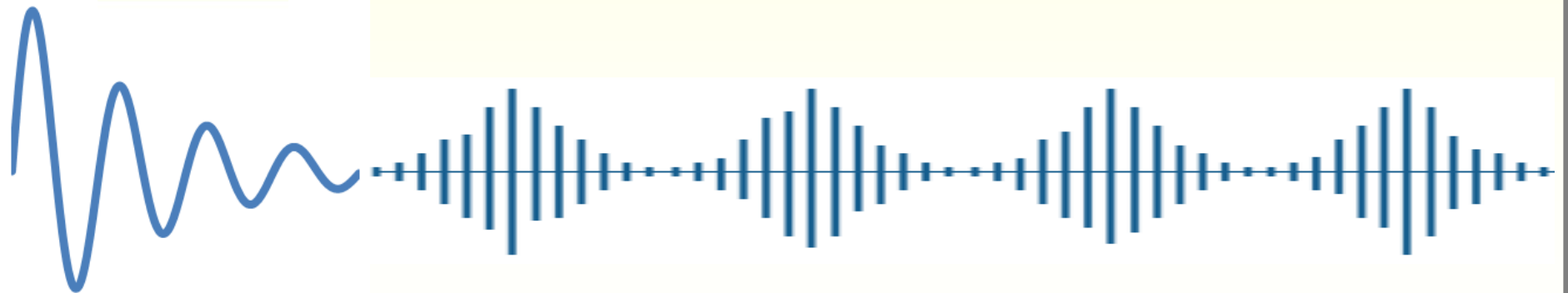




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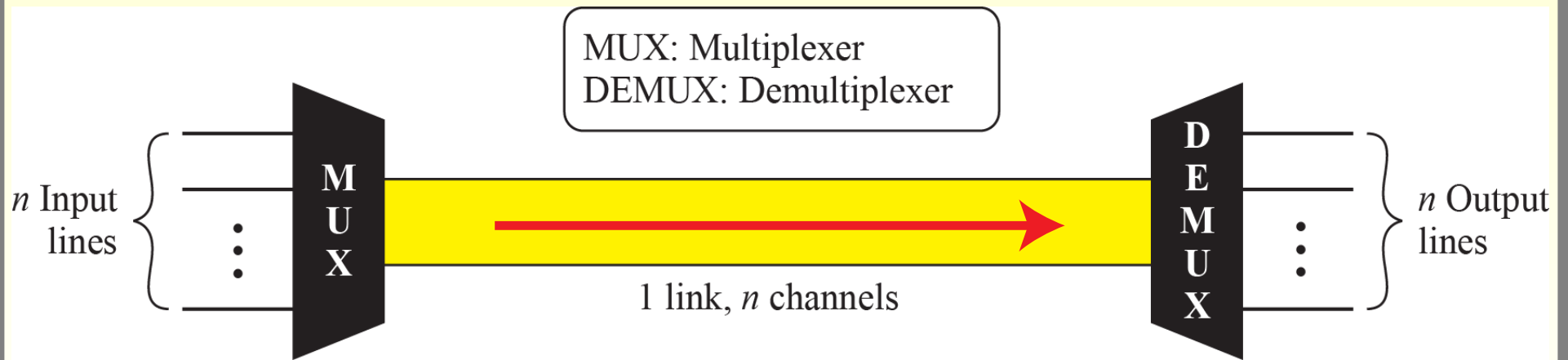
# Bandwidth Utilization



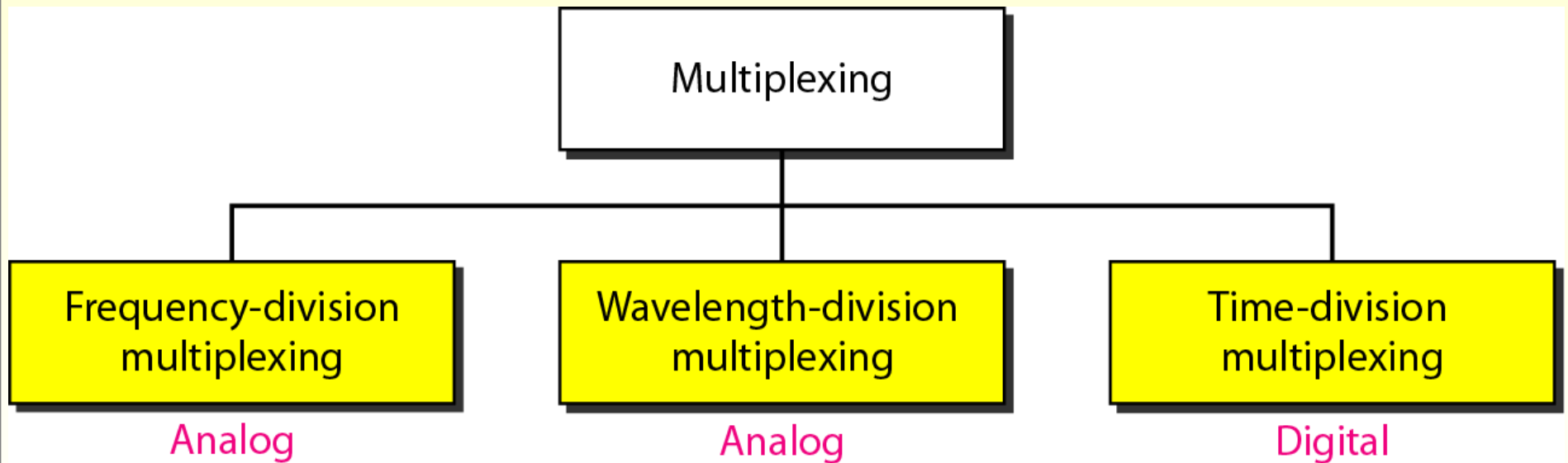
# 1- MULTIPLEXING

Multiplexing is the set of techniques that allows the 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 is needed, or we can install higher-bandwidth links and use each to carry multiple signals.

## Dividing a link into channels



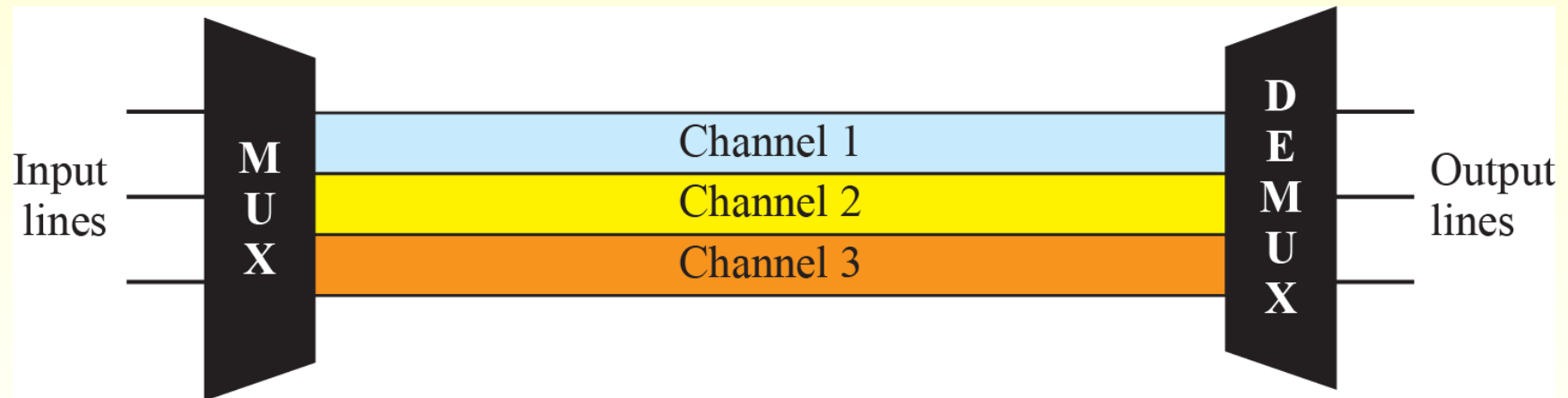
## Categories of multiplexing



# 1-1 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.

## Frequency-division multiplexing

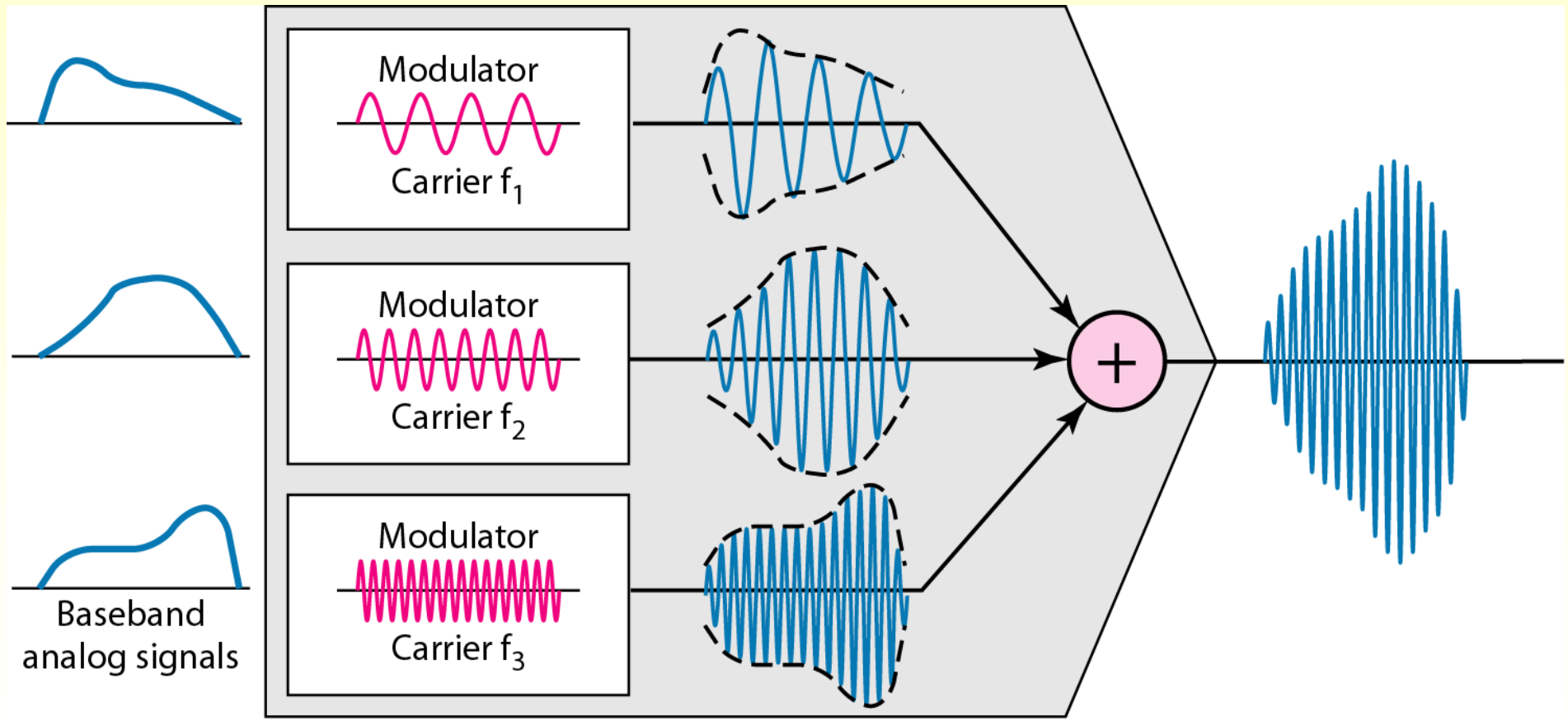


FDM is an analog multiplexing technique that combines analog signals.

## *Multiplexing Process*

Next figure is a conceptual illustration of the multiplexing process. Each source generates a signal of a similar frequency range. Inside the multiplexer, these similar signals modulate different carrier frequencies ( $f_1$ ,  $f_2$ , and  $f_3$ ). The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

# FDM Process

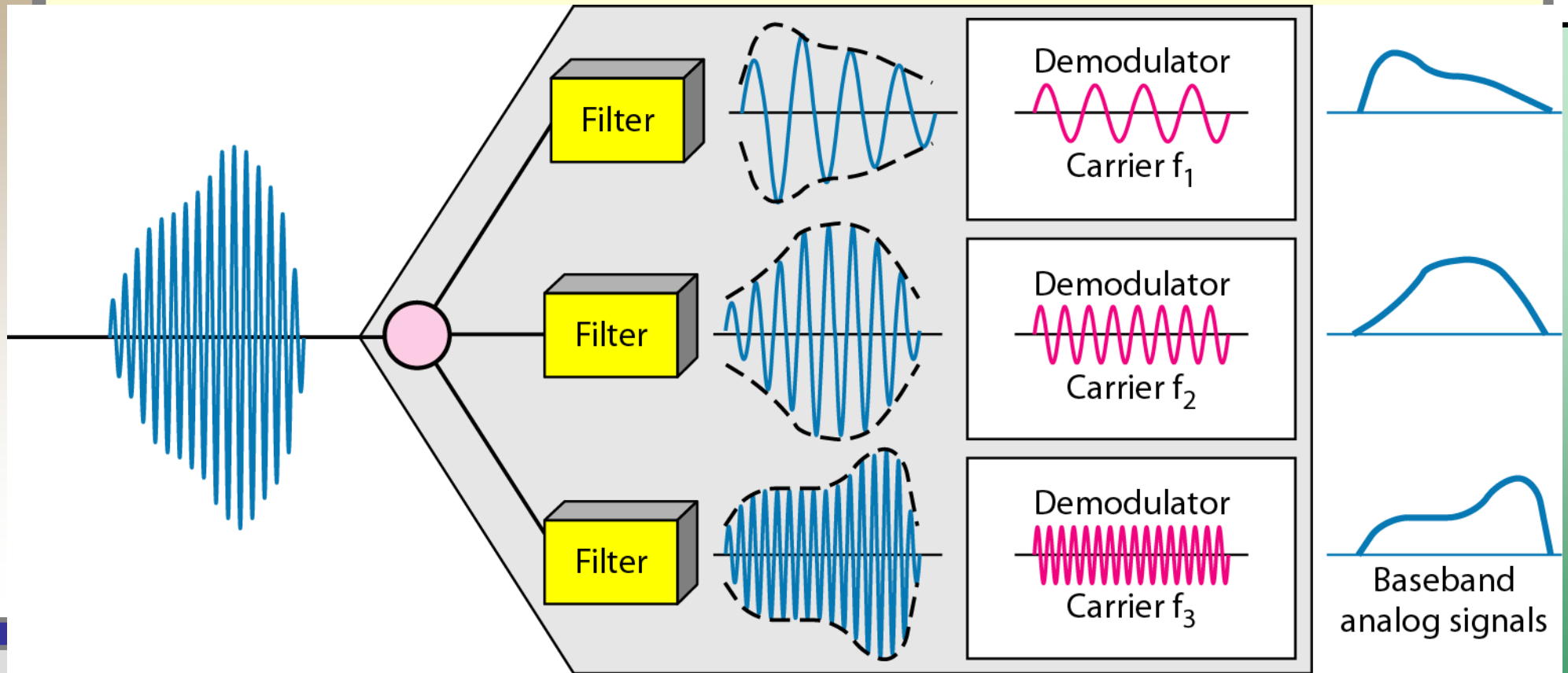




## *Demultiplexing Process*

The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines. Next figure is a conceptual illustration of demultiplexing process.

## FDM demultiplexing example



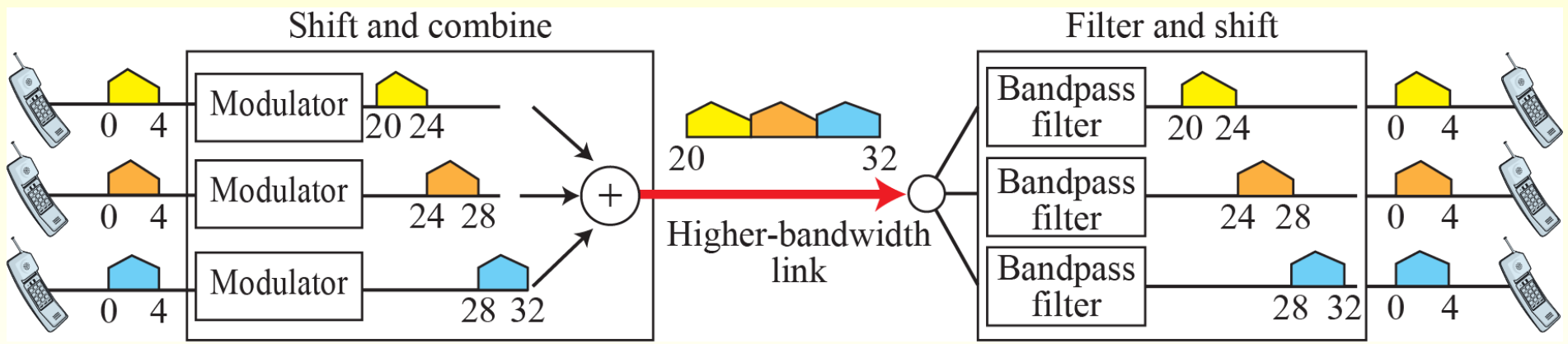
## Example 1

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

We shift (modulate) each of the three voice channels to a different bandwidth, as shown in next figure.

# Example 1



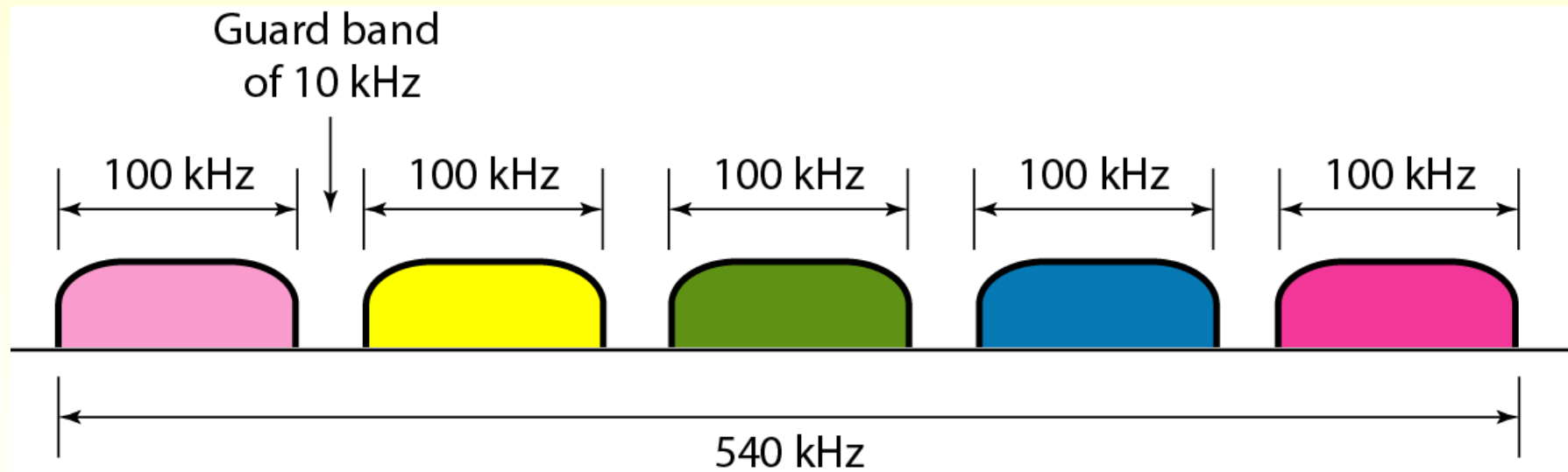
## Example 2

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?

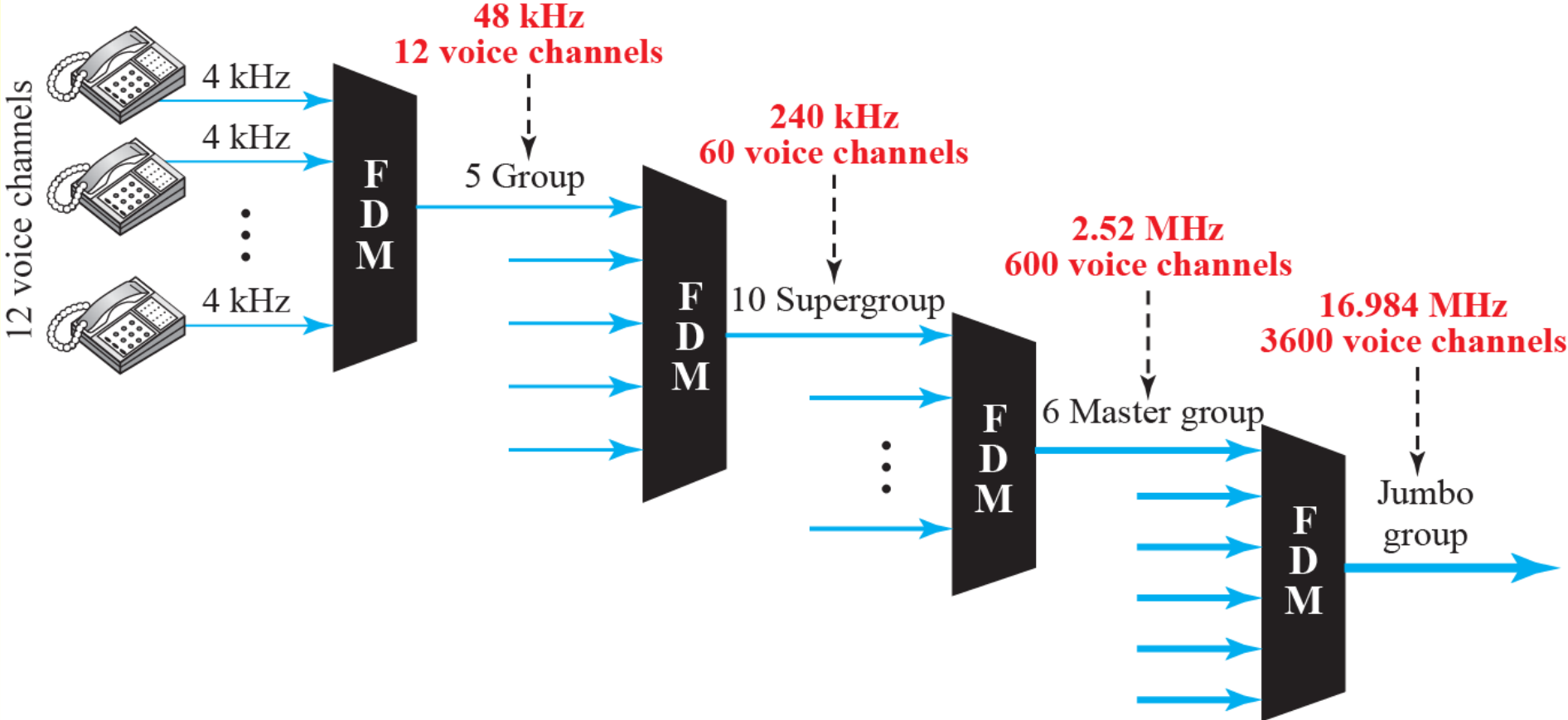
### Solution

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 next figure .

## Example 2



# Analog hierarchy

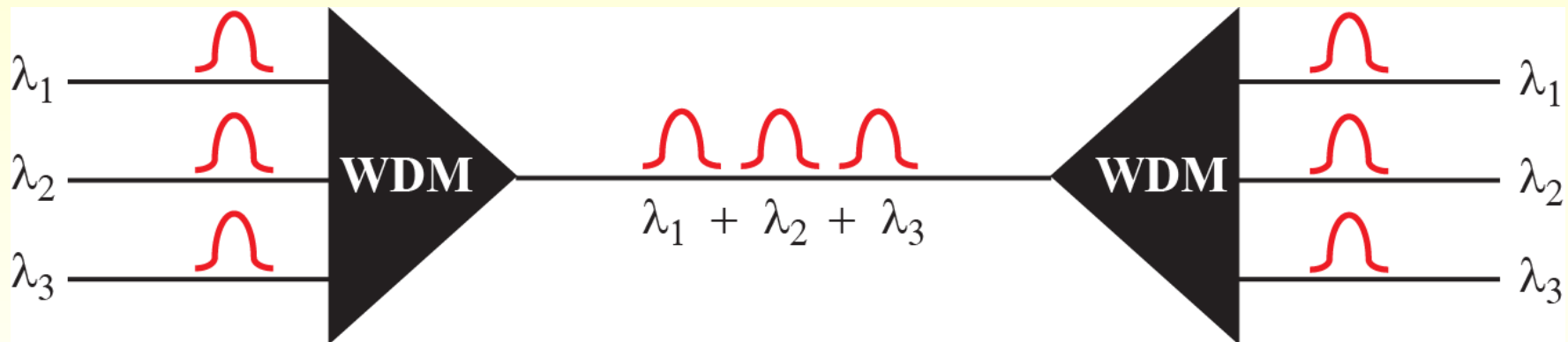


## 1-2 Wavelength-Division Multiplexing

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

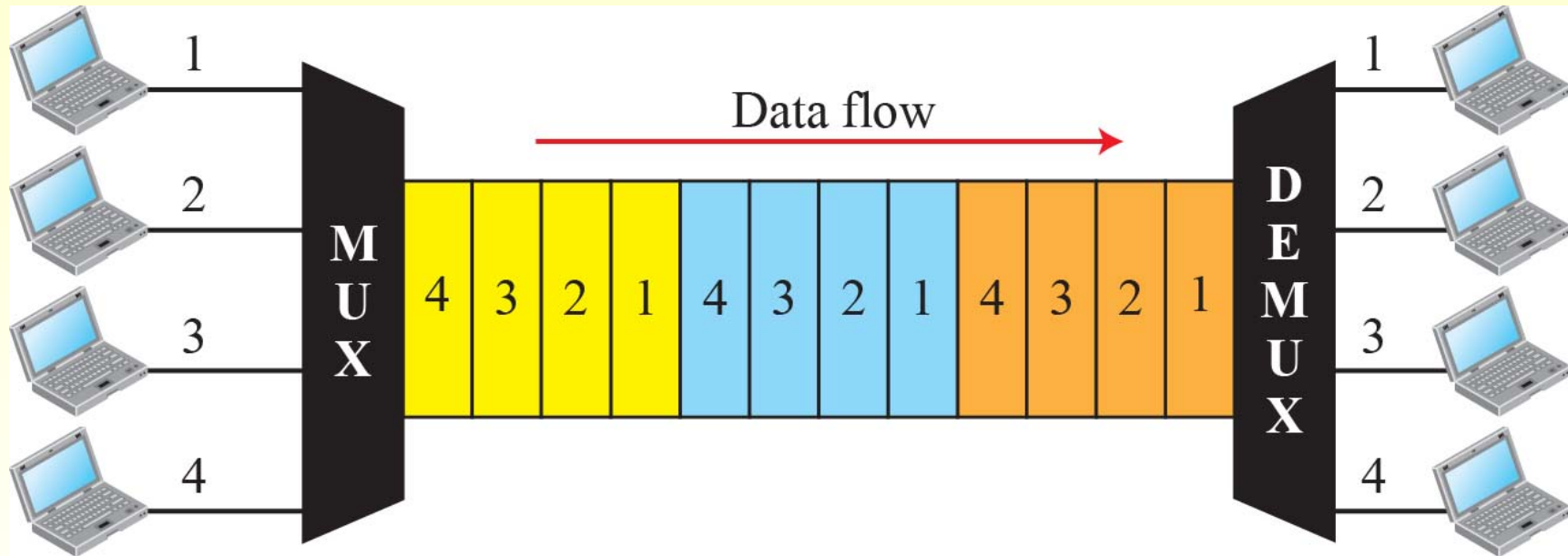


WDM is an analog multiplexing technique to combine optical signals.

## 1-3 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. Next figure gives a conceptual view of TDM. 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.

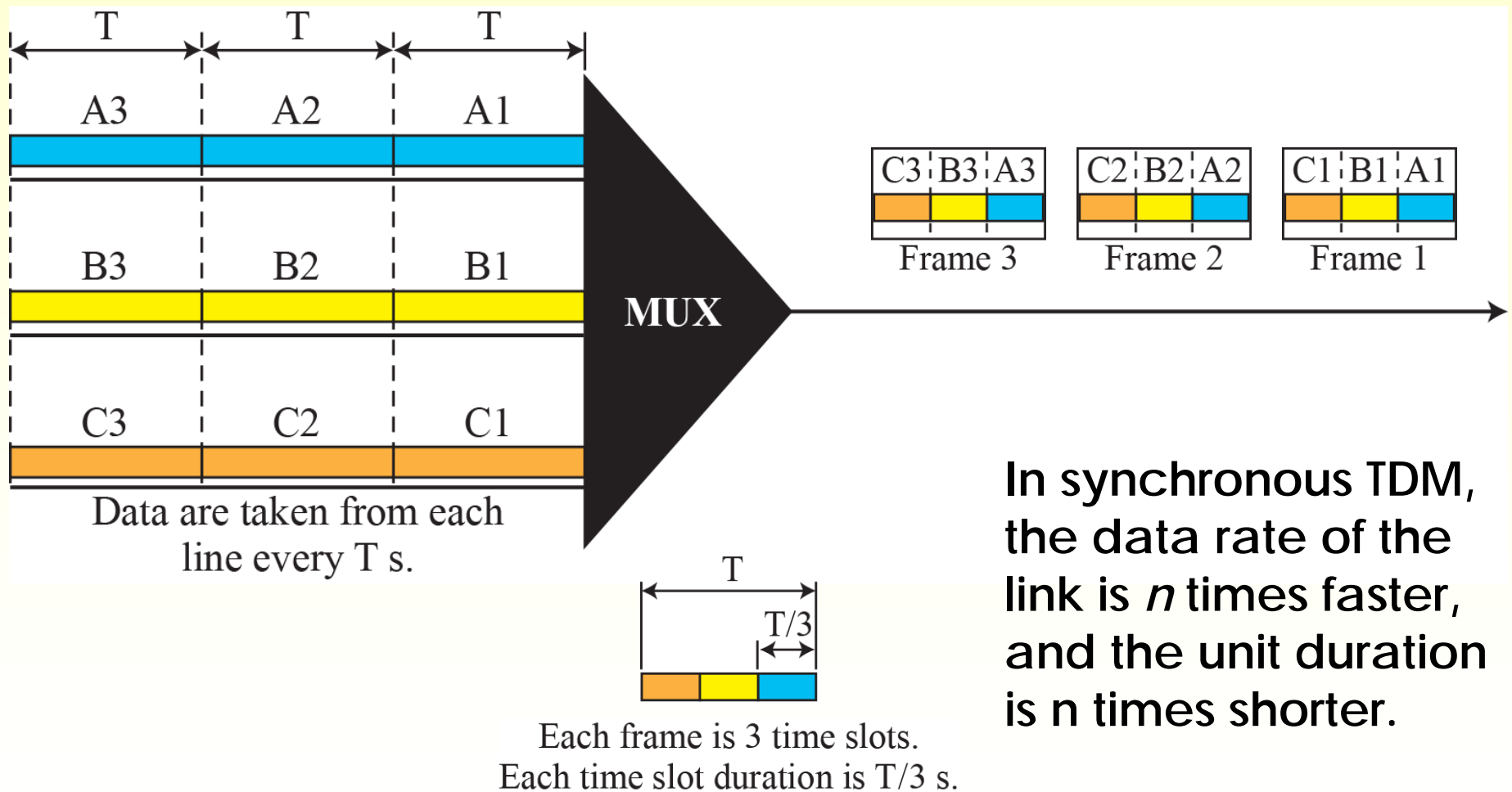
# TDM



TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

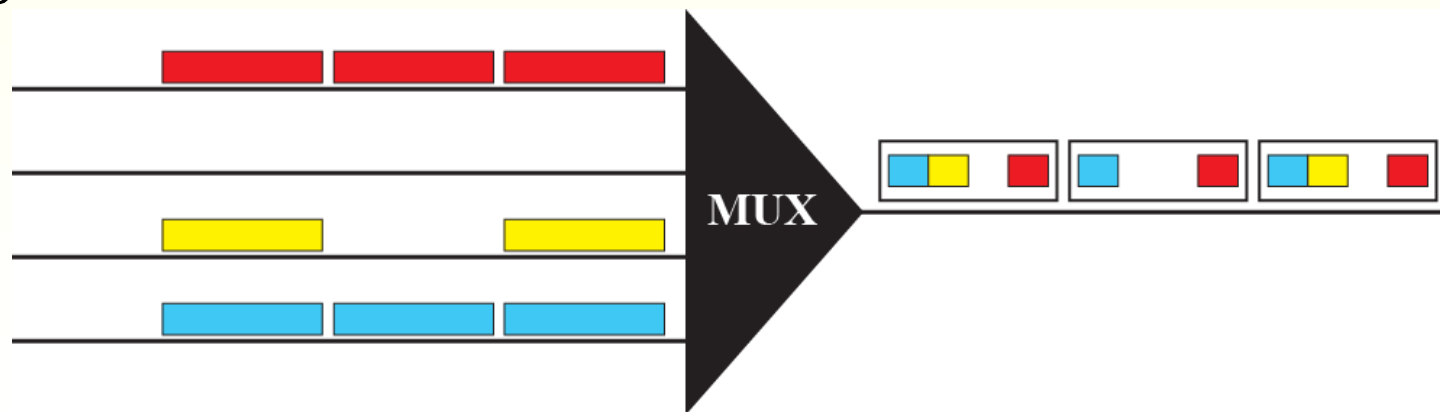
# Synchronous time-division multiplexing

In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.



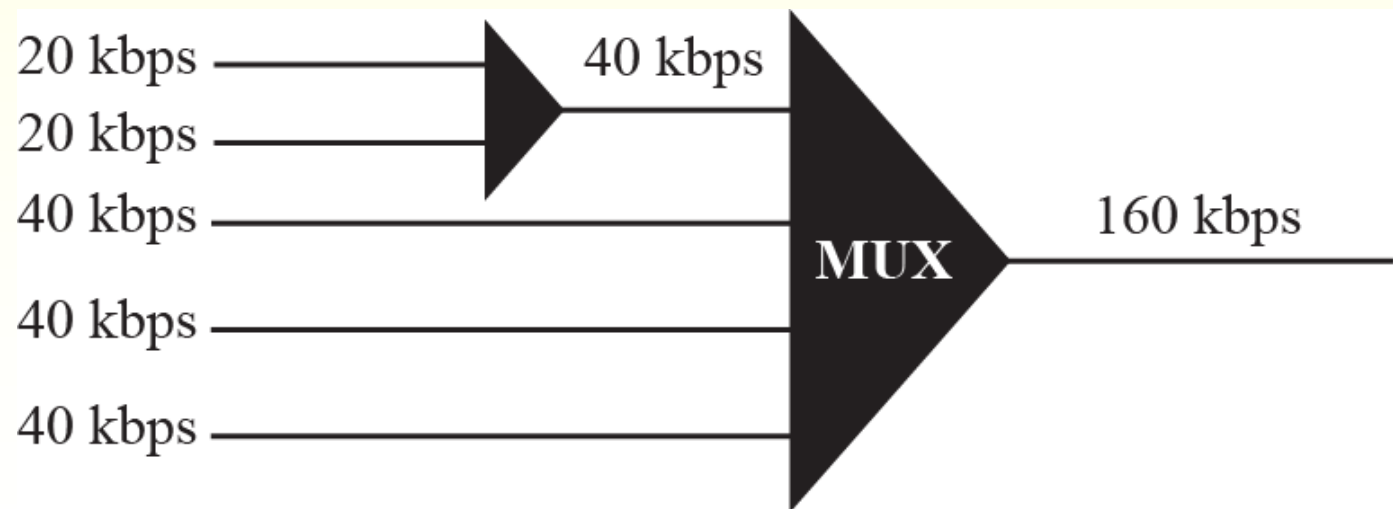
## *Empty Slots*

Synchronous TDM is not as efficient as it could be. If a source does not have data to send, the corresponding slot in the output frame is empty. Figure shows a case in which one of the input lines has no data to send and one slot in another input line has discontinuous data. The first output frame has three slots filled, the second frame has two slots filled, and the third frame has three slots filled. No frame is full. We learn in the next section that statistical TDM can improve the efficiency by removing the empty slots from the frame.



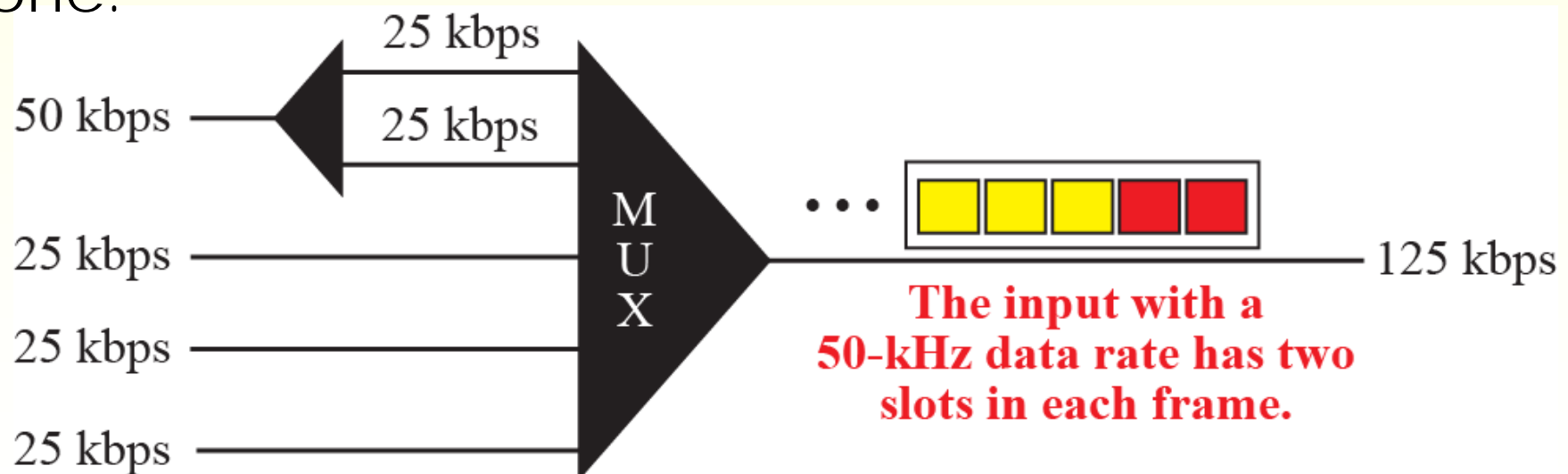
## Multilevel multiplexing

*Multilevel multiplexing* is a technique used when the data rate of an input line is a multiple of others. For example, in Figure, we have two inputs of 20 kbps and three inputs of 40 kbps. The first two input lines can be multiplexed together to provide a data rate equal to the last three. A second level of multiplexing can create an output of 160 kbps.



## Multiple-slot multiplexing

Multiple-Slot Allocation Sometimes it is more efficient to allot more than one slot in a frame to a single input line. For example, we might have an input line that has a data rate that is a multiple of another input. In Figure 6.20, the input line with a 50-kbps data rate can be given two slots in the output. We insert a demultiplexer in the line to make two inputs out of one.



# Further Reading:-

- Data Communications and Networking ,  
Forouzan, 5e , **Chapter - 6, PP 155** .