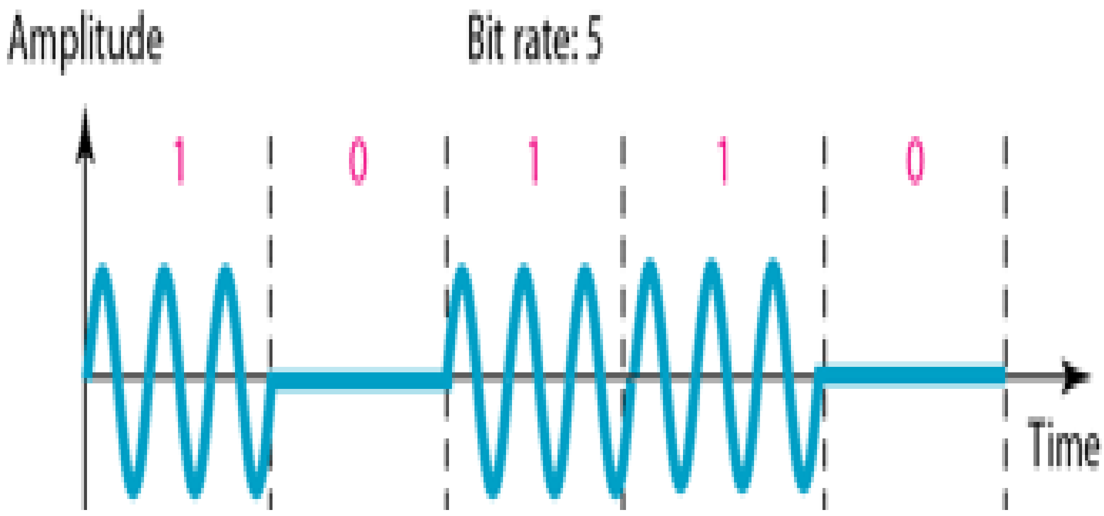
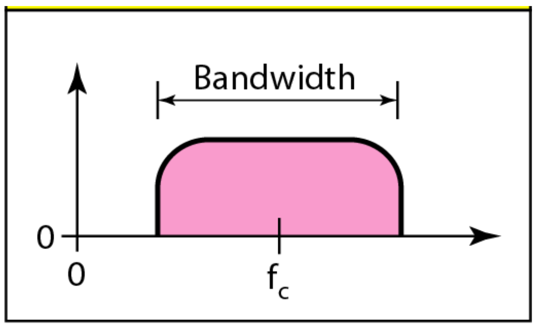
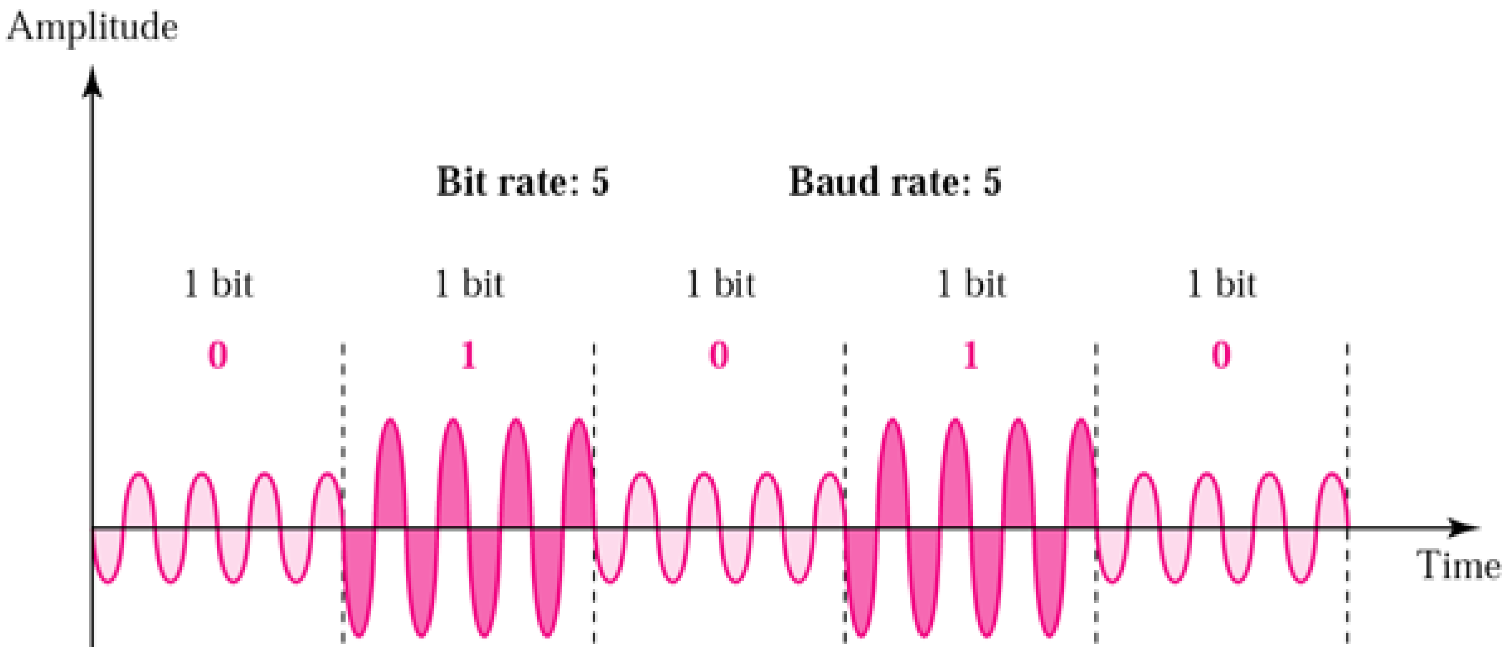
Digital data, Analog signals

Binary amplitude shift keying

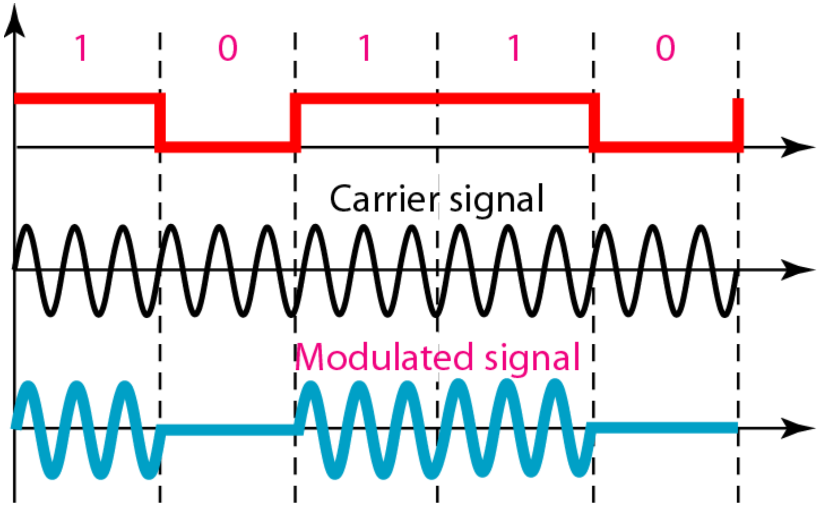


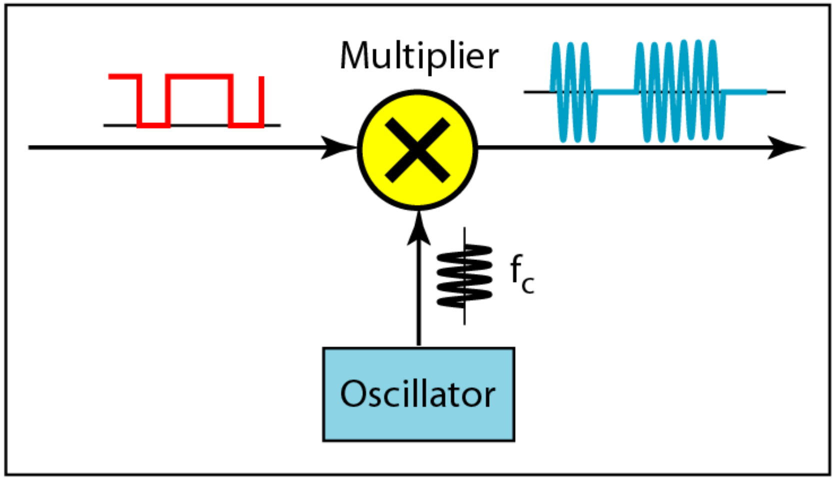


Binary amplitude shift keying



Implementation of binary ASK

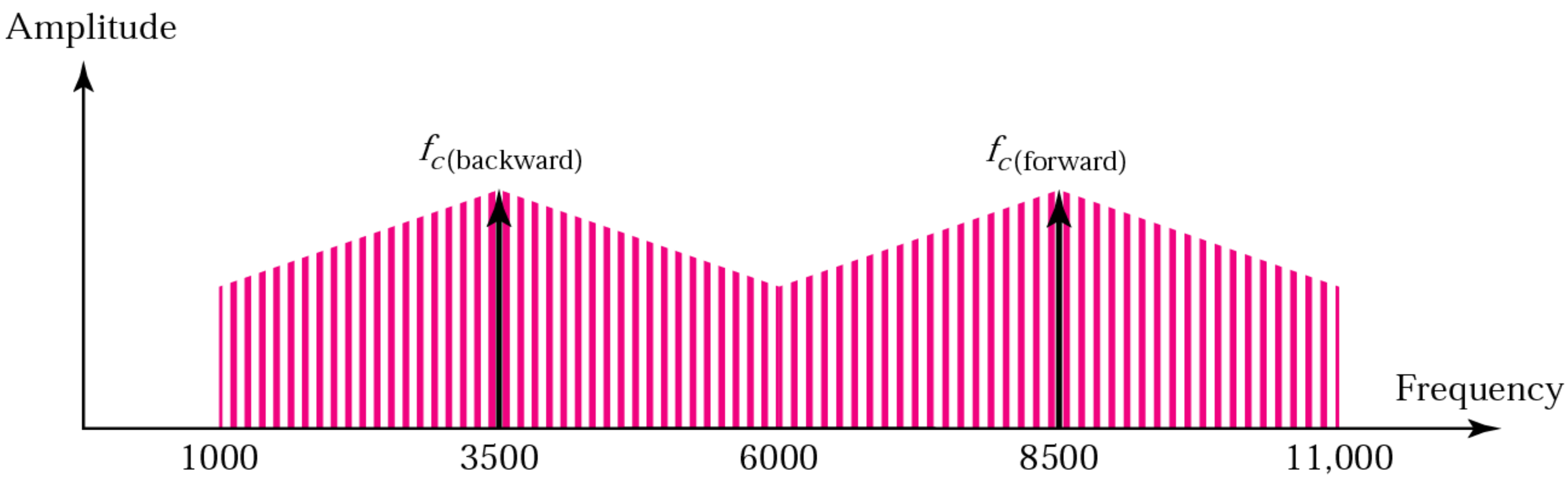




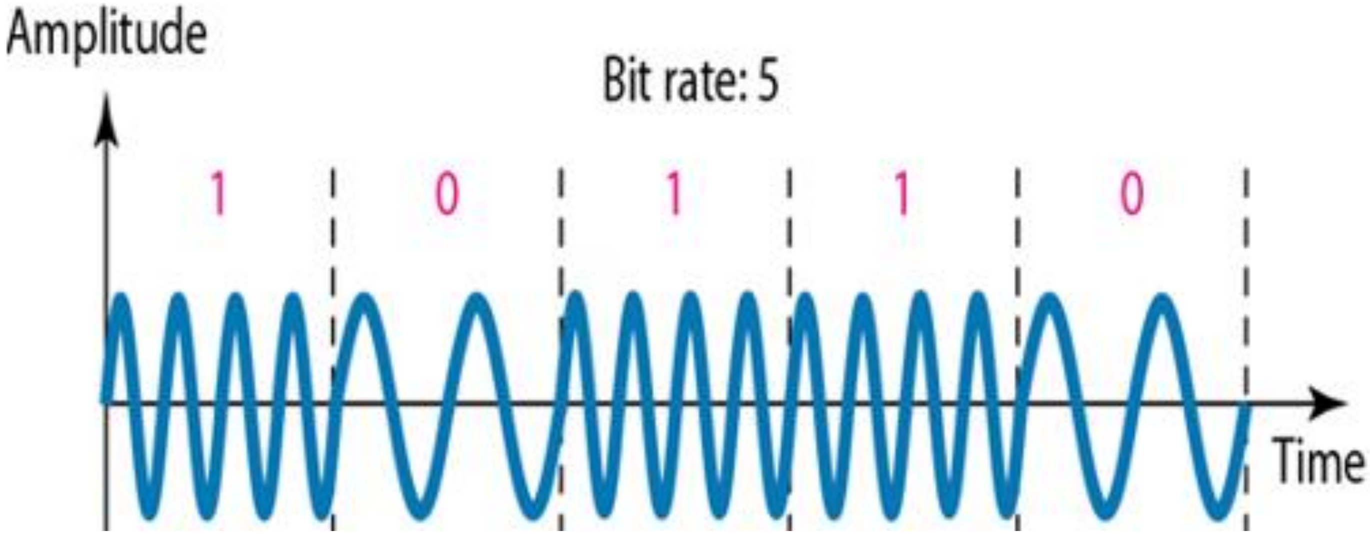
Example

- Given a bandwidth of 10,000 Hz (1000 to 11,000 Hz), draw the full-duplex ASK diagram of the system. Find the carriers and the bandwidths in each direction. Assume there is no gap between the bands in the two directions.

- For full-duplex ASK, the bandwidth for each direction is
- BW = 10000 / 2 = 5000 Hz
- The carrier frequencies can be chosen at the middle of each band
- fc (backward) = 1000 + 5000/2 = 3500 Hz
- fc (forward) = 11000 – 5000/2 = 8500 Hz



Binary frequency shift keying



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

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

$$f_c = \textit{the carrier frequency}$$

$$f_d = \textit{the difference frequency}$$

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

$$L = \textit{number of bits per signal element}$$

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

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

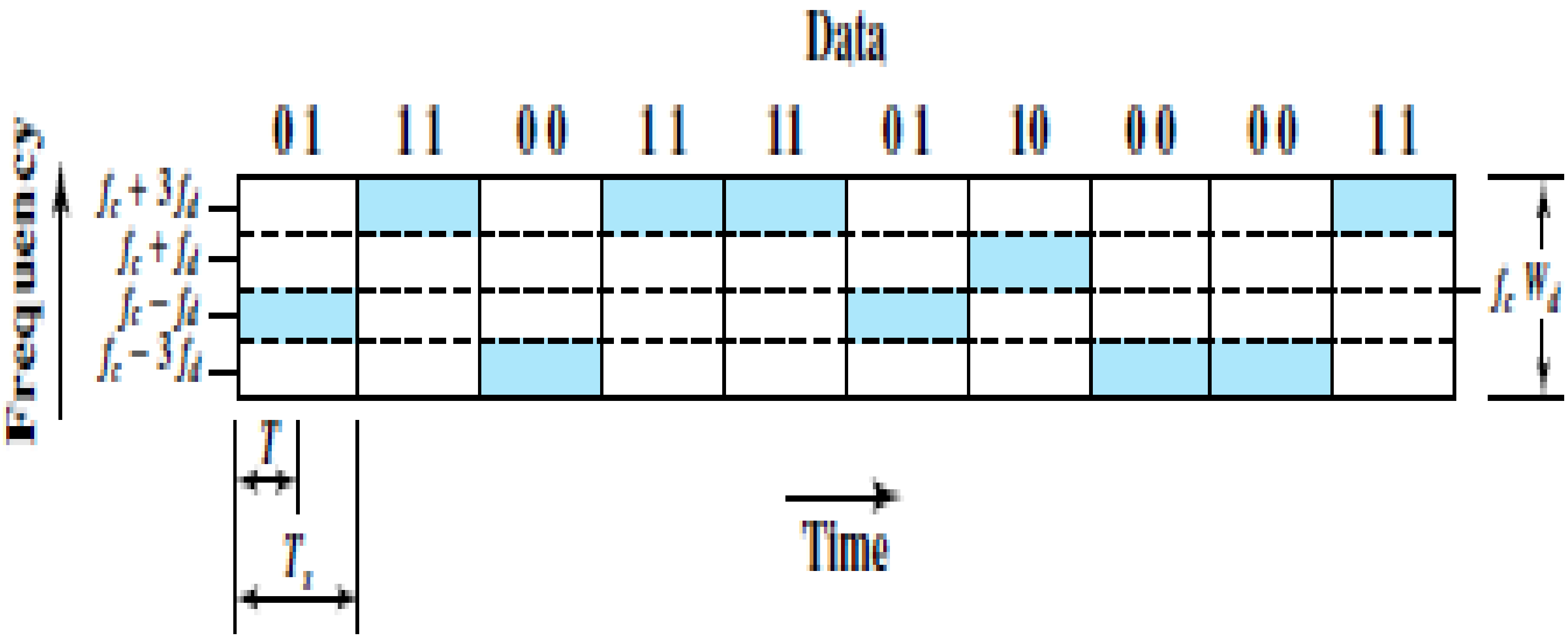
Minimum frequency separation

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

MFSK signal bandwidth:

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

MFSK


Data
01 11 00 11 11 01 10 00 00 11
Frequency
$f_c + 3f_d$
$f_c + f_d$
$f_c - f_d$
$f_c - 3f_d$
f_c W_d
T
T_s
Time

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:

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

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

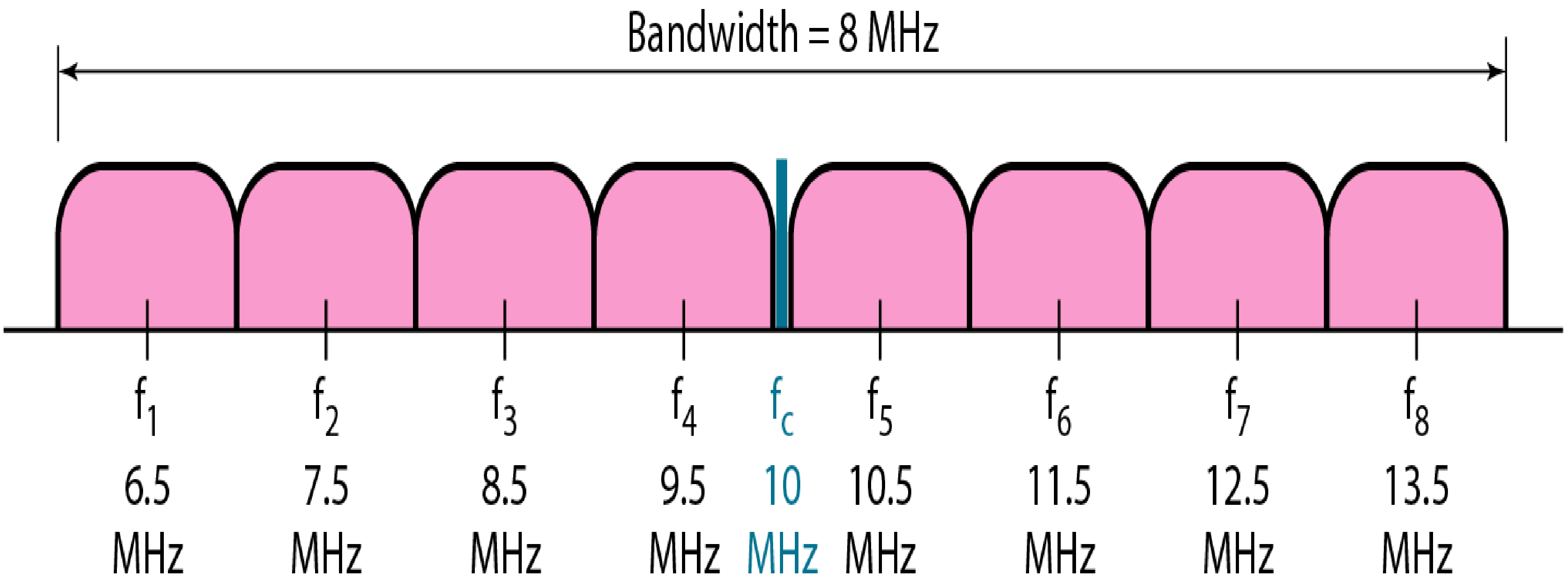
- This scheme can support a data rate of:

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

Example

- *We need to send data 3 bits at a time at a bit rate of 3 Mbps. The carrier frequency is 10 MHz. Calculate the number of levels (different frequencies), the baud rate, and the bandwidth.*

- *We can have L=3,* $M = 2^3 = 8$.
- *The baud rate is D=R/L*
- *D= 3 Mbps/3 = 1 Mbaud.*
- *The bandwidth is :* $W_d = M(2f_d) = 2Mf_d$
- *T=Bit period=1/3 micro sec*
- $T_S = LT = 3*(1/3)$ *=1 micro sec*
- $2f_d = 1/T_S$ *=1MHz*
- *Bandwidth=8MHz*

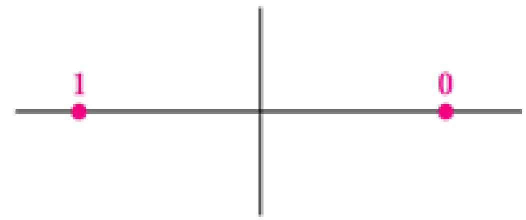

Bandwidth = 8 MHz
f1
f2
f3
f4
fc
f5
f6
f7
f8
6.5 MHz
7.5 MHz
8.5 MHz
9.5 MHz
10 MHz
10.5 MHz
11.5 MHz
12.5 MHz
13.5 MHz

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

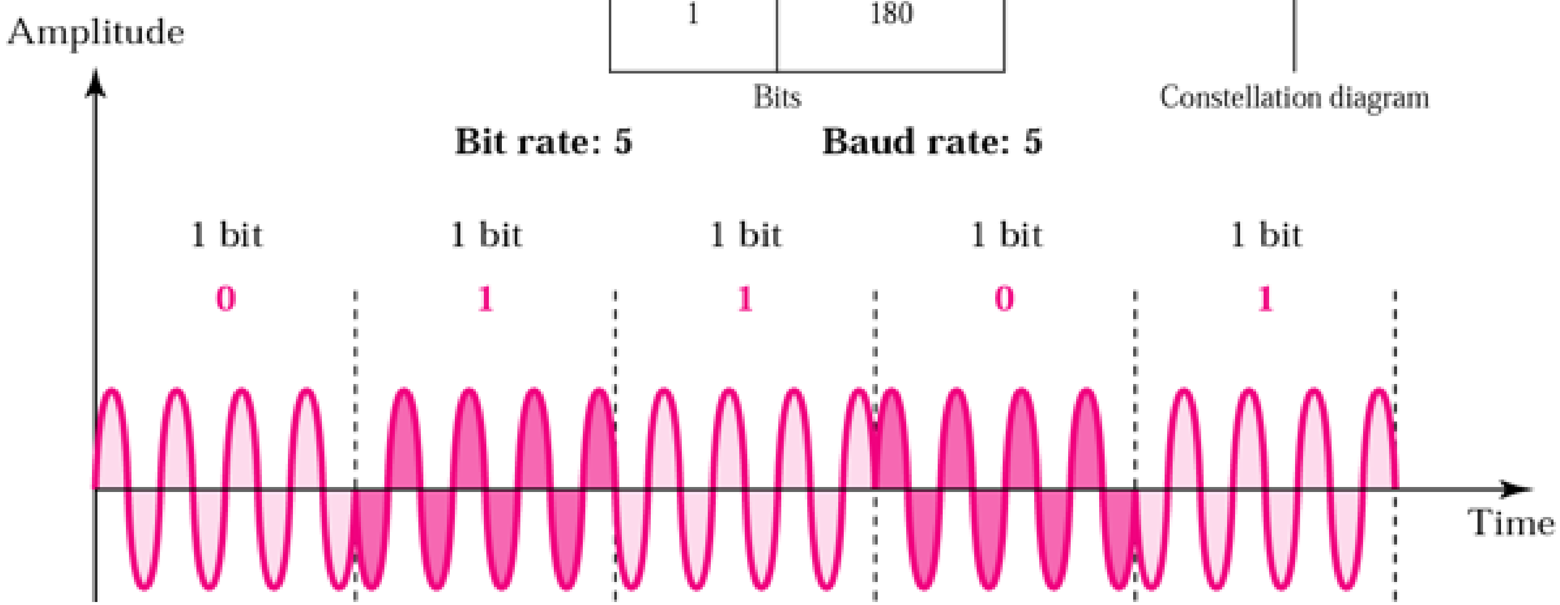
Phase Shift Keying

Bit	Phase
0	0
1	180

Bits



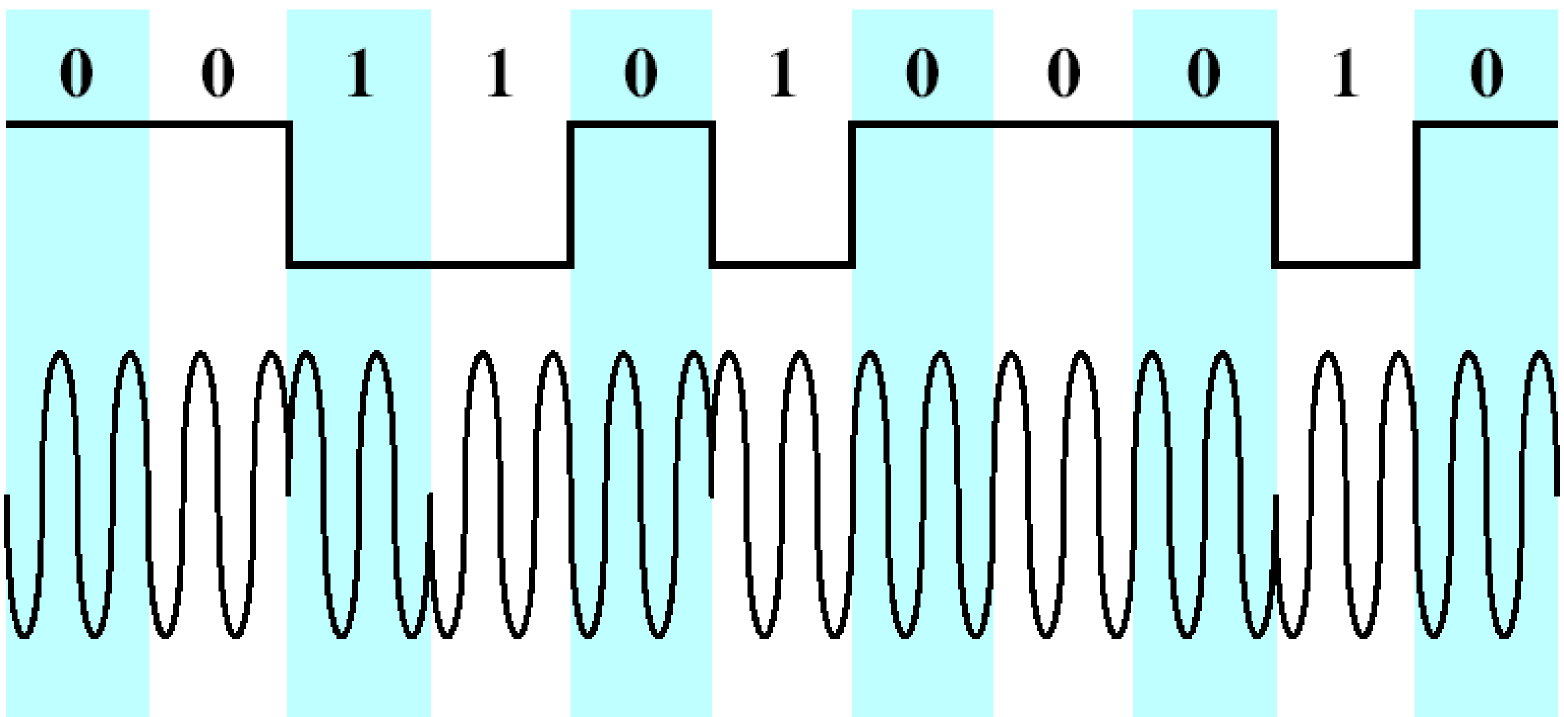
Constellation diagram



- Phase of the carrier is varied to represent digital data (binary 0 or 1)
- Amplitude and frequency remains constant.
- If phase 0 deg to represent 0, 180 deg to represent 1. (2-PSK)
- PSK is not susceptible to noise degradation that affects ASK or bandwidth limitations of FSK

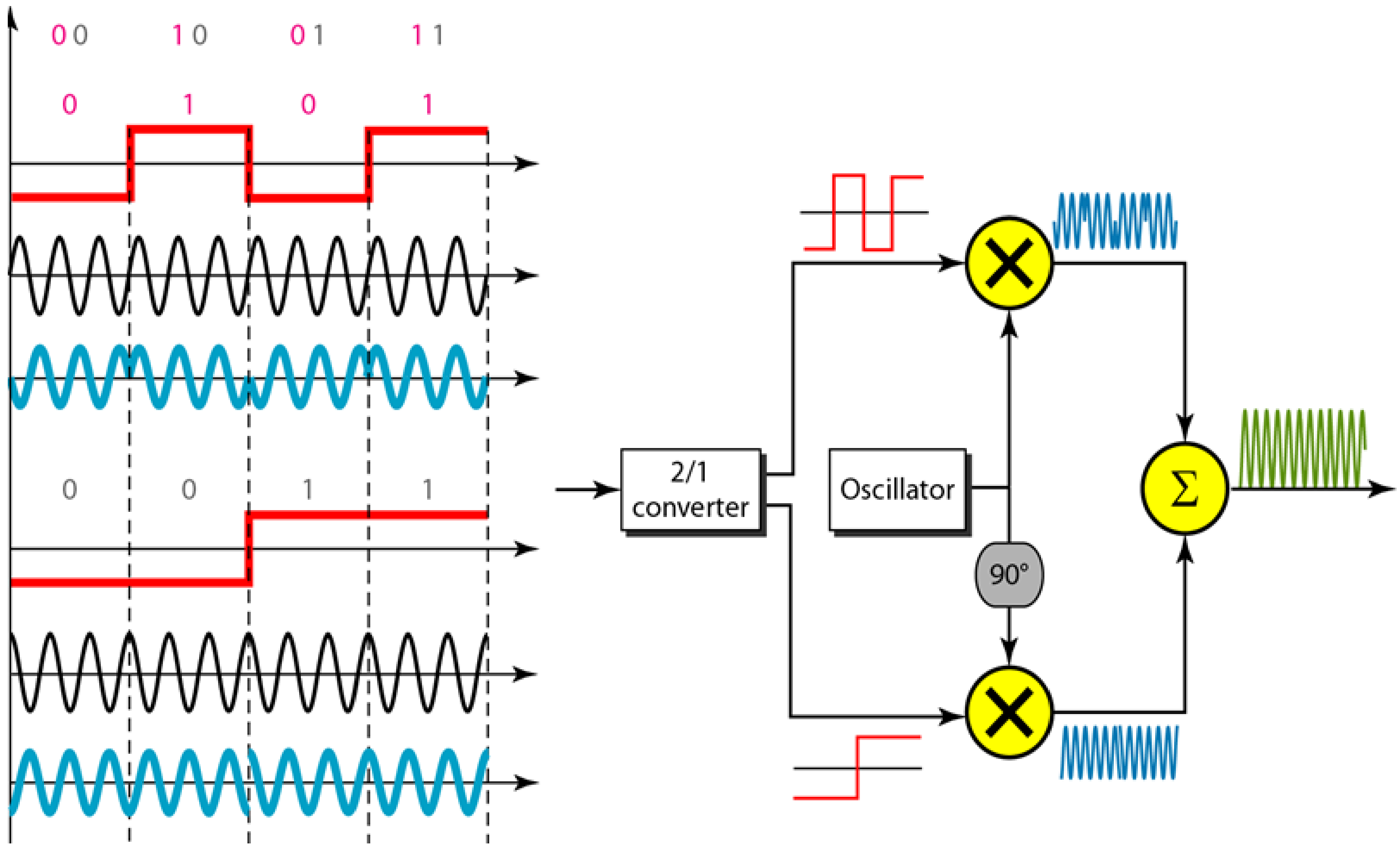
Differential PSK (DPSK)

- 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

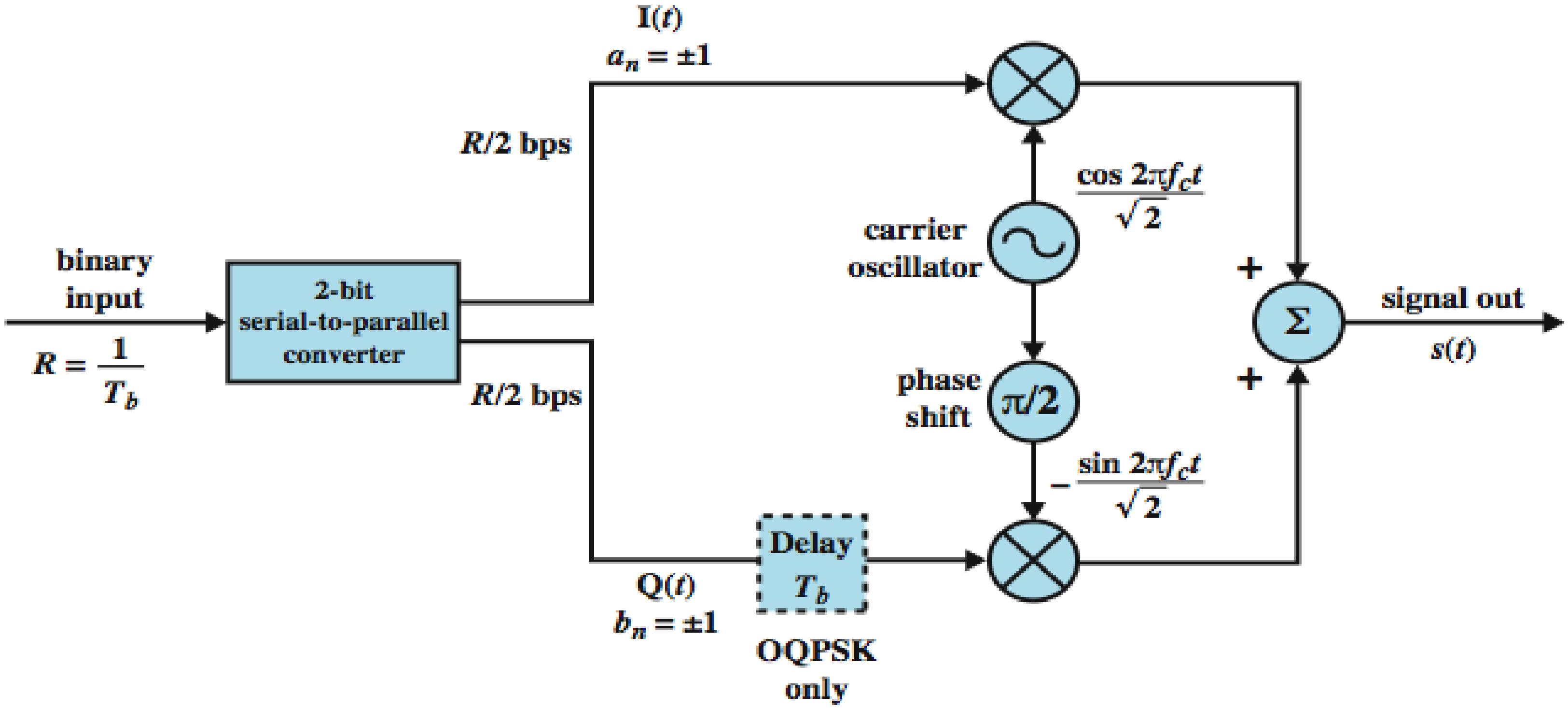


Quadrature PSK

- To increase the bit rate, we can code 2 or more bits onto one signal element.
- In QPSK, we parallelize the bit stream so that every two incoming bits are split up and PSK a carrier frequency. One carrier frequency is phase shifted 90^o from the other - in quadrature.
- The two PSKed signals are then added to produce one of 4 signal elements. L = 4

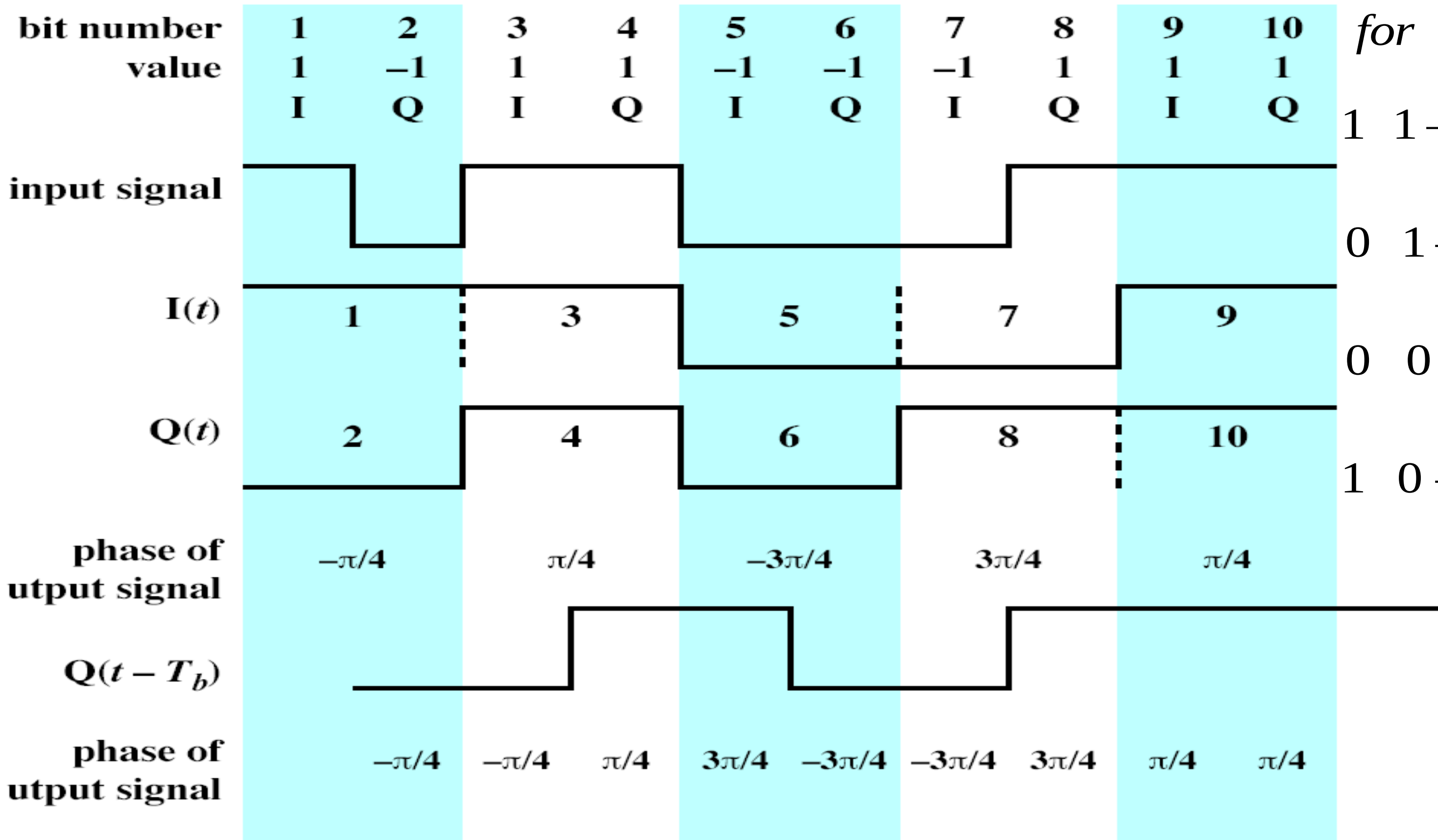

0 0
1 0
0 1
1 1
0
1
0
1
0
0
1
1
2/1 converter
Oscillator
90°
Σ

QPSK and Offset QPSK (OQPSK) Modulators



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

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



$for\quad QPSK:$

$$1\ \ 1 \rightarrow 1\ \ 1 \rightarrow \frac{\pi}{4}$$

$$0\ \ 1 \rightarrow -1\ \ 1 \rightarrow \frac{3\pi}{4}$$

$$0\ \ 0 \rightarrow -1\ -1 \rightarrow \frac{-3\pi}{4}$$

$$1\ \ 0 \rightarrow 1\ -1 \rightarrow \frac{-\pi}{4}$$

- Transmission bandwidth B_T for ASK, PSK and FSK is of the form
  - $B_T = (1+r)R$
  - R- Bit rate
  - r- Related to technique typically $0<r<1$

Bandwidth Efficiency

- ASK/PSK: $$\frac{data\ rate}{transmission\ bandwidth} = \frac{R}{B_T} = \frac{1}{1+r}, \qquad 0 < r < 1$$

- MPSK: $$\frac{R}{B_T} = \frac{\log_2 M}{1+r}, M: number\ of\ different\ signal\ elements$$

- MFSK: $$\frac{R}{B_T} = \frac{\log_2 M}{(1+r)M}$$

Example

- *We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What should be the carrier frequency and the bit rate if we modulated our data by using FSK with r = 1?*

- *The midpoint of the band is at 250 kHz. B=100KHz, r=1*
  - $B_T=(1+r)R$
  - $100=2R$
  - $R=100/2=50$ *kbps*

Example

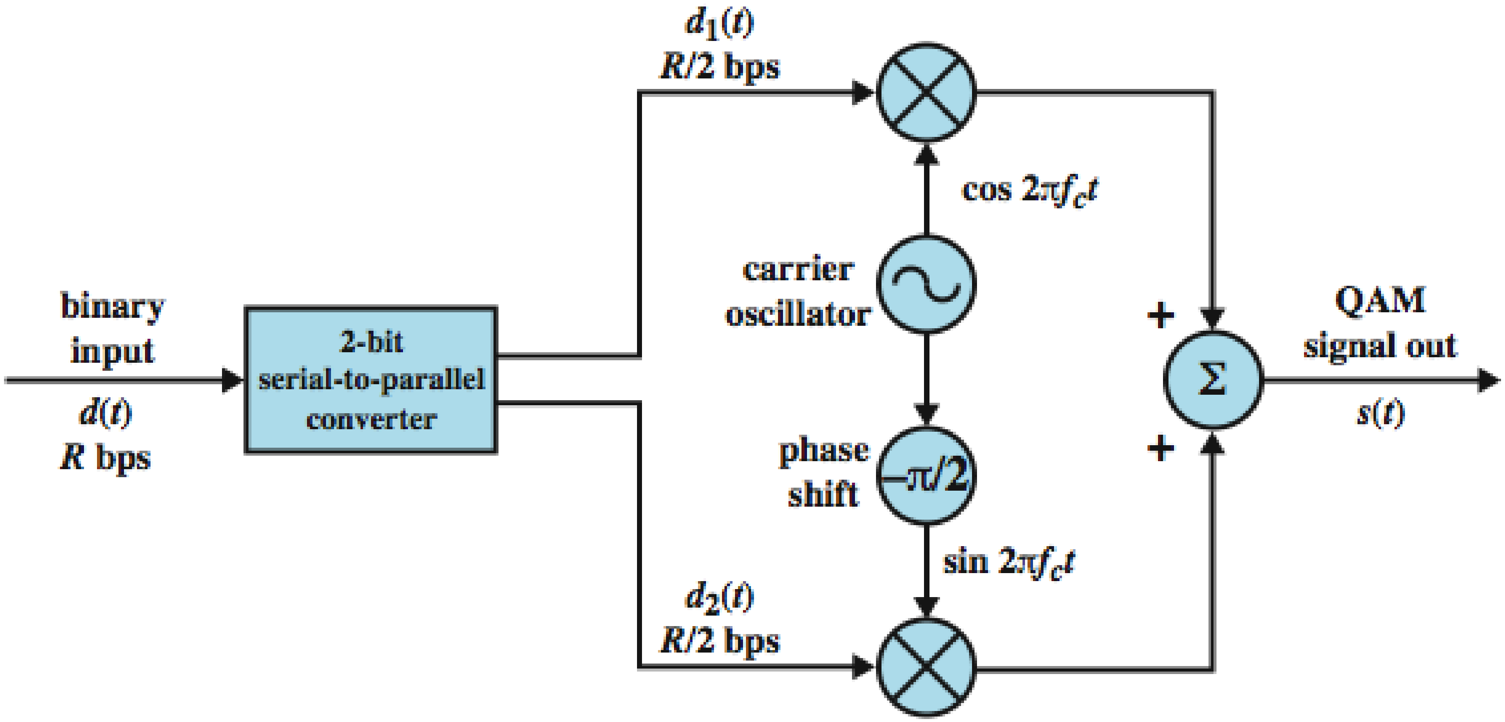
- *We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What are the carrier frequency and the bit rate if we modulated our data by using ASK with r= 1?*
  - $B_T=(1+r)R$

Quadrature Amplitude Modulation (QAM)

- QAM used on asymmetric digital subscriber line (ADSL) and some wireless standards
- combination of ASK and PSK
- logical extension of QPSK
- send two different signals simultaneously on same carrier frequency
  - use two copies of carrier, one shifted by 90°
  - each carrier is ASK modulated

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

QAM modulator



$$QAM: \qquad s(t) = \underbrace{d_1(t)\cos(2\pi f_c t)}_{ASK} + \underbrace{d_2(t)\sin(2\pi f_c t)}_{ASK}$$

QAM Variants

- Two level ASK (two different amplitude levels)
  - each of two streams in one of two states
  - four state system
  - essentially QPSK
- Four level ASK (four different amplitude levels)
  - combined stream in one of 16 states
- Have 64 and 256 state systems
- Improved data rate for given bandwidth
  - but increased potential error rate