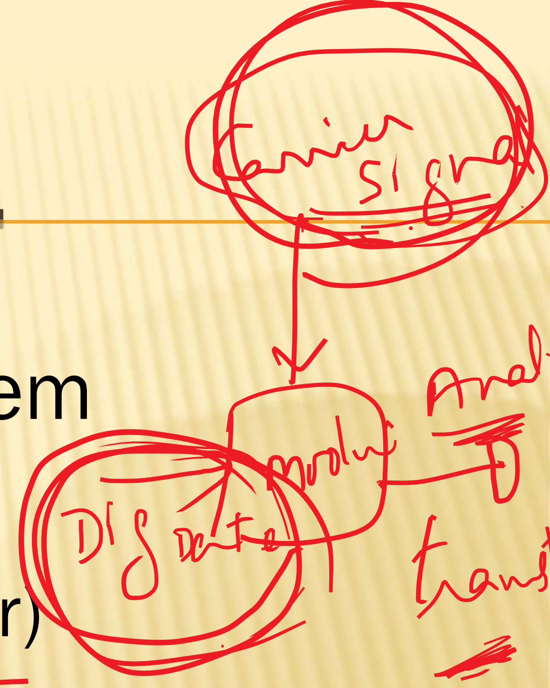
Signal Encoding Techniques

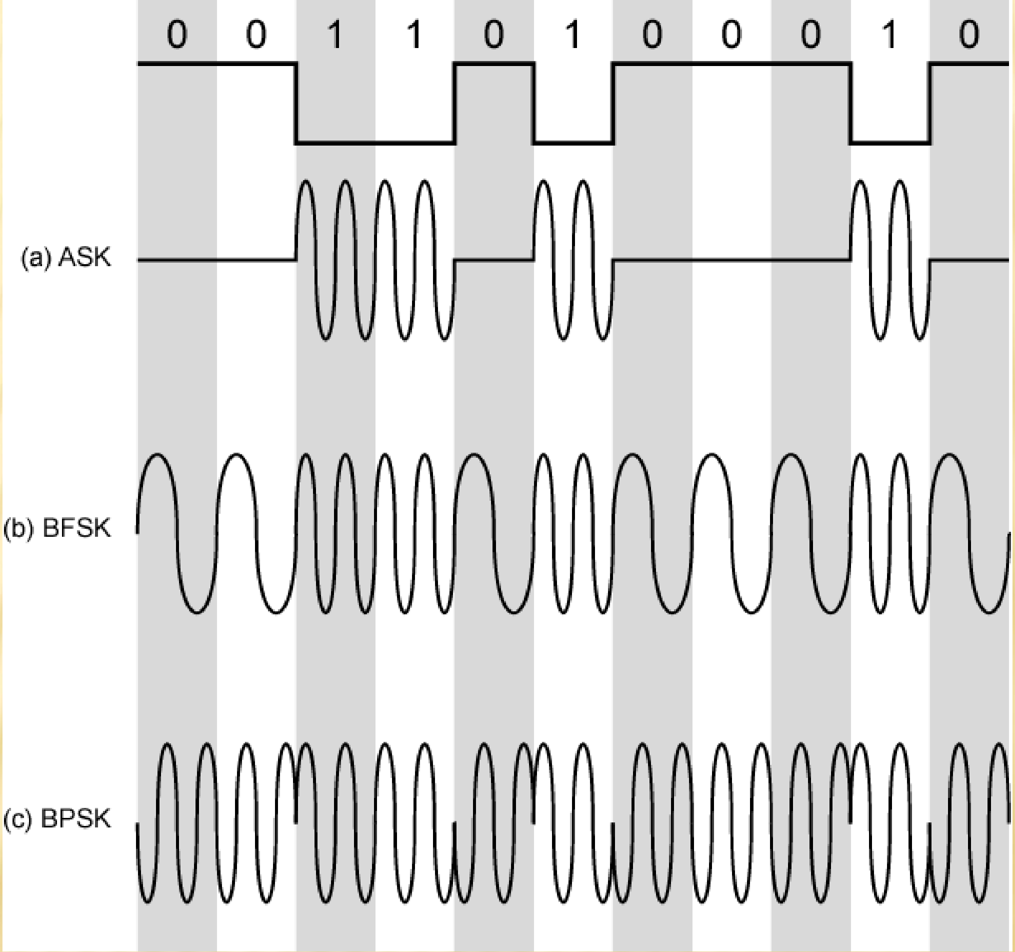
CHAPTER 5

DIGITAL DATA, ANALOG SIGNAL

- main use is public telephone system
  - has freq range of 300Hz to 3400Hz
  - use modem (modulator-demodulator)
- encoding techniques
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PSK)



MODULATION TECHNIQUES



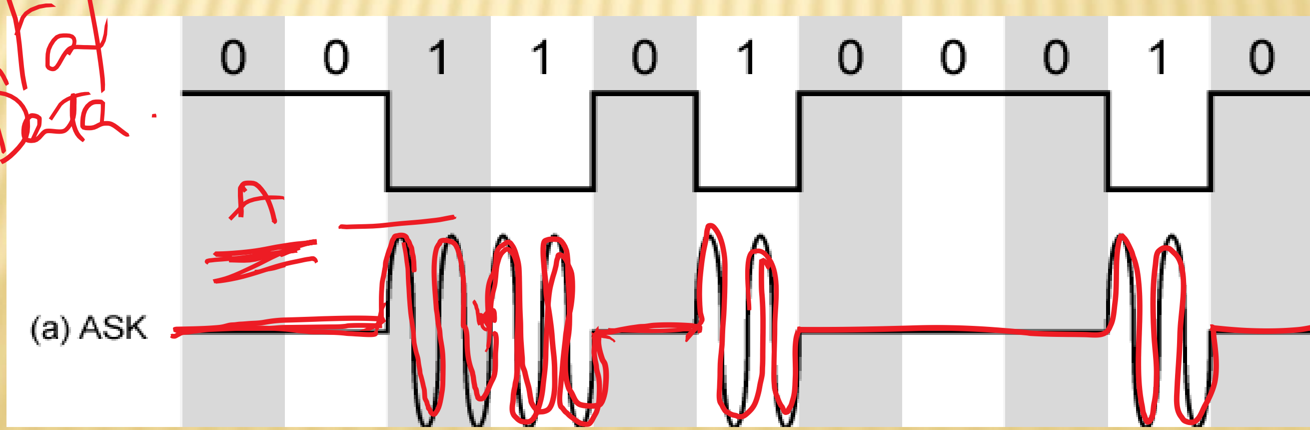
AMPLITUDE SHIFT KEYING

- encode 0/1 by different carrier amplitudes
  - usually have one amplitude zero

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

- susceptible to sudden gain changes
- inefficient
- used for
  - up to 1200bps on voice grade lines
  - Transmit digital data over optical fiber

Digital Data

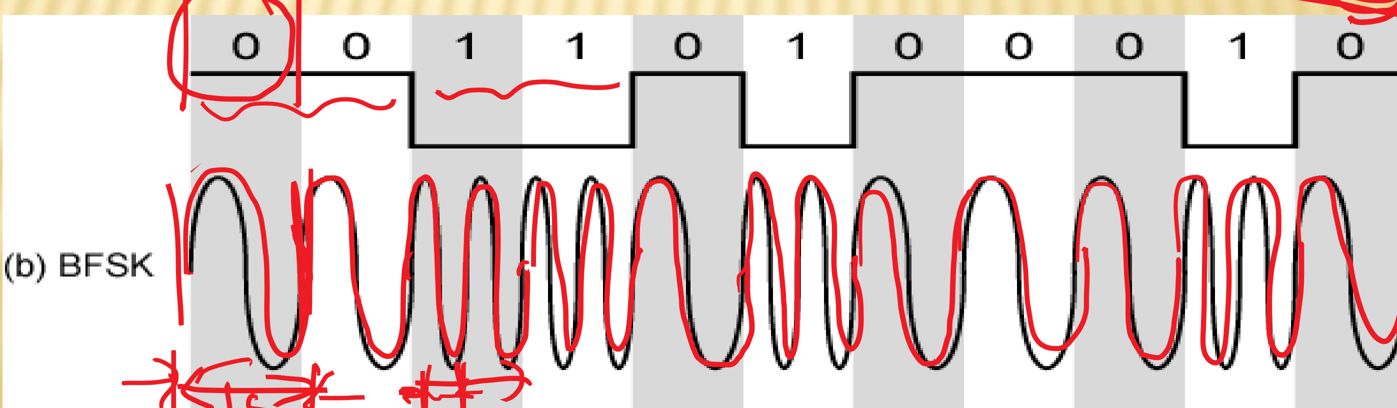


FREQUENCY SHIFT KEYING: BINARY FREQUENCY SHIFT KEYING(BFSK)

- most common is binary FSK (BFSK)
- two binary values represented by two different frequencies

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

- less susceptible to error than ASK
- used for
  - up to 1200bps on voice grade lines
  - high frequency radio
  - higher frequency on LANs using coaxial cable.



MULTIPLE FSK(MFSK)

- each signalling element represents more than one bit
- more than two frequencies used
- more bandwidth efficient
- more prone to error

Multiple FSK (MFSK)

- MFSK signal:

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

$1 \le i \le 4$

where

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

$f_1 = f_c - 3f_d \quad f_2 = f_c - f_d$

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

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

00 → f_1
01 → f_2
10 → f_3
11 → f_4

- Period of signal element

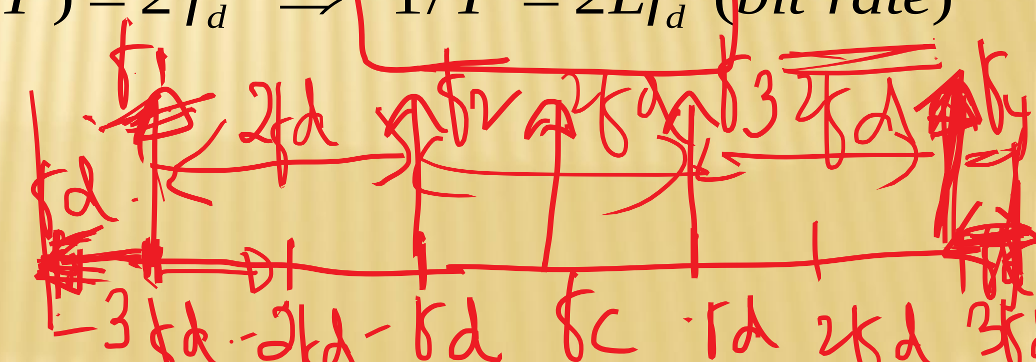
$$T_s = LT, \qquad T_s: \textit{signal element period} \qquad T: \textit{bit period}$$

- Minimum frequency separation

$$1/T_s = 2f_d \;\Rightarrow\; 1/(LT) = 2f_d \;\Rightarrow\; \boxed{1/T = 2Lf_d \text{ (bit rate)}}$$

- MFSK signal bandwidth:

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



Example

$1 \le i \le 4$

- 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.

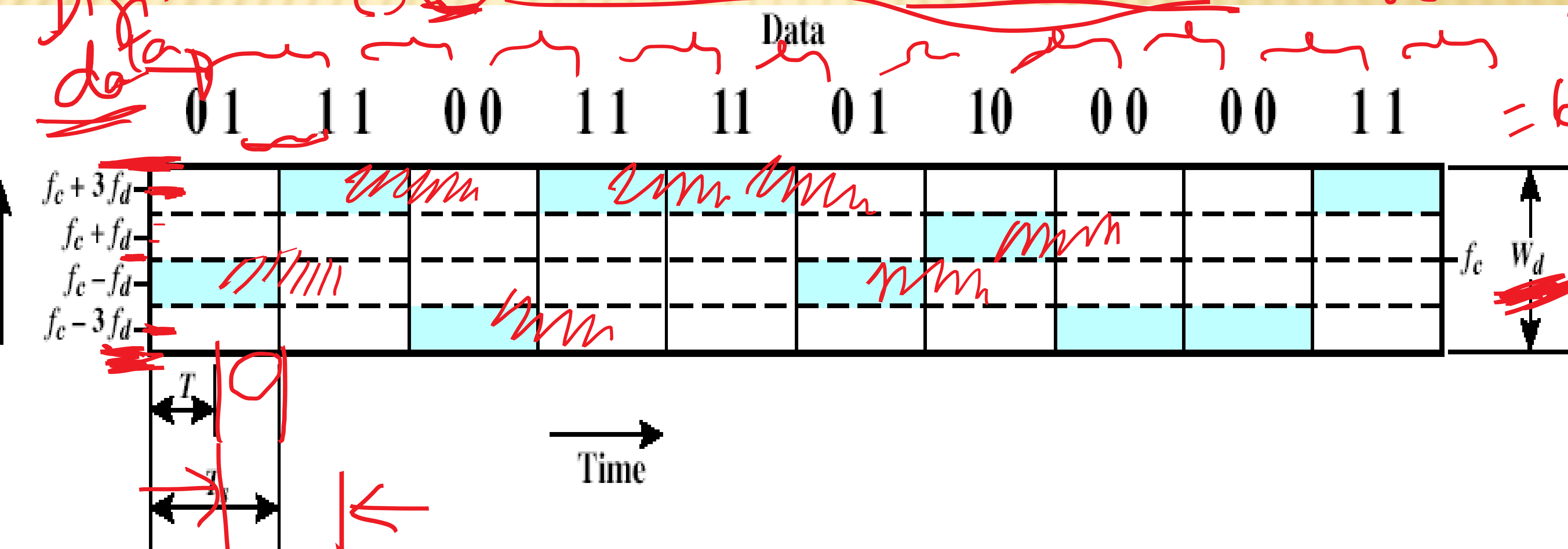
$$f_i = f_c + (2i - 1 - M)\,f_d$$

$\Rightarrow f_2 = f_c + (2\times2-1-4)\,f_d = f_c - f_d$

0	00	$\rightarrow$	$i=1$	$\rightarrow$	$f_1 = f_c - 3f_d$
1	01	$\rightarrow$	$i=2$	$\rightarrow$	$f_2 = f_c - f_d$
2	10	$\rightarrow$	$i=3$	$\rightarrow$	$f_3 = f_c + f_d$
3	11	$\rightarrow$	$i=4$	$\rightarrow$	$f_4 = f_c + 3f_d$

$f_c + 3f_d - f_c + 3f_d = 6f_d$

Digital data



Example

$8 = 2^L$

$L = 3$

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

$1 \le i \le 8$

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

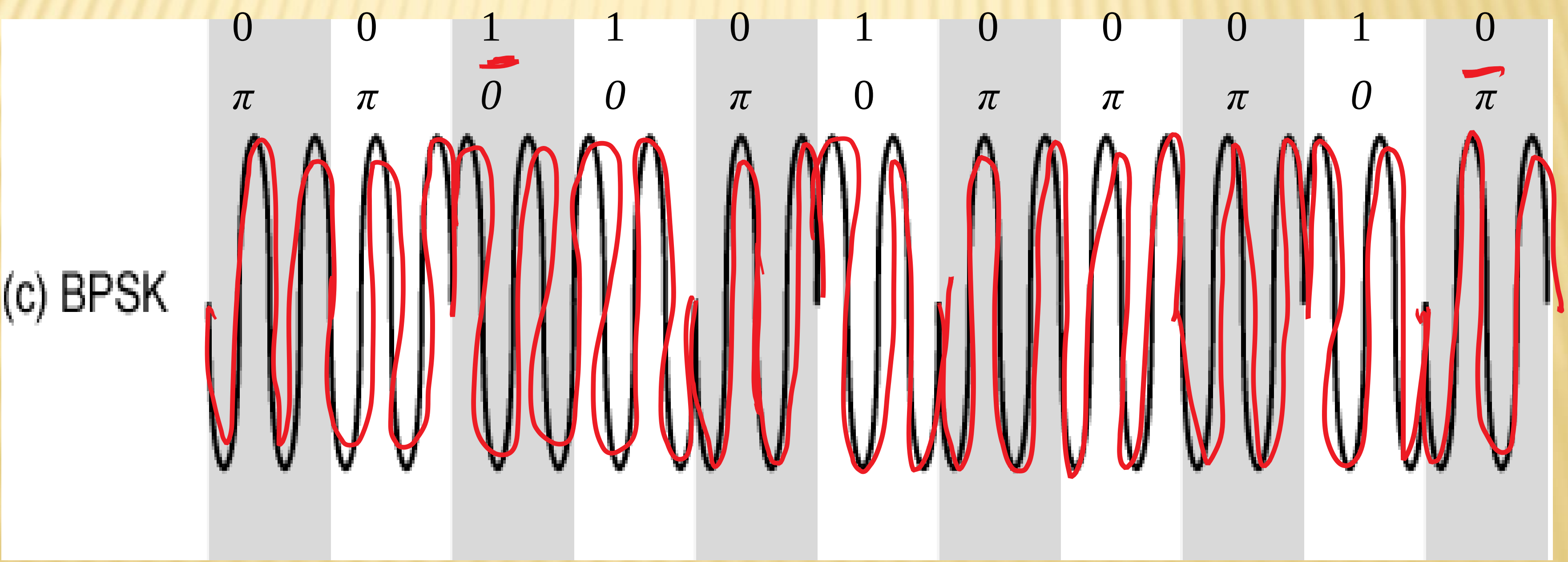
- This scheme can support a data rate of:

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

PHASE SHIFT KEYING

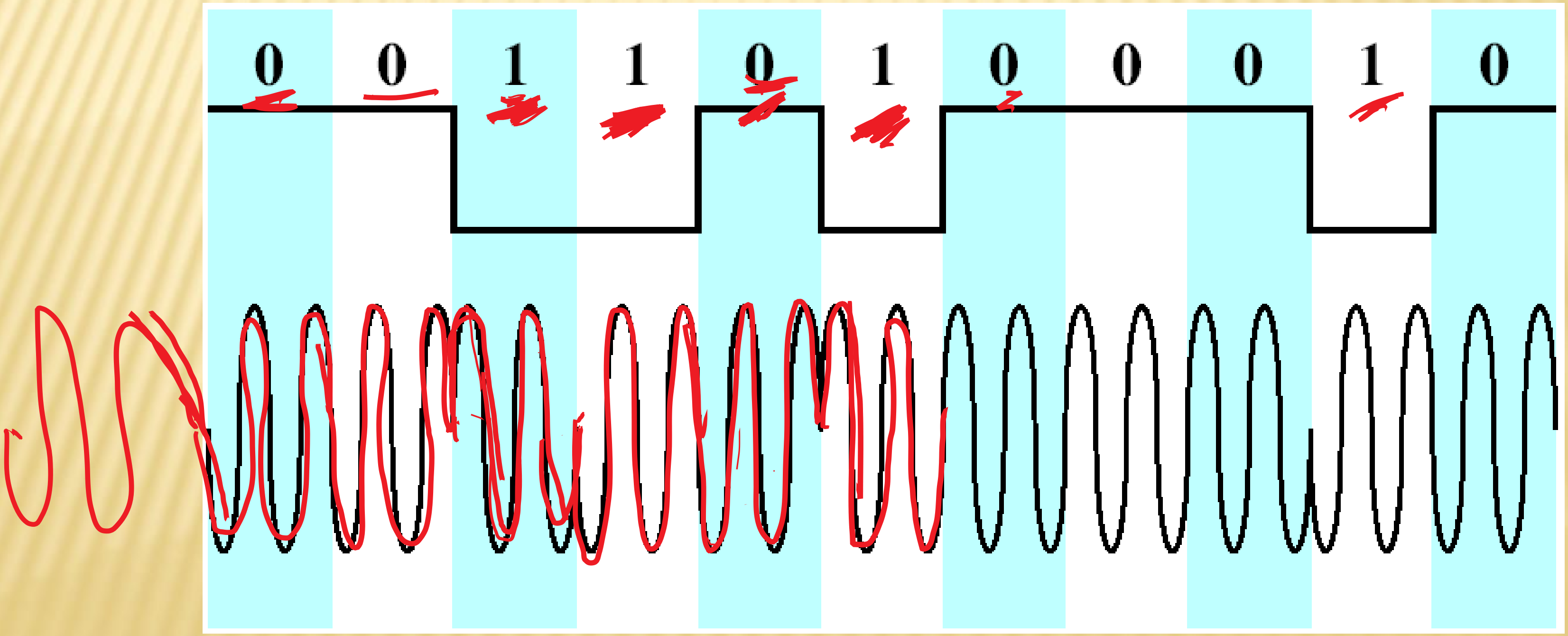
- phase of carrier signal is shifted to represent data
- binary PSK
  - two phases represent two binary digits

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



DPSK

- differential PSK
  - phase shifted relative to previous transmission rather than some constant reference signal



FOUR-LEVEL PSK: QUADRATURE PSK

(QPSK)

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

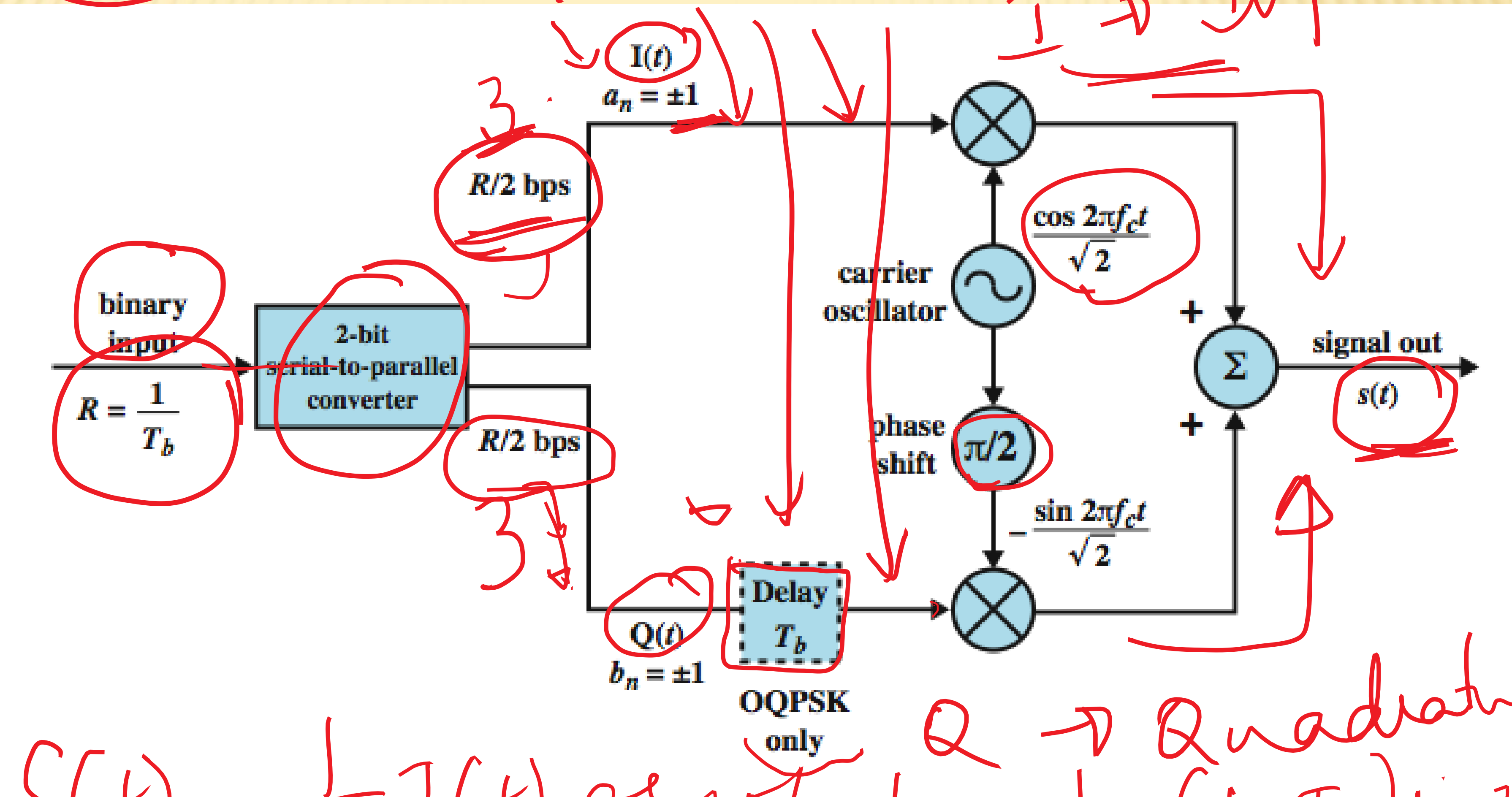
$$\textbf{QPSK} \qquad s(t) = \begin{cases} A\cos\left(2\pi f_c t + \dfrac{\pi}{4}\right) & 11 \\ A\cos\left(2\pi f_c t + \dfrac{3\pi}{4}\right) & 01 \\ A\cos\left(2\pi f_c t - \dfrac{3\pi}{4}\right) & 00 \\ A\cos\left(2\pi f_c t - \dfrac{\pi}{4}\right) & 10 \end{cases}$$

QPSK AND OQPSK MODULATORS

→ Offset QPSK & orthogonal QPSK

101110

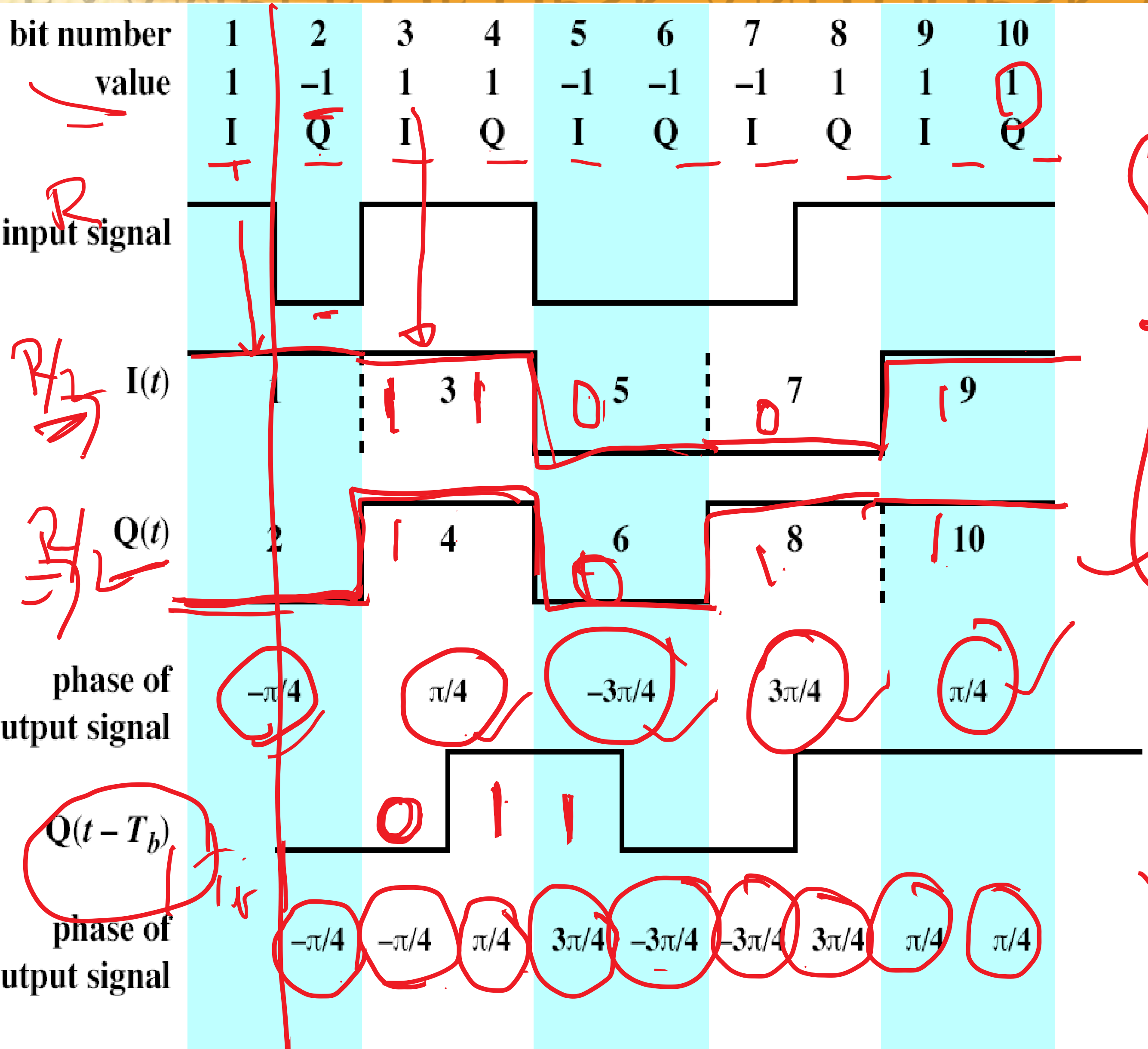
I → Inphase



Q → Quadrature

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

EXAMPLE OF QPSK AND OQPSK WAVEFORMS



$for \quad QPSK:$

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

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

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

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

MULTILEVEL PSK:

- More than 2 bits at a time.
- Possible to transmit 3 bits at a time using 8 different phase angles & more than one amplitude
- 9600bps modem uses 12 angles, four of which have two amplitudes. Therefore can represent 16 signal elements.

PERFORMANCE OF DIGITAL TO ANALOG MODULATION SCHEMES

- Bandwidth Efficiency
  - ASK/PSK: $\dfrac{data\ rate}{transmission\ bandwidth} = \dfrac{R}{B_T} = \dfrac{1}{1+r}, \qquad 0 < r < 1$
  - MPSK: $\dfrac{R}{B_T} = \dfrac{\log_2 M}{1+r}, \qquad M: number\ of\ different\ signal\ elements$
  - MFSK: $\dfrac{R}{B_T} = \dfrac{\log_2 M}{(1+r)M}$
- Bit Error Rate (BER)
  - bit error rate of DPSK and BPSK are about 3dB superior to ASK and BFSK
  - for MFSK & MPSK have tradeoff between bandwidth efficiency and error performance

PERFORMANCE OF MFSK AND MPSK

- MFSK: increasing M decreases BER and decreases bandwidth Efficiency
- MPSK: Increasing M increases BER and increases bandwidth efficiency

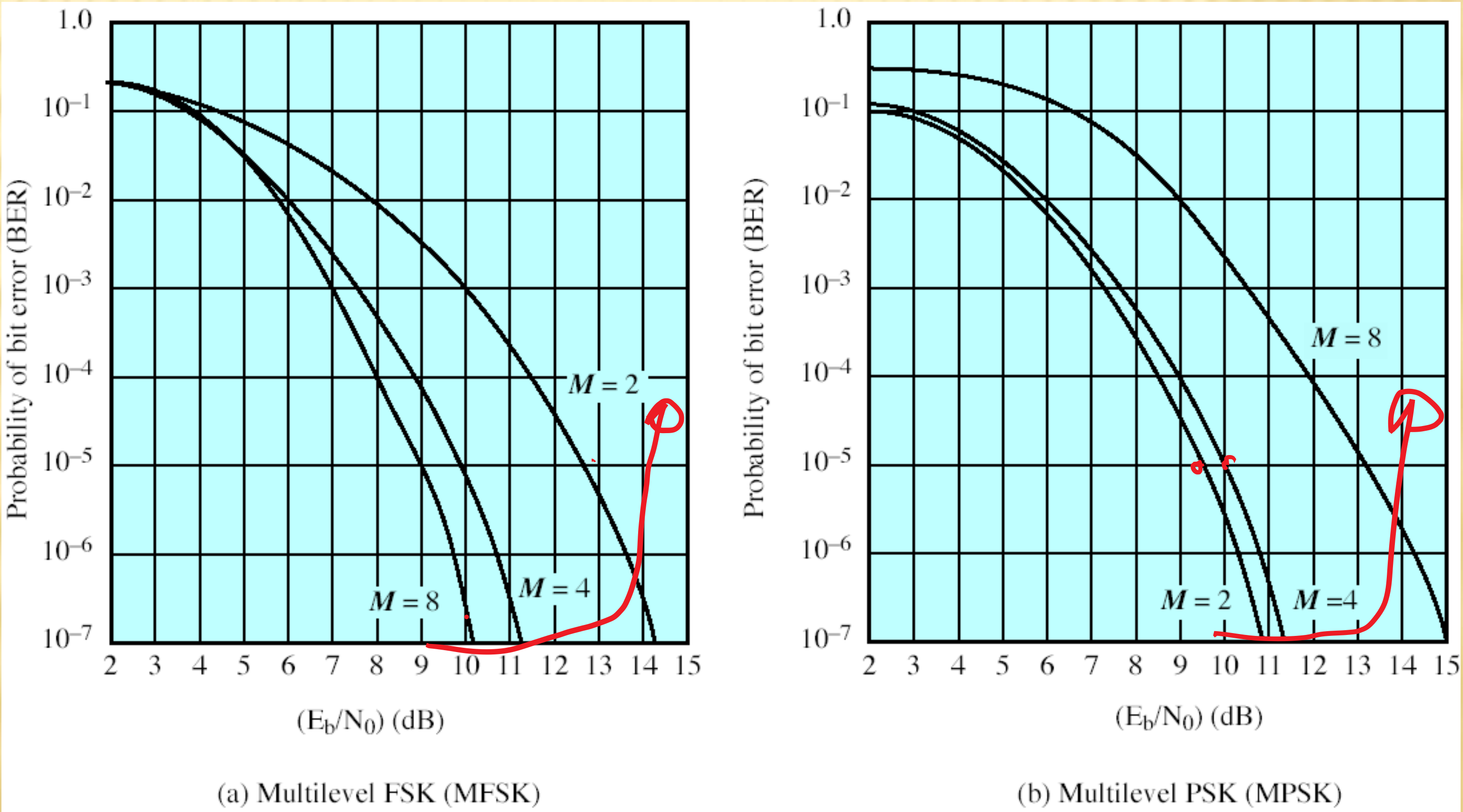


Figure 5.13 Theoretical Bit Error Rate for Multilevel FSK and PSK

Bandwidth requirement for Digital signaling

$B_T = 0.5(1 + r)D$ where D is the modulation rate.

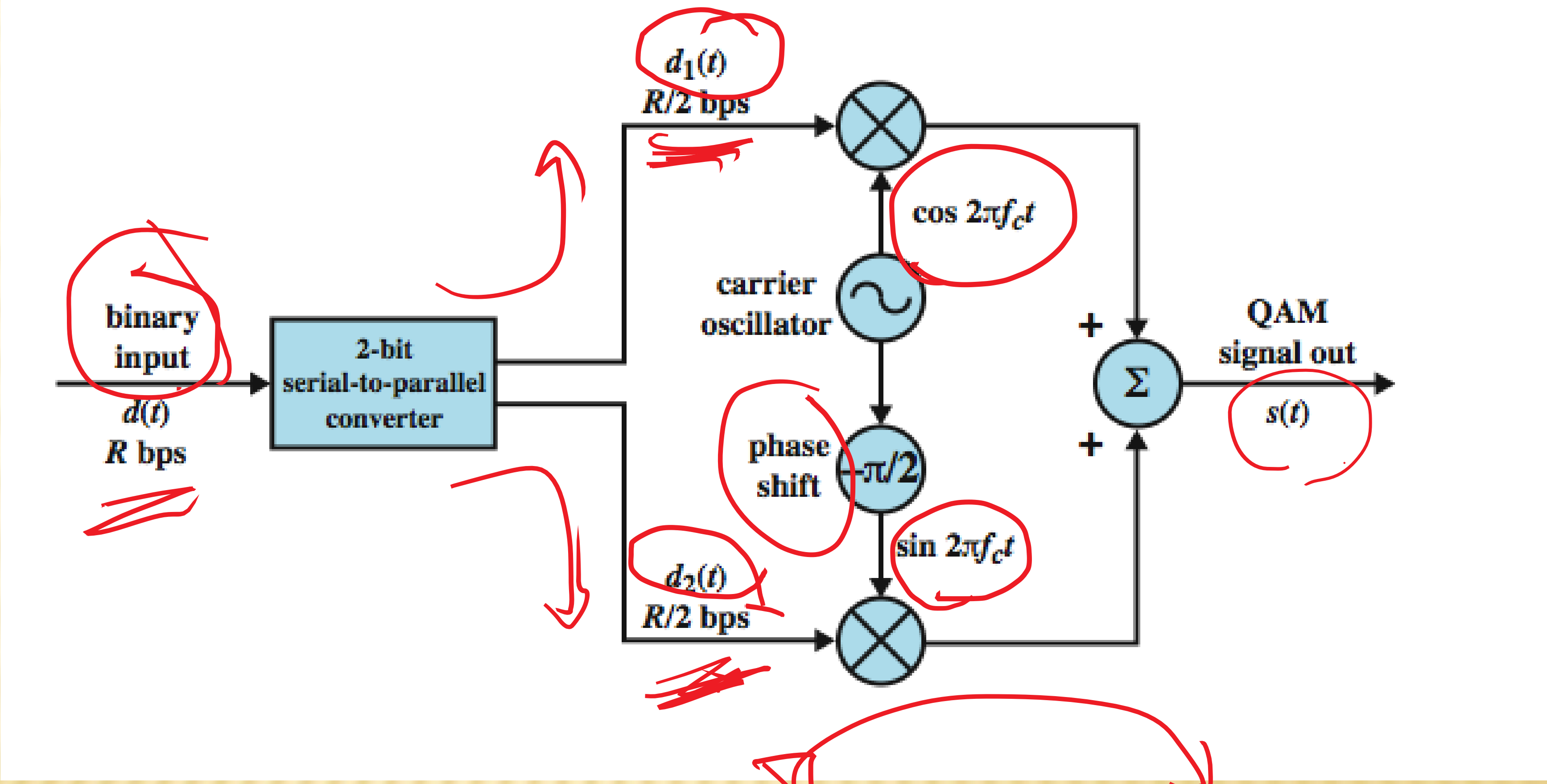
For NRZ, D = R, and we have

$$\frac{R}{B_T} = \frac{2}{1 + r}$$

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 medium.
  - use two copies of carrier, one shifted by 90°
  - each carrier is ASK modulated

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 4 ×4=16 states
- Have 64 and 256 state systems
- Improved data rate for given bandwidth
  - but increased potential error rate due to noise and attenuation.

Given the bit pattern 01100, encode this data using ASK, BFSK, and BPSK.