DEPT & SEM : ECE & I SEM

SUBJECT NAME : RADAR SYSTEMS

UNIT : I

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UNIT 1-OUTLINE

- Radar –Def & History
- Nature Of Radar
- Maximum Unambiguous Range
- Radar Specifications
- Radar Range Equation
- Radar Block Diagram

- **Radar Frequencies**
- **Radar Applications**
- **Prediction of Range Performance**
- **Minimum Detectable Signal**
- **Receiver Noise**
- **Modified Radar Range Equation**

RADAR DEFINITION & HISTORY

WHAT IS RADAR

- **RADAR** stands for **RADIO DETECTION AND RANGING**
- Radar is an object-detection system that uses radio waves to determine the range altitude, direction, or speed of objects.

HISTORY OF RADAR

- 1886: H.R.Hertz Discovered Electromagnetic wave.
- 1897: G.Marconi (known as pioneer of radio communication) firstly transmitte electromagnetic wave for long distance.
- 1930: L.A.Hyland,Locates an aircraft for first time

NATURE OF RADAR

- Radar operates by radiating energy
- Duplexer
- Echo signal
- Doppler effect
- 1 Nautical mile=1.852 km

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

Terminology of Radar Systems

Following are the basic terms, which are useful in this tutorial.

- Range
- Pulse Repetition Frequency
- Maximum Unambiguous Range
- Minimum Range

Now, let us discuss about these basic terms one by one.

Range

The distance between Radar and target is called **Range** of the target or simply range, R. We know that Radar transmits a signal to the target and accordingly the target sends an echo signal to the Radar with the speed of light, C.

Let the time taken for the signal to travel from Radar to target and back to Radar be 'T'. The two way distance between the Radar and target will be 2R, since the distance between the Radar and the target is R.

Now, the following is the formula for **Speed**.

$$Speed = \frac{Distance}{Time}$$

$$=> Distance = Tpeed \times Time$$

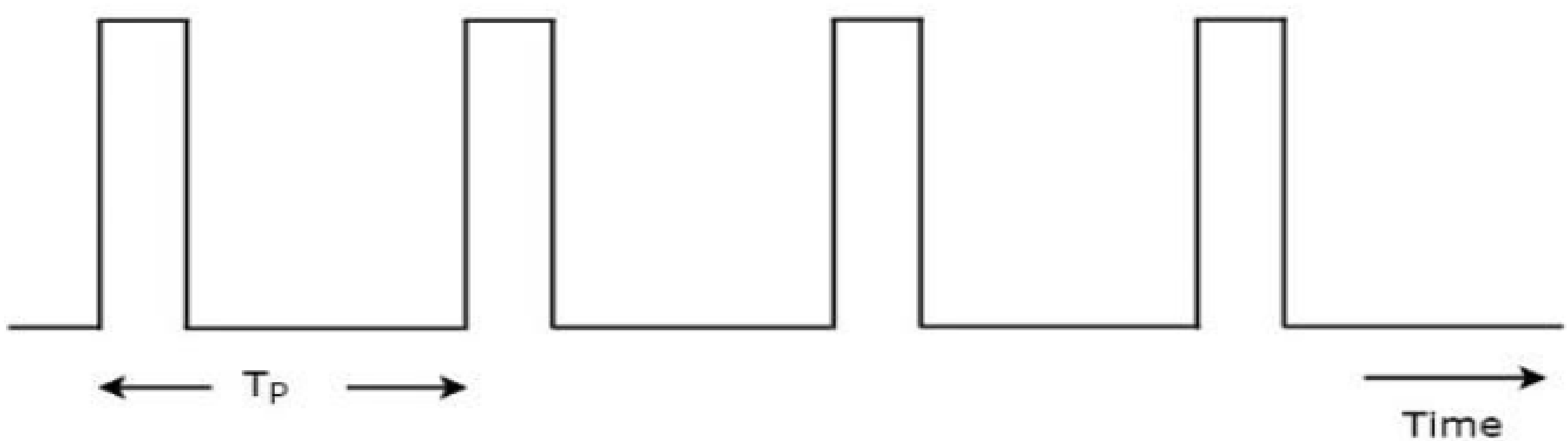
$$=> 2R = C \times T$$

$$R = \frac{CT}{2} \qquad \text{Equation 1}$$

We can find the **range of the target** by substituting the values of C & T in Equation 1.

Pulse Repetition Frequency

Radar signals should be transmitted at every clock pulse. The duration between the two clock pulses should be properly chosen in such a way that the echo signal corresponding to present clock pulse should be received before the next clock pulse. A typical **Radar wave form** is shown in the following figure.



As shown in the figure, Radar transmits a periodic signal. It is having a series of narrow rectangular shaped pulses. The time interval between the successive clock pulses is called **pulse repetition time,** T_P.

The reciprocal of pulse repetition time is called **pulse repetition frequency**, f_P. Mathematically, it can be represented as

$$f_P = \frac{1}{T_P} \qquad \text{Equation 2}$$

Maximum Unambiguous Range

We know that Radar signals should be transmitted at every clock pulse. If we select a shorter duration between the two clock pulses, then the echo signal corresponding to present clock pulse will be received after the next clock pulse. Due to this, the range of the target seems to be smaller than the actual range.

So, we have to select the duration between the two clock pulses in such a way that the echo signal corresponding to present clock pulse will be received before the next clock pulse starts. Then, we will get the true range of the target and it is also called maximum unambiguous range of the target or simply, **maximum unambiguous range**.

Substitute, $R = R_{un}$ and $T = T_P$ in Equation 1.

$$R_{un} = \frac{CT_P}{2} \qquad \text{Equation 3}$$

$$T_P = 1/f_P$$

$$R_{un} = \frac{C}{2 f_P}$$

Minimum Range

We will get the **minimum range** of the target, when we consider the time required for the echo signal to receive at Radar after the signal being transmitted from the Radar as pulse width. It is also called the shortest range of the target.

Substitute, $R = R_{min}$ and $T = \tau$ in Equation 1.

$$R_{min} = \frac{C\tau}{2} \qquad \text{Equation 6}$$

We will get the value of minimum range of the target, R_{min} by substituting the values of C and τ in Equation 6.

Pulse Transmission

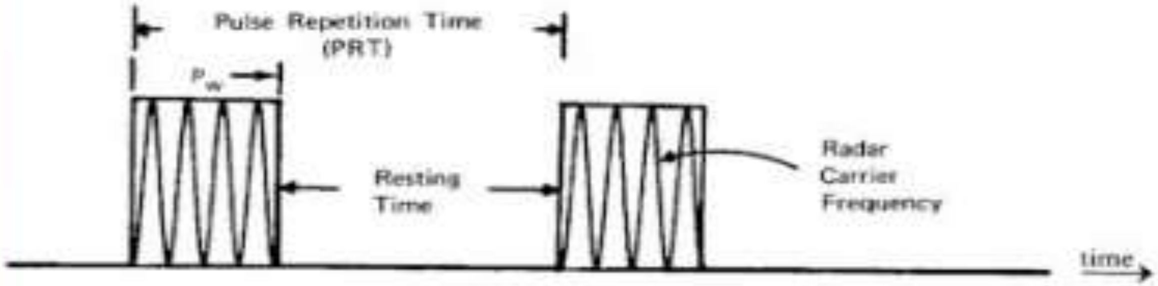


Figure 2–1. Pulse transmission.

- 2. Pulse repetition frequency (PRF)
  - a. Pulses per second
  - b. Relation to pulse repetition time (PRT)
  - c. Effects of varying PRF
    - (1) Maximum range
    - (2) Accuracy
- 3. Peak power
  - a. Maximum signal power of any pulse
  - b. Affects maximum range of radar

- 4. Average power
  - a. Total power transmitted per unit of time
  - b. Relationship of average power to PW and PRT
- 5. Duty cycle
  - a. Ratio PW (time transmitting) to PRT (time of entire cycle, time transmitting plus rest time)
  - b. Also equal to ratio of average power to peak power

- **C. Discuss the determination of range with a pulse radar.**

Pulse Transmission

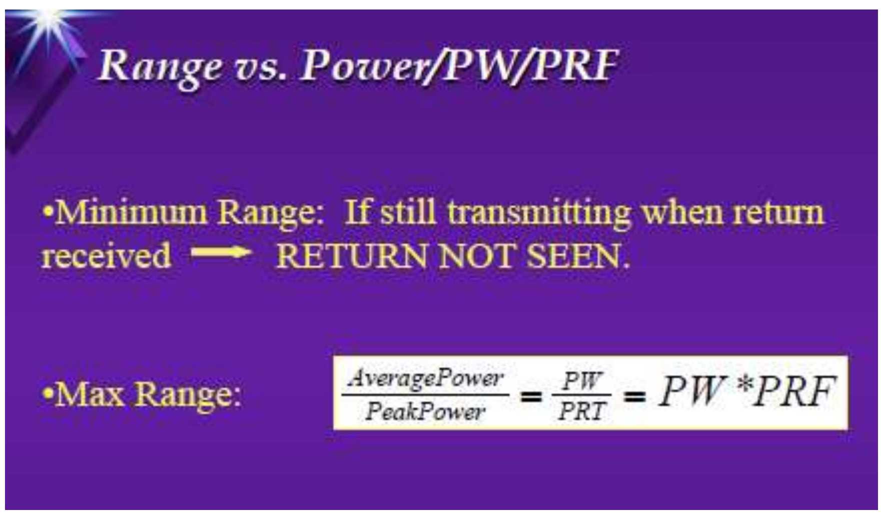
- **Pulse Width (PW)**
  - Length or duration of a given pulse
- **Pulse Repetition Time (PRT=1/PRF)**
  - PRT is time from beginning of one pulse to the beginning of the next
  - PRF is frequency at which consecutive pulses are transmitted.
- **PW can determine the radar's minimum detection range; PW can determine the radar's maximum detection range.**
- **PRF can determine the radar's maximum detection range.**

RADAR SPECIFICATIONS

- Transmitted Power :: 1 Mega watt
- Pulse Width :: 1 Microsecond
- Pulse Repetition Period ::1 Milli second
- Average Power can be calculated as

  Transmitted Power * Pulse Width *Pulse Repetition Frequency

- Energy :: Transmitted Power * Pulse Width



RADAR RANGE EQUATION

- If the power of the radar transmitter is denoted by Pt , and if an isotropic antenna is used (one which radiates uniformly in all directions), the power density(watts per unit area) at a distance R from the radar is equal to the transmitter power divided by the surface area 4Π R2 of an imaginary sphere of radius R,

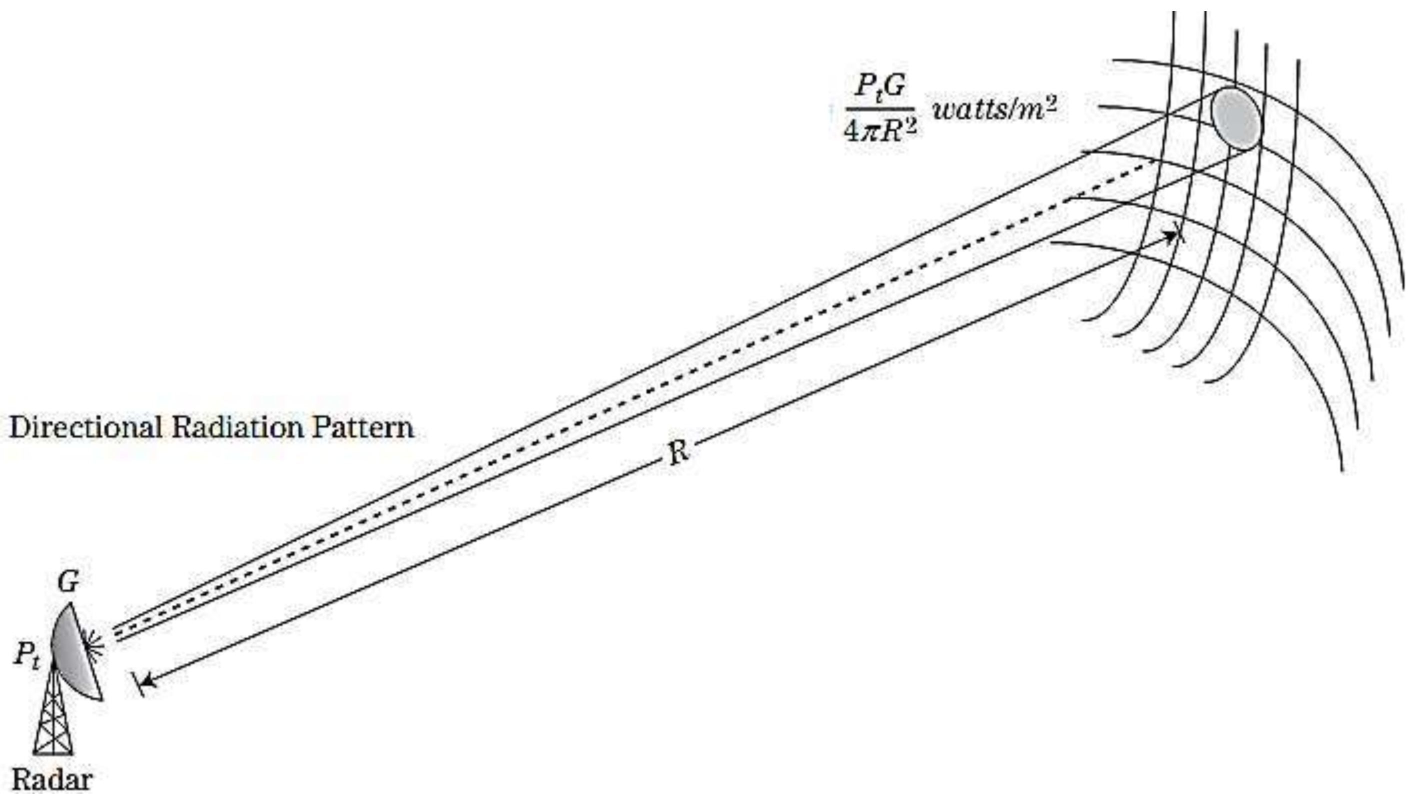
$$\text{Power density from isotropic antenna} = \frac{P_t}{4\pi R^2}$$

- The power density at the target from an antenna with a transmitting gain G 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 in the direction of the radar is denoted as the radar cross section σ, and is defined by the relation

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


$\frac{P_t G}{4\pi R^2}$ watts/m^2
Directional Radiation Pattern
R
G
P_t
Radar

RADAR RANGE EQUATION

- If the effective area of the receiving antenna is denoted Ae, the power Pr, 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 Rmax is the distance beyond which the target cannot be detected. It occurs when the received echo signal power P, just equals the minimum detectable signal Smin,

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

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

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

- Two other forms of Radar Equation are

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

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

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

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

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

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

We know the following formula for **operating wavelength, λ in terms of operating frequency, f.**

$$c = 10^8 m / s$$

Problem 1

Calculate the **maximum range of Radar** for the following specifications:

- Peak power transmitted by the Radar, $P_t = 250KW$
- Gain of transmitting Antenna, $G = 4000$
- Effective aperture of the receiving Antenna, $A_e = 4\ m^2$
- Radar cross section of the target, $\sigma = 25\ m^2$
- Power of minimum detectable signal, $S_{min} = 10^{-12}W$

Solution

We can use the following **standard form** of Radar range equation in order to calculate the maximum range of Radar for given specifications.

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

Substitute all the given parameters in above equation.

$$R_{Max} = \left[\frac{(250 \times 10^3)(4000)(25)(4)}{(4\pi)^2(10^{-12})}\right]^{1/4}$$

$$=> R_{Max} = 158\ KM$$

Therefore, the **maximum range of Radar** for given specifications is **158 *KM***.

Problem 2

Calculate the **maximum range of Radar** for the following specifications.

- Operating frequency, $f = 10GHz$
- Peak power transmitted by the Radar, $P_t = 400KW$
- Effective aperture of the receiving Antenna, $A_e = 5\ m^2$
- Radar cross section of the target, $\sigma = 30\ m^2$
- Power of minimum detectable signal, $S_{min} = 10^{-10}W$

Solution

We know the following formula for **operating wavelength, λ** in terms of operating frequency, f.

$$\lambda = \frac{C}{f}$$

Substitute, $C = 3 \times 10^8 m/sec$ and $f = 10GHz$ in above equation.

$$\lambda = \frac{3 \times 10^8}{10 \times 10^9}$$

$$=> \lambda = 0.03m$$

So, the **operating wavelength, λ** is equal to $\mathbf{0.03m}$, when the operating frequency, f is $10GHz$.

We can use the following **modified form** of Radar range equation in order to calculate the maximum range of Radar for given specifications.

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

Substitute, the given parameters in the above equation.

$$R_{Max} = \left[\frac{(400 \times 10^3)(30)(5^2)}{4\pi (0.03)^2 (10^{-10})}\right]^{1/4}$$

$$=> R_{Max} = 128KM$$

Therefore, the **maximum range of Radar** for given specifications is **128 KM**.

RADAR BLOCK DIAGRAM

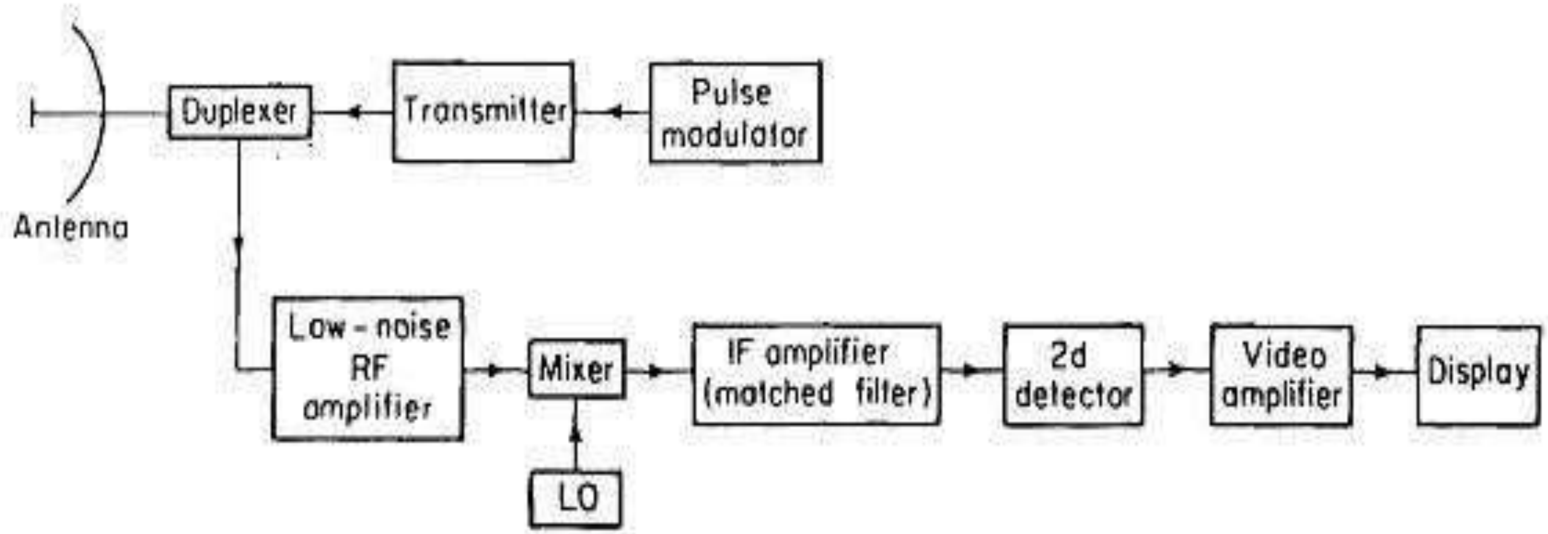


Fig 1.1: Block diagram of a pulse radar

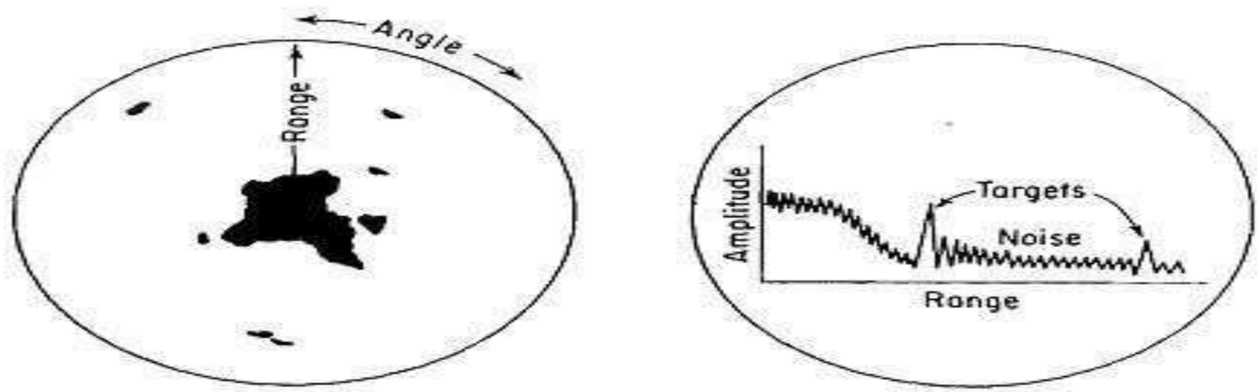


Fig 1.2(a) PPI presentation displaying Range vs. Angle (intensity modulation)
(b) A-scope presentation displaying Amplitude vs. Range (deflection modulation)

Given below are 6 major parts of a RADAR System:

A Transmitter: It can be a power amplifier like a Klystron, Travelling Wave Tube or a power Oscillator like a Magnetron. The signal is first generated using a waveform generator and then amplified in the power amplifier.

Waveguides: The waveguides are transmission lines for transmission of the RADAR signals.

Antenna: The antenna used can be a parabolic reflector, planar arrays or electronically steered phased arrays.

Duplexer: A duplexer allows the antenna to be used as a transmitter or a receiver. It can be a gaseous device that would produce a short circuit at the input to the receiver when transmitter is working.

Threshold Decision: The output of the receiver is compared with a threshold to detect the presence of any object. If the output is below any threshold, the presence of noise is assumed.

Receiver: It can be super heterodyne receiver or any other receiver which consists of a processor to process the signal and detect it.

The super heterodyne receiver changes the rf frequency into an easier to process lower IF- frequency. This IF- frequency will be amplified and demodulated to get a video signal.

The RF-carrier comes in from the antenna and is applied to a filter. The output of the filter are only the frequencies of the desired frequency-band. These frequencies are applied to the mixer stage. The mixer also receives an input from the local oscillator. These two signals are beat together to obtain the IF through the process of heterodyning. There is a fixed difference in frequency between the local oscillator and the rf-signal at all times by tuning the local oscillator. The IF-carrier is applied to the IF-amplifier. The amplified IF is then sent to the detector. The output of the detector is the video component of the input signal.

RADAR FREQUENCIES

Band designation	Nominal frequency range	Specific radiolocation (radar) bands based on ITU assignments for region 2
HF	3–30 MHz	
VHF	30–300 MHz	138–144 MHz
		216–225
UHF	300–1000 MHz	420–450 MHz
		890–942
L	1000–2000 MHz	1215–1400 MHz
S	2000–4000 MHz	2300–2500 MHz
		2700–3700
C	4000–8000 MHz	5250–5925 MHz
X	8000–12,000 MHz	8500–10,680 MHz
K_u	12.0–18 GHz	13.4–14.0 GHz
		15.7–17.7
K	18–27 GHz	24.05–24.25 GHz
K_a	27–40 GHz	33.4–36.0 GHz
mm	40–300 GHz	

RADAR APPLICATIONS

- **Civilian Use**:
- **Air Traffic Control (ATC)**
  - All airports are equipped with ATC Radars, for safe landing and take-off and guiding of aircraft in bad weather and poor visibility conditions.
- **Aircraft Navigation**
  - All aircrafts fitted with weather avoidance radars. These Radars give warning information to pilot about storms, snow precipitation etc. lying ahead of aircraft's path.
  - Radar is used as an altimeter to indicate the height of the aircraft or helicopter.
-

RADAR APPLICATIONS

- **Maritime ship's safety and Navigation:**
    - Radar used to avoid collision of ships during poor visibility conditions (storms, cyclones etc.)
    - Guide ships into seaports safely.
- **Meteorological Radar:**
    - Used for weather warnings and forecasting. Provides sufficient advance information to civilian administration for evacuation of population in times cyclones, storms etc.

RADAR APPLICATIONS

- **<u>Military Applications</u>**
- Early warning of intruding enemy aircraft & missiles
- Tracking hostile targets and providing location information to Air Defense systems consisting of Tracking Radars controlling guns and missiles.
- Battle field surveillance
- Information Friend or Foe IFF
- Navigation of ships, aircraft, helicopter etc.

PREDICTION OF RANGE PERFORMANCE

- The simple form of the radar equation expressed the maximum radar range Rmax, 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 σ.

From the above equation, we can conclude that the following **conditions** should be considered in order to get the range of the Radar as maximum.

- Peak power transmitted by the Radar P_t should be high.
- Gain of the transmitting Antenna G should be high.
- Radar cross section of the target σ should be high.
- Effective aperture of the receiving Antenna A_e should be high.
- Power of minimum detectable signal S_{min} should be low.

It is difficult to predict the range of the target from the standard form of the Radar range equation. This means, the degree of accuracy that is provided by the Radar range equation about the range of the target is less. Because, the parameters like Radar cross section of the target, σ and minimum detectable signal, S_{min} are **statistical in nature**.

MINIMUM DETECTABLE SIGNAL

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

- A matched filter for a radar transmitting a rectangular- shaped pulse is usually characterized by a bandwidth B approximately the reciprocal of the pulse width τ,or $B\tau \approx 1$

- 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.

MINIMUM DETECTABLE SIGNAL

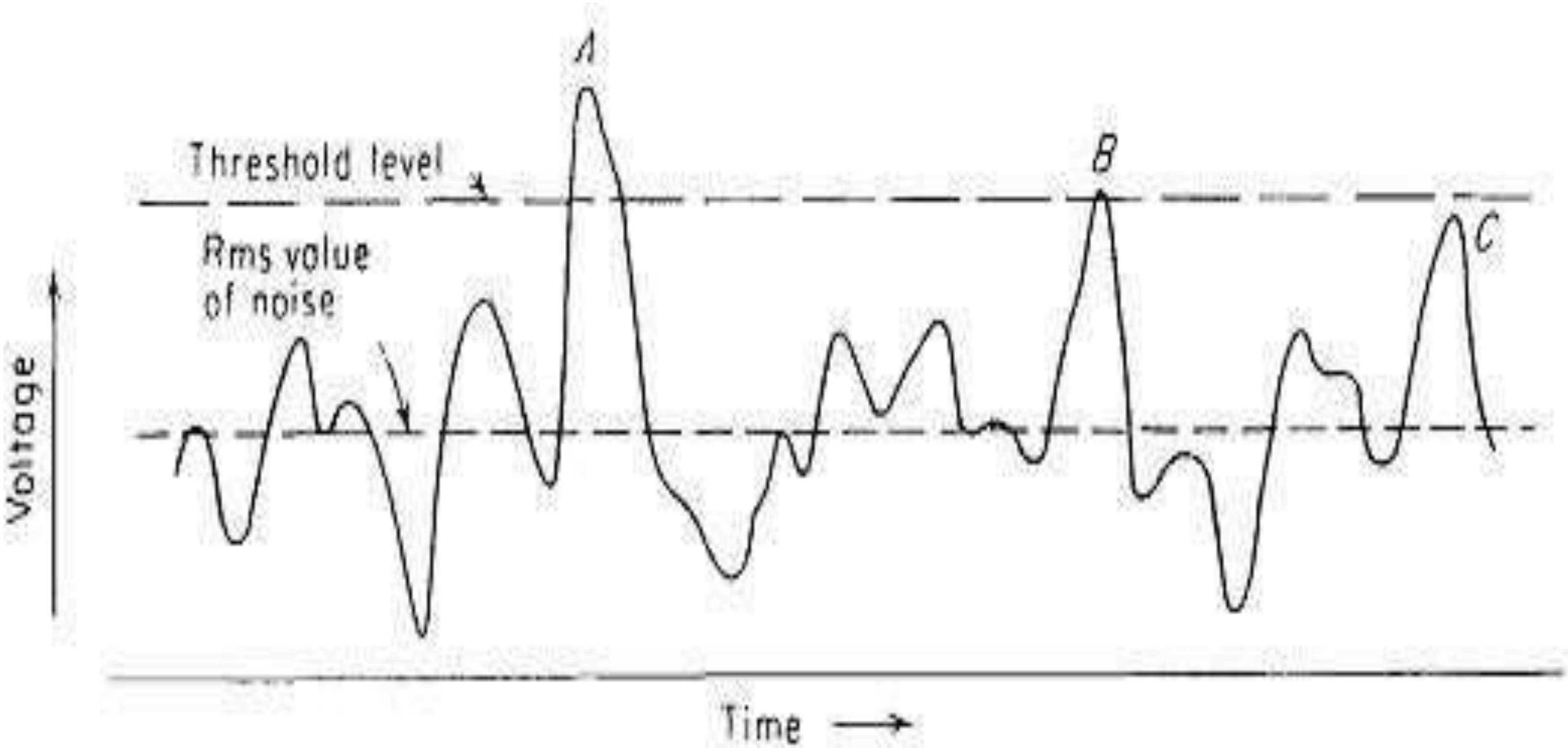


Fig 1.3: Typical envelope of the radar receiver output as a function of time. A, B, and C are three targets representing signal plus noise. A and B are valid detections, but C is a missed detection.

We have considered three points, A, B & C in above figure for identifying the valid detections and missing detections.

- The value of the signal at point A is greater than threshold value. Hence, it is a **valid detection**.

- The value of the signal at point B is equal to threshold value. Hence, it is a **valid detection**.

- Even though the value of the signal at point C is closer to threshold value, it is a **missing detection**. Because, the value of the signal at point C is less than threshold value.

So, the points, A & B are valid detections. Whereas, the point C is a missing detection.

Receiver Noise

If the receiver generates a noise component into the signal, which is received at the receiver, then that kind of noise is known as **receiver noise**. The receiver noise is an unwanted component; we should try to eliminate it with some precautions.

However, there exists one kind of noise that is known as the thermal noise. It occurs due to thermal motion of conduction electrons. Mathematically, we can write **thermal noise power, N_i** produced at receiver as:

$$N_i = KT_oB_n$$

Where,

K is the Boltzmann's constant and it is equal to $1.38 \times 10^{-23} J/deg$

T_o is the absolute temperature and it is equal to $290^0 K$

B_n is the receiver band width

RECEIVER NOISE AND SNR

- Since noise is the chief factor limiting receiver sensitivity, it is necessary to obtain some means of describing it quantitatively
- Noise is unwanted electromagnetic energy which interferes with the ability of the receiver to detect the wanted signal
- The available thermal-noise power generated by a receiver of bandwidth Bn, (in hertz) at a temperature T (degrees Kelvin) is

where k = Boltzmann's constant = 1.38 x 10-23 J/deg.

Bandwidth and is given by

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

RECEIVER NOISE AND SNR

- If the minimum detectable signal Smin, is that value of Si corresponding to the minimum ratio of output (IF) signal-to-noise ratio (So /No)min necessary for detection.

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

$$F_n = \frac{N_o}{kT_0 B_n G_a} = \frac{\text{noise out of practical receiver}}{\text{noise out of ideal receiver at std temp } T_0}$$

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

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

ENVELOPE DETECTOR

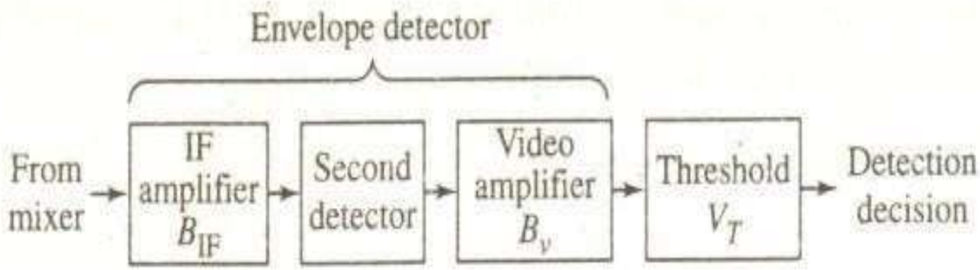


Fig 1.4.Envelope Detector

The details of system that is considered:

- **IF** amplifier with bandwidth $\mathbf{B_{IF}}$ followed by a second detector and a video amplifier with bandwidth $\mathbf{B_V}$ as shown in the figure above.
- Envelope detector, that is, one which rejects the carrier frequency but passes the modulation envelope.
- To extract the modulation envelope, the video bandwidth must be wide enough to pass the low-frequency components generated by the second detector,.
- The video bandwidth $\mathbf{B_V}$ must be greater than $\mathbf{B_{IF}/2}$ in order to pass all the video modulation.

PROBABILITY

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

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

- where ***R is the amplitude of the envelope of the filter output.***

- The probability that the envelope of the noise voltage will lie between the values of V1 and V2 is

$$\text{Probability } (V_1 < R < V_2) = \int_{V_1}^{V_2} \frac{R}{\psi_0} \exp\left(-\frac{R^2}{2\psi_0}\right) dR$$

- The probability that the noise voltage envelope will exceed the voltage threshold VT is

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

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

FALSE ALARM TIME

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

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

Where T_K **is the time between crossings of the threshold *VT by the noise envelope***

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

FALSE ALARM TIME

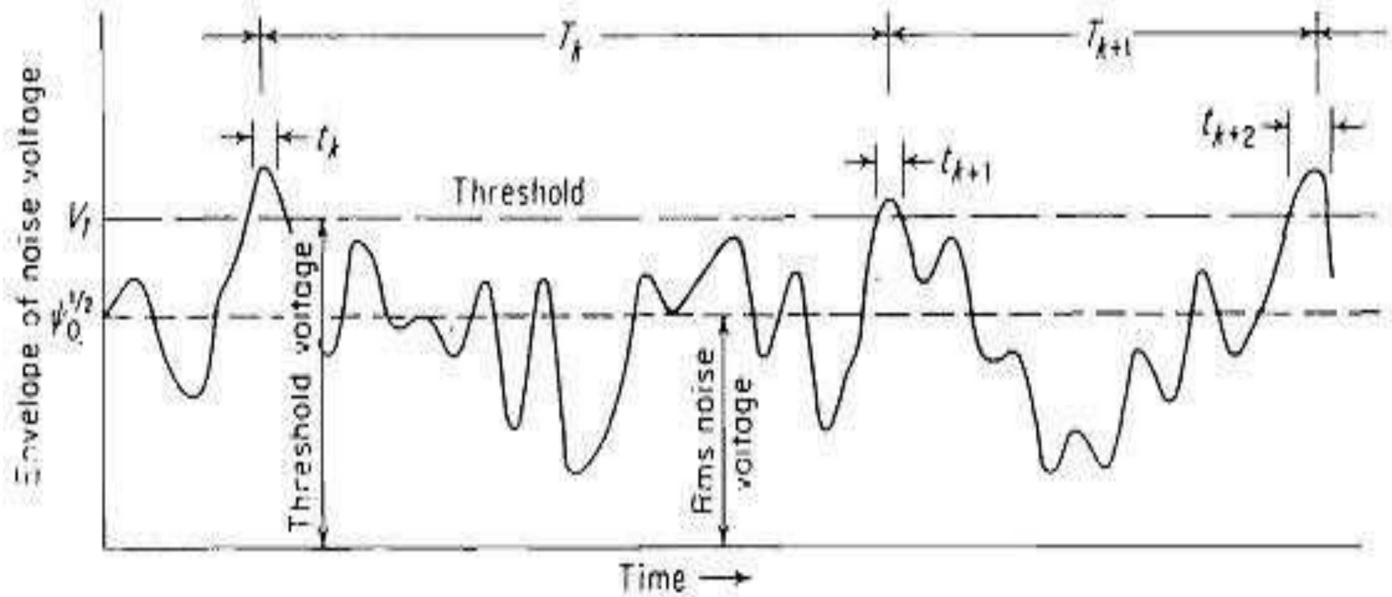


Fig 1.5: Envelope of receiver output illustrating false alarms due to noise.

Where t_K and T_K are shown in the Figure above. ***The average duration of a noise pulse is approximately the reciprocal of the bandwidth B,*** which in the case of the envelope detector is B_{IF}. Equating eqs. **7** and **8** we get

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

INTEGRATION OF RADAR PULSES

Integration may be accomplished in the radar receiver either before the second detector (in the IF) or after the second detector (in the video).

Integration before the detector is called pre detection or coherent integration

post detection integration is not concerned with preserving RF phase.

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

where **θB**= antenna beam width, deg
fP= pulse repetition frequency, **Hz**
θ'S = antenna scanning rate, deg/s
ωm= antenna scan rate, rpm

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

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

RADAR CROSS SECTION

Radar Cross section is given by

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

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

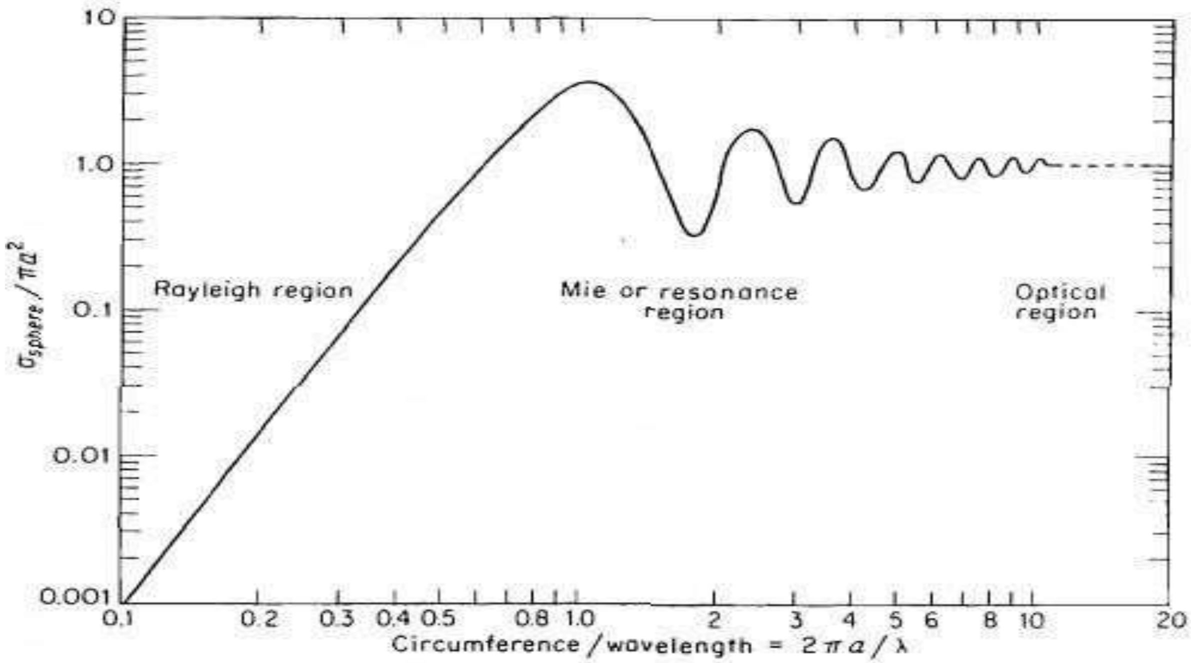


Fig 1.6.Radar cross section of the sphere. a = radius; λ= wavelength.

Radar cross section of a simple sphere: is shown in the figure below as a function of its circumference measured in wavelengths.($2\pi a/\lambda$ where a is the radius of the sphere and λ is the wavelength). The plot consists of three regions.

1. Rayleigh Region:

- The region where the size of the sphere is small compared with the wavelength (**$2\pi a/\lambda$. 1**) is called the **Rayleigh** region.
- The Rayleigh scattering region is of interest to the radar engineer because the cross sections of raindrops and other meteorological particles fall within this region at the usual radar frequencies. **2. Optical region**:
- It is at the other extreme from the **Rayleigh** region where the dimensions of the sphere are large compared with the wavelength (**$2\pi a/\lambda$ 1**). For large **$2\pi a/\lambda$**, the radar cross section approaches the optical cross section **πa^2**.

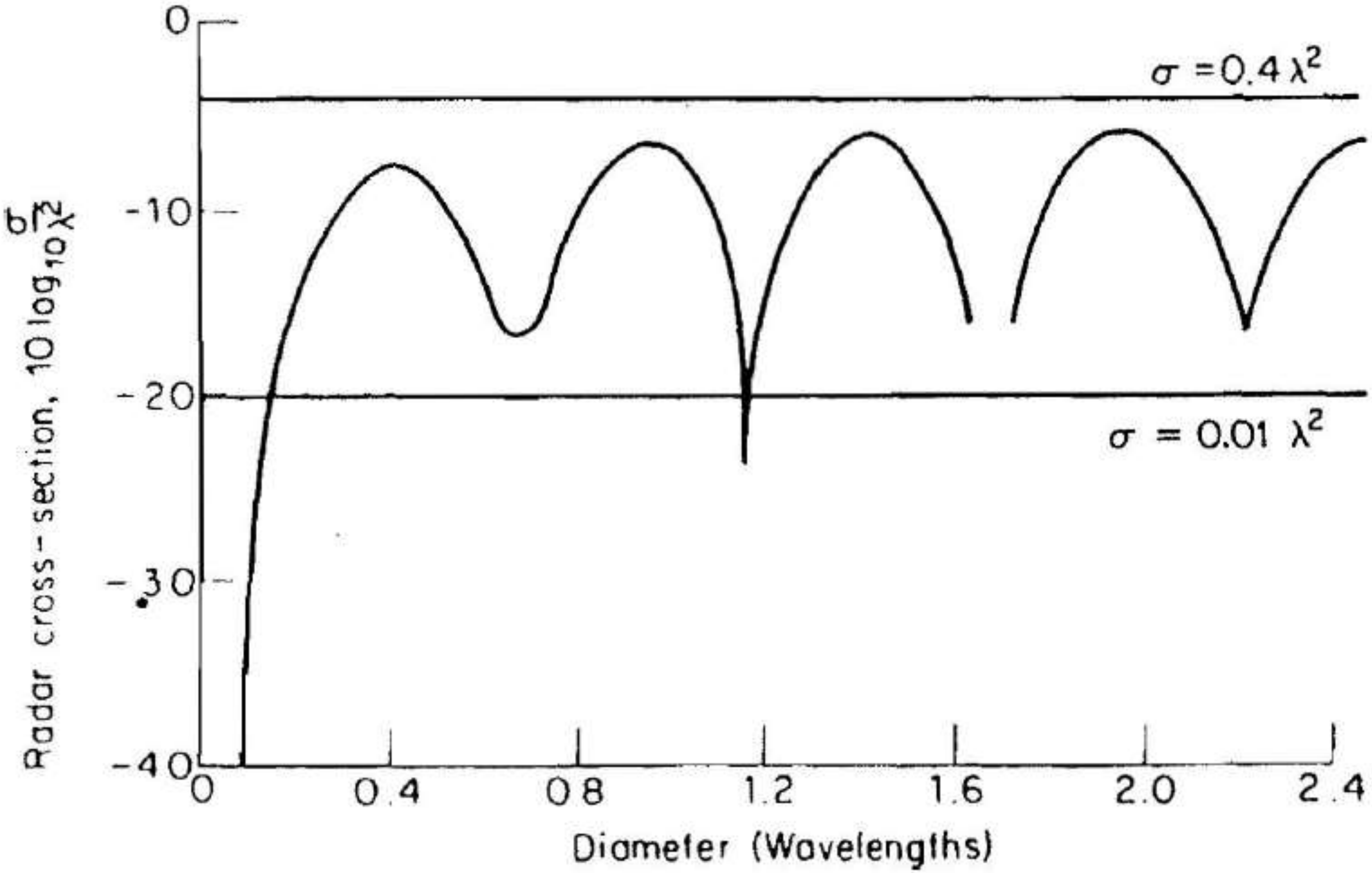
3. Mie or Resonance region:

- Between the optical and the Rayleigh region is the *Mie*, or resonance, region. The cross section is oscillatory with frequency within this region. The maximum value is 5.6 dB greater than the optical value, while the value of the first null is 5.5 dB below the optical value. (The theoretical values of the maxima and minima may vary according to the method of calculation employed.

Radar cross section of a cone-sphere

Scattering from any object occurs from discontinuities. The discontinuities, and hence the backscattering, of the
cone-sphere are from the tip and from the join between the cone and the sphere.
The nose-on radar cross section is small and decreases as the square of the wavelength. The cross section is small over
a relatively large angular region.

The nose-on cross section of the cone-sphere varies, but its maximum value is approximately **$0.4\lambda^2$ and its minimum**
is **$0.01\lambda^2$ for a wide range of half-angles for frequencies above the Rayleigh region.**



Radar cross section of a cone sphere with 150 half angle as a function of the diameter in Wave lengths.

TRANSMITTED POWER

The peak power: The power Pt in the radar equation is called the *peak power. This is not the instantaneous peak*
power of a sine wave. It is the power averaged over that carrier-frequency cycle which occurs at the maximum power of the pulse

The average radar power P_{av}: It 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 $\mathbf{T_p = 1/f_p}$, then the average power is related to the peak power by

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

Duty cycle: The ratio P_{av}/P_t, τ/T_P, or $\tau.f_P$ is called the duty cycle of the radar. A pulse radar for detection of aircraft might have typically a duty cycle of 0.001, while a CW radar which transmits continuously has a duty cycle of unity.

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.

PULSE REPETITION FREQUENCIES

- 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 ***multiple time around echoes.***
- Consider the three targets labeled ***A, B,*** and **C** in the figure(a) below
- The appearance of the three targets on an A-scope is shown in the figure (b)below.Only the range measured for target ***A*** is correct; those for **B** and **C** are not.

One method of distinguishing multiple-time-around echoes from unambiguous echoes is to operate with a varying pulse repetition frequency.

- echoes from multiple-time-around targets will be spread over a finite range as shown in the figure (c) below.
- The number of separate pulse repetition frequencies will depend upon the degree of the multiple time around targets

PULSE REPETETION FREQUENCIES

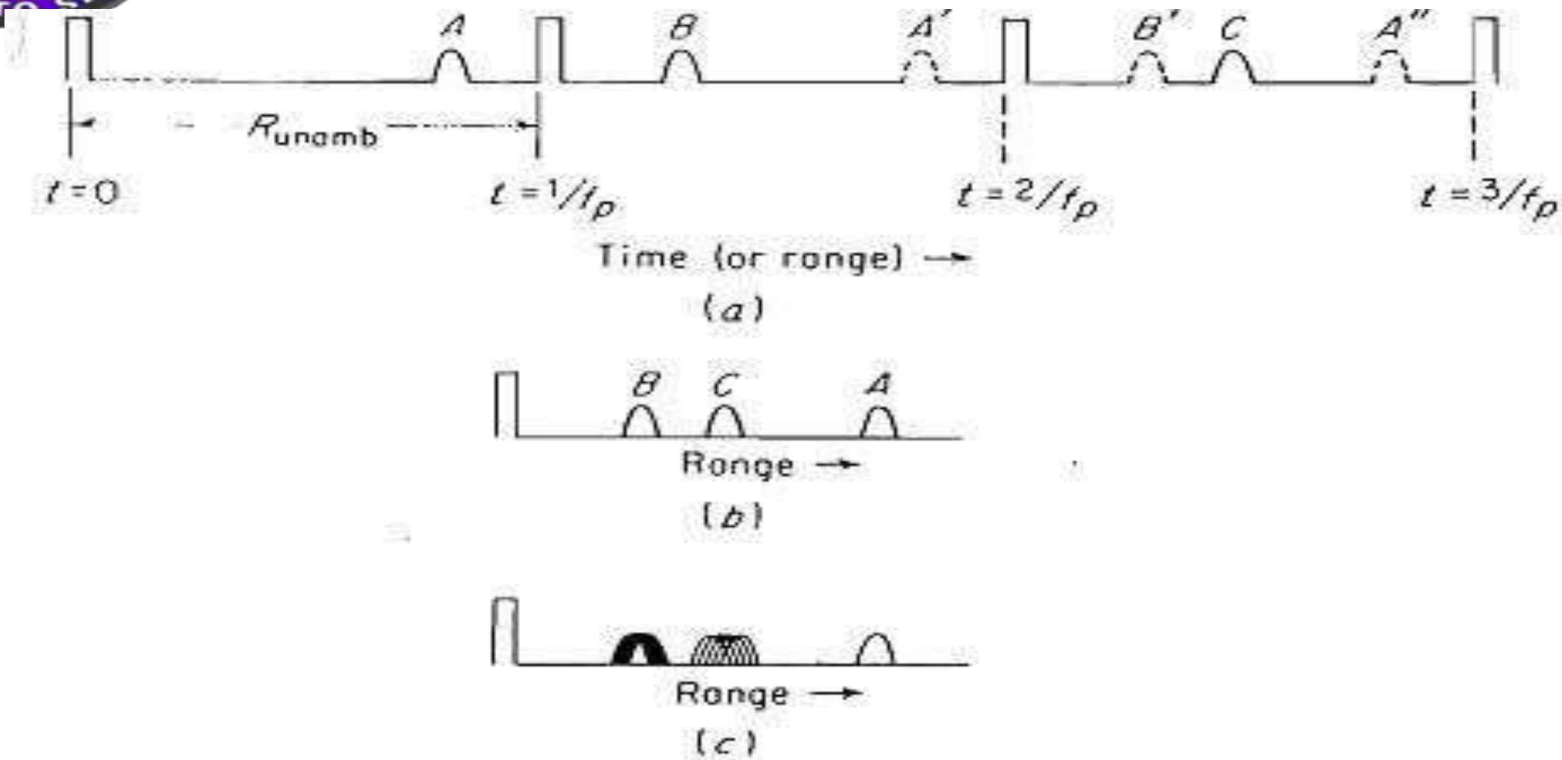


Fig. 1.7. Multiple-time-around echoes that give rise to ambiguities in range. (a) Three targets A, B and C, where A is within Runamb, and B and Care multiple-time-around targets(b)the appearance of the three targets on the A-scope (c) appearance of the three targets on the A-scope with a changing prf.

SYSTEM LOSSES

Transmit Losses – Typically associated with the feed, waveguides and other components between the power amplifier and the antenna. These are typically 1 to 2 dB in a well designed radar.

Receive Losses – Typically associated with the feed, waveguides and other components between the mouth of the feed and RF amplifier. These are also typically 1 to 2 dB for a well designed radar. If the noise figure is referenced to the antenna terminals, receive losses are included in the noise figure.

Atmospheric Losses – These are losses due to absorption by the atmosphere. They are dependent upon the radar operating frequency, the range to the target and the elevation angle of the target relative to the radar. Both Skolnik's text and Radar Handbook have graph depicting these losses.

Scanning or Beamshape Loss – This loss term accounts for the fact that, as the beam scans across the target, the signal amplitudes of the pulses coherently, or non-coherently, integrated varies. Because of this, the full integration gain of the integrator can't be realized. From the Skolnik Radar Handbook typical values are

o 1.6 dB for a scanning, fan beam radar

o 3.2 dB for a thinner beam, scanning radar

Range-Gate Straddling Loss – If the radar samples in range at a rate of once per range resolution cell the loss is usually taken to be 3 dB.

� Doppler Straddling Loss – The loss associated with forming the Doppler dimension of a range-Doppler map. Its particular value depends upon the specific Doppler processor implementation but typical values are 1 to 2 dB.

Collapsing Loss – If the coherent or non-coherent integrator integrates only noise over some if its integration time (due to the fact that the beam has moved fairly far off of the target) the radar will incur a loss that is given by

$$L_C = \frac{n+m}{n}$$

where n is the number of pulses containing signal-plus-noise and m is the number of pulses containing only noise.

Signal Processing Loss – If the radar uses an MTI with a staggered PRF waveform, and a good MTI and PRF stagger design, it will suffer 0 to 1 dB signal processing loss.

Miscellaneous Loss – Radar designers and analysts usually include an additional 1 to 2 dB loss to account for various factors they forgot to consider

DIGITAL RESOURCES

- **Lecture Notes – Lecture Notes**
- **Video Lectures - https://www.youtube.com/watch?v=baAyZ8Nbxv4**
- **E-Book - Radar Systems by Skolnik**
- **Model Papers - JNTUA Question Papers**