TRACKING RADAR

Tracking with Radar

Sequential Lobing

Conical Scan

Monopulse Tracking Radar

Amplitude Comparison Monopulse (One and two coordinate)

Phase Comparison Monopulse

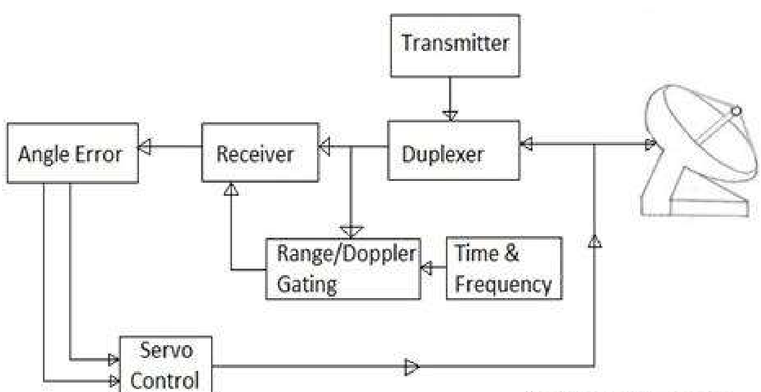
Tracking in Range

Acquisition and Scanning Patterns

Comparison of Trackers

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.



Simple Tracking Radar

- 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)

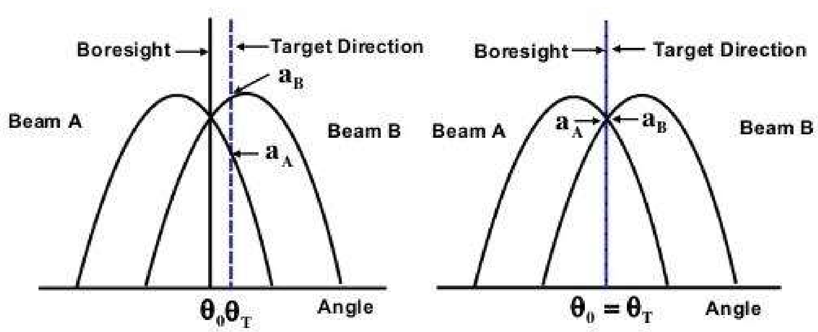
- This rapidly scans a limited angular sector to maintain tracks with a moderate data rate on more than one target within the coverage of antenna (another name for ADT).
- Scans a limited angular sector to maintain tracks – **simultaneous track & search**
- Data rate : moderate
- Can track a number of 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
- Simultaneous lobing or monopulse

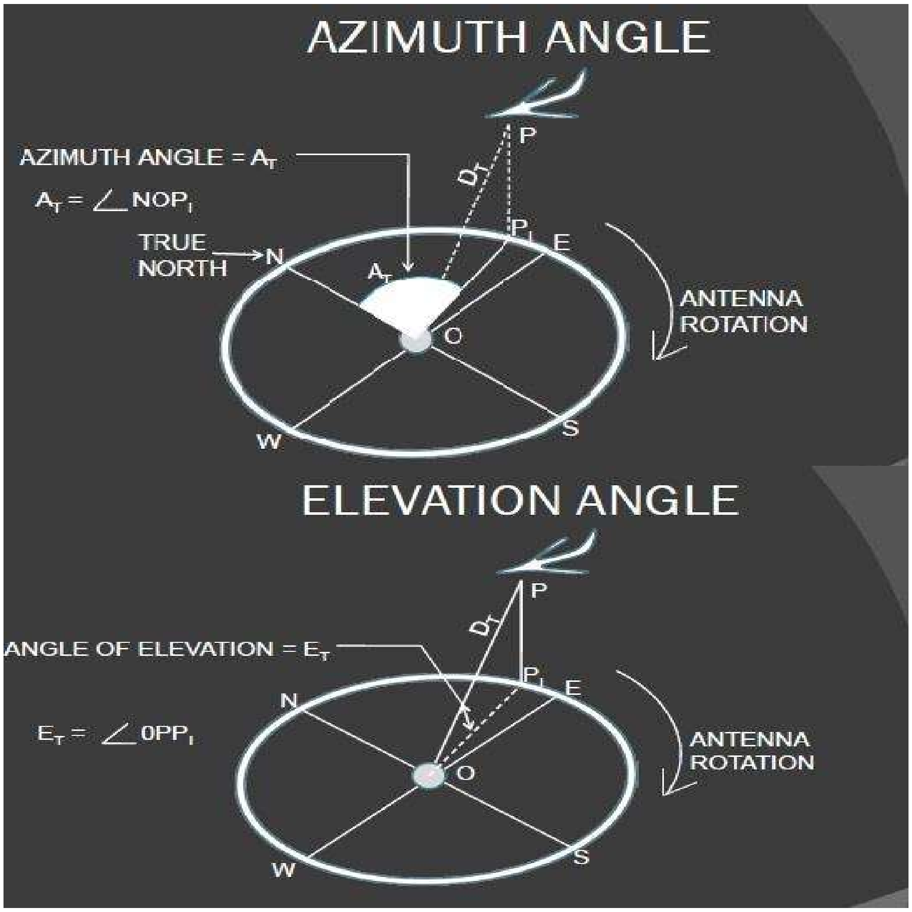
Sequential lobing and Conical scan:

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

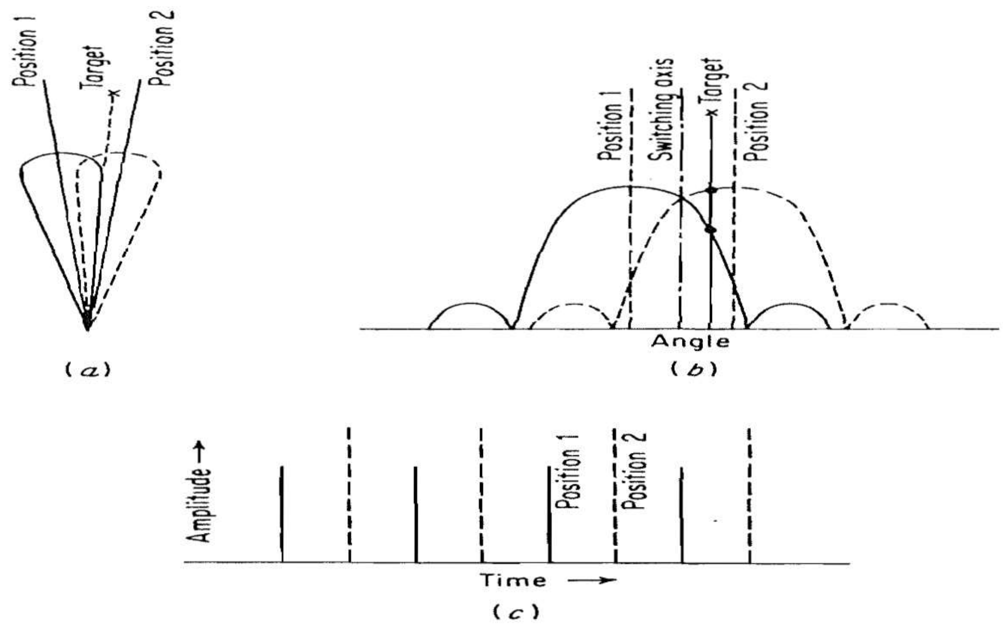
Single beam on time sharing basis.	Multiple beam.
Sequential lobing Radar and Conical scan Radar	Simultaneous lobing or monopulse Radar]
Simpler	Complex
One antenna	Multiple antennas
Less equipment	More equipments
Not accurate	Accurate
No of pulses are required to extract the error signal	Single pulse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



Sequential Lobing

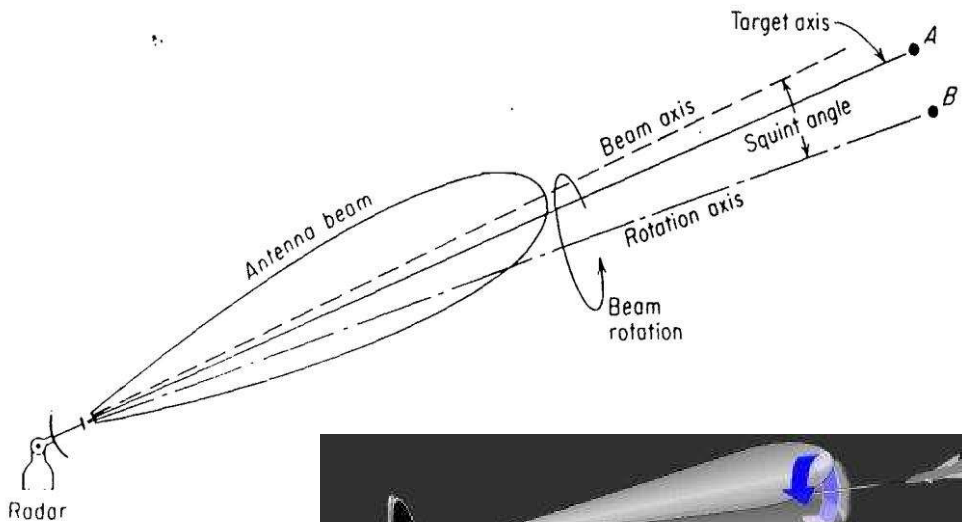
- The antenna pattern commonly employed with tracking radars is the symmetrical pencil beam in which the, elevation and azimuth beam widths are approximately equal.
- Actually the difference between the target position and the reference direction is the angular error.
- The tracking radar attempts to 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.

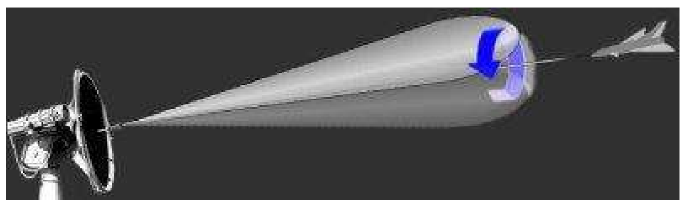
Fig 1-a is a polar representation of the antenna beam (minus the side lobes) in the two switched positions. A plot in rectangular coordinates is shown in **Fig.1-b,** and the error signal obtained from a target not on the switching axis (reference direction) is shown in **Fig.1-c.**



- 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.

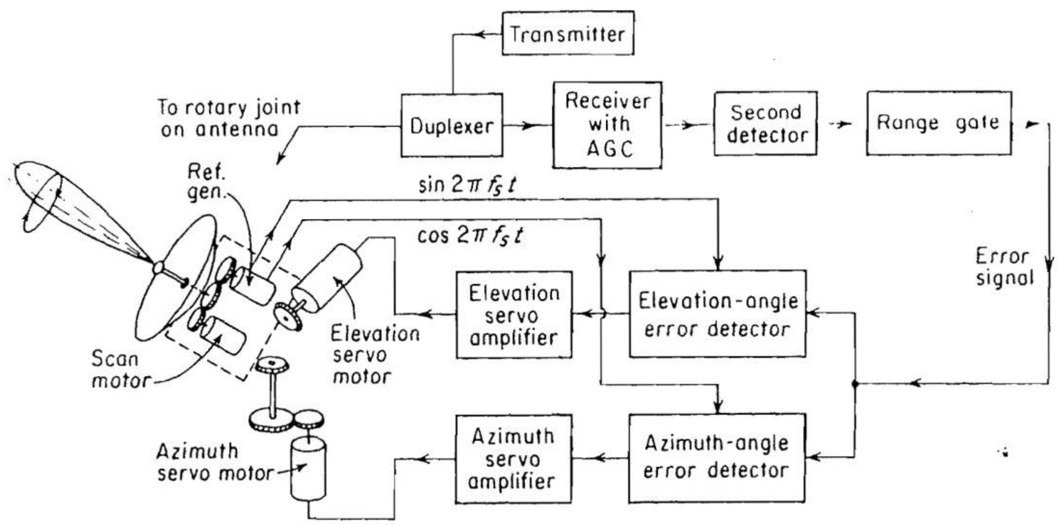
Conical Scan





- 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

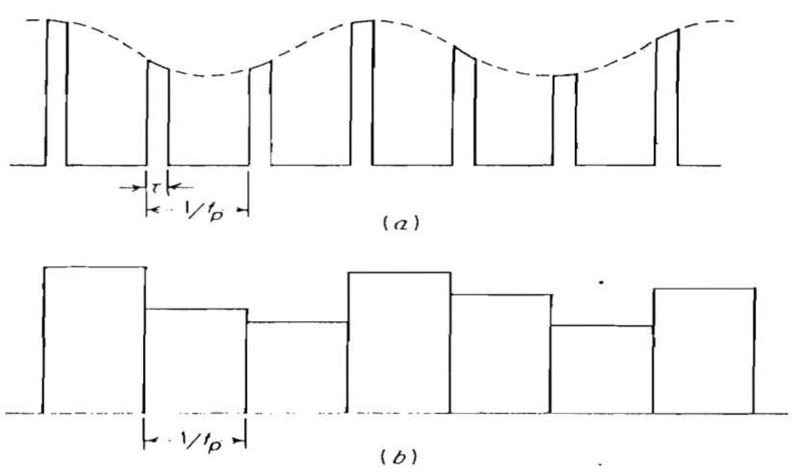
Block diagram of conical scan tracking radar



- 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.

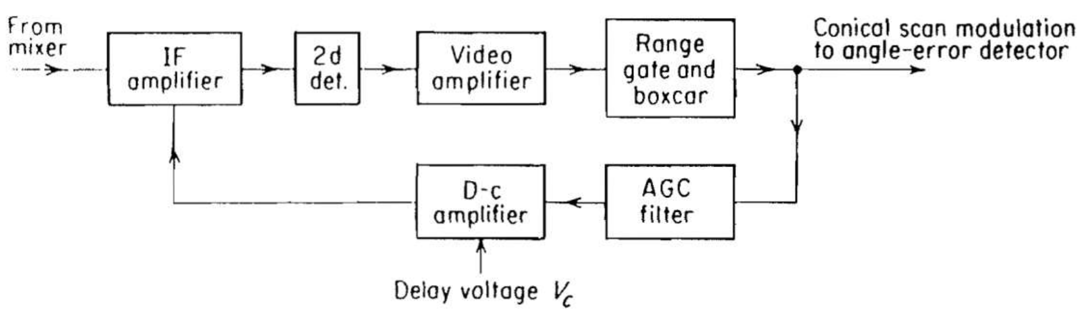


Figure: Block diagram of the AGC portion of a tracking-radar receiver

•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 $\mathbf{10^0}$ and in some applications, it should be as little as $\mathbf{2^0}$.
- 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

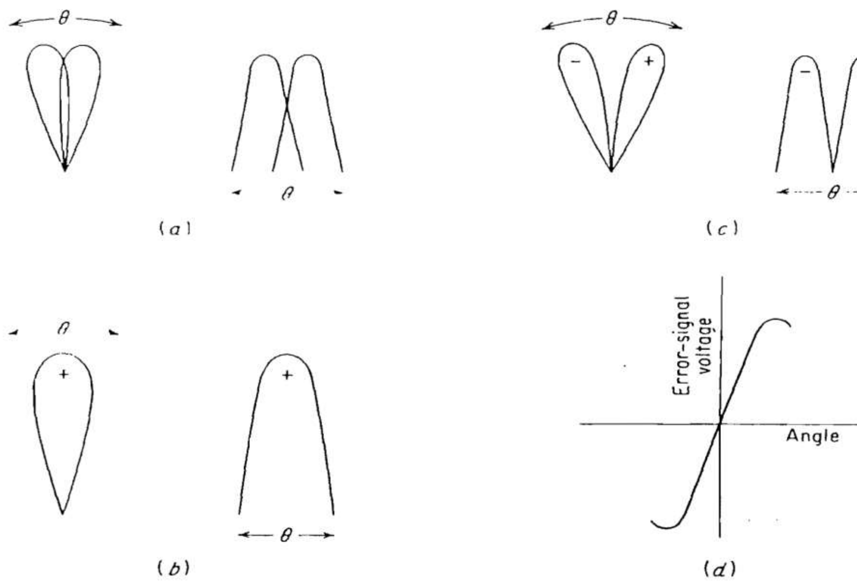


Figure: Monopulse antenna patterns and error signal. Left-hand diagrams in (a-c) are in polar coordinates. Right-hand diagrams are in rectangular coordinates. (a) Overlapping antenna patterns (b) sum pattern (c) difference pattern (d) product (error) signal.

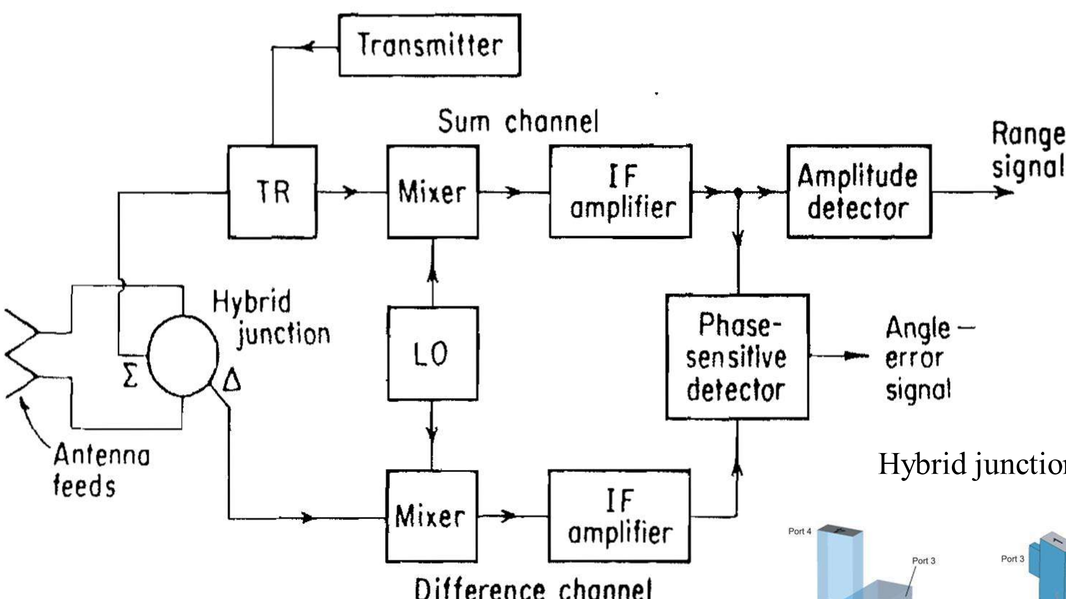
- In this technique, the RF signals received from two offset antenna beams are combined so that both the sum and the difference signals are obtained simultaneously.
- The sum and difference signals are multiplied in a **phase-sensitive detector** to obtain both the magnitude and the direction of the 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

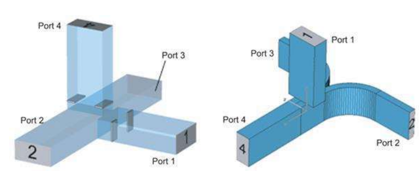
- The system contains a phase sensitive detector that compares two signals of the same frequency.
- It is a nonlinear device
- The output indicates the direction of the angle error relative to the boresight.
- Though phase comparison is done, the magnitude of the angle error signal is determined by comparison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



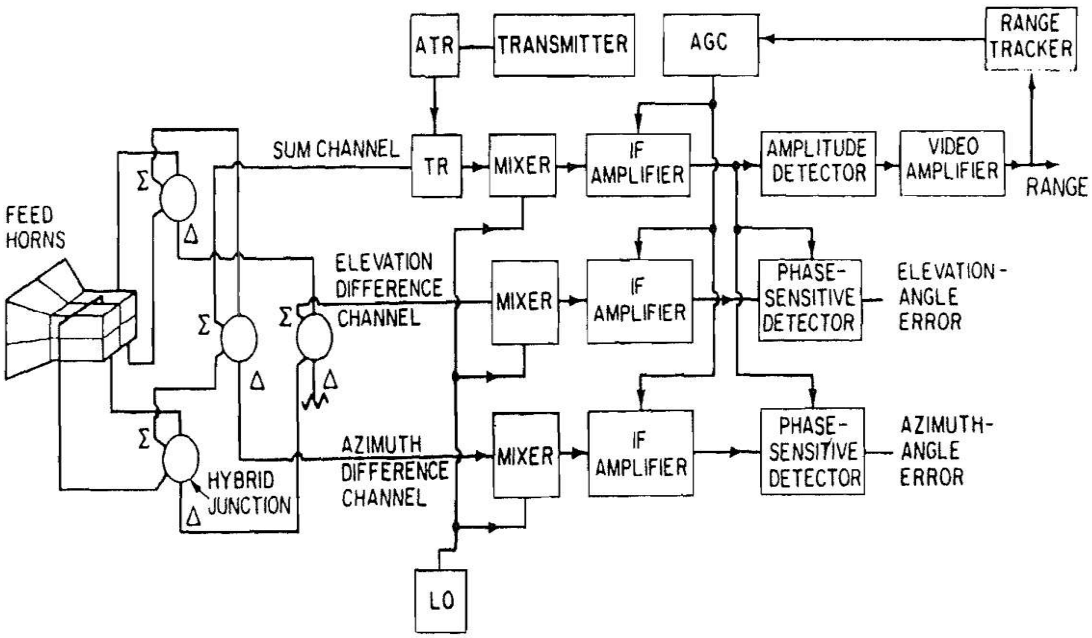
Hybrid junctions



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

Amplitude-comparison monopulse
(Two angular Coordinate)



- A block diagram of a monopulse radar with provision for extracting error signals in both elevation and azimuth is shown in above **Fig**
- The cluster of four feeds generates four partial overlapping antenna beams. The feeds might be used with a parabolic reflector, Cassegrain antenna, or a lens.
- All four feeds generate the sum pattern. The difference pattern in one plane is formed by taking the sum of two adjacent feeds and subtracting this from the sum of the other two adjacent feeds.
- The difference pattern in the orthogonal plane is obtained by adding the differences of the orthogonal adjacent pairs.
- A total of four hybrid junctions generate the sum channel, the azimuth difference channel, and the elevation difference channel.
- Three separate mixers and IF amplifiers are shown, one for each channel.
- All three mixers operate from a single local oscillator in order to maintain the phase relationships between the three channels.
- Two phase-sensitive detectors extract the angle-error information, one for azimuth, the other for elevation.
- Range information is extracted from the output of the sum channel after amplitude detection.

- An alternative approach to using three identical amplifiers in the monopulse receiver is to use only one IF channel which amplifies the sum signal and the two difference signals on a time-shared basis.
- The sum signal is passed through the single IF amplifier followed by the two difference signals delayed in time by a suitable amount.
- Automatic gain control (AGC) is required in order to maintain a stable closed-loop servo system for angle tracking and to insure that angle error signal is not affected by changes in the received signal amplitude.
- The AGC results in a constant angle sensitivity independent of target size and range.
- With AGC the output of the angle-error detector is proportional to the difference signal normalized (divided) by the sum signal. The output of the sum channel is constant.

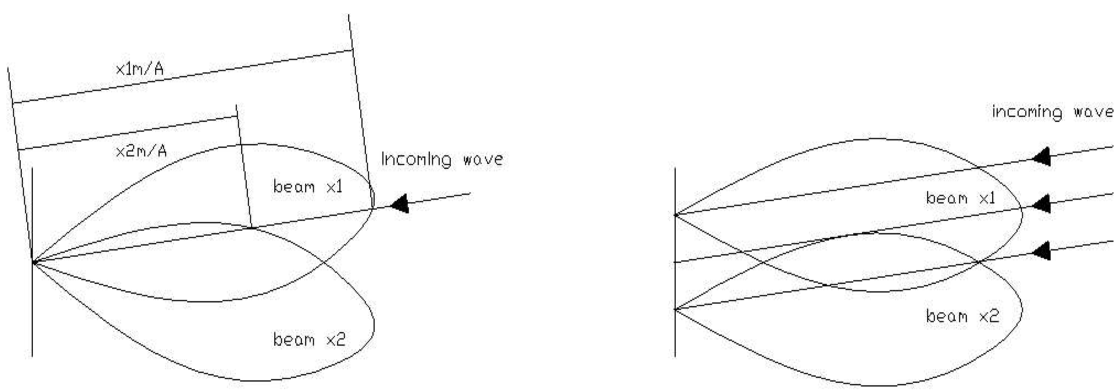
[SUM PATTERN : A+B +C +D
AZIMUTH DIFF. PATTERN : (A+B) – (C +D)
ELEVATION DIFF. PATTERN : (B+D) – (A+C)]

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 the desired polarization characteristics.

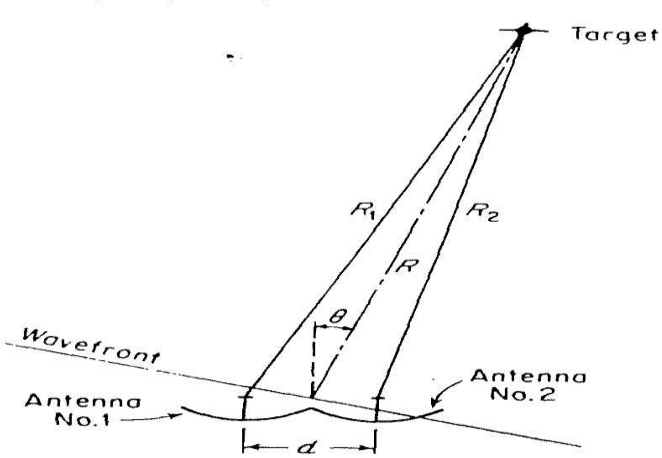
Phase comparison Monopulse

- **Th**e tracking techniques discussed thus far in this chapter are based on the comparison of the amplitude of echo signals received from two or more antenna positions.
- The sequential-lobing and conical-scan techniques used a single, time-shared antenna beam while the Monopulse technique used two or more simultaneous beams.
- The difference in amplitudes in the several antenna positions is proportional to the angular error.
- A tracking radar which operates with phase information is similar to an **active interferometer** and is also called ***interferometer radar.*** It has also been called ***simultaneous phase comparison radar*** or ***phase-comparison Monopulse***.
- Phase comparison monopulse uses two antenna beams to obtain an angle measurement in one coordinate. But the two beams cover the same region of space.
- Here the two beams look in the same direction whereas in earlier case they looked at slightly different directions



Amplitude comparison monopulse

Phase comparison monopulse



Wave front phase relationships in phase comparison Monopulse Radar

- In above **Fig** two antennas are shown separated by a distance **d**.
- The distance to the target is **R** and is assumed large compared with the antenna separation **d**.
- The line of sight to the target makes an angle **θ** to the perpendicular bisector of the line joining the two antennas.
- The distance from antenna 1 to the target is:

$$\mathbf{R_1 = R + (d/2)\sin\theta}$$

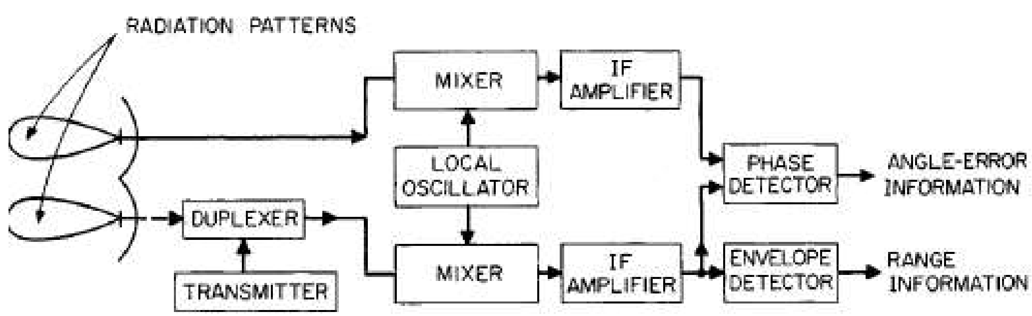
and the distance from antenna 2 to the target is:

$$\mathbf{R_2 = R - (d/2)\sin\theta}$$

- The phase difference between the echo signals in the two antennas is approximately:

$$\mathbf{\Delta\text{Ø} = (2\pi/\lambda).d.\,Sin\,\theta}$$

For small angles where **sin θ ≈ θ,** the phase difference is a linear function of the angular error and may be used to position the antenna via a servo-control loop.



Block diagram of a phase comparison monopulse radar (one angle coordinate).

Limitations

•.Effect of grating lobes due to wide separation between the antennas

•Ambiguities in the angle measurement

•To overcome these problems, a portion of the parabolic reflectors is sliced off to achieve this.

Important points to remember in amplitude and phase comparison monopulse

- A total of four hybrid junctions generate sum, azimuth and elevation difference channel
- Range information is extracted form the output of the sum channel after amplitude detection
- The angular error signal is obtained by comparing echo amplitudes which actuates a servo mechanism to position the antenna.
- The angle of arrival is determined by comparing the phase difference between signals from two separate antennas
- Antennas of phase comparison are not offset from the axis

Limitations to Tracking Accuracy

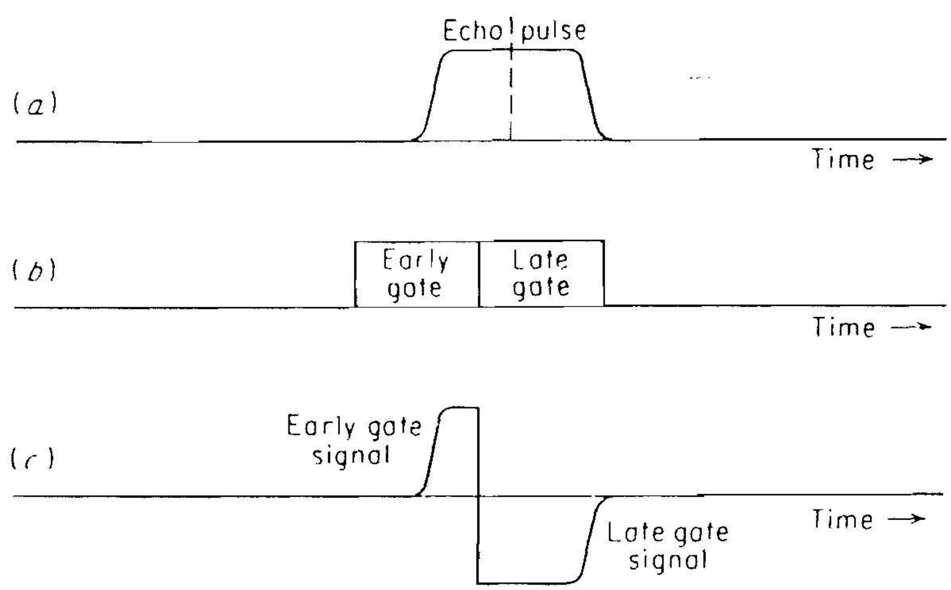
Major effects that determine the accuracy of a tracking radar:

- Glint or angle noise or angular scintillation: which affects all tracking radars especially at short range. The greater the target in angle, the greater is the glint error.
- Receiver noise: affects all radars and mainly determines tracking accuracy at long range.
- RCS or Amplitude fluctuations of the target echo that bother conical scan and sequential lobing trackers but not monopulse.
- Servo noise
- Antenna Beamwidth
- Atmospheric effects

Tracking in range

- In the early days o radar, tracking of target in range was usually done manually by an operator who watched an A-scope or similar presentation and positioned a handwheel to maintain a marker on the display over desired target pip.
- The setting of the handwheel was a measure of the target range and was converted to an electrical signal and supplied to a data processor.
- Manually tracking has many limitations and it cannot be used in systems such as missiles where there is no operator present.
- It was soon replaced by closed loop automatic tracking, such as ***split gate tracker.***
- Split gate tracker uses two split range gates called early gate and late gate.
- The echo pulse is shown in Fig.**a**, the relative position of the gates at a particular instant shown in **Fig.b,** and the error signal shown in Fig c.
- The portion of the signal energy contained in the early gate is less than that in the late gate.
- If the outputs of the two gates are subtracted, an error signal **shown in fig c** will result which is used to reposition the center of the gates.

Figure : Split-range-gate tracking.(a)Echo pulse (b)early-late range gates(c) difference signal between early and late range gates



- The magnitude of the error signal is a measure of the difference between the center of the pulse and the center of the gates.
- The sign of the error signal determines the direction in which the gates must be repositioned by a feedback-control system.
- When the error signal is zero the range gates are centered on the pulse.
- The range gating necessary to perform automatic tracking in Range offers several advantages as by products.
- It isolates one target, excluding targets at other ranges. This permits the boxcar generator to be employed.
- Also, range gating improves the signal-to-noise ratio since it eliminates the noise from the other range intervals. Hence the width of the gate should be sufficiently narrow to minimize extraneous noise.
- A reasonable compromise is to make the gate width two to five times of the pulse width.

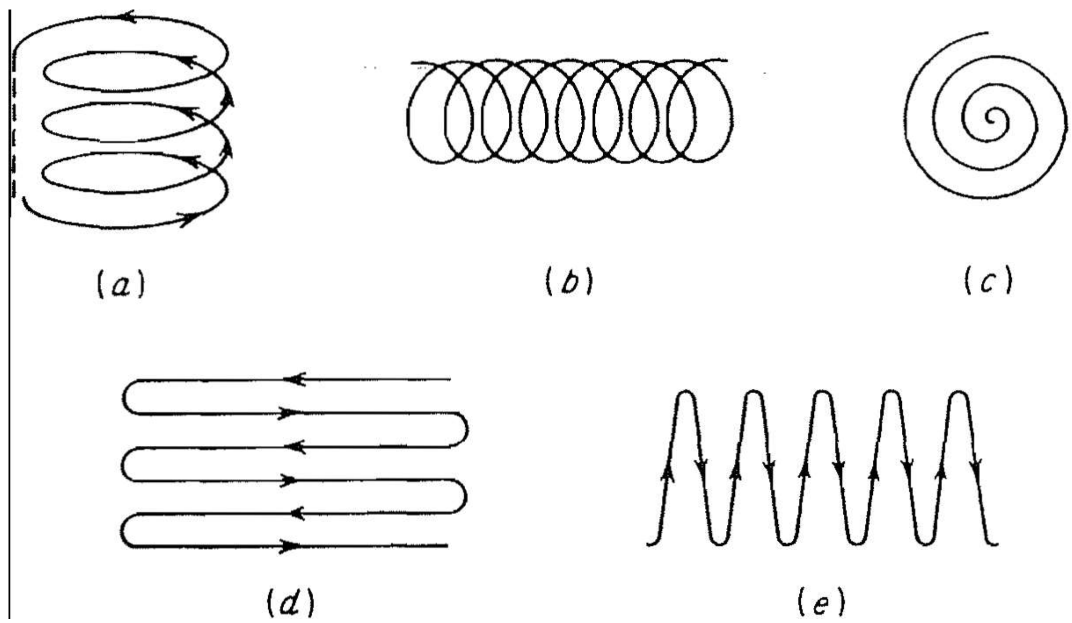
Acquisition and Scanning Patterns

- 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

Monopulse Tracking	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

DETECTION OF RADAR SIGNALS IN NOISE

Introduction

Matched filter receiver

Response characteristics and derivation

Correlation function and cross correlation receiver

Efficiency of Non-matched filters

Matched filter with non-white noise

- The two basic operations performed by radar are **(1)** ***detection*** of the presence of reflecting objects, and (2) ***extraction*** of information from the received waveform to obtain such target data as position, velocity, and perhaps size.
- In this chapter some aspects of the problem of detecting radar signals in the presence of noise will be considered. Noise ultimately limits the capability of any radar.

Matched-Filter Receiver

- A network whose frequency-response function maximizes the output peak-signal-to- mean-noise (power) ratio is called a matched filter. This criterion, or its equivalent, is used for the design of almost all radar receivers.
- The frequency-response function, denoted H(f), expresses the relative amplitude and phase of the output of a network with respect to the input when the input is a pure sinusoid.
- The magnitude |H(f)|of the frequency-response function is the receiver amplitude pass band characteristic.
- If the bandwidth of the receiver pass band is wide compared with that occupied by the signal energy, extraneous noise is introduced by the excess bandwidth which lowers the output signal-to-noise ratio. On the other hand, if the receiver bandwidth is narrower than the bandwidth occupied by the signal, the noise energy is reduced along with a considerable part of the signal energy.

- The net result is again a lowered signal-to-noise ratio. Thus there is an optimum bandwidth at which the signal-to-noise ratio is a maximum. This is well known to the radar receiver designer.
- The rule of thumb quoted in pulse radar practice is that the receiver bandwidth B should be approximately equal to the reciprocal of the pulse width τ. This is a reasonable approximation for pulse radars with conventional superheterodyne receivers. It is not generally valid for other waveforms.
- The exact specification of the optimum receiver characteristic involves the frequency- response function and the shape of the received waveform.
- The receiver frequency-response function, is assumed to apply from the antenna terminals to the output of the IF amplifier.
- The second detector and video portion of the well designed radar superheterodyne receiver will have negligible effect on the output signal-to- noise ratio if the receiver is designed as a matched filter. Narrow banding is most conveniently accomplished in the IF.
- The bandwidths of the RF and mixer stages of the normal superheterodyne receiver are usually large compared with the IF bandwidth. Therefore the frequency-response function of the portion of the receiver included between the antenna terminals to the output of the IF amplifier is taken to be that of the IF amplifier alone.

- Thus we need only obtain the frequency-response function that maximizes the signal-to-noise ratio at the output of the IF. The IF amplifier may be considered as a filter with gain.

- For a received waveform s(t) with a given ratio of signal energy E to noise energy No (or noise power per hertz of bandwidth), North showed that the frequency-response function of the linear, time-invariant filter which maximizes the output peak-signal-to-mean- noise (power) ratio for a fixed input signal-to-noise (energy) ratio is

$$H(f) = G_a S^*(f) \exp(-j2\pi f t_1)$$

where $S(f) = \int_{-\infty}^{\infty} s(t) \exp(-j2\pi f t)\, dt$ = voltage spectrum (Fourier transform) of input signal

$S^*(f)$ = complex conjugate of $S(f)$

t_1 = fixed value of time at which signal is observed to be maximum

G_a = constant equal to maximum filter gain (generally taken to be unity)

- The noise that accompanies the signal is assumed to be stationary and to have a uniform spectrum (white noise). It need not be Gaussian.

- The filter whose frequency-response function is given by Eq. above has been called the North filter, the conjugate filter, or more usually the matched filter. It has also been called the Fourier transform criterion.

- The frequency-response function of the matched filter is the conjugate of the spectrum of the received waveform except for the phase shift exp (- j2Πft1). This phase shift varies uniformly with frequency. Its effect is to cause a constant time delay.

- The frequency spectrum of the received signal may be written as an amplitude spectrum |S(f)|and a phase spectrum exp [- jφs (f)].

- The matched- filter frequency-response function may similarly be written in terms of its amplitude and phase spectra |H(f)| and exp [- jφm(f)]. Ignoring the constant Ga, Eq. above for the matched filter may then be written as

$$|H(f)| \exp[-j\phi_m(f)] = |S(f)| \exp\{j[\phi_s(f) - 2\pi f t_1]\}$$

or

$$|H(f)| = |S(f)|$$

and

$$\phi_m(f) = -\phi_s(f) + 2\pi f t_1$$

- Thus the amplitude spectrum of the matched filter is the same as the amplitude spectrum of the signal, but the phase spectrum of the matched filter is the negative of the phase spectrum of the signal plus a phase shift proportional to frequency.

- The matched filter may also be specified by its impulse response h(t), which is the inverse Fourier transform of the frequency-response function.

$$h(t) = \int_{-\infty}^{\infty} H(f) \exp(j2\pi ft)\, df$$

- Physically, the impulse response is the output of the filter as a function of time when the input is an impulse (delta function).

Since $S^*(f) = S(-f)$, we have

$$h(t) = G_a \int_{-\infty}^{\infty} S(f) \exp[j2\pi f(t_1 - t)]\, df = G_a s(t_1 - t)$$

- A rather interesting result is that the impulse response of the matched filter is the image of the received waveform; that is, it is the same as the received signal run backward in time starting from the fixed time t1.
- Figure 1 shows a received waveform s(t) and the impulse response h(t) of its matched filter. The impulse response of the filter, if it is to be realizable, is not defined for t< 0. (One cannot have any response before the impulse is applied.) Therefore we must always have t < t1.

- This is equivalent to the condition placed on the transfer function H(f) that there be a phase shift exp (-j2Πft1). However, for the sake of convenience, the impulse response of the matched filter is sometimes written simply as s(- t).

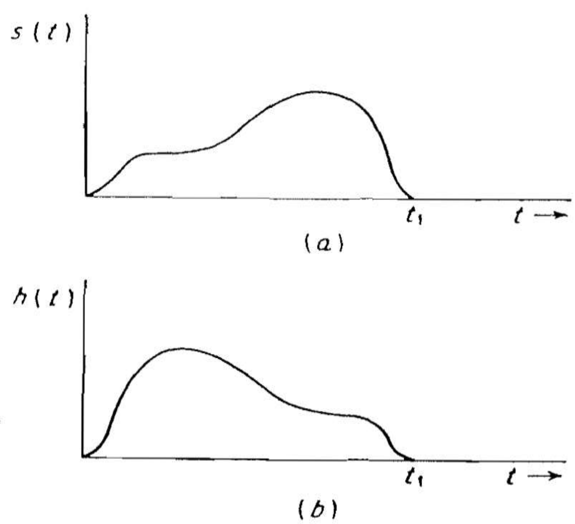


Fig.1 (a) Received waveform s(t); (b) impulse response h(t) of the matched filter.