BHARAT INSTITUTE OF ENGINEERING & TECHNOLOGY

MANGANPALLY 501510

IBRAHIMPATNAM RR DISTRICT

ECE DEPARTMENT

AS PER : R18 B.TECH. ECE SYLLABUS
EC812PE: RADAR SYSTEMS (PE – V)

ANSWERS TO QUESTIONS APPEARED IN PREVIOUS JNTUH EXAMINATIONS

PREPARED BY

Prof. G.KUMARASWAMY RAO

ECE DEPARTMENT

(FORMER DIRECTOR DLRL DRDO MINISTRY OF DEFENCE)

ANSWERS TO QUESTIONS APPEARED IN PREVIOUS JNTUH EXAMINATIONS
RADAR SYSTEMS
UNIT — ONE

- **Q1.** What are the desirable pulse characteristics and the factors that govern them Or Define a) PRF b) Unambiguous range

- There are 4 important pulse characteristics to be considered for the radar pulse
- 1. Carrier 2. Pulse width –PW 3. Pulse repetition frequency –PRF
  4. Unambiguous Range
- **1. CARRIER:**
  The carrier used in a Radar is called the RF (Radio frequency) or Micro-wave signal. Their range may be from 3 MHZs to 300 MHZs. They are divided into VHF, UHF, L,S,C,X,Ku,K,Ka bands and mm (millimetric) frequencies. High frequencies are used in Radar to keep the radar antenna within reasonable size
- **2. PULSE WIDTH**:
  In a Pulse radar the Carrier is modulated to get the range of the target. The Carrier is switched ON and OFF with the short duration pulse. The pulse width determines the dead zone of the range of the target. For example if the pulse width is 1 micro sec, detection of target range less than 150 meters is not possible. During the transmission of 1 micro sec high power pulse, the Radar receiver is blanked to protect it from damage because of high power transmission leakage. Similarly if a pulse width of 10.8 micro sec is used there is no detection of target for 1 standard mile from the radar antenna. However in CW (Continuous Wave) radar no modulation is used. The doppler principle is used to extract the radial velocity of the target
- **3. PULSE REPETITION FREQUENCY : (PRF)**
  Pulse radar continuously transmits RF pulses continuously at a particular frequency. The echo (reflection) from the target is painted on the display by the Signal processor every time echo pulse is received
  PRF is the number of pulses transmitted in a second
- PRF = $\dfrac{1}{\text{PRT}\ (pulse\ repetition\ time)} = \dfrac{1}{\text{PRI}\ (pulse\ repetition\ interval)}$
  = $\dfrac{1}{\text{IPP}(inter\ pulse\ period)}$
- PRF is important because it determines the maximum target range R unambiguous and maximum doppler velocity
- **4. MAX UNAMBIGUOUS RANG**E (R unambiguous)
  It is the greatest range the transmitted pulse travels and comeback to the radar antenna before the transmission of next pulse
  Echoes from target must arrive before the next pulse is transmitted to avoid Range Ambiguity
  Echoes that arrive after the transmission of next pulse is transmitted are called Second /multi time around echoes. These second/multi time around echoes give wrong measurement of target range. They are interpreted as shorter target range than the actual.
  There is a relation between PRF and Runamb. Larger the PRF shorter is the Runamb
- Max (Runamb) = $\dfrac{C}{2\ fp}$ where f_p = PRF in HZs

- Problem 1: Calculate the range of the target , if the time taken by the signal to travel and return is 100 microsecs.

- Given T_R = 100 microsec = 100x 10^{-6} secs
  find R = ?
- $R = \frac{C\,T_R}{2}$ (from the formula)
- C = 3×10^8 meters /second
- $R = \frac{3\times10^8\times100\times10^{-6}}{2}$ = 15000mts= 15 Kms

- Problem 2 : What should be the pulse repetition frequency and duty cycle of radar in order to achieve a maximum unambiguous range of 60 nmi with a pulse width of
  1.5 µs ?

- Given : Max unambiguous range = 60 nmi = 60 x 1.852 x 10^3 meters
  (1nmile = 1.852Km)
- Pulse width = τ =1.5 µs= 1.5 x 10^{-6} sec
- Find fp= Pulse repetition frequency
  $fp = \frac{C}{2\,R_{max}} = \frac{3\times10^8}{2\times60 \times 1.852 \times 103}$ = 1349.89 Hz
- $Tp = \frac{1}{fp} = \frac{1}{1349.89}$ sec
- Duty cycle = $\frac{\tau}{Tp}$ = 1.5 x 10^{-6} × 1349.89 = 0.0020248

- Problem 3. The unambiguous range of radar is 200 Kms.It has a bandwidth of 1.0 MHz. find i) Pulse repetition frequency ii) Pulse width

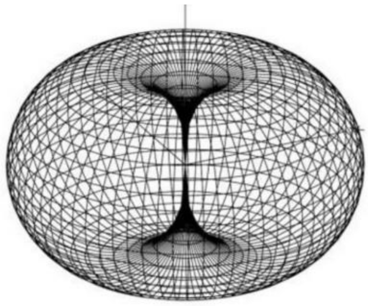
- Given: Rmax = 200 km and Band width = 1.0 MHz
  Find fp and τ
- Pulse repetition frequency $fp = \frac{C}{2\,R_{max}}$ =
- $fp = \frac{3\times10^6}{2\times200\times10^3}$ = 750 Hz
- Pulse width $\tau = \frac{1}{\text{Band width}} = \frac{1}{1\times10^6}$ = 1 µsec

- Q2. Derive the radar range equation/ Derive the basic radar equation OR Derive the maximum range for a radar system from first principles OR Obtain the basic radar equation in terms of minimum detectable power, gains of transmitting and receiving antennas etc.

Radar Equation is relation between
(1) Transmitter Power

(2) Receiver Power
(3)Antenna Characteristics
(4)Target Cross section
(5)Frequency of Transmission
(6)Environmental Noise

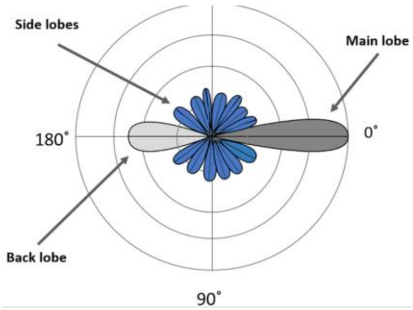
- Radar Equation is most useful for (i)Design (ii)Implementation (iii)Testing of Radar System
- Let P_t = Transmitted power of the radar
- Initially assume the antenna is isotropic . The isotropic antenna transmits power uniformly in all directions as shown in figure



- Let the target be at a distance of R from the antenna on an imaginary sphere of radius R

Power density at any point on the sphere of radius R $= \frac{P_t}{4 \pi R^2}$

- However instead of isotropic antenna Directional antenna is used in practice



- Let the target be at a distance of R from the antenna on an imaginary sphere of radius R
- Power density at any point on the sphere of radius R

$$= \frac{P_t}{4 \pi R^2}$$

- Since instead of isotropic antenna Directional antenna is used in practice
- Power Density of directional antenna = Power Density of Isotropic antenna × Transmitting Gain

$$= \frac{P_t}{4 \pi R^2} \times G_t$$ where G_t is the gain of transmitting antenna

- Let us assume the radar cross-section of the target is σ (sigma). The σ is defined as the amount of transmitted power intercepted by the target and reradiated back in the direction of the radar antenna
- So the power reradiated from target $= \frac{P_t}{4 \pi R^2} \times G_t \times \sigma$

- This reflected signal acts a microwave source and spread power in all directions like a Omni antenna
- Power density of reradiated signal at the radar antenna
- $= \dfrac{\dfrac{P_t}{4\pi R^2} \times G_t \times \sigma}{4\pi R^2} = \dfrac{P_t G_t}{4\pi R^2} \dfrac{\sigma}{4\pi R^2}$

- Let the antenna has an Effective aperture area of A_e .
  A portion of the reradiated power is captured by the radar antenna.
- The received power Pr by the radar antenna
  $= \dfrac{P_t G_t}{4\pi R^2} \dfrac{\sigma}{4\pi R^2} A_e = \dfrac{P_t G_t A_e \sigma}{(4\pi R^2)^2}$
- $P_r = \dfrac{P_t G_t A_e \sigma}{(4\pi R^2)^2}$
- Let Rmax is the maximum range beyond which the Pr becomes small so that radar receiver stops detecting the target. At this Rmax , Pr is denoted as Smin. So Pr = Smin
- $Smin = \dfrac{P_t G_t A_e \sigma}{(4\pi R_{max}^2)^2}$
- $R_{max} = [\dfrac{P_t G_t A_e \sigma}{(4\pi)^2 S_{min}}]^{\frac{1}{4}}$
- The above is called the basic Radar Range Equation or the first Radar Range Equation

- SECOND FORM OF RADAR RANGE EQUATION:
- From Micro wave theory we know that
- $G_r = \left[\dfrac{4\pi A_e}{\lambda^2}\right]$
- Substitute this value in the basic radar equation. But $G_t = G_r = G$ since single antenna is used both for transmission and reception
- $R_{max} = \left[\dfrac{P_t \dfrac{4\pi A_e}{\lambda^2} A_e\sigma}{(4\pi)^2 S_{min}}\right]^{\frac{1}{4}} = \left[\dfrac{P_t A_e^2 \sigma}{4\pi \lambda^2 S_{min}}\right]^{\frac{1}{4}}$
- This is called the second form of Radar equation

- THIRD FORM OF RADAR RANGE EQUATION:
- Substituting A_e in the above equation

$R_{max} = \left[\dfrac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right]^{\frac{1}{4}}$ this is called the Third form of Radar range equation

Three forms of Radar Range Equation are as given below

- $R_{max} = \left[\frac{P_t\, G_t\, A_e\, \sigma}{(4\,\pi)^2\, S_{min}}\right]^{\frac{1}{4}}$ First Form
- $R_{max} = \left[\frac{P_t\, A_e{}^2\, \sigma}{4\,\pi\,\lambda^2\, S_{min}}\right]^{\frac{1}{4}}$ Second Form
- $R_{max} = \left[\frac{P_t\, G^2\, \lambda^2\, \sigma}{(\,4\,\pi\,)^3\, S_{min}}\right]^{\frac{1}{4}}$ Third form

- Problem 4. A pulsed radar operating at 10 GHz. has an antenna with a gain of 28 dB and a transmitter power of 2 Kw (pulse power). If it is designed to detect a target with a cross section of 12 sq.m. and the minimum detectable signal is Pmin = −90 dBm. What is the maximum range of the radar?
- Frequency = 10 GHz= 10×10^9 Hz
- Antenna gain = 28 dB (antilog of $\frac{28}{20}$ = 25.12)
- Transmitted Power = 2 KW = 2×10^3 watt
- Target cross section = 12 sq.m
- Minimum detectable signal = S_{min} = −90 dBm = −90 −30 = − 120 dBW = Antilog (− 120/10) = 10^{-12} W
- $R_{max} = \left[\frac{P_T\, G^2 \sigma\, \lambda^2}{(4\,\pi)^3 S_{min}}\right]^{\frac{1}{4}}$
- $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{10 \times 10^9} = 0.03$ m
- $R_{max} = \left[\frac{2 \times 10^3 \times 25.12 \times 25.12 \times 0.03 \times 0.03 \times 12}{(4 \times \pi)^3 \times 10^{-12}}\right]^{\frac{1}{4}}$
- R_{max} = 1619 mt

- Problem No.5 If the Radar is designed for operation at 10 GHz with an antenna diameter is 2m. Calculate the peak pulse power required to have a maximum range of 1000Km with a target of cross section area of 20 m^2. assume minimum detectable noise power is 36×10^{-15} W
- Given quantities:
  frequency = 10 GHz
  Antenna diameter = 2 m
  Maximum range of radar = R_{max} = 1000Km =10^6m
  Cross sectional area = 20 m
  Minimum detectable noise power=
  $S_{min} = 36 \times 10^{-15}$ W
- Solution: Aperture area of antenna = $\frac{\pi\, D^2}{4} = \frac{\pi\, 2^2}{4}$ = 3.14 sq.m
- Wave length $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{10 \times 10^9}$ =0.03m

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

$P_T = \frac{4 \pi \lambda^2 S_{min} R_{max}^4}{A_e^2 \sigma}$

$P_T = \frac{4 \times 3.14 \times 0.03 \times 0.03 \times 36 \times 10^{-15} \times (1000 \times 10^3)^4}{3.14 \times 3.14 \times 20}$

P_T= 2063694.268 W= 2.064 MW

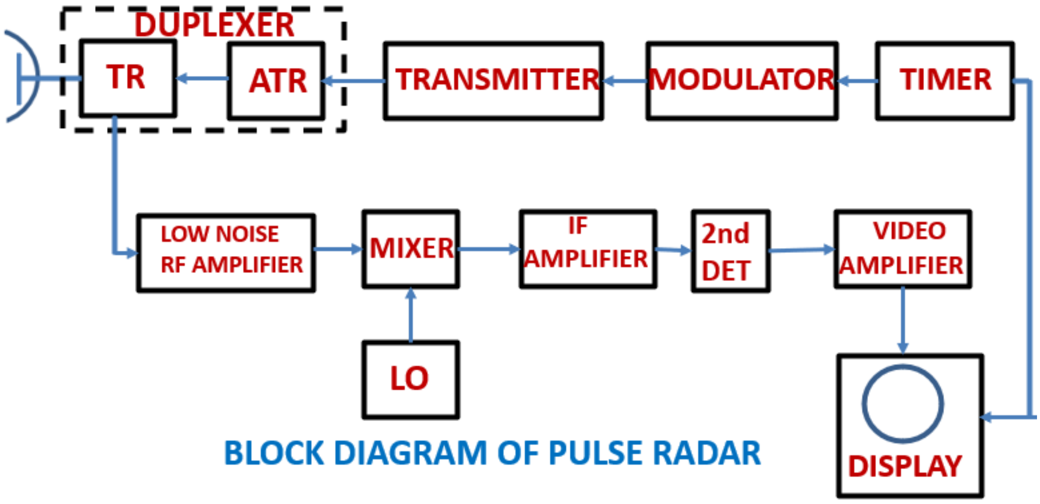
- Q 3.1. Describe the working principle of Pulsed Radar System

or

- Q 3.2. With a block diagram explain the operation of Pulse Radar

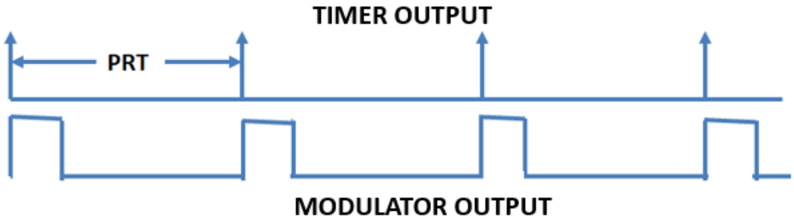
or

- Q 3.3. Draw the block diagram of a Pulsed Radar and explain its operation



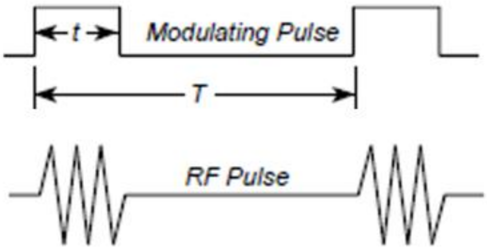
BLOCK DIAGRAM OF PULSE RADAR

- **1. TIMER**: This generates a series of narrow timing trigger pulses at pulse repetition frequency of radar. This is also called trigger generator or synchronizer. This is a small unit compared to the Modulator.
- **2. MODULATOR:** The narrow trigger pulses when given to the modulator, generates the fixed duration radar pulses whose pulse width ranges from sub microsecs to a few microsecs. The frequency of these pulses is the Pulse repetition frequency of the radar.



- **3. TRANSMITTER:**

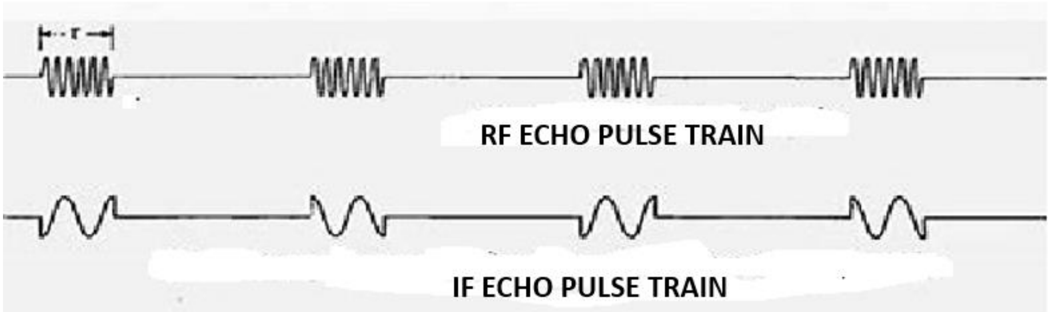
A typical radar may detect aircraft at ranges from 50 to 500 kms. It employs a peak power of the order of 1 to 10 Mega watts. The transmitter generates modulated RF pulses. The modulated RF energy travels along the transmission line to the antenna

- 

- There are two types of Transmitters
- (i) Power Oscillator Ex:Magnetron-1 M Watt or more. Pulse Modulator switches power on or off
- (ii) Power Amplifier: Ex: Klystron, TWT Amplifies Low Power signal
- **4. DUPLEXER:** Single antenna is used for both transmission and reception. The Duplexer unit connects the Transmitter to the antenna while transmitting. It disconnects the Receiver from the antenna during transmission. The Receiver is disconnected from the Transmitter to avoid damage to the sensitive receiver circuits since the transmitting power is very high. While receiving echoes from target, the Duplexer unit connects the Receiver to the antenna. It disconnects the Transmitter from the antenna during this period. This is done in order to avoid even a small portion of echo power gets connected to Transmitter and getting wasted. Since the switching speed is in nano secs, Gas Discharge tube is used.
- 4. Duplexer consists of TR and ATR switch.
  4(a) TR (Transmit and Receive Switch): This is a fast- acting switch which disconnects Receiver during transmission. If the Receiver is not disconnected, since the transmitter power is very high, the Receiver may be damaged. Once the pulsed RF signal has stopped the TR switch reconnects the Receiver to the antenna. The target echo power received enters the Receiver
- 4(b) ATR (Anti Transmit and Receive Switch): ATR switch do not act during transmission. During reception it switches and disconnects transmitter from antenna. If ATR is absent , a portion of the received power would go to transmitter rather than all the power going to the Receiver
- **5. ANTENNA:**
- (i)Antenna converts the Electrical signal to Electro-magnetic signal and radiates it into space.
- (ii)Same antenna is used for transmission and reception in a Pulse Radar.
- (iii)Antenna is mounted on a pedestal and servo controlled to steer it in the direction of the target.
- (iv)Normally parabolic Antenna is used for radar applications
- **6. LOW NOISE RF AMPLIFIER: (LNA)**
- (i)This is a RF Amplifier such as parametric amplifier or Low Noise transistor amplifier.
- (ii)LNA is used immediately after the antenna since the power of the echoes are very low
- (iii) Gain of LNA reduces the Noise Figures of the succeeding devices by dividing the N.F. of the device by the Gain of the LNA.
- **7.MIXER & LOCAL OSCILLATOR**

- Receiver uses the principle of super heterodyning
- (i) Converts R.F. Signal to I.F. (Intermediate Frequency)
- (ii) IF is usually at 30 MHZ or 60 MHZ. With a bandwidth of 1 to 2 MHz. It is easier to design and build High gain amplifiers and filters at IF frequencies. Widespread availability of components at these frequencies is also one of the reasons for Super-heterodyning

(iii) L.O. frequency is $f_L = f_{RF} \mp 30$ MHZ, where f_{RF} = RF frequency and f_L = LO frequency

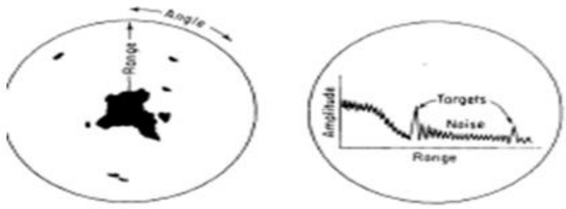


-
- **8. IF AMPLIFIER & MATCHED FILTER**
- (i)The signal level of Echo, is very low. It is amplified to an appropriate level by the IF Amplifier.
- (ii)The I.F. centre frequency is 30 MHZ with a band width of 1 MHZ (depending on Pulse width)
- (iii)The matched filter frequency response is such that it maximizes the peak signal to mean noise power ratio at output.
- (iv)Usually the IF Amplifier and matched filter are designed into a single subsystem.

- **9. 2ND DETECTOR**
- (i)2nd Detector removes the IF modulation.
- (ii)Output of the 2nd Detector is the Video Pulse.
- (iii)2nd Detector uses the high frequency diode.It is called as 2nd Detector since it is the second diode used in the chain. The first diode is used in the mixer.

- **10.VIDEO AMPLIFIER**
- The low signal level of Video Pulse is amplified such that the voltage level is high enough to drive the CRT (Cathode Ray Tube). CRT is used as the Display.

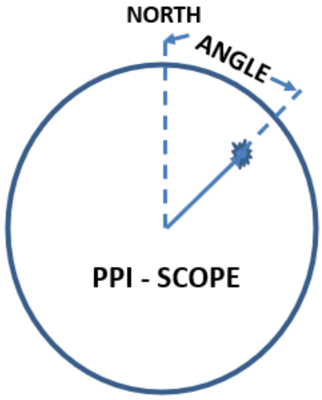
- **11.DISPLAY**
- i)The Display is generally uses a CRT (Cathode Ray Tube)
- (a) 'A' scope (b) PPI(Plan position indicator) etc.
- (ii)'A' scope provides Range and Echo power.
- (iii)PPI measures Range and bearing (azimuth angle)
- (iv)In addition there are other displays like 'B' scope, ' D ' scope etc.
-

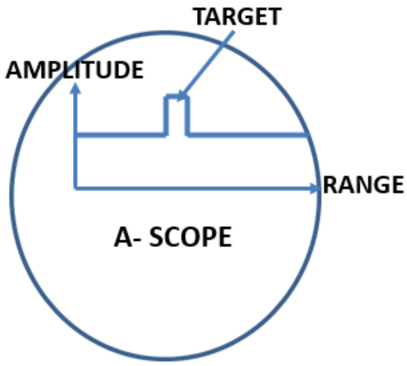


(a) (a)

- Q 4. Discuss how the Direction and range of an object is determined using Pulse Radar

- **PPI –SCOPE:** The output from the Video Amplifier of Pulse Radar is displayed using PPI (Plan Position Indicator) scope. PPI maps the position of target in azimuth and range. North is taken as the reference direction. PPI scope is an intensity modulated circular display. The range and angle is displayed in polar coordinates.



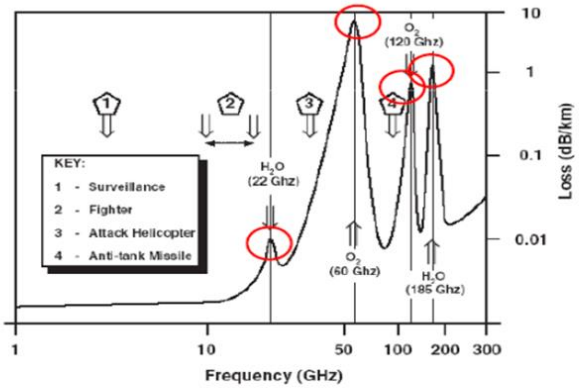


- **A SCOPE**: This display also plots the range and angle of the echo signal. It is connected to the output of Video amplifier. X axis gives the range and Y axis displays the amplitude of echo signal

Q 5. Discuss about Radar Frequencies

- RF spectrum is very scarce and as such Radars are allotted only a certain frequency bands for its operation by International Telecom Union ITU
- During 2nd world war to keep the secrecy, certain code words were used. They are L,S,C,X, Ku,K,Ka etc. The same designations are continued. Lema Band(L)1GHZ-2GHZ, Sierra band(S) 2GHZ- 4GHZ, Charlie Band (C) 4GHZ-8GHZ, Xera Band (X) 8GHZ-12GHZ
- ITU(International Telecommunication Union) allocates a portion of these bands for Radar use.

Atmospheric attenuation vs frequency



•

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	

Q 6. Explain about applications of Radar

- Radar has wide range of applications. They are used on ground, in air, in sea and in space. They can be broadly divided into i) for Civilian use and ii) for Military use
- **CIVILIAN USE:**
- **1. AIR TRAFFIC CONTROL (ATC):**
  Radars are without exception used in the Airports for controlling the Aircraft traffic. A high resolution radar is used to monitor the aircraft and guide the pilots to safely land on the runways and take off. In bad weather and poor visibility conditions in association with GCA (Gound Control Approach) radar is used to guide the aircraft safely to land. 2.
- **2. AIRCRAFT NAVIGATION**:
  a) All modern aircrafts are fitted with 'Weather Avoidance Radars'. These radars give warning information about the outline regions of precipitation of snow or storms to the pilot lying ahead of aircrafts path. Some radars are used for terrain avoidance and terrain following . Ground mapping radars can be mounted on aircrafts for terrain mapping purposes.
  b) Radar is mounted on Helicopters and used as altimeter to indicate the height of Helicopter from the ground
- **3. MARITIME RADARS FOR SHIPS SAFETY AND NAVIGATION:**
  Large portion of our merchandise between nations is transported through sea. Because of poor visibility in sea due to haze, smoke, rain, storm, cyclone etc. possibility of collision of

Ships is high. Using radars mounted on ships, collision of ships can be avoided in the middle of sea.

- Radars guide ships in seaports safely.
- **4. SPACE:**
  Radar is used for rendezvous and docking of space vehicles and landing of space vehicles on celestial objects like moon, mars etc. Ground based radars are used for tracking of satellites.
- **5. REMOTE SENSING:**
  Radar is used as a remote sensor of the weather. The earth resources which are to be probed by the radar are i) Measurement and mapping of sea conditions ii)water resources iii) ice cover iv) agriculture and forestry conditions v) environmental pollution vi) geological formations
- **6. LAW ENFORCING AGENCIES:**
  Radars are used by Police personnel to measure and restrict the speed of automobile vehicles to avoid fatal accidents.
- **7. MILITARY USE:**
  Radars are widely used in military applications.
- (i)Early warning of intruding enemy aircrafts & missile
- (ii)Tracking hostile targets and providing location information to Air Defense systems consisting of Tracking Radars controlling guns and missiles.
- (iii)Battle field surveillance
- (iv)Information Friend or Foe IFF
- (v)Navigation of ships, aircrafts, helicopter etc.

Q 7. List out major applications of Radar in military

- **1. GROUND PENETRATING RADAR :**
  These type of Radars are useful for finding out Land mines buried a few centimeters beneath the ground surface. The radars can detect these mines and make movement of persons or vehicles safe. If the moisture content of soil is not very high, radar signals can penetrate into the ground.
- **2. AREA SURVEILLANCE OR GROUND SURVEILLANCE**:
  These radars are kept on tripods and keep watching in a particular direction over an area. They give alert when there is an activity in that area like an intruder approaching, crawling, running etc. they are called BFSR (Battle field surveillance Radar)
- **3. AIR SURVEILLANCE RADARS**:
  For detecting enemy aircraft and directing defensive measures against them monitoring of airspace is required. For better and maximum coverage these radars are located on airborne platforms for detecting low height flying hostile aircrafts. These are called AWACS (Airborne Warning and Control System). OTH (Over The Horizon) radars exploit certain ground features and can detect low flying aircrafts at thousands of kilometers away
- **4. TARGET TRACKING RADAR:**

  Target tracking is associated with Gun control weapon and Missile weapon system. They track the incoming hostile aircraft in azimuth and elevation very accurately using the principle of

Mono-pulse. The location of hostile aircraft in three (azimuth, elevation and range) coordinates will be provided to the weapon system like the Gun control weapon or to the guided missile so that the hostile target is shot down.

5. PHASE ARRAY RADAR: In case of multiple target tracking, radar beam is quickly switched from one position to other and thus multiple target tracking is accomplished, These Radars are called Phased array radars

- Q 8.1 Explain the prediction of range performance

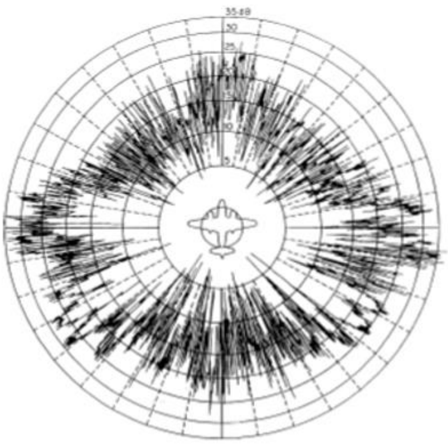
  OR

  Discuss in detail the choice of various parameters that are affecting the radar range

  OR

  Briefly discuss about the prediction of range performance

- $R_{max} = \left[\frac{P_T \; G_T \; \sigma \; A_e}{[4 \; \pi]^2 \quad S_{min}}\right]^{\frac{1}{4}}$
- P_T = Transmitted Power (watts)
- G_T = Transmitting Antenna Gain (number)
- A_e = Receiving Antenna Effective aperture mt^2
- σ = Radar cross-section mt^2
- S_{min} = Minimum Detectable Signal (Watts)
- Except for σ (RCS) all the other above quantities are design parameters . σ is random with respect to angle and given as a statistical quantity



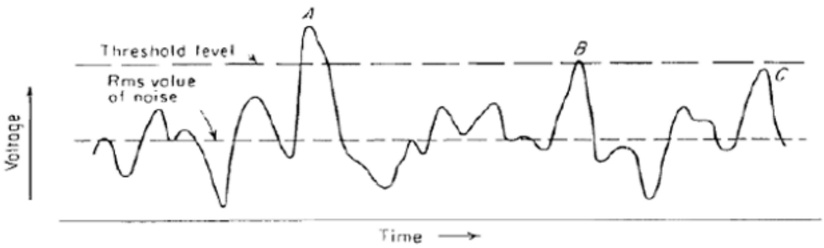
- If long Range (Rmax) is desired the following are required
- i) P_T Transmitted Power must be high
- ii) G_T should be high. For this Transmitted Power must be concentrated into a narrow beam
- iii) A_e must be high. Large aperture antenna is necessary
- iv) S_{min} must be low. Receiver must be sensitive to weak signals

- Practical Range obtained using the above Range equation is often less because we have not considered the following aspects
- Various losses because of Electronic equipment used in operational field
- σ are statistical in nature . σ change with even a small change in angle
- Meteorological conditions during propagation
- Performance of radar operator
- Because of the above R_{max} cannot be given by a single number
- Radar range can only be predicted with a certain probability for a practical target
- The Radar will detect a given target at a particular range by including the term probability in its radar equation

Q 9 What is meant by minimum detectable signal in radar?

- S_{min} – Signal detectable by a Receiver (Rx) is limited by Noise energy that is present in the frequency spectrum of signal energy
- Minimum Detectable signal (S_{min}) :
- Minimum Detectable signal is the weakest signal the Receiver can detect
- Presence or absence of a target is determined by
- i) S_{min}
- ii) threshold criterion
- iii) human operator

- **THRESHOLD DETECTION:**
- Threshold level is set at the output of Rx. If Rx output crosses the threshold, signal which is a mixture of echo and noise is assumed to represent a target



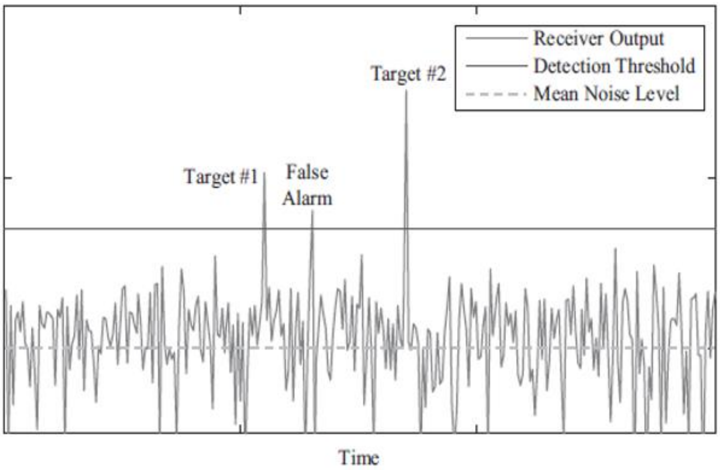
RADAR RECEIVER OUTPUT

- Envelope (echo + noise) has fluctuating appearance because of random nature of Noise
- Envelope shown has passed through Matched filter which makes echoes no more look like rectangular pulses. They appear as triangular as shown in the graph
- Diagram shown is the combination of echo and noise. Threshold level is set such that noise alone does not cross the level and falsely taken as target

- **TARGET A :**
- Target A has large signal echo, greater than the surrounding noise amplitude and crosses threshold on its own and declared as a valid target without any ambiguity

- Let Target echoes of B & C are of equal voltage amplitudes.
- **TARGET B :**
- Noise voltage amplitude at occurrence of signal is large. Signal echo combined with noise at that instant is just sufficient enough to cross the threshold and declared as a valid target.
- **TARGET C :**
- Here the noise level is small at this instant of time the resultant of echo and noise signal does not cross the threshold level. So target presence is not declared. The target has missed being detected.
- Therefore noise sometimes enhance the detection of weak echo signals.

- **FALSE ALARM:**
- Weak signal C would not have been lost, if threshold level is lower. But low threshold increases the likelihood of noise alone crossing the threshold and declared as a real target. This is called as False alarm.



- **THRESHOLD LEVEL SETTING:**
- If threshold level is set too low so that weak echo signals also can be declared as valid targets, false targets are declared, since at some instant in time noise may cross the threshold level
- If threshold level is set too high, weak echoes are missed. Thus real targets are missed.
- Selection of threshold has to be done judiciously depending on the goals set in the design parameter. Probability of miss or Probability of false alarm

- **PROBABILITY OF MISS:**
- Failing to indicate the presence of real target
- **PROBABILITY OF FALSE ALARM:**
- Falsely indicating presence of target even though there is no real target

- **MANUAL SETTING OF THRESHOLD BY OPERATOR:**
- Probability of miss and Probability of False alarm depends on i) skill of operator ii) motivation of operator iii) state of operator's fatigue

- Q10.1 Discuss in detail the quantitative analysis of Receiver noise and hence derive expression for minimum detectable signal

OR

Q10.2 Describe different noise components present in radar systems

- **RECEIVER NOISE**:
- Noise interferes with detection of echo from target. i) Noise may exist within the Receiver itself. ii) Noise also enters the Receiver along with echo. Iii) Even if the radar is operated in a noise free environment, thermal noise still exists. Thermal noise is due to the thermal motion of electronics in the Receiver circuits.

- **THERMAL NOISE OR JOHNSON NOISE**
- Noise that is generated due to thermal agitation of conduction electrons in the Ohmic portion of Receiver input stages is called Thermal Noise
- Thermal Noise Power (watts) = $K\ T\ B_n$
- K = Boltzmann's constant = 1.38×10^{-23} joules/degree
- T = Temperature in Degrees Kelvin
- B_n = Noise Band width Hz
- We know that (Radar equation)
- $$R_{max}^4 = \frac{P_T\ G_T\ A_e\ \sigma}{(4\ \pi)^2\ \ S_{min}}$$
- But we have
- $$(S/N)_{in(min)} = K\,T_0\,B_n\,F_n\ (S/N)_{out(min)}$$
- Combining the two above equations
- $$R_{max}^4 = \frac{P_T\ G_T\ A_e\ \sigma}{(4\ \pi)^2\ K\,T_O\ B_n\ F_n\ (S/N)_{out(min)}}$$
- $$R_{max}^4 = \frac{P_T\ G_T\ A_e\ \sigma}{(4\ \pi)^2\ K\,T_O\ B_n\ F_n\ (S/N)_{min}}$$

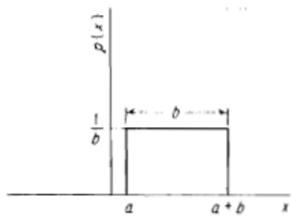
- Poblem No.6: A low power, short range radar is solid state throughout, including a low noise RF amplifier which gives it an overall Noise Figure of 4.77 dB. If the antenna diameter is 1m , the IF bandwidth is 500 kHz, the operating frequency is 8 GHz and the radar set is supposed to be capable of detecting targets of 5 m^2 cross-sectional area at a maximum distance of 12 km, what must be the peak transmitted pulse power?

- Given parameters:
- F_n = 4.77 dB = Antilog $\left(\frac{4.77}{10}\right)$ = 3

  D = 1 mt

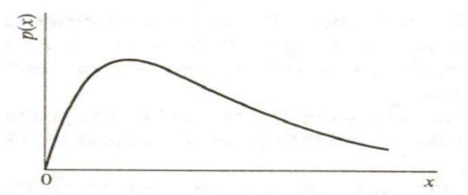
  f = 8 GHz

  σ = 5 mt^2

- R_{max} = 12 Km = 12 × 10^3 mts
- (S/N) =10 (assumed)
- K = 1.38 × 10^{-23} joules /degree
- T_0 = 290 Kelvin
- $A_e = \frac{\pi D^2}{4} = \frac{3.14 \times 1^2}{4}$ = 0.785 mt^2
- $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{8 \times 10^9} = 0.0375\, m$
- $G = \frac{4\pi A_e}{\lambda^2} = \frac{4 \times 3.14 \times 0.785}{0.0375^2}$ =7011
- $R_{max}{}^4 = \left[\frac{P_T\ G\ A_e\ \sigma}{(4\pi)^2\ K\ T_O\ B_n\ F_n\ (S/N)_{min}}\right]$
- $(12 \times 10^3)^4 = \left[\frac{P_T\ 7011 \times 0.785 \times 5}{(4 \times 3.14)^2 \times 1.38 \times 10^{-23} \times 290 \times 500 \times 10^3 \times 3 \times 10}\right]$
- P_T = 7.13 W
- Q11. Discuss about probability density functions
- **PROBABILITY:** is a measure of the likelihood of the occurrence of an event. Its value lies between 0 to 1
- **PROBABILITY DENSITY FUNCTION:**
- $p(x) = \lim_{\substack{\Delta x \to 0 \\ N \to \infty}} \frac{(\text{Number of values within } \Delta x)/_{\Delta x}}{\text{total number of values} = N}$
- Where x = random quantity say noise voltage
- Let 'x' represents Noise voltage
- Probability that a particular value 'x' lies within infinitesimal interval 'dx' centered at 'x' = p(x) dx
- Probability (x_1< 'x' < x_2) = $\int_{x1}^{x2} p(x)\, dx$
- $\int_{-\infty}^{+\infty} p(x)\, dx = 1$
- Uniform Distribution:
- p(x) = 1/b   for a < 'x' < a+b
-     = 0   for 'x' < a and 'x' > a+b
- 

- **GAUSSIAN OR NORMAL DISTRIBUTION:**
- 

- $p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp \frac{-(x - x_0)^2}{2\sigma^2}$
- 'x' = Variable
- $\boldsymbol{\sigma^2}$ = variance = mean square deviation of 'x' about its
- mean = Ψ
- x_0 = Mean 'x' = average 'x'
- Many sources of noise like Thermal Noise or shot noise are represented by Gaussian Distribution.
- **RALEIGH DISTRIBUTION:**

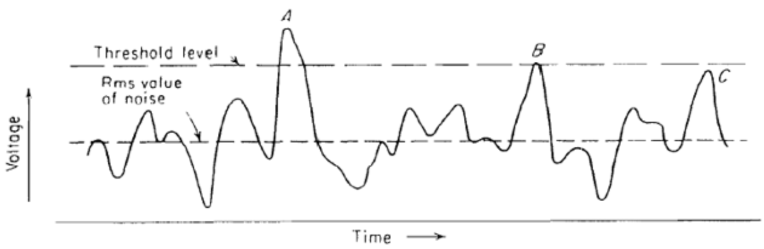


$$p(x) = \frac{2x}{m_2} \exp\left(-\frac{x^2}{m_2}\right)$$

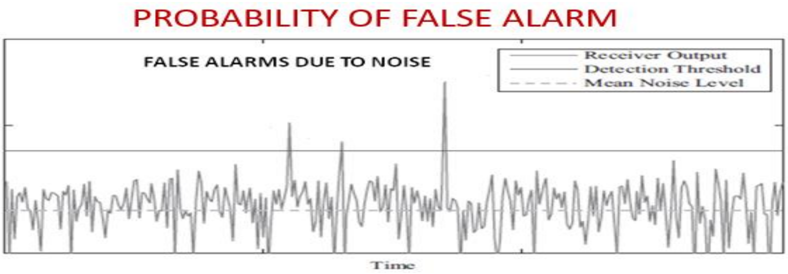
- Where $m_2 = (x^2)_{av}$ is the mean square value of x

- Q12 What is False alarm, Probability of detection and False alarm time?
- The Parameters for design are
  1. Probability of detection
  2. Probability of false alarm
  3. False alarm time

- **PROBABILITY OF DETECTION:**



- **PROBABILITY OF FALSE ALARM**:
- Probability that noise crosses threshold and declared as a target



v = noise voltage

R = envelope

Ψo = mean square value of noise voltage

- If Gaussian noise with pdf p(v) is passed through a narrow band filter whose Bandwidth is small compared to mid frequency fo, output p(R) is shown to be Rayleigh pdf by 'RICE'
- $p(v)= \frac{1}{\sqrt{2\ \pi\ \phi_0}}\ \exp \frac{-v^2}{2\ \phi_0}$

v = noise voltage, φ_0 = variance= σ^2(mean square value)
Mean value of v is taken as zero

$p(R)= \frac{R}{\phi_0}\ \exp\left(\frac{-R^2}{2\ \phi_0}\right)$ R= amplitude of IF filter output

- Probability 'R' lies between v_1 and v_2 is given by
- $\int_{V1}^{V2} \frac{R}{\phi_0}\ \exp\left(\frac{-R^2}{2\ \phi_0}\right)$
- Probability that noise voltage 'R' exceeds voltage Threshold V_T is
- Probability (v_T<R< ∞) =
- $\int_{VT}^{\infty} \frac{R}{\phi_0} \exp\left(\frac{-R^2}{2\ \phi_0}\right)$ dR
- $= \frac{R}{\phi_0} \int_{V_T}^{\infty}\ \exp\left(\frac{-R^2}{2\ \phi_0}\right) \frac{d(\frac{-R^2}{2\ \phi_0})}{\frac{-2R}{2\ \phi_0}}$
- $\left(-\exp\frac{-R^2}{2\ \phi_0}\right)_{V_T}^{\infty} = -\exp\frac{-\infty^2}{2\ \phi_0} + \exp\frac{-V_T{}^2}{2\ \phi_0}$
- Probability that noise voltage 'R' exceeds voltage Threshold V_T is P_{fa}
- $P_{fa}= -\exp\frac{-\infty^2}{2\ \phi_0} + \exp\frac{-V_T{}^2}{2\ \phi_0}$
- $\exp^{-\infty^2} = \frac{1}{\exp^{\infty^2}} = \frac{1}{\infty} = 0$

- Probability that Noise crosses Threshold V_T
- = Probability of False Alarm = P_{fa}
- $P_{fa} = \exp \frac{-V_T^2}{2\ \phi_0}$

- **FALSE ALARM TIME**: is defined as the average time interval between crossings of the Threshold (when slope of crossings is positive) = T_{fa}

- $T_{fa} = \lim \frac{1}{N} \sum_{K=1}^{N} T_K = \left[\frac{T_K + T_{K+1} + T_{K+2} + \ldots}{N}\right]$

- where T_k = Time between crossings of Threshold V_T

- False Alarm Probability = P_{fa}

- $P_{fa} = \frac{\text{Duration of time envelope above threshold}}{\text{Total time it could have been above threshold}}$

- $P_{fa} = \frac{\sum_{K=1}^{N} t_K}{\sum_{K=1}^{N} T_K} = \frac{(t_K)_{av}}{(T_K)_{av}}$

$$= \frac{\text{Average duration of Noise pulse}}{T_{fa}}$$

- t_k = average duration of a noise Pulse = $\frac{1}{B_{IF}}$

- B_{IF} = Bandwidth of IF Amplifier

- $P_{fa} = \frac{1}{T_{fa}\ B_{IF}}$

- But from earlier derivation $P_{fa} = \exp\left[\frac{-V_T^2}{2\ \phi_0}\right]$

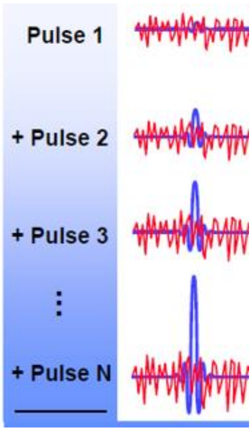
- $P_{fa} = \frac{1}{T_{fa}\ B_{IF}} = \exp\left[\frac{-V_T^2}{2\ \phi_0}\right]$

- Therefore $T_{fa} = \frac{1}{B_{IF}} \exp\left[\frac{V_T^2}{2\ \phi_0}\right]$

- **RELATIONSHIP BETWEEN P_{fa} AND T_{fa}:**
- i) $P_{fa} = \exp\left[\frac{-V_T^2}{2\ \phi_0}\right]$
- ii) $T_{fa} = \frac{1}{B_{IF}} \exp\left[\frac{V_T^2}{2\ \phi_0}\right]$
- iii) $P_{fa} = \frac{1}{T_{fa}\ B_{IF}}$
- iv) $T_{fa} = \frac{1}{P_{fa}\ B_{IF}}$

- Q 13. Discuss the effect of integration of radar pulses
- Radar range equation is given as
- $R_{max}^4 = \frac{P_T\ G\ A_e\ \sigma}{(4\ \pi)^2\ K\ T_0\ B\ F_n\ (S/N)_1}$

where $(S/N)_1$ is the Signal to Noise ratio for a single pulse

- One of the ways to increase R_{max} is by decreasing $(S/N)_1$
- This is accomplished by **Pulse Integration**
- In the Radar equation $(S/N)_1$ need to be replaced by $(S/N)_n$ where $(S/N)_1$ is the signal to noise ratio for a single pulse and $(S/N)_n$ is the Signal to noise ratio for 'n' number of pulses
- $R_{max}^4 = \frac{P_T\ G\ A_e\ \sigma}{(4\ \pi)^2\ K\ T_0\ B\ F_n\ (S/N)_n}$
- $R_{max}^4 = \frac{P_T\ G\ A_e\ \sigma}{(4\ \pi)^2\ K\ T_0\ B\ F_n\ \frac{(S/N)_1}{n}}$
- $R_{max}^4 = \frac{P_T\ G\ A_e\ \sigma\ n}{(4\ \pi)^2\ K\ T_0\ B\ F_n\ (S/N)_1}$
- 

- **NUMBER OF PULSES AVAILABLE FOR INTEGRATION IN A SEARCH RADAR:**

- Time for which beam illuminates target =

$$\frac{\theta_B}{\dot{\theta}_S}$$

- $\frac{\text{Beam width}}{\text{Angular speed}}$
- Number of Pulses returned from a target "n"

$$n = \frac{\theta_B}{\dot{\theta}_S} \times f_P$$

- where f_p = PRF =No. of pulses/sec
- where ω_s = Revolutions of antenna per minute

$$\dot{\theta}_S = \omega_S \times \frac{360}{60} = 6\ \omega_S$$

- Angular Speed =
- where ω_s = Revolutions of antenna per minute
- So $n = \frac{\theta_B}{6\ \omega_S} \times f_P$

- **Pulse Integration:**
- Process of summing vectorially all Radar echoes from a target is called Pulse Integration

- **Methods for integration:**
- i) Take advantage of persistence of Phosphor of CRT display combined with integrating properties of eye
- ii) Analog or Digital method of integration

- **TYPES OF INTEGRATION:**
- i) Coherent or Pre-detection integration
- ii) Non coherent or Post integration

- (I) **COHERENT INTEGRATION:**
- Integration is accomplished in IF (before second detector)
- The phase of echo signal is preserved for summing up with the next pulse.
- More efficient than noncoherent integration.
- If 'n' pulses were integrated the resultant S/N ratio would be exactly 'n' times the S/N ratio of single pulse.
- The integration is difficult to implement and consists of a narrow band comb IF filter.
- The phase of IF carrier oscillation be maintained coherent over a time corresponding to the time on target.

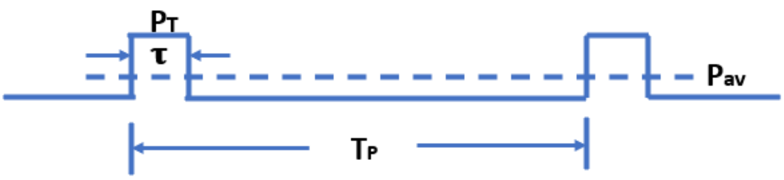
- **II) NON COHERENT (POST) INTEGRATION:**
- Integration is accomplished in video (after the second detection).

- Phase information is destroyed by the second detector and so phase information about echo (RF) pulse is not available.
- The pulses that are summed are video pulses.
- If n pulses are integrated the resultant S/N is less than n times S/N of single pulse.
- The loss in efficiency is due to the nonlinear action of the detector.
- The integration is easier to implement and consists of low pass filter in the video portion of the Receiver.

- **EFFICIENCY OF INTEGRATION $E_i(N)$**
- $E_i(n) = \dfrac{(S/N)_1}{n \; (S/N)_n}$
- where n = number of pulses integrated
- $(S/N)_1$ = S/N ratio of single pulse required to produce given probability of detection.
- $(S/N)_n$ = S/N ratio per pulse required to produce same probability when 'n' pulses are
- integrated.
-
- **INTEGRATION IMPROVEMENT FACTOR : $I_i(N)$**
- $I_i(n)$ for pre integration = n
- $I_i(n)$ for post detection = $n \, E_i(n)$

- **INTEGRATION LOSS : L_i (N)**
- $L_i(n) \quad 10 \, Log_{10} \left[\dfrac{1}{E_{i(n)}}\right]$

- Q 14. Define and explain transmitted power in Radar equation and express Radar equation in terms of the energy contained in the transmitted power
- P_T = Peak Power ; P_{av} = Average Power ;
- Energy = Power x time
- Energy in Peak power = Energy in Average Power



- $P_T \, \tau = P_{av} \, T_P$; So $P_{av} = \dfrac{P_T \, \tau}{T_P} = P_T \, \tau \, f_p$
- A Duty cycle = $\dfrac{\tau}{T_P} = \dfrac{P_{av}}{P_T}$ Therefore $P_T = \dfrac{P_{av}}{\tau \, f_p}$ Eq. No.1
- $R_{max} = \left[\dfrac{P_T \;\; G \;\; A_e \;\; \sigma \;\; n \;\; E_i(n)}{(4\pi)^2 \;\; K \;\; T_0 \;\; B_n \;\; F_n \;\; (S/N)_1}\right]^{\frac{1}{4}}$ Eq. No. 2
- $E_i(n)$ = Integration efficiency ; F_n = Receiver noise power
- $(S/N)_1$ = Signal-to- Noise ratio of single pulse
- Combining Eq.No.1 & 2

- $R_{max} = \left[\frac{P_{av}\ G\ A_e\ \sigma\ n\ E_i(n)}{(4\pi)^2\ K\ T_0\ (B_n\tau)\ F_n\ (S/N)_1\ f_p}\right]^{\frac{1}{4}}$ Eq. No. 3
- $(B_n\ \tau)$ = Band width × Pulse width (normally set to 1 in radars)
- Substituting Eq. No. 4 in Eq. No. 3 we have
- $R_{max} = \left[\frac{E_T\ G\ A_e\ \sigma\ n\ E_i(n)}{(4\pi)^2\ K\ T_0\ F_n\ (S/N)_1}\right]^{\frac{1}{4}}$
- Range R_{max} depends on i) E_T Total transmitted energy
- ii) Gain of Antenna
  iii) Aperture area of antenna
  iv) Receiver noise power

- Q 15. Explain how the transmitted power affects the range
- $R_{max} = \left[\frac{P_T\ G\ A_e\ \sigma}{(4\pi)^2\ S_{min}}\right]^{\frac{1}{4}}$
- Considering all factors other than P_T, constant
- $R_{max} = [K\ P_T]^{\frac{1}{4}}$
- $R_{max} \propto [P_T]^{\frac{1}{4}}$
- To get double the range transmitter power has to be increased by 16 times

Range	P_T
2 Times	16 Times
3 Times	81 Times
Half	1/16 Times $(1/2)^4$

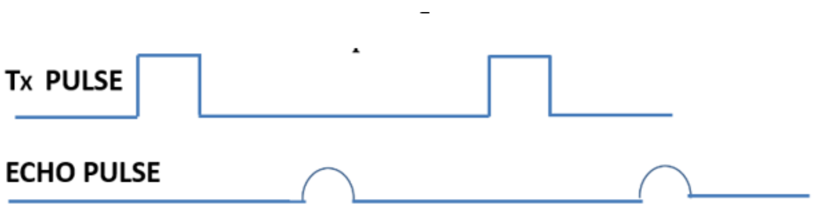
- Q 15. Describe how pulse repetition frequency of a radar system controls the range of its detection

  OR
- Discus the factors of PRF and range ambiguities

  OR
- Bring out the restrictions on the selection of Pulse Repetition Frequency in radar operation

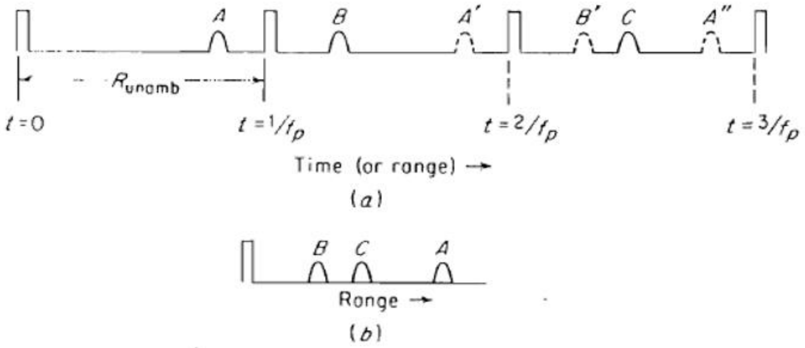
  OR
- Discuss the factors affecting the PRF and range of a radar

- A Max Range = $\frac{C\ T_P}{2} = \frac{C}{2\ f_p}$
- **RANGE AMBIGUITY:**
- Once the transmitted pulse is sent into space , sufficient length of time must be allowed for the Echo to return, before the next pulse is sent



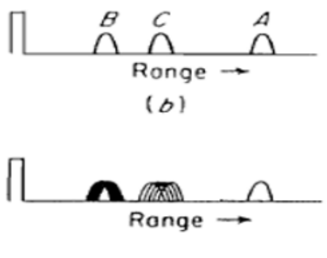
- If PRF is high (T_P is low), Echo from the target may arrive after the transmission of next pulse . This causes confusion and is called Range Ambiguity Echoes that arrive after the transmission of second pulse are called 2nd time around Echoes

- **MULTIPLE TIME AROUND ECHOES:**
- If f_P is very high, R_{max} is low, there is likelihood of receiving target echoes from targets beyond R_{max}
- Echo signals received after the Pulse Repetition Interval ($1/f_P$) are called multiple-time around echoes. They result in confusing Range measurements.



- Target 'A'located within unambiguous Range R_{max}
- Target 'B' located beyond R_{max} but less than $2R_{max}$.
- Target 'C' located beyond $2R_{max}$ but less than $3\ R_{max}$
- On the 'A' scope only the Range measured of Target A is correct but for target 'B' and 'C'. The range is erroneous (ambiguous).
- The multiple time around Echoes can be found out from the Unambiguous Echoes by using a varying PRF

- **DISTINGUISHING MULTIPLE –TIME - AROUND ECHOES**
- Operate the Radar with varying PRF
- Echo signal from 'A' (unambiguous range) appear
- at the same place on the sweep irrespective of change in PRF. Targets echoes 'B' & 'C' will spread as shown in Figure



- **DISTINGUISHING MULTIPLE –TIME - AROUND ECHOES**
- Second Time targets need 2 separate PRFs in order to be distinguished.
- Other methods to resolve Range Ambiguities are by changing from pulse to pulse
- (i) Amplitude (ii)Pulse width (iii) Polarization

- Problem 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 Time
- $T_{fa} = \frac{1}{BIF} \exp \frac{V_T^2}{2\ \phi_O}$
- where $B_{IF} = 1X\ 10^6$ HZ
- Threshold to Noise Ratio = 12.8 dB
- $10 \log_{10} \frac{V_T^2}{2\ \phi_O} = 12.8$ dB
- $\frac{V_T^2}{2\ \phi_0} = \text{Antilog}_{10} \frac{12.8}{10} = 19.05$
- $T_{fa} = \frac{1}{1 \times 10^6}\ e^{19.05} = \frac{187633284.2}{10^6} = 187.6$ sec

- Problem 8 The PRF of envelope of Noise Voltage is

  $P(R) = \frac{R}{b} \exp \frac{-R^2}{2\,b}$ for $R \geq 0$ If P_{fa} needed is $\leq 10^{-5}$

  Determine Threshold Level.

- $P(R) = \frac{R}{b} \exp \frac{-R^2}{2\,b}$
- $P(R) = \frac{R}{\varphi_0} \exp\left[-\frac{V_T{}^2}{2\ \varphi_o}\right]$
- Where $b = \phi_0$

  $P_{fa} = 10^{-5} = \exp \frac{-V_T^2}{2\ \phi_o}$

- Taking Anti (Natural) Logarithms.
- $-5 \text{ Log } e^{10} = -\frac{V_T{}^2}{2\ \varphi_o}$
- $-5 \times 2.3026 = -11.5 = -\frac{V_T{}^2}{2\ \varphi_o}$
- $V_T^2 = 11.5 \times 2\ \psi_0$
- $V_T = \sqrt{23}\ \sqrt{\phi_o} = 4.8 \sqrt{\phi_o}$

END OF FIRST UNIT

ANSWERS TO JNTUH EXAMINATION QUESTIONS
RADAR SYSTEMS
UNIT — TWO

Q 1. 1. What is Doppler effect ? What are some of the ways in which it manifests itself

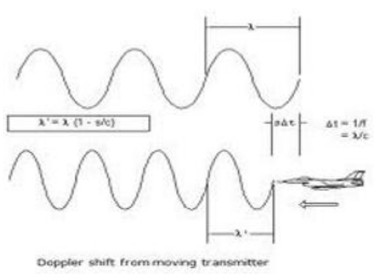
OR

2. Define Doppler frequency. Explain the significance of Doppler frequency while detecting the target

DOPPLER EFFECT:

- If the source of oscillation or the observer of the oscillation is in motion, the frequency observed is not the same as the frequency of oscillation. There is an apparent shift in the frequency.

- **DOPPLER FREQUENCY SHIFT:**
- Shift in frequency f_d due to target motion is called Doppler shift frequency.
- Let R = Distance between Radar and target.
- λ= Wavelength of transmitted frequency
- f_d = Doppler frequency
- $\lambda = \frac{C}{f}$
- where $C = 3 \times 10^8$ mt /sec
- f = frequency of transmission
-



- Q 2. Derive the expression for relative velocity of the target in CW Radar

- **DOPPLER FREQUENCY SHIFT EQUATION:**
- Number of wavelengths in the distance 2R
- $= \frac{2R}{\lambda}$ wavelengths
- One wavelength corresponds to angular excursion of 2 π radians
- Angular excursion made by EM wave in $\frac{2R}{\lambda}$ wavelengths is
- $\phi = 2\pi \times \frac{2R}{\lambda} = \frac{4\pi R}{\lambda}$ radians
- If target is in motion R continuously changes therefore ϕ also continually changes with time.
- Change in ϕ with time represents angular frequency
- ω_d in radians / sec $\omega_d = \frac{d\phi}{dt}$
- $\omega_d = 2\pi f_d$ (ω_d in radians / sec and f_d is doppler frequency in HZ (c/s)

- $\emptyset = \frac{4\pi R}{\lambda}$ radians
- $\frac{d\emptyset}{dt} = \omega_d = \frac{d}{dt}\left[\frac{4\pi R}{\lambda}\right] = \frac{4\pi}{\lambda}\frac{dR}{dt}$
- $\frac{dR}{dt}$ = Rate of change of Range = V_r (relative velocity of target)
- $\omega_d = 2\pi f_d = \frac{4\pi}{\lambda} V_r$
- So $f_d = \frac{2V_r}{\lambda} = \frac{2V_r f_o}{C}$ and $V_r = \frac{f_d C}{2V_r}$
- $f_d = \frac{2V_r}{\lambda} = \frac{2V\cos\theta_{az}}{\lambda}$
- V_r = relative (radial) velocity of target with respect to radar. It is the component of target velocity directly towards or away from radar.
- V = velocity of target with respect to ground
- θ_{az} = Angle between target trajectory and line joining target and Radar (LOS)

- **APPROACHING AND RECEDING TARGETS:**
- Approaching targets $f_o + f_d$
- Receding target $f_o - f_d$
- If the target is moving at an angle θ_{el} in elevation and an angle θ_{az} in azimuth relative to the line of sight (LOS) then the expression for the Doppler shift in frequency becomes
- $f_d = \frac{2V}{\lambda}\cos\theta_{el}\cos\theta_{az}$

- Problem 1. Calculate Doppler frequency shift (fd) when the relative velocity of target with respect to radar is 50 knots at a transmitted frequency of 80 MHZ.
- Given Data :
- (i) Transmitted frequency = 80 MHZ = 80×10^{6}
- (ii) Speed = 50 knots = 50 x 1.852 = 92.6 km/hour
- 1 knot = 1 nautical mile / hour = 1.852 km/hour
- Speed = $\frac{92.6 \times 10^3}{60 \times 60}$ = 25.72 mt/sec
- $f_d = \frac{2V_r}{\lambda} = \frac{2V_r}{C} \times f$ (where $\lambda = \frac{C}{f}$)
- $f_d = \frac{2 \times 25.72}{3 \times 10^6} \times 80 \times 10^6 = 13.7$ HZ
- **ALTERNATIVE SOLUTION**
- $fd = \frac{1.03\, V_r}{\lambda}$ (Formula)
- Where V_r = knots λ = meters
- $fd = \frac{1.03 \times 50}{C} \times f = \frac{1.03 \times 50}{3 \times 10^8} \times 80 \times 10^6 =$

  = 13.7 Hz

- Problem No.2 : An MTI Radar System operating at 10 GHZ and a repetition rate of 1000 HZ receives echoes from an aircraft that is approaching the radar with a radial velocity component of 1 km / sec. Determine the shift in frequency as measured by the radar

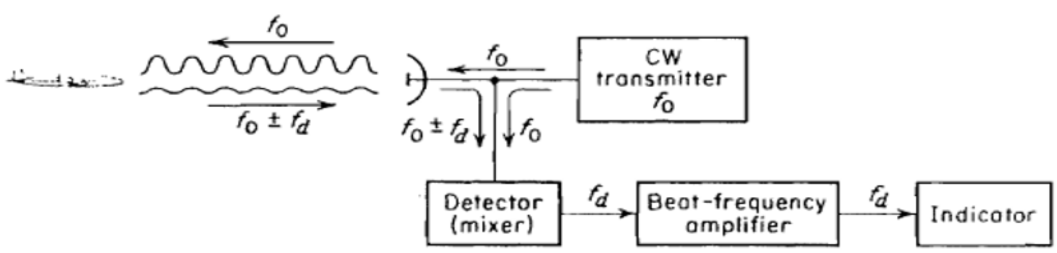
- Given Data :
- (i) Frequency of operation = 10×10^9 HZ

  $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{10 \times 10^9} = 0.03$ meter
- (ii) Vr = 1 km / sec = 1000Mt / sec.

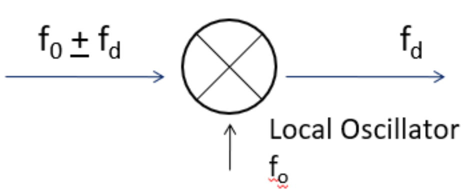
- $f_d = \frac{2\ V_r}{\lambda} = \frac{2\ \times 1000}{0.03}$ =66666HZ=66.666 KHz
- Problem No.3 : With a transmit (CW) frequency of 5 GHz calculate the doppler frequency seen by a stationary Radar when the target radial velocity is 100 km/h (62.5 mph)

- f= $5 \times 10^9\ Hz$
- $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{5\ \times\ 10^9}$ =0.06 mt
- $V_r\ = \frac{100 \times 10^3}{60 \times 60}$ = 27.78 mt/sec
- $f_d = \frac{2\ V_r}{\lambda} = \frac{2 \times 27.78}{0.06}$ =926 Hz

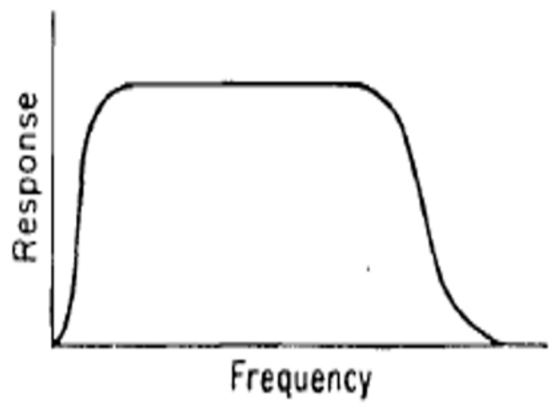
- Q 3. 1. Draw the block diagram of a simple CW Radar and explain its working



- **CW TRANSMITTER :**
- generates a continuous (unmodulated) oscillation of frequency f_o
- **T_X ANTENNA :** radiates RF frequency f_o into space
- **R_X ANTENNA :** Target reflects and a portion of RF is received at R_X antenna. Since the target is moving (Range changing), the echo frequency is $f_o \pm f_d$
- f_d has plus sign if target is approaching towards antenna (closing target)
- f_d has negative sign if target is receding from antenna
- **MIXER (DETECTOR):**
- $f_o \pm f_d$ enters through antenna, heterodyned in the mixer with a portion of f_o to produce doppler beat frequency f_d . Sign of f_d is lost in the process



- **DOPPLER AMPLIFIER:**
- O/P from Mixer is amplified and filtered. Amplifier level should be sufficient to operate the indicator.



- Purpose of Doppler Amplifier is not only to amplify but to eliminate echoes from stationary targets (Buildings, Towers, etc.)
- DC component caused by stationary targets is removed by low frequency cut off.
- Cut off should be sharp enough to pass smallest doppler frequency expected.
- Upper cut off frequency is such that it passes the highest doppler frequency expected.
- **INDICATOR**
- (i) Earphone (ii) Frequency meter
- **I). EARPHONE**
- Act as a selective band pass filter with 50 HZ band
- Because of narrow band S/N ratio is high (N=KTB)
- Minimum f_d (helicopter) and Maximum f_d (supersonic fighter aircraft) falls within the listening range of audio frequencies of the ears. Ear cannot measure f_d, so determination of velocity is not possible.
- **II) FREQUENCY METER**
- Usually a frequency counter measures f_d in HZ
- So accurate determination of V_r (relative velocity of target) is possible.

- Q 4. What is the importance of providing isolation between Transmitter and Receiver? OR Explain clearly the different methods of providing isolation in the case of CW Radar
- In CW Radar T_x and R_x are simultaneously operating.
- Echo signal power might be as little as 10^{-18} to that of the Transmitted power.
- R_x is designed to handle only very low power. T_x power which is very high should not leak into the R_x and damage the R_x. So isolation is required.
- Though Ferrite circulator (monostatic CW Radar) is used to block the T_x power entering the R_x , Circulators have only 30 dB maximum blockage. So this type of CW Radars work with low power.
- A Bistatic radar using separate antennas for transmission and receiving can be one of the solution. The distance between T_x and receiving antennas determines the Isolation achieved.
- As a result of doppler, echo frequency is $(f_o \pm f_d)$ different from transmitted frequency (f_o). So a proper filter can separate the echo. However leakage is still present in practice. A certain amount of leakage can be utilized in a mixer to extract doppler frequency shift.

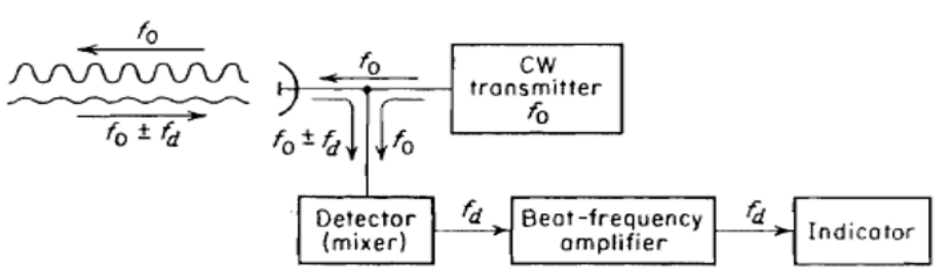
- **PRACTICAL LIMITS FOR LEAKAGE POWER:**
- The practical limit is the maximum power the R_x can withstand before damaged and in extreme case burn out takes place.
- Because of the above, the R_x sensitively is reduced
- So additional Isolation is required for CW Radar to operate at higher powers.
- **AMOUNT OF ISOLATION REQUIRED:**
- Safe value of Rx = 10 mws
- T_x Power = 1 KW
- Isolation required $\frac{1\text{ KW}}{10\text{ mws}} = \frac{1 \times 10^3}{10 \times 10^{-3}} = 10^5 = 50\text{ dB}$
- **METHODS FOR ISOLATION:**
- Hybrid Junctions like magic T
- Short slot coupler
- Ferrite circulator (20 to 50 dB isolation)

- Turnstile Junction (40 to 50 dB isolation)
- Use of orthogonal polarizations for transmission and reception.
- Use of dual antenna one for transmission and another for receiving.
- **SOURCES OF LEAKAGE POWER:**
- Noise in the T_x which falls in the range of doppler frequencies.
- Reflections produced in transmission line by the Antenna. To achieve an isolation of 20 dB or 40 dB, VSWRs, required are 1.22 to 1.02 respectively.
- **USE OF 2 ANTENNAS TO INCREASE ISOLATION**
- Tx and Rx antennas are physically separated and kept at a distance.
- Isolation of 80 dB or more achieved depending on
- i)Distance between antennas
- ii)Directivity of antennas
- iii)Metallic baffles that are used
- iv)Absorbing material placed between antennas, enhances isolation

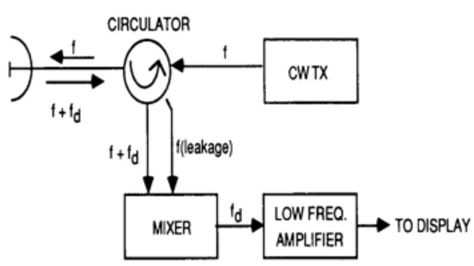
- Q 5. 1. Explain the operation of Non Zero IF receiver with neat block diagram. Compare it with Zero IF receiver and bring out its advantages

  2. Explain the operation of Sideband Super-heterodyne CW doppler Radar with block diagram

- **1. Homodyne Receiver: (Zero IF Receiver)**

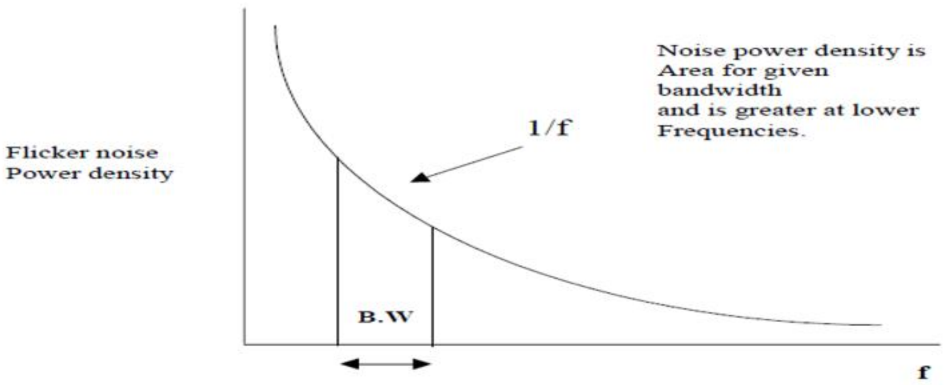


- Mixer is used to obtain Doppler frequency.
- Receiver is simpler.
- But not sensitive enough because of increased flicker noise at low frequencies.



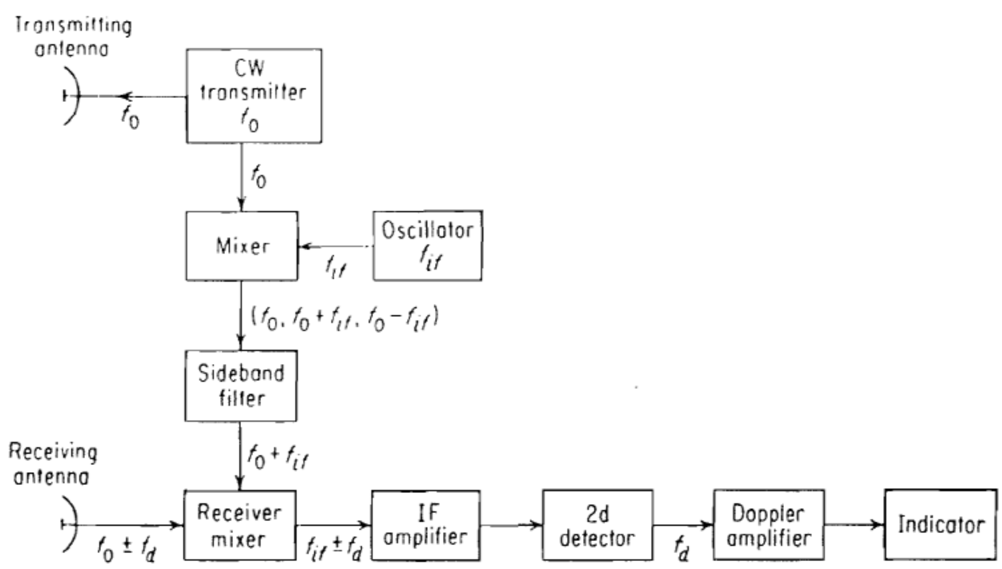
- Advantage of Non Zero IF Receiver over Zero IF receiver

- For f_o = 2 GHZ., ships produce doppler frequency range 0 to 200 HZ
- Doppler frequencies lie in the lower frequency band of Flicker Noise
- (Noise Power $\propto \frac{1}{\text{frequency}}$)
- So if Doppler frequency is amplified along with it flicker noise is also amplified.
- So Doppler frequency is shifted to a higher frequency usually 30 MHZ or 60 MHZ and amplified where flicker noise is less. To obtain superior range of target, Non Zero (Super heterodyne) receiver is used

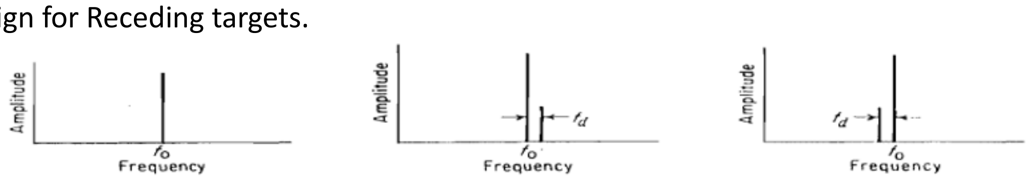


- . **Flicker noise versus frequency**

Non Zero IF R_x (Super Heterodyne R_x)



- **OPERATION:**
- **(1) 2 SEPARATE ANTENNAS** are used (i) Transmission & (ii) Receiving to improve the isolation and overcome leakage from high power T_x
- **(2) MIXER:** Input to mixer are (i) f_o small portion of T_x power (ii) f_{if} – from IF oscillator
- Output of mixer is f_o, $(f_o + f_{if})$, $(f_o – f_{if})$
- **(3) SIDEBAND FILTER:** Allows only one side band $f_o + f_{if}$
- **(4) R_X ANTENNA:**
- Output of antenna is Echo signal from the target i.e. $(f_o \pm f_d)$. + sign for approaching targets – sign for Receding targets.

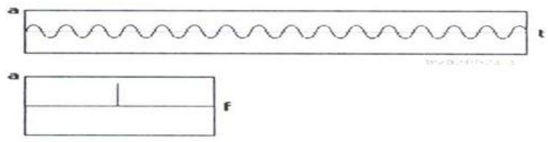


- **(5) RECEIVER MIXER:**
- I/P to mixer are (i) $(f_o + f_{if})$ from side band filter (ii) $(f_o \pm f_d)$ from Rx antenna.
- Output of Mixer is $(f_{if} \pm f_d)$ i.e. if $\pm$ Doppler frequency
- **(6) IF AMPLIFIER:**
- Amplifies $(f_{if} \pm f_d)$ to a sufficient level
- **(7) 2[ND] DETECTOR:**
- This is an envelope detector. Removes IF carrier. Output is f_d. Sign information is lost.
- **(8) DOPPLER AMPLIFIER:**
- Amplifies f_d signal to a level suitable to Indicator.
- **(9) INDICATOR:**

- This can be a frequency meter which can be calibrated in terms of speed i.e. meters/sec or Kms/hour.

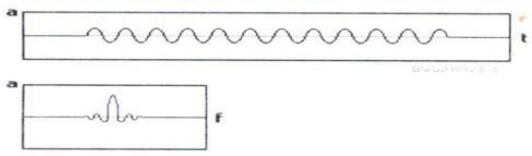
- Q 6. 1. Several factors tend to spread to the CW signal to the CW signal energy over a finite band of frequencies. Explain
- OR
  2. Bring out the factors that tend to spread the CW signal energy over a finite frequency and explain the spreading reasons clearly

Ideal CW (sine wave of infinite duration)



TIME VS. FREQUENCY DOMAIN (1)

Practical CW (Sine wave of finite duration)



TIME VS. FREQUENCY DOMAIN (2)

- Frequency Spectrum of Sine wave of Infinite duration is a delta function. This does not occur in practice.
- Echo signal is a sine wave of finite duration. This has a spectrum (also called SINC function)
- Sin $\dfrac{\pi\ (f - f_0)\ \delta}{\pi\ (f - f_0)}$
- f_0 = frequency of Sine wave
- δ = Duration of Sine wave
- Echo spectrum is broadened because of i) scanning
- ii) fluctuation in RCS (iii) change in target velocity etc.
- **(I) SPREAD OF B.W. DUE TO SCANNING:**
- θ_B = Antenna Beam width in Deg.
- $\dot{\theta}$= Scanning Rate Deg / Sec.
- δ = Time on target = $\dfrac{\theta_B}{\dot{\theta}_S}$ secs.
- B.W. = $\dfrac{1}{\text{Time on target}} = \dfrac{\dot{\theta}_S}{\theta_B}$ Hz
-
- **Example:** θ_B = 2 Deg, θ_S = 36^0 / sec (6 rpm)
- Spread in spectrum B.W = 36 / 2 = 18 HZ

- **(II) SPREAD OF B.W. DUE FLUCTUATIONS IN RCS:**
- Example 1: RCS changes by 15 dB (31.6) for a change in target aspect of as little as 1/3 Deg.
- Example 2: Propeller Driven aircraft (World War-II produces a frequency modulation B.W. of 50 to 60 HZ.

- **(III) SPREAD OF B.W. DUE TO FLUCTUATIONS IN VELOCITIEs**
- Widening of B.W. = $\Delta f_d = \left[\dfrac{2\, a_r}{\lambda}\right]^{\frac{1}{2}}$
- where a_r = target acceleration

- Problem No.1 Determine the acceleration of a target if the received signal bandwidth is 40 Hz and the operating wave length is 9 cms

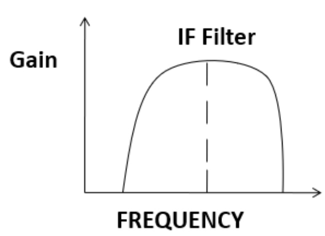
- $\Delta f_d = \left[\frac{2\, a_r}{\lambda}\right]^{\frac{1}{2}}$
- $\Delta f_d = 40$ Hz
- $\boldsymbol{\lambda} = 9$ cms $= 0.09$ mt
- $a_r = (\Delta f_d)^2 \times \frac{\lambda}{2} = \frac{40^2 \times 9 \times 10^{-2}}{2} = 72$ mt/sec^2

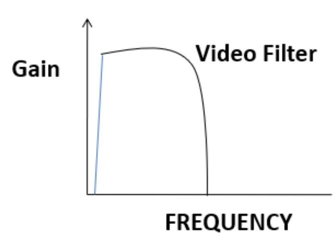
- A Problem No.2 Determine the operating frequency if the target is moving with acceleration as same as acceleration of gravity and the received signal bandwidth is 50 Hz.

- $\Delta f_d = \left[\frac{2\, a_r}{\lambda}\right]^{\frac{1}{2}}$
- $\boldsymbol{\lambda} = \frac{2\ a_r}{(\Delta f_d)^2} = \frac{2 \times 9.8}{50^2} = 0.00784$
- Frequency = $f = \frac{C}{\lambda} = \frac{3 \times 10^8}{0.00784} = 3.827 \times 10^{10}$
- $= 38.27$ GHz

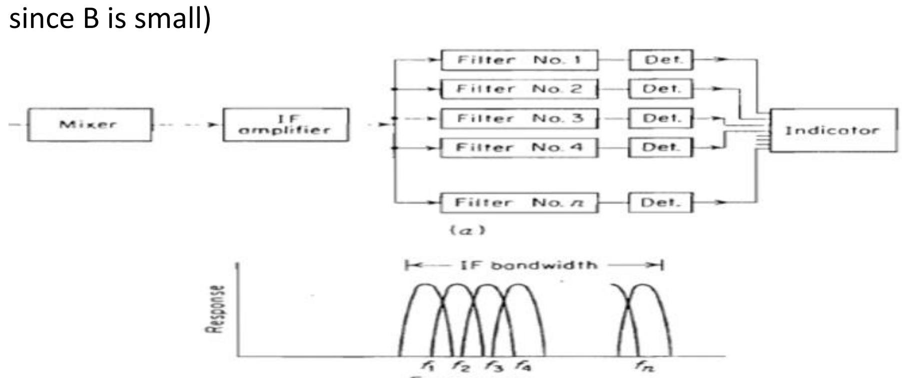
- **Q 7. 1.What is the purpose of filter banks in CW Radar Receiver ? Draw the block diagram of IF Doppler filter bank and draw its frequency response**

- Doppler Frequency filter should pass all the ranges of Doppler frequencies pertaining to all possible velocities of target.
- The Bandwidth of individual filter should be wide enough to pass the signal energy, but not so wide to introduce more noise than need be because thermal noise (KTB) increases with wider (increase) bandwidth
- There are 3 methods to realize the Doppler filter
- (i) Wide Band Doppler Filter
- (ii) Narrow Band Doppler Filter Bank
- (iii) Tunable narrow Band Filter
- Filter may be used either in (a) IF or (b) Video
- **(I) WIDE BAND DOPPLER FILTER:**
- This is a single filter and passes all the possible Doppler frequencies for the given minimum and maximum velocities of target
- Since B.W. is wide, noise is large ($N_o = K\,T\,B$)
- The filter can be in I.F. or after the detection in video





- **(II) NARROW BAND DOPPLER FILTER BANK:**
- In order to improve S/N Ratio a bank of narrow band filters spaced throughout the frequency range of Doppler frequencies are used in place of a single wideband filter (This reduces $N = KT_oB$ since B is small)

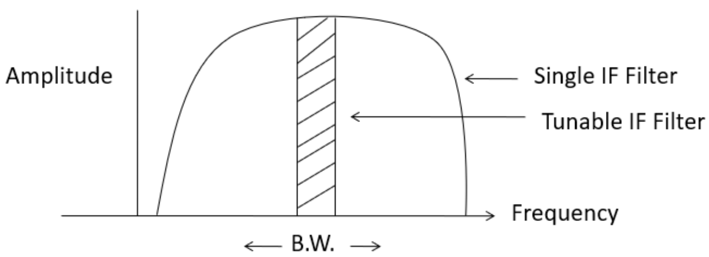


- The centre frequencies are spread to cover the entire range of Doppler frequencies.

- The half power points of individual filters are over-lapped so that the S/N reduction is 3dB.
- If more filters are used loss in S/N is reduced but the complexity and cost increases.
- The Narrow band Doppler Filter Bank can be used either in (a) IF or (b) after the detection of Video

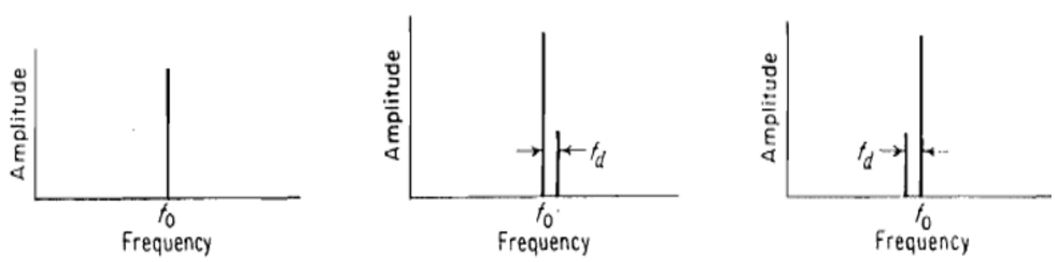
- **COMPARISON OF FILTERS IN IF AND IN VIDEO:**
- (a)The improvement in S/N is more in IF Filter bank than in Video Filter Bank.
- (b)Sign of Doppler shift is lost in Video Filter Bank.
- As such the discrimination between approaching and receding targets is lost. Frequency spectrum folds over in Video because of Detector.
- (c)No. of filter banks in Video Filter Bank is half the no. of filter banks in IF Filter Bank.

- **(III) TUNABLE NARROW BAND FILTER:**



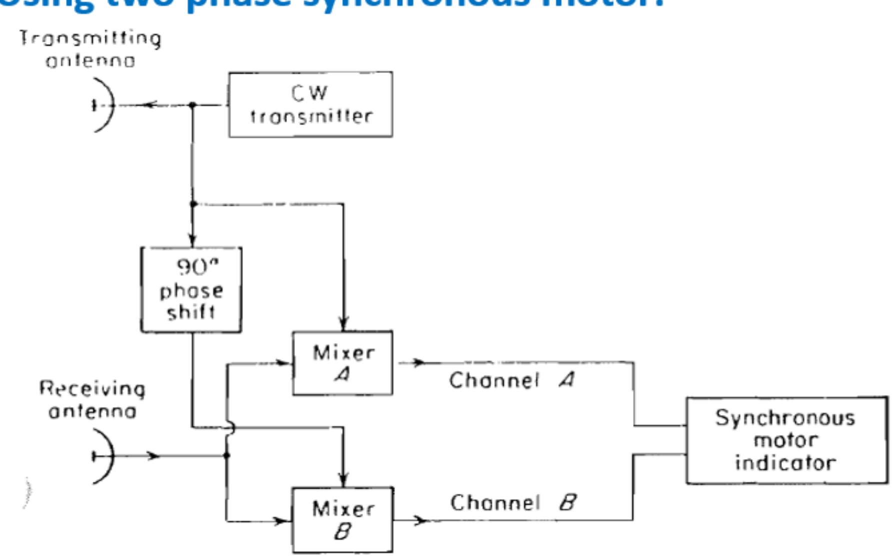
- Bank of Filters increases the complexity and cost.
- Single narrow band tunable filter searches the incoming echo signal until signal is found.
- After recognizing the signal the filter may be programmed to continue search for next target

- Q 8. 1. Explain with necessary block schematic and analysis how Doppler direction is identified in CW Radar



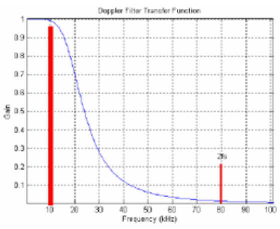
- **IF FILTERING:** if signal is present on right of IF, Echo frequency is above IF carrier . This indicates target approaching
- If signal is present on left of IF, Echo frequency is below IF carrier. This indicates target receding
- **VIDEO FILTERING:** Doppler frequency spectrum folds over in Video because of Detector.

Using two phase synchronous motor:



- Transmitter signal $E_t = E_o \cos \omega_o t$
- Echo Signal $E_r = E_d \cos [(\omega_o \pm \omega_d) t + \phi]$
- T_x frequency ω_o
- Doppler frequency ω_d **$\cos A . \cos B = 1/2 [\cos (A+B)+\cos (A-B)]$**

- ϕ is Phase Shift due to Range
- Mixer A multiplies $(E_o \cos \omega_o t)$ and $(E_d \cos[(\omega_o \underline{+} \omega_d) t + \phi])$
- $E_A = E_o E_d \cos \omega_o t \times \cos [(\omega_o \underline{+} \omega_d) t + \phi]$
- $k [\cos \{(2\omega_o \underline{+} \omega_d) t + \phi\} + \cos (\underline{+}\omega_d t + \phi)]$
- where $k = E_o E_d / 2$
- As we are not interested in signal at $(2 \omega_o t + \omega_d)$ it is filtered out using a low pass filter
- So $E_A = k \cos (\underline{+} \omega_d t + \phi)$
- Mixer B multiplies $(E_o \cos \omega_o t + \pi / 2)$ and $(E_d \cos [(\omega_o \underline{+} \omega_d) t + \phi])$

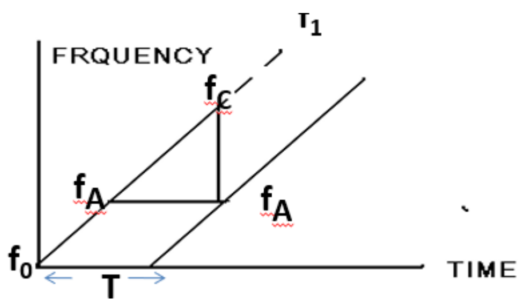


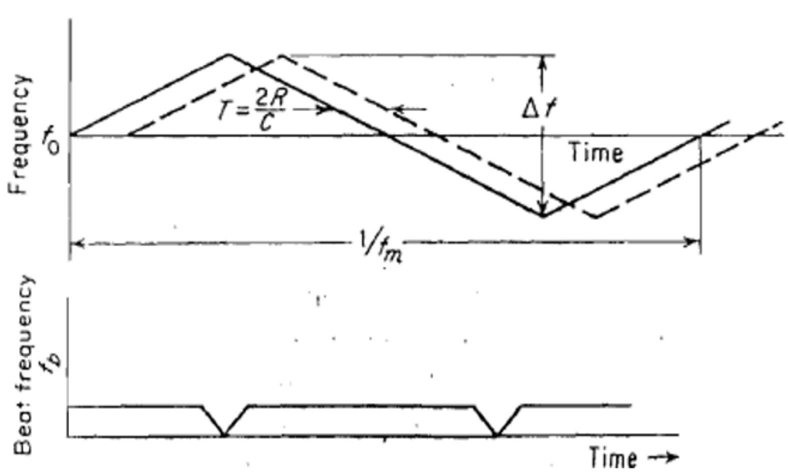
- So $E_B = k \cos (\underline{+}\omega_d t + \phi + \pi / 2)$
- $E_A = k \cos(\omega_d t + \phi)$ for approaching targets
- $E_B = k \cos (\omega_d t + \phi + \pi /2)$ for approaching targets
- For Approaching target output E_B leads E_A
- Direction of target is determined by sign of ω_d
- $E_A = k \cos(-\omega_d t + \phi)$ for receding targets
- $E_A = k \cos(\omega_d t - \phi)$ (since $\cos(-\theta) = \cos \theta$)
- $E_B = k \cos (-\omega_d t + \phi + \pi /2)$ for receding target
- $E_B = k \cos (\omega_d t - \phi - \pi /2)$
- For Receding target output E_B lags E_A
- For Approaching target output E_B leads E_A
- Channel A & B are given to 2 phases of synchronous motor. The direction of rotation of synchronous motor indicates the direction of target motion.

- Q 9. 1. What are the applications of CW Radar
- (1) Measurement of velocity of target – Police speed monitor.
- (2) Rate of climb meter for vertical-take-off aircraft
- (3) Control of traffic lights
- (4) Regulation of toll booths
- (5) Vehicle counting
- (6) Sensor in antilock braking system
- (7) Collision avoidance
- (8) Monitoring of docking speed of large ships
- (9) Velocity of missiles, ammunition and baseball
- (10) Measurement of vibration of turbine blades

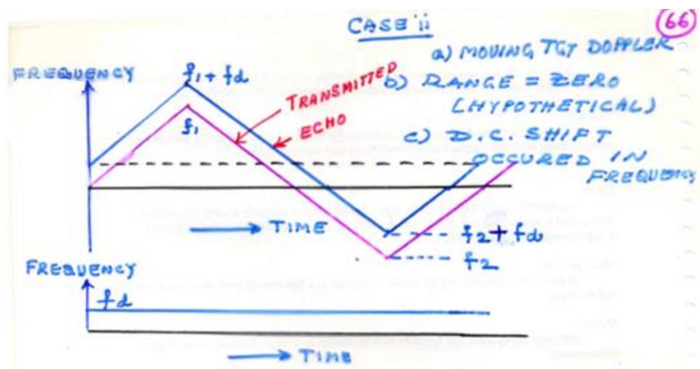
- Q 10. What are the advantages and disadvantages of CW radar?
- **ADVANTAGES**
- 1. Simple to design and manufacture compared to Pulse radar
- 2. Measures velocity of target accurately using the principle of Doppler
- 3. The echo frequency is shifted by the doppler frequency compared to transmitted frequency
- 4. The shifted frequency is proportional to the velocity of target
- **DISADVANTAGES:**
- 1. Can not measure the range of the target
- 2. Two antennas are required one for transmission and another for receiving.
- 3. Sufficient isolation is required between the transmitting and receiving antennas to protect the receiver from damage

- Q 11. 1. Derive an expression for range & doppler measurement for a FM CW Radar (for doppler derivation see earlier pages)
  2. Explain the operation of FM-CW Radar when modulation is linear and triangular and target is assumed to be stationary with the help of neat sketches
  3. Derive an expression for range frequency in case of FM CW radar

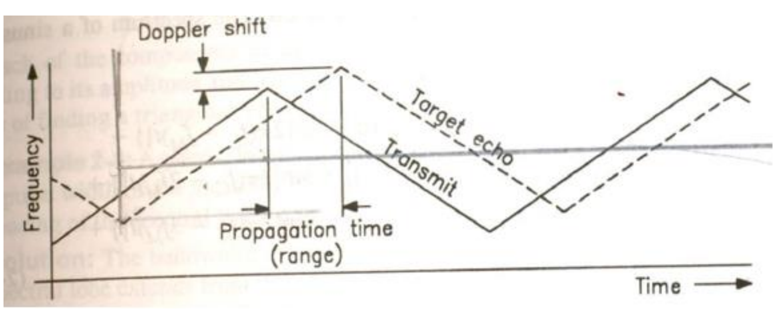
- **Linear Frequency Modulation:**
- 

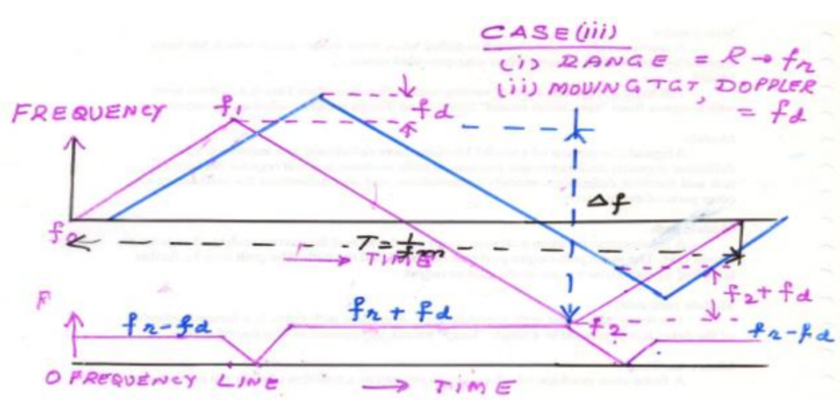
- $(f_C - f_A) = f_r$ = Beat frequency because of Range
- But $\frac{(f_C - f_A)}{T} = \dot{f}_0$
- Where $f_r = (f_C - f_A) = \dot{f}_0 T = \dot{f}_0 \frac{2R}{C}$
- **TRIANGULAR FREQUENCY MODULATION**
- Triangular modulation is more popular and easy to implement
- 4 distinct cases arise in measurement of range and radial velocity
- **4 Cases:**
- (i) Target at Range R ($f_r \neq 0$) but not moving ($f_d = 0$)
- (ii) Target at Range R =0 ($f_r = 0$) but moving ($f_d \neq 0$)
- (iii) Target at Range R ($f_r \neq 0$) ,moving ($f_d \neq 0$) target approaching but $f_r > f_d$
- (iv) Target at Range R ($f_r \neq 0$) ,moving ($f_d \neq 0$) target approaching but $f_r < f_d$ (high speed at short range)
- **Case (i)**
- **Target at Range R ($f_r \neq 0$), not moving ($f_d = 0$)**
- 

- Since $f_r = \frac{2R}{C} \dot{f}_o$
- Rate of change of frequency = $\dot{f}_o = \frac{\Delta f}{\frac{1}{2 f_m}}$
- Where **Δf** = Maximum frequency – Minimum frequency

- $\frac{1}{f_m}$ = period of one cycle of triangular wave
- Substituting f_o in f_r
- $f_r = \frac{2R}{C} f_o = \frac{2R}{C} \frac{\Delta f}{[\frac{1}{2 f_m}]} = \frac{4 R f_m \Delta f}{C}$
- **Inference: Echo wave is shifted in Time Axis**
- **Case (ii):Target Range R= 0 (f_r=0); moving ($f_d \neq 0$)**
- 

- **Inference: Echo wave is shifted in frequency Axis**
- **Case (iii) Target at Range R ($f_r \neq 0$), moving ($f_d \neq 0$), approaching target, but $f_r > f_d$**
- f_r beat frequency for Range shifts the curve laterally sideways (time axis)
- f_d beat frequency for Doppler shifts the curve up vertically (frequency axis)

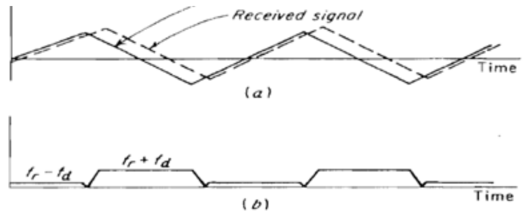


- 

-

$f_b(Up) = f_r - f_d$

$f_b(down) = f_r + f_d$



$$f_r = \frac{f_b(up) + f_b(down)}{2}$$ Average measurement

$$f_d = \frac{f_b(down) - f_b(up)}{2}$$ Difference measurement

- **Case (iv) Target at Range R ($f_r \neq 0$), moving ($f_d \neq 0$), approaching target, but $f_r < f_d$**

- Roles of Averaging & Difference measurements are reversed
- Average meter measures Doppler velocity
- $f_d = \dfrac{f_b(up) + f_b(down)}{2}$
- Difference meter measures Range
- $f_r = \dfrac{f_b(down) - f_b(up)}{2}$
- Problem 3: A CW Radar has center frequency of 10.0 GHZ and triangularly sweeps a bandwidth of 2.0 MHZ at 200 HZ rate. The frequency difference between transmit and receive in the up swing is 65510 and on downswing 82650 HZ. What is the target range and radial velocity
- Solution: Approaching target is assumed.
- $f_r = \dfrac{f_b(up) + f_b(Down)}{2}$
- $f_r = \dfrac{(65510 + 82650)}{2} = 74080$ Hz
- $R = \dfrac{f_r\ C}{4\ \Delta f\ f_m} = \dfrac{74080 \times 3 \times 10^8}{4 \times 2 \times 10^6 \times 200} =$
- 13890 mts =13.89 Kms

- $f_d = \dfrac{f_b(down) - f_b(up)}{2}$
- $f_d = \dfrac{82650 - 65510}{2} = 8570$
- $f_d = \dfrac{2\ V_r}{\lambda} = \dfrac{2\ V_r\ f}{C}$
- So $V_r = \dfrac{C\ f_d}{2\ f} = \dfrac{3 \times 10^8 \times 8570}{2 \times 10 \times 10^9}$
- $V_r = 128.55$ Mt/sec

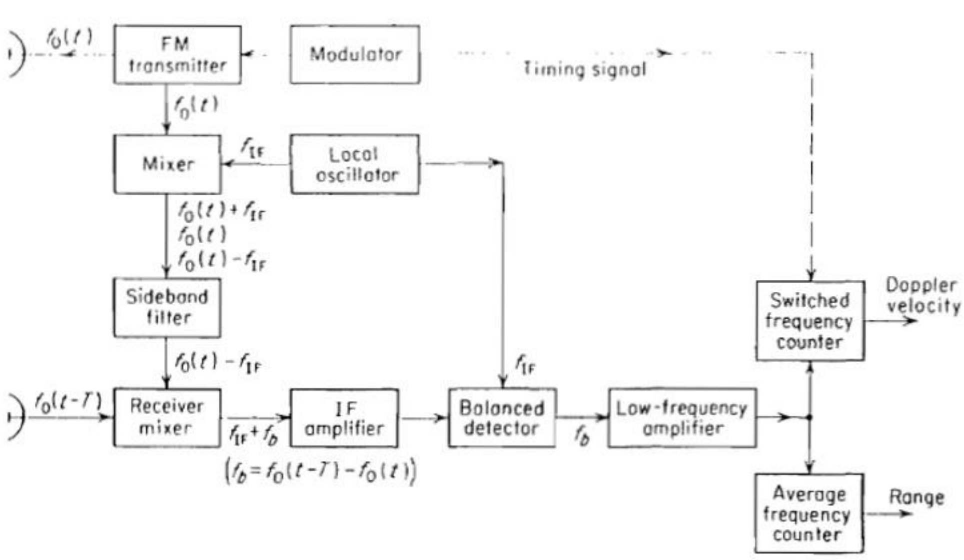
- Problem 4. Determine the range and doppler velocity for a FM-CW if the target is approaching the Radar. Given the beat frequency fb(up) = 20 kHz and fb(down) =30KHz for the triangular modulation , the modulating frequency is 1 MHz and doppler shift is 1 KHz
- fb(up) = 20 KHz and fb(down)= 30 KHz
- fm = 1 MHz and Δf = 1 KHz
- Range frequency $f_r = \dfrac{f_b(up) + f_b(down)}{2}$
- $f_r = \dfrac{20 \times 10^3 + 30 \times 10^3)}{2} = 25 \times 10^3$ Hz
- $fr = \dfrac{4\ R\ f_m\ \Delta f}{C}$
- $25 \times 10^3 = \dfrac{4\ R \times 1 \times 10^6 \times 1 \times 10^3}{3 \times 10^8}$
- R = 1875 meters

- $f_d = \frac{f_b(down) - f_b(up)}{2} = \frac{30 \times 10^3 - 20 \times 10^3}{2}$
- = 5000Hz

- **Problem 5: In an FM CW Radar the frequency changes by 2000 Hz every micro second. What will be the beat frequency if a target is at 8000 ft away from a radar.**
- Rate of change of frequency = $f_0 = \frac{f_1 - f_0}{T_{mod}}$
- Rate of change of frequency = $\frac{2000}{1 \times 10^{-6}}$ = 2 x 10^9 Hz/sec
- $R = 8000 \times \frac{12 \times 2.54}{100}$ =2438.4
- $f_r = f_0 \; T = f_0 \frac{2R}{C}$
- $f_r = \frac{2 \times 10^9 \times 2 \times 2438.4}{3 \times 10^8} = 32512 \text{ Hz}$

- Problem 6: An FM CW Radar transmits a triangular frequency modulation in which the frequency changes 1000 Hz every micro second. Show how a filter bank can be included in the radar to produce a range resolution of 1000 ft. What should be band width of each filter be
- Solution:
- $R = 1000 \text{ ft} = \frac{1000 \times 12 \times 2.54}{100}$ = 304.8 Mt =
- $T_R = \frac{2R}{C} = \frac{2 \times 304.8}{3 \times 10^8} = 2.034 \times 10^{-6}$ sec
- f_r =rate of change of frequency $\times T_R$
- $f_r = \frac{1000}{10^{-6}} \times 2.034 \times 10^{-6} = 2034$ Hz
- Band width of filter = 2000 Hz

- Q 13. Draw the block diagram of FM–CW Radar

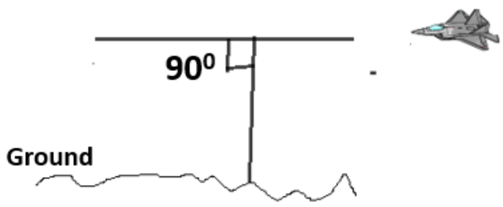


- Reference signal required for the Mixer is a portion of Transmitter.
- Isolation between T_X and R_X antenna is made large so that leakage is negligible
- The beat frequency is amplified and limited to remove any amplitude fluctuations
- Frequency is measured with a cycle-counting frequency meter.

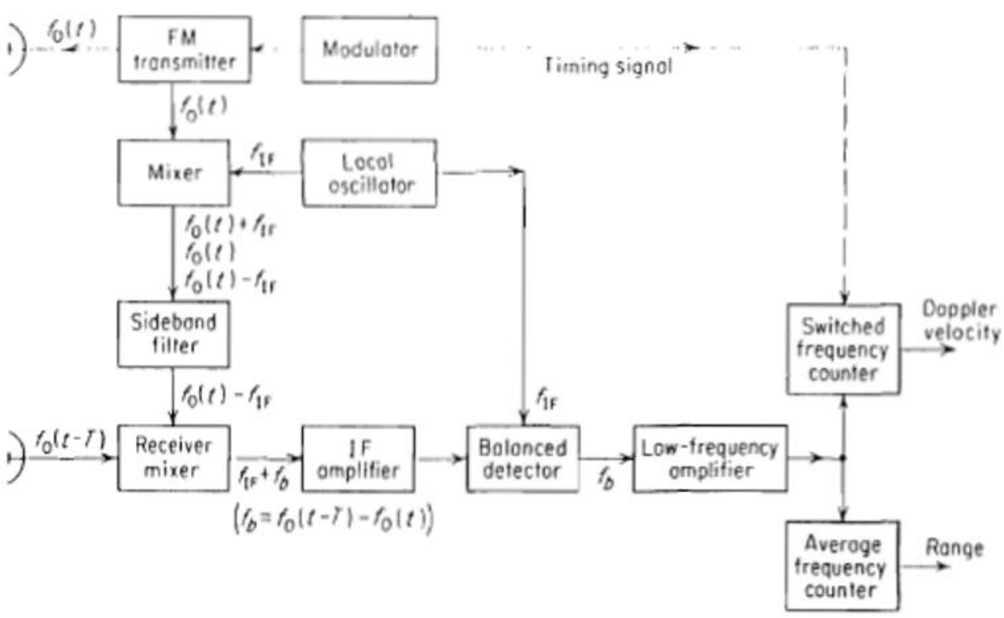
- Q 14. **Explain the principle of operation of FM-CW Altimeter with suitable diagram**

- **PRINCIPLE OF FM-CW ALTIMETER**
- Radio (FM-CW) Altimeter measures the height of the aircraft above the surface of Earth.
- Earth is a large scatter . Its RCS is very high.

- Relatively short (heights) ranges are required to be measured by aircraft(say max 25 Kms). So low power transmitter can be used. Antenna size also can be small(low gain)



- Echo from ground consists of f_r (due to range) and f_d (due to Doppler) so $f_b = f_r + f_d$
- $f_d = \frac{2 V_r}{\lambda} = \frac{2 V \cos \phi}{\lambda} = \frac{2 V \cos 90^0}{\lambda} = 0$
- $f_b = f_r = \frac{4 R \; f_m \; \Delta f}{C}$
- So
- Where f_m = modulating frequency = Rate of change of frequency
- $\Delta f = f_1 - f_2$ (Max.Frequency – Min.Frequency)
- R = Height of Aircraft above ground = h
- $f_r = \frac{4 h \; f_m \; \Delta f}{C} \quad \therefore \quad h = \frac{f_r \, C}{4 f_m \; \Delta f}$



- **(i) FM TX & Modulator:**
- High power FM-CW is generated and applied to TX antenna.

- **(II) ANTENNA :**
- Separate antennas are used for
- (i) Transmission and
- (ii) Reception of Echo

- **(III) LOCAL OSCILLATOR** :
- Fixed frequency f_{IF} generated and applied to (a) Mixer & (b) Balanced detector. This is the IF frequency used in the system

- **(IV) MIXER :**
- Inputs (a) $f_0(t)$ portion of FM transmitted signal (frequency varying with time)
- (b) f_{IF} fixed frequency from L O
- outputs
- (a) $f_0(t) + f_{IF}$ upper side band
- (b) $f_0(t)$ transmitted frequency

- (c) $f_0(t) - f_{IF}$ lower side band

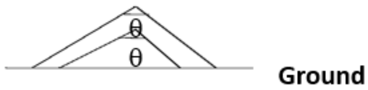
- **(V) SIDEBAND FILTER :**
- Filter selects the lower sideband}
- Rejects $f_0(t)$ carrier, & $f_0(t) + f_{IF}$ upper side band
- Bandwidth should be sufficient to pass the modulation frequency

- **(VI) RECEIVER MIXER**
- Inputs a) $f_0 (t - T)$
- b) $f_0 (t) - f_{IF}$
- Outputs : $f_{IF} + f_b$ where $f_b = f_0((t - T) - f_0 (t)$
- Where f_b is composed of f_r (range frequency) and f_d (Doppler frequency)
-
- **(VII) IF AMPLIFIER:**
- $f_{IF} + f_b$ is amplified
-
- **(VIII) BALANCED DETECTOR:**
- Inputs (a) f_{IF}
- (b) $f_{IF} + f_b$
- Output: f_b
- (IX) LOW-FREQUENCY AMPLIFIER:
- Low frequency f_b is amplified to match the level of indicator

- **(X) AVERAGE FREQUENCY COUNTER:**
- The input is the amplified f_b
- Frequency counter is calibrated in terms height
- $h = \frac{f_r C}{4 f_m \Delta f}$ since $f_b = f_r$
-
- **(X I) SWITCHED FREQUENCY COUNTER**
- The input f_b is then amplified
- Since $f_d = 0$, this counter reads zero

- Q 15. **Explain how the noise signals are limiting the performance of FM altimeter**
- A **NECESSITY FOR SHAPING OF GAIN OF LOW FREQUENCY AMPLIFIER:**
- The swing of echo signal is large. It depends on height
- It is desirable to shape the gain characteristics such that the output of the amplifier remains constant inspite of large swing in input echo power.
- The variation in echo power occurs due to Change of height (Range)
- $P_r = \frac{P_t G A_e \sigma}{(4 \pi)^2 h^4}$
- (ii) Change in area of ground scattering σ (RCS) due to change in height of Antenna.
- **(I) CHANGE OF HEIGHT (RANGE)**
- Echo Power $\propto \frac{1}{Height^4}$
- Doubling (Octave) of height decreases echo power by 16 times (10 log 16 = 12dB) $f_r = \frac{4 h f_m \Delta f}{C}$
- At low height, beat frequency f_r is low but echo power is high. So gain should be low.
- At larger height beat frequency f_r is high but echo power is low. So gain should be high.
- The Echo power has a negative slope of 12dB/octave. The Gain characteristic should have a positive slope of 12 dB/octave, to keep the output of the Amplifier constant.

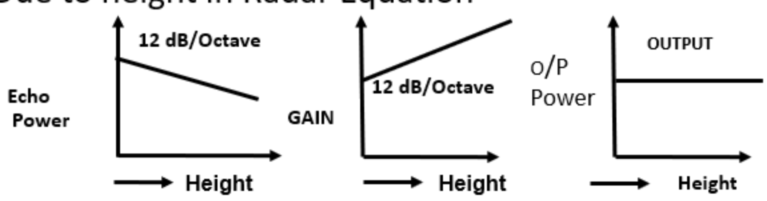
- **CHANGE IN HEIGHT OF ANTENNA:**



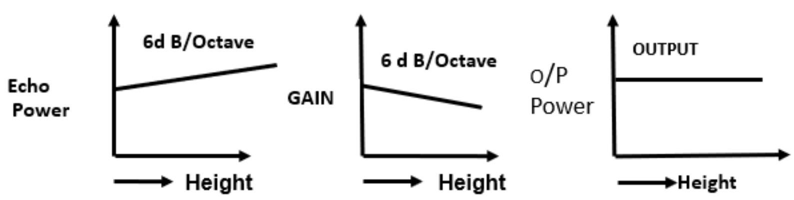
- As the height of transmitter Antenna is increased, the echo area illuminated by the antenna increases. As such RCS increase**s**
- Echo Power α area α height ^{2}
- Doubling (octave) of height increases power by 4 times (10 log 4 = 6dB). Echo power has a positive slope of 6 dB/octave.
- At low height fr is low **(** $f_r \propto height$ **)** but Echo Power also is low. So Gain should be high.
- At larger height fr is high, but Echo Power is also high. So Gain should be Low.

- **COMBINED GAIN CHARACTERISTICS:**

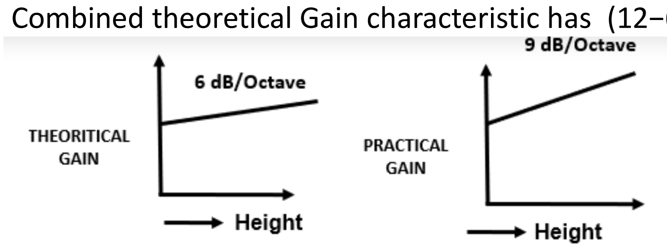
(i) Due to height in Radar Equation



(ii) Due to Antenna Height:



- **(III) COMBINED GAIN CHARACTERISTICS:**
- Combined theoretical Gain characteristic has (12−6) = 6dB/octave with positive slope



- However practical Amplifier has a positive slope of 9dB/Octave

- **ADVANTAGES OF GAIN SHAPING :**
- Gain shaping makes the output of Amplifier constant , Thus lowers the dynamic range.
- (ii) Flicker noise is high at low frequencies. Since the gain of Amplifier is small at low frequencies , the overall S/N is better
- At low heights, the signal from unwanted reflections is large. But Gain of Amplifier is small at low frequencies (low height). The overall S/N is better.
- **METHOD TO REDUCE NOISE BY USING A NARROW BAND FILTER**
- $f_r = \dfrac{4\ h\ f_m\ \Delta f}{C}$
- f_r will have a band of frequencies because of minimum and maximum heights
- Noise is more for a large band of frequencies (N =KTB)

- f_r is maintained constant by varying Δf (excursion of minimum and maximum frequencies) by a servo loop. This reduces 'B' and there by Noise.
- The value of Δf is a measure of altitude.

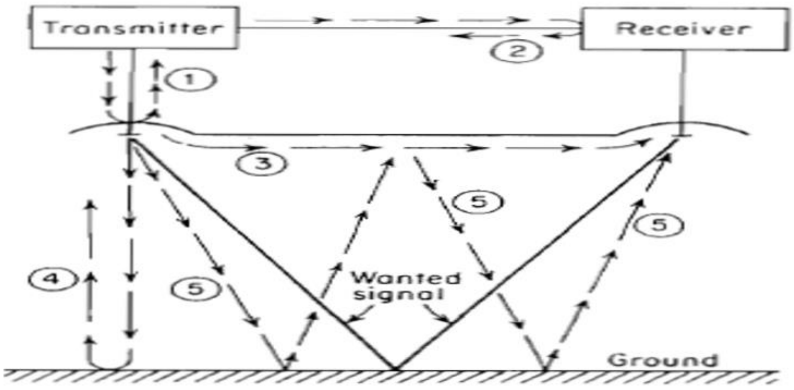
- Q 16. Briefly explain how the errors introduced in an Altimeter are measured

- At low altitudes the absolute accuracy is of more importance than at high altitudes
- **Example:** Error of 5 mts. is not of much concern when the aircraft is flying at a height of 10 kmts compared to when it is cruising at low altitude especially when it is blind landing.
- Theoretical accuracy depends on

- (i) Band width of transmitted signal
- (ii) S/N ratio
- (iii) Measurement accuracy
- Measurement Errors occur due to practical restrictions like
- i) Accuracy of measuring device
- ii) Residual path length error caused by transmission lines and circuit delays
- iii) Errors caused by multiple reflections
- iv) Transmitter leakage
- v) Frequency error due to turn-around of frequency modulation
- (i) Frequency Measuring Device Error:
- Cycle counter measures only integral cycles and not fraction of a cycle. This is called Quantization error.
- N = Average No. of cycles of f_r in one period of modulation cycle = $\frac{\text{Average } f_r}{f_m}$
- But $f_r = \frac{4 h f_m \Delta f}{C}$
- $\frac{f_r}{f_m} = N = \frac{4 h \Delta f}{C}$
- Therefore $h = \frac{C N}{4 \Delta f}$
- Since N is an integral number
- Quantization error $\delta R = \frac{C}{4 \Delta f}$
- $\delta R \text{ (mts)} = \frac{75}{\Delta f(\text{MHz})}$
- Quantization error is not a function of altitude or carrier frequency but depends on Δf (Frequency Excursion)
- So for quantization error (δR) to be low Δf should be large.

- **METHOD TO REDUCE QUANTIZATION ERROR :**
- δR is reduced by wobbling the modulation frequency or phase of transmission.
- The cycle counter reads the average of N and N+1 given by each cycle of modulation.
- Averaging reduces δR in cases of Normal fluctuations in altitude due to
- i) Uneven ground terrain
- ii) Waves on water
- iii) Turbulent air

- **OTHER CAUSES FOR MEASUREMENT ERRORS**
- Variation in Transmitter frequency
- Variation in Modulation frequency
- Variation in frequency excursion.
- Target motion
- Error in height = $v_r \; T_0$
- Where T_0 = observation Time and v_r = relative velocity
- v) Residual path errors due to delays in the circuitry and transmission time. This becomes significant percentage at low altitudes.

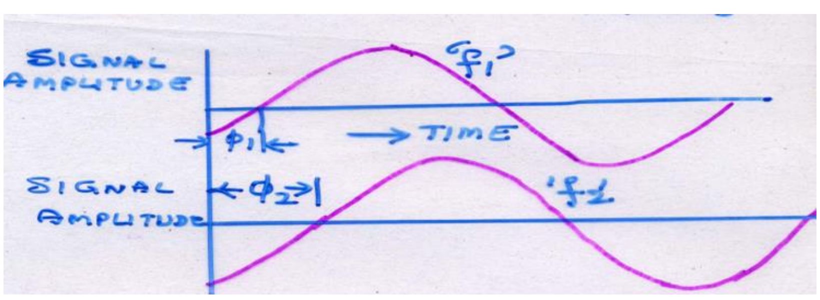
- **MULTI PATH ERROR**
- 

- **Wanted signal is shown by solid line**
- The unwanted Multipath Signals are
- (a) Reflection of transmitted signal at the antenna caused by impendence mismatch
- (b) Standing wave pattern on the cable feeding the reference signal to R_x , due to poor mismatch
- (c) Leakage signal entering R_x via coupling between T_x and R_x antennas
- (d) Interference due to power being reflected back to T_x causing a change in impedance. applicable at low altitudes.
- (e) Double bounce signal

- **VII) TRANSMITTER LEAKAGE:**
- Sensitivity is limited by the noise leaked into Rx from the Tx
- Techniques used to overcome are
- i) Use of separate antennas for Tx and Rx
- ii) Direct cancellation of leakage signal

- Q 17. **Derive an expression for unambiguous range of two frequency CW radar**
- Range is extended considerably by utilizing 2 separate CW signals differing slightly in frequency.
- Unambiguous range corresponds to $\lambda/2$ of Difference frequency

- Example : Difference in frequency = 1 KHZ
- $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{1 \times 10^3} = 3 \times 10^5 = 300$ Kms
- Unambiguous Range $= \frac{\lambda}{2} = \frac{300}{2} = 150\ Kms$
- V_1T and V_2T are the two transmitted sine waves with frequencies f_1 and f_2. separated by Δf.
- $V_1T = \sin(2\pi f_1 t + \emptyset_1)$
- $V_2T = \sin(2\pi f_2 t + \emptyset_2)$
- $\emptyset_1$ and $\emptyset_2$ are arbitrary constant phase angles.

- 

- Echoes of V_1T and V_2T changes due (i) Doppler fd (ii) Range computed from

- $\Delta\emptyset = \frac{4\pi R f}{c}$
- $V_1 R = \sin\left[2\pi(f_1 \pm f_{d1})t - \frac{4\pi f_1 R_0}{c}\right] - \emptyset_1$
- $V_2 R = \sin\left[2\pi(f_2 \pm f_{d2})t - \frac{4\pi f_2 R_0}{c}\right] - \emptyset_2$
- $f_2 = f_1 + \Delta f$ where $\Delta f = f_2 - f_1$
- Δf is a very small compared to f_1
- so $f_2 \approx f_1$
- $f_{d1} = f_{d2} = f_d$
- V_1T heterodyned with V1R
- V_2T heterodyned with V2R
- $\boxed{\sin A \cdot \sin B = \frac{\cos(A - B) - \cos(A + B)}{2}}$

- $V_1 D = \cos(\pm 2\pi f_d t - \frac{4\pi f_1 R_0}{C})$
- $V_2 D = \cos(\pm 2\pi f_d t - \frac{4\pi f_2 R_0}{C})$
- V_1 D and V_2 D applied to Phase Detector
- $\Delta\emptyset = \frac{4\pi R_0}{C}(f_2 - f_1) = \frac{4\pi R_0 \Delta f}{C}$
- $R_0 = \text{Range} = \frac{C \Delta\emptyset}{4\pi \Delta f}$
- (Note: For a single frequency f_1
- $R_0 = \text{Range} = \frac{C \Delta\emptyset}{4\pi f_1}$)
- Both equations above are same except that f_1 is replaced by Δf.
- **METHOD OF TRANSMISSION:**
- f_1 and f_2 are transmitted simultaneously

  OR
- f_1 and f_2 transmitted sequentially by rapidly switching RF sources
- Two frequencies CW radar is essentially a single target radar since only one phase difference is measured
- **MAXIMUM UNAMBIGUOUS RANGE :**
- $R_0 = \frac{C \Delta\emptyset}{4\pi \Delta f}$
- Maximum Unambiguous range (Runamb) occurs when $\Delta\emptyset = 2\pi$ Radians
- $R\ unamb = \frac{C\ 2\pi}{4\pi \Delta f} = \frac{C}{2\Delta f}$
- R unamb is large when Δf is small

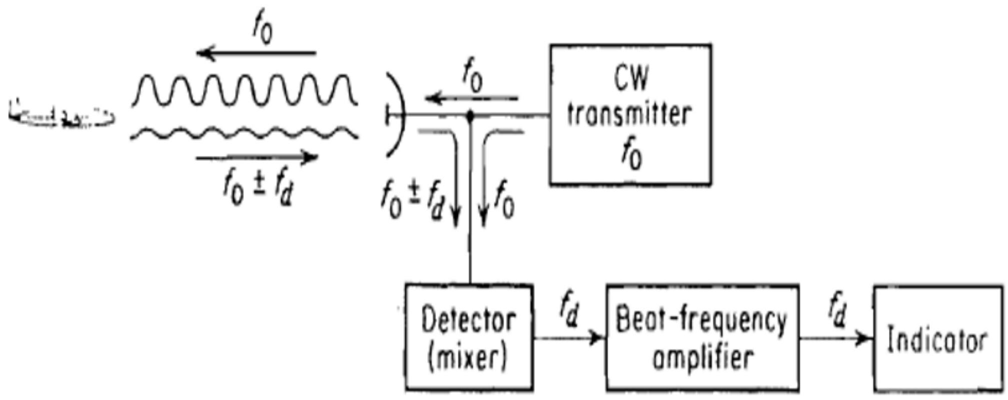
- Q 18. Explain the principle of Multi Frequency Radar
- **NECESSITY FOR MULTIPLE FREQUENCY CW RADAR**
- Theoretical RMS Range error (formula assumed)
- $\delta R = \frac{C}{4\pi \Delta f \left(\frac{2E}{N_0}\right)^{\frac{1}{2}}}$
- To get δR small , Δf should be large
- But from $R_{unamb} = \frac{C}{2\Delta f}$
- Δf should be small to get large R_{unamb}.
- For small range Error (δR) Δf should be large.
- For large unambiguous range (R_{unamb}) Δf should be small.
- This controversial requirement is solved by going to multiple - frequency Radar.
- One more frequency f_3 is transmitted in air along with f_1 and f_2.
- However $(f_3 - f_1) = \Delta f$ is made large to obtain high accuracy ie., small range error. This gives raise to less unambiguous range.
- $(f_2 - f_1) = \Delta f$ is made small to obtain large unambiguous range . This resolves the range ambiguity because of $(f_3 - f_1)$ being large.
- $(f_3 - f_1) = K\ (f_2 - f_1)$
- K lies between 10 to 20.

- Q 19. 1. Differentiate the operation of Pulsed Radar from simple CW Radar
  2. Explain how do you distinguish between CW Radar and Pulsed Radar
  3. What are the advantages and disadvantages for CW Radar
  4. Explain the limitations of CW Radar

CW Radar	Pulse Radar
1. A simple CW radar cannot measure range. (However with FM modulations , Range measurement is possible.)	**1. A Conventional pulse Radar cannot measure velocity of target. (However with Pulse Doppler/MTI Radars can measure velocity of target)**
2. Rx Bandwidth is low Hzs. (Difference between maximum & minimum f_d)	**2. Rx Bandwidth is in Mega Hzs (1/ Pulse width)**
3. Duty cycle is unity and hence peak power is less	**3. Duty cycle is low therefore peak power is high**
4. No High voltage modulator needed	**4. High voltage modulator needed to pulse the power tube. Electrical breakdown due to high voltage is a problem**
5. Transmitters are smaller in size and weight.	**5. Pulse T_x is 25 to 50 percent heavy compared to CW T_x**
6. FM CW Radars operate to almost zero range.	**6. Minimum Range depends on pulse width and duplexer recovery time.**
7. Permits clutter to be rejected since it works on Doppler principle.	**7. Conventional Pulse Radar cannot Reject clutter , (However Pulse Doppler/ MTI Radar can reject clutter)** 52
8. Tangent or crossing trajectories whose paths are perpendicular to Radar beam have zero relative velocities.	8. Conventional Pulse Radar measures r velocity. Pulse Doppler/MTI Radar which measures Range behave the same way as in the CW Radar.
9. Number of targets that can be resolved at one time depends on the number of Doppler filters.	9. If delay line canceller is used, there is no restrictions on number of targets as Delay Line Canceller is a time Domain Filter.
10. Practical limit to the maximum power employed; This depends on the amount of isolation and TX noise leaking into the R_x.	10. No such Limit , as the Duplexer switches off the Rx during transmission.
11. Used as (i) Police Radar (ii) Proximity fuze (iii) Altimeter (iv) Rate of Climb meter Etc.;	11. Used as (i) Surveillance Radar (ii) Airborne Radar

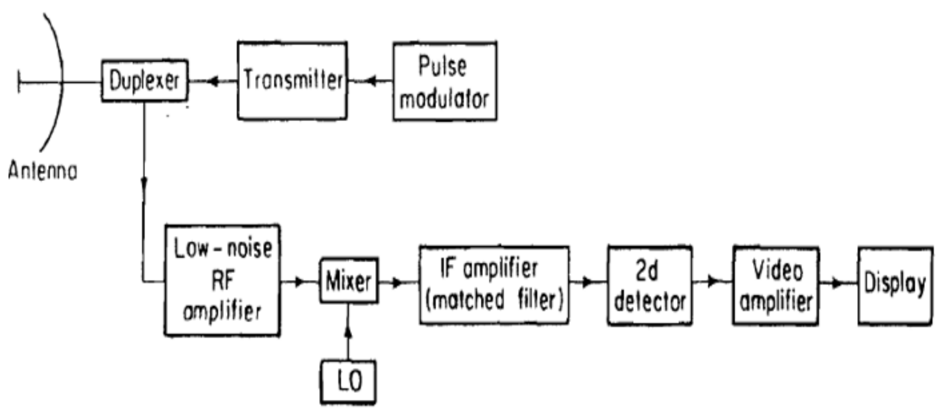
- Q 20. Distinguish the principle of operation of a simple pulse radar from a simple CW Radar. Explain the difference with neat schematic block diagram

- **CW Radar block diagram**



- For description of each block See earlier pages

- **Pulse Radar block diagram**



- For description of each block See earlier pages

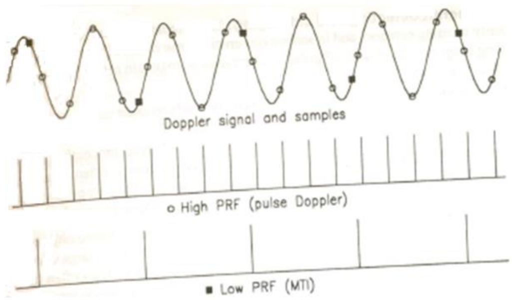
END OF UNIT 2

ANSWERS TO JNTUH EXAMINATION QUESTIONS
RADAR SYSTEMS
UNIT — THREE

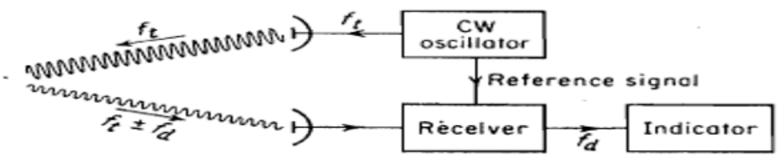
Q 1. Distinguish between MTI radar and Pulse doppler radar

- **MTI Radar :**
- Operates with ambiguous Doppler measurements (velocities) and blind speeds
- Range measurements are unambiguous (no second time around Echoes)
- $R_{unamb} = \frac{T_p\, C}{2}$
- PRF is low $f_P = (1 / T_p)$ ie Time between pulses large
- **Pulse Doppler Radar :**
- Operates with unambiguous Doppler measurements and no blind speeds
- Range measurement are ambiguous
- PRF is high ie. Time between pulses small

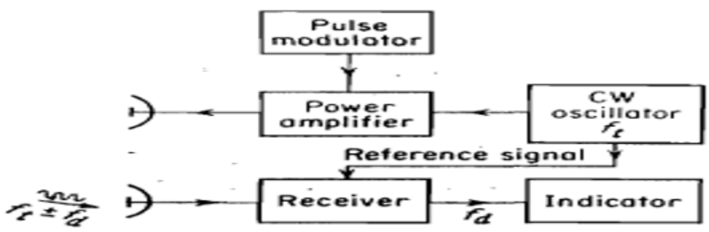
Pulse Doppler VS MTI



- Q 2. 1. How does a MTI/Pulse doppler radar differ from CW radar
  2. What is the principle of MTI radar
  3. With an MTI radar we can get the radial velocity as well as the distance of the moving target. Justify this



SIMPLE CW RADAR

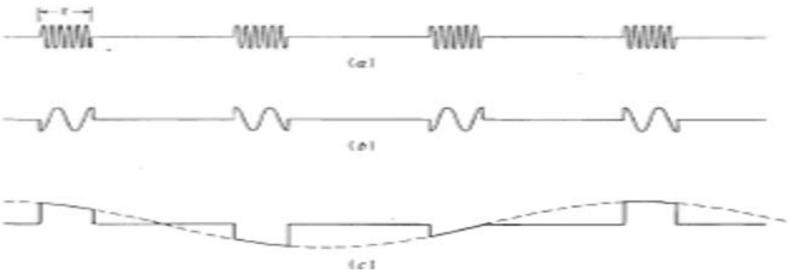


PULSE DOPPLER RADAR

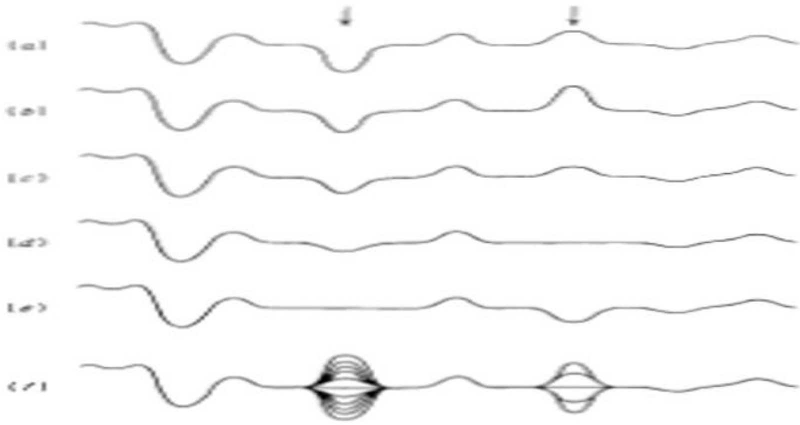
- **CONVERSION OF CW RADAR TO PULSE DOPPLER RADAR**
- Power amplifier and modulator are added to CW Radar.
- In Pulse Doppler Radar, a small portion of the CW oscillator power is diverted to R_X in place of local oscillator . This replaces the function of LO.
- This also acts as the coherent reference needed to detect the Doppler frequency shift.
- Coherency means that the phase of T_X signal is preserved as the reference signal
- $V_{osc} = A_1 \sin 2\pi f_t t$
- Reference Signal $V_{ref} = A_2 \sin 2\pi f_t t$
- Echo Signal = V_{echo}
- $= A_3 \sin \left[2\pi (f_t \pm f_d) t - \frac{4\pi f_t R_0}{c}\right]$
-
- where A_1, A_2, A_3 are peak amplitudes of Sine Wave.
- f_t = Transmitted Frequency
- f_d = Doppler frequency shift
- V_{echo} & V_{ref} are heterodyned.

- $\sin A \times \sin B = \frac{1}{2} [\cos (A - B) - \cos (A + B)]$
- $\cos (A - B) = \cos \left[2\pi f_t t + 2\pi f_d t - \frac{4\pi f_t R_0}{c} - 2\pi f_t t\right]$
- $= \cos \left[2\pi f_d t - \frac{4\pi f_t R_0}{c}\right]$
- $\cos (A + B) = \cos \left[4\pi f_t t + 2\pi f_d t - \frac{4\pi f_t R_0}{c}\right]$
- $= \cos \left[2\pi f_d t - \frac{4\pi f_t R_0}{c}\right]$
- Sum is filtered out by low pass filter
- Output of Mixer $V_d = A_d$
- $V_{diff} = A_d \sin \left[2\pi f_d t - \frac{4\pi f_t R_0}{c}\right]$
- V_{diff} has 2 components . Sine wave at Doppler frequency and the other is a phase shift which depends on the range of the target (R_o).
- For stationary targets R_0 is constant, $(fd = \frac{2 V_r}{\lambda})$, Doppler frequency shift $f_d = 0$ and so V_{diff} is constant.
- For moving targets, f_d has a value, V_{diff} will be a function of time.
- Doppler frequency can be determined by
- i) measuring the frequency with frequency counter
- ii) measuring the phase with Phase meter at PRF intervals since Frequency = Rate of change of phase $\frac{d\phi}{dt}$

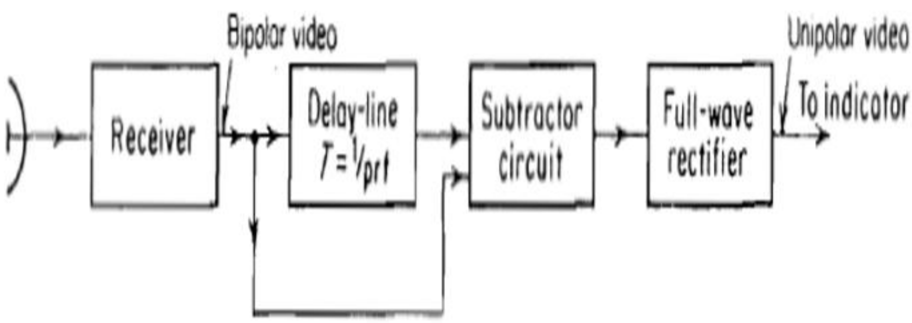
- Q 3. A) Explain the Butterfly effect that is produced by MTI
- B) Draw the different sweeps of MTI radar in a A scope display
- Depending upon f_d , 2 cases will arise (τ = Pulse Width).
- $f_d > 1/\tau \rightarrow f_d$ can be found quickly.
- $f_d < 1/\tau \rightarrow$ many pulses need to be sent to find f_d



- Moving targets can be distinguished from stationary targets by observing the video output on an A scope

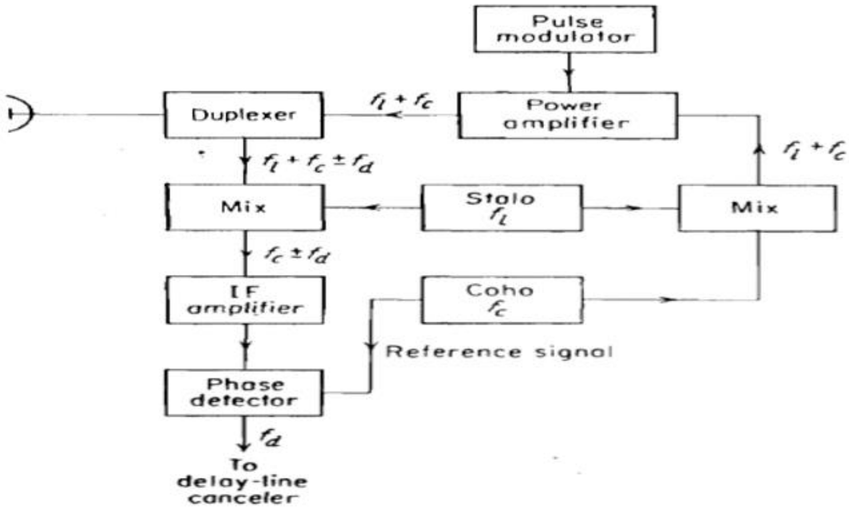


- Several successive sweeps are required to distinguish a moving target.
- Echoes (phases) from fixed targets remain constant throughout.
- Echoes (phases) from moving targets varies in magnitude from sweep to sweep.
- Rate of change of phases corresponds to Doppler frequency.
- Super position of successive sweeps is shown at the bottom trace.
- The moving targets are distinguishable by the Butterfly Effect on the A Scope.
- **MTI R_X WITH A DELAY LINE CANCELLER**
- Delay Line Canceller is employed.
- Butterfly effect is not suitable for PPI (Plan Position Indicator) Display. Z input (intensity of spot) of PPI requires only positive pulses. So full-wave rectifier is used.



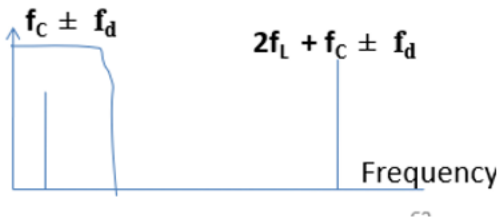
- Bipolar video is divided into 2 channels
- Normal video channel
- Delayed video channel. Time Delay is equal to one PRT (=PRI).
- Output from channels (i) and (ii) are subtracted
- Fixed Targets (clutter) do not change their phases. As such they are cancelled out.
- Moving targets change their phases . Subtraction results in an uncancelled residue.
- Bipolar video is converted to unipolar video by full wave rectifier and applied to PPI.

- Q 4. What is MOPA ? Write a technical note on it
- 2 types of T_x are possible i. Power Amplifier ii. Power Oscillator
- **MTI RADAR WITH POWER AMPLIFIER**

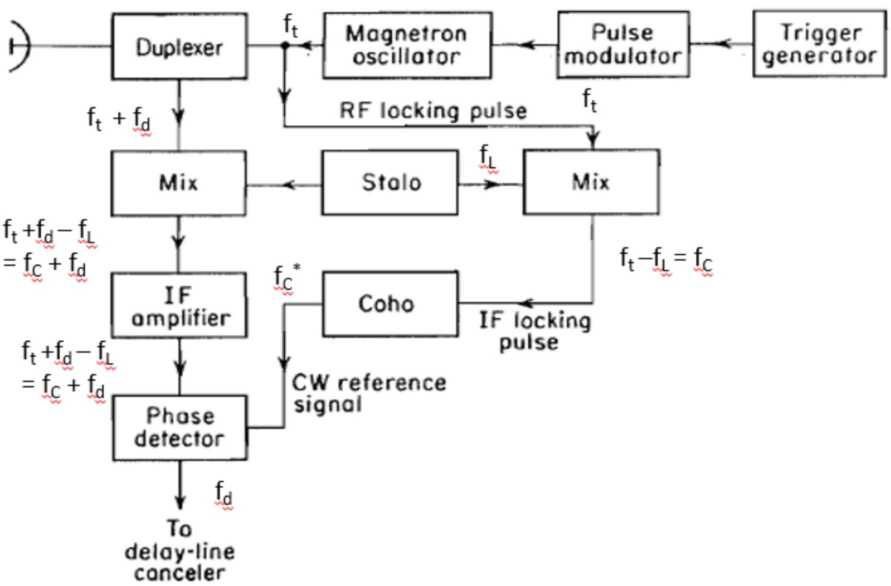


- Stable reference signal is required for comparing the phases of transmitted pulse and the Echo pulse.
- Coherent reference is supplied by the coherent oscillator (COHO).
- COHO is a stable oscillator and its frequency should be the IF frequency used in the R_x.
- COHO frequency f_C (usually 30 or 60 MHZ) is mixed with local oscillator frequency f_L (Example 1 GHZ, 2 GHZ,10 GHZ etc.)
- Local oscillator frequency also should be stable(STALO).
- The function of STALO is to provide the frequency translation from IF to T_x frequency. However the reference signal for comparison of phase is the COHO.
- Phase of STALO influences the phase of T_x signal but this shift does not matter, as the STALO is cancelled out in the Mixer.
- T_x Frequency = $f_L + f_C$.
- Echo frequency = $f_L + f_C \pm f_d$.
- 2nd mixer output (i) $2f_L + 2f_C \pm f_d$ (Sum)
- (ii) $2f_C \pm f_d$ (Difference).
- $2f_L + f_C \pm f_d$ suppressed by low pass filter.
- Inputs to phase detector are i) $f_C \pm f_d$ and ii) f_c .
- Output of phase detector is f_d

- **Types of Power Amplifiers available:**
- Triode
- Tetrode
- Klystron
- Travelling wave tube
- Crossed – field amplifier.
- The portion of Radar which has low-power source followed by the power amplifier is called **MOPA** chain (Master Oscillator Power Amplifier).



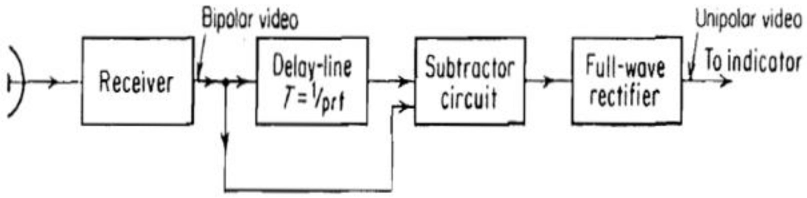
- **MTI RADAR WITH POWER OSCILLATOR**
- Magnetron which is a high power oscillator is used



- Magnetrons are ON/OFF devices.
- When Magnetron is pulsed, it starts up with a phase whose value is random from pulse to pulse. No coherence of phase is possible.
- COHO is used as a reference signal. However its phase is locked to magnetron using (phase lock loop) PLL. The phase of COHO is readjusted at the beginning of every transmitted pulse.
- A portion of T_x signal is mixed with STALO to produce IF signal. The phase of IF signal is directly related to phase of the transmitter.
- The IF signal and COHO signals are phase locked using phase lock loop.
- Now the phase of COHO is related to the phase of transmitted signal and forms as the reference signal (f_c).
- The reference signal forms as one of the inputs of the phase detection. The other input to phase detector is $f_c \pm f_d$

- The output of the phase detector is applied to Delay Line Canceller.

- Q 5.i) Explain in detail the filter characteristics of delay Line canceller
  ii)A simple MTI delay canceller is an example of time of domain filter. Why ? Explain
- DLC (Delay Line Canceller) rejects the DC component of Clutter
- Because of periodic nature, clutter appears at 0x PRF, 1 x PRF , 2 x PRF ,......n x PRF
- DLC rejects the clutter at not only at zero frequency (DC) but also at 1 PRF, 2PRF, ..n PRF
- The 2 Inputs to the subtractor are i) Current Echo ii) Previous Echo delayed by one PRT

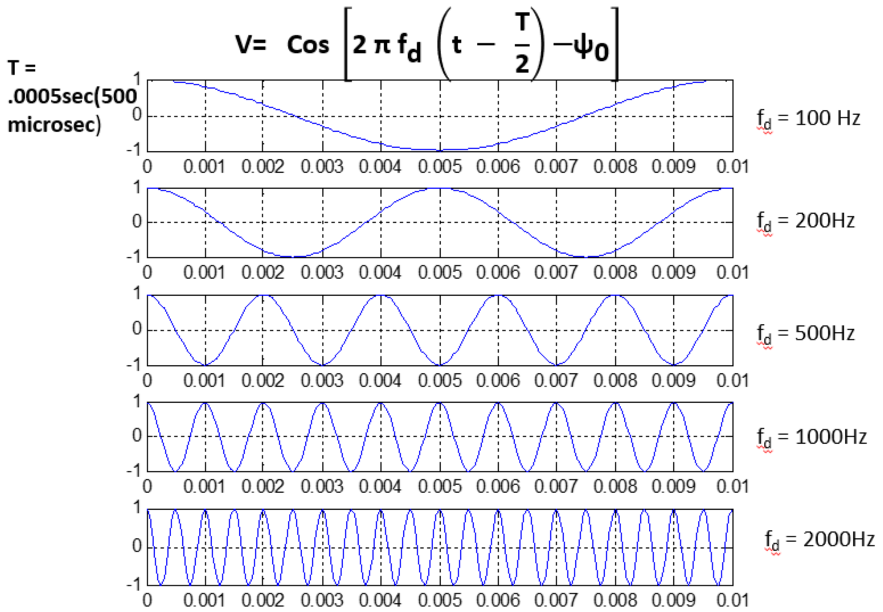


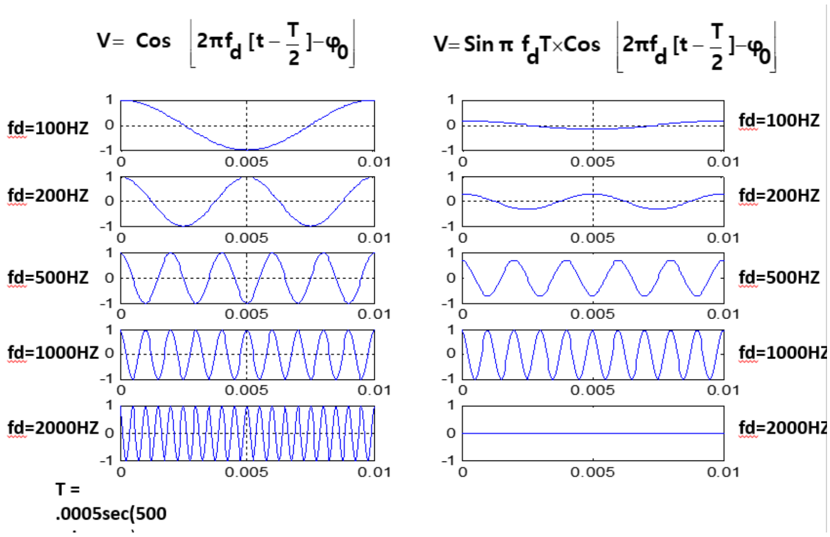
- Echo received from a particular target $= V_1$
- $V_1 = K \sin[2\pi f_d t - \phi_0] = K \sin A$
- $\phi_0 =$ Phase shift due to range R_0 $\phi_o = \frac{4\pi f_0 R_0}{c}$
- $K =$ Amplitude of the Video signal
- Echo from the previous transmission delayed by one PRT $= V_2$
- $V_2 = K \sin[2\pi f_d (t - T) - \phi_0] = K \sin B$
- $V = (V_1 - V_2) = K(\sin A - \sin B)$
- $V = K \sin\left(\frac{A-B}{2}\right) \times \cos\left(\frac{A+B}{2}\right)$
- $V_1 = K \sin[2\pi f_d t - \phi_0] = K \sin A$
- $V_2 = K \sin[2\pi f_d (t - T) - \phi_0] = K \sin B$
- $\sin\left[\frac{A-B}{2}\right]$
- $= \sin\left[\frac{2\pi f_d t - \phi_0 - 2\pi f_d t + 2\pi f_d T + \phi_0}{2}\right]$

  $= \sin \pi f_d T$
- $V_1 = K \sin[2\pi f_d t - \phi_0] = K \sin A$
- $V_2 = K \sin[2\pi f_d (t - T) - \phi_0] = K \sin B$
- $\cos\left[\frac{A+B}{2}\right]$
- $= \cos\left[\frac{2\pi f_d t - \phi_0 + 2\pi f_d t - 2\pi f_d t - \phi_0}{2}\right]$
- $\cos[2\pi f_d t - \pi f_d t - \phi_0]$
- $\cos\left[2\pi f_d \left(t - \frac{T}{2}\right) - \phi_0\right]$
- Since
- $V = K\, 2 \sin\left[\frac{A-B}{2}\right] \times \cos\left[\frac{A+B}{2}\right]$

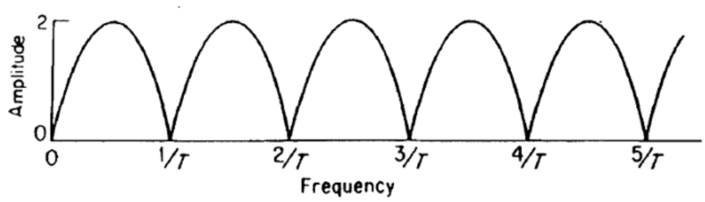
- $V=[2\ K\ \text{Sin}\ \pi\ f_d\ T] \times \text{Cos}\left[2\ \pi f_d\left(t - \frac{T}{2}\right) - \phi_0\right]$
- Above is a Cosine function like $\{A_{max}\ \text{Cos}\ (2\ \pi\ f\ t)\}$ varying with time 't'
- Its peak amplitude A_{max} is $2K\ \text{Sin}\ \pi\ f_d\ T$
- For a fixed values of f_d and T peak amplitude of Cosine wave is $2K\ \text{Sin}\ \pi\ f_d\ T$ is fixed
- So $2K\ \text{Sin}\ \pi\ f_d\ T$ is the characteristics of DLC. It is a Sine function whose value depends on f_d and T

- Q 6. Draw the output waveforms from mixer for the different range of doppler frequencies





- **FILTER CHARACTERISTICS OF DLC**
- Frequency Response is the filter characteristic of DLC
- $2K\ \text{Sin}\ \pi\ f_d\ T$ varies as per f_d and is shown in the figure below. $\text{Sin}\ \pi\ f_d\ T$ will have only positive values since the angle does not extend beyond π
- **FREQUENCY RESPONSE OF SINGLE DLC**



- **Q 6. What are Blind Speeds? Explain**
- **Blind Speeds:**
- i) Output of DLC is a Cosine function whose amplitude is varying with time
- Ii) Peak value of cosine function $A_{max} = 2K \sin \pi f_d T$
- The value of $\sin \pi f_d T$ (response of DLC) is zero when $\pi f_d T$ is $0 , \pi , 2\pi$, ...etc.
- $\pi f_d T = n \pi$
- $f_d = \frac{n}{T} = nf_p$ where f_p = PRF

  n= integer number
- This means the amplitude of cosine function $\text{Cos}\left[2 \pi f_d \left(t - \frac{T}{2}\right) - \phi_0\right]$ is zero whenever
- $f_d = \frac{n}{T}$
- When $f_d = f_p$ (ie $f_d = \frac{2 V_r}{\lambda}$ ie $V_r = \frac{f_p \lambda}{2}$) the following happens
- $\text{Sin } \pi f_d T = \text{Sin } \frac{\pi f_d}{f_p} = 0$
- Peak Amplitude of cosine function
- $\text{Cos}\left[2 \pi f_d \left(t - \frac{T}{2}\right) - \phi_0\right] = 0$
- So DLC output = 0. The output disappears.
- Velocity V_r under this condition is called **Blind speed.**
- Same happens when n = 2,3,4,... etc. since
- $\sin \pi = \sin 2\pi = \sin 3\pi \ldots\ldots = 0$
- DLC eliminates DC component caused by clutter
- But it fails to record the moving target whose $f_d = f_p$ or $f_d = nf_p$ (multiple of f_p)
- $f_d = \frac{2 V_r}{\lambda}$ therefore $V_r = \frac{\lambda f_d}{2}$
- The relative target velocities which results in zero DLC response are called blind speeds.
- Blind speeds are those speed of targets which give no output from DLC.
- Targets at these speeds fail to be detected or recorded.

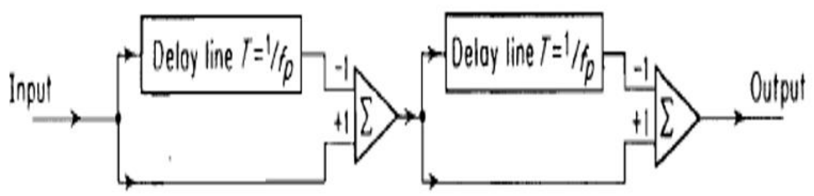
.

- So first blind speed $= \frac{\lambda f_p}{2}$
- Second blind speed $= \frac{2 \lambda f_p}{2}$
- n th blind speed $= \frac{n \lambda f_p}{2}$

- Blind speeds are the limitations of MTI Radar.
- Blind speeds do not occur in CW Radar.
- They occur in MTI because Doppler is measured by discrete samples (pulses) at PRF rather than continuously.
- IF first Blind Speed is required to be large
- $V_r = \frac{\lambda \ f_p}{2}$
- $\lambda \ f_p$ must be large.
- λ large means , operating radar frequency small
- $\lambda = \frac{c}{f}$
- Low frequency radar for a given Antenna size will have a large Beam width and therefore less angular accuracy.
- f_p large means Maximum unambiguous Range is less $R_{unamb} = \frac{C}{2 \ f_p}$

- Q 7. What is the difference between simple cancellation and double in a delay line canceller?

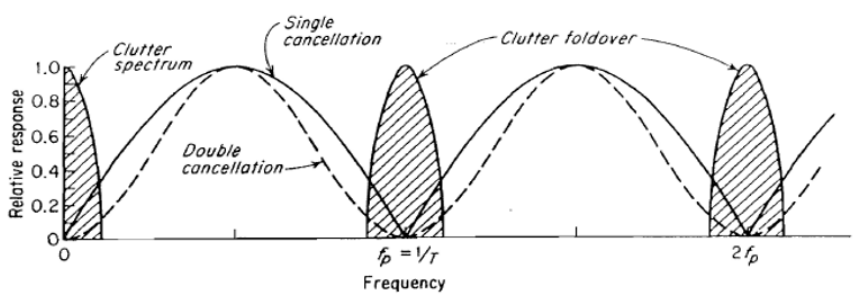
- **Double Delay Line Canceller (2 DLC in Cascade)**



- Output = $f(t) - f(t + T) - f(t + T) + f(t + 2T)$
- $= f(t) - 2 f(t + T) + f(t + 2T)$

- Q 8. Show that the percentage of clutter rejection is better in case of double cancellation as compared to single cancellation

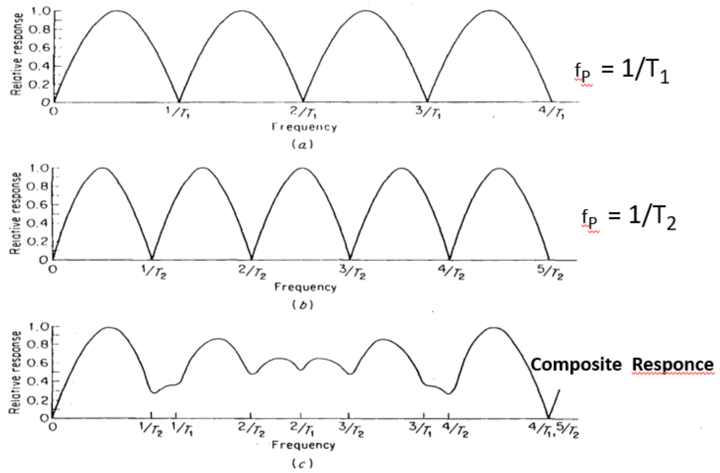
- More clutter noise attenuated by using a Double Delay Line canceller.



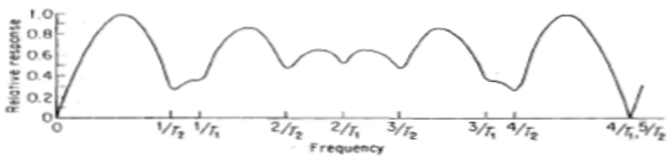
- Q 9. 1. Explain how the effect of blind speed reduced by operating at more than one PRF
  2. What is staggered PRF ? Where and why is it used in a radar system
  3. Explain the operation of a MTI radar with 2 PRFs

- Use of more than 1 PRF increases the value of First Blind speed. It also has a sharper low-frequency cutoff.
- Two PRFs on a single Radar, will not have the same blind speeds. The PRFs are switched every scan or every half beam width or every alternate pulse width.
- When switching from pulse to pulse, it is known as Staggered PRF.

- **STAGGERED PRF**

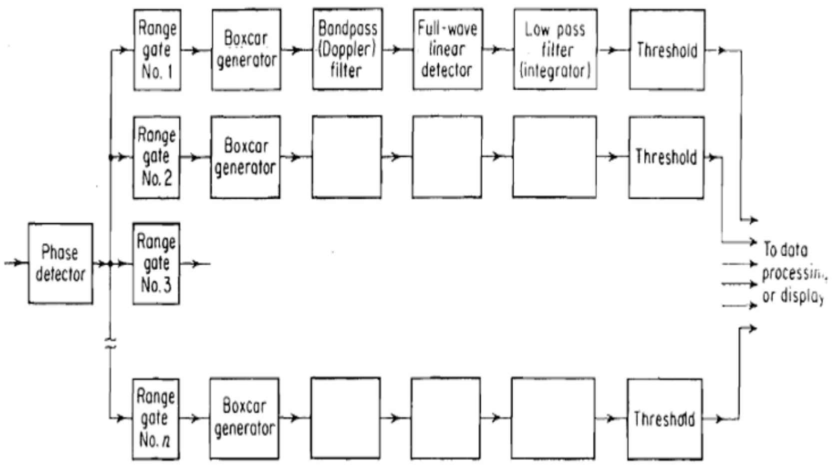


- The PRFs are in the ratio 5:4
- The first blind speed of composite response is increased several times over the blind speed of single PRF
- The blind speeds are coincident for $\frac{4}{T_1} = \frac{5}{T_1}$

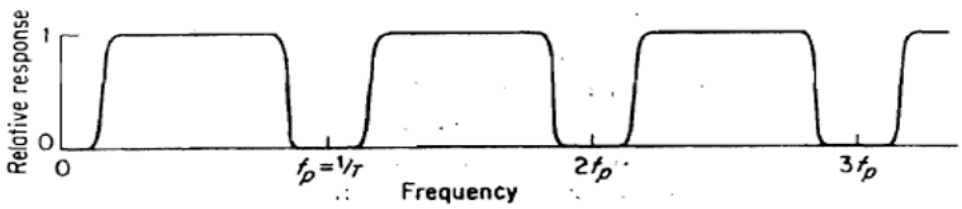


- Q 10. 1. Draw the block diagram of Range- gated doppler filters and explain
  2. Draw and explain the frequency response characteristics of a MTI using gates and filters

- **RANGE GATED DOPPLER FILTERS:**
- Pulse interval time is divided into small intervals.
- Interval time corresponds to Range resolution.
- Minimum interval is equal to Pulse width.
- This is called Range Gating. Range Resolution is established by gating. Shape of pulse need not be preserved. Noise from the other range intervals is excluded.
-



- Output for a stationary target is a series of constant Amplitude pulses from the phase detector
- Output for moving target is a series of varying amplitude pulses according to Doppler frequency.
- Output from phase detector is passed sequentially through the range gates. Each range gate is switched in sequence at proper time for the duration of the sample.
- Output of each range gate is stretched in a Sample-and-hold circuit (Box car). This aids in eliminating harmonics of PRF.
- **Band pass filter :**
- This is also called clutter rejection filter. The bandwidth is designed to conform to the clutter conditions.

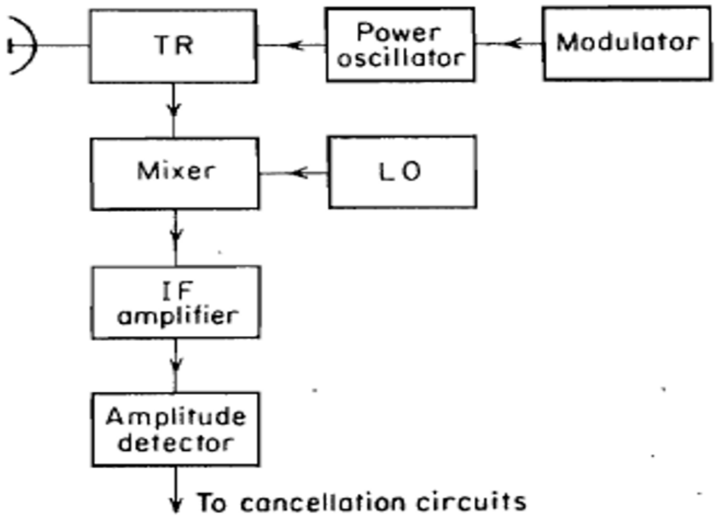


- The lower cutoff can be adjusted by an operator to reject the unwanted spectrum from birds.
- Width of the notch is controlled manually to suit local conditions.
- **Full Wave linear detector:**
- Converts the Bipolar video into unipolar video
- **Low Pass Filter:**
- Integrates the video.
- **Threshold:**
- Allows those signals which cross the threshold are reported as targets.
- Outputs from each of the Range cells are combined for display on the PPI or 'A' scope.

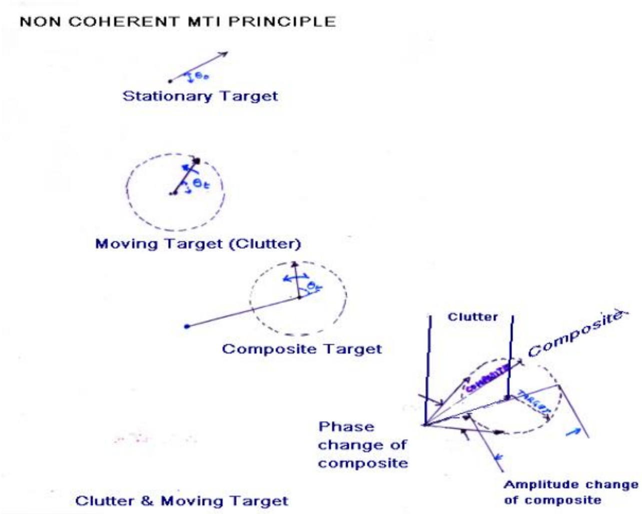
- Q 11. Draw the block diagram of Non-coherent MTI radar and explain the function of each block in detail

- **Echo consists of**
- Signal from moving target.
- Clutter (stationary target).
- **Echo fluctuates in**
- i. Phase and ii. Amplitude

- COHERENT MTI Uses PHASE Fluctuations. Phase Detector removes Amplitude fluctuations. Reference signal is locked to transmitted signal
- Non coherent MTI uses Amplitude fluctuations. This does not require internal reference as such no Phase Detector is used.
- In this case Amplitude limiting should not be used . IF Amplifier should be linear. For large Dynamic range, logarithmic IF amplifier is used. L.O. frequency need not be stable.
- As such complexity & cost of Noncoherent MTI is less.
- Output of IF Amplifier is given to an Envelope detector.
- Envelope detector is followed by DLC.
- Amplitude fluctuations due to Doppler produce Butterfly modulation. They ride on clutter.
-



-



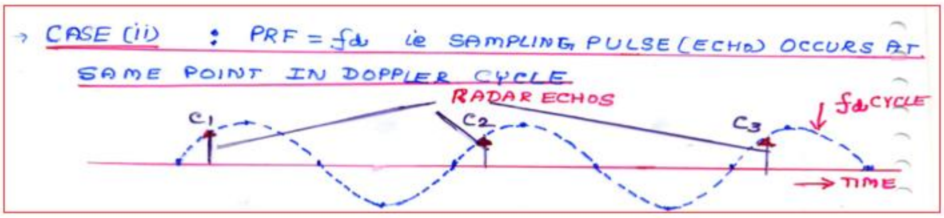
-
- Q 12. Give the advantages of Non-coherent MTI radar

- **ADVANTAGE OF NONCOHERENT MTI:**
- Simple, less expensive(stable LO not needed)
- Preferred for Airborne applications where space and weight are limited.
- **CHIEF LIMITATIONS:**
- Moving target can be detected only when there is large clutter.

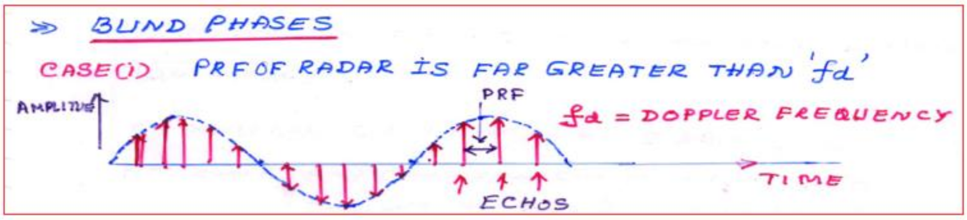
- But clutter may be present at sufficient level throughout the range cells. If clutter not present Doppler cannot be detected. Noncoherent Radar fails here.
- Improvement factor poor compared to coherent MTI since clutter not that stable as reference oscillator of coherent MTI.

- Q 13. Differentiate Blind phases from Blind speeds

- When PRF < 2 f_d Ambiguity occurs.
- When PRF = 1 f_d Blind Speed occurs.



- When PRF > 2f_d (No Ambiguity occurs, But blind Phases likely to occur)

- 

- When Phase between Doppler signal and sampling PRF results in loss, it is called Blind Phase.
- Blind Speed and Blind Phase are totally different.

END OF UNIT 3

ANSWERS TO JNTUH EXAMINATION QUESTIONS
RADAR SYSTEMS
UNIT — FOUR

- **Q 1. Briefly explain the various tracking techniques of radar**
- Tracking Radar provide the following data accurately
- (i) Azimuth Angle
- (ii) Elevation Angle
- (iii) Range
- (iv) Doppler Velocity
- The first three parameters are the 3 dimensional coordinates for the target.
- The three types of methods used for improving the accuracy of angle tracking are:
- A) Sequential lobing.
- B) Conical scanning.
- C) Monopulse Tracking a) Amplitude comparison
- b) Phase comparison
- Tracking is associated with a mechanical servo pedestal, which steers the antenna in the direction of the target until servo error becomes zero.
- So the angular servo error has both magnitude and direction and it is the electrical equivalent to the physical difference between target direction and a reference direction.

- Q 2. Distinguish between Search radar and Tracking radar

SEARCH RADAR	TRACKING RADAR
1. Long Range surveillance. Detects targets Hundreds of Kms away.	1. Tracks targets at medium ranges and mainly used during military operations
2. Determines parameters in 2 Dimensions Ex: (i) Range (ii) Azimuth Angle	2. Determines parameters in 3 Dimensions Ex: (i) Range (ii) Azimuth Angle (iii) Elevation Angle
3. Accuracy of parameters moderate	3. Accuracy of parameters is very high

SEARCH RADAR	TRACKING RADAR
4. Uses a mechanically rotating antenna. The antenna beam scans the Azimuth 360^0 at a fixed rpm. In modern times Electronically scanned phased Array antenna is used	4. In case of single target ,servo system mechanically steers the antenna in the direction of target. In case of multiple targets an Electrically scanning beam is generated using a Phased Array Antenna
5. During the scan, Echoes are received only for a short period when the antenna looks in the direction of target.	5. Echoes are continuously received at the rate of PRI. All 3 co-ordinates are available continuously.

•

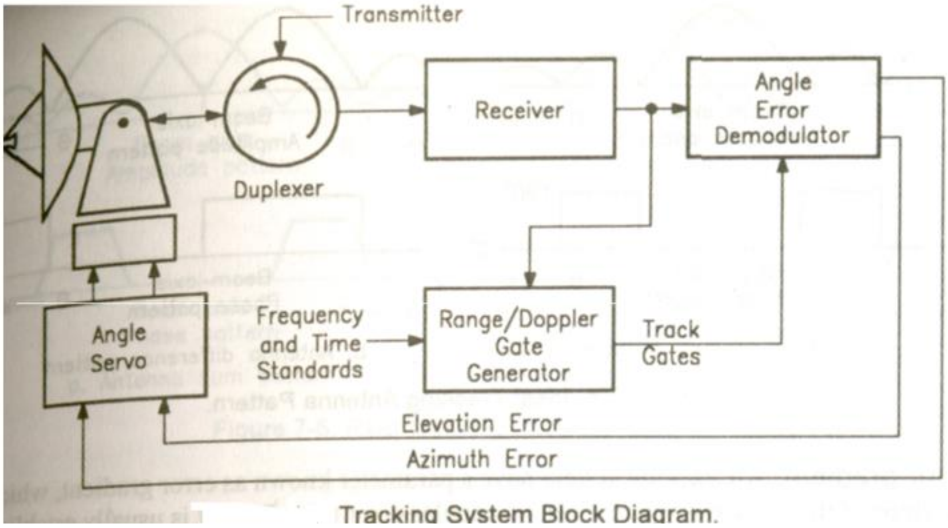
SEARCH RADAR	TRACKING RADAR
6. For obtaining the coordinates in between scans when antenna is not looking in the direction of target, TWS(Track While Scan) method is used. Based on previous coordinates future positions are extrapolated by using prediction filters like Kalman Filter	6. The Radar Antenna continuously follows the target and looks in the direction of target . Coordinates of target are continuously available
7. Coordinates of multiple targets in 2 Dimensions possible using TWS method	7. 3 Dimensional tracking of single target possible. Using Phased Array multiple targets tracking is possible.

SEARCH RADAR	TRACKING RADAR
8. Radar operates independently	8. Radar is used in conjunction with a Acquisition Radar. Initial coordinates are required before tracking.
9. Uses a single Fan beam in scanning.	9. Uses 2 pencil beams one in azimuth & other in elevation.
10. Comparatively less complex and less expensive.	10 Complex, Costly.
11.Used for civilian & military purposes.	11. Usually used for military purposes.

- Q 3. Explain the tracking principle
- Tracking is the process where the radar antenna follows the target in space (Azimuth ϴ, Elevation Ø).
- Tracking radars dwell on individual targets and follow their motion in Azimuth, Elevation where as Range tracking is done Electronically,

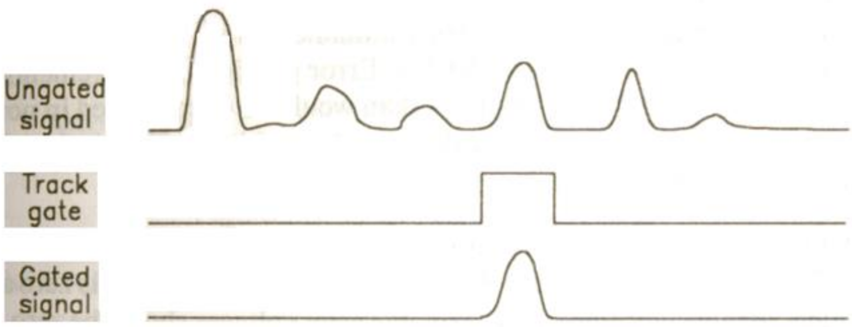
- Most tracking radars follow a single target.
- A few modern radars can track multiple targets simultaneously. These are called Phased Array Radars which electronically steer the beam and move the position of beam instantaneously from one target to another.

- **BLOCK DIAGRAM OF A TRACKING SYSTEM**



Tracking System Block Diagram.

- **SINGLE TARGET TRACKING:**
- Target of interest is selected by gating. This also improves S/N as noise in other range cells is stopped by gating

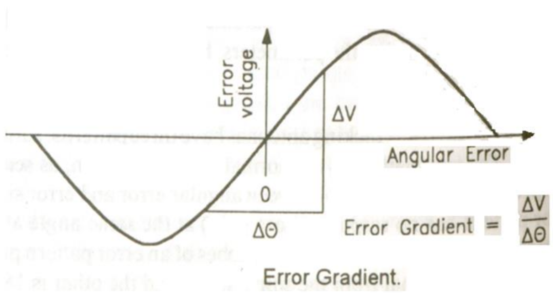


- Q 4. 1. What factors determine the range and angular accuracies in a radar

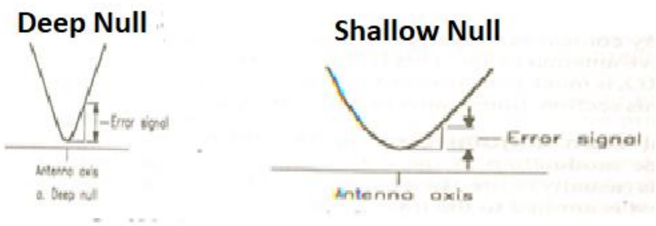
  OR

  2. Explain in detail about limitations to tracking accuracy

- **FACTORS THAT DETERMINE THE ACCURACY OF TRACKING:**
- (i) Error gradient (ii) Depth of Null
- The above two factors mainly determine the tracking system's ability to convert angular tracking errors into signals which can be applied to servos to move the antenna beam to the location of the target.
- They apply to (i) Angle tracking (servo) (ii) Range Tracking (electronic). and (iii) Doppler Tracking (electronic)
- **ERROR GRADIENT:**
- Servo error voltage Vs Angular error (Volts/Degree)

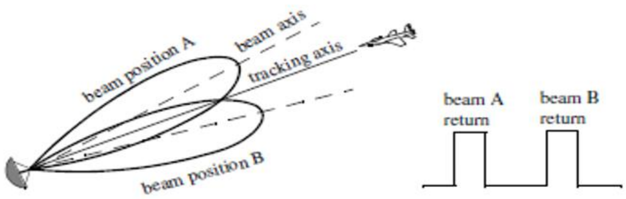


- **DEPTH OF NULL:** At zero track angular error, the error voltage should be zero. At this point abrupt change of error polarity takes place from zero to plus or minus.
- If Null is deep and has more gradient (slope) accuracy improves as per Control theory



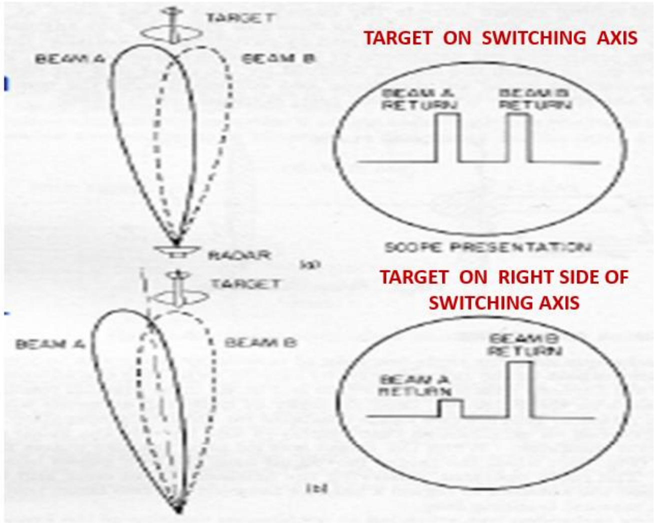
- Q 5. Explain about Sequential lobe tracking

- The antenna beam is switched between 2 positions
- Symmetrical pencil beam is used
- Tilting the beam is obtained by offsetting the feed or the sub reflector

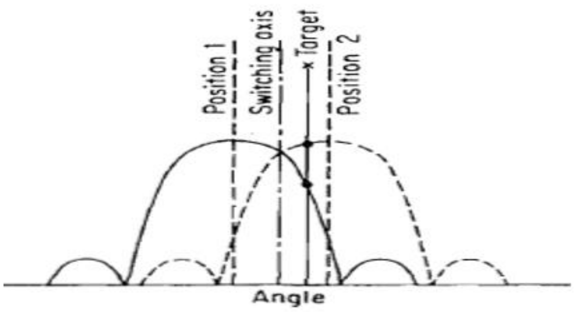


- Sequential lobing is also called **Lobe Switching** or **Sequential Switching**.
- The radar beam is switched between 2 positions in order to gain improved angular information.
- If the target is in the center of the 2 beams (i.e. on switching axis), signals of equal strengths will be observed in each beam.
- If the target is on left or right of LOS, the signal strengths are different.
- The sign of the difference determines the direction in which the antenna is required to be moved and the magnitude gives the amount of error to the servo

POLAR REPRESENTATION



RECTANGULAR REPRESENTATION



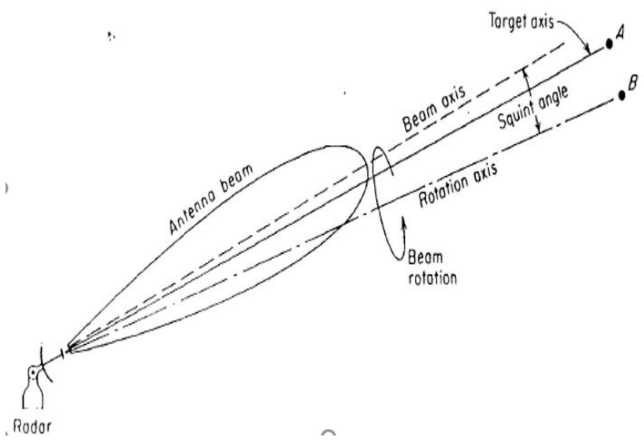
- 2 switching positions are used for Azimuth (Right & Left) and 2 more switching positions used for Elevation (Up & Down).
- The 2 dimensional Sequential lobing radar consists of a cluster of 4 feed horns illuminating a single target. Right- left, Up-down sectors are covered by these 4 horns
- A cluster of 5 feeds also can be used . The central feed is used for transmission and the rest 4 for receiving
- The angular accuracy obtained by this method will be far better than the beam width of a single beam

- **ADVANTAGES:**
- i) Uses only one Receiver in switching mode
- ii) Simple, less complex, less expensive, less weight. So ideally suitable for air borne
- applications
- iii) Beacon tracking can be implemented without Transmitter & without range gating
- **LIMITATIONS:**
- i) System noise caused by electrical and mechanical fluctuations limit the Accuracy of tracking
- ii) 4 pulses are required to resolve target in 2 dimensions. Time taken is more. So Bandwidth is reduced.

- iii) Fluctuations in signal level from pulse to pulse reduce tracking accuracy. Fluctuations occur because of (a) Target RCS fluctuations b) Modulation due to propeller wings etc.
- iv) Antenna gain is reduced on tracking axis due to squint. This limits the operational range .
- v) Servo tracking error limits the accuracy of tracking.

- Q 6. With a block diagram sketch explain Conical scanning method of tracking an acquired target. How is this an improvement over lobe switching?

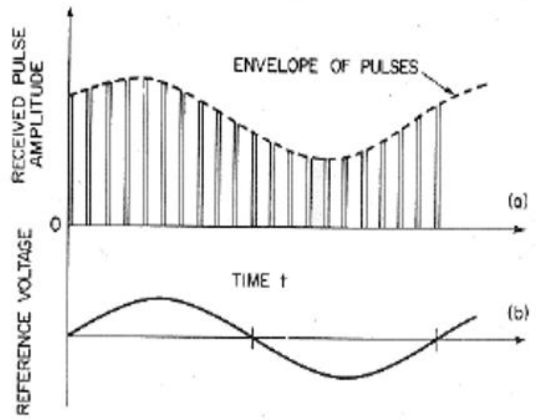
- **PRINCIPLE**
- Logical extension to switched lobing is the simultaneous lobing.
- The beam is rotated continuously instead of discontinuously connecting the Receiver to 4 feeds, put in 4 discrete positions (right-left , up-down)
- This method is known as Conical Scan.
- There are 3 Axes (i) Beam Axis (ii) Rotating Axis (iii) Target Axis
- **BEAM AXIS:** Line joining the center of antenna to the highest gain point on the beam (Lobe axis)
- **ROTATION AXIS:** Antenna rotated circularly along this axis. (Tracking axis) Beam Axis is offset from the Rotation axis by a squint angle. The angle between Beam axis and the Rotation axis is called Squint angle
- **TARGET AXIS:** Line joining the center of the antenna to the position of target
- **ORIENTATION OF THE AXES**



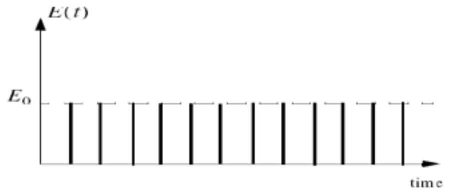
SQUINT ANGLE: Angle between Rotation Axis and the Beam Axis

- Purpose of conical scan technique is to bring Rotation axis on to the Target Axis, i.e. make Rotation Axis coincides with Target Axis.
- Consider a target at position A on Target Axis.
- Echo signal from target at 'A' is modulated by the rotation of the beam through Rotation Axis.
- The modulated frequency of echo signal is same as the rotation frequency of the beam.
- **CONICAL SCAN MODULATION**
- The amplitude of the echo-signal modulation will depend on (i) Shape of antenna pattern (ii) squint angle (iii) Angle between Rotation axis and Target Axis.
- The phase depends on the position (right- left and up-down) of target axis with respect to the rotation axis

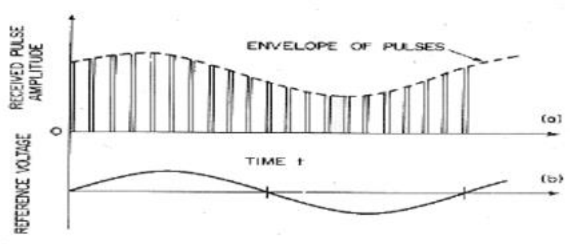
- The echo-signal modulation is called the **Conical scan modulation.**



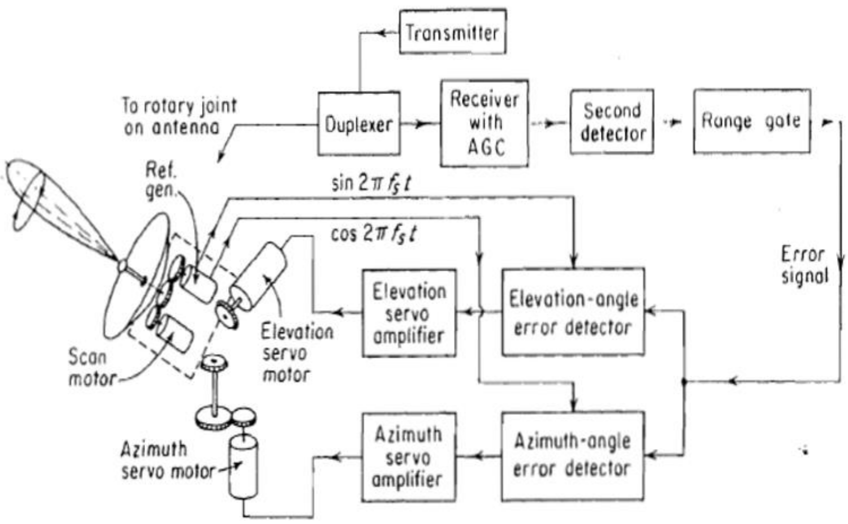
- The error in azimuth and elevation planes are extracted from the echo-signal modulation.
- The errors are applied to 2 separate servo controlled pedestals containing the antenna.
- The servo rotate the antenna configuration and bring position 'B' to 'A' (See above figure)
- The rotation Axis is made to coincide with target Axis.
- **TARGET ON ROTATION AXIS:** Zero modulation (zero error)



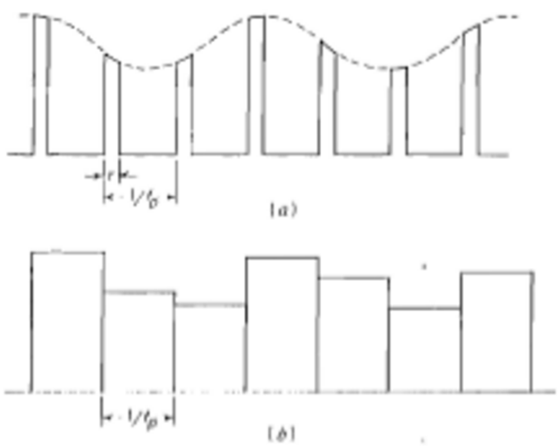
- **TARGET AWAY FROM ROTATION AXIS**



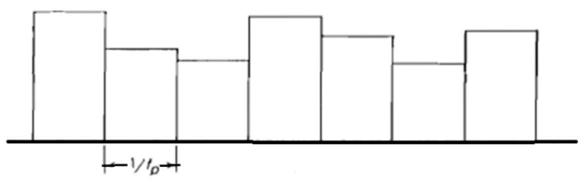
- When target and rotation axis do not coincide, the echo pulses will be modulated.
- This magnitude (depth) of modulation depends on the angle error between target axis and rotation axis.
- The modulation envelope contain the azimuth error and elevation error. This is extracted by using the reference given by the scanning motor.



- Rx is a conventional super-heterodyne type.
- Rx is followed by an Angle error Detectors (one for Azimuth and another for Elevation)
- The envelope of the scan modulation is the video signal obtained from the output of second detector.
- Range Gate selects the particular target chosen for tracking. This reduces noise
- Scan modulation has both Azimuth & Elevation Errors in its video envelope.
- Scanned modulation signal is compared with azimuth & elevation reference signals in a Phase sensitive Detector (PSD).
- PSD extracts the azimuth and elevation error signals.
- The magnitude of the DC error signal is proportional to the angular difference between target axis and rotation axis. The polarity (positive or Negative) gives the indication whether the target axis is to the right or left of the rotation axis in case of azimuth and up or down in case of elevation.
- The angle errors are amplified and applied to the servo systems(one in Azimuth and one in Elevation).
- The accurate position of the target is obtained by measuring the values of angle transducers mounted on the pedestal (like synchros, potentiometers, angle encoders etc)

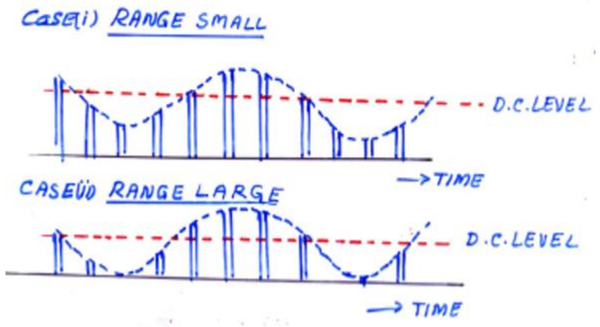


-
  - **BOX-CAR GENERATOR:**
  - Before extracting modulation of the train of narrow echo pulses, it is stretched (sample & Hold) before low pass filtering.

- 

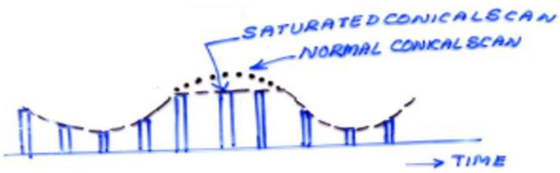
➤ **BOX CAR CIRCUIT:**

- Box-Car eliminates the Pulse repetition frequency and reduces its harmonics.
- Pulse stretching done by the Box car. It puts more energy between pulses and this amounts to amplification and result in increase of S/N ratio
- To satisfy the Nyquist criterion the PRF should be sufficiently more than the conical scan frequency (>2 scanning frequency)
- **AUTOMATIC GAIN CONTROL (AGC):**
- The amplitude of Echo varies because of Target is moving in range
- (Echo signal $\propto \frac{1}{R^4}$)
- Conical scan modulation (used for error extraction) of error signal
- Amplitude fluctuations in RCS.
- Function of AGC is to increase or decrease the gain of the Rx automatically, such that the D.C level output is maintained constant without disturbing the Conical scan modulation at Sl.no.2 above
- **WHAT HAPPENS WHEN AGC NOT THERE**
- **(I) TARGET MOVING IN RANGE:**
- Amplitude of echo signal vary with range.
- $P_r = \frac{(P_t \ G \ A_e \ \sigma)}{(4\pi)^2} \times \frac{1}{R^4}$
- Echo power varies in inverse proportion to R^4
- Though the physical angular error is same, the DC level (servo error) is different. AGC acts to overcome this variation



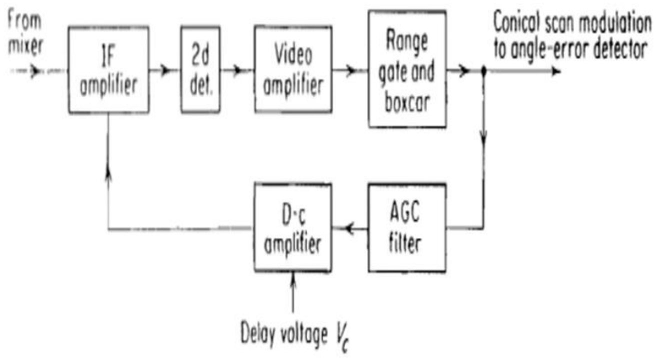
- Though the physical angular error is same, the DC level (servo error) is different. AGC acts to overcome this variation

(ii) Conical Scan Modulation:



- aIf output video saturates, modulation envelop is lost. Error extraction becomes faulty.
- **FUNCTIONS OF AGC:**
- Remove variations in DC voltage due to Conical modulation
- Remove variations in DC voltage because of inverse fourth power relationship.
- Prevent saturation because of large echo power
- If saturation is not prevented Conical modulation is lost, thereby error extraction not possible.

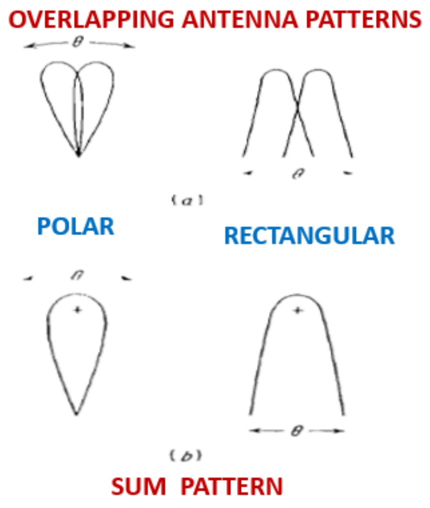
- Q 7. Explain the block diagram of AGC portion of tracking radar receiver
- **FUNCTIONS OF AGC FILTER:**
- Pass all frequencies from DC to just below Conical scan modulation frequency.
- Blocks Conical modulation.
- Should not introduce excessive phase shift (10^0 maximum). Beyond this cross talk occurs.
- **CROSS TALK**: Azimuth & elevation planes are independent. But due to cross-talk variation in one plane affect the other.
- iv. For weak signals loop gain is high and for strong signals, loop gain is less
- i) Pass all frequencies from DC to just below Conical scan modulation frequency.
- ii)Blocks Conical modulation.
- iii) Should not introduce excessive phase shift (10^0 maximum). Beyond this cross talk occurs.
- **CROSS TALK**: Azimuth & elevation planes are independent. But due to cross-talk variation in one plane affect the other.
- iv. For weak signals loop gain is high and for strong signals, loop gain is less
-

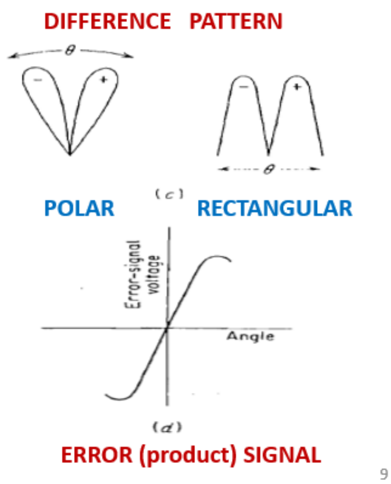


- The video envelope obtained from range gate and Boxcar is fed to a low pass (smoothening) filter.
- The DC output of filter is amplified in a D.C Amplifier.
- The Amplifier output is used to control the gain of IF Amplifier.
- If the video o/p voltage is high, the IF Amplifier gain is reduced, if it is less gain is increased. This keeps the amplitude of error signal constant.
- The filter should not disturb the conical scan modulation frequency which contains the error. The filter should pass all frequencies from DC to just below the scan modulation.

- Q 8, What are the advantages of mono-pulse radar over the conical scan radar

- **ADVANTAGE OF MONO-PULSE OVER CONICAL SCANNING & SEQUENTIAL LOBING**
- Conical scan and sequential lobing require a minimum number of pulses to extract angular error.
- Ideally the train of echo pulses must not contain any amplitude modulation other than the scanning modulation.
- But in reality due to fluctuation in RCS of the target, the echo pulse train contains additional modulation which may be near to the conical frequency.
- This degrades the tracking accuracy in case of conical scan and sequential lobing.
- The tracking accuracy will be superior if the extraction of error is done based on a single pulse instead of a number of pulses.
- Mono pulse (means single pulse) method of tracking computes error based on a single pulse. As such a mono pulse tracking radar has higher accuracy to conical scanning and sequential lobing.
- **PRINCIPLE OF MONO-PULSE**
- Mono pulse uses more than one antenna beam simultaneously. It is also called simultaneous lobing.
- Where as conical scanning or sequential lobing uses only one antenna beam on a time shared basis.
- Mono pulse derives the angle error on the basis of a single pulse but uses simultaneous beams.
- There are two ways to derive angular errors
- Using the relative amplitudes of echo pulses received in different beams due to single pulse transmitted.
- Using the relative phases of echo pulses received in different beams due to single pulse transmitted.
- **METHODS IN MONO PULSE TRACKING**
- Amplitude Comparison Monopulse.
- Phase Comparison Monopulse.

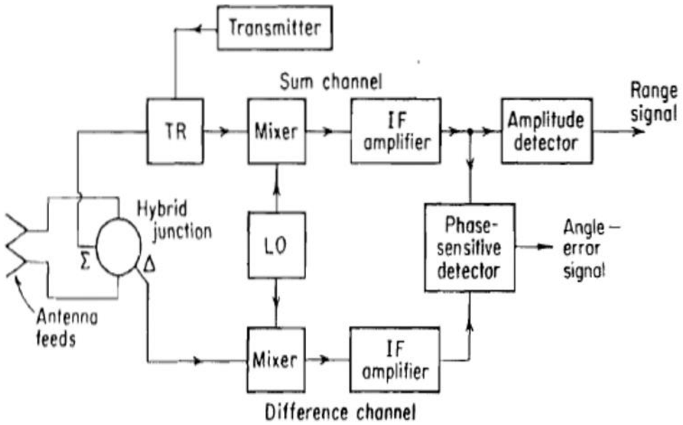




- There are 3 antenna tracking patterns
- (i) Sum
- (ii) Azimuth Error

  (iii) Elevation Error
- Error pattern is the signal Amplitude Vs Angular error (in azimuth or elevation)
- At Null, the error pattern has zero gain and sum pattern has maximum gain.

- Q 9. Explain the block diagram of amplitude comparison mono-pulse radar for single angular co-ordinate and explain its operation

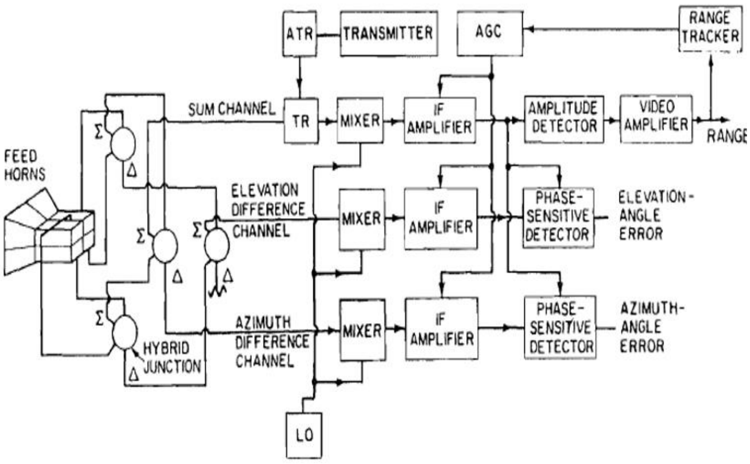


- Magic T is used as a hybrid junction.
- $\sum$ (sum) channel used for transmission. Duplexer introduced in this channel for protection of R_x.
- Δ (Difference) channel is used for receiving the Echo.
- $\sum$ and Δ are converted to IF frequencies using the principle of super heterodyning.
- Phase sensitive Detector (PSD) extracts the amplitude and polarity of the error signal. The two inputs to PSD are the $\sum$ and Δ IF signals.
- aAngular error signal actuates the servo to position the antenna in the direction of target.
- Sign or polarity of error signal is obtained by comparing the phase of difference signal with phase of sum signal.
- Sum signal = $A_s \cos \omega_{IF} t$
- Difference signal = $A_d \cos \omega_{IF} t$ (In phase)

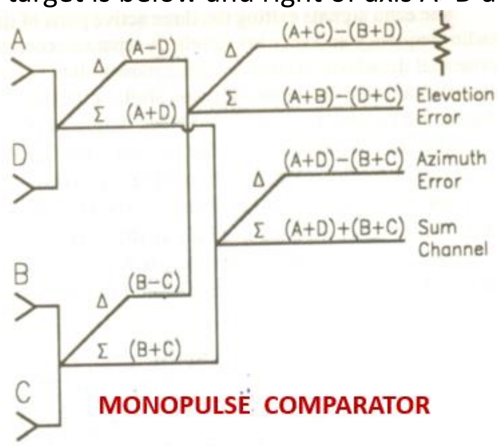
or

- $= A_d \cos \omega_{IF} (t + \pi)$ (180^0 Phase)

- Q 10. Explain the block diagram of amplitude comparison mono-pulse radar for extracting errors in both elevation and azimuth

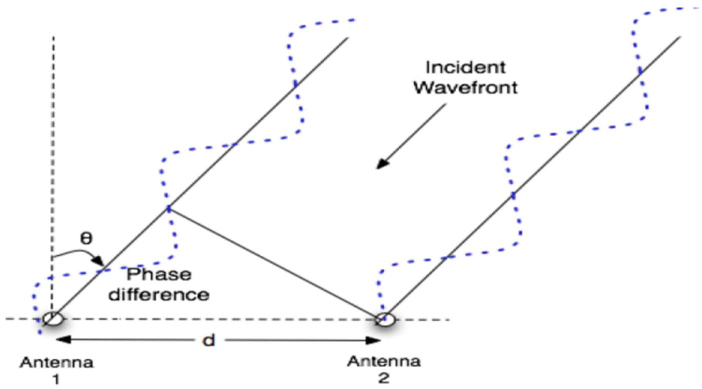


- The cluster of 4 feeds is called the monopulse comparator. The feeds are used with a parabolic reflector
- All the 4 feeds generate sum pattern
- Difference pattern in Azimuth plane is
  = sum of 2 adjacent feeds – sum of the other 2 adjacent feeds (B+D) — (A+C)
- Difference pattern in Elevation plane is
  = Difference of 2 adjacent feeds + Difference of other
  2 adjacent feeds (B — D) + (A — C) + (B+A) — (C+D)
- All 3 mixers operate from a single Local Oscillator to maintain same phase relationship between the 3 channels
- 2 PSDs extract the angle error information one for Azimuth and the other for Elevation
- Range information is obtained from Sum channel
- If target is on antenna axis all the energy is focused at parabola's focal point
- A comparator antenna with 4 feeds is placed at the focus of parabolic dish
- If target is on antenna axis all feeds receive the same amount energy A=B=C=D
- If target is on left of antenna A=D, B=C, and A<B
- If target is above axis A=B, D=C and A < D
- If target is below and right of axis A>D and B>C

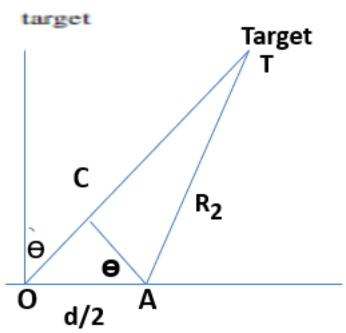
- 

- Feeds are connected in pairs, A and D is a pair and B and C is another pair.
- Signals from the 2 feeds are combined so that their sum and difference are formed.
- Azimuth error = (A+D) – (B+C) .
- Elevation error (A+B) – (D+C).
- Sum channel (A+D) + (B+C).
- Magic T can be used for obtaining sum and difference.

- Q 11. Explain phase comparison mono-pulse tracking technique
- Angle of Error is determined by comparing the phase difference between signals from two separate antennas.
- For phase comparison antennas are not offset from the axis (unlike in amplitude comparison).
- The individual antenna bore sight are made parallel.
- This makes far-field radiation illuminate the same volume in space.
- Amplitudes of Echoes received in the antennas are same. But their phases are different.



- 2 Antennas are located by a separation distance 'd'
- Distance to target R is very large compared to 'd'.
- θ = Angle between target line (LOS) to perpendicular bisector of line joining the 2 antennas



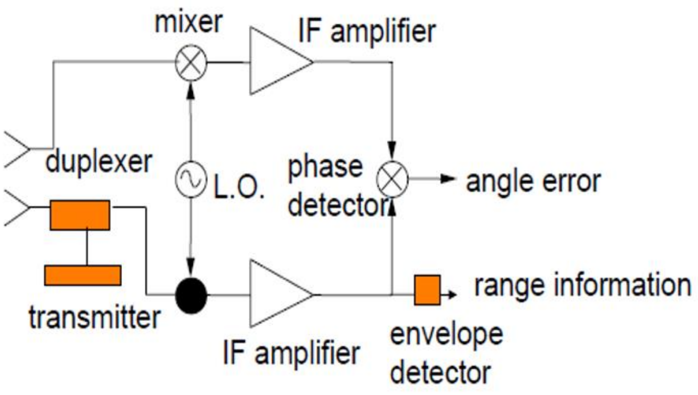
- SIN θ = OC / OA
- OC = OA × SIN θ
- OC = d/2 × SIN θ
- AT = R_2 = CT
- OT = R = OC + CT
- R_2 = CT = R – OC

- $R_2 = R - d/2 \times \text{SIN } \theta$

$$R_2 = R - \frac{d}{2} \text{ Sin } \theta$$

- $$R_1 = R + \frac{d}{2} \text{ Sin } \theta$$

- Difference in distance travelled by the wave front to reach Antenna 2 after reaching Antenna 1.
- $R_1 - R_2 = d \sin \theta$
- But λ distance corresponds to 2π phase.
- $d \sin \theta$ distance corresponds to phase angle $\Delta \emptyset$
- $\Delta \emptyset = \frac{2\pi}{\lambda} d \text{ Sin } \theta = K \text{ Sin } \theta$
- $\Delta \emptyset = K\theta$ (Since $\sin \theta = \theta$ for small angles)
- So $\Delta \emptyset$ is used as the error to position the antenna by servo system



- Signal received at Antenna 1 = $E1 = E \cos \omega_i t$
- Signal received at Antenna 2 = $E2 = E[\cos \omega_i t + \Delta\emptyset]$
- Sum $\sum = E1 + E2 = E \cos W_c t + E[\cos \omega_i t + \Delta\emptyset]$
- Difference $D = E1 - E2 = E \cos \omega_i t - E[\cos \omega_i t + \Delta\emptyset]$
- $\text{Cos A} + \text{Cos B} = 2 \text{ Cos} \frac{A+B}{2} \text{ Cos} \frac{A-B}{2}$
- $\text{Cos A} - \text{Cos B} = — 2 \text{ Sin} \frac{A+B}{2} \text{ Sin} \frac{A-B}{2}$
- Output of correlator = $\sum \text{x} \Delta$
- $\sum = 2 \text{ E Cos} \frac{[\omega_i t + \omega_i t + \Delta\emptyset]}{2} \times \text{Cos} \frac{[\omega_i t - \omega_i t + \Delta\emptyset]}{2}$
- $\sum = 2 \text{ E Cos} \left[\omega_i t + \frac{\Delta\emptyset}{2}\right] \times \text{Cos} \left[- \frac{\Delta\emptyset}{2}\right]$
- $\Delta = 2 \text{ E Sin} \frac{[\omega_i t + \omega_i t + \Delta\emptyset]}{2} \times \text{Sin} \frac{[\omega_i t - \omega_i t + \Delta\emptyset]}{2}$
- $\Delta = 2 \text{ E Sine} \left[\omega_i t + \frac{\Delta\emptyset}{2}\right] \times \text{Sine} \left[- \frac{\Delta\emptyset}{2}\right]$

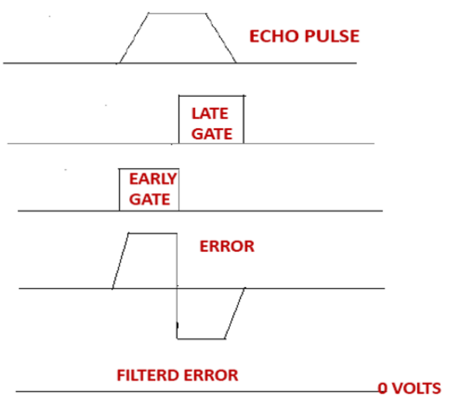
- $\Sigma \times \Delta = 2\text{ E Cos}\left[\omega_i t + \frac{\Delta\emptyset}{2}\right] \text{Cos}\left[-\frac{\Delta\emptyset}{2}\right] \times$
- $- 2\text{ E Sin}\left[\omega_i t + \frac{\Delta\emptyset}{2}\right] \text{Sin}\left[-\frac{\Delta\emptyset}{2}\right]$
- $\left[\omega_i t + \frac{\Delta\emptyset}{2}\right] = \omega_i t$ since $\frac{\Delta\emptyset}{2}$ is small
- $\Sigma \times \Delta = 2\text{ E Cos}(\omega_i t)\text{Cos}\left[\frac{\Delta\emptyset}{2}\right] \times 2\text{ E Sin}(\omega_i t)\text{ Sin}\left[\frac{\Delta\emptyset}{2}\right]$

- But $\text{Sin } 2A = 2 \text{ Sin } A \ \text{ Cos } A$

- $\Sigma \times \Delta = E^2 \text{ Sin}[2\ \omega_i t]\ \text{Sin}\ \Delta\emptyset$
- $\Sigma \times \Delta = \text{Sin}\ \Delta\emptyset\ E^2\ Sin\,[2\ \omega_i\, t]$
- Output of Amplitude Detector

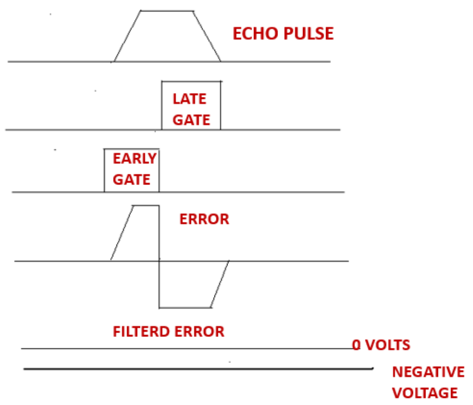
  $\text{Ed} = E^2 \sin(\Delta\emptyset) = E^2\, \Delta\emptyset$ (For small values of $\Delta\phi$)
- Ed is applied to servo system for making $\Delta\emptyset$ zero
- **LIMITATIONS :**
- i) High side lobe levels – give rise to large inaccuracies
- ii) 4 Antennas are mounted to point the beams in same direction. Awkwardness of arrangement of antennas

- Q 12. Explain how tracking in range is achieved using split range gates
- Tracking radars track the target in angle as well as in Range.
- Range can be tracked by an operator by positioning the range gate by a hand wheel while looking in 'A' or 'J' scope.
- It becomes difficult to continuously move the hand wheel if the target is moving fast .
- So Automatic range tracking becomes a necessity.
- 2 Range gates are generated (i) Early Gate (ii) Late Gate.
- Split range gates are placed on the Echo signal.
- ➢ Case(i) Range Gates Stationary
- When the centre position of the split range gates and the centre position of Echo coincides, the portion of signal energy in Early Gate is same as the portion of signal energy in Late Gate. Subtraction of these areas under these Gates gives a value Zero. In this case the Range Gates remain stationary.
- **CASE i) RANGE GATES STATIONARY:**

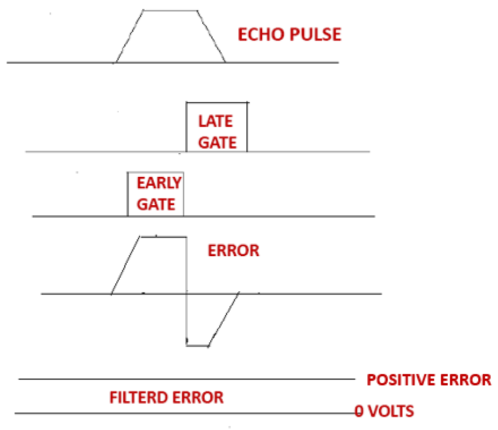


-

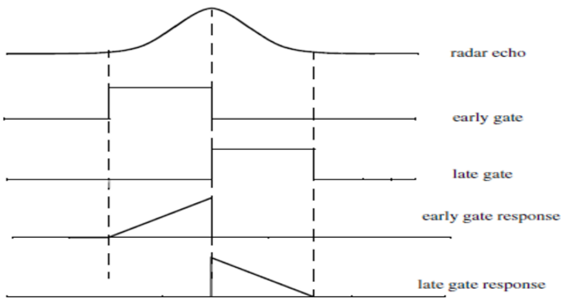
- **CASE ii) RANGE GATES MOVE TO RIGHT**
- Case(ii) Range Gate Move to Right
- Portion of Echo energy in Early gate is less compared to portion of Echo energy in Late gate.
- Echo energies are subtracted . An error signal is produced because of subtraction.
- Error signal is the measure of the difference between centre of the Echo pulse and centre of the split gates
- Sign of Error signal (in this case negative) determines the direction of movement of split Gates.
- An Automatic feed back control system moves the split gate until the split range gates are centered on the pulse. The gates are moved until the error becomes zero.



- **CASE iii) RANGE GATES MOVE TO LEFT**
- Echo energy in Early gate is more than in the Late Gate.
- Subtraction of the echo energies result in Position Error.
- Feedback servo moves the position of the split range gates to the left and repositions the centre of the gates until error becomes zero
- Thus automatic tracking is established without operators interference when the target moves in range.



- **PRACTICAL RANGE GATE :**



-
- **ADVANTAGES:**
- 1. Isolates one target from the other targets at different ranges.
- 2. Improves S/N Ratio since it eliminates noise from other range cells.
- 3. Box car generator can be used which in turn improves S/N
- **TARGET TRACKING ACCURACY**
- **i.** Narrow width of gates corresponds to less noise.
- ii. To capture all the signal energy in the echo, gate width need to be large.
- So width of gates is a compromise of the above two controversial requirements.
- Also accuracy depends on
- i. pulse shape and width of the echo pulse
- ii. band width
- iii. number of pulses.

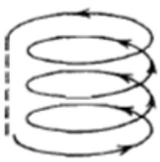
Q 13. A)What are the various methods of acquisition before tracking a target with a radar? Explain

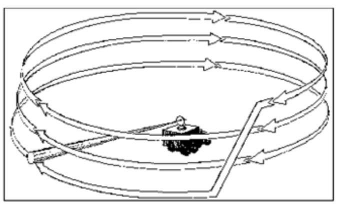
B) Explain scanning pattern employed with pencil beam antenna

- Various common types of scanning patterns employed are

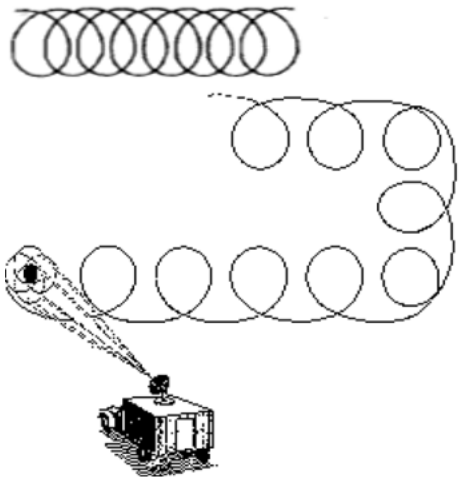
(i) Helical scan
(ii) Palmer scan
(iii) Spiral scan
(iv) Raster scan
(v) Nodding scan

- **i) HELICAL SCAN:**
- Antenna is continuously rotated in azimuth while it is simultaneously raised or lowered in elevation.
- Movement of beam is like a helix in space.
- Helical scan was employed in search mode of SCR-584 fire control radar.

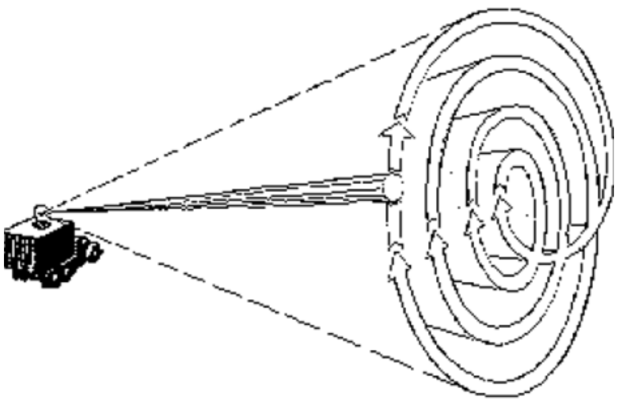




- **ii) PALMER SCAN:**
- Rapid circular scan(conical scan) about the axis of antenna, combined with a linear movement of the axis of rotation is called Palmer scan.
- When aim of rotation is held stationary, the palmer scan reduces to the Conical scan.
- Palmer scan is used with conical scan tracking radars
- Track radar with conical scan will operate with an acquisition as well as track .
- During acquisition, squint angle is increased to reduce the time required to scan a given volume.



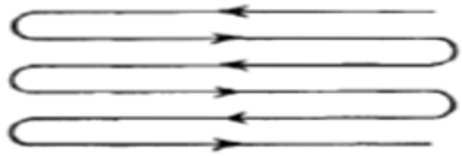
- **(iii) SPIRAL SCAN**
- Spiral scan covers an angular search volume with circular symmetry.

- 

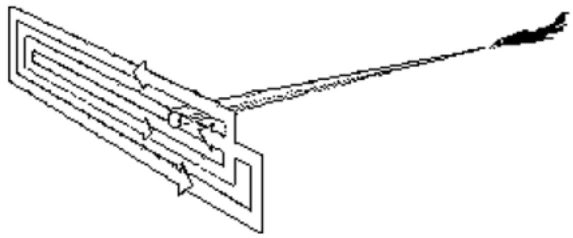
- **DISADVANTAGE OF PALMER AND SPIRAL SCAN:**
- All parts of the scan volume do not receive the same energy unless the scanning speed is varied during the scan cycle.

- Number of echoes from a target, when searching with constant rate depends upon the position of the target with in the search area.

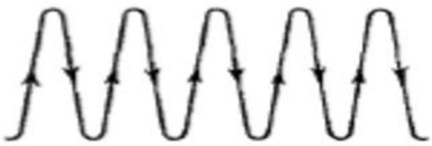
- **(iv) RASTER OR TV SCAN:**



-



- **(v) NODDING SCAN**
- Produced by oscillating the antenna beam rapidly in elevation and slowly in azimuth.



Q 14 . Compare the tracking techniques

- **ADVANTAGE OF SEQUENTIAL LOBE SWITCHING::** simple, light weight, single Rx

- **DISADVANTAGES OF SEQUENTIAL LOBE SWITCHING:**

i) 4 pulses required to determine the position in 2 Dimensions. Time taken is more. So reduced Bandwidth.

ii) Fluctuations in signal level from pulse to pulse reduce tracking accuracy. Fluctuations are caused because of a) target RCS aspect ratio b) Modulation due to propeller blades (in helicopter)

iii) Antenna Gain at Boresight is less than Antenna peak Gain. So operational range reduces

Iv)Reduction in S/N Ratio.

- **COMPARISON OF MONO-PULSE VS CONICAL SCAN**

Sl.No.	Characteristics	Conical Scan	Mono-Pulse (Amplitude)
1	S/N Ratio	S/N ratio less Tracks target away from peak of antenna beam	S/N ratio large Sum pattern is used
2	Tracking Accuracy	Less since S/N ratio is less and fluctuations in Pulse to Pulse Echoes	•Superior due to large S/N ratio •Not affected because of fluctuations from Pulse to Pulse
3	Minimum number of pulses required	Requires minimum of 4 pulses per revolution of beam to extract angle in azimuth and elevation	3 D extraction position requires only one pulse per transmission
4	Beam width	Beam width larger and so collects more noise	Beam width less and so collects less noise
5	Complexity	•Less complex •Uses single feed •Requires one Rx channel	•More complex & expensive •Requires antenna comparator •Requires 3 Rx sum, Difference in Azimuth & Elevation
6	Susceptibility to jamming	•More susceptibility to jamming •Inverse conical scan jamming is used	•Less susceptibility to jamming •difference channel subtracts jamming noise
7	Application	•Gun control tracking Radar	•Missile Guidance Radar •Missile Homing Radars

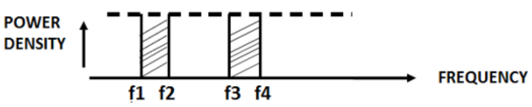
END OF UNIT 4

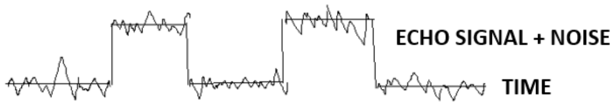
ANSWERS TO JNTUH EXAMINATION QUESTIONS
RADAR SYSTEMS
UNIT — FIVE

- Q 1. Explain the characteristics of a matched filter receiver with necessary equations
- s(t) = Received waveform (Echo waveform)
- E = Signal Energy
- N_o = Noise Power (Noise power per hertz of Band width)
- "North" showed that the (Linear Time Invariant) LTI filter which maximizes.
- $\dfrac{\text{output peak signal power}}{\text{mean noise power}}$
- has a frequency response function H (f) .
- $H(f) = G_a S^*(f) \exp(-J 2 \pi f t_1)$
- where H (f) is the transfer function of matched filter

$$H(f) = G_a S^*(f) \exp(-J 2 \pi f t_1)$$

- Where $S(f) = \int s(t) \exp(-J 2 \pi f t_1)\, dt$
-
- S (f) = Voltage frequency spectrum of input signal.
- $S^*(f)$ = Complex conjugate of S (f)
- t_1 = fixed value of time at which signal is observed to be maximum (related to time delay between transmission and reception).
- G_a = Filter Gain taken as '1' for simplification.
- Characteristics of Noise is assumed to be white noise.
- White noise is stationary and has a uniform spectrum
- $H(f) = G_a S^*(f) \exp(-J 2 \pi f t_1)$
- Matched filter is also called North Filter or conjugate filter.



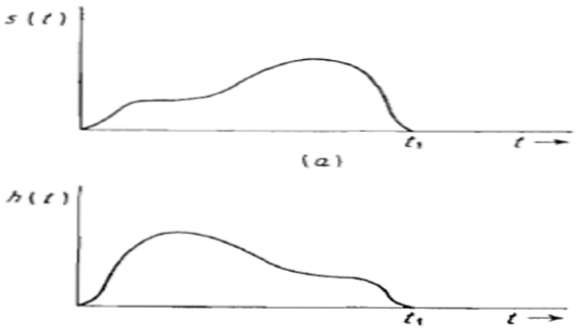
- 

- $S(f) = |S(f)| \exp\{-J \varnothing_s(f)\}$
- where $|S(f)|$ = Amplitude (Magnitude) spectrum of input echo
- $\{-J \varnothing_s(f)\}$ = Phase spectrum of echo
- $S^*(f) = |S(f)| \exp\{+J \varnothing_s(f)\}$
- similarly $H(f) = |H(f)| \exp\{-J \varnothing_m(f)\}$
- where $|H(f)|$ = Amplitude spectrum of matched filter

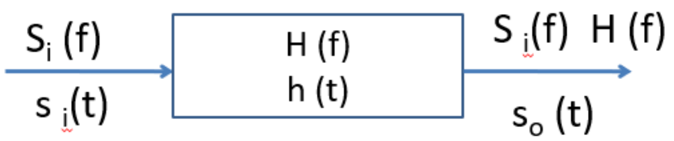
- $-J\,\phi_m(f)$ = Phase spectrum of matched filter
- $H(f) = |H(f)|\exp\{-J\,\phi m(f)\}$ Eq-1
- $S^*(f) = |S(f)|\exp\{+J\,\phi_s(f)\}$
- But $H(f) = G_a S^*(f)\exp(-J\,2\pi f t_1)$
- $H(f) = G_a|S(f)|\exp\{+J\,\phi_s(f)\}\exp\{-J\,2\pi f t_1\}$
- $H(f) = G_a|S(f)|\exp(+J\{\phi_s(f) - 2\pi f t_1\}$ Eq-2
- $H(f) = |H(f)|\exp\{-J\,\phi m(f)\}$ Eq-1
- Comparing eq-2 and Eq-1 above and taking $G_a = 1$
- $|H(f)| = |S(f)|$
- $\phi m(f) = -\phi_s(f) + 2\pi f t_1$
-
- amplitude spectrum of matched filter = amplitude spectrum of the echo signal.
- phase spectrum of matched filter = negative of the phase spectrum of the echo signal + phase shift proportional to frequency.

- **IMPULSE RESPONSE:**
- $h(t)$ = impulse response (Transfer function) of matched filter.
- $h(t) = \int_{-\infty}^{+\infty} H(f)\exp(J\,2\pi f t)\,df$
- But $H(f) = G_a S^*(f)\exp(-J\,2\pi f t_1)$
- Substituting $H(f)$ in $h(t)$
- $h(t) = G_a\int_{-\infty}^{+\infty} S^*(f)\exp(-J\,2\pi f t_1)\exp(J\,2\pi f t)\,df$
- $h(t) = G_a\int_{-\infty}^{+\infty} S^*(f)\exp\{-J\,2\pi f(t_1 - t)\}\,df$
- But $S^*(f) = S(-f)$
- $h(t) = G_a\int_{-\infty}^{+\infty} S^*(f)\exp\{-J\,2\pi f(t_1 - t)\}\,df$
- $h(t) = G_a\int_{-\infty}^{+\infty} S(-f)\exp\{-J\,2\pi f(t_1 - t)\}\,df$
- But $df = -d(-f)$
- $h(t) = -G_a\int_{-\infty}^{+\infty} S(-f)\exp\{J\,2\pi(-f)(t_1 - t)\}\,d(-f)$

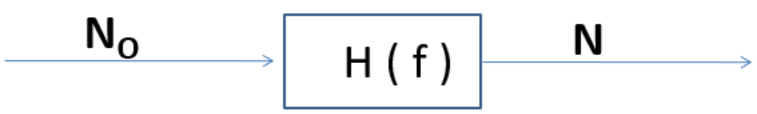
- $= -G_a \int_{+\infty}^{-\infty} S\ (f) \exp\{J\ 2\pi f\ (t_1 - t)\}\ df$
- $h\ (t) = G_a \int_{-\infty}^{+\infty} S\ (f) \exp\{J\ 2\pi f\ (t_1 - t)\}\ df$
- But $s\ (t) = \quad S\ (f) \exp\{J\ 2\pi f\ t\}\ df$
- So $h\ (t) = G_a \int_{-\infty}^{+\infty} s\ (t\ 1 - t)$
-
- $ah(t) = G_a\ s\ (t_1 - t)$
- So impulse response of matched filter = image of the echo signal wave form = echo signal run backward in time starting from fixed time 't_1'.



- Q 2. Explain the principle and characteristics of a matched filter. Hence derive the expression for its frequency response function
- **DERIVATION**:
- To prove $\frac{output\ peak\ signal\ power}{mean\ noise\ power} = R_f$
- $R_f = \frac{|S_0\ (t)|^2}{N} \quad = \qquad$ EQ-1
- is optimum (maximum) when
- $H\ (f) = G_a\ S^*\ (f) \exp(-J\ 2\pi f\ t_1)$



-
- $|\ s_o\ (t)\ | = |\int S_i(f)\ H\ (f) \exp\{J\ 2\pi f\ t\}\ df\ |$ EQ-2
-



-

- $B_n = \dfrac{\int_{-\infty}^{+\infty} |H(f)|^2 \, df}{|H(f_0)|^2}$
- when $H(f_0)$ is normalised to unity at mid band Bandwidth
- $B_n = \int_{-\infty}^{+\infty} |H(f)|^2 \, df$
- Let N_0 = Input noise Power per unit band width
- Mean noise Output Power is N =

$$\frac{N_0}{2} \int_0^{+\infty} |H(f)|^2 \, df \qquad EQ - 3$$

- 1 / 2 because N is computed for 0 to ∞
- Substitute EQ (2) & (3) in EQ (1)
- $R_f = \dfrac{\left| \int_{-\infty}^{+\infty} S(f) \times H(f) \ \exp \ (J\, 2\, \pi\, f\, t)\, df \right|^2}{\frac{N_0}{2} \int_{-\infty}^{+\infty} |H(f)|^2 \, df}$
- Since $|s_0(t)|^2$ maximum occurs at $t=t_1$.
- $R_f = \dfrac{\left| \int_{-\infty}^{+\infty} S(f) \times H(f) \ \exp \ (J\, 2\, \pi\, f\, t_1)\, df \right|^2}{\frac{N_0}{2} \int_{-\infty}^{+\infty} |H(f)|^2 \, df}$ EQ – 4
- A Numerator of EQ-4 is $|\int S(f)\, H(f) \exp(J\, 2\, \pi\, f\, t_1)|^2$
- $= |\int S(f) \exp\{J\, 2\, \pi\, f\, t_1\} \ H(f) \ df \ |^2$ EQ-5
- Schwartz inequality says that
- $|\int P^*Q \, df \,|^2 \le \int P^*P \, df \int Q^*Q \, df$
- ≤ becomes when P = K Q where K is a constant
- (But according to Parsvel $\int P^*P \, df = \int |P|^2 \, df$)
- So $|\int P^*Q \, df\,|^2 \le \int |P|^2 \, df \int |Q|^2 \, df$ EQ-6
- EQ-6 & EQ-5 are similar when
- $P^* = S(f) \exp(j\, 2\, \pi\, f\, t_1)$
- and $Q = H(f)$

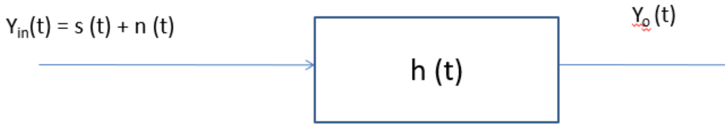
- Since $P^* = S(f) \exp\{j 2\pi f t_1\}$
- $P = S^*(f) \exp(-j 2\pi f t_1)$
- So $|P|^2 = |S(f)|^2$ (Parsvel)
- Similarly since $Q = H(f)$
- So $|Q|^2 = |H(f)|^2$
- EQ – 5 is $|\int S(f) \exp\{J 2\pi f t_1\} H(f) \, df|^2$
- $| \int |S(f)|^2 df \int |H(f)|^2 df$ EQ-7
- $R_f \le \dfrac{\int |S(f)|^2 df \int |H(f)|^2 df}{\frac{N_0}{2} \int |H(f)|^2 df}$
- $R_f \le \dfrac{\int |S(f)|^2 df}{\frac{N_0}{2}}$
- But Parsvel's Theorem says
-
- $\int |S(f)|^2 df = \int s^2(t) dt = E$ (Energy)
- $R_f \le \dfrac{2E}{N_0}$
- ∴ R_f is maximum when $R_f = \dfrac{2E}{N_0}$
- Equality sign appears when P = K Q
- $R_f = \dfrac{2E}{N_0} \le \dfrac{\int |S(f)|^2 df}{\frac{N_0}{2}}$
- When P = K Q
- But $P = S^*(f) \exp\{-j 2\pi f t_1\}$
- $Q = H(f)$
- So $S^*(f) \exp\{-j 2\pi f t_1\} = K H(f)$
- $H(f) = \frac{1}{K} S^*(f) \exp\{-j 2\pi f t_1\}$
- **$H(f) = G_a S^*(f) \exp\{-j 2\pi f t_1\}$**

- **INTERESTING PROPERTY OF MATCHED FILTER:**
- Irrespective of shape of input signal waveform

$$R_f = \frac{\text{Output peak signal power}}{\text{mean noise power}}$$

- $R_f = \frac{2E}{N_0} = \frac{2 \times \text{Energy contained in signal}}{\text{Noise power per hertz bandwidth } N_0}$

- i.e. maximum ratio of peak signal power to mean noise power is simply twice the energy contained in the signal divided by the noise power per hertz of band width Noise power per hertz of Bandwidth $N_0 = K T_0 F$
- Where K = Boltzmann constant
- T_0 = Standard Temperature.
- F = Noise Figure

- Q 3. A) Discuss the relations between the matched filter characteristics and correlation function
  B) Explain the principle and process of correlation detection
- Matched filter output is proportional to input signal (Echo) cross correlated with replica of transmitted signal, expect for the time delay t_1
- Proof:
- $y(\lambda)$, $s(\lambda)$ are 2 signals each of finite duration
- $R(t)$ is cross correlation of $y(\lambda)$ and $s(\lambda)$
- $R(t) = \int y(\lambda)\, s(\lambda - t)\, d\lambda$ --- EQ (1)
- 

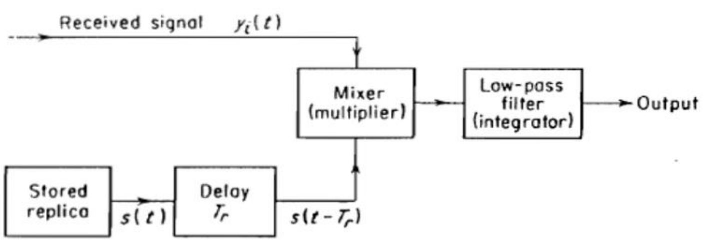
- $y_o(t) = \int y_{in}(\lambda)\, h(t - \lambda)\, d\lambda$ -----EQ (2)
- Since the filter is matched filter $h(\lambda) = s(t_1 - \lambda)$
- EQ (2) becomes
- $y_o(t) = \int y_{in}(\lambda)\, s(t_1 - t + \lambda)\, d\lambda$ ---EQ (3)
- Comparing EQ (3) & EQ (1)
- $y_o(t) = R(t - t_1)$
- So matched filter response = Cross correlation of received signal corrupted by noise and replica of transmitted signal
- Replica of the transmitted signal is "built in" to the matched filter via the frequency response function
- If input signal $y_{in}(t)$ were the same as the signal
- $s(t)$ for which the matched filter was designed the output is the Autocorrelation function (noise is assumed zero)

- Q 4. Briefly explain about the efficiency of non matched filters
- Matched filter cannot be realized exactly in practice.
- Efficiency

$$= \frac{Peak\ S/N\ ratio\ of\ nonmatched\ filter}{peak\ S/N\ ratio\ of\ matched\ filter}$$

Input signal	Filter	Optimum $B\tau$	Loss in SNR compared with matched filter, dB
Rectangular pulse	Rectangular	1.37	0.85
Rectangular pulse	Gaussian	0.72	0.49
Gaussian pulse	Rectangular	0.72	0.49
Gaussian pulse	Gaussian	0.44	0 (matched)
Rectangular pulse	One-stage, single-tuned circuit	0.4	0.88
Rectangular pulse	2 cascaded single-tuned stages	0.613	0.56
Rectangular pulse	5 cascaded single-tuned stages	0.672	0.5

- Q 5. Derive the expression for frequency function of the matched filter with non-white noise
- White noise is assumed in derivation of equation for matched filter.
- For Non White Noise (NWN) the frequency response is
- $H(f) = \dfrac{G_a\ S^*(f)\ \exp\ (-J\,2\,\pi f\, t_1)}{|N_i(f)|^2}$
- $|\ N_i(f)\ |^2$ = Constant for white noise.
- $H(f) = \dfrac{1}{N_i(f)}\ G_a \left|\dfrac{S(f)}{N_i(f)}\right|^* \exp\ (-J\,2\,\pi f\, t_1)$
- $H(f) = \dfrac{1}{N_i(f)}\ G_a \left|\dfrac{S(f)}{N_i(f)}\right|^* \exp\ (-J\,2\,\pi f\, t_1)$
- $|\ N_i(f)\ |^2$ = Constant for white noise.
- The above is a cascade of 2 filters.
- First filter $\dfrac{1}{N_i(f)}$ acts to make noise spectrum uniform and called whitening filter.
- Second filter is matched filter when input is white noise &

  Signal spectrum is $\dfrac{S(f)}{N_i(f)}$
- **CROSS CORRELATION R_x**
- Alternate implementation of matched filter is the cross – correlation R_x. The matched filter is replaced by cross-correlation R_x.
- Output of matched filter = cross correlation between the input signal (echo) and delayed replica of the transmitted signal.
- 

- aInput signal y(t) is multiplied by delayed replica of the transmitted signal s ($t-T_r$).
- Product is passed through a low-pass-filter to perform integration.
- Rx tests the presence of target at a single delay T_r
- Targets at other time delays are dealt with by varying the time delays (takes more time) or by using parallel channels.

- Q 6. List out the general characteristics and requirements for a radar receiver
- **FUNCTION OF RECEIVER**
  1. Detect desired echo signal in the presence of noise,interference,clutter etc.
  2. Amplify the wanted signal to a level, where it is easily displayed on a Display or used in a Automatic Data Processor.
  3. R_x design depends on (i) Type of waveform to be detected (ii) nature of noise, interference ,Clutter echoes
- **Noise in R_xs:**
- Noise enters the R_x along with signal. It enters via the antenna. (This is quite low compared to Internal noise generated)
- Noise is generated with in the R_x. Measurement of this internal noise is the Noise-Figure.
- **R_x Design:**
- Should have sufficient gain and phase.
- Should have amplitude stability
- Should have sufficient dynamic range
- Protection against overload or saturation
- Protection from burnout due to nearby Transmitters
- **Types of Radar R_xs used in Radar:**
- Super-heterodyne
- Homodyne
- Crystal Video
- Turned R F
- **Superhetrodyne R_xs:**
- Radar Rxs are mostly Super-heterodyne.
- RF is converted to IF for the following reasons.
- **Advantages:**
- Easier to achieve good filter shape
- **FRONT END IN A RADAR R_x:**
- i) Mixer stage after Antenna.
- ii) Low noise Amplifier.
- **(i) Mixer Stage:**
- **Merits:**
- 1.Greater Dynamic Range
- 2. Lesser sensitivity avoids saturation when jamming signals are present.
- **De Merits**: Larger noise Figure, affects range.
- $R_{max}{}^4 = \dfrac{P_t\, G\, A_e\, \sigma}{(4\pi)^2\, K\, T_0\, B\, F_n\, S/N}$
- Compensated by using i) a bigger antenna ii) Larger T_x power.
-

- **ii) LNA Front End:**
- **Merits:**
- i) Greater MTI Improvement factor (MTI Improvement Factor = Clutter Attenuation x Average gain)
- ii) Higher sensitivity which achieves larger maximum range.
- **De Merits:**
- Cost of systems goes up.
- Vulnerability to Burnout because of high sensitivity.

- Q 5. a)Define noise figure. Derive the expression for the two networks that are cascaded
  b) Define the noise figure for a radar receiver and obtain an expression for the noise figure for three networks in cascade
  c) Define and distinguish between terms: noise figure ,noise temperature and system noise temperature of receiver
- **Ideal Receiver:**
- i) No noise due to external source
- ii) Rx does not generate any noise
- iii) only Thermal noise is present
- **Practical Receiver :**
- Noise power of Practical Rx greater than that from thermal noise alone
- **Noise Figure : (F_n)**
- $F_n = \dfrac{\text{Noise output power of practical reciver}}{\text{Noise output of ideal receiver}}$

-
- A Noise Figure
- $F_n = \dfrac{N_{out}}{K\ T_0\ B_n\ G} = \dfrac{\text{Input S/N Ratio}}{\text{output S/N Ratio}} = \dfrac{S_{in}/N_{in}}{S_{out}/N_{out}}$
- **Noise Figure:**
- $F_n = \dfrac{\text{Noise output power of practical reciver}}{\text{Noise output of ideal receiver}}$
-

$$= \frac{N_{out}}{K\ T_0\ B\ G}$$

- N_{out} = Noise output of practical Rx
- G = available Gain = $\dfrac{S_{out}}{S_{in}}$
- S_{in} = signal input of Rx,
- S_{out} = signal output of Rx
- T_0 = 290 K (273 + 17) Room temp =17^0 C
- $G = \dfrac{S_{out}}{S_{in}}$
- Noise input in an Ideal Rx = $N_{in} = K\ T_0\ B_n$

- But

$$F_n = \frac{N_{0ut}}{K\ T_0\ B_n\ G} = \frac{N_{out}}{N_{in}\ \dfrac{S_{out}}{S_{in}}}$$

- So

$$F_n = \frac{\left\{\dfrac{S_{in}}{N_{in}}\right\}}{\left\{\dfrac{S_{0ut}}{N_{out}}\right\}} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}}$$

- Noise figure is interpreted as the degradation of S/N ratio as signal passes through Receiver
- **Interpretation 1:** Noise figure is the degradation in Signal to Noise Power as the signal passes through the network.
- **Interpretation 2:** Noise Figure is the ratio of output Noise power of practical receiver to output Noise power of an ideal receiver.

- **IDEAL Rx :**

-
- Noise figure F_n = 1 or 0 dB
-

$$G = \frac{S_{out}}{S_{in}}$$

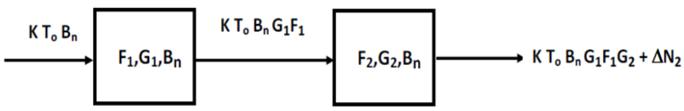
- Noise input in an Ideal Rx = $N_{in} = K\ T_0\ B_n$
- But

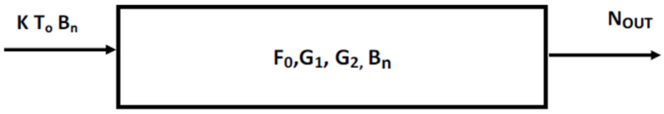
$$F_n = \frac{N_{0ut}}{K\ T_0\ B_n\ G} = \frac{N_{out}}{N_{in}\ \dfrac{S_{out}}{S_{in}}}$$

- So

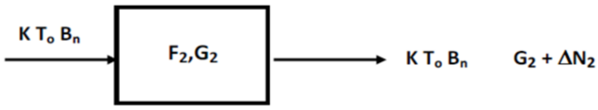
$$F_n = \frac{\left\{\dfrac{S_{in}}{N_{in}}\right\}}{\left\{\dfrac{S_{0ut}}{N_{out}}\right\}} = \frac{S_{in}/N_{in}}{S_{out}/N_{out}}$$

- Noise figure is interpreted as the degradation of S/N ratio as signal passes through Rx
- **PRACTICAL RX**
- $F_n = \dfrac{K\ T_o\ B_n\ G + \Delta N}{K\ T_0\ B_n\ G} = 1 + \dfrac{\Delta N}{K\ T_0\ B_n\ G}$
- ΔN is the additional Noise introduced by the network
- $\Delta N = [F_n - 1]\ K\ T_o\ B_n\ G$





-
- Taking the 2nd network alone



-
- $\mathbf{F_n = \dfrac{K\ T_0\ B_n\ G + \Delta N_2}{K\ T_0\ B_n\ G_2} = 1 + \dfrac{\Delta N_2}{K\ T_0\ B_n\ G_2}}$
- $(F_2 - 1)\ K\ T_0\ B_n\ G_2 = \Delta N_2$ — EQ (2)
- N_{OUT} = Noise from Network 1 at output of Network 2
- +
- Noise ΔN_2 Introduced by Network 2
- Taking the resultant cascaded Network (by definition)

$$F_0 = \frac{N_{out}}{K\ T_o\ B_n\ G_1\ G_2} \qquad \text{EQ-1}$$

- EQ (1) states
- $F_0 = \dfrac{N_{out}}{K\ T_o\ B_n\ G_1\ G_2}$
- $N_{out} = F_o\ K\ T_o\ B_n\ G_1\ G_2 = F_1\ K\ T_o\ B_n\ G_1\ G_2 + \Delta N_2$
-
- $F_o\ K\ T_o\ B_n\ G_1\ G_2 = F_1\ K\ T_o\ B_n\ G_1\ G_2$
- $+ (F_2 - 1)\ K\ T_o\ B_n\ G_2$
- $F_0\ G_1 = F_1\ G_1 + (F_2 - 1)$
- $F_0 = F_1 + \dfrac{(F_2 - 1)}{G_1}$
- F_0 Noise figure of Cascade Network =
- F_1 (Noise Figure of Network I) + $\dfrac{(F_2 - 1)}{G_1}$ [(Noise Figure of Network 2) – 1] $\div G_1$
- Noise Figure of cascaded Network = Noise Figure of Network 1 (if G_1 is large)
- Noise Figure of N networks in Cascade:
- $F_0 = F_1 + \dfrac{F_2 - 1}{G_1} + \dfrac{F_3 - 1}{G_1\ G_2} + \dots + \dfrac{F_n - 1}{G_1\ G_2 \ldots\ldots G_{n-1}}$

- **NOISE TEMPERATURE:**
- Some times Performance of Rx is expressed in terms of Effective Noise temperature T_e
- T_e is the Temperature at input of network that account for additional noise ΔN at output
- 

- $$F_n = \frac{K\ T_0\ B_n\ G + \Delta N}{K\ T_0\ B_n\ G} = 1 + \frac{\Delta N}{K\ T_0\ B_n\ G}$$
- Let $\Delta N = K\ T_e\ B_n\ G$
-
- From previous slide

$$F_n = 1 + \frac{\Delta N}{K\ T_0\ B_n\ G}$$

- $$F_n = 1 + \frac{K\ T_e\ B_n\ G}{K\ T_0\ B_n\ G} = 1 \quad \frac{T_e}{T_0}$$
- So $T_e = [\, F_n - 1 \,]\ T_o$

- **NOISE TEMPERATURE OF CASCADED NETWORK:**
- System Noise Temperature = T_s
- Antenna Temperature = T_a
- Rx Effective noise temperature = T_e
- $T_s = T_a + T_e = (F_s - 1)\, T_0$
- where F_s = system noise figure
- **Cascade of Networks :**
- $$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1\ G_2} + \ldots\ldots + \frac{T_n}{G_1\ G_2\ \ldots.\ G_{n-1}}$$

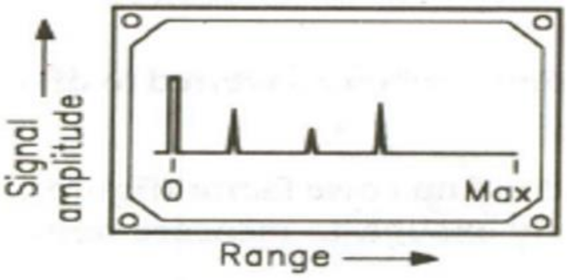
- **Problem 1:** Determine Noise Figure for a Rx that has RF Amplifier of Gain 10 dB & Noise figure of 6 dB, a Mixer down converter with a noise figure of 10 dB and converter gain of –6 dB and an IF stage with 40 dB gain & Noise figure of 6 dB
- 

- a $G_1 = 10dB\ (10)$ $G_2 = -\,6dB\ (.25)$ $G_3 = 40dB(10^4)$
- $F_1 = 6dB\ (3.98)$ $F_2 = 10dB\ (10)$ $F_3 = 6dB(3.98)$
- $$F_0 = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1\ G_2} = 3.98 + \frac{10 - 1}{10} + \frac{3.98 - 1}{10 \times 0.25}$$
- $= 6.07$ or 7.83 dB
- Asd

- **Problem 2:** Three networks units each of 6 db noise figure and 10 dB, 6dB, and 6 dB gain respectively are cascaded . Determine overall Noise figure of system

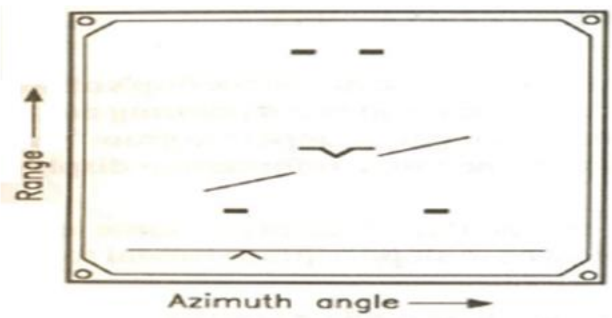
- G_1 = 10 dB (10) ; F_1 = 6 dB (3.98)
- G_2 = 6 dB (3.98) ; F_2 = 6 dB (3.98)
- G_3 = 6 dB (3.98) ; F_3 = 6 dB (3.98)
- $F_0 = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \, G_2} = 3.98 + \frac{3.98 - 1}{10} + \frac{3.98 - 1}{10 \times 3.98}$
- a = 4.35 or 7.83 dB
- **(Convert all values in dB to ratios before applying the formulae)**

- **Q 6. A) List out the different types of displays used for radar applications and their characteristics**
  B)Explain various types of radar displays
  C) Explain the characteristics and requirements of radar display units
- **(1) 'A' SCOPE :**



a. A–scope

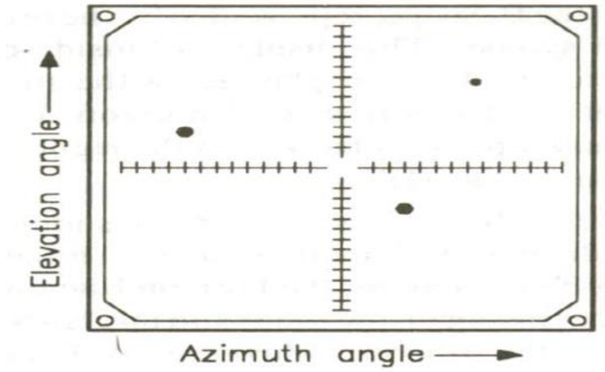
- A Deflection modulated display.
- X Axis (Horizontal co-ordinate) = Time (Range)
- Y Axis (Vertical co-ordinate) = Target echo signal strength
- Most commonly used display.
- Used in Tracking Radar for weapon control.
- As
- **(2) 'B' SCOPE :**
-



- a. B–scope
- Intensity modulated display.
- X Axis = Azimuth angle
- Y Axis = Range
- Echo signal strength is shown by brightness of spot.

- Used in air – to – air combat display.

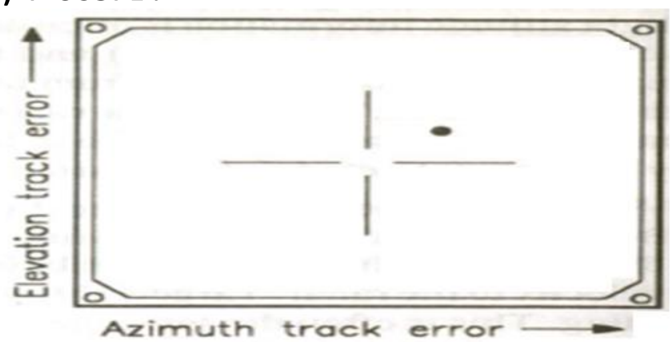
- **(3) 'C' SCOPE :**



a. C—scope

- aIntensity modulated display.
- X Axis = Azimuth angle
- Y Axis = Elevation angle
- **(4) 'D' SCOPE :**
- This is same as 'C' Scope.
- Except that the Blip extends vertically to give rough estimate of range.
- **(5) 'E' SCOPE :**
- This is similar to 'B' Scope except in place of Azimuth, Elevation is displayed.
- X Axis = Range
- Y Axis = Elevation

- **(6) 'F' SCOPE :**



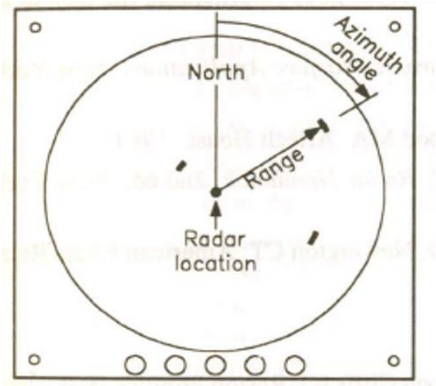
b. F—scope

- Centre of Display = Axis of antenna beam.
- Blip's displacement from centre indicates target position relative to beam axis.
- X Axis = Azimuth track error
- Y Axis = Elevation track error
- **OTHER DISPLAYS USED ARE**:
- (i) 'G' Scope (ii) 'H' Scope (iii) 'I' Scope
- (iv) 'J' Scope (v) 'K' Scope (vi) 'L' Scope
- (vii) 'M' Scope (viii) 'N' Scope (ix) 'O' Scope
- **PPI – PLAN POSITION INDICATOR- 'P' SCOPE**
- Most commonly used Display
- Intensity modulated circular display
- Echo signals are shown on a map (plan position) viewed from above the radar.

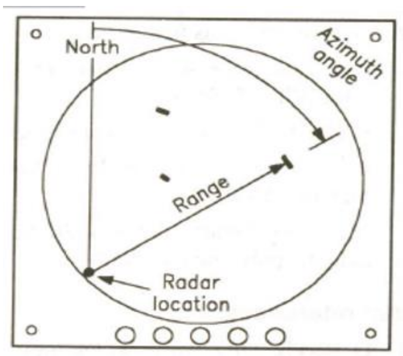
- **Range – Height Indicator**
- Intensity modulated display
- X Axis = Range
- Y Axis = Altitude
- Primarily height finding display
- All types of displays are defined in IEEE standard definitions.

- Q 7. Explain the functioning and characteristics of PPI display

- **PPI – Plan Position Indicator- 'P' Scope**
- Most commonly used Display
- Intensity modulated circular display
- Echo signals are shown on a map (plan position) viewed from above the radar.
- Range is indicated by radial position from radar.
- Azimuth angle indicated by target angle clock wise from top of scope (usually north).
- 2 Types of PPI Scope
- Most commonly used for search radars
- 2 types of PPI Display
  (i) Radar centered PPI
  (ii) Offset PPI
- **(I) RADAR CENTERED PPI**



- **(II) OFFSET PPI**



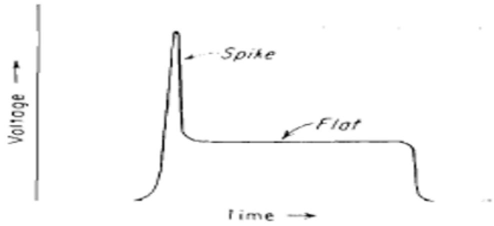
- Zero position of time base at a position other than at the centre of the display.
- Provides larger display for a selected position
- Asd

- Q 8. **Explain the need for a Duplexer and its requirement for a Pulse radar**

- **DUPLEXER:**
- is a Fast Acting Switching device. It enables the antenna to time share between T_x and R_x. 2 modes of operation.
- **1. Transmission:**
- Connects T_x to antenna
- Protect R_x from damages or burnouts.
- Loss between T_x and Antenna Low.
- **2. Reception:**
- Connects echo signal to R_x and disconnects T_x from antenna
- Switch rapidly changes from Transmission mode to reception within nano seconds.
- Loss between Antenna and R_x low.
- Duplexer is a Gas – Discharge device and called TR (Transmit – Receive) Switch.
- **OPERATION OF TR SWITCH**:
- High Power Pulse causes Gas Discharge device to breakdown and short circuit the path going to R_x. Thus R_x is protected from damage.
- During reception the device is cold and directs, echo signal to the R_x and not to T_x.
- AT_x Power ≈ 1 mega watt
- Safe Power of tolerance in $R_x \approx$ 1 watt
- Isolation provided by Duplexer = $\left[\frac{1 \times 10^6}{1}\right]$
- = 10^6 or 10 log 10^6 = 60 dB
- **TR TUBE :**
- Gas – Discharge Device.
- Break down & Ionize quickly when high R.F. Power is applied.
- Deionize quickly once power is removed.
- **CONSTRUCTION OF TR TUBES:**
- Contain Resonate filters.
- 2 Glass – to – Metal windows sealed
- Noble Gas like Argon is filled in tube.
- Argon has a low Break – down voltages.
- Water vapour or Halogen gas added. This speeds up deionizing time.
- To speed up break down, auxiliary source of Electronics is attached to help initiate discharge
- Small source of Radio activity 'Tritium' (Radio Active Isotope of Hydrogen) produces low energy 'Beta' rays to generate supply of electrons. This is called Tritiated Ignitior.
- This has more leakage during transmission.
- Because of leakage, pin diode limiter stages are used to attenuate leakages.
- Tritium Igniter needs no active voltages. So R_x protection is ensured when Radar is OFF.
- This avoids use of mechanical shutter.
- **DISADVANTAGE :**
- Because of Radio activity, the unit should be carefully handled from hazard

- **TR TUBE:**
- aT_x Power always leaks to the R_x

- Spike is of short duration, but has large amplitude. Finite time of sharp pulse is due to the time it takes for ionization. Typical time for ionization is 10 nano secs

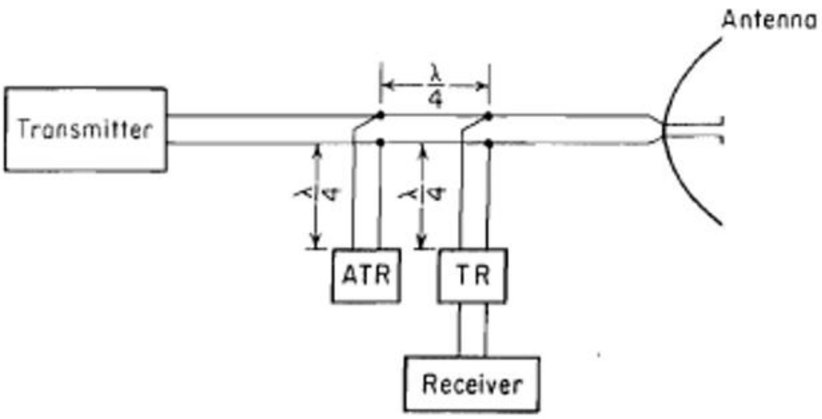


LEKAGE PULSE THROUGH TR TUBE

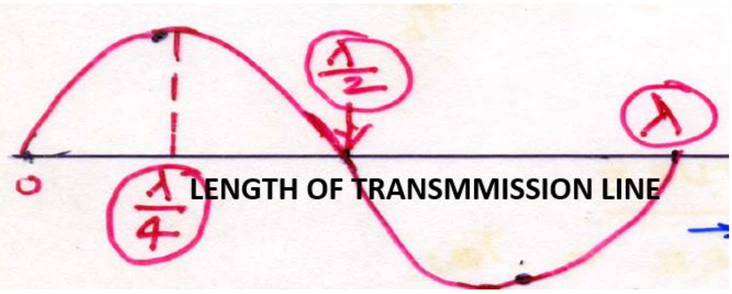
- Damage to R_x occurs when combined energy of spikes and flat portions of curve is too large Typical leakage energy is one 'ERG'
- Protection against leakage is 70 to 90 dB.
- TR tube loss in signal is 0.5 to 1 dB.

- Q 8. Explain and distinguish between the branch type and balanced duplexers

- **BRANCH TYPE DUPLEXER:**
-



- One of the earliest configuration.
- Consists of TR (Transmit – Receive) Switch.
- Consists of ATR (Anti TR) Switch.
- Both are Gas – Discharge Tubes.

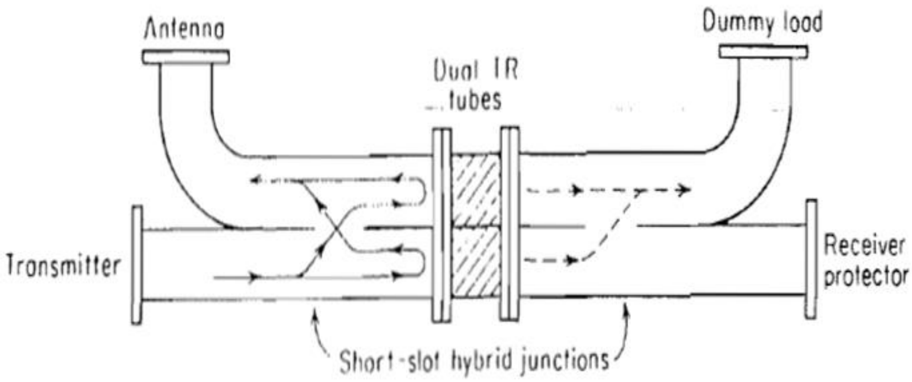


- **TRANSMIT**:
- TR and ATR tubes ionize and break down.

- (ii) TR located at λ/4 distance from main transmission appears as short circuit at R_x and open circuit at transmission line.
- (iii) ATR is λ/4 distance, so it allows power from T_x - open circuits at transmission line.
- **RECEIVE :**
- TR and ATR not fired since T_x is off.
- (ii) ATR is open circuited. But it is λ/4 distance from reception line. So it shorts transmission line. All echo power directed to R_x.
- (iii) TR is open circuited. But it is λ/4 distance from Receiving line. So it is short circuited at Receiving line. T_x is effectively disconnected.
- **DISADVANTAGES OF BRANCH TYPE DUPLEXER:**
- (i) Limited Bandwidth (ii) Limited Power.

- **BALANCED DUPLEXER:**

- **Transmit Mode** :
- Consists of 2 sections of waveguide.
- Slots cut in common wall.
- 2 TR tubes one in each section.
- Both Gas – Discharge TR tubes break down and reflect power to Antenna.
- When power passes through slit, 90^0 phase advance occurs.
- Leakage power directed to Dummy load instead of to R_x.
- a**Transmit Mode** :
- Consists of 2 sections of waveguide.
- Slots cut in common wall.
- 2 TR tubes one in each section.
- Both Gas – Discharge TR tubes break down and reflect power to Antenna.
- When power passes through slit, 90^0 phase advance occurs.
- Leakage power directed to Dummy load instead of to R_x.



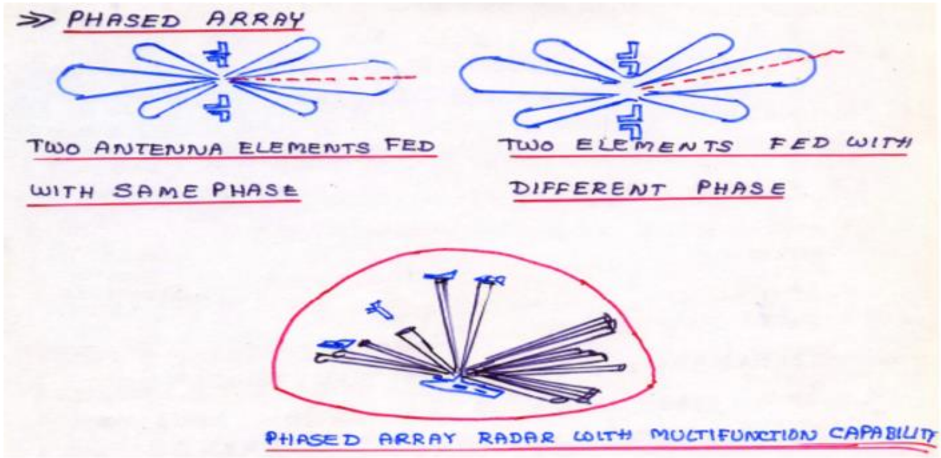
- **TRANSMIT MODE** :
- Consists of 2 sections of waveguide.
- Slots cut in common wall.
- 2 TR tubes one in each section.
- Both Gas – Discharge TR tubes break down and reflect power to Antenna.

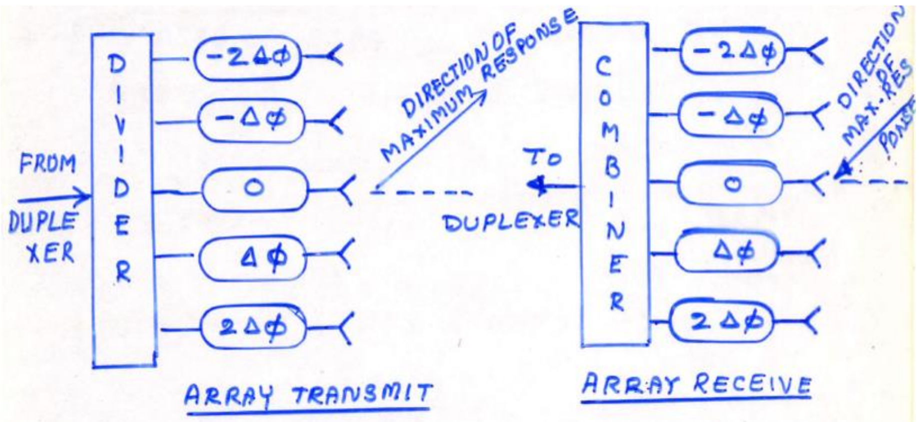
- When power passes through slit, 90^0 phase advance occurs.
- Leakage power directed to Dummy load instead of to R_x.

- **RECEIVE MODE** :
- TR tube does not break down (fire).
- Echo signals pass through TR tubes
- Power splits at First junction. Power passing through slit undergoes 90^0 phase advance.
- Power recombines in receiving arm but not in arm with dummy load.

- Q 9. What is a Phased Array antenna and explain about its radiation pattern

- Radar Beam is rapidly moved in space without moving large mechanical pedestal on which antenna is mounted
- **PHASED ARRAY ANTENNAS**





- PASSIVE VS ACTIVE:
- PESA: In a passive electronically scanned array, the microwave feed network in the back of the antenna is powered by a single RF source (magnetron, klystron, TWT etc.)

sending its waves into phase shift modules (usually digitally controlled) which in turn feed the numerous emitting elements

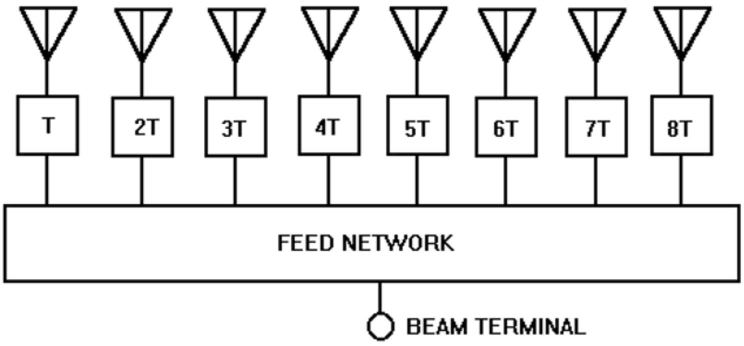
- AESA: An AESA, instead has individual RF source for each of its many transmit/receive elements, making them active. This provides for a graceful degradation, so that T/R modules may fail and the radar would not stop functioning.

- Q 10. List out the merits and demerits of Phased array antenna

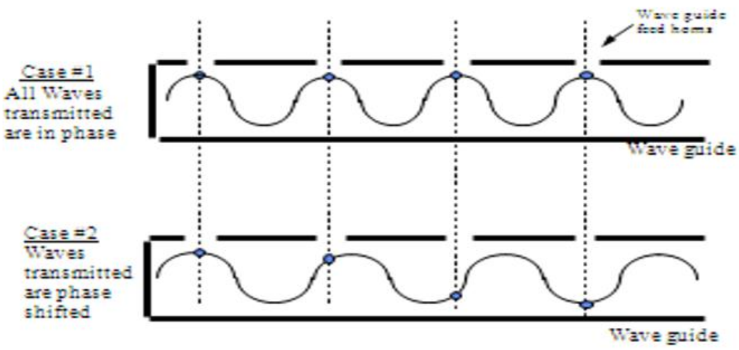
- **ADVANTAGES:**
- Short to instantaneous (milliseconds) scanning rates
- Much higher range
- Multiple angle beams tremendous number of targets being tracked
- Desirable low probability of intercept
- Solid state devices with vastly simpler mechanical designs
- No complex hydraulics for antenna movement
- Occupies less space than a typical radar
- Distributed transmit function eliminates most common single point failure seen in a conventional radar
- Low maintenance much more reliable
- Ability to function as a radio jammer
- High electronic counter measure (ECM) resistance
- Less susceptible to voltage failures. Very low voltage in individual elements
-
- **ELECTRONICALLY STEERED PHASED ARRAY ANTENNAS :**
- Phased Array Antenna is a directive Antenna.
- Radiation pattern is made up of number of Radiating elements.
- Shape & Direction of Radiation pattern depends on
- (i) Relative phases of elements
- (ii) Amplitude of currents at the elements.
- Direction of the Radiation pattern changed by varying relative phases between radiation elements.
- **ADVANTAGES:**
- i)Beam switched from one direction to another in a few micro secs
- ii)Rapid beam steering – Rapid location of Beam in any direction
- iii)Large number of radiating elements used. Each may have its own transmitter. Large peak/ large average power is possible. Power aperture product is large
- iv) Multiple target tracking is possible. Single beam is switched rapidly in any desired direction. This is done sequentially to view more than one target
- OR
- Multiple simultaneous independent beams are generated to track multiple targets
- V) Solid state transmitters can be used with each radiating element. Solid state Tx power is low. But summation of number of low power beams gives large power
- Vi) Control of aperture illumination is easy & convenient
- aVii) Multi function is possible, like search, sector/volume, search, track, dwell etc.
- Viii) Graceful degradation of power is possible. Even if a few Txs go bad, Radar continues to function with some degradation
-

- **DISADVANTAGES OF ESPA:**
- i) Complex, computer required for control of phase between elements
- Ii) High cost
-
- Q 11. Briefly explain the concept of beam steering Phased array antenna

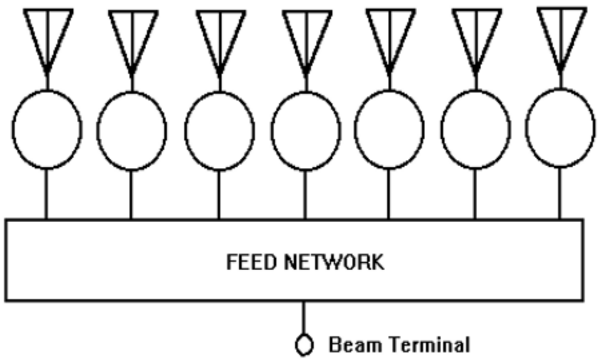
- Beam may be rapidly steered in space without moving large mechanical pedestal on which antenna is mounted
- Methods of Beam Steering - 3 kinds
- A) Time delay scanning
- B) Frequency scanning
- C) Phase scanning
- The last method ie Phase scanning is very commonly used because of lesser cost & less complexity
- **TIME DELAY SCANNING :**
- Time delay is used is used to achieve the desired phase relationship
- Time delay networks installed in front of each radiating element
- Expensive , complex & heavy



- **FREQUENCY SCANNING:**
- Physical length of waveguide is used to delay the frequency interval
- Vary the frequency about a base frequency
- Very simple and relatively less cost



-
- **Phase Scanning:**
- Radiating elements fed by Phase shifters
- Phases are electronically adjusted & controlled
- More expensive than frequency scanning but cheaper than time delay

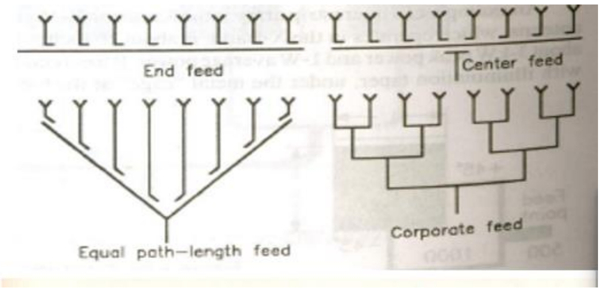


-
- Phase of signal applied to each radiating element varied to obtain beam in desired direction
- If same phase is used in all elements the relative phase between adjacent elements is zero. The beam is at angle θ =0 to the array
- If phase difference between adjacent elements is not zero, the direction of beam is different from broadside
- $\Phi = 2\pi\ [d/\lambda]\ \sin\theta_0$
- Where Φ = Phase difference between adjacent elements
- θ_0 = Direction of beam
- Phase at every element is $\Phi_e + m\,\Phi$ where m = 0, 1,2 ,... (N–1)
- G (θ) =

$$\frac{\sin^2\{N\pi\ [d/\lambda][\sin\theta - \sin\theta_o]}{N^2\sin^2\{\pi\ [d/\lambda][\sin\theta - \sin\theta_0]}$$

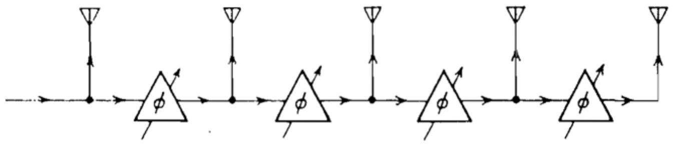
- Maximum occurs when $\sin\theta = \sin\theta_0$
- By properly inserting phase shift φ at each element , the main beam position ie θ_0 can be changed.
- For this purpose Phase shifters are used
- Grating lobes appears at angle θ_g whenever denominator is zero
- $|\sin\theta_g - \sin\theta_0| = \pm n\,[\lambda/d]$
- When $d = \lambda/2$, grating lobe appears at -90^0 when main beam is steered to $+90^0$
- Element spacing should not be larger than $\lambda/2$ if beam is required to be steered over a wide angle
- If $d = 0.54\lambda$, the steering is limited to angle
- $\pm 60^0$

- Q 12. Distinguish between Series and parallel feed array arrangements
- **CONVENTIONAL FEEDS:**

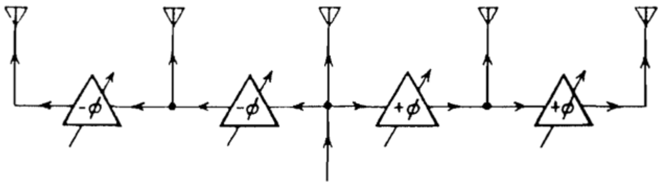


-

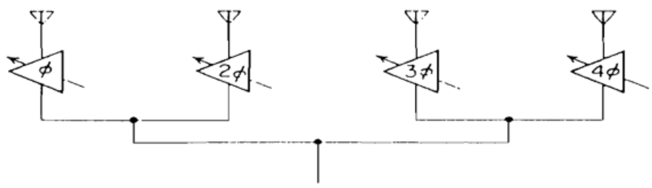
- Relative phase shift between adjacent elements must be $\varphi = 2\pi [d/\lambda] \sin\theta_0$
- Where φ = Phase shift
- θ_0 = Position of main beam pattern
- Arrangement to get necessary phase shift
- i) Series fed feed
- ii) Parallel fed feed
- **SERIES FED FEED:**
- Energy transmitted i) fed from one end of the line



- Energy transmitted ii) fed from the centre to reach both ends



- Adjacent elements are connected by a phase shifter with phase shift of φ
- All phase shifters are identical and the phase shift is less that 2π radians
- In series arrangement where signal is fed from one end, the position of the beam will vary with frequency
- So this arrangement is limited in bandwidth
- Center fed feed does not have this problem
- **PARALLEL FEED:**
- Power Splitter is used to divide the energy
- Series of power splitter are used to create a tree like structure. This is also called Corporate feed
- Equal lengths of line , transmit energy to each element so that no unwanted phase difference are introduced by lines themselves



- The Phase shifts required in succeeding elements are φ, 2φ, 3φ, …… $(N-1)\varphi$
- Maximum phase change required for each phase shifter is many times 2π radians
- Since phase shift is periodic with period 2π , phase shifter can have a value of maximum 2π radians
- If the pulse width is small signal bandwidth is large compared to antenna bandwidth
- In above such case the received pulse which is the sum of number of elements gets smeared. This problem is overcome by replacing the 2π modulo phase shifter with Delay lines
- **COMPARISON OF SERIES & PARALLEL FED ARRAYS:**
- **INSERTION LOSS:**
- In series fed array the insertion loss is N times the loss of a single element
- In parallel fed array the insertion loss is introduced only once

- So individual phase shifter in a Series fed array should have low insertion loss compared to that on parallel fed array. Some times Amplifiers are introduced to compensate for signal attenuation
- **CONTROL SIGNAL :**
- In Series fed array only one control signal is required to steer the beam since same value of phase shift is used
- In Parallel fed array (N – 1) control signals are required
- 2 Dimensional M x N array requires M + N – 2 separate control signals. A Series fed array requires only 2 control signals

END OF UNIT 5