

## Lecture 1 :-

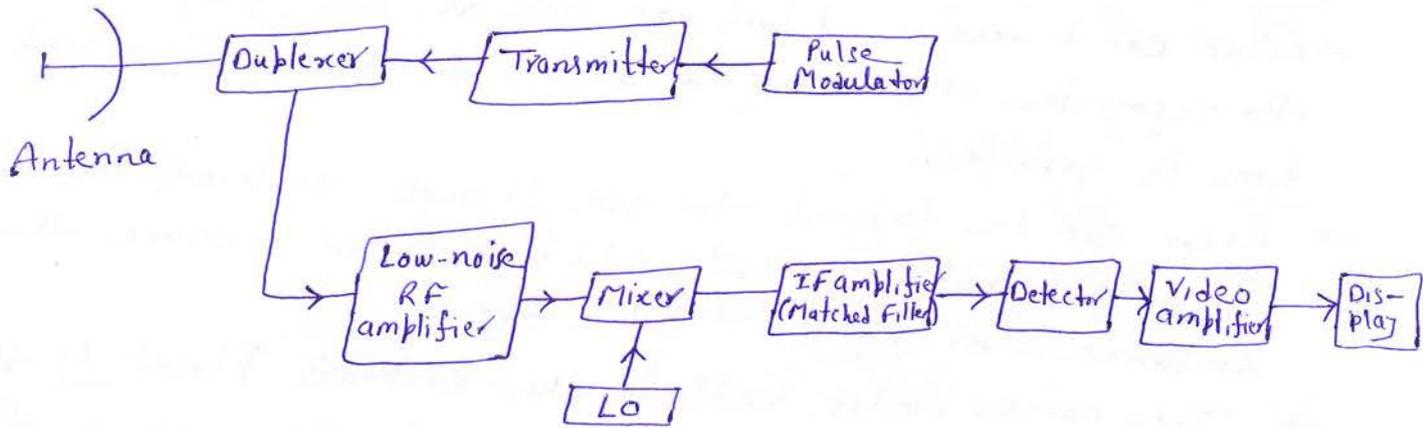
### Introduction to Radar :-

- 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 resolve 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 taken by the pulse to travel to the target and return.

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

$$R (\text{km}) = 0.15 T_R (\mu\text{s})$$

### Radar Block Diagram :-



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#### Block Diagram operation :-

The transmitter may be an oscillator, such as a 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 microseconds 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 serve to channel the returned echo signals to the receiver and not to transmitter. Duplexer consist of two gas discharge devices, one known as TR (transmit-receive) and

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

Receiver: → It is usually of the super-heterodyne type. First stage 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. its 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 direction 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 observing aircraft.
- ③ Airborne radar may be used to detect other aircraft, ships, or land vehicles, or may be mapping of lands.

Storm avoidance, terrain avoidance, and navigation,  
④ In space, radar has assisted in the guidance of spacecraft and for remote sensing of the land and sea.  
Major areas 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  $R$ .

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

Radar employ directive antenna having gain  $G$ .

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

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

where  $\sigma \Rightarrow$  radar cross section

Radar cross section  $\sigma$  has units of area. It is a characteristic 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  $S_{min}$ .

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

$\swarrow$  Fundamental form of Radar Eq<sup>n</sup>

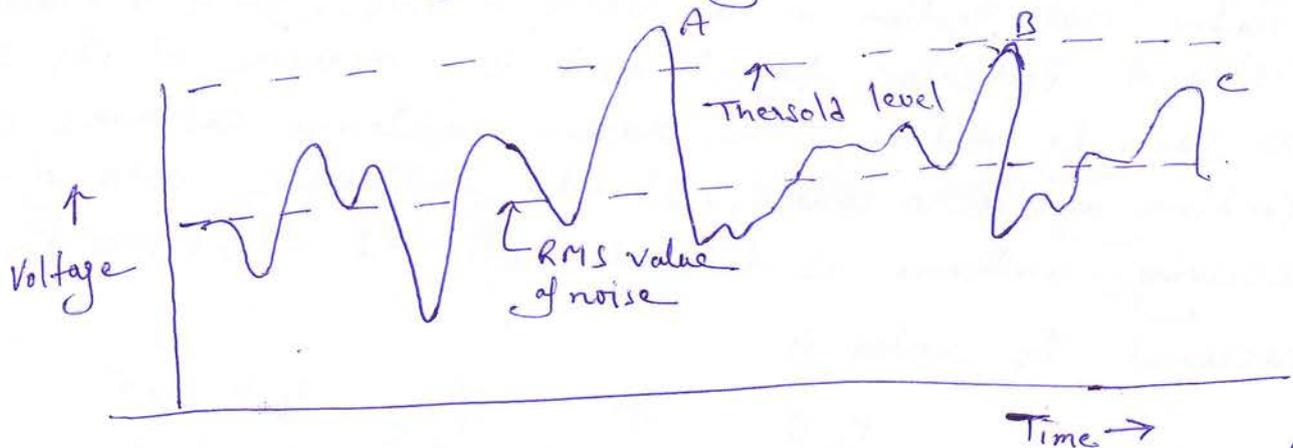
Minimum Detectable Signal :  $\rightarrow$

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.  $\rightarrow$  The weakest signal the receiver can detect is called minimum detectable signal.

MDS not easy to detect in some times because of statistical nature and criterion to decide whether the target present or not.

Detection is based on threshold level at the OIP of the receiver. i.e. threshold detection.

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



Typical envelope of the radar receiver OIP at a function of time

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

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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<sup>n</sup>  $T$  ( $^{\circ}K$ ) is equal to

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

$$k = 1.38 \times 10^{-23} \frac{J}{deg} = \text{Boltzman constant.}$$

For super-hetrodyne receivers mostly used in radar, the receiver B.W is approximately that of the intermediate frequency B.W.

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

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 ~~is~~ 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.

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

Where

$N_o$  = noise o/p from receiver

$G_a$  = Gain,  $T_0 = 290 \text{ K}$ , standard temp.

$$\text{Also } F_n = \frac{S_i / N_i}{S_o / N_o} \quad A_s \quad G_a = \frac{S_o}{S_i} \quad \text{and } k T_0 B_n = N_i$$

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

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

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<sup>n</sup>

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

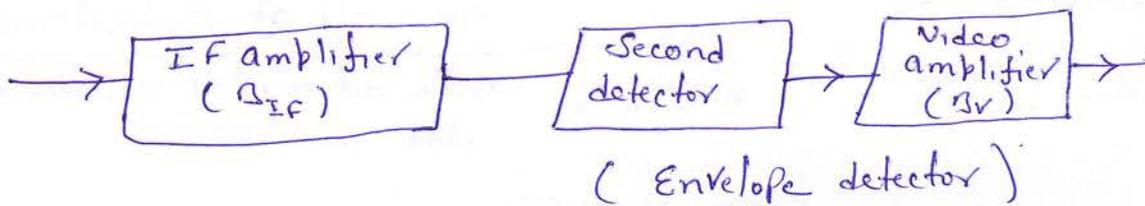
Put value of  $S_{min}$

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

## Signal-to-Noise Ratio: →

Signal to noise ratio is very important as far as radar is concerned, because presence of target or not have small difference. Statistical noise theory will be applied to obtain S/N. at the output of the IF amplifier necessary to achieve a specified probability of detection 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 must be greater than  $B_{IF}/2$  in order to pass all the video modulation.

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### Signal to noise Ratio: →

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

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

with mean zero and variance  $\sigma^2$ .

$P(v) \cdot dv$  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 probability density of the envelope of noise voltage  $v$  is given by

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

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 threshold voltage ( $V_T$ )

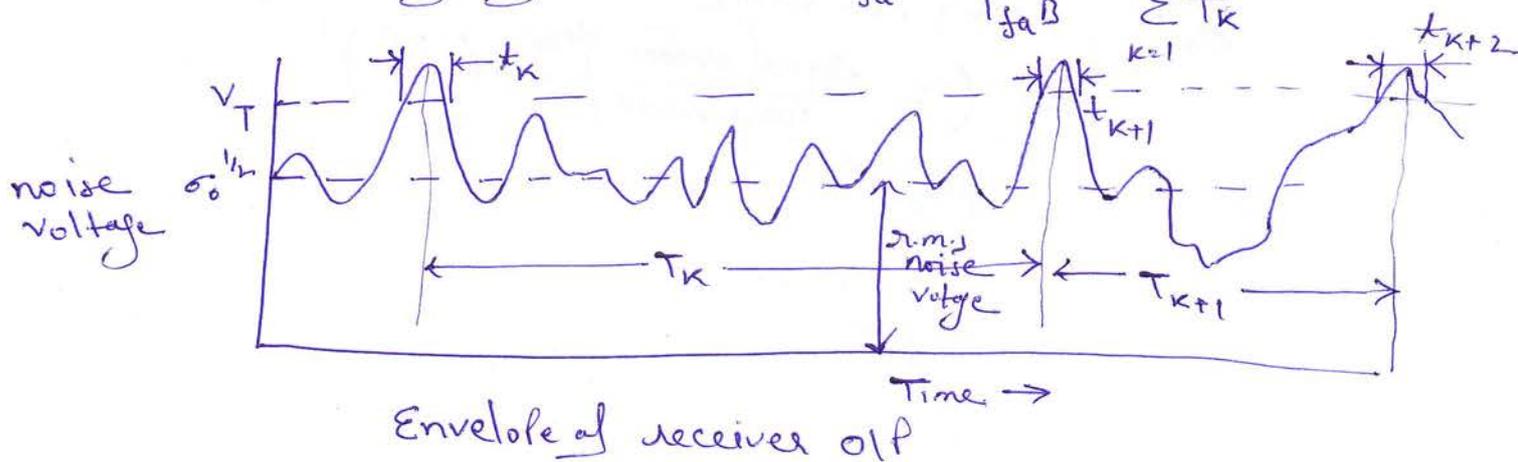
$$P(V_T < R < \infty) = \int_{V_T}^{\infty} \frac{R}{\sigma_0} \exp\left(-\frac{R^2}{2\sigma_0}\right) dR = \exp\left(-\frac{V_T^2}{2\sigma_0}\right) = P_{fa} \quad \text{--- (1)}$$

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

- $\rightarrow$  Probability of false alarm is the probability that noise will cross threshold.
- $\rightarrow$  The average time interval b/w crossings of the threshold by noise alone is defined by false alarm time  $T_{fa}$

$$T_{fa} = \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{k=1}^N T_k$$

$$\text{Probability of false alarm } P_{fa} = \frac{1}{T_{fa} B} = \frac{\sum_{k=1}^N t_k}{\sum_{k=1}^N T_k} \quad \text{--- (2)}$$



From (1) and (2)

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

A receiver with only noise o/p has been discussed. Now assume a sine wave signal of amplitude  $A$  present with noise.

Frequency of the signal is the same as the IF midband freq.  
 The OP of the Envelope detector has a Probability-density function

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

where  $I_0(z)$  is the modified Bessel func<sup>n</sup> of zero order and argument  $z$ . Eq<sup>n</sup> (3) sometime called Rice PDF.

Now Probability of detection  $P_d$  is given by

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

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

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

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

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

$$\begin{aligned} \frac{A}{\sigma_0} &= \frac{\text{Signal amplitude}}{\text{r.m.s noise voltage}} = \frac{\sqrt{2} (\text{r.m.s signal voltage})}{\text{r.m.s noise voltage}} \\ &= \left( 2 \frac{\text{Signal Power}}{\text{noise Power}} \right)^{1/2} = \left( \frac{2S}{N} \right)^{1/2} \end{aligned}$$

## Lecture - 6

### Transmitter Power:-

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

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  $\tau$  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  $P_{av}/P_t$ ,  $\tau/T_p$  or  $\tau f_p$  is called duty cycle

writing eq<sup>n</sup> (1) in terms of average power

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

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 appl<sup>n</sup>.

If the transmitted waveform is not a rectangular pulse, it is sometimes more convenient to express radar eq<sup>n</sup> in terms of Energy.

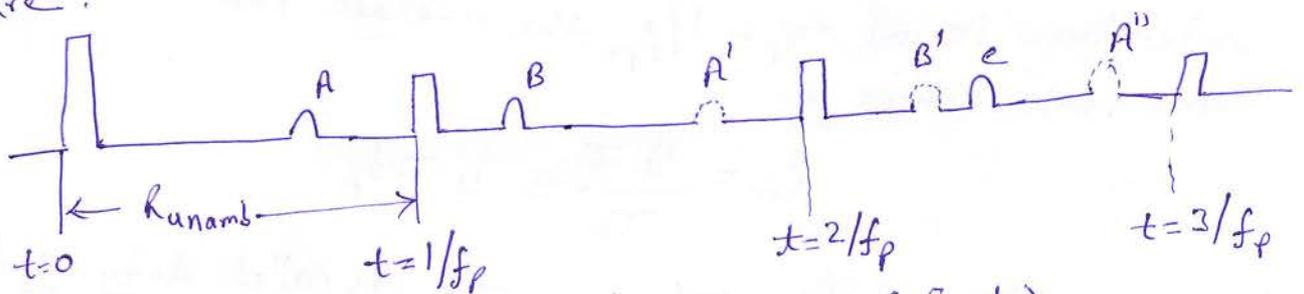
$$\begin{aligned} E_z &= P_{av} / f_p \\ \Rightarrow R_{\max} &= \frac{E_z G_r A_e \sigma \eta E_i(n)}{(4\pi)^2 K T_0 F_n (B_n \tau) (S/N)_I} \end{aligned}$$

The important parameters affecting range are the total transmitted energy  $\eta E_z$ , Transmitter gain  $G_r$ , effective receiver aperture  $A_e$ , and receiver noise figure  $F_n$ .

## Pulse Repetition Frequency and Range Ambiguities

The pulse repetition frequency (Prf) is determined primarily by the maximum range at which targets are expected. If the Prf is made too high, the likelihood 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 Ambiguity



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

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

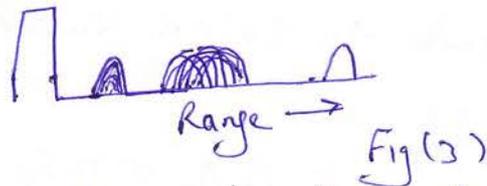


Fig (3) Shows three targets on A-scope with changing Prf.

Ambiguities may theoretically be resolved by observing the variation of echo signal with time (range). This is not always practical technique, however since the echo signal amplitude can fluctuate strongly for reasons other than a change in range. Instead the range ambiguities in multiple Prf radar can be conveniently decoded and the true range found by computational algorithms.

## Lecture - 7

### System losses: →

one of the main factors omitted from the simple radar Eq<sup>n</sup> was the losses that occur throughout the radar system. The losses reduce the SN at the receiver. They may be of two kinds depending upon whether 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 examples 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 occurred in radar

Plumbing loss: — There is always some finite loss in the transmission lines which connect the OP 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 be small and may have to be taken into account. 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 for transmission, the larger will be insertion loss. In an S-band (3000 MHz) radar, plumbing losses might be

100ft of waveguide TX line (two way)	1.0 dB
loss due to poor connection	0.5 dB
Rotary joint loss	0.4 dB
Duplexer loss	1.5 dB

Beam Shape loss: → The antenna gain in radar equation was assumed constant equal to maximum value. But in reality the train of pulse returned from a target with scanning radar is modulated in amplitude by the shape of antenna beam. Instead of beam shape loss is added to radar equation to account for the fact that maxi. gain is employed in radar equation rather than a gain that changes pulse to pulse.

When the antenna scan rapidly enough that the gain on transmit is not the same as the gain on receive, this loss is scanning loss.

Limiting loss: — Limiting in the radar receiver can lower the probability of detection. Although a well-designed and engineered receiver will not limit the received signal under normal circumstances. Some receiver, however, might employ limiting for some special purpose, as for pulse compression processing for example.

Limiting results in a loss of only a fraction of dB for a large no. of pulses integrated, provided the limiting ratio.

Collapsing loss: — if the radar were to integrate additional noise samples along with a wanted S/N pulses, the added noise results in degradation called collapsing loss. It can occur in displays which collapse the range information. A collapsing loss can occur when the OP of high resolution radar is displayed on a device whose resolution is coarser than that inherent in radar. A collapsing loss also result if

One of two or more radar receivers 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 ERP power. However transmitting devices (or components) not uniform in quality, nor should it be expected that any individual ~~the~~ BJT or JFET (FET) remain at same level of performance through-out its useful 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 degradation are poor tuning, 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 introduced 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 processor.

## 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 instances 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.