RADAR SYSTEMS

- EC812PE: RADAR SYSTEMS (PE – V)

(ELECTIVE V)

UNIT – 1A

B.TECH IV YEAR II SEMESTER

BY

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(Former Director DLRL Ministry of Defence)

BIET

Acknowledgements

The contents , figures , graphs etc., are taken from the following Text book & others

“ INTRODUCTION TO RADAR SYSTEMS “

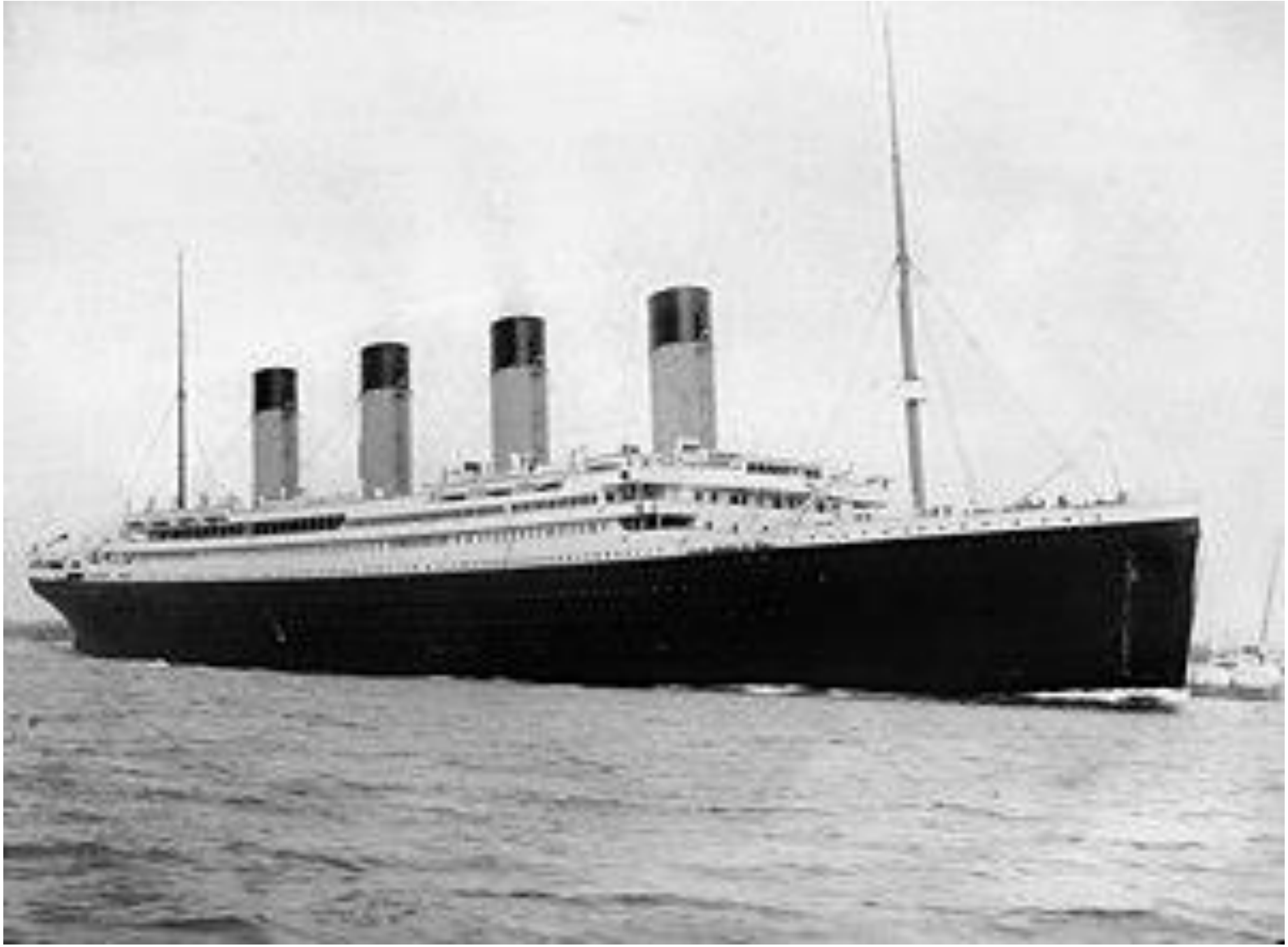
Merill I.Skolnik

Second Edition

Tata Mcgraw – Hill publishing company

Special indian edition

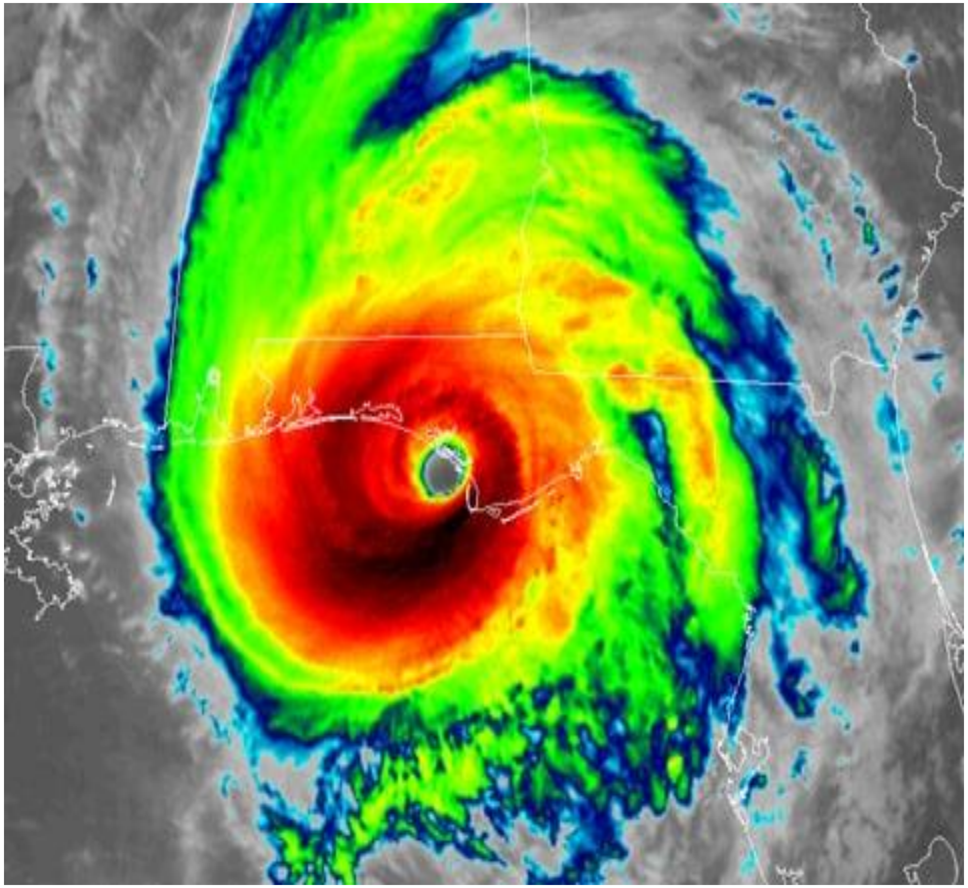
TITANIC SHIP

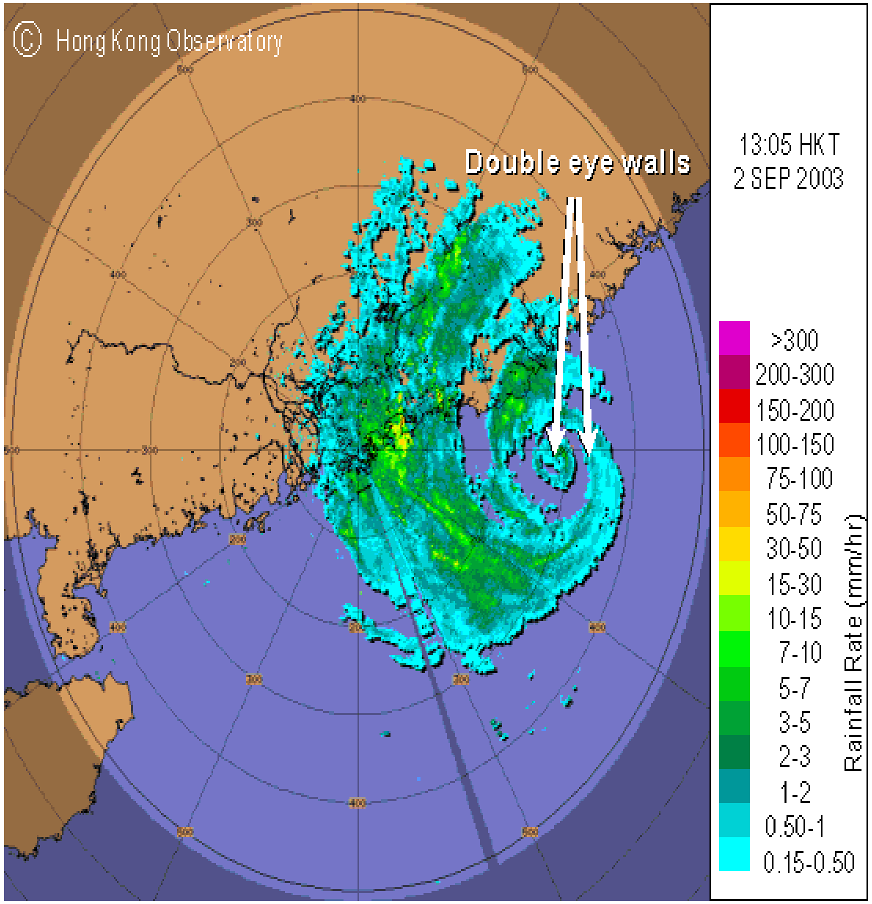


TITANIC SHIP

- **British largest passenger ship sank in North Atlantic on 15 April 1912 after colliding with Ice berg**
- **Broke, disintegrated water entered and the ship sank**
- **Maiden voyage from Southampton to New-york city**
- **Luxurious ship for wealthy people . Swimming pools, libraries, high class restaurants , gymnasiums etc**
- **1500 died in the cold water**
- **Worst deadliest disaster**

CYLONES





© Hong Kong Observatory
Double eye walls
13:05 HKT
2 SEP 2003
>300
200-300
150-200
100-150
75-100
50-75
30-50
15-30
10-15
7-10
5-7
3-5
2-3
1-2
0.50-1
0.15-0.50
Rainfall Rate (mm/hr)

BATS

To echolocate, bats send out sound waves from the mouth or nose. When the sound waves hit an object they produce echoes The wavelength of a 34 kHz note (which is what the Free-tailed Bat *Tadarida brasiliensis* uses), is a mere 1 cm

AIR PORT AIR TRAFFIC CONTROL DISPLAY

RADAR INVENTION LINKED TO WORLD WARS

- World war I : 1914 to 1918
- France , UK, Russia Vs Germany, Austria, Hungary, Italy
- Casualities : 4 Crores of population equivalent to Population of Telengana
- World War II : 1939 to 1944
- Britain, France , Austria , Canada, Soviet Union , USA

Vs

- Germany, Italy, Japan
- Casualities : 8.5 crores Population

SYLLABUS

- EC812PE: RADAR SYSTEMS (PE – V)

ELECTIVE-V

B.TECH IV YEAR II SEMESTER

UNIT I

- Basics of Radar: Introduction, Maximum Unambiguous Range, Simple form of Radar Equation, Radar Block Diagram and Operation, Radar Frequencies and Applications, Prediction of Range Performance, Minimum Detectable Signal, Receiver Noise, Modified Radar Range Equation, Illustrative Problems.
- 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.

RADAR is Acronym for

RAdio Detection And Ranging

BASICS OF RADAR

➢ What is a RADAR?

RADAR is an Electromagnetic system doing the following functions.

(i) Detects the presence of reflective object

(ii) Gives the Range of the reflective object

(iii) Locates the reflective object in angle (azimuth & elevation)

(iv) Gives the Radial velocity of moving object

BASICS OF RADAR

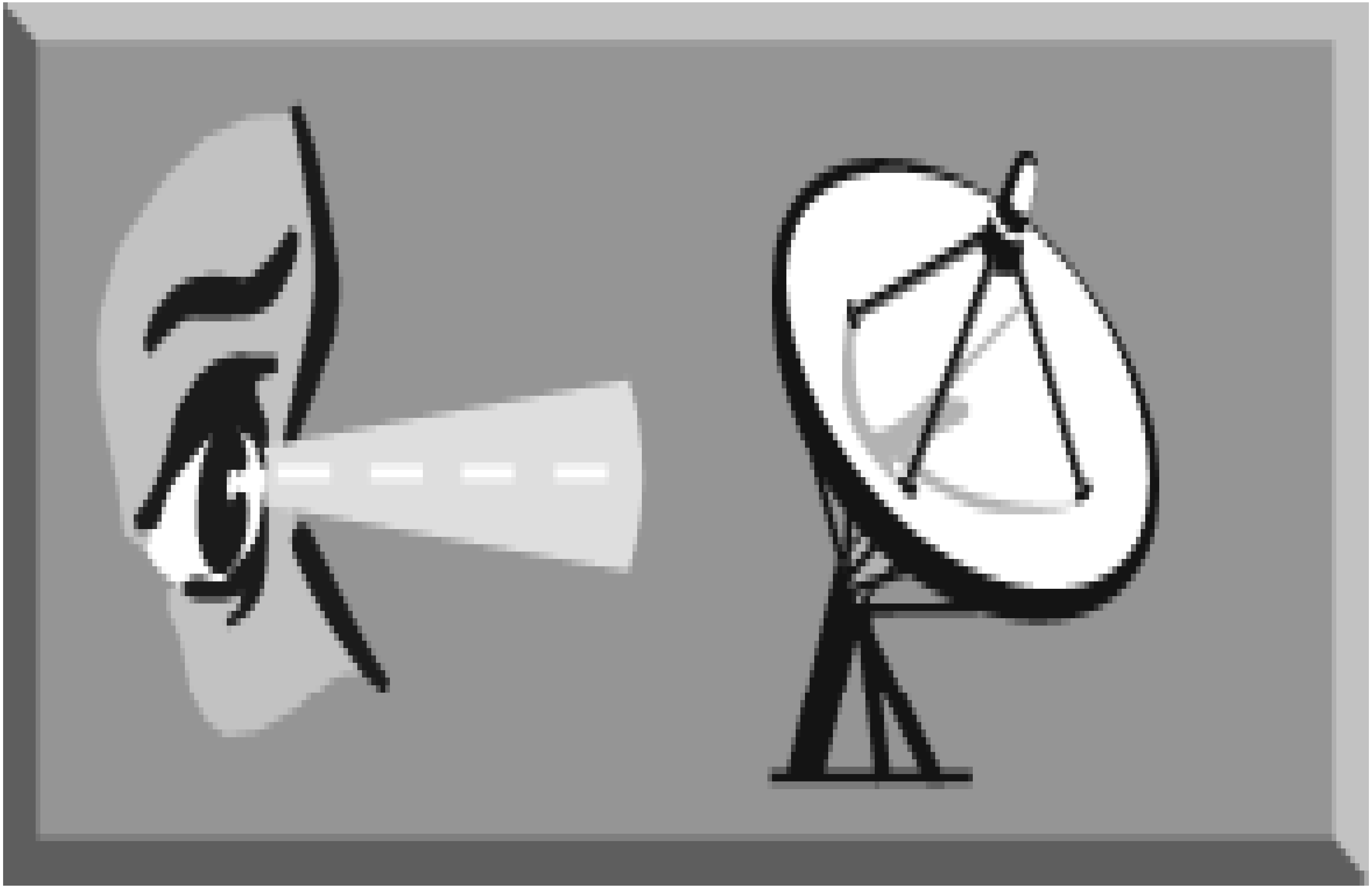
- **What is a RADAR? Simpler definition**
- RADAR is a detection system that uses radio waves to determine the distance (ranging), angle , and velocity of objects

Basics Of Radar (contd…)

- What are the Reflective objects (with high die-electric constant like Aluminum and its alloys)

  (i) Aircraft (ii) Ship (iii) Missile (iv) Motor Vehicle etc.
- The Reflective object is called TARGET
- In fact all objects reflect EM energy to some extent, some more, some less.

RADAR Vs HUMAN EYE



Radar Advantages and Disadvantages

Advantages of Radar over Human eye:

(i) Radar detects and locate targets hundreds of Kms. away.

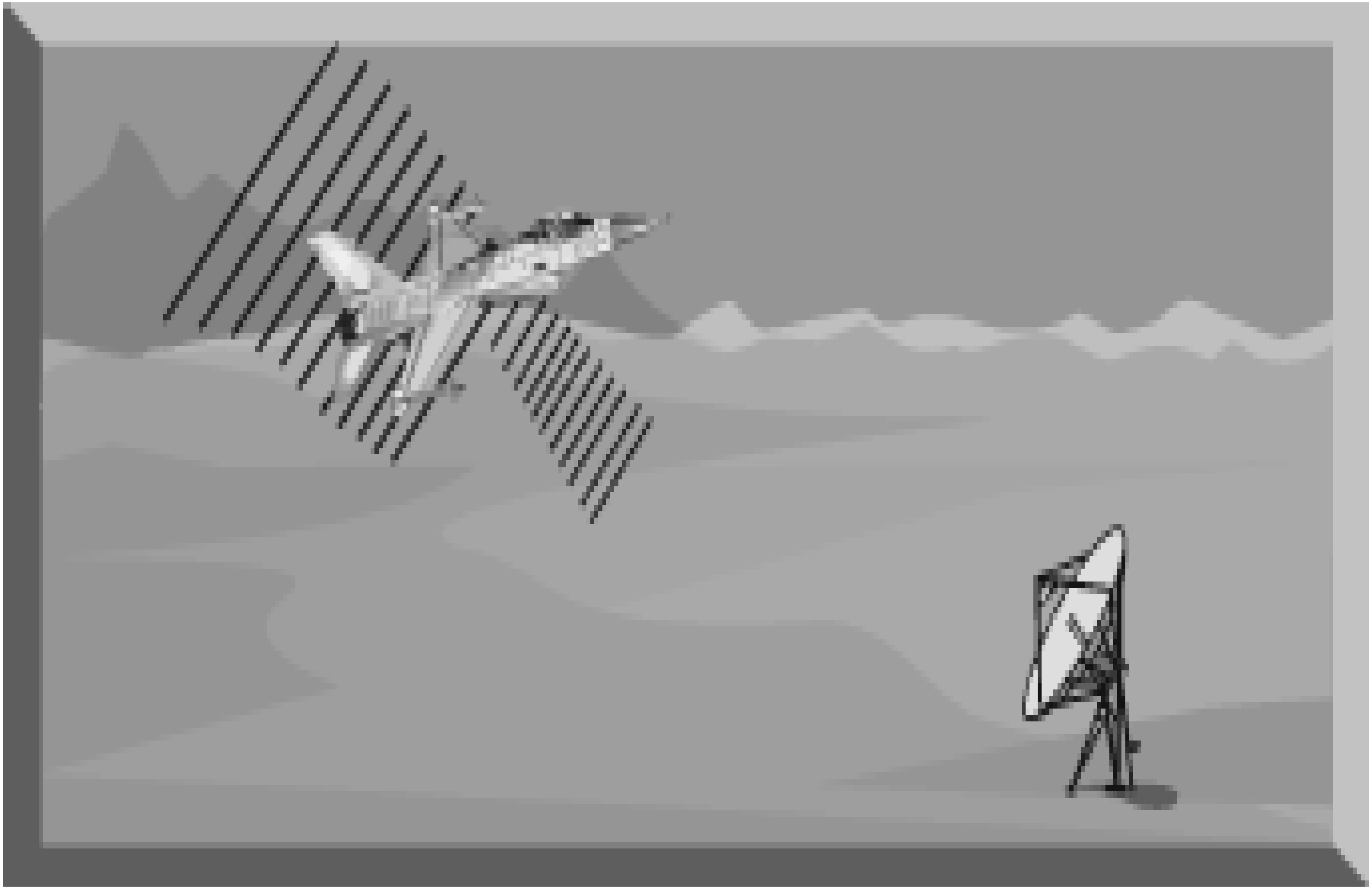
(ii) Radar detects targets in darkness, rain, snow, haze, smoke etc. where human eye fails.

Disadvantages of Radar:

(i) Resolution is poor compared to eye.

(ii) Cannot discriminate colours.

- Infra Red also can detect targets but it is heavily attenuated in snow, rain and haze.



Pulse Radar Operation

PRINCIPLE OF RADAR

- Metallic surfaces reflect E.M. (Electro Magnetic) energy (known in early 18th century)
- Principle of Radar:

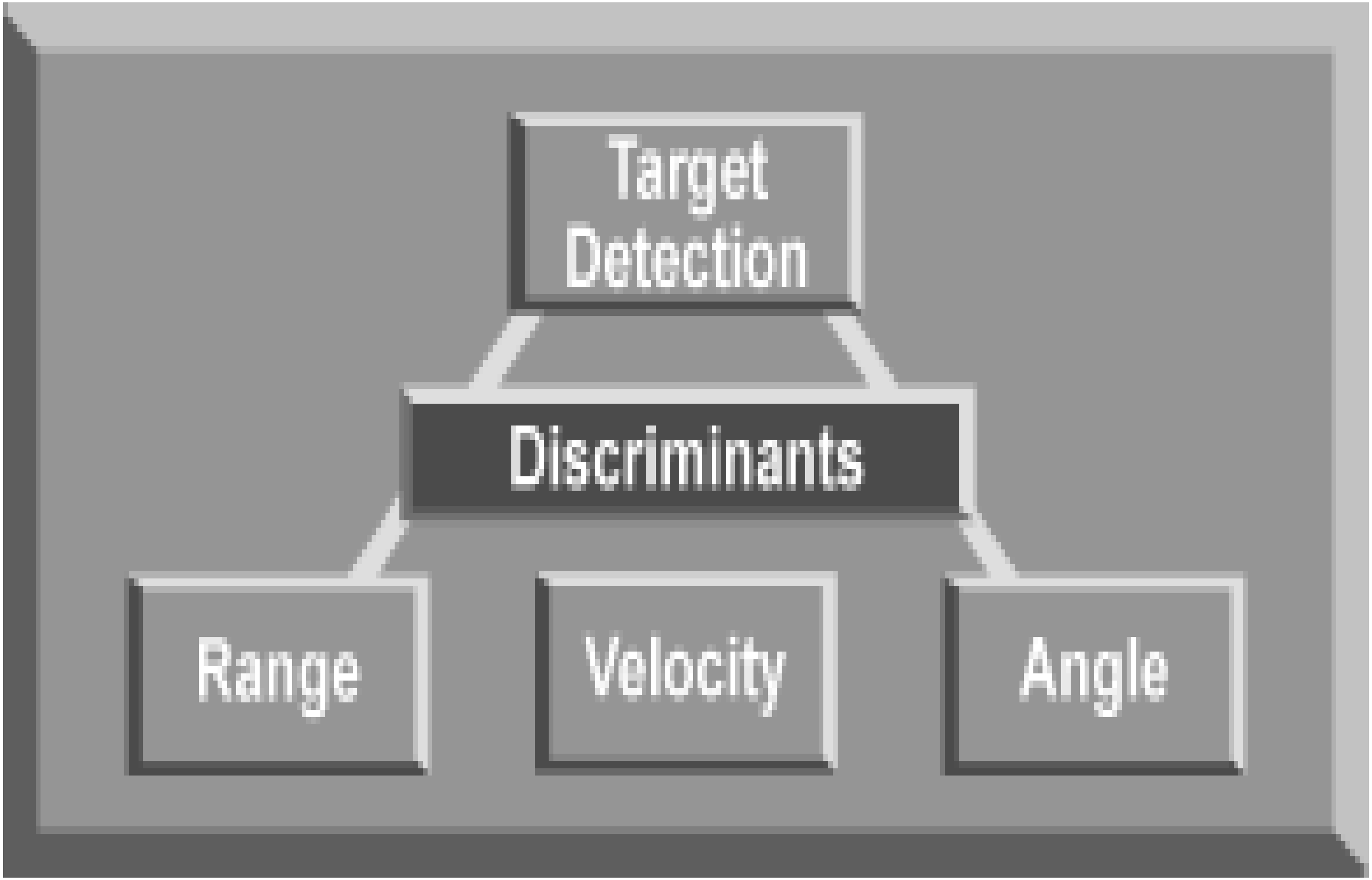
(i) E.M. energy radiated into space

(ii) When a metallic or high dielectric constant object say aircraft or ship comes in its path, a portion of energy is reflected.

(iii) The reflected energy is called ECHO. Echo indicates presence of target.

(iv) Echo is detected in a high sensitive receiver called Radar Receiver.

(v) Echo is amplified and shown visually on a Radar display.



Radar Target Discriminants

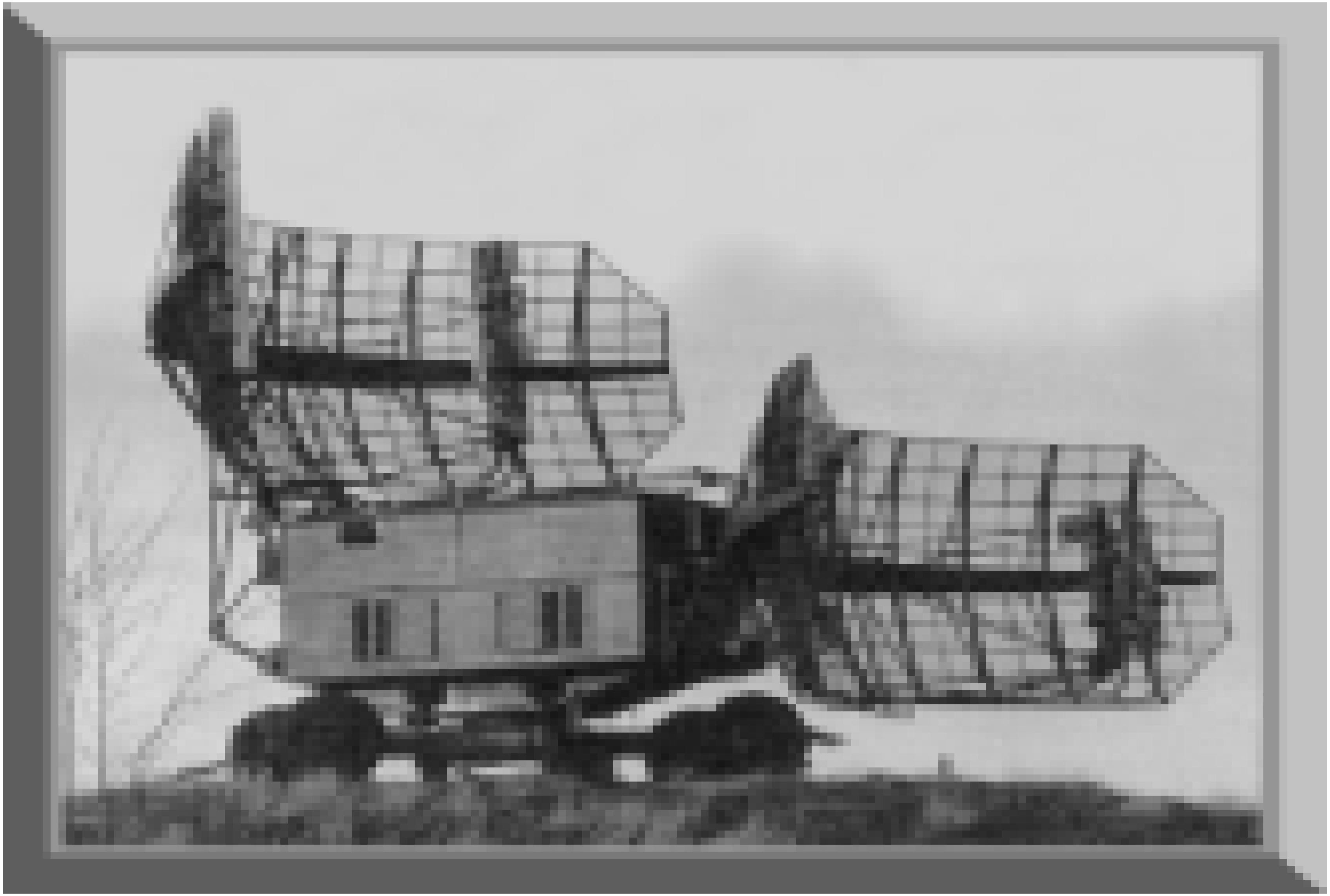
PHOTOGRAPHS OF
A FEW EXISTING RADARS

Surveillance and Fire Control Radars

Airborne and Air Traffic Control Radars


Radar Fundamentals

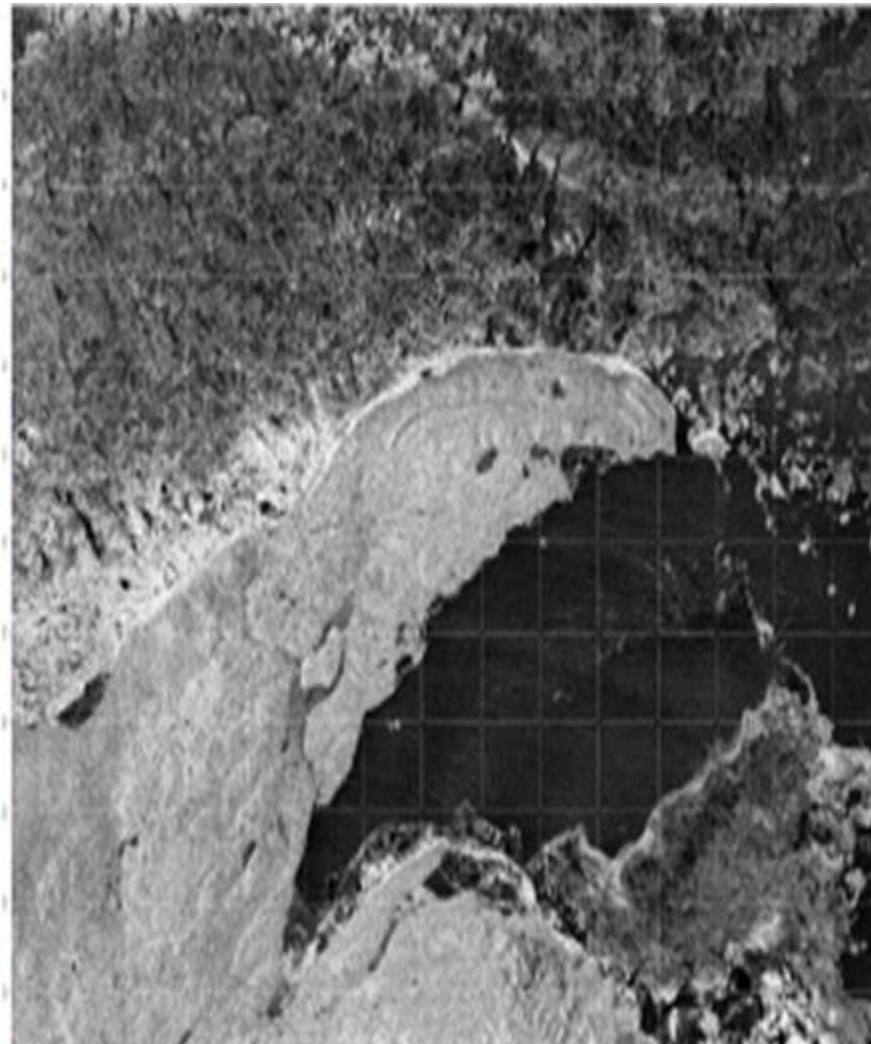
Early Warning Radar System



Radar System

GCI Radar

TTR with Acquisition



INDIRA RADAR

Rohini Radar

Rajendra Radar

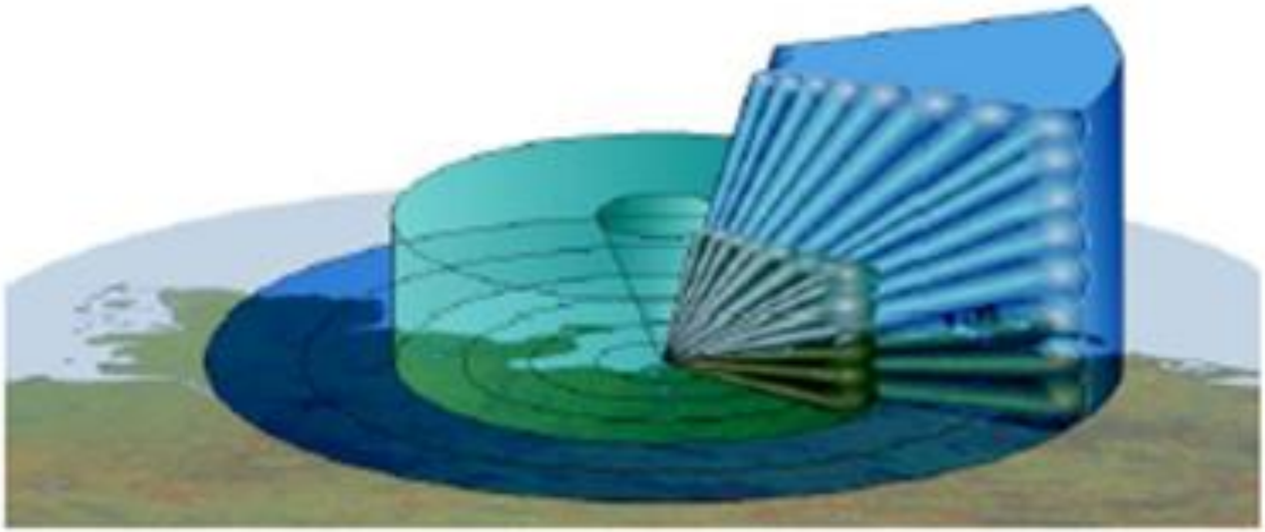


Diagram of a typical 3D-Radar, a mix of vertical electronic beam steering and horizontal movement of a pencil-beam

SWORD FISH RADAR

FLY CATCHER RADAR

TARGET DETECTION BEFORE RADAR

PRE RADAR AIRCRAFT DETECTION

- Before World war II (1939-44) locating aircraft was done by Sound Locators. Maximum Detection range was 20 miles (32.1 Kms)

Pre-Radar Aircraft Detection – Optical Systems

Courtesy of US Army Signal Corps.

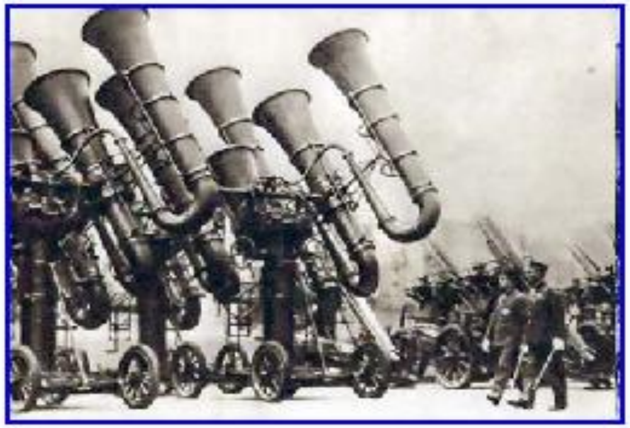
Courtesy of UK Government

- Significant range limitation
  - Attenuation by atmosphere
- Narrow field of view
  - Caused by very small wavelength
- Clouds Cover limits operational usefulness
  - Worldwide - 40-80% of the time

Courtesy of National Archives.

Pre-Radar Aircraft Detection – Acoustic Systems

Japanese Acoustic Detection System



Courtesy of Wikimedia

- Developed and used in first half of 20th century
- Attributes
  - Limited Range
    approximately 10+ miles
  - Limited field of view
  - Ambient background noise limited (weather, etc)
- Used with searchlights at night

US Acoustic Detection Systems

Courtesy of US Army Signal Corps.

Courtesy of US Army Signal Corps.

HISTORICAL BACKGROUND OF RADAR DEVELOPMENTS

HISTORICAL BACKGROUND OF RADAR DEVELOPMENTS

- 1886 -Henrich Hertz demonstrated the similarity between Radio waves and light waves
  - He showed Radio waves could be reflected by metallic and dielectric objects
  - He performed experiment with short waves ie., 66 cms wavelength (454 MHz)
  - Later Experiments were all on long wave lengths (low frequencies) until late 1930s
- 1903 - Hullsmeyer (German scientist) showed that Radio waves reflected from ships
  - Not much interest was shown by German Navy then

Radar Developments (contd.)

- **1922 - Marconi predicted Radio waves could be reflected back from a ship or steamer.**
- **Receiver could capture and reveal the presence and bearing of the ship in fog or thick weather**
- **1922 - A.H. Taylor and L.C. Young (National Research lab NRL) detected a wooden ship using CW wave Interference Radar (uses Doppler principle)**

  - They used a separate transmitter and receiver (Bi-static Radar) Wave length 5 Mts (60 MHz.)

Radar Developments (contd.)

- **1925 -** Breit and Tuve used the pulse technique for measuring the height of the Ionosphere
- 1930 - L.A. Hyland working with Direction finding apparatus found whenever an aircraft crossed the transmitted beam of 33 MHz, an increase in the received signal frequency was observed
- **Principle of CW Interference Radar:**

  Because of Doppler effect there was an interference produced between the direct signal of the transmitter and the doppler frequency shifted signal reflected by a moving target. This effect is called CW wave interference

Radar Developments (contd.)

- 1933 - **T**aylor, Young and Hyland took a patent on a Pulse "System for detecting objects by Radio" using principle of CW Wave Interference
- CW Transmission does not give Range of the target They give only the presence or absence of a target
- 1934 - R.M. Page made efforts to get position information using Pulse transmission
- 1936 - At NRL 28.3 MHz., with pulse width of 5 Micro sec. practical Pulse radar was experimented. Range obtained was 25 Miles (40.2 Kms)

Radar Developments (contd.)

- **1938 -** 200 MHz. Pulse Radar was installed on Destroyer ship LEART. Power transmitted 6 KW Range 50 Miles (80.5 Kms)
- 1941 - SCR 270/271 Early warning Radars produced in large numbers.
  SCR 268 was tracking radar, used in gun firing at enemy aircraft.
- 1941 - Attack on Pearl harbour was detected by this Radar. Unfortunately the significance of blips were not realised until after the bombs were dropped
- 1944 - SCR 584, most significant tracking radar controlled a battery of 4 anti aircraft guns.

World War 2 Air Defense System

SCR-584 Fire Control Radar

M9 Predictor

Courtesy of US Army

Radar Proximity Fuze

Courtesy of US Navy

British 3.7" AAA Gun

US 90 mm AAA Gun

Courtesy of US Navy

Courtesy of US Army

When deployed on British coast, V-1 "kill rate" jumped to 75%, when this integrated system was fully operational in 1944

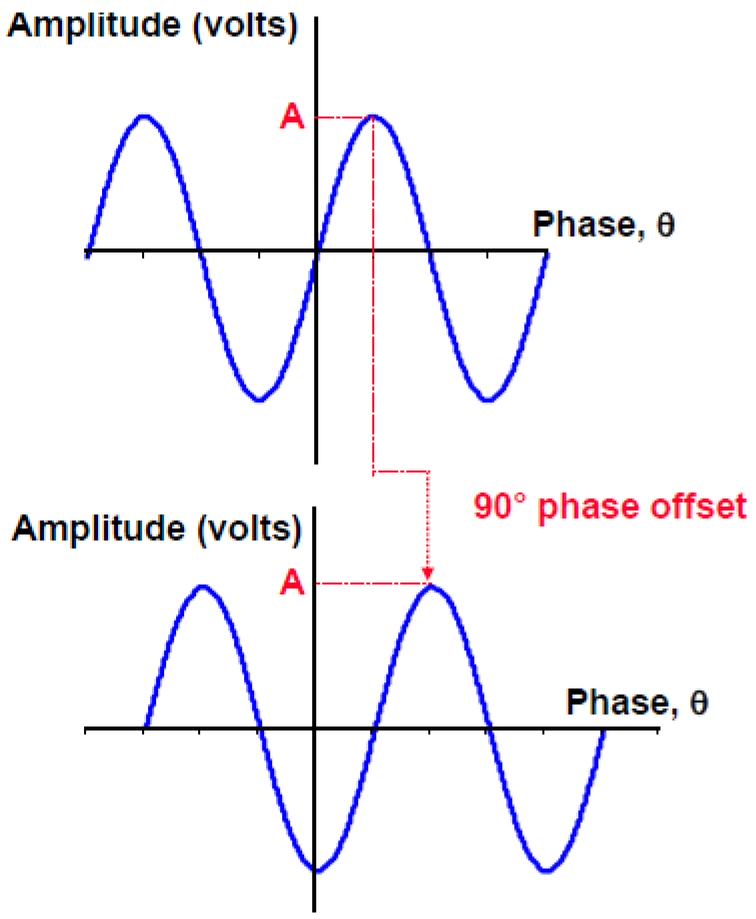
BRITISH RADAR DEVELOPMENTS

- **1935 - 12 MHz. Pulse Radar obtained 40 Miles (64.3 Kms) range**
- **1937 April - CH (Chain Home) Radar were demonstrated. Played the most crucial role in defeat of German Aircrafts over London. Sir. Robert Watson was the Chief Architect of this Radar**

British Radar Developments (contd.)

- **1939 - Aircraft Interception Radar mounted on aircraft at 200 MHz. was developed. It detected aircrafts, surface ships and submarines**
- **1940 - after this year developments carried out jointly by US and Britain**
- **For better angular resolution and smaller size antenna higher frequency ie at microwave is necessary**
- **1940 - Cavity Magnetron was developed. Tube was developed by Randell and Boot. It is a cavity backed microwave tube operating at 10cms (3GHz) and output of 1 KW . (First Microwave Radar) This gave the necessary thrust to further Radar developments**

Properties of Waves
Phase and Amplitude

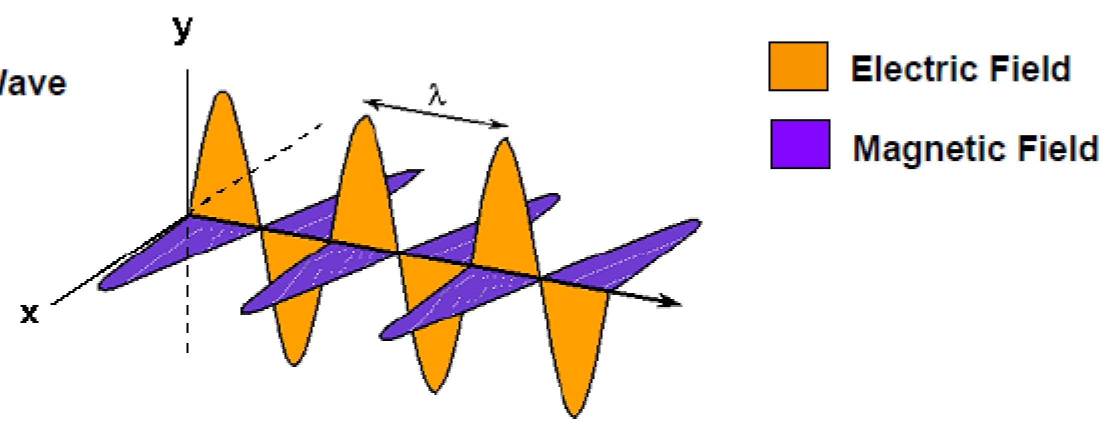


$A\sin(\theta)$

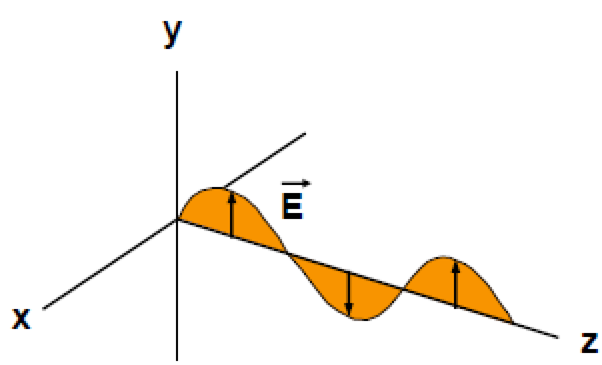
$A\sin(\theta - 90^{o})$

Polarization

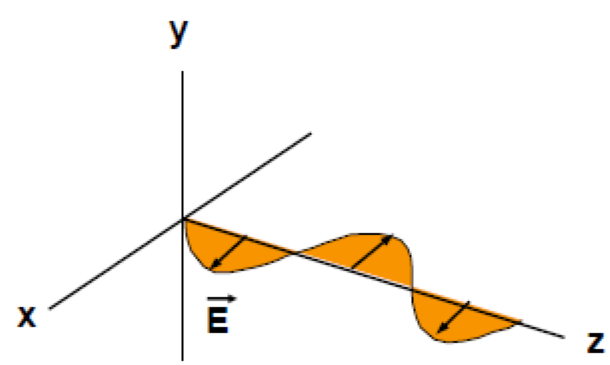
Electromagnetic Wave



Vertical Polarization



Horizontal Polarization



The relative value of two things, measured on a logarithmic scale, is often expressed in deciBel's (dB)

Example:

$$\text{Signal-to-noise ratio (dB)} = 10 \log_{10}\left[\frac{\text{Signal Power}}{\text{Noise Power}}\right]$$

Factor of:	Scientific Notation	dB
10	10^1	10
100	10^2	20
1000	10^3	30
.		
.		
.		
1,000,000	10^6	60

0 dB = factor of 1

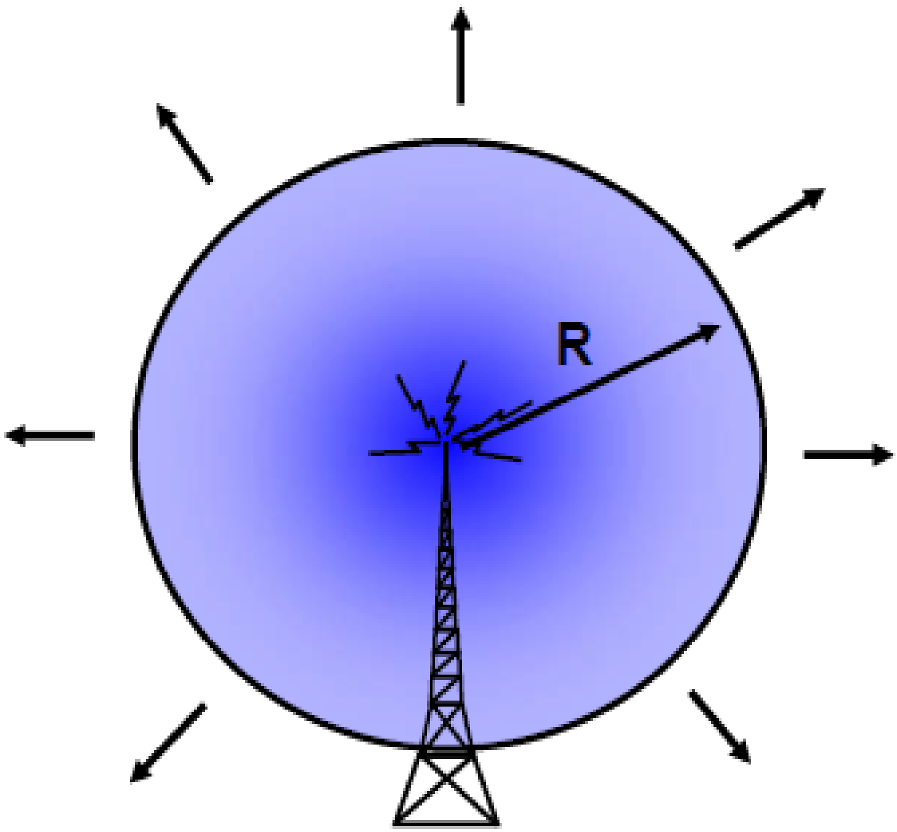
-10 dB = factor of 1/10

-20 dB = factor of 1/100

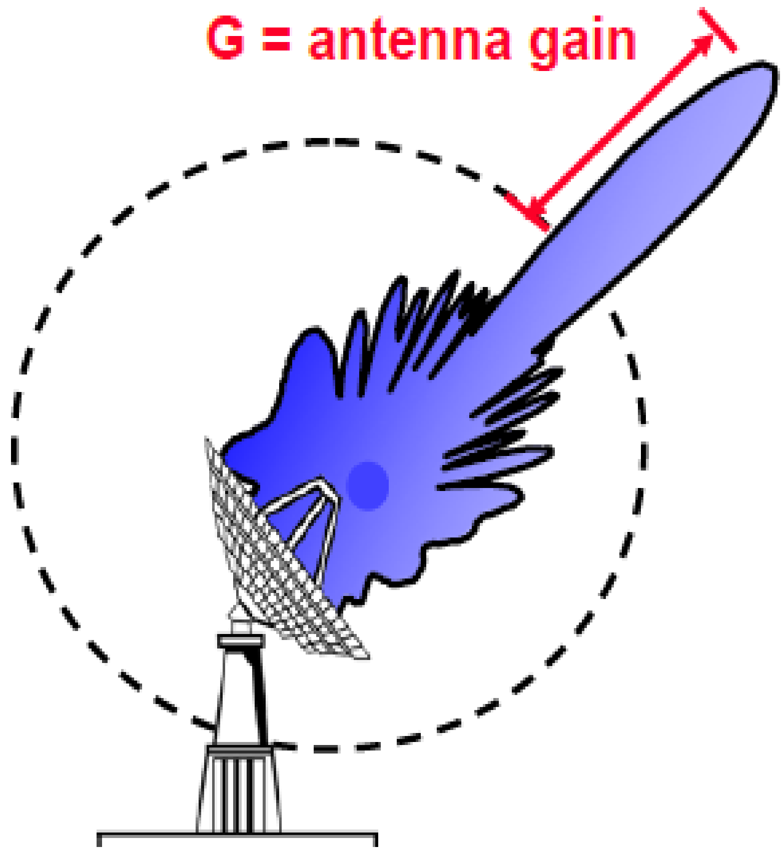
3 dB = factor of 2

-3 dB = factor of 1/2

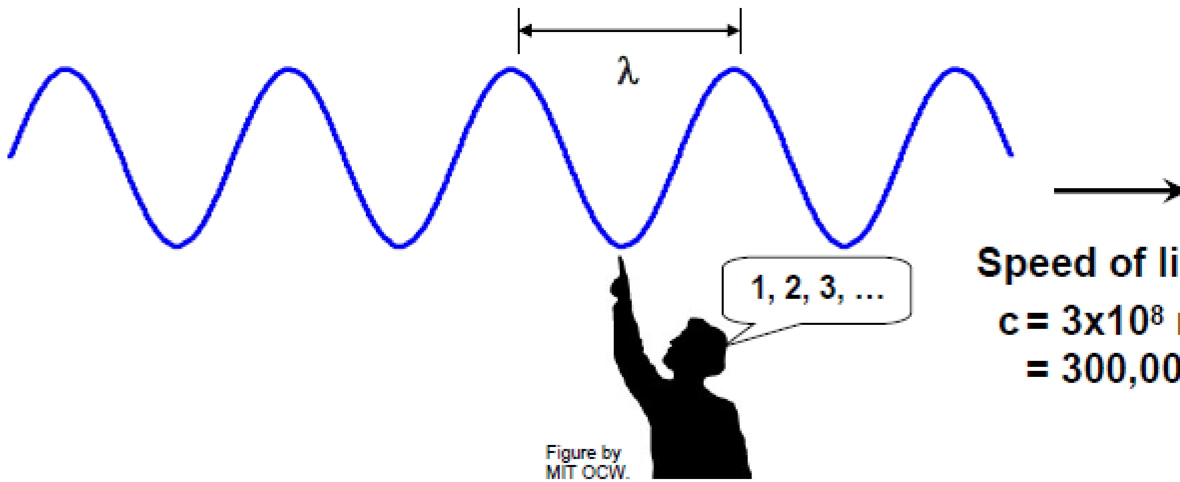
Isotropic antenna



Directional antenna



Properties of Waves
Relationship Between Frequency and Wavelength



Speed of light, c

$c = 3\text{x}10^8$ m/sec

= 300,000,000 m/sec

$$\text{Frequency (1/s)} = \frac{\text{Speed of light (m/s)}}{\text{Wavelength } \lambda \text{ (m)}}$$

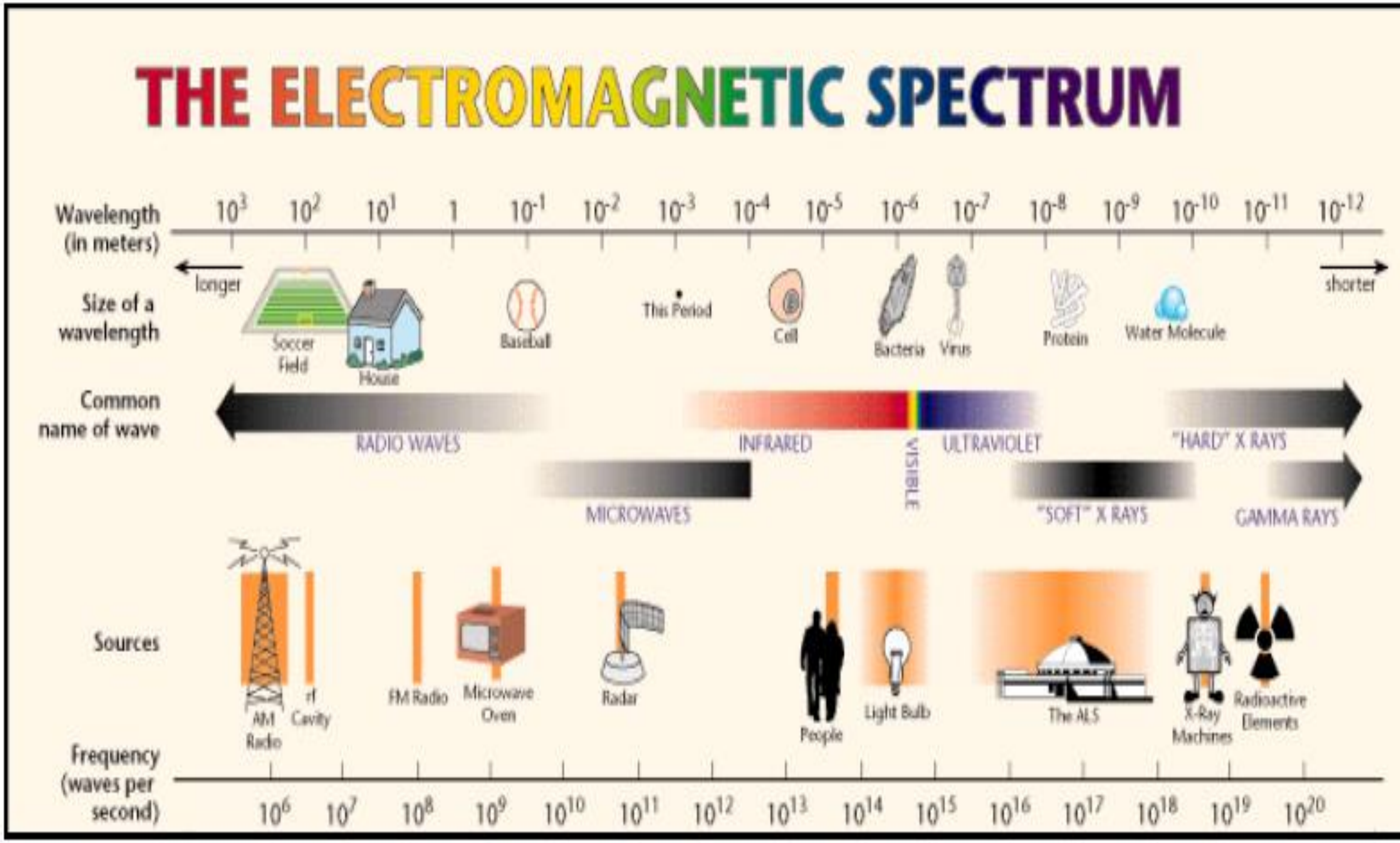
Examples:

Frequency	Wavelength
100 MHz	3 m
1 GHz	30 cm
3 GHz	10 cm
10 GHz	3 cm

Scientific Notation and Greek Prefixes

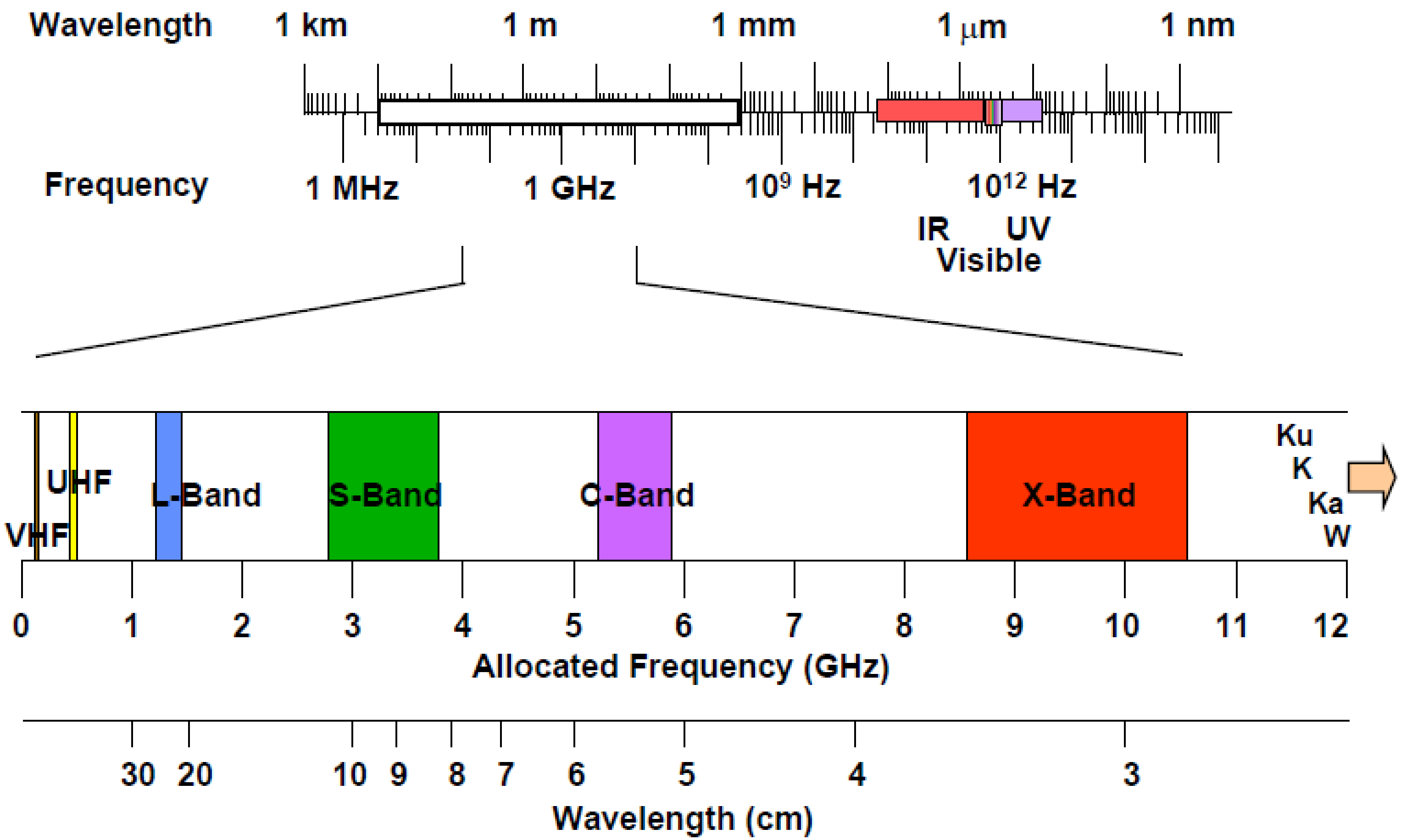
Scientific Notation	Standard Notation	Greek Prefix	Radar Examples
10^9	1,000,000,000	Giga	GHz
10^6	1,000,000	Mega	MHz, MW
10^3	1,000	kilo	km
10^1	10	-	-
10^0	1	-	-
10^{-3}	0.001	milli	msec
10^{-6}	0.000,001	micro	µsec

MHz = Megahertz
MW = Megawatt



Courtesy Berkeley National Laboratory

Radar Frequencies



Wavelength
1 km
1 m
1 mm
1 μm
1 nm
Frequency
1 MHz
1 GHz
10^9 Hz
10^12 Hz
IR
UV
Visible
VHF
UHF
L-Band
S-Band
C-Band
X-Band
Ku
K
Ka
W
0
1
2
3
4
5
6
7
8
9
10
11
12
Allocated Frequency (GHz)
30
20
10
9
8
7
6
5
4
3
Wavelength (cm)

IEEE Standard Radar Bands
(Typical Use)

HF	3 – 30 MHz
VHF	30 MHz–300 MHz
UHF	300 MHz–1 GHz
L-Band	1 GHz–2 GHz
S-Band	2 GHz–4 GHz
C-Band	4 GHz–8 GHz
X-Band	8 GHz–12 GHz
Ku-Band	12 GHz–18 GHz
K-Band	18 GHz–27 GHz
Ka-Band	27 GHz–40 GHz
W-Band	40 GHz – 100+ GHz

Search Radars

Search & Track Radars

Fire Control & Imaging Radars

Missile Seekers

Radar Developments (contd.)

- **For mounting on ships and aircrafts smaller antennas are required. To achieve this one need to use higher frequencies ie lower wave lengths.**
- **However technology to make components at higher frequencies were not available at that point in time.**
- **Antenna size is directly proportional to the wave length and indirectly proportional to frequency (λ =C/f)**

Frequency	Wave length	Frequency	Wave length
20 MHz	15 Mts	1 GHz(1000 MHz)	0.3 Mts
60 MHz	5 Mts	2 GHz	0.15 Mts
200 MHz	1.5 Mts	4 GHZ	0.075 Mts
600 MHz	0.5 Mts	10 GHz	0.03 Mts(3 Cms)

The Early Days of Radar

- Sir Robert Watson-Watt
  - Considered by many "the inventor of radar"
  - Significant early work occurred in many other countries, including the United States (1920sand 1930s)
  - After experimental verification of the principles, Watson-Watt was granted a patent in 1935
  - Leader in the development of the Chain Home radar systems
    - Chain Home, Chain Home Low
    - Ground Control Intercept and Airborne Intercept Radar

Sir Robert Watson-Watt

Courtesy of Wikimedia

- Tizard Mission
- MIT Radiation Laboratory

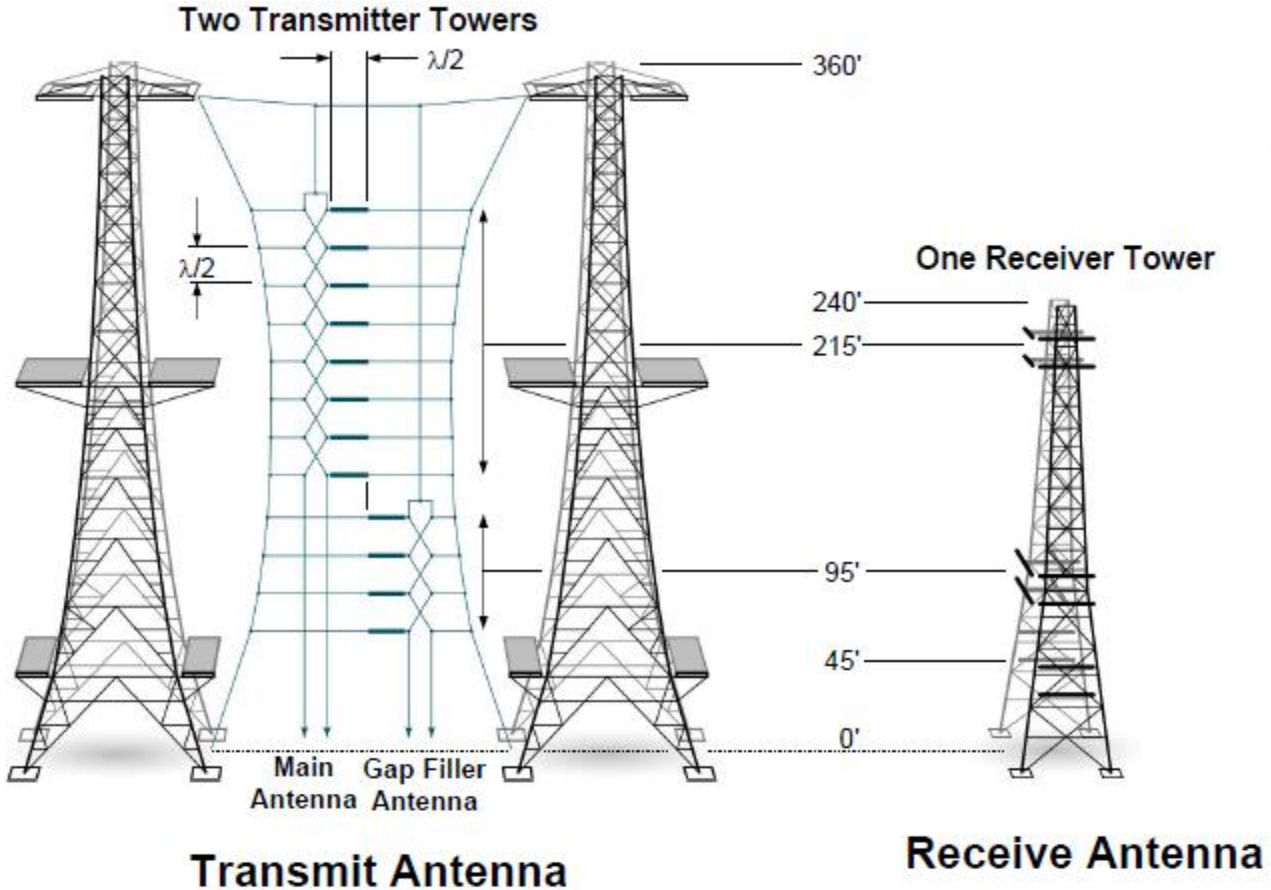
Chain Home Radar System

Typical Chain Home Radar Site

Chain Home Radar Parameters

- Wavelength
  - 10 to 15 m
- Frequency
  - 20 to 30 MHz
- Antenna
  - Dipole Array on Transmit
  - Crossed Dipoles on Receive
- Azimuth Beamwidth
  - ~ 100°
- Peak Power
  - 350 kW
- Detection Range
  - ~160 nmi on JU-88 German Bomber

Chain Home Transmit & Receive Antennas



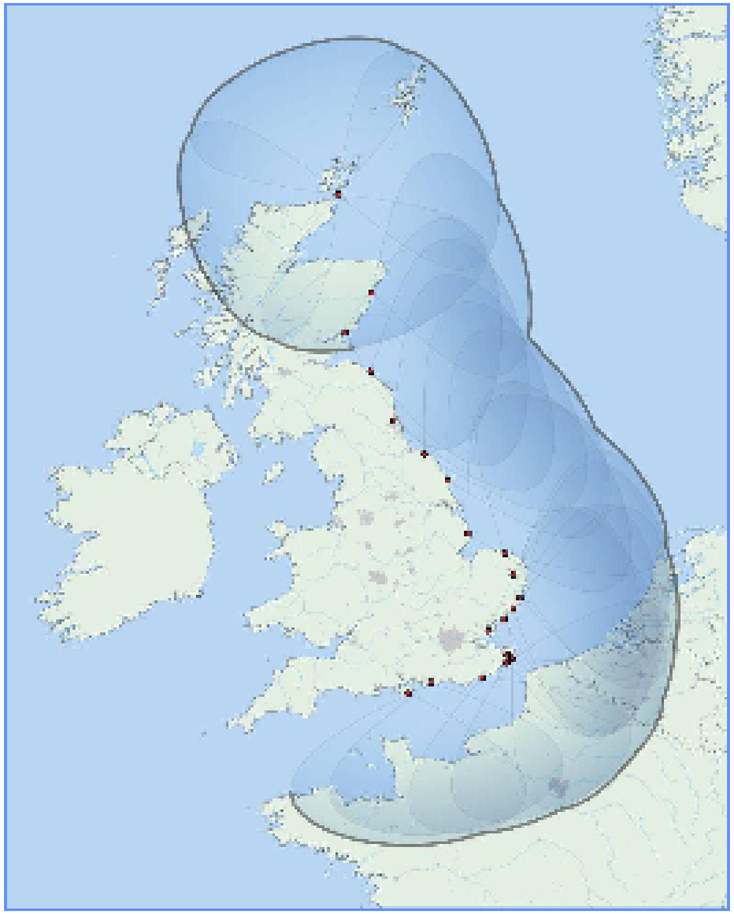
Chain Home Radar Operations

Plotting Area in Chain Home Radar Receiver Room

Operation Room at Air Group 10

Radar and "The Battle of Britain"

Approximate Chain Home Radar Coverage
Sept 1940
(21 Early Warning Radar Sites)



- The Chain Home Radar
  - British "Force Multiplier" during the Battle of Britain"
- Timely warning of direction and size of German aircraft attacks allowed British to
  - Focus their limited numbers of interceptor aircraft
  - Achieve numerical parity with the attacking German aircraft
- Effect on the War
  - Germany was unable to achieve Air Superiority
  - Invasion of Great Britain was postponed indefinitely

Utility and Positive Attributes of Radar

- Long range detection and tracking of targets
  - 1000's of miles
- All weather and day/night operation
- Wide area search capability
- Coherent operation enables
  - Simultaneous reliable target detection and rejection of unwanted "clutter" objects
  - Target imaging (fixed and moving)
  - Very fast beam movement with electronic scanning of antennas (microseconds)
  - Ability to adaptively shape antenna beam to mitigate interference and jamming
- "Relatively lossless, straight line propagation at microwave frequencies

Negative Attributes / Challenges of Radar

- Long range detection requires
  - Large and heavy antennas
  - High power transmitters
  - Significant power usage
  - $$$$$
- Radar beams not propagate well
  - through the Earth, water, or heavy foliage
  - around obstacles
- Vulnerable to jamming, and anti-radiation missiles
- Target can detect that it is being illuminated
- Target can locate the radar in angle-space
- The echo from some targets is becoming very small
  - Low observable technology

TECHNOLOGIES USED IN RADAR

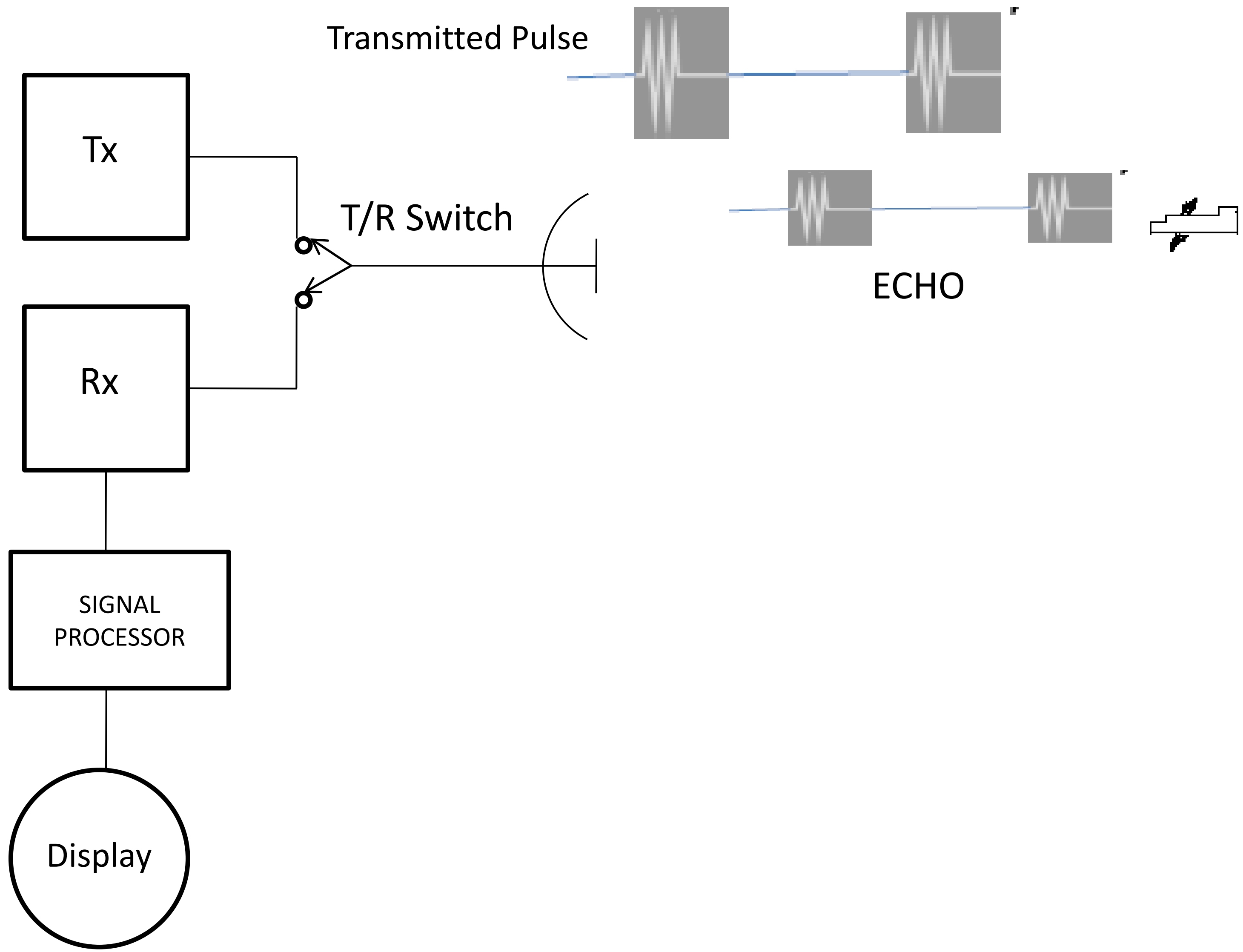
- **Radar is an Engineering system and integrates many of following technologies.**

  (i) Microwaves Engineering
  (ii) Antenna Technology
  (iii) R.F. Plumbing
  (iv) High Power Microwave Transmitter
  (v) High Sensitivity Microwave Receiver
  (vi) I.F. Circuit
  (vii) Matched Filter
  (viii) Signal Processing
  (ix) Display Technology
  (x) Control Systems

FUNCTIONS OF RADAR

1. **Detect the presence of target**
2. **Gives the range of the target from the Radar station**
3. **Gives the azimuth angle and elevation angle of the target**
4. **Gives the radial velocity of target.**

PRINCIPLE OF RADAR



Principle Of Radar (Contd..)

1. Transmitter generates a high power Pulse modulated sine wave.
2. T/R switch connects Antenna to T_X
3. Antenna converts Electrical Pulse to EM Wave and transmits in space.
4. T/R switch now connect Antenna to R_X
5. Aircraft reflects a portion of EM energy called Echo.
6. Echo collected by Antenna converts EM pulse to RF Pulse.
7. Signal Processor converts RF Pulse to video pulse after amplification.
8. Display shows visually the Echo.

SUBSYSTEMS OF RADAR

1. **Transmitter:** This generates the Electrical energy at R.F.(Radio Frequency). This may be a power oscillator or a power amplifier.

2. **Antenna:** This is a transducer which converts the RF electrical signals to EM signals and transmits in space.

- ❖ It also function as a receiving antenna and converts EM signal to Electrical signal.

Subsystems of Radar(contd…)

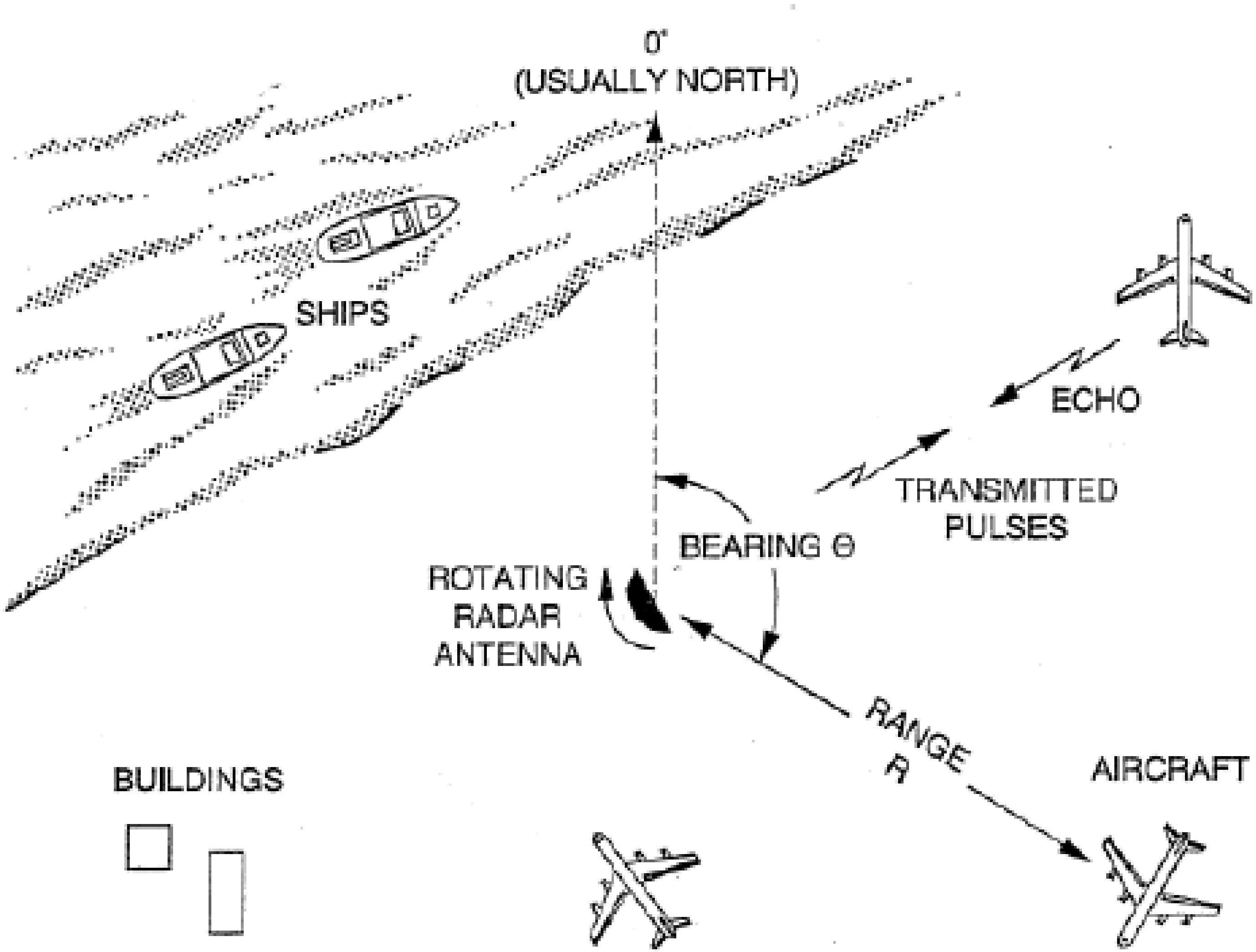
3.Receiver: The weak Echo is amplified and processed to detect presence of target.

- **This consists of Signal Processing Circuits to optimize the signal to Noise ratio.**
- **The R.F. Echo is envelope detected to obtain Video and amplified to suit the Display requirements.**

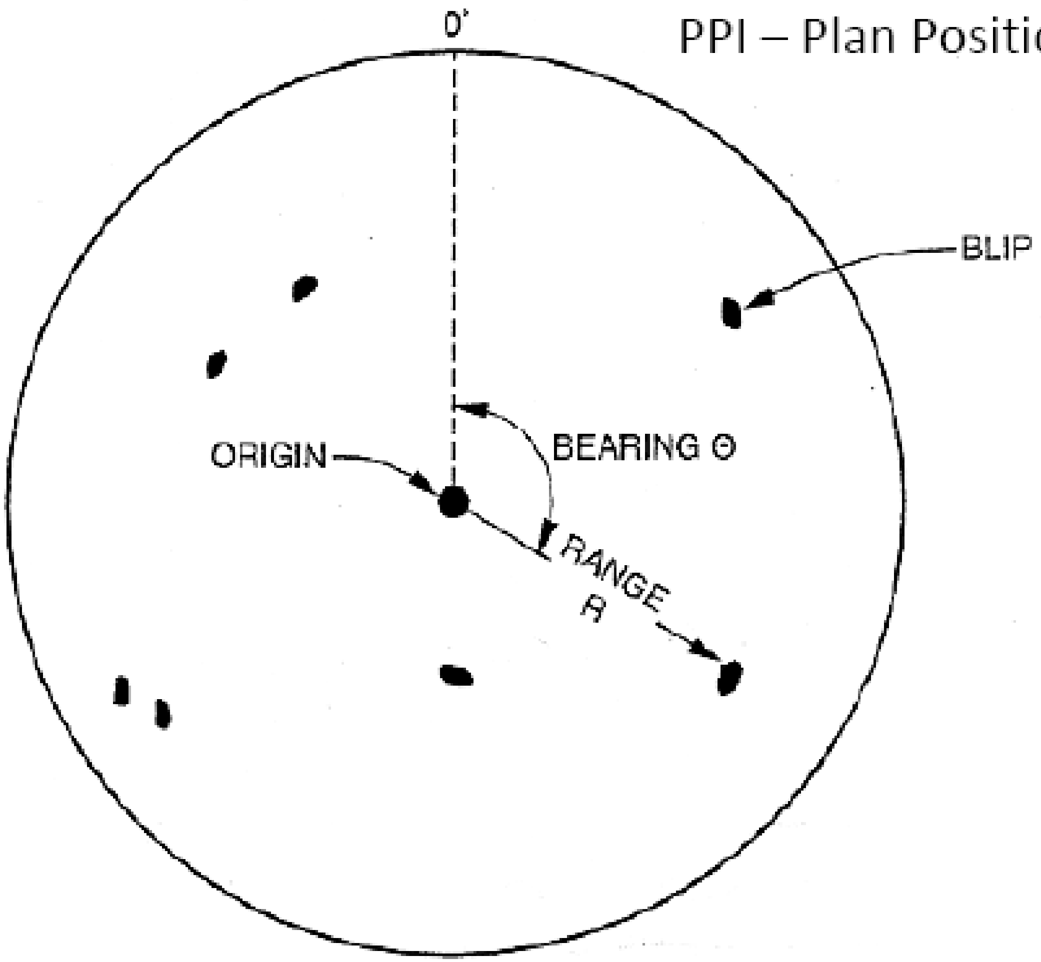
4.Display: Presence and location of a target is displayed on a CRT usually called the PPI (Plan Position Indicator).

- **The dot (spot) on the CRT gives out the target coordinates i.e. Range, Azimuth & Elevation.**

Radar Principles



Radar Principles



PPI – Plan Position Indicator

WHERE DO YOU USE RADAR

1.Defence: Detection and location of military

(i) Aircrafts (ii)Ships (iii)Tanks (iv) Missiles

2.Civilian: (i) Air Traffic Control(ATC)

(ii) Ships Navigation

(iii) Collision Avoidance

3.Meterology: Weather prediction(storms & cyclones)

4.Remote Sensing: (i)Imaging (ii)Ground Mapping

(iii)Agricultural Crop Monitoring

5.Police: Speed monitiring & Control

APPLICATIONS OF RADAR

- Radar has been employed on

(i) **Ground:** To detect, locate and track aircraft or space targets.

(ii) **Sea:** To navigate in sea or ocean in bad weather. Navigate safely in harbour and dock in the allotted berth without collision with other ships

(iii) **Air:** (1) To detect other aircrafts, ships or land vehicles, (2) To avoid storms (3) terrain avoidance (4) Navigate from one air port to another.

(iv) **Space:** (1) Guidance of Spacecraft, (2) Remote sensing of planets.

Applications of Radar (contd..)

1. AIR TRAFFIC CONTROL (ATC):

- **Safely controlling aircraft traffic enroute airports.**
- **Controlling air traffic in the vicinity of airport when the density of aircraft trying to land on runway and take-off from runway is heavy.**
- **Radar is a part of Ground Control Approach (GCA) systems or ATC Radar Beacon System which guide aircrafts to a safe landing or take-off in bad weather.**

Applications of Radar (contd..)

2. AIRCRAFT NAVIGATION:

- **Radar mounted on aircraft gives a visual picture of weather conditions to the pilot in front of the moving aircraft. Regions of precipitation, heavy storm, clouds etc. shown by the radar enable pilot to steer the aircraft away from the danger regions.**
- **Radio Altimeter (FMCW Radar) gives the height of the aircraft from the ground.**

Applications of Radar (contd..)

3. SHIP SAFETY:

- Ships are mounted with Radars which warns the navigator about other ships in its vicinity especially in poor visibility conditions and avoid collisions.
- Ship radar facilitate the navigator for docking safely in the given berth in a harbour.
- Shore based Radars used for surveillance and navigation in a harbour and control the movement of ships in the harbour.

Applications of Radar (contd..)

4.REMOTE SENSING:

- Radars are used for remote sensing of environment, like cyclones, storms, tornadoes etc.
- Radars are used for mapping the conditions of agricultural crops by sensing the water content in the plants. They are used in mapping forestry coverage and its density.
- Radars are used to probe moon and other geophysical objects like planets (radar astronomy) Radars are mounted on satellites or aircrafts for this purpose.
- Radars are used to detect and locate earth resources like water, ice cover, geological formations, environmental pollution, mapping sea conditions etc.
- Radars are used for satellite monitoring.

Applications of Radar (contd..)

5. SPACE:

- Radars are mounted on space vehicles for rendezvous and docking, and for landing on planets like moon, mars etc.

6. LAW ENFORCEMENT:

- Police Officers use Radars to measure the speed of automobiles like 4 wheelers, 2 wheelers on highway and avoid accidents due to over speeding
- Radars are used to detect intruding vehicles or persons in high security premises.

APPLICATIONS OF RADAR (Contd..)

7. MILITARY:

- Radar is extensively used for military purposes.
- Long range surveillance of country's borders.
- Navigation of military aircraft and naval ships.
- Tracking hostile targets (aircraft or ships) and control the Anti aircraft Guns or control and guide missiles.

MILITARY RADARS

Post World War–II Radars:

1.N/SPY-1 Multifunction ship borne tactical Radar

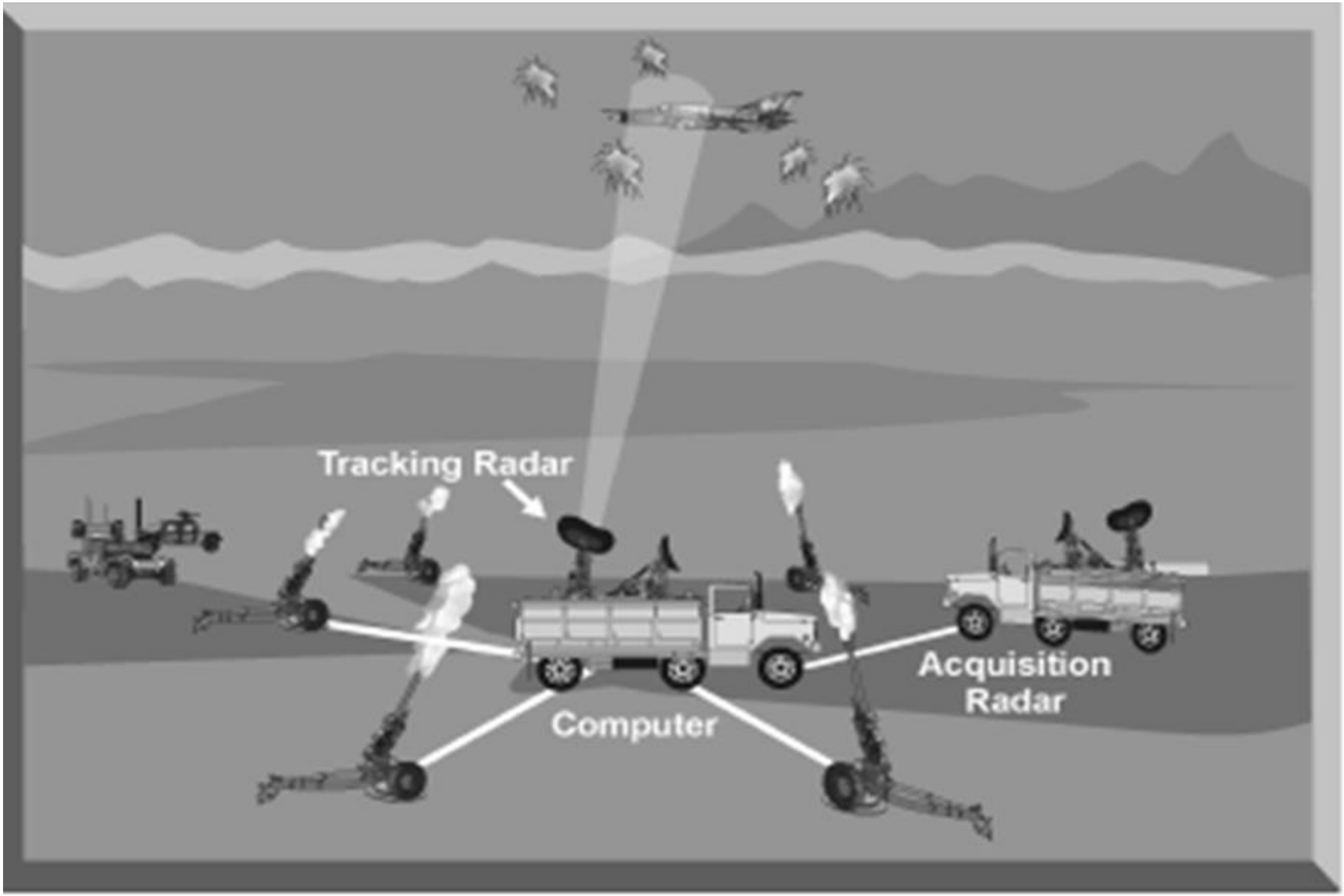
2.AN/MPQ-53 Patriot Air Defence Radar

3.AN/FPS-108 COBRADANE Long Range Radar

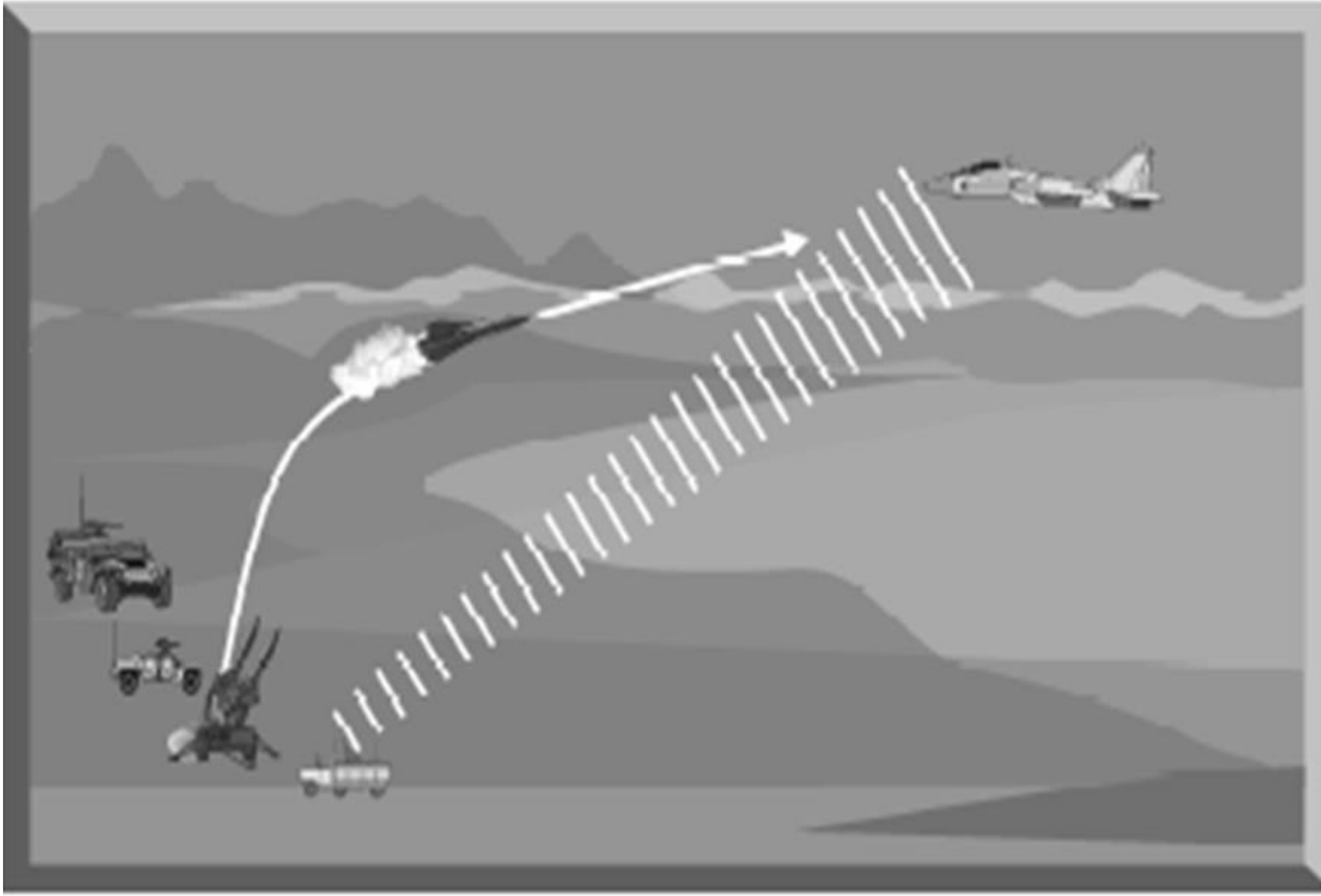
4.AN/FPS-115 PAVE PAWS solid state early warning Radar

DRDO Developed Radars:

1.Indra I & II 2.Rajendra-Phased Array Radar for use with AKASH missile 3.Battle Field Surveillance Radar 4.Naval Maritime Radar



Radar-Directed AAA



Semi-Active Guidance (Mid-Course)

CONTINUED IN RADAR 1B

RADAR SYSTEMS

- EC812PE: RADAR SYSTEMS (PE – V)

(ELECTIVE V)

UNIT – 1B

B.TECH IV YEAR II SEMESTER

BY

Prof.G.KUMARASWAMY RAO

(Former Director DLRL Ministry of Defence)

BIET

Acknowledgements
The contents , figures , graphs etc., are taken from the following Text book & others
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Second Edition
Tata Mcgraw – Hill publishing company
Special indian edition

SYLLABUS

- EC812PE: RADAR SYSTEMS (PE – V)

UNIT I

- Basics of Radar: Introduction, Maximum Unambiguous Range, Simple form of Radar Equation, Radar Block Diagram and Operation, Radar Frequencies and Applications, Prediction of Range Performance, Minimum Detectable Signal, Receiver Noise, Modified Radar Range Equation, Illustrative Problems.
- 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.

(Jntuh)

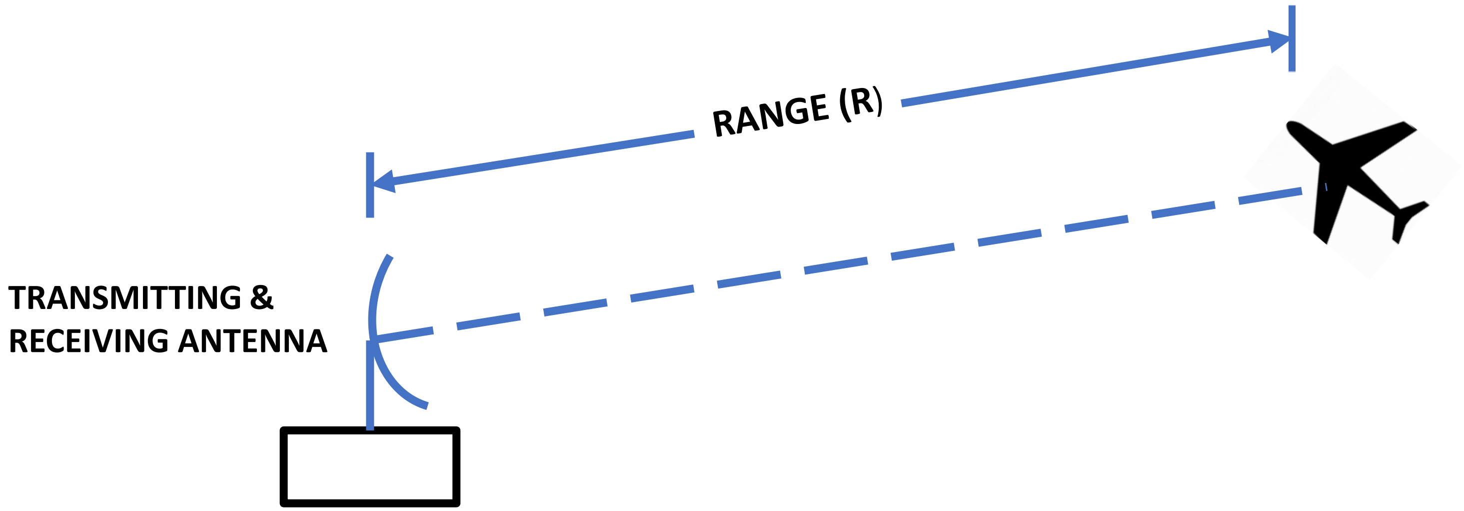
INTRODUCTION

PRINCIPLE OF RADAR

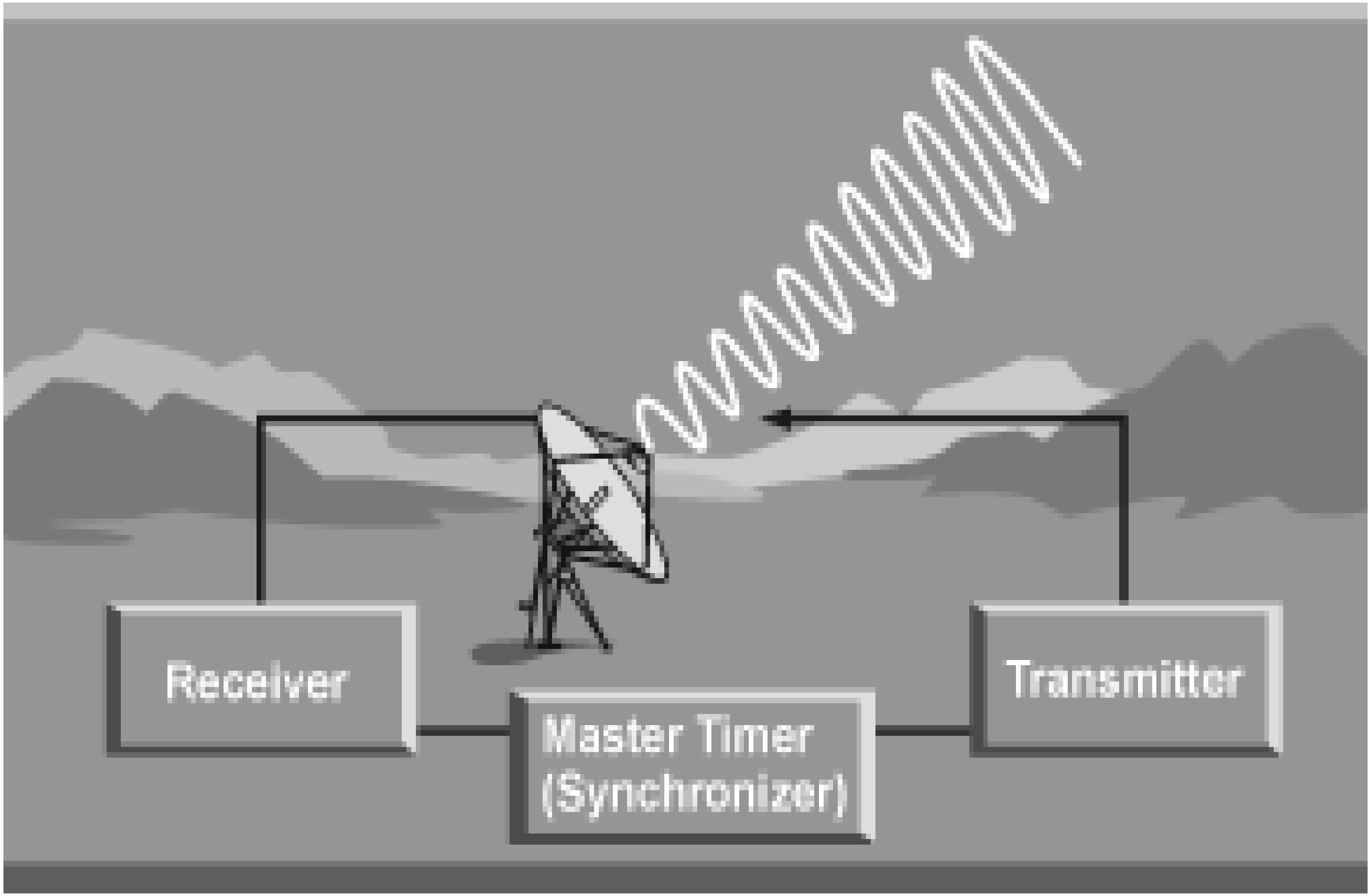
- What are the basic functions of Radar? Explain
- Radar stands for **R**adio **D**etection **A**nd **R**anging
- Basic functions of Radar are
- 1. Detect the object (also called target)
- 2. Calculate the Range of the target (Range of a target is the radial distance between the Radar antenna and target)
- Additional functions of Radar are
- 1. Give the direction of target. (By mounting the Radar antenna on a rotating servo pedestal, the azimuthal direction of target can be found out)

PRINCIPLE OF RADAR (contd)

- 2. Give the radial velocity of the target. (By using the Doppler principle, the radial velocity can be computed)
- PRINCIPLE OF RADAR:

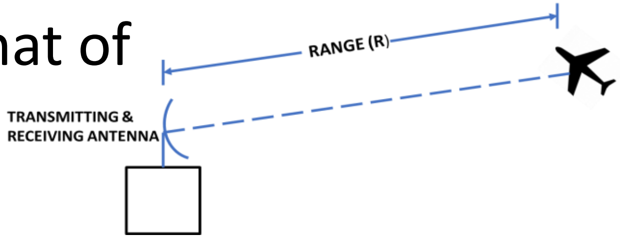


PRINCIPLE OF RADAR

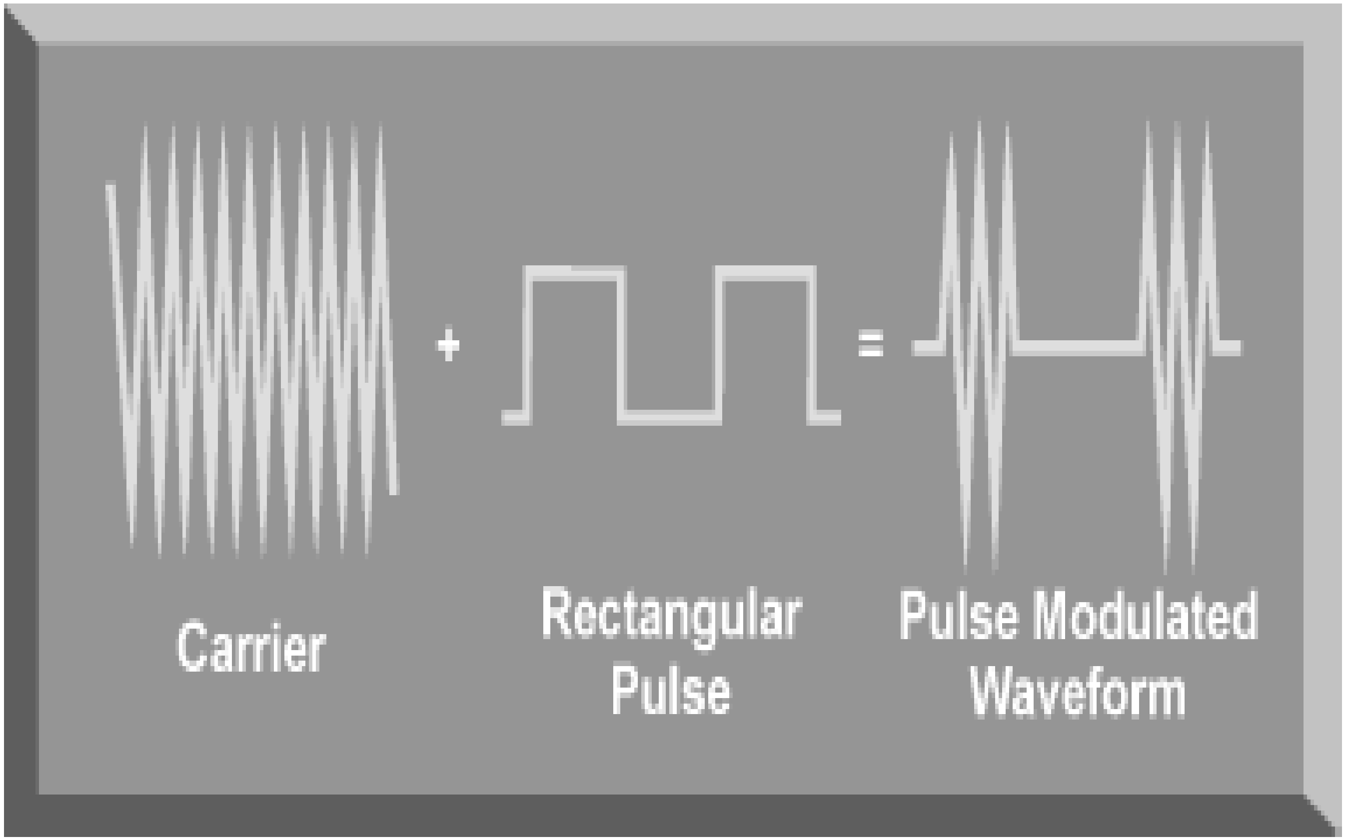


PRINCIPLE OF RADAR (contd)

- 1. The transmitting antenna transmits the electro-magnetic radiations in space for a short duration (pulsed). Its speed is that of light 3 x 10^8 meters/second. If an object (also called target) is present

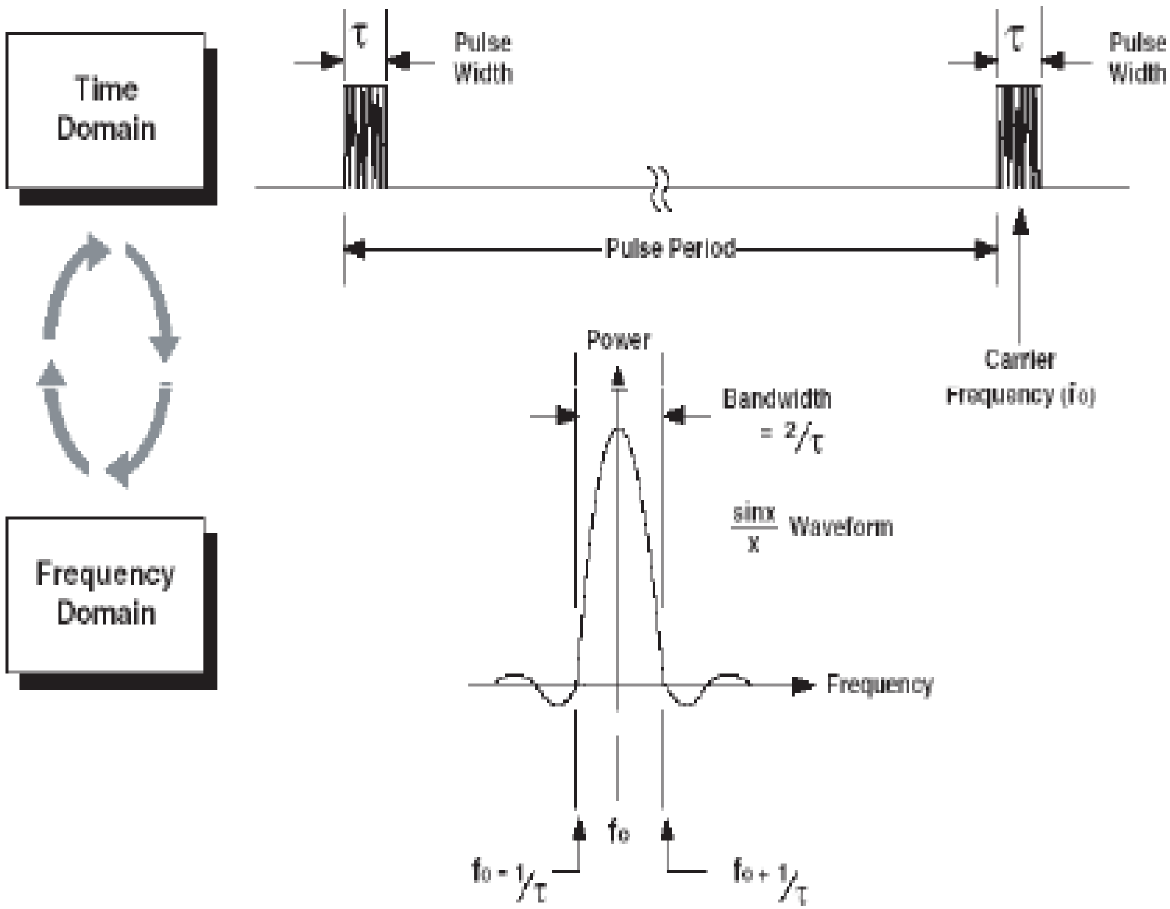


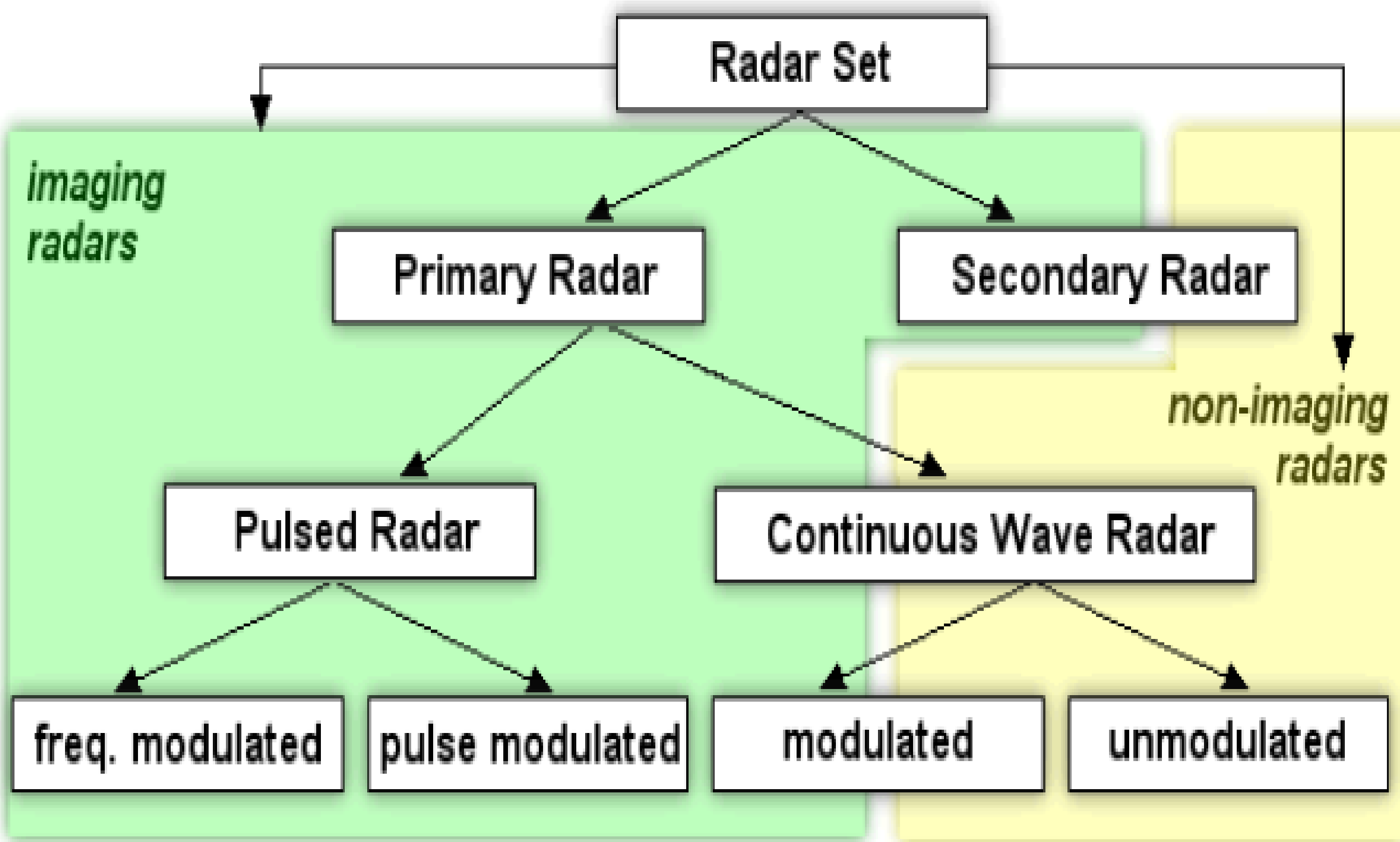
in the path of the EM pulse, it intercepts the radiation and backscatters the signal in all directions (omni). A portion of scattered signal reaches the radar antenna. The Receiving antenna captures the back-scattered radiation and applies it to the Radar Receiver. The receiver amplifies and processes the low energy signal and processes it. It measures the amount of time **TR** taken by the pulsed EM wave to reach the target and return back to the antenna.



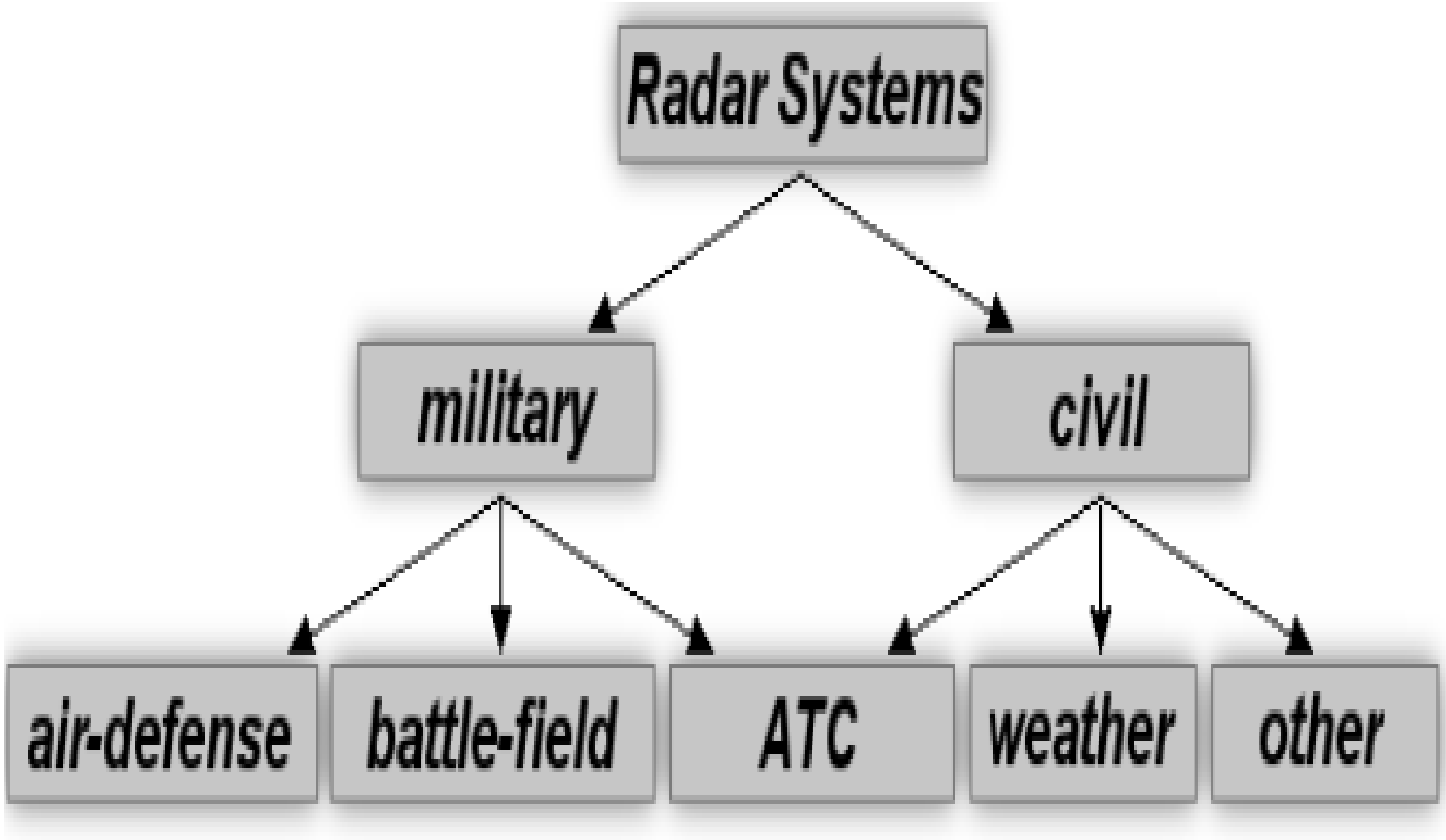
Pulse Modulation

Pulse Mode Operation





Radar systems classified according to specific function



Classification of radar sets according its use

PULSE CHARACTERISTICS

(Jntuh) What are the desirable pulse characteristics and the factors that govern them Or Define a) PRF b) Unambiguous range

- There are 4 important pulse characteristics to be considered for the radar pulse
- 1. Carrier 2. Pulse width 3. Pulse repetition frequency –PRF
  4. Unambiguous Range

PULSE CHARACTERISTICS

- 1. CARRIER:
  The carrier used in a Radar is called the RF (Radio frequency) or Micro-wave signal. Their range may be from 3 MHzs to 300 MHzs. They are VHF, UHF, L,S,C,X,Ku,K,Ka bands and mm (millimetric) frequencies. High frequencies are used in Radar to keep the radar antenna within reasonable size

PULSE CHARACTERISTICS(contd)

- 2. PULSE WIDTH:

  In a Pulse radar the Carrier is modulated to get the range of the target. The Carrier is switched ON and OFF with the short duration pulse. The pulse width determines the dead zone of the range of the target. For example if the pulse width is 1 micro sec, detection of target range less than 150 meters is not possible. During the transmission of 1 micro sec high power pulse, the Radar receiver is blanked to protect it from damage because of high power transmission. Similarly if a pulse width of 10.8 micro sec is used there is no detection of target for 1 standard mile from the radar antenna

PULSE CHARACTERISTICS(contd)

- 2. PULSE WIDTH (C0NTD):

However in CW (Continuous Wave) radar no modulation is used. However the doppler principle is used to extract the radial velocity of the target

PULSE CHARACTERISTICS(contd)

- 3. PULSE REPETITION FREQUENCY : (PRF)

  Pulse radar continuously transmits RF pulses continuously at a particular frequency. The echo (reflection) from the target is painted on the display by the Signal processor every time echo pulse is received

  PRF is the number of pulses transmitted in a second

  $$\text{PRF} = \frac{1}{\text{PRT}\ (\textit{pulse repetition time})} = \frac{1}{\text{PRI}\ (\textit{pulse repetition interval})} = \frac{1}{\text{IPP}(\textit{inter pulse period})}$$

  PRF is important because it determines the maximum target range R unambiguous and doppler velocity

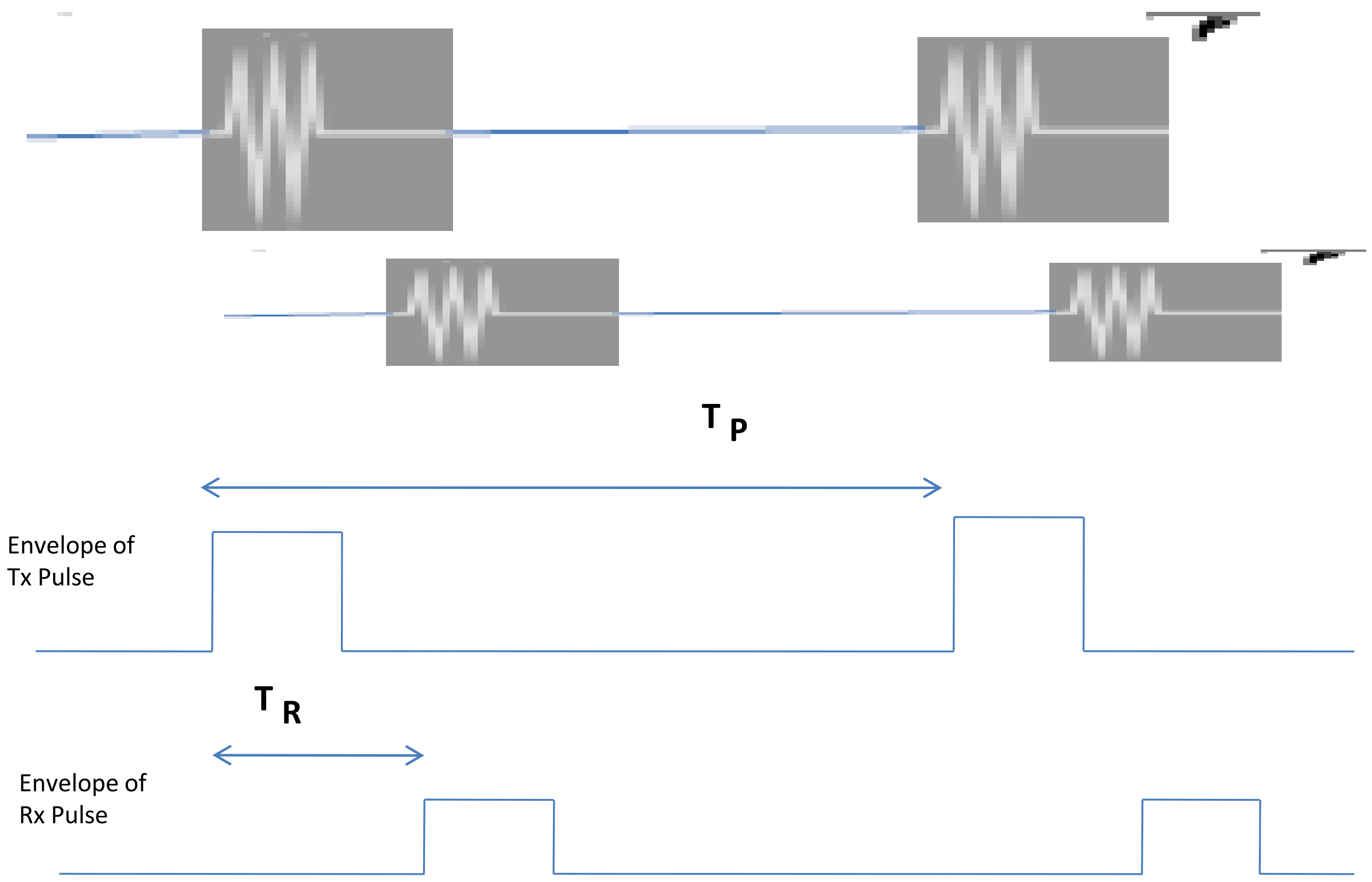
PULSE CHARACTERISTICS(contd)

- 4. MAX UNAMBIGUOUS RANGE (Runambiguous)
  It is the greatest range the transmitted can travel and comeback to the radar antenna before the transmission of next pulse
  Echoes from target must arrive before the next pulse is transmitted to avoid Range Ambiguity
  Echoes that arrive after the transmission of next pulse is transmitted are called Second Time around echoes. These second time around echoes give wrong reading of target range. They are interpreted as shorter target range than the actual.
  There is a relation between PRF and (Runamb). Larger the PRF shorter is the (Runamb)
  Max (Runamb) = $\frac{C}{2\ fp}$ where f_p = PRF in HZs

RADAR RANGE OF A TARGET

- RF Sine wave (Between 1G_{HZ} TO 40 G_{HZ}) modulated with a short pulse (Between 0.1 to 5 μ sec)
- RF Pulse travels in air from Antenna to Target
- Portion of EM energy is reflected after hitting the target (ECHO)
- Echo reaches the same antenna

RADAR RANGE OF A TARGET



RADAR RANGE OF A TARGET

T_P – Pulse Repetition Time

T_R – Time taken by EM pulse to travel to target and come back to same antenna – Elapsed Time between Transmission and Echo Pulse

f_P – Pulse Repetition frequency = $\frac{1}{T_p}$

R – Range of Target

C – Velocity of EM waves = 3×10^8 Meters/sec

= $1.86 \text{ X } 10^5$ miles /sec

RADAR RANGE OF A TARGET

- The Range of the target from the Radar antenna is computed as follows
- Distance (Range) = Velocity X Time (elapsed between transmitted & received EM pulse)
- Range R= $C \times \frac{T_R}{2} = \frac{C\,TR}{2}$
- where C = Velocity of EM waves and TR = elapsed between transmitted & received EM pulse
- 2 is used because the radiation travels twice the range before it reaches antenna

RADAR RANGE OF A TARGET

- If TR = 1 micro second R = $\frac{3 \text{ x } 108 \text{ x } 1 \text{ x } 10 - 6}{2}$ = 150 meters
- If TR = 10.8 micro second and c= 1,86,000 miles per sec
  R = $\frac{186000 \text{ x } 10.8 \text{x } 10 - 6}{2}$ = 1 mile (standard)

RADAR RANGE OF A TARGET

Distance= Velocity x Time taken

$2\,R = C \times T_R$

- $R = C \times T_R / 2 =$
- $R(km) = 0.15\ T_R\ (\mu s)$ or $\frac{C\ T_R}{2}$
- $R(nmi) = 0.081\ T_R\ (\mu s)$
- If $T_R = 1\mu s$, R=150 meters = 164 Yards = 492 ft.

1 Km=0.62137 statue mile = 0.53995 nautical miles
1 statue mile = 5280 ft = 1.60934 Km
1 Nautical mile = 6076.12 ft=1.852 Km

TARGET RANGE

- Target range =

$$= \frac{\text{Measurement time } (T_R) \times \text{ Speed of light } (C)}{2}$$

RELATION BETWEEN PRF, PRT & PRI

- PRF = Pulse Repetition frequency(HZ)
- PRT = Pulse Repetition Time (secs)
- PRI = Pulse Repetition Interval (secs)
- PRF = $\frac{1}{\mathrm{PRT}} = \frac{1}{\mathrm{PRI}}$

MAXIMUM DETECTION RANGE

PRT	PRF	MAXIMUM DETECTION RANGE
10 μs	100 KHZ	1.5 KMS
100 μs	10 KHZ	15 KMS
1000 μs	1 KHZ	150 KM

UNAMBIGUOUS RANGE

- T_R is the time elapsed between transmission pulse and Echo pulse.

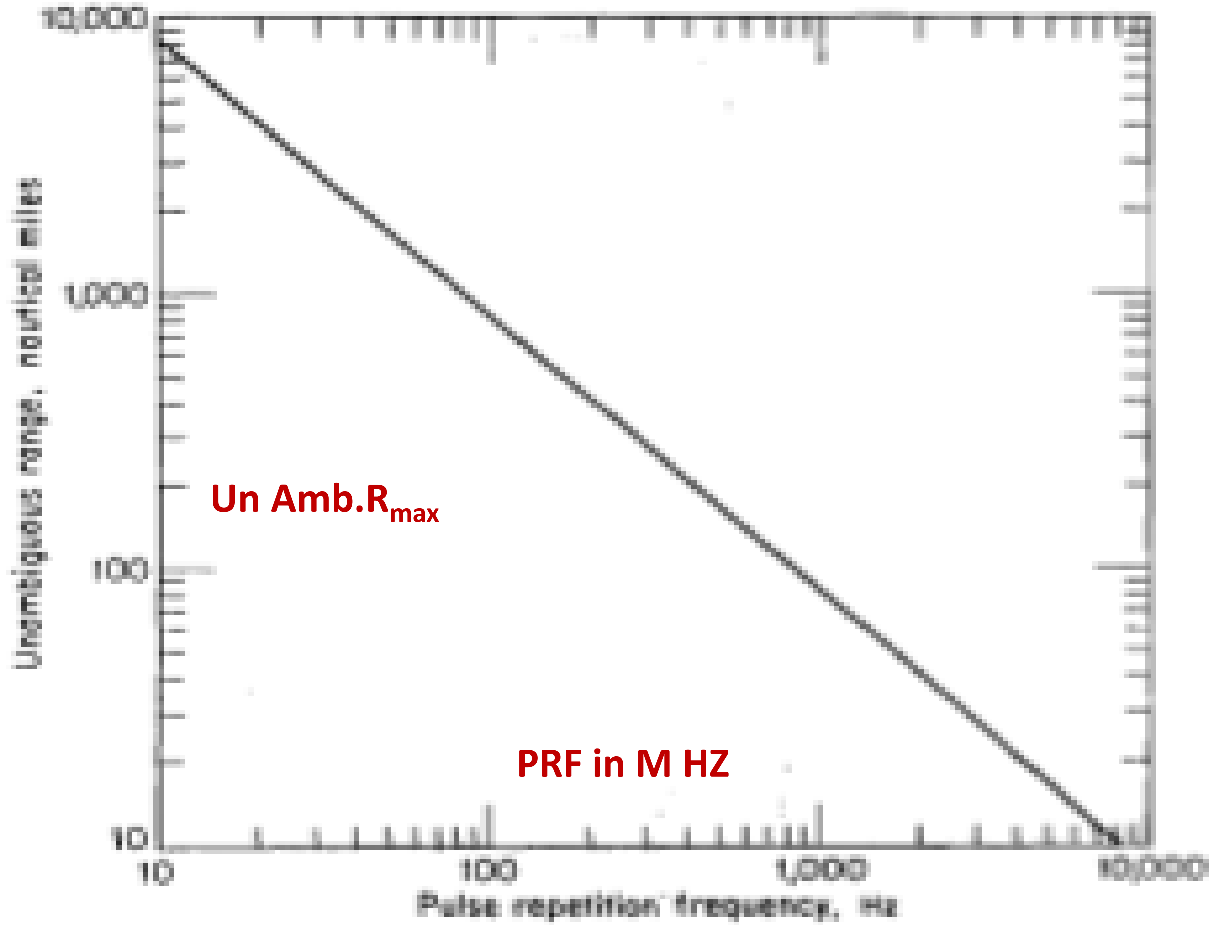
  But $T_R = \frac{2\,R}{C}$ where R= Range of target
- T_R increases with Range R and in extreme case Echo pulse merges with Transmitted Pulse
- $T_{R\,max} = T_P$ and R thus becomes R_{max}
- T_P = Pulse Repetition Time
- $T_{R\,max} = T_P = \frac{2\,Rmax}{C}$ R_{max} also known as
- Max $R_{unambiguous}$ So $R_{max} = \frac{C\,TP}{2}$
-

UNAMBIGUOUS RANGE

- When a pulse is transmitted, the Radar receiver listens for echoes until the next pulse is transmitted. This means that echoes must reach the Receiver within the pulse interval T_P
- Unambiguous Maximum Range is the maximum range the radar is capable of determining without ambiguity .If the range of target is more than Unambiguous Max Range, multiple time around echoes occur and range computed is erroneous

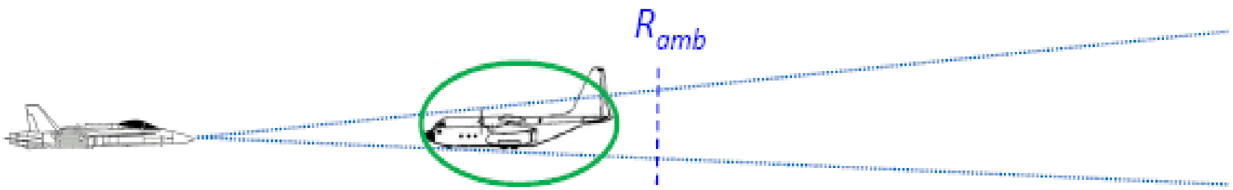
RELATION BETWEEN UNAMB R_{MAX} AND PRF

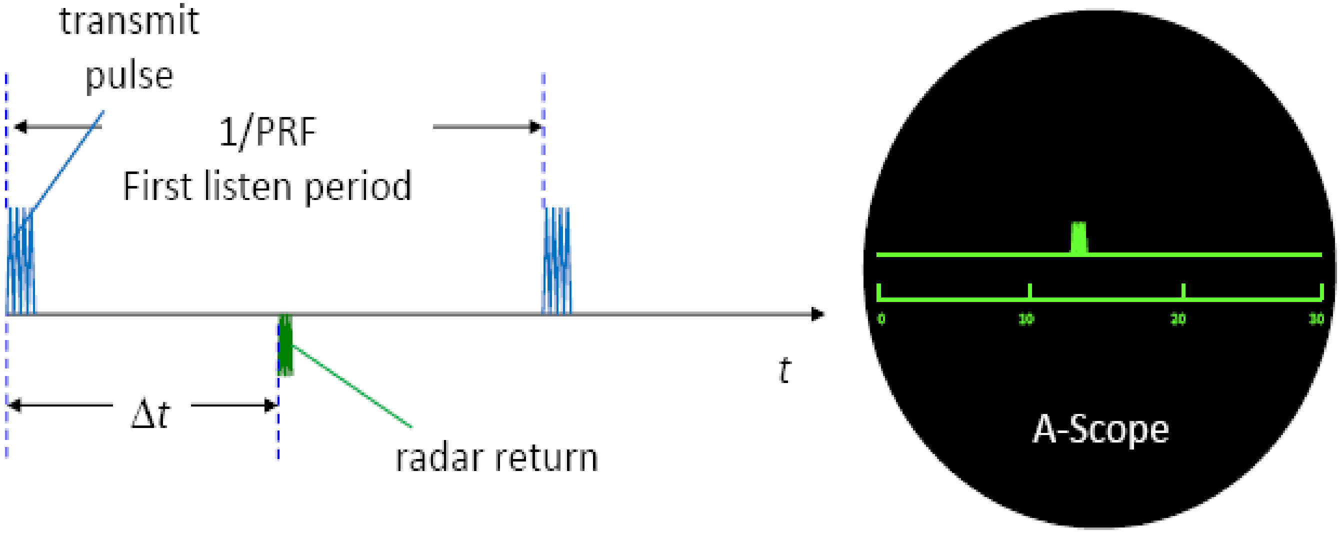
- Unamb $R_{max} = \dfrac{C\,T_P}{2}$ (from earlier slide)
- But PRF $= \dfrac{1}{T_P} = \dfrac{C}{2\,R_{max}}$
- So Unamb $R_{max} = \dfrac{C}{2\,PRF}$
- The relation between PRF and Unamb R_{max} is linear and shown in the graph.



Maximum Unambiguous Range Vs Pulse Repetition Frequency

Range Ambiguity – True Range

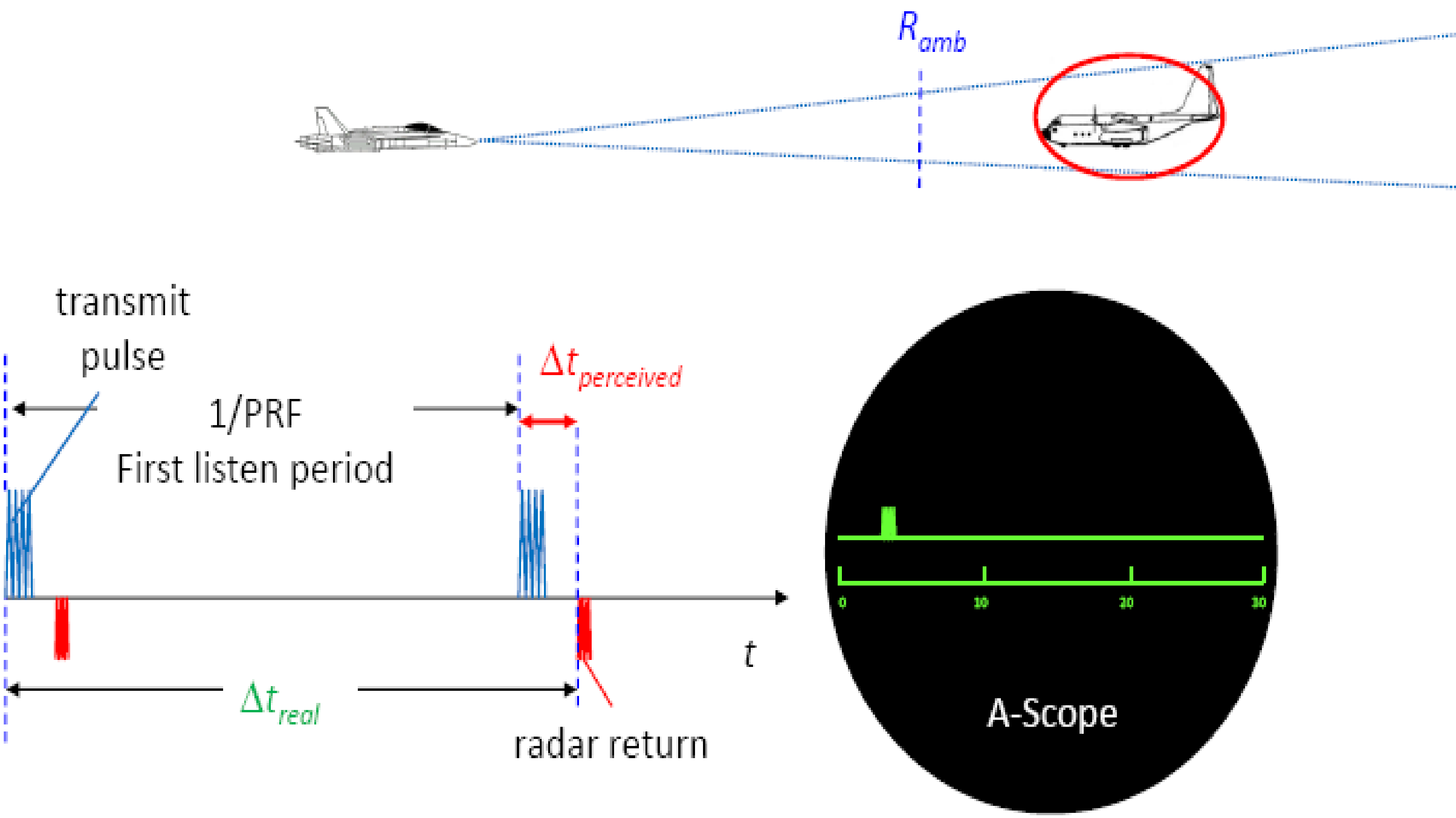




Target range $R = c\Delta t / 2$

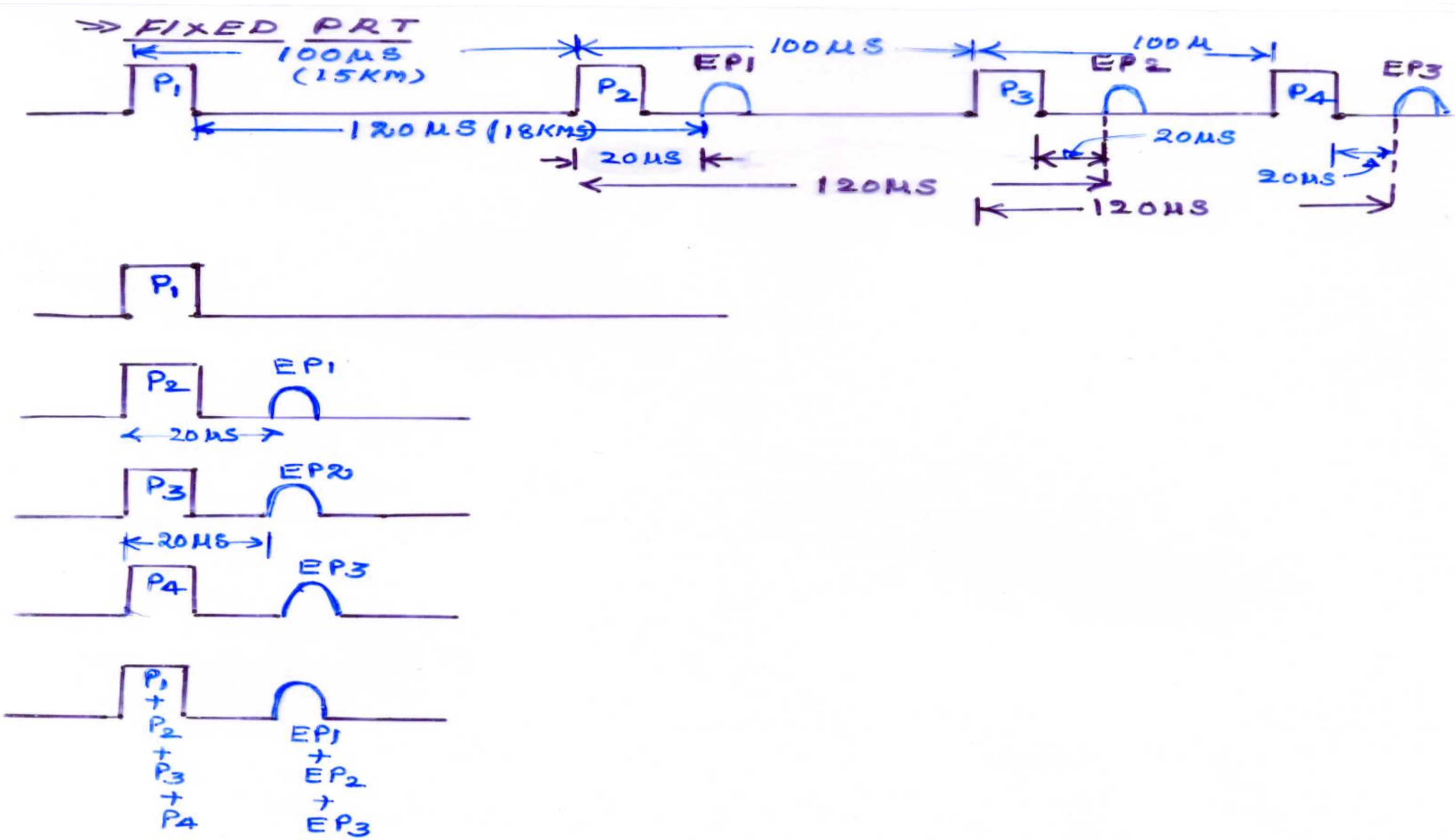
Tektronix

Range Ambiguity – False Range



Target range $R = c\Delta t_{perceived} / 2$

SECOND/MULTIPLE TIME AROUND ECHOES – RANGE AMBIGUITIES

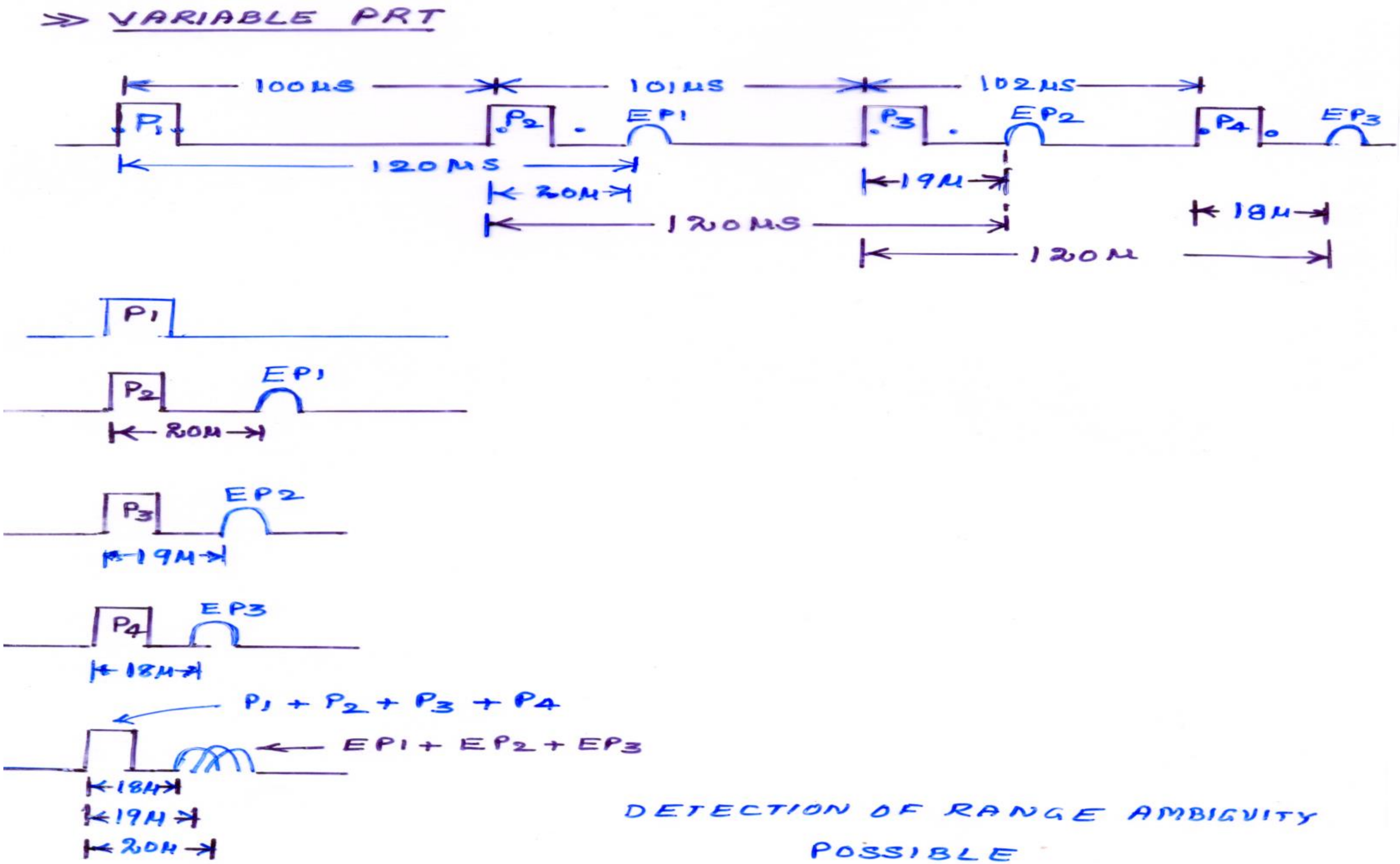


> DETECTION OF RANGE AMBIGUITY NOT POSSIBLE

SECOND/MULTIPLE TIME AROUND ECHOES – RANGE AMBIGUITIES

- Display above gives the Range as 3 Kms (20 μs) whereas actual Range of target is 18 Kms. This is called Range Ambiguity.
- Maximum unambiguous range is the range beyond which target echo appears as second or multiple time around echo.
- Unambiguous Range for this Radar is 15 Kms.

SECOND/MULTIPLE TIME AROUND ECHOES – RANGE AMBIGUITIES



RELATIONS BETWEEN RADAR PARAMETERS

1. $R = \frac{C \ T_R}{2}$

2. Unambiguous $R_{max} = \frac{C \ T_p}{2}$

3. Minimum Range $R_{min} = \frac{C \ \tau}{2}$

4. Range Resolution = $\frac{1}{\tau}$

5. Duty Cycle= $\frac{\text{Pulse width}}{\text{Pulse repetetion time}} = \frac{\tau}{T_P}$

RELATIONS BETWEEN RADAR PARAMETERS

6. $f_P = \frac{1}{T_P}$

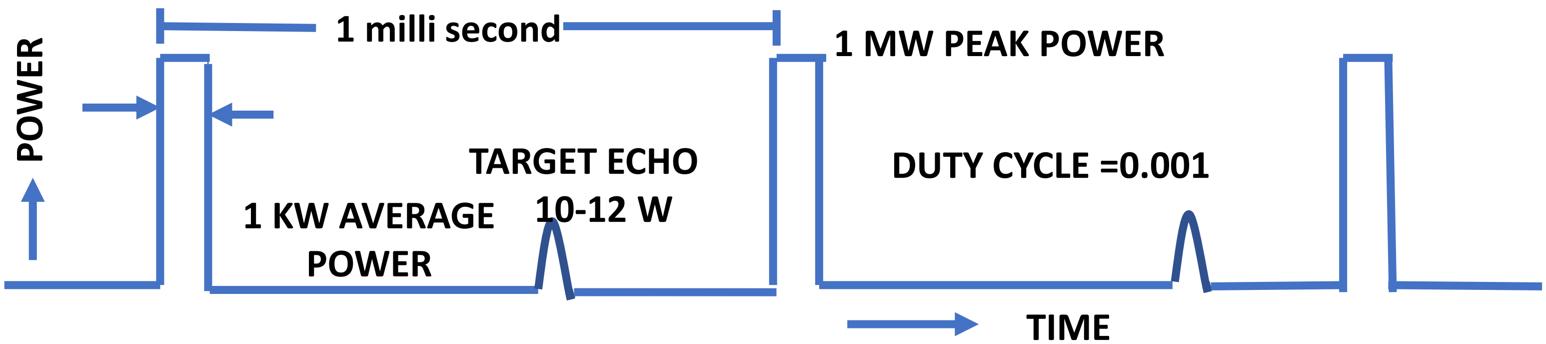
7. Average Power $P_{avg} = P_T \times \frac{\tau}{T_P}$

8. Energy transmitted = $P_T \times \tau$

9. Bandwidth = $\frac{1}{\tau}$

RADAR POWER PEAK AND AVERAGE POWER

(Jntuh) Briefly discuss about the radar waveforms with respect to Peak Power, Average power, Duty cycle.



Peak power P_T = 1 MW ; PRT = 1 milli sec

so PRF = 1/PRT = $1/1x10^{-3}$ =1000HZ

Pulse width = 1 micro sec ;

.

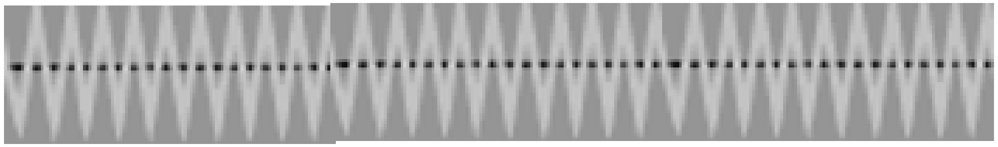
RADAR PEAK POWER AND AVERAGE POWER

- Average Power $P_{avg} = P_T \times \frac{\tau}{T_p} = P_T\ \tau\ f_P$
- $P_{avg} = 1 \times 10^6 \times \frac{1x\ 10^{-6}}{1x10^{-3}} = 1000\ W = 1\ KW$
- Duty cycle $= \frac{\tau}{T_p} = \frac{1x\ 10^{-6}}{1x10^{-3}} = 0.001$
- Energy of pulse $= P_T \times \tau = 1x\ 10^6 \times 1x\ 10^{-6} = 1$ joule

RADAR WAVE FORMS

(Jntuh) Discuss briefly about the radar waveforms

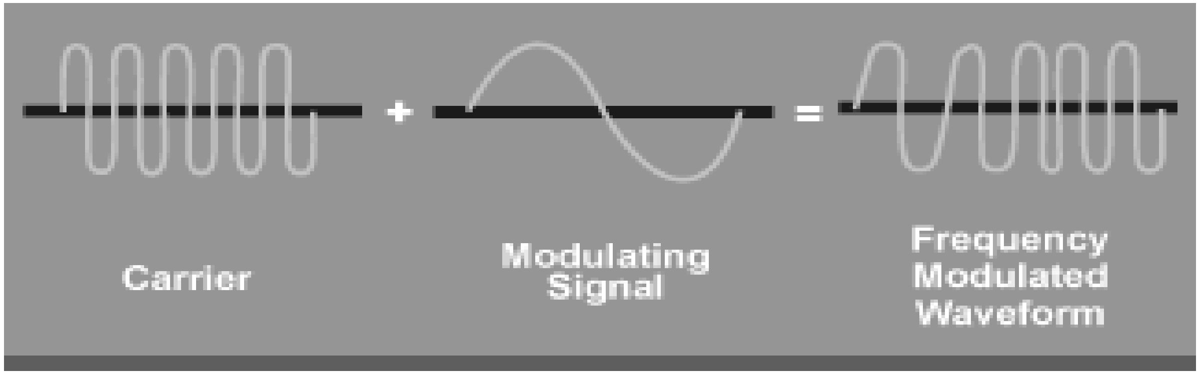
1.CW Radar:



- CW Radar has monotonic unmodulated continuous wave forms.
- Well suited for extracting radial velocity of target using Doppler principle.
- Can not give range of target

RADAR WAVE FORMS(contd)

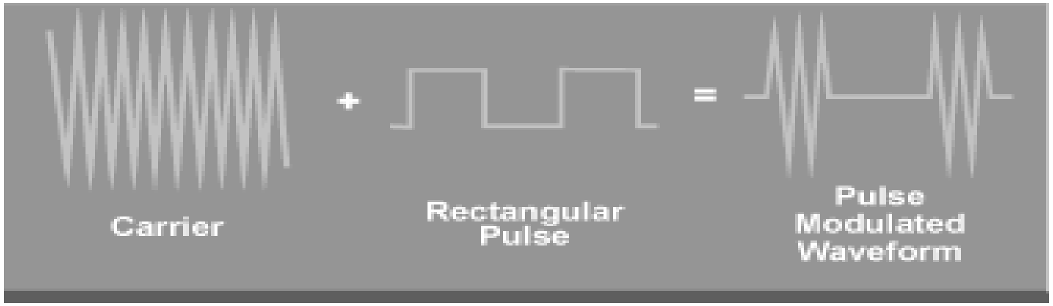
2. Modulated CW Radar (Sinsoidal Modulation)



- Gives the radial velocity and range of target
- Other modulations are Triangular ,sawtooth etc.,

RADAR WAVE FORMS(contd)

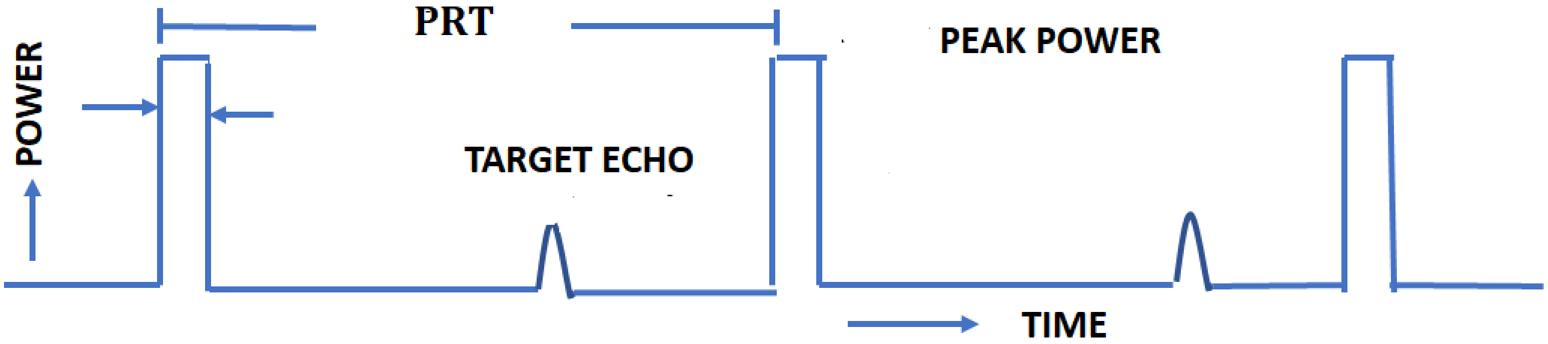
3. Pulse Radar (Pulse Modulated CW Radar)



- Extensively used for Range Determination
- Modified Pulse Radar in the name of Pulse Doppler
- radar and MTI Radar is used for obtaining radial velocity

RADAR WAVE FORMS(contd)

- Pulse Radar (Envelop of Tx and Rx pulses)



RADAR PROBLEMS

(Jntuh) 1 Calculate the range of the target , if the time taken by the signal to travel and return is 100 microsecs.

- Given TR = 100 microsec = 100x 10−6 secs

  To find R = ?
- $R = \frac{C\,T_R}{2}$ (from the formula)
- $C = 3 \times 10^8$ meters /second
-
- $R = \frac{3 \times 10^8 \times 100 \times 10^{-6}}{2}$ = 15000mts= 15 Kms

RADAR PROBLEMS(contd)

- 2 What should be the pulse repetition frequency and duty cycle of radar in order to achieve a maximum unambiguous range of 60 nmi with a pulse width of 1.5 μs ?

•Given : 1. Max unambiguous range = 60 nmi = 60 x 1.852 x 10^3 meters

(1nmile = 1.852Km)

•2. Pulse width = τ =1.5 μs= 1.5 x 10^{-6} sec

•Find fp= Pulse repetition frequency

$$fp = \frac{C}{2\,R_{max}} = \frac{3\times10^8}{2\times60 \text{ x } 1.852 \text{ x } 103} = 1349.89 \text{ Hz}$$

$$Tp = \frac{1}{\text{fp}} = \frac{1}{1349.89} \text{ sec}$$

- Duty cycle = $\frac{\tau}{Tp}$ = 1.5 x 10^{-6} $\times$ 1349.89 = 0.0020248

RADAR PROBLEMS(contd)

3. The unambiguous range of radar is 200 Kms.It has a bandwidth of 1.0 MHz. find i) Pulse repetition frequency ii) Pulse width

- Given: Rmax = 200 km and Band width = 1.0 MHz
  Find fp and τ
- Answer: Pulse repetition frequency fp = $\frac{C}{2\ R_{max}}$ =
- fp = $\frac{3 \times 10^6}{2 \times 200 \times 10^3}$ = 750 Hz
- Pulse width τ = $\frac{1}{\text{Band width}} = \frac{1}{1 \times 10^6}$ = 1 μsec

TO BE CONTINUED IN 1C

(Jntuh)

RADAR SYSTEMS

EC812PE: RADAR SYSTEMS (PE – V)

UNIT – 1C

B.TECH IV YEAR II SEMESTER

BY

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(Former Director DLRL Ministry of Defence)

BIET

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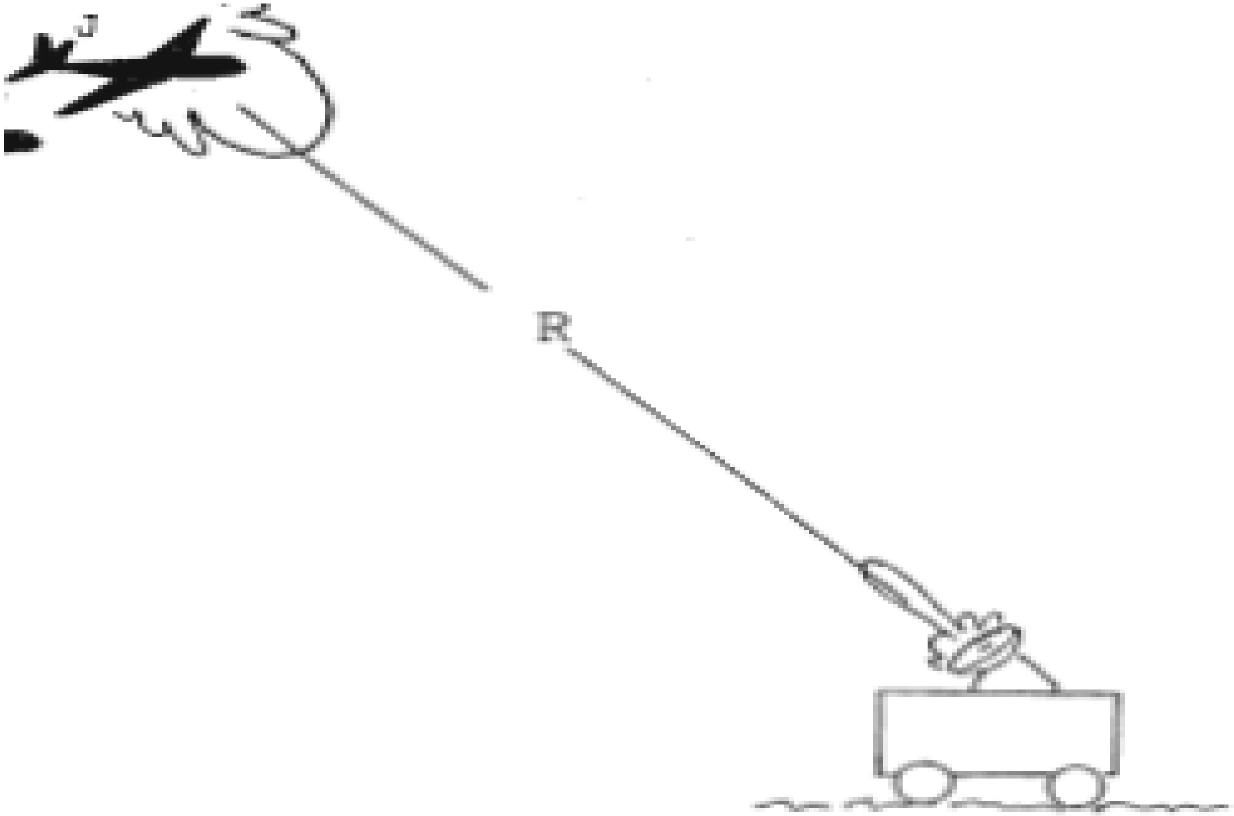
SIMPLE FORM OF RADAR RANGE EQUATION

SIMPLE FORM OF RADAR RANGE EQUATION



SIMPLE FORM OF RADAR RANGE EQUATION

Radar Equation is relation between

(1) Transmitter Power

(2) Receiver Power

(3)Antenna Characteristics

(4)Target Cross section

(5)Frequency of Transmission

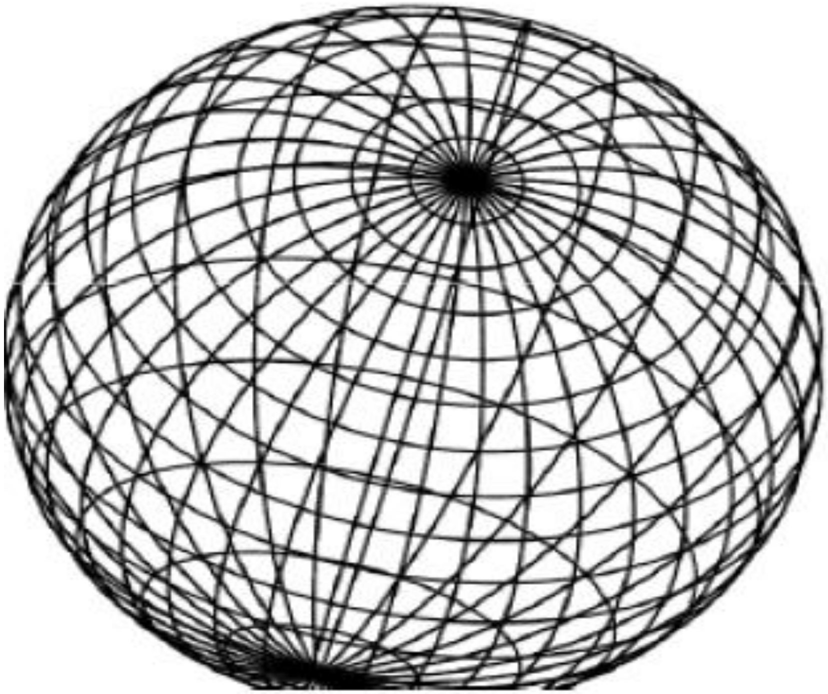
(6)Environmental Noise

- Radar Equation is most useful for (i)Design (ii)Implementation (iii)Testing of Radar System

ISOTROPIC ANTENNA (CONCEPT)

An isotropic antenna (also known as an *omnidirectional antenna*) emits the signal uniformly in all directions. In other words, at distance *'R'* from the antenna, in any direction, the transmitted signal power is the same. Although building a truly omnidirectional antenna is not feasible, this ideal antenna is frequently used to simplify range estimation analysis as well as provide a reference point in comparing different types of antennas.

Radar Range Equation (Contd….)



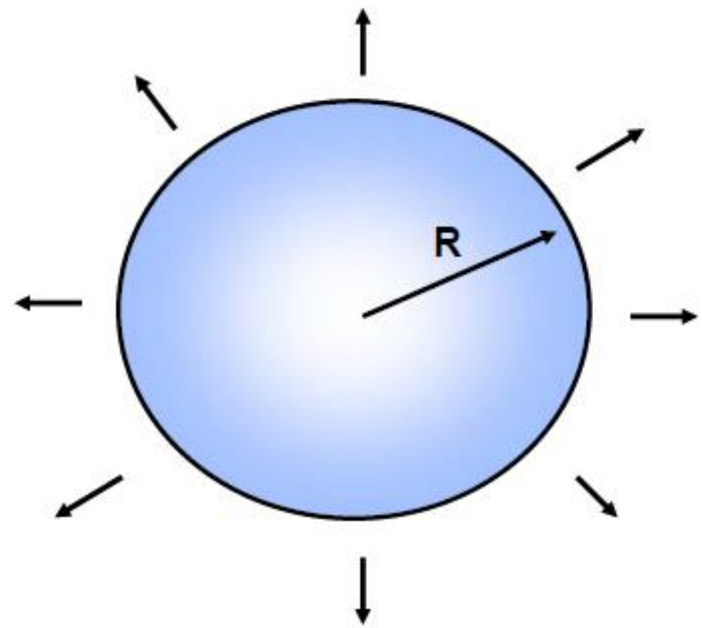
❖ Isotropic (Omni) Antenna radiates Power in all directions uniformly

Radar Range Equation

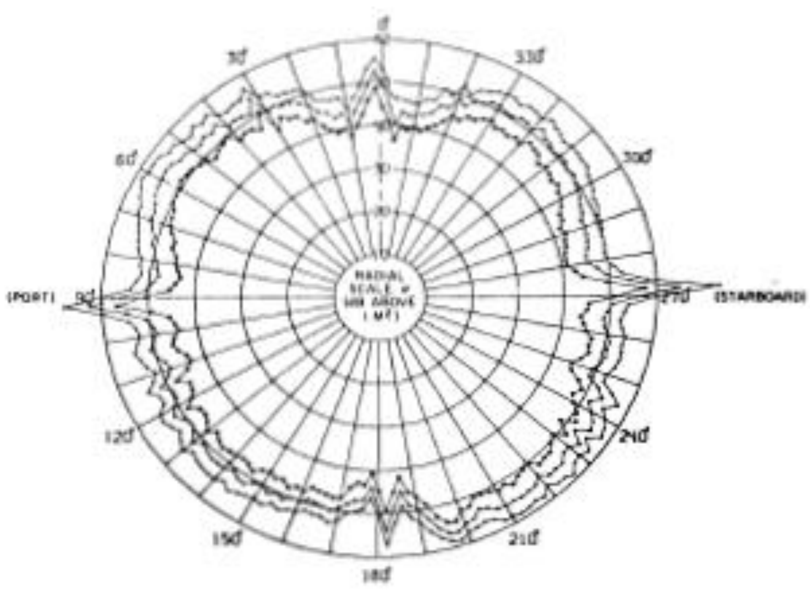
Power density from uniformly radiating antenna transmitting spherical wave

$$\frac{P_t}{4 \pi R^2}$$

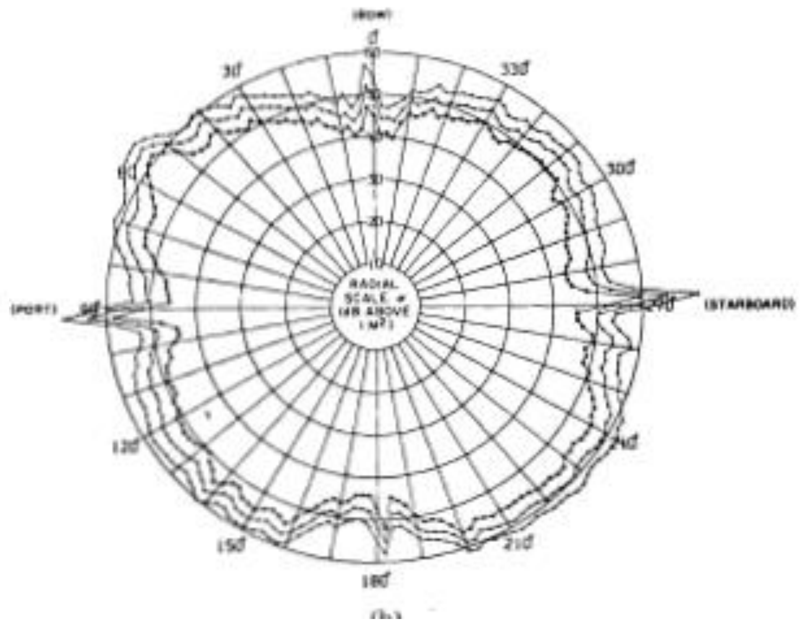
P_t = peak transmitter power
R = distance from radar



Omni Antenna Radiation Pattern



Azimuth



Elevation

Radar Range Equation (contd..)

- P_T = Transmitted Power (watts)
- Antenna assumed Isotropic ie., radiates power in all directions
- Power Density at a distance 'R' from Radar

  =Power density on the surface of the sphere

  with radius 'R'

$$= \frac{P_T}{\text{Surface Area of Sphere of Radius } 'R'}$$

$$= \frac{P_T}{4\,\pi\,R^2}$$

Radar Range Equation (continued)

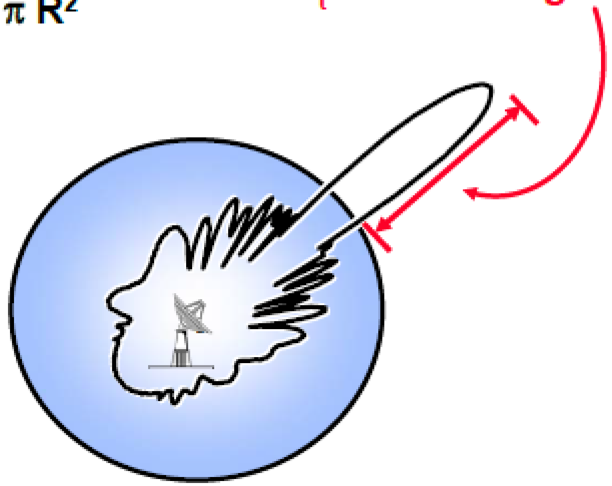
Power density from isotropic antenna $\frac{P_t}{4 \pi R^2}$

Power density from directive antenna $\frac{P_t G_t}{4 \pi R^2}$

P_t = peak transmitter power

R = distance from radar

G_t = transmit gain



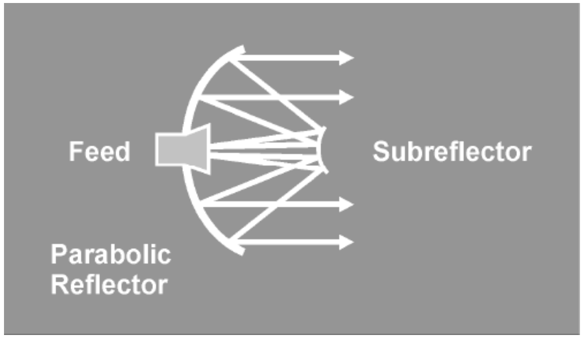
Gain is the radiation intensity of the antenna in a given direction over that of an isotropic (uniformly radiating) source

Gain = $4 \pi A / \lambda^2$

Radar Range Equation (Contd….)

- Radar Antennas are Directional
- G_T = Gain of Antenna =

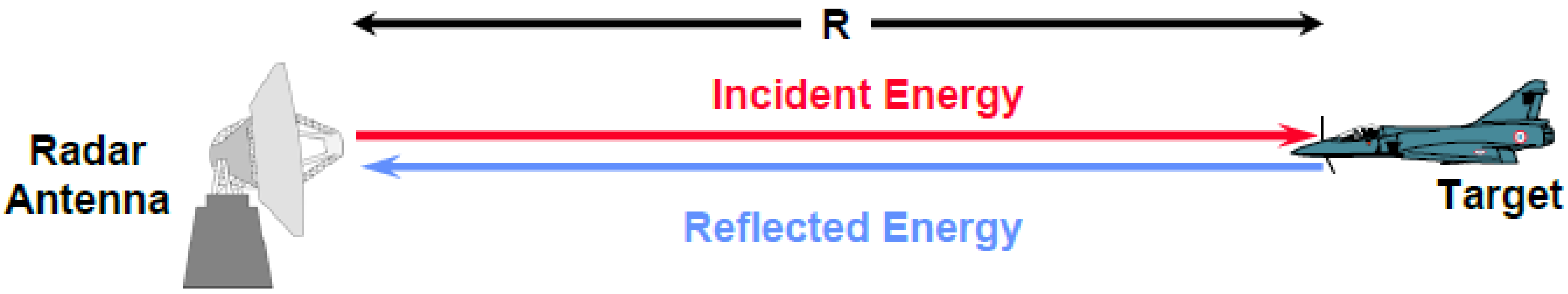
$$\frac{\text{Power Density in Directive Antenna}}{\text{Power Density in Isotropic Antenna}}$$



- Power Density at Range 'R' from Directive Antenna

$$= \frac{P_T \times G_T}{4 \pi R^2}$$

Definition of Radar Cross Section (RCS or σ)



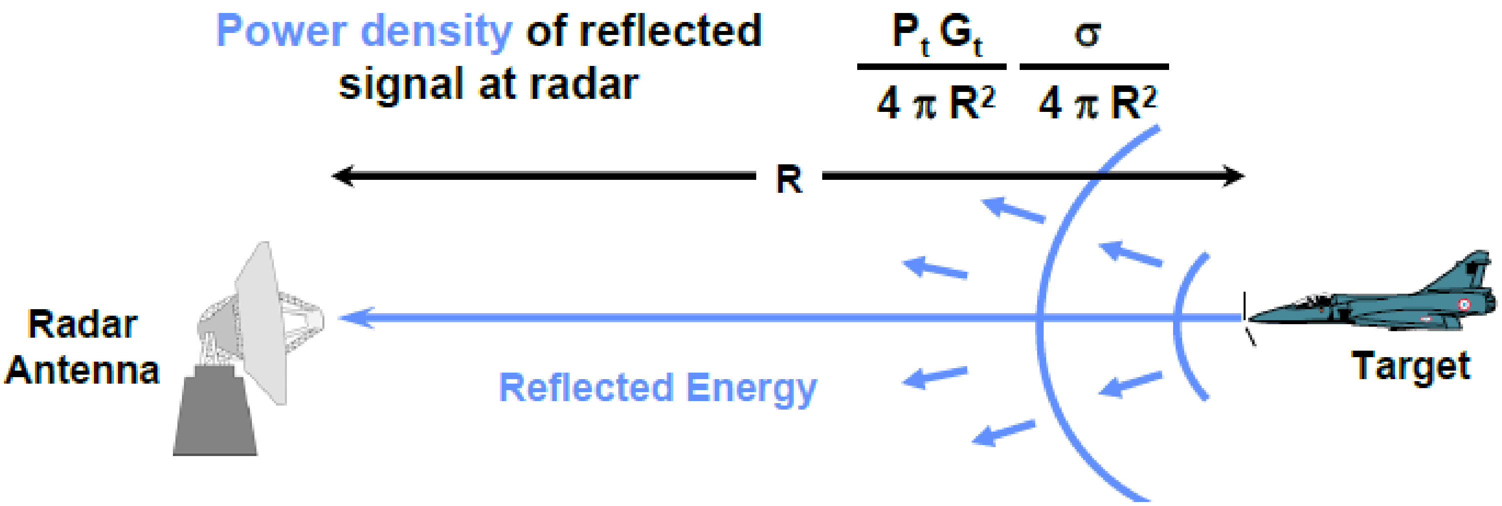
Radar Cross Section (RCS or σ) is a measure of the energy that a radar target intercepts and scatters back toward the radar

Power of reflected signal at target

$$\frac{P_t G_t \sigma}{4 \pi R^2}$$

σ = radar cross section units (meters)^2

Radar Range Equation (Contd….)



- Echo Power density at Receiver at distance R from target

$$= \frac{P_T \; G_T}{4 \pi R^2} \times \frac{1 \times \sigma}{4 \pi R^2}$$

Radar Range Equation (Contd….)

The received power = the power density at the radar times the area of the receiving antenna

Power of reflected signal from target and received by radar

$$P_r = \frac{P_t G_t}{4 \pi R^2} \frac{\sigma A_e}{4 \pi R^2}$$

P_r = power received

A_e = effective area of receiving antenna

- Where A_e=Aperture area of receiving antenna
- Power received at the output of Antenna = P_R

$$\frac{P_T \; G_T \; \sigma}{[4 \pi R^2]^2} \times A_e$$

- If Range 'R' increases, P_R decreases until it is equal to S_{min}=Minimum Detectable signal by the Receiver and R= R_{max}

Radar Range Equation (Contd….)

- S_{min} = $$\frac{P_T \; G_T \; \sigma}{[4\,\pi\, R_{max}{}^2\,]^2} \, x \, A_e$$

- R_{max} = $$\left[\frac{P_T \; G_T \; \sigma \, A_e}{[4\,\pi\,]^2 \, x \, S_{min}}\right]^{\frac{1}{4}}$$

- The above is called **Radar Range Equation**------(A)

ALTERNATE FORMS OF RADAR RANGE EQUATION

➢ $$R_{max} = \left[\frac{P_T\ G_T\ \sigma\ A_e}{[4\ \pi\ ]^2\ S_{min}}\right]^{\frac{1}{4}} \text{--------- (A)}$$

- From Antenna Theory

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

Where G_R =Receiving Antenna Gain

λ =Wavelength ($\lambda = \frac{c}{f}$)

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

Alternate Forms Of Radar Range Equation (Contd….)

- Substituting A_e in Equation (A)
- $$R_{max} = \left[\frac{P_T \; G_T \; \sigma \; G_R \; \lambda^2}{[4 \pi]^3 \; S_{min}}\right]^{\frac{1}{4}}$$

- If same antenna is used for transmission and reception. $G_T = G_R = G$

$$R_{max} = \left[\frac{P_T \; G^2 \; \sigma \; \lambda^2}{[4 \pi]^3 \; S_{min}}\right]^{\frac{1}{4}} \quad \text{-------------} \quad (B)$$

Alternate Forms of Radar Range Equation (Contd..)

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

- Substituting this in Equation B. We get

- $$R_{max} = \left[\frac{P_T\;G^2\;\sigma\;\lambda^2}{[4\,\pi\;]^3\;S_{min}}\right]^{\frac{1}{4}}$$ -------------------- (B)

- $$R_{max} = \left[\frac{P_T\;A_e^{\;2}\;\sigma}{4\,\pi\,\lambda^2\;S_{min}}\right]^{1/4}$$ --------------------(C)

THREE FORMS OF RADAR EQUATION

$$R_{max} = \left[\frac{P_T \; G_T \; \sigma \; A_e}{[4\pi]^2 \; S_{min}}\right]^{\frac{1}{4}} \qquad \text{--------- A}$$

$$R_{max} = \left[\frac{P_T \; G^2 \lambda^2 \sigma}{[4\pi]^3 \; S_{min}}\right]^{\frac{1}{4}} \qquad \text{---------- B}$$

$$R_{max} = \left[\frac{P_T \; A_e^2 \; \sigma}{4\pi \lambda^2 \; S_{min}}\right]^{1/4} \qquad \text{----------- C}$$

Relation between R_{max} and P_T when other parameters are held constant

$$R_{max} = \left[\frac{P_T \; G^2 \, \lambda^2 \, \sigma}{[4\pi]^3 \; S_{min}} \right]^{\frac{1}{4}}$$

- When all parameters like G, λ , σ , S_{min} are held constant
- $R_{max} = K \, P_T^{1/4}$

Range Vs P_T

Range	P_T
2 Times	16 Times
3 Times	81 Times
Half	1/16 Times $(1/2)^4$

RADAR RANGE EQUATION (ANSWER TO JTUH QUESTION)

Simple Radar Equation (Answer to JNTUH question)

- (Jntuh) (Jntuh) (Jntuh)
- Derive the radar range equation/ Derive the basic radar equation/Derive the maximum range for a radar system from first principles/Obtain the basic radar equation in terms of minimum detectable power, gains of transmitting and receiving antennas etc.

Simple Radar Equation (Answer to JNTUH question)

Radar Equation is relation between

(1) Transmitter Power

(2) Receiver Power

(3)Antenna Characteristics

(4)Target Cross section

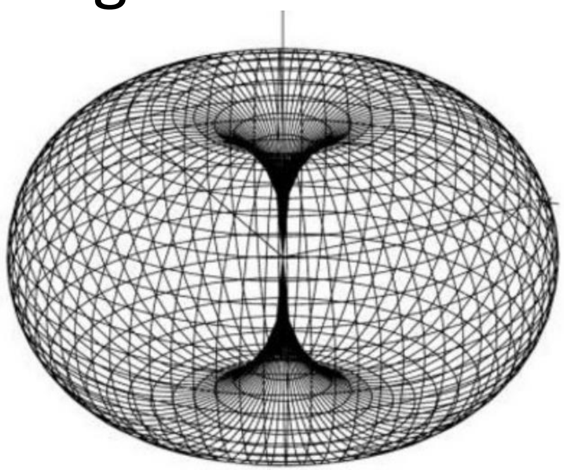
(5)Frequency of Transmission

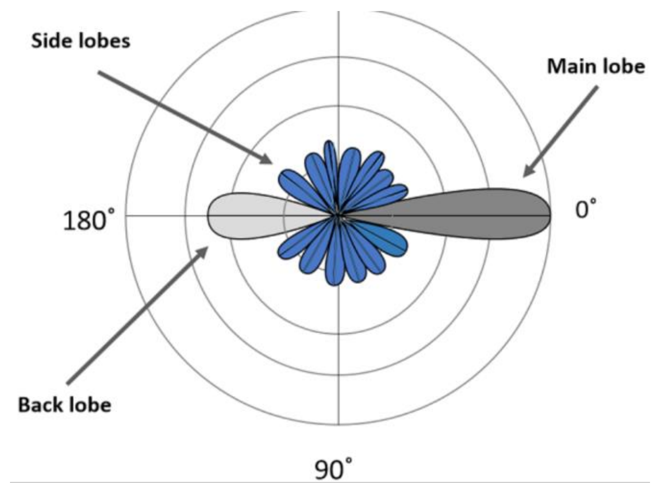
(6)Environmental Noise

- Radar Equation is most useful for (i)Design (ii)Implementation (iii)Testing of Radar System

Simple Radar Equation Answer to JNTUH question

- P_t = Transmitted power of the radar
- Initially assume the antenna is isotropic . The isotropic antenna transmits power uniformly in all directions as shown in figure



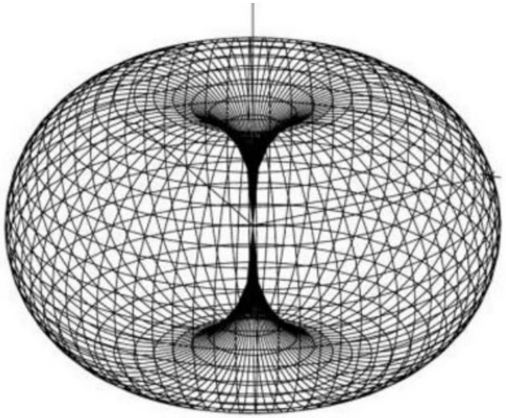


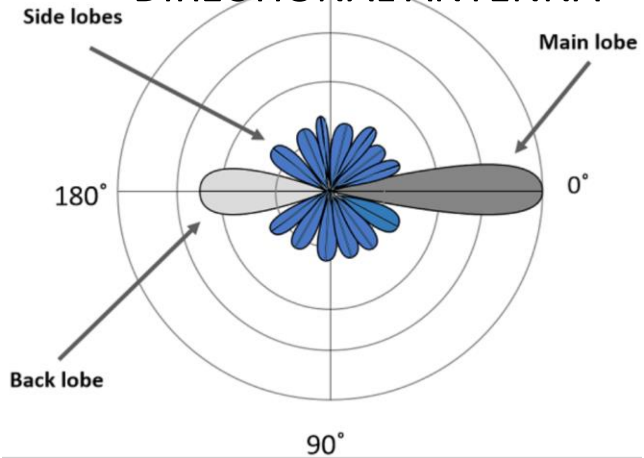
SIMPLE FORM OF RADAR EQUATION

OMNI ANTENNA

DIRECTIONAL ANTENNA

- .





- Let the target be at a distance of R from the antenna on an imaginary sphere of radius R
- Power density at any point on the sphere of radius R

$$= \frac{P_t}{4\,\pi\,R^2}$$

- Since instead of isotropic antenna Directional antenna is used in practice
-

Simple Radar Equation (Answer to JNTUH question)

- Power Density of directional antenna = Power Density of Isotropic antenna × Transmitting Gain
  $= \frac{P_t}{4\,\pi\,R^2} \times G_t$ where G_t is the gain of transmitting antenna
- Let us assume the radar cross-section of the target is σ (sigma). The σ is defined as the amount of transmitted power intercepted by the target and reradiated back in the direction of the radar antenna
- So the power reradiated from target $= \frac{P_t}{4\,\pi\,R^2} \times G_t \times \sigma$
- This reflected signal acts a microwave source and spread power in all directions like a Omni antenna

Simple Radar Equation Answer to JNTUH question

- Power density of reradiated signal at the radar antenna

$$= \frac{\frac{P_t}{4\,\pi\,R^2} \times G_t \times \sigma}{4\,\pi\,R^2} = \frac{P_t\,G_t}{4\,\pi\,R^2}\,\frac{\sigma}{4\,\pi\,R^2}$$

- Let the antenna has an Effective aperture area of A_e . A portion of the reradiated power is captured by the radar antenna.
- The received power Pr by the radar antenna

$$= \frac{P_t\,G_t}{4\,\pi\,R^2}\,\frac{\sigma}{4\,\pi\,R^2}\,A_e = \frac{P_t\,G_t\,A_e\,\sigma}{(4\,\pi\;R^2)^2}$$

- $P_r = \frac{P_t\,G_t\,A_e\,\sigma}{(4\,\pi\;R^2)^2}$

Simple Radar Equation Answer to JNTUH question

- .

$$Pr = \frac{P_t\, G_t\, A_e\, \sigma}{(4\,\pi\, R^2)^2)}$$

- Let Rmax is the maximum range beyond which the Pr becomes small so that radar receiver stops detecting the target. At this Rmax Pr is denoted as Smin. So Pr = Smin
- Smin = $\frac{P_t\, G_t\, A_e\, \sigma}{(4\,\pi\;\; R_{max}{}^2)^2}$
- $R_{max} = [\frac{P_t\, G_t\, A_e\, \sigma}{(4\,\pi)^2\, S_{min}}]^{\frac{1}{4}}$ This is called the Radar equation

Simple Radar Equation Answer to JNTUH question

- . $R_{max} = [\frac{P_t\, G_t\, A_e\, \sigma}{(4\,\pi)^2\, S_{min}}]^{\frac{1}{4}}$
- The above is called the basic Radar Range Equation or the first Radar Range Equation
- Second Form of Radar Range equation:
- From Micro wave theory we know that $G_r = \left[\frac{4\,\pi\, A_e}{\lambda^2}\right]$ Substituting this value in the basic radar equation. But $G_t = G_r = G$ since single antenna is used
- $R_{max} = \left[\frac{P_t \frac{4\,\pi\, A_e}{\lambda^2}\, A_e \sigma}{(4\,\pi)^2\, S_{min}}\right]^{\frac{1}{4}} = \left[\frac{P_t\, {A_e}^2\, \sigma}{4\,\pi\,\lambda^2\, S_{min}}\right]^{\frac{1}{4}}$ This is called the second form Radar equation

Simple Radar Equation Answer to JNTUH question

- Third Form of Radar Range equation:

- Substituting A_e in the above equation

- $R_{max} = \left[\frac{P_t\, G^2\, \lambda^2\, \sigma}{(4\ \pi)^3\ \ S_{min}}\right]^{\frac{1}{4}}$ this is called the Third form of Radar range equation

Simple Radar Equation Answer to JNTUH question

- (Jntuh) Three forms of Radar Range Equation
- $R_{max} = \left[\frac{P_t \, G_t \, A_e \, \sigma}{(4\,\pi)^2 \, S_{min}}\right]^{\frac{1}{4}}$ First Form
- $R_{max} = \left[\frac{P_t \, {A_e}^2 \, \sigma}{4\,\pi\,\lambda^2 \, S_{min}}\right]^{\frac{1}{4}}$ Second Form
- $R_{max} = \left[\frac{P_t \, G^2 \, \lambda^2 \, \sigma}{(\,4\,\pi\,)^3 \; S_{min}}\right]^{\frac{1}{4}}$ Third form

ALTERNATE ANSWER FOR RADAR RANGE EQUATION

(Jntuh) .Derive the Radar Range equation

- Let us assume a Transmitter which gives out a peak power P_T
- For analysis sake, let it be connected to a Omni (isotropic antenna). Omni antenna transmits RF energy in all directions
- Power density on any point on an imaginary sphere of radius R is $\frac{P_T}{4\,\pi\,R^2}$
- In practical field , a directional antenna is used in place of omni antenna to avoid wastage of power. Let its gain = G_T

ALTERNATE ANSWER FOR RADAR RANGE EQUATION

- The Power density on the sphere with radius R with directional antenna $= \frac{P_T}{4\,\pi\,R^2}\,G_T$
- Assume there is a target with a cross-section σ on the outer surface of the sphere
- But Power = Power density x Area
- So the power reflected by the target is $\frac{P_T}{4\,\pi\,R^2}\,G_T\,\sigma$
- The reflected power acts as a microwave source and radiates RF power in all directions (like an Omni antenna)

ALTERNATE ANSWER FOR RADAR RANGE EQUATION

- The power density at the receiving antenna which is on a sphere of radius R =$[\frac{P_T}{4\,\pi\,R^2}\ G_T\ \sigma]\ \frac{1}{4\,\pi\,R^2}$
- R = $\frac{P_T\ G_T\ \sigma}{(4\,\pi\,R^2)^2}$
- If the aperture area of receiving antenna = Ae
- Then the power received at the output of receiving antenna P_R
- $P_R = \left[\frac{P_T\ G_T\ \sigma}{(4\,\pi\,R^2)^2}\right] A_e$

ALTERNATE ANSWER FOR RADAR RANGE EQUATION

- P_R denotes the receiving power and denotes the sensitivity of receiver
- P_R keeps decreasing when R is increasing. At some value of R= R_{max} , P_R = S_{min} where S_{min} is the minimum receiver power, less than S_{min} radar does not function
- $S_{min} = \left[\frac{P_T\, G_T\, \sigma\, A_e}{(4\,\pi\, R_{max}{}^2)^2}\right] = \left[\frac{P_T\, G_T\, \sigma\, A_e}{(4\,\pi)^2\,(R_{max})^4}\right]$
- $(R_{max})^4 = \left[\frac{P_T\, G_T\, \sigma\, A_e}{(4\,\pi)^2 S_{min}}\right]$

ALTERNATE ANSWER FOR RADAR RANGE EQUATION

- $R_{max} = \left[\frac{P_T\, G_T\, \sigma\, A_e}{(4\,\pi)^2 S_{min}}\right]^{\frac{1}{4}}$ -------EQ-A
- This is called Radar Range equation
- From Microwave theory $G_R = \frac{4\,\pi\, A_e}{\lambda^2}$ where G_R is the gain of receiving antenna, Same antenna is used for transmission and reception. So G_R = G_T = G
- Substituting $A_e = \frac{G\ \lambda^2}{4\,\pi}$ in EQ- A, above we get

$$R_{max} = \left[\frac{P_T\, G^2 \sigma\ \lambda^2}{(4\,\pi)^3 S_{min}}\right]^{\frac{1}{4}}$$ EQ -B

ALTERNATE ANSWER FOR RADAR RANGE EQUATION

- Substituting G$= \frac{4\,\pi\,A_e}{\lambda^2}$ in EQ-B we get

$$R_{max} = \left[\frac{P_T\,(\frac{4\,\pi\,A_e}{\lambda^2})^2\sigma\;\lambda^2}{(4\,\pi)^3 S_{min}}\right]^{\frac{1}{4}}$$

$$R_{max} = \left[\frac{P_T\,{A_e}^2\sigma}{(4\,\pi)\,\lambda^2\,S_{min}}\right]^{\frac{1}{4}}$$ EQ-C

PROBLEM ON RADAR RANGE EQUATION

- (Jntuh) A pulsed radar operating at 10 Ghz. has an antenna with a gain of 28 dB and a transmitter power of 2 Kw (pulse power). If it is designed to detect a target with a cross section of 12 sq.m. and the minimum detectable signal is Pmin = −90 dBm. What is the maximum rangeof the radar?
- Frequency = 10 Ghz= 10×10^9 Hz
- Antenna gain = 28 dB (antilog of $\frac{28}{20} = 25.12$)
- Transmitted Power = 2 KW = 2 x 10^3 watt
- Target cross section = 12 sq.m

PROBLEM ON RADAR RANGE EQUATION

- Minimum detectable signal = S_{min} = $-90\ \text{dBm} = -90 - 30 = -\ 120\ \text{dBW} = \text{Antilog}\ (-\ 120/10) = 10^{-12}\ \text{W}$

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

- $\boldsymbol{\lambda} = \dfrac{C}{f} = \dfrac{3 \times 10^8}{10 \times 10^9} = 0.03\ \text{m}$

- $R_{max} = [\dfrac{2 \times 10^3 \times 25.12 \times 25.12 \times 0.03 \times 0.03 \times 12}{(4 \times \pi)^{\,3} \times 10^{-12}}]^{\frac{1}{4}}$

- $R_{max} = 1619\ \text{mt}$

PROBLEM ON RADAR RANGE EQUATION

- (Jntuh) Problem No.2 If the Radar is designed for operation at 10 GHz with an antenna diameter is 2m. Calculate the peak pulse power required to have a maximum range of 1000Km with a target of cross section area of 20 $m^{2.}$ assume minimum detectable noise power is 36 is 36 x 10^{-15} W
- Given quantities:
  frequency = 10 Ghz
  Antenna diameter = 2 m
  Maximum range of radar = R_{max} = 1000Km =10^6m
  Cross sectional area = 20 m
  Minimum detectable noise power=

$$S_{min} = 36 \times 10^{-15} \text{ W}$$

PROBLEM ON RADAR RANGE EQUATION

- Solution:

  Aperture area of antenna = $\frac{\pi D^2}{4} = \frac{\pi\, 2^2}{4}$ = 3.14 sq.m

- Wave length $\boldsymbol{\lambda}$ = $\frac{c}{f} = \frac{3\times 10^8}{10\times 10^9} = 0.03\text{m}$

- $R_{max} = \left[\frac{P_T\, {A_e}^2 \sigma}{(4\,\pi\,\lambda^2\, S_{min}}\right]^{\frac{1}{4}}$

  $P_T = \frac{4\,\pi\,\lambda^2\, S_{min} {R_{max}}^4}{{A_e}^2 \sigma}$

  $P_T = \frac{4\times 3.14\times 0.03\times 0.03\times 36\times 10^{-15}\times(1000\times 10^3)^4}{3.14\times 3.14\times 20}$

  P_T= 2063694.268 W= 2.064 MW

BLOCK DIAGRAM OF PULSE RADAR (ANSWER TO JNTUH QUESTION)

BLOCK DIAGRAM OF PULSE RADAR (JNTUH QUESTION)

(Jntuh) (Jntuh) (Jntuh)

- 1. Describe the working principle of Pulsed Radar System

or

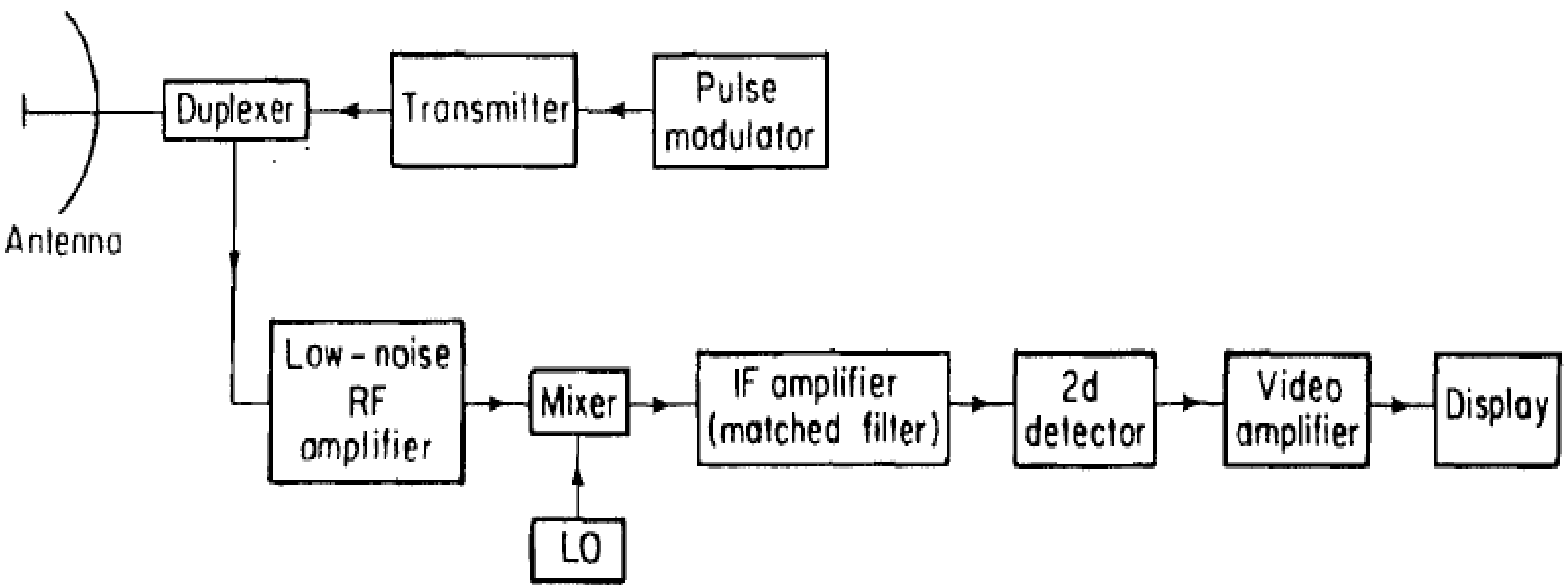
- 2. With a block diagram explain the operation of Pulse Radar

or

- 3. Draw the block diagram of a Pulsed Radar and explain its operation

RADAR SYSTEM BLOCK DIAGRAM

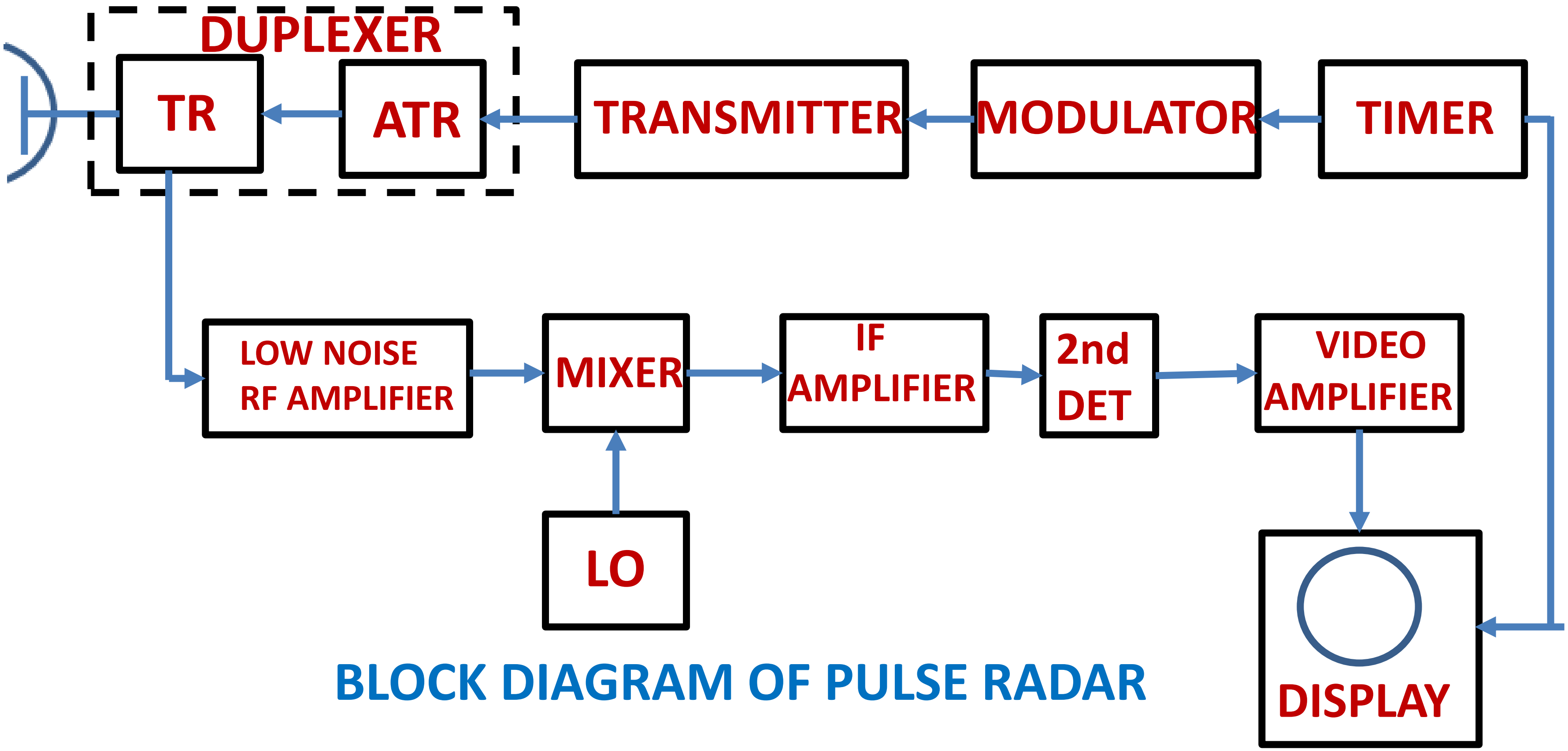
- Radar shown in the block diagram is called mono-static Radar since same antenna is used for transmission and reception.



BLOCK DIAGRAM OF RADAR SYSTEM

Block Diagram of Pulse Radar (Answer to Jntuh Question)

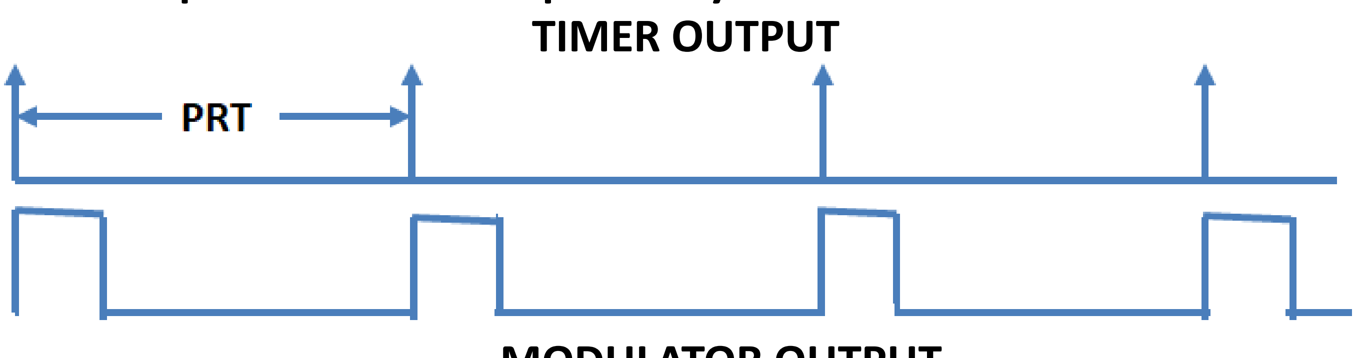
- BLOCK DIAGRAM OF PULSE RADAR.



BLOCK DIAGRAM OF PULSE RADAR

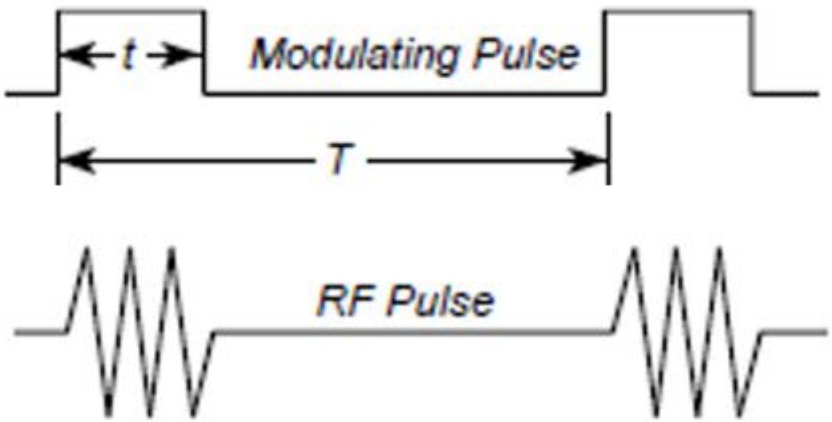
Block Diagram of Pulse Radar (Answer to Jntuh Question)

- 1. TIMER: This generates a series of narrow timing trigger pulses at pulse repetition frequency of radar. This is also called trigger generator or synchronizer. This is a small unit compared to the Modulator.
- 2. MODULATOR: The narrow trigger pulses when given to the modulator, generates the fixed duration radar pulses whose pulse width ranges from sub microsecs to a few microsecs. The frequency of these pulses is the Pulse repetition frequency of the radar.



Block Diagram of Pulse Radar (Answer to Jntuh Question)

- 3. TRANSMITTER:
  A typical radar may detect aircraft at ranges from 50 to 500 kms. It employs a peak power of the order of 1 to 10 Mega watts. The transmitter generates modulated RF pulses. The modulated RF energy travels along the transmission line to the antenna



Block Diagram of Pulse Radar (Answer to Jntuh Question)

3. TRANSMITTER(contd)

There are two types of Transmitters

(i) Power Oscillator Ex:Magnetron-1 M Watt or more.
   Pulse Modulator switches power on or off

(ii) Power Amplifier: Ex: Klystron, TWT Amplifies Low
   Power signal

Block Diagram of Pulse Radar (Answer to Jntuh Question)

- 4. DUPLEXER: Single antenna is used for both transmission and reception. The Duplexer unit connects the Transmitter to the antenna while transmitting. It disconnects the Receiver from the antenna during transmission. The Receiver also is disconnected from the Transmitter to avoid damage to the sensitive receiver since the transmitting power is very high.

Block Diagram of Pulse Radar (Answer to Jntuh Question)

- 4. DUPLEXER: (contd)
  While receiving target echoes from target, the Duplexer unit connects the Receiver to the antenna. It disconnects the Transmitter from the antenna during this period. This is done in order to avoid even a small portion of echo power gets connected to Transmitter and getting wasted. Since the switching speed is in nano secs, Gas Discharge tube is used.

Block Diagram of Pulse Radar (Answer to Jntuh Question)

- 4 Duplexer consists of TR and ATR switch.
  4(a) TR (Transmit and Receive Switch): This is a fast-acting switch which disconnects Receiver during transmission. If the Receiver is not disconnected, since the transmitter power is very high, the Receiver may be damaged. Once the pulsed RF signal has stopped the TR switch reconnects the Receiver to the antenna. The target echo power received enters the Receiver
- 4(b) ATR (Anti Transmit and Receive Switch): ATR switch do not act during transmission. During reception it switches and disconnects transmitter from antenna. If ATR is absent , a portion of the received power would go to transmitter rather than all the power going to the Receiver

Block Diagram of Pulse Radar (Answer to Jntuh Question)

5. ANTENNA:

(i)Antenna converts the Electrical signal to Electro magnetic signal and radiates it into space.

(ii)Same antenna is used for transmission and reception in a Pulse Radar.

(iii)Antenna is mounted on a pedestal and servo controlled to steer it in the direction of the target.

(iv)Normally parabolic Antenna is used for radar applications

Block Diagram of Pulse Radar (Answer to Jntuh Question)

6. LOW NOISE RF AMPLIFIER: (LNA)

(i)This is a RF Amplifier such as parametric amplifier or Low Noise transistor amplifier.

(ii)LNA is used immediately after the antenna since the power of the echoes are very low

(iii) Gain of LNA reduces the Noise Figures of the succeeding devices by dividing the N.F. of the device by the Gain of the LNA.

Block Diagram of Pulse Radar (Answer to Jntuh question)

7.MIXER & LOCAL OSCILLATOR

- Receiver uses super heterodyne principle

(i) Converts R.F. Signal to I.F. (Intermediate Frequency)

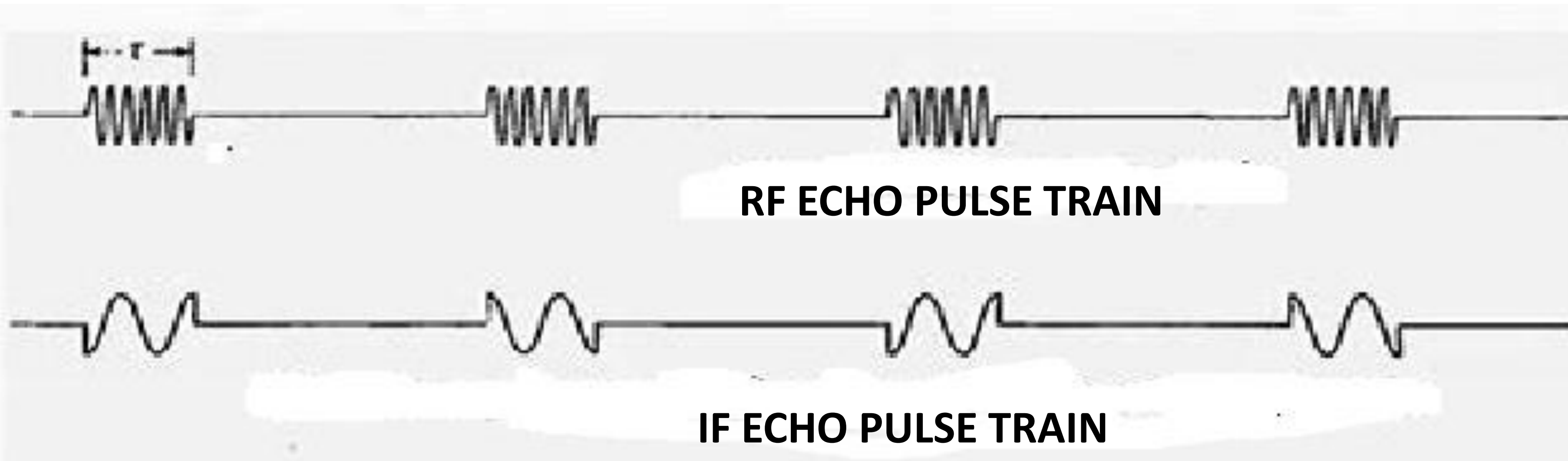
(ii) IF is usually at 30 MHZ or 60 MHZ. With a bandwidth of 1 to 2 MHz. It is easier to design and build High gain amplifiers and filters at IF frequencies. Widespread availability of components at these frequencies is also one of the reasons for Super-heterodyning

(iii) L.O. frequency is $f_L = f_{RF} \mp 30$ MHZ,

where f_{RF} = RF frequency and f_L = LO frequency

Block Diagram of Pulse Radar (Answer to Jntuh question)

7 MIXER & LOCAL OSCILLATOR (contd)



Block Diagram of Pulse Radar (Answer to Jntuh Question)

8. IF AMPLIFIER & MATCHED FILTER

(i)The signal level of Echo, is very low. It is amplified to an appropriate level by the IF Amplifier.

(ii)The I.F. centre frequency is 30 MHZ with a band width of 1 MHZ (depending on Pulse width)

(iii)The matched filter frequency response is such that it maximizes the peak signal to mean noise power ratio at output.

(iv)Usually the IF Amplifier and matched filter are designed into a single subsystem.

Block Diagram of Pulse Radar (Answer to Jntuh Question)

9. 2ND DETECTOR

(i)2nd Detector removes the IF modulation.

(ii)Output of the 2nd Detector is the Video Pulse.

(iii)2nd Detector is the high frequency diode.

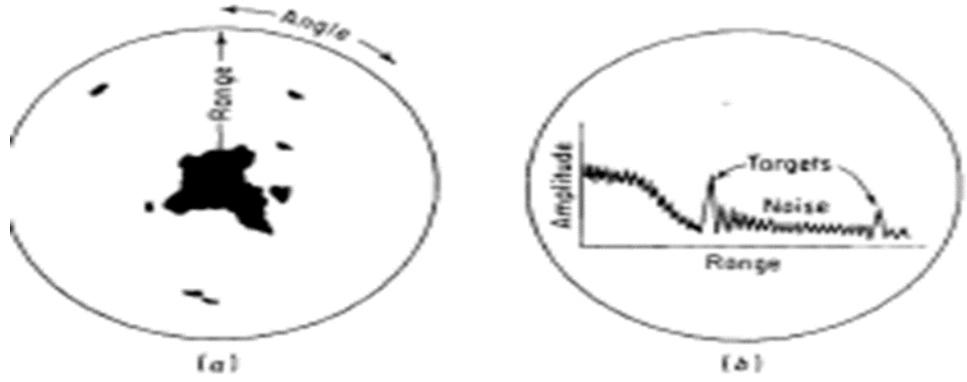
(iv)It is called as 2nd Detector since it is the second diode used in the chain. The first diode is used in the mixer.

10.VIDEO AMPLIFIER

The low signal level of Video Pulse is amplified such that the voltage level is high enough to drive the CRT (Cathode Ray Tube). CRT is used as the Display.

Block Diagram of Pulse Radar (Answer to Jntuh Question)

11.DISPLAY



i)The Display is generally a CRT (Cathode Ray Tube)

(a) ‘A’ scope (b) PPI(Plan position indicator) etc.

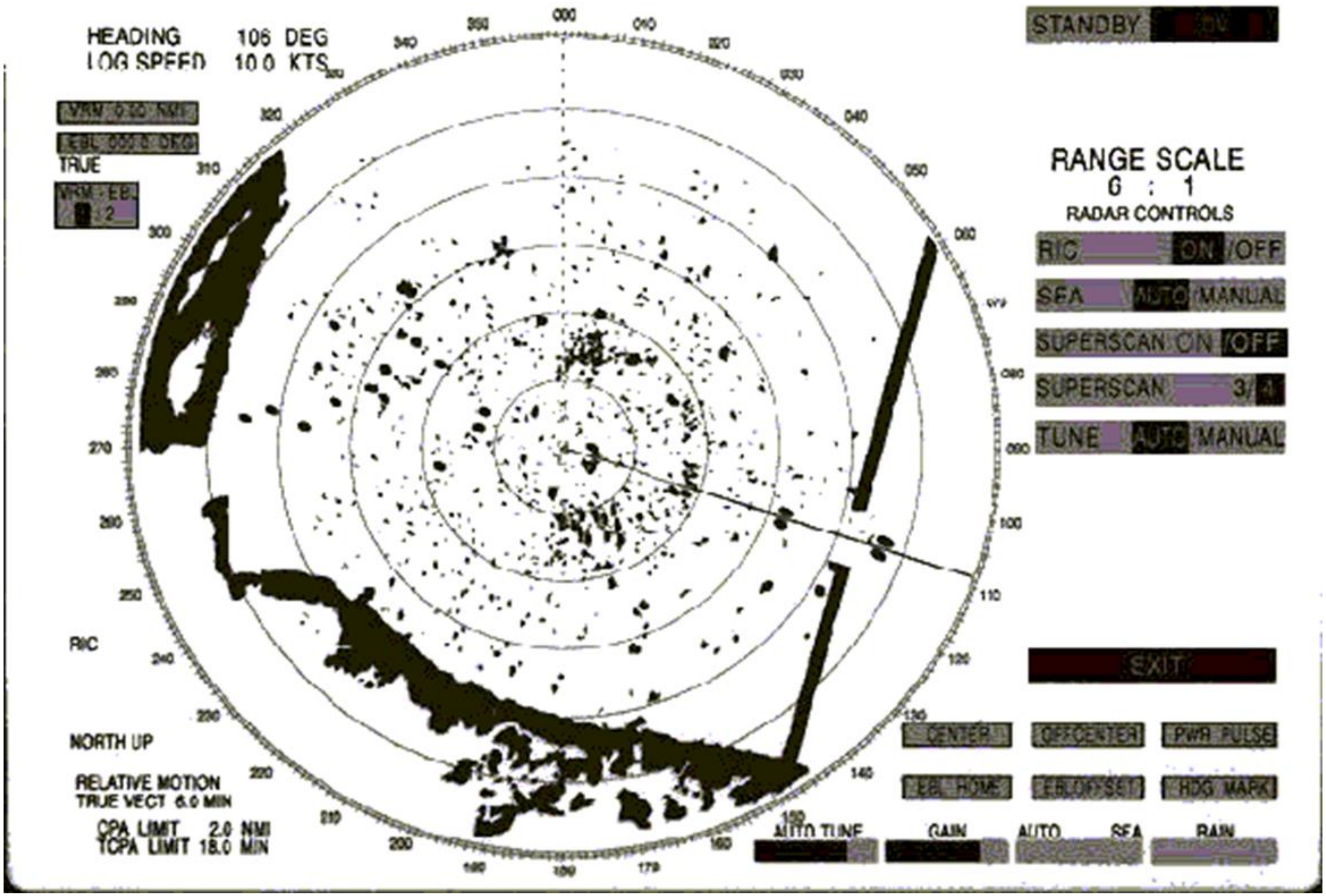
(ii)’A’ scope provides Range and Echo power.

(iii)PPI measures Range and bearing (azimuth angle)

(iv)In addition there are other displays like ‘B’ scope, ‘ D ‘ scope etc.

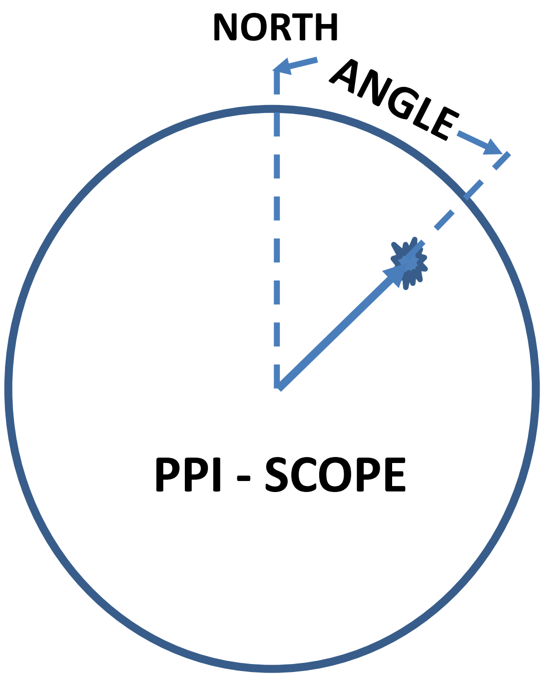
PRACTICAL RADAR DISPLAY

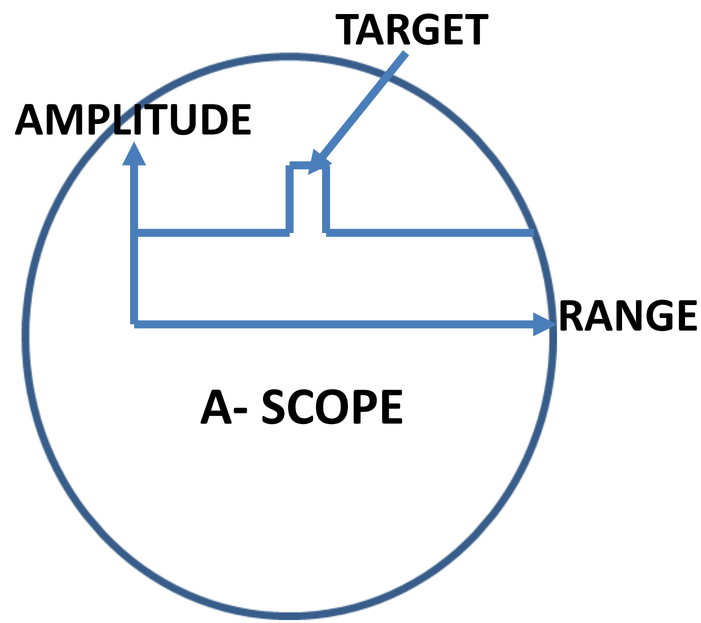
- .



RANGE & DIRECTION IN A PULSE RADAR

- (Jntuh) Discuss how the Direction and range of an object is determined using Pulse Radar





RANGE & DIRECTION IN A PULSE RADAR

- PPI –SCOPE: The output from the Video Amplifier 0f Pulse Radar is displayed using PPI (Plan Position Indicator) scope. PPI maps the position of target in azimuth and range. North is taken as the reference direction. PPI scope is an intensity modulated circular display. The range and angle is displayed in polar coordinates.
- A SCOPE: This display also plots the range and angle of the echo signal. It is connected to the output of Video amplifier. X axis gives the range and Y axis displays the amplitude of echo signal

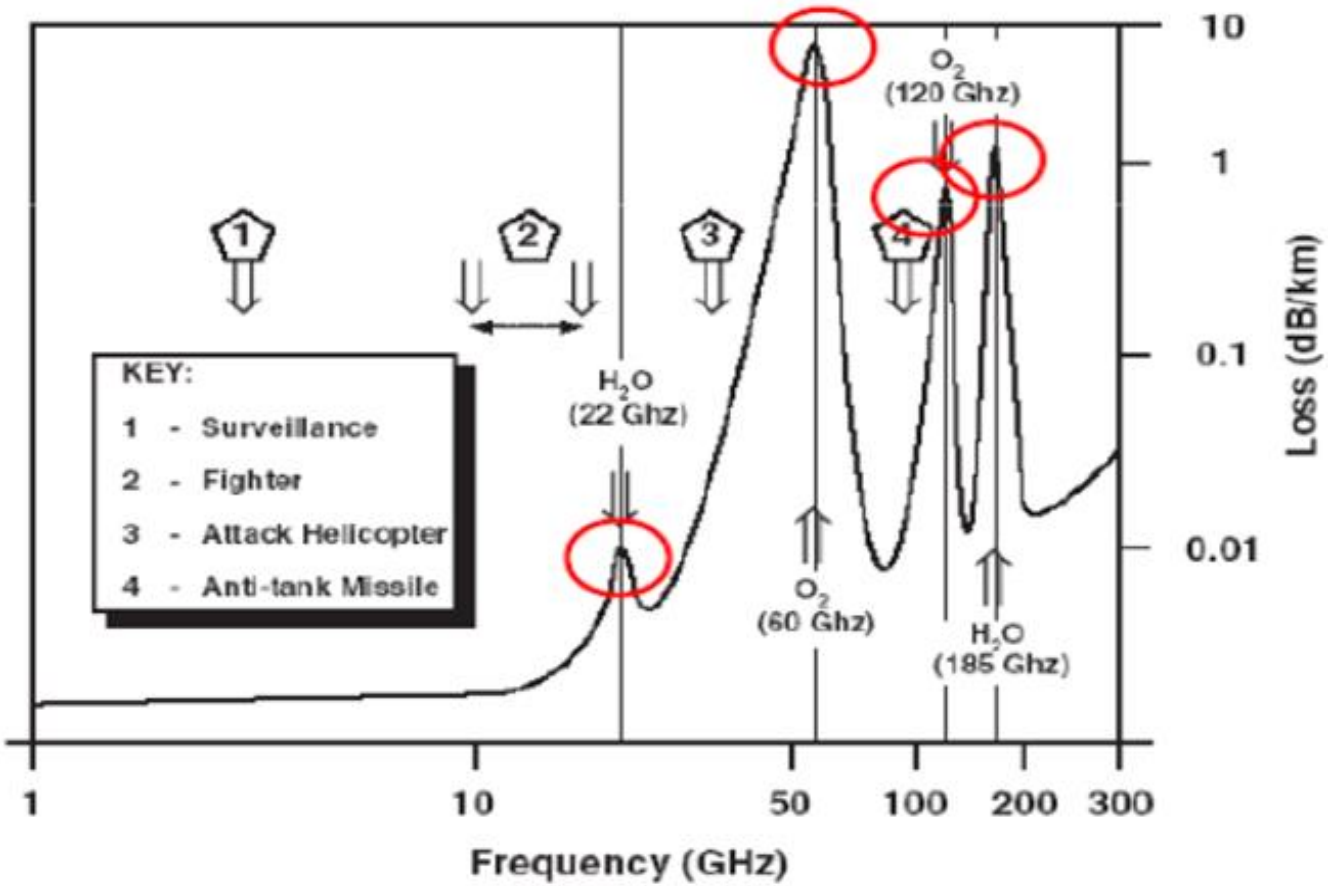
RADAR FREQUENCIES

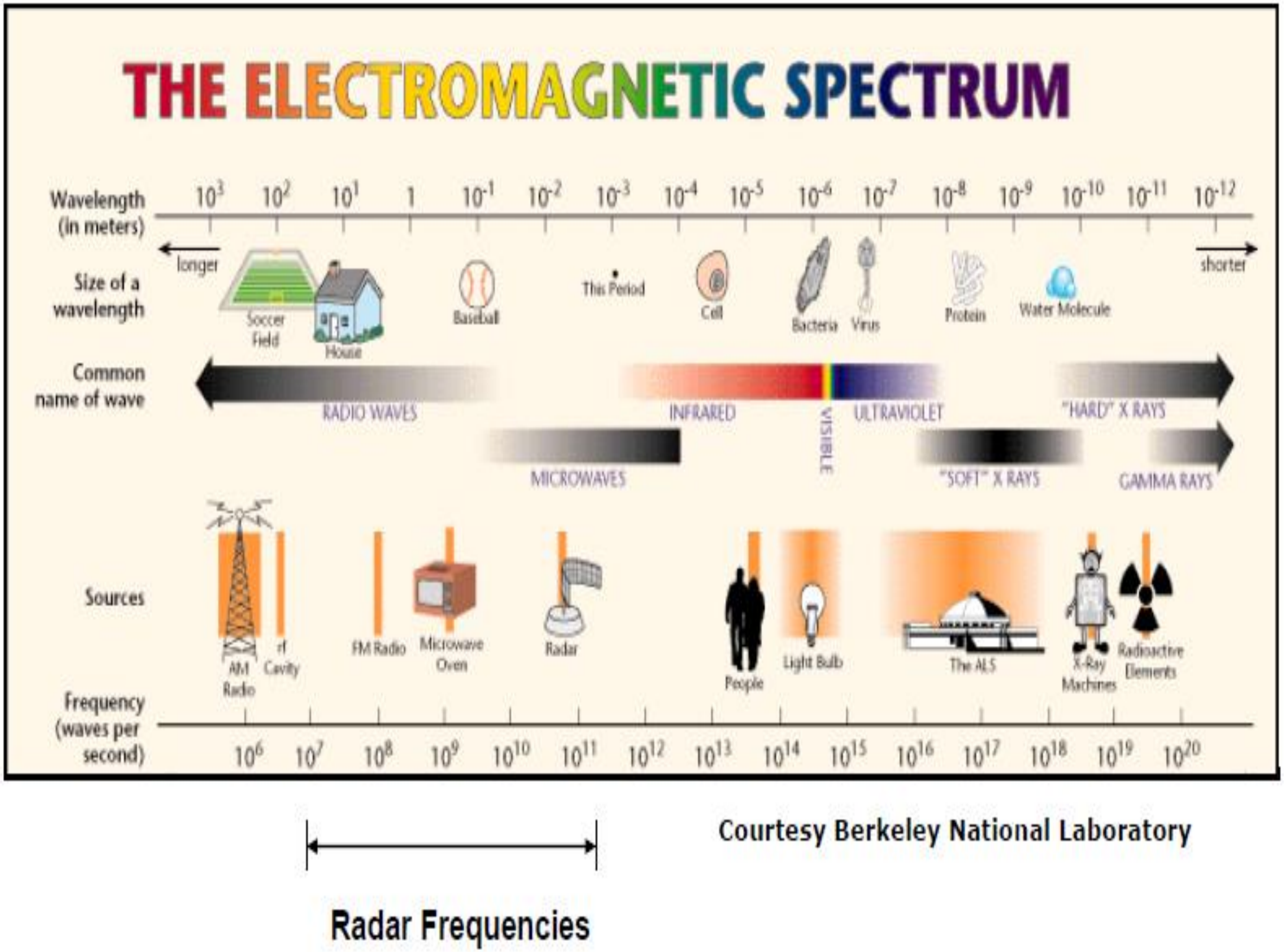
RADAR FREQUENCIES

- (Jntuh) Discuss about Radar Frequencies
- RF spectrum is very scarce and as such Radars are allotted only a certain frequency bands for its operation by International Telecom Union ITU
- During 2nd world war to keep the secrecy, certain code words were used. They are L,S,C,X, Ku,K,Ka etc. The same designations are continued.
- Lema Band(L)1GHZ-2GHZ, Sierra band(S) 2GHZ- 4GHZ, Charlie Band (C) 4GHZ-8GHZ, Xera Band (X) 8GHZ-12GHZ
- ITU(International Telecommunication Union) allocates a portion of these bands for Radar use.

ELECTROMAGNETIC SPECTRUM (contd..)

Atmospheric attenuation vs frequency





Courtesy Berkeley National Laboratory

IEEE Standard Radar Bands
(Typical Use)

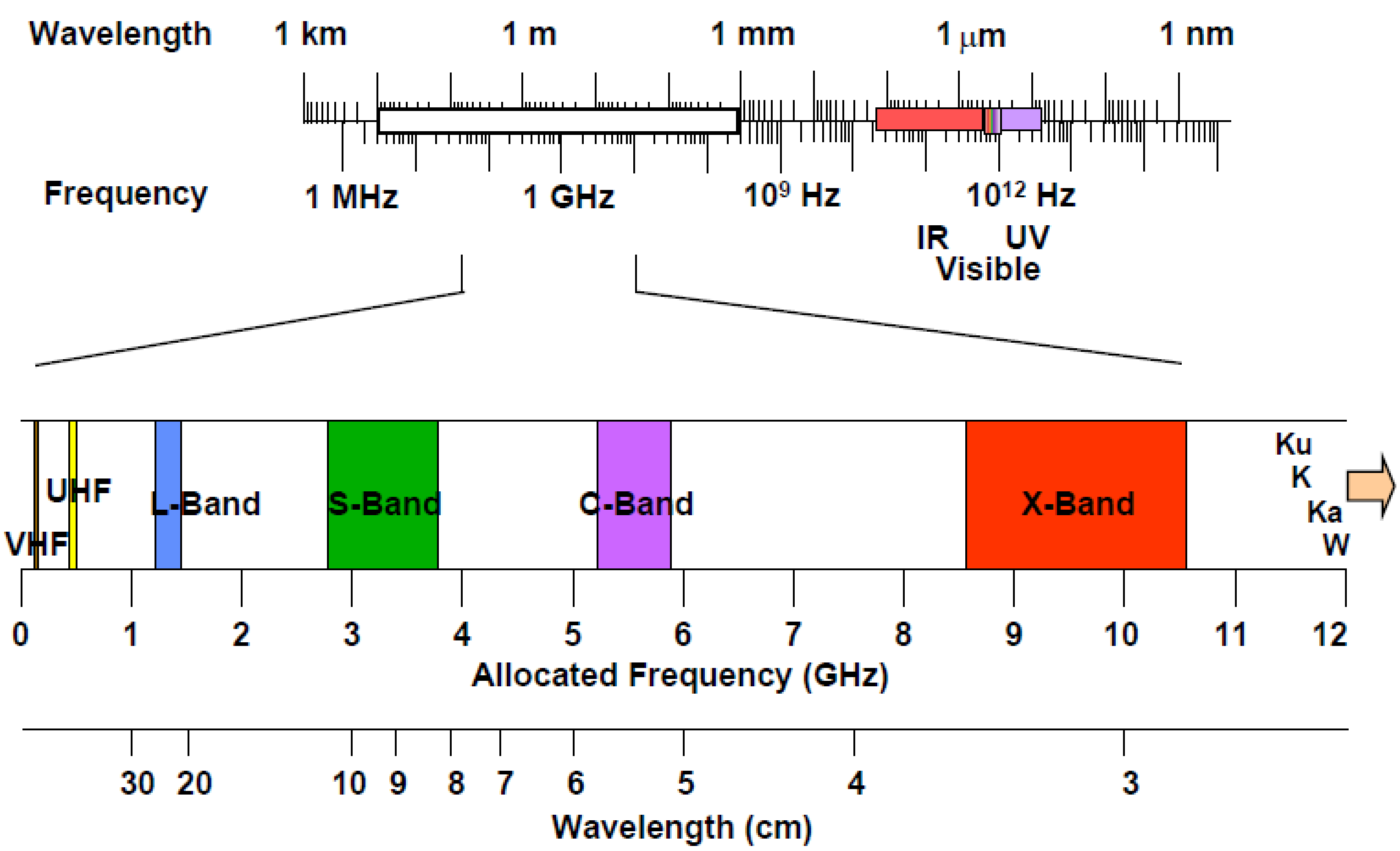
HF	3 – 30 MHz
VHF	30 MHz–300 MHz
UHF	300 MHz–1 GHz
L-Band	1 GHz–2 GHz
S-Band	2 GHz–4 GHz
C-Band	4 GHz–8 GHz
X-Band	8 GHz–12 GHz
Ku-Band	12 GHz–18 GHz
K-Band	18 GHz–27 GHz
Ka-Band	27 GHz–40 GHz
W-Band	40 GHz – 100+ GHz

Search Radars

Search & Track Radars

Fire Control & Imaging Radars

Missile Seekers


Wavelength
1 km
1 m
1 mm
1 μm
1 nm
Frequency
1 MHz
1 GHz
10^9 Hz
10^12 Hz
IR
UV
Visible
VHF
UHF
L-Band
S-Band
C-Band
X-Band
Ku
K
Ka
W
0 1 2 3 4 5 6 7 8 9 10 11 12
Allocated Frequency (GHz)
30 20 10 9 8 7 6 5 4 3
Wavelength (cm)

STANDARD FREQUENCY BANDS

Band designation	Nominal frequency range	Specific radiolocation (radar) bands based on ITU assignments for region 2
HF	3–30 MHz	
VHF	30–300 MHz	138–144 MHz
		216–225
UHF	300–1000 MHz	420–450 MHz
		890–942
L	1000–2000 MHz	1215–1400 MHz
S	2000–4000 MHz	2300–2500 MHz
		2700–3700
C	4000–8000 MHz	5250–5925 MHz
X	8000–12,000 MHz	8500–10,680 MHz
K_u	12.0–18 GHz	13.4–14.0 GHz
		15.7–17.7
K	18–27 GHz	24.05–24.25 GHz
K_a	27–40 GHz	33.4–36.0 GHz
mm	40–300 GHz	

CAPABILITIES OF RADAR

CAPABILITIES OF RADAR

1. Detect, locate & identify aircraft for Air Traffic Control(ATC).
2. Detect, locate & classify aircraft(Friend or Foe) for military purpose.
3. Locate ships and land features for ships collision avoidance.
4. Navigate ships and aircrafts even in bad weather (rain, snow fog, storm, cyclone etc). or in night.
5. Measures height of flying aircraft, helicopter
6. Give early warning of intruding enemy aircraft or missile.

CAPABILITIES OF RADAR(contd….)

7. Provide accurate three - dimensional co-ordinates of enemy aircraft for gun control or missile guidance.
8. As a part of Geographical survey, maps land and sea areas from space.
9. Remote sensing of agriculture crops and their pattern using special signal processing techniques.
10. Detect mines and foreign objects inside the grounds.
11. Measure speeding motor vehicle’s, speed for use by Law enforcing authorities.
12. Used for Space vehicle docking and landing on moon, Mars etc.

APPLICATIONS OF RADAR

APPLICATIONS OF RADAR

- (Jntuh) Explain about applications of Radar
- Radar has wide range of applications. They are used on ground, in air, in sea and in space. They can be broadly divided into i) Civilian use and ii) Military use
- CIVILIAN USE:
- 1. AIR TRAFFIC CONTROL (ATC):
  Radars are without exception used in the Airports for controlling the Aircraft traffic. A high resolution radar is used to monitor the aircraft and guide the pilots to safely land on the runways and take off. In bad weather and poor visibility conditions in association with GCA (Gound Control Approach) radar is used to guide the aircraft safely to land.

APPLICATIONS OF RADAR

• 2. AIRCRAFT NAVIGATION:

a) All modern aircrafts are fitted with 'Weather Avoidance Radars'. These radars give warning information about the outline regions of precipitation of snow or storms to the pilot lying ahead of aircrafts path. Some radars are used for terrain avoidance and terrain following . Ground mapping radars can be mounted on aircrafts for terrain mapping purposes.

b) Radar is mounted on Helicopters and used as altimeter to indicate the height of Helicopter from the ground

APPLICATIONS OF RADAR

- 3. MARITIME RADARS FOR SHIPS SAFETY AND NAVIGATION:

•Large portion of our merchandise between nations is transported through sea. Because of poor visibility in sea due to haze, smoke, rain, storm, cyclone etc. possibility of collision of Ships is high. Using radars mounted on ships, collision of ships can be avoided in the middle of sea.

•Radars guide ships in seaports safely.

- 4. SPACE:

Radar is used for rendezvous and docking of space vehicles and landing of space vehicles on Celestial objects like moon, mars etc.

Ground based radars are used for tracking of satellites

APPLICATIONS OF RADAR

5.REMOTE SENSING:

Radar is used as a remote sensor of the weather. The earth resources which are to be probed by the radar are i) Measurement and mapping of sea conditions ii)water resources iii) ice cover iv) agriculture and forestry conditions v) environmental pollution vi) geological formations

6. LAW ENFORCING AGENCIES:

Radars are used by Police personnel to measure and restrict the speed of automobile vehicles to avoid fatal accidents.

APPLICATIONS OF RADAR

7.MILITARY USE:

Radars are widely used in military applications.

(i)Early warning of intruding enemy aircrafts & missile

(ii)Tracking hostile targets and providing location information to Air Defense systems consisting of Tracking Radars controlling guns and missiles.

(iii)Battle field surveillance

(iv)Information Friend or Foe IFF

(v)Navigation of ships, aircrafts, helicopter etc.

World War 2 Air Defense System

SCR-584 Fire Control Radar

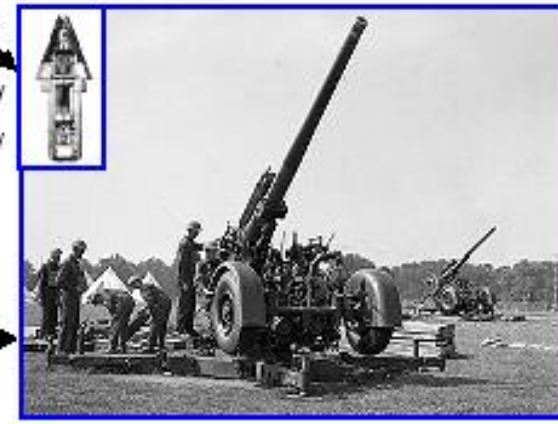
Courtesy of Department of Defense

M9 Predictor

Courtesy of US Army

Radar Proximity Fuze

British 3.7" AAA Gun



Courtesy of US Navy

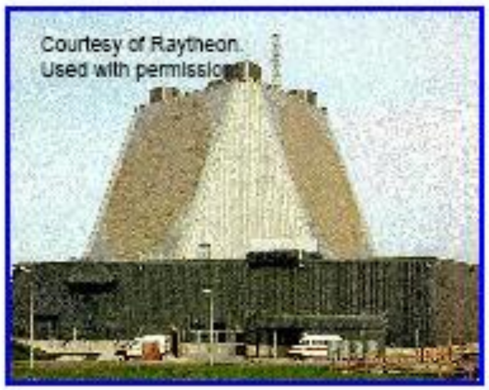
US 90 mm AAA Gun

Courtesy of US Navy

Courtesy of US Army

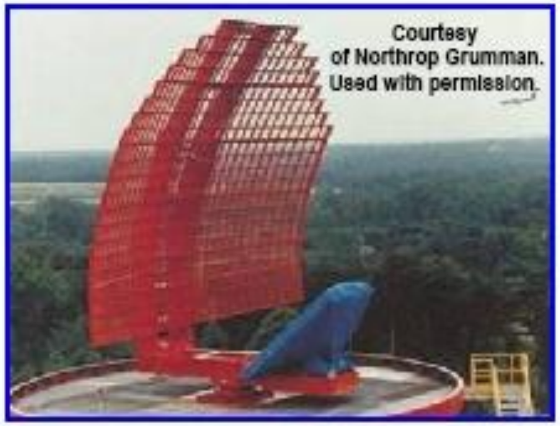
When deployed on British coast, V-1 "kill rate" jumped to 75%, when this integrated system was fully operational in 1944

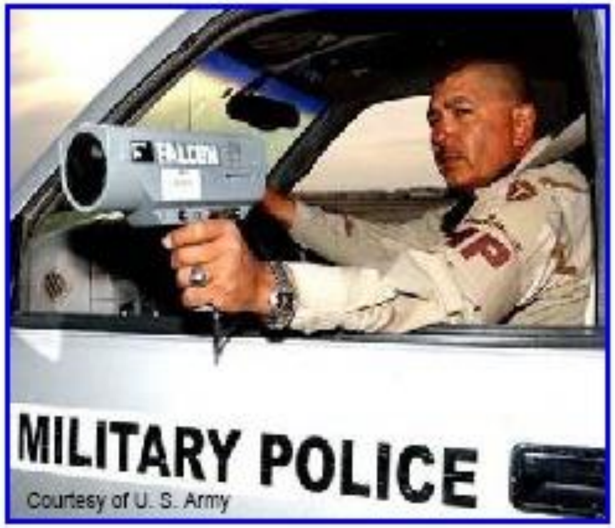
Surveillance and Fire Control Radars



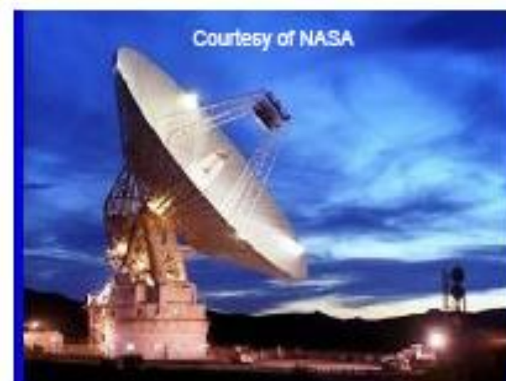
Airborne Radars

Civil Radars

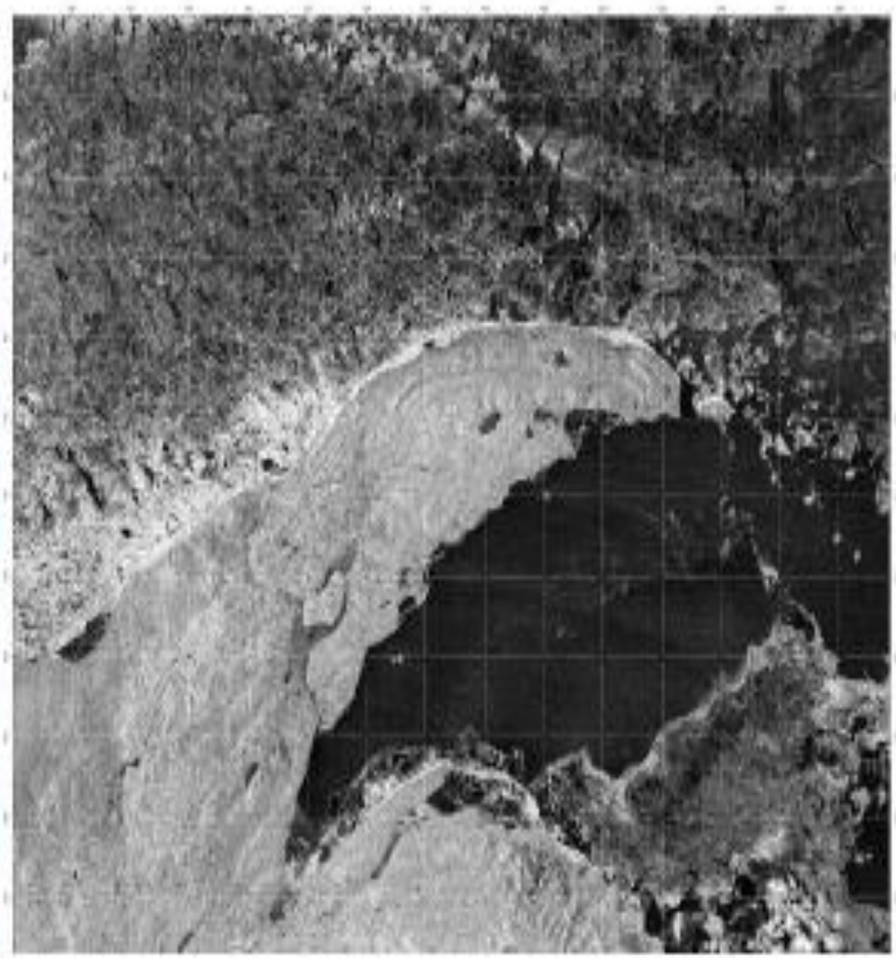




More Civil Radars



SAR Imaging



MILITARY APPLICATIONS OF RADAR

(Jntuh) List out major applications of Radar in military

- 1. GROUND PENETRATING RADAR :

These type of Radars are useful for finding out Land mines buried a few centimeters beneath the ground surface. The radars can detonate these mines and make movement of persons or vehicles safe. If the moisture content of soil is not very high, radar signals can penetrate into the ground.

MILITARY APPLICATIONS OF RADAR

- 2. AREA SURVEILLANCE OR GROUND SURVEILLANCE: These radars are kept on tripods and keep watching in a particular direction over an area. They give alert when there is an activity in that area like an intruder approaching, crawling, running etc. they are called BFSR (Battle field surveillance Radar)

MILITARY APPLICATIONS OF RADAR

- 3. AIR SURVEILLANCE RADARS:

For detecting enemy aircraft and directing defensive measures against them monitoring of airspace is required. For better and maximum coverage these radars are located on airborne platforms for detecting low height flying hostile aircrafts. These are called AWACS (Airborne Warning and Control System). OTH (Over The Horizon) radars exploit certain ground features and can detect low flying aircrafts at thousands of kilometers away

MILITARY APPLICATIONS OF RADAR

4. TARGET TRACKING RADAR:

Target tracking is associated with Gun control weapon and Missile weapon system. They track the incoming hostile aircraft in azimuth and elevation very accurately using the principle of Mono-pulse. The location of hostile aircraft in three (azimuth, elevation and range) coordinates will be provided to the weapon system like the Gun control weapon or to the guided missile so that the hostile target is shot down.

In case of multiple target tracking radar beam is quickly switched from one position to other and thus multiple target tracking is accomplished, These Radars are called Phased array radars

CONTINUED IN RADAR 1D

RADAR SYSTEMS
(EC 812 PE)
(ELECTIVE V)
UNIT – 1D
B.TECH IV YEAR II SEMESTER
BY

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(Former Director DLRL Ministry of Defence)
BIET

Acknowledgements
The contents , figures , graphs etc., are taken from the following Text book & others
“ INTRODUCTION TO RADAR SYSTEMS “
Merill I.Skolnik
Second Edition
Tata Mcgraw – Hill publishing company
Special indian edition

PREDICTION OF RANGE PERFORMANCE

PREDICTION OF RANGE PERFORMANCE

- (Jntuh) Explain the prediction of range performance

  OR

  Discuss in detail the choice of various parameters that are affecting the radar range

  OR

  Briefly discuss about the prediction of range performance

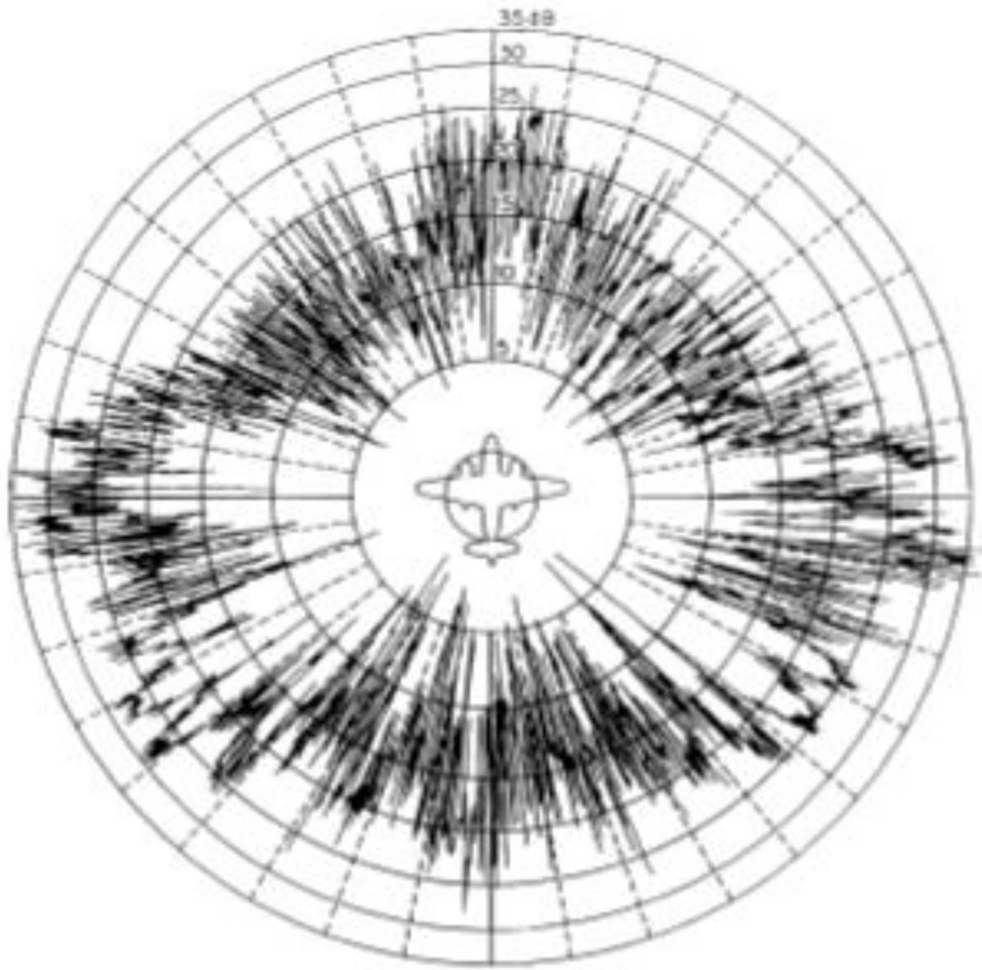
PREDICTION OF RANGE PERFORMANCE

- $$R_{max} = \left[\frac{P_T \; G_T \; \sigma \; A_e}{[4 \; \pi]^2 \; S_{min}} \right]^{\frac{1}{4}}$$
- P_T = Transmitted Power (watts)
- G_T = Transmitting Antenna Gain (number)
- A_e = Receiving Antenna Effective aperture mt^2
- σ = Radar cross-section mt^2
- S_{min} = Minimum Detectable Signal (Watts)

➢ Except for σ (RCS) all the other above quantities are design parameters . σ is random with respect to angle and given as a statistical quantity

PREDICTION OF RANGE PERFORMANCE

- Radar Cross section σ varies randomly with a slight change in the angle of incident of RF energy



PREDICTION OF RANGE PERFORMANCE(CONTD..)

- If long Range (Rmax) is desired the following are required
- i) P_T Transmitted Power must be high
- ii) G_T should be high. For this Transmitted Power must be concentrated into a narrow beam
- iii) A_e must be high. Large aperture antenna is necessary
- iv) S_{min} must be low. Receiver must be sensitive to weak signals

PREDICTION OF RANGE PERFORMANCE(CONTD..)

- Practical Range obtained using the above Range equation is often less because we have not considered the following aspects

i) Various losses because of Electronic equipment used in operational field

ii) σ are statistical in nature . σ change with even a small change in angle

iii) Meteorological conditions during propagation

iv) Performance of radar operator

Because of the above R_{max} cannot be given by a single number

PREDICTION OF RANGE PERFORMANCE(CONTD..)

- Radar range can only be predicted with a certain probability for a practical target
- The Radar will detect a given target at a particular range by including the term probability in its radar equation

MINIMUM DETECTABLE SIGNAL , RECEIVER NOISE AND SNR

MINIMUM DETECTABLE SIGNAL

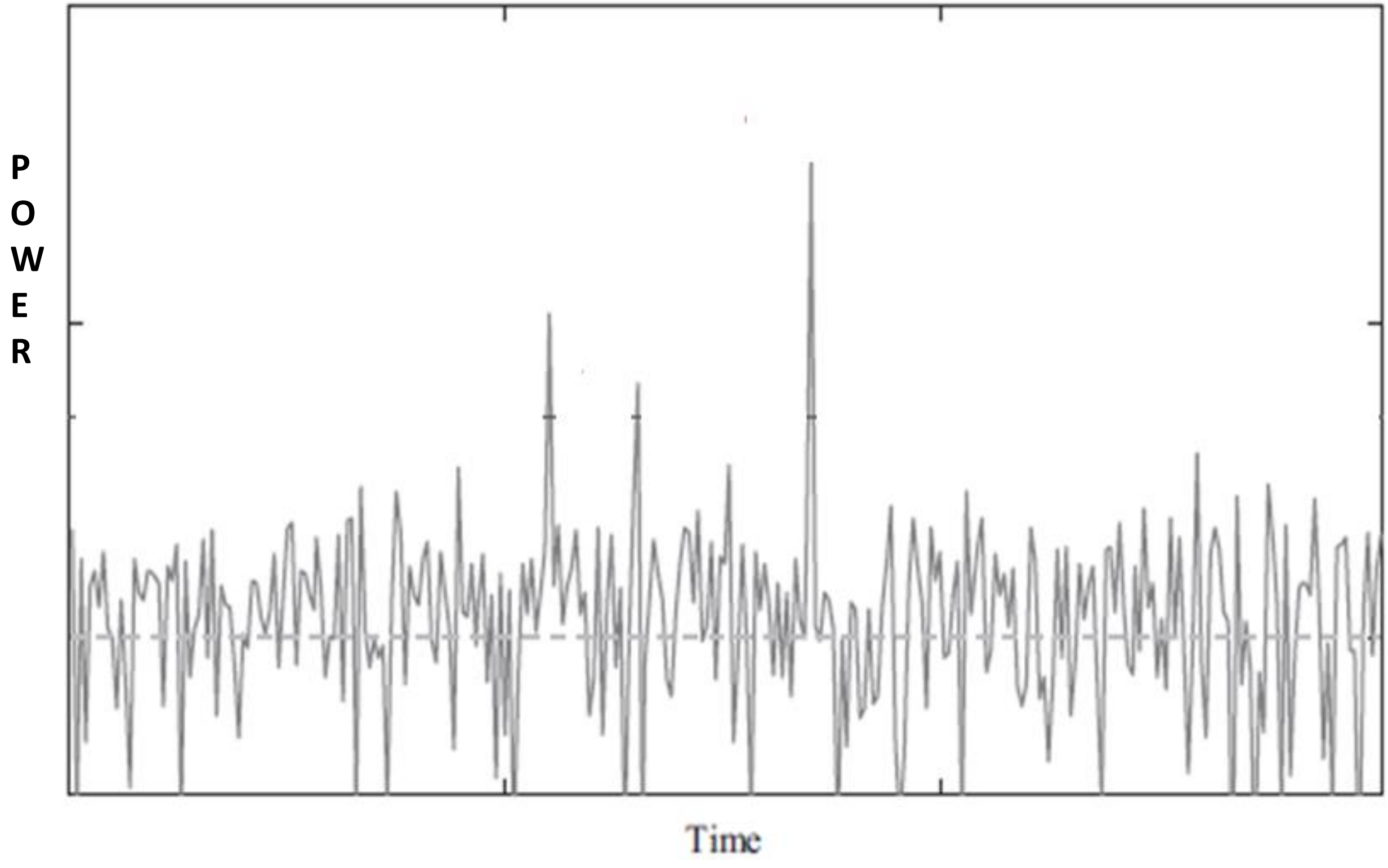
MINIMUM DETECTABLE SIGNAL

- (Jntuh) What is meant by minimum detectable signal in radar

- S_{min} – Signal detectable by a Receiver (Rx) is limited by Noise energy that is present in the frequency spectrum of signal energy

NOISE

- NOISE



MINIMUM DETECTABLE SIGNAL

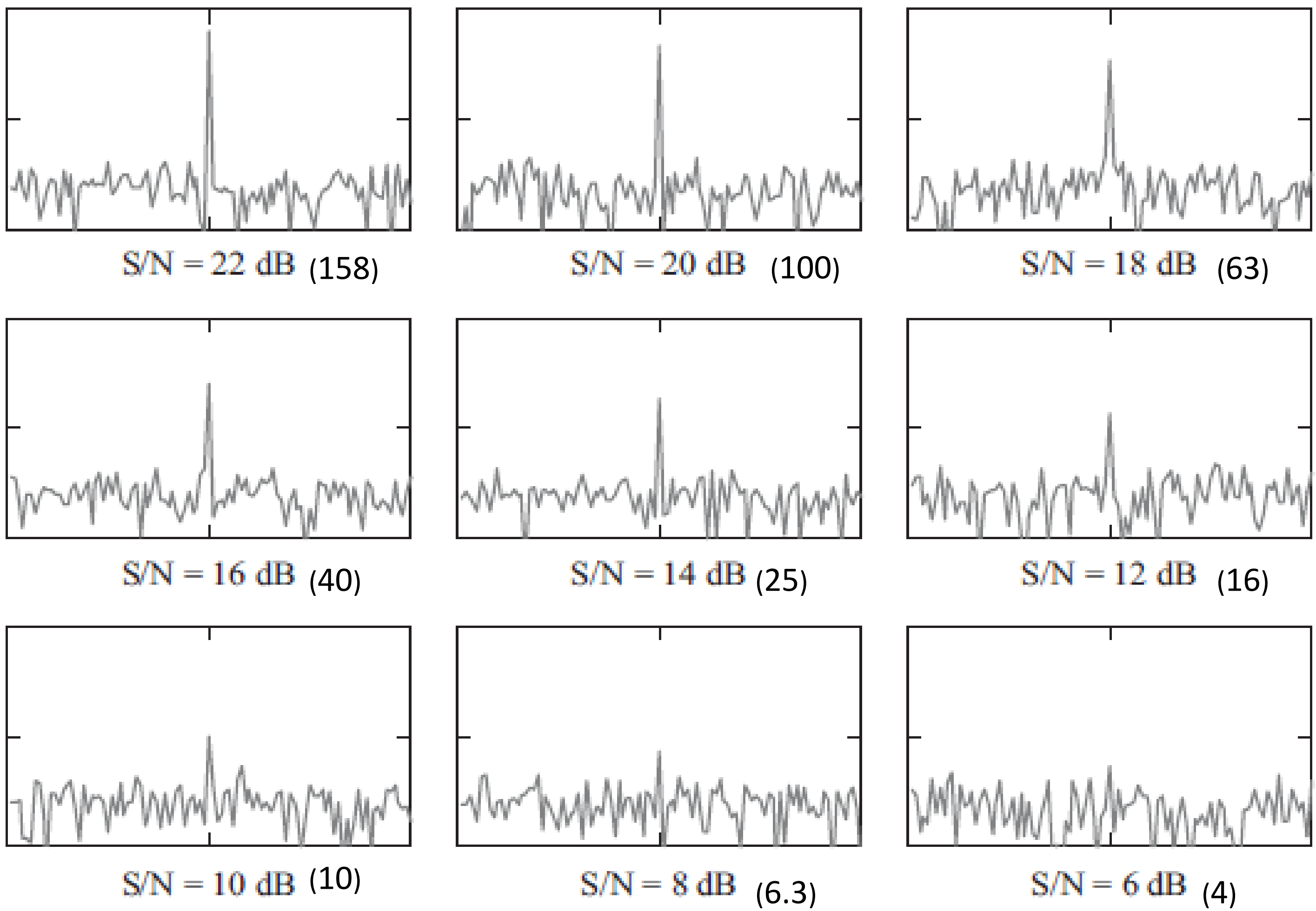
- **Minimum Detectable signal (S_{min}) :**
- Minimum Detectable signal is the weakest signal the Receiver can detect
- Presence or absence of a target is determined by

i) S_{min}

ii) threshold criterion

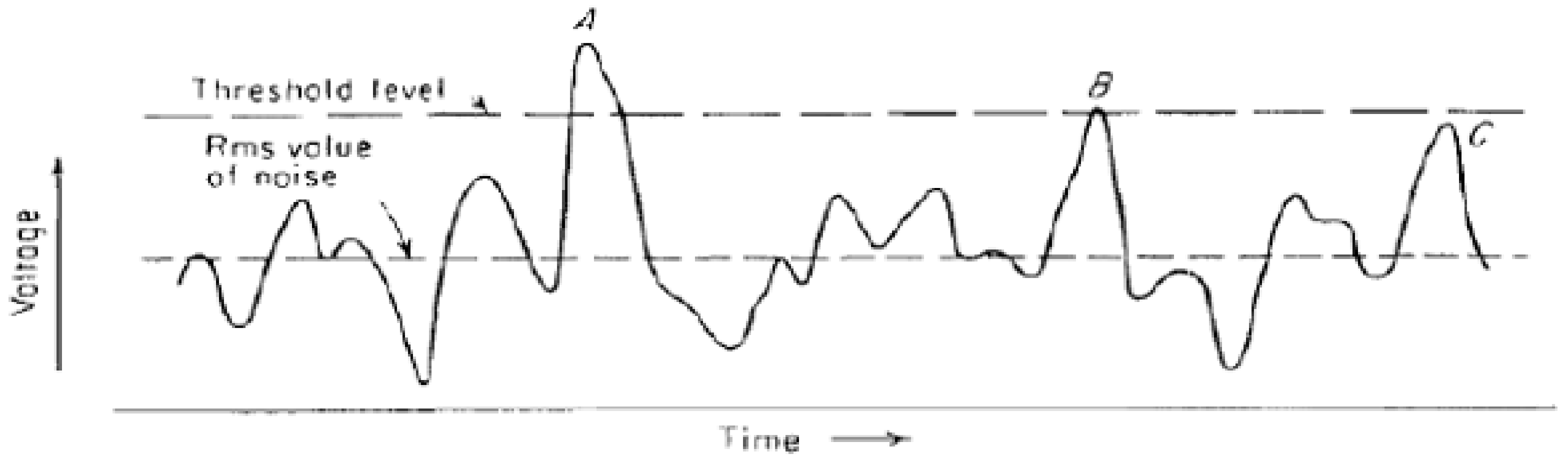
iii) human operator

Target Detection



MINIMUM DETECTABLE SIGNAL

- THRESHOLD DETECTION:
- Threshold level is set at the output of Rx. If Rx output crosses the threshold, signal which is a mixture of echo and noise is assumed to represent a target



RADAR RECEIVER OUTPUT

MINIMUM DETECTABLE SIGNAL (CONTD..)

- Envelope (echo + noise) has fluctuating appearance because of random nature of Noise
- Envelope shown has passed through Matched filter which makes echoes no more look like rectangular pulses. They appear as triangular as shown in the graph
- Diagram shown is the combination of echo and noise. Threshold level is set such that noise alone does not cross the level and falsely taken as target

MINIMUM DETECTABLE SIGNAL (CONTD..)

- **Target A :**
- Target A has large signal echo, greater than the surrounding noise amplitude and crosses threshold on its own and declared as a valid target without any ambiguity
- Let Target echoes of B &C are of equal voltage amplitude
- **Target B :**
- Noise voltage amplitude at occurrence of signal is large. Signal echo combined with noise at that instant is just sufficient enough to cross the threshold and declared as a valid target

MINIMUM DETECTABLE SIGNAL (CONTD..)

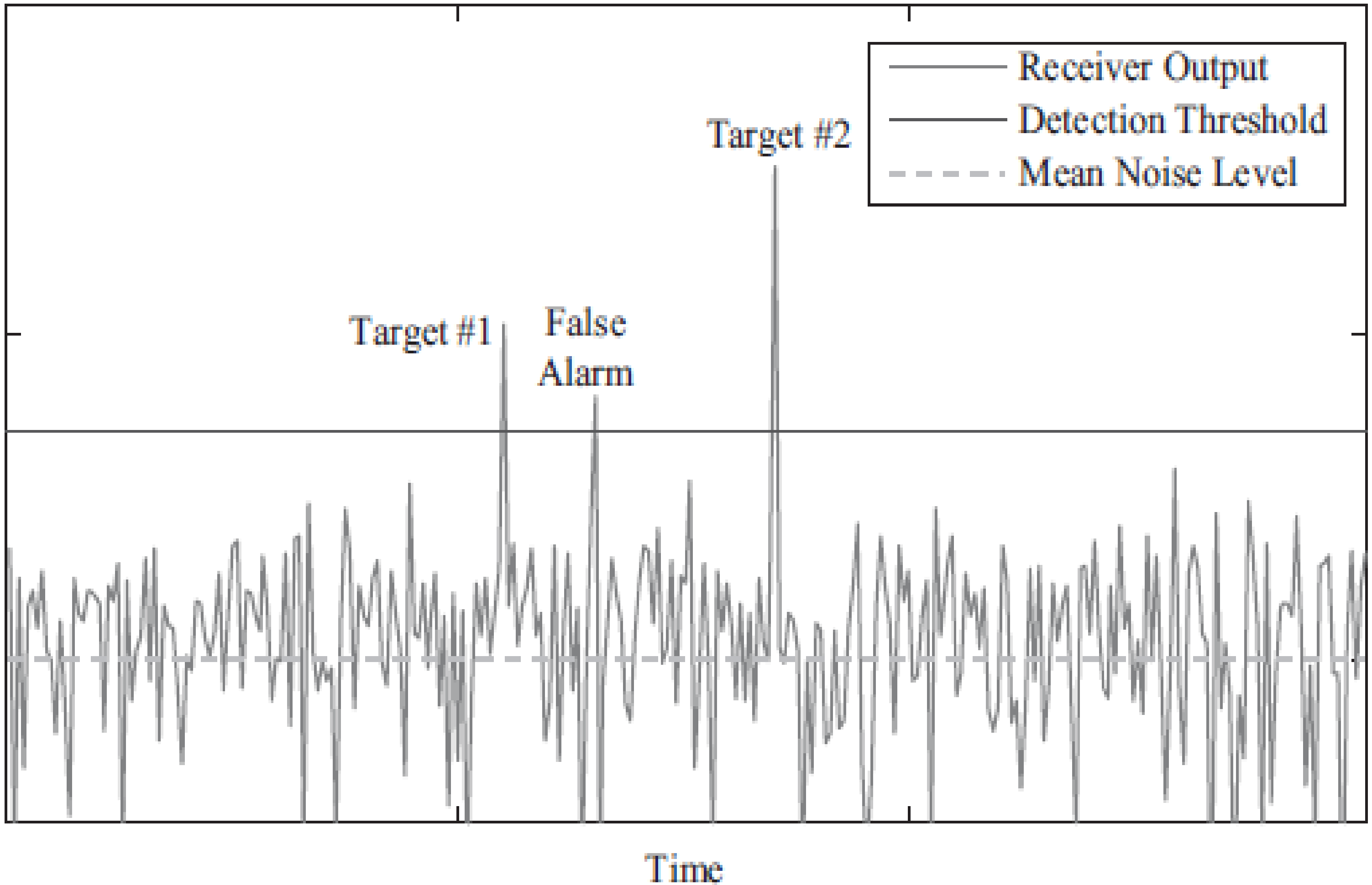
- **Target C :**

- Here the noise level is small at this instant of time the resultant of echo and noise signal does not cross the threshold level. So target presence is not declared. The target has missed being detected.
- Noise sometimes enhance the detection of weak echo signals

- **False Alarm:**

- Weak signal C would not have been lost if threshold level is lower. But low threshold increases the likelihood of noise alone crossing the threshold and declared as a real target. This is called as False alarm.

THRESHOLD DETECTION OF TARGET SIGNALS



MINIMUM DETECTABLE SIGNAL (CONTD..)

Threshold level Setting:

- If threshold level is set too low so that weak echo signals also can be declared as valid targets, false targets are declared, since at some instant in time noise may cross the threshold level
- If threshold level is set too high, weak echoes are missed. Thus real targets are missed.
- Selection of threshold has to be done judiciously depending on the goals set in the design parameter. Probability of miss or Probability of false alarm

MINIMUM DETECTABLE SIGNAL (CONTD..)

- **Probability of Miss:**
  - Failing to indicate the presence of real target
- **Probability of False Alarm:**
  - Falsely indicating presence of target even though there is no real target

- **Manual setting of Threshold by operator:**
  - Probability of miss or Probability of False alarm depends on i) skill of operator ii) motivation of operator iii) state of operator’s fatigue

RECEIVER NOISE
AND
SIGNAL TO NOISE (S/N) RATIO

RECEIVER NOISE & S/N RATIO

- (Jntuh) Discuss in detail the quantitative analysis of Receiver noise and hence derive expression for minimum detectable signal
- (Jntuh) Describe different noise components present in radar systems
- Receiver noise: Noise interferes with detection of echo from target. i) Noise may exist within the Receiver itself. ii) Noise also enters the Receiver along with echo. Iii) Even if the radar is operated in a noise free environment, thermal noise still exists. Thermal noise is due to the thermal motion of electronics in the Receiver circuits

RECEIVER NOISE & S/N RATIO

Thermal noise or Johnson Noise

- Noise that is generated due to thermal agitation of conduction electrons in the Ohmic portion of Receiver input stages is called Thermal Noise
- Thermal Noise Power (watts) = $K\ T\ B_n$

  K = Boltzmann's constant = 1.38×10^{-23} joules/degree

  T = Temperature in Degrees Kelvin

  B_n = Noise Band width Hz

RECEIVER NOISE & S/N RATIO (CONTD..)

- **Ideal Receiver:**
  - i) No noise due to external source
  - ii) Rx does not generate any noise
  - iii) only Thermal noise is present
- **Practical Receiver :**
  - A practical Receiver has additional noise components other than thermal noise. Noise power of Practical Rx is greater than that from thermal noise alone
- **Noise Figure : (F_n)**
- $$F_n = \frac{\text{Noise output power of Practical Receiver}}{\text{Noise output of Ideal Receiver}}$$

RECEIVER NOISE & S/N RATIO (CONTD..)

➢ Noise Figure:

$$F_n = \frac{\text{Noise output power of Practical Receiver}}{\text{Noise output of Ideal Receiver}}$$

- $= \dfrac{N_{out}}{K\ T_O\ B_n\ \ G_A}$

N_{out} = Noise output of practical Rx

G_A = Amplifier Gain = $\dfrac{S_{out}}{S_{in}}$

S_{in} = signal input of Rx,

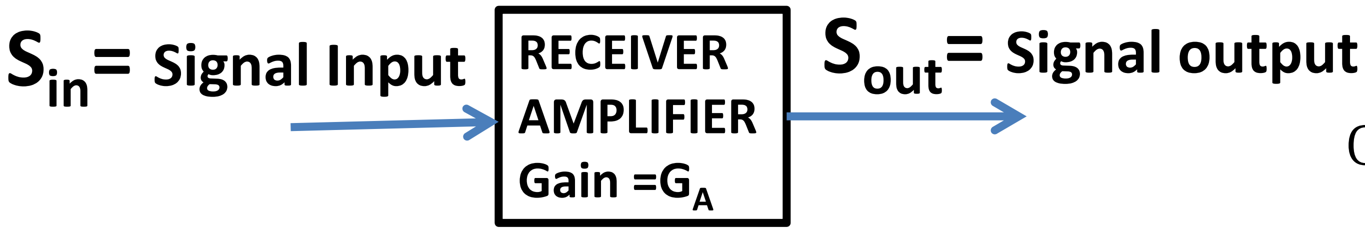
S_{out} = signal output of Rx

T_0 = 290 K (273 + 17) Room temp =17^0 C

B = Bandwidth of Receiver

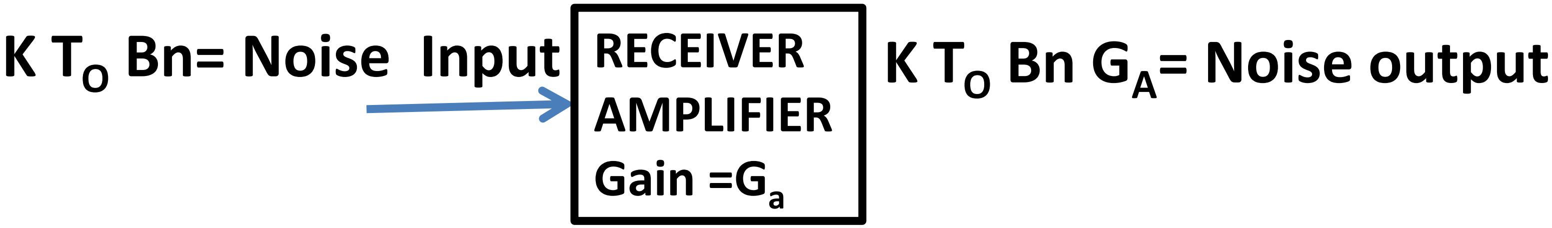
NOISE FIGURE

- SIGNAL TO NOISE RATIO:

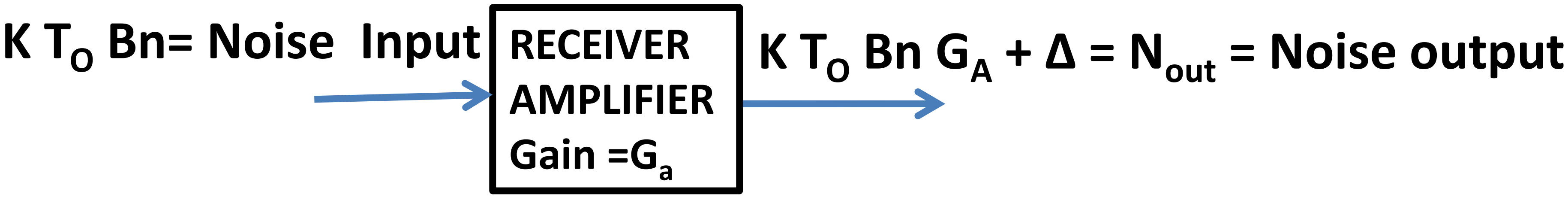


$$G_A = \frac{S_{out}}{S_{in}}$$

- IDEAL AMPLIFIER:



- PRACTICAL RECEIVER



NOISE FIGURE (CONT)

- Noise figure $= F_n = \dfrac{\text{Noise output of practical receiver}}{\text{Noise output of Ideal receiver}}$

- $F_n = \dfrac{N_{out}}{K\,T_0\,B_N\,G_A}$

$$F_n = \frac{N_{out}}{K\,T_0\,B_N\,\frac{S_{out}}{S_{in}}} = \frac{N_{out}}{N_{in}\,\frac{S_{out}}{S_{in}}}$$

$$F_n = \frac{S_{in}}{N_{in}} \times \frac{1}{\frac{S_{out}}{N_{out}}} = \frac{\frac{S_{in}}{N_{in}}}{\frac{S_{out}}{N_{out}}}$$

- $F_n = \dfrac{\text{Input Signal to Noise Ratio}}{\text{output Signal to Noise Ratio}}$

NOISE FIGURE (CONT)

- $$F_n = \frac{\text{Input Signal to Noise Ratio}}{\text{output Signal to Noise Ratio}}$$

- This means F_N is degradation in signal to noise ratio when signal passes through practical R_X

NOISE FIGURE (CONT)

- $F_n = \frac{\frac{S_{in}}{N_{in}}}{\frac{S_{out}}{N_{out}}}$
- $\frac{S_{in}}{N_{in}} = F_n \frac{S_{out}}{N_{out}} = F_n(S/N)_{out}$
- $S_{in} = N_{in} F_n (S/N)_{out} = K\ T_0\ B_n F_n (S/N)_{out}$
- In limiting case S_{in} becomes $(S/N)_{in(min)}$ and $(S/N)_{out}$ becomes $(S/N)_{out(min)}$

  $(S/N)_{in(min)} = K\, T_0\, B_n\, F_n\ (S/N)_{out(min)}$

Noise Figure (cont)

- We know that (Radar equation)
- $R_{max}{}^{4} = \dfrac{P_T \; G_T \; A_e \; \sigma}{(4\;\pi)^2 \;\; S_{min}}$

- But from the previous slide we have
- $(S/N)_{in(min)} = K\,T_0\,B_n\,F_n\;(S/N)_{out(min)}$
- Combining the two above
- $R_{max}{}^{4} = \dfrac{P_T \; G_T \; A_e \; \sigma}{(4\,\pi)^2\,K\,T_O\;B_n\;F_n\;(S/N)_{out(min)}}$
- $R_{max}{}^{4} = \dfrac{P_T \; G_T \; A_e \; \sigma}{(4\,\pi)^2\,K\,T_O\;B_n\;F_n\;(S/N)_{min}}$

PROBLEM

PROBLEM

- A low power, short range radar is solid state throughout, including a low noise RF amplifier which gives it an overall Noise Figure of 4.77 dB. If the antenna diameter is 1m , the IF bandwidth is 500 kHz, the operating frequency is 8 GHz and the radar set is supposed to be capable of detecting targets of 5 m^2 cross-sectional area at a maximum distance of 12 km, what must be the peak transmitted pulse power?

PROBLEM

- Given parameters:
- F_n = 4.77 dB = Antilog $(\frac{4.77}{10})$ = 3

  D = 1 mt

  f = 8 GHz

  σ = 5 mt^2
- R_{max} = 12 Km = 12×10^3 mts
- (S/N) =10 (assumed)
- K = 1.38×10^{-23} joules /degree
- T_0 = 290 Kelvin

PROBLEM

- $A_e = \frac{\pi \ D^2}{4} = \frac{3.14 \times \ 1^2}{4} = 0.785 \text{ mt}^2$
- $\boldsymbol{\lambda} = \frac{C}{f} = \frac{3 \times 10^8}{8 \times 10^9} = 0.0375\, m$
- $G = \frac{4\,\pi \ A_e}{\lambda^2} = \frac{4 \times 3.14 \times 0.785}{0.0375^2} = 7011$
- $R_{max}{}^4 = \left[\frac{P_T \ G \ A_e \ \sigma}{(4 \ \pi)^2 \ K \ T_O \ B_n \ F_n \ (S/N)_{min}}\right]$
- $(12 \times 10^3)^4 = \left[\frac{P_T \ 7011 \times 0.785 \times 5}{(4 \times 3.14)^2 \times 1.38 \times 10^{-23} \times 290 \times 500 \times 10^3 \times 3 \times 10}\right]$
- $P_T = 7.13$ W

CONTINUED IN RADAR 1 E