What is a signal ?

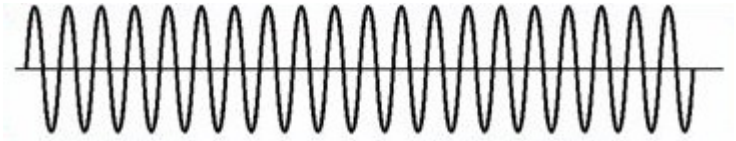
- A function of one or more independent variables which contain some information.
- Voltage, Current ,temperature are all different signals.
- Thus signal is a mathematical representation of any physical energy .

Objectives

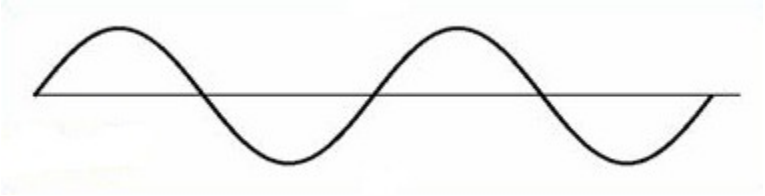
- What is signal , its types
- What is modulation
- Why is modulation done
- Sampling theorem
- Detailing about sampling theorem
- Communication systems
- Types of modulation

What is modulation ?

- It is a process in which some characteristics of a signal called carrier signal is varied in accordance with the value of the message signal.
- The message signal is also known as modulating or baseband signal
- The resultant signal after modulation is known as modulated or bandpass signal.



Carrier Wave



Modulating Signal

Why use modulation ?

1)To achieve practicality of antenna

The dimensions of transmitting antenna is limited by the wavelength of the signal it can transmit.

2)To remove interference

Types of modulation

- A carrier wave can be described by 3 parameters: amplitude, frequency and phase.

$$v(t) = A \sin(\omega t + \varphi)$$

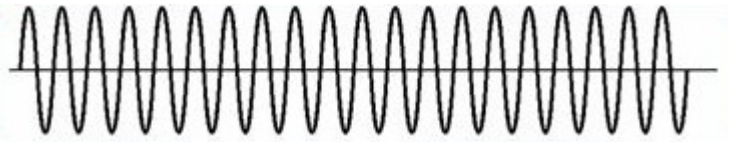
A=amplitude
ω=frequency
φ=phase

Thus we can have :-

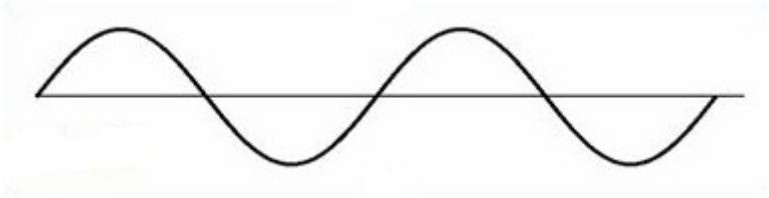
Amplitude Modulation
Frequency Modulation
Phase Modulation

Amplitude Modulation

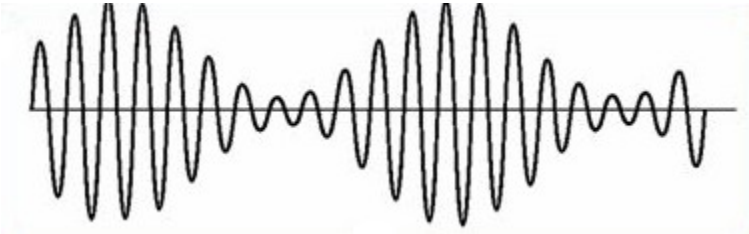
- It is a process in which amplitude of the carrier wave is varied according to message (modulating) signal.
- In the process of amplitude modulation the frequency and phase of the carrier wave remains constant.



Carrier wave



Sinusoidal modulating signal



Amplitude modulated signal

Suppose **C**arrier wave ,$c(t)= A_c \cos \omega_c t$

(baseband) **M**odulating signal , $x(t)= V \cos \omega_m t$

Amplitude Modulated wave is given by :-

$$s(t)=A_C \cos (2\pi f_C t) \{1 + m \cos (2\pi f_m t)\}$$

where A_C= *unmodulated peak carrier amplitude*

f_m = *modulating frequency*

f_C = carrier frequency

m= modulation index (degree of modulation)

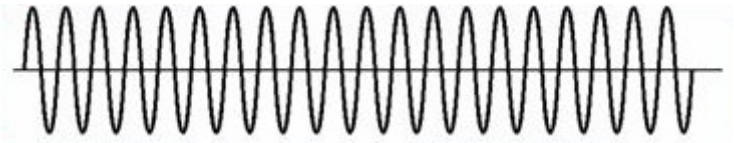
the value of m must be between ‘0’ and ‘1’ .

Modulation Index

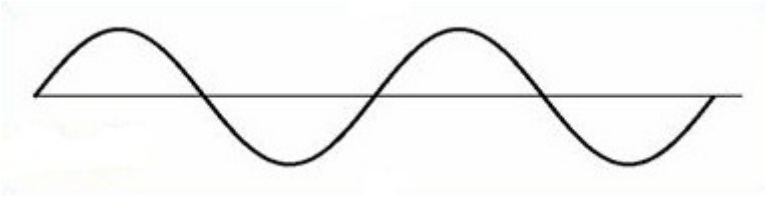
- Indicates by how much the modulated variable varies around its 'original' level.
- In terms of AM it can be defined as the measure of extent of amplitude variation about an unmodulated maximum carrier.
- also known as *modulation depth*
- *For AM* ,
- $$m = \frac{\text{peak value of modulated signal}}{\text{amplitude of carrier signal}} = \frac{V}{A_c}$$

Frequency Modulation

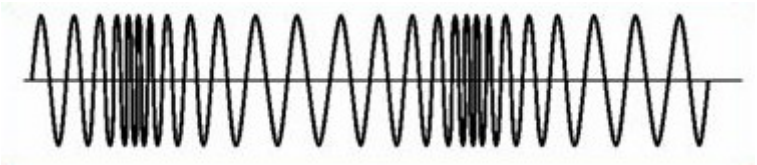
- It is a process in which frequency of the carrier wave is varied according to message (modulating) signal.
- In the process of frequency modulation , the amplitude and phase of the carrier wave remains constant.



Carrier wave



Sinusoidal modulating signal



Frequency modulated signal

Suppose carrier wave , $c(t)= A_c \cos \omega_c t$

Modulating signal ,$x(t)= V \cos \omega_m t$

Frequency modulated wave is given by :-

$$v(t) = A_C \cos \{2\pi f_C t - m \sin(2\pi f_m t)\}$$

where A_C = unmodulated peak carrier amplitude

f_C = carrier frequency

f_m = modulation frequency

m = modulation index (“degree” of modulation)

In case of FM ,modulating index describes variations in the frequency of the carrier signal.

$$m = \frac{\blacktriangle f}{f_m}$$ *where* $\blacktriangle f$ *is the peak frequency variation*

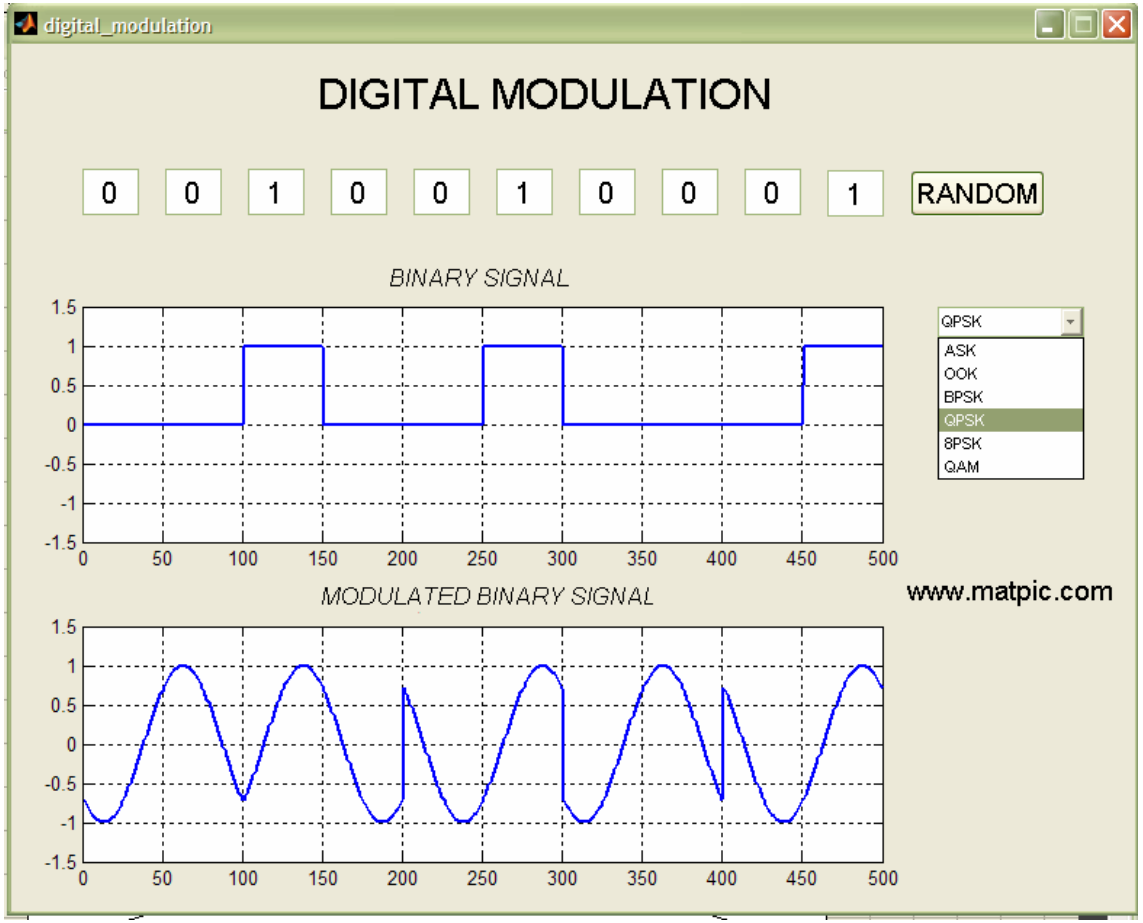
How are frequency and wavelength related?

$$\text{Wavelength} = \frac{\text{Speed of Light}}{\text{Frequency of Oscillation}}$$

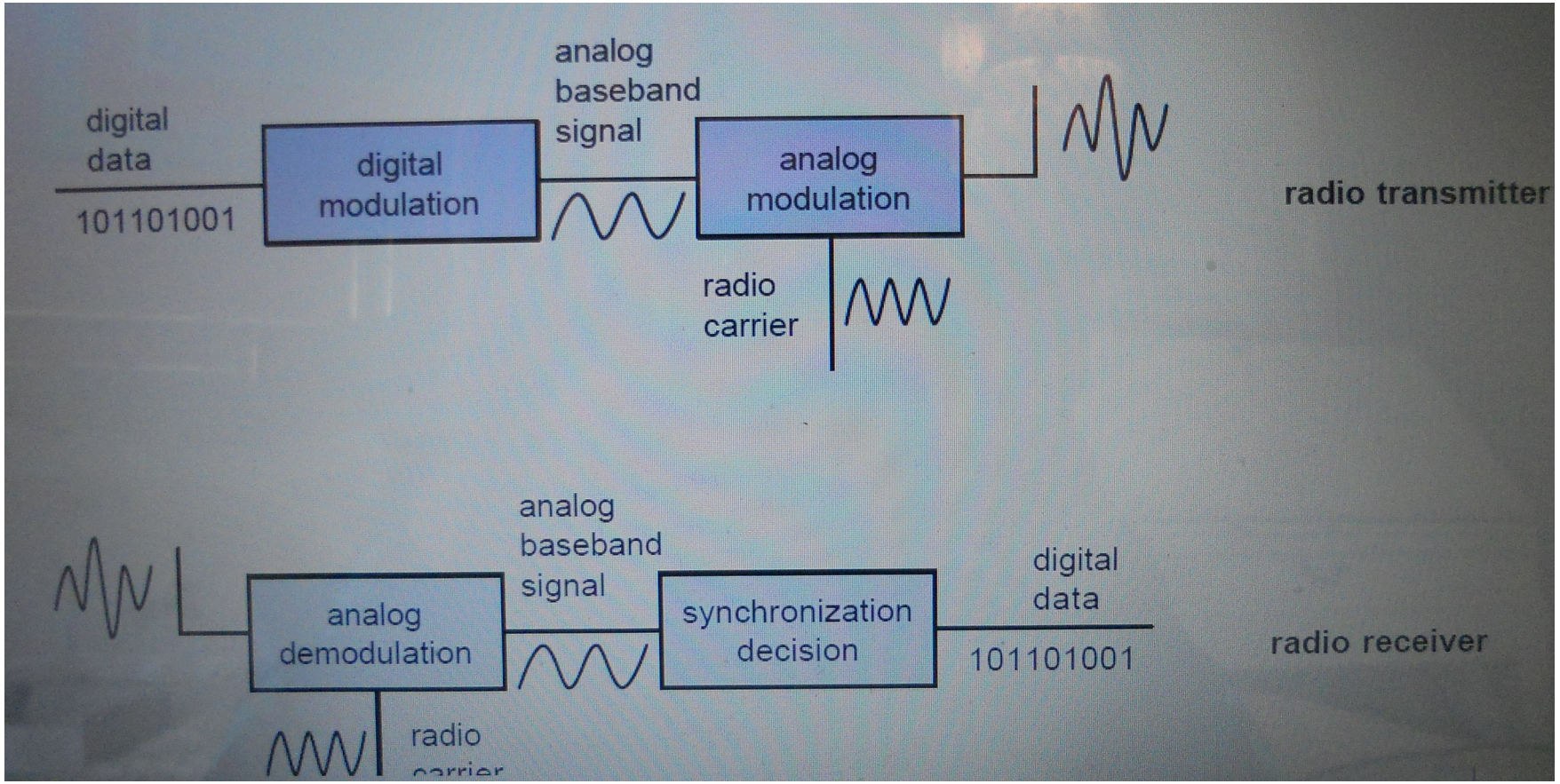
$$\text{Frequency of Oscillation} = \frac{\text{Speed of Light}}{\text{Wavelength}}$$

Digital Modulation

– Analog signal carrying digital data



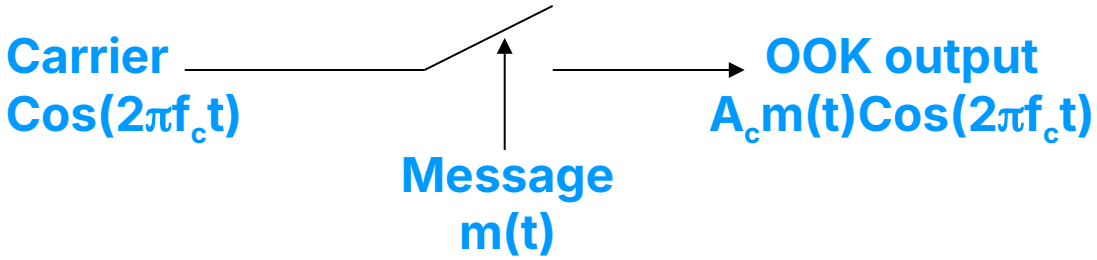
Digital to Analog/Analog to Digital

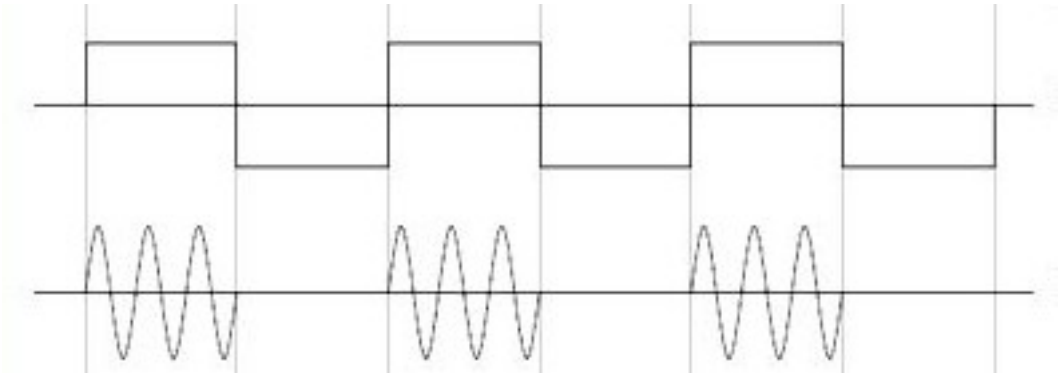


Amplitude Shift Keying

- The amplitude of an analog carrier signal varies in accordance with the digital (modulating signal), keeping frequency and phase constant.
- The level of amplitude can be used to represent binary logic 0s and 1s. We can think of a carrier signal as an ON or OFF switch.
- In the modulated signal, logic 0 is represented by the absence of a carrier and logic 1 is represented by the presence of a carrier , thus giving OFF/ON keying operation and hence the name given.
- The ASK technique is also commonly used to transmit digital data over optical fiber

On-Off Keying (OOK)





Modulating Signal , m(t)

Modulated Signal

- The complex envelope is



- The OOK signal is represented by



Phase-shift keying (PSK)

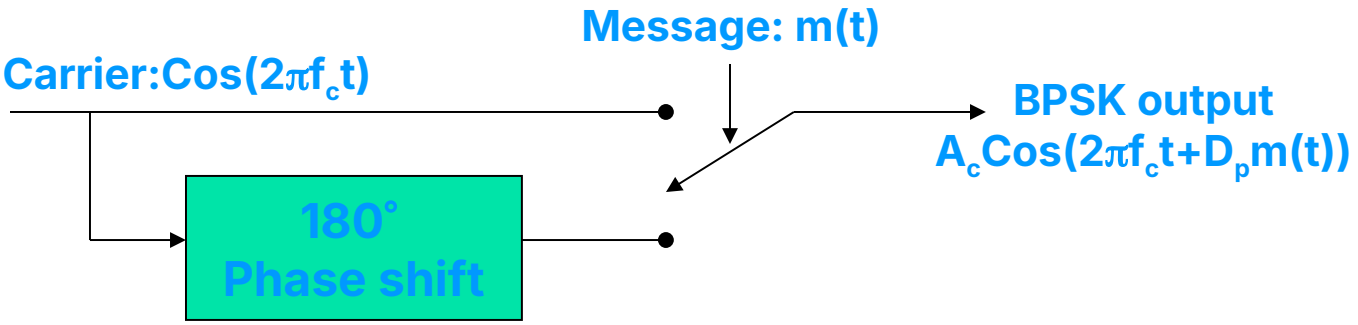
- A digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave).
- PSK uses a finite number of phases, each assigned a unique pattern of binary digits.
- Two common examples of phase shift keying are :-

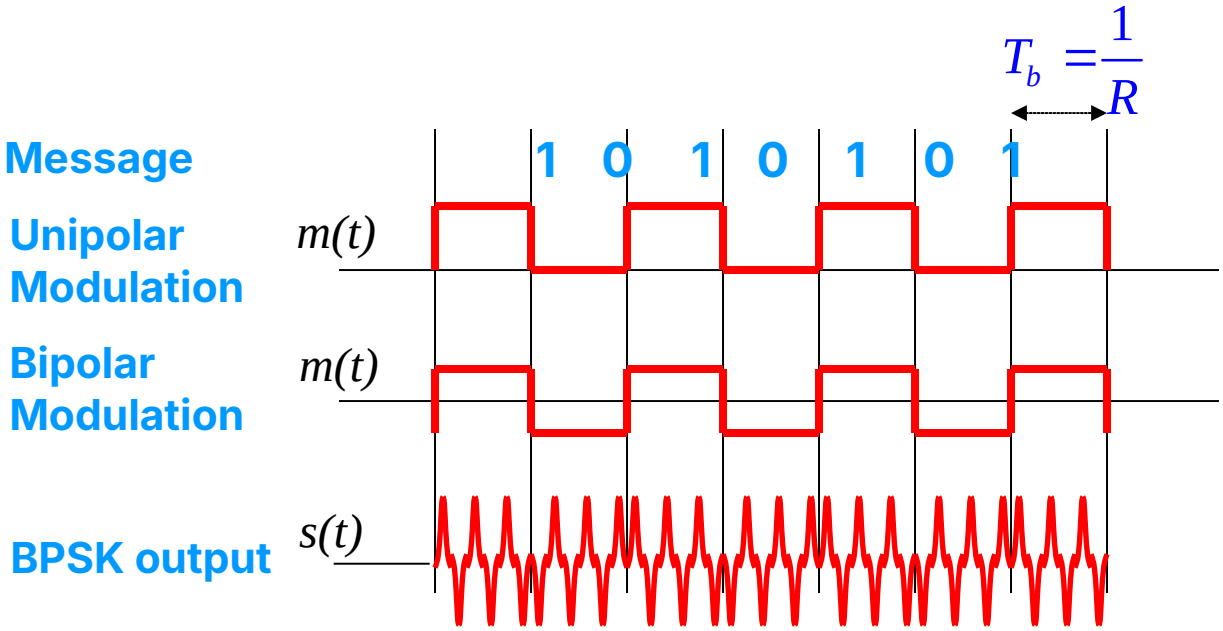
  Binary shift keying which uses 2 different phases

  Quadrature phase shift keying which uses 4 different phases.

Binary Phase Shift Keying (BPSK)

Generation:





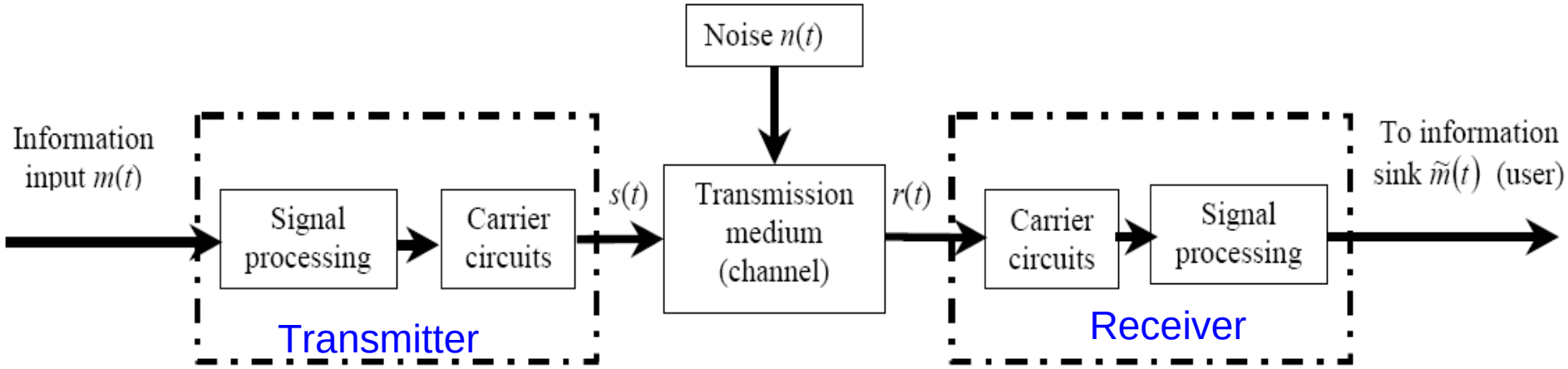
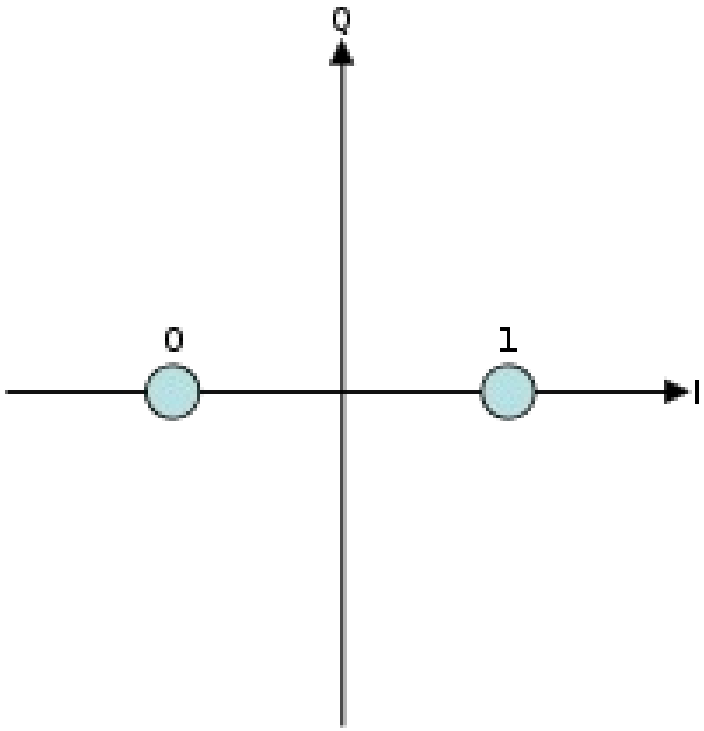


Fig. 1-1 Communication system.

BPSK defined using Constellation Diagram



BPSK

The general form for BPSK follows the equation:

$$s_n(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \pi(1-n)), n = 0, 1.$$

This yields two phases, 0 and π. In the specific form, binary data is often conveyed with the following signals:

$$s_0(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t - \pi) = -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t)$$ for binary "0"

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t)$$ for binary "1"

where f_c is the frequency of the carrier-wave.

Hence, the signal-space can be represented by the single basis function

$$\phi(t) = \sqrt{\frac{2}{T_b}}\cos(2\pi f_c t)$$

where 1 is represented by $\sqrt{E_b}\phi(t)$ and 0 is represented by $-\sqrt{E_b}\phi(t)$. This assignment is, of course, arbitrary.

- E_b = Energy-per-bit
- E_s = Energy-per-symbol = nE_b with n bits per symbol
- T_b = Bit duration
- T_s = Symbol duration
- $N_0 / 2$ = Noise power spectral density (W/Hz)
- P_b = Probability of bit-error
- P_s = Probability of symbol-error

BPSK
bit error rate/symbol error rate

The bit error rate (BER) of BPSK in AWGN

$$P_b \quad Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \quad \text{or} \quad P_b = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$$

Since there is only one bit per symbol, this is also the symbol error rate.

Quadrate phase shift keying

$$s_n(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c t + (2n-1)\frac{\pi}{4}\right), \quad n = 1, 2, 3, 4.$$

This yields the four phases π/4, 3π/4, 5π/4 and 7π/4 as needed.

This results in a two-dimensional signal space with unit basis functions

$$\phi_1(t) = \sqrt{\frac{2}{T_s}} \cos(2\pi f_c t)$$

$$\phi_2(t) = \sqrt{\frac{2}{T_s}} \sin(2\pi f_c t)$$

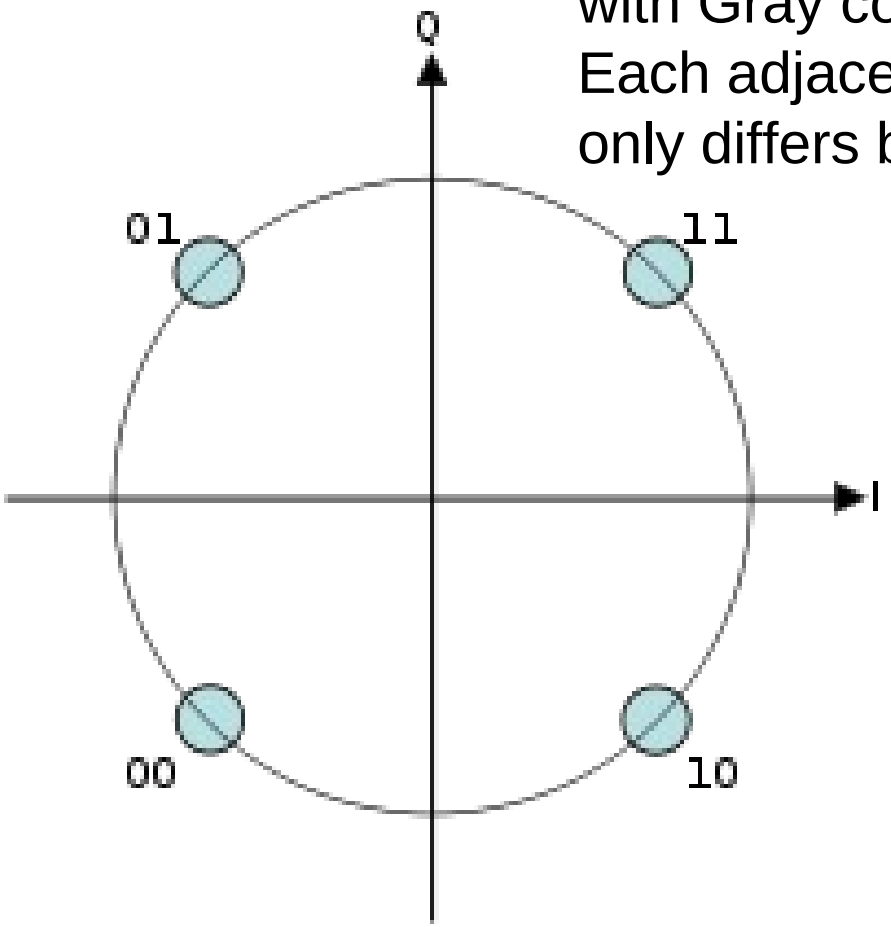
The first basis function is used as the in-phase component of the signal and the second as the quadrature component of the signal.

Hence, the signal constellation consists of the signal-space 4 points

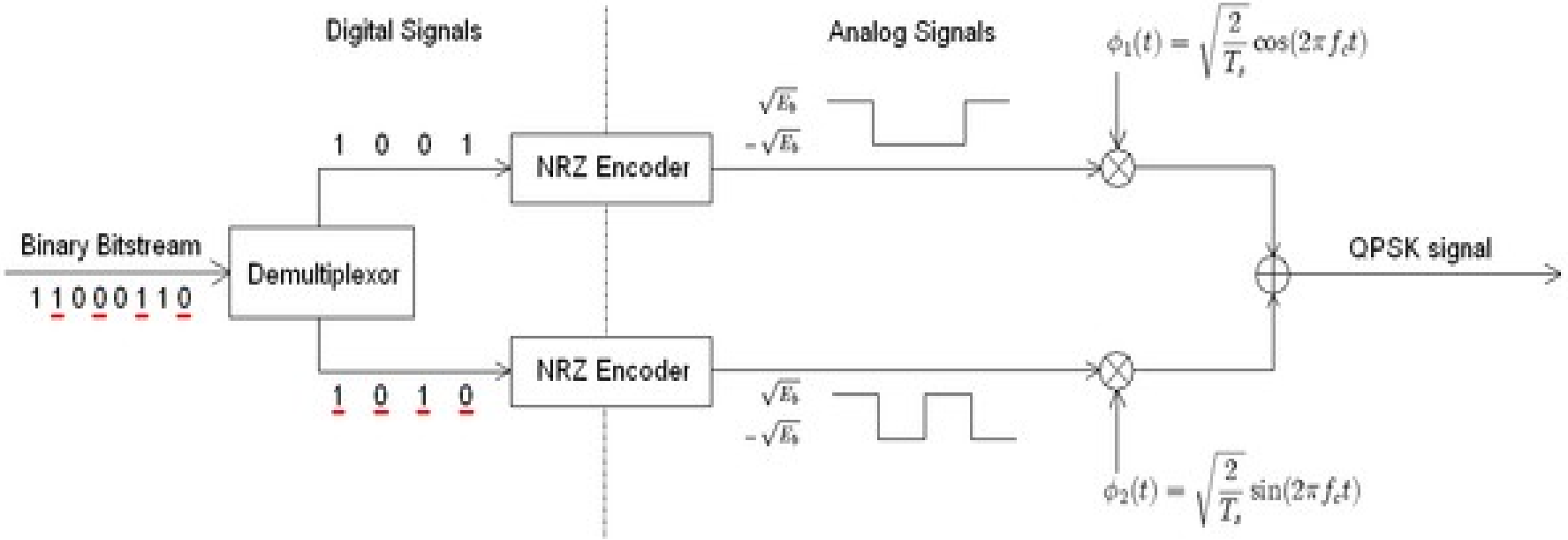
$$\left(\pm\sqrt{E_s/2}, \pm\sqrt{E_s/2}\right).$$

QPSK defined using Constellation Diagram

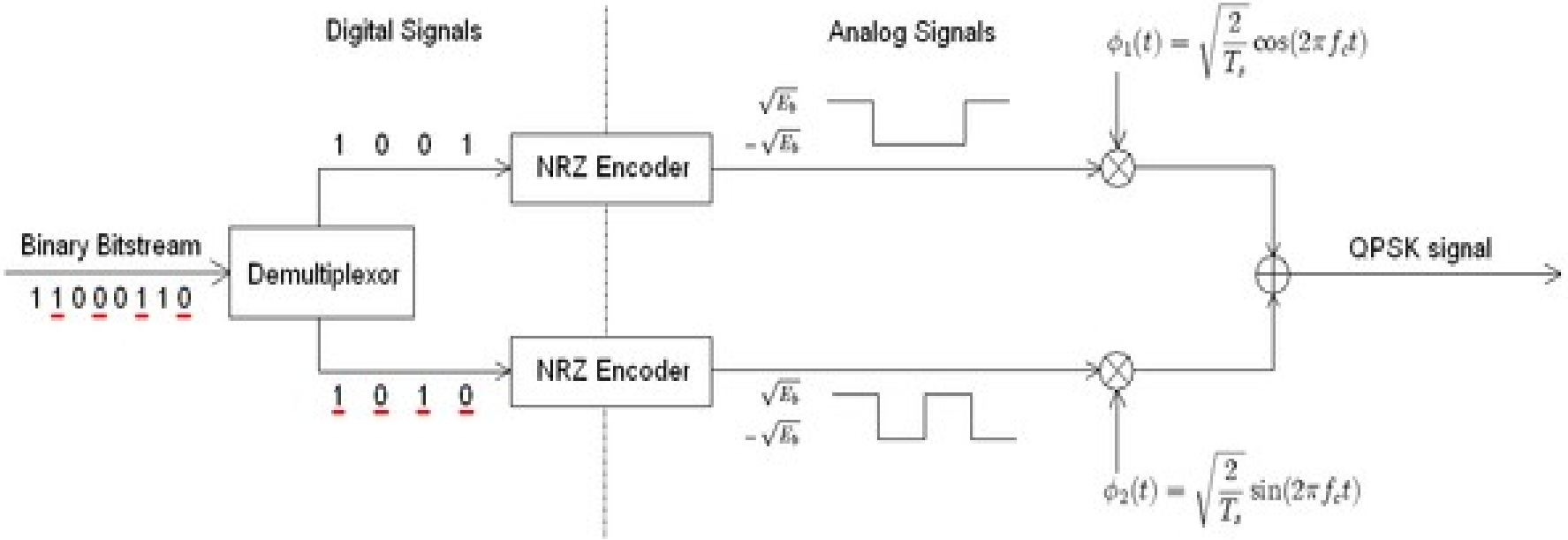
Constellation diagram for QPSK with Gray coding.
Each adjacent symbol only differs by one bit.



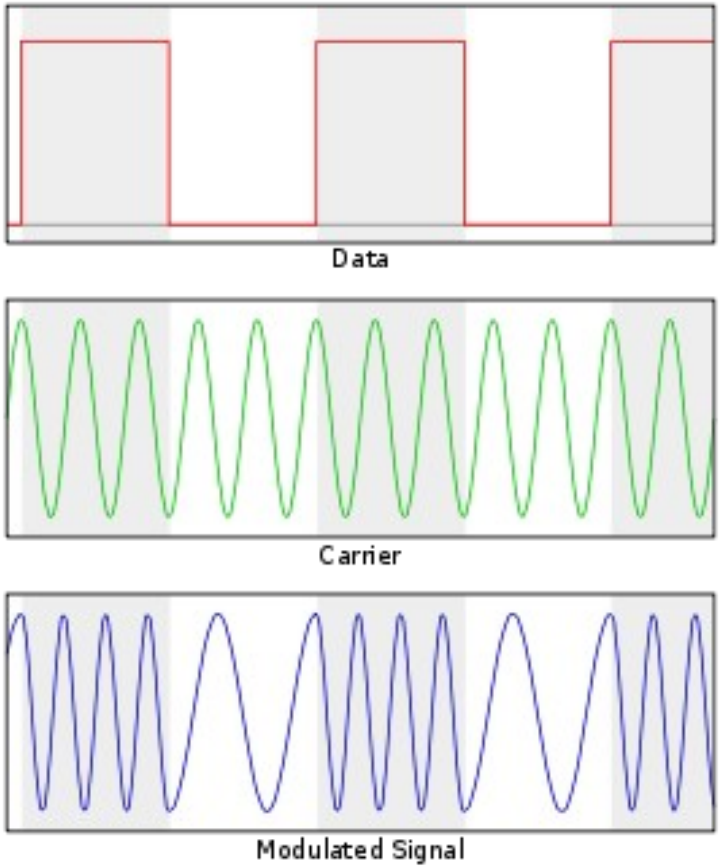
Conceptual transmitter structure for QPSK

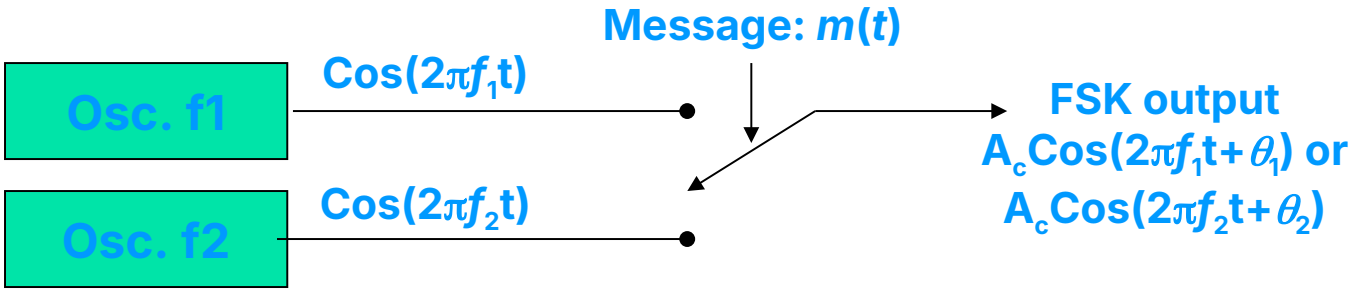


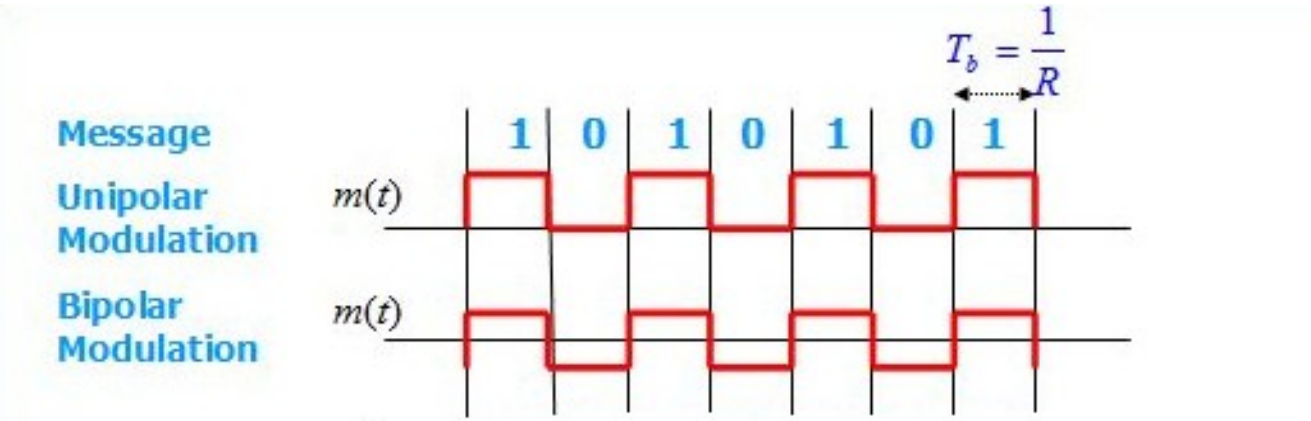
Receiver structure for QPSK

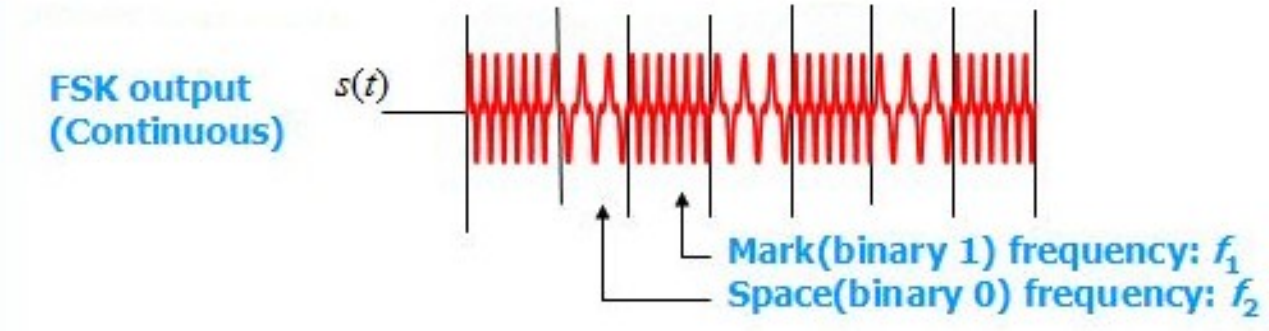


Frequency Shift Keying




Message: m(t)
Osc. f1
Cos(2πf1t)
Osc. f2
Cos(2πf2t)
FSK output
AcCos(2πf1t+θ1) or
AcCos(2πf2t+θ2)


Tb = 1/R
Message
1 0 1 0 1 0 1
Unipolar Modulation
m(t)
Bipolar Modulation
m(t)


FSK output (Continuous)
s(t)
Mark(binary 1) frequency: f1
Space(binary 0) frequency: f2

Other Forms of FSK

- MSK
- Audio FSK

Minimum Frequency Keying MSK

$$\delta = 0.25\, f_m,$$

where ***fm*** *is the maximum modulating frequency. As a result, the modulation index m is 0.25.*

Audio Frequency Shift Keying

- digital data is represented by changes in the frequency (pitch) of an audio tone

Quadrature amplitude modulation

- (**QAM**) is both an analog and a digital modulation scheme.
- It conveys two analog message signals, or two digital bit streams, by changing (*modulating*) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme. These two waves, usually sinusoids, are out of phase with each other by 90° and are thus called quadrature carriers or quadrature components — hence the name of the scheme. The modulated waves are summed, and the resulting waveform is a combination of both phase-shift keying (PSK) and amplitude-shift keying (ASK), or in the analog case of phase modulation (PM) and amplitude modulation. In the digital QAM case, a finite number of at least two phases, and at least two amplitudes are used.
- QAM is used extensively as a modulation scheme for digital telecommunication systems.

Sampling

- A mechanism for converting continuous signal to discrete time signal.
- Acc. to sampling theorem :-

  A continuous time signal may be completely represented in its samples and recovered back if the sampling frequency is $f_s \geq 2f_m$,where f_s is the sampling frequency and fm is the maximum frequency present in the signal.

Pulse Modulation

- In this case the carrier wave is no longer a continuous signal but consists of a pulse train whereas

Pulse Amplitude Modulation

- In PAM, the amplitude of the carrier pulse train is varied in accordance to the modulating signal.

Pulse Width Modulation

- In PWM , the width of the pulses is proportional to amplitude of modulating signal.

Pulse Position Modulation

- In PPM , the position of the pulse with reference to the position of reference pulse is changed according to the value of the modulating signal.

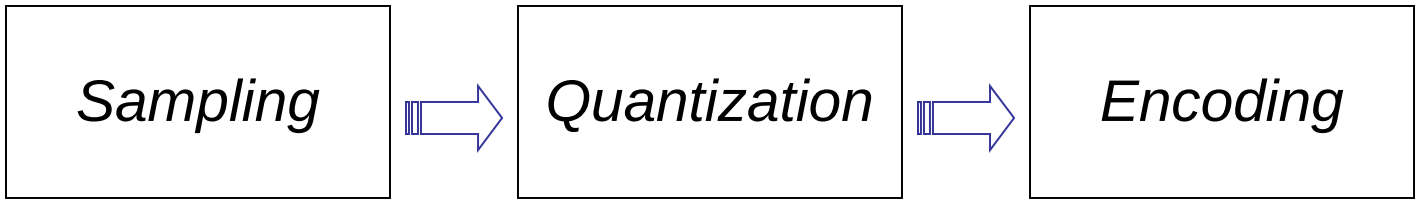
Pulse Code Modulation

- It is a digital pulse modulation system.
- The output of PCM is in the coded digital pulses of constant amplitude ,width and position .
- The basic operations in PCM are :-

  Sampling

  Quantization

  Encoding



- Quantization – It is a process of dividing the total amplitude range into number of standard levels.
- Encoder – It basically converts the quantized input signal to binary words.