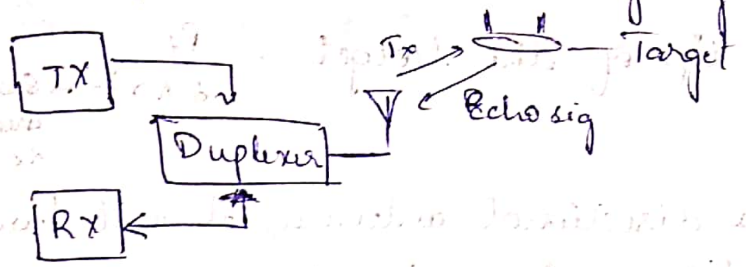
Unit-4

RADAR Principles.

RADAR - RAdio Detection And Ranging.

Radar - " Gathering info about distant targets by sending em waves & analysing values".



Parameters obtained -
* Range.
* Direction / Position.
* Velocity
* Direction of motion.

Round trip delay: - Time taken by signal to move from Tx → Duplexer → Target → Back to duplexer → Rx

* $T = \frac{D}{V}$

* 1 Radar mile = 6000 ft or 2000 yards

* $T = \frac{1 \text{ radar mile}}{3\times10^{8} m/s} = \underline{12.36 \mu s}$

* $\text{Range} = \frac{\Delta t}{12.36}$

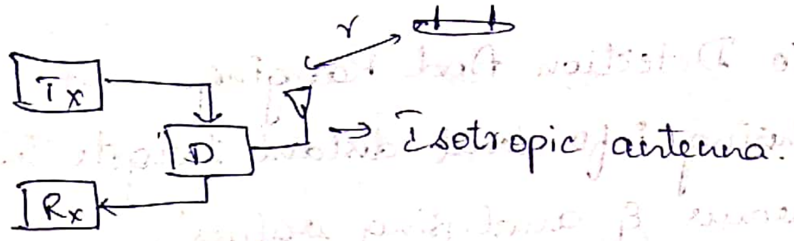
* MUR - Max Unambiguous Range

  $MUR = \frac{PRT}{12.2}$ → Pulse Repitition Time

* $\text{Duty cycle} = \frac{\tau}{PRT}$ - Pulse width

Radar Range Equation:

If $P_t \rightarrow$ Peak Pulse Power transmitted



P_1 - Power at the tip of the target $= \dfrac{P_t}{4\pi r^2}$ → Surface area of Rx sphere

If the antenna is a directional antenna, it will have gain A_p. Power at tip of ~~antenna~~ target is

$$\therefore P_2 = P_1 \cdot A_p$$
$$= \frac{A_p P_t}{4\pi r^2}.$$

If S is the cross sectional area of ~~target~~ reflected part of target as observed from antenna, power intercepted / reflected by the target

$$\therefore P_3 = P_2 \cdot S.$$
$$= \frac{A_p P_t S}{4\pi r^2}$$

P_4 is the power density at the recieving antenna.

$$P_4 = \frac{P_3}{4\pi r^2} = \frac{A_p P_t S}{16\pi^2 r^4}.$$

If A_0 is aperture area of Rx antenna, Power is given by

$$P_5 = A_0 P_4 = \frac{A_0 A_p P_t S}{(4\pi r^2)^2} \qquad \left(A_p = \frac{4\pi A_0}{\lambda^2}\right)$$

$$\therefore P_5 = \frac{P_t A_0^2 S \cancel{4\pi}}{4\pi r^4 \lambda^2} \quad \text{or} \quad \frac{A_p^2 \lambda^2 P_t S}{64\pi^3 r^4}$$

Strength of echo signal (Power density / Power)

If $P_S = P_{r_{min}}$ (i.e. less power for r_{max})

$$\therefore r_{max} = \left(\frac{P_t A_0^2 S}{4\pi \lambda^2 P_{r_{min}}} \right)^{1/4} \quad \text{——(1)}$$

Effect of noise:

$P_{r_{min}} \rightarrow$ Min detectable power $\rightarrow$ Thermal noise limit

$P_{r_{min}} = K T_0 \delta_f (F-1)$ where K - proportional constant
——(2)

T_0 - Absolute temp (°K)

δ_f - BW of reciever

F - ~~Noise~~ SNR

Using (2) in (1),

$$r_{max} = \left[\frac{P_t A_0^2 S}{4\pi\lambda^2 K T_0 \delta_f (F-1)} \right]^{1/4} \quad \text{——(3)}$$

$\rightarrow$ Considering noise

For dish antenna (parabolic dish)

$A_0 = \frac{K\pi D^2}{4}$, where K - aperture efficiency

D - mouth diameter of dish.

$$= \frac{0.65 \pi D^2}{4} \quad \text{——(4)}$$

Assuming $T_0 \simeq 290°K$, $K = 1.38 \times 10^{-23}$ J/K & using (4) in (3),

$$r_{max} = 48 \left[\frac{P_t D^4 S}{\delta_f \lambda^2 (F-1)} \right]^{1/4}$$

Factors affecting the range (To ↑ r_{max})

1.) $r_{max} \propto \sqrt[4]{P_t}$

To double the range, P_t shld be ↑ by 4 folds. Thus it is not economical

2.) $r_{max} \propto \frac{1}{\sqrt[4]{P_{r_{min}}}}$

$\Rightarrow$ To ↑ r_{max}, $P_{r_{min}}$ has to be ↓. Consequences of ↓ P_r

→ Jamming

→ Rx must be too sensitive for $P_{r_{min}}$ ↓

3.) $r_{max} \propto D$ ... To double range, double diameter. Effective

4.) Beam width $= \frac{70\lambda}{D}$ for dish antenna.

So if $D\uparrow$, $BW\downarrow$ $\Rightarrow$ disadvantage for search antenna (radar)
advantage for tracking radar

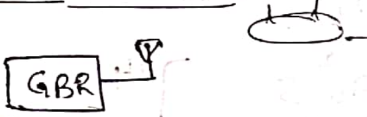
* Pulse — Tracking - small b.w.
  — Search - large bw

4.) $r_{max} \propto \frac{1}{\sqrt{\lambda}}$

$\lambda = \frac{c}{f}$ = $\lambda\downarrow, f\uparrow$ $\Rightarrow$ affects B.W.

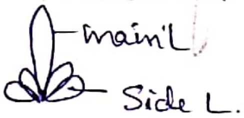
5.) $r_{max} \propto \sqrt[4]{S}$

Radar Beacons:



* Radiation pattern from antenna has loop struc.

i.e,



These side loops may come in contact with earth surface & interference may cause as earth behaves as a magnet.

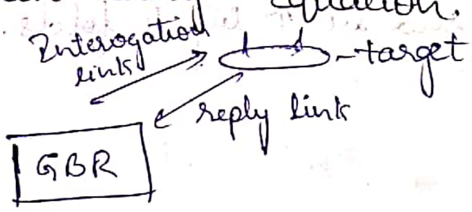
Radar Beacons are used in

* Defence - IFF (Identification of Friend or Foe)
* Satellite transponders
* Aircraft - Altimeter (adjust height)

The 2 links b/w Radar & targents -

1.) Introgation link - Ground Base Radar - T_x, Target - R_x
2.) Reply link - Ground Base Radar - R_x, Target - T_x

Beacon Range Equation.



GBR - Ground Base Radar
Target - has T_x & R_x - active

If P_B is the power density at tip of target antenna

$$P_B = \frac{A_{PT} \cdot P_{tB} A_{eB}}{4\pi r^2}$$

P - Power
B - Beacon antenna
T - GBR

I - Interrogation link

$r_{max.I} \Rightarrow$ If P_B is min, R.$r_{max.I} \rightarrow$ max

$$r_{max.I} = \sqrt{\frac{A_{PT}\, P_{TT}\, A_{OB}}{4\pi P_{min.B}}}$$

$A_{PT} = \frac{4\pi A_{OT}}{\lambda^2}$, $P_{min.B}$ - Thermal noise limit $= KT_0 \delta_f (F_B - 1)$

$\downarrow$

Min detectable power.

Substituting these values,

$$r_{max.I} = \sqrt{\frac{A_{OT}\, P_{TT}\, A_{OB}}{\lambda_1^2 K T_0 \delta_f (F_B - 1)}} \quad \text{---} (1)$$

Range for reply link,

$$r_{max.R} = \sqrt{\frac{A_{OB}\, P_{TB}\, A_{OT}}{\lambda_2^2 K T_0 \delta_{f_T} (F_T - 1)}} \quad \text{---} (2)$$ - Beacon range eqn for reply link

Min of (1) & (2) is called Beacon Range

Example: In an operating system $f = 2.5 \text{ Hz}$,

	GBR	BR
P_{tT}	0.5 MW	$P_{TB} = 50 W$
D_T	64 m	$D_B = 1m$
F_T	1.1 (ratio)	$F_B = 13 dB$
δ_{fT}	5 KHz	$\delta_{fB} = 5 KHz$

$T_0 = 290 K$

$K_B = 1.38 \times 10^{-23} J/K$

$r_{max.I} = 9.87 \times 10^{12} m = \underline{9870 \text{ million km}}$

$r_{max R} = 1.36 \times 10^{11} Km = \underline{136 \text{ million km}}$

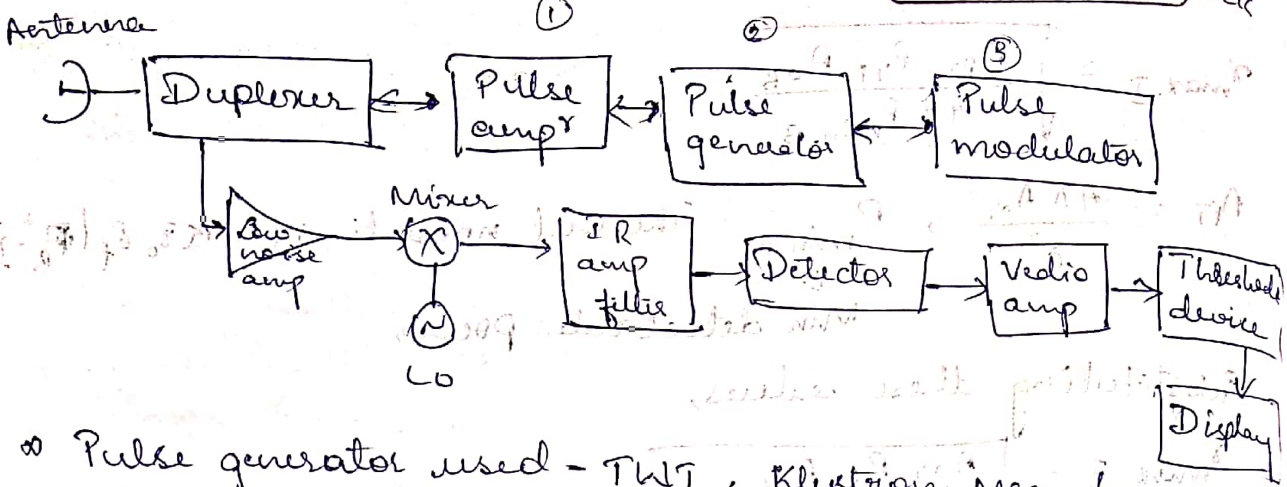
Beacon range is the min range.

$\therefore r_{max R}$ i.e, Reply link is the beacon range

Different forms of RADARs

1. Pulse Radar:

1,2,3 - Tx block, other Rx block



* Pulse generator used - TWT, Klystron, Magnetron
* Here instead of using 2 separate antenna for Tx & Rx, single antenna is used with a duplexer.
* Duplexer has Tx & anti Tx recieve switch. (T note)

Specifications:

* Pulse width, P - 0.1 μs to 1 μs.
* Time period of pulse, $\gg \tau$, i.e, 1 ms.
* Resolution - 0.5 τ c.
* BW = $1/\tau$.
* If Pulse repitition rate (pr), range = 0.15 pr.
* Nautical miles is used to determine range.

1 Nautical mile = 1.852 Km

→ For ATC application,
range - 100 to 200 nautical mile
Power = 1 MW

→ Surveillance radar,
Power = 100 kW.
IR freq - 30-60 MHz used,
BW - 1 MHz

Parabolic antenna are used
↳ Power gain - 31 dB
↳ Half power beamwidth - 11 to 19°

↳ Pulse width - 60 sec

↳ R_{min} : 2 nautical miles

↳ Pr freq - 300Hz

↳ Noise ratio : (S_f) = ~~Ego~~ 4.2

Classification
1) Based on task

Pulse radar — Search radar
— Tracking radar.

2) Based on reciever
— Monostatic - Tx & Rx present in same place
— Bistatic - Different place

* Search radars are used for detecting presence or absence of target
* Tracking radar establishes link b/w target

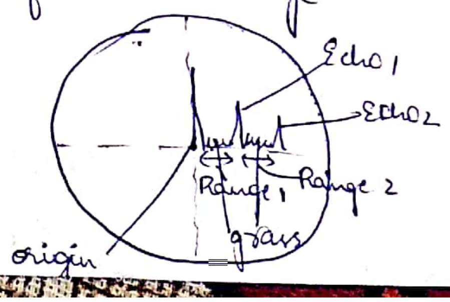
Applications of Pulse radar
1. Long distance comm (Deep Space tracking)
2. ATC (Air Traffic Control)
3. Weather monitoring
4. Remote sensing application

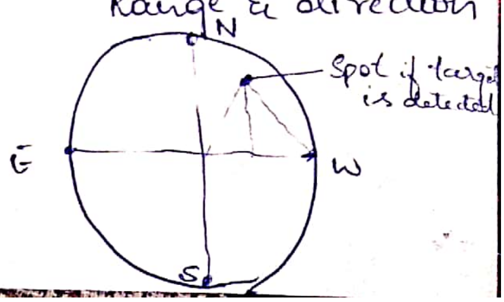
Display unit: (of pulse radar)

① A ~~Star~~ Scope display ② PPI display (Plan Position Indicator)

	①	②
Parameters		
1) Type of mod.	Reflection modulation	Intensity mod.
2) Parameter found	Range	Range & direction

3) Crt screen of A scope display





3.) Deflection	Electrostatic deflection	Magnetic deflection
4.) Scanning	Spiral scanning	Conical scanning
5.) Application	Tracking radar	Search radar
6.) Display	Uses cartesian co-ordinate system	Uses polar co-ordinate system
7.) Phospher used	Short persistant & Long persistant P	Long persistant P

2) Continuous Wave Radar: [CW Radar]

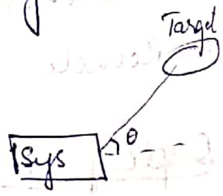
(*) Uses continuous wave [sine wave] (*) uses modulation - AM, FM (*) Can determine radial velocity, direction of motion.

Basic Principle:

It works on "Dopler Principle".

If there is a observer & target, suppose if target is in relative motion with observer, then if it transmits f_0, then the recieved freq will be $f_c = f_d \pm f_0$. where f_d is the doppler shift in freq. '+' when moving towards observer, '-' → away from observer.

$$f_d = \frac{2V_r \cos\theta}{\lambda}$$, V_r - radial velocity
θ - inclination angle
$\lambda = c/f$

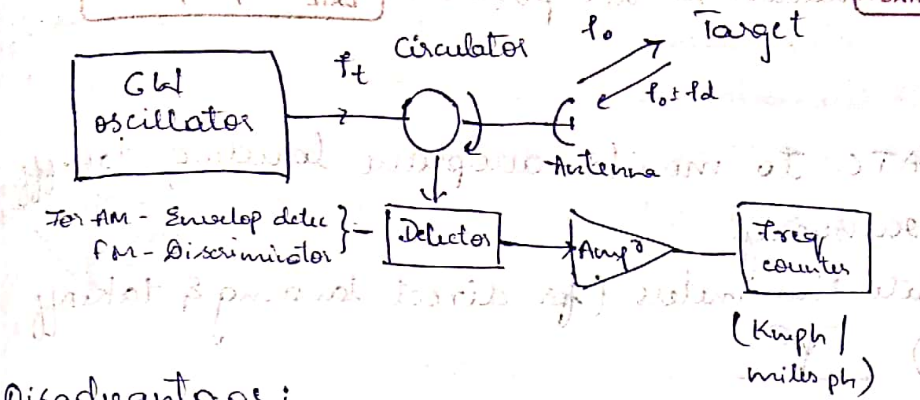


Here θ is variable parameter

at $\theta = 0$, $f_d = f_{dmax}$, inclined reception.,

$\theta = 90°$, $f_d = 0$, orthogonal reception.

Single antenna / Monostatic Continuous wave Radar:

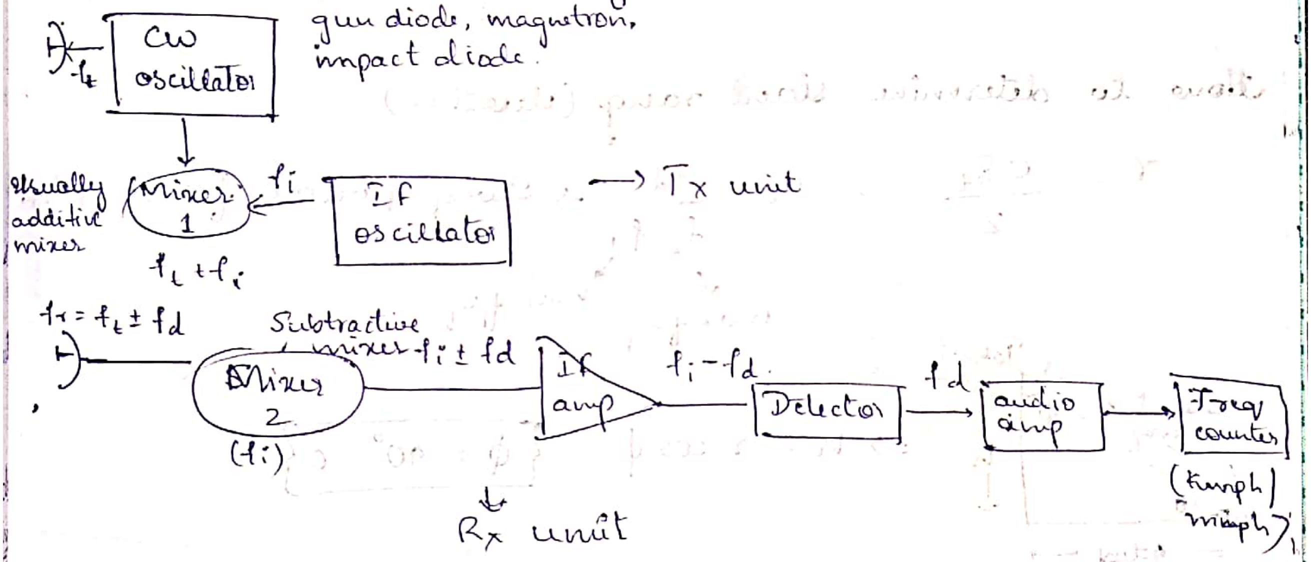


Disadvantage:

* Polarity cannot be ~~determined~~ preserved
* Thus direction of motion cannot be determined

Bistatic system:

oscillator made of gun diode, magnetron, impact diode.



Advantages of CW radars:

* Accurate measurement of radial velocity is possible
* Low transmitted power so low cooling
* Improved sensitivity
* r can be 0. i.e, upto zero range it ~~can work~~ detection possible
* Drift will preserve polarity of f_d, direction of motion can be determined
* Navigation of target (o) can be determined

Disadvantages

* Since Tx power is low, the range is limited. i.e, can't detect beyond certain range.

* Multiple target results in ambiguity.
* Range determination is not possible

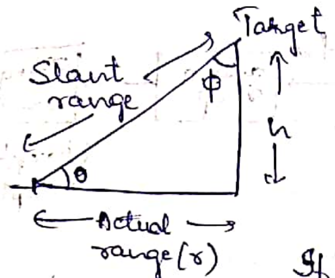
Applications:

* Used in ATC to monitor aeroplane landing, takeoff from the runway.
* Used in Rate line meters (for direct landing & takeoff of aircraft)
* Police radars for speed limit control.
* Direction of motion can be determined if ~~fd~~ Polarity is known
* Radial velocity determined.
* FM CW radars is used widely.

How to determine slant range (elevation)

$$r = \frac{c\,\delta_t}{2} \quad , \quad \delta_t = \frac{f_d}{f_2 - f_1}$$ → Sweep period from f_2 to f_1

f_2 → max freq, f_1 → min freq



$$\Rightarrow h = r\cos\phi \qquad \boxed{\phi = 90^\circ - \theta}$$

If Δr is the small error in calculating range

$$\Delta r = \frac{c}{8 f_d}$$

3) Moving Target Indicators (MTI) Radars

Uses 2 types of display

→ A scope display.

→ Plan Position Indicators (PPI)

a) A scope display →

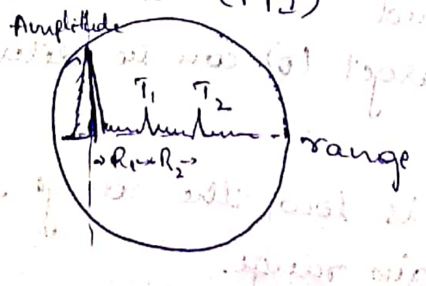
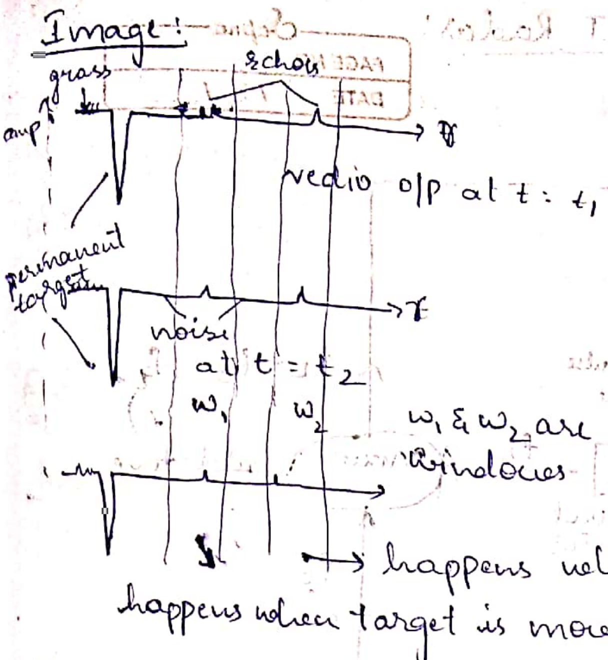
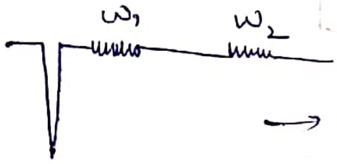


Image :-



From these 2 images it can be observed that
* It can be refrence pulse
* or echo from permenent target are

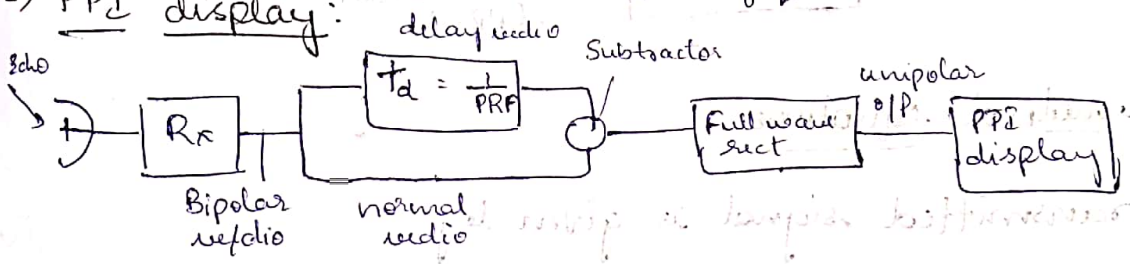
By super imposing all the obtained vedios together,

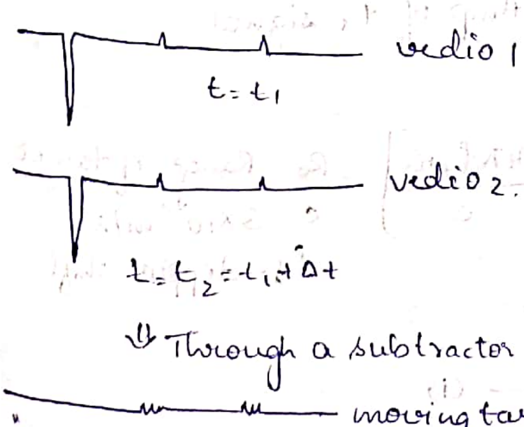


→ called as Butterfly effect. It indicates the moving target.

b.) PPI display:

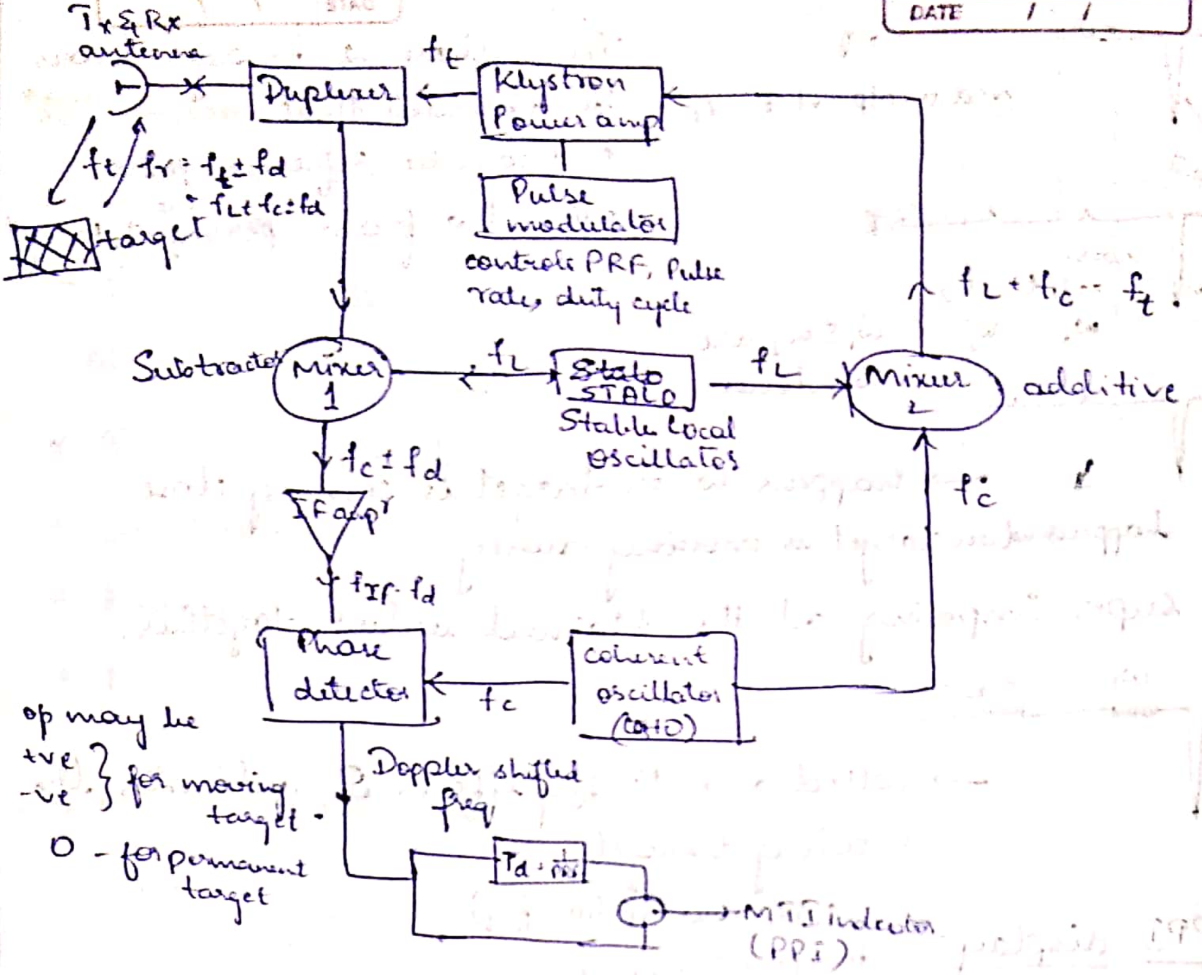
(PRF - Pulse Repition freq)





Cancellation of permanent echos must be possible, then only you can view your moving target perfectly.

Power amplifier type of MTI Radar:



Mathematical equations:

Transmitted signal is given by

$V_t = A_1 \sin 2\pi f_t t$, A_1 - Amp of tx signal

Echoed signal is given by

$V_{echo} = A_2 \sin\left[(2\pi f_t t \pm f_d t) - \frac{4\pi f_t R_0}{c}\right]$, R_0 - Range of target, c - 3×10^8 m/s. f_d - doppler shift

The difference signal from mixer 1,

$V_{diff} = A_3 \sin\left(2\pi f_d t - \frac{4\pi f_t R_0}{c}\right)$ —— (1)

* If $f_d = 0$, ⇒ target is stationary.
  V_{diff} will not vary w.r.t time for stationary target.
* If $f_d \neq 0$ ⇒ Moving target. Thus target can be detected on the screen

Blind speed:

For a given doppler freq. V_R decides a phase difference of 2π radians b/w 2 successive pulses. This means no phase change. The MTI radars blindly cancels the signals thinking that its stationary target

$V_{tn} = PRF \cdot \frac{n\lambda}{2}$, n = 1,2,3 - order of blind speed.

Remedies to overcome:

* Operate at ↑ wavelength or ↓ freq ⇒ V_t becomes large.
* Constantly change λ.
* Operate with finite PRF

Charac of MTI Radars

* Pulse | Continuous wave
* No range ambiguity : $\frac{c}{PRF}$
* If fd is known, radial velocity known
* Correct detection of moving targets, cancels echos from permanent target
* Ground thrutter | Background noise is eliminated

Applications:

* ATC - Takeoff & landing
* Ground Base radars - mainly police radars - speed limit apl^n
  - traffic control
* Monitoring of ships - in harbours & lighthouse
* Space - Satellite tracking
  - Missile guidance
  - ONGC support
* Mobile - GPS appl^n
* Sea mapping - Fisherman
  - Flood mapping
  - Tsunami | Earthquage
* Millitary - Monitor enemy target
  - Satellite locations

Sapna

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Scanning:

Scanning in RADAR System:

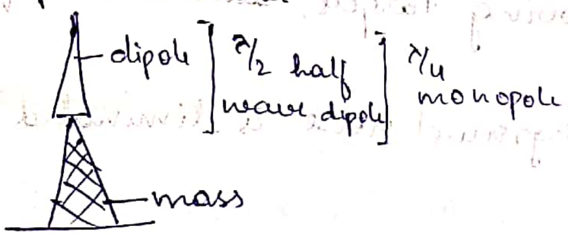
It is rotating the antenna in ~~certain pattern~~ regular fashion which ~~gets~~ generates radiation pattern, used to detect presence or absence of target.

Requirements for selecting antenna:

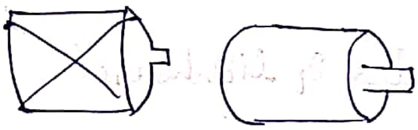
* Antenna must be compact => low weight, short.
* Withstand wind blowing
* ~~&~~ Use small driver motors
* Antenna must be easily rotatable
* Must have no losses

* Types of Antenna

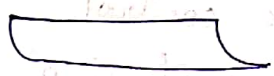
1) Dipole antenna



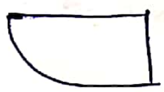
2) Dish antenna



3) Paraboloid cylinder antenna



4) Pillbox antenna

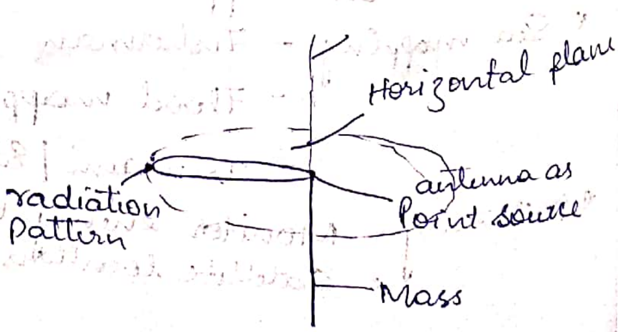


Types of Scanning:

1. Horizontal scanning

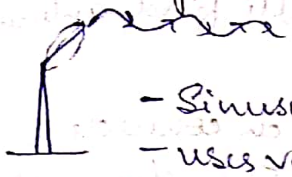
Antenna is rotated horizontally

The radiation pattern discovers the target's presence or absence.



* Used in plane to plane commⁿ in airspace
* Ship to ship commⁿ
* Terrestrial commⁿ.

2) Noding scanning



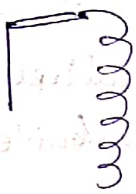
- Sinusoidal path
- uses vertical plane
- Also called as Vertical scanning.

* Used in tracking heavenly body i.e. stars, comets
* Air navigation.

3) Spiral Scanning

* ~~Vertical~~ Horizontal plane.
* Used in military
↳ Missile guidance, commanding targets

4. Helical scaning



* Both horizontal & vertical motion.
* Used in satellite commun"
* Wireless appʳ.

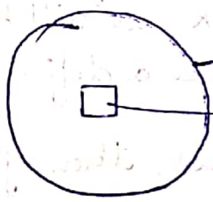
→ All these types are used in search radars.

5. Conical scanning:

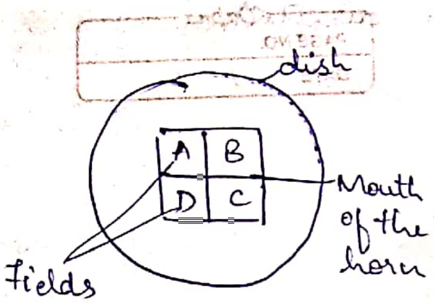
* Used in tracking radars.

* Used in setting pineave link in filters

Front view of dish antenna



* For short distance comm. this is used for both T_x & R_x
* This recieved echo if detected by the horn and then moves to the reciever

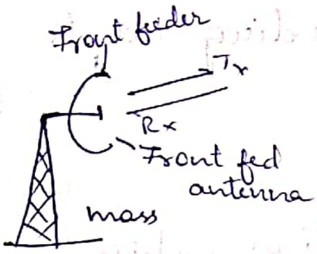


For long distance comm^n, we will face the prob of maximum anamoly (i.e, the reciever must need sufficient amt of time to detect the echo). Hence we need to use a multi field antenna.

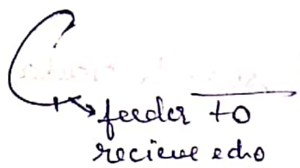
It consists of decision making ckt, which connects a particular field (A|B|C|D) to the reciever. The strongest echo recieved by 4 fields will be processed. This is for better detection. This is also called 'Max signal sampling'

For parabolic dish:

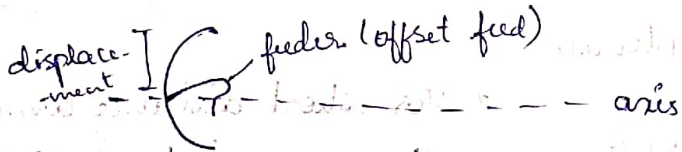
The mouth of the dish contains redirect elements in the front side, so as to tx & rx echo.



If the target is located very close, then you get an echo very soon. In case of multiple targets, there is confusion in monitoring. Hence we mount a recieving antenna at the backside



Suppose the recieving echo comes along the axis of the antenna, the feeder is placed in such a way as shown.



This is only Rx antenna. For Tx, we will have to use a diff antenna.

Whenever we want to recieve a best signal, then you need to go for multiple antenna, multiple imaging w.r.t the rx system. This is called Diversity reception method

Divetsity Reception method :

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1. Space diversity: Use multiple antenna arranged in regular pattern. Suppose it is doppler radar, for inline reception. we recieve no dopler freq. so we have to switch on the antenna which has orthogonal reception. so that the signal will be having max doppler shift.

2. Frequency diversity: change the freq regularly w.r.t Tx & Rx

3 Polarization diversity.
- ↳ Linear
- ↳ Circular
- ↳ Elliptical

Using differend polarization to different targets, with the help of diversity of reception methods, correct detection of targets is possible which in turn helps in detecting correct range, presence or absence of target, direction of motion, elevation.

RADAR Frequency Bands and applications.

Band name	Frequency	Applications.
1. HF (High Freq)	3MHz - 30MHz.	Coastal applications, OTH (Over the horizon)
2. P (previous) band	30M - 300 MHz.	Conventional Radars (Terrestrial appⁿ)
3. UHF	300M - 1GHz.	Very long range applⁿ, ground remote sensing
4. L (Long) band	1G - 2 GHz.	Long distance air plane control Surveillance applⁿ.
S (Short) band	2G - 4GHz.	ATC, weather monitoring (forecasting for the day, & for long term prediction), Marine (Ship - Ship, Ship - Shore)

Scanned with CamScanner

6.	C (comparision) band	4G - 8GHz.	Satellite transponders, Radar Beacons, Weather monitoring
7.	X (Secret) band	8 - 12 GHz	Lab app^n (Defence), Missile guidance, Weather mapping, Ground surveillance, ATC, Defence
8.	KU (outer K) band	12 - 18 GHz	High resolution mapping, Satellite telemetry,
9.	K band	18 - 27 GHz.	Monitoring clouds, storms (Metrology). Police radars (for monitor), traffic control, Automotive appl^n.
10.	KA (Above K) band	27 - 40 GHz	Flood mapping, Surveillance, RTO (no. plate tracking)
11.	Q band	40 - 60 GHz	Millitary Comm^n,
12.	V band	60 - 75 GHz	Atmospheric monitoring. High resolution appl^n.
13.	W band	75 - 110 GHz	Metrological app^l, Weather Appl^n, Automotive appl^n.

Advanced Radars.

1. MST Radar: M - Meosphere, S - Stratosphere, T - Tropostsphere

* Height - 50 - 100km.   10 - 50 Km   ground - 10 km
* Used to determine wind ~~storm~~ speed
* Atmospheric parameters - rain, storm, hail storms.
* Weather monitoring.

Characteristics.

* Pulse radar, → Pulse Repitition freq - 62.5 Hz - 8 KHz.

  Power - 2.5 MHz - high - to penetrate different layers

  Antenna → Array antenna

  → Dish antenna (dia - 100 - 300 km)

2. SAR ~~Radar~~ (Synthetic Aperture Radar)

* ~~Used~~ Dynamic Control of antenna is possible. (i.e, radiation pattern) corresponding to elevation, range of target, cross sectional area of target, 2-D images
* Can work with both stationary & moving target
* Monitoring movement of aircrafts orships
* Can monitor multiple echos.
* Weapon targeting (Missile destination), Mineral exploration
* Can work in adverse weather conditions

8. LIDAR (Light Detection and Ranging)

* Used for determining range of enemy targets (both fixed & moving) - Surgical appl^n. - 3D imaging is possible
* Uses large beam width antenna (generally dish antenna)
* Fractional f_d (Doppler freq) can be determined for monitoring slow targets
* Antenna's are unidirectional, No ~~sight house~~ side lobes i.e, →