Course Title: Microwave and Antennas	***Course Code: 20EC520***
Credits: 4	***Total Contact Hours (L:T:P): 52:0:0***
Type of Course: Theory	***Category: Professional Core course***
CIE Marks: 50	***SEE Marks: 100***

Course Outcomes: After completing this course, students should be able to:

CO2:	Analyze different terminologies associated with satellite communication, TV, RADAR, their applications.

Unit No.	Course Content	No. of Hours
4	**Radar Communications:** Nature of Radar and Radar equations, CW and FM radar, MTI radar, Pulse Doppler Radar, Scanning and Tracking Radars, Radar Displays and Radar Beacons	**10**

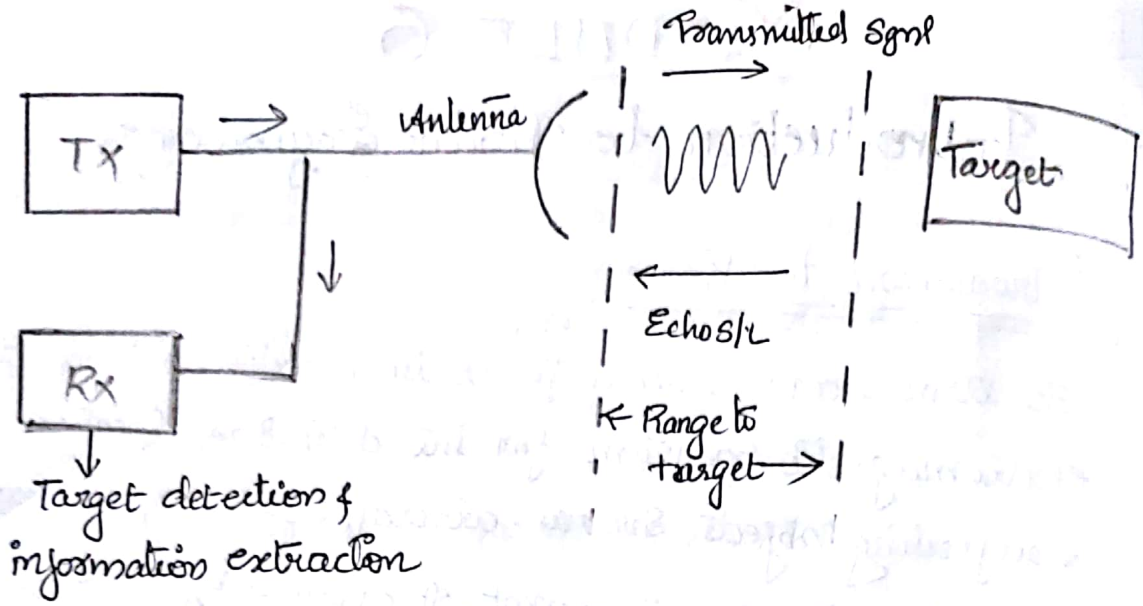
Introduction to Radar Engineering

Introduction to Radar

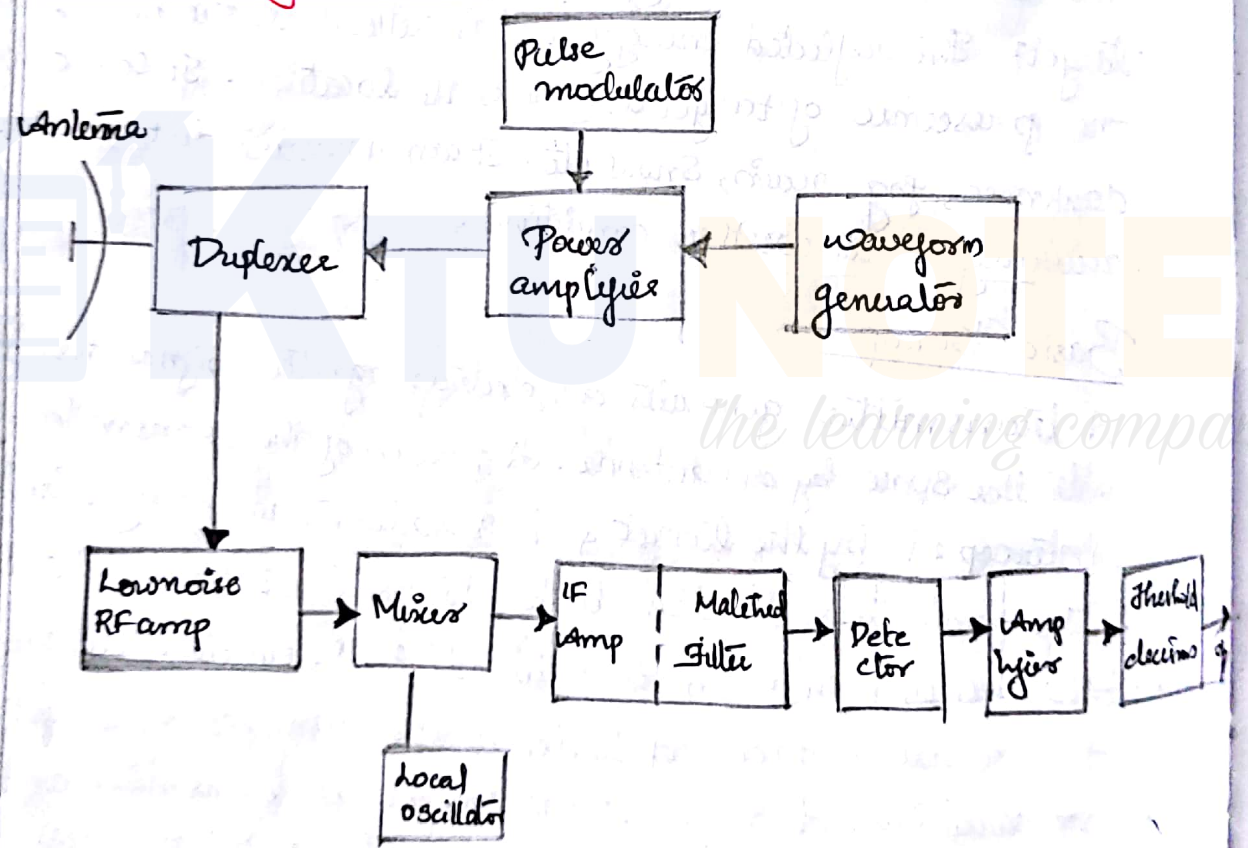
The term radar stands for radio detection & ranging. It is an electromagnetic spectrum for the detection & location of reflecting objects such as aircraft, ships, space crafts, vehicles, people & natural environment. It operates by radiating energy into the space & detecting the echo signal reflected from the object or target. The reflected energy that is returned to the radar indicates the presence of target as well as its location. It can operate in darkness, fog, rain, snow etc. It can measure distance with high accuracy in all weather conditions.

Basic Principle

A transmitter generates an electromagnetic signal that is radiated into the space by an antenna. A portion of the transmitted energy is intercepted by the target & is reradiated in many directions. The radiations directed back towards the radar is collected by the receiving antenna & is delivered to the receiver at the receiver the signal is processed to detect the presence of target & determine its location. A single antenna can act as transmitter and receiver. The range or distance to the target is found out by measuring the time taken by the radar signal to travel to the target and return back to radar.



Block diagram of Radar



The transmitter can be a power amplifier such as klystron, travelling wave tube etc. It can also be a power oscillator such as magnetron. The radar signal is produced at low power by a waveform generator which is then amplified by the power amplifier. The o/p of the power amplifier is delivered to the antenna by a duplexer which is then radiated into the space. The duplexer allows a single antenna to be used as both transmitter and receiver. Duplexer is a device that produces a short circuit at the i/p to the receiver when the transmitter is operating so that high power flows to the antenna & not to the receiver. On reception the duplexer directs the echo signal to the receiver & not to the transmitter. The receiver is always superheterodyne in nature. The i/p stage is a low noise RF amplifier. The mixer and LO convert the RF signal to an intermediate frequency which is amplified by the IF amplifier. The IF amplifier is designed as a matched filter which maximizes the o/p signal to peak ratio. The matched filter maximizes the detectability of weak echo signals & attenuates unwanted signal. The IF amplifier is followed by a detector or demodulator. Its purpose is to extract the modulating signal from the carrier signal. The combination of IF amplifier and detector acts as an envelope detector which transmits the modulating signal & rejects the carrier signal. The signal at the o/p of detector is amplified by an amplifier to provide sufficient gain to the signal. At the o/p of the receiver a decision is made whether or not a target is present. If the o/p is greater than the threshold, the decision is that target is present. If the o/p is less than threshold it is assumed that only noise is present.

Radar Equation

The radar equation relates the range of the radar to the characteristics of transmitter, receiver, target and environment. It is useful for determining the maximum range at which a radar can detect a target. If the transmitting antenna used is isotropic in nature, the power density is given by

Power density at a range, R from an isotropic antenna is

$$P_{is} = \frac{P_t}{4\pi R^2} \quad \text{— (1)}$$

If a directive antenna of gain, G is used the power density is given by

power density at a range, R from a directive antenna is

$$P_{dir} = \frac{P_t G}{4\pi R^2} \quad \text{— (2)}$$

The radiated back pwr density is given by.

Re P.

$\therefore$ radiated back power density, $P_{rerad} = \frac{P_t G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2}$

where, σ - radar cross section

The received Sgnl power, P_r = radiated pwr density x effective area.

$$\text{ie, } P_r = \frac{P_t G \sigma A_e}{(4\pi)^2 R^4}$$

The maximum range of radar, R_{max} is the distance beyond which the target cannot be detected. It occurs when the received sgnl pwr P_r = minimum detectable Sgnl, S_{min}

$$\therefore \quad S_{min} = \frac{P_t G \sigma A_e}{(4\pi)^2 R_{max}^4}$$

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

This is the fundamental form of radar range eqn.

If the same antenna is used for transmitting & receiving

The relation between gain and effective area is

$$G = \frac{4\pi A_e}{\lambda^2}$$

$$A_e = \rho_a A$$

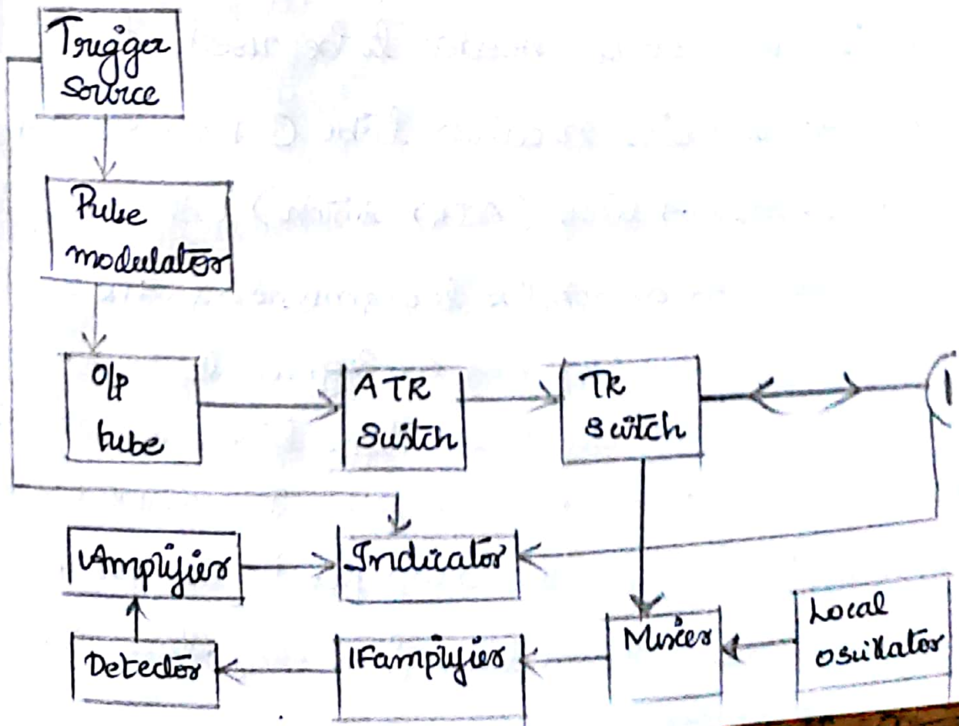
where, ρ_a - apperture

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

$$\boxed{R_{max} = \left[\frac{P_t \sigma A_e^2}{4\pi \lambda^2 S_{min}}\right]^{1/4}}$$

Pulsed Radar

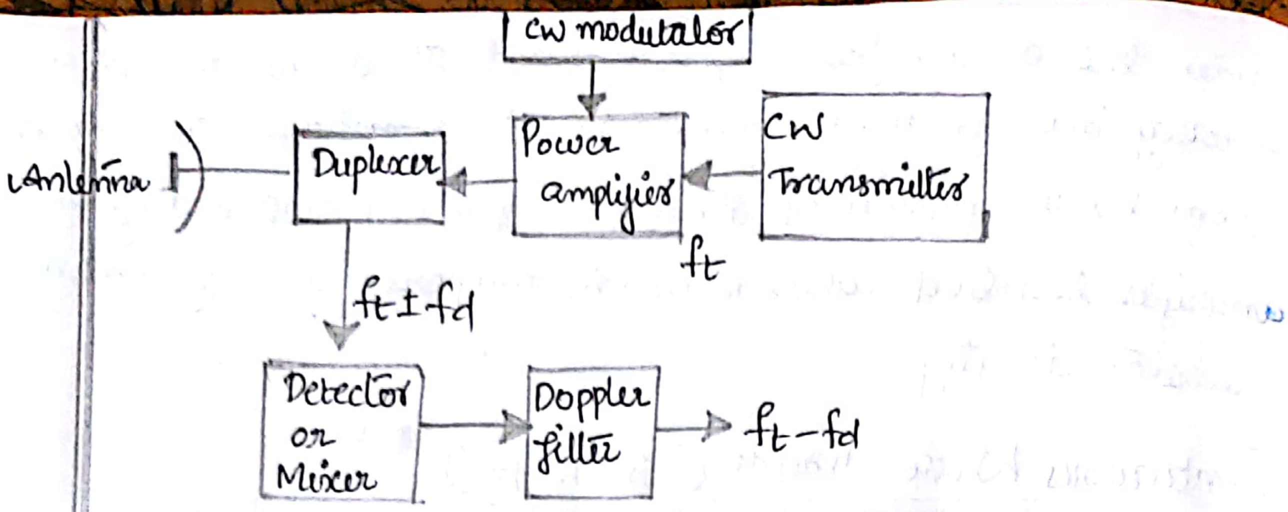
It is a high power, high freq radar which transmits pulses towards the target object. The range & resolution of radar depends on pulse repetition frequency. The radio frequency transmitted by the pulsed radar consist of series of equally spaced pulses having duration about 1μsec seperated by very short intervals.



The transmitter may be an oscillator such as a magnetron that is pulsed (turned on & off) by the modulator to generate repetitive train of pulses. The wave form generated by the transmitter travells through the transmission line through the antenna where it is radiated into the space. The trigger source provides pulses for the modulator. The trigger source or synchronizer coordinates the timing for range detection. The pulse modulator provides rectangular voltage pulses which act as the supply voltage to the o/p tube thus switching it on and off as required. It provides high power to the transmitter to transmit during the transmission period. The o/p tube may be an oscillator such as a magnetron or amplifier such as klystron amplifier. The pulse modulated wave travels through the duplexer where it is radiated into space. A single parabolic antenna is used for both transmission & reception. The duplexer alternately switches the antenna betn the transmitter & receiver so that only one antenna needed to be used. The duplexer consist of transmitter receiver tube (TR switch) & anti transmitter, receiver tube (ATR switch). The TR switch protects the receiver during the transmission & ATR switch helps in directing the received eco signals to the receiver. The receiver is usually superheterodyne type. The 1st stage of the receiver is a low noise amplifier. The mixer & LO convert the RF o/p from the amplifier to comparatively lower frequency level called intermediate frequency state. Thus in a mixer the carrier frequency is reduced. The detector used is a schotty barrier diode which extracts the modulated pulse waveform from the IF amplifier o/p. The detector o/p is then amplified by an amplifier to a level where it can be properly displayed on an indicator directly.

Continuous Wave Radar (CW Radar)

The CW radar transmits high freq signals continuously. The eco signal is received and processed permanently. It is a type of radar system where a known stable frequency continuous wave radio energy is transmitted and received from reflecting objects. These radars determine the target velocity rather than its location and they are simple, compact and less costly. CW radar works on the principle of doppler effect. The Doppler effect is the change in frequency that occurs when a source & target are in relative motion. The CW radar uses the doppler effect to determine the velocity with which the target is moving. The transmitter generates a continuous sinusoidal signl at a frequency 'f_t' which is radiated by the antenna, on reflection by a moving object the transmitted signal is shifted by doppler effect by an amount $\pm f_d$ when, the target is moving towards the transmitter or source f_d will be +ve. If the target is moving away from the source f_d will be -ve. The detector or mixer multiplies the ecoye signal at a freq $f_t \pm f_d$. The doppler filter allows the difference freq component & pass through & rejects the higher freq. The o/p of the detector is amplified by a power amplifier.



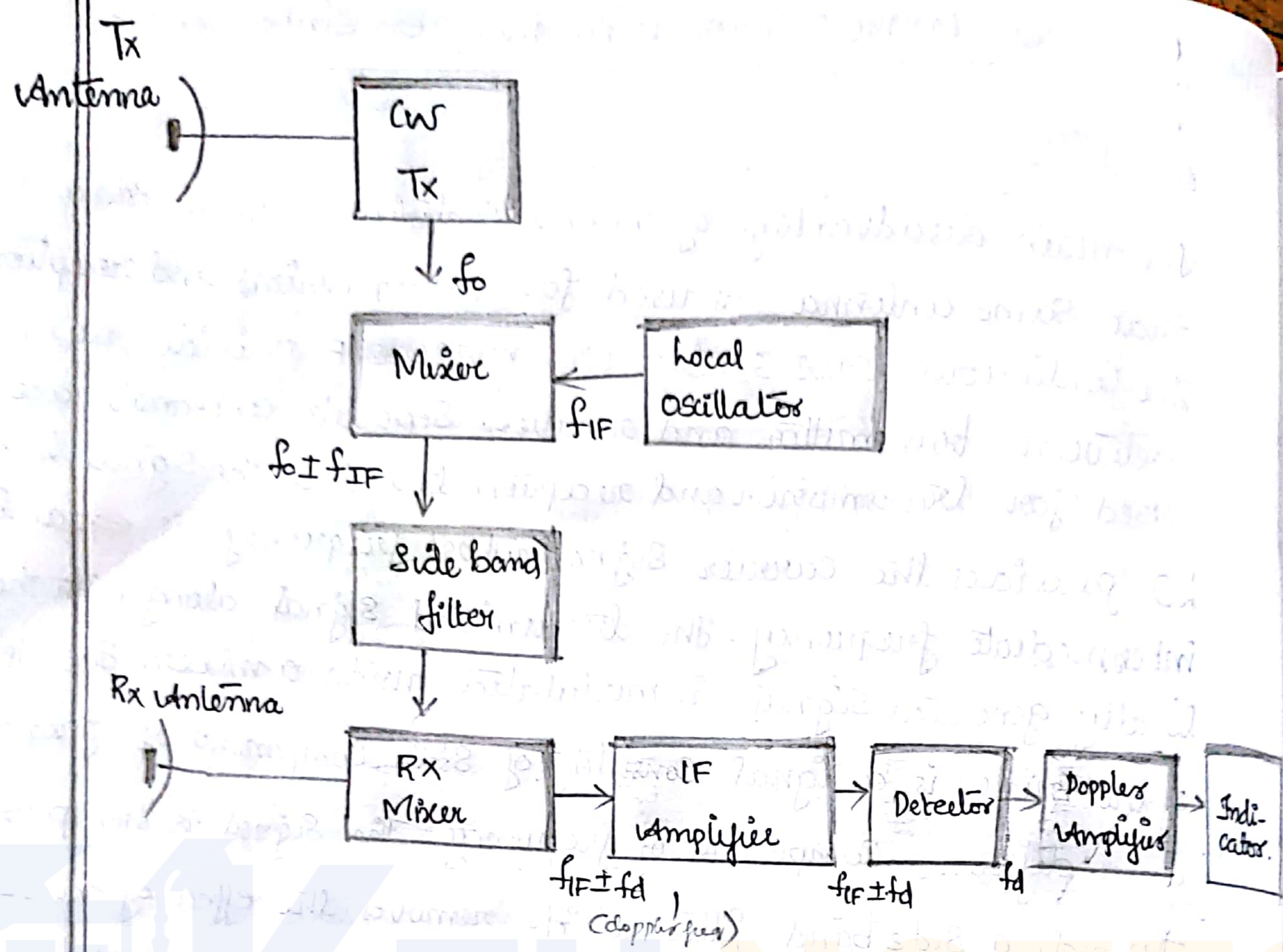
Comparison between Pulsed Radar & CW Radar

Pulsed Radar	CW Radar
1. In this system pulse modulated signal is used for transmission.	1. This system uses continuous wave modulated signals for transmission.
2. Duplexer is used to use common antenna for transmission & reception.	2. Circulator is used to seperate antenna for transmission & reception.
3. It indicates the range of the radar	3. It indicates the velocity of the moving target
4. Higher Transmission power.	4. Lower transmission power
5. Complicated & Complex	5. Simple
6. Does not use doppler shift	6. Uses Doppler shift for working

8/11/18

Continuous Wave Radar With Nonzero Intermediate Frequency

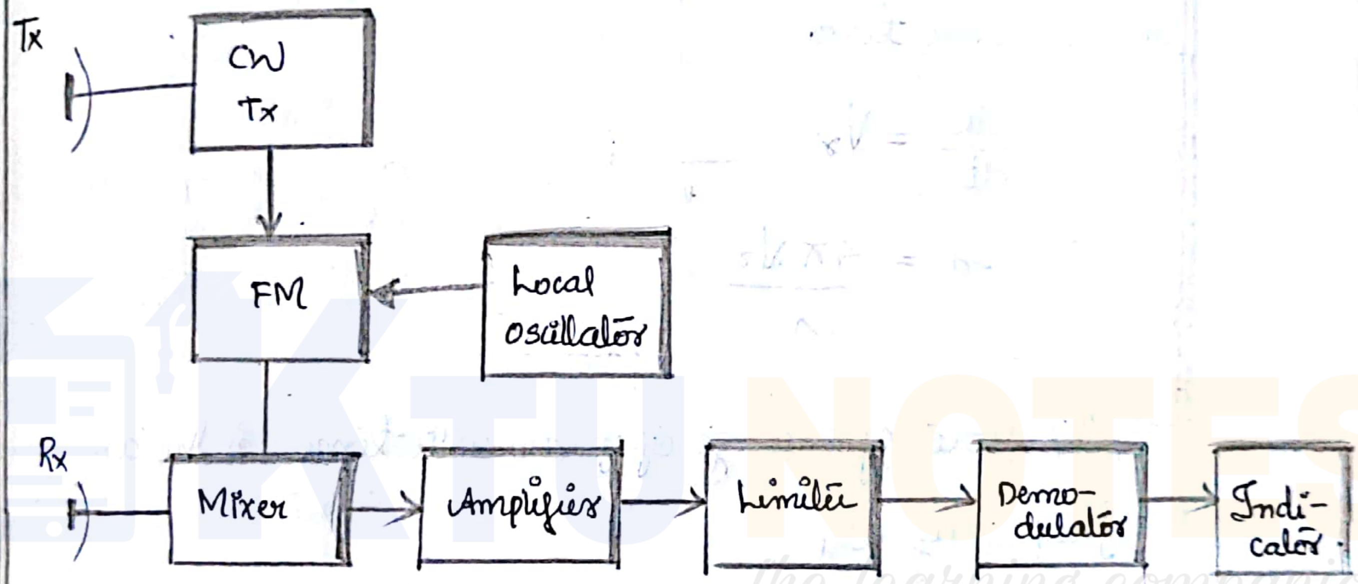
The main disadvantage of normal Continuous wave radar is that same antenna is used for transmission and reception. The Continuous wave radar with nonzero IF provides isolation between transmitter and receiver. Seperate antenna's are used for transmission and reception to reduce the signal leakage. LO provides the carrier signal whose frequency is equal to intermediate frequency. The transmitted signal along with the locally generated signal is modulated inside a mixer. The o/p of the mixer is a signal consisting of sum components of frequency and difference components of frequency. The signal is then passed through a side band filter which removes the effect of noise & reduce the receiver sensitivity. The o/p of the side band filter is fed onto a receiver mixer where the doppler frequency is added along with the original frequency of the signal. The doppler freq. can be +ve or -ve depending on the location of the target. The o/p of the receiver mixer is then amplified and passed onto a detector. The detector removes the IF component from the received signal and passes only the doppler freq component. The doppler freq component is then amplified by a doppler amplifier. The o/p of the doppler amplifier is fed on to an indicator which provides the location of the target depending on the value of doppler frequency.



Frequency Modulated Continuous Wave Radar

The frequency modulated Continuous wave radar (FMCW) radar is capable of measuring the relative velocity and range of the target depending on the BW of the signal. The time taken by the transmitted signal to reach the receiver and return back to the transmitter is calculated. In the transmitting section the transmitted signal is freq. modulated by using a FM modulator. The modulated signal is propagated on to the receiver. In the receiving section the freq modulated signal is mixed with a high BW signal inside a mixer. The o/p of the mixer is a signal having large BW. This signal is amplified and applied to a limiter circuit. The limiter circuit removes the unwanted freq

Components. This signal is demodulated and applied to an indicator which provides the location of the target. The location of the target is ~~decised~~ decised by comparing the signal ~~was~~ value with a predefined threshold value. If the value of the signal is greater than the threshold value it is decised that a target is present at a certain distance. If the value of the signal is less than the threshold value it is decided that noise is present.



Equation for Doppler Frequency Shift

The Doppler effect is the process by which the target or object is detected with change in frequencies. The change in frequency can be +ve or -ve depending on the location of the target. If the target is moving towards the radar the freq. shift will be +ve and if the target is moving away from the radar the frequency shift will be -ve. If the range to the target is R and the wavelength is λ, then the total no: of signals in propagation from radar to the target and return is $\frac{2R}{\lambda}$. The total Phase change $\phi = 2\pi \times$(Total no: of signals) ie, $\phi = 2\pi \times \frac{2R}{\lambda}$

ie $\phi = \frac{4\pi R}{\lambda}$.

If the target is in motion the angular frequency is given as $\omega_d = \frac{d\phi}{dt}$

ie, $\omega_d = \frac{4\pi}{\lambda}\frac{dR}{dt}$

The term $\frac{dR}{dt}$ is the radial velocity or rate of change of range with time.

$$\frac{dR}{dt} = V_r$$

$$\therefore \omega_d = \frac{4\pi V_r}{\lambda}$$

→ The rate of change of phase with time is the angular frequency ω_d.

$$\omega_d = 2\pi f_d$$

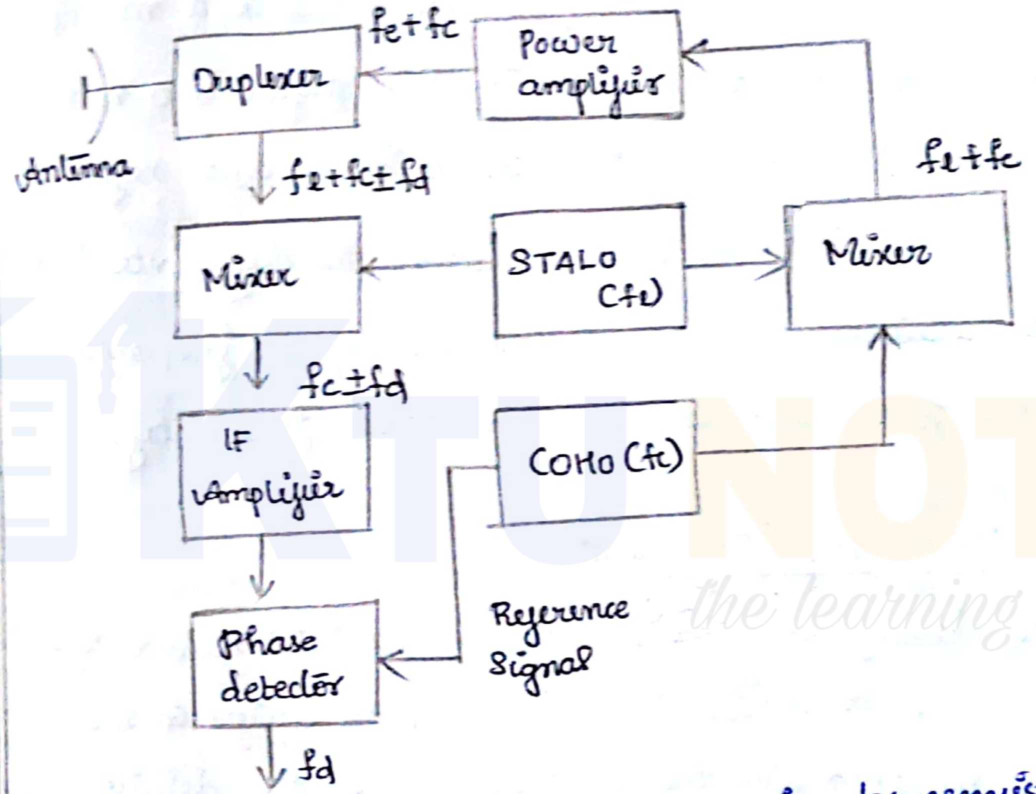
where, f_d is the doppler frequency shift.

$$f_d = \frac{2V_r}{\lambda}$$

ie, $f_d = \frac{2fV_r}{c}$

Moving Target Indication (MTI) Radar (with power amplifier)

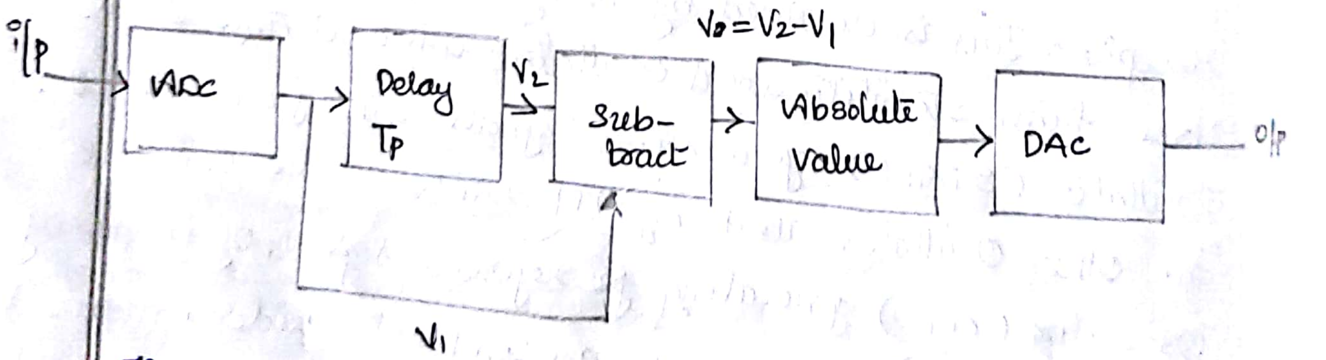
The radar's are used to detect targets in the presence of noise. In practical cases the radars have to deal with more receiver noise when detecting targets since there will be a echos receiving from a natural environment. These echos are known as 'clutters'. Clutter echo's can be orders of larger magnitude. MTI radar is a type of radar that employs the doppler shift for detecting moving objects in the presence of clutters. These type of radars can detect the location of object more efficiently compared to normal radars.



The MTI radar uses a single antenna for transmission and reception. This is achieved by using a duplexer. The radar uses high stability local oscillator called stable local Oscillator (STALO) generating signals with frequency fe. The other Oscillator used by MTI radar is the coherent Oscillator (COHO) generating for reference signals of frequency fc. The frequencies fe and fc are combined inside a mixer producing the sum of the signals. This signal is amplified by a power amplifier and is transmitted through antenna. The combination of STALO and COHO is called the receiver exciter portion of the MTI radar. This Combination is used to ensure better stability for the Operation of radar. When the amplified signal is transmitted the doppler frequency Component f_d is added along with the Signal. The o/p of the mixer will be an IF Signal. The IF Signal is amplified by an IF amplifier which acts as a matched filter. The phase detector following the IF amplifier is a mixer like device that Combines the received Signal and reference signal from the COHO So as to produce the difference between the received signal and reference Signal frequencies. The o/p of the phase detector is the doppler frequency.

Delay Line Canceller

The delay line canceler is used in MTI radar System and it works as a filter. It elliminates the Clutters in received signal there by improving the resolution of target detection. The delay line canceler Subtracts echos from the Successive Signals.



The o/p of the MTI radar is given as i/p to delay line canceler. The i/p Signal is Converted to its Equivalent digital value by an ~~ato~~ analog to digital Converter. The signal is delayed which is achieved by slowing the radar o/p during the pulse transmission. The original signal and delayed version of the signal are then subtracted to produce an o/p signal which is free from echos. The absolute value of the difference signal is then taken and is fed to a digital to analog converter to produce the o/p signal.

Let $V_1 = k \sin[2\pi f_d t - \phi]$

$V_2 = k \sin(2\pi f_d(t - T_p) - \phi)$

$\therefore V = V_2 - V_1$

$= k \sin(2\pi f_d(t - T_p) - \phi) - k \sin[2\pi f_d t - \phi]$

$\sin A - \sin B = 2 \sin \frac{A-B}{2} \cos \frac{A+B}{2}$

$$= 2k \left\{ \sin\left[\frac{2\pi f_d(t - T_p) - \phi - (2\pi f_d t - \phi)}{2}\right] \cos\left[\frac{2\pi f_d(t - T_p) - \phi + 2\pi f_d t - \phi}{2}\right] \right\}$$

$$= 2k \left\{ \sin\left[\frac{\cancel{2\pi f_d t} - 2\pi f_d T_p - \cancel{\phi} \cancel{- 2\pi f_d t} + \cancel{\phi}}{2}\right] \cos\left[\frac{2\pi f_d t - 2\pi f_d T_p - \phi + 2\pi f_d t - \phi}{2}\right] \right\}$$

$$= 2k \sin(\cancel{2\pi f_d t} - \pi f_d T_p) \cos\left(\frac{4\pi f_d t - 2\pi f_d T_p - 2\phi}{2}\right)$$

$$= 2k \sin(-\pi f_d T_p) \cos(2\pi f_d t - \pi f_d T_p - \phi)$$

$$= 2k \sin(\cancel{-}\pi f_d T_p) \cos(2\pi f_d t - \pi f_d T_p - \phi)$$

Considering only the magnitude of the signal

$V = 2k \sin(\pi f_d T_p) \cos(2\pi f_d t - \pi f_d T_b - \phi)$

i.e, $V = H(f) \times \cos(2\pi f_d t - \pi f_d T_p - \phi)$

where, $H(f)$ is the amplitude of the transmitted signal and

$H(f) = 2\pi \sin(\pi f_d T_p)$

→ The delay line cancellers have a disadvantage called 'blind speed' where the target will not be detected and there will be ~~no~~ an uncancelled clutter remaining interfering with target detection process. The Doppler shift frequency in presence of clutter is defined as

$$f_d = n f_p \quad —(1)$$

The general equation for Doppler shift frequency is

$$f_d = \frac{2 f_t V_r}{c} \quad —(2)$$

equating eqn (1) & (2)

$$n f_p = \frac{2 f_t V_r}{c}$$

$$\therefore V_r = \frac{c n f_p}{2 f_t}$$

$$= \frac{n f_p \lambda}{2}$$

$$V_r = \frac{n\lambda}{2 T_p}$$

V_r, represents the velocity for calculating blind speed

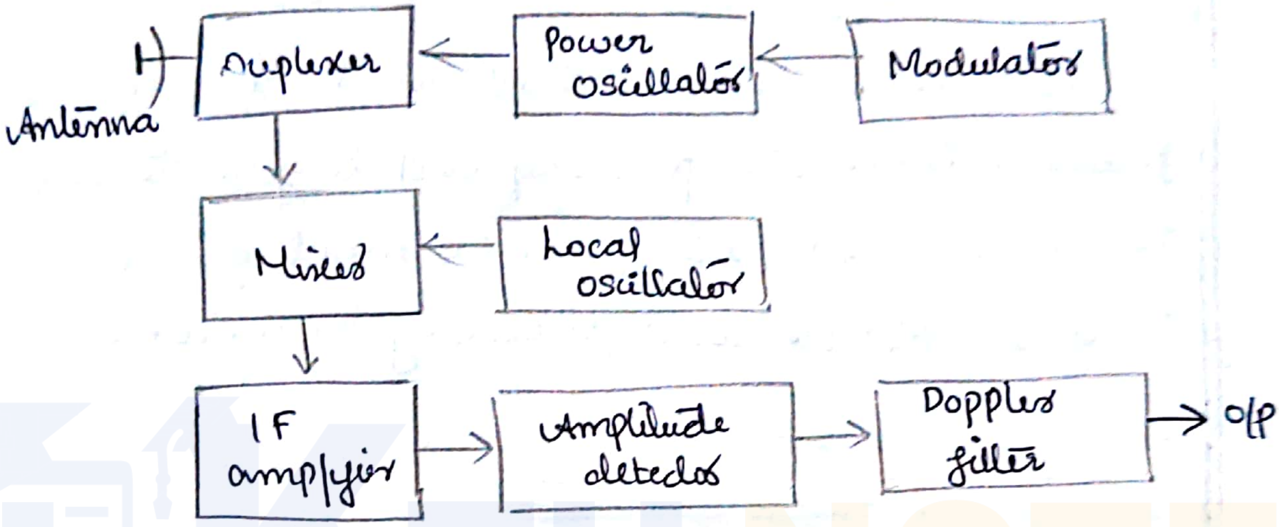
four methods for reducing the effects of blind speed are

- Operate radar at longer wavelengths.
- Operate radar with high pulse repetition frequency

3. Operate with more than 1 repetition frequency.
4. Operate with more than one radio frequency.

Non Coherent MTI radar (with power oscillator)

A radar that uses the clutter signals as the reference signal to extract the doppler shifted target is called non Coherent MTI radar. It is also known as externally coherent MTI radar.



The signal to be transmitted is combined inside a mixer with the locally generated carrier signal. The o/p of the mixer is an IF signal which is amplified by the IF amplifier. The amplitude detector following the IF amplifier is a nonlinear device which is used to compare the clutter signal and the doppler shifted signal to produce the doppler frequency as the output. This o/p signal is then extracted by a doppler filter to indicate the location of the target.

Radar Transmitters

The radar transmitter is generally a RF power source it include exciter and driver amplifiers that provide amplification for the signal to be transmitted. If the transmitter generates a pulse waveform then the modulator used is a pulse modulator. There must be a DC power supply for generating necessary voltages and currents to operate the device. The transmitter conversion efficiency is defined as the ratio of RF power o/p available from the device to the dc pwr i/p. Normally the RF conversion efficiency is between 10 to 60%. The transmitter system efficiency is the ratio of RF power available from the transmitter to the total power required to operate the transmitter. The total power includes the pwr required to generate electron beams from the cathode, the power required to generate electromagnetic fields, the pwr required for cooling the device etc.

Types of Radar Transmitters.

1. Klystron

→ It has high gain and efficiency.

→ It has high avg and peak pwr.

2. Travelling Wave tube

→ It has less power, less gain & less efficiency than klystron.

→ It has wider BW.

3. Hybrid klystron

→ They are similar to klystron but single cavity is replaced by multiple cavities.

4. Solid state Transistor Amplifiers

→ They are wider BW devices which operate with low voltages.

→ They are easy to maintain & have long life.

5. Magnetron

→ They are smaller in size and utilizes low voltages for operation.

The klystron, travelling wave tube & magnetron are called slow wave devices in which the phase velocity of electromagnetic wave is slow compared to velocity of electrons. The Gyrotron is a fast wave device in which the phase velocity of the EM wave is higher than velocity of electron.

14/11/18 wed.

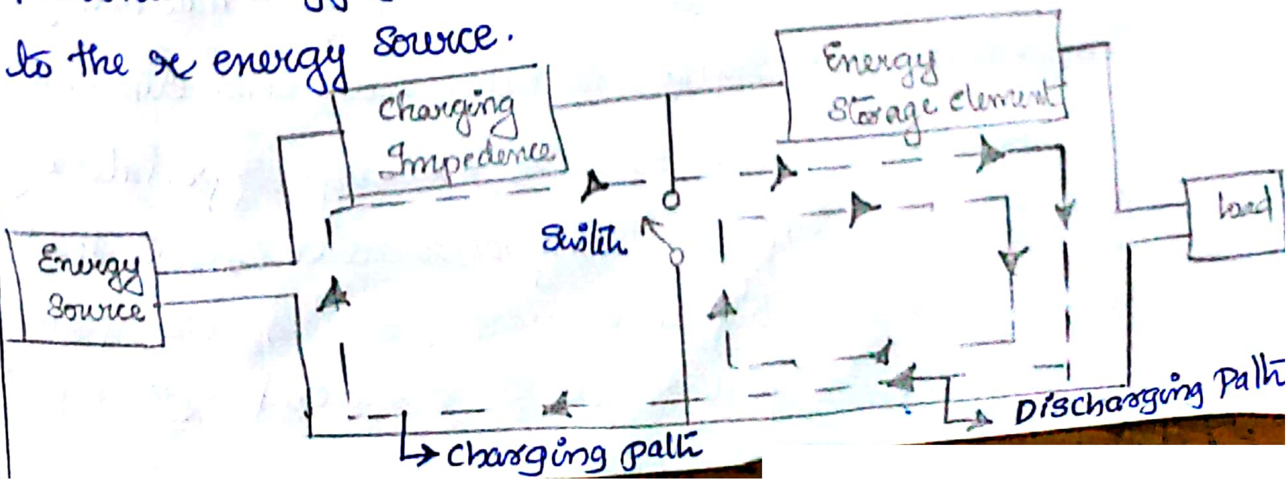
Radar Modulators

→ The function of the modulator is to turn on and off the transmitter to generate the desired waveform. When the waveform is a pulse the modulator is called pulse modulator or pulser.

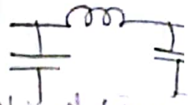
→ Energy from the external power source is accumulated in the energy storage element.

→ The charging impedence limits the rate at which energy is delivered to storage element. When the pulse is ready to be formed the switch is closed and the stored energy is discharged through the load.

→ During the discharge path of the cycle the charging impedence being returned prevents energy from the storage element to the energy source.



Line Type Modulator



In this device a delay line or pulse forming n/w (collections of ind & capacity) is used storage element. The switch can be a silicon controlled rectifier (SCR) that can initiate the discharge of pulse forming n/w to form a rectangular pulse. The shape & duration of the pulse are determined by passive elements of pulse forming n/w. This type of modulator is simple, compact in size and can tolerate abnormal load conditions.

Active Switch Modulator.

The switch in the active switch modulator controls both the beginning and end of the pulse. The energy storage element is a capacitor. Large capacitance can be obtained with a collection of capacitors known as 'capacitor bank'. The active switch modulator permits more flexibility than line type modulators.

Radar Receivers

The function of the receiver is to extract the weak eco signals and amplify them. It employs a matched filter to maximize the signal to noise ratio and eliminate unwanted signals. The radar receiver is always superheterodyne in nature. The superheterodyne receiver converts the RF i/p signal to an IF signal to achieve desired BW, gain and stability. The first stage or front end of a superheterotype receiver is a low noise amplifier.

Reciever Noise Figure

It is defined as the measure of noise produced by a practical receiver compared to noise of an ideal receiver. The noise figure is expressed as

$$\boxed{F_n = \frac{N_{out}}{K T_0 B_n G}}$$

where, N_{out} - available o/p noise power.

k - Boltzmann's Constant G - Gain.

T_0 - standard temperature

B_n - noise BW.

If additional noise is introduced by practical n/w then,

$$\text{noise figure} = F_n = \frac{K T_0 B_n G + \Delta N}{K T_0 B_n G}.$$

$$F_n = 1 + \frac{\Delta N}{K T_0 B_n G}$$

Noise Figure in Cascade Networks.

Consider two n/w's in cascade each with same noise and BW but with different gain. Let the noise from the 1st n/w be $F_1 K T_1 B_n G_1 G_2$ and the noise from the 2nd n/w be $(F_2-1) K T_0 B_n G_2$.

$\therefore$ the o/p noise, N_{out} = noise from 1st n/w + noise from 2nd n/w

$$\text{ie, } N_{out} = F_1 K T_1 B_n G_1 G_2 + (F_2 - 1) K T_0 B_n G_2$$

Let, $N_{out} = F_0 K T_0 B_n G_1 G_2$

$\therefore$ the above eqn becomes

$$F_0 K T_0 B_n G_1 G_2 = F_1 K T_1 B_n G_1 G_2 + (F_2 - 1) K T_0 B_n G_2$$

$$F_0 = \left(F_1 K T_1 B_n G_1 G_2 + (F_2 - 1) K T_0 B_n G_2\right) / K T_0 B_n G_1 G_2$$

provides two o/p frequencies that are sum and difference of two i/p frequencies.

ie, $f_{RF} \pm f_{LO}$.

The difference frequency $f_{RF} - f_{LO}$ is the desired IF frequency. The sum frequency $f_{RF} + f_{LO}$ is removed by filtering. If the RF signal frequency is greater than local oscillator frequency the o/p IF frequency will be

$$f_{IF} = f_{RF} - f_{LO}$$

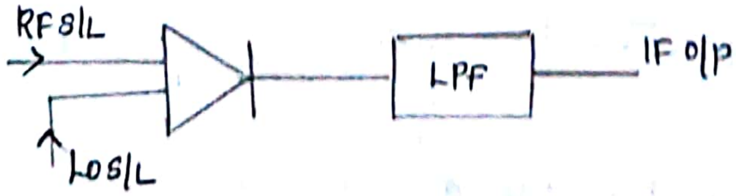
This is known as desired frequency.

→ If the RF signal frequency is less than local oscillator freq, then the o/p IF signal will be

$f_{IF} = f_{LO} - f_{RF}$. This is called image frequency.

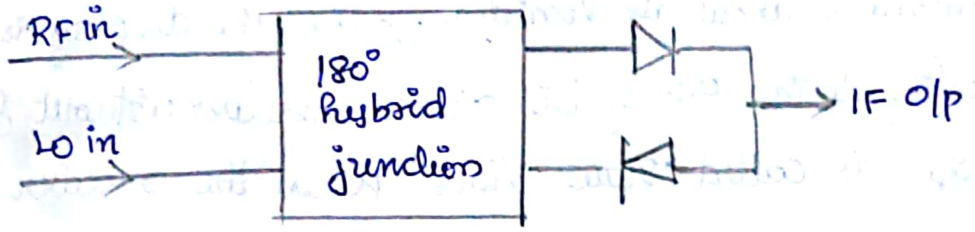
a) Single Ended Mixer

It uses a single diode. The LO signal is inserted through a directional coupler. A low pass filter following the diode allows the IF signal to pass through it by rejecting high frequencies. The diode of the mixer can produce nonlinearities called spurious responses which are unwanted intermediate frequency components



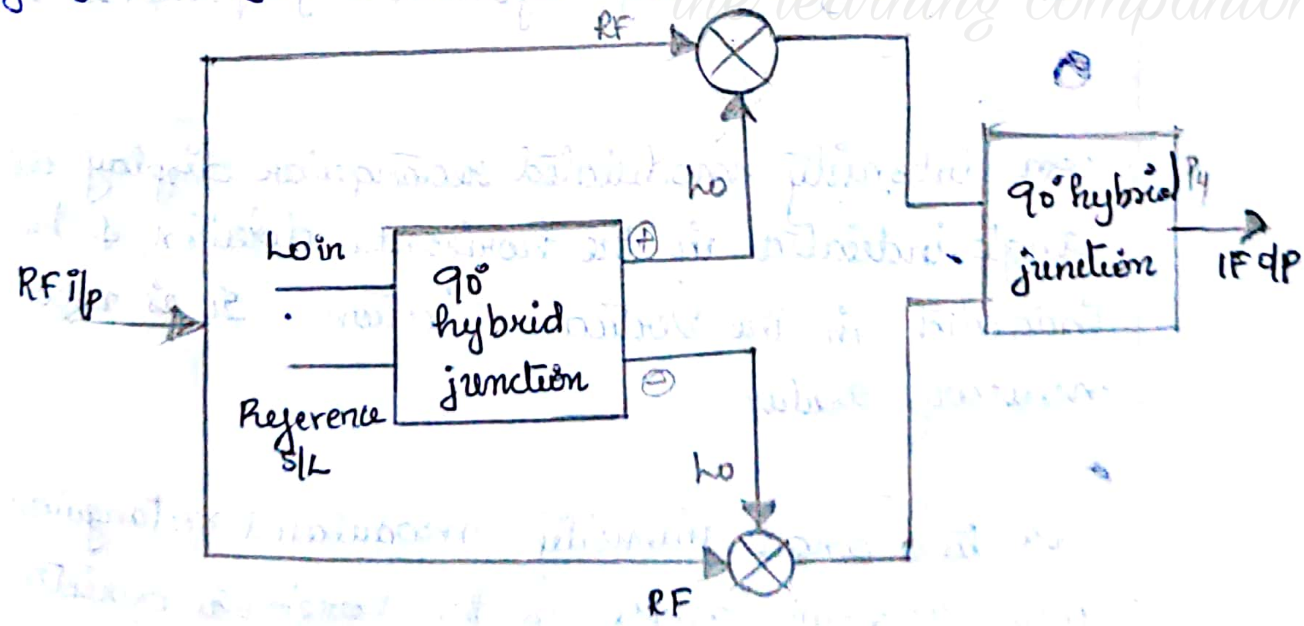
b) Balanced Mixer

The balanced mixer can be considered as two single ended mixers in parallel & 180° out of phase. The LO signal is applied to one port and RF signal is applied to second port. The signals inserted at these two ports appear in the 3rd port as sum and 4th port as difference. The IF signal is obtained by subtracting the o/p of the two diode mixers. A double balanced mixer utilises four diodes connected in ring or bridge to produce the IF signal output.



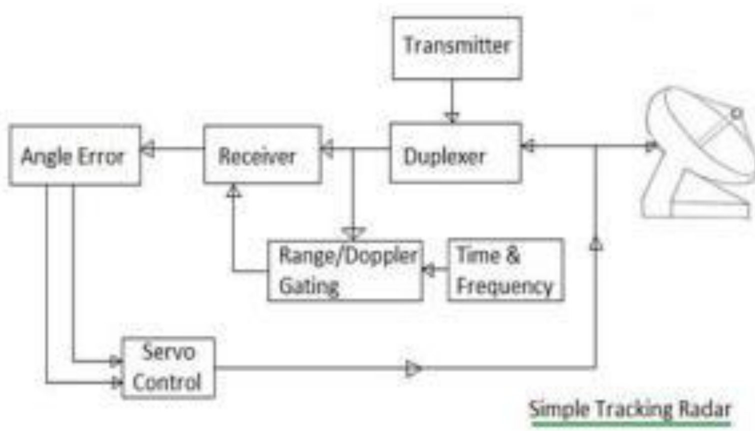
c) Image Rejection Mixer

In an image rejection mixer the RF signal is split and fed to two mixers. The LO signal is fed into one port of a 90° hybrid junction that produces 90° phase difference between the LO i/p's to the two mixers. The IF hybrid junction provides another 90° phase difference in such a manner that signal frequency & image frequency are seperated.



Tracking With Radar

- Tracking is the process of continuously maintaining the antenna beam on the target and also the echo signal within the range gate.
- The radar which detects target and determines location as well as predict its trajectory path as well as its future coordinates is known as tracking radar.
- Based on the measured coordinates error signal will be generated.
- Antenna should be moved based on error signal to maintain the target within the beam.
- Use pencil beam
- The figure below mentions block diagram of simple **tracking radar**.
- As shown tracking operation in the radar depends upon angular information. very narrow antenna beam is used here which will track one target object at one time. This can be performed using range gating and doppler filtering module.
- Range tracking is carried out using timing control unit. Doppler tracking is carried out using Doppler gating unit.



- The angle error signal is provided as input for servo motor based control system. This servo system will steer the antenna as per error input and hence will track the target.
- The various methods for generating the error signal are classified as sequential lobing, conical scan, and simultaneous lobing or Monopulse.
- The data available from a tracking radar may be presented on a cathode-ray-tube (CRT) display

Tracking Radar Types

Following are the types of tracking radar:

- STT Radar (Single Target Tracking Radar)
- ADT Radar (Automatic Detection and Tracking Radar)
- TWS Radar (Track While Scan Radar)
- Phased Array Tracking Radar
- Monopulse Tracking Radar

STT Radar (Single Target Tracking Radar)

- Tracks a single target at fast data
- High Data rate – 10 obs/sec.
- Employs a closed loop servo system to keep the error signal small.
- Application – tracking of aircraft/missile targets

ADT Radar (Automatic Detection and Tracking Radar)

- This Tracking is preferred in air surveillance tracking radar.
- Lower data rate than STT.
- Can track hundreds/ a few thousand targets simultaneously.
- Tracking is open loop i.e antenna position is not controlled by data processing.

TWS Radar (Track While Scan Radar)

- This rapidly scans a limited angular sector to maintain tracks with a moderate data rate on more than one target within the coverage of antenna (another name for ADT).

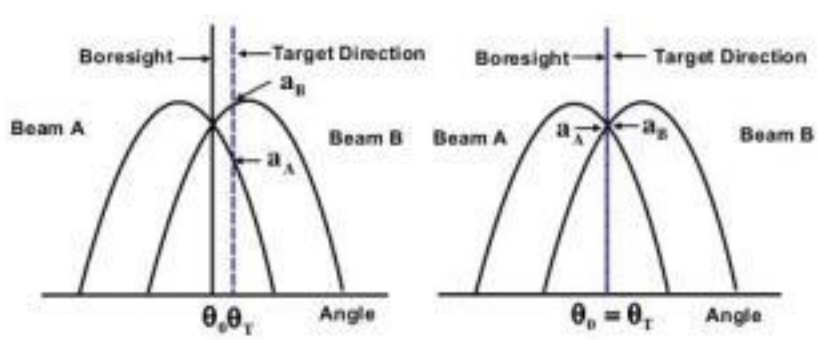
- Scans a limited angular sector to maintain tracks – **simultaneous track & search**
- Data rate : moderate
- Can track a number of targets.
- Equivalent of track while scan is **ADT**
- TWS systems are used for air-defense radars, air craft landing radars and in air borne intercept radars to track multiple objects

Phased Array Tracking Radar

- A large number of targets can be held in track
- This is done on time sharing basis
- Beam is electronically switched from one angular position to another in a few microseconds.
- It combines the rapid update rate of a single target tracker with the ability of ADT to hold many targets in track
- High data rate (like in STT)
- The cost is very very high.
- These radars are used in air defense weapon systems.

Angle Tracking

- When a target is approaching, the antenna is to be moved continuously to track the target
- To determine the direction in which the antenna beam needs to be moved, a measurement has to be made at two different beam positions.
- Below figure shows the basic principle of continuous angle tracking

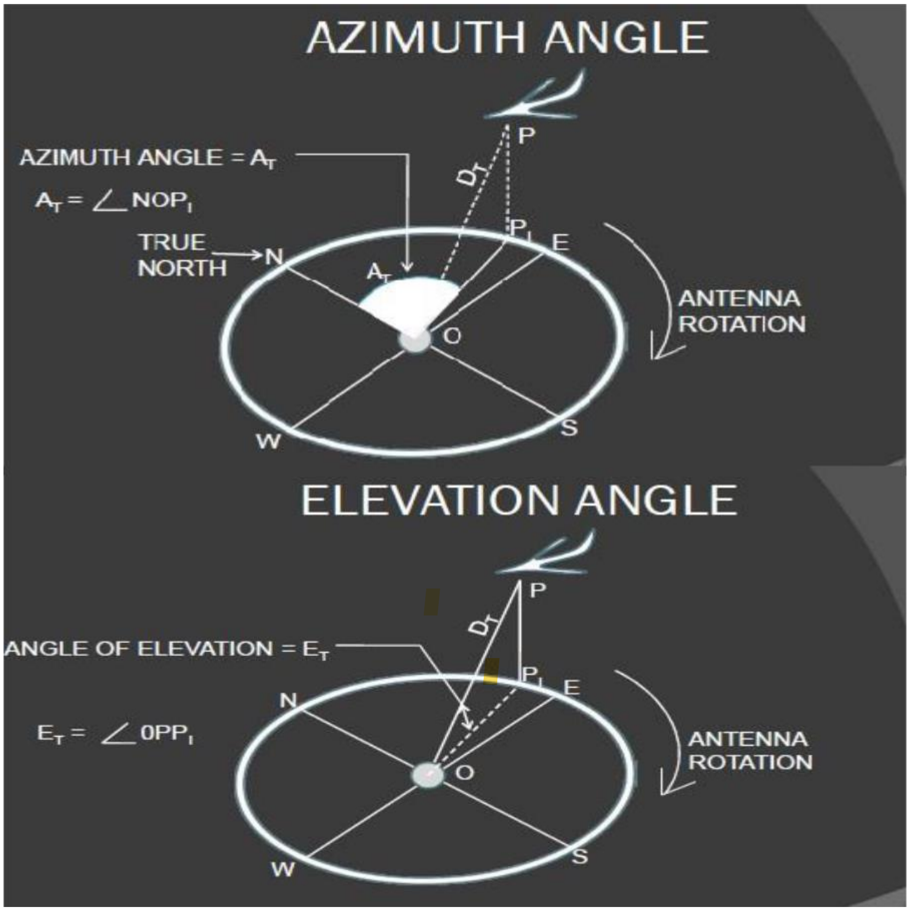


- Two overlapping antenna patterns that crossover at the boresight direction θ_0
- A target is located in this example to the right of the boresight at an angle θ_T
- The amplitude a_B of the target echo in beam B is larger than the amplitude a_A in the beam A
- Which indicates that the two beams should moved to the right to bring the target to the boresight position.
- If you want to track the target the boresight is always maintained in the direction of the target.

Methods to extract error signal may be classified as

- Sequential lobing
- Conical scan
  1. Time shares a single beam
  2. Antenna beam is switched between two positions
- Simultaneous lobing or monopulse
  1. More than one simultaneous beam is used for tracking
  2. Usually 4 simultaneous beams used for 2-dimensional tracking

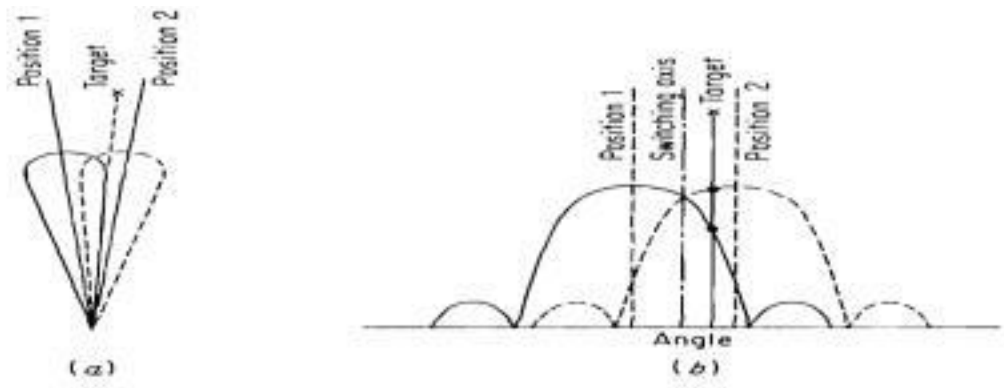
Sequential lobing Radar and Conical scan Radar	**Simultaneous lobing or monopulse Radar]**
Simpler	Complex
One antenna	Multiple antennas
Less equipment	More equipments
Not accurate	Accurate
No of pulses are required to extract the error signal	Single pulse is used to determine the angular error.

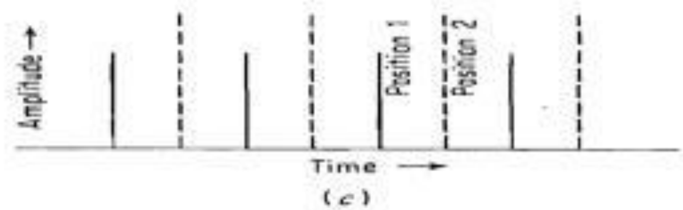


Sequential Lobing

- The antenna pattern commonly employed with tracking radars is the symmetrical pencil beam in which the, elevation and azimuth beam widths are approximately equal.
- Actually the difference between the target position and the reference direction is the angular error.
- The tracking radar attempts to position the antenna to make the angular error zero. When the angular error is zero, the target is located along the reference direction.
- One method of obtaining the direction and the magnitude of the angular error in one coordinate is switching the single antenna beam between two squinted angular positions. This is called as lobe switching, sequential switching or sequential lobing.
- The error signal is obtained from a target not on the switching axis.
- The direction in which to move the beam to bring the target on boresight is found by observing which beam position has the larger signal.

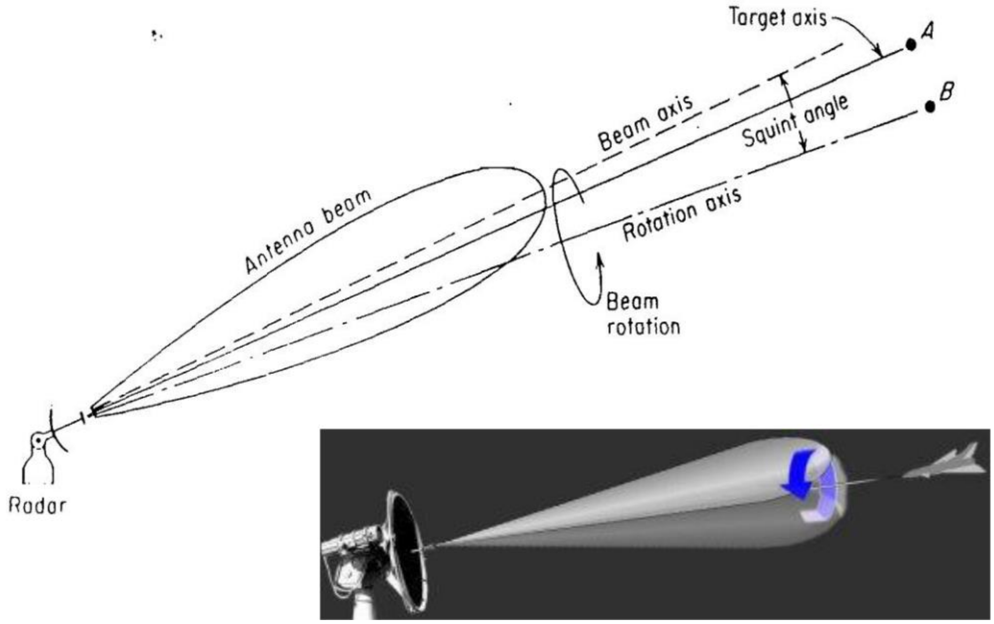
Fig 1-a is a polar representation of the antenna beam (minus the side lobes) in the two switched positions. A plot in rectangular coordinates is shown in **Fig.1-b,** and the error signal obtained from a target not on the switching axis (reference direction) is shown in **Fig.1-c.**





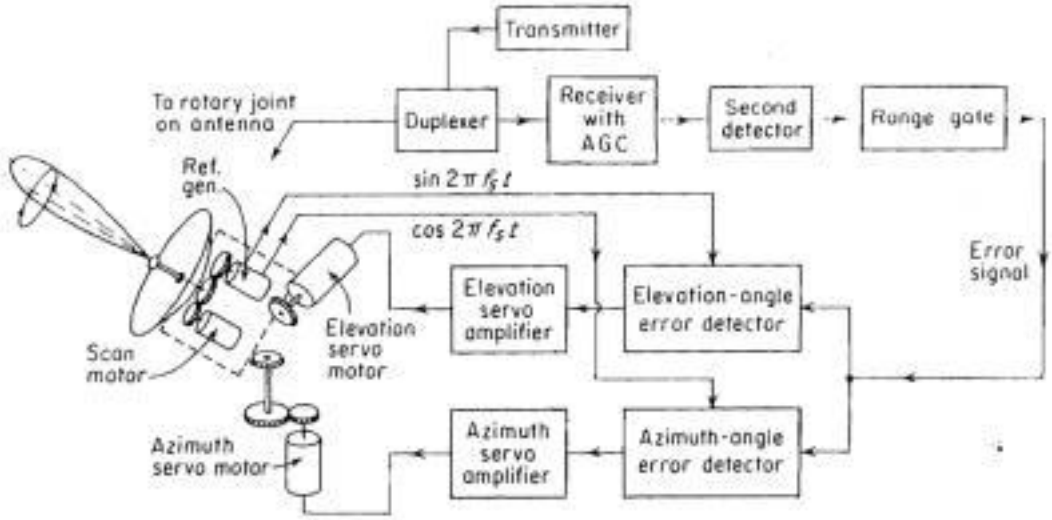
- When the echo signals in the two beam positions are equal, the target is n axis and its direction is that of the switching axis.
- If orthogonal angle information is needed, two more switching positions are needed.
- So, two dimensional sequentially lobing radar might consists of four feed horns illuminating a single reflector antenna.
- An improvement over this can be a single squinted feed which could be rotated continuously to obtain angle measurements in two coordinates . This results in conical scan.
- One of the limitations of a simple unswitched non-scanning pencil-beam antenna is that the angle accuracy can be no better than the size of the antenna beam width.
- An important feature of sequential lobing (as well as the other tracking techniques to be discussed) is that the target-position accuracy can be far better than that given by the antenna beam width.

Conical Scan



- The angle between the axis of rotation and the axis of the antenna beam is called the Squint Angle.
- Consider a target at position A**.**
- The echo signal amplitude will be modulated at a frequency equal to the rotation frequency of the beam.
- The amplitude of the echo signal modulation will depend upon the shape of the antenna pattern, the squint angle and the angle between the target line of sight & the rotation axis. This amplitude of the echo signal will be modulated ata frequency equal to the beam rotation frequency (conical Scan frequency).
- The phase of the modulation depends on the angle between the target and the rotation axis.
- The conical scan modulation is extracted from the echo signal and applied to a servo-control system which continually positions the antenna rotation axis in the direction of the target. [Note that two servos are required because the tracking is required in two-dimensions.
- When the antenna is on target, as in B of **Fig. 2,** the line of sight to the target and the rotation axis coincide, and the conical-scan modulation is zero.
- Two servo motors are required, one for azimuth and the other for elevation

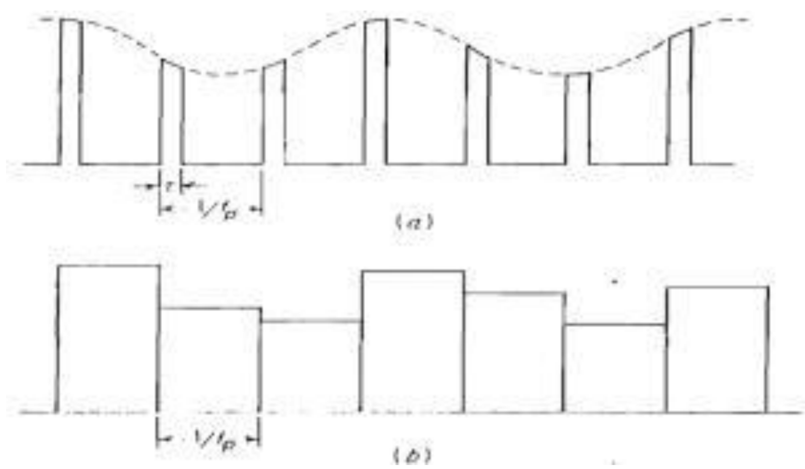
Block diagram of conical scan tracking radar



- The antenna is mounted so that it can be positioned in both azimuth and elevation by separate m
- Redirection of beam i) Rotating feed ii) Nutating feed.
- When the feed is designed to maintain the plane of polarization as it rotates about the axis, it is called ' nutating feed'.
- A rotating feed is one which causes the plane of polarization to rotate.
- The nutating feed is preferred over the rotating feed since a rotating polarization can cause the amplitude of the target echo signal to change with time even for a stationary target on axis.
- A change in amplitude caused by a modulated echo signal can result in degraded angle tracking accuracy.
- The nutating feed is more complicated than the rotating feed.
- A typical conical scan rotation speed might be in the vicinity of 30 rev/sec.
- The same motor that provides the conical-scan rotation of the antenna beam also drives a two-phase reference generator with two sinusoidal outputs **90^0** apart in phase.

- These two outputs serve as a reference to extract the elevation and azimuth errors.
- The received echo signal is fed to the receiver from the antenna via two rotary joints (not shown in the block diagram). One rotary joint permits motion in azimuth; the other, in elevation.
- The receiver is conventional super heterodyne except for features related to the conical scan tracking.
- The error signal is extracted in the video after the second detector.
- Range gating eliminates noise and excludes other targets.
- The error signal from the range gate is compared with both the elevation and azimuth reference signals in the angle error detectors.
- The angle error outputs are amplified and used to drive the antenna elevation and azimuth servo motors.
- The video signal is a pulse train modulated by the conical scan frequency.
- It is usually convenient to stretch the pulses before low pass filtering so as to increase the energy at the conical scan frequency to perform A/D conversion.
- This pulse stretching is accomplished by a sample-and hold circuit which also known as boxcar generator.

Fig 4: (a) Pulse train with conical scan modulation (b)same pulse train after passing through boxcar generator.(stretching by a sample and hold circuit)



- PRF must be sufficiently large compared to conical scan frequency for proper filtering and avoiding inaccuracy of the angle measurement.
- The PRF must be atleast four times of conical scan frequency but normally 10 times.

Automatic Gain Control (AGC) :

- The echo-signal amplitude at the tracking-radar receiver will not be constant but will vary with time. The three major causes of variation in amplitude are:
  - The inverse-fourth-power relationship between the echo signal and range
  - The conical scan modulation (angle-error signal) and
  - Amplitude fluctuations in the target cross Section.
- The function of the automatic gain control (AGC) is to maintain the d-c level of the receiver output constant and to smooth or eliminate as much of the noise like amplitude fluctuations as possible without disturbing the extraction of the desired error signal at the conical-scan frequency.
- AGC is also important for avoiding saturation by large signals which could cause the loss of the scanning modulation and the accompanying error signal.

An example of the AGC portion of a tracking-radar receiver is shown in Fig

- A portion of the video-amplifier output is passed through a low-pass or smoothing filter and fed back to control the gain of the IF amplifier.
- The larger the video output, the larger will be the feedback signal and the greater will be the gain reduction.

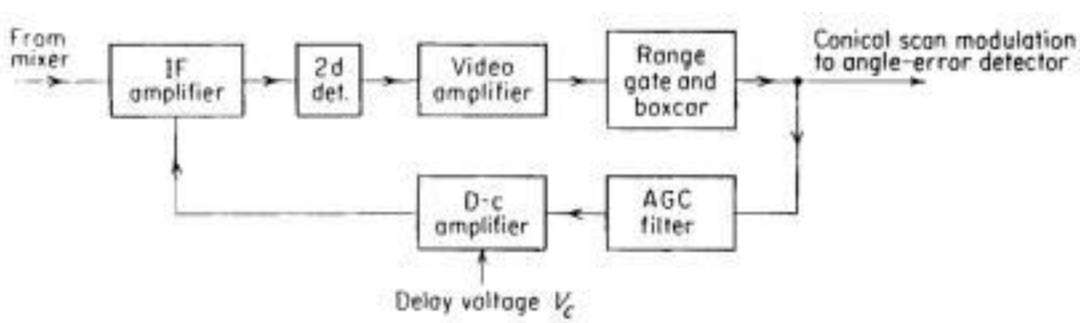


Figure: Block diagram of the AGC portion of a tracking-radar receiver

•The filter in the AGC loop should pass all frequencies from direct current to just below the conical-scan-modulation frequency.

•The loop gain of the AGC filter measured at the conical-scan frequency should be low so that the error signal will not be affected by AGC action.

•The phase shift of this filter must be small if its phase characteristic is not to influence the error signal.

•A phase change of the error signal is equivalent to a rotation of the reference axes and introduces cross coupling, or "cross talk," between the elevation and azimuth angle-tracking loops.

- Cross talk affects the stability of the tracking and might result in an unwanted nutating motion of the antenna.

- In conventional tracking radar applications, the phase change introduced by the feedback-loop filter should be less than **10_0** and in some applications, it should be as little as **2_0.**

- For this reason, a filter with a sharp attenuation characteristic in the vicinity of the conical-scan frequency might not be desirable because of the relatively large amount of phase shift which it would introduce.

Other considerations:

- In both the sequential-lobing and conical-scan techniques, the measurement of the angle error in two orthogonal coordinates (azimuth and elevation) requires that a minimum of three pulses be processed.
- In practice, however, the minimum number of pulses in sequential lobing is usually four-one per quadrant. Although a conical scan radar can also be operated with only four pulses per revolution, it is more usual to have ten or more per revolution. This allows the modulation due to the angle error to be more that of a continuous sine wave.
- Thus, the **PRF** is usually at least an order of magnitude greater than the conical-scan frequency.
- The scan frequency also must be at least an order of magnitude greater than the tracking bandwidth.
- A conical-scan-on-receive-only (COSRO) tracking radar radiates a non-scanning transmit beam, but receives with a conical scanning beam to extract the angle error. The analogous operation with sequential lobing is called lobe-on-receive-only (LORO).

DISADVANTAGES

Sequential lobing

- Angle accuracy can be no better than the size of the antenna beamwidth.
- Variation in echo strength on a pulse-by-pulse basis changes the signal level thereby reducing tracking accuracy
- The antenna gain is less than the peak gain in beam axis direction, reducing maximum range that can be measured

Conical scan

- The antenna scan rate is limited by the scanning mechanism (mechanical or electronic)
- Sensitive to target modulation
- Mechanical vibration and wear and tear due to rotating feed
- It creates confusion by rapid changes in signal strength

MONOPULSE TRACKING RADAR

- Pulse-to-pulse amplitude fluctuations of the echo signal have no effect on tracking accuracy if the angular measurement is made on the basis of one pulse rather than many.
- There are several methods by which angle-error information might be obtained with only a single pulse.
- More than one antenna beam is used simultaneously in these methods, in contrast to the conical-scan or lobe-switching tracker, which utilizes one antenna beam on a time-shared basis.
- The angle of arrival of the echo signal may be determined in a single-pulse system by measuring the relative phase or the relative amplitude of the echo pulse received in each beam.
- The names **simultaneous lobing** and **monopulse** are used to describe those tracking techniques which derive angle-error information on the basis of a single pulse.
- Most popular monopulse is – Amplitude Comparison Monopulse

Amplitude Comparison Monopulse

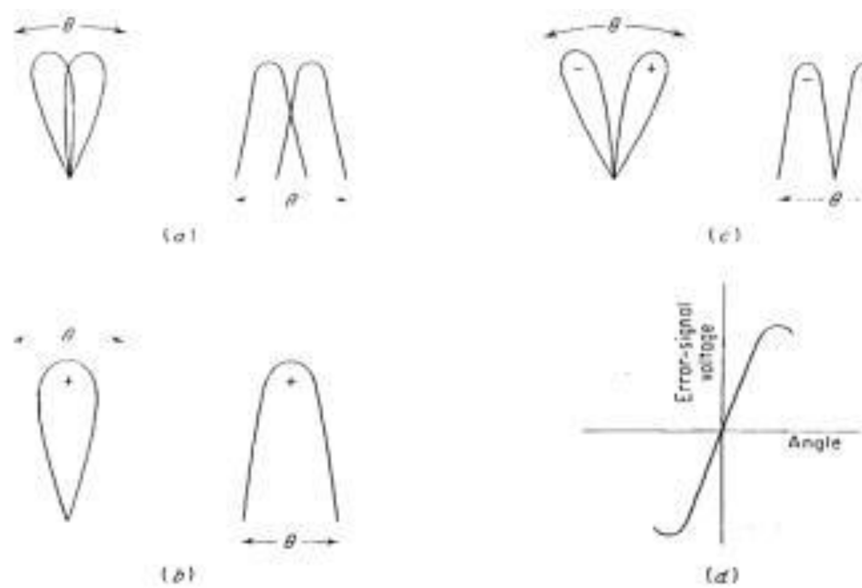


Figure: Monopulse antenna patterns and error signal. Left-hand diagrams in (a-c) are in polar coordinates. Right-hand diagrams are in rectangular coordinates. (a) Overlapping antenna patterns (b) sum pattern (c) difference pattern (d) product (error) signal.

- In this technique, the RF signals received from two offset antenna beams are combined so that both the sum and the difference signals are obtained simultaneously.

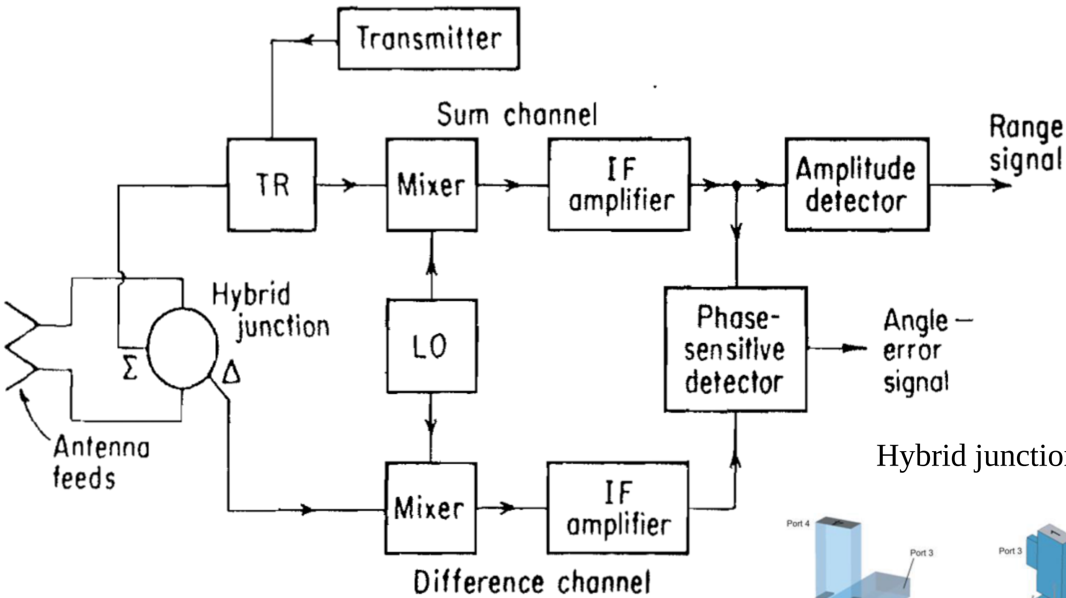
- The sum and difference signals are multiplied in a **phase-sensitive detector** to obtain both the magnitude and the direction of the error signal.
- All the information necessary to determine the angular error is obtained on the basis of a single pulse; hence the name **monopulse**.
- The amplitude-comparison monopulse employs two overlapping antenna patterns to obtain the angular error in one coordinate.
- The sum of the two antenna patterns of **Fig (a)** is shown in **Fig (b),** and the difference in **Fig(c).**
- The sum pattern is used for transmission, while both the sum pattern and the difference pattern are used on reception.
- The signal received with the difference pattern provides the magnitude of the angle error.
- The sum signal provides the range measurement and is also used as a reference to extract the sign of the error signal.
- Signals received from the sum and the difference patterns are amplified separately and combined in a phase-sensitive detector to produce the error-signal characteristic shown in **Fig (d).**

Phase-sensitive detector

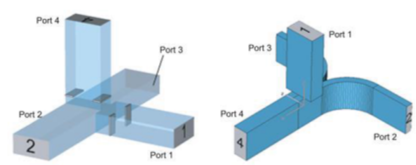
- The system contains a phase sensitive detector that compares two signals of the same frequency.
- It is a nonlinear device
- The output indicates the direction of the angle error relative to the boresight.
- Though phase comparison is done, the magnitude of the angle error signal is determined by comparison of amplitude signals.

Amplitude-comparison monopulse (One angular coordinate)

- A block diagram of the amplitude-comparison-monopulse tracking radar for a single angular coordinate is shown in below **Fig.**



Hybrid junctions



- The two adjacent antenna feeds are connected to the two arms of a ***hybrid junction*** such as a ***"magic T,*** a ***"rat race,"*** or a ***"short-slot coupler".***
- The sum and difference signals appear at the two other arms of the ***hybrid***. On reception, the outputs of the sum arm and the difference arm are each heterodyned to an intermediate frequency and amplified as, in any super heterodyne receiver.
- The transmitter is connected to the sum arm. Range information is also extracted from the sum channel.
- A duplexer is included in the sum arm for the protection of the receiver.
- The output of the phase-sensitive detector is an error signal whose magnitude is proportional to the angular error and whose sign is proportional to the direction.
- The output of the monopulse radar is used to perform automatic tracking.
- The angular error signal actuates a servo-control system to position the antenna, and the range output from the sum ***channel feeds*** into an automatic-range-tracking unit.

- The sign of the difference signal (and the direction of the angular error) is determined by comparing the phase of the difference signal with the phase of the sum signal.
- If the sum signal in the IF portion of the receiver were $\boldsymbol{A_S \cos(\omega_{IF}t)}$ the difference signal would be either $\boldsymbol{A_d \cos(\omega_{IF}t)}$ or– $\boldsymbol{A_d \cos(\omega_{IF}t)}$ **(**$\boldsymbol{A_s > 0, A_d > O}$**),** depending on which side of center is the target.
- Since – $\boldsymbol{A_d \cos(\omega_{IF}t)} = \boldsymbol{A_d \cos \omega_{IF}(t+\pi)}$**,** the sign of the difference signal may be measured by determining whether the difference signal is in phase with the sum or $\mathbf{180^0}$ out of phase.
- The purpose of the phase-sensitive detector is **only** to conveniently furnish the ***sign*** of the error signal.

Important Requirements of Amplitude-comparison monopulse

- The monopulse antenna must generate a sum pattern with high efficiency (maximum boresight gain), and a difference pattern with a large value of slope at the crossover of the offset beams.
- ***The greater the signal-to-noise ratio and the steeper the slope of the error signal in the vicinity of zero angular error, the more accurate is the measurement of angle.***
- Furthermore, the side lobes of both the sum and the difference patterns must be low.
- The antenna must be capable of the desired bandwidth, and the patterns must have

Acquisition and Scanning Patterns

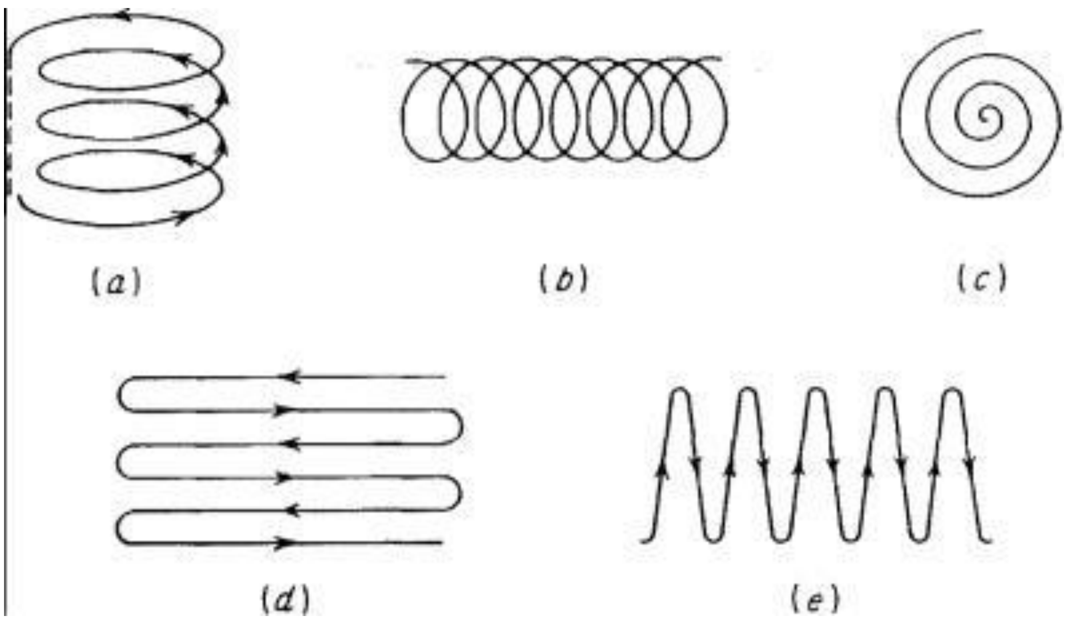
- A tracking radar must first find and acquire its target before it can operate as a tracker.
- Most tracking radars employ a narrow pencil beam for accurate tracking in angle; but it can be difficult to search a large volume targets when using a narrow antenna beamwidth.

- Search must be done with care to cover the entire volume uniformly and efficiently.
- Some other radar, therefore must first find the target to be tracked and then designated the target's coordinates to the tracker. These radars have been called acquisition radars or designation radars that search a large volume.

Types of Scanning Patterns

The purpose of using scanning antenna is to find the direction of the target with respect to the transmitter. The direction of the antenna at the instance when echo is received, gives the direction of location of the target.

]**Examples of acquisition search patterns: (a) Trace of helical scanning beam (b) Palmer scan**
(c) spiral scan(d) raster, or TV, scan (e) nodding scan. The raster scan is sometimes called an n-bar scan, where *n* is the number of horizontal rows.



a) Helical Scanning

- Helical scanning covers a hemisphere.
- In the ***helical scan***, the antenna is continuously rotated in azimuth while it is simultaneously raised or lowered in elevation.
- It's typical speed of rotation is 6rpm along with a rise of 20% and was utilized in world war II for anti-aircraft gun batteries as fire controlled radar.

b) Palmer Scan

- The ***Palmer*** scan consists of a rapid circular scan (conical scan) about the axis of the antenna, combined with a linear movement of the axis of rotation.

- When the axis of rotation is held stationary the Palmer scan reduces to the ***conical* scan**.

- Because of this feature the palmer scan is used with conical scan tracking radars which must operate in both search and track mode.

c) Spiral Scan

- The spiral scan covers an angular search volume with circular symmetry.
- Both the spiral scan and the Palmer scan suffer from the disadvantage that all parts of the scan volume do not receive the same energy unless the scanning speed is varied during the scan cycle.
- As a consequence, the number of hits returned from a target when searching with a constant scanning rate depends upon the position of the target within the search area.

d) Raster Scan

- The raster or TV, scan, unlike the Palmer or the spiral scan, scans the search area in a uniform manner.
- The raster scan is a simple and convenient means for searching a limited sector, rectangular in shape.

e) Nodding Scan

- The antenna is moved rapidly in elevation while it rotates slowly in azimuth thus scanning in both planes.
- The pattern covers the complete hemisphere i.e. elevation angle extending to $90^0$and the azimuth scan angle to 360^0
- Used in height finding radars

Comparison of Trackers

- Of the four continuous-tracking-radar techniques that have been discussed (sequential lobing, conical scan, amplitude-comparison monopulse, and phase-comparison monopulse), conical scan and amplitude-comparison monopulse have seen more application than the other two.

- In phase comparison four antennas are placed in awkward direction and its side lobe levels are higher than desired.

- Sequential lobing suffers more losses with complex antenna and feed system

- Amplitude comparison has high SNR

- It has higher precision in target tracking due to the absence of target amplitude fluctuations

- Angle error in two coordinates can be obtained by a single pulse

- Conical scan integrates no of pulses and then extracts angle measurement but vice versa in monopulse.

SNR

- The SNR from a monopulse radar is greater than that from a conical scan since it views target at the peak of sum pattern.
- SNR is 2 to 4 db greater.

Accuracy

- Due to high SNR, the range accuracy is also high in monopulse.
- The accuracy is not affected by fluctuations in the amplitude of the echo signal.
- Both systems are degraded by the wandering of the apparent position of the a target caused by glint.

Complexity

- Monopulse is more complex of the two.
- Conical scan has to rotate or nutate the beam at high speed.
- The cassegrain is a popular choice for monopulse
- A space fed phased array can implement monopulse by using a multiple feed similar to cassegrain.

Min No. of Pulses

- A monopulse can perform on the basis of a single pulse. For a phased array one pulse is sufficient
- The conical scan tracker requires a minimum no. of four pulses per revolution of beam to extract an angle measurement in two coordinates.
- The monopulse first makes its angle measurement and then integrates a no. of measurements to obtain the required SNR.
- The conical scan integrates a no. of pulses first and then extracts the angle measurement.

Susceptibility to ECM

- Conical scan tracker is more vulnerable to spoofing that takes advantage of its conical scan frequency
- It can also suffer from deliberate amplitude fluctuations.
- A well designed monopulse is hard to deceive.

Application

- Monopulse trackers should be used when good angle accuracy is needed.
- When high performance tracking is not necessary, the conical scan tracker might be used for its low cost.

Comparison of Monopulse Tracking and Conical Scan Tracking

Multiple beams are used to determine the angle of arrival of the echo signal	A single antenna beam on a time shared basis is used
Signle pulse is required to derive angle error information	Multiple pulses are required
High SNR	Low SNR
More acuurate tracking	Less accurate tracking
Complex Design	Simple Design
Cassegrain antenna is used	Horn antenna is used
High cost	Low cost

The **Search radar** is usually less precise and only distinguishes between targets that are hundreds of yards or even miles apart. Radar resolution is usually divided into two categories viz. range resolution and angular resolution (i.e. bearing resolution).

- Distance coverage: Long, medium, short ranges (20 km to 2000 km)
- High power density on the target: high peak power, long pulses, long pulse trains, high antenna gain
- Low PRFs
  Search options: rapid search rate with narrow beams or slower search rate with wide beams

Tracking Radar

The **Tracking radar** continuously emits the EM waves in the air and detects the targetted object when it comes in the path of the waves.

- Accurate angle and range measurement required

  Minimize time on target for rapid processing

  Special tracking techniques: monopulse, conical scan, beam switching

Radar Displays

The radar display has the important purpose of visually presenting the o/p of radar receiver in a form such that an operator could accurately detect the presence of a target and extract information about its location. When the display is connected directly to the o/p of the radar receiver without further processing, the o/p is called 'raw video'. When the receiver o/p is processed by a detector it is called synthetic video or processed video.

Types of Displays.

- **A Scope**

  A deflection modulated rectangular display in which vertical deflection is proportional to amplitude of receiver o/p and horizontal angle deflection is proportional to range.

- **B Scope**

  An intensity modulated rectangular display with azimuth angle indicated in the horizontal direction & the range indicated in the vertical direction. It is used in military radar.

- **C Scope**

  A two angle intensity modulated rectangular display with azimuth angle in the horizontal direction & the elevation angle in the vertical direction.

- **E Scope Display**

  An intensity modulated rectangular display with range indicated in the horizontal coordinate & elevation angle in the vertical coordinate.

- Plan Position Indicator (PPI)

An intensity modulated circular display in which echo signals from the reflecting objects are shown with range and azimuth angle displayed in polar coordinates.

- Range Height Indicator. (RHI)

An intensity modulated rectangular display with height of the target or altitude of the target along vertical axis and range along horizontal axis.

The cathode ray tube displays were used in early stages of the radar, the deflection modulated CRT, such as A scope display in which a target is indicated by deflection of the electron beam was commonly used. The other type of CRT called intensity modulated CRT in which an echo is indicated by intensi-fying the electron beam & presenting a display on the CRT was also in use.