LECTURE NOTES
ON
RADAR SYSTEMS

IV B.Tech II semester (JNTUH-R13)

ELECTRONICS AND COMMUNICATION ENGINEERING
SYLLABUS

UNIT–I:
RADAR EQUATION: SNR, Envelope Detector, False Alarm Time and Probability, Integration of Radar Pulses, Radar Cross Section of Targets (simple targets - sphere, cone-sphere), Transmitter Power, PRF and Range Ambiguities, System Losses (qualitative treatment), Illustrative Problems.

UNIT–II:

UNIT–III:

UNIT–IV:
TRACKING RADAR: Tracking with Radar, Sequential Lobing, Conical Scan, Monopulse Tracking Radar – Amplitude Comparison Monopulse (one- and two coordinates), Phase Comparison Monopulse, Tracking in Range, Acquisition and Scanning Patterns, Comparison of Trackers.

UNIT–V:
RADAR RECEIVERS: Noise Figure and Noise Temperature, Displays – types. Duplexers – Branch type and Balanced type, Circulators as Duplexers. Introduction to Phased Array Antennas – Basic Concepts, Radiation Pattern, Beam Steering and Beam Width changes, Series versus Parallel Feeds, Applications, Advantages and Limitations.

TEXT BOOKS:

REFERENCES:
1. Introduction to radar systems-Merrill I.Skolnik 3rd Ed., TMH, 2001
UNIT-I
NATURE OF RADAR
INTRODUCTION:

The name Radar stands for Radio Detection and Ranging

Radar is a remote sensing technique: Capable of gathering information about objects located at remote distances from the sensing device.

Two distinguishing characteristics:

1. Employs EM waves that fall into the microwave portion of the electromagnetic spectrum

   \[1 \text{ mm} < l < 75 \text{ cm}\]

2. Active technique: radiation is emitted by radar – radiation scattered by objects is detected by radar.
Radar is an electromagnetic system for the detection and location of objects (Radio Detection and Ranging). Radar operates by transmitting a particular type of waveform and detecting the nature of the signals reflected back from objects.

Radar can’t resolve detail or color as well as the human eye (an optical frequency passive scatter meter).

Radar can see in conditions which do not permit the eye to see such as darkness, haze, rain, smoke.

Radar can also measure the distances to objects. The elemental radar system consists of a transmitter unit, an antenna for emitting electromagnetic radiation and receiving the echo, an Energy detecting receiver and a processor.
A portion of the transmitted signal is intercepted by a reflecting object (target) and is reradiated in all directions. The antenna collects the returned energy in the backscatter direction and delivers it to the receiver. The distance to the receiver is determined by measuring the time taken for the electromagnetic signal to travel to the target and back.

The direction of the target is determined by the angle of arrival (AOA) of the reflected signal. Also, if there is relative motion between the radar and the target, there is a shift in frequency of the reflected signal (Doppler Effect) which is a measure of the radial component of the relative velocity. This can be used to distinguish between moving targets and stationary ones.

Radar was first developed to warn of the approach of hostile aircraft and for directing anti-aircraft weapons. Modern radars can provide AOA, Doppler, and MTI etc.
RADAR RANGE MEASUREMENT
Target range = \(2 \times \text{round trip time}\) where \(c = \text{speed of light}\).
The simplest radar waveform is a train of narrow (0.1µs to 10µs) rectangular pulses modulating a sinusoidal carrier the distance to the target is determined from the time $T_R$ taken by the pulse to travel to the target and return and from the knowledge that electromagnetic energy travels at the speed of light.

Since radio waves travel at the speed of light ($v = c = 300,000$ km/sec)

$$\text{Range} = \frac{c \times \text{time}}{2}$$

The range or distance, $R = \frac{cT_R}{2}$

$$R \text{ (in km)} = 0.15T_R \text{ (µs)} ; R \text{ (in nmi)} = 0.081T_R \text{ (µs)}$$

**NOTE:**

- 1 nmi = 6076 feet = 1852 meters.
- 1 Radar mile = 2000 yards = 6000 feet
- **Radar mile** is commonly used unit of distance.

**NOTE:**

Electromagnetic energy travels through air at approximately the speed of light:-
1. 300,000 kilometers per second.

2. 186,000 statute miles per second.

3. 162,000 nautical miles per second.

Once the pulse is transmitted by the radar a sufficient length of time must elapse before the next pulse to allow echoes from targets at the maximum range to be detected. Thus the maximum rate at which pulses can be transmitted is determined by the maximum range at which targets are expected. This rate is called the pulse repetition rate (PRF).

If the PRF is too high echo signals from some targets may arrive after the transmission of the next pulse. This leads to ambiguous range measurements. Such pulses are called second time around pulses.

The range beyond which second time around pulses occur is called the maximum unambiguous range.

\[ R_{\text{UNAMBIG}} = \frac{c}{2f_p} \]  

Where \( f_p \) is the PRF in Hz.

More advanced signal waveforms then the above are often used, for example the carrier may be frequency modulated (FM or chirp) or phase modulated (pseudorandom bi phase) too permit the echo signals to be compressed in time after reception. This achieves high range resolution without the need for short pulses and hence allows the use of the higher energy of longer pulses. This technique is called pulse compression. Also CW waveforms can be used by taking advantage of the Doppler shift to separate the received echo from the transmitted signal.

**Note:** unmodulated CW waveforms do not permit the measurement of range.
What is done by Radar?

Radar can see the objects in

- day or night
- rain or shine
- land or air
- cloud or clutter
- fog or frost
- earth or planets
- stationary or moving and
- Good or bad weather.

In brief, Radar can see the objects hidden anywhere in the globe or planets except hidden behind good conductors.
INFORMATION GIVEN BY THE RADAR:

Radar gives the following information:

- The position of the object
- The distance of objects from the location of radar
- The size of the object
- Whether the object is stationary or moving
- Velocity of the object
- Distinguish friendly and enemy aircrafts
- The images of scenes at long range in good and adverse weather conditions
- Target recognition
- Weather target is moving towards the radar or moving away
- The direction of movement of targets
- Classification of materials

NATURE AND TYPES OF RADARS:

The common types of radars are:

- Speed trap Radars
- Missile tracking Radars
- Early warning Radars
- Airport control Radars
- Navigation Radars
- Ground mapping Radars
- Astronomy Radars
- Weather forecast Radars
- Gun fire control Radars
- Remote sensing Radars
- Tracking Radars
- Search Radars
- IFF (Identification Friend or Foe)
- Synthetic aperture Radars
- Missile control Radars
- MTI (Moving Target Indication) Radars
- Navy Radars
- Doppler Radars
- Mesosphere, Stratosphere and Troposphere (MST) Radars
- Over-The-Horizon (OTH) Radars
- Mono pulse Radars
- Phased array Radars
- Instrumentation Radars
- Gun direction Radars
- Airborne weather Radars
PULSE CHARACTERISTICS OF RADAR SYSTEMS:

There are different pulse characteristics and factors that govern them in a Radar system.

- **Carrier**

- **Pulse width**

- **Pulse Repetition Frequency (PRF)**

- **Unambiguous Range**

**NOTE:** ECHO is a reflected EM wave from a target and it is received by a Radar receiver.

**CARRIER:** The carrier is used in a Radar system is an RF(radio frequency) signal with microwave frequencies.

Carrier is usually modulated to allow the system to capture the required data.

In simple ranging Radars, the carrier will be pulse modulated but in continuous wave systems such Doppler radar modulation is not required.
In pulse modulation, the carrier is simply switched ON & OFF in synchronization.

**PULSE WIDTH:** The pulse width of the transmitted signal determines the dead zone. When the Radar transmitter is active, the receiver input is blanked to avoid the damage of amplifiers. For example, a Radar echo will take approximately 10.8 µsec to return from 1 standard mile away target.

**PULSE REPETITION FREQUENCY (PRF):** PRF is the number of pulses transmitted per second. PRF is equal to the reciprocal of pulse repetition time (PRT). It is measured in Hertz

\[
\text{PRF} = \frac{1}{\text{PRT}}
\]

Pulse Interval Time or Pulse Reset Time (PRT) is the time interval between two pulses. It is expressed in milliseconds.

Pulse Reset Time = Pulse Repetition Time – Pulse Width

**UNAMBIGUOUS RANGE:** In simple systems, echoes from targets must be detected and processed before the next transmitter pulse is generated if range ambiguity is to be avoided.
Range ambiguity occurs when the time taken for an echo to return from a target is greater than the pulse repetition period (T).

Echoes that arrive after the transmission of the next pulse are called as second-time-around echoes.

The range beyond which targets appear as second-time-around echoes is called as the Maximum Unambiguous Range and is given by

\[ R_{UNAMBIG} = \frac{c}{2f_p} \]

\( c = \text{velocity of propagation} \quad \text{Where, } T_p = f_p \)
f_r is the PRF(PULSE REPETITION FREQUENCY) in Hz

TYPES OF BASIC RADARS:

- Monostatic and Bistatic
- CW
- FM-CW
- Pulsed radar

Monostatic radar uses the same antenna for transmit and receive. Its typical geometry is shown in the below fig.
Bistatic radars use transmitting and receiving antennas placed in different locations.

CW radars, in which the two antennas are used, are not considered to be bistatic radars as the distance between the antennas is not considerable. The bistatic radar geometry is shown in below fig.
RADAR WAVE FORMS:

The most common Radar waveform is a train of narrow, rectangular shape pulses modulating a sine-wave carrier.

The figure shows a pulse waveform, which can be utilized by the typical Radar.
From the given Radar waveform:

Peak power $p_t = 1 \text{ Mwatt}$

Pulse Width $\tau = 1 \mu\text{sec.}$

Pulse Repetition Period $T_p = 1 \text{ msec.}$

A maximum unambiguous range of 150 km was provided by the PRF $f_p = 1000 \text{ Hz.}$

$$R_{UNAMBIG} = \frac{c}{2f_p} \implies 150 \times 10^3 = \frac{3 \times 10^8}{2f_p}$$

$$\implies f_p = 1000 \text{ Hz.}$$

Then, the average power $P_{avg}$ of a repetitive pulse train wave form is given by $P_{avg} = p_t \tau / T_p$ $\implies$ 

$$P_{avg} = p_t \tau f_p$$

In this case, $P_{avg} = 1 \text{ Kwatt}$

For a Radar wave form, the ratio of the total time that the Radar is radiating to the total time it could have radiated is known as duty cycle.
Duty Cycle = \( \frac{\tau}{T} = \frac{\tau}{T_p} = \frac{P_{av}}{P_t} \)

Duty Cycle = \( \frac{\tau}{T_p} = 0.001 \)

The energy of the pulse is given by, \( E = \tau p_t = 1 \text{ Joule} \).

The Radar waveform can be extended in space over a distance of 300 meters using a pulse width of 1 \( \mu \)sec.

\( \text{i.e., Distance} = c \tau = 300 \text{ m.} \)

Half of the above distance (\( \text{i.e.} c \frac{\tau}{2} \)) can be used to recognize the two equal targets which are being resolved in range. In this case, a separation of 150m between two equal size targets can be used to resolve them.
<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Units</th>
<th>Typical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitted Frequency</td>
<td>f₀</td>
<td>MHz, GHz</td>
<td>1000-12500 MHz</td>
</tr>
<tr>
<td>Wavelength</td>
<td>ℓ</td>
<td>cm</td>
<td>3-10 cm</td>
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<td>Pulse Duration</td>
<td>t₀</td>
<td>sec</td>
<td>1 sec</td>
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<tr>
<td>Pulse Length</td>
<td>h</td>
<td>m</td>
<td>150-300 m (h=c/ℓ)</td>
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<tr>
<td>Pulse Repetition Frequency</td>
<td>PRF</td>
<td>sec⁻¹</td>
<td>1000 sec⁻¹</td>
</tr>
<tr>
<td>Interpulse Period</td>
<td>T</td>
<td>Milli sec</td>
<td>1 milli sec</td>
</tr>
<tr>
<td>Peak Transmitted Power</td>
<td>P₀</td>
<td>MW</td>
<td>1 MW</td>
</tr>
<tr>
<td>Average Power</td>
<td>P_{avg}</td>
<td>kW</td>
<td>1 kW (P_{avg} = P₀ / PRF)</td>
</tr>
<tr>
<td>Received Power</td>
<td>P_r</td>
<td>mW</td>
<td>10⁻⁶ mW</td>
</tr>
</tbody>
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The Radar Range Equation:

The radar range equation relates the range of the radar to the characteristics of the transmitter, receiver, antenna, target and the environment.

It is used as a tool to help in specifying radar subsystem specifications in the design phase of a program. If the transmitter delivers $P_\text{T}$ Watts into an isotropic antenna, then the power density ($\text{w/m}^2$) at a distance $R$ from the radar is
Here the $4\pi R^2$ represents the surface area of the sphere at distance $R$.

Radars employ directional antennas to channel the radiated power $P_t$ in a particular direction. The gain $G$ of an antenna is the measure of the increased power radiated in the direction of the target, compared to the power that would have been radiated from an isotropic antenna.
\[ \text{Power density from a directional antenna} = \frac{P_t G}{4\pi R^2} \]

The target intercepts a portion of the incident power and redirects it in various directions.

The measure of the amount of incident power by the target and redirected back in the direction of the radar is called the cross section \( \sigma \).

Hence the Power density of the echo signals at the radar is:

\[ \frac{P_t G \sigma}{4\pi R^2 4\pi R^2} \]

**Note:** the radar cross-section \( \sigma \) has the units of area. It can be thought of as the size of the target as seen by the radar.

The receiving antenna effectively intercepts the power of the echo signal at the radar over a certain area called the effective area \( A_e \).

Since the power density (Watts/m\(^2\)) is intercepted across an area \( A_e \), the power delivered to the receiver is

\[ P_r = \frac{P_t G \sigma}{4\pi R^2 4\pi R^2 A_e} \]

\[ P_r = \frac{(P_t G \sigma A_e)}{(4\pi R^2)^2} \Rightarrow R^4 = \frac{(P_t G \sigma A_e)}{(4\pi)^2 P_r} \]
\[ R = \left[ \frac{(P_t G \sigma A_e)}{(4\pi)^2 P_r} \right]^{1/4} \]

Now the maximum range \( R_{\text{max}} \) is the distance beyond which the target cannot be detected due to insufficient received power \( P_r \), the minimum power which the receiver can detect is called the minimum detectable signal \( S_{\text{min}} \). Setting, \( P_r = S_{\text{min}} \) and rearranging the above equation gives

\[ R_{\text{max}} = \left[ \frac{P_t G A_e \sigma}{(4\pi)^2 S_{\text{min}}} \right]^{\frac{1}{3}} \]

Note here that we have both the antenna gain on transmit and its effective area on receive.

\[ \frac{G}{4\pi} = \frac{A_e}{\lambda^2} \]

These are related by:

As long as the radar uses the same antenna for transmission and reception we have
Example: Use the radar range equation to determine the required transmit power for the TRACS radar given: $P_{rmin} = 10^{-13}$ Watts, $G=2000$, $\lambda=0.23m$, $PRF=524$, $\sigma=2.0 \text{ m}^2$

Now, $R_{max} = \frac{c}{PRF}$

From

$$P_r = \frac{P_r (4\pi)^{\frac{3}{2}} R^4}{G^2 \lambda (PRF)^3 \sigma}$$

$$P_r = \frac{(10^{-13})(4\pi)^{\frac{3}{2}} \left(\frac{3(10^3)}{2}\right)^4}{(2000)^2 (0.23)^3 (524)^3 (2.0)} = 3.1 \text{ MW}$$

Note 1: these three forms of the equation for $R_{max}$ vary with different powers of $\lambda$. This results from implicit assumptions about the independence of $G$ or $Ae$ from $\lambda$.

Note 2: the introduction of additional constraints (such as the requirement to scan a specific volume of space in a given time) can yield other $\lambda$ dependence.
**Note 3:** The observed maximum range is often much smaller than that predicted from the above equation due to the exclusion of factors such as rainfall attenuation, clutter, noise figure etc.

**RADAR BLOCK DIAGRAM AND OPERATION:**

The Transmitter may be an oscillator (magnetron) that is pulsed on and off by a modulator to generate the pulse train.

- the magnetron is the most widely used oscillator

- typical power required to detect a target at 200 NM is MW peak power and several kW average power

- typical pulse lengths are several μs

- typical PRFs are several hundreds of pulses per second
The waveform travels to the antenna where it is radiated. The receiver must be protected from damage resulting from the high power of the transmitter. This is done by the duplexer.

- Duplexer also channels the return echo signals to the receiver and not to the transmitter

- Duplexer consists of 2 gas discharge tubes called the TR (transmit/receive) and the and an ATR (anti transmit/receive) cell

- The TR protects the receiver during transmission and the ATR directs the echo to the receiver during reception.

- Solid state ferrite circulators and receiver protectors with gas plasma (radioactive keep alive) tubes are also used in duplexers
The receiver is usually a superheterodyne type. The LNA is not always desirable. Although it provides better sensitivity, it reduces the dynamic range of operation of the mixer. A receiver with just a mixer front end has greater dynamic range, is less susceptible to overload and is less vulnerable to electronic interference.

The mixer and Local Oscillator (LO) convert the RF frequency to the IF frequency.

- The IF is typically 300MHz, 140Mz, 60 MHz, 30 MHz with bandwidths of 1 MHz to 10 MHz.
The IF strip should be designed to give a matched filter output. This requires its $H(f)$ to maximize the signal to noise power ratio at the output.

This occurs if the $|H(f)|$ (magnitude of the frequency response of the IF strip is equal to the signal spectrum of the echo signal $|S(f)|$, and the $\text{ARG}(H(f))$ (phase of the frequency response) is the negative of the $\text{ARG}(S(f))$.

i.e. $H(f)$ and $S(f)$ should be complex conjugates

For radar with rectangular pulses, a conventional IF filter characteristic approximates a matched filter if its bandwidth $B$ and the pulse width $\tau$ satisfy the relationship
EFFECT OF LNA ON DYNAMIC RANGE
The pulse modulation is extracted by the second detector and amplified by video amplifiers to levels at which they can be displayed (or A to D’d to a digital processor). The display is usually a CRT; timing signals are applied to the display to provide zero range information. Angle information is supplied from the pointing direction of the antenna.

- The most common type of CRT display is the plan position indicator (PPI) which maps the location of the target in azimuth and range in polar coordinates.
- The PPI is intensity modulated by the amplitude of the receiver output and the CRT electron beam sweeps outward from the centre corresponding to range.
- Also the beam rotates in angle in synchronization with the antenna pointing angle.
- A B scope display uses rectangular coordinates to display range vs angle i.e. the x axis is angle and the y axis is range.
- Since both the PPI and B scopes use intensity modulation the dynamic range is limited.
- An A scope plots target echo amplitude vs range on rectangular coordinates for some fixed direction. It is used primarily for tracking radar applications than for surveillance radar.

The simple diagram has left out many details such as

- AFC to compensate the receiver automatically for changes in the transmitter
- AGC
- Circuits in the receiver to reduce interference from other radars
Rotary joints in the transmission lines to allow for movement of the antenna

- MTI (moving target indicator) circuits to discriminate between moving targets and unwanted stationary targets
- Pulse compression to achieve the resolution benefits of a short pulse but with the energy benefits of a long pulse.
- Monopulse tracking circuits for sensing the angular location of a moving target and allowing the antenna to lock on and track the target automatically
- Monitoring devices to monitor transmitter pulse shape, power load and receiver sensitivity
Built in test equipment (BITE) for locating equipment failures so that faulty circuits can be replaced quickly.

Instead of displaying the raw video output directly on the CRT, it might be digitized and processed and then displayed. This consists of:

- Quantizing the echo level at range-azimuth resolution cells
- Adding (integrating) the echo level in each cell
- Establishing a threshold level that permits only the strong outputs due to target echoes to pass while rejecting noise
- Maintaining the tracks (trajectories) of each target
- Displaying the processed information

This process is called automatic tracking and detection (ATD) in surveillance radar.

Antennas:

- The most common form of radar antenna is a reflector with parabolic shape, fed from a point source (horn) at its focus
The beam is scanned in space by mechanically pointing the antenna

Phased array antennas are sometimes used. Here the beam is scanned by varying the phase of the array elements electrically

Radar Frequencies:

Most Radar operates between 220 MHz and 35 GHz.

Special purpose radars operate outside of this range.

- Skywave HF-OTH (over the horizon) can operate as low as 4 MHz

- Groundwave HF radars operate as low as 2 MHz

- Millimeter radars operate up to 95 GHz

- Laser radars (lidars) operate in IR and visible spectrum
The radar frequency letter-band nomenclature is shown in the table. Note that the frequency assignment to the latter band radar (e.g., L band radar) is much smaller than the complete range of frequencies assigned to the letter band.
### Applications of Radar

#### General

i. Ground-based radar is applied chiefly to the detection, location and tracking of aircraft and space targets.
ii. Shipborne radar is used as a navigation aid and safety device to locate buoys, shorelines and other ships. It is also used to observe aircraft.

iii. Airborne radar is used to detect other aircraft, ships and land vehicles. It is also used for mapping of terrain and avoidance of thunderstorms and terrain.

iv. Spaceborne radar is used for the remote sensing of terrain and sea, and for rendezvous/docking.
**Major Applications**

1. **Air Traffic Control**

   - Used to provide air traffic controllers with position and other information on aircraft flying within their area of responsibility (airways and in the vicinity of airports)

   - High resolution radar is used at large airports to monitor aircraft and ground vehicles on the runways, taxiways and ramps.

   - GCA (ground controlled approach) or PAR (precision approach radar) provides an operator with high accuracy aircraft position information in both the vertical and horizontal. The operator uses this information to guide the aircraft to a landing in bad weather.

   - MLS (microwave landing system) and ATC radar beacon systems are based on radar technology

2. **Air Navigation**

   - Weather avoidance radar is used on aircraft to detect and display areas of heavy precipitation and turbulence.

   - Terrain avoidance and terrain following radar (primarily military)

   - Radio altimeter (FM/CW or pulse)

   - Doppler navigator

   - Ground mapping radar of moderate resolution sometimes used for navigation

3. **Ship Safety**
These are one of the least expensive, most reliable and largest applications of radar

Detecting other craft and buoys to avoid collision

Automatic detection and tracking equipment (also called plot extractors) are available with these radars for collision avoidance

Shore based radars of moderate resolution are used from harbour surveillance and

as an aid to navigation

4. Space

Radars are used for rendezvous and docking and was used for landing on the moon
Large ground based radars are used for detection and tracking of satellites

Satellite-borne radars are used for remote sensing (SAR, synthetic aperture radar)

5. Remote Sensing

- Used for sensing geophysical objects (the environment)
- Radar astronomy - to probe the moon and planets
- Ionospheric sounder (used to determine the best frequency to use for HF communications)
- Earth resources monitoring radars measure and map sea conditions, water resources, ice cover, agricultural land use, forest conditions, geological formations, environmental pollution (Synthetic Aperture Radar, SAR and Side Looking Airborne Radar SLAR)

6. Law Enforcement

- Automobile speed radars
- Intrusion alarm systems

7. Military

- Surveillance
- Navigation, Fire control and guidance of weapons
ADVANTAGES OF BASIC RADAR:

- It acts as a powerful eye.
- It can see through: fog, rain, snow, darkness, haze, clouds and any insulators.
- It can find out the range, angular position, location and velocity of targets.

LIMITATIONS:

- Radar cannot recognize the color of the targets.
- It cannot resolve the targets at short distances like human eye.
- It cannot see targets placed behind the conducting sheets.
- It cannot see targets hidden in water at long ranges.
It is difficult to identify short range objects.

The duplexer in radar provides switching between the transmitter and receiver alternatively when a common antenna is used for transmission and reception.

The switching time of duplexer is critical in the operation of radar and it affects the minimum range. A reflected pulse is not received during the transmit pulse.

subsequent receiver recovery time

The reflected pulses from close targets are not detected as they return before the receiver is connected to the antenna by the duplexer.

Other Forms of the Radar Equation:-

FIRST EQUATION:-

If the transmit and receive antennas are not the same and have different gains, the radar equation will
where $G_t$ is the gain of transmit antenna and $G_r$ is the gain of receive antenna.

SECOND EQUATION:-

If the target ranges are different for transmit and receive antennas. The equation will be:

$$S = \frac{PG_t G_r \lambda^2 \sigma}{N (4\pi)^3 R_t^2 R_r FKB_n}$$

and $R_t$ and $R_r$ are ranges between the target and the transmit antenna and the target and the receive antenna respectively.

THIRD EQUATION:-

The first radar equation we discussed was derived without incorporating losses of energy which accompany transmission, reception, and the processing of electromagnetic radiation. It is sufficient to incorporate all of these losses in one term and write equation as follows:

$$S = \frac{PG^2 \lambda^2 \sigma}{N (4\pi)^3 R^4 FKB_n L}$$

Where $L$ is the total loss term.
FOURTH EQUATION:-

If we know that the signal power equals the noise power $S/N = 1$ the equation will be:

$$R_0^4 = \frac{PG^2 \lambda^2 \sigma}{(4\pi)^3 FKB_n L}$$

The terms appearing in the $R_0$ equation, with the exception of the target cross section, are a characteristic of the radar system.

Once a design is established, $R_0$ can be determined for a given target from the fourth size. Using the value of $R_0$ we get:

$$\frac{S}{N} = \left(\frac{R_0}{R}\right)^4$$

From this equation, it is noted that $S/N$ is inversely proportional to the fourth power of Range, $R$.

Parameters Affecting the Radar Range Equation:-

The radar equation was derived in the previous section and is below for reference:-
\[
\frac{S}{N} = \frac{PG^2 \lambda^2 \sigma}{(4\pi)^3 R^4 FKTB_n L} = \left[ \frac{R_o}{R} \right]^4
\]

The terms of this equation, which depend on the:-

1) Physical structure of antenna.  
2) Radar transmitter.

3) Processing of received signal.  
4) System losses.

5) Characteristics of the target.

Type of Transmission:-

- **Passive**: there is no transmission.  
- **Active**: there is transmission.
RADAR PARAMETERS AND DEFINITIONS:

**RADAR:** Radio means Radio Detection and Ranging. It is a device useful for detecting and ranging, tracking and searching. It is useful for remote sensing, weather forecasting, speed trapping, fire control and astronomical abbreviations.

**Echo:** Echo is a reflected electromagnetic wave from a target and it is received by radar receiver. The echo signal power is captured by the effective area of the receiving space antenna.

**Duplexer:** It is a microwave switch which connects the transmitter and receiver to the antenna alternatively. It protects the receiver from high power output of the transmitter. It allows the use of the single antenna for both radar transmission and reception. It blanks the receiver during the transmitting period.

**Antenna:** It is a device which acts as a transducer between transmitter and free space and between free space and receiver. It converts electromagnetic energy into electrical energy at receiving side and converts the electrical energy into electromagnetic energy at the transmitting side. Antenna is a source and a sensor of electromagnetic waves. It is also an impedance matching device and a radiator of electromagnetic waves.

**Transmitter:** It conditions the signals interest and connects them to the antenna. The transmitter generates high power RF energy. It consists of magnetron or klystron or travelling wave tube or cross field amplifier.

**Receiver:** It receives the signals from the receiving antenna and connects them to display. The receiver amplifies weak return pulses and separates noise and clutter.

Synchronizer: It synchronizes and coordinates the timing for range determination. It regulates PRF and resets for each pulse. Synchronizer connects the signals simultaneously to transmitter and display. It maintains timing of transmitted pulses. It ensures that all components and devices operate in a fixed time relationship.
**Display:** It is a device to present the received information for the operator to interpret. It provides visual presentation of echoes.
Bearing or Azimuth Angle: It is an angle measured from true north in a horizontal plane. In other words, it is the antenna beams angle on the local horizontal plane from some reference. The reference is usually true north.

Elevation Angle: It is an angle measured between the horizontal plane and line of sight. In other words, it is an angle between the radar beam antenna axis and the local horizontal.

Resolution: It is the ability to separate and detect multiple targets or multiple features on the same target. In other words, it is the ability of radar to distinguish targets that are very close in either range or bearing. The targets can be resolved in four dimensions range, horizontal cross-range, vertical cross-range and Doppler shift.

Range Resolution (RS): It is the ability of Radar to distinguish two or more targets at different ranges but at the same bearing. It has the units of distance.

\[
RS = v_o \times (PM/2) \text{ in meters}
\]

Bearing Resolution: It is the ability of Radar to distinguish objects which are in different bearing but at the same range. It is expressed in degrees.

Range of Radar: It is the distance of object from the location of radar, \( R = v_o \Delta t / 2 \)

Where, \( v_o = \text{velocity of EM wave}, \Delta t = \text{The time taken to receiver echo from the object.} \)

Radar Pulse: It is a modulated radiated frequency carrier wave. The carrier frequency is the transmitter oscillator frequency and it influences antenna size and beam width.
Figure 2–1. Pulse transmission.
Cross-Range Resolution of Radar: It is the ability of Radar to distinguish multiple targets at the same range. It has linear dimension perpendicular to the axis of the Radar antenna. It is of two types:

- Azimuth (Horizontal) cross-range
- Elevation (Vertical) cross-range

Narrow beam of radar antennas resolve closed spaced targets. The cross-range resolution $\Delta x$ is given by, 

$$\Delta x = \frac{R\lambda}{L_{\text{eff}}}$$

Where $R$ = Target range in meters

$L_{\text{eff}}$ = Effective length of the antenna in the direction of the beam width is estimated.

$\lambda$ = Wavelength in meters

Doppler Resolution: It is the ability to distinguish targets at the same range, but moving at different radial velocities. The Doppler resolution $\Delta f_d$ is given by, 

$$\Delta f_d = \frac{1}{T_d} \text{ in Hz}$$

Here $T_d$ = The look time in seconds.
The Doppler resolution is possible if Doppler frequencies differ by at least one cycle over the time of observation. It depends on the time over which signal is gathered for processing.

**Radar Signal**: Radar signal is an alternating electrical quantity which conveys information. It can be voltage or current. The different types of radar signals are:

- Echoes from desired targets
- Echoes from undesired targets
- Noise signals in the receiver
- Jamming signals
- Signals from hostile sources

**Radar Beam**: It is the main beam of radar antenna. It represents the variation of a field strength or radiated power as a function of θ in free space.
**ECM:** ECM represents Electronic Counter Measure. It is also known as jamming. It is an electronic technique which disrupt radar or communication.

**Radar Beam Width:** It is the width of the main beam of radar antenna between two half power points or between two first nulls. It is expressed in degrees.

**Search Radar:** These are used for searching the targets and they scan the beam a few times per minute. These are used to detect targets and find their range, angular velocity and sometimes velocity. The different types of search radars are:

- Surface Search Radar
- Air Search Radar
- Two-dimensional Search Radar
- Three-dimensional Search Radar

**Pulse Width:** It is the duration of the radar pulse. It is expressed in milli seconds. The pulse width influences the total pulse energy. It determines minimum range and range resolution. In fact it represents the transmitter ‘ON’ time.

**Pulse Interval Time or Pulse Reset Time (PRT):** It is the time interval between two pulses. It is expressed in milli seconds.

\[
Pulse\ Reset\ Time\ (PRT) = Pulse\ Repetetion\ Time\ (PRT) – Pulse\ Width\ (PW)
\]
**Pulse Repetition Frequency (PRF):** It is the number of pulses transmitted per second. It is equal to the reciprocal of pulse repetition time. It is measured in hertz.

\[ \text{PRF} = \frac{1}{\text{PRT}} \]

**Pulse Repetition Time (PRT):** It is the time interval between the start of one pulse and the start of next pulse. It is the sum of pulse width and pulse reset time (PRT). In other words it is the time. It is measured in microseconds.

\[ \text{PRT} = \text{PW} + \text{PRT} \]
**Duty Cycle** ($D_c$): It is the ratio of average power to the peak power. It is also defined as the product of pulse width and PRF. It has no units.

\[
D_c = \frac{PW \times PRF}{PW \times PRT} = \frac{P_{avg}}{P_{peak}}
\]

**Average Power** ($P_{avg}$): It is the average transmitted power over the pulse repetition period. $P_{peak}$

---

**Two-Dimensional Radars**: These are the radars which determine:

- Range
- Bearing of targets

**Three-Dimensional Radars**: These are the radars which determine:

- Altitude
- Range
- Bearing of object
**Target resolution of Radar:** It is the ability of Radar to distinguish targets that are very close in either range or bearing.

**Navigational Radars:** They are similar to search radars. They basically transmit short waves which can be reflected from earth, stones and other obstacles. These are either ship borne or airborne.

**Weather Radars:** These are similar to search radars. They radiate EM waves with circular polarization or horizontal or vertical polarization.

**Radar Altimeter:** It is radar which is used to determine the height of the aircraft from the ground.

**Air Traffic Control Radars:** This consists of primary and secondary radars to control the traffic in air.
**Primary Radars:** It is radar which receives all types of echoes including clouds and aircrafts. It receives its own signals as echoes.

**Secondary Radars:** It transmits the pulses and receives digital data coming from aircraft transponder. The data like altitude, call signs interms of codes are transmitted by the transponders. In military applications, these transponders are used to establish flight identity etc. Example of secondary radar is IFF radar.

**Pulsed Radar:** It is radar which transmits high power and frequency pulse. After transmitting one pulse, it receives echoes and then transmits another pulse. It determines direction, distance and altitude of an object.

**CW Radar:** It is radar which transmits high frequency signal continuously. The echo is a received and processed.

**Un modulated CW Radar:** It is radar in which the transmitted signal has constant amplitude and frequency. It useful to measure velocity of the object but not the speed.

**Modulated CW Radar:** It is radar in which the transmitted signal has constant amplitude with modulated frequency.

**MTI Radar:** It is pulsed radar which uses the Doppler frequency shift for discriminating moving targets from fixed ones, appearing as clutter.

**Local Oscillator:** It is an oscillator which generates a frequency signal which is used to convert the received signal frequency into a fixed intermediate frequency.

**Mixer:** It is a unit which mixes or heterodynes the frequency of the received echo signal and the frequency of local oscillator and then produces a signal of fixed frequency known as intermediate frequency. This unit is useful to increase the signal-to-noise ratio.
**Doppler Frequency**: Is the change in the frequency of a signal that occurs when the source and the observer are in relative motion, or when the signal is reflected by a moving object, there is an increase in frequency as the source and the observer (or the reflecting object) approach, and a decrease in frequency as they separate.

**Doppler Effect**: Doppler Effect is discovered by Doppler. It is a shift in frequency and the wavelength of the wave as perceived by the source when the source or the target is in motion.

**Astronomy Radar**: It is radar which is used to probe the celestial objects.

**OTH Radar**: It represents Over-The-Horizon radar. It is radar which can look beyond the radio horizon. It uses ground wave and sky wave propagation modes between 2MHz and 30MHz.

**MST Radar**: It represents Mesosphere, Stratosphere and Troposphere radar. Mesosphere exists between 50km and 100km above the earth. Stratosphere exits between 10km and 50km above the earth. Troposphere exists between 0 and 10km above the earth. MST Radar is used to observe wind velocity, turbulence etc.

**PPI**: It represents Plan position Indicator. It is a circular display with an intensity modulated map. It gives the location of a target in polar coordinates.

**A-Scope**: It is a radar display and represents an oscilloscope. Its horizontal coordinate represents the range and its vertical coordinate represents the target echo amplitude. It is the most popular radar display.

**B-Scope**: It is a radar display and it is an intensity modulated radar display. Its horizontal axis represents azimuth angle and its vertical axis represents the range of the target. The lower edge of the display represents the radar location.
**Tracking Radar:** It is radar which tracks the target and it is usually ground borne. It provides range tracking and angle tracking. It follows the motion of a target in azimuth and elevation.

**Monostatic Radar:** It is radar which contains transmitter and receiver at the same location with common antenna.

**Bistatic Radar:** In this radar transmitting and receiving antennas are located at different locations. The receiver receives the signals both from the transmitter and the target.

**Laser Radar:** It is radar which uses laser beam instead of microwave beam. Its frequency of operation is in between 30 THz and 300 THz.

**Remote Sensing Radar:** It provides the data about the remote places and uses the shaped beam antenna. The angle subtended at the radar antenna is much smaller than the angular width of the antenna beam.

**Phased Array Radar:** It is radar which uses phased array antenna in which the beam is scanned by changing the phase distribution of array. It is possible to scan the beam with this radar at a fraction of microseconds.

**Clutter:** The clutter is an unwanted echo from the objects other than the targets.

**LIDAR:** It represents Light Detection and Ranging. It is sometimes called as LADAR or Laser Radar.

**Pulse Doppler radar:** It is radar that uses series of pulses to obtain velocity content.

**Radar Signature:** It is the identification of patterns in a target radar cross-section.
**Range Tracking Radar:** It is radar which tracks the targets in range.

**TWS Radar:** It represents Tract-While-Scan Radar. This radar scans and tracks the targets simultaneously.

**Blind Range:** is a range corresponding to the time delay of an integral multiple of the inter pulse period plus a time less than or equal to the transmitted pulse length. Radar usually cannot detect targets at a blind range because of interference by subsequent transmitted pulses. The problem of blind ranges can be solved or largely mitigated by employing multiple PRFs.
A radar display is an electronic instrument for visual representation of radar data. Radar displays can be classified from the standpoint of their functions, the physical principles of their implementation, type of information displayed, and so forth. From the viewpoint of function, they can be detection displays, measurement displays, or special displays. From the viewpoint of number of displayed coordinates, they can be one dimensional (1D), two dimensional (2D), or three dimensional (3D).
An example of a 1D display is the range display (A-scope). Most widely used are 2D displays, represented by the altitude range display (range-height indicator, or RHI), azimuth elevation display (C-scope), azimuth range display (B-scope), elevation range display (E-scope), and plan position indicator (PPI). These letter descriptions date back to World War II, and many of them are obsolete. From the viewpoint of physical implementation, active and passive displays are distinguished. The former are represented mainly by cathode ray tube (CRT) displays and semiconductor displays. Passive displays can be of liquid crystal or ferroelectric types. In most radar applications CRT displays remain the best choice because of their good performance and low cost.

From the viewpoint of displayed information, displays can be classified as presenting radar signal data, alphanumeric’s, or combined displays. These can be driven by analog data (analog or raw video displays) or digital data (digital or synthetic video displays). Displays in modern radar are typically synthetic video combined displays, often using the monitors of computer based work stations.

Now we will discuss the classifications of radar display from this figure.
Other types of radar display

Amplitude display
Amplitude differential display
Range display
Phase differential display
Moving map display
Mosaic display
Remote display

(D-scope)

(G-scope) (F-scope)

(H-scope)

(I-scope)

(J-scope)

(K-scope) (L-scope)

(M-scope)

(N-scope)

(O-scope)

(P-scope)

(R-scope)
OBJECTIVE TYPE QUESTIONS

1. The Doppler shift $D_f$ is given by _______  
   
   a. $2V_r/k$  
   b. $V_r/2k$  
   c. $2k/V_r$  
   d. $k/V_r$

2. Magnetrons are commonly used as radar transmitters because _______  
   
   a. high power can be generated and transmitted to aerial directly from oscillator  
   b. it is easily cooled  
   c. it is a cumbersome device  
   d. it has least distortion.

3. A simple CW radar does not give range information because _______  
   
   a. it uses the principle of Doppler shift  
   b. continuous echo cannot be associated with any specific part of the transmitted wave  
   c. CW wave do not reflect from a target  
   d. multi echoes distort the information

4. Increasing the pulse width in a pulse radar _______  

73
a. increases resolution  b. decreases resolution

c. has no effect on resolution  d. increase the power gain

5. COHO in MTI radar operates  
   a. at supply frequency  
   b. at intermediate frequency  
   c. pulse repetition frequency  
   d. station frequency.

6. A high noise figure in a receiver means  
   a. poor minimum detectable signal  
   b. good detectable signal  
   c. receiver bandwidth is reduced  
   d. high power loss.

7. Which of the following will be the best scanning system for tracking after a target has been acquired  
   a. Conical  
   b. Spiral  
   c. Helical  
   d. Nodding
8. A RADAR IS used for measuring the height of an aircraft is known as _______ [  ]

   a. radar altimeter   b. radar elevator   c. radar speedometer   d. radar latitude

9. VOR stands for ________ [  ]

   a. VHF omni range   b. visually operated radar
   c. voltage output of regulator.   d. visual optical radar

10. The COHO in MTI radar operates at the _____________ [  ]

    a. received frequency   b. pulse repetition frequency
    c. transmitted frequency   d. intermediate frequency.

11. Radar transmits pulsed electromagnetic energy because ________ [  ]
a. it is easy to measure the direction of the target.  
b. it provides a very ready measurement of range  
c. it is very easy to identify the targets  
d. it is easy to measure the velocity of target

12. A scope displays ______________  
[   ]  
a. neither target range nor position, but only target velocity.  
b. the target position, but not range  
c. the target position and range  
d. the target range but not position.

13. Which of the following is the remedy for blind speed problem __________  
[   ]  
a. change in Doppler frequency  
b. use of MTI  
c. use of Monopulse  
d. variation of PRF.

14. Which of the following statement is incorrect? Flat topped rectangular pulses must be transmitted in radar to ______________  
[   ]
a. allow accurate range measurements  b. allow a good minimum range. c. prevent frequency changes in the magnetron.
d. make the returned echoes easier to distinguish from noise.

15. In case the cross section of a target is changing, the tracking is generally done by [  ]

a. duplex switching  b. duplex scanning  c. mono pulse  d. cw radar

16. Which of the following is the biggest disadvantage of the CW Doppler radar? [  ]

a. it does not give the target velocity  b. it does not give the target position  c. a transponder is required at the target  d. it does not give the target range.

17. The sensitivity of a radar receiver is ultimately set by [  ]

a. high S/N ratio  b. lower limit of signal input  c. overall noise temperature  d. higher figure of merit
18. A rectangular wave guide behaves like a______ [ ]

a. band pass filter  b. high pass filter

c. low pass filter  d. m - derived filter

19. Non linearity in display sweep circuit results in [ ]

a. accuracy in range  b. deflection of focus

c. loss of time base trace.  d. undamped indications

20. The function of the quartz delay line in a MTI radar is to [ ]

a. help in subtracting a complete scan from the previous scan

b. match the phase of the Coho and the output oscillator.  c. match the phase of the Coho and the stalo

d. delay a sweep so that the next sweep can be subtracted from it,
Answers:

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ESSAY TYPE QUESTIONS

1. Discuss the parameters on which maximum detectable range of a radar system depends.

2. What are the specific bands assigned by the ITU for the radar? What are the corresponding frequencies?

3. What are the different range frequencies that radar can operate and give their applications?

4. What are the basic functions of radar? In indicating the position of a target, what is the difference between azimuth and elevation?

5. Derive fundamental radar range equation governed by minimum receivable echo power $s_{\text{min}}$.

6. Modify the range equation for an antenna with a transmitting gain $G$ and operating at a wavelength.

7. Draw the functional block diagram of simple pulse radar and explain the purpose and functioning of each block in it.

8. List major applications of radar in civil and military systems.

9. With the help of a suitable block diagram explain the operation of a pulse radar.

10. Explain how the Radar is used to measure the range of a target?
11. Draw the block diagram of the pulse radar and explain the function of each block.

12. Explain how the Radar is used to measure the direction and position of target?

13. What are the peak power and duty cycle of a radar whose average transmitter power is 200W, pulse width of 1µs and a pulse repetition frequency of 1000Hz?

14. What is the different range of frequencies that radar can operate and give their applications?

15. What are the basic functions of radar? In indicating the position of a target, what is the difference between azimuth and elevation?

16. Determine the probability of detection of the Radar for a process of threshold.

17. Draw the block diagram of Basic radar and explain how it works?

18. Write the simplifier version of radar range equation and explain how this equation does not adequately describe the performance of practical radar?

19. Derive the simple form of the Radar equation.

20. Compute the maximum detectable range of a radar system specified below:

   a. Operating wavelength = 3.2 cm

   b. Peak pulse transmitted power = 500 kW.

   c. Minimum detectable power = $10^{-3}$ W

   d. Capture area of the antenna = 5 sq.m.

   e. Radar cross-sectional area of the target = 20 sq.m.