7

Data Communication

Week 7 Analog Transmission

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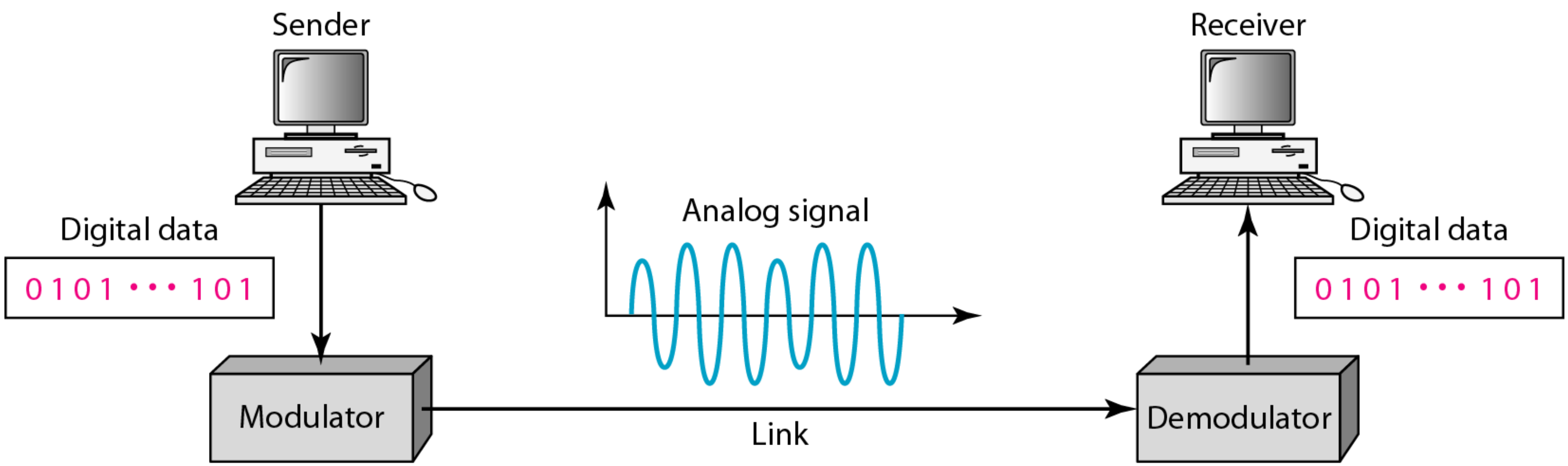
Analog Transmission

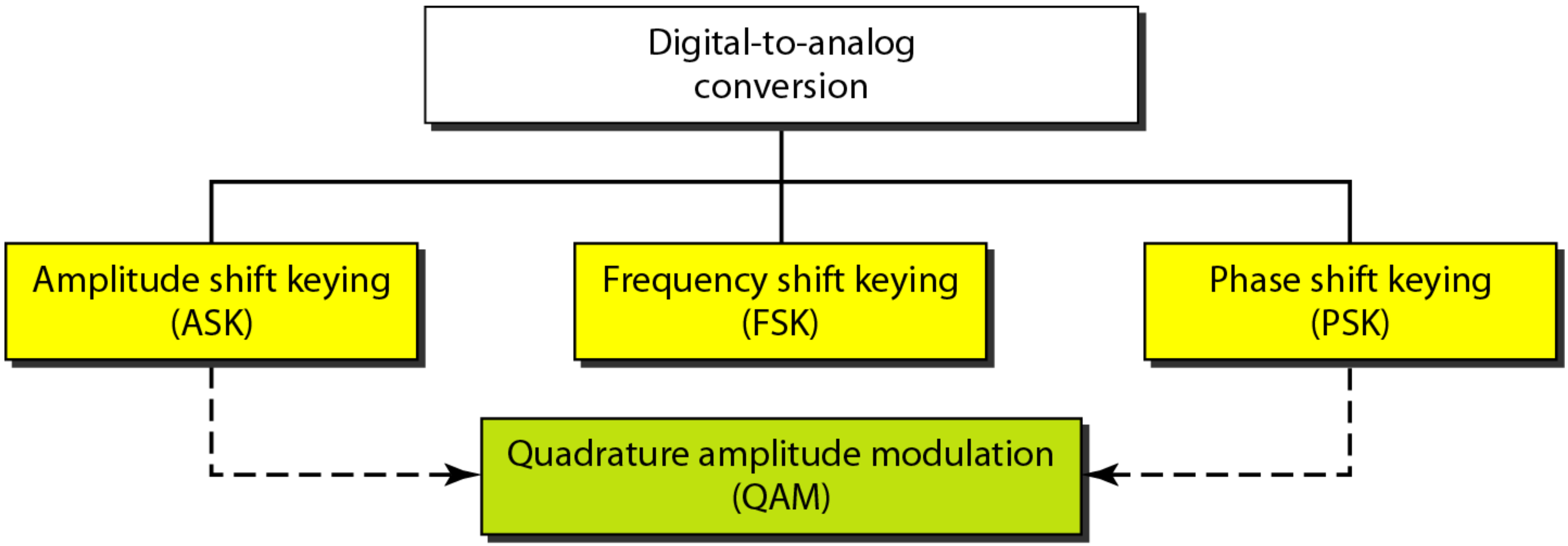
- In chapter 3, we discussed the advantages and disadvantage of digital and analog transmission. We saw that while digital transmission is very desirable, a low-pass channel is needed. We also saw that analog transmission is the only choice if we have a bandpass channel. Digital transmission was discussed in Chapter 4; we discuss analog transmission in this chapter.
- Converting digital data to a bandpass analog signal is traditionally called digital-to-analog conversion. Converting a low-pass analog signal to a bandpass analog signal is traditionally called analog-to-analog conversion.
- In this chapter, we discuss these two types of conversions.
    - **Digital to Analog Conversion**
    - **Analog to Analog Conversion**

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



Aspects of Digital to Analog Conversion

- **Data Element vs Signal Element**
  - Data Element is a smallest piece of information to be exchanged, the bit
  - Signal Element is the smallest unit of a signal that is constant.
- **Data Rate vs Signal Rate**
  - Bit rate is the number of bits per second.
  - Baud Rate is the number of signal element per second.
  - In the analog transmission of digital data, the baud rate is less than or equal to the bit rate.
  - Relationship between Data Rate and Signal Rate:

$$S = N \times \frac{1}{r} \quad baud$$

Examples

- An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate.
- Solution
  - In this case, r = 4, S = 1000, and N is unknown. We can find the value of N from

$$S = N \times \frac{1}{r} \qquad \text{or} \qquad N = S \times r = 1000 \times 4 = 4000 \text{ bps}$$

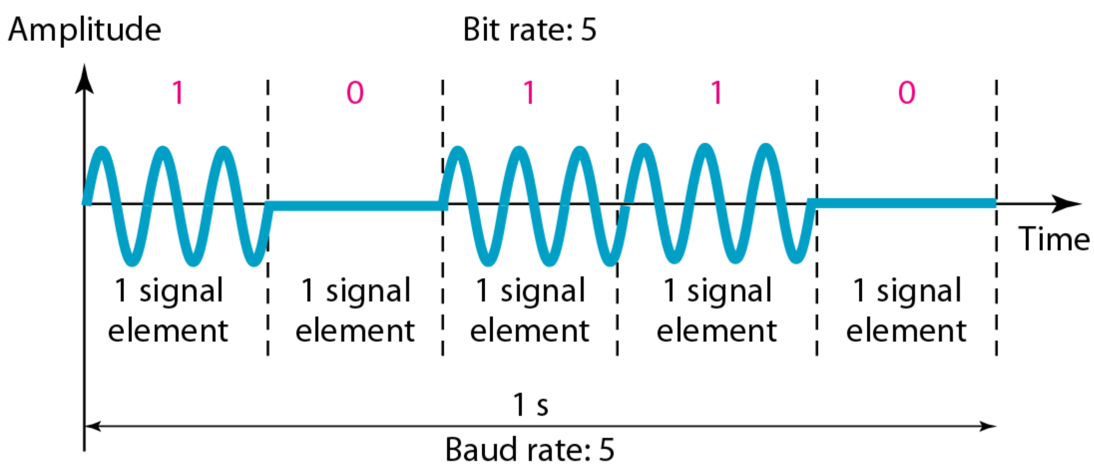
- An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?
- Solution
  - In this example, S = 1000, N = 8000, and r and L are unknown. We find first the value of r and then the value of L.

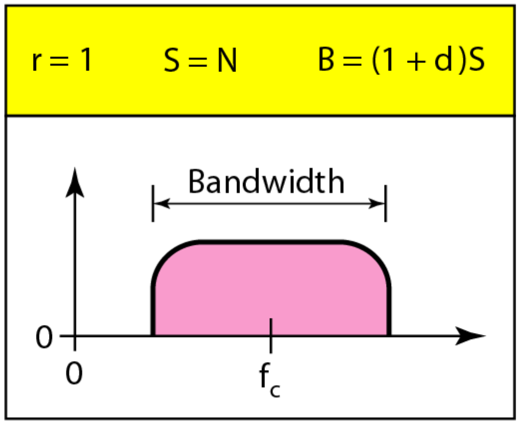
$$S = N \times \frac{1}{r} \quad \rightarrow \quad r = \frac{N}{S} = \frac{8000}{1000} = 8 \text{ bits/baud}$$

$$r = \log_2 L \quad \rightarrow \quad L = 2^r = 2^8 = 256$$

Amplitude Shift Keying (ASK)

- Binary Amplitude Shift Keying (BASK)

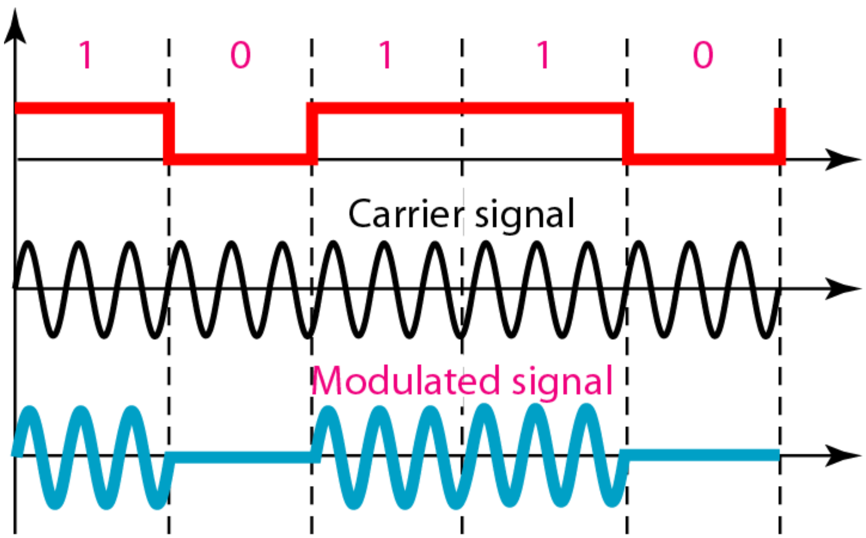


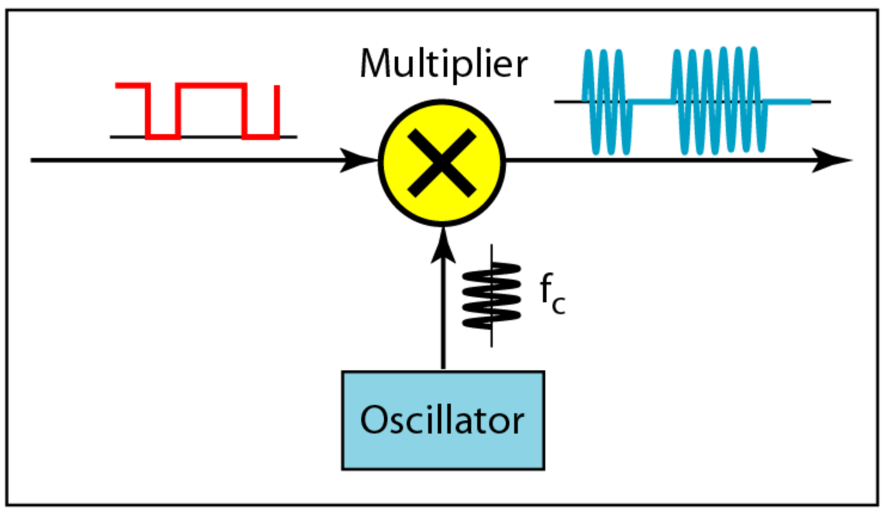


- d ≥ 0 ➔ related to the condition of the line

Implementation of Binary ASK

- If digital data are represented as a unipolar NRZ, digital signal with high voltage of 1 V ad a low voltage of 0 V, the implementation can achieved by mulitplying the NRZ digital signal by the carrier signal coming from oscilator.
- When the amplitude of the NRZ signal is 1, the amplitude of the carrier frequency is held; when the amplitude of the NRZ signal is 0, the amplitude of the carrier frequency is zero





Pro, Con and Applications

- **Pro**
  - Simple implementation
- **Con**
  - Major disadvantage is that telephone lines are very susceptible to variation in transmission quality that can affect amplitude.
  - Susceptible to sudden gain changes
  - Inefficient modulation technique for data.
- **Applications**:
  - On voice grade lines, used up to 1200 bps
  - Used to transmit digital data over optical fibre
  - Morse code
  - Laser transmitters

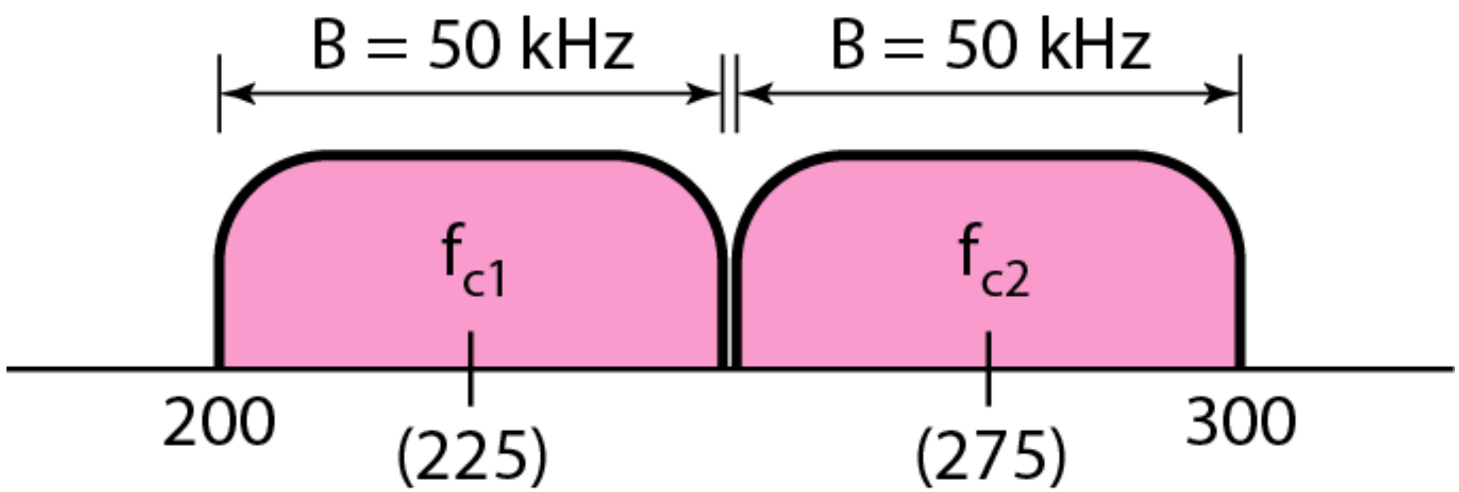
Example

- We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What are the carrier frequency and the bit rate if we modulated our data by using ASK with d = 1?
- Solution
  - The middle of the bandwidth is located at 250 kHz. This means that our carrier frequency can be at fc = 250 kHz. We can use the formula for bandwidth to find the bit rate (with d = 1 and r = 1).

$$B = (1 + d) \times S = 2 \times N \times \frac{1}{r} = 2 \times N = 100 \text{ kHz} \rightarrow N = 50 \text{ kbps}$$

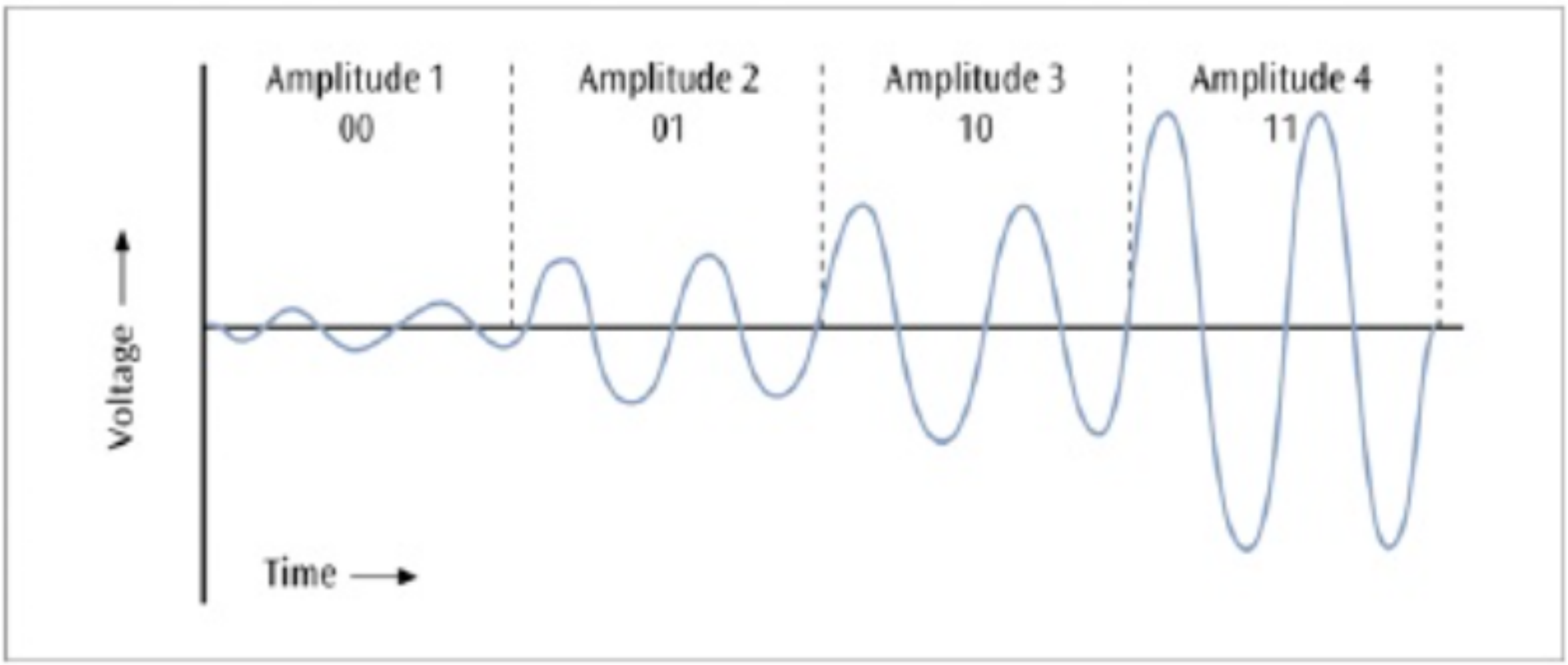
Example

- In data communications, we normally use full-duplex links with communication in both directions. We need to divide the bandwidth into two with two carrier frequencies, as shown in Figure below. The figure shows the positions of two carrier frequencies and the bandwidths. The available bandwidth for each direction is now 50 kHz, which leaves us with a data rate of 25 kbps in each direction.



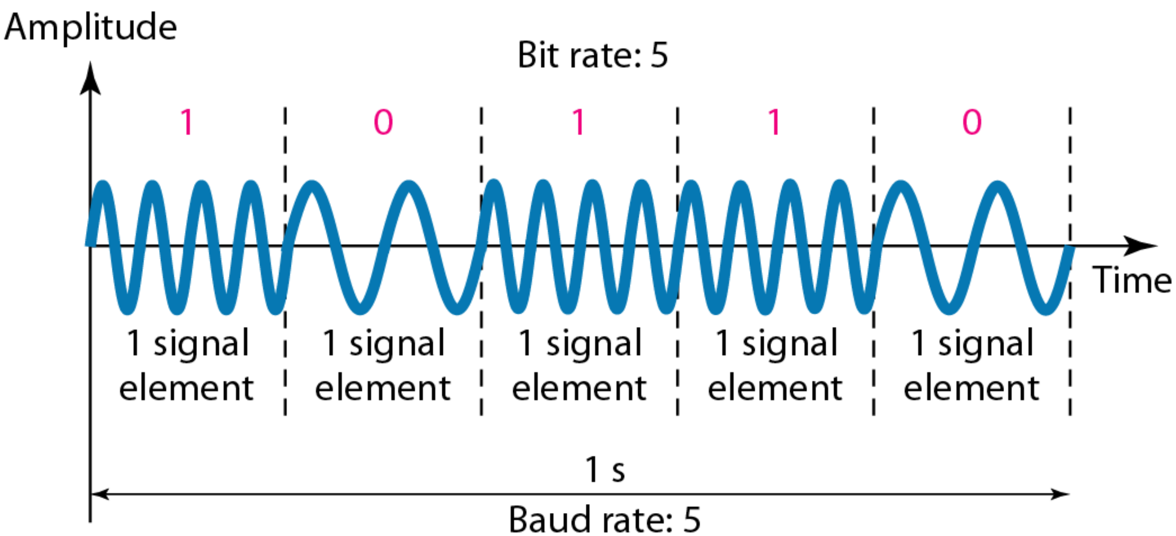
OOK and Multilevel ASK

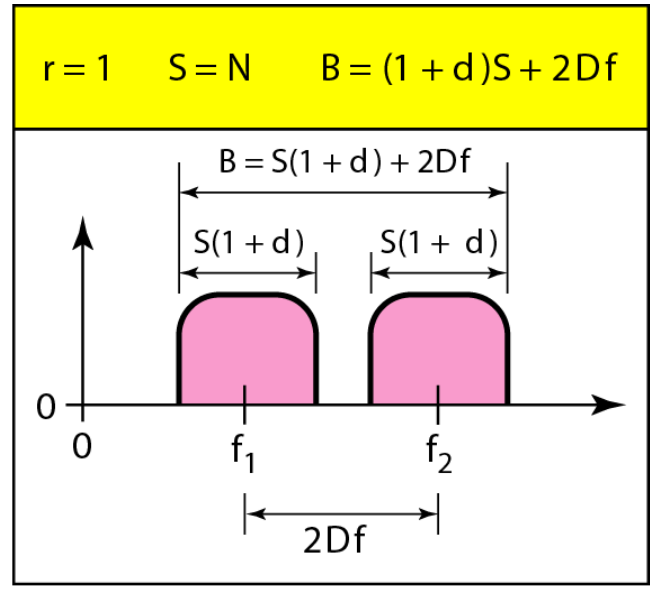
- OOK (On Off Keying)
  - 0 silence
  - Sensor networks: battery life, simple implementation
- Multilevel ASK : Multiple Amplitude Levels



Frequency Shift Keying (FSK)

- Binary Frequency Shift Keying





$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary } 1 \\ A\cos(2\pi f_2 t) & \text{binary } 0 \end{cases}$$

Example

- We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What should be the carrier frequency and the bit rate if we modulated our data by using FSK with d = 1?
- Solution
  - The midpoint of the band is at 250 kHz. We choose 2Δf to be 50 kHz; this means

$$B = (1 + d) \times S + 2\Delta f = 100 \;\rightarrow\; 2S = 50 \text{ kHz} \quad S = 25 \text{ kbaud} \quad N = 25 \text{ kbps}$$

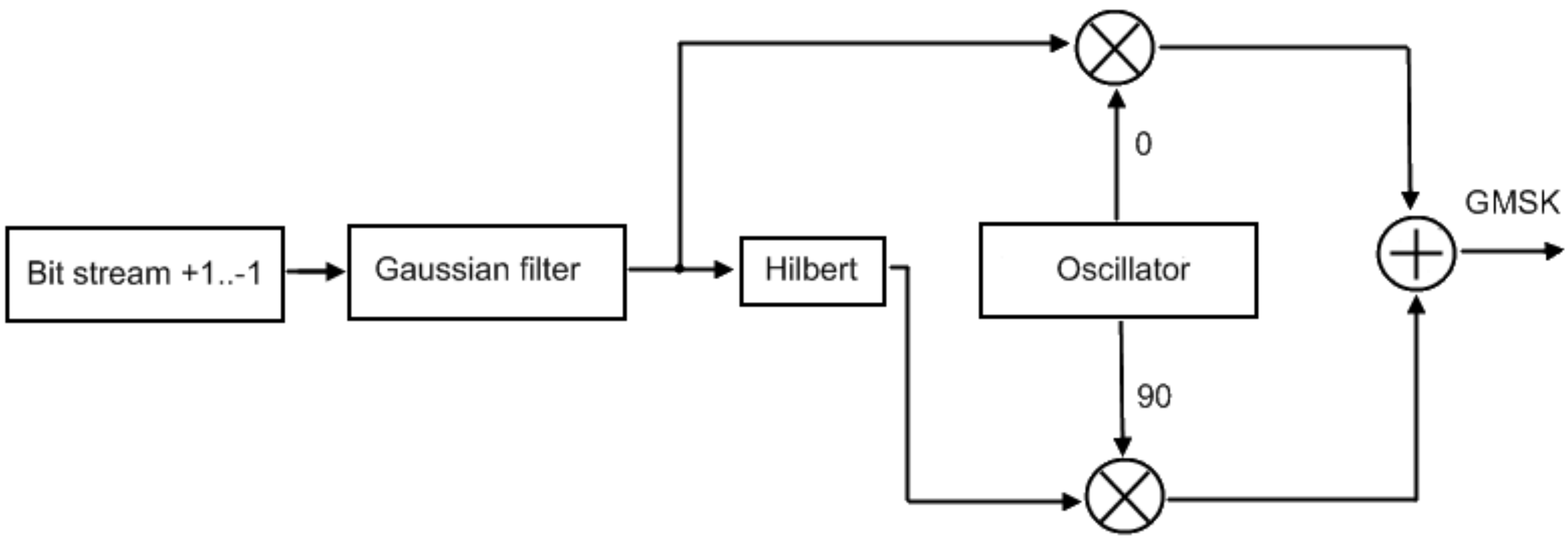
Pro and Con on FSK

- Limiting factor: Physical capabilities of the carrier
- Not susceptible to noise as much as ASK
- Applications:
  - On voice grade lines, used up to 12000bps
  - Used fr high frequency (3 to 20 MHz) radio transmission
  - Used at higher frequencies on LANs that use coaxial cable

Gaussian FSK (GFSK)

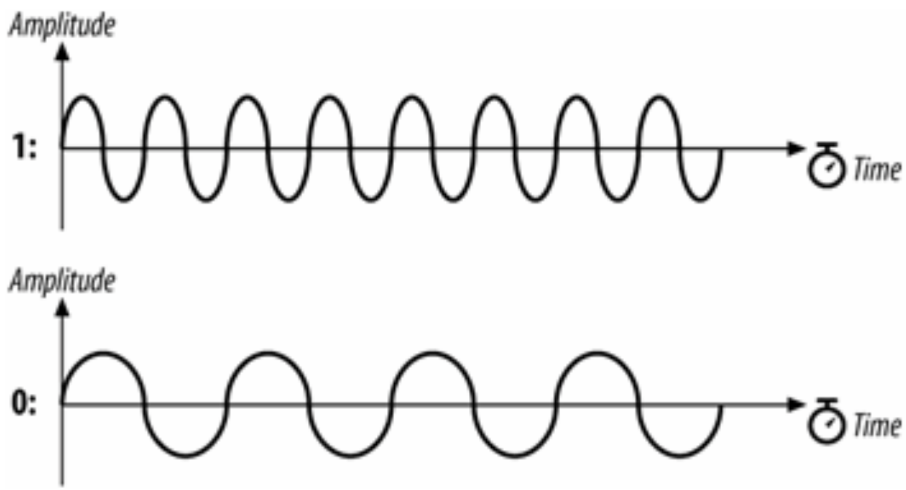
- Rather than directly modulating the frequency with the digital data symbols, "instantaneously" changing the frequency at the beginning of each symbol period, Gaussian frequency-shift keying (GFSK) filters the data pulses with a Gaussian filter to make the transitions smoother. This filter has the advantage of reducing sideband power, reducing interference with neighboring channels, at the cost of increasing intersymbol interference. It is used by DECT, Bluetooth, Cypress WirelessUSB, Nordic Semiconductor, Texas Instruments LPRF, Z-Wave and Wavenis devices. For basic data rate Bluetooth the minimum deviation is 115 kHz.
- A GFSK modulator differs from a simple frequency-shift keying modulator in that before the baseband waveform (levels −1 and +1) goes into the FSK modulator, it is passed through a Gaussian filter to make the transitions smoother so to limit its spectral width. Gaussian filtering is a standard way for reducing spectral width; it is called "pulse shaping" in this application.
- In ordinary non-filtered FSK, at a jump from −1 to +1 or +1 to −1, the modulated waveform changes rapidly, which introduces large out-of-band spectrum. If we change the pulse going from −1 to +1 as −1, −.98, −.93 ..... +.93, +.98, +1, and we use this smoother pulse to determine the carrier frequency, the out-of-band spectrum will be reduced.[7]

Gaussian FSK (GFSK) Modulator

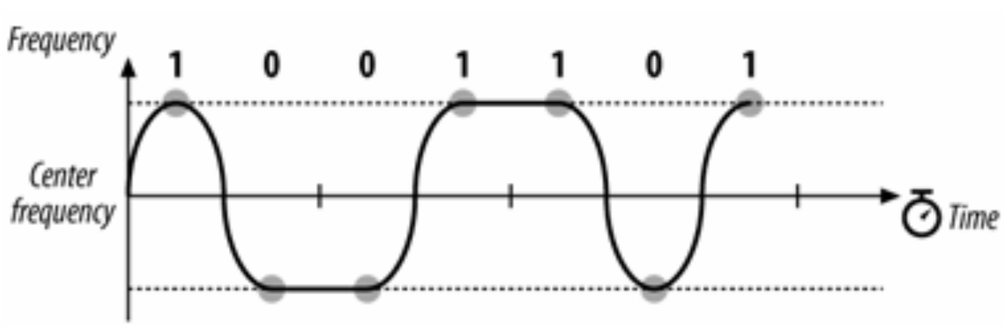


2 Level GFSK

- **2-level GFSK**

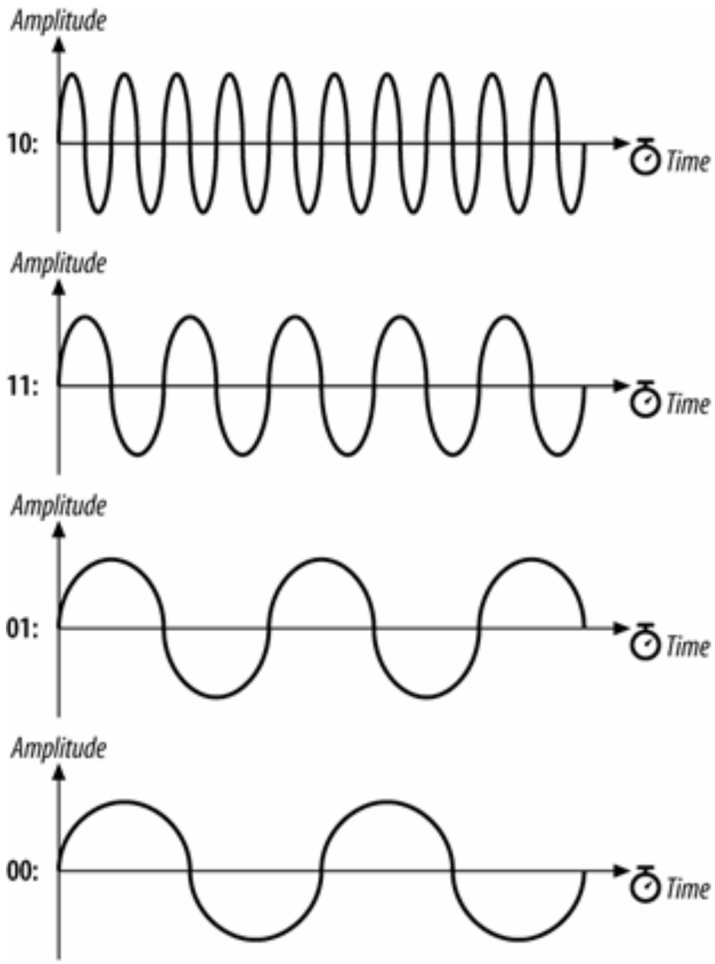


- **GFSK encoding of the letter “M”**

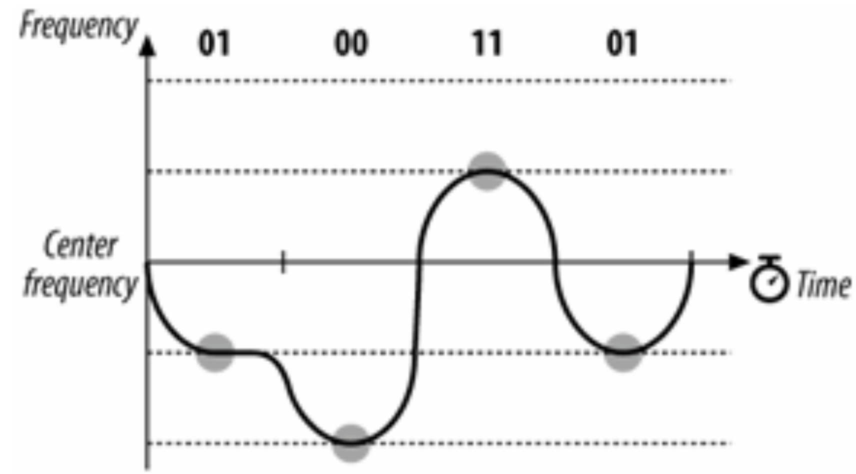


4 Level GFSK

- 4-level GFSK



GFSK encoding of the letter “M”



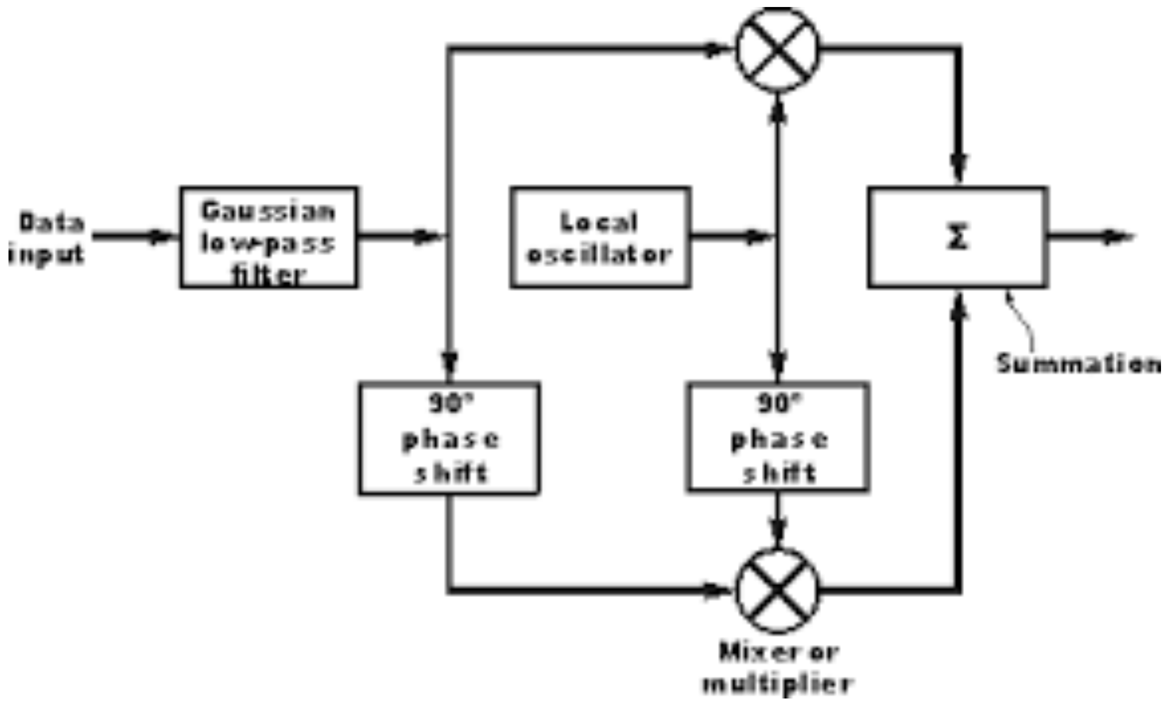
ANT vs Bluetooth

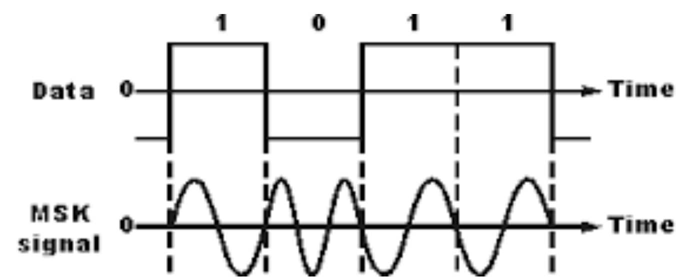
COMMON ANT AND BLUETOOTH LOW ENERGY FEATURES		
Technology	ANT	Bluetooth Low Energy
Frequency	2.4 to 2.483 GHz	2.4 to 2.483 GHz
Topologies supported	P2P, star, tree, mesh	P2P, star
Modulation	GFSK	GFSK
Channel width	1 MHz	2 MHz
Protocol	Simplest	More complex
Data rate	1 Mbit/s	1 Mbit/s
Range	50 meters	50 meters
Security	64-bit key	128-bit AES

Gaussian Minimum Shift Keying (GMSK)

- In digital communication, Gaussian minimum shift keying or GMSK is a continuous-phase frequency-shift keying modulation scheme.
- GMSK is similar to standard minimum-shift keying (MSK); however the digital data stream is first shaped with a Gaussian filter before being applied to a frequency modulator, and typically has much narrower phase shift angles than most MSK modulation systems. This has the advantage of reducing sideband power, which in turn reduces out-of-band interference between signal carriers in adjacent frequency channels.[2]
- However, the Gaussian filter increases the modulation memory in the system and causes intersymbol interference, making it more difficult to differentiate between different transmitted data values and requiring more complex channel equalization algorithms such as an adaptive equalizer at the receiver. GMSK has high spectral efficiency, but it needs a higher power level than QPSK, for instance, in order to reliably transmit the same amount of data.
- GMSK is most notably used in the Global System for Mobile Communications (GSM) and the Automatic Identification System (AIS) for maritime navigation.

Gaussian Minimum Shift Keying (GMSK)



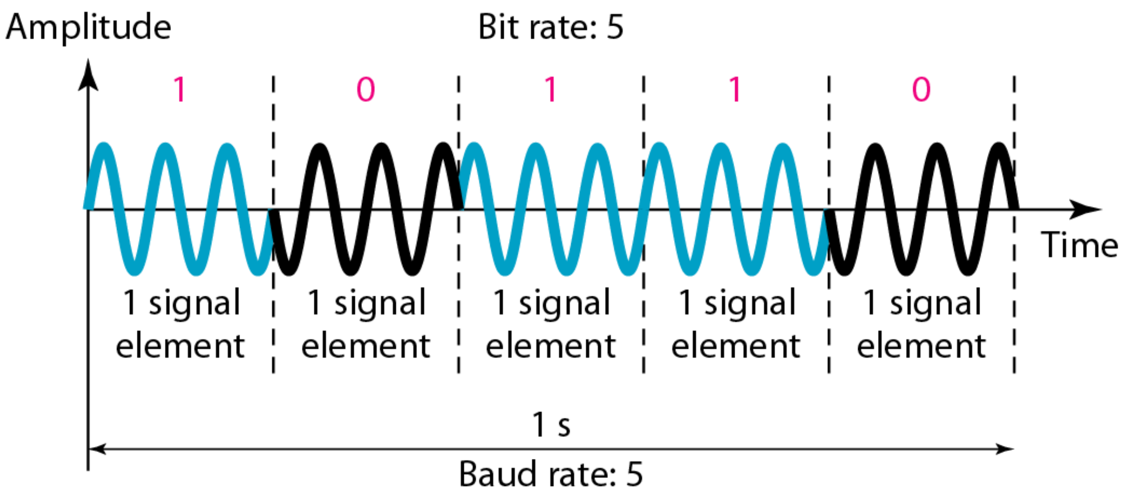


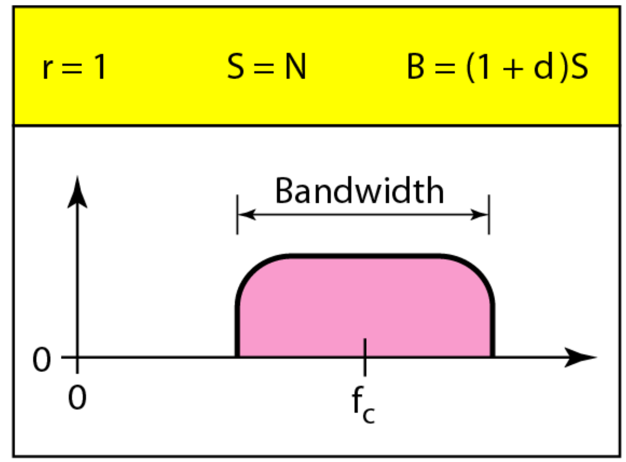
Cellular Technologies Comparison

	AMPS	GSM	CDMA/IS-95
Multiple Access	FDMA	TDMA	DS-CDMA
Modulation	FM	GMSK	QPSK
RF Bandwidth	30 kHz	200 kHz	1,25 MHz
Channel/RF Carrier	1	8	20 – 30
Uplink Frequency	824 – 849 MHz	890 – 915 MHz	824 – 849 MHz
Downlink Frequency	869 – 894 MHz	935 – 960 MHz	869 – 894 MHz

Phase Shift Keying (PSK)

- In phase shift keying, 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. Today, PSK is more common than ASK or FSK

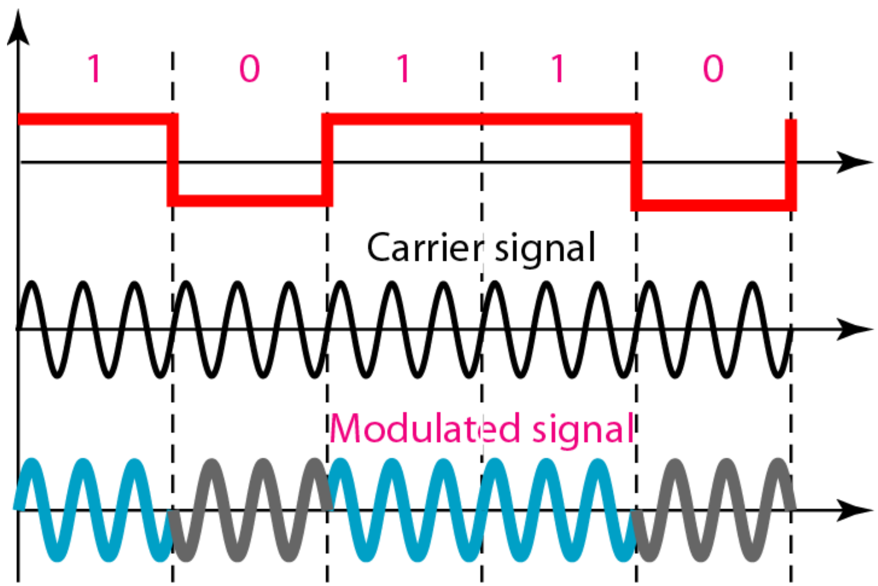


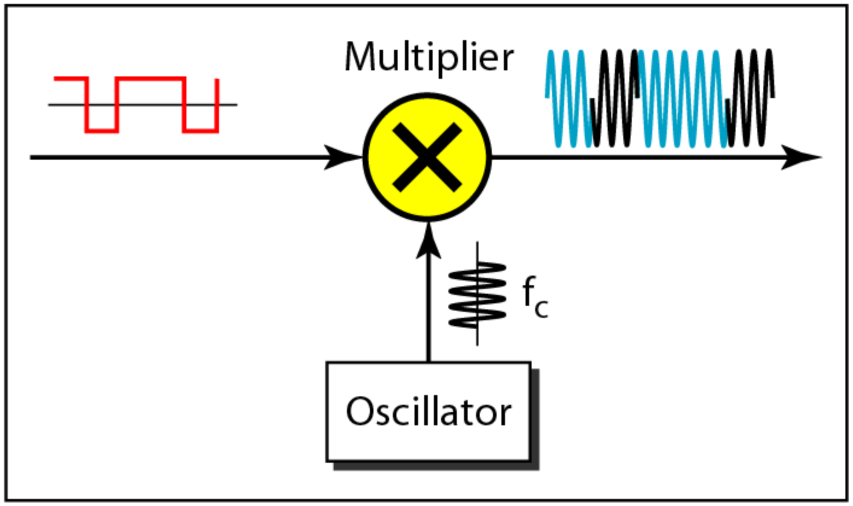


$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary } 1 \\ A\cos(2\pi f_2 t) & \text{binary } 0 \end{cases}$$

Implementation BPSK

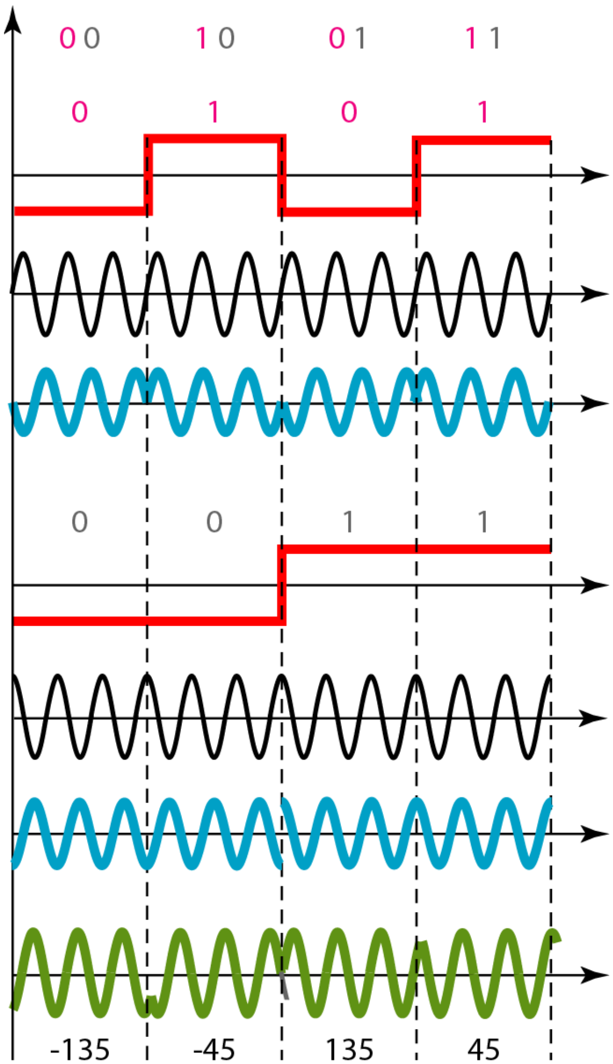
- Binary PSK is as simple as binary ASK with one big advantage-it is less susceptible to noise. In ASK, the criterion for bit detection is the amplitude of the signal; in PSK, it is the phase. Noise can change the amplitude easier than it can change the phase. In other words, PSK is less susceptible to noise than ASK. PSK is superior to FSK because we do not need two carrier signals.

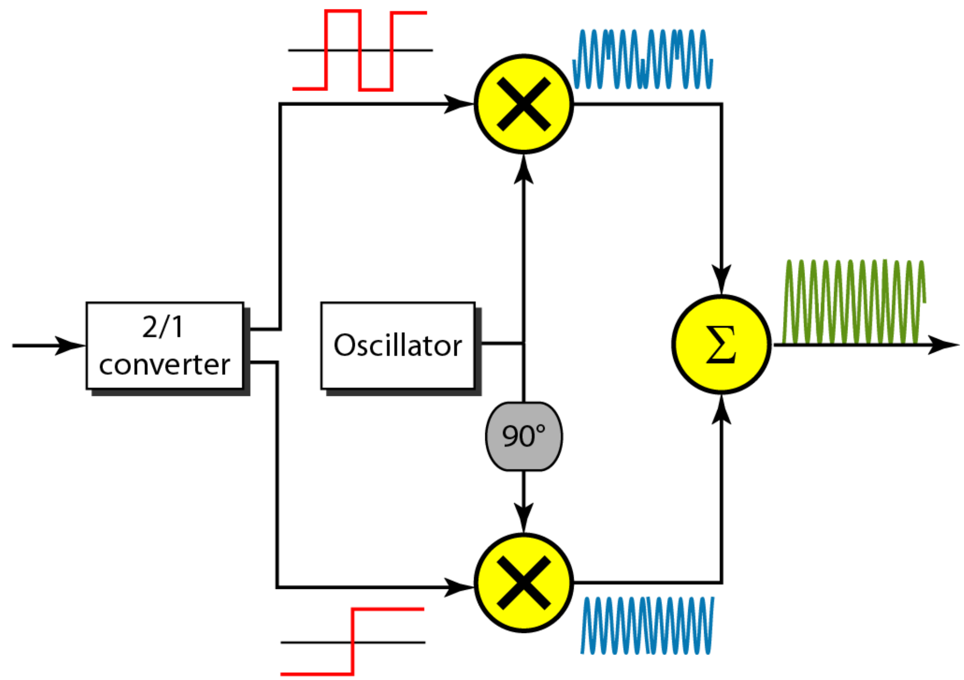




- The implementation of BPSK is as simple as that for ASK. The reason is that the signal element with phase 180° can be seen as the complement of the signal element with phase 0°. This gives us a clue on how to implement BPSK. We use the same idea we used for ASK but with a polar NRZ signal instead of a unipolar NRZ signal, as shown in Figure 5.10. 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°.

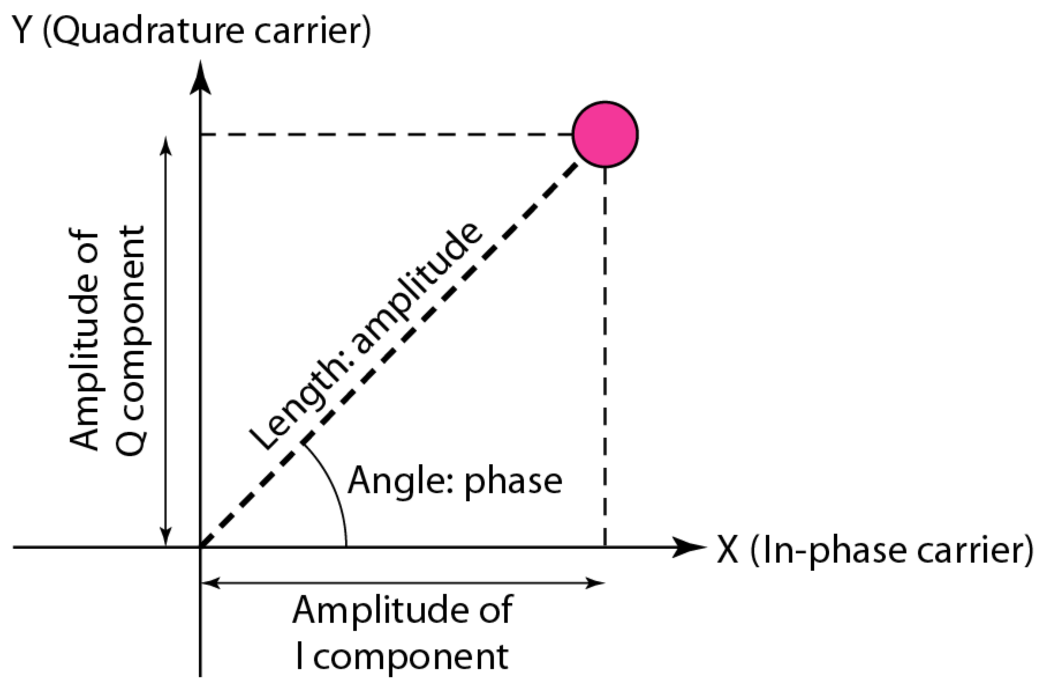
Quadrature Phase Shift Keying (QPSK)





Concept of a Constellation Diagram

- A constellation diagram can help us define the amplitude and phase of a signal element, particularly when we are using two carriers (one in-phase and one quadrature), The diagram is useful when we are dealing with multilevel ASK, PSK, or QAM (see next section). In a constellation diagram, a signal element type is represented as a dot. The bit or combination of bits it can carry is often written next to it.

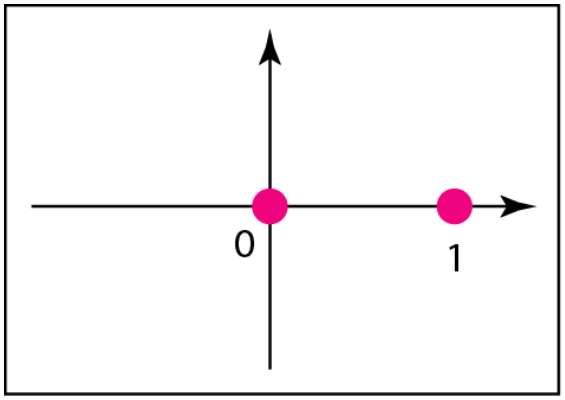


Quadrature Amplitude Modulation

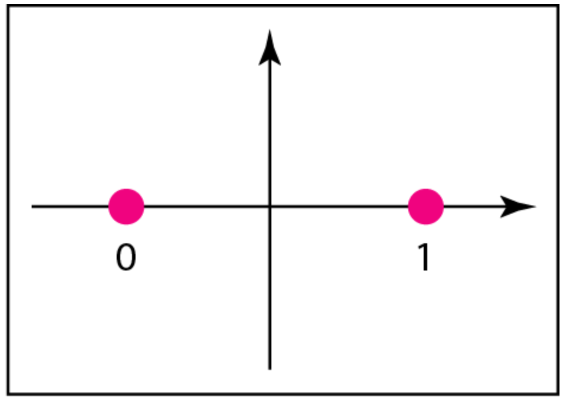
- PSK is limited by the ability of the equipment to distinguish small differences in phase. This factor limits its potential bit rate. So far, we have been altering only one of the three characteristics of a sine wave at a time; but what if we alter two?
- Why not combine ASK and PSK? The idea of using 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 Diagram

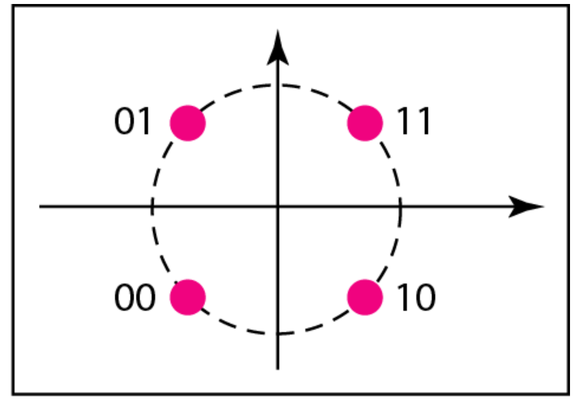
- Show the constellation diagrams for an ASK (OOK), BPSK, and QPSK signals.



a. ASK (OOK)



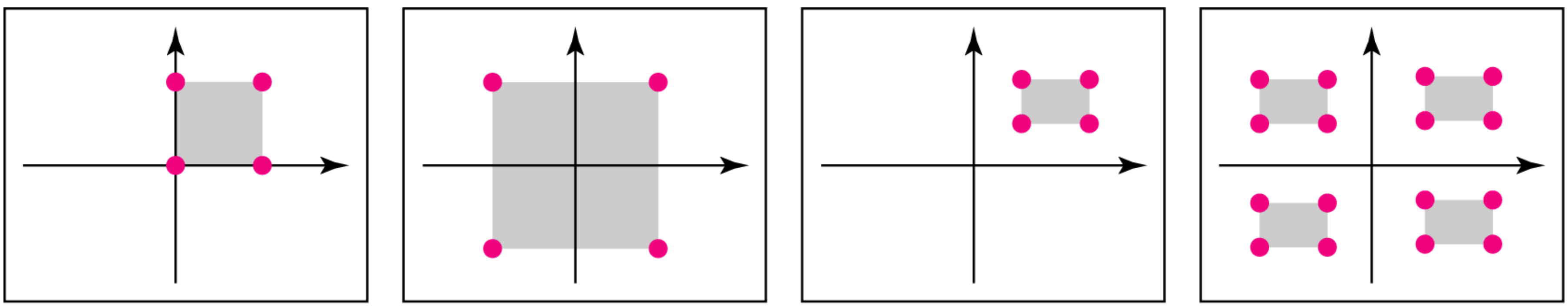
b. BPSK



c. QPSK

Constellation Diagram

- The possible variations of QAM are numerous. Figure below shows some of these schemes. Figure a shows the simplest 4-QAM scheme (four different signal element types) 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 exactly the same as QPSK. 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 d shows a 16-QAM constellation of a signal with eight levels, four positive and four negative.

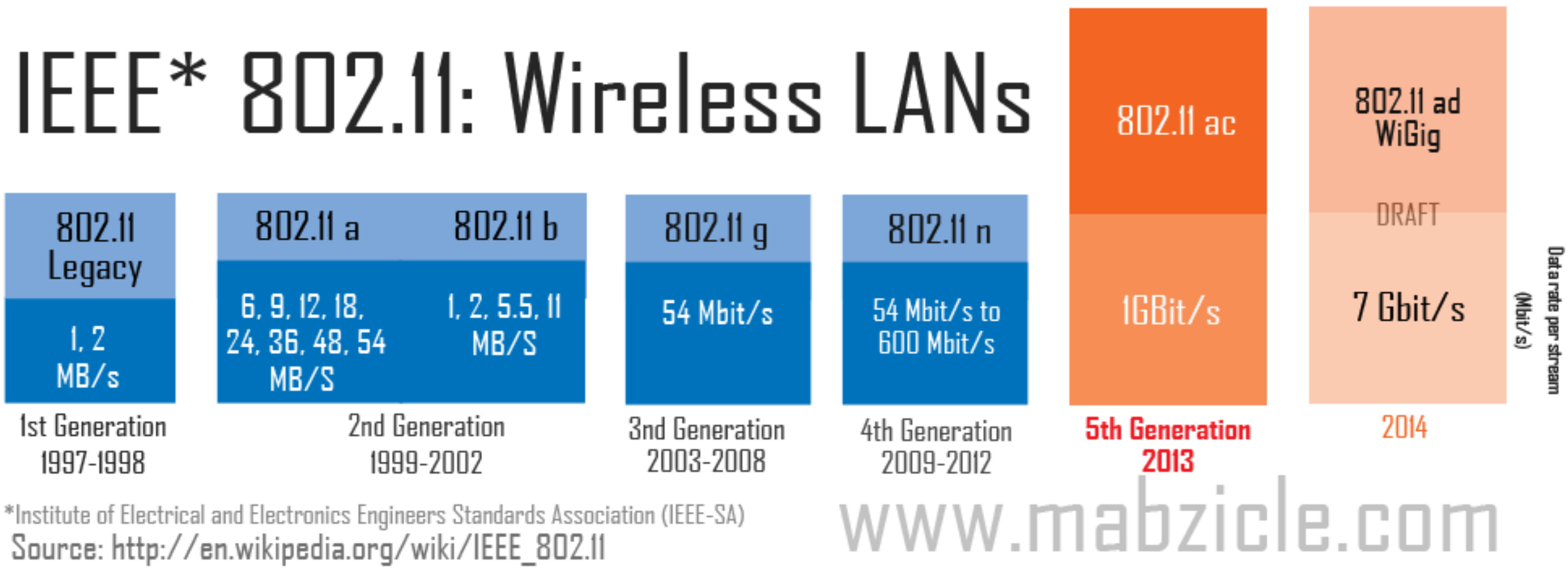


a. 4-QAM b. 4-QAM c. 4-QAM d. 16-QAM

QAM Implementation

- A variety of communication protocols implement quadrature amplitude modulation (QAM). Current protocols such as 802.11b wireless Ethernet (Wi-Fi) and digital video broadcast (DVB), for example, both utilize 64-QAM modulation. In addition, emerging wireless technologies such as Worldwide Interoperability for Microwave Access (WiMAX), 802.11n, and HSDPA/HSUPA (a new cellular data standard) will implement QAM as well. Thus, understanding QAM is important because of its widespread use in current and emerging technologies.
- source: http://www.ni.com/white-paper/3896/en/

IEEE 802.11 Wireless LANs

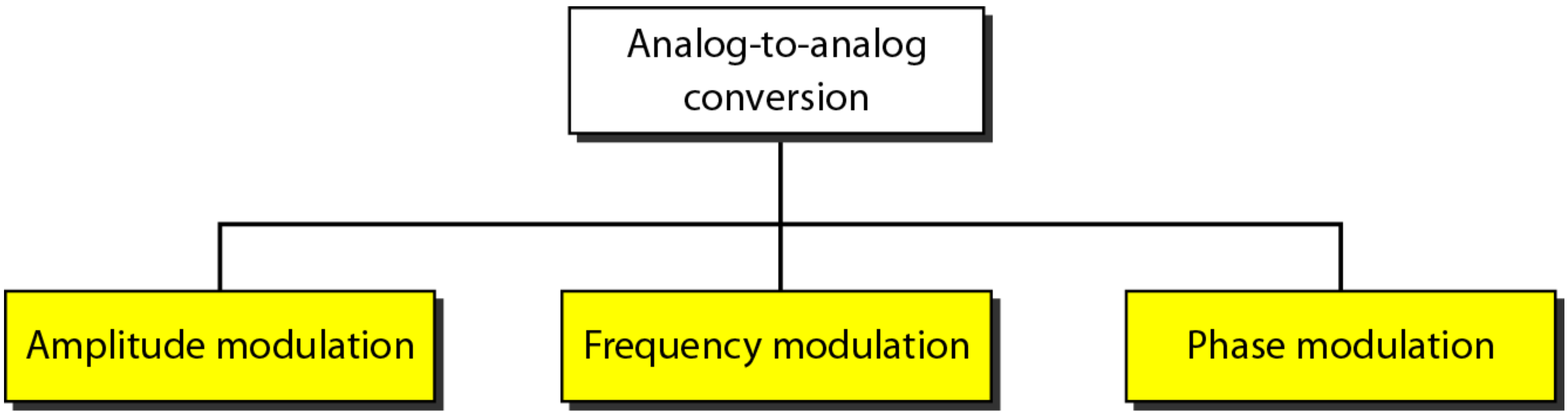


IEEE 802.11 Wireless LANs

	802.11ac	802.11ad	802.11af "White-Fi"	802.11ah
Bands	5 GHz	60 GHz	TV White Spaces 54 to 790 MHz	< 1 GHz (ISM Bands vary by country)
Modulation Schemes	BPSK to 256-QAM	BPSK to 64-QAM	BPSK to 256-QAM	BPSK to 256-QAM
Channel Architecture	OFDM	OFDM and Single Carrier	OFDM	OFDM
Channel Bandwidth	20, 40, 80, 80 + 80, and 160 MHz	2.16 GHz	6, 7, and 8 MHz	1, 2, 4, 8, and 16 MHz
Year Introduced	Draft in 2011 Finalized in 2014	2012 Wi-Gig in 2016	2013	Will be Finalized In Early 2016

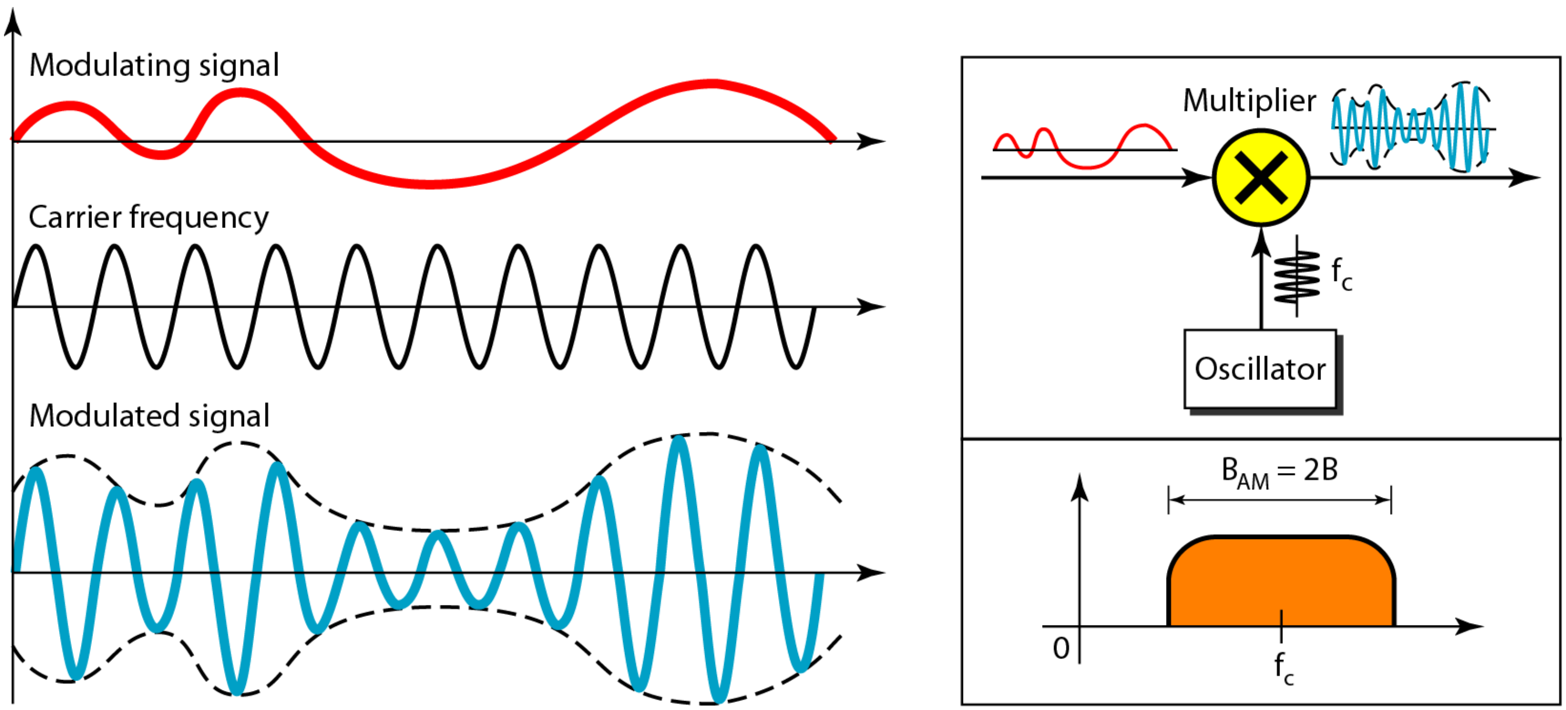
Analog to Analog Conversion

- 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.

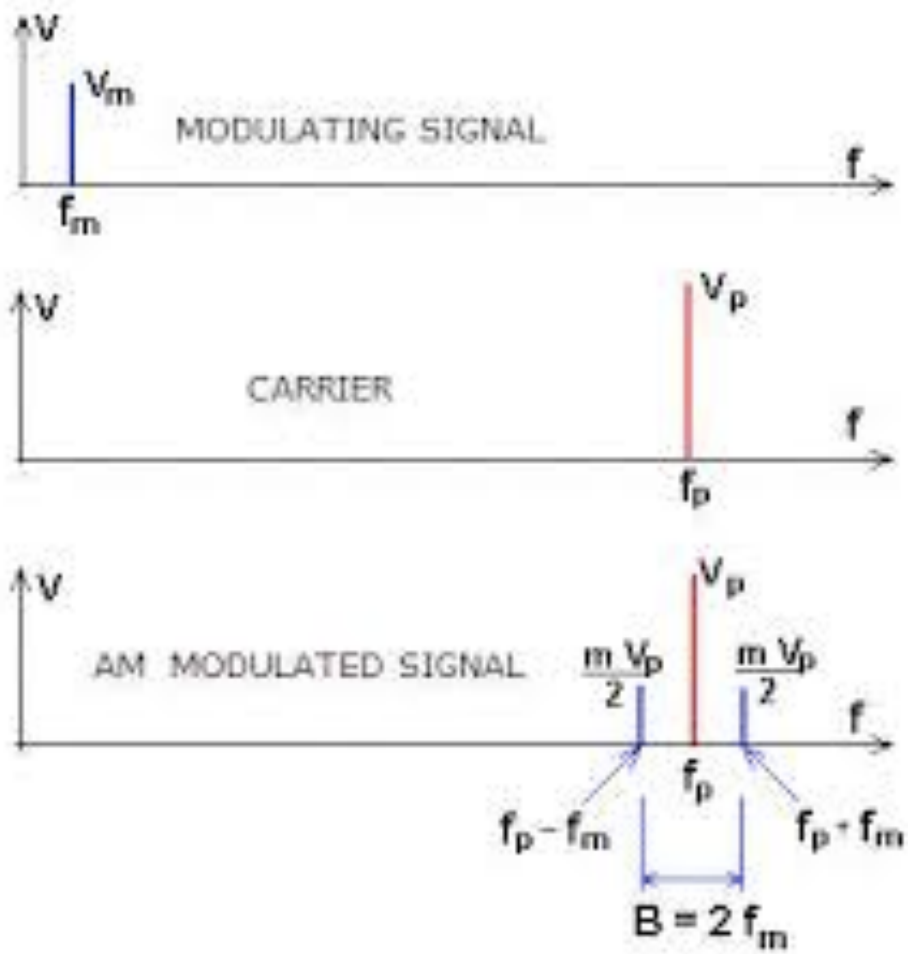


Amplitude Modulation (AM)

- 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

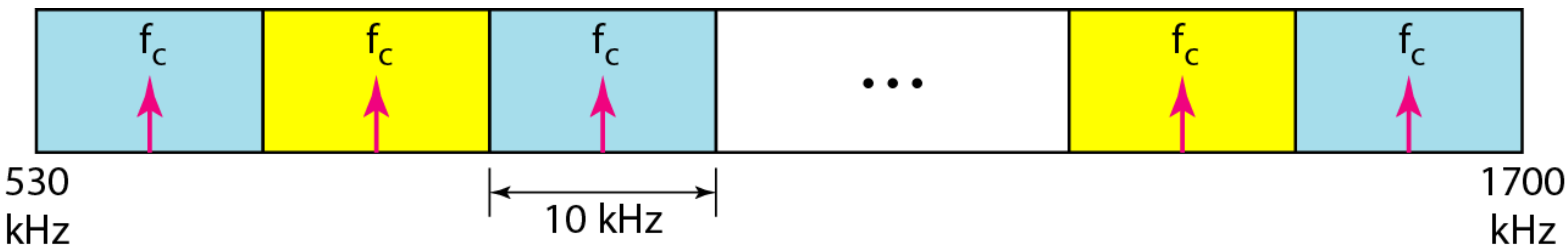


The total bandwidth required for AM can be determined from the bandwidth of the audio signal: $B_{AM} = 2B$


V
Vm
MODULATING SIGNAL
f
fm
V
Vp
CARRIER
f
fp
V
Vp
AM MODULATED SIGNAL
m Vp / 2
m Vp / 2
f
fp
fp - fm
fp + fm
B = 2 fm

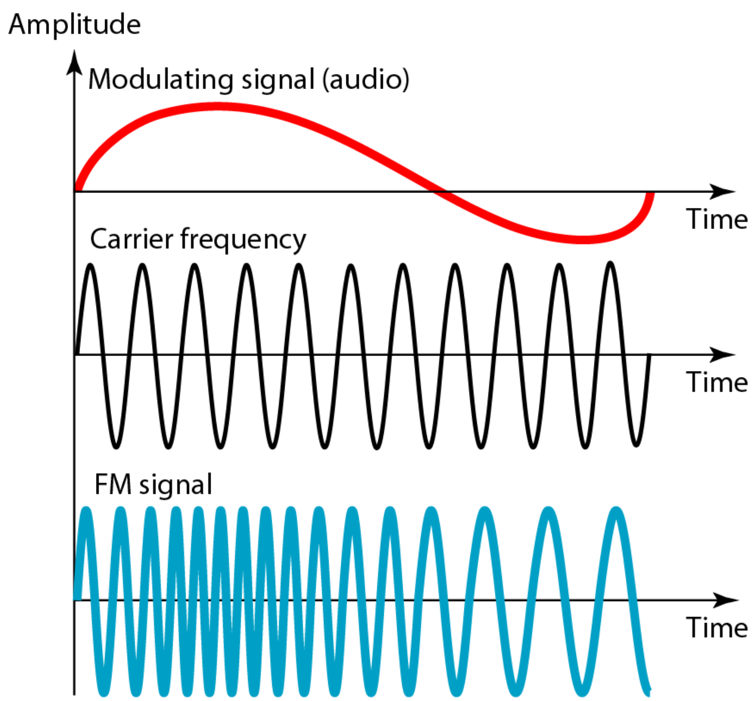
Standar Bandwidth Allocation for AM Radio

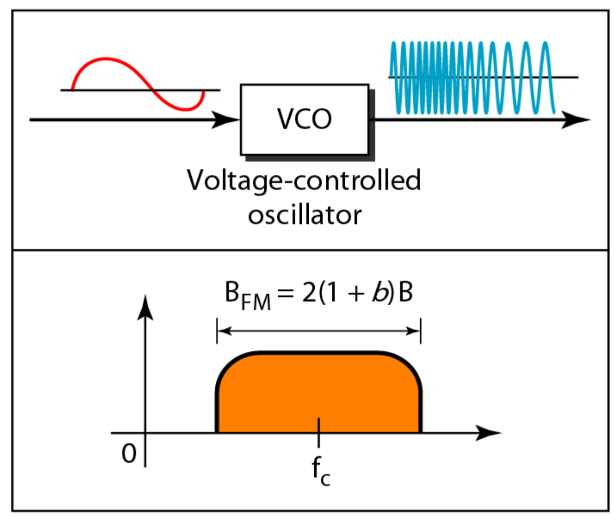
- The bandwidth of an audio signal (speech and music) usually 5 kHz. Therefore, an AM radio station needs a bandwidth of 10KHz.
- AM stations are allowed carrier frequencies anywhere between 530 and 1700 kHz. However, each station's carrer frequency must be separated from those on either side of it at least 10 kHz (one AM bandwidth) to avoid interference.



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 od the carrier signal remain constant, but as the amplitude of the information signal changes, the frequency of the carrier changes correspondingly.

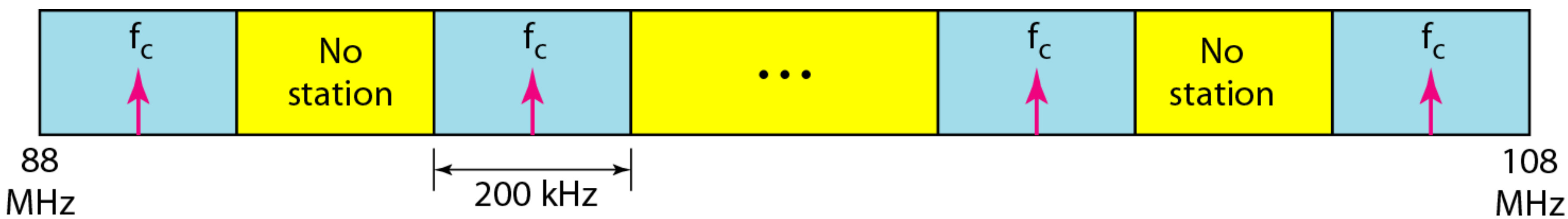




The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 + \beta)B$.

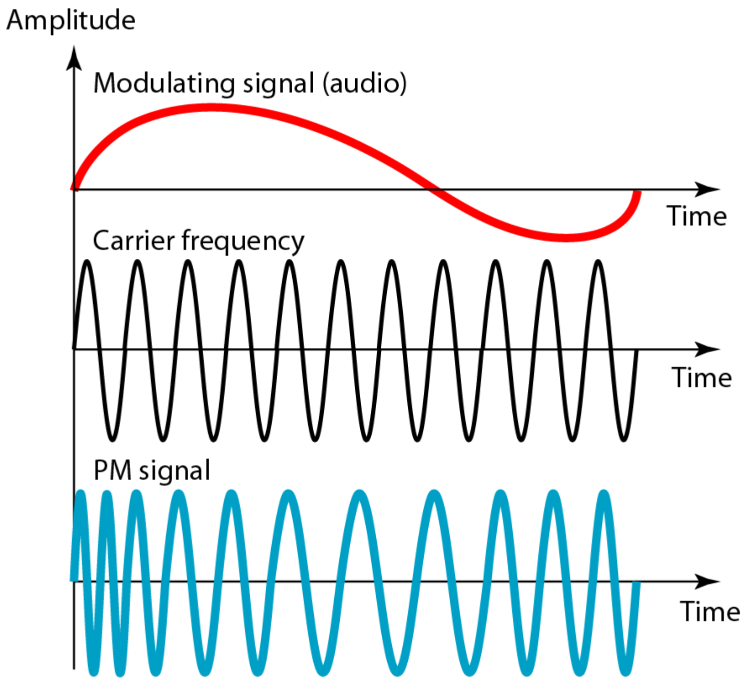
Standard Bandwidth Allocation for FM Radio

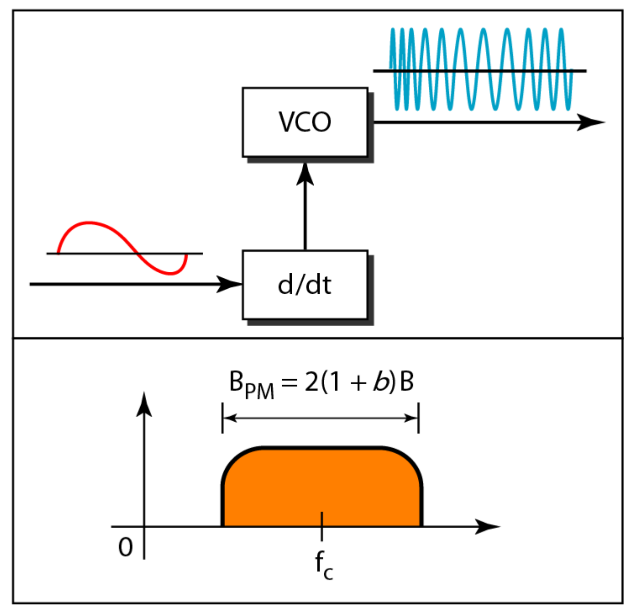
- The bandwidth of an audio signal (speech and music) broadcast in stereo is almost 15 kHz. The FCC allows 200 kHz for each station. This mean β = 4 with some extra guard band. FM frequencies anywhere between 88 and 108 MHz. Stations must be separated by at least 200 MHz to keep their bandwidths from overlapping. Given 88 to 108 MHz as a range, there are 100 potential FM bandwidth in an area, of which 50 can operate at any one time.



Phase Modulation

- 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.





The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal: $B_{PM} = 2(1 + \beta)B$.