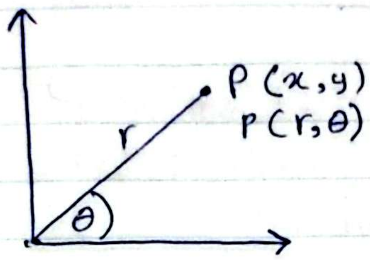
* 

r - range
θ - bearing

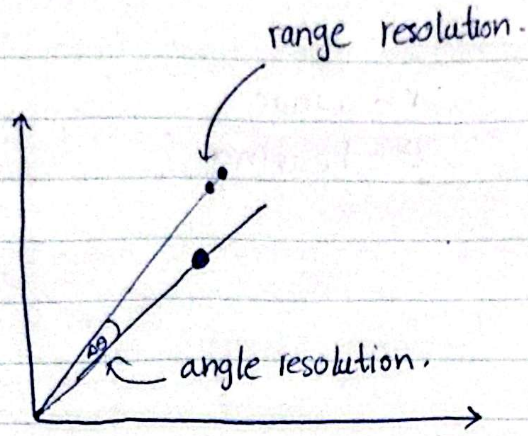
* environment
* propagation characteristics of the path.
* antenna characteristics
* Tx Rx characteristics

Types of radars.

- Search radars - scan a large area (pulses of short radio)
- Fire control radars (targeting radars) - same principle but small area.
- Navigational radars. - short waves that reflect off hard surface
- Mapping radars - scans a large regions for remote sensing and geography applications.
- Wearable radars - help the visually impaired as a substitute to eye
- Air traffic control
- Weather radar.

SONAR and RADAR.

Ionized particles in specially sea water will absorb the radio waves. They have two different fields. Those charged particles will convert the energy in electric field of EM waves to heat.

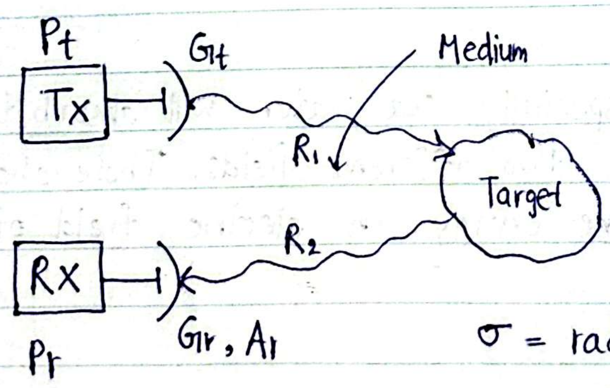


RAdio Detection And Ranging

EM polarization - The e field of the wave is either vertically or horizontally polarized.

		IEEE band	ITU
VLF	upto 30 kHz.	4	L
LF	30 kHz - 300 kHz	5	S
MF	300 kHz - 3 MHz	6	C
HF	3 MHz - 30 MHz	7	X
VHF	30 MHz - 300 MHz	8	Ku
UHF	300 MHz - 3 GHz	9	K
SHF	3 GHz - 30 GHz	10	Ka
EHF	30 GHz - 300 GHz	11	Mm

Radar range equation



same antenna, $R_1 = R_2$ (Range)

σ = radar cross section.

Assumptions.

1. Free space medium
2. No other scattering than the target
3. Target is at far field the antenna.
4. → plane wave illumination of target
→ Rx also get plane wave scattering from the target
4. No loss in the entire radar system

Power intensity received by the target $\Big\}$ $= \dfrac{P_t G_t}{4\pi R_1^2}$

Power scattered in the direction of target $\Big\}$ $= \dfrac{P_t G_t}{4\pi R_1^2} \times \sigma$

Scattered power intensity at the receiver $\Big\}$ $= \dfrac{P_t G_t}{4\pi R_1^2} \times \sigma \times \dfrac{1}{4\pi R_2^2}$

Power received by the antenna $\Big\}$ $= \dfrac{P_t G_t \sigma}{(4\pi R_1^2)(4\pi R_2^2)} \times A_e$

$$P_r = \frac{P_t G_t \sigma A_e}{(4\pi R_1^2)(4\pi R_2^2)}$$

$$\left(G = \frac{4\pi A_e}{\lambda^2}\right) \qquad \boxed{P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^2 R_1^2 R_2^2}}$$

Monostatic Antenna Radar.

$$R = R_1 = R_2$$

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4}$$

$$G = G_t = G_r$$

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

$$PRF = \frac{1}{PRI}$$

Pulse Repetitive Interval

Pulse Repetitive Frequency

$$\text{Duty Cycle} = \frac{\text{Pulse length}}{PRI}$$

Average power = Peak power · Duty cycle.

Continous wave (CW) radar = Duty cycle = 100%.
(always on

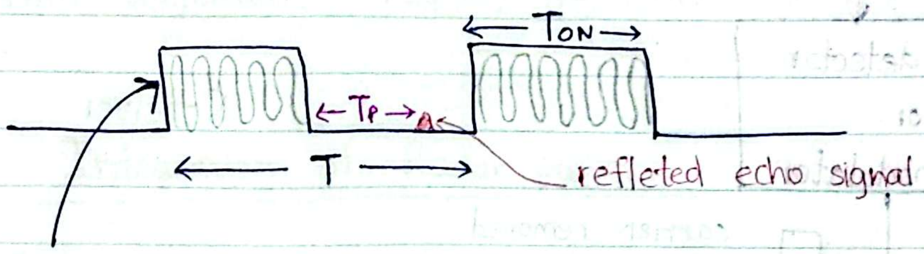
Maximum Radar range.

$$R = \left(\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 P_r} \right)^{1/4}$$

$R\uparrow \rightarrow \downarrow P_r \Longleftarrow S_{min}$ - Minimum detectable signal strength.

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

Pulse Radar block diagram.



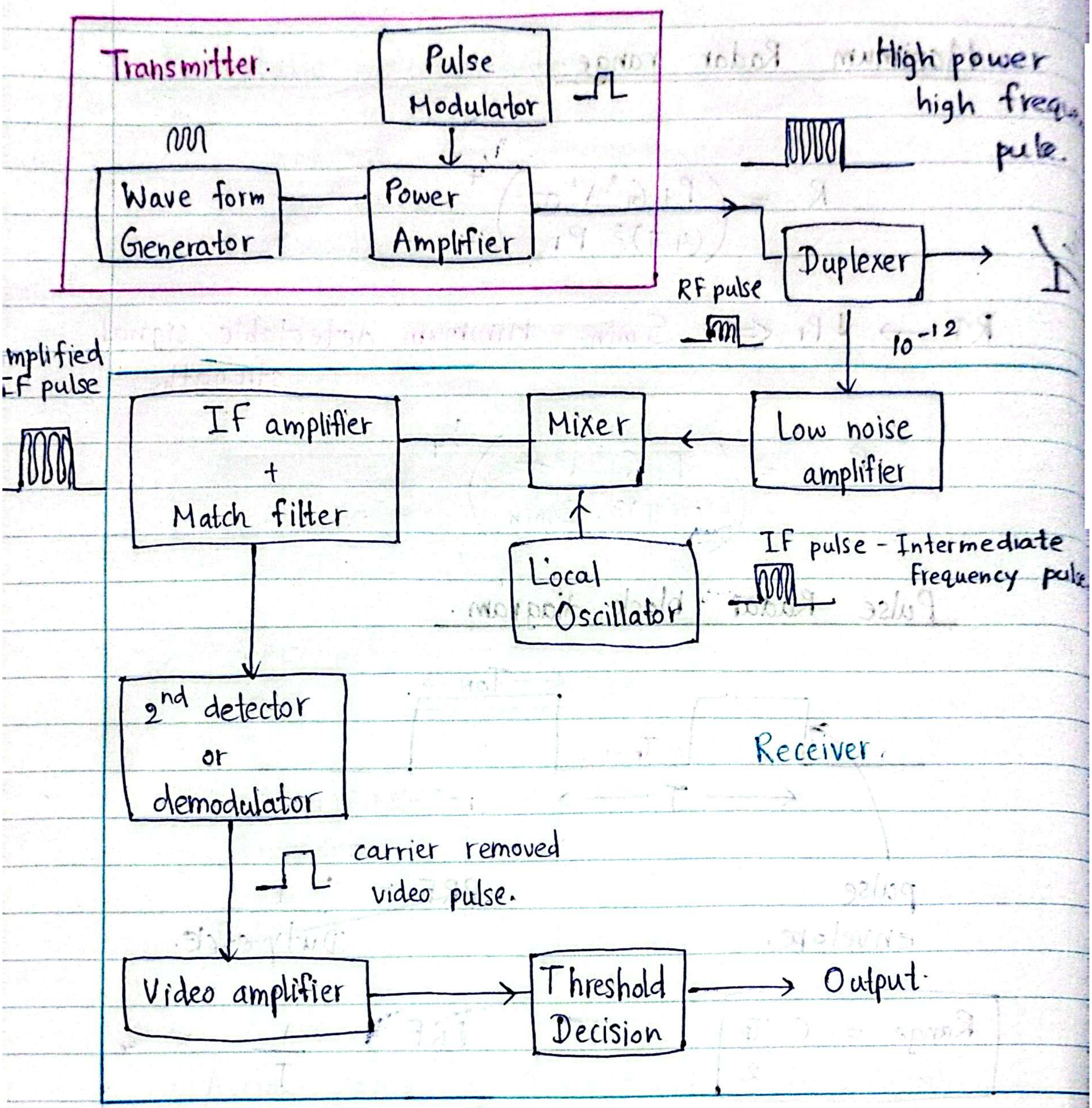
pulse envelope.

$$\cancel{PRF = \frac{1}{\text{Duty cycle}}}$$

$$\boxed{\text{Range} = C \cdot \frac{T_P}{2}}$$

$$PRF = \frac{1}{T}$$

$$\text{Duty cycle} = \frac{T_{ON}}{T}$$



Pulse Radar Block diagram

Pulse Modulator – Generates pulse with pulse repetitive frequency.
(Around 1MHz and duty cycle of 0.001)

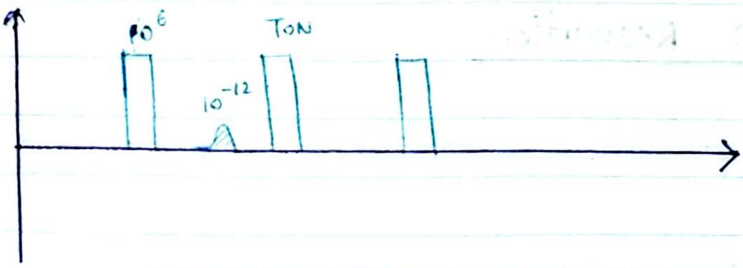
Wave generator – Generates high frequency continous wave.
(Carrier wave interms of GHz).

Pulse amplifier – is used to amplify signal with pulse width.

Duplexer – is used to isolate high power transmitter and low power receiver.

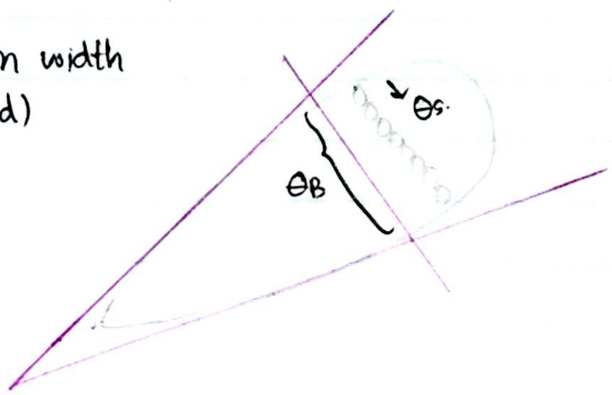
Low noise amplifier – Amplify the signal without the noise.

Integration of Radar pulses.



> Pulse integration is an improvement technique to address gain of echo signal by integrating multiple echo signals.

θ_B = beam width (rad)



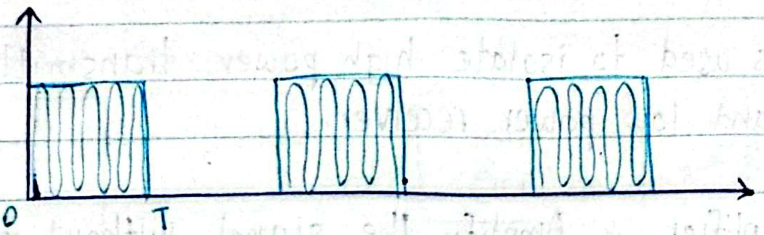
θ_s = scanning rate of antennas (rad^{-1})

$\frac{\theta_B}{\theta_s}$ = How much object is staying within the beam (s)

$$\boxed{n = \frac{\theta_B}{\theta_s} \times PRF}$$

n = number of pulses

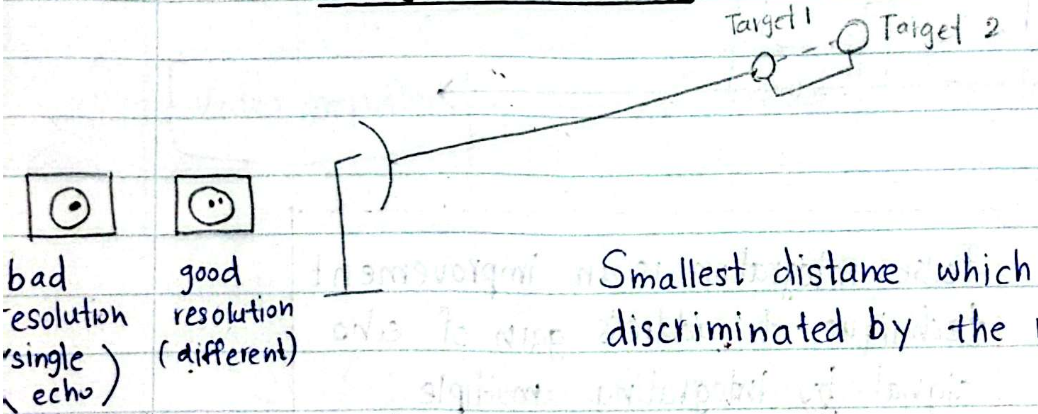
Minimum Range (Rmin)



$$\boxed{R_{min} = \frac{CT}{2}}$$

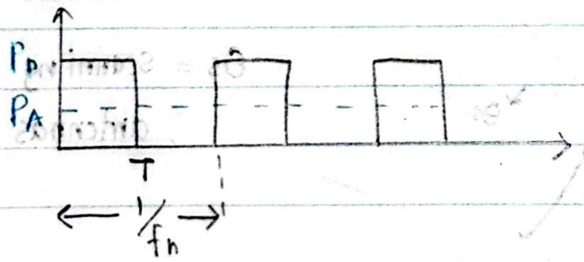
28/08/2025

Range Resolution



Smallest distance which can be discriminated by the radar receiver

Average Power



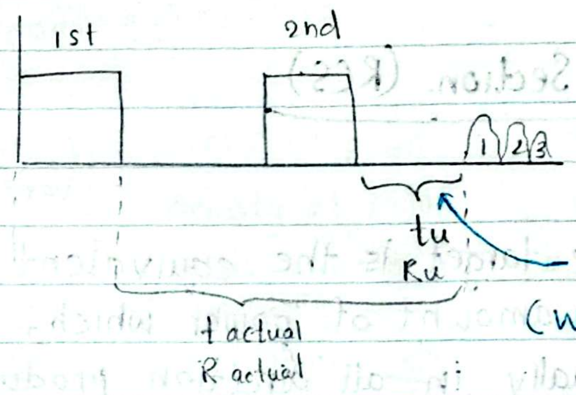
$$\text{Duty cycle} = \frac{T}{1/f_n}$$

$$P_p \times (T) = P_A \times (PRT)$$

$$P_p \times T = \frac{P_A}{f_n}$$

$$\boxed{P_A = P_p \times T \times f_n} \Rightarrow \boxed{P_A = P_p \times \text{Duty cycle}}$$

Unambigous Range.



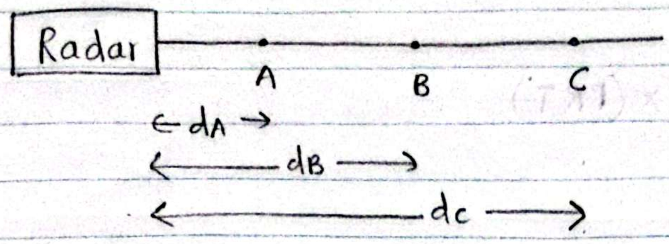
unambigous time (which one is correct w.r.t. 2nd)

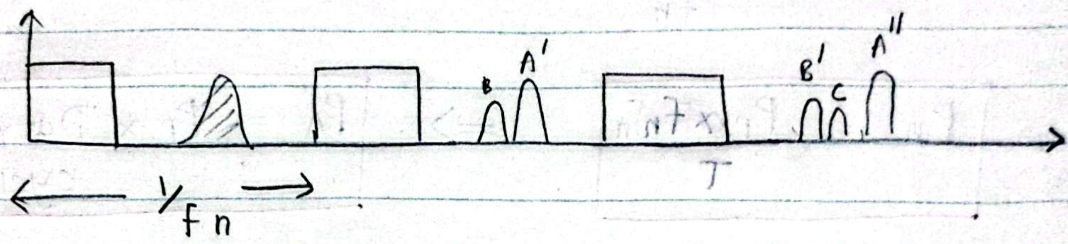
$$\boxed{R_{unambigous} = \frac{CT}{2}}$$

Max time radar should be in listening made to detect the ~~current tar~~ correct target.

(Assuming all the echos are arrived with in given PRI)

Pulse Staggering.

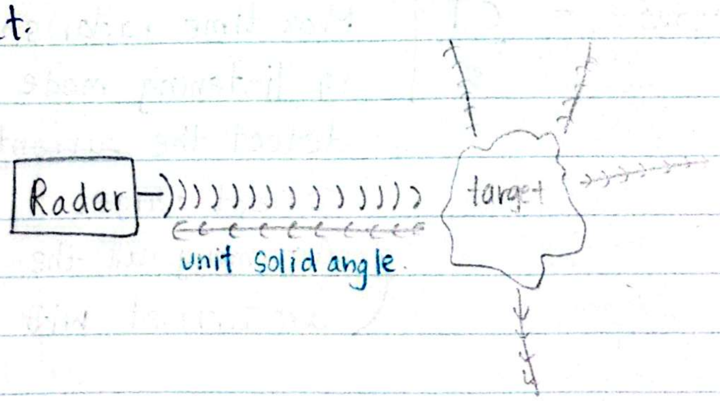




$\boxed{\text{Changing PRF.}}$ ← solution for the unambigous range.

Radar Cross Section. (RCS)

The RCS of the target is the equivalent area intercepting that amount of power which, when ~~st~~ scattering equally in all direction produces and echo at the radar receiver equal to that from the target.



σ = power scattered towards radar receiving antenna per unit solid angle.

Incident power densing redirected equally in all direction

$$\sigma = \frac{\frac{dP}{d\Omega}}{\frac{W_{incident}}{4\pi}}$$

Ω = solid angle

W_{inc} = incident power densing at the target W/m^2

$$\lim_{R \to \alpha}$$

$$W_{inc} = \frac{|E_{inc}|^2}{\eta_0} \quad — ①$$

from the radar eq^n

from plane wave equati-

$$\frac{P_t G_t}{4\pi r^2}\left(\frac{\sigma}{4\pi r^2}\right)$$ = scattered power density at radar receiving antenna;

a. target is at farfield of radar Tx antenna.

b. radar receiving antenna is at farfield of target.

$$= \frac{|E_s|^2}{\eta_0} \quad — ②$$

radar eq^n

$$W_{inc} = \frac{P_t G_t}{4\pi r^2} \quad — ③$$

from ③ and ②

$$W_{inc}\left(\frac{\sigma}{4\pi R^2}\right) = \frac{|E_s|^2}{\eta} \quad — ④$$

put in ① in the eq^n ④

$$\frac{(E_{inc})^2}{\eta_0}\left(\frac{\sigma}{4\pi r^2}\right) = \frac{|E_s|^2}{\eta}$$

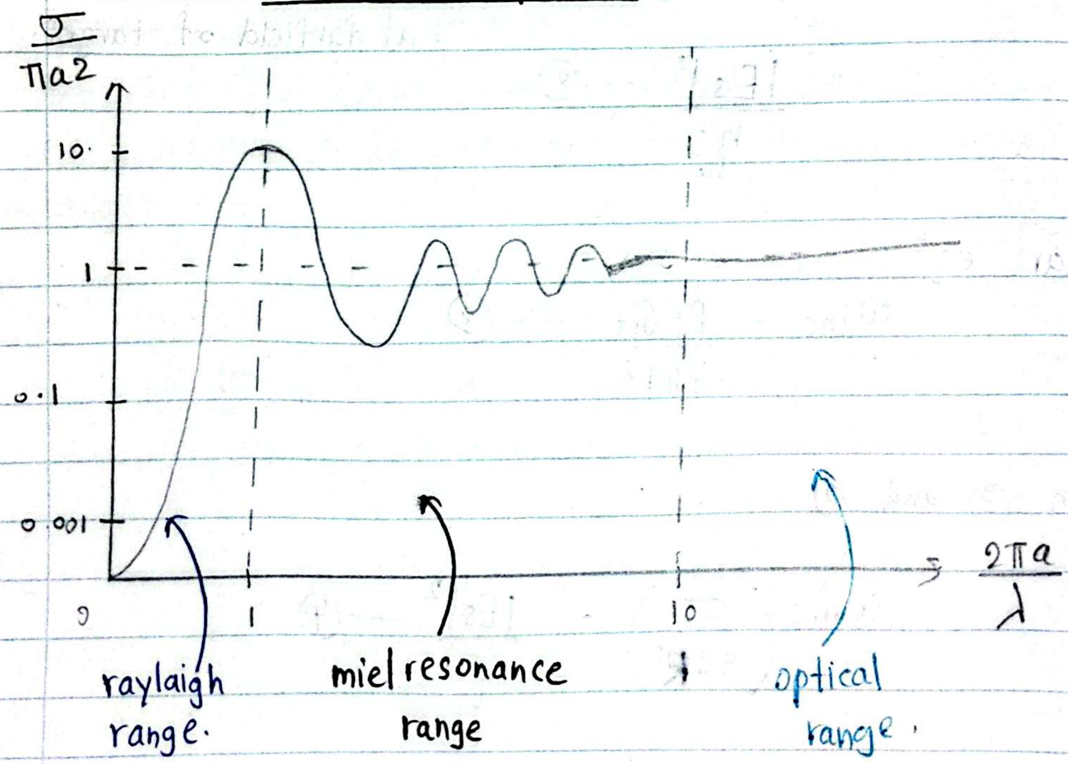
$$\boxed{RCS = \sigma = \lim_{R \to \infty} 4\pi r^2 \frac{|E_s|^2}{|E_{inc}|^2}}$$ unit $= m^2$.

$\sigma = f$ (shape of the body , size of the body , orientation, composition of the body σ ϵ μ

frequency of illumination

electric, magnetic field.

RCS of a sphere.



Stealth Mechanism

Wave impedence Matching = Instrinsic Material Impedence of target.

The instrintic impedence of a material is the ratio of the complex electric field to the Complex Magnetic field of an electromagnetic wave propagating through a material.

$$\eta = \sqrt{\frac{j\omega\mu}{\sigma' + j\omega\epsilon}}$$

$\omega = 2\pi f$

μ = magnetic permitivity

ϵ = dielectric permitivity

σ' = electrical conductivity

Free space,

$\sigma' \approx 0$

$\mu_r = 1$

$\varepsilon_r = 1$

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \cong 376.73\ \Omega$$

$$= 377\ \Omega$$

Change Polarization

$$\begin{bmatrix} \sigma_{hh} & \sigma_{hv} \\ \sigma_{vh} & \sigma_{vv} \end{bmatrix}$$

polarization of transmitting antenna.

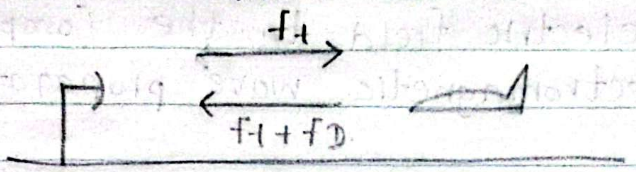
polarization of receiving antenna.

12 09 2026

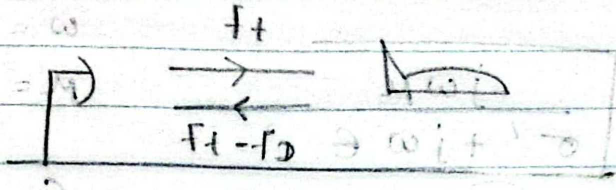
Doppler effect

Basic effect.

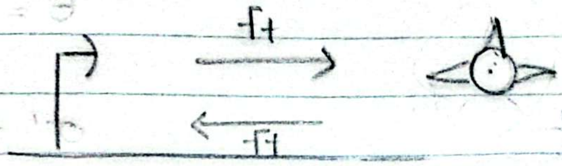
If the source (radar) or observer (target) is in motion the resultant change in transmitted wave frequency is known as Doppler effect.



Velocity toward the radar.

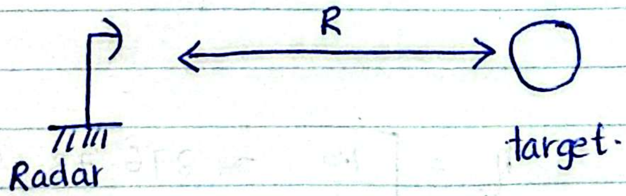


velocity away from the radar.



plane

එක ඉස්සරහට



$$R(t) \Rightarrow \frac{d\,R(t)}{dt} \leftarrow \text{velocity}$$

Range measurement

At real time t.

Doppler angular frequency = ω_d

$$\boxed{\omega_d = 2\pi f_d} \text{ — } ①$$

$$\boxed{(\phi) = \text{space phase} = 2\pi\left(\frac{2R}{\lambda}\right)}$$

ω_d (doppler angular frequency) $= \dfrac{d\theta}{dt} = \dfrac{d\left(\dfrac{2\pi \cdot 2R}{\lambda}\right)}{dt} = \dfrac{4\pi}{\lambda} \cdot \dfrac{dR}{dt}$

$$\boxed{\omega_d = \frac{4\pi V_R}{\lambda}} \text{ — } ②.$$

When V_R is the relative vertical velocity between target with respect to radar.

① ≡ ②.

* Rate of change of a phase spare is the doppler angular frequency.

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

$$\boxed{f_d = \frac{2V_R}{\lambda}}$$

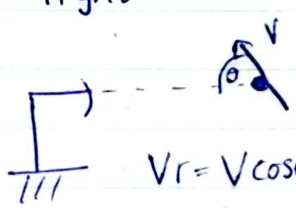
$\lambda_0 = \dfrac{c}{f_0}$

$c = f_0\lambda_0$

$f_d = \dfrac{2V_R f_0}{c}$

transmitted frequency = EMW

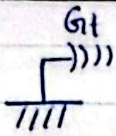
speed of light.



$V_r = V\cos\theta$

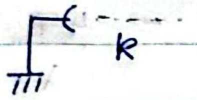
$\theta = 90^\circ \quad V_r = 0$

Radar range equation



$$P_r = \frac{P_t G_t}{4\pi R_1^2}$$

$$P_r = \frac{P_t G_t}{4\pi R_1^2} \cdot \sigma$$



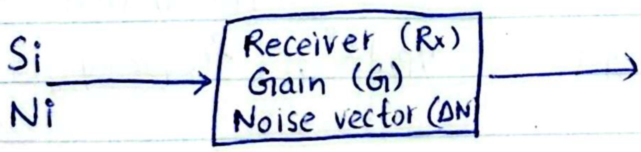
$$P_r = \frac{P_t G_t \sigma}{4\pi R_1^2} \times \frac{1}{4\pi R_1^2}$$

$$P_r = \frac{P_t G_t \sigma}{4\pi R_1^2} \cdot \frac{A_e}{4\pi R_1^2}$$ ← Affective aperture area

$$P_r = \frac{P_t G_t \sigma A_e}{(4\pi)^2 R_1^4} \qquad G = \frac{4\pi A_r}{\lambda^2}$$

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R_1^2 R_2^2}$$

Radar range based on "Noise figure" of receiver.



$S_o = G S_i + \Delta N$ ← $\Delta N \lll$

$N_o = G N_i + \Delta N$

S_i - input signal
S_o - output signal
N_i - input noise
N_o - output noise.

Assumptions

$\Delta N <<<< GSi$

$\therefore$ ΔN is negligible.

ΔN is not negligible ~~for~~ when compared with GNi

$$\text{Noise figure} = \frac{\text{SNR input}}{\text{SNR output}}$$

$$F = \frac{Si/Ni}{So/No}$$

$$= \frac{Si\,No}{So\,Ni}$$

$$= \frac{Si\,(GNi + \Delta N)}{(GSi)\,Ni}$$

$$\boxed{F = 1 + \frac{\Delta N}{GNi}}$$

$\Delta N = (F-1)\,GNi$ ← Noise at input side primly based on temperature.

$$\boxed{\left.\begin{array}{l}\text{Noise of}\\ \text{input } Ni\end{array}\right\} = K\,T_o\,B}$$

Boltsman constant 1.35×10^{-23} J/deg K

Temperature (K°)

Bandwidth of the receiving signal.

So, $\Delta N = (F-1)GNi$

$$\boxed{\Delta N = (F-1)GKT_oB}$$ Noise added by the receiver.

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

minimum detectable signal strength.

for proper operation of the radar,

$$\Delta N < S_{min}$$

minimum detectable signal of the receiver.

Noise added by the receiver

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

$$R_{max} = \frac{P_t \sigma A_e^2}{4\pi \lambda^2 (\Delta N)}$$

$$\boxed{R_{max} = \frac{P_t \sigma A_e^2}{4\pi \lambda^2 (F-1) GKT_oB}}$$

$F \neq 1$

since $F = 1 + \frac{\Delta N}{GNi}$ F never became $F = 1$.

Continous Wave Radar
(Doppler Radar)

* In continous wave radar, range measurements are not possible.
* Only the moving targets can be detected using doppler effect

$$f_d = \frac{2V}{\lambda}$$ ← radial velocity of the target

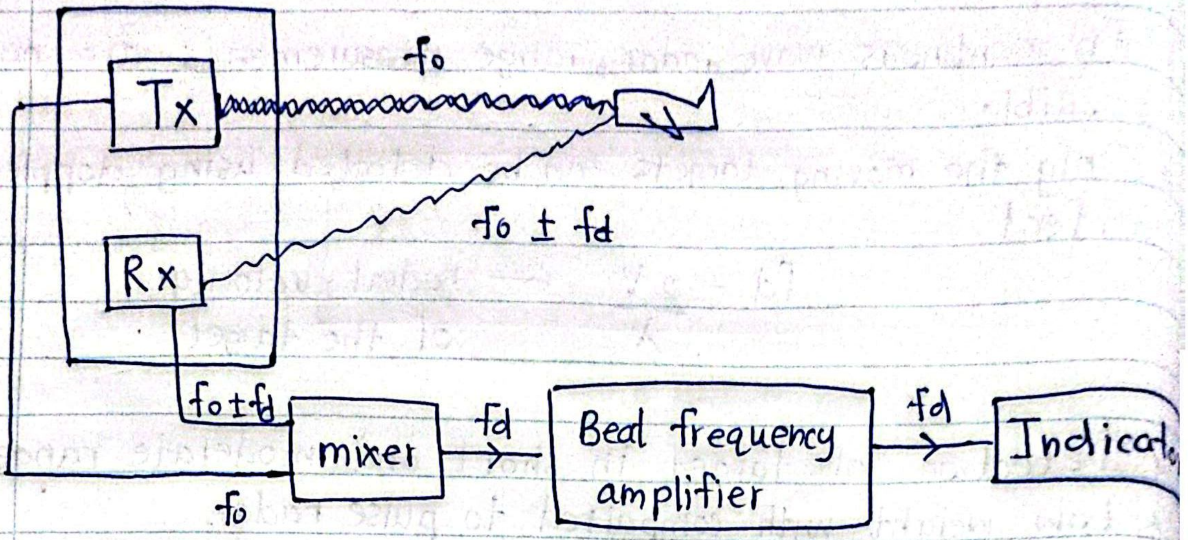
* Detection of target in short and moderate range.
* Low weight with compaired to pulse radar.
* CW radars cannot detect huge range because, Tx and Rx works simultaneously at the antenna space, so installation is high.
* Can operate to very close target (No minimum detactabi range)
* Clutter can be easily removed from radar screen.

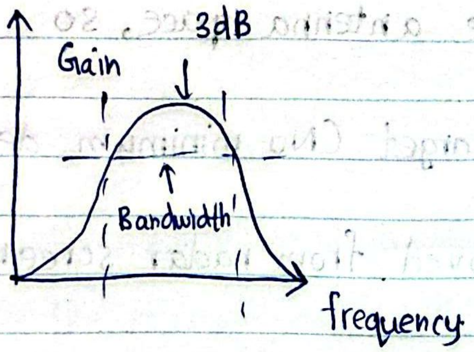
↑ moving targets ගොඩවල land marks etc.

Radar applications.

1) Radar proximity fuse (modern artilary)
2) VTO aircraft
3) Police speed meter.
4) Tornodo dedection
5) Aircraft velocity measurement
6) In laboratory use.

Block diagram of CW radar





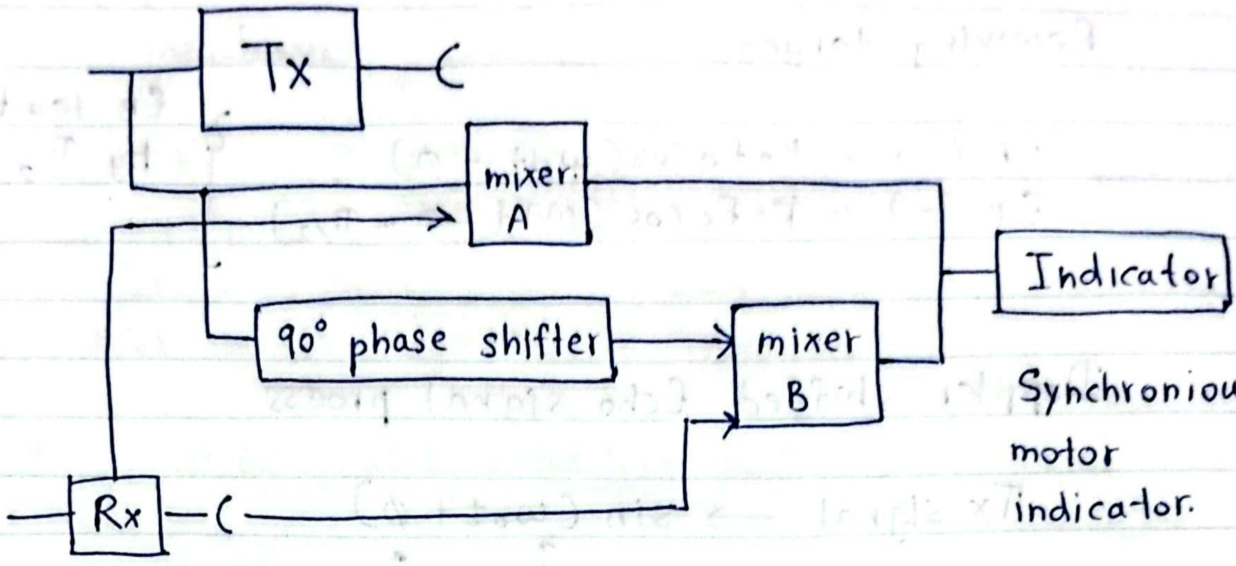
Closing target - target coming to radar side.
$= f_o + f_d$

Residing target = target leaving the radar
$= f_o - f_d$

* Homedyne mixer is used to seperate drift in frequency (f_d)

$$\boxed{f_d = \frac{2V}{\lambda}}$$

* Beat frequency (Doppler frequency) amplifier use to amplify seperated frequency drift radar before sending to indicator.



Synchronious motor indicator.

Tx signal (o) = $E_o \cos \omega t$

Rx signal = $K_1 E_o \cos(\omega_o I \omega_d)t + \phi]$

Echo from the signal.

Mixer A output signal

$$E_A = K_2 E_o \cos(I \omega_d t + \phi)$$

Mixer B output signal

$$E_B = K_2 E_o \cos(I \omega_d t + \phi + \pi/2)$$

additional phase shift

Closing target

$$E_A(t) = K_2 E_o \cos(\omega_d t + \phi)$$
$$E_B(t) = K_2 E_o \cos(\omega_d + \phi + \pi/2)$$

mixer E_B output is lagging E_A by $\pi/2$

Receiving target

$$E_A(-) = K_2 E_0 \cos(\omega_d t - \phi)$$
$$E_B(-) = K_2 E_0 \cos(\omega_d t - \phi - \pi/2)$$

E_B leads by $\pi/2$.

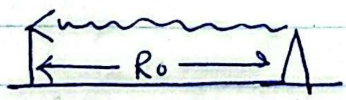
Doppler shifted Echo signal process

Tx signal $\longrightarrow \sin(\omega_0 t + \phi)$

angular frequency — initial phase of the signal.

Assumptions

* Target Stationary w.r.t. radar at range R_0.



* Signal at the target $= \sin[\omega_0(t - R_0/c) + \phi]$ — ①

Sout $\rightarrow R_0 = Vt'$

$t' = \frac{R_0}{c}$

times need to travel to the target.

* Echo signal at radar $= \sin(\omega_0(t - 2R_0/c) + \phi)$

- Target radar velocity $= V_r$
  Target accelaration $= 0$

When the target is moving

$$R(t) = R_0 \pm V_0(t - t_0) \quad \text{—— (2)}.$$

$-V_r$ = sign implies closing target
$+V_r$ = sign implies receiving target

$R(t) \Rightarrow$ at the initial condition $= R_0$.

Signal of moving target $\Big\} = \sin\left[\omega_0\left(t - 2R_t/c\right) + \phi\right]$

$$= \sin\left[\omega_0\left(t - \frac{2(R_0 \pm V_r(t-t_0))}{c}\right) + \phi\right]$$

$$= \sin\left[\omega_0\left(t - \frac{2R_0}{c} \pm \frac{2V_r t}{c} \pm \frac{2V_r t_0}{c}\right) + \phi\right]$$

$$= \sin\left[\omega_0\left(1 \pm \frac{2V_r}{c}\right)t - \frac{2\omega_0}{c}(R_0 \pm V_0 t_0) + \phi\right]$$

$$\omega_d = 2\omega_0 \frac{V_r}{c}$$

$$\therefore = \sin\left[\omega_0\left(1 \pm \frac{\omega_d}{\omega_0}\right)t - \frac{2\omega_0(R_0)}{c} \pm \frac{2\omega_0 V_0 t_0}{c} + \phi\right]$$

Further explanation

$$= \sin\left[\left(\omega_0 \pm \frac{2\omega_0 V_r}{c}\right)t - \frac{2\omega_0 R_c}{c} \pm \frac{2\omega_0 V_r t_0}{c} + \phi\right]$$

$$= \sin\left[(\omega_0 \pm \omega_d)t - \frac{2\omega_0 R_0}{c} - \omega_d t_0 + \phi\right]$$

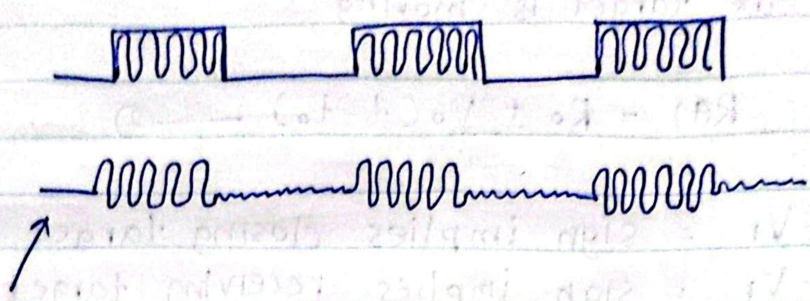
frequency has changed by ω_d phase has changed by ω_d

If we can detect phase detection $\longrightarrow$ can find velocity
" " " frequency " $\longrightarrow$ can find velocity.

Frequency Modulating CW Radar.

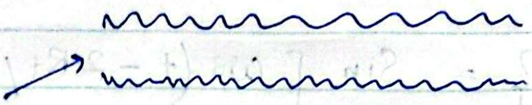
Pulse

FMCW



technically frequency modulation.

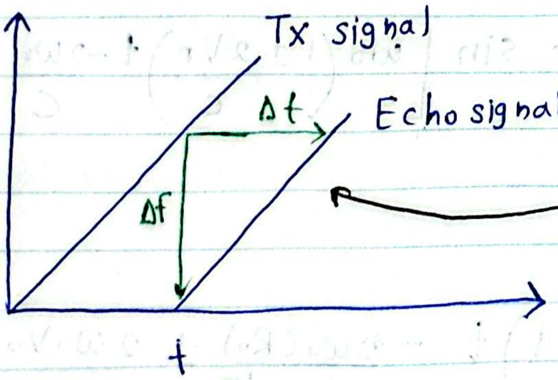
①



technique

② → using two signals with different frequency

Transmitted Signal.



difference in frequency just because after modulation

The time indicated that echo comes.

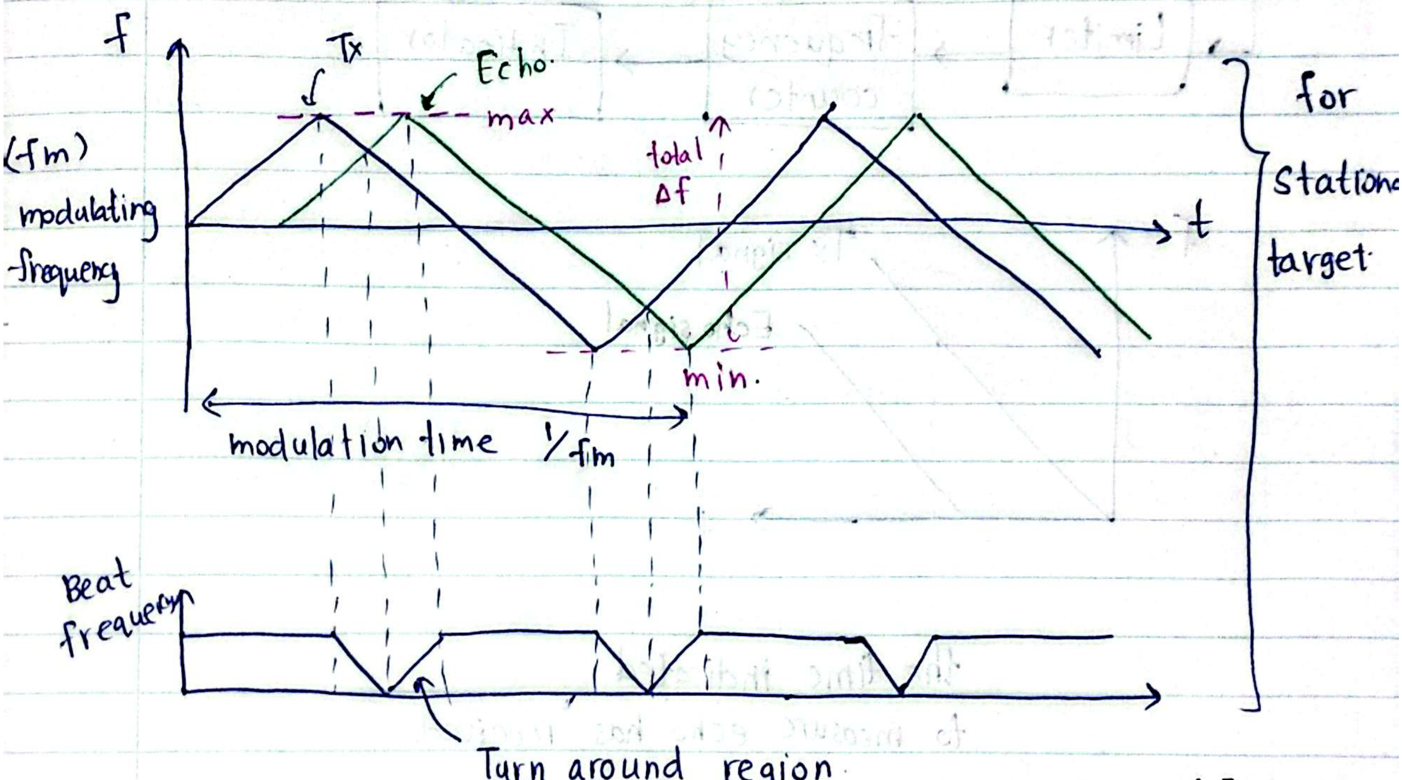
beat frequency $\rightarrow f_b$

Beat frequency is due to change of range of the target $\Big\}\ f_r$

Beat frequency is due to change of f velocity $= f_d$

When the target stationary

$f_o = f_r \ (f_d = 0)$.



$\Delta f / \left(\frac{1}{f_m}\right)$

$\Delta f = f . \Delta t$

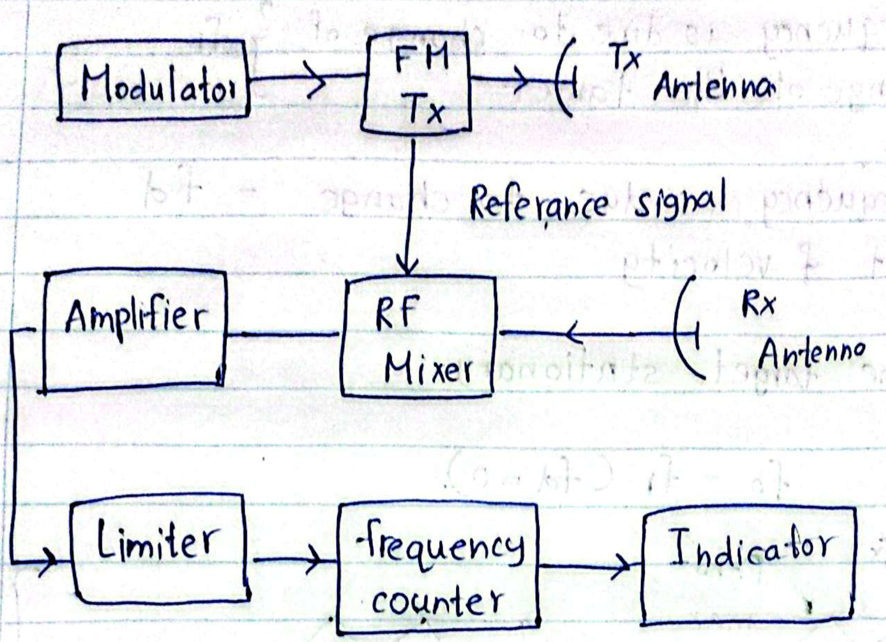
$f_r = \Delta f$

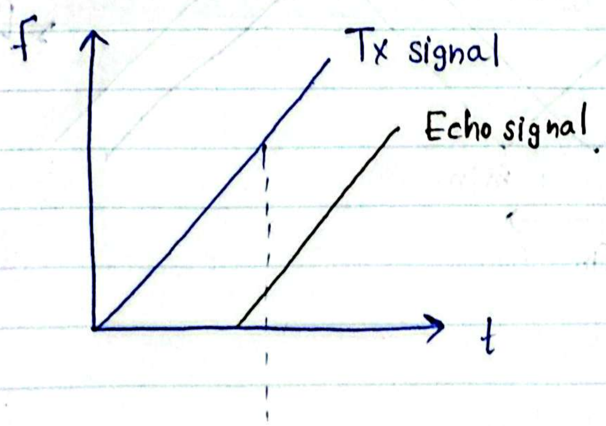
$f_r = f \Delta t$.

$$\boxed{f_r = f\left(\frac{2R}{c}\right)}$$

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

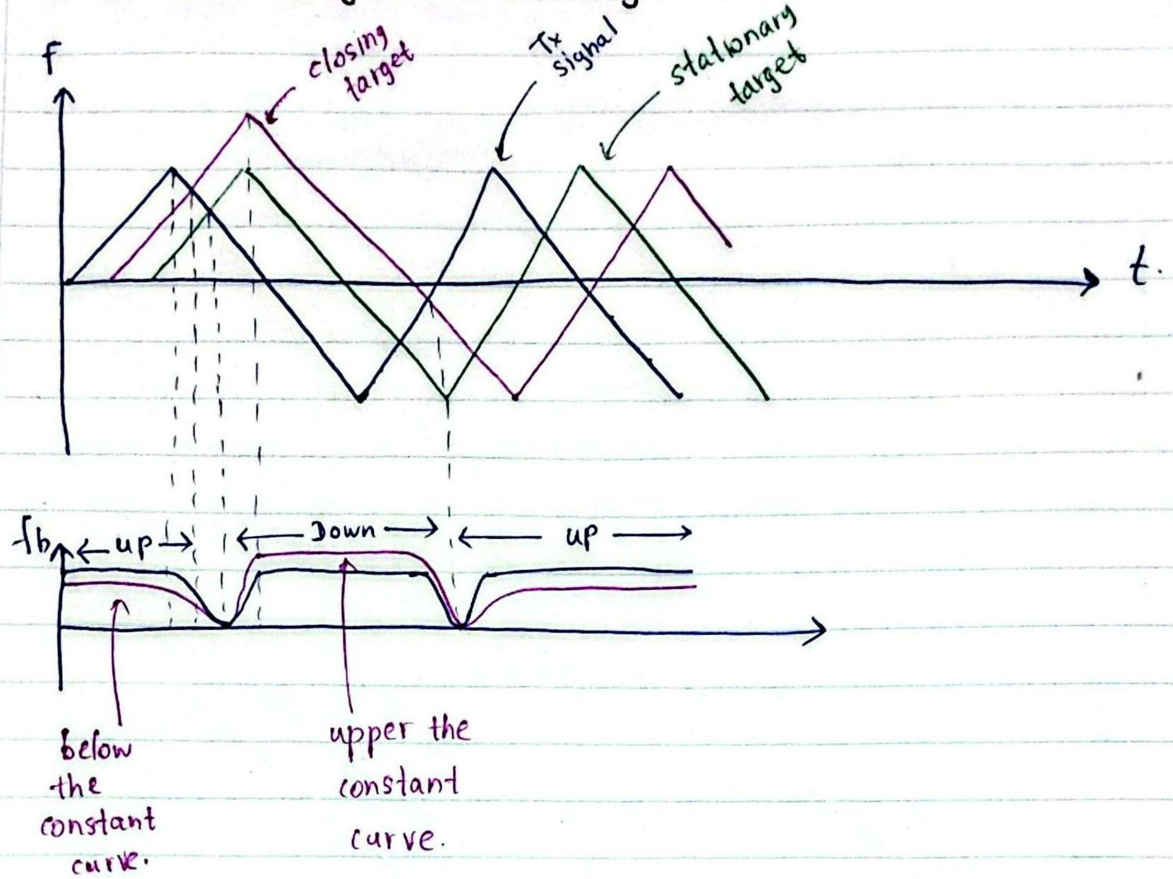
Frequency Modulated CW Radar





the time indicated
to measure echo has received.

When the target is moving.



closing target

$$f_r > f_d$$

$$f_{b(up)} = f_r - f_d \quad \text{—} \ ①$$

$$f_{b(down)} = f_r + f_d \quad \text{—} \ ②$$

① + ② $\quad f_r = \frac{1}{2}\left[f_{b(up)} + f_{b(down)}\right]$ average circuit.

① − ② $\quad f_d = \frac{1}{2}\left[f_{b(down)} - f_{b(up)}\right]$ difference circuit