Radar System

UNIT – 1

Topics to be covered :-

→ Introduction
→ Maximum Unambiguous Range
→ Simple Radar Range Equation
→ Radar Block Diagram and operation
→ Radar Frequencies and Applications
→ prediction of Range performance
→ Minimum Detectable Signal
→ Receiver Noise
→ Modified Radar Range Equation
→ Signal to Noise Ratio
→ probability of detection
→ probability of False Alarm
→ Integration of Radar pulses
→ Radar cross section of Targets (simple Targets – sphere, cone-sphere)
→ Creeping wave
→ Transmitter power
→ pulse repetition frequency and Range ambiguities
→ system losses
→ Illustrative problems.

→ Radar acronym is Radio Detection And Ranging.

Radar is an electromagnetic system for the detection and location of reflecting objects such as aircrafts, ships, space craft, vehicles, and the natural enviroment.

✓ It operates by radiating energy into space and detecting the echo signal reflected from an object (or) target.

✓ The reflected energy that is returned to the radar not only indicates the presence of a target, but by comparing the received echo signal with the signal that was transmitted, its location can be determined along with other target-related information.

✓ Radar can perform its function at long (or) short distances and under conditions impervious to optical and infrared sensors. It can operate in darkness, haze, fog, rain and snow. Its ability to measure distance with high accuracy and in all weather is one of its most important attributes.

→ Advantages of Radars :-

✓ Radars can see through darkness, Haze, fog, rain and snow.

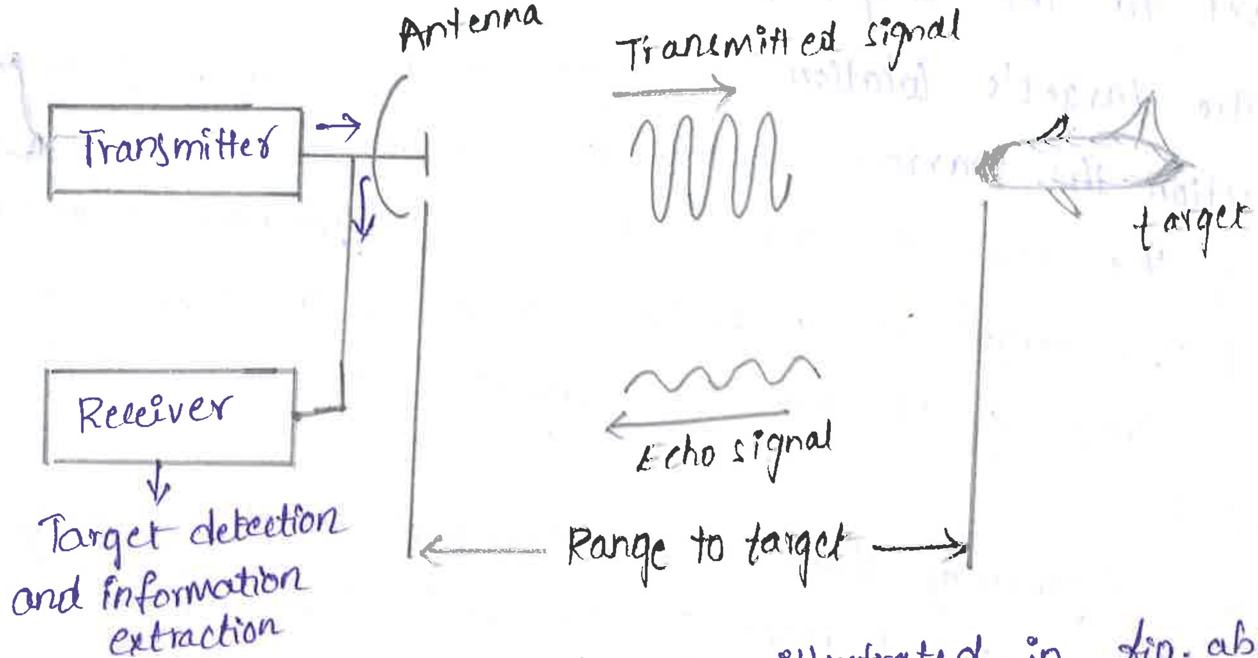
✓ They can determine the range and angle i.e the location of the target very accurately.

→ Disadvantages of Radars :-

✓ Radars cannot resolve in detail like the human eye, especially at short distances.

✓ They cannot recognize the colour of the target.

→ Basic principle of Radar :-



✓ The basic principle of radar is illustrated in fig. above. (the figure)

A transmitter (in the upper left portion of the figure) generates an electromagnetic signal (such as a short pulse of sine wave) that is radiated into space by an antenna.

✓ A portion of the transmitted energy is intercepted by the target and reradiated in many directions.

✓ The reradiation directed back towards the radar is collected by the radar antenna, which delivers it to a receiver. There it is processed to detect the presence of the target and determine its location.

✓ A single antenna is usually used on a time-shared basis for both transmitting and receiving when the radar waveform is a repetitive series of pulses.

✓ The range, or distance, to a target is found by measuring the time it takes for the radar signal to travel to the target and return back to the radar.

✓ The target's location in angle can be found from the direction the narrow-beamwidth radar antenna points when the received echo signal is of maximum amplitude.

✓ If the target is in motion, there is a shift in the frequency of the echo signal due to the doppler effect.

✓ This frequency shift is proportional to the velocity of the target due relative to the radar (also called the radial velocity).

✓ The doppler frequency shift is widely used in radar as the basis for separating desired moving targets from fixed (unwanted) "clutter" echoes reflected from the natural environment such as land, sea or rain. Radar can also provide information about the nature of the target being observed.

Measurement of Range :-

→ Range to a Target / Measurement of Range :-

The most common radar signal, or waveform, is a series of short-duration, somewhat rectangular-shaped pulses modulating a sine wave carries. This is sometimes called a pulse train.

✓ The range to a target is determined by the time T_R it takes the radar signal to travel to the target and back.

- Electromagnetic energy in free space travels with the speed of light, which is $c = 3\times10^8$ m/s.
- Thus, the time for the signal to travel to a target located at a range R, and return back to the radar is $2R/c$.

The range to a target is then

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

- The factor 2 appears in the denominator because of the two-way propagation of radar, with the range R in kilometers or nautical miles, and T_R in microseconds, the above relation becomes

$$R(km) = 0.15\, T_R\,(\mu s) \quad \text{or} \quad R(nmi) = 0.081\, T_R\,(\mu s)$$

Each microsecond of round-trip travel time corresponds to a distance of 150 meters, 164 yards, 492 feet, 0.081 nautical mile or 0.093 statute mile. It takes 12.35 µs for a radar signal to travel a nautical mile and back.

→ <u>Maximum Unambiguous Range</u> :-

The range beyond which targets appear as second-time around echoes is the maximum unambiguous range, Run and is given by

$$R_{un} = \frac{cT_p}{2} = \frac{c}{2f_p}.$$

where T_p = pulse repetition period = $1/f_p$

f_p = pulse repetition frequency (prf). hertz (or) pps.
pulse per second

Once a signal is radiated into space by a radar, sufficient time must elapse to allow all echo signals to return to the radar before the next pulse is transmitted.

✓ The rate at which pulses may be transmitted, therefore is determined by the longest range at which targets are expected.

✓ If the time b/w pulses T_p is too short, an echo signal from a long-range target might arrive after the transmission of the next pulse and be mistakenly associated with that pulse rather than the actual pulse transmitted earlier.

✓ This can result in an incorrect or ambiguous measurement of the range.

✓ Echoes that arrive after the transmission of the next pulse are called second-time-around echoes (or multiple-time-around echoes if from even earlier pulses). Such an echo would appear to be at a closer range than actual and its range measurement could be misleading if it were not known to be a second-time-around echo.

✓ So, the range beyond which targets appear as second-time-around echoes is the maximum unambiguous range R_{un}.

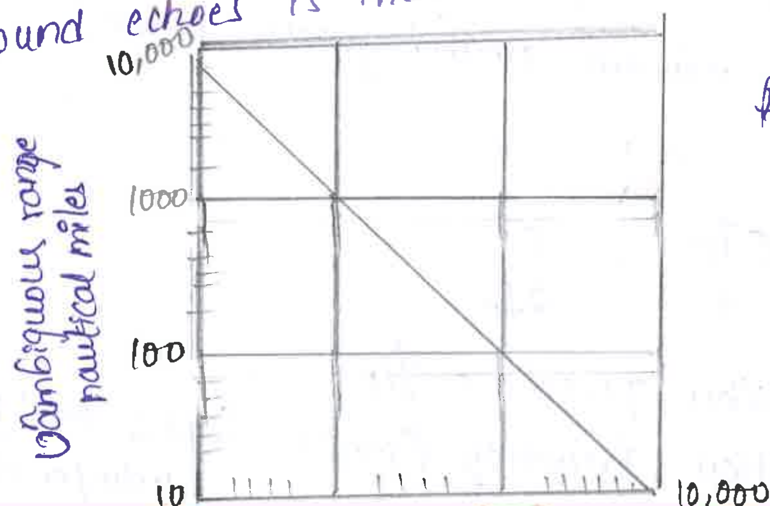


fig: The R_{unamb} as a function of prf.

→ Simple form of the Radar Equation :-

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

✓ It is useful not only for determining the maximum range at which a particular radar can detect a target, but it can serve as a means for understanding the factors affecting radar performance.

✓ The simple form of the radar range equation is derived.

✓ If the transmitted power P_t is radiated by an isotropic antenna (one that radiates uniformly in all directions), the power density at a distance R from the radar is equal to the radiated power divided by the surface area $4\pi R^2$ of an imaginary sphere of radius R,

Power density at range R from an isotropic antenna

$$= \frac{P_t}{4\pi R^2} \quad \text{--- (1)}$$

Power density is measured in units of watts per square meter.

✓ Radars, however, employ directive antennas (with narrow beamwidths) to concentrate the radiated power P_t in a particular direction.

✓ The gain of an antenna is a measure of the increased power density radiated in some direction as compared to the power density that would appear in that direction from an isotropic antenna.

- The maximum gain G of an antenna may be defined as

$$G = \frac{\text{maximum power density radiated by a directive antenna}}{\text{Power density radiated by a lossless isotropic antenna with the same power input}}$$

- The power density at the target from a directive antenna with a transmitting gain G is then

$$\text{Power density at range } R \text{ from a directive antenna} = \frac{P_t G}{4\pi R^2} \quad \text{--- (2)}$$

- The target intercepts a portion of the incident energy and reradiates it in various directions. It is only the power density reradiated in the direction of the radar (the echo signal) that is of interest.

- The radar cross section of the target determines the power density returned to the radar for a particular power density incident on the target. It is denoted by 'σ' and is often called for short, target cross section, radar cross section, or simply cross section.

- The radar cross section is defined by the following equation

$$\text{Reradiated power density back at the radar} = \frac{P_t G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \quad \text{--- (3)}$$

- The radar Cross section has units of area, but it can be misleading to associate the radar cross section directly with the target's physical size. Radar cross section is more dependent on the target's shape than on its physical size.

✓ The radar ~~cross section~~ antenna captures a portion of the echo energy incident on it.

✓ The power received by the radar is given as the product of the incident power density times the effective area A_e of the receiving antenna.

✓ The effective area is related to the physical area A by the relationship $A_e = \rho_a A$, where ρ_a = antenna aperture efficiency.

The received signal power P_r (watts) is then

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

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

subistituting $S_{min} = P_r$ in Eq (4) then

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}}\right]^{1/4} \longrightarrow (5)$$

This is the fundamental form of the radar range equation.

✓ If the same antenna is used for both transmitting and receiving, as it usually is in radar, antenna theory gives the relationship between the tranmit gain G and the receive effective area A_e as

where $\lambda \rightarrow$ wavelength.

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \rho_a A}{\lambda^2} \longrightarrow (6)$$

Eq (6) can be substituted in Eq (5), first for A_e and then for G, to give two other forms of the radar equation.

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

→ Radar Block Diagram :-

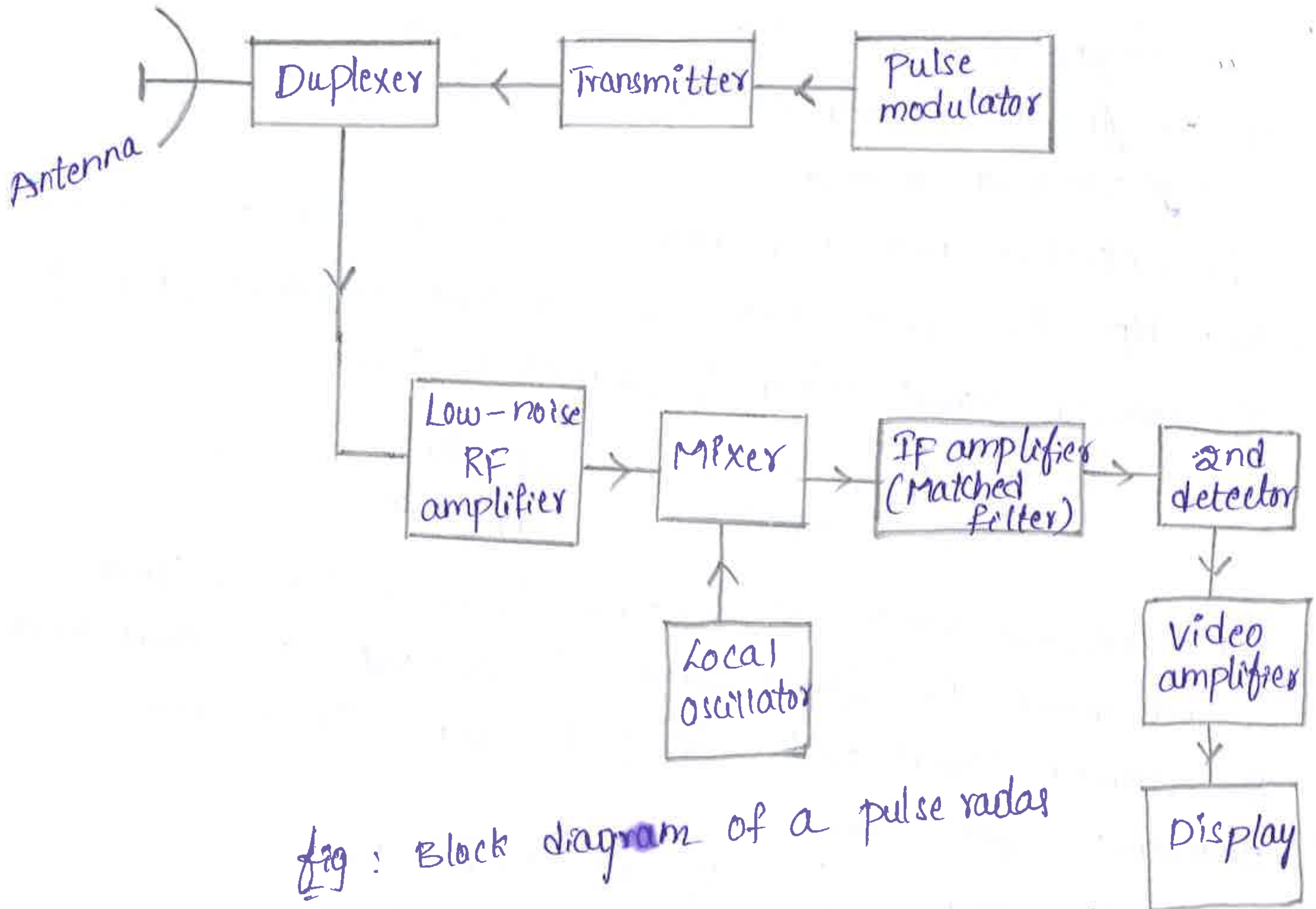


fig : Block diagram of a pulse radar

- ✓ The operation of a typical pulse radar may be described with the aid of block diagram shown in above figure.
- ✓ The 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 radars.
- ✓ A typical radar for the detection of aircraft at ranges of 100 (or) 200 nmi might employ a peak power of the order of a megawatt, an average power

of several Kilowatts, a pulse width of several micro seconds (6)
and a pulse repetition frequency of several hundred pulses per second.

The wave form generated by the transmitter travels via a transmission line to the antenna, where it is radiated into space.

A single antenna is generally used for both transmitting and receiving. The receiver must be protected from damage caused by the high power of the transmitter. This is the function of the duplexer.

The duplexer also serves to channel the returned echo signals to the receiver and not to the transmitter.

The duplexer might consists of two gas-discharge devices, one known as a TR (Transmit-receive) and the other an ATR (Anti-transmit-receive).

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

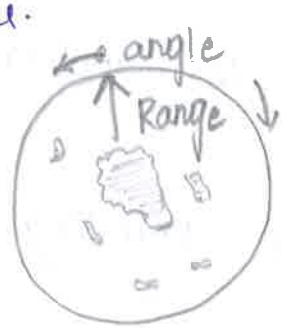
Solid-state ferrite circulators and receiver protected with gas-plasma TR devices and/or diode limiters are also employed as duplexers.

The receiver is usually of the superheterodyne type. The first stage might be a low-noise RF amplifier such as a parametric amplifier or a low-noise transistor.

- The receiver input can simply be the mixer stage, especially in military radars that must operate in a noisy environment.
- 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 vulnerability to electronic interference.
- The mixer and local oscillator (LO) convert the RF signal to an intermediate frequency (IF).
- A typical IF amplifier for an air-surveillance radar might have a center frequency of 30 (or) 60 MHz and a bandwidth of the order of one megahertz.
- The IF amplifier should be designed as a matched filter; i.e its frequency response function $H(f)$ should be maximize the peak-signal-to-mean noise power ratio at the output.
- This occurs when the magnitude of the frequency response function $|H(f)|$ is equal to the magnitude of the echo signal spectrum $|S(f)|$, and the phase spectrum of the matched filter is the negative of the phase spectrum of the echo signal.
- In a radar whose signal waveform approximates a rectangular pulse, the conventional IF filter bandpass characteristic approximates a matched filter when the product of the IF bandwidth B and the pulse width τ is of the order of unity, that is $B\tau \simeq 1$.

- After the maximizing the signal-to-noise ratio in the IF amplifier, the pulse modulation is extracted by the second detector and amplified by the video amplifier to a level where it can be properly displayed, usually on a cathode-ray-tube (CRT).
- Timing signals are also supplied to the indicator to provide the range zero.
- Angle information is obtained from the pointing direction of the antenna.
- The most common form of cathode-ray tube display is the plan position indicator or PPI, which maps in polar co-ordinates the location of the target in azimuth and range. This is an intensity-modulated display in which the amplitude of the receiver output modulated the electron-beam intensity (z-axis) as the electron beam is made to sweep outward from the center of the tube.
- The beam rotates in angle in response to antenna position. A B-scope display is similar to the PPI except that it utilizes rectangular rather than polar coordinates to display range vs angle.
- Both the B-scope and the PPI, being intensity modulated, have limited dynamic range.
- Another form of display is the A-scope shown

in fig 2(b), which plots target amplitude (y-axis) Vs range (x-axis) for some fixed direction. This is a deflection modulated display. It is more suited for tracking radar application than for surveillance radar.



(a)

(b)

fig:
(a) PPI presentation displaying range Vs angle (intensity modulation)
(b) A-scope presentation displaying amplitude Vs range (deflection modulation)

✓ A common form of radar antenna is a reflector with a parabolic shape, fed (illuminated) from a point source at its focus. The parabolic reflector focuses the energy into a narrow beam, just as does a searchlight or an automobile headlamp.

✓ The beam may be scanned in space by mechanical pointing of the antenna.

✓ Phased array antennas have also been used for radar. In a phased array, the beam is scanned by electronically varying the phase of the current across the aperture.

→ <u>Nature</u> and <u>Types of Radars</u> :-

The common types of radars are
① speed trap radars
② missile tracking radars
③ Early warning radars
④ Airport control radars.

5. Navigation radars
6. Astronomy radars
7. Ground mapping radars
8. weather forecast radars
9. Gunfire control radars
10. Remote sensing radars
11. Tracking radars
12. Search radars
13. Missile control radars.
14. MTI radars
15. Navy radars
16. Doppler radars
17. over the Horizon (OTH) radars
18. Monopulse radars
19. phased array radars
20. Instrumentation radars
21. Gun direction radars
22. Airborne weather radars

→ Radar frequencies :-

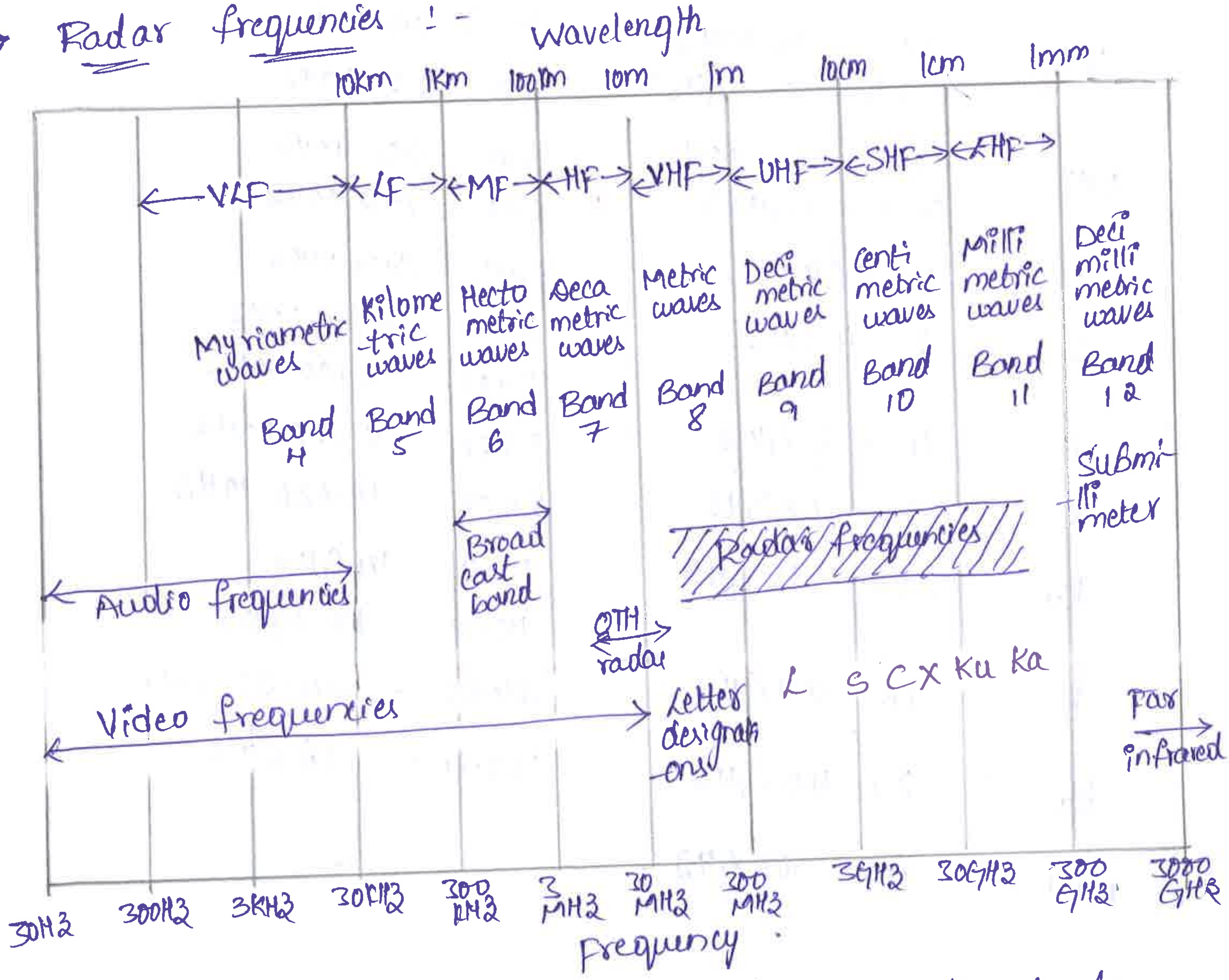


fig: Radar frequencies and the Electromagnetic spectrum.

✓ conventional radars generally operate in what is called the microwave region. operational radars in the part have been at frequencies ranging from about 100 MHz to 36 GHz which covers more than eight octaves.

IEEE standard radar-frequency letter-band nomenclature

Band designation	Nominal frequency range	specific radiolocation (radar) Bands based on ITU assignments for region 2.
HF	3 - 30 MHz (0.003 - 0.03 GHz)	
VHF	30 — 300 MHz (0.03 — 0.3 GHz)	138 — 144 MHz 216 — 225 MHz
UHF	300 — 1000 MHz (0.3 — 1 GHz)	420 — 450 MHz 890 — 942 MHz
L	1 — 2 GHz	1215 — 1400 MHz
S	2 — 4 GHz	2300 — 2500 MHz 2700 — 3700 MHz
C	4 — 8 GHz	5250 — 5925 MHz
X	8 — 12 GHz	8500 — 10,680 MHz
Ku	12 — 18 GHz	13.4 — 14 GHz 15.7 — 17.7 GHz
K	18 — 27 GHz	24.05 — 24.25 GHz
Ka	27 — 40 GHz	33.4 — 36 GHz
mm	40 — 300 GHz	

✓ conventional radars generally have been operated at frequencies extending from about 220MHz to 35 GHz, a spread of more than seven octaves. These are not necessarily the limits, since radars can be and have been operated at frequencies outside either end of this range.

✓ Sky wave HF over the - horizon (OTH) radar might be at frequencies as low as 4 or 5 MHz and groundwave HF radars as low as 2 MHz.

✓ At the other end of the spectrum millimeter radars have operated at 94 GHz. Laser radars operate at even higher frequencies.

✓ Early in the development of radar, a letter code such as S, X, L etc., was employed to designate radar frequency bands.

✓ Although its original purpose was to guard military secrecy, the designations were maintained, probably out of habit as well as the need for some convenient short nomenclature. This usage has continued and is now an accepted practice of radar engineers. Table lists the radar frequencies letter band nomenclature adopted by the IEEE.

✓ Letter—band nomenclature is not a substitute for the actual numerical frequency limits of radars. The specific numerical frequency limits should be used whenever appropriate but the letter designations of table may be used whenever a short notation is desired.

→ Applications of radar :-

Radar has been employed to detect targets on the ground, on the sea, in the air, in space, and even below ground.

✓ The major areas of radar application are briefly described below.

① Military :- Radar is an important part of air-defense systems as well as the operation of offensive missile and other weapons. In air-defense it performs the functions of surveillance and weapon control. Surveillance includes target detection, target recognition, target tracking and designation to a weapon system.

✓ weapon-control radars track targets, direct the weapon to an intercept, and assess the effectiveness of the engagement. (called battle damage assessment).

✓ A missile system might employ radar methods for guidance and fuzing of the weapon.

✓ High-resolution imaging radars, such as synthetic aperture radar, have been used for reconnaissance purposes and for detecting fixed and moving targets on the battlefield.

✓ Many of the civilian applications of radar are also used by the military. The military has been the major user of radar and the major means by which new radar technology has been developed.

(2) Remote sensing :- All radars are remote sensors ; however this term is used to imply the sensing of the environment Four important examples of radar remote sensing are

(1) weather observation, which is a regular part of TV weather reporting as well as input to national weather prediction.

(2) planetary observation, such as the mapping of venus Beneath its visually opaque clouds.

(3) short -range below - ground probing and

(4) mapping of sea ice to route shipping in an efficient manner.

Air Traffic control (ATC) :- Radars have been employed around the world to safely control air traffic in the vicinity of airports (Air surveillance Radar, or SAR) and enroute from one airport to author (Air route surveillance radar or ARSR) as well as ground vehicle traffic and taxing aircraft on the ground (Airport surface detection equipment or ASDE). The ASR also maps regions of rain so that aircraft can be directed around them. There are also radars specifically dedicated to observing weather in the vicinity of airports, which are called Terminal Doppler weather radar, or TDWR. The air Traffic control Radar Beacon system (ATCRBS and Mode-S) widely used for the control of air Traffic, although not a radar, originated from military IFF (Identification friend or Foe) and uses radar like Technology.

Law Enforcement and Highway safety :- The radar speed meter, familiar to many, is used by police for enforcing speed limits (A variation is used in sports to measure the speed of a pitched baseball). Radar has been considered for making vehicles safer by warning of pending collision, actuating the air bag, or warning of obstructions or people behind a vehicle or in the side blind zone. It is also employed for the detection of instruders.

Aircraft safety and Navigation :- The airborne weather-avoidance radar outlines regions of precipitation and dangerous wind shear to allow the pilot to avoid hazardous conditions. Low-flying military aircraft rely on terrain avoidance and terrain following radars to avoid colliding with obstructions or high terrain. Military aircraft employes ground-mapping radars to image a scene. The radio altimeter is also a radar used to indicate the height of an aircraft above the terrain and as a part of self-contained guidance systems overland.

Ship safety :- Radar is found on ships and boats for collision avoidance and to observe navigations buoys, especially when the visibility is poor. Similar shore-based radars are used for surveillance of harbors and river traffic

Space :- space vehicles have used radar for rendezvous and docking, and for landing on the moon. As mentioned they have been employed for planetary exploration, especially the planet earth.

✓ Large ground-based radars are used for the detection and tracking of satellites and other space objects.

✓ The field of radar astronomy using Earth based system helped in understanding the nature of meteors, establishing an accurate measurement of the astronomical unit and observing the moon and nearby planets before adequate space vehicles were available to explore them at close distances.

Other :- Radar has also found application in industry for the noncontact measurement of speed and distance. It has been used for oil and gas exploration. Entomologists and ornithologists have applied radar to study the movement of inspects and birds, which cannot be easily achieved by other means.

Radar Applications

1. Air Traffic control
2. weather forecasting
3. Identification of friend or foe.
4. Range, velocity, height of a flying target can be measured.
5. Missile guidance.
6. Air surveillance
7. Jamming radars (transmission of confusing signals at enemy radars).
8. Police radars for the control of traffic speed.

→ Civilian Applications

1. Navigational aid on ground and sea (navigation is not affected by poor visibility or darkness).
2. Radar altimeters for determining the height of plane above ground.
3. Radar Blind lander for aiding aircraft to land under poor visibility, at night, under adverse weather conditions etc.
4. Airborne radar for satellite surveillance
5. police radars for directing and detecting speeding vehicles.
6. Radars for determining the speed of moving targets, automobile shells, guided missiles etc,

Military applications:

1. Detection and ranging of enemy targets even at night.
2. Aiming guns at aircraft and ships.
3. Bombing ships, aircraft or cities even during overcast or at night.
4. Early warning regarding approaching aircraft (or) ships.
5. Directing guided missiles.
6. Searching for submarines, land masses and buoys.

→ prediction of Range performance :-

The simple form of the radar equation expressed the maximum radar range R_{max} in terms of radar and target parameters.

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

where, P_t = Transmitted power, watts
G = Antenna gain
A_e = Antenna effective aperture, m^2
σ = Radar cross section, m^2
S_{min} = minimum detectable signal, watt.

✓ except for the targets radar cross section of the parameters of this simple form of the radar equation are under the control of the radar designer.

✓ The radar equation states that if long ranges are desired. The transmitted power must be large, the radiated energy must be concentrated into a narrow beam (large transmitting gain), the echo energy should be received by a large antenna aperture (also synonyms with large gain) and the receiver should be sensitive to weak signals.

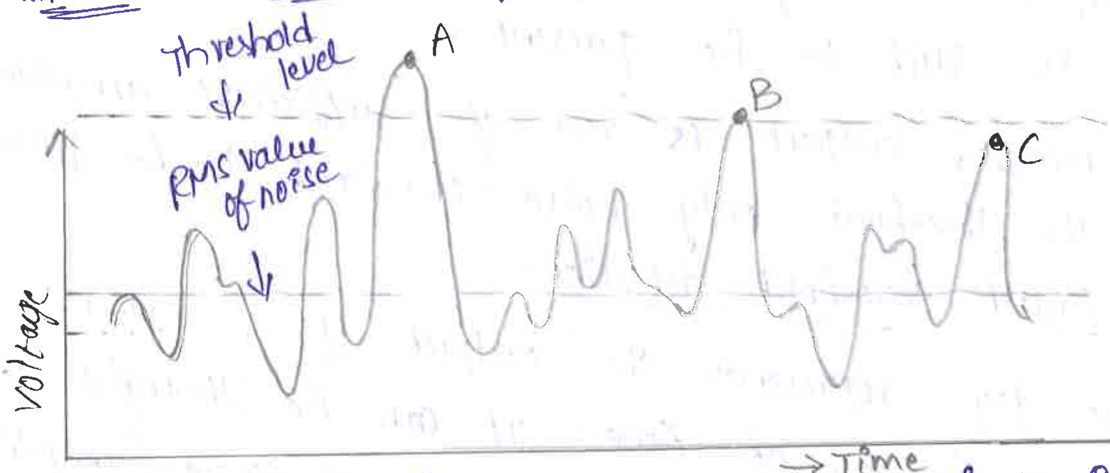
✓ In practice, however the simple radar equation does not accurately predict the range performance of actual radars.

✓ The predicted values of radar range are usually optimistic. In some cases the actual range might be only half of that predicted.

- The failure of the simple form of radar equation is due to ① the statistical nature of the minimum detectable signal (usually determined by receiver noise) ② fluctuations and uncertainties in the target's radar cross section. ③ The losses experienced throughout a radar system and ④ propagation effects caused by the earth's surface and atmosphere.
- The statistical nature of receiver noise and the target cross section requires that the maximum radar range be described probabilistically rather than by a single number. Thus the specification of range must include the probability that the radar will detect a specified target at a particular range, and with a specified probability of making a false detection when no target echo is present.
- The range of a radar, therefore will be a function of the probability of detection P_d and the probability of false alarm P_{fa}.
- The prediction of radar range can not be performed with arbitarily high accuracy because of uncertainities in many of the parameters that determine the range. Even if the factors affecting the range could be predicted with high accuracy the statistical nature of radar detection and the variability of the target's radar cross section and other effets make it difficult to accurately verify the predicted range.

Inspite of it not being as precise as one might wish, the radar equation is an important tool for ① assessing the performance of a radar ② deteemining the system trade-offs that must be considered when designing a new radar system and ③ aiding in generating the technical requirements for a new radar procurement.

→ <u>Minimum</u> <u>Detectable</u> <u>signal</u> (S_{min}) :-



<u>fig</u> : Typical envelope of the radar receiver output as a function of time. A, B and C represent signal plus noise. A and B would be valid detections but C is a missed detection.

The ability of a radar receiver to detect a weak echo signal is limited by the ever-present noise energy that occupies the same portion of the frequency spectrum as does the signal.

<u>Definition</u> :- The weakest signal the receiver can detect is called the <u>minimum detectable signal</u>. (or)
The weakest signal that can just be detected by a radar receiver is the <u>minimum detectable signal</u>. In the radar equation, it was denoted as S_{min}.

- The specification of the minimum detectable signal is sometimes difficult because of its statistical nature and because the criterion for deciding whether a target is present or not may not be too well defined.

- Detection of a radar signal is based on establishing a threshold at the output of the receiver. If the receiver output is large enough to exceed the threshold, a target is said to be present.

- If the receiver output is not of sufficient amplitude to cross the threshold, only noise is said to be present. This is called Threshold detection.

- The above fig. represents the output of a radar receiver as a function of time. It can be thought of as the video output displayed on an A-scope (amplitude Vs time or range).

- The envelope has a fluctuating appearance caused by the random nature of noise.

- If a large signal is present such as at A in fig. It is greater than the surrounding noise peaks and can be recognized on the basis of its amplitude. Thus if the threshold level were set sufficiently high, the envelope would not generally exceed the threshold if noise alone were present, but would exceed it if a strong signal were present.

- If the signal were small, however it would be more difficult to recognize its presence. The threshold level must be low if weak signals are to be detected, but it cannot be so low that noise peaks across the threshold and give a false indication of the presence of targets.
- The voltage envelope of above fig. is assumed to be from a matched-filter receiver.
- A matched filter is one that maximizes the output signal-to-noise ratio. Almost all radars employ a matched filter or a close approximation.
- Let us return to the receiver output as represented in fig. A threshold level is established, as shown by the dashed line. A target is said to be detected if the envelope crosses the threshold. If the signal is large such as at A, it is not difficult to decide that a target is present.
- But consider the two signals at B and C, representing target echoes of equal amplitude.
- The noise voltage accompanying the signal at B is large enough so that the combinational of signal plus noise exceeds the threshold. At C the noise is not as large and the resultant signal plus noise does not cross the threshold.
- Thus the presence of noise will sometimes enhance the detection of weak signals but it may also cause the

loss of a signal which would otherwise be detected.

weak signals such as c would not be lost, if the threshold level were lower. But too low a threshold increases the likelihood that noise alone will rise above the threshold and be taken for a real signal. such an occurrence is called a false alarm.

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 weak signal that is present (probability of a miss) or by (2) falsely indicating the presence of a target signal when none exists (false alarm).

The signal to noise ratio is a better measure of a radar's detection performance than is the minimum detectable signal.

→ Receiver noise and SNR :-

The noise affects the maximum radar range as it determines the minimum received power that the radar can detect. Also, the radar range can be increased by decreasing minimum detectable power which depend on the sensitivity of the receivers and hence on its noise figure.

✓ Since noise is the chief factor limiting receiver sensitivity, it is necessary to obtain some means of describing it quantitatively.

✓ Noise is unwanted EM 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.

✓ If the radar were to operate in a perfectly noise-free environment so that no external sources of noise accompained 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 of electrons in the ohmic portions of the receiver input stages. This is called Thermal noise (or) Jhonson noise. and is directly proportional to the temperature of the ohmic portions of the circuit and the receiver bandwidth.

✓ The available thermal noise power generated at the input of a receiver of Bandwidth B_n (hertz) at temperature T (degree Kelvin) is

$$\boxed{\text{Available thermal noise power} = K T B_n} \quad \text{——} (1)$$

where K = Boltzmann's constant $= 1.38 \times 10^{-23}$ J/deg.

✓ The Bandwidth of a superhetrodyne receiver (and almost all radar receivers are of this type) is taken to be that of the IF amplifier (or matched filter).

In eq (1) the bandwidth B_n is called the noise bandwidth, defined as

$$B_n = \frac{\int_{-\infty}^{\infty} |H(f)|^2 \, df}{|H(f_0)|^2} \qquad (2)$$

where $H(f)$ = frequency-response characteristic of IF amplifier (filter) and f_0 = frequency of the maximum response (usually occurs at the midband).

✓ Noise bandwidth is not the same as the more familiar half-power, or 3-dB bandwidth

✓ Eqn (2) states that the noise bandwidth is the bandwidth of the equivalent rectangular filter whose noise-power output is the same as the filter with frequency response function $H(f)$.

✓ The half-power bandwidth is defined by the separation between the points of the frequency response function $H(f)$ where the responce is reduced to 0.707 (3 dB in power) from its maximum value. Although it is not the same as the noise bandwidth, the half-power bandwidth is a reasonable approximation for many practical radar receivers. Thus the half-power bandwidth B is usually used to approximate the noise bandwidth B_n.

✓ The noise power in practical receivers is greater than that from thermal noise alone.

The measure of the noise out of a real receiver to that from the ideal receiver with only thermal noise is called the noise figure and is defined as

The noise figure of a receiver

$$F_n = \frac{\text{Noise out of practical receiver}}{\text{Noise out of ideal receiver at standard temperature } T_0}$$

$$\boxed{F_n = \frac{N_{out}}{K T_0 B_n G_a}} \quad \text{(or)} \quad F_n = \frac{N_o}{K T_0 B_n G_a} \longrightarrow (3).$$

where, N_o = noise out of the receiver

G_a = Available gain.

The standard temperature T_0 is taken to be 290K, according to the IEEE definition. This is close to room temperature (62°F).

With this definition, $K T_0 = 4 \times 10^{-21}$ W/Hz.

But G_a can be defined as,

$$G_a = \frac{\text{signal out } (S_{out})}{\text{signal in } (S_{in})} \quad \text{or} \quad G_a = \frac{S_o}{S_i}$$

The input noise, N_i in an ideal receiver is

$$\boxed{N_i = K T_0 B_n}$$

The definition of noise figure given by eqn (3) therefore can be written as

$$F_n = \frac{N_o}{K T_0 B_n G_a} = \frac{N_o}{N_i \cdot \frac{S_o}{S_i}} = \frac{S_i N_o}{N_i S_o} = \frac{S_i/N_i}{S_o/N_o}$$

$$F_n = \frac{S_i/N_i}{S_o/N_o} = \frac{\text{I/p signal to noise ratio}}{\text{O/p signal to noise ratio}} \quad \text{---} (4)$$

- This equation shows that the noise figure may be interpreted as a measure of the degradation of the signal-to-noise ratio as the signal passes through the receiver.
- Rearranging eqn (4), the input signal may be expressed as

$$S_i = \frac{F_n N_i S_o}{N_o} = \frac{K T_o B_n F_n S_o}{N_o} \quad \text{---} (5)$$

- If the minimum detectable signal S_{min} is that value of S_i which corresponds to the minimum detectable signal-to-noise ratio at the output of IF, $(S_o/N_o)_{min}$ then,

$$S_{min} = K T_o B_n F_n \left(\frac{S_o}{N_o}\right)_{min} \quad \text{---} (6)$$

substituting eq (6) into radar equation

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

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

omitting the subscripts on S and N results in

$$R^4_{max} = \frac{P_t G A_e \sigma}{(4\pi)^2 K T_o B_n F_n (S/N)_{min}}$$

The radar range can be predicted fairly accurated using above equation. still there are other factors which affect the radar range and for very accurate ~~accord~~ calculations these factors have also to be consider. These factors include:

1, system losses
2, Receiver non-linearities
3, Antenna imperfections
4, Anomalous propagation
5, Interference by nearby noise sources
6, Operators Error.

Note: $F_n = \dfrac{S_i/N_i}{S_o/N_o}$ (or) $\dfrac{P_{si}/P_{ni}}{P_{so}/P_{no}} = \dfrac{P_{si}}{P_{so}} \cdot \dfrac{P_{no}}{P_{ni}}$

where, P_{si} = input signal power
P_{so} = output signal power
P_{ni} = input noise power
P_{no} = output noise power

$$F_n = \frac{P_{si}}{G_r P_{si}} \cdot \frac{G_r (P_{ni} + P_{nri})}{P_{ni}}$$

G_r = Power gain of receiver
P_{nri} = Noise power generated at the receiver i/p.

$$\boxed{F_n = \frac{P_{ni} + P_{nri}}{P_{ni}} = 1 + \frac{P_{nri}}{P_{ni}}}$$

$$\therefore \boxed{\frac{P_{nri}}{P_{ni}} = F_n - 1}$$

$P_{nri} = P_{ni}(F-1)$

$P_{nri} = T_0 B (F-1)$

where kT_0B = Noise i/p power of receiver.

T_0 = Ambient temperature = 290 K.

B = Bandwidth of the receiver, Hz.

✓ If the target is moving and it moves significant between successive scans, a system called moving-target indicator is used. Therefore minimum detectable signal S_{min} should be atleast equal to

$$S_{min} = K T_0 B (F_n - 1)$$

Substituting S_{min} in radar range equation.

$$\boxed{R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 K T_0 B (F_n - 1)}\right]^{1/4}}$$

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

$$A_e = \eta A$$

$$A_e = 0.65 \left(\frac{\pi D^2}{4}\right)$$

$$G = \frac{4\pi}{\lambda^2} \cdot 0.65 \left(\frac{\pi D^2}{4}\right) = 0.65 \left(\frac{\pi D}{\lambda}\right)^2$$

Also $T_0 = 290°K$ and $K = 1.38 \times 10^{-23}$ J/°K.

✓ The expression for maximum radar range is

$$\boxed{R_{max} = 48 \left[\frac{P_t D^4 \sigma}{B \lambda^2 (F - 1)}\right]^{1/4}}$$

P_t = Peak transmitted power, watts

D = Diameter at antenna, meters

σ = effective cross sectional area of target, m^2

B = Bandwidth of receiver, Hz λ = wavelength, metre

F (or) F_n = noise figure ratio

→ Integration of Radar pulses :-

- The number of pulses returned after hitting target is given by

$$\boxed{n = \frac{\theta_B f_p}{\theta_s} = \frac{\theta_B f_p}{6\,\omega_r}}$$

where, θ_B = antenna beamwidth (degrees)

f_p = pulse repetition frequency (Hz).

θ_s = Antenna scanning rate (deg per second).

ω_r = revolutions per minute (rpm) for a 360° rotating antenna.

- The number of pulses received n is usually called hits per scan or pulses per scan. It is the number of pulses within the one way beamwidth θ_B.
- The process of summing all the radar echo pulses received from a target is called integration of pulses.
- Many techniques are used for integration of pulses. A common integration method in early radars was to take advantage of the persistance of the phosphor of the CRT display combined with the integrating properties of the eye and brain of the radar operator (or human being).
- The integration of pulses that is performed in the radar receiver before the second detector (In the IF) is called Predetection integration (or) coherent Integration.

- Predetection integration is theoritically lossless, but it requires the phase of the echo signal pulses to be known and preserved in order to combine the sinewave pulses in phase without loss.
- The integration after the second detector is known as post detection integration (or) Noncoherent integration.
- If n pulses of same SNR are integrated by a lossless prediction integrator, then the integrated SNR will be exactly n times that of a single pulse. Therefore, in this case, we can replace the single-pulse-signal to noise ratio $(S/N)_1$ in the radar eqn with $(S/N)_n$.

$$(S/N)_n = \frac{(S/N)_1}{n}$$

where $(S/N)_n$ is the required signal-to-noise ratio per pulse when there are n pulses integration prediction without loss.

- If the same n pulses were integrated by an ideal post detection device, the resultant SNR would be less than n times that of a single pulse.
- This loss in integration efficiency is caused by the nonlinear action of the second detector, which converts some of the signal energy to noise energy in the rectification process.
- An integration efficiency for post detection integration may be defined as

$$\boxed{E_i(n) = \frac{(S/N)_1}{n(S/N)_n}}$$

The improvement in signal-to-noise ratio when n pulses are integrated is called the integratio improvement factor $\boxed{I_i(n) = nE_i(n)}$. It can also be thought of as the ~~equipment~~ equivalent number of pulse integrated n_{eq} is $\boxed{n_{eq} = nE_i(n)}$. For post detection integration n_{eq} less than n; for ideal predetection integration $n_{eq} = n$

Thus for the same integrated signal-to-noise ratio, post detection integration requires more pulses than predetection, assuming the signal-to-noise ratio per pulse in the two cases is the same

The radar equation when n pulses are integrated is

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 K T_0 B_n F_n (S/N)_n}\right]^{1/4}$$

where $(S/N)_n$ is signal-to-noise ratio of each pulse.

→ Probability of false alarm :-

A false alarm is an erroneous radar target detection decision caused by noise or other interfering signals exceeding the detection threshold. In general it is an indication of the presence of a radar target when there is no valid aim.

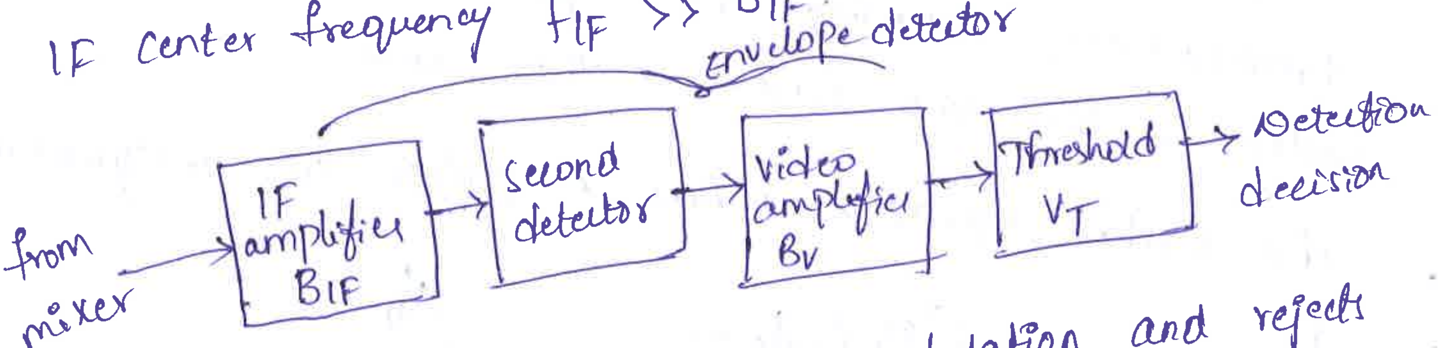
The minimum signal-to-noise ratio required to achieve specified probability of false alarm.

The below fig shows a portion of a superheterodyne radar receiver with IF amplifier of bandwidth B_{IF}, second detector, video amplifier with Bandwidth B_V and a threshold where the detection decision is made.

The IF filter, second detector, and video filter ~~from~~ form an envelope detector in that the output of the video amplifier is the envelope or modulation.

Video Bandwidth $B_V \geq B_{IF}/2$.

IF center frequency $f_{IF} \gg B_{IF}$



The envelope detector passes the modulation and rejects the carrier.

The bandwidth of the radar receiver is the bandwidth of the IF amplifier. The envelope of the IF amplifier output is the signal applied to the threshold detector. When the receiver output crosses the threshold, a signal is declared to be present.

The receiver noise at the input to the IF ~~am~~ filter is described by the gaussian probability density function.

$$P(v) = \frac{1}{\sqrt{2\pi \psi_0}} \exp\left(-\frac{v^2}{2\psi_0}\right)$$

where $p(v)\, dv$ is the probability of finding the noise voltage v between the values of v and v+dv and ψ_0 is the mean square value of the noise voltage, The probability density function of the envelope R is given by

$$P(R) = \frac{R}{\psi_0} \exp\left(-\frac{R^2}{2\psi_0}\right)$$

✓ The probability that the envelope of the noise voltage will exceed the voltage threshold V_T is the integral of $P(R)$.

$$V_T < R < \alpha = \int_{V_T}^{\alpha} \frac{R}{\psi_0} \exp\left(-\frac{R^2}{2\psi_0}\right) dR.$$

$$= \exp\left(-\frac{V_T^2}{2\psi_0}\right)$$

✓ This is the probability of a false alarm, since it represents the probability that noise will cross the threshold and be called a target when only noise is present. The probability of a false alarm, denoted as P_{fa} is

$$P_{fa} = \exp\left(-\frac{V_T^2}{2\psi_0}\right)$$

✓ The average time between crossings of the decision threshold when noise alone is present is called false alarm time T_{fa} is given by.

$$T_{fa} = \lim_{N \to \alpha} \frac{1}{N} \sum_{K=1}^{N} T_K.$$

where T_K is the time between crossings of the threshold V_T by the noise envelope.

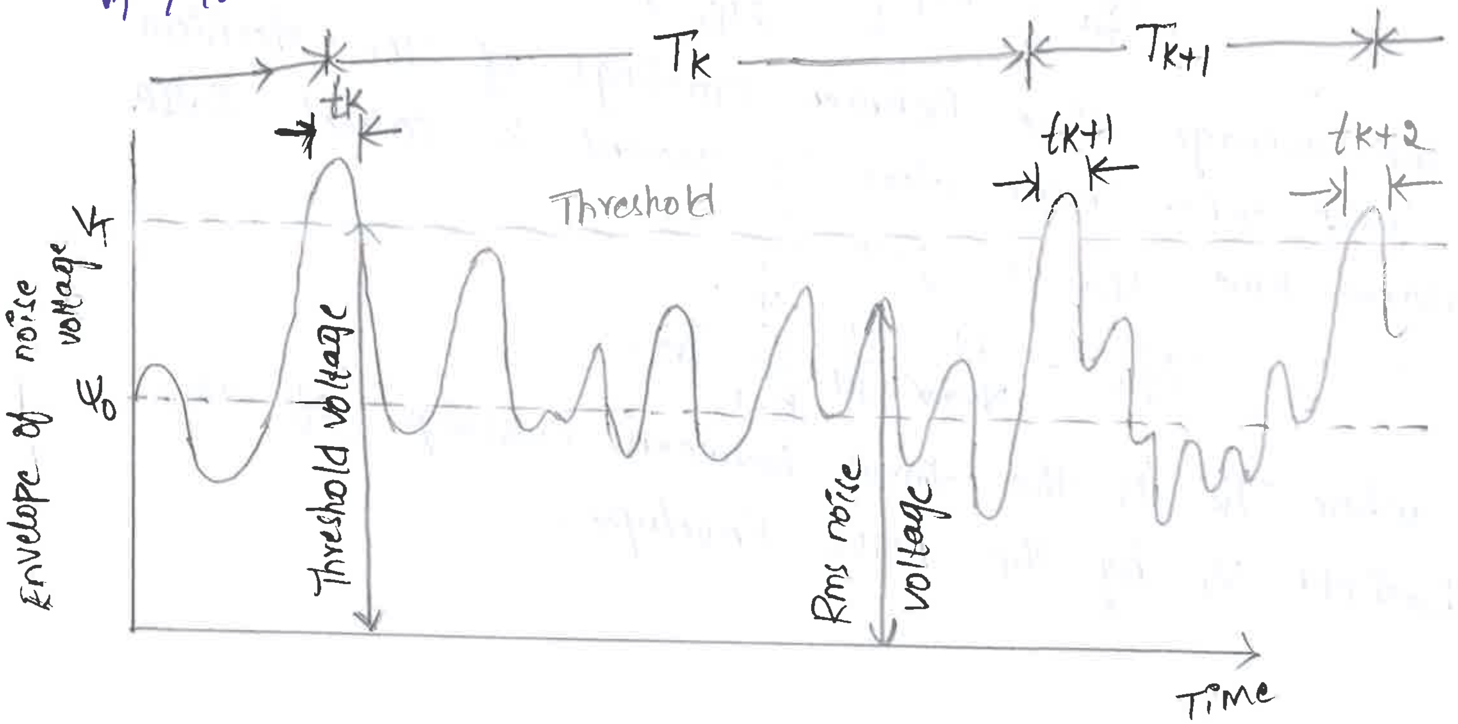
✓ The false-alarm probability can be expressed in terms of false alarm time by noting that the false alarm probability P_{fa} is the ratio of the time, the envelope is actually above the threshold to the total time it could have been above the threshold.

$$P_{fa} = \frac{1}{T_{fa} B}.$$

✓ The average duration of threshold crossing by noise $(t_K)_{av}$ is approximately the reciprocal of the IF bandwidth B. The average of T_K is the false-alarm time T_{fa}.

$$T_{fa} = \frac{1}{B} \exp\left(\frac{V_T^2}{2\psi_0}\right)$$

for ex: The bandwidth of the IF amplifier were 1MHz and the average time between false alarms were specified to be 15 min, the probability of false alarm is 1.11×10^{-9}. The threshold voltage is 6.42 time, the power ratio V_T^2/ψ_0 is 16.2 dB.



- False alarms are more likely to occur from Clutter echoes (ground, sea, ~~[illegible]~~, weather, birds and insects) that enter the radar and are large enough to cross the threshold. In the specification of the radar's false alarm time, however, Clutter is almost never included
- The crossing of the threshold by noise is called false alarm, it is not necessarily a false target report.

→ **Probability of Detection:-**

To find the detection consider an echo signal represented as a sinewave of amplitude A along with guassian noise at the input of the envelope detection.

- The probability density function of the envelope R at the video output is given by

$$P_s(R) = \frac{R}{\psi_0}\exp\left(-\frac{R^2+A^2}{2\psi_0}\right) I_0\left(\frac{RA}{\psi_0}\right).$$

where $I_0(z)$ is the modified Besel function of zero order and argument z for large z, an expression for $I_0(z)$ is

$$I_0(z) = \frac{e^2}{\sqrt{2\pi z}}\left(1+\frac{1}{8z}+----\right)$$

A = 0

- The probability of detecting the signal is the probability of that the envelope R will exceed the threshold V_T. The probability of detection is

$$P_d = \int_{V_T}^{\alpha} P_s(R)\, dR.$$

The probability density function $P_s(R)$ is substituted in the above Eqn. then

$$P_d = \int_{V_T}^{\infty} \frac{R}{\psi_0} \exp\left(-\frac{R^2 + A^2}{2\psi_0}\right) I_0\left(\frac{RA}{\psi_0}\right)$$

$$P_d = \frac{1}{\psi_0} \exp\left(-\frac{V^2}{2\psi_0}\right)$$

$$P_d = \frac{1}{\psi_0} \exp\left(\frac{-V^2}{2\psi_0}\right)$$

for the ideal Radar system the probability of detection will be defined as the ratio of signal powee to noise power.

$$P_d = \left[2 \frac{\text{signal power}}{\text{noise power}}\right]^{1/2}$$

$$P_d = \left(\frac{2S}{N}\right)^{1/2}.$$

→ Radar cross-section of Targets :-

✓ The amount of power reflected by the target depends on many factors including the size, shape, material (metal, plastic, wood or water) and edges (sharp or round) of the target, as well as the frequency of the incident radar signal and the angle between the radar system and the target.

✓ The radar cross section of a target is the (fictional) area intercepting that amount of power which, when scattered equally in all directions produces an echo at the radar equal to that from the target (or)

(22)

✓ The radar cross section σ is said to be a (fictional) area that intercepts a part of the power ~~include~~ incident at the target which, if scattered uniformly in all directions, produces an echo power at the radar equal to that produced at the radar by the real target. Real targets of course, do not scatter the incident energy uniformly in all directions.

✓ The radar cross section σ is the property of a scattering object, or target, that is include in the radar equation to represent the magnitude of the echo signal returned to the radar by the target.

✓ Radar cross section depends on the characteristic dimensions of the object compared to the radar wavelength. When the wavelength is large compared to the object's dimensions, scattering is said to in the Rayleigh region.

✓ The radar cross section in the Rayleigh region is proportional to the fourth power of the frequency and is determined more by the volume of the scatter than by its sphere. At radar frequencies, the echo from rain is usually described by Rayleigh scattering.

✓ At the other extreme, where the wavelength is small compared to the object's dimensions is called the optical region.

✓ In between the Rayleigh and the optical regions is the resonance region (or) Mie region where the radar wavelength is comparable to the object's dimensions.

For many objects the radar cross section is larger in the resonance region than in the other two regions. These three distinct scattering regions are illustrated by the scattering from the sphere.

Definition of RCS :-

A target's radar cross section is defined as the ratio of its effective isotropically scattered power to the incident power density.

$$RCS = \sigma = \frac{\text{Power reflected (or scattered) toward source / unit solide angle}}{\text{Incident power density} / 4\pi}$$

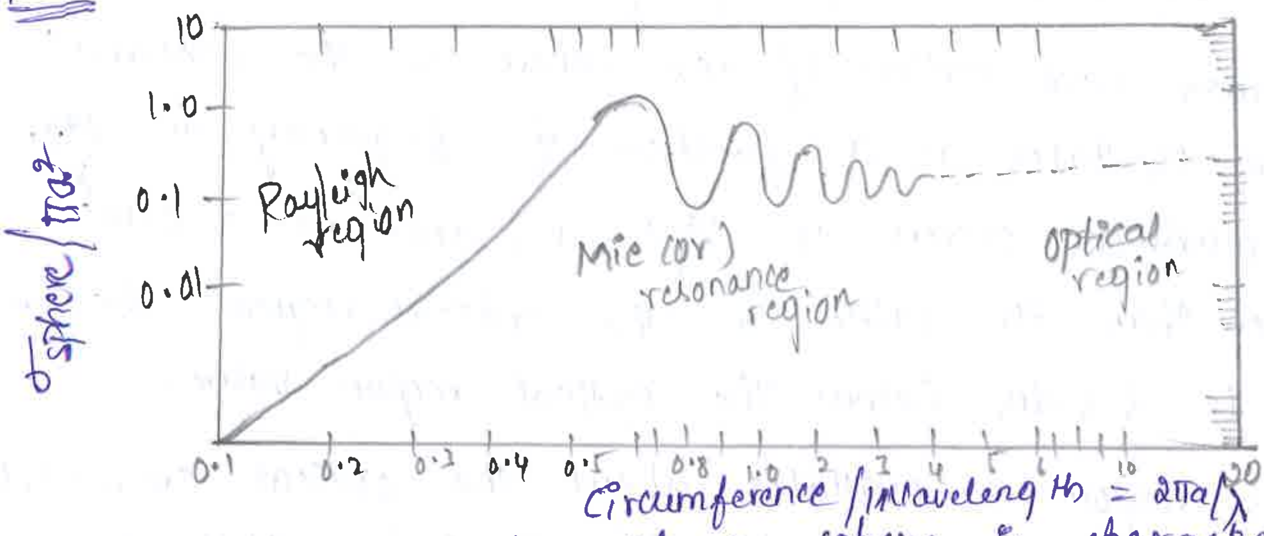
$$\sigma = \lim_{R \to \infty} 4\pi R^2 \left| \frac{E_r}{E_i} \right|^2$$

where R = distance between Radar and target or range to the target.

E_r = reflected field strength at radar or the electric field strength of the echo signal back at the radar.

E_i = strength of incident field at target (or) electric field strength incident on the target.

RCS of simple targets :- RCS is a strong function of azimuth and elevation in spherical coordinate system. Also RCS is strong function of frequency and polarization. RCS of simple targets are calculated by using electromagnetic theory. some simple targets are sphere, cylinder, flat, rod, and cone etc., Sphere :-



The radar cross section of a sphere is characterized into three regions :

1. Rayleigh region
2. optical region
3. Mie or resonance region.

1. Rayleigh region : $\left[\frac{2\pi a}{\lambda} << 1 \text{ or } a << \lambda\right]$.

In the Rayleigh region where $\frac{2\pi a}{\lambda} << 1$, the radar cross section is proportional to f^4 i.e

$$\boxed{RCS \propto f^4} \quad \text{(or)} \quad RCS \propto \frac{1}{\lambda^4}.$$

where f = frequency = $\frac{c}{\lambda}$ and c is velocity of propogation.

2. optical region : $\left(\frac{2\pi a}{\lambda} >> 1 \text{ or } a >> \lambda\right)$.

The region where $\frac{2\pi a}{\lambda} >> 1$ or $a >> \lambda$ is the optical region. In this region, the radar cross section approaches the physical area of the sphere as the frequency is increased.

$$RCS = \pi a^2$$

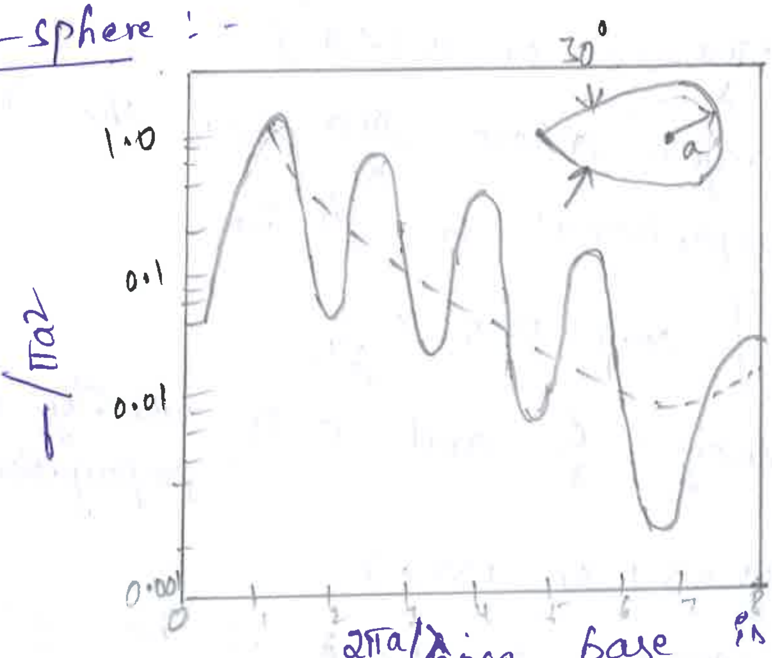
where a = radius of the sphere.

3. Mie (or) Resonance region $\left(\frac{2\pi a}{\lambda} = 1 \text{ or } a \simeq \lambda\right)$

A radar cross section of the sphere in the resonance region oscillates as a function of frequency or $\frac{2\pi a}{\lambda}$. Its maximum occurs at $\frac{2\pi a}{\lambda} = 1$, and is 5-6 dB greater than its value in the optical region. The first null is 5.5 dB below the optical region value.

✓ In this region σ oscillates about the optical cross-section (πa^2) with maximum and minimum values that close together with increasing a/λ. It means that RCS fluctuates above and below πa^2 depending on the exact wavelength.

② cone-sphere :-



✓ This is a cone whose base is capped with a sphere.

✓ The above fig is a plot of the calculated nose-on radar cross section of a cone sphere with 30° cone angle as a function of $2\pi a/\lambda$ where 'a' is the radius of the sphere.

- The cross-section of cone sphere is a very low and is considered to be of ballistic missile. A large cross-section occurs when a radar views the cone perpendicular to its surface.

→ Transmitter Power :-

The power P_t in the simple radar equation was not actual specified but is usually peak power of the pulse.

- The average power P_{av} of a radar is also of interest since it is a more important measure of radar performance than the peak power.
- Average transmitter power is defined over the duration of total transmission period.
- If the transmitter waveform is a train of rectangular pulses of width τ and constant pulse repetition period T_p.

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

where f_p = Pulse repetition frequency.

- The average power is related to the peak power

By $P_{av} = \frac{P_t \tau}{T_p} = P_t \tau f_p$.

- The radar duty cycle (sometimes called duty factor) can be expressed as P_{av}/P_t or τ/T_p or τf_p.
- The duty cycle of radar is ratio of pulse width to pulse repetition time.

$$\text{Duty cycle} = \frac{\text{Pulse width}}{\text{Pulse repetition time}} = \frac{\tau}{T_p} = \tau f_p.$$

- The duty cycle depends on
  1. Type of waveform
  2. pulse compression
  3. pulse width
  4. Radar range
  5. Type of transmitter.
- pulse radars might typically have duty cycle of from 0.001 to 0.5, more or less.
- A CW radar has a duty cycle of unity.
- The radar range equation in terms of average power can be expressed as

$$R_{max} = \left[\frac{P_{av}\, G\, A_e\, \sigma\, n\, E_i(n)}{(4\pi)^2 K T_0 F_n (B\tau)(S/N)_1 f_p} \right]^{1/4} \longleftarrow (1)$$

from the definition of duty cycle given above, the energy per pulse, $E_p = P_t \tau = P_{av}/f_p$. substituting this into equation (1) gives the radar equation interms of energy,

$$R_{max} = \left[\frac{E_p\, G\, A_e\, \sigma\, n\, E_i(n)}{(4\pi)^2 K T_0 F_n (B\tau)(S/N)_1} \right]^{1/4} = \left[\frac{E_T\, G\, A_e\, \sigma\, E_i(n)}{(4\pi)^2 K T_0 F_n (B\tau)(S/N)_1} \right]^{1/4}$$

where P_{av} = Average transmitted power
G = Antenna gain
A_e = Antenna aperture
σ = Radar cross-section of targets (m^2)
$E_i(n)$ = Integration efficiency
K = Boltzmann's constant = 1.38×10^{-23} J/deg

F_n = Receiver noise figure

B = Receiver bandwidth (Hz)

τ = Pulse width (sec)

$(S/N)_1$ = SNR required as if direction were based on only single pulse.

f_p = pulse repetition frequency (Hz).

E_p = energy per pulse.

$E_T = nE_p$ = Total energy of n pulses.

→ Pulse repetition frequency (PRF) and Range ambiguities :-

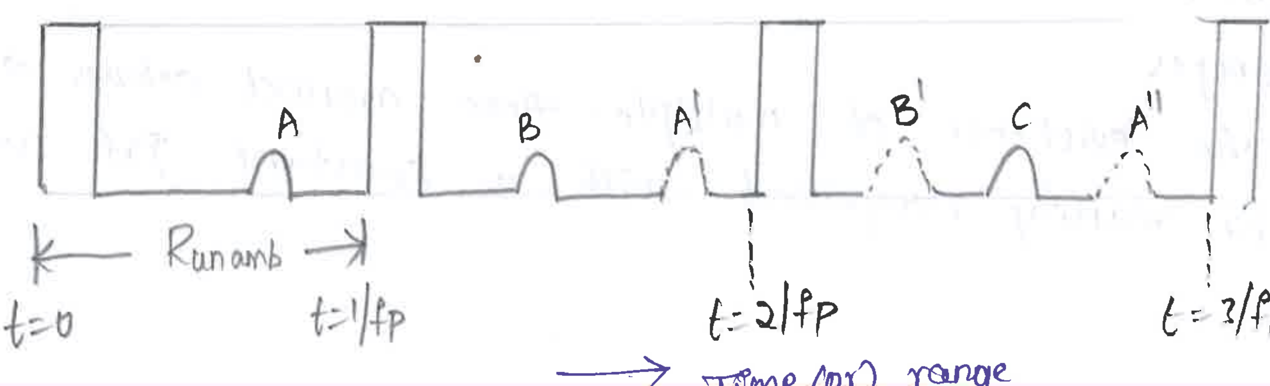
The pulse repetition frequency (PRF) is often determined by the maximum unambiguous range beyond which targets are not expected.

✓ The PRF corresponding to maximum unambiguous range is given by.

$$\boxed{PRF = f_p = \frac{c}{2 R_{un}}}$$

where c is velocity of propagation.

✓ If the PRF is made too high, the likelihood of obtaining target echoes from the wrong pulse transmission is increased.



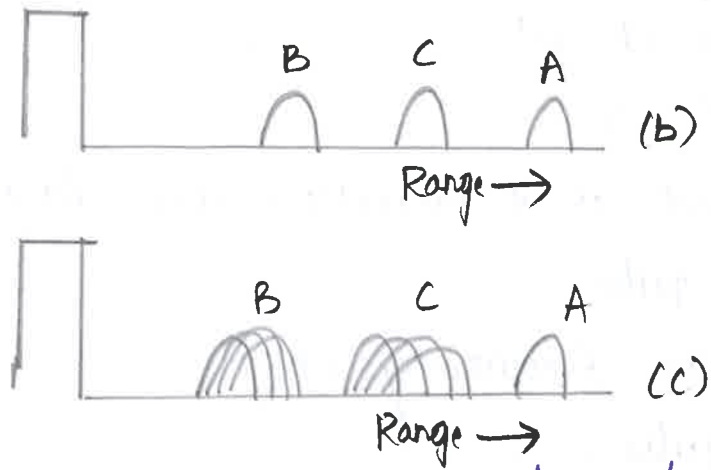


fig :- Multiple-time around radar echoes that gives rise to ambiguities in range (a) Three targets A, B and C, where A is within the unambiguous range R_{un}, B is a second-time around echo, and C is a multiple-time around echo (b) The appearance of the three echoes on the A-scope (c) The appearance ~~of the~~ three echoes on the A-scope with a changing prf.

- Echo signals that arrive at a time later than pulse-repetition period are called <u>second-time-around echoes</u>. They are also called multiple-time-around echoes, particularly when they arrive from ranges greater than $2R_{un}$. These echoes may cause error or confusion.
- Another problem with multiple-time-around echoes is that clutter echoes from ranges greater than R_{un} can mask unambiguous target echoes at the shorter ranges.
- The existence of multiple-time-around echoes cannot be readily recognized with a constant prf waveform.

✓ consider three-targets labelled A, B and C in fig(a)

✓ Target A is within the unambiguous range interval R_{un}.

✓ Target B is at a distance greater than R_{un} but less than $2R_{un}$.

✓ while target C is greater than $2R_{un}$ but less than $3R_{un}$.

✓ Target B is a second-time-around echo; target C is a multiple-time-around echo is shown in fig(a).

✓ fig(b) shows radar display (such as A-scope or PPI) when these three pulse repetition intervals are superimposed

✓ The ambiguous echoes B and C looks very similar to unambiguous range echo of A.

✓ out of these three echoes only the range of A is correct but it cannot be determined from this display that the other two are not at their apparent range.

✓ Ambiguous range echoes can be recognized by changing the prf of the radar.

✓ when the prf is changed, the unambiguous echo ($< R_{un}$) remains at its true range.

✓ Ambiguous range echoes appear at different ~~chan~~ apparent ranges for each prf. fig (c) shows these three echoes on A-scope

✓ If the first pulse repetition frequency (prf) f_1 has an unambiguous range R_{un1} and if the apparent range measured with prf f_1 is denoted R_1 then the true range is one of the following

$$R_{true} = R_1 \quad \text{or} \quad R_{true} = R_1 + R_{un1}$$

$$(\text{or}) \quad R_{true} = R_1 + 2R_{un1}$$

Anyone of these might be the true range.

✓ To find which is correct, the prf is changed to f_2, with an unambiguous range R_{un2} and if the apparent measured range is R_2. then true range is one of the following.

$$R_{true} = R_2 \quad (\text{or}) \quad R_{true} = R_2 + R_{un2}$$

$$(\text{or}) \quad R_{true} = R_2 + 2R_{un2}.$$

✓ The correct range is same for two prfs. Thus two (or) more prfs can be used to correct range ambiguity with increased accuracy and avoiding fake values.

→ System losses :-

The losses within the radar system is called system losses. It is denoted by L_s, L_s is inserted in the denominator of the radar eqn. It is the reciprocal of efficiency.

✓ Losses within the system itself are from many sources. some major source of losses are mentioned below.

1. Microwave plumbing losses.
2. Antenna losses — a. Beam shape loss
   b. scanning loss
   c. Radome
   d. Phase array losses.

3. Signal processing losses.
   a. Non-matched filter
   b. Constant false - alarm rate receiver
   c. Automatic Integrator
   d. Threshold level
   e. Limiting loss
   f. Stradling loss
   g. Sampling loss.
4. Losses in Doppler - processing Radar.
5. Collapsing losses
6. Operator loss
7. Equipment / field degradation
8. Propagation effects
9. Radar system losses.

① Plumbing losses:-

✓ At all times a finite loss is associated with the transmitter and transmission lines used to join the antenna.

✓ At lower radar frequencies the loss associated with the transmission line is extremely small, unless its length is very lengthy.

✓ The attenuation caused by plumbing losses is taken into consideration at higher radar frequencies

✓ A part from this additional losses arise due to each bend or connection in the line and the antenna rotary joint.

✓ The attenuation caused by the connector losses varies depending upon the quality of connection.

✓ If the connection is poor, then large attenuation is caused

✓ The loss to be inserted in the radar equation is 2 times the one-way loss, because same transmission line is employed for transmission and reception.

✓ when the signal passes through the duplexer, it suffers attenuation. Generally, the greater the isolation required from the duplexer on transmission, the larger will be the insertion loss.

✓ The insertion loss is more, when the isolation required from the duplexer on transmission is more.

✓ The insertion loss means, the loss which is introduced when the component (duplexer) is inserted into the transmission line is called insertion loss.

✓ For a typical duplexer it might be of the order of 1dB in S-band (3000 MHz) radar, the plumbing losses will be

① waveguide transmission line — 1.0 dB
② loss due to poor connection — 0.5 dB
③ Rotary joint loss — 0.4 dB
④ Duplexer loss — 1.5 dB
⑤ Total plumbing loss — 3.4 dB

Antenna losses: Antenna losses include radiation loss, beam shape loss, scanning loss, radome and phase array losses.

① Beam-shape loss:-

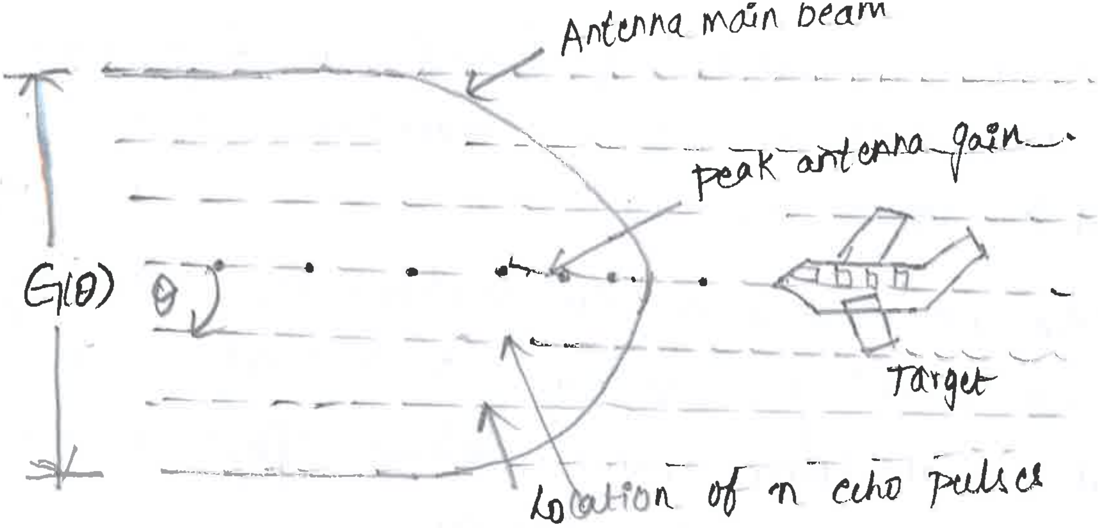


fig: Antenna beam shape loss.

- In radar eq^n antenna gain is assumed as constant at its maximum value but in practice as a search antenna scans across a target, it does not offer its peak gain to all echo pulses.
- when the system integrates several echo pulses maximum antenna gain G occurs when the peak of antenna beam is in the direction of target. The above fig shows beam shape loss.
- The beam shape loss is computed by

$$\text{Beam shape loss} = \frac{n}{1 + 2\sum_{k=1}^{(n-1)/2} \exp\left[-5.55k^2/(n_B - 1)^2\right]}$$

where, n is total number of pulses integrated.
n_B is number of pulses received within one-way half-power beamwidth (θ_B).
half-power beamwidth.
θ_B is half-power beamwidth.

(2) scanning loss :- when radar antenna scans rapidly compared to round trip time of echo signal, the gain of the antenna receiving of echoes. This variation of antenna gain result in scanning loss.

- The scanning loss is most significant in long range scanning radars, such as space surveillance and ballistic missile defense radars.

③ <u>Radome</u>: The loss introduced by radome is decided by its type and operating frequency. A commonly used ground based metal space frame radome offers a loss of 1.2 dB for two way transmission.

- Air supported radomes have lower loss and radomes with dielectric space frame has higher loss.

④ <u>Phased Array losses</u>:-

- Additional transmission losses are observed in phased array radars because of distribution network used for connecting receiver and transmitter to multiple elements of array.
- These losses reduce antenna power gain. sometimes phased array losses are accounted in system losses.

<u>Signal processing losses</u>:-

For detecting targets in clutters and in extraction information from radar echo signals very precise and lossless signal processing is necessary. Various losses accounted during signal processing are mentioned.

	Process/Components	Loss
1.	Non matched filter	0.5 to 1.0 dB
2.	Constant false alarm (rate CFAR)	> 2.0 dB
3.	Automatic integrator	1.5 to 2.0 dB
4.	Limiting loss	1 dB
5.	Straddling loss	1.0 to 2.0 dB
6.	Sampling loss	2.0 dB

Collapsing loss :-

When additional noise samples are integrated with signal plus noise pulses, this added noise causes degradation called collapsing loss.

The collapsing loss is given by L_C

$$\boxed{L_C(m,n) = \frac{L_i(m+n)}{L_i(n)}}$$

where, $L_i(m+n)$ — integration loss for $m+n$ pulses
$L_i(n)$ — integration loss for n pulses
n — signal to noise pulses
m — noise pulses.

Operator loss :-

- Most modern high-performance radars provide the detection decision automatically without intervention of a human operator.
- When distracted, overloaded or not properly trained, the resulting loss in operator performance will decrease. The system performance is called operator loss.
- Processed information is presented directly to an operator or to a computer for some other action. Then the operator efficiency factor is given by

$$\boxed{P_0 = 0.7\,(P_d)^2}$$

where P_d = single-scan probability of detection.

Propagation effects :- The propagation effects of radar wave has significant impact on losses. Major effects of propagation on radar performance are under mentioned.

1. Reflections from earth's surface
2. Refraction
3. Propagation in atmospheric ducts
4. Attenuation in clear atmosphere.

The propagation effects are not computed under system loss but under propagation factor.

Problems

① Calculate the maximum range of radar which operates at a frequency of 10 GHz, peak pulse power of 600 KW. If the antenna effective area is $5 m^2$ and the area of target is $20 m^2$, minimum receivable power is 10^{-13} W.

Sol Given

$P_t = 600 KW = 600 \times 10^3 W$.

$\sigma = 20 m^2$ $\quad A_e = 5 m^2$ $\quad f = 10 GHz$ $\quad \lambda = \frac{c}{f} = \frac{3 \times 10^8}{10 \times 10^9} = 0.03 m$

$S_{min} = 10^{-13} W$.

$$G_t \text{ (or) } G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi}{(0.03)^2} \cdot 5 = 69.813 \times 10^3$$

Max. range of radar is

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

$$R_{max} = \left[\frac{(600 \times 10^3)(69.813 \times 10^3) \times 5 \times 20}{(4\pi)^2 \times 10^{-13}}\right]^{1/4}$$

$$= 717.639 \times 10^3$$

$$R_{max} = 717 \text{ Km}.$$

The received power by the antenna is given by

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

$$= \frac{200\times10^3 \times 11.3\times10^{-3} \times 9 \times 20}{(4\pi)^2 \times (5.556\times10^5)^4} = \underline{27.034 \times 10^{-15} W}$$

(4) Find the maximum range of a radar, the transmitted power is 250 KW, cross-sectional area of the target is 12.5 sqm, minimum power received is 10^{-13} W, receiver antenna gain is 2000 and operating wavelength = 16 cm.

Sol Given $P_t = 250$ KW

$\sigma = 12.5$ sqm $= 12.5 m^2$

$S_{min} = 10^{-13}$ W $\quad G_r = 2000 \quad \lambda = 16 cm = 16\times10^{-2} m = 0.16 m$

The maximum radar range is given by.

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

Here same antenna is used for transmitting and receiving purpose.

$\therefore G_t = G_r = G = 2000$

$$R_{max} = \left[\frac{(250\times10^3)\times(2000)^2\times(0.16)^2\times12.5}{(4\pi)^3\times(10^{-13})}\right]^{1/4}$$

$$\underline{R_{max} = 200.39 \text{ Km}}$$

(30)

② An S-band radar transmitting at 3 GHz radiates 200 kW. Determine the signal power density at ranges 100 nautical miles if the effective area of the radar antenna is $9m^2$

Sol Given $f = 3GHz = 3\times10^9 Hz$

$P_t = 200kW = 200\times10^3 W$

$R = 100\ nmi \qquad 1nmi = 1852\ m$

$R = 100nmi = 100\times1852 = 1.852\times10^5 m$

$A_e = 9m^2$

The power density by directive antenna is given by

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

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

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{3\times10^9} = 0.1m$$

$$G = \frac{4\pi}{(0.1)^2}\times9 = 11.3\times10^3$$

$$\therefore P = \frac{200\times10^3\times11.3\times10^3}{4\pi\times(1.852\times10^5)^2}$$

$P = 5.248\ mW/m^2$

③ A radar operating at 3GHz radiating power of 200 kW. Calculate the power of the reflected signal at the radar with a $20m^2$ target at 300 nmi. Take $A_e = 9m^2$

Sol Given $f = 3GHz = 3\times10^9 Hz$

$P_t = 200kW = 200\times10^3 W$

$\sigma = 20m^2$ = cross section of target

$R = 300\ nmi = 300\times1852\ m = 5.556\times10^5 m$

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{3\times10^9} = 0.1m$$

$$G = \frac{4\pi}{\lambda^2}A_e = \frac{4\pi}{(0.1)^2}\times9 = 11.3\times10^3$$

(5) A marine radar operating at 10 GHz has a maximum range of 50 km with an antenna gain of 4000. If the transmitter has a power of 250 kw and minimum detectable signal of 10^{-11} w. Determine the cross-section of the target the radar can sight.

Sol

$f = 10\ GHz$

$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03m$

G_t (or) $G = 4000$

$R_{max} = 50\ km$

$P_t = 250\ kw$.

S_{min} or $P_{min} = 10^{-11}\ W$

The maximum range of radar is given by

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

$$R^4_{max} = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}} \Rightarrow \sigma = \frac{R^4_{max} (4\pi)^3 S_{min}}{P_t G^2 \lambda^2}$$

$$\sigma = \frac{(50\times10^3)^4 (4\pi)^3 \times 10^{-11}}{(250\times10^3)(4000)^2 (0.03)^2}$$

$$\sigma = 34.45\ m^2$$

(6) A radar operating at 1.5 GHz uses a peak pulse power of 2.5 MW, and have a range of 100 nmi for objects whose radar cross-section is $1m^2$. If the maximum receivable power of the receiver is 2×10^{-13} w. what is the smallest diameter the antenna reflector could have, assuming it to be a full paraboloid with $\eta = 0.65$.

Sol $f = 1.5\ GHz$ $\lambda = \frac{c}{f} = \frac{3\times10^8}{1.5\times10^9} = 0.2m$.

$P_t = 2.5 MW$

$R_{max} = 100 \text{ nmi} = 100 \times 1852 m = 1.852 \times 10^5 m = 185.2 \times 10^3 m$

$\sigma = 1 m^2$

$S_{min} = 2 \times 10^{-13} W.$

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

G_t (or) $G = \frac{4\pi}{\lambda^2} A_e$

Putting this value in above Eqn.

$$R^4_{max} = \left[\frac{P_t \left(\frac{4\pi}{\lambda^2}\right) \cdot A_e \cdot A_e \sigma}{(4\pi)^2 S_{min}}\right]$$

$$R^4_{max} = \frac{P_t A_e^2 \cdot \sigma}{4\pi \lambda^2 S_{min}} \Rightarrow A_e^2 = \frac{R^4_{max} \cdot 4\pi \lambda^2 S_{min}}{P_t \cdot \sigma}$$

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

$$A_e = \frac{(185.2 \times 10^3)^4 \times 4\pi \times (0.2)^2 \times 2 \times 10^{-13}}{2.5 \times 10^6 \times 1}$$

$A_e = 6.877 m^2$

$A_e = \eta A$ and $\eta = 0.65$

$$A = \frac{A_e}{\eta} = \frac{6.877}{0.65} \Rightarrow A = 10.58 m^2$$

Diameter of antenna $A = \frac{\pi D^2}{4}$

$$10.58 = \frac{\pi D^2}{4}$$

$$D^2 = \frac{10.58 \times 4}{\pi}$$

$$D = \left(\frac{10.58 \times 4}{\pi}\right)^{1/2} \quad \boxed{D = 3.67 m}$$

(32)

(7) calculate the max. range of a radar system which operates at 3cm with peak pulse power of 600KW if its antenna is $5m^2$, maximum detectable signal is 10^{-13} W and the radar cross-sectional area of the target is $20m^2$.

Sol $\lambda = 3cm = 3\times10^{-2}$ m.

$P_t = 600KW$ $\quad S_{min} = 10^{-13}$ W. $\quad A_e = 5m^2$

$\sigma = 20m^2$ $\quad R_{max} = ?$

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

$$= \frac{600\times10^3 \times (5)^2 \times 20}{4\pi \times (3\times10^{-2})^2 \times 10^{-13}} = 717.657 \text{ Km}.$$

1nmi = 1852 m = 1.852 KM.

$$R_{max} = \frac{717.657}{1.852} = 387 \text{ nmi}$$

(8) A 10 GHz radar has the following characteristics, Peak transmitted power = 250 KW, Power gain of antenna = 2500, minimum detectable peak signal power by receiver = 10^{-14} W, cross-sectional area of the radar antenna is $10m^2$. If the radar were to be used to detect a target of $2m^2$ equivalent cross-section, find the max. range possible.

Sol $P_t = 250$ KW, $G = 2500$, $S_{min} = 10^{-14}$ W, $A_e = 10m^2$

$\sigma = 2m^2$, $f = 10$ GHz.

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03 \text{ m}$$

$$R_{max} = \left[\frac{P_t\, G \cdot A_e\, \sigma}{(4\pi)^2 S_{min}}\right]^{1/4} = \left[\frac{250\times10^3 \times 2500 \times 10 \times 2}{(4\pi)^2 \times 10^{-14}}\right]^{1/4}$$

$R_{max} = 298.28$ Km

(9) A pulsed radar operating at 10 GHz has an antenna with a gain of 28 dB and a transmitting power of 2 kW. If it is desired to detect a target with a cross-section of 12 sq.m and the minimum detectable signal is $S_{min} = -90$ dBm. What is the maximum range of radar?

Sol

$f = 10$ GHz

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03\,m$$

$G = 28$ dB

$$G(dB) = 10\log_{10} G$$

$$\log_{10} G = \frac{28}{10} = 2.8$$

$$G = 10^{2.8} = 630.95$$

$P_t = 2$ kW, $\sigma = 12$ sq.m, $S_{min} = -90$ dBm

$$dBm = 10\log\left(\frac{S_{min}}{1mw}\right)$$

$$-90 = 10\log\left(\frac{S_{min}}{1mw}\right)$$

$$\log_{10}\left(\frac{S_{min}}{1mw}\right) = -9$$

$$\frac{S_{min}}{1mw} = 10^{-9}$$

$$S_{min} = 10^{-9}\,mW$$

$$= 10^{-9}\cdot10^{-3}\,W$$

$$S_{min} = 10^{-12}\,W$$

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

$$= \left[\frac{2\times10^3 \times (630.95)^2 (0.03)^2 \times 12}{(4\pi)^3 \times 10^{-12}}\right]^{1/4}$$

$$R_{max} = 1619\,m = 1.619\,Km$$

(10) With the 3 MHz bandwidth of the radar receiver, calculate the highest range resolution realizable with the radar?

Sol Given that

Bandwidth of the receiver = 3 MHz.

Highest range resolution, $\Delta R = ?$

Pulse duration of radar waveform is given by

$$T = \frac{1}{B} = \frac{1}{3\times10^6} = 0.333\,\mu s$$

The highest range resolution which can be realized with the radar is given by

$$\Delta R = \frac{cT}{2} = \frac{3\times10^8 \times 0.333\times10^{-6}}{2} = 50\,m.$$

(53)

(11) A square law detector integrates 10 signal plus noise pulse along with 30 noise pulses. If integration loss for signal plus noise pulses is 3.5dB. and integration loss due to noise pulses is 1.7dB. Calculate collapsing loss of the radar antenna.

Sol Given

Signal plus noise pulses $(m) = 10$

Noise pulses $(n) = 30$

Integration loss $L_i(m+n) = 3.5\,dB$

Integration loss due to noise pulses $= 1.7\,dB = L_i(n)$

Collapsing loss is given by

$$L_c(m+n) = \frac{L_i(m+n)}{L_i(n)}$$

$$= \frac{3.5}{1.7} = 1.8\,dB$$

$$\boxed{L_c(m+n) = 1.8\,dB}$$