RADAR ENGINEERING

UNIT-1 BASICS OF RADAR

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Unit-1
BASICS OF RADAR

Introduction

Radar is an electromagnetic system for the detection and location of objects. It operates by Transmitting a particular type of waveform, and detects the nature of the echo signal.

- An elementary form of radar consists of a transmitting antenna emitting electromagnetic 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(target) 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.

RADAR is a contraction of the words **Radio Detection and Rangingor Radio Direction and Ranging .**

The most common radar waveform is a train of narrow, rectangular-shape pulses modulatinga sine wave carrier. The distance, or range, to the target is determined by measuring the time $\mathbf{T_R}$taken by the pulse to travel to the target and return. Since electromagnetic energypropagates at the speed of light **c = 3*10^{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.

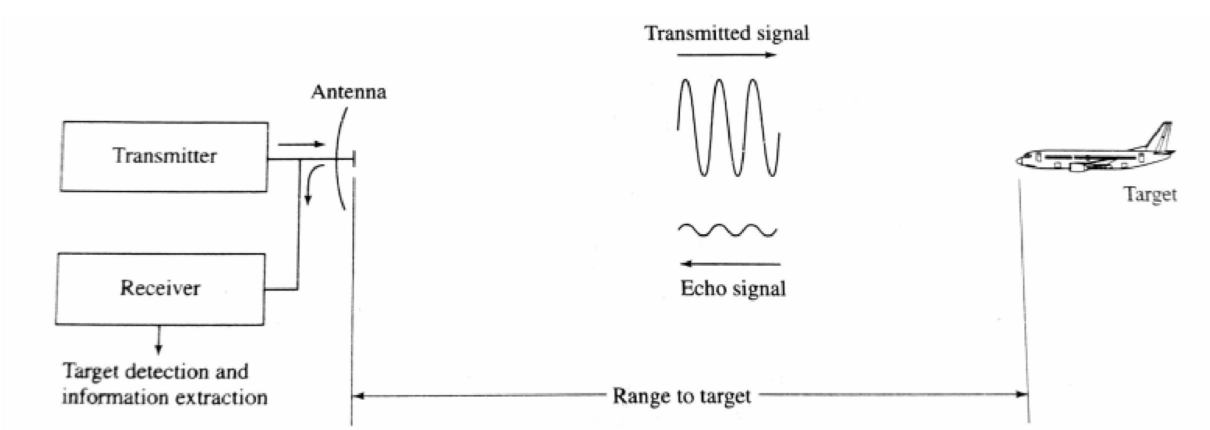


Fig : Basic principle of RADAR

1 mile = 0.8689 nautical mile or 1.6 km
1 nautical mile = 1.15078 miles or 1.8412 km

Maximum Unambiguous Range

Once the transmitted pulse is emitted by the radar, a sufficient length of time must elapse to allow any echo signals to return and be detected before the next pulse may be transmitted.

Echoes that arrive after the transmission of the next pulse are called **second-time-around (or multiple-time-around) echoes**. The range beyond which targets appear as second-time-around echoes is called as**maximum unambiguous range** and is

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

Where f_p= pulse repetition frequency, in Hz.

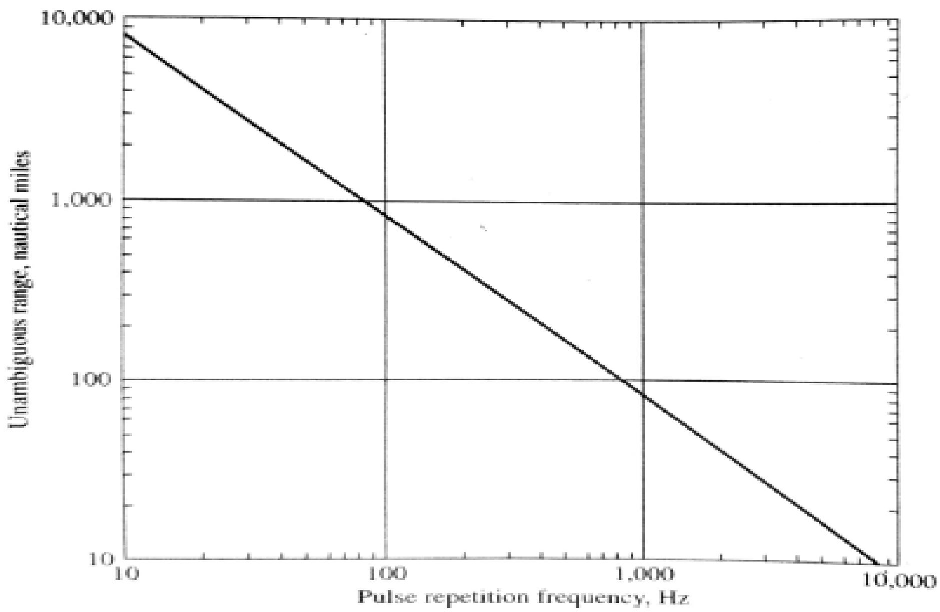


Fig : The maximum unambiguous range R_{um} as a function of the pulse repetition frequency f_p

THE SIMPLE FORM OF THE RADAR EQUATION

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

If the power of the radar transmitter is denoted by$\mathbf{P_t}$ and if an isotropic antenna is used (one which radiates uniformly in all directions), the ***power*** density (watts per unit area)at a distance Rfrom the radar is equal to the transmitter power divided by the surface area $4\pi R^2$of an imaginary sphere of radius R, or

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

Radars employ directive antennas to channel, or direct, the radiated power $P_t$into someparticular direction.The power density at the target from an antenna with a transmitting gain **G**(Antenna gain is the ability of the antenna to radiate more or less in any direction) is

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

The measure of the amount of incident power intercepted by the target and reradiated back inthe direction of the radar is denoted as the radar cross section **σ**(Radar cross section is the measure of a target's ability to reflect radar signals in the direction of the radar receiver), and is defined by the relation

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

The radar cross section σ has 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 echopower. If the effective area of the receiving antenna is denoted $\mathbf{A_e}$, **(**Then the *effective aperture* parameter describes how much power is captured from a given plane wave.)the power $\mathbf{P_r}$, received by the radar is

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

The 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, just equals the minimum detectable signal $\mathbf{S_{min}}$.Therefore

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

Antenna theory gives the relationship between the transmitting gain and the receiving effective area of an antenna as

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

Since radars generally use the same antenna for both transmission and reception, G can be substituted into Eq. above, first for A_e, then for G, to give two other forms of the radar equation

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

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

RADAR BLOCK DIAGRAM

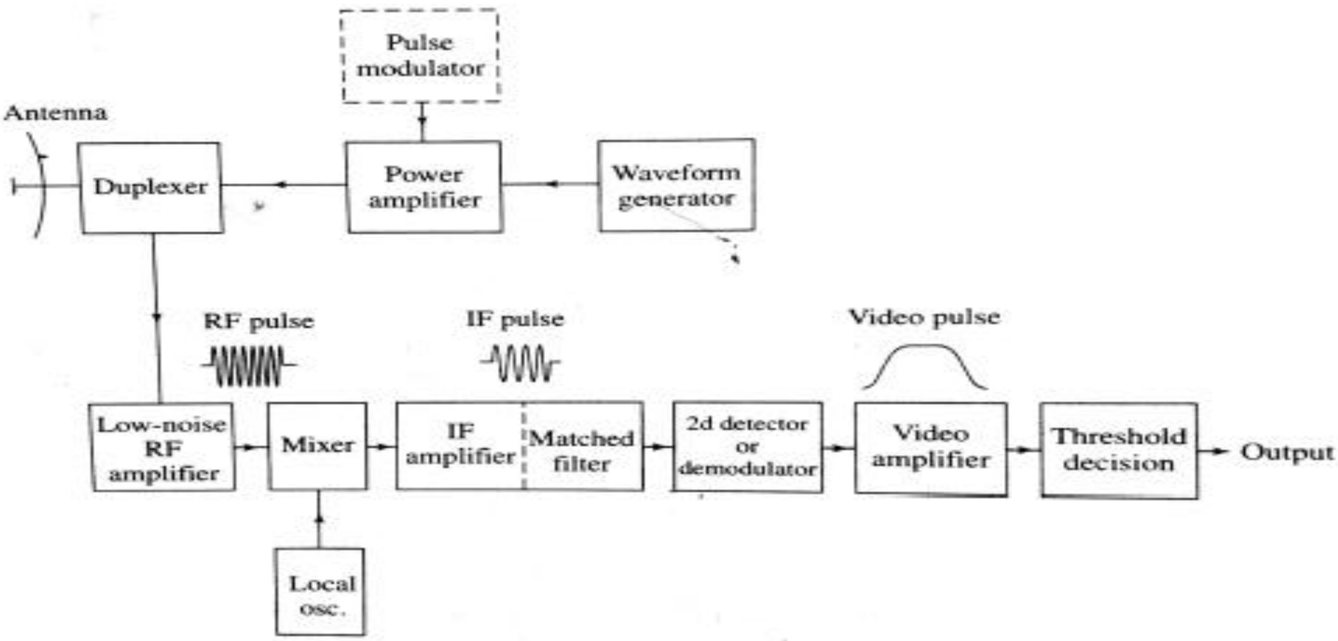


Fig :Radar block diagram.

• **Transmitter:-**

Thetransmitter may be an oscillator, such as a magnetron, that ispulsed (turned on and on) by the modulator to generate a repetitive train of pulses. The magnetron has probably been the most widely used of the various microwave generators for radar.

• **Pulse Modulator:-**

The radar modulator is a device, which provides the high power to the transmitter tube to transmit during transmission period. It makes the transmitting tube ON and OFF to generate the desired waveform. Modulator allows the storing the energy in a capacitor bank during rest time.

The stored energy then can be put into the pulse when transmitted. It provides rectangular voltage pulses which act as the supply voltage to the output tube such as magnetron, thus switching it ON and OFF as required.

•**Power Amplifier:-**

The main function of power amplifier is to increase A.C power, with the help of huge power, the signal can travel longer distances.

• **Antenna:-**

The waveform generated by the transmitter travels via a transmission line to the antenna, where it is radiated into space. A single antenna is generally used for both transmitting andreceiving. The antenna must focus the energy into a well-defined beam which increase the power and permits a determination of the direction of the target.

- **Duplexer:-**

The duplexer allows a single antenna to be used on a time – shared basis of both transmitting and receiving. The receiver must be protected from damage caused by the high power of the transmitter. This is the function of the duplexer.The duplexer also serves to channel the returned echo signals to the receiver and not to the transmitter.

The duplexer might consist of two gas-discharge devices, one known as a TR (transmit-receive) and the other an ATR(anti-transmit-receive). The TR protects the receiver during transmission and the ATR directs the echo signal to the receiver during reception.

- **Receiver:-**

The receiver is usually of the super-heterodyne type whose function is to detect the desired signal in the presence of noise, interference and clutter. The receiver in pulsed radar consists of low noise RF amplifier, mixer, local oscillator, IF amplifier, detector, video amplifier and radar display.

- **Low Noise RF Amplifier:-**

The first stage might be a low-noiseRFamplifier, such as a parametric amplifier or a low-noise transistor. The low-noise amplifier amplifies the signal with less extra noise.

- **Mixer and Local Oscillator:-**

The mixer and local oscillator (LO) convert the RF signal to an intermediate frequency**(IF).** A typical" IF amplifier for an air-surveillance radar might have a center frequency of 30or 60 MHz and a bandwidth of the order of one megahertz.

- **IF Amplifier:-**

The IF amplifier should be designed as a matched filter; i.e., its frequency-response function H(f)should maximize the peak-signal-to mean noise powerratio at the output. Thus matched filter maximizes the detectability of weak eco signals and attenuates unwanted signals.

- **Detector:-**

After maximizing the signal-to-noise ratio in the IF amplifier, the pulse modulation is extracted by the second detector and amplified by the video amplifier to a level where it can be properly displayed, usually on a cathode-ray tube (CRT).

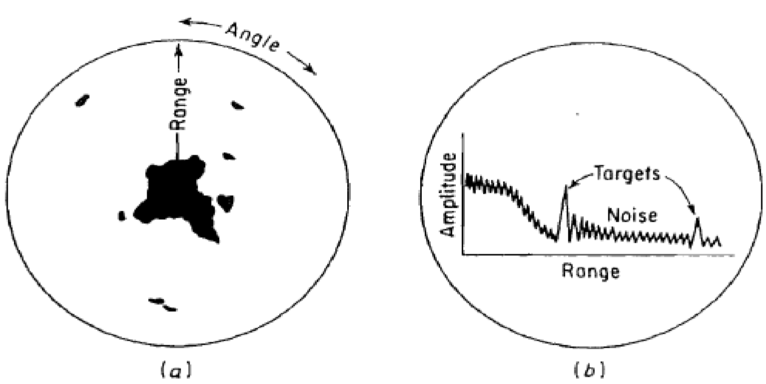


Figure 1.3 (*a*) **PPI** presentation displaying range vs. angle (intensity modulation); (*b*) A-scope presentation displaying amplitude vs. range (deflection modulation).

• **Display Unit:-**

The most common form of cathode-ray tube display is the plane position indicator, or **PPI** (Fig. **1.3a),** which maps in polar coordinates the location of the target in azimuth and range. And another one is A-scope presentation.

• **Threshold Decision**

At the output of the receiver a decision is made whether or not a target is present. The decision is based on the magnitude of the receiver output. If the output is large enough to exceed a predetermined threshold, the decision is that a target is present. Ifit does not cross the threshold, only noise is assumed to be present.

Radar Frequencies

Conventional radars generally have been operated at frequencies extending from about220 MHz to 35 GHz. Sky wave HF over-the-horizon (OTH) radars operate at frequencies as low as 4 or 5 MHz. Ground wave HF radars operate as low as 2 MHz. Millimeter radars operate at 94 GHz. Laser radars operate at even higher frequencies.

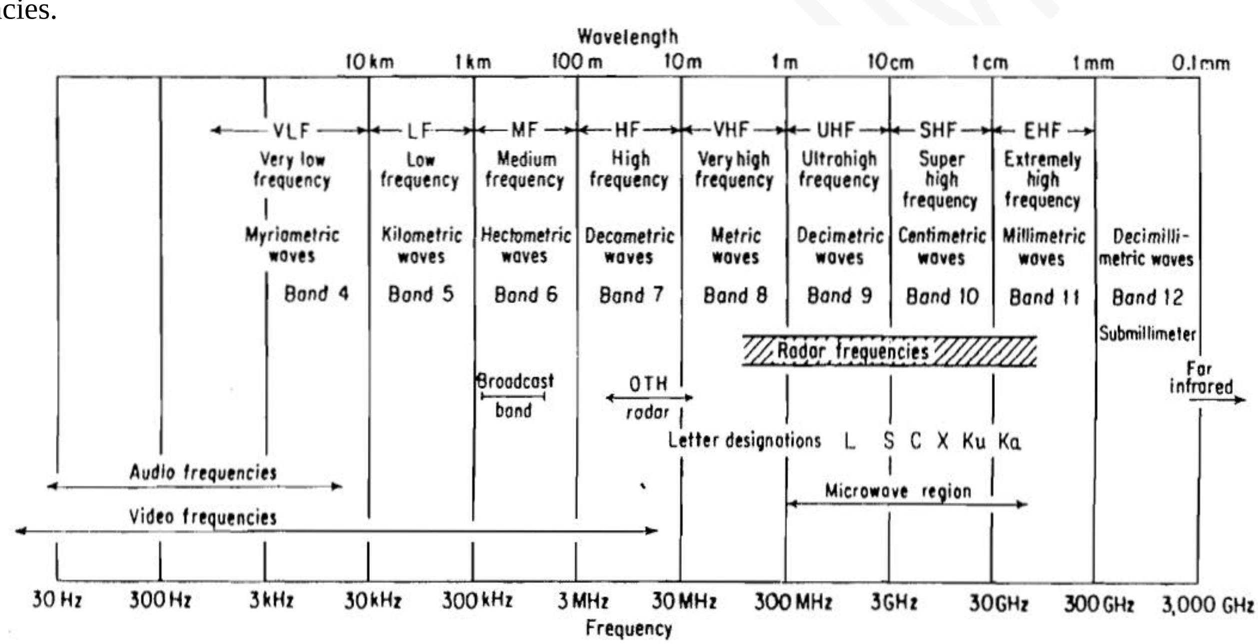


Fig. Radar frequencies and the electromagnetic spectrum

Table: IEEE Standard RADAR – frequency letter - band

Band Designation	**Nominal Frequency Range**	**Specific Radar bands based on ITU assignments for region 2**
HF	3-30 MHz	216-225 MHz
VHF	30-300 MHz	138-144 MHz
		216-225 MHz
UHF	300-100 MHz	420-450 MHz
		890-942 MHz
L	1000-2000 MHz	1215-1400 MHz
S	2000-4000 MHz	2300 - 2500 MHz
		2700 - 3700 MHz
C	4-8GHz	5250 - 5925 MHz

X	8 -12GHz	8500 - 10680 MHz
Ku	12-18 GHz	13.4 - 14.0 GHz
		15.7 - 17.7 GHz
K	18 -27 GHz	24.05 - 24.25 GHz
Ka	40 – 300 GHz	33.4 - 36.0 GHz
mm	40 – 100+GHz	

APPLICATIONS OF RADAR

Radar has been employed on the ground, in the air, on the sea, and in space.Ground-based radar has been applied chiefly to' the detection, location, and tracking of aircraft or space targets.

Air Traffic Control (ATC).

Radars are employed throughout the world for the purpose of safely controlling air traffic en route and in the vicinity of airports.

Aircraft and ground vehicular traffic at large airports are monitored by means of high-resolution radar. Radar has been used with **GCA** (ground-control approach) systems to guide aircraft to a safelanding in bad weather.

Air craft Navigation.

The weather-avoidance radar used on aircraft to outline regions of precipitationto the pilot is a classical form of radar.

Radar is also used for terrain avoidance and terrain following. Although they may not always be thought of as radars, the radio altimeter (either **FM/CW** or pulse) and the Doppler navigator are also radars.

Ship Safety

Radar is used for enhancing the safety of ship travel by warning of potentialcollision with other ships, and for detecting navigation buoys, especially in poor visibility.

In terms of numbers, this is one of the larger applications of radar, but in terms of physicalsize and cost it is one of the smallest. It has also proven to be one of the most reliableradar systems

Space

Space vehicles have used radar for rendezvous and docking, and for landing on themoon. Some of the largest ground-based radars are for the detection and tracking ofsatellites.

Remote Sensing.

All radars are remote sensors; however, as this term is used it implies thesensing of geophysical objects, or the "environment."

Remote sensing with radar is also concerned with Earth resources, which includes the measurement and mapping of sea conditions, water resources, ice cover, agriculture, forestry conditions, geological formations, and environmental pollution.

Law Enforcement

In addition to the wide use of radar, to measure the speed of automobiletraffic by highway police, radar has also been employed as a means for the detection ofintruders.

Military

The traditional role of radar for military application has been for surveillance, navigation, and for the control and guidance of weapons.

PREDICTION OF RANGE PERFORMANCE

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

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

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 for the target cross section .

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

In practice, however, the simple radar equation does not predict the range performance of actual radar equipment's to a satisfactory degree of accuracy. Part of this discrepancy is due to the failure of above Eq. to explicitly include the various losses that can occur throughout the system or the loss in performance usually experienced when electronic equipment is operated in the field rather than under laboratory-type conditions.

Another important factor that must be considered in the radar equation is the statistical orunpredictable nature of several of the parameters. The minimum detectable signal $S_{min}$and the target cross section $\boldsymbol{\sigma}$ are both statistical in nature.

Other statistical factors which do not appear explicitly in Eq. (3) but which have an effect on the radar performance are the meteorological conditions along the propagation path and the performance of the radar operator, if one is employed.

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 target is assumed to be present. This is called threshold detection**.** Consider the output of a typical radar receiver as a function of time (Fig. 2.1).

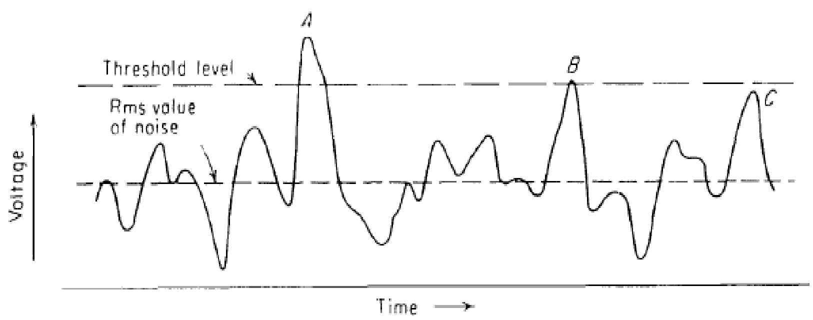


Figure 2.1 Typical envelope of the radar receiver output as a function of time. *A*, and *B*, and *C* represent signal plus noise. *A* and *B* would be valid detections, but *C* is a missed detection.

A threshold level is established, as shown by the dashed line. A target is said to be detected if the envelope crosses the threshold.

If the signal is large such as at A**,** it is not difficult to decide that a target is present.butconsider the two signals at B and C, representing target echoes of equal amplitude. The noise voltage accompanying the signal at B is large enough so that the combination of signal plus noise exceeds the threshold. At ***C*** the noise is not as large and the resultant signal plus noise does not cross the threshold. Thus the presence of noise will sometimes enhance the detection of weak signals but it may also cause the loss of a signal which would otherwise be detected.

If the threshold level were set to low, noise might exceed it and be mistaken for a target. This is caked a **false alarm**. If the threshold level were set too high, but weak target echoes might not exceed the threshold and would not be detected. It is called a **missed detection**. Choose proper threshold voltage such that to eliminate false alarm and missed detection.

RECEIVER NOISE AND MODIFIED RADAR RANGE EQUATION

Noise is unwanted electromagnetic energy which interferes with the ability of the receiver to detect the wanted signal.

It may originate within the receiver itself, or it may enter via the receiving antenna along with the desired signal.

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

Where K= Boltzmann's constant = 1.38 x10^{-23}J/deg. B_n= Receiver or noise bandwidth, T =temperature in (degrees Kelvin). N_o= noise output from receiver,

B_n an integrated bandwidth and is given by

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

Where H(f) = frequency-response characteristic of IF amplifier and fo = frequency of maximum response.H(fo) =1.

The noise figure **F_n** also represented as

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

The noise figure may be interpreted, therefore, as a measure of the degradation of signal-to noise-ratio as the signal passes through the receiver.

From above equation, the input signal may be expressed as

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

If the minimum detectable signal **S_{min}** is that value of S_i corresponding to the minimum ratio of output (I F) signal-to-noise ratio (S_o/N_o) necessary for detection. Then

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

Substituting **Eq.** Above into Eq. of radar range results in the following form of the radar equation:

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

PROBABLITIES OF DETECTION AND FALSE ALARM (or)

ENVELOPE DETECTOR and SIGNAL-TO-NOISE RATIO

Consider an **IF** amplifier with bandwidth B_{IF} followed by a second detector and a video amplifier with bandwidth B_v shown in (Fig. 2.3).

The second detector and video amplifier are assumed to form an envelope detector, that is, one which rejects the carrier frequency 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.

Figure 2.3 Envelope detector.

Probability of False Alarm

The noise entering the IF filter (the terms filter and amplifier are used interchangeably) is assumed to be Gaussian, with probability-density function given by

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

Where $\psi_o$is the variance,

If Gaussian noise were passed through a narrowband IF filter-one whose bandwidth is small compared with the mid frequency. The probability density of the envelope R of the noise voltage output is shown by Rice to be

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

WhereR is the amplitude of the envelope of the filter output. The above Equation is a form of the Rayleigh probability-density function.

The probability that the noise voltage envelope will exceed the voltage threshold V_T is the integral of p(R) evaluated from V_T to ∞

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

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

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

Since the probability of a false alarm is the probability that noise will cross the threshold and be called a target when only noise is present. Thus, the probability of a false alarm, denoted $\mathbf{P_{fa}}$ is

$$\boxed{P_{\mathbf{fa}} = \exp\left(-\frac{-V_T^2}{2\Psi_0}\right)}$$

The average time interval between crossings of the threshold by noise alone is defined asthe ***false-alarm time*** $\mathbf{T_{fa}}$.

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

Where$\mathbf{T_k}$is the time between crossings of the threshold V_T by the noise envelope, when the slope of the crossing is positive.

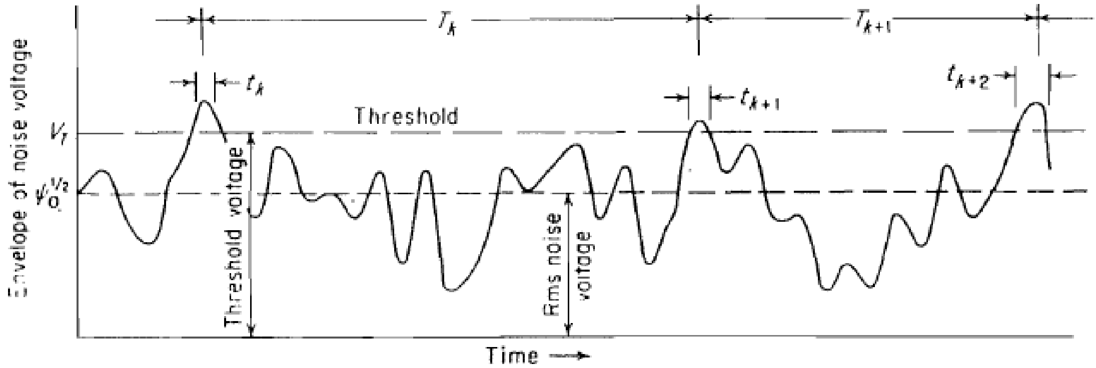


Figure 2.4 Envelope of receiver output illustrating false alarms due to noise.

False-alarm probability also defined as

$$P_{fa} = \frac{\sum_{k=1}^{N} t_k}{\sum_{k=1}^{N} T_k} = \frac{\langle t_k \rangle_{av}}{\langle T_k \rangle_{av}} = \frac{1}{T_{fa} B}$$

Where B is the bandwidth of the IF amplifier of the radar receiver. The average duration of a threshold crossing by noise **<t $_k$ >**is approximately the reciprocal of the IF bandwidth B**.** From above equation T_{fa} is given by

$$\boxed{T_{fa} = \frac{1}{B_{IF}} \exp \frac{V_T^2}{2\psi_0}}$$

Probability of Detection

Consider a sine-wave signal of amplitude A to be present along with noise at the input to the IF filter. The frequency of the signal is the same as the IF mid band frequency f_{IF}The output of The envelope Detectorhas a probability-density function of the envelope R at the video output is given by

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

where$I_o(Z)$ is the modified Bessel function of zero order and argument Z. For Z large, an asymptotic expansion for $I_o(Z)$is

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

When the signal is absent, A=0 and above Equation reduces to , the probability-density function for noise alone.

The probability that the signal will be detected (which is the *probability of detection)* is thesame as the probability that the envelope *R* will exceed the predetermined threshold V_T.
Probability of detection $P_d$is therefore

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

Equation discussed above may be converted to power by replacing the signal to -rms-noise-voltage ratio with the following:

$$\frac{A}{\Psi_0^{1/2}} = \frac{\text{signal amplitude}}{\text{rms noise voltage}} = \frac{\sqrt{2}\ (\text{rms signal voltage})}{\text{rms noise voltage}}$$

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

INTEGRATION OF RADAR PULSES

The process of summing all the radar echo pulses for the purpose of improving detection is called integration. Many techniques might be employed for accomplishing integration.

Many pulses are usually returned from any particular target on each radar scan and can be used to improve detection. The number of pulses **n** returned from a point target as the radar antenna scans through its beam width is

$$\boxed{n = \frac{f_p\ \theta_B}{\theta_S} = \frac{f_p\ \theta_B}{6\ w_r}}$$

Where θ_B = antenna beam width, deg

θ_S= antenna scam rate, deg/s

f_p = pulse repetition frequency, Hz

w_r =antenna scan rate, rpm

Proof:

θ_S Angle gets scanned in 1 sec

θ_B Angle gets scanned $\frac{\theta_B}{\theta_S}$sec

In 1 sec radar sent f_p number of pulses

$\frac{\theta_B}{\theta_S}$Sec radar sent $\frac{f_p\,\theta_B}{\theta_S} = \boxed{n}$ pulses

If n pulses, all of the same signal-to-noise ratio, were perfectly integrated by an ideal lossless prediction integrator, the integrated signal-to-noise ratio would be exactly n times that of a single pulse An integration efficiency may be defined as

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

Where n = number of pulses integrated

(S/N)₁ = value of signal-to-noise ratio of a single pulse required to produce a given probability of detection(for **n = 1**)
(S/N)ₙ = value of signal-to-noise ratio per pulse required to produce the same probability of detection when **n** pulses (of equal amplitude) are integrated

The radar equation when n pulses are integrated is

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

Sub $\mathbf{(S/N)_n} = \frac{(\frac{S}{N})_1}{n\ E_i(n)}$ in above equation

The final modified Radar equation including integration efficiency.

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

TRANSMITTER POWER

The power P_t in the radar equation is called by the radar engineer the peak power. (Peak power is usually equal to one-half the maximum instantaneous power.) The average radar power P_{av}, is also of interest in radar and 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 $T_p = l/f_p$, the average power is related to the peak power by

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

The ratio $\mathbf{P_{av}/P_t}$, $\boldsymbol{\tau/T_p}$, or $\boldsymbol{\tau f_p}$ is called the **duty cycle** of the radar.
Writing the radar equation in terms of the average power rather than the peak power, we get

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

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, it is sometimes more convenient to express the radar equation in terms of the energy per pulse, $\mathbf{E_p} = P_t \tau = \mathbf{P_{av}/f_p}$ contained in the transmitted waveform:

$$\boxed{R^4_{max} = \frac{E_p G A_e \sigma n E_i(n)}{(4\pi)^2 k T_0 F_n (B\tau)(S/N)_1} = \frac{E_T G A_e \sigma E_i(n)}{(4\pi)^2 k T_0 F_n (B\tau)(S/N)_1}}$$

Where $\mathbf{E_T}$ is the total energy of the n pulses, which equals $\mathbf{nE_P}$

In this form, the range does not depend explicitly on either the wavelength or the pulse repetition frequency. The important parameters affecting range are the total transmitted energy nE_P, thetransmitting gain G, the effective receiving aperture A_e, and the 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. Echo signals received after an interval exceeding the pulse-repetition period are called second - time-around echoes or multiple-time-around echoes. They can result in erroneous or confusing range measurements.

Consider the three targets labeled A. B, and C in Fig. 9 a. Target A is located within the maximum unambiguous range R_{unamb} of the radar, target B is at a distance greater thanR_{unamb} but less than $2R_{unamb}$ while target C is greater than $2R_{unamb}$ but less than $3R_{unamb}$. The appearance of the three targets on an A-scope is sketched in Fig. 9 b.

The multiple-time-around echoes on the A-scope cannot be distinguished from proper target echoes actually within the maximum unambiguous range. Only the range measured for target A is correct; those for Band C are not.

One method of 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 the same place on the A-scope on each sweep no matter whether the prf is modulated or not.

However, echoes from multiple-time-around targets will be spread over a finite range as shown in Fig.9 c. Second-time targets need only two separate repetition frequencies in order to be resolved.

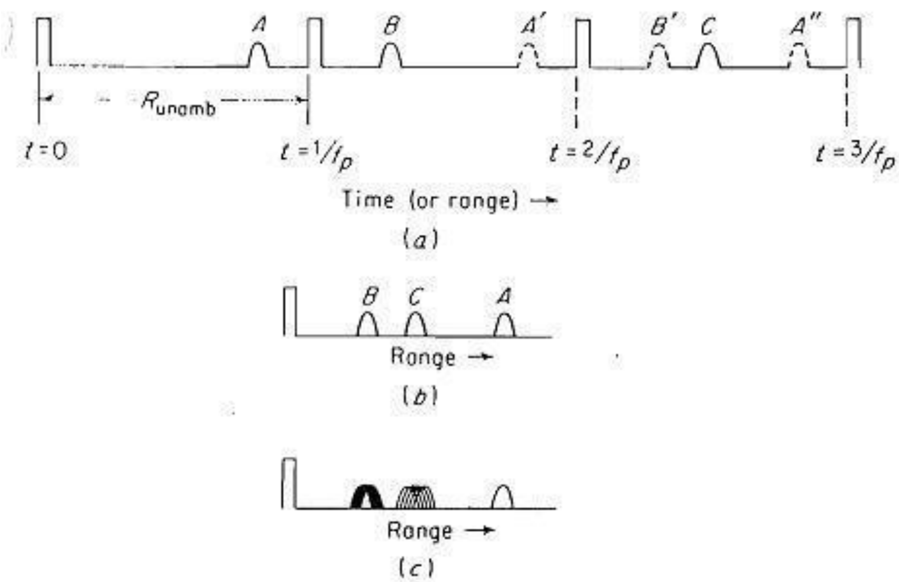


Fig.9 Multiple-time-around echoes that give rise to ambiguities in range (a) Three targets A, B and C, where A is within R_{unamb}, and B and C are multiple-time-around targets; (b) the appearance of the three targets on the A-scope; (c) appearance of the three targets on the A-scope with a changing prf.

Instead of modulating the prf, other schemes that might he employed to" mark" successive pulses so as to identify multiple-time-around echoes include changing the pulse amplitude, pulse width, frequency, phase, or polarization of transmission from pulse to pulse.

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

SYSTEM LOSSES

One of the important factors omitted from the simple radar equation was the losses that occur throughout the radar system. The losses reduce the signal-to-noise ratio at the receiver output.
The antenna beam-shape loss, collapsing loss, and losses in the microwave plumbing are examples of losses which can be calculated if the system configuration is known.

Plumbing loss:

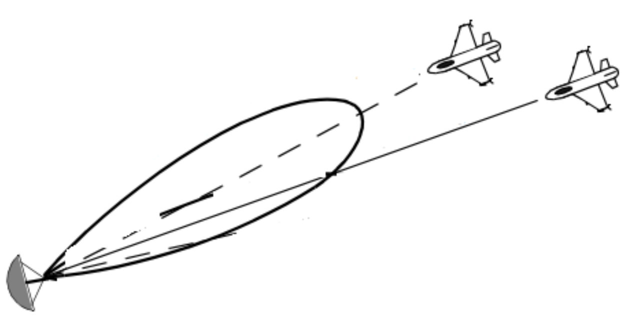
There is always some finite loss experienced in the transmission lines which connectthe output of the transmitter to the antenna. In addition to the losses in the transmission line itself, an additional loss can occur at each connection or bend in the line and at the antenna rotary joint if used. Connector losses are usually small, but if the connection is poorly made, it can contribute significant attenuation. The signal suffers attenuation as it passes through the duplexer.

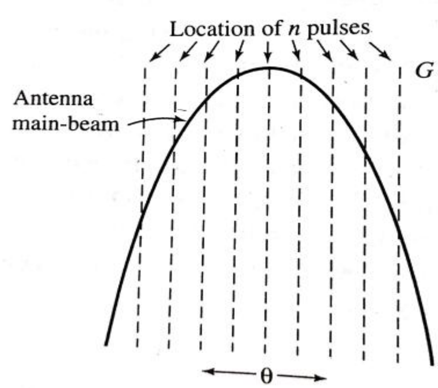
Beam-shape loss:

The antenna gain that appears in the radar equation was assumed to be a constantequal to the maximum value. But in reality the train of pulses returned from a target with a scanning radar is modulated in amplitude by the shape of the antenna beam.
To properly take into account the pulse-train modulation caused by the beam shape, the computations of the probability of detection would have to be performed assuming a modulated train of pulses rather than constant-amplitude pulses.

The pulses received within the half-power beam width $\theta_B$isn_B, and n is the total number of pulses integrated (n does not necessarily equal n_B), then the beam-shape loss (number greater than unity) relative to a radar that integrates all n pulses with an antenna gain corresponding to the maximum gain at the beam center is

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





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, intensity modulated CRT displays such as the PPI or the B-scope have limited dynamic range and may limit.

Some receivers, 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 a decibel for a large number of pulses integrated provided the limiting ratio (ratio of video limit level to rms noise level) is as large as 2 or 3.

Collapsing loss:

If the radar were to integrate additional noise samples along with the wanted signal-to-noise pulses, the added noise results in degradation called the collapsing loss. It can occur in displays which collapse the range information, such as the C-scope which displays elevation vs. azimuth angle.

- The collapsing loss in this case is equal to the ratio of the integration loss L_i for m + n pulses to the integration loss for n pulses, i.e

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

Propagation Effects

The effect of the environment on the propagation of radar waves can be significant. Propagation effects can increase the free – space range as well as decrease it. The major effects of propagation on radar performance are:

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

Operator loss

Most modern high-performance radars provide the detection decision automatically without intervention of a human operator. Processed information is processed directly to an operator or to a computer for some other action.

In the early days of radar, operators were depended upon to find targets on a display. Sometimes, when the radar range performance was less than predicted, the degradation of performance was attributed to an operator loss.

RADAR CROSS SECTION OF TARGETS:

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

$$\sigma = \frac{\text{power reflected toward source/unit solid angle}}{\text{incident power density}/4\pi} = \lim_{R\to\infty} 4\pi R^2 \left|\frac{E_r}{E_i}\right|^2$$

where R = distance between radar and target
E_r = reflected field strength at radar
E_i = strength of incident field at target

This equation is equivalent to the radar range equation. For most common types of radar targets such as aircraft, ships, and terrain, the radar cross section does not necessarily bear a simple relationship to the physical area, except that the larger the target size, the larger the cross section is likely to be.

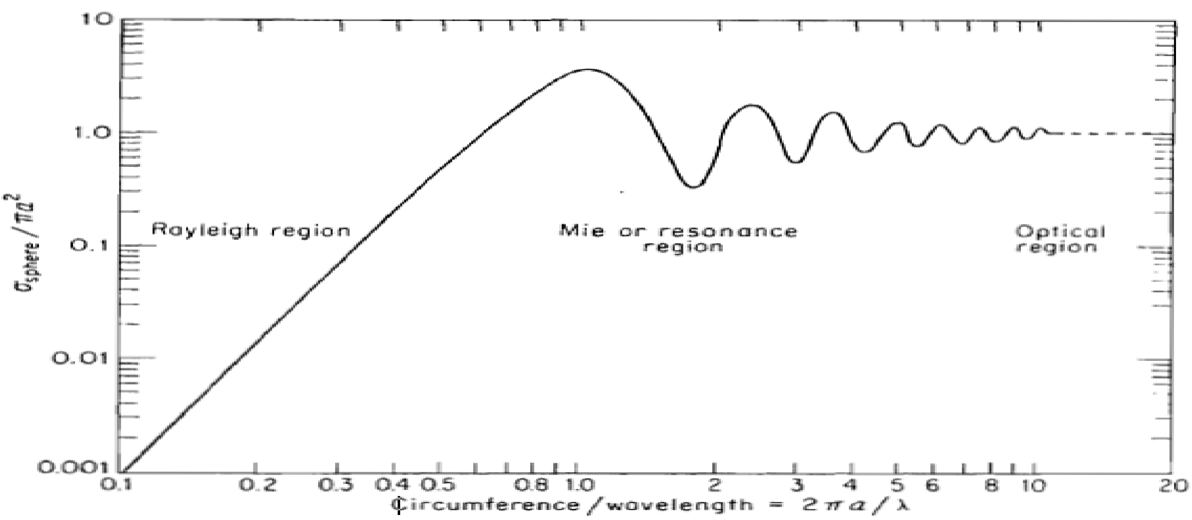


Fig: Radar cross section of the sphere.*a* = radius; λ= wavelength.

In theory, the scattered field, and hence the radar cross section, can be determined by solving Maxwell's equations with the proper boundary conditions applied. Unfortunately, the determination of the radar cross section with Maxwell's equations can be accomplished only for the most simple of shapes, and solutions valid over a large range of frequencies are not easy to obtain.

The radar cross section of a simple sphere is shown in Fig.1.4 as a function of its circumference measured in wavelengths *(*$2\pi a/\lambda$*)* where *a* is the radius of the sphere and λ is wavelength). The region where the size of the sphere is small compared with the Wavelength *(*$2\pi a/\lambda \ll 1$) is called the Rayleigh region.

At the other extreme from the Rayleigh region is the *optical* region, where the dimensionsof the sphere are large compared with the wavelength ($2\pi a/\lambda \gg 1$). For large $2\pi a/\lambda$, the radar cross section approaches the optical cross section πa^2. In between the optical and the Rayleigh region is the Mieor resonance, region. The cross section is oscillatory with frequency within this region.

CROSS-SECTION FLUCTUATIONS

In the minimum signal-to-noise ratio it is assumed that the echo signal received from a particular target did not vary with time. In practice, however, the echo signal from a target in motion is almost never constant. Variations in the echo signal may be caused by meteorological conditions, the lobe structure of the antenna pattern, equipment instabilities, or variations in the target cross section.

One method of accounting for a fluctuating cross section in the radar equation is to select a lower bound, that is, a value of cross section that is exceeded some specified (large) fraction of time. The fraction of time that the actual cross section exceeds the selected value would be close to unity (0.95 or 0.99 being typical). For all practical purposes the value selected is a minimum and the target will always present a cross section greater than that selected. This procedure results in a conservative prediction of radar range and has the advantage of simplicity.

However, to properly account for target cross-section fluctuations,the probability- density function and the correlation properties with time must be knownfor the particular target and type of trajectory. Curves of cross section as a function of aspectand knowledge of the trajectory with respect to the radar are needed to obtain a true description of thedynamical variations of cross section.

A more economical method to assess the effects of a fluctuating crosssection is to postulate a reasonable model for the fluctuations and to analyze it mathematically.Swerling has calculated the detection probabilities for four different fluctuation models of crosssection. In two of the four cases, it is assumed that the fluctuations are completely correlated during a particular scan but are completely uncorrelated from scan to scan. In the other two cases, thefluctuations are assumed to be more rapid and uncorrelated pulse to pulse. The four fluctuationmodels are as follows:

Case 1 .

The echo pulses received from a target on any one scan are of constant amplitude throughout the entire scan but are independent (uncorrelated) from scan to scan. This assumption ignores the effect of the antenna beam shape on the echo amplitude. An echo fluctuation of this type willbe referred to as scan-to-scan fluctuation. The probability density function for the crosssection σ is given by the density function.

$$p(\sigma) = \frac{1}{\sigma_{av}} \exp\left(-\frac{\sigma}{\sigma_{av}}\right) \qquad \sigma \geq 0$$

where$\sigma_{av}$is the average cross section over all target fluctuations.

Case 2: The probability-density function for the target cross section is also given by Eq. above butthe fluctuations is more rapid than in case 1 and are taken to be independent from pulse to pulse instead of scan to scan.

Case 3: In this case the fluctuation is assumed to be independent from scan to scan as in case 1 butthe probability-density function is given by

$$p(\sigma) = \frac{4\sigma}{\sigma_{av}^2} \exp\left(-\frac{2\sigma}{\sigma_{av}}\right)$$

Case 4:

The fluctuation is pulse to pulse according to Eq. above. The probability-density function assumed in cases 1 and 2 applies to a complex target consisting of many independent scatterers of approximately equal echoing areas. Although, in theory, the number of independent scatterers must be essentially infinite, in practice the number may be as few as four or five. The probability-density function assumed in cases 3 arid 4 is more indicative of targets that can be represented as one large reflector together with other small reflectors. In all the above cases, the value of cross section to be substituted in the radar equation is the average cross section $\sigma_{av.}$ The signal-to-noise ratio needed to achieve a specified probability of detection without exceeding a specified false-alarm probability can be calculated for each model of target behavior. For purposes of comparison, the non-fluctuating cross section will be called case 5.

Displays

The purpose of the display is to visually present the information contained in the radar echo signal in a form suitable for operator interpretation and action. The cathode-ray tube (CRT) has been almost universally used as the radar display.

There are two basic cathode-ray tube displays. One is the **deflection-modulated CRT,** such as the A-scope, in which a target is indicated by the deflection of the electron beam. The other is the **Intensity modulated CRT** such as the **PPI**, in which a target is indicated by intensifying the electron beam and presenting a luminous spot on the face of the CRT.

The deflection of the beam or the appearance of an intensity-modulated spot on a radar display caused by the presence of a target is commonly referred to as a **blip.**

With the advent of technology in the display systems being used in other applications like computer monitors and TVs , the modern Radars now a days use the state of the art LCD and LED displays along with digital storage techniques overcoming many of the limitations of CRT displays used earlier.

Types of display presentations:

The various types of displays which were used forsurveillance and tracking radars are defined as follows:

A-scope*: A*deflection-modulated display in which the vertical deflection is proportional to target echostrength and the horizontal coordinate is proportional to range.

B-scope: An intensity-modulated rectangular display with azimuth angle indicated by the horizontalcoordinate and range by the vertical coordinate.

C-scope:An intensity-modulated rectangular display with azimuth angle indicated by the horizontalcoordinate and elevation angle by the vertical coordinate.

D-scope:A C-scope in which the blips extend vertically to give a rough estimate of distance.

E-scope:An intensity-modulated rectangular display with distance indicated by the horizontal coordinateand elevation angle by the vertical coordinate.

F –Scope: A rectangular display in which a target appears as a centralized blip when the radar antenna isaimed at it. Horizontal and vertical aiming errors are respectively indicated by the horizontal andvertical displacement of the blip.

PPI, or ***Plan Position Indicator*** (also called ***P-scope):*** An intensity-modulated circular display on whichecho signals produced from reflecting objects are shown in plan position with range and azimuthangle displayed in polar (rho-theta) coordinates, forming a map-like display.

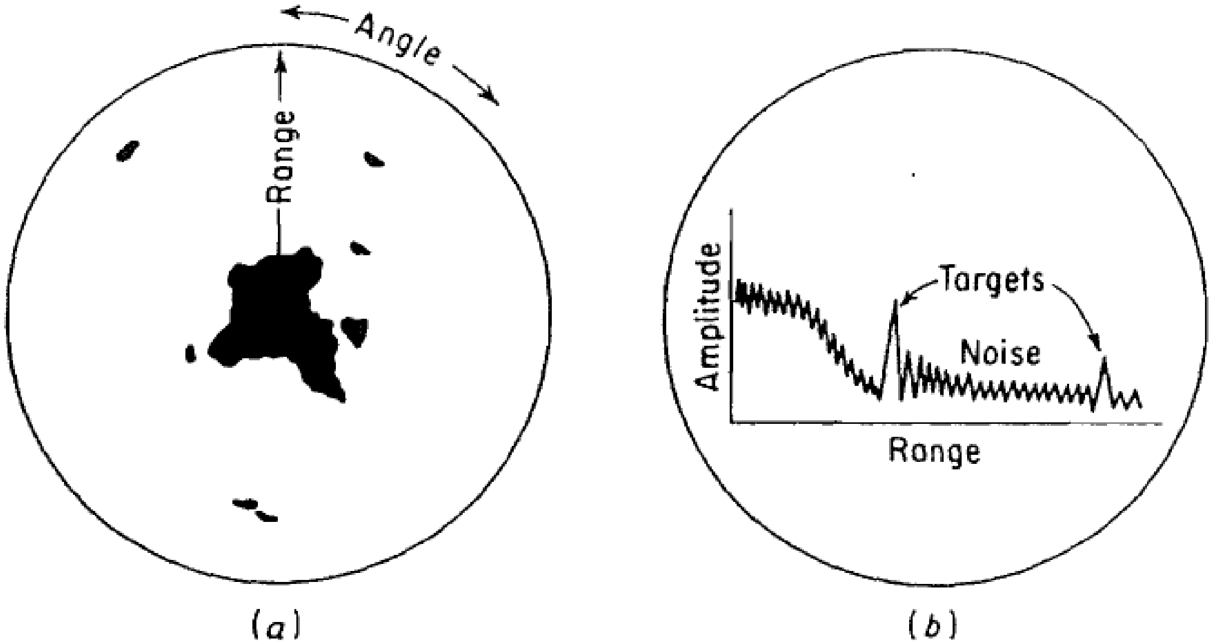


Fig. (a) PPI presentation displaying range vs. angle (intensity modulation) (b) *A-scope presentation* displaying amplitude vs. range (deflection modulation).

Problems

Example 1. A radar operating at 10 GHz with a peak power of 500 KW, the power gain of the antenna is 5000 and minimum power of receiver is 10^{-14} w. calculate maximum radar range if effective area of the antenna is 10 m^2 And radar cross section is 4 m^2 .

Ans : Given data f_p = 10 GHz P_t = 500 KW G = 5000 S_{min} = 10^{-14} W A_e = 10 m^2 σ = 4 m^2

Sub above values in below eq

$$R_{\max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{\min}} \right]^{\frac{1}{4}}$$ **= 501672 m = 501.6 Km**

Example 2 What is the peak power Unambiguous range of a radar whose average transmitter power is 200w, pulse width of 1μs and a pulse repetition frequency of 1000Hz.

Ans :P_{av}= 200 W τ = 1μs f_p = 1000 Hz

Average Power $P_{av} = P_t \, x\tau / T_P$ $P_t = P_{av} / \tau f_P$

P_t=200 / 1 x 10^{-6} x 1000 = **200 KW**

Example 3 A missile Radar operating at 10GHz, has a maximum range of 50Km with an antenna gain of 4000.If the transmitter has a power of 250KW and minimum detectable signal of 10^{-11}w.Determine the cross section of the target the radar can sight.

Ans: Given data

f_p = 10GHz R = 50 Km G = 4000 P_t = 250 KW $S_{min} = 10^{-11}$W

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

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

λ = C / f = 3 x 10^8 / 10 x 10^{12} = 3 x 10^{-5} m

Sub values in above Equation **σ** =

Example 4: A certain Radar has PRF of 1250 pulses per second. What is the maximum unambiguous range? **Ans**:Max. Unambiguous Range is given by

R unambig. = C /2fp R unambig. = 3x10^8/2x1250mtrs = 120X103mts **= 120Kms**

Example 5: Aground based air surveillance radar operates at a frequency of 1.3 GHz(L Band). Its maximum range is 200 Km for the detection of a target with a RCS of 1 m^2. Its antenna is a horn of 12 m wideby 4 m high; its gain is 17 dB. The receiver sensitivity - 100dBm. The minimum detection range is required to be 300 m. Determine the following

a) Peak transmitter power.

b) PRF to achieve a maximum range of 200 Km

c) Average transmitter power.

d) Range resolution

e) Azimuthal beamwidth

Ans: a) Peak transmitter power.

$f_{c/}$ = 1.3 GHz R_{max} = 200 Km σ = 1 m^2 G= 17 dB

Receiver sensitivity S_{min} = - 100 dBmR_{min} = 300 m

$$P_t = {P_r (4\pi)^3 R^4}\Big/{G_t^2 \lambda^2 \sigma}$$

For maximum range $P_r = S_{min}$

$$\boxed{\mathbf{P_t} = \frac{S_{min}(4\pi)^3 R_{max}^4}{G_t^2 \lambda^2 \sigma}}$$

$10 \log S_{min} = -100$ dBm$\Rightarrow S_{min} = 10^{-10}$ mw $= 10^{-13}$ w

$R_{max} = 200$ Km $= 2 \times 10^5$ m

$G_t = 17$ dB $= 10^{1.7} = 50.12$

$\lambda = C / f = 3 \times 10^8 / 1.3 \times 10^9$ m $= 0.23$ m

Sub the values in above equation

$\mathbf{P_t = 2.38 \times 10^9 W = 2380\ MW}$

b) PRF to achieve a maximum range of 200 Km

R unambig. = C /2fp=>f_p= C / 2 R_{unam} = **750 Hz**

c) Average transmitter power.

The pulse width τ of transmitted signal gives minimum detectable range of target(R_{min})

$R_{min} = \tau C / 2 \Rightarrow \tau = 2 R_{min} / C = 2 \times 10^{-6}$ sec

$P_{av} = P_t \times \tau \times f_p$ =**3.57 MW**

d) Range resolution

Range resolution ≈ R_{min} **= 300 m**

e) Azimuthal beamwidth

From antenna theory, Azimuthal beamwidth (deg) = 70 λ / D = 70 λ / 12 m **= 1.34°**

Example 6: A Pulse Radar transmits a peak power of 1 Mega Watt. It has a PRT equal to 1000 micro sec and the transmitted pulse width is 1 micro sec. Calculate (i)Maximum unambiguous range (ii) Average Power (iii)Duty Cycle (iv) Energy transmitted & (v)Bandwidth

Ans:

(i) Maximum unambiguous range = c.T_P /2 = $3 \times 10^8 \times 1000 \times 10^{-6}/2 = 150 \times 10^3$ mtrs = **150 Kms**

(ii) Average Power = $P_P \times \tau / T_P = 1 \times 10^6 1 \times 10^{-6}/1000 \times 10^{-6}$ = 1000 watts = **1kw**

(iii)Duty Cycle = $\tau / T_P = 1 \times 10^{-6}/1000 \times 10^{-6}$ = **0.001**

(iv) Energy transmitted = $P_P \times \tau$ (Peak power xTime) = $1 \times 10^6 \times 1 \times 10^{-6}$ = **1 Joule**

(v)Bandwidth = $1/\tau = 1/10^{-6}$ = **1Mhz**

Example 7: The Bandwidth of I.F. Amplifier in a Radar Receiver is 1 MHZ. If the Threshold to noise ratio is 12.8 dB determine the False Alarm Time.

T_{fa}= False Alarm TimeT_{fa}= $[1/B_{IF}]$Exp$\mathbf{V_T^2/2\psi_0}$where B_{IF} = 1X 10^6 HZ

Threshold to Noise Ratio = 12.8 dB i.e. 10 $\text{Log}_{10}$$[\mathbf{V_T^2/2\psi_0}]$ **= 12.8db**

$\mathbf{V_T^2/2\psi_0}$**= Antilog$_{10}$ [12.8/10] = 19.05**

T_{fa}= $1/(1\text{X } 10^6)$ Exp 19.05 = $187633284/10^6$= **187.6 Seconds**

Example 8 The probability density of the envelope of the noise voltage output is given by the Rayleigh probability-density function

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

where R is the amplitude of the envelope of the filter output for $R \geq 0$. If P_{fa}needed is $\leq 10^{-5}$. Determine the Threshold Level.

Ans:

The probability of false alarm P_{FA} in terms of the threshold voltage level is given by :

P_{FA}= $\text{Exp}(-V_T^2/2\psi_0) = 10^{-5}$

Taking logarithms on both the sides we get

$- 5 \text{ Log}_e 10 = (-V_T^2/2\psi_0)$

$5 \times 2.3026 = (V_T^2/2\psi_0)$

$V_T^2 = 11.5 \times 2\ \psi_0$

$V_T = \sqrt{23} \times \sqrt{\psi} =$ **4.8** $\boldsymbol{\sqrt{\psi_0}}$

Example9 : The bandwidth of an IF amplifier is 1 MHz and the average false-alarm time that could be tolerated is 15 min. Find the probability of a false alarm.

Ans: The relationship between average false-alarm time T_{FA}, probability of a false alarm P_{FA} and the IF bandwidth B is given by **P_{fa}= 1/ T_{fa}. B**

Substituting **B** = 1 MHz i.e. $10^6$and **T_{fa}**=15 mnts. I.e. 900 secs. We get **PFA=1.11 X 10^{-9}**

Example 10: What is the ratio of threshold voltage to the rms value of the noise voltage necessary to achieve this false-alarm time?

Ans: This is found out using the relationship **P_{FA} = Exp $(-V_T^2/2\psi_0)$**

from which the ratio of Threshold voltage to rms value of the noise voltage is given by

$V_T/\sqrt{\psi_0} = \sqrt{2 \ln (1/P_{fa})} = \sqrt{2 \ln 9X10^8}$ **= 6.45 = 20 log 6.45 = 16.2dB**

Example 11: Typical parameters for a ground-based search radar are : 1. Pulse repetition frequency :300 Hz, 2. Beam width : 1.5^0, and 3. Antenna scan rate: 5 rpm (30^0/s). Find out the number of pulses returned from a point target on each scan.

Ans : The number of pulses retuned from a point target on each scan n_B is given by**:**

$$n_B = \theta_B . f_P / \theta'_S = \theta_B . f_P / 6\, \omega_m$$

Substituting the above values we get **:** $n_B = 1.5 \times 300 / 30 = 15$

Example 12: A ship board radar has 0.9 micro sec transmitted pulse width. Two small boats in the same direction are separated in range by 150 mts. Will the radar detect the two boats as two targets?

Ans: Radar Range Resolution: The range resolution of a Radar is its ability to distinguish two closely spaced targets along the same line of sight (LOS). The Range resolution is a function of the pulse length, where the pulse length $LP = c\ \tau/2$ **(Two way range corresponding to the pulse width)**

Radar Range resolution = $R_{min} = 3x10^8 x0.9x10^{-6}/2 =$ **135 mtrs.**

Since the boats are at 150 Mts. apart, which is greater than the range Resolution of 135mtrs, the radar can detect the 2 boats as 2 separate targets.