Digital Data, Analog Signals

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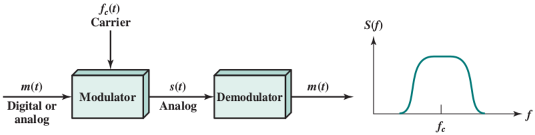
Analog transmission

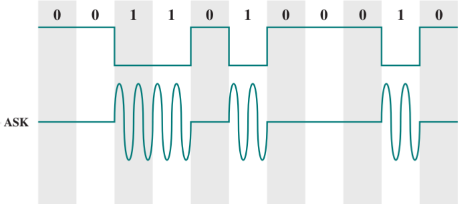


- The telephone network was designed to receive, switch, and transmit analog signals in the voice frequency range (300 to 3400 Hz)
- Digital signals cannot be transmitted as they are using a telephone network
- Devices emitting digital signals are connected to a telephone network using a modulator-demodulator (modem)
- **Modulation** is the process of encoding source data onto a carrier signal with frequency f_c.
- A **carrier frequency** is a continuous frequency capable of being modulated or impressed with a second (information-carrying) signal.

Three modulation techniques

- All modulation techniques involve operation on one or more of the three fundamental carrier signal parameters: amplitude, frequency, and phase.
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)
- The resulting signal occupies a bandwidth centered on the carrier frequency.

Amplitude Shift Keying

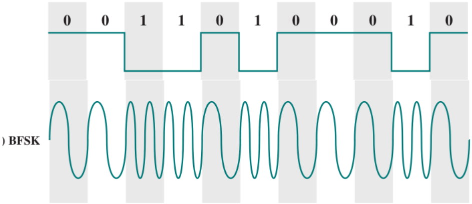


- Two binary values are represented by two different amplitudes
- The resulting transmitted signal for 1 bit time is

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

- $A\cos(2\pi f_c t)$ is the carrier signal
- Used to transmit digital data over optical fiber
- Light Emitting Diode transmitters and Laser transmitters
- Noise affects amplitude — ASK is susceptible to noise

Frequency Shift Keying



- Binary FSK (BFSK) : the two binary values are represented by two different frequencies near the carrier frequency
- Transmitted signal for 1 bit time is

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

where f_1 and f_2 are offset from f_c by equal but opposite amounts

Question

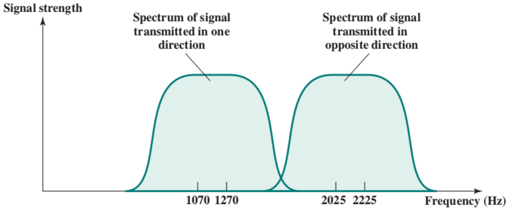
In full-duplex operation

(A) signals can be transmitted only in one direction

(B) signals are transmitted in both directions but not at the same time

(C) signals are transmitted in both directions at the same time

Full duplex operation over a voice-grade line



- Two center frequencies of 1170 Hz and 2125 Hz
- 100 Hz shifted on either side
- One center frequency is for transmit and another for receive
- 1070 Hz and 2025 Hz represent 1 and 1270 Hz and 2225 Hz represent 0
- Less susceptible to error than ASK
- Used up to 1200bps on voice-grade lines
- Also used for high-frequency (3 to 30 MHz) radio transmission

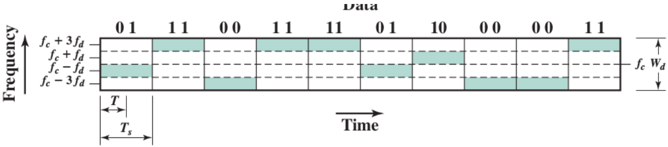


Figure: MFSK, M=4

- More than 2 frequencies are used
- Each signalling element represents more than 1 bit
- The transmitted signal for 1 signal element:

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

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 Frequency Shift Keying

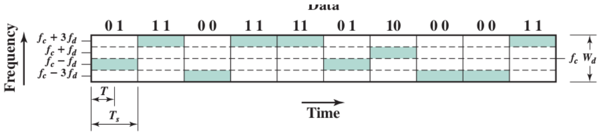


Figure: MFSK, M=4

- L = number of bits per signal element
- One signal element encodes L bits
- T is the bit period. Data rate $= 1/T$
- Each output signal element is held for a period $T_s = LT$ seconds
- Total bandwidth=

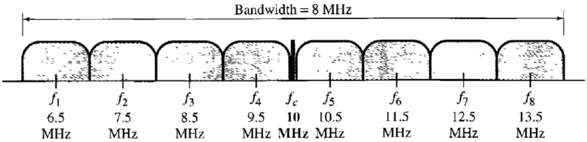
$$f_c + (2 * M - 1 - M)f_d - [f_c + (2 * 1 - 1 - M)f_d] + 2f_d = 2Mf_d$$

- Minimum frequency separation $= 2f_d$ (check with i=1 and i=2)
- For proper operation of the modem, it can be shown that $T_s = \frac{1}{2f_d}$. Therefore, bandwidth $=2Mf_d = \frac{M}{T_s}$

Question

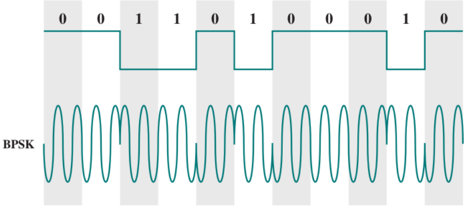
1. We need to send data 3 bits at a time at a bit rate of 3Mbps. The carrier frequency is 10 MHz. Calculate the number of levels (different frequencies), the difference frequency, the baud rate and the bandwidth.
2. Suppose the carrier frequency is 250kHz, the difference frequency is 50kHz and 3 bits need to be transmitted per signal element. What is the data rate supported by this scheme?

Question 1 of previous slide



Phase Shift Keying (PSK)

The phase of the carrier signal is shifted to represent data **Binary Phase Shift Keying (BPSK):**



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

Suppose

$$d(t) = \begin{cases} 1 \text{ binary } 1 \\ -1 \text{ binary } 0 \end{cases}$$

then $s_d(t) = Ad(t)\cos(2\pi f_c t)$

Question

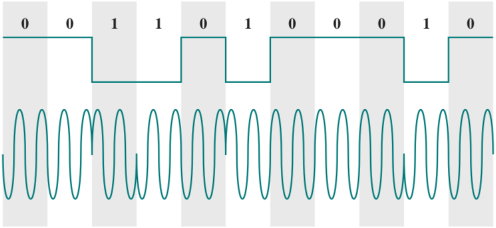
In differential encoding the information to be transmitted is represented in terms of the changes between successive data symbols rather than the signal elements themselves

(A) True

(B) False

Differential Phase Shift Keying

- binary 0 : a signal burst of the same phase as the previous signal burst sent
- binary 1 : a signal burst of phase opposite to the preceding one
- DPSK avoids the requirement for an accurate local oscillator phase at the receiver that is matched with the transmitter
- Only the preceding phase needs to be received correctly

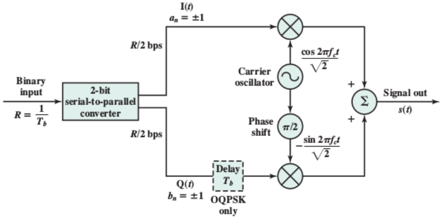


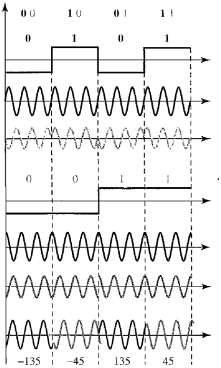
Quadrature Phase Shift Keying (QPSK)

- Each signalling element represents more than 1 bit. For what purpose?
- QPSK uses phase shifts separated by multiples of $\pi/2$

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

QPSK Modulation Scheme

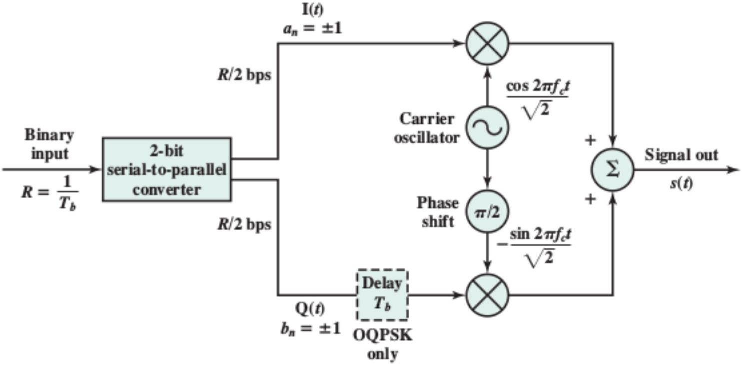




$$s(t) = \frac{1}{\sqrt{2}} I(t) \cos 2\pi f_c t - \frac{1}{\sqrt{2}} Q(t) \sin 2\pi f_c t$$

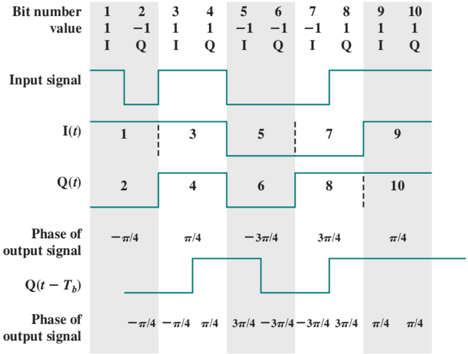
- Each of the two modulated bit streams is a BPSK signal
- Each stream has half the rate of the original signal. Therefore the combined signal has a symbol rate that is half the rate of the input

Offset QPSK Modulation Scheme or Orthogonoal QPSK



$$s(t) = \frac{1}{\sqrt{2}} I(t) \cos 2\pi f_c t - \frac{1}{\sqrt{2}} Q(t - T_b) \sin 2\pi f_c t$$

Offset QPSK Modulation Scheme or Orthogonoal QPSK



- A delay of T_b for the quadrature signal
- Maximum phase change in the combined signal = ______
- Large phase shifts at high bit rates is difficult for modulators. A lower phase change is an advantage
- Easier to control spreading of bandwidth if there are less phase changes

Multilevel PSK

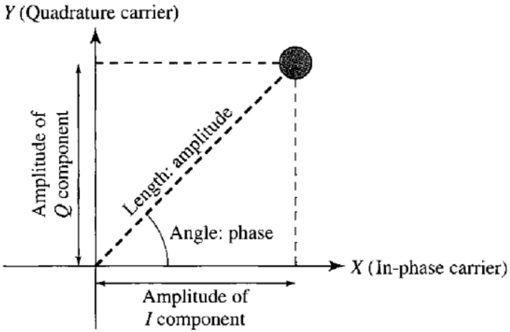
- Possible to transmit 3 bits at a time using eight different phase angles
- Each angle can have more than one amplitude
- Suppose a 9600 bps modem uses 12 phase angles, 4 of which have two amplitude values. The number of signal elements is m______

Multilevel PSK

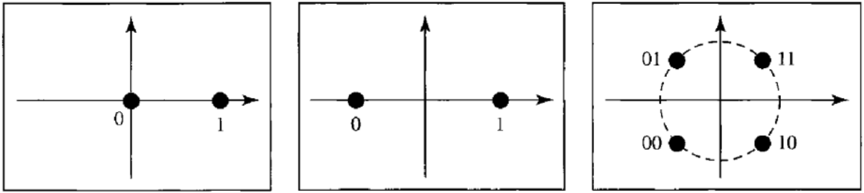
- 1 is represented by a low level and 0 by a high level
- Let the data rate $R = \frac{1}{T_b}$
- The number of bits in each signal element using M=16 combinations of phase and amplitude is L=4
- Modulation rate $= \frac{R}{4}$ as each change of signal element communicates 4 bits
- The line signalling speed is $9600/4 = 2400 baud$
- Thus higher bit rates can be achieved by employing complex modulation schemes

Constellation Diagram

- A signal element type is represented as a dot
- The bit (or combination of bits) it carries is written next to it
- X-axis: in phase carrier, Y-axis: quadrature carrier
- the peak amplitudes of the in-phase and quadrature components, the peak amplitude of the signal element, phase of the signal element can be deduced



Constellation Diagram



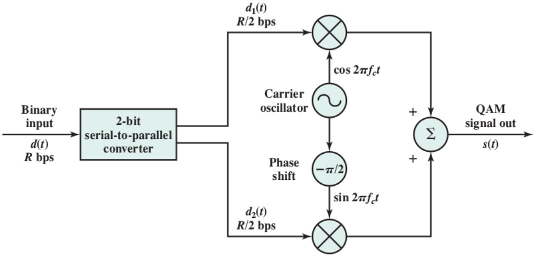
a. ASK (OOK) b. BPSK c. QPSK

- Binary ASK is also called On-Off Keying (OOK). (a) shows a unipolar NRZ signal
- (b): a polar NRZ signal for modulation, for BPSK
- (c): QPSK, uses two carriers

Quadrature Amplitude Modulation, QAM

- A lower phase change is better for PSK
- PSK is limited by the ability of the equipment to distinguish small differences in phase (limits potential bit rate)
- Suppose we alter more than one characteristic of a sine wave?
- Use two carriers: one in-phase and another quadrature, but with different *amplitudes* — combine ASK and PSK!
- Asymmetric Digital Subscriber Line (ADSL), some wireless standards use QAM

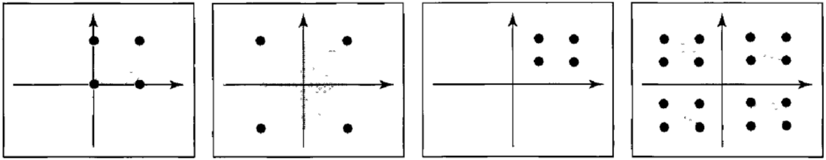
QAM Modulator



$$s(t) = d_1(t)\cos 2\pi f_c t + d_2(t)\sin 2\pi f_c t$$

- If 2-level ASK is used, each of the streams can be in one of two states and the combined stream can be in one of 4 states (QPSK)
- If 4-level ASK is used (4 amplitude levels), the combined stream can be in one of 16 states (16-QAM)
- In 16 QAM, each digital signal encodes 2 bits

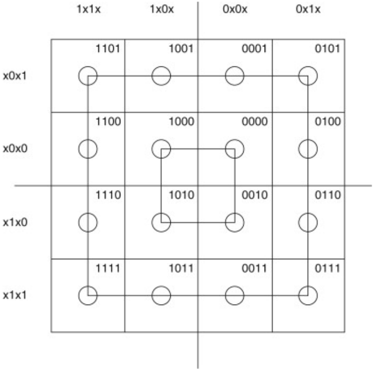
QAM: Constellation diagram



a. 4-QAM b. 4-QAM c. 4-QAM d. 16-QAM

- (a) 4 signal elements, using a unipolar NRZ signal to modulate each carrier
- (b) uses polar NRZ — the same as QPSK
- (c) uses a signal with two positive levels to modulate two carriers
- (d) a signal with eight levels to modulate (4 levels for each carrier)

16QAM


1x1x
1x0x
0x0x
0x1x
x0x1
x0x0
x1x0
x1x1
1101
1001
0001
0101
1100
1000
0000
0100
1110
1010
0010
0110
1111
1011
0011
0111

Question

The greater the number of states in QAM

(A) the higher the data rate possible with a given bandwidth

(B) the lower the data rate possible with a given bandwidth