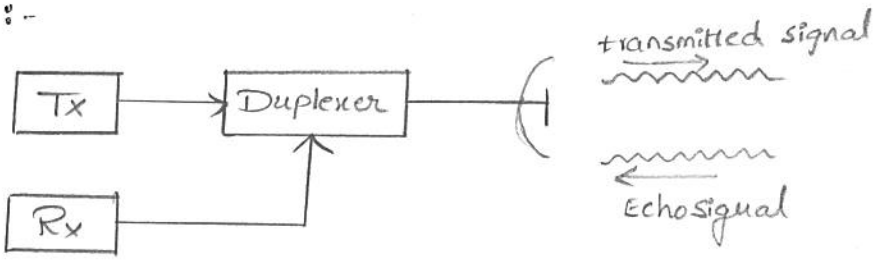
1. RADAR

Radar is electromagnetic system for detection and location of objects. RADAR is a contraction of the words Radio detection and ranging.

Simple Radar :-



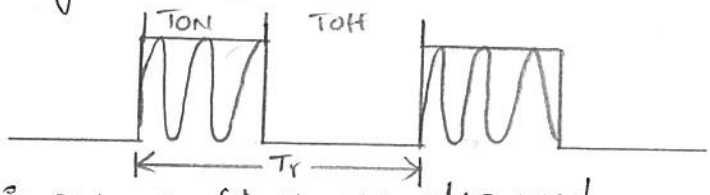
The distance of target is determined by measuring the time taken by the radar signal to travel to the target and reflected back. Science electromagnetic wave travels with velocity of light. The range is given by

$$R = \frac{C\Delta t}{2} = \frac{3\times10^{8}\times10^{-6}}{2} = 150\,m$$

(Δt) in terms of micro seconds

1 Nautical miles = 1NM = 1852m

Radar signal is pulse modulated sine wave (general)



→ continuous waveforms are also used.

Maximum unambiguous range :-

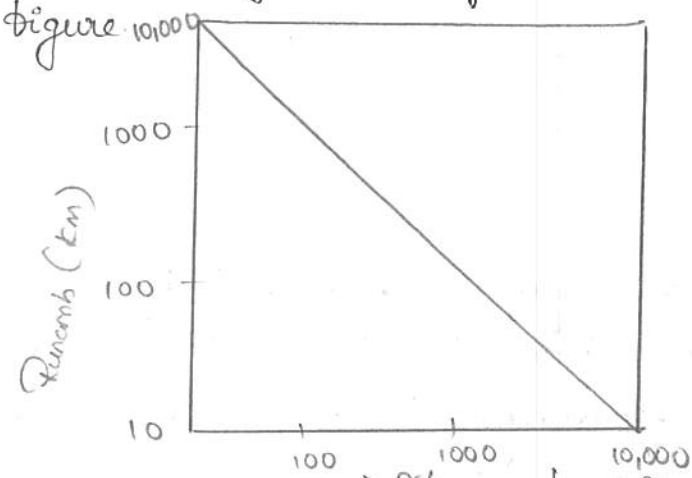
When transmitted pulse in emitted by the radar a sufficient one should be allowed so that echo signal is received and detected before next pulse transmission. Therefore the rate of pulses i.e., prf is determined by the longest range at which targets are expected.

The echosignals from certain targets may be received after the transmission of the next pulse are called second time around echos. The range beyond which targets appears as second time around echos is called max unambiguous range and is given by

$$R_{unamb} = \frac{c}{2f_r}$$

where f_r = pulse repetition frequence

Plot t_{max} unambiguous range as a function of prf is shown in figure



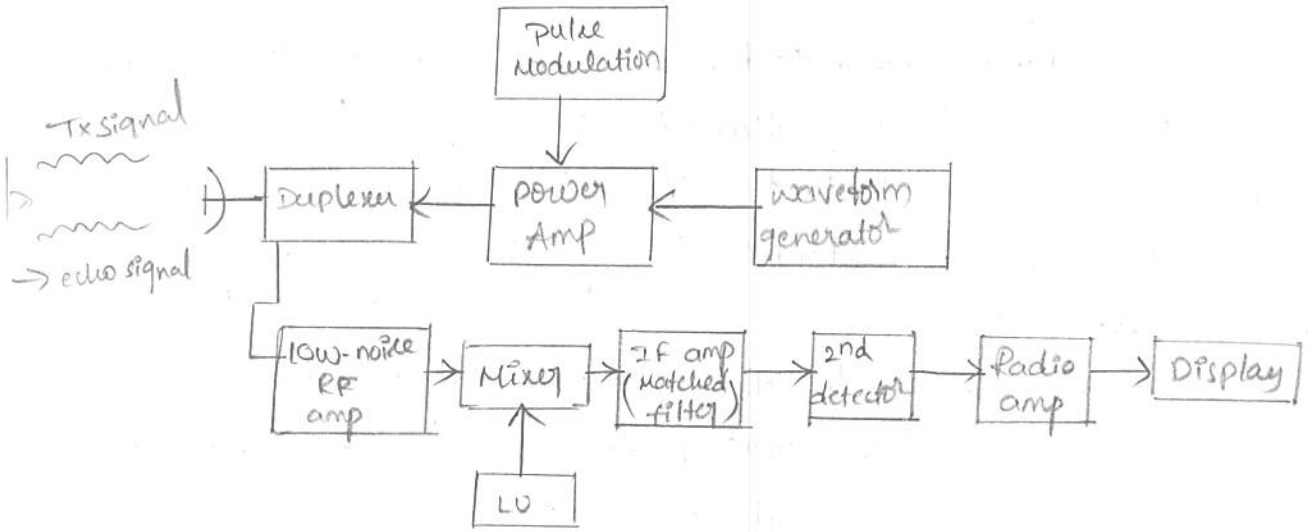
→ **Problem:-** A medium range search radar is working at 12GHz has prf of 300 cps find unambiguous range in kms and in national miles and also find the wavelength of transmission

$$R_{unamb} = \frac{c}{2f_r} = \frac{3\times10^8}{2\times300} = \frac{10^6}{2} = 500\text{kms}$$

$$R_{unamb} = \frac{500}{1.852} = 270 \text{ nautical miles}$$

$$\text{wavelength } \lambda = \frac{c}{f} = \frac{3\times10^8}{12\text{GHz}}$$

→ **Radar block diagram:-**



Block diagram of pulse radar is shown in figure.

Power amp may klystron of travelling wave transistor amp generator may be magnetron. low power signal is generated by wave-form generator and, is amplified by power amplifier.

The transmitter turn on (or) off by pulse modulator.

The output of transmitter travel via transmission line to antenna where it is radiated into ~~via transmission line to~~ free space

A single antenna is generally used for both transmission and reception. A Duplexer protect receiver from high power of transmitter.

The receiver is always super heterodyne receiver. The input or RF stage is low noise transistor amplifier.

The mixer and local oscillator converts RF signal into IF signal. If the output of mixer is amplified by IF amp. It amp is designed as matched filter which maximum output peak signal to mean noise ratio.

The signal bandwidth of S-H receiver is bandwidth of IF amp i.e., the receiver bandwidth is inverse of pulse width

i.e., $BT = 1$

After maximising the signal to noise ratio the IF amp, the pulse modulation is extracted by 2nd detector which is crystal detector.

Video amplifier amplify the input signal upto a level where it can properly displayed on displays.

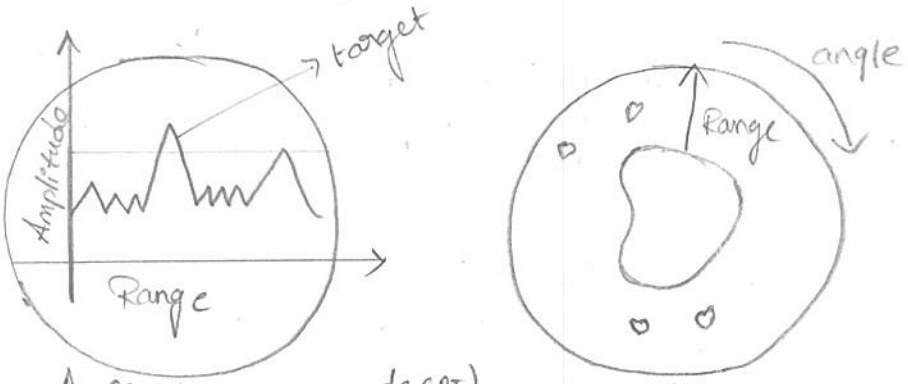
The two most common forms of displays using CRT are A-scope (deflection modulated CRT) and PPI plan position indicator (intensity modulated CRT). PPI maps in polar coordinates

· the location of target in azimuth and range.

The A-scope displays target amp (Y-axis) vs Range (X-axis) and no angle information is shown.

At the output of receiver we make whether target is present or not. If the output of receiver is larger than the predetermined threshold the target is present. It does not cross the threshold target is not present.

→



A. scope (Deflition mode CRT) PPI (Intensity mode CRT)

→ **Simple form of Radar Equation :-**

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

Let P_t is the power of the transmitter and the isotropic antenna.

power density at a distance R from the radar is transmitted power divided by surface area $4\pi R^2$ of imaginary sphere of radius R.

power density from isotropic antenna $= \frac{P_t}{4\pi R^2}$ watts/m^2

Radars usually employer directive antennas

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

The gain G of antenna is a measure of increment power radiated in the direction of target as compared with power that have been radiated from an isotropic antenna.

The target intercepts a position of the incident power and radiates it in various directions.

A measure of the amount of incident power interepted by the target and reradiated back in the direction of radar is denoted as the Radar cross section of the target (σ). σ is also defined as the area of the target as seen by radar.

The total power intercepted by target and reradiated in the direction of radar is

$$= \frac{P_t G \sigma}{4\pi R^2} \text{ watts.}$$

The power ~~radiated~~ density of echo signal at the radar is

$$= \frac{P_t G \sigma}{4\pi R^2} \left(\frac{1}{4\pi R^2}\right) \text{ watts}/m^2$$

The radar antenna captures a portion of the echopower. If the effective area of the receiving antenna is denoted by A_e.

power received by radar is

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

The max radar range is the distance beyond which target can't be detected. It occures when received echo signal power P_r is equal to minimum detectable signal.

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

$$R^4 = \frac{P_t G \sigma A_e}{(4\pi)^2 S_{min}} \Rightarrow R = \left(\frac{P_t G \sigma A_e}{(4\pi)^2 S_{min}}\right)^{1/4} \rightarrow (1)$$

The relation between gain and effective area is

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

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

Sub A_e in equation in (1)

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

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

Sub eq (1) G^2 in eq (2)

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

The correct relationship depends on whether it is assume that gain is content of effective area community

→ **Applications of Radar:-**

Radar has been employed on the ground, in air, and on the sea and in space ground based radar has been used to detect and locate aircrafts on space targets.

Ship board radar may observe otherships on aircrafts (or) it may be used as navigational aid to locate shore lines.

Air bolne radar may be used to detect other aircraft. ships or land vehicals.

→ **The Major areas of radar application:-**

- **Aircraft control:-** Radars are employed throughout the world for purpose of safety controlling airtraffic in the vicinity of airport (Air Surviellance Radar, or ASR) and enroute from one airport to another (Air Route Surviellance Radar or ARSR)

→ **Aircraft Navigation** :- The weather - avoidance radar used an air-craft to outline regions of precipitations to pilot. Radar is also used for command or rule and terrain following.

→ **Ship Safety** :- Radar is found on ships and boats for collision avoidance and to observe navigation bow buoys.

→ **Space** :- space vehicals have used radar for rendenzour and ducking and for landing on moon Same of largest ground-based radars are used for tracking and detection of satellites.

→ **Remote Sensing** :- All radars are remote sensors. Four important-examples of radar remote sensing are

(1) weather observation (2) planetary observation

(3) Short-range below-ground probing (4) Mapping of sea

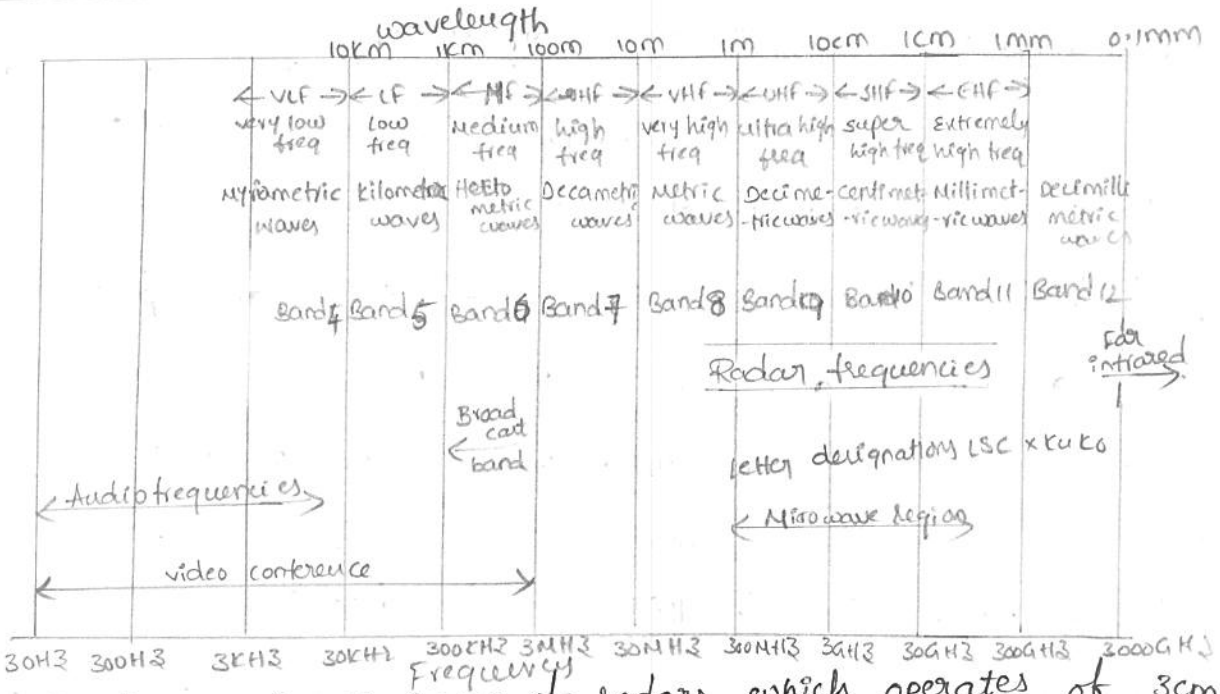
→ **Military** :- The traditional rote of radar for military appli-cations hasbeen for Surveliance, navigation, and the control and guidance of weapons. It is largest use of radars.

→ **Others** :- oil and gas exploration, to study the movement of birds and insects.

Radar frequency :-

Radar generally works in Microwave region. Conventional Radars operate of frequencies ranging from 220 MHz to 35GHz

The figure will shown in below.



->1. Calculate the maximum range of radars which operates of 3cm with peak pulse power of 600kw. If its antenna $5m^2$ and the radar crosssectional area of the target is $20m^2$ minimum detectable peak signal power is $10^{-13}w$.

Sol:- $\lambda = 3cm$, $P_t = 600kw$, $S_{min} = 10^{-13}$, $A_e = 5m^2$

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

$$R_{max} = \left(\frac{P_t A_e^2 \sigma}{4\pi\lambda^2 S_{min}}\right)^{1/4} = \left(\frac{600\times10^3 \times 5^2 \times 20}{4\pi \times (3\times10^{-2})^2 \times 10^{-13}}\right)^{1/4}$$

$$= 717.657 \text{ km}$$

In nautical miles $1nm = 1.853km = 387nm$

2. A 10GHz radar has the following characteristics peak transmitted power = 250kw, power gain of antenna = 2500 minimum detectable peak signal power by receiver $10^{-14}w$ crossectional area of radar antenna = $10m^2$.

If the this radar wire to be used to detect a target of $2m^2$ equalent crossection signal the max range possible.

Sol:- $P_t = 250 kW$; $G = 2500$; $S_{min} = 10^{-14} W$; $A_e = 10 m^2$

$\sigma = 2 m^2$; $f = 10 GHz$; $\lambda = c/f = \frac{3\times10^8}{10\times10^9} = 0.03 m$

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}}\right]^{1/4} = 298.28 km$$

3. A marine radar operating at 10GHz has a max range of 50km with an antenna gain of 4000. If the transmitter has a power of 250kW and minimum detected signal of $10^{-11} W$. Determine the crosssection of the radar ——.

Sol:- $f = 10 GHz$; $P_t = 250 kW$; $G = 4000$; $R = 50 km$ $P_r = 10^{-11} W$

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

$$\sigma = \frac{P_r (4\pi R^2)^2}{P_t G A_e} = 34.45 m^2$$

4. A military radar operates at 5GHz with 2.54kW power output if the antenna diameter is 5m, the received bandwidth is 1.6MHz and has a 12dB noise signal. what is the maximum detection range for $1 m^2$ target.

Sol:- $P_t = 2.5\times10^6 W$, $D = 5m$, $\sigma = 1 m^2$, $D = 1.6\times10^6 Hz$

$\lambda = 0.06 m$

$F = 15.85$

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

$= 556 km$

5. The guided missile tracking radar has following Specifications Tx power = 400kw, pulse — 1500 prf pulse width 0.85 sec.
Determine the (a) unambiguous (b) Duty cycle (c) avg pulse d) Suitable bandwidth of radar.

$P_t = 400kw$; $P_{rf} = 1500 PDf$ $f_w = 0.8 \mu sec$

6. A - radar operating at 10GHz has an antenna with a gain of 20dB and a transmitter power of 2kw (pulse power). If it is defined to detect a target with a cross section of 12 sq.m and the min detectable signal is $P_{min} = -90dBm$. what is the max range of the target.

Sol:- $P_t = 2kw$, $\sigma = 12 sqm$, $G = 20db$, $S_{min} = -90 dB/m$

$G = 20dB$

$20 = 10\log_{10} x$

$x = 100$

$S_{min} = -90dB/m$

$-90 = +10\log_{10}\left(\frac{4}{1mw}\right)$

$\frac{4}{1mw} = 10^{-9}$

$4 = 10^{-12} w$

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

$R = 3.22 km$

7. A tracking radar transmitter has a peak power of 400kw and PRF of 1500 cps and pulse width of 0.8 μs. Calculate a) unambiguous range b) Duty cycle c) Average power

Sol:- $\tau = 0.8\,\mu sec$ $\quad Prf = 1500\,cps$ $\quad P = 400\,kW$

a) $R_{unamb} = \dfrac{c}{2f_r} = 100\,km$

b) Duty cycle $= \dfrac{T_{ON}}{T_{ON}+T_{OFF}} = T_{ON} \times Prf$

$= 0.8 \times 10^{-6} \times 1500 = 0.0012$

c) Average power = peak power × Duty cycle

$= 48\,kW$

→ 1. Ground based air survillance radar with peak transmitter-power 300kW. pulse width 1msec operates at a frequency of 3000-MHz it's antenna is having a radius of 6 feet and the antenna efficiency is 0.95 calculate the maximum signal power at the range of 50nm. for the detection of a target with a radar cross section of $1m^2$.

Sol:-

$P_t = 300\,kW$

pulse width = 1ms

$f = 3000\,MHz$

$r = 6$ feet

$r = 6 \times 12 \times 2.5 = 180\,cm = 1.8\,m$

[1inch = 2.5]

Antenna efficiency = 0.95

effective area = 0.95 × Antenna area

$A_e = 0.95 \times \pi r^2 = 9.669\,m^2$

$\sigma = 1\,m^2$

$R_{max} = 50\,nm$

$$\lambda = \frac{3\times10^8}{3000\times10^6} = 0.1\,m$$

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

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

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

$$= \frac{300\times10^3\times1\times(9.67)^2}{4\pi(0.1)^2(50\times1852)^4}$$

$$S_{min} = 3.03\times10^{-12}\,W$$

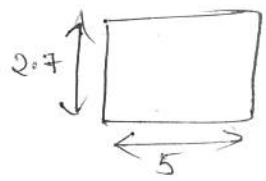
2. what is the range of a radar in nautical miles if it has to detect a target with a radar cross section of $2m^2$, when it operates at a freq of 2.9 GHz with a rectangular shaped antenna that is 5m wide, 2.7m height antenna aperture efficiency of 0.6 and a min detectable signal 10^{-12} W.

sol :-

$f = 2.9\,GHz$

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

$\sigma = 2m$



Physical area $= 5\times2.7 = 13.5\,m^2$

$A_e = 0.6\times13.5\,m^2$

$= 8.1\,m^2$

$$\lambda = c/f = \frac{3\times10^8}{2.9\times10^9} = 0.103$$

$$R_{max} = \left(\frac{P_t\,2\times(8.1)^2}{4\pi\,(0.103)^2\times10^{-12}}\right)$$

$$R_{max} = P_t\times9.84\times10^{14}$$

3. what should be range of pulse reputation frequency and duty cycle of radar in order to achive maximum unambiguous range 60nm of with a pulse of 1.5 μsec.

Sol:-

$R_{unamb} = 60nmi$

$= 60 \times 1852 = 111120 m$

$T_{ON} = 1.5 = 1.5 \times 10^{-6} sec$

$R_{unamb} = \frac{c}{2f_r}$

$11120 = \frac{3 \times 10^8}{2f_r}$

$222240 f_r = 3 \times 10^8$

$f_r = 1349.89 Hz$

$f_r = 1.349 KHz$

$D = \frac{T_{ON}}{T_{ON} + T_{OFF}} = T_{ON} \times f_r$

$= 2.02 \times 10^{-3}$

$= 0.002$

4. Find the max range of radar operating at a freq of 12GHz upto which a target of $3m^2$ can be detected if the average transmitter power of 1kW. with a pulse width of 2μsec, prf of 600Hz and power gain of the antenna is 2400. the minimum detectable signal power by the receiver is 10^{-14} w.

Sol:-

$f = 12G$

$\sigma = 3m^2$

peak power × duty cycle = Average power

$D = \frac{T_{ON}}{T_{ON} + T_{OFF}}$ $\lambda = \frac{3 \times 10^8}{12 \times 10^9} = 0.025$

$D = T_{ON} \times Prf = 2\mu \times 600 Hz$

$= 1.2 \times 10^{-3}$

peak power $= \frac{1K}{1.2 \times 10^{-3}} = 833.33 kw$

$G = 2400$

$S_{min} = 10^{-14}$

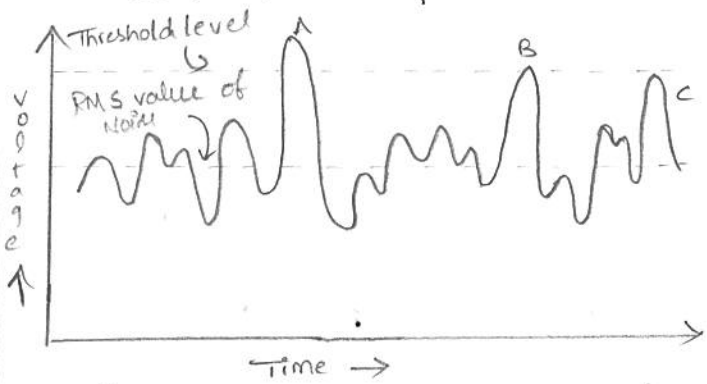
$$R_{max} = \left(\frac{8338.33 \times 10^{3} \times (2400)^{2} \times 3 \times (0.025)^{2}}{(4\pi)^{3} \times 10^{-14}} \right)^{1/4}$$

$= 82064.02 m$

RADAR EQUATION

Min Detectable signal:- The weakest signal that can be detected by Radar Receiver is called "Minimum Detectable Signal". In radar equation it was denoted as S_{min}.

Detection of Radar signal is based on establishing a threshold at the output of a receiver. If the receiver output exceeds, the threshold, Target is said to be present. If the receiver output does not exceeds threshold, only noise is said to be present. This is called "threshold detection".



Figure, represents the output of receiver as function of time. that is video output displayed on A-Scope.

[Threshold level set properly so that receiver output should not exceed the threshold if noise alone were present, but the output would exceed the threshold if strong echo signal were present along with Noise]

If threshold level were set to low, the noise might be exceed threshold and give a false information of the presence of target, this is called "False Alarm". If the threshold level were set to high, weak target echos might not exceed the threshold and couldnot be detected. It is called "missed detection". In early radars, the threshold level was set based on the judgement of radar operator viewing the radar output on a cathode ray tube display.

Threshold level is shown by long dash line. If signal is large enough as at A, it is not difficult to decide

that a target Echo signal is present. But consider the two signals at B and C. representing two target Echos of Equal amplitude.

The Noise accompanying the Signal at B is assumed to be positive Amplitude and adds to the target Signal. So the combination of signal plus noise crosses the threshold and is declared as a target

At C the noise is assumed to subtract from the target signal so the resultant of signal and noise cross-the threshold and is a missed detection.

The signal at C would have been detected if thres-hold were lower. But too low a threshold increases False-alarm.

→ PREDICTION OF RANGE PERFORMANCE :-

Max. Radar range equation in terms of Radar and target parameters is given by,

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

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, watts

All the parameters are to some extent under the control of the radar designer, Except the target cross-Section σ. If long ranges are required, P_t should be large

and the gain of antenna should be high, but antenna beam should be narrow beam and the receiver must be sensitive to weaker signals.

In practice, the range equation does not predict the range performance of the actual radar equipment. In some cases the actual range is half of the predicted. This is because the equation does include losses of various types that can occur throughout the system. This will be experienced in field than the laboratory type conditions. Another reason is due to unpredictable and statistical nature of minimum detectable signal and radar construction.

RECEIVER NOISE :-

[Noise is chief factor limiting receiver sensitivity which interfaces with the ability of the receiver to detect the wanted signal]. The noise may be generated within the receiver (or) it may enter with the receiving antenna along with the desired signal.

If the radar were to be operate inperfectly noise free environment so that no external source of noise accompany the target signal and if the receiver it self were so perfect that it didnot generate any excess noise, there would be still noise generated ~~any excess~~ by the thermal agitation of conduction electrons in the ohmic position of the receiver input stages. This is called "thermal noise (or) Johnson noise", Its magnitude is directly proportional to Bandwidth & absolute temperature of ohmic potions of receiver input stages.

The mean square noise voltage across a resistor is $e_n^2 = 4KTB_nR$

Available thermal noise power $= KTB_n \rightarrow (1)$ $\left(\because P_n = \frac{e_n^2}{4R} = \frac{4KTB_nR}{4R} = KTB_n\right)$

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

B_n = Receiver Bandwidth

(In the above Equation, the Bandwidth 'Bn' is known as the Noise bandwidth and is given by,

$$B_n = \frac{\int_0^{\infty} |H(f)|^2 df}{|H(f_0)|^2}$$

where, $H(f)$ = frequency Response function of IF amplifier (filter)

f_0 = Frequency of Max. response.

The above Equation, states that the noise bandwidth is the bandwidth of the equivalent rectangular filter, whose noise-power output is same as the filter with frequency-response $H(f)$].

[The noise power in particular receiver is greater than that from thermal noise alone]. The measure of the noise out-of real receiver to the ideal receiver with only thermal-noise is called the "Noise figure".

$$\therefore F_n = \frac{\text{Noise out of practical Receiver}}{\text{Noise out of ideal receiver at std. temp } T_0} = \frac{N_{out}}{KT_0B_nG_a}$$

where, N_{out} = Noise out of practical receiver

G_a = Available gain.

The Noise figure may also be defined as,

$$\therefore F_n = \frac{S_i/N_i}{S_o/N_o} \Rightarrow S_i = KT_0BF_n\left(\frac{S_o}{N_o}\right) \quad (\because N_i = KT_0B_n)$$

If minimum detectable signal S_{min} is the value of S_i which corresponds to minimum ratio of output.

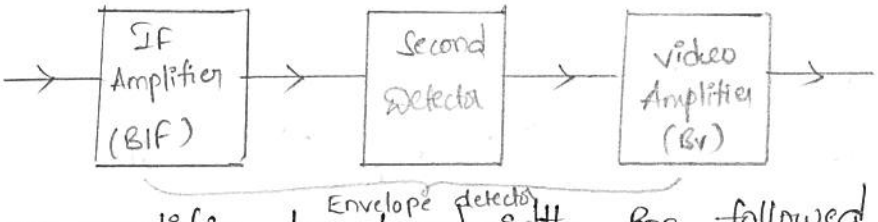
$$\therefore S_{min} = KT_0B_nF_n\left(\frac{S_o}{N_o}\right)_{min}$$

on substituting in radar range Equation, we get,

$$\therefore R_{max}^4 = \frac{P_tGA_e\sigma}{(4\pi)^2KT_0B_nF_n(S_o/N_o)_{min}}$$

The minimum detectable signal is replaced in the radar equation by minimum detectable signal to noise ratio. The advantage is that $(S_o/N_o)_{min}$ is independent of the receiver bandwidth and Noise figure.

SIGNAL - TO - NOISE RATIO :-



Let IF amplifier has bandwidth B_{IF} followed by Second-Detector and video Amplifier with Bandwidth B_v.

The second detector and video amplifier are assumed to form an envelope detector i.e., one which rejects the carrier frequency and passes the modulation Envelope.

To Extract the modulation Envelope, the video Bandwidth must be wide Enough to pass the low-frequency components generated by second detector but not so wide to pass higher frequencies near the immediate frequency.

The video Bandwidth 'B_v' must be greater than $B_{IF}/2$ inorder to pass all the video modulation.

The Noise Entering the IF amplifier is assumed to be Gaussian with probability Density function.

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

when, ψ_0 = variance (or) Mean Square value of Noise voltage Mean value of 'v' is taken to be 'zero'.

If Gaussian noise were passed through a Narrow Band IF filter, the probability density of the envelope of the Noise voltage output is shown by,

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

where, R is the amplitude of the envelope of the filter output. It is in the form of Rayleigh probability - Density function.

The probability that the noise voltage will lie between the values of v_1 and v_2 is,

$$\text{probability } (v_1 < R < v_2) = \int_{v_1}^{v_2} \frac{R}{\psi_0} \exp\left(\frac{-R^2}{2\psi_0}\right) dR$$

The probability that the noise voltage envelope will exceed the voltage threshold v_T is,

$$\text{probability } (v_T < R < \infty) = \int_{v_T}^{\infty} \frac{R}{\psi_0} \exp\left(-\frac{R^2}{2\psi_0}\right) dR$$

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

whenever noise voltage Envelope exceeds threshold, considered as target detection i.e., false alarm.

probability of false alarm is probability that Noise will cross the threshold denoted by P_{fa}.

$$\boxed{\therefore \; P_{fa} = \exp\left(\frac{-v_T^2}{2\psi_0}\right)}$$

INTEGRATION OF RADAR PULSES :-

Many pulses may be return from any target on each radar scan these can be used to improve Detection.

The number of pulses n_B returned from a point target as the radar antenna scans through its beamwidth θ_B is given by,

$$\therefore \; n_B = \frac{\theta_B f_b}{\theta_2} = \frac{\theta_B f_p}{6\omega_m}$$

where, θ_B = Antenna Beamwidth, deg

f_p = pulse repetition frequency, Hz

θ_S = Antenna scanning rate, deg/s

ω_m = Antenna Scan rate, rpm

The process of scanning all the radar echo pulses for the purpose of improving detection is called integration.

Integration may be accomplished in the radar receiver either before the second detector (In IF) (or) after the second detector (In video Amp). Integration, while Integration after the second is called post detection (or) Non-coherent Integration.

predetection Integration requires that the phase of the echo signal be preserved on the otherhand. The phase integration is destroyed by the second detector. Hence post detection integration is not concern with preserving RF phase. For this reason post detection Integration is not as efficient as predetection Integrator.

If 'n' pulses, all of the same signal-to-Noise ratio were integrated by an ideal predetection integration, the integrated by an ideal post detection device, the resultant S/N ratio would be less than that of n-times of a single pulse. The less in integration efficiency is caused by the non-linear action of the Second Detector.

[The efficiency of post detection integration relative to ideal predetection integration is] when all pulses are of equal amplitude. The integration efficiency may be defined as,

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

where, n = No. of pulses integrated

$(S/N)_1$ = value of S/N ratio of a single pulse required to produce given probability of detection.

$(S/N)_n$ = value of S/N ratio per pulse required to produce same probability of detection when 'n' pulses are integrated.

The radar equation with 'n' pulses integrated can be written as,

$$\therefore R^4_{max} = \frac{P_t G A_e \sigma}{(4\pi)^2 K T_0 B_n F_n (S/N)_n}$$

$$\boxed{R^4_{max} = \frac{P_t G A_e \sigma_n E_i(n)}{(4\pi)^2 K T_0 B_n F_n (S/N)_1}}$$

TRANSMITTER POWER :-

The power 'P_t' in the radar Equation is called 'peak-power'.

[The peak pulse power as used in the radar is not the instantaneous peak power of a sinewave. It is defined as the power averaged over that carrier-frequency cycle which occurs at max. of pulse of power)

The average power 'pav' is defined as the average transmitter power over the pulse repetition period.

If the transmitted waveform is a train of rectangular pulses of width 'τ' and pulse repetition period $T_P = 1/f_P$, the average power is related to peak power as,

$$P_{avg} = \frac{P_t \tau}{T_P} = P_t \tau f_P$$

where $\frac{P_{avg}}{P_t}$, $\frac{\tau}{T_p}$ is called the duty cycle.

Radar Range Equation interms of Average power is

$$R^4_{max} = \frac{P_{av} G A_e \sigma n E_i(n)}{(4\pi)^2 K T_0 F_n (B_n \tau)(S/N)_1 f_p}$$

$$\left(\because P_{avg} = P_t \tau f_p \quad P_t = \frac{P_{av}}{\tau f_p} \right)$$

The Bandwidth & pulsewidth are grouped together since the product of the two is usually of the order of unity.

If the transmitted waveform is not a rectangular pulse, it is convenient to express the radar Equation interms of energy, i.e., $E_t = P_{av}/f_p$

$$\therefore R^4_{max} = \frac{E_t G A_e \sigma n E_i(n)}{(4\pi)^2 K T_0 F_n (B_n \tau)(S/N)_1}$$

PULSE REPETITION FREQUENCY AND RANGE A

The pulse repetition frequency (PRF) is determined primarly by the maximum range at which targets are ~~expected~~ expected. ($R_{un} = c/2f_r$)

consider three targets A, B & C in figure (a)

Target A is located within the max. unambiguous range R_{unamb} of radar,

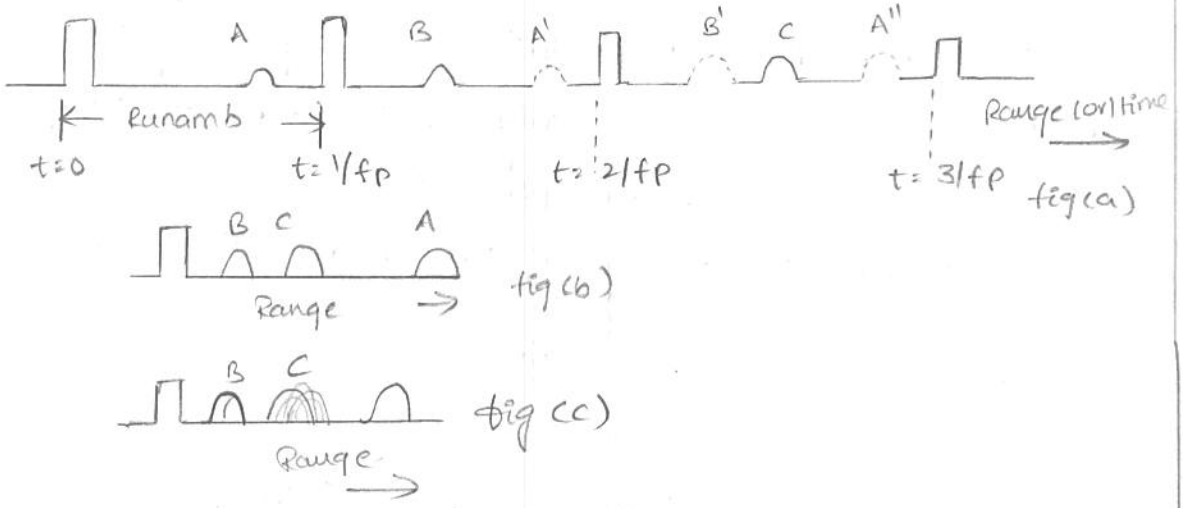
Target B is at a distance greater than R_{unamb} but less than $2R_{unamb}$,

Target C is greater than $2R_{unamb}$ but less than $3R_{unamb}$.

The appearance of the three targets on an A-scope is shown in figure (b). The multiple-time-around echos on the A-slope cannot be distinguished from proper target echos in figure (b).

only the range measured for target A is correct; those for B, are not.

One method for distinguishing multiple-time-around echoes from unambiguous echoes is to operate with a varying-pulse repetition frequency. The echo signal from an unambiguous range target will appear at same place on the A-scope on each sweep. However echoes from multiple-time-around targets will be spread over a finite range as shown in figure (c)



RADAR CROSS SECTION OF TARGETS:-

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

$$\therefore \sigma = \frac{\text{Power reflected toward source / unit solid angle}}{\text{Incident power density} / 4\pi}$$

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

where, R = Distance b/w Radar & target

E_r = Reflected field strength at Radar

E_i = Strength of incident field at target

The Scattering field and hence the radar cross section can be determined by solving Maxwells equations with the proper boundary conditions applied. unfortunately, the determination of the radar cross section with Maxwell's equations can be accomplished only for most simple of shapes.

The Radar cross section of a simple sphere, target is shown as function of its circumference measured in wavelengths ($2\pi a/\lambda$, where a = Radius of sphere
λ = wavelength)

The RAYLEIGH REGION :-

The region where the size of the sphere is small compared with wavelength ($\frac{2\pi a}{\lambda} << 1$) is called Rayleigh region. It is named after Lord Rayleigh. In this region, The radar cross-section is proportional to λ^{-4}.

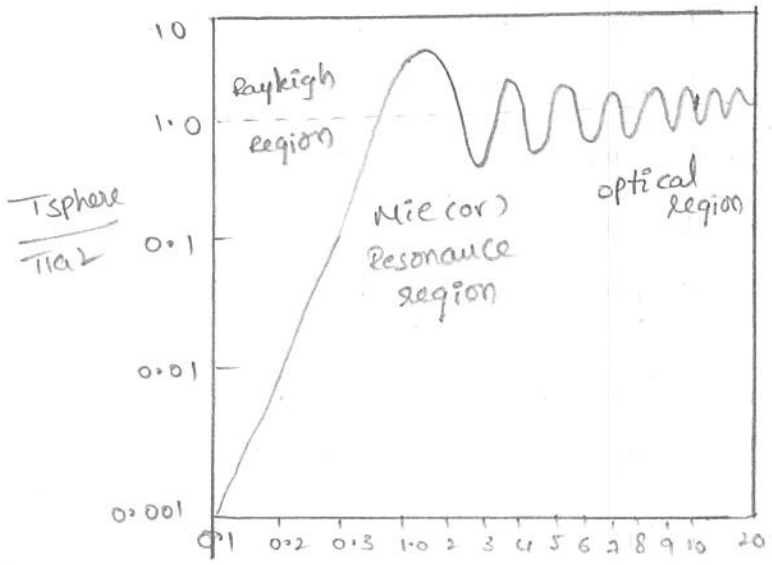
THE MIE REGION :-

This region is also known as Resonance region. The Mie Region is in between the Rayliegh and optical regions. In this region the radar cross-section is oscillatory with frequency.

THE OPTICAL REGION :-

This region is to the other extreme of the Rayleigh region. In this region, the size of the sphere is large compared with wavelength ($2\pi a/\lambda >> 1$). For large $2\pi a/\lambda$ is the radar cross section approches the optical cross section - πa^2. Target across in this region only, we can calculate the radar cross section by using formula,

$\therefore \sigma = \pi R_1 R_2$ where, R_1, R_2 = Radii of curve.



Circumference / wavelength $= 2\pi a/\lambda$

System losses :-

Losses are occurred throughout the Radar Systems. The losses reduce the system S/N ratio at the output of the receiver these losses are antenna beam shaping losses, collapsing losses & losses in the microwave plumbing. These losses are very real and cannot be ignored in any prediction of radar performance.

PLUMBING LOSS :-

There is always some finite loss Experienced in the transmission lines which connect the output of the transmitter to the antenna.

In an S-Band (3000 MHz) radar, for Example, the Plumbing losses might be as follows:

100ft of RG-113/U Aluminium waveguide Tx-line (Two-way)	1.0 dB
Loss due to pool connections (Estimate)	0.5 dB
Rotary - Joint loss	0.4 dB
Duplexer Loss	1.5 dB
Total plumbing loss	3.4 dB

BEAM - SHAPE LOSS :-

we take antenna gain as max. in Radar Equation should be maximum value. But in reality. (the trains of pulses returned from target with Scanning radar is modulated in amplitude by the shape of antenna beam], it is unlikely that the target always will not be in the direction corresponds to max. gain.

To get max pulses in each scan the antenna pattern should be rectangular but in practice it is not so. The amplitude of echo path vary with the antenna beam shape of pattern. Therefore, it results in loss due to shape.

COLLAPSING LOSS :-

It may happen that radar integrates a no. of unwanted pulses along with wanted signal plus noise pulses.

The noise added to the signal results in a degradation S/N ratio accounted for the collapsing loss. The typical value is 1.5 dB to 1.8 dB.

OPERATOR LOSS :-

An operator capacity for searching a CRT display and recognizing the presence of target echoes (is limited].

The rate at which information can be displayed on PPI is many times the capacity of the operator bandwidth. If the rate at which information can be displayed on PPI is many times the capacity of operator Bandwidth, there will be loss. This loss will result in few dB's.

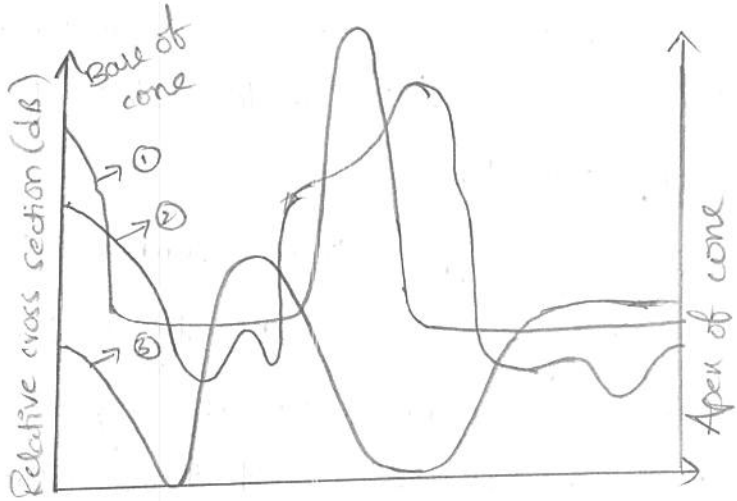
Since sphere is a sphere no matter from what aspect it is viewed. The cross section of other objects will depend upon the direction as viewed by the radar.

Figure shows the Experimentally measured radar cross-section for a right - circular cone as function of aspect three different sizes of cones are shown each with apex-angle of 15°. The diameter of base of large cone is 2λ. that of intermediate cone λ, and that of small cone λ/2.

① large cone

② Intermediate cone

③ Small cone



UNIT I

BASICS OF RADAR &

RADAR EQUATION

Lecture 1 :—

Introduction to Radar :—

Radar is an Electro-magnetic System for the detection and location of objects. It operates by transmitting a particular type of waveform and detect the nature of echo signal.

→ Radar can't revolve detail as well as the eye, nor able to recognise the color of objects to the degree which the eye is capable.

→ Radar can be designed to see through darkness, haze, fog, rain and snow. In addition radar measure the distance or range to the object.

→ The name radar reflects the emphasis placed by the early experiments on a device to detect the presence of a target and measure its range. Radar is contraction of words radio detection and ranging. It was first developed as a detection device to warn of the approach of hostile aircraft and for directing antiaircraft weapons.

→ Basic radar consist of a transmitting antenna emitting EM waves generated by an oscillator of some sort, a receiving antenna, and a energy detection device, or receiver. A portion of transmitted signal is intercepted by a reflecting object (target) and is re-radiated in all directions. The receiver antenna collect the return energy, where receiver process to detect the presence of target and also its location. The distance to the target is determined by measuring the time taken for the radar signal to travel to the target back. The direction and angular position of the target may be determined from the direction of arrival of reflected wave front.

→ The most common radar waveform is a train of narrow, rectangular-shape pulses modulating a sine carrier. The distance or range to the target is determined by measuring the time

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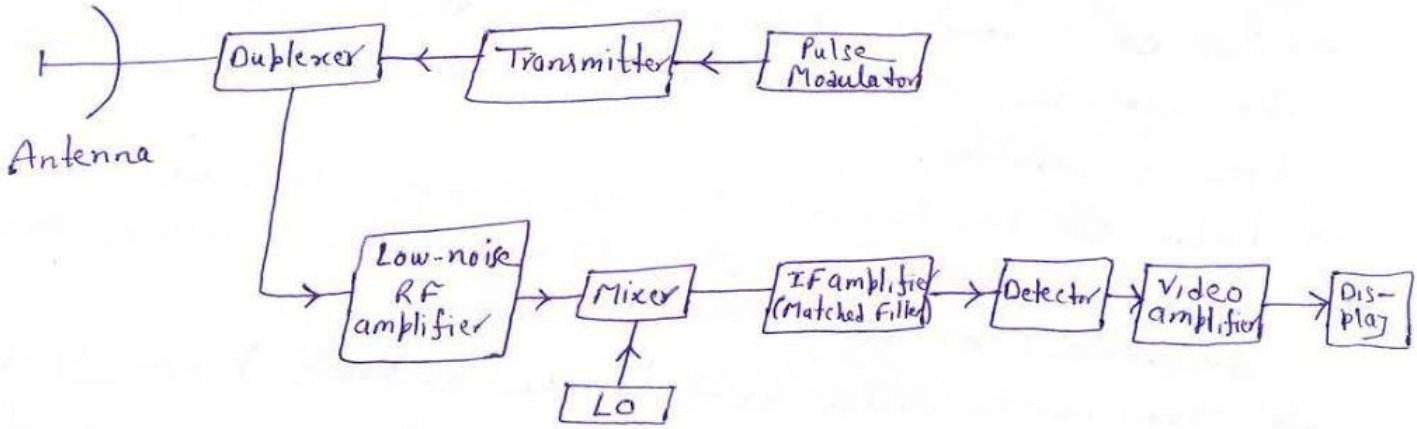
Range $R = \frac{c T_R}{2}$.

$R(km) = 0.15\, T_R (\mu s)$

Radar Block Diagram :-



Lecture - 2

Block Diagram operation :-

The transmitter may be an oscillator, such as an magnetron, that is pulsed by the modulator to generate a repetitive train of pulses. Magnetron used most widely of various microwave generators for radar. A typical radar for the detection of aircraft at ranges of 100 or 200 (nmi → nautical miles) might employ a peak power of the order of megawatt, an average power of several kilowatts, a pulse width of several micro-seconds and a pulse repetition frequency of several hundred pulses per second.

→ The waveform generated by the transmitter travels via a transmission line to the antenna.

Duplexer :- ① Protect receiver from damage caused by the high power of transmitter, also ② Server to channel the returned echo signals to the receiver and not to transmitter. Duplexer consist of two gas discharge

other an ATR (anti-transmit-receive). TR for ① task and ATR for ②. Solid state ferrite circulator and receiver protector with gas plasma TR devices employed as duplexer.

Receiver: → It is usually of the super-heterodyne type. First state might be low-noise RF amplifier but not always desirable. The mixer and LO convert the RF signal to the intermediate frequency (IF). A typical IF amplifier for radar have a center frequency of 30 to 60 MHz and B.W of the order one MHz. The IF amplifier should be designed as a matched filter i.e it frequency-response function $|H(f)|$ should ~~be~~ maximize peak-signal to mean noise power ratio at the output. It occur when magnitude of $|H(f)|$ is equal to magnitude of the echo signal spectrum $|S(f)|$, and the phase spectrum of matched filter is the negative of phase spectrum of echo signal.

After maximizing the SNR in the IF amplifier, the pulse modulation is extracted by detector and amplified by video amplifier to a level where it can be properly displayed usually on CRT. Timing signals are also supplied to the indicator to provide the range zero. Angle information is obtained from the pointing directions of antenna.

Applications of Radar: →

Radar has been employed on the ground, in the air, on the sea, and in space.

① Ground based radar has been applied chiefly to the detection, location, and tracking of aircraft or space targets.

② Shipboard radar is used for navigation aid and safety device to locate buoys, shore lines and other ships, as well as for obstacle avoidance.

③ Airborne radar may be used to detect other aircraft,

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Storm avoidance, terrain avoidance, and navigation.

④ In space, radar has assisted in the guidance of space-craft and for remote sensing of the land and sea.

Major area of radar applications are.

→ Air Traffic control (ATC

→ Air craft Navigation

→ Ship Safety

→ Space

→ Remote sensing

→ law Enforcement

→ Military

Lecture - 3

Simple Form of Radar equation: →

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

let Power of radar transmitter is P_t, and if isotropic antenna is used, the Power density (watt/area) at a distance R from the radar is equal to the transmitter Power divided by the surface area of an imaginary sphere of radius R.

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

Radar employ directive antenna having gain G.

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

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

where $\sigma \Rightarrow$ radar cross section

Radar cross section σ has units of area. It is a characteristics of particular target and is a measure of its size as seen by radar. The radar antenna captures a portion of echo power. If the effective area of the receiving antenna is denoted A_e, and the power P_r received by radar is

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

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

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

Fundamental form of Radar Eqn.

<u>Minimum Detectable ~~Si~~ Signal</u> :→

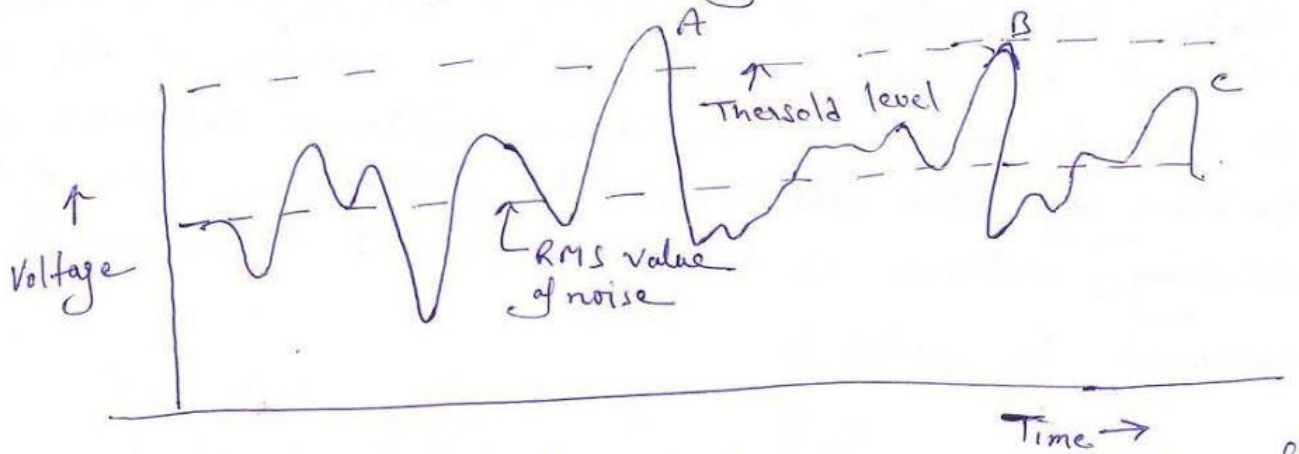
The ability of radar receiver to detect a weak echo signal is limited by noise that occupies the same portion of the frequency spectrum as does the signal energy.

→ The weakest signal the receiver can detect is called minimum detectable signal.

MDS not easy to detect in some times because of

Detection is based on thersold level at the O/P of the receiver. i.e thersold detection.

The thersold level must be low if weak signals are to be detected, but it can't be so low that noise peaks cross the thersold and give a false indication of the presence of ~~noise~~ targets.



Typical envolpe of the radar receiver O/P as a func^n of time

As shown in figure a target is said to be detected if the envolpe crosses the thersold level. Target A ~~has~~ is not a difficult to decide as in the case of B and C.

Lecture - 4

Receiver Noise: → Noise is the main factor limiting receiver sensitivity, it is necessary to obtain some means of describing it quantitatively. Noise is unwanted EM energy interfere with wanted signal.

The available thermal noise power generated by a receiver of B.W B_n (Hertz) at temp^r T (°K) is equal to

$$\text{Thermal noise Power} = KTB_n$$

$K = 1.38 \times 10^{-23}$ J/°K Boltzmann constant.

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For fully heterodyne receiver mostly used in radar, the receiver

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

where $H(f)$ = frequency-response characteristic of IF amplifier
f_0 = frequency of maximum response

Except the thermal-noise some noise components also present. The exact origin of extra noise components is not important except to know that it exist. No matter wether the noise is generated by a thermal mechanism or by some other mechanism the total noise at the o/p of receiver may be considered to be equal to the thermal noise power obtained from an ideal receiver multiplied by a factor called a noise figure.

$$\text{Noise Figure} = F_n = \frac{N_o}{K T_0 B_n G_a} = \frac{\text{noise o/p of Practical receiver}}{\text{noise out of ideal receiver at std temp}^r\ T_0}$$

where

N_o = noise o/p from receiver
G_0 = Gain, $T_0 = 290\,K$, standard temp^r.

Also $\quad F_n = \dfrac{S_i/N_i}{S_o/N_o} \quad$ As $G_a = \dfrac{S_o}{S_i}$ and $K T_0 B_n = N_i$

$$\Rightarrow \quad F_n = \frac{S_i N_o}{S_o K T_0 B_n}$$

$$\Rightarrow \quad S_i = \frac{K T_0 B_n F_n S_o}{N_o}$$

if the minimum detectable signal S_{min} is the value of S_i corresponding to the minimum ratio of o/p signal to noise ratio $(S_o/N_o)_{min}$ necessary for detection, then

$$S_{min} = K T_0 B_n F_n \left(\frac{S_o}{N_o}\right)_{min}$$

Also from Radar Eq^n

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

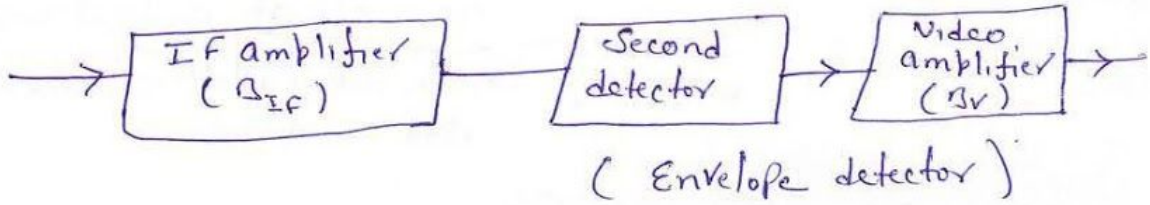
Put value of S_{min}

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

Signal-to Noise Ratio: →

Signal to noise ratio is very importan as far as Radar is concerned, Because Presence of targ or not have Small difference. Statistical noise theory will be applied to obtain S/N. at the o/p of the IF amplifier necessary to achieve a Specified Probability of detecti without exceeding a Specified Probability of false alarm.

Consider an IF amplifier with B.W B_{IF} followed by a Second detector and a video amplifier with B.W B_V.



To Extract modulation Envelope, the video B.W must be wide enough to Pass the low frequency component generated by Second detector, but not So wide Enough to Pass high frequency component at or near I.F. The video B.W mu be greater than $B_{IF}/2$ in order to Pass all the video modu-lation.

Lecture-5

Signal to noise Ration: →

The noise entering the IF amplifier is assumed to be gaussian, with Pdf given by

$$P(v) = \frac{1}{\sqrt{2\pi\sigma}} \, Exp\left(\frac{-v^2}{2\sigma}\right)$$

with mean zero and variance σ.

$P(v).dv$ is the Probability of finding noise voltage v b/w the values of v and $v+dv$.

If gaussian noise Passed through a narrowband IF filter one whose B.W is Small compared with the mid frequency - the Probabili

$$P(R) = \frac{R}{\sigma_0} \exp\left(-\frac{R^2}{2\sigma_0}\right) \quad \text{(Rayleigh Pdf)}$$

where $R \rightarrow$ amplitude of envelope of the filter o/p.

The probability that the envelope of the noise voltage will lie b/w the values of V_1 and V_2 is

$$P(V_1 < R < V_2) = \int_{V_1}^{V_2} \frac{R}{\sigma_0} \exp\left(-\frac{R^2}{2\sigma_0}\right) dR$$

The probability that the noise voltage envelope will exceed the thersold voltage (V_T)

$$P(V_T < R < \infty) = \int_{V_T}^{\infty} \frac{R}{\sigma} \exp\left(-\frac{R^2}{2\sigma_0}\right) dR = \exp\left(-\frac{V_T^2}{2\sigma_0}\right) = P_{fa} \quad \text{— (1)}$$

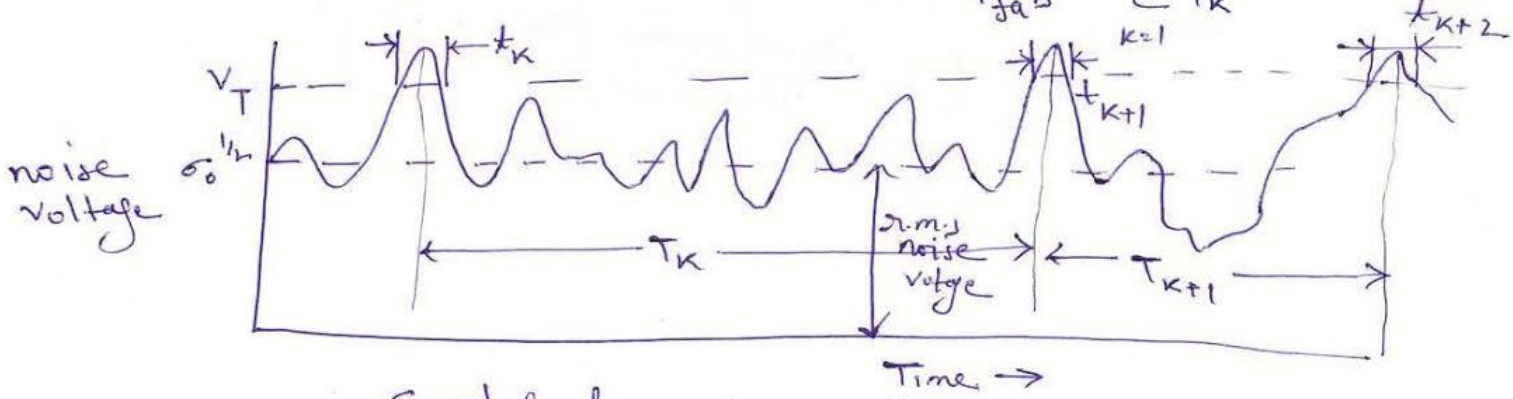
whenever the voltage envelope exceeds the thersold, a target detection is considered to have occured, by defination.

→ Probability of false alarm is the probability that noise will cross thersold.

→ The average time interval b/w crossings of the thersold by noise alone is defined by false alarm time T_{fa}

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

Probability of false alarm $P_{fa} = \dfrac{1}{T_{fa} B} = \dfrac{\sum_{K=1}^{N} t_K}{\sum_{K=1}^{N} T_K}$ — (2)



Envelope of receiver o/p

From (1) and (2)

$$T_{fa} = \frac{1}{B_{IF}} \exp\left(\frac{V_T^2}{2\sigma_0}\right)$$

Frequency of the signal is the same as the IF mid band freq.
The O/P of the envelope detector has a probability-density func^n

$$P_s(R) = \frac{R}{\sigma_0} \exp\left(-\frac{R^2+A^2}{2\sigma_0}\right) I_0\left(\frac{RA}{\sigma_0}\right) \quad -(3)$$

where $I_0(Z)$ is the modified Bessel func^n of zero order and argument Z. Eq^n (3) sometime called Rice PDF.

Now probability of detection P_d is given by

$$P_d = \int_{V_T}^{\infty} P_s(R)\, dR = \int_{V_T}^{\infty} \frac{R}{\sigma_0} \exp\left(-\frac{R^2+A^2}{2\sigma_0}\right) I_0\left(\frac{RA}{\sigma_0}\right)$$

Solving this and assuming $RA/\sigma_0 >> 1$ and $A >> |R-A|$

$$P_d = \frac{1}{2}\left(1 - \operatorname{erf}\frac{V_T - A}{\sqrt{2\sigma_0}} + \frac{\exp\left[-(V_T-A)^2/2\sigma_0\right]}{2\sqrt{2\pi}\,(A/\sqrt{\sigma_0})} \times \left[1 - \frac{V_T - A}{4A} + \frac{1-(V_T-A)^2/}{8A^2/\sigma_0} + \cdots\right]\right.$$

$$\text{where} \quad \operatorname{erf} Z = \frac{2}{\sqrt{\pi}} \int_0^Z e^{-u^2} du \quad -(4)$$

Although the receiver designer prefer to operate with voltages, it is more convenient for radar system engineering to employ power relationships.

$$\frac{A}{\sigma_0^{1/2}} = \frac{\text{Signal amplitude}}{\text{r.m.s noise voltage}} = \frac{\sqrt{2}\ (\text{r.m.s signal voltage})}{\text{r.m.s noise voltage}}$$

$$= \left(2\,\frac{\text{Signal Power}}{\text{noise Power}}\right)^{1/2} = \left(\frac{2S}{N}\right)^{1/2}$$

Lecture - 6

Transmitter Power:-

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

where transmitted Power P_t also called Peak Power. This is not instantaneous Power of Sine wave. The average radar Power P_{av} is also of interest in radar and defined as the average Power over the Pulse repetition Period.

If transmitted Pulse is rectangular with width τ and Pulse repetition Period $T_p = 1/f_p$, the average Power is related to the Peak Power by

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

The ratio P_{av}/P_t, τ/T_p or τf_p is called duty cycle

writting Eqn (1) in terms of average Power

$$R_{max}^4 = \frac{P_{av} G A_e \sigma n E_i(n)}{(4\pi)^2 K T_0 F_n (B_n \tau)(S/N)_I f_p}$$

The B.W and Pulse width are grouped together since the Product of two is usually of the order of unity in most Pulse-radar applⁿ.

if the transmitted waveform is not a rectangular Pulse, it is sometimes more convenient to Express radar Eqⁿ in terms of Energy.

$$E_\tau = P_{av}/f_p$$

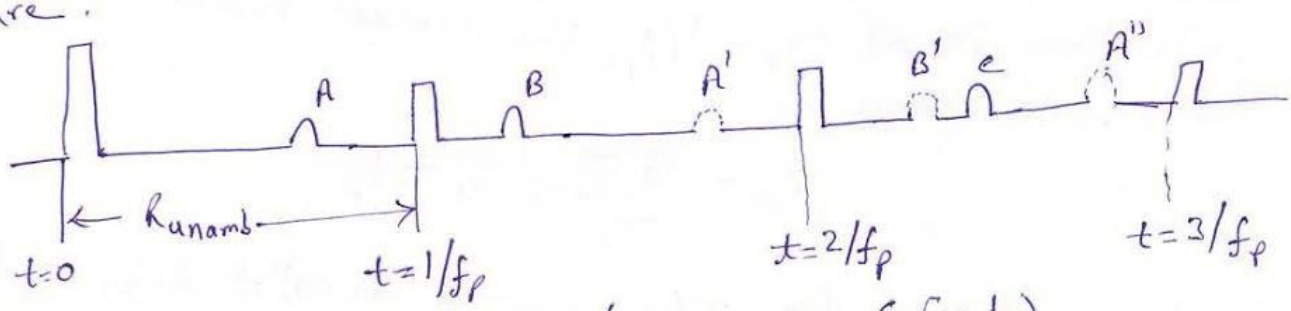
$$\Rightarrow R_{max}^4 = \frac{E_\tau G A_e \sigma n E_i(n)}{(4\pi)^2 K T_0 F_n (B_n \tau)(S/N)_I}$$

The important Parameters affecting range are the total transmitted Energy nE_τ, Transmitter gain G, effective receiver aperture A_e, and receiver noise Figure F_n.

Pulse Repetition Frequency and Range Ambiguities

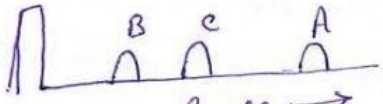
The pulse repetion frequency (Prf) is determined primarily by the maximum range at which targets are expected. if the Prf is made too high, the likehood of obtaining target echoes from the wrong pulse transmission is increased. Echo signals received after an interval exceeding the pulse repetition period are called multiple-time around echoes.

Consider the three targets labeled A, B and C as shown in Figure.



Time (or range) (Fig 1)

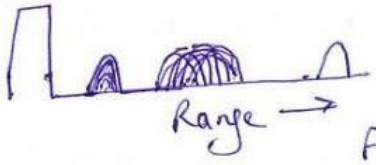
Multiple-time around echoes that give rise to Ambiguiti



Range → Fig(2)

In above Fig.1, Three targets A, B, C, where A within R_{unamb} and B and C are mutiple time around targets.

Fig(2) Shows three targets on A-scope.



Range → Fig(3)

Fig(3) Shows three targets on A-scope with changing Prf.

Ambiguities may theoretically be resolved by observing the variatio of echo signal with time (range). This is not always practica technique, however since the echo signal amplitude can fluctuate strongly for reasons other than a change in range.

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Lecture-7

System losses:→ one of the main factors omitted from the simple radar Eqn was the losses that occur throughout the radar system. The losses reduce the S/N at the receiver o/p. They may be of two kinds depending upon wether or not they can be predicted with ~~the~~ any degree of precision beforehand. The antenna beam shape loss, collapsing loss, and losses in microwave plumbing are example of losses which can be calculated if the system configuration is known. These losses are real and can't be ignored in any serious prediction of radar performance.

Following are the main losses occured in Radar

Plumbing loss:— There is always some finite loss in the transmission lines which connect the o/p of the transmitter to the antenna. The losses in decibels per 100ft for radar transmission lines. At the lower radar frequencies the transmission line introduce little loss, unless its length is exceptionally long. At the higher radar frequencies, attenuation may not always small and may have to be taken into accont. one more loss that can occur at each connection or bend in the line and at the antenna rotary joint if used.

Connector losses are usually small but if the connectors are poorly made, it can contribute significant attenuation.

Since the same Tx line is generally used for both receiving and transmission, the loss to be inserted in the radar equation is twice the one way loss.

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

In an S-band (3000 MHz) the Plumbing losses might be

O/P of two or more radar receiver are combined and only one contain signal while other contain noise.

Lecture - 7

Nonideal equipment:— The transmitter power in radar equation was assumed to be O/P power. However transmitting devices (or components) not uniform in quality, nor should it be expected that any individual ~~tra~~ BJT or JFET (FET) remain at same level of performance through-out its usefull life. Also all the power is usually not uniform over the operating band of the devices. Thus for one or more reasons a loss factor may be introduced.

Operator loss:— Distracted, tired, overloaded, or not properly trained operator performance will decrease that will cause losses.

Field degradation:→ Factors which contribute to field degra-dation are poor tunning, weak components, water in Tx lines, incorrect mixer. crystal current, deterioration of receiver noise figure, loose cable connection etc.

Other loss factors:→ A radar designed to discriminate b/w moving targets and stationary objects may introduce additional loss over a radar without this facility. This discrimination technique results in complete loss of sensitivity for certain values of target velocity relative to the radar. These are called blind speeds.

The straddling loss accounts for the loss in SNR for targets not at the center of the range gate or at the center of the filter in multiple filter bank receiver.

Propagation Effects :-

In analyzing radar performance it is convenient to assume that the radar and target are both located in free space. However there are very few radar applications which approximate free space condition.

In most cases of practical interest, the earth surface and medium in which radar wave propagate can have a significant effect on radar performance. In some instant propagation factor might be important enough to overshadow all other factors that contribute to abnormal radar performance.

The effect of non-free space propagation on the radar are of three categories

1) Attenuation of the radar wave as it propagates through the earth's atmosphere,
2) Refraction of radar wave by the earth's atmosphere. and
3) lobe structure caused by interference b/w the direct wave from radar to target and the wave which arrives at the target via reflection from the ground.