UNIT-I

# BASICS OF RADAR



## Introduction :-

(RADIO DETECTION & RANG

Radar is an Electromagnetic system for the detection and location of objects. It operates by - transmitting a particular type of waveform, a pulse modul sinewave for example, and detects the nature of the echo signal.

Radar is used to extend the capability of obser- -ving the environment. Radar can be designed to see through those conditions impervious to normal human vision, such as darkness, haze, fog, rain and snow. In addition, radar has advantage of being able to measure the distance or range to the object.

An elementary form of radar consists of a transmitting antenna emitting EM radiation generated by an oscillator of some sort, a receiving antenna and an energy detecting device or receiver. A portion of the transmitted signal is intercepted by a reflecting object and is reradiated in all directions. It is the energy reradiated in the back direction that is of prime interest to the radar. The receiving antenna collects the returned energy and delivers it to a receiver,. where it is processed to detect the presence of the target and to extract its location and relative velocity.

* The distance of the target is determined by measuring the time taken for the radar signal to travel to the target and back. The usual method of finding the direction of arrival is with narrow antenna beams.

The name Radar means detect the presence of target and measure its range. Radar is a contraction of the words Radio detection and Ranging. There is no other competitive technique which can measure range as well as rapidly as can a radar.

The most common radar waveform is a train of narrow, rectangular-shape pulses modulating sinewave carrier. The distance, or range to the target is determined by measuring the time $T_R$ taken by the pulse to travel to the target and return. Since EM energy propagates at the speed of light $c = 3\times10^8$ m/s, the range $R$ is

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

The factor 2 appears in the denominator because of the two-way propagation of radar.

$$\Rightarrow \boxed{R(km) = 0.15\, T_R(\mu s)}$$

$$\boxed{R(nmi) = 0.081\, T_R(\mu s)}$$

→ Once a transmitted pulse is emitted by the Radar, a sufficient time must be provided to allow any reflecti signal to return and ~~directiof~~ detected before the nex pulse may be txd.

Echoes or reflected signal or pulse that arrive after the transmission of the next pulse are called second-time around echoes.

* The range beyond which targets appear as second-tin around echoes is called the maximum unambiguous range and is

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

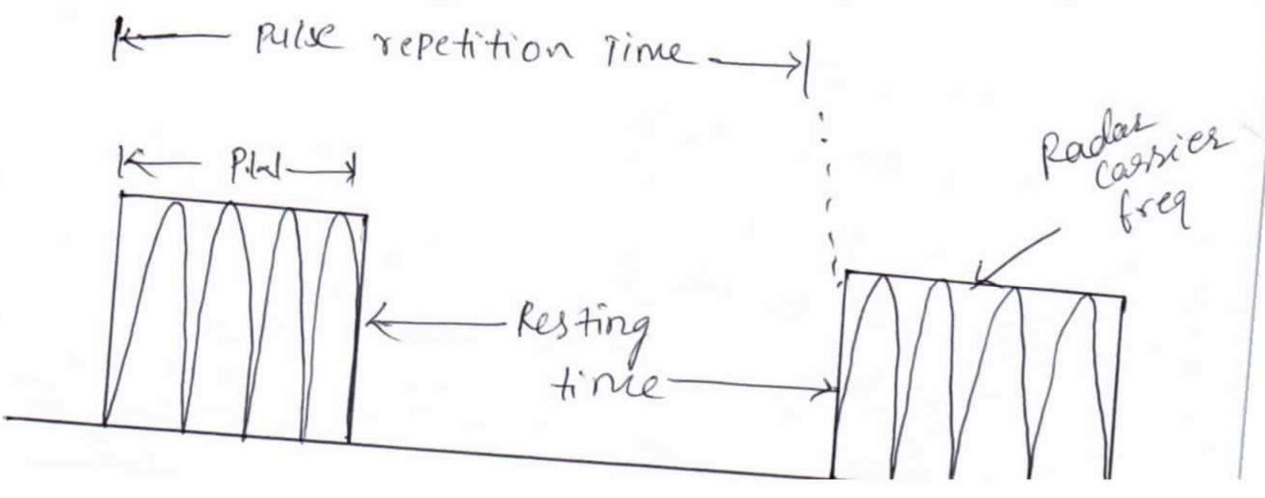
where $f_p$ = pulse repetition frequency.

→ Radar transmits pulse modulated waveform.

→ The technique of using a long modulated pulse to obtain the resolution of a short pulse but with the energy of a long pulse is known as pulse compression.

~~Simple form of Radar Equation:-~~

Figure: pulse transmission



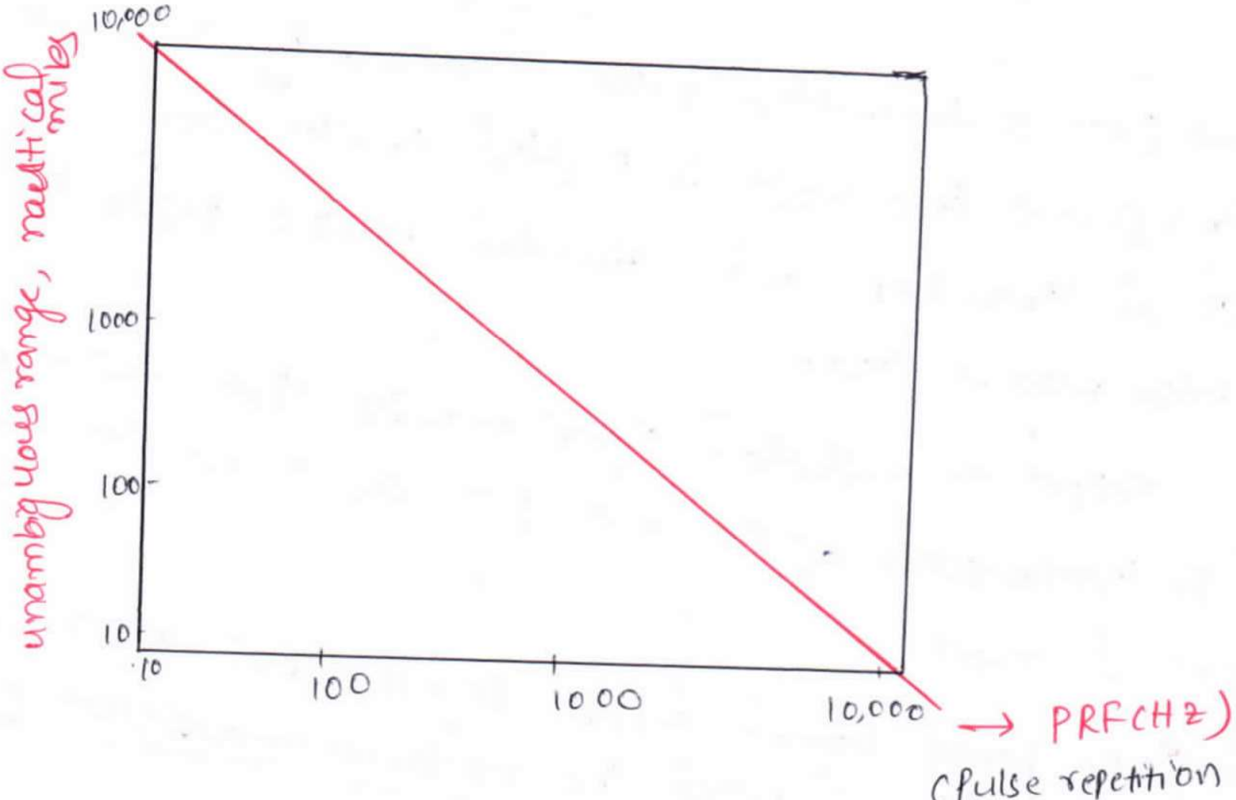
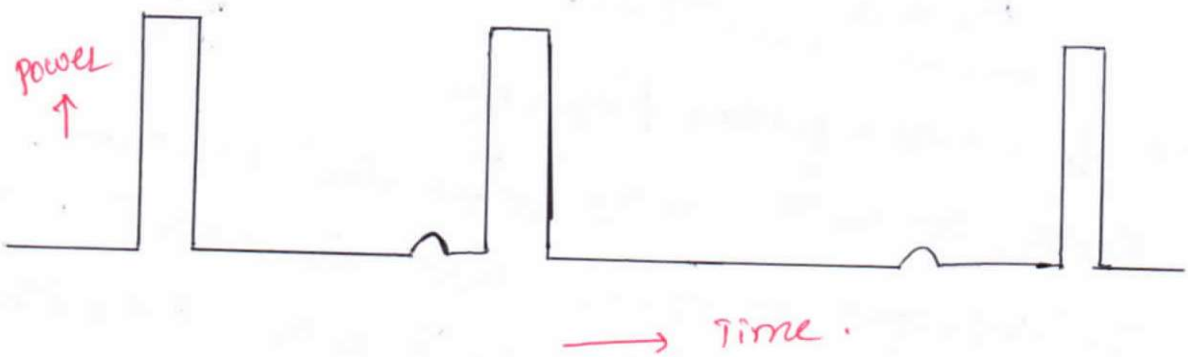



figure: Plot of maximum unambiguous range as a function of the PRF




characteristics :-

Radar can see the objects in

- day or night
- Rain or shine
- Land or air
- cloud or clutter
- fog or frost
- Earth or Planets
- Stationary or moving and
- Good or bad weather

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Radar gives following information:

- → The position of the object
- → The distance of objects from the location of radar
- → The size of the object
- → wheather the object is stationary or moving
- → velocity of the object
- → Distinguish friendly and enemy aircrafts
- → classification of materials.

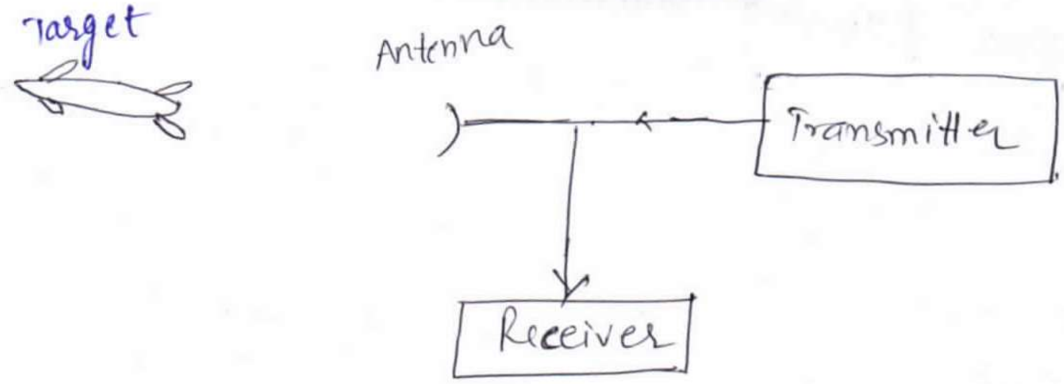
The range $\boxed{R = \frac{CT_R}{2}}$

$$\boxed{\begin{aligned} R(km) &= 0.15\ T_R(\mu s) \\ R(nmi) &= 0.081\ T_R(\mu s) \end{aligned}}$$ or

Each microsecond of round trip travel time corresponds to a distance of 0.081 nautical mile, 0.093 statute mile, 150 meters, 164 yards or 492 feets.

## Elements of Radar System:-

The elemental radar system consists of a transmitter unit, an antenna for emitting EM radiation & receiving the echo an energy detecting receiver & a processor.




→ A Portion of the transmitted signal is intercepted by a reflecting object (target) and is reradiated in all directions.

→ The antenna collects the returned energy in the backscatter direction and delivers it to the receiver

→ The distance to the receiver is determined by measuring the time taken for the EM signal to travel to the target & back.

→ The direction of the target is determined by the angle of arrival (AOA) of the reflected signal

→ If there is relative motion between the radar & the target, there is a shift in frequency of the reflected signal. which is a measure of the radial component of the relative velocity. This can be used to distinguish between moving targets & stationary targets.

## Pulse characteristics of Radar Systems:-

There are different pulse characteristics and factors that govern them in a Radar System.

→ Carrier.
→ Pulse width
→ pulse repetition frequency.
→ Unambiguous range.

Echo is a reflected EM wave from a target and it is received by a Radar receiver.

**Carrier:-** The carrier is used in a Radar system is an RF (Radio frequency) signal with microwave frequencies.

→ It is usually modulated to allow the system to capture the required data.

**Pulse width:-** The pulse width of the transmitted signal determines the dead zone.

→ When the Radar transmitter is active, the receiver input is blanked to avoid the damage of amplifiers.

**Pulse repetition frequency (PRF):-**

→ It is the number of pulses transmitted per second.

→ PRF is equal to the reciprocal of pulse repetition time (PRT). It is measured in Hz

$$\boxed{PRF = 1/_{PRT}}$$

→ Pulse interval time or pulse reset time (PRT) is the time interval between two pulses. It is expressed in milliseconds.

$$\boxed{\text{Pulse reset time} = \text{pulse repetition time} - \text{pulse width}}$$

## Types of Basic Radars :-

→ Monostatic and Bistatic

→ Pulsed radar

→ Continuous wave

→ FM - CW

→ Monostatic radar uses the same antenna for transmit and receive.

→ Bistatic radars use different antennas for transmission and reception.

→ In pulsed radar the transmitting signal is pulse.

→ In CW radar the transmitting signal is continuous

FM-CW radar transmits frequency modulated continuous wave

## Radar Range Equation :-

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

→ It is used as a tool to help in specifying radar subsystem 1-5 specifications in the design phase of a program.

→ If the transmitter delivers transmitter power ($P_t$) watts in to an isotropic antenna, then the power density ($W/m^2$) at a distance R from the radar

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

Here $\underline{4\pi R^2}$ represents the surface area of the sphere at distance $\underline{R}$.

Radars employ directive antennas to channel the radiated power $P_t$ into some particular direction.

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

where G is gain of an antenna.

→ It is defined as the ratio of the maximum radiation intensity from the subject antenna to the radiation intensity from a lossless isotropic antenna with the same power input.

→ The target intercepts a portion of the incident power and reradiates it in various directions.

→ The measure of the amount of incident power intercepted by the target and reradiated back in the direction of the radar is denoted as the radar cross section $\sigma$.

Power density of echo signal at radar $= \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2}$ — (3)

→ The radar cross-section $\sigma$ has the units of area. It is a characteristic of the particular target and is a measure of its size as seen by the radar.

→ The radar antenna captures a portion of the echo power.

→ If the effective area of the receiving antenna is denoted by $A_e$,

The Power $P_r$ received by the radar

$$\boxed{P_R = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2} A_e = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4}} \quad \text{— (4)}$$

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

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

This is the fundamental form of the radar equation.

→ The relationship between the transmitting gain and the receiving effective area of an antenna is

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

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

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

Note 1: These three forms of the equation for Rmax vary with different powers of $\lambda$. This results from implicit assumptions.

Note 2: The introduction of additional constraints can yield other $\lambda$ dependence.

Note 3: The observed maximum range is often much smaller than that predicted from the above eqn due to the exclusion of factors such as rainfall attenuating, clutter, noise figure etc.

## RADAR BLOCK DIAGRAM:-

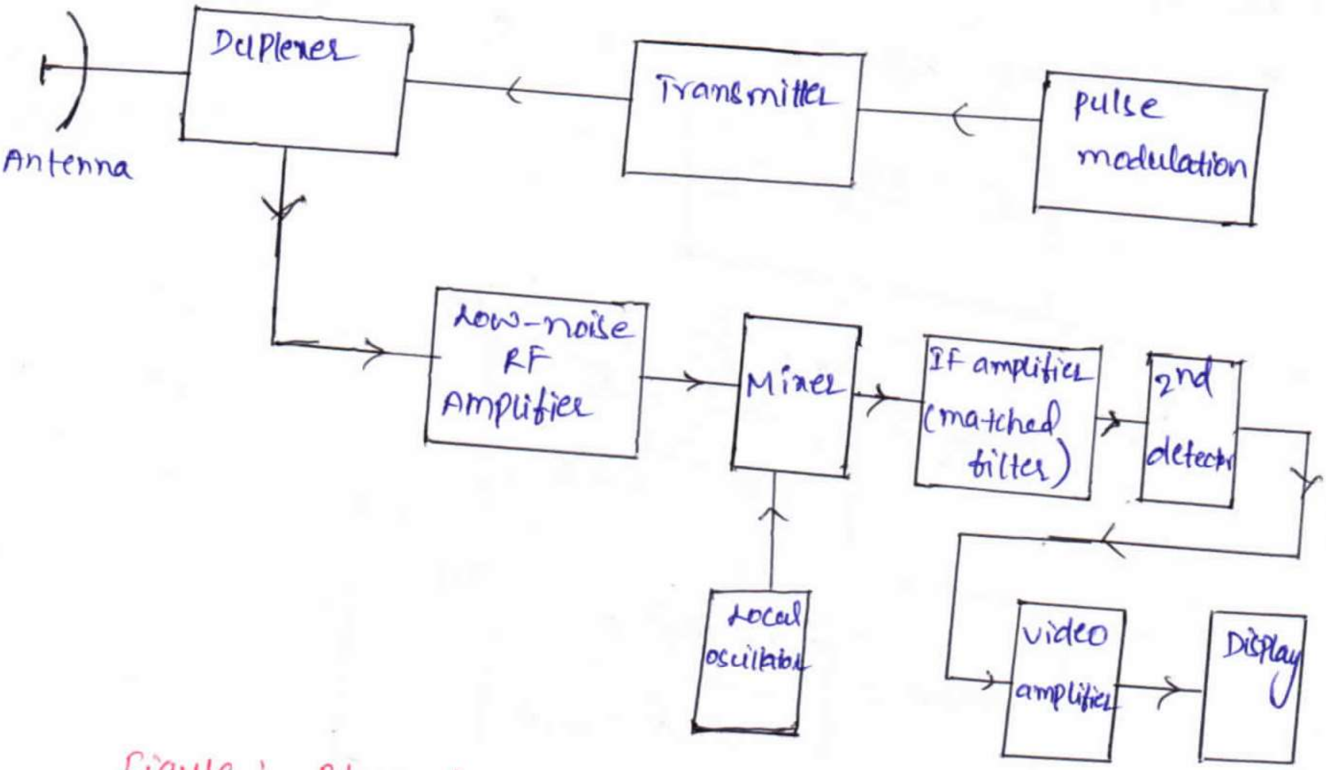



Figure: Block diagram of a Pulse radar.

Operation:-

→ The transmitter may be an oscillator, such as magnetron that is pulsed on and off by a modulator to generate the pulse train.

- → Magnetron is the most widely used oscillator
- → The typical power required to detect a target at 200NM is MW peak power and several KW average power.
- → Typical pulse lengths are several μs.
- → Typical PRFs are several hundreds of pulses per second.

→ The waveform travels to the antenna where it is radiated. The receiver must be protected from damage resulting from the high power of the transmitter. This is done by the duplexer.

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

→ Duplexer Consists of two gas discharge tubes called the TR (transmit/receive) and an ATR (Anti transmit/receive) cell.

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

→ Solid State ferrite circulators and receiver protectors with gas plasma tubes are also used in duplexers.

## Receiver :-

→ The receiver is usually a super heterodyne type.

→ The LNA is not always desirable. It provides better sensitivity, it reduces the dynamic range of operation of the mixer.

→ A receiver with just a mixer has greater dynamic range. It is less susceptible to overload and is less vulnerable to electronic interference.

→ The mixer and local oscillator convert the RF frequency to the IF frequency.

* The IF is typically 300 MHz, 140 MHz, 60 MHz, 30 MHz with bandwidths of 1 MHz to 10 MHz.

* The IF strip should be designed to give a matched filter output. This requires its H(f) to maximise the signal to noise power ratio at the output.

* for radar with rectangular pulses, a conventional IF filter characteristics approximates a matched filter if its bandwidth B and the pulse width $\tau$ satisfy the relationship

$$\boxed{B\tau \simeq 1}$$

* Signal to noise ratio is maximised if the $|H(f)|$ (magnitude of the frequency response) of the IF strip is equal to the signal spectrum of the echo signal $|S(f)|$ and the ARG H(f) (phase of freq response) is the negative of the ARG[S(f)]

i.e. H(f) and S(f) should be complex conjugates.

→ After maximising the SNR in the IF amplifier, the pulse modulation is extracted by the second detector & amplified by the video amplifier to a level where it can be properly displayed.

→ The display is usually a <u>CRT</u>.

→ <u>Timing signals</u> are applied to the display to provide zero range information. Angle information is supplied from the pointing direction of the antenna.

* The most common type of CRT displays is the Plan Position indicator (PPI) which maps the location of the target in azimuth and range in polar co-ordinat

* The PPI is intensity modulated by the amplitude of the receiver output and CRT electron beam sweeps outword from the centre corresponding to range.
* The beam rotates in angle in synchronisation with the antenna pointing angle.
* A B scope display uses rectangular co-ordinates to display range vs angle.
  i.e. the x-axis is angle and the y-axis is range.
* Since both the PPI and B scopes use intensity modulation, the dynamic range is limited.

* An Ascope plots target echo amplitude vs range on rectangular coordinates from some fixed direction. It is used primarily for tracking radar applications than for surveillance radar.

Instead of displaying the raw video output directly on the CRT, it might be digitised and processed and then displayed. This consists of

* Quantising the echo level at range - azimuth cells.
* Adding echo levels in each cell.
* Establishing a threshold level that permit...

the strong outputs due to target echoes to pass while rejecting noise.

* Maintaining the tracks (trajectories) of each target.
* Displaying the processed information.

This process is called automatic tracking and detection (ATD) in surveillance Radar.

## Antennas:-

→ The most common form of radar antenna is a reflector with parabolic shape, fed from a point source (horn) at its focus.

→ The beam is scanned in space by mechanically pointing the antenna.

→ Phased array antennas are sometimes used, then the beam is scanned by varying the phase of the array elements electrically.

## Radar display:-

→ A radar display is an electronic instrument for visual representation of radar data.

→ Radar displays can be classified from the stand point of their functions, the physical principles of their implementation, type of

# Radar frequencies :-



→ conventional Radars operates between 220MHz & 35GHz

→ Special purpose radars operate outside of this range.

* Sky wave HF - OTH (over - the - Horizon) can operate as low as 4 MHz

* Ground wave HF radars operate as low as 2MHz.

* Millimeter radars operate upto 95GHz.

* Lasers radars (Lidars) operate in IR and visible spectrum.

→ The radar frequency letter-band nomenclature is shown in the table.

| Band designation | Nominal frequency range | Specific radar bands based on ITU for region 2 |
|---|---|---|
| HF | 3-30MHz | |
| VHF | 30-300MHz | 138-144 MHz<br>216-225 MHz |
| UHF | 300-1000MHz | 420-450 MHz<br>890-942 MHz |
| L | 1GHz-2GHz | 1215-1400 MHz |
| S | 2-4 GHz | 2300-2500 MHz<br>2700-3700 MHz |
| C | 4-8 GHz | |
| X | 8-12 GHz | |
| Ku | 12-18GHz | 13.4-14.0GHz<br>15.7-17.7 GHz |
| K | 18-27GHz | 24.05-24.25 GHz |
| Ka | 27-40 GHz | 33.4-36.0 GHz |
| mm | 40-300 GHz | |

Table :- Standard radar-frequency band nomenclature.

Applications of radar:-

→ Radar has been emplyed on the ground, in the air, on the sea and in space

→ Ground based radar is applied chiefly to the detection, location and tracking of aircraft of space targets.

→ Shipborne radar is used as navigation aid and Safety device to locate buoys, shore lines and other ships. It is also used to observe aircraft.

→ Airborne radar is used to detect other aircraft, ships and land vehicles. It is also used for mapping of terrain and avoidance of terrain and thunderstorms.

→ Spaceborne radar is used for the remote sensing of terrain and sea, and for rendezvous/ docking.

Air traffic control:-

→ Radars are used to provide air traffic controllers with position and other information on aircraft flying with in their area of responsibility.

→ High resolution radar is used at large airports to monitor aircraft etc.

→ GCA (Ground controlled Approach) provides an operater with high accuracy aircraft position information in both the vertical and horizontal.

→ MLS (Microwave Landing System) and ATC radar beacon system are based on radar technology. 

* Air Navigation
  - → weather avoidance radar is used on aircraft to detect
  - → Terrain avoidance
  - → Radio altimeter
  - → Ground mapping radar

* Ship Safety
  - → Avoids collision with other ships.
  - → Detection and tracking.
  - → Shore based radars of moderate resolution are used.

* Space :-
  - → Landing on moon.
  - → Detection and tracking of satellites.
  - → Remote Sensing.

* Law Enforcement
  - → Speed of automobiles.
  - → Detection of intruders.

* Remote Sensing:-
  - → Used for sensing geophysical objects (Environment)
  - → Probe the moon and the pulses (Radio astronomy)
  - → Radar is used to determine the best frequency.

Military :-

The traditional role for surveillance, navigation and for the control and guidance of weapons.

Advantages :-

→ It acts as a powerful eye

→ Can see through fog, rain, snow, darkness, haze, clouds and any in insulators.

→ It can find out the range, angular position, location and velocity of targets.

Limitations :-

→ Cannot recognise the color of the object.

→ It cannot resolve the targets at short distances like human eye.

→ It cannot see targets placed behind the conducting sheets.

→ It cannot see targets hidden in water at long ranges.

Prediction of Range Performance :-

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

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



→ Radar equation states that if long ranges are desired, the transmitted power must be large, the radiated energy must be concentrated in to a narrow beam, the received echo energy must be collected with a large antenna aperture, and the receiver must be sensitive to weak signals.

→ The actual range would be one half of the maximum.

→ This is due to failure of above equation to include the various losses.

→ It is also due to the statistical nature of several parameters such as $S_{min}$, $\sigma$ (radar cross section of target) and propagation losses.

→ Because of the above, the range is described by the probability that the radar will detect a certain type of target at a certain distance.

## Minimum detectable signal:-

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

→ Detection is based on establishing a threshold level at the output of the receiver.

* If the receiver output exceeds the threshold, a signal is assumed to be present. This is called threshold detection.

consider the output of a typical radar receiver as a function of time is as shown in figure.

→ This might represent one sweep of the video output displayed on an A-scope.

→ The envelope has a fluctating appearance caused by the random nature of noise.

→ If a large signal is present such as at A in figure.

It is greater than the surrounding noise peaks and can be recognised on the basis of its amplitude

→ If the threshold level is set sufficiently high, the envelope would not generally exceed the threshold if noise alone were present.

If the signal is small, it would be more difficult to recognise its presence

→ The threshold level must be low if weak signals are to be detected, but it cannot be so low that noise peaks cross the threshold and give a false indication of the presence of targets.

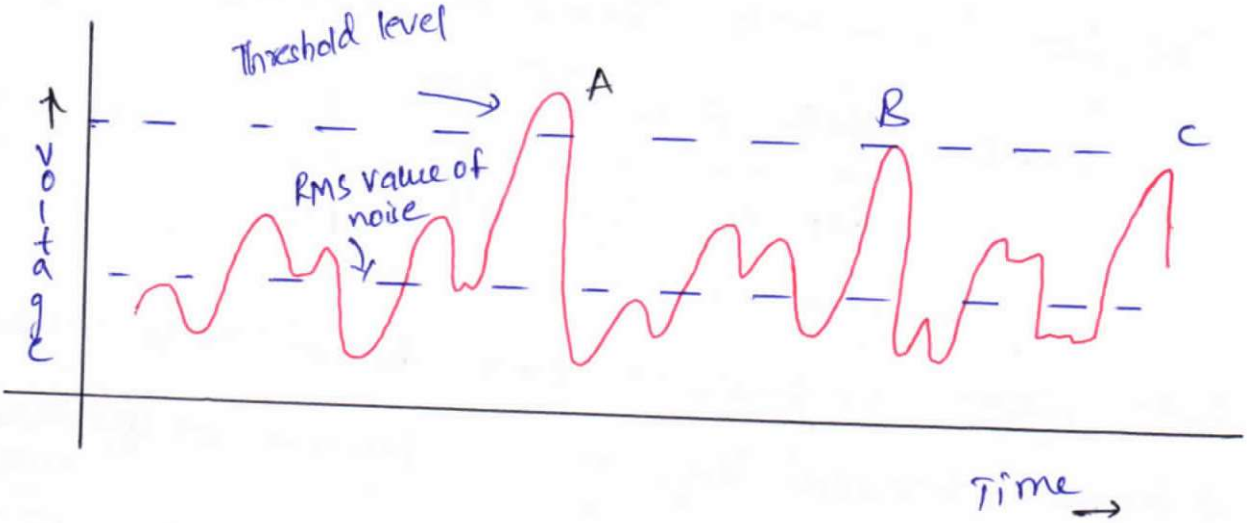



Figure: Typical envelope of the radar receiver output as a function of time.

→ The selection of proper threshold level is a compromise that depends up on how important it is.

→ If a mistake is made either by

1) failing to recognise a signal that is present (probability of a miss)

or by

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

## False alarm:-

False alarm is an erroneous radar target 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 target.

→ The false alarm rate (FAR) is calculated using

$$\boxed{FAR = \frac{\text{false targets per PRT}}{\text{No. of range cells}}}$$

→ False alarms are generated when thermal noise exceeds a pre-set threshold level, by the presence of spurious signal.

→ If threshold is set too low, large number of false alarms will mask detection of valid targets.

* Threshold is set too high : probability of detection = 20%
* " " optimal : probability of detection = 80%

But one false alarm araises.

false alarm rate = 1/666

* Threshold is set too low: large no. of false alarms arise
* Threshold is set variable: Constant false alarm rate.

## 1. Receiver Noise :-

→ Noise is unwanted EM energy which interferes with the ability of the receiver to detect the wanted signal

→ Noise may originate with in the receiver itself, or it may enter via the receiving antenna along with the desired signal

→ Noise generated by the thermal motion of the conduction e⁻s in the ohmic portions of the receiver input stages is known as thermal Noise or Jhonson Noise.

$$\boxed{\text{Available thermal - Noise power} = KTB_n} \rightarrow (1)$$

K = Boltzmanns constant.

for radar receivers of the super heterodyne type, the receiver bandwidth is approximately

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

$|H(f)|$ = frequency - response characteristic of IF amplifier

$f_0$ = freq of max. response.

$B_n$ = Noise Bandwidth.

# Radar Equation

## Probability density functions :-

→ The basic concepts of probability theory needed in solving noise problems.

→ Noise is a random phenomenon.

→ Phenomena of a random nature can be described with the aid of probability theory.

→ Probability is a measure of the likelihood of occurance of an event.

→ The scale of probability ranges from 0 to 1.

→ Probability density function is needed to analyse the detection of signals in noise.

## Probability density function (PDF) :-

Consider the variable $x$ as representing a typical measured value of a random process such as a noise voltage or current.

Then pdf $f(x)$ is defined as

$$f(x) = \lim_{\substack{\Delta x \to 0 \\ N \to \infty}} \frac{(\text{Number of values in range } \Delta x \text{ at } x)/\Delta x}{\text{Total number of values}} \quad -①$$

$$P(x_1 < x < x_2) = \int_{x_1}^{x_2} f(x)\,dx \quad -②$$

→ By defination, the pdf is positive

$$\boxed{\int_{-\infty}^{\infty} f(x)\, dx = 1}$$

→ The average value of a variable function $\phi(x)$ is describ by pdf $f(x)$

$$\langle \phi(x) \rangle_{av} = \int_{-\infty}^{\infty} \phi(x) f(x)\, dx$$

→ The avg value of a variable function $\phi(x)$ of a random variable $x$ is

$$\langle \phi(x) \rangle_{avg} = \int_{-\infty}^{\infty} \phi(x) f(x)\, dx$$

$$\langle x \rangle_{avg} = \int_{-\infty}^{\infty} x f(x)\, dx = m_1$$

and the mean square value is

$$\langle x^2 \rangle_{av} = m_2 = \int_{-\infty}^{\infty} x^2 f(x)\, dx$$

→ The quantities $m_1$ & $m_2$ are sometimes called the 1st and 2nd moments of the random variable $x$.

→ variance is defined as

$$\mu_2 = \sigma^2 = \langle (x-m_1)^2 \rangle_{av} = \int_{-\infty}^{\infty} (x-m_1)^2 f(x)\, dx$$

$$= m_2 - m_1^2$$

$$= \langle x^2 \rangle_{av} - (x)^2_{av}$$

→ The variance is the mean square deviation of $x$ about its mean & is sometimes called the second central moment

→ The square root of the variance $\sigma$ is called the standard deviation and is the root mean square (rms) value of the ac- component.

→ In RADAR systems, there are different types of pdf

→ Uniform pdf

→ Gaussian (Normal) pdf

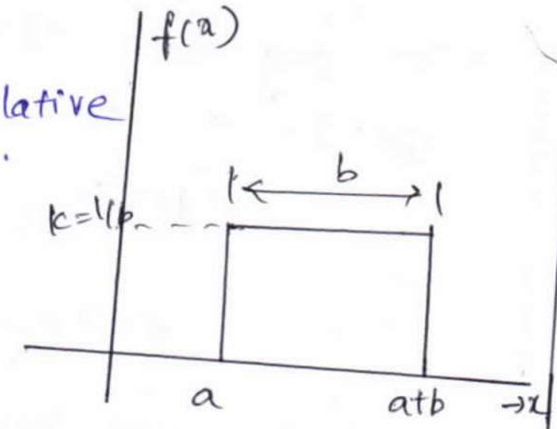
→ Rayleigh pdf

→ Eponential pdf

## Uniform probability density function (pdf):-

It is defined as

$$f(x) = \begin{cases} k & a < x < b \\ 0 & x < a, x > a+b \end{cases}$$




Ex: Phase of a random sine wave relative to a particular origin of time.

→ The constant k maybe found by using

$$\int_{-\infty}^{\infty} f(x)\, dx = 1$$

$$\int_{a}^{a+b} k\, dx = 1 \quad \text{and} \quad k = \frac{1}{b}$$

→ The average value of $x$ is

$$m_1 = \int_{a}^{a+b} \frac{1}{b} x\, dx = \frac{1}{b} \frac{x^2}{2} \Big]_{a}^{a+b} = a + \frac{b}{2}$$

$$m_2 = \int_{a}^{a+b} \frac{x^2}{b}\, dx = a^2 + ab + \frac{b^2}{3}$$

Variance $= \sigma^2 = m_2 - m_1^2$

$$= a^2 + ab + \frac{b^2}{3} - \left(a + \frac{b}{2}\right)^2$$

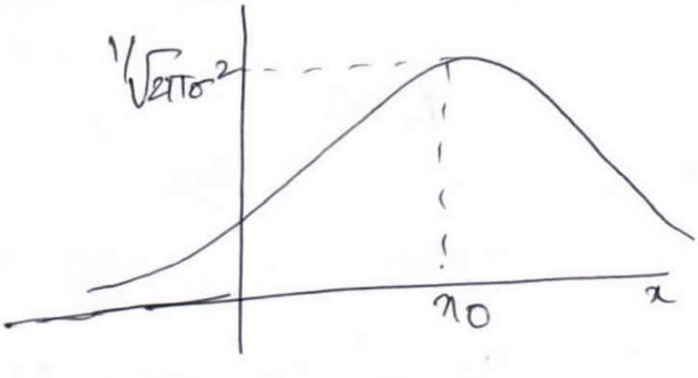
$$\Rightarrow \sigma^2 = b^2/12$$

Standard deviation $= \sigma = \dfrac{b}{2\sqrt{3}}$

## Gaussian probability density function:-

→ Thermal noise or shot noise, may be represented by gaussian statistics.

→ The gaussian density function has a bell-shaped appearance




→ It is defined by

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-x_0)^2}{2\sigma^2}}$$

$$m_1 = x_0 = \int_{-\infty}^{\infty} x f(x) dx$$

$$m_2 = \int_{-\infty}^{\infty} x^2 f(x) dx = x_0^2 + \sigma$$

$$\sigma^2 = m_2 - m_1^2$$

## central limit theorem:-

→ for the normal distribution, no matter how large a value of $x$, we may choose, there is always a finite probability of finding a greater value.

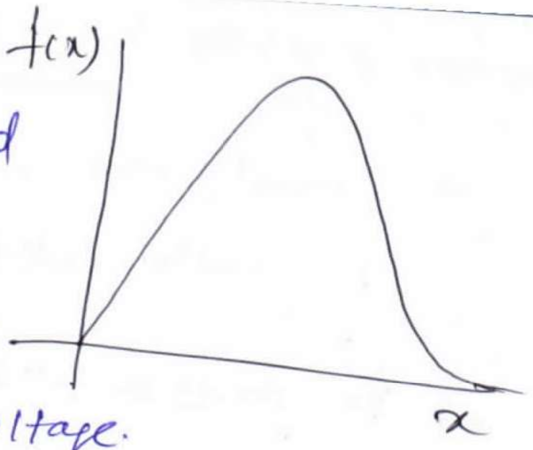
→ Hence if noise at the input to a threshold detector is normally distributed there is always a chance for a false alarm.

## Rayleigh probability density function:-

It is defined by

$$f(x) = \frac{2x}{\langle x^2 \rangle_{av}} e^{-\frac{x^2}{\langle x^2 \rangle_{av}}} \qquad x \geq 0$$

→ It describes the envelope of the noise output from a narrow band filter.




→ If $x^2$ is replaced by $w$, where $w$ represents power instead of voltage.

$$f(w) = \frac{1}{w_0} e^{-w/w_0} \qquad w \geq 0$$

where $w_0$ = avg power

This is exponential pdf and sometimes called as Rayleigh-Power pdf.

## Signal to Noise Ratio:—

→ SNR will be obtained at the output of IF amplifier.

→ This is necessary to achieve a specific probability of detection without exceeding a specified prob. of false alarm.

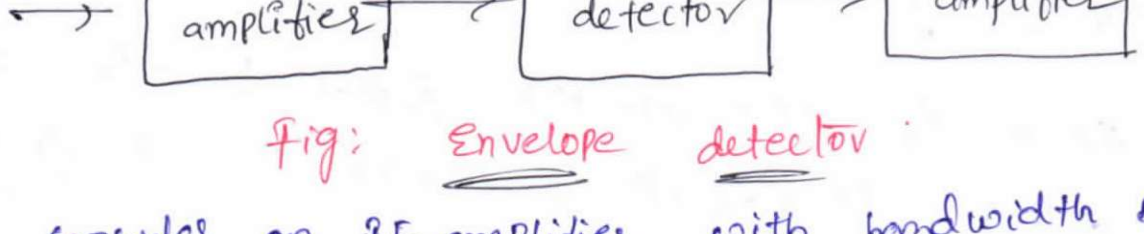



Fig: Envelope detector

→ consider an IF amplifier with bandwidth $B_{IF}$ followed by a second detector and a video amplifier with bandwidth $B_V$.

→ The second detector and vide amplifier are assumed to form an envelope detector.

i.e. one which rejects the carrier freq but passes the modulation envelope.

→ The video bandwidth $B_V$ must be greater than $B_{IF}/2$ in order to pass all the video modulation.

→ The Envelope detector may be either a square law or linear detector.

→ The noise entering the IF amplifier is Gaussian with the pdf given by

$$f(v) = \frac{1}{\sqrt{2\pi\psi_0}} e^{-v^2/2\psi_0} \quad - (1)$$

where $f(v)\,dv$ is the probability of finding the noise voltage $v$ between the values $v$ and $v+dv$. $\psi_0$ is the variance and the mean value of $v$ is taken to be zero.

→ when this gaussian noise is passed through the narrow band IF strip, the prob d.f of the envelope of the noise is Rayleigh pro df

$$f(R) = \frac{R}{\psi_0} e^{-R^2/2\psi_0} \quad - (2)$$

where $R$ is the amplitude of the envelope of the filter output.

→ The Prob. of the envelope of the noise voltage will lie between the values of $V_1$ & $V_2$ is

$$\text{Probability}\ (V_1 < R < V_2) = \int_{V_1}^{V_2} \frac{R}{\psi_0} e^{-\frac{R^2}{2\psi_0}}\, dR \quad -(3)$$

The prob. that the noise voltage envelope will exceed the voltage threshold $V_T$ is

$$\text{Probability}\ (V_T < R < \infty) = \int_{V_T}^{\infty} \frac{R}{\psi_0} e^{\frac{-R^2}{2\psi_0}}\, dR$$

$$= e^{\frac{-V_T^2}{2\psi_0}} = P_{fa} \quad -(4)$$

→ whenever the voltage envelope exceeds the threshold, a target detection is considered to have occurred.

→ The prob of a false alarm is the prob that noise will cross the threshold. The above eqn gives the prob of false alarm.

→ The average time interval between crossings of the threshold by noise alone is defined as false-alarm time $T_{fa}$

$$\boxed{T_{fa} = \lim_{N \to \infty} \frac{1}{N} \sum_{k=1}^{N} T_k} \quad -(5)$$

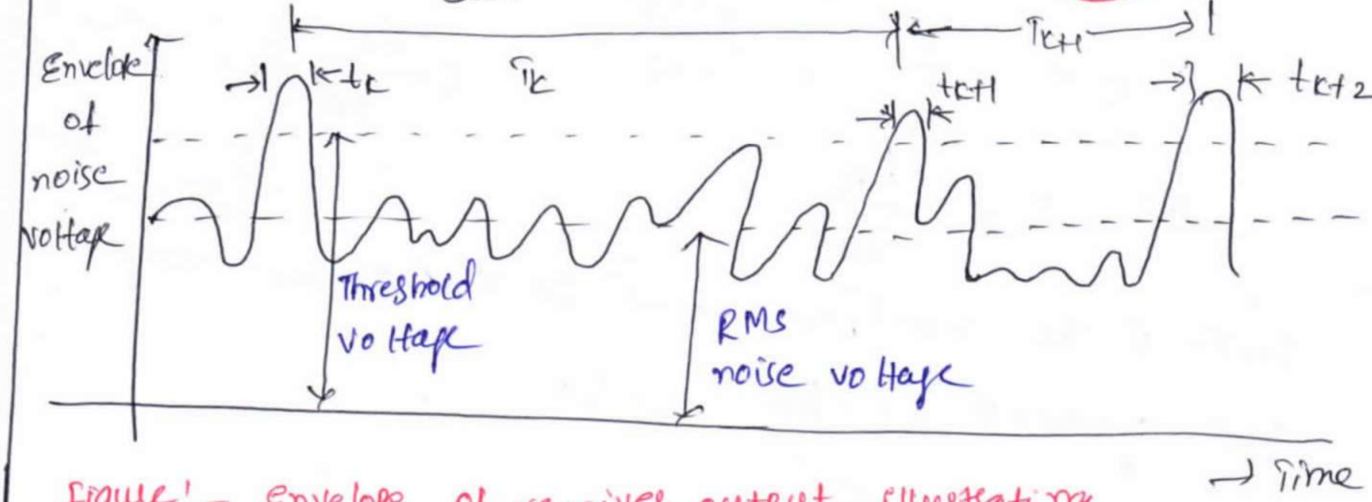
where $T_k$ is the time between crossings of the threshold $V_T$ by the noise envelope, when the slope of the crossing is +ve.

→ The false-alarm prob is defined as the ratio of the duration of time the envelope is actually above the threshold time.

$$P_{fa} = \frac{\sum_{k=1}^{N} t_k}{\sum_{k=1}^{N} T_k} = \frac{\langle t_k \rangle_{av}}{\langle T_k \rangle_{av}} = \frac{1}{T_{fa} B} \quad \text{— (6)}$$

for envelope detector

$$T_{fa} = \frac{1}{B_{IF}} e^{+V_T^2/2\psi_0} \quad \text{— (7)}$$




figure!– Envelope of receiver output illustrating false alarms due to noise.

→ Above figure illustrates occurance of false alarm. The average time between crossings of the decision threshold when noise alone is present is called the false alarm time.

$$T_{fa} = \lim_{N\to\infty} \frac{1}{N} \sum_{k=1}^{N} T_k \quad \rightarrow (8)$$

Ex!– Bandwidth of the IF amplifier were 1 MHz
$T_{fa} = 15\,min$

$$P_{fa} = \frac{1}{T_{fa} B} = \frac{1}{1\times10^{6}\times15\times60} = 1.11\times10^{-9}$$

Probability of detection:—

consider an echo signal represented as sine wave of amplitude A along with gaussian noise at the input of the envelope detector.

The pdf of the envelope R at the video output

$$P_s(R) = \frac{R}{\psi_0} e^{\frac{-(R^2+A^2)}{2\psi_0}} \quad I_0\left(\frac{RA}{\psi_0}\right) \quad -(1)$$

let $z = \frac{RA}{\psi_0}$

$I_0(z)$ is the modified Bessel function of zero order and argument z. for large z.

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

when the signal is absent $A = 0$, equation reduces to

$$P_s(R) = \frac{R}{\psi_0} e^{-R^2/2\psi_0} \quad -(2)$$

Equation (1) is called the Rice prob. d. f.

→ The prob. of detecting the signal is the prob that the envelope R will exceed the threshold $V_T$.

The prob. of detection.

$$P_d = \int_{V_T}^{\infty} P_s(R)\, dR \quad -(3)$$

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

This cannot be evaluated by simple means & numerical techniques or a series approximation must be used.

A series approximation valid when $\frac{RA}{\psi_0} \gg 1$, $A \gg |R-A|$

$$P_d = \frac{1}{2}\left(1 - \operatorname{erf}\frac{V_T - A}{\sqrt{2\psi_0}}\right) + \frac{e^{-(V_T-A)^2/2\psi_0}}{2\sqrt{2\pi}(A/\sqrt{\psi_0})} \times \left[1 - \frac{V_T - A}{4A} + \frac{(V_T-A)^2\psi_0}{8A^2/\psi_0} + \cdots\right]$$

$\psi$ = mean noise power

$$\frac{A}{\sqrt{\psi_0}} = \frac{\text{Signal amplitude}}{\text{rms noise Voltage}} = 3 \qquad \operatorname{erf} z = \frac{2}{\sqrt{\pi}}\int_0^z e^{-x^2}dx$$

$$= \frac{\sqrt{2}(\text{rms Signal Voltage})}{\text{RMS noise voltage}}$$

$$\frac{A}{\sqrt{\psi_0}} = \left(2\frac{S}{N}\right)^{1/2} \text{ and } \frac{V_T^2}{2\psi_0} = \ln\frac{1}{P_{fa}}$$

→ The probability of detection $P_d$ can be expressed in terms of S/N and ratio of the threshold-to-noise ratio $V_T^2/2\psi_0$

→ The probability of flase alarm is also a function of $V_T^2/2\psi_0$

$$S/N = A + 0.12AB + 1.7B$$

where $A = \ln\left[\frac{0.62}{P_{fa}}\right]$ and $B = \ln\left[\frac{P_d}{1-P_d}\right]$

$$P_d = \frac{1}{2}\left[1 - \operatorname{erf}\frac{V_T - A}{\sqrt{2\psi_0}}\right] + \left[\frac{(V_T-A)^2/2\psi_0}{e\, 2\sqrt{2}\pi A/\sqrt{\psi_0}}\right] + \left[1 - \frac{V_T}{4A} + \frac{(V_T-A)^2/\psi_0}{8A^2/\psi_0}\right]$$

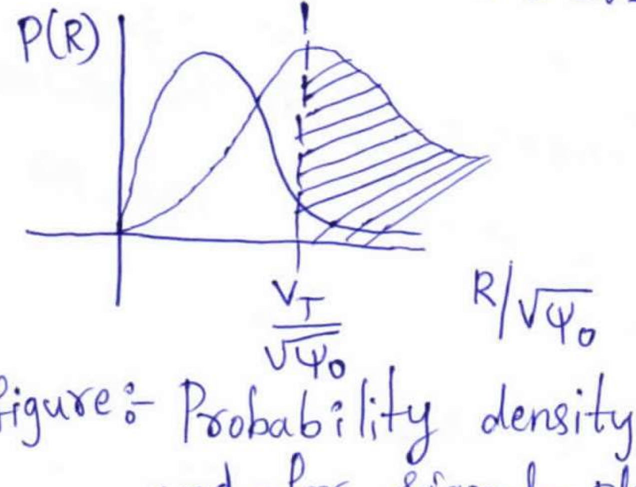



figure:- Probability density function for noise alone and for signal-plus-noise, illustrating the process of Threshold detection.

## Integration of Radar Pulses :-

→ Many pulses are usually returned from any particular target and can be used to improve detection.

The number of pulses $n_B$ as the antenna scans is

$$n_B = \frac{\theta_B f_P}{\theta_S} = \frac{\theta_B f_P}{6\omega_m}$$

where $\theta_B$ = antenna beamwidth (deg)

$f_P$ = pulse repetition freq

$\theta_S$ = antenna scan rate (deg/sec)

$\omega_m$ = antenna scan rate (rpm)

→ Integration of pulses is two types

1. prediction (or) coherent integration (detection)
2. post detection (or) Non-coherent integration.

→ The process of summing radar echoes to improve detection is called Integration.

→ Integration before detection is called pre detection or coherent detection.

→ Integration can be accomplished in the receiver either before the second detector or after the second detector.

If predetection is used

$$SNR_{integrated} = n\ SNR.$$

If post detection is used 

$SNR_{integrated} \leq n\,SNR_1$ due to losses in the detector.

→ Pre detection integration is difficult because it requir maintaining the phase of pulse returns.

→ post detection is relatively easy especially using digital processing techniques by which digitised version of all returns can be recorded and manipulated.

→ Integration efficiency $E_i(n) = \dfrac{(S/N)_1}{n(S/N)_n}$

→ $E_i(n) < 1$ [except for prediction].

→ $(S/N)_1$ is the SNR required to produce the required Pd for one pulse.

→ $(S/N)_n$ is the signal to noise ration required to produce the required Pd for n pulses.

→ The improvement in SNR where n pulses are integrated is called improvement factor.

The integration improvement factor

$$I_i(n) = I_i = n\,E_i(n)$$

$$I_i(n) < n$$

$$n_{eq} = n\,E_i(n)$$

voltage integrator $V = \sum_{i=1}^{n} V_i\, e^{-c(i-1)v}$

$$R_{max}^4 = \frac{P_t G A_e \sigma n\, E_i(n)}{(4\pi)^2 kTB_n F_n (S/N)_1}$$

## Radar cross section ($\sigma$):-

when the radar pulse hits a target, the energy is reflected and refracted in many ways depending on

→ The material it is made of

→ Its shape

→ Its Orientation with respect to the radar.

→ 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.

→ In other words it is defined as the ratio of its effective reflected power to the incident power density

$$RCS = \sigma = 4\pi \frac{\text{Reflected / unit solid angle}}{\text{Incident power / unit area}}$$

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

where $R$ = distance between radar & target

$E_r$ = reflected field intensity at radar

$E_i$ = Strength of incident field at target

→ for most targets such as aircraft, ships and terrain the $\sigma$ does not bear a simple relationship to physical area.

→ scattered field is defined as the difference between the total field in the presence of the object & the field that would exist if the object were absent.

→ Diffracted field is the total field in the presence of the object (1-20)

→ for radar backscatter, the two fields are the same.

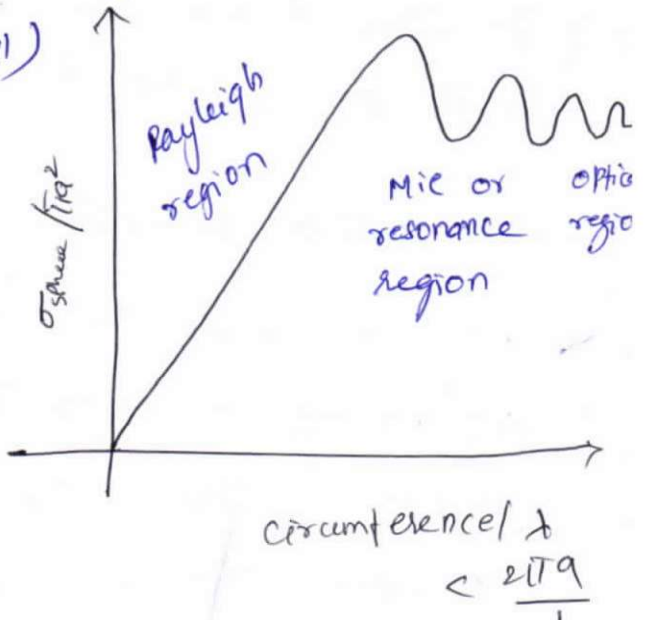
→ The $\sigma$ can be calculated by using maxwell's equations only for simple targets such as sphere.

→ The radar cross section of a simple sphere is as shown in figure as a function of its circumference measured in wavelength.

→ $\frac{2\pi a}{\lambda}$ is circumference of sphere in wavelengths.

→ where 'a' is the radius of sphere.

→ The region where the size of the sphere is compared with wavelength ($\frac{2\pi a}{\lambda} << 1$) is called Rayleigh region.




→ The crosssection of rain drops and other meterological particles fall with in this region at the usual radar freq's.

→ Since cross section of objects within Rayleigh region varies as $\lambda^{-4}$.

→ At long wavelengths (low freq's), rain & clouds are essentially invisible to radars.

→ The usual radar targets are much larger than raindrops or cloud particles.

→ If $\frac{2\pi a}{\lambda} \gg 1$, the region is known as optical region.

→ for large $\frac{2\pi a}{\lambda}$, the $\sigma$ approaches the optical cross section $\pi a^2$.

→ The region between Rayleigh and optical region is known as Mie or resonance regions.

→ In this region the $\sigma$ is oscillatory with frequency.

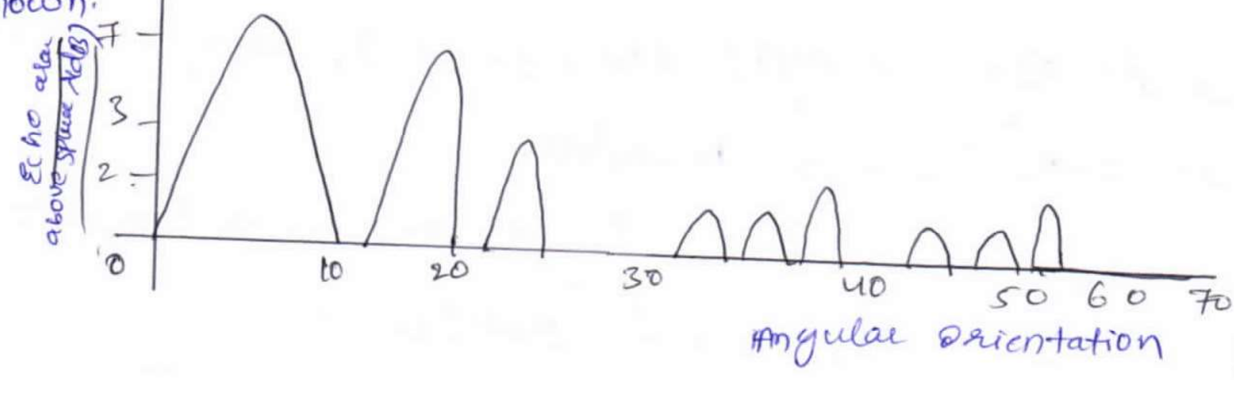
→ The cross-section of other objects will depend up on the direction as viewed by the radar.

→ The Sphere is no matter from what aspect it is viewed, so its $\sigma$ will not be aspect sensitive.

→ consider backscatter cross section of a long thin rod as a function aspect.

→ The rod is $39\lambda$ long & $\lambda/4$ in diameter and is made of silver. If rod is madeup of steel instead of silver. The $\sigma$ of the thin rod is small when $\theta = 0°$ since the physical area is small.

→ The first max would be about 5 dB below that shown.



## Radar cross section of targets (cone sphere):-

→ A cone whose base is capped with a sphere such that the first derivatives of the cone & sphere contours are equ at the join between the two.

→ The crosssection of the cone-sphere from the vicinity of the noise-on direction is quite low.

→ Scattering from any object occurs from discontinuities.

→ Hence the backscattering of the cone-sphere are from the tip and from the join between the con and the sphere.

→ There is also a backscattering contribution from a "creeping wave" which travels around the base of the sphere.

→ The nose on radar cross section is small & decreases as the square of the wavelength.

→ The cross section is small over a relatively large angular region.

* when the cone is viewed at ⊥lar incidences ($\theta = 90 - \alpha$, where $\alpha$ is the half angle) a large specular return is obtained.

* from the rear, the $\sigma$ is approximately that of a sphere

* The nose one $\sigma$ for 'f' above the Rayleigh region & for a wide range of $\alpha$, has a max of $0.4\lambda^2$ & min of $0.01\lambda^2$. This gives a very low backscatter. (Ex at $\lambda = 3cm$, $\sigma = 10^{-4} m^2$).

→ In Practice to achieve a low σ with a cone sphere, the tip must be sharp, the surface must be smooth and no holes or protuberances allowed. The join between the cone and the sphere must have a continuous first derivative.

→ The use of materials such as carbon fibre composites can further reduce σ.

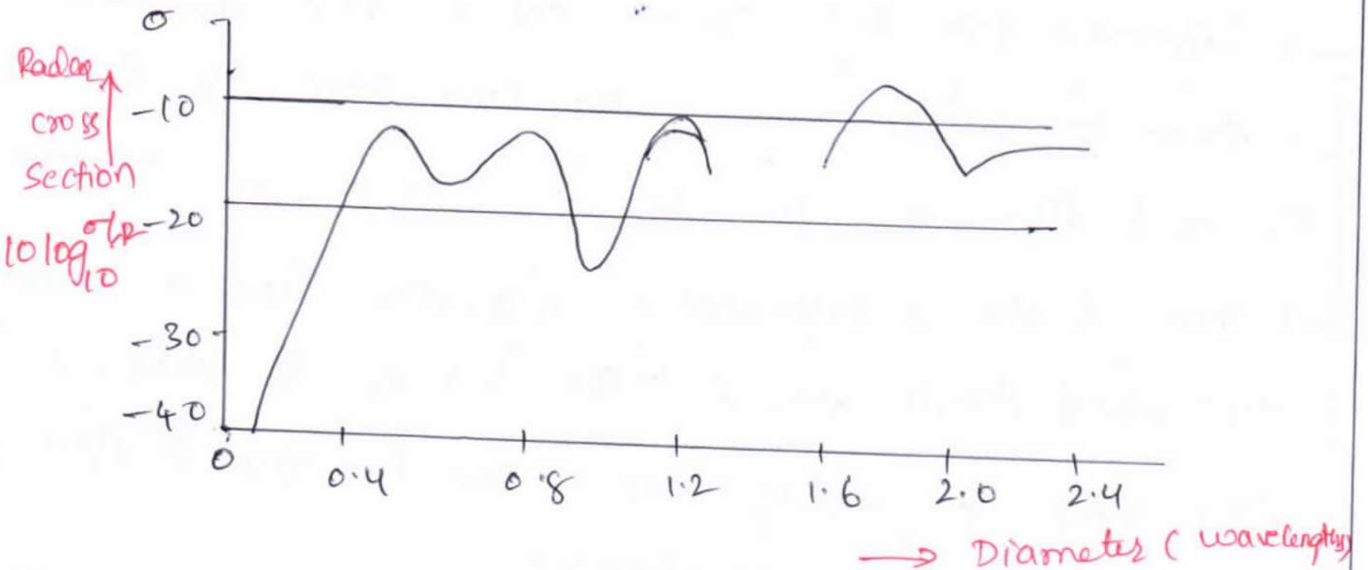



Figure:- Radar crosssection of a cone sphere with 15° half angle as a function of the diameter in wavelengths.

Ex:- σ at S band for 3 targets having the same projected area.

| | | |
|---|---|---|
| corner reflector | : | $1000 m^2$ |
| Sphere | : | $1 m^2$ |
| cone Sphere | : | $10^{-3} m^2$ |

Transmitter Power:-

→ The power $P_t$ in the radar range eqn

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

is the peak power

→ The peak pulse power is not the instantaneous peak power of a sine wave.

→ It is defined as the power averaged over that carrier-freq cycle which occurs at the maximum of the pulse of power.

Peak power = $\frac{1}{2}$ the maximum instantaneous power.

→ The average power ($P_{av}$) is defined as the average transmitter power over the pulse repetition period.

→ If the txd waveform is a train of rectangular pulses of width $\tau$ and pulse-repetition period $T_p = 1/f_p$

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

$P_{av}/P_t = \tau/T_p = \tau f_p$ is called duty cycle of the radar

$$\boxed{\text{Duty cycle} = \frac{P_{av}}{P_t} = \frac{\tau}{T_p} = \tau f_p}$$

The duty cycle for pulse radar = 0.001

The " of CW radar = 1

The radar eqn interms of the avg power rather than the peak power

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

The bandwidth and the pulse width are grouped together since the product of the two is usually of the order of unity in most pulse radar applications.

→ If the transmitted waveform is not a rectangular pulse, radar equation is expressed in terms of energy

$$\boxed{E_T = P_{av} / f_p}$$

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

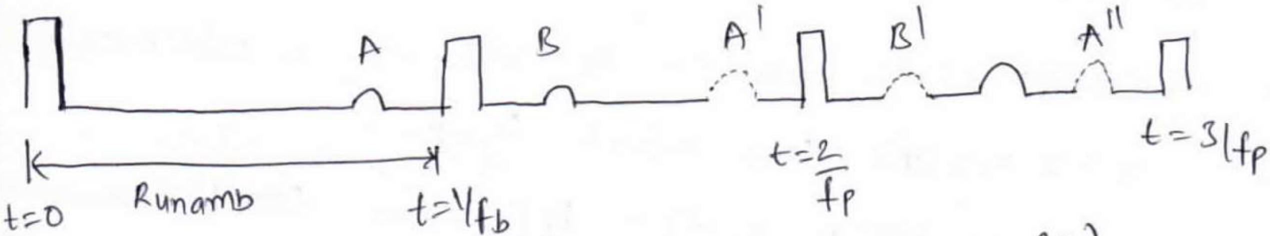
## Pulse repetition frequency & Range ambiguities :-

→ The pulse repetition freq (prf) is determined primarily by the maximum range at which targets are expected.

→ If the prf is made too high, the prob of false alarm is increased.

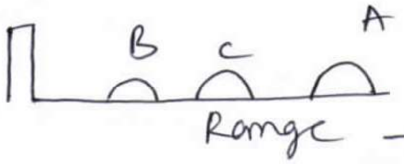
→ Echo signals received after an interval exceeding the pulse repetition period are called multiple-time-around echoes. They can result in erroneous or confusing range measurements.

Consider the three targets labelled A, B & C as shown in the figure. Target A is located within the maximum unambiguous range $R_{unamb}$ of the Radar, target B is at a distance greaterthan Runamb but lessthan 2 Runamb. while targe c is greater than 2 Runamb but lessthan 3 Runamp.




(a)

Time (or Range) ⟶




(b)


(c)

→ The multiple - time around echoes on the A-scope cannot be distinguished from proper target echoes actually with in the maximum unambiguous range.

→ Only the range measured for target A is correct, those for B & C are not.

→ By varying pulse repetition frequency, the multiple - time - around echoes can be distinguished from unambiguous echoes.

→ However, echoes from multiple - time - around targets will be spread over a finite range as shown in fig (c).

→ The prf may be changed continuously within prescribed limits or it may be changed directly among degree of the multiple time targets

→ Second - time targets need only two separate repetition frequencies in order to be resolved.

→ Alternative method to mask successive pulses to identify multiple times around targets include changing amplitude, pulse width, freq, Phase or Polarisation from pulse to pulse. These schemes are not successful.

→ One limitation is the foldover of nearby targets which can mask weak multiple time around targets.

→ The range ambiguity in multiple PRF radar can be conveniently decoded by use of the chinese remainder theorem.

## System losses:-

Losses in the radar reduce the signal to noise ratio at the receiver output.

Losses which can be calculated include the

* antenna beam shape loss
* Collapsing loss
* Plumbing loss

→ Losses which cannot be calculated include

* Losses due to field degradation
* Operator fatigue
* lack of operator motivation.

Loss has value $> 1$

$$\text{Loss} = [\text{Gain}]^{-1}$$

## Plumbing Loss:-

→ Loss in transmission lines between the transmitter and antenna & between antenna & receiver.

→ At low frequencies, the transmission lines introduce little loss. At high frequencies the attenuation is may not always be small. (1-24)

→ Additional loss occurs at connectors, bends and at rotary joints.

connectors = 0.5dB
Bends = 0.1dB
Rotary joint : 0.4dB.

→ If a line is used for both transmission & reception its loss is added twice.

→ The duplexer typically adds 1.5dB insertion loss. In general, the greater the isolation required, the greater the insertion loss.

## Beam shape loss:-

→ The train of pulses returned from the target for a scanning radar are modulated in amplitude by the shape of the antenna beam.

→ A beam shape loss occurs for the fact that the maximum gain is used in the radar equation rather than a gain which changes from pulse to pulse.

→ Let the one way power pattern be approximated by a Gaussian shape

$$s^2 = e^{-\frac{2.78\theta^2}{\theta_B^2}}$$

where $\theta_B$ = HPBW
$n_B$ = No. of pulses received within $\theta_B$
$n$ = The no. of pulse integratio

Then the beamshape loss is

$$\boxed{L(\text{Beam shape}) = \frac{n}{1+2\sum_{k=1}^{(n-1)/2} e^{(-5.55k^2/n_B^2)}}}$$

Ex:- The 11 pulses integrating gives L(Beam shape) = 1.66 dB

→ when the antenna scans so rapidly that the gain on transmission is not the same as the gain on reception, an additional "scanning loss" is added.

## limiting loss :-

→ Limiting in radar can lower the Probability of detection. This is not a desirable effect and is due to a limited dynamic range.

→ Limiting can be due to pulse compression processing and intensity modulation of CRT (such as PPI).

→ Limiting results in a loss of only a fraction of a dB for large numbers of pulses integrated providing the limiting ratio is greater than 2.

$$\boxed{\text{Limiting ratio} = \frac{\text{Video limit level}}{\text{RMS noise level}}}$$

→ for small SNR in bandpass limiters, the reduction of SNR of a sine wave in narrow band gaussian noise is $\pi/4 \approx 1\,dB$

## Collapsing Loss:-

→ If the radar integrates additional noise samples along with the desired signal-to-noise pulses, the add noise causes degradation called the collapsing loss.

→ This occurs on displays which collapse range informat

→ In some 3D radar that display outputs at all elevations on one PPI display, the collapsing of the 3D information into 2D display results in loss.

→ Marcum has shown that for a square law detector, the integration of m noise pulses, along with n signal + noise pulses with SNR per pulse $(S/N)_n$, is equivalent to the integration of m + n signal-to-noise pulses each with SNR of

$$\left(\frac{S}{N}\right)_{(m+n)\,equiv} = \frac{n}{m+n}\left(\frac{S}{N}\right)_n$$

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

$$\because \quad L_i(n) = \frac{1}{E_i(n)}$$

Ex:- 10 signal pulses are integrated with 30 noise pulses required $P_d = 0.9$, $n^f = 10^8$ from fig $L_i(40) = 3.5\,dB$, $L_i(10) = 1.7\,dB$.

$$\therefore \; L_i(m,n) = 1.8\,dB$$

→ collapsing loss for a linear detector can be much ~~generation~~ greater than for a square law detector.

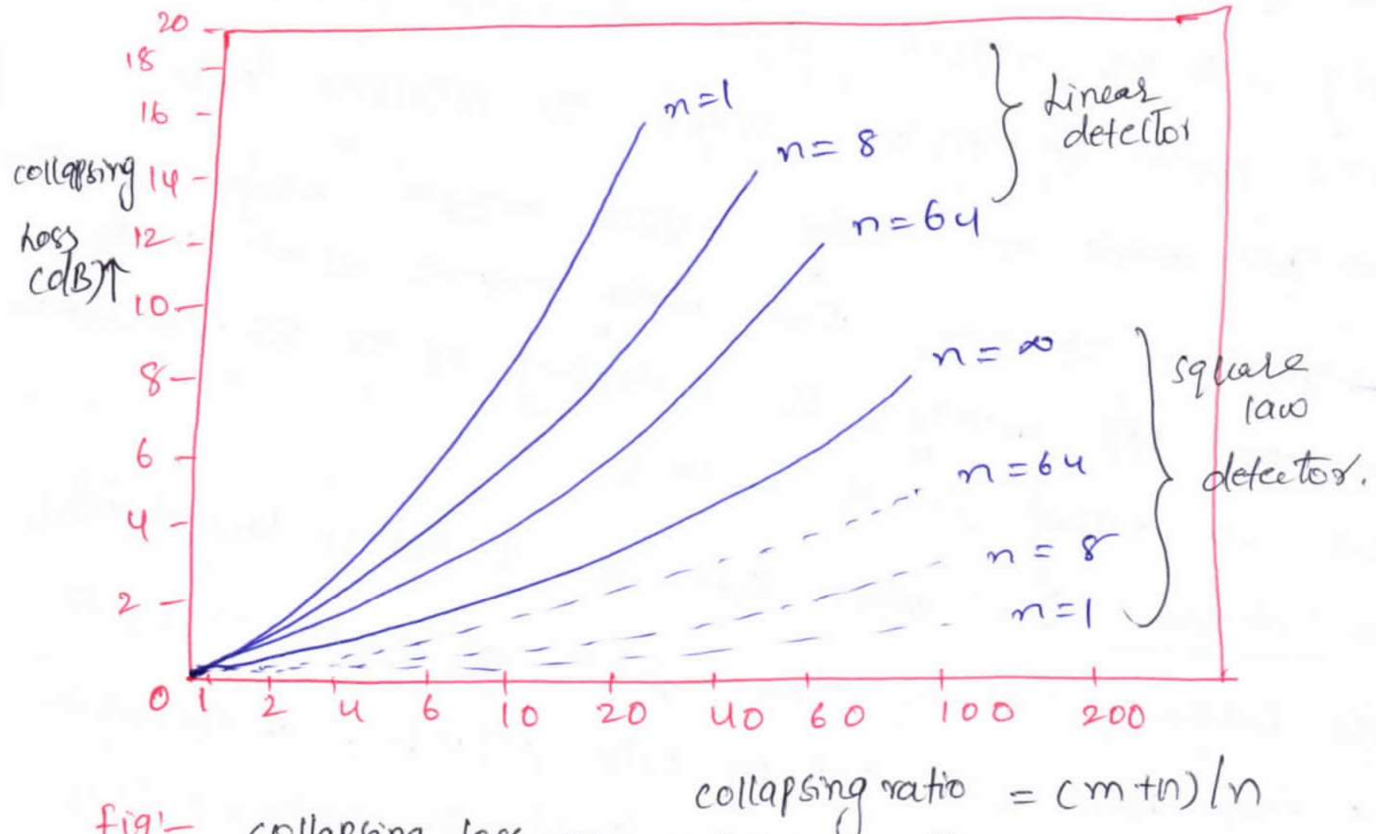



fig:- collapsing loss vs collapsing ratio.

## Operator loss:-

A distracted, tired, overloaded, poorly trained operator will perform less efficiently. The operator efficiency factor (empirical) is where $P_d$ is the single scan prob of detection.

## Field degradation:-

when a Radar is operated under field conditions, the performance deteriorates even more than can be accounted for in the above losses.

factors which cause field degradation are:

→ poor training

→ weak ~~tubes~~

→ water in the transmission Lines.

→ Incorrect mixer crystal current

→ Deterioration in the receiver

→ Poor TR tube recovery

→ loose cable connections.

Built in Test equipment to be monitored are (BITE)

→ Transmitted power $P_t$

→ NF of receiver

→ Transmitter pulse shape

→ Recovery time of TR tube.

Other loss factors:-

→ MTI radars introduce additional loss. The MTI discrimination technique results in complete loss of sensitivity for certain target values.

→ In a radar with overlapping range gates, the gates may be wider than optimum for practical reasons.