b(t − Tb) | 0 1 1 0 ...

d(t) = b(t) ⊕ b(t − Tb)   1 0 1 1 0 1 0

(b)

b(t)   0 | 1 1 $\boxed{1}$ 1 1 0 0 |

b(t − Tb) | 0 1 1 $\boxed{1}$ 1 1 0 | 0

| 1 0 $\boxed{0\ 0}$ 0 1 0 |

error bits

→ **BFSK (Binary Frequency Shift Keying)** :-

$$\boxed{V_{BFSK}(t) = \sqrt{2P_s}\cos\left[\omega_0 t + d(t)\,\Omega t\right]}$$

where $d(t) = +1V$ for Txion of 1 bit

$= -1V$ for Txion of '0' bit

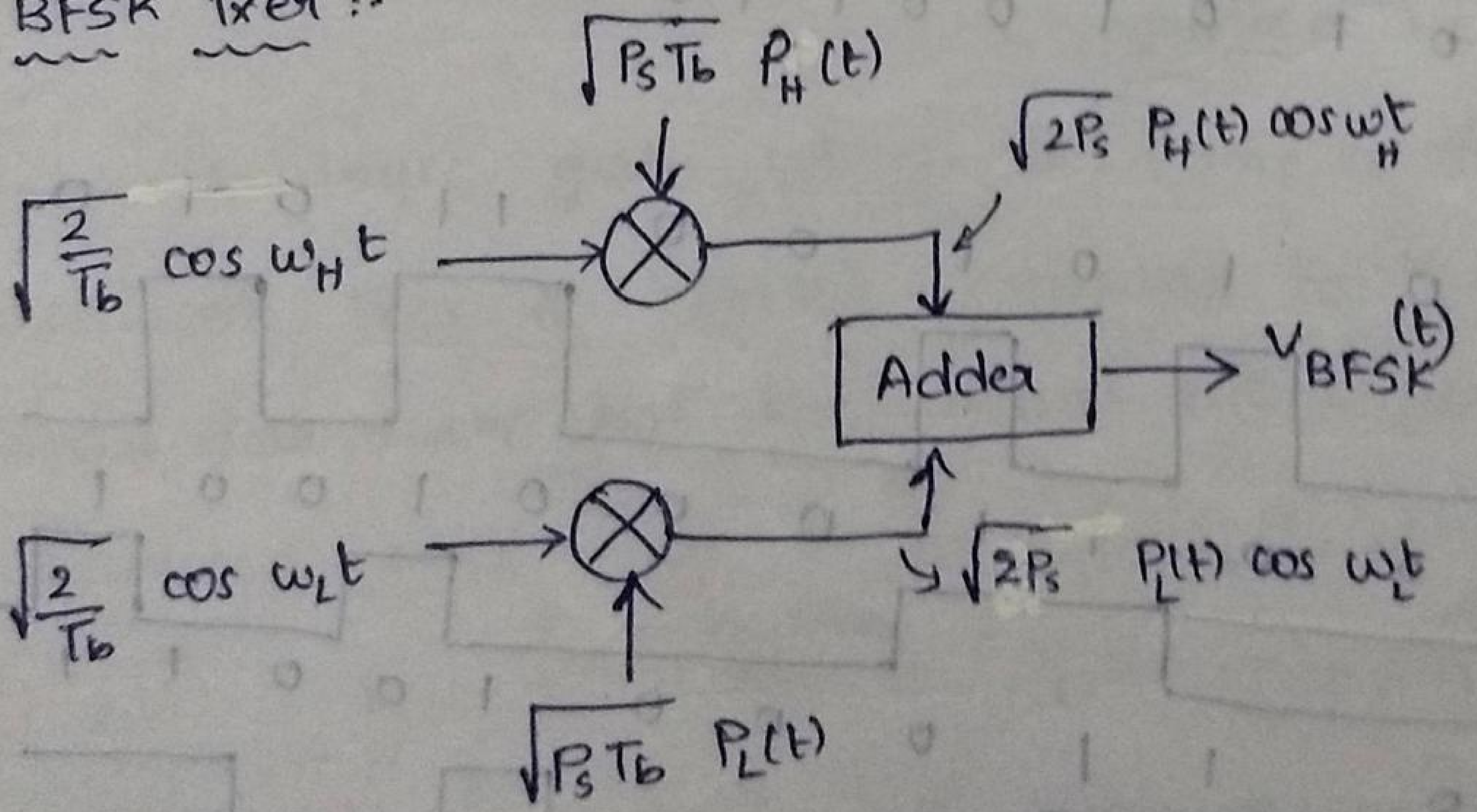
1 bit : $\omega_H = \omega_0 + \Omega$, higher angular freq → ω_H

0 bit : $\omega_L = \omega_0 - \Omega$, lower angular freq → ω_L

Ω → offset freq

ω_0 → carrier angular freq

BFSK Txer :-



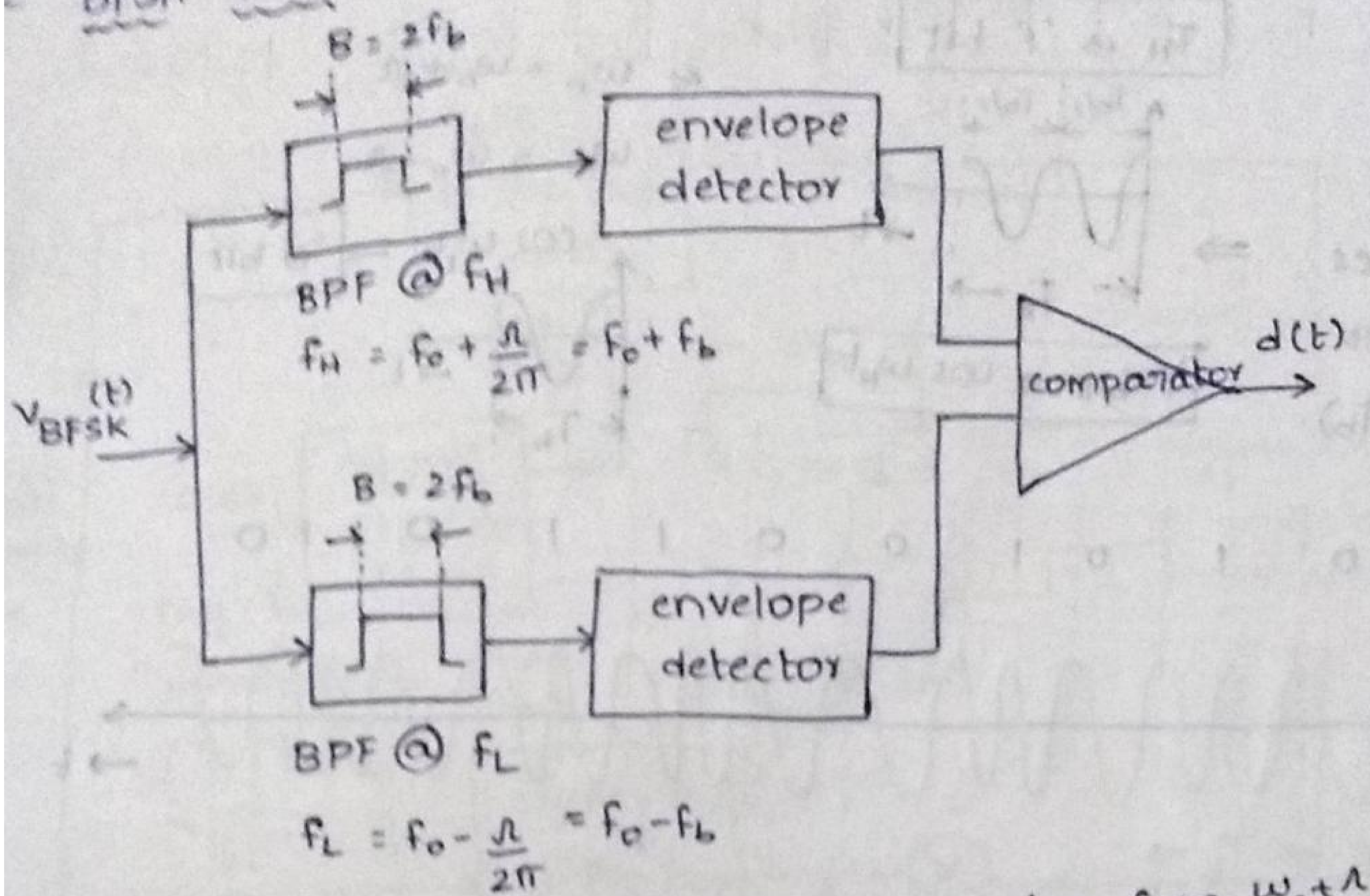
d(t)	$P_H(t)$	$P_L(t)$
+1 V	+1 V	0 V
−1 V	0 V	+1 V

$$\therefore \text{Adder o/p} = \underbrace{\sqrt{2P_s}\, P_H(t)\cos\omega_H t}_{1\ \text{bit}} + \underbrace{\sqrt{2P_s}\, P_L(t)\cos\omega_L t}_{0\ \text{bit}}$$

∴ At each bit interval only '1' or '0' is Txed.

Scanned by TapScanner

BFSK Rxer:-



BFSK Txer:- The BFSK s/g has an angular freq $\omega_0 + \Omega$ or $\omega_0 - \Omega$ with Ω a constant offset from the nominal carrier freq ω_0. Two balanced modulators are used, one with carrier at ω_H & other with carrier at ω_L. The adder o/p is

$$\sqrt{2P_s}\, P_H(t) \cos \omega_H t + \sqrt{2P_s}\, P_L(t) \cos \omega_L t$$

where

d(t)	$P_H(t)$	$P_L(t)$
+1 V	+1 V	0 V
−1 V	0 V	+1 V

At any time either $P_H(t)$ or $P_L(t)$ is '1' but not both, so that adder o/p is BFSK s/g which is either at ω_H or at ω_L.

BFSK Rxer:- The Rxed BFSK s/g is applied to two BPF's one with centre freq at f_H & other at f_L. The filter o/p's are applied to envelope detectors & finally envelope detector o/ps are compared by comparator such that its o/p is at one level or other depending on which i/p is larger.

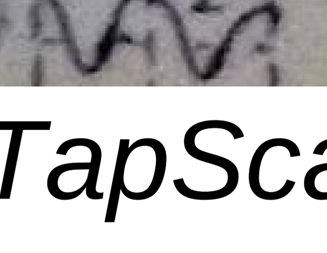
→ The bit stream d(t) 0 0 1 0 1 0 0 1 1 0 1 0 is to be Txed using BFSK. Sketch the Txed waveform by assuming $f_L = f_b$ & $f_H = 2f_b$

Ans: $f_L = f_b$

$\Rightarrow \frac{1}{T_L} = \frac{1}{T_b} \Rightarrow \boxed{T_b = T_L}$

; $f_H = 2f_b \Rightarrow \frac{1}{T_H} = \frac{2}{T_b}$

$\Rightarrow \boxed{\frac{T_b}{2} = T_H}$ → for T_H, one cycle requires $T_b/2$



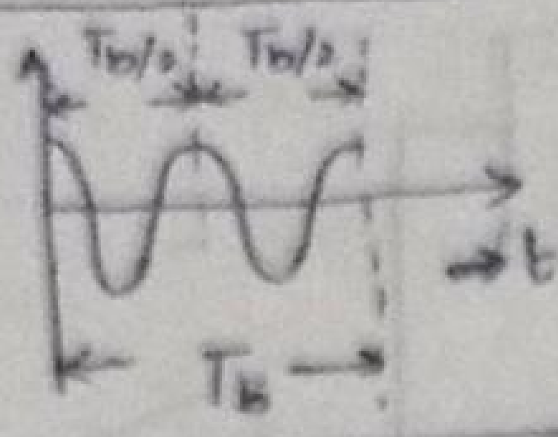
$\therefore T_H = \frac{T_b}{2}$

$T_L = T_b$

2 cycles per one bit duration (T_b) $\Rightarrow$

$\therefore$ Here

$\boxed{T_H \rightarrow \text{'1' bit}}$



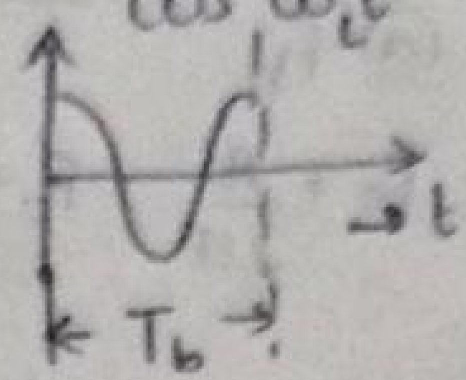
$\boxed{\text{'1' bit} \rightarrow \cos \omega_H t}$

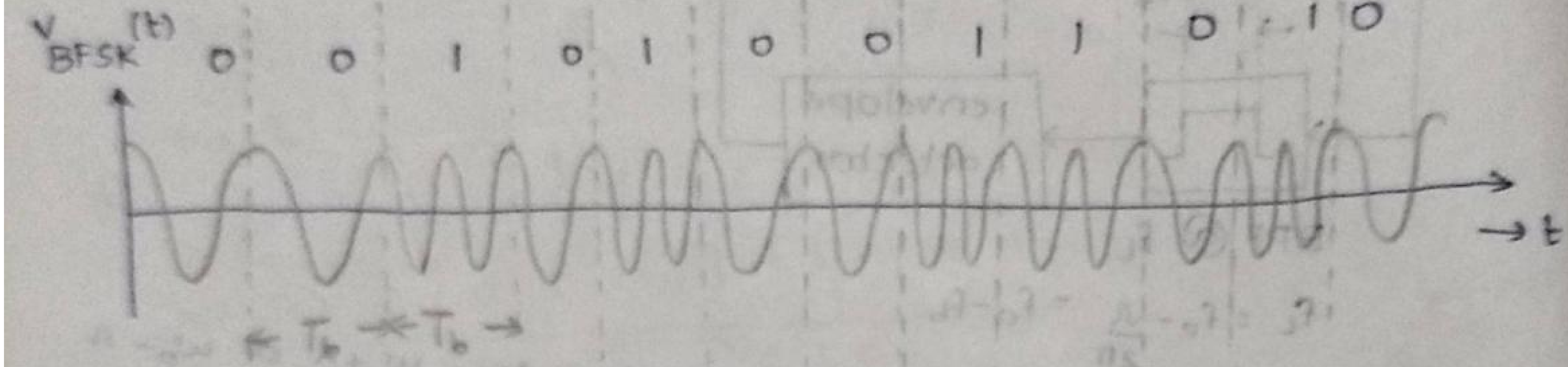
$v_{BFSK}(t) = \sqrt{2P_s} \cos\left[\omega_0 t + d(t)\, \Omega t\right]$

& $\omega_H = \omega_0 + \Omega$

$\omega_L = \omega_0 - \Omega$

$\cos \omega_L t \rightarrow \boxed{\text{'0' bit}}$





$f_H = 2T_b \Rightarrow f_H > f_L$ $\boxed{\text{as } f_H \uparrow \Rightarrow T_H \downarrow}$ $\Rightarrow$ time required to complete one cycle $\downarrow$es

$f_L = f_b$

→ **QPSK system** (Quadrature Phase shift keying) or

Staggered QPSK or **Offset QPSK** (OQPSK)

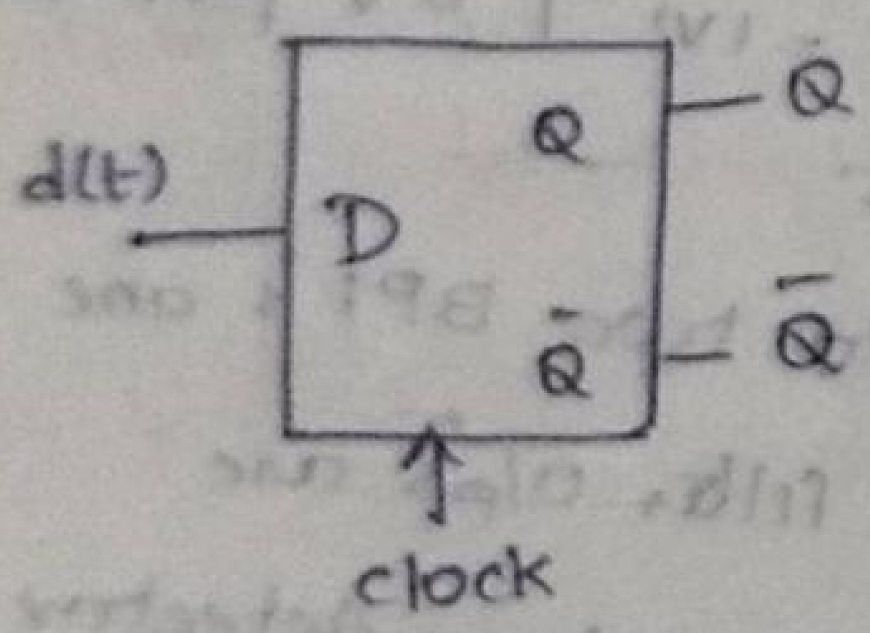


fig: Type-D flip flop symbol

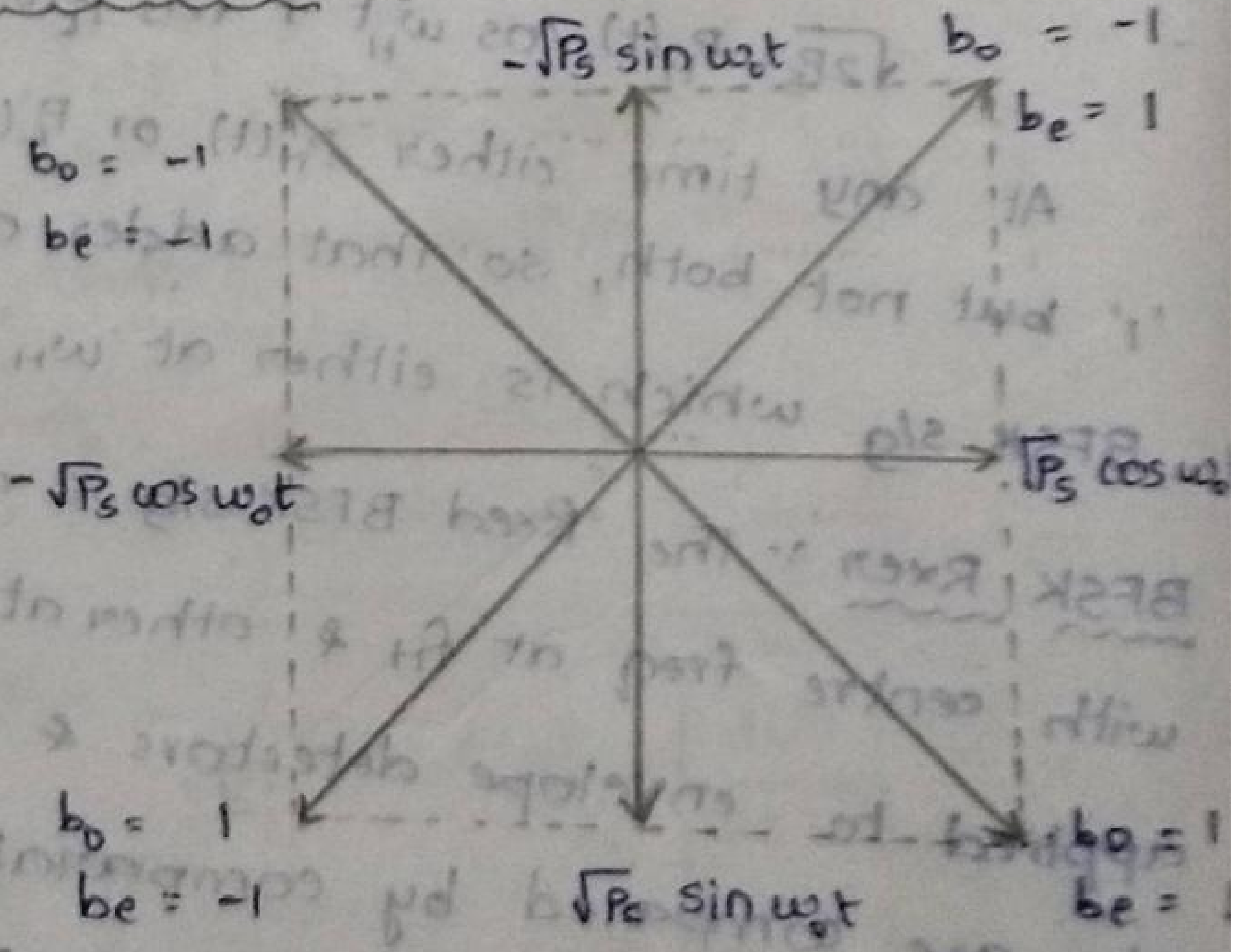
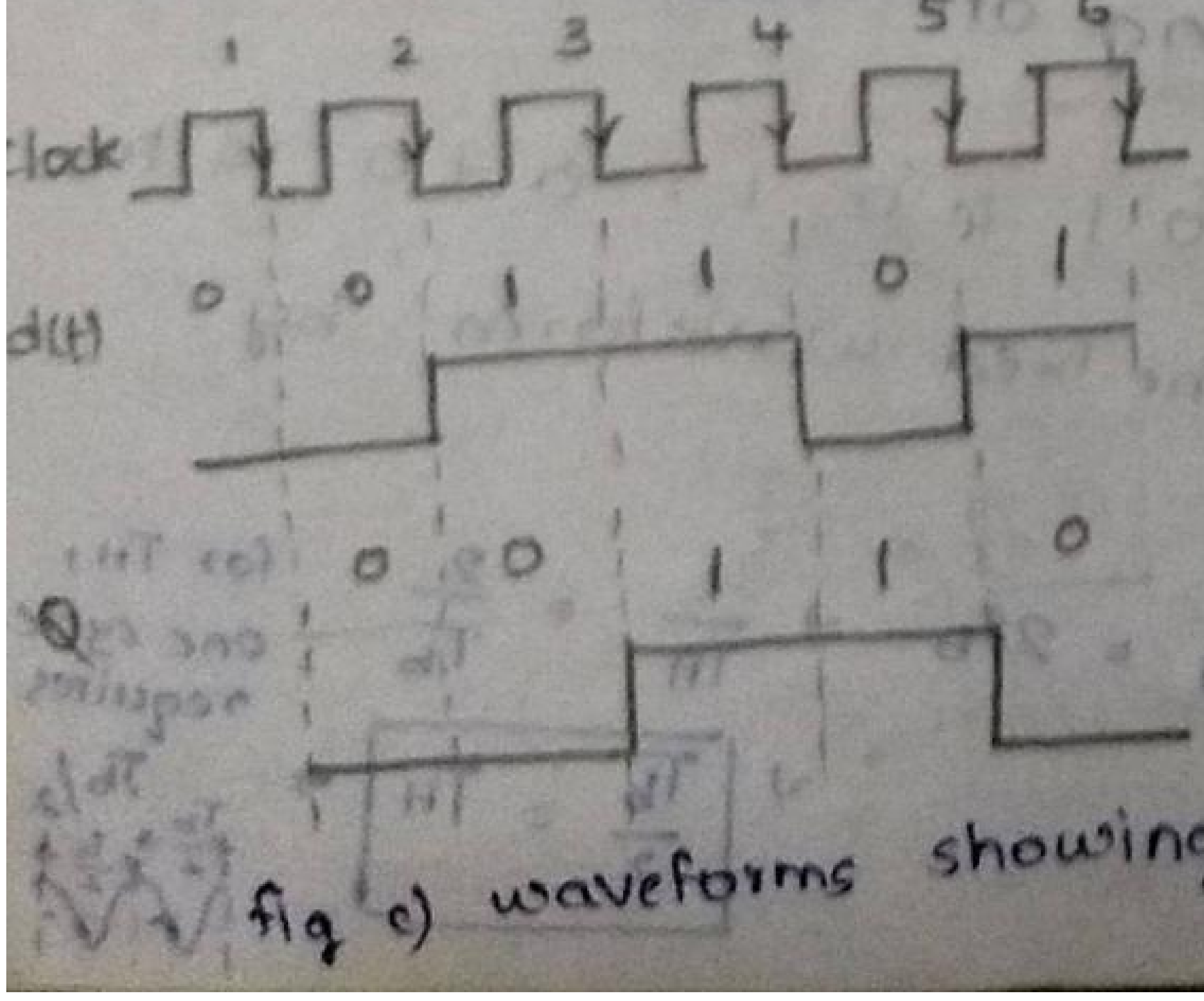


fig b) Phasor diagram



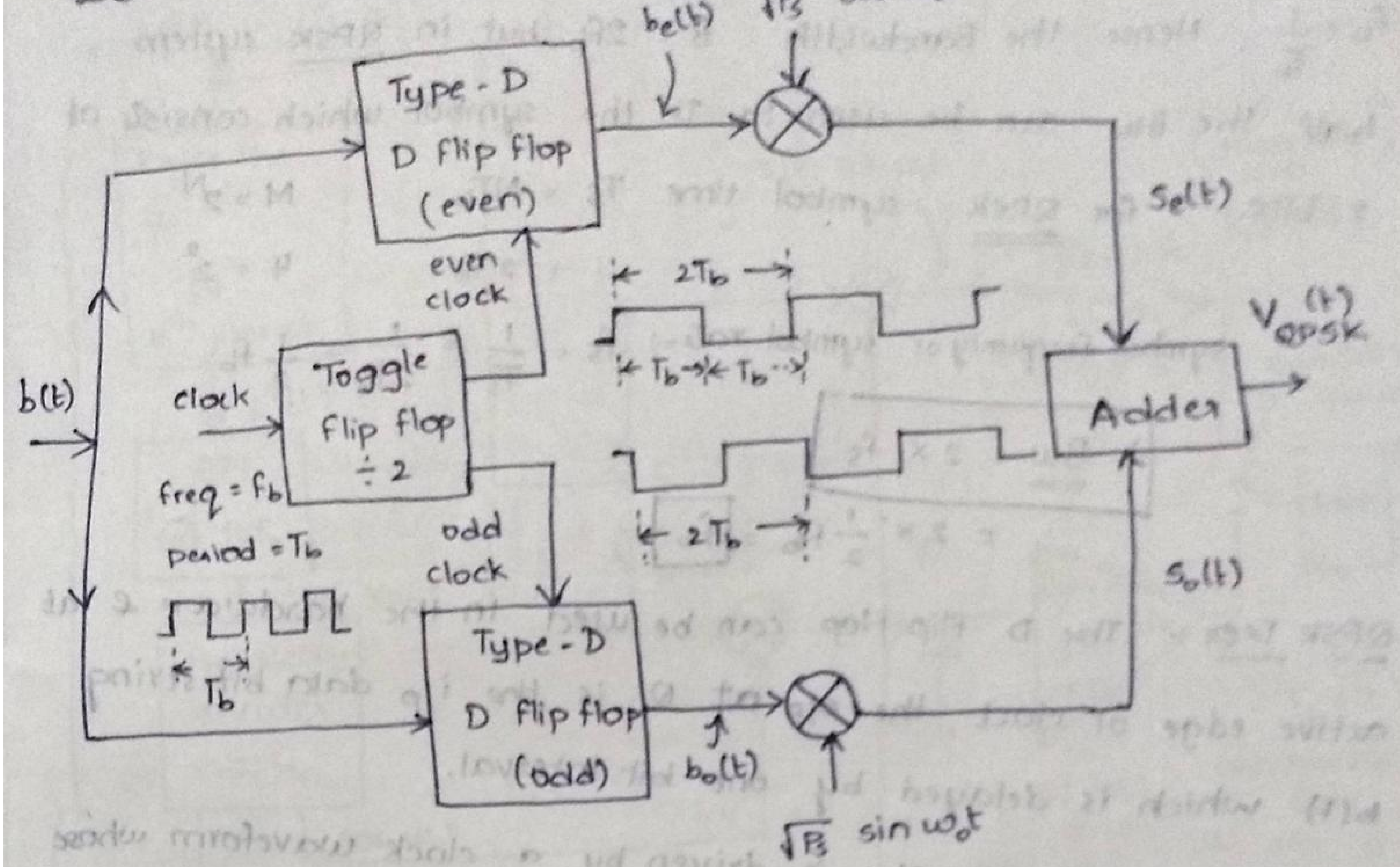
D flip flop $\Longrightarrow$ delay flip flop

i/p	o/p
0	0
1	1

but delay by 1 bit interval

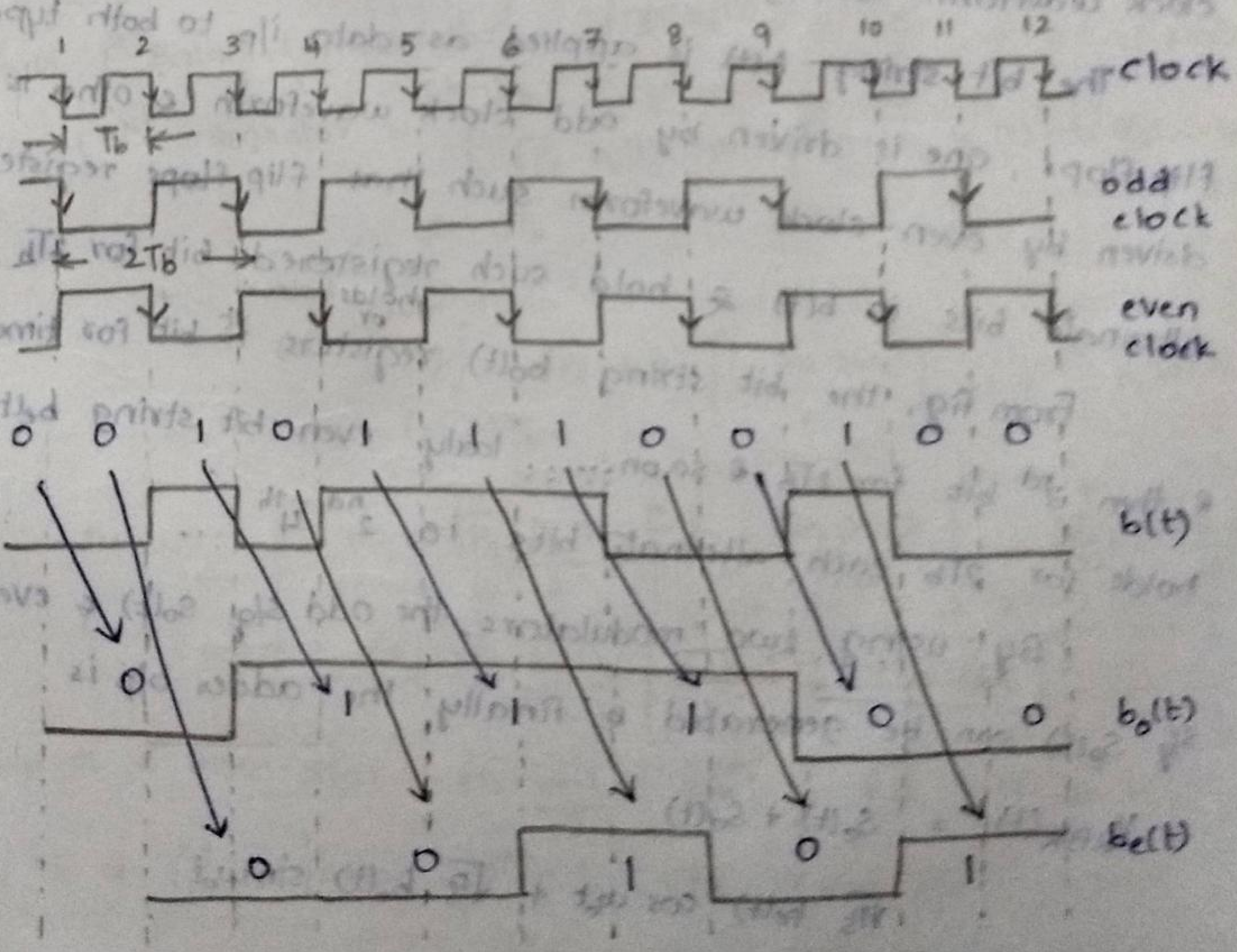
fig c) waveforms showing flip flop characteristics

QPSK Txer :-



$$V_{QPSK}(t) = S_e(t) + S_o(t)$$

$$= \sqrt{P_s}\, b_e(t) \cos \omega_0 t + \sqrt{P_s}\, b_o(t) \sin \omega_0 t$$



b(t) 0 0 1 0 1 1 1 0 0 1 0 0

$b_o(t)$: 0 1 1 1 0 0 ; $b_e(t)$: 0 0 1 0 1 0

For **BPSK**, the data bit duration is T_b sec. Hence bit rate $f_b = \frac{1}{T_b}$. Hence the Bandwidth $B = 2f_b$ but in **QPSK** system half the BW can be used to Tx the symbol which consists of 2 bits. for **QPSK**, symbol time $T_s = NT_b$

$M = 2^N$

$4 = 2^2$

$= 2T_b$

symbol frequency or symbol rate → $f_s = \frac{1}{T_s} = \frac{1}{2T_b} = \frac{1}{2} f_b$

$$\boxed{\therefore BW = 2 \times f_s}$$

$$= 2 \times \frac{1}{2} f_b = \boxed{f_b}$$

QPSK Txer :- The D flip flop can be used in the hardware & at active edge of clock, the o/p at Q is the i/p data bit string b(t) which is delayed by one bit interval.

The Toggle flip flop is driven by a clock waveform whose period is T_b & generates an odd clock waveform & an even clock waveform having time period $2T_b$.

The bit string b(t) is applied as data i/p to both type-D flip flops, one is driven by odd clock waveform & other is driven by even clock waveform such that flip flops register alternate bits in b(t) & hold such registered bit for $2T_b$.

From fig. the bit string $b_o(t)$ (registers) holds or 1^{st} bit for time $2T_b$ & then 3^{rd} bit for $2T_b$ & so on ..... lly even bit string $b_e(t)$ holds for $2T_b$ each alternate bits i.e, 2^{nd}, 4^{th} ...

By using two modulators, the odd s/g $S_o(t)$ & even s/g $S_e(t)$ can be generated & finally the adder o/p is

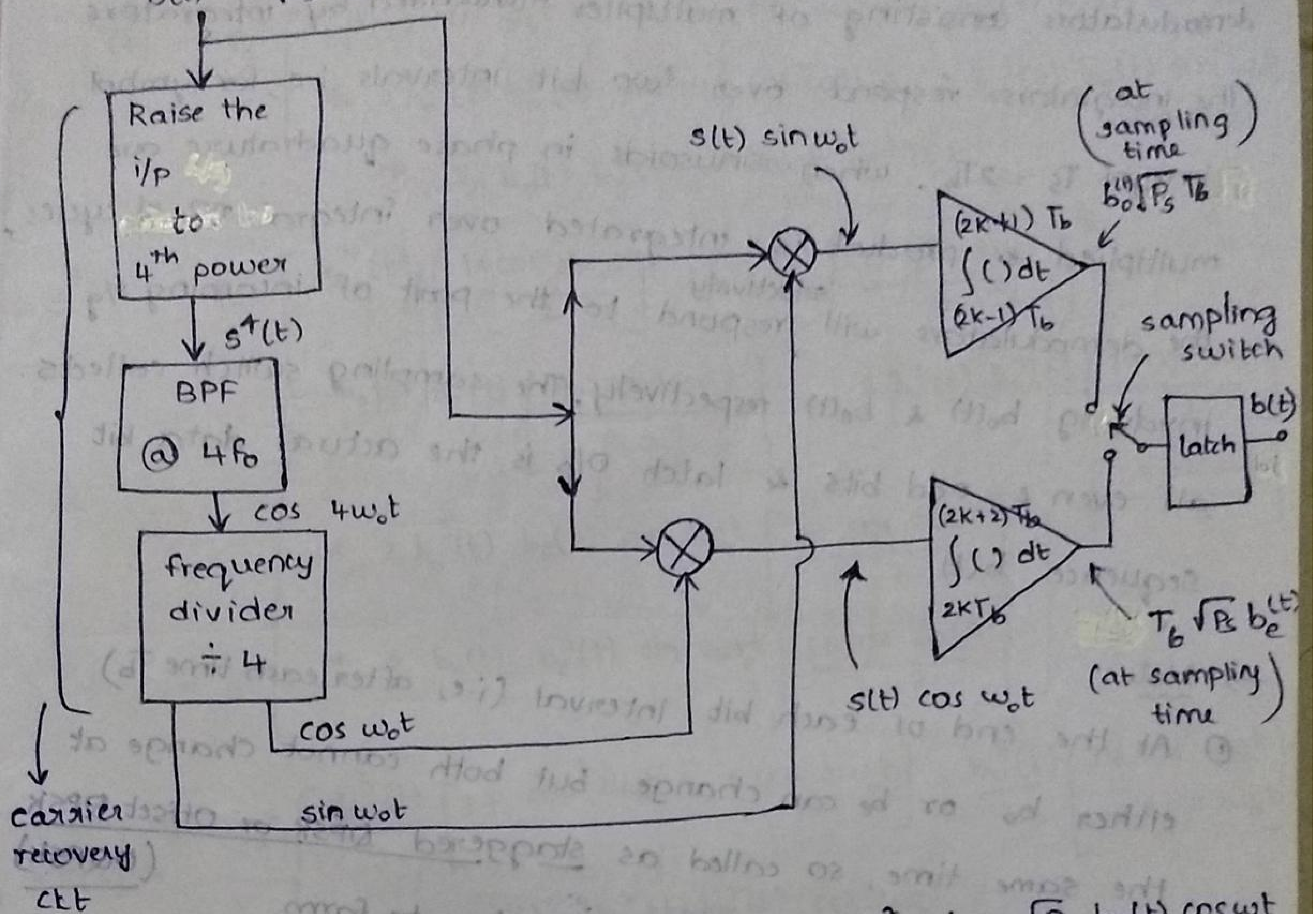
$$V_{QPSK}(t) = S_e(t) + S_o(t)$$

$$= \sqrt{P_s}\, b_e(t) \cos \omega_0 t + \sqrt{P_s}\, b_o(t) \sin \omega_0 t.$$

→ The phase difference b/w two successive phasors $= \pi/2$

QPSK Receiver :-

$$s(t) = \sqrt{P_s}\, b_o(t) \sin \omega_o t + \sqrt{P_s}\, b_e(t) \cos \omega_o t$$



o/p of 1st Balanced modulator $= \sqrt{P_s}\, b_o(t) \sin^2 \omega_o t + \sqrt{P_s}\, b_e(t) \cos \omega_o t \sin \omega_o t$

o/p of 1st integrator $= \int_{(2k-1)T_b}^{(2k+1)T_b} \sqrt{P_s}\, b_o(t) \sin^2 \omega_o t + \sqrt{P_s}\, b_e(t) \cos \omega_o t \sin \omega_o t \; dt$

$$= \int_{(2k-1)T_b}^{(2K+1)T_b} \sqrt{P_s}\, b_o(t) \left[\frac{1 - \cos 2\omega_o t}{2}\right] dt + \frac{\sqrt{P_s}}{2} b_e(t) \sin 2\omega_o t$$

$$= \sqrt{P_s}\, \frac{b_o(t)}{2} \left[t - \frac{\sin 2\omega_o t}{2\omega_o} \right]_{(2k-1)T_b}^{(2k+1)T_b} + \underbrace{\frac{\sqrt{P_s}}{2} b_e(t) \left[\frac{\cos 2\omega_o t}{2\omega_o}\right]_{(2k-1)T_b}^{(2k+1)T_b}}_{0}$$

odd interval

$$= \sqrt{P_s}\, \frac{b_o(t)}{2} \left[(2k+1) T_b - (2k-1) T_b \right]$$

$\therefore$ O/p of 1st integrator $= \sqrt{P_s}\, \frac{b_o(t)}{2} \left[2T_b \right] = \sqrt{P_s}\; b_o(t)\, T_b$ ✓

$\therefore b_e(t)$ is not reqd.

Illy o/p of 2nd integrator $= \sqrt{P_s}\; b_e(t)\, T_b$

By using carrier recovery ckt, regenerate the carriers $\cos \omega_o t$ & $\sin \omega_o t$ as shown in fig. The procedure is similar to that of BPSK system. The incoming s/g is also applied to two synchronous demodulators consisting of multiplier followed by integrators. The integrators respond over two bit intervals i.e, for symbol time of $T_s = 2T_b$. when sinusoids in phase quadrature are multiplied & product is integrated over integral no. of cycles the demodulators will selectively respond to the part of incoming s/g involving $b_o(t)$ & $b_e(t)$ respectively. The sampling switch collects all even & odd bits & latch O/p is the actual data bit sequence $b(t)$.

→ Note :-

① At the end of each bit interval (i.e, after each time T_b) either b_o or b_e can change but both cannot change at the same time, so called as staggered QPSK or Offset QPSK (OQPSK)

② In QPSK, we lump two bits together to form which is termed as symbol.

→ In a QPSK system, the received s/g is

$$S(t) = \sqrt{P_s}\, b_e(t) \cos \omega_o t + \sqrt{P_s}\, b_o(t) \sin \omega_o t.$$

Find the O/p's available at each block in the hardware related to recovery of synchronous carrier.

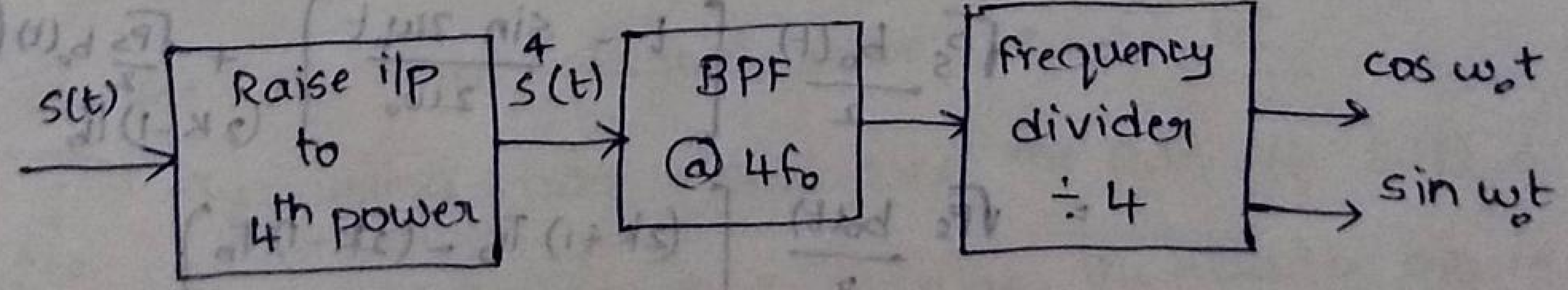
Ans] 

Fig : carrier recovery ckt in QPSK Rxer

$$s(t) = \sqrt{P_s}\, b_e(t) \cos \omega_o t + \sqrt{P_s}\, b_o(t) \sin \omega_o t$$

$$\therefore s^2(t) = P_s \left[b_e^2(t) \cos^2 \omega_o t + b_o^2(t) \sin^2 \omega_o t + 2\, b_e(t)\, b_o(t) \sin \omega_o t \cos \omega_o t \right]$$

$$= P_s \left[b_e^2(t) \left[\frac{1+\cos 2\omega_o t}{2}\right] + b_o^2(t) \left[\frac{1-\cos 2\omega_o t}{2}\right] + b_e(t)\, b_o(t) \sin 2\omega_o t \right.$$

$$\Rightarrow s^2(t) = P_s\left[b_e^2(t)\cos^2\omega_0 t + b_o^2(t)\sin^2\omega_0 t + b_o(t)\,b_e(t)\sin 2\omega_0 t\right]$$

$$\therefore s^4(t) = P_s^2\left[b_e^4(t)\cos^4\omega_0 t + b_o^4(t)\sin^4\omega_0 t + b_o^2(t)\,b_e^2(t)\sin^2 2\omega_0 t + 2b_e^2(t)\,b_o^2(t)\sin^2\omega_0 t\cos^2\omega_0 t + 2b_o^3(t)\,b_e(t)\sin^2\omega_0 t\,\sin 2\omega_0 t + 2\,b_o(t)\,b_e^3(t)\sin 2\omega_0 t\cos^2\omega_0 t\right]$$

$$\Rightarrow s^4(t) = P_s^2\left[b_e^4(t)\left[\frac{1+\cos 2\omega_0 t}{2}\right]^2 + b_o^4(t)\left[\frac{1-\cos 2\omega_0 t}{2}\right]^4 + b_o^2(t)\,b_e^2(t)\left[\frac{1-\cos 4\omega_0 t}{2}\right] + 2b_e^2(t)\,b_o^2(t)\left[\frac{1-\cos 2\omega_0 t}{2}\right]\left[\frac{1+\cos 2\omega_0 t}{2}\right] + 2b_o^3(t)\,b_e(t)\sin 2\omega_0 t\left[\frac{1-\cos 2\omega_0 t}{2}\right] + 2\,b_o(t)\,b_e^3(t)\sin 2\omega_0 t\left[\frac{1+\cos 2\omega_0 t}{2}\right]\right]$$

$$\Rightarrow s^4(t) = P_s^2\left[\frac{b_e^4(t)}{4}\left[1+\cos^2 2\omega_0 t + 2\cos 2\omega_0 t\right] + \frac{b_o^4(t)}{4}\left[1+\cos^2 2\omega_0 t - 2\cos 2\omega_0 t\right] + \frac{b_o^2(t)\,b_e^2(t)}{2} - \frac{b_o^2(t)\,b_e^2(t)\cos 4\omega_0 t}{2} + \frac{b_e^2(t)\,b_o^2(t)}{2}\left[1+\cancel{\cos 2\omega_0 t} - \cancel{\cos 2\omega_0 t} - \cos^2 2\omega_0 t\right] + \frac{2\,b_o^3(t)\,b_e(t)}{2}\left[\sin 2\omega_0 t - \frac{1}{2}\sin 4\omega_0 t\right] + \frac{2\,b_o(t)\,b_e^3(t)}{2}\left[\sin 2\omega_0 t + \frac{1}{2}\sin 4\omega_0 t\right]\right]$$

$$\Rightarrow s^4(t) = P_s^2\left[\frac{b_e^4(t)}{4}\left[1+\cos^2 2\omega_0 t + 2\cos 2\omega_0 t\right] + \frac{b_o^4(t)}{4}\left[1+\cos^2 2\omega_0 t - 2\cos 2\omega_0 t\right] + \frac{b_o^2(t)\,b_e^2(t)}{2}\left[1-\cos 4\omega_0 t\right] + \frac{b_e^2(t)\,b_o^2(t)}{2}\left[1-\cos^2 2\omega_0 t\right] + b_o^3(t)\,b_e(t)\left[\sin 2\omega_0 t - \frac{1}{2}\sin 4\omega_0 t\right] + b_o(t)\,b_e^3(t)\left[\sin 2\omega_0 t + \frac{1}{2}\sin 4\omega_0 t\right]\right]$$

$$\Rightarrow s^4(t) = P_s^2\left[\frac{b_e^4(t)}{4}\left[1+2\cos 2\omega_0 t + \left[\frac{1+\cos 4\omega_0 t}{2}\right]\right] + \frac{b_o^4(t)}{4}\left[1-2\cos 2\omega_0 t + \left(\frac{1+\cos 4\omega_0 t}{2}\right)\right.\right.$$

$$\left[+ \frac{b_e^2(t)\, b_o^2(t)}{2}\left[1-\cos 4\omega_o t\right] + \frac{b_e^2(t)\, b_o^2(t)}{2}\left[1 - \left(\frac{1+\cos 4\omega_o t}{2}\right)\right] + b_o^3(t)\, b_e(t)\left[\sin 2\omega_o t - \frac{1}{2}\sin 4\omega_o t\right] + b_o(t)\, b_e^3(t)\left[\sin 2\omega_o t + \frac{1}{2}\sin 4\omega_o t\right]\right]$$

$$\Rightarrow s^4(t) = P_s^2 \left[\frac{b_e^4(t)}{4}\left[1 + 2\cos 2\omega_o t + \frac{1}{2} + \frac{\cos 4\omega_o t}{2}\right] + \frac{b_o^4(t)}{4}\left[1 - 2\cos 2\omega_o t + \frac{1}{2} + \frac{1}{2}\cos 4\omega_o t\right] + \frac{b_e^2(t)\, b_o^2(t)}{2}\left[1-\cos 4\omega_o t\right] + \frac{b_e^2(t)\, b_o^2(t)}{2}\left[\frac{1-\cos 4\omega_o t}{2}\right] + b_o^3(t) b_e(t)\left[\sin 2\omega_o t - \frac{1}{2}\sin 4\omega_o t\right] + b_o(t)\, b_e^3(t)\left[\sin 2\omega_o t + \frac{\sin 4\omega_o t}{2}\right]\right]$$

Now this $s^4(t)$ is passed through a BPF with cut off freq $4f_o$.

$\therefore$ The o/p of BPF @ $4f_o$ is

$$P_s^2 \left[\frac{b_e^4(t)}{4}\,\frac{\cos 4\omega_o t}{2} + \frac{b_o^4(t)}{4}\left(\frac{\cos 4\omega_o t}{2}\right) - \frac{b_e^2(t)\, b_o^2(t)}{2}\cos 4\omega_o t - \frac{b_e^2(t)\, b_o^2(t)\cos 4\omega_o t}{2\times 2} - \frac{b_o^3(t)\, b_e(t)\, \sin 4\omega_o t}{2} + b_o(t)\, b_e^3(t)\frac{\sin 4\omega_o t}{2}\right]$$

This o/p is passed through $\div 4$, then the o/p of freq divider is

$$P_s^2 \left[\frac{b_e^4(t)\cos\omega_o t}{8} + \frac{b_o^4(t)\cos\omega_o t}{8} - \frac{3\, b_o^2(t)\, b_e^2(t)\cos\omega_o t}{4} - \frac{b_o^3(t)\, b_e(t)}{2}\sin\omega_o t + b_o(t)\, b_e^3(t)\frac{\sin\omega_o t}{2}\right]$$

Thus the synchronous carriers $\cos\omega_o t$ & $\sin\omega_o t$ are recovered.

→ M-ary Phase Shift Keying (MPSK) :-

$$\boxed{\begin{matrix} M = 2^N \\ T_S = N T_b \end{matrix}}$$

① For BPSK :- $M = 2 \Rightarrow 2 = 2^1$

$\Rightarrow N = 1$

& $T_S = T_b$