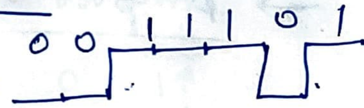
DIGITAL MODULATION TECHNIQUES [redacted]

→ $\underbrace{0011101}$ → Line Coding →



Unipolar NRZ

Line coding: It is the process of converting DIGITAL BITS to DIGITAL SIGNAL

Can I transmit this signal on a wireless medium or wired medium.

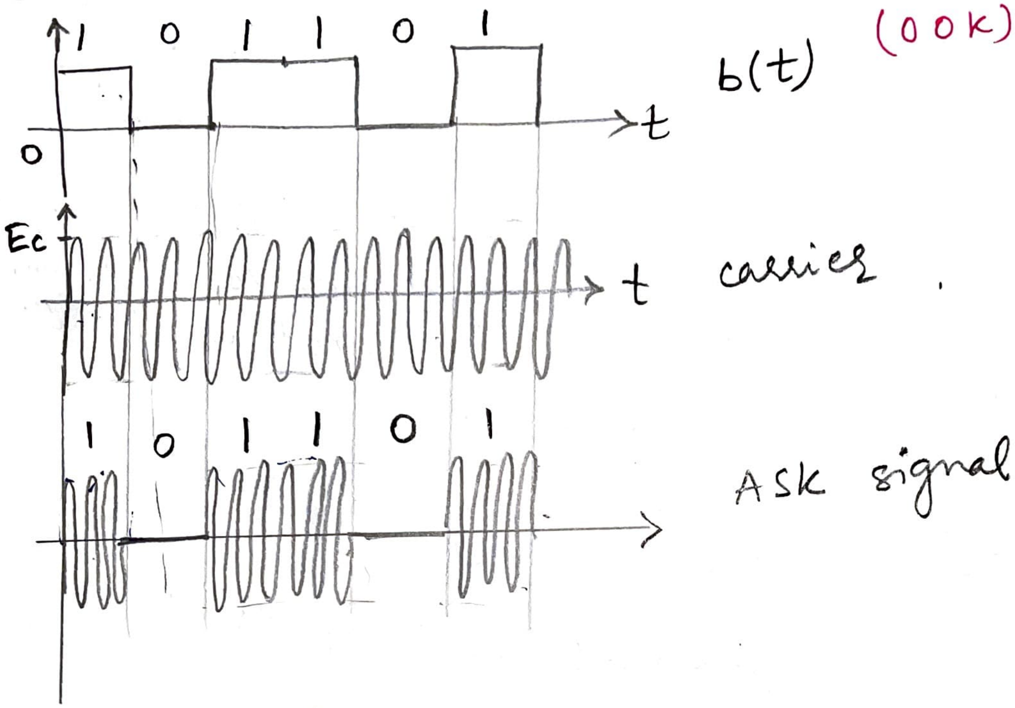
modulate this !!
using a high freq carrier.
⇓
Digital Mod. Techniques.

TYPES OF DIG MOD. TECH

- **Binary** (Two possible signals)
  - ASK
  - FSK
  - PSK or BPSK
- **M-ary** (send one of the M possible signals)
  - QPSK (4-PSK)
  - 8-PSK ....
  - QAM
  - DPSK
  - MSK
  - Mary-FSK.

→ ASK → Amplitude shift keying
FSK → frequency shift keying.
BPSK → Binary phase shift keying
QPSK → Quadrature phase shift keying

Binary Amplitude Shift keying (ASK) – (ON-OFF KEYING (OOK))



ASK generator –

Carrier

$E_c \cos w_c t$

$\left[\sqrt{2P_c} \cos 2\pi f_c t\right]$

$P_c = \frac{E_c^2}{2R}$

$\Rightarrow E_c = \sqrt{2P_c}$

when $R = 1\,\Omega$

$$s(t) = \sqrt{2P_c} \cos 2\pi f_c t \quad , \text{ for } b(t) = 1$$

$$= 0 \quad , \text{ for } b(t) = 0$$

$$s(t) = b(t) \sqrt{2P_c} \cos 2\pi f_c t \quad \left[\text{unipolar NRZ signal}\right]$$

→ ASK Detector –

$s(t) \rightarrow$ BPF f_c $\rightarrow$ Envelope detector $\rightarrow$ Decision device $\rightarrow b(t)$

Envelope detector ⇓ Rectifier + C-filter.

Decision device ↑ Threshold ↓ To overcome effects due to noise

→ Binary frequency Shift Keying – (BFSK)

→ Frequency of carrier is shifted according to the binary symbol.

→ If "1" $\quad S_H(t) = \sqrt{2P_c}\cos(2\pi f_c + \Omega)t$

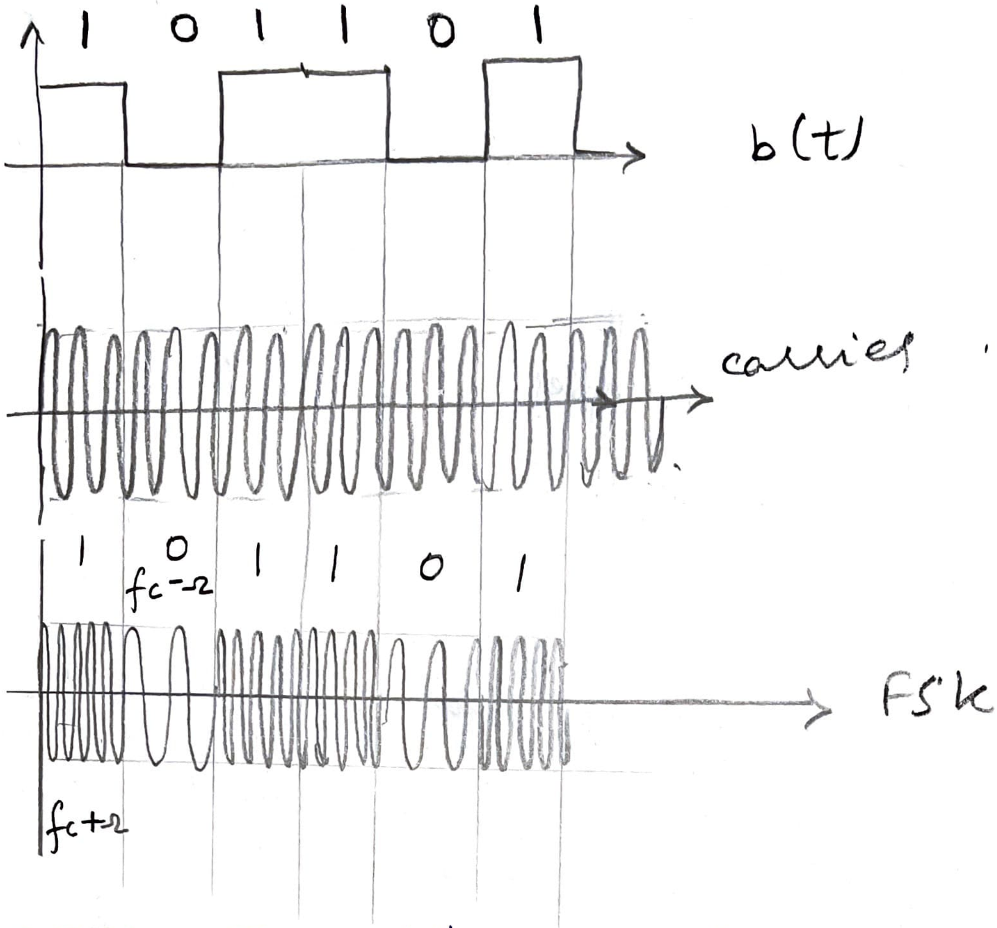
If "0" $\quad S_L(t) = \sqrt{2P_c}\cos(2\pi f_c - \Omega)t$

$$\therefore\ s(t) = \sqrt{2P_c}\cos\left[(2\pi f_c + d(t)\,\Omega)t\right]$$

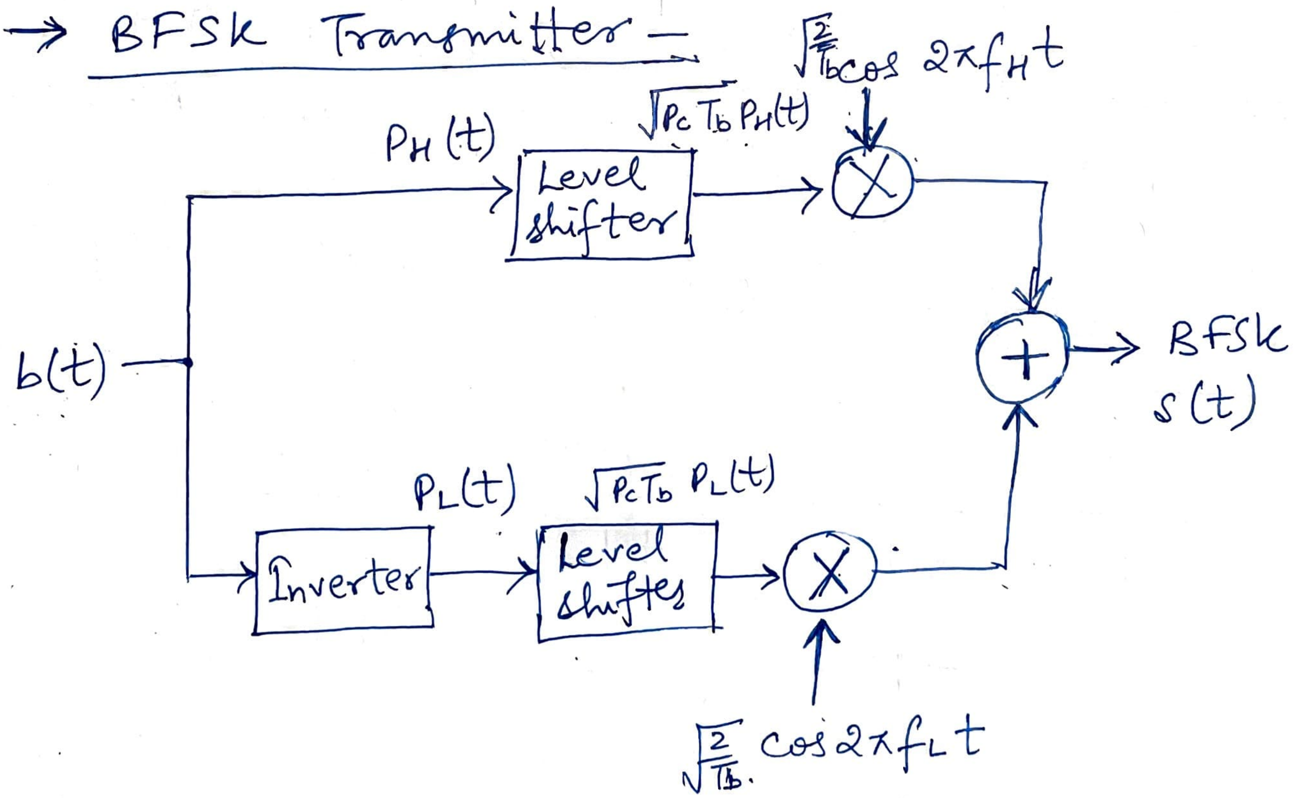
$b(t)$	$d(t)$	$P_H(t)$	$P_L(t)$
1	+1	+1	0
0	−1	0	+1

⇒ $P_H(t)$ is same as $b(t)$

$P_L(t)$ is inverted version of $b(t)$



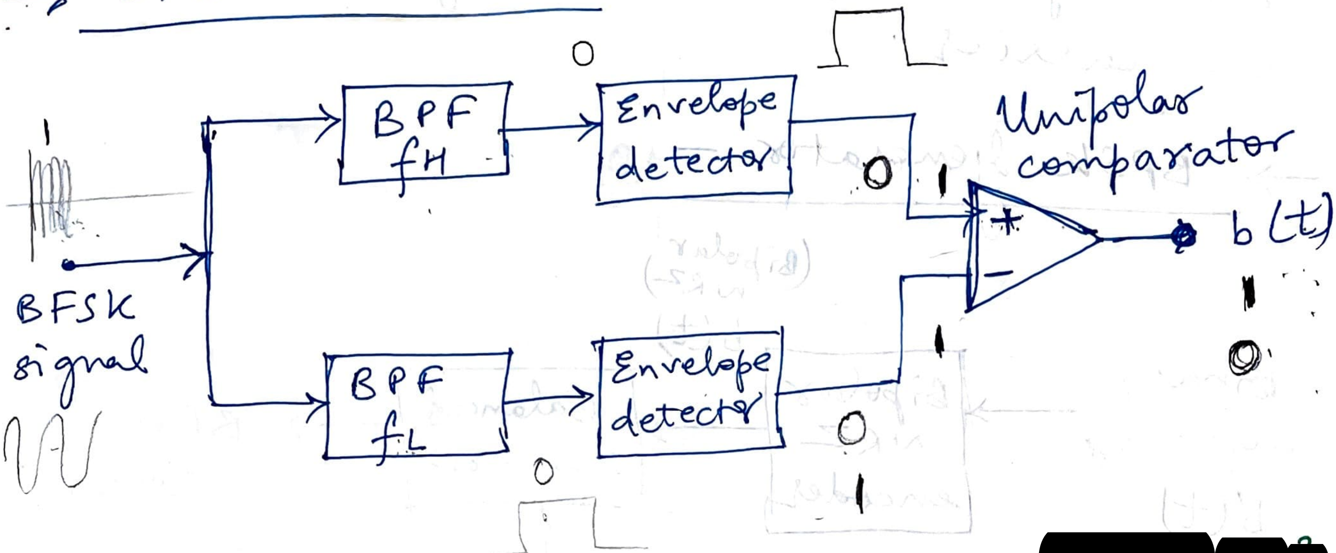
→ BFSK Transmitter –



→ output from both $\otimes$ not possible at a time because $P_H(t)$ and $P_L(t)$ are complementary to each other.

$$\therefore\ s(t) = \sqrt{2P_c}\ P_H(t)\cos(2\pi f_H t) + \sqrt{2P_c}\ P_L(t)\cos(2\pi f_L t)$$

→ **BFSK Receiver –**



[redacted]

→ **Binary Phase shift keying – (BPSK) –**

→ "1" & "0" → change in phase of carrier.

Let the carrier be represented as –

$$s_1(t) = \sqrt{2P_c}\cos 2\pi f_c t \quad \rightarrow \text{for "1"}$$

Then for "0",

$$s_2(t) = \sqrt{2P_c}\cos(2\pi f_c t + \pi)$$

Now, $\cos(\theta + \pi) = -\cos\theta$

$$\therefore\ s(t) = -\sqrt{2P_c}\cos(2\pi f_c t)$$

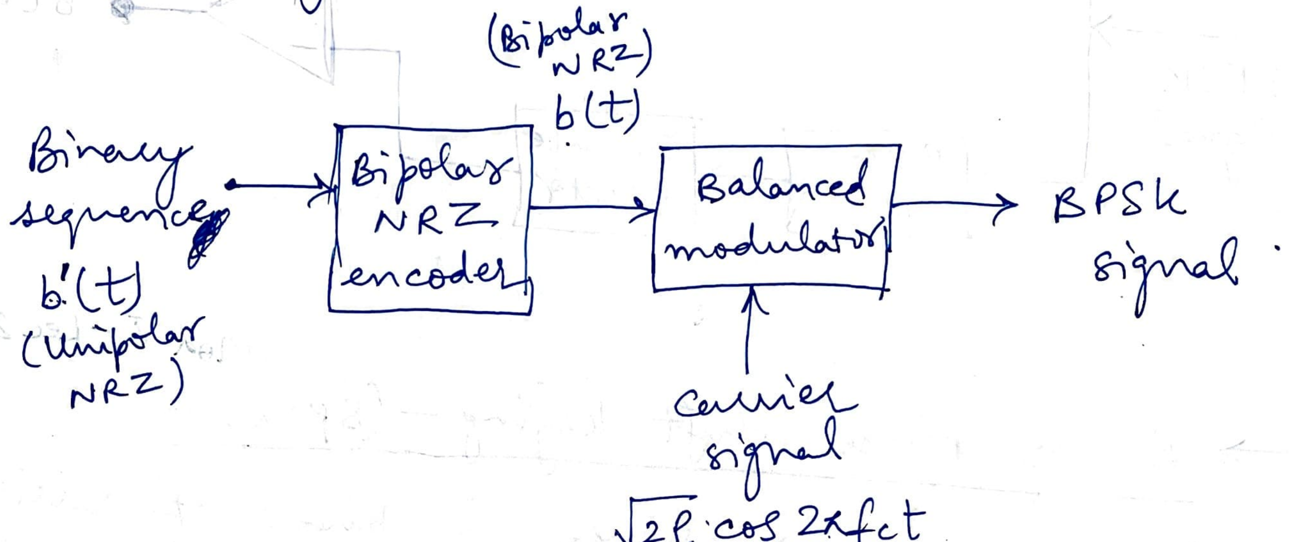
⇒ BPSK output,

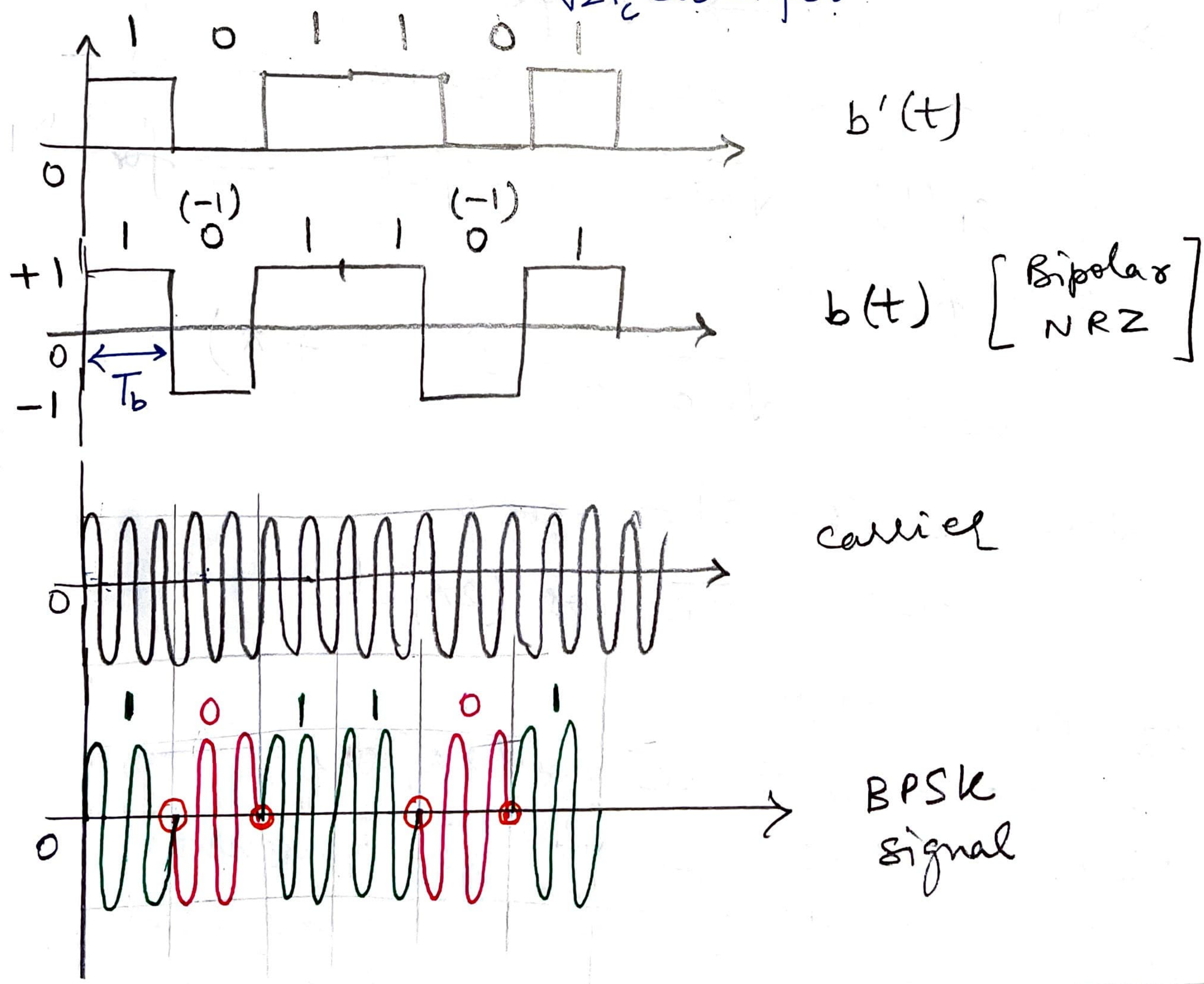
$$s(t) = b(t)\sqrt{2P_c}\cos(2\pi f_c t)$$

where, $b(t) = +1$ if "1" is transmitted
$= -1$ if "0" is transmitted.

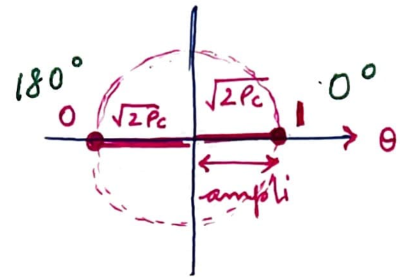
∴ We must convert a unipolar NRZ s[ignal] into a bipolar NRZ signal first. This signal can then directly modulate the carrier.

→ BPSK Generator





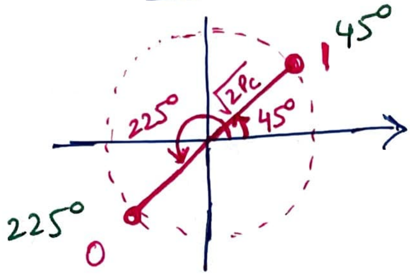
2 bits = 2 pts on the constellation (180° out of phase)



$1 \rightarrow 0°$
$0 \rightarrow 180°$

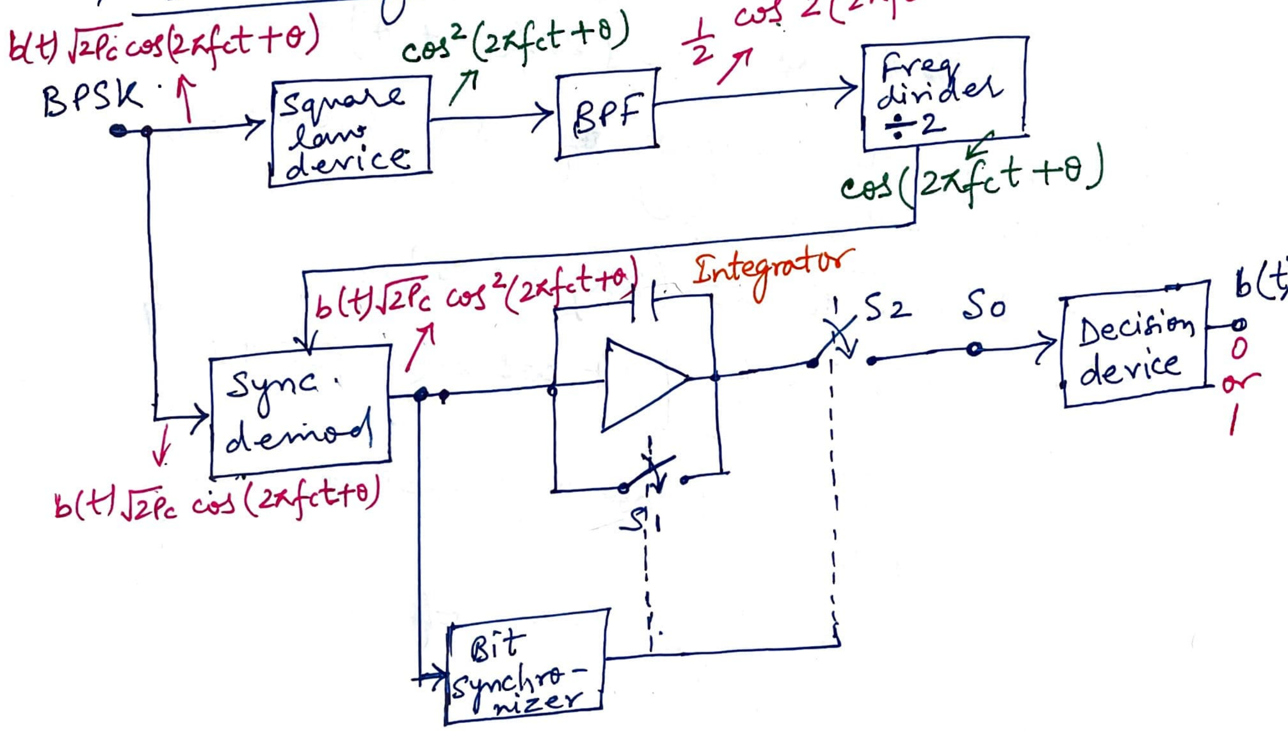
Constellation Diagram

OR



$1 \rightarrow 45°$
$0 \rightarrow 225°$

→ BPSK Degeneration –



→ Signal undergoes phase change depending on time delay from Tx to Rx.
This phase shift (θ) is normally fixed
$\therefore S_2(t) = b(t)\sqrt{2P_c}\cos(2\pi f_c t+\theta)$

→ Output of square law device $= \cos^2(2\pi f_c t + \theta)$
[amplitude neglected)

Now, $\cos^2\theta = \frac{1+\cos 2\theta}{2}$

$$\therefore \cos^2(2\pi f_c t+\theta) = \frac{1+\cos 2(2\pi f_c t+\theta)}{2}$$

$$= \underset{\substack{\swarrow \\ \text{dc level.}}}{\frac{1}{2}} + \underbrace{\frac{1}{2}\cos 2(2\pi f_c t+\theta)}.$$

(BPF filter it out)

→ This signal of frequency $2f_c$ is passed through a frequency divider by 2,

∴ Output as $\cos(2\pi f_c t+\theta)$

→ Now, at the output of synchronous demodulator, we get

$$= b(t)\sqrt{2P_c}\cos^2(2\pi f_c t+\theta)$$

$$= b(t)\sqrt{2P_c} \times \frac{1}{2}\left[1+\cos 2(2\pi f_c t+\theta)\right]$$

$$= b(t)\sqrt{\frac{P_c}{2}}\left[1+\cos 2(2\pi f_c t+\theta)\right]$$

→ Bit synchronizer takes care of starting and ending time ~~of~~ of a bit.

→ Integrator integrates the signal over one bit period.

→ At the end of bit duration, synchronizer closes S_2 temporarily.

$+\theta$ → This connects output of integrator to the decision device

→ Then, the synchronizer opens S_2 & closes S_1 temporarily.
This resets the integrator voltage to zero.

→ Integrator then integrates next bit.
[Assume one bit period, T_b contains integral number of cycles of carrier)
∴ Phase change occurs in carrier only at zero crossing.

→ In k^{th} bit interval, output signal is

$$s_o(kT_b) = b(kT_b)\sqrt{\frac{P_c}{2}}\left[\int_{(k-1)T_b}^{kT_b}[1+\cos 2(2\pi f_c t+\theta)]\,dt\right]$$

$$= b(kT_b)\sqrt{\frac{P_c}{2}}\left[\int_{(k-1)T_b}^{kT_b} 1\cdot dt + \underbrace{\int_{(k-1)T_b}^{kT_b}\cos 2(2\pi f_c t+\theta)\cdot dt}_{=0}\right]$$

∴ avg value $=0$

$$= b(kT_b)\sqrt{\frac{P_c}{2}}\,\big[t\big]_{(k-1)T_b}^{kT_b}$$

$$= b(kT_b)\sqrt{\frac{P_c}{2}}\left[kT_b-(k-1)T_b\right]$$

$$\therefore s_o(kT_b) = b(kT_b)\sqrt{\frac{P_c}{2}}\,T_b$$

$$\Rightarrow s_o(kT_b) \propto b(kT_b)$$

→ $S_0(kT_b)$ given to decision device which decides whether transmitted symbol was zero or one.

Mod [redacted]-L[redacted]

→ Quadrature Phase shift keying (QPSK) — (4-PSK).

→ In ASK, FSK, BPSK, → we transmit one bit at a time.

BW = no. of bits/sec.

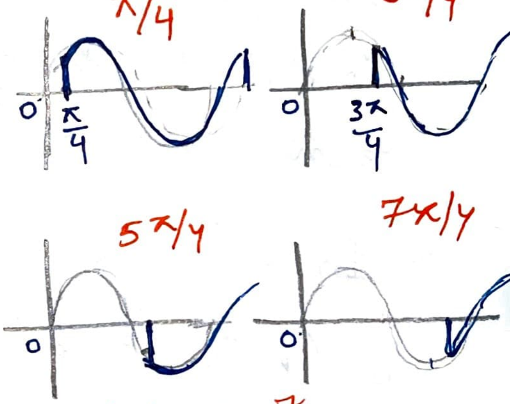
→ In QPSK → we combine 2 bits to form a symbol.

$S_1 \rightarrow 10 \longrightarrow \pi/4 \rightarrow 45^\circ$

$S_2 \rightarrow 00 \longrightarrow 3\pi/4 \rightarrow 135^\circ$

$S_3 \rightarrow 01 \longrightarrow 5\pi/4 \rightarrow 225^\circ$

$S_4 \rightarrow 11 \longrightarrow 7\pi/4 \rightarrow 315^\circ$.



2bits → 1 symbol

Eg. 01 10 11 11 00 10 11

225° 45° 315° 315° 135° 45° 315°

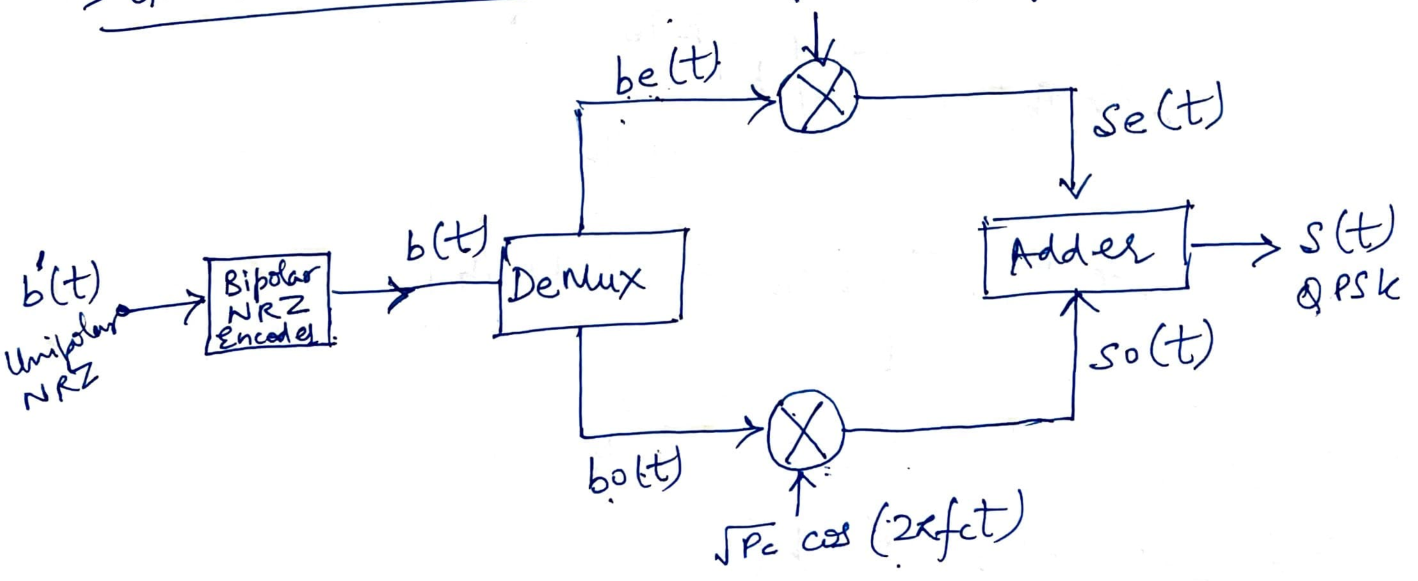
→ suppose, I transmit 10 symbol/sec → Baud Rate

↓ 2 bits

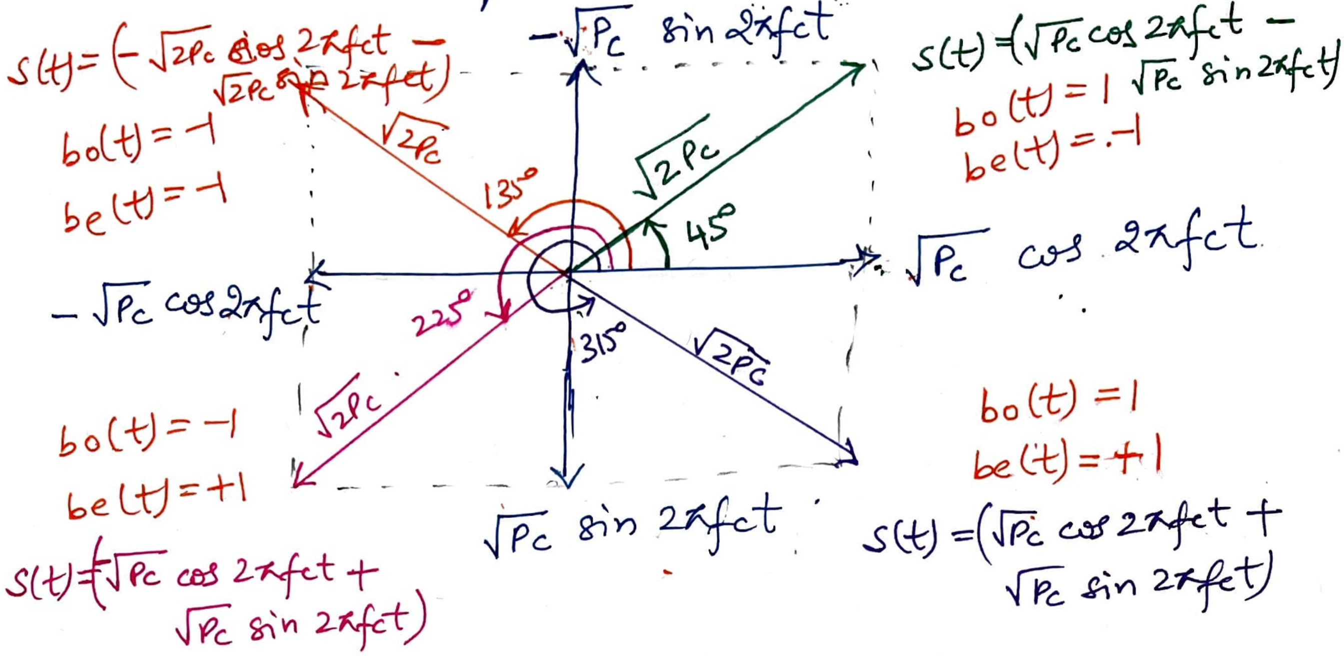
∴ 2×10 bits/sec

~~Bit~~ Bit rate ↑

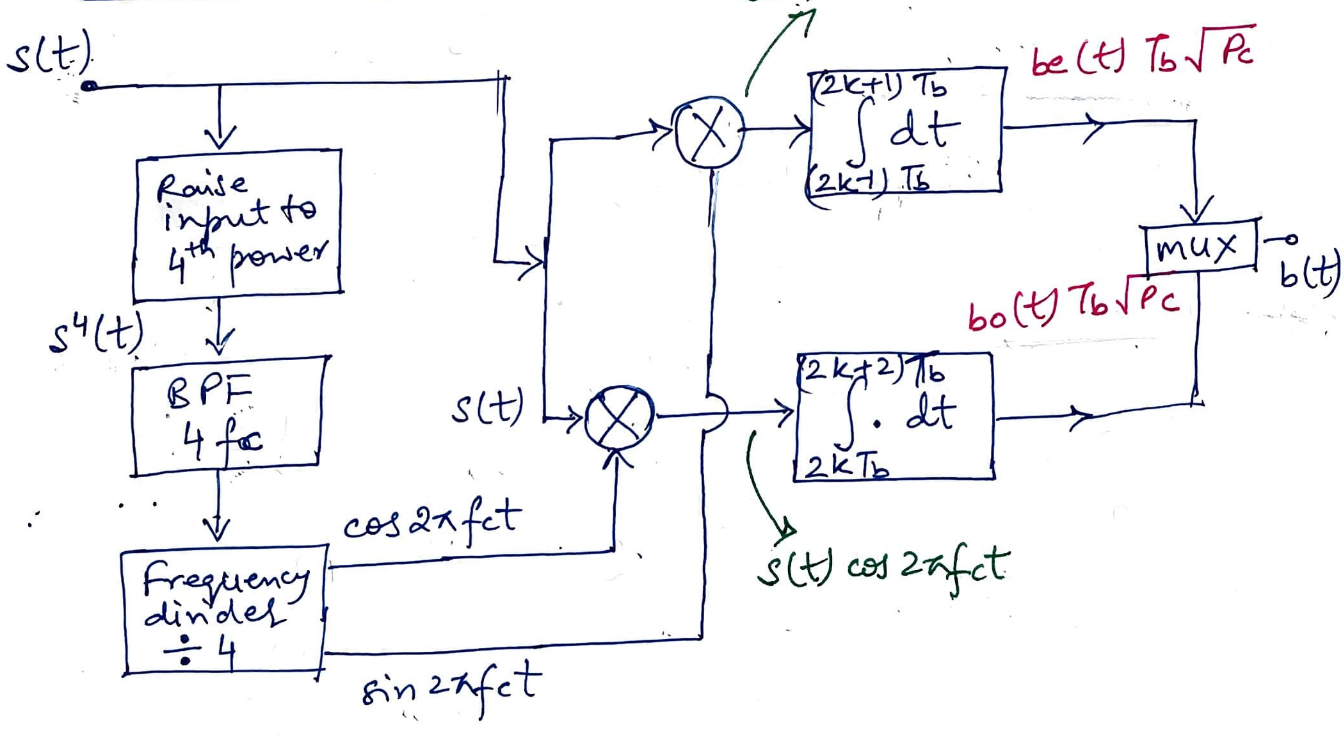
→ QPSK Transmitter —

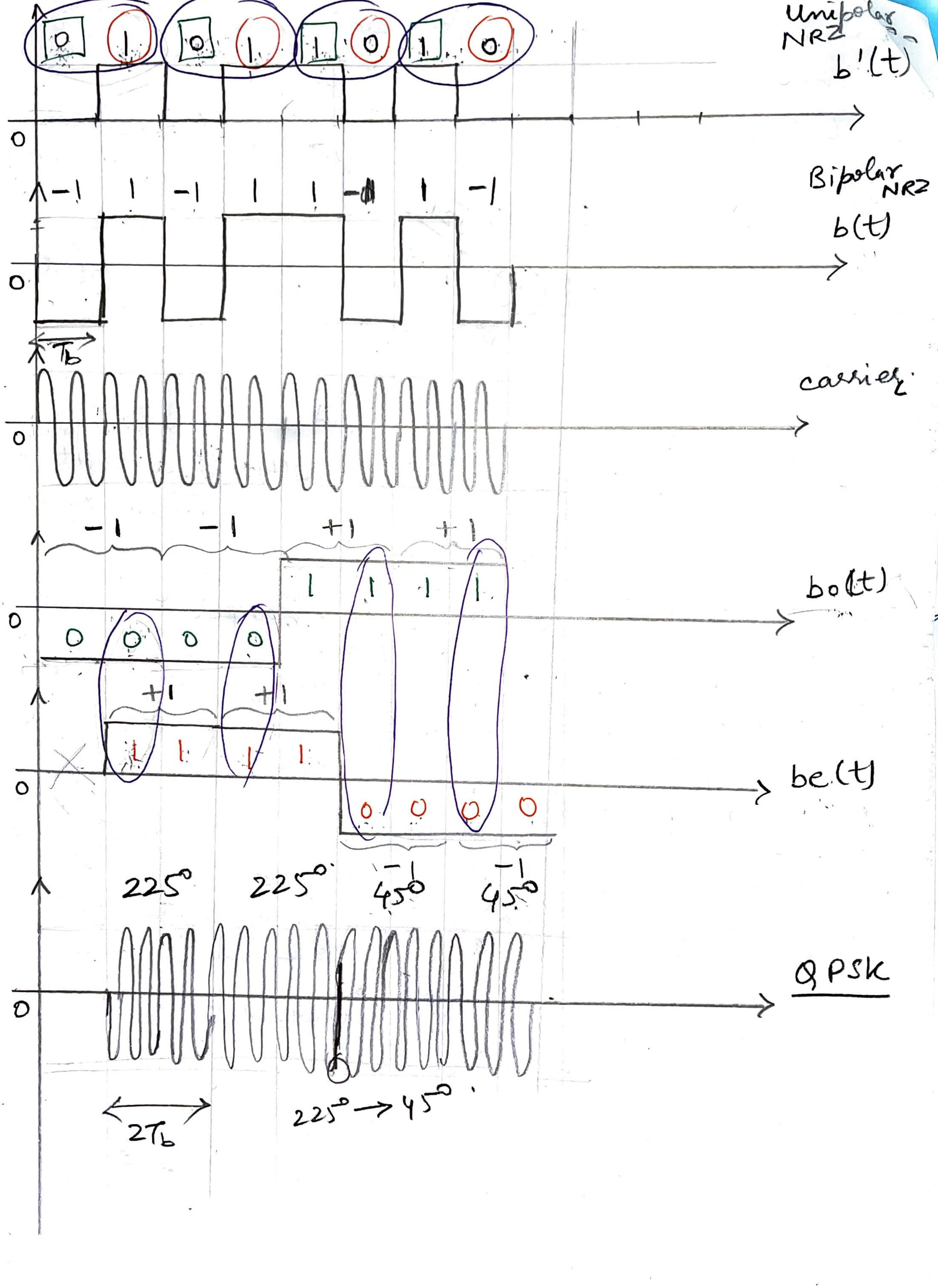


→ Symbol duration for both odd & even numbered sequence is $2T_b$.



→ QPSK Receiver –





Unipolar NRZ
$b'(t)$
0 1 0 1 1 0 1 0
0
Bipolar NRZ
$b(t)$
-1 1 -1 1 1 -1 1 -1
0
T_b
carrier
0
$b_o(t)$
-1 -1 +1 +1
1 1 1 1
0 0 0 0
0
$b_e(t)$
+1 +1
1 1 1 1
0 0 0 0
-1 -1
0
225° 225° 45° 45°
QPSK
0
$2T_b$
225° → 45°

Mod V
Lec 4

→ MULTIPLEXING TECHNIQUES –

→ Most communication systems requires sharing of channel.
Eg. Cable TV system, telephony system, radio transmission.

→ When a number of signals / users share a channel (all signals generate from same source), it is called multiplexing.

→ Multiple Access – combining / sharing the channel BUT signals originate from different sources.

→ ☆☆
The multiplexer combines all input signals into a single composite signal and then transmit over a communication channel.

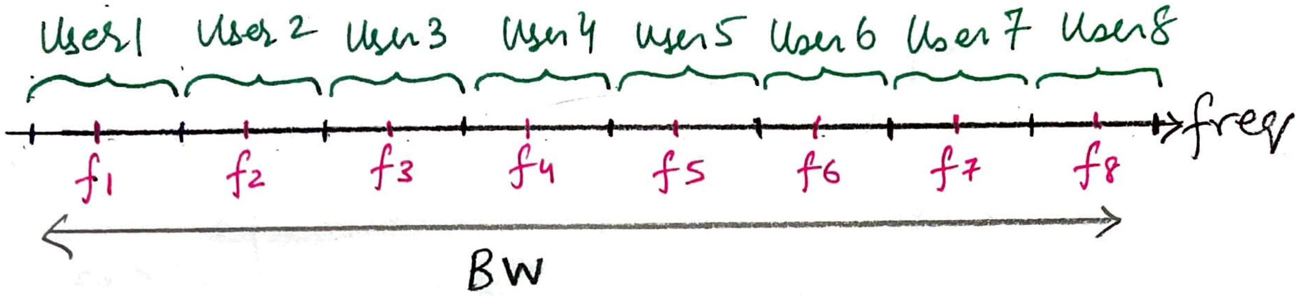
→ This composite signal may be further modulated.

→ This signal is then demultiplexed at the receiver end.

→ CLASSIFICATION OF MULTIPLEXING TECH –

- FDM – Frequency division multiplexing
- TDM – Time division multiplexing
- OFDM – Orthogonal frequency division multiplexing.

→ Frequency Division multiplexing –

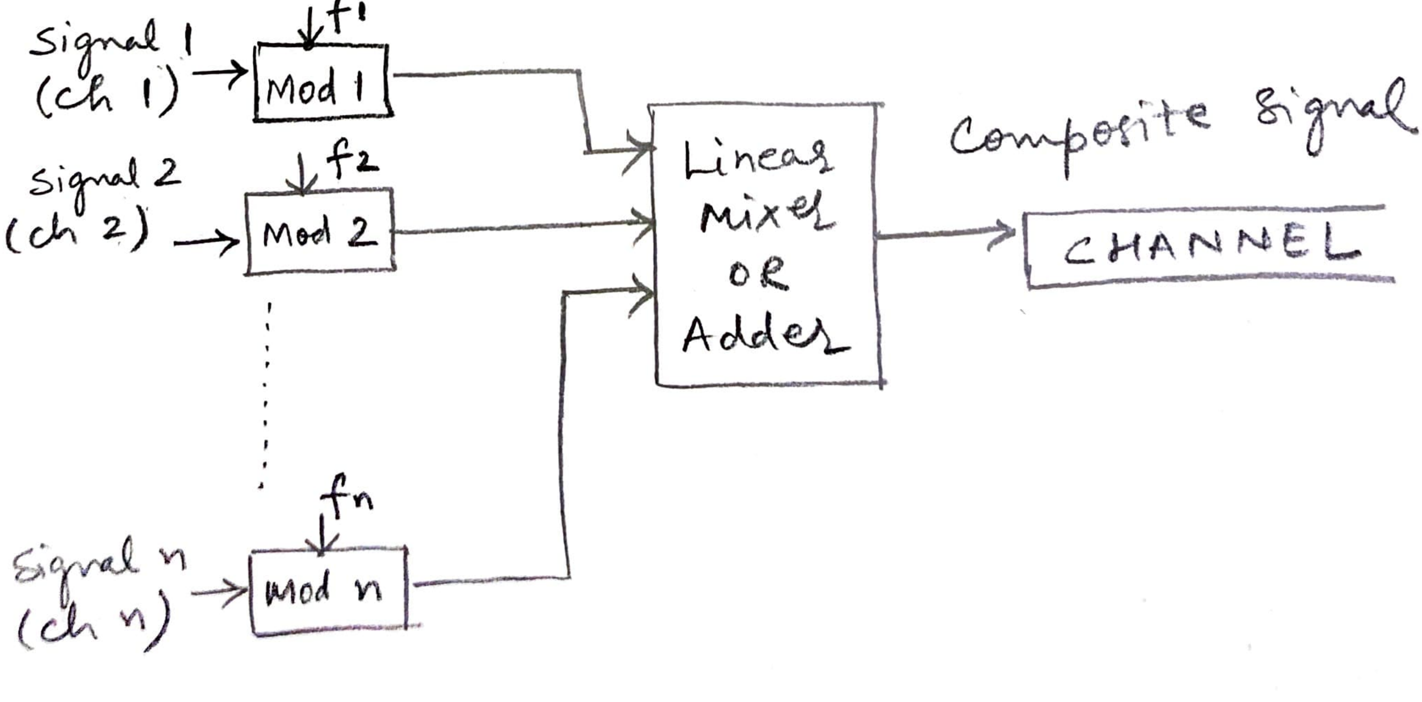


→ Each station assigned a band of frequency on full time basis
i.e. Each signal occupies a different frequency slot within a common BW.
i.e. sharing the available BW.

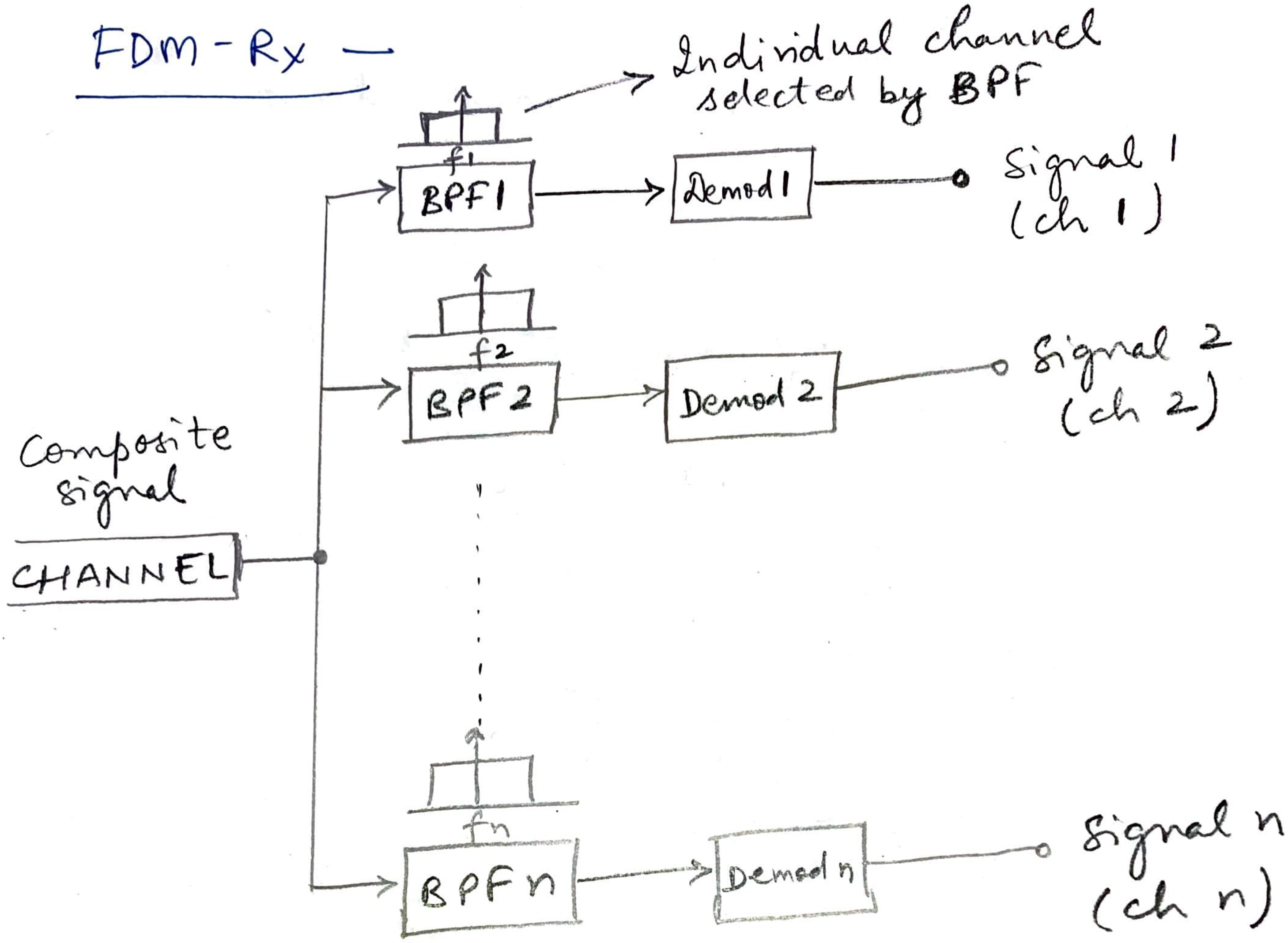
→ The modulated signals are then added together to form a composite signal which is transmitted over a single channel.

→ Guard bands are provided between adjacent frequency bands in order to avoid interference.

→ FDM – Tx –



FDM - Rx -



Each BPF has a centre frequency corresponding to one of the carriers.

→ Advantages -

→ Large number of signals (channels) can be transmitted simultaneously

→ Does not need synchronization between Tx and Rx

→ Demodulation easy.

→ Disadvantages –

→ Communication channel must have very large BW.

→ Intermodulation distortion takes place.

→ Large number of modulators & filters required.

→ Applications –

Telephone networks, cellular networks, satellite comm.

(Sharing over Cu/coaxial/OF cable) is mandatory.

→ Multiplexing Hierarchy in FDM –

Level 1 → Basic Group [12 voice channels MUX'ed together]

↓

Level 2 → Super Group [upto 5 basic groups MUX'ed together]

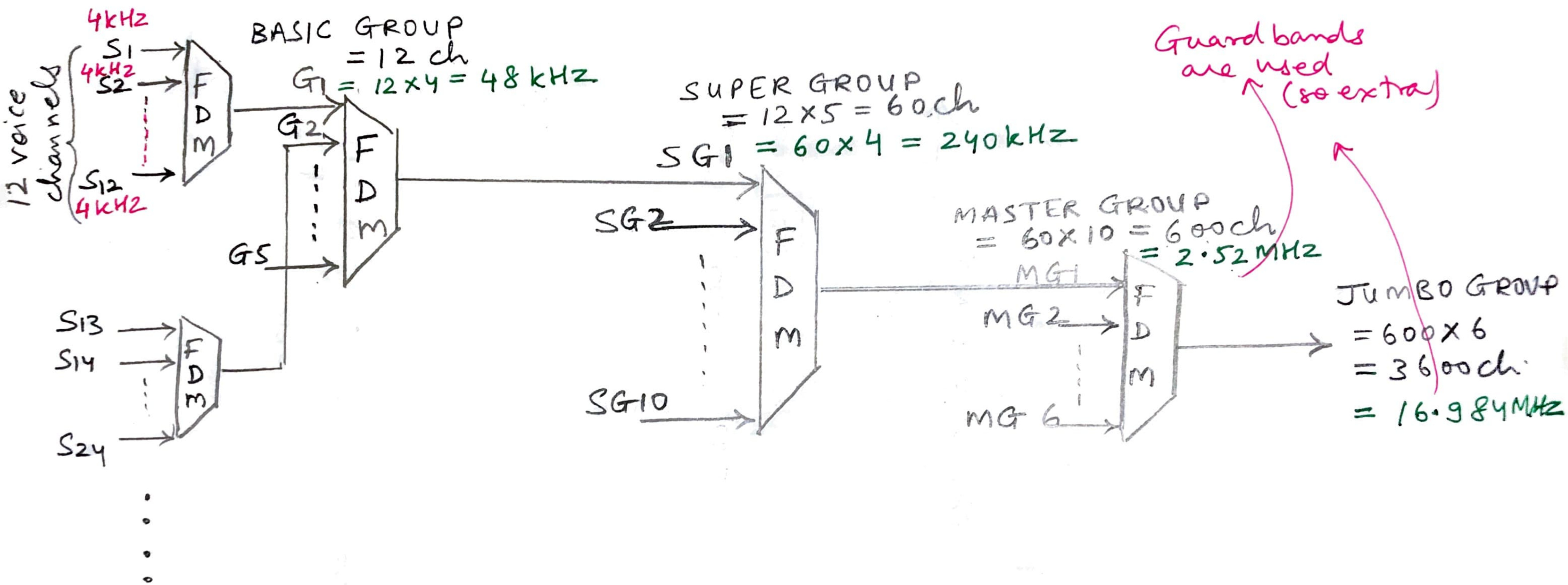
↓

Level 3 → Master Group [upto 10 supergroups MUX'ed together]

↓

Level 4 → Jumbo Group [upto 6 mastergroups MUX'ed together]

→ Used by AT & T – (SSB-SC)

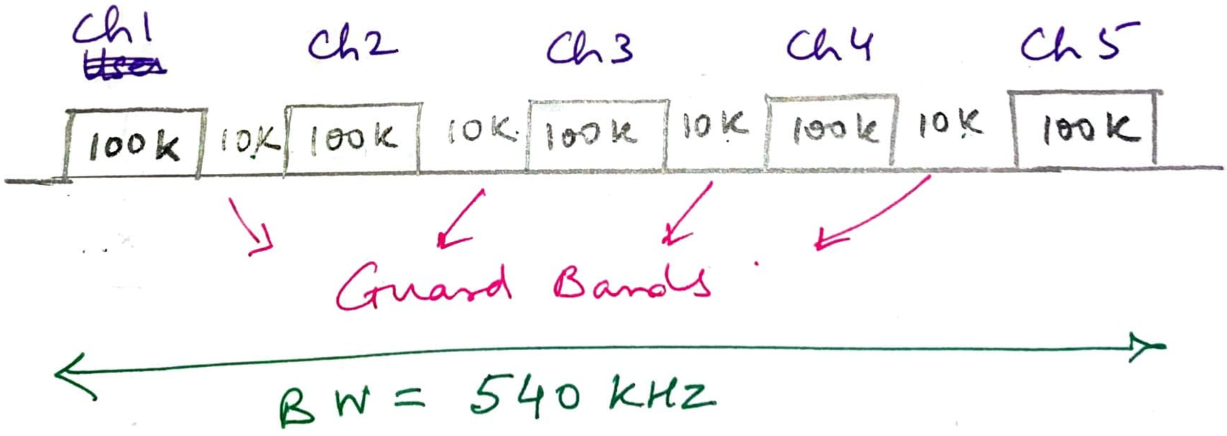


Q1. 5 channels, each with a 100 kHZ BW are to be multiplexed together using FDM. What is the minimum BW requirement of the link (channel) if there is a need for a guard band of 10 kHZ between the channels to prevent interference. Draw the pictorial representation of the same.

Soln: BW requirement $= (5 \times 100\ \text{kHZ}) + (5-1) \times 10\ \text{kHZ}$

$= 500\ \text{kHZ} + 40\ \text{kHZ}$

$= 540\ \text{kHZ}$



Q2. A cellular system uses two bands. First band of 824 - 849 MHZ is used for uplink and 869 - 894 MHZ is used for downlink. Each user needs a BW of 25 kHZ in each direction. How many users can use their cell phones simultaneously.

Soln: Uplink BW = 849 − 824 = 25 MHz

Downlink BW = 894 − 869 = 25 MHz

No. of channels in uplink $= \dfrac{25 \text{ MHz}}{25 \text{ KHz}}$

$= 1000$ ch.

No. of channels in downlink $= \dfrac{25 \text{ MHz}}{25 \text{ kHz}}$

$= 1000$ ch.

Each user required one pair of uplink & downlink channel;

$\therefore$ 1000 users can simultaneously use their cell phones.

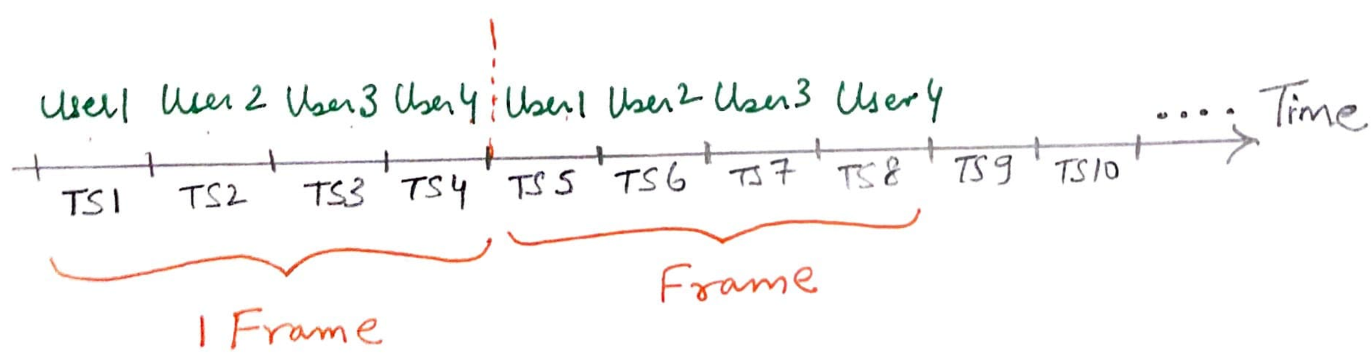
Mod V
Lec 5

→ Time Division Multiplexing (TDM) –

→ Works on the concept of Time sharing

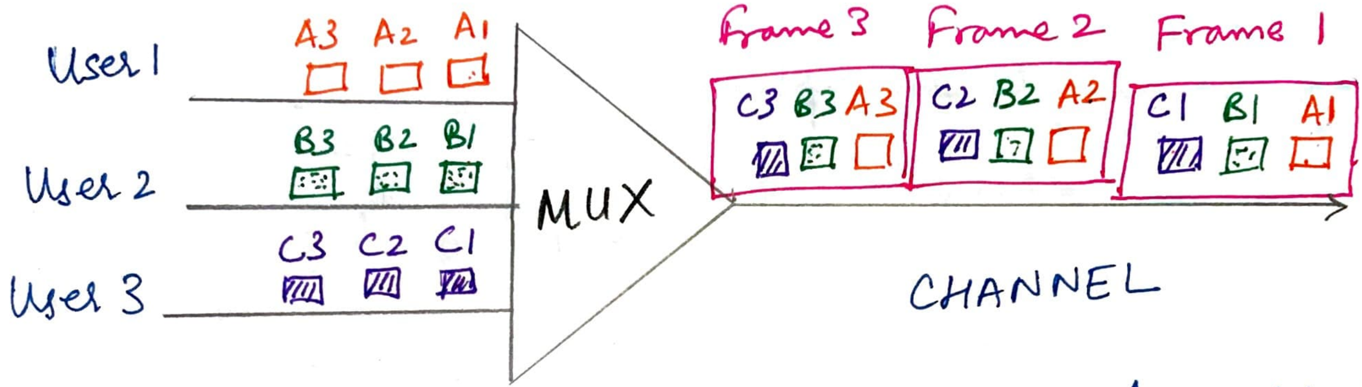
→ Not suitable for continuously varying signal

Used for digital communication systems.



TS → Time Slot

→ <u>TDM System</u> –



→ Data flow is divided into units (eg. A1, A2, A3, ... B1, B2, B3..., C1, C2, C3...)

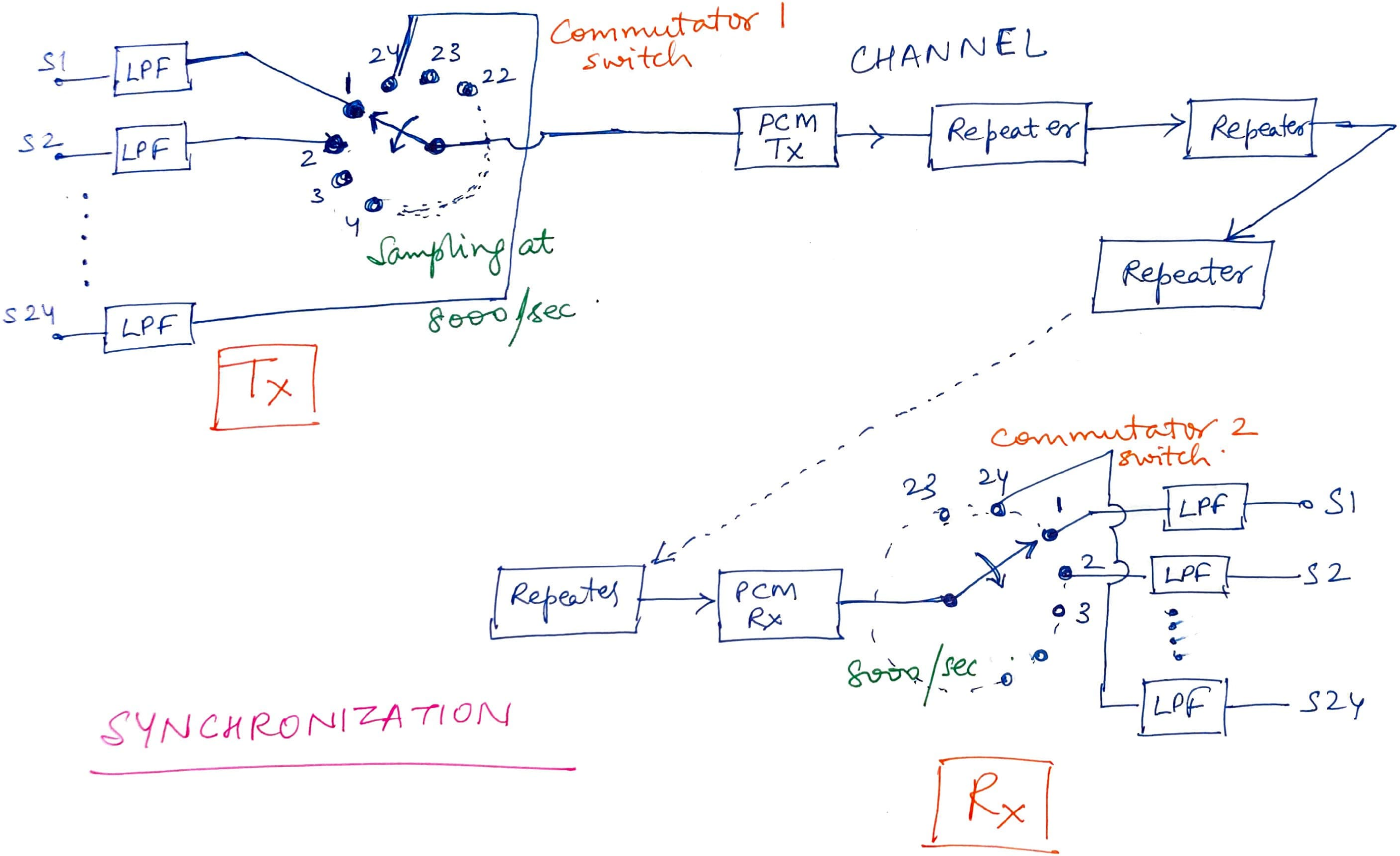
→ One unit from each source is taken and combined to form one <u>frame</u>.
[Size of each unit can be 1-bit or several bits]

→ Data rate of the multiplexed signal is always n times the data rate of individual sources, where, n is the number of sources.

∴ BW requirement ↑ as n ↑

- → multiplexes 24 voice channels ($S1 - S24$)
- → Each channel is bandlimited ~~to~~ to 3·3 kHz
- → Sampling is done at $f_s (\geq 2 f_m) = 8$ kHz
- → Sampling done by commutator switch.
- → Each ~~sampled~~ sampled signal is applied to a PCM transmitter which converts it into a digital signal.
- → Periodically, after every 6000 feet, PCM-TDM signal is regenerated using repeaters.
- → At PCM Rx, signal is decoded and demultiplexed.
- → PCM Rx output is connected to different LPF via commutator switch
- → Synchronization between Tx and Rx commutator switch is essential.

PCM - TDM System - (T1 Digital System)



SYNCHRONIZATION

→ Bits / Frame –

→ Commutator sweeps from S1 – S24 @ 8000 rev/sec.

$\Rightarrow$ 8000 samples / sec of each signal

→ Each sample encoded into a 8-bit digital (code) word.

→ ∴ In 1 Frame = 1 Revolution
= 24 channels (Time slots)
= $24 \times 8 = 192$ bits

→ for synchronization, one bit called F-bit also transmitted per frame.

$\Rightarrow$ 1 frame = 192 + 1 (sync bit)
= 193 bits.

~~xxxx~~

→ Bit Rate –

→ No. of bits / sec.

→ Each signal is sampled 8000 time/sec.

1 Frame = 1 Revolution = $\frac{1}{8000}$ = 125 μsec.

→ But, 1 frame = 193 bits (Transmitted in 125 μsec)

193 bits $\longrightarrow$ 125 μs.

We know,

$$\text{Bit Rate} = \text{no. of bits/sec}$$

$$= \frac{193}{125\,\mu sec} = 1.544 \text{ M bits/sec}$$

$$BW = \frac{1}{2} \times \text{Bit Rate} = \frac{1.544 \text{ Mbits/sec}}{2}$$

$$= 772 \text{ KHZ}$$

→ <u>Duration of each bit</u> –

193 bits $\longrightarrow$ 125 μsec

$$1 \text{ bit} = \frac{125\,\mu sec}{193}$$

$$= 0.6476\ \mu sec$$

<u>Q1.</u> Four channels are multiplexed using TDM. If each channel sends 100 bytes/sec and we multiplex 1 byte/channel, calculate – size of frame, frame rate, Bit rate and Duration of frame.

<u>Soln.</u> Each frame carries 1 byte/channel

∴ Size of frame = 1 byte/channel × 4 channels

= 4 bytes = 4×8 = 32 bits

Frame rate = frames/sec = 100 frames/sec

Bit rate = 100 frames/sec × 32 bits/frame

= 3200 bps

$$\text{Duration of frame} = \frac{1}{100} = 0.01 \text{ sec.}$$

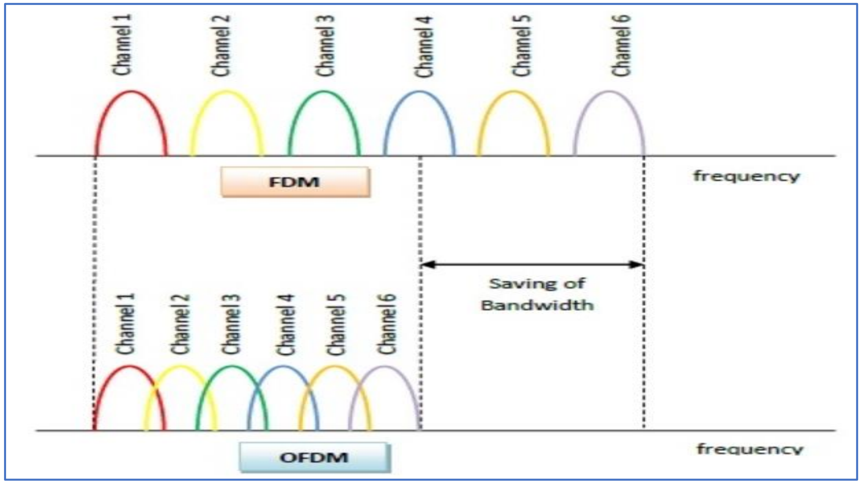
Module V

Lecture

- Orthogonal Frequency Division Multiplexing (OFDM)

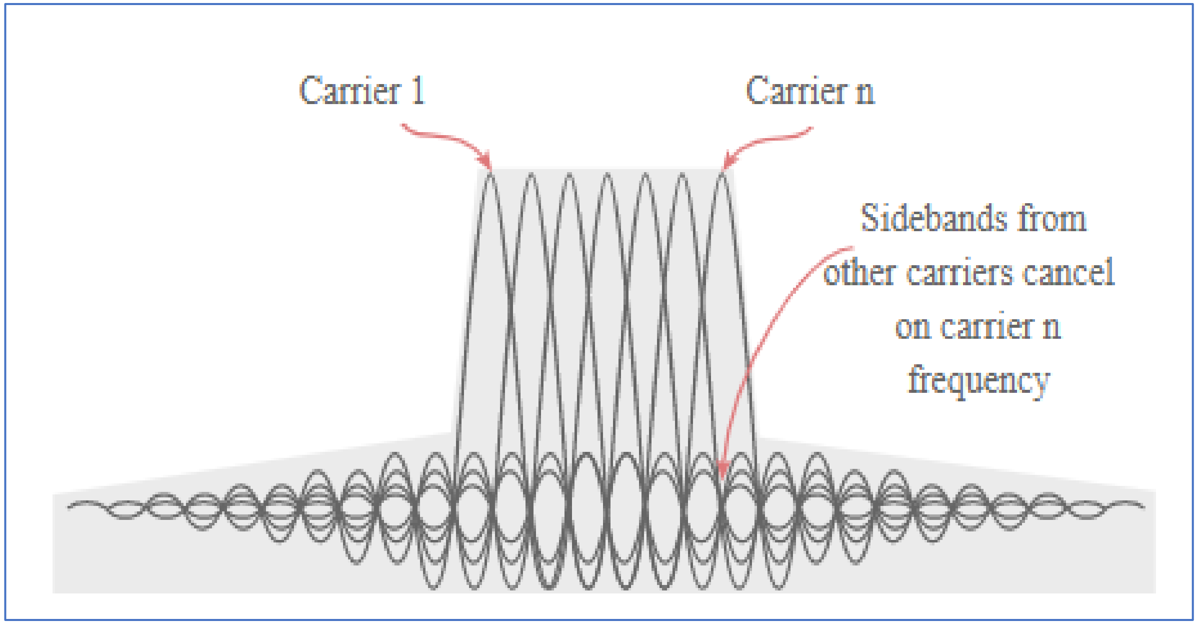
Orthogonal Frequency Division Multiplexing (OFDM)

- **The same harmless channel for low rate communication becomes harsh for high rate communication due to ISI**
- Use of OFDM can help solve this issue…
- OFDM scheme differs from traditional FDM in the following interrelated ways:
  - Multiple carriers (called subcarriers) carry the information stream
  - Subcarriers are orthogonal to each other
  - A guard interval is added to each symbol to minimize the channel delay spread and intersymbol interference



https://www.electronics-notes.com/articles/radio/multicarrier-modulation/ofdm-orthogonal-frequency-division-multiplexing-what-is-tutorial-basics.php

- OFDM consists of a number of closely spaced modulated carriers that are orthogonal to each another
  - Although the sidebands from each carrier overlap, they can still be received without the interference
- Achieved by having the carrier spacing equal to the reciprocal of the symbol period



https://www.electronics-notes.com/articles/radio/multicarrier-modulation/ofdm-orthogonal-frequency-division-multiplexing-what-is-tutorial-basics.php

- **Principle of working**
- **In FDM…**
- Different streams of information are mapped onto separate parallel frequency channels
- Data is sent over a radio channel serially, one bit after another
- Each FDM channel is separated from others by a guard band to reduce interference between adjacent channels
- Since, this relies on a single channel and any interference on that single frequency can disrupt the whole transmission

- **In OFDM…**
- We break one serial fast bit stream into many parallel slow bit streams
- ie. extend the concept of single subcarrier modulation by using multiple subcarriers within the same single channel
- So, rather than transmit a high-rate stream of data with a single subcarrier, it uses a large number of closely spaced orthogonal subcarriers that are transmitted in parallel
- Each subcarrier is modulated with a conventional digital modulation scheme (such as QPSK, 16QAM, etc.) at low symbol rate
- This reduces interference among symbols and makes it easier to receive each symbol accurately while maintaining the same throughput
- Being split into a number of parallel "substreams" the overall data rate is that of the original stream, but that of each of the substreams is much lower, and the symbols are spaced further apart in time

Advantages of OFDM

- **Immunity to selective fading:** More resistant to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels
- **Resilience to interference:** Interference appearing on a channel may be bandwidth limited and in this way will not affect all the sub-channels. This means that not all the data is lost.
- **Spectrum efficiency:** Using close-spaced overlapping sub-carriers, OFDM makes efficient use of the available spectrum.
- **Resilient to ISI:** It is very resilient to inter-symbol and inter-frame interference because of low data rate on each of the sub-channels.
- **Resilient to narrow-band effects:** Using adequate channel coding and interleaving it is possible to recover symbols lost due to frequency selectivity of channel and narrow band interference. Not all data is lost.
- **Simpler channel equalisation:** Since OFDM uses multiple sub-channels, channel equalization becomes much simpler.

Disadvantages of OFDM

- **High peak to average power ratio:** OFDM signal has a noise like amplitude variation and has a relatively high large dynamic range (peak to average power ratio). This impacts RF amplifier efficiency as amplifiers need to be linear and accommodate large amplitude variations
- **Sensitive to carrier offset and drift:** OFDM is sensitive to carrier frequency offset and drift as compared to single carrier systems that are less sensitive

- **Applications**
- OFDM is the technology behind many high speed systems such as –
  - WiFi (IEEE 802.11a, g, n, ac)
  - WiMAX (IEEE 802.16)
  - 4G mobile communications (3GPP LTE)
  - DSL internet access
  - Digital television

- **References**

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