CHAPTER-VI

TRACKING RADAR

6.1. Tracking Radar

A tracking-radar system measures the coordinates of a target and 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 normally considered a **tracking radar** from any other radar.

6.2. Target acquisition

The tracking radar must first find its target before it can track. Some radars operate in a search, or acquisition, mode in order to find the target before switching to a tracking mode. Although it is possible to use a single radar for both the search and the tracking functions, such a procedure usually results in certain operational limitations. Obviously, when the radar is used in its tracking mode, it has no knowledge of other potential targets. Also, if the antenna pattern is a narrow pencil beam and if the search volume is large, a relatively long time might be required to find the target. Therefore many radar tracking systems employ separate search radar to provide the information necessary to position the tracker on the target. **A search radar when used for this purpose is called an acquisition radar.** The acquisition radar designates the targets to the tracking radar by providing the coordinates where the targets are to be found. The tracking radar acquires a target by performing a limited search in the area of the designated target coordinates.

6.2.1. Acquisition methods

A tracking radar must first find and acquire its target before it can operate as a tracker. Therefore it is 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. Searching a volume in space for an aircraft target with a narrow pencil beam would be somewhat analogous to searching for a fly in a darkened auditorium with a flashlight. It must be done with some care if the entire volume is to be covered uniformly and efficiently. Examples of the common types of scantling patterns employed with pencil-beam antennas are illustrated in the figure 6.1. below.

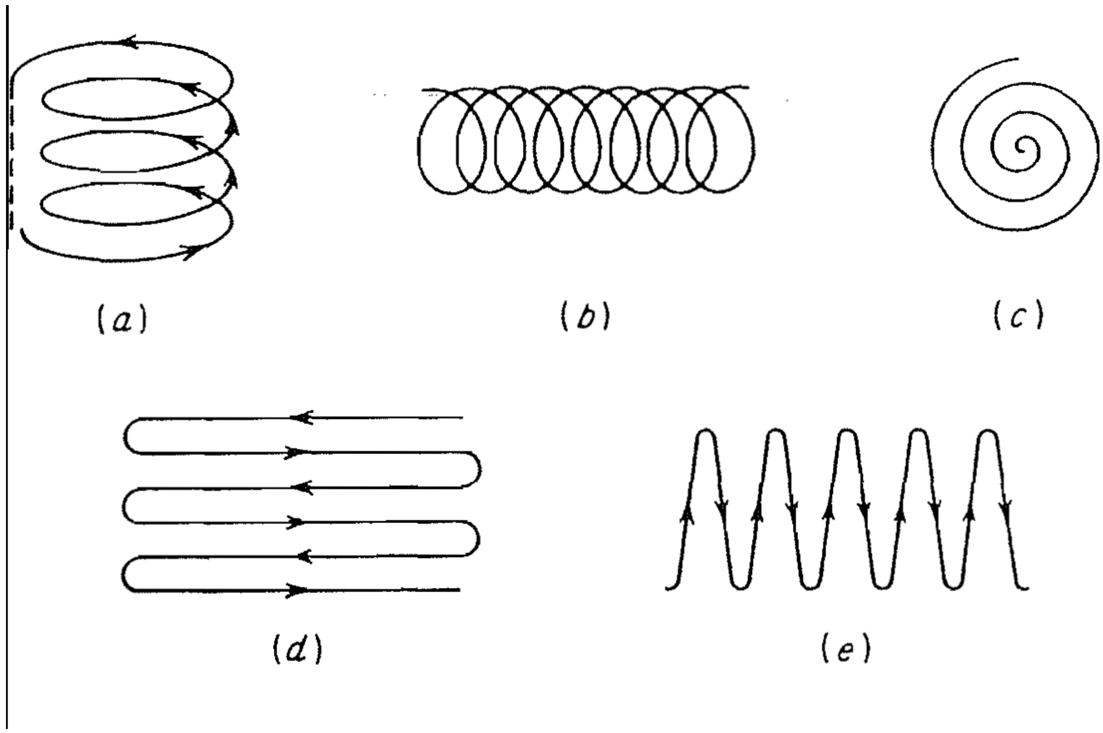

Figure 6.1. :Examples of acquisition search patterns.
(a) Trace of helical scanning beam; *(b)* Palmer scan;
(c) spiral scan; *(d)* raster, or TV, scan; (e) nodding scan.

1. 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.

2. *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.

(c) ***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) ***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.

(e) ***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 $\mathbf{90^0}$ and the azimuth scan angle to $\mathbf{360^0}$**.**

6.3. Angle tracking Methods

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

1. **Sequential lobing**,
2. **Conical scan,** and
3. **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. The information available from a tracking radar may be presented on a cathode-ray-tube (CRT) display for action by an operator, or may be supplied to an automatic computer which determines the target path and calculates its probable future course.

6.3.1. Sequential lobing (also called as Lobe switching or sequential switching)

The antenna pattern commonly employed with tracking radars is the symmetrical pencil beam in which the, elevation and azimuth beam-widths 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 arid 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 **5.l 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**T.h e 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 tow switched positions are equal , the target is on axis and its position may be determined from the axis direction.

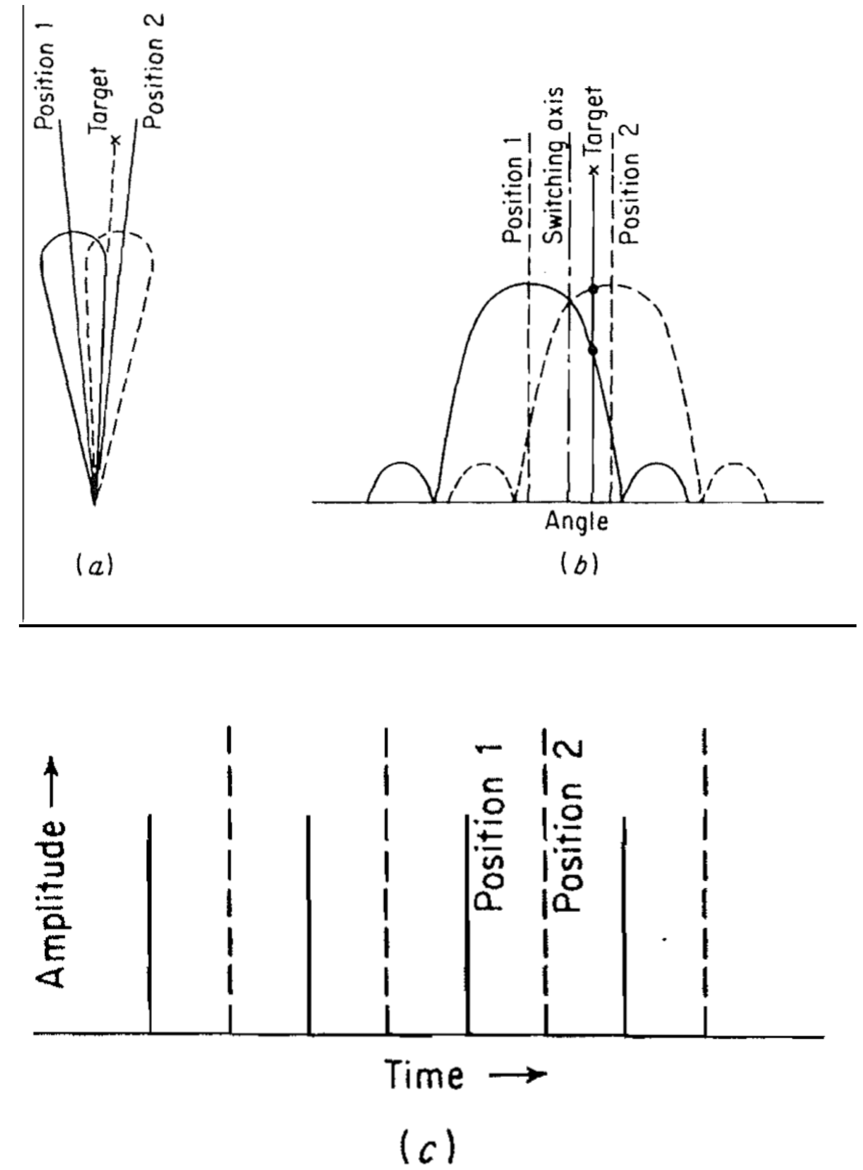

Figure 6.2 Lobe-switching antenna patterns and error signal (one dimension). (a) Polar representation of switched antenna patterns; (b) rectangular representation; (c)error signal.

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 non-scanning 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.**

6.3.2. Conical Scan

Some older tracking radar uses the conical scanning principle. You can generate a conical scan pattern, as shown in figure 6.3., by using a rotating feed driven by a motor in the housing at the rear of the dish. The axis of the radar lobe is made to sweep out a cone in space; the apex of this cone is, of course, at the radar transmitter antenna or reflector.

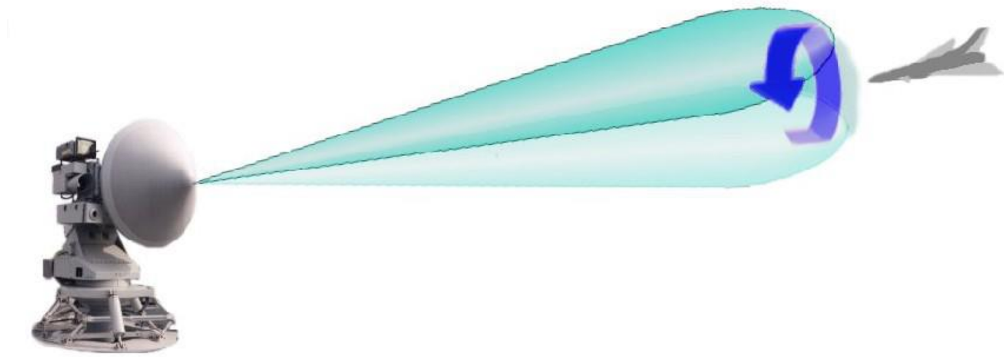

Figure 6.3 a; At conical scan the antenna traces a cone pattern around its central axis. Used in tracking radars conical scan with target azimuth and elevation being taken from the mechanical position of the antenna.

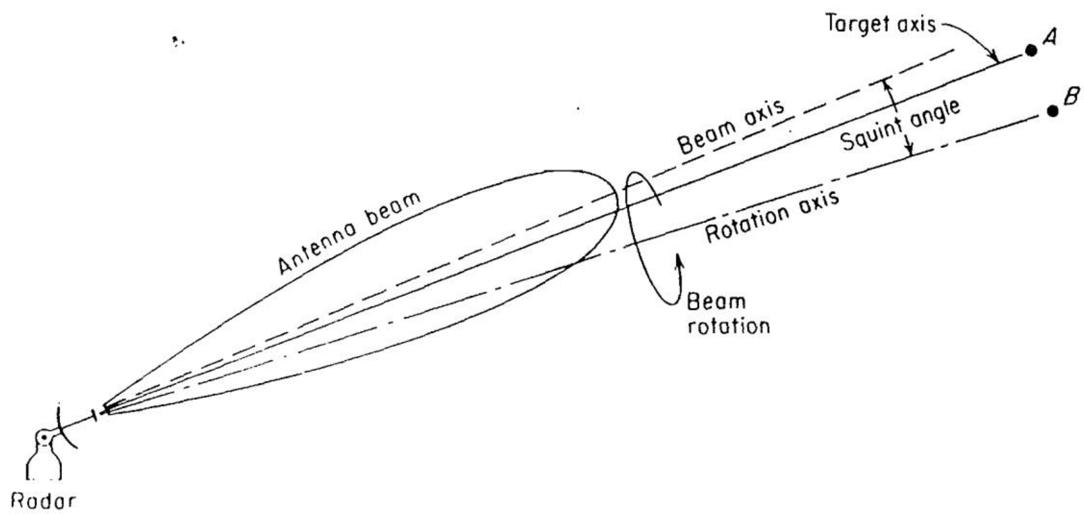

Figure 6.3 b Conical-scan tracking: Squint Angle

At any given distance from the antenna, the path of the lobe axis is a circle. Within the useful range of the beam, the inner edge of the lobe always overlaps the axis of scan. Now assume that we use a conically scanned beam for target tracking. If the target is on the scan axis, the strength of the reflected signals remains constant (or changes gradually as the range changes). But if the target is slightly off the axis, the amplitude of the reflected signals will change at the scan rate. For example, if the target is to the left of the scan axis, as shown in the Figure 6.4 the reflected signals will be of maximum strength as the lobe sweeps through the left part of its cone; the signals will quickly decrease to a minimum as the lobe sweeps through the right part. Information on the instantaneous position of the beam, relative to the scan axis, and on the strength of the reflected signals is fed to a computer. Such a computer in the radar system is referred to as the angle-tracking or angle-servo circuit (also angle-error detector). If the target moves

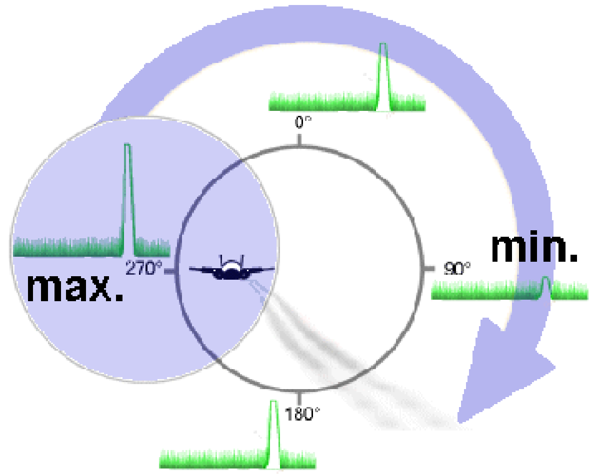

Figure 6.4 : Principle of conical scan: if the target isn't in the boresight direction, then a maximum of backscattered power will be received in direction of the eccentric moving. The antenna must follow in this direction now.

off the scan axis, the computer instantly determines the direction and amount of antenna movement required to continue tracking. The computer output is used to control servomechanisms that move the antenna. In this way, the target is tracked accurately and automatically. Commonly used conical scan pattern include Conical Scan on Receive Only (abbreviated to COSRO) in which a conical scan pattern is used while the radar is in receive mode only.

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 2-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.

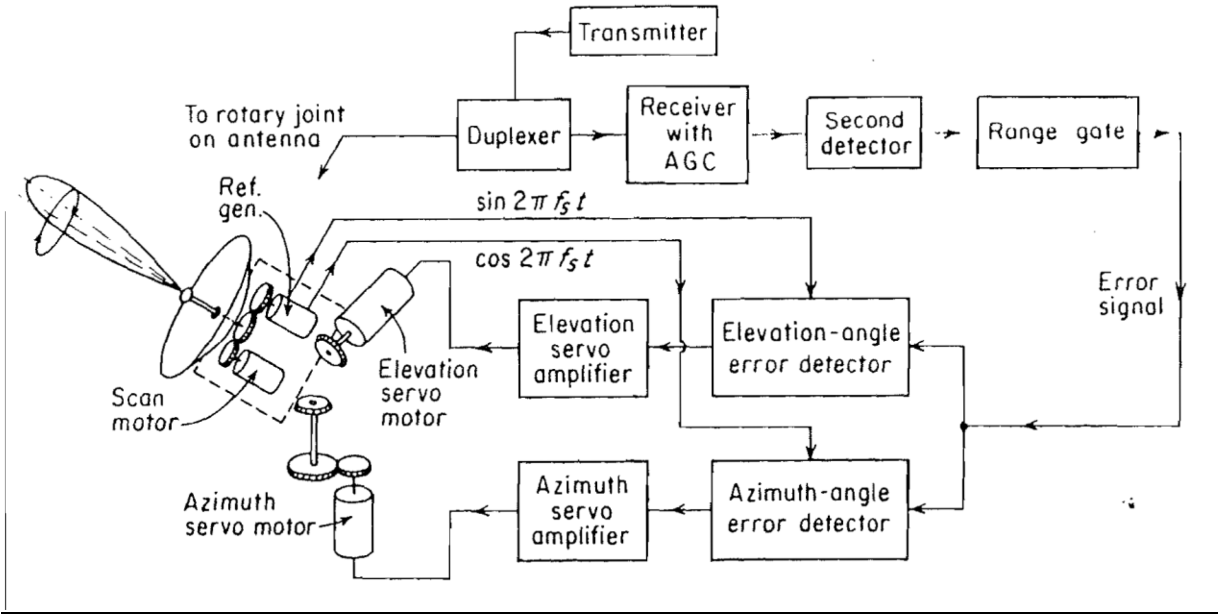

Fig 6.5: Block diagram of a conical scan tracking radar

The receiver is a conventional super heterodyne 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 180^0. 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 of 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.

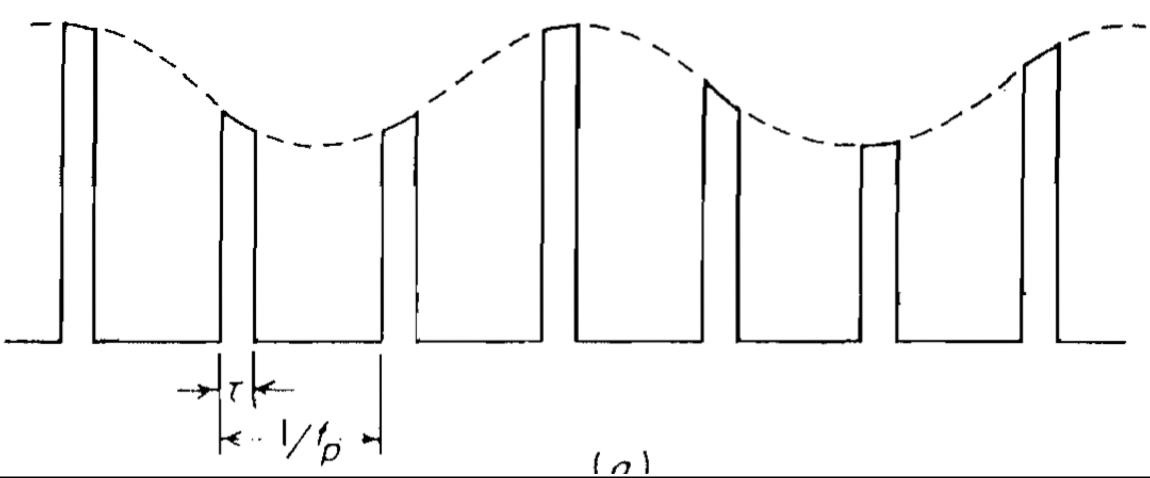

Fig 6.6: Angle Error Signal

6.3.2.1. Automatic gain control. 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 be lost if the receiver were to saturate. In the conical scan tracking radar an AGC that maintains the dc 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.

Ari example of the AGC portion of a tracking-radar receiver is shown in Fig. 6.7. 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. (If the AGC responds to the conical-scan frequency, the error signal might be lost.)

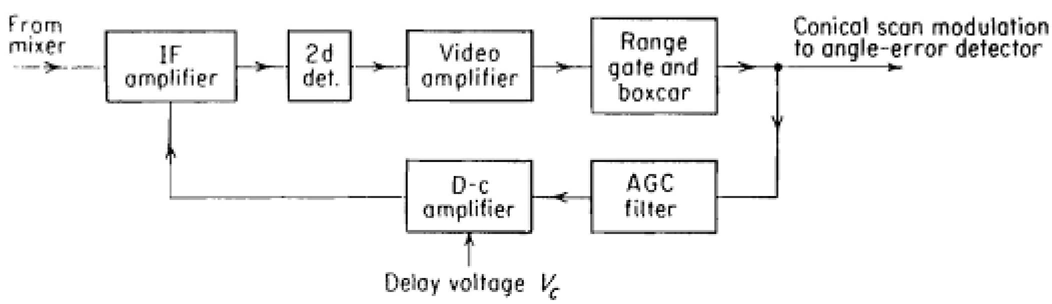

Figure 6.7: Block diagram of The AGC portion of a tracking-radar receiver.

The phase shift of this filter must be small if its phase characteristic is not to influence the error signal. A phase change of the error signal is equivalent to a rotation of the reference axes and introduces cross coupling, or "cross talk," between the elevation and azimuth angle-tracking loops. Cross talk affects the stability of the tracking and might result in an unwanted nutating motion of the antenna. In conventional tracking radar applications the phase change introduced by the feedback-loop filter should be less than 10^0**,** and in some applications it should be as little as **2°.** For this reason, a tilter 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.

The output of the feedback loop will be zero unless the feedback voltage exceeds a pre-specified 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 terminology may be a bit misleading since the delay is not in time but in amplitude. 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.

The required dynamic range of the **AGC** will depend upon the variation in range over which targets are tracked and the variations expected in the target cross section. If the range variation were 10 to 1, the contribution to the dynamic range would be 40 dB. The target cross section might also contribute another 40 dB variation. Another 10 dB ought to be allowed to account for variations in the other parameters of the radar equation. Hence the dynamic range of operation required of the receiver **AGC** might be of the order of 90 dB, or perhaps more.

6.3.2.2.Squint angle

The angle-error-signal voltage is shown in Fig. 6.6 as a function of θ_T**,** the angle between the axis of rotation and the direction to the target.'' The squint angle θ_q**,** is the angle between the antenna-beam axis and the axis of rotation; and θ_B is the half-power beamwidth. The antenna beam shape is approximated by a gaussian function in the calculations leading to Fig. 6.8.

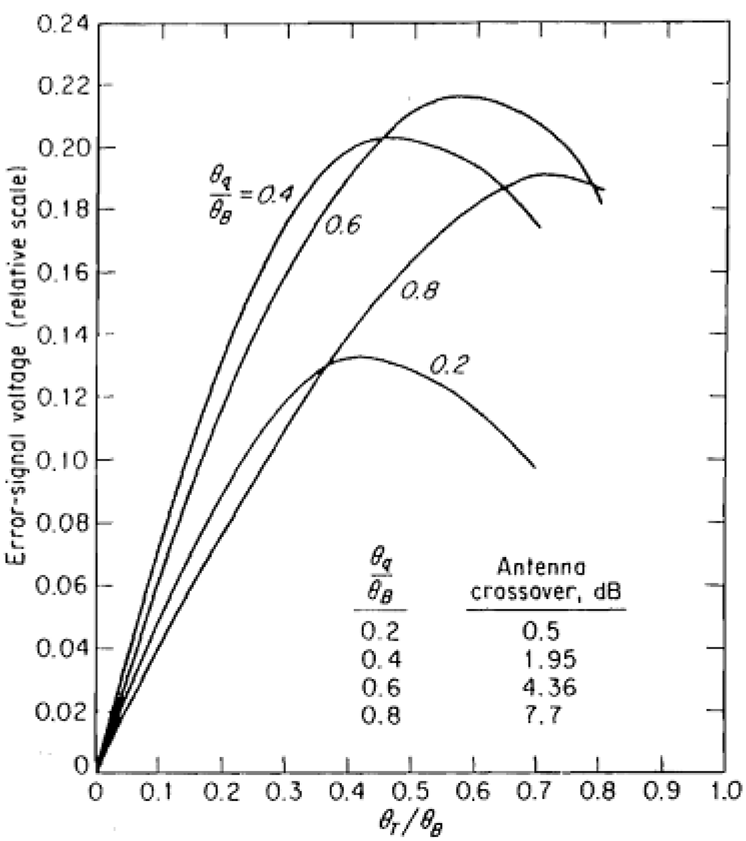

Fig 6.8 Plot of the relative angle-error signal from the conical-scan radar as a function of target angle (θ_T / θ_B) and squint angle (θ_q / θ_B). θ_B = half-power beamwidth.

The greater the slope of the error signal, the more accurate will be the tracking of the target. The maximum slope occurs for a value θ_q/θ_B slightly greater than **0.4.** This corresponds to a point on the antenna pattern (the antenna crossover) about 2 dB down from the peak. It is the optimum crossover for maximizing the accuracy of angle tracking. The accuracy of range tracking, however, is affected by the loss in signal but not by the slope at the crossover point. Therefore, as a compromise between the requirements for accurate range and angle tracking, a crossover nearer the peak of the beam is usually selected rather than that indicated from Fig. 6.8. It has been suggested that the compromise value of θ_q/θ_B be about **0.28,** corresponding to a point on the antenna pattern about 1.0 dB below the peak.

6.3.3. Monopulse Tracking Radar

The conical-scan and sequential-lobing tracking radars require a minimum number of pulses in order to extract the angle-error signal. In the time interval during which a measurement is made with either sequential lobing or conical scan, the train of echo pulses must contain no amplitude-modulation components other than the modulation produced by scanning. If the echo pulse-train did contain additional modulation components, caused, for example, by a fluctuating target cross section, the tracking accuracy might he degraded, especially if the frequency components of the fluctuations were at or near the conical-scan frequency or the sequential-lobing rate. The effect of the fluctuating echo can be sufficiently serious in some applications to severely limit the accuracy of those tracking radars which require many pulses to be processed in extracting the error signal.

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. The widely used monopulse techniques are

1. **Amplitude-comparison monopulse.**
2. **Phase-comparison monopulse.**

6.3.3.1. Amplitude-comparison monopulse.

The amplitude-comparison monopulse employs two overlapping antenna patterns (Fig. 6.9a) 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. 6.9(a) is shown in Fig. 6.9(b), and the difference in Fig. 6.9(c).

The sum patterns 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. 6.9(d).

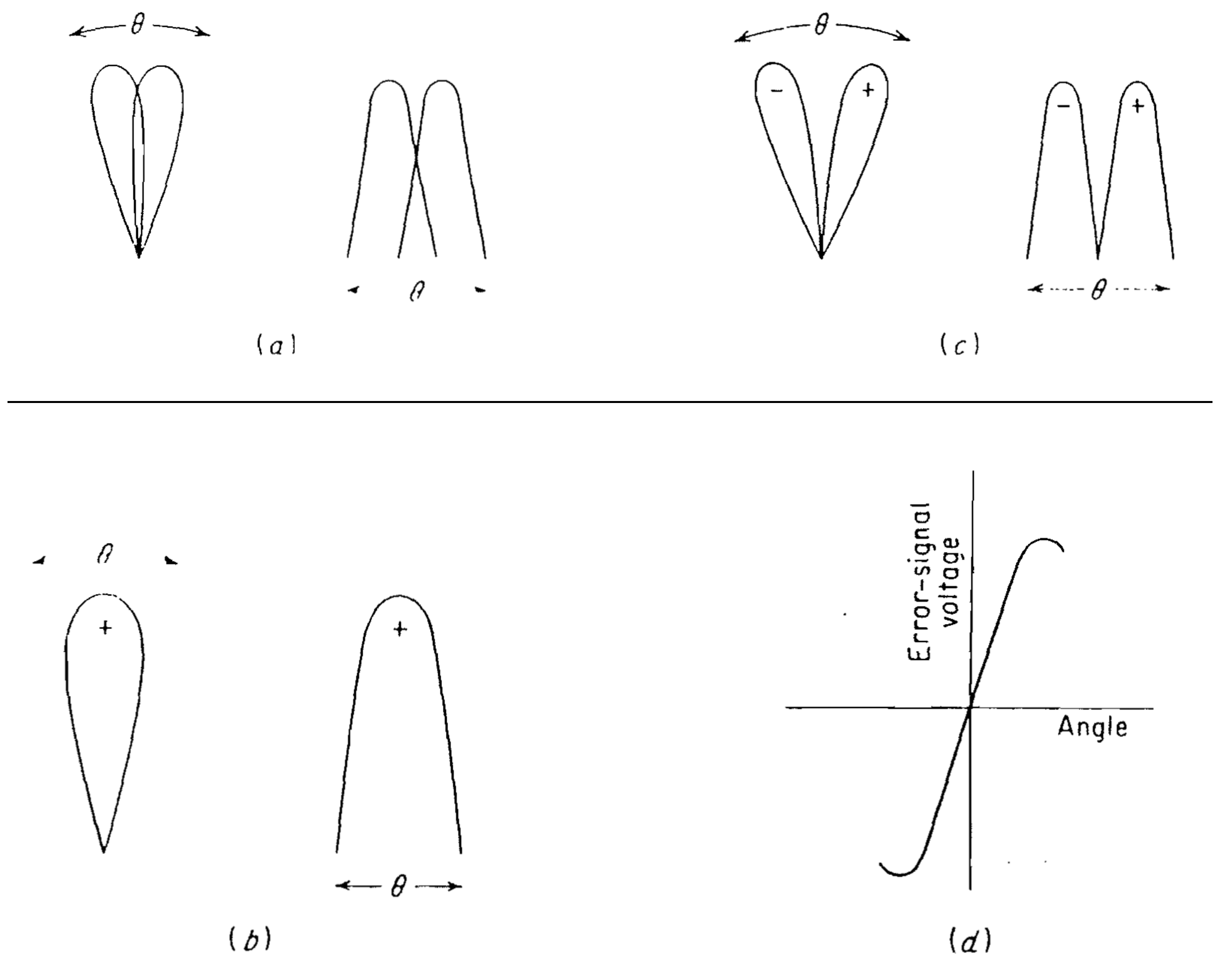

Figure 6.9: Monopulse antenna patterns and error signal. Left-hand diagrams in (a-c) are in polar coordinates; right-hand diagrams are in rectangular coordinates. (a) Overlapping antenna patterns; (b) sum pattern; (c) difference pattern; (d) product (error) signal.

A block diagram of the amplitude-comparison-monopulse tracking radar for a single angular coordinate is shown in Fig. 6.10. 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.

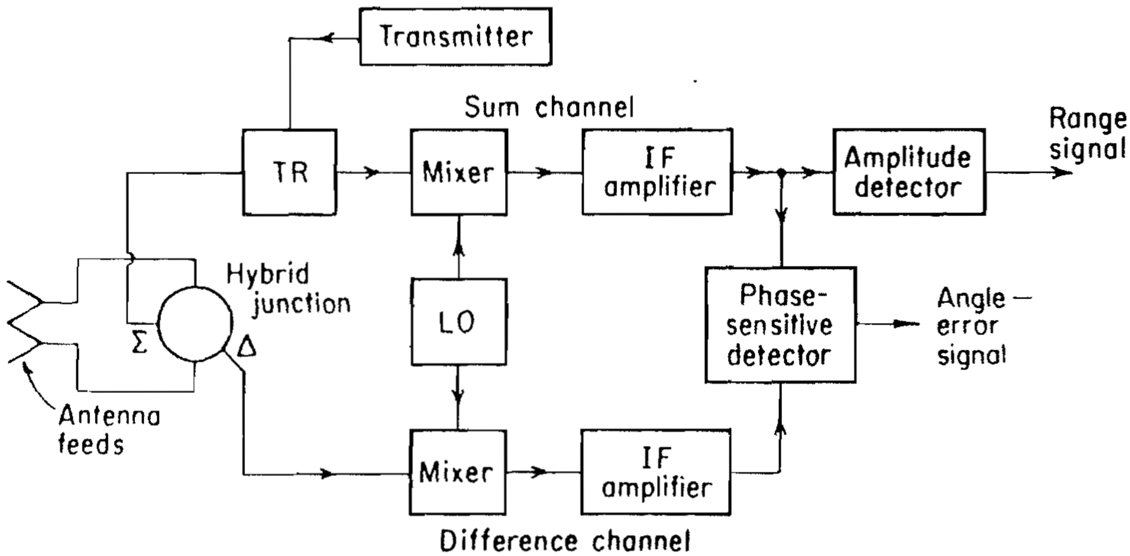

Figure 6.10: Block diagram of amplitude-comparison monopulse radar (one angular coordinate).

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.

6.3.3.2. Mono Pulse Phase Comparison Method

The tracking techniques discussed thus far in this chapter were based on a comparison of the amplitudes 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 mono pulse technique used two or more simultaneous beams The difference in amplitudes in the several antenna positions was proportional to the angular error. **The angle of arrival (in one coordinate) may also be determined by comparing the phase difference between the signals from two separate antennas.** Unlike the antennas of amplitude- comparison trackers. those used in phase-comparison systems are not offset from the axis. The individual boresight axes of the antennas are parallel, causing the (far-field) radiation to illuminate the same volume in space. The amplitudes of the target echo signals are essentially the same from each antenna beam, but the phases are different. 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. The latter term is the one which will be used here.

θ In Fig. 6.11 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 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

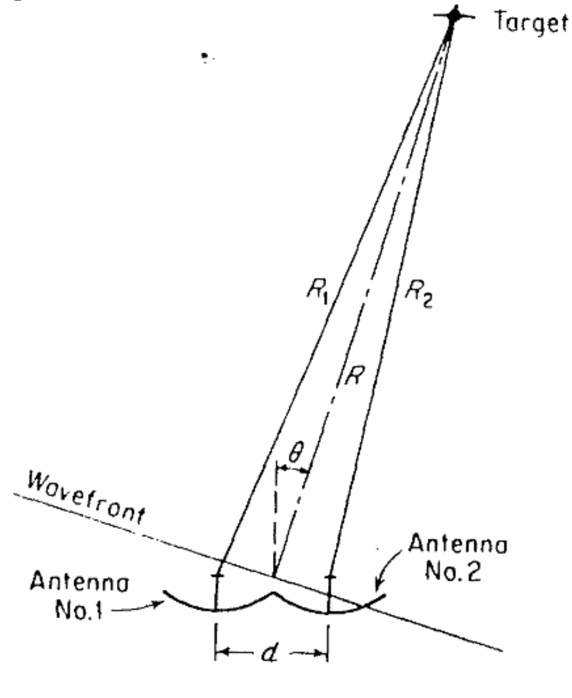

Figure 6.11 Wavefront phase relationships in phase-comparison monopulse radar.

$$R_1 = R + \frac{d}{2}\sin\theta$$

and the distance from antenna 2 to the target is

$$R_2 = R - \frac{d}{2}\sin\theta$$

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

$$\Delta\phi = \frac{2\pi d}{\lambda}\sin\theta$$

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.

Although tracking radars based upon the phase-comparison monopulse principle have been built and operated, this technique has not been as widely used as some of the other angle-tracking methods. The sum signal has higher sidelobes because the separation between the phase centers of the separate antennas is large. (These high sidelobes are the result of *grating lobes* similar to those produced in phased arrays.) The problem of high sidelobes can be reduced by overlapping the antenna apertures. With reflector antennas, this results in a loss of angular sensitivity and antenna gain.

6.4. Target Reflecting properties and angular accuracy

The angular accuracy of tracking radar will be influenced by such factors as

1. Mechanical properties of the radar antenna and pedestal,

2. Method by which the angular position of the antenna is measured,
3. Quality of the servo-system,
4. Stability of the electronic circuits,
5. Noise level of the receiver,
6. Antenna beam width,
7. Atmospheric fluctuations,
8. Reflection characteristics of the target.

These factors can degrade the tracking accuracy by causing the antenna beam to fluctuate in a random manner about the true target path. These noise like fluctuations are sometimes called **tracking noise, or jitter**.

6.4.1. 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. This time corresponds in the conical-scan tracker to at least one revolution of the antenna beam. With lobe switching, the minimum time is that necessary to obtain echoes at the four successive angular positions. In either case four pulse-repetition periods are required to make a measurement; in practice, many more than four are often used. If the target cross section were to vary during this observation time, the change might he erroneously interpreted as an angular-error signal. The monopulse radar, on the other hand. determines the-angular error on-the-basis of a single pulse. Its accuracy will therefore not be affected by changes in amplitude with time.

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. The percentage modulation of the echo signal due to cross-section amplitude fluctuation is independent of range if AGC is used. Consequently, the angular error as a result of amplitude fluctuations will also be independent of range.

6.4.2. 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. In fact, it need not be confined to the physical extent of the target and may be off the target a significant fraction of the time. 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.

Angle fluctuations in a tracking radar are reduced by increasing the time constant of the AGC system (reducing the band width). However, this reduction in angle fluctuation is accompanied by a new component of noise caused by the amplitude fluctuations associated with the echo signal; that is, narrowing the AGC bandwidth generates additional noise in the vicinity of zero frequency, and poorer tracking results. Amplitude noise modulates the tracking-error signals and produces a new noise component, proportional to true tracking errors, that is enhanced with a slow AGC. Under practical tracking conditions it seems that a wide-bandwidth (short-time constant) AGC should be used to minimize the overall tracking noise. However, the servo bandwidth should be kept to a minimum consistent with tactical requirements in order to minimize the noise.

6.4.3. 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.

Summary of errors.

The contributions of the various factors affecting the tracking error are summarized in Fig. 6.12. Angle-fluctuation noise varies inversely with range; receiver noise varies as the square of the range; and amplitude fluctuations and servo noise are independent of range. This is a qualitative plot showing the gross effects of each of the factors. Two different resultant curves are shown. Curve A is the sum of all effects and is representative of conical-scan and sequential-lobing tracking radars. Curve B does not include the amplitude fluctuations and is therefore representative of monopulse radars. In the previous paragraphs amplitude fluctuations are assumed to be larger than servo noise. If not, the improvement of monopulse tracking over conical scan will be negligible. In general, the tracking accuracy deteriorates at both short and long target ranges, with the best tracking occurring at some intermediate range.

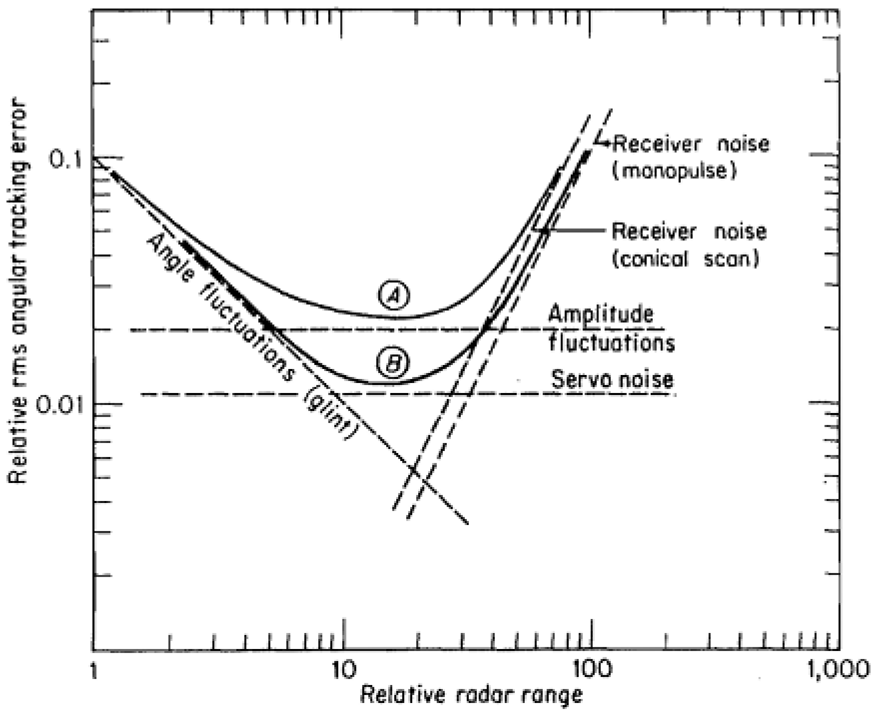

Figure 6.12 Relative contributions to angle tracking error due to amplitude fluctuations, angle fluctuations, receiver noise, and servo noise as a function of range. (A) Composite error for a conical-scan or sequential-lobing radar; (B) composite error for monopulse.

6.4.4. Frequency agility and glint reduction

The angular error due to glint, which affects all tracking radars, results from the radar receiving the vector sum of the echoes contributed by the individual scattering centers of a complex target, and processing it as if it were the return from a single scattering center. If the frequency is changed, the relative phases of the individual scatterers will change and a new resultant is obtained as well as a new angular measurement. Measurements are independent if the frequency is changed by an amount

$$\Delta fc = \frac{\mathrm{c}}{2\mathrm{D}}$$

where
c = velocity of propagation
D = target depth.

The glint error can be reduced by averaging the independent measurements obtained with frequency agility. (The depth D as seen by the radar might be less than the geometrical measurement of target depth if the extremities of the target result in small backscatter.)

The improvement 'I' in the tracking accuracy when the frequency is changed pulse-to-pulse is approximately

$$I^2 = \frac{1}{2\Delta f_c / B_{fa} + 2B_g / f_p} \approx \frac{DB_{fa}}{c}$$

where

B_{fa} = the frequency agility bandwidth, D = target depth, c = velocity of propagation, B_g, = glint bandwidth, and f_p = pulse repetition frequency.

6.5. Tracking in Range

In most tracking-radar applications the target is continuously tracked in range as well as in angle. The technique for automatically tracking in range is based on the split range gate. Two range gates are generated as shown in Fig. 6.13. One is the **early gate**, and the other is the **late gate**. The echo pulse is shown in Fig. 6.13a, the relative position of the gates at a particular instant in Fig. 6.13b, and the error signal in Fig. 6.13c. 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. 6.13c) 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

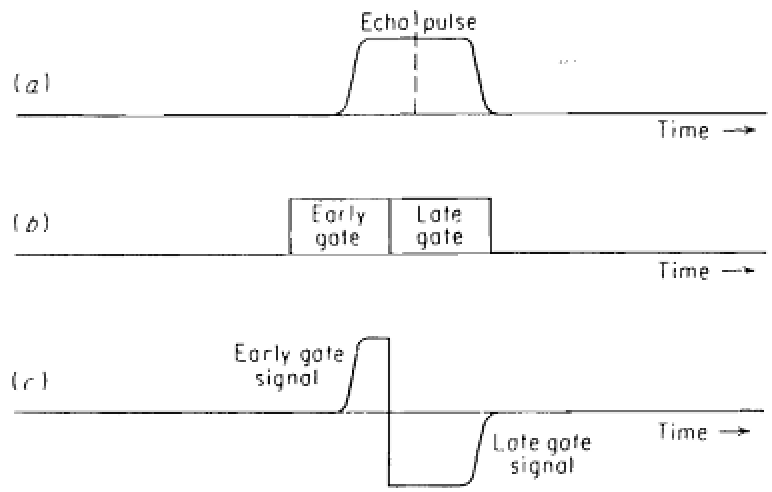

Figure 6.13 Split-range-gate tracking. (I) Echo pulse; (h) early-late range gates; (c) difference signal between early and late range gates.

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 on the length of the target and its shape

Solved Problems: No solved problems in this unit

Essay type questions

1. With a suitable block diagram explain the working of a conical scan tracking radar. Explain the various factors that need to be considered in determining the optimum squint angle. [JNTU May 2013]

2. Draw the block diagram of mono-pulse tracking radar and explain the operation. [JNTU May 2013]
3. Explain the block diagram of amplitude comparison mono pulse for extracting error signals in both elevation and azimuth. [JNTU May 2012]
4. With diagrams explain Split-range-gate tracking. [JNTU May 2012]
5. Describe the conical scanning method. [JNTU May 2012]
6. Explain how AGC is achieved in conical scan tracking Radar receiver. What is the chief advantage of automatic detection and tracking? What are its limitations? Explain. [JNTU May 2012]
9. Explain phase comparison mono pulse tracking radar. [JNTU May 2012]
10. Discuss in detail about the Angle fluctuations. [JNTU May 2012]
11. Describe the essential characteristics, functions and major applications of search Radar Systems. [JNTU May 2011]
12. Describe Acquisition with respect to Tracking radar. [JNTU May 2011]
13. Explain in detail about Target-reflection characteristics and Angular Accuracy. [JNTU May 2011]
14. Describe the conical scanning method. [JNTU May 2011]
15. Explain how AGC is achieved in conical scan tracking Radar receiver. [JNTU May 2011]
16. Explain the basic principle of low angle tracking. [JNTU May 2011]
17. How is radar target acquired in a typical radar. [JNTU May 2011]
18. Compare the tracking techniques. [JNTU May 2010]
19. Explain in detail about limitations to tracking accuracy. [JNTU May 2010]
20. Compare the performance of simultaneous lobing technique with conical scanning technique? [JNTU Jan 2010]
21. Explain about AGC in tracking radar receiver? [JNTU Jan 2010]
22. Explain about split – range – gate tracking? [JNTU Jan 2010]
23. Compare the four continuous tracking radar techniques? [JNTU Jan 2010]
24. Explain the principle of operation of phase comparison monopulse tracking radar. [JNTU May 2009]
25. Explain the following: [JNTU May 2009]
    i) Low angle tracking
    ii) Tracking in range
    iii) Acquisition.

Objective type questions

1. This radar designates targets to the tracking radar by providing the coordinates where the targets are to be found.

a. TWS radar　　b. Sequential radar　　c. Acquisition radar　　d. CW radar

2. The antenna pattern commonly employed with tracking radar is the

a. Symmetrical beam　　b. Symmetrical Pencil Beam
c. Asymmetrical Pencil beam　　d. Asymmetrical beam

3. One of method of obtaining the direction and magnitude of the angular error in

one coordinate is by alternately switching the antenna beam between two positions. This is called

a. Lobe switching
b. Asymmetrical switching
c. Symmetrical switching
d. Sequential tracking

4. When the output from more than one radar are automatically combined to provide target tracks, the processing is called

a. ADIT
b. IDAT
c. GCA
d. PPI

5. A surveillance radar that provides target tracks is sometimes called a

a. Track acquisition radar
b. Track-while-scan radar
c. Integrated ADT
d. ADT

6. Landing radars used for

a. ADT
b. IADT
c. GCA
d. ADIT

7. ADIT stands for

a. Automatic Decode Interlink Track
b. Automatic Decode Integrated Track
c. Automatic Detection and Integrated Track
d. Automatic Demodulation and Interlink Track

8. The difference between the target position and the reference direction is the

a. Lobe error
b. Tracking error
c. Angular error
d. Sequential error

9. When the target is located along the reference direction

a. Lobe error is zero
b. Lobe error is maximum
c. Angular error is maximum
d. Angular error is zero

10. GCA stands for

a. General Control of Approach
b. Ground Connection of Approach
c. Ground Control of Approach
d. General Connection of Approach

11. 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

a. Monopulse
b. Pulse to pulse comparison
c. Fixed lobing
d. Sequential lobing

12. The mono pulse antenna must generate a sum pattern with

a. Minimum boresight gain
b. Maximum boresight gain
c. Minimum pulse gain
d. Maximum pulse gain

13. This is used to rotate continuously an offset antenna beam

a. rotating Feed
b. rotational scanning
c. conical scanning
d. nutating feed

14. The process of stretching the pulses before low-pass filtering is called

a. Sampling
b. Quantizing
c. Sample and hold
d. Detecting

15. A conical scan-on-receive-only tracking radar radiates a

a. Scanning transmit beam
b. Scanning non-transmit beam
c. Non scanning receive beam
d. Non scanning transmit beam

16. The angle between the axis of rotation and the axis of the antenna beam is called the

a. Lobe Angle
b. Conical Angle
c. Squint Angle
d. Rotation Angle

17. If the feed maintains the plane of polarization fixed as it rotates it is called a

a. Rotating Feed
b. Fixed feed
c. Nutating Feed
d. Flexible feed

18. When the antenna is an target, the line of sight to the target and the rotation axis coincide, and the conical scan modulation is

a. Maximum
b. Zero
c. Constant
d. Infinity

19. Extracting the modulation imposed on a repetitive train of narrow pulses is called

a. Scanning
b. Conical scanning
c. Box caring
d. Sampling

20. LORO stands for

a. Lobe of radiation only
b. Lobe on radiation only
c. Lobe on receive only
d. Lobe on radar only

21. The difference in amplitudes in the several antenna positions was proportional to the

a. Angle of arrival
b. Phase
c. Angular error
d. Tracking accuracy

22. A tracking radar which operates with phase information is similar to an active interferometer and might be called a

a. Amplitude comparison monopulse radar
b. Phase monopulse radar
c. Simultaneous phase comparison radar
d. Hybrid Tracking

23. The antenna beams not offset in

a. Amplitude comparison monopulse radar
b. Phase comparison monopole radar
c. Hybrid tracking radar
d. Automatic tracking radar

24. The monopulse radar used

a. Single beam
b. Time shared beam
c. Two or more timeshared beams
d. Two or more simultaneous beams

25. High sidelobes are the result of

a. Sequential lobes
b. Grating lobes
c. Simultaneous lobes
d. Symmetrical lobes

26. Hybrid tracking system is a

a. Monopulse system
b. Conical scan system

c. Combination of monopulse and conical scan d. Sequential lobing

27. In this technique, target amplitude fluctuations do not affect the tracking accuracy [

a. Cono pulse system b. Monopulse system
c. Conical scan system d. Phase comparison monopulse

28. The sequential lobing and conical scan techniques used

a. Simultaneous beam b. Two or more simultaneous beams
c. Single time shared antenna beam d. Two or more time shared beam

29. The phase and amplitude comparison principles can be combined in a single radar to produce

a. Two dimensional angle tracking with four antenna beams
b. One dimensional angle tracking with four antenna beams
c. Two dimensional angle tracking with only two antenna beams
d. One dimensional angle tracking with only two antenna beams

30. The problem of high side lobes can be reduced by

a. Reducing antenna apertures b. Reducing the angular error
c. Overlapping the antenna apertures d. Reducing angle sensitivity

31. This scan covers an angular search volume with circular symmetry

a. Palmer scan b. Spiral scan c. Helical scan d. Circular scan

32. This 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

a. Helical scan b. Palmer scan c. Lowpass filter d. Conical scan

33. The range gating

a. Isolates one target, excluding targets at other ranges
b. Does not permits the box cargenerator
c. Antenna is continuously rotated
d. Can cause noise in an analogous manner

34. These are used to obtain hemispheric coverage with a pencil beam

a. Spiral and palmer scan b. Spiral and helical scan
c. Helical and nodding scan d. Helical and conical scan

35. The random wandering of the apparent radar reflecting center gives rise to

a. Target glint b. Random noise
c. Radar fluctuations d. Center fluctuations

36. This type of noise depends on the length of the target and its shape

a. Random Noise b. Gating Noise
c. Range-tracking noise d. Radar-tracking noise

37. In this scan the antenna is continuously rotated in azimuth while it is simultaneously raised or lowered in elevation

a. Plamer scan b. Spiral Scan c. Circular scan d. Helical scan

38. It consists of a rapid circular scan about the axis of the antenna combined with a linear movement of the axis of the rotation

a. Palmer Scan b. Spiral Scan c. Helical scan d. Circular scan

39. When the axis of rotation is held stationary, the palmer scan reduces to the

a. Stationary scan b. Spiral scan c. Conical scan d. Helical scan

40. It is used with high-finding radars

a. Helical scan b. Nodding scan **c.** Palmer scan d. Conical scan

41. When the target is being tracked, the signal-to-noise ratio available from the monopulse radar is

a. Less than that of a conical scan radar
b. Equal to that of a conical scan radar
c. Greater than that of a conical scan radar
d. Zero

42. This radar first makes its angle measurement and then integrates a number of pulses to obtain the required signal-to-noise ratio and to smooth the error

a. Conical scan radar b. Monopulse radar
c. Sequential lobing d. Helical scan radar

43. This radar integrates a number of pulses first and then extracts the angle measurement

a. Conical scan radar b. Monopulse radar
c. Helical scan radar d. Spiral scan radar

44. With the monopulse tracker it is possible to obtain a measure of the angular error in two coordinates on the basis of

a. Four pulses b. Single Pulses c. Dual Pulses d. Many Pulses

45. The side lobe levels are higher than desired in this radar

a. Sequential lobbing b. Conical scan
c. Amplitude comparison monopulse d. Phase comparison monopulse

46. It suffers less loss and the antenna and feed systems are usually less complex

a. Sequential lobing b. Conical scan c. Helical scan d. Spiral scan

47. This radar having more tracking accuracy

a. Conical scan radar b. Helical scan radar
c. Monopulse radar d. Sequential lobing

48. **It is the preferred technique for precision tracking**

a. Conical scan b. Monopulse radar
c. Circular scan d. Spiral scan

49. It is not degraded by amplitude fluctuations

a. Conical scan radar b. Monopulse radar
c. Helical scan d. Spiral scan

50. It is less costly and less complex

a. Conical scan radar
b. Surveillance radar
c. Monopulse radar
d. Phased array radar

Key

Q	A	Q	A	Q	A	Q	A	Q	A	Q	A	Q	A
1	C	2	B	3	A	4	A	5	B	6	C	7	C
8	C	9	D	10	C	11	A	12	B	13	C	14	C
15	D	16	C	17	C	18	B	19	C	20	C	21	C
22	C	23	B	24	D	25	B	26	C	27	A	28	C
29	C	30	C	31	D	32	D	33	A	34	A	35	C
36	A	37	C	38	D	39	A	40	C	41	B	42	D
43	C	44	A	45	C	46	D	47	B	48	C	49	B
50	B												

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