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Internal Assessment Test 3 – July 2021(Scheme & Solution)

Sub:	RADAR ENGINEERING				Sub Code:	17EC833/ 15EC833	Branch:	ECE	
Date:	18-07-2021 (Sunday)	Duration:	90 mins (1pm-2.30pm)	Max Marks:	50	Sem/Sec:	VIII - A,B,C,D		OBE

Answer any **FIVE FULL** Questions.

		MARKS	CO	RBT
1	a) Define the term “Tracking” in Radar Systems. Mention the various types of tracking employed in Radars and explain them briefly.	[10 = 5+5]	CO4	L1

Solution :

- A radar not only recognizes the presence of target, but also determines the range.
- Radar determines the Target’s location in Range and in one or two angle coordinates.
- After continuous observation of target over a time, radar provides the target’s trajectory, or **track**, and predicts its future location also.
- This is called **Tracking With Radar**.

- Atleast 4 types of Radars that can provide the tracks of Targets.

1) Single Target Tracker (STT).
Continuously Tracks a single Target at a relatively Rapid data rate (10 observations per second - “typical”).
The antenna beam of the STT follows the target by obtaining an angle-error signal.
Error signal is kept small by using a closed loop servo system.
Used Popularly as a Continuous Tracking Radar.
Application in tracking the Aircraft and/or Missile Targets to support a military weapon control system.

2) Automatic Detection and Track (ADT).
Used in almost all modern Civil Air-Traffic Control & Military Air-Surveillance Radars.
Observation rate depends on one rotation time of the Antenna (“few” to 12 seconds).
Has lower data rate than STT.
Advantage – can track a large number of targets (“many hundreds” to “a few thousands” of aircrafts).
Tracking is done in Open Loop (unlike STT).

3) Phased Array Radar Tracking.

Tracks large number of Targets with a High Data Rate.
Uses an Electronically Steered Phased Array Radar.
Multiple Targets Tracked on a Time-Shared basis under Computer Control.
The Beam can be Rapidly Switched between angular directions (sometimes in a few microseconds).
Has High Data Rate (like STT) & Tracks many Targets (like ADT).
Basis for Air-Defense weapon systems like Aegis & Patriot. Example is a Radar called MOTR (a C-band instrumentation Radar).

4) Track While Scan (TWS).

Rapidly scans a limited angular sector to maintain tracks.
Scans more than one Target within the coverage of the Antenna.
Data Rate is Moderate.
Used in past for – Air-Defense Radars, Aircraft Landing Radars & some Airborne Intercept Radars – to track multiple targets.
Unfortunately, in past, same name was used for ADT also, but now, they are different.

b) Compare monopulse and conical radar tracking systems.
Solution :

- **<u>Signal To Noise ratio (SNR)</u> : The SNR of Monopulse is 2 to 4 dB greater than that of Conical Scan.**
- **The monopulse views the target at the peak of its sum pattern.**
- **The conical-scan radar views the target at some angle off the peak of the antenna beam.**
- **The above reason gives more SNR from a monopulse than from a conical-scan radar.**

- **<u>Accuracy</u> : Due to higher SNR, the monopulse radar will have greater angle accuracy and also better range accuracy than conical scan radar.**

- **<u>Complexity</u> : The monopulse radar is the more complex of the 2 radars.**
- **Monopulse requires RF combining circuitry at the antenna & 3 receiving channels.**
- **Conical Scan has only 1 receiving channel & uses a single feed.**
- **But, conical scan radar has to rotate or nutate the antenna beam at a high speed.**

- **<u>Minimum Number of Pulses</u> : Due to its 2 to 4 dB lower SNR than the monopulse tracker, the conical scan tracker has to process more pulses.**
- **The Conical-Scan tracker requires a minimum of 4 pulses (10**

pulses usually) per revolution of the beam to find angle in 2 coordinates.

- **A Monopulse radar can perform an angle meas. in 2 coordinates on the basis of a single pulse (usually a no. of pulses used to increase SNR & accuracy).**

- **<u>Susceptibility to Electronic Countermeasures (ECM)</u> :**
A military conical-scan tracker is more vulnerable to spoofing countermeasures.
- **The spoofing countermeasures take advantage of its conical-scan frequency.**
- **It can also suffer from deliberate amplitude fluctuations.**
- **A well-designed monopulse tracker is much harder to deceive.**

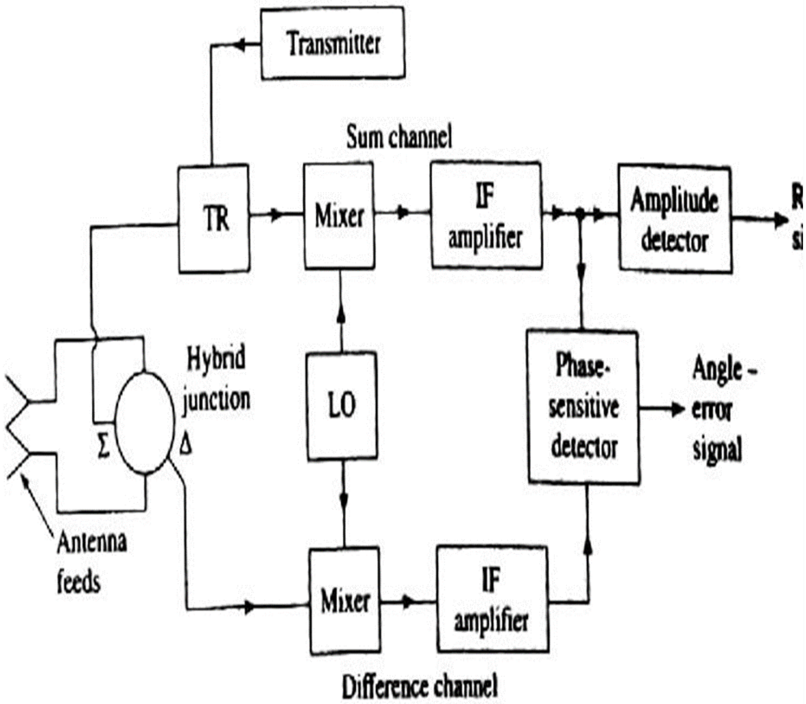
- **<u>Application</u> :**
- **Monopulse trackers should be used when good angle accuracy is wanted and/or when susceptibility to ECM is to be minimized.**
- **Conical-Scan trackers might be used when high-performance tracking is not necessary.**
- **Conical-Scan trackers have lower cost and reduced complexity.**

2	Define monopulse tracker. Using block diagram, explain amplitude comparison monopulse tracking radar in one angle coordinates. **Solution:**	[10]	CO4	L2

- Definition : A Monopulse Tracker is one which obtains angular locat of a target by comparison of signals received in 2 or more **Simultane Beams**.
- A Measurement of Angle may be made on the basis of a single pu hence, called **Monopulse**.
- In Practice, Multiple Pulses are used for –

1) Increasing the Probability of Detection.
2) Improving the accuracy of the angle estimate.
3) Providing Resolution in Doppler when needed.

Figure 4.4 Simple block diagram of the amplitude-comparison monopulse in one angle coordinate. Σ denotes the sum channel. Δ denotes the difference channel.



- The 2 adjacent antenna feeds are connected to the two input arms c **Hybrid Junction**.
- Hybrid Junction is a 4 port microwave device with 2 input & 2 out ports.
- When 2 signals (from the 2 squinted beams), are inserted at the 2 in ports, the sum & difference are found at the 2 output ports.
- On reception, the output of the sum & diff. ports are each heterodynec an Intermediate Frequency and amplified in the Superheterod Receiver.

- A single Local Oscillator (LO) is shared between the 2 channels (Sum Diff.).
- This ensures same Phase & Amplitude characteristics for the 2 chann (Important).
- The Transmitter (TX) is connected to the sum port of the Hybrid Juncti
- A Duplexer (TR) is included between TX and the Sum channel receiver protection.
- Often, TR is inserted in diff. channel (though not needed) to maint phase & amplitude balance of the 2 channels (sum & diff.).

- Automatic Gain Control (not shown in Fig.4.4) is also used to h maintain balance.
- The outputs of Sum & Diff. channels are inputs to the Phase Sensit Detector (PSD).

- PSD is a nonlinear device that compares 2 signals of the same frequenc
- The output of the PSD is the Angle-Error Signal (AES).
- AES magnitude is proportional to theta$_T$ (Target Angle) – th (Boresight or Crossover Angle).
- The sign of the output of PSD indicates the direction of AES relative the Boresight.

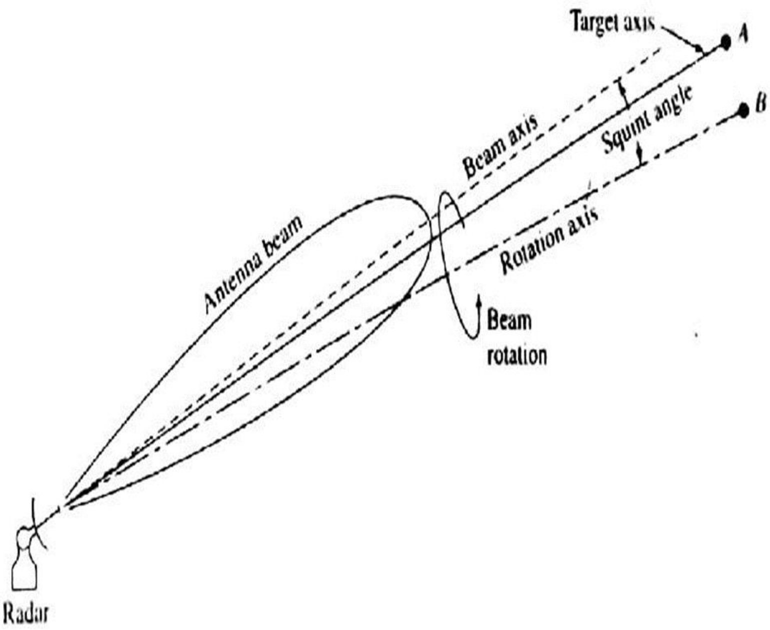
3	With a neat block diagram, explain conical scan tracking radar.	[10]	CO4	L3

Solution :

- Time Sharing a single Antenna Beam (as in Conical Scan & Sequential Lobing) is Simpler than using Simultaneous Beams (as in Monopulse Tracker).
- It uses Less Equipment.
- But, it is not as Accurate as using Simultaneous Beams.
- Time Sharing was used in early Tracking Radars.

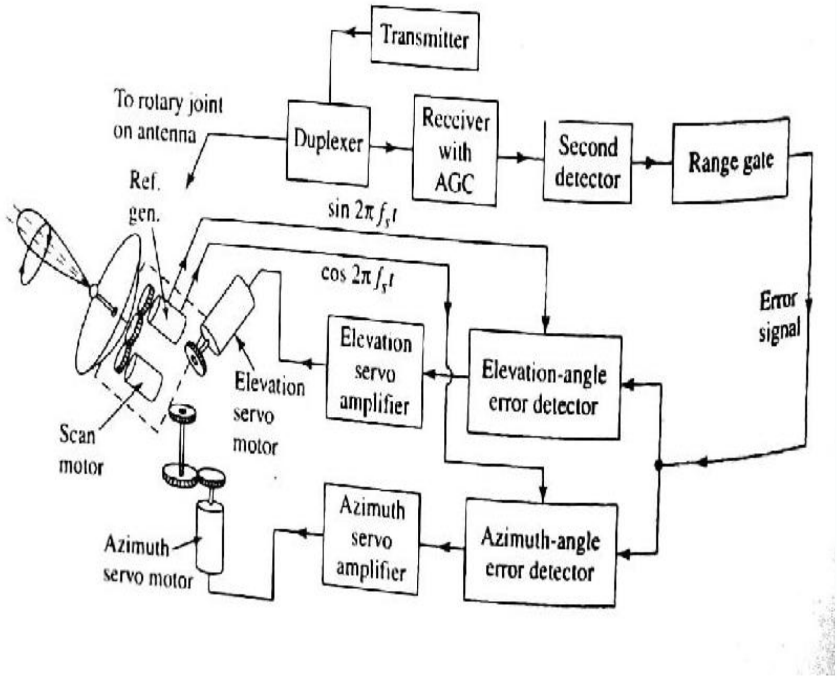
- The basic concept of **Conical Scan**, or, **Con-Scan**, is shown in Fig.4.11.
- The angle between the axis of rotation (**Rotation axis**) & the axis of the antenna beam (**Beam axis**) is the **Squint angle**.
- Consider a Target located at position A.
- The Squinted Beam rotates around the Rotation Axis.
- The Target is having an offset from the Rotation Axis.
- The above 2 situations result in the amplitude of the echo signal to be modulated at a frequency equal to the Beam Rotation Frequency.
- Beam Rotation Frequency is also called the Conical-Scan frequency.
- The amplitude of the modulation depends on the angular distance between the Target direction & the Rotation axis.
- The location of the Target in 2 angle coordinates is determined.
- This gives the phase of the conical-scan modulation , relative to the conical-scan beam rotation.

Figure 4.11 Conical-scan tracking.



- The conical-scan modulation is extracted from the echo signal and applied to a servo control system (SCS).
- The SCS continually positions the antenna rotation axis in the direction of the Target.
- This is done by moving the antenna such that the Target line of sight lies along the Beam rotation axis (Position B in Fig.4.11).
- 2 Servos are required, one for the azimuth and the other for elevation.
- When the Antenna is “On Target”, the Conical-scan modulation is of zero amplitude.

Figure 4.12 Block diagram of conical-scan tracking radar.



- Fig.4.12 shows the block diagram of the angle-tracking portion of a conical-scan tracking radar.
- The Antenna is mounted such that it can be mechanically positioned in both azimuth & elevation by separate motors.
- The Antenna beam is squinted by displacing the feed slightly off the focus of the parabola.
- When the feed is designed to maintain the same plane of polarization while rotating about the axis, it is called a **Nutating** feed.

- If the plane of polarization is made to rotate, the feed is called a **Rotating** feed.
- Nutating feed is preferred over Rotating feed.
- A rotating polarization can cause the amplitude of the Target echo signal to change with time even for a stationary target on-axis.
- This results in degraded angle-tracking accuracy.
- However, a Nutating feed is usually more complicated than the Rotating feed.

- The same motor provides the Conical Scan rotation & also drives a 2-phase Reference Generator (Ref.gen.).
- The Ref.gen. has electrical outputs at the conical scan frequency that are 90° apart in phase.
- These 2 outputs serve as reference signals to extract elevation error and azimuth error, as in Fig.4.12.
- The echo signal received is fed to the receiver from the antenna via 2 rotary joints (not shown in Fig.4.12).
- One joint permits azimuth motion & the other permits elevation motion.

- The receiver is a superheterodyne receiver, except for features related to the conical-scan tracking.
- The error signal is extracted in the video after the second detector.

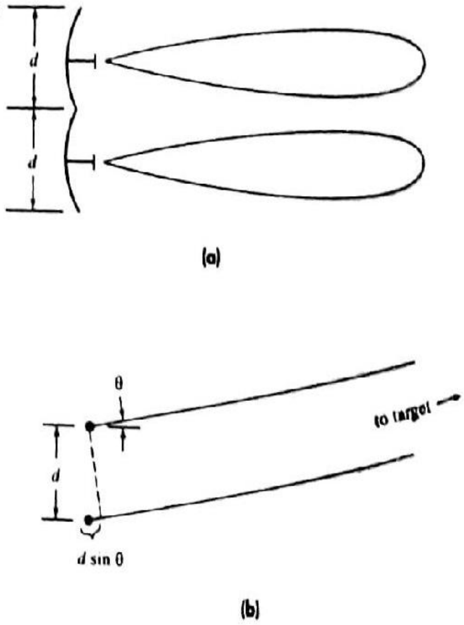
A single Target is tracked by having the receiver scan a range gate to search for the target, lock onto it & continually track it in range.
Range Gating eliminates Noise & excludes all targets other than the desired target.
The ERROR SIGNAL from the range gate is compared with both elevation & azimuth reference signals in the angle-error detectors.
Angle-Error Detectors are Phase-Sensitive Detectors.

- The Magnitude of the dc output from the angle-error detector is proportional to the angle error.
- Its Sign (Polarity) indicates the direction of the error.
- The angle error outputs are amplified and used to drive the antenna elevation & azimuth servo motors.
- The angular position of the target is found from the elevation & azimuth of the antenna axis.

4	a) Discuss the concept of phase comparison monopulse with diagrams. **Solution :**	[10 = 5+5]	CO4	L2

- 2 Antenna Beams are used to obtain an Angle Measurement in one coordinate (Just as in Amplitude-Comparison Monopulse).
- The 2 Beams look in the same direction & cover the same region of space.
- The 2 Beams are **not Squinted** to look in 2 slightly different directions.
- 2 Antennas are used (Fig.4.9a), rather than 2 feeds at the focus of a single antenna (used in Amplitude-Comparison Monopulse).
- The amplitudes of 2 signals are same, but their phases are different (opposite of the Amplitude-Comparison Monopulse).

Figure 4.9 Phase-comparison monopulse in one angle coordinate. (a) Two antennas radiating identical beams in the same direction; (b) geometry of the signals at the two antennas of (a) when received from a target at an angle θ, measured with respect to the perpendicular to the baseline of the two radiators.



- Consider 2 antennas spaced a distance d apart, as in Fig.4.9b.
- If the signal arrives from a direction "theta" with respect to the normal to the base line, the phase difference in the signals received in the two antennas is

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

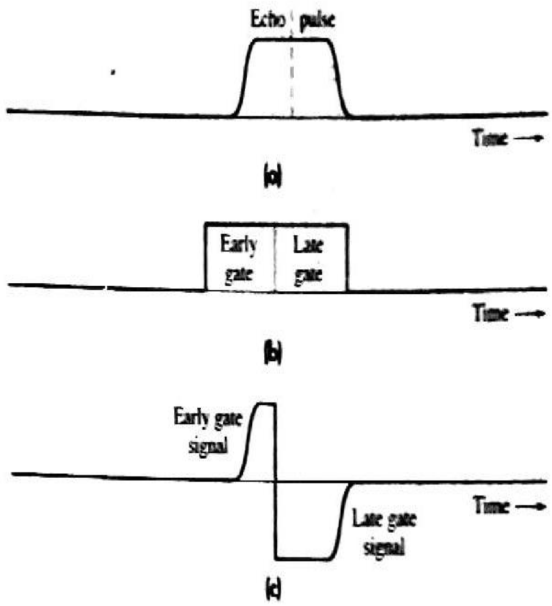
where λ = wavelength. A measurement of the phase difference of the signals receiv the two antennas can provide the angle θ to the target. The phase-comparison monop is sometimes known as an *interferometer radar*.

b) Discuss the concept of split-gate tracker with waveforms.
Solution:

- Manual Tracking is dependent largely on the skill of the operator.
- To maintain operator alertness & efficiency, operators need to be changed every half an hour to 40 min. etc.
- It cannot be used in systems such as missiles where there is no operator present.
- It was soon replaced by closed loop automatic tracking (such as the "**Split-Gate Tracker**").
- The technique for automatically tracking in range is based on the **Split Range Gate**.
- Two range gates are generated (Fig.4.19) –
  1) **Early Gate** , 2) **Late Gate.**
- Fig.4.19a depicts the video echo pulse.

- Fig.4.19b depicts relative gate positions at a particular instant of time.
- Fig.4.19c depicts the difference signal.
- In this example fig., the portion of the signal in the early gate < the portion of the signal in the late gate.

Figure 4.19 Split-gate range tracking: (a) Echo pulse, (b) early–late range gates, (c) difference signal between early and late range gates.



- The signals in the 2 gates (early & late) are integrated & subtracted to produce the **difference error signal**.
- The sign of the diff. error signal indicates the direction in which the 2 gates are to be moved to straddle (track) the echo pulse.
- The amplitude of the diff. error signal determines how far the junction of the 2 gates is from the **centroid** (**centre** of the **echo pulse**).
- The diff. error signal is zero when the junction of the 2 range gates coincides with the centre of the echo pulse.
- In the above situation, position of the 2 gates gives the target's range.

  Deviation of the junction of the pair of gates from the centre of the echo pulse may result.

  This increases the signal energy in one gate & decreases it in the other gate.

  This produces a non-zero difference error signal.

  Thus, the 2 gates are moved once again such that equilibrium is reestablished.

  Range Gating allows a Single Target to be isolated.

  The Gate rejects unwanted signals & noise from other ranges & hence improves the Signal-To-Noise Ratio.

  Generally, the Gate Width is approximately equal to the echo pulse width.

5	• Define an Antenna. List the different functions served by the radar antenna. **Solution :** **Antenna is a transition device between a guided wave and a free Space wave.** • The radar antenna is a distinctive & important part of any radar. • It serves the following functions : • Acts as the Transducer between propagation in space & guided-wave propagation in the transmission lines. • Concentrates the radiated energy in the direction of the Target (as meas by the antenna gain). • Collects the echo energy scattered back to the radar from a Target (as measured by the Antenna Effective Aperture). • Measures the angle of arrival of the received echo signal so as to provic location of a target in azimuth, elevation, or both. • Acts as a spatial filter to separate (resolve) targets in angle (spatial) dor and rejects undesired signals from directions other than the main beam. • Provides the desired volumetric coverage of the radar. • Usually establishes the time between radar observations of a target (rev time). • In addition, the antenna is that part of a radar system that is most often portrayed when a picture of a radar is shown. • Explain the different types of radar display systems. **Solution:** • Originally, the radar display had the important purpose of visually pre: the output of the radar receiver. • The output was presented in a form such that an operator could ea accurately detect the presence of a target. • Additionally, it could extract information about its location. • The display had to be designed so as not to degrade the radar informati • Also, it had to make it easy for the operator to perform with effectiven detection & information extraction function. • It was not uncommon for an operator to employ a grease pencil to m the face of a cathode-ray-tube display. • Marking was done for the location of a target from scan to scan & ma extract the target speed & direction. • As digital signal processing & digital data processing improved, m more of the detection & information extraction was done. • This was done automatically by electronic means so that the role operator was less.	[10 = 5+5]	CO3	L1

- When the display is connected directly to the output of the radar r without further processing, the output is called **raw video**.
- When the receiver output is first processed by an automatic dete automatic detector & tracker before display, it is called **synthetic vi processed video**.
- The requirements for the display differ somewhat depending on wheth or processed video is displayed.
- Some radar operators prefer to see, on a display, the raw video superimposed on the processed video.
- Thus, the role of the display has changed as the need for o interpretation has decreased.
- Given next are some of the more popular formats that have been emplo

<u>A-Scope</u>

- **A deflection-modulated rectangular display**.
- **The vertical deflection is proportional to the amplitude of the r output**.
- **The horizontal coordinate is proportional to range (or time delay)**.
- This display is well suited to a staring or manually tracking radar.
- It is not appropriate for a continually scanning surveillance radar.
- This is because the ever-changing background scene makes it diffi detect targets & interpret what the display is seeing.

<u>B-Scope</u>

- **An intensity-modulated rectangular display.**
- **Azimuth angle is indicated by one coordinate (usually horizonta range by the orthogonal coordinate (usually vertical)**.
- It has been used in airborne military radar.
- In these radars, the range & angle to the target are more importa concern about distortion in the angle dimension.

<u>C-Scope</u>

- **A two-angle intensity-modulated rectangular display**.
- **The azimuth angle is indicated by the horizontal coordinate & ele angle is indicated by the vertical coordinate**.
- One application is for airborne intercept radar.
- In this radar, the display is similar to what a pilot might see when l through the windshield.
- It is sometimes projected on the windshield as a heads-up display.
- The range coordinate is collapsed on this display.
- So, a collapsing loss might occur, depending on how the radar informa processed.

<u>E-Scope</u>

- **An intensity-modulated rectangular display**.
- **Range is indicated by the horizontal coordinate & elevation angle vertical coordinate**.

- The E-scope provides a vertical profile of the radar coverage at a pa azimuth.
- It is of interest with 3D radars & in military airborne terrain-followin systems.
- In these systems, the radar antenna is scanned in elevation to obtain v profiles of the terrain ahead of the aircraft.
- The E-Scope is related to the RHI display.

<u>PPI-display, or plan-position indicator</u>

- **An intensity-modulated circular display.**
- **In this, echo signals from reflecting objects are shown in plan view.**
- **The range & azimuth angle are displayed in polar (rho coordinates to form a map-like display.**
- Usually, the centre of the display is the location of the radar.
- A **sector-scan PPI** might be used with a forward looking airborne r provide surveillance or ground mapping over a limited azimuth sector.
- An **offset PPI** is one where the origin (or location of the radar) location other than the centre of the display.
- This provides a larger display area for a selected portion of the coverag
- The location of the radar with an offset PPI may be outside the face display.

<u>RHI-display, or range-height indicator</u>

- **An intensity-modulated rectangular display with height (target al as the vertical axis & range as the horizontal axis**.
- The scale of the height coordinate is usually expanded relative to the coordinate.
- It has been used with meteorological radars to observe the vertical pro weather echoes.

- In addition, imaging radars such as synthetic aperture radar (SAR) & looking airborne radar (SLAR) generally display their output as a strip
- The strip map has range as one co-ordinate and cross-range as the coordinate.
- With expanding graphics technology, available from the computer in there is much more flexibility available in displaying radar informatio previously.

6	Define and explain the following antenna parameters : 1) Directive Gain, 2) Power Gain, 3) Antenna Radiation Pattern, 4) Effective Aperture, 5) Polarization.	[10 = 2*5]	CO3	L2

<u>Solution :</u>

- **Directive Gain :**
- **Gain** is a measure of the ability of an antenna to concentrate the transmitted energy in a particular direction.
- Antenna gain is of 2 types : 1) **Directive Gain** (or **Directivity**) , and 2) **Power Gain** (or **Gain**).
- Both are used in Radar Engineering.
- Directive Gain is descriptive of the nature of the antenna radiation pattern.
- Directive Gain is usually the definition of Gain that interests the Antenna Engineer.
- The power gain is related to the directive gain, but it takes account of loss in the antenna itself.
- The power gain is more appropriate for use in the radar range equation & is therefore of more interest for the radar engineer.
- Let Directive Gain be denoted as G_D. Then,

$$G_D = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}} \quad [9.1]$$

- Hence Eq.9.1 can be written as

$$G_D = \frac{4\pi(\text{maximum power radiated per unit solid angle})}{\text{total power radiated by the antenna}} \quad [9.2]$$

- Eq.9.2 indicates the procedure by which the directive gain may be found from the antenna radiation pattern.

Power gain

Power Gain The power gain, which we denote by G, is similar to the directive gain except that it takes account of dissipative losses in the antenna. (It does not include loss arising from mismatch of impedances or loss due to polarization mismatch.) It can be defined similarly to the definition of directive gain, Eq. (9.2), if the denominator is the net power accepted by the antenna from the connected transmitter, or

$$G = \frac{4\pi(\text{maximum power radiated per unit solid angle})}{\text{net power accepted by the antenna}} \quad [9.6a]$$

An equivalent definition is

$$G = \frac{\text{maximum radiation intensity from subject antenna}}{\text{radiation intensity from a lossless isotropic radiator with the same power input}} \quad [9.6b]$$

Antenna Radiation Pattern

- It is common to speak of antenna gain (maximum value) as a function of angle (Antenna Radiation Pattern).
- Quite often, the ordinate of a radiation pattern is given as the gain as a function of angle, normalized to unity.
- It is then known as **relative gain**.
- The actual pattern is a plot of the radiation intensity $P(\theta, \varphi)$ as a function of two angles.
- A complete 3-dimensional plot of the radiation pattern can be complicated to display & interpret, and is not always necessary.
- The complete radiation pattern in 2 coordinates can be determined from 2 single-coordinate patterns in the θ & φ planes as given by Eq.9.8.

$$P(\theta,\phi) = P(\theta,0)\, P(0,\phi) \quad [9.8]$$

Effective Aperture

- The effective aperture of a receiving antenna is a measure of the effective area presented to the incident wave by the antenna.
- The transmitting gain G and receiving effective area A_e of a lossless antenna are related by

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \rho_a A}{\lambda^2} \quad [9.9]$$

- In Eq.9.9, λ=wavelength, ρ_a=antenna aperture efficiency, A=physical area of the antenna, and $Ae=\rho_a A$.
- The aperture efficiency depends on the nature of the current illumination across the antenna aperture.
- With a uniform illumination, $\rho_a = 1$.
- The advantage of high efficiency is obtained with a uniform illumination.
- This advantage is tempered by the radiation pattern having a relatively high peak-sidelobe level.
- The aperture illumination that is maximum at the centre of the aperture & tapers off in amplitude towards the edges has lower sidelobes.
- But, the above type of illumination has less efficiency than the uniform illumination.

Polarization

- The polarization of an electromagnetic wave is defined by the orientation of the electric field.
- Most radar antennas are **linearly polarized**, with the orientation of the electric field being either horizontal or vertical.
- Air-surveillance radars generally employ horizontal polarization.

- Most tracking radars are vertically polarized.
- **Circular polarization** occurs when the electric field rotates at a rate equal to the RF frequency.
- It is sometimes used to enhance the detectability of aircraft targets in the midst of rain.
- There is also **elliptical polarization**, where the electric field also rotates at the RF frequency.
- Unlike circular polarization, the amplitude of the elliptically polarized electric field varies during the rotation period.
- Circular & linear polarizations are special cases of elliptical polarization.

7 a) Define Noise Figure of a receiver with relevant equations. Derive expression for Noise Figure of N networks in cascade. [10 = 6+4] CO3 L3

Solution :

- Definition – The receiver noise figure is a measure of the noise produced by a practical receiver compared to that of an ideal receiver.
- The noise figure of a linear network may be defined as :

$$F_n = \frac{N_{out}}{kT_0B_nG} \quad \text{or} \quad \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \qquad (11.1)$$

where N_{out} = available output noise power; $kT_0B_n = N_{in}$ = available input noise power; k = Boltzmann's constant = 1.38×10^{-23} J/deg; T_0 = standard temperature of 290 K (approximately room temperature); B_n = noise bandwidth defined by Eq. (2.3); $G = S_{out}/S_{in}$ = available gain; S_{out} = available output signal power; and S_{in} = available input signal power. The term "available power" refers to the power that would be delivered to a matched load. (The term "available" will be understood in the following discussion of noise figure and is not mentioned further.) The product $kT_0 = 4 \times 10^{-21}$ W/Hz

- The reason for a standard temperature T_o in the definition of noise figure is to refer measurements made under different temperatures to a common basis.
- Equation (11.1) permits 2 different, but equivalent, interpretations of the noise figure.
  - ✓ It may be considered (RHS) as the degradation of the SNR as the signal passes through the network.
  - ✓ It may be interpreted (LHS) as the ratio of the noise-power out of the actual network to the noise-power out of an ideal network.
  - ✓ The ideal network above is that which amplifies the input thermal noise & introduces no additional noise of its own.
- The noise figure of Eq.(11.1) can be expanded as

$$F_n = \frac{kT_0B_nG + \Delta N}{kT_0B_nG} = 1 + \frac{\Delta N}{kT_0B_nG} \qquad [11.2]$$

where ΔN is the additional noise introduced by the practical (nonideal) network.

The noise figure is commonly expressed in decibels; that is, $10 \log F_n$. The term *noise factor* has also been used at times instead of noise figure. The definition of noise figure assumes that the input and output of the network are matched. In some devices, less noise is obtained under mismatched, rather than matched, conditions. In spite of definitions, such networks would be operated so as to achieve the maximum output signal-to-noise ratio.

Noise Figure of Networks in Cascade

- Consider 2 networks in cascade, each with the same noise bandwidth B_n but with different noise figures & gain, Fig.11.1.
- Let F_1, G_1 be the noise figure & gain of the first network & F_2,G_2 be similar parameters for the second network.
- The problem is to find F_0, the overall noise figure of the 2 networks in cascade.
- From the definition of noise figure given by Eqs.(11.1) and (11.2), the output noise N_{out} of the 2 networks in cascade is :

N_{out} = noise from network 1 at output of network 2 + noise ΔN_2 introduced by network 2

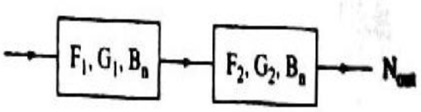
$$= F_0kT_0B_nG_1G_2 = F_1kT_0B_nG_1G_2 + \Delta N_2 = F_1kT_0B_nG_1G_2 + (F_2 - 1)\, kT_0B_nG_2$$

which results in

$$F_0 = F_1 + \frac{F_2 - 1}{G_1} \qquad [11.3]$$

It is not sufficient that the first stage of a low-noise receiver have a low noise figure. The second stage must also have a low noise figure or, if not, the gain of the first stage needs to be large. Too large a first-stage gain, however, is not always desirable since the dynamic range of the receiver is reduced by the gain G_1 of the low-noise amplifier. If the first network is not an amplifier, but is a diode mixer, the gain G_1 should be interpreted as a number less than unity (a loss).

Figure 11.1 Two networks in cascade with different noise figures and gains, but the same noise bandwidths.



The noise figure of N networks in cascade may be shown to be

$$F_0 = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_N - 1}{G_1 G_2 \cdots G_{N-1}} \quad [11.4]$$

Similar expressions may be derived when the bandwidth and/or temperature of the individual networks are not the same.[4]

b) Explain Noise Temperature with relevant equations.
Solution:

- The noise introduced by a network may also be expressed as the **effective noise temperature**, T_e.
- It is defined as the (fictional) temperature at the input of the network, that accounts for the additional noise ΔN at the output.
- Therefore, $\Delta N = kT_eB_nG$ and from Eq.(11.2), we have,

and from Eq. (11.2) we have

$$F_n = 1 + \frac{T_e}{T_0} \quad [11.5]$$

$$T_e = (F_n - 1)T_0 \quad [11.6]$$

The *system noise temperature* T_s is defined as the effective noise temperature of the receiver including the effects of antenna temperature T_a. If the receiver effective noise temperature is T_e, then

$$T_s = T_a + T_e = (F_s - 1)T_0 \quad [11.7]$$

where F_s is the *system noise figure*. This equation also defines the system noise figure when it includes the effects of the antenna temperature T_a and receiver effective noise temperature T_e.

The effective noise temperature of a receiver consisting of a number of networks in cascade is

$$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \cdots \quad [11.8]$$

where T_i and G_i are the effective noise temperature and gain of the ith network.

The effective noise temperature and the noise figure both describe the same characteristic of a network. The effective noise temperature generally is used to describe the noise performance of very low-noise receivers, lower than might be of interest for radar. It is also preferred by some radar engineers and many receiver designers as being more useful than noise figure for analysis purposes. The noise figure, however, seems to be the more widely used term to describe radar receiver performance, and is used in this text for that purpose.

8	a) What is the role of duplexers in radar system? Illustrate the transmit condition and receive condition in the case of balanced duplexer.	[10 = 6+4]	CO3	L2

Solution :

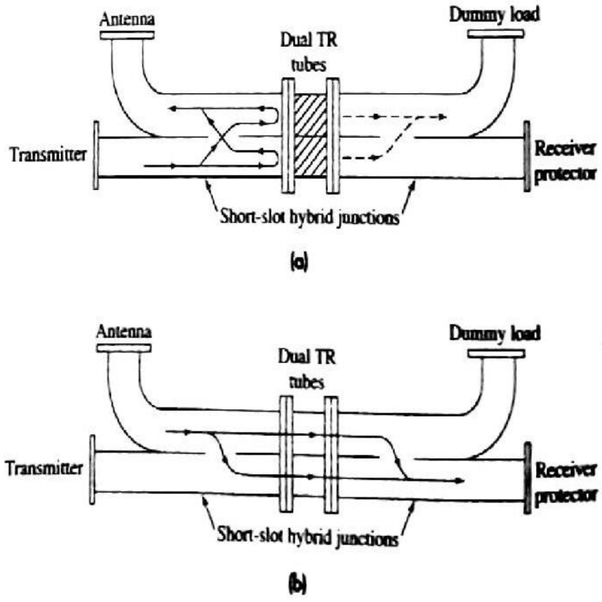
- A pulse radar can time share a single antenna between the transmitter and receiver by employing a **duplexer**.
- Duplexer is a fast-acting switching device.
- On transmission, the duplexer must protect the receiver from damage or burnout.
- On reception, it must channel the echo signal to the receiver & not to the transmitter.
- Furthermore, it must accomplish the switching rapidly, in microseconds or nanoseconds, & it should be of low loss.
- For high power applications, the duplexer is a gas-discharge device called a TR (transmit-receive) switch.
- The high-power pulse from the transmitter causes the gas discharge device to break down.
- This causes the receiver to be short circuited to protect it from damage.
- On receive, the RF circuitry of the "cold" duplexer directs the echo signal to the receiver rather than the transmitter.
- Solid state devices have also been used in duplexers.
- In a typical duplexer application, the transmitter peak power might be a megawatt or more.
- The maximum safe power that can be tolerated by the receiver might be less than a watt.
- The duplexer, therefore, must provide more than 60 dB to 70 dB of isolation between the transmitter and recovery.
- It should accomplish this with negligible loss on transmit and receive.

<u>Balanced Duplexer</u>

- The balanced duplexer is a popular form of duplexer with good power handling capability and wide bandwidth.
- The balanced duplexer, shown in Fig.11.3, is based on the short-slot hybrid junction.
- This junction consists of 2 sections of waveguides joined along one of their narrow walls.
- A slot is cut in the common wall to provide coupling between the two.
- The slot hybrid junction may be thought of as a broadband directional coupler with a coupling ratio of 3dB (Half Power).
- 2 TR tubes are used, one in each section of waveguide.
- In the transmit condition, Fig.11.3a, power is divided equally into each waveguide.
- This is done by the 1^{st} hybrid junction (on the left).
- Both gas-discharge TR tubes break down & reflect the incident power out of the antenna arm as shown.
- The short-slot hybrid junction has the property that each time power passes through the slot in either direction, its phase is advanced by 90°.

- The power travels as indicated by the solid lines.
- Any power that leaks through the TR tubes (shown by the dashed lines) is directed to the arm with the matched dummy load.
- It is not directed to the receiver.
- In addition to the attenuation provided by the TR tubes, the hybrid junctions provide an additional 20dB to 30dB of isolation.

Figure 11.3 Balanced duplexer using dual TR tubes and two short-slot hybrid junctions. (a) Transmit condition and (b) receive condition.



- On reception, the TR tubes do not fire and the echo signals pass through the duplexer & into the receiver as shown in Fig.11.3b.
- The power splits equally at the 1st junction.
- Because of the 90° phase advance on passing through the slot, the signal recombines.
- This happens in the receiving arm & not in the arm with the dummy load.

b) Explain electronically steered phased array antennas.
Solution :

- A phased array is a directive antenna made up of a number of individual antennas, or radiating elements.
- Its radiation pattern is determined by the amplitude & phase of the current at each of its elements.
- The phased array antenna has the advantage of being able to have its beam electronically steered in angle.
- This is done by changing the phase of the current at each element.
- The beam of a large fixed phased-array antenna can be rapidly steered from one direction to another.
- There is no need for mechanically positioning a large & heavy antenna.

A typical phased array radar for microwave radar might have several thousand individual radiating elements.
These radiating elements are, for eg., ferrite or diode phase shifters that allow the beam to be switched.
The switching is done from one direction to another in several microseconds, or less.

Electronically steerable phased arrays are of interest because they can provide:

- Agile, rapid beam-steering.
- Potential for large peak and large average power. Each element can have its own transmitter. The power-aperture product can be large, especially at the lower frequencies.
- Multiple-target tracking. This can be accomplished either by generating multiple, simultaneous, independent beams or by rapidly switching a single beam to view more than one target in sequence.
- A convenient means to employ solid-state transmitters.
- Convenient shape for flush mounting or for blast hardening.
- Control of the aperture illumination because of the many antenna elements available.
- A lower radar cross section, if properly designed.
- Operation with more than one function (a multifunction radar), especially if all functions are best performed at the same frequency.

- The chief disadvantages of a phased array radar are that :
  - It is complex.
  - Can be of high cost.
  - Its ability to employ multiple functions requires serious compromises for some applications.
- A **linear array** consists of antenna elements arranged in a straight line in one dimension.
- A **planar array** is a 2-dimensional configuration of antenna elements arranged to lie in a plane.

- In both linear & planar arrays, the element spacings usually are uniform (equal spacing).
- The planar array may be thought of as a linear array of linear arrays.
- Most phased arrays of interest for radar are planar.
- A **broadside array** is one in which the direction of maximum radiation is perpendicular (or almost so) to the plane (or line) of the antenna.
- An **endfire array** has its maximum radiation parallel to the array or at a small angle to the plane of the array.
- Fig.9.14, shows a receiving linear array made up of N elements equally spaced a distance **d** apart.

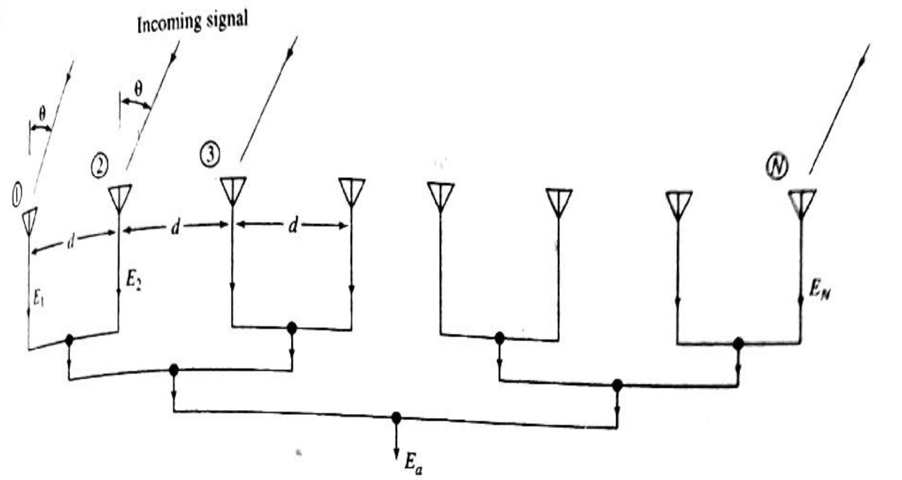


Figure 9.14 N-element receiving, parallel-feed, linear array, with equal lengths of transmission lines between each antenna element and the antenna output (at the bottom on the figure).

***NOTE* : THE QUESTIONS SHOULD BE NEATLY WRITTEN & ANSWERED IN STUDENT'S OWN HANDWRITING. ON TOP OF EACH PAGE, WRITE YOUR NAME, USN & PAGE NO. BEFORE MAKING A PDF AND UPLOADING THE PDF IN GOOGLE CLASSROOM. TOTAL TIME TAKEN SHOULD NOT EXCEED 2 HOURS FOR BOTH ANSWERING & UPLOADING THE PDF (1.5 HOUR FOR ANSWERING + 0.5 HOUR FOR UPLOADING PDF). PDF SUBMITTED AFTER 2 HOURS OR NOT AS PER THE ABOVE INSTRUCTIONS WILL NOT BE VALUATED AND MARKS ALLOTED WILL BE ZERO FOR THE TEST.**

ALL THE BEST