1. Explain tracking principles.

A tracking-radar system

(1) measures the coordinates of a target and
(2) provides data which may be used to determine the target path and to predict its future position.

All or only part of the available radar data-range, elevation angle, azimuth angle, and doppler frequency shift may be used in predicting future position; that is, a radar might track in range, in angle, in doppler, or with any combination. Almost any radar can be considered a tracking radar provided its output information is processed properly. But, in general, it is the method by which angle tracking is accomplished that distinguishes what is normal normally considered a tracking radar from any other radar. It is also necessary to distinguish between a continuous tracking radar and a track-while-scan (TWS) radar.

The continuous tracking radar supplies continuous tracking data on a particular target, while the track-while-scan supplies sampled data on one or more targets. In general, the continuous tracking radar and the TWS radar employ different types of equipment.

The antenna beam in the continuous tracking radar is positioned in angle by a servomechanism actuated by an error signal. The various methods for generating the error signal may be classified as sequential lobing, conical scan, and simultaneous lobing or monopulse. The range and doppler frequency shift can also be continuously tracked, if desired, by a servo-control loop actuated by an error signal generated in the radar receiver.

2. Explain sequential lobing.

The antenna pattern commonly employed with tracking radars is the symmetrical pencil beam in which the elevation and azimuth beamwidths are approximately equal. However, a simple pencil-beam antenna is not suitable for tracking radars unless means are provided for determining the magnitude and direction of the target's angular position with respect to some reference direction, usually the axis of the antenna. 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 by alternately switching the antenna beam between two positions (Fig. 6.2). This is called lobe switching, sequential switching, or sequential lobing. Figure 6.2 (a) is a polar representation of the antenna beam (minus the sidelobes) in the two switched positions. A plot in rectangular coordinates is shown in Fig. 6.2 (b), and the error signal obtained from a target not on the switching axis (reference direction) is shown in Fig. 6.2 (c). The difference in amplitude between the voltages obtained in the two switched positions is a measure of the angular displacement of the target from the switching axis. The sign of the difference determines the direction the antenna must be moved in order to align the switching axis with the direction of the target. When the voltages in the two switched positions are equal, the target is on axis and, its position may be determined from the axis direction.

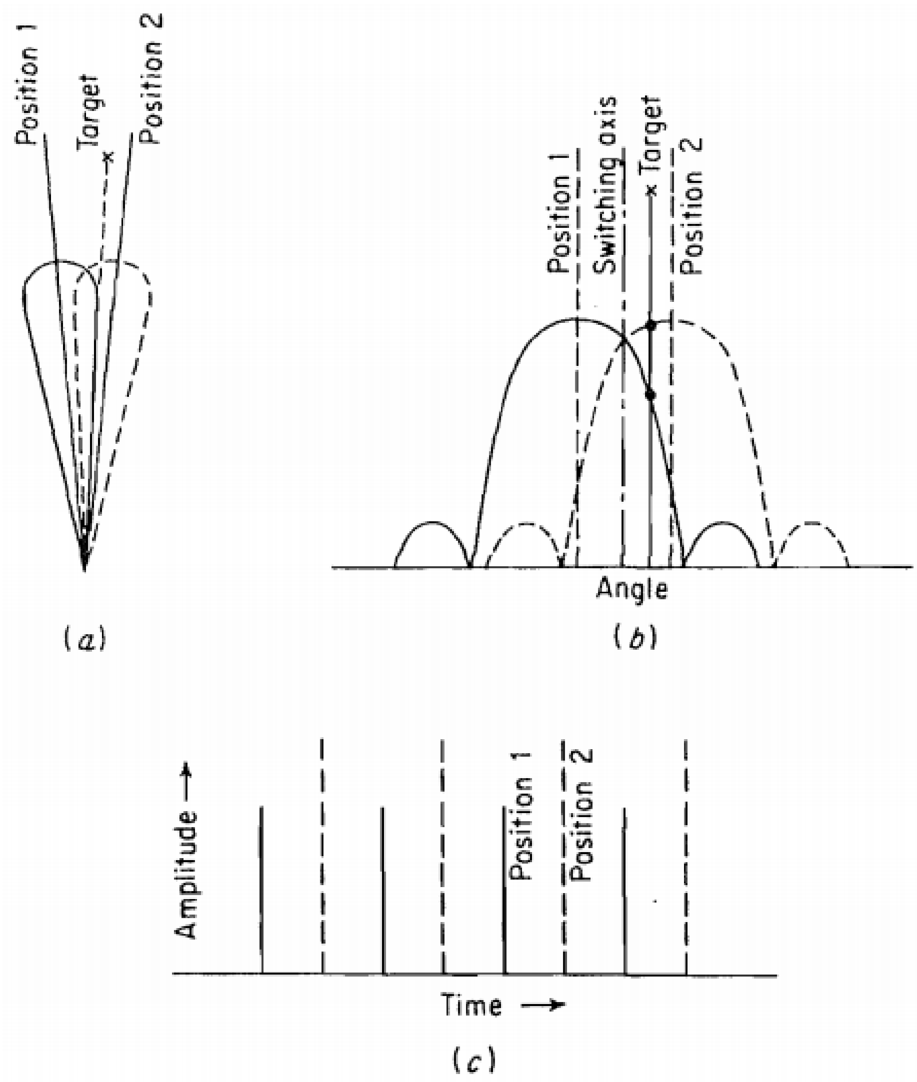

Fig 6.2 Lobe-switching antenna patterns and error signal (one dimension). (a) Polar representation of switched antenna patterns (b) rectangular representation (c) error signal.

Two additional switching positions are needed to obtain the angular error in the orthogonal coordinate. Thus a two-dimensional sequentially lobing radar might consist of a cluster of four feed horns illuminating a single antenna, arranged so that the right-left, up-down sectors are covered by successive antenna positions. Both transmission and reception are accomplished at each position. A cluster of five feeds might also be employed, with the central feed used for transmission while the outer four feeds are used for receiving. High-power RF switches are not needed since only the receiving beams, and not the transmitting beam, are stepped in this five-feed arrangement.

One of the limitations of a simple unswitched nonscanning pencil-beam antenna is that the angle accuracy can be no better than the size of the antenna beamwidth. 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 beamwidth. The accuracy depends on how well equality of the signals in the switched positions can be determined. The fundamental limitation to accuracy is system noise caused either by mechanical or electrical fluctuations.

Sequential lobing, or lobe switching, was one of the first tracking-radar techniques to be employed. Early applications were in airborne-interception radar, where it provided directional information for homing on a target, and in ground-based antiaircraft fire-control radars. It is not used as often in modern tracking-radar applications.

3. Explain conical scanning method.

The logical extension of the sequential lobing technique is to rotate continuously an offset antenna beam rather than discontinuously step the beam between four discrete positions. This is known as conical scanning (Fig. 6.3.1). The angle between the axis of rotation (which is usually, but not always, the axis of the antenna reflector) and the axis of the antenna beam is called the squint angle.

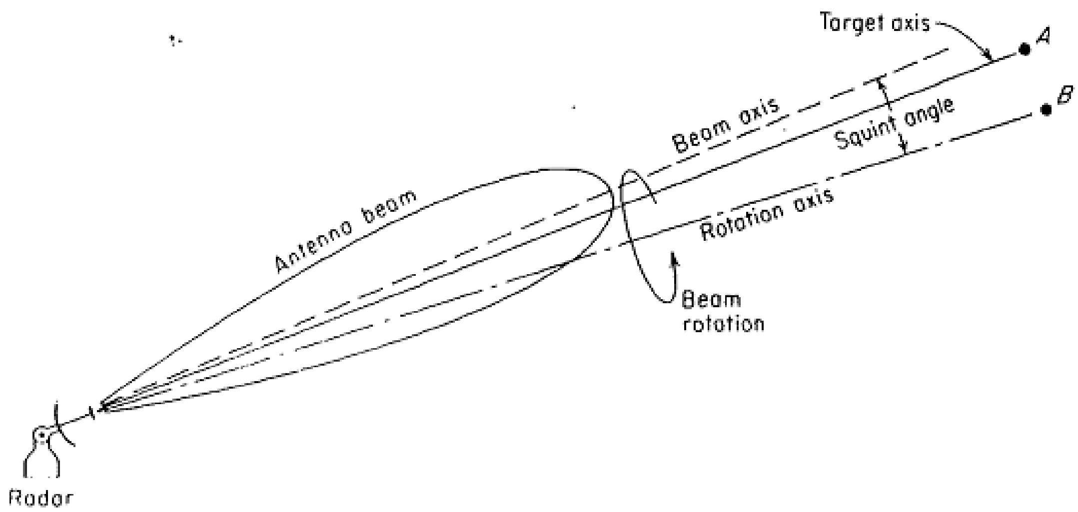

Fig 6.3.1 Conical-scan tracking

Consider a target at position A. The echo signal 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 and the rotation axis. 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 on the target. When the antenna is on target, as in B of Fig. 6.3.1, the line of sight to the target and the rotation axis coincide, and the conical-scan modulation is zero.

A block diagram of the angle-tracking portion of a typical conical-scan tracking radar is shown in Fig. 6.3.2. The antenna is mounted so that it can be positioned in both azimuth and elevation by separate motors, which might be either electric- or hydraulic-driven. The antenna beam is offset by tilting either the feed or the reflector with respect to one another.

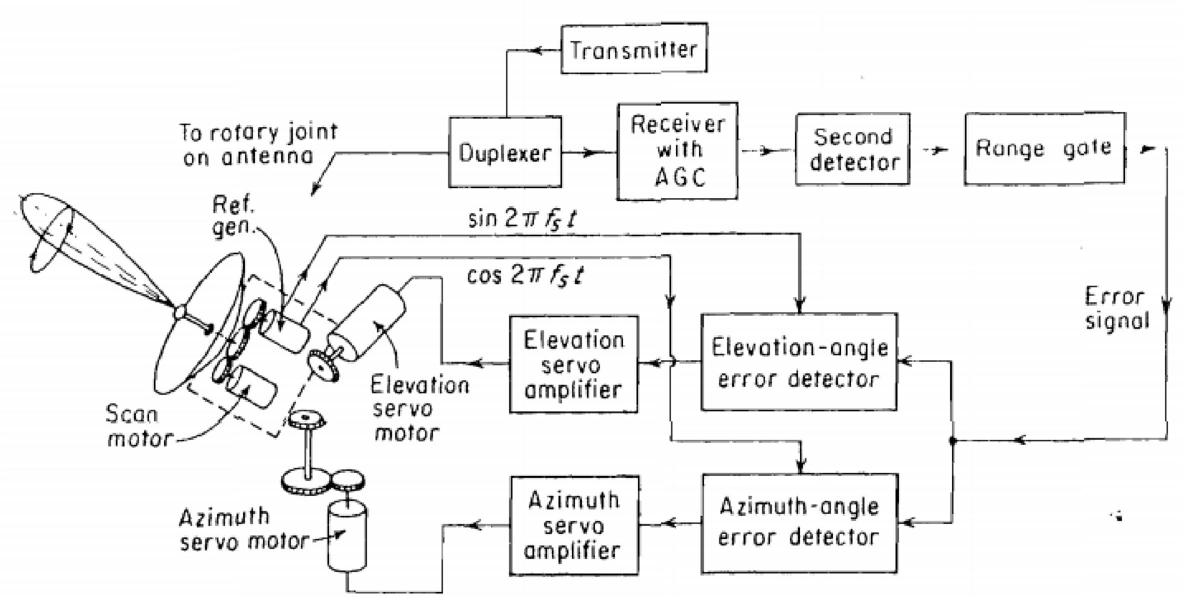

Fig 6.3.2 Block diagram of conical-scan tracking radar

One of the simplest conical-scan antennas is a parabola with an offset rear feed rotated about the axis of the reflector. If the feed maintains the plane of polarization fixed as it rotates, it is called a nutating feed. A rotating feed causes the polarization to rotate. The latter type of feed requires a rotary joint. The nutating feed requires a flexible joint. If the antenna is small, it may be easier to rotate the dish, which is offset, rather than the feed, thus avoiding the problem of a rotary or flexible RF joint in the feed. A typical conical-scan rotation speed might be 30 r/s. The same motor that provides the conical-scan rotation of the antenna beam also drives a two phase reference generator with two outputs 90° 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 a conventional superheterodyne except for features peculiar to the conical scan tracking radar. One feature not found in other radar receivers is a means of extracting the conical-scan modulation, or error signal. This is accomplished after the second detector in the video portion of the receiver. The error signal is compared with the elevation and azimuth reference signals in the angle-error detectors, which are phase-sensitive detectors. A phase-sensitive detector is a nonlinear device in which the input signal (in this case the angle-error signal) is mixed with the reference signal. The input and reference signals are of the same frequency. The output d-c voltage reverses polarity as the phase of the input signal changes through 180°. The magnitude of the d-c output from the angle-error detector is proportional to the error, and the sign (polarity) is an indication of the direction of the error. The angle-error-detector outputs are amplified and drive the antenna elevation and azimuth servo motors.

The angular position of the target may be determined from the elevation and azimuth o the antenna axis. The position can be read out by means of standard angle transducers such as synchros, potentiometers, or analog-to-digital-data converters.

4. Explain the block diagram of the AGC portion of tracking radar receiver.

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 (1) the inverse-fourth-power relationship between the echo signal and range, (2) the conical- scan modulation (angle-error signal), and (3) 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.

One of the purposes of AGC in any receiver is to prevent saturation by large signals. The scanning modulation and the error signal would he lost if the receiver were to saturate. In the conical-scan tracking radar an AGC that maintains the d-c level constant results in an error signal that is a true indication of the angular pointing error. The d-c level of the receiver must be maintained constant if the angular error is to be linearly related to the angle-error signal voltage.

An example of the AGC portion of a tracking-radar receiver is shown in Fig. 6.4. 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. 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.

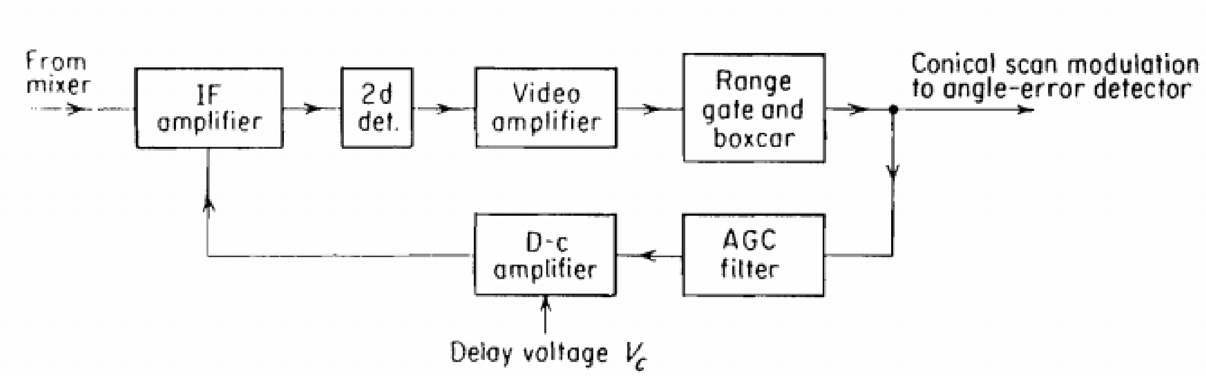

Fig 6.4 Block diagram of the AGC portion of a tracking-radar receiver

The output of the feedback loop will be zero unless the feedback voltage exceeds a prespecified minimum value V_c. In the block diagram the feedback voltage and the voltage V_c are compared in the d-c amplifier. If the feedback voltage exceeds V_c, the AGC is operative, while if it is less, there is no AGC action. The voltage V_c is called the delay voltage. The purpose of the delay voltage is to provide a reference for the constant output signal and permit receiver gain for weak signals. If the delay voltage were zero, any output which might appear from the receiver would be due to the failure of the AGC circuit to regulate completely.

In many applications of AGC the delay voltage is actually zero. This is called undelayed AGC. In such cases the AGC can still perform satisfactorily since the loop gain is usually low for small signals. Thus the AGC will not regulate weak signals. The effect is similar to having a delay voltage, but the performance will not be as good.

5. Explain the Block diagram of amplitude-comparison monopulse radar for single angular coordinate and explain its operation.

The amplitude-comparison monopulse employs two overlapping antenna patterns (Fig. 6.5.1 (a)) to obtain the angular error in one coordinate. The two overlapping antenna beams may be generated with a single reflector or with a lens antenna illuminated by two adjacent feeds. (A cluster of four feeds may be used if both elevation- and azimuth-error signals are wanted.) The sum of the two antenna patterns of Fig. 6.5.1 (a) is shown in Fig. 6.5.1 (b), and the difference in Fig. 6.5.1 (c). The sum patterns are 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. 6.5.1 (d).

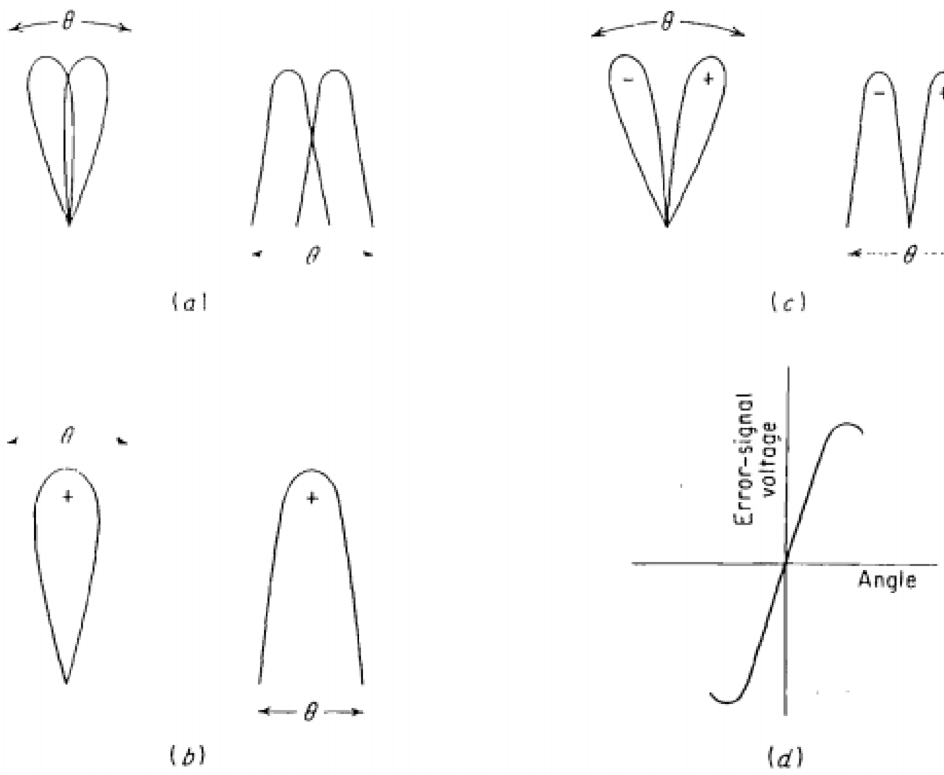

Fig. 6.5.1 Monopulse antenna patterns and error signal

A block diagram of the amplitude-comparison-monopulse tracking radar for a single angular coordinate is shown in Fig. 6.5.2. 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 superheterodyne 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.

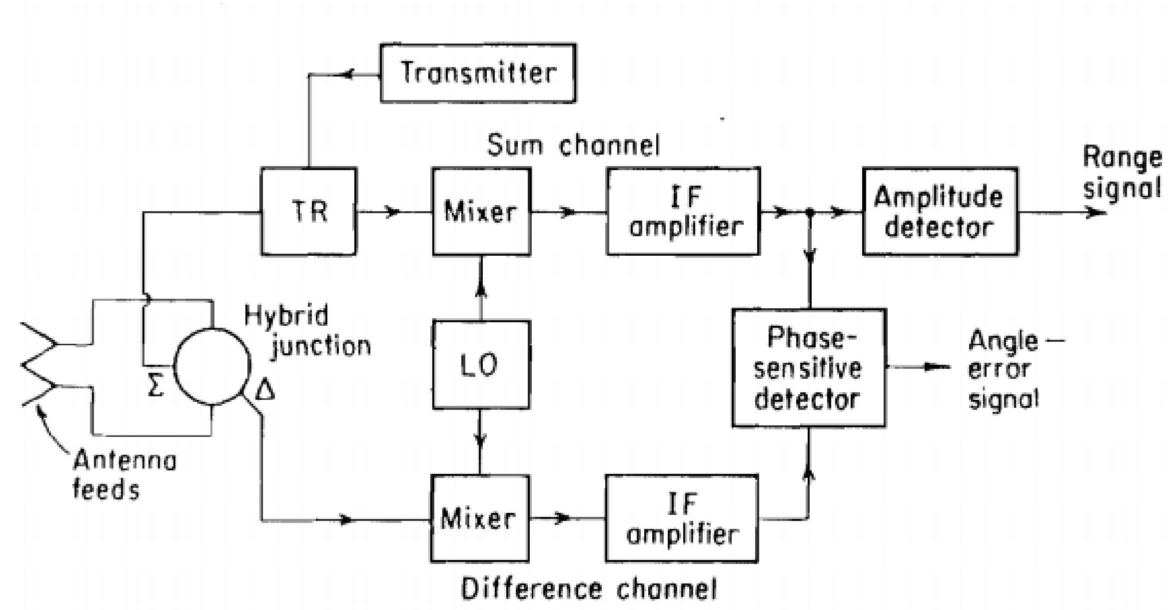

Fig 6.5.2 Block diagram of amplitude-comparison monopulse radar

6. Explain the Block diagram of amplitude-comparison monopulse radar for extracting error signals in both elevation and azimuth.

A block diagram of a monopulse radar with provision for extracting error signals in both elevation and azimuth is shown in Fig. 6.6. The cluster of four feeds generates four partially 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.

Since a phase comparison is made between the output of the sum channel and each of the difference channels, it is important that the phase shifts introduced by each of the channels be almost identical. The phase difference between channels must be maintained to within 25° or better for reasonably proper performance. The gains of the channels also must not differ by more than specified amounts.

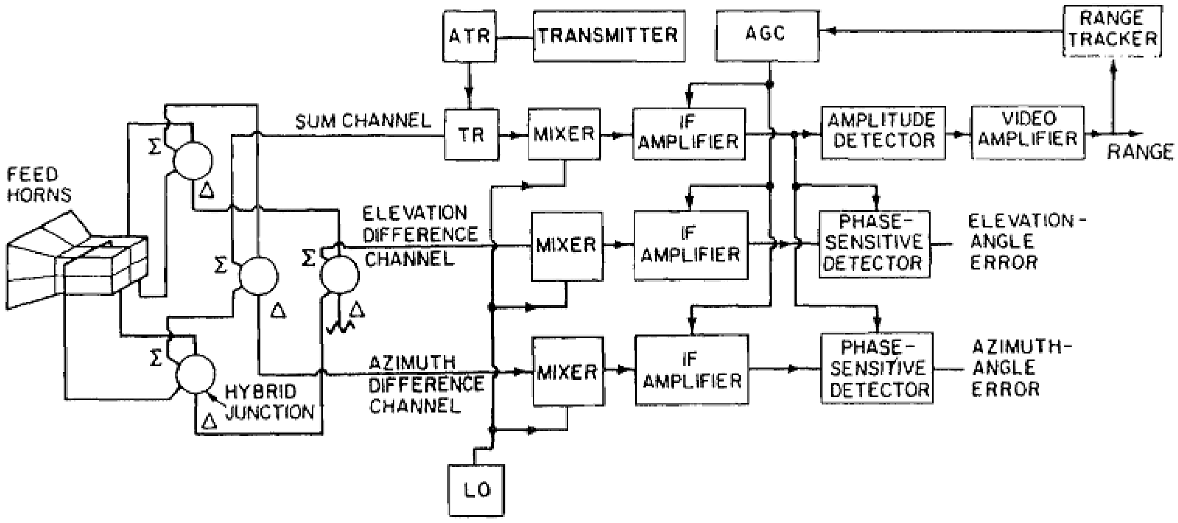

Fig 6.6 Block diagram of two-coordinate (azimuth and elevation) amplitude-comparison monopulse tracking radar

The purpose in using one- or two-channel monopulse receivers is to ease the problem associated with maintaining identical phase and amplitude balance among the three channels of the conventional receiver. Two-channel monopulse receivers have also been used by combining the sum and the two difference signals in a manner such that they can be again resolved into three components after amplification.

The approximately "ideal" feed-illuminations for a monopulse radar is shown in Fig. 6.6.1. This has been approximated in some precision tracking radars by a five-horn feed consisting of one horn generating the sum pattern surrounded by four horns generating the difference patterns.

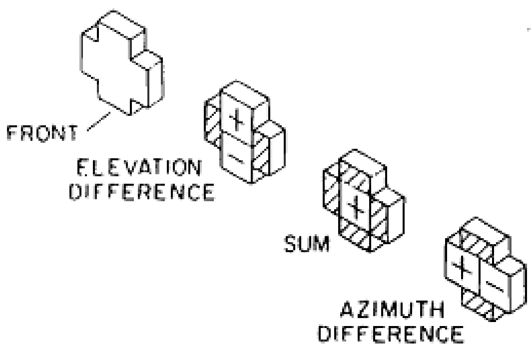

Fig 6.6.1 approximately ideal feed-aperture illumination for monopulse sum and difference channels

7. Explain Phase-comparison monopulse tracking radar technique.

The measurement of angle of arrival by comparison of the phase relationships in the signals from the separated antennas of a radio interferometer has been widely used by the radio astronomers for precise measurements of the positions of radio stars. The interferometer as used by the radio astronomer is a passive instrument, the source of energy being radiated by the target itself. A tracking radar which operates with phase information is similar to an active interferometer and might be called an interferometer radar. It has also been called Simultaneous phase comparison radar, or phase-comparison monopulse.

In Fig. 6.7 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

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

and the distance from antenna 2 to the target is

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

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

$$\Delta\varphi = 2\pi\, d \sin\theta / \lambda$$

For small angles where sin θ = 0, the phase difference is a linear function of the angular error and may be used to position the antenna via a servo-control loop.

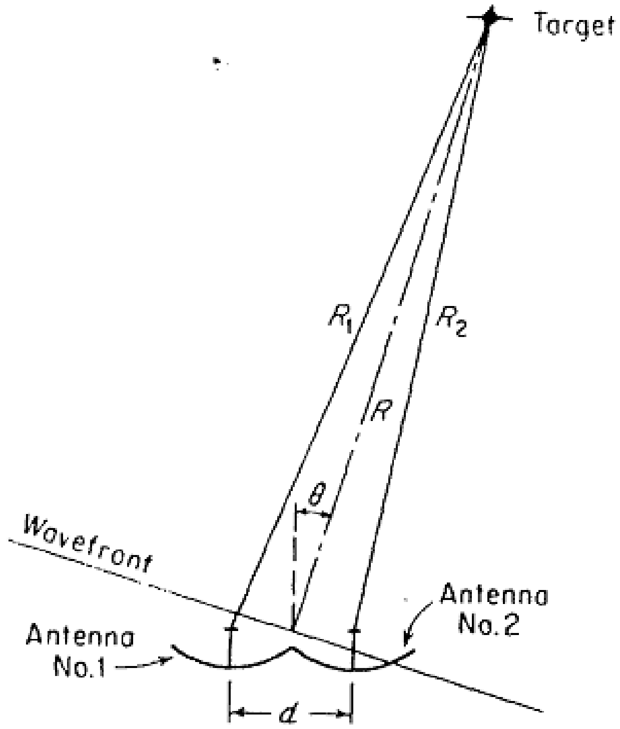

Fig 6.7 Wavefront phase relationships in phase- comparison monopulse radar

In the early versions of the phase-comparison monopulse radar, the angular error was determined by measuring the phase difference between the outputs of receivers connected to each antenna. The output from one of the antennas was used for transmission and for providing the range information. With such an arrangement it was difficult to obtain the desired aperture illuminations and to maintain a stable boresight. A more satisfactory method of operation is to form the sum and difference patterns in the RF and to process the signals as in a conventional amplitude-comparison monopulse radar.

8. Explain how tracking in range is achieved using split range gates.

The technique for automatically tracking in range is based on the split range gate. Two range gates are generated as shown in Fig.6.8. One is the early gate, and the other is the late gate. The echo pulse is shown in Fig. 6.8(a), the relative position of the gates at a particular instant in Fig. 6.8(b), and the error signal in Fig. 6.8(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 (Fig. 5.l7c) will result which may be used to reposition the center of the 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 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. On the other hand, it must not be so narrow that an appreciable fraction of the signal energy is excluded. A reasonable compromise is to make the gate width of the order of the pulse width.

A target of finite length can cause noise in range-tracking circuits in an analogous manner to angle-fluctuation noise (glint) in the angle-tracking circuits. Range-tracking noise depends or the length of the target and its shape. It has been reported that the rms value of the range noise is approximately 0.8 of the target length when tracking is accomplished with a video split-range-gate error detector.

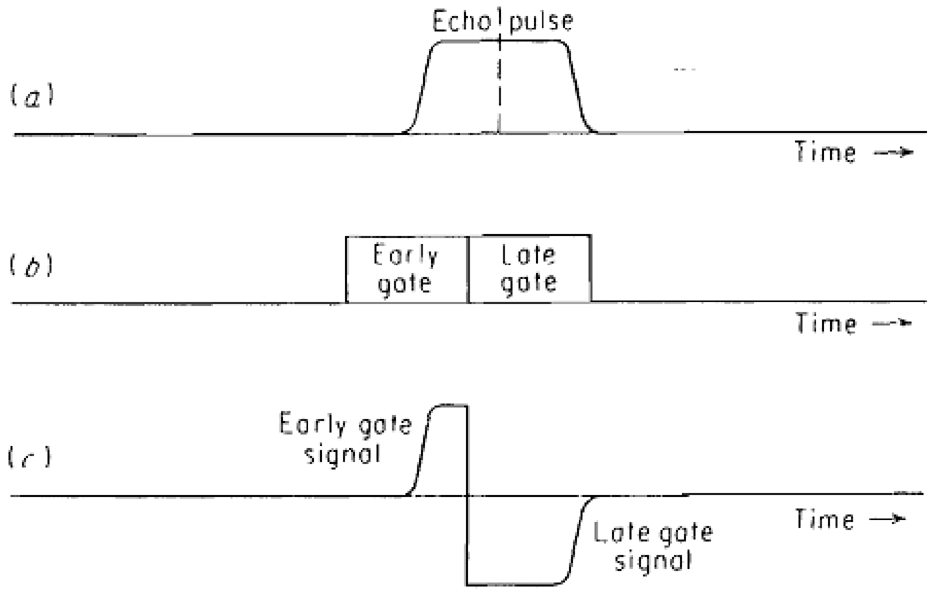

Fig. 6.8 Split-range-gate tracking (a) Echo pulse; (h) early-late range gates; (c) difference signal between early and late range gates.

9. What are the various methods of acquisition before tracking a target with a radar? Explain in detail.

A tracking radar must first find and acquire its target before it can operate as a tracker. Therefore it is usually necessary for the radar to scan an angular sector in which the presence of the target is suspected. Most tracking radars employ a narrow pencil-beam antenna. Examples of the common types of scanning patterns employed with pencil-beam antennas are illustrated in Fig. 6.9.

In the helical scan, the antenna is continuously rotated in azimuth while it is simultaneously raised or lowered in elevation. It traces a helix in space. Helical scanning was employed for the search mode of the SCR-584 fire-control radar, developed during World War II for the aiming of antiaircraft-gun batteries. The SCR-584 antenna was .rotated at the rate of 6 rpm and covered a 20" elevation angle in 1 min.

The Palmer scan derives its name from the familiar penmanship exercises of grammar school days. It 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 property, the Palmer scan is sometimes used with conical-scan tracking radars which must operate with a search as well as a track mode since the same mechanisms used to produce conical scanning can also be used for Palmer scanning.

Some conical-scan tracking radars increase the squint angle during search in order to reduce the time required to scan a given volume. The conical scan of the SCR-584 was operated during the search mode and was actually a Palmer scan in a helix. In general, conical scan is performed during the search mode of most tracking radars.

The Palmer scan is suited to a search area which is larger in one dimension than another. 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.

The raster, or TV, scan, unlike the Palmer or the spiral scan, paints the search area in a uniform manner. The raster scan is a simple and convenient means for searching a limited sector, rectangular in shape. Similar to the raster scan is the nodding scan produced by oscillating the antenna beam rapidly in elevation and slowly in azimuth. Although it may be employed to cover a limited sector-as does the raster scan-nodding scan may also be used to obtain hemispherical coverage, that is, elevation angle extending to 90^0 and the azimuth scan angle to 360^0.

The helical scan and the nodding scan can both be used to obtain hemispheric coverage with a pencil beam. The nodding scan is also used with height-finding radars. The Palmer, spiral, and raster scans are employed in fire-control tracking radars to assist in the acquisition of the target when the search sector is of limited extent.

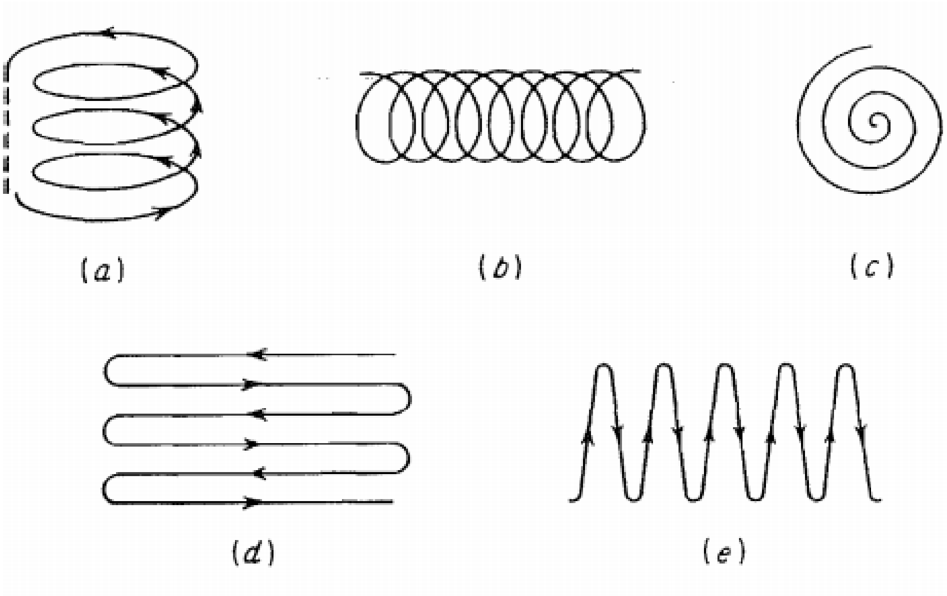

Fig. 6.9 Examples of acquisition search patterns. (a) Trace of helical scanning beam; (b) Palmer scan; (c) spiral scan; (d) raster, or TV, scan; (e) nodding scan.

10. Explain in detail about the limitations to tracking accuracy.

Main limitations to tracking accuracy of radar are,

1. Amplitude fluctuations.
2. Angle fluctuations.
3. Receiver and servo noise

Amplitude fluctuations:

A complex target such as an aircraft or a ship may be considered as a number of independent scattering elements. The echo signal can be represented as the vector addition of the contributions from the individual scatterers. If the target aspect changes with respect to the radar-as might occur because of motion of the target, or turbulence in the case of aircraft targets-the relative phase and amplitude relationships of the contributions from the individual scatterers also change. Consequently, the vector sum, and therefore the amplitude change with changing target aspect.

Amplitude fluctuations of the echo signal are important in the design of the lobe-switching radar and the conical-scan radar but are of little consequence to the monopulse tracker. Both the conical-scan tracker and the lobe-switching tracker require a finite time to obtain a measurement of the angle error.

To reduce the effect of amplitude noise on tracking, the conical-scan frequency should be chosen to correspond to a low value of amplitude noise. If considerable amplitude fluctuation noise were to appear at the conical-scan or lobe-switching frequencies, it could not be readily eliminated with filters or AGC. A typical scan frequency might be of the order of 30 Hz. Higher frequencies might also be used since target amplitude noise generally decreases with increasing frequency.

It has been found experimentally that the tracking accuracy of radars operating with pulse repetition frequencies from 1000 to 4000 Hz and a lobing or scan rate one-quarter of the prf are not limited by echo amplitude fluctuations.

Angle fluctuations:

Changes in the target aspect with respect to the radar can cause the apparent center of radar reflections to wander from one point to another. (The apparent center of radar reflection is the direction of the antenna when the error signal is zero.) In general, the apparent center of reflection might not correspond to the target center. .

The random wandering of the apparent radar reflecting center gives rise to noisy or jittered angle tracking. This form of tracking noise is called angle noise, angle scintillations, angle fluctuations, or target glint. The angular fluctuations produced by small targets at long range may be of little consequence in most instances. However, at short range or with relatively large targets (as might be seen by a radar seeker on a homing missile), angular fluctuations may be the chief factor limiting tracking accuracy. Angle fluctuations affect all tracking radars whether conical-scan, sequential lobing, or monopulse.

Receiver and servo noise:

Another limitation on tracking accuracy is the receiver noise power. The accuracy of the angle measurement is inversely proportional to the square root of the signal-to-noise power ratio. Since the signal-to-noise ratio is proportional to $1/R^4$ (from the radar equation), the angular error due to receiver noise is proportional to the square of the target distance.

Servo noise is the hunting action of the tracking servomechanism which results from backlash and compliance in the gears, shafts, and structures of the mount. The magnitude of servo noise is essentially independent of the target echo and will therefore be independent of range.

11. Explain low angle tracking.

A radar that tracks a target at a low elevation angle, near the surface of the earth, can receive two echo signals from the target, Fig. 6.11. One signal is reflected directly from the target, and the other arrives via the earth's surface. The direct and the surface-reflected signals combine at the radar to yield angle measurement that differs from the true measurement that would have been made with a single target in the absence of surface reflections. The result is an error in the measurement of elevation. The surface-reflected signal may be thought of as originating from the image of the target mirrored by the earth's surface. Thus, the effect on tracking is similar to the two-target model used to describe glint. The surface-reflected signal is sometimes called a multipath signal.

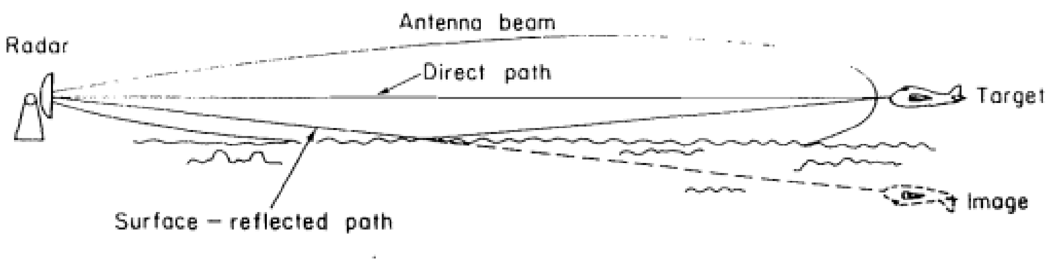

Fig 6.11 Low-angle tracking

The surface-reflected signal travels a longer path than the direct signal so that it may be possible in some cases to separate the two in time (range). Tracking on the direct signal avoids the angle errors introduced by the multipath. The range-resolution required to separate the direct from the ground-reflected signal is

$$\Delta R = \frac{2h_a h_t}{R}$$

Where,

h_a = radar antenna height,

h_t = target height,

R = range to the target.

For a radar height of 30 m, a target height of 100 m and a range of 10 km, the range-resolution must be 0.6 m, corresponding to a pulse width of 4 ns. This is a much shorter pulse than is commonly employed in radar. Although the required range-resolutions for a ground-based radar are achievable in principle, it is usually not applicable in practice.

The use of frequency diversity can also reduce the multipath tracking error.