Radar System

UNIT - 1

Topics to be covered :-

→ Introduction
→ Maximum Unambiguous Range
→ Simple Radar Range Equation
→ Radar Block Diagram and operation
→ Radar Frequencies and Applications
→ prediction of Range performance
→ Minimum Detectable signal
→ Receiver Noise
→ Modified Radar Range Equation
→ Signal to Noise Ratio
→ probability of detection
→ probability of False Alarm
→ Integration of Radar pulses
→ Radar cross section of Targets (simple Targets – sphere, cone-sphere)
→ Creeping wave
→ Transmitter power
→ pulse repetition frequency and Range ambiguities
→ system Losses
→ Illustrative problems.

→ Radar acronym is Radio Detection And Ranging.

Radar is an electromagnetic system for the detection and location of reflecting objects such as aircrafts, ships, space craft, vehicles, and the natural environment.

✓ It operates by radiating energy into space and detecting the echo signal reflected from an object (or) target.

✓ The reflected energy that is returned to the radar not only indicates the presence of a target, but by comparing the received echo signal with the signal that was transmitted, its location can be determined along with other target-related information.

✓ Radar can perform its function at long (or) short distances and under conditions impervious to optical and infrared sensors. It can operate in darkness, haze, fog, rain and snow. Its ability to measure distance with high accuracy and in all weather is one of its most important attributes.

→ Advantages of Radars :-

✓ Radars can see through darkness, Haze, fog, rain and snow.

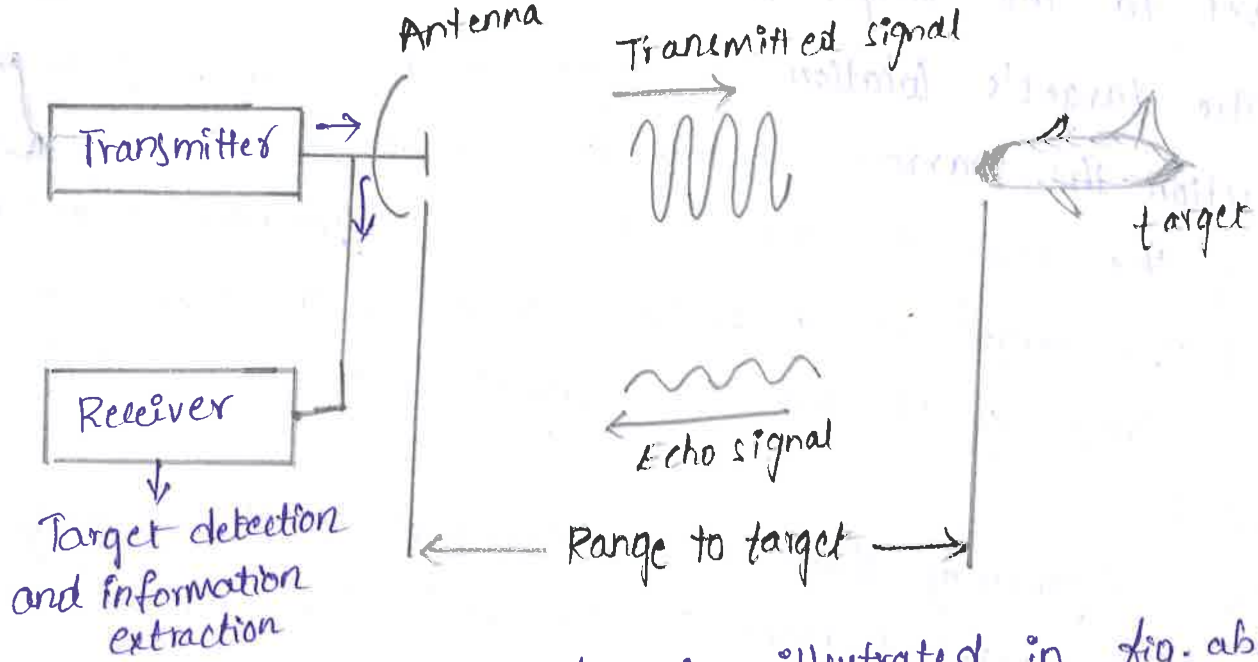
✓ They can determine the range and angle i.e the location of the target very accurately.

→ Disadvantages of Radars :-

✓ Radars cannot resolve in detail like the human eye, especially at short distances.

✓ They cannot recognize the colour of the target.

→ **Basic principle of Radar :-**



✓ The basic principle of radar is illustrated in fig. above. A transmitter (in the upper left portion of the figure) generates an electromagnetic signal (such as a short pulse of sine wave) that is radiated into space by an antenna.

✓ A portion of the transmitted energy is intercepted by the target and reradiated in many directions.

✓ The reradiation directed back towards the radar is collected by the radar antenna, which delivers it to a receiver. There it is processed to detect the presence of the target and determine its location.

✓ A single antenna is usually used on a time-shared basis for both transmitting and receiving when the radar waveform is a repetitive series of pulses.

✓ The range, or distance, to a target is found by measuring the time it takes for the radar signal to travel to the target and return back to the radar.

✓ The target's location in angle can be found from the direction the narrow-beamwidth radar antenna points when the received echo signal is of maximum amplitude.

✓ If the target is in motion, there is a shift in the frequency of the echo signal due to the doppler effect.

✓ This frequency shift is proportional to the velocity of the target due relative to the radar (also called the radial velocity).

✓ The doppler frequency shift is widely used in radar as the basis for separating desired moving targets from fixed (unwanted) "clutter" echoes reflected from the natural environment such as land, sea or rain. Radar can also provide information about the nature of the target being observed.

Range to a Target / Measurement of Range :-

→ The most common radar signal, or waveform, is a series of short-duration, somewhat rectangular-shaped pulses modulating a sine wave carries. This is sometimes called a pulse train.

✓ The range to a target is determined by the time T_R it takes the radar signal to travel to the target and back.

✓ Electromagnetic energy in free space travels with the speed of light, which is $c = 3\times10^8$ m/s.

✓ Thus, the time for the signal to travel to a target located at a range R, and return back to the radar is $2R/c$.

The range to a target is then

$$R = \frac{C T_R}{2}.$$

✓ The factor 2 appears in the denominator because of the two-way propagation of radar, with the range R in kilometers or nautical miles, and T_R in microseconds, the above relation becomes

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

Each microsecond of round-trip travel time corresponds to a distance of 150 meters, 164 yards, 492 feet, 0.081 nautical mile or 0.093 statute mile. It takes 12.35 μs for a radar signal to travel a nautical mile and back.

→ **Maximum Unambiguous Range :-**

The range beyond which targets appear as second-time around echoes is the maximum unambiguous range, Run and is given by

$$R_{un} = \frac{C T_p}{2} = \frac{C}{2 f_p}.$$

where T_p = pulse repetition period = $1/f_p$

f_p = pulse repetition frequency (prf). hertz (or) pps. pulse per second once a signal is radiated into space by a radar, sufficient time must elapse to allow all echo signals to return to the radar before the next pulse is transmitted.

✓ The rate at which pulses may be transmitted, therefore is determined by the longest range at which targets are expected.

✓ If the time b/w pulses Tp is too short, an echo signal from a long-range target might arrive after the transmission of the next pulse and be mistakenly associated with that of the next pulse and be mistakenly associated with that pulse rather than the actual pulse transmitted earlier.

✓ This can result in an incorrect or ambiguous measurement of the range.

✓ Echoes that arrive after the transmission of the next pulse are called second-time-around echoes (or multiple-time-around echoes if from even earlier pulses). such an echo would appear to be at a closer range than actual and its range measurement could be misleading if it were not known to be a second-time-around echo.

✓ So, the range beyond which targets appear as second-time-around echoes is the maximum unambiguous range Run.

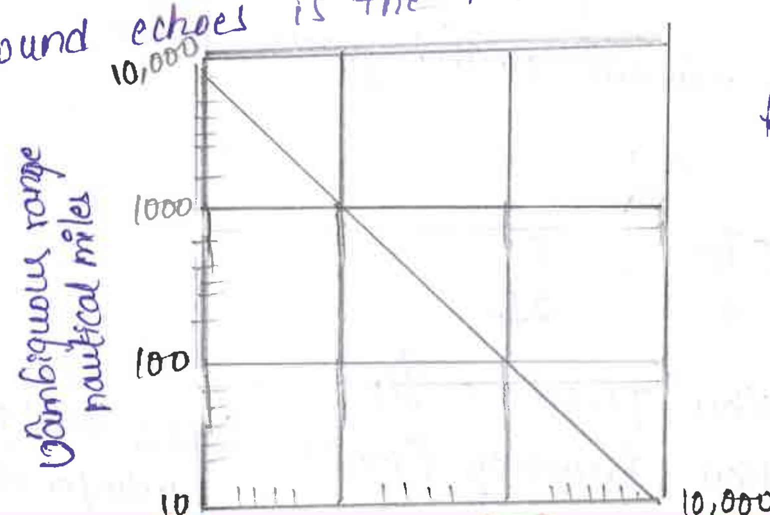


fig: The Run amb as a function of prf.

→ Simple form of the Radar Equation :-

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

✓ It is useful not only for determining the maximum range at which a particular radar can detect a target, but it can serve as a means for understanding the factors affecting radar performance.

✓ The simple form of the radar range equation is derived.

✓ If the transmitted power P_t is radiated by an isotropic antenna (one that radiates uniformly in all directions), the power density at a distance R from the radar is equal to the radiated power divided by the surface area $4\pi R^2$ of an imaginary sphere of radius R,

Power density at range R from an isotropic antenna

$$= \frac{P_t}{4\pi R^2} \quad \text{--- (1)}$$

Power density is measured in units of watts per square meter.

✓ Radars, however, employ directive antennas (with narrow beamwidths) to concentrate the radiated power P_t in a particular direction.

✓ The gain of an antenna is a measure of the increased power density radiated in some direction as compared to the power density that would appear in that direction from an isotropic antenna.

✓ The maximum gain G of an antenna may be defined as

$$G = \frac{\text{maximum power density radiated by a directive antenna.}}{\text{Power density radiated by a lossless isotropic antenna with the same power input.}}$$

✓ The power density at the target from a directive antenna with a transmitting gain G is then

$$\text{power density at range R from a directive antenna} = \frac{P_t G}{4\pi R^2} \quad \text{--- (2)}$$

✓ The target intercepts a portion of the incident energy and reradiates it in various directions. It is only the power density reradiated in the direction of the radar (the echo signal) that is of interest.

✓ The radar cross section of the target determines the power density returned to the radar for a particular power density incident on the target. It is denoted by 'σ' and is often called for short, target cross section, radar cross section, or simply cross section.

✓ The radar cross section is defined by the following Equation

$$\text{Reradiated power density back at the radar} = \frac{P_t G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \quad \text{--- (3)}$$

✓ The radar cross section has units of area, but it can be misleading to associate the radar cross section directly with the target's physical size. Radar cross section is more dependent on the target's shape than on its physical size.

✓ The radar antenna captures a portion of the echo energy incident on it.

✓ The power received by the radar is given as the product of the incident power density times the effective area A_e of the receiving antenna.

✓ The effective area is related to the physical area A by the relationship $A_e = \rho_a A$, where ρ_a = antenna aperture efficiency.

The received signal power P_r (watts) is then

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

✓ The maximum range of a radar R_{max} is the distance beyond which the target cannot be detected. It occurs when the received signal power P_r just equals the minimum detectable signal S_{min}.

substituting $S_{min} = P_r$ in Eq (4) then

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}}\right]^{1/4} \longrightarrow (5)$$

This is the fundamental form of the radar range equation.

✓ If the same antenna is used for both transmitting and receiving, as it usually is in radar, antenna theory gives the relationship between the transmit gain G and the receive effective area A_e as where $\lambda \rightarrow$ wavelength.

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \rho_a A}{\lambda^2} \quad \text{—— (6)}$$

Eq (6) can be substituted in Eq (5), first for A_e and then for G, to give two other forms of the radar equation.

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

→ Radar Block Diagram :-

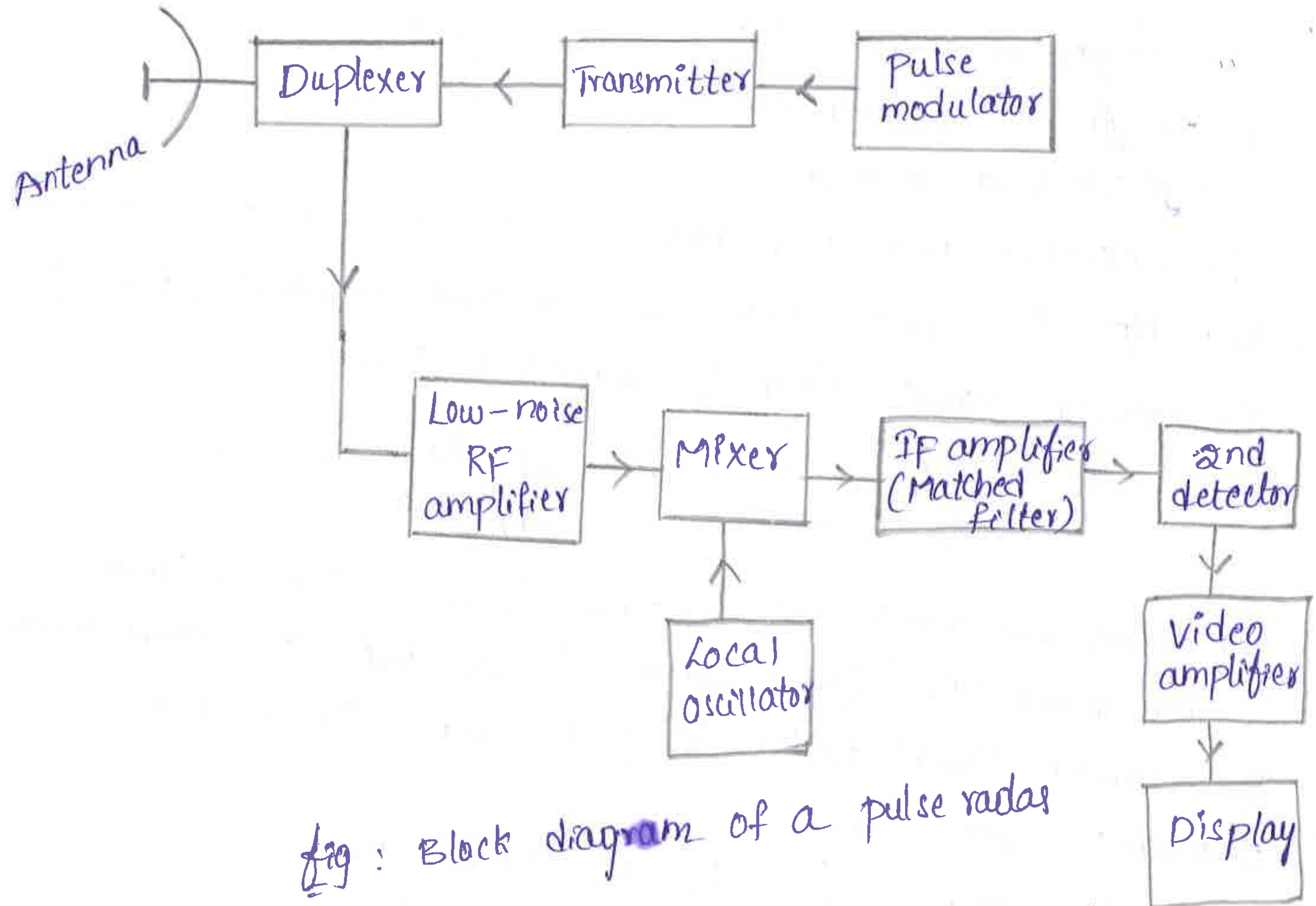


fig : Block diagram of a pulse radar

✓ The operation of a typical pulse radar may be described with the aid of block diagram shown in above figure.

✓ The transmitter may be an oscillator such as a magnetron, that is "pulsed" (turned on and off) by the modulator to generate a repetitive train of pulses.

✓ The magnetron has probably been the most widely used of the various microwave generators for radars.

✓ A typical radar for the detection of aircraft at ranges of 100 (or) 200 nmi might employ a peak power of the order of a megawatt, an average power of several Kilowatts, a pulse width of several micro seconds and a pulse repetition frequency of several hundred pulses per second.

✓ The wave form generated by the transmitter travels via a transmission line to the antenna, where it is radiated into space.

✓ A single antenna is generally used for both transmitting and receiving. The receiver must be protected from damage caused by the high power of the transmitter. This is the function of the duplexer.

✓ The duplexer also serves to channel the returned echo signals to the receiver and not to the transmitter.

✓ The duplexer might consists of two gas-discharge devices, one known as a TR (Transmit-receive) and the other an ATR (Anti-transmit-receive).

✓ The TR protects the receiver during transmission and ATR directs the echo signal to the receiver during reception.

✓ Solid-state ferrite circulators and receiver protected with gas-plasma TR devices and/or diode limiters are also employed as duplexers.

✓ The receiver is usually of the superheterodyne type. The first stage might be a low-noise RF amplifier such as a parametric amplifier or a low-noise transistor.

- The receiver input can simply be the mixer stage, especially in military radars that must operate in a noisy environment.
- Although a receiver with a low-noise front-end will be more sensitive, the mixer input can have greater dynamic range, less susceptibility to overload and less vulnerability to electronic interference.
- The mixer and local oscillator (LO) convert the RF signal to an intermediate frequency (IF).
- A typical IF amplifier for an air-surveillance radar might have a center frequency of 30 (or) 60 MHz and a bandwidth of the order of one megahertz.
- The IF amplifier should be designed as a matched filter; i.e its frequency response function H(f) should be maximize the peak-signal-to-mean noise power ratio at the output.
- This occurs when the magnitude of the frequency response function |H(f)| is equal to the magnitude of the echo signal spectrum |S(f)|, and the phase spectrum of the matched filter is the negative of the phase spectrum of the echo signal.
- In a radar whose signal waveform approximates a rectangular pulse, the conventional IF filter bandpass characteristic approximates a matched filter when the product of the IF bandwidth B and the pulse width τ is of the order of unity, that is $B\tau \simeq 1$.

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

✓ Timing signals are also supplied to the indicator to provide the range zero.

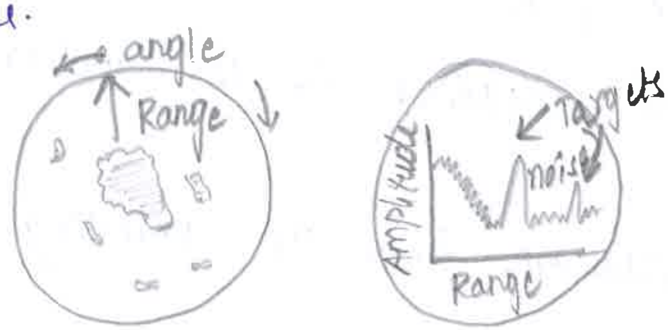
✓ Angle information is obtained from the pointing direction of the antenna.

✓ The most common form of cathode-ray tube display is the plan position indicator or PPI, which maps in polar co-ordinates the location of the target in azimuth and range. This is an intensity-modulated display in which the amplitude of the receiver output modulated the electron-beam intensity (z-axis) as the electron beam is made to sweep outward from the center of the tube.

✓ The beam rotates in angle in response to antenna position. A B-scope display is similar to the PPI except that it utilizes rectangular rather than polar coordinates to display range vs angle.

✓ Both the B-scope and the PPI, being intensity modulated, have limited dynamic range.

✓ Another form of display is the A-scope shown in fig 2(b), which plots target amplitude (y-axis) Vs range (x-axis) for some fixed direction. This is a deflection modulated display. It is more suited for tracking radar application than for surveillance radar.



(a) (b)

fig:
(a) PPI presentation displaying range Vs angle (intensity modulation)
(b) A-scope presentation displaying amplitude Vs range (deflection modulation)

✓ A common form of radar antenna is a reflector with a parabolic shape, fed (illuminated) from a point source at its focus. The parabolic reflector focuses the energy into a narrow beam, just as does a searchlight or an automobile headlamp.

✓ The beam may be scanned in space by mechanical pointing of the antenna.

✓ Phased array antennas have also been used for radar. In a phased array, the beam is scanned by electronically varying the phase of the current across the aperture.

→ Nature and Types of Radars :-

The common types of radars are

① speed trap radars
② missile tracking radars
③ Early warning radars
④ Airport control radars.

5. Navigation radars
6. Astronomy radars
7. Ground mapping radars
8. weather forecast radars
9. Gunfire control radars
10. Remote sensing radars
11. Tracking radars
12. Search radars
13. Missile control radars.
14. MTI radars
15. Navy radars
16. Doppler radars
17. Over the Horizon (OTH) radars
18. Monopulse radars
19. phased array radars
20. Instrumentation radars
21. Gun direction radars
22. Airborne weather radars

→ Radar frequencies :-

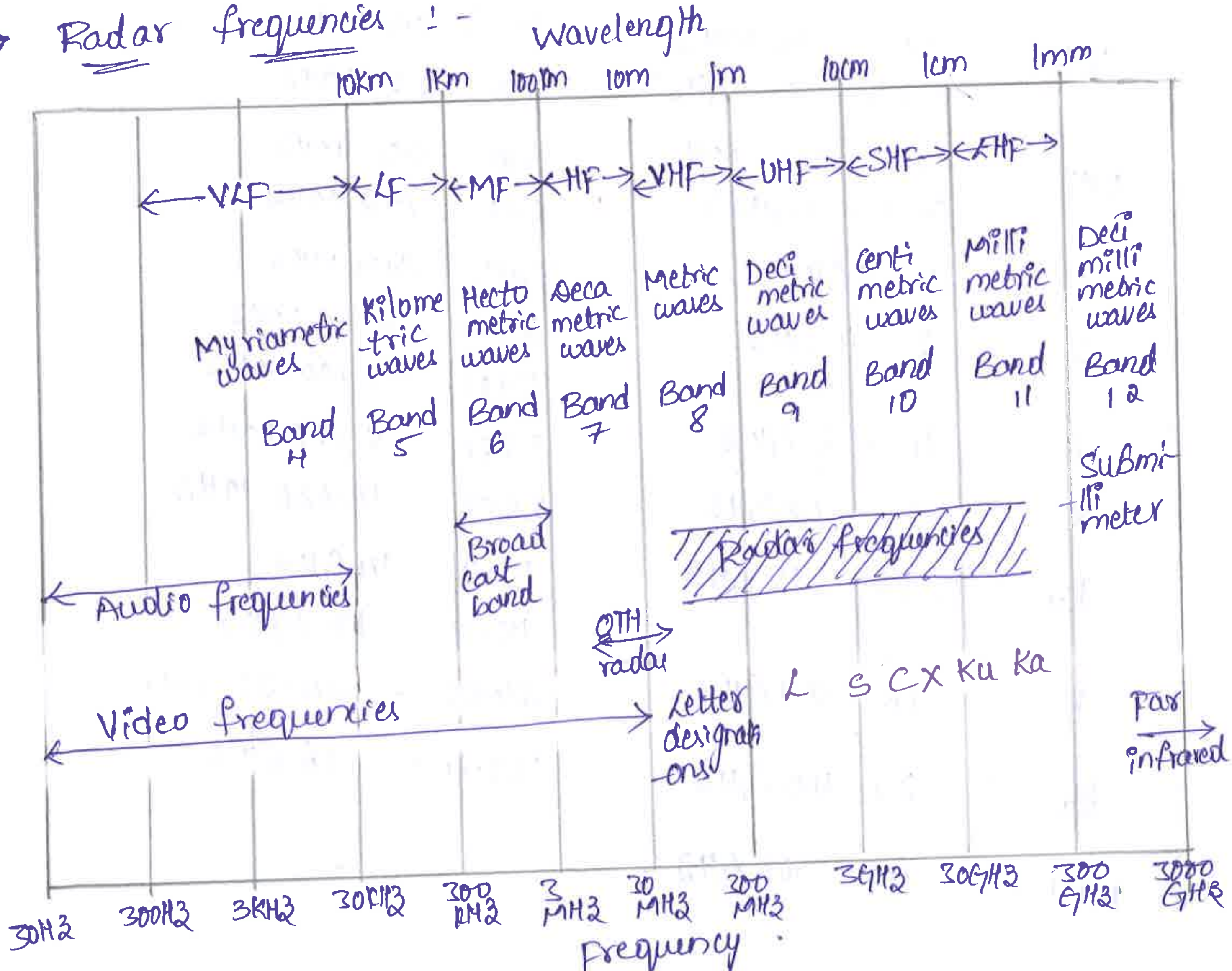


Fig: Radar frequencies and the Electromagnetic spectrum.

✓ conventional radars generally operate in what is called the microwave region. operational radars in the part have been at frequencies ranging from about 100 MHz to 36 GHz which covers more than eight octaves.

IEEE standard radar-frequency letter-band nomenclature

Band designation	Nominal frequency range	specific radiolocation (radar) Bands based on ITU assignments for region 2.
HF	3 - 30 MHz (0.003 - 0.03 GHz)	
VHF	30 - 300 MHz (0.03 - 0.3 GHz)	138 - 144 MHz 216 - 225 MHz
UHF	300 - 1000 MHz (0.3 - 1 GHz)	420 - 450 MHz 890 - 942 MHz
L	1 - 2 GHz	1215 - 1400 MHz
S	2 - 4 GHz	2300 - 2500 MHz 2700 - 3700 MHz
C	4 - 8 GHz	5250 - 5925 MHz
X	8 - 12 GHz	8500 - 10,680 MHz
Ku	12 - 18 GHz	13.4 - 14 GHz 15.7 - 17.7 GHz
K	18 - 27 GHz	24.05 - 24.25 GHz
Ka	27 - 40 GHz	33.4 - 36 GHz
mm	40 - 300 GHz	

✓ conventional radars generally have been operated at frequencies extending from about 220MHz to 35 GHz, a spread of more than seven octaves. These are not necessarily the limits, since radars can be and have been operated at frequencies outside either end of this range.

✓ Sky wave HF over the-horizon (OTH) radar might be at frequencies as low as 4 or 5 MHz and groundwave HF radars as low as 2MHz.

✓ At the other end of the spectrum millimeter radars have operated at 94 GHz. Laser radars operate at even higher frequencies.

✓ Early in the development of radar, a letter code such as S, X, L etc., was employed to designate radar frequency bands.

✓ Although its original purpose was to guard military secrecy, the designations were maintained, probably out of habit as well as the need for some convenient short nomenclature. This usage has continued and is now an accepted practice of radar engineers. Table lists the radar frequencies letter band nomenclature adopted by the IEEE.

✓ Letter-band nomenclature is not a substitute for the actual numerical frequency limits of radars. The specific numerical frequency limits should be used whenever appropriate but the letter designations of table may be used whenever a short notation is desired.

→ **Applications of radar :-**

Radar has been employed to detect targets on the ground, on the sea, in the air, in space, and even below ground.

✓ The major areas of radar application are briefly described below.

① **Military :-** Radar is an important part of air-defense systems as well as the operation of offensive missile and other weapons. In air-defense it performs the functions of surveillance and weapon control. Surveillance includes target detection, target recognition, target tracking and designation to a weapon system.

✓ weapon-control radars track targets, direct the weapon to an intercept, and assess the effectiveness of the engagement. (called battle damage assessment).

✓ A missile system might employ radar methods for guidance and fuzing of the weapon.

✓ High-resolution imaging radars, such as synthetic aperture radar, have been used for reconnaissance purposes and for detecting fixed and moving targets on the battlefield.

✓ Many of the civilian applications of radar are also used by the military. The military has been the major user of radar and the major means by which new radar technology has been developed.

(2) Remote Sensing :- All radars are remote sensors ; however this term is used to imply the sensing of the environment. Four important examples of radar remote sensing are
(1) weather observation, which is a regular part of TV weather reporting as well as input to national weather prediction.
(2) planetary observation, such as the mapping of venus Beneath its visually opaque clouds.
(3) short-range Below-ground probing and
(4) mapping of sea ice to route shipping in an efficient manner.

Air Traffic control (ATC) :- Radars have been employed around the world to safely control air traffic in the vicinity of airports (Air surveillance Radar, or SAR) and enroute from one airport to author (Air route surveillance radar or ARSR) as well as ground vehicle traffic and taxing aircraft on the ground (Airport Surface Detection equipment or ASDE). The ASR also maps regions of rain so that aircraft can be directed around them. There are also radars specifically dedicated to observing weather in the vicinity of airports, which are called Terminal Doppler weather radar, or TDWR. The air Traffic control Radar Beacon system (ATCRBS and Mode-S) widely used for the control of air Traffic, although not a radar, originated from military IFF (Identification friend or Foe) and uses radar like Technology.

Law Enforcement and Highway safety :- The radar speed meter, familiar to many, is used by police for enforcing speed limits (A variation is used in sports to measure the speed of a pitched baseball). Radar has been considered for making vehicles safer by warning of pending collision, actuating the air bag, or warning of obstructions or people behind a vehicle or in the side blind zone. It is also employed for the detection of instrudees.

Aircraft safety and Navigation :- The airborne weather-avoidance radar outlines regions of precipitation and dangerous wind shear to allow the pilot to avoid hazardous conditions. Low-flying military aircraft rely on terrain avoidance and terrain following radars to avoid colliding with obstructions or high terrain. Military aircraft employ ground-mapping radars to image a scene. The radio altimeter is also a radar used to indicate the height of an aircraft above the terrain and as a part of self-contained guidance systems overland.

Ship safety :- Radar is found on ships and boats for collision avoidance and to observe navigations buoys, especially when the visibility is poor. Similar shore-based radars are used for surveillance of harbors and river traffic

Space :- space vehicles have used radar for rendezvous and docking, and for landing on the moon. As mentioned they have been employed for planetary exploration, especially the planet earth.

✓ Large ground-based radars are used for the detection and tracking of satellites and other space objects.

✓ The field of radar astronomy using Earth based system helped in understanding the nature of meteors, establishing an accurate measurement of the astronomical unit and observing the moon and nearby planets before adequate space vehicles were available to explore them at close distances.

Other :- Radar has also found application in industry for the noncontact measurement of speed and distance. It has been used for oil and gas exploration. Entomologists and ornithologists have applied radar to study the movement of inspects and birds, which cannot be easily achieved by other means.

Radar Applications

1. Air Traffic control
2. weather forecasting
3. Identification of friend or foe.
4. Range, velocity, height of a flying target can be measured.
5. Missile guidance.
6. Air surveillance
7. Jamming radars (transmission of confusing signals at enemy radars).
8. Police radars for the control of traffic speed.

→ Civilian Applications

1. Navigational aid on ground and sea (navigation is not affected by poor visibility or darkness).
2. Radar altimeters for determining the height of plane above ground.
3. Radar Blind lander for aiding aircraft to land under poor visibility, at night, under adverse weather conditions etc.
4. Airborne radar for satellite surveillance
5. police radars for directing and detecting speeding vehicles.
6. Radars for determining the speed of moving targets, automobile shells, guided missiles etc,

Military applications:

1. Detection and ranging of enemy targets even at night.
2. Aiming guns at aircraft and ships.
3. Bombing ships, aircraft or cities even during overcast or at night.
4. Early warning regarding approaching aircraft (or) ships.
5. Directing guided missiles.
6. Searching for submarines, land masses and buoys.

→ Prediction of Range performance :-

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

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

where, P_t = Transmitted power, watts
G = Antenna gain
A_e = Antenna effective aperture, m^2
σ = Radar cross section, m^2
S_{min} = minimum detectable signal, watt.

- ✓ except for the targets radar cross section of the parameters of this simple form of the radar equation are under the control of the radar designer.
- ✓ The radar equation states that if long ranges are desired. The transmitted power must be large, the radiated energy must be concentrated into a narrow beam (large transmitting gain), the echo energy should be received by a large antenna aperture (also synonyms with large gain) and the receiver should be sensitive to weak signals.
- ✓ In practice, however the simple radar equation does not accurately predict the range performance of actual radars.
- ✓ The predicted values of radar range are usually optimistic. In some cases the actual range might be only half of that predicted.

✓ The failure of the simple form of radar equation is due to ① the statistical nature of the minimum detectable signal (usually determined by receiver noise) ② fluctuations and uncertainties in the target's radar cross section. ③ The losses experienced throughout a radar system and ④ propagation effects caused by the earth's surface and atmosphere.

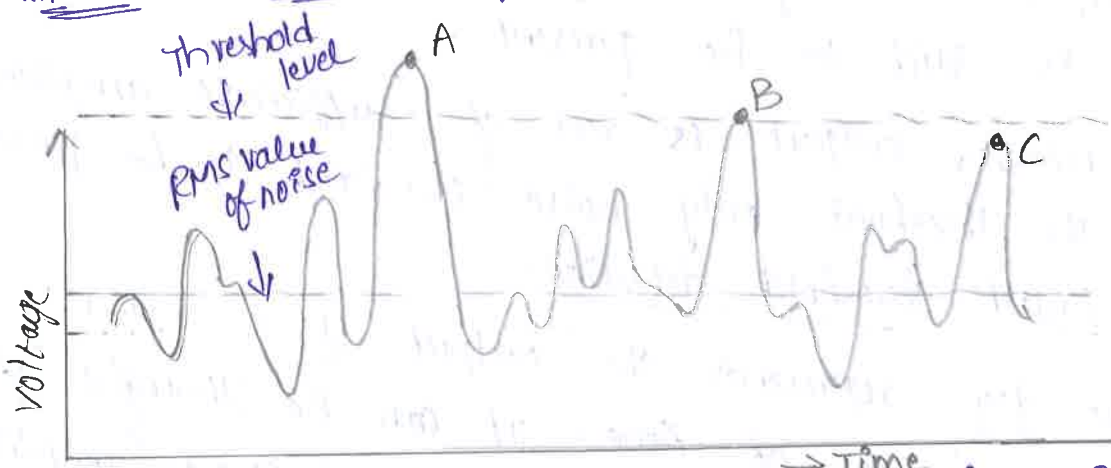
✓ The statistical nature of receiver noise and the target cross section requires that the maximum radar range be described probabilistically rather than by a single number. Thus the specification of range must include the probability that the radar will detect a specified target at a particular range, and with a specified probability of making a false detection when no target echo is present.

✓ The range of a radar, therefore will be a function of the probability of detection Pd and the probability of false alarm Pfa.

✓ The prediction of radar range cannot be performed with arbitarily high accuracy because of uncertainities in many of the paremeters that determine the range. Even if the factors affecting the range could be predicted with high accuracy the statistical nature of radar detection and the variability of the target's radar cross section and other effets make it difficult to accurately verify the predicted range.

✓ Inspite of it not being as precise as one might wish, the radar equation is an important tool for ① assessing the performance of a radar ② determining the system trade-offs that must be considered when designing a new radar system and ③ aiding in generating the technical requirements for a new radar procurement.

→ **Minimum Detectable signal (S_{min}) :-**



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

✓ The ability of a radar receiver to detect a weak echo signal is limited by the ever-present noise energy that occupies the same portion of the frequency spectrum as does the signal.

Definition :- The weakest signal the receiver can detect is called the minimum detectable signal. (or)
The weakest signal that can just be detected by a receiver is the minimum detectable signal. In the radar equation, it was denoted as S_{min}.

✓ The specification of the minimum detectable signal is sometimes difficult because of its statistical nature and because the criterion for deciding whether a target is present or not may not be too well defined.

✓ Detection of a radar signal is based on establishing a threshold at the output of the receiver. If the receiver output is large enough to exceed the threshold, a target is said to be present.

✓ If the receiver output is not of sufficient amplitude to cross the threshold, only noise is said to be present. This is called Threshold detection.

✓ The above fig. represents the output of a radar receiver as a function of time. It can be thought of as the video output displayed on an A-scope (amplitude Vs time or range).

✓ The envelope has a fluctuating appearance caused by the random nature of noise.

✓ If a large signal is present such as at A in fig. It is greater than the surrounding noise peaks and can be recognized on the basis of its amplitude. Thus if the threshold level were set sufficiently high, the envelope would not generally exceed the threshold if noise alone were present, but would exceed it if a strong signal were present.

- If the signal were small, however it would be more difficult to recognize its presence. The threshold level must be low if weak signals are to be detected, but it cannot be so low that noise peaks across the threshold and give a false indication of the presence of targets.
- The voltage envelope of above fig. is assumed to be from a matched-filter receiver.
- A matched filter is one that maximizes the output signal-to-noise ratio. Almost all radars employ a matched filter or a close approximation.
- Let us return to the receiver output as represented in fig. A threshold level is established, as shown by the dashed line. A target is said to be detected if the envelope crosses the threshold. If the signal is large such as at A, it is not difficult to decide that a target is present.
- But consider the two signals at B and C, representing target echoes of equal amplitude.
- The noise voltage accompanying the signal at B is large enough so that the combinational of signal plus noise exceeds the threshold. At C the noise is not as large and the resultant signal plus noise does not cross the threshold.
- Thus the presence of noise will sometimes enhance the detection of weak signals but it may also cause the

loss of a signal which would otherwise be detected.

✓ weak signals such as C would not be lost, if the threshold level were lower. But too low a threshold increases the likelihood that noise alone will rise above the threshold and be taken for a real signal. such an occurrence is called a false alarm.

✓ Therefore, if the threshold is set too low, false target indications are obtained, but if it is set too high, targets might be missed. The selection of the proper threshold level is a compromise that depends upon how important it is if a mistake is made either by (1) failing to recognize a weak signal that is present (probability of a miss) or by (2) falsely indicating the presence of a target signal when none exists (false alarm).

✓ The signal to noise ratio is a better measure of a radar's detection performance than is the minimum detectable signal.

→ Receiver noise and SNR :-

The noise affects the maximum radar range as it determines the minimum received power that the radar can detect. Also, the radar range can be increased by decreasing minimum detectable power which depend on the sensitivity of the receivers and hence on its noise figure.

✓ Since noise is the chief factor limiting receiver sensitivity, it is necessary to obtain some means of describing it quantitatively.

✓ Noise is unwanted EM energy which interferes with the ability of the receiver to detect the wanted signal. It may originate within the receiver itself, or it may enter via the receiving antenna along with the desired signal.

✓ If the radar were to operate in a perfectly noise-free environment so that no external sources of noise accompanied the desired signal, and if the receiver itself were so perfect that it did not generate any excess noise, there would still exist an unavoidable component of noise generated by the thermal motion of the conduction of electrons in the ohmic portions of the receiver input stages. This is called Thermal noise (or) Johnson noise and is directly proportional to the temperature of the ohmic portions of the circuit and the receiver bandwidth.

✓ The available thermal noise power generated at the input of a receiver of bandwidth Bn (hertz) at temperature T (degree Kelvin) is

$$\boxed{\text{Available thermal noise power} = KTB_n} \quad \text{---} (1)$$

where K = Boltzmann's constant = 1.38×10^{-23} J/deg.

✓ The bandwidth of a superhetrodyne receiver (and almost all radar receivers are of this type) is taken to be that of the IF amplifier (or matched filter).

In eq ① the bandwidth B_n is called the noise bandwidth, defined as

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

where $H(f)$ = frequency-response characteristic of IF amplifier (filter) and f_0 = frequency of the maximum response (usually occurs at the midband).

✓ Noise bandwidth is not the same as the more familiar half-power, or 3-dB bandwidth

✓ Eqn ② states that the noise bandwidth is the bandwidth of the equivalent rectangular filter whose noise-power output is the same as the filter with frequency response function H(f).

✓ The half-power bandwidth is defined by the separation between the points of the frequency response function H(f) where the response is reduced to 0.707 (3dB in power) from its maximum value. Although it is not the same as the noise bandwidth, the half-power bandwidth is a reasonable approximation for many practical radar receivers. Thus the half-power bandwidth B is usually used to approximate the noise bandwidth B_n.

✓ The noise power in practical receivers is greater than that from thermal noise alone.

✓ The measure of the noise out of a real receiver to that from the ideal receiver with only thermal noise is called the noise figure and is defined as

The noise figure of a receiver

$$F_n = \frac{\text{Noise out of practical receiver}}{\text{Noise out of ideal receiver at standard temperature } T_0}$$

$$\boxed{F_n = \frac{N_{out}}{K T_0 B_n G_a}} \quad (\text{or}) \quad F_n = \frac{N_o}{K T_0 B_n G_a} \quad \text{—— (3)}$$

where, N_o = noise out of the receiver
G_a = Available gain.

The standard temperature T_0 is taken to be 290K, according to the IEEE definition. This is close to room temperature (62°F).

with this definition, $KT_0 = 4 \times 10^{-21}$ W/Hz.

But G_a can be defined as,

$$G_a = \frac{\text{signal out } (S_{out})}{\text{signal in } (S_{in})} \quad \text{or} \quad G_a = \frac{S_o}{S_i}$$

✓ The input noise, N_i in an ideal receiver is

$$\boxed{N_i = K T_0 B_n}$$

✓ The definition of noise figure given by eqn (3) therefore can be written as

$$F_n = \frac{N_o}{K T_0 B_n G_a} = \frac{N_o}{N_i \cdot \frac{S_o}{S_i}} = \frac{S_i N_o}{N_i S_o} = \frac{S_i/N_i}{S_o/N_o}$$

$$F_n = \frac{S_i/N_i}{S_o/N_o} = \frac{\text{I/p signal to noise ratio}}{\text{O/p signal to noise ratio}} \quad (4)$$

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

✓ Rearranging eqn (4), the input signal may be expressed as

$$S_i = \frac{F_n N_i S_o}{N_o} = \frac{K T_o B_n F_n S_o}{N_o} \quad (5)$$

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

$$S_{min} = K T_o B_n F_n \left(\frac{S_o}{N_o}\right)_{min} \quad (6)$$

substituting eq (6) into radar equation

$$R^4_{max} = \frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}}$$

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

omitting the subscripts on S and N results in

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

✓ The radar range can be predicted fairly accurated using above equation. still there are other factors which affect the radar range and for very accurate ~~accord~~ calculations these factors have also to be consider. These factors include:

1. system losses
2. Receiver non-linearities
3. Antenna imperfections
4. Anomalous propagation
5. Interference by nearby noise sources
6. operators error.

Note:

$$F_n = \frac{S_i/N_i}{S_o/N_o} \text{ (or) } \frac{P_{si}/P_{ni}}{P_{so}/P_{no}} = \frac{P_{si}}{P_{so}} \cdot \frac{P_{no}}{P_{ni}}$$

where, P_{si} = input signal power

P_{so} = output signal power

P_{ni} = input noise power

P_{no} = output noise power

$$F_n = \frac{P_{si}}{G_r P_{si}} \cdot \frac{G_r(P_{ni} + P_{nri})}{P_{ni}}$$

G_r = power gain of receiver

P_{nri} = Noise power generated at the receiver i/p.

$$F_n = \frac{P_{ni} + P_{nri}}{P_{ni}} = 1 + \frac{P_{nri}}{P_{ni}}$$

$$\therefore \frac{P_{nri}}{P_{ni}} = F_n - 1$$

$P_{nri} = P_{ni}(F-1)$

$P_{nri} = T_0 B (F-1)$

where kT_0B = Noise i/p power of receiver.

T_0 = Ambient temperature = 290 K.

B = Bandwidth of the receiver, Hz.

✓ If the target is moving and it moves significant between successive scans, a system called moving-target indicator is used. Therefore minimum detectable signal S_{min} should be atleast equal to

$$S_{min} = K T_0 B (F_n - 1)$$

Substituting S_{min} in radar range equation.

$$\boxed{R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 K T_0 B (F_n - 1)} \right]^{1/4}}$$

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

$$A_e = \eta A$$

$$A_e = 0.65 \left(\frac{\pi D^2}{4} \right)$$

$$G = \frac{4\pi}{\lambda^2} \cdot 0.65 \left(\frac{\pi D^2}{4} \right) = 0.65 \left(\frac{\pi D}{\lambda} \right)^2$$

Also $T_0 = 290°K$ and $K = 1.38 \times 10^{-23}\ J/°K$.

✓ The expression for maximum radar range is

$$\boxed{R_{max} = 48 \left[\frac{P_t D^4 \sigma}{B \lambda^2 (F-1)} \right]^{1/4}}$$

P_t = Peak transmitted power, watts

D = Diameter at antenna, meters

σ = effective cross sectional area of target, m^2

B = Bandwidth of receiver, Hz λ = wavelength, metre

F (or) F_n = noise figure ratio

→ Integration of Radar pulses :-

- The number of pulses returned after hitting target is given by

$$n = \frac{\theta_B f_p}{\dot{\theta}_s} = \frac{\theta_B f_p}{6\,\omega_r}$$

where, θ_B = antenna beamwidth (degrees)

f_p = pulse repetition frequency (Hz).

$\dot{\theta}_s$ = Antenna scanning rate (deg per second).

ω_r = revolutions per minute (rpm) for a 360° rotating antenna.

- The number of pulses received n is usually called hits per scan or pulses per scan. It is the number of pulses within the one way beamwidth θ_B.
- The process of summing all the radar echo pulses received from a target is called integration of pulses.
- Many techniques are used for integration of pulses. A common integration method in early radars was to take advantage of the persistance of the phosphor of the CRT display combined with the integrating properties of the eye and brain of the radar operator (or human being).
- The integration of pulses that is performed in the radar receiver before the second detector (In the IF) is called Predetection integration (or) Coherent Integration.

✓ Predetection integration is theoritically lossless, but it requires the phase of the echo signal pulses to be known and preserved in order to combine the sinewave pulses in phase without loss.

✓ The integration after the second detector is known as <u>post detection integration</u> (or) <u>non coherent integration</u>.

✓ If n pulses of same SNR are integrated by a lossless prediction integrator, then the integrated SNR will be exactly n times that of a single pulse. Therefore, in this case, we can replace the single-pulse-signal to noise ratio $(S/N)_1$ in the radar eqn with $(S/N)_n$.

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

where $(S/N)_n$ is the required signal-to-noise ratio per pulse when there are n pulses integration prediction without loss.

✓ If the same n pulses were integrated by an ideal post detection device, the resultant SNR would be less than n times that of a single pulse.

✓ This loss in integration efficiency is caused by the nonlinear action of the second detector, which converts some of the signal energy to noise energy in the rectification process.

✓ An integration efficiency for post detection integration may be defined as

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

✓ The improvement in signal-to-noise ratio when n pulses are integrated is called the integratio improvement factor $I_i(n) = nE_i(n)$. It can also be thought of as the ~~equipment~~ equivalent number of pulse integrated n_{eq} is $n_{eq} = nE_i(n)$. For post detection integration n_{eq} is less than n; for ideal predetection integration $n_{eq} = n$ for ideal predetection integration $n_{eq}=n$ ...

✓ Thus for the same integrated signal-to-noise ratio, post detection integration requires more pulses than predetection, assuming the signal-to-noise ratio per pulse in the two cases is the same

✓ The radar equation when n pulses are integrated is

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 K T_0 B_n F_n (S/N)_n}\right]^{1/4}$$

where $(S/N)_n$ is signal-to-noise ratio of each pulse.

→ **Probability of false alarm :-**

A false alarm is an erroneous radar target detection decision caused by noise or other interfering signals exceeding the detection threshold. In general it is an indication of the presence of a radar target when there is no valid aim.

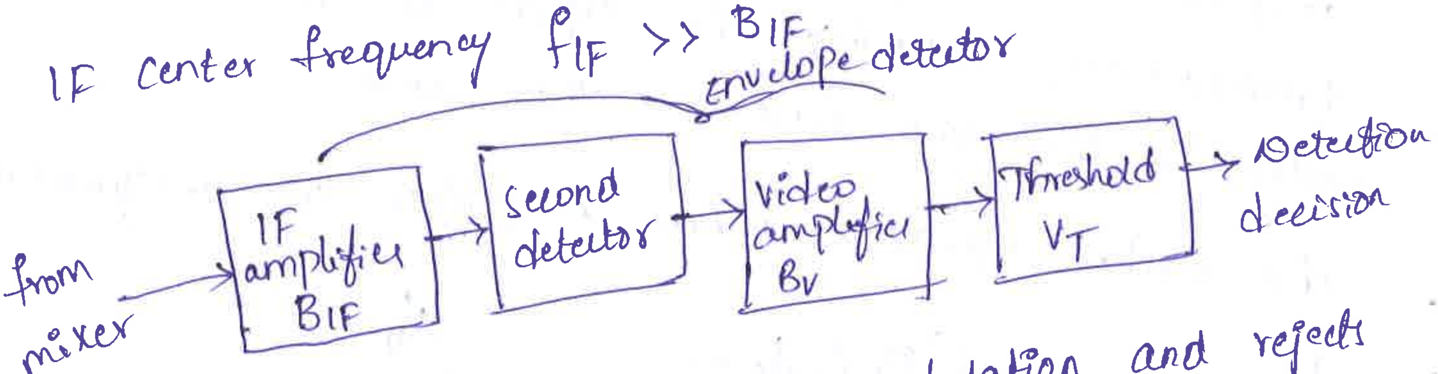
✓ The minimum signal-to-noise ratio required to achieve specified probability of false alarm.

- The below fig shows a portion of a superheterodyne radar receiver with IF amplifier of bandwidth B_{IF}, second detector, video amplifier with Bandwidth B_V and a threshold where the detection decision is made.

- The IF filter, second detector, and video filter form an envelope detector in that the output of the video amplifier is the envelope or modulation.

Video Bandwidth $B_V \geq B_{IF}/2$.

IF center frequency $f_{IF} \gg B_{IF}$



- The envelope detector passes the modulation and rejects the carrier.
- The bandwidth of the radar receiver is the bandwidth of the IF amplifier. The envelope of the IF amplifier output is the signal applied to the threshold detector. When the receiver output crosses the threshold, a signal is declared to be present.

- The receiver noise at the input to the IF filter is described by the gaussian probability density function.

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

where $p(v)\,dv$ is the probability of finding the noise voltage v between the values of v and $v+dv$ and ψ_0 is the mean square value of the noise voltage, The probability density function of the envelope R is given by

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

✓ The probability that the envelope of the noise voltage will exceed the voltage threshold V_T is the integral of $P(R)$.

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

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

✓ This is the probability of a false alarm, since it represents the probability that noise will cross the threshold and be called a target when only noise is present. The probability of a false alarm, denoted as P_{fa} is

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

✓ The average time between crossings of the decision threshold when noise alone is present is called false alarm time T_{fa} is given by.

$$T_{fa} = \lim_{N\to\alpha} \frac{1}{N} \sum_{K=1}^{N} T_K.$$

where T_K is the time between crossings of the threshold V_T by the noise envelope.

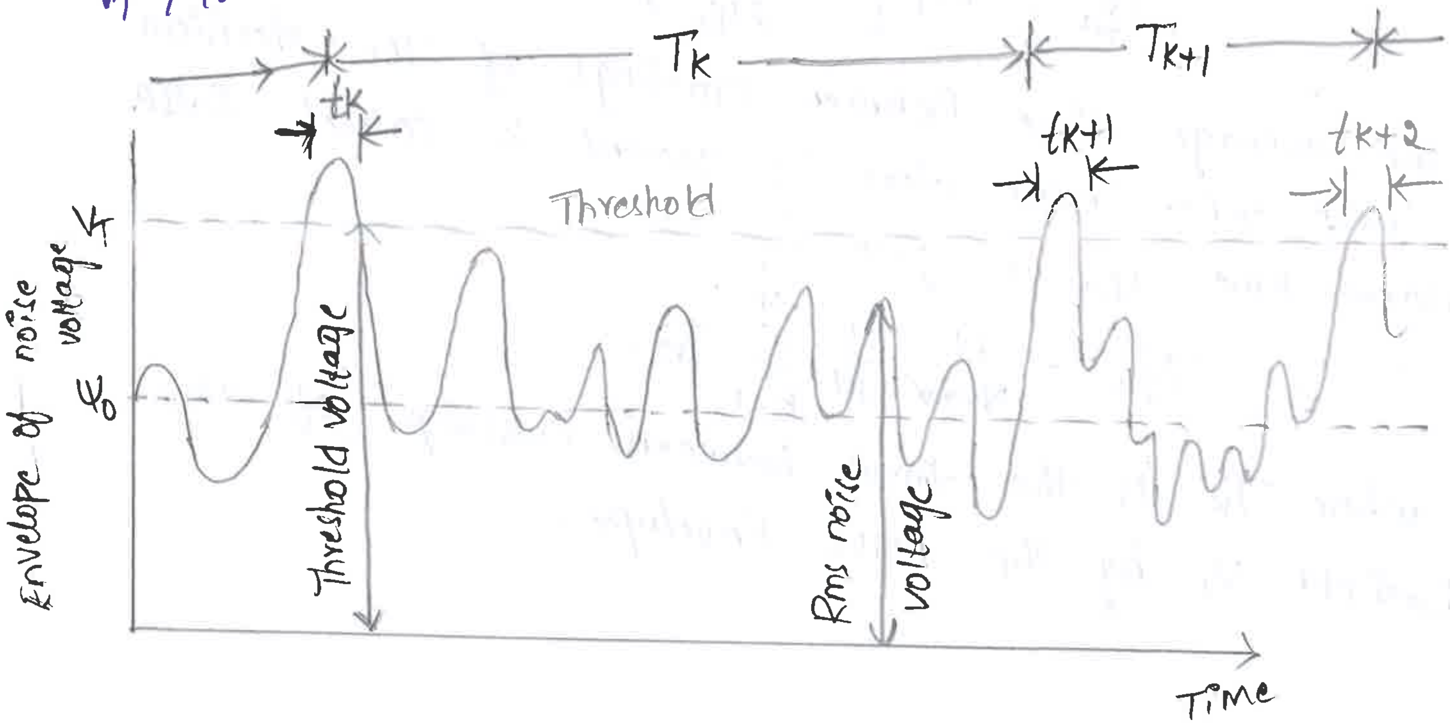
✓ The false-alarm probability can be expressed in terms of false alarm time by noting that the false alarm probability P_{fa} is the ratio of the time, the envelope is actually above the threshold to the total time it could have been above the threshold.

$$P_{fa} = \frac{1}{T_{fa} B}.$$

✓ The average duration of threshold crossing by noise $(t_K)_{av}$ is approximately the reciprocal of the IF bandwidth B. The average of T_K is the false-alarm time T_{fa}.

$$T_{fa} = \frac{1}{B} \exp\left(\frac{V_T^2}{2\psi_0}\right)$$

for ex: The bandwidth of the IF amplifier were 1MHz and the average time between false alarms were specified to be 15min, the probability of false alarm is 1.11×10^{-9}. The threshold voltage is 6.42 time, the power ratio V_T^2/ψ_0 is 16.2 dB.



- False alarms are more likely to occur from clutter echoes (ground, sea, weather, birds and insects) that enter the radar and are large enough to cross the threshold. In the specification of the radar's false alarm time, however, clutter is almost never included.
- The crossing of the threshold by noise is called false alarm, it is not necessarily a false target report.

→ **Probability of Detection:-**

To find the detection consider an echo signal represented as a sinewave of amplitude A along with guassian noise at the input of the envelope detection.

- The probability density function of the envelope R at the video output is given by

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

where $I_0(z)$ is the modified Bessel function of zero order and argument z for large z, an expression for $I_0(z)$ is

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

$A = 0$

- The probability of detecting the signal is the probability of that the envelope R will exceed the threshold V_T. The probability of detection is

$$P_d = \int_{V_T}^{\infty} P_s(R)\, dR$$

The probability density function $P_s(R)$ is substituted in the above Eq^n. then

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

$$P_d = \frac{1}{\psi_0} \exp\left(-\frac{V^2}{2\psi_0}\right)$$

$$P_d = \frac{1}{\psi_0} \exp\left(\frac{-V^2}{2\psi_0}\right)$$

for the ideal Radar system the probability of detection will be defined as the ratio of signal power to noise power.

$$P_d = \left[2 \frac{\text{signal power}}{\text{noise power}}\right]^{1/2}$$

$$P_d = \left(\frac{2S}{N}\right)^{1/2}.$$

→ Radar cross-section of Targets :-

✓ The amount of power reflected by the target depends on many factors including the size, shape, material (metal, plastic, wood or water) and edges (sharp or round) of the target, as well as the frequency of the incident radar signal and the angle between the radar system ~~of~~ and the a target.

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

(22)

✓ The radar cross section σ is said to be a (fictional) area that intercepts a part of the power include incident at the target which, if scattered uniformly in all directions, produces an echo power at the radar equal to that produced at the radar by the real target. Real targets of course, do not scatter the incident energy uniformly in all directions.

✓ The radar cross section σ is the property of a scattering object, or target, that is include in the radar equation to represent the magnitude of the echo signal returned to the radar by the target.

✓ Radar cross section depends on the characteristic dimensions of the object compared to the radar wavelength. When the wavelength is large compared to the object's dimensions, scattering is said to in the Rayleigh region.

✓ The radar cross section in the Rayleigh region is proportional to the fourth power of the frequency and is determined more by the volume of the scatter than by its sphere. At radar frequencies, the echo from rain is usually described by Rayleigh scattering.

✓ At the other extreme, where the wavelength is small compared to the object's dimensions is called the optical region.

✓ In between the Rayleigh and the optical regions is the resonance region (or) Mie region where the radar wavelength is comparable to the object's dimensions.

For many objects the radar cross section is larger in the resonance region than in the other two regions. These three distinct scattering regions are illustrated by the scattering from the sphere.

Definition of RCS :-

A target's radar cross section is defined as the ratio of its effective isotropically scattered power to the incident power density.

$$RCS = \sigma = \frac{\text{Power reflected (or scattered) toward source/unit solid angle}}{\text{Incident power density}/4\pi}$$

$$\sigma = \lim_{R \to \infty} 4\pi R^2 \left| \frac{E_r}{E_i} \right|^2$$

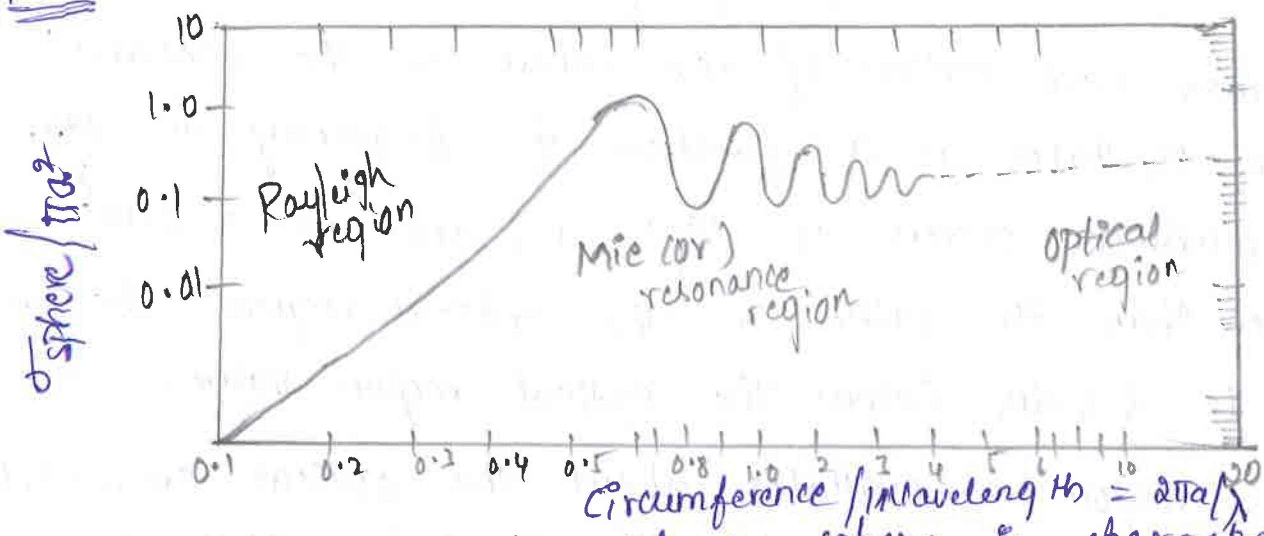
where R = distance between Radar and target or range to the target.

E_r = reflected field strength at radar or the electric field strength of the echo signal back at the radar.

E_i = strength of incident field at target (or) electric field strength incident on the target.

RCS of simple target :- RCS is a strong function of azimuth and elevation in spherical coordinate system. Also RCS is strong function of frequency and polarization. RCS of simple targets are calculated by using electromagnetic theory. Some simple targets are sphere, cylinder, flat, rod, and cone etc.,

Sphere :-



The radar cross section of a sphere is characterized into three regions :

1. Rayleigh region
2. optical region
3. Mie or resonance region.

1. Rayleigh region : $\left[\frac{2\pi a}{\lambda} << 1 \text{ or } a << \lambda\right]$.
In the Rayleigh region where $\frac{2\pi a}{\lambda} << 1$, the radar cross section is proportional to f^4 i.e

$$\boxed{RCS \propto f^4} \quad \text{(or)} \quad RCS \propto \frac{1}{\lambda^4}.$$

where f = frequency = $\frac{c}{\lambda}$ and c is velocity of propogation.

2. optical region : $\left(\frac{2\pi a}{\lambda} >> 1 \text{ or } a >> \lambda\right)$.
The region where $\frac{2\pi a}{\lambda} >> 1$ or $a >> \lambda$ is the optical region. In this region, the radar cross section approaches the physical area of the sphere as the frequency is increased.

$$RCS = \pi a^2$$

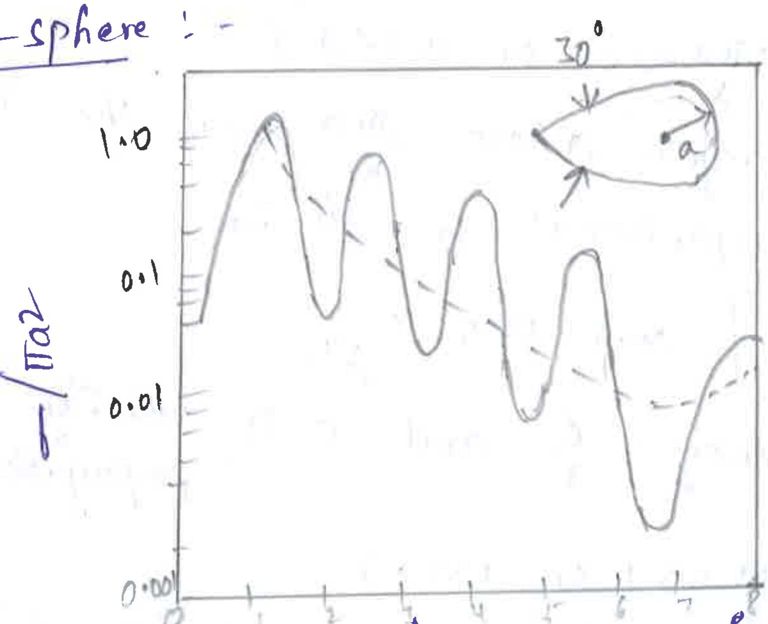
where a = radius of the sphere.

3. Mie (or) Resonance region $\left(\frac{2\pi a}{\lambda} = 1 \text{ or } a \simeq \lambda\right)$

A radar cross section of the sphere in the resonance region oscillates as a function of frequency or $\frac{2\pi a}{\lambda}$. Its maximum occurs at $\frac{2\pi a}{\lambda} = 1$, and is 5.6 dB greater than its value in the optical region. The first null is 5.5 dB below the optical region value.

✓ In this region σ oscillates about the optical cross-section (πa^2) with maximum and minimum values that close together with increasing a/λ. It means that RCS fluctuates above and below πa^2 depending on the exact wavelength.

② cone-sphere :-



✓ This is a cone whose base is capped with a sphere.

✓ The above fig is a plot of the calculated nose-on radar cross section of a cone sphere with 30° cone angle as a function of $2\pi a/\lambda$ where 'a' is the radius of the sphere.

- ✓ The cross-section of cone sphere is a very low and is considered to be of ballistic missile. A large cross-section occurs when a radar vecure the cone perpendicular to its surface.

→ Transmitter Power :-

The power P_t in the simple radar equation was not actual specified but is usually peak power of the pulse.

- ✓ The average power P_{av} of a radar is also of interest since it is a more important measure of radar performance than the peak power.
- ✓ Average transmitter power is defined over the duration of total transmission period.
- ✓ If the transmitter waveform is a train of rectangular pulses of width τ and constant pulse repetition period T_p.

$$T_p = \frac{1}{f_p}$$

where f_p = Pulse repetition frequency.

- ✓ The average power is related to the peak power

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

- ✓ The radar duty cycle (sometimes called duty factor) can be expressed as P_{av}/P_t or τ/T_p or τf_p.
- ✓ The duty cycle of radar is ratio of pulse width to pulse repetition time.

$$\text{Duty cycle} = \frac{\text{Pulse width}}{\text{Pulse repetition time}} = \frac{\tau}{T_p} = \tau f_p.$$

✓ The duty cycle depends on

1. Type of waveform
2. pulse compression
3. pulse width
4. Radar range
5. Type of transmitter.

✓ pulse radars might typically have duty cycle of from 0.001 to 0.5, more or less.

✓ A CW radar has a duty cycle of unity.

✓ The radar range equation in terms of average power can be expressed as

$$R_{max} = \left[\frac{P_{av} G A_e \sigma n E_i(n)}{(4\pi)^2 K T_0 F_n (B\tau)(S/N)_1 f_p} \right]^{1/4} \longleftarrow (1)$$

from the definition of duty cycle given above, the energy per pulse, $E_p = P_t \tau = P_{av}/f_p$. substituting this into Equation (1) gives the radar equation in terms of energy,

$$R_{max} = \left[\frac{E_p G A_e \sigma n E_i(n)}{(4\pi)^2 K T_0 F_n (B\tau)(S/N)_1} \right]^{1/4} = \left[\frac{E_T G A_e \sigma E_i(n)}{(4\pi)^2 K T_0 F_n (B\tau)(S/N)_1} \right]^{1/4}$$

where P_{av} = Average transmitted power
G = Antenna gain
A_e = Antenna aperture
σ = Radar cross-section of targets (m^2)
$E_i(n)$ = Integration efficiency
K = Boltzmann's constant = 1.38×10^{-23} J/deg

F_n = Receiver noise figure

B = Receiver bandwidth (Hz)

τ = Pulse width (sec)

$(S/N)_1$ = SNR required as if direction were based on only single pulse.

f_p = pulse repetition frequency (Hz).

E_p = energy per pulse.

$E_T = nE_p$ = Total energy of n pulses.

→ **Pulse repetition frequency (PRF) and Range ambiguities:**

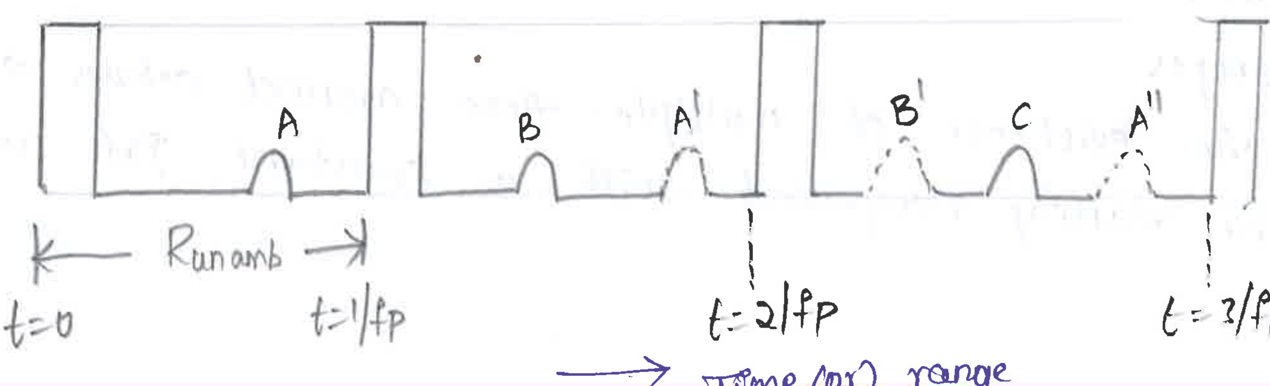
The pulse repetition frequency (PRF) is often determined by the maximum unambiguous range beyond which targets are not expected.

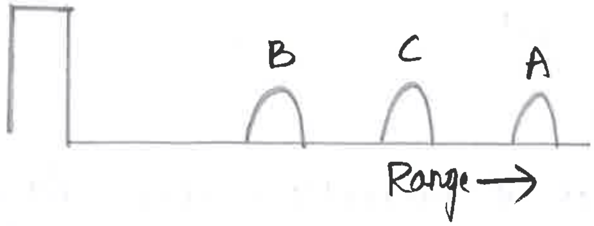
✓ The PRF corresponding to maximum unambiguous range is given by.

$$PRF = f_p = \frac{c}{2R_{un}}$$

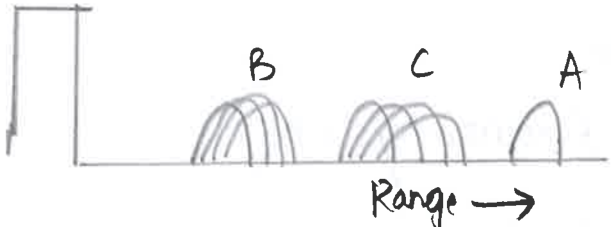
where c is velocity of propagation.

✓ If the PRF is made too high, the likelihood of obtaining target echoes from the wrong pulse trans-mission is increased.





(b)



(c)

fig :- Multiple - time around radar echoes that gives rise to ambiguities in range (a) Three targets A, B and C, where A is within the unambiguous range Run, B is a second-time around echo, and C is a multiple-time around echo (b) The appearance of the three echoes on the A-scope (c) The appearance ~~of the~~ three echoes on the A-scope with a changing Prf.

- Echo signals that arrive at a time later than pulse-repetition period are called second-time-around echoes. They are also called multiple-time-around echoes, particularly when they arrive from ranges greater than 2Run. These echoes may cause error or confusion.

- Another problem with multiple-time-around echoes is that clutter echoes from ranges greater than Run can mask unambiguous target echoes at the shorter ranges.

- The existence of multiple-time-around echoes cannot be readily recognized with a constant Prf waveform.

- consider three - targets labelled A, B and C in fig(a)
- Target A is within the unambiguous range interval Run.
- Target B is at a distance greater than Run but less than 2 Run.
- while target C is greater than 2 Run but less than 3Run.
- Target B is a second-time-around echo; target C is a multiple-time-around echo is shown in fig(a).
- fig(b) shows radar display (such as A-scope or PPI) when these three pulse repetition intervals are superimposed
- The ambiguous echoes B and C looks very similar to unambiguous range echo of A.
- out of these three echoes only the range of A is correct but it cannot be determined from this display that the other two are not at their apparent range.
- Ambiguous range echoes can be recognized by changing the prf of the radar.
- when the prf is changed, the unambiguous echo (< Run) remains at its true range.
- Ambiguous range echoes appear at different apparent ranges for each prf. fig (c) shows these three echoes on A-scope
- If the first pulse repetition frequency (prf) f_1 has an unambiguous range R_{un1} and if the apparent

range measured with prf f_1 is denoted R_1 then the true range is one of the following

$R_{true} = R_1$ or $R_{true} = R_1 + R_{un1}$

(or) $R_{true} = R_1 + 2 R_{un1}$

Anyone of these might be the true range.

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

$R_{true} = R_2$ (or) $R_{true} = R_2 + R_{un2}$

(or) $R_{true} = R_2 + 2 R_{un2}$.

✓ The correct range is same for two prfs. Thus two (or) more prfs can be used to correct range with increased accuracy and avoiding ambiguity with fake values.

→ **System losses :-**

The losses within the radar system is called system losses. It is denoted by L_s, L_s is inserted in the denominator of the radar eqn. It is the reciprocal of efficiency.

✓ Losses within the system itself are from many sources. some major source of losses are mentioned below.

1. Microwave plumbing losses.
2. Antenna losses — a. Beam shape loss
   b. scanning loss
   c. Radome
   d. Phase array losses.

3. Signal processing losses.
   a. Non-matched filter
   b. Constant false - alarm rate receiver
   c. Automatic Integrator
   d. Threshold level
   e. Limiting loss
   f. Stradling loss
   g. Sampling loss.
4. Losses in Doppler - processing Radar.
5. collapsing losses
6. operator loss
7. Equipment / field degradation
8. propagation effects
9. Radar system losses.

① Plumbing losses :-

✓ At all times a finite loss is associated with the transmission lines used to join the transmitter and the antenna.

✓ At lower radar frequencies the loss associated with the transmission line is extremely small, unless its length is very lengthy.

✓ The attenuation caused by plumbing losses is taken into consideration at higher radar frequencies

✓ A part from this additional losses arise due to each bend or connection in the line and the antenna rotary joint.

✓ The attenuation caused by the connector losses varies depending upon the quality of connection.

✓ If the connection is poor, then large attenuation is caused.

✓ The loss to be inserted in the radar equation is 2 times the one-way loss, because same transmission line is employed for transmission and reception.

✓ When the signal passes through the duplexer, it suffers attenuation. Generally, the greater the isolation required from the duplexer on transmission, the larger will be the insertion loss.

✓ The insertion loss is more, when the isolation required from the duplexer on transmission is more.

✓ The insertion loss means, the loss which is introduced when the component (duplexer) is inserted into the transmission line is called insertion loss.

✓ For a typical duplexer it might be of the order of 1dB in S-band (3000 MHz) radar, the plumbing losses will be

1. Waveguide transmission line — 1.0 dB
2. Loss due to poor connection — 0.5 dB
3. Rotary joint loss — 0.4 dB
4. Duplexer loss — 1.5 dB
5. Total plumbing loss — 3.4 dB

Antenna losses: Antenna losses include radiation loss, beam shape loss, scanning loss, radome and phase array losses.

1. Beam-shape loss:-

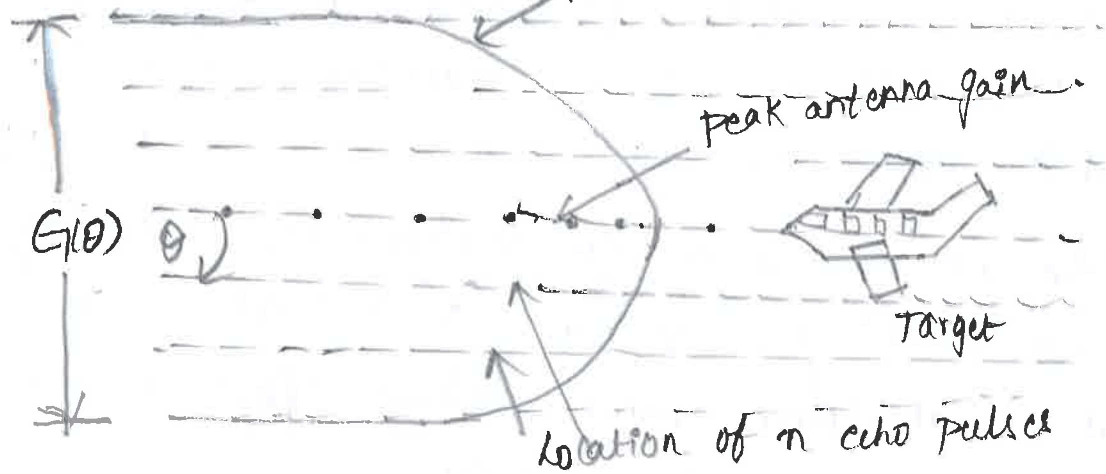


fig: Antenna beam shape loss.

✓ In radar eq^n antenna gain is assumed as constant at its maximum value but in practice as a search antenna scans across a target, it does not offer its peak gain to all echo pulses.

✓ when the system integrates several echo pulses maximum antenna gain G occurs when the peak of antenna beam is in the direction of target. The above fig shows beam shape loss.

✓ The beam shape loss is computed by

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

where, n is total number of pulses integrated.

n_B is number of pulses received within one-way half-power beamwidth (θ_B).

half-power beamwidth.

θ_B is half-power beamwidth.

(2) scanning loss :- when radar antenna scans rapidly compared to round trip time of echo signal, the gain of the receiving of echoes. This variation of antenna gain result in scanning loss.

✓ The scanning loss is most significant in long range scanning radars, such as space surveillance and ballistic missile defense radars.

③ Radome: The loss introduced by radome is decided by its type and operating frequency. A commonly used ground based metal space frame radome offers a loss of 1.2 dB for two way transmission.

✓ Air supported radomes have lower loss and radomes with dielectric space frame has higher loss.

④ Phased Array losses :-

✓ Additional transmission losses are observed in phased array radars because of distribution network used for connecting receiver and transmitter to multiple elements of array.

✓ These losses reduce antenna power gain. Sometimes phased array losses are accounted in system losses.

Signal processing losses :-

For detecting targets in clutters and in extraction information from radar echo signals very precise and lossless signal processing is necessary. Various losses accounted during signal processing are mentioned.

	Process/Components	Loss
1.	Non matched filter	0.5 to 1.0 dB
2.	Constant false alarm (rate CFAR)	> 2.0 dB
3.	Automatic integrator	1.5 to 2.0 dB
4.	Limiting loss	1 dB
5.	Straddling loss	1.0 to 2.0 dB
6.	Sampling loss	2.0 dB

Collapsing loss :-

When additional noise samples are integrated with signal plus noise pulses, this added noise causes degradation called collapsing loss.

The collapsing loss is given by L_C

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

where, $L_i(m+n)$ — integration loss for $m+n$ pulses

$L_i(n)$ — integration loss for n pulses

n — signal to noise pulses

m — noise pulses.

Operator loss :-

- Most modern high-performance radars provide the detection decision automatically without intervention of a human operator.
- When distracted, overloaded or not properly trained, operator performance will decrease. The resulting loss in system performance is called operator loss.
- Processed information is presented directly to an operator or to a computer for some other action. Then the operator efficiency factor is given by

$$P_o = 0.7(P_d)^2$$

where P_d = single-scan probability of detection.

Propagation effects: The propagation effects of radar wave has significant impact on losses. Major effects of propagation on radar performance are under mentioned.

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

The propagation effects are not computed under system loss but under propagation factor.

Problems

① Calculate the maximum range of radar which operates at a frequency of 10 GHz, peak pulse power of 600 KW. If the antenna effective area is $5 m^2$ and the area of target is $20 m^2$, minimum receivable power is 10^{-13} W.

Sol Given

$P_t = 600 KW = 600 \times 10^3$ W.

$\sigma = 20 m^2$ $A_e = 5m^2$ $f = 10 GHz$ $\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9}$

$S_{min} = 10^{-13}$ W. $= 0.03 m$

$$G_t \text{ (or) } G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi}{(0.03)^2} \cdot 5 = 69.813 \times 10^3$$

Max. range of radar is

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

$$R_{max} = \left[\frac{(600\times10^3)(69.813\times10^3)\times5\times20}{(4\pi)^2\times10^{-13}}\right]^{1/4}$$

$$= 717.639 \times 10^3$$

$R_{max} = 717$ Km.

The received power by the antenna is given by

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

$$= \frac{200\times10^3 \times 11.3\times10^{-3}\times 9\times 20}{(4\pi)^2\times(5.556\times10^5)^4} = 27.034\times10^{-15}\,W$$

(4) Find the maximum range of a radar, the transmitted power is 250 KW, cross-sectional area of the target is 12.5 sqm, minimum power received is 10^{-13} W, receiver antenna gain is 2000 and operating wavelength = 16 cm.

Sol Given $P_t = 250$ KW

$\sigma = 12.5$ sqm $= 12.5\,m^2$

$S_{min} = 10^{-13}$ W $G_r = 2000$ $\lambda = 16$ cm $= 16\times10^{-2}$ m $= 0.16$ m

The maximum radar range is given by

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

Here same antenna is used for transmitting and receiving purpose.

$\therefore G_t = G_r = G = 2000$

$$R_{max} = \left[\frac{(250\times10^3)\times(2000)^2\times(0.16)^2\times12.5}{(4\pi)^3\times(10^{-13})}\right]^{1/4}$$

$R_{max} = 200.39$ Km

(30)

② An S-band radar transmitting at 3 GHz radiates 200 kW. Determine the signal power density at ranges 100 nautical miles if the effective area of the radar antenna is $9 m^2$

Sol Given $f = 3 GHz = 3 \times 10^9 Hz$

$P_t = 200 kW = 200 \times 10^3 W$

$R = 100 nmi$ $1 nmi = 1852 m$

$R = 100 nmi = 100 \times 1852 = 1.852 \times 10^5 m$

$A_e = 9 m^2$

The power density by directive antenna is given by

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

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

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{3 \times 10^9} = 0.1 m$$

$$G = \frac{4\pi}{(0.1)^2} \times 9 = 11.3 \times 10^3$$

$$\therefore P = \frac{200 \times 10^3 \times 11.3 \times 10^3}{4\pi \times (1.852 \times 10^5)^2}$$

$$P = 5.248 mW/m^2$$

③ A radar operating at 3 GHz radiating power of 200 kW. Calculate the power of the reflected signal at the radar with a $20 m^2$ target at 300 nmi. Take $A_e = 9 m^2$

Sol Given $f = 3 GHz = 3 \times 10^9 Hz$

$P_t = 200 kW = 200 \times 10^3 W$

$\sigma = 20 m^2$ = cross section of target

$R = 300 nmi = 300 \times 1852 m = 5.556 \times 10^5 m$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{3 \times 10^9} = 0.1 m$$

$$G = \frac{4\pi}{\lambda^2} A_e = \frac{4\pi}{(0.1)^2} \times 9 = 11.3 \times 10^3$$

(5) A marine radar operating at 10 GHz has a maximum range of 50 km with an antenna gain of 4000. If the transmitter has a power of 250 kw and minimum detectable signal of 10^{-11} w. Determine the cross-section of the target the radar can sight.

Sol

$f = 10\ GHz$

$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03\,m$

$R_{max} = 50\,km$ $\quad G_t$ (or) $G = 4000$

S_{min} or $P_{min} = 10^{-11}\,W$ $\quad P_t = 250\,kw$.

The maximum range of radar is given by

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

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

$$\sigma = \frac{(50\times10^3)^4 (4\pi)^3 \times 10^{-11}}{(250\times10^3)(4000)^2 (0.03)^2}$$

$$\sigma = 34.45\,m^2$$

(6) A radar operating at 1.5 GHz uses a peak pulse power of 2.5 MW, and have a range of 100 nmi for objects whose radar cross-section is $1\,m^2$. If the maximum receivable power of the receiver is 2×10^{-13} W. what is the smallest diameter the antenna reflector could have, assuming it to be a full paraboloid with $\eta = 0.65$.

Sol $\quad f = 1.5\,GHz \quad \lambda = \frac{c}{f} = \frac{3\times10^8}{1.5\times10^9} = 0.2\,m.$

$P_t = 2.5 MW$

$R_{max} = 100 \text{ nmi} = 100 \times 1852 m = 1.852 \times 10^5 m = 185.2 \times 10^3 m$

$\sigma = 1 m^2$

$S_{min} = 2 \times 10^{-13} W.$

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

G_t (or) $G = \frac{4\pi}{\lambda^2} A_e$

Putting this value in above Eqn.

$$R^4_{max} = \left[\frac{P_t \left(\frac{4\pi}{\lambda^2}\right) \cdot A_e \cdot A_e \sigma}{(4\pi)^2 S_{min}} \right]$$

$$R^4_{max} = \frac{P_t A_e^2 \cdot \sigma}{4\pi \lambda^2 S_{min}} \Rightarrow A_e^2 = \frac{R^4_{max} \cdot 4\pi \lambda^2 S_{min}}{P_t \cdot \sigma}$$

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

$$A_e = \frac{(185.2 \times 10^3)^4 \times 4\pi \times (0.2)^2 \times 2 \times 10^{-13}}{2.5 \times 10^6 \times 1}$$

$A_e = 6.877 m^2$

$A_e = \eta A$ and $\eta = 0.65$

$A = \frac{A_e}{\eta} = \frac{6.877}{0.65} \Rightarrow A = 10.58 m^2$

Diameter of antenna $A = \frac{\pi D^2}{4}$

$$10.58 = \frac{\pi D^2}{4}$$

$$D^2 = \frac{10.58 \times 4}{\pi}$$

$$D = \left(\frac{10.58 \times 4}{\pi}\right)^{1/2}$$

$\boxed{D = 3.67 m}$

(7) calculate the max. range of a radar system which operates at 3cm with peak pulse power of 600kW if its antenna is $5m^2$, maximum detectable signal is 10^{-13} W and the radar cross-sectional area of the target is $20m^2$.

Sol $\lambda = 3cm = 3\times10^{-2}$ m. $A_e = 5m^2$

$P_t = 600kW$ $S_{min} = 10^{-13}$ W.

$\sigma = 20m^2$ $R_{max} = ?$

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

$$= \frac{600\times10^3 \times (5)^2 \times 20}{4\pi \times (3\times10^{-2})^2 \times 10^{-13}} = 717.657 \text{ km}.$$

1nmi = 1852 m = 1.852 KM.

$$R_{max} = \frac{717.657}{1.852} = 387 \text{ nmi}$$

(8) A 10 GHz radar has the following characteristics, peak transmitted power = 250 kW, power gain of antenna = 2500, minimum detectable peak signal power by receiver = 10^{-14} W, cross-sectional area of the radar antenna is $10m^2$. If the radar were to be used to detect a target of $2m^2$ equivalent cross-section, find the max. range possible.

Sol $P_t = 250$ kW, $G = 2500$, $S_{min} = 10^{-14}$ W, $A_e = 10m^2$

$\sigma = 2m^2$, $f = 10$ GHz.

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03 \text{ m}$$

$$R_{max} = \left[\frac{P_t\, G \cdot A_e\, \sigma}{(4\pi)^2 S_{min}}\right]^{1/4} = \left[\frac{250\times10^3 \times 2500 \times 10 \times 2}{(4\pi)^2 \times 10^{-14}}\right]^{1/4}$$

$R_{max} = 298.28$ km

(9) A pulsed radar operating at 10 GHz has an antenna with a gain of 28 dB and a transmitting power of 2KW. If it is desired to detect a target with a cross-section of 12 sq.m and the minimum detectable signal is Smin = −90 dBm. What is the maximum range of radar?

Sol

$f = 10\ GHz$

$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03\,m$

$G = 28\,dB$

$G(dB) = 10\log_{10} G$

$\log_{10} G = \frac{28}{10} = 2.8$

$G = 10^{2.8} = 630.95$

$P_t = 2KW$, $\sigma = 12\,sq.m$, $S_{min} = -90\,dBm$

$dBm = 10\log\left(\frac{S_{min}}{1mw}\right)$

$-90 = 10\log\left(\frac{S_{min}}{1mw}\right)$

$\log_{10}\left(\frac{S_{min}}{1mw}\right) = -9$

$\frac{S_{min}}{1mw} = 10^{-9}$

$S_{min} = 10^{-9}\,mW$

$= 10^{-9}\cdot10^{-3}\,W$

$S_{min} = 10^{-12}\,W$

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

$= \left[\frac{2\times10^3 \times (630.95)^2 (0.03)^2 \times 12}{(4\pi)^3 \times 10^{-12}}\right]^{1/4}$

$R_{max} = 1619\,m = 1.619\,Km$

(10) With the 3MHz bandwidth of the radar receiver, calculate the highest range resolution realizable with the radar?

Sol Given that

Bandwidth of the receiver = 3MHz.

Highest range resolution, ΔR = ?

Highest range resolution of radar waveform is given by

Pulse duration of

$T = \frac{1}{B} = \frac{1}{3\times10^6} = 0.333\,\mu s$

The highest range resolution which can be realized with the radar is given by

$\Delta R = \frac{cT}{2} = \frac{3\times10^8 \times 0.333\times10^{-6}}{2} = 50m.$

(1) A square law detector integrates 10 signal plus noise pulse along with 30 noise pulses. If integration loss for signal plus noise pulses is 3.5dB and integration loss due to noise pulses is 1.7dB. Calculate collapsing loss of the radar antenna.

Sol Given

Signal plus noise pulses (m) = 10

Noise pulses (n) = 30

Integration loss $L_i(m+n) = 3.5\,dB$

Integration loss due to noise pulses $= 1.7\,dB = L_i(n)$

Collapsing loss is given by

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

$$= \frac{3.5}{1.7} = 1.8\,dB$$

$$\boxed{L_c(m+n) = 1.8\,dB}$$

CW AND FMCW RADAR

Topics :-

* Doppler Effect
* CW Radar – Block Diagram.
* Isolation between Transmitter and Receiver
* Non-zero IF Receiver
* Receiver Bandwidth Requirements.
* Applications of CW Radar
* Range and Doppler Measurement
* FMCW Radar Block diagram, characteristics.
* FM-CW altimeter
* Multiple frequency CW Radar
* problems

→ The radar which operates with continuous signal or wave is called continuous wave radar.

- They use doppler effect for detecting non-stationary targets.
- Continuous wave radars can be classified into two types.
  1. Unmodulated continuous wave radar.
  2. Frequency modulated continuous wave radar.

- Unmodulated CW radar :- The radar which operates with continuous signal for detecting non stationary targets is called unmodulated CW radar (or) simply CW radar (or) CW doppler radar.

✓ This type of radar requires two antennas. One antenna for transmitting the signal and other for receiving the signal.

✓ It measures only the speed of the target but not the distance of the target from the radar.

Frequency modulated CW radar (FMCW radar) :- If cw radar uses the frequency modulation then that radar is FMCW radar (or) it can also called as continuous wave frequency modulated radar.

✓ This radar also requires two antennas. This radar measures not only the speed of the target but also the distance of target from the radar.

→ Doppler Effect :-

Doppler effect implies that the frequency of a wave, when transmitted by a source is not necessarily the same as the frequency of the transmitted wave when picked up by a receiver.

✓ The Received frequency depends upon the relative motion between the transmitter and receiver.

✓ If the transmitter and receiver both are moving towards each other, the received frequency is higher. This is true, even if one is moving.

✓ If they are moving apart, the received signal frequency decreases. If both are stationary, the frequency.

remains the same. This change in frequency is known as Doppler shift. Doppler shift depends on the relative velocity between the two.

Doppler shift is given by

$$\Delta f = \frac{2V_r}{\lambda}$$

where V_r = Relative velocity between the source and target.

λ = Transmitted wavelength.

This principle is used in Doppler radar to find the velocity of the moving target.

Doppler frequency shift :-

If the target is in motion, (then the radar can sends Electromagnetic (EM) signals) then it results in a frequency shift the resultant frequency shift is called Doppler effect.

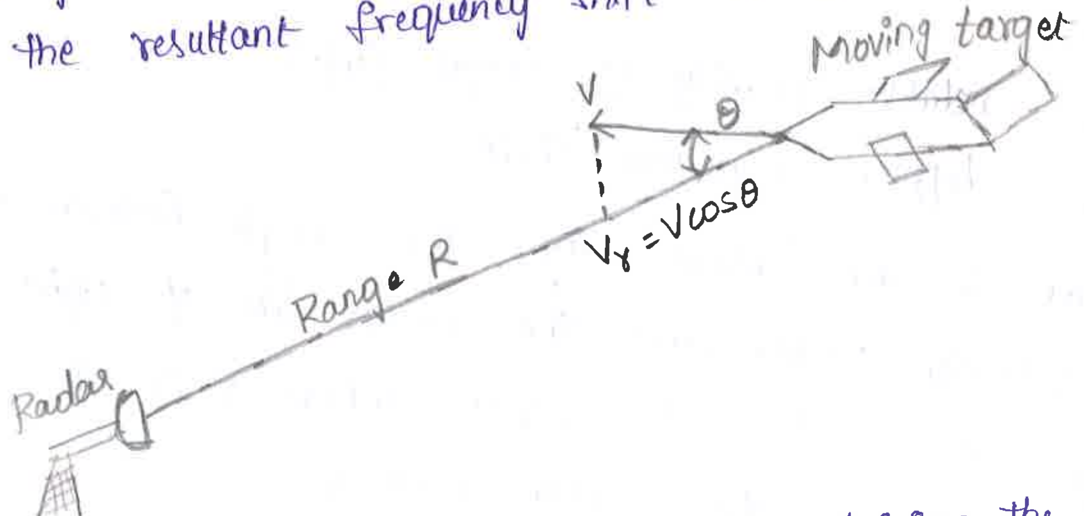


fig : Geometry of radar and target in deriving the Doppler frequency shift.

If 'R' is the distance from radar to the target, the total number of wavelengths λ is contained in the two way path from radar to the target is $\frac{2R}{\lambda}$.

✓ Each wavelength corresponds to phase change of 2π radians.

✓ The total phase change in the two-way propagation path is given.

$$\boxed{\phi = 2\pi \times \frac{2R}{\lambda} = \frac{4\pi R}{\lambda}} \quad \text{—— (1)}$$

✓ The target is in motion relative to the radar, R is changing and so will the phase.

✓ Differentiating the above equation with respect to time gives the rate of change of phase, which is the angular frequency (or doppler angular frequency ω_d) is given by

$$\omega_d = \frac{d\phi}{dt} = \frac{d}{dt}\left(\frac{4\pi R}{\lambda}\right) = \frac{4\pi}{\lambda}\frac{dR}{dt}$$

$$= \frac{4\pi V_r}{\lambda} \quad \left(\because \frac{dR}{dt} = V_r\right) \quad \text{—— (2)}$$

where,

V_r = relative velocity of target. (m/s).

f_d = doppler frequency shift.

✓ If as in the above fig, the angle between the target's velocity vector and the radar line of sight to the target is θ, the $V_r = V\cos\theta$, where V is the speed (or) magnitude of the vector velocity.

✓ The rate of change of ϕ with time is the angular frequency, $\boxed{\omega_d = 2\pi f_d}$

from equation (2).

$$\omega_d = \frac{4\pi V_r}{\lambda}$$

$$2\pi f_d = \frac{4\pi V_r}{\lambda}$$

$$f_d = \frac{2V_r}{\lambda} = \frac{2V_r f_t}{\lambda} \text{ (or) } \frac{2V_r f_0}{\lambda} \quad (\because \lambda = c/f).$$

where, f_0 (or) f_t = transmitted frequency and
c = Velocity of propagation = 3×10^8 m/s.

✓ If f_d is in Hertz, V_r in Knots and λ in metres, we can write

$$f_d\,(Hz) = \frac{1.03\,V_r(Kt)}{\lambda(m)} \simeq \frac{V_r(Kt)}{\lambda\,m}$$

Problems :-

(1) Find the doppler shift caused by a vehicle moving toward a radar at 96 km/h, if the radar operates at 10 GHz

sol Relative velocity $V_r = 96\,Km/h = \frac{96\times1000}{3600} = 26.7$ m/sec.

$f = 10\,GHz = 10\times10^9$ Hz

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03\,m$$

Doppler shift is given by

$$f_d \text{ (or) } \Delta f = \frac{2V_r}{\lambda} = \frac{2\times26.7}{0.03} = 1.78\,KHz$$

② What is the Doppler shift when tracking a car moving away from radar at 100 miles/hour? The radar is operating at 1GHz.

Sol

$V = 100$ miles/hr 1 mile/hr = 0.5 m/s

$f = 1GHz$ ∴ 100 miles/hr = 100 × 0.5 = 50 m/sec.

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{1\times10^9} = 0.3 \text{ m/sec.}$$

Car is moving away from radar, therefore $\theta = 0^\circ$ and $\cos 0^\circ = 1$.

→ The doppler shift is given by

$$f_d \text{ (or) } \Delta f = \frac{2V\cos\theta}{\lambda} = \frac{2\times50\times1}{0.3} = 333.34 \text{ Hz}$$

→ CW radar / CW Doppler radar :-

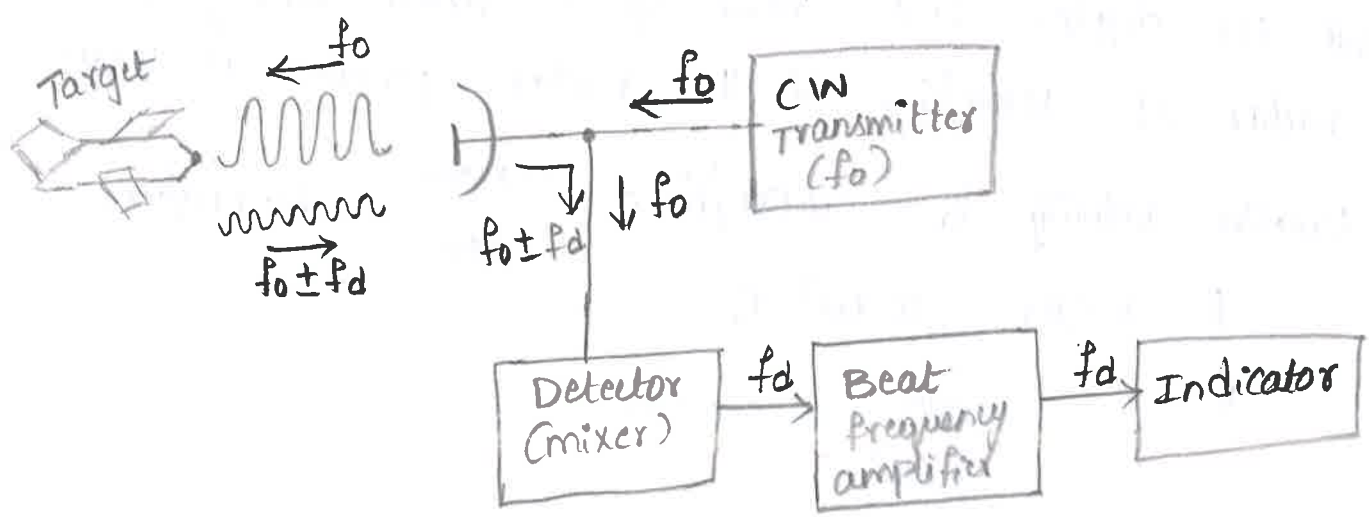


fig : Block diagram of CW radar

✓ The transmitter generates a continuous wave of oscillation frequency fo, which is radiated by an antenna.

✓ The amount of radiated energy is intercepted by the target and some of the energy is scattered back in the direction of radar. This energy is collected by the receiving antenna.

✓ On reflection by a moving target, the transmitted signal is shifted by the doppler effect by an amount ± fd.

✓ The plus sign applies when the distance between radar and target is decreasing (a closing target). Thus the echo signal from a closing target has a larger frequency than that which was transmitted.

✓ The minus sign applies when the distance is increasing (a receding target).

✓ To utilize doppler frequency shift a radar must be able to recognize that the received echo signal has a frequency different from that which was transmitted.

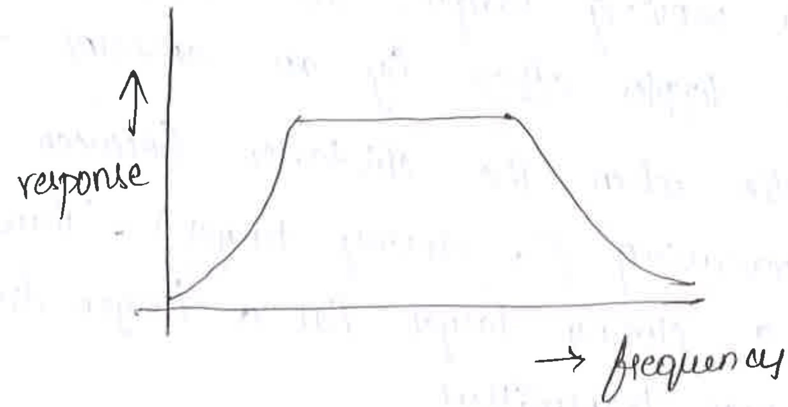
✓ This is the function of that portion of the transmitter signal that finds its way (or leaks) into the receiver.

✓ The transmitter leakage signal acts as a reference to determine that a frequency change has taken place.

✓ The Received signal (echo signal) fo ± fd is mixed in the detector, to produce doppler frequency fd.

✓ It is given to the doppler amplifier, which eliminates echoes from stationary targets and amplify the doppler echo signals.

- The doppler filter allows the difference frequency from the detector to pass and rejects the higher frequencies.
- The filter characteristic is shown in below fig.



- It has a lower frequency cut-off, it must be high to reject DC components. and the upper frequency cut-off is selected to pass highest doppler frequency.
- The Indicator must be used as a pair of earphones (or) frequency meter.
  * Ear phones provided doppler frequencies like with in the audio frequency response of the ear.
  * Frequency meters are used to count the cycles.

→ Difference between CW Radar and pulse radar :-

CW Radar	Pulse radar
→ The radar which employes continuous transmission for detecting target is called CW radar.	→ The radar which employes a pulse transmission i.e during the transmission receiver is in off state, during the reception, transmitter is in OFF state for detecting targets is called pulse radar

→ Using CW radar it cannot measure the range at which the target is detected.	→ we can measure range along with the relative velocity of the target.
→ simple circuitary.	→ complex circuitary
→ small size	→ large size.
→ CW radar most likely used IF doppler filter banke.	→ Pulsed radar used range gated doppler filter banke.
→ It is more sensitive to clutter and they cannot used gating to ignore clutter.	→ These radars are more capable of reducing clutter.

→ **Isolation between Transmitter and Receiver :-**

The main purpose of Providing Isolation between Transmitter and Receiver is to eliminate the Transmitter leakage signal.

✓ Generally separate antennas are used for Transmission and reception, so that there is no chance of leakage entering the Receiver.

✓ The isolation between Transmitter and receiver is possible using single antenna as in CW radar.

✓ In CW radar, separation of frequency as a result of doppler effect. In practice, it is not possible to eliminate completely the Transmitter leakage. A moderate of amount of leakage entering the Receiver along with the echo signal for the detection of doppler frequency shift.

- If the transmitter having leakage power then the receiver sensitivity can be reduces.
- There are 2 practical effects which limit the amount of power which can be tolerated at the receiver.

i) The maximum amount of power the receiver i/p circuitary can withstand before its sensitivity reduced.

ii) The amount of transmitter noise due to hum, microphonics, stray pick up, instability which enters the receiver from the transmitter.

- The noise that accompanies the transmitter leakage signal will determine the amount of Isolation needed in a long range CW radar.
- For Example, 10mw of leakage signal is appeared at the Receiver. for a proper Isolation b/w Transmitter and Receiver. The transmitter noise must be 110dB below the transmitted carrier for a minimum detectable signal of 10^{-13} watt.
- The Isolation between Transmitter and Receiver can be obtained with a single antenna (like CW radars) By using a hybrid-Junction, circulator, turnstile Junction or with separate polarizations.
- The Isolation achieved by hybrid Junctions such as magic Tee, rat race (or) directional coupler is 60dB in extreme cases, the isolation in Practical cases is order of 20 (or) 30dB.

- The limitation of hybrid junction is 6dB loss in overall performance which results waste half of Transmitted power & half of received power. Thus hybrid junctions are applicable to short-range radars.

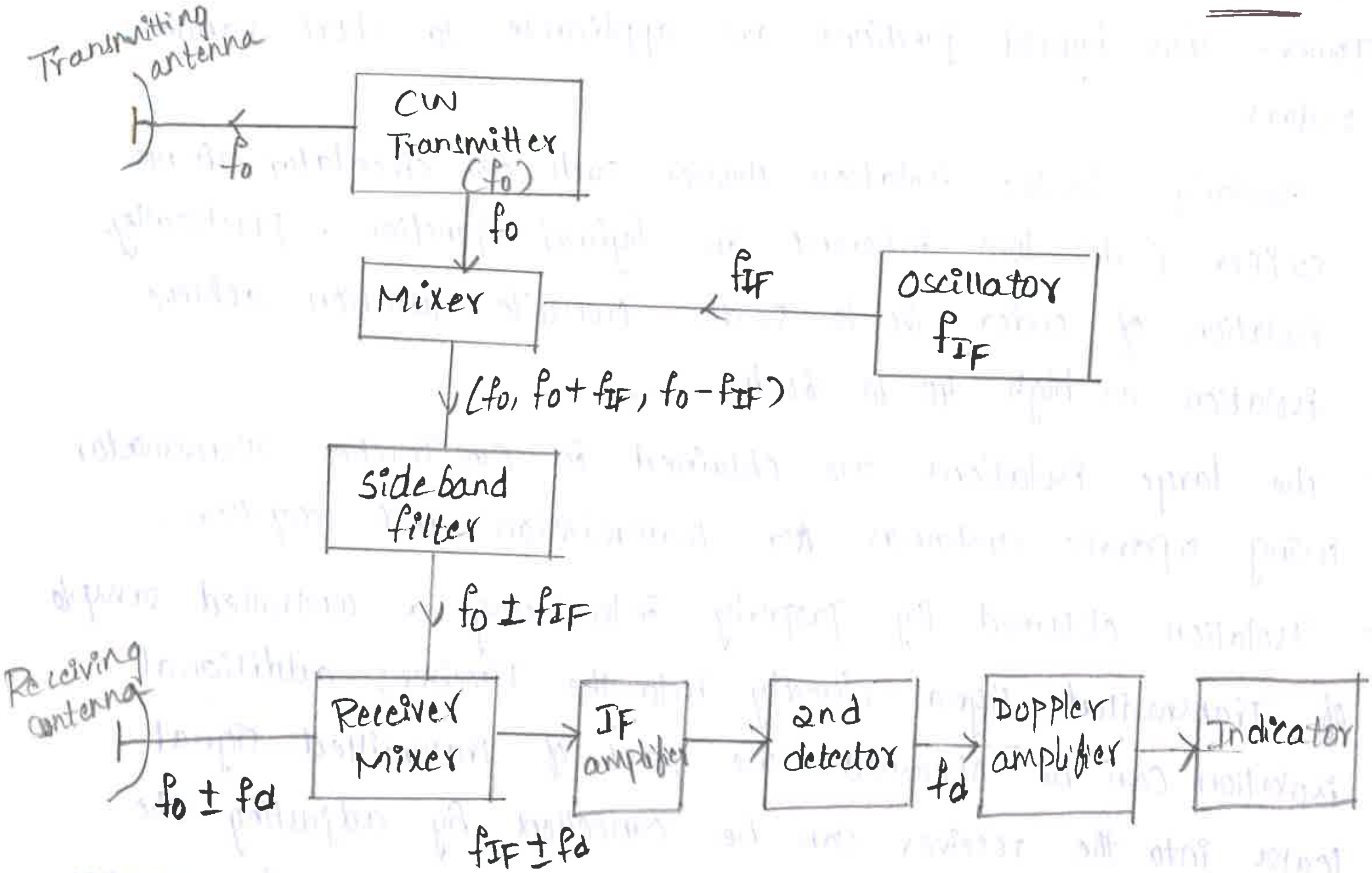
- Similarly, ferrite isolation devices such as circulator do not suffer 6-dB loss inherent in hybrid junction. practically isolation of order 20 to 50 dB. Turnstile junction achieve isolation as high 40 to 60dB.

- The large isolations are obtained in CW Tracker - illuminator using separate antennas for Transmission and reception.

- Isolation obtained By properly introducing a controlled sample of Transmitted signal directly into the Receiver; additional isolation can be obtained. The part of Transmitted signal leaks into the receiver can be cancelled by adjusting the phase and amplitude of the "buck-off" signal. The arrangement introduces additional 10dB isolation, but the amplitude and phase of leakage signal may vary as the antenna scans.

- Thus a dynamic canceller can be used that senses the proper phase and amplitude of leakage signal for obtaining the additional isolation. Thus, the dynamic cancellation of leakage signal can exceed isolation to 30dB.

→ Non-zero IF Receiver (or) Homodyne Receiver (or) Superheterodyne Receiver :-



To remove the transmitter leakage, we are using two separate antennas in the section for Transmission and reception.

✓ CW Transmitter can generates continuous wave of frequency f_0 is given to transmitting antenna.

✓ Some portion of Transmitted signal is mixed with a locally generated signal of frequency equal to that of receiver IF is given by local oscillator.

✓ The output of mixer is given by f_0 and $f_0 \pm f_{IF}$. This output is given to sideband filter. At this stage, it can select one of the sideband from output of mixer which contains two side bands on either side of carrier and higher harmonics, then side band filter can eliminate frequency fo and passes fo ± fIF to the receiver mixer.

- ✓ In receiver mixer, can combine two outputs one from side band filter i.e fo ± fIF and other is from receiving antenna i.e fo ± fd.
- ✓ At this stage, we detect fo frequency and passes fIF ± fd to the IF amplifier.
- ✓ To amplify the IF signals and passes this frequency (fIF ± fd) to the second detector at this stage.
- ✓ At this stage, to detect IF frequencies and passes only doppler frequencies fd to the doppler amplifier. and it is used to increase the strength of the signal.
- ✓ Finally, an indicator (A-scope (or) PPI display) is used to find the doppler frequency shift fd.
- ✓ The improvement in receiver sensitivity with a non-zero IF receiver might be around 30dB over the zero IF receiver.

<u>Advantages</u>

1. The effects of flicker noise can be drastically reduced
2. Because of the high receiver sensitivity, it is preferred in maximum efficiency CW radar.
3. The sensitivity of non-zero IF receiver is much higher than simpler CW receivers i.e around 30dB.

→ Receiver bandwidth requirements (or) IF doppler filter bank :-

A relative wideband of frequencies called as bank of narrow band filters are used to measure the frequency of echo signal. These are used to improve the signal-to-noise ratio of Receiver.

The Bandwidth of each individual filter is such that,

✓ The Bandwidth of each individual filter is such that it accepts the signal energy But should be taken that it doesnot introduce more noise Because of wide bandwidth.

✓ The center frequencies of filters are Staggered to cover the entire range of doppler frequencies.

✓ If the filters are spaced with their half power points overlapped, the maximum reduction in signal-to-noise ratio of signal which lies midway between adjacent channels compared with signal to noise ratio of midband is 3dB.

✓ By using large no. of filters, the maximum loss will be reduced. ~~But~~ ~~sometimes~~ noise is introduced also the probability of false alarm is more.

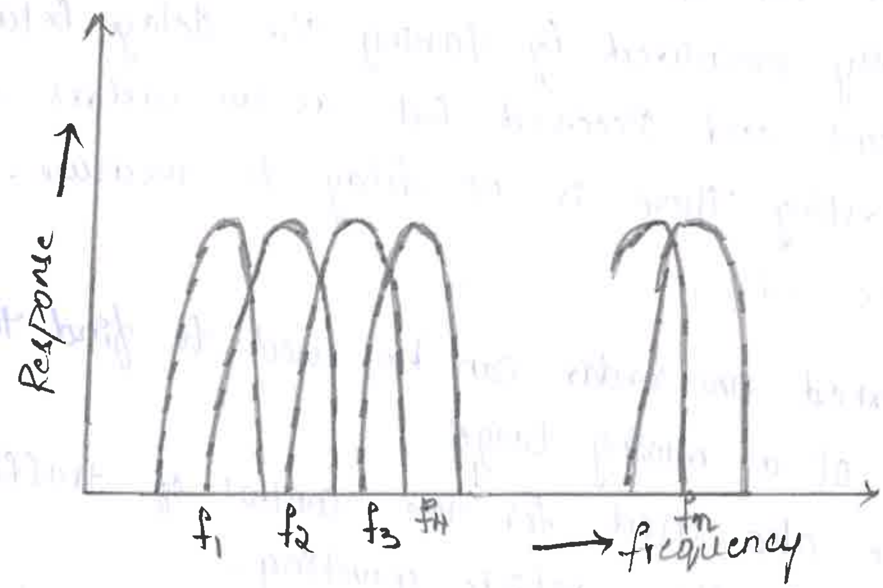
The figure shows block diagram of IF doppler filter bank.

✓ A bank of narrow band filters may be used after the detector in the video of sample CW radar instead of in the IF. The ability to measure the magnitude of doppler frequency and improvement in signal-to-noise ratio better in IF filter bank.

✓ The sign of doppler shift is lost in video filter bank and it can't be directly determined whether the doppler frequency corresponds to an approaching (or) to a receding target.

- One disadvantage of IF filter Bank has it requires more no. of filters. The complexity of Receiver increases by the bank of overlapping doppler filters whether in IF (or) video.
- The bank of doppler filters may be replaced by a single narrow band Tunnable filter, when the system requirements permit a time sharing of the doppler frequency range.

The frequency response characteristics of doppler filter bank as shown in figure.



Advantages of CW radar:-

1. CW radars are not pulsed and simple to manufacture.
2. These radars have no minimum (or) maximum range and maximize power on a target because they are always Broadcasting.
3. These are having the ability to measure velocity with extreme accuracy by means of the doppler shift in the frequency echo.
4. The detected, reflected wave is shifted in frequency by an amount which is a function of relative velocity between the target and Transmitter power.
5. Range data are extracted from the change in doppler frequency.

Disadvantages of cw radar:-

① when a single antenna is used for both transmission & reception, It is difficult to protect the receiver against the transmitter Because in constant to pulse radar, both are ON all the time.

② These are able to detect only moving targets, at stationary targets will not cause doppler shift & reflected signals will be filtered out.

③ cw radars are not able to measure the range, where the range is normally measured by timing the delay between a pulse being sent and Received but as cw radars are always broadcasting there is no delay to measure.

Applications of cw radar:-

① simple unmodulated cw radar can be used to find the relative velocity of a moving target.

② cw radars are also used for the control of traffic lights, regulations of toll booths, vehicle counting.

③ In railways cw radars can be used as a speed meter, to replace the conventional axle-driven tachometer.

④ In measurement of rail road frieght car velocity during humping operations in marshalling yards.

⑤ It can be used as detection device to give track maintenance personnel advance warning of approaching trains.

⑥ It also employed for monitoring the docking speed of large ships.

(7) In Industry has been applied to measurement of peripheral speed of grinding wheels & monitoring of vibrations in the cabels of suspension bridges.

(8) Measurement of velocity of missiles, ammunition and Base balls the CW radars are used.

(9) Measuring motion of waves on water level.

(10) Find weather an object is approaching (or) moving away from the target.

(11) Monitoring respiration rate of humans.

(12) Scatterometer (used to measure scattering properties of target (or) clutter).

→ FM-CW Radar (Frequency Modulated CW radar):-

In CW radars have the disadvantage that they cannot measure distance.

characteristic features of FM-CW radar:-

1. The distance measurement is done by comparing the actual frequency of Received signal to a given reference signal (usually the transmitted signal).

2. The duration of Transmitted signal is much larger than the time required for measuring the maximum range of radar.

Operation :- The block diagram of FMCW radar shown in below figure:

→ A portion of the transmitted signal act as the reference signal required to produce the beat frequency. It is Introduced directly into Receiver.

→ Ideally the isolation between transmitting and receiving antennas is made sufficiently large so as to reduce to a negligible level the transmitter leakage signal which arrives at the Receiver via the coupling between antennas.

→ The beat frequency is amplified and limited to remove any amplitude fluctions.

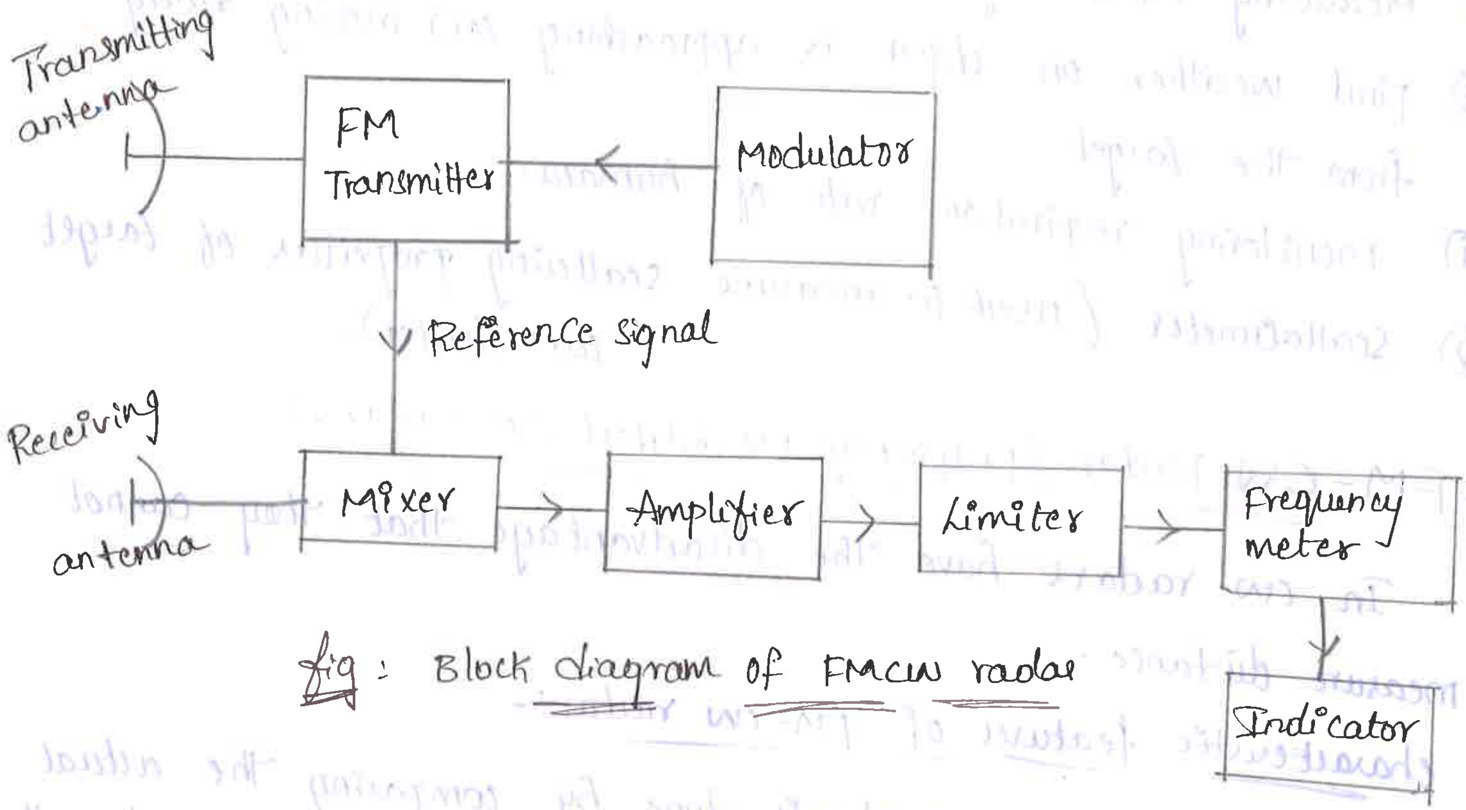


fig: Block diagram of FMCW radar

→ The frequency of amplitude-limited beat note is measured with a cycle counting frequency meter calibrated in distance.

→ In the above, target was assumed to be stationary. If the assumption is not applicable, a doppler frequency shift will be super imposed on the FM range beat note and an erroneous range measurement results.

→ The doppler frequency shift causes the frequency-time plot of the echo signal to be shifted up (or) down [fig 2(a)]

On one portion of the frequency-modulation cycle the beat frequency (fig 2(b)) is increased by doppler shift, while on the other portion it is decreased.

For example,

Target is approaching the radar, the beat frequency fb(up) produced during the increasing portion and fb(down) produced during the decreasing portion of FM cycle.

$$f_b(up) = f_r - f_d$$

$$f_b(down) = f_r + f_d.$$

when the target is moving away from the radar, the beat frequency fb(up) is produced during the decreasing portion and fb (down) is produced during the increasing portion of FM cycle.

$$f_b(up) = f_r + f_d$$

$$f_b(down) = f_r - f_d.$$

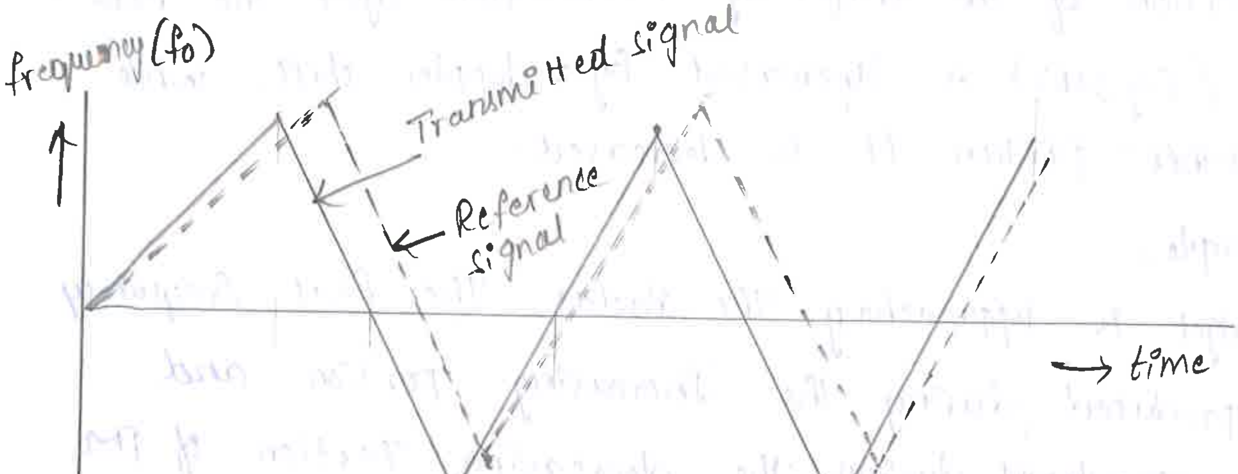
The range frequency (f_r) may be extracted by measuring the average beat frequency.

$$\text{i.e } f_r = \frac{1}{2}\left[f_b(up) + f_b(down)\right]$$

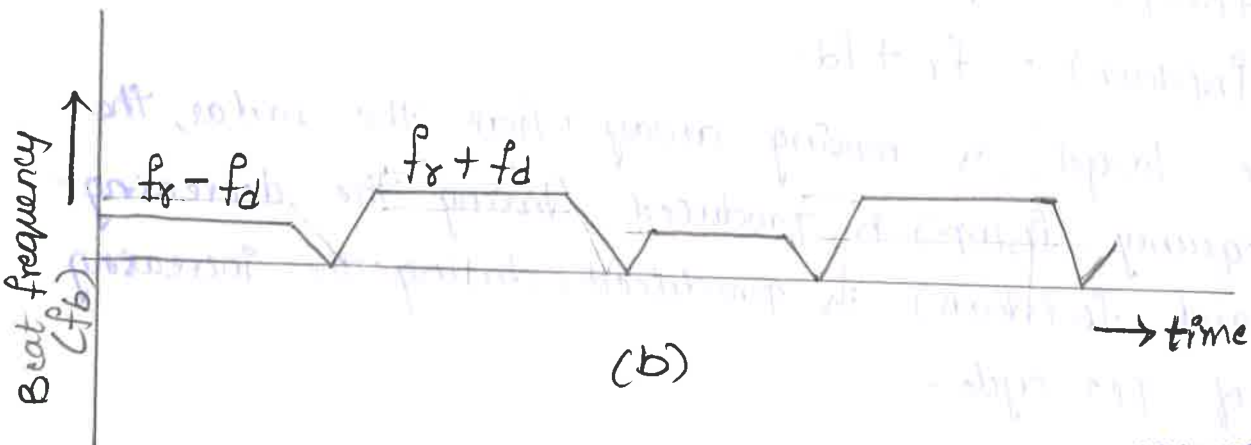
and subtracting condition,

$$f_d = \frac{1}{2}\left[f_b(down) - f_b(up)\right].$$

The frequency-time relationships in FM-CW radar is shown in below fig. when the received signal is shifted in frequency by the doppler effect (a) Transmitted (solid curve) and echo (dashed curve) frequencies (b) beat frequency.



(a)



(b)

→ when $f_r > f_d$, f_b(up) and f_b(down) are measured separately, By switching a frequency counter every half modulation cycle, one half the difference between the frequencies will yield doppler frequencies.

→ If $f_r < f_d$, that is occurence of high-speed target at short range.

→ The roles of averaging and difference frequency measurements are reversed:

→ The average meter will measure doppler velocity and difference meter will measure range.

→ It is not known that the roles of the meters are reversed Because of change in the Inequality sign b/w f_r & f_d an Incorrect Interpretation of the measurements may result.

Expression for Range and doppler Measurement :-

In the frequency modulated CW radar, the transmitted frequency is changed as a function of time in a known manner.

- Assume that the transmitted frequency increases linearly with time as shown in fig (a).
- If there is a reflecting object at a distance R, an echo signal will return after a time $T = \frac{2R}{C}$. The dashed line in the fig. represents the echo signal in a nonlinear element such as diode, a beat note f_b will be produced.
- If there is no doppler frequency shift, the beat note (diff. frequency) is measure of the targets range and $f_b = f_r$, where f_r is the beat frequency due to only targets range.

$$f_r = \dot{f_0} T = \frac{2R\dot{f_0}}{C}$$

- In any practical CW radar, the frequency cannot be continuously changed in one-direction only. It introduces the necessity of periodicity in modulation.

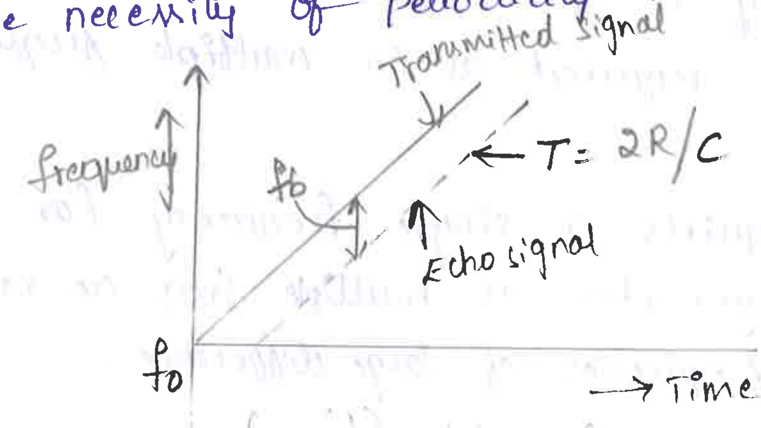


fig (a): Linear frequency modulation.

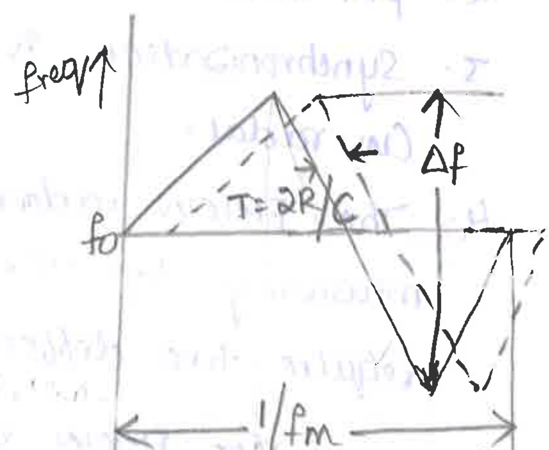


fig (b): Triangular freq. modulation

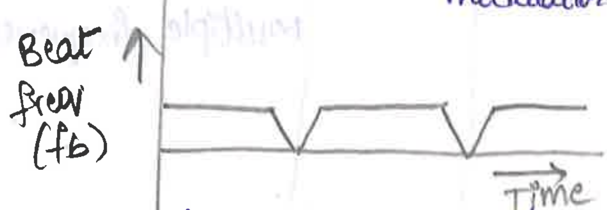


fig (c): Beat note of fig (b)

fig (b) shows triangular frequency modulation. It can be anything like sawtooth, sinusoidal (or) some other shape. The resulting beat frequency as a function of time is shown in fig (c). The beat note is of constant frequency except at the turn around region.

If the frequency is modulated at a rate f_m over a range Δf, beat frequency is.

$$f_r = 2 \times \frac{2R}{c} f_m = \frac{4R f_m \Delta f}{c}$$

$$\therefore \text{Range} \quad \boxed{R = \frac{c f_r}{4 f_m \Delta f}}$$

Advantages of FMCW Radar :-

1. Range can be measured by simple broadening of frequency spectrum.
2. FM modulation is easy to generate than linear modulation.
3. Synchronization is not required as in multiple frequency CW radar.
4. The FMCW radar requires a single frequency for measuring ~~the~~ the range, where as multiple freq. CW radar require two different frequencies of large difference.

For FMCW radar, $R = \frac{C \Delta \phi}{4\pi f_0}$.

Multiple frequency CW radar, $R = \frac{C \Delta \phi}{4 \pi \Delta f}$, $\Delta f = f_2 - f_1$

Disadvantages of FM CW radar :-

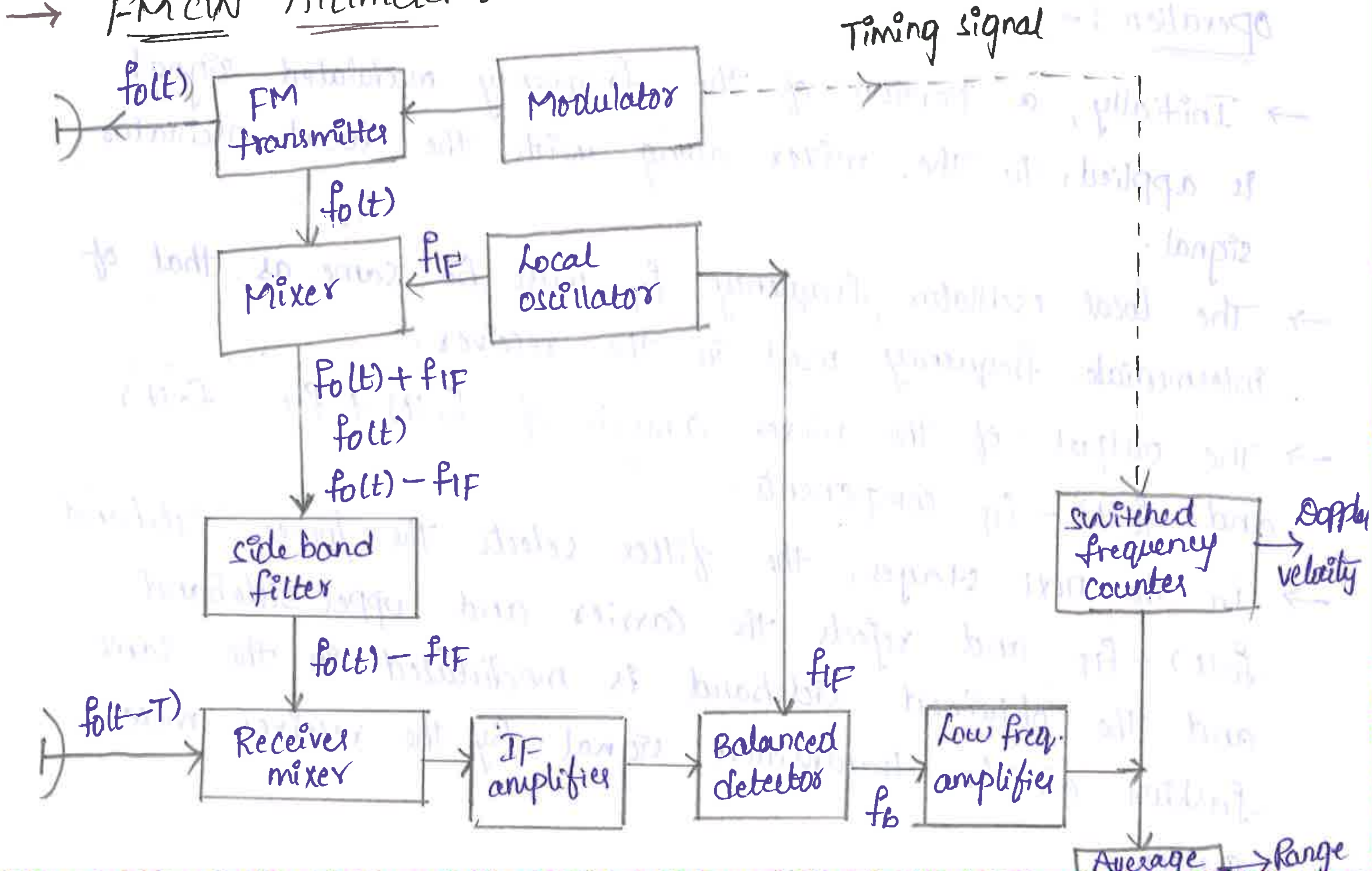
1. FM CW radar can be used to detect single targets only
2. Accuracy of FMCW radar is less compared to multiple frequency CW radar.
3. Measurement of range is more difficult, when FM signal is non-uniform or mixer is not operating in linear region.

Applications of FMCW Radar :-

FMCW Radar is used to measure

→ slant range of the target.
→ Bearing and elevation angles of target and
→ Height of the target.

→ FMCW Altimeter :-



→ The FMCW radar principle is used in the aircraft radio altimeter to measure height above the surface of the earth.

→ To permit low transmitter power and low antenna gain, the altimeter requirements are

1. The large backscatter cross section and
2. The relatively short ranges.

→ There is no effect of doppler frequency shift as the relative motion between the aircraft and the ground is small.

→ The frequency band of radio altimeters over which they be operated is 4.2 to 4.4 GHz.

→ The altimeter can employ a simple homodyne receiver but for better sensitivity and stability the superheterodyne receiver is to preferred.

<u>Operation</u> :-

→ Initially, a portion of the frequency modulated signal is applied to the mixer along with the local oscillator signal.

→ The local oscillator frequency f_{IF} must be same as that of intermediate frequency used in the receiver.

→ The output of the mixer consists of $f_0(t) + f_{IF}$, $f_0(t)$ and $f_0(t) - f_{IF}$ components.

→ In the next stages, the filter selects the lower-sideband $f_0(t) - f_{IF}$ and rejects the carrier and upper sideband and the obtained sideband is modulated in the same fashion as the transmitted signal by the receiver mixer fashion.

→ The output of the receiver ~~must~~ mixer is an IF signal of frequency $f_{IF} + f_b$.

→ The IF signal is amplified to a certain level applied to the balanced detector with local oscillator signal f_{IF}.

→ The output of detector is a beat frequency f_b which can be amplified by a low frequency amplifier.

→ The output of the low frequency amplifier is divided into two channels.

1. An average frequency counter to measure range.
2. A switched frequency counter to determine Doppler velocity.

Different noise signals occuring in a FM altimeter are,

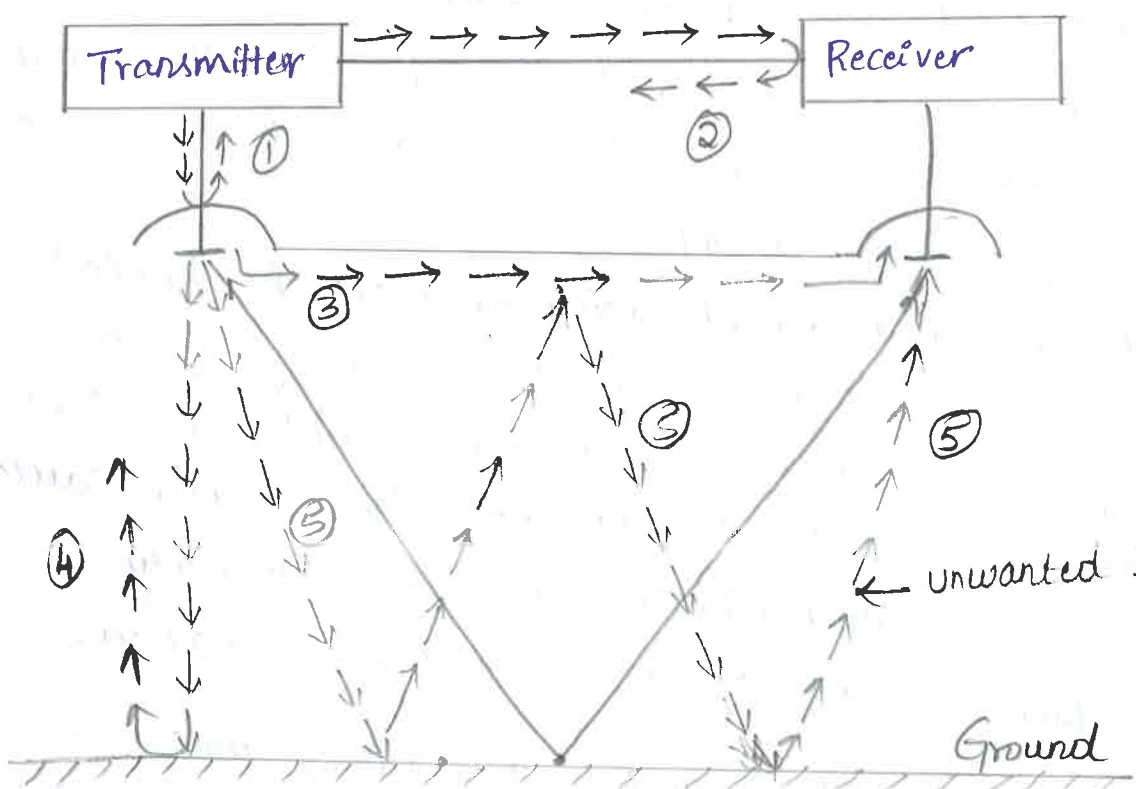


fig : Unwanted signals in FM altimeter

——→ wanted signals

→→ ——→ unwanted signals.

✓ i) Due to mismatch in Impedance a part of the Transmitted signal gets reflected from the space causing error in the altimeter.

✓ ii) The mismatch between the sideband filter and Receiver gives rise to standing wave pattern.

✓ iii) the leakage signal due to Transmitting and Receiver antennas reach the receiver and cause error.

✓ iv) The Interference due to power being reflected back to the transmitter cause a change in the impedance seen by the transmitter.

✓ v) The double-bounce signal.

Measurement Errors :-

→ The absolute accuracy of radar altimeters is usually of more importance at low altitudes than at high altitudes.

→ The distance can be measured depends upon the parameters like bandwidth of transmitted signal and the ratio of signal energy to noise energy.

→ In addition, measurement accuracy might be limited by such practical restrictions as the accuracy of the frequency measuring device, errors caused by multiple reflections & Transmitter leakage, the residual path length error caused by circuits and transmission lines and frequency error due to turn-around of the frequency modulation.

→ A common form of frequency-measuring device is the cycle counter, which measures the no. of cycles (or) half cycles of the beat during the modulation period.

→ The total cycle count is a discrete number. since the counter is unable to measure fractions of cycle.

The discreteness of frequency measurement gives rises to an error called fixed error (or) step error. It also called Quantization error.

The average number of cycles 'N' of the beat frequency f_b in one period of modulation cycle f_m is $\overline{f_b}/f_m$.

where, f_b → beat frequency.

$\overline{f_b}$ → Time average of beat frequency.

f_m → modulating frequency.

The range is given by $R = \frac{CN}{4\Delta f}$ ——— (1)

C → velocity of propagation (m/s) R → Range (altitude) (m)

N → No. of cycles Δf → frequency excursion (Hz).

The output of frequency counter 'N' is an Integer and range will be an Integral multiple of $C/4\Delta f$, which gives Quantization error equal to $\delta R = \frac{C}{4\Delta f}$.

$$\delta R\,(m) = \frac{75}{\Delta f\,(MHz)} \quad \text{——— (2)}$$

from Eqn (2), Note that the fixed error is Independent of the range and carrier frequency. At the same time, for small fixed error large frequency excursions are required.

→ Target is in motion can cause an error in range equal to $V_r \cdot T_0$ where V_r → relative velocity T_0 → Time

Problems

① Determine the range & doppler velocity for FMCW radar. if the target is approaching radar. Given that fb(up) = 20KHz & fb(down) = 30KHz for triangular modulation, modulating freq. is 1MHz & doppler frequency shift is 1KHz.

Sol $R = ?$ $V_r = ?$

Target approaching to radar,

$f_b(up) = f_r - f_d$. $f_b(down) = f_r + f_d$.

$\Rightarrow f_r = \frac{1}{2}[f_b(up) + f_b(down)] = \frac{1}{2}[20\times10^3 + 30\times10^3] = 25KHz$.

$f_d = \frac{1}{2}[f_b(down) - f_b(up)] = \frac{1}{2}[30\times10^3 - 20\times10^3] = 5KHz$.

$f_r = \frac{4Rf_m\Delta f}{c} \Rightarrow R = \frac{f_r c}{4f_m\Delta f} = \frac{25\times10^3\times3\times10^8}{4\times1\times10^6\times1\times10^3} = 1.875km$

$f_d = \frac{2V_r f_r}{c} \Rightarrow V_r = \frac{c f_d}{2f_r} = \frac{3\times10^8\times5\times10^3}{2\times25\times10^3} = 3\times10^7 m/sec$

② An FMCW radar operates at a frequency of 9.25 GHz. A symmetrical triangular modulating waveform is used. The magnitude of slope being 800MHz/sec. The return from a moving target produces a beat freq 3.85KHz over the +ve slope & 3.5KHz over the −ve slope. Determine i) Target range ii) Range rate iii) whether the targets is moving towards (or) away from the radar.

Sol G.T $f_0 = 9.25GHz$, $m = 800MHz/sec$

i) Target range $R = \frac{f_0 c}{2m} = \frac{9.25\times10^9\times3\times10^8}{2\times8\times10^8} = 1.73\times10^9 m$

ii) W.K.T $f_d = \frac{2V_r f_0}{c} \Rightarrow f_d = \frac{1}{2}[f_b(down) - f_b(up)]$

$f_d = \frac{1}{2}(3.85\times10^3 - 3.5\times10^3) = 175Hz \Rightarrow f_d$

$\therefore V_r = \frac{c f_d}{2f_0} = \frac{3\times10^8\times175}{2\times9.25\times10^9} = 2.837\times10^3 m$

iii) $f_d = 175$

$f_r = \frac{1}{2}[3.85\times10^3 + 3.5\times10^3] = \frac{1}{2}[7350] = 3675Hz$.

$\therefore$ $f_r > f_d$. Therefore, the target is moving towards the radar.

→ Multiple frequency CW radar :-

The multiple frequency cw radar is used to measure the accurate range.

✓ consider multiple frequency cw radar, Transmitting two continuous sinewaves of frequency f_1 & f_2 seperated by an amount Δf.

✓ consider amplitudes of all signals as unity, The corresponding two voltage signals are given by,

$$V_{T1} = \sin(2\pi f_1 t + \phi_1) \quad \text{——} (1)$$

$$V_{T2} = \sin(2\pi f_2 t + \phi_2) \quad \text{——} (2)$$

where ϕ_1 & ϕ_2 are phase angles.

The echo signal is shifted in frequency by the doppler effect. The form of the doppler shifted signals at each of two frequencies f_1, f_2 may be written as

$$V_{R1} = \sin\left[2\pi(f_1 \pm f_{d1})t - \frac{4\pi f_1 R_0}{C} + \phi_1\right] \quad \text{——} (3)$$

$$V_{R2} = \sin\left[2\pi(f_2 \pm f_{d2})t - \frac{4\pi f_2 R_0}{C} + \phi_2\right] \quad \text{——} (4)$$

where, R_0 = Range to target at time t.

f_{d1}, f_{d2} = doppler frequency shifts related to f_1 & f_2.

The frequency seperation b/w f_1 & f_2 is Δf.

$$\therefore \Delta f = f_1 - f_2 \Rightarrow f_2 = \Delta f + f_1$$

But $\Delta f << f_1$, so it can be neglected

$$\therefore f_2 = f_1$$

Similarly, doppler frequency shifts f_{d1} & f_{d2} are related to $f_{d1} = f_{d2}$

The Receiver seperates two components of the echo signal & heterodynes each received signal component with the corresponding transmitted waveform & extracts the two doppler frequency components given by.

$$V_{1D} = \sin\left(\pm 2\pi f_{d_1} t - \frac{4\pi f_1 R_0}{c}\right) \quad \text{—(5)}$$

$$V_{2D} = \sin\left(\pm 2\pi f_{d_2} t - \frac{4\pi f_2 R_0}{c}\right) \quad \text{—(6)}$$

from eqn (5) & (6) Phase diff. b/w 2 components is given by

$$\Delta\phi = \frac{4\pi(f_2 - f_1) R_0}{c} = \frac{4\pi \Delta f R_0}{c}$$

$$\therefore \Delta\phi = R_0 \frac{4\pi \Delta f}{c} \Rightarrow R_0 = \frac{c\,\Delta\phi}{4\pi \Delta f}.$$

The range will be unambiguous as long as $\Delta\phi$ does not exceed 2π radians.

$$\therefore \Delta\phi = 2\pi.$$

$$\Rightarrow R_0 = \frac{c\,(2\pi)}{4\pi\,\Delta f} \Rightarrow \frac{c}{2\Delta f}$$

$\therefore$ Maximum unambiguous range

$$R_{unamb} = \frac{c}{2\Delta f}$$

→ Note that when Δf is replaced by the pulse repetition rate (PRF) gives the maximum unambiguous range of a pulse radar.

→ The two frequency CW radar is essentially a single-target radar since only one phase difference can be measured at a time.

→ If more than one target is present the echo signal becomes complicated and the meaning of the phase measurement is doubtful.

→ The theoritical accuracy with which range can be measured with the two-frequency cw radar can be found.

→ The theoritical r.m.s range error is given by

$$\delta R = \frac{c}{4\pi \Delta f (2E/N_0)^{1/2}}$$

where E = Energy contained in received signal.

N_0 = Noise per hertz of bandwidth.

...and Pulse Doppler Radar

...red ...: Any unwanted radar echo is called clutter. Such e...oes can 'Clutter' the radar output and thus mak... difficult to detect the desired targets. examples. ...f clutter include the reflections from land, sea ...rain, birds insects and craft.

-> clutter can also be due to clean-air turbulance and other atmospheric effects as well as due to ionized media like the aurora and meteor, trails.

-> Un wanted echoes might also be obtained from 'point' or fixed targets as poles, towers and similar objects.

-> echoes from land or sea are called surface clutter while those from rain or other atmospheric phenomena are called volume clutter.

-> The pulsed radar system shows echoes from any reflecting object in the signal path. These stationary objects may be buildings, towers, hills, geographic features. The echoes created due to these objects are unwanted. These stationary objects are called as clutter. and can affect the radar performance.

-> The echoes of the clutter do not change on successive sweeps of radar antenna. It is very difficult to trace echoes when a target is moving constantly e.g in airport landing system or in vehicle direction system.

-> Because of the ...

is affected in two ways.

1. The clutter provides many reflections which slows down the radar signal processing capability.

2. If the reflections due to clutter are larger compared to reflection of moving targets, this smaller echo due to moving target may not be distinguished.

→ The radars were required to detect targets in the presence of noise.

→ In the real world, radars have to deal with more than received noise when detecting targets since they can also receive echoes from the natural environment such as land, sea and weather. These echoes are called clutter since they can "clutter" the radar display.

→ clutter echoes can be many orders of magnitude larger than aircraft echoes.

→ when an aircraft echo and a clutter echo appear in the same radar resolution cell, the aircraft might not be detectable.

→ clutter echoes can be greater than the desired target echoes by as much as 60 or 70 dB more depending on the type of the radar and the environment.

→ The doppler frequency shift produced by a moving target may be used in a pulse radar, Just as in the CW radar, to determine the relative velocity of a target or to Separate desired moving target from Undesired stationary objects.

→ Although there are applications of pulse radar where a determination of targets relative velocity is made from the doppler frequency shift, The use of doppler to separate Small moving targets in the presence of large clutter has probably been of greater interest. Such a pulse radar that utilizes the doppler frequency shift as a means for discriminating moving from fixed targets is called an MTI (moving Target Indicator) or pulse doppler radar. The two are based on the Same physical principle but in practice, There are generally recognizable differences between them.

The MTI radar, for instance, usually operates with ambi-guous doppler measurement (so Called blind speed) but with unambiguous range measurement (no second time around echoes).

→ The opposite is generally the Case for pulse doppler radar. Its pulse repetition frequency is usually high enought to operate with a unambiguous doppler (no blind Speeds) but at the expense of range ambiguities.

→ An MTI radar has a low Prf and a low duty cycle.

→ A pulse doppler radar, On the other hand, has a high Prf

-> A Moving target indicator (MTI) uses the doppler effect to minimize the clutter effects to locate the target that is moving. The relative phase of echo signals received from a moving target Continuously change with respect to the phase of the transmitted pulse when there is a Continuous Change in the distance of the target. The MTI Senses the target movement by Comparing the phase Shift of the received Signal with respect to the transmitted Signal.

-> MTI radar uses the doppler effect to detect the Moving target

-> MTI radar eliminates the clutter Signals and reduces the effect of noise.

-> Delay-line Cancellers are used in MTI radar to remove the effect of ~~noise~~: blind Speeds.

MTI radar: A pulse radar which utilizes the doppler frequency shift for discriminating moving targets from fixed Ones, appearing as clutter, is known as moving target indication (MTI) radar.

-> It usually Operates with ambiguous doppler measurement but with Unambiguous range measurement.

-> The opposite is generally the Case for a pulse doppler radar which also discriminates moving targets from Clutter by doppler frequency shift measurements.

-> The design of an MTI radar is much more challenging than a simple pulse radar or a CW radar.

-> MTI is a necessity in high quality air-surveillance in the doppler domain.

→ It determines target velocity and distinguishes moving targets from stationary targets.

Principle of operation:

→ MTI radar employs the doppler effect in its operation.

→ It eliminates clutter due to stationary objects and identifies moving targets.

→ In above fig. STALO means stable local oscillator and Cotto means Coherent oscillator.

→ Cotto provides refrence Signal, which has the phase of transmitter Signal.

→ The block diagram Consists of transmitter and receiver sections. The STALO, mixer1, modulator, microwave Signal amplifier, and duplexer are Parts of transmitter

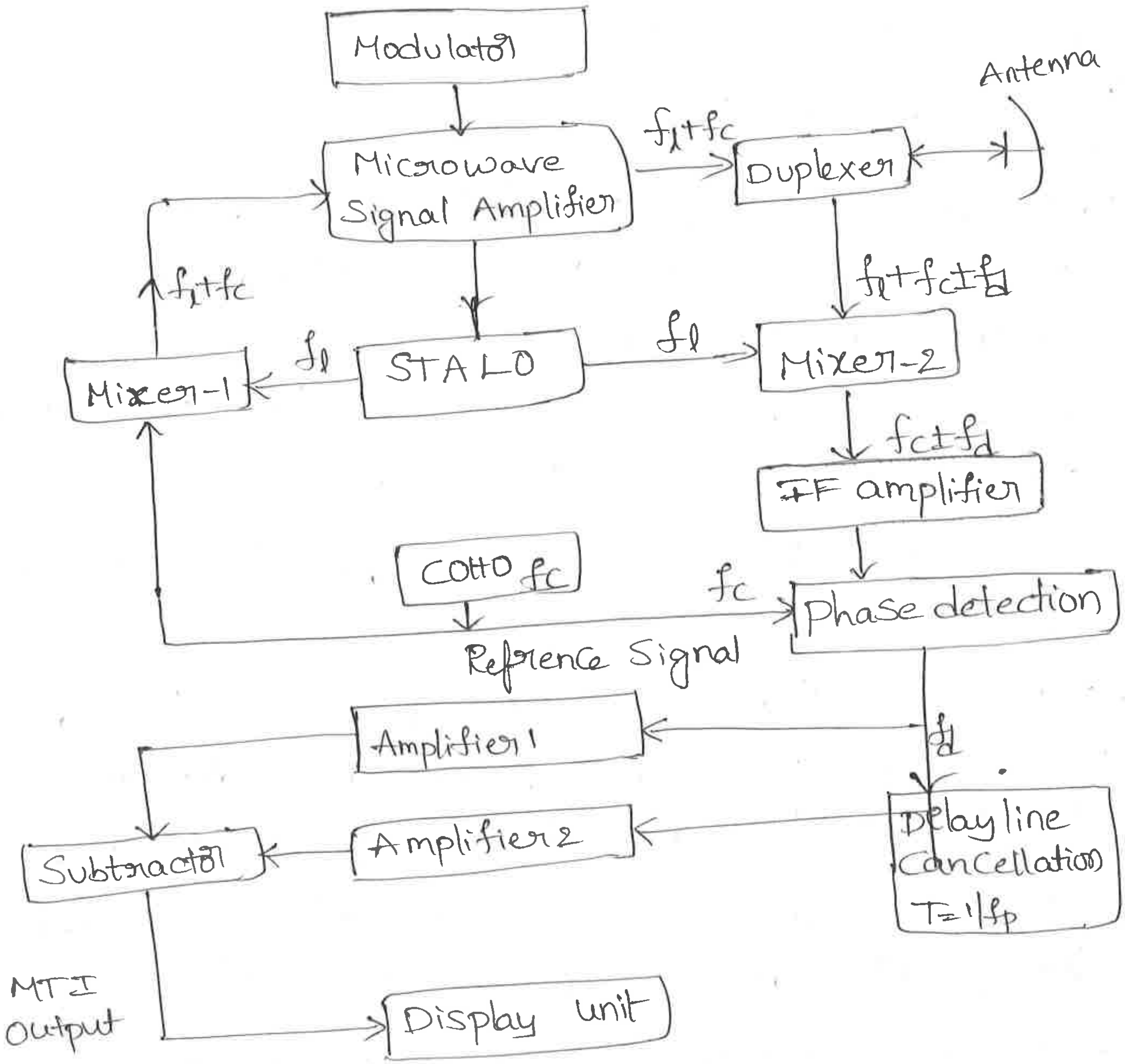
→ The duplexer, mixer2, STALO, IF amplifier2, Subtractor and display units are parts of the MTI radar.

→ MTI radar operates by Comparing a set of received echoes with those of received in the preceding Sweep. The echoes of Constant Pulse are Cancelled out. This applicable to the stationary objects. The echoes of changing phase due to moving targets are not Cancelled. The clutter due to stationary objects is removed to identify the moving objects in the display easily.

→ The input to mixer1 is from two oscillators namely STALO and Cotto.

→ The ...

MTI Radar block diagram and principle of operation:



→ MTI radar means Moving Target Indicator radar. This is one form of pulsed radar.

→ MTI radar is characterised by its very low Prf and hence there is no range ambiguity in MTI radar.

The unambiguous range is given by

$$R_{un} = \frac{v_o}{f_p}$$

where f_o = pulse repetition frequency

v_o = velocity of EM wave in free-space.

→ Mixer 1 and 2 use the same local oscillator, STALO and they are Identical.

→ The input to Mixer2 is $f_l + f_c \pm f_d$. This signal $f_c \pm f_d$ is given to the IF amplifier.

→ The o/p of IF amplifier is given to the phase detector whose o/p is f_d. This output goes to the delay line Canceller and also to amplifier1.

→ The o/p of the delay line Canceller is given to the ~~phase detector whose~~ amplifier2.

→ The outputs from amplifier1 and amplifier2 are given to the Subtractor. Its o/p goes to the display unit.

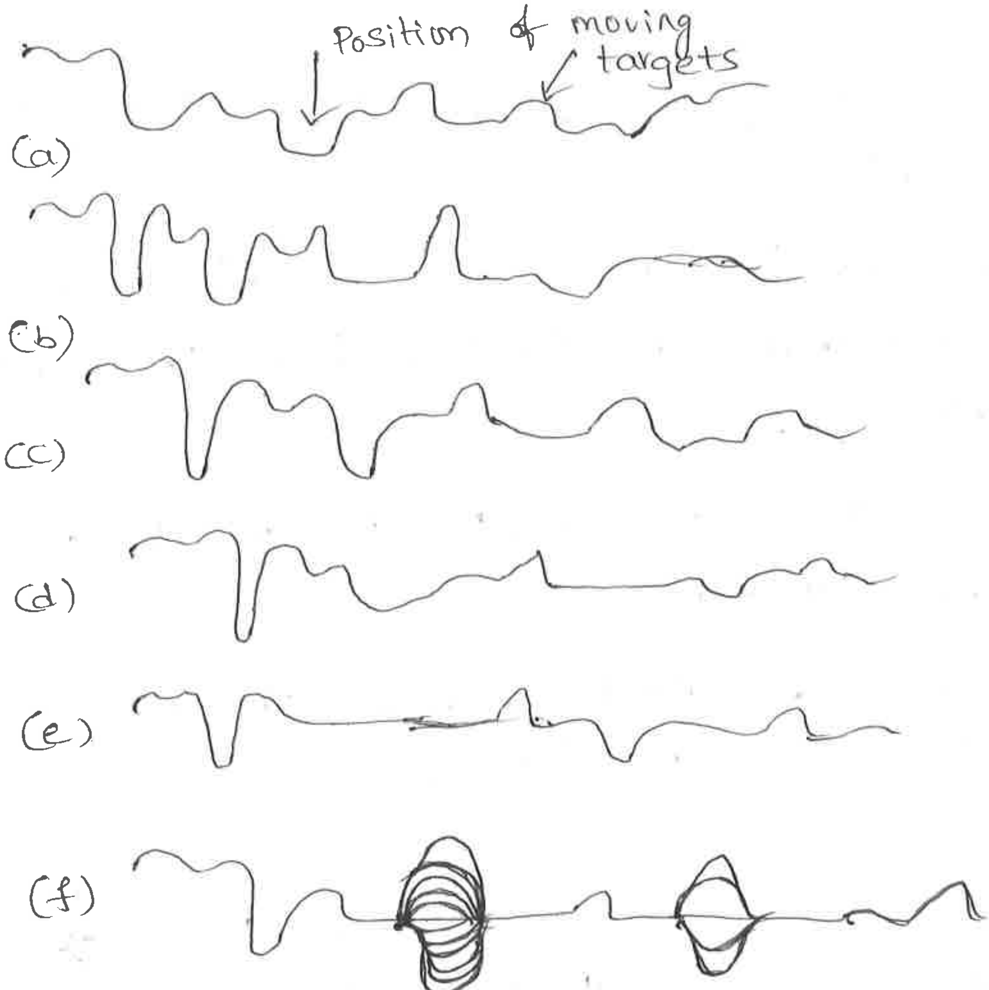
→ The delay line Canceller is a time domain filter. It rejects stationary clutter at zero frequency. Its frequency response function is derived from the signals in time domain.

Advantages of MTI radar:

The important advantages of MTI radar system are as under

1. It eliminates the clutter signals.
2. It can detect the echoes of much smaller moving targets compared to clutter. Therfore moving targets that are much smaller than the stationary ones can be observed.
3. It reduces the effect of noise.
4. For a given power the useful range is increased.

Butterfly effect :



fig② (a-e) Successive Sweeps of an MTI radar A-scope display (echo amplitude as a function of time);
(f). Super position of many Sweeps, arrows indicate position of moving targets.

→ Moving targets may be distinguished from stationary targets by observing the video output on an A-scope display By looks like a point target and moving target as extended target for different pulse repetition intervals A-scope display is shown in 2 as a, b, c, d and e.

→ At the rate of doppler frequency, echoes from moving targets vary in amplitude from Sweep to Sweep. Echoes from fixed targets remains Constant. The

-> The principle of MTI radar is similar to the pulse doppler radar but the main difference is the way of generation of refrence signal.

-> In MTI radar, the refrence Signal is generated by a Stable oscillator which is Called Coho i.e Coherent oscillator

-> The Coho is a stable. Oscillator whose frequency is Same as the intermediate frequency used in the receiver.

-> In addition to providing the refrence Signal the output of the coho f_c is also mixed with the local oscillator frequency f_l. The local oscillator must also be a Stable oscillator and is Called stalo, for Stable local oscillator

-> The RF echo Signal is heterodyned with the stalo Signal to produce. the IF Signal.

-> The stalo, coho and the mixer in which they are Combined plus any two-level amplification are Called the receiver-exicter.

-> The Main function of stalo is to provide the necessary frequency translation from the IF to the transmitted (RF) frequency.

-> As the stalo acts as local oscillator is the receiver the stalo phase shift is Canceled.

-> Finally, the coho refrence signal and IF echo Signal are fed to a phase detector, whose o/p is Proportional to the phase difference between the input Signals.

Which looks like "butterfly" shape. Therefore it is called as butterfly effect of MTI radar.

→ The moving target produce, with time, a "butterfly" effect on the A-scope.

Advantages of butterfly effect:

1. Butterfly effect helps to recognize a particular moving target from a multiple moving targets.
2. Amplitude versus range output on an A-scope helps in distinguishing the moving targets from stationary targets.

MTI radar with Power-amplifier transmitter

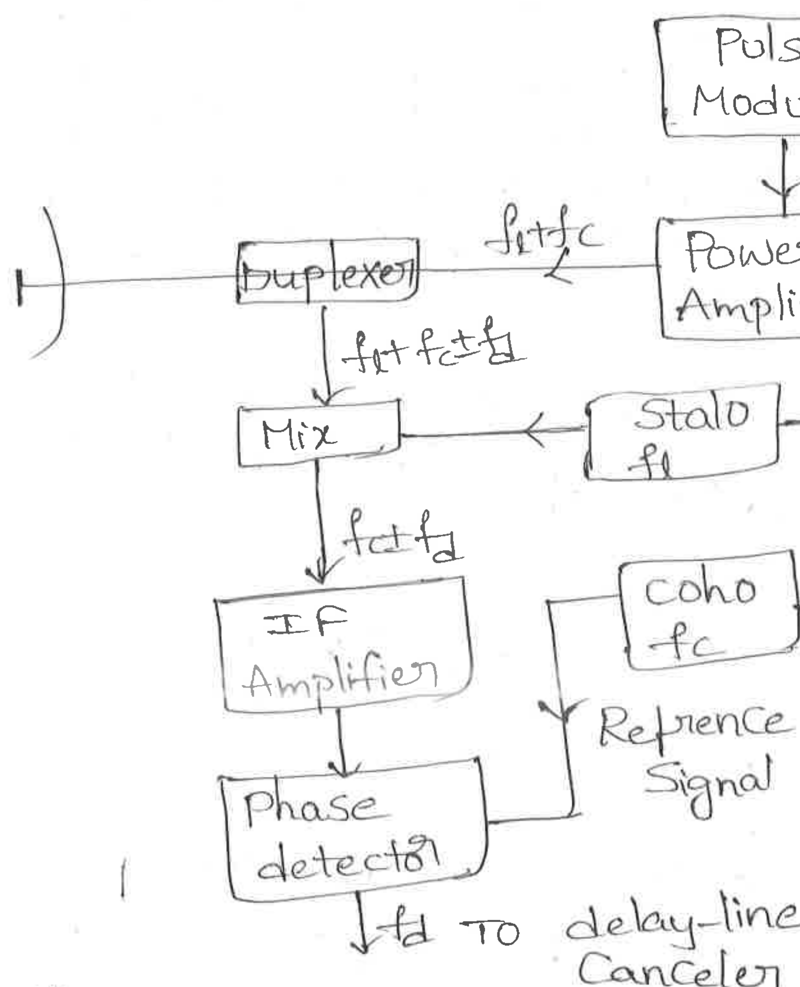


fig: Block diagram of MTI radar with power amplifier transmitter.

→ The radar which uses the concept of doppler frequency shift for distingcishing desired moving target from undesired stationary objects i.e clutter is called as moving target

MTI Radar with Power-oscillator transmitter :

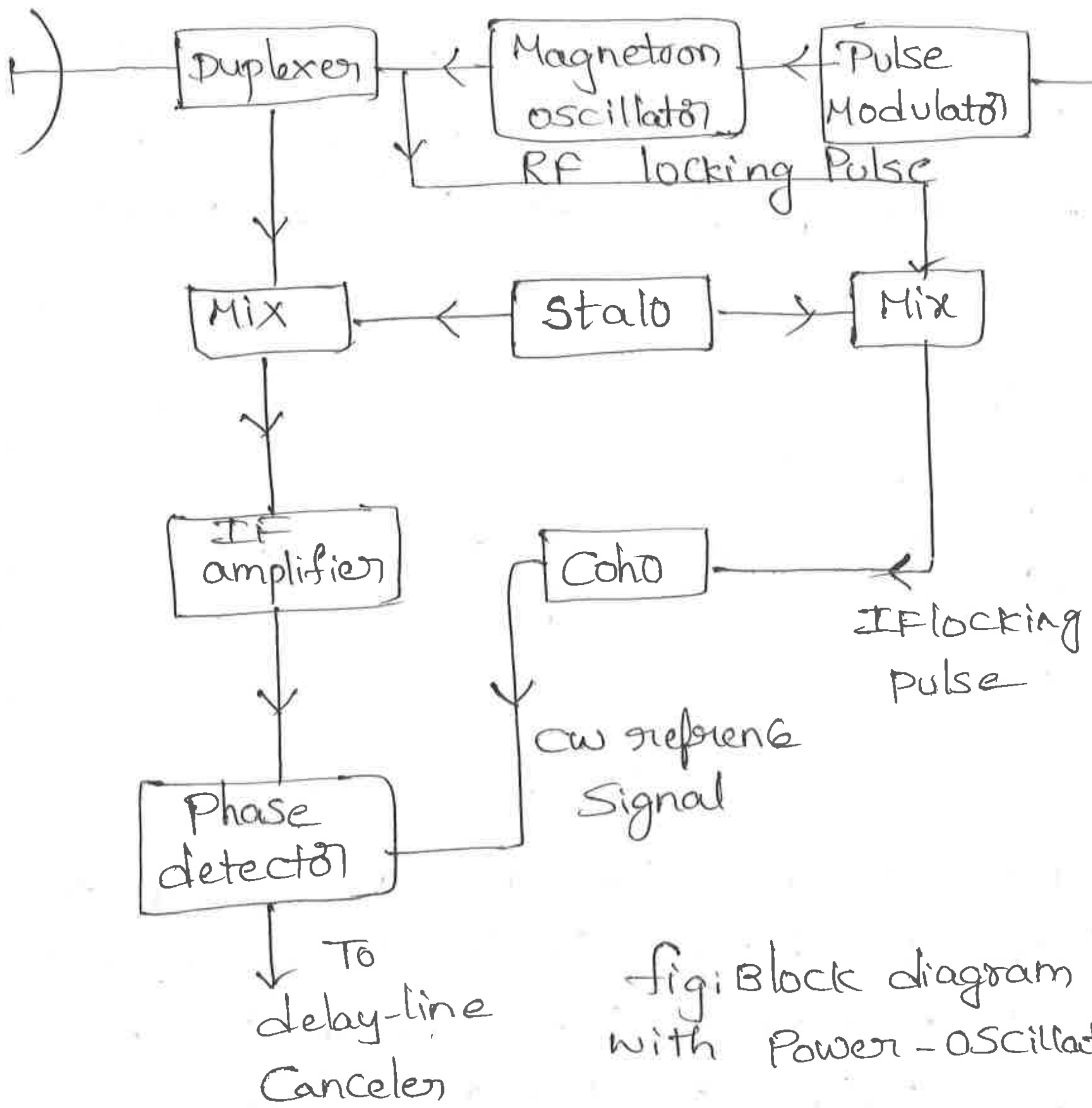


fig: Block diagram of MTI radar with Power-oscillator transmitter.

→ A block diagram of an MTI radar with a power oscillator is shown in above fig.

→ A portion of the transmitted signal is mixed with the stalo output to produce an IF beat signal whose phase is directly related to the phase of the transmitter. This IF Pulse is applied to the Coho and causes the phase of the coho CW oscillation to "lock" in step with the phase of the IF refrence pulse.

→ The phase of the coho is then related to the phase of the transmitted pulse and may be used as the

Particular transmitted pulse.

-> Upon the next transmission another IF locking pulse is generated to relock the phase of the cw Coho untill the next locking pulse comes along. The type of MTI radar illustrated in above fig. has had wide application.

<u>Delay line Cancelers:</u>

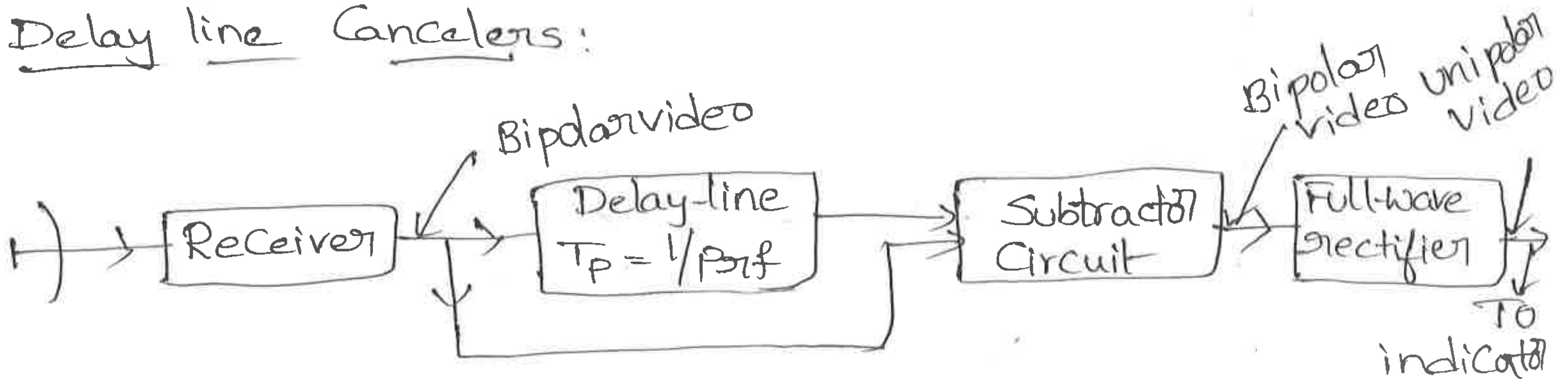


fig: MTI receiver with delay-line Canceler.

-> In case of MTI radars, Sometimes phase shift effect is not appropriate for display on the PPI. One Method Commonly employed to extract doppler information in a form suitable for display on the PPI scope is with a delay line Canceler shown in fig above.

-> The delay line canceler is a time domain filter. It rejects Stationary clutter at zero frequency. Its frequency response function is derived from the signals in time domain.

-> The delay line Canceler acts as a filter to eliminate the d.c Component of fixed targets and to pass the a.c Components of moving targets.

-> The video portion of the receiver is divided into two channels. One is a normal video channel. In the equal to one pulse repetition period.

→ The outputs from the two channels are subtracted from one another.

→ The fixed targets with unchanging amplitudes from pulse to pulse are canceled on subtraction.

→ However, the amplitudes of the moving target echoes are not constant from pulse to pulse and subtraction results in an uncanceled residue.

→ The output of the subtraction circuit is bipolar video just as was the input.

→ Before bipolar video can intensity modulate a PPI display, it must be converted to unipotential voltages (unipolar video) by a full wave rectifier.

__Filter characteristics of the delay-line canceler__:

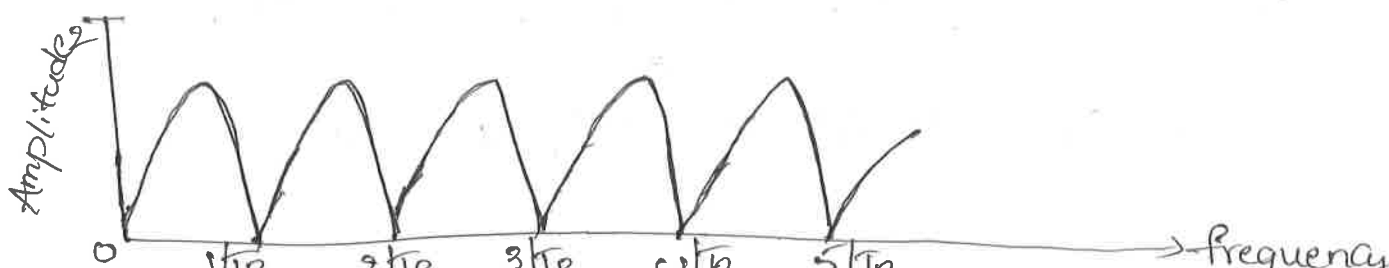


fig: frequency response of the single delay line canceler

→ The simple delay-line canceler is an example of time domain filter. The capability of this device depends on the quality of medium used as delay line.

→ The delay line canceler acts as a filter which rejects the dc component of clutter (unwanted target)

→ Because of its periodic nature, the filter also rejects energy in the vicinity of the pulse repeti-

→ The video signal received from a particular target at range R_0 is

$$V_1 = k\sin(2\pi f_d t - \phi_0)$$

where ϕ_0 = phase shift

k = amplitude of video signal

→ The signal which is delayed by a time T_p = pulse repetition interval is

$$V_2 = k\sin(2\pi f_d(t - T_p) - \phi_0)$$

→ The output from the subtractor circuit is

$$V = V_1 - V_2$$

$$V = k\sin(2\pi f_d t - \phi_0) - k\sin(2\pi f_d(t - T_p) - \phi_0)$$

$$V = k[\sin(2\pi f_d t - \phi_0) - \sin(2\pi f_d(t - T_p) - \phi_0)]$$

$$\sin C - \sin D = 2\cos\frac{(C+D)}{2} \cdot \sin\frac{(C-D)}{2}$$

$$V = k\,2\cos\frac{[2\pi f_d t - \phi_0 + 2\pi f_d(t - T_p) - \phi_0]}{2} \times \sin\frac{[2\pi f_d t - \phi_0 - 2\pi f_d(t - T_p) + \phi_0]}{2}$$

$$= 2k\cos\frac{(2\pi f_d t - \phi_0 + 2\pi f_d t - 2\pi f_d T_p - \phi_0)}{2} \times \sin\frac{(2\pi f_d t - 2\pi f_d t + 2\pi f_d T_p)}{2}$$

$$= 2k\cos\frac{(4\pi f_d t - 2\phi_0 - 2\pi f_d T_p)}{2}\sin\frac{(2\pi f_d T_p)}{2}$$

$$= 2k\cos(2\pi f_d t - \phi_0 - \pi f_d T)\sin(\pi f_d T_p)$$

$$V = 2k\sin(\pi f_d T_p)\cos\left[\left(2\pi f_d\left(t - \frac{T_p}{2}\right) - \phi_0\right)\right] \rightarrow (1)$$

→ It is assumed that the gain through the delay line canceler is unity. The output from the canceler consists of cosine wave at the doppler frequency f_d with an amplitude $2k\sin \pi f_d T_p$.

Thus the amplitude of the canceled video output is a function of the doppler frequency shift and the pulse repetition interval or prf.

→ The magnitude of the relative frequency response of the delay line canceler is shown in above fig.

→ The frequency response of delay line canceler is the ratio of the amplitude of the output from the delay line canceler to the amplitude of the normal radar video

→ When two delay line cancelers are used in cascaded form then it is called double delay line canceler.

→ Double delay line canceler is used when single delay line does not detect the target properly.

Blind Speeds:

Def: Blind speed is defined as the radial velocity (or relative velocity) of the target at which the MTI response is zero.

Def: It is also defined as the radial velocity of the target which results in a phase difference of exactly 2π radians between successive pulses.

Def: Blind speed is defined as the radial velocity of the target at which no shift appears making the target appearing stationary and echoes from the target are cancelled.

→ The response of the single delay-line canceler will be zero whenever the $\pi f_d T_0$ is the ai - factor of eq①

M, 0, π, 2π, 3π ... etc.

$$\pi f_d T_p = n\pi$$

$$f_d T_p = n$$

$$f_d = \frac{n}{T_p} = n f_p$$

where $n = 0, 1, 2 \ldots\ldots$ and f_p = Pulse repetition frequency

→ The delay-line canceler not only eliminates the d.c component caused by clutter ($n=0$), but it also rejects any moving target whose doppler frequency happens to be the same as the pulse repetition frequency which causes the effect of blind speed and is given by

Blind speed of the target is given by

$$V_n = \frac{n\lambda}{2T_p} = f_p \cdot \frac{n\lambda}{2} \quad , n = 1, 2, 3$$

where V_n is the n^{th} blind speed

f_p = pulse repetition frequency (Hz)

n = Any integer $= 1, 2, 3$

λ = wavelength (m)

T_p = pulse repetition interval $= 1/f_p$ or $1/Prf$

→ If λ is measured in meters, f_p in Hz and the relative velocity is knots, the blind speeds are given by

$$V_n = \frac{n\lambda f_p}{1.02} \simeq n\lambda f_p$$

→ If λ is in meters f_p in Hz and radial velocity

→ The blind speeds are one of the limitations of pulse MTI radar which do not occur with CW radar. Usually only the first blind speed v_1 is considered since others are integer multiples of v_1.

Problem:

① For an MTI radar what are first three blind speeds at 2 GHz when the PRF is 1 KHz

Sol: $f = 2GHz$, $\lambda = \frac{c}{f} = \frac{3\times10^8}{2\times10^9} = 0.15m$

$$f_p = PRF = 1KHz$$

Blind speed are given by

$$v_n = f_p \frac{n\lambda}{2} \text{ (or) } PRF\left(\frac{n\lambda}{2}\right)$$

For first blind speed $n=1$

$$v_1 = 10^3 \frac{(1\times0.15)}{2} = 75\ m/s = 270\ km/hr$$

For second blind speed $n=2$

$$v_2 = 10^3\left(\frac{2\times0.15}{2}\right) = 150\ m/s = 540\ km/hr$$

For third blind speed, $n=3$

$$v_3 = 10^3\left(\frac{3\times0.15}{2}\right) = 225\ m/s = 810\ km/hr$$

② An MTI radar operates at a PRF of 1.5 KHz. Its operating wavelength is 3cm. Determine lowest blind speed

Sol: $PRF = 1.5\ KHz$

$$\lambda = 3\ cm = 3\times10^{-2}\ m$$

$$V_n = Prf\left(\frac{n\lambda}{2}\right)$$

- n=1 gives the lowest blined speed

$$V_1 = 1.5\times10^3\left(\frac{1\times3\times10^{-2}}{2}\right) = 22.5\ m/s.$$

(3) What are the three lowest blind frequencies of the radar when it is operating at 10GHz with a PRF of 1KHz.

Sol:

PRF = 1KHz

f = 10GHz

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03m$$

The blind frequencies are given by

$$f_n = n\times PRF$$

For n = 1, 2, 3

$$f_1 = 1\times1\times10^3 = 1KHz$$

$$f_2 = 2\times1\times10^3 = 2KHz$$

$$f_3 = 3\times1\times10^3 = 3KHz$$

∴ The lowest three blind frequencies are 1kHz, 2kHz, 3KHz.

(4) If an MTI radar operates at 10GHz with PRF of 0.8KHz, then find the three lowest blind speeds.

Sol: f = 10 GHz, $\lambda = \frac{c}{f} = \frac{3\times10^8}{10\times10^9} = 0.03\ m$

PRF = 0.8 KHz

The blind speed is given by

$$V_n = PRF\left(\frac{n\lambda}{2}\right)$$

The first lowest blind speed is given by (n=1).

$$V_1 = 0.8\times10^3\left(\frac{1\times0.03}{2}\right) = 12\ m/s.$$

The second lowest blind speed is given by (n=2)

$$V_2 = 0.8\times10^3 \left(\frac{2\times0.03}{2}\right) = 24\ m/s$$

The third lowest blind speed is given by (n=3)

$$V_3 = 0.8\times10^3 \left(\frac{3\times0.03}{2}\right) = 48\ m/s.$$

<u>Limitation</u> <u>of MTI</u> <u>radar</u>:

The blind speeds can be a serious limitation in MTI radar since they cause some desired moving targets to be canceled along with the undesired clutter at zero frequency.

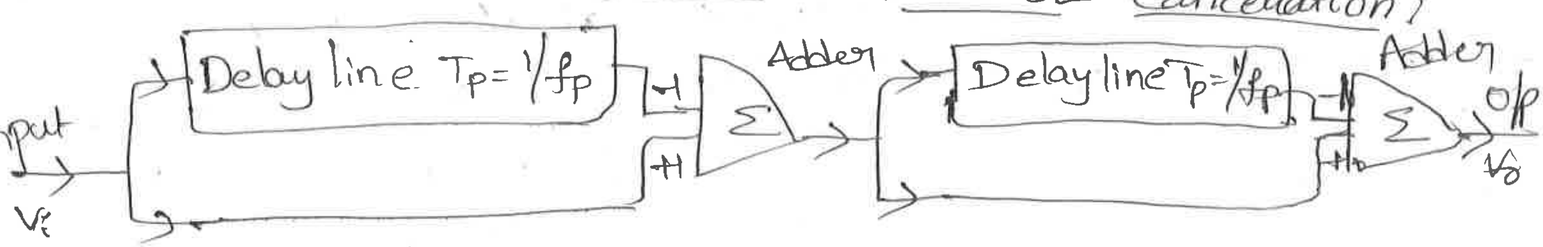
There are four methods to reduce the effect of blind speeds by operating the radar at

1. Long wavelengths (Low frequencies)
2. high pulse repetition frequency
3. more than one pulse repetition frequency and
4. More than one wavelength (or more than one RF frequency)

<u>Notes</u>: The presence of blind speeds with in the doppler frequency band reduces the detection capabilities of the of the radar

<u>Notes</u>: The effect of blind speeds can be reduced by operating with more than one pulse repetition frequency. This is called a staggered Prf MTI. operating at more than one PRF frequency can also reduce the effect of blind speeds.

<u>Double</u> <u>Delay</u> <u>Line</u> <u>Canceler</u> (or) <u>Double</u> <u>Cancellation</u>:



Here, two single delay-line cancelers are cascaded with the help of adders. The delay is given by $T_p = (T_p = 1/f_p)$ where f_p is the pulse repetion frequency and T is pulse repetition period

The o/p of delay line canceler is given by

$$V_i = V_i(t) - V_2(t+T_0) - V_2(t+T_0) + V_2(t+2T_0)$$

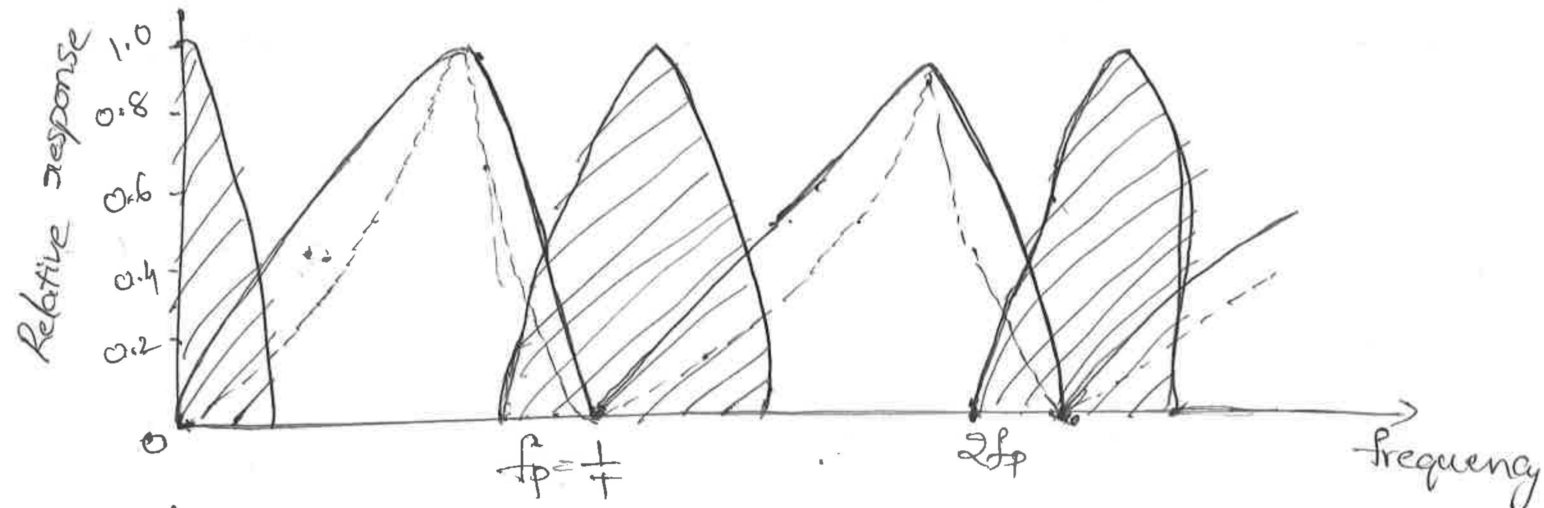


fig (2): Relative frequency response of the single delay-line canceler (solid curve) and the double delay-line canceler (dashed curve). Shaded area represents the clutter spectrum.

-> The frequency response of a single delay line canceler does not always have as broad a clutter-rejection null as might be desired in the vicinity of d.c.

-> The clutter rejection matches may be widened by passing the output of the delay line canceler through a second delay line canceler as shown in fig(1).

-> The output of the two-single delay-line cancelers cascade in the square of that from a single canceler. Thus the frequency response is $4\sin^2 \pi f_d T_0$

→ The configuration of fig(i) is called a double-delay line" canceler or simply a double canceler.

→ The relative response of the double canceler compared with that of a single delay-line canceler is shown in fig (2).

→ The finite width of the clutter spectrum is also shown in this figure so as to illustrate the additional cancellation of clutter offered by the double canceler

Multiple or Staggered PRFs:

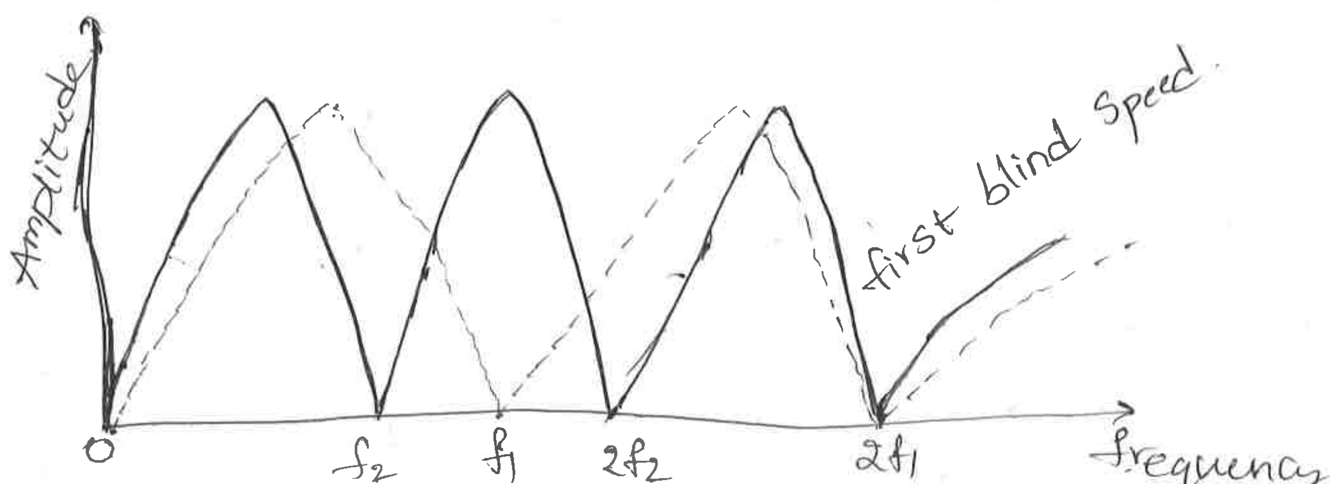


fig: frequency response of a single delay-line canceler with two different Prfs, f_1 (dash curve) and f_2 (solid curve)

→ The use of multiple waveforms with different pulse repetition frequencies allows the detection of moving targets that can be eliminated with a constant Prf waveform if their radial velocities were at or in the vicinity of a blind speed.

→ A simple illustration is shown in above fig. which graphs the frequency response of a single delay line canceler with two diffrent Prfs

→ At Prf, f_1 blind speeds (nulls) occur when the doppler frequency is f_1 or $2f_1$ (other integer multiples are not shown)

→ With Prf $f_2 = 2f_1/3$, blind speeds occur when the doppler frequency equals f_2, $2f_2$ or $3f_2$.

→ It can be seen in fig(1) that targets not detectable because of a blind speed in the frequency response of one prf will be detectable with the other prf.

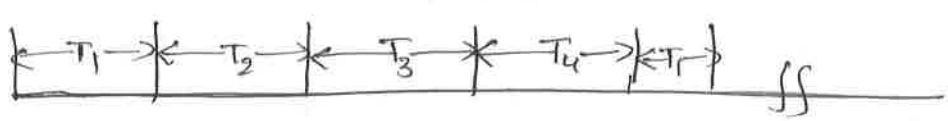
→ A target is lost on both prfs, however, when the blind speeds occur simultaneously, as when $2f_1 = 3f_2$.

→ The above illustrates the benifit of using more than one prf to reduce the effects of blind speeds, but it might be cautioned that it is not usual to use prfs with the relatively large ratio of 3/2.

→ There are several methods for employing multiple prfs to avoid losing target echoes due to blind speeds. The prfs can be changed ① scan to scan ② dwell to dwell ③ pulse to pulse usually called staggered prfs.

→ Staggered prfs have been popular for air traffic control radars.

→ An example of the lower intervals of a staggered prf waveform is given in below fig(2). The four interval sequence is then repeated.



fig(2): Staggered pulse-train with four different pulse periods or intervals

-> In pulse-to-pulse staggered Prfs, as in fig(2), the time between pulses is an interval or a period

-> Multiple staggered Prfs can be processed with a transversal filter.

-> The use of more than one pulse repetition frequency offers additional complexity in the design of MTI doppler filters.

-> The blind speeds of two independent radars operating at the same frequency will be different if their pulse repetition frequencies are different. Therfore, if one radar were "blind" to moving targets, it would be unlikely that the other radar would be "blind" also. Instead of using two different radars the same result can be obtained with one radar which time-shares its Prf between two or more different values.

-> The pulse repetition frequency might be switched every other half beam width, or the period might be altered on every other pulse. when the switching is pulse-to-pulse it is known as staggered Prf.

Range Gated Doppler filters

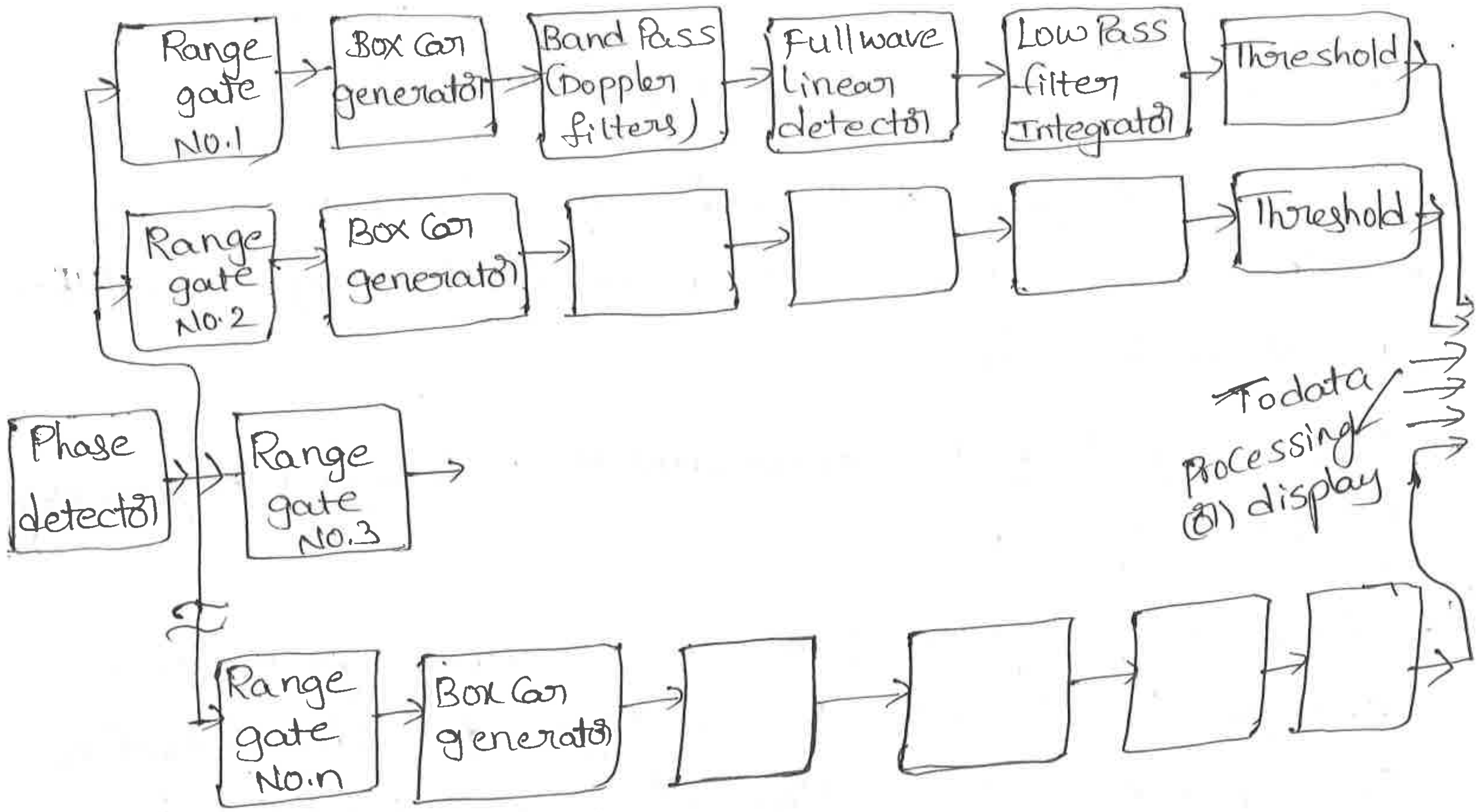
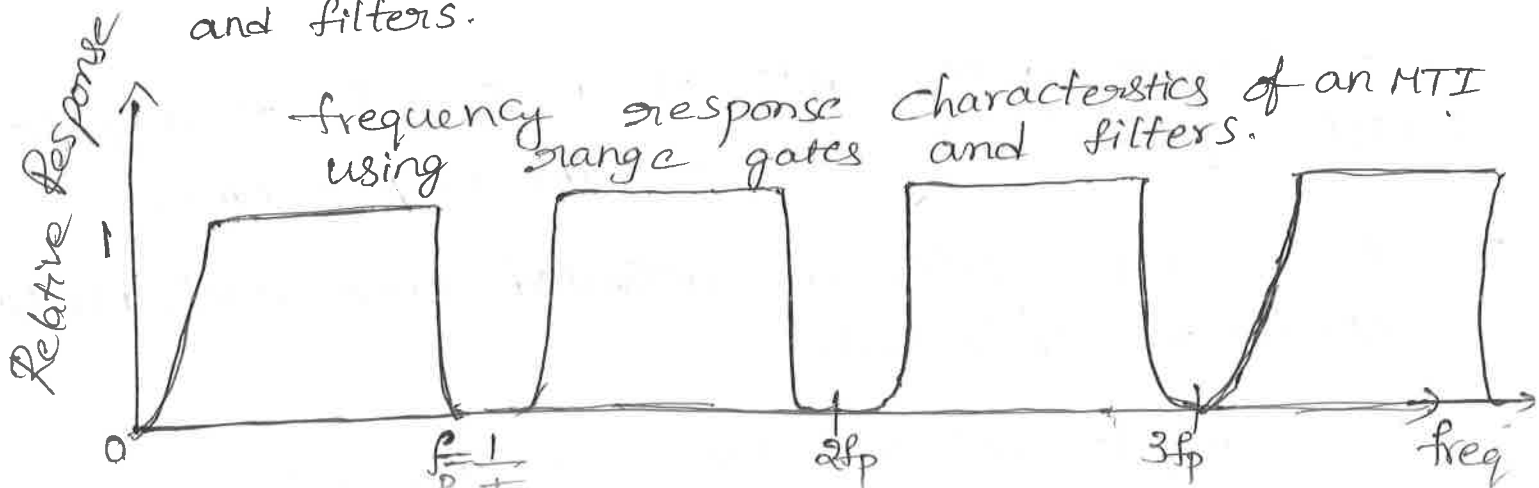


fig (1): Block diagram of MTI radar using range gates and filters.



— Range gating: The loss of the range information and the collapsing loss may be eliminated by first quantizing the range (time) into small intervals. This process is called range gating.

→ The width of the range gates depends upon the range accuracy desired and the complexity which can be tolerated

→ Range resolution is established by gating.

→ A collapsing loss does not take place since noise from the other range intervals is excluded.

→ A block diagram of the video of an MTI radar with multiple range gates followed by clutter-rejection filters is shown in fig (1).

→ The output of the phase detector is sampled sequentially by the range gates.

→ Each range gate opens in sequence just long enough to sample the voltage of video waveform corresponding to a different range interval in space.

→ The range gate acts as a switch or a gate which opens and closes at the proper time.

→ The range gates are activated once each pulse repetition interval.

→ The output for a stationary target is a series of pulses of constant amplitude.

→ An echo from a moving target produces a series of pulses which vary in amplitude according to the doppler frequency.

→ The output of the range gates is stretched in a circuit called the boxcar generator and detection process by emphasizing the fundamental of the modulation frequency and eliminating harmonics of the pulse repetition frequency.

-> The clutter rejection filter is a bandpass filter whose bandwidth depends upon the extent of the expected clutter spectrum.

-> Following the doppler filter is a full wave linear detector and an integrator (a LPF)

-> The purpose of the detector is to convert the bipolar video to unipolar video.

-> The output of the integrator is applied to a threshold detection circuit.

-> Only those signals which cross the threshold are reported as targets.

-> Following the threshold detector the outputs from each of the range channels must be properly combined for display on the PPI or A-scope or for any other appropriate indicating or data-processing device.

-> The shape of the rejection band is determined primarily by the shape of the bandpass filter.

-> The frequency response characteristic of an MTI using range gates and filters is shown in fig(2)

Limitation to MTI Performance:

→ An improvement in the Signal-to-noise ratio of an MTI is affected by several factors other than the design of the doppler signal processor.

→ The performance of MTI radars degraded because of the following reasons.

1. equipment instabilities.
2. Internal fluctuation of clutter
3. Antenna Scanning modulation.
4. Limiting in MTI radar.

Equipment Instabilities: pulse-to-pulse changes in the amplitude, frequency or phase of the transmitter signal lower the improvement factor of an MTI radar.

→ If the Coho from stationary clutter on the first pulse is $A\cos\omega t$ and from the second pulse $A\cos(\omega t+\Delta\phi)$. Then the difference between the two is

$$A\cos\omega t - A\cos(\omega t+\Delta\phi) = A - 2\sin\left(\frac{\omega t+\omega t+\Delta\phi}{2}\right)\sin\left(\frac{\omega t-\omega t-\Delta\phi}{2}\right)$$

$$= (A)-2\sin\left(\frac{2\omega t+\Delta\phi}{2}\right)\sin\left(\frac{-\Delta\phi}{2}\right)$$

Notes:

$$\sin C-\sin D = -2\sin\frac{(C+D)}{2}\cdot\sin\frac{(C-D)}{2}$$

$$= 2A\sin\left(\omega t+\frac{\Delta\phi}{2}\right)\sin\left(\frac{\Delta\phi}{2}\right)$$

→ For small phase errors the amplitude of the resultant difference

$$2A \sin\left(\frac{\Delta\phi}{2}\right) \approx 2A \frac{\Delta\phi}{2} = A\Delta\phi$$

→ So, the limitation on the improvement factor due to oscillator instability is $I =$

→ This would apply to the Coho locking or to the phase change which is introduced by a power amplifier.

Internal fluctuation of clutter: There are many types of clutter which are not absolutely stationary like that due to buildings, water, towers hills, mountaines etc. Echoes from these limit the performance of MTI radar.

→ Most of the fluctuating clutter targets situated within the resoluation cell of the radar.

→ Experimentally measured power spectra of clutter signals may be approximately written as.

$$W(f) = |g(f)|^2 = |g_0|^2 \exp\left[-a\left(\frac{f}{f_0}\right)^2\right]$$

where $W(f)$ = clutter power spectrum as a function of frequency

$g(f)$ = fourier transform of the input waveform

f_0 = radar carrier frequency

a = parameter which depends on the clutter

→ The expression for improvement factor for an N-Pulse canceler with $N_i = N-1$ delay lines can be written as

$$I_{NC} = \frac{2^{N_i}}{\ldots}\left(\frac{f_p}{\ldots}\right)^{2N_i}$$

Antenna Scanning Modulation:

-> As the antenna Scans by a target, it observes the target for a finite time to

where $t_0 = \frac{n_B}{f_P} = \frac{\theta_B}{\theta_S}$

Here -

n_B = number of hits received

f_P = pulse repitition frequency

θ_B = antenna beam width

θ_S = antenna Scanning rate.

-> The received pulse train of duration to has a frequency Spectrum whose width is propotional to $1/t_0$

=> Therfore, even if the clutter were perfectly Stationary there will still be a finite width to the clutter Spectrum because of the finite time on target.

-> when the clutter Spectrum is too wide, it affects the improvement factor. This limitation is also called Scanning modulation or Scanning fluctuations.

-> The limitation to the improvement factor caused by antenna Scanning are.

$$I_{1S} = \frac{n_B^2}{1.388}$$

$$I_{2S} = \frac{n_B^4}{3.853}$$

Limiting in MTI radar: Before the MTI processor, a limiter is generally employed in the IF amplifier for preventing the residue from large clutter echoes. An ideal MTI radar should reduce the clutter to a level comparable to receiver noise

→ If the limit level relative to noise is set higher than the improvement factor clutter residue obscures part of the display, while if it is set too low there may be a "black hole" effect on the display.

→ The limiter provides a constant false alarm rate and thus it serves a very essential part to obtain usable MTI performance.

→ The use of the limiter eliminates the amplitude information of the IF output holding it constant to the limiting level and, therefore, such an MTI radar may be called a phase processing MTI, since only the phase information is retained after limiting.

<u>MTI radar versus pulse doppler radar:</u>

MTI radar	Pulse doppler radar
1. In this, range ambiguities are avoided with low pulse repetition frequencies	1. In this doppler frequency ambiguities are avoided with high pulse repetition frequencies.
2. It has blind speed effect	2. There is no chance of blind speed effect.
3. MTI radar has unambiguous range	3. pulse doppler radar has ambiguous range
4. MTI radars use magnetron clutter	4. They use range gate doppler filters for separating the moving targets from
5. These are more widely used in radar applications.	
6. It operates at low duty	

7. They use delay-line Cancelers for separating the Moving targets from Stationary Clutter.	5. pulse doppler radars are klystron oscillators 6. These are rarely used in radar applications 7. It operates at high duty Cycle.

~~Tracking~~ Tracking Radar: Tracking radar detects, determines the location and tracks the moving targets.

-> A radar which detects a target, determines its location and trajectory in future is called tracking radar.

Block diagram of tracking radar and its operation:

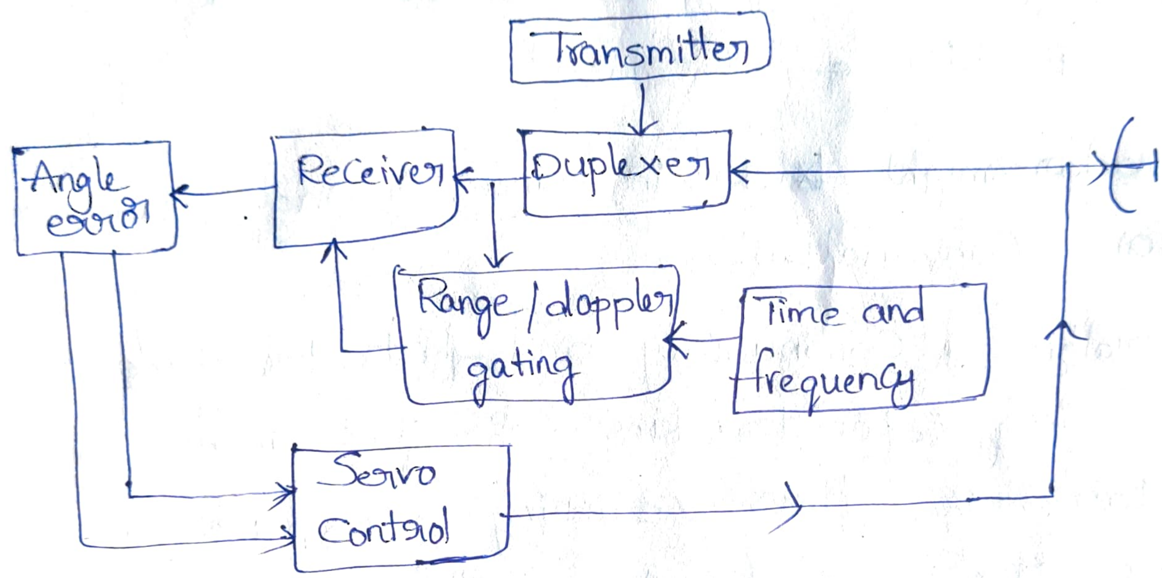


fig: Block diagram of a simple tracking radar

Operation: Its tracking operation usually depends on angular information. The antenna beam is very narrow and it tracks one target at a time. This is achieved by range gating and doppler filtering. The timing control is used for range tracking and doppler gating is used for doppler tracking. The angle error signal is fed to servo control system. This servo system steers the antenna to track the targets.

Tracking with Radar:

→ A tracking radar System measures the Co-ordinate[s] of a target and provides data which may be us[ed to] determine the target path and to predict its future position of the target.

→ By using range, elevation angle azimuth angle and doppler frequency shift, we can also predict the future position of the target.

→ A radar might track in range, in angle, in doppler, or with any Combination.

→ Generally, a Continuously and fast tracking radar is necessary for tracking the fast moving Target. To obtain the faster scanning rates, we have to reduce the size of the antenna and increasing the operating frequency of radar.

→ The target Can be tracked by

1. Angular tracking of a target
2. Range tracking of a target
3. Doppler frequency shift tracking of a target.

→ The angular type of tracking is implemented in all types of radars. These are two types

1. Continuous tracking radar
2. Track-while-Scan (TWS) radar

→ Continuously tracking radar supplies Continuous data on a particular target.

This radar supplies sampled data on one or more targets.

The antenna beam in the continuous tracking radar is positioned in angle by a servomechanism actuated by an error signal.

→ The various methods for generating the error signal may be classified as 1. Sequential lobing 2. Conical scan 3. Simultaneous lobing or monopulse.

→ The range and doppler frequency shift can also be continuously tracked, if desired by a servo control loop actuated by an error signal generated in the radar receiver.

→ The information available from a tracking radar may be presented on a CRT display for action by an operator or may be ~~presented~~ supplied to an automatic computer which determines the target path and calculates its probable future course.

→ The tracking radar must first find its target before it can track.

Differences between Search radar and Tracking radar

Search radar	Tracking radar
1. The radar is only used for detecting the target	1. This radar is used for both detecting and tracking
2. This radar is operated in only search or acquisition	2. This radar is operated in both search and tracking

modes	modes.
3. It will have the knowledge of other potential targets	3. for this, in tracking it has no idea of other Potential targets.
4. In this radar, an antenna with narrow Pencil beam is sufficient for finding the target	4. In this radar, an antenna with narrow Pencil beam is not sufficient for detecting and ranging Therfore Separate radar is used for Searching
5. Search radar is mainly used in metrological, surveillance applications	5. The principal applications of tracking radar are weapon Control and missile range instrumentation.

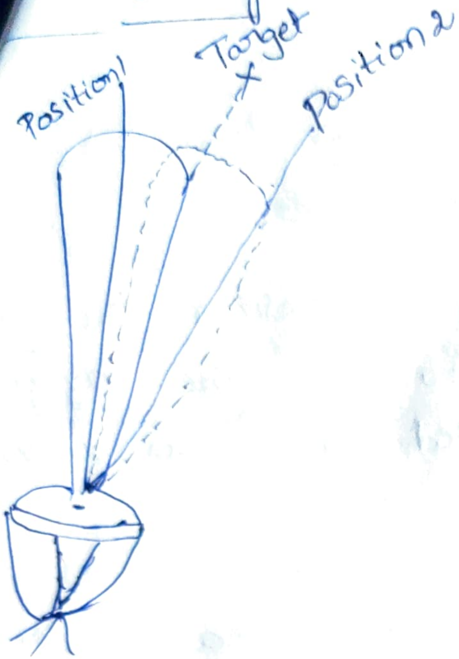
Antenna Tracking:

Need: The location of the target has to be very accurately known after it has been Scanned. An antenna with narrow pencil shaped beam is useful in this regard, but this type of antenna is insufficient therfore more precise and useful method i.e tracking is employed

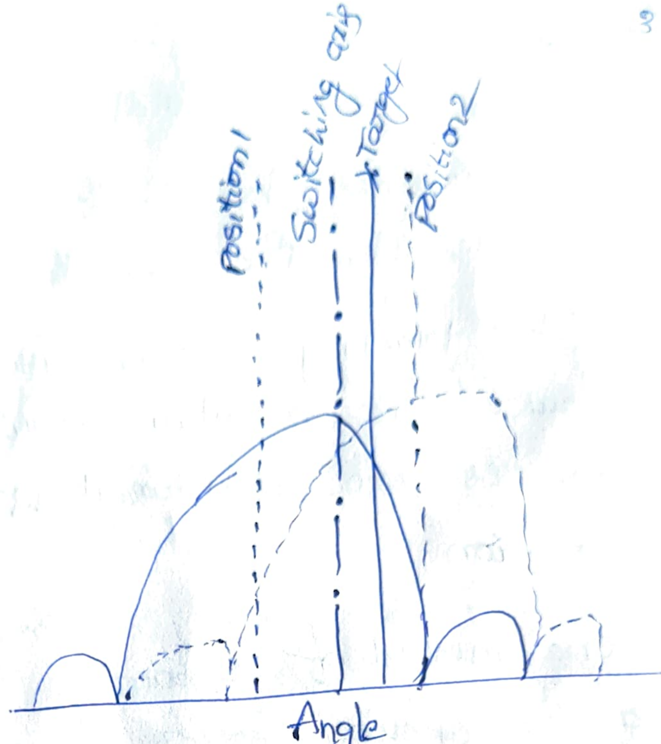
Types: Two most Commonly used antenna tracking mechanism are

1. Sequential lobing
2. Conical Scanning

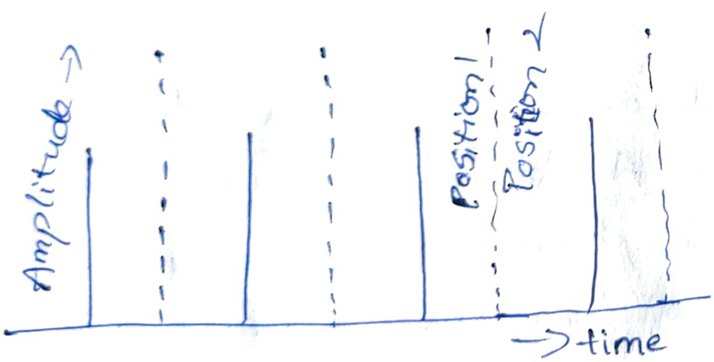
ial Lobing



(a) Polar representation of Switched antenna patterns



(b) Rectangular representation



(c) error Signal

fig(1) Lobe Switching antenna patterns and error Signal

→ In Sequential lobing the direction of antenna beam is rapidly Switched between two positions so that the strength of echo from target will fluctuate at the switching rate, unless the target is exactly midway between the two direction. The echo Strength will be the same in both antenna positions.

→ Sequential lobing is also called as lobe switching.

→ An important feature of Sequential lobing is that the target

Position accuracy can be far better than that giv... the antenna beamwidth.

-> The difference between the target position and the refrence direction in the angular error.

-> The tracking radar attempts to position the antenna to make the angular error zero. when the angular error is zero, the target is located along the refrence direction.

-> One method of obtaining the direction and the magnitude of the angular error is one Co-ordinate is by alternative switching antenna beam between two position. This is called lobe Switching, Sequential switching or sequential Lobing.

=> fig (a) is a polar representation of the antenna beam in the two Switched positions. A plot in rectangular Co-ordinate is shown in fig (b). and the error signal obtained from a target not on the Switching axis (reference direction) is show in fig (c).

-> The difference in amplitude between the voltages obtained in the two Switched positions is a measure of the angular displacement of the target from the switching axis.

-> The sign of the difference determines the direction the antenna must be moved in order to align the Switching axis with the direction of the target.

-> when the voltages in the two Switched positions are equal the target is on axis and its position may be determined from the axis direction.

additional switching positions are needed to obtain angular error in the orthogonal co-ordinate.

Thus a two-dimensional sequentially lobing radar might consist of a cluster of four feed horns illuminating a single antenna, arranged so that the right-left, up-down sectors are covered by successive antenna positions. Both transmission and reception are accomplished at each position.

→ Sequential lobing, or lobe switching, was one of the first tracking radar techniques to be employed.

<u>Advantages of Sequential lobing radar:</u>

1. It requires only one antenna
2. Its operation is simple.
3. It requires less equipment.
4. It is cost effective

<u>Disadvantages of Sequential lobing radar.</u>

1. It is not very accurate.

<u>Conical Scan Tracking:</u>

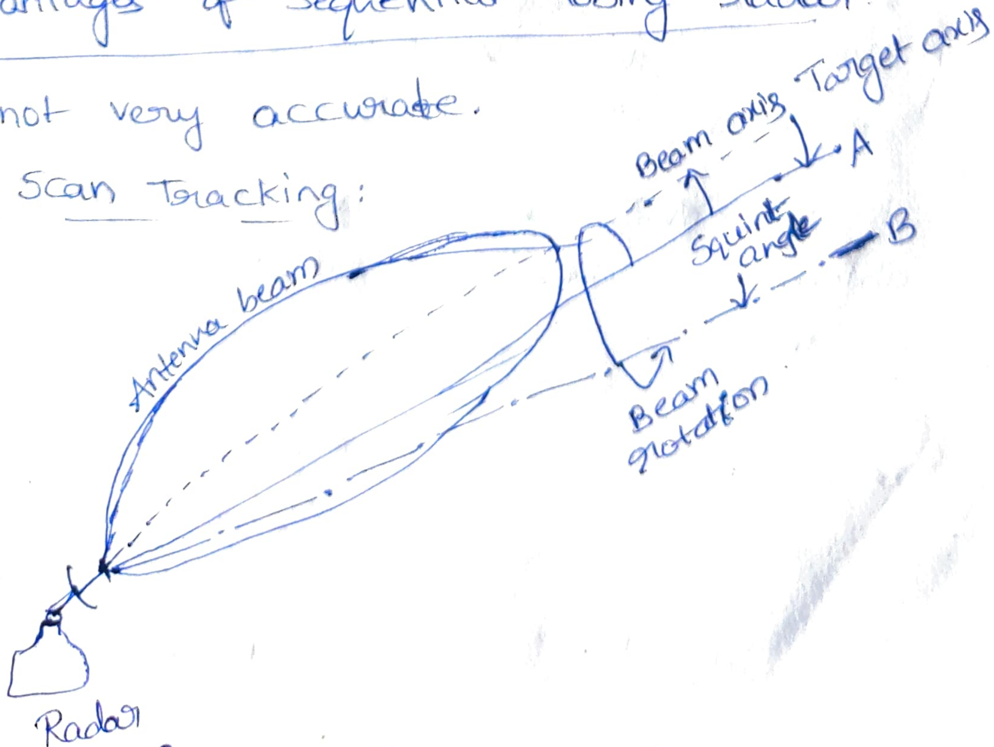


Fig: Conical scan tracking

-> A logical extension of the simultaneous lobing te is to rotate continuously an offset antenna beam than discontinuously step the beam between four -ate positions. This is known as Conical Scanning.

-> The angle between the axis of rotation and the a of antenna beam is called the squint angle.

-> Consider a target at position A. The echo signal will be modulated at a frequency equal to the rotation frequency of the beam.

-> The amplitude of the echo signal modulation will depend upon the shape of the antenna pattern, the squint angle and the angle between the target line of sight and the rotation axis.

-> The phase of the modulation depends on the angle between the target and the rotation axis.

-> The conical scan modulation is extracted from echo signal and applied to a servo-control system which continually positions the antenna on the target.

-> Note that two servos are required because the tracking problem is two dimensional. Both the rectangular and polar tracking co-ordinates may be used.

-> When the antenna is on target as in B fig (1) the line of sight to the target and the rotation axis coinside and the conical-scan modulation is zero.

...e Tracking: A monopulse tracker is defined as on which information concerning the angular location of ...get is obtained by comparision of signals received two or more simultaneous beams. A measurement of angle may be made on the basis of a single pulse hence the name monopulse.

(or)

→ A type of radar in which angular location of target is obtain by comparing signals received by two or more simultaneous beams is called monopulse tracker. The measurement of target angle is done on the basis of single pulse hence called Monopulse.

→ In practice, multiple pulses are usually employed to increase the probability of detection, improve the accuracy of the angle estimate, and provide resolution in doppler angle estimate, and provide resolution in doppler when neccessary.

→ By making an angle measurement based on the signals that appear simultaneously in more than one antenna beam, the accuracy is improved compared to time-shared single beam tracking systems (such as conical scan or sequential lobing) which suffer degradation when the echo signal amplitude changes with time.

→ Thus the accuracy of monopulse is not affected by amplitude fluctuations of the target echo. It is the preferred tracking technique. when accurate measurements are required.

→ The monopulse angle method may be used in a tracking radar to develop an angle error signal in two orthogonal angle Co-ordinates that Mechanically drive the line of Sight of the track antenna using a closed-loop servo system to keep the boresight positioned in the direction of the moving target.

→ In radars such as the phased array, angle measurements Can be obtained in an open-loop fashion by Calibrating the error signal voltage in terms of angle.

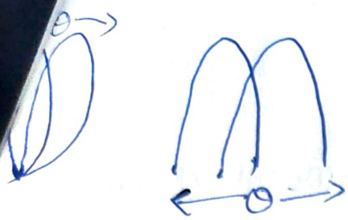
Methods of monopulse angle measurement:

There are Several methods by which a monopulse angle measurement Can be made. The most Popularly used methods are.

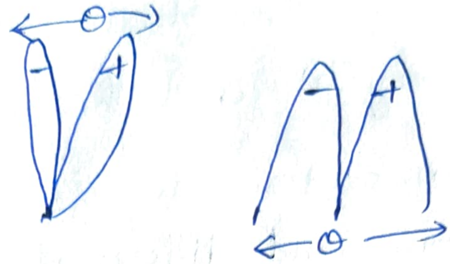
1. Amplitude - Comparision monopulse (or simply monopulse)
2. Phase - Comparision monopulse.

→ The amplitude Comparision monopulse which Compares the amplitude of the Signals simultaneously received in multiple Squinted beam to determine the angle. While in phase Comparision monopulse the phase difference between two antenna beams gives the target angle.

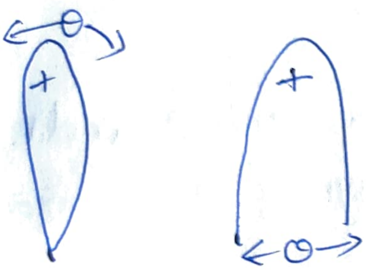
...ude - Comparision Monopulse



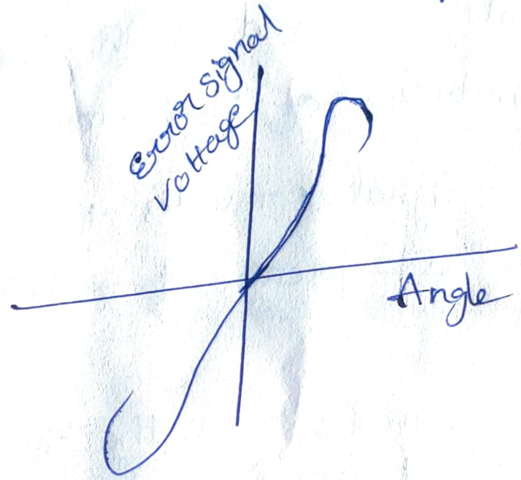
(a) Two Squinted antenna beams



(C) Difference pattern.



(b) Sum pattern of two Squinted beams shown in (a)



(d) Error Signal

-> The amplitude-Comparision monopulse employs two over-lapping antenna patterns fig (a) to obtain the angular error in one Co-ordinate.

-> Two overlapping antenna patterns with their main beams Point in Slightly different directions are used fig (a). The two beams in this figure are said to be Squinted or offset.

-> The two overlapping antenna beams may be generat-ed with single reflector or with a lens antenna illuminated by two adjacent feeds.

-> A cluster of four feeds may be used if both elevation and azimuth error signals are wanted.

→ The sum of the two antenna patterns of fig shown in fig (b) and the difference in fig (c).

→ The sum patterns is used for transmission, while sum pattern and difference pattern are used on reception.

→ The signal received with the difference pattern provides the magnitude of the angle error.

→ The sum signal provides the range measurement and is also used as a refrence to extract the sign of the error signal.

→ Signals received from the sum and the difference patterns are amplified separately and combined in a phase sensitive detector to produce the error-signal characteristic shown in fig (d).

→ Amplitude comparision monopulse can have two forms.

1. one angle Co-ordinate
2. Two angle co-ordinate.

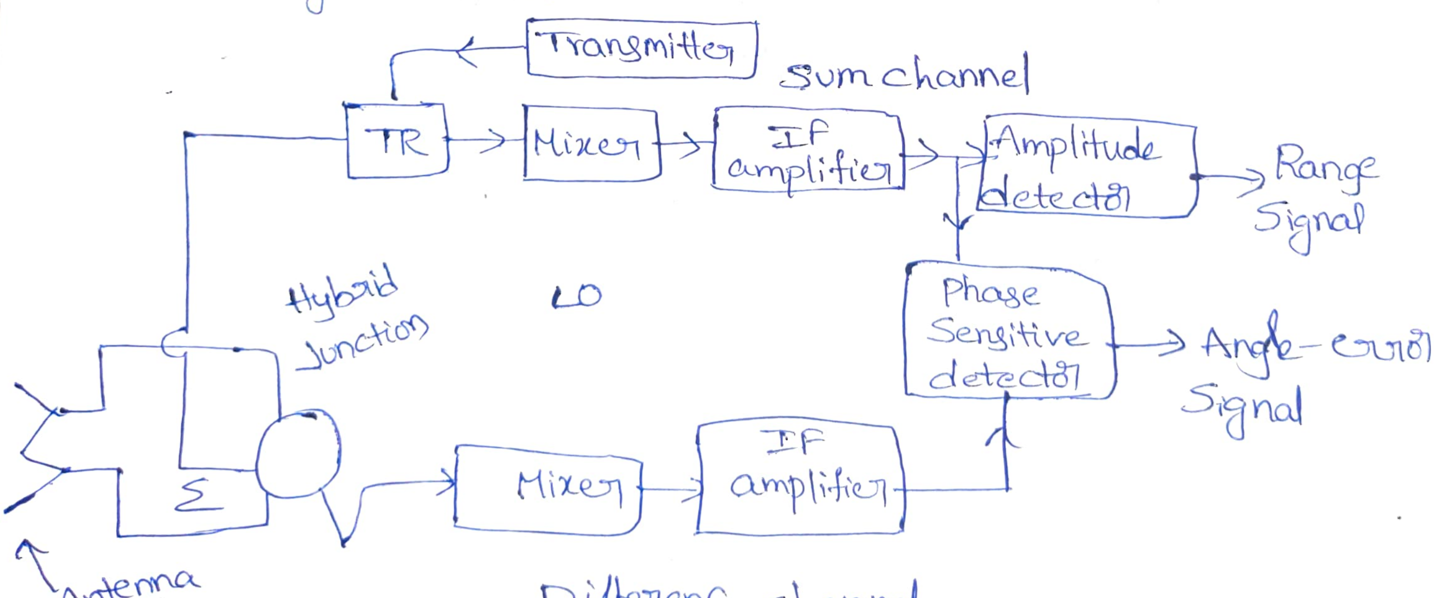


fig: Block diagram of a amplitude - comparision monopulse radar in one angle co-ordinate

Σ denotes sum channel, Δ denotes difference channel.

Block diagram of the amplitude Comparision monopulse tracking radar for a single angular co-ordinate is shown in above fig:

→ The two adjacent antenna feeds are connected to the two arms of a hybrid junction such as a "magic T" a "rat-race" or a short-slot coupler.

→ The sum and difference signals appear at the two other arms of the hybrid.

→ On reception, the o/ps of the sum arm and the difference arm are each hetrodyned to an intermediate frequency and amplified as in any superheterodyne receiver.

→ The transmitter is connected to the sum arm.

→ Range information is also extracted from the sum channel.

→ A duplexer is included in the sum arm for the protection of the receiver.

→ The output of the phase sensitive detector is an error signal whose magnitude is proportional to the angular error and whose sign is proportional to the direction

→ The output of the monopulse radar is used to perform automatic tracking.

→ The angular error signal actuates a servo-control system to position the antenna and the range output from the sum channel feeds into an automatic-range tracking unit

→ The sign of the difference signal (and the direction of the angular error) is determined by comparing the phase of the difference signal with the phase of the sum signal.

→ If the sum signal in the IF portion of the receiver is $A_s \cos \omega_{IF} t$, the difference signal would be either $A_d \cos \omega_{IF} t$ or $-A_d \cos \omega_{IF} t$ ($A_s > 0$, $A_d > 0$) depends on which side of center is the target.

→ Since $-A_d \cos \omega_{IF} t = A_d \cos \omega_{IF} (t + \pi)$, the sign of the difference signal may be measured by determining whether the difference signal is in phase with the sum or 180° out of phase.

→ Although a phase comparision is a part of the amplitude-comparision-monopulse radar, the angular error signal is basically derived by comparing the echo amplitudes from simultaneous offset beams.

→ The phase relationship between the signals in the offset beam is not used.

→ The purpose of the phase-sensitive detector is to conveniently furnish the sign of the error signal.

Amplitude - comparision monopulse tracking radar in two-coordinates (azimuth and elevation):

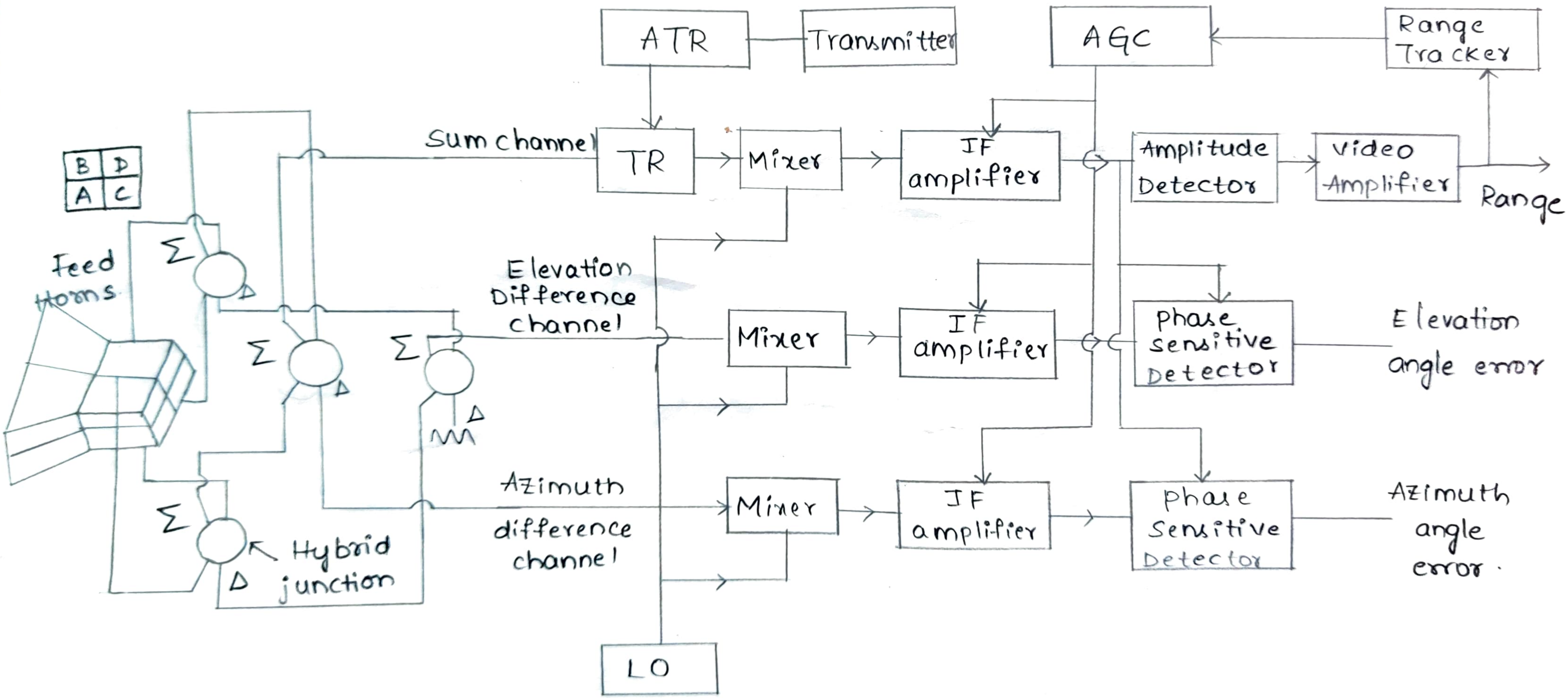


fig:- Block diagram of two-coordinate (azimuth and elevation) amplitude comparision monopulse tracking radar. Diagram in the upper left corner represents the four-horn feed diagram of monopulse radar for extracting angle in both azimuth and elevation is shown in above

cluster of four feed horns generate four partially overlapping (squinted) beams.

→ The four feeds might be used to illuminate a parabolic reflector, Cassegrain reflector, or a space-fed phased array antenna.

→ The arrangement of four feeds is shown in the upper left-hand portion of the figure.

→ All four feeds are used to generate the sum pattern on transmission and reception.

→ The difference pattern in plane is formed by taking the sum of two adjacent feeds and subtracting from the sum of the other two adjacent feeds.

→ The difference pattern in the orthogonal plane is obtained Similarly.

→ for example, based on the arrangement of feeds shown in above fig, the sum pattern is found from A+B+C+D; the azimuth difference pattern is obtained from (A+B)-(C+D) and the elevation difference pattern is (B+D)-(A+C)

→ Note that the upper feeds form the lower beams when radiated by a reflector antenna.

→ A total of four hybrid junctions are needed to obtain the Sum Pattern and the two difference Patterns

→ The three mixers for the sum, elevation difference and azimuth difference channels use a Common local oscillator to better maintain the phase relationships among the three Channels.

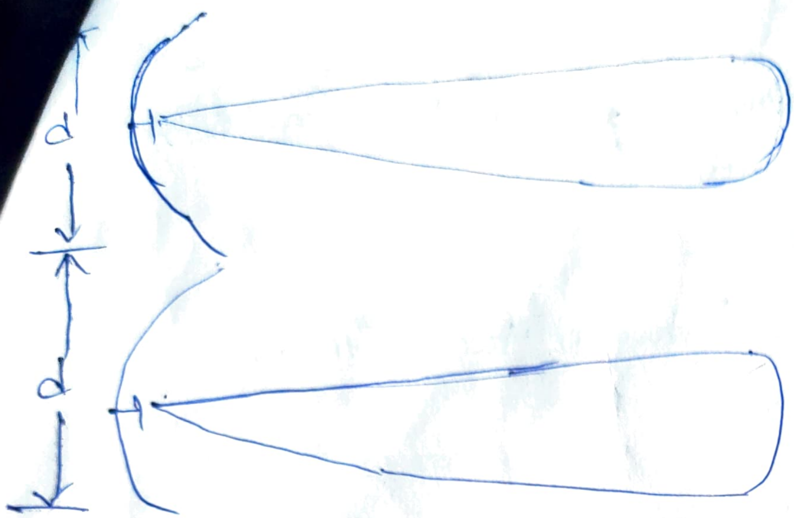
-> Two phase - Sensitive detectors extract the angle e[illegible] information; one for azimuth and the other for eleva[illegible] information is extracted from the output of the channel after envelope detection.

-> Since phase comparision is made between the outpu[t] the sum channel and each of the difference channel, it is important that large relative phase difference bet[we]-n channels should be maintaed to within 25° or better for reasonably proper performance.

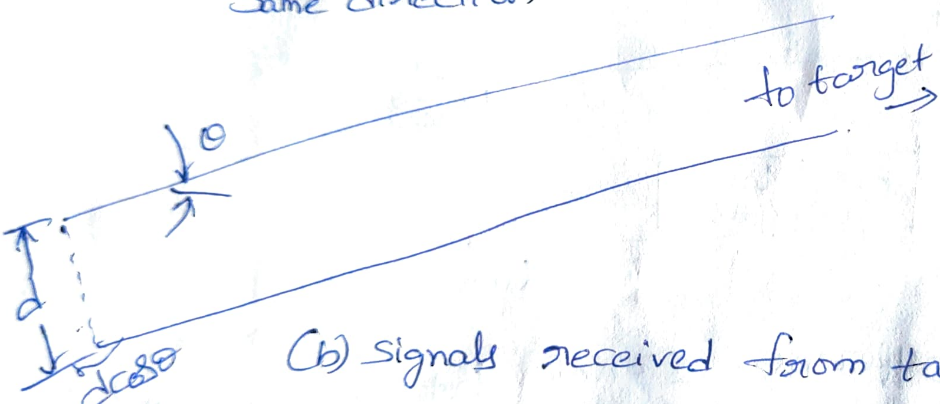
Automatic gain Control (AGC): AGC is required in the recei-ving system in order to maintain a stable. Closed-loop servo system for angle tracking and to ensure that the angle error signal is not affected by changes in the received signal amplitude. As indicated in the above block diagram. the AGC signal is obtained from the peak voltage of the sum channel and generates a negative dc voltage proportional to the peak signal voltage.

-> The AGC signal from the sum channel is fed back to control the gain of all three channels so as to provide a constant angle sensitivity independent of changes in target cross-section fluctuations or changes in range.

Comparision Monopulse



(a) Two antennas radiating identical beams is Same direction



(b) signals received from target.

→ In a phase-Comparision monopulse, two antenna beams are used to obtain an angle measurement in one Co-ordinate.

→ The two beams look in the same direction and Cover the Same region of Space rather than be Squinted to look in two slightly different directions.

→ The phase Comparision monopulse is also known as interfero-meter radar.

→ The amplitudes of the signals are same, but their Phases are different.

→ Consider two antennas Spaced a distance 'd' a part as in fig (b). If the Signal arrives from a direction θ with respect to the normal to the base line, the

Phase difference in the signals received in the two a...

$$\Delta\phi = 2\pi \frac{d}{\lambda} \sin\theta$$

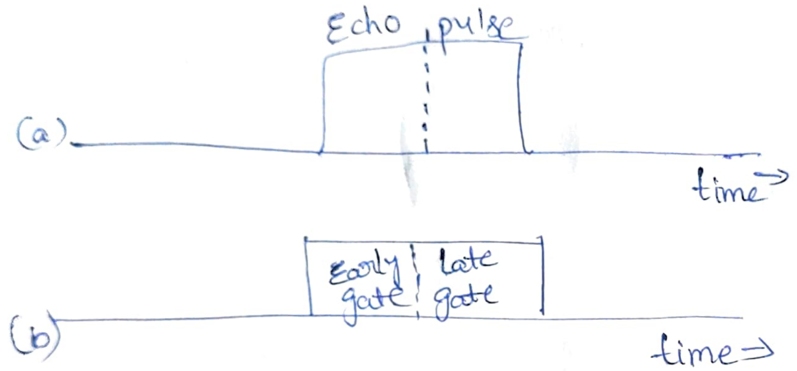
where

θ is signal arriving from a direction θ w.r.t normal to baseline.

λ is wave length

d is the distance between two antennas.

Tracking in Range:



(c) fig: Difference Signal between early and late range gates.

fig(1) Split-range-gate tracking (a) echo pulse (b) Early gate range gates.

→ The technique for automatically tracking in range is base on the split range gate.

→ Two range gates are generated as shown in fig(1) One is in the early gate, and the other is the late gate.

→ The echo pulse is shown in fig(a) the relative position of the gates at a particular instant in fig(b) and the error signal in fig(c).

→ In this example the portion of the signal in the early gate is less than that of the late gate.

...signals in the two gates are integrated and subtracted ...duce the difference error signal.

... magnitude of the error signal is a measure of the ...fference between the center of the pulse and the center of the gates.

→ The sign of the error signal determines the direction in which the gates must be repositioned by a feedback control system. When the error signal is zero, the range gates are centered on the pulse.

→ The position of the two gates indicates the target's range. If there exists deviation of the pair of the gates from the center, then the echo pulse increases the signal energy in one of the gates and decreases in the other gate. This produces an error signal that causes the other pulses to be moved so as to reestablish the equilibrium.

Advantages of range gating:

1. It allows to isolate a single target.
2. The gate rejects the unwanted signals.
3. It improves SNR
4. It eliminates the noise.

Acquisition and Scanning patterns:

-> A tracking radar must first find and acquire its target before it can operate as a tracker. Therefore it is usually necessary for the radar to scan an angular in which the presence of the target is suspected.

-> Most tracking radars employ a narrow pencil-beam antenna for accurate tracking in angle; but it can be difficult to search a large volume for targets when use a narrow antenna beamwidth.

-> Some other radar must first find its target to be track and then designate the targets coordinates to the tracker. These radars have been called acquisition radars or designation radars and are surveillance radars that search a large volume.

-> The various scanning patterns which are employed with pencil-beam antenna are.
1. Helical scanning 2. Palmer scanning 3. Spiral scanning 4. Raster or TV scanning 5. Nodding scanning.

Helical Scanning:

fig: Trace of helical scanning beam.

helical Scan is used to obtain hemispheric Cover as with encil beam.

helical Scan, the antenna is Continuously rotated in azimuth hile it is simultaneously raised or lowered in elevation It traces a helix in Space.

-> Here, the tracking is basically helical.

-> Helical Scanning was employed for the Search mode of the SCR-584 fire-control radar, during world war-II for the aiming of antiaircraft - gun batteries.

-> The SCR-584 antenna was rotated at the rate of 6Pm and Covered a 20° elevation angle in 1 min.

Palmer Scan:

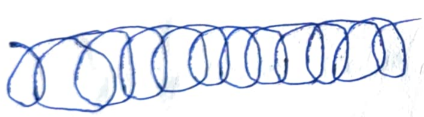


fig: Palmer Scan.

-> Palmer Scan Consists of a rapid Circular scan (Conical scan) about the axis of the antenna, Combined with a linear movement of the axis of rotation.

-> When the axis of rotation is held stationary, the Palmer Scan reduces to the Conical Scan. Because of this property the palmer scan is sometimes used with Conical Scan tracking radar

-> which must operate in both search and track mode.

-> The mechanisms used to produce Conical Scanning Can also be used for palmer scanning. This type of Scanning is

Suited to a Search area which is larger in one than the other.

Spiral Scan :

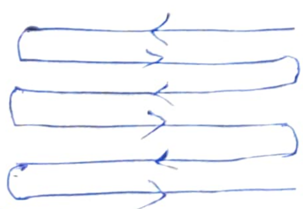
fig: Spiral Scan

-> If a limited area of circular shape is to be covered spiral scan may be used.

-> Spiral Scanning covers an angular search volume with circular symmetry.

-> Spiral Scanning covering a circular area as shown in above fig.

Raster or TV Scan:

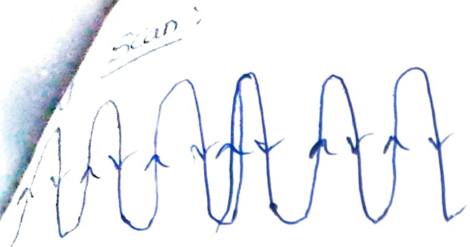


fig, Raster a TV Scan.

-> In raster scan, the antenna scans the area in a uniform manner.

-> The raster scan is a simple and convenient means for searching a limited area, usually rectangular shaped

-> It is also called as TV Scan.



figi Nodding Scan

The noding Scan produced by oscillating the antenna beam rapidly in elevation and slowly in azimuth.

-> Nodding Scan may also be used to obtain hemisphere Coverage that is elevation angle extending to 90° and the azimuth Scan angle to 360°

-> The nodding Scan is also used with height finding radars.

Comparision of Trackers:

Monopulse Tracking	Conical Scan Tracking
1. multiple beams are used to determine the angle of arrived of echo signal Single pulse is required to derive the angle error information.	1. A single antenna beam on a time Shared basis is used.
	2. Multiple pulses are required to derive the angle error information.
2. High SNR	3. Low SNR
3. More accurate tracking	4. Less accurate tracking
4. High Cost	5. Low Cost
5. Complex design.	6. Simple design
6. Cassegrain antenna is used	7. Horn antenna is used.
7. This radar first makes angle measurement and the integrate's a number of pulses to obtain required SNR	8. This radar first Integrates number of pulses then extractes the angle measurement.

Monopulse Tracking Radar:-	Conical Scan tracking radar:-
1. It is a simultaneous scanning system	1. It is a sequential scanning system
2. Signal-to-Noise ratio is large	2. Signal-to noise ratio is small
3. Angle accuracy is better	3. Angle accuracy is inferior to that of monopulse radar
4. Range accuracy is better	4. Range accuracy is inferior to that of monopulse radar.
5. Angle accuracy is not affected by fluctuation in the echo amplitude	5. Angle accuracy is also not affected by the fluctuation in echo amplitude.
6. System performance is degraded by glint	6. System performance is degrade by glint.
7. It is more complex	7. It is not complex.
8. Monopulse system come into existence first	8. Conical scan came later.
9. It has two receiving channels	9. It has only one receiving channel
10. It has two feeds	10. It has single feed.
11. Rotation of antenna beam is done at a relatively low speed.	11. Rotation of antenna beam is done at a relatively high speed.
12. It requires a single pulse	12. It requires a minimum of four pulses.
13. Angle measurement is made in two co-ordinates	13. Angle measurements is made in two coordinates
14. In this, angle measurement is made first and then are integrated.	14. In this the number of pulses are integrated first and then angle measurement is made.
15. Its cost is relatively high	15. Its cost is relatively low.

UNIT-V

Detection of Radar Signals in noise:

Introduction: The two basic operations performed by radar are.

1. detection of the presence of reflecting objects, and
2. extraction of information from the received waveform to obtain such target data as position, velocity and perhaps size.

→ The operation of detection and extraction may be performe separately and in either order, although a radar that is good detection device is usually a good radar for extracting information and vice-versa.

→ The detection of radar signals in noise, clutter requires special circuitary.

→ Methods for detection of desired signals along with rejection of undesired noise, clutter and interference in radar is called signal processing.

→ Important radar signal processor includes - Matched filter correlation receiver, matched filter with non-white noise logarithemic detector I, Q detector, Chohorent detector etc.

Matched - filter Receiver:

Def: A linear network which maximizes the output peak signal-to-noise power ratio of a radar receiver maximizes the detectability of a target is called a matched filter.

(or)

A network whose frequency response function maximizes the output peak-signal-to-mean noise (power) ratio is called a matched filter.

→ Thus a matched filter, or a close approximation to basis for the design of almost all radar receivers. |H(f)|

Matched filter frequency response function:

Matched filter maximizes the output peak SNR when the input noise spectral density is uniform (white noise). The frequency response function of matched filter is given by

$$H(f) = G_a S^*(f)\, e^{-j2\pi f t_m}$$

where

G_a is a constant

t_m is time at which output of matched filter is maximum.

$S^*(f)$ is complex conjugate of spectrum of input signal $s(t)$.

→ The fourier transform of received signal $s(t)$ is

$$S(f) = \int_{-\infty}^{\infty} s(t)\, e^{-j2\pi f t}\, dt$$

→ The received signal spectrum is now

$$S(f) = |S(f)|\, e^{[j\phi_s(f)]}$$

where $|S(f)|$ is amplitude spectrum

$|\phi_s(f)|$ is phase spectrum

→ The matched filter frequency response function in terms of amplitude and phase is expressed as

$$H(f) = |H(f)|\, e^{[j\phi_m(f)]}$$

Let $G_a = 1$ then.

$$|H(f)|\, e^{[-j\phi_m(f)]} = |G_a S^*(f)\, e^{-j2\pi f t_m}|$$

$$= |G_a|\, |S^*(f)|\, |e^{-j2\pi f t_m}|$$

$$= |S(f)|^*\, e^{-j2\pi f t_m}$$

$$= |S(f)|\, e^{+j\phi_s(f)}\, e^{-j2\pi f t_m}$$

$$|H(f)|\, e^{-j\phi_m(f)} = |S(f)|\, e^{j(\phi_s(f) - 2\pi f t_m)}$$

Equating amplitude and phases in above equation.

$$|H(f)| = |S(f)|$$

$$-\phi_m(f) = \phi_s(f) - 2\pi f t_m$$

$$\phi_m(f) = -\phi_s(f) + 2\pi f t_m$$

Above expression indicates that the magnitude of matched filter frequency response function is the same as the amplitude spectrum of input signal and the phase of the matched filter frequency response is negitive sign before of phase spectrum of signal plus phase shift proportional to frequency

→ The negitive sign before $\phi_s(f)$ cancels the phase components of received signal so that all frequency components at output of filter are of same phase and add coherently to maximize the signal.

Scanned with CamScanner

Matched filter Impulse response:

Matched filter is also described by its impulse response h(t), which is the inverse fourier transform of the frequency response function H(f) and is given by

$$h(t) = \int_{-\infty}^{\infty} H(f)\, e^{j2\pi f t}\, df$$

But $H(f) = G_a S^*(f)\, e^{-j2\pi f t_m}$

$$= \int_{-\infty}^{\infty} G_a S^*(f)\, e^{-j2\pi f t_m}\, e^{j2\pi f t}\, df$$

$$= G_a \int_{-\infty}^{\infty} S^*(f)\, e^{-j2\pi f (t_m - t)}\, df$$

Since $S^*(f) = S(-f)$

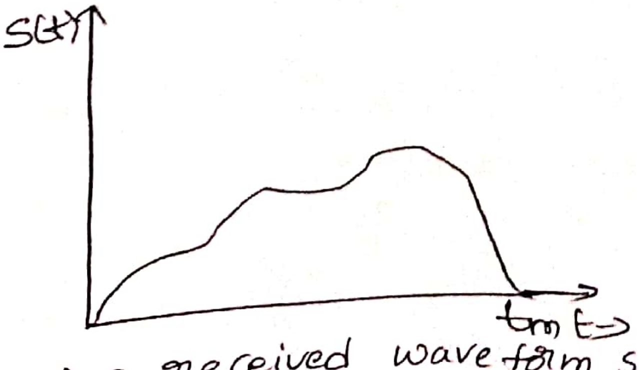
$$h(t) = G_a \int_{-\infty}^{\infty} S(f)\, e^{-j2\pi (-f)(t_m - t)}\, df$$

$$h(t) = G_a \int_{-\infty}^{\infty} S(f)\, e^{j2\pi f (t_m - t)}\, df$$

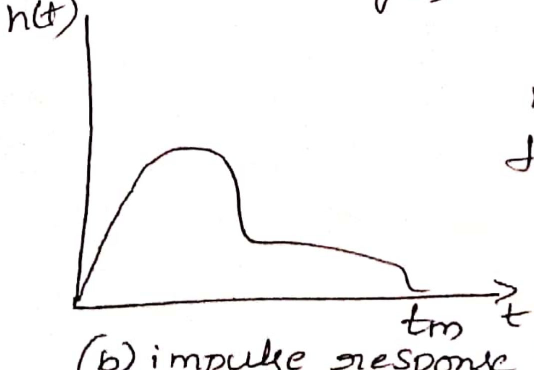
$$h(t) = G_a s(t_m - t)$$

→ This equation shows impulse response of a matched filter is the time inverse of the received signal. The received signal is reversed in time i.e starting from fixed time t_m.

→ The received signal s(t) and its impulse response h(t) of matched filter is shown in below fig(1).



(a) a received waveform s(t)



(b) impulse response h(t) of matched filter for the i/p sig

Received signal $s(t)$ and impulse response $h(t)$ of matched filter.

The impulse response of a filter must not have any output if the input signal is not applied. Therefore, impulse response of filter to be realizable should have $(t_m - t) > t < t_m$. This condition is equivalent to the frequency response function with phase $(e^{-j2\pi f t_m})$, which means a time delay of t_m.

→ For convenience, the impulse response is often written simply as $s(t)$ and the frequency response function as $S^*(f)$, with realizability conditions understood.

Derivation of the Matched-filter frequency Response:

→ The frequency response function of matched filter is derived by using Schwartz's inequality. The frequency response function of the linear, time invarient filter which maximizes the output SNR is given by

$$H(f) = G_a S^*(f)\, e^{-j2\pi f t_m}$$

→ When the input noise is stationary and has uniform spectral density (white). The ratio to be maximized is

$$R_f = \frac{|S_o(t)|^2_{max}}{N}$$

Where

$|S_o(t)|_{max}$ = is maximum output signal

N is mean square noise power at receiver output

→ The ratio R_f is twice the average SNR when the input signal $s(t)$ is a rectangular sine pulse. The magnitude of the output voltage of a filter with frequency response function $H(f)$ is

$$|S_o(t)| = \left| \int_{-\infty}^{\infty} S(f) \cdot H(f)\, e^{j2\pi f t}\, df \right|$$

where, $S(f)$ is the fourier transform of the input signal.

→ The mean output noise power is given as

$$N = \frac{N_0}{2} \int_{-\infty}^{\infty} |H(f)|^2 df$$

where N_0 is the input noise power per unit bandwidth

→ The ½ factor before integral sign is because the limits are taken from $-\infty$ to $+\infty$. But N_0 is defined as noise power per unit BW over positive values of f.

→ Substituting expression of $|s_0(t)|$ and N is the expression of R_f

$$R_f = \frac{\left| \int_{-\infty}^{\infty} S(f) \cdot H(f) \, e^{j2\pi f t_m} df \right|^2}{\frac{N_0}{2} \int_{-\infty}^{\infty} |H(f)|^2 df}$$

Assuming t_m is the time t at which output $|s_0(t)|^2$ is maximum.

→ According to Schwartz's inequality, if P and Q are two complex functions.

$$\int P^* P \, dx \int Q^* Q \, dx \geq \left| \int P^* Q \, dx \right|^2$$

→ The equality sign applies when $P = kQ$ where k is a constant

let $P^* = S(f) \, e^{j2\pi f t_m}$ and

$Q = H(f)$

also $\int P^* P \, dx = \int |P|^2 dx$

→ Applying Schwartz's inequality to numerator of R_f

$$R_f = \frac{\int_{-\infty}^{\infty} |H(f)|^2 df \int_{-\infty}^{\infty} |S(f)|^2 df}{\frac{N_0}{2} \int_{-\infty}^{\infty} |H(f)|^2 df}$$

$$= \frac{\int_{-\alpha}^{\alpha} |S(f)|^2 df}{\frac{N_o}{2}}$$

-> Parseval's Theorem states energy in frequency and time domain states Signal energy is

$$E = \int_{-\alpha}^{\alpha} |S(f)|^2 df = \int_{-\alpha}^{\alpha} |s(t)|^2 dt = \text{Signal energy}$$

Therefore, $R_f \leq \frac{2E}{N_o}$

-> The above expression indicates that the output Peak to mean noise ratio from a matched filter depends total energy of received Signal and noise power per unit bandwidth only. It does not depend on shape of the Signal duration and bandwidth. Therfore these characteristics of Signals can be used to achieve radar capabilities.

-> when Constant k is set equal to $1/G_a$ then the frequency response function which maximizes peak Signal to mean noise ratio (R_f) is given by

$$H(f) = G_a\, S^*(f)\, e^{-j2\pi f t_m}$$

-> An important property of matched filter is that ~~time~~. irrespective of shape, time duration or bandwidth of input Signal waveform, the maximum ratio of output Peak Signal-to-mean noise power is twice the energy (E) Contained in the received Signal divided by noise power Per unit BW (N_o)

-> The noise power per hertz of bandwidth $n = kT_oF_n$ where

k = Boltzman's Constant

T_0 = Standard Temperature (290°K)

F_n = Receiver noise figure.

→ The matched filter assumes that the input signal $s(t)$ is same as transmitted signal except the amplitude. It requires that the shape of transmitted signal does not change due to reflection by target or by propagation through atmosphere

<u>Correlation Detection</u>:

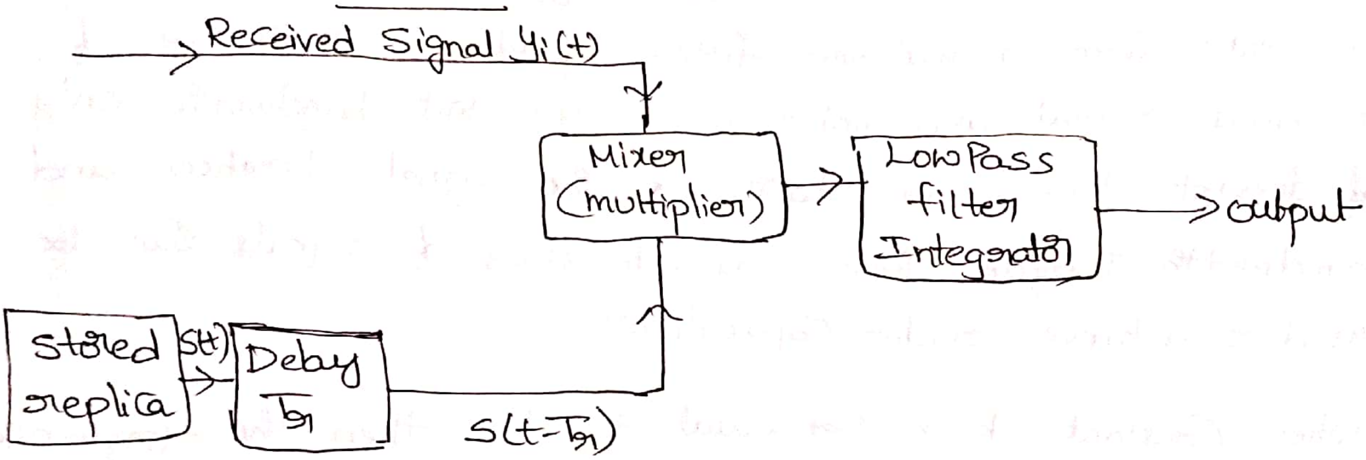


fig: Block diagram of a cross-correlation receiver

→ The output of the matched filter is the cross correlation function of the received signal and the transmitted signal

→ In a correlation receiver, the input signal $y_i(t)$ is multiplied by a delayed replica of transmitted signal $s(t-T_R)$, where T_R is an estimate of the time delay of the target echo signal

→ The product is passed through a low pass filter to perform the integration.

→ If the output of the integrator (filter) exceeds a pre-determined threshold at a time T_R, a target is said.

be at a range $R = \frac{CT_R}{2}$, where c is the velocity of propagation.

Sig → The cross correlation receiver tests for the presence of a target at only a single time delay T_R. Targets at time delay other than T_R are found by varying T_R on successive transmissions, searching possible values of T_R complicates the correlation receiver.

→ Mathematically the cross-correlation receiver and matched filter receiver are equivalent. Hence selection as which to use in a particular radar application is determined by ease of implementation. The matched filter receiver is preferred over correlation filter in most radar applications

→ The cross-correlation receiver correlates the received signal $y_i(t)$ with stored delayed replica of known signal $s(t)$.

→ The above fig. shows the block diagram of cross-corre-lation receiver.

→ The correlation receiver performs cross-correlation between signal $y_i(t)$ corrupted by noise and replica of transmitted signal $S(t)$. The correlation receiver is a linear, time-invarient receiver and linear, time invariant filter which maximizes output peak signal to mean noise power ratio for a fixed input signal to noise ratio.

→ The signal energy is given by

$$E = \int_{-\infty}^{\infty} |S(f)|^2 \, df$$

→ The maximum ratio of peak signal power to the mean noise power is proportional to energy spectral density of the input signal, irrespective of the shape of input wave.

Detection Criteria:

→ Detection of signals is equivalent to deciding whether the receiver output is due to noise alone or to signal plus noise. This is the type of decision made by a human operator from the information presented on a radar display.

→ When the detection process is carried out automatically by electronic means without the aid of an operator, the detect criterion must be carefully specified and built into the decision making device.

→ The radar detection process was described in terms of threshold detection. If the envelope of the receiver output exceeds a pre-established threshold, a signal is said to be present.

→ The threshold level divides the output into a region of no detection and a region of detection.

...ncy of non-matched filters: The efficiency of non-matched filters compared with the ideal matched filter. The measure of efficiency is taken as the peak signal to-noise ratio from the non-matched filter divided by the peak signal-to-noise ratio from the Matched filter.

→ the efficiency for a single tuned (RLC) resonant filter and rectangular-shaped filter of half-power bandwidth B, when the input is a rectangular pulse of width τ. The Maximum efficiency of the single-tuned filter occurs for Bτ≈0.4

→ Efficiency of non-matched filters compared with the Matched filter

Input Signal	Filter	Optimum Bτ	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
Rectangular pulse	one-stage Gaussian	0.44	0.88
Rectangular pulse	2 Cascaded Single tuned Stages	0.613	0.56
Rectangular pulse	5 Cascaded Single-tuned Stages	0.672	0.5

→ The values of Bτ which maximize the signal-to-noise-ratio (SNR) for various combinations of filters and pulse shapes. It can be seen that the loss in SNR incurred by use of these non-matched filters is small.

Matched filter with non white noise:

→ The signal was assumed to be white. that is it was independent of frequency. If this assumption were not true, the filter which maximizes the output signal-to-noise ratio would not be the same as the matched filter.

The frequency-response function of the filter which maximizes the output signal-to noise ratio is

$$H(f) = \frac{G_a S^*(f)\, e^{-j2\pi f t_1}}{[N_i(f)]^2}$$

When the noise in non-white, the filter which maximizes the output signal-to-noise ratio is called the NWN (non-white noise) matched filter. for white noise $[N_i(f)]^2$ = constant and the NWN matched-filter frequency-response function and the equation can be written as.

$$H(f) = \frac{1}{N_i(f)} \times G_a \left(\frac{S(f)}{N_i(f)}\right) e^{-j2\pi f t_1}$$

→ This indicates that the NWN matched filter can be considered as the cascade of two filters. The first filter with frequency-response function $1/N_i(f)$, acts to make the noise spectrum uniform or white. It is sometimes called the whitening filter. The second is the matched filter described. when the input is white noise and a signal whose spectrum is $S(f)/N_i(f)$.

Noise figure of a receiver:

- The noise figure of a receiver can be described as a measure of the noise produced by a practical receiver compared to the noise of an ideal receiver.

-> The noise figure, F_n of a linear network may be defined as

$$\text{Noise figure } F_n = \frac{\text{Input Signal-to-noise ratio}}{\text{output Signal-to-noise ratio}}$$

$$F_n = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} = \frac{N_{out}}{kT_0 B_n G}$$

where

S_{in} = Available input signal power

N_{in} = Available input noise power $= kT_0 B_n$

S_{out} = Available output Signal power

N_{out} = Available output Noise power

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

k = Boltzman's Constant $= 1.38 \times 10^{-23}$ J/deg

T_0 = Standard Temparature of 290K

B_n = Noise Bandwidth

-> The above equation allows two different but equivalent interpretations of noise figure.

-> It may be interpreted as the degradation of the signal to noise ratio caused by the receiver or may be considered a the ratio of the actual available output noise power to the noise power which would be available if the network amplified the thermal noise.

→ The noise figure can alternately be expressed

$$F_n = \frac{kT_0 B_n G_1 + \Delta N}{kT_0 B_n G_1} = 1 + \frac{\Delta N}{kT_0 B_n G_1}$$

Where ΔN is the additional noise introduced by the practical network.

→ The noise figure is commonly expressed in decibels i.e

$$F_n (dB) = 10 \log_{10} F_n$$

→ Sometimes instead of the term noise figure, the term noise factor is also used, when F_n is expressed as a ratio.

Noise figure of networks in Cascade:

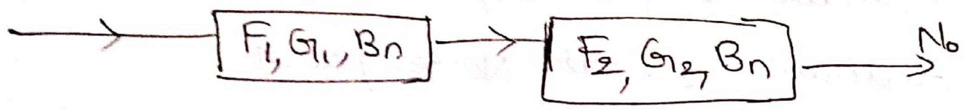


fig: Two networks in Cascade.

→ Let us consider two networks in Cascade, each of the same noise bandwidth B_n but of different noise figures F_1 and F_2 and available gains G_1 and G_2 respectively. This is shown in above fig.

→ To find the overall noise figure F_0 of the two circuits in Cascade, we may write the output noise N_0 of two circuits as.

$N_0 = F_0 G_1 G_2 kT_0 B_n$ = Noise from network 1 at output of network 2 + noise ΔN_2 introduced by network 2

$$= kT_0 B_n F_1 G_1 G_2 + \Delta N_2$$

$$= kT_0 B_n F_1 G_1 G_2 + (F_2 - 1) kT_0 B_n G_2$$

pressed

$$F_0 = \frac{K T_0 B_n F_1 G_1 G_2 + (F_2 - 1) K T_0 B_n G_2}{K T_0 B_n G_1 G_2}$$

$$F_0 = F_1 + \frac{F_2 - 1}{G_1}$$

If the gain of the first network is large than one the may neglect the contribution of the second network. For the design of multistage receivers, this concept is important

-> If N number of networks are cascaded then the noise figure can be shown, in the above manner to be.

$$F_0 = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_n - 1}{G_1 G_2 \cdots G_{N-1}}$$

<u>Noise Temperature</u>: (Effective Noise temperature T_e)

-> The noise introduced by a network can be expressed as an effective noise temperature of the receiver system including the effects of antenna temperature. T_a.

-> If T_e represents the effective noise temperature, then

$$T_S = T_a + T_e = T_0 T_S$$

where F_S = System noise figure.

-> The effective noise temperature of receiver consisting of a number of networks in cascade is

$$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \cdots$$

Where T_1 and G_1 are the effective noise temperature and gain of the 1st network, T_2 and G_2 are those for the 2nd network and so on.

Noise figure Measurement:

→ The receiver noise figure is measured with a broad-band noise source of known intensity. The noise figure F_n can't shown to be.

$$F_n = \frac{T_2/T_0 - 1}{Y-1}$$

Where $Y = \frac{N_2}{N_1}$

The noise figure is found by measuring

N_1 = the noise power output N_1 of the receiver when an Impedance at $T_0 = 290^\circ k$ is Connected to the receiver input

N_2 = The noise power output N_2 when a matched noise generator at T_2 is Connected to the receiver input

UNIT - VI

Radar Receivers

Displays: The purpose of the radar display is to visually present the output of the radar receiver in a form such that an operator could readily and accurately detect the presence of a target and extract information about its location.

(or)

The purpose of the display is to visually present in a form suitable for operator interpretation and action the information contained in the radar echo signal.

-> Display is a unit of radar receiver which presents the radars information. It is a coupling link between the information and human operator.

-> The cathode ray tube (CRT) has been almost universally used as the radar display.

Types of Radar display:

There are two basic cathode ray tube displays

1. Deflection modulated CRT display, such as the A-scope in which a target is indicated by the deflection of the electron beam. These displays have simple ckts than those of intensity modulated CRTS

2. Intensity modulated CRT display, such as the PPI in which a target is indicated by intensifying the electron beam and representing a luminous spot on the face of the CRT. These displays presenting data in

a convenient and easily interpreted form.

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

-> The deflection modulated CRTs, such as the A-scope generally employ electrostatic deflection.

-> Intensity modulated CRTs, such as the PPI, generally employ electromagnetic deflection.

Salient features of Type - A scope display:

1. It presents range only
2. Its vertical axis represents echo strength and horizontal axis represents range.
3. Its circuit is simple
4. It is the most popular display
5. It is suitable with tracking radar
6. It is deflection - modulated CRT display

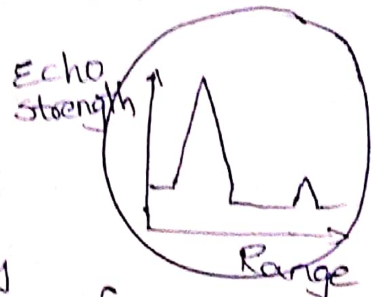


fig: A-scope display

Salient features of PPI

1. It is also called P-scope
2. It displays the map of target area
3. It is intensity modulated CRT display
4. It provides range information
5. It is used in search radars.

types of displays:

The other types of displays are A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, R and RHI Scopes (Range-height Indicator)

Duplexers:

The duplexer is the device that allows a single antenna to serve both the transmitter and the receiver. On transmission it must protect the receiver from burnout or damage and on reception it must channel the echo signal to the receiver.

→ Duplexers, especially for high-power applications, Sometimes employ a form of gas-discharge device. Solid-state devices are also utilized.

Def: It isolates transmitter while receiving and isolates receiver while transmitting. It is basically a microwave switch. It permits a single antenna to serve both the transmitter and the receiver.

Functions of Duplexer:

1. It isolates the receiver while transmitting
2. It isolates the transmitter while receiving.
3. It protects the receiver from high power transmitted by isolation.
4. It also protects the receiver from high power radiation from nearby radars during inter-pulse period or when the radar is shut down.

Types of Duplexers:

The common types of duplexer are:

1. Branch type duplexer.
2. Balanced type duplexer.
3. Ferrite Circulator.

Branch-type Duplexer:

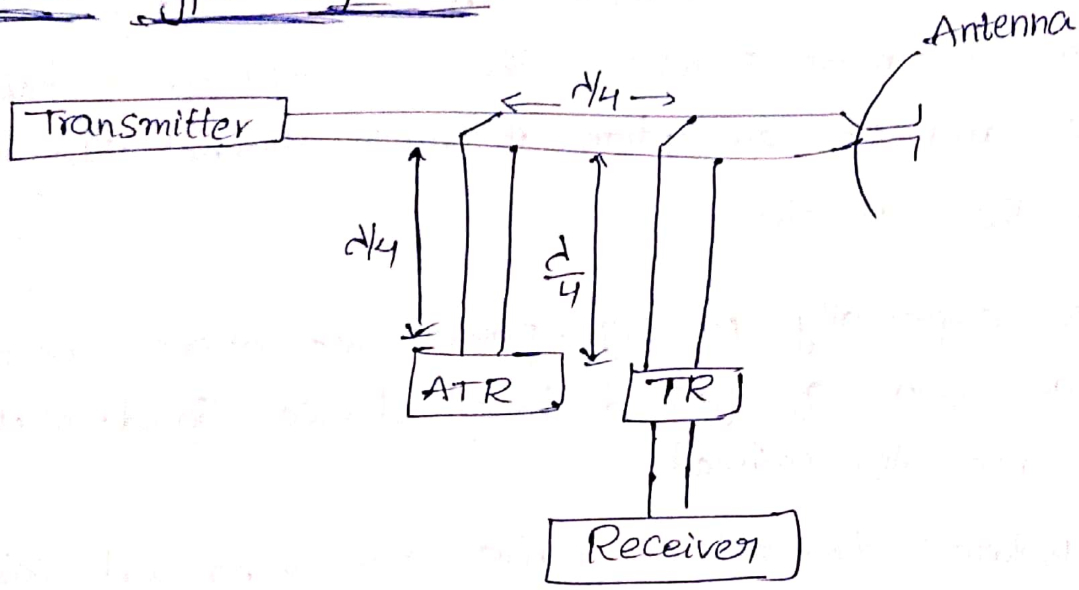


fig: principle of branch-type duplexer

→ The principle of the branch-type duplexer is illustrated in above fig:

→ It consists of a TR (transmit-receive) switch and an ATR (Anti-transmit-receive) switch, both of which are gas-discharge tubes.

→ When the transmitter is turned on, the TR and the ATR tubes ionize, that is they break down & fire.

→ The TR in the fired condition acts as a short circuit to prevent transmitter power from entering the receiver

...ce the TR is located at a quarter wavelength from ...e main transmission line, it appears as a short circuit at the receiver but as an open circuit at the transmission line so that it does not impede the flow of transmitter power.

-> Since the ATR is displaced a quarter wavelength from the main transmission line, the short circuit it produces during the fired condition appears as an open circuit on the transmission line and thus has no effect on trans--mission.

-> During reception, the transmitter is off and neither TR nor the ATR is fired.

-> The open circuit of the ATR, being a quarter wave the transmission line, appears as a short circuit across the line.

-> Since this short circuit is located a quarter wave from the receiver branch-line, the transmitter is effectively disconnected from the line and the echo signal power is directed to the receiver.

-> The diagram of above fig is a parallel configuration Series or Series-parallel configurations are possible.

Advantages:

1. Its cost is low.

Disadvantages:

1. Bandwidth is limited
2. power handling Capability is limited.

Balanced Duplexers :

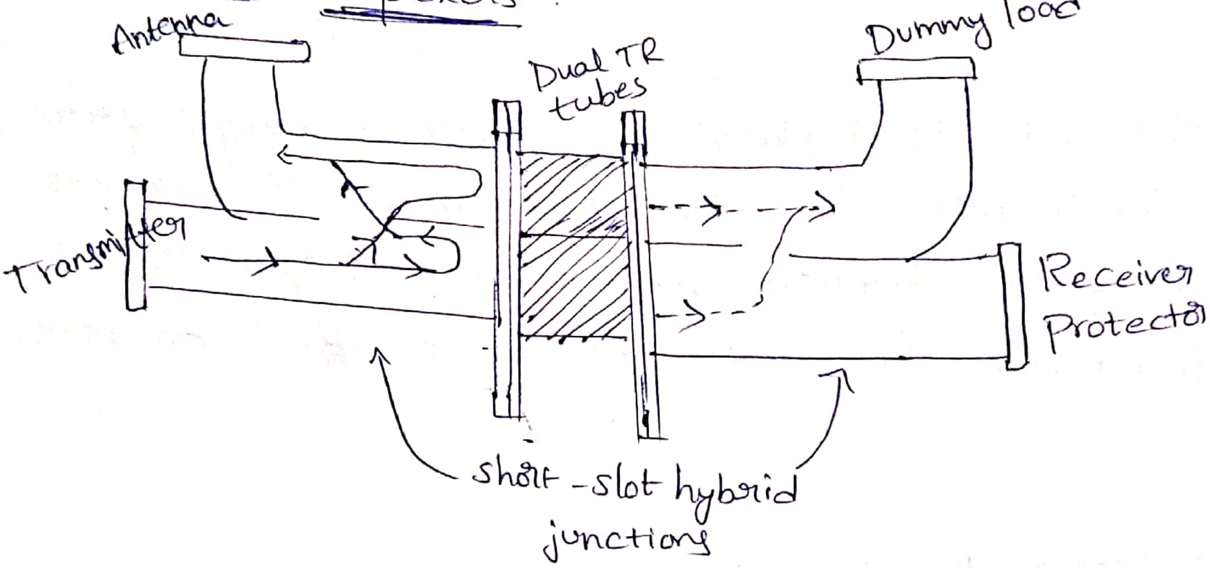
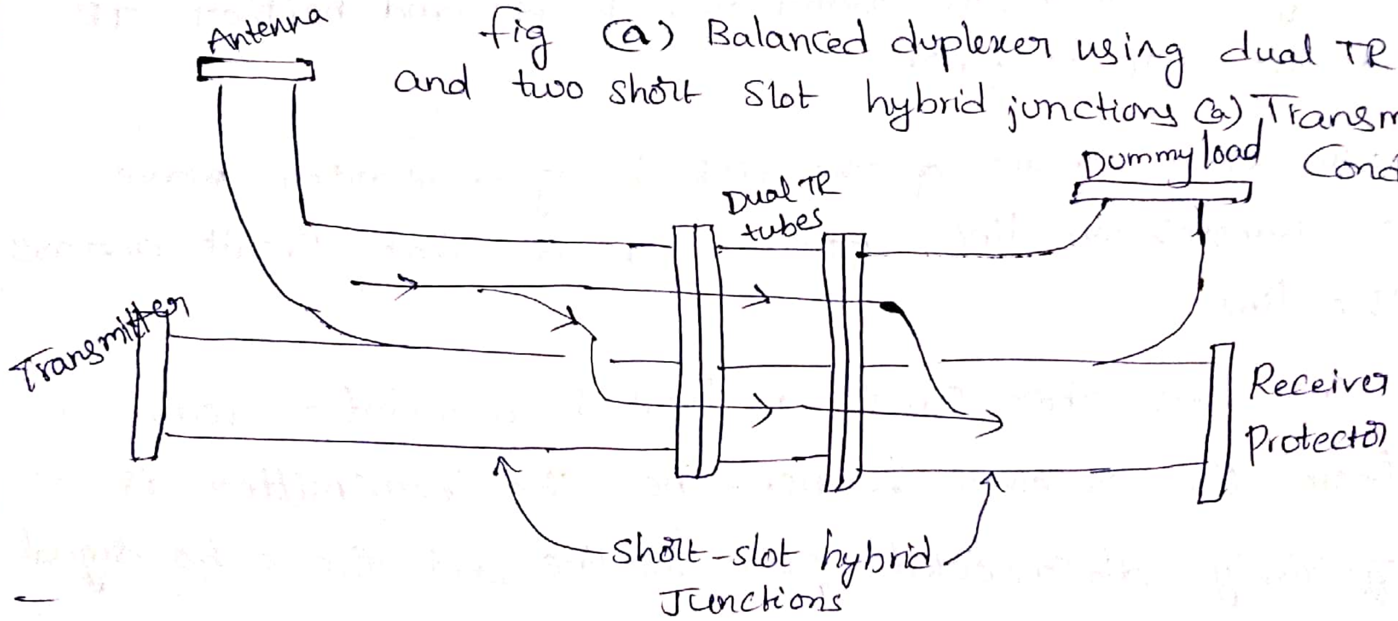


fig (a) Balanced duplexer using dual TR tubes and two short slot hybrid junctions (a) Transmit Condition



(b) Receive Condition.

-> The balanced duplexer is based on the short-circuit hybrid junction which Consists of two sections of waveguide joined along one of their narrow walls with a slot cut in the Common narrow wall to provide Coupling between the two.

to prevent transmitter power from entering the receiver.

short-slot hybrid may be Considered as a broadband -tional Coupler with a Coupling ratio of 3dB.

In the transmit Condition [fig(a)] power is divided equally into each waveguide by the first short-slot hybrid junction.

-> Both TR tubes breakdown and reflect the incident power out the antenna arm as shown.

-> The short-slot hybrid has the property that each time the energy passes through the slot in either direction its phase is advanced 90°. Therfore, the energy must travel as indicated by the solid lines.

-> Any energy which leaks through the TR tubes (shown by the dashed lines) is directed to the arm with the matched dummy load and not to the receiver.

-> In addition to the attenuation provided by the TR tubes, the hybrid junctions provide an additional 20 to 30 dB of isolation.

-> On reception the TR tubes are unfired and the echo Signal pass through the duplexers and into the receiver as shown in fig (b).

-> The power Splits equally at the first junction and because of the 90° phase advance on passing through the slot, the energy recombines in the receiving arm and not in the dummy load arm.

Advantages:

1. The power handling capability of the balanced duplexer is greater than that of the branch-type duplexer.
2. It has wide bandwidth.

Circulators as duplexers

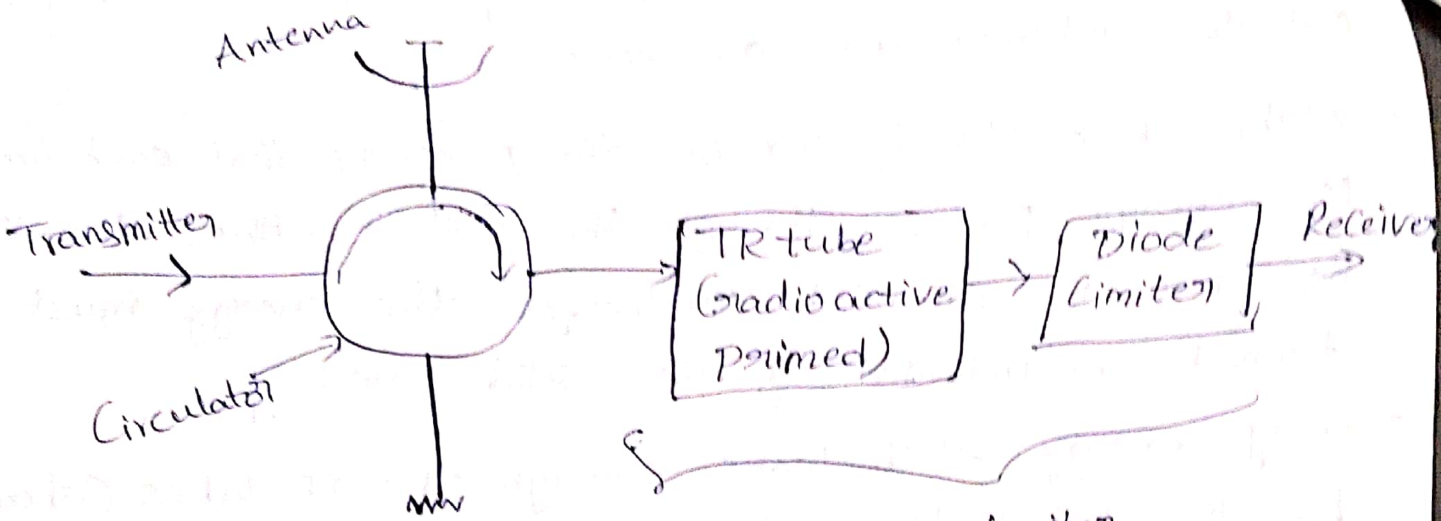


fig: circulator and receiver protector. A four-port circulator is shown with the fourth port terminated in a matched load to provide greater isolation between the transmitter and the receiver than provided by a three port circulator.

→ The ferrite circulator is a three or four-port device that can offer separation of the transmitter and receiver without the need for the conventional duplexer configurations.

→ The circulator does not provide sufficient protection by itself and requires a receiver protector as in above fig.

→ The isolation between the transmitter and receiver that usually determines the amount of transmitter Power the receiver, but the impedance mismatch at the antenna which reflects transmitter power back into the receiver.

-> The VSWR is a measure of the amount of Power reflected by the antenna. For example, a VSWR of 1.5 means that about 4 percent of the transmitter power will be reflected by the antenna mismatch in the direction of the receiver which corresponding an isolation of only 14 dB. About 11 Percent of the power reflected when the VSWR is 2, Corresponding to less than 10dB isolation.

-> Thus a receiver protector is almost always required It also reduces to a Safe level radiations from nearby transmitters.

-> The receiver protector might use solid-state diodes for an all solid-state Configuration, or it might be a Passive TR-limit Consisting of radioactive primed TR tube followed by a diode limiter.

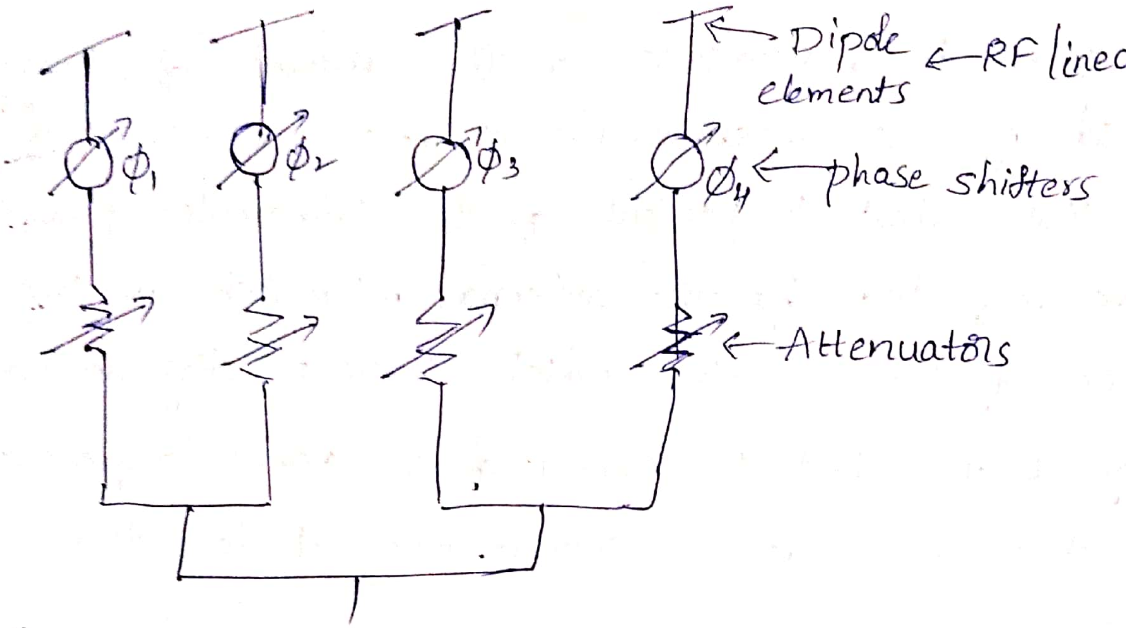
Advantages:

1. Long life
2. wide bandwidth
3. Compact design

-> Ferrite circulator provides isolation of about 20 to 30 dB between the transmitter and receiver.

-> Small size circulator along with the receiver pr... can be used as duplexer in solid state TR modules on active aperture phase arrays.

Introduction to phased array antennas



(a) phase array fed by Corporate structure (or phased array with parallel feed).

-> Def: A phased array is a directive antenna made up of individual radiating elements or antennas, which generate a radiation pattern whose shape and direction is determine by the relative phases and amplitudes of the currents at the individual elements. By properly varying the relative phases it is possible to steer the direction of the radiation.

-> The radiating elements might be dipoles, open-ended wave guides, slots cut in waveguide, or any other type of antenna.

-> The inherent flexibility offered by the phased array antenna in steering the beam by means of electronic control is what has made it of interest for radar.

-> It has been considered in those radar applications where it is necessary to shift the beam rapidly from one

odules in Space to another, or where it is required to obtain
ation about many targets at a flexible, rapid data

The full potential of a phased array antenna requires the use of a Computer that Can determine in real time, on the basis of the actual operational situation, how best to use the Capability offered by the radar.

> The above fig. is the Schematic of a phased array with phase shifter and attenuator at each element.

-> Although the elements of any antenna array must be phased in Some manner, the term phased array has Come to mean an array of many elements with the phase of each element being a variable, providing Control of the beam direction and pattern shape including side lobes.

-> Specialized phased arrays given different names are the frequency Scanning array, the retro array and the adaptive array.

-> In the Scanning array, Phase change is accomplished by Varying the frequency. These frequency Scanning arrays are among the simplest phased arrays Since no phase Control is required at each element.

-> A retro array is one which automatically reflects an in Common Signal back toward its source.

-> An adaptive array Can automatically Steer its beam toward a desired Signal while steering a null toward an undesired or interfering signal.

→ An objective of a phased array is to accomplish Steering without the mechanical and inertial problem of rotating the entire array. In principle, the beam Steering of a phased array can be instantaneous and with suitable n/w's all beams can be formed simultaneously.

→ Another objective of the phased array is to provide beam control at a fixed frequency or at any number of frequencies within a certain bandwidth in frequency-independent manner.

→ Instead of controlling the beam by switching cables, a phase shifter can be installed at each element. Phase shifting may be accomplished by a ferrite device. The same effect may be reduced by the insertion of sections of cable (delay line) by electronic switching. Thus insertion of cables of $\lambda/4$, $\lambda/2$, $3\lambda/4$ and no cable provides phase increments of 90°.

Basic Concepts of arrays:

An array antenna consists of a number of individual radiating elements suitably spaced with respect to one another.

→ The relative amplitude and phase of the signals applied to each of the elements are controlled to obtain the desired radiation pattern from the combined action of all the elements.

Two common geometrical forms of array antennas of interest in the radar are the Linear array and the planar array.

A linear array Consists of elements arranged in a straight line in One dimension.

-> A planar array is a two-dimensional Configuration of elements arranged to lie in a plane. The planar array may be thought of as a Linear array of Linear arrays.

-> A broadside array is one in which the direction of maximum radiation is perpendiclur, or almost perpendiclur to the line of the array.

-> An end-fire array has its maximum radiation parallel to the array.

-> The Linear array generates a fan beam when the phase relationships are such that the radiation is perpendicular to the array.

-> When the radiation is at some angle other than broadside the radiation pattern is a Conical-shaped beam.

-> The broadside Linear-array antenna may be used when broad Coverage in One plane and narrow beam width orthogonal plane are desired.

-> The linear array Can also act as a feed for a Parabolic Cylinder antenna.

-> The Combination of the linear array feed and the parabolic Cylinder generates a more Controlled fan beam than is possible with either a simple linear array or with a section of a parabola.

-> The combination of a linear array and the parabolic cylinder can also generate a pencil beam.

-> The end fire array is a special case of the linear or the planar array when the beam is directed along the array.

-> End-fire linear arrays have not been widely used in radar applications. They are usually limited to low or medium gains since an endfire linear antenna of high gain require an excessively long array.

-> The two-dimensional planar array is probably the array of most interest in radar applications since it is fundamentally the most versatile of all radar antennas.

-> A rectangular aperture can produce a fan-shaped beam.

-> A square or circular aperture produces a pencil beam.

-> The array can be made to simultaneously generate many search and/or tracking beams with the same aperture.

-> An array whose elements are distributed on a non-plane surface is called a Conformal array.

-> An array in which the relative phase shift between elements is controlled by electronic devices is called an electronically scanned array.

Pattern of N-element linear array or Radiation in Phased arrays

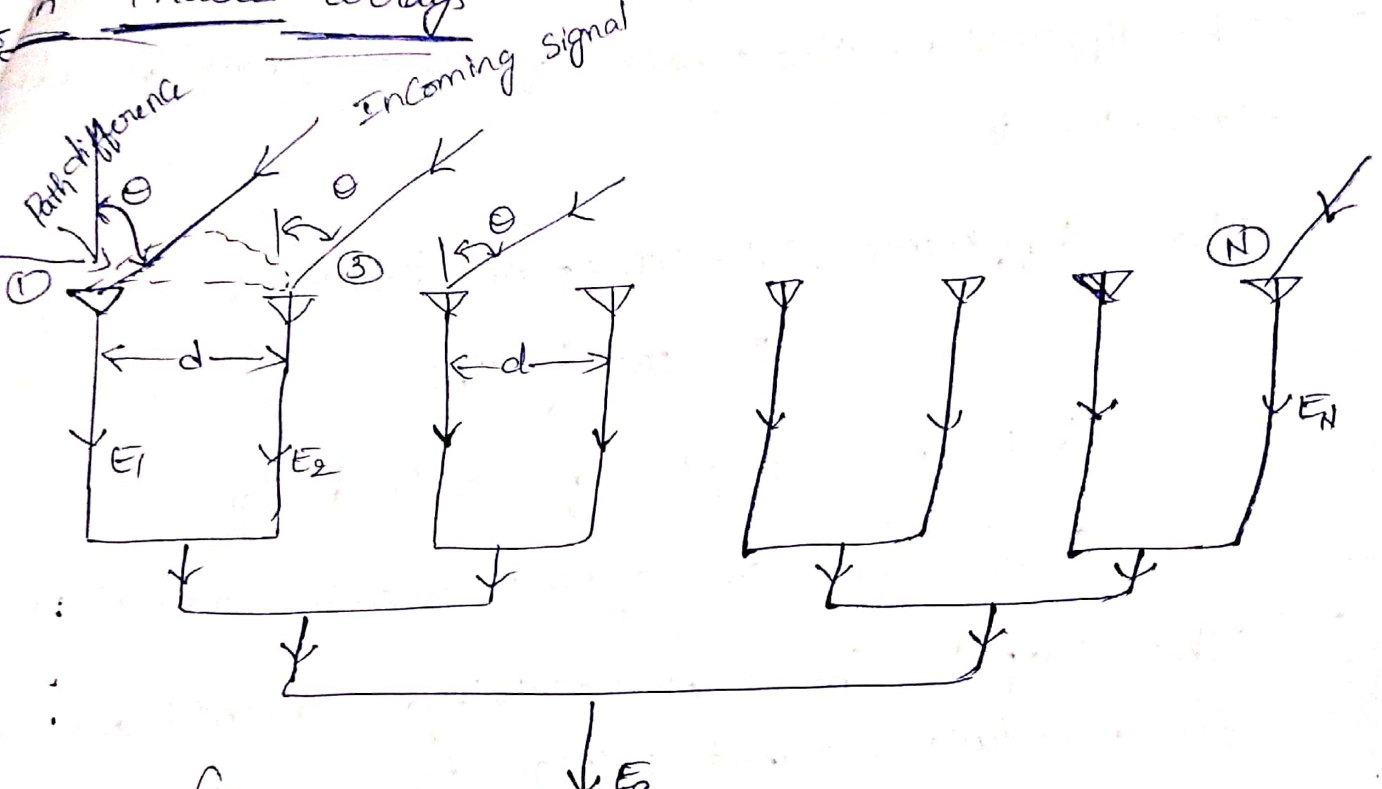


fig: N-element Linear array.

-> Consider a linear array made up of N elements equally spaced a distance 'd' apart. The elements are assumed to be isotropic point sources with equal amplitude and phase.

-> element 1 will be taken as reference signal with zero phase.

-> θ is the direction of incoming radiation.

-> It is assumed that the amplitudes and phases of the signals at each element are weighted uniformly.

-> Therefore the amplitudes of the voltages in each element are the same, and for convience, will be taken to be unity.

-> The above array is a parallel feed, linear array.

-> **Path difference:**

$\cos(90^\circ - \theta) = P.d/d \Rightarrow \sin\theta = Pd/d \Rightarrow Pd = d\sin\theta$

Path difference $= \frac{d}{\lambda} \sin\theta$ wavelength.

→ The difference in the phase of the signals in adajac[ent] elements is

- Phase difference, $\psi = 2\pi \times$ path difference

$$\psi = 2\pi \frac{d}{\lambda} \sin\theta$$

λ is wave length of received Signal

θ is direction of the incoming radiation.

→ The output from N receiving elements are summ[ed] to produce output voltage E_a

→ The sum of all the voltages from the individual elements can be written as

$$E_a = \sin\omega t + \sin(\omega t + \psi) + \sin(\omega t + 2\psi) + \cdots + \sin(\omega t + (N-1)\psi)$$

where ω is the angular frequency of the signal.

→ The Sum can be written

$$E_a = \underbrace{\sin\left[\omega t + (N-1)\frac{\psi}{2}\right]}_{\text{frequency \& phase shift}} \underbrace{\frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)}}_{\text{amplitude factor.}} \longrightarrow (1)$$

→ The field intensity pattern is the magnitude of eq (1) or

$$E_a(\theta) = \left| \frac{\sin[N\pi(\frac{d}{\lambda})\sin\theta]}{\sin[\pi(d/\lambda)\sin\theta]} \right|$$

field intensity pattern has zeros (or nulls) when [nume]rator is zero. It occurs if

$$N\pi\left(\frac{d}{\lambda}\right)\sin\theta = 0, \pm\pi, \pm 2\pi + \cdots \pm n\pi$$

where n is integer.

Also the field intensity pattern has zeros when denominator zero. It occures if $\pi\left(\frac{d}{\lambda}\right)\sin\theta = 0, \pm\pi, \pm 2\pi \cdots \pm n\pi$

When the denominator is zero, numerator also becomes zero and the value $|E_a(\theta)| = \frac{0}{0}$ is indeterminate. Applying L-hospital's rule (differentiating numerator and denominator separately it concludes that $|E_a(\theta)|$ is maximum and equals to N when $\sin\theta = \pm n\frac{\lambda}{d}$.

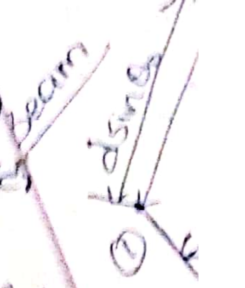
-> The maximum at $\sin\theta = 0$ indicates the main beam of field intensity pattern. The other maxima are called grating lobes. The grating lobes are of same magnitude as main beam hence they are undesirable and are to be avoided. The grating lobes can be avoided by adjusting spacing 'd' between elements equal to or less than λ.

-> To avoid ambiguities, the backward radiation is usually eliminated by placing a reflecting screen behind the array.

<u>Array factor</u>: The normalized radiation pattern of an array of isotropic elements is called array factor and is expressed as

$$G_a(\theta) = \frac{|E_a|^2}{N^2} = \frac{\sin^2\left[N\pi\left(\frac{d}{\lambda}\right)\sin\theta\right]}{N^2\sin^2\left[\pi\left(\frac{d}{\lambda}\right)\sin\theta\right]}$$

→ When non-isotropic radiators (directive antennas) are used, the resultant array antenna radiation pattern



$$G(\theta) = G_e(\theta) \frac{\sin^2[N\pi(\frac{d}{\lambda})\sin\theta]}{N^2 \sin^2[\pi(\frac{d}{\lambda})\sin\theta]} = G_e(\theta)\, G_a(\theta)$$

Where $G_e(\theta)$ is the radiation pattern of an individual element

→ The resultant radiation pattern is the product of the element factor $G_e(\theta)$ and the array factor $G_a(\theta)$.

→ The array factor has also been called the space-factor

Two-dimensional Radiation Pattern.

If the radiation pattern in the two principal planes are $G_1(\theta_e)$ and $G_2(\theta_a)$ the two-dimensional antenna pattern is

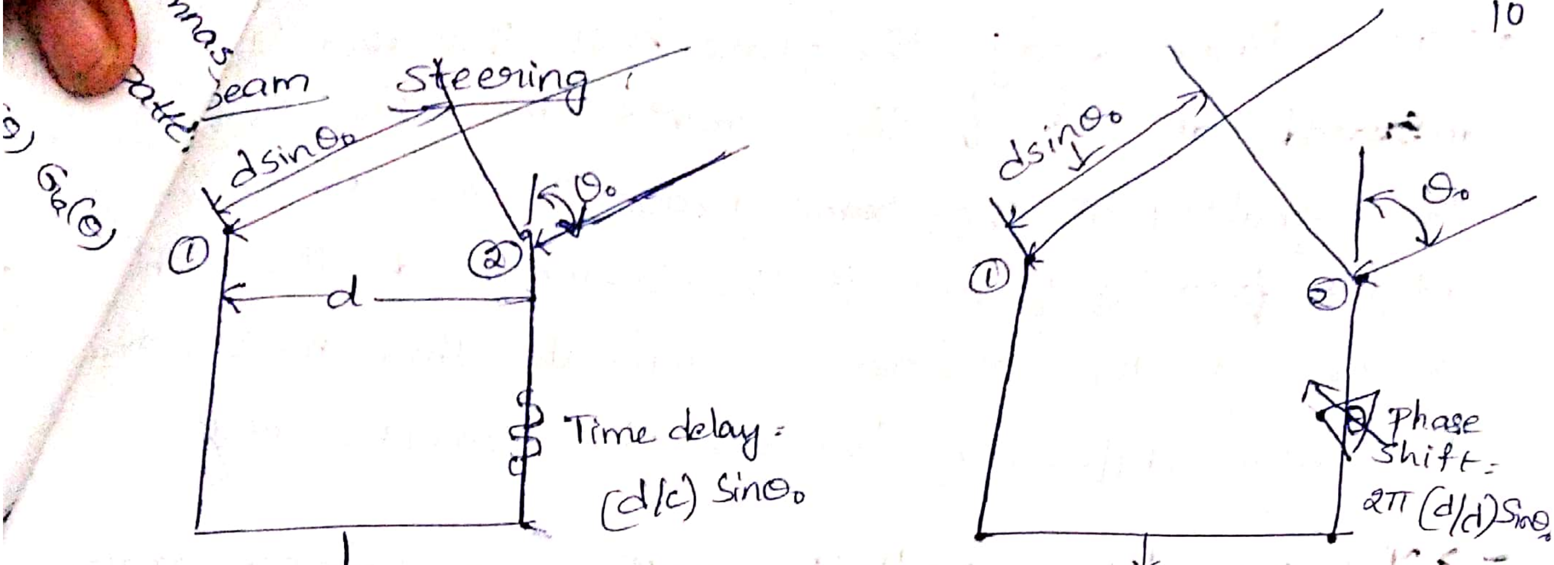
$$G(\theta_e, \theta_a) = G_1(\theta_e)\, G_2(\theta_a)$$

Note that the angles θ_e and θ_a are not necessarily the elevation and azimuth angles normally associated with radar.

→ The normalized radiation pattern of a uniformly illuminated rectangular array is

$$G(\theta_e, \theta_a) = \frac{\sin^2[N\pi(\frac{d}{\lambda})\sin\theta_a]\, \sin^2[M\pi(\frac{d}{\lambda})\sin\theta_e]}{N^2 \sin^2[\pi(\frac{d}{\lambda})\sin\theta_a]\, M^2 \sin^2[\pi(\frac{d}{\lambda})\sin\theta_e]}$$

Where N = number of radiating elements in θ_a dimension with spacing d and M = number in θ_e direction.



(a) Beam steering based on true time-delay

(b) Beam steering using phase shifter.

→ The beam of a linear array can be steered in angle by changing the relative time delays between the elements.

→ Consider two array elements spaced at a distance 'd' a part.

→ The signal from a direction θ_0, relative to the normal to the two elements, arrive at element 2 before it arrives at element.

→ If the signal is delayed at element ② for a time $\Delta T = (d/c)\sin\theta$ it will be in time coincidence with the signal at element 1. If they are added together it is as though the "main beam" of this simple two-element array was pointed in the direction θ_0. Beam steering occurs by changing time delay.

→ Beam steering is also possible by using a phase shifter which provides a phase shift equal to

$$\phi = 2\pi f_0 \Delta T = 2\pi \left(\frac{d}{\lambda}\right)\sin\theta_0$$

as shown in fig (b). The signals are in phase rather than coincident in time. This is shown in fig (b).

→ In a linear array, the phase shift that needs to be inserted at each of the elements in order to have the signals with the same phase is $m\phi$, where m, integer from 0 to N-1, is the number of the element relative to the reference element. This means that the phase difference between the elements is ϕ.

Sin m value Denote

→ The normalised radiation pattern of a linear array of isotropic elements is

$$G(\theta) = \frac{\sin^2[N\pi(d/\lambda)(\sin\theta - \sin\theta_0)]}{N^2 \sin^2[\pi(d/\lambda)(\sin\theta - \sin\theta_0)]}$$

→ The maximum of this pattern occurs when $\sin\theta = \sin\theta_0$, hence θ_0 is the direction at which the main beam points.

→ As before, the element pattern should multiply this equation to get the antenna radiation pattern. Thus the beam can be steere in an array by changing the phase shift at each element.

Change of beamwidth with steering angle:

As the beam of a phased array scans in angle θ_0 from broadside, its beamwidth increases as $(1/\cos\theta_0)$. This may be shown by assuming the sine in the denominator of eq $G(\theta)$ can be replaced by its argument, so that the radiation pattern is of the form $\sin^2 u/u^2$, where $u = N\pi(d/\lambda)(\sin\theta - \sin\theta_0)$

$\sin^2 u/u^2$ antenna pattern is reduced to half its maximum value when $u = \pm 0.443\pi$.

Denote by θ_+ the angle corresponding to the half-power point when $\theta > \theta_0$, and denote by θ_- the angle corresponding $u = +0.443\pi$ and θ_- to $u = -0.443\pi$

→ The $\sin\theta - \sin\theta_0$ term in the expression for u can be written as $\sin\theta - \sin\theta_0 = \sin(\theta-\theta_0)\cos\theta_0 - [1-\cos(\theta-\theta_0)]\sin\theta_0$

→ The second term on the right-hand side of this equation can be neglected when θ_0 is small so that $\sin\theta - \sin\theta_0 \approx \sin(\theta-\theta_0)\cos\theta_0$ with this approximation, the two angles corresponding to the half-power (3dB) point of the antenna pattern is

$$\theta_+ - \theta_0 = \sin^{-1}\frac{0.443\lambda}{Nd\cos\theta_0} \approx \frac{0.443\lambda}{Nd\cos\theta_0}$$

$$\theta_- - \theta_0 = \sin^{-1}\frac{-0.443\lambda}{Nd\cos\theta_0} \approx \frac{-0.443\lambda}{Nd\cos\theta_0}$$

→ The half-power beam width is

$$\theta_B = \theta_+ - \theta_- \approx \frac{0.886\lambda}{Nd\cos\theta_0}$$

Thus when the beam is scanned an angle θ_0 from broadside, the beamwidth in the plane of scan increases as $(\cos\theta_0)^{-1}$.

This expression, however, is not valid when θ_0 is large, and the array performance can be much worse

→ Eq ① applies for a uniform line-source distribution, which seldom is used in radar with a cosine-on-a-pedestal "aperture illumination of the form $a_0 + 2a_1 \cos(2\pi n$ ... a linear array of N elements with spacing d, the ... width is approximately

$$\theta_B \simeq \frac{0.886 d}{N d \cos\theta_0}\left[1 + 0.636\left(2a_1/a_0\right)^2\right] \ldots$$

where a_0 and a_1 are constants and the parameter n in the aperture illumination represents the position of the element

The beam width varies approximates inversly as $\cos\theta_0$

$$\therefore \theta_B \propto \frac{1}{\cos\theta_0}$$

→ A consequence of the beam width increasing with scan angle is that the antenna gain also decreases with scan angle as $\cos\theta_0$

Parallel-fed array

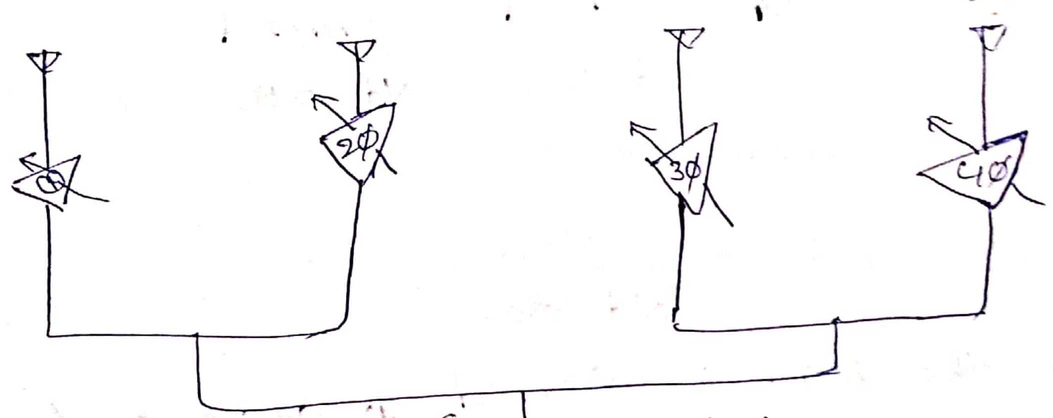


fig: parallel-fed (Corporate-fed) linear array.

→ Variable phase shifters may be used at each element of a linear array to steer the beam is called parallel-fed antenna array.

→ The above shows four element array

→ for N element array (N-1) phase commands are to be generated.

The phase difference between elements is given by

$$\phi = 2\pi\left(\frac{d}{\lambda}\right)\sin\theta_0$$

Series fed array:

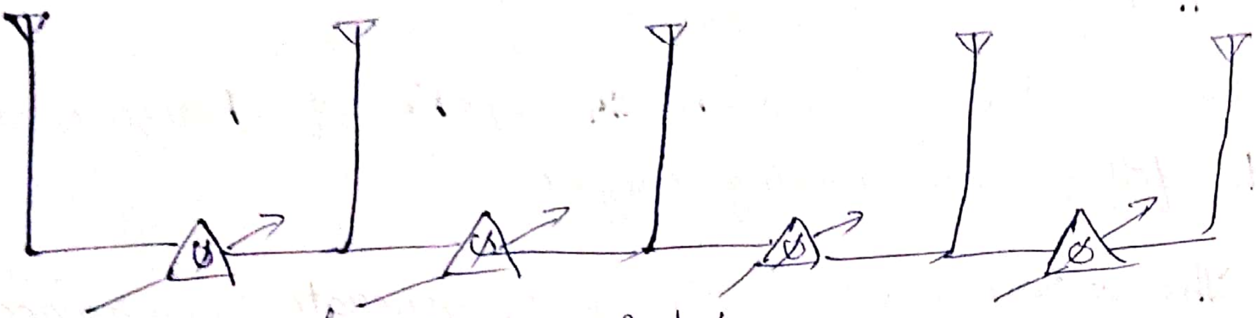


fig: Series-fed linear array.

-> In Series fed linear array each phase shifter has the Same phase and only one steering Command is to be generated

-> The above fig shows series fed linear array.

-> One major disadvantage of series fed array is its high loss. The total loss in Series fed array network is given by

$$\text{Total loss} = (N-1)\,L_{ps}$$

Where L_{ps} is loss of each phase shifter.

Series Vs parallel feeds

Series feeds	Parallel feeds
1. each phase shifter has Same phase.	1. Each element has variable phase shifter.
2. Only one steering Command is needed	2. (N-1) steering Commands are needed.
3. High Loss in array	3. Low Loss
4. Losses change with frequency	4. Almost fixed losses

Advantages of phased array radar :

1. The primary advantage is that phased array radars eliminates the need for mechanically rotating antenna elements

2. The radiation pattern is capable of changing rapidly to follow the moving target.

3 - The array has the ability to generate simultaneously many independent beams from the same antenna aperture. The array might generate fixed beams, scanning beams or both at the same time.

4. Large peak or large average powers may be obtained with separate transmitters at each of the elements of the array.

5. The spill over loss is almost absent in phased array

6. The efficiency of phased array radar is higher compared to all other systems.

Limitations of phased array:

1. Limited coverage available from a single plane array. Theoritically, a single plane array should be able to cover hemisphere but practically it is difficult.

2. The phased array radars are the costliest and the complexity is the biggest disadvantage.

...ions of phased array antenna

radar antenn... ...sed array antennas are electrically steerable. A phased array may be used to point a fixed radiation pattern or to scan rapidly in azimuth or elevation.

3. It is used in optical Communication as a wavelength selective spliter.

4. Am broad casting: used in many Am broadcast radio stations to enhance signal strength and therfore coverage in the city of License while minimising interference to other areas.

5. FM broadcasting: which greatly increase the antenna gain magnifying the emitted RF energy toward the horizantal which greatly increases the stations broadcast range.

6. Naval usage: phased array radars allow a warship to use one radar system for surface detection and tracking, air detection and tracking and missile uplink capabilities.

7. Weather research usage: for better understanding of thunder storms and tornados, eventually leading to increased warning times and enhanced prediction of tornados

8. Radio frequency Identification: phased arrays has been included in RFID systems in order to significantly boost the reading capability of passive UHF tags passing from 30 feet to 600 feet.