Multiplexing Techniques

Session Objectives

- **Introduction**
  - Multiplexing
  - Categories of multiplexing
- **Frequency-division multiplexing (FDM)**
  - Multiplexing process
  - De-multiplexing process
  - Examples
- **Wavelength division multiplexing (WDM)**
- **Time-division multiplexing (TDM)**
  - Synchronous TDM
  - Time slots and frames
  - Interleaving
  - Empty slots
  - Data rate management: multilevel, multiple-slot, and pulse stuffing

MULTIPLEXING

- Multiplexing is the set of techniques that allows simultaneous transmission of multiple signals across a single data link.
- As data and telecommunications use increases, so does traffic.
- We can accommodate this increase by continuing to add individual links each time a new channel as needed, or we can install higher-bandwidth links and use each to carry multiple signals.

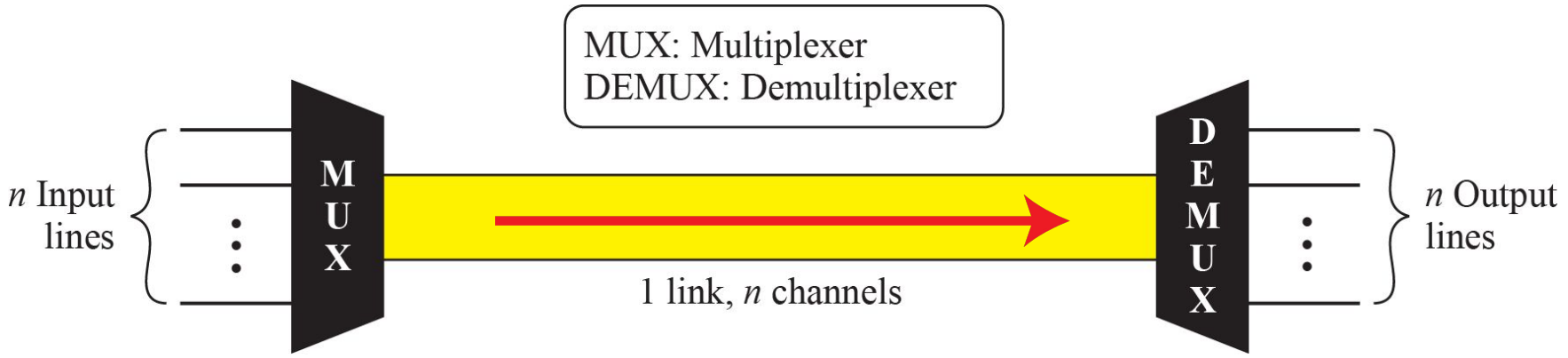
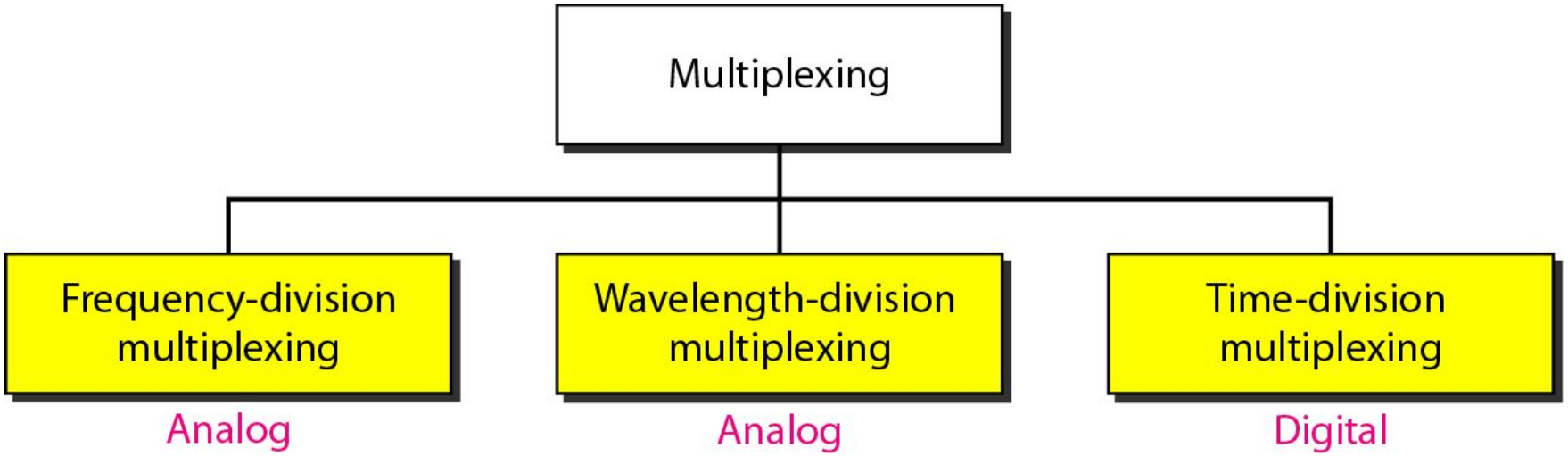


Figure-1 : Dividing a link into channels

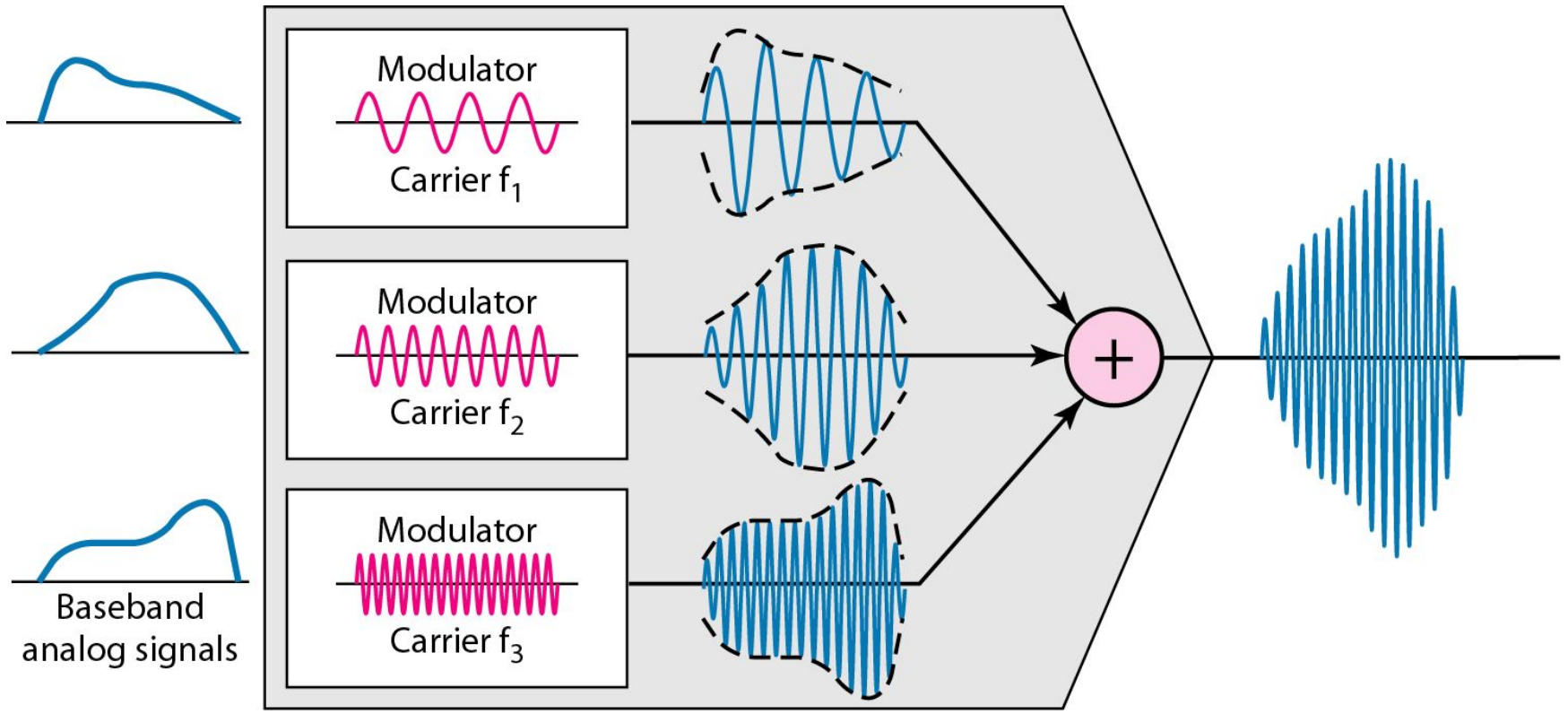
Categories of Multiplexing



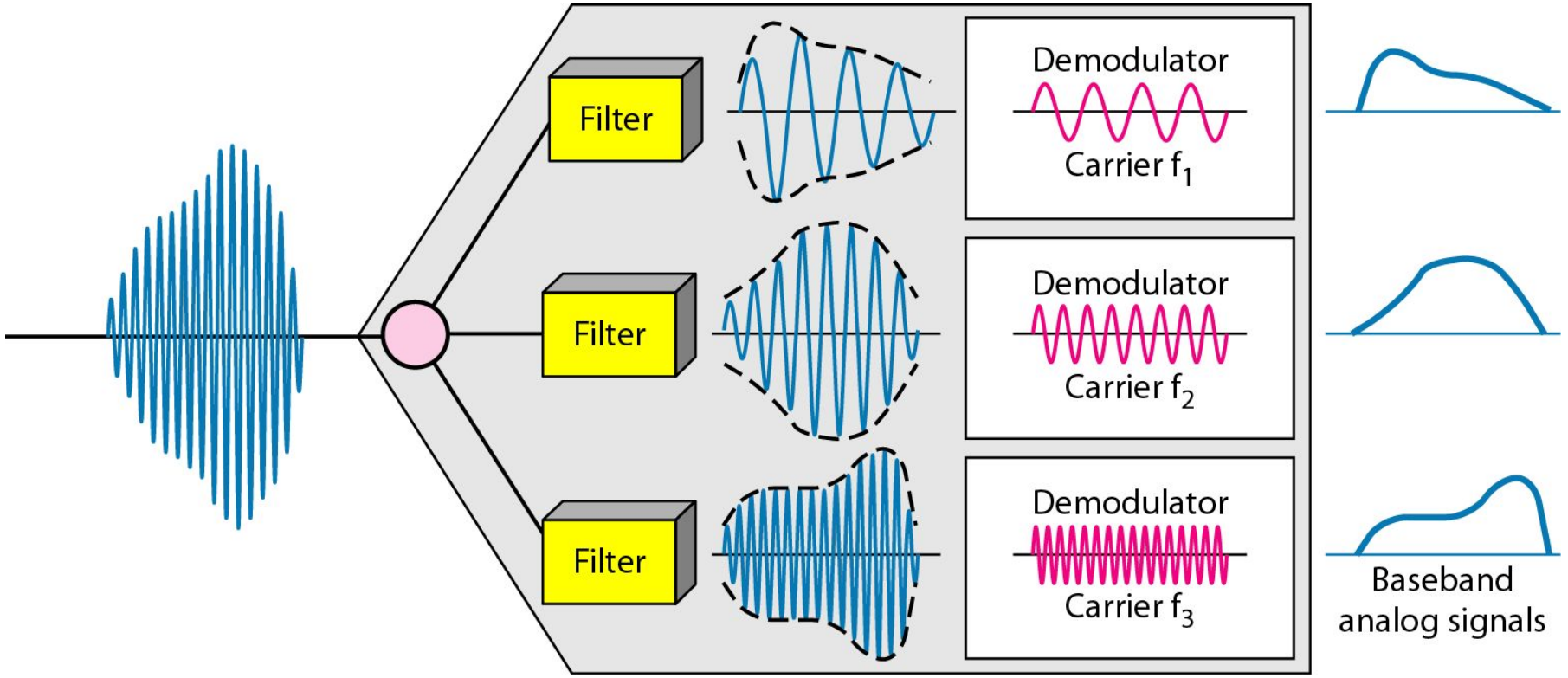
Frequency-Division Multiplexing

- Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.
- In FDM, signals generated by each sending device modulate different carrier frequencies.
- These modulated signals are then combined into a single composite signal that can be transported by the link.

Multiplexing Process



De-multiplexing Process

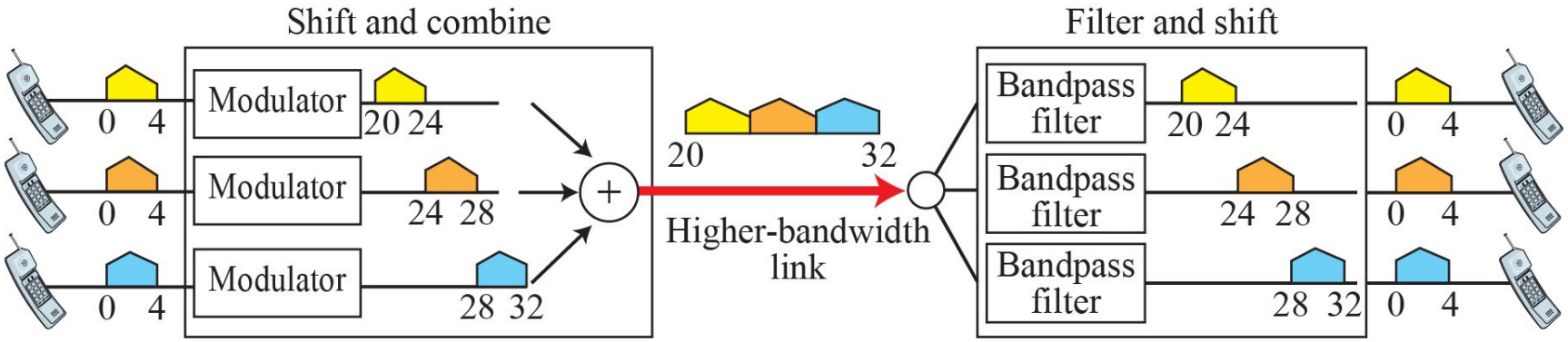


Example 1

Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. *Show the configuration, using the frequency domain*. Assume there are ***no guard bands***.

Solution

Shift (modulate) each of the three voice channels to a different bandwidth, as shown in ***below.***

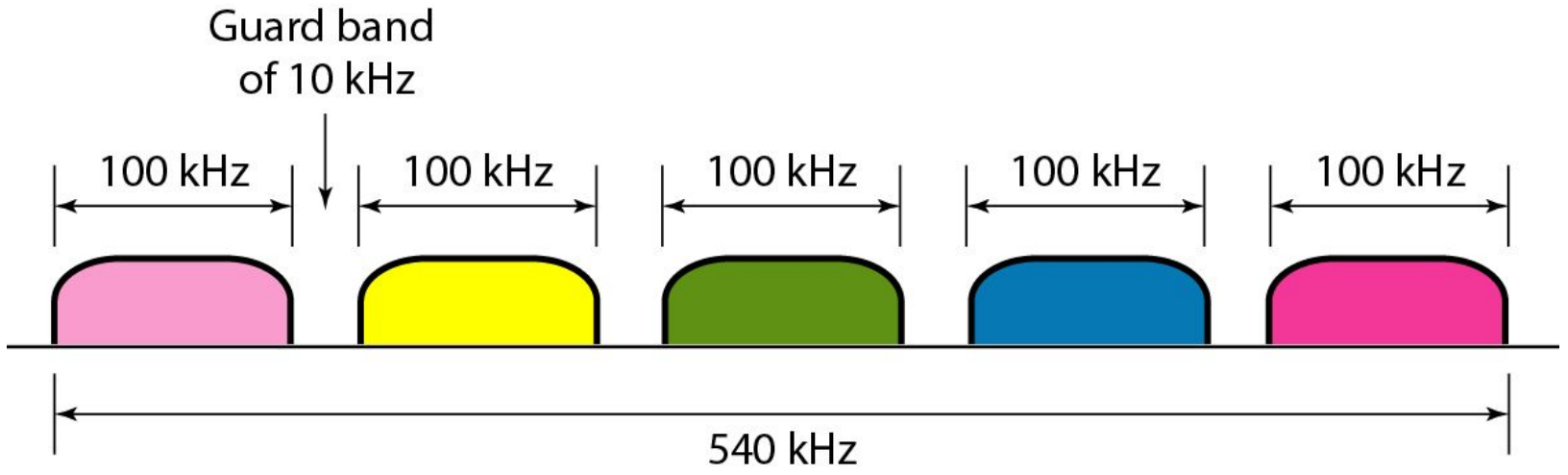


Example 2

Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?

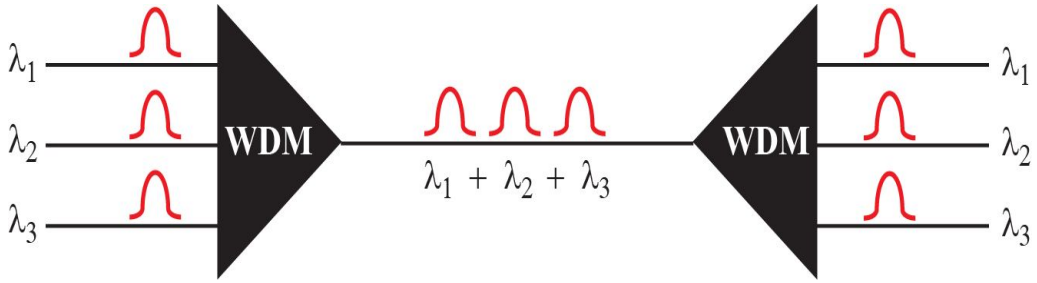
Solution

For five channels, we need at least four guard bands. This means that the required bandwidth is at least $5 \times 100 + 4 \times 10 = 540$ kHz, as shown in ***Figure.***

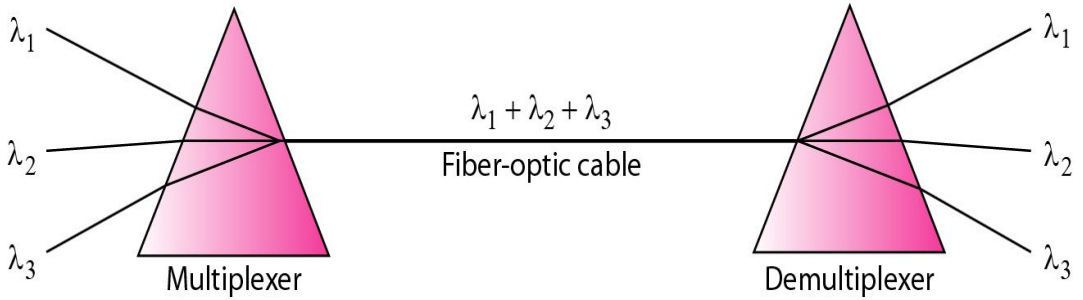


Wavelength-Division Multiplexing

- Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable.
- The optical fiber data rate is higher than the data rate of metallic transmission cable, but using a fiber-optic cable for a single line wastes the available bandwidth.
- Multiplexing allows us to combine several lines into one.



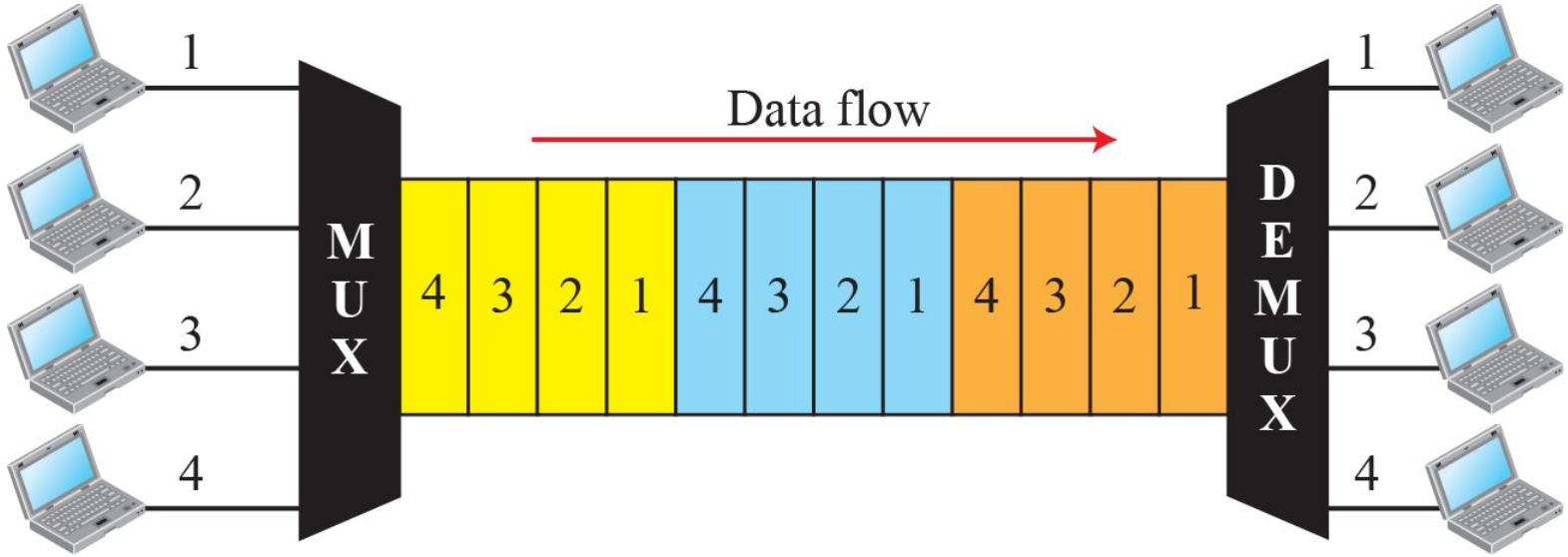
Wavelength-division multiplexing



Prisms in wave-length division multiplexing

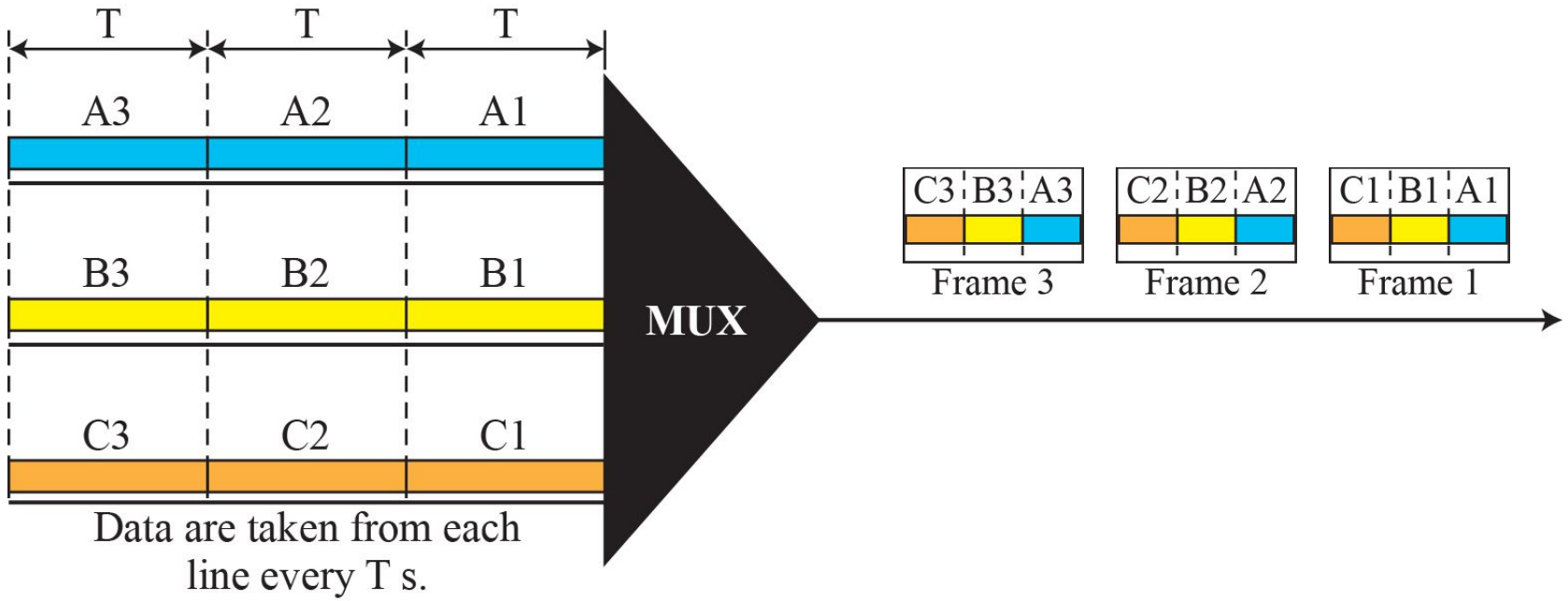
Time-Division Multiplexing

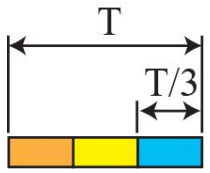
- Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link.
- Instead of sharing a portion of the bandwidth as in FDM, time is shared.
- Each connection occupies a portion of time in the link.



- ***Note that the same link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency.***
- ***In the figure, portions of signals 1, 2, 3, and 4 occupy the link sequentially.***

Synchronous Time-Division Multiplexing: Time slots and frames





Each frame is 3 time slots.
Each time slot duration is T/3 s.

In Synchronous TDM, the data rate of the link is n times faster, and unit duration is n time shorter

Example 3

In ***above figure***, the data rate for each input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), *what is the duration of*

1. each input slot,

2. each output slot, and

3. each frame?

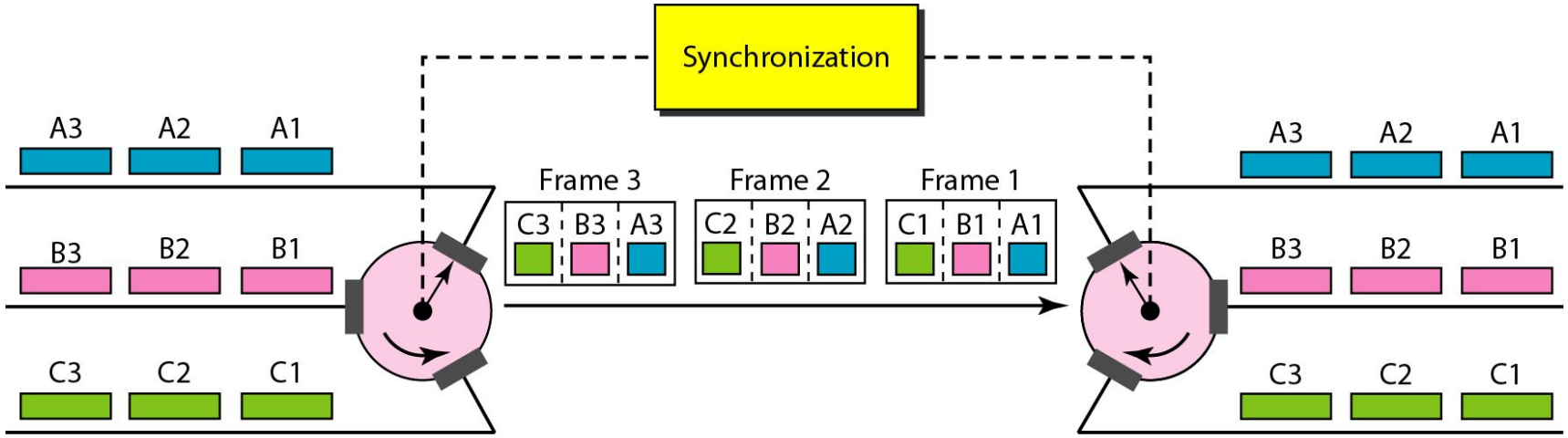
Solution

1. The data rate of each input connection is 1 kbps. This means that the ***bit duration*** *is 1/1000 s or 1 ms. The duration of the input time slot is 1 ms (same as bit duration).*

2. The duration of each output time slot is one-third of the input time slot. This means that the duration of the output time slot is 1/3 ms.

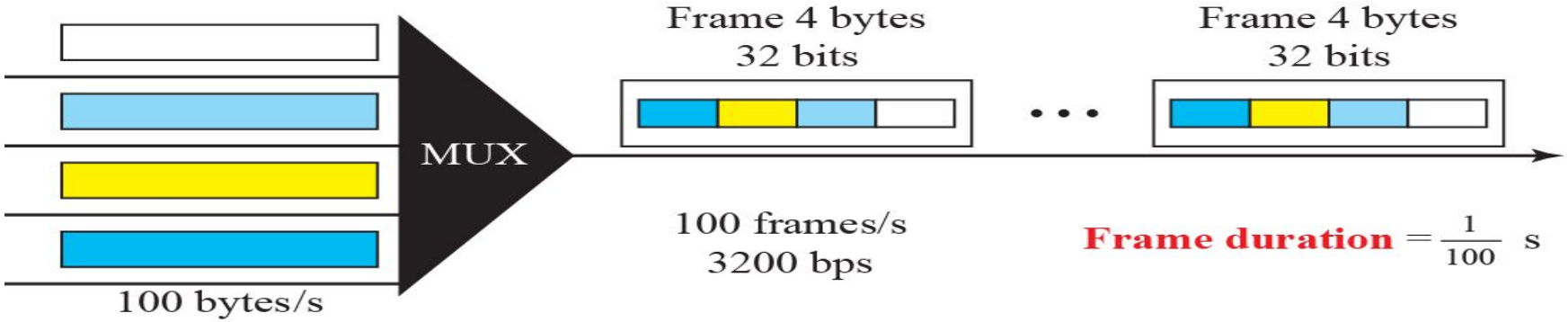
3. Each frame carries three output time slots. So the duration of a frame is 3 × (1/3) ms, or 1 ms. The duration of a frame is the same as the duration of an input unit.

INTERLEAVING



Example 4

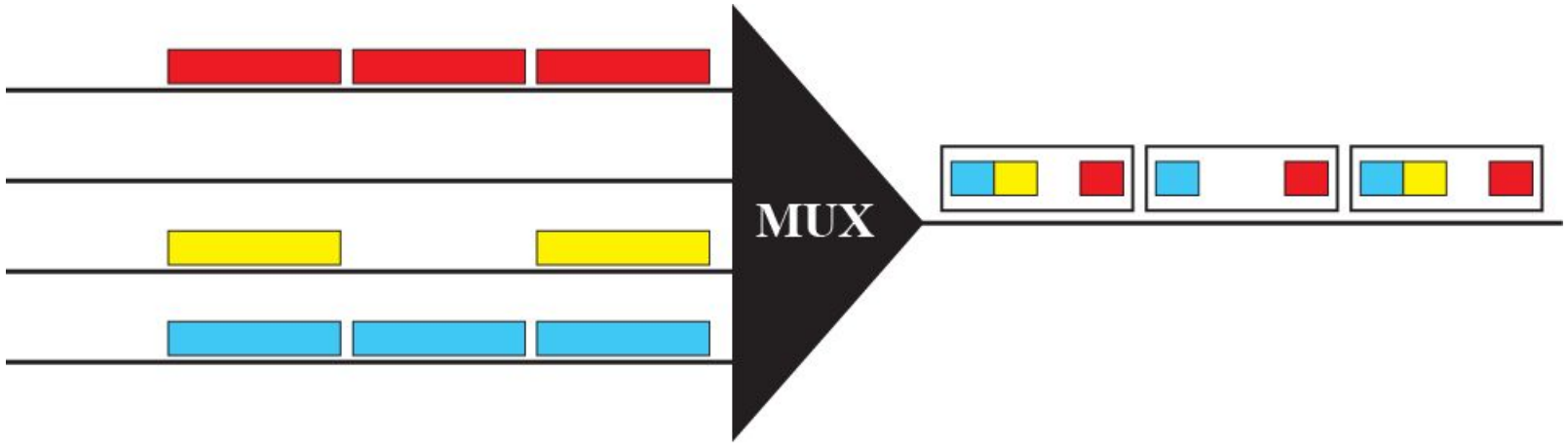
Four channels are multiplexed using TDM. If each channel sends 100 bytes/s and we multiplex 1 byte per channel, *show the frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link.*



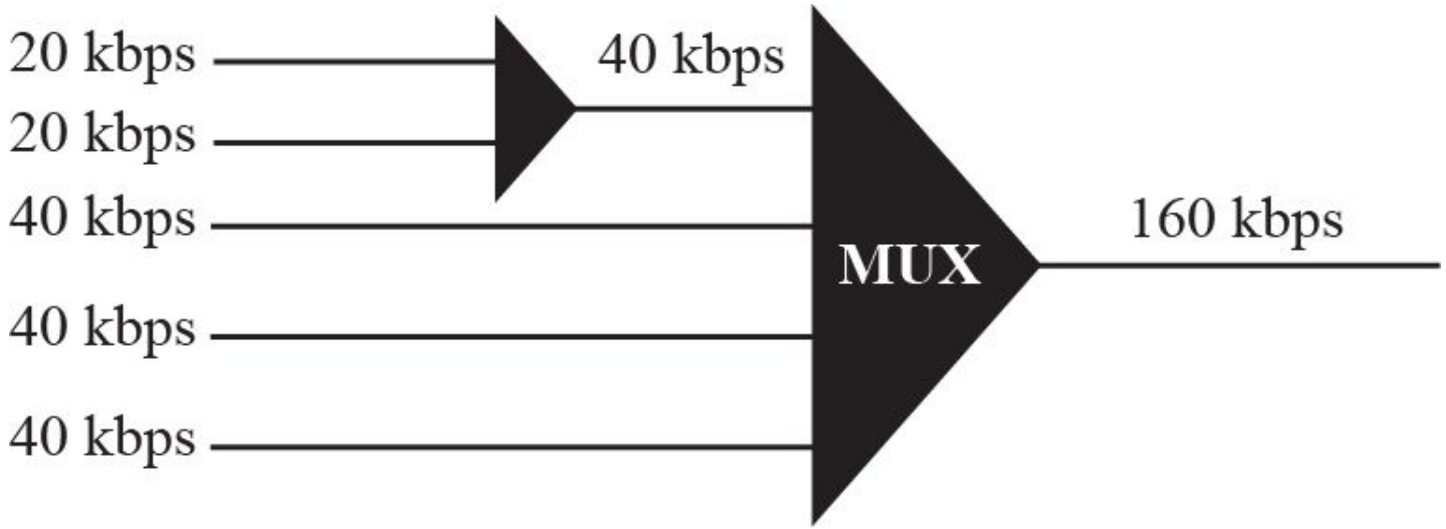
Solution

- The multiplexer is shown in ***Figure***. Each frame carries 1 byte from each channel; the size of each frame, therefore, is 4 bytes, or 32 bits.
- The frame rate is 100 frames per second. [100 * 8=800 bits/s; 800 * 4 =3200 bits/s; 3200/32=100 frame/sec]
- The duration of a frame is therefore 1/100 s.
- The link is carrying 100 frames per second, and since each frame contains 32 bits, the bit rate is 100 × 32, or 3200 bps.

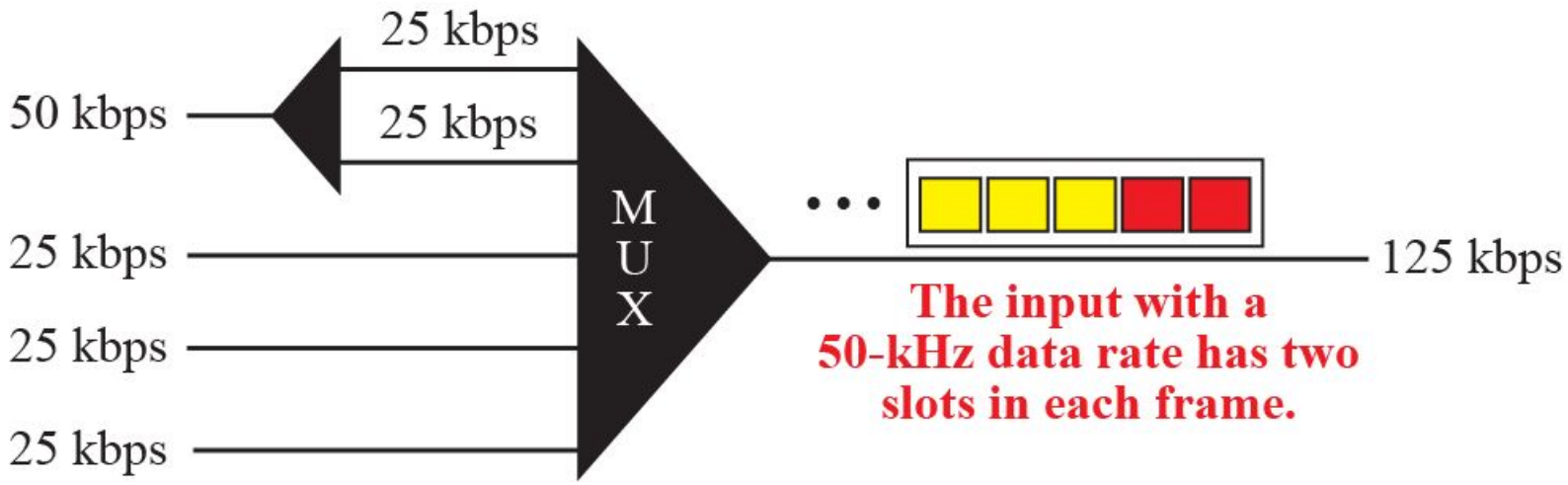
Empty Slots



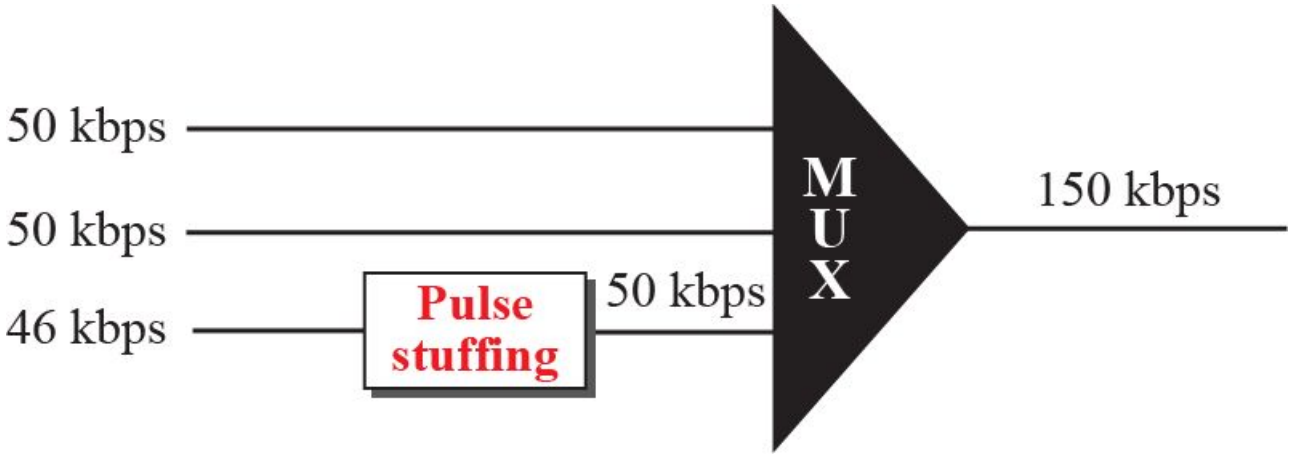
Multilevel Multiplexing



Multiple-slot Multiplexing



Pulse stuffing



Summary

In this section we have discussed the following:

- ✔ Multiplexing concept
- ✔ Multiplexing techniques as TDM, FDM and WDM.
- ✔ Interleaving and bit stuffing


Thank
you!