Radar and Navigation(EC0607)
Unit-1
B.Tech (Electronics and Communication)
Semester-VI

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Introduction
and Radar Equation

How does Radar Work?

We can see objects in the world around us because light (usually from the Sun) reflects off them into our eyes. If you want to walk at night, you can shine a torch in front to see where you're going. The light beam travels out from the torch, reflects off objects in front of you, and bounces back into your eyes. Your brain instantly computes what this means: it tells you how far away objects are and makes your body move so you don't trip over things

- Radar works in much the same way. The word "radar" stands for **ra**dio **d**etection **a**nd **r**anging.

- Imagine an airplane flying at night through thick fog. The pilots can't see where they're going, so they use the radar to help them.

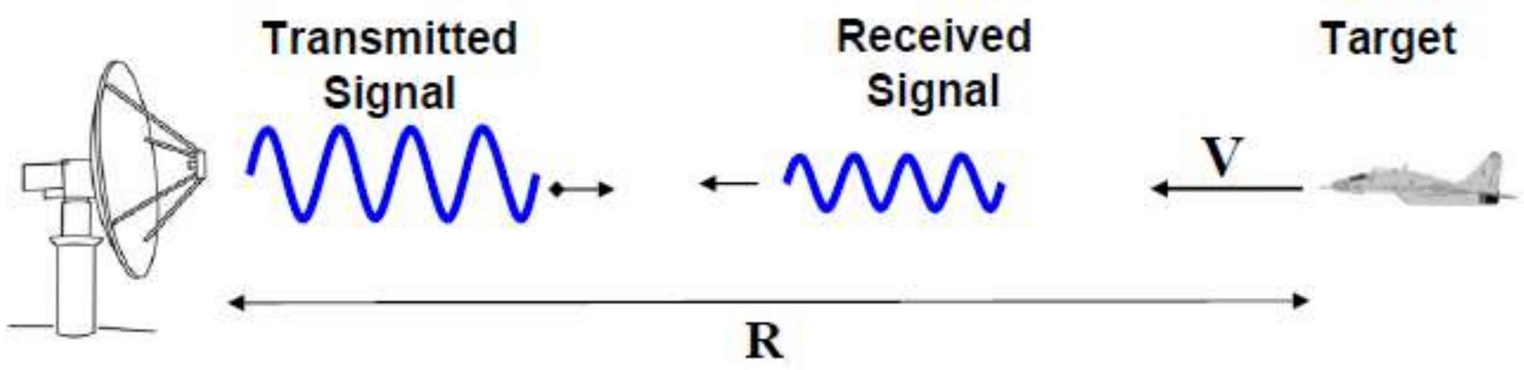
- An airplane's radar is a bit like a torch that uses radio waves instead of light. The radar on plane transmits an intermittent (occurring at irregular intervals) radar beam (so it sends a signal only part of the time) and for the rest of the time, "listens" out for any reflections of that beam from nearby objects.
- If reflections are detected, the plane knows something is nearby and it can use the time taken by the reflections to arrive at plane to figure out how far away the object is.

Introduction

- The word RADAR is an acronym for **Radio Detection And Ranging**
- A Radar is an electromagnetic system for the detection and location of objects. It operates by transmitting a particular type of waveform and detects the nature of the echo signal
- Radars can operate in situations like darkness, fog, rain or when the object is located far away. In such situations the human eye is almost useless
- Its main function is to measure the distance or range to an object

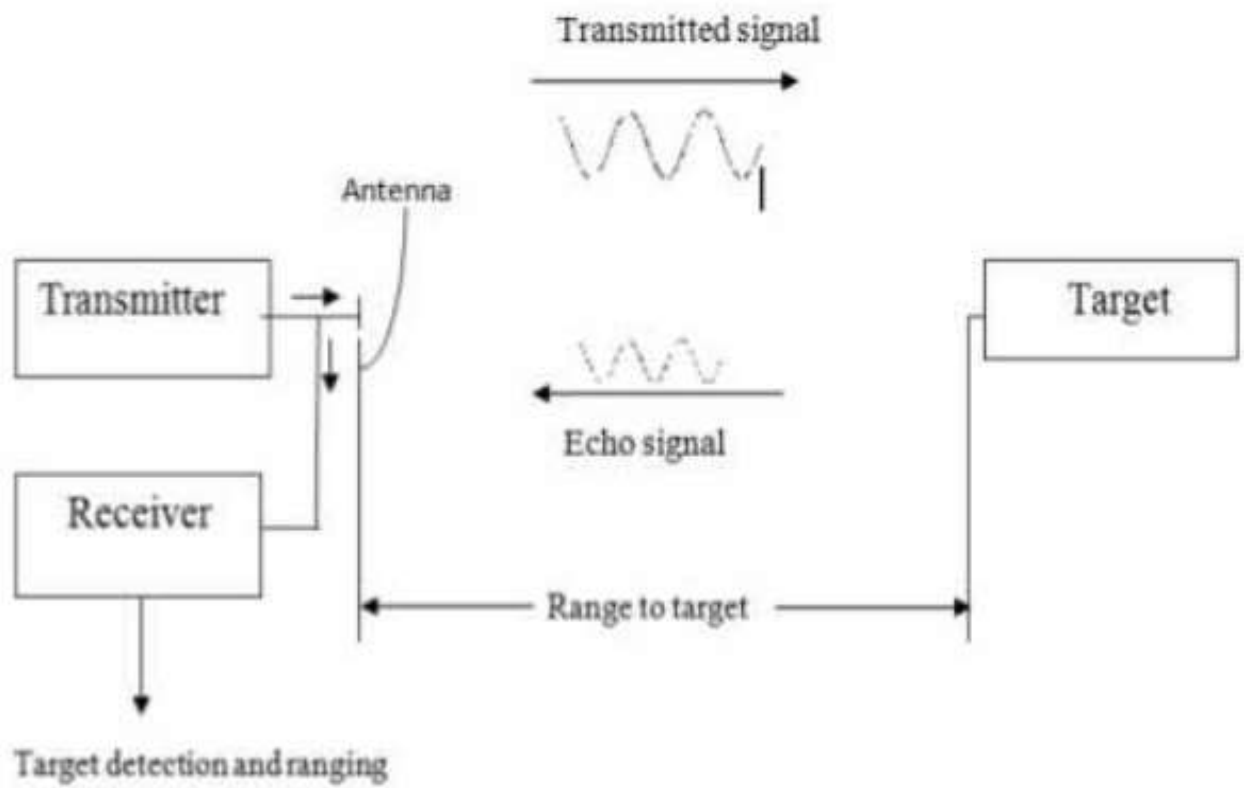
Introduction

- A radar consists of three main parts:
  - *A transmitting antenna.*
  - *A receiving antenna*
  - *An energy detecting device, or a receiver.*



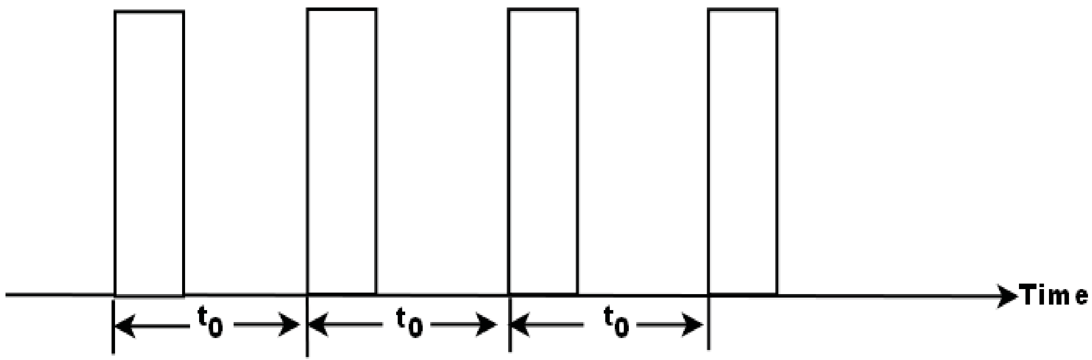
Introduction

- The transmitting antenna emits electromagnetic radiation, a portion of which is reflected back by the target
- The receiving antenna receives this reflected energy and delivers it to the receiver
- The receiver processes this energy to detect the presence of the target and to extract its location, relative velocity, and other information.
- The energy emitted by the radar is usually in the form of a train of narrow, rectangular-shaped pulses. This is called a radar waveform

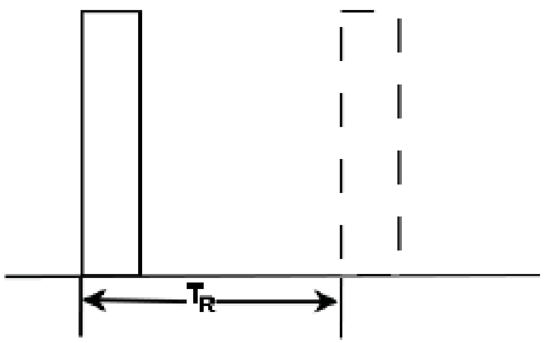


Basic Principles of the Radar

Introduction



A typical radar waveform



Transmitted and received pulse

- No of pulses per second OR pulse repetition frequency is given by

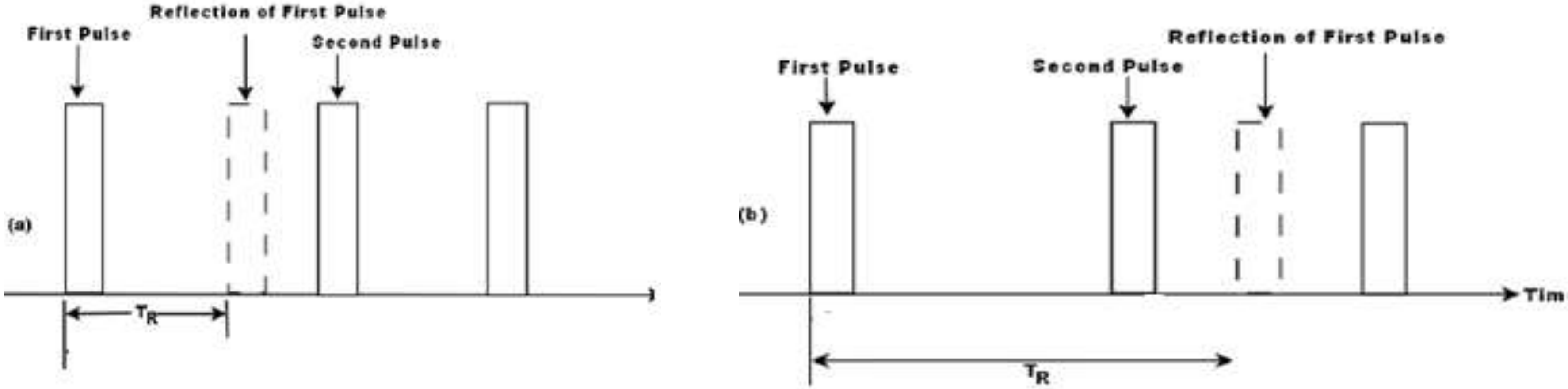
$$f_p = \frac{1}{t_0}$$

- The reflected energy is received at the radar T_R *seconds after sending* the pulse(see Fig.2.2).

- Distance or range to a target is given by

$$R = \frac{cT_R}{2}$$

Ambiguity Range of Radar



(a) No ambiguity in range measurement

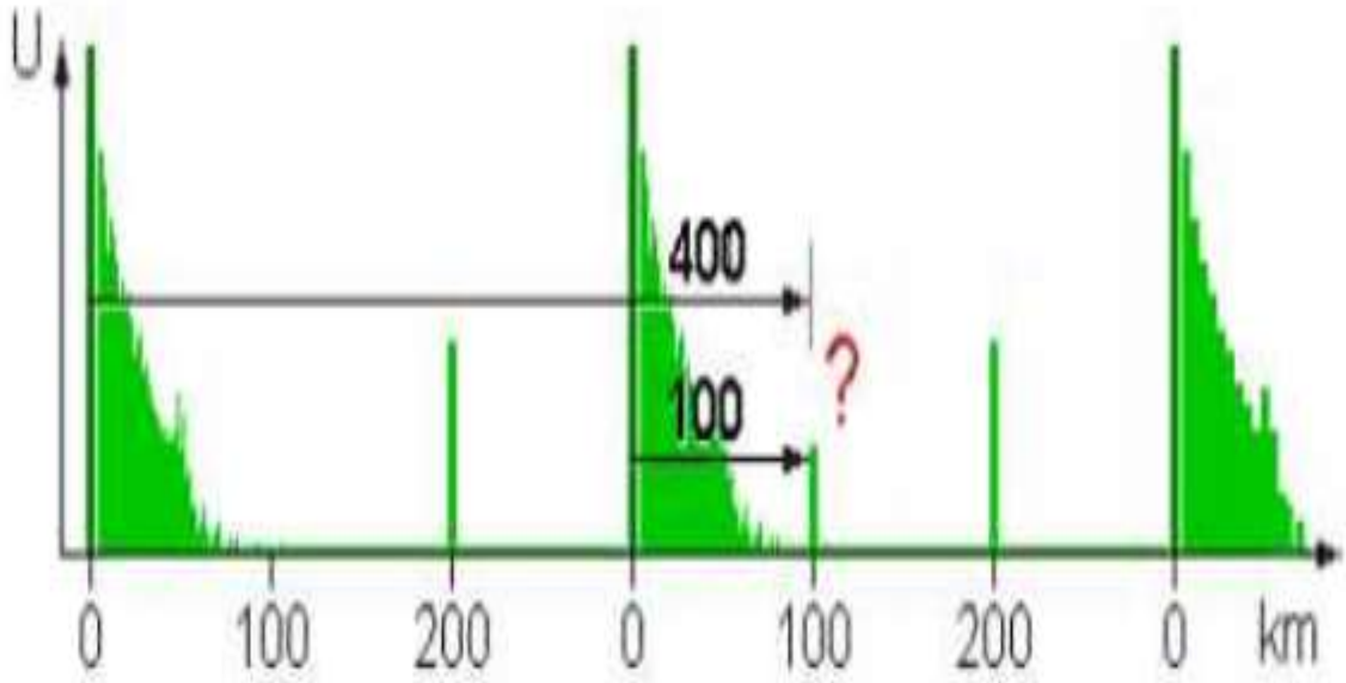
(b) ambiguity in range measurement

$$T_R < t_0,$$

$$R_{unamb} = \frac{ct_0}{2} = \frac{c}{2f_p}$$

- **<u>Maximum Unambiguous Range</u> is the distance of the target which does not cause any ambiguity is denoted by R unamb**

- **If the target is beyond this distance then the reflection of a pulse is received after the next pulse has been transmitted. This is known as the <u>second-time-around echoes</u> effect.**



a second-time-arounr-echo in a distance of 400 km assumes a wrong range of 100 km

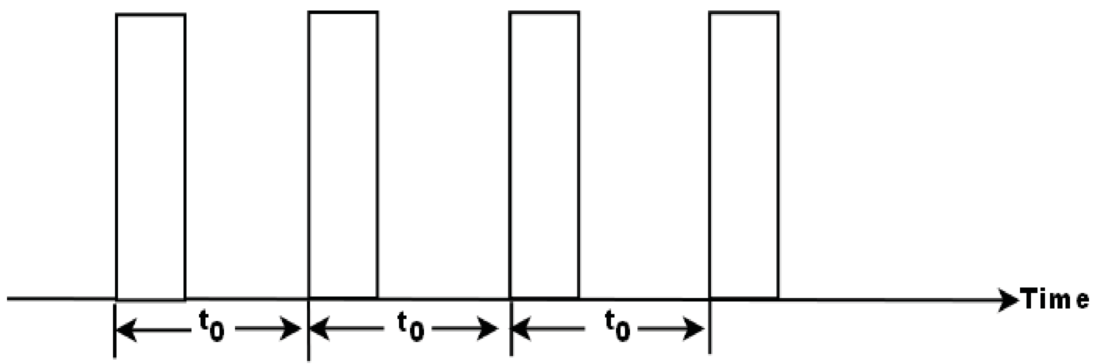
Example

- Consider a radar with pulse repetition frequency 1000 Hz.

(a) Find the time duration between two pulses.

(b) Suppose an echo from a distant object is received 20 μ *sec after a pulse is transmitted, what is* the distance of the object from the radar?

(c) Is there a second -time-around echo from this object?



Typical Radar Waveform

- Pulse width of radar waveform= τ
- Duty cycle of radar waveform is the ratio of pulse width to the total time of radar .

$$DC = \frac{\tau}{t_o}$$

Applications of RADAR

- **On ground** : Detection, location, and tracking of aircrafts
- **In the air :** Detection of other aircraft, ships, or land vehicles; mapping of land; storm avoidance, terrain(a stretch of land, especially with regard to its physical features.) avoidance, and navigation
- **On the sea :** Navigation aid and safety device to locate buoys(is a floating device that can have many purposes), shore lines, other ships, and for observation of aircraft, especially in poor visibility
- **In space :** Guidance of spacecraft; remote sensing of land and sea

- **Air traffic control** : Controlling of air traffic in the vicinity of airports; and also for automated landing
- **Aircraft navigation** : Weather avoidance to indicate regions of rain; terrain following/terrain avoidance (TF/TA) radio altimeter and Doppler navigator are also radars
- **Ship safety :** Collision avoidance; detection of navigation buoys.
- **Space :** landing on the moon and other planets; detection and tracking of satellites
- **Remote sensing:** Sensing of geophysical object, or the ”environment” like weather, cloud cover, earth resources, water resources, agriculture, forests, geological formation, etc. This is usually done from aircraft or satellites
- **Law enforcement :** To monitor speed of vehicles in traffic

In aviation ,

Aircraft are equipped with radar devices that warn of aircraft or other obstacles in or approaching their path, display weather information, and give accurate altitude readings. The first commercial device fitted to aircraft was a 1938 Bell Lab unit on some United Air Lines aircraft. Such aircraft can land in fog at airports equipped with radar – assisted ground - controlled approach systems in which the plane's flight is observed on radar screens while operators radio landing directions to the pilot.

Marine radars

Used to measure the bearing (a person's way of standing or moving)and distance of ships to prevent collision with other ships, to navigate, and to fix their position at sea when within range of shore or other fixed references such as islands, buoys(A *buoy* is a floating object that is used to show ships and boats where they can go and to warn them of danger.), and lightships. In port, vessel traffic service radar systems are used to monitor and regulate ship movements in busy waters

Military : Surveillance and navigation(systems are key to the delivery of safe and efficient air traffic management); for control and guidance of weapons. The largest use of radars occurs here.

ASR-9 [Airport Surveillance Radar]

- It provides the coverage of the air traffic in the vicinity(the area near or surrounding a particular place) of airport.

The air-defense radar AN/FPS-117

- This radar system consists of a primary radar, a secondary radar and a subsystem for simulation.
- It provides 3D- target information in real time over the whole range of detection correlated with the replies of the secondary radar.

Origins of RADAR

Developed in the early 1900s (pre-World War II)

- 1904 Europeans demonstrated use for detecting ships in fog
- 1922 U.S. Navy Research Laboratory (NRL) detected wooden ship on Potomac River
- 1930 NRL engineers detected an aircraft with simple radar system

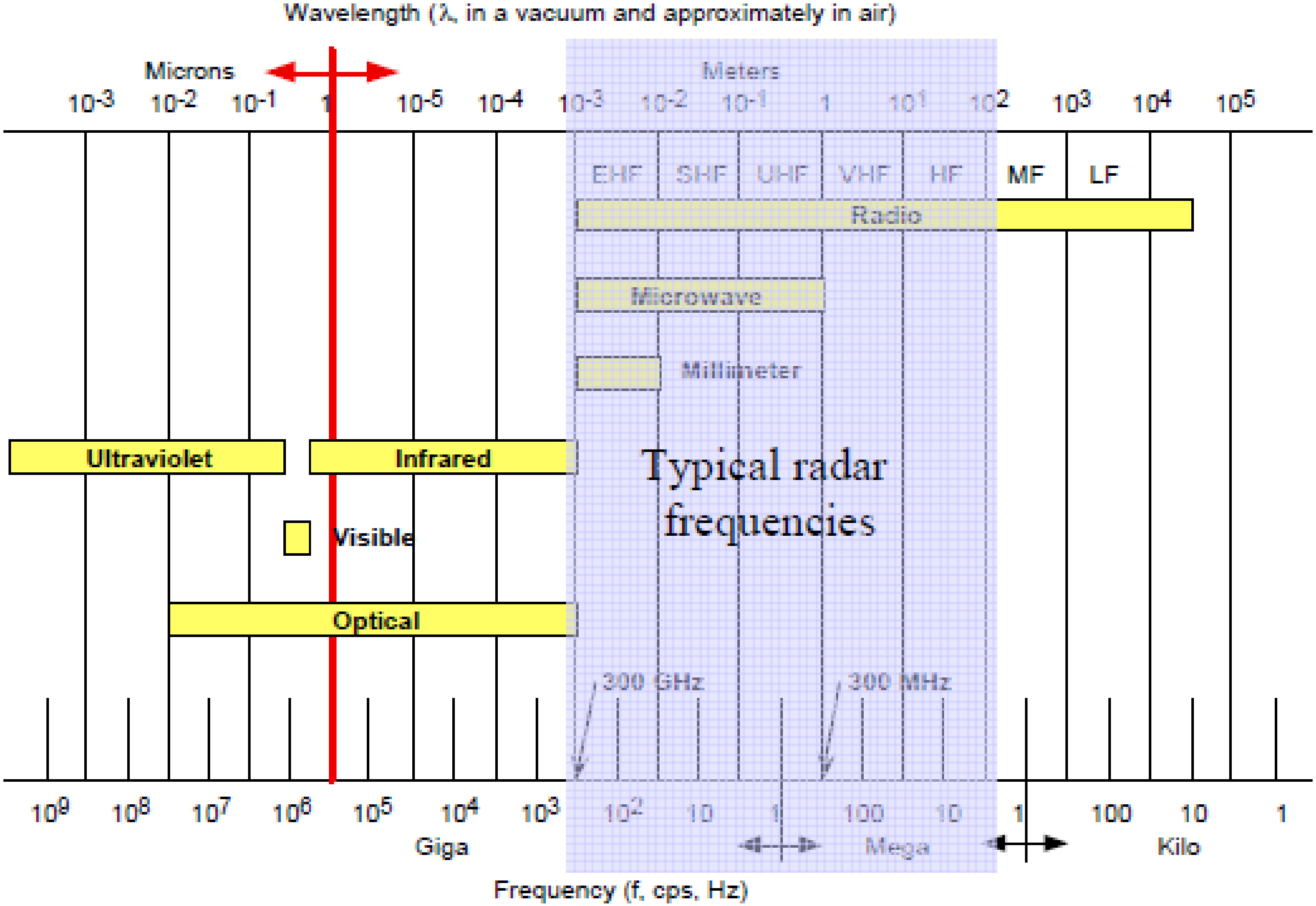
World War II accelerated radar's development

- Radar had a significant impact on militarily
- Called "The Invention That Changed The World" in two books by Robert Buderi

Radar's has deep military roots

- It continues to be important for militarily applications
- Growing number of civil applications
- Objects often called 'targets' even in civil applications

Electromagnetic Spectrum



IEEE Standard Radar Bands

UHF - VHF
ALTAIR

UHF
UEWR – Fylingsdales, UK

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

*From IEEE Standard 52

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	8–12 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

Radar Range Equation

- It relates the range of radar to the characteristics of transmitter, receiver, antenna , target and the environment in which radar operates.

- It is useful in determining the distance of the target from the radar.
- It is a tool for understanding the radar operation.
- It serves a basis for radar design.

- If the power of the radar transmitter is denoted by (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 R from the radar.(is the amount of **power** per unit surface area**)(Power radiated by antenna)**

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

- The power density at the target (at distance R) from a directive antenna with a transmitting gain G **is(Power density at the target when a directive antenna is used)**

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

- 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 (**σ**) of the target.
- Power collected by the target at distance R from the radar is given by (**The amount of power intercepted by the target**)

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

- This power gets reradiated in all the directions, therefore, power density of the reflected signal at the receiving antenna is

$$\text{Power density of echo signal at radar} = \frac{P_t G}{4\pi R^2}\frac{\sigma}{4\pi R^2}$$

- The radar antenna captures a portion of reflected power. How much of this power is captured depends on what is known as the effective area of the receiving antenna & is denoted by Ae.

- The power (Pr) 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 radar receiver must be capable of detecting the power received. Suppose it can detect only those signals which are greater than a value Smin (Minimum Detectable Signal), then the maximum range of the radar can be obtained from Pr= S_{min} and R= R_{max}

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

$$S_{min} = \frac{P_t G A_e \sigma}{(4\pi)^2 R_{max}^4}$$

- The maximum radar range (R_{max})is the distance beyond which the target cannot be detected. It occurs when the received echo signal power P, just equals the minimum detectable signal (S_{min})

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

- Most Radars employ the same antenna for transmission and reception

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

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

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

Example

(a) Find the power density at a target situated at a distance of 50km from a radar radiating a power of 100 MW from a lossless isotropic antenna

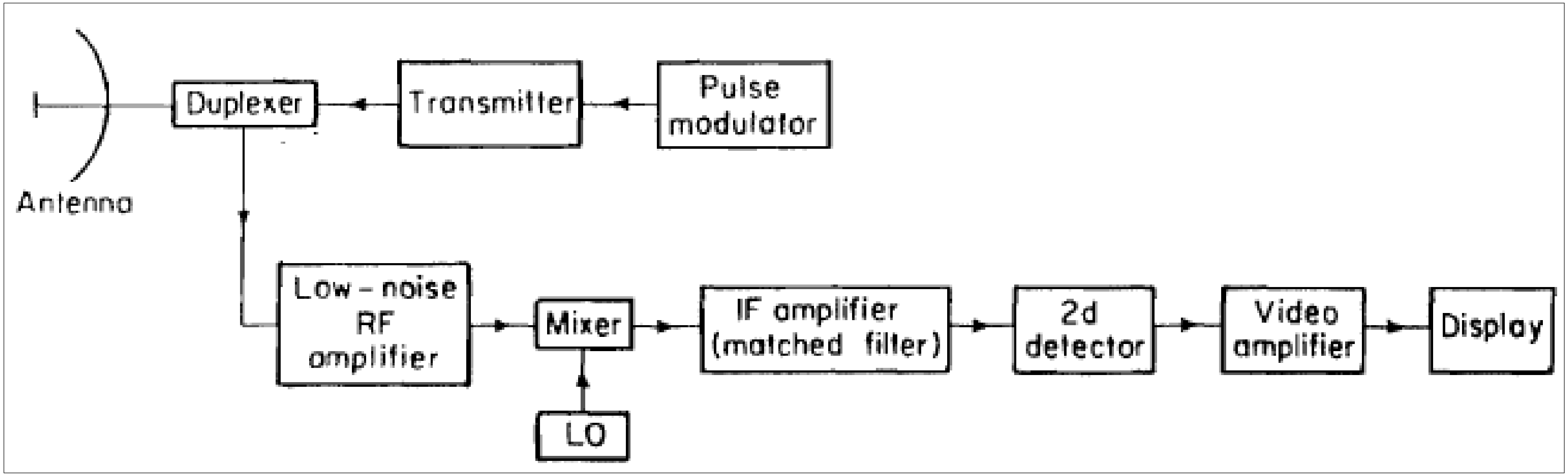
(b) If this radar now employs a lossless isotropic antenna with a gain of 5000 and the target has a radar cross-section of 1.2 m2, then what is the power density of the echo signal at the receiver?

(c) If the minimum detectable signal of the radar is 10−*8 mW and the* wavelength of the transmitted energy is 0.02 m, then what is the maximum range at which the radar can detect targets of the kind mentioned in (b)?

(d) Suppose, due to some modifications made in the radar system components, the antenna gain is doubled while keeping the antenna effective aperture constant. Find the new radar range.

(e) What is the new radar range if the antenna gain doubles while λ remains constant?

Block Diagram of Radar & its operation



(1)Transmitter :

- Transmitter may be an oscillator, such as a magnetron, that is " pulsed“ (turned on and off) by the modulator to generate a repetitive train of pulses.
- The magnetron has probably been the most widely used of the various microwave generators for radar.
- Power of the order of a megawatt, an average power of several kilowatts, a pulse width of several microseconds, and a pulse repetition frequency of several hundred pulses per second.

Block Diagram of Radar & its operation

- The waveform generated by the transmitter travels along a transmission line to the antenna, which is generally used for both transmitting and receiving.
- Antennas can be mechanically steered parabolic reflectors, mechanically steered planar arrays or electrically steered phased arrays..

- **Duplexer** allows the single antenna to be used on time shared basis for both transmitting & receiving.

- The duplexer consists of two devices, one known as TR (Transmit-Receive) and the other as ATR (Anti-Transmit-Receive).

1. The TR protects the delicate circuits of the receiver from the high power of the transmitter during transmission.
2. The ATR channels the returned echo signal to the receiver, and not to the transmitter, during reception.

Block Diagram of Radar & its operation

(2) Receiver :

- The receiver is usually of the super heterodyne type.
- The first stage might be a low-noise RF amplifier, such as a parametric amplifier or a low-noise transistor.
- Although a receiver with a low-noise front-end will be more sensitive, the mixer input can have greater dynamic range, less susceptibility to overload, and less interference.
- The mixer and local oscillator **(LO)** convert the RF signal to an intermediate frequency **(IF)** signal**.**
- The IF amplifier is designed as matched filter to maximize the output peak signal-to-noise ratio.
- The IF amplifier is followed by crystal diode (2^{nd} detector) which assists in extracting the signal modulation from the carrier.

Block Diagram of Radar & its operation

- The combination of IF amplifier, second detector & video amplifier act as an envelope detector to pass the pulse modulation (envelope) and reject the carrier frequency.

- The combination of IF amplifier and video amplifier is designed to provide the amplification, to raise the level of input signal to a magnitude where it can be seen on display, such as CRT or be the input to a digital computer for further processing.

- At the output of a receiver decision is made whether target is present or not. The decision based on the magnitude of the receiver output. If output is large to exceed the threshold, decision is that target is present.

Block Diagram of Radar & its operation

- The **signal processor,** is the part of radar whose function is to pass the desired echo signal and reject the unwanted signals, noise or clutter.
- It is found in the receiver before the detection decision is made. (ex: matched filter)
- Another example is Doppler filter that separates the desired moving targets from undesired stationary clutter echoes.

- Some radar process the detected signal further in **data processor,** before displaying the information to an operator.
- Example is an automatic tracker which uses the locations of the target measured over a period of time to establish the track of the target.

Receiver Noise

- Noise is unwanted electromagnetic energy which interferes with the ability of the receiver to detect the wanted signal.
- It may originate within the receiver itself, or it may enter via the receiving antenna along with the desired signal. (eg. clutter echoes from ground, sea, whether, birds)
- If the radar were to operate in a perfectly noise-free environment so that no external sources of noise accompanied the desired signal, and if the receiver itself were so perfect that it did not generate any excess noise, there would still exist an unavoidable component of noise generated by the thermal motion of the conduction‘ electrons in the ohmic portions of the **receiver input stages**.

✓This is called thermal noise generated at the input of a receiver

$$\text{Available thermal-noise power} = kTB_n$$

Receiver Noise

- The noise power in practical receivers is greater than that from thermal noise alone. The measure of noise out of a real receiver to that from the ideal receiver with only thermal noise is called the noise figure.
- Noise figure is defined a

$$F_n = \frac{S_i/N_i}{S_o/N_o}$$

- It is a measure of the degradation of the SNR as the signal passes through the receiver.
- So, the input signal is

$$S_i = \frac{kT_0 B_n F_n S_o}{N_o}$$

Receiver Noise

- If minimum detectable signal Smin is that value of Si Which corresponds to the minimum detectable SNR at the output of receiver,

$$S_{min} = kT_0 B_n F_n \left(\frac{S_o}{N_o}\right)_{min}$$

- This results in radar range equation as below:

$$R_{max}^4 = \frac{P_t G A_e \sigma}{(4\pi)^2 k T_0 B_n F_n (S_o/N_o)_{min}}$$

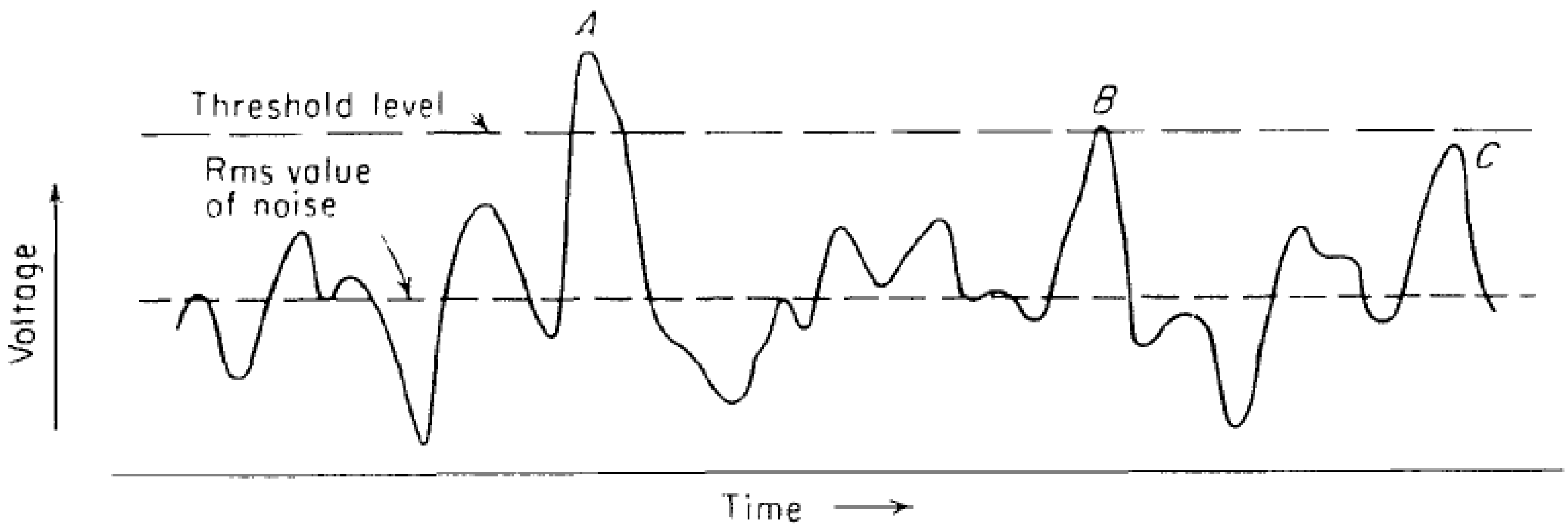
Minimum Detectable Signal

•The weakest signal, the receiver can detect is called the ***minimum detectable signal.***

•The specification of the minimum detectable signal is sometimes difficult because of the presence of noise and criterion for deciding whether target is present or not may not be too well defined.

•Detection is usually done by specifying threshold at the output of the receiver. If signal exceeds this threshold then target is assumed to be present. **This is called threshold detection.**

Minimum Detectable Signal



Typical envelope of the radar receiver output as a function of time. A, B and c represent signal plus noise but A and B is valid detection but c is missed detection

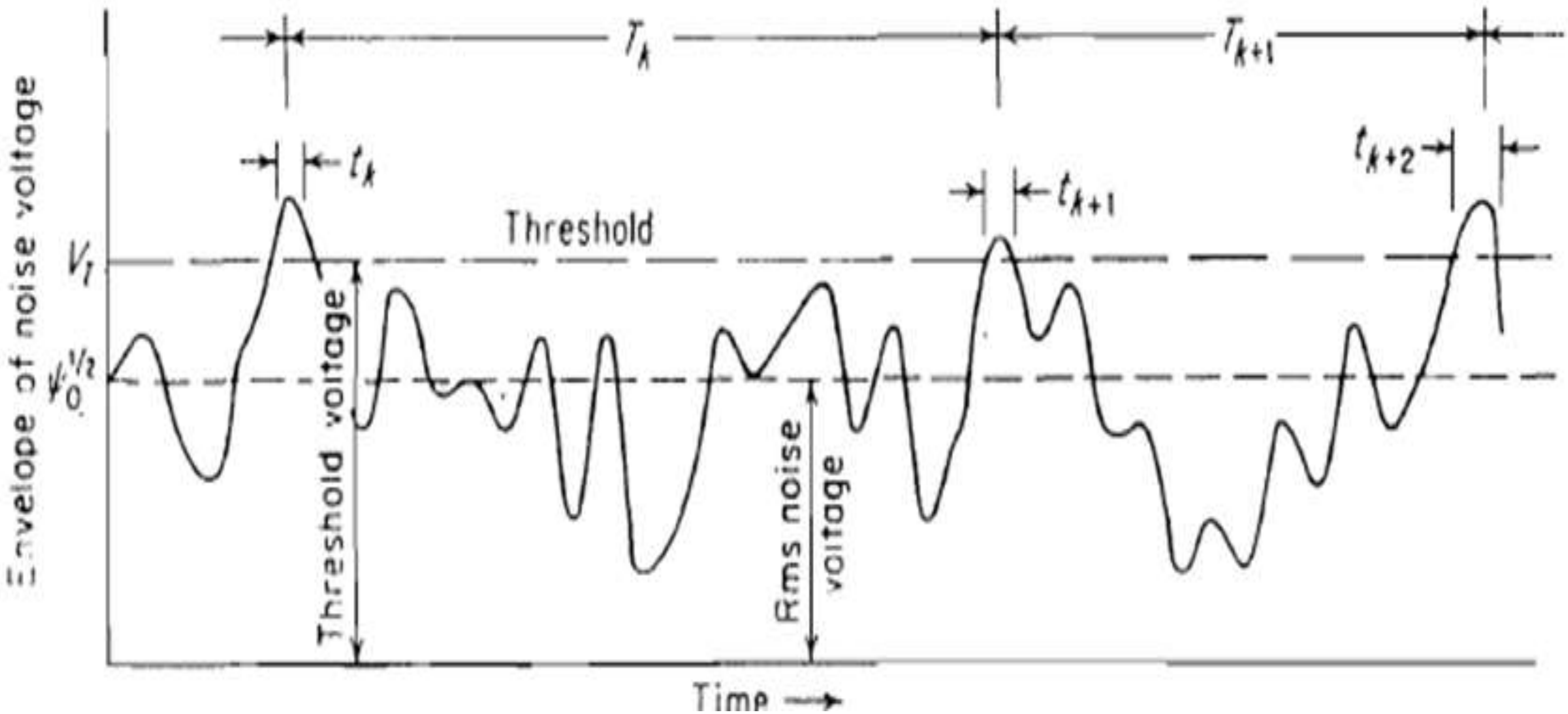
Minimum Detectable Signal

- Noise sometimes may enhance some weak signals so they cross the threshold (signal at B).
- Harmful effect of noise arises from the fact that threshold level has to be raised to avoid spurious signals, that causing non detection of signal which might have been otherwise detected. (signal at C)
- Therefore, if the threshold is set too low, false target indications are obtained, but if it is set too high, targets might be missed.
- The **selection of the proper threshold level is a compromise** that depends upon how important it is if a mistake is made either by

  (1) failing to recognize a signal that is present

  (**probability of missing signal**)

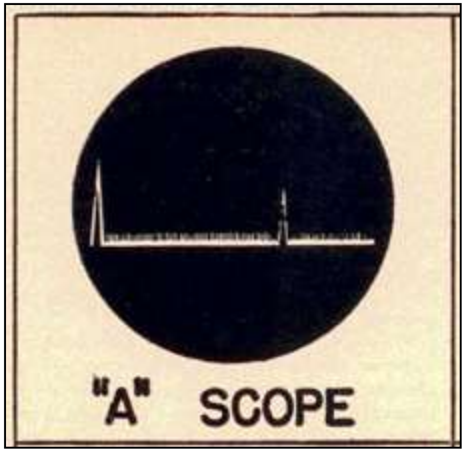
  (2) falsely indicating the presence of a signal when none exists (**probability of a false alarm**).



Envelope of the receiver output with noise alone, illustrating the duration of false alarms & time between false alarms.

Different Types of displays

A-scope displays amplitude of echo on the vertical axis and range on the horizontal axis.
It is used for manual tracking radar.



Plan Position Indicator(PPI) display unit is circular in shape and is large. This PPI radar scope is used for surveillance. It displays range and azimuth(referred as bearing information). This polar kind of radar display indicates range using concentric circles.

Different Types of displays

The **B-Scope** shows a picture like a Cartesian diagram. It provides a 2-D “top down” representation of space. The horizontal axis (abscissa) typically represents the measurement of the azimuth and the vertical axis represents the measurement of the range. Signals appear as bright spots.
Utilization for Air-bone radar(radar is placed to side of an aircraft)

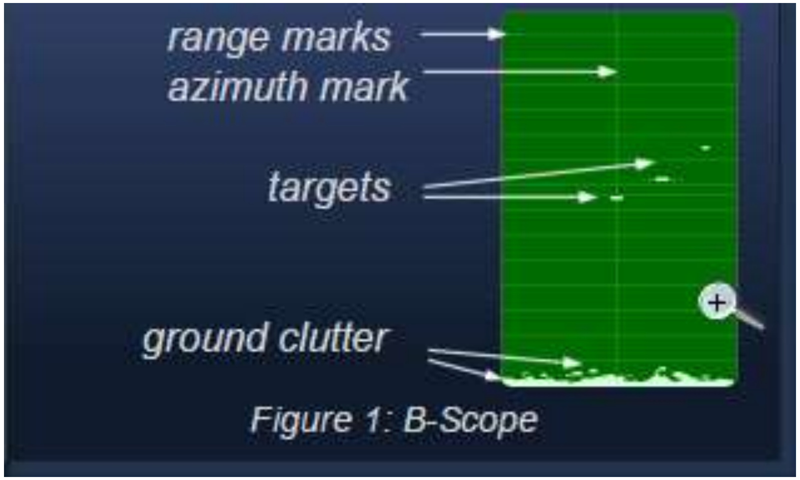
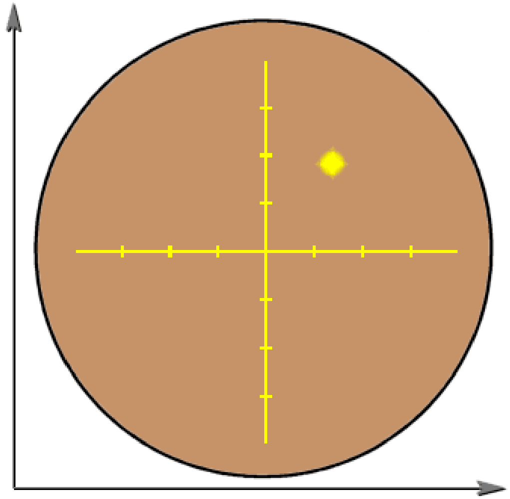


Figure 1: B-Scope

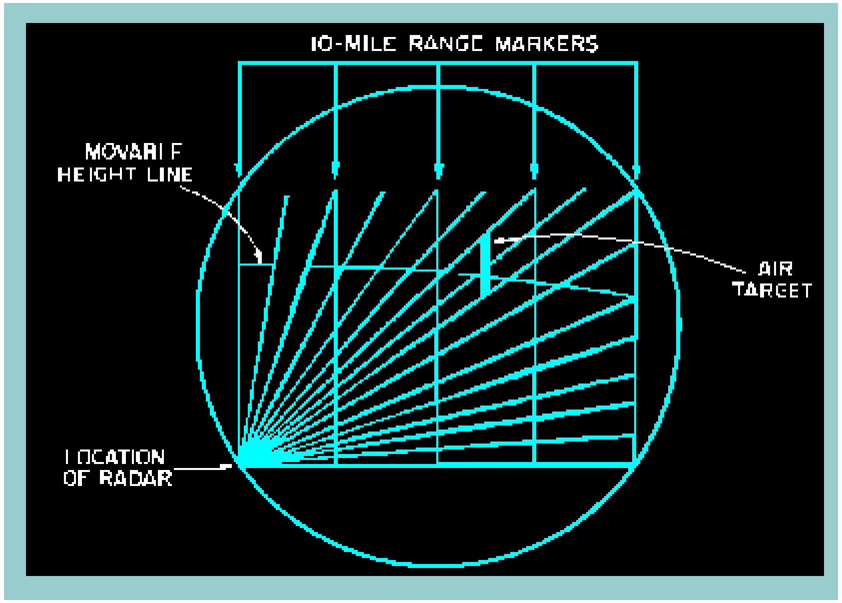
C-scope displays azimuth angle of target on horizontal axis and elevation angle on vertical axis



Different Types of displays

Range Height Indicator (RHI) displays altitude on vertical axis and range of target on horizontal axis.

- Height –vertical axis
- Range –horizontal axis
- Utilization for meteorological radar



Radar & Navigation

- Text Book and Reference book :

1. Introduction to Radar System M.I. Skolnik , McGraHill
2. Radar Systems and Radio Aids to Navigation, A K Sen & Bhattacharya, Khanna publishers
3. NPTEL Video Lecture
4. Internet