Bit rate and Baud rate

- Bit rate (R) - It is number of bits/sec.
- Baud rate (γ) - It is number of symbols/sec [elements/sec]
- If n = number of bits/symbol [bits/element].
- $\boxed{\gamma = \frac{R}{n}}$
- Total number of symbols [elements] = $L = 2^n$

$\overline{n}$

- Total number of symbols [elements] $= L = 2^n$

Example - An Analog signal carries 4 bits / signal elements. If 1000 signal elements are sent per second. Find the bit rate.

- $n = 4$ bits / elements
- $r = 1000$ baud $\left[\frac{\text{elements}}{\text{sec}}\right]\left[\frac{\text{symbols}}{\text{sec}}\right]$
- $R = n r$

$= 4 \times 1000 = 4000$ bits/sec $= 4$ Kbps

$\rightarrow L = 2^n$

$= 2^4$

$= 16$

Example - An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

- $R = 8000$ bps
  $r = 1000$ baud
  $n = ?$
  $L = ?$

- $n = \frac{R}{r}$
  $= \frac{8000}{1000}$
  $= 8$ bits/element

- $L = 2^n$
  $= 2^8$
  $= 256$

- Advantages of ASK
- Disadvantages of ASK
- Applications of ASK

- Basics of ASK

- It is digital to Analog conversion technique

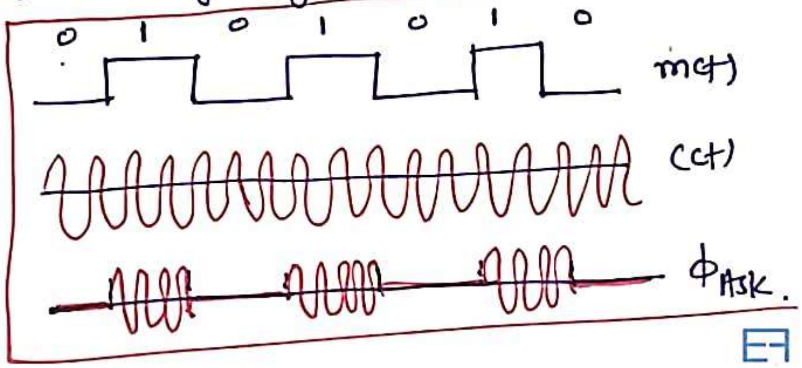
Definition : The amplitude of carrier signal varies w.r.t amplitude of message signal.

010101

$m(t) \longrightarrow \otimes \longrightarrow \phi_{ASK}$

$\uparrow$ carrier

$c(t) = \cos \omega_c t$



→ for binary n = 1

BASK or OOK

BASK or OOK

- Bandwidth of ASK

$$m(t) \longrightarrow \otimes \longrightarrow \phi_{ASK} = m(t)\cos\omega_c t$$

$$\uparrow$$

$$c(t) = \cos\omega_c t$$

$\Rightarrow$ $BW \propto r$

$\Rightarrow$ $BW = (1+d)\,r$

$\Rightarrow$ $\boxed{BW = (1+d)\dfrac{R}{n}}$

where r = baud rate

R = data rate

n = no of bits req.^{d} for sample.

d = Factor for modulation & filtering process.

$d \in (0, 1)$

$\boxed{BW = r}$ $\leftarrow$ For ideal — 0

1 — worse modulation $\boxed{BW = 2r}$

Modulation of ASK

$$\begin{tikzcd} m(t) \overset{01010}{} \arrow[r] & \otimes \arrow[r] & \phi_{ASK} = m(t)\cos\omega_c t \\ & c(t) = \cos\omega_c t \arrow[u] & \end{tikzcd}$$

where, $m(t) = \begin{cases} 1 & \text{+Ve voltage} \\ 0 & \text{No voltage} \end{cases}$

Demodulation of ASK

Demodulation of ASK

Synchronous (Coherent)

$m(t)\cos\omega_c t \longrightarrow \otimes \xrightarrow{m(t)\cos^2\omega_c t} \boxed{\text{LPF}} \longrightarrow m(t).$

$\uparrow \cos\omega_c t$

Adv – It is efficient

Disadv – It is Costly

Non Synchronous (Non Coherent).

$m(t)\cos\omega_c t \longrightarrow \boxed{\text{Envelope}} \longrightarrow m(t).$

Adv – Cost is low.

Disadv – Performance is Poor with Less SNR received signal.

(Coherent)

$$m(t)\cos\omega_c t \longrightarrow \bigotimes \xrightarrow{m(t)\cos^2\omega_c t} \boxed{\text{LPF}} \longrightarrow m(t).$$

$$\uparrow \cos\omega_c t$$

Adv – It is efficient

Disadv – It is costly.

$$m(t)\cos\omega_c t \longrightarrow \boxed{\text{Envelope}} \longrightarrow m(t).$$

Adv – Cost is low.

Disadv – Performance is poor with less SNR received signal.

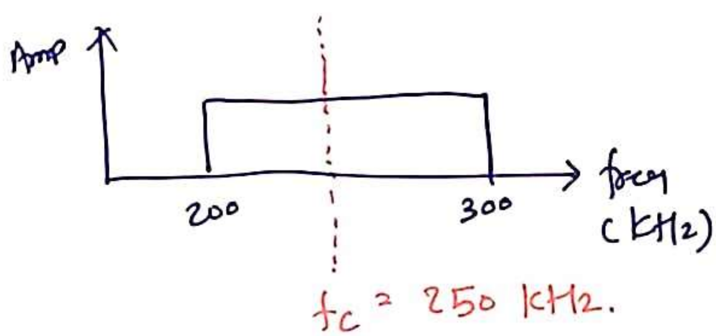
Applications of ASK.

- broadcasting of signal
- In optical fiber communication for laser intensity modulation

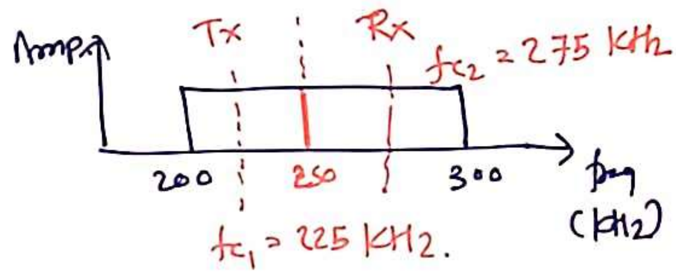
Example on ASK (Amplitude Shift Keying)

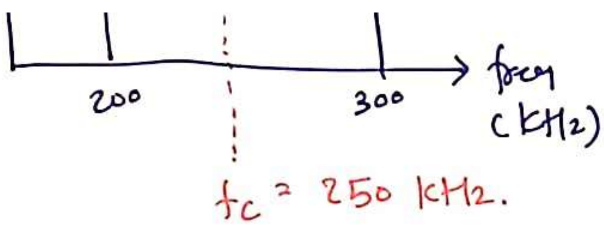
- We have an available BW of 100 KHz which spans from 200 to 300 KHz. What are the carrier frequency and bit rate, if we modulated our data by using BASK with $d = 1$?

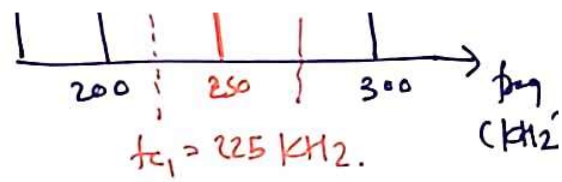
→ Half duplex



→ Full duplex







$\rightarrow$ $BW = 100\ KHz.$

$n = 1$

$d = 1$

$R = ?$

$\Rightarrow BW = (1+d)\,r$

$\Rightarrow 100\ KHz = 2r$

$\Rightarrow r = 50\ K\ sample/sec$

$\Rightarrow r = \dfrac{R}{n}$

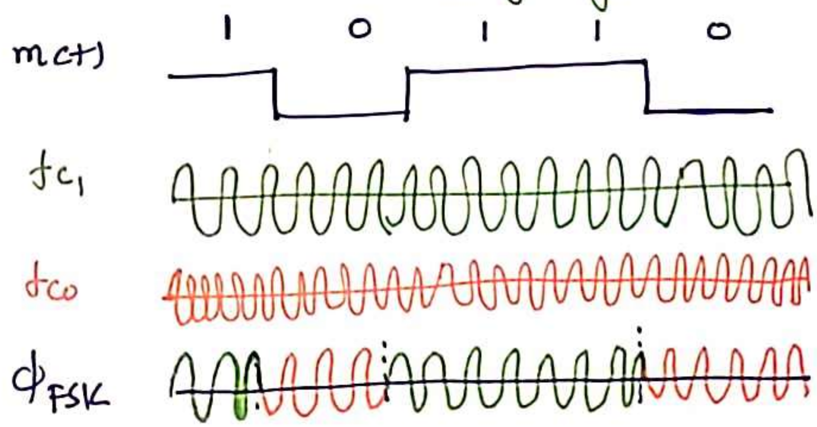
$\Rightarrow R = rn$

$= (50\,K) \times 1$

$\boxed{R = 50\ Kbps}$

- Demodulation of FSK
- Applications of FSK
- Basics of FSK
- It is used to convert digital data into analog data.

Definition - Freq. of carrier signal varying w.r.t amplitude of message signal.

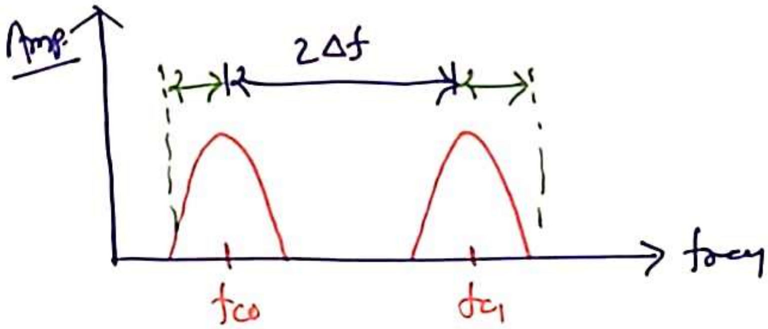


$$\phi_{FSK} = m_0(t)\cos\omega_{c0}t + m_1(t)\cos\omega_{c1}t$$

$$m(t) = \begin{cases} 1 \rightarrow f_{c1} \\ 0 \rightarrow f_{c0} \end{cases}$$

- Spectrum and BW of FSK

- Spectrum and BW of FSK



$$BW = (1+d)r$$

- total BW of FSK

$$= \frac{(1+d)r}{2} + \frac{(1+d)r}{2} + 2\Delta f$$

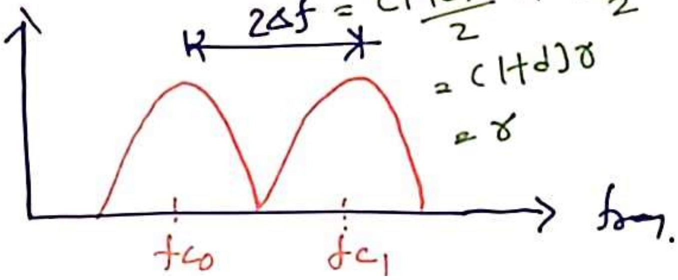
$$= (1+d)r + 2\Delta f$$

→ for min BW. $(d=0)$

$$2\Delta f = \frac{(1+d)r}{2} + \frac{(1+d)r}{2}$$

$$= (1+d)r$$

$$= r$$



$$\rightarrow (BW_{min})_{FSK} = r + r$$

$$= 2r$$

Multi Level FSK

$BW = (1+d)r + 2\Delta f$

→ For BFSK

$L = 2 = 2^n \rightarrow n = 1 \rightarrow f_{c0}, f_{c1}$

→ $L = 4 = 2^n \rightarrow n = 2 \rightarrow f_{c0}, f_{c1}, f_{c2}, f_{c3}$

→ $L = 8 = 2^n \rightarrow n = 3 \rightarrow f_{c0}, f_{c1}, \ldots, f_{c7}$

→ For L Level FSK BW.

$$BW = (1+d)r + (L-1)(2\Delta f)$$

→ min BW. $(d = 0)$

$$BW = (1+0)r + (L-1)r = Lr$$

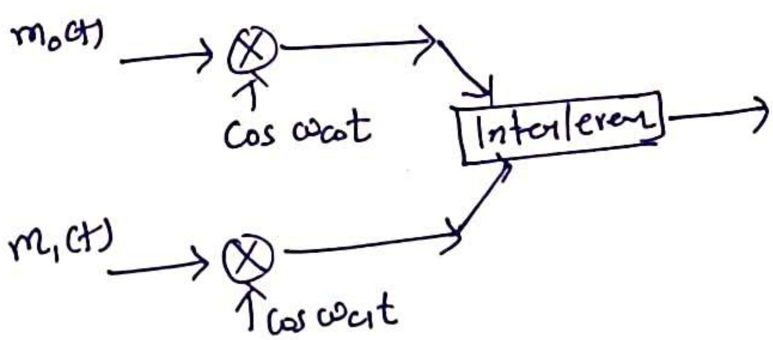
→ For L Level FSK BW.

$$BW = (1+d)r + (L-1)(2\Delta f)$$

→ min BW. $(d = 0)$

$$BW = (1+0)r + (L-1)r = Lr$$

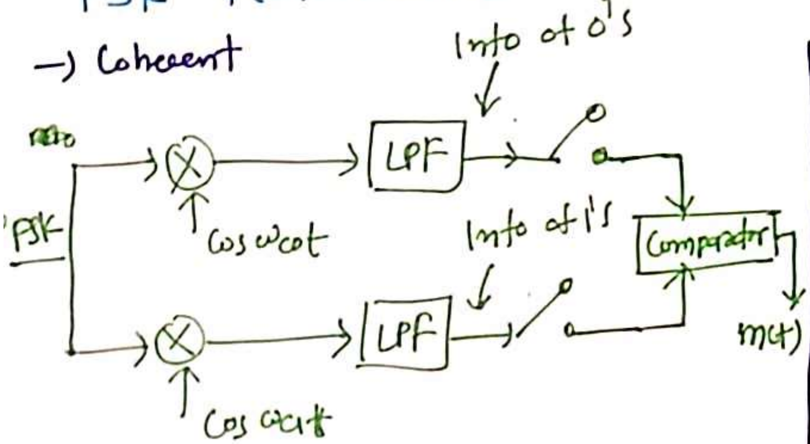
FSK Modulation



$$\phi_{FSK} = m_0(t) \cos \omega_{c0} t + m_1(t) \cos \omega_{c1} t$$

FSK Demodulation

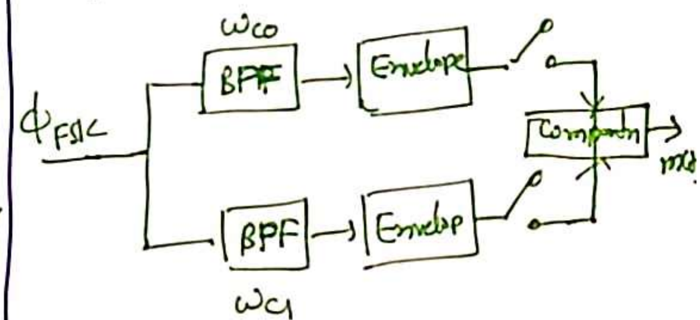
→ Coherent



Adv - Simple

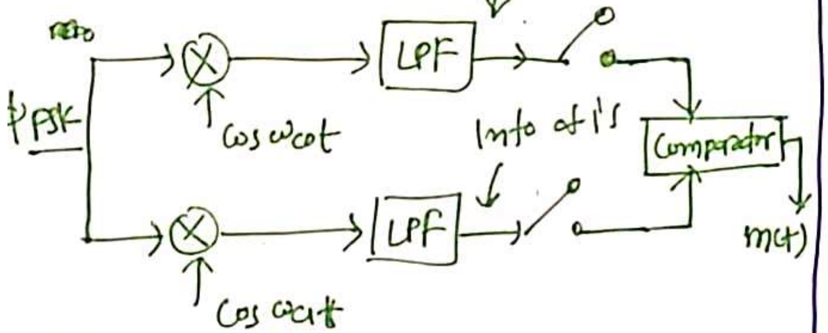
Disadv - Costly

→ Non coherent



Adv - low cost

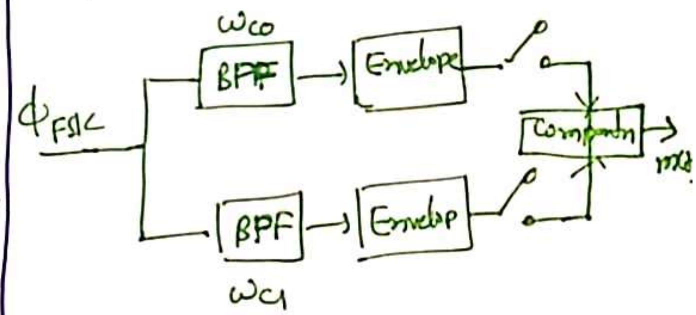
→ Coherent



<u>Adv</u> - simple

<u>Disadv</u> - costly

→ Non coherent



<u>Adv</u> - low cost

Application of FSK

- In telephone line modem used FSK to transmit 300 bits/sec at two freq. 1070 Hz & 1270 Hz

Examples on FSK

We need to send data 3 bits at a time at a bit rate of 3 mbps. The carrier freq is 10 MHz. Calculate the number of levels, the baud rate and the BW.

→ $n = 3$ bits

$R = 3$ mbps

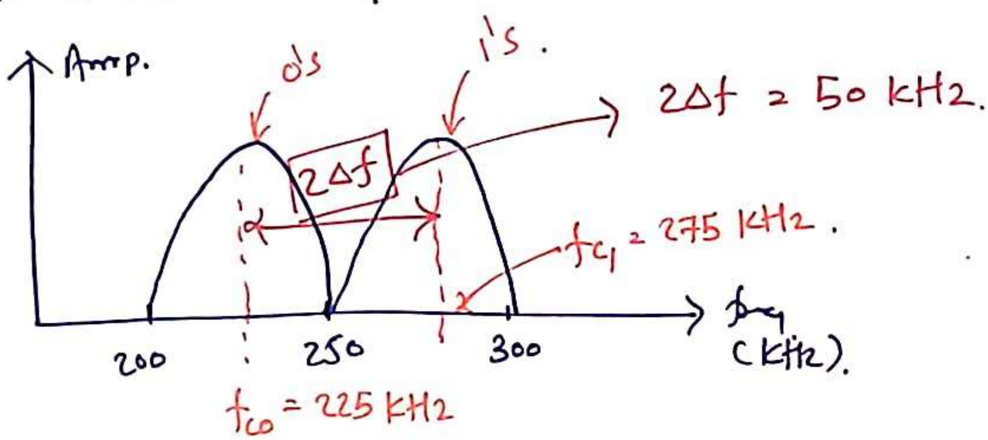
$f_c = 10$ MHz.

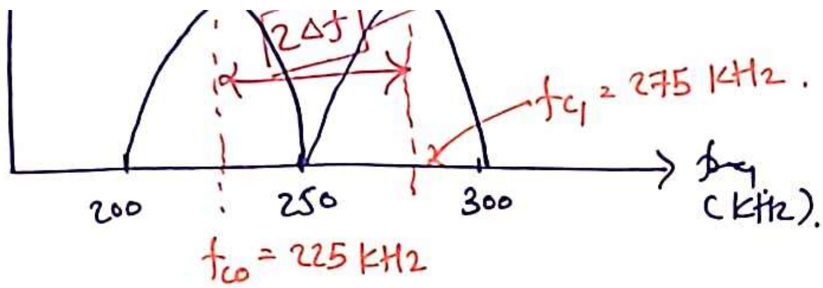
→ $L = 2^n = 2^3 = 8$

→ $r = \frac{R}{n} = \frac{3}{3} = 1$ mbaud

→ $BW = Lr = 8 \times 1 = 8$ MHz.

we have an available BW of 100 KHz which spans from 200 to 300 KHz. what should be carrier freq. and the bit rate if we modulated our data by using FSK with d = 1 ?





→ For 2 Level FSK

$L = 2 = 2^n$

→ $\boxed{n = 1 \text{ bit}}$

— BW = 100 KHz

$2\Delta f$ = 50 KHz

$\Rightarrow BW = (1+d)r + \overbrace{2\Delta f}^{(L-1)}$

$\Rightarrow 100 \text{ KHz} = (1+1)r + 50 \text{ KHz}$

$\Rightarrow 50 \text{ KHz} = 2r$

$\Rightarrow r = 50/2 = 25$ kbaud

$\Rightarrow r = \frac{R}{n}$

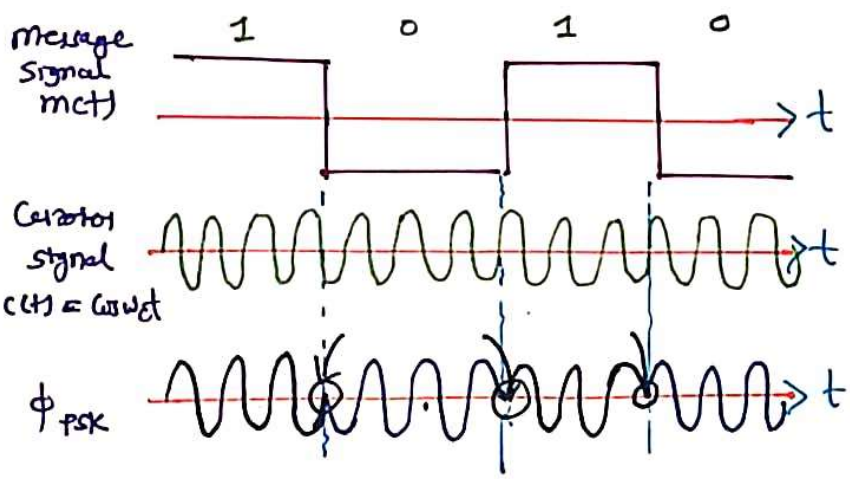
$\Rightarrow R = nr$

$= 1 \times 25$

$\boxed{R = 25 \text{ Kbps}}$

- Applications of FSK

- Defination of PSK
  - Carrier phase is varrying according to the amplitude of message signal.
- waveforms of PSK



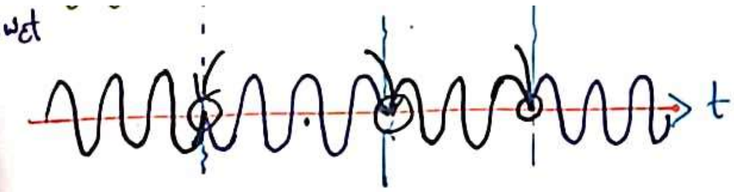
Polar wave NRZ

→ for 1 to 0 phase reversal.

→ $1 \rightarrow \phi = 0^\circ$

$0 \rightarrow \phi = 180^\circ$

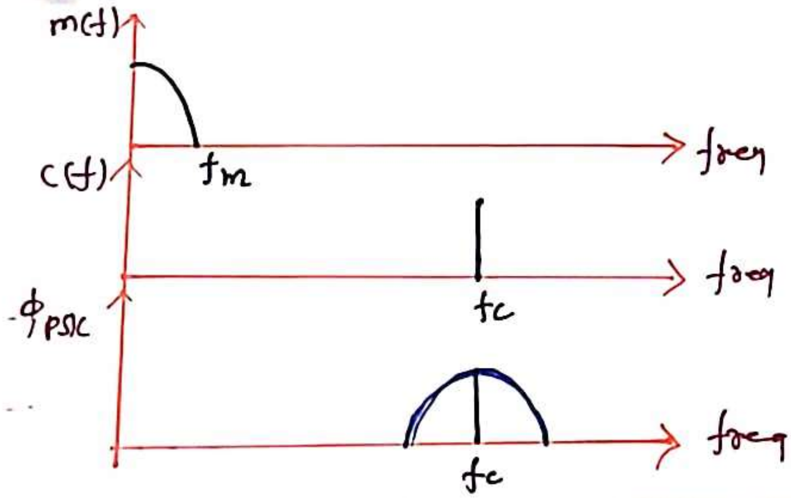
$c(t) = \cos\omega_c t$



$1 \to \phi = 0$

$0 \to \phi = 180^\circ$

- Bandwidth of PSK



$\Rightarrow BW_{PSK} \propto r$

$\Rightarrow BW_{PSK} = (1+d)r$

where $d \in (0, 1)$

ideal — worse

Multi level PSK

$\rightarrow$ BPSK $\rightarrow$ $L = 2 = 2^n$, $\rightarrow$ $n = 1$ $\rightarrow$ $\phi = 0, 180^\circ$

$\rightarrow$ $L = 4 = 2^n$ $\rightarrow$ $n = 2$ $\rightarrow$ $\phi = 0, 90, 180, 270$

$\rightarrow$ $L = 8 = 2^n$ $\rightarrow$ $n = 3$ $\rightarrow$ $\phi = 0, 45, 90, 135, 180, 225, 270, 315$

$$\boxed{BW = (1+d)r}$$

$\rightarrow L = 4 = 2^n \rightarrow n = 2 \rightarrow \phi = 0, 90, 180, 270$

$\rightarrow L = 8 = 2^n \rightarrow n = 3 \rightarrow \phi = 0, 45, 90, 135, 180, 225, 270, 315$

$$\boxed{BW = (1+d)r}$$

for $L = 4$, $n = 2$

$$\phi = \underset{00}{0}, \underset{01}{90}, \underset{10}{180}, \underset{11}{270}$$

odulation of PSK

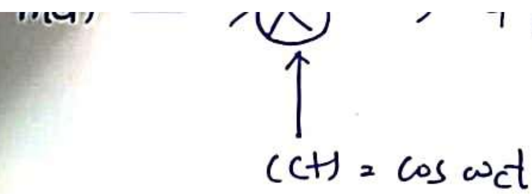
1010

$$m(t) \longrightarrow \otimes \longrightarrow \phi_{PSK} = \pm m(t) \cos \omega_c t$$

$$c(t) = \cos \omega_c t \uparrow$$

* For multilevel PSK

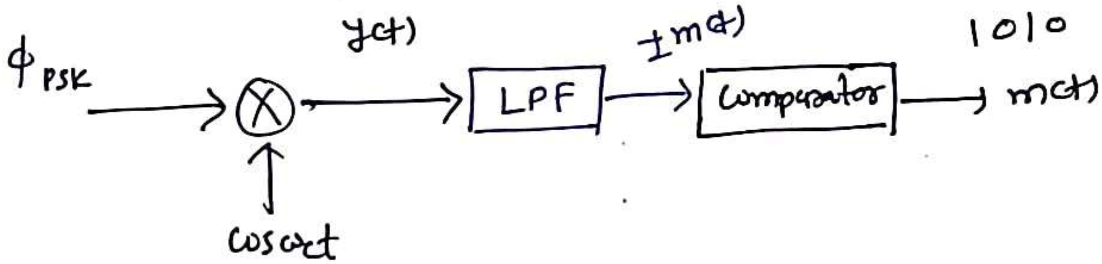
$$\phi_{PSK} = m(t) \cos(\omega_c t + \phi)$$



* For multilevel PSK

$$\phi_{PSK} = m(t)\cos(\omega_c t + \phi)$$

Demodulation of PSK



$$- \; y(t) = \phi_{PSK}\cos\omega_c t$$
$$= \pm m(t)\cos^2\omega_c t$$

$$\Rightarrow y(t) = \pm m(t)\left[\frac{1+\cos 2\omega_c t}{2}\right]$$
$$= \underbrace{\boxed{\pm\frac{m(t)}{2}}}_{\text{data}} \pm \frac{m(t)}{2}\cos 2\omega_c t$$

Advantages of PSK

- $y(t) = \phi_{PSK} \cos \omega_c t$
  $= \pm m(t) \cos^2 \omega_c t$

$\Rightarrow y(t) = \pm m(t) \left[\frac{1 + \cos 2\omega_c t}{2} \right]$

$= \underbrace{\boxed{\pm \frac{m(t)}{2}}}_{\text{data}} \pm \frac{m(t)}{2} \cos 2\omega_c t$

Advantages of PSK

- Better then ASK, FSK
- BW is better then FSK
- Noise Immunity
- Datarate better then FSK

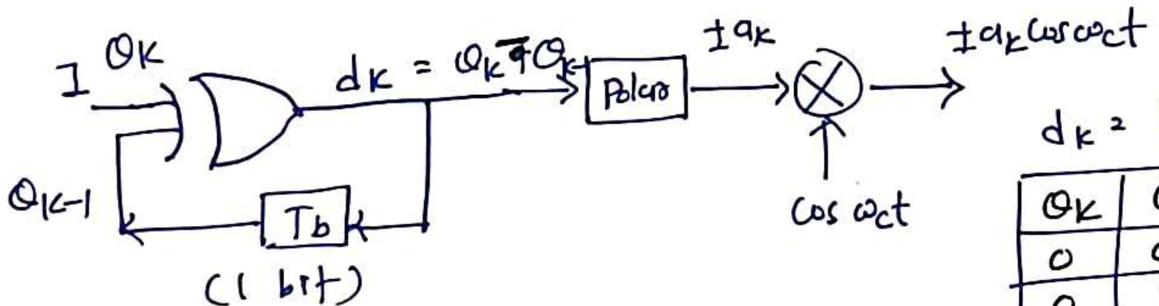
Drawbacks of PSK

- No Non coherent detection
- Costly

Applications of PSK

- In digital Communication
- It was also used in earliest telephon modems with data rate [2400 and 4800 bits/sec]

- Basics of DPSK
    - It is not possible to have non coherent detection of PSK
    - to detect non coherent detection of phase we use DPSK
    - It reduces cost of circuit.
- DPSK transmitter



$d_k = \theta_k - \theta_{k-1}$

θ_k	θ_{k-1}	d_k
0	0	0
0	1	1
1	0	1
1	1	0

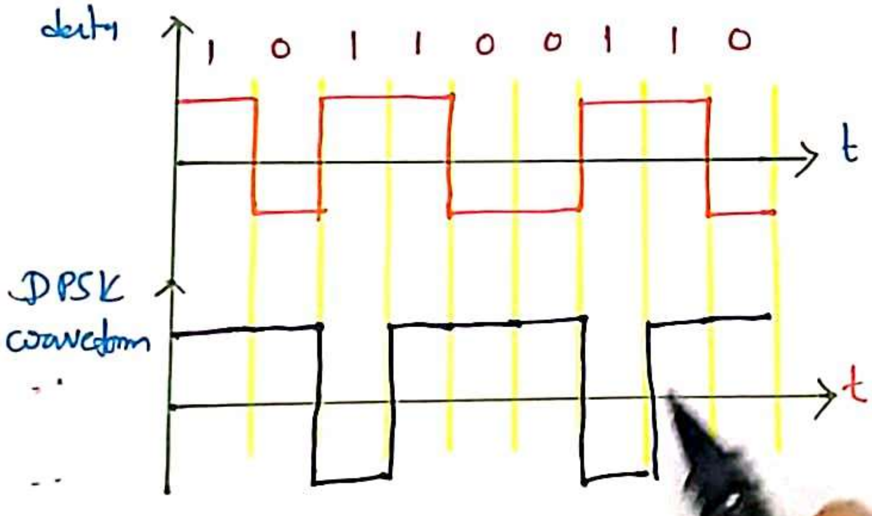
E

- DPSK ~~Receiver~~ waveforms

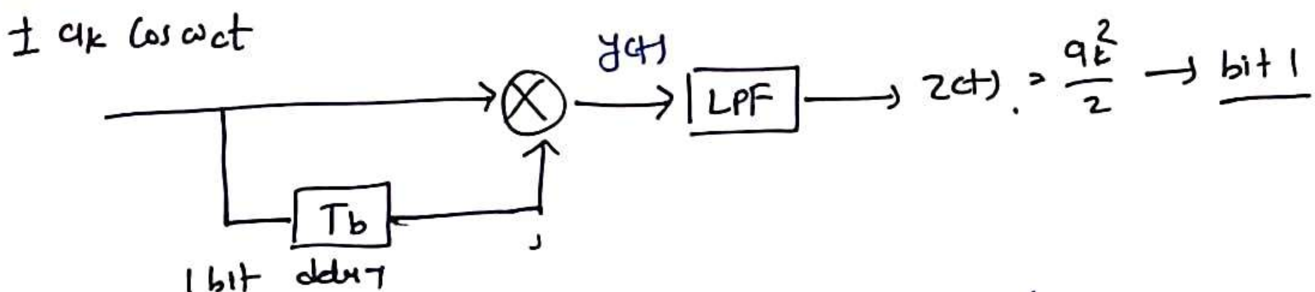
1	1	0

- DPSK waveforms

  - If next data is 1, then change polarity of o/p.
  - If next data is 0, then do not change polarity of o/p.



DPSK Receiver

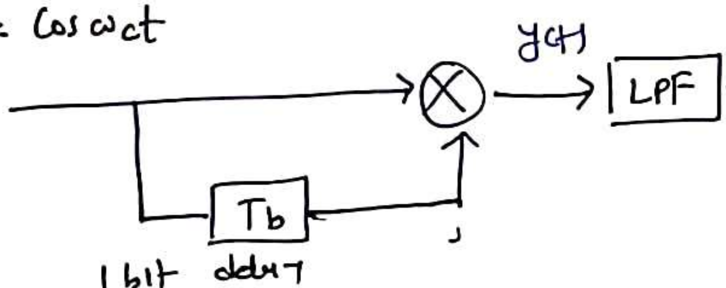


- Case-1 [Same polarity of Input & delayed Signal]

- $y(t) = (a_k \cos\omega_c t)(a_k \cos\omega_c t) = a_k^2 \cos^2\omega_c t$

$$= \frac{a_k^2}{2}[1+\cos 2\omega_c t] = \frac{a_k^2}{2} + \frac{a_k^2}{2}\cos 2\omega_c t \xrightarrow{LPF} = \frac{a_k^2}{2}.$$

$\pm a_k \cos\omega_c t$



$\longrightarrow z(t) = \dfrac{a_k^2}{2} \rightarrow$ bit 1

$= -\dfrac{a_k^2}{2} \rightarrow$ bit 0

- Case-I [same polarity of Input & delayed signal]
  - $y(t) = (a_k \cos\omega_c t)(a_k \cos\omega_c t) = a_k^2 \cos^2\omega_c t$
    $= \dfrac{a_k^2}{2}[1+\cos 2\omega_c t] = \dfrac{a_k^2}{2} + \dfrac{a_k^2}{2}\cos 2\omega_c t \xrightarrow{LPF} = \dfrac{a_k^2}{2}$.
- Case-II [opposite polarity of Input & delayed signal]
  - $y(t) = (a_k \cos\omega_c t)(-a_k \cos\omega_c t) = -\dfrac{a_k^2}{2} - \dfrac{a_k^2}{2}\cos 2\omega_c t$
    $\xrightarrow{LPF} = -\dfrac{a_k^2}{2}$

Advantages of DPSK

$\frac{\quad}{2} \quad \frac{\quad}{2}$

$\xrightarrow{LPF} = -\frac{a_k^2}{2}$

Advantages of DPSK

- Non coherent detection is possible
- Cost is less
- Circuit complexity is less

Drawbacks of DPSK

- Noisy

- Quadrature phase shift keying (QPSK) is a form of PSK (Phase shift keying), In which two bits are modulated at once.

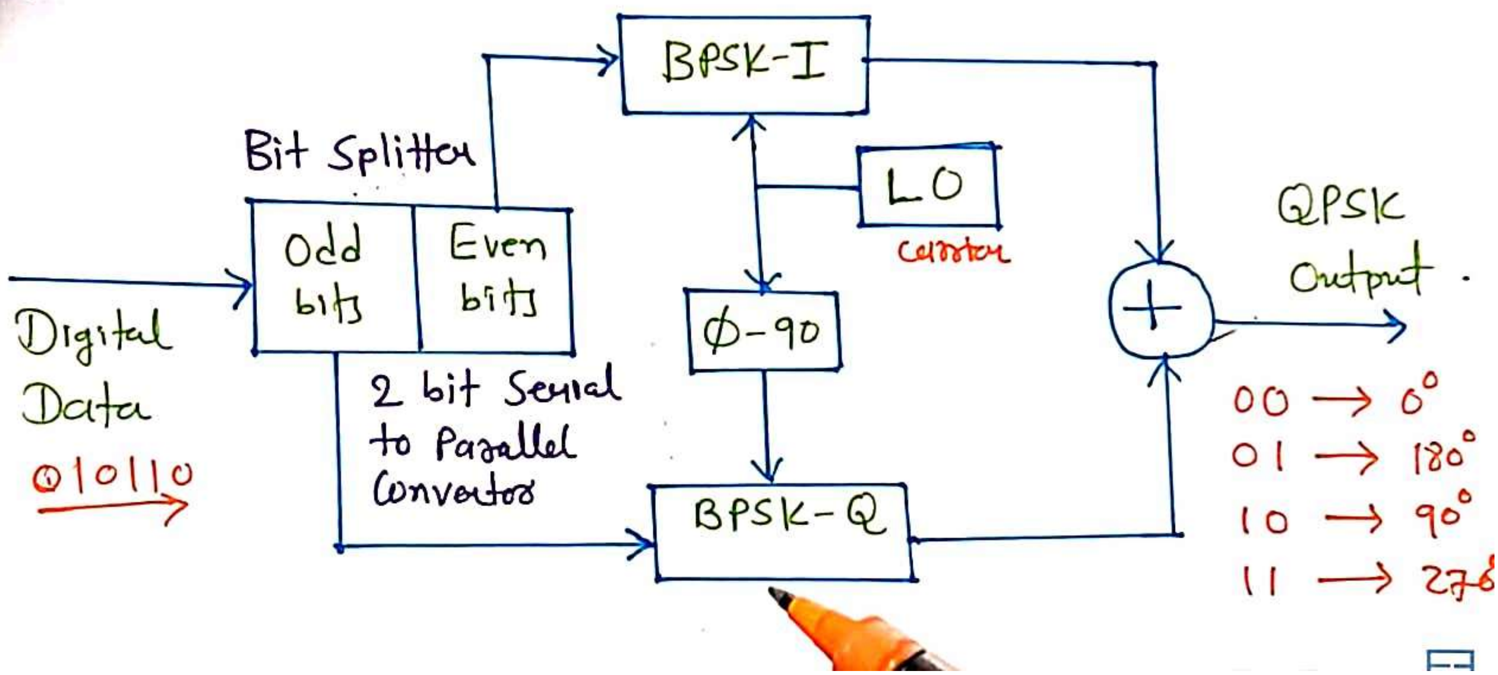
- It selects one of four possible carrier phase shifts [0°, 90°, 180°, 270°]

- QPSK allows the signal to carry twice as much information as ordinary PSK using the same BW.

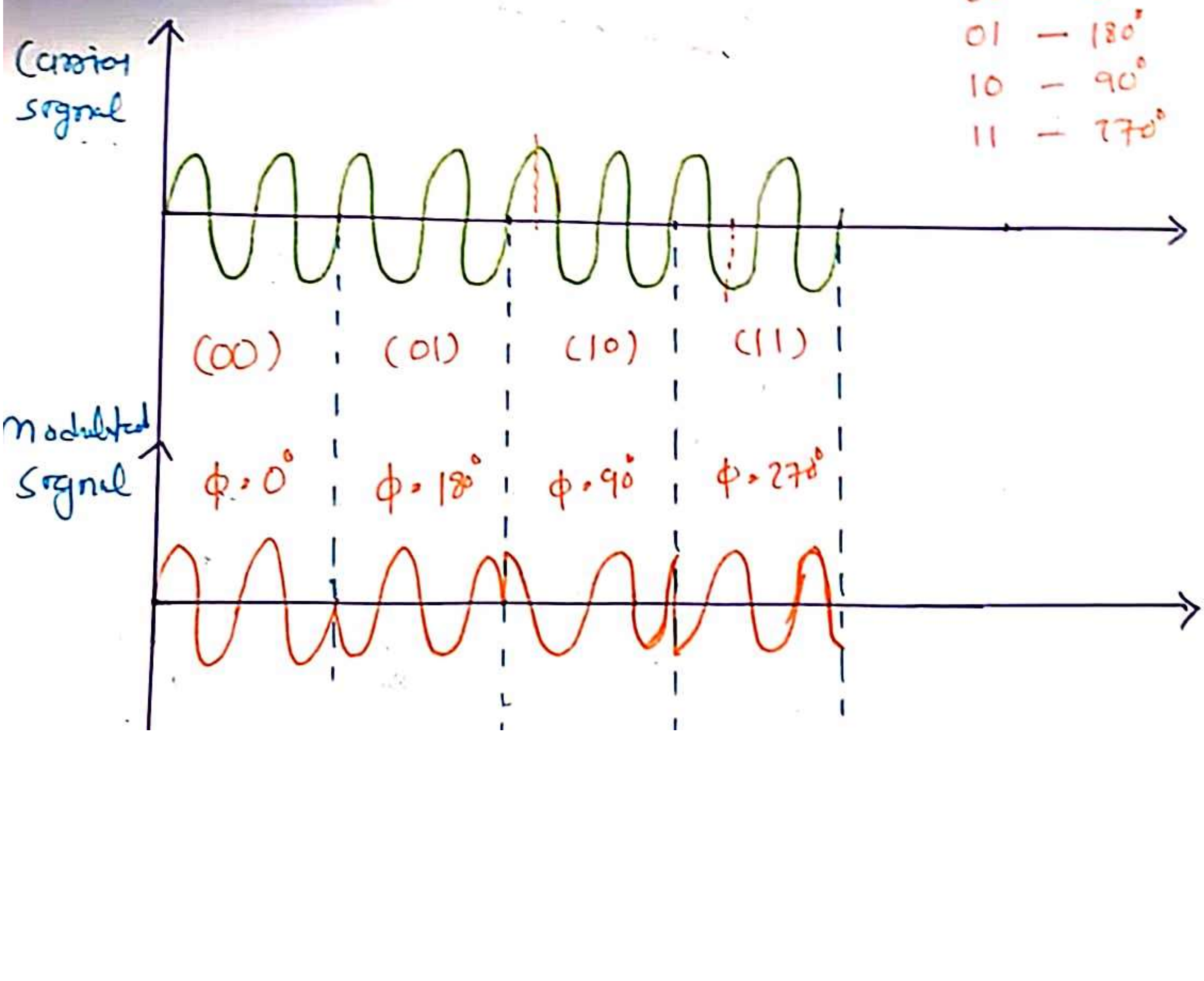
- QPSK is used for satellite transmission of MPEG2, cable modem, cellular phone system etc.

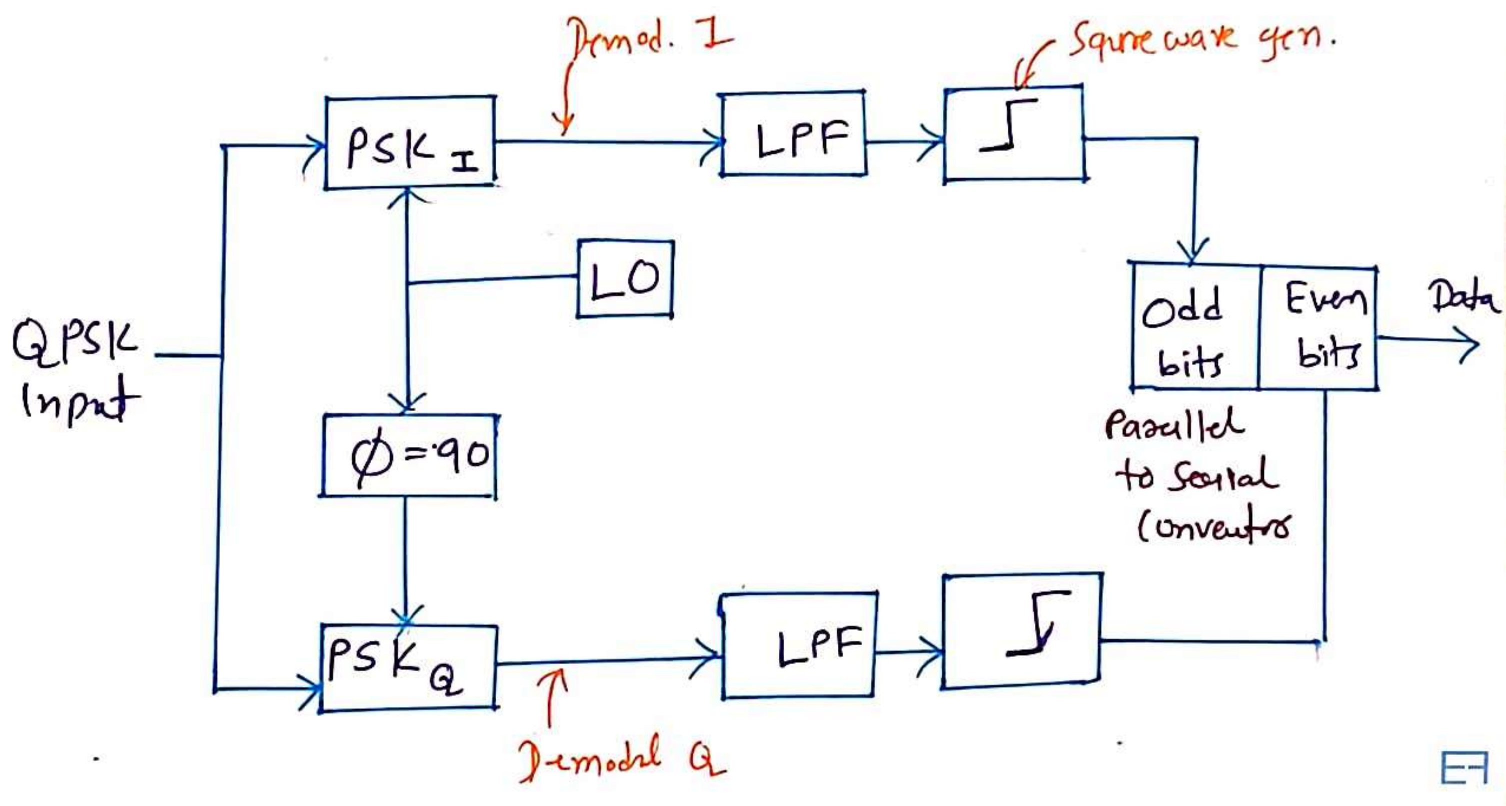
Cable modem, cellular phone system etc.

QPSK Modulator



00 — 0
01 — 180°
10 — 90°
11 — 270°





Demod. I
Square wave gen.
PSK I
LPF
LO
QPSK Input
Odd bits
Even bits
Data
Parallel to Serial Convertor
ϕ=90
PSK Q
LPF
Demodul Q

BPSK [Binary Phase Shift Keying]

↑
$m = 2$

$x_1(t) \longrightarrow 1$

$x_2(t) \longrightarrow 0$

→ Here Carrier signal

$c(t) = A \cos(2\pi f_c t + \phi)$

bit 0 $\longrightarrow$ $\phi = 0$

bit 1 $\longrightarrow$ $\phi = 180$

- $x_1(t) = A \cos(2\pi f_c t) \longrightarrow$ bit 1

  $x_2(t) = -A \cos(2\pi f_c t). \longrightarrow$ bit 0.

$$[\; 0 \leq t \leq T_b \;]$$

- E_b is Energy per bit

$$E_b = \int_0^{T_b} x_1^2(t)\, dt$$

$$= \int_0^{T_b} A^2 \cos^2(2\pi f_c t)\, dt$$

$$= A^2 \int_0^{T_b} \frac{1 + \cos(4\pi f_c t)}{2}\, dt$$

$$= \frac{A^2}{2} \int_0^{T_b} 1 + \cos(4\pi f_c t)\, dt$$

'1

$m = 2$

$x_1(t) \rightarrow 1$

$x_2(t) \rightarrow 0$

→ Here carrier signal

$c(t) = A\cos(2\pi f_c t + \phi)$

bit 0 $\longrightarrow$ $\phi = 0$

bit 1 $\longrightarrow$ $\phi = 180$

- $x_1(t) = A\cos(2\pi f_c t) \longrightarrow$ bit 1

$x_2(t) = -A\cos(2\pi f_c t). \longrightarrow$ bit 0.

$[\,0 \le t \le T_b\,]$

- E_b is Energy per bit

$$E_b = \int_0^{T_b} x_1^2(t)\,dt$$

$$= \int_0^{T_b} A^2\cos^2(2\pi f_c t)\,dt$$

$$= A^2 \int_0^{T_b} \frac{1+\cos(4\pi f_c t)}{2}\,dt$$

$$= \frac{A^2}{2}\int_0^{T_b} \underline{1} + \underline{\cos(4\pi f_c t)}\,dt$$

$$\Rightarrow E_b = \frac{A^2}{2}(T_b) \Rightarrow A = \sqrt{\frac{2E_b}{T_b}}.$$

- $x_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \longrightarrow$ bit 1

$x_2(t) = -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t). \longrightarrow$ bit 0

→ As per Gram Smith Orthogonalization procedure, we will find number of basis function.

$$N \le M = 2$$

→ $\phi_1(t) = \frac{x_1(t)}{\sqrt{E_b}} = \frac{\sqrt{2E_b/T_b}}{\sqrt{E_b}}\cos(2\pi f_c t) = \sqrt{\frac{2}{T_b}}\cos(2\pi f_c t).$

→ Here, $x_1(t) = -x_2(t)$

$N = 1$, BPSK $\longrightarrow$ 1D Modulation

→ As per Orthogonalization

$$\int_0^{T_b} \phi_1^2(t)\,dt = 1$$

→ Scatter plot / Constellation point / Space diagram

- $x_{ij} = \int_0^{T_b} x_i(t)\,\phi_j(t)\,dt$ $\quad i = 1, 2, \dots M$, $\quad j = 1, 2, \dots N$

- $x_{11} = \int_0^{T_b} x_1(t)\,\phi_1(t)\,dt$

$= \int_0^{T_b} \sqrt{E_b}\,\phi_1^2(t)\,dt$

$= \sqrt{E_b}\int_0^{T_b} \phi_1^2(t)\,dt$

$= \sqrt{E_b}$

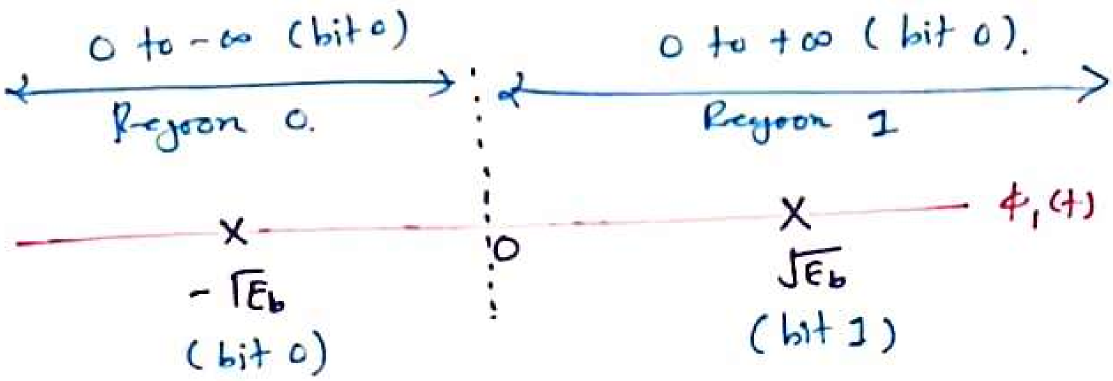
- $x_{21} = \int_0^{T_b} x_2(t)\,\phi_1(t)\,dt$

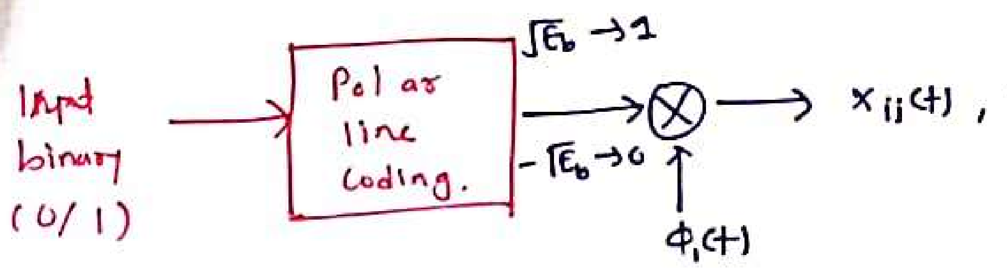
$= \int_0^{T_b} -\sqrt{E_b}\,\phi_1^2(t)\,dt$

$= -\sqrt{E_b}\int_0^{T_b} \phi_1^2(t)\,dt$

$= -\sqrt{E_b}.$

Constellation Diagram / Space diagram / Scatter plot





Mary Frequency Shift Keying (MFSK) or M-array FSK

- m = Modulation order or Number of possible Signals.
- In BFSK, m = 2 $[0 \le t \le T_b]$

$$x_1(t) = A\cos(2\pi f_1 t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_1 t) \leftarrow \text{bit } 1$$

$$x_2(t) = A\cos(2\pi f_2 t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_2 t) \leftarrow \text{bit } 0$$

$k = \log_2 m$

↑ No of bits / Symbol

For example
- k = 2
- m = 4

m = 8
k = 3.

- So generalised eq.^{n} for mFSK

$$x_i(t) = A\cos(2\pi f_i t). \quad [0 \le t \le T]$$

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

f_i — Freq of i^{st} signal.
f_c — Center freq.
f_d — freq. deviation

- Ex - 4FSK, f_c = 250 KHz, f_d = 25 KHz.

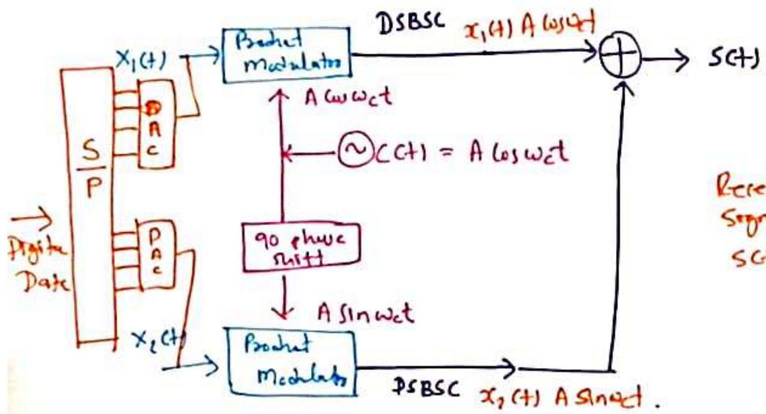
m = 4

$k = \log_2 m = \log_2 4 = 2$ bits/Symbol

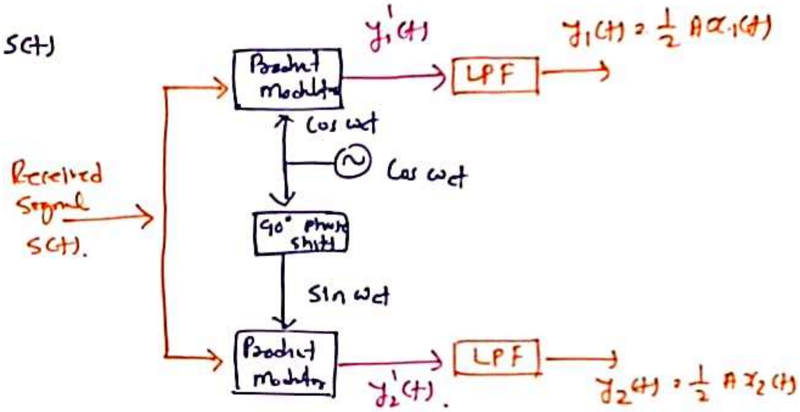
	bits
$f_1 = 250 + (2\times1-1-4)\,25 = 175$ KHz.	00
$f_2 = 250 + (2\times2-1-4)\,25 = 225$ KHz	01
$f_3 = 250 + (3\times2-1-4)\,25 = 275$ KHz	10
$f_4 = 250 + (4\times2-1-4)\,25 = 325$ KHz	11

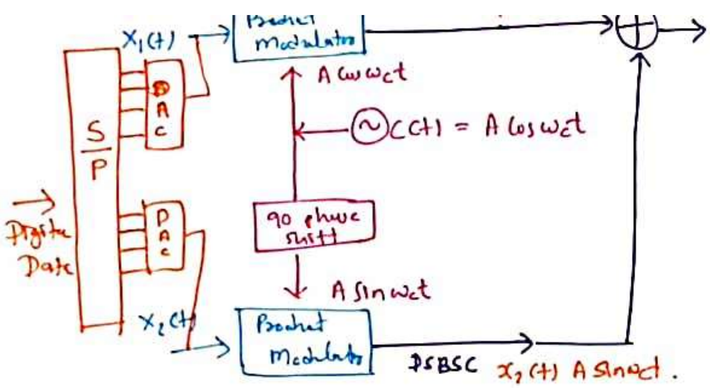
- So at Tx & Rx, we need 4 local Oscillator.
- So It Increases cost & complexity of the System.
- It is widely used in FHSS
- <u>Application</u> - Bluetooth.

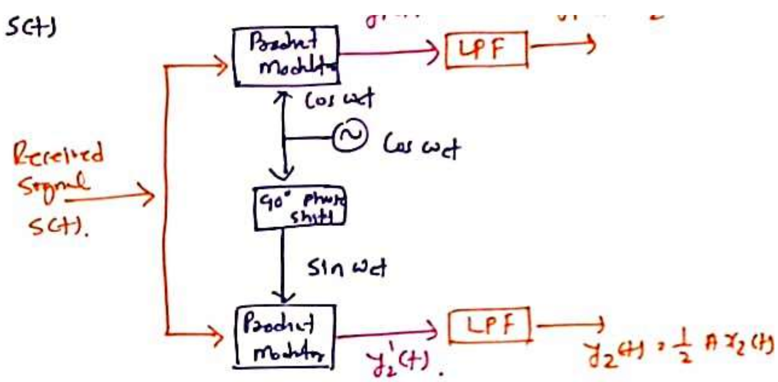
QAM [Quadrature Amplitude Modulation]



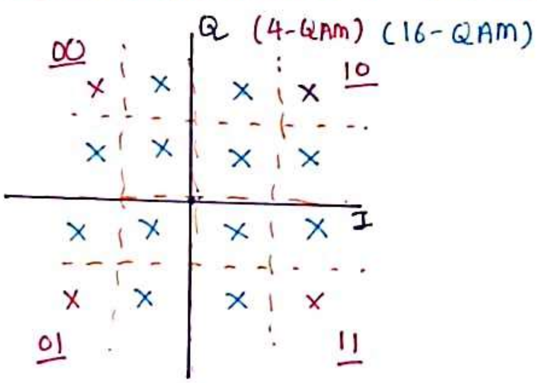
$\rightarrow s(t) = x_1(t)\, A\cos\omega_c t + x_2(t)\, A\sin\omega_c t$







$\rightarrow s(t) = x_1(t)\, A\cos\omega_c t + x_2(t)\, A\sin\omega_c t$



$\rightarrow y_1'(t) = s(t)\cos\omega_c t$

$= [x_1(t)\, A\cos\omega_c t + x_2(t)\, A\sin\omega_c t] \times \cos\omega_c t$

$= x_1(t)\, A\cos^2\omega_c t + x_2(t)\, A\sin\omega_c t\cos\omega_c t$

$= x_1(t)\, A\left[\frac{1+\cos 2\omega_c t}{2}\right] + \frac{x_2(t)\, A}{2}\sin 2\omega_c t$

$= \frac{x_1(t)\, A}{2} + \underbrace{\frac{x_1(t)\, A}{2}\cos 2\omega_c t}_{\times} + \underbrace{\frac{x_2(t)\, A}{2}\sin 2\omega_c t}_{\times}$

$\rightarrow$ After LPF

$y_1(t) = x_1(t)\, A/2$

Coherent Detection

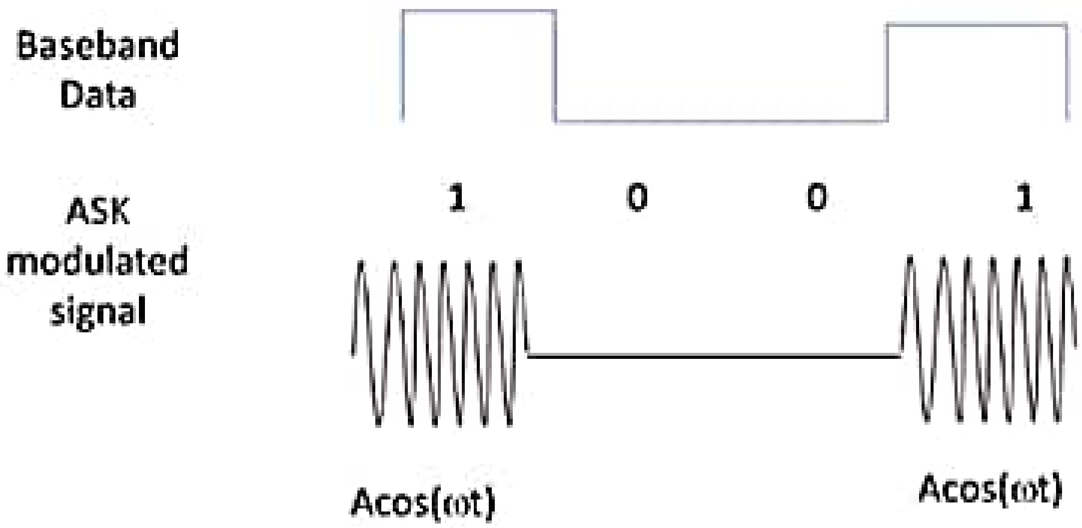
- An estimate of the channel phase and attenuation is recovered. It is then possible to reproduce the transmitted signal and demodulate.
- Requires a replica carrier wave of the same frequency and phase at the receiver.
- The received signal and replica carrier are cross-correlated using information contained in their amplitudes and phases.
- Also known as synchronous detection

- Applicable to
  - Phase Shift Keying (PSK)
  - Frequency Shift Keying (FSK)
  - Amplitude Shift Keying (ASK)

Non-Coherent Detection

- Requires no reference wave; does not exploit phase reference information (envelope detection)
  - Differential Phase Shift Keying (DPSK)
  - Frequency Shift Keying (FSK)
  - Amplitude Shift Keying (ASK)
  - Non coherent detection is less complex than coherent detection (easier to implement), but has worse performance.

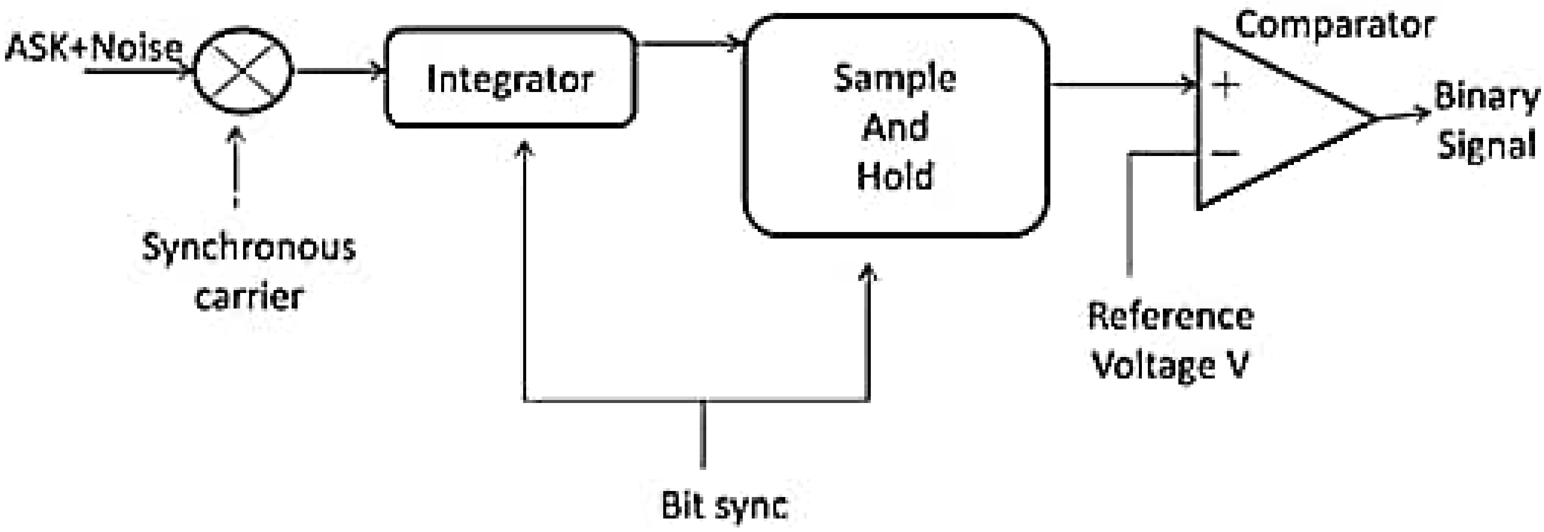
Amplitude Shift Keying (ASK)



Pulse shaping can be employed to remove spectral spreading

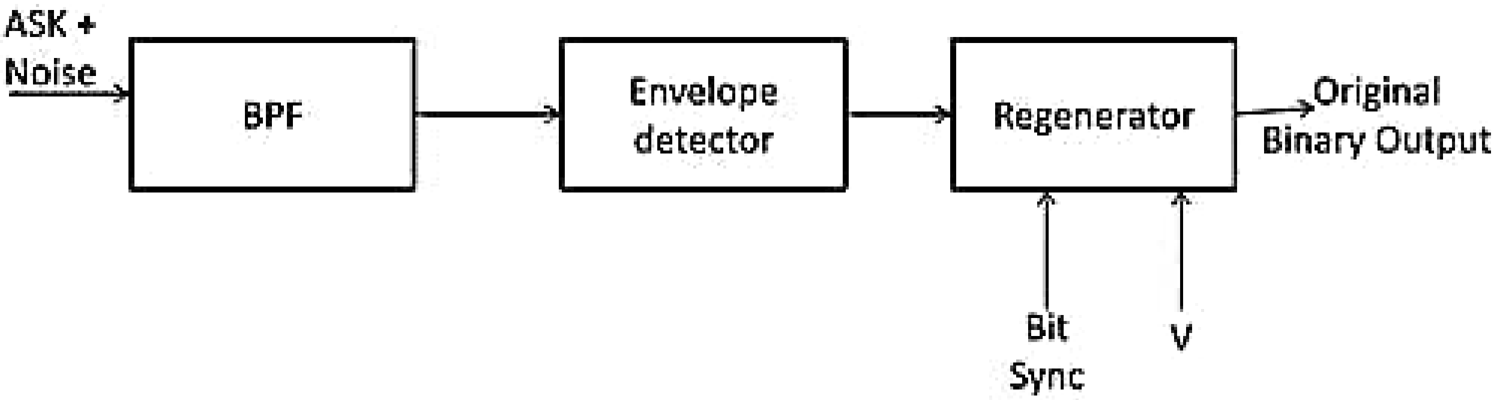
ASK demonstrates poor performance, as it is heavily affected by noise, fading, and interference

COHERENT DETECTION OF ASK



Coherent ASK receiver

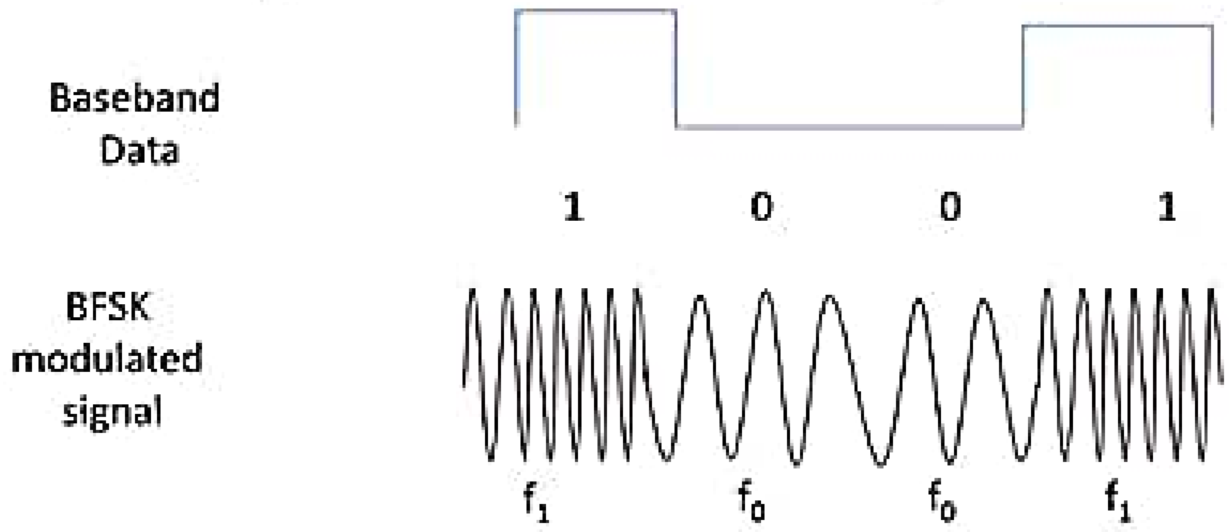
NON-COHERENT DETECTION OF ASK



Non-coherent ASK receiver

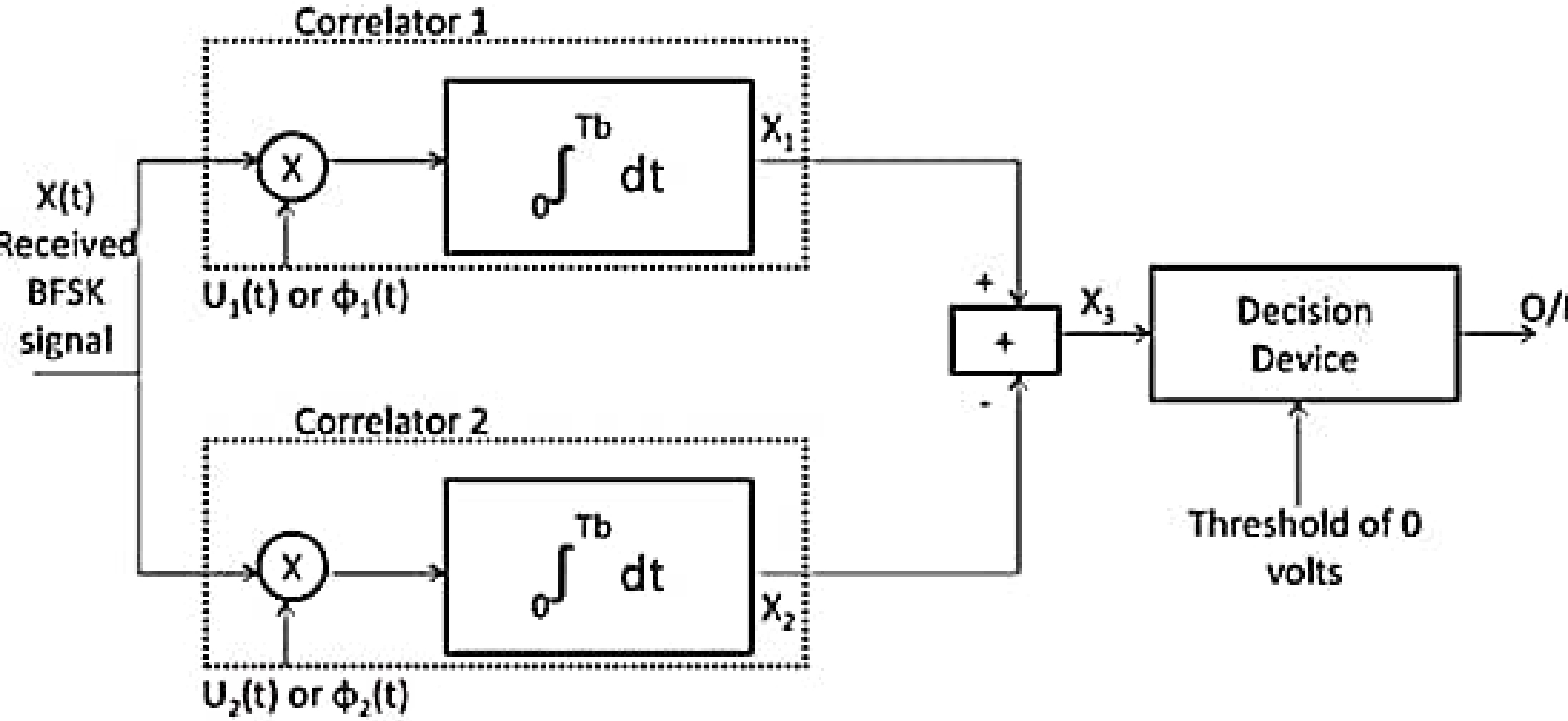
- Bandpass Filter
- Envelope Detector
- Regenerator

Frequency Shift Keying (FSK)



where $f_0 = A\cos(\omega_c - \Delta\omega)t$ and $f_1 = A\cos(\omega_c + \Delta\omega)t$

COHERENT DETECTION OF FSK



Coherent BFSK receiver

- Multiplier
- Integrator
- Sample and Hold
- Comparator

If,

o/p < V , then signal is 0.

o/p > V , then signal is 1.

- $U_1(t)$ or $\phi_1(t) = \sqrt{2/T_b} \quad \cos\omega_H t$ or
- $U_2(t)$ or $\phi_2(t) = \sqrt{2/T_b} \quad \cos\omega_L t$

- $f_H = m\, f_b$
- $f_L = n\, f_b$

- $U_1(t) = \sqrt{2/T_b} \quad \cos(2\pi m\, f_b\, t)$
- $U_2(t) = \sqrt{2/T_b} \quad \sin(2\pi n\, f_b\, t)$

- $s_H(t) = \sqrt{P_s T_b}\ \sqrt{2/T_b}\ \cos(2\pi m\, f_b\, t)$
- $s_L(t) = \sqrt{P_s T_b}\ \sqrt{2/T_b}\ \sin(2\pi n\, f_b\, t)$

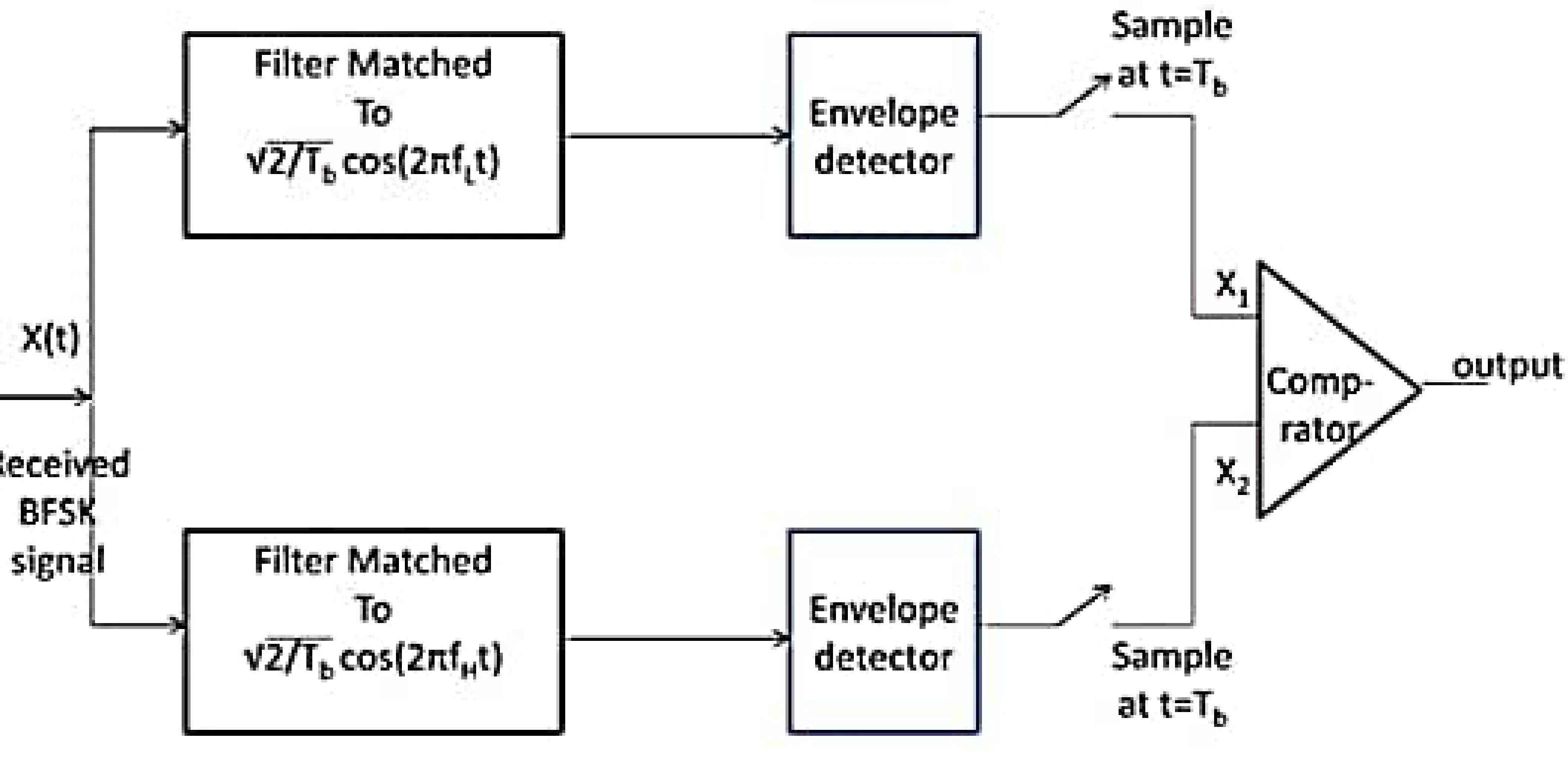
  where, $2\pi m\, f_b = \omega_H$

  $2\pi n\, f_b = \omega_L$

$s_H(t) = \sqrt{P_s T_b}\ X\ U_1(t)$

$s_L(t) = \sqrt{P_s T_b}\ X\ U_2(t)$

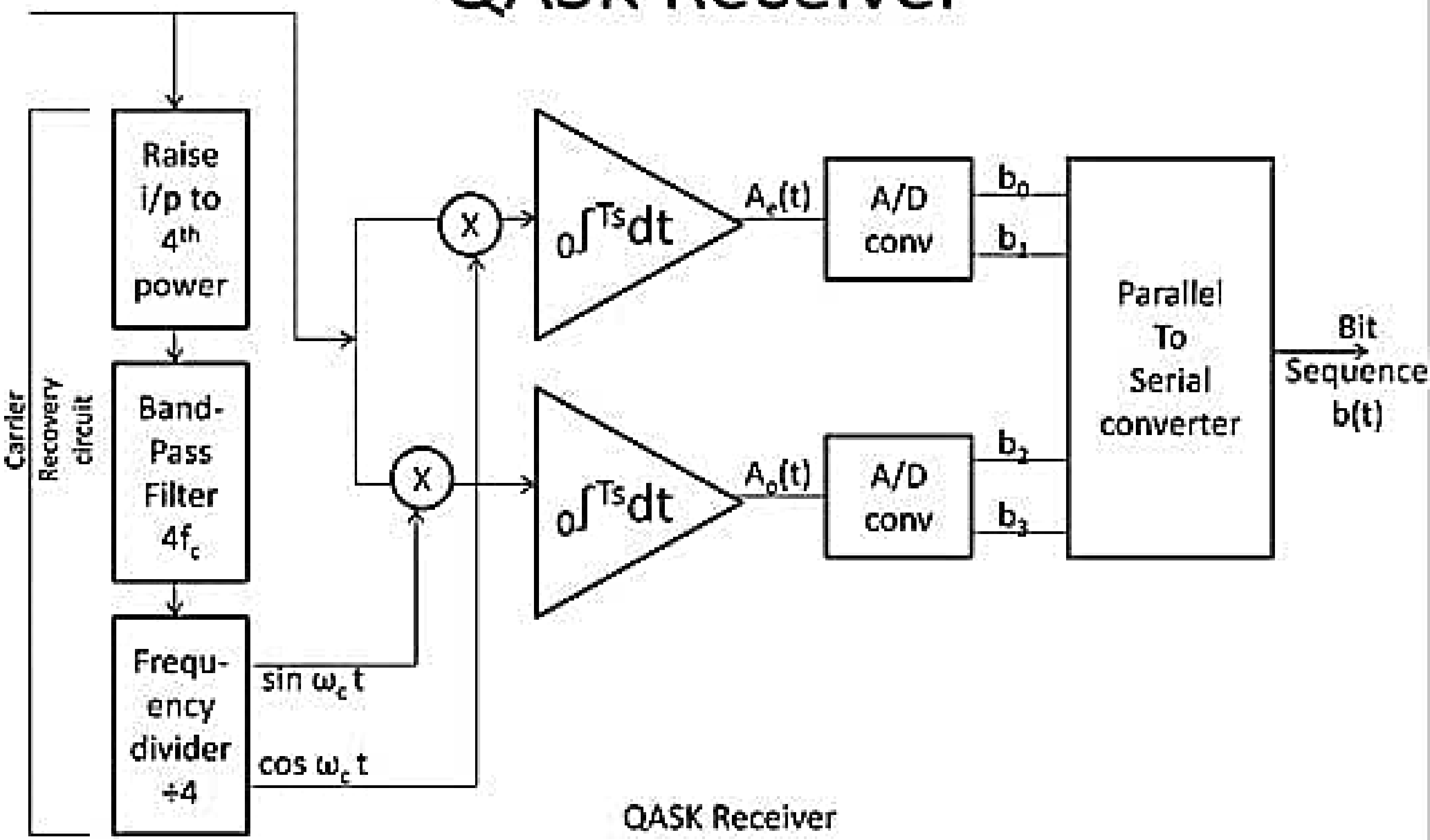
NON-COHERENT DETECTION OF FSK



Non-coherent BFSK receiver

$V_{QASK}(t)=\sqrt{P_s}A_e(t)\cos\omega_c t+\sqrt{P_s}A_o(t)\sin\omega_c t$

QASK Receiver



QASK Receiver