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Internal Assessment Test 2 – Nov. 2025

Subject/Code: RADAR COMMUNICATION				Code: BEC714D
Date:28.11.2025	Duration: 90 mins	Max. Marks: 50	Semester: 07	Branch: ECE

Sl.	Answer any FIVE FULL Questions	Marks	CO	RBT
1	Explain in detail the RADAR the various RADAR accuracy measurements such as range,accuracy ,resolution and velocity accuracy.Provide mathematical expressions wherever applicable.	10	CO2	L2
2	Derive the surface clutter RADAR equation and explain the role of backscatter coefficient,grazing angle and illuminated area.	10	CO3	L2
3	Explain the construction and working principle of Linear power tubes used in RADAR transmitters with suitable diagram.	10	CO3	L2
4	Explain the working of superheterodyne radio reciever with diagram and describe IF processing	10	CO3	L2
5	Explain the concept and working principle of Synthetic aperture Radar(SAR) with neat diagrams.	10	CO4	L2
6	Explain the introduction and Principles of Over-the-Horizon-RADAR and discuss its need in long range surveillenace.	10	CO4	L2
7	Describe range performance of SSR and explain factors determining maximum range and accuracy.	10	CO4	L2

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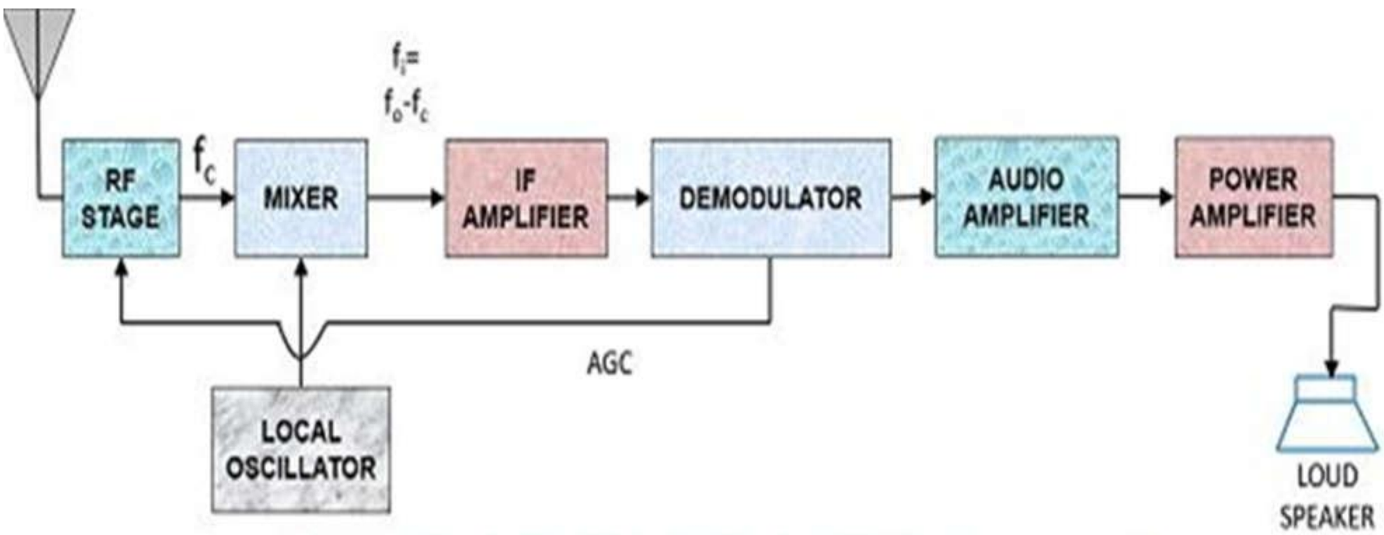

The superheterodyne radio was one of the most successful forms of radio being used almost exclusively as the RF circuit design topology of choice until recent years.

It works on the principle of heterodyning which simply means mixing.

The superheterodyne radio receiver mixes the received signal frequency with the frequency of the signal generated by a local oscillator.

Working of Superheterodyne Receiver

The incoming signal of the superheterodyne receiver goes through the antenna and is filtered to reject the image frequency and then amplified by the RF amplifier.

RF amplifier amplifies a particular carrier frequency within the AM broadcast range.

The selected frequency and two sidebands are allowed to go through the amplifier.

The carrier of the received signal is called radio frequency carrier and its frequency is radio frequency f_{RF} and the local oscillator signal operates at f_{OSC}.

Then this amplified RF frequency is mixed with the local oscillator frequency.

The mixer combines these two signals which produce the sum and difference of frequency signals of the incoming carrier signal and local oscillator signal, which are $f_{OSC}+f_{RF}$ and $f_{OSC}-f_{RF}$.

The (fOSC+fRF) sum of frequency is rejected by the filter and the remaining difference frequency ($f_{OSC}-f_{RF}$) signal which is a down-converted frequency signal is called an intermediate frequency (IF) carrier ($f_{IF}= f_{OSC}-f_{RF}$).

The original carrier signal and the IF carrier signal of the modulation is the same and it has a fixed frequency of 455kHz which is amplified by one or more stages of amplification.

The IF amplifier amplified the IF signal which raises its level for the information extraction process.

The IF amplifier fulfills the gain and bandwidth requirements of the receiver.

The detector received the amplified IF signal to detect the information signal component from 455 kHz IF, to reproduce the original information data, which is generally in the form of the audio signal.

The detector stage is used to eliminate one of the sidebands which are still present and separates the RF from the audio components of the other sideband.

The RF component is filtered out and audio is applied to the audio stages for amplification.

The amplified audio signal is then applied to the AF amplifier to increase the audio frequency level of the signal and to provide enough gain to drive the speaker or headphones.

A speaker is connected to the AF amplifier to play the audio information signal.

The superheterodyne receiver is Automatic gain control (AGC) which is given to the RF, IF and mixer stages to generate constant output irrespective of the varying input signal.

2.Surface Clutter RADAR Equation – Derivation and Explanation

The surface clutter radar equation describes the power received by a radar from ground or sea clutter. It is derived from the basic radar equation by considering distributed targets instead of a single point target.

Basic Radar Equation

For a point target, the received power Pr is:

$$P_r = (P_t * G^2 * \lambda^2 * \sigma) / ((4\pi)^3 * R^4 * L)$$

where:
Pt = transmitted power
G = antenna gain
λ = wavelength
σ = radar cross section (RCS)
R = range to target

L = system losses

Distributed Surface Clutter Concept

For surface clutter, the radar echo comes from a large number of small scatterers distributed over an illuminated area A. Instead of a single RCS σ, the surface is characterized by the backscatter coefficient σ^0 (sigma-naught).

σ^0 is defined as:

$$\sigma^0 = \sigma / A$$

Thus, the total radar cross section of the illuminated surface becomes:

$$\sigma = \sigma^0 * A$$

Surface Clutter Radar Equation

Substituting $\sigma = \sigma^0 * A$ into the basic radar equation:

$$Pr = (Pt * G^2 * \lambda^2 * \sigma^0 * A) / ((4\pi)^3 * R^4 * L)$$

This is the surface clutter radar equation.

Illuminated Area (A)

The illuminated area depends on the radar beamwidth and pulse length. For a real aperture radar:

$$A \approx (R * \theta_{az}) * (c\tau / (2 \sin \psi))$$

where:
θ_{az} = azimuth beamwidth
c = speed of light
τ = pulse width
ψ = grazing angle

This shows that the illuminated area increases with range and decreases with increasing grazing angle.

Role of Backscatter Coefficient (σ^0)
The backscatter coefficient σ^0 represents the scattering strength of the surface per unit area. It depends on surface roughness, material properties, polarization, frequency, and grazing angle.

Higher σ^0 → stronger clutter returns.

Role of Grazing Angle (ψ)
The grazing angle is the angle between the radar line-of-sight and the surface. It strongly influences clutter power:

- At low grazing angles, σ^0 is usually small but the illuminated area is large.
- At higher grazing angles, σ^0 increases but the illuminated area decreases.

Thus, grazing angle affects clutter power both through σ^0 and A.

1.RADAR Accuracy Measurements

Radar accuracy measurements describe how precisely a radar system can determine target parameters such as range, angle, velocity, and how well it can distinguish between closely spaced targets. The major radar accuracy measures include range accuracy, range resolution, angular accuracy, angular resolution, and velocity (Doppler) accuracy.

Range Accuracy

Range accuracy refers to how precisely a radar can measure the distance to a target.

For a pulsed radar, range R is given by:

$$R = c\, t / 2$$

where:
c = speed of light
t = round-trip time delay

The range accuracy ΔR depends on the ability to measure time delay accurately:

$$\Delta R = c\, \Delta t / 2$$

Range accuracy is influenced by:
- Signal-to-noise ratio (SNR)
- Receiver bandwidth
- Pulse shape and timing jitter

Range Resolution

Range resolution is the radar's ability to distinguish between two targets that are close together in range.

For a pulsed radar, the range resolution ΔRr is:

$$\Delta Rr = c\, \tau / 2$$

where τ is the pulse width.

A shorter pulse width results in better range resolution.

For pulse-compression radars:

$$\Delta Rr = c / (2B)$$

where B is the signal bandwidth.

Angular Accuracy

Angular accuracy refers to how precisely a radar can determine the direction (azimuth and elevation) of a target.

The angular accuracy $\Delta\theta$ depends on antenna beamwidth and SNR:

$$\Delta\theta \approx \theta BW / (2 \sqrt{SNR})$$

where θBW is the antenna half-power beamwidth.

Higher SNR and narrower beamwidth improve angular accuracy.

Angular Resolution

Angular resolution is the ability of the radar to separate two targets at the same range but at different angles.

It is approximately equal to the antenna beamwidth:

$$\Delta\theta r \approx \theta BW \approx \lambda / D$$

where:
λ = wavelength
D = antenna aperture dimension

A larger antenna aperture provides better angular resolution.

Velocity (Doppler) Accuracy

Radar measures target velocity using the Doppler frequency shift.

The Doppler frequency fd is:

$$fd = 2v / \lambda$$

where v is the radial velocity of the target.

Velocity accuracy Δv depends on Doppler frequency measurement accuracy Δfd:

$$\Delta v = (\lambda / 2) \Delta fd$$

For coherent radars, Doppler frequency resolution is:

$$\Delta fd = 1 / Tc$$

where Tc is the coherent processing interval (CPI).

Thus:

$$\Delta v = \lambda / (2 Tc)$$

Factors Affecting Radar Accuracy

Radar accuracy is influenced by several factors:

• Transmitted signal bandwidth
• Antenna size and beamwidth
• Signal-to-noise ratio (SNR)
• Pulse repetition frequency (PRF)

• System stability and calibration

5.Synthetic Aperture Radar (SAR)

Introduction

Synthetic Aperture Radar (SAR) is an advanced form of radar used to generate high-resolution images of the Earth's surface. Unlike conventional real-aperture radar, SAR uses the motion of the radar platform (aircraft or satellite) to synthesize a very large antenna aperture electronically, thereby achieving much finer azimuth resolution.

Basic Concept of SAR
In a real aperture radar, azimuth resolution depends directly on the physical antenna length. In SAR, as the radar platform moves forward, echoes from a target are collected over a long distance. These echoes are coherently processed to simulate a large antenna, known as a synthetic aperture.

This synthetic aperture provides high azimuth resolution independent of range.

Geometry of SAR (Neat Diagram)
Side-looking SAR geometry:

```
      Flight Direction →
 --------------------------------
    *     *     *     *     *   ← Radar positions
     \     \     \     \     \
      \     \     \     \     \  Slant Range (R)
       \     \     \     \     \
        ●  Target on ground
```

The radar illuminates the same target from multiple positions as it moves forward.

Working Principle of SAR
The working of SAR involves the following steps:

1. The radar transmits a sequence of coherent pulses while moving along its flight path.
2. Each ground target remains within the antenna beam for a certain time called the dwell time.
3. Echoes from the same target are received at multiple radar positions with different phases.
4. These echoes are stored and coherently processed using Doppler frequency information.
5. Signal processing synthesizes a long antenna, producing fine azimuth resolution.

Azimuth Resolution in SAR

For a real aperture radar, azimuth resolution is:

$$\Delta Az_{real} = R \lambda / D$$

where:
R = range
λ = wavelength
D = antenna length

For SAR, the azimuth resolution is:

$$\Delta Az\_SAR = D / 2$$

This shows that SAR azimuth resolution is independent of range and wavelength.

Range Resolution in SAR

Range resolution in SAR is determined by the transmitted signal bandwidth:

$$\Delta R = c / (2B)$$

where:
c = speed of light
B = signal bandwidth

Pulse compression techniques are commonly used to achieve high range resolution.

Advantages of SAR

• High-resolution imaging independent of altitude
• Day-and-night and all-weather operation
• Ability to penetrate clouds, rain, and fog
• Suitable for Earth observation, surveillance, and reconnaissance

Applications of SAR
• Remote sensing and Earth observation
• Military surveillance and reconnaissance
• Disaster monitoring (floods, earthquakes)
• Oceanography and ice monitoring
• Terrain mapping

6.Over-the-Horizon Radar (OTHR)

Introduction

Over-the-Horizon Radar (OTHR) is a type of radar system designed to detect and track targets at very long ranges, typically beyond the normal line-of-sight limit of conventional radars. Traditional radars are limited by the curvature of the Earth, restricting their detection range to a few hundred kilometers. OTHR overcomes this limitation by using special propagation mechanisms that allow radar waves to travel beyond the horizon.

OTHR systems are widely used for long-range surveillance, early warning, and strategic defense applications.

Limitation of Conventional Radar

The maximum detection range of a conventional radar is limited by Earth’s curvature and is given approximately by:

$$R\_max \approx \sqrt{2 h R\_e}$$

where:

h = height of the radar antenna
R_e = radius of the Earth

This limitation makes conventional radars unsuitable for very long-range surveillance.

Principle of Over-the-Horizon Radar

Over-the-Horizon Radar operates by transmitting high-frequency (HF) radio waves, typically in the 3–30 MHz band. These waves can travel beyond the Earth's curvature using one of the following propagation mechanisms:

1. Sky-wave (ionospheric) propagation
2. Surface-wave propagation

Sky-Wave OTHR (Ionospheric Reflection)

In sky-wave OTHR, the transmitted HF radar waves are directed toward the ionosphere. The ionosphere reflects or refracts these waves back toward the Earth's surface, allowing them to illuminate targets well beyond the horizon. The reflected echoes from the targets follow the same path back to the receiver.

This method enables detection ranges of 1000 to 3000 km.

Surface-Wave OTHR

Surface-wave OTHR exploits the ability of vertically polarized HF waves to propagate along the Earth's surface, following the curvature of the Earth. This mode is particularly effective over seawater due to its high conductivity.

Surface-wave OTHR is commonly used for maritime surveillance with ranges up to 300–500 km.

Working Principle of OTHR

The basic working principle of OTHR involves the following steps:

1. The radar transmits HF signals toward the horizon or ionosphere.
2. The signals propagate via sky-wave or surface-wave mechanisms.
3. Targets beyond the line of sight scatter the incident waves.
4. The scattered echoes return to the radar receiver.
5. Signal processing techniques estimate target range, velocity, and direction.

Need for OTHR in Long-Range Surveillance

The need for Over-the-Horizon Radar arises due to several strategic and operational requirements:

- Early detection of aircraft, missiles, and ships at long distances
- Wide-area surveillance covering thousands of kilometers
- Reduced reliance on satellites for continuous monitoring
- Cost-effective solution for national border and maritime surveillance
- Ability to detect low-flying or stealth targets

Advantages of OTHR

- Extremely long detection range
- Large area coverage
- All-weather, day-and-night operation
- Capability to detect targets beyond Earth’s curvature

Limitations of OTHR

- Lower resolution compared to microwave radars
- Dependence on ionospheric conditions
- Susceptibility to interference and noise
- Complex signal processing requirements

7.Range Performance of Secondary Surveillance Radar (SSR)

Introduction to SSR

Secondary Surveillance Radar (SSR) is a cooperative radar system widely used in air traffic control. Unlike Primary Surveillance Radar (PSR), SSR does not rely on reflected echoes from targets. Instead, it operates by interrogating aircraft transponders, which reply with coded signals containing identification and altitude information. The range performance of SSR is a critical parameter that determines its effectiveness in airspace surveillance.

Basic Principle of SSR Range Measurement

In SSR, the radar measures range based on the time delay between the transmitted interrogation signal and the received reply from the aircraft transponder.

The range R is given by:

$$R = (c \cdot t) / 2$$

where:
c = speed of light
t = round-trip time delay between interrogation and reply

Range Performance of SSR

The range performance of SSR refers to its ability to detect, identify, and accurately locate aircraft over a specified maximum distance. Since SSR relies on active transponder replies, its detection range is generally greater and more reliable than that of primary radar for the same transmitted power.

SSR range performance is influenced by transmitter power, antenna characteristics, transponder sensitivity, and propagation conditions.

Maximum Range of SSR

The maximum usable range of SSR is determined by the radar link budget and is limited by the ability of the ground radar to receive the transponder reply signal.

The maximum range R_{max} can be approximated using the radar range equation for SSR:

$$R_{max} \propto \sqrt{P_t \cdot G_t \cdot G_r / S_{min}}$$

where:
P_t = transmitted interrogation power
G_t = ground radar antenna gain
G_r = receiving antenna gain
S_{min} = minimum detectable signal at the receiver

Factors Determining Maximum Range

The main factors affecting the maximum range of SSR are:

- Transmitted interrogation power
- Antenna gain and beam shape
- Sensitivity and performance of aircraft transponder
- Receiver sensitivity and noise figure
- Line-of-sight and Earth curvature limitations
- Atmospheric propagation conditions

Range Accuracy of SSR

Range accuracy in SSR refers to how precisely the radar can determine the distance to an aircraft.

Range accuracy ΔR is related to timing accuracy Δt:

$$\Delta R = (c \cdot \Delta t) / 2$$

High timing precision in the interrogator and receiver circuits leads to better range accuracy.

Factors Affecting Range Accuracy

Several factors influence the range accuracy of SSR:

- Timing jitter in interrogation and reply signals
- Transponder reply delay variations
- Receiver bandwidth and signal processing
- Multipath propagation effects
- Synchronization accuracy of radar electronics

Advantages of SSR Range Performance
- Longer detection range compared to primary radar
- High reliability due to cooperative target response
- Improved accuracy in aircraft positioning
- Reduced clutter and interference effects

3.Linear Power Tubes Used in RADAR Transmitters

Introduction

Linear power tubes are microwave vacuum electronic devices used in radar transmitters to amplify RF signals linearly. They are called linear devices because the output RF signal is an amplified replica of the input signal without distortion. Linear power tubes are essential in modern radar systems, especially in applications requiring high power, high frequency, and good spectral purity.

The most commonly used linear power tubes in radar transmitters are:
• Klystron amplifier
• Traveling Wave Tube (TWT)

Klystron Amplifier

Construction of Klystron

A klystron amplifier consists of the following main components:

• Electron gun – produces and accelerates an electron beam
• Input cavity (buncher cavity)
• Drift space
• Output cavity (catcher cavity)
• Collector

Neat diagram (schematic):

```
 Electron Gun   Buncher     Drift Space     Catcher     Collector
   [====>]    | |   -----------   | |      [====]
```

Working Principle of Klystron

The klystron works on the principle of velocity modulation and electron bunching:

1. The electron gun emits a focused electron beam.
2. The RF input signal is applied to the buncher cavity, causing velocity modulation of electrons.
3. Faster electrons catch up with slower ones in the drift space, forming electron bunches.
4. These bunches pass through the catcher cavity, inducing a strong RF output signal.
5. The spent electron beam is collected by the collector.

The klystron provides high gain and high output power with good linearity.

Traveling Wave Tube (TWT)

Construction of TWT

A Traveling Wave Tube consists of the following components:

• Electron gun
• Slow-wave structure (helix)
• RF input coupler
• RF output coupler

• Collector
• Magnetic focusing system

Neat diagram (schematic):

Electron Gun → Helix (Slow-wave Structure) → Collector
RF Input ---------------------- RF Output

Working Principle of TWT
The TWT operates based on continuous interaction between the electron beam and the RF wave:

1. The electron gun produces a narrow electron beam.
2. The RF signal is fed into the helix, which slows down the RF wave.
3. The slowed RF wave interacts with the electron beam, causing velocity modulation.
4. Energy is transferred continuously from the electron beam to the RF wave.
5. An amplified RF signal is extracted at the output.

TWTs provide very wide bandwidth and high gain, making them suitable for modern radar systems.

Comparison of Linear Power Tubes

Klystron:
• High power capability
• Narrow bandwidth
• Used in high-power radar transmitters

TWT:
• Wide bandwidth
• Moderate to high power
• Used in airborne and spaceborne radars

Applications in Radar Transmitters

Linear power tubes are used in radar transmitters for:

• Pulse compression radars
• Phased array radars
• Airborne and spaceborne radars
• Continuous wave and Doppler radars