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Internal Assessment Test 2 – June 2022 (QP-1) (Solution)

Sub:	RADAR ENGINEERING					Sub Code:	17EC833/ 15EC833	Branch:	ECE
Date:	11-06-2022 (Saturday)	Duration:	90 mins (08.30am-10.00am)	Max Marks:	50	Sem/Sec:	VIII - E		OBE

	Answer any **FIVE FULL** Questions.	MARKS	CO	RBT
1	Derive the modified RADAR equation in terms of signal-to-noise ratio.	[10]	CO 4	L3

Soln.

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}}\right]^{1/4} \quad [2.1]$$

where

P_t = transmitted power, W
G = Antenna gain
A_e = Antenna effective aperture, m^2
σ = Radar cross section of the target, m^2
S_{min} = Minimum detectable signal, W

- Range R can be maximised by altering all the above parameters except Radar Cross Section of Target.
- P_t, G and A_e should be increased for maximum R.
- S_{min} should be decreased for realising maximum R.
- Radar cross section is not under the control of the radar designer.

In practice, the simple form of Radar Equation given in Eq.2.1

fails to accurately predict range R due to the following 4 reasons :

- The statistical nature of S_{min} (usually determined by receiver noise).
- Fluctuations and Uncertainties in the Target's Radar Cross Section.
- The Losses experienced throughout a radar system.
- Propagation Effects caused by the Earth's Surface and Atmosphere.

- Even if we assume ideal conditions –
  1) The Radar operates in a perfectly noise free environment (no external sources of noise present with Target Signal).
  2) The Receiver of Radar is perfect (does not generate any excess noise).
- Noise will still be present which is generated by thermal agitation of the

conduction electrons in the ohmic portion of the receiver input stages (**Thermal Noise** or **Johnson Noise**).

Generated at the input of a Radar Receiver.
If receiver has Bandwidth Bn(hertz) at Temperature T(degrees Kelvin), then,

$$\text{available thermal-noise power} = kTB_n \qquad [2.2]$$

where k = Boltzmann's constant = 1.38×10^{-23} J/deg. (The term *available* means that the device is operated with a matched input and a matched load.) The bandwidth of a superheterodyne receiver (and almost all radar receivers are of this type) is taken to be that of the IF amplifier (or matched filter).

In Eq. (2.2) the bandwidth B_n is called the *noise bandwidth*, defined as

$$B_n = \frac{\int_0^{\infty} |H(f)|^2 \, df}{} \qquad [2.3]$$

Where H(f)= frequency response function of the IF amplifier (filter), and
fo = frequency of the maximum response (usually occurs at midband).

- Half power bandwidth B is usually used to approximate the noise bandwidth B_n.
- Noise power in practical receivers is greater than

that from Thermal Noise alone.

- Noise Figure (F_n) –
  - The measure of the noise out of a real receiver (or network) to that from the ideal receiver with only Thermal Noise.

$$F_n = \frac{\text{noise out of practical receiver}}{\text{noise out of ideal receiver at std temp } T_0} = \frac{N_{out}}{kT_0 B G_a} \qquad [2.4]$$

Where

- Nout = noise out of the receiver,
- Ga = available gain,
- To= standard temperature, defined by IEEE as 290 K (62°F). (Close to Room Temperature) [kTo thus becomes $4*10^{-21}$ W/Hz].

If

- Sout= Signal Out , and Sin= Signal In, with both the output and input matched to deliver maximum output power, then,
- Ga=Sout/Sin, and Input Noise Nin , in an ideal receiver = kToBn.

Therefore, Eq.2.4 can be rewritten as,

$$F_n = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \qquad [2.5]$$

This equation shows that the noise figure may be interpreted as a measure of the degradation of the signal to noise ratio as the signal passes through the receiver.

Rearranging Eq. (2.5), the input signal is

$$S_{in} = \frac{kT_0BF_nS_{out}}{N_{out}} \quad [2.6]$$

If the minimum detectable signal S_{min} is that value of S_{in} which corresponds to the minimum detectable signal-to-noise ratio at the output of the IF, $(S_{out}/N_{out})_{min}$, then

$$S_{min} = kT_0BF_n\left(\frac{S_{out}}{N_{out}}\right)_{min} \quad [2.7]$$

Substituting the above into Eq. (2.1), and omitting the subscripts on S and N, results in the following form of the radar equation:

$$R^4_{max} = \frac{P_tGA_e\sigma}{(4\pi)^2kT_0BF_n(S/N)_{min}} \quad [2.8]$$

For convenience, R_{max} on the left-hand side is usually written as the fourth power rather than take the fourth root of the right-hand side of the equation.

The minimum detectable signal is replaced in the radar equation by the *minimum detectable signal-to-noise ratio* $(S/N)_{min}$. The advantage is that $(S/N)_{min}$ is independent of the receiver bandwidth and noise figure, and, as we shall see in Sec. 2.5, it can be expressed in terms of the probability of detection and the probability of false alarm, two parameters that can be related to the radar user's needs.

2	Make use of a portion of the radar receiver block diagram, and discuss with necessary equations, the probability of false alarm and probability of detection.	[10]	CO4	L3

Soln.

- The basic concepts for the detection of signals in noise are found in a classical review paper by S.O.Rice or a text book on detection theory.

- In order to find R_{max}, we need $(S/N)_{min}$ to be computed first.
- (S/N) computation further needs a knowledge of P_d and P_{fa}.
- Hence, we need to find P_d and P_{fa} to compute (S/N) using which we can compute R_{max}.

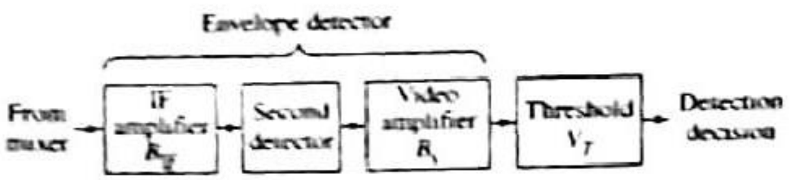


Figure 2.3 Portion of the radar receiver where the echo signal is detected and the detection decision is made.

- Figure 2.3 is a portion of a superheterodyne radar receiver.
- IF amplifier shown has a bandwidth B_{IF}.
- Second Detector is a diode stage (the name ‘Second Detector’ distinguishes it from other detectors like ‘Phase Detector’ etc.).

- Video amplifier has a bandwidth B_v.
- Envelope detector is collective name for the 3 above stages as it gives output which is the envelope or modulation of the IF Signal (passes the modulation and rejects the carrier).
- Requirement for Envelope Detector – 1) $B_v \geq B_{IF}/2$ and 2) $f_{IF} >> B_{IF}$ (both conditions are usually met in radar).
- If input to Threshold Detector crosses the threshold V_T , a signal is declared to be present.

Probability of False Alarm (P_{fa}) :

- Receiver Noise at the input of IF Filter (terms 'filter' and 'amplifier' are interchangeably used here) is described as follows:
- It is considered to have a Gaussian Probability density function with mean value of zero, or ,

$$p(v) = \frac{1}{\sqrt{2\pi\Psi_0}} \exp\left(-\frac{v^2}{2\Psi_0}\right) \quad [2.20]$$

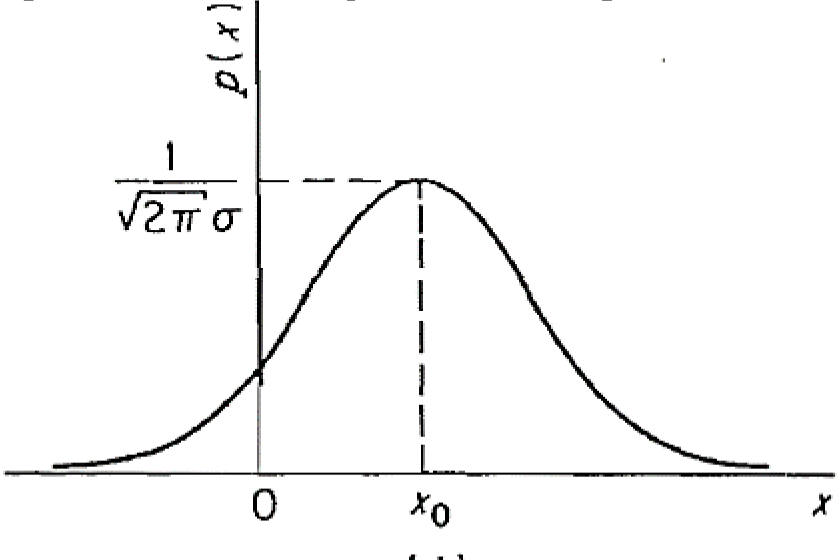
- p(v) dv = probability of finding noise voltage v between the values v and v+dv and = Ψ_0 = mean square value of noise voltage (mean noise power).

- The gaussian density function has a bell-shaped appearance and is defined by :

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

- x_o is the mean

(=0 in Eqn.2.20)



(b)

- When above gaussian noise is passed through the IF Filter, the probability density function (pdf) of the envelope R is a form of Rayleigh pdf (shown by S.O.Rice) as follows :

$$p(R) = \frac{R}{\Psi_0} \exp\left(-\frac{R^2}{2\Psi_0}\right) \qquad [2.21]$$

- Integrating p(R) from V_T to infinity gives the probability that R will exceed V_T and we get :

$$\text{Probability } (V_T < R < \infty) = \int_{V_T}^{\infty} \frac{R}{\Psi_0} \exp\left(-\frac{R^2}{2\Psi_0}\right) dR = \exp\left(\frac{-V_T^2}{2\Psi_0}\right) \qquad [2.22]$$

- The above integration of p(R) represents that when only noise is present, noise will cross the V_T value with the given probability and be falsely called the Target.
- Thus, it is same as the **Probability of False Alarm** (P_{fa}) , and hence, we have :

$$P_{fa} = \exp\left(-\frac{-V_T^2}{2\Psi_0}\right) \quad [2.23]$$

- But, to measure the effect of noise on radar performance (measuring if excessive false alarms are troubling or not) , T_{fa} (false alarm time) is better than P_{fa}.

Probability of Detection (P_d) :

- Let the echo signal be a sine wave of amplitude A, appearing along with gaussian noise at envelope detector input.
- The pdf of envelope R at video output is then:

$$p_s(R) = \frac{R}{\Psi_0} \exp\left(-\frac{R^2 + A^2}{2\Psi_0}\right) I_0\left(\frac{RA}{\Psi_0}\right) \qquad [2.27]$$

where $I_0(Z)$ is the modified Bessel function of zero order and argument Z. For large Z, an asymptotic expansion for $I_0(Z)$ is

$$I_0(Z) = \frac{e^Z}{\sqrt{2\pi Z}}\left(1 + \frac{1}{8Z} + \cdots\right) \qquad [2.28]$$

When the signal is absent, $A = 0$ and Eq. (2.27) reduces to Eq. (2.21), the pdf for noise alone. Equation (2.27) is called the *Rice probability density function.*

The probability of detecting the signal is the probability that the envelope R will exceed the threshold V_T (set by the need to achieve some specified false-alarm time). Thus the probability of detection is

$$P_d = \int_{V_T}^{\infty} p_s(R)\, dR \qquad [2.29]$$

When the probability density function $p_s(R)$ of Eq. (2.27) is substituted in the above, the probability of detection P_d cannot be evaluated by simple means. Rice[9] used a series approximation to solve for P_d. Numerical and empirical methods have also been used.

The expression for P_d, Eq. (2.29), along with Eq. (2.27), is a function of the signal amplitude A, threshold V_T, and mean noise power Ψ_0. In radar systems analysis it is more convenient to use signal-to-noise power ratio S/N than $A^2/2\Psi_0$. These are related by

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

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

The probability of detection P_d can then be expressed in terms of S/N and the ratio of the threshold-to-noise ratio $V_T^2/2\Psi_0$. The probability of false alarm, Eq. (2.23) is also a function of $V_T^2/2\Psi_0$. The two expressions for P_d and P_{fa} can be combined, by eliminating the threshold-to-noise ratio that is common to each, so as to provide a single expression relating the probability of detection P_d, probability of false alarm P_{fa} and the signal-to-noise ratio S/N. The result is plotted in Fig. 2.6.

Albersheim[11,12] developed a simple empirical formula for the relationship between S/N, P_d, and P_{fa}, which is

$$S/N = A + 0.12AB + 1.7B \qquad [2.30]$$

where

$$A = \ln\,[0.62/P_{fa}] \quad \text{and} \quad B = \ln\,[P_d/(1 - P_d)]$$

3	Write notes on the following : i) Transmitter Power Soln.	[10 = 5+5]	CO4	L2

- The power Pt in the radar equation is called by the radar engineer the peak 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.

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

- The radar **duty cycle** (or **duty factor**) = P_{av}/P_t .
- **A** pulse radar for detection of aircraft might have typically a duty cycle of 0.001 to 0.5, while a CW radar which transmits continuously has a duty cycle of unity.

Writing the range equation of Eq. (2.45) in terms of average power by sub Eq. (2.50) for P_t gives

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

From the definition of duty cycle given above, the energy per pulse, $E_p = P_t\tau$ equal to P_{av}/f_p. Substituting the latter into Eq. (2.51) gives the radar equation in t energy, or

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

where E_T is the total energy of the n pulses, which equals nE_p.

ii) Signal Losses in Radar

Soln.

- System loss, Ls is a number greater than 1.
- Ls is inserted in the denominator of the radar equation.
- It is the reciprocal of efficiency (a number less than 1).
- Sometimes, Loss and efficiency are used interchangeably.

Types of System Losses:

1) Microwave Plumbing Losses (Transmission Line Loss, Duplexer Loss).
2) Antenna Losses (Beam Shape Loss, Scanning Loss, Radome Loss, Phased Array Losses).
3) Signal Processing Losses (Nonmatched Filter, Constant False Alarm Rate(CFAR) Receiver, Automatic Integrators, Threshold Level, Limiting Loss, Straddling Loss, Sampling Loss).
4) Losses in Doppler-Processing Radar.
5) Collapsing Loss.
6) Operator Loss.
7) Equipment Degradation.
8) Propagation Effects.
9) Radar System Losses – the Seller and Buyer.

4	Illustrate the concepts of pulse-repetition frequency and range ambiguities in the case of RADAR with suitable diagrams and equations.	[10]	CO1	L2

Soln.

- 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-repitition period are called *multiple-time-around* echoes.

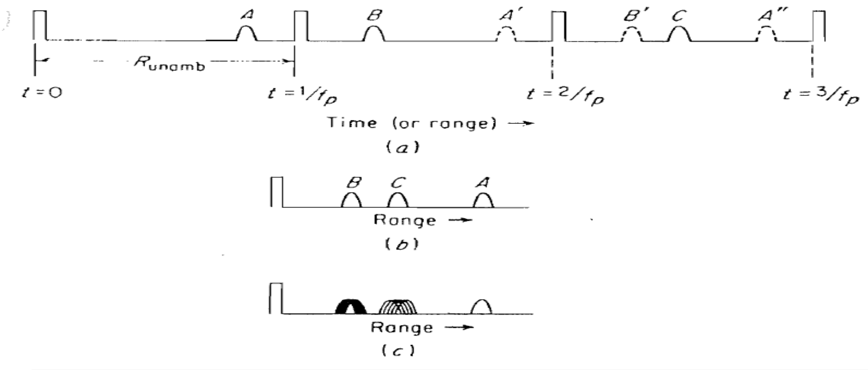


Figure 2.24 Multiple-time-around radar echoes that give rise to ambiguities in range. (a) Three targets A, B, and C, where A is within the unambiguous range R_{un}, B is a second-time-around echo, and C is a multiple-time-around echo; (b) the appearance of the three echoes on an A-scope; (c) appearance of the three echoes on the A-scope with a changing prf.

- Ambiguous range echoes can be recognized by *changing the prf* of the radar.
- In that case, the unambiguous echo remains at its true range.
- Echoes from multiple-time-around targets will be spread

over a finite range.

- The prf may be changed continuously within prescribed limits, or it may be changed discretely among several predetermined values.

- Instead of modulating the prf, other schemes that might be employed to "mark" successive pulse so as to identify multiple-time-around echoes include changing:
  - the pulse amplitude
  - pulse width
  - frequency
  - Phase

- polarization of transmission from pulse to pulse.

If the first pulse repetition frequency f_1 has an unambiguous range R_{un1}, and if the apparent range measured with prf f_1 is denoted R_1, then the true range is one of the following

$$R_{true} = R_1, \text{ or } (R_1 + R_{un1}), \text{ or } (R_1 + 2R_{un1}), \text{ or} \ldots$$

Anyone of these might be the true range. To find which is correct, the prf is changed to f_2 with an unambiguous range R_{un2}, and if the apparent measured range is R_2, the true range is one of the following

$$R_{true} = R_2, \text{ or } (R_2 + R_{un2}), \text{ or } (R_2 + 2R_{un2}), \text{ or} \ldots$$

The correct range is that value which is the same with the two prfs.

5	What do you understand by "Radar Cross Section of Targets" ? Give the relevant equation and definition. Give an account of the radar cross section of simple targets like Sphere and Cone-Sphere.	[10]	CO1	L1

Soln.

- The radar cross section of a target is the property of a scattering object, or target, that is included in the radar equation to represent the magnitude of the echo signal returned to the radar by the target.
- The radar cross section was defined as:

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

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

where

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

- Larger the target size, the larger the cross section is likely to be.

- Real targets do not scatter the incident energy uniformly in all directions.

Sphere:

- Since the sphere is a sphere no matter from what aspect it is viewed, its cross section will not be aspect-sensitive.

- The cross section of other objects, however, will depend upon the direction as viewed by the radar
- The radar cross section of a simple sphere is shown in Fig.

2.9 as a function of its circumference measured in wavelengths ($2\pi a/\lambda$, where a is the radius of the sphere and λI is wavelength).

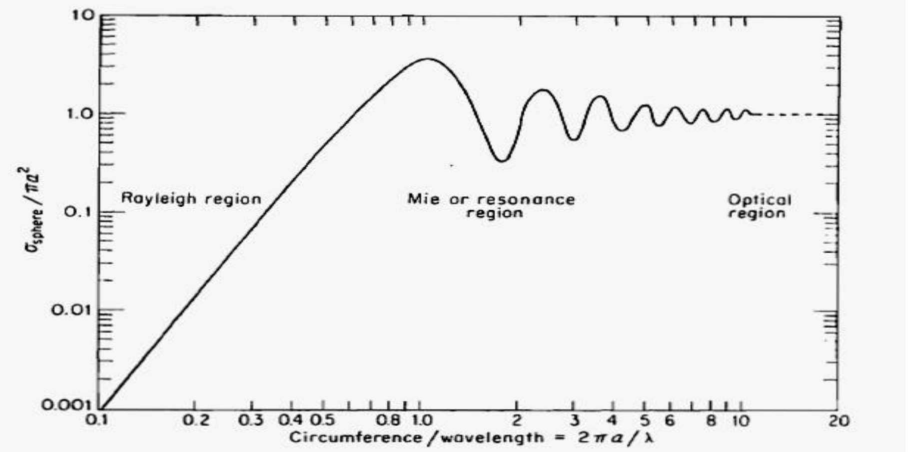


Figure 2.9 Radar cross section of the sphere. a = radius; λ = wavelength.

- **Rayleigh scattering** is the predominantly elastic scattering of light or other electromagnetic radiation by particles much smaller than the wavelength of the radiation. It does not change the state of material. ($2\pi a/\lambda << 1$)

- Rayleigh scattering is strongly dependent upon the size of the particle and the wavelengths.

❖ The intensity of the Rayleigh scattered radiation increases rapidly
as the ratio of particle size to wavelength increases.

- For wave frequencies well below the resonance frequency of the scattering particle, the amount of scattering is inversely proportional to the fourth power of the wavelength.
- At radar frequencies, echo from rain is usually described by Rayleigh scattering.

- The Mie solution to Maxwell's equations (also known as **Mie scattering**) describes the scattering of an electromagnetic plane wave by a homogeneous sphere.

- More broadly, "Mie scattering" suggests situations where the size of the scattering particles is comparable to the wavelength of the light, rather than much smaller or much larger.
- Dust, pollen, smoke and microscopic water droplets that

form clouds are common causes of Mie scattering.

- Mie scattering occurs mostly in the lower portions of the atmosphere, where larger particles are more abundant, and dominates in cloudy conditions.
- The cross section is **oscillatory** with frequency within this region.

- At the other extreme is the **optical 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.

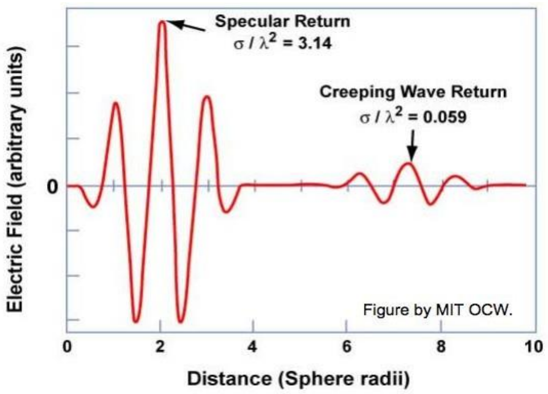
- This unique circumstance can mislead one into thinking that the geometrical area of a target is a measure of its radar cross section ---------> It applies to only sphere.
- In the optical region scattering does not take place over the entire hemisphere that faces the radar, but only from a small *bright spot at the tip* of the smooth sphere (ex. Polished metallic sphere).

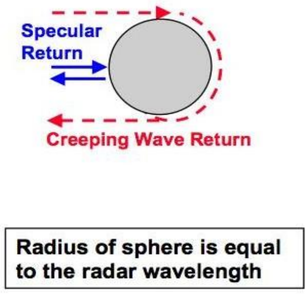
- The RCS of sphere in the resonance (Mie) region oscillates as a

function of frequency or $2\pi a/\lambda$.

- Its maximum occurs at $2\pi a/\lambda = 1$ and is 5.6 dB greater than its value in the optical region.
- Changes in cross section occur with changing frequency because there are two waves that interfere *constructively and destructively*.

- One is the <u>direct reflection</u> from the front face of the sphere.
- Other is the <u>creeping wave</u> that travels around the back of the sphere and returns to the radar where it interferes with the reflection from the front of the sphere.





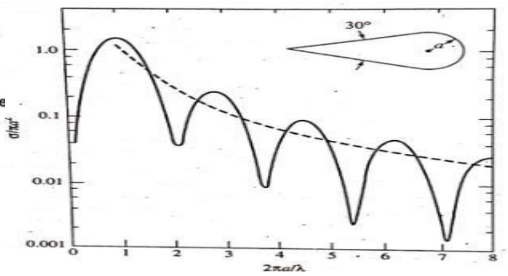
- Longer the electrical path around the sphere, greater the loss, so smaller will be the magnitude of the fluctuation with increasing frequency.
- Figure: illustrates the backscatter that would be produced by a very short pulse radar that can resolve the specular echo from the creeping wave.
- The creeping wave lags the specular return by the time

required to travel one half the circumference of the sphere plus the diameter.

Cone Sphere:

- This is a cone whose base is capped with a sphere.
- The first derivatives of the cone and sphere contours are equal at the join between the two.

Figure 2.12 Theoretical normalized nose-on radar cross section of a cone-sphere based on an approximate impulse analysis; 15° half cone-angle (30° included cone-angle), a = radius of the sphere, and λ = wavelength. The dashed curve represents the approximation



6 With neat block diagram, explain how simple pulse radar extracts the Doppler frequency shift of the echo signal from the moving target. Also derive the equation for Doppler frequency shift. [10] CO2 L2

Soln.

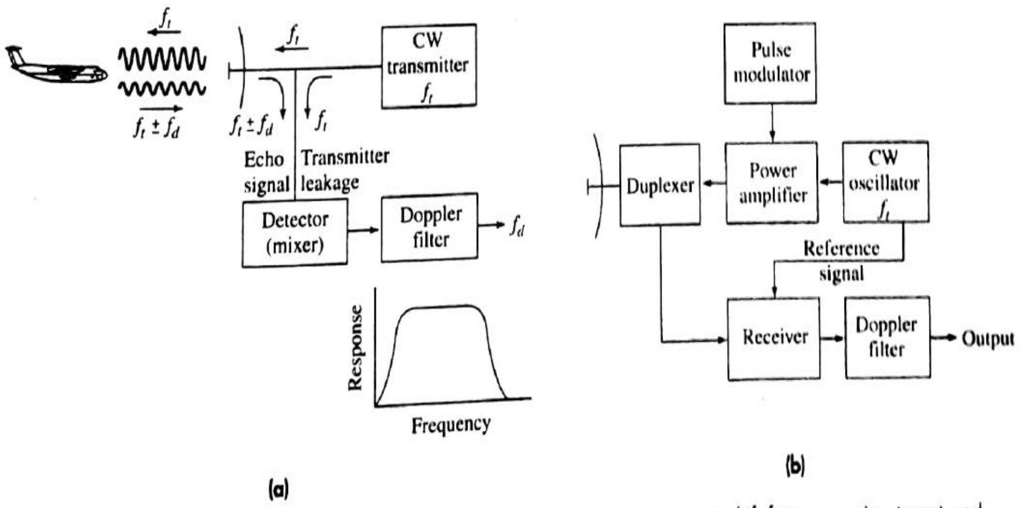


Figure 3.3 (a) Simple CW radar block diagram that extracts the doppler frequency shift from a moving target and rejects stationary clutter echoes. The frequency response of the doppler filter is shown at the lower right. (b) Block diagram of a simple pulse radar that extracts the doppler frequency shift of the echo signal from a moving target.

The transmitter generates a continuous (unmodulated) sinusoidal oscillation at frequency f_t, which is then radiated by the antenna. On reflection by a moving target, the transmitted signal is shifted by the doppler effect by an amount $\pm f_d$, as was given by Eq. (3.3). The plus sign applies when the distance between radar and target is decreasing (a closing target); thus, the echo signal from a closing target has a largér frequency than that which was transmitted. The minus sign applies when the distance is increasing (a receding target). To utilize the doppler frequency shift a radar must be able to recognize that the received echo signal has a frequency different from that which was transmitted. This is the function of that portion of the transmitter signal that finds its way (or leaks) into the receiver, as indicated in Fig. 3.3a. The transmitter leakage signal acts as a reference to determine that a frequency change has taken place. The detector, or mixer, multiplies the echo signal at a frequency $f_t \pm f_d$ with the transmitter leakage signal f_t. The doppler filter allows the difference frequency from the detector to pass and rejects the higher frequencies. The filter characteristic is shown in Fig. 3.3a just below the doppler-filter block. It has a lower frequency cutoff to remove from the receiver output the transmitter leakage signal and clutter echoes. The upper frequency cutoff is determined by the maximum radial velocity expected of moving targets. The doppler filter passes signals with a doppler frequency f_d located within its pass band, but the sign of the doppler is lost along with the direction of the target motion. CW radars can be much more complicated than this simple example, but it is adequate as an introduction to a pulse radar that utilizes the doppler to detect moving targets in clutter.

- One cannot simply convert the CW radar of Fig.3.3a to a pulse radar by turning the CW oscillator on & off to generate pulses.
- Generating pulses in this manner also removes the reference signal at the receiver.
- This reference signal is needed to recognize that a doppler frequency shift has occurred.
- One way to introduce the reference signal is illustrated in Fig.3.3b.

- The output of a stable CW oscillator is amplified by a high-power amplifier.
- The amplifier is turned on & off (modulated) to generate a series of high-power pulses.
- The received echo signal is mixed with the output of the CW oscillator which acts as a *coherent reference*.
- This coherent reference is used to allow the recognition of any change in the received echo-signal frequency.

- By *coherent* is meant that the phase of the transmitted pulse is preserved in the reference signal.
- The change in frequency is detected (recognized) by the doppler filter.

The doppler frequency shift is derived next in a slightly different manner than was done earlier in this section. If the transmitted signal of frequency f_t is represented as $A_t \sin(2\pi f_t t)$, the received signal is $A_r \sin[2\pi f_t(t - T_R)]$, where A_t = amplitude of transmitted signal and A_r = amplitude of the received echo signal. The round-trip time T_R is equal to $2R/c$, where R = range and c = velocity of propagation. If the target is moving toward the radar, the range is changing and is represented as $R = R_0 - v_r t$, where v_r = radial velocity (assumed constant). The geometry is the same as was shown in Fig. 3.1. With the above substitutions, the received signal is

$$V_{rec} = A_r \sin\left[2\pi f_t\left(1 + \frac{2v_r}{c}\right)t - \frac{4\pi f_t R_0}{c}\right] \qquad [3.5]$$

The received frequency changes by the factor $2f_t v_r/c = 2v_r/\lambda$, which is the doppler frequency shift f_d.* If the target had been moving away from the radar, the sign of the doppler frequency would be minus, and the received frequency would be less than that transmitted.

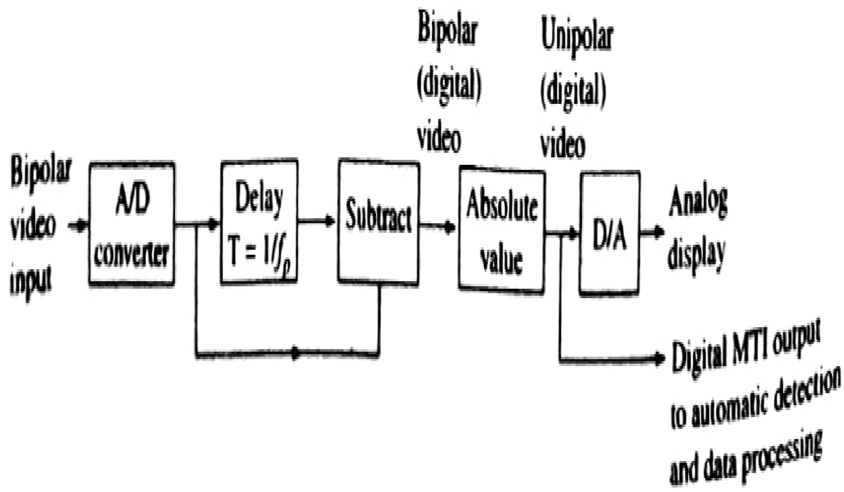
The received signal is heterodyned (mixed) with the reference signal $A_{ref} \sin 2\pi f_t t$ and the difference frequency is extracted, which is given as

$$V_d = A_d \cos (2\pi f_d t - 4\pi R_0/\lambda) \qquad [3.6]$$

where A_d = amplitude, $f_d = 2v_r/\lambda$ = doppler frequency, and the relation $f_t\lambda = c$ was used. (The cosine replaces the sine in the trigonometry of the heterodyning process.) For stationary targets $f_d = 0$ and the output signal is constant. Since the sine takes on values from +1 to −1, the sign of the clutter echo amplitude can be minus as well as plus. On the other hand, the echo signal from a moving target results in a time-varying output (due to the doppler shift) which is the basis for rejecting stationary clutter echoes (with zero doppler frequency) but allowing moving-target echoes to pass.

7	Explain single Delay line canceller with neat block diagram. Derive an expression for frequency response of single DLC. Soln.	[10]	CO2	L2

Figure 3.6 Block diagram of a single delay-line canceler.



- Subtraction of the echoes from 2 successive sweeps is accomplished in a *delay-line canceler*.

- This is indicated by the diagram of Fig.3.6.
- The output of the MTI receiver is digitized & is the input to the delay line canceler.
- This delay line canceler performs the role of a doppler filter.
- The delay T is achieved by storing the radar output from one pulse transmission, or sweep.
- This is done in a digital memory for a time equal to the pulse repetition period so that $T=T_P=1/f_P$.

- The output obtained after subtraction of 2 successive sweeps is *bipolar (digital) video*.
- This is because the clutter echoes in the output contain both positive & negative amplitudes [as can be seen from Eq.(3.6) when f_d=0].
- It is usually called *video*, even though it is a series of digital words rather than an analog video signal.
- The absolute value of the bipolar video is taken, which is then *unipolar video*.

- Unipolar video is needed if an analog display is used that requires positive signals only.
- The unipolar digital video is then converted to an analog signal.
- This is done by the digital-to-analog (D/A) converter if the processed signal is to be displayed on a PPI (plan position indicator).
- Alternatively, the digital signals may be used for automatically making the detection decision & for further data processing, such as automatic tracking and/or target recognition.
- The term *delay-line canceler* was originally applied when analog delay lines (usually acoustic) were used in the early MTI radars.
- Though analog delay lines are replaced by digital memories, the name delay-line canceler is still used to describe the operation of Fig.3.6.

ALL THE BEST

CCI **HOD**