Analog Transmission and Bandwidth Utilization

Course Code: COE 3201 Course Title: Data Communication

Dept. of Computer Engineering
Faculty of Engineering

Lecture: 08

Lecture Outline

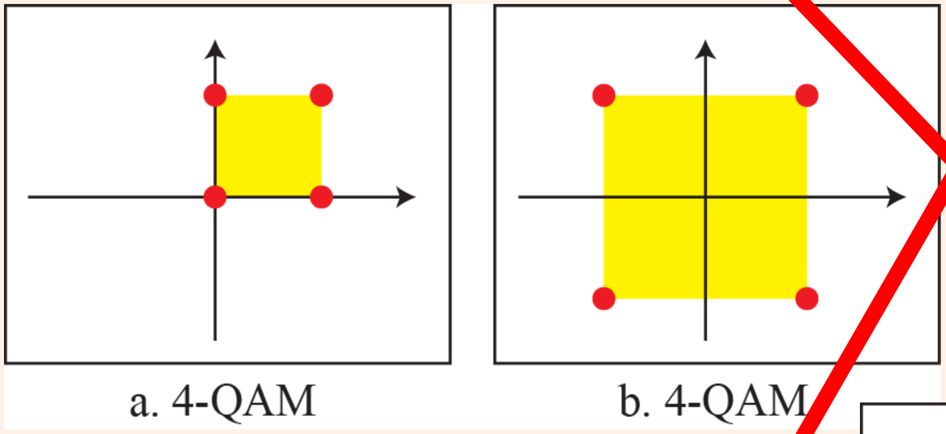
1. QAM
2. Analog to Analog Conversion
3. Amplitude Modulation (AM)
4. Frequency Modulation (FM)
5. Phase Modulation (PM)
6. Multiplexing
7. Frequency-Division Multiplexing

not required

QAM

- PSK is limited by the ability of the equipment to distinguish small differences in phase.
- This factor limits its potential bit rate.
- So far, we have been altering only one of the three characteristics of a sine wave at a time; but what if we alter two? Why not combine ASK and PSK?
- The idea of using two carriers, one in-phase and the other quadrature, with different amplitude levels for each carrier is the concept behind quadrature amplitude modulation (QAM).

Constellation diagrams for some QAMs



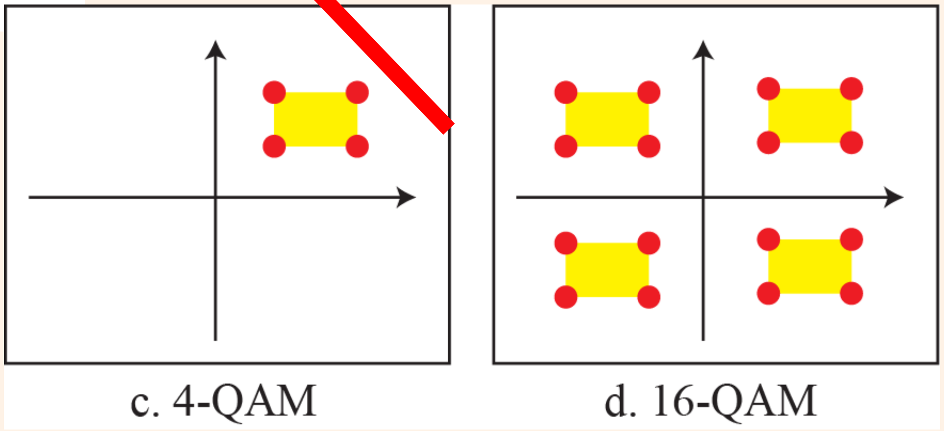
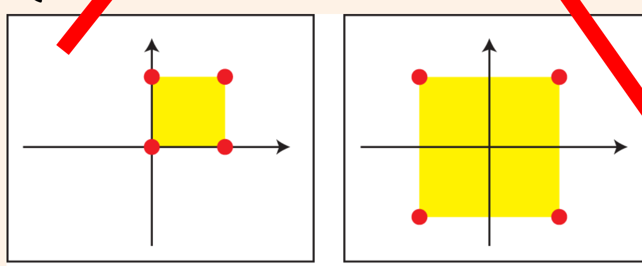


Figure 5.14: Constellation diagrams for some QAMs

Constellation diagrams for some QAMs

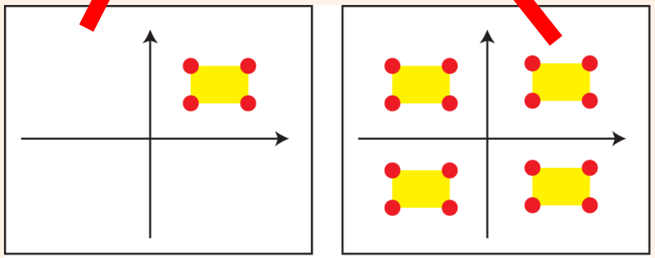
- Figure 5.14 shows some of these schemes. Figure 5.14a shows the simplest 4-QAM scheme using a unipolar NRZ signal to modulate each carrier. This is the same mechanism we used for ASK (OOK).
- Part b shows another 4-QAM using polar NRZ, but this is the same as QPSK.



a. 4-QAM b. 4-QAM

Constellation diagrams for some QAMs

- ~~Part c shows another QAM-4 in which we used a signal with two positive levels to modulate each of the two carriers.~~
- ~~Finally, Figure 5.14d shows a 16-QAM constellation of a signal with eight levels, four positive and four negative.~~



c. 4-QAM d. 16-QAM

Analog to Analog Conversion

- Analog-to-analog conversion, or analog modulation, is the representation of analog information by an analog signal. One may ask why we need to modulate an analog signal; it is already analog. Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us. Analog-to-analog conversion can be accomplished in three ways: AM FM and PM.

Analog to Analog Conversion

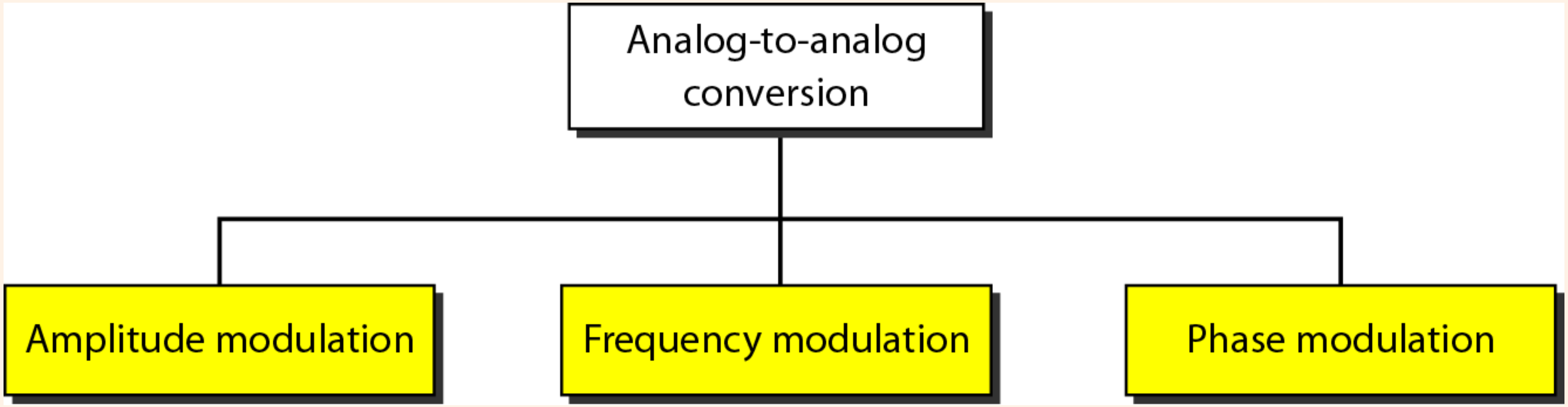


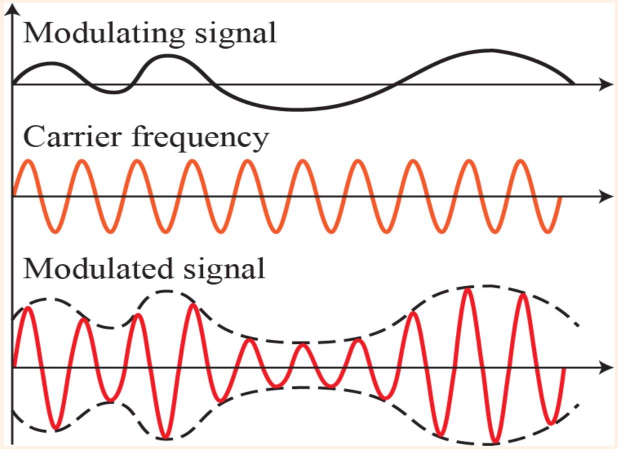
Figure 5.15: Types of analog-to-analog modulation

Amplitude Modulation (AM)

- In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal.
- The frequency and phase of the carrier remain the same; only the amplitude changes to follow variations in the information.
- Figure 5.16 shows how this concept works.
- The modulating signal is the envelope of the carrier.

Amplitude Modulation (AM)

- As Figure 5.16 shows, AM is normally implemented by using a simple multiplier because the amplitude of the carrier signal needs to be changed according to the amplitude of the modulating signal.



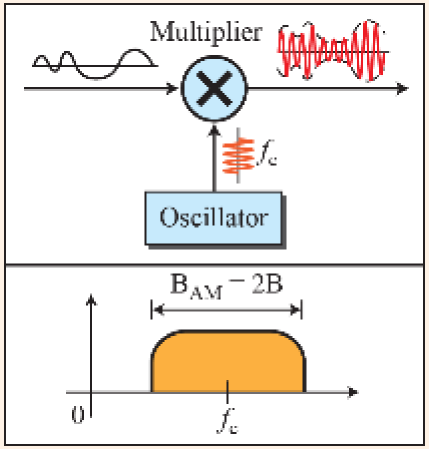


Figure 5.16: Amplitude modulation

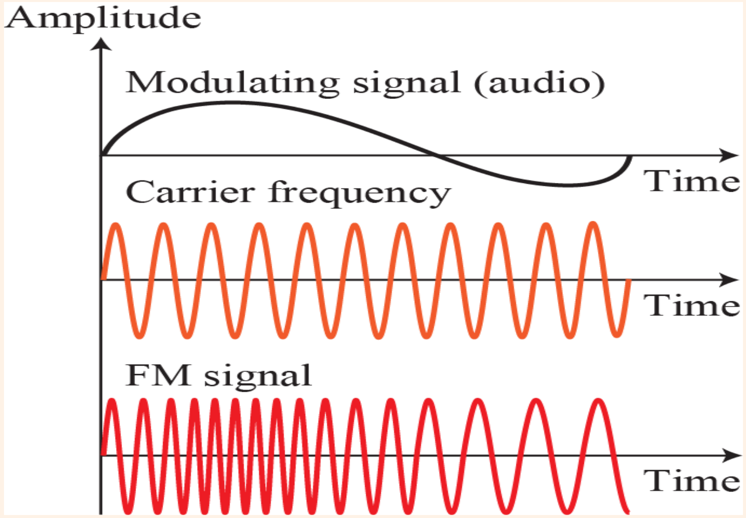
Amplitude Modulation (AM)

- An increase in the amplitude of the modulating signal causes the amplitude of the carrier to increase.
- An increase or a decrease in the amplitude of the modulating signal causes a corresponding increase or decrease in both the positive and the negative peaks of the carrier amplitude.
- An imaginary line connecting the positive peaks and negative peaks of the carrier waveform (the dashed line in the figure) gives the exact shape of the modulating information signal.
- This imaginary line on the carrier waveform is known as the envelope.

Frequency Modulation (FM)

- In FM transmission, the frequency of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.
- The peak amplitude and phase of the carrier signal remain constant, but as the amplitude of the information signal changes, the frequency of the carrier changes correspondingly.
- Figure 5.18 shows the relationships of the modulating signal, the carrier signal, and the resultant FM signal.

Frequency Modulation (FM)



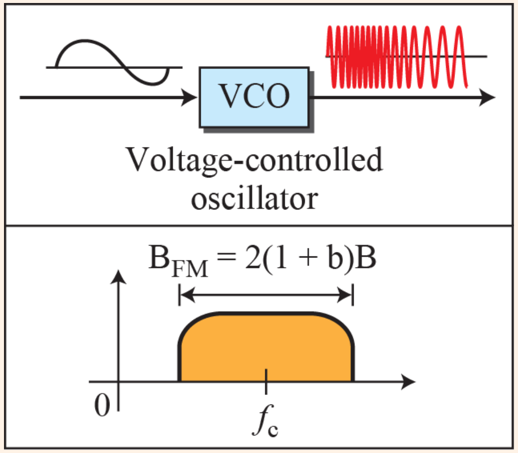
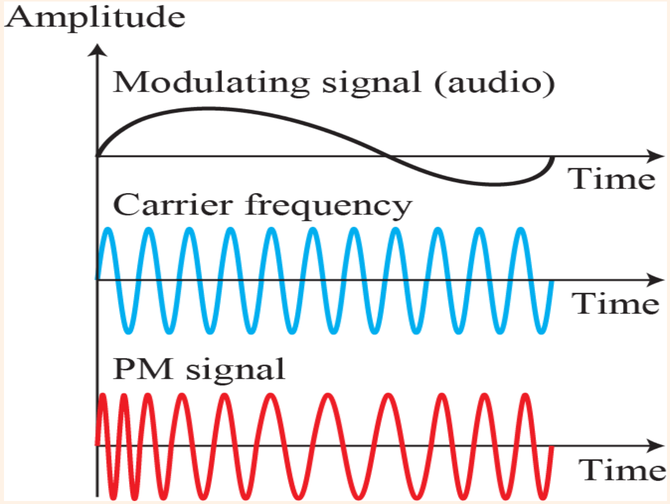


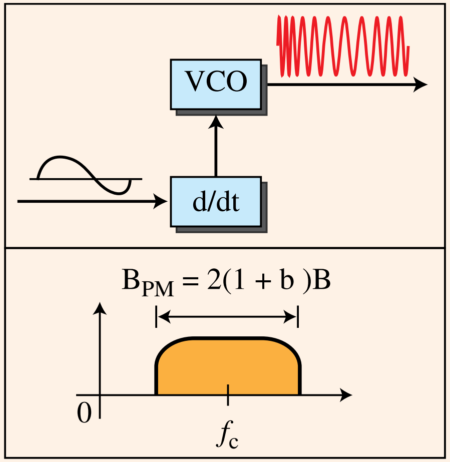
Figure 5.18: Frequency modulation

Phase Modulation (PM)

- In PM transmission, the phase of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.
- The peak amplitude and frequency of the carrier signal remain constant, but as the amplitude of the information signal changes, the phase of the carrier changes correspondingly.

Phase Modulation (PM)





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.

Multiplexing

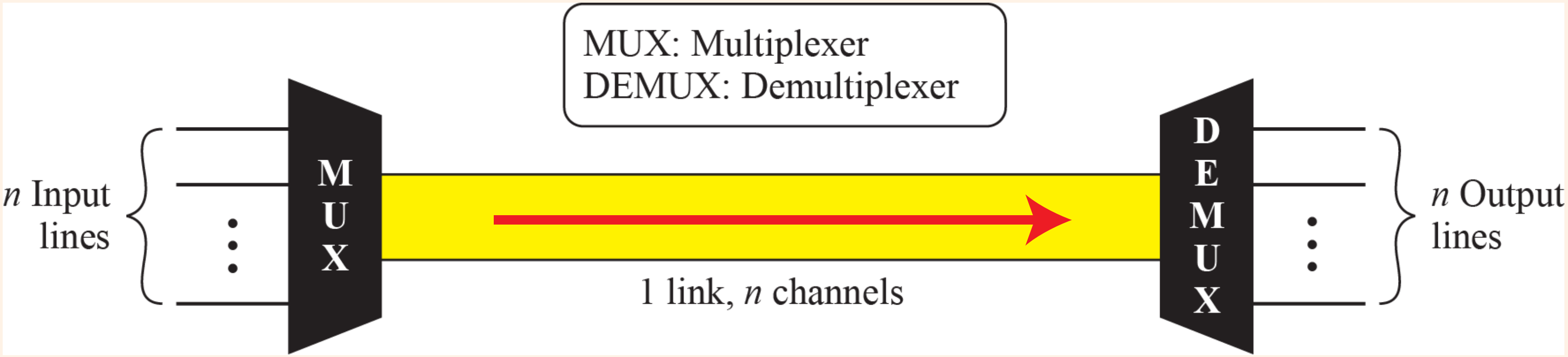


Figure 6.1: Dividing a link into channels

Multiplexing

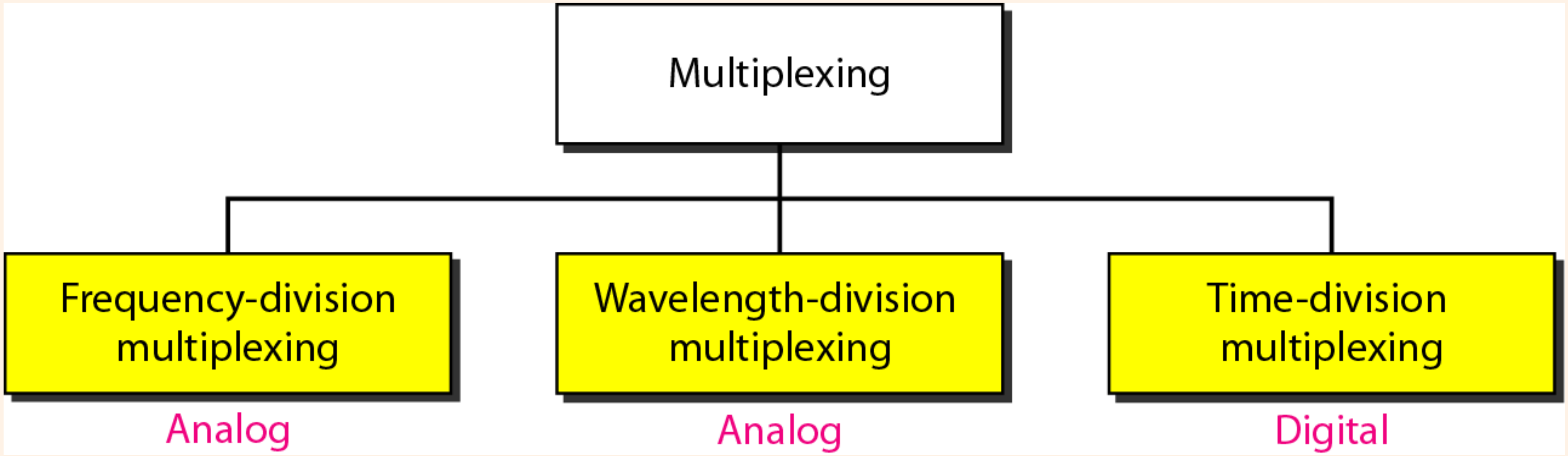
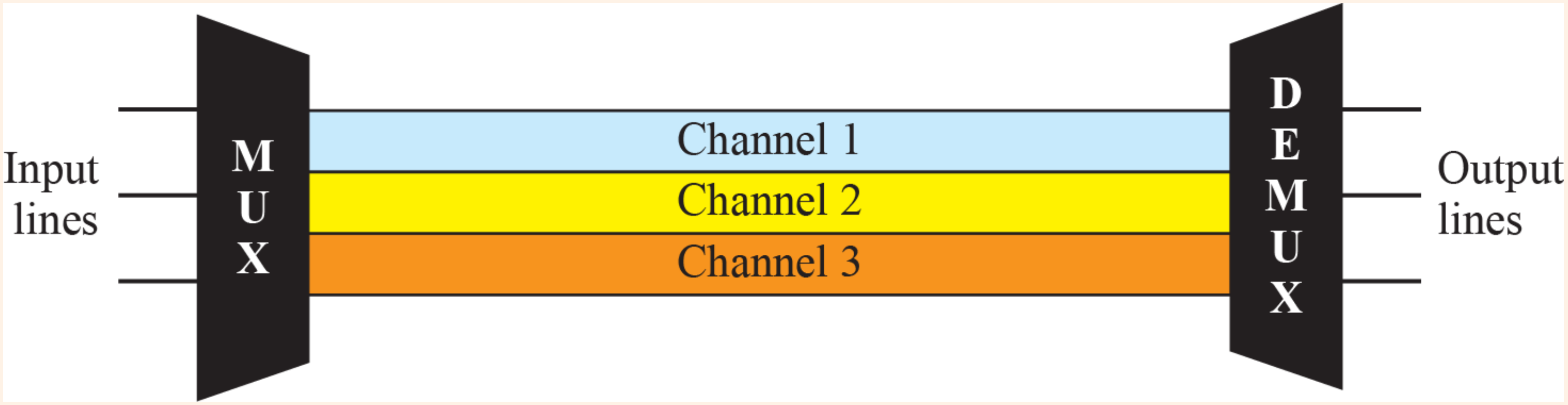


Figure 6.2: Categories of multiplexing

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 Process

- Figure 6.4 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 (f1, f2, and f3).
- 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

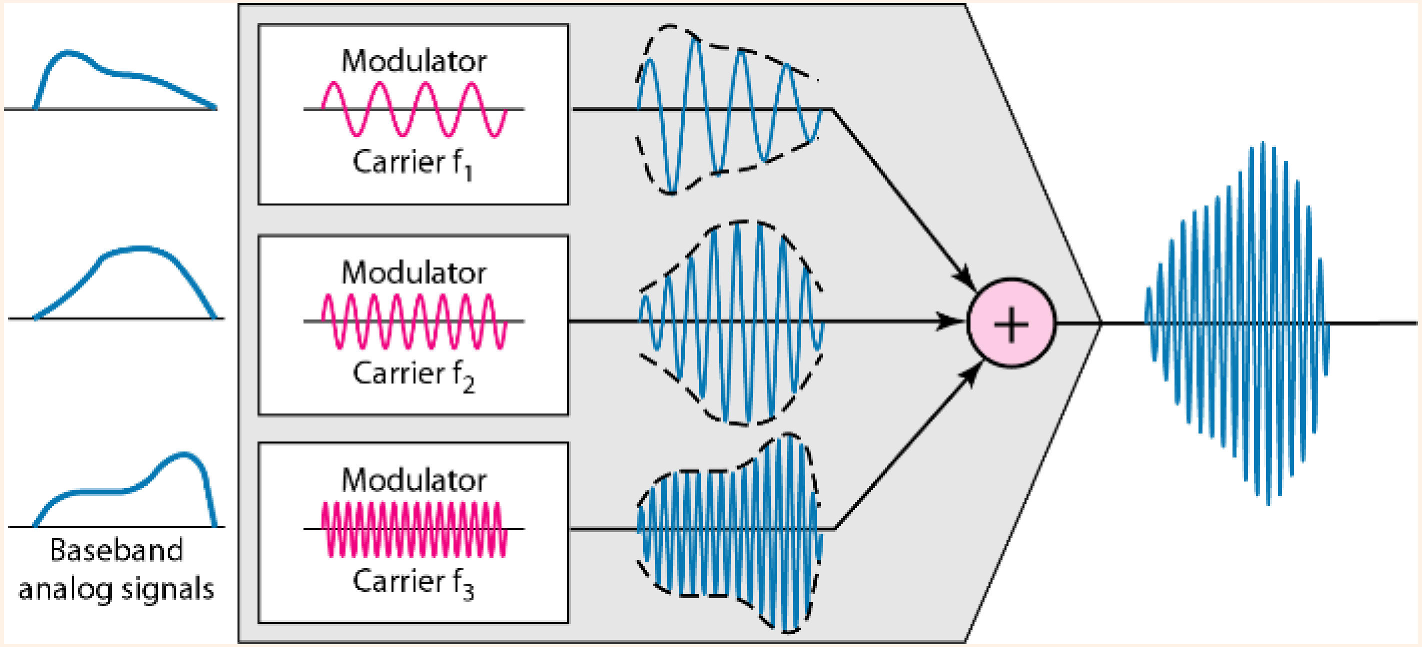


Figure 6.4: FDM Process

Multiplexing Process

Figure 8.4 *FDM multiplexing process, time domain*

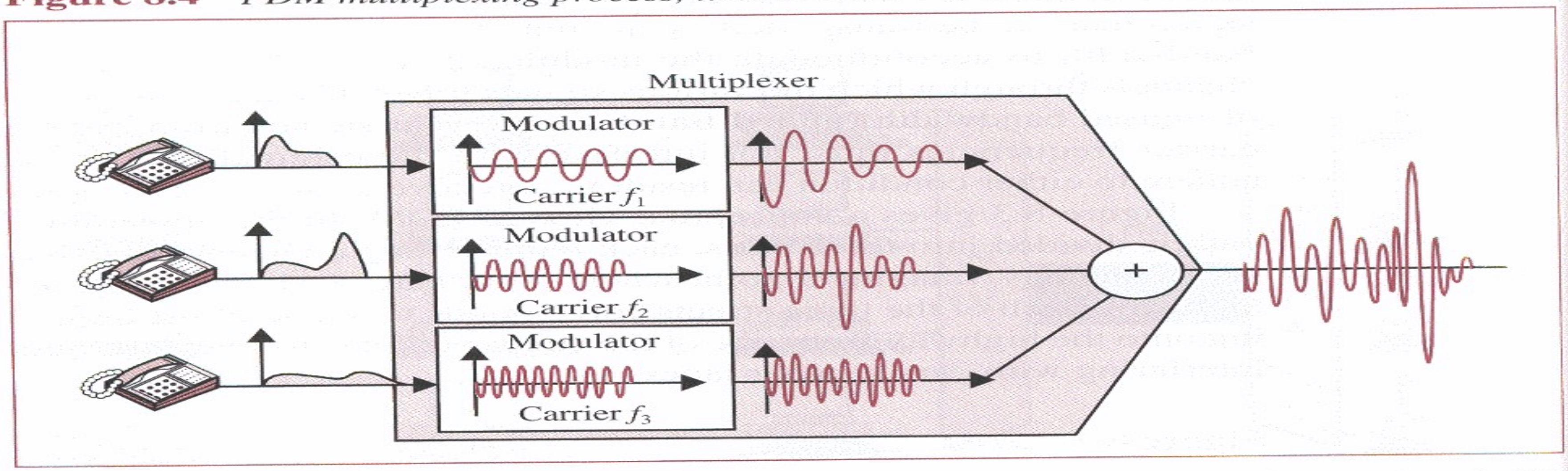
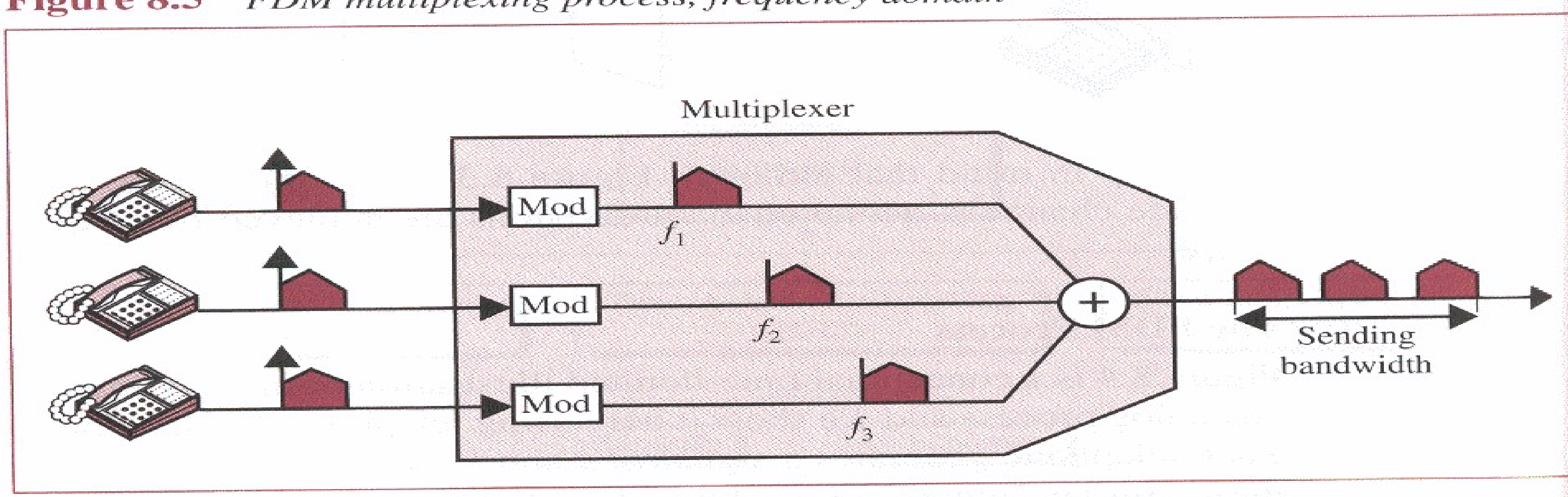


Figure 8.5 *FDM multiplexing process, frequency domain*



FDM Demultiplexing

- 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.
- Figure 6.5 is a conceptual illustration of demultiplexing process.

FDM Demultiplexing

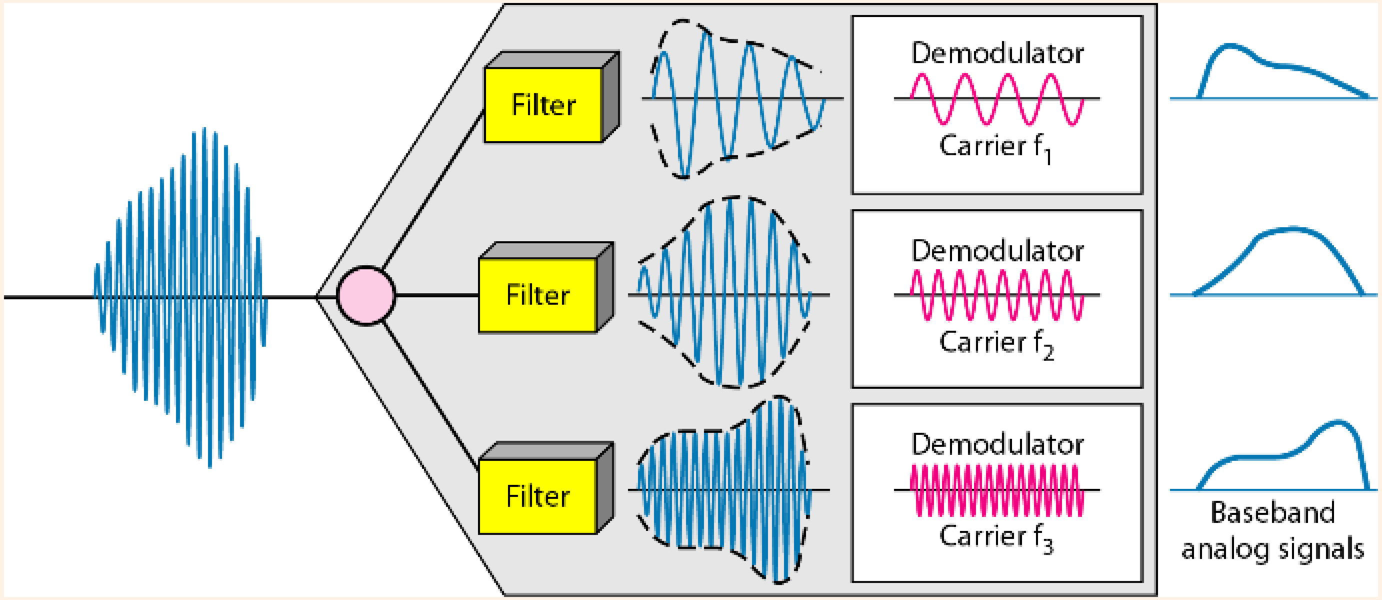


Figure 6.5: FDM demultiplexing example

Demultiplexing Process

Figure 8.6 *FDM demultiplexing process, time domain*

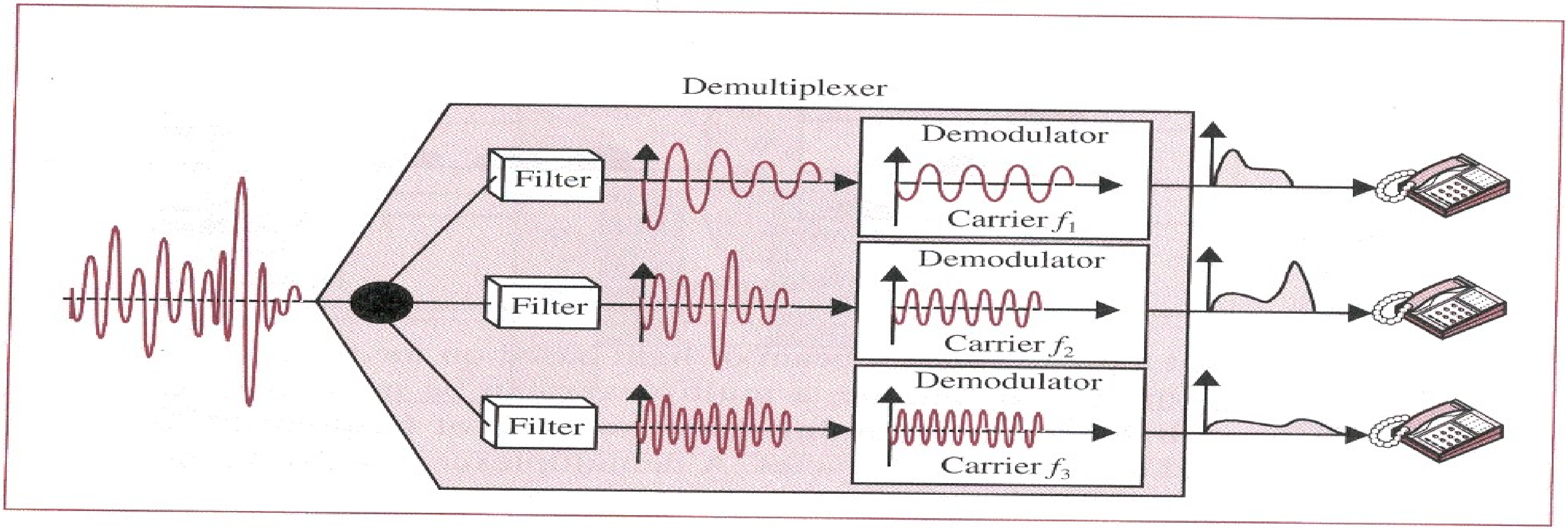
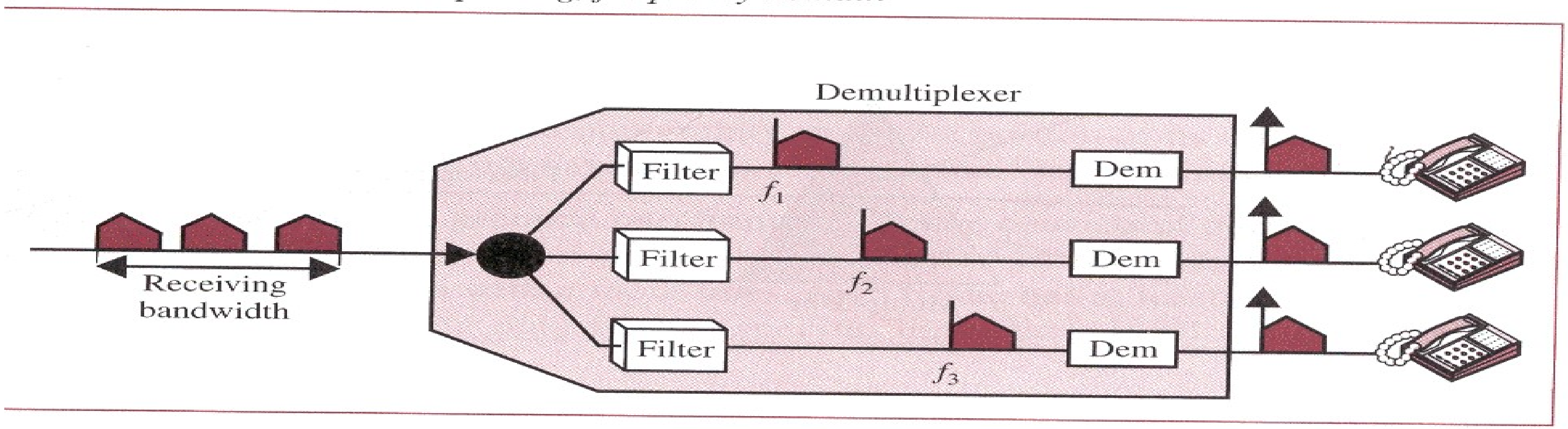


Figure 8.7 *FDM demultiplexing, frequency domain*

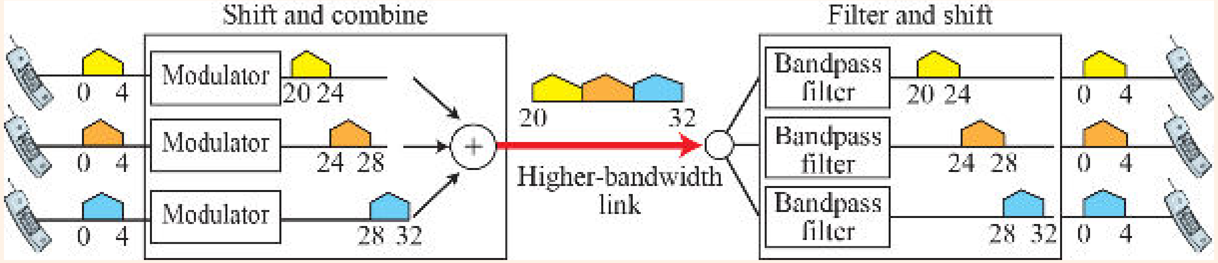


important for assignment

Frequency-Division Multiplexing

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 the figure,

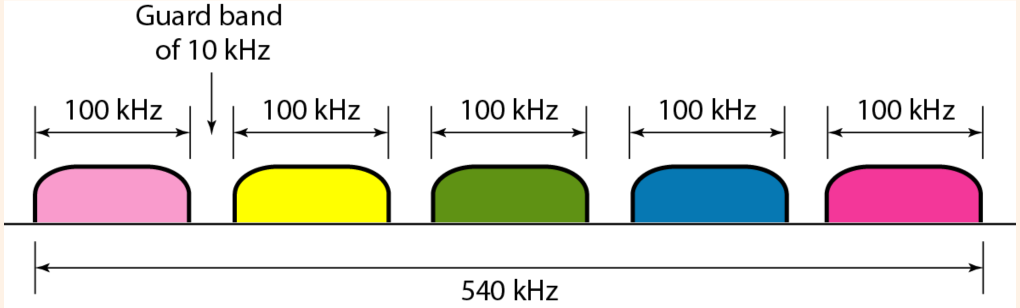


important for assignment

Frequency-Division Multiplexing

Example 6.1: 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 the figure.



Frequency-Division Multiplexing

Example 6.1: Four data channels (digital), each transmitting at 1 Mbps, use a satellite channel of 1 MHz. Design an appropriate configuration, using FDM.

Solution: The satellite channel is analog. We divide it into four channels, each channel having a 250-kHz bandwidth. Each digital channel of 1 Mbps is modulated so that each 4 bits is modulated to 1 Hz. One solution is 16-QAM modulation. Figure 6.8 shows one possible configuration.

Frequency-Division Multiplexing

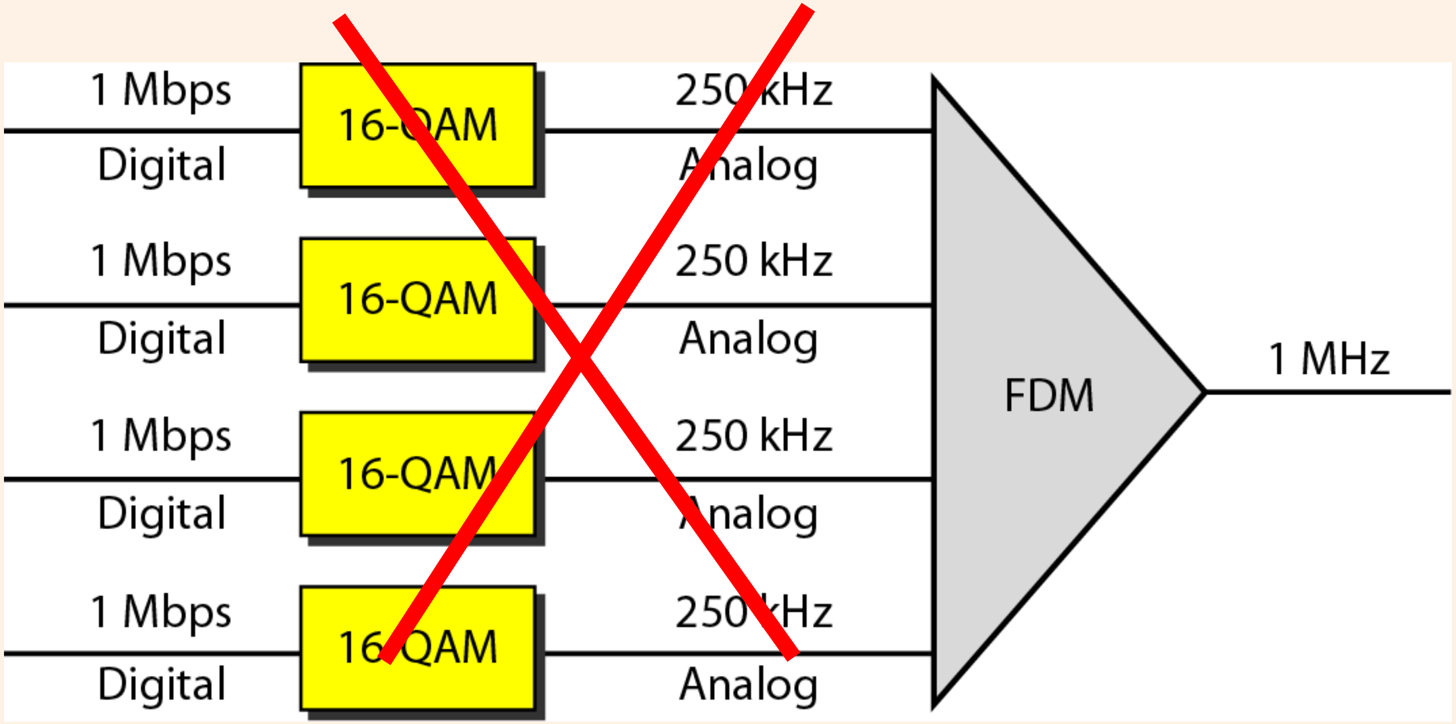


Figure 6.8: Example 6.3

Analog Hierarchy

- To maximize the efficiency of their infrastructure, telephone companies have traditionally
- multiplexed signals from lower-bandwidth lines onto higher-bandwidth lines.
- In this way, many switched or leased lines can be combined into fewer but bigger channels. For analog lines, FDM is used.
- One of these hierarchical systems used by telephone companies is made up of
- groups, supergroups, master groups, and jumbo groups (see Figure 6.9).

Analog Hierarchy

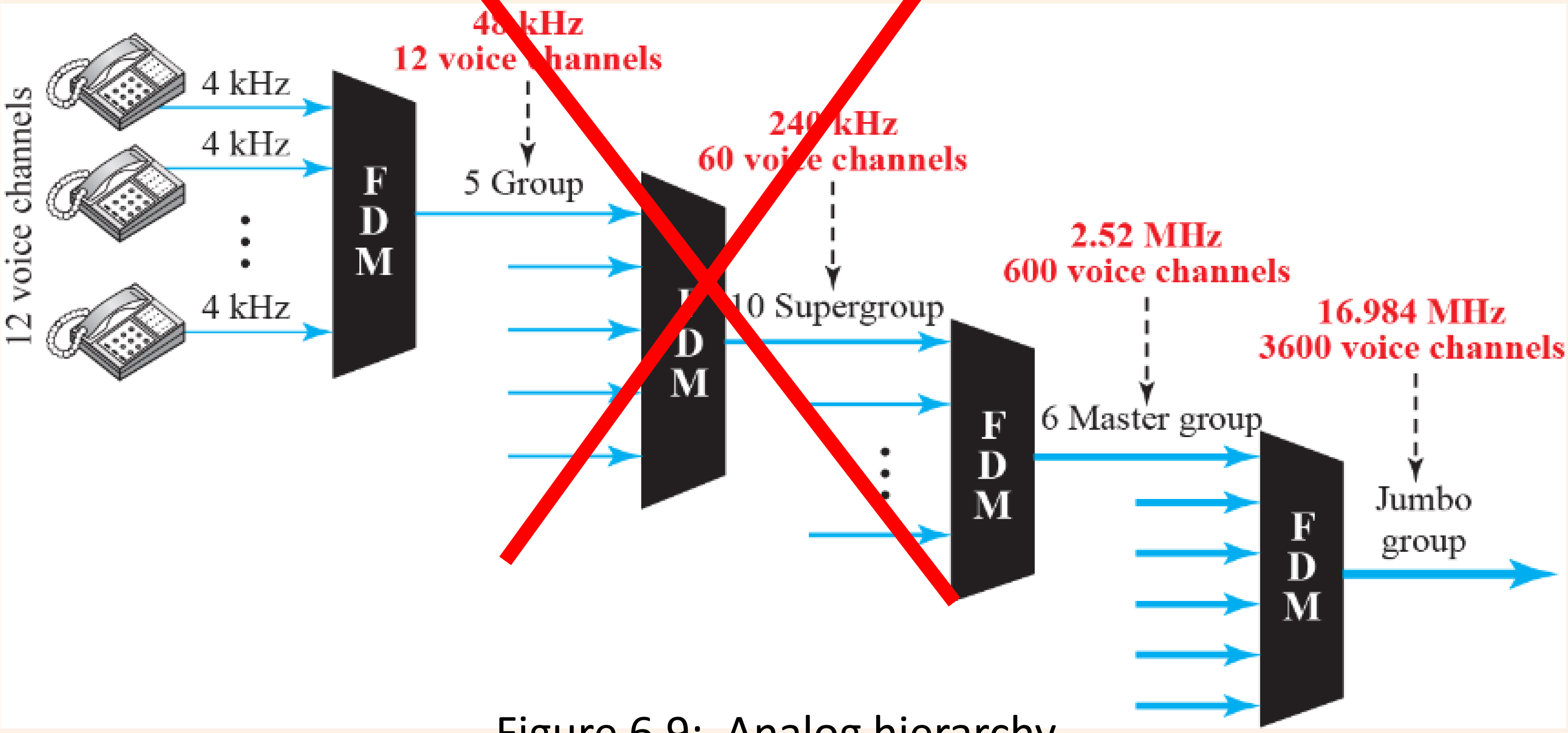


Figure 6.9: Analog hierarchy

Analog Hierarchy

- In this analog hierarchy, 12 voice channels are multiplexed onto a higher-bandwidth line to create a group. A group has 48 kHz of bandwidth and supports 12 voice channels.
- At the next level, up to five groups can be multiplexed to create a composite signal called a supergroup. A supergroup has a bandwidth of 240 kHz and supports up to 60 voice channels. Supergroups can be made up of either five groups or 60 independent voice channels.

Analog Hierarchy

- At the next level, 10 supergroups are multiplexed to create a master group. A master group must have 2.40 MHz of bandwidth, but the need for guard bands between the supergroups increases the necessary bandwidth to 2.52 MHz. Master groups support up to 600 voice channels.
- Finally, six master groups can be combined into a jumbo group. A jumbo group must have 15.12 MHz (6 × 2.52 MHz) but is augmented to 16.984 MHz to allow for guard bands between the master groups.