandwidth=5f-f =4f
If f=2Mhz, then the bandwidth = 8Mhz

T=0.5 microsecond; we can send two bits per 0.5 microseconds or 4 bits per microsecond, so the data rate = 4 * 10^6 = 4Mbps

Double the bandwidth, double the data rate!

Ex(3): Sine Wave 2



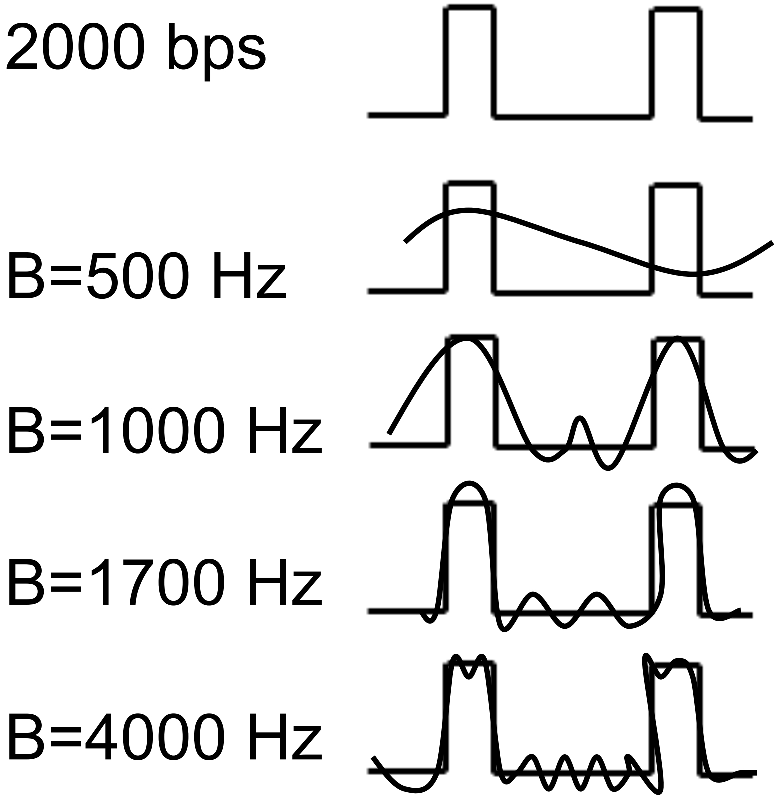
$$s(t) = 4/\pi[\sin(2\pi ft) + 1/3\sin(2\pi(3f)t)]$$

Bandwidth=3f-f =2f
If f=2Mhz, then the bandwidth = 4Mhz

T=0.5 microsecond; we can send two bits per 0.5 microseconds or 4 bits per microsecond, so the data rate = $4 * 10^6$ = 4Mbps

Still possible to get 4Mbps with the "lower" bandwidth, but our receiver must be able to discriminate from more distortion!

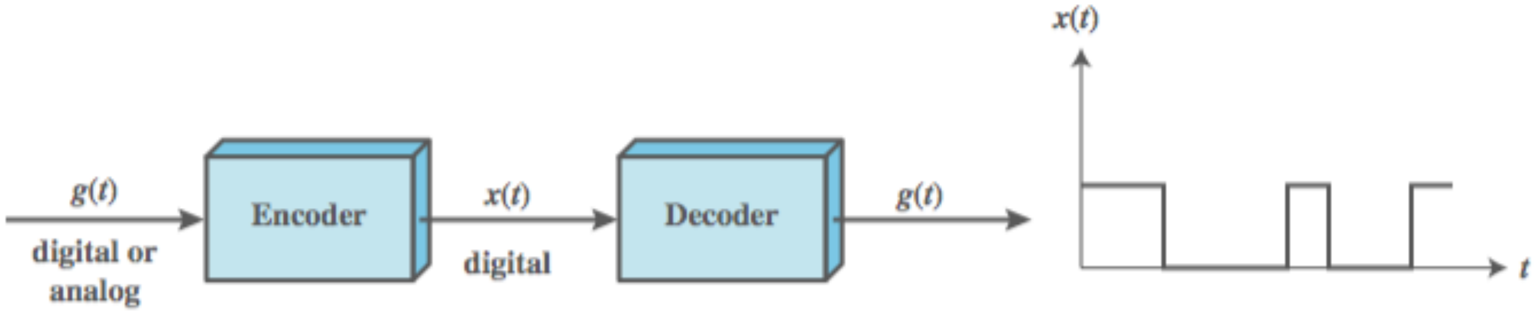
Bandwidth / Representation



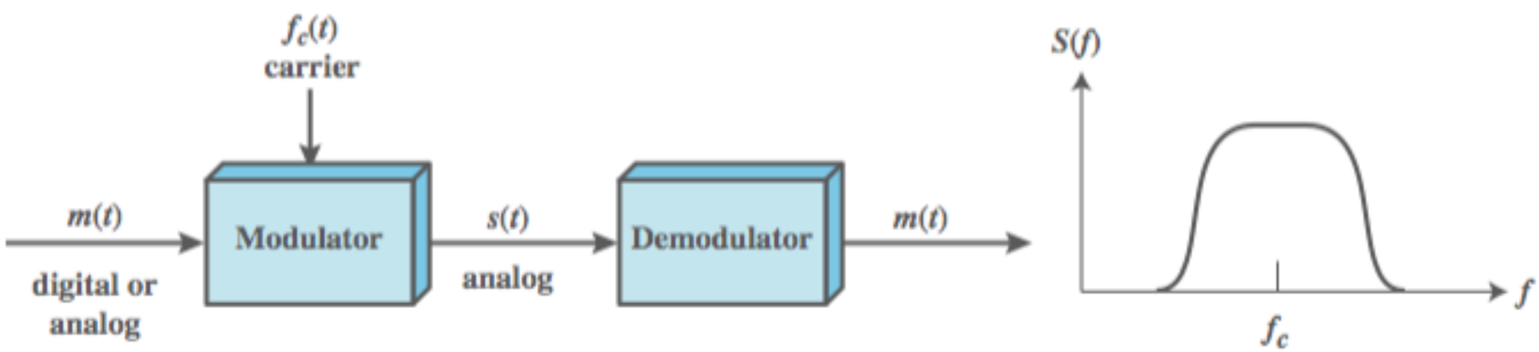
Increasing bandwidth improves the representation of the data signal.

500Hz too low to reproduce the signal. Want to maximize the capacity of the available bandwidth.

Encoding and Modulation Techniques



(a) Encoding onto a digital signal



(b) Modulation onto an analog signal

Encoding and Modulation Techniques

Digital Signaling Versus Analog Signaling

- **Digital signaling**
  - **Digital or analog data** is encoded into a digital signal
  - Encoding may be chosen to conserve bandwidth or to minimize error
- **Analog Signaling**
  - **Digital or analog data** modulates analog carrier signal
  - The frequency of the carrier fc is chosen to be compatible with the transmission medium used
  - Modulation: the amplitude, frequency or phase of the carrier signal is varied in accordance with the modulating data signal
  - by using different carrier frequencies, multiple data signals (users) can share the same transmission medium

Digital Signaling

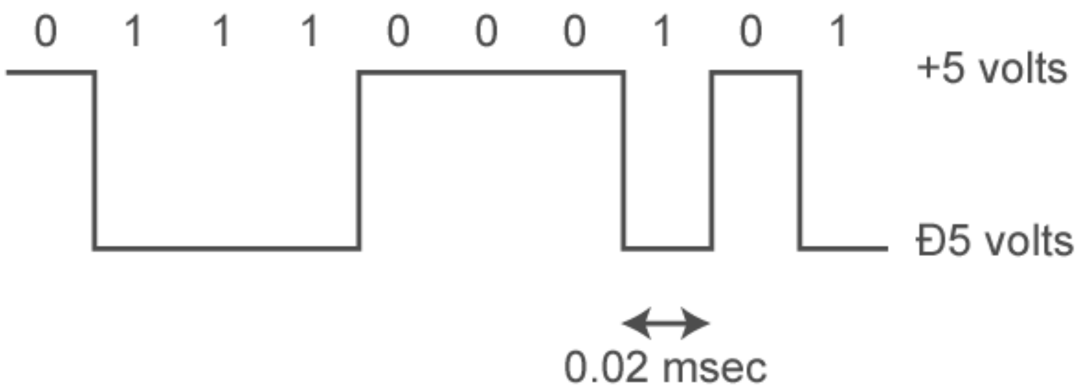
- **Digital data, digital signal**
  - Simplest encoding scheme: assign one voltage level to binary one and another voltage level to binary zero
  - More complex encoding schemes: are used to improve performance (reduce transmission bandwidth and minimize errors).
  - Examples are NRZ-L, NRZI, Manchester, etc.
- **Analog data, Digital signal**
  - Analog data, such as voice and video
  - Often digitized to be able to use digital transmission facility
  - Example: Pulse Code Modulation (PCM), which involves **sampling** the analog data periodically and **quantizing** the samples

Analog Signaling

- **Digital data, Analog Signal**
  - A modem converts digital data to an analog signal so that it can be transmitted over an analog line
  - The digital data modulates the amplitude, frequency, or phase of a carrier analog signal
  - Examples: Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK)
- **Analog data, Analog Signal**
  - Analog data, such as voice and video modulate the amplitude, frequency, or phase of a carrier signal to produce an analog signal in a different frequency band
  - Examples: Amplitude Modulation (AM), Frequency Modulation (FM), Phase Modulation (PM)

Digital Data, Digital Signal

- Digital signal
  - discrete, discontinuous voltage pulses
  - each pulse is a signal element
  - binary data encoded into signal elements



Periodic signals

- **Data element:** a single binary 1 or 0
- **Signal element:** a voltage pulse of constant amplitude
- **Unipolar:** All signal elements have the same sign
- **Polar:** One logic state represented by positive voltage the other by negative voltage
- **Data rate:** Rate of data (R) transmission in bits per second
- **Duration or length of a bit:** Time taken for transmitter to emit the bit (T_b=1/R)
- **Modulation rate:** Rate at which the signal level changes, measured in baud = signal elements per second. Depends on type of digital encoding used.

Bits Rate Versus Baud Rate Versus Symbol Rate

The terms <u>bit rate</u> (the number of bits per second) and <u>baud rate</u> are used incorrectly much of the time. They are not the same.

A bit is a unit of information, a baud is a unit of signaling speed, the number of times a signal on a communications circuit changes. ITU-T now recommends the term baud rate be replaced by the term <u>symbol rate</u>.

Bits Rate Versus Baud Rate Versus Symbol Rate

The bit rate and the symbol rate (or baud rate) are the same only when one bit is sent on each symbol. If we use QAM or TCM, the bit rate would be several times the baud rate.

Interpreting Signals

- Need to know
  - timing of bits: when they start and end
  - signal levels: high or low
- factors affecting signal interpretation
  - Data rate: increase data rate increases Bit Error Rate (BER)
  - Signal to Noise Ratio (SNR): increase SNR decrease BER
  - Bandwidth: increase bandwidth increase data rate
  - encoding scheme: mapping from data bits to signal elements

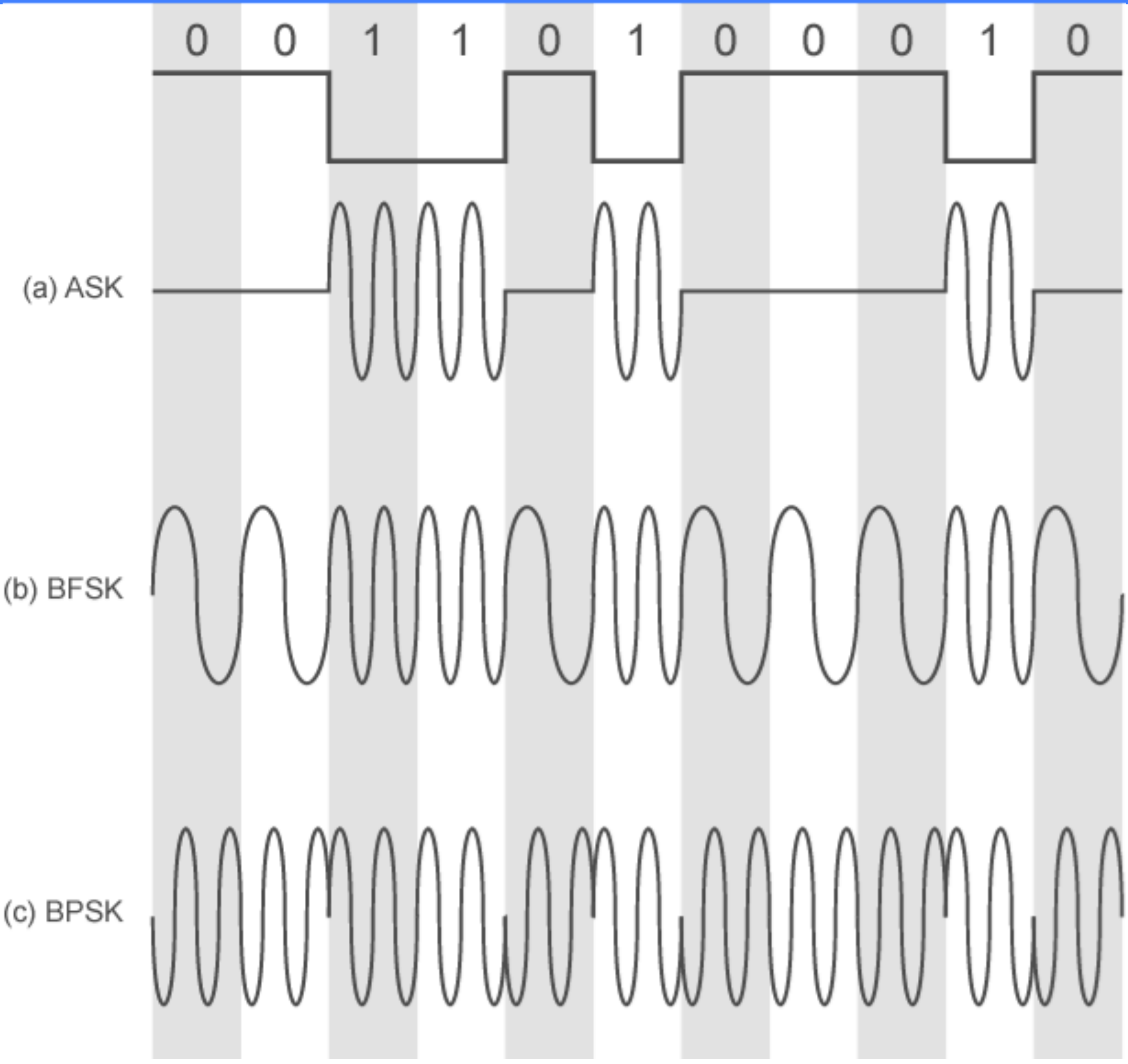
Digital Data, Analog Signal

- Main use is public telephone system
  - has freq range of 300Hz to 3400Hz
  - use modem (modulator-demodulator)
- The digital data modulates the amplitude A, frequency f_c, or phase θ of a carrier signal

$$A\cos(2\pi f_c t + \theta)$$

- Modulation techniques
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)

Modulation Techniques



Amplitude Shift Keying (ASK)

Binary Frequency Shift Keying (BFSK)

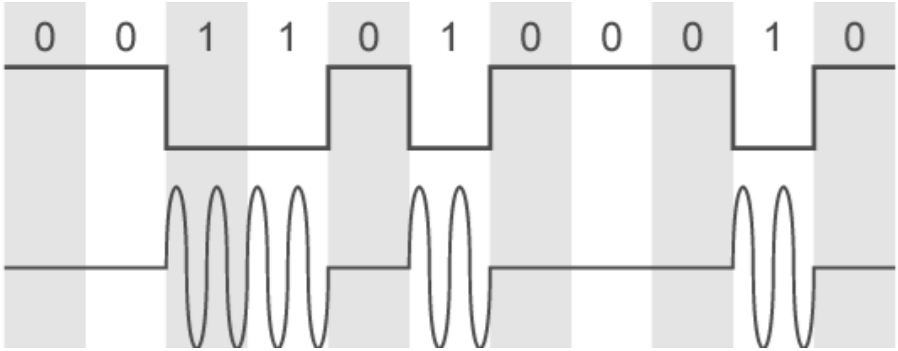
Binary Phase Shift Keying (BPSK)

Amplitude Shift Keying (ASK)

- In ASK, the two binary values are represented by to different amplitudes of the carrier frequency
- The resulting modulated signal for one bit time is

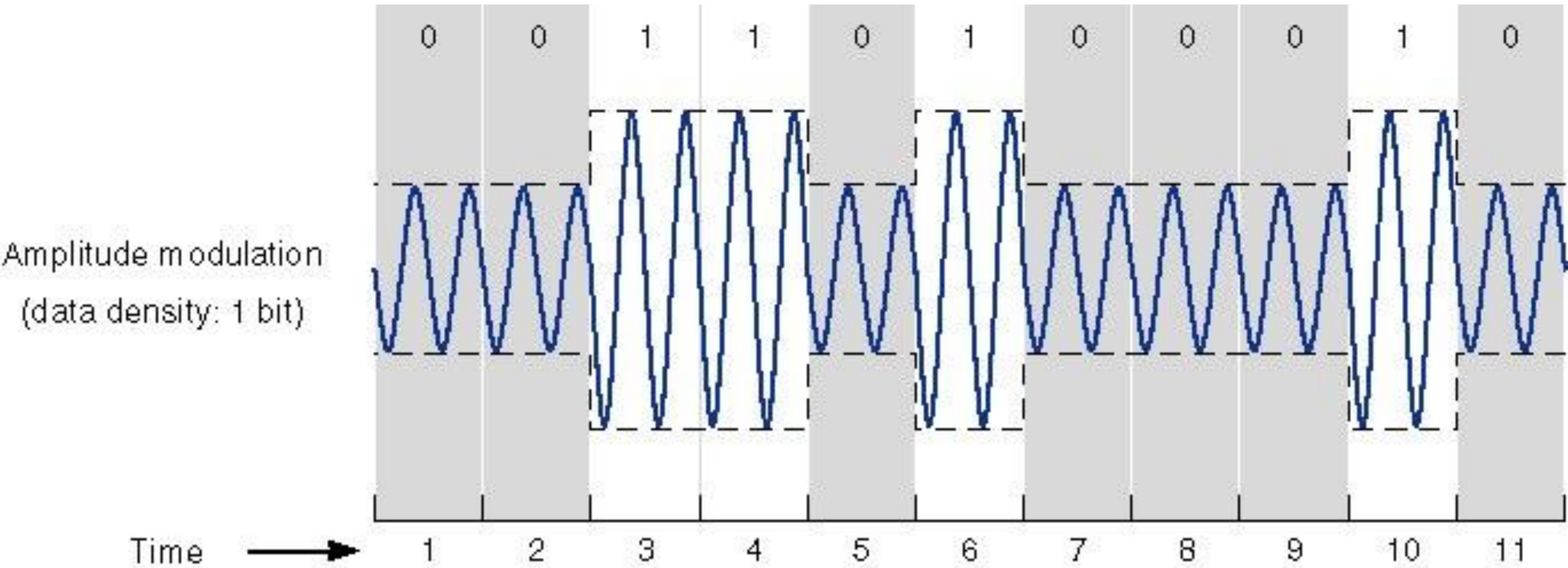
$$s(t) = \begin{cases} A\cos(2\pi f_c t), & binary\ 1 \\ 0, & binary\ 0 \end{cases}$$

(a) ASK



- Susceptible to noise
- Inefficient modulation technique
- used for
  - up to 1200bps on voice grade lines
  - very high speeds over optical fiber

Amplitude Modulation and ASK

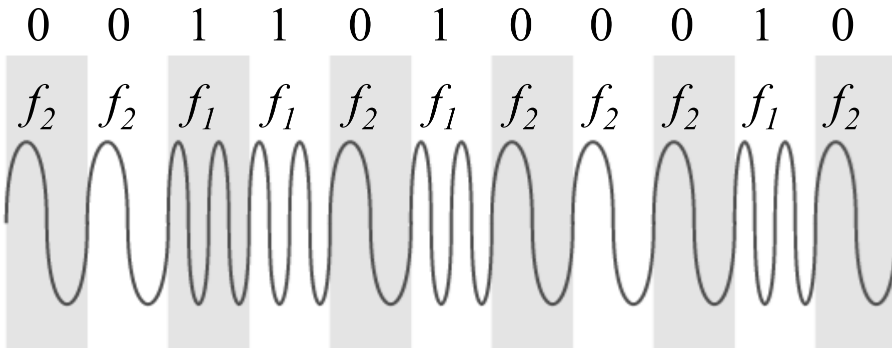


Binary Frequency Shift Keying (BFSK)

- The most common form of FSK is Binary FSK (BFSK)
- Two binary values represented by two different frequencies (f_1 and f_2)

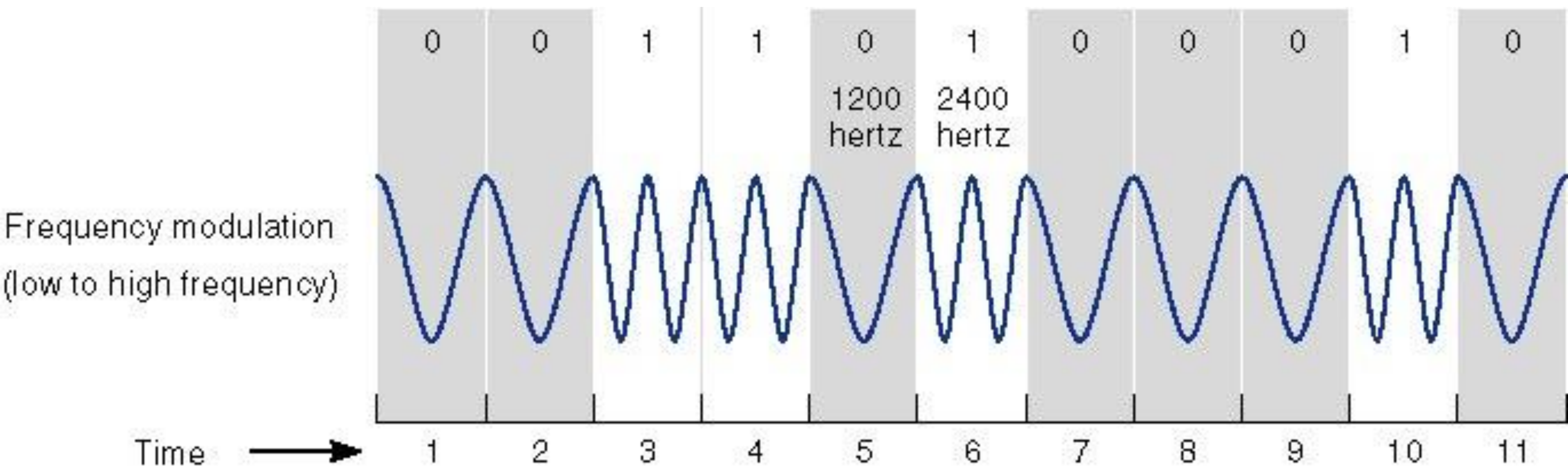
$$s(t) = \begin{cases} A\cos(2\pi f_1 t), & binary\ 1 \\ A\cos(2\pi f_2 t), & binary\ 0 \end{cases}$$

(b) BFSK



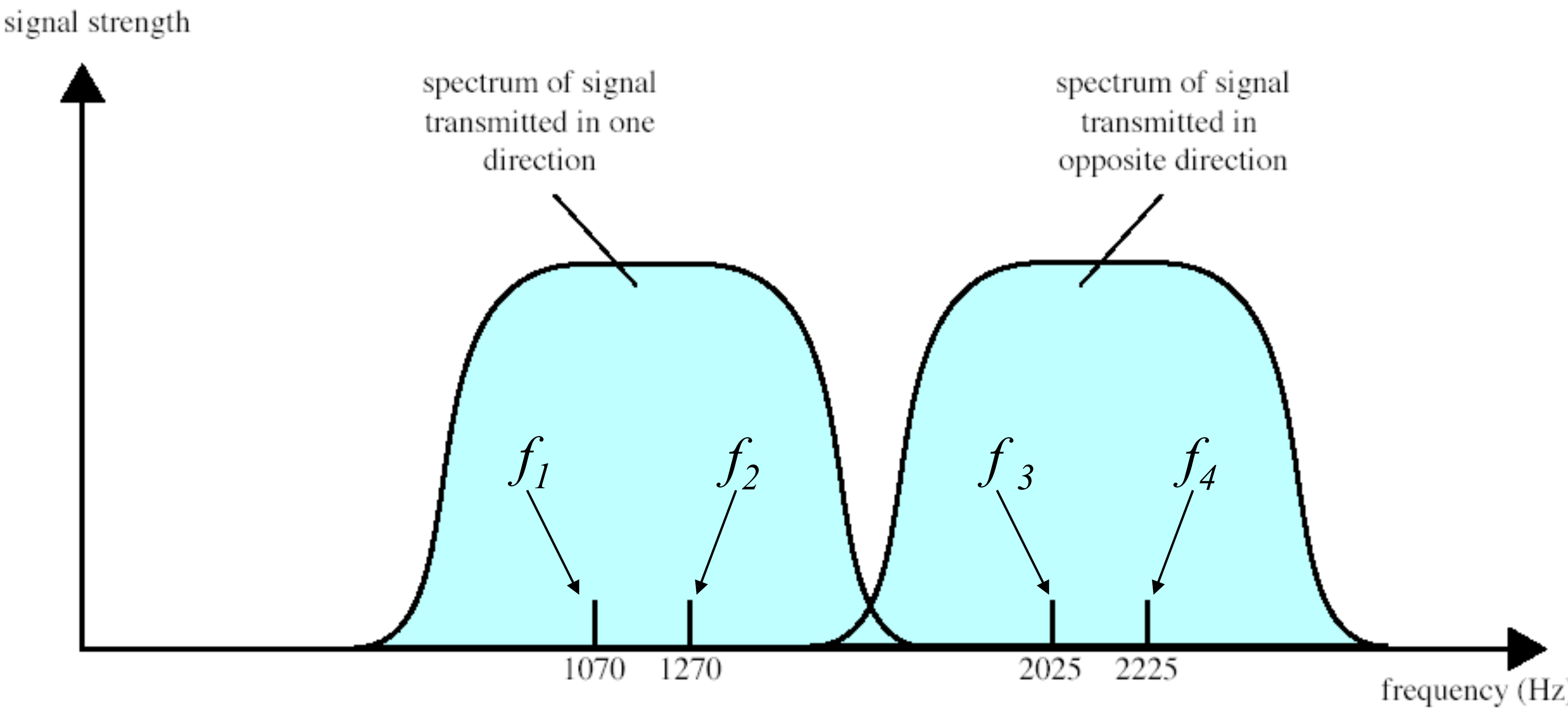
- less susceptible to noise than ASK
- used for
  - up to 1200bps on voice grade lines
  - high frequency radio (3 to 30MHz)
  - even higher frequency on LANs using coaxial cable

Frequency Modulation and FSK



Full-Duplex BFSK Transmission on a Voice-Grade line

- Voice grade lines will pass voice frequencies in the range 300 to 3400Hz
- Full duplex means that signals are transmitted in both directions at the same time



Multiple FSK (MFSK)

- More than two frequencies (M frequencies) are used
- More bandwidth efficient compared to BFSK
- More susceptible to noise compared to BFSK
- MFSK signal:

$$s_i(t) = A\cos(2\pi f_i t), \qquad 1 \le i \le M$$

$$where$$

$$f_i = f_c + (2i - 1 - M) f_d$$

$$f_c = the\ carrier\ frequency$$

$$f_d = the\ difference\ frequency$$

$$M = number\ of\ different\ signal\ elements = 2^L$$

$$L = number\ of\ bits\ per\ signal\ element$$

Multiple FSK (MFSK)

- MFSK signal:

$$s_i(t) = A\cos(2\pi f_i t), \qquad 1 \le i \le M$$

$$where$$

$$f_i = f_c + (2i - 1 - M)f_d$$

$$M = number\ of\ different\ signal\ elements = 2^L$$

$$L = number\ of\ bits\ per\ signal\ element$$

- Period of signal element

$$T_s = LT_b, \qquad T_s : signal\ element\ period \quad T_b : bit\ period$$

- Minimum frequency separation

$$1/T_s = 2f_d \quad \Rightarrow \quad 1/(LT_b) = 2f_d \quad \Rightarrow \quad 1/T_b = 2Lf_d\ (bit\ rate)$$

- MFSK signal bandwidth:

$$W_d = M(2f_d) = 2Mf_d$$

Example

- With f_c=250KHz, f_d=25KHz, and M=8 (L=3 bits), we have the following frequency assignment for each of the 8 possible 3-bit data combinations: $$f_i = f_c + (2i - 1 - M) f_d$$

$$\left.\begin{array}{lll}
000 & \rightarrow & f_1 = 75KHz \\
001 & \rightarrow & f_2 = 125KHz \\
010 & \rightarrow & f_3 = 175KHz \\
011 & \rightarrow & f_4 = 225KHz \\
100 & \rightarrow & f_5 = 275KHz \\
101 & \rightarrow & f_6 = 325KHz \\
110 & \rightarrow & f_7 = 375KHz \\
111 & \rightarrow & f_8 = 425KHz
\end{array}\right\} \quad bandwidth = W_s = 2Mf_d = 400KHz$$

- This scheme can support a data rate of:

$$1/T_b = 2Lf_d = 2(3bits)(25Hz) = 150Kbps$$

Example

- The following figure shows an example of MFSK with M=4. An input bit stream of 20 bits is encoded 2bits at a time, with each of the possible 2-bit combinations transmitted as a different frequency.

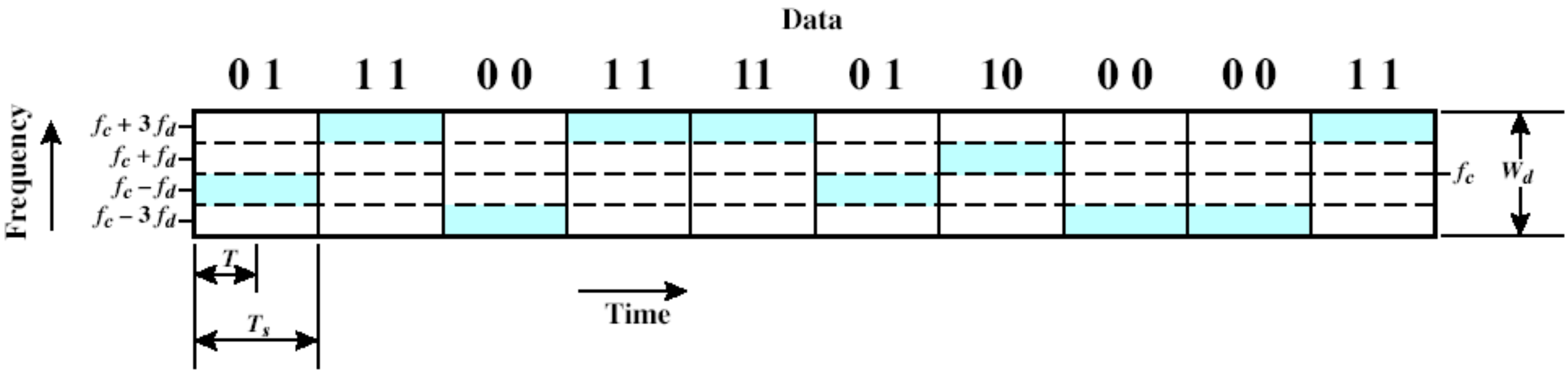
$$f_i = f_c + (2i - 1 - M) f_d$$

$$00 \rightarrow i = 1 \rightarrow f_1 = f_c - 3f_d$$

$$01 \rightarrow i = 2 \rightarrow f_2 = f_c - f_d$$

$$10 \rightarrow i = 3 \rightarrow f_3 = f_c + f_d$$

$$11 \rightarrow i = 4 \rightarrow f_4 = f_c + 3f_d$$



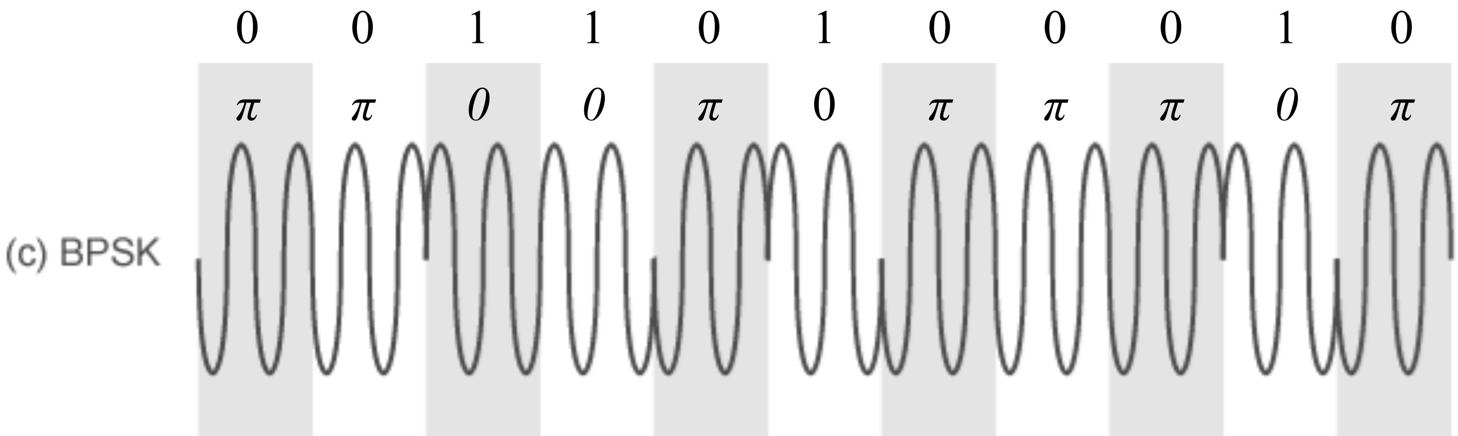
Phase Shift Keying (PSK)

- Phase of carrier signal is shifted to represent data
- Binary PSK (BPSK): two phases represent two binary digits

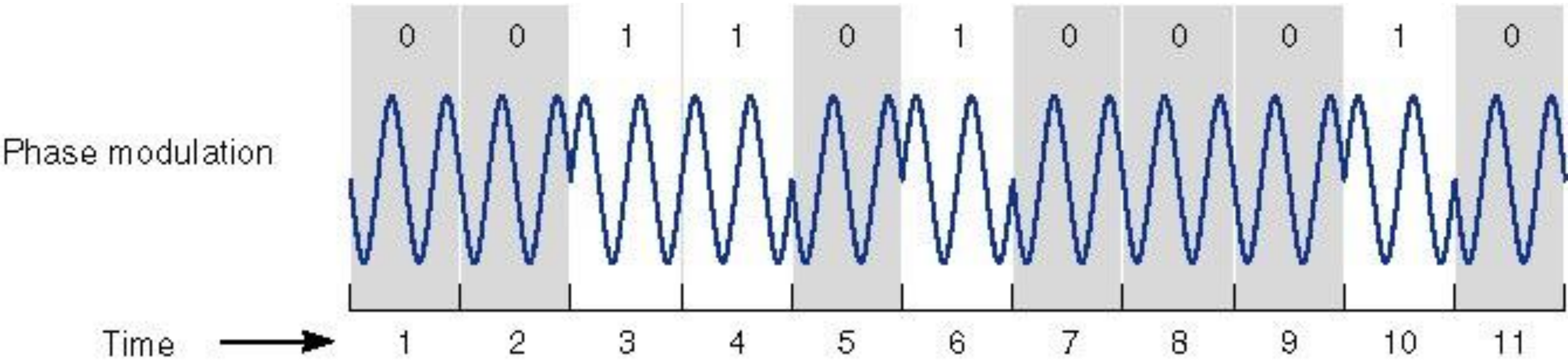
$$s(t) = \begin{cases} A\cos(2\pi f_c t), & binary\ 1 \\ A\cos(2\pi f_c t + \pi), & binary\ 0 \end{cases}$$

$$= \begin{cases} A\cos(2\pi f_c t), & binary\ 1 \\ -A\cos(2\pi f_c t), & binary\ 0 \end{cases}$$

$$= Ad(t)\cos(2\pi f_c t), \qquad d(t) = \pm 1$$

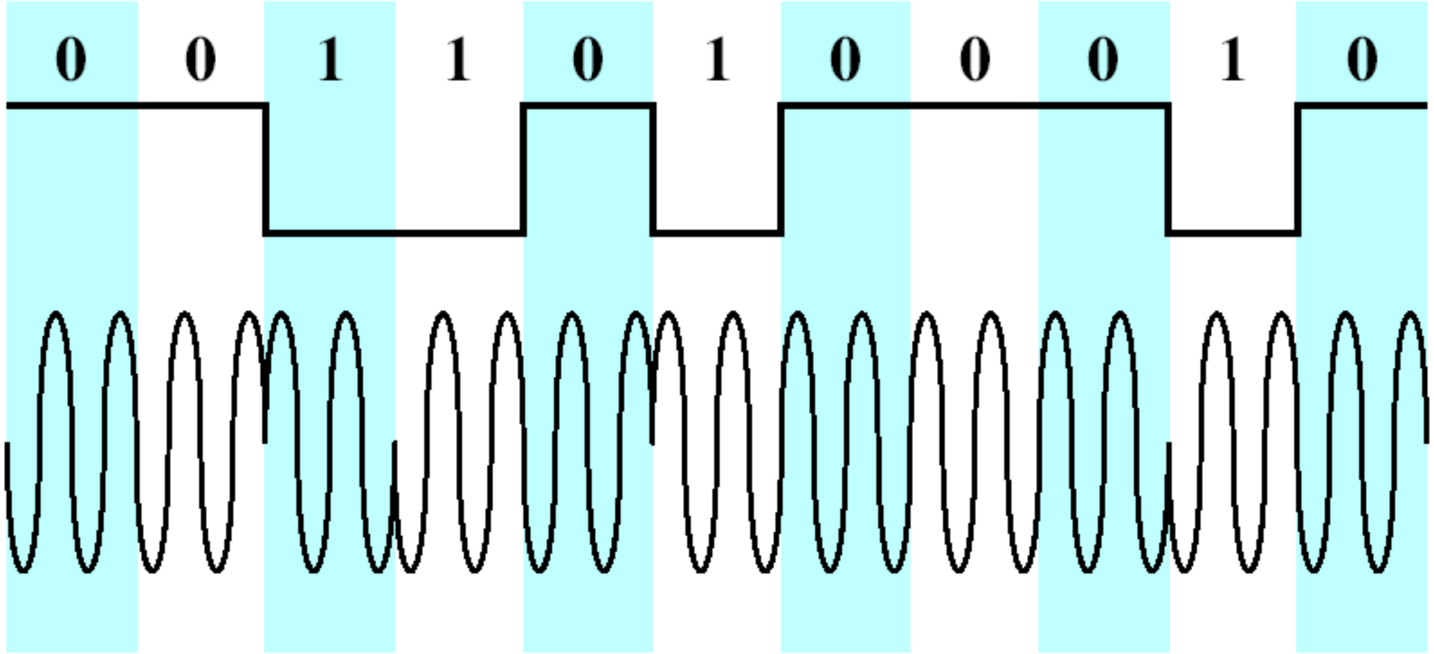


Phase Modulation and PSK



Differential PSK (DPSK)

- In DPSK, the phase shift is with reference to the previous bit transmitted rather than to some constant reference signal
- Binary 0:signal burst with the same phase as the previous one
- Binary 1:signal burst of opposite phase to the preceding one



Four-level PSK: Quadrature PSK (QPSK)

- More efficient use of bandwidth if each signal element represents more than one bit
  - eg. shifts of $\pi/2$ (90^o)
  - each signal element represents two bits
  - split input data stream in two & modulate onto the phase of the carrier

$$s(t) = \begin{cases} A\cos(2\pi f_c t + \frac{\pi}{4}) & \leftrightarrow \quad 11 \\ A\cos(2\pi f_c t + \frac{3\pi}{4}) & \leftrightarrow \quad 01 \\ A\cos(2\pi f_c t + \frac{3\pi}{4}) & \leftrightarrow \quad 00 \\ A\cos(2\pi f_c t - \frac{\pi}{4}) & \leftrightarrow \quad 10 \end{cases}$$

- can use 8 phase angles & more than one amplitude
  - 9600bps modem uses 12 phase angles, four of which have two amplitudes: this gives a total of 16 different signal elements

Performance of ASK, FSK, MFSK, PSK and MPSK

Bandwidth Efficiency

- ASK/PSK: $$\frac{data\ rate}{transmission\ bandwidth} = \frac{R}{B_T} = \frac{1}{1+r}, \qquad 0 < r < 1$$
- MPSK: $$\frac{R}{B_T} = \frac{\log_2 M}{1+r}, \qquad M : number\ of\ different\ signal\ elements$$
- MFSK: $$\frac{R}{B_T} = \frac{\log_2 M}{(1+r)M}$$

Bit Error Rate (BER)

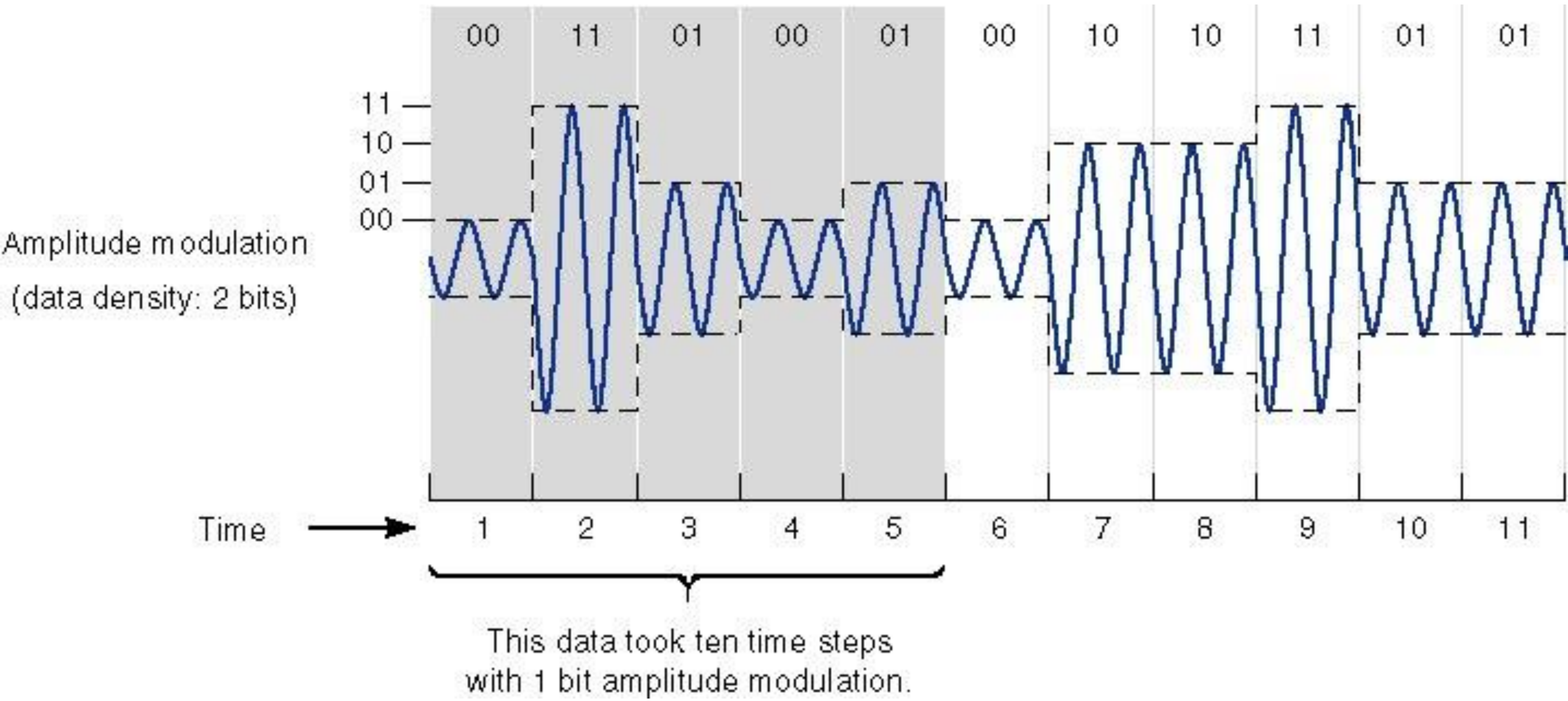
- bit error rate of PSK and QPSK are about 3dB superior to ASK and FSK (see Fig. 5.4)
- for MFSK & MPSK have tradeoff between bandwidth efficiency and error performance

Sending Multiple Bits Simultaneously

Each of the three modulation techniques can be refined to send more than one bit at a time. It is possible to send two bits on one wave by defining four different amplitudes.

This technique could be further refined to send three bits at the same time by defining 8 different amplitude levels or four bits by defining 16, etc. The same approach can be used for frequency and phase modulation.

Sending Multiple Bits Simultaneously



Sending Multiple Bits Simultaneously

In practice, the maximum number of bits that can be sent with any one of these techniques is about five bits. The solution is to combine modulation techniques.

One popular technique is quadrature amplitude modulation (QAM) involves splitting the signal into eight different phases, and two different amplitude for a total of 16 different possible values, giving us lg(16) or 4 bits per value.

2-D Diagram of QAM