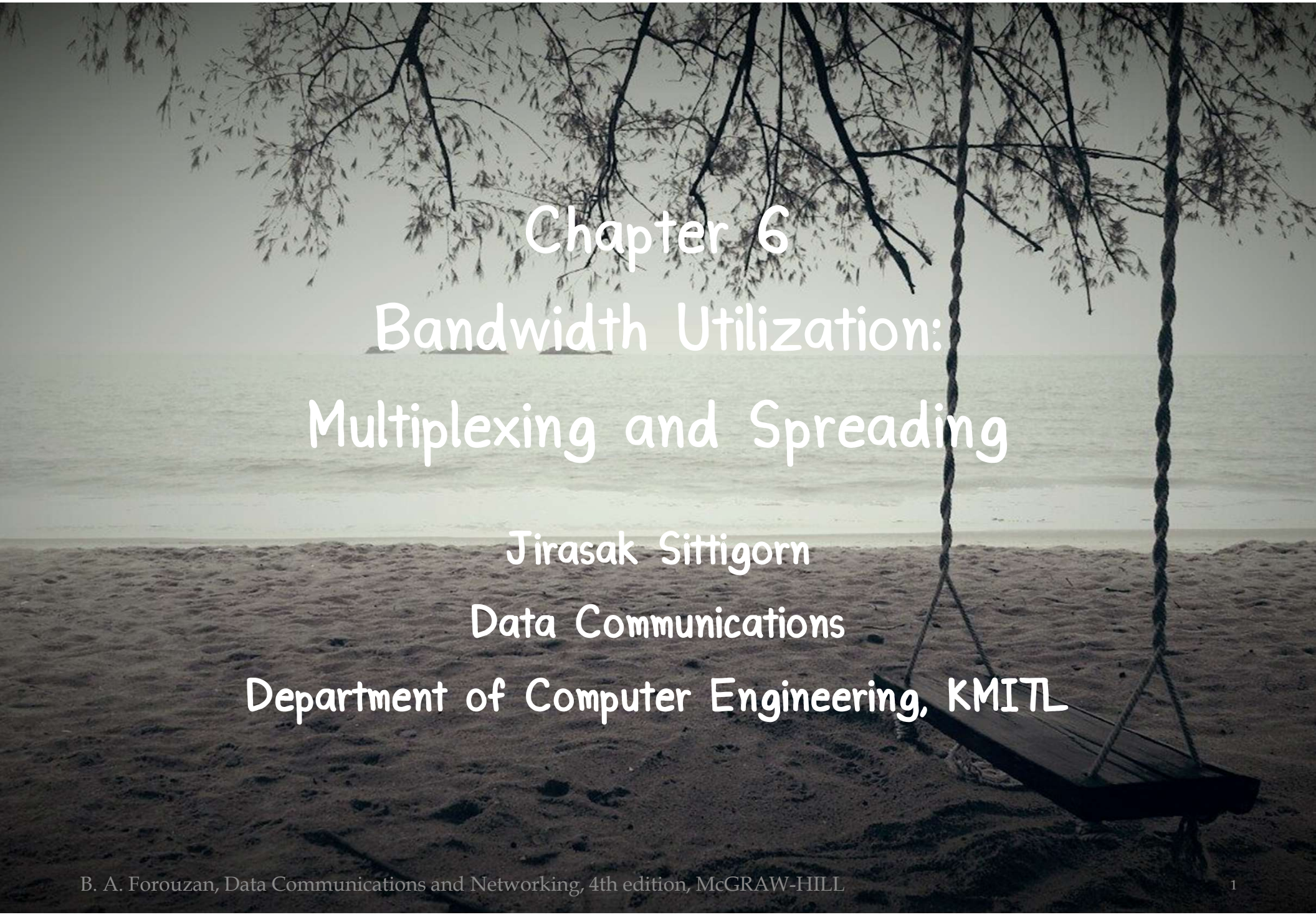

Chapter 6
Bandwidth Utilization: Multiplexing and Spreading

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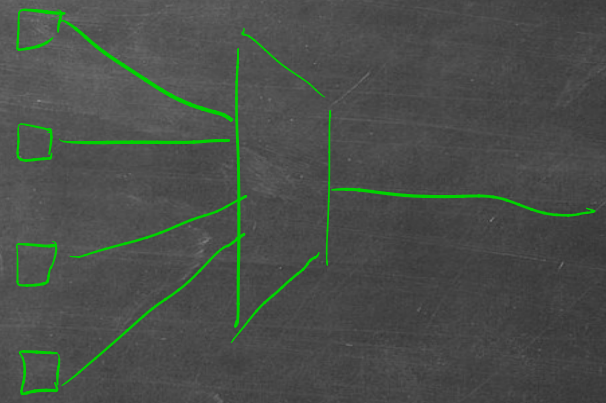
Bandwidth Utilization

- MULTIPLEXING
  - Frequency-Division Multiplexing
  - Wavelength-Division Multiplexing
  - Synchronous Time-Division Multiplexing
  - Statistical Time-Division Multiplexing



- SPREAD SPECTRUM
  - Frequency Hopping Spread Spectrum (FHSS)
  - Direct Sequence Spread Spectrum Synchronous (DSSS)

MULTIPLEXING

- FREQUENCY-DIVISION MULTIPLEXING FDM
- WAVELENGTH-DIVISION MULTIPLEXING
- SYNCHRONOUS TIME-DIVISION MULTIPLEXING
- STATISTICAL TIME-DIVISION MULTIPLEXING

MULTIPLEXING

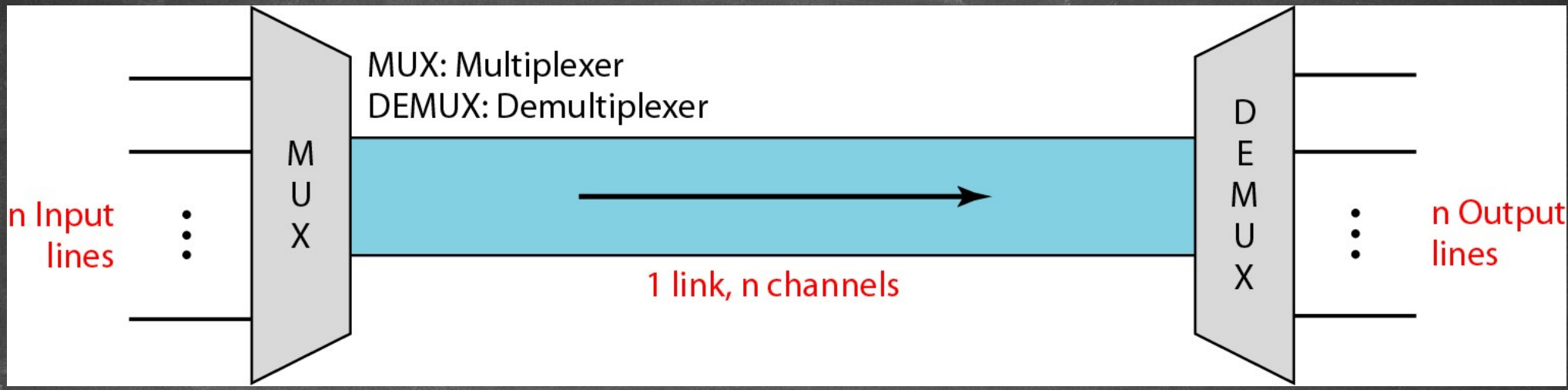


Figure 6.1 Dividing a link into channels

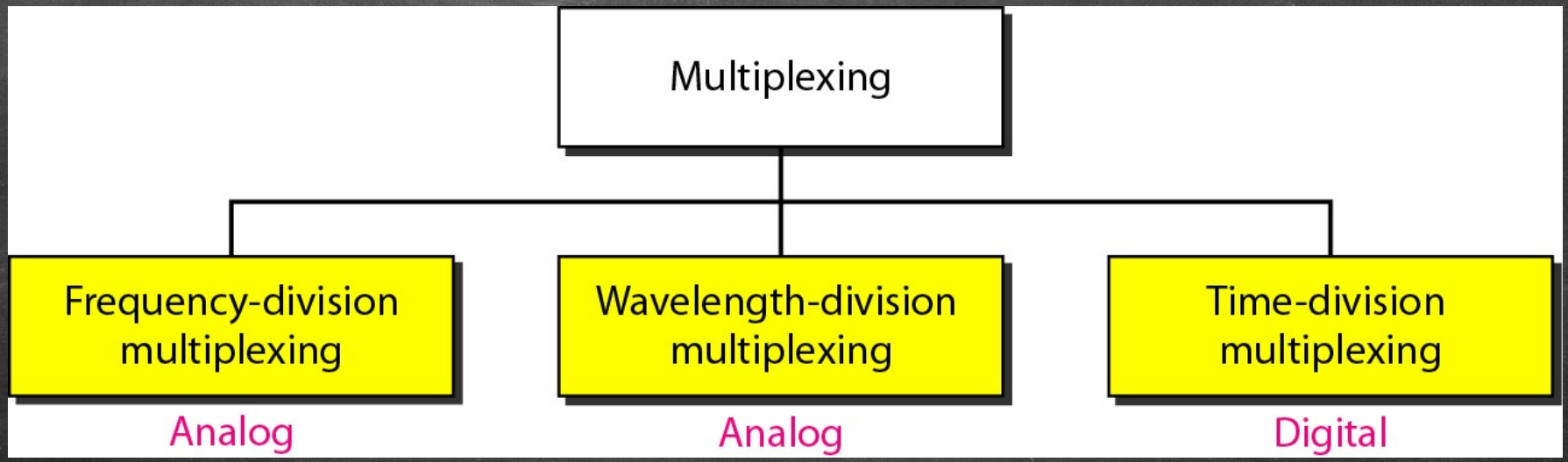


Figure 6.2 Categories of multiplexing

Frequency-Division Multiplexing

Figure 6.3 Frequency-division multiplexing

- FDM is an analog multiplexing technique that combines analog signals.

Multiplexing Process

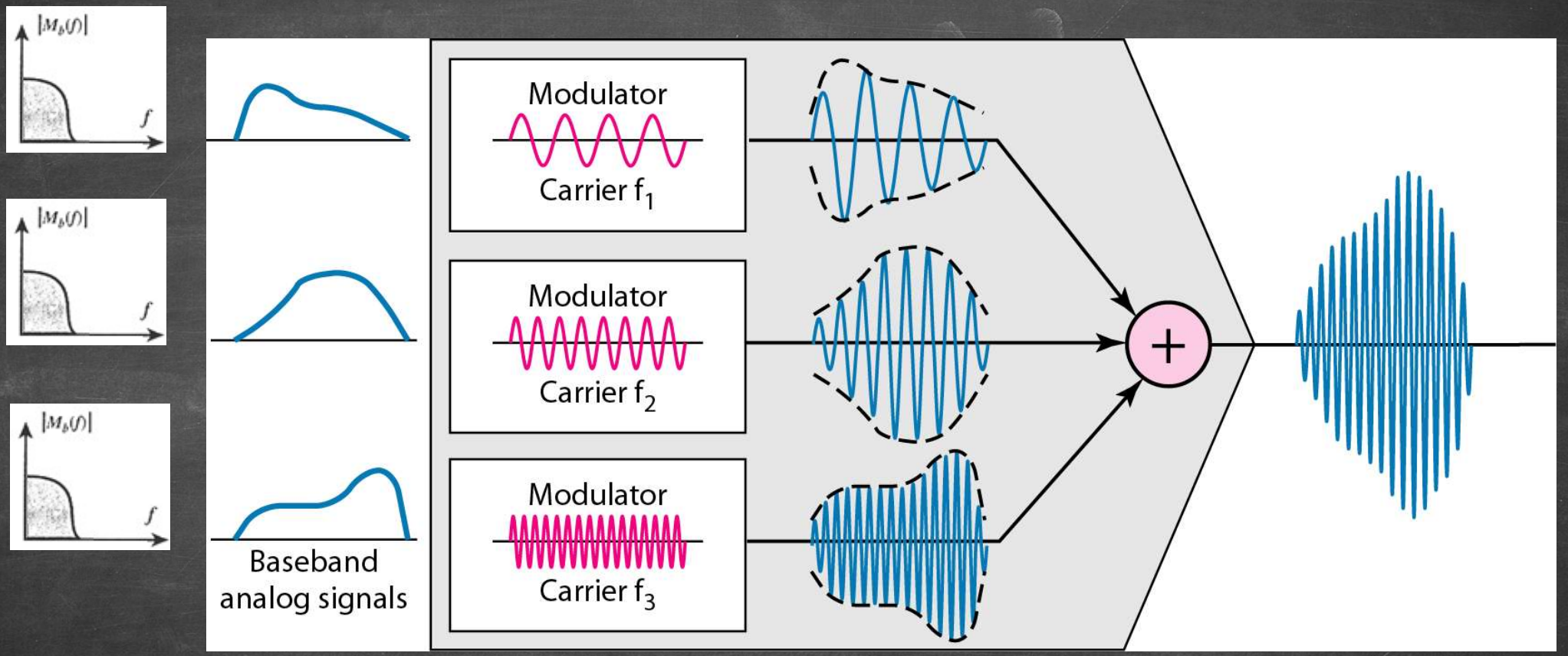
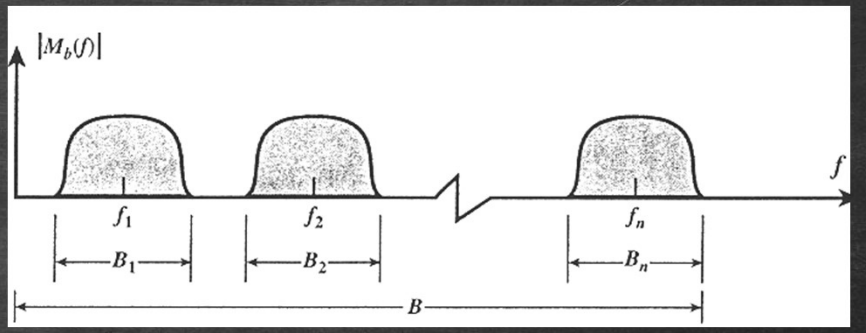


Figure 6.4 FDM process



Demultiplexing Process

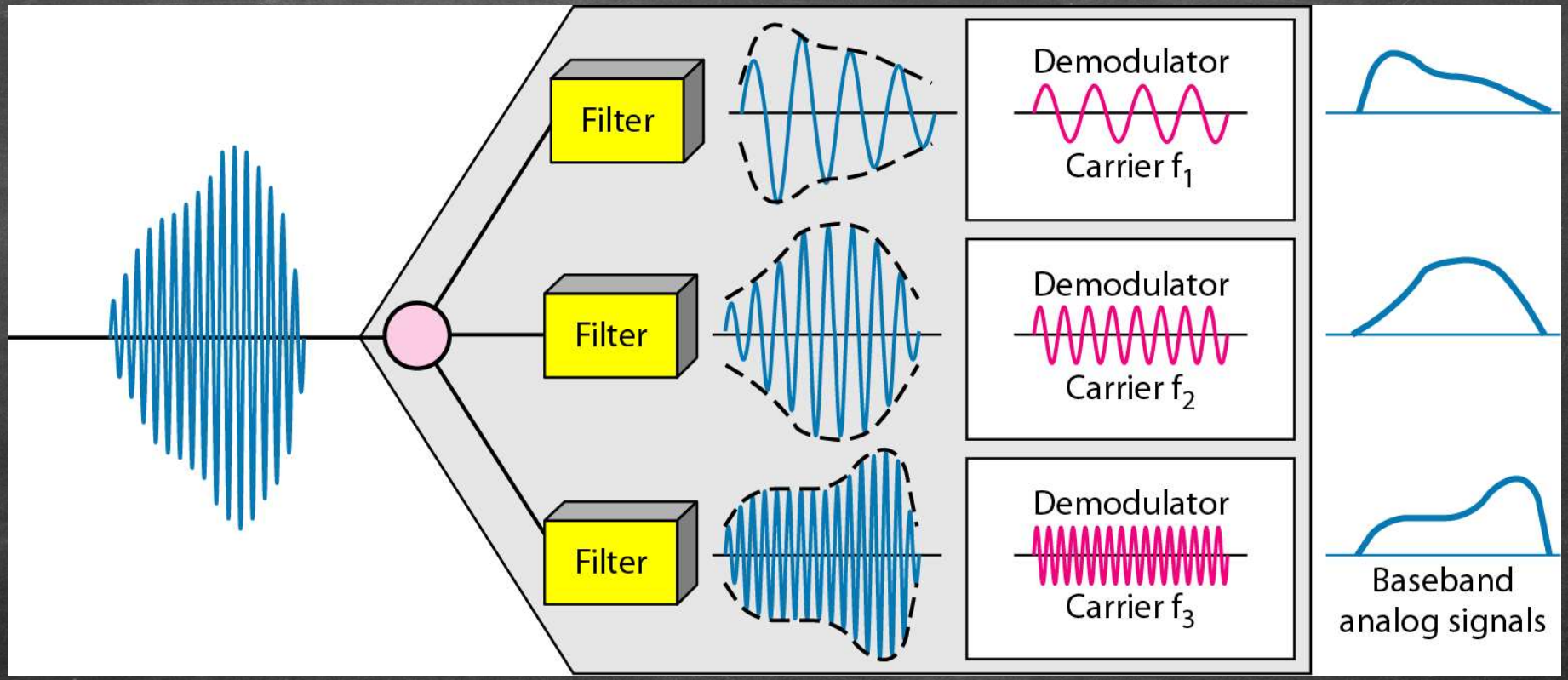
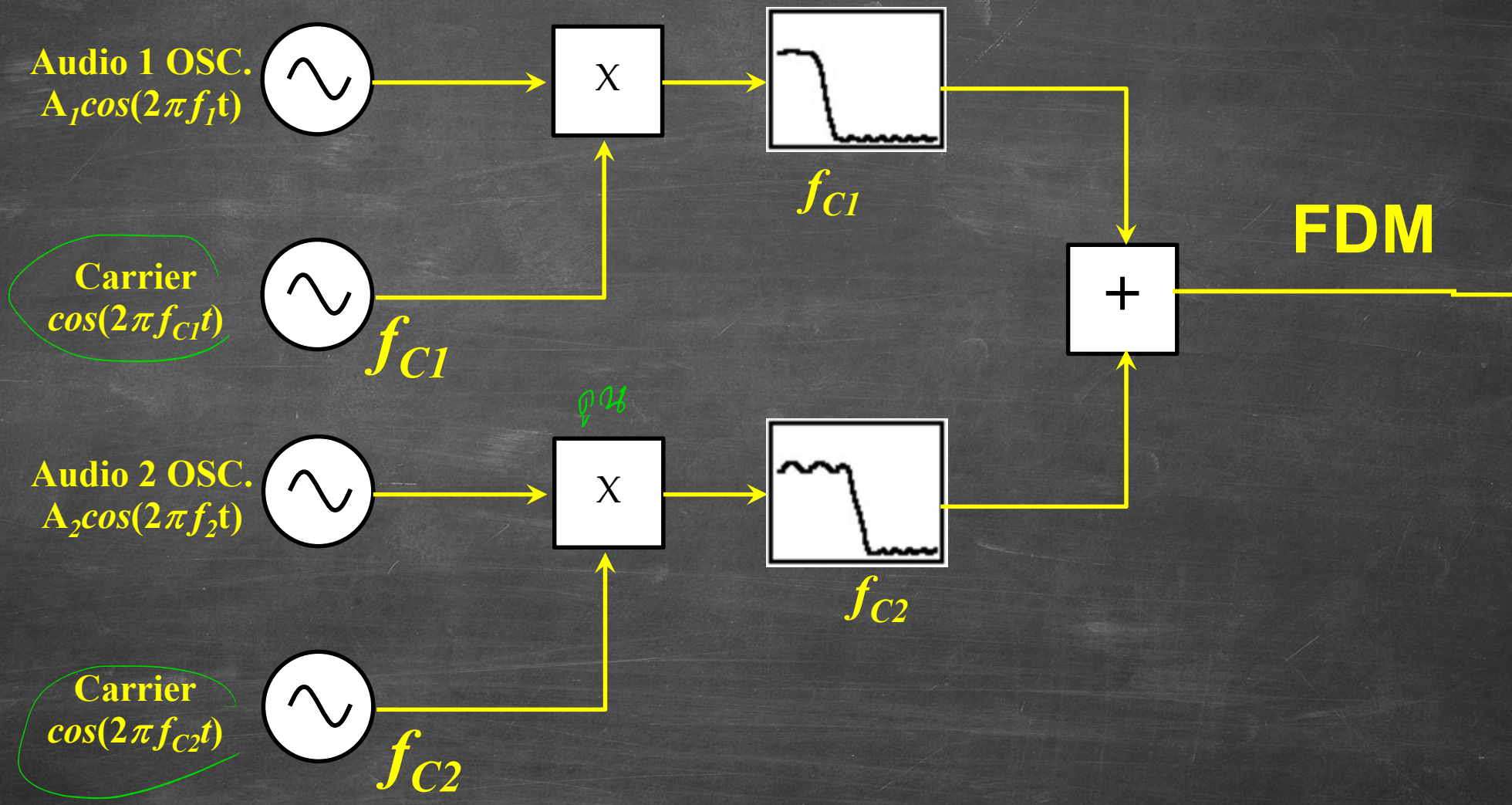
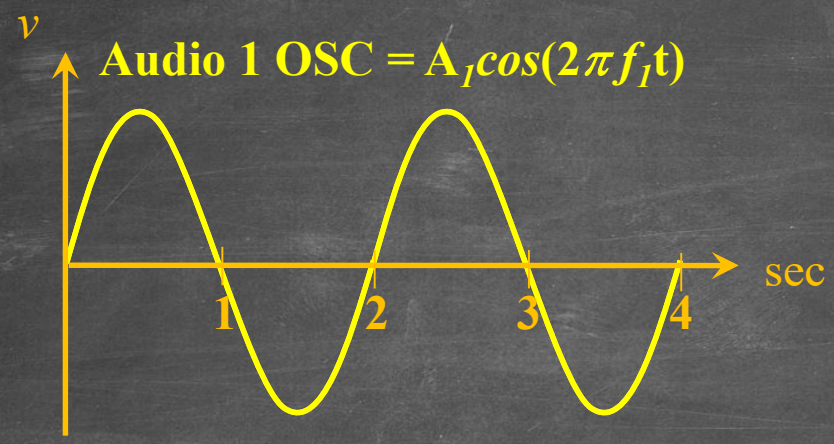


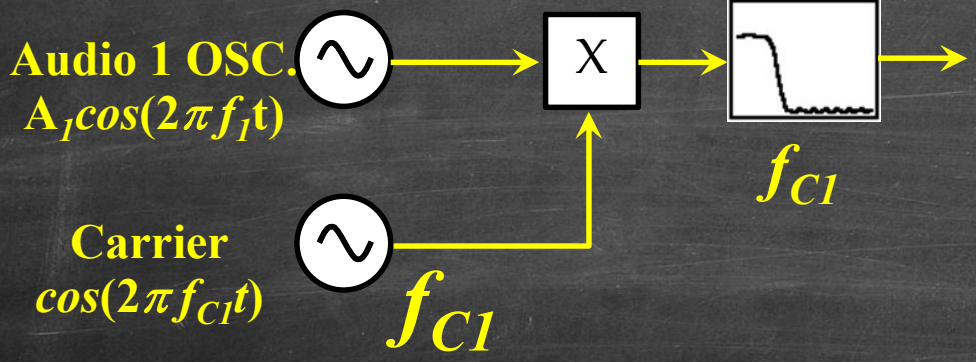
Figure 6.4 FDM process

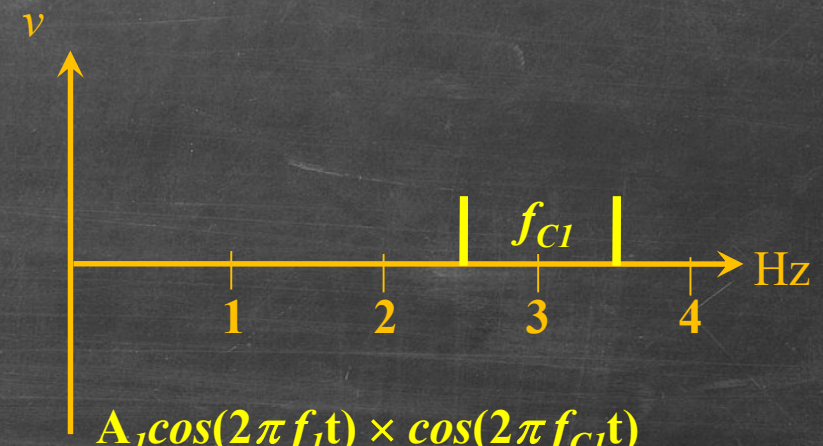
Multiplexing Process



Multiplexing Process



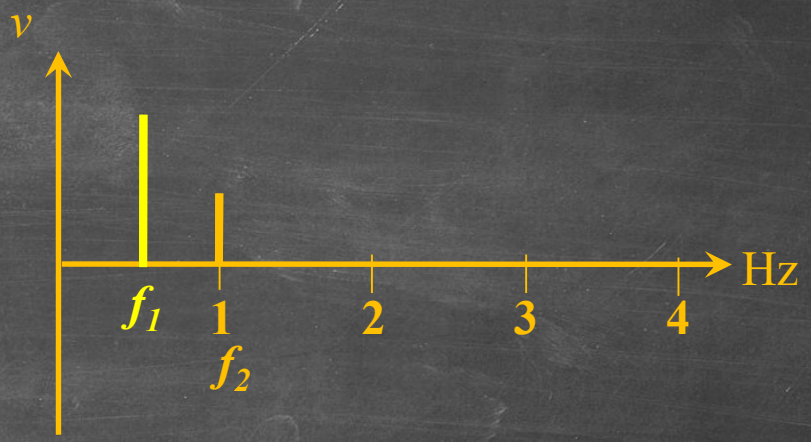


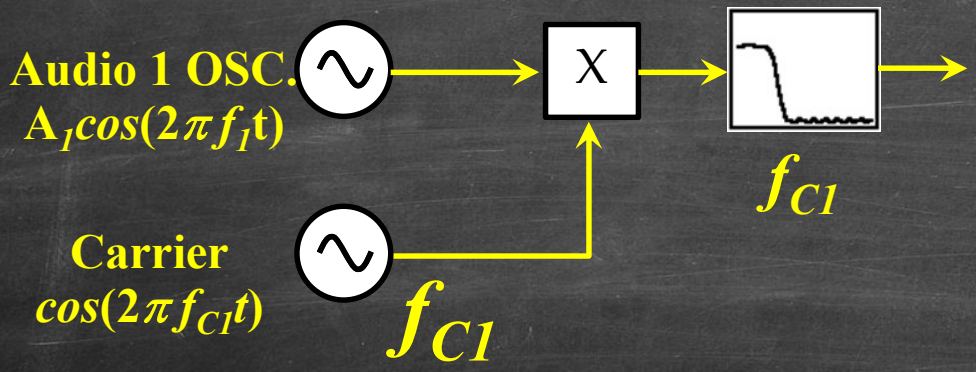


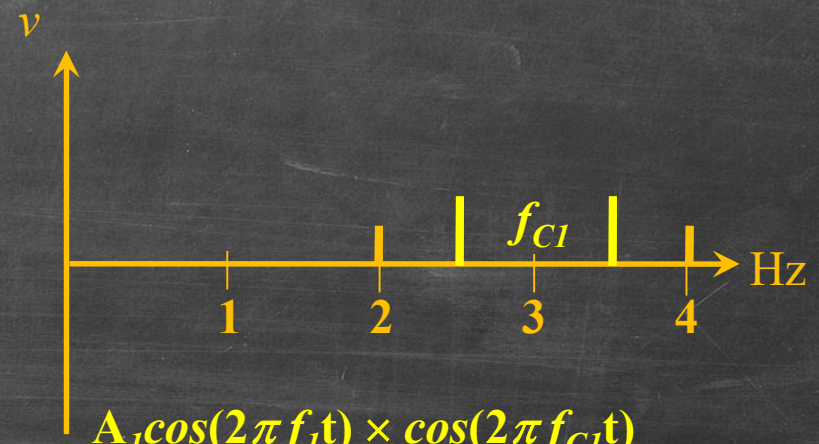
Multiplexing Process

ถ้า Audio 1 OSC

$= A_1 cos(2\pi f_1 t) + A_2 cos(2\pi f_2 t)$



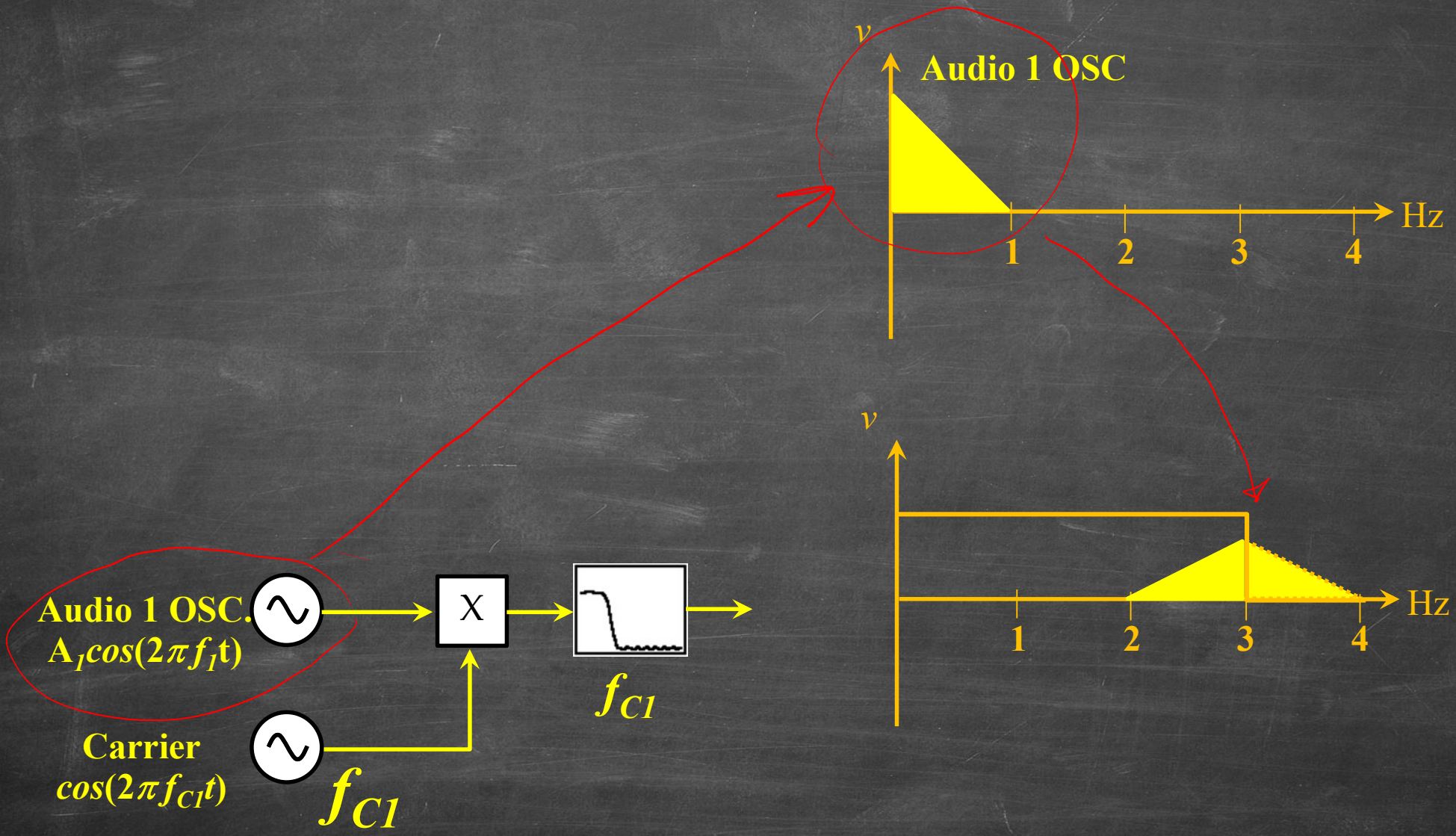




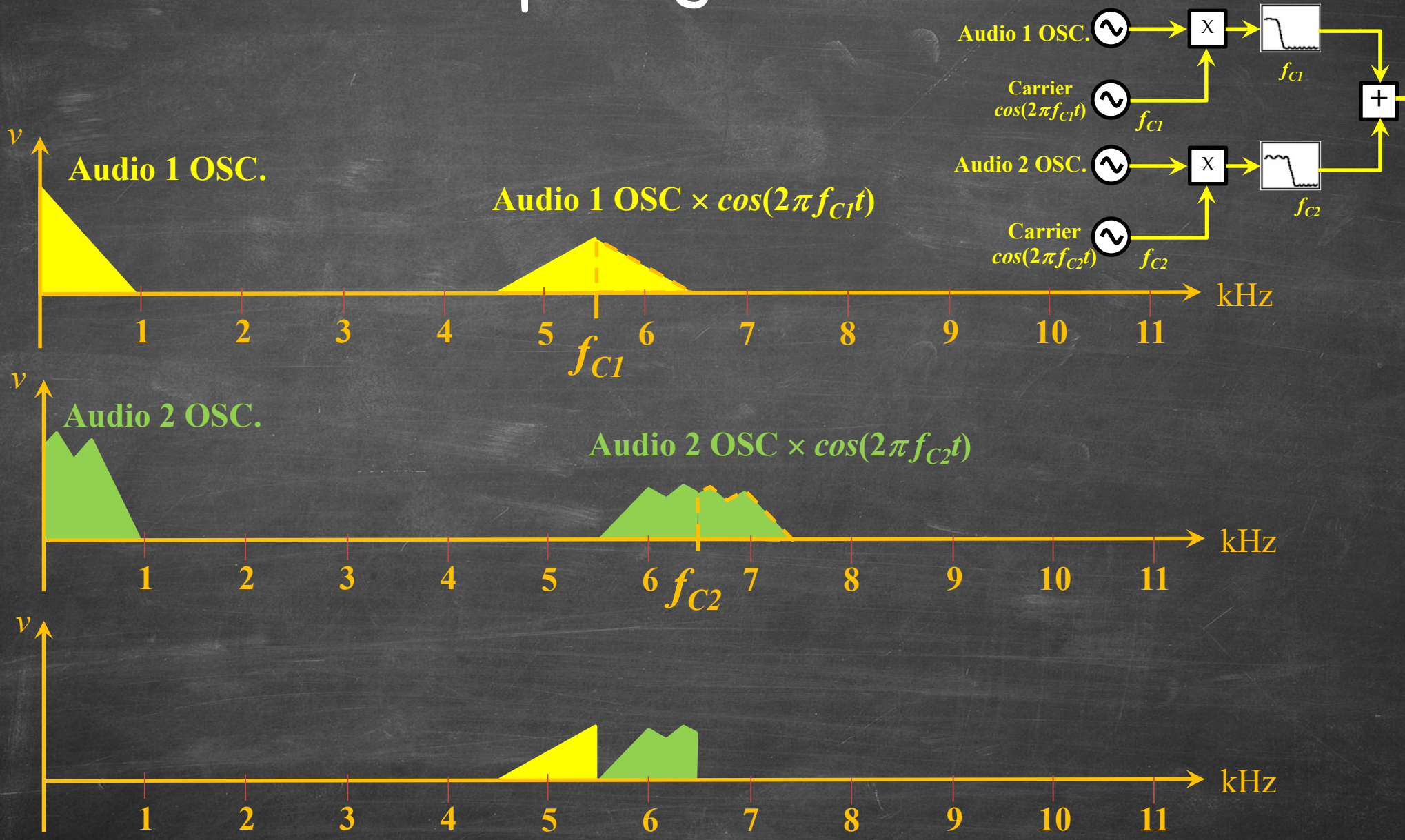
$A_1 cos(2\pi f_1 t) \times cos(2\pi f_{C1} t)$

$+A_2 cos(2\pi f_2 t) \times cos(2\pi f_{C1} t)$

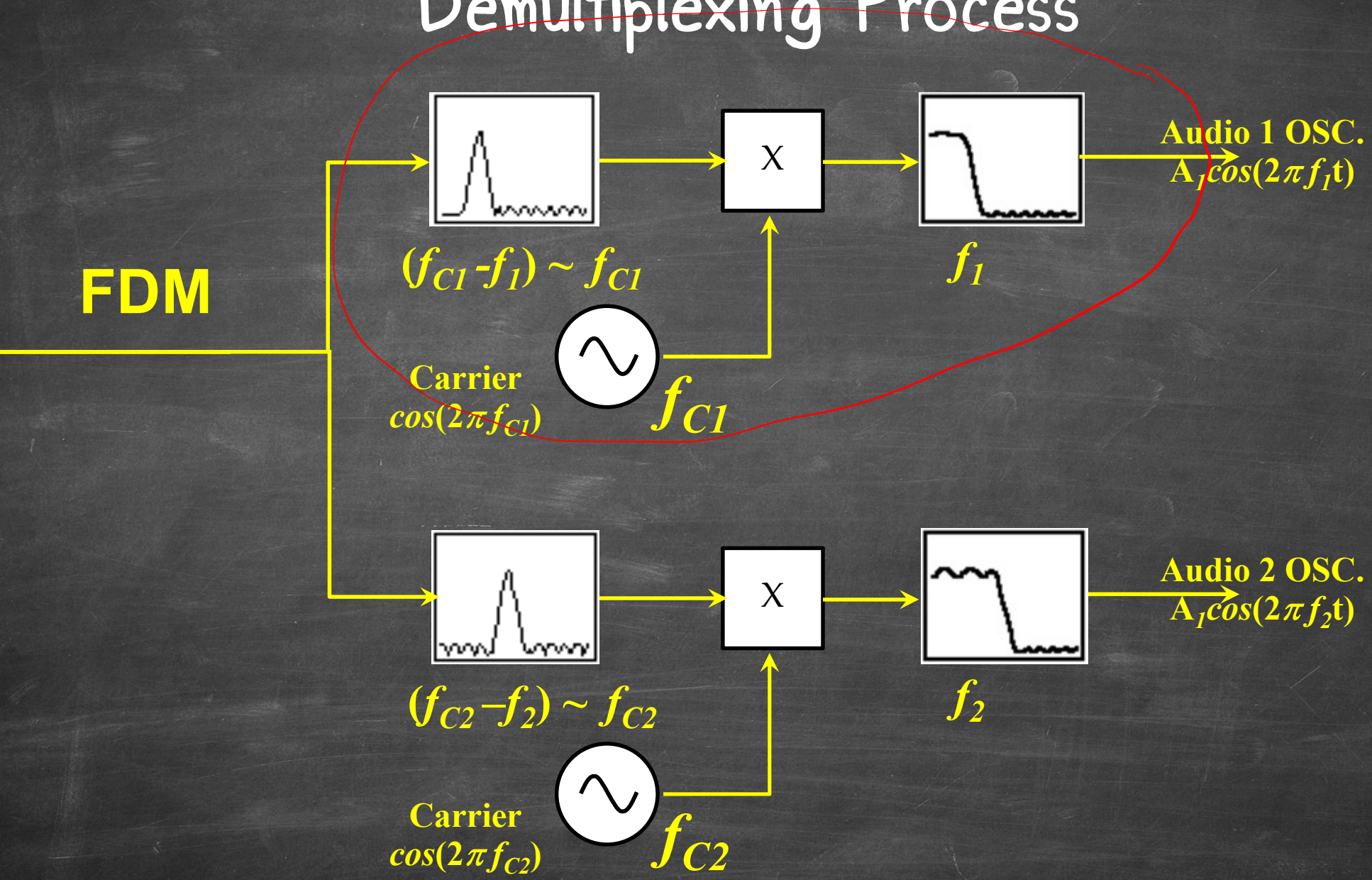
Multiplexing Process



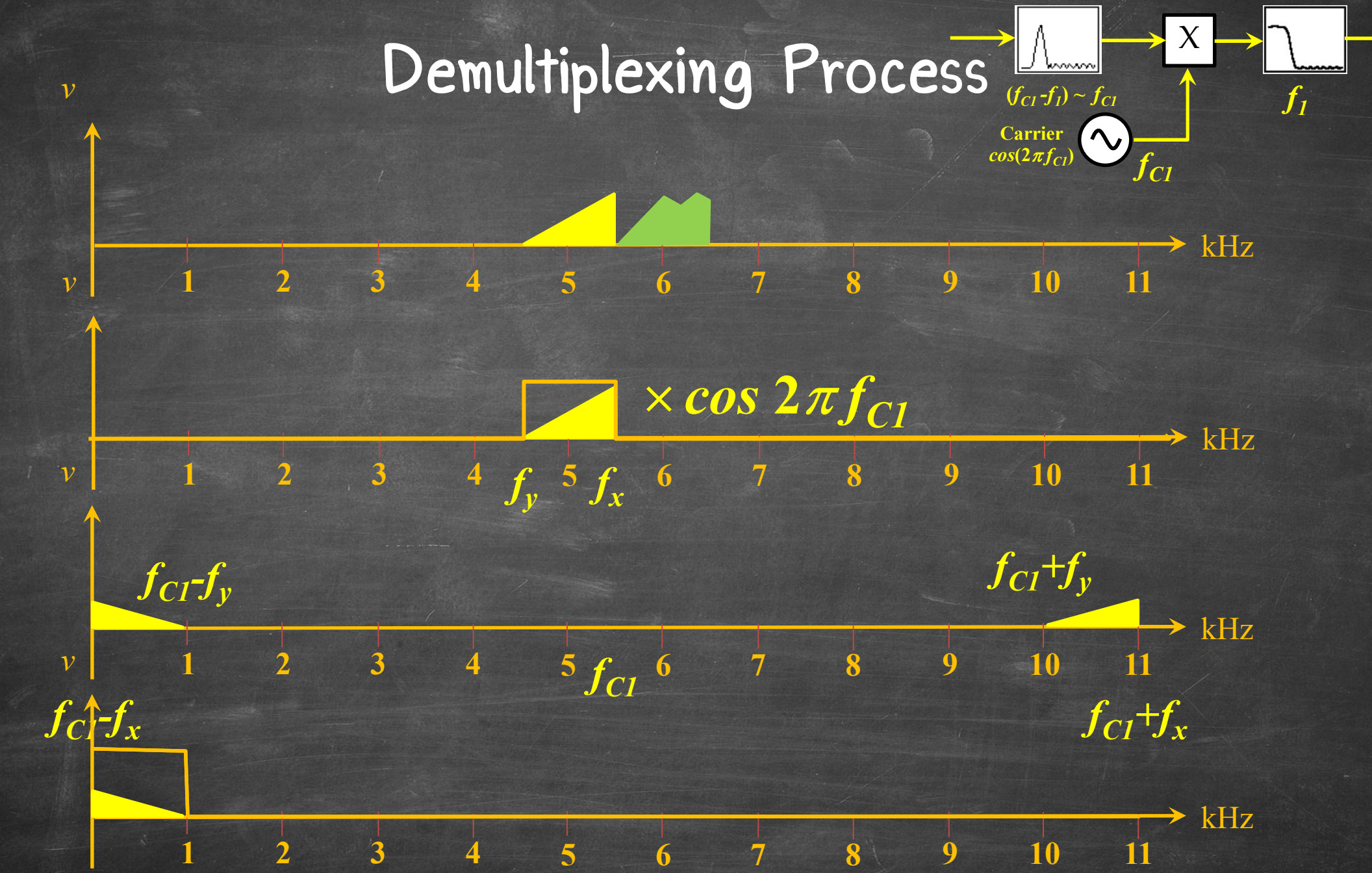
Multiplexing Process



Demultiplexing Process



Demultiplexing Process



Example 6.1

- 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

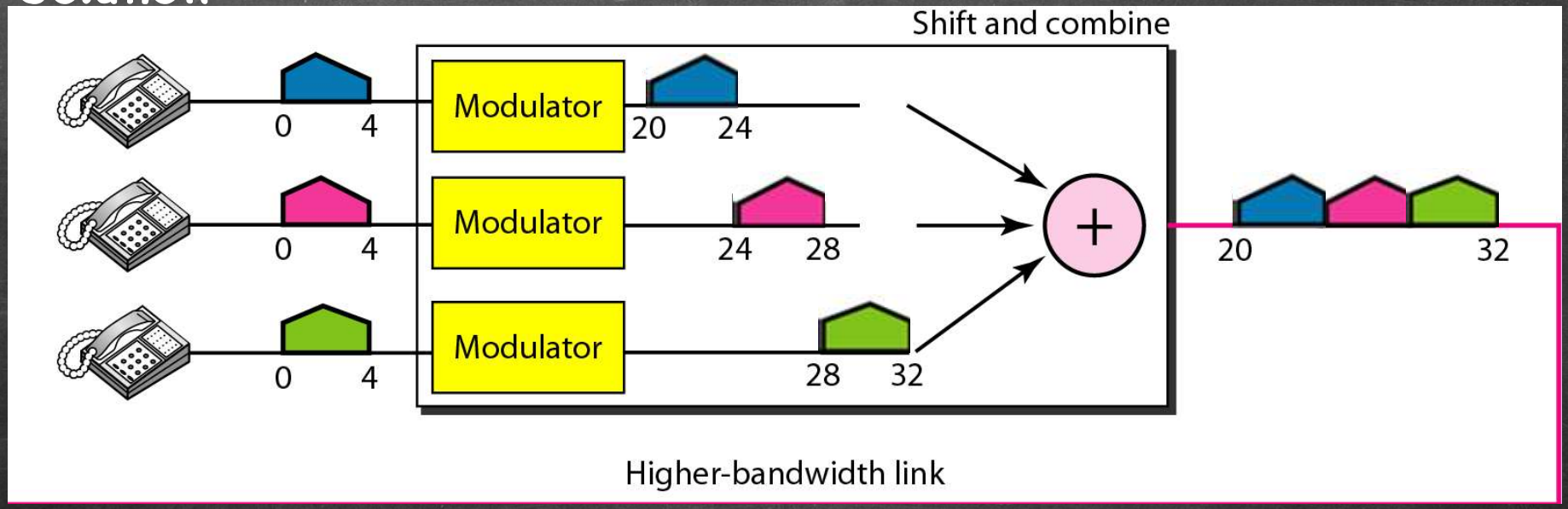


Figure 6.6 Example 6.1

Example 6.1

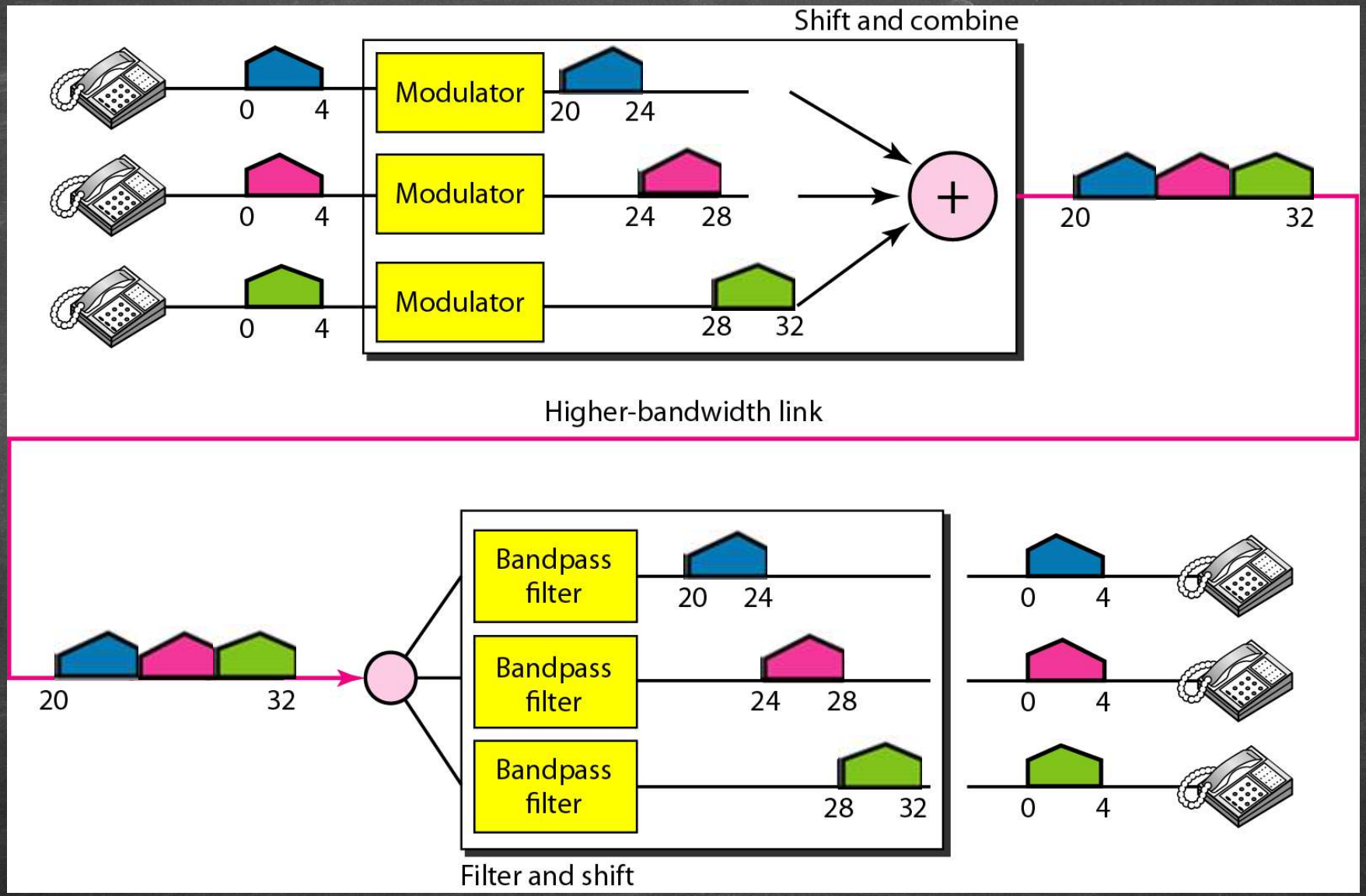


Figure 6.6 Example 6.1

Example 6.2

- 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

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

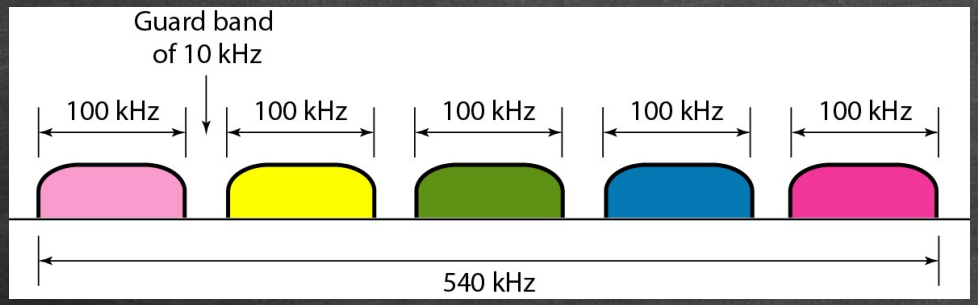


Figure 6.7 Example 6.2

Example 6.3

- Four data channels (digital), each transmitting at 1 Mbps, use a satellite channel of 1 MHz. Design an appropriate configuration, using FDM.
- Solution

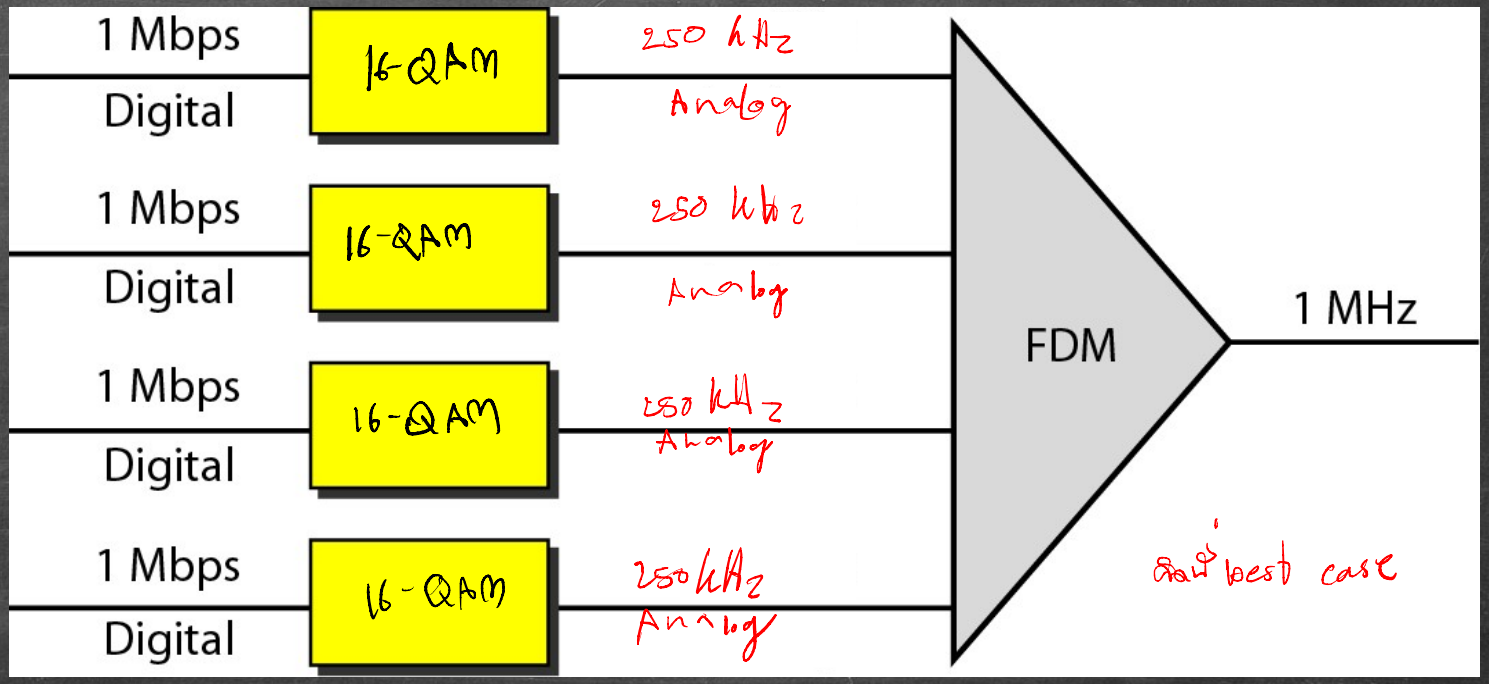


Figure 6.8 Example 6.3

Analog hierarchy

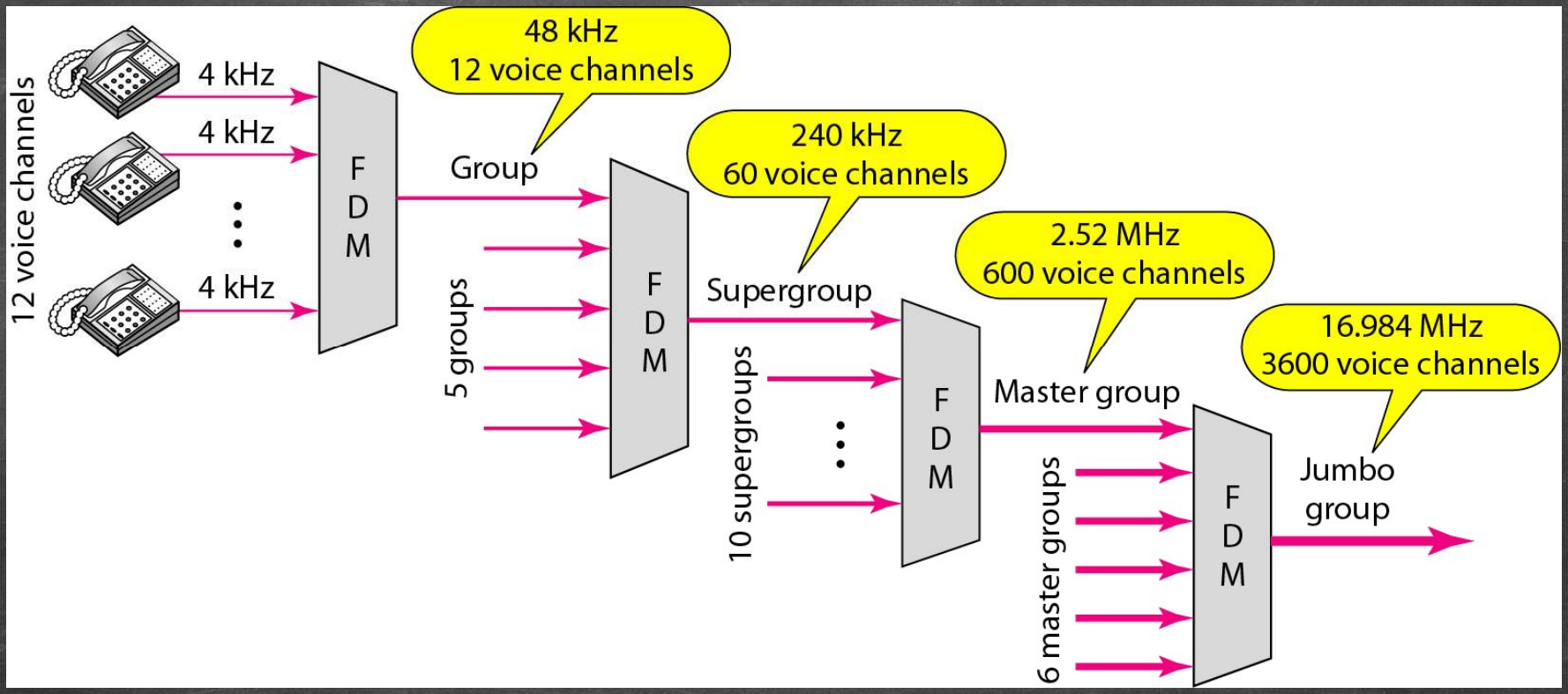
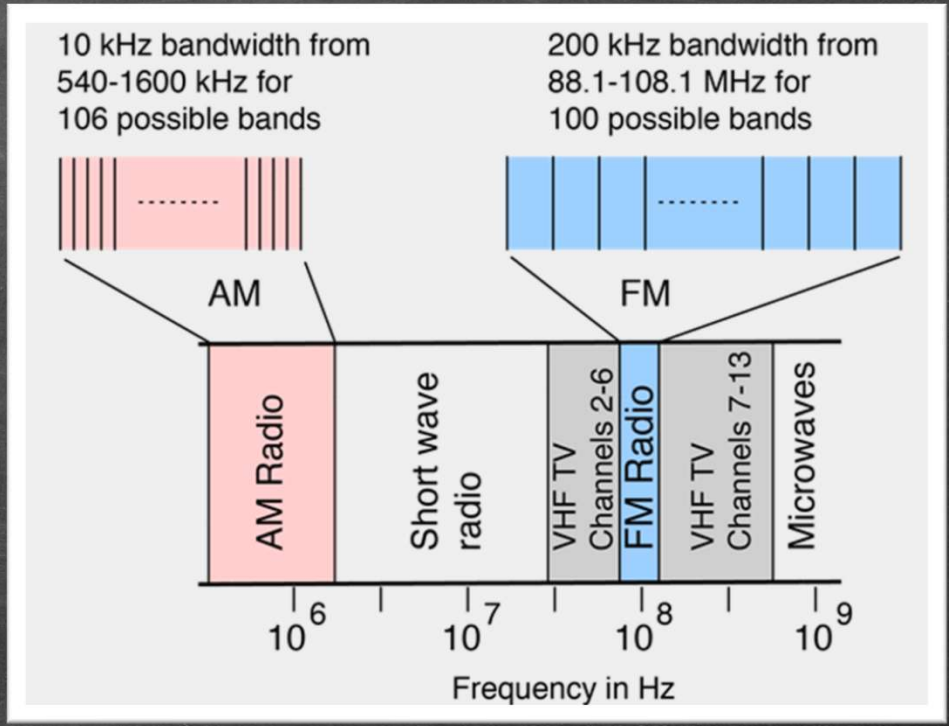


Figure 6.9 Analog hierarchy

Other Applications of FDM

- AM : Bw 10kHz special band from 530 to 1700 kHz
- FM : Bw 200kHz wider band of 88 to 108 MHz
- TV broadcasting : 6 MHz
- The first generation of cellular telephones : Each user is assigned two 30-kHz channels from 300 to 3300 Hz



http://hyperphysics.phy-astr.gsu.edu/hbase/Audio/radio.html

Example 6.4

- The Advanced Mobile Phone System (AMPS) uses two bands. The first band of 824 to 849 MHz is used for sending, and 869 to 894 MHz is used for receiving. Each user has a bandwidth of 30 kHz in each direction. How many people can use their cellular phones simultaneously?
- Solution
  - Each band is 25 MHz. If we divide 25 MHz by 30 kHz, we get 833.33. In reality, the band is divided into 832 channels. *Of these, 42 channels are used for control, which means only 790 channels are available for cellular phone users.*

832 − 42 → 790

Wavelength-Division Multiplexing

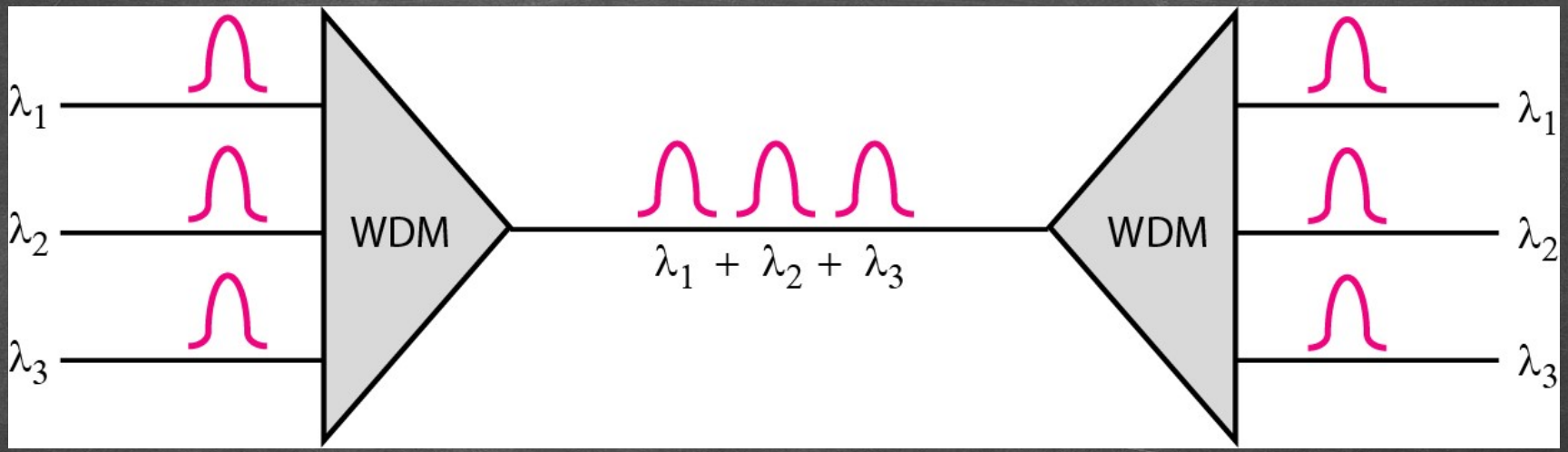


Figure 6.10 Wavelength-division multiplexing

- WDM is an analog multiplexing technique to combine optical signals.

Wavelength-Division Multiplexing

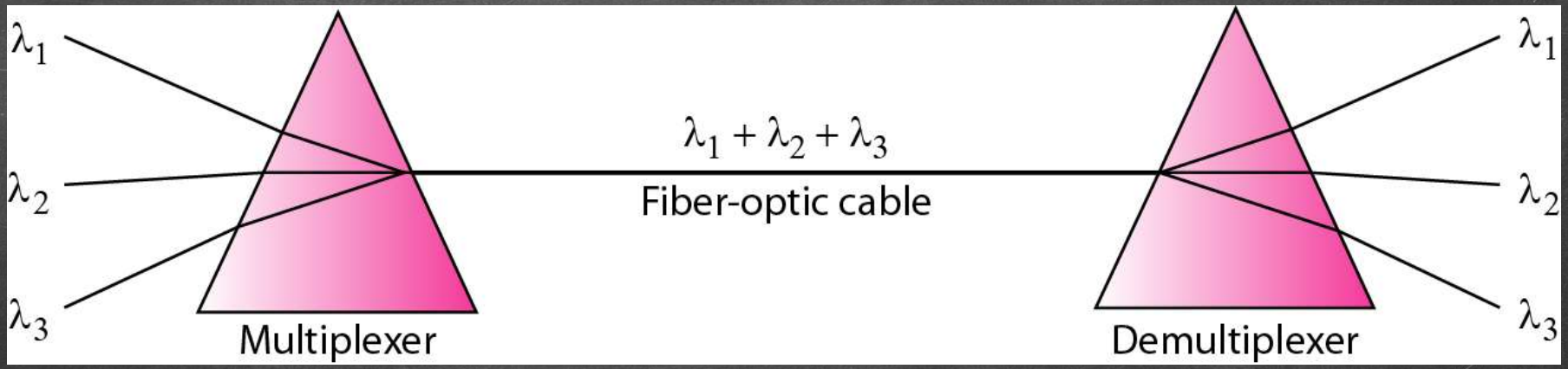


Figure 6.11 Prisms in wavelength-division multiplexing and demultiplexing

Time-division multiplexing

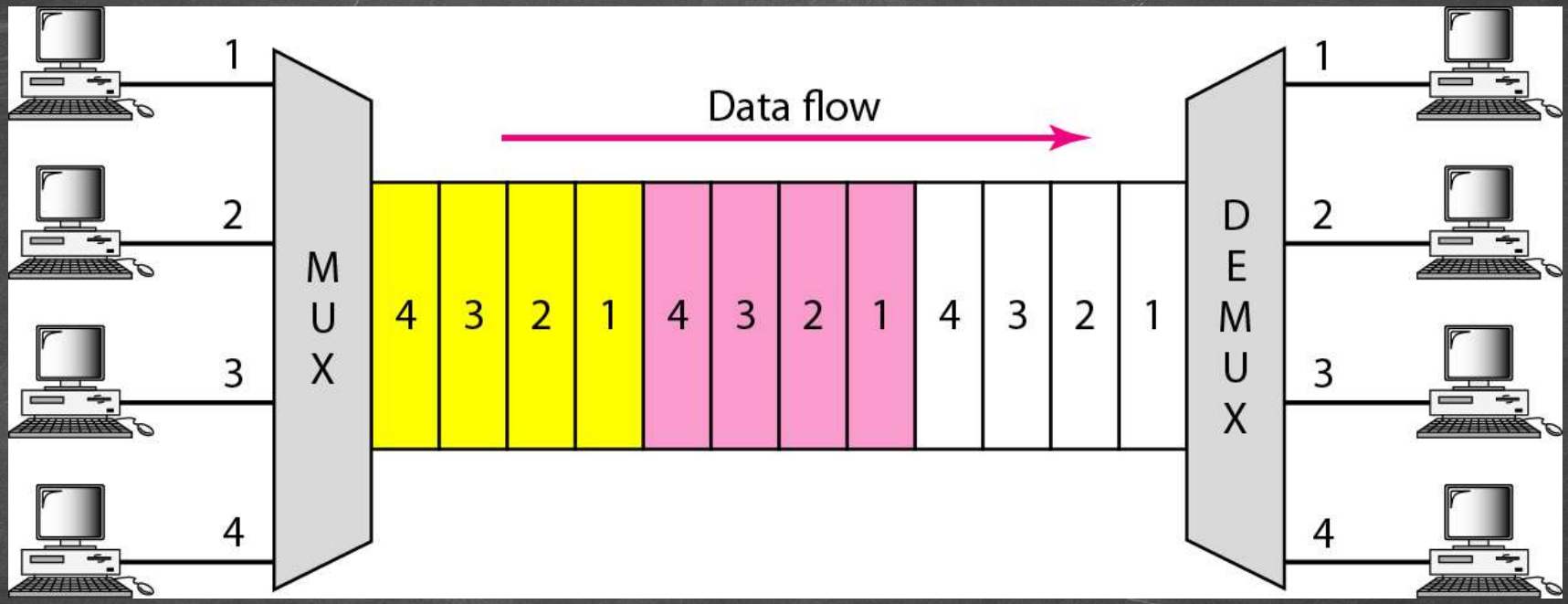


Figure 6.12 TDM

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

Time Slots and Frames

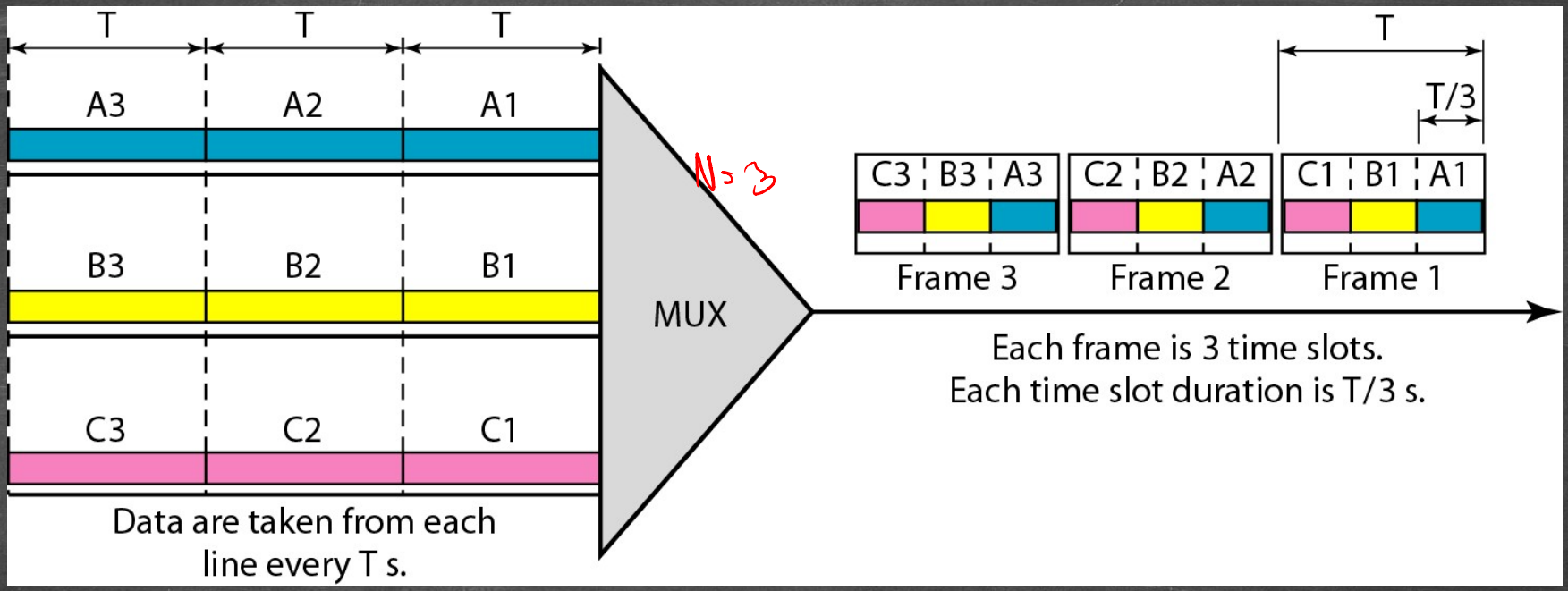


Figure 6.13 Synchronous time-division multiplexing

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

Example 6.5

- In Figure 6.13, the data rate for each input connection is 3 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of
  - (a) each input slot
  - (b) each output slot
  - (c) each frame?

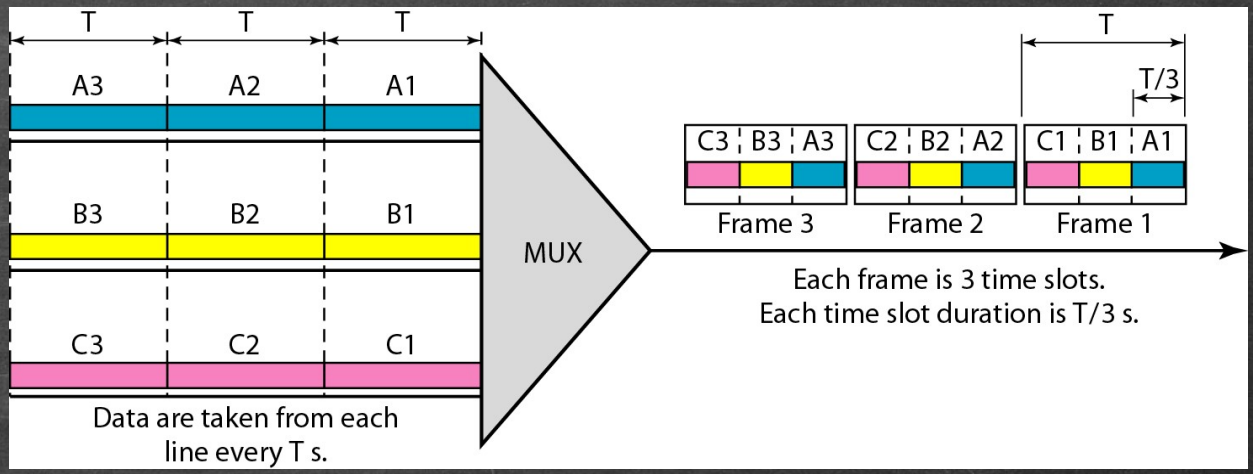


Figure 6.13 Synchronous time-division multiplexing

Example 6.6

- Figure 6.14 shows synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is 1 bit. Find
  - (a) the input bit duration
  - (b) the output bit duration
  - (c) the output bit rate
  - (d) the output frame rate.

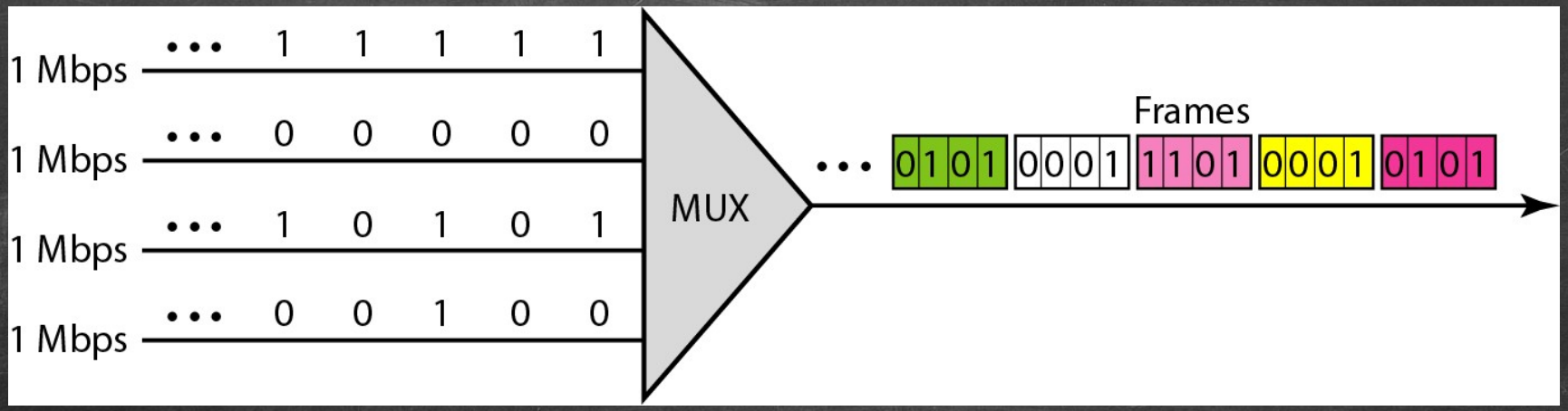


Figure 6.14 Example 6.6

Example 6.7

- Four 1-kbps connections are multiplexed together. A unit is 1 bit. Find
  - (a) the duration of 1 bit before multiplexing
  - (b) the transmission rate of the link
  - (c) the duration of a time slot
  - (d) the duration of a frame

Interleaving

- TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side. The switches are synchronized and rotate at the same speed, but in opposite directions.

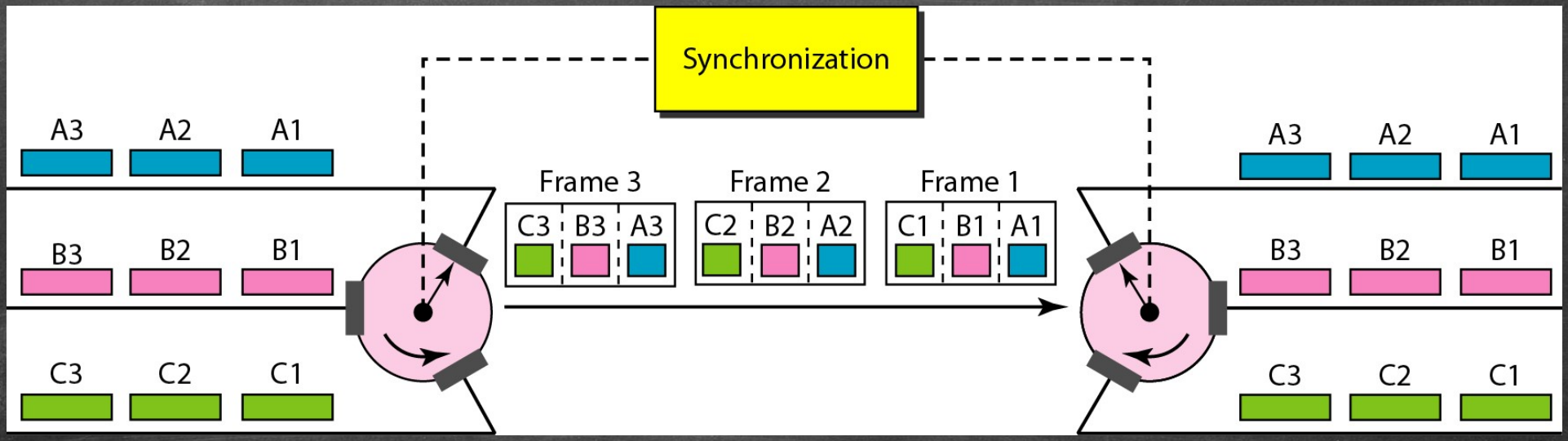


Figure 6.15 Interleaving

Example 6.8

- 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.

Figure 6.16 Example 6.8

Example 6.9

- A multiplexer combines four 100-kbps channels using a time slot of 2 bits. Show the output with four arbitrary inputs. What is the frame rate? What is the frame duration? What is the bit rate? What is the bit duration?

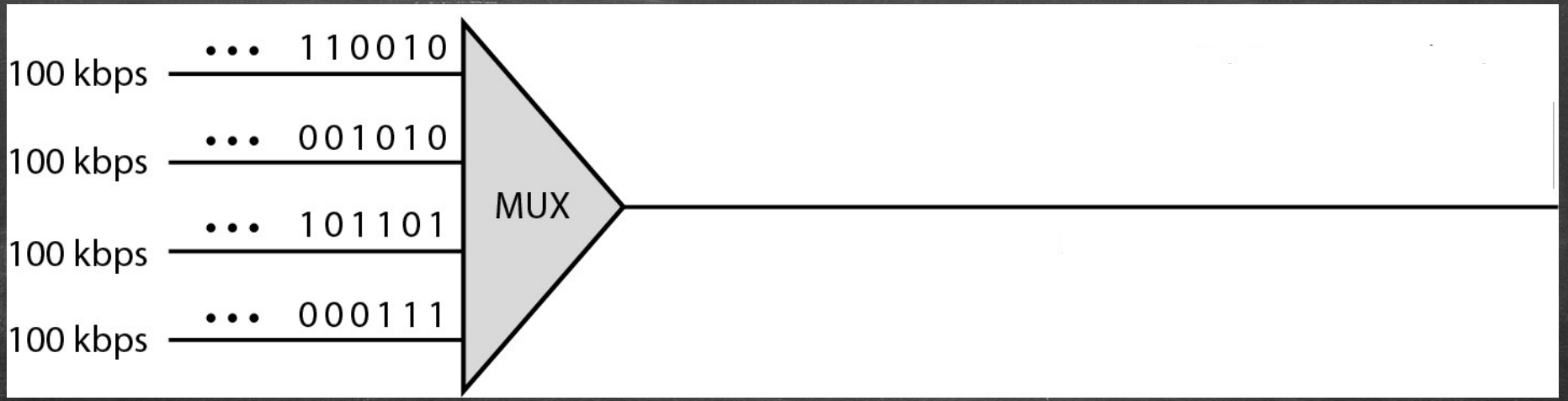


Figure 6.17 Example 6.9

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.

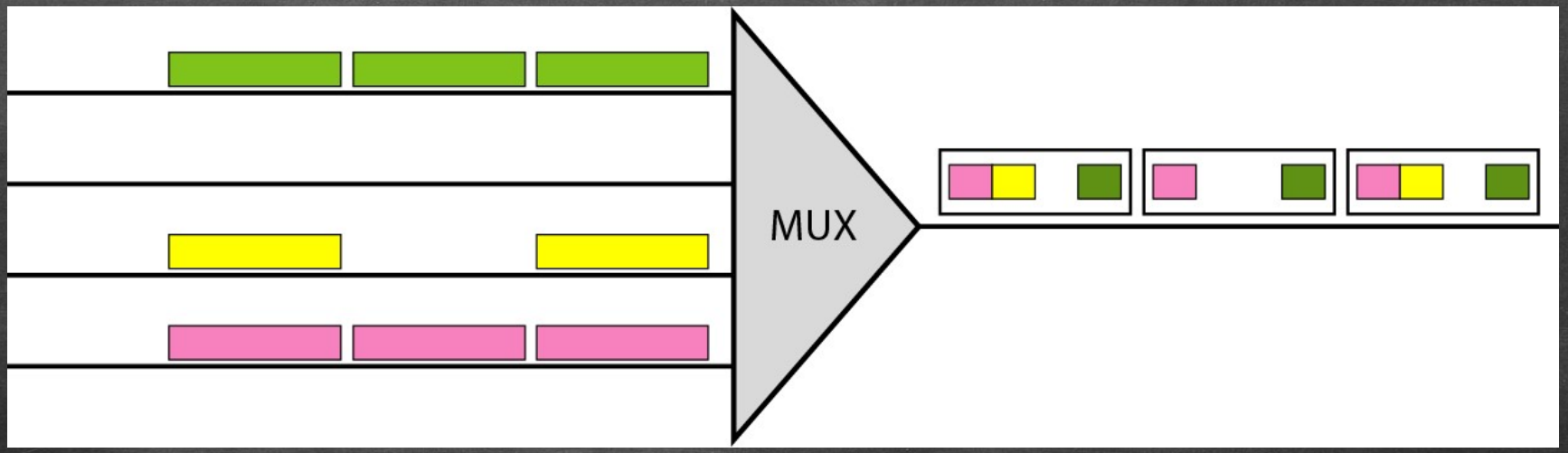


Figure 6.18 Empty slots

Data Rate Management

- Data Rate Management
  - multilevel multiplexing
  - multiple-slot allocation
  - pulse stuffing.

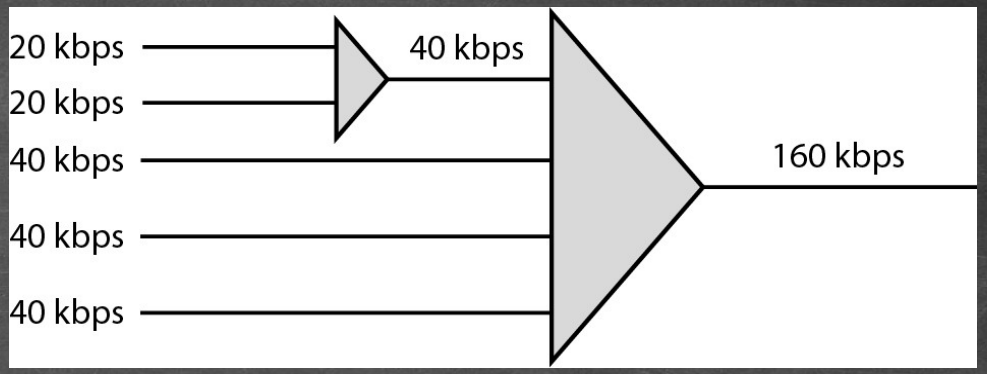


Figure 6.19 Multilevel multiplexing

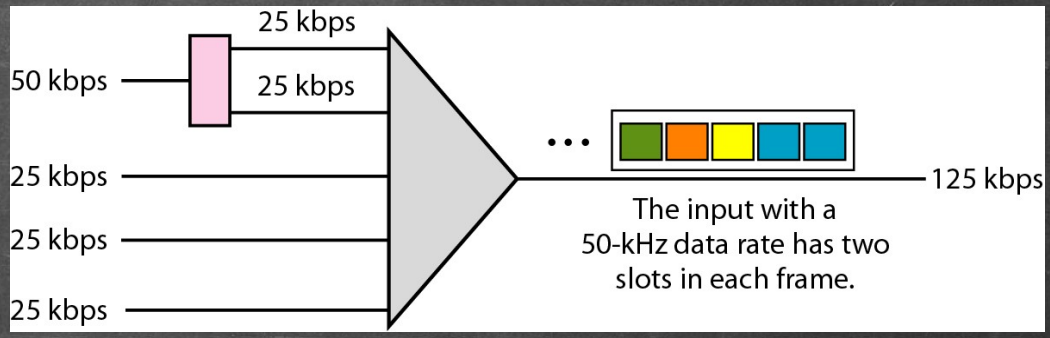


Figure 6.20 Multiple-slot multiplexing

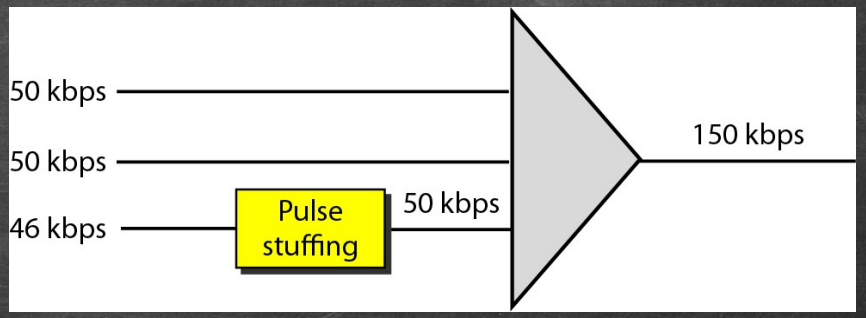


Figure 6.21 Pulse stuffing

Frame Synchronizing

- Synchronization between the multiplexer and demultiplexer is a major issue. If the. multiplexer and the demultiplexer are not synchronized, a bit belonging to one channel may be received by the wrong channel.

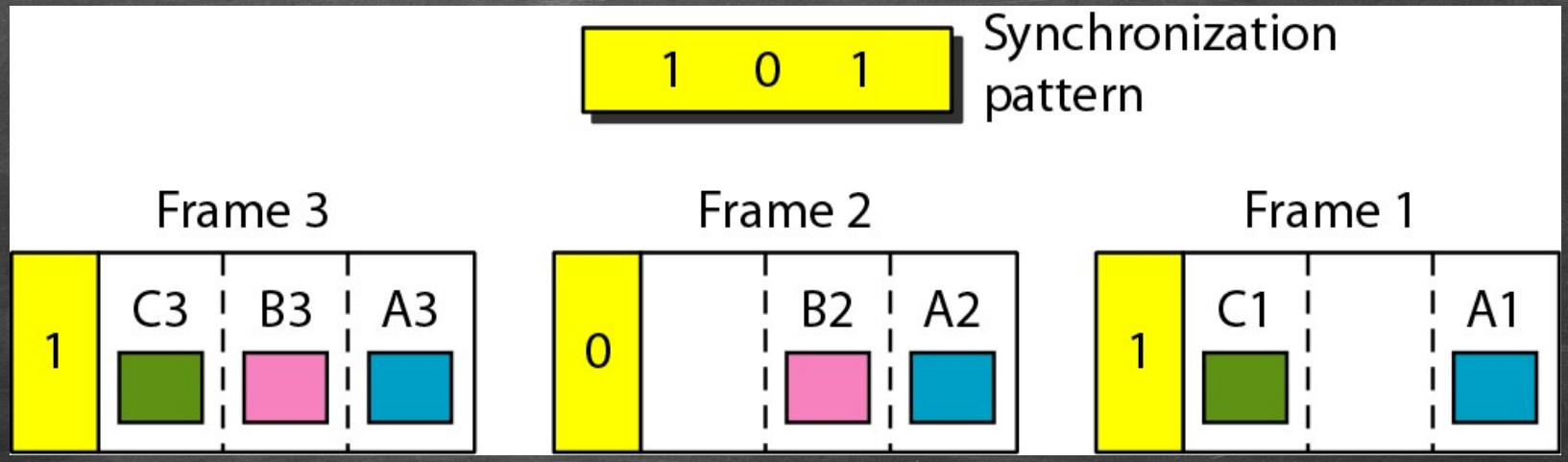


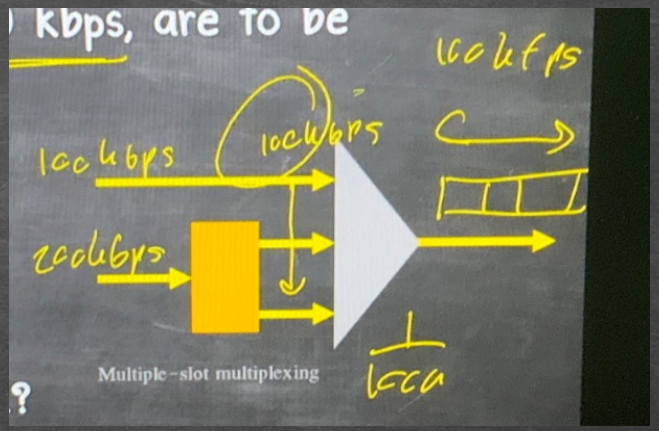
Figure 6.22 Framing bits

Example 6.10

- We have four sources, each creating 250 characters per second. If the interleaved unit is a character and 1 synchronizing bit is added to each frame, find
  - (a) the data rate of each source
  - (b) the duration of each character in each source
  - (c) the frame rate
  - (d) the duration of each frame
  - (e) the number of bits in each frame
  - (f) the data rate of the link.

Example 6.11

- Two channels, one with a bit rate of 100 kbps and another with a bit rate of 200 kbps, are to be multiplexed.
  - How this can be achieved?
  - What is the frame rate?
  - What is the frame duration?
  - What is the bit rate of the link?



300 kbps

Digital Signal Service

- Telephone companies implement TDM through a hierarchy of digital signals, called digital signal (DS) service or digital hierarchy.

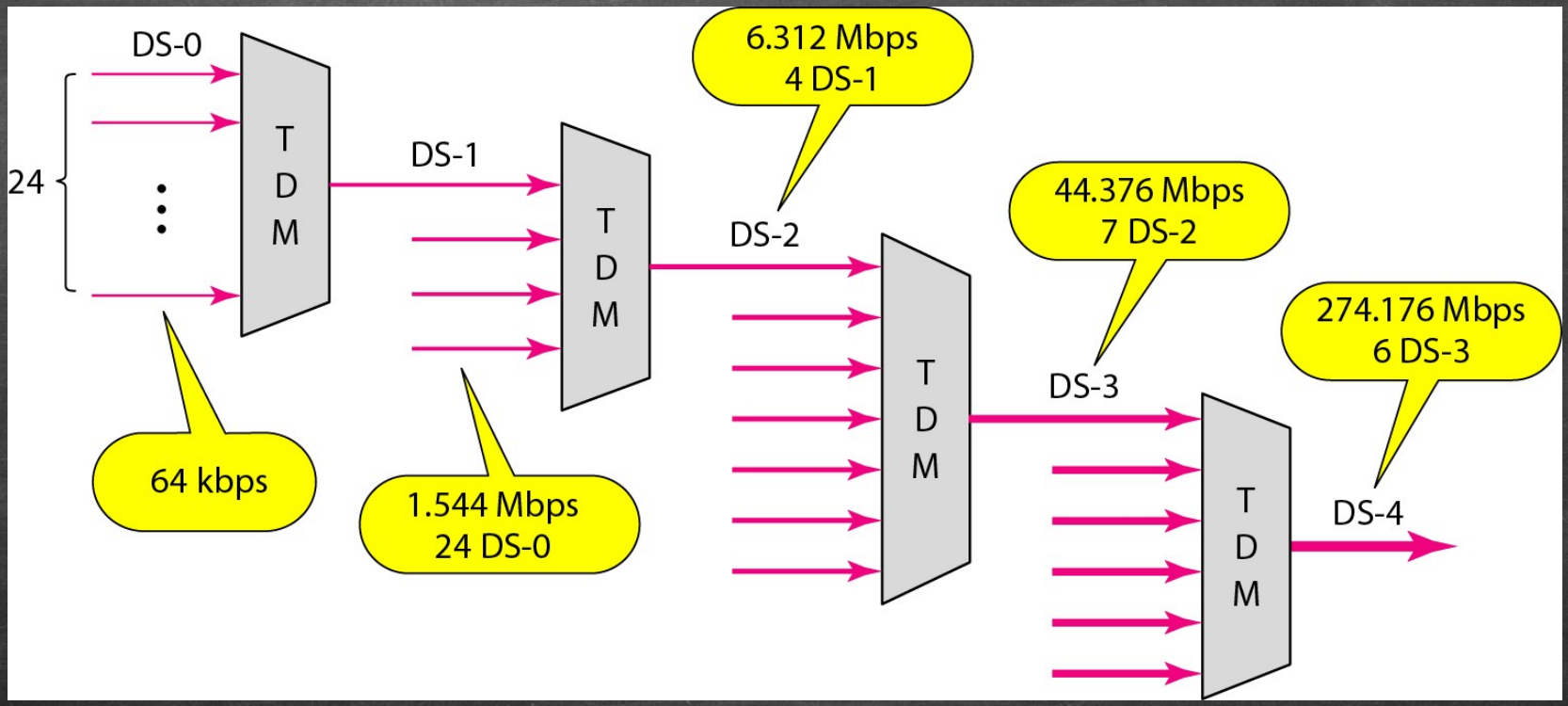


Figure 6.23 Digital hierarchy

T Lines

- Telephone companies implement TDM through a hierarchy of digital signals, called digital signal (DS) service or digital hierarchy.

Table 6.1 DS and T line 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

T Lines for Analog Transmission

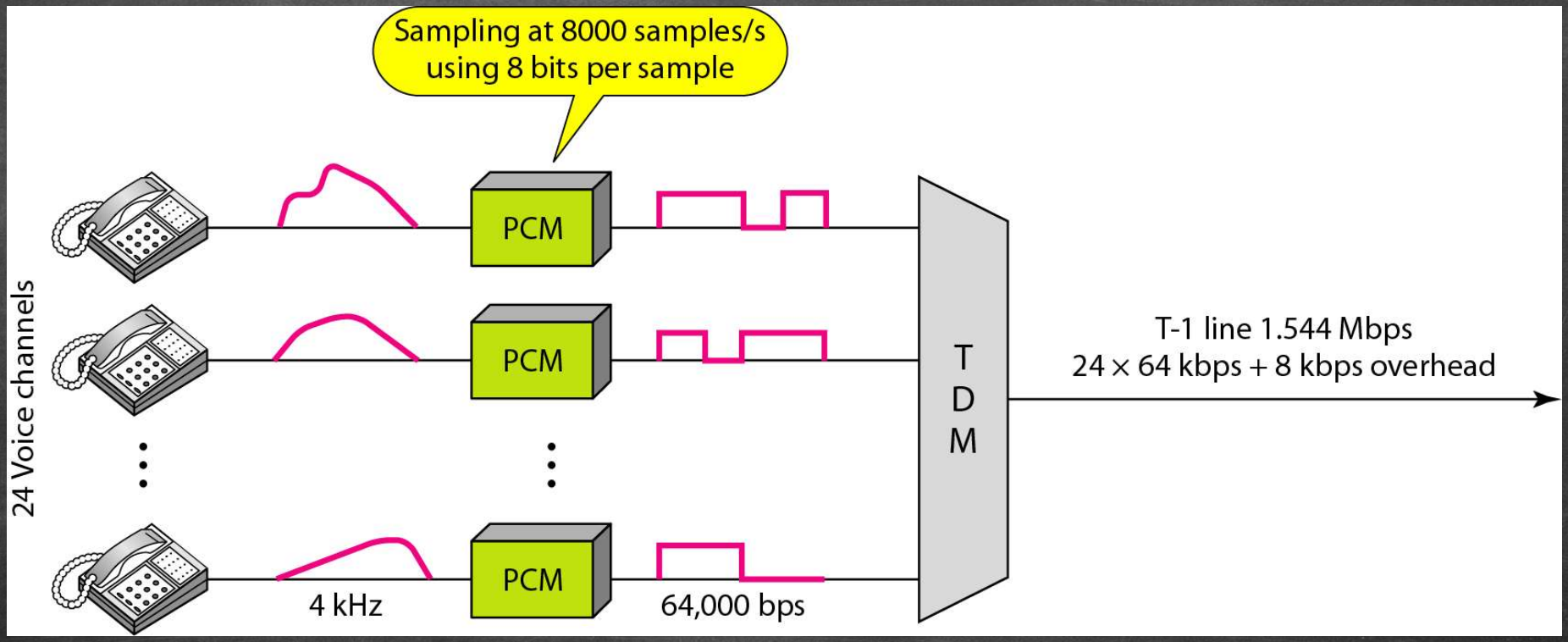


Figure 6.24 T-1 line for multiplexing telephone lines

The T-1

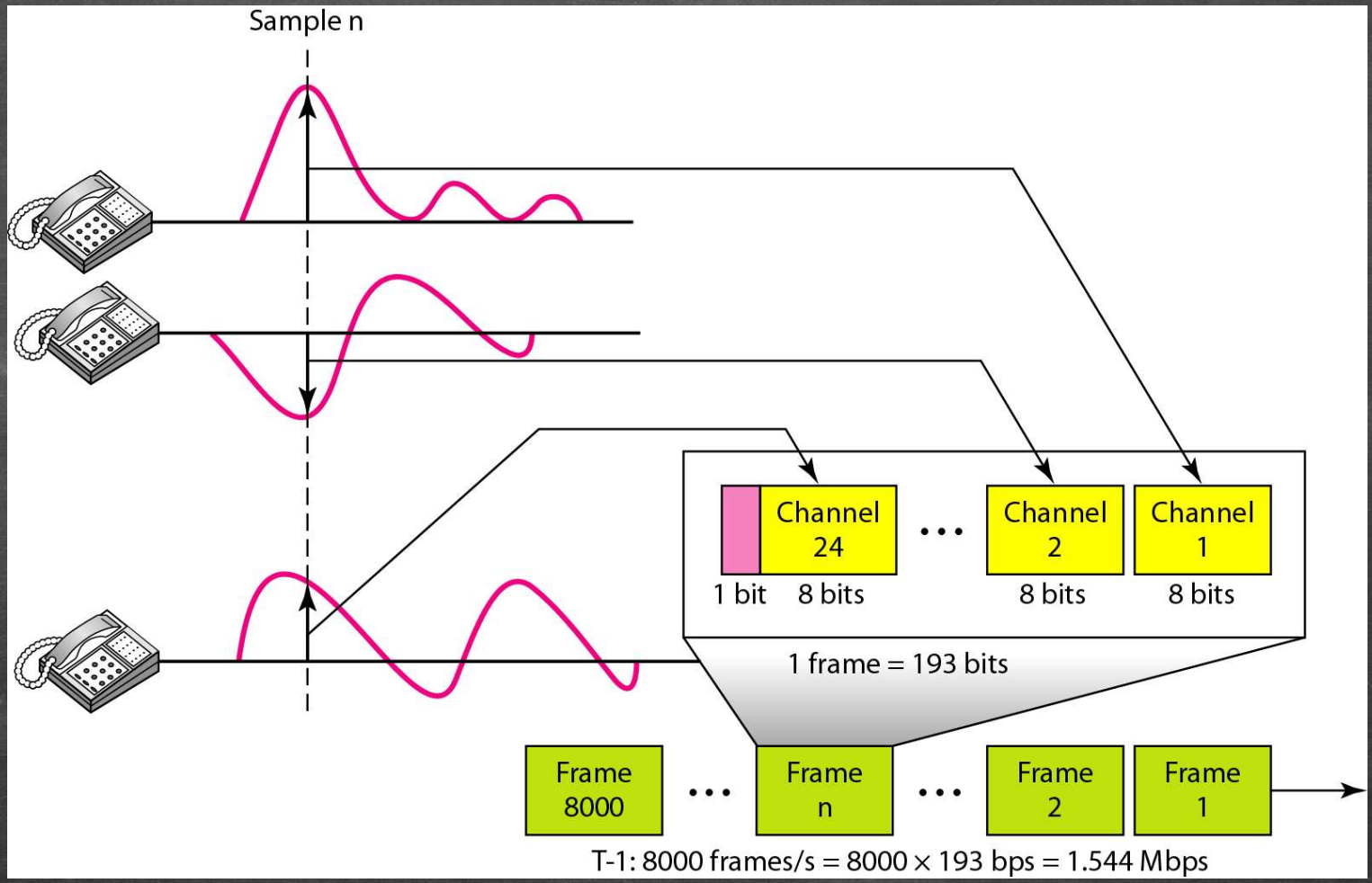


Figure 6.25 T-1 frame structure

E Lines

- Europeans use a version of T lines called E lines.

Table 6.2 E line rates

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

Statistical Time-Division Multiplexing

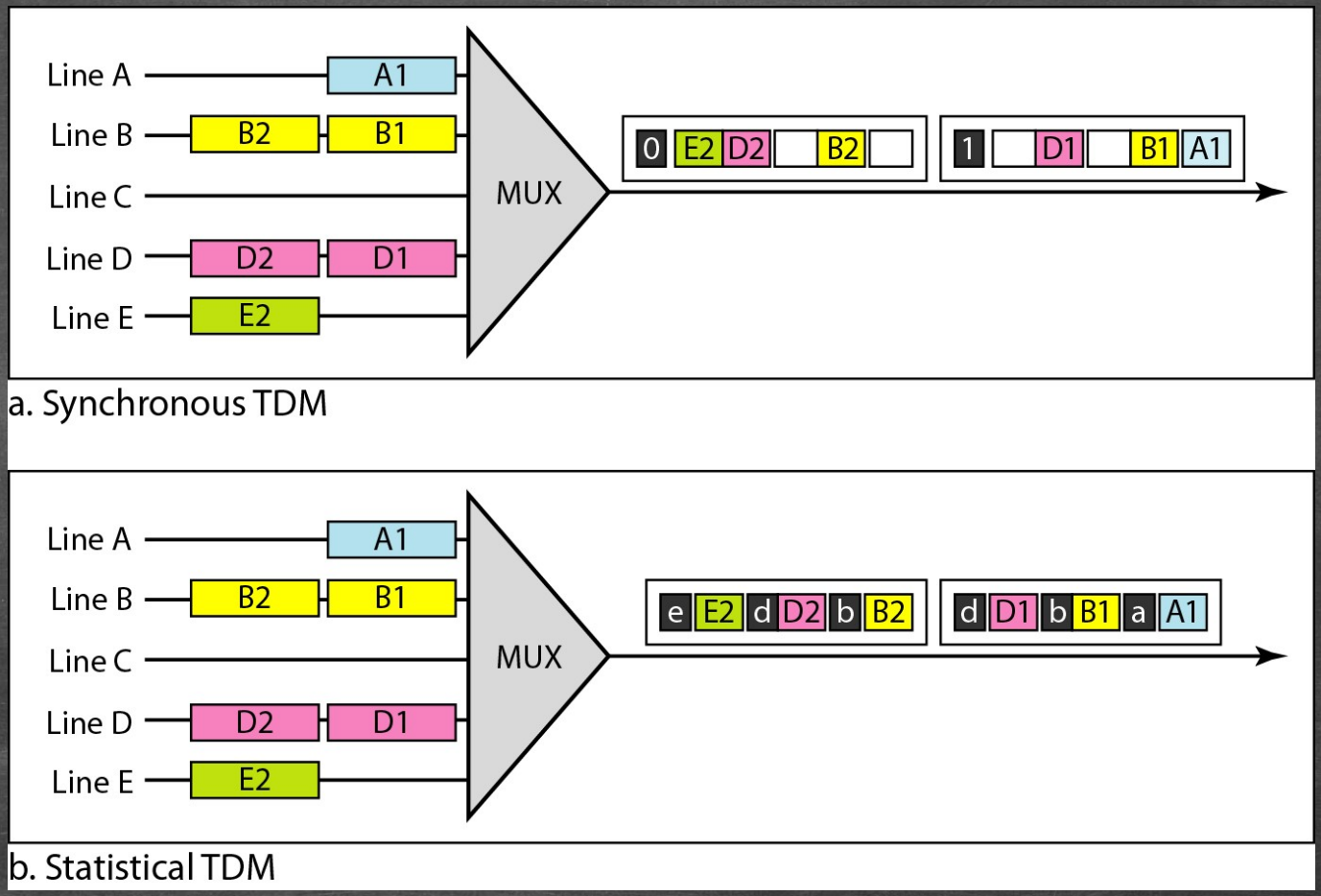


Figure 6.26 TDM slot comparison

SPREAD SPECTRUM

- FREQUENCY HOPPING SPREAD SPECTRUM (FHSS)
- DIRECT SEQUENCE SPREAD SPECTRUM SYNCHRONOUS (DSSS)

SPREAD SPECTRUM

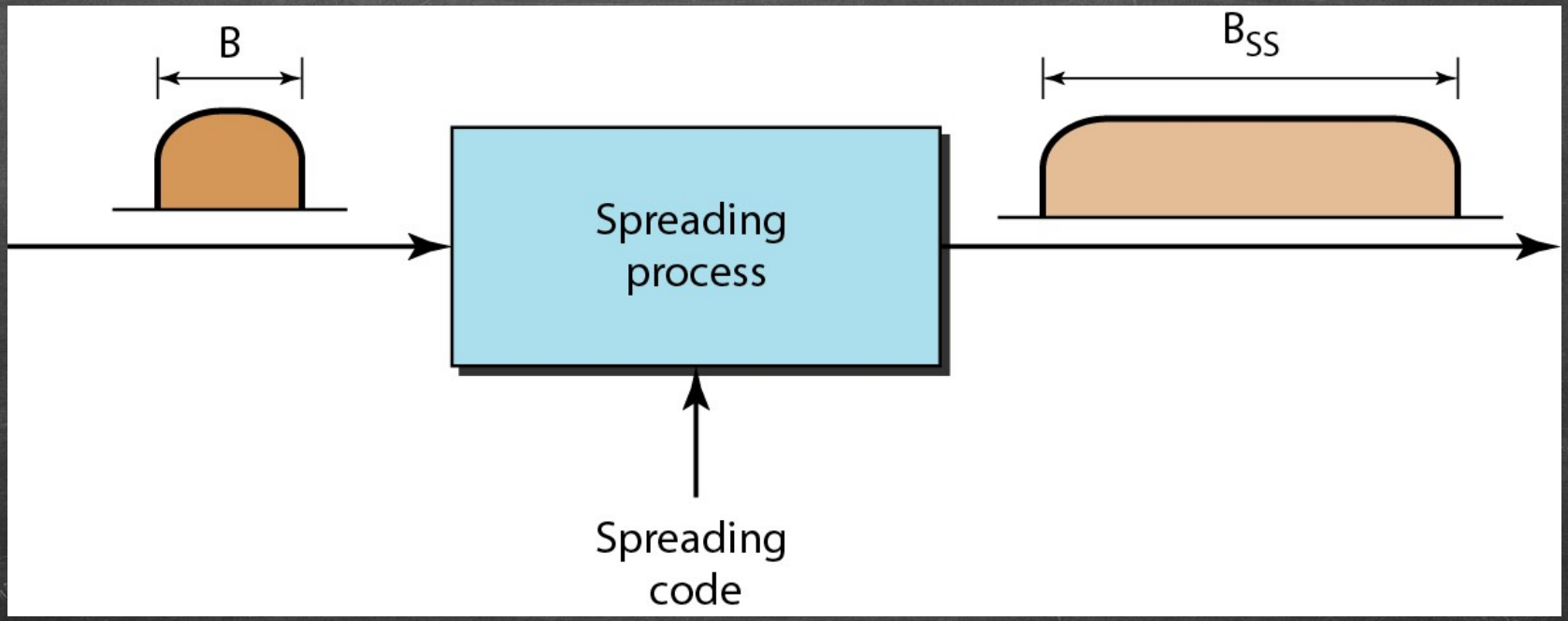


Figure 6.27 Spread spectrum

Frequency Hopping Spread Spectrum (FHSS)

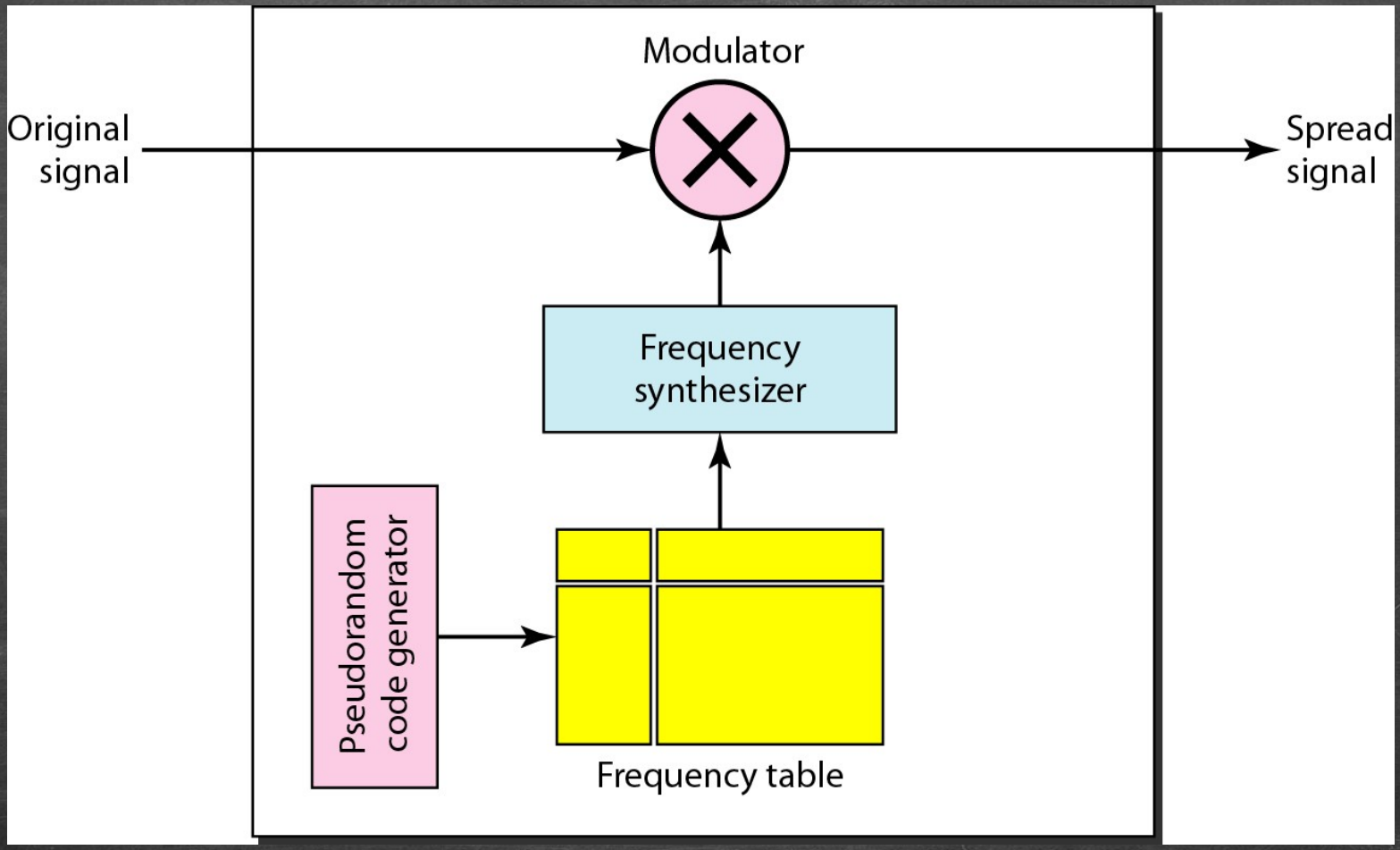


Figure 6.28 Frequency hopping spread spectrum (FHSS)

Frequency Hopping Spread Spectrum (FHSS)

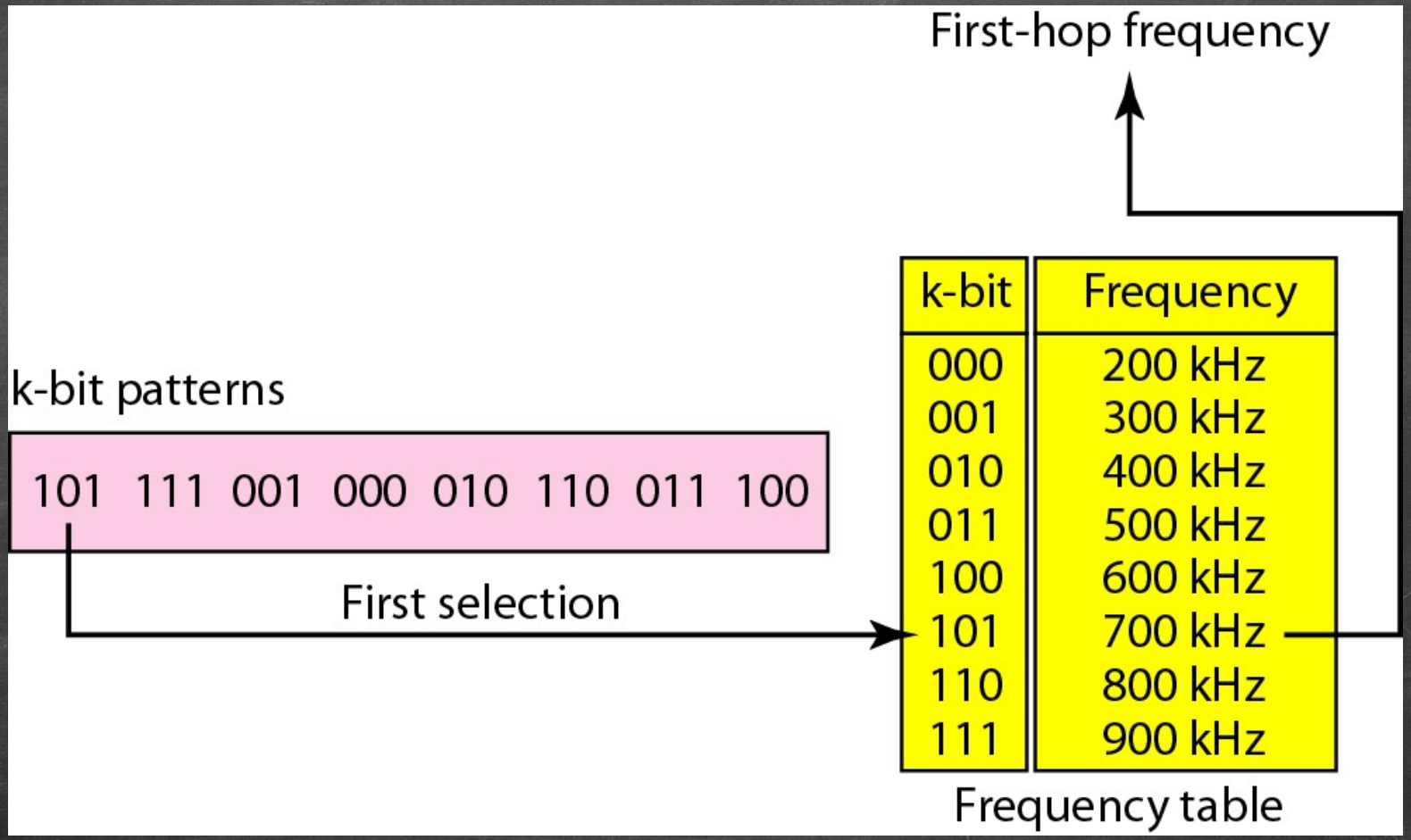


Figure 6.29 Frequency selection in FHSS

Frequency Hopping Spread Spectrum (FHSS)

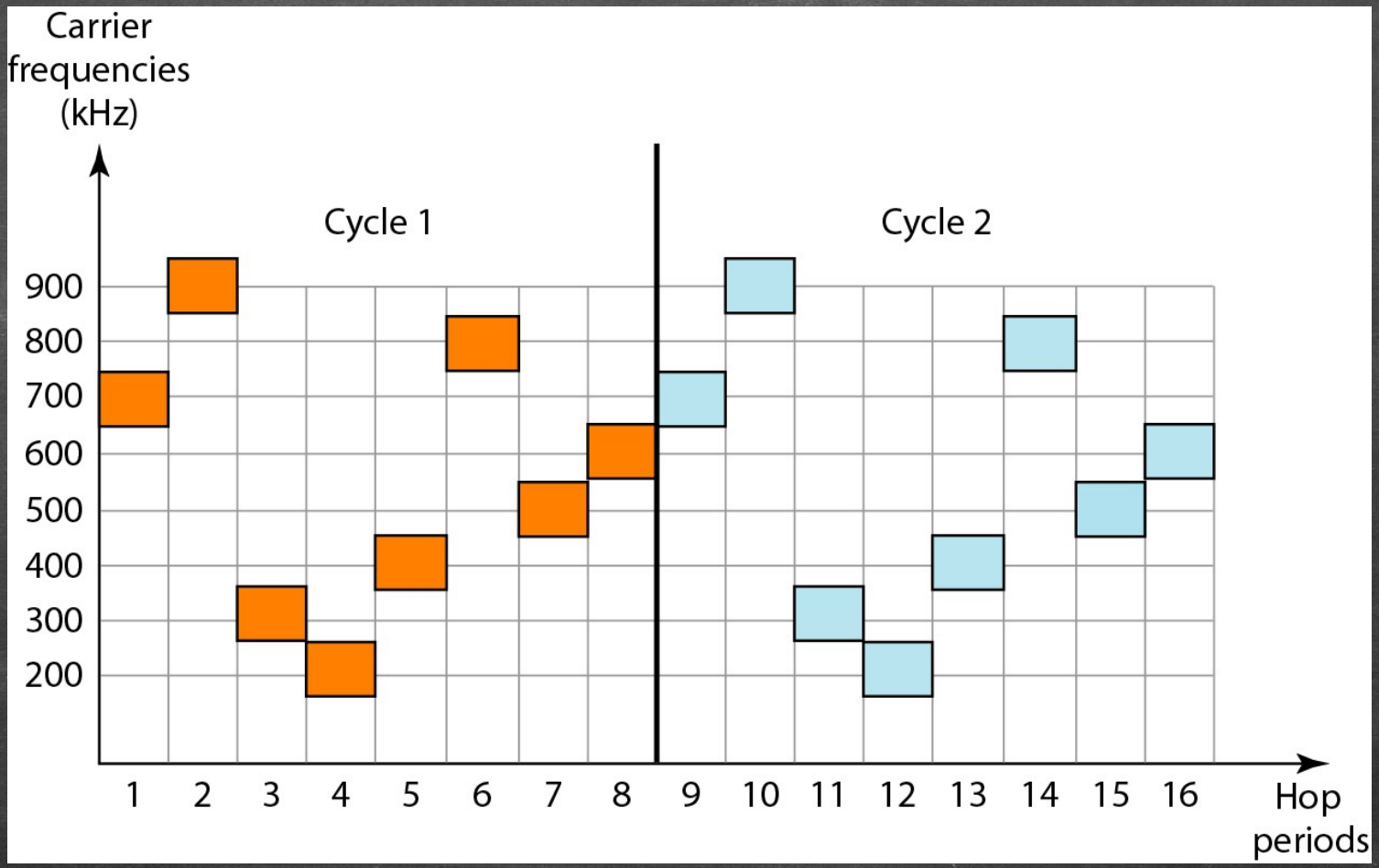


Figure 6.30 FHSS cycles

Bandwidth Sharing

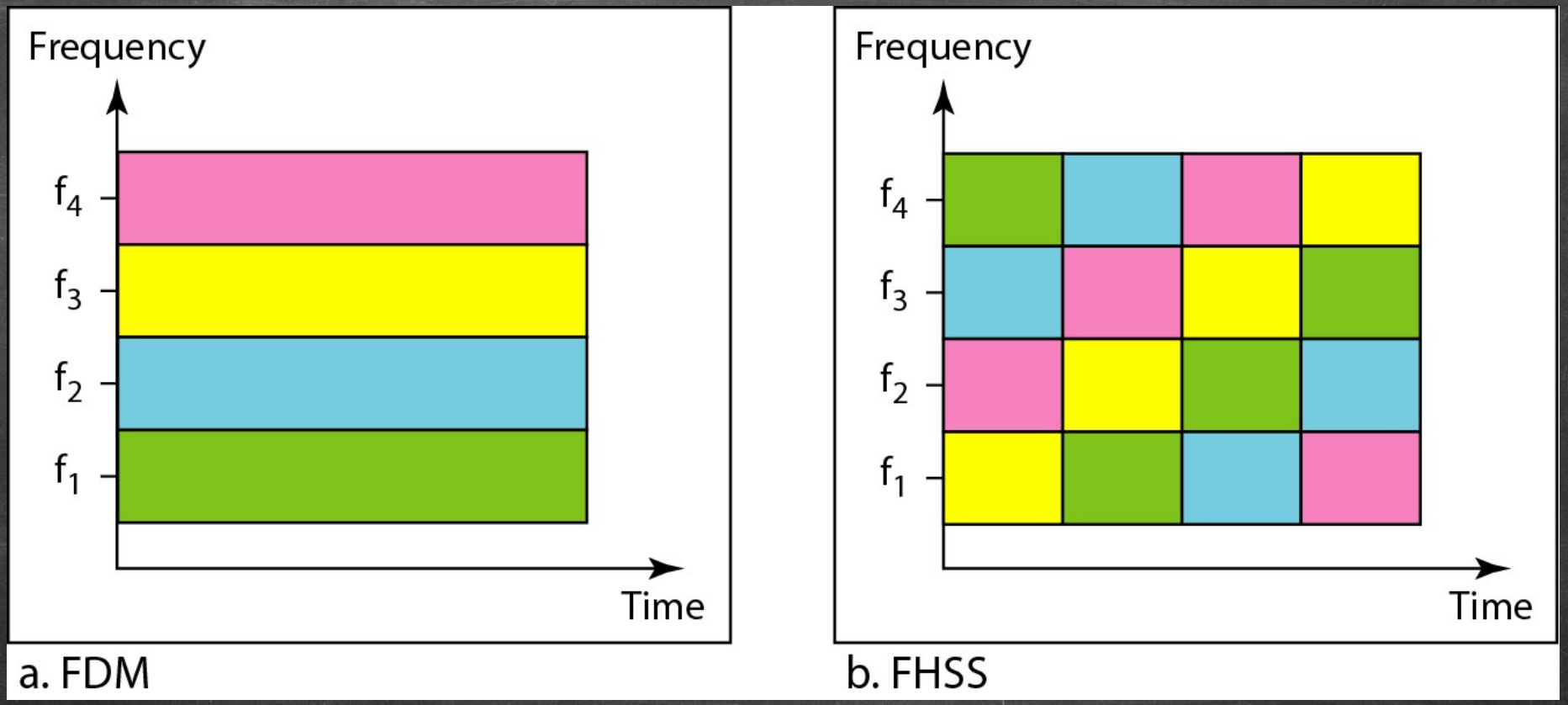


Figure 6.31 Bandwidth sharing

Direct Sequence Spread Spectrum

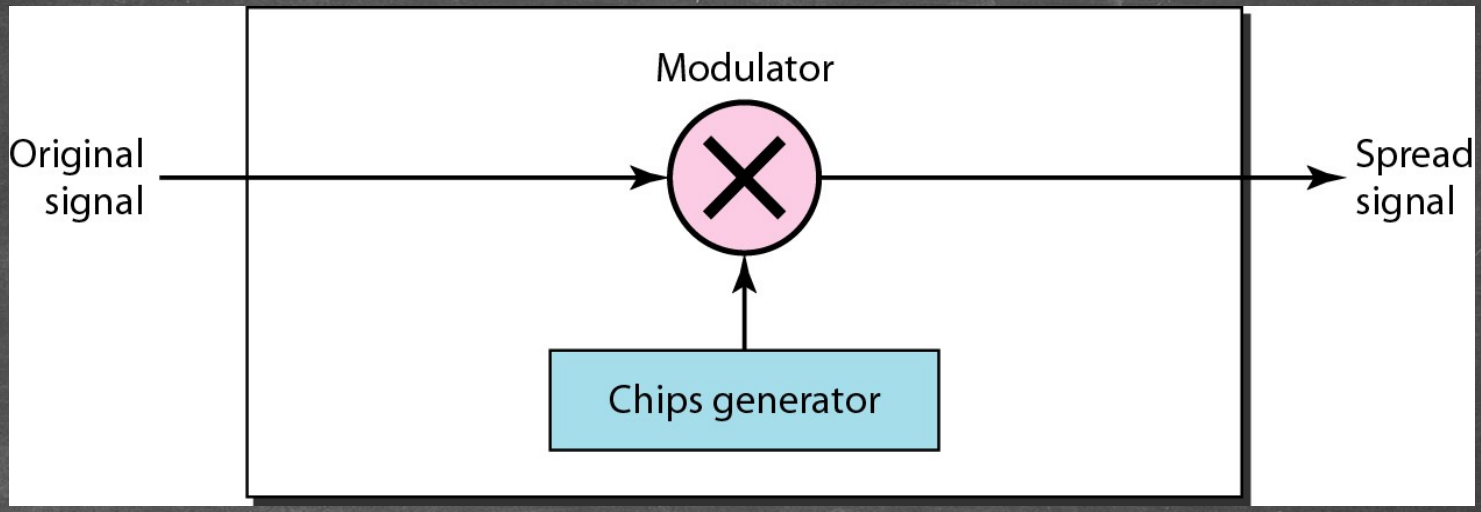


Figure 6.32 DSSS

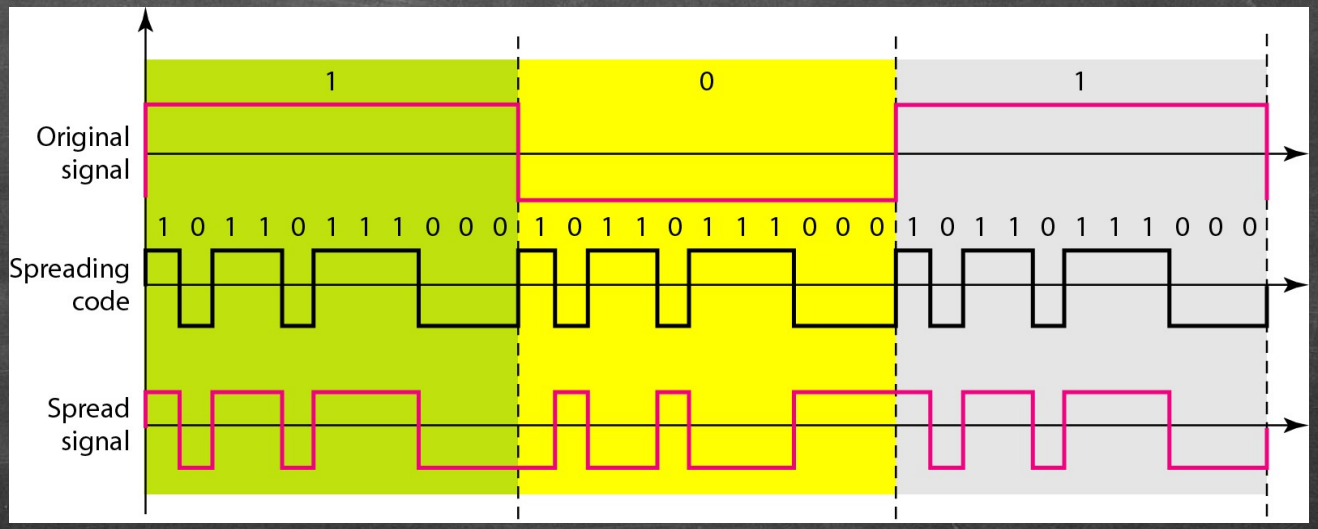


Figure 6.33 DSSS example