Multiplexing

Figure *Dividing a link into channels*

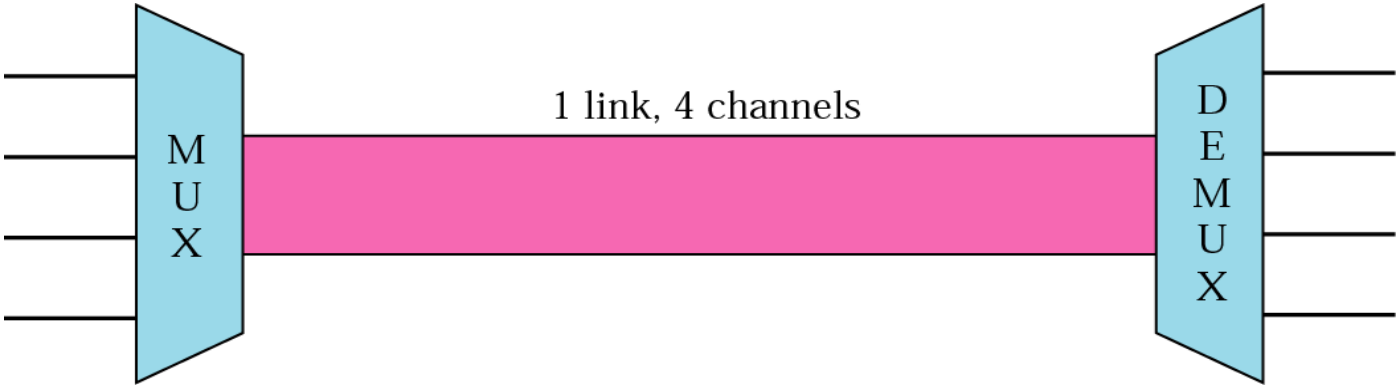
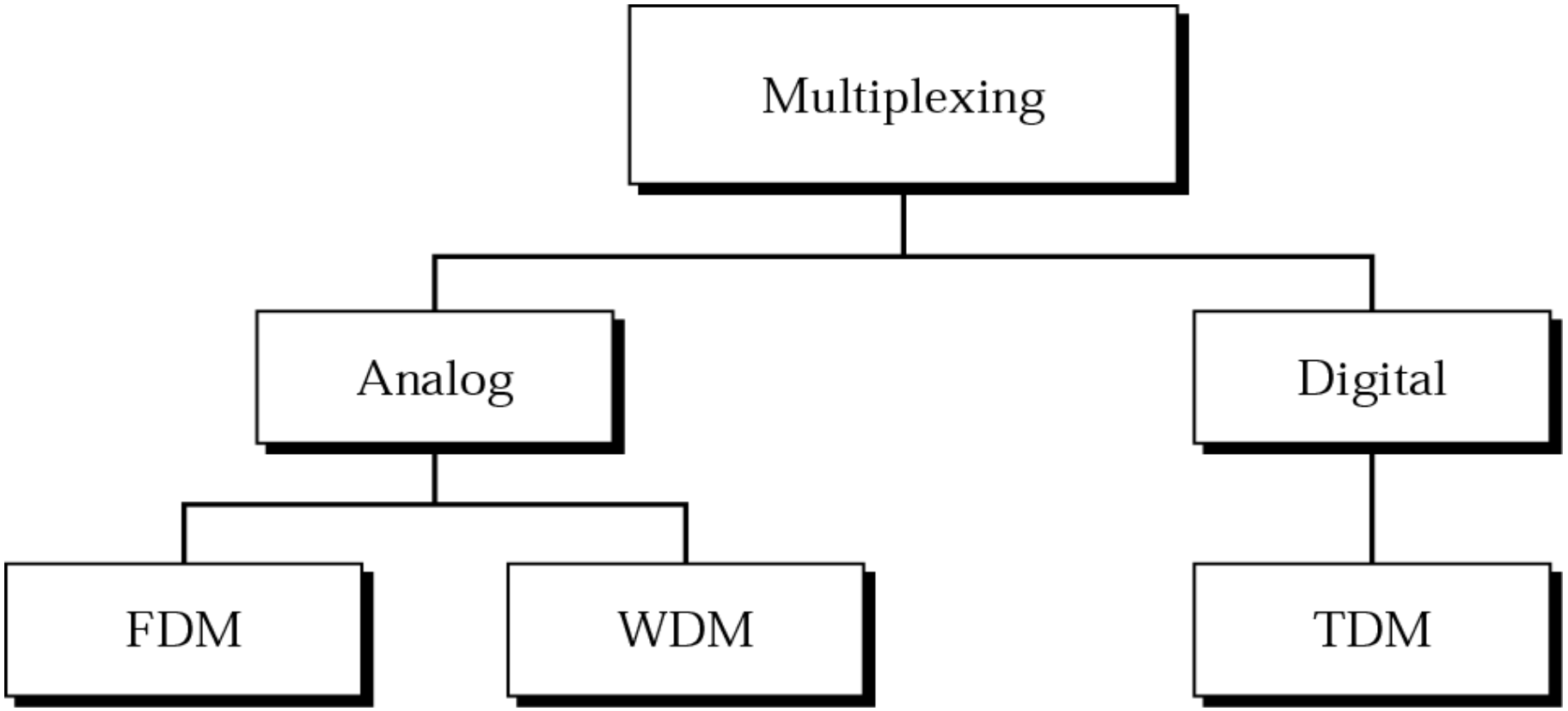


Figure ***Categories of multiplexing***



FDM

Multiplexing Process
Demultiplexing Process
The Analog Hierarchy
Other Applications of FDM
Implementation

Figure ***FDM***

Note:

FDM is an analog multiplexing technique that combines signals.

Figure 6 *FDM process*

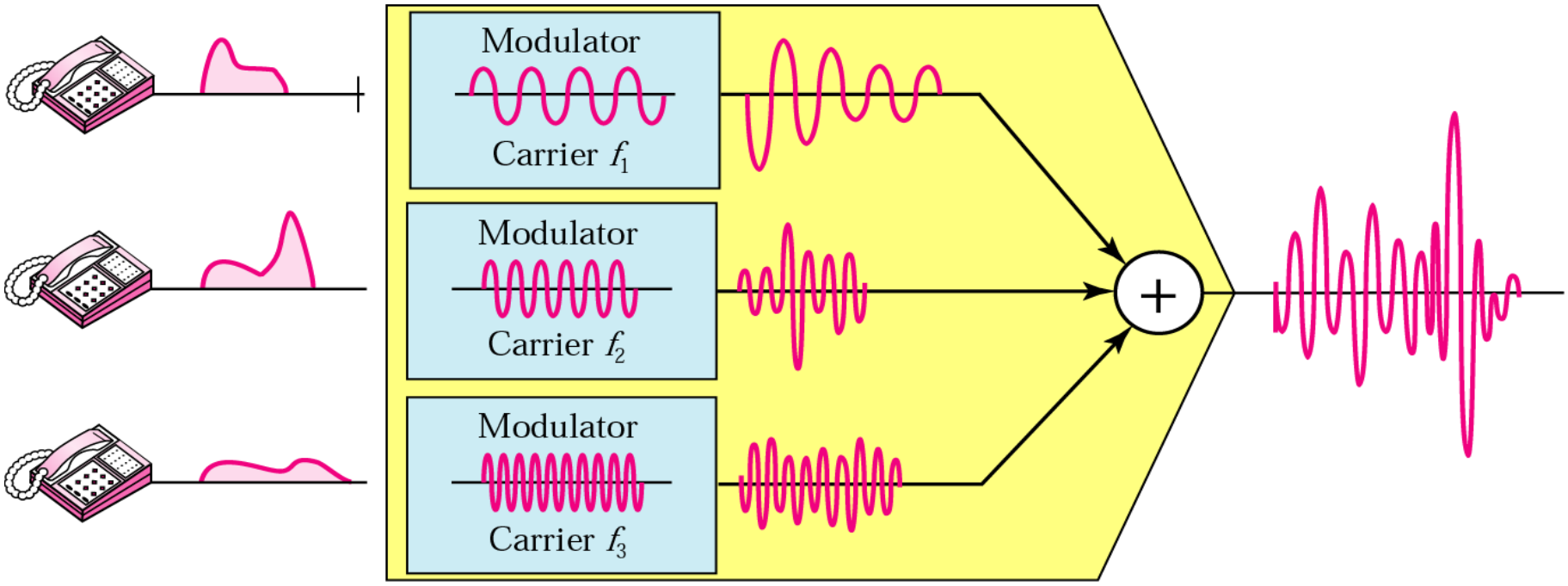
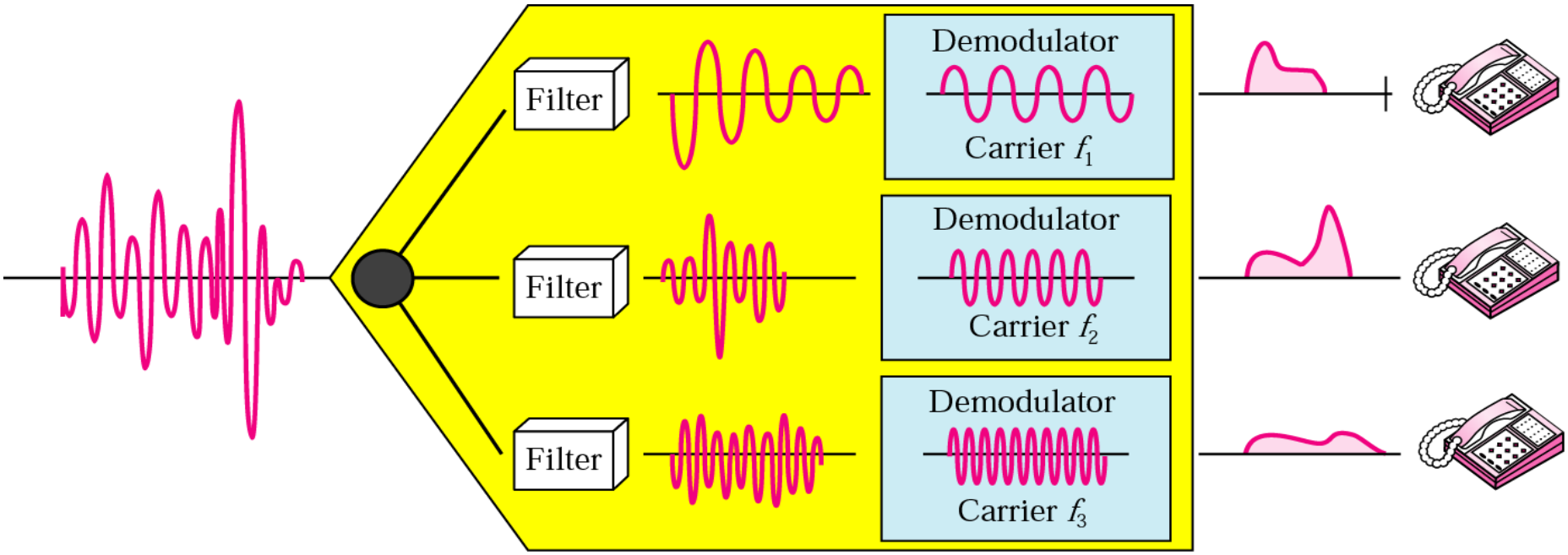


Figure *FDM demultiplexing example*



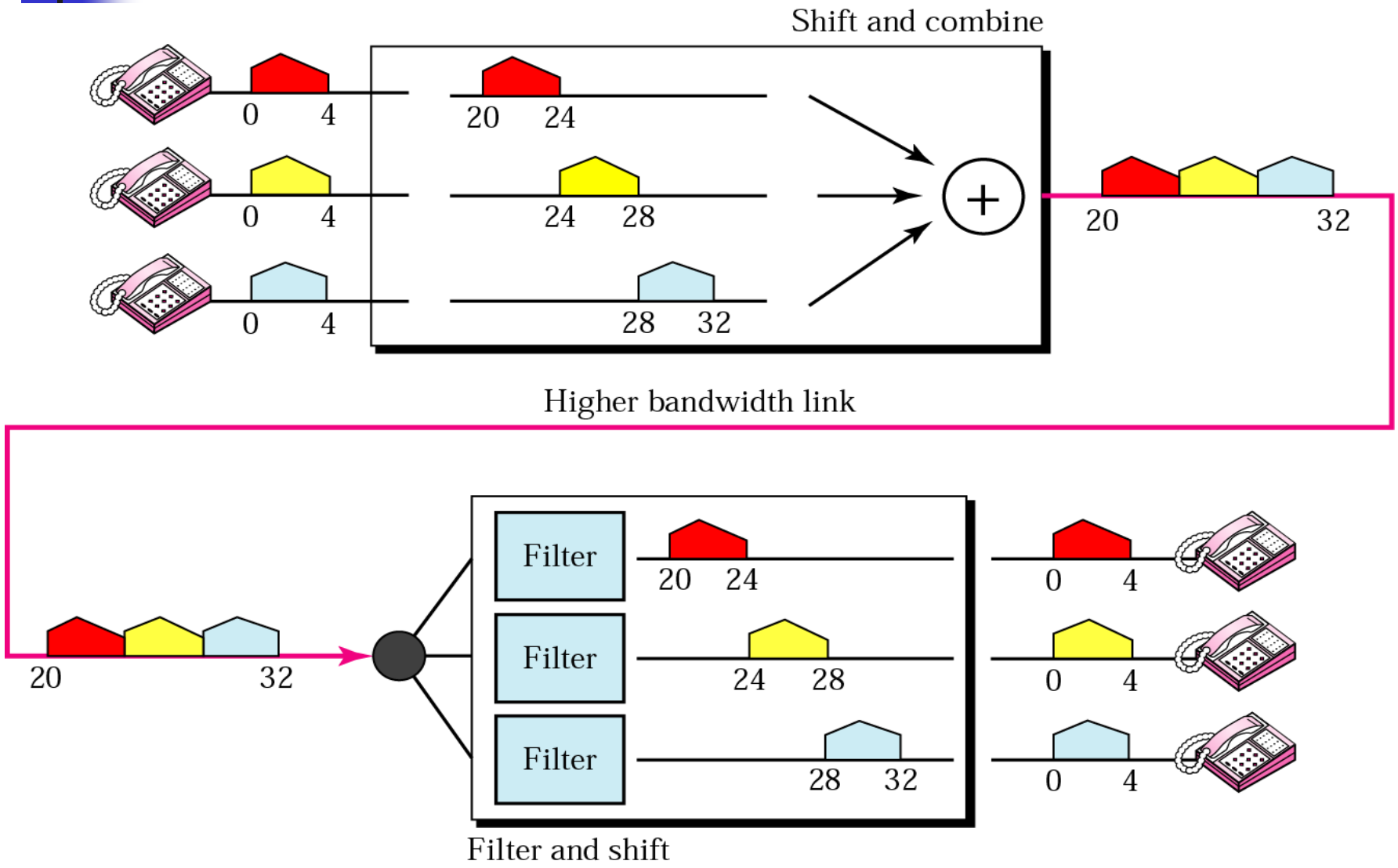
Example 1

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 without the use of guard bands.

Solution

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

Figure 6 *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

$$5 \times 100 + 4 \times 10 = 540 \text{ KHz},$$

as shown in Figure 6.7.

Figure Example 2

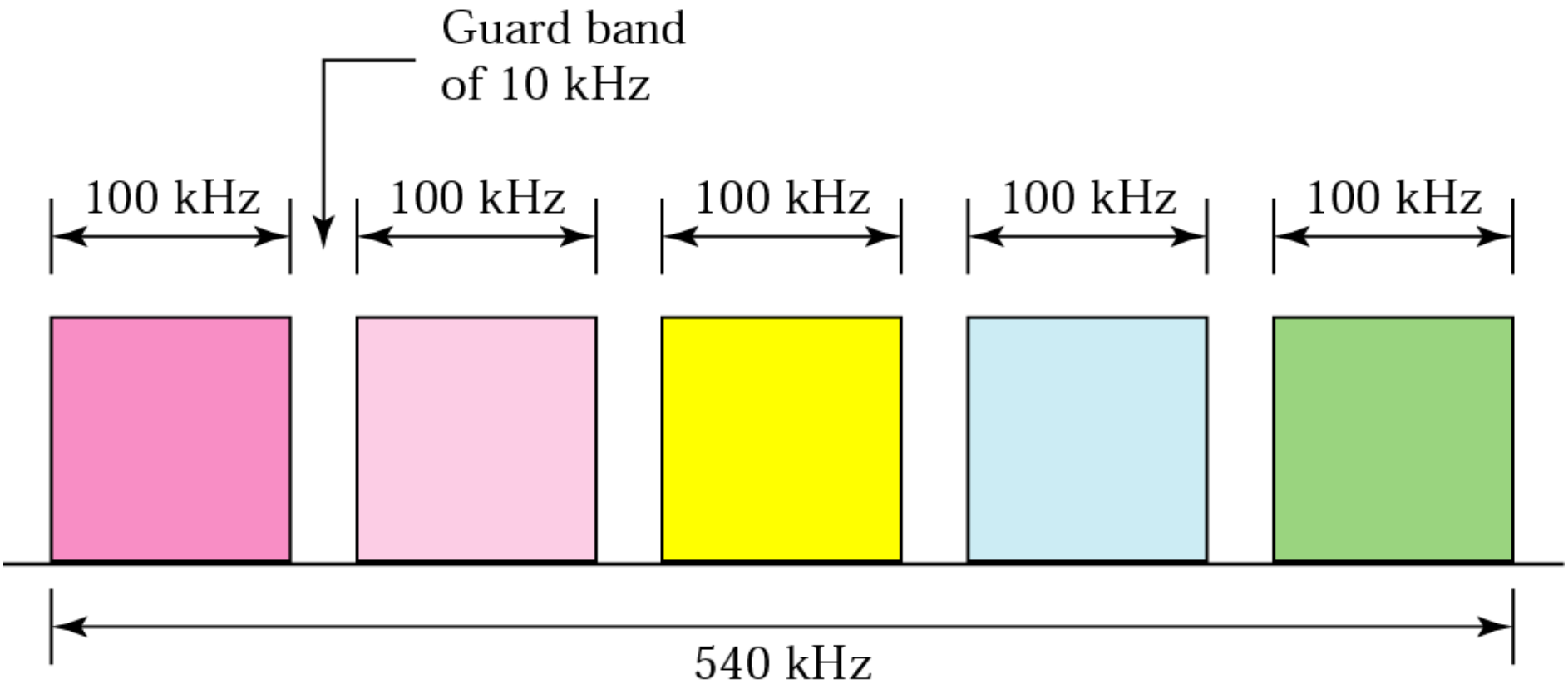
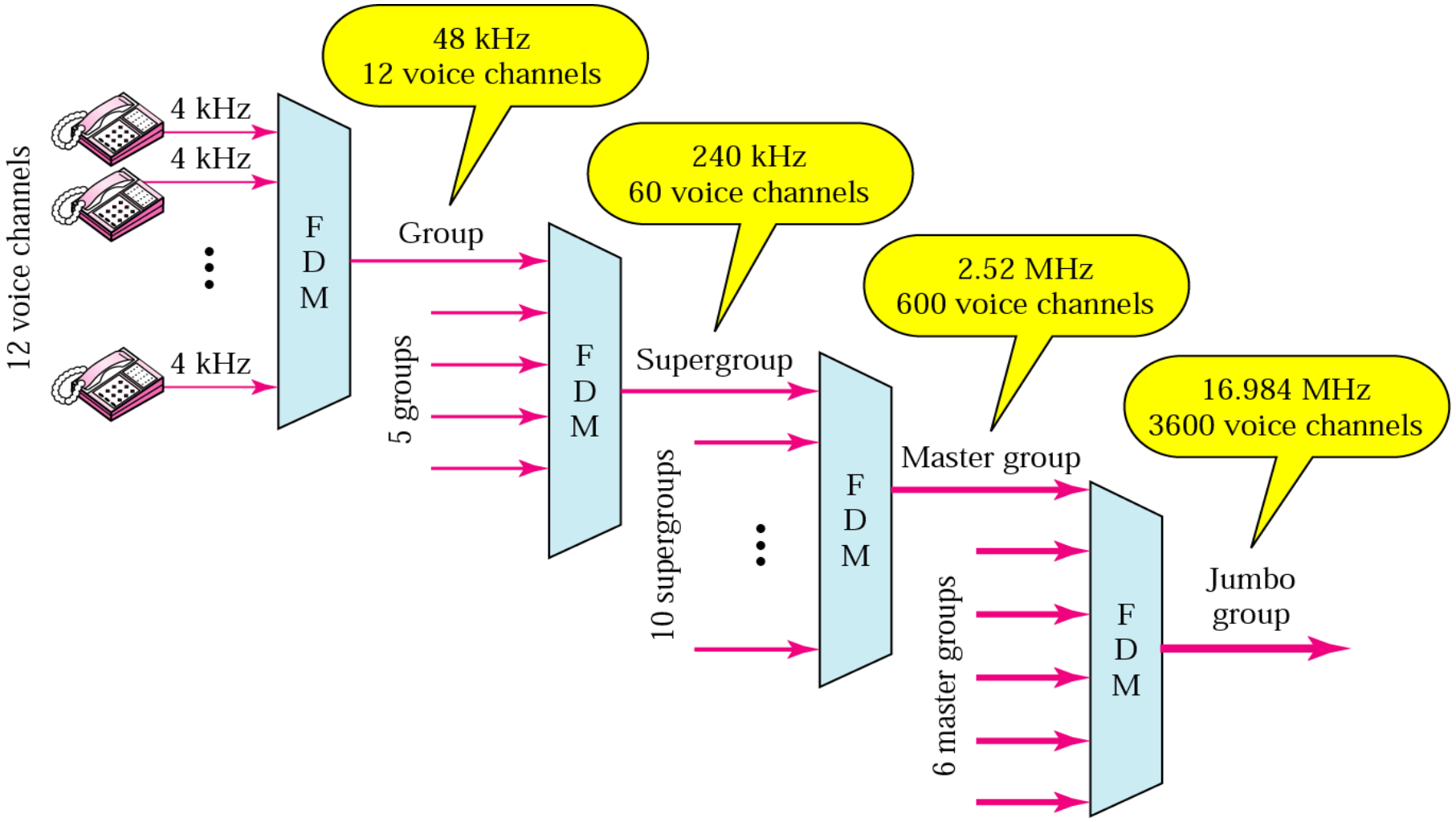


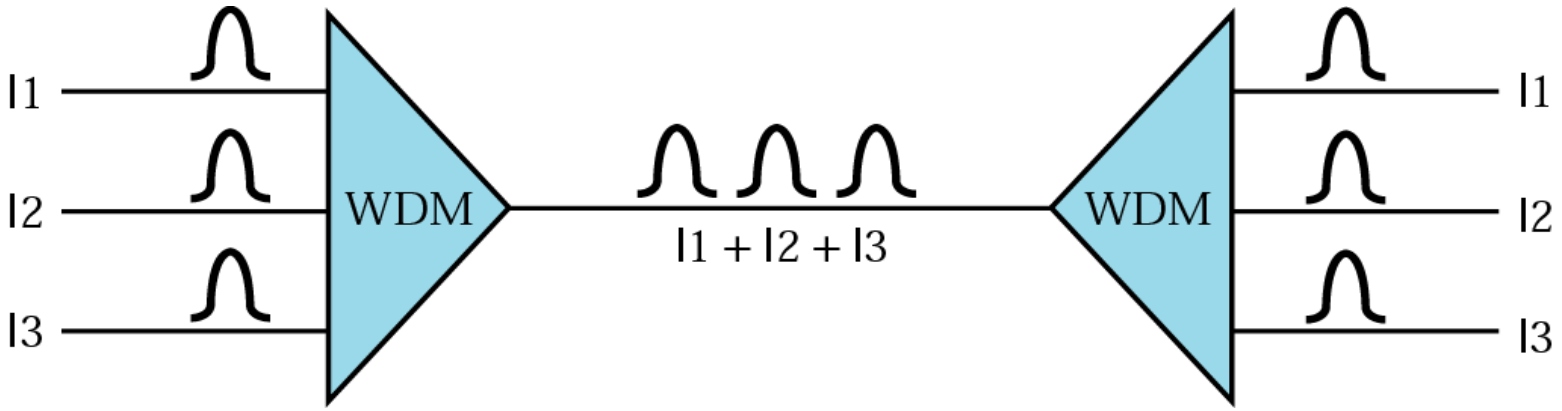
Figure *Analog hierarchy*



WDM

Wave Division Multiplexing

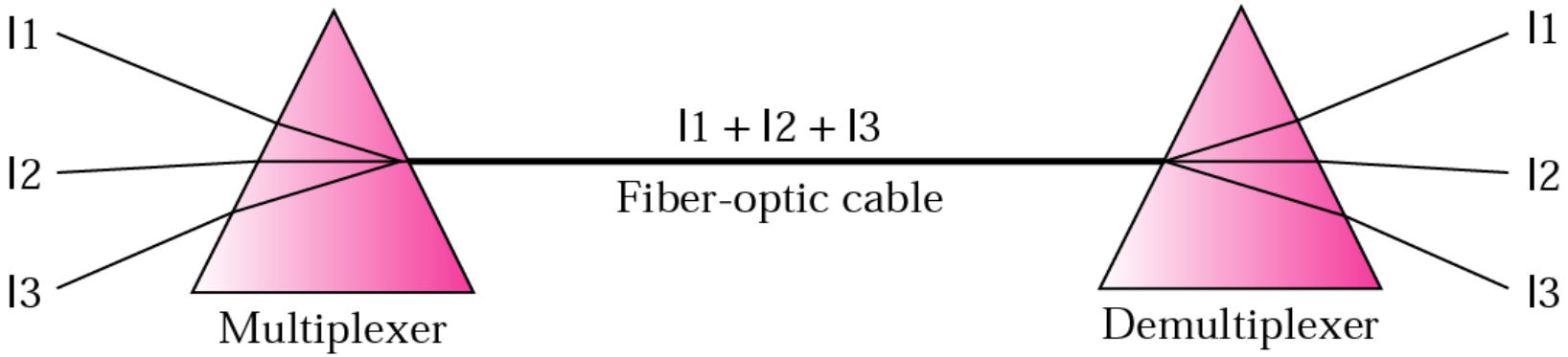
Figure *WDM*



Note:

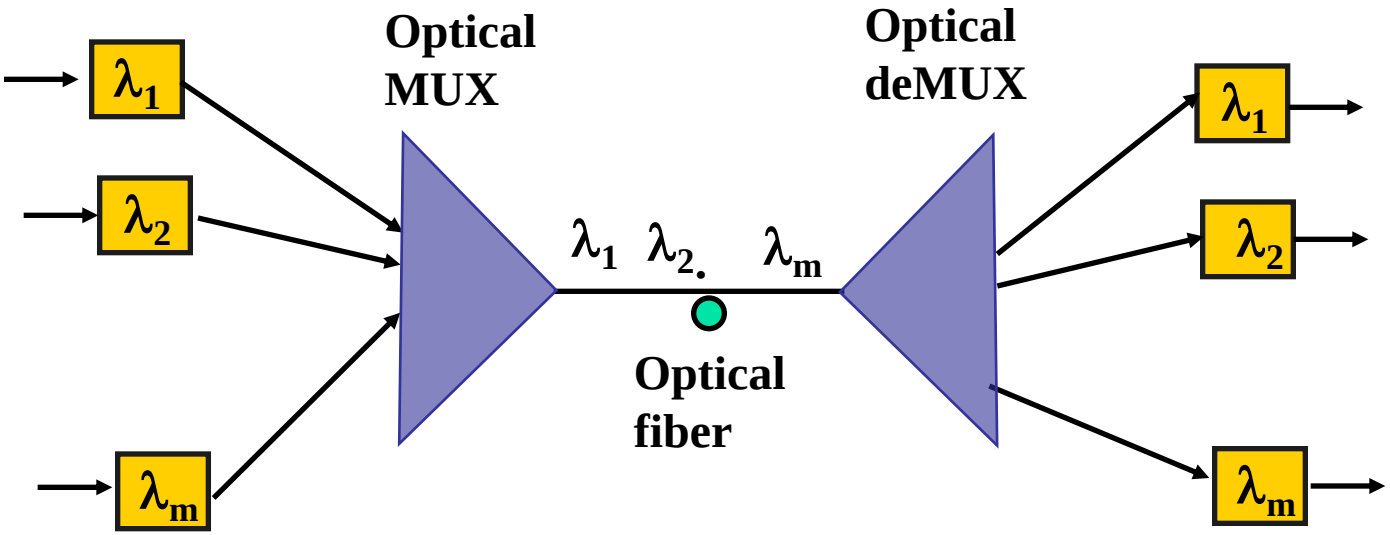
WDM is an analog multiplexing technique to combine optical signals.

Figure *Prisms in WDM multiplexing and demultiplexing*



Wavelength-Division Multiplexing

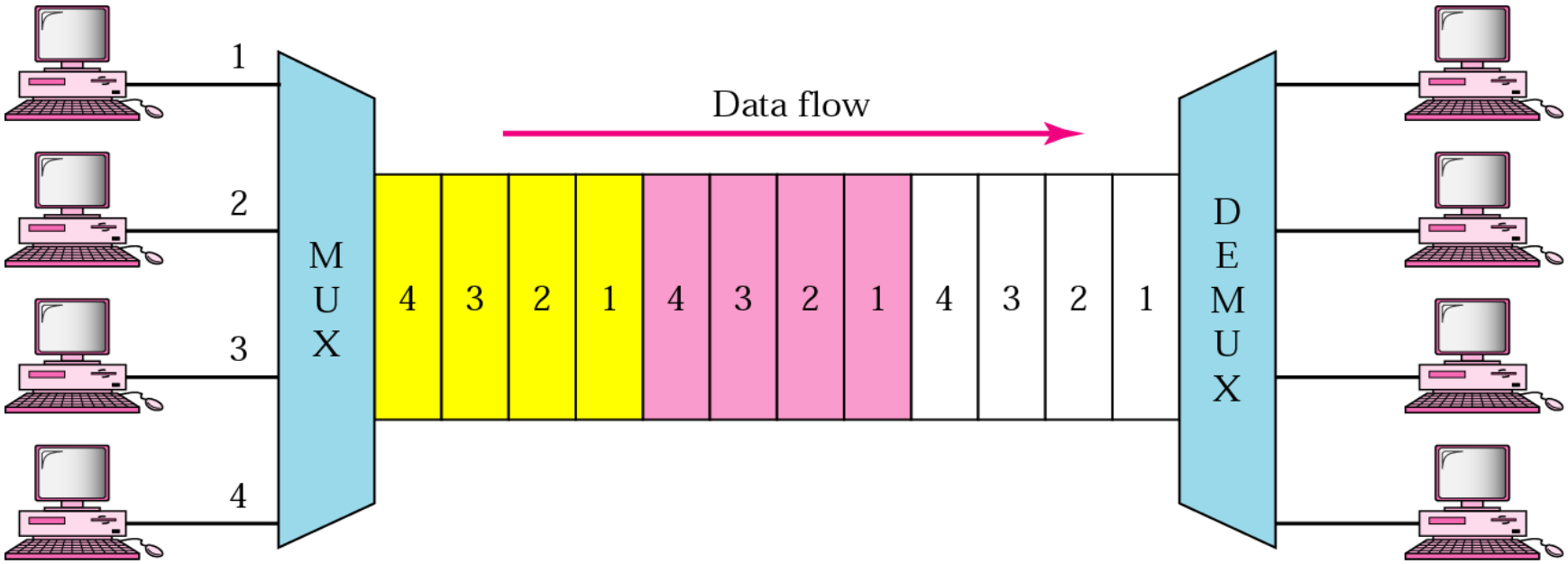
- Optical fiber link carries several wavelengths
  - From few (4-8) to many (64-160) wavelengths per fiber
- Imagine prism combining different colors into single beam
- Each wavelength carries a high-speed stream
  - Each wavelength can carry different format signal
  - e.g., 1 Gbps, 2.5 Gbps, or 10 Gbps



TDM

Time Slots and Frames
Interleaving
Synchronizing
Bit Padding
Digital Signal (DS) Service
T Lines
Inverse TDM
More TDM Applications

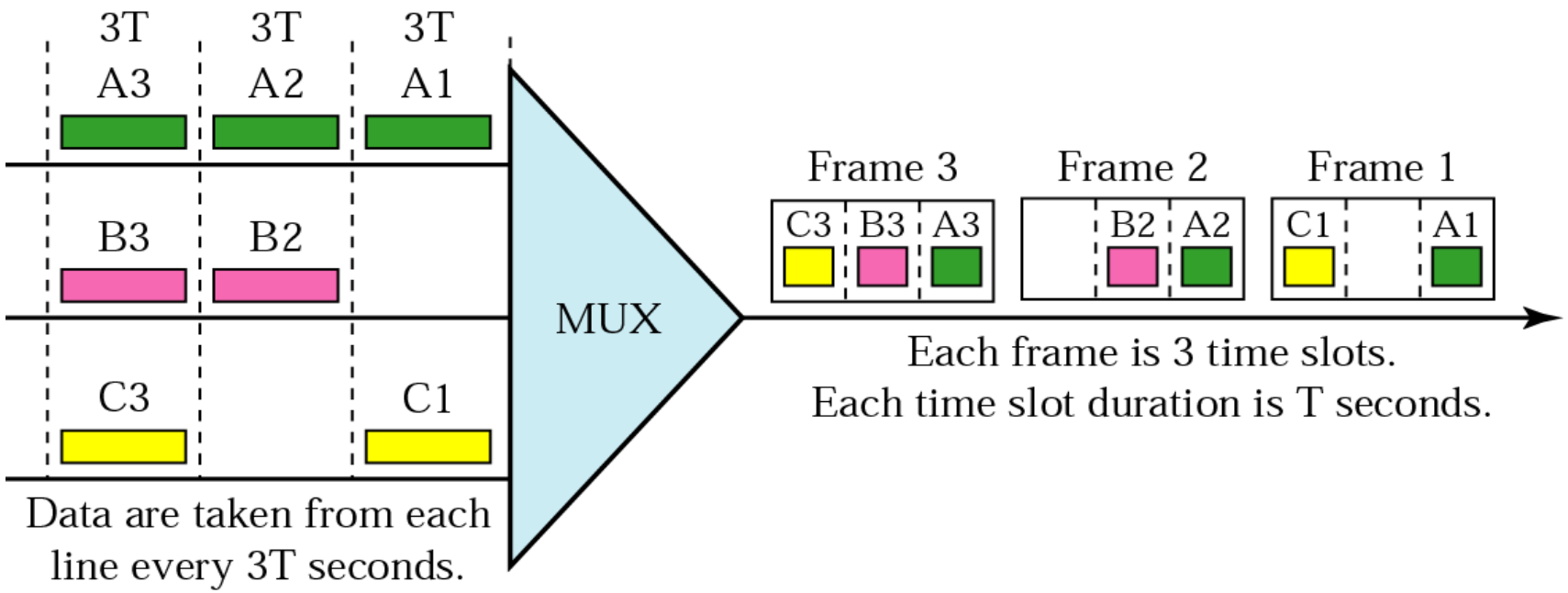
Figure ***TDM***



Note:

TDM is a digital multiplexing technique to combine data.

Figure *TDM frames*



Note:

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

Figure ***Interleaving***

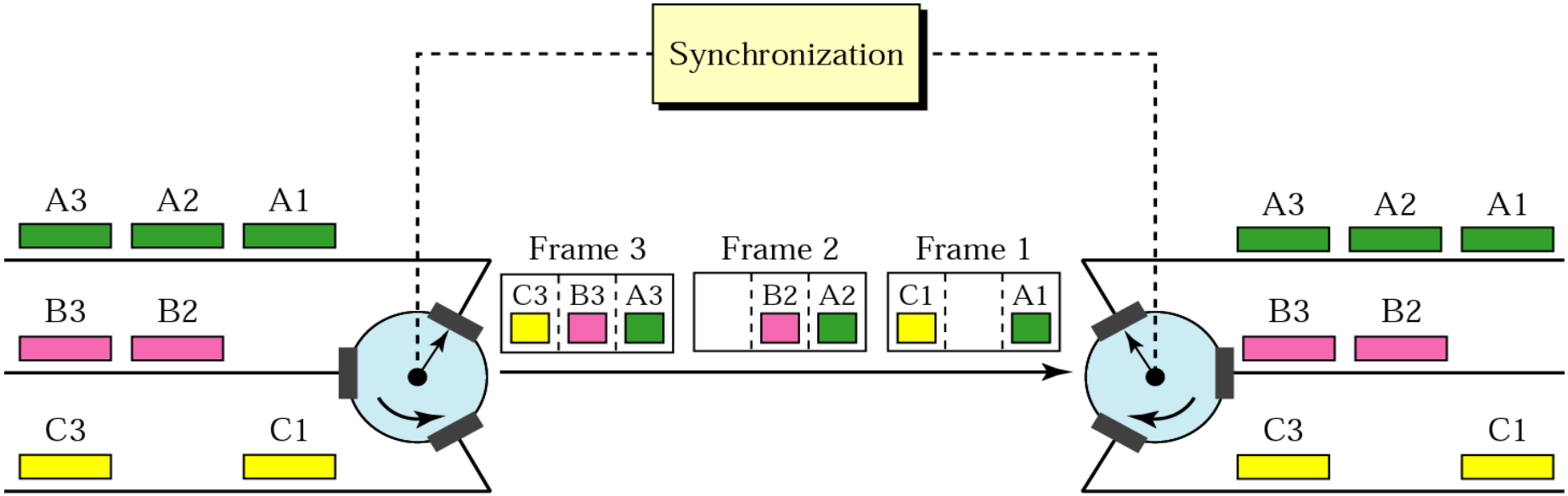


Figure *Example*

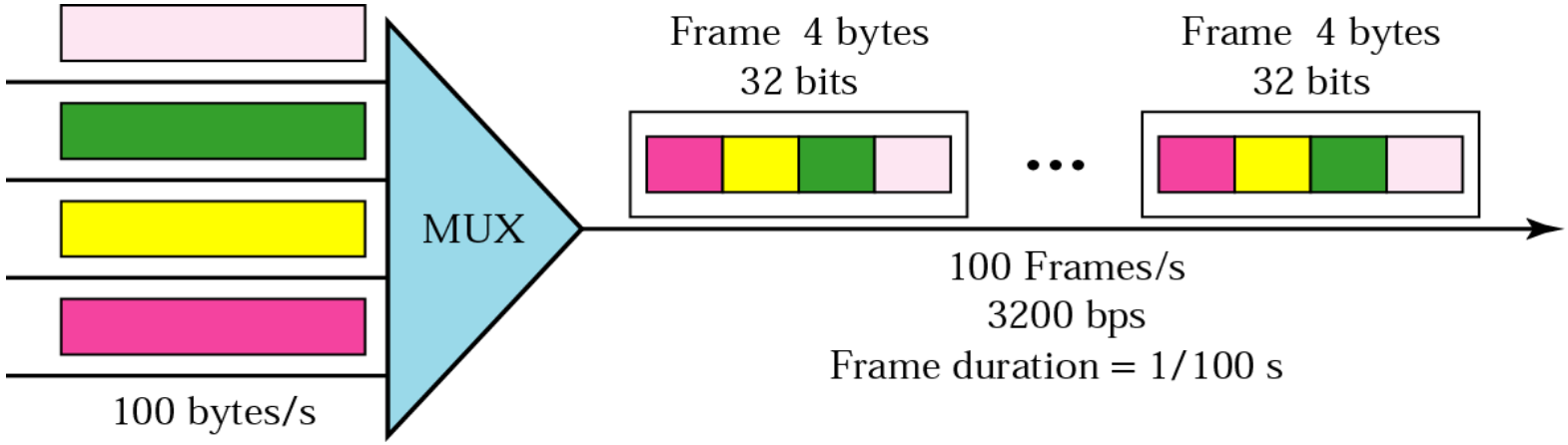


Figure ***Framing bits***

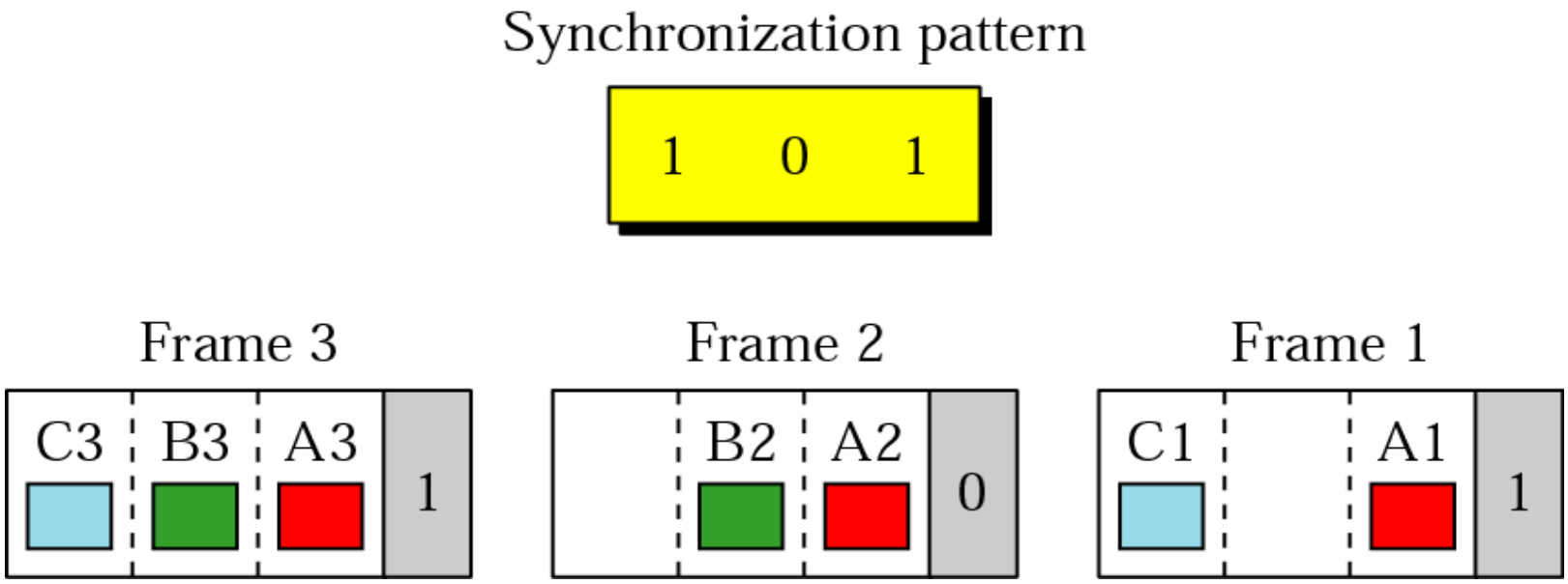


Figure *DS hierarchy*

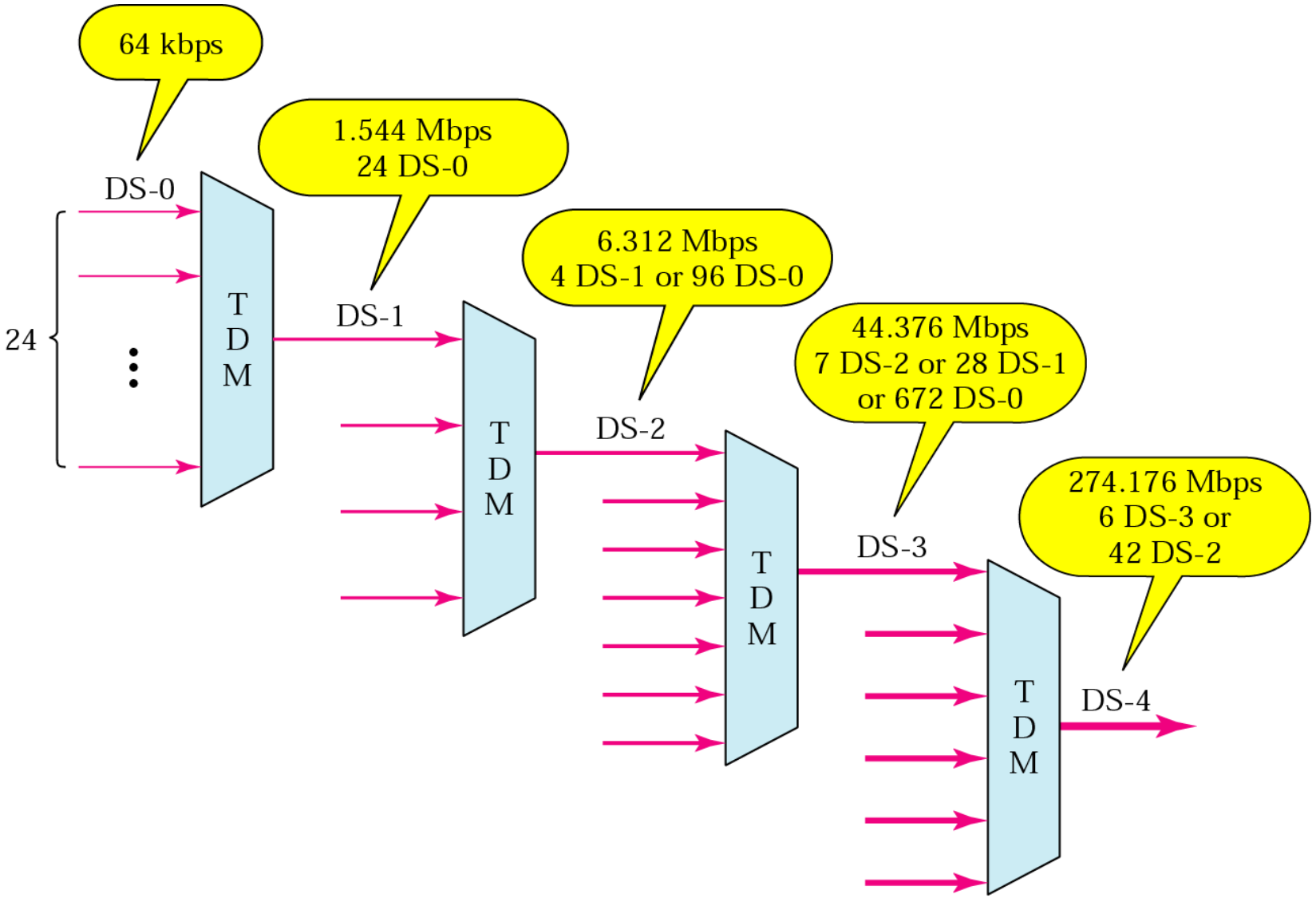


Table 6.1 DS and T lines rates

Service	Line	Rate (Mbps)	Voice Channels
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

Figure *T-1 line for multiplexing telephone lines*

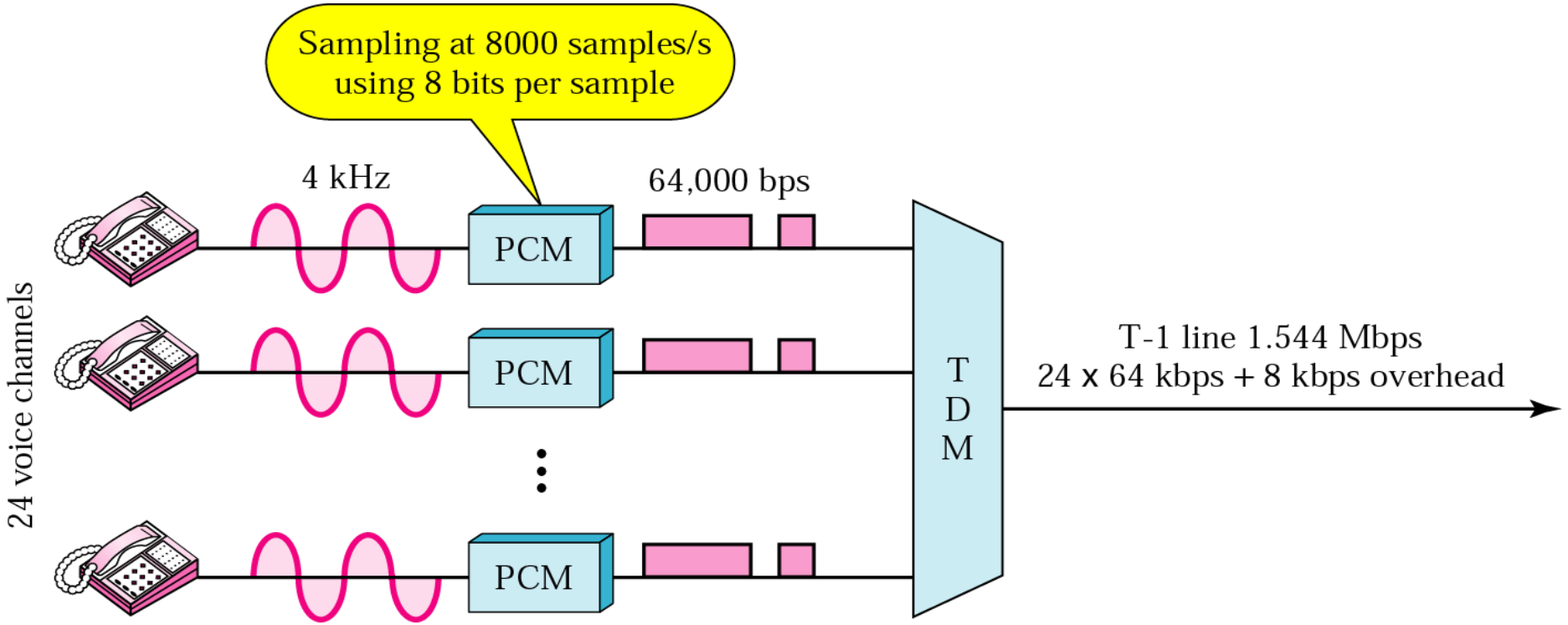


Figure *T-1 frame structure*

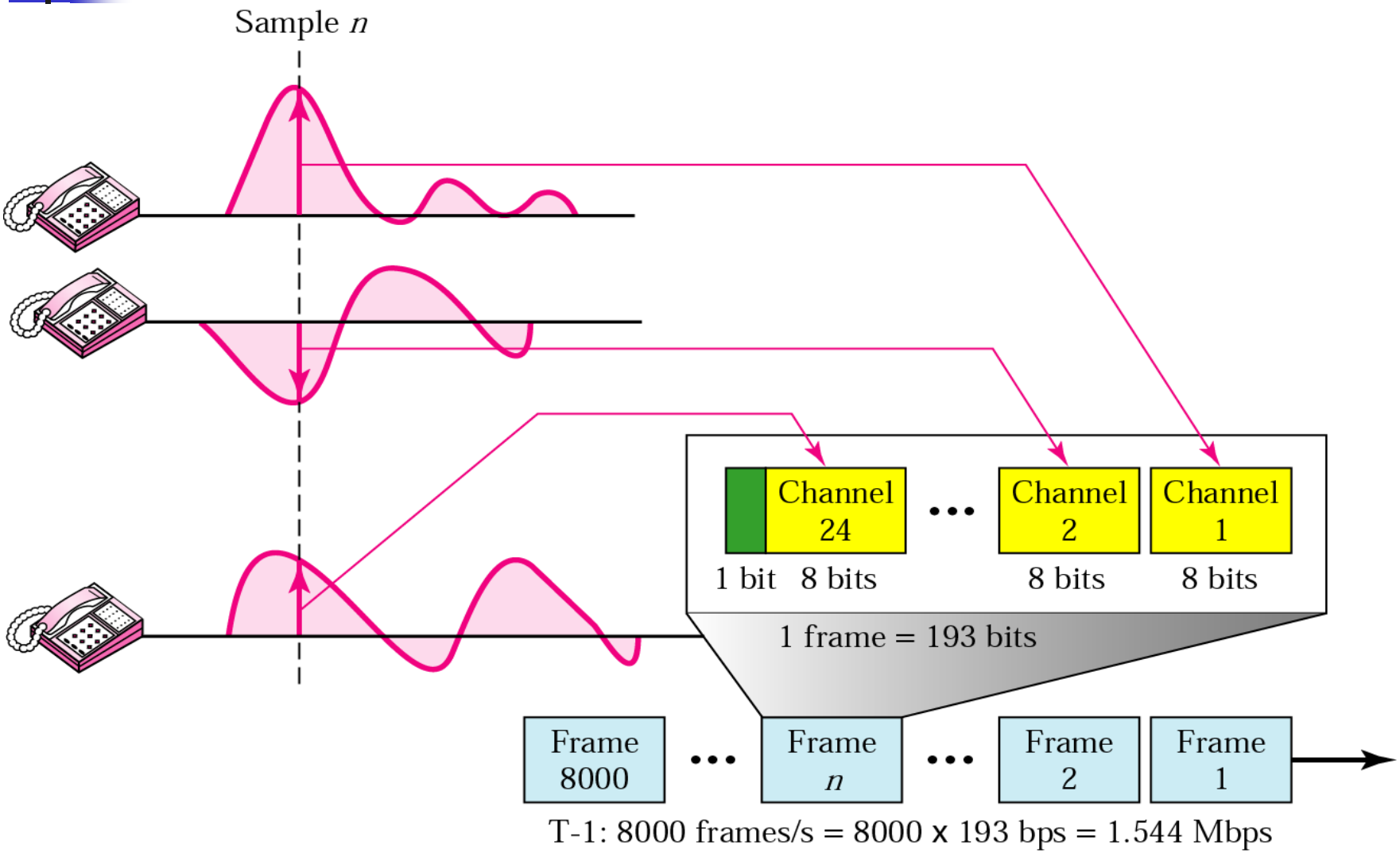
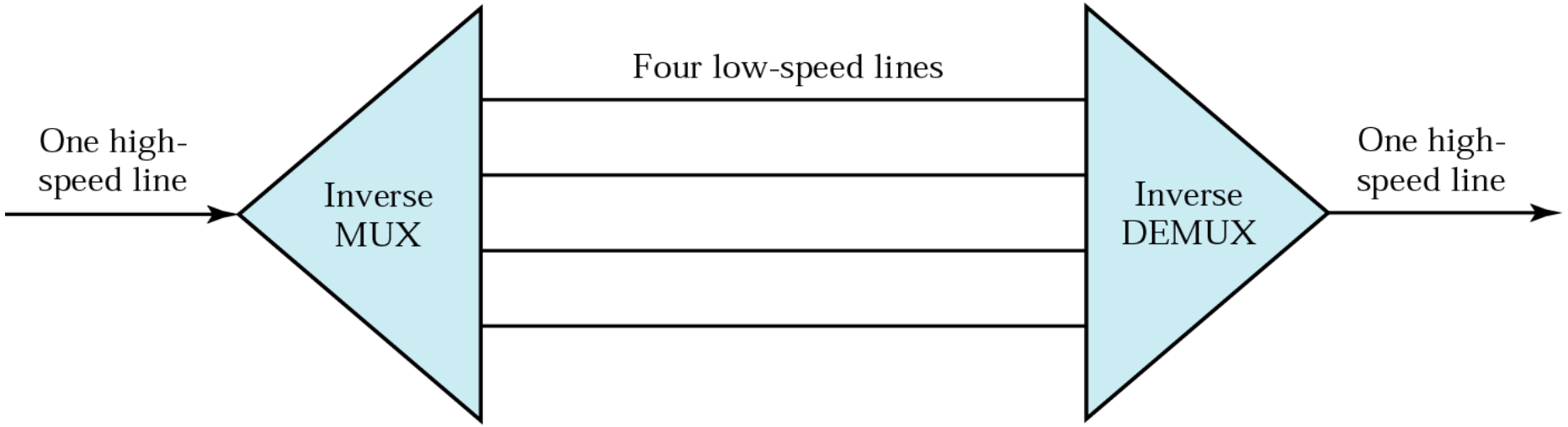


Table 6.2 E line rates

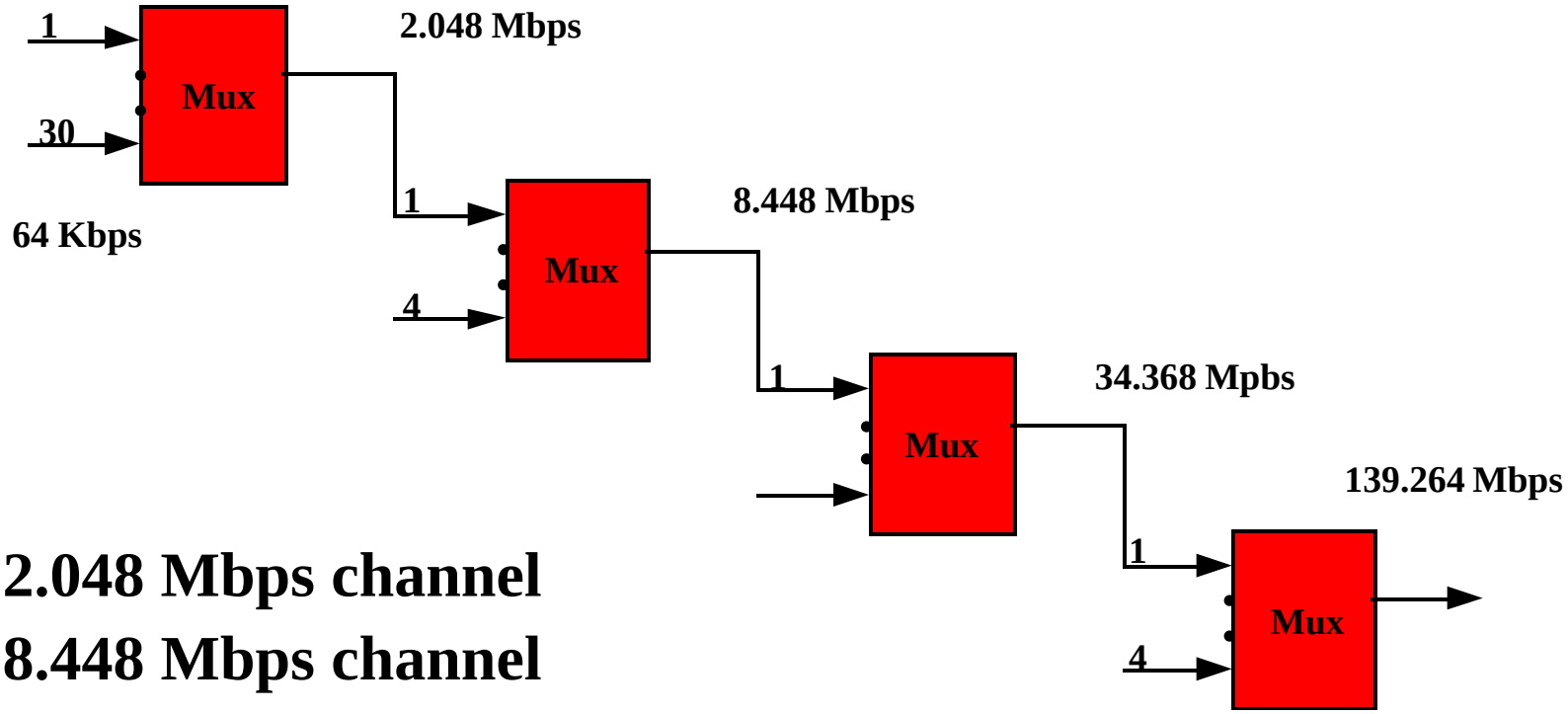
E Line	Rate (Mbps)	Voice Channels
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

Figure *Multiplexing and inverse multiplexing*



CCITT Digital Hierarchy

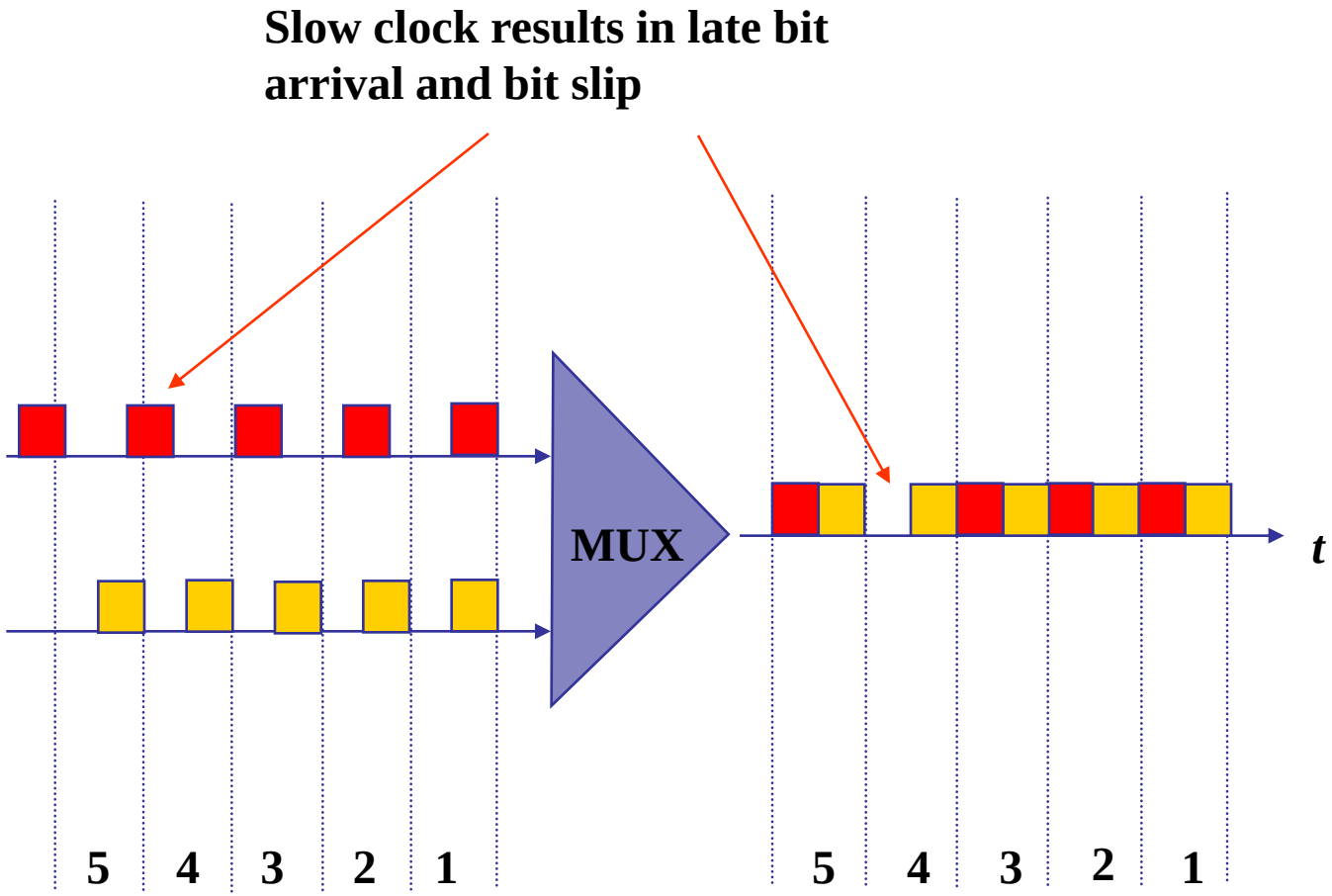
- CCITT digital hierarchy based on 30 PCM channels



- **E1, 2.048 Mbps channel**
- **E2, 8.448 Mbps channel**
- **E3, 34.368 Mbps channel**
- **E4, 139.264 Mbps channel**

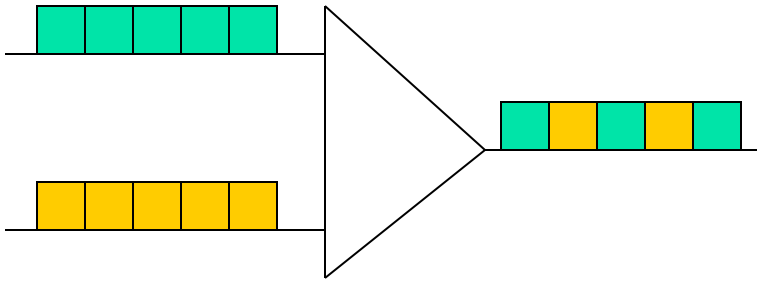
Clock Synch & Bit Slips

- Digital streams cannot be kept perfectly synchronized
- Bit slips can occur in multiplexers



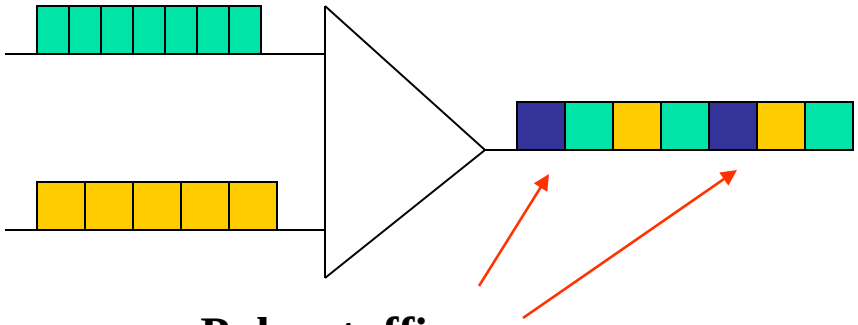
Pulse Stuffing

- Pulse Stuffing: synchronization to avoid data loss due to bit slips
- Output rate > R1+R2
  - i.e. DS2, 6.312Mbps=4x1.544Mbps + 136 Kbps
- Pulse stuffing format
  - Fixed-length master frames with each channel allowed to stuff or not to stuff a single bit in the master frame.
  - Redundant stuffing specifications
  - signaling or specification bits (other than data bits) are distributed across a master frame.



Muxing of equal-rate signals

requires perfect synch



Pulse stuffing