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1. Satellite Communication – Introduction

In general terms, a **satellite** is a smaller object that revolves around a larger object in space. For example, moon is a natural satellite of earth.

We know that **Communication** refers to the exchange (sharing) of information between two or more entities, through any medium or channel. In other words, it is nothing but sending, receiving and processing of information.

If the communication takes place between any two earth stations through a satellite, then it is called as **satellite communication.** In this communication, electromagnetic waves are used as carrier signals. These signals carry the information such as voice, audio, video or any other data between ground and space and vice-versa.

Soviet Union had launched the world's first artificial satellite named, Sputnik 1 in 1957. Nearly after 18 years, India also launched the artificial satellite named, Aryabhata in 1975.

Need of Satellite Communication

The following two kinds of propagation are used earlier for communication up to some distance.

- **Ground wave propagation:** Ground wave propagation is suitable for frequencies up to 30MHz. This method of communication makes use of the troposphere conditions of the earth.
- **Sky wave propagation:** The suitable bandwidth for this type of communication is broadly between 30–40 MHz and it makes use of the ionosphere properties of the earth.

The maximum hop or the station distance is limited to 1500KM only in both ground wave propagation and sky wave propagation. Satellite communication overcomes this limitation. In this method, satellites provide **communication for long distances**, which is well beyond the line of sight.

Since the satellites locate at certain height above earth, the communication takes place between any two earth stations easily via satellite. So, it overcomes the limitation of communication between two earth stations due to earth's curvature.

How a Satellite Works

A **satellite** is a body that moves around another body in a particular path. A communication satellite is nothing but a microwave repeater station in space. It is helpful in telecommunications, radio and television along with internet applications.

A **repeater** is a circuit, which increases the strength of the received signal and then transmits it. But, this repeater works as a **transponder**. That means, it changes the frequency band of the transmitted signal from the received one.

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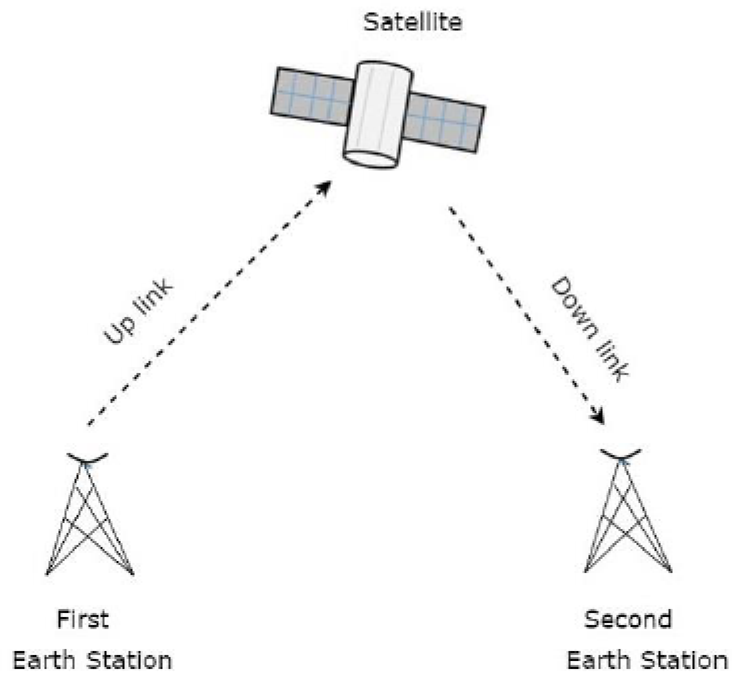
The frequency with which, the signal is sent into the space is called as **Uplink frequency**. Similarly, the frequency with which, the signal is sent by the transponder is called as **Downlink frequency**. The following figure illustrates this concept clearly.



The transmission of signal from first earth station to satellite through a channel is called as **uplink**. Similarly, the transmission of signal from satellite to second earth station through a channel is called as **downlink**.

Uplink frequency is the frequency at which, the first earth station is communicating with satellite. The satellite transponder converts this signal into another frequency and sends it down to the second earth station. This frequency is called as **Downlink frequency**. In similar way, second earth station can also communicate with the first one.

The process of satellite communication begins at an earth station. Here, an installation is designed to transmit and receive signals from a satellite in an orbit around the earth. Earth stations send the information to satellites in the form of high powered, high frequency (GHz range) signals.

The satellites receive and retransmit the signals back to earth where they are received by other earth stations in the coverage area of the satellite. Satellite's **footprint** is the area which receives a signal of useful strength from the satellite.

Pros and Cons of Satellite Communication

In this section, let us have a look at the advantages and disadvantages of satellite communication.

Following are the **advantages** of using satellite communication:

- Area of coverage is more than that of terrestrial systems
- Each and every corner of the earth can be covered
- Transmission cost is independent of coverage area
- More bandwidth and broadcasting possibilites

Following are the **disadvantages** of using satellite communication:

- Launching of satellites into orbits is a costly process.
- Propagation delay of satellite systems is more than that of conventional terrestrial systems.
- Difficult to provide repairing activities if any problem occurs in a satellite system.
- Free space loss is more.
- There can be congestion of frequencies.

Applications of Satellite Communication

Satellite communication plays a vital role in our daily life. Following are the applications of satellite communication:

- Radio broadcasting and voice communications
- TV broadcasting such as Direct To Home (DTH)
- Internet applications such as providing Internet connection for data transfer, GPS applications, Internet surfing, etc.
- Military applications and navigations
- Remote sensing applications
- Weather condition monitoring & Forecasting

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2. Satellite Communication – Orbital Mechanics

We know that the path of satellite revolving around the earth is known as **orbit**. This path can be represented with mathematical notations. Orbital mechanics is the study of the motion of the satellites that are present in orbits. So, we can easily understand the space operations with the knowledge of orbital motion.

Orbital Elements

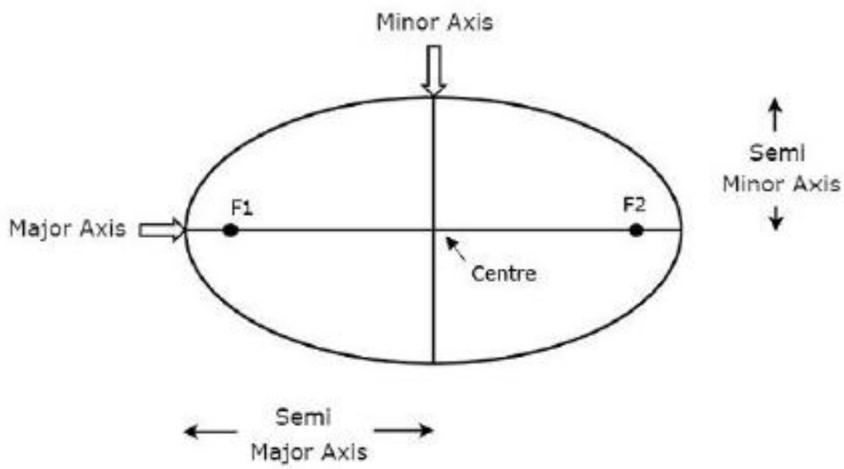
Orbital elements are the parameters, which are helpful for describing the orbital motion of satellites. Following are the **orbital elements**.

- Semi major axis
- Eccentricity
- Mean anomaly
- Argument of perigee
- Inclination
- Right ascension of ascending node

The above six orbital elements define the orbit of earth satellites. Therefore, it is easy to discriminate one satellite from other satellites based on the values of orbital elements.

Semi major axis

The length of **Semi-major axis (a)** defines the size of satellite's orbit. It is half of the major axis. This runs from the center through a focus to the edge of the ellipse. So, it is the radius of an orbit at the orbit's two most distant points.



Both semi major axis and semi minor axis are represented in above figure. Length of **semi major axis** (a) not only determines the size of satellite's orbit, but also the time period of revolution.

If circular orbit is considered as a special case, then the length of semi-major axis will be equal to **radius** of that circular orbit.

Eccentricity

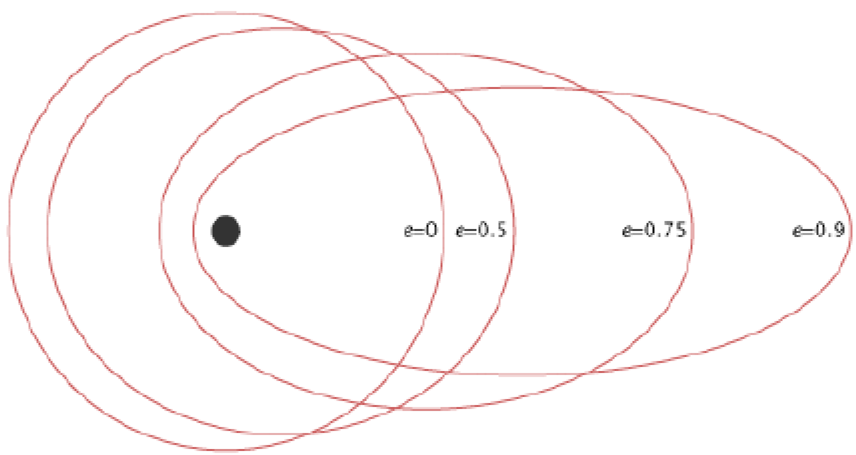
The value of **Eccentricity (e)** fixes the shape of satellite's orbit. This parameter indicates the deviation of the orbit's shape from a perfect circle.

If the lengths of semi major axis and semi minor axis of an elliptical orbit are a & b, then the mathematical expression for **eccentricity (e)** will be

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

The value of eccentricity of a circular orbit is **zero**, since both a & b are equal. Whereas, the value of eccentricity of an elliptical orbit lies between zero and one.

The following **figure** shows the various satellite orbits for different eccentricity (e) values.



In above figure, the satellite orbit corresponding to eccentricity (e) value of zero is a circular orbit. And, the remaining three satellite orbits are of elliptical corresponding to the eccentricity (e) values 0.5, 0.75 and 0.9.

Mean Anomaly

For a satellite, the point which is closest from the Earth is known as Perigee. **Mean anomaly** (M) gives the average value of the angular position of the satellite with reference to perigee.

If the orbit is circular, then Mean anomaly gives the angular position of the satellite in the orbit. But, if the orbit is elliptical, then calculation of exact position is very difficult. At that time, Mean anomaly is used as an intermediate step.

Argument of Perigee

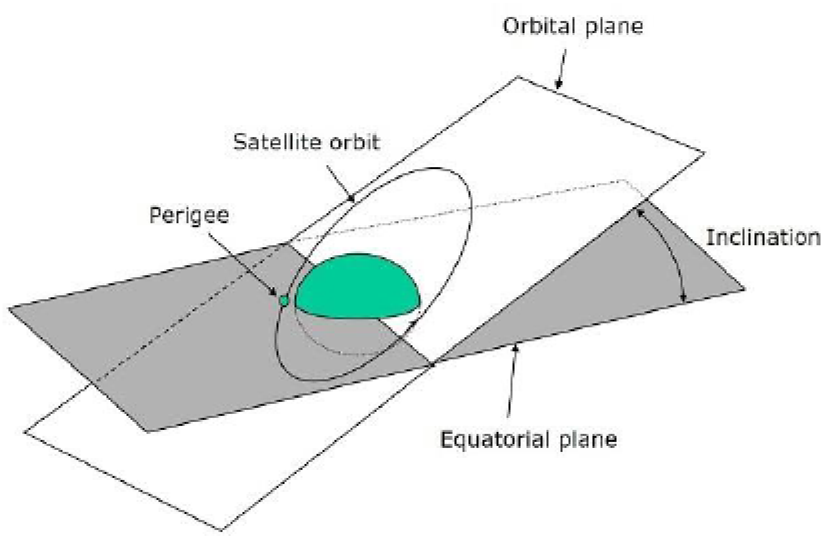
Satellite orbit cuts the equatorial plane at two points. First point is called as **descending node**, where the satellite passes from the northern hemisphere to the southern hemisphere. Second point is called as **ascending node**, where the satellite passes from the southern hemisphere to the northern hemisphere.

Argument of perigee (ω) is the angle between ascending node and perigee. If both perigee and ascending node are existing at same point, then the argument of perigee will be zero degrees.

Argument of perigee is measured in the orbital plane at earth's center in the direction of satellite motion.

Inclination

The angle between orbital plane and earth's equatorial plane is known as **inclination** (i). It is measured at the ascending node with direction being east to north. So, inclination defines the orientation of the orbit by considering the equator of earth as reference.



There are four types of orbits based on the angle of inclination.

- **Equatorial orbit** – Angle of inclination is either zero degrees or 180 degrees.
- **Polar orbit** - Angle of inclination is 90 degrees.
- **Prograde orbit** - Angle of inclination lies between zero and 90 degrees.
- **Retrograde orbit** - Angle of inclination lies between 90 and 180 degrees.

Right Ascension of Ascending node

We know that **ascending node** is the point, where the satellite crosses the equatorial plane while going from the southern hemisphere to the northern hemisphere.

Right Ascension of ascending node (Ω) is the angle between line of Aries and ascending node towards east direction in equatorial plane. Aries is also called as vernal and equinox.

Satellite's **ground track** is the path on the surface of the Earth, which lies exactly below its orbit. The ground track of a satellite can take a number of different forms depending on the values of the orbital elements.

Orbital Equations

In this section, let us discuss about the equations which are related to orbital motion.

Forces acting on Satellite

A satellite, when it revolves around the earth, it undergoes a pulling force from the earth due to earth's gravitational force. This force is known as **Centripetal force** (F_1) because this force tends the satellite towards it.

Mathematically, the **Centripetal force** (F_1) acting on satellite due to earth can be written as

$$F_1 = \frac{GMm}{R^2}$$

Where,

- ***G*** is universal gravitational constant and it is equal to 6.673 x 10^{-11} N·m²/kg².
- ***M*** is mass of the earth and it is equal to 5.98 x 10^{24} Kg.
- ***m*** is mass of the satellite.
- ***R*** is the distance from satellite to center of the Earth.

Mathematically, the **Centrifugal force** (F_2) acting on satellite can be written as

$$F_2 = \frac{mv^2}{R}$$

Where, ***v*** is the orbital velocity of satellite.

Orbital Velocity

Orbital velocity of satellite is the velocity at which, the satellite revolves around earth. Satellite doesn't deviate from its orbit and moves with certain velocity in that orbit, when both Centripetal and Centrifugal forces are **balance** each other.

So, **equate** Centripetal force (F_1) and Centrifugal force (F_2).

$$\frac{GMm}{R^2} = \frac{mv^2}{R}$$

$$=> \frac{GM}{R} = v^2$$

$$=> v = \sqrt{\frac{GM}{R}}$$

Therefore, the **orbital velocity** of satellite is

$$v = \sqrt{\frac{GM}{R}}$$

Where,

- ***G*** is gravitational constant and it is equal to 6.673×10^{-11} $N \cdot m^2/kg^2$.
- ***M*** is mass of the earth and it is equal to 5.98×10^{24} Kg.
- ***R*** is the distance from satellite to center of the Earth.

So, the orbital velocity mainly **depends** on the distance from satellite to center of the Earth (R), since G & M are constants.

3. Satellite Communication – Kepler's Laws

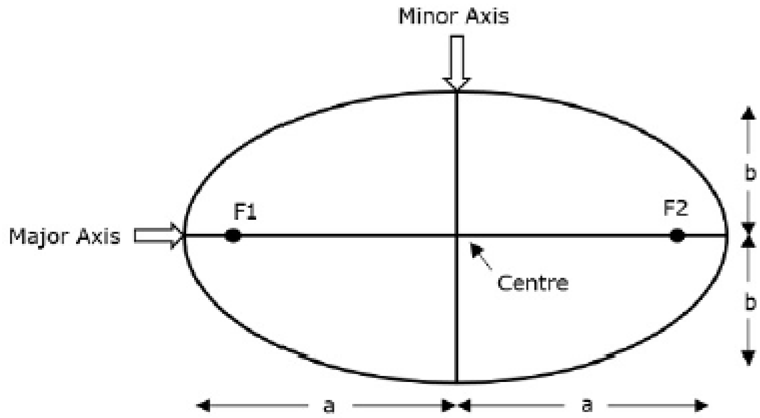
We know that satellite revolves around the earth, which is similar to the earth revolves around the sun. So, the principles which are applied to earth and its movement around the sun are also applicable to satellite and its movement around the earth.

Many scientists have given different types of theories from early times. But, only **Johannes Kepler** (1571-1630) was one of the most accepted scientist in describing the principle of a satellite that moves around the earth.

Kepler formulated three laws that changed the whole satellite communication theory and observations. These are popularly known as **Kepler's laws**. These are helpful to visualize the motion through space.

Kepler's First Law

Kepler's first law states that the path followed by a satellite around its primary (the earth) will be an **ellipse**. This ellipse has two focal points (foci) F1 and F2 as shown in the figure below. Center of mass of the earth will always present at one of the two foci of the ellipse.



Kepler's 1st law

If the distance from the center of the object to a point on its elliptical path is considered, then the farthest point of an ellipse from the center is called as **apogee** and the shortest point of an ellipse from the center is called as **perigee.**

Eccentricity "e" of this system can be written as:

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

Where, **a** & **b** are the lengths of semi major axis and semi minor axis of the ellipse respectively.

For an **elliptical path**, the value of eccentricity (e) is always lie in between 0 and 1, i.e. $0 < e < 1$, since a is greater than b. Suppose, if the value of eccentricity (e) is zero, then the path will be no more in elliptical shape, rather it will be converted into a circular shape.

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1. Radar Systems — Overview

RADAR is an electromagnetic based detection system that works by radiating electromagnetic waves and then studying the echo or the reflected back waves.

The full form of **RADAR** is **RA**dio **D**etection **A**nd **R**anging. Detection refers to whether the target is present or not. The target can be stationary or movable, i.e., non-stationary. Ranging refers to the distance between the Radar and the target.

Radars can be used for various applications on ground, on sea and in space. The **applications** of Radars are listed below.

- Controlling the Air Traffic
- Ship safety
- Sensing the remote places
- Military applications

In any application of Radar, the basic principle remains the same. Let us now discuss the principle of radar.

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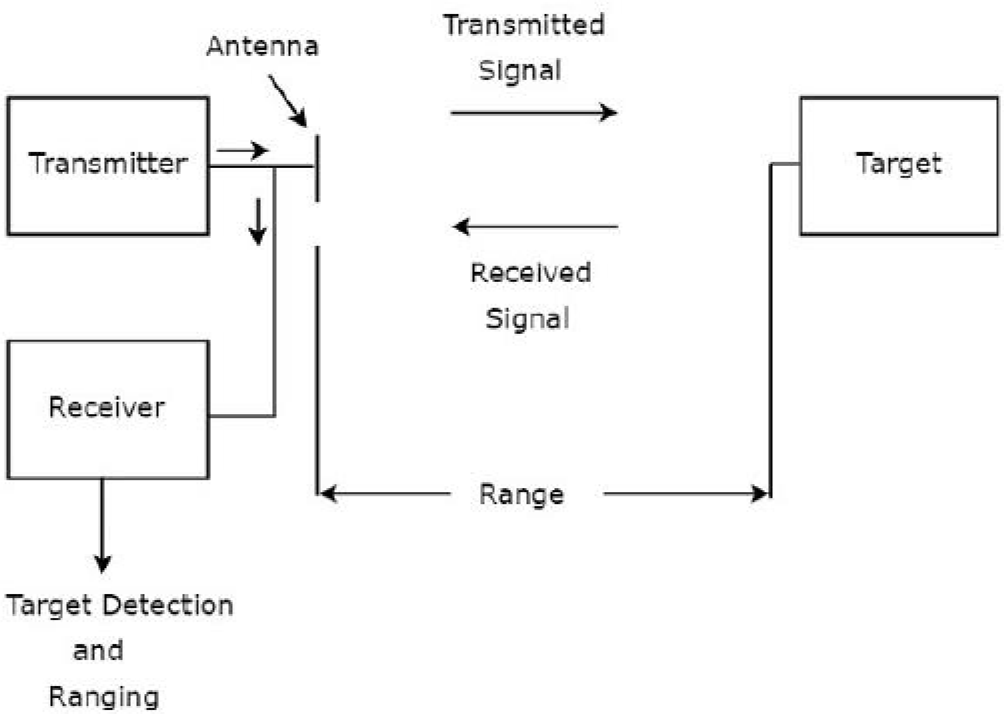
Basic Principle of Radar

Radar is used for detecting the objects and finding their location. We can understand the **basic principle** of Radar from the following figure.



As shown in the figure, Radar mainly consists of a transmitter and a receiver. It uses the same Antenna for both transmitting and receiving the signals. The function of the **transmitter** is to transmit the Radar signal in the direction of the target present.

Target reflects this received signal in various directions. The signal, which is reflected back towards the Antenna gets received by the **receiver**.

Terminology of Radar Systems

Following are the basic terms, which are useful in this tutorial.

- Range
- Pulse Repetition Frequency
- Maximum Unambiguous Range
- Minimum Range

Now, let us discuss about these basic terms one by one.

Range

The distance between Radar and target is called **Range** of the target or simply range, R. We know that Radar transmits a signal to the target and accordingly the target sends an echo signal to the Radar with the speed of light, C.

Let the time taken for the signal to travel from Radar to target and back to Radar be 'T'. The two way distance between the Radar and target will be 2R, since the distance between the Radar and the target is R.

Now, the following is the formula for **Speed.**

$$Speed = \frac{Distance}{Time}$$

$$=> Distance = Tpeed \times Time$$

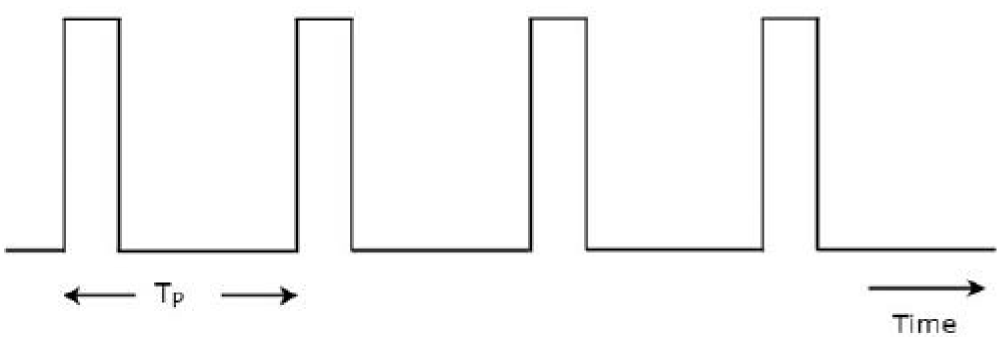
$$=> 2R = C \times T$$

$$R = \frac{CT}{2} \qquad \text{Equation 1}$$

We can find the **range of the target** by substituting the values of C & T in Equation 1.

Pulse Repetition Frequency

Radar signals should be transmitted at every clock pulse. The duration between the two clock pulses should be properly chosen in such a way that the echo signal corresponding to present clock pulse should be received before the next clock pulse. A typical **Radar wave form** is shown in the following figure.



As shown in the figure, Radar transmits a periodic signal. It is having a series of narrow rectangular shaped pulses. The time interval between the successive clock pulses is called **pulse repetition time**, T_P.

The reciprocal of pulse repetition time is called **pulse repetition frequency**, f_P. Mathematically, it can be represented as

$$f_P = \frac{1}{T_P} \qquad \text{Equation 2}$$

Therefore, pulse repetition frequency is nothing but the frequency at which Radar transmits the signal.

Maximum Unambiguous Range

We know that Radar signals should be transmitted at every clock pulse. If we select a shorter duration between the two clock pulses, then the echo signal corresponding to present clock pulse will be received after the next clock pulse. Due to this, the range of the target seems to be smaller than the actual range.

So, we have to select the duration between the two clock pulses in such a way that the echo signal corresponding to present clock pulse will be received before the next clock pulse starts. Then, we will get the true range of the target and it is also called maximum unambiguous range of the target or simply, **maximum unambiguous range**.

Substitute, $R = R_{un}$ and $T = T_P$ in Equation 1.

$$R_{un} = \frac{CT_P}{2} \qquad \text{Equation 3}$$

From Equation 2, we will get the pulse repetition time, T_P as the reciprocal of pulse repetition frequency, f_P. **Mathematically**, it can be represented as

$$T_P = \frac{1}{f_P} \qquad \text{Equation 4}$$

Substitute, Equation 4 in Equation 3.

$$R_{un} = \frac{C\left(\frac{1}{f_P}\right)}{2}$$

$$R_{un} = \frac{C}{2f_P} \qquad \text{Equation 5}$$

We can use either Equation 3 or Equation 5 for calculating maximum unambiguous range of the target.

- We will get the value of maximum unambiguous range of the target, R_{un} by substituting the values of C and T_P in Equation 3.
- Similarly, we will get the value of maximum unambiguous range of the target, R_{un} by substituting the values of C and f_P in Equation 5.

Minimum Range

We will get the **minimum range** of the target, when we consider the time required for the echo signal to receive at Radar after the signal being transmitted from the Radar as pulse width. It is also called the shortest range of the target.

Substitute, $R = R_{min}$ and $T = \tau$ in Equation 1.

$$R_{min} = \frac{C\tau}{2} \qquad \text{Equation 6}$$

We will get the value of minimum range of the target, R_{min} by substituting the values of C and τ in Equation 6.

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3. Radar Systems — Performance Factors

The factors, which affect the performance of Radar are known as Radar performance factors. In this chapter, let us discuss about those factors. We know that the following **standard form** of Radar range equation, which is useful for calculating the maximum range of Radar for given specifications.

$$R_{Max} = \left[\frac{P_t G \sigma A_e}{(4\pi)^2 S_{min}}\right]^{1/4}$$

Where,

P_t is the peak power transmitted by the Radar

G is the gain of transmitting Antenna

σ is the Radar cross section of the target

A_e is the effective aperture of the receiving Antenna

S_{min} is the power of minimum detectable signal

From the above equation, we can conclude that the following **conditions** should be considered in order to get the range of the Radar as maximum.

- Peak power transmitted by the Radar P_t should be high.
- Gain of the transmitting Antenna G should be high.
- Radar cross section of the target σ should be high.
- Effective aperture of the receiving Antenna A_e should be high.
- Power of minimum detectable signal S_{min} should be low.

It is difficult to predict the range of the target from the standard form of the Radar range equation. This means, the degree of accuracy that is provided by the Radar range equation about the range of the target is less. Because, the parameters like Radar cross section of the target, σ and minimum detectable signal, S_{min} are **statistical in nature.**

Minimum Detectable Signal

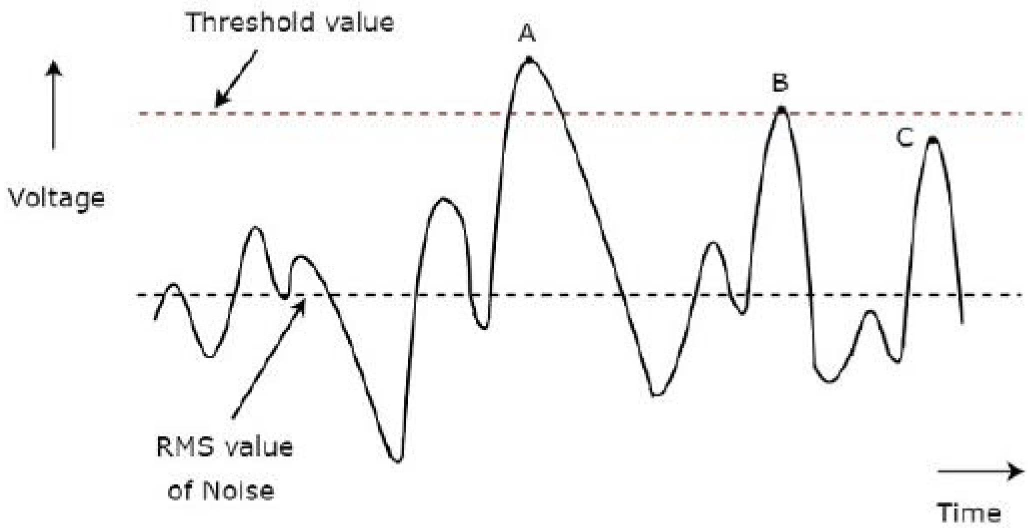
If the echo signal has minimum power, detecting that signal by the Radar is known as **minimum detectable signal**. This means, Radar cannot detect the echo signal if that signal is having less power than that of minimum power.

In general, Radar receives the echo signal in addition with noise. If the threshold value is used for detecting the presence of the target from the received signal, then that detection is called **threshold detection.**

We have to select proper threshold value based on the strength of the signal to be detected.

- A high threshold value should be chosen when the strength of the signal to be detected is high so that it will eliminate the unwanted noise signal present in it.
- Similarly, a low threshold value should be chosen when the strength of the signal to be detected is low.

The following **figure** illustrates this concept:



A **typical waveform** of the Radar receiver is shown in the above figure. The x-axis and y-axis represent time and voltage respectively. The rms value of noise and threshold value are indicated with dotted lines in the above figure.

We have considered three points, A, B & C in above figure for identifying the valid detections and missing detections.

- The value of the signal at point A is greater than threshold value. Hence, it is a **valid detection**.
- The value of the signal at point B is equal to threshold value. Hence, it is a **valid detection**.
- Even though the value of the signal at point C is closer to threshold value, it is a **missing detection**. Because, the value of the signal at point C is less than threshold value.

So, the points, A & B are valid detections. Whereas, the point C is a missing detection.

Receiver Noise

If the receiver generates a noise component into the signal, which is received at the receiver, then that kind of noise is known as **receiver noise**. The receiver noise is an unwanted component; we should try to eliminate it with some precautions.

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However, there exists one kind of noise that is known as the thermal noise. It occurs due to thermal motion of conduction electrons. Mathematically, we can write **thermal noise power, N_i** produced at receiver as:

$$N_i = KT_oB_n$$

Where,

K is the Boltzmann's constant and it is equal to $1.38 \times 10^{-23} J/deg$

T_o is the absolute temperature and it is equal to $290^0 K$

B_n is the receiver band width

Figure of Merit

The **Figure of Merit**, F is nothing but the ratio of input SNR, $(SNR)_i$ and output SNR, $(SNR)_o$. Mathematically, it can be represented as:

$$F = \frac{(SNR)_i}{(SNR)_o}$$

$$=> F = \frac{S_i/N_i}{S_o/N_o}$$

$$=> F = \frac{N_oS_i}{N_iS_o}$$

$$=> S_i = \frac{FN_iS_o}{N_o}$$

Substitute, $N_i = KT_oB_n$ in above equation.

$$=> S_i = FKT_oB_n\left(\frac{S_o}{N_o}\right)$$

Input signal power will be having minimum value, when output SNR is having minimum value.

-

$$=> S_{min} = FKT_oB_n\left(\frac{S_o}{N_o}\right)_{min}$$

Substitute, the above S_{min} in the following standard form of Radar range equation.

$$R_{Max} = \left[\frac{P_tG\sigma A_e}{(4\pi)^2S_{min}}\right]^{1/4}$$

$$=> R_{Max} = \left[\frac{P_tG\sigma A_e}{(4\pi)^2FKT_oB_n\left(\frac{S_o}{N_o}\right)_{min}}\right]^{1/4}$$

From the above equation, we can conclude that the following **conditions** should be considered in order to get the range of the Radar as maximum.

- Peak power transmitted by the Radar, P_t should be high.
- Gain of the transmitting Antenna G should be high.

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- Radar cross section of the target σ should be high.
- Effective aperture of the receiving Antenna A_e should be high.
- Figure of Merit F should be low.
- Receiver bandwidth B_n should be low.

4. Radar Systems — Types of Radars

In this chapter, we will discuss in brief the different types of Radar. This chapter provides the information briefly about the types of Radars. Radars can be classified into the following **two types** based on the type of signal with which Radar can be operated.

- Pulse Radar
- Continuous Wave Radar

Now, let us discuss about these two types of Radars one by one.

Pulse Radar

The Radar, which operates with pulse signal is called the **Pulse Radar**. Pulse Radars can be classified into the following two types based on the type of the target it detects.

- Basic Pulse Radar
- Moving Target Indication Radar

Let us now discuss the two Radars briefly.

Basic Pulse Radar

The Radar, which operates with pulse signal for detecting stationary targets, is called the **Basic Pulse Radar** or simply, Pulse Radar. It uses single Antenna for both transmitting and receiving signals with the help of Duplexer.

Antenna will transmit a pulse signal at every clock pulse. The duration between the two clock pulses should be chosen in such a way that the echo signal corresponding to the present clock pulse should be received before the next clock pulse.

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Moving Target Indication Radar

The Radar, which operates with pulse signal for detecting non-stationary targets, is called Moving Target Indication Radar or simply, **MTI Radar.** It uses single Antenna for both transmission and reception of signals with the help of Duplexer.

MTI Radar uses the principle of **Doppler effect** for distinguishing the non-stationary targets from stationary objects.

Continuous Wave Radar

The Radar, which operates with continuous signal or wave is called **Continuous Wave Radar.** They use Doppler Effect for detecting non-stationary targets. Continuous Wave Radars can be classified into the following two types.

- Unmodulated Continuous Wave Radar
- Frequency Modulated Continuous Wave Radar

Now, let us discuss the two Radars briefly.

Unmodulated Continuous Wave Radar

The Radar, which operates with continuous signal (wave) for detecting non-stationary targets is called Unmodulated Continuous Wave Radar or simply, **CW Radar.** It is also called CW Doppler Radar.

This Radar requires two Antennas. Of these two antennas, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal. It measures only the speed of the target but not the distance of the target from the Radar.

Frequency Modulated Continuous Wave Radar

If CW Doppler Radar uses the Frequency Modulation, then that Radar is called the Frequency Modulated Continuous Wave (**FMCW**) Radar or FMCW Doppler Radar. It is also called Continuous Wave Frequency Modulated Radar or CWFM Radar.

This Radar requires two Antennas. Among which, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal. It measures not only the speed of the target but also the distance of the target from the Radar.

In our subsequent chapters, we will discuss the operations of all these Radars in detail.

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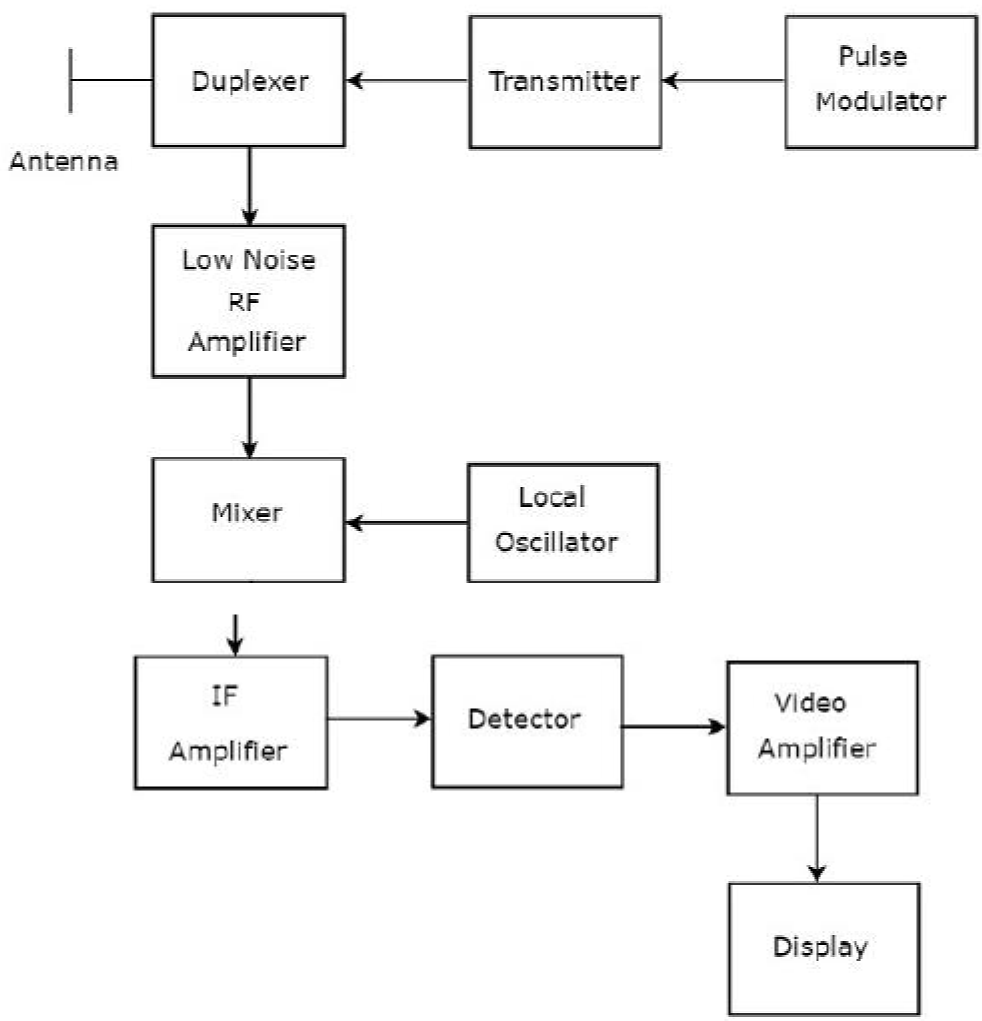
5. Radar Systems — Pulse Radar

The Radar, which operates with pulse signal for detecting stationary targets is called Basic Pulse Radar or simply, **Pulse Radar.** In this chapter, let us discuss the working of Pulse Radar.

Block Diagram of Pulse Radar

Pulse Radar uses single Antenna for both transmitting and receiving of signals with the help of Duplexer. Following is the **block diagram** of Pulse Radar:



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Let us now see the **function** of each block of Pulse Radar:

- **Pulse Modulator:** It produces a pulse-modulated signal and it is applied to the Transmitter.
- **Transmitter:** It transmits the pulse-modulated signal, which is a train of repetitive pulses.
- **Duplexer:** It is a microwave switch, which connects the Antenna to both transmitter section and receiver section alternately. Antenna transmits the pulse-modulated signal, when the duplexer connects the Antenna to the transmitter. Similarly, the signal, which is received by Antenna will be given to Low Noise RF Amplifier, when the duplexer connects the Antenna to Low Noise RF Amplifier.
- **Low Noise RF Amplifier:** It amplifies the weak RF signal, which is received by Antenna. The output of this amplifier is connected to Mixer.
- **Local Oscillator:** It produces a signal having stable frequency. The output of Local Oscillator is connected to Mixer.
- **Mixer:** We know that Mixer can produce both sum and difference of the frequencies that are applied to it. Among which, the difference of the frequencies will be of Intermediate Frequency (IF) type.
- **IF Amplifier:** IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure allows only the Intermediate Frequency, which is obtained from Mixer and amplifies it. It improves the Signal to Noise Ratio at output.
- **Detector:** It demodulates the signal, which is obtained at the output of the IF Amplifier.
- **Video Amplifier:** As the name suggests, it amplifies the video signal, which is obtained at the output of detector.
- **Display:** In general, it displays the amplified video signal on CRT screen.

In this chapter, we discussed how the Pulse Radar works and how it is useful for detecting stationary targets. In our subsequent chapters, we will discuss the Radars, which are useful for detecting non-stationary targets.

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6. Radar Systems — Doppler Effect

In this chapter, we will learn about the Doppler Effect in Radar Systems.

If the target is not stationary, then there will be a change in the frequency of the signal that is transmitted from the Radar and that is received by the Radar. This effect is known as the **Doppler effect.**

According to the Doppler effect, we will get the following two possible cases:

- The **frequency** of the received signal will **increase**, when the target moves towards the direction of the Radar.
- The **frequency** of the received signal will **decrease**, when the target moves away from the Radar.

Now, let us derive the formula for Doppler frequency.

Derivation of Doppler Frequency

The distance between Radar and target is nothing but the **Range** of the target or simply range, R. Therefore, the total distance between the Radar and target in a two-way communication path will be 2R, since Radar transmits a signal to the target and accordingly the target sends an echo signal to the Radar.

If λ is one wave length, then the number of wave lengths N that are present in a two-way communication path between the Radar and target will be equal to $2R/\lambda$.

We know that one wave length λ corresponds to an angular excursion of 2π radians. So, the **total angle of excursion** made by the electromagnetic wave during the two-way communication path between the Radar and target will be equal to $4\pi R/\lambda$ radians.

Following is the mathematical formula for **angular frequency**, ω:

$$\omega = 2\pi f \qquad \text{Equation 1}$$

Following equation shows the mathematical relationship between the angular frequency ω and phase angle $\emptyset$:

$$\omega = \frac{d\emptyset}{dt} \qquad \text{Equation 2}$$

Equate the right hand side terms of Equation 1 and Equation 2 since the left hand side terms of those two equations are same.

$$2\pi f = \frac{d\emptyset}{dt}$$

$$=> f = \frac{1}{2\pi} \cdot \frac{d\emptyset}{dt} \qquad \text{Equation 3}$$

Substitute, $f = f_d$ and $\emptyset = 4\pi R/\lambda$ in Equation 3.

$$f_d = \frac{1}{2\pi} \cdot \frac{d}{dt}\left(\frac{4\pi R}{\lambda}\right)$$

$$=> f_d = \frac{1}{2\pi} \cdot \frac{4\pi}{\lambda}\frac{dR}{dt}$$

$$=> f_d = \frac{2V_r}{\lambda} \qquad \text{Equation 4}$$

Where,

f_d is the Doppler frequency

V_r is the relative velocity

We can find the value of Doppler frequency f_d by substituting the values of V_r and λ in Equation 4.

Substitute, $\lambda = C/f$ in Equation 4.

$$f_d = \frac{2V_r}{(C/f)}$$

$$=> f_d = \frac{2V_r f}{C} \qquad \text{Equation 5}$$

Where,

f is the frequency of transmitted signal

C is the speed of light and it is equal to $3 \times 10^8 m/sec$

We can find the value of Doppler frequency, f_d by substituting the values of V_r, f and C in Equation 5.

Note: Both Equation 4 and Equation 5 show the formulae of Doppler frequency, f_d. We can use either Equation 4 or Equation 5 for finding **Doppler frequency,** f_d based on the given data.

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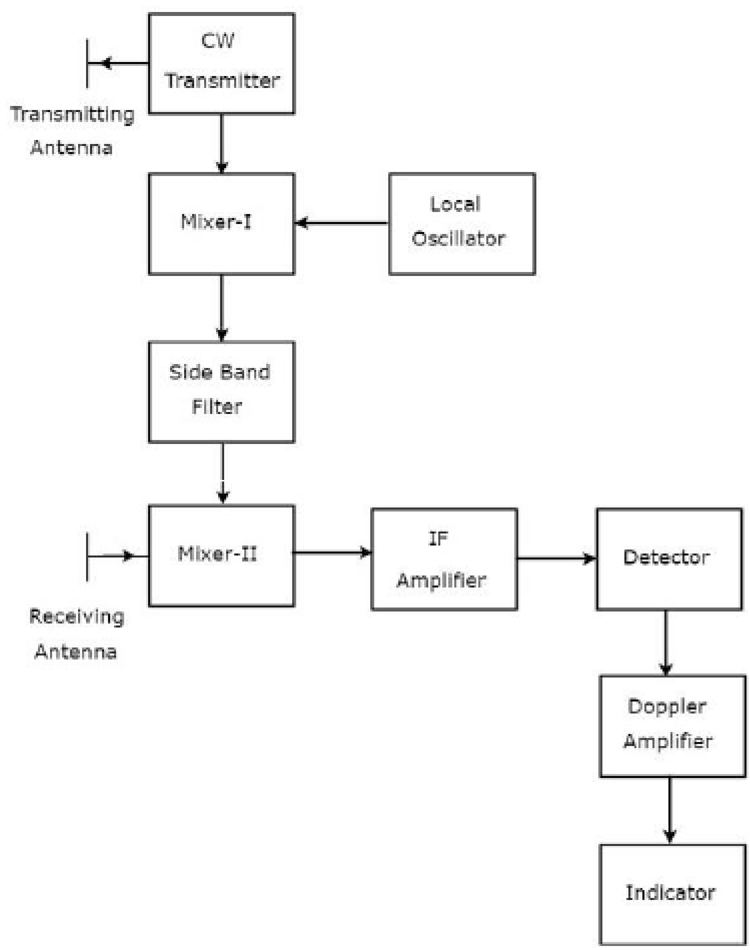
7. Radar Systems — CW Radar

A basic Radar uses the same Antenna for both transmission and reception of signals. We can use this type of Radar, when the target is stationary, i.e., not moving and / or when that Radar can be operated with pulse signal.

The Radar, which operates with continuous signal (wave) for detecting non-stationary targets, is called Continuous Wave Radar or simply **CW Radar**. This Radar requires two Antennas. Among which, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal.

Block Diagram of CW Radar

We know that CW Doppler Radar contains two Antennas — transmitting Antenna and receiving Antenna. Following figure shows the **block diagram** of CW Radar:



The block diagram of CW Doppler Radar contains a set of blocks and the **function** of each block is mentioned below.

- **CW Transmitter:** It produces an analog signal having a frequency of f_o. The output of CW Transmitter is connected to both transmitting Antenna and Mixer-I.
- **Local Oscillator:** It produces a signal having a frequency of f_l. The output of Local Oscillator is connected to Mixer-I.
- **Mixer-I:** Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of f_o and f_l are applied to Mixer-I. So, the Mixer-I will produce the output having frequencies $f_o + f_l$ or $f_o - f_l$.
- **Side Band Filter:** As the name suggests, side band filter allows a particular side band frequencies — either upper side band frequencies or lower side band frequencies. The side band filter shown in the above figure produces only upper side band frequency, i.e., $f_o + f_l$.
- **Mixer-II:** Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of $f_o + f_l$ and $f_o \pm f_d$ are applied to Mixer-II. So, the Mixer-II will produce the output having frequencies of $2f_o + f_l \pm f_d$ or $f_l \pm f_d$.
- **IF Amplifier:** IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure allows only the Intermediate Frequency, $f_l \pm f_d$ and amplifies it.
- **Detector:** It detects the signal, which is having Doppler frequency, f_d.
- **Doppler Amplifier:** As the name suggests, Doppler amplifier amplifies the signal, which is having Doppler frequency, f_d.
- **Indicator:** It indicates the information related relative velocity and whether the target is inbound or outbound.

CW Doppler Radars give accurate measurement of **relative velocities**. Hence, these are used mostly, where the information of velocity is more important than the actual range.

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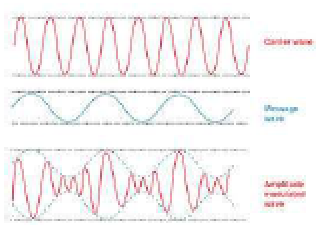
AM, PM and FM modulation

What is amplitude modulation

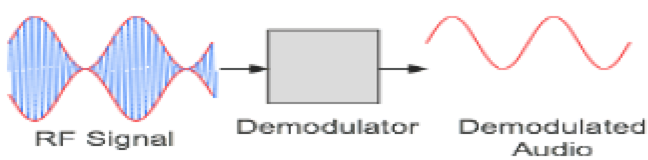
- In order that a radio signal can carry audio or other information for broadcasting or for two way radio communication, it must be modulated or changed in some way. Although there are a number of ways in which a radio signal may be modulated, one of the easiest is to change its amplitude in line with variations of the sound.



Amplitude modulation

Amplitude demodulation

- Amplitude modulation, AM, is one of the most straightforward ways of modulating a radio signal or carrier. It can be achieved in a number of ways, but the simplest uses a single diode rectifier circuit.
- Other methods of demodulating an AM signal use synchronous techniques and provide much lower levels of distortion and improved reception where selective fading is present.
- One of the main reasons for the popularity of amplitude modulation has been the simplicity of the demodulation. It enables costs to be kept low - a significant advantage in producing vast quantities of very low cost AM radios.



Advantages & disadvantages of AM

Advantages

- It is simple to implement
- it can be demodulated using a circuit consisting of very few components
- AM receivers are very cheap as no specialised components are needed.

Disadvantages

- It is not efficient in terms of its power usage
- It is not efficient in terms of its use of bandwidth, requiring a bandwidth equal to twice that of the highest audio frequency
- It is prone to high levels of noise because most noise is amplitude based and obviously AM detectors are sensitive to it.

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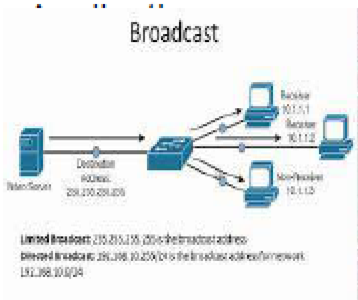
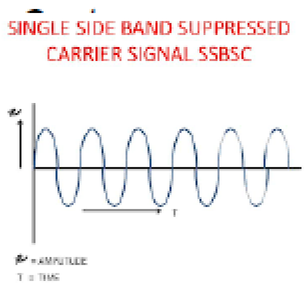
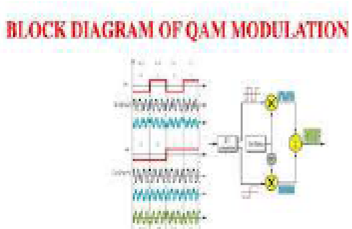


- ***Broadcast transmissions:*** AM is still widely used for broadcasting on the long, medium and short wave bands. It is simple to demodulate and this means that radio receivers capable of demodulating amplitude modulation are cheap and simple to manufacture. Nevertheless many people are moving to high quality forms of transmission like frequency modulation, FM or digital transmissions.

- ***Air band radio:*** VHF transmissions for many airborne applications still use AM. . It is used for ground to air radio communications as well as two way radio links for ground staff as well.



- ***Single sideband:*** Amplitude modulation in the form of single sideband is still used for HF radio links. Using a lower bandwidth and providing more effective use of the transmitted power this form of modulation is still used for many point to point HF links.



- ***Quadrature amplitude modulation:*** AM is widely used for the transmission of data in everything from short range wireless links such as Wi-Fi to cellular telecommunications and much more. Effectively it is formed by having two carriers 90° out of phase.

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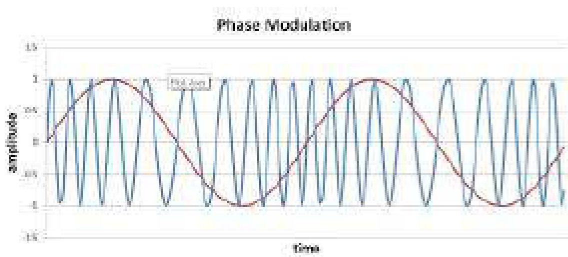
What is Phase Modulation

- Phase modulation, PM is sometimes used for analogue transmission, but it has become the basis for modulation schemes used for carrying data. Phase shoft keying, PSK is widely used for data communication.Phase modulation is also the basis of a form of modulation known as quadrature amplitude modulation, where both phase and amplitude are varied to provide additional capabilities.



Phase modulation basics

- A radio frequency signal consists of an oscillating carrier in the form of a sine wave is the basis of the signal. The instantaneous amplitude follows this curve moving positive and then negative, returning to the start point after one complete cycle - it follows the curve of the sine wave.

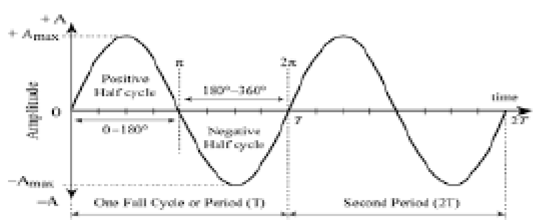


Figure 1

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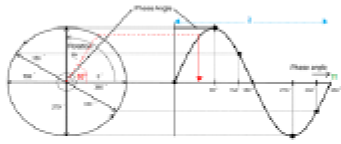
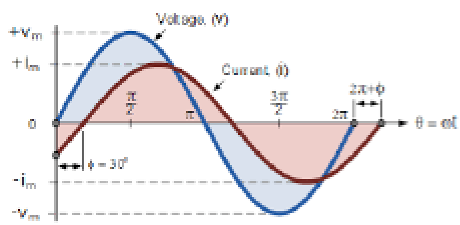
- The sine wave can also be represented by the movement of a point around a circle, the phase at any given point being the angle between the start point and the point on the waveform as shown.

- Phase angle of poin  phase advances as time progresses can be said to have a phase differe

- Phase modulation works by modulating the phase of the signal, i.e. changing the rate at which the point moves around the circle. This changes the phase of the signal from what it would have been if no modulation was applied. In other words the speed of rotation around the circle is modulated about the mean value.



Forms of phase modulation

Although phase modulation is used for some analogue transmissions, it is far more widely used as a digital form of modulation where it switches between different phases. This is known as phase shift keying, PSK, and there are many flavours of this. It is even possible to combine phase shift keying and amplitude keying in a form of modulation known as quadrature amplitude modulation, QAM.

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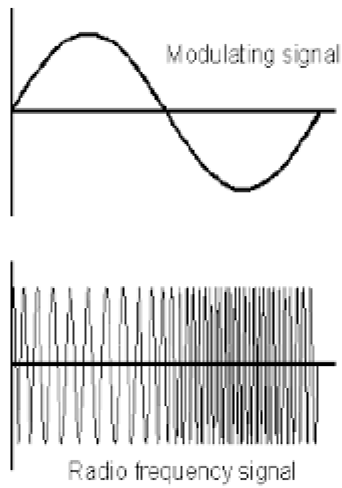
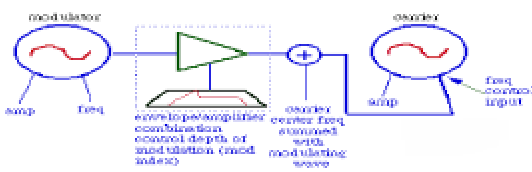
What is frequency modulation, FM

- As with any form of modulation, it is necessary to be able to successfully demodulate it and recover the original signal. The FM demodulator may be called a variety of names including FM demodulator, FM detector or an FM discriminator.
- There are a number of different types of FM demodulator, but all of them enable the frequency variations of the incoming signal to be converted into amplitude variations on the output. These are typically fed into an audio amplifier, or possibly a digital interface if data is being passed over the system.



FM modulators

- ***Varactor diode oscillator:*** This method simply requires the use of a varactor diode placed within the tuned circuit of an oscillator circuit. It is even possible to use a varactor diode within a crystal oscillator circuit. Typically when crystal oscillators a re used the signal needs to be multiplied in frequency, and only narrow band FM is attainable.

- ***Phase locked*** 

:ellent method of generating fr y to manage the constraints w it provides and excellent solution.

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Frequency demodulation

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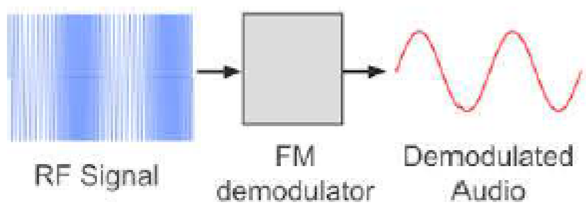

The list below gives some of the forms of phase shift keying that are used:

- PM - Phase Modulation
- PSK - Phase Shift Keying
- BPSK - Binary Phase Shift Keying
- QPSK - Quadrature Phase Shift Keying
- 8 PSK - 8 Point Phase Shift Keying
- 16 PSK - 16 Point Phase Shift Keying
- OPSK - Offset Phase Shift Keying

Advantages of frequency modulation, FM:

- ***Resilience to noise:*** One particular advantage of frequency modulation is its resilience to signal level variations. The modulation is carried only as variations in frequency.
- ***Easy to apply modulation at a low power stage of the transmitter:*** Another advantage of frequency modulation is associated with the transmitters.
- ***It is possible to use efficient RF amplifiers with frequency modulated signals:*** It is possible to use non-linear RF amplifiers to amplify FM signals in a transmitter and these are more efficient than the linear ones required for signals with any amplitude variations (e.g. AM and SSB).

disadvantages of frequency modulation, FM

- ***FM has poorer spectral efficiency than some other modulation formats:*** Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission than frequency shift keying, a form of frequency modulation.
- ***Requires more complicated demodulator:*** One of the minor disadvantages of frequency modulation is that the demodulator is a little more complicated, and hence slightly more expensive than the very simple diode detectors used for AM.

- ***Some other modes have higher data spectral efficiency:*** Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission that frequency shift keying, a form of frequency modulation.
- ***Sidebands extend to infinity either side:*** The sidebands for an FM transmission theoretically extend out to infinity. They are normally significant for wideband frequency modulation transmissions, although small for narrow band FM.