Chapter 5

Analog Transmission

Partially Edited and Presented by

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5-1 DIGITAL-TO-ANALOG CONVERSION

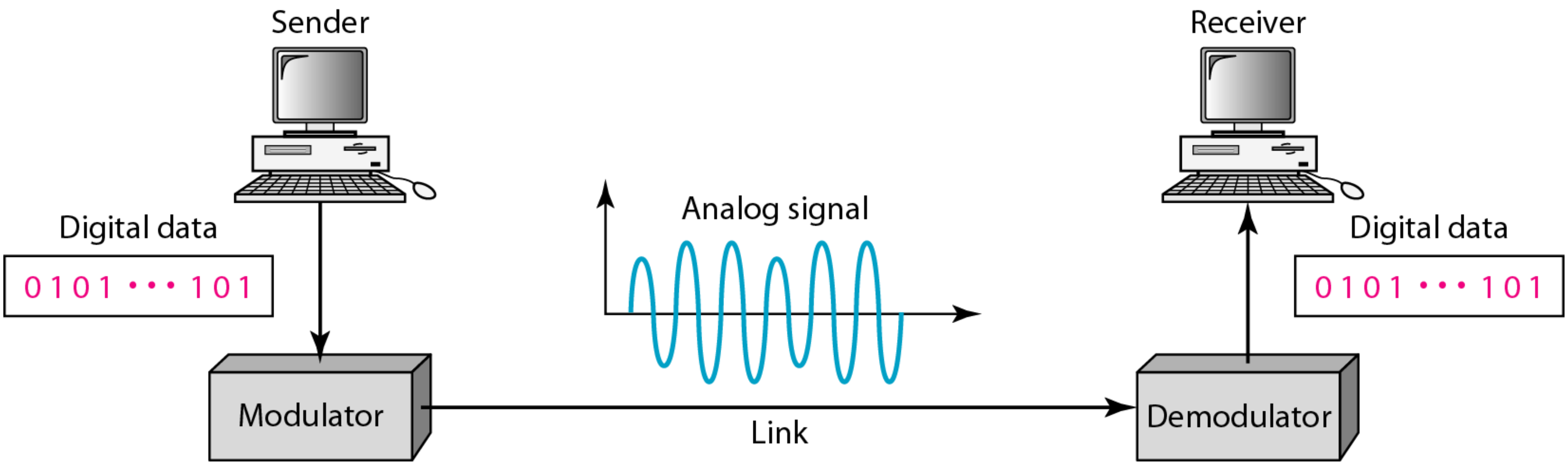
Digital-to-analog ***conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.***

Topics discussed in this section:

Aspects of Digital-to-Analog Conversion
Amplitude Shift Keying
Frequency Shift Keying
Phase Shift Keying
Quadrature Amplitude Modulation

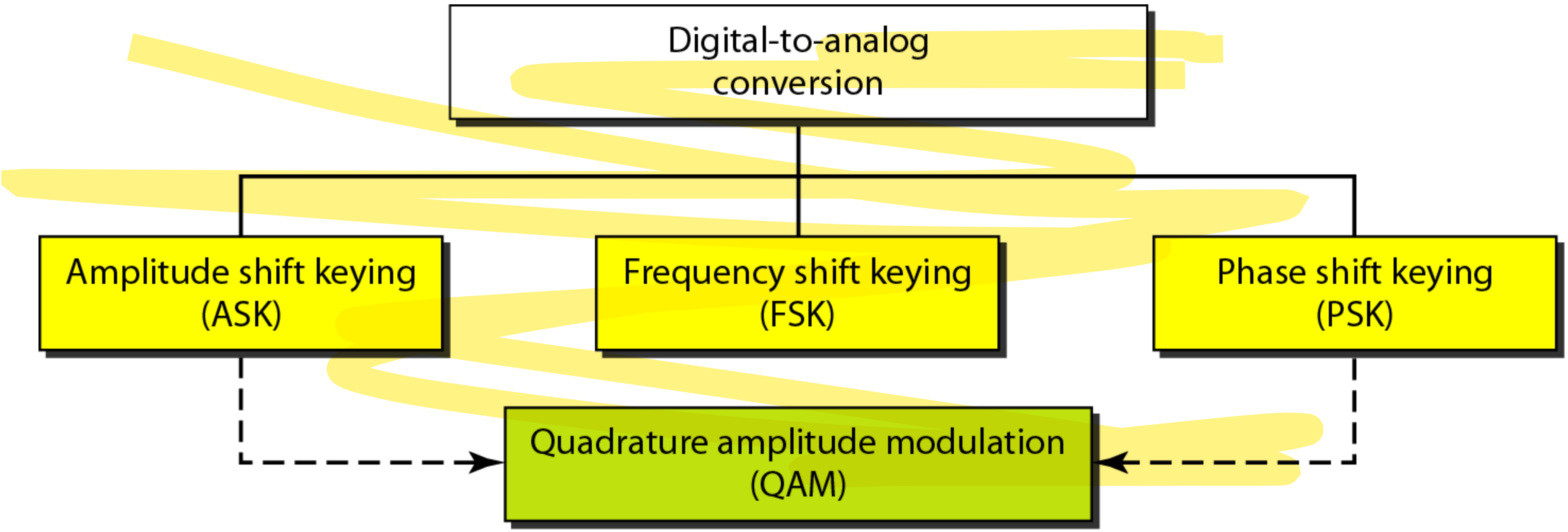
Digital-to-analog conversion

- Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.



Types of Digital-to-analog conversion

- A sine wave is defined by three characteristics: amplitude, frequency, and phase.
- Among any of the three characteristics can be used to for modulating digital data into an analog signal: amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK).



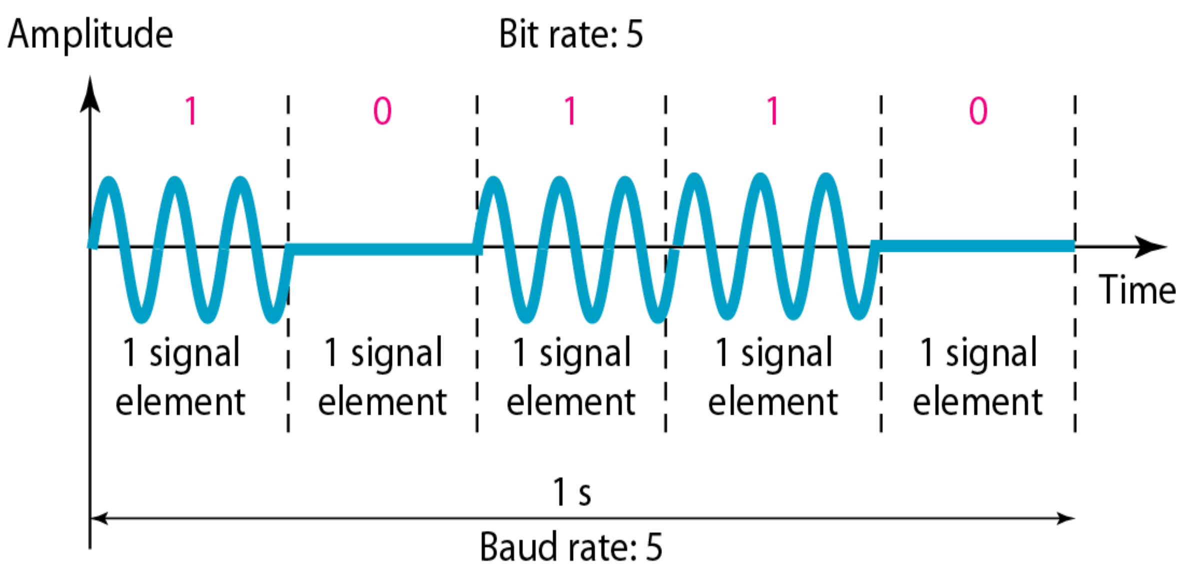
Note

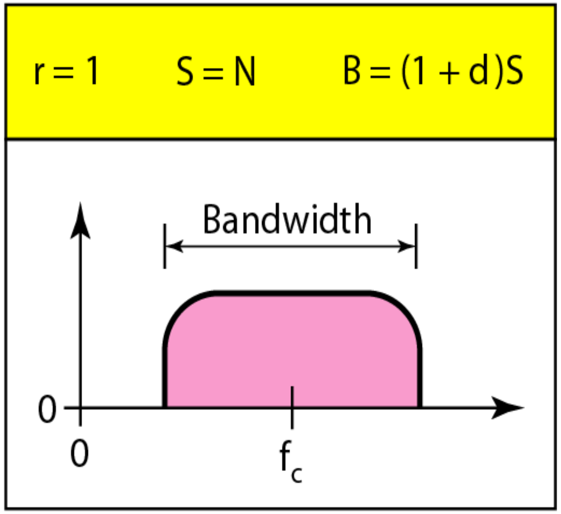
Bit rate is the number of bits per second. Baud rate is the number of signal elements per second.

In the analog transmission of digital data, the baud rate is less than or equal to the bit rate.

Binary amplitude shift keying(BASK)

- In amplitude shift keying(ASK), the amplitude of the carrier signal is varied to create signal elements. Both frequency and phase remain constant while the amplitude changes.
- Binary ASK is normally implemented using only two levels, that's why it is referred to as referred to as binary amplitude shift keying or on-off keying (OOK).





Bandwidth for BASK

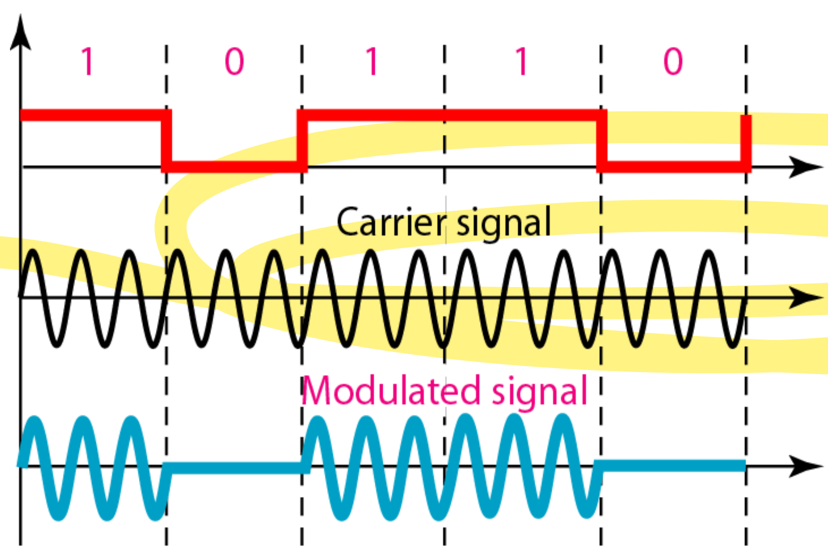
- Bandwidth is proportional to signal rate(Baud rate).
- Modulation index factor called d, which depends on the modulation and filtering process.
- The value of d is between 0 and 1.
- This bandwidth B can be expressed as shown, where S is the signal rate of the signal.

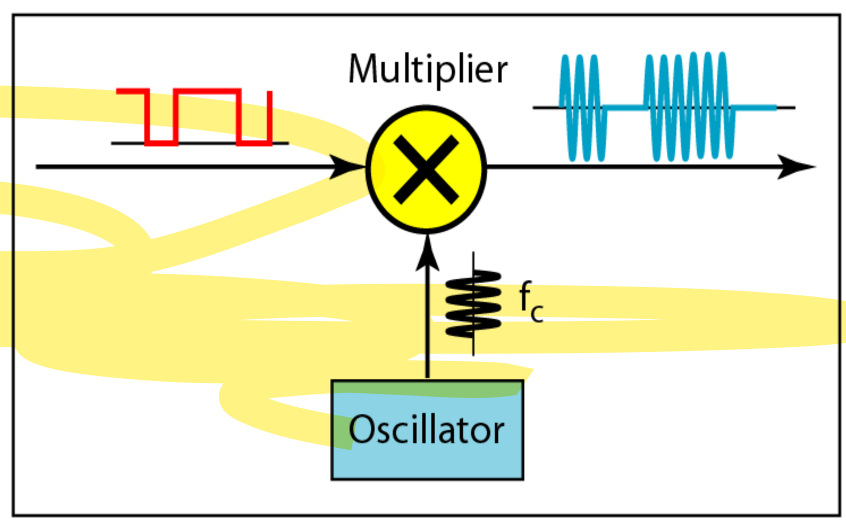
$$B = (1 + d) \times S$$

- The formula shows that the required bandwidth has a minimum value of S and a maximum value of 2S.

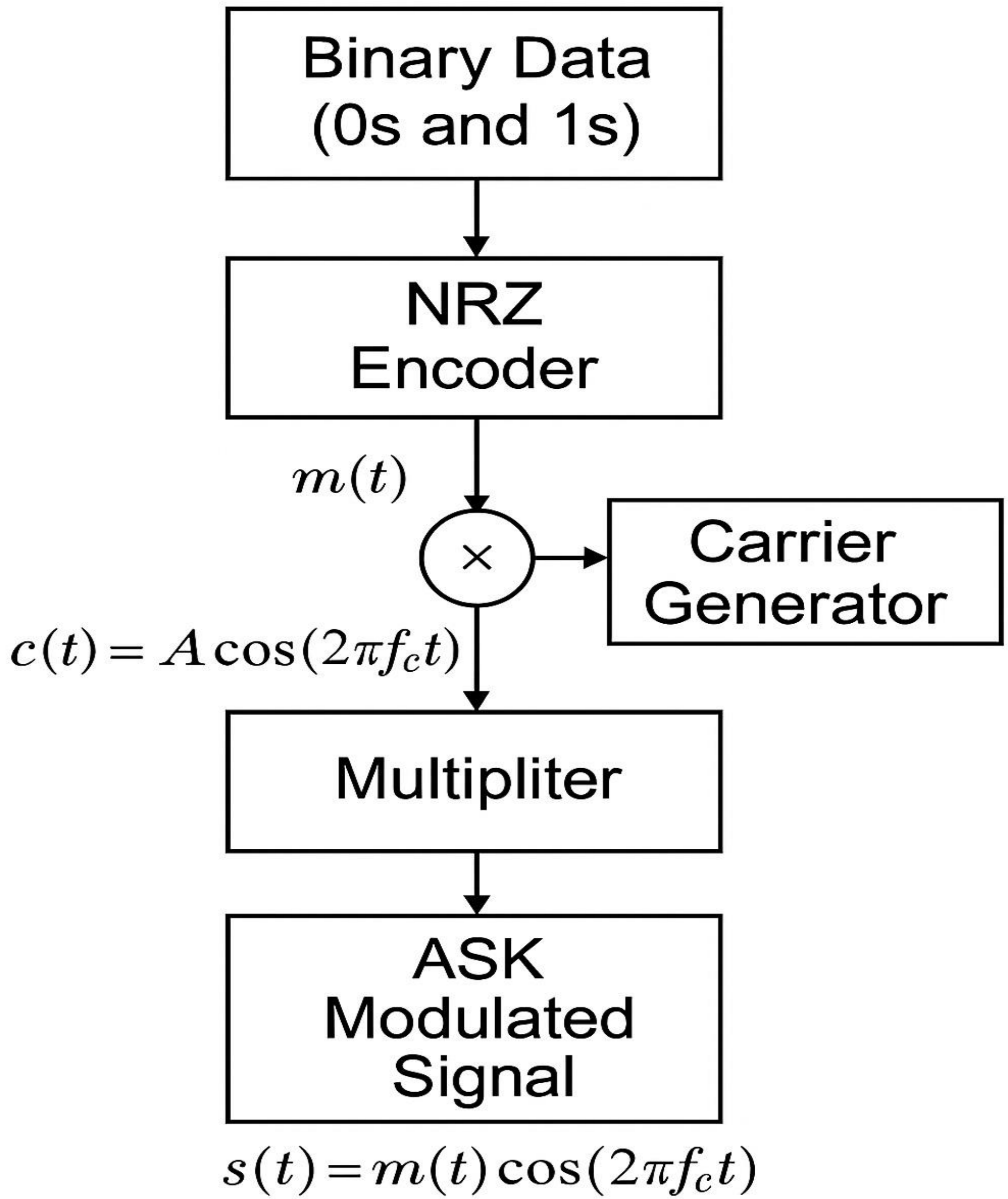
Implementation of binary ASK

- If digital data are presented as a unipolar NRZ digital signal with a high voltage of 1 V and a low voltage of 0 V.
- The implementation can achieved by multiplying the NRZ digital signal by the carrier signal coming from an oscillator.
- When the amplitude of the NRZ signal is 1, the amplitude of the carrier frequency is held, and
- When the amplitude of the NRZ signal is 0, the amplitude of the carrier frequency is zero.





Implementation of binary ASK

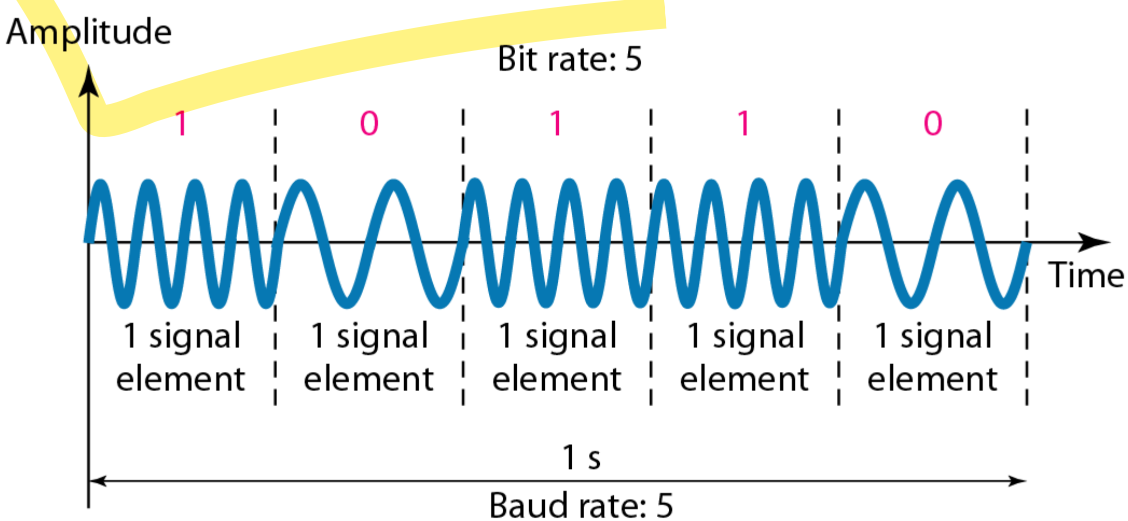


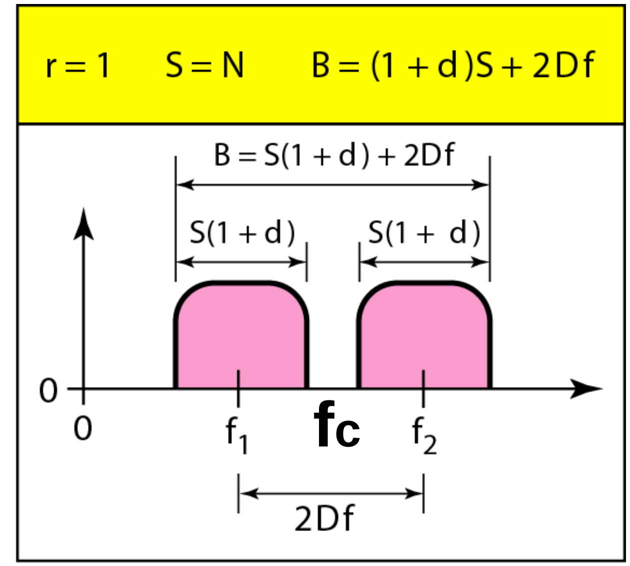
Binary frequency shift keying(BFSK)

- In frequency shift keying, the frequency of the carrier signal is varied to represent data.
- The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes.
- Both peak amplitude and phase remain constant for all signal elements.
- In binary FSK (or BFSK), considered two carrier frequencies f1 and f2.
- We can think of FSK as two ASK signals, each with its own carrier frequency (f1 or f2).
- The first carrier f1 is used when the data element is 0; and the second f2 used for the data element 1.
- If the difference between the two frequencies is $2\Delta f$, then the required bandwidth is

$$B = (1 + d) \times S + 2\Delta_f$$

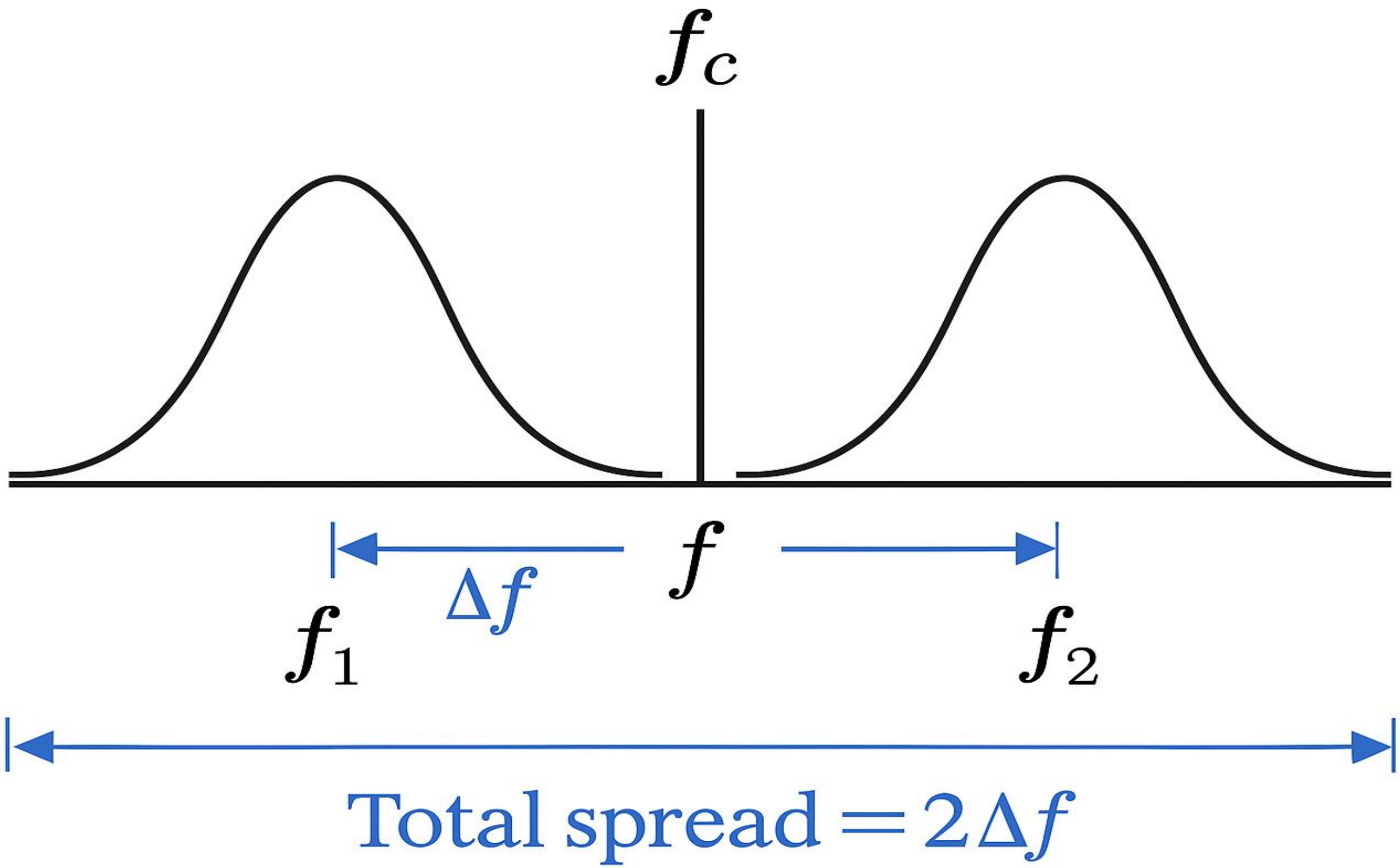
Binary frequency shift keying(BFSK)





- The first carrier f1 is used if the data element is 0; and f2 used if the data element is 1.
- The middle of one bandwidth is f1 and the middle of the other is f2.
- Both f1 and f2 are Δf apart from the midpoint between the two bands means f1=fc - Δf and f2= fc + Δf.
- The difference between the two frequencies, f2-f1= fc + Δf - fc + Δf = 2Δf.

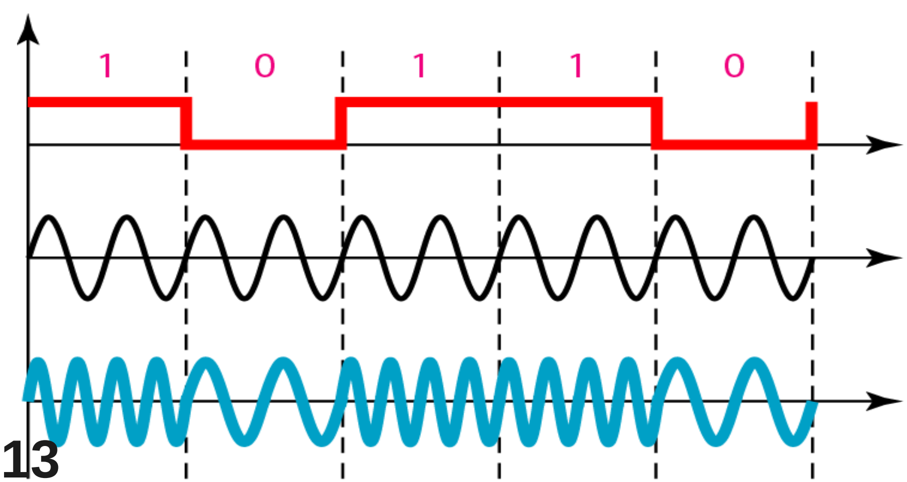
Binary frequency shift keying(BFSK)

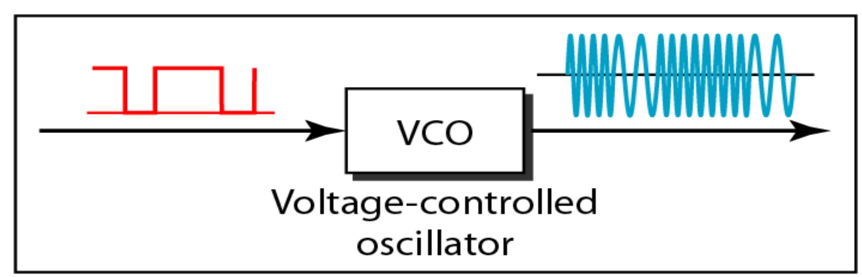


The difference between the two frequencies, f2-f1= fc + Δf - fc + Δf = 2Δf

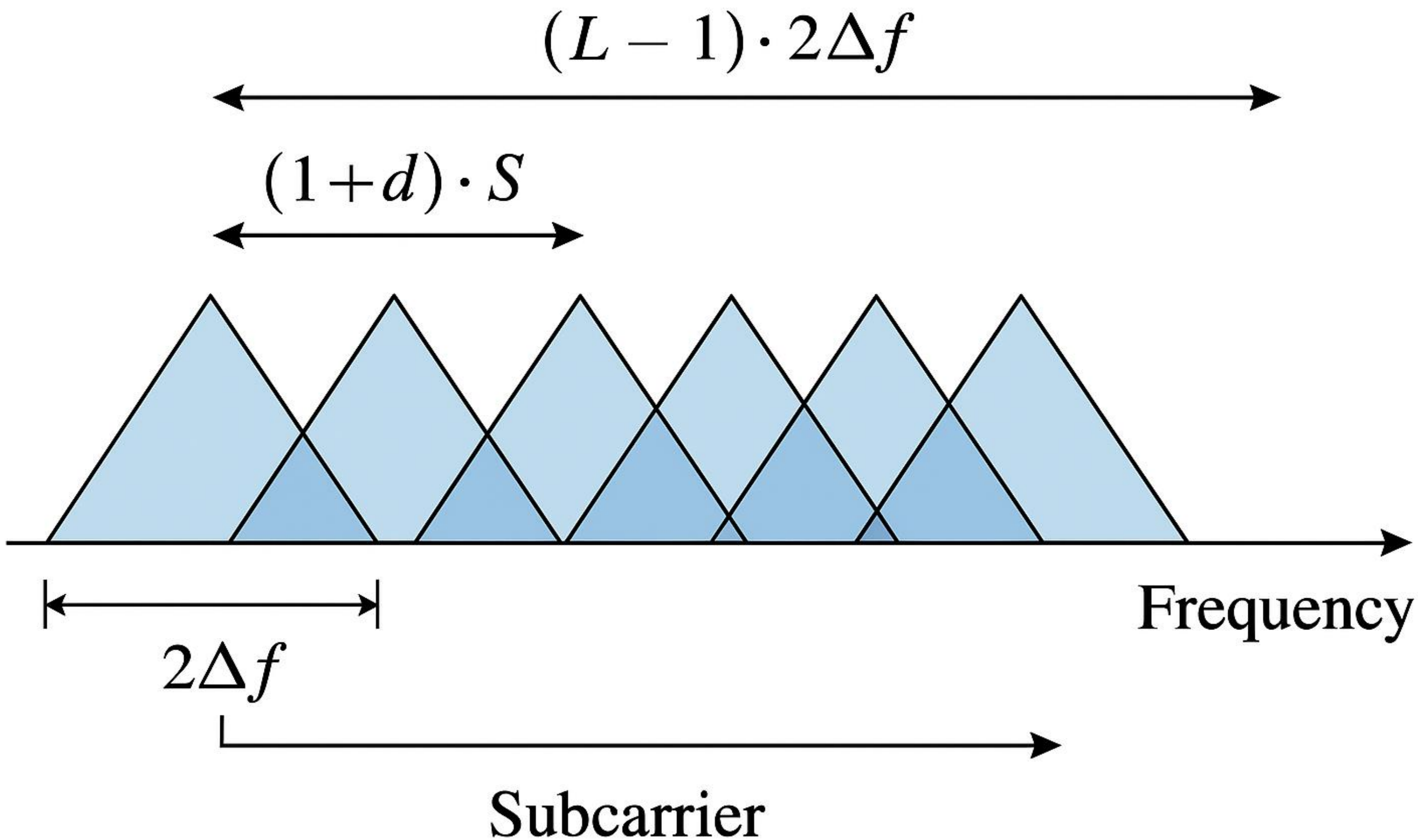
Multilevel frequency shift keying(MFSK)

- Coherent BFSK can be implemented by one voltage-controlled oscillator (VCO) that changes its frequency according to the input voltage.
- The input to the oscillator is the unipolar NRZ signal.
- When the amplitude of NRZ is zero, the oscillator **keeps its regular frequency**, and
- When the amplitude is positive, the frequency **is increased**.
- We can use more than two frequencies. For example, we can use four different frequencies f1, f2, f3, and f4 to send 2 bits at a time, to send 3 bits it needs 8 frequencies and so on.
- The frequencies need to be 2Δf apart.





Multilevel frequency shift keying(MFSK)



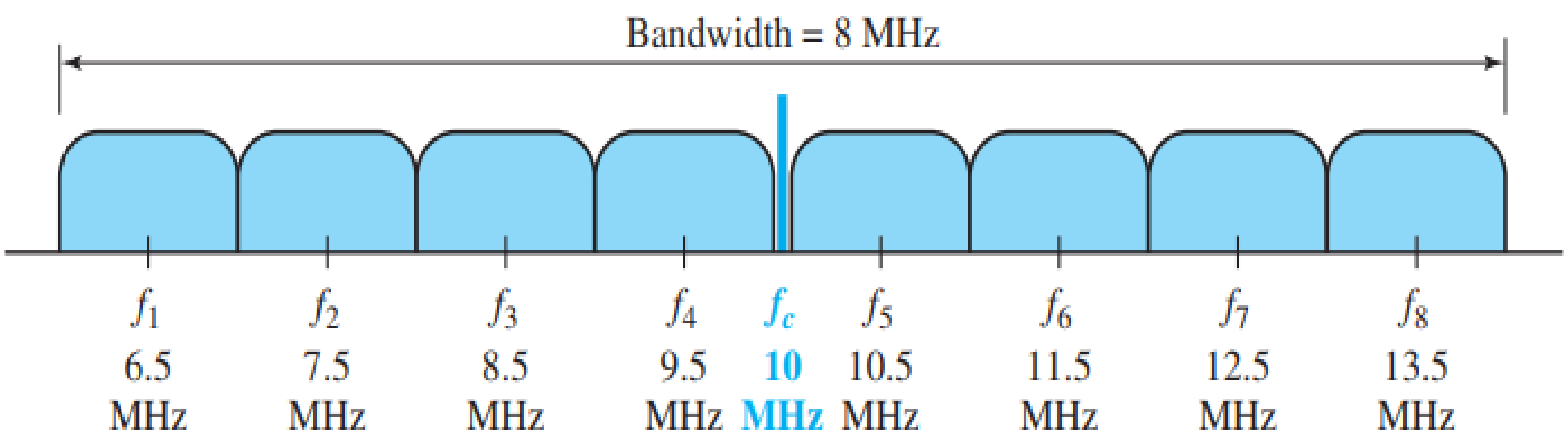
Multilevel frequency shift keying(MFSK)

We need to send data 3 bits at a time at a bit rate of 3 Mbps. The carrier frequency is 10 MHz. Calculate the number of levels (different frequencies), the baud rate, and the bandwidth.

Solution

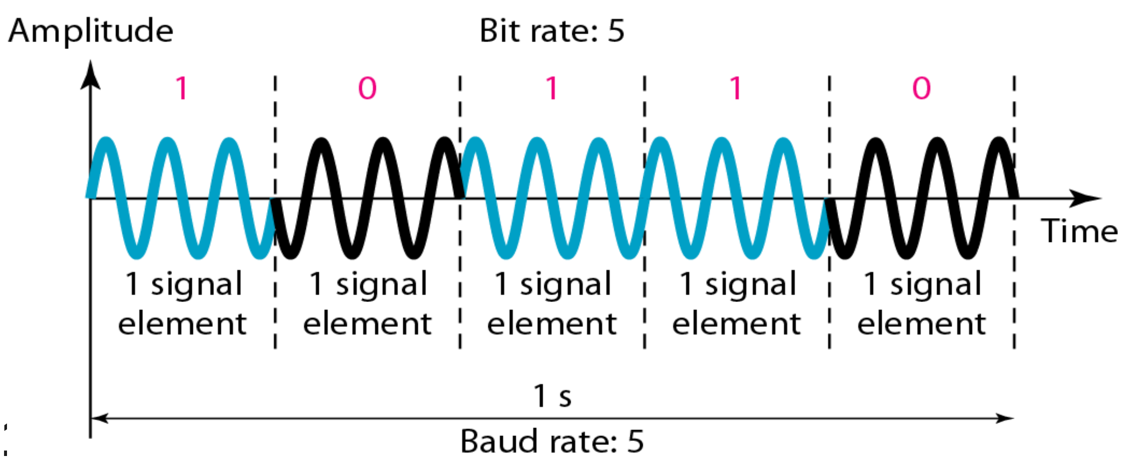
We can have $L = 2^3 = 8$. The baud rate is $S = 3$ MHz/3 = 1 Mbaud. This means that the carrier frequencies must be 1 MHz apart ($2\Delta_f$ = 1 MHz). The bandwidth is $B = 8 \times 1 = 8$ MHz. Figure 5.8 shows the allocation of frequencies and bandwidth.

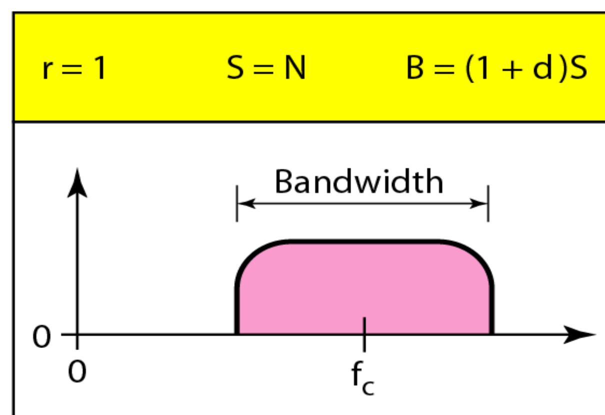
Figure 5.8 *Bandwidth of MFSK used in Example 5.6*



Binary phase shift keying(BPSK)

- In phase shift keying(PSK), the phase of the carrier is **varied** to represent two or more different signal elements. Both peak amplitude and frequency remain constant as the phase changes.
- Two signal elements, one with a phase of 0°, and the other with a phase of 180°.
- Binary PSK has an advantage that, it is less susceptible to noise. Noise can change the amplitude easier than it can change the phase.
- PSK is superior to FSK because we do not need two carrier signals but required sophisticated hardware to handle it.
- The bandwidth is the same as binary ASK, but less than that for BFSK.

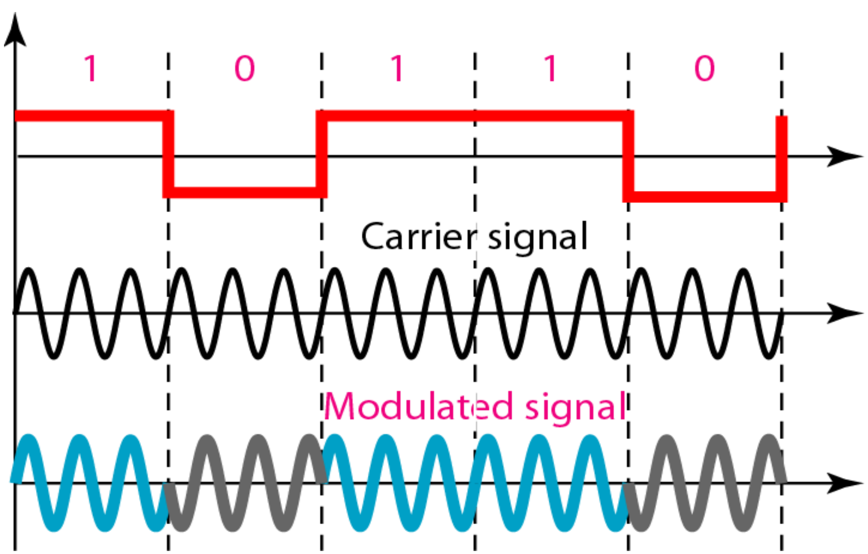


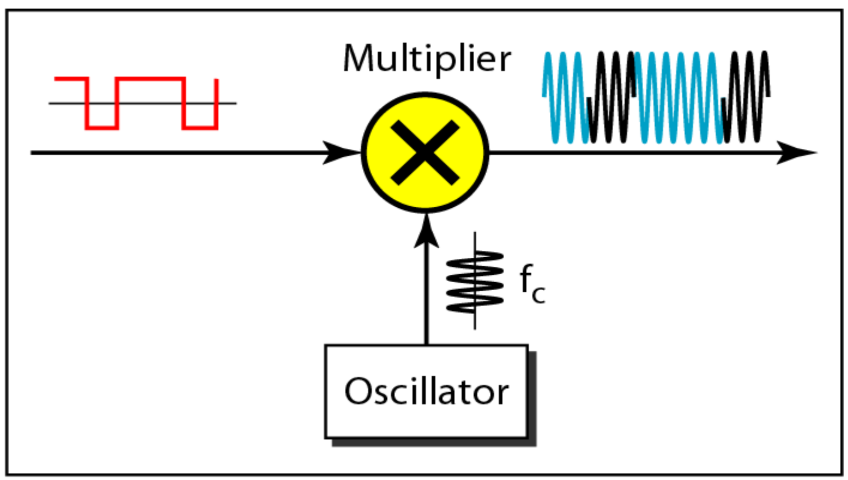


5.:

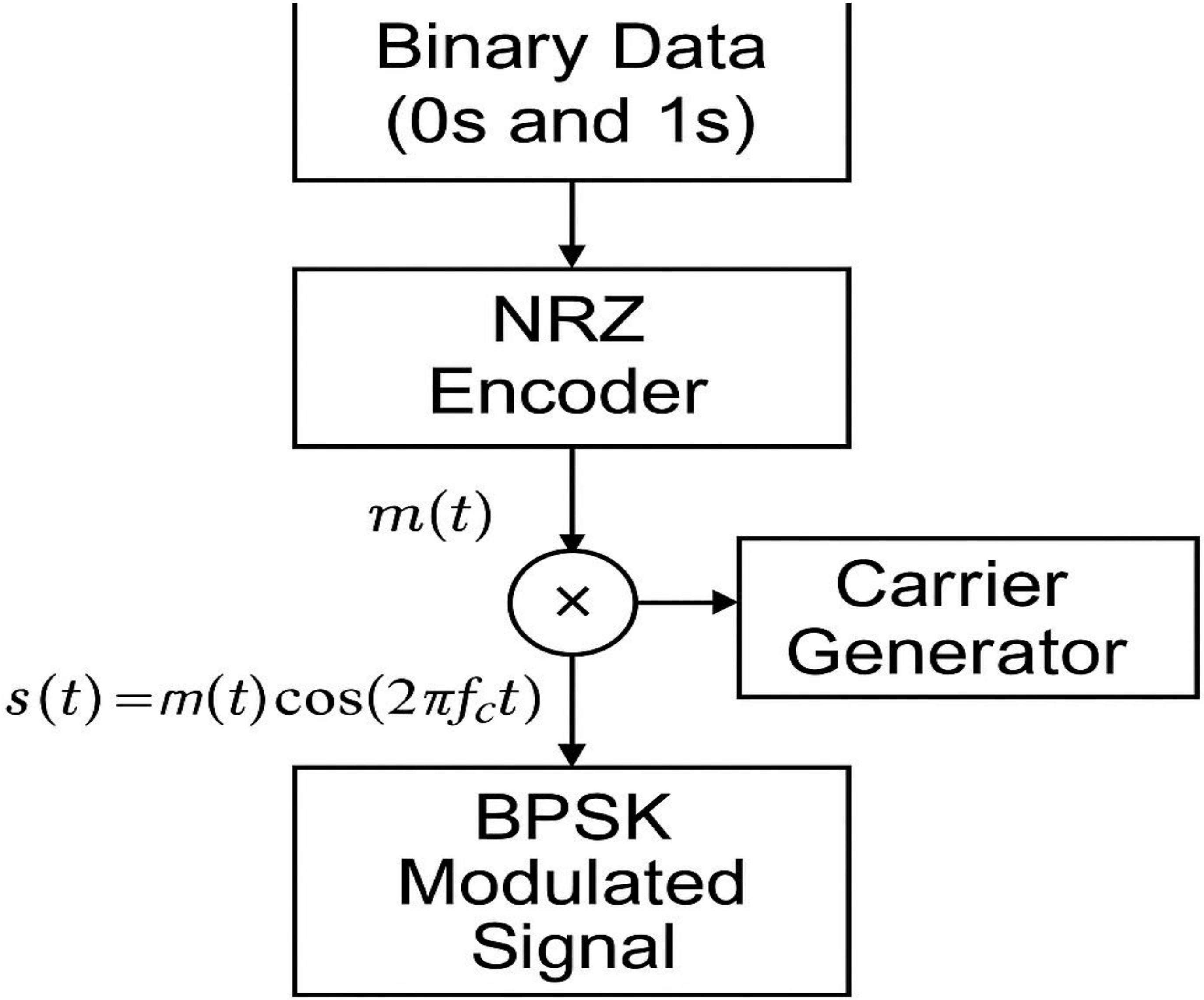
Implementation of BPSK

- The signal element with phase 180° can be seen as the complement of the signal element with phase 0°
- The polar NRZ signal is multiplied by the carrier frequency.
- The 1 bit (positive voltage) is represented by a phase starting at 0°;
- The 0 bit (negative voltage) is represented by a phase starting at 180°.





Implementation of BPSK



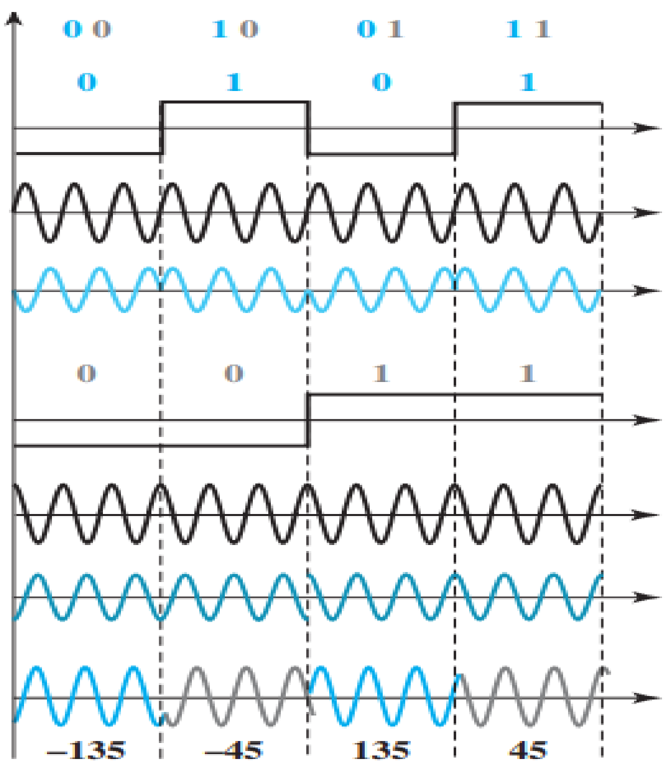
$$s(t)=m(t)\cos(2\pi f_c t)$$

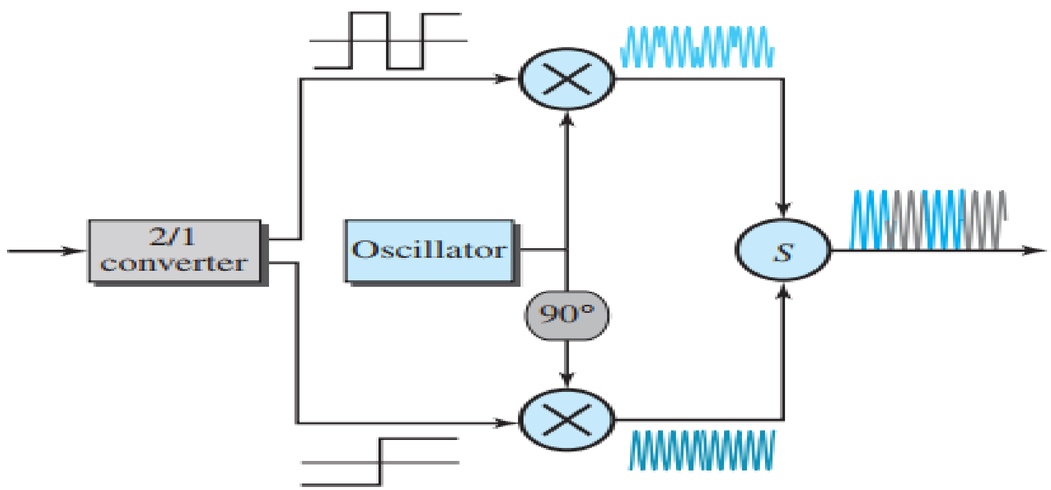
Quadrature PSK (QPSK)

- In QPSK, 2 bits sent at a time in each signal element, which decreasing the baud rate and the required bandwidth.
- The scheme is called quadrature PSK or QPSK because it uses two separate BPSK modulations; one is in-phase(Cosine), the other quadrature (out-of-phase)(Sine).
- The incoming bits are first passed through a serial-to-parallel conversion that sends one bit to one modulator and the next bit to the other modulator.
- The two composite signals created by each multiplier are sine waves with the same frequency, but different phases.
- When they are added, the result is another sine wave, with one of four possible phases: 45°, −45°, 135°, and −135°
- There are four kinds of signal elements in the output signal (L = 4), so we can send 2 bits per signal element (r = 2).

Quadrature PSK (QPSK)

Input Bits	I	Q	Resulting Phase
00	+1	+1	+45°
01	−1	+1	+135°
11	−1	−1	−135°
10	+1	−1	−45°

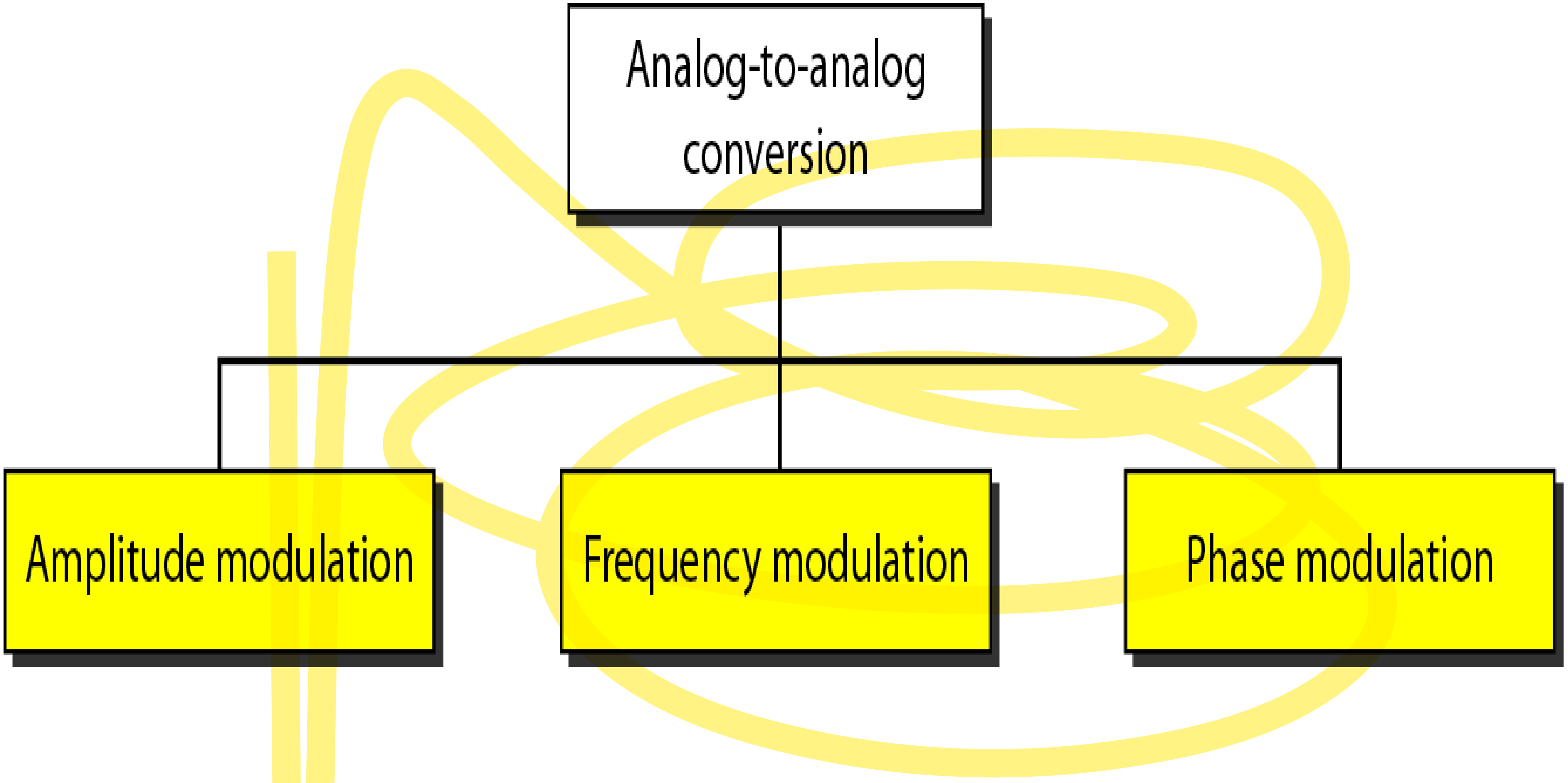




5-2 ANALOG-TO-ANALOG CONVERSION

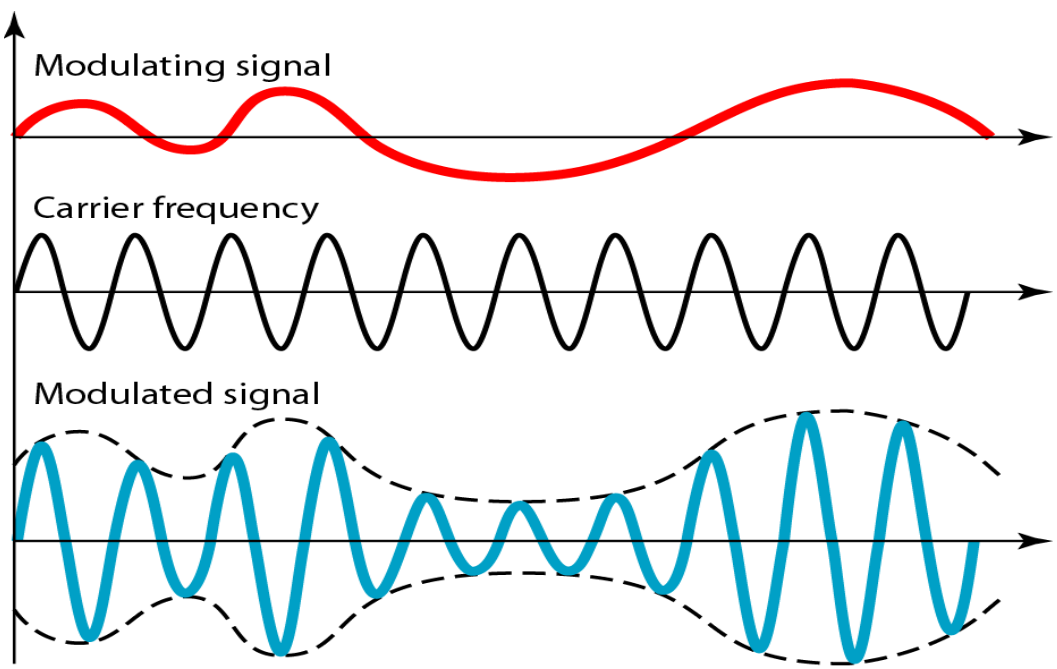
- ***Analog-to-analog conversion is the representation of analog information by an analog signal. One may ask why we need to modulate an analog signal; it is already analog. Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us.***
- ***Analog-to-analog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

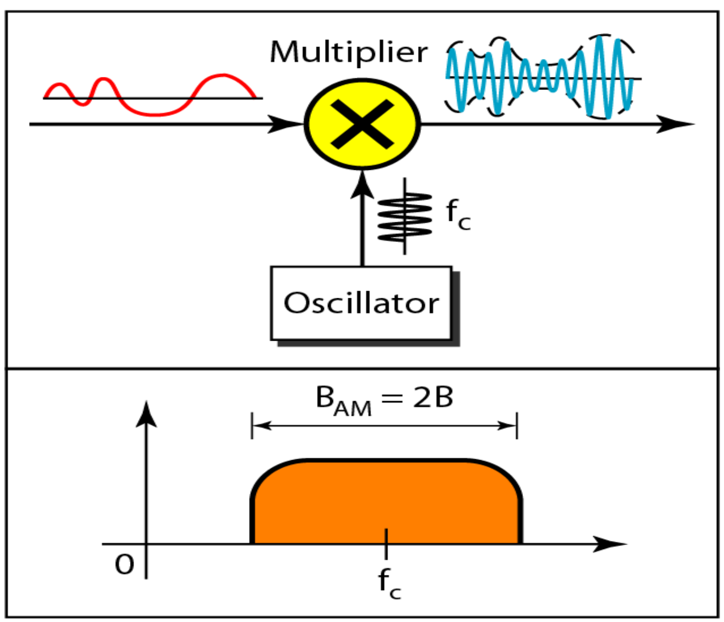
Types of analog-to-analog modulation



Amplitude modulation

- 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.
- The modulation creates a bandwidth that is twice the bandwidth of the modulating signal and covers a range centered on the carrier frequency.
- The total bandwidth required for AM can be determined from the bandwidth of the audio signal: $B_{AM} = 2B$.





Amplitude modulation

- Let the message signal be:

$$m(t) = A_m\,cos(2\pi f_m t)$$

- Let the carrier signal be:

$$\mathrm{c}(t) = A_c\,cos(2\pi f_c t)$$

- Then the AM signal is:

$$s(t) = [A_c + m(t)]cos(2\pi f_c t)$$

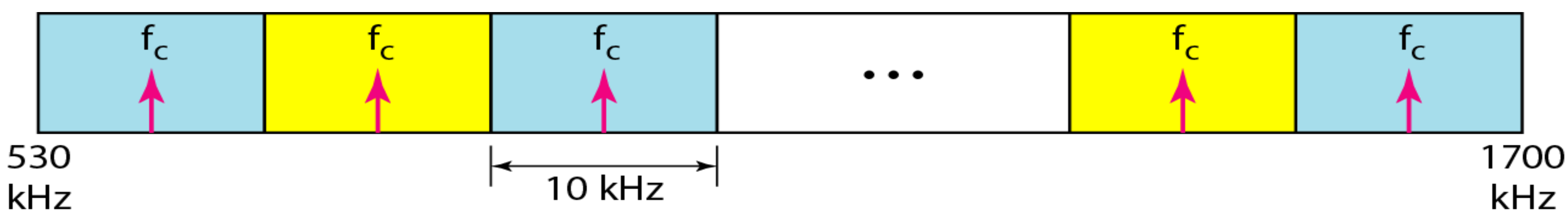
Substituting $m(t)$, $s(t) = [A_c + A_m\,cos(2\pi f_m t)]cos(2\pi f_c t)$

- The message signal m(t) controls how much the frequency of the carrier deviates from its center frequency.
- AM produces three frequency components :Carrier: fc, Upper Sideband (USB): $fc + fm$, and Lower Sideband (LSB): $fc - fm$

Condition	Value of m(t)	Output Amplitude
m(t) = 0	No message	Just carrier
m(t) > 0	Positive wave	Carrier amplitude increases
m(t) < 0	Negative wave	Carrier amplitude decreases

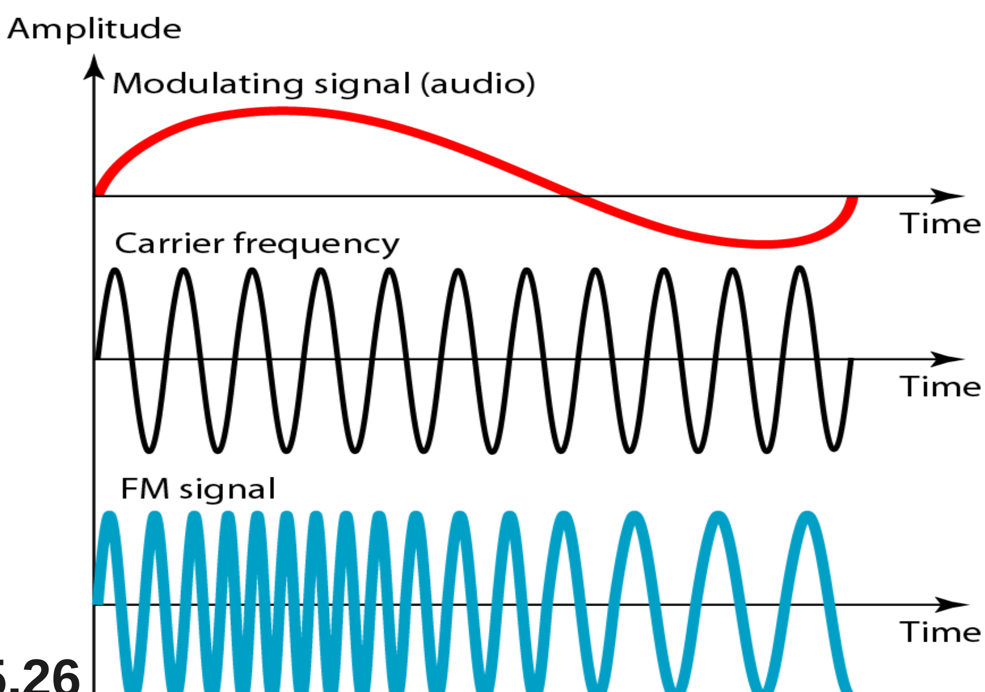
AM band allocation

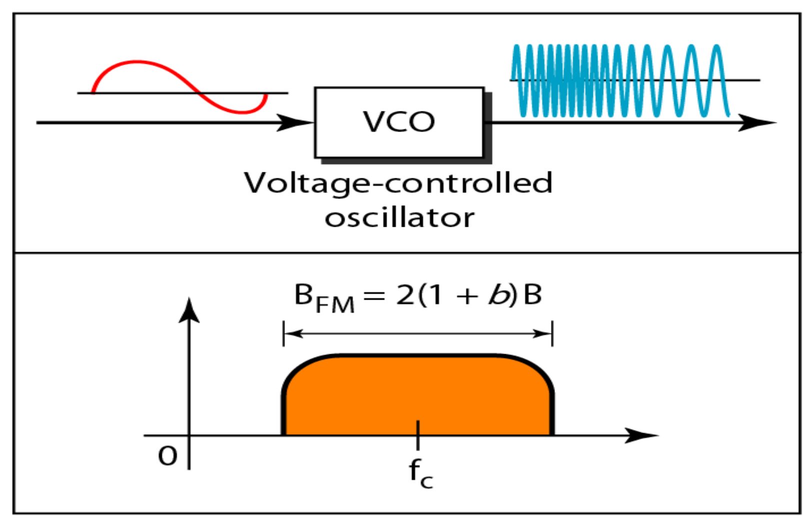
- The bandwidth of an audio signal (speech and music) is usually 5 kHz. Therefore, an AM radio station needs a bandwidth of 10 kHz.
- In fact, the Federal Communications Commission (FCC) allows 10 kHz for each AM station.
- AM stations are allowed carrier frequencies anywhere between 530 and 1700 kHz (1.7 MHz).
- However, each station's carrier frequency must be separated from those on either side of it by at least 10 kHz (one AM bandwidth) to avoid interference.



Frequency modulation

- In FM, the frequency of the carrier wave is varied in proportion to the amplitude of the modulating (message) signal, while the amplitude of the carrier remains constant.
- FM is normally implemented by using a voltage-controlled oscillator as with FSK.
- The frequency of the oscillator changes according to the input voltage which is the amplitude of the modulating signal.





Frequency modulation

- The basic FM equation is

$$s(t) = A_c\, cos[2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau\,]$$

Where A_c = Amplitude of carrier, fc = Carrier frequency, k_f= Frequency sensitivity (Hz per volt), and m(t) = Message signal.

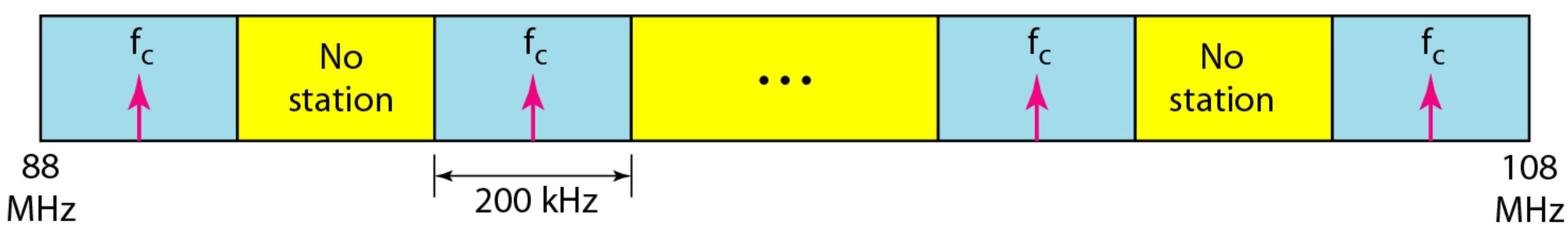
- The Instantaneous Frequency of the signal is

$$f_i(t) = f_c + k_f.m(t)$$

- The message signal m(t) controls how much the frequency of the carrier deviates from its center frequency.

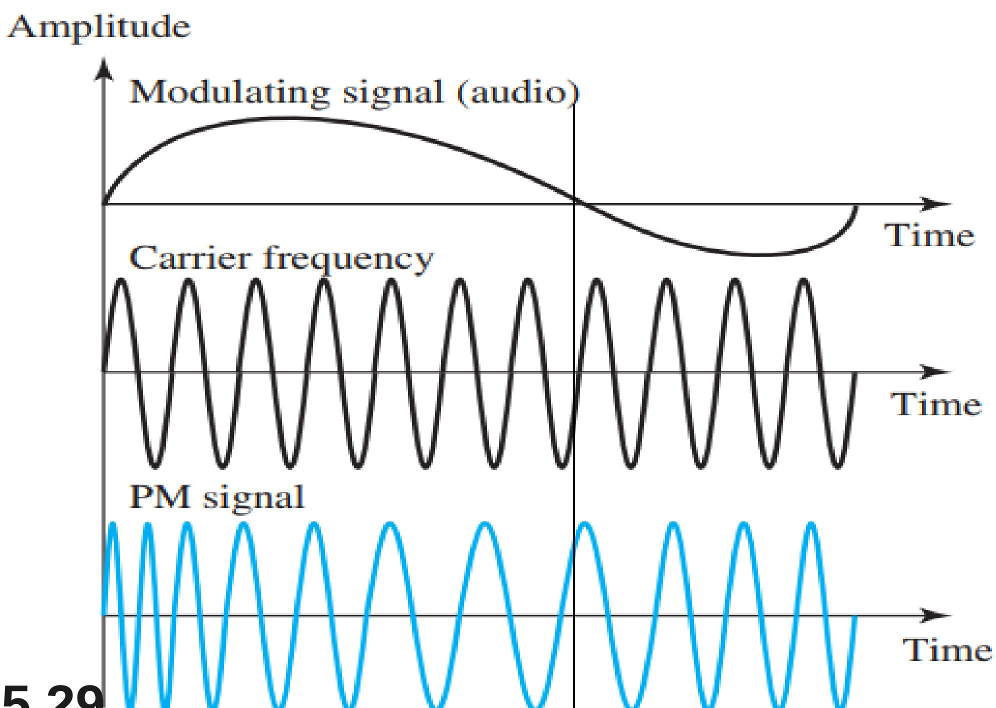
$$if\ m(t) = \left\{\begin{matrix} 0 & f_i(t) = f_c \\ > 0 & f_i(t) = f_c + k_f m(t) \\ < 0 & f_i(t) = f_c + k_f m(t) \end{matrix}\right\}$$

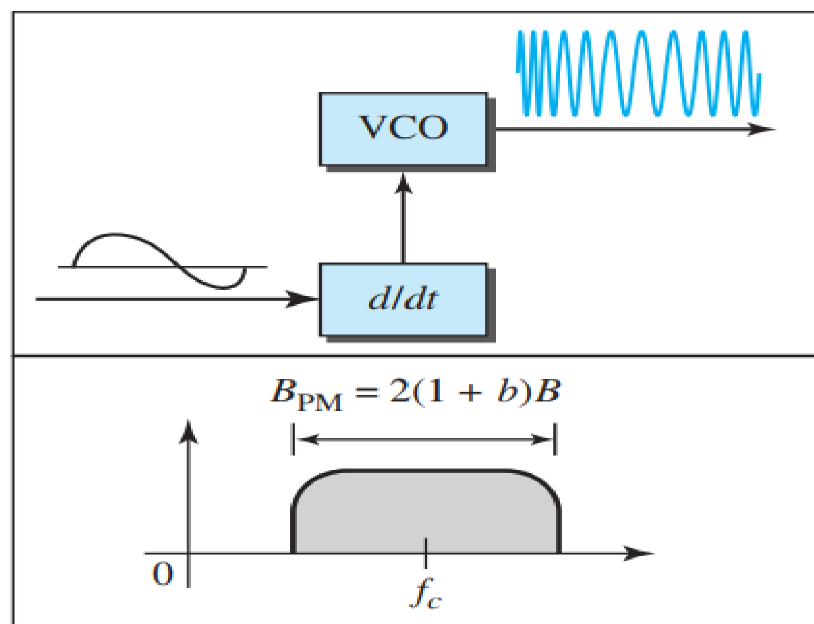
FM band allocation

- The total bandwidth required for FM can be determined from the bandwidth of the audio signal: BFM = 2(1 + β)B
- The bandwidth of an audio signal (speech and music) broadcast in stereo is almost 15 kHz.
- The FCC allows 200 kHz (0.2 MHz) for each station.
- This mean β = 4 with some extra guard band.
- FM stations are allowed carrier frequencies anywhere between 88 and 108 MHz.
- Stations must be separated by at least 200 kHz to keep their bandwidths from overlapping.
- 

Phase modulation(PM)

- The phase of the carrier signal is varied proportionally to the instantaneous amplitude of the message signal.
- The PM is the same as FM with one difference.
- In FM, the instantaneous change in the carrier frequency is proportional to the amplitude of the modulating signal, but
- In PM the instantaneous change in the carrier frequency is proportional to the derivative of the amplitude of the modulating signal





Phase modulation(PM)

- Let the message signal be $m(t)$ and the carrier signal be:

$$c(t) = A_c\, cos(2\pi f_c t)$$

- Then the PM signal is:

$$s(t) = A_c \cos(2\pi f_c t + k_p m(t))$$

- Where Ac is Carrier amplitude, fc is Carrier frequency, kp is Phase sensitivity (radians per unit of $m(t)$), and $m(t)$ is Message signal.
- PM is normally implemented by using a voltage-controlled oscillator along with a derivative.
- The frequency of the oscillator changes according to the derivative of the input voltage, which is the amplitude of the modulating signal.
- The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal:

$$B_{PM} = 2(1 + \beta)B$$

- The value of β is lower in the case of PM (around 1 for narrowband and 3 for wideband).

Frequency vs Phase modulation(FM vs PM)

Feature	**Frequency Modulation (FM)**	**Phase Modulation (PM)**
Modulated Feature	Frequency of the carrier	Phase of the carrier
Instantaneous Frequency	Proportional to *m(t)*	Proportional to *d/dt [m(t)]*
Instantaneous Phase	$\varphi(t) = 2\pi f_n t + k_x \int m(t)dt$	$\varphi(t) = 2\pi f_n t + k_p m(t)$
Modulated Signal	$s(t) = A_c\, cos[2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau\,]$	$s(t) = A_c \cos(2\pi f_c t + k_p m(t))$

Thank You