Tracking Radar
INTRODUCTION

- Basic operating principle
- Tracking radars
- Techniques of target detection
- Examples of monopulse radar systems
RADAR FUNCTIONS

- NORMAL RADAR FUNCTIONS
  1. Range (from pulse delay)
  2. Velocity (from Doppler frequency shift)
  3. Azimuth and Elevation (from antenna pointing)

- SIGNATURE ANALYSIS and INVERSE SCATTERING
  1. Target size (from magnitude of return)
  2. Target shape and components (return as a function of direction)
  3. Moving parts (modulation of the return)
  4. Material composition
SLANT RANGE

DISTANCE TO TARGET = $D_T$ (SLANT RANGE)

ANTENNA ROTATION
AZIMUTH ANGLE

AZIMUTH ANGLE = \( A_T \)

\( A_T = \angle NOP_i \)

TRUE NORTH

ANTENNA ROTATION
ELEVATION ANGLE

ANGLE OF ELEVATION = $E_T$

$E_T = \angle 0P P_I$
TRACKING RADAR

- Measures the coordinates and provides data to determine target path
- Tracking can be performed in range, angle and doppler
- Classified into two types
  - Continuous tracking radar
  - Track-While-Scan radar
- Acquisition radar designates targets to the tracking radar
TRACKING RADAR

- MISSILE TRACKING
- SPACE APPLICATIONS
- TRACKING RADAR
- MISSILE GUIDANCE
- INSTRUMENTATION RADARS
Single Target Tracker

- This is for single target with rapid data rate.
- 10 Observations per second is very typical
- Closed loop servo system is used to keep the error between the target and antenna look direction very less
Automatic Detection and Track

- Tracking is part of air surveillance
- Rate depends on the time for the antenna to make one rotation
- It can simultaneously track a large no. of targets
- But it has open loop system
Phased Array Radar

- A large number of targets can be held in track
- This is done on time sharing basis
- It combines the rapid update rate of a single target tracker with the ability of ADT to hold many targets in track
- The cost is very very very high.
Track while scan

- 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).
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.
For this the antenna is operated in difference mode where in there will be a null along the boresight direction with two main lobes on either side.

This is achieved by giving equal and opposite phase signals to both sides of the antenna array.

The two main lobes are said to be squinted with a squint angle of $\pm \delta_q$ relative to boresight.
Contd....

- The crossover of the two beams determines the boresight direction.
- The tracking radar has to position the two beams so that \( d_0 = d_T \).
- If there is more signal output when a beam is placed on the right than on the left with reference to the target, it means that antenna is to be moved right so that the left beam can see more target size and can give more output equal to that of the right beam.
Contd...

- This is for one coordinate
- If two additional positions are taken in the orthogonal plane, another angle can be tracked.
Error signal generating methods
1. Sequential lobing
2. Conical scan
3. Simultaneous lobing (monopulse)
SEQUENTIAL LOBING

- Two lobes are required to track in each axis, each lobe must be sequentially switched four pulses are required.
- The radar measures the returned signal levels.
- The voltages in the two switched position should be equal.
Two lobes are required to track in each axis. As each lobe must be sequentially switched a total of four pulses are required for tracking in both axes.
Contd..

- A single beam is switched between two squinted angular positions to obtain an angle measurement.
- 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.
Contd...

- When the echo signals in the two beam positions are equal, the target is on axis and its direction is that of the switching axis.
- If orthogonal angle information is needed, two more switching positions are needed
Contd...

- 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. This results in conical scan.
The antenna is continuously rotated at an offset angle.

- Redirection of beam
  - Rotating feed
  - Nutating feed
Feed Types

- When the feed is designed to maintain the plane of polarization as it rotates, it is called a 'nutation feed'.
- A rotating feed is one which causes the plane of polarization to rotate.
Comparison of feeds

- A rotating polarization can cause the amplitude of the target echo signal to change with time even for a stationary target on axis.
- The nutating feed is more complex.
Contd...

- A typical conical scan rotation speed might be in the vicinity of 30 rev/sec.
- The same motor also drives a two phase reference generator with electrical outputs at the conical scan frequency that are $90^0$ apart in phase.
- These two outputs serve as reference signals to extract the elevation and azimuth errors.
Receiver details

- The receiver is a superhet 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.
Operational Aspects

- 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.
Practical points

- To perform analog-to digital conversion pulse stretching is accomplished by sample and hold circuit.
- The PRF must be sufficiently large compared to conical scan frequency for proper filtering and avoiding inaccuracy of the angle measurement.
- The PRF must be at least four times of conical scan frequency but normally 10 times.
AGC

- It has the purpose of maintaining constant angle error sensitivity in spite of amplitude fluctuations or changes of the echo signal due to change in range.
- AGC is also important for avoiding saturation by large signals which could cause the loss of the scanning modulation and the accompanying error signal.
Practical issue

- The gain of the AGC loop at the conical scan frequency should be low so that error signal will not be suppressed by the AGC section
All target returns have the same amplitude (zero error signal)

Thus, no action is required
CONICAL SCAN
Contd..

Because of the rotation of the squinted beam and the target's offset from the rotation axis, the amplitude of the echo signal will be modulated at a frequency equal to the beam rotation frequency.
The amplitude of the modulation depends on angular distance between the target direction and the rotation axis.

The location of the target in two angle coordinates determines the phase of the conical scan modulation relative to conical scan beam rotation.
The scan modulation is extracted from the echo signal and applied to a servo control to position antenna axis on target.

Two servos are required.

When the antenna is on target, the conical scan modulation is of zero amplitude.
DISADVANTAGES

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

Conical scan
1) The antenna scan rate is limited by the scanning mechanism (mechanical or electronic).
2) Sensitive to target modulation.
3) Mechanical vibration and wear and tear due to rotating feed.
SIMULTANEOUS LOBING

- With a single pulse angular coordinates can be obtained
- Maximum unambiguous range is limited only by PRF
- Monopulse is free of mechanical vibrations
- Errors due to amplitude fluctuation of target echoes are greatly reduced
MONOPULSE

- It is defined as one in which information concerning the angular location of a target is obtained by comparison of signals received in two or more simultaneous beams
- A measurement is done based on a single pulse -- MONOPULSE
But, many pulses are employed to increase the accuracy

The accuracy of monopulse is not affected by amplitude fluctuations of the target echo.

Most popular monopulse is Amplitude Comparison Monopulse
Amp comp MONOPULSE

- It compares the amplitudes of the signals simultaneously received in multiple squinted beams to determine the angle.
- The required squinted beams are generated by two slightly displaced feeds on a parabolic reflector.
- While the difference pattern is for angle measurement, the sum pattern is used for ranging.
Contd..

- Signals received from the sum and difference patterns are amplified separately.
- They are combined in a phase sensitive detector to produce the angle error signal.
- The sum signal is used to get the range and sign of the angle.
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.
How does a 2D MONOPULSE work?
SUM AND DIFFERENCE PATTERNS

\[ \Sigma = W + X + Y + Z \]
\[ \Delta_{AZ} = (W + Y) - (X + Z) \]
\[ \Delta_{EL} = (W + X) - (Y + Z) \]
HYBRID JUNCTIONS

Hybrid T junction

Hybrid ring (RAT race junction)
MONOPULSE IN TWO ANGLE COORDINATES

Transmitter

Hybrid junctions

Receiver

Signal processor

Antenna servo

Sum channel

Elevation difference channel

Azimuth difference channel

Range

Azimuth drive

Elevation drive

W+X

Y+Z

W+X

Y+Z

W+Y

X+Z
Precautions

- It is important that large relative phase differences do not occur among the three channels.
- A typical value generally tolerable will be $25^0$ for proper performance.
- AGC is required to maintain a stable closed loop system for angle tracking and to insure that the angle error signal is not affected by changes in the received signal amplitude.
Practical issues

- A cassegrain reflector is normally used to place the microwave circuitry at the back of the antenna.
- Feed system can also be used supported.
- The greater the squint angle the better will be the accuracy of the angle measurement.
Trade off

- But the on axis gain of the sum pattern decreases if the squint angle increases.

- Simpler and more compact feed system can be obtained by using higher order waveguide modes to obtain independent control of the sum and difference patterns.
Phase Comparison Monopulse

- Two antenna beams are used to obtain an angle measurement in one coordinate.
- Here the two beams look in the same direction whereas in earlier case they looked at slightly different directions.
- Due to displacement of antennas, the two received signals will have slightly different phases but same amplitude.
But the phase difference will be quite small if the electrical spacing between the antennas is small.

Angle information can also be extracted in a phase comparison monopulse by employing sum and difference patterns and processing the signals similar to amplitude comparison method.
An analysis of the sum and difference patterns for the phase comp monopulse shows that a $90^0$ phase shift has to be introduced in the difference signal so that output of the phase sensitive detector is an error signal whose amplitude is a function of the sine of the angle of arrival from the target measured w.r.t. the perpendicular to the two antennas.
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.
AMPLITUDE AND PHASE COMPARISON MONOPULSE

- A total of four hybrid junctions generate sum, azimuth and elevation difference channel
- Range information is extracted from 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
COMPARISON OF TRACKERS

- In phase comparison four antennas are placed in awkward direction and its side lobe levels are high.
- 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 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.
- A no. of pulses are usually integrated.
- 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.
Glint

- It is angle noise or angle fluctuation
- It occurs with complex targets that have more than one scattering center within the resolution cell of the radar
- A single point scatterer such as sphere does not show GLINT.
- Aircrafts can cause GLINT
- The greater the target in angle, the greater is the glint error.
NIKE AJAX GUIDANCE SYSTEM

- First missile guidance system to employ monopulse technique
- Developed in 1953
**PATRIOT AIR DEFENCE SYSTEM**

1. **Radar Set.** Radar sweeps the sky for threats. If an incoming object is found, the radar helps determine if it is a missile, fighter jet, cruise missile, or a remotely piloted vehicle.

2. **Control Station.** Operators communicate with friendly forces, monitor threats, and prioritize targets, but the system is capable of working autonomously.

3. **Missile Launcher.** Launcher points and fires a missile, which is shipped ready to launch in a canister. A missile can be made ready to fire in less than 9 seconds. The launcher can be remotely located from the radar.

4. **Patriot missile.** The missile is tracked by the radar set and guided to a target with help from the control station’s computer and its own homing sensors.

5. **PAC-3 missile.** Destroys targets by ramming them; 16 per launcher. Length: 17.1 ft. Weight: 688 lbs. Speed: Mach 5+

CONCLUSION

- It is used if extreme accuracy is needed
- Its improved interference immunity, resolution, radar signal processing and angular accuracy made it imperative in all modern missile tracking/guidance systems

QUERIES?

THANK YOU
Question 1

- How mono pulse tracking radar is free of mechanical vibration?
- In conventional radars, the antenna will be continuously rotating while transmitting the pulses. The echoes of several pulses which will contain mechanical vibrations will be integrated first before the data is processed. But, in the case of monopulse, the data processing of a single pulse is done first (that is the name of monopulse). So, there is no mechanical vibration for a single pulse.
Question 2

- How the accuracy of the mono pulse tracking radar is not effected by the amplitude fluctuation of the target echo?

- The amplitude fluctuation of a target occurs because the radar looks at the target differently for different pulses due to its movement. But in the case of a monopulse, the target information is processed with a single pulse. Hence, the look angle is not changed while the data is being collected.
Question 3

- Why is the echo modulated by conical scan frequency?
- It is due to rotation of squinted beam.
Question 4

- Why do we use several pulses though single pulse is sufficient in a monopulse?
- To increase accuracy
Question 5

- Why do we need AGC in a monopulse system?

- AGC is required to maintain a stable closed loop system for angle tracking and to insure that the angle error signal is not affected by changes in the received signal amplitude.