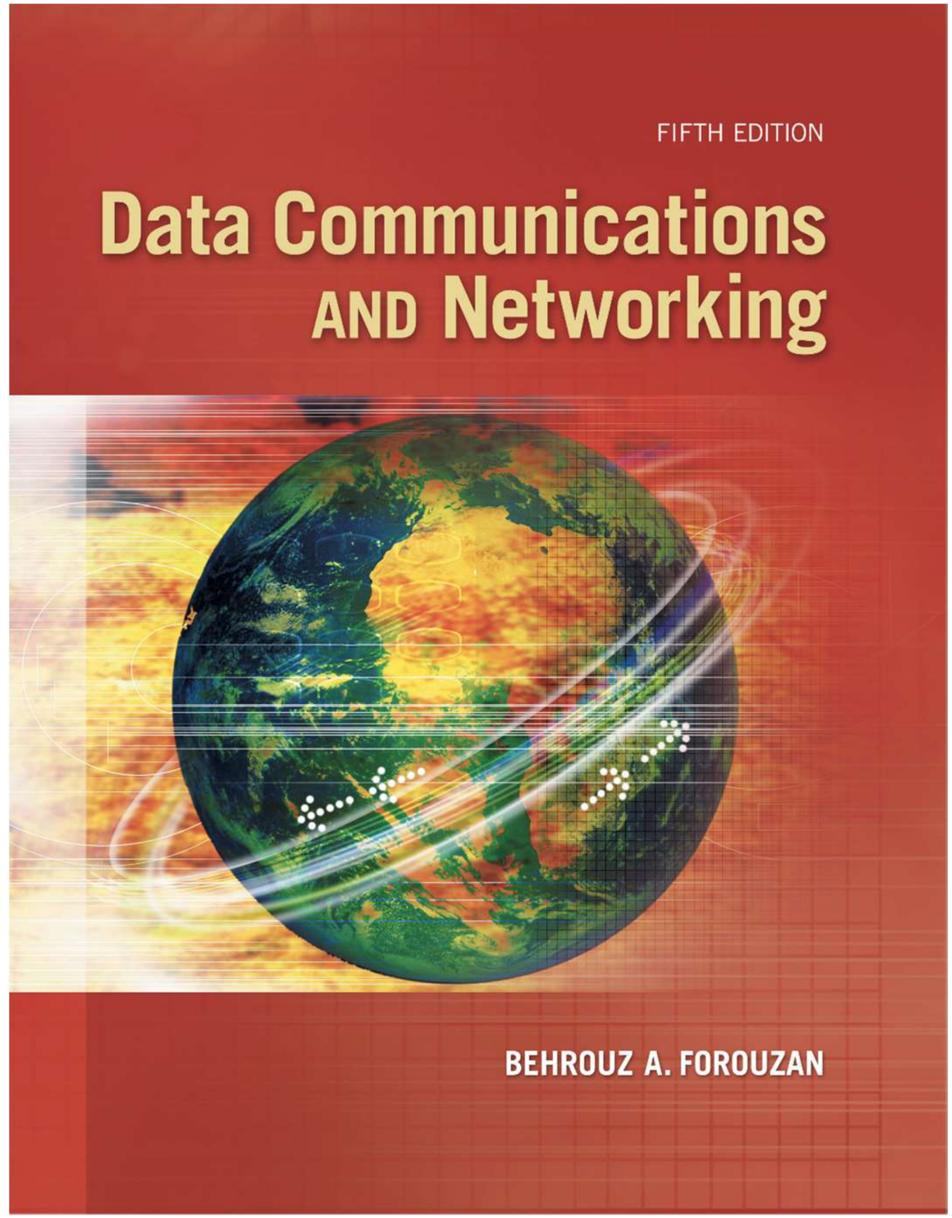
Chapter 6

Bandwidth Utilization



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Chapter 6: Outline

6.1 MULTIPLEXING

6.2 SPREAD SPECTRUM

6-1 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.

Figure 6.1: Dividing a link into channels

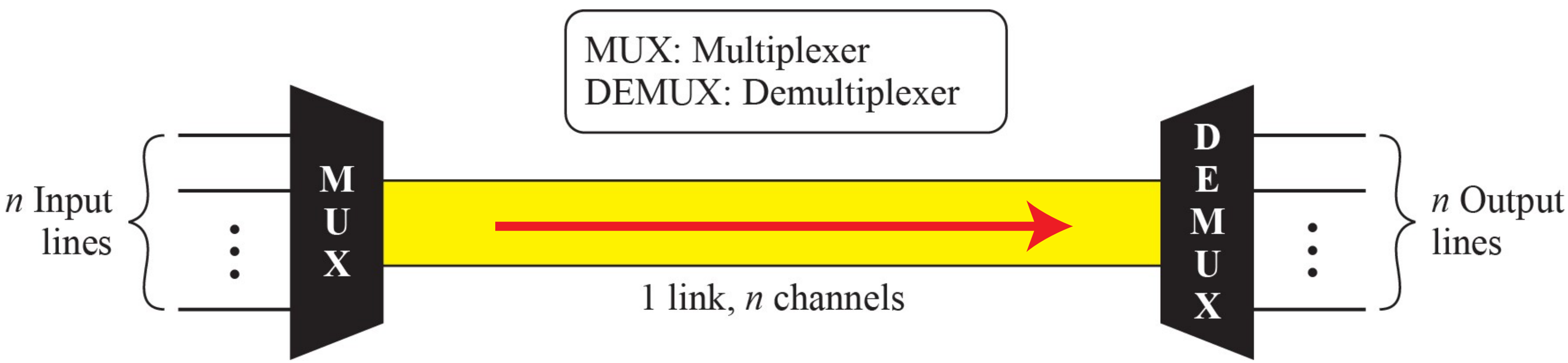
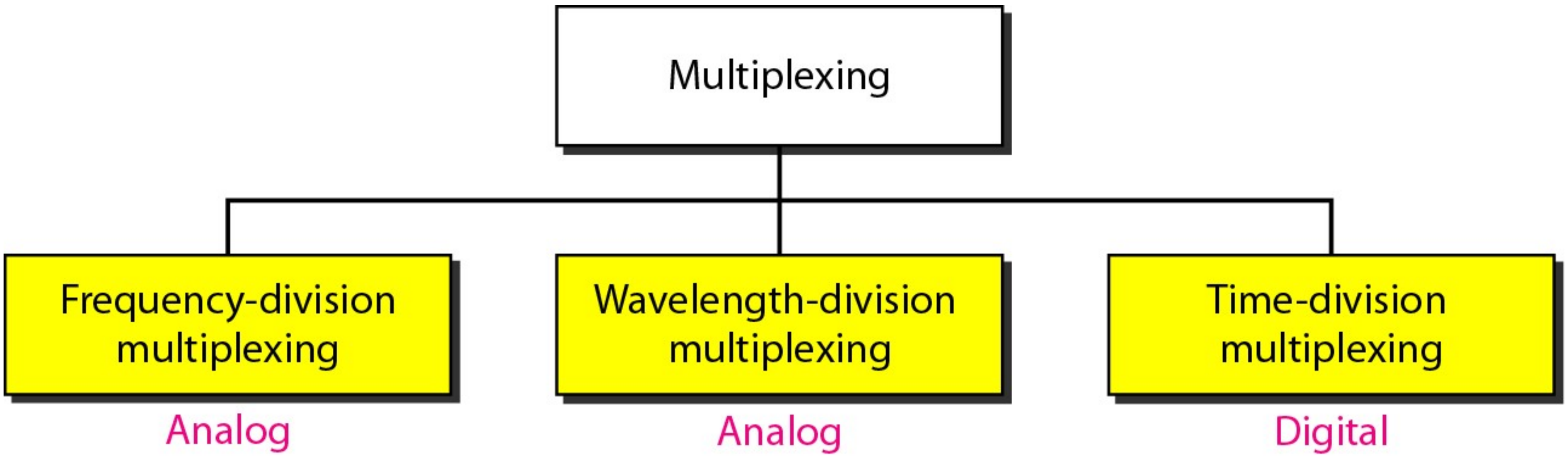


Figure 6.2: Categories of multiplexing



6.6.1 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.

Figure 6.3: Frequency-division multiplexing

Figure 6.4: FDM Process

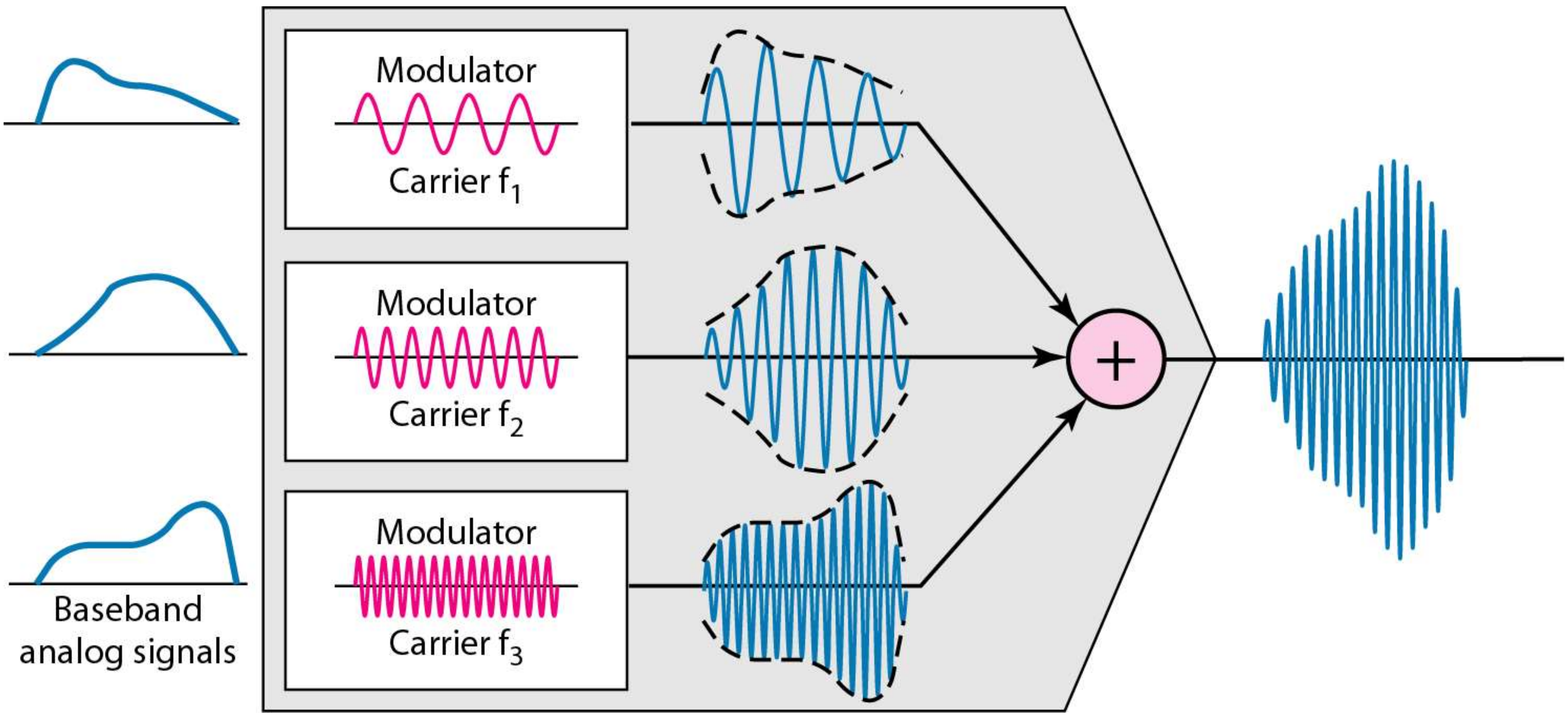
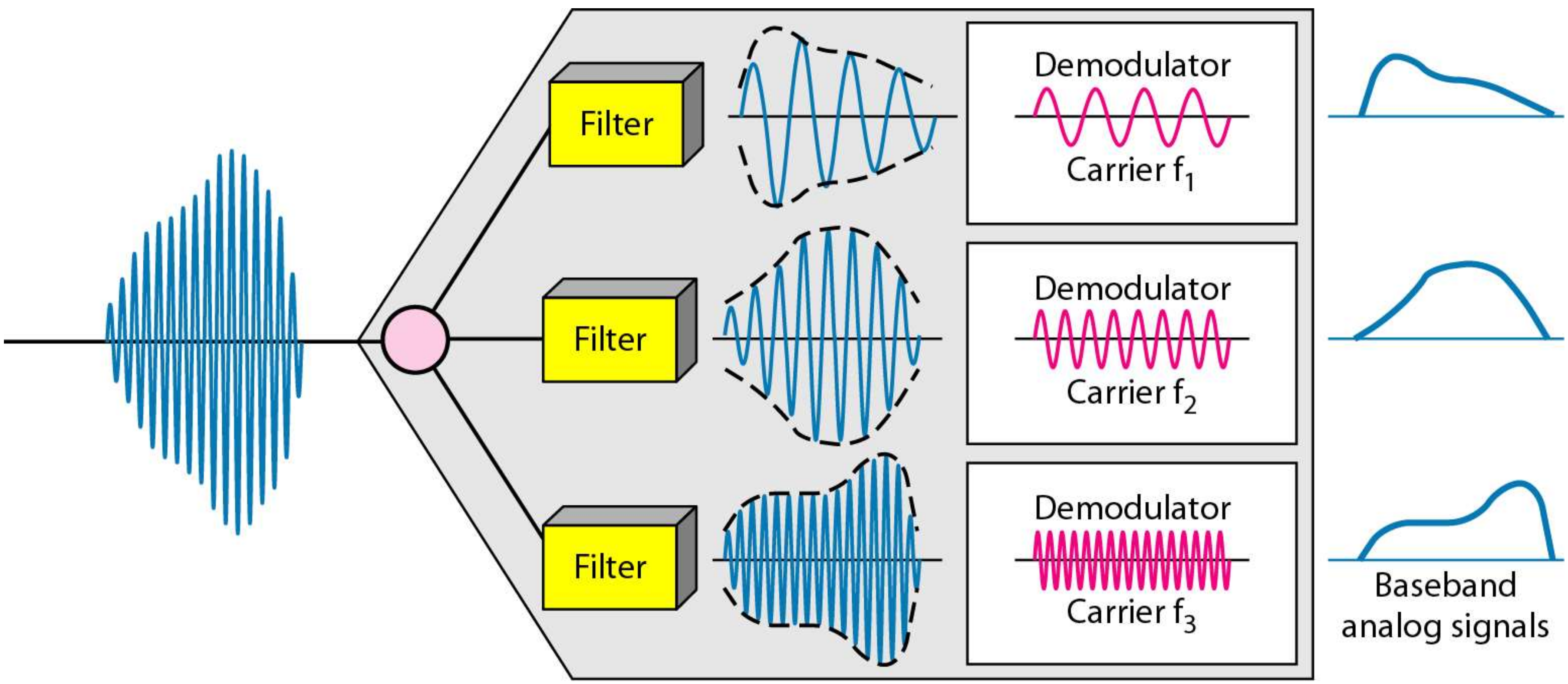


Figure 6.5: FDM demultiplexing example



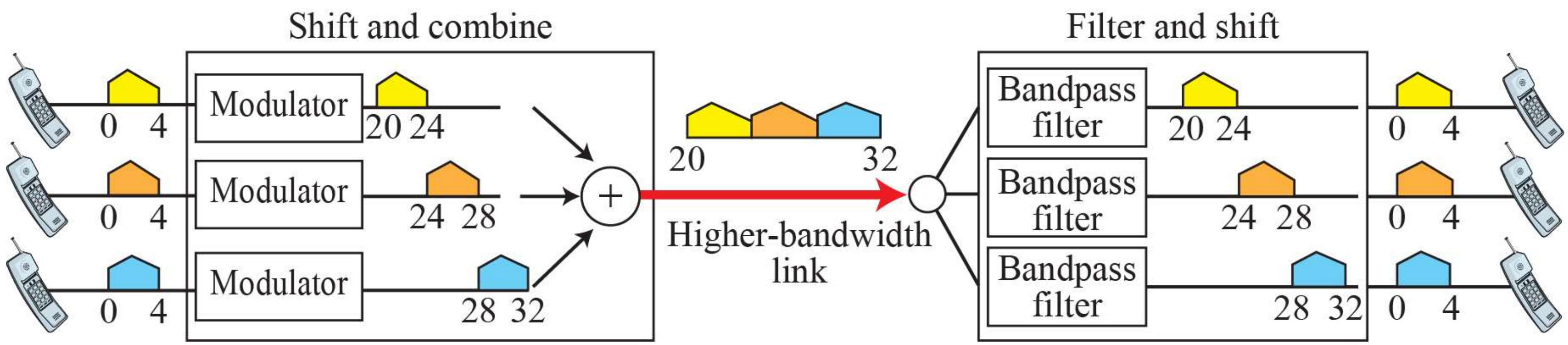
Example 6.1

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

We shift (modulate) each of the three voice channels to a different bandwidth, as shown in Figure 6.6.

Figure 6.6: Example 6.1



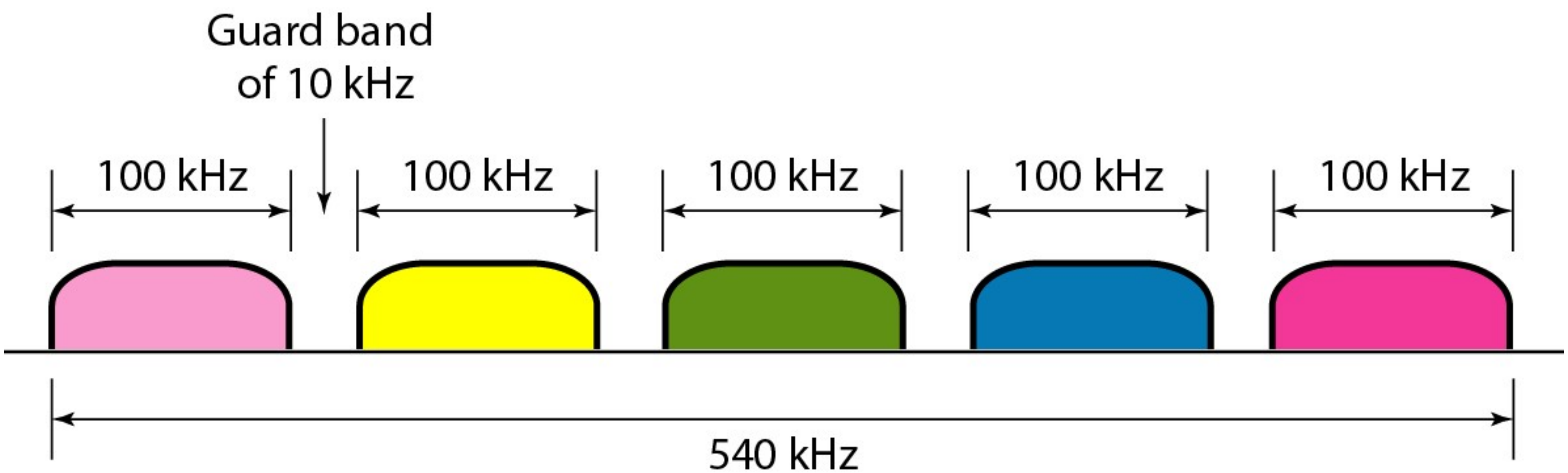
Example 6.2

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 $5 \times 100 + 4 \times 10 = 540$ kHz, as shown in Figure 6.7.

Figure 6.7: Example 6.2



6.6.2 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.

Figure 6.10: Wavelength-division multiplexing

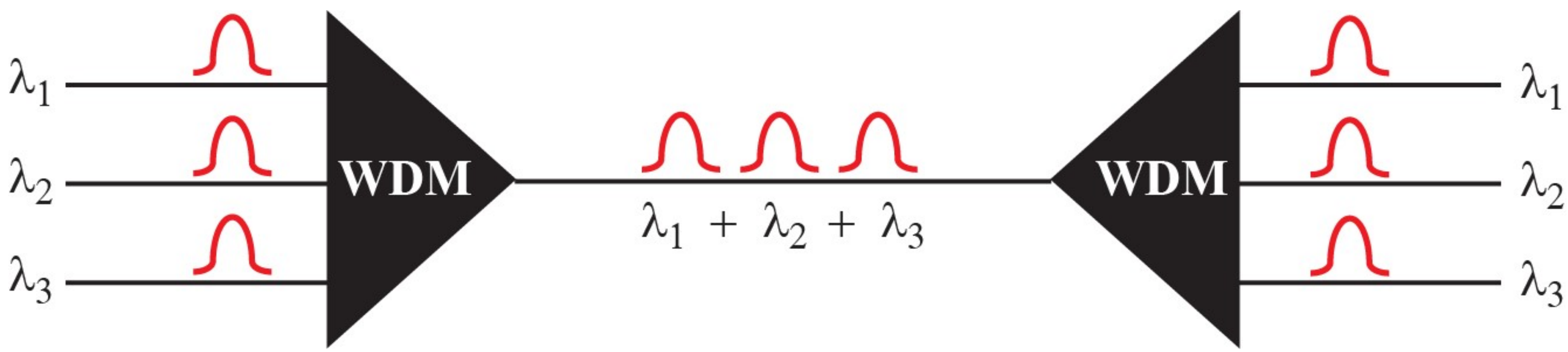
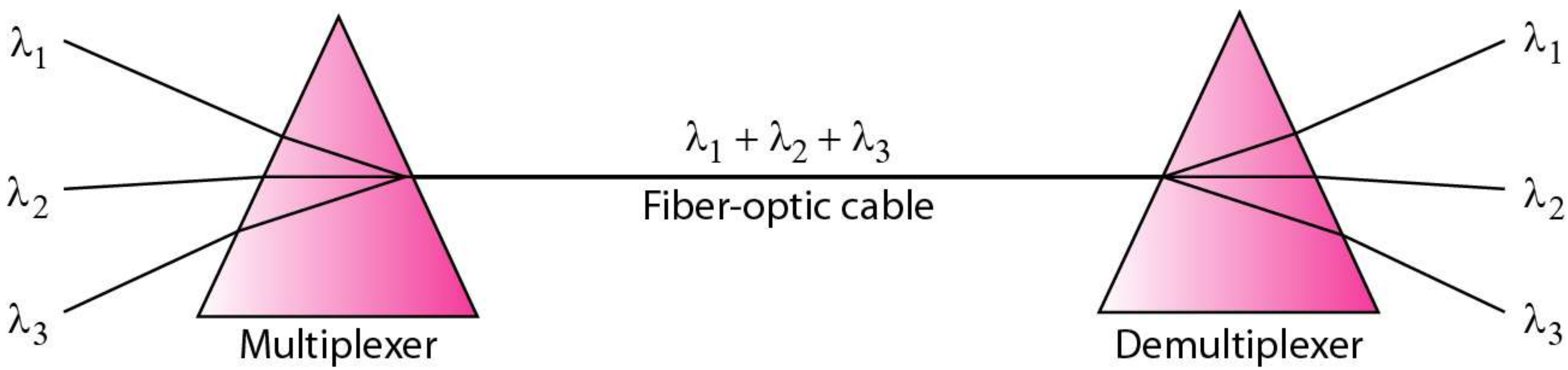


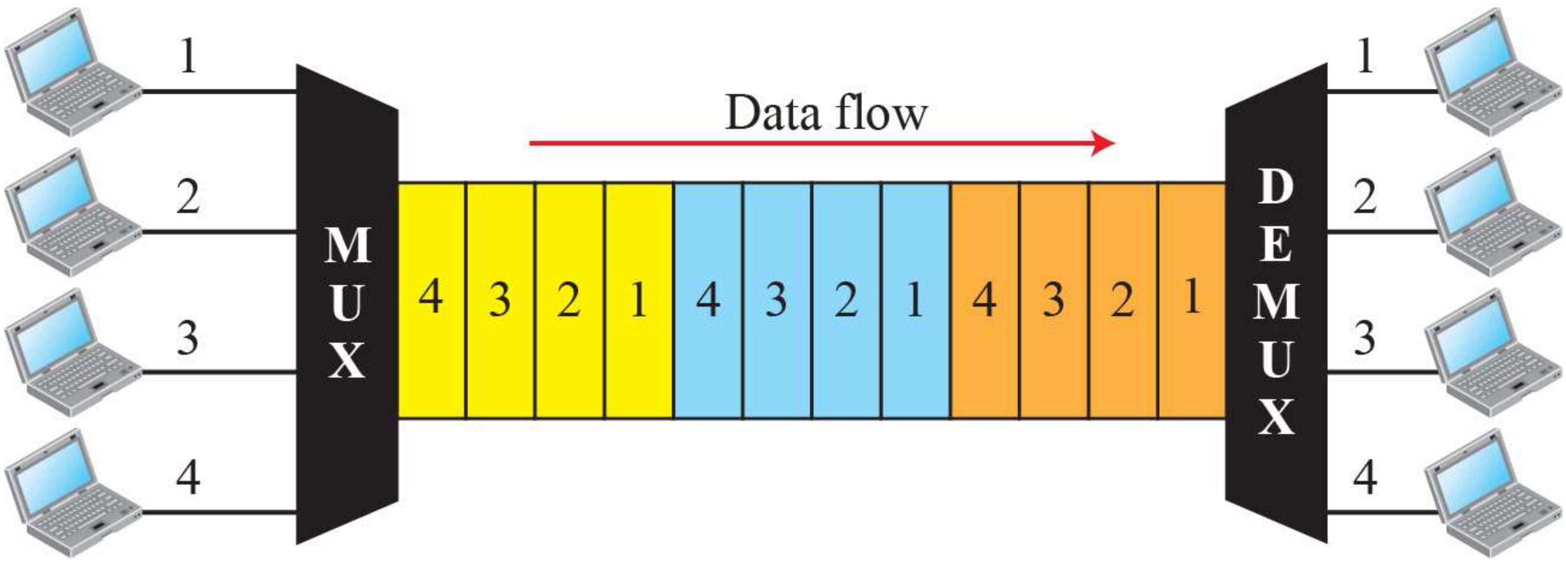
Figure 6.11: Prisms in wave-length division multiplexing



6.6.3 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. Figure 6.12 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.

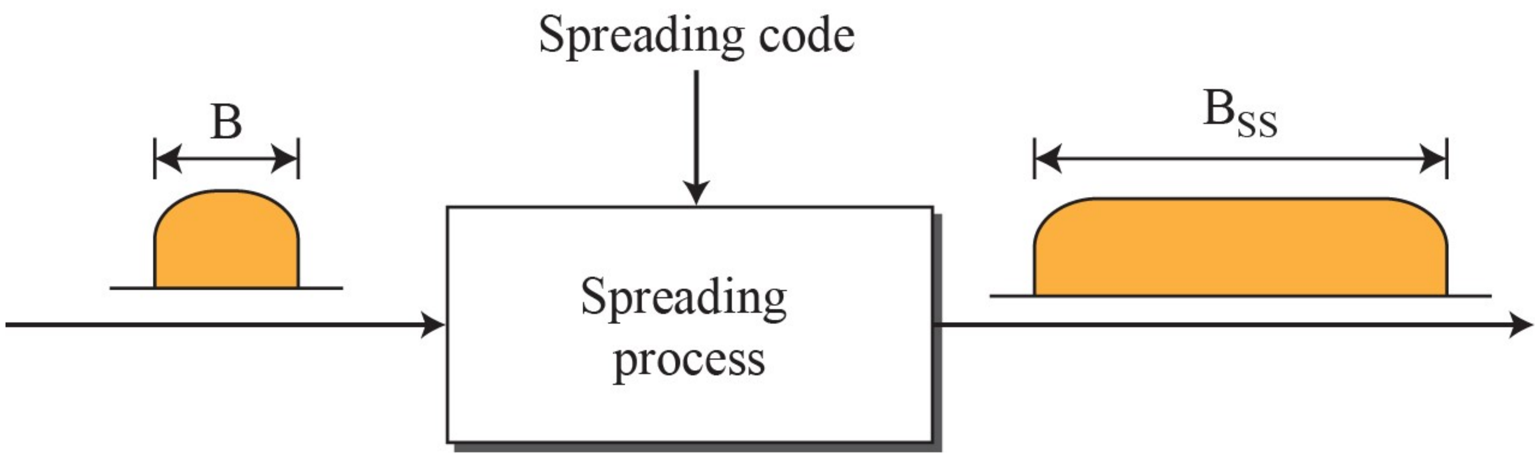
Figure 6.12: TDM



6-2 SPREAD SPECTRUM

In some applications, we have some concerns that outweigh bandwidth efficiency. In wireless applications, stations must be able to share this medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder To achieve these goals, spread spectrum techniques add redundancy;

Figure 6.27: Spread spectrum



6.2.1 FHHS

The Frequency Hopping Spread Spectrum (FHSS) technique uses M different carrier frequencies that are modulated by the source signal. At one moment, the signal modulates one carrier frequency; at the next moment, the signal modulates another carrier frequency. Although the modulation is done using one carrier frequency at a time, M frequencies are used in the long run.

The bandwidth occupied by a source after spreading is $B_{FHSS} >> B$

Figure 6.28: Frequency hopping spread spectrum (FHSS)

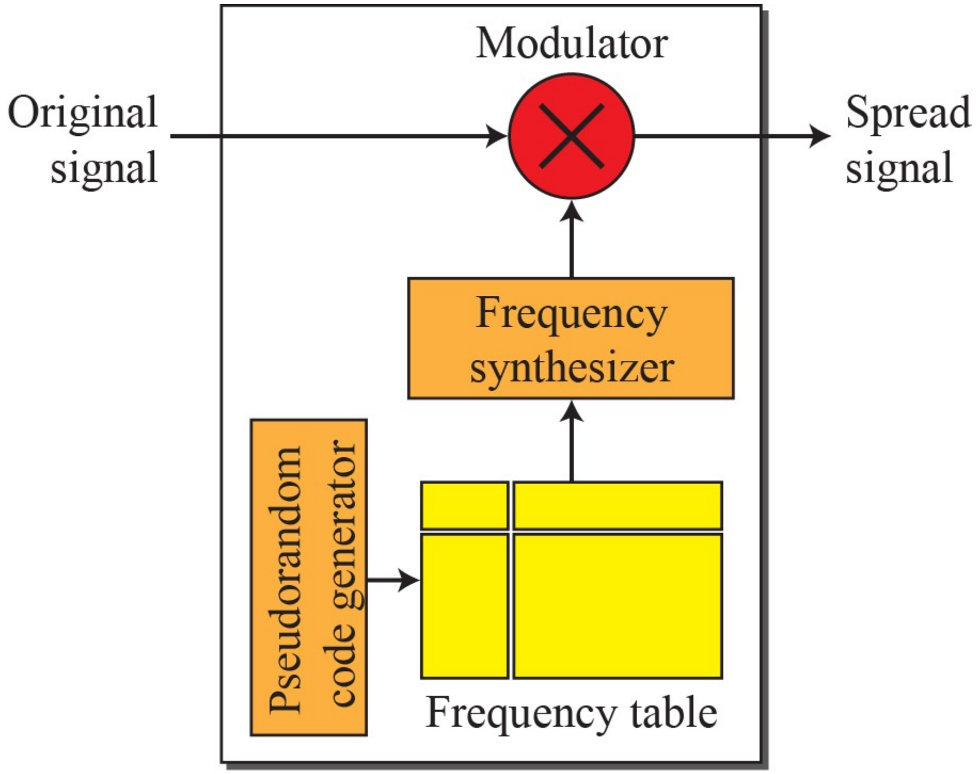


Figure 6.29: Frequency selection in FHSS

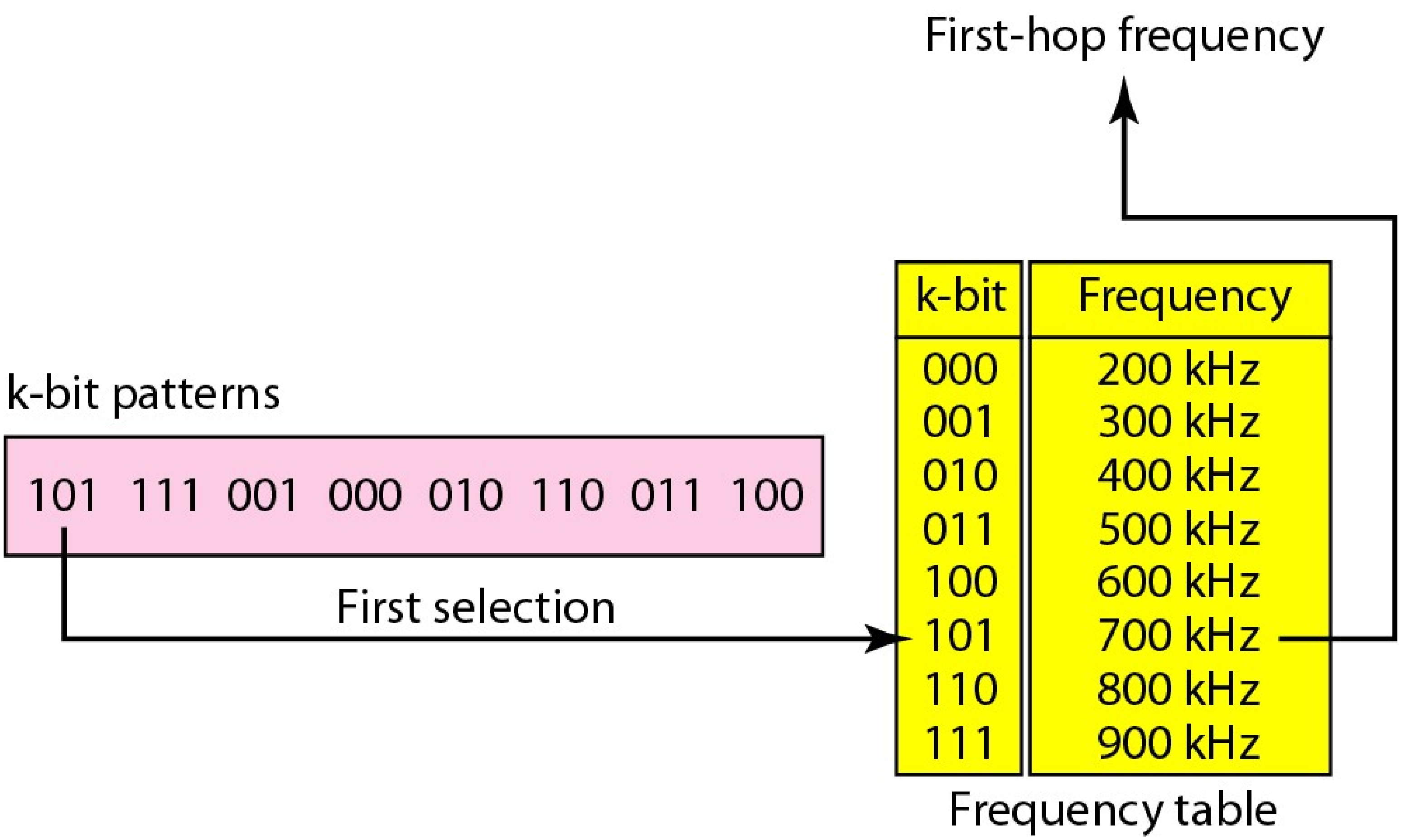


Figure 6.30: FHSS cycles

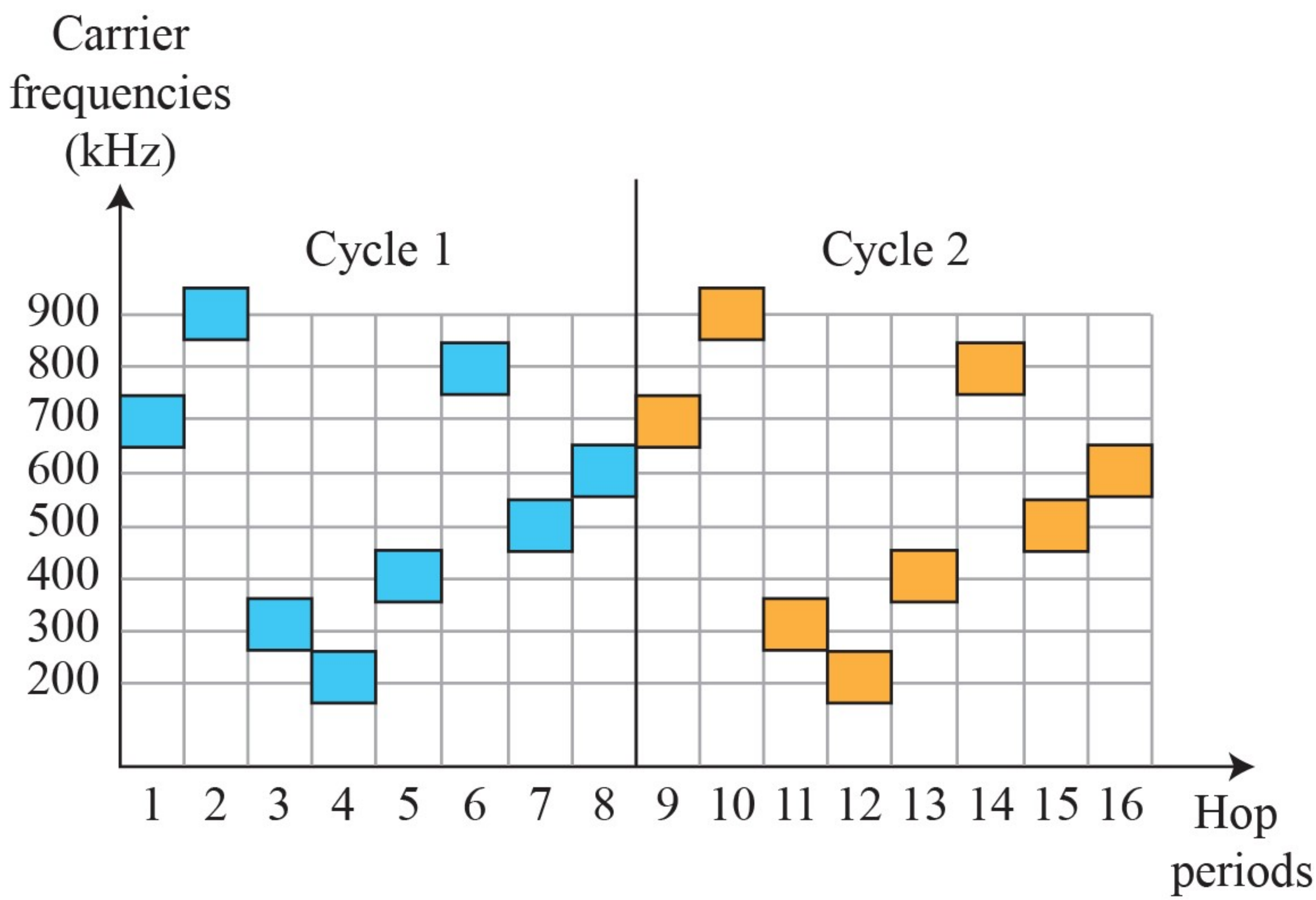
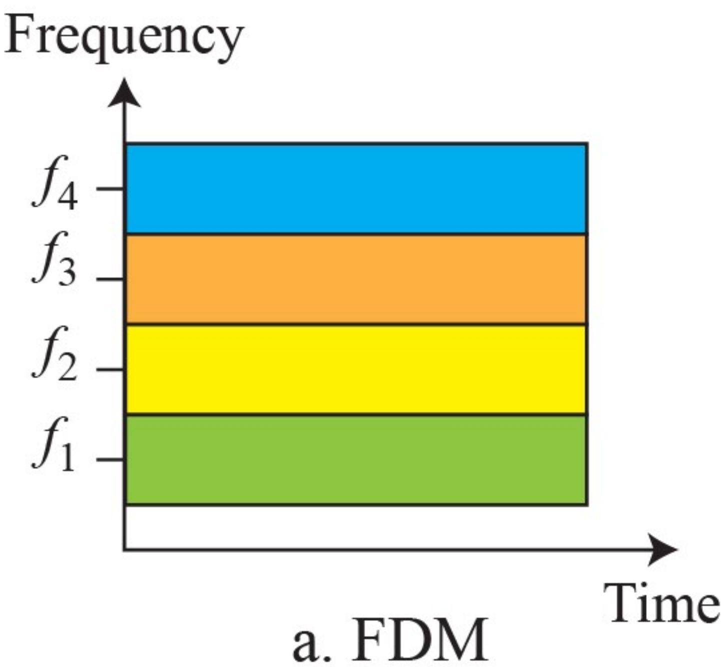
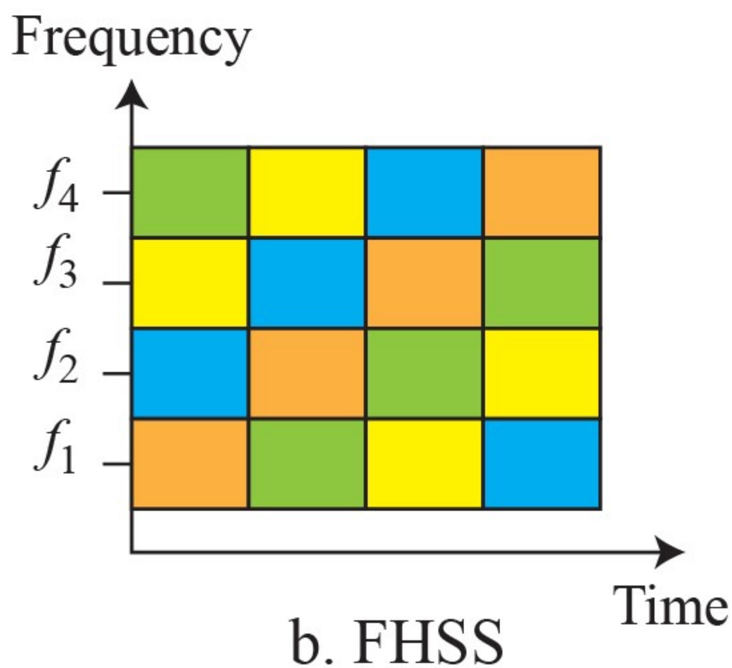


Figure 6.31:** **Bandwidth sharing





6.2.2 DSSS

The direct sequence spread spectrum (DSSS) technique also expands the bandwidth of the original signal, but the process is different. In DSSS, we replace each data bit with n bits using a spreading code. In other words, each bit is assigned a code of n bits, called chips, where the chip rate is n times that of the data bit. Figure 6.32 shows the concept of DSSS.

Figure 6.32: DSSS

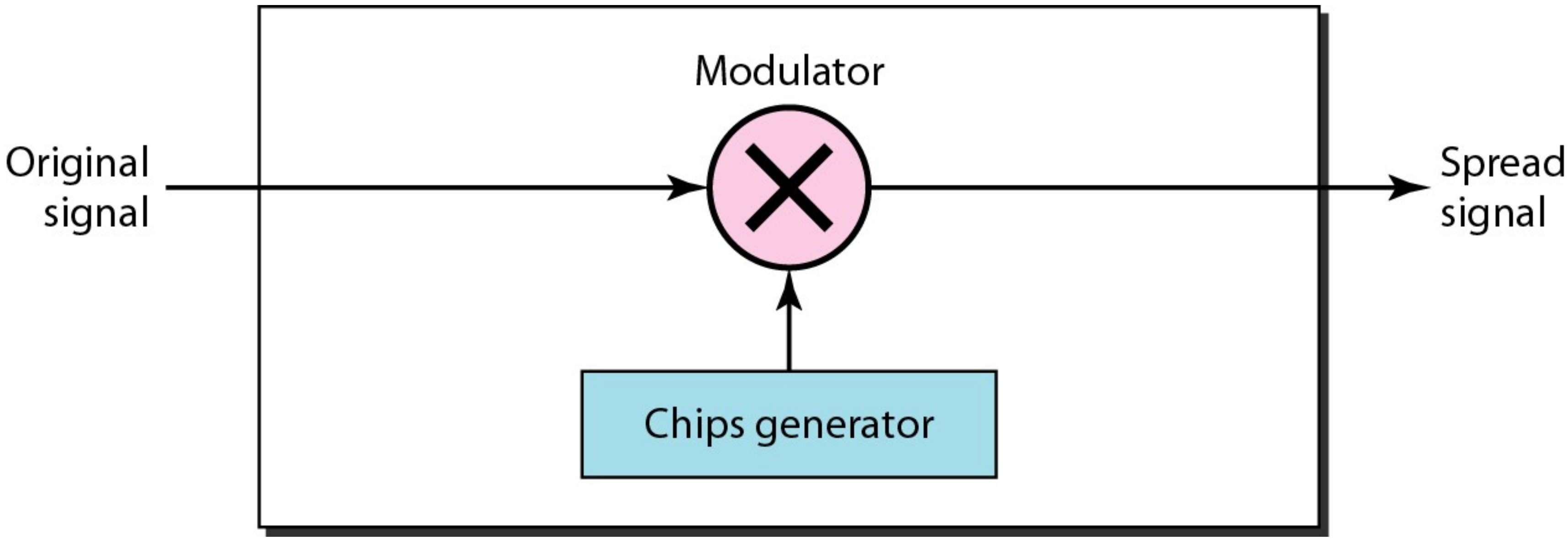


Figure 6.32: DSSS example