UNIT-I

INTRODUCTION TO RADAR

Course Outcomes

At the end of the course the student is able to

1. Understand basics of Pulse Radar, Radar Applications, Radar Range and various terminology associate with the Radar.
2. Understand principle of operation of Continuous wave Radar, limitations and its applications.
3. Understand principle of operation of MTI Radar, its parameters, limitations and applications.
4. Understand principle operation of tracking radar and different error determination methods, parameters associate with them.
5. Understand functioning of various sub systems of Radars, antenna arrays and their basic parameters.
6. Understand functioning of matched and non -matched filters, correlation receivers in maximization of Signal to Noise ratio.

The word RADAR is a contraction of **RA**dio **D**etecting **A**nd **R**anging

1.1. Historical Overview

Neither a single nation nor a single person is able to say, that he (or it) is the inventor of the radar method. One must look at the "Radar" than an accumulation of many Developments and improvements earlier, which scientists of several nations parallel made share. There are nevertheless some milestones with the discovery of important basic knowledge and important inventions:

1865 The English physicist **James Clerk Maxwell** developed his electro-magnetic light theory (Description of the electro-magnetic waves and her propagation)

1886 The German physicist **Heinrich Rudolf Hertz** discovers the electro-magnetic waves and prove the theory of Maxwell with that.

1904 The German high frequency engineer **Christian Hülsmeyer** invents the "Telemobiloskop" to the traffic supervision on the water. He measures the running time of electro-magnetic waves to a metal object (ship) and back. A calculation of the distance is thus possible. This is the first practical radar test. Hülsmeyer registers his invention to the patent in Germany and in the United Kingdom.

1917 The French engineer **Lucien Lévy** invents the super-heterodyne receiver. He uses as first the denomination *"Intermediate Frequency"* and allude the possibility of double heterodyning.

1921 The invention of the Magnetron as an efficient transmitting tube by the US American physicist **Albert Wallace Hull**

1922 The American electrical engineers **Albert H. Taylor** and **Leo C. Young** of the Naval Research Laboratory (USA) locate a wooden ship for the first time.

1930 Lawrence A. Hyland (also of the Naval Research Laboratory), locates an aircraft for the first time.

1931 A ship is equipped with radar. As antennae are used parabolic dishes with horn radiators.

1936 The development of the Klystron by the technicians **George F. Metcalf** and **William C. Hahn**, both General Electric. This will be an important component in radar units as an amplifier or an oscillator tube.

1940 Different radar equipments are developed in the USA, Russia, Germany, France and Japan.

1.2. Basic Principle of Radar

Radar uses high power electromagnetic energy pulses at microwave frequencies in much the same way as in the figure below, The radio-frequency (RF) energy is transmitted to and reflected from the reflecting object. A small portion of the reflected energy returns to the radar receiver. This returned energy is called an Echo, just as it is in sound terminology. Radar uses the echo signal to determine the direction and distance of the reflecting object.

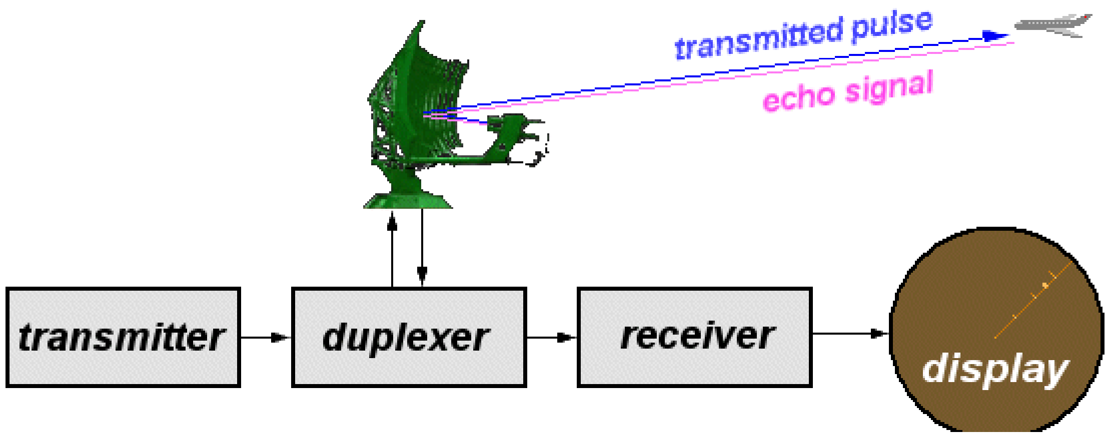


Fig 1.1: Basic block diagram of a Radar

- The radar transmitter produces short duration high-power RF- pulses of energy at microwave frequencies.

- The duplexer alternately switches the antenna between the transmitter and receiver so that only one antenna can be used. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver.

- The antenna transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception.

- The transmitted pulses are radiated into space by the antenna as an electromagnetic wave. This wave travels in a straight line with a constant velocity and will be reflected by a target.

- The antenna receives the back scattered echo signals.

- During reception the duplexer lead the weakly echo signals to the receiver.

- The hypersensitive receiver amplifies and demodulates the received RF-signals. The receiver provides video signals on the output.

- The indicator should present to the observer a continuous, easily understandable, graphic picture of the relative position of radar targets.

All targets produce a diffuse reflection i.e. it is reflected in a wide number of directions. The reflected signal is also called scattering. Backscatter is the term given to reflections in the opposite direction to the incident rays.

Radar signals can be displayed on the traditional plan position indicator (PPI) or other more advanced radar display systems. A PPI has a rotating vector with the radar at the origin, which indicates the pointing direction of the antenna and hence the bearing of targets. It shows a map-like picture of the area covered by the radar beam.

The time between the beginning of one pulse and the start of the next pulse is called pulse-repetition time (PRT) and is equal to the reciprocal of PRF as follows:

$$PRF = 1/ PRT$$

The Pulse Repetition Frequency (PRF) of the radar system is the number of pulses that are transmitted per second. The frequency of pulse transmission affects the maximum range that can be displayed,

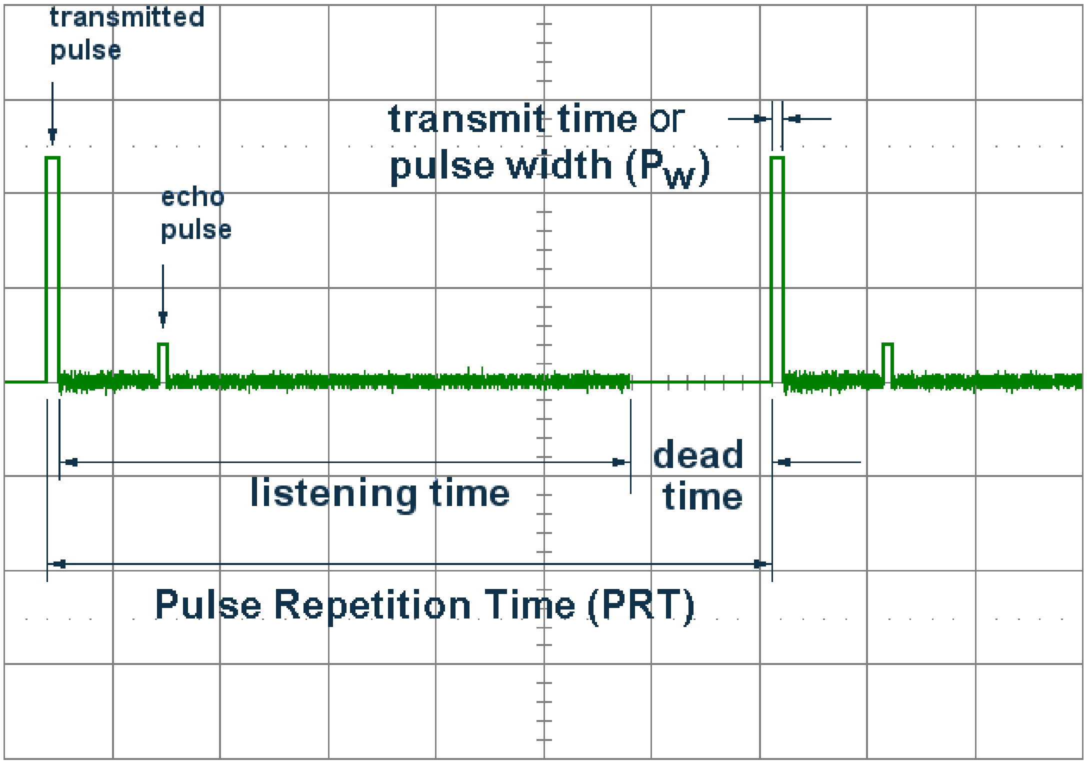


Fig 1.2: Transmitted and received pulses from a target

1.2.1. Ranging

The distance of the target is determined from the running time of the high-frequency transmitted signal and the propagation velocity *c*. The actual range of a target from the radar is known as slant range. Slant range is the line of sight distance between the radar and the object illuminated. While ground range is the horizontal distance between the emitter and its target and its calculation requires knowledge of the target's elevation. Since the waves travel to a target and back, the round trip time is divide by two in order to obtain the time the wave took to reach the target. Therefore the following formula arises for the slant range:

$$R= T_R / 2\ c$$

R is the slant range
T_R is the time taken for the signal to travel to the target *and* return
c is the speed of light (approximately 3 x 10^8 m/s)

1.2.2. Slant Range

Slant Range 'R' is the topographical distance of the target from the Radar.

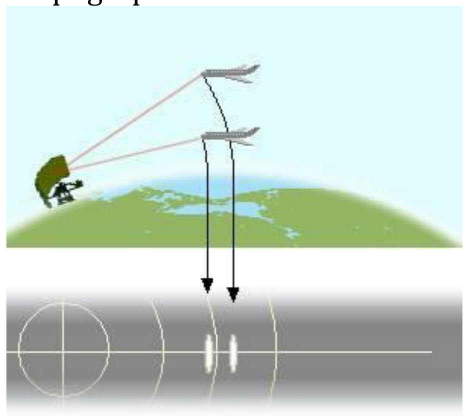


Fig 1.3: Slant Range

1.3. Maximum Unambiguous Range

A problem with pulsed radars and range measurement is how to unambiguously determine the range to the target if the target returns a strong echo. This problem arises because of the fact that pulsed radars typically transmit a sequence of pulses. The radar receiver measures the time between the leading edges of the last transmitting pulse and the echo pulse. It is possible that an echo will be received from a long range target after the transmission of a second transmitting pulse.

In this case, the radar will determine the wrong time interval and therefore the wrong range. The measurement process assumes that the pulse is associated with the second transmitted pulse and declares a much reduced range for the target. This is called range ambiguity and occurs where there are strong targets at a range in excess of the pulse repetition time. The pulse repetition time defines a maximum unambiguous range. To increase the value of the unambiguous range, it is necessary to increase the PRT, this means: to reduce the PRF.

Echo signals arriving after the reception time are placed either into the

- transmit time where they remain unconsidered since the radar equipment isn't ready to receive during this time, or
- into the following reception time where they lead to measuring failures (ambiguous returns).

$$\mathbf{R}_{\mathbf{un\ amb}} = PRT * c / 2$$

Eg: *A Pulse Radar is operating at a frequency of 1.2 G Hz and PRF of 330 Hz. Find out its Maximum unambiguous Range.*

PRT = 1/PRF = 1/330 = 0.00303 s

$\boldsymbol{R}_{un\ amb} = PRT * c / 2 = 0.00303 \times 3 \times 10^8 / 2 = 0.00454545 \times 10^8\ m = 454.54\ km$

1.4. Direction determination

Bearing

The direction to the target is determined by the direction in which the radar antenna is pointing at that instant of time. By measuring the direction in which the antenna is pointing when the echo is received, both the azimuth and elevation angles from the radar to the object or target can be determined. The accuracy of angular measurement is determined by the beam width of the antenna in azimuth and elevation respectively.

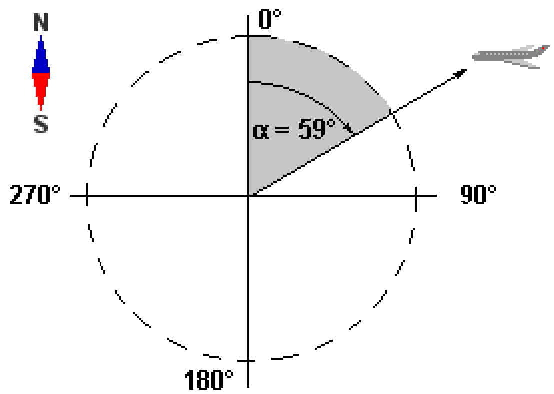


Fig 1.4: Measurement of True bearing

The **True Bearing** (referenced to true north) of a radar target is the angle between true north and a line pointed directly at the target. This angle is measured in the horizontal plane and in a clockwise direction from true north. The bearing angle to the radar target may also be measured in a clockwise direction from the centerline of your own ship or aircraft and is referred to as the **relative bearing**. The rapid and accurate transmission of the bearing information between the turntable with the mounted antenna and the scopes can be carried out for

- Servo systems and
- Counting of azimuth change pulses.
-

1.5. Type of Radars

Bi-static: the transmit and receive antennas are at different locations as viewed from the target (e.g., ground transmitter and airborne receiver)

Mono static: the transmitter and receiver are co-located as viewed from the target (i.e., the same antenna is used to transmit and receive)

Quasi-mono static: the transmit and receive antennas are slightly separated but still appear to be at the same location as viewed from the target (e.g., separate transmit and receive antennas on the same aircraft)

1.6. The Simple Form of The Radar Equation

The radar equation relates the range of a radar to the characteristics of the transmitter, receiver, antenna, target, and environment. It is useful not just as a means for determining the maximum distance from the radar to the target, but it can serve both as a tool for understanding radar operation and as a basis for radar design.

If the power of the radar transmitter is denoted by $\mathbf{P_t}$ and if an isotropic antenna is used (one which radiates uniformly in all directions), the ***power*** density (watts per unit area) at a distance $\boldsymbol{R}$ from the radar is equal to the transmitter power divided by the surface area $\boldsymbol{4\pi R^2}$ of an imaginary sphere of radius R, or

Power density from isotropic antenna = $\mathbf{P_t / 4\pi R^2}$

Radars employ directive antennas to direct, the radiated power $\boldsymbol{Pt}$ into some particular direction. The ***gain*** G of an antenna is a measure of the increased power radiated in the direction of the target as compared with the power that would have been radiated from an isotropic antenna.

The power density at the target from an antenna with a transmitting gain G is

Power density from directive antenna = $\mathbf{P_t G / 4\pi R^2}$

The target intercepts a portion of the incident power and reradiates it in various directions. The measure of the amount of incident power intercepted by the target and reradiated back in the direction of the radar is denoted as the radar cross section $\boldsymbol{\sigma}$ and is defined by the relation

Power density of the echo signal at the radar = $\mathbf{P_t G \sigma / (4\pi R^2)^2}$

The radar antenna captures a portion of the echo power. If the effective area of the receiving antenna is denoted $\boldsymbol{A_e}$, the power $\boldsymbol{P_r}$ received by the radar is

$$P_r = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2} A_e = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4}$$

The maximum radar range $\boldsymbol{R_{max}}$ is the distance beyond which the target cannot be detected. It occurs when the received echo signal power $\boldsymbol{P_r}$ just equals the minimum detectable signal $\boldsymbol{S_{min}}$.

Therefore

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

Antenna theory gives the relationship between the transmitting gain and the receiving effective area of an antenna as

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

Since radars generally use the same antenna for both transmission and reception, Above equation Can be substituted first for A_e then for G, to give two other forms of the radar equation

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

$$R_{\max} = \left[\frac{P_t A_e^2 \sigma}{4\pi \lambda^2 S_{\min}}\right]^{1/4}$$

1.7. Radar Cross Section

The size and ability of a target to reflect radar energy can be summarized into a single term, σ, known as the radar cross section RCS, which has units of m^2. If absolutely all of the incident radar energy on the target were reflected equally in all directions, then the radar cross section would be equal to the target's cross-sectional area as seen by the transmitter. In practice, some energy is absorbed and the reflected energy is not distributed equally in all directions. Therefore, the radar cross-section is quite difficult to estimate and is normally determined by measurement.

The target radar cross sectional area depends of:

- the airplane's physical geometry and exterior features,
- the direction of the illuminating radar,
- the radar transmitters frequency,
- the used material types of the reflecting surface.

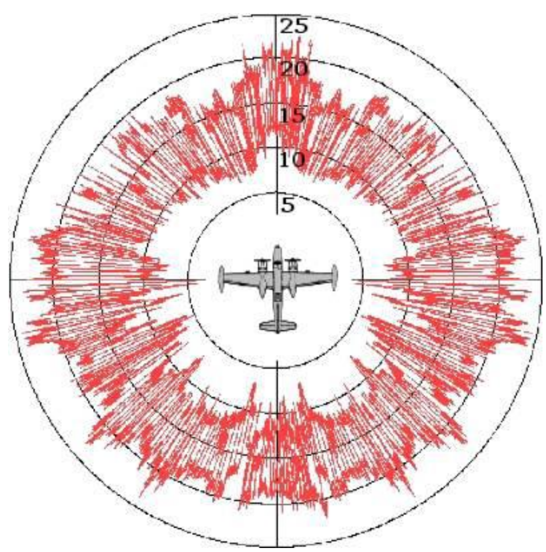


Figure1.5: the experimental radar cross section of a typical aircraft at 3 GHz frequency as a function of azimuth angle

Targets	**RCS** [Sq m]
Jumbo Jet	100
jet airliner 13 … 16	20 to 40
large fighter	6 to 8
helicopter	3 to 7
four-passenger jet	2 to 3
small aircraft	1
stealth jet	0.1

Table 1: Examples of Radar Cross Section

1.8. Radar Resolution

The target resolution of a radar is its ability to distinguish between targets that are very close in either range or bearing. Weapons-control radar, which requires great precision, should be able to distinguish between targets that are only yards apart. Search radar is usually less precise and only distinguishes between targets that are hundreds of yards or even miles apart. Radar resolution is usually divided into two categories; range resolution and angular (bearing) resolution.

1.8.1. Range Resolution

Range resolution is the ability of a radar system to distinguish between two or more targets on the same bearing but at different ranges. The degree of range resolution depends on the width of the transmitted pulse, the types and sizes of targets, and the efficiency of the receiver and indicator.

Pulse width is the primary factor in range resolution.

$$S_r = c\, P_w /2$$

Where
c = speed of light
P_w = transmitters pulse width
S_r = range resolution as a distance between the two targets

1.8.2. Angular Resolution

Angular resolution is the minimum angular separation at which two equal targets at the same range can be detected separately. The half-power points of the antenna radiation pattern (i.e. the -3 dB beam width) are normally specified as the limits of the antenna beam width for the purpose of defining angular resolution; two identical targets at the same distance are, therefore, resolved in angle if they are separated by more than the antenna beam width. An important remark has to be made immediately: the smaller the beam width Θ, the higher the directivity of the radar antenna, the better the bearing resolution.

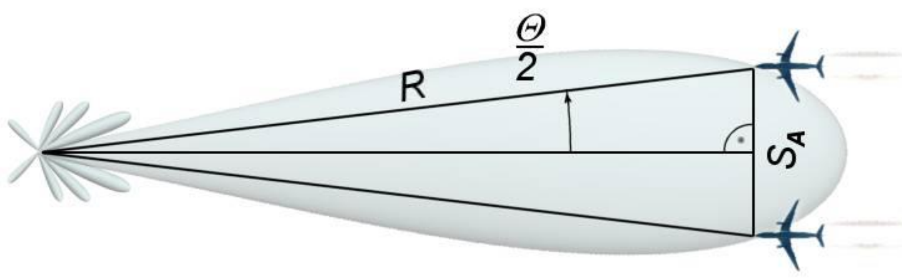


Fig 1.6: Angular resolution

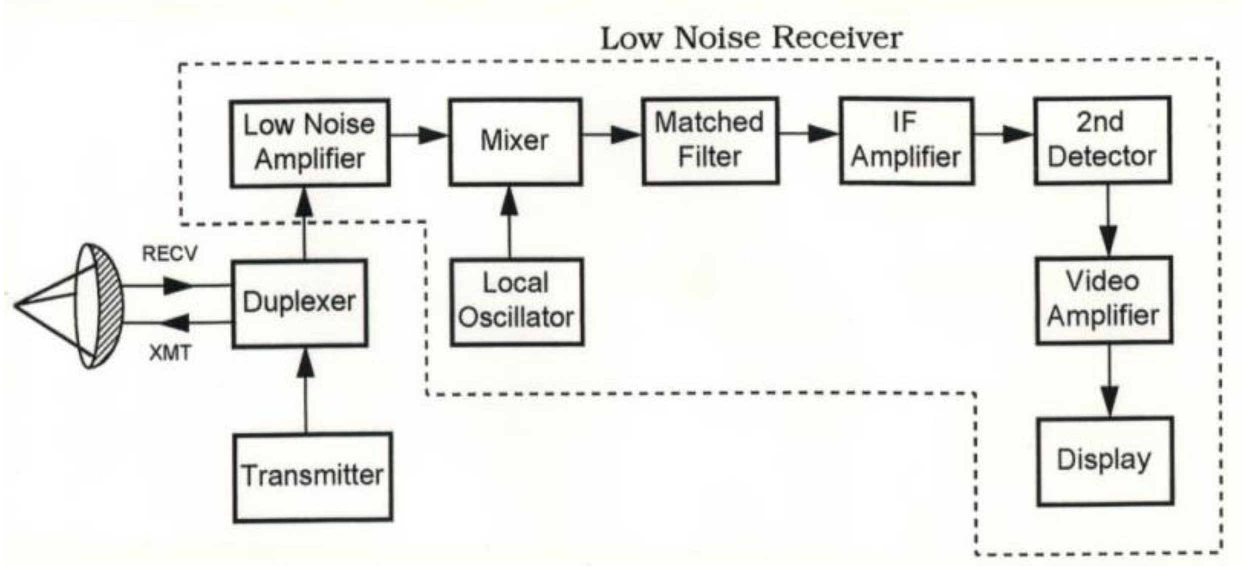
The angular resolution as a distance between two targets depends on the slant-range and can be calculated with help of the following formula:

$$S_A \leqq 2R \cdot \sin\frac{\Theta}{2} \; [m]$$

Where
θ = antenna beam width
S_A = angular resolution as a distance between the two targets
R = slant range in m

1.9. Basic Pulse Radar Block Diagram and Operation

The operation of a typical pulse radar may be described with the aid of the block diagram shown in Figure below



Basic description of System Components

Duplexer: An antenna switch that allows the transmit and receive channels to share the antenna. Often it is a circulator. The duplexer must effectively isolate the transmit and receive channels.

Transmitter: Generates and amplifies the microwave signal.

Low Noise Amplifier(LNA): Amplifies the weak received target echo without significantly increasing the noise level.

Mixer: Mixing (or heterodyning) is used to translate a signal to a higher frequency

Matched Filter: Extracts the signal from the noise

IF Amplifier: Further amplifies the intermediate frequency signal

Detector: Translates the signal from IF to baseband (zero frequency)

Video Amplifier: Amplifies the baseband signal

Display: Visually presents the radar signal for interpretation by the operator.

1.10. Radar Bands and Usage

Band Designation	Frequency Range	Usage
HF	3–30 MHz	OTH surveillance
VHF	30–300 MHz	Very-long-range surveillance
UHF	300–1,000 MHz	Very-long-range surveillance
L	1–2 GHz	Long-range surveillance En route traffic control
S	2–4 GHz	Moderate-range surveillance Terminal traffic control Long-range weather
C	4–8 GHz	Long-range tracking Airborne weather detection
X	–12 GHz	Short-range tracking Missile guidance Mapping, marine radar Airborne intercept
K_u	12–18 GHz	High-resolution mapping Satellite altimetry
K	18–27 GHz	Little use (water vapor)
K_a	27–40 GHz	Very-high-resolution mapping Airport surveillance
millimeter	40–100+ GHz	Experimental

1.11. Radar Applications

Area	Application
Military and Civil Aviation	Surveillance Radar
	Air Traffic Control Radar
	Tracking Radar
	Weapon Control Radar
	Air Borne Early Warning System
	Radio Altimeter
	Distance Measuring Equipment
	Ground Control Approach Radar
	Weather Radar
	Terrain Following Radar
	Identification of Friend or Foe Radar
	Proximity Fuse
	Secondary Radar
Remote Sensing	Radar Imaging or Mapping
Law Enforcement	Doppler Radar for Vehicle speed indication
Space	Measurement of Astronautical distances
Industry	Non Distructive Tests
	Oil & Gas Exploration
	Biological Applications
Medical	2-D Doppler Echo Tests of the Heart
	Ultra Sonic Scanning

Solved Examples

1. Calculate the a maximum range of a radar system which operates at 3 cm with a peak pulse power of 500 kW, if its minimum receivable power is 10^{-13} W, the capture area of its antenna is 5 m^2 and the radar cross sectional area of the target is 20 Sq m. [JNTU May 2011]

Given

$\lambda = 3$ cm
$P_t = 500$ kW
$S_{min} = 10^{-13}$
$A_e = 5$ Sq m
$\sigma = 20$ Sq m

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

.

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

G = (4π x 5) / 0.0009 = 69841

$R_{max}{}^4$ = [500 x 10^3 x 69841x 5 x 20] / [4π x 4π x10^{-13}] =

= [34920.6X 10^8] / [158 X 10^{-13}]

= 22101000 x 10^{16}

R_{max} = 685.6 km

2. Pulsed radar operating at 10 GHz has an antenna with a gain of 28 dB and a transmitter power of 2 kW. What is the maximum range of the radar if its defined to detect a target with a cross section of 12 Sq m and the minimum detectable signal is -90dBm. [JNTU May 2010] [JNTU May 2009]

Given

f = 10 G Hz., λ = 3 cm
G = 28 dB or G = 10 $^{2.8}$ = 630.9
P_t = 2 kW
S_{min} = -90 dBm 0r 10^{-9}
σ = 12 Sq m

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

$R_{max}{}^4$ = [2 x 10^3 x 398034 x .0009 x 12] / [4π x 4π x4π x10^{-9}] =

= [8597.55 x 10^3] / [1.986 x 10^{-6}]

= 432.9 x 10^{10}

R_{max} = 1442 m

3. Consider for a given radar, if minimum receiver sensitivity is -120dB, trans-mitted peak power is 100kW, gain of antenna is 30dB, target cross section is 5 square meter and maximum range of the radar is 300km, calculate the effective area of the receiving antenna. [JNTU May 2011]

S_{min} = -120 dBm 0r 10^{-12}

$P_t = 100$ kW
G = 30 dB or $G = 10^{3} = 1000$
$\sigma = 5$ Sq m
$R_{max} = 300$ km

Solution

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

$$Ae = \frac{(4\pi)^2\ S_{min}\ Rmax^4}{P_t\ G\ \sigma} = \frac{(4\pi)^2\ (10)^{-12}\ (300X\ 1000)^4}{100000\ X\ \ 1000\ X\ 5} = 2555 \text{ Sq m}$$

Essay type questions

1. What is Radar range resolution? State the range resolution dependence parameters. [JNTU May 2013]
2. Differentiate mono-static and bi-static radar systems. [JNTU May 2013]
3. Refine RCS (Radar Cross Section). [JNTU May 2013]
4. What is meant by multiple- time-around echoes? When they are obtained. [JNTU May 2012]
5. What types of modulations are used in Radar? Compare them. [JNTU May 2012]
6. What are the various applications of Radar? [JNTU May 2012] [JNTU May 2009]
7. What is Radar? How it is used in communications? [JNTU May 2012]
8. Derive the equation for maximum Radar range in terms of radar and target parameters. [JNTU May 2012]
9. Explain the basic principle of elementary form of Radar. [JNTU May 2012]
10. Explain how the power received by the radar is related to the radar cross-section? Explain the significance of each term. [JNTU May 2012]
11. Discuss about the factors that influence the prediction of Radar range. [JNTU May 2012]
12. Write the simplifier version of radar range equation and explain how this equation does not adequately describe the performance of practical radar? [JNTU May 2012] [JNTU May 2011]
13. Describe the essential characteristics, functions and major applications of search Radar Systems. [JNTU May 2011]
14. What are the specific bands assigned by the ITU for the Radar? What the corresponding frequencies? [JNTU May 2011]
15. What is maximum unambiguous range? How to find it? [JNTU May 2011]
16. Explain how a single antenna can be used for both transmitter and receiver of pulse radar? [JNTU May 2011]
17. Explain how the Radar is used to measure the range of a target? [JNTU May 2011]
18. Draw the block diagram of the pulse radar and explain the function of each block. [JNTU May 2011]
19. Explain the transmission lines losses introduced in higher radar frequencies and also write the name of other components responsible for plumbing losses. [JNTU May 2011]
20. Explain how the Radar cross-section depends on distance? [JNTU May 2011]

21. Derive the maximum range equation for a Radar system, from first principles. [JNTU May 2010]
22. Define and explain Transmitter power in Radar equation and express the Radar equation in terms of the energy contained in the transmitted wave- form. [JNTU May 2010]
23. Discuss the factors of PRF and range ambiguities. [JNTU May 2010]
24. Obtain the radar equation and discuss various parameters which improve the performance of radar. [JNTU May 2009]
25. Show that the wavelength of operation has an effect on the radar range. [JNTU May 2013]
26. Show how primary radar can be used to measure range and azimuth. [JNTU May 2013]
27. Explain how to choose the PRF at which Radar pulses may be transmitted? [JNTU May 2011]
28. Expand Radar? b) Define maximum unambiguous range? [JNTU Jan2010]
29. In the pulse repetition frequency is 10KHZ, calculate the maximum unambiguous range? [JNTU Jan 2010]
30. Write about the frequencies that are used for Radar communications? [JNTU Jan2010]
31. Discuss the factors of PRF and range ambiguities. [JNTU May 2010]

Objective type questions

1. The reflected signal from the target is called
   A. Clutter **B. Echo**
   C. Noise D. None of the above

2. The letter 'D' in acronym RADAR stands for
   A. Doppler B. Duplexer
   C. Detection D. Distance

3. The reflected signal from static objects is called
   A. Noise B. Video Pulse
   C. Echo **D. Clutter**

4. The unambiguous range of a Pulse Radar primarily depends upon
   A. Pulse Width B. Frequency of RF signal
   C. PRF D. Transmitted power

5. The range of radar is primarily restricted by
   A. Line of sight B. Transmitted power
   C. Frequency of RF signal D. Antenna directivity

6. The radar range is not influenced by
   A. Cross section of the target B. PRF
   C. Antenna directivity **D. Pulse width**

7. If 'T' is the transit time, the Range is given by
   A. T* c **B. T*c/2**
   C. T/c D. T/2c

8. The weakest signal that can be detected by radar receiver is called

A. Minimum target cross section	**B. Minimum detectable signal**
C. Maximum detectable signal	D. Minimum S/N ratio

9. Reduction of PRT below maximum unambiguous range value results in

A. Increase in false alarm probability	B. **Multiple time around echoes**
C. Reduction in S/N ratio	D. Enhancement of range resolution

10. If the maximum transmitted power of a radar in increased by 16 times with all other parameters unchanged, the radar range in increased by

A. 16 times	B. 4 times
C. 2 times	D. 8 times

11. The range resolution of a pulse radar depends upon

A. PRF	B. **Pulse width**
C. Transmitted power	D. Receiver sensitivity

Answers

UNIT-I & II	
01	B
02	C
03	D
04	C
05	A
06	D
07	B
08	B
09	B

10	C
11	B

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