CSE / T / 315A
Data Communications
Topic 6- Multiplexing and Spreading

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Bandwidth utilization

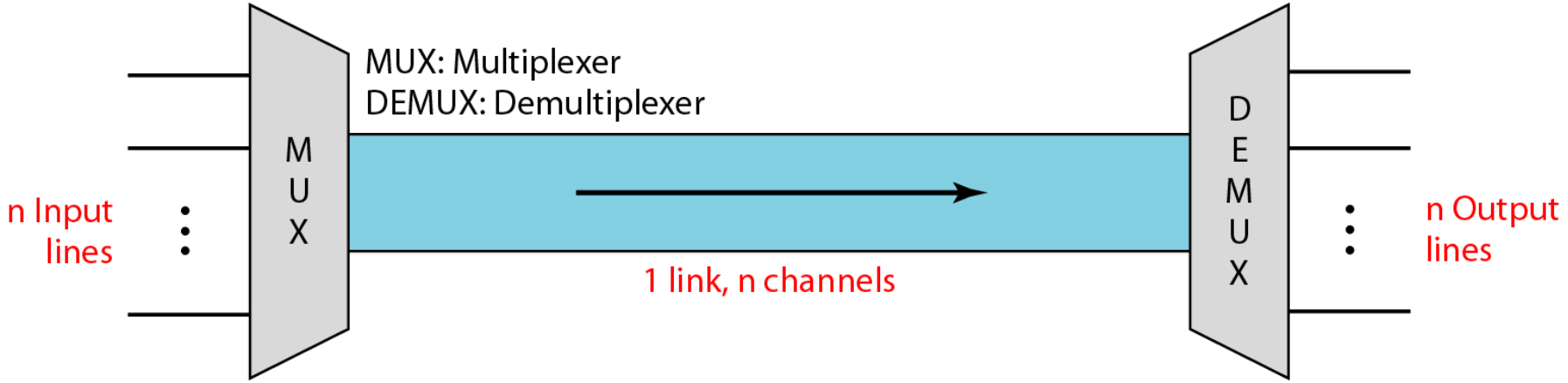
- Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.

- Efficiency can be achieved by multiplexing; i.e., sharing of the bandwidth between multiple users.

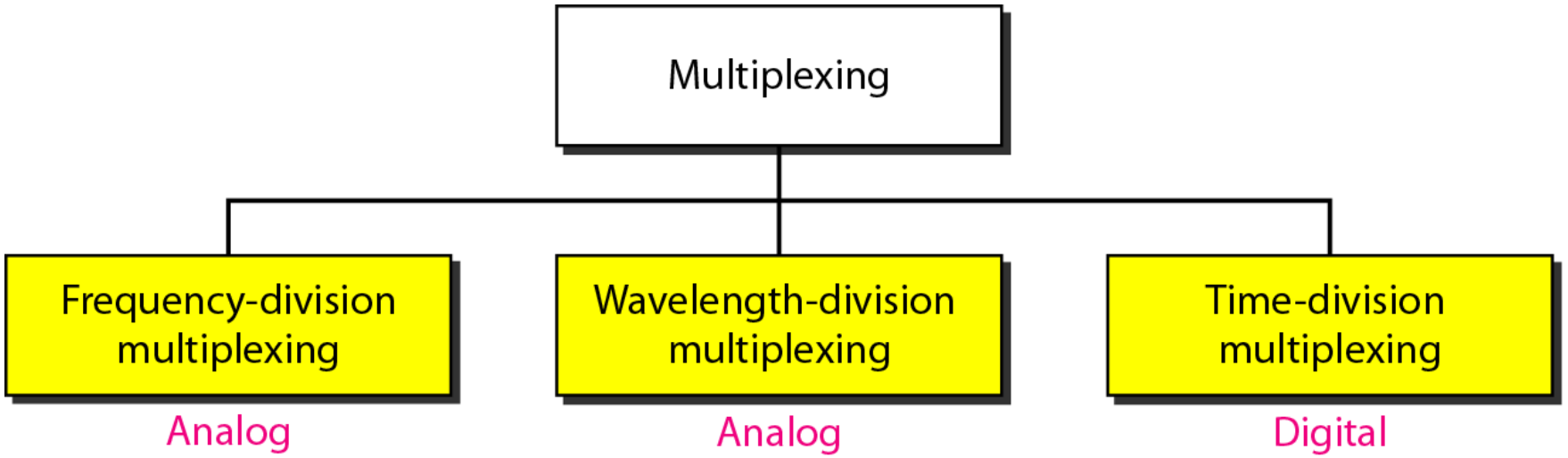
Multiplexing

- Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared.
- 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.
  - ✓ Frequency-Division Multiplexing
  - ✓ Wavelength-Division Multiplexing
  - ✓ Synchronous Time-Division Multiplexing
  - ✓ Statistical Time-Division Multiplexing

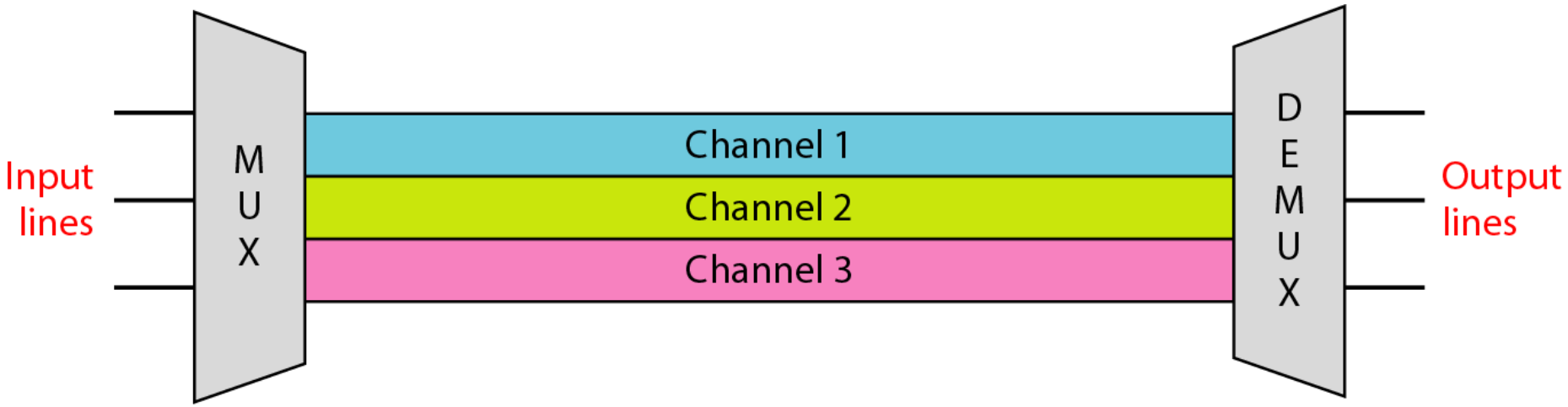
Dividing a link into channels



Categories of multiplexing

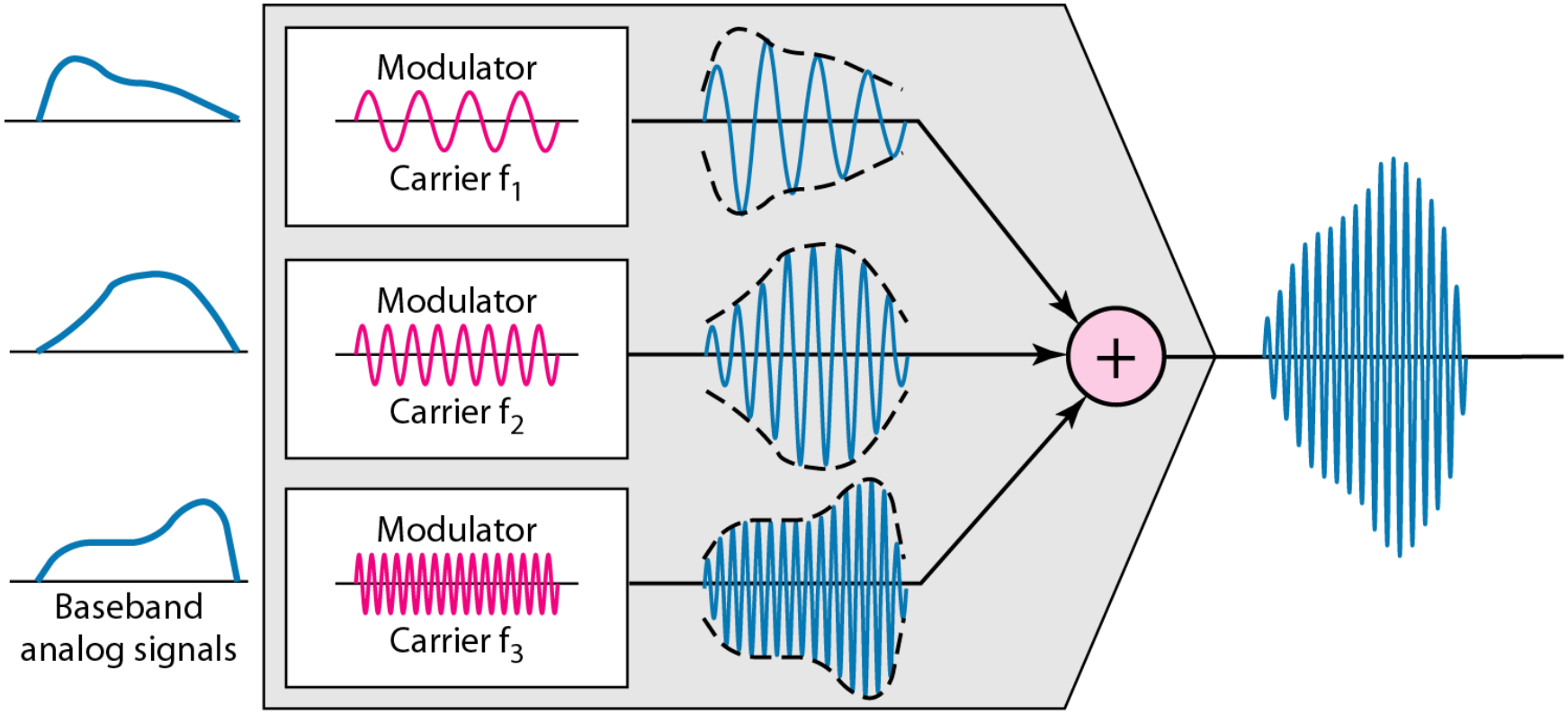


Frequency-division multiplexing (FDM)



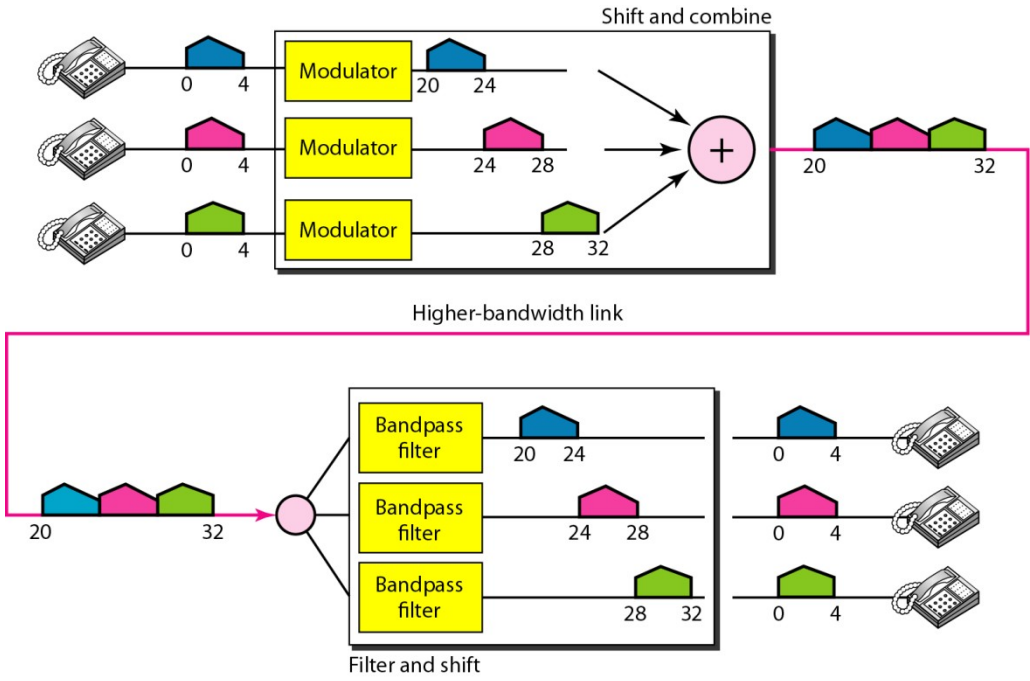
- FDM is an analog multiplexing technique that combines analog signals.
- It uses the concept of modulation as discussed earlier.

FDM process


Modulator
Carrier f_1
Modulator
Carrier f_2
Modulator
Carrier f_3
+
Baseband
analog signals

Example

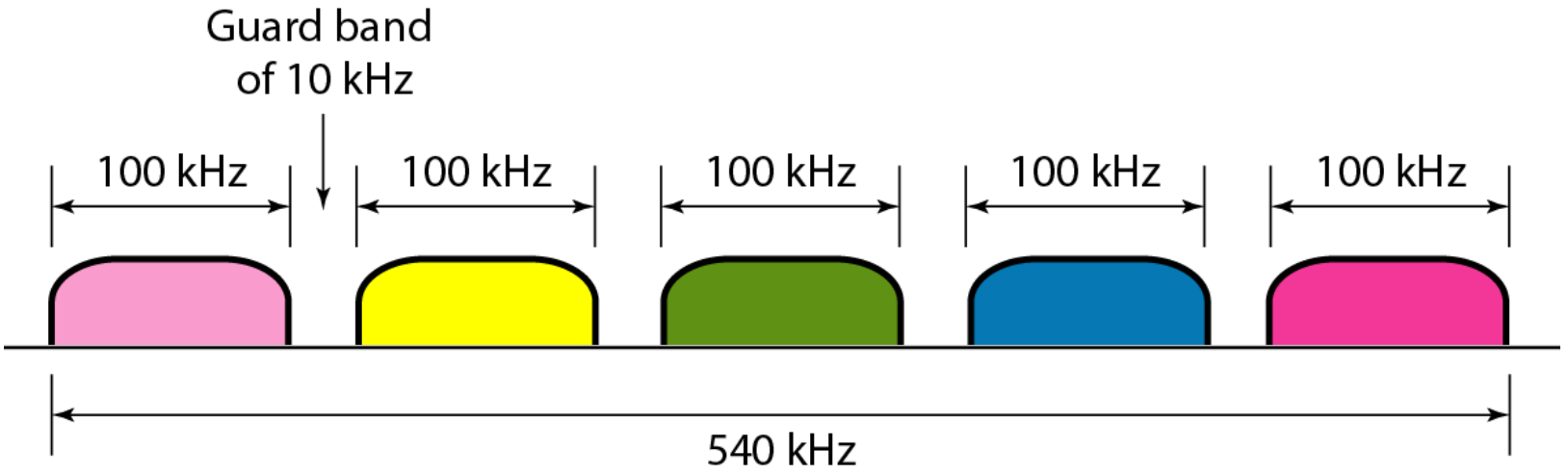
- Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.
- Solution:
  - *We shift (modulate) each of the three voice channels to a different bandwidth, as shown in Figure. We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them as shown*



Example

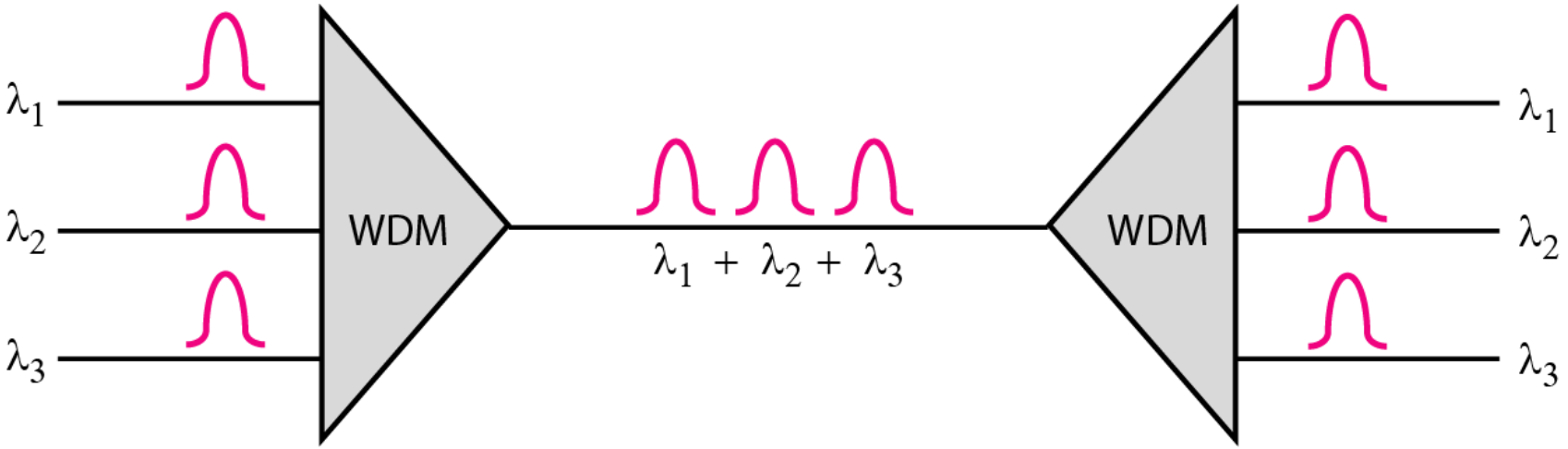
- Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?
- Solution
  - *For five channels, we need at least four guard bands. This means that the required bandwidth is at least*

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

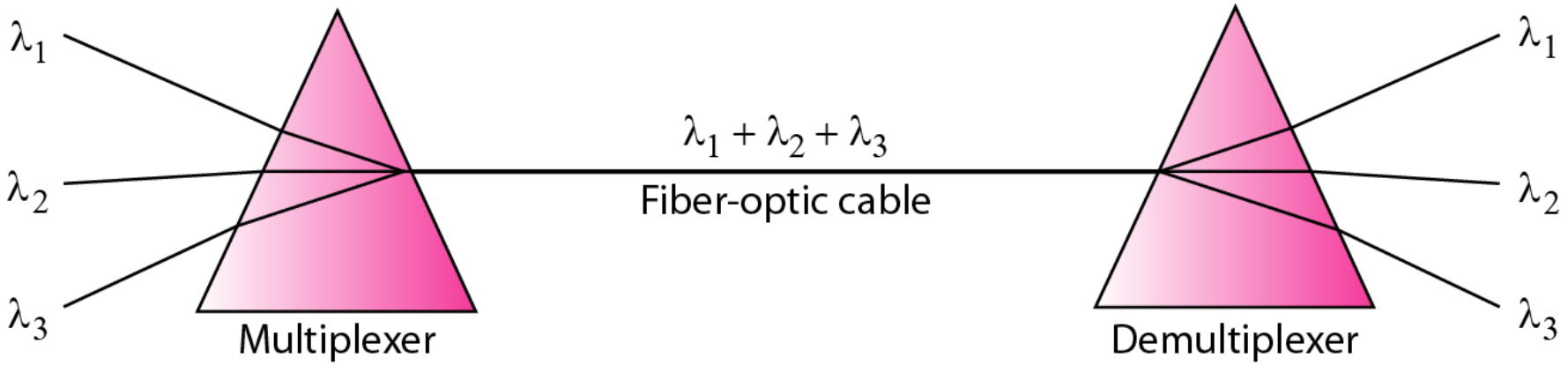


Wavelength-division multiplexing (WDM)

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

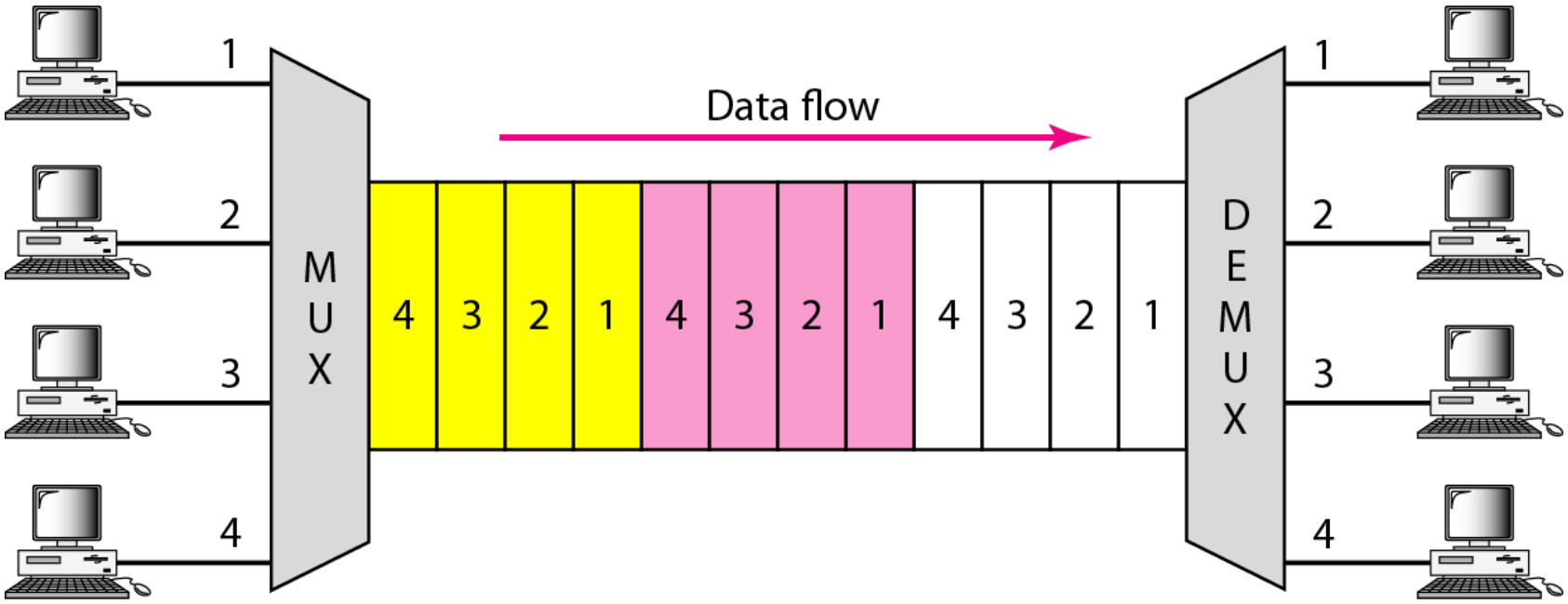


Prisms in wavelength-division multiplexing and demultiplexing



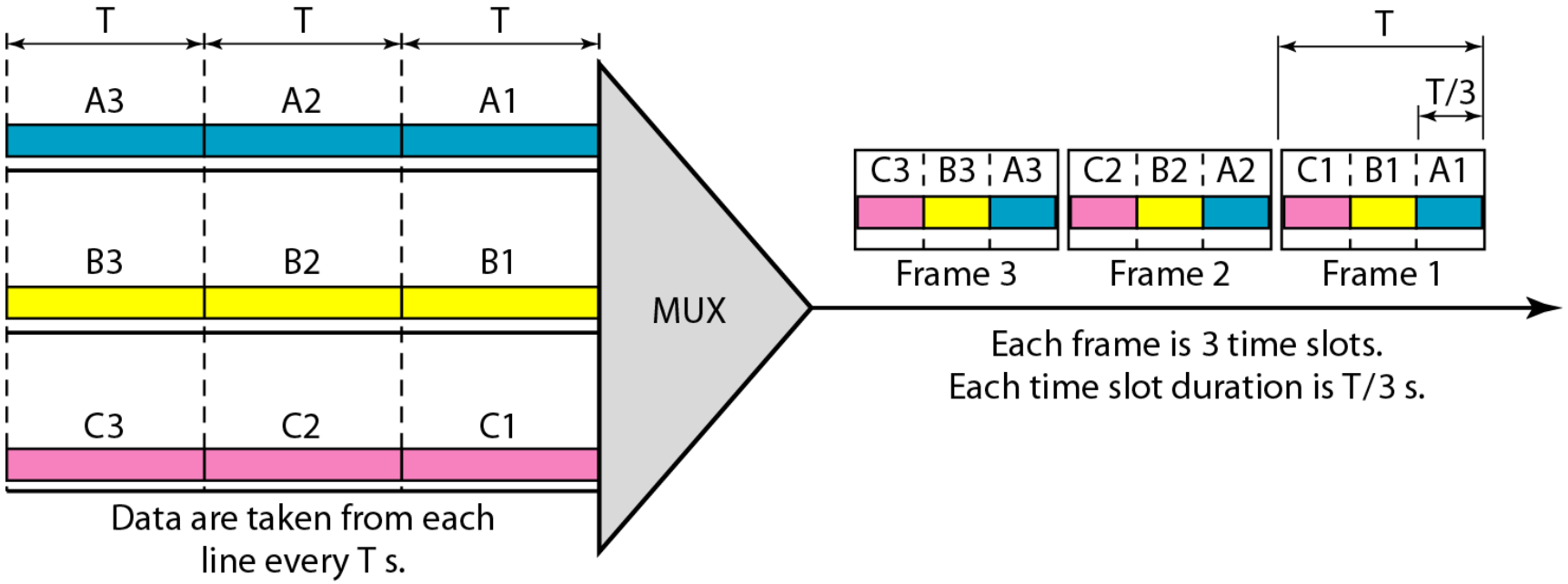
Time Division Multiplexing (*TDM*)

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



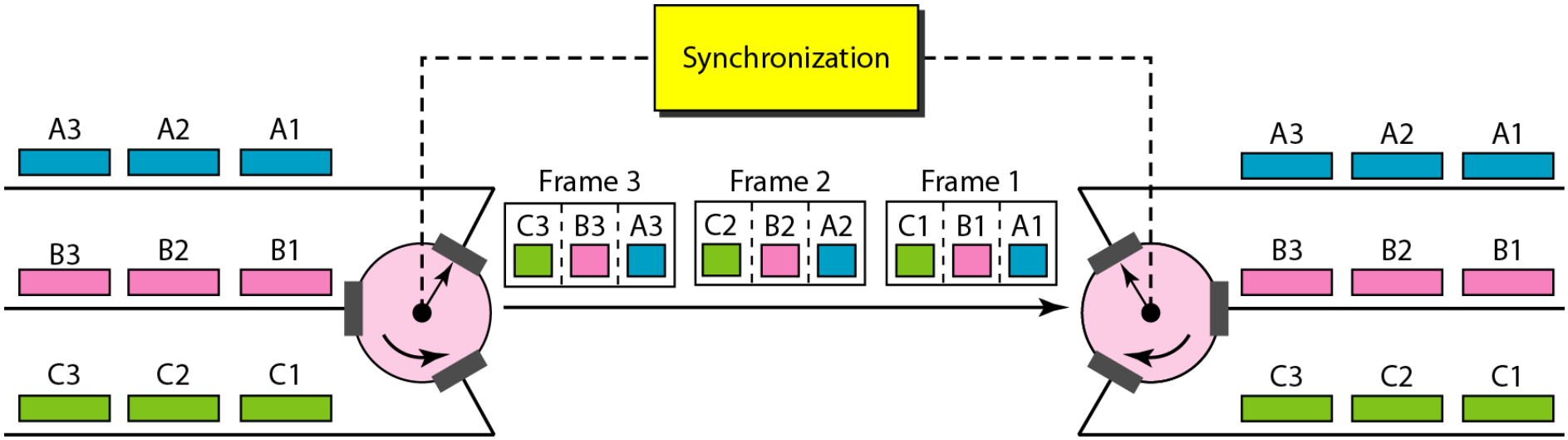
Synchronous time-division multiplexing

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



Interleaving

- The process of taking a group of bits from each input line for multiplexing is called interleaving.
- We interleave bits from each input onto one output.



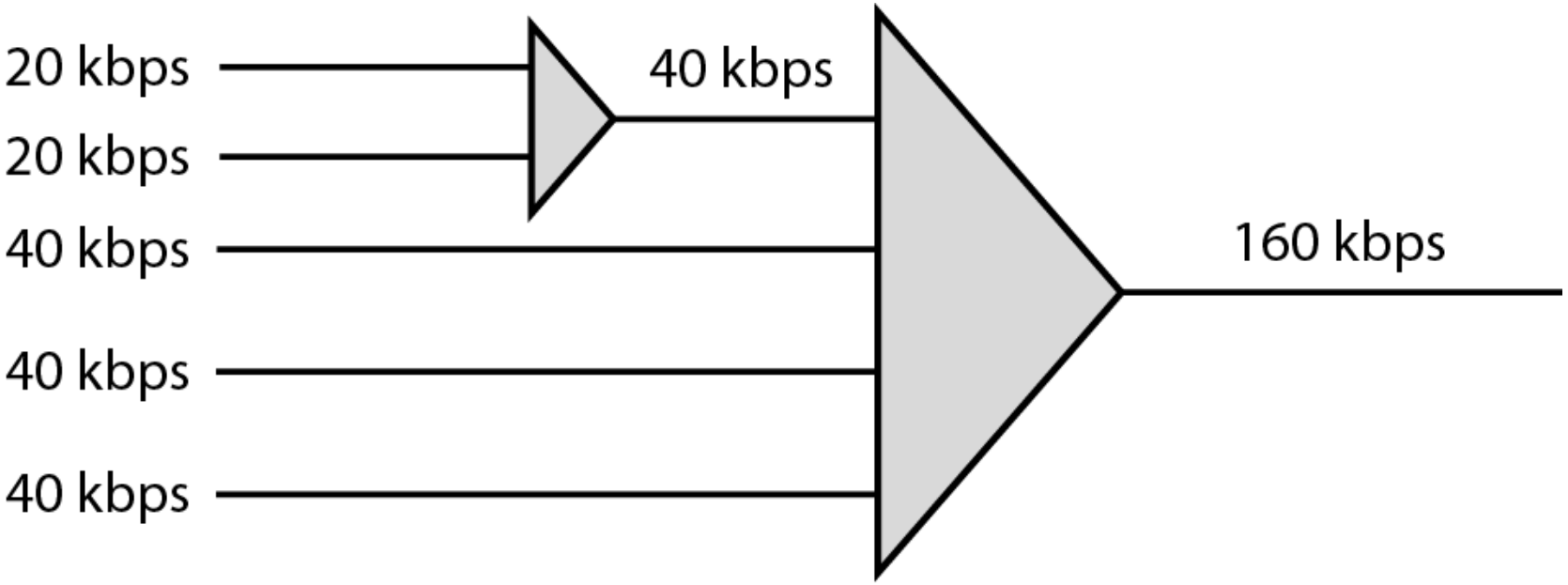
Data Rate Management

- Not all input links maybe have the same data rate.
- Some links maybe slower. There maybe several different input link speeds
- There are three strategies that can be used to overcome the data rate mismatch:
  - multilevel,
  - multislot and
  - pulse stuffing

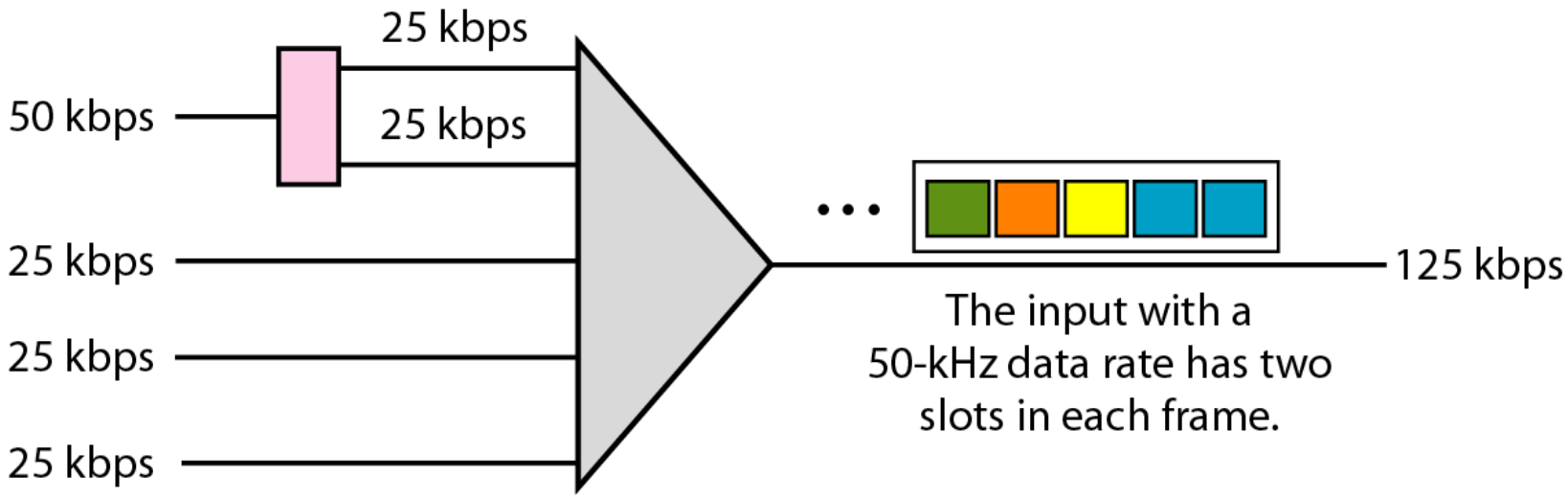
Data rate matching

- Multilevel: used when the data rate of the input links are multiples of each other.
- Multislot: used when there is a GCD between the data rates. The higher bit rate channels are allocated more slots per frame, and the output frame rate is a multiple of each input link.
- Pulse Stuffing: used when there is no GCD between the links. The slowest speed link will be brought up to the speed of the other links by bit insertion, this is called pulse stuffing.

Multilevel multiplexing

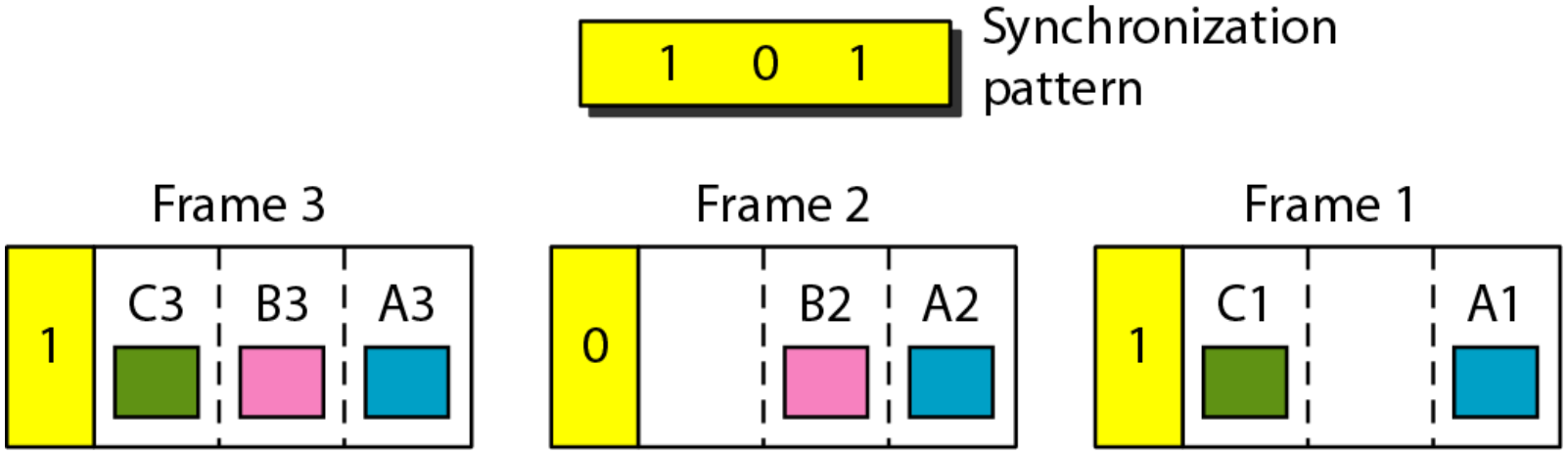


Multiple-slot multiplexing



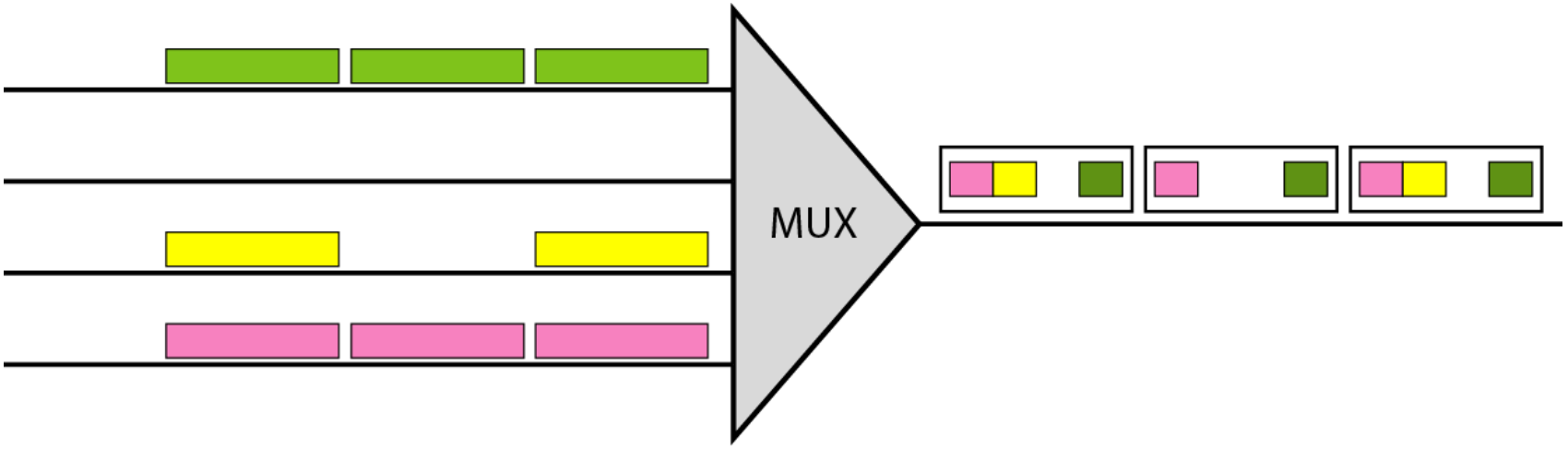
Synchronization

- To ensure that the receiver correctly reads the incoming bits, i.e., knows the incoming bit boundaries to interpret a “1” and a “0”, a known bit pattern is used between the frames.
- The receiver looks for the anticipated bit and starts counting bits till the end of the frame.
- Then it starts over again with the reception of another known bit.
- These bits (or bit patterns) are called synchronization bit(s).
- They are part of the overhead of transmission.



Inefficient use of Bandwidth

- Sometimes an input link may have no data to transmit, as shown in the figure, *Empty slots*
- When that happens, one or more slots on the output link will go unused.
- That is wasteful of bandwidth.



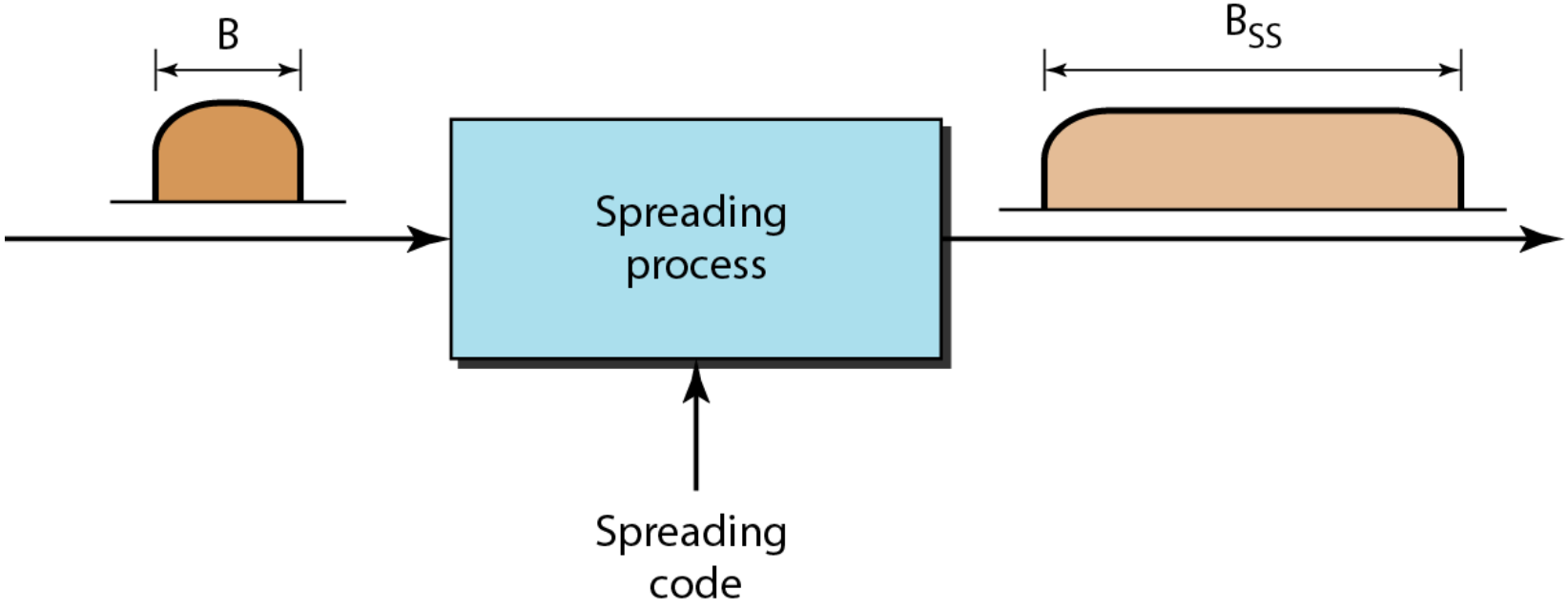
SPREAD SPECTRUM

Spread Spectrum

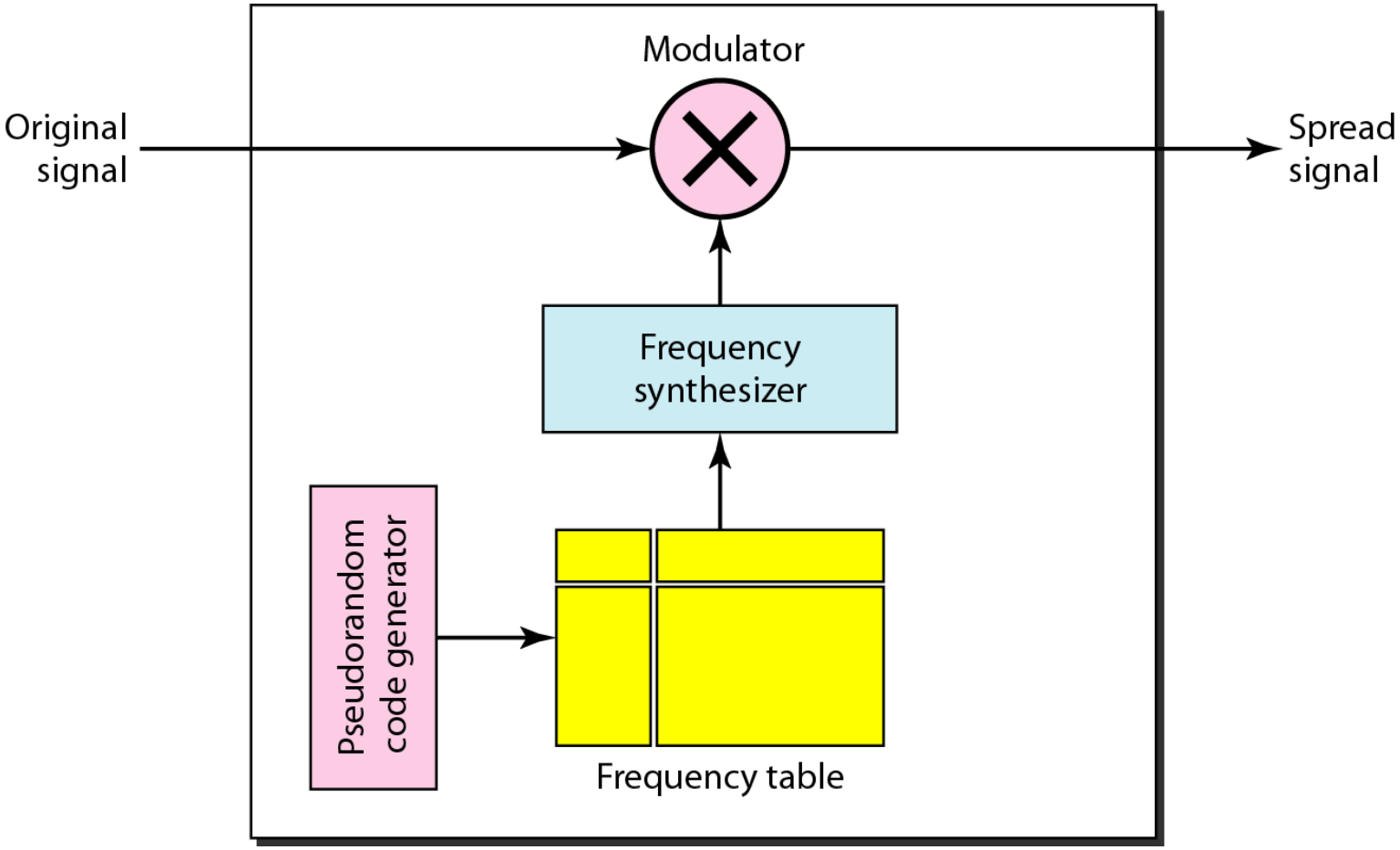
- In spread spectrum (SS), we combine signals from different sources to fit into a larger bandwidth, but our goals are to prevent eavesdropping and jamming. To achieve these goals, spread spectrum techniques add redundancy.
  - Frequency Hopping Spread Spectrum (FHSS)
  - Direct Sequence Spread Spectrum (DSSS)

Spread Spectrum

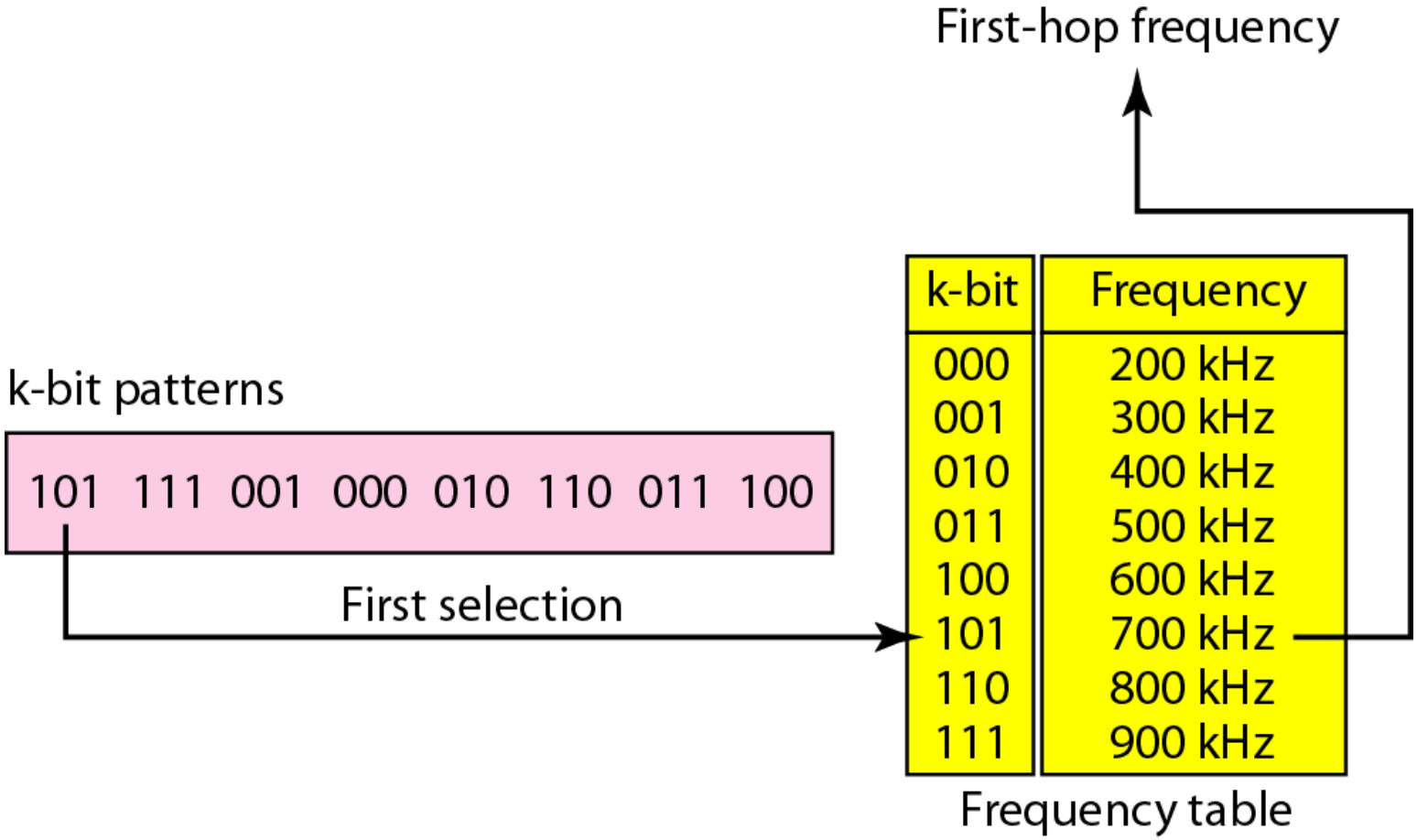
- A signal that occupies a bandwidth of B, is spread out to occupy a bandwidth of B_{ss}
- All signals are spread to occupy the same bandwidth B_{ss}
- Signals are spread with different codes so that they can be separated at the receivers.
- Signals can be spread in the frequency domain or in the time domain.



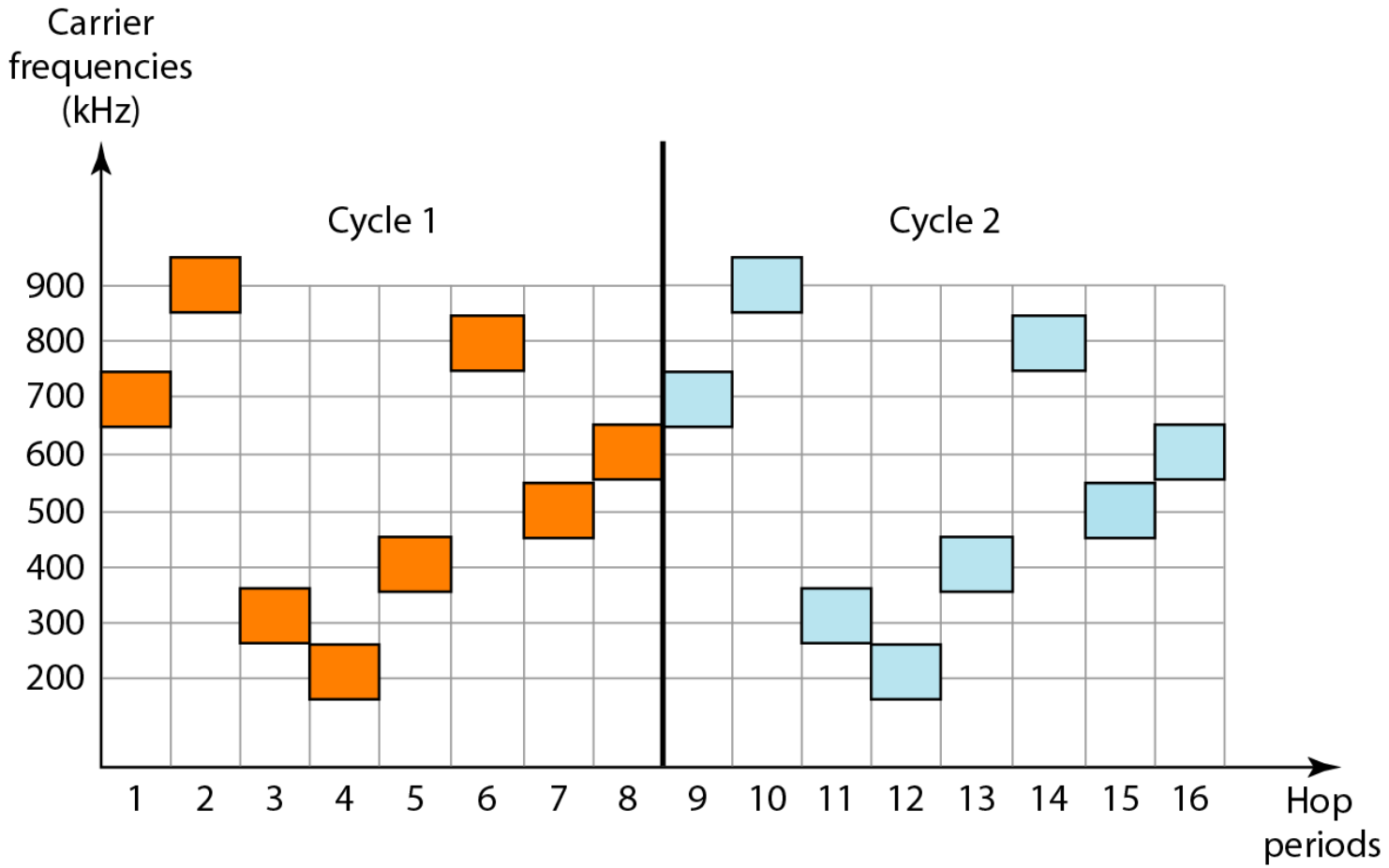
Frequency hopping spread spectrum (FHSS)



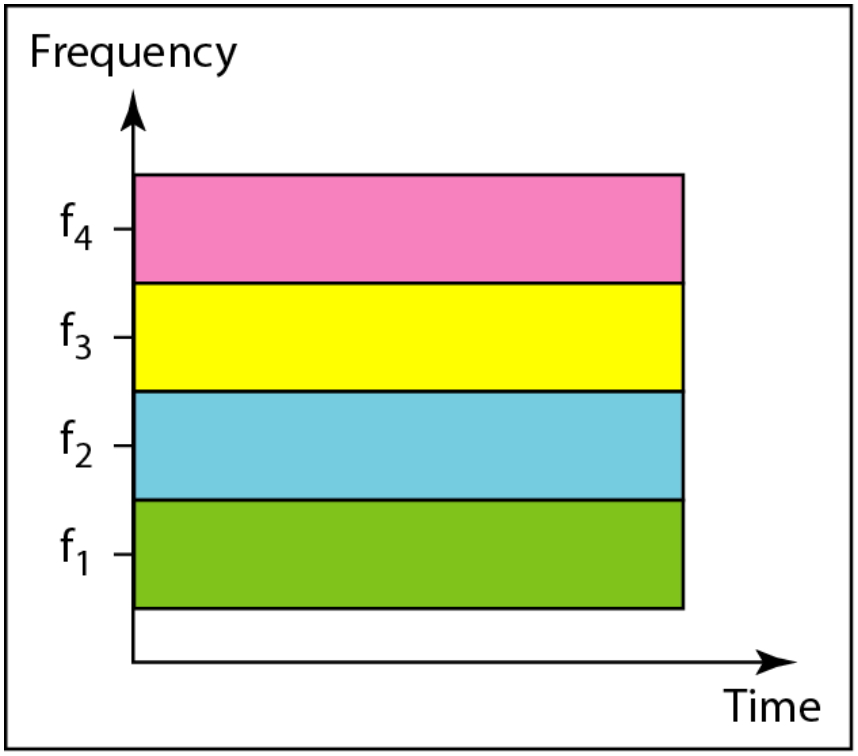
Frequency selection in FHSS



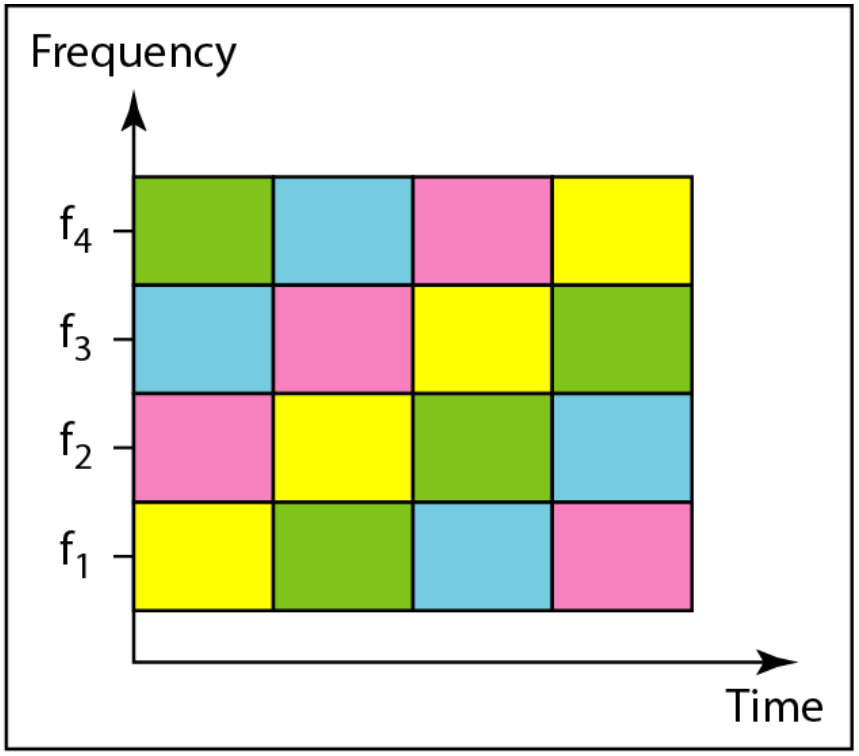
FHSS cycles


Carrier
frequencies
(kHz)
Cycle 1
Cycle 2
900
800
700
600
500
400
300
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Hop
periods

Bandwidth sharing

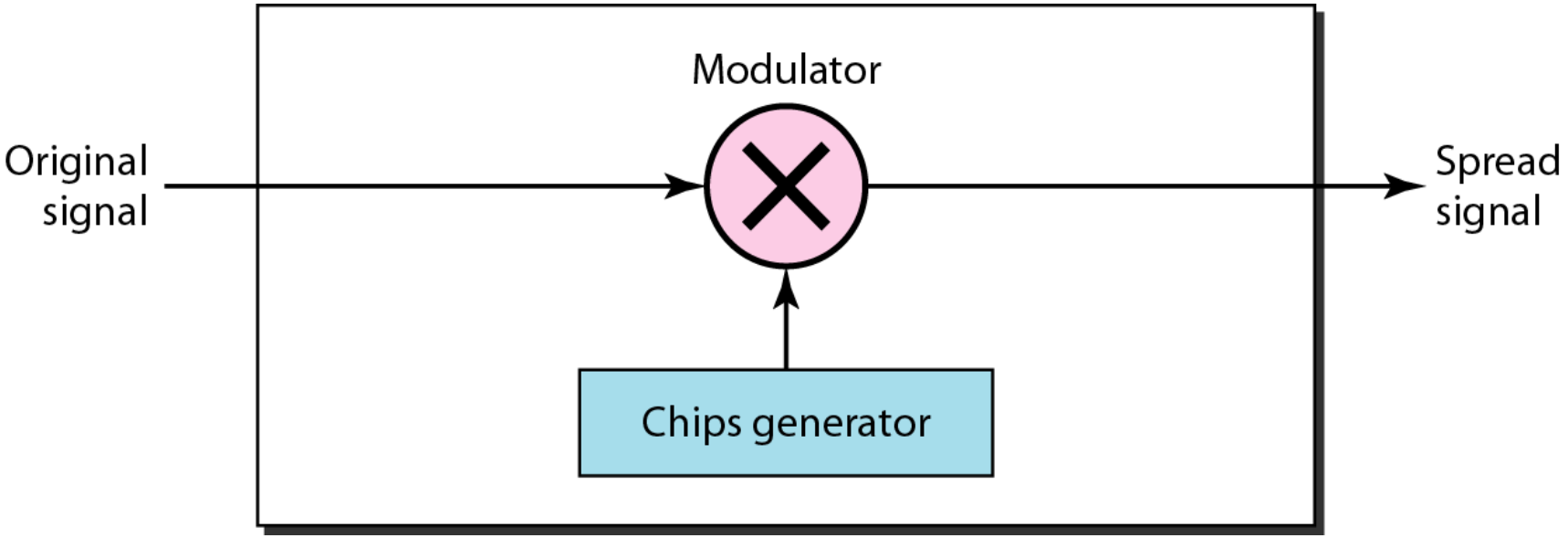


a. FDM



b. FHSS

DSSS



DSSS Example