(DEEMED TO BE UNIVERSITY)

Digital Communication 23EC2208A

Digital Carrier Modulation

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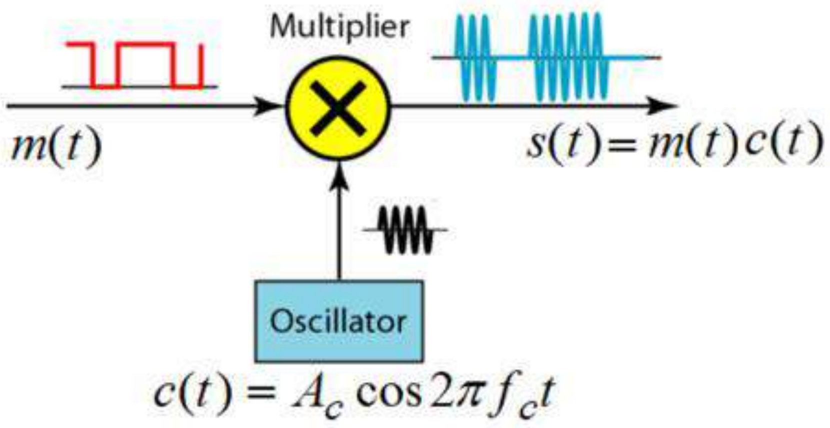
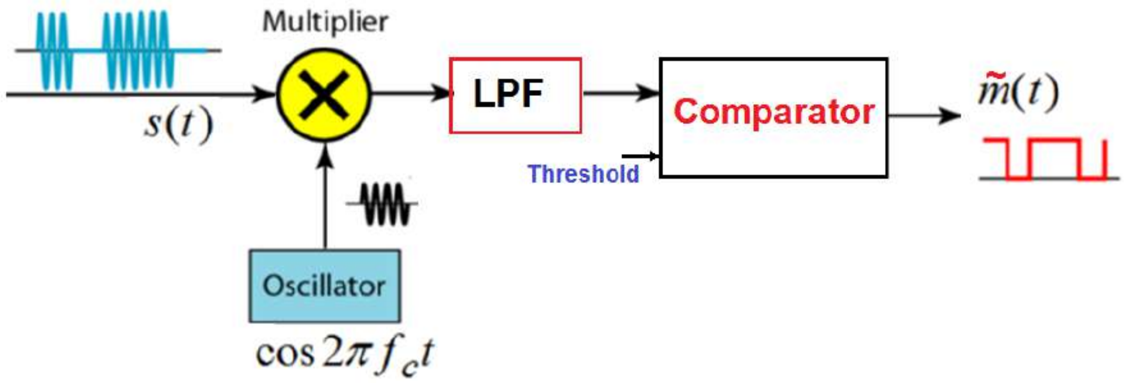
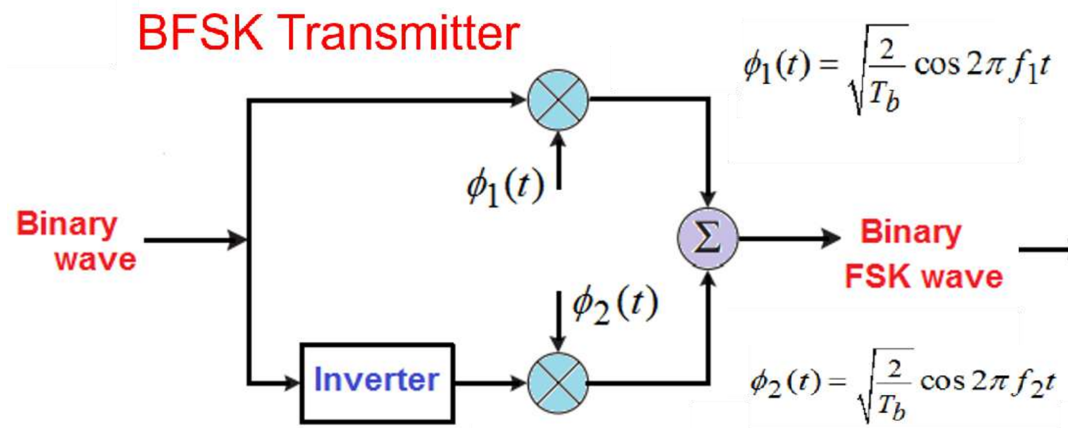
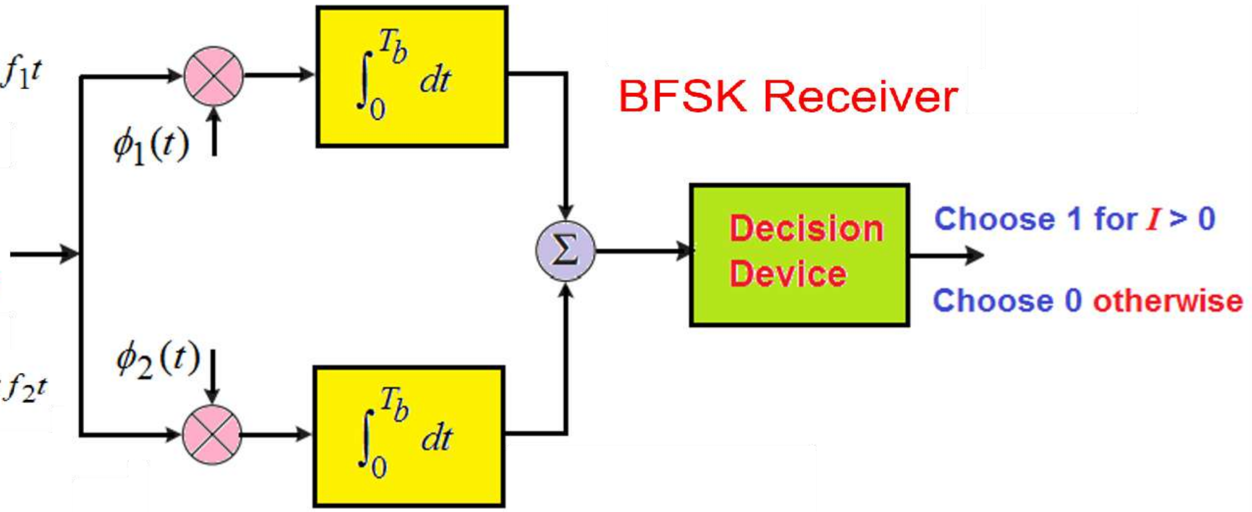
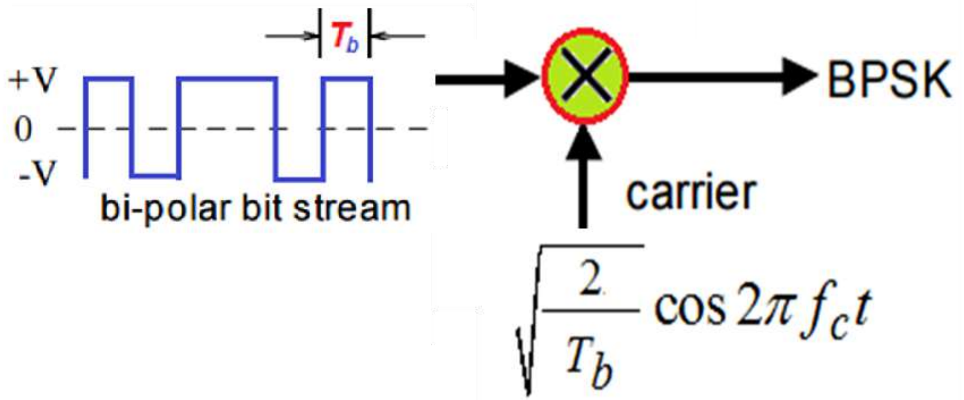
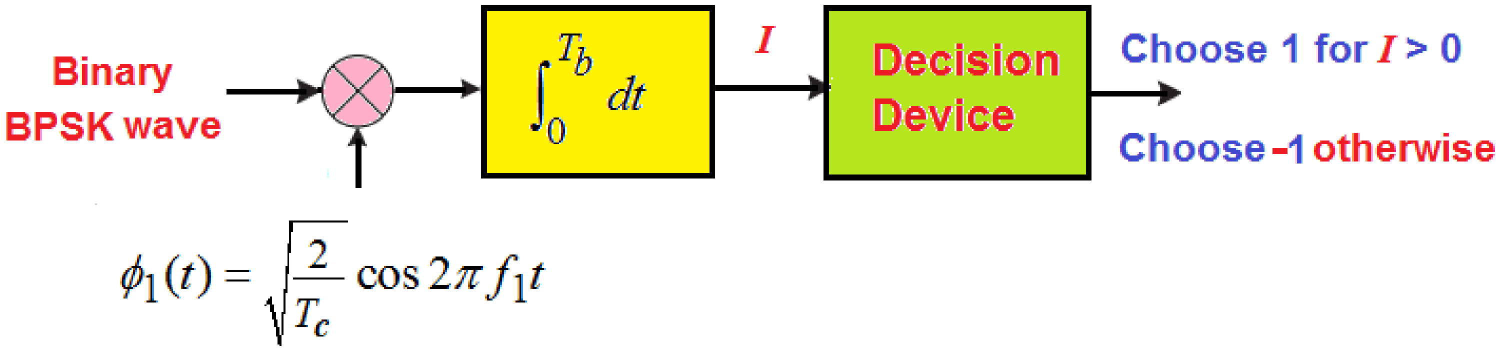

Multiplier
$m(t)$
$s(t)=m(t)c(t)$
Oscillator
$c(t) = A_c \cos 2\pi f_c t$


Multiplier
$s(t)$
LPF
Comparator
Threshold
$\tilde{m}(t)$
Oscillator
$\cos 2\pi f_c t$


BFSK Transmitter
Binary wave
Inverter
$\phi_1(t)$
$\phi_2(t)$
Σ
Binary FSK wave
$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_1 t$
$\phi_2(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_2 t$


BFSK Receiver
$\phi_1(t)$
$\phi_2(t)$
$\int_0^{T_b} dt$
$\int_0^{T_b} dt$
Σ
Decision Device
Choose 1 for $I > 0$
Choose 0 otherwise

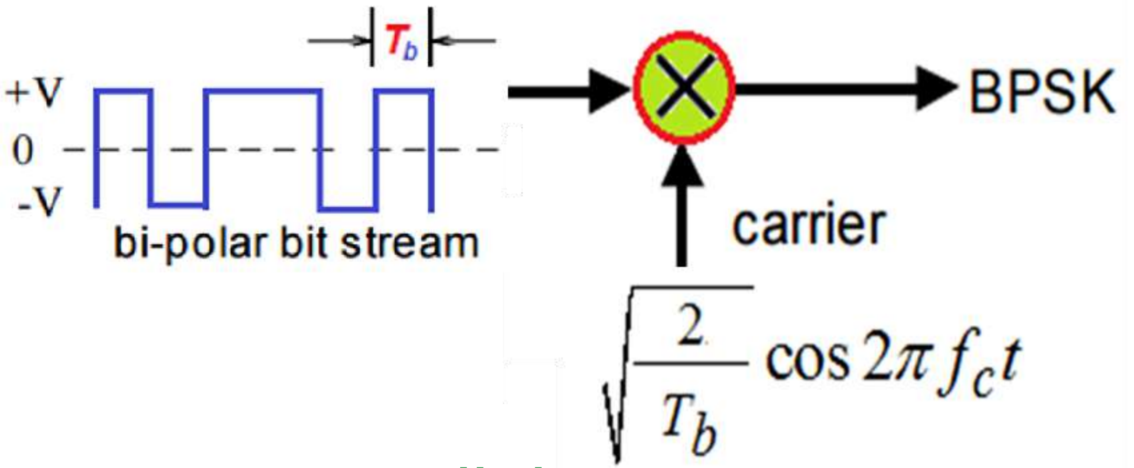

T_b
+V
0
-V
bi-polar bit stream
BPSK
carrier
$\sqrt{\frac{2}{T_b}} \cos 2\pi f_c t$


Binary BPSK wave
$\int_0^{T_b} dt$
I
Decision Device
Choose 1 for $I > 0$
Choose -1 otherwise
$\phi_1(t) = \sqrt{\frac{2}{T_c}} \cos 2\pi f_1 t$

Binary Phase Shift Keying (BPSK)

Binary Phase-shift keying (BPSK)

- Phase-shift keying (PSK) is another form of angle-modulated, constant-amplitude digital modulation.



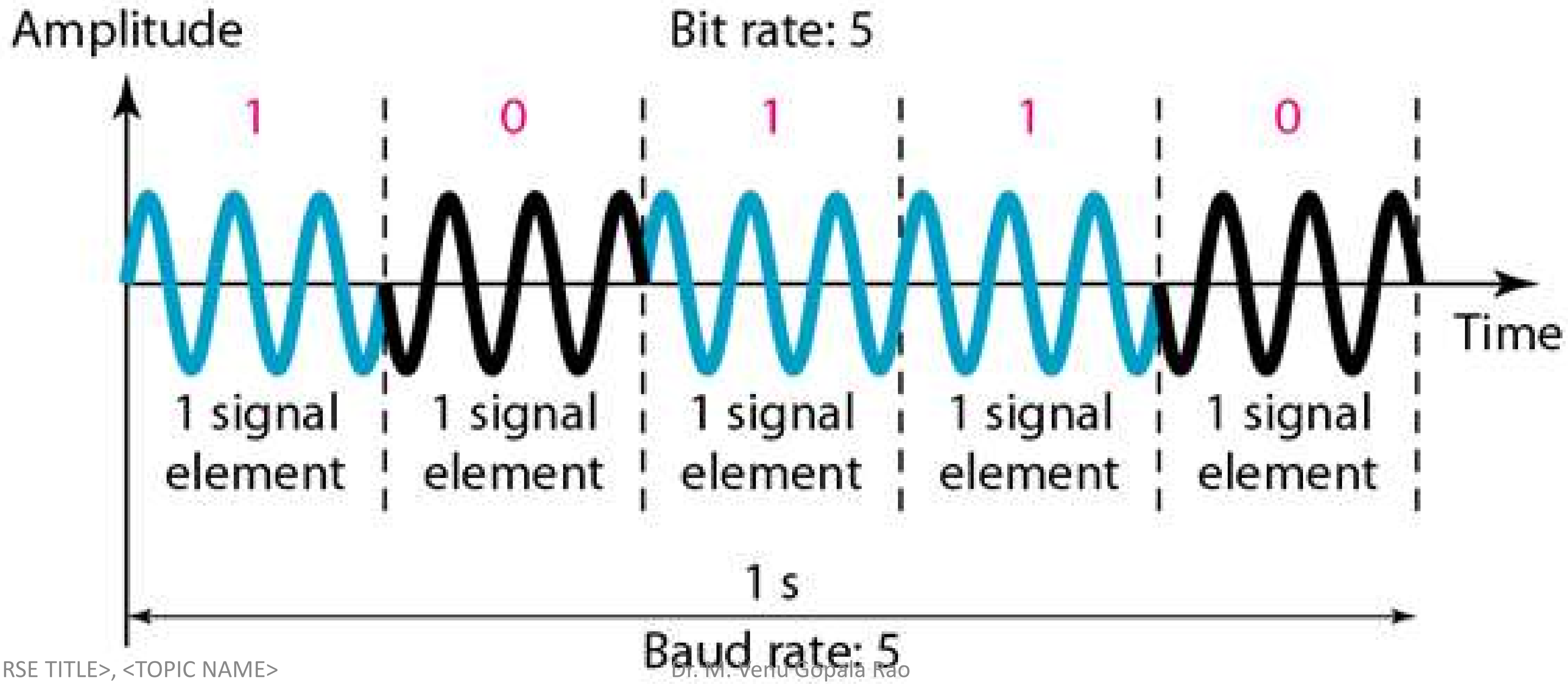
- Vary the phase shift of the carrier signal to represent digital data.

$$E_b = T_b P_c = \frac{A_c^2}{2} T_b$$

$$s(t) = \begin{cases} s_1(t) = \sqrt{\dfrac{2E_b}{T_b}}\cos 2\pi f_c t, & \text{for Symbol '1'} \\ s_2(t) = \sqrt{\dfrac{2E_b}{T_b}}\cos(2\pi f_c t + \pi) = -\sqrt{\dfrac{2E_b}{T_b}}\cos 2\pi f_c t & \text{for Symbol '0'} \end{cases}, 0 \le t \le T_b$$

$$
s(t) = \begin{cases} s_1(t) = \sqrt{\dfrac{2E_b}{T_b}} \cos 2\pi f_c t, & \text{for Symbol '1'} \\ s_2(t) = -\sqrt{\dfrac{2E_b}{T_b}} \cos 2\pi f_c t + \pi) & \text{for Symbol '0'} \end{cases}
$$

180^{o} Phase shift



Signal Space for BPSK

Two orthogonal basis functions are required for BFSK

$$E_b = T_b P_c = \frac{A_c^2}{2} T_b$$

$$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_1 t,\ 0 \le t \le T_b;\ s_1(t) = \sqrt{2E_b}\,\phi_1(t)$$

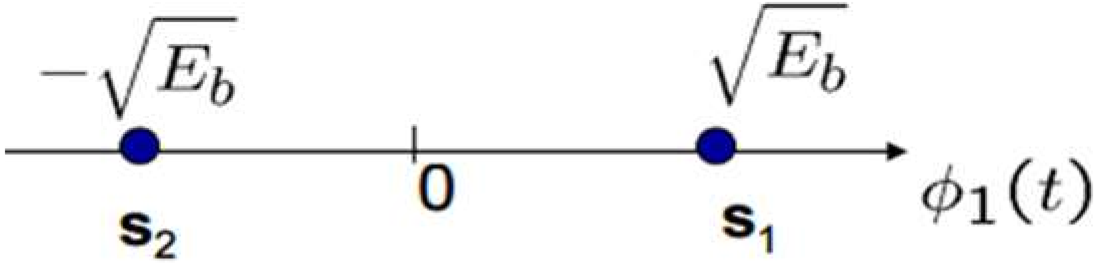
$$s_1(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_1 t,\ 0 \le t \le T_b;$$

$$\phi_2(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_2 t,\ 0 \le t \le T_b;\ s_2(t) = \sqrt{2E_b}\,\phi_2(t)$$

$$s_2(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_2 t,\ 0 \le t \le T_b;$$

Signal Space Representation for BPSK

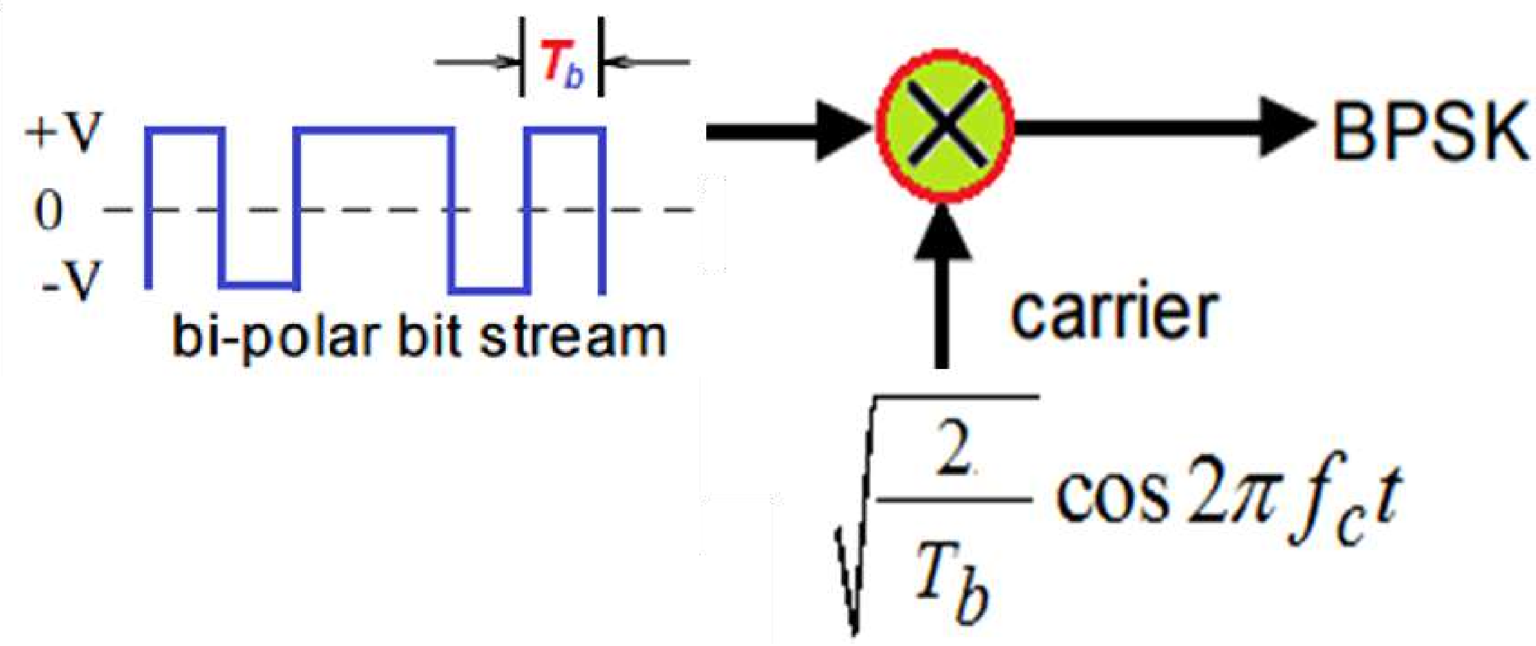
- There is **one** basis function $\phi_1(t) = \sqrt{\frac{2}{T_b}}\cos(2\pi f_c t)$ with $0 \le t < T_b$
- Then $s_1(t) = \sqrt{E_b}\phi_1(t)$ and $s_2(t) = -\sqrt{E_b}\phi_1(t)$
- A binary PSK system is characterized by a signal space that is one-dimensional (i.e. ***n*=1**), and has two message points (i.e. $M=2$)



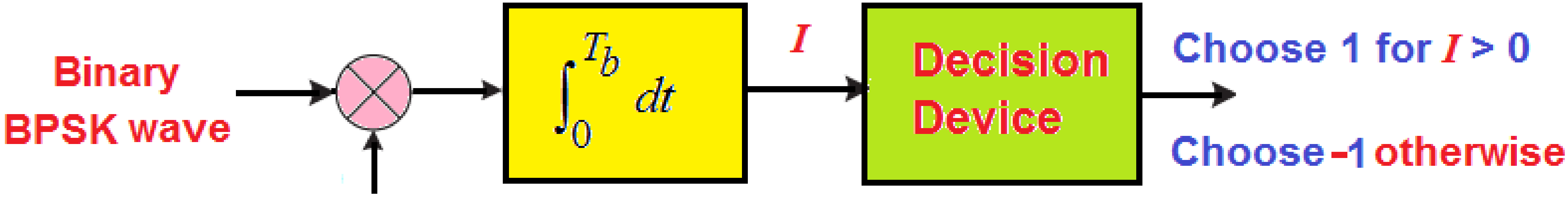
$$d_{12} = 2\sqrt{E_b}$$

Assume that the two signals are equally likely, i.e. $P(s_1) = P(s_2) = 0.5$

BPSK Transmitter



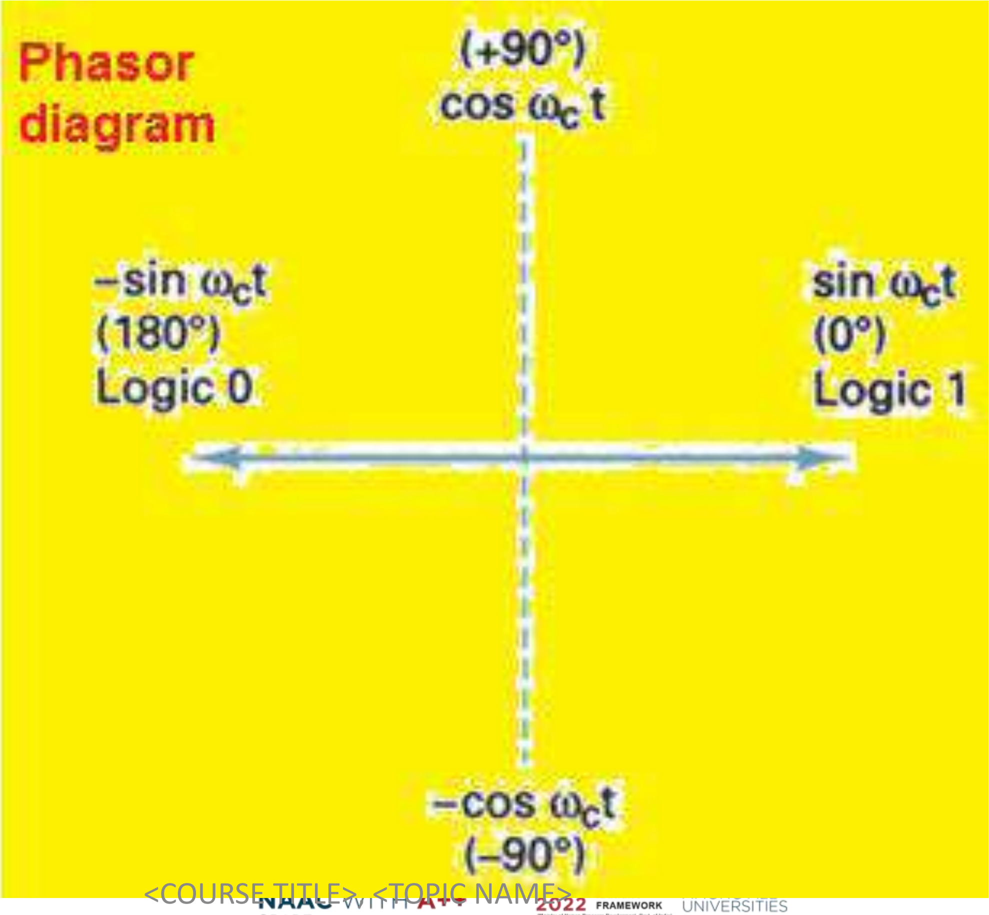
BPSK Receiver

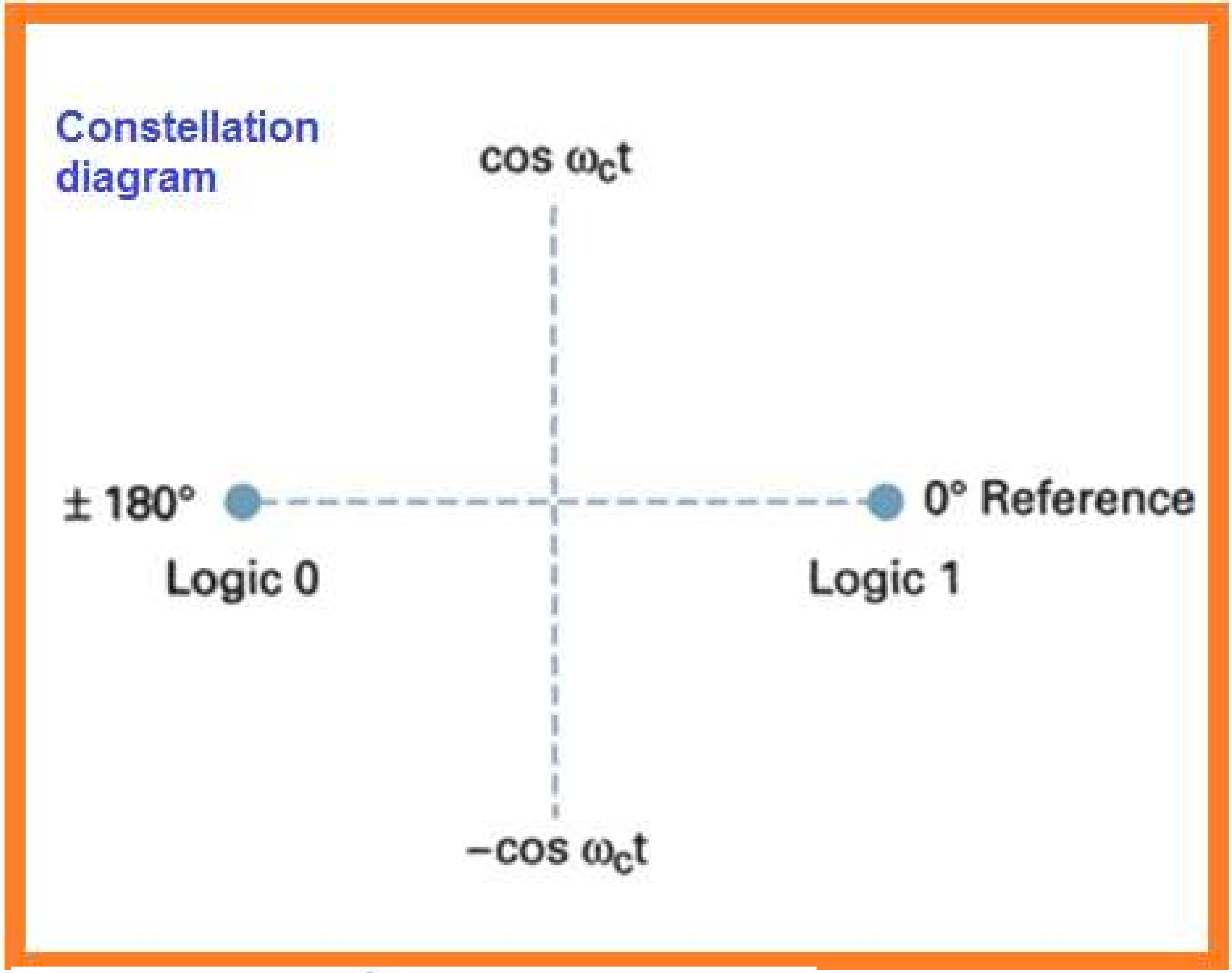


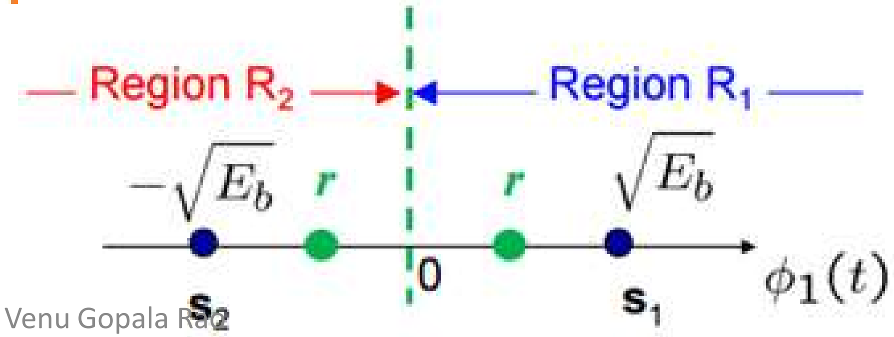
$$\phi_1(t) = \sqrt{\frac{2}{T_c}} \cos 2\pi f_1 t$$

Truth Table

Binary input	Output phase
Logic 0	180°
Logic 1	0°







Bit Error Rate for BPSK

$$BER_{BPSK} = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

Compare the SNR / bit and average power required at the demodulator to maintain a BER = 10^{-6} using BPSK and BFSK for data transmission over a radio channel at 56 kbps. Assume that the channel adds white Gaussian noise with power spectral density $N_0 = 10^{-10}$.

(Hint: $Q(x) = 10^{-6} \Rightarrow x = 4.75$)

Ans: (i) $BER_{BPSK} = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \Rightarrow \sqrt{\frac{2E_b}{N_0}} = 4.75 \Rightarrow E_b = 1.128\text{x}10^{-9}$

$$P_{av} = \frac{E_b}{T_b} = E_b R_b = 1.128\text{x}10^{-9}\text{x}56\text{x}10^3 = 63.17\,\mu\text{W}$$

(ii) $BER_{BFSK} = Q\left(\sqrt{\frac{E_b}{N_0}}\right) \Rightarrow \sqrt{\frac{E_b}{N_0}} = 4.75 \Rightarrow E_b = 2.256\text{x}10^{-9}$

$$P_{av} = \frac{E_b}{T_b} = E_b R_b = 2.256\text{x}10^{-9}\text{x}56\text{x}10^3 = 126.34\,\mu\text{W}$$

Find the bit error probability for a BPSK system with a bit rate of 1 Mbps. The received waveforms $s_1(t) = A\cos\omega_0 t$ and $s_2(t) = -A\cos\omega_0 t$ are coherently. The value of A is 10 mV. Assume that the single sided noise power spectral density is $N_o = 10^{-11}$ W/Hz.

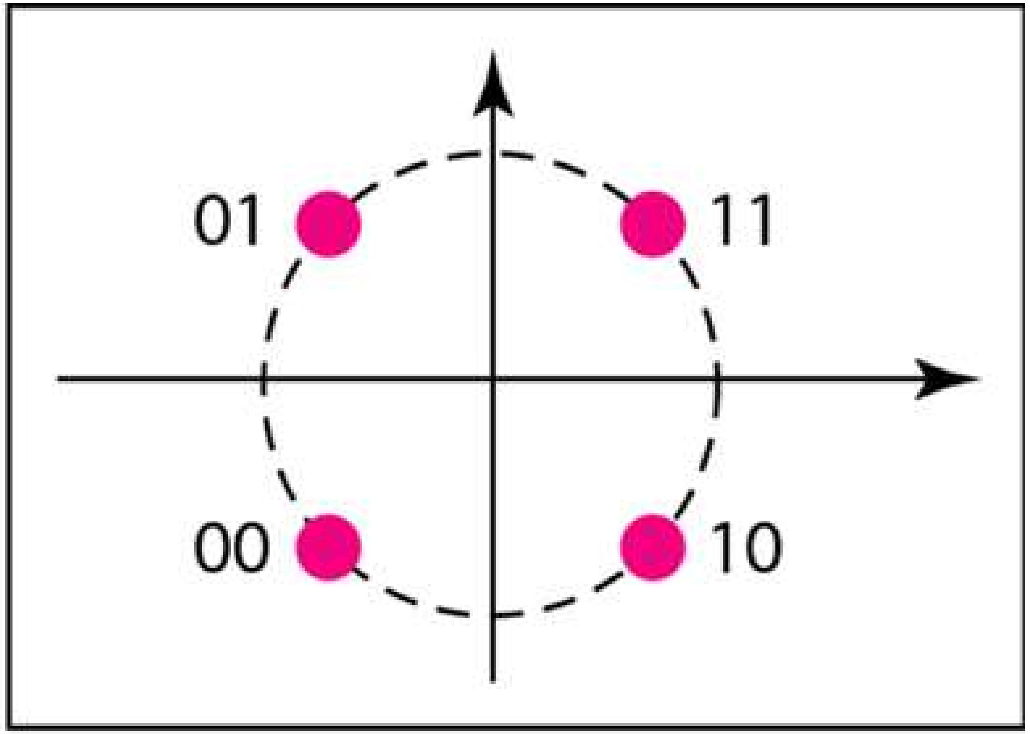
Use $Q(\sqrt{10}) = 8\text{x}10^{-4}$.

Quaternary Phase-Shift Keying (Quadriphase-shift Keying) QPSK

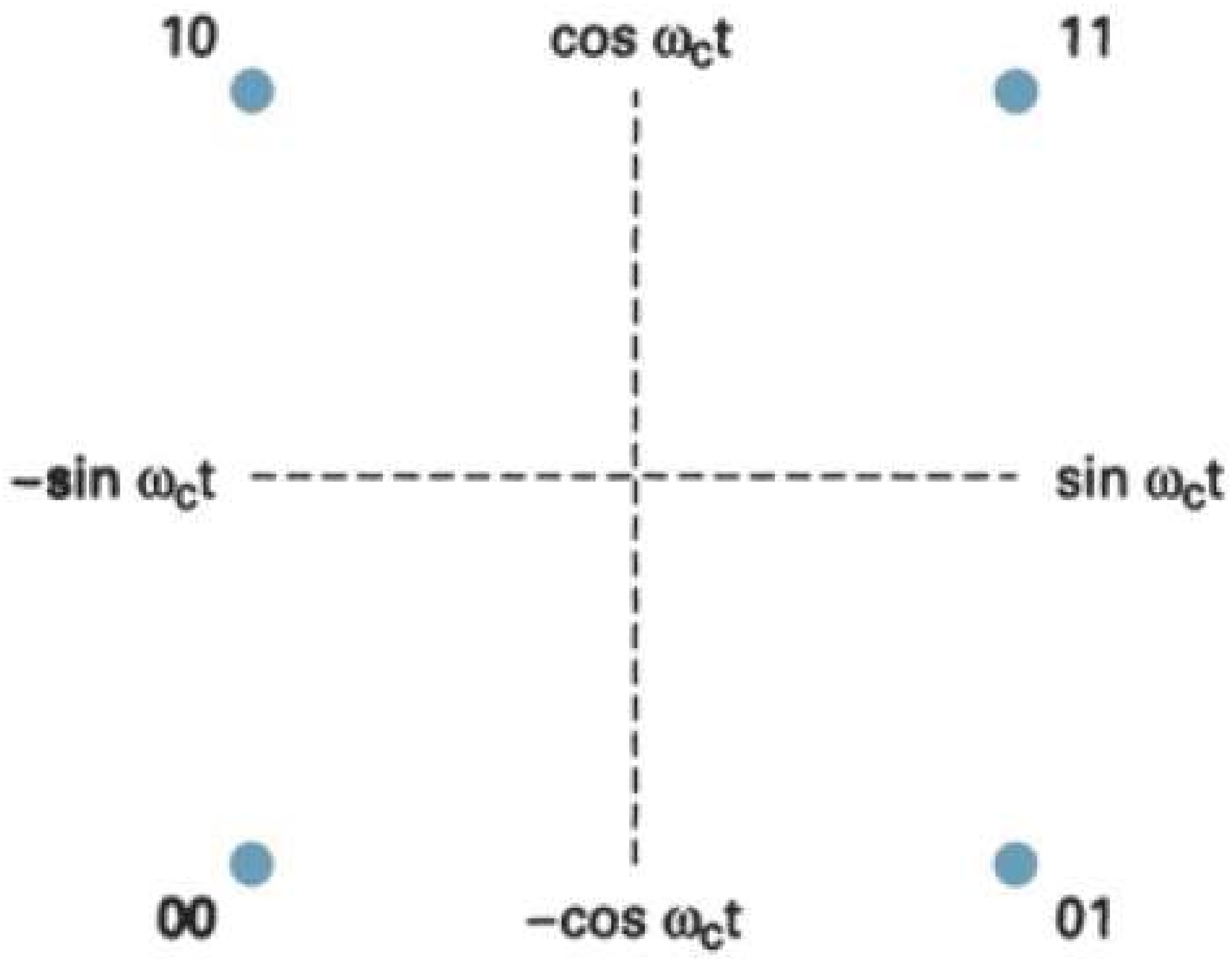
- Quaternary phase shift keying (QPSK), or quadrature PSK as it is sometimes called, is another form of angle-modulated, constant-amplitude digital modulation.
- QPSK is an M-ary encoding scheme where n = 2 and M = 4 (hence, the name "quaternary" meaning "4").
- With QPSK, four output phases are possible for a single carrier frequency. Because there are four output phases, there must be four different input conditions.
- With two bits, there are four possible conditions: 00, 01, 10, and 11.
- Therefore, with QPSK, the binary input data are combined into groups of two bits, called dibits.
- In the modulator, each dibit code generates one of the four possible output phases (-45°, -135°, 45°, and 135°).

$$s_i(t) = \begin{cases} \sqrt{\dfrac{2E_b}{T_b}} \cos\left\{2\pi f_c t + (2i-1)\dfrac{\pi}{4}\right\}, & 0 \le t \le T_b \\ 0, & Otherwise \end{cases} \qquad i = 1, 2, 3, 4$$

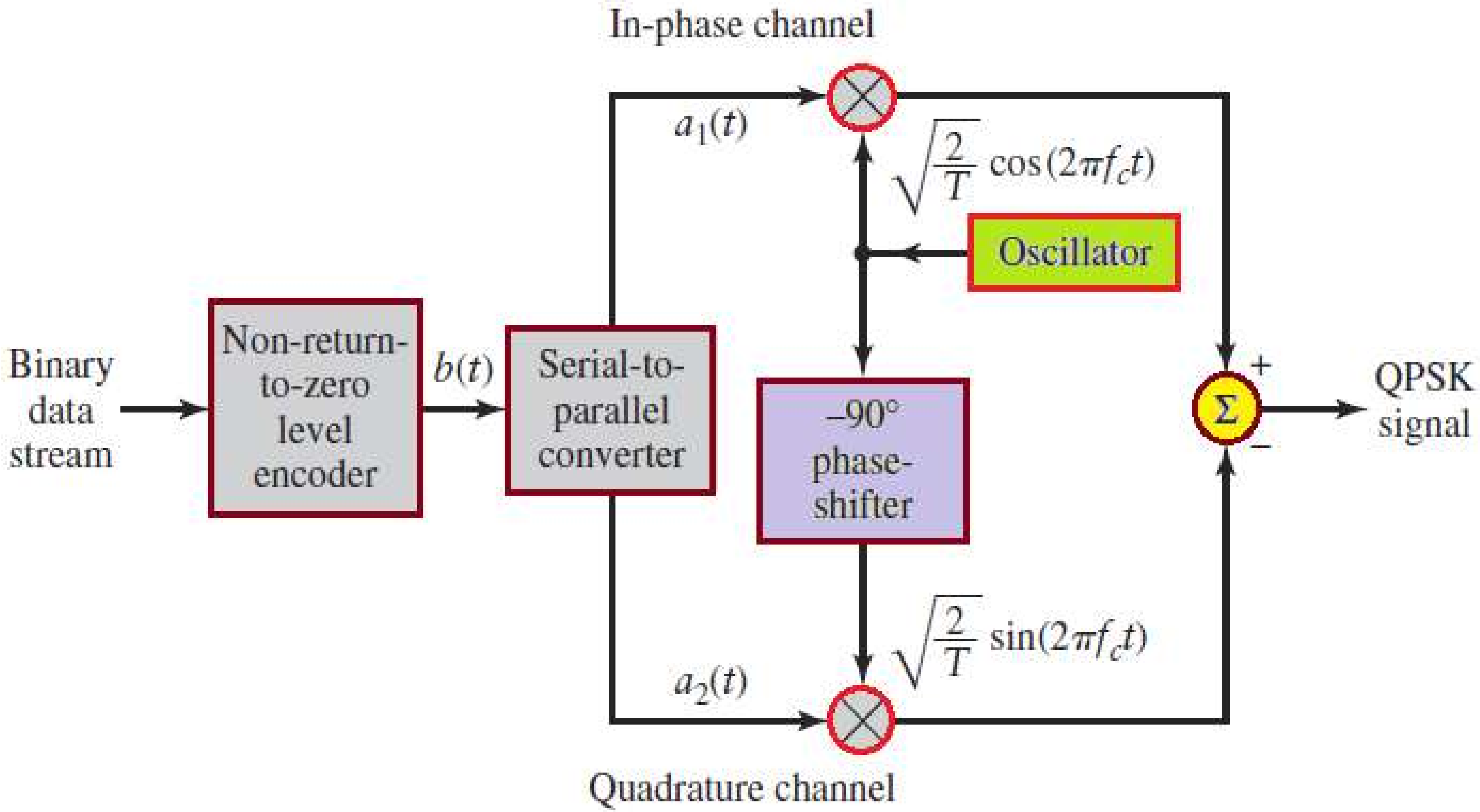
$$s(t) = \begin{cases} A\cos\left(2\pi f_c t + \dfrac{\pi}{4}\right) & 11 \\ A\cos\left(2\pi f_c t + \dfrac{3\pi}{4}\right) & 01 \\ A\cos\left(2\pi f_c t - \dfrac{3\pi}{4}\right) & 00 \\ A\cos\left(2\pi f_c t - \dfrac{\pi}{4}\right) & 10 \end{cases}$$



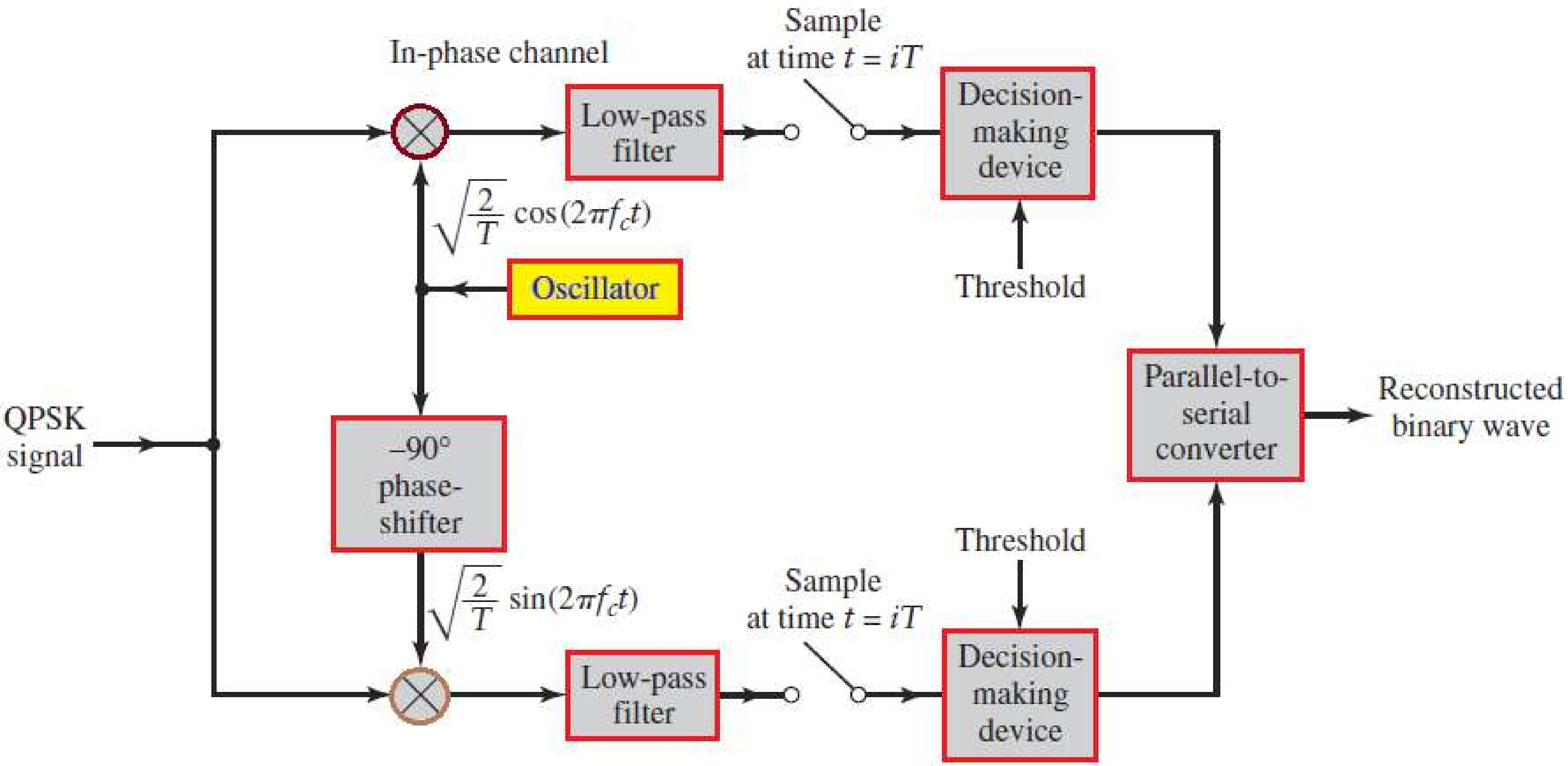
Constellation diagram



QPSK Modulator



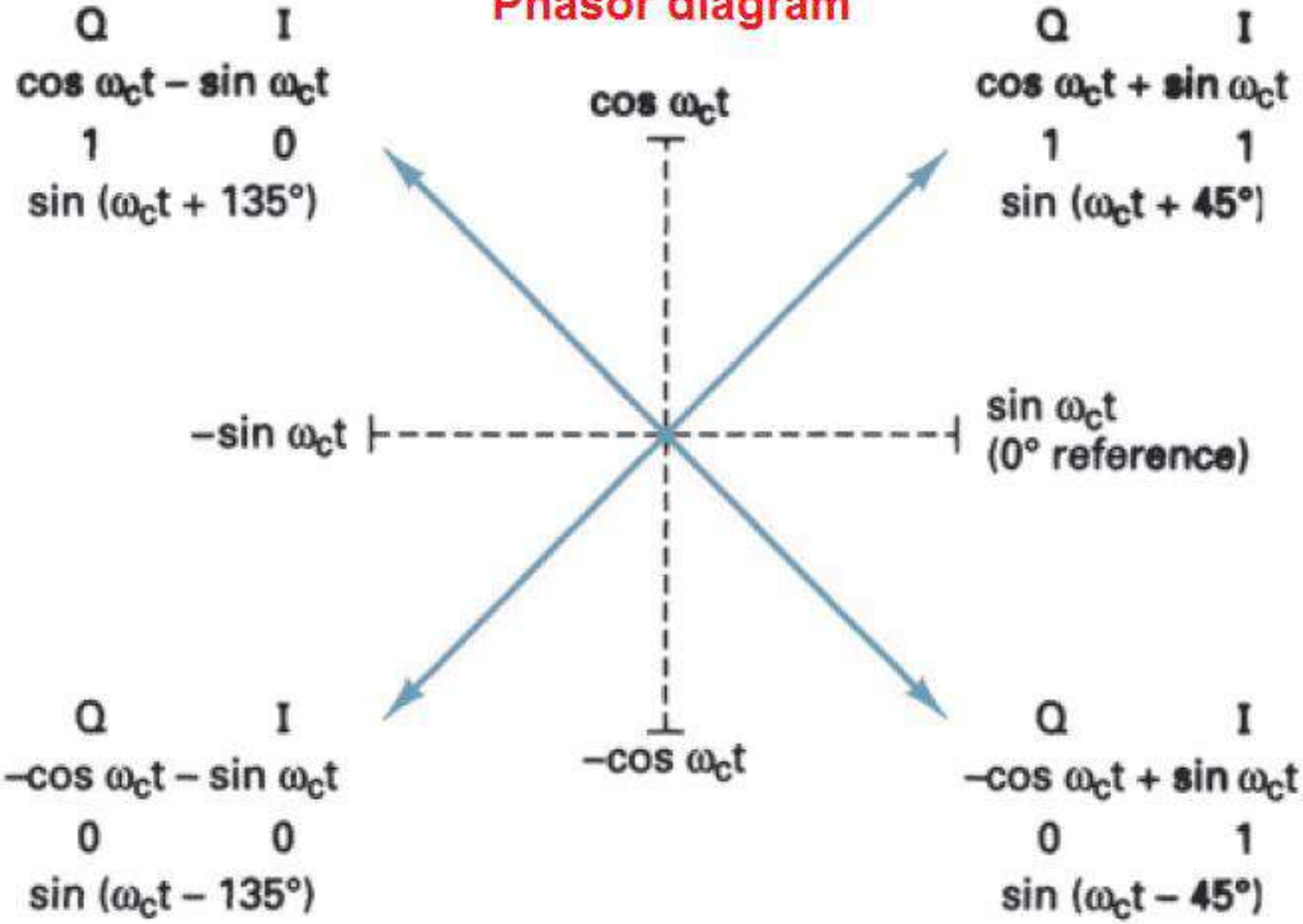
Receiver


In-phase channel
Low-pass filter
Sample at time $t = iT$
Decision-making device
$\sqrt{\frac{2}{T}}\cos(2\pi f_c t)$
Oscillator
Threshold
QPSK signal
$-90°$ phase-shifter
Parallel-to-serial converter
Reconstructed binary wave
Threshold
$\sqrt{\frac{2}{T}}\sin(2\pi f_c t)$
Sample at time $t = iT$
Low-pass filter
Decision-making device

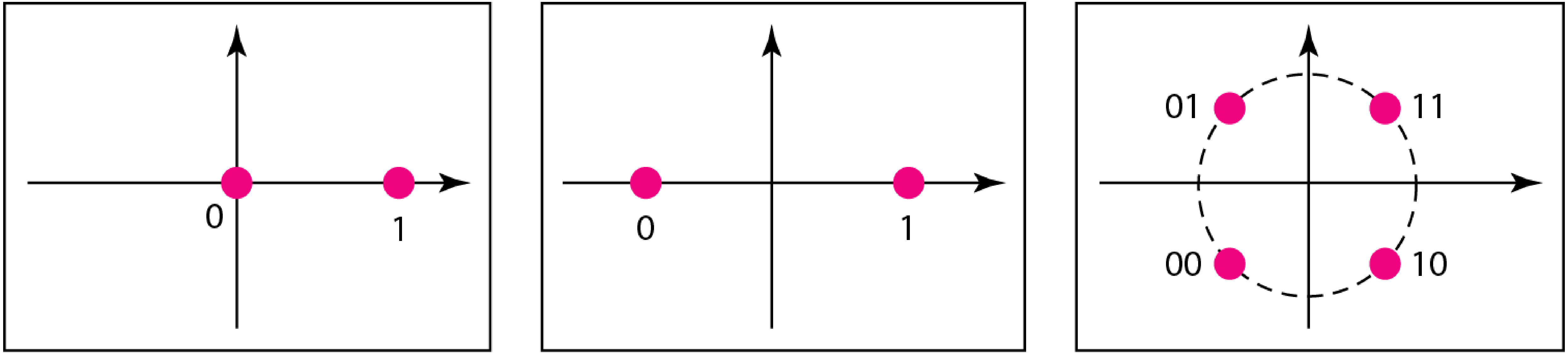
Truth Table

Binary input Q	Binary input I	QPSK output phase
0	0	−135°
0	1	−45°
1	0	+135°
1	1	+45°

Phasor diagram



The constellation diagrams for an ASK (OOK), BPSK, and QPSK signals.



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

- Amplitude Shift Keying (ASK): Bandwidth = bit rate.
- Frequency Shift Keying (FSK): Bandwidth = 2 x (frequency deviation + bit rate).
- Phase Shift Keying (PSK): Bandwidth = bit rate.
- Quadrature Phase Shift Keying (QPSK): Bandwidth = 2 x bit rate

$$BER_{ASK} = Q\left(\sqrt{\frac{E_b}{N_0}}\right) \qquad BER_{FSK} = Q\left(\sqrt{\frac{E_b}{N_0}}\right)$$

$$BER_{BPSK} = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \qquad BER_{QPSK} = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

End