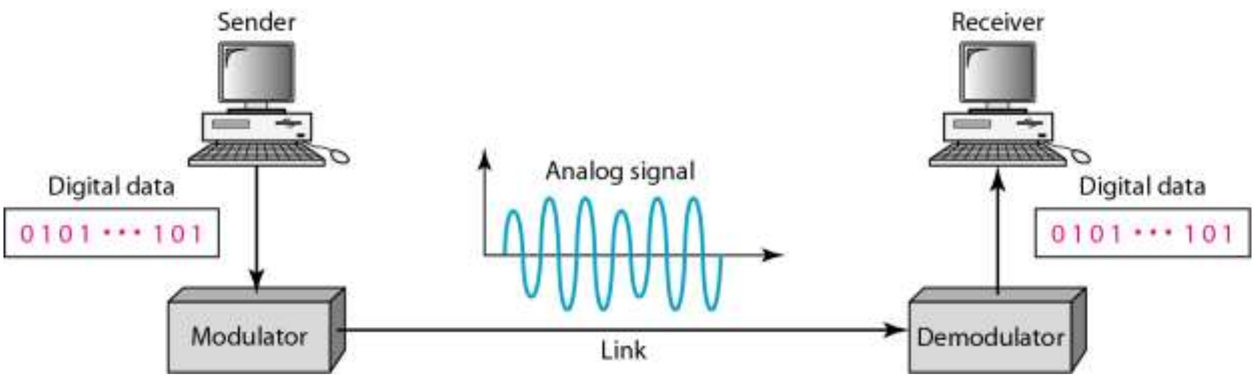
Analog Transmission

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.



Following are Digital to Analog conversion techniques:

- *Amplitude Shift Keying*
- *Frequency Shift Keying*
- *Phase Shift Keying*
- *Quadrature Amplitude Modulation*

Aspects of Digital-to-Analog Conversion

Data Element versus Signal Element

Data element is the smallest piece of information to be exchanged, the bit. A signal element is the smallest unit of a signal that is constant.

Data Rate versus Signal Rate

The relationship between Data Rate (N) & Signal Rate(S) is

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

where *N* is the data rate (bps) and *r* is the number of data elements carried in one signal element. The value of *r* in analog transmission is $r = \log_2 L$, where *L* is the type of signal element, not the level.

Bandwidth

The required bandwidth for analog transmission of digital data is proportional to the signal rate except for FSK, in which the difference between the carrier signals needs to be added.

Carrier Signal

In analog transmission, the sending device produces a high-frequency signal that acts as a base for the information signal. This base signal is called the carrier signal or carrier frequency. The receiving device is tuned to the frequency of the carrier signal that it expects from the sender.

Amplitude Shift Keying

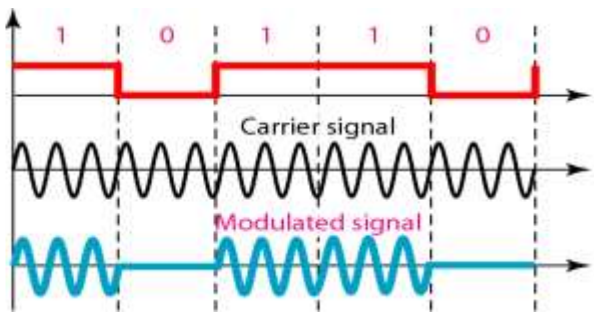
In amplitude shift keying, the amplitude of the carrier signal is varied to create signal elements. Both frequency and phase remain constant while the amplitude changes.

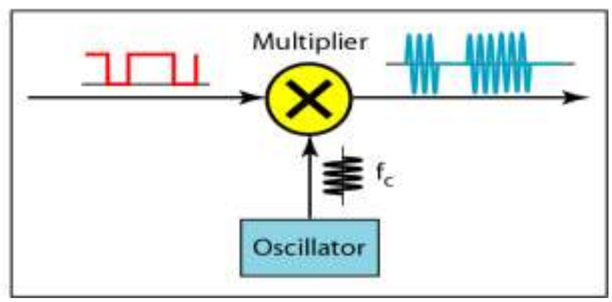
Binary ASK (BASK)

ASK implemented using only two levels is referred to as **binary amplitude shift keying or *on-off keying* (OOK)**. The peak amplitude of one signal level is 0; the other is the same as the amplitude of the carrier frequency.
Bandwidth is calculated as follows:

$$\boldsymbol{B = (1 + d) \times S}$$

where d = factor which depends on the modulation and filtering process, The value of *d* is between 0 and 1, S = signal rate.





Implementation: If digital data are presented as a unipolar NRZ digital signal with a high voltage of 1V and a low voltage of 0V, 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; when the amplitude of the NRZ signal is 0, the amplitude of the carrier frequency is zero.

Multilevel ASK

We can have multilevel ASK in which there are more than two levels. We can use 4, 8, 16, or more different amplitudes for the signal and modulate the data using 2, 3, 4, or more bits at a time. In these cases, *r* = 2, *r* = 3, *r* =4, and so on.

Frequency Shift Keying

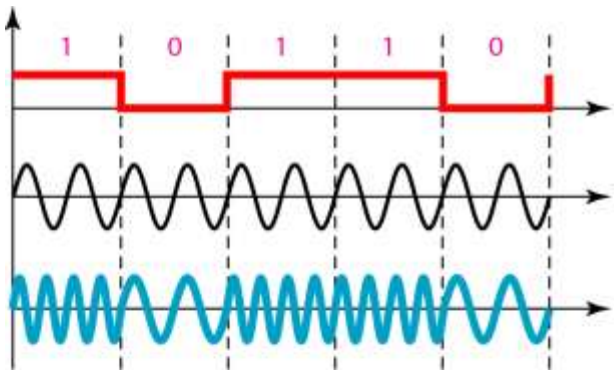
In frequency shift keying, the frequency of the carrier signal is varied to represent data. The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes. Both peak amplitude and phase remain constant for all signal elements.

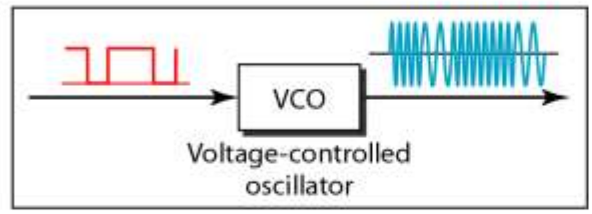
Binary FSK (BFSK)

One way to think about binary FSK (or BFSK) is to consider two carrier frequencies. We use the first carrier if the data element is 0; we use the second if the data element is 1.

The bandwidth is calculated as follows,

$$\boldsymbol{B = (1 + d) \times S + 2\Delta f}$$





<u>Implementation</u>: There are two implementations of BFSK: **non-coherent** and **coherent**.
In **non-coherent BFSK**, there may be discontinuity in the phase when one signal element ends and the next begins. Non-coherent BFSK can be implemented by treating BFSK as two ASK modulations and using two carrier frequencies. In **coherent BFSK**, the phase continues through the boundary of two signal elements. Coherent BFSK can be implemented by using one *voltage-controlled oscillator* (VCO) that changes its frequency according to the input voltage. Figure above shows the simplified idea behind the second implementation. The input to the oscillator is the unipolar NRZ signal. When the amplitude of NRZ is zero, the oscillator keeps its regular frequency; when the amplitude is positive, the frequency is increased.

Multilevel FSK

Multilevel modulation (MFSK) is common with the FSK method. 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 at a time, we can use eight frequencies.

Phase Shift Keying

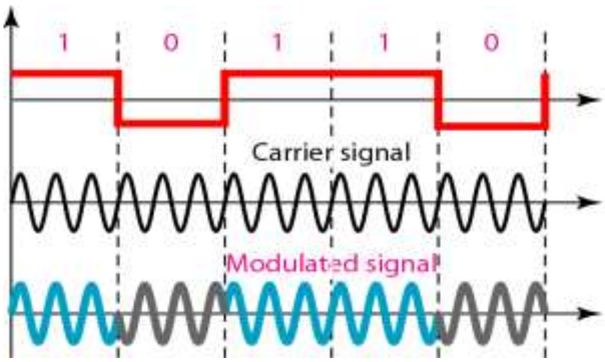
In phase shift keying, the phase of the carrier is varied to represent two or more different signal elements. Both amplitude and frequency remain constant as the phase changes.

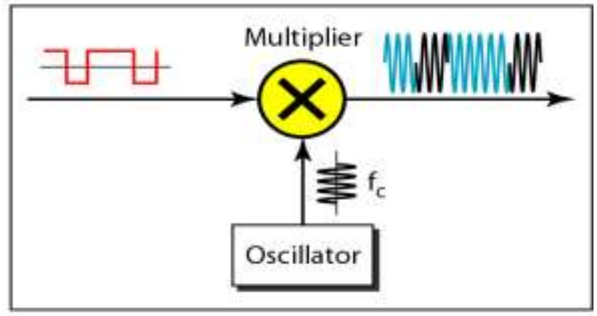
Binary PSK (BPSK)

The simplest PSK is binary PSK, in which we have only two signal elements, one with a phase of 0°, and the other with a phase of 180°. Noise can change the amplitude easier than it can change the phase. So, **PSK is less susceptible to noise than ASK**. PSK is superior to FSK because we do not need two carrier signals. The bandwidth is the same as that for binary ASK.

<u>Implementation</u>: 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°. 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°.

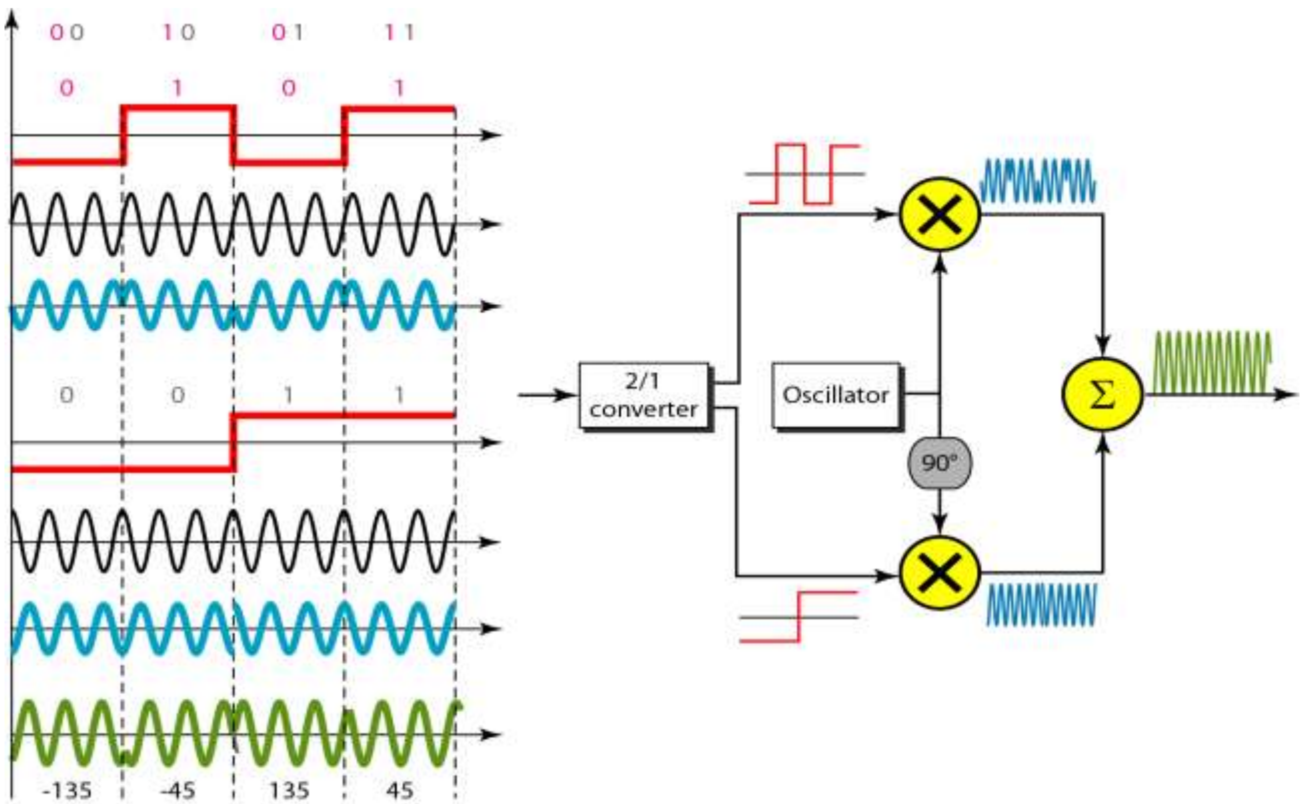
krishnaprasad@nitte.edu.in





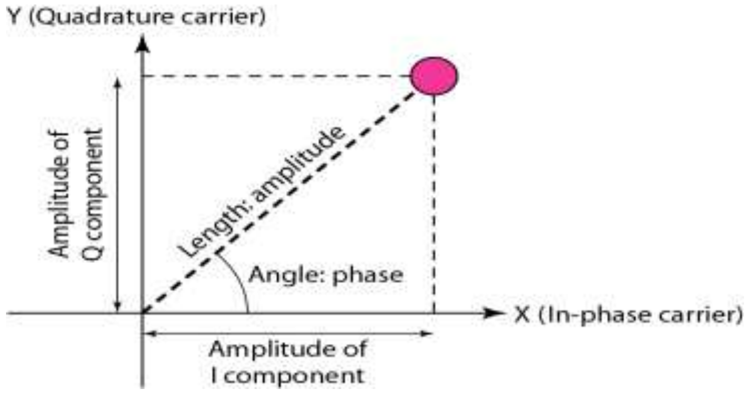
Quadrature PSK (QPSK)

This scheme is called quadrature PSK or QPSK because it uses two separate BPSK modulations; one is **in-phase**, the other **quadrature (out-of-phase)**. 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).



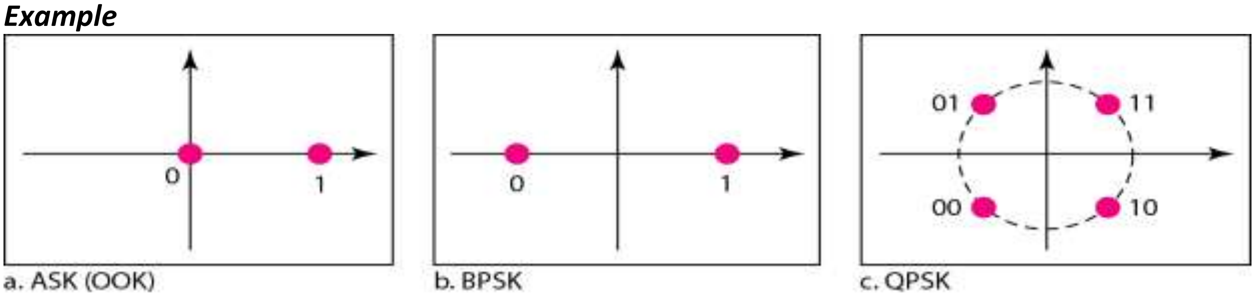
Constellation Diagram

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. 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.



The diagram has two axes. The horizontal X axis is related to the in-phase carrier; the vertical *Y* axis is related to the quadrature carrier. The projection of the point on the X axis defines the peak amplitude of the in-phase component; the projection of the point on the *Y* axis defines the peak amplitude of the quadrature component. The length of the line (vector) that connects the point to the origin is the peak amplitude of the signal element (combination of the X and *Y* components); the angle the line makes with the X axis is the phase of the signal element.

Example



Let us analyze each case separately:

a. For ASK, we are using only an in-phase carrier. Therefore, the two points should be on the X axis. Binary 0 has an amplitude of 0 V; binary 1 has an amplitude of 1V.

b. BPSK also uses only an in-phase carrier. However, we use a polar NRZ signal for modulation. It creates two types of signal elements, one with amplitude 1 and the other with amplitude -1. In other words: BPSK creates two different signal elements, one with amplitude 1V and in phase and the other with amplitude 1V and 180° out of phase.

c. QPSK uses two carriers, one in-phase and the other quadrature. The point representing 11 is made of two combined signal elements, both with an amplitude of 1V. The argument is similar for the other three points. All signal elements have an amplitude of $2^{1/2}$, but their phases are different (45°, 135°, -135°, and -45°).

Quadrature Amplitude Modulation

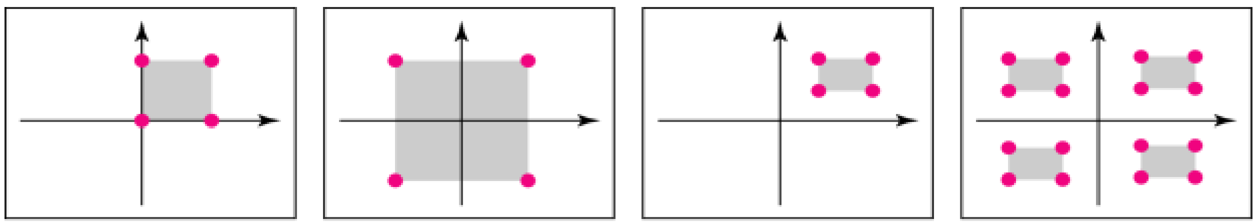
The idea of using two carriers, one in-phase and the other quadrature, with different amplitude levels for each carrier is the concept behind quadrature amplitude modulation (QAM). Quadrature amplitude modulation is a combination of ASK and PSK.

Figure.a shows the simplest 4-QAM scheme (four different signal element types) using a unipolar NRZ signal to modulate each carrier.

Figure.b shows another 4-QAM using polar NRZ, but this is exactly the same as QPSK.

Figure.c shows another 4-QAM in which we used a signal with two positive levels to modulate each of the two carriers.

Figure.d shows a 16-QAM constellation of a signal with eight levels.



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