MULTIPLE CHANNEL ACCESS
OR
MULTIPLEXING

Definition of multiplexing-

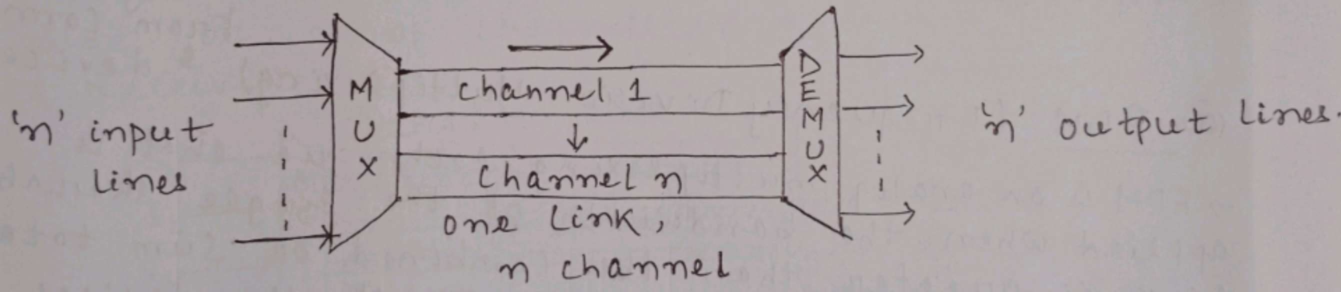
It is a technique that allows the simultaneous transmission of multiple signals across a single sharable data link.

Why multiplexing is required?

If the bandwidth of a link assigned to a source is greater than the bandwidth requirement of the device connected to the link, then the bandwidth of the link is wasted. Consequently, the bandwidth remain inefficiently utilized. which is the most precious resource of data communication process.

When multiplexing can be applied?

When the bandwidth of a transmission medium or link is greater than the bandwidth requirement of the devices connected to it then the bandwidth of the sharable link can be shared.



→ In multiplexing system, 'n' input lines & 'n' output lines share the bandwidths of the sharable link.

→ A link is a physical path, that consist of 'n' no. of channels. So, a channel is a portion of a link that communicate between a pair of sender & receiver.

→ From sending side, 'n' input lines are combined to the multiplexer. So at a time only one input lines can direct its data to the O/P single link. Similarily, at the receiver side, data stream flowing over the single sharable link directs towards the identified output line.

Types of Multiplexing →

There are 3 basic types of multiplexing techniques. They are –

a. Frequency division technique of multiplexing (FDM)
b. Time division multiplexing. (TDM)
c. wave length division multiplexing. (WDM)

Multiplexing

Frequency division multiplexing. (FDM)

→ It is an analog multiplexing technique because it combines or collects analog signals from the connected devices.

Time division multiplexing (TDM)

→ It is digital multiplexing technique because it combines or collects digital signals from the connected sources.

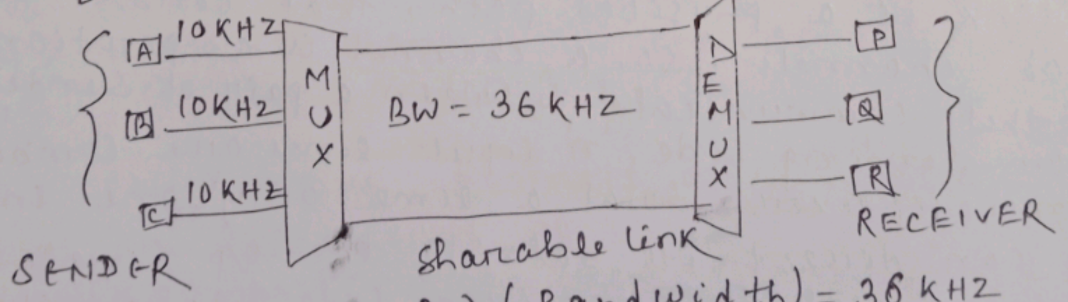
wavelength division multiplexing (WDM)

→ It is also analog multi-plexing tech-nique because it combines or collects optical or light waves from connected devices.

ⓐ FDM (Frequency Division Multiplexing)

→ FDM is an analog multiplexing technique that is applied when the bandwidth of the Single sharable link is greater than the combined or sum total of the bandwidth requirement of the devices connected with the link at source side.

i.e:



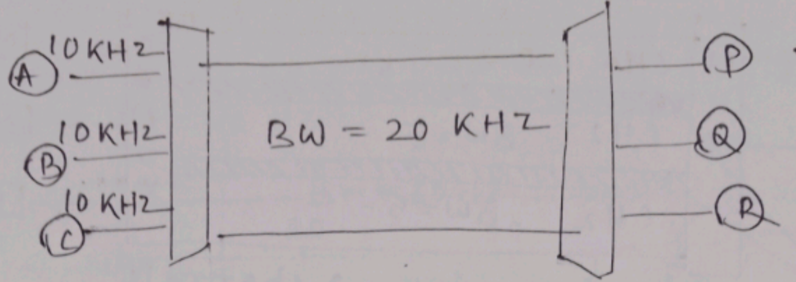
BW (Bandwidth) = 36 KHZ

The pair of sender & receiver in this e.g. are, A & P, B & Q, C & R.

So, Here $36 \text{ KHZ} > 10 + 10 + 10 = 30 \text{ KHZ}$

Hence FDM can be applied for this example.

e.g. (2)

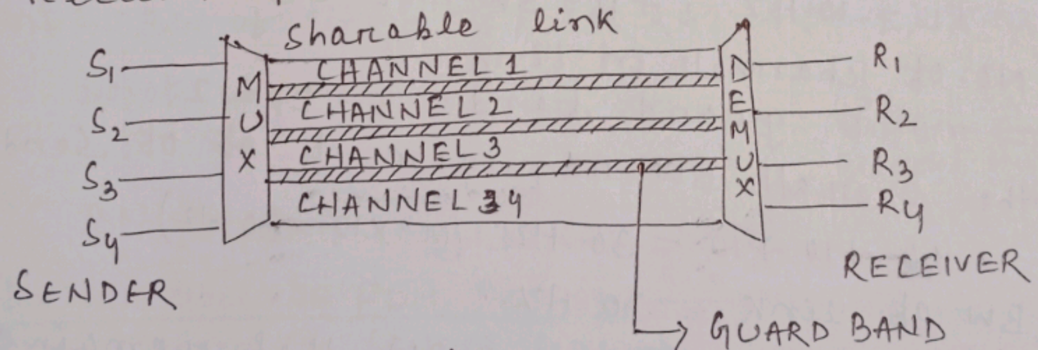


Here $20\ KHZ < 10 + 10 + 10 = 30\ KHZ$

Hence, FDM can not be applied here.

→ FDM is analog multiplexing technique but it does not mean that it can not combine digital signals. Digital signals also can go by using FDM by using a Digital to Analog converter. So, before using FDM for digital signals, the digital signals are converted to analog one then we can go for FDM.

→ In FDM, the overall BW (bandwidth) or capacity of the link is divided into channels. And no. of channels present in a link is equals to no. of devices connected with the link at the source side. or, no. of channels in a link = no. of sender & receiver pair.



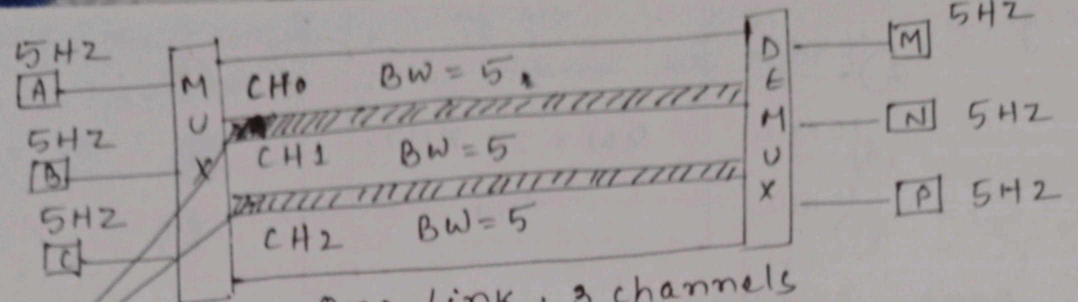
No. of sender & receiver pairs for the above diagram is 4. So, no. of channels in the link is also 4.
(S_1, R_1), (S_2, R_2), (S_3, R_3) & (S_4, R_4) → pair of sender & receiver.

→ The consecutive channels are separated by strips or collections of unused bandwidth known as guard band. Hence guard band avoid interference between consecutive channels.

→ No. of guard bands present = no. of channels − 1.

The bandwidth (BW) of guard band is always very very less than BW of the channel.

e.g.



One link, 3 channels

BW of guard band is always less than 5 for this example. (By considering BW of link)

NOTE:
BW of guard band depends on —
(a) no. of channels in a link
(b) BW of each channel.
(c) BW of link.

e.g. Calculate the no. of guard band & BW of guard band for the case where 3 input lines are multiplexed using FDM, each input line ~~of BW~~ generate signal of frequency 10 HZ. The link with which the 3 input lines are connected using FDM is of BW = 30 HZ. ($f_L = 10$ HZ).

<u>Ans</u> BW of link = 30 HZ

$f_L = 10$ HZ, $f_H = BW + f_L = 30 + 10 = 40$ HZ.

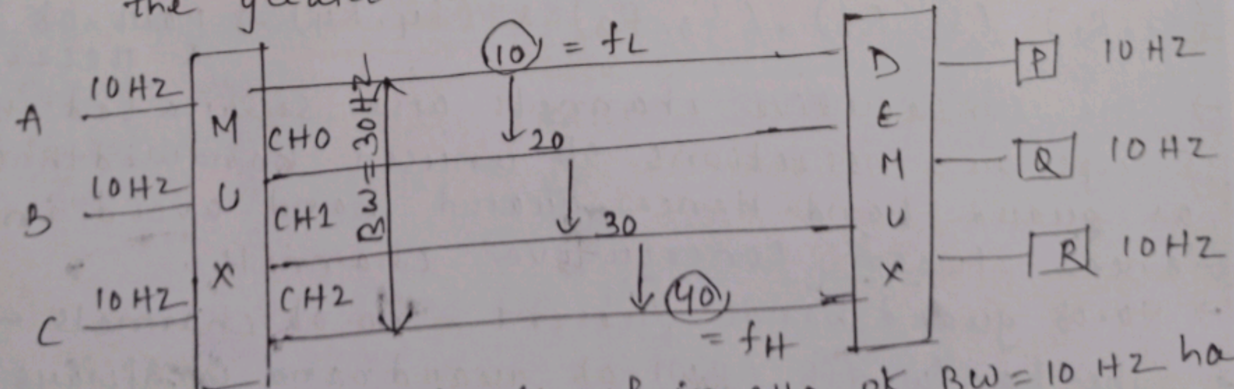
No. of channels in link = 3

$\Rightarrow$ no. of guard band = 3 − 1 = 2

Now, the overall BW requirement ~~of~~ of sender side
= 10 + 10 + 10 = 30 HZ (or 3×10 = 30 HZ)

And, BW of link = 30 HZ.

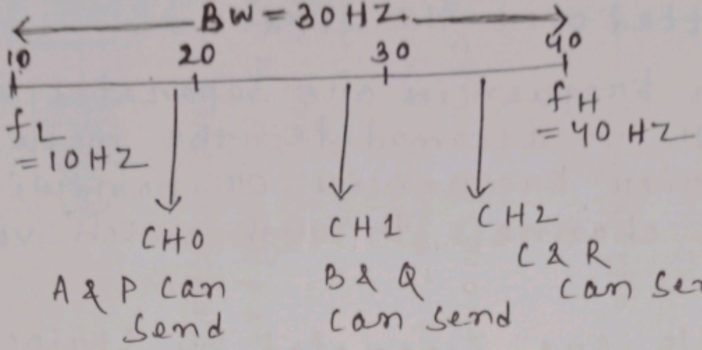
$\Rightarrow$ There is no unused BW that remained for the guard band.



→ A & P can send 10 HZ signal in CH0 of BW = 10 HZ having $f_L = 10$ HZ & $f_H = 20$ HZ.

→ B & Q can send 10 HZ signal in CH1 of BW = 10 HZ having $f_L = 20$ & $f_H = 30$ HZ

→ C & R can also do the Same by using CH2 with $f_L = 30$ & $f_H = 40$ HZ.



→ Bandwidth or capacity of the link can be evaluat-ed by,

BW (capacity) = (no. of channels × BW of each channel) + (no. of guard bands × BW of each guard band)

e.g. Four channels, each with a 100 KHZ BW are to be multiplexed together, what is the BW of the link if the guard band is of BW = 10 KHZ ?

Ans: BW of link = $\underbrace{4}_{\text{No. of channels}} \times \underbrace{100 \text{ KHZ}}_{\text{BW of each channel}} + \underbrace{(4-1)}_{\text{No. of guard band}} \times \underbrace{10 \text{ KHZ}}_{\text{BW of guard band}}$

BW of link = 430 KHZ (Ans)

→ <u>DESCRIPTION OF FDM PROCESS</u> →

<u>At the SOURCE On SENDER SIDE</u> →

→ Each Source generates a signal of similar frequen-cy range or of Same frequency.

→ Inside multiplexer, these similar frequency signals modulates different carrier frequencies. i.e.

Source A Signal modulates Carrier frequency f_1.

" B " " " " f_2.

" C " " " " f_3

& so on.

This modulation is required because, the low frequency signals generated by the source must accomodate within the Lowest & highest frequency of the channel.

→ Now, the modulated signals from different modulators are combined into a single composite signal. And this composite signal propagate or transmitted over the link.

→ Carrier frequencies are separated by sufficient bandwidth to accomodate the modulated signal. The carrier frequencies or bandwidth ranges are the channels through which various signals travels.

→ Channels are separated by strips of unused BW known as guard band to prevent overlapping of signals between consecutive channels.

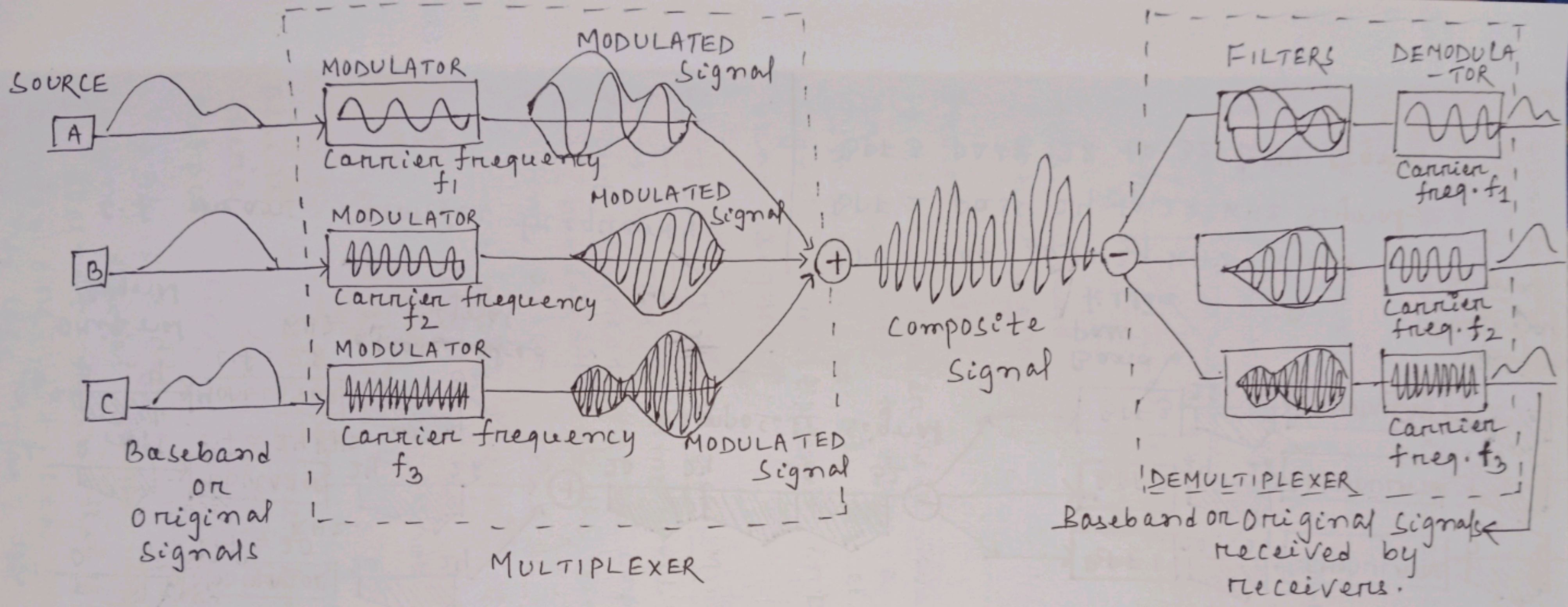
→ <u>At the Destination or receiver side</u> →

→ At the receiver side, the demultiplexer uses no. of band pass filters to filter out or to decompose the multiplexed signal into its constit-uent components. i:e: the composite signal broke down into simple modulated signals. And the filters pass the required or identified frequency based modulated signal to the corresponding demodulator.

→ The individual modulated signals are then pass to the demodulator that separates the carrier frequencies from the ~~origi~~ modulated one & pass original signal to the receiver.

<u>Application of FDM</u> –

FDM is applied in case of AM or FM broadcasting i:e: FDM is implemented in AM & FM Radio broad-casting. & TV broadcasting.



(Block Diagram of FDM)

Q. Assume that a voice channel occupies a bandwidth of 4 KHZ. We need to combine 3 voice channels into a link with a BW of 12 HZ from 20 to 32 KHZ. Show the frequency domain diagram.

Ans: BW of link = 12 KHZ

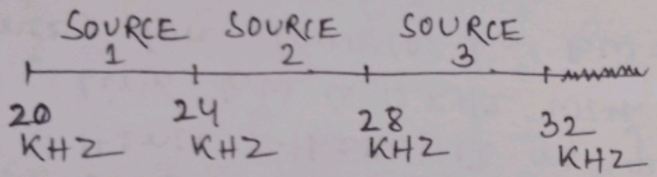
Overall BW requirement of all the sources = 3×4 KHZ = 12 KHZ.

Hence, there is no guard band.

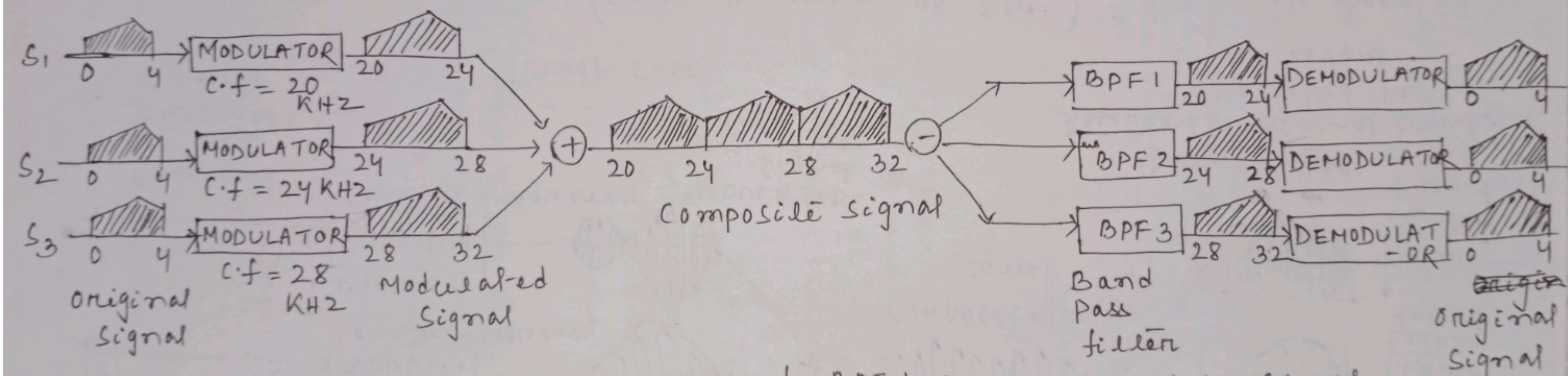
Link BW is 12 KHZ with $f_L = 20$ KHZ & $f_H = 32$ KHZ.

Hence, for Source 1, BW = 4 KHZ, $f_L = 20 + 0 = 20$ KHZ, $f_H = 20 + 4 = 24$ KHZ — For Source 1 carrier frequency = 20 KHZ.

for Source 2, BW = 4 KHZ, $f_L = 24 + 0 = 24$ KHZ, $f_H = 24 + 4 = 28$ KHZ — for SOURCE 2 carrier frequency = 24 KHZ for Source 3, $BW = 4\,KHZ$, $f_L = 28+0 = 28\,KHZ$, $f_H = 28+4 = 32\,KHZ$] for Source 3, Carrier frequency = 28 KHZ.



NOTE: for f_L evaluation 0 is added & for f_H evaluation 4 is added because the BW of channel is 4 KHZ &. So if BW of input channel is 4KHZ & the input lines generates ~~are~~ always low frequency signals, so $f_L = 0\,KHZ$ & $f_H = 4\,KHZ$ $(4-0 = 4\,KHZ = BW)$ for all input lines.



c.f means carrier frequency

BPF 1 pass 20 to 24 KHZ Signal

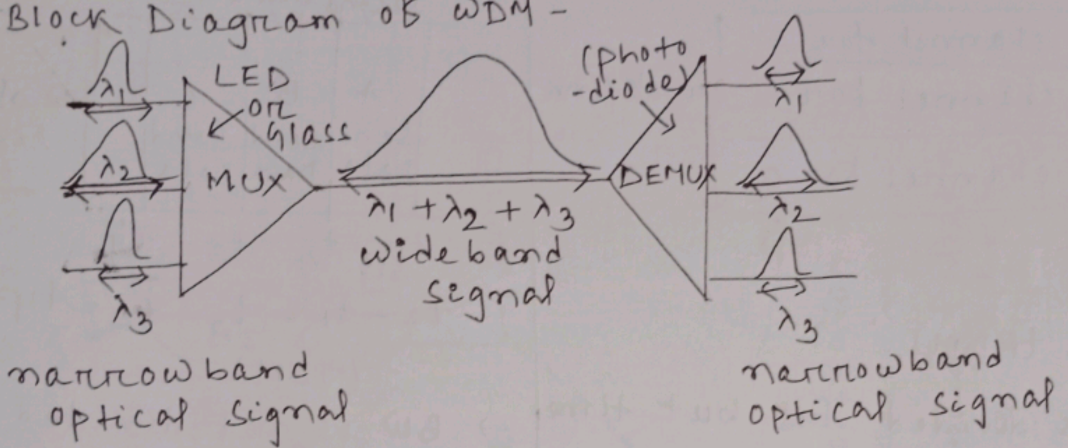
BPF 2 pass 24 to 28 KHZ Signal

BPF 3 pass 28 to 32 KHZ Signal.

(b) Wavelength Division Multiplexing - (WDM)

WDM is also analog multiplexing technique that combine optical signals to efficiently utilize the the high data rate capabilities of fiber optic cable.

Block Diagram of WDM -



Process of WDM -

→ At the sender side several narrowband signals are combined to make a wideband signal. Similarily, at the receiver side the wideband signals demultiplexed into constituent narrow band signals.

(c) TDM (Time Division Multipleexing)

→ In TDM or time division multipleexing several input connections or input lines share the high BW (bandwidth) of the link in terms of division of time axis.

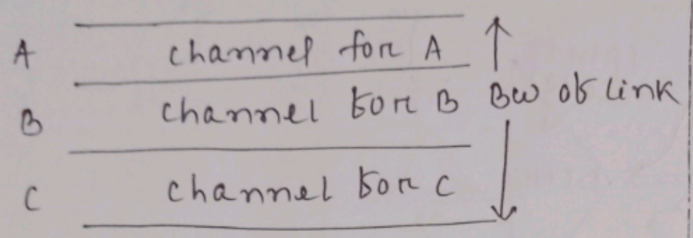
→ TDM allows several input connection to share the high bandwidth of the link based on time. rather than dividing the bandwidth of the link & assiging a channel of the link to input source like FDM.

→ In TDM the whole capacity of the link is assign to each input line on time basis. Hence there is a time slot for each input line at the output link.

→ It is a digital multipleexing technique to combine digital signals from different sources. It doesnot mean that the source can not be analog one, it can be analog. But before going to use TDM, the analog signal get ~~converted~~

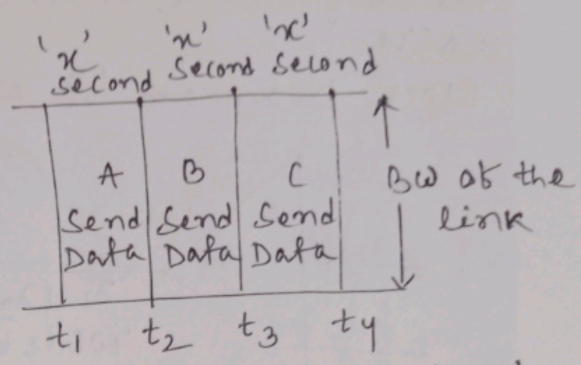
converted to digital one by using analog to digital converter.

→ So, consequently, several low data rate channels are combined into one high data rate channel or link.



(FDM)

→ BW is divided ~~but~~ but time is not. i.e: A, B & C can simultaneously send ~~of~~ data but in their respective channel.



$$t_2 - t_1 = t_3 - t_2 = t_4 - t_3$$

(TDM)

→ BW is not divided, time is divided. i.e: the whole bandwidth or capacity assigned to A for time $t_2 - t_1$ then the whole capacity of the link is assigned to B for time $t_3 - t_2$ and similarily to device C in time $t_4 - t_3$.

<u>Time slots are of equal</u>

$$t_4 - t_3 = t_3 - t_2 = t_2 - t_1$$

<u>Types of TDM</u> –

There are 2 different types of TDM,

(a) Synchronous TDM.

(b) Statistical TDM.

(a) <u>Synchronous TDM</u> →

→ Each input connection has an allotment in the output line even if it does not have any data to send.

→ Each input connection data flow is divided into data units of same size & these data units occupies one time slot at the output link when the data unit transmitted over the sharable output link.

The data Units of input lines also reserve a time slot at input Lines. Therefore, the reservation of time slot at out-put link for each input Line is done statically.

Each frame contain 'n' no. of time slot of duration same as input line time slot. i:e: $\frac{T}{n}$

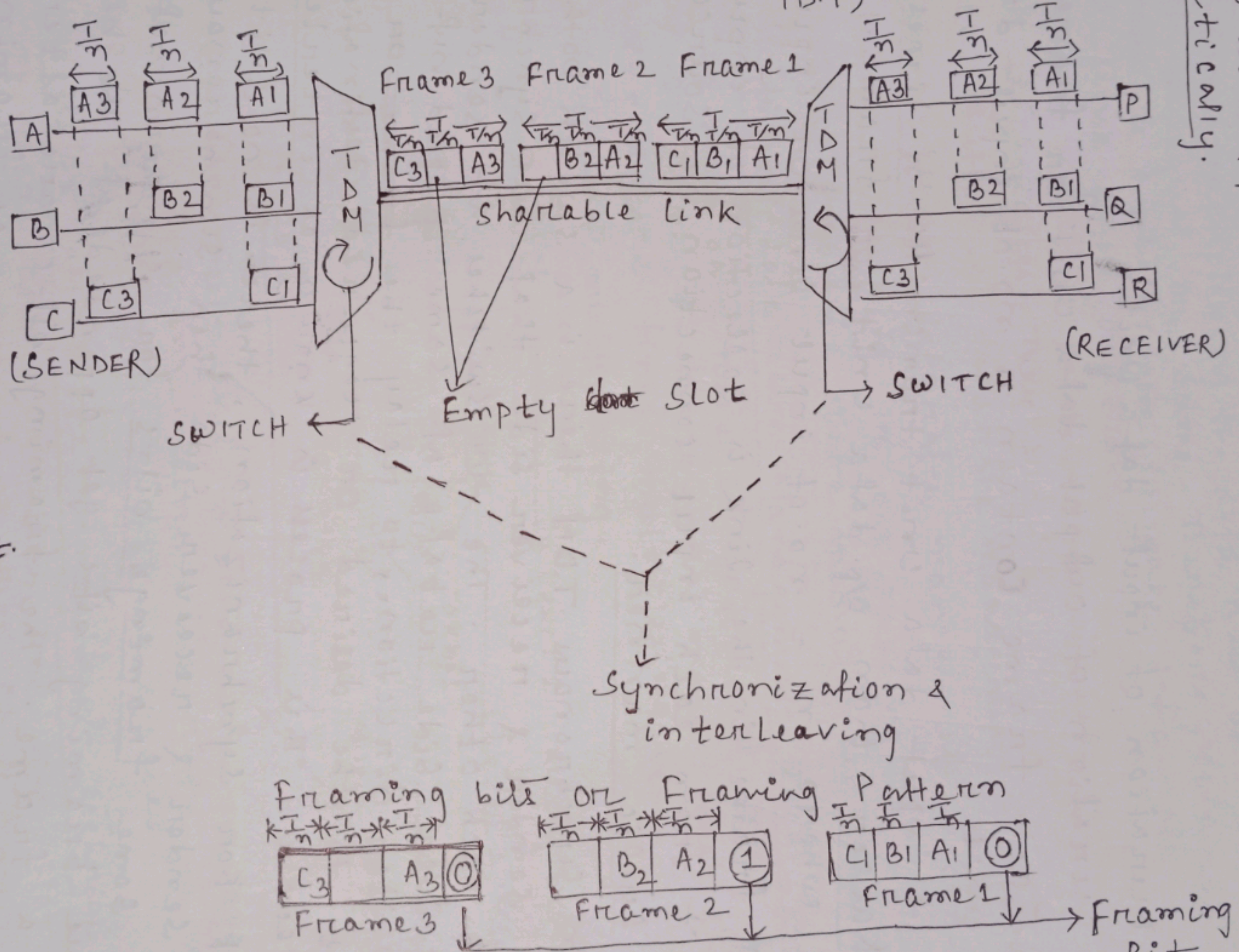
where n = no. of input lines.

Hence the duration of frame is $= n \times \frac{T}{n} = T$

$\frac{T}{n}$ → Duration of each time slot.

n → no. of time slots in each frame.

(BLOCK Diagram of Synchronous TDM)



Framing pattern for these frames is: 01010101 ....

→ The duration of input ~~sorslot~~ slot is $\frac{T}{n}$. The duration of output data unit known as T. But duration of input data unit at the output side frame is same $\frac{T}{n}$.

Duration of input data unit = $\frac{T}{n}$

Duration of output data unit or frame = T.

Each frame contain 'n' no. of input data unit.

⇒ A input data unit transmitts 'n' times faster than o/p data unit or frame.

where 'n' = no. of input lines or input source

→ A frame in the link is collection of input data unit from each input connection or source in a cyclic manner.

→ In synchronous TDM there is a switch both at the sender & receiver side that are synchronized with each other. The two switches at sender & receiver side rotate at same ~~sp~~ speed but in opposite directions, to relay the ~~frame or~~ data unit to the desired or required destination or receiver. This process is known as interleaving.

→ If for synchronization, there is no switch at sender & receiver side then synchronous TDM use some framings bits for synchronization. These framing bits get appended at the beginning of a frame. The framing bits are alteration of 0's & 1's. ~~This~~ This is known as framing pattern.

Drawback of synchronous TDM →

1. Because of statical reservation of time slots, the bandwidth of the link is not efficiently used whenever there is empty slot in a frame.

An empty ~~so~~ slot will occur when an input line has time slot allotment in output link but donot have data ~~to~~ to transmitts or send.

Data Rate Management techniques →

Before multiplexing the data rate of input lines must be equal or same. Therefore, data rate management is a technique to make data rate of individual lines equal or same.

There are 3 different types of data rate management techniques. They are -

(a) Multilevel data rate management technique.

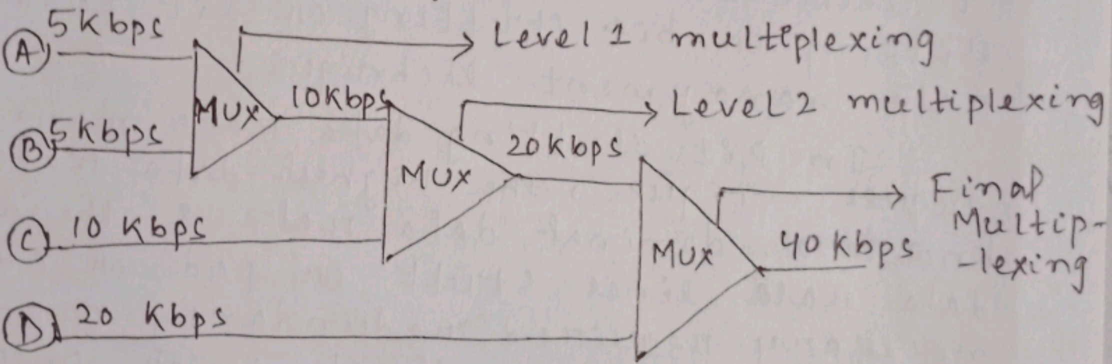
(b) Multislot data rate management technique.

(c) Bit stuffing or bit padding or pulse ~~stuffing~~ stuffing data rate management technique.

(a) Multilevel data rate Management technique →

To make data rate of individual input lines equal or same, if there are more level of multiplexing before final multiplexing then it is known as multilevel multiplexing.

e.g.

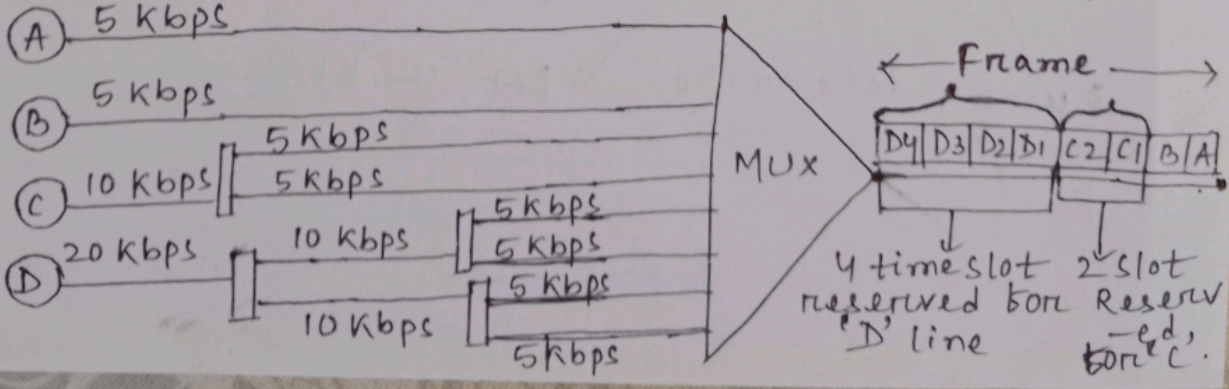


NOTE: For multilevel ~~ra~~ data rate management technique, one input line data rate is multiple of others, then only it can be applied.

(b) Multislot data rate management technique →

If there are more than One time slot reserved for a single input line then it is known as ~~ra~~ multislot data rate management technique.

e.g.



In the given example,
→ input line A has only one time slot reserved at output line.
→ input line B has only ~~ti~~ one time slot reserved at output line.
→ input line C has 2 time slot reserved at output line
→ input line D has 4 time slot reserved at output line.

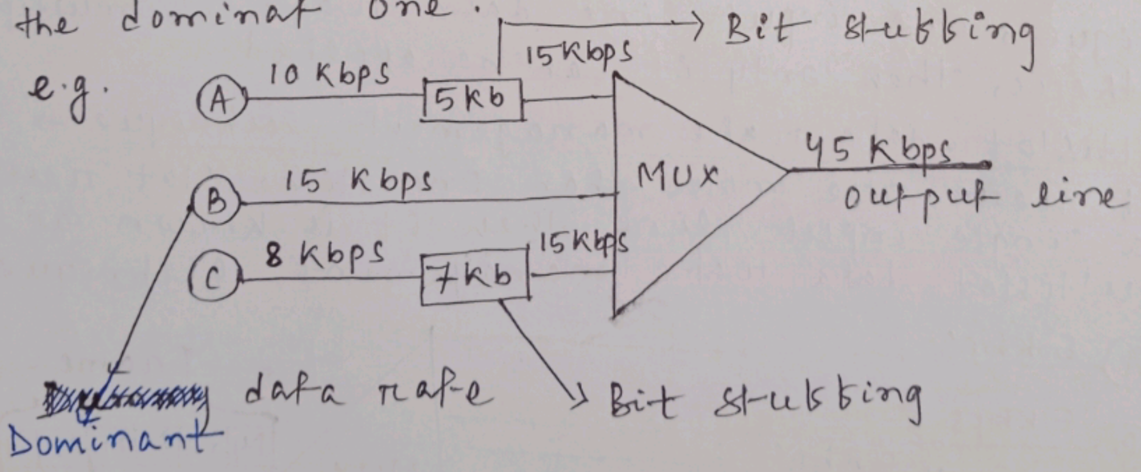
NOTE: Multislot data rate management technique is also applicable when data rate of one input line is multiple of other.

(c) <u>Bit stuffing</u> or <u>Pulse stuffing</u> or <u>Bit padding</u> <u>data rate management technique</u> →

It multilevel or multislot data rate management technique can not be applied then use pulse stuffing or bit stuffing or Bit padding data rate management technique.

In Bit stuffing data rate management tech-~~niques~~ -nique, the highest data rate line is known as dominant data rate & the other lower data rate lines stuff or pad or add ~~necessary~~ necessary required redundancy or dummy bits to make the data rate of lower ones equal with the dominant one.

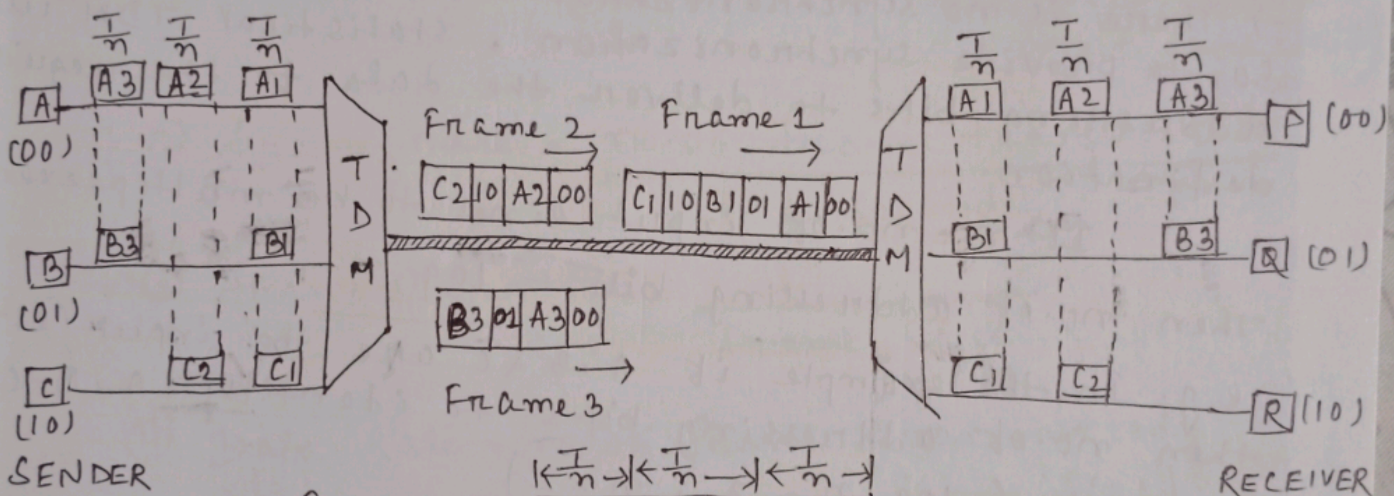
e.g.

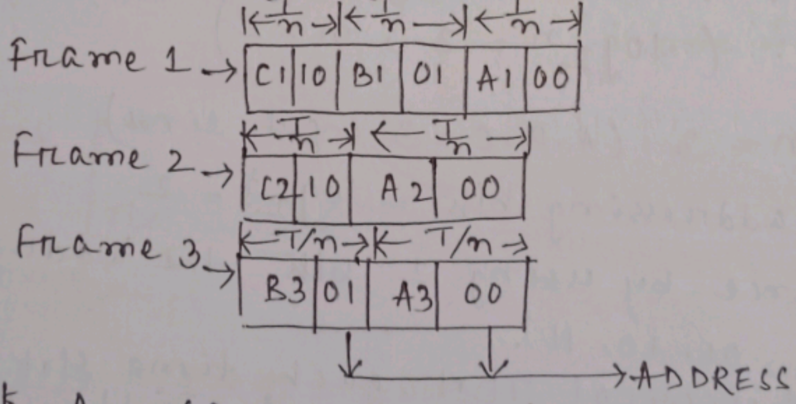


(b) Statistical TDM →

Statistical TDM remove the drawback of synchronous TDM. The statical allotment of time slot at out-put line for each input line even if it does not ~~dr~~ have data to send gives rise to the drawback in synchronous TDM known as Empty slot. Empty slot means for that perticular time slot nothing is to be send over ~~th~~ the output link or the link is idle at that time or the bandwidth or capacity of the link remain unused or wasted.

But in statistical TDM, the time slot of the ~~ou~~ output line get reserved for an input line only when it has some data to ~~be~~ transmit or send. Hence, the time slot allotment in statistical TDM is dynamical.





ADDRESS of A — 00
B — 01
C — 10

Similarily, ADDRESS of P — 00
Q — 01
R — 10

→ Each time slot is of duration $\frac{T}{n}$.

→ Each slot contain two field – data & address.

→ e.g. $\boxed{A3 \mid 00}$

Data ← → ADDRESS

→ The duration of timeslot for each input data unit is $\frac{T}{n}$. The data flow of individual input line is divided interms of data units of same size & same duration.

→ In statistical TDM, input data unit from each input lines are collected in round robin manner or cyclic manner. If an input line has nothing to send then there is no empty slot in statistical TDM. Hence there is no chance of wastage of bandwidth of the link.

→ The size of frames may or may not be equal. And the duration of ~~eat~~ all the frames may or may not be T. i.e: duration of frames may be T or less than T.

→ There is no synchronization bits in statistical TDM. So, to provide synchronization, statistical TDM use addressing bits to deliver the data to the required destination.

If n = no. of input lines to be multiplexed.

Then no. of addressing bits = $\log_2 n$.

e.g. In the example if A, B & C are the input lines, then no. of addressing bits to identify A, B, C are 2. ($\log_2 n = 3$; $n = 2$)

$n = 3$ (A, B, C = 3 input lines)

⇒ addressing bits = $\log_2 3 = 2$

Hence by using 2 bits the addresses are,

00, 01, 10, 11.

→ In statistical TDM, each time slot contain 2 field, one for data & another for address of data. Hence there must be a reasonable ratio between data & address so that the time slot contain maximum bits for data values than addressing bits.

e.g.

Data	Address
10 bits	3 bits

↳ 3 bits are used for addressing.

↳ 10 bits reserved for data representation

→ A Statistical TDM is named so because the bandwidth of the link depends on statistics of load imposed by individual input lines.

Q.1 Two channels, one with bit rate of 150 kbps & another with bit rate of 140 kbps are to be multiplexed using bit stuffing TDM using no synchronization bit. Answer the following -
(a) what is frame size in bits?
(b) what is frame rate?
(c) what is duration of a frame?
(d) what is data rate?

Ans:-

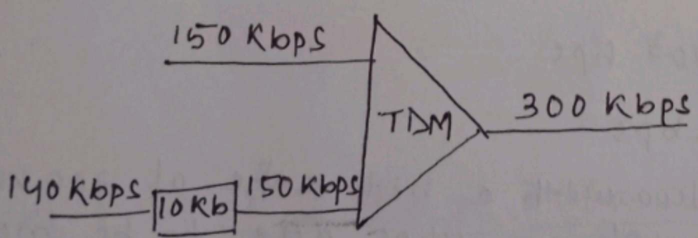
NOTE: $\boxed{\text{Formulas}}$

① frame size = (no. of time slots) × (size of one input data unit)

② frame rate = $\dfrac{\text{no. of frames transmitted}}{1 \text{ second}}$

③ frame Duration = $\dfrac{1}{\text{frame Rate}}$

④ Data Rate = (no. of frames transmitted) × (frame size)



(a) frame size = $\underbrace{2}_{\text{no. of time slots}} \times \underbrace{1}_{\text{size of input data unit}}$ = 2 bits

Because of two input lines, no. of time slots reserved at output line is 2.
From each input line, the switch pick 1 bit only. So, the size of input data unit is 1 bit.

(b) frame rate = $\frac{\text{no. of frame transmitted}}{1 \text{ second}}$

$$\boxed{\text{No. of frames produced or send} = \frac{\text{Data rate of input line}}{\text{input data Unit size}}}$$

$$\text{No. of frames send or Produced} = \frac{150 \text{ Kb}}{1 \text{ bit}}$$

$$= 150 \times 10^3 \text{ no. of frames}$$

$$\Rightarrow \text{frame rate} = \frac{150 \times 10^3 \text{ frames}}{1 \text{ second}}$$

$$= 150 \times 10^3 \text{ frames per second.}$$

(c) frame duration $= \frac{1}{\text{frame Rate}}$

$$= \frac{1}{150 \times 10^3} \text{ second}$$

$$= 0.0066 \text{ ms}$$

(d) Data rate = Total no. of bits send over the link in 1 second.

$$= \text{no. of frames send} \times \text{frame size}$$

$$= 150 \times 10^3 \times 2 \text{ bps}$$

$$= 300 \times 10^3 \text{ bps}$$

$$= 300 \text{ Kbps}$$

Q.2 Four channels, two with a bit rate of 300 kbps & two with a bit rate of 250 kbps are to be multiplexed using multislot TDM with no synchronization bits. Answer the following -

(a) Size of frame in bits.
(b) what is frame rate?
(c) what is ~~Bt~~ frame duration?
(d) what is data rate?