(Jntuh)

RADAR SYSTEMS
(EC 812 PE)
(ELECTIVE V)
UNIT – 2A
B.TECH IV YEAR II SEMESTER
BY

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BIET

Acknowledgements

The contents , figures , graphs etc., are taken from the following Text book & others

" INTRODUCTION TO RADAR SYSTEMS "

Merill I.Skolnik

Second Edition

Tata Mcgraw – Hill publishing company

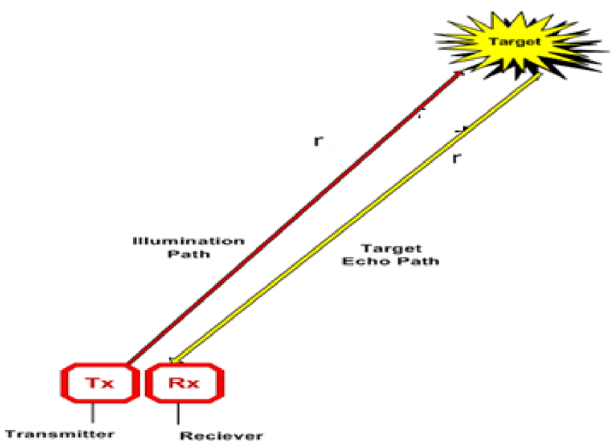
Special indian edition

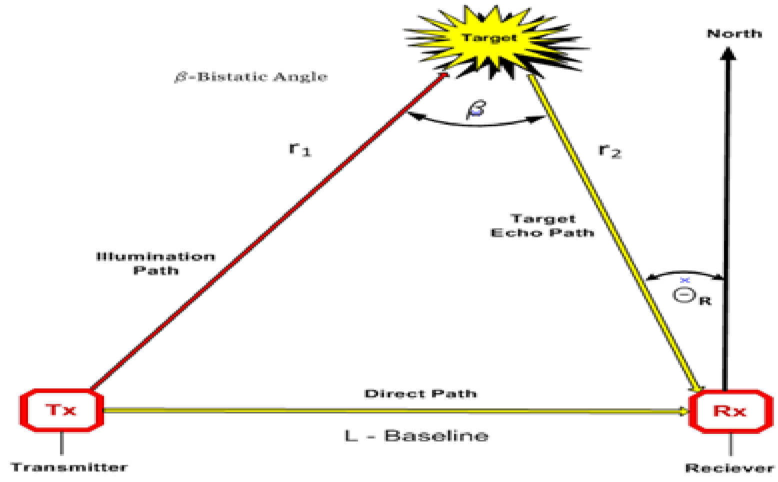
SYLLABUS
(A80450)
ELECTIVE-VI
B.TECH IV YEAR II SEMESTER
UNIT 2

- CW and Frequency Modulated Radar: Doppler Effect, CW Radar-Block Diagram, Isolation between Transmitter and Receiver, Non-zero IF Receiver, Receiver Bandwidth Requirements, Applications of CW radar, Illustrative Problems
- EM-CW Radar, Range and Doppler Measurement, Block Diagram and Characteristics, (Approaching / Receding Targets), FM-CW altimeter, Multiple Frequency CW Radar.

CATEGORIES OF RADAR

1. (a) Monostatic (b) Bistatic





2. Pulsed Radar

- Detects target
- Measures range
- **But cannot measure velocity of target**
- Mono-static

CW Radar (Contd….)

3. CW Radar

- Detects objects
- Measures velocity from Doppler shift
- But cannot measure range
- Mostly Bi-static

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

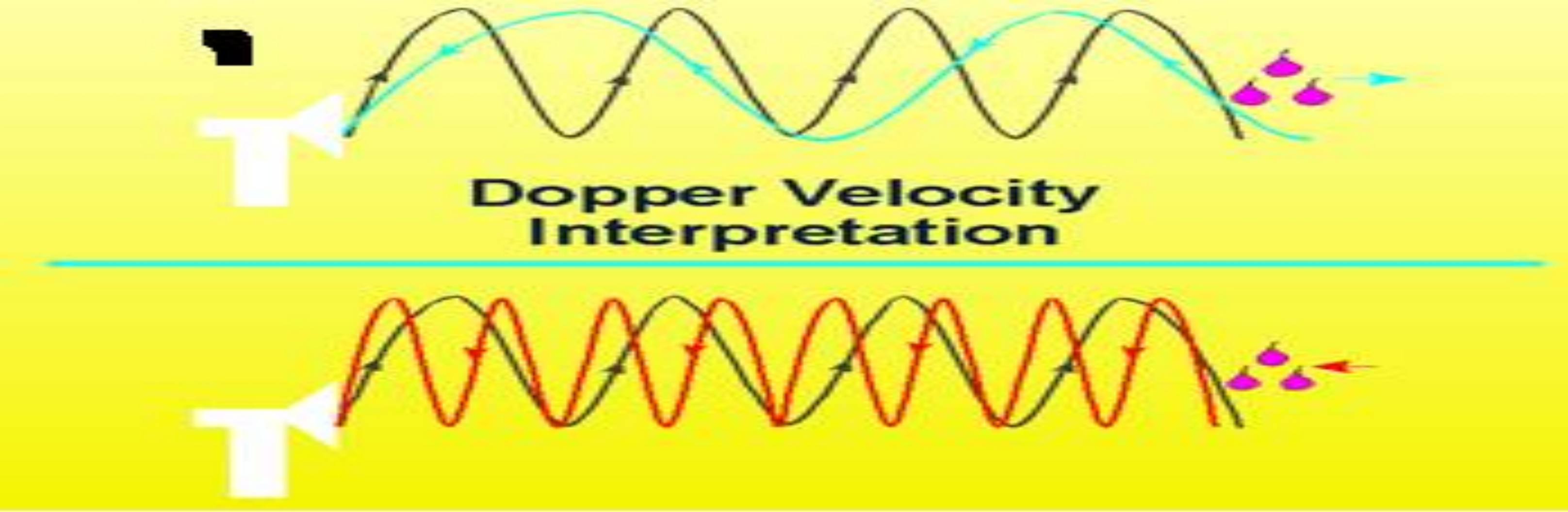
(Jntuh) 2. Define Doppler frequency. Explain the significance of Doppler frequency while detecting the target

DOPPLER EFFECT

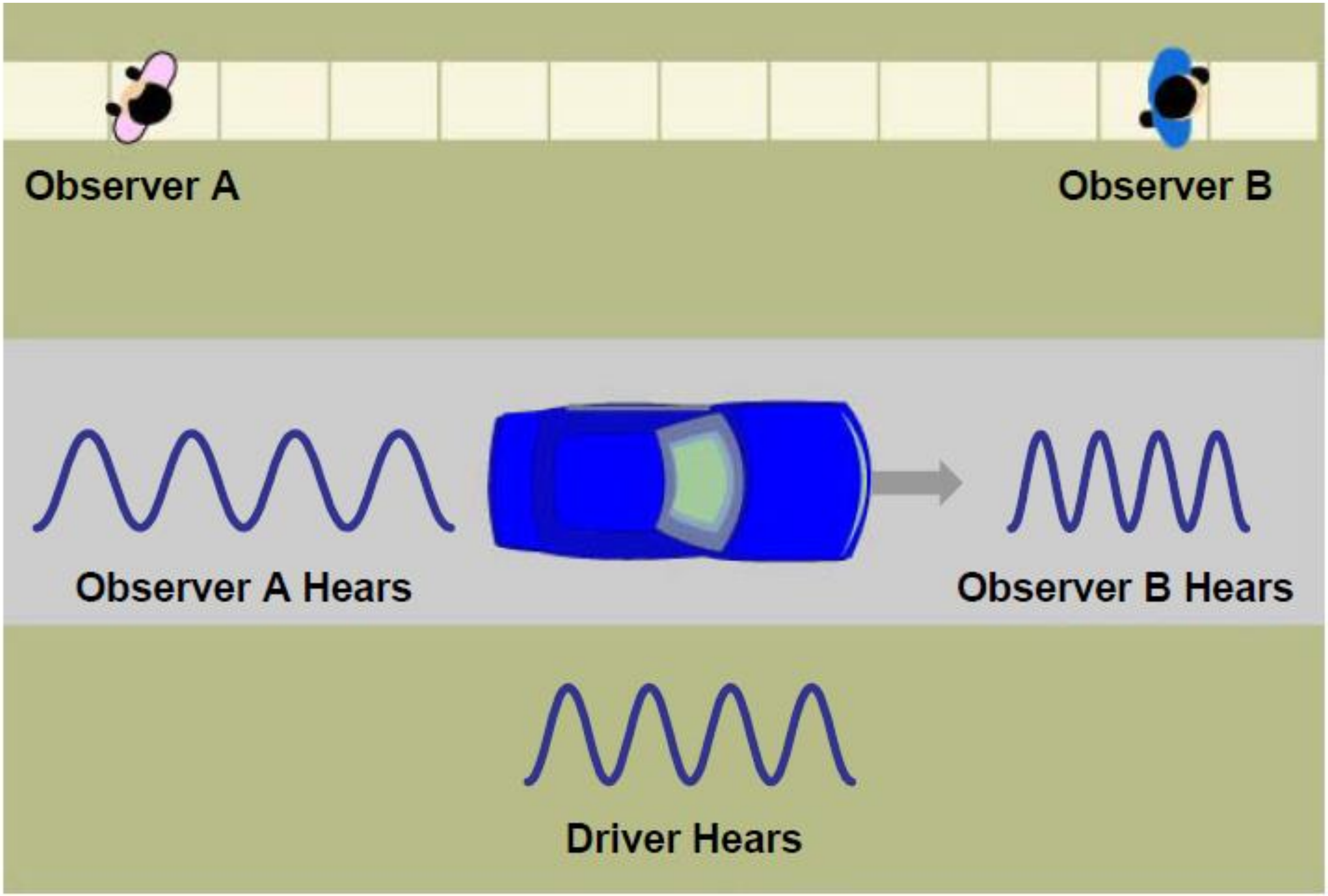
DOPPLER EFFECT

➢ Doppler Effect:

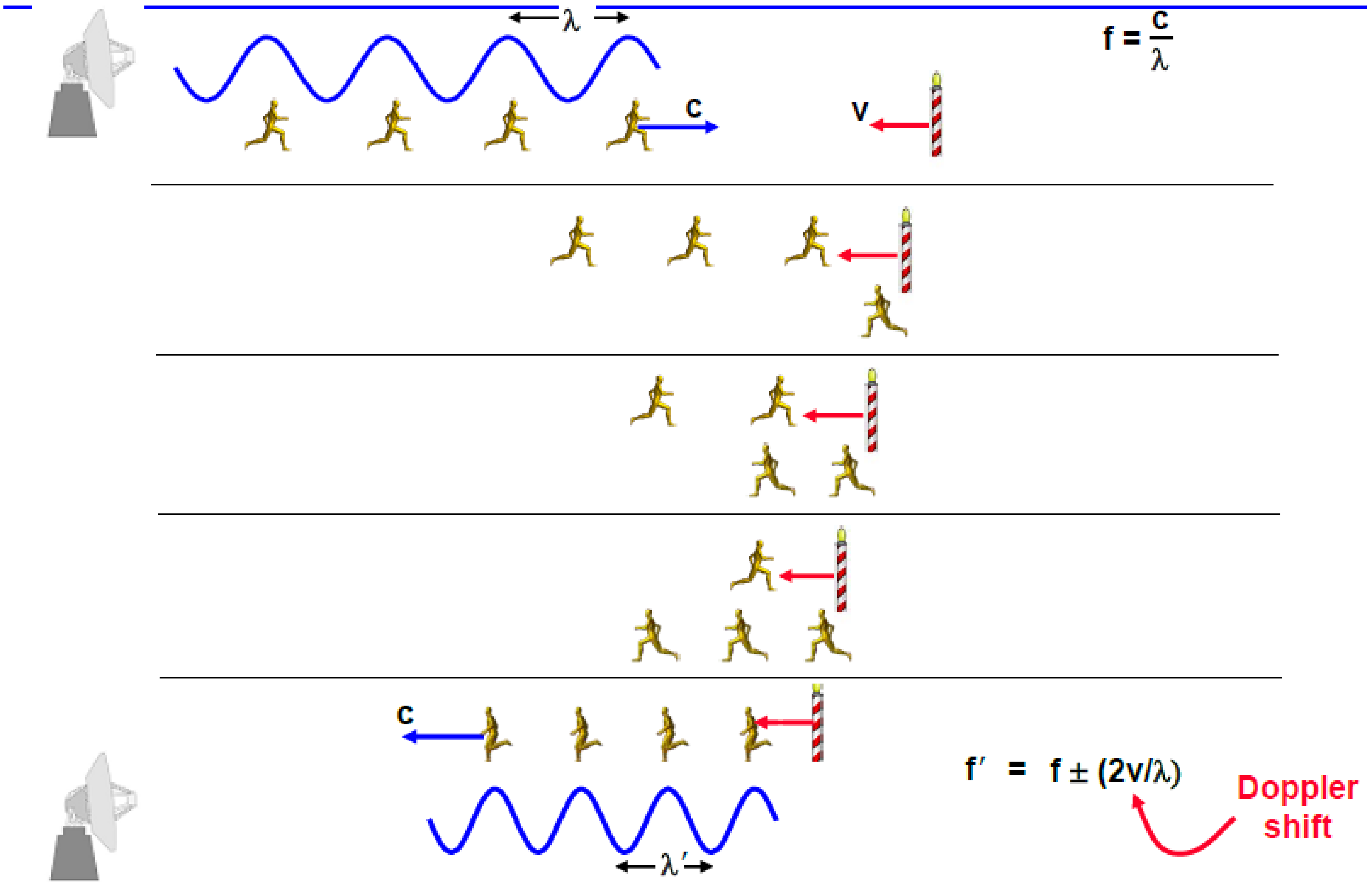
- If the source of oscillation or the observer of the oscillation is in motion, the frequency observed is not the same as the frequency of oscillation, but there is an apparent shift in the frequency.



Doppler Effect



Doppler Shift Concept



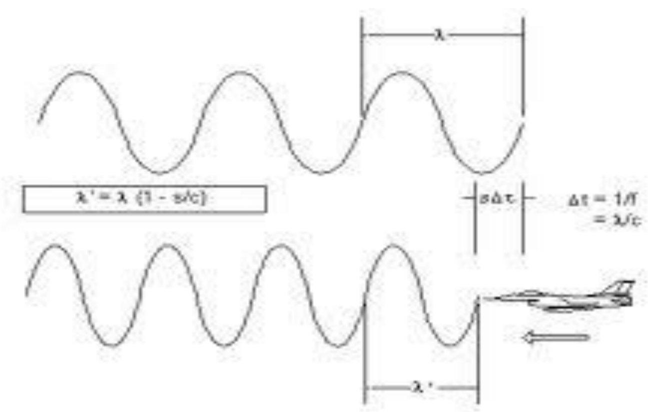
DOPPLER EFFECT (CONTD…)

➢ Doppler Frequency Shift:

- Shift in frequency f_d due to target motion is called Doppler shift frequency.
- Let R = Distance between Radar and target.

  λ = Wavelength of transmitted frequency

  f_d = Doppler frequency



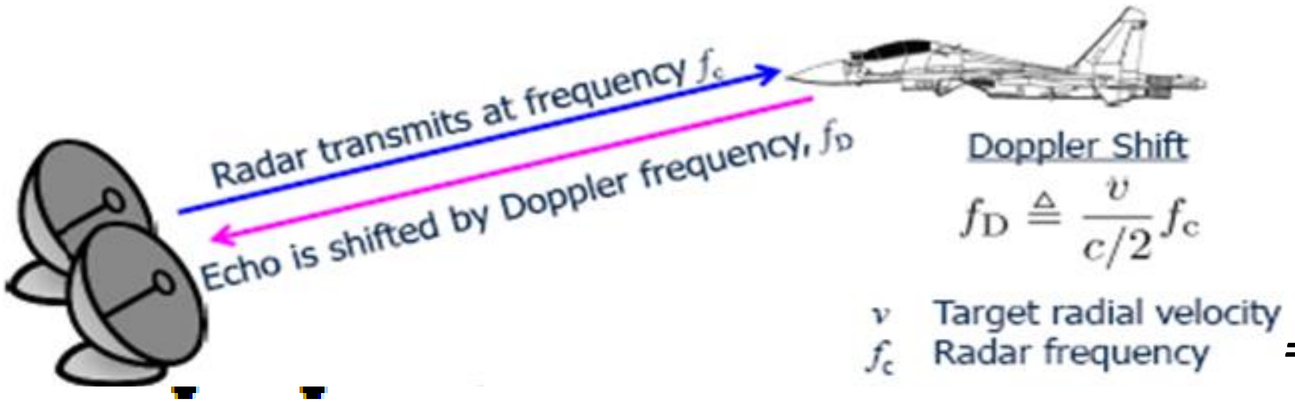
Doppler shift from moving transmitter

$$\lambda = \frac{C}{f}$$

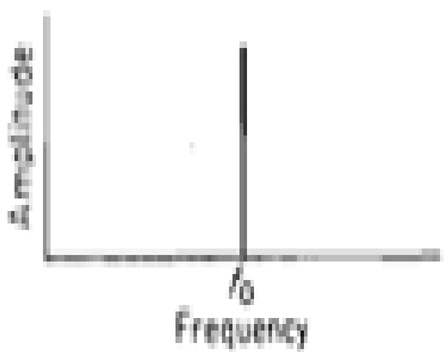
where C = 3 x10^8 mt /sec

f = frequency of transmission

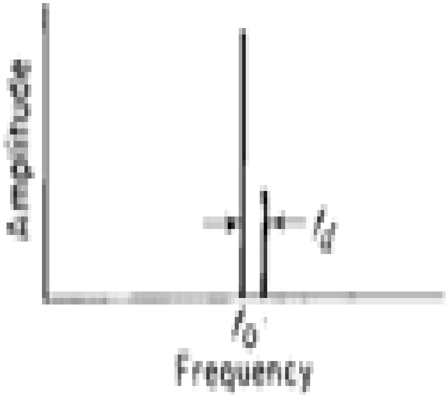
Measuring Doppler with a CW Radar



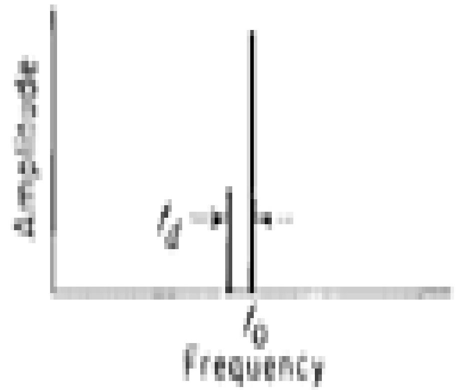
$= f_o$



Stationary Target



Approaching Target



Receeding Target

(Jntuh) 1. Derive the expression for relative velocity of the target in CW Radar

DOPPLER EFFECT (CONTD…)

➢ Doppler Frequency Shift Equation:

- Number of wavelengths in the distance 2R (transmit

  $= \frac{2R}{\lambda}$ wavelengths

- One wavelength corresponds to angular excursion of 2π radians.

- Angular excursion made by EM wave in $\frac{2R}{\lambda}$ wave lengths is $\phi = 2\pi \times \frac{2R}{\lambda} = \frac{4\pi R}{\lambda}$ radians.

- If target is in motion R continuously changes therefore ϕ also continually changes with time.

- Change in ϕ with time represents angular frequency

  ω_d in radians / sec $\omega_d = \frac{d\phi}{dt}$

Doppler Effect (Contd…)

- **Doppler Frequency Shift (Contd…)**
- $\omega_d = 2\pi f_d$ (ω_d in radians / sec and f_d is doppler frequency in HZ (c/s)
- $\emptyset = \frac{4\pi R}{\lambda}$ radians
- $\frac{d\emptyset}{dt} = \omega_d = \frac{d}{dt}\left[\frac{4\pi R}{\lambda}\right] = \frac{4\pi}{\lambda}\frac{dR}{dt}$
- $\frac{dR}{dt}$ = Rate of change of Range = V_r (relative velocity of target)
- $\omega_d = 2\pi f_d = \frac{4\pi}{\lambda} V_r$
- So $f_d = \frac{2 V_r}{\lambda} = \frac{2 V_r f_o}{C}$ and $V_r = \frac{f_d C}{2V_r}$

Doppler Effect (Contd…)

- Relation between v_r and v

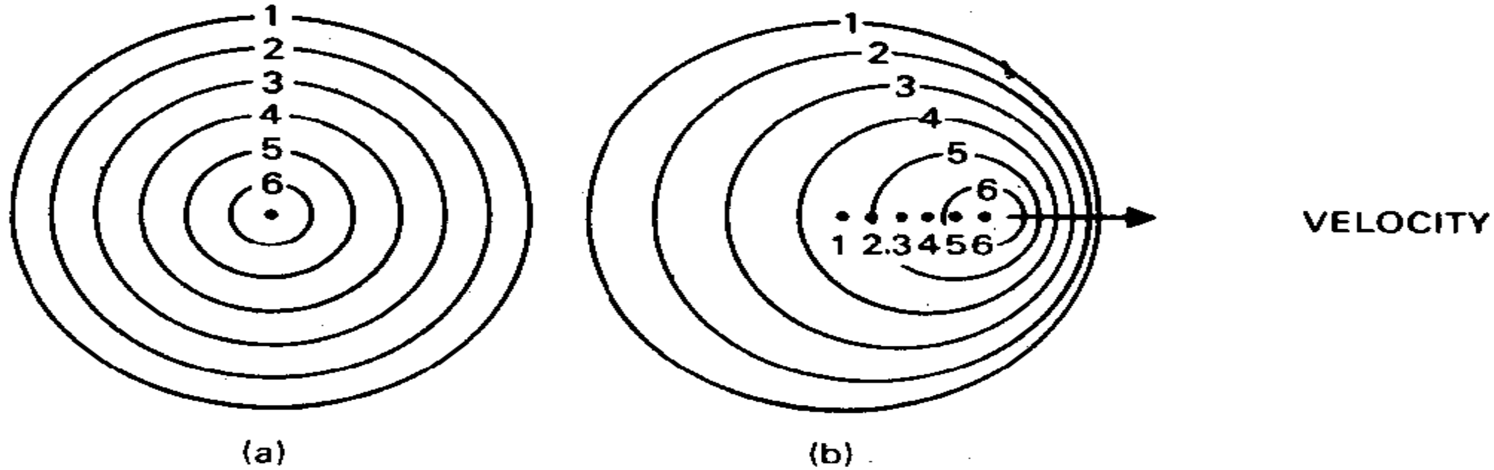
$$\text{Cos}\ \theta_{az} = \frac{\text{Adjacent side}}{\text{Hypoteneus}}$$

$$\text{Cos}\ \theta_{az} = \frac{V_r}{V}$$

- V_r = relative (radial) velocity of target with respect to radar. It is the component of target velocity directly towards or away from radar.
- V = velocity of target with respect to ground
- θ_{az} = Angle between target trajectory and line joining target and Radar (LOS)
- $f_d = \dfrac{2\ V_r}{\lambda} = \dfrac{2\ V\ \text{Cos}\ \theta_{az}}{\lambda}$

DOPPLER EFFECT (CONTD…)

- Approaching and Receding Targets:
  - (i) Approaching targets $f_o + f_d$ (f_d is positive)
  - (ii) Receding target $f_o - f_d$ (f_d is negative)

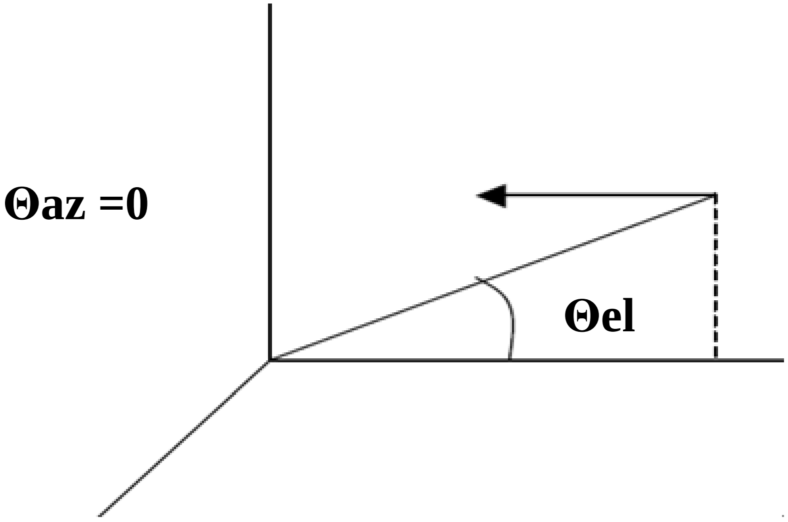


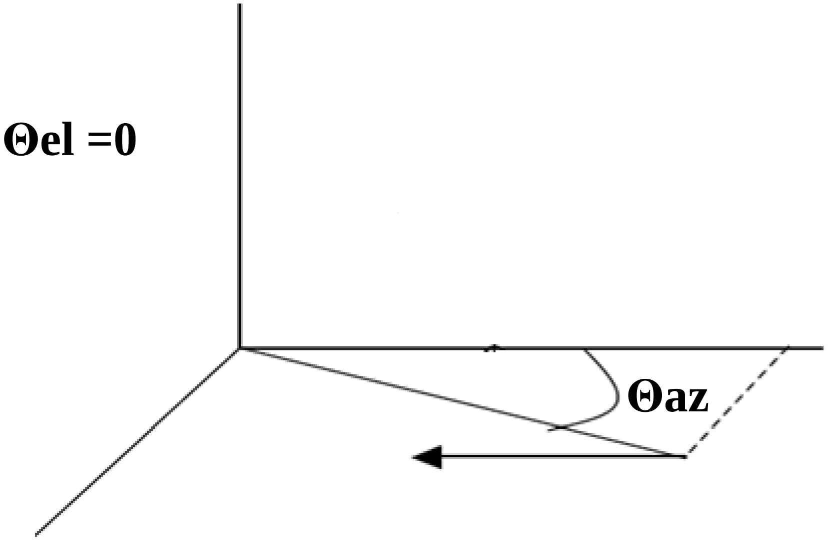
1. A wave radiated from a point source when stationary (a) and when moving (b). Wave is compressed in direction of motion, spread out in opposite direction, and unaffected in direction normal to motion.

DOPPLER EQUATION WITH AZIMUTH & ELEVATION ANGLES

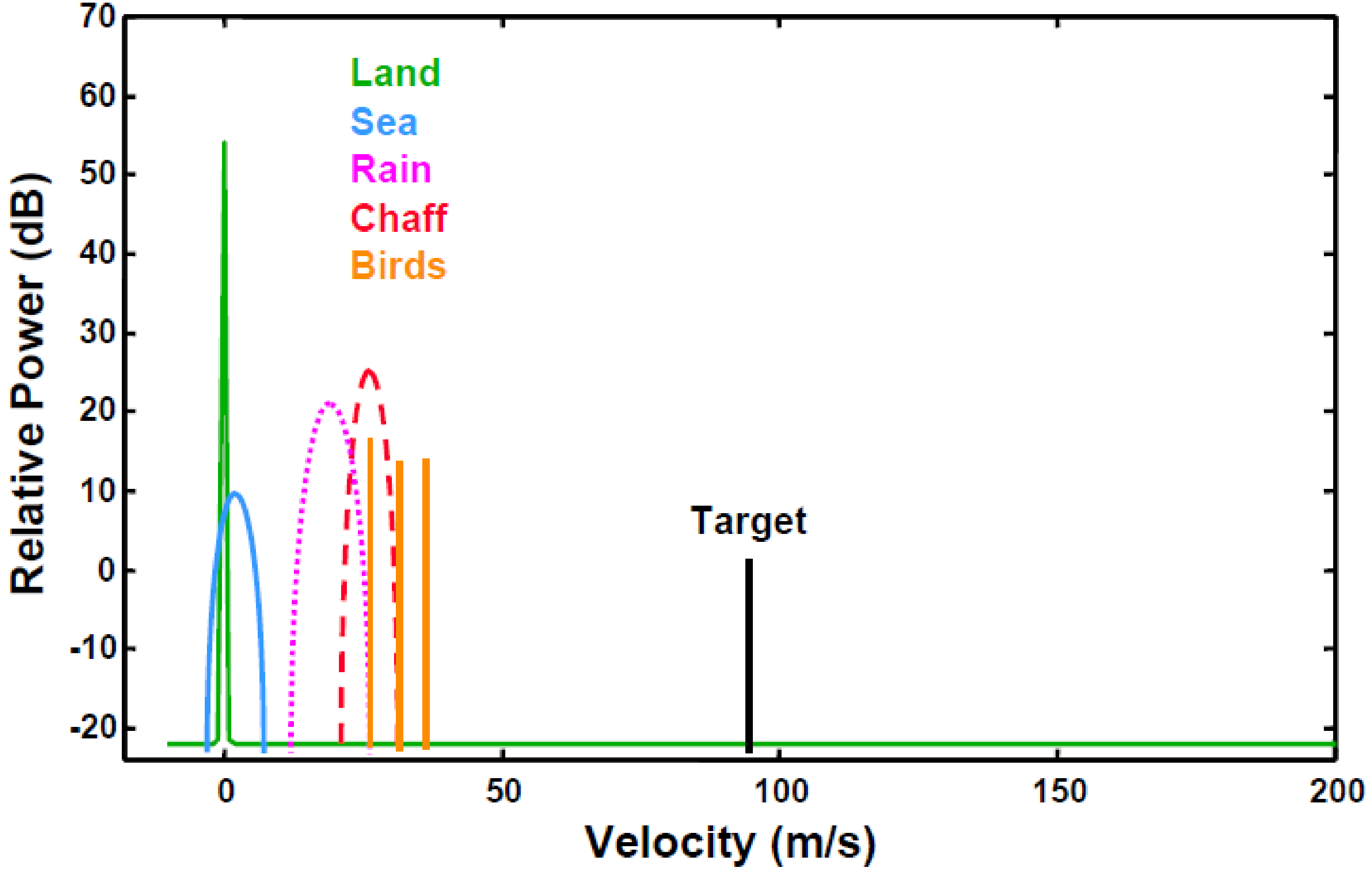
- If the target is moving at an angle θ_{el} in elevation and an angle θ_{az} in azimuth relative to the line of sight (LOS) then the expression for the Doppler shift in frequency becomes
- $f_d = \frac{2V}{\lambda} \cos\theta_{el} \cos\theta_{az}$

DOPPLER EQUATION WITH AZIMUTH & ELEVATION ANGLES(CONT)



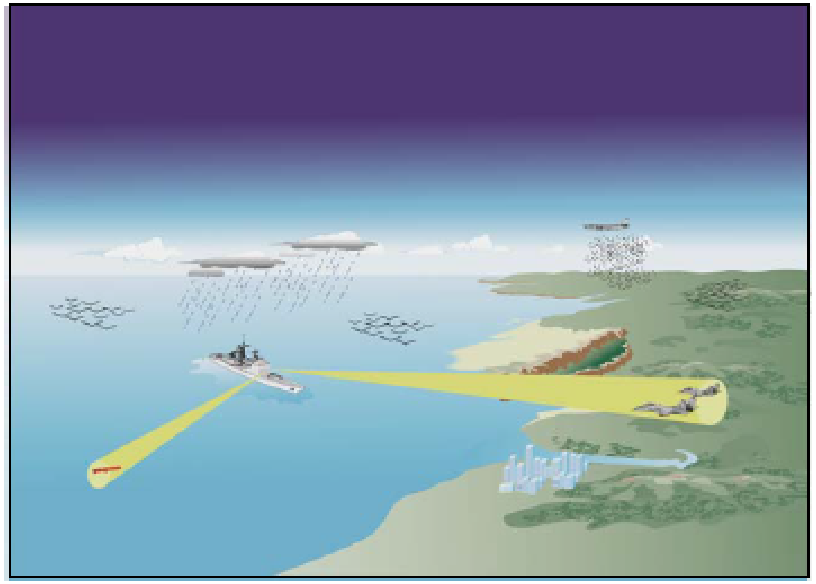


Clutter Doppler Spectra



Why Doppler is Important

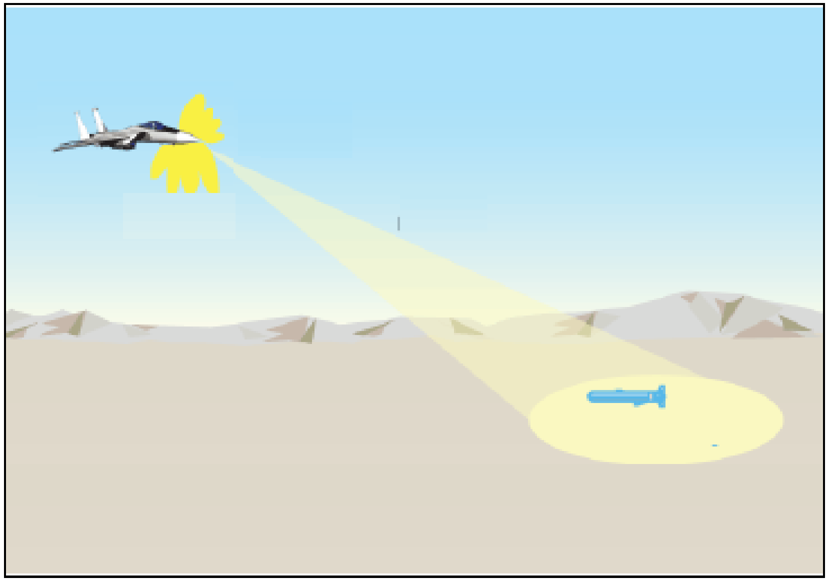
Surface Radar



Clutter returns are much larger than target returns…

…however, targets move, clutter doesn't.

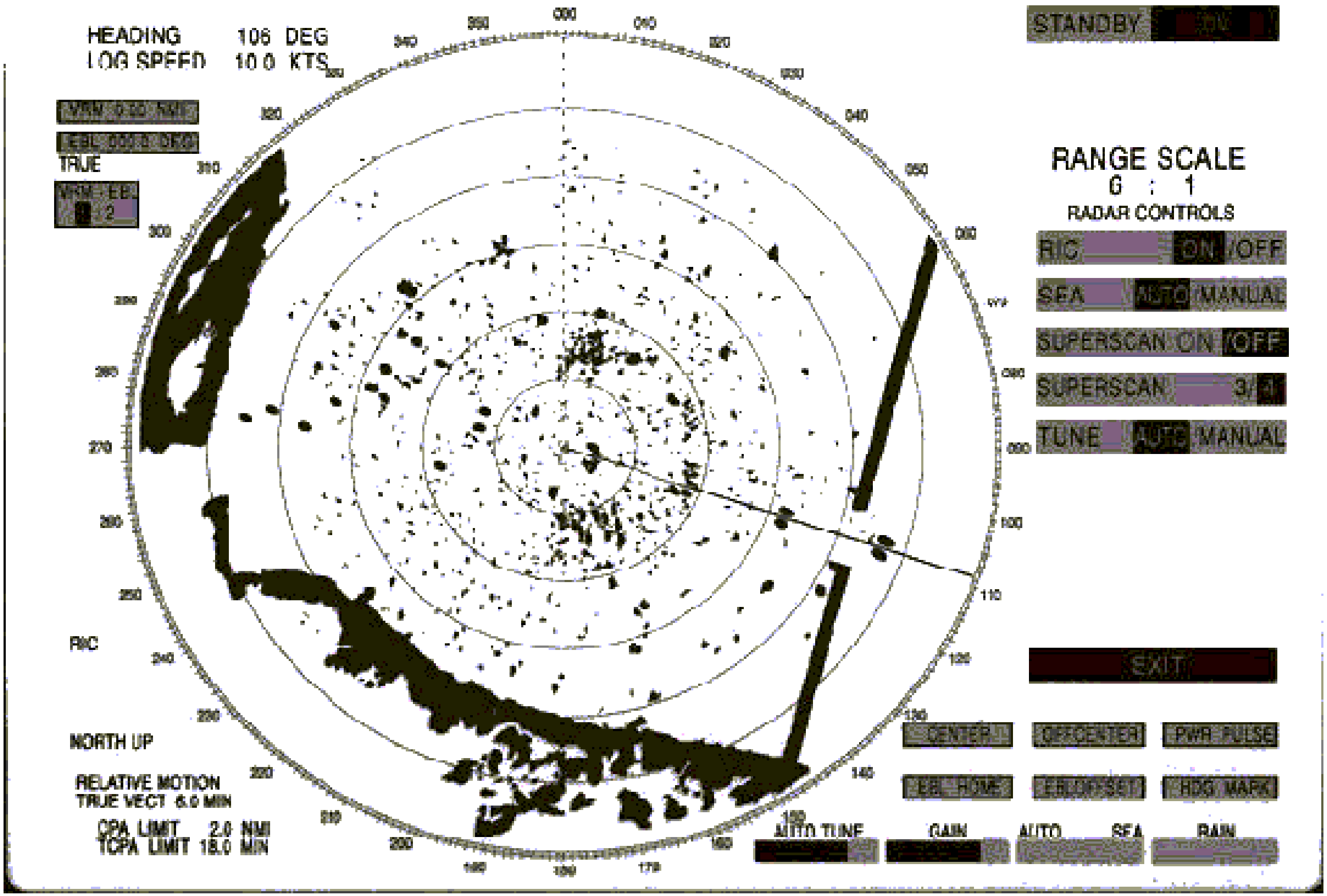
Airborne Radar



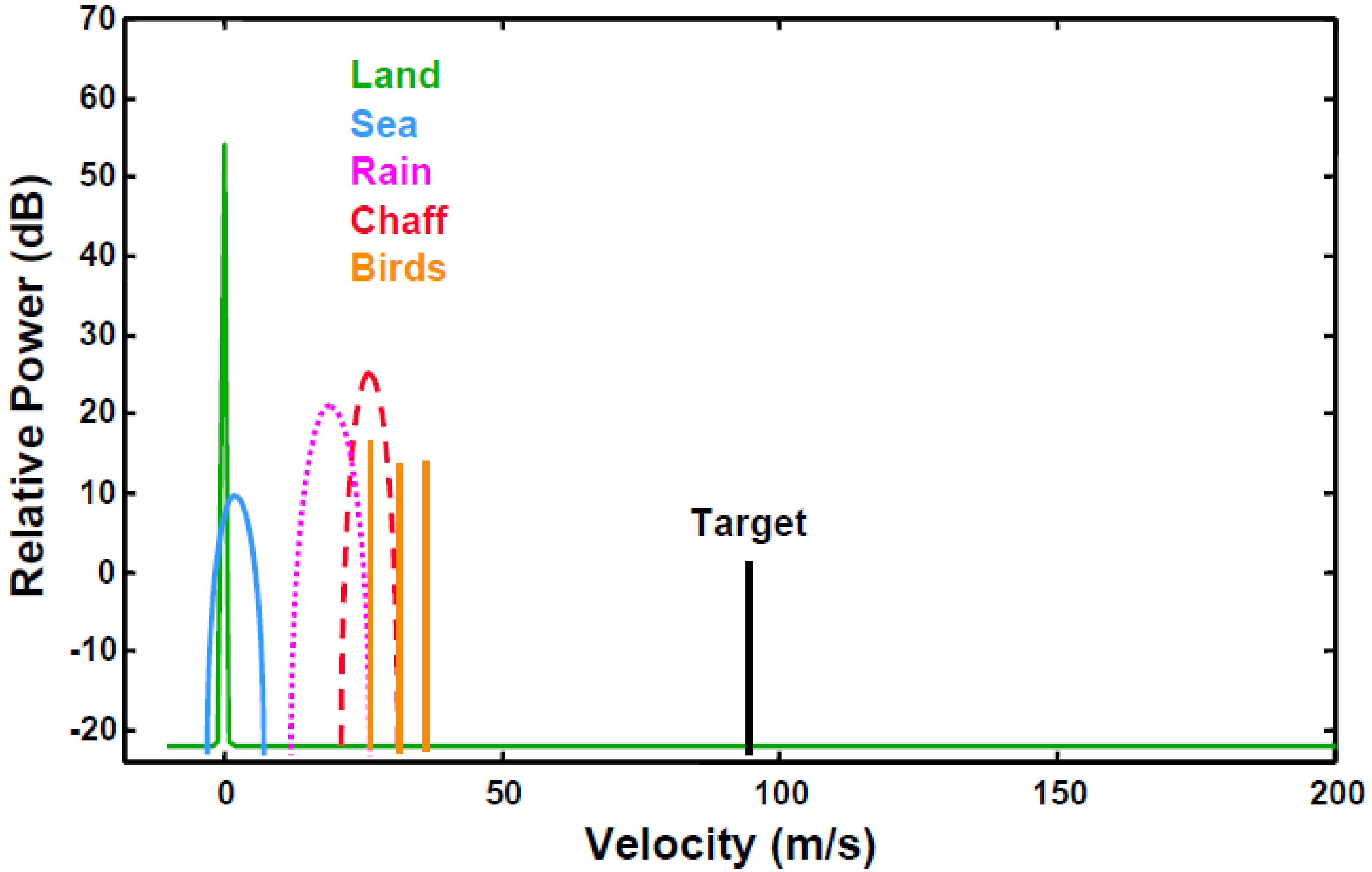
Note: if you're moving too, you need to take that into account.

Doppler lets you separate things that are moving from things that aren't

RADAR DISPLAY



Clutter Doppler Spectra



PROBLEMS.

(Jntuh) PROBLEM NO.1

- Calculate Doppler frequency shift (fd) when the relative velocity of target with respect to radar is 50 knots at a transmitted frequency of 80 MHZ.
- Given Data :
- (i) Transmitted frequency = 80 MHZ = 80 x 10 ^{6}
- (ii) Speed = 50 knots = 50 x 1.852 = 92.6 km/hour
- 1 knot = 1 nautical mile / hour = 1.852 km/hour
- Speed = $\frac{92.6 \times 10^3}{60 \times 60} = 25.72 \text{ mt/sec}$

PROBLEMS (CONT)

- Formula used:
- $f_d = \frac{2 \ V_r}{\lambda} = \frac{2 \ V_r}{C} \times f \ (\text{where } \boldsymbol{\lambda} = \frac{C}{f})$
- $f_d = \frac{2 \times 25.72}{3 \times 10^6} \times 80 \times 10^6 = 13.7 \text{ HZ}$

PROBLEMS (CONT)

Or

$$fd = \frac{1.03\ V_r}{\lambda}$$

Where V_r = knots λ = meters

- $fd = \frac{1.03 \times 50}{C} \times f = \frac{1.03 \times 50}{3 \times 10^8} \times 80 \times 10^6 =$

 = 13.7 Hz

PROBLEMS (CONT)

- (Jntuh) PROBLEM NO.2 :
- An MTI Radar System operating at 10 GHZ and a repetition rate of 1000 HZ receives echoes from an aircraft that is approaching the radar with a radial velocity component of 1 km / sec. Determine the shift in frequency as measured by the radar
- Given Data :
- (i) Frequency of operation = 10 x 10^9 HZ
- $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{10 \times 10^9}$ = 0.03 meter

PROBLEMS (CONTD..)

- (ii) Vr = 1 km / sec = 1000Mt / sec.
- Formula used:
- $f_d = \frac{2\ V_r}{\lambda} = \frac{2\ \times 1000}{0.03} = 66666\text{HZ} = 66.666\ \text{KHz}$

PROBLEMS (CONTD..)

- (Jntuh) PROBLEM NO.3 :
- With a transmit (CW) frequency of 5 GHz calculate the doppler frequency seen by a stationary Radar when the target radial velocity is 100 km/h (62.5 mph)
- f= $5 \times 10^9 \ Hz$
- $\boldsymbol{\lambda} = \frac{C}{f} = \frac{3 \times 10^8}{5 \times 10^9}$ =0.06 mt
- $V_r = \frac{100 \times 10^3}{60 \times 60}$ = 27.78 mt/sec
- $f_d = \frac{2 \ V_r}{\boldsymbol{\lambda}} = \frac{2 \times 27.78}{0.06} = 926 \text{ Hz}$

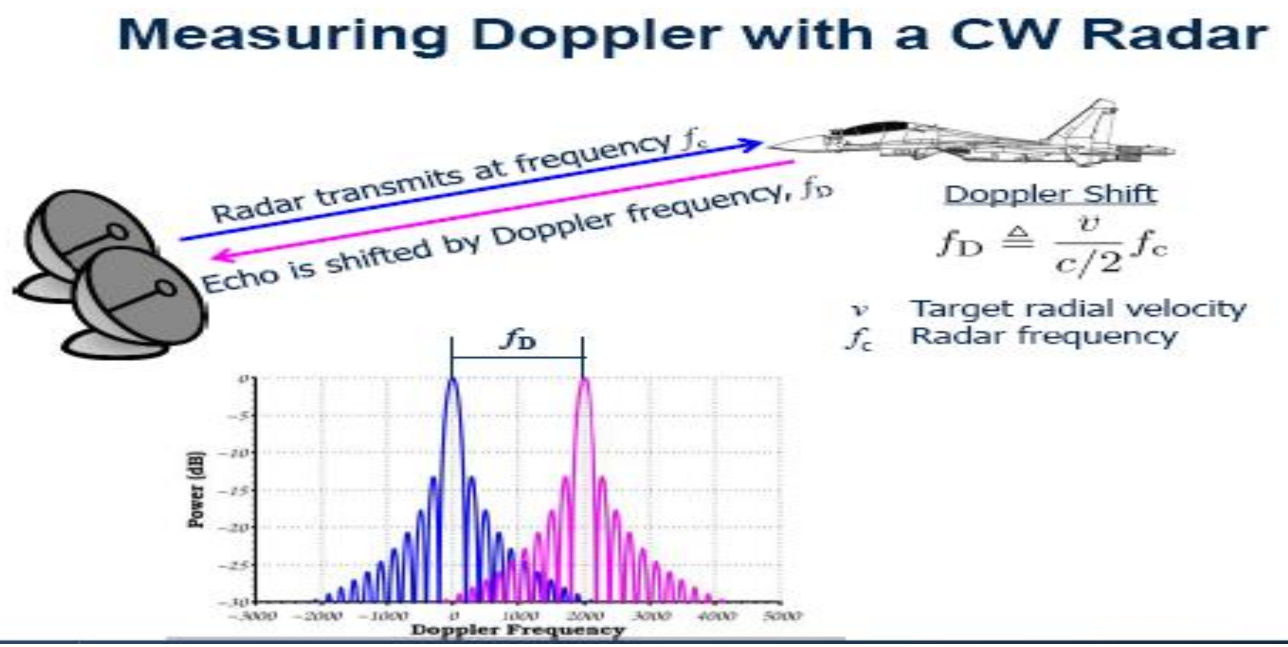
Q. (Jntuh) 1. Draw the block diagram of a simple CW Radar and explain its working

CW (CONTINUOUS WAVE) RADAR

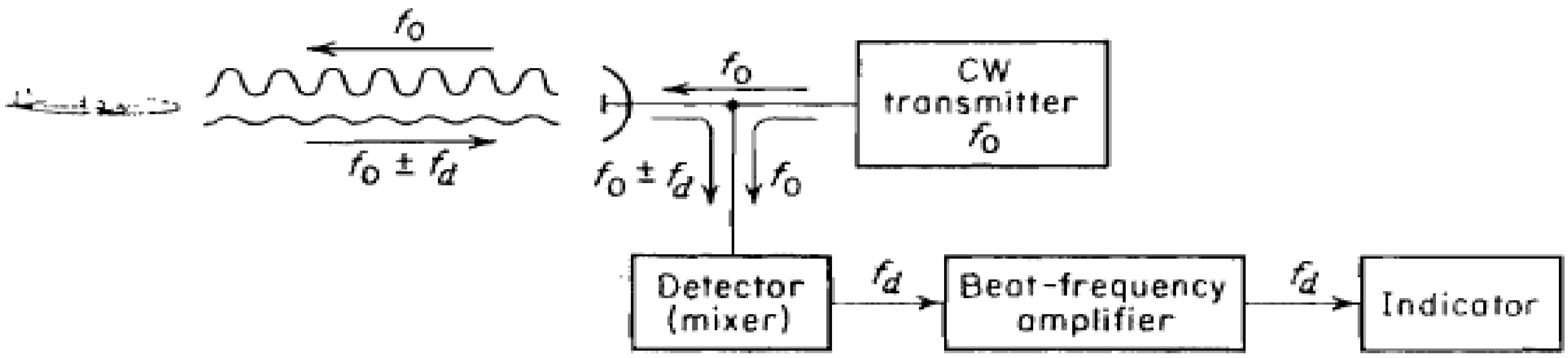
CW RADAR

CW Radar

- Detects objects
- Measures velocity from Doppler shift
- **But cannot measure range**
- Mostly Bistatic



CW RADAR (CONTD….)



CW Radar Block Diagram

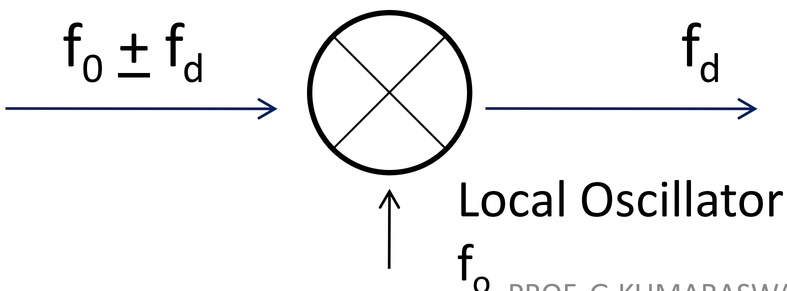
- **CW Transmitter :** generates a continuous (unmodulated) oscillation of frequency f_o
- **T_x Antenna :** radiates RF frequency f_o into space
- **R_x Antenna :** Targets reflects and a portion of RF is received at R_X antenna. Since the target is moving (Range changing), the echo frequency is $f_o \pm f_d$

CW RADAR (CONTD….)

- f_d has plus sign if target is approaching towards antenna (closing target)
- f_d has negative sign if target is receding from antenna

➢ **Mixer (Detector):**

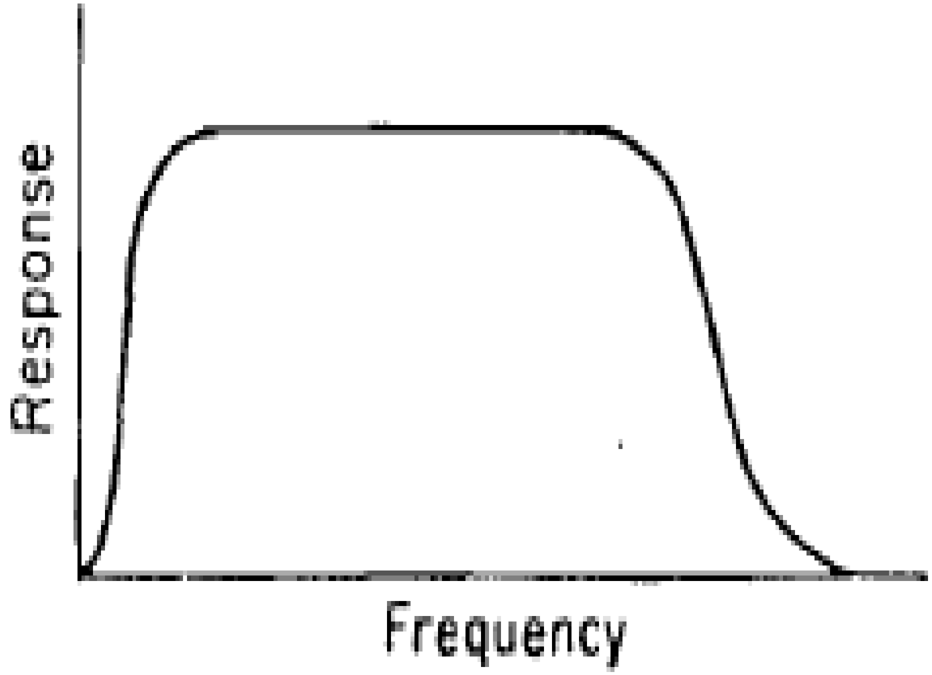
- $f_o \pm f_d$ enters through antenna, heterodyned in the mixer with a portion of f_o to produce doppler beat frequency f_d .
- Sign of f_d is lost in the process



CW RADAR (CONTD….)

➤ **Doppler Amplifier:**

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



Beat Frequency Amplifier Response

CW RADAR (CONTD….)

- **Doppler Amplifier (Contd…)**
  - Purpose of Doppler Amplifier is not only to amplify but to eliminate echoes from stationary targets (Buildings, Towers, etc.)
  - DC component caused by stationary targets removed by low frequency cut off.
  - Cut off should be sharp enough to pass smallest doppler frequency expected.
  - Upper cut off frequency is such that it passes the highest doppler frequency expected.

CW RADAR (CONTD….)

- **Indicator**

  (i) Earphone (ii) Frequency meter

- **i). Earphone**

- Act as a selective band pass filter with 50 HZ band
- Because of narrow band S/N ratio is high (N=KTB)
- Minimum f_d (helicopter) and Maximum f_d (supersonic fighter aircraft) falls within the listening range of audio frequencies of the ears.
- Ear cannot measure f_d, so determination of velocity is not possible.

CW RADAR (CONTD….)

ii) Frequency meter

- Usually a frequency counter measures f_d in HZ
- So accurate determination of v_r (relative velocity of target) is possible.

Q. (Jntuh) 1. What is the importance of providing isolation between Transmitter and Receiver ? Explain clearly the different methods of providing isolation in the case of CW Radar

ISOLATION BETWEEN TRANSMITER & RECEIVER

ISOLATION BETWEEN T_X & R_X

- In CW Radar T_x and R_x are simultaneously operating.
- Echo signal power might be as little as 10^{-18} to that of the Transmitted power.
- R_x is designed to handle only very low power. T_x power which is very high should not leak into the R_x and damage the R_x. So isolation is required.
- Though Ferrite circulator (monostatic CW Radar) is used to block the T_x power entering the R_x. Circulators have only 30 dB maximum blockage.
- This type of CW Radars work with low power.

ISOLATION BETWEEN T_X & R_X

- A Bistatic radar using separate antennas for transmission and receiving can be one of the solution. The distance between T_x and receiving antennas determines the Isolation achieved.
- As a result of doppler, echo frequency is $(f_o \pm f_d)$ different from transmitted frequency (f_o). So a proper filter can separate the echo. However leakage is still present in practice. A certain amount of leakage can be utilized in a mixer to extract doppler frequency shift.

ISOLATION BETWEEN T_X & R_X

- **Practical limits for leakage Power:**

(i) Maximum power the R_x can withstand before damaged.

(ii) Amount of transmitter noise due to hum, microphones, stray pick up that enters the R_x from Transmitter as a leakage.

- Because of the above, the R_x sensitively is reduced and in extreme case burn out takes place.
- Additional Isolation is required for CW Radar to operate at higher powers.

ISOLATION BETWEEN T_X & R_X

AMOUNT OF ISOLATION REQUIRED:

Safe value of Rx = 10 mws

T_x Power = 1 KW

Isolation required $\frac{1\text{ KW}}{10\text{ mws}} = \frac{1 \times 10^3}{10 \times 10^{-3}} = 10^5$

$= 50\text{ dB}$

METHODS FOR ISOLATION:

(i) Hybrid Junctions like magic T
(ii) Short slot coupler
(iii) Ferrite circulator (20 to 50 dB isolation)
(iv) Turnstile Junction (40 to 50 dB isolation)
(v) Use of orthogonal polarizations for transmission and reception.
(vi) Use of dual antenna one for transmission and another for receiving.

ISOLATION BETWEEN T_X & R_X

➢ SOURCES OF LEAKAGE POWER:

(i) Noise in the T_x which falls in the range of doppler frequencies.

(ii) Reflections produced in transmission line by the Antenna. To achieve an isolation of 20 dB or 40 dB VSWRs, required are 1.22 to 1.02 respectively.

$$\sigma = \frac{(\sigma - 1)}{(\sigma + 1)}$$

ISOLATION BETWEEN T_X & R_X

- USE OF 2 ANTENNAS:

- Tx and Rx antennas physically separated.
- Isolation of 80 dB or more achieved depending on

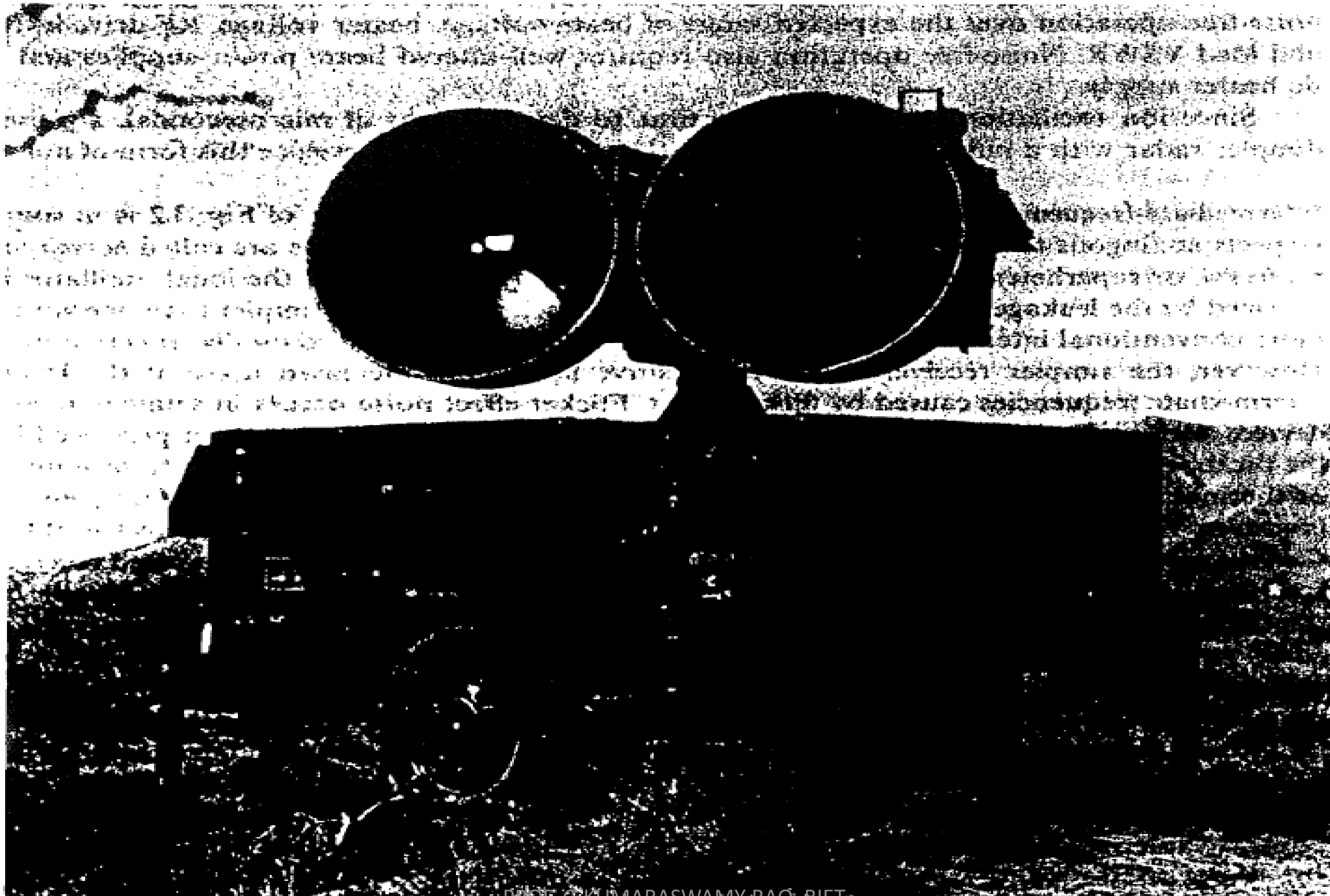
(i) Distance between antennas

(ii) Directivity of antennas

(iii) Metallic baffles

(iv) Absorbing material placed between antennas, enhances Isolation

ISOLATION BETWEEN T_X & R_X



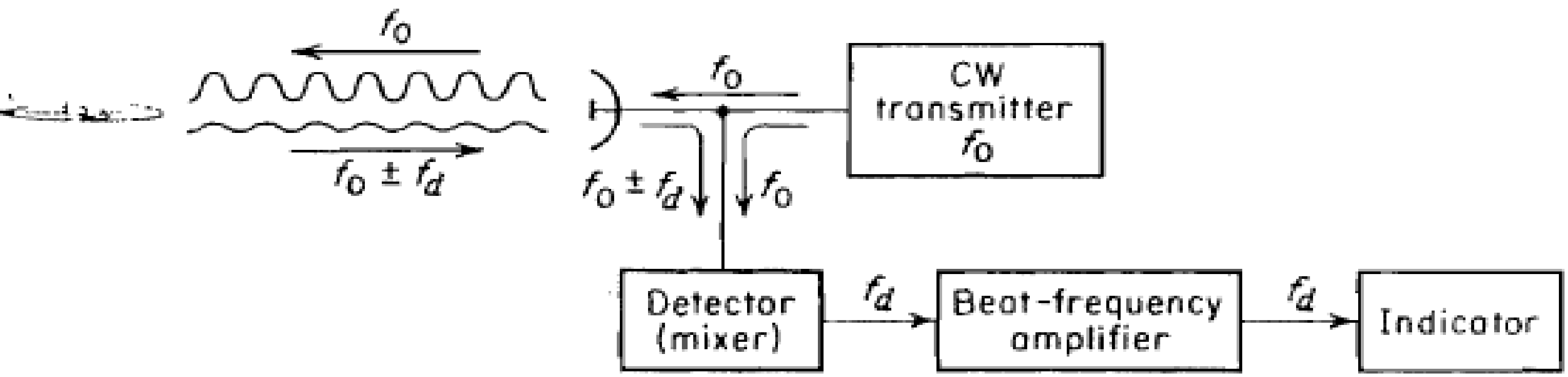
(Jntuh) **1. Explain the operation of Non Zero IF receiver with neat block diagram. Compare it with Zero IF receiver and bring out its advantages**

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

ZERO & NON ZERO IF R_x

TYPES OF CW R_{xs}

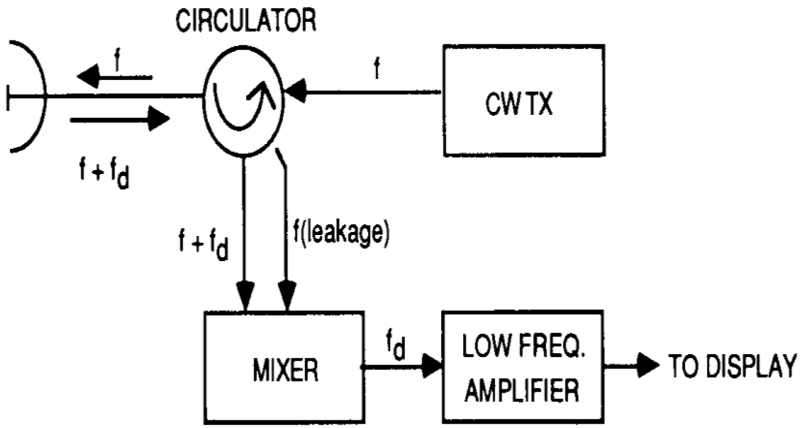
➢ 1. Homodyne Receiver: (Zero IF Receiver)



Mixer is used to obtain Doppler frequency.

- Receiver is simpler.
- But not sensitive enough because of increased flicker noise at low frequencies.

TYPES OF CW R_{XS} (CONTD…)



- For f_o = 2 GHZ., ships produce doppler frequency range 0 to 200 HZ
- Doppler frequencies lie in the lower frequency band of Flicker Noise (Noise Power $\propto \frac{1}{\text{frequency}}$)
- So if Doppler frequency is amplified along with it flicker noise is also amplified.

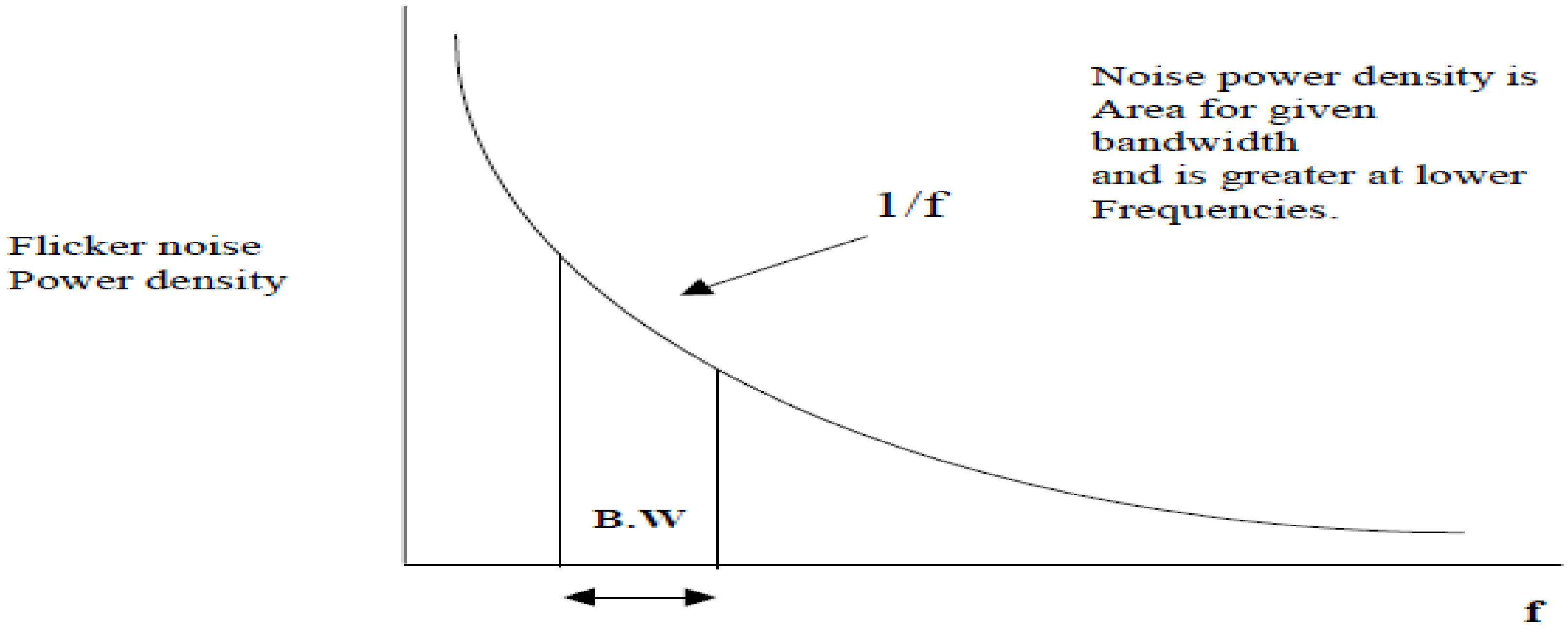
RANGE OF DOPPLER FREQUENCIES FOR REAL TARGETS

- Frequency of operation = 8 GHz
- $\lambda = c / f = (3 \times 10^{8}) / (8 \times 10^{9}) = 0.0375$ mt
- Let v_r = 50 mt/sec
- $f_d = 2 v_r / \lambda = (2 \times 50) / 0.0375 = 2667$ Hz

v_r	f_d	v_r	f_d
50 mt/sec	2.67 KHZ	400mt/sec	21.3 KHZ
100mt/sec	5.3 KHZ	500mt/sec	26.7 KHZ
200mt/sec	10.6 KHZ	750mt/sec	40 KHZ
300mt/sec	16 KHZ	1000mt/sec	53.3 KHZ

TYPES OF CW R_{XS} (CONTD…)

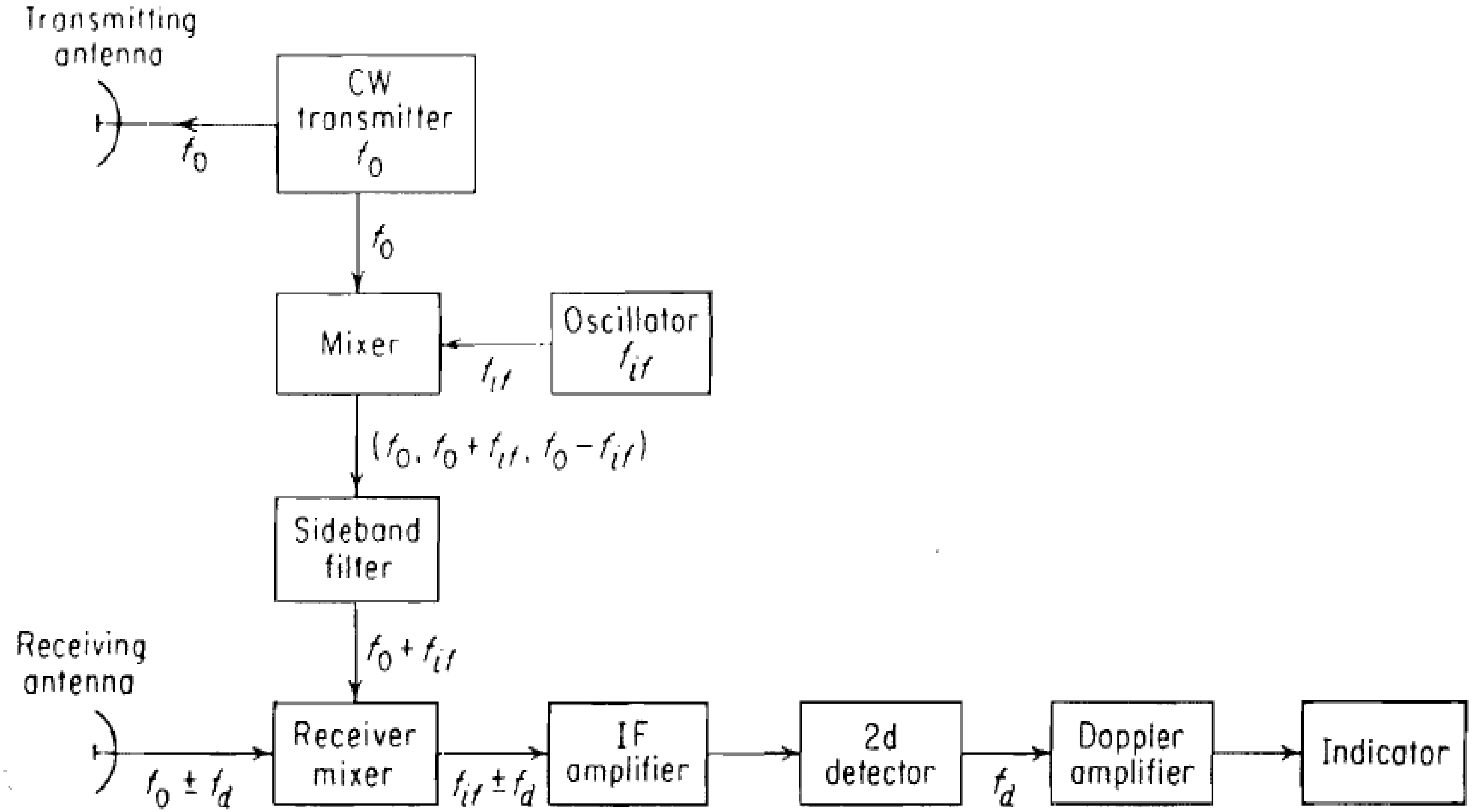
- So Doppler frequency is shifted to a higher frequency usually 30 MHZ or 60 MHZ and amplified where flicker noise is less



. **Flicker noise versus frequency**

SUPER HETERODYNE R_X

- **Non Zero IF R_x (Super Heterodyne R_x)**



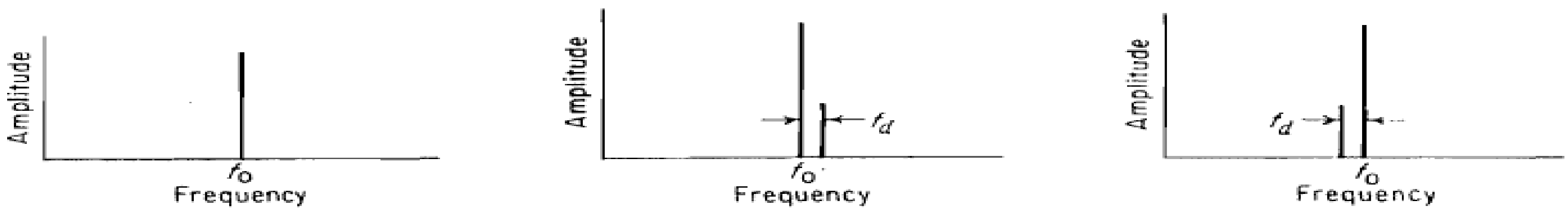
SUPER HETERODYNE R_X (CONTD…)

- **Operation:**
- **(1) 2 Separate antennas** are used (i) Transmission & (ii) Receiving to improve the isolation and overcome leakage from high power T_x
- **(2) Mixer:** Input to mixer are (i) f_o small portion of T_x power (ii) f_{if} – from IF oscillator
- Output of mixer is f_o, $(f_o + f_{if})$, $(f_o – f_{if})$
- **(3) Sideband Filter:**
- Allows only one side band $f_o + f_{if}$

SUPER HETERODYNE R_X (CONTD…)

➢ (4) R_x Antenna:

- Output of antenna is Echo signal from the target i.e. $(f_o \pm f_d)$. + sign for approaching targets – sign for Receding targets.



Stationary Target **Approaching Target** **Receding Target**

➢ (5) Receiver Mixer:

- I/P to mixer are (i) $(f_o + f_{if})$ from side band filter (ii) $(f_o \pm f_d)$ from Rx antenna.
- Output of Mixer is $(f_{if} \pm f_d)$ i.e. if $\pm$ Doppler frequency

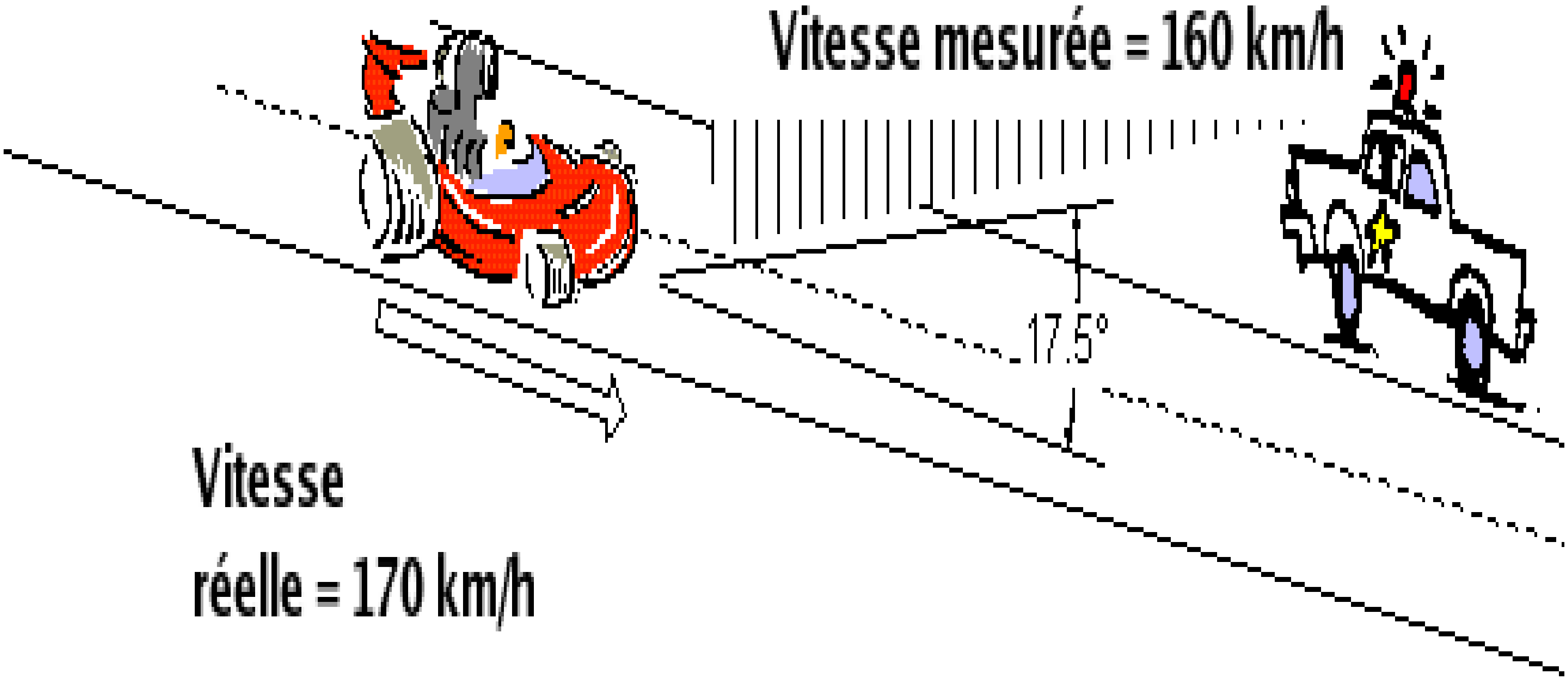
SUPER HETERODYNE R_X (CONTD…)

- **(6) IF Amplifier:**
- Amplifies ($f_{if} \pm f_d$) to a sufficient level
- **(7) 2nd Detector:**
- This is an envelope detector. Removes IF carrier.
- Output is fd. Sign information is lost.
- **(8) Doppler Amplifier:**
- Amplifies f_d signal to a level suitable to Indicator.
- **Indicator:**
- This can be a frequency meter which can be calibrated in terms of speed i.e. meters/sec or Kms/sec.

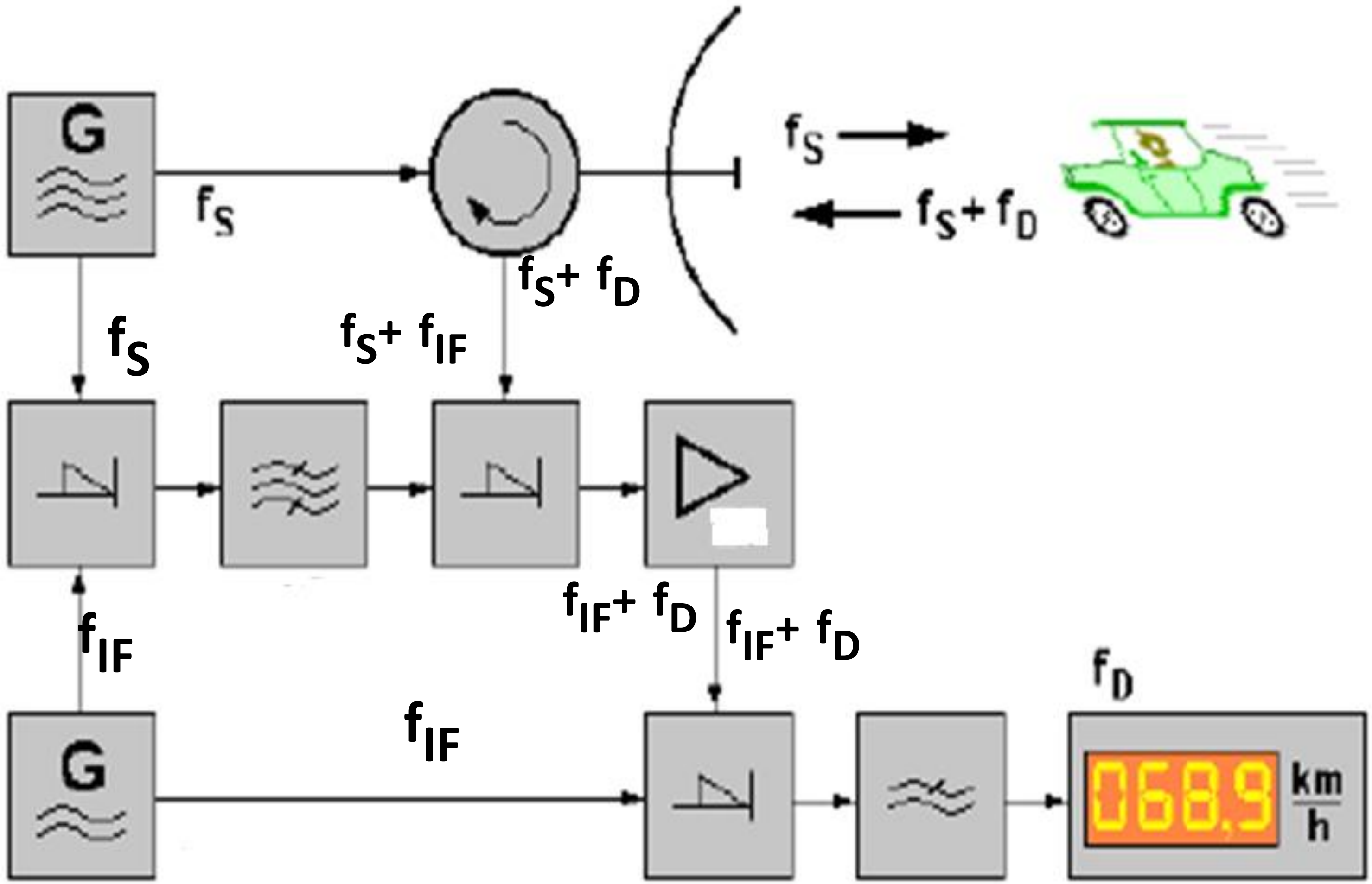
POLICE RADAR

TRAFFIC POLICE RADAR

➢ Application of CW Radar



TRAFFIC POLICE RADAR (CONTD…)



Schematic diagram of a CW Doppler- Radar

PROBLEM

- **Problem :**
- A 8 GHZ police Radar measures a Doppler frequency of 1788 HZ from a car approaching the stationary police vehicle in an 80 km/h speed limit zone. What should be the police officer do.
- (i) Frequency of operation = 8 x 10^9 HZ
- $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{8 \times 10^9} = 0.0375$ meter
- (ii) fd = 1788 HZ.

PROBLEM (CONT)

- Formula used:
- $f_d = \frac{2\ V_r}{\lambda}$
- $1788 = \frac{2\ V_r}{0.0375}$

- $V_r = \frac{1788 \times 0.0375}{2} = 33.525\ \text{Mt/sec}$
- = 33.525 X 60 X 60 = 120690 = 120.69 km/hr.
- Since the vehicle has crossed the 80 km/hr limit, the police officer has to proceed against the driver as per the law of the country.

CONTINUED IN RADAR 2B

(Jntuh)

RADAR SYSTEMS
(EC 812 PE)
(ELECTIVE V)
UNIT – 2B
B.TECH IV YEAR II SEMESTER
BY
Prof.G.KUMARASWAMY RAO
(Former Director DLRL Ministry of Defense)
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Acknowledgements

The contents , figures , graphs etc., are taken from the following Text book & others

“ INTRODUCTION TO RADAR SYSTEMS “

Merill I.Skolnik

Second Edition

Tata Mcgraw – Hill publishing company

Special indian edition

QUESTIONS

(Jntuh) 1. Several factors tend to spread to the CW signal to the CW signal energy over a finite band of frequencies. Explain

(Jntuh) 2. Bring out the factors that tend to spread the CW signal energy over a finite frequency and explain the spreading reasons clearly

RECEIVER BANDWIDTH REQUIREMENTS

RANGE OF DOPPLER FREQUENCIES FOR REAL TARGETS

- Frequency of operation = 2 GHz

  $\lambda = c / f = (3 \times 10^{8}) / (2 X 10^{9}) = 0.15$ mt

  Let $v_r = 50$ mt/sec

  $f_d = 2 v_r / \lambda = (2 \times 50) / 0.155 = 667$ Hz

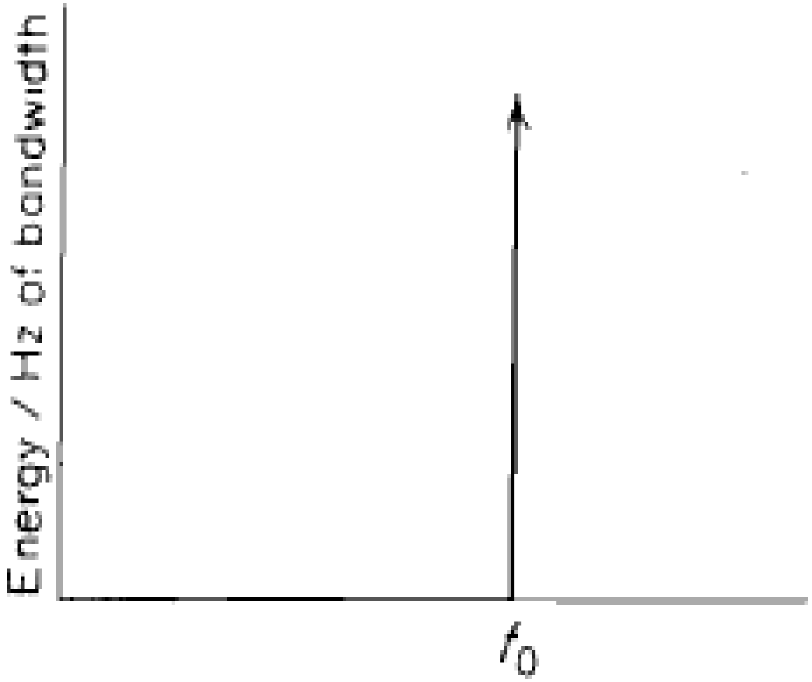
v_r	f_d	v_r	f_d
5 mt/sec	66.75 HZ	50 mt/sec	667 Hz
10mt/sec	132 HZ	100 mt/sec	1320Hz
20mt/sec	265 HZ	200 mt/sec	2650 KHz
300mt/sec	400 HZ	300mt/sec	4000 KHz

RECEIVER BANDWIDTH

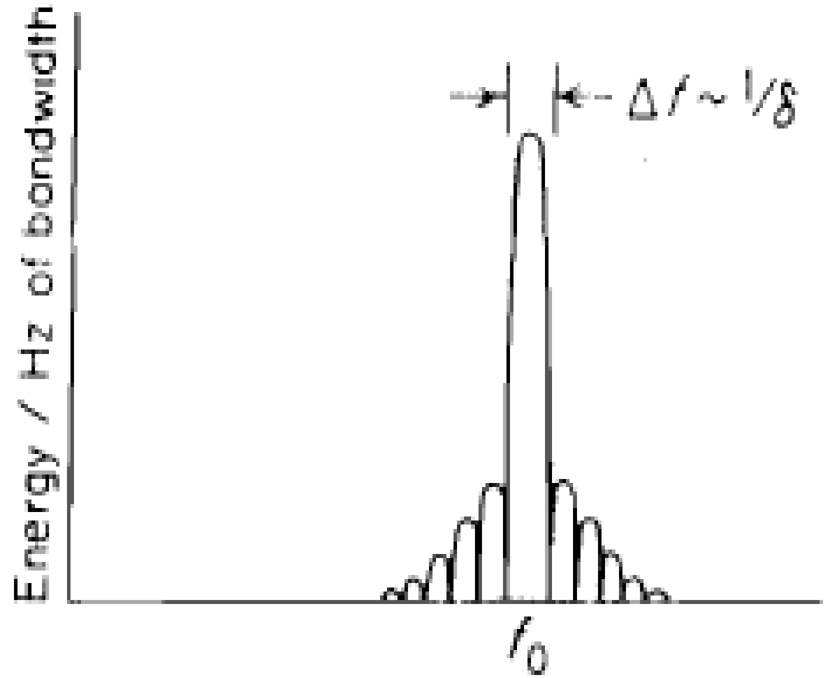
- Doppler Frequency Amplifier is part of the Receiver (R_x)
- R_x. should have a wide enough bandwidth to pass the expected range of Doppler Frequency spectrum (i.e. minimum and maximum velocities of the target)
- In real practice the BW required is slightly more than the Doppler spectrum.
- However Noise ($K T_o B$) increases with widening of the Bandwidth. This reduces S/N ratio and thereby decreasing R_x. sensitivity and reducing R_{max}

RECEIVER BANDWIDTH (CONTD….)

- **B.W. of R_x:**



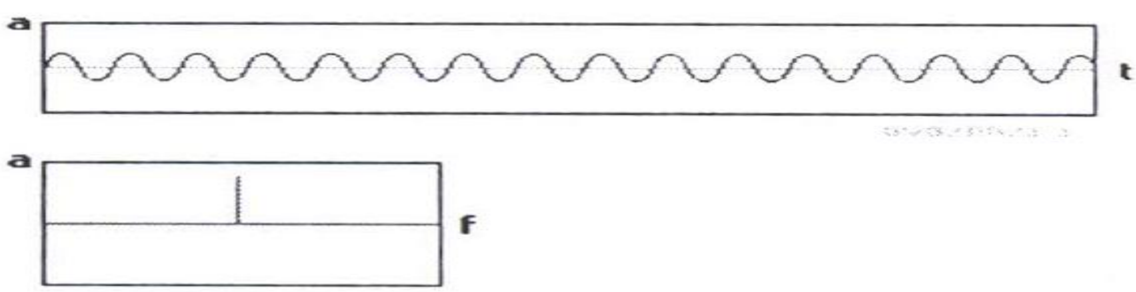
Spectrum of Sine wave of Infinite Duration



Spectrum of Sine wave of Finite Duration

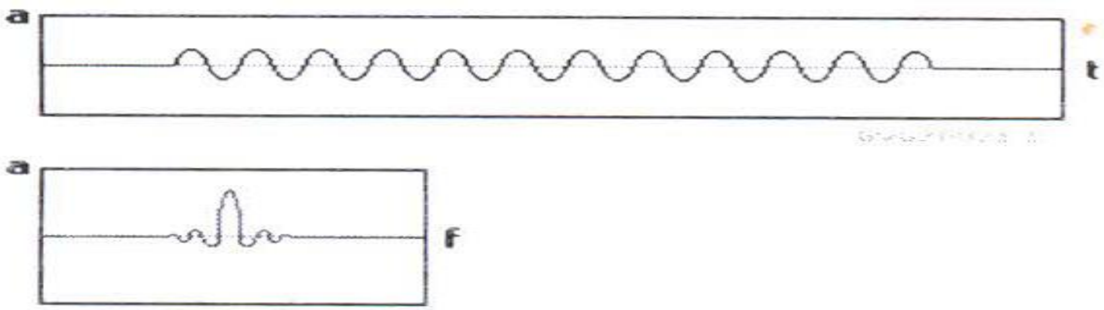
CW SPECTRUM

- **Ideal CW (sine wave of infinite duration)**



TIME VS. FREQUENCY DOMAIN (1)

- **Practical CW (Sine wave of finite duration)**



TIME VS. FREQUENCY DOMAIN (2)

RECEIVER BANDWIDTH (CONTD….)

- Frequency Spectrum of Sine wave of Infinite duration is a delta function. This does not occur in practice.
- Echo signal is a sine wave of finite duration. This has a spectrum (also called SINC function)
- $$\mathrm{Sin}\ \frac{\pi\ (f - f_0)\ \delta}{\pi\ (f - f_0)}$$

f_0 = frequency of Sine wave

δ = Duration of Sine wave

SPREAD OF B.W. OF R_X

- Echo spectrum is broadened because of i) scanning ii) fluctuation in RCS (iii) change in target velocity etc.
- **(i) Spread of B.W. due to Scanning:**

θ_B = Antenna Beam width in Deg.

$\dot{\theta}_S$ = Scanning Rate Deg / Sec.

$$\delta = \text{Time on target} = \frac{\theta_B}{\dot{\theta}_S} \text{ secs.}$$

$$\text{B.W.} = \frac{1}{\text{Time on target}} = \frac{\dot{\theta}_S}{\theta_B} \text{ Hz}$$

SPREAD OF B.W. OF R_X

$$B.W. = \frac{1}{\text{Time on target}} = \frac{\dot{\theta}_S}{\theta_B} \text{ Hz}$$

 # Example: θ_B = 2 Deg, $\dot{\theta}_S$ **=** 36^0 / sec (6 rpm)

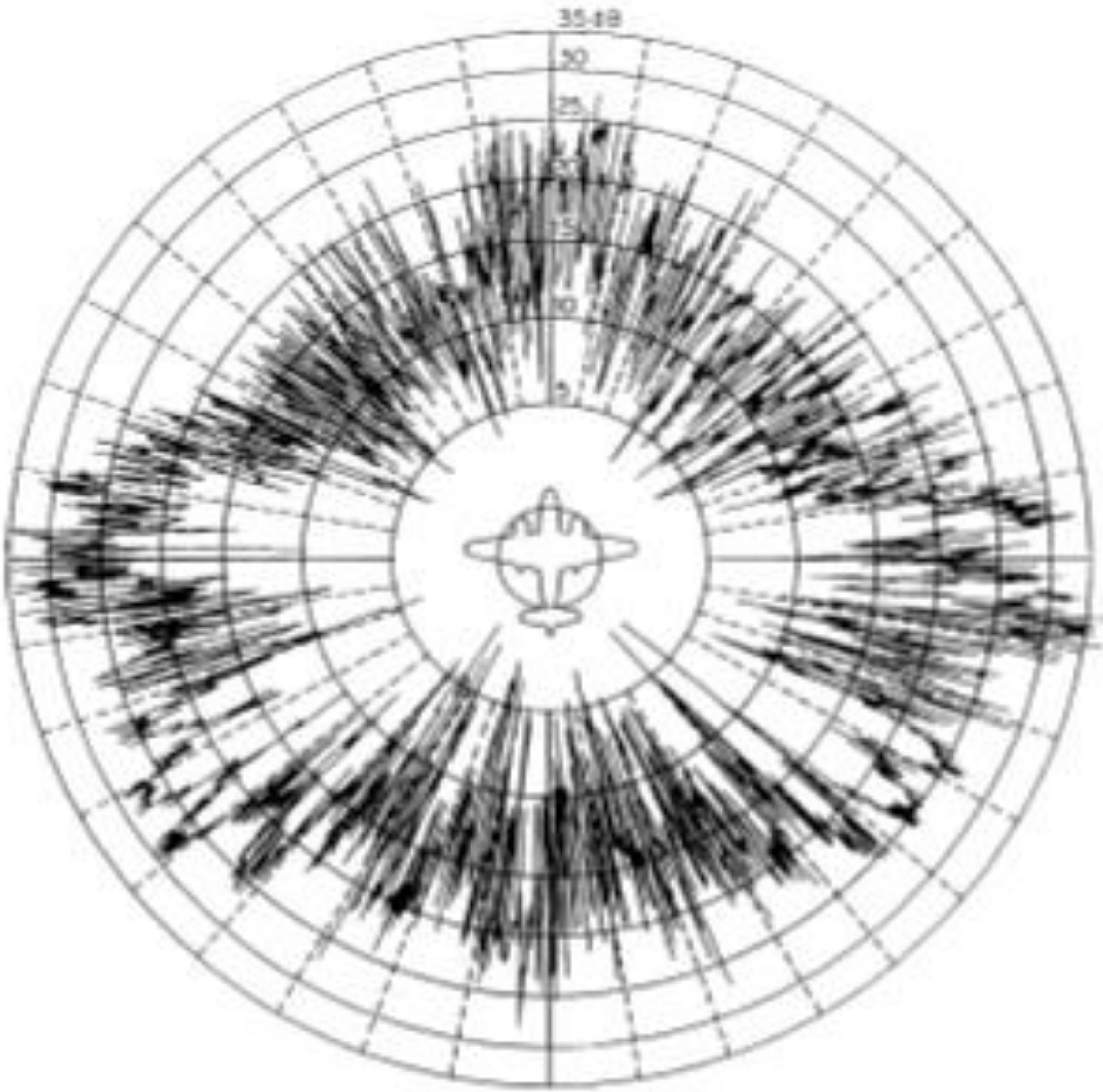
Spread in spectrum B.W = 36 / 2 = 18 HZ

SPREAD OF B.W. OF R $_X$ (CONTD…)

- **(ii) Spread of B.W. due fluctuations in RCS:**

Example 1: RCS changes by 15 dB (31.6) for a change in target aspect of as little as 1/3 Deg.

Example 2: Propeller Driven aircraft (World War-II) produces a frequency modulation B.W. of 50 to 60 HZ.



RCS (σ) OF AN AIRCRAFT

SPREAD OF B.W. OF R_X (CONTD…)

- **(iii)** Spread of B.W. due to fluctuations in velocities

- Widening of B.W. = $\Delta f_d = \left[\frac{2\, a_r}{\lambda}\right]^{\frac{1}{2}}$

  where a_r = target acceleration

\# Example: a_r = 2 x 9.8 mt / sec (2 x gravity)

Δf_d = 20 HZ (when λ = 10 cms)

PROBLEM

(Jntuh) Determine the acceleration of a target if the received signal bandwidth is 40 Hz and the operating wave length is 9 cms

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

PROBLEM

(Jntuh) Determine the operating frequency if the target is moving with acceleration as same as acceleration of gravity and the received signal bandwidth is 50 Hz.

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

QUESTION

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

DOPPLER FREQUENCY FILTER

RANGE OF DOPPLER FREQUENCIES FOR REAL TARGETS

- Frequency of operation = 2 GHz

  $\lambda = c / f = (3 \times 10^{8}) / (2 X 10^{9}) = 0.15$ mt

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300mt/sec	400 HZ	300mt/sec	4000 KHz

DOPPLER FREQUENCY FILTER

- Doppler Frequency filter should pass all the range of Doppler frequencies pertaining to all possible velocities of target.
- The Bandwidth of individual filter should be wide enough to pass the signal energy, but not so wide to introduce more noise than need be because thermal noise (KTB) increases with wider (increase) bandwidth

DOPPLER FREQUENCY FILTER (CONTD…)

- There are 3 methods to realize the Doppler filter

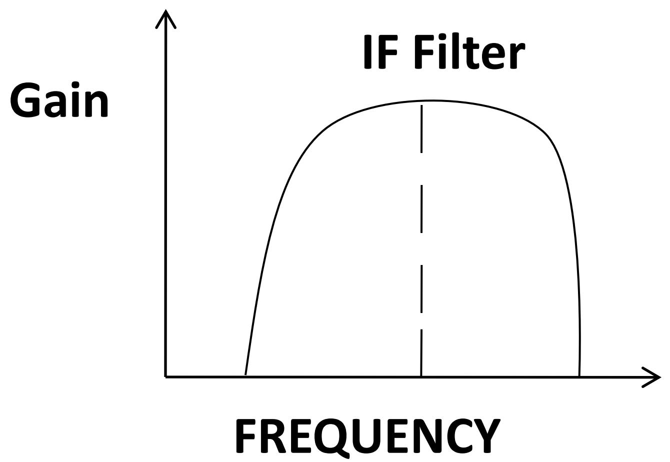
  (i) Wide Band Doppler Filter

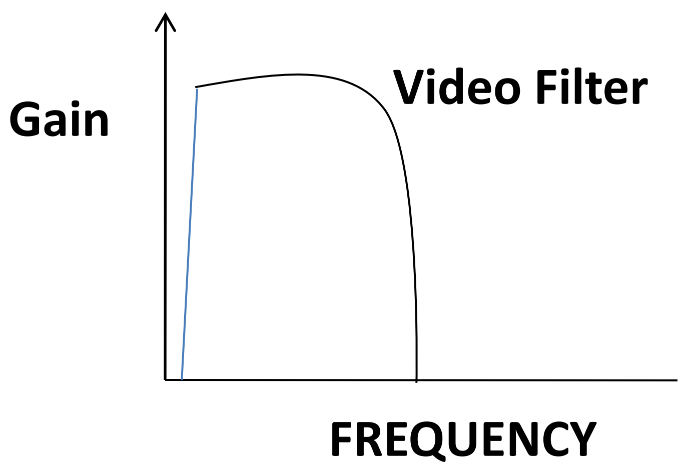
  (ii) Narrow Band Doppler Filter Bank

  (iii) Tunable narrow Band Filter
- Filter may be used either in (a) IF or (b) Video

DOPPLER FREQUENCY FILTER (CONTD…)

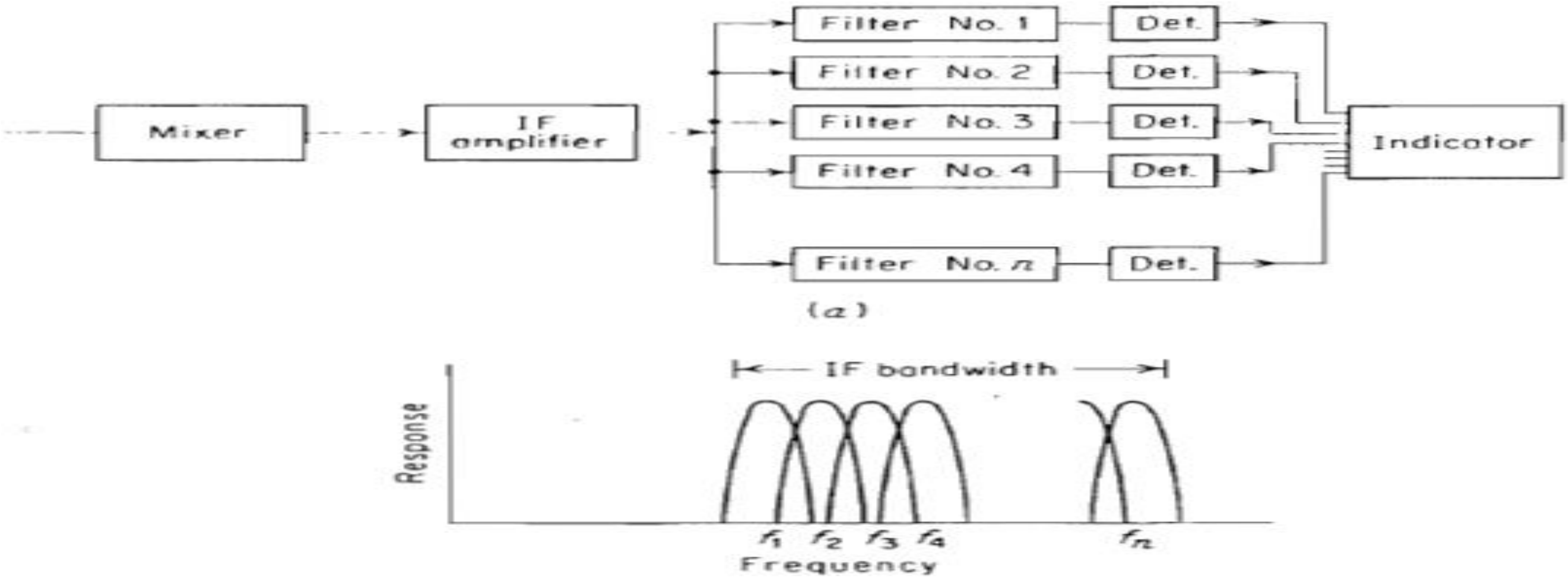
- **(i) Wide Band Doppler Filter:**
- This is a single filter and passes all the possible Doppler frequencies for the given minimum and maximum velocities of target.
- Since B.W. is wide, noise is large ($N_o = K\,T\,B$)
- The filter can be in I.F. or after the detection in video





DOPPLER FREQUENCY FILTER (CONTD…)

- **(ii) Narrow Band Doppler Filter Bank:**
- In order to improve S/N Ratio a bank of narrow band filters spaced throughout the frequency range of Doppler frequencies are used in place of a single wideband filter (This reduces $N = KT_o B$ since B is small)



DOPPLER FREQUENCY FILTER (CONTD…)

- **(ii) Narrow Band Doppler Filter Bank (Contd..)**
- The centre frequencies are spread to cover the entire range of Doppler frequencies.
- The half power points of individual filters are over-lapped so that the S/N reduction is 3dB.
- If more filters are used loss in S/N is reduced but the complexity and cost increases.

DOPPLER FREQUENCY FILTER (CONTD…)

- **(ii) Narrow Band Doppler Filter Bank (Contd..)**
- The Narrow band Doppler Filter Bank can be used either in (a) IF or (b) after the detection of Video
- **Comparison of filters in IF and in Video:**

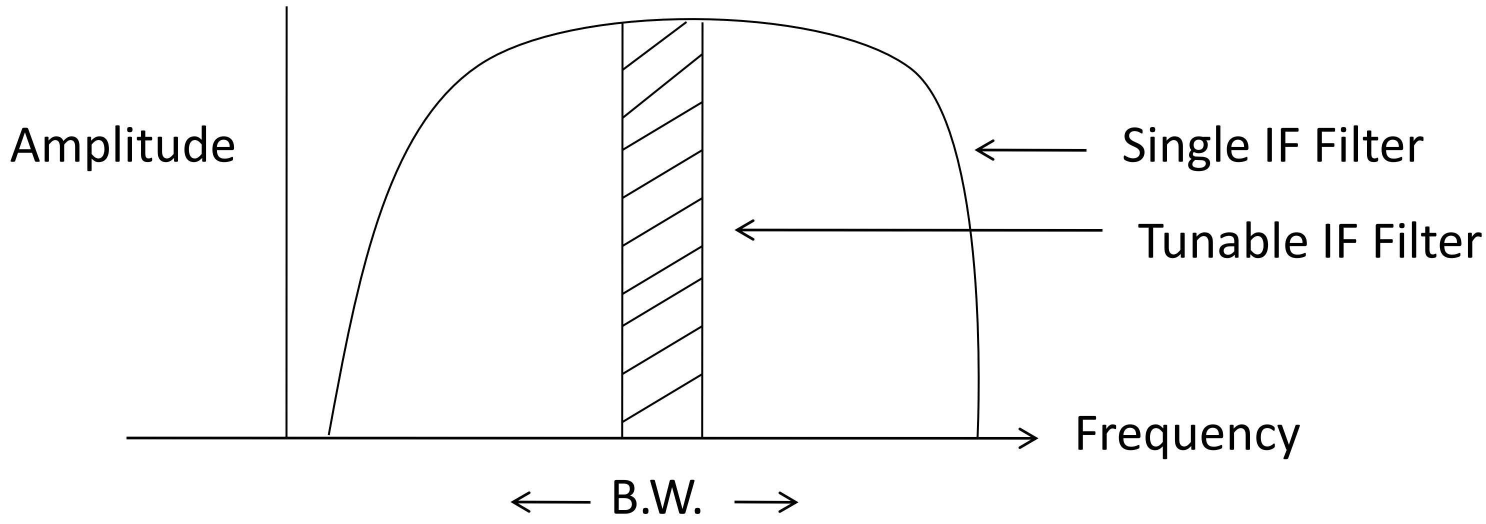
(a)The improvement in S/N is more in IF Filter bank than in Video Filter Bank.

(b)Sign of Doppler shift is lost in Video Filter Bank. As such the discrimination between approaching and receding targets is lost. Frequency spectrum folds over in Video because of Detector.

(c)No. of filter banks in Video Filter Bank is half the no. of filter banks in IF Filter Bank.

DOPPLER FILTER BANK (CONTD…)

- **(iii) Tunable narrow band filter:**

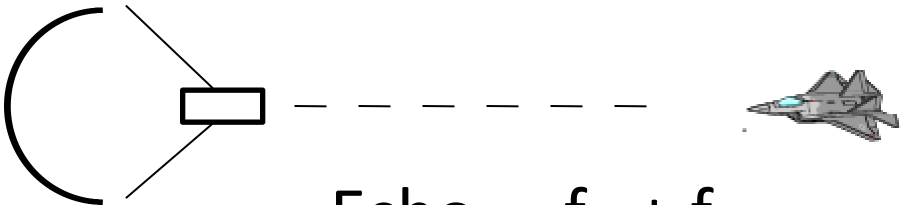


- Bank of Filters increases complexity and cost.
- Single narrow band tunable filter searches the Incoming echo signal until signal is found.
- After recognizing the signal the filter may be programmed to continue search for next target.

SIGN OF RADIAL VELOCITY

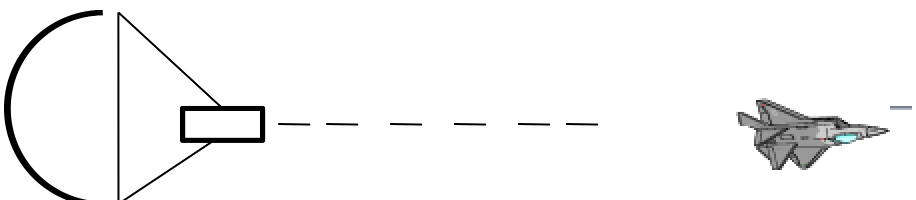
SIGN OF RADIAL VELOCITY

- **Case (i) Approaching target:**



$$Echo = f_0 + f_d$$

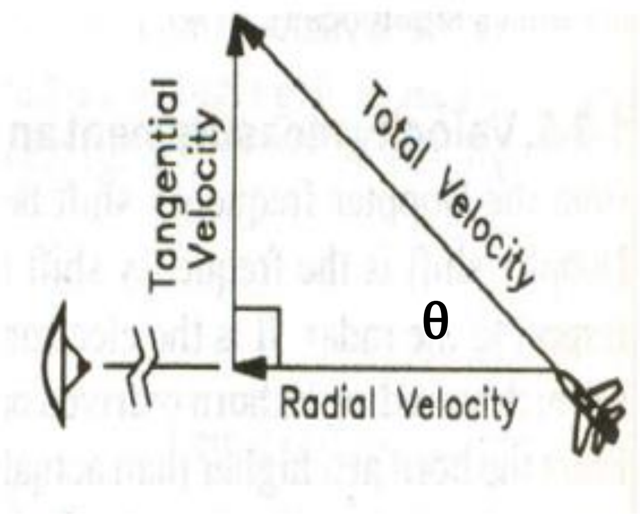
- **Case(ii) Receding Target**



$$Echo = f_0 - f_d$$

SIGN OF RADIAL VELOCITY

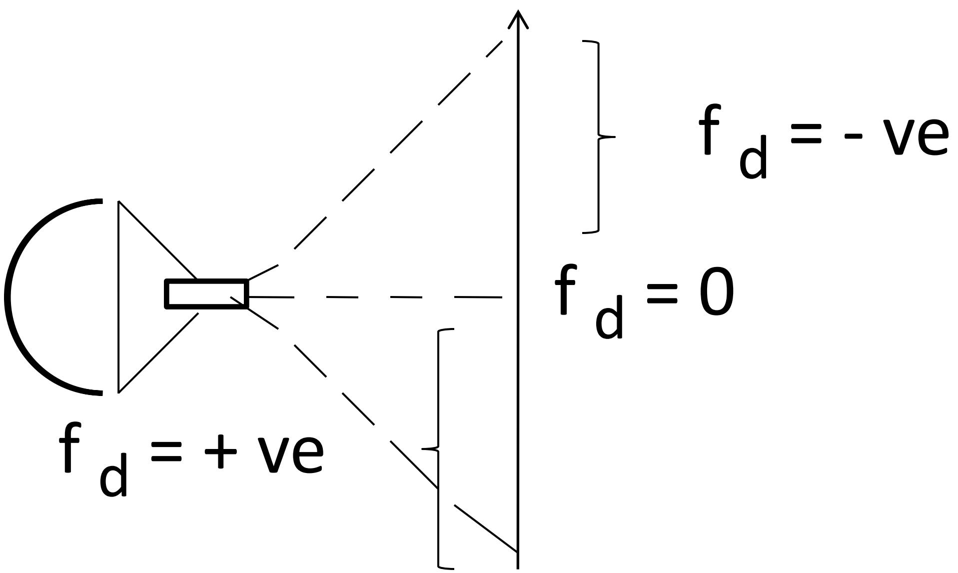
- **Case(iii) Inclined Velocity Target**



- $f_d = \frac{2\ V_r}{\lambda} = \frac{2\ V \cos\theta}{\lambda}$

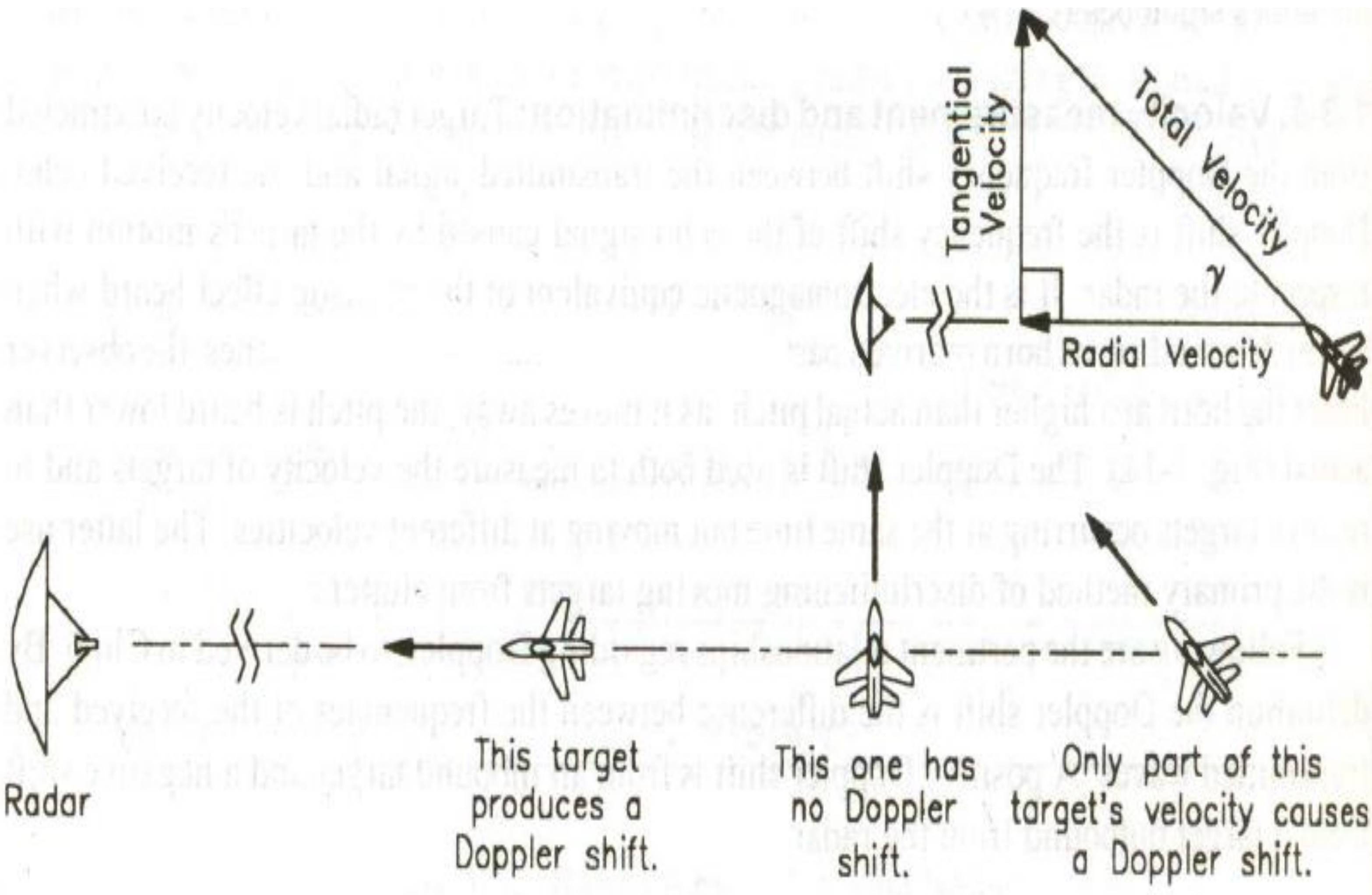
SIGN OF RADIAL VELOCITY (CONTD…)

➢ Case (iv) Straight line target

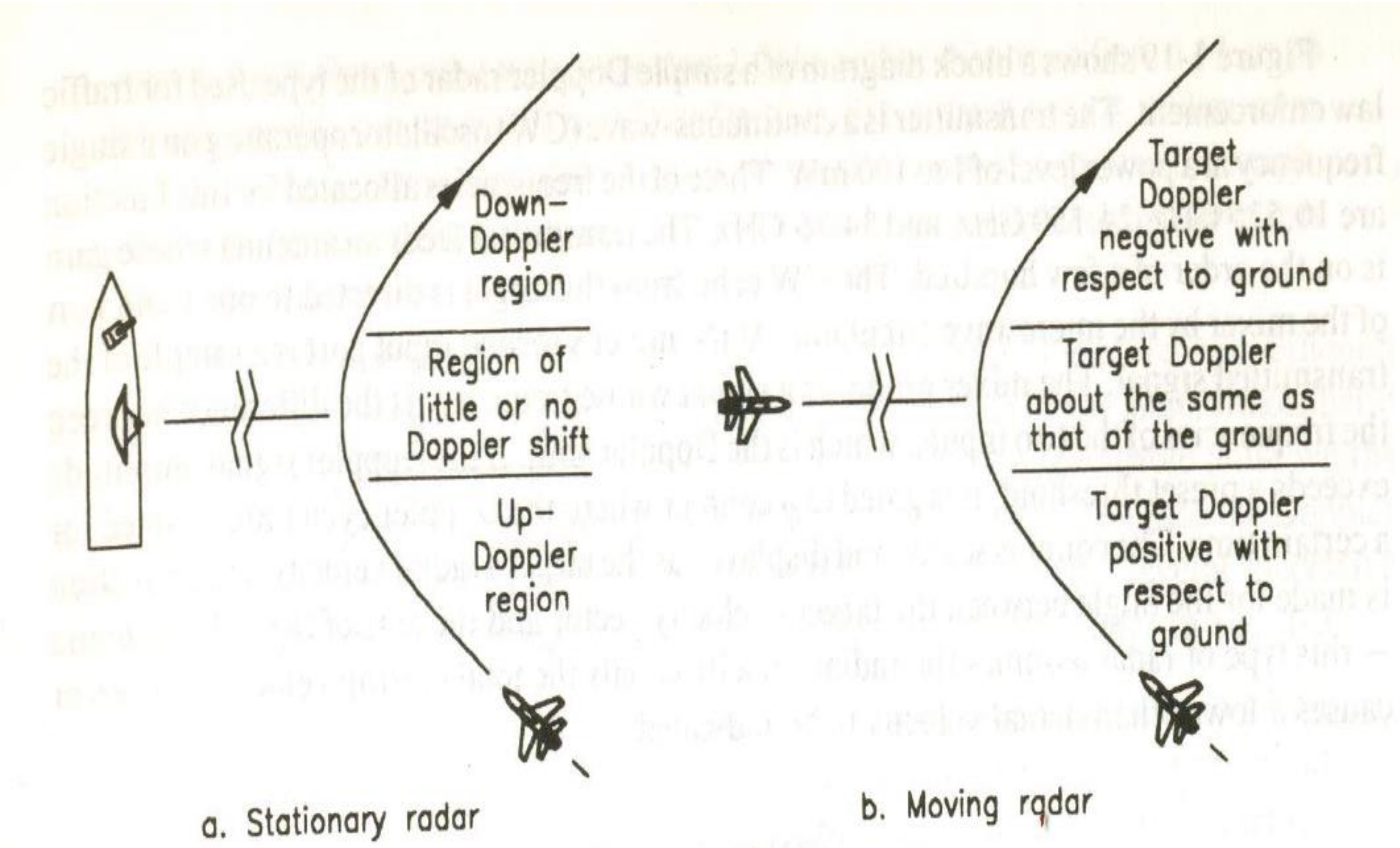


- Radial speed of a target is that part of the speed which acts towards the radar or away from the radar

SIGN OF RADIAL VELOCITY (CONTD..)



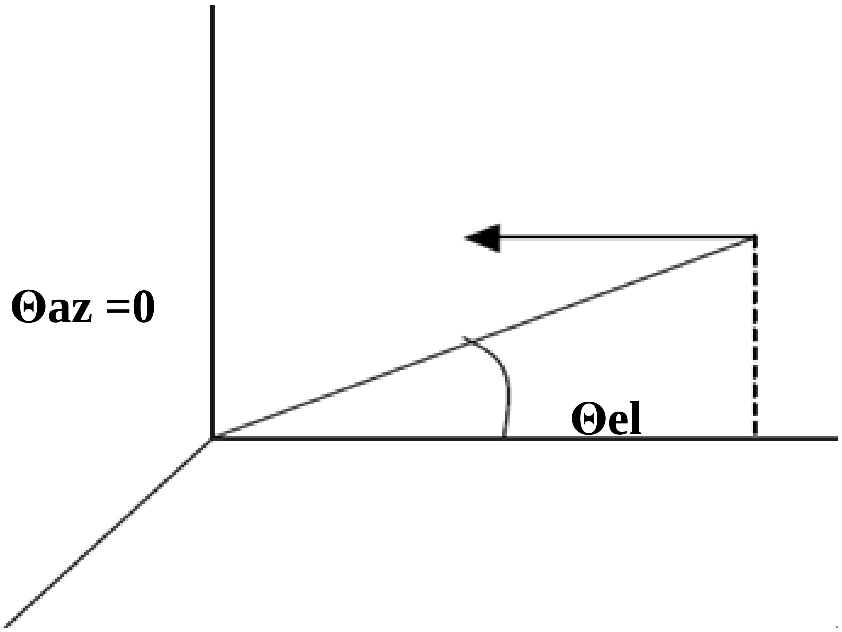
SIGN OF RADIAL VELOCITY (CONTD..)

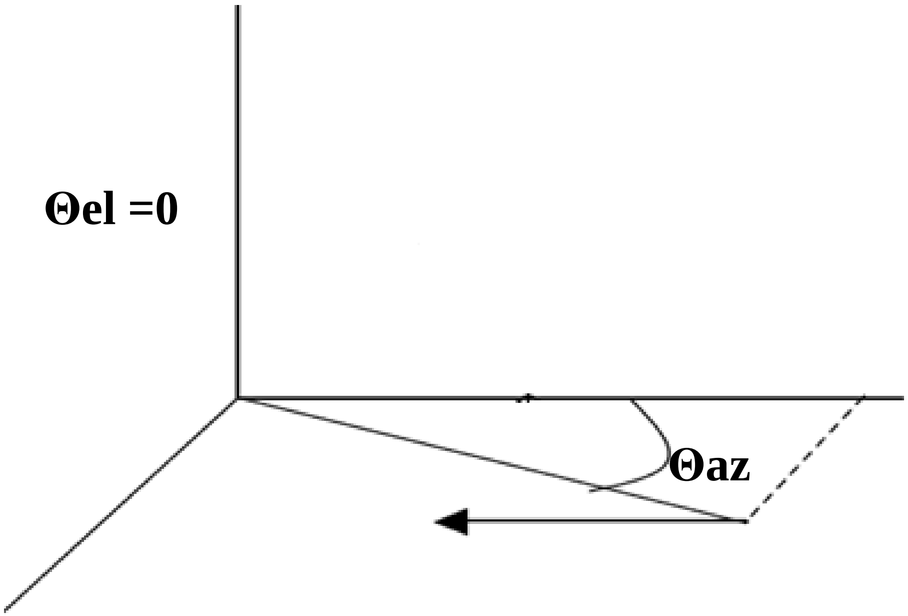


SIGN OF RADIAL VELOCITY (CONT)

- **Target in 3 dimensions**
- If the target is moving at an angle θ_{el} in elevation and an angle θ_{az} in azimuth relative to the line of sight (LOS) then the expression for the Doppler shift in frequency becomes
- $f_d = -\frac{2\ V}{\lambda}\ \text{Cos}\,\theta_{el}\ \text{Cos}\,\theta_{az}$ for opening target
- $f_d = +\frac{2\ V}{\lambda}\ \text{Cos}\,\theta_{el}\ \text{Cos}\,\theta_{az}$ for closing target

SIGN OF RADIAL VELOCITY (CONT)



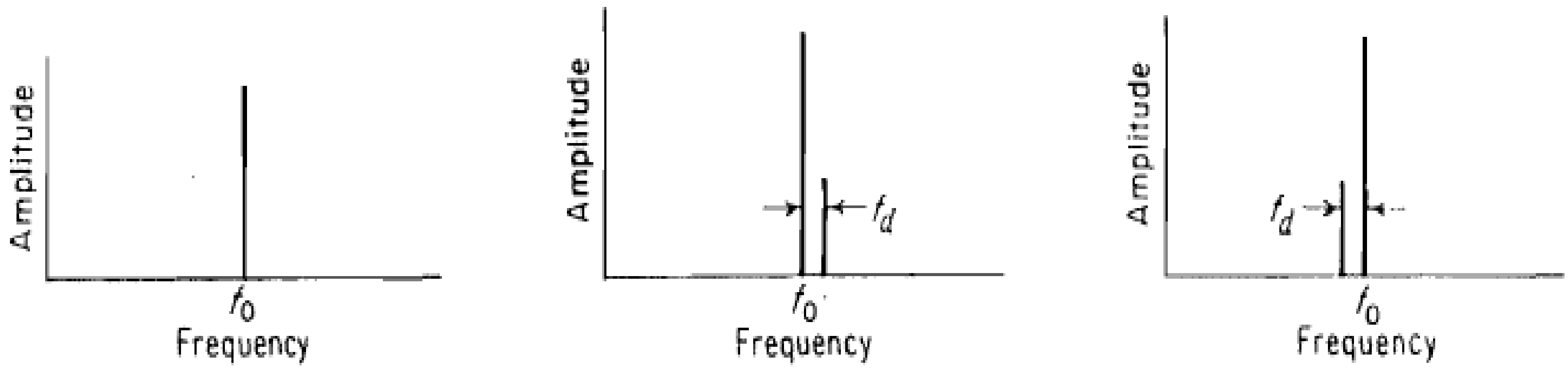


QUESTION

(Jntuh) **1. Explain with necessary block schematic and analysis how Doppler direction is identified in CW Radar**

MEASUREMENT OF DOPPLER DIRECTION

MEASUREMENT OF DOPPLER DIRECTION



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

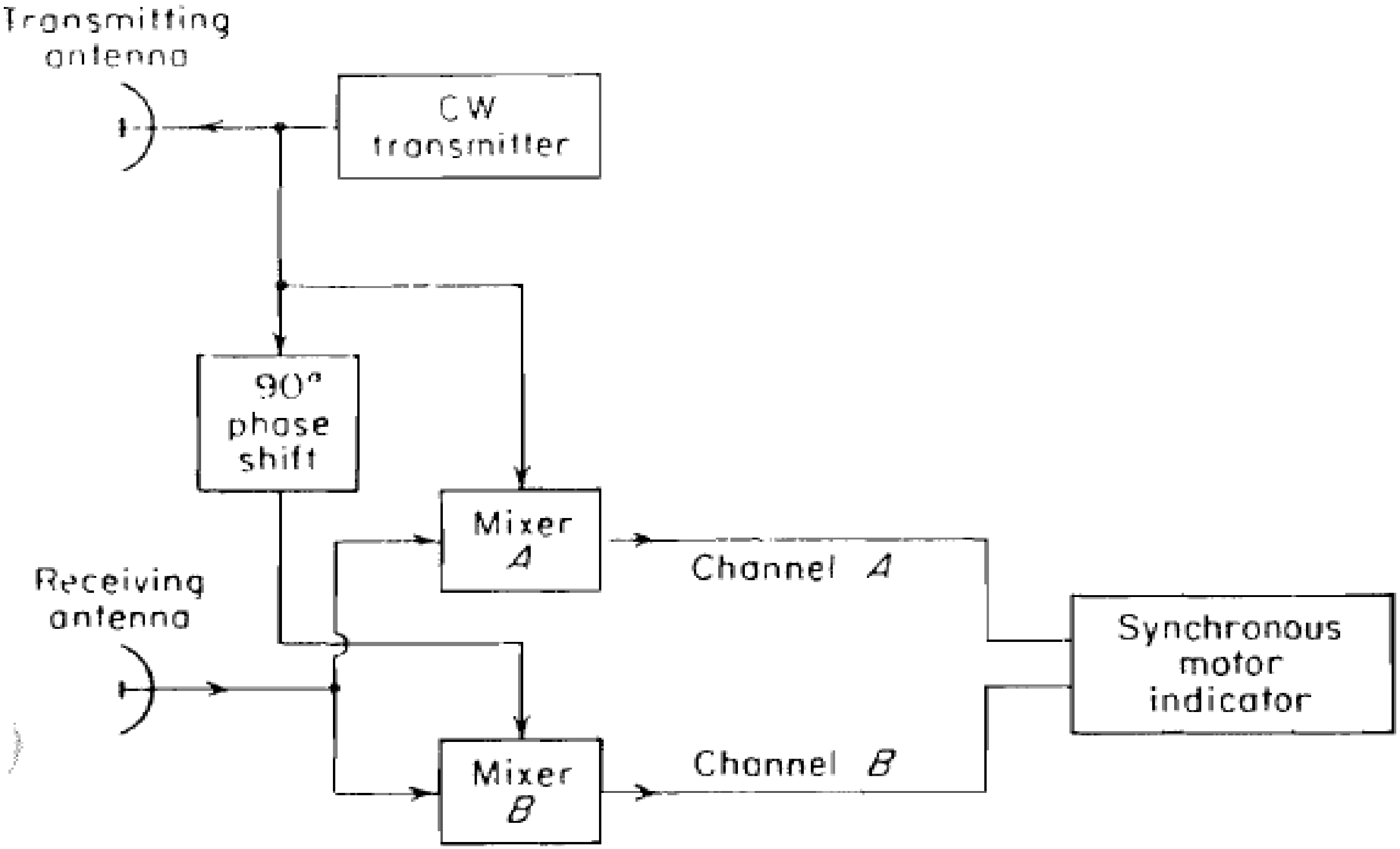
MEASUREMENT OF DOPPLER DIRECTION (CONTD..)

Doppler Direction Discrimination

- The mixing process described in the previous slides can only provide an absolute difference in frequency. It contains no information regarding the direction of motion
- The following are the most common techniques used to preserve the direction information
  - Sideband filtering
  - Offset carrier demodulation
  - In phase / Quadrature demodulation
- In the descriptions remember that
  - $\varpi_d > 0$ Target velocity towards the sensor
  - $\varpi_d < 0$ Target velocity away from the sensor

IN PHASE / QUADRATURE DEMODULATION

- Using two phase synchronous motor:



IN PHASE / QUADRATURE DEMODULATION (CONTD..)

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

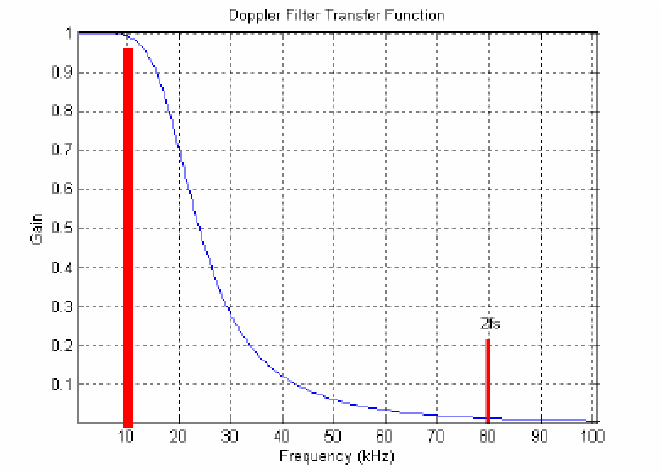
$\cos A . \cos B = 1/2 [\cos (A+B) + \cos (A-B)]$

- ϕ is Phase Shift due to Range
- Mixer A multiplies $(E_o \cos \omega_o t)$

  and $(E_d \cos[(\omega_o \pm \omega_d) t + \phi])$
- $E_A = E_o E_d \cos \omega_o t \times \cos [(\omega_o \pm \omega_d) t + \phi]$
- $k [\cos \{ (2\omega_o \pm \omega_d) t + \phi \} + \cos (\pm\omega_d t + \phi)]$
- where $k = E_o E_d / 2$

IN PHASE / QUADRATURE DEMODULATION (CONTD..)

- As we are not interested in signal at $(2\,\omega_o t + \omega_d)$ it is filtered out using a low pass filter



- So $E_A = k \cos(\underline{\pm\,\omega}_d\, t + \phi)$
- Mixer B multiplies $(E_o \cos \omega_o t + \pi / 2)$ and $(E_d \cos[(\omega_o \pm \omega_d)\, t + \phi])$
- So $E_B = k \cos(\underline{\pm\omega}_d\, t + \phi + \pi / 2)$
- $E_A = k \cos(\omega_d\, t + \phi)$ for approaching targets
- $E_B = k \cos(\omega_d\, t + \phi + \pi /2)$ for approaching target

IN PHASE / QUADRATURE DEMODULATION (CONTD..)

- $E_A = k \cos(\omega_d t + \phi)$ for approaching targets
- $E_B = k \cos(\omega_d t + \phi + \pi/2)$ for approaching target

- For Approaching target output E_B leads E_A

IN PHASE / QUADRATURE DEMODULATION (CONTD..)

- Direction of target is determined by sign of ω_d
- $E_A = k \cos(-\omega_d t + \phi)$ for receding targets
- $E_A = k \cos(\omega_d t - \phi)$ (since $\cos(-\theta) = \cos\theta$)
- $E_B = k \cos(-\omega_d t + \phi + \pi/2)$ for receding target
- $E_B = k \cos(\omega_d t - \phi - \pi/2)$
- For Receding target output E_B lags E_A
- For Approaching target output E_B leads E_A

- Channel A & B are given to 2 phases of synchronous motor. The direction of rotation of synchronous motor indicates the direction of target motion.

(Jntuh) **1. What are the applications of CW Radar**

APPLICATIONS OF CW RADAR

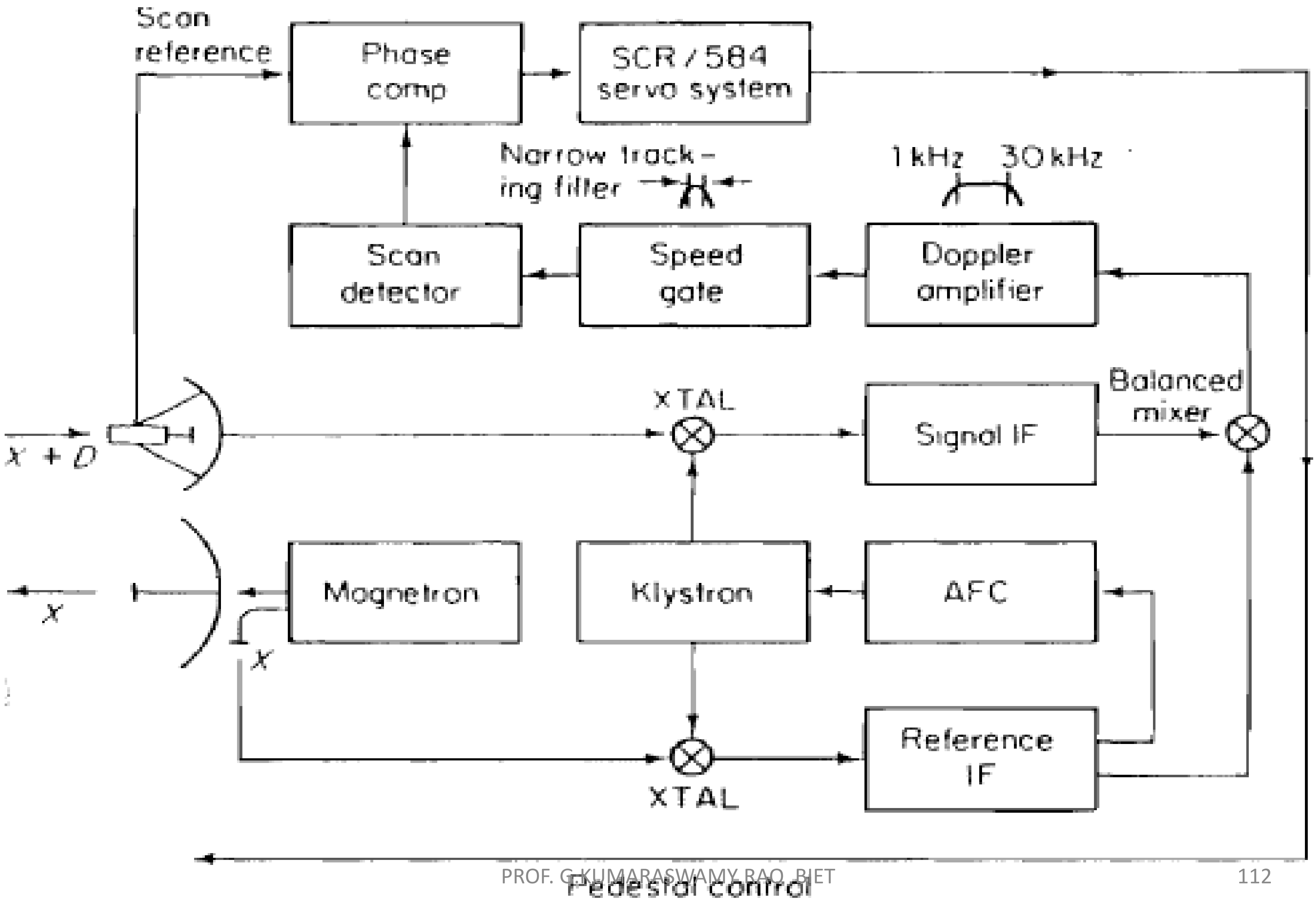
APPLICATIONS OF CW RADAR

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

APPLICATIONS OF CW RADAR (CONTD…)

- **Advantage of CW Radar :** For measurement of speed no physical contract with object is necessary.
- Difficulty in eliminating leakage of T_x signal into R_x has limited the CW Radar to short range applications
- CW Radar does not measure range of target. (However this limitation is overcome by modulating the CW)
- Amount of power that can be used depends on the Isolation achieved between T_x and R_x

HACK CW TRACKING ILLUMINATOR

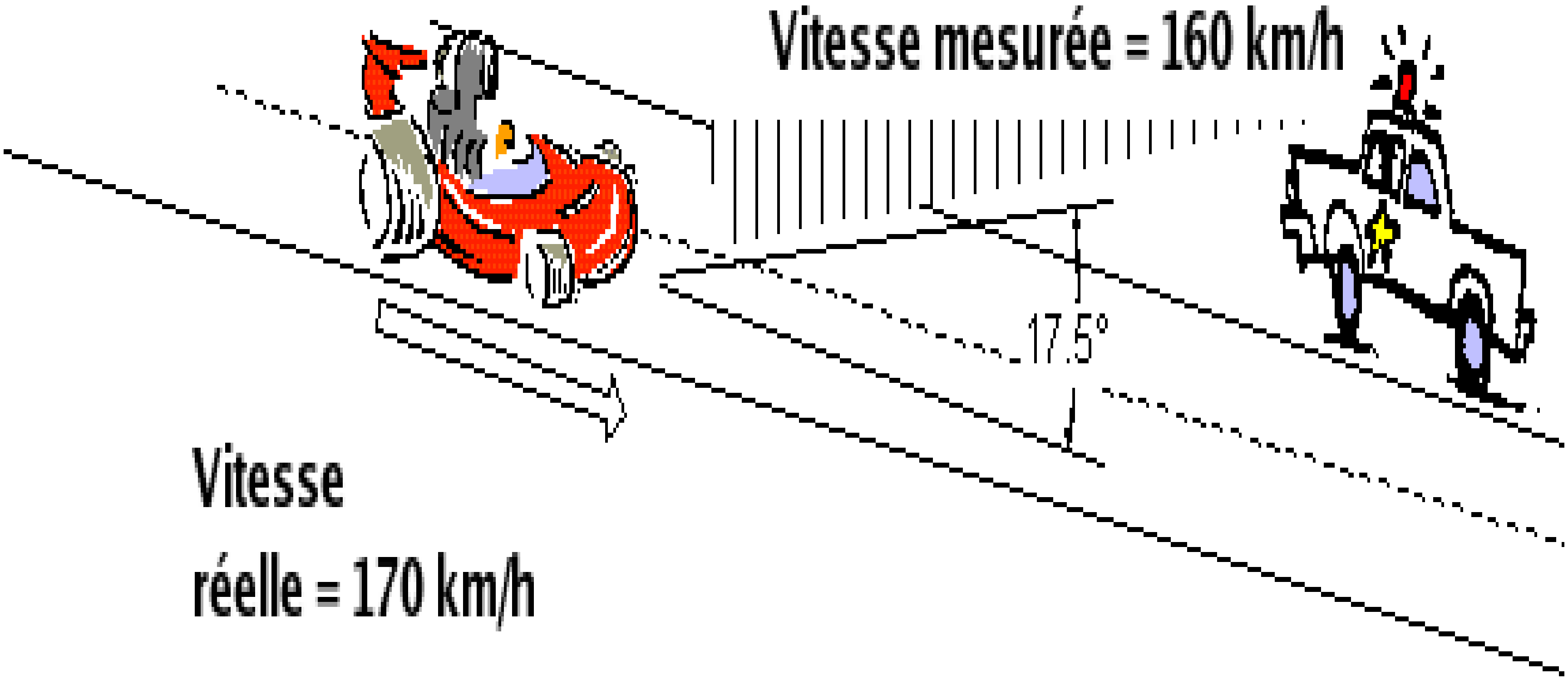


HAWK CW Tracking Illuminator (contd..)

- Employs semi active homing guidance
- CW is transmitted from an illuminator located at the launch platform
- R_x on the missile receives CW echo from the target
- Ground Radar is a tracking radar as well as an illuminator. It's Antenna follows the target through space.
- It is a low altitude missile defence system, as such large amount of clutter is present. Clutter is removed by the CW Radar allowing only Doppler frequencies.

TRAFFIC POLICE RADAR

- Application of CW Radar



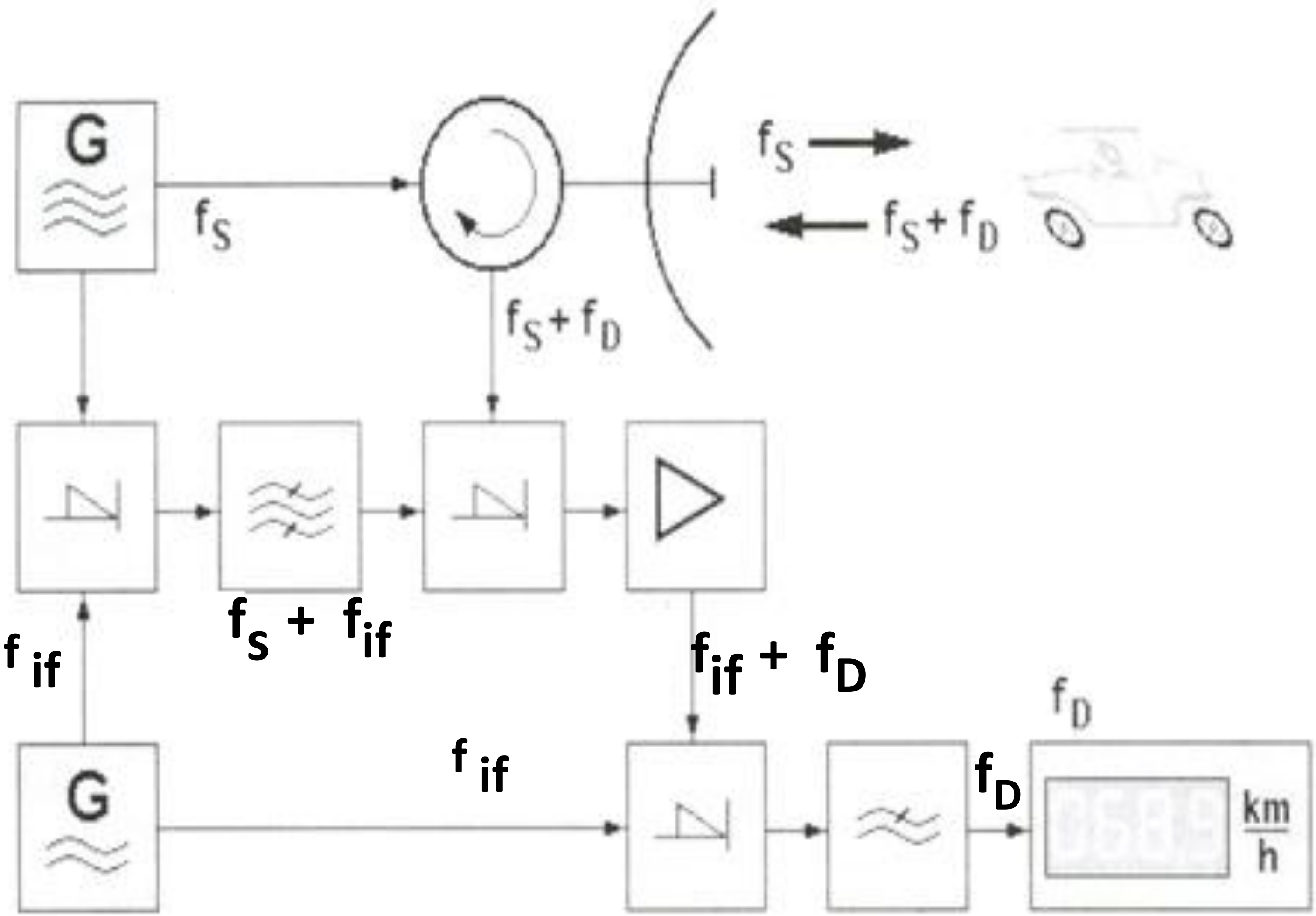
TRAFFIC POLICE RADAR (CONTD…)

TRAFFIC POLICE RADAR (CONTD…)

➢ Important Characteristics:

- Power level 1 to 100 mw (0 to 20 dBm)
- Antenna Gain = few hundreds
- If velocity of a speeding target exceeds a particular threshold, alarm is sounded.
- Doppler cycles counted for certain time and displayed
- Radial velocity is considered as the actual velocity, since the angle between target & Rx is small (cos θ is near to 1)

BLOCK DIAGRAM OF POLICE RADAR



APPLICATION OF CW RADAR

Automotive Applications

- Anti-Collision – Measures velocity to avoid accidents
- Parking Sensor – Measures distance to avoid collision
- Traffic Sensor – Detects flow or speed of traffic

ADVANTAGES AND DISADVANTAGES OF CW RADAR

- What are the advantages and disadvantages of CW radar?
- ADVANTAGES
- 1. Simple to design and manufacture compared to Pulse radar
- 2. Measures velocity of target accurately using the principle of Doppler
- 3. The echo frequency is shifted by the doppler frequency compared to transmitted frequency
- 4. The shifted frequency is propotional to the velocity of target

ADVANTAGES AND DISADVANTAGES OF CW RADAR

- DISADVANTAGES:

- 1. Can not measure the range of the target
- 2. Two antennas are required one for transmission and another for receiving.
- 3. Sufficient isolation is required between the transmitting and receiving antennas to protect the receiver from damage

CONTINUED IN RADAR 2 C

RADAR SYSTEMS
(EC 812 PE)
(ELECTIVE V)
UNIT – 2C
B.TECH IV YEAR II SEMESTER
BY

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CATEGORIES IN RADARS

SL. NO	TYPE RADAR	DETECTION	RANGE	VELOCITY	AZIMUTH ANGLE	ELEVATION ANGLE
1	PULSE	YES	YES	NO	YES	NO
2	CW	YES	NO	YES	YES	NO
3	FM CW	YES	YES	YES	YES	NO
4	PULSE DOPPLER	YES	YES	YES	YES	NO
5	TRACKING RADAR+ PULSE DOPPLER	YES	YES	YES	YES HIGH ACCURACY	YES HIGH ACCURACY

FREQUENCY MODULATED CW RADAR

FREQUENCY MODULATED CW RADAR

➢ Necessity for Frequency Modulation:

- Pure CW radar cannot measure the range of the target.
- With modulating the frequency , Range can be measured

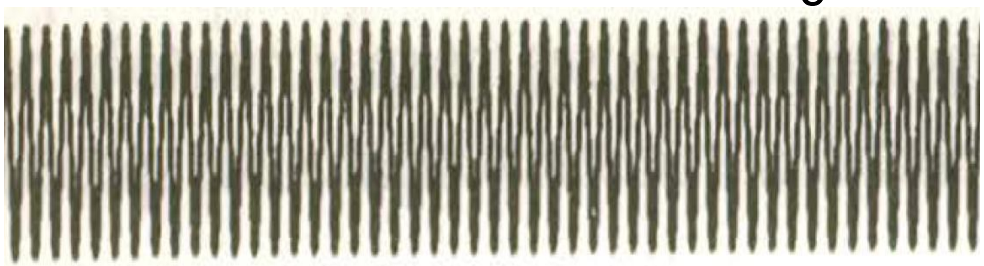
➢ Reasons for inability to measure range by CW Radar:

- some kind of timing mark (say the raising edge of pulse Radar) is necessary. Timing mark makes it possible to measure the time difference between transmission and receiving of echo. CW radar does not have Timing mark since the wave form is continuous

INABILITY TO MEASURE RANGE

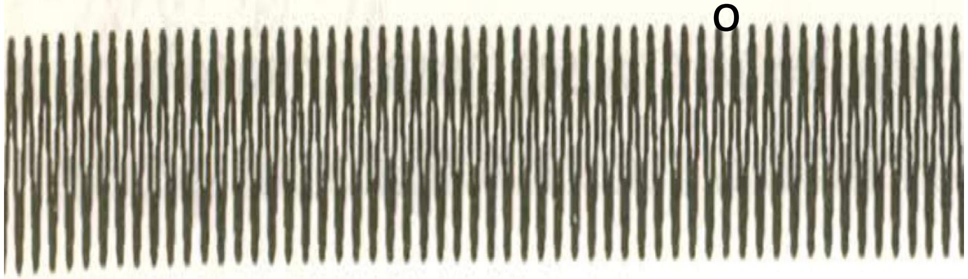
CW Radar

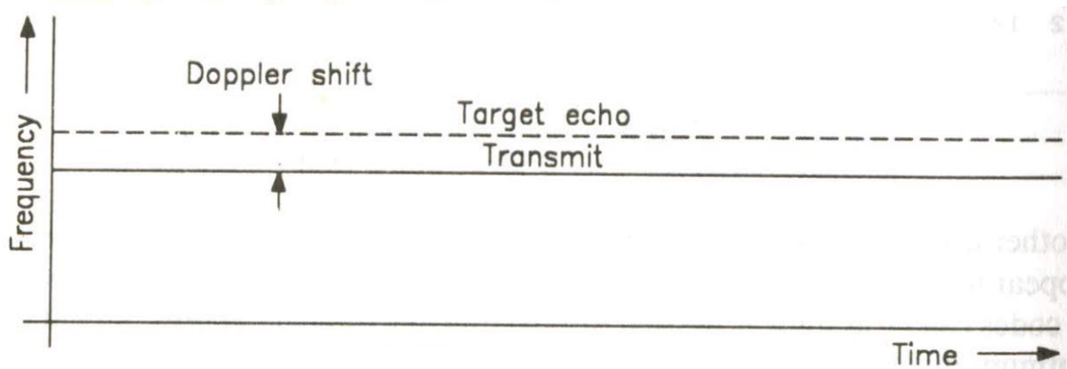
f_0



a. Time domain

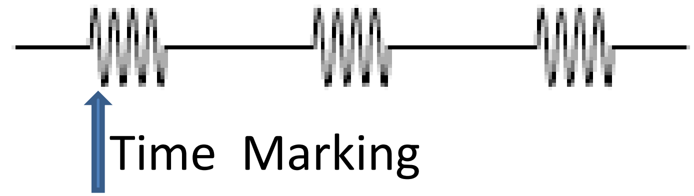
$f_0 + f_d$





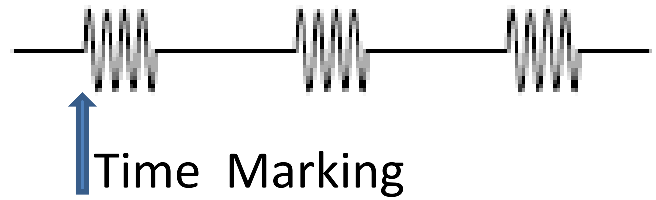
Pulse Radar

Tx Pulses



Time Marking

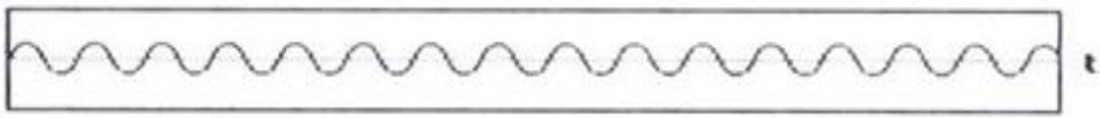
Echo Pulses



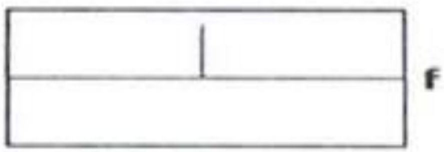
Time Marking

FREQUENCY MODULATED CW RADAR (CONTD..)

- Frequency spectrum :
- CW Radar:

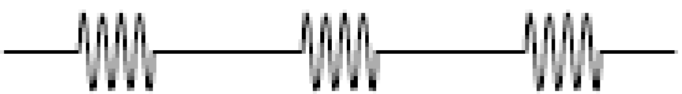


Time

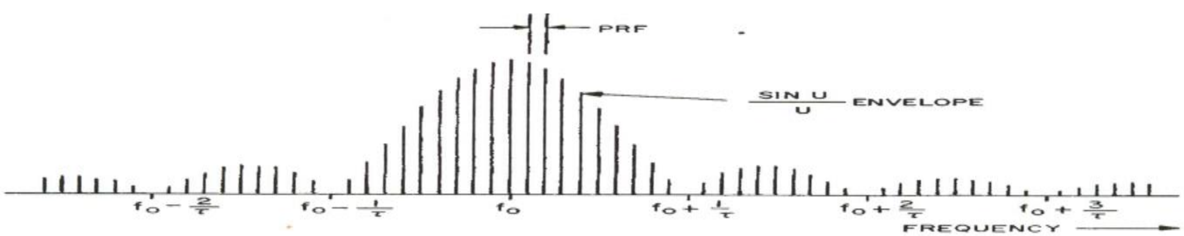


Frequency

- Pulse Radar:



Time



Frequency

FREQUENCY MODULATED CW RADAR (CONTD..)

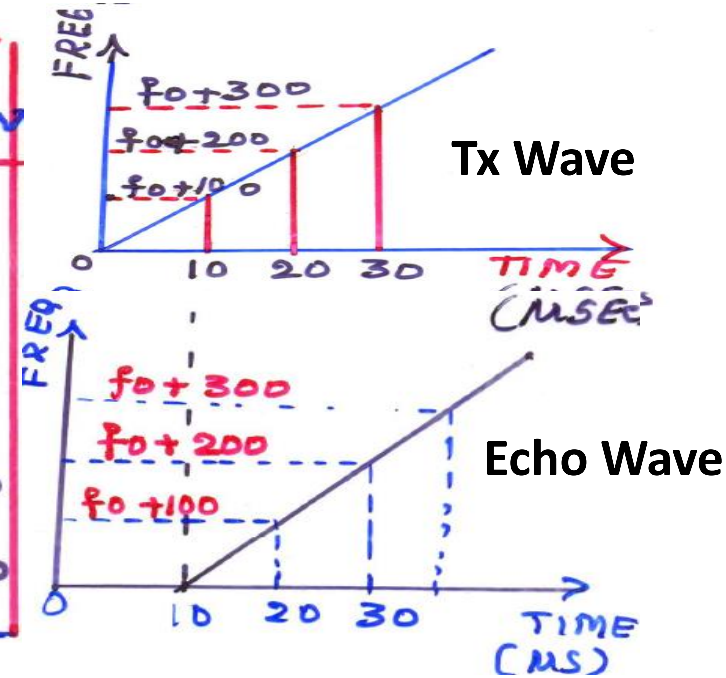
- In the frequency domain the timing mark means a broad spectrum is necessary (CW has a very narrow spectrum (B.W.))
- For accurate measurement of time difference, the timing marker should be sharp (distinct). This means the spectrum should be broader.
- Pulse Radar has a broader spectrum as such range is easily measureable.

RANGE BY MODULATING CW

- Timing mark is obtained by changing the frequency i.e., Modulating CW

❖ Let us say every $10_{\mu secs}$ frequency increases by 100 c/s

TIME μsecs	TRANSMISSION FREQUENCY	ECHO FREQUENCY
0	f_0	0
10	f_0+100	f_0
20	f_0+200	f_0+100
30	f_0+300	f_0+200
40	f_0+400	f_0+300



❖ Difference in frequency of Tx & Echo =100c/s

But 100c/s corresponds to $10_{\mu secs} \rightarrow$ 1500 mts.

Range of target = 1.5 Kms

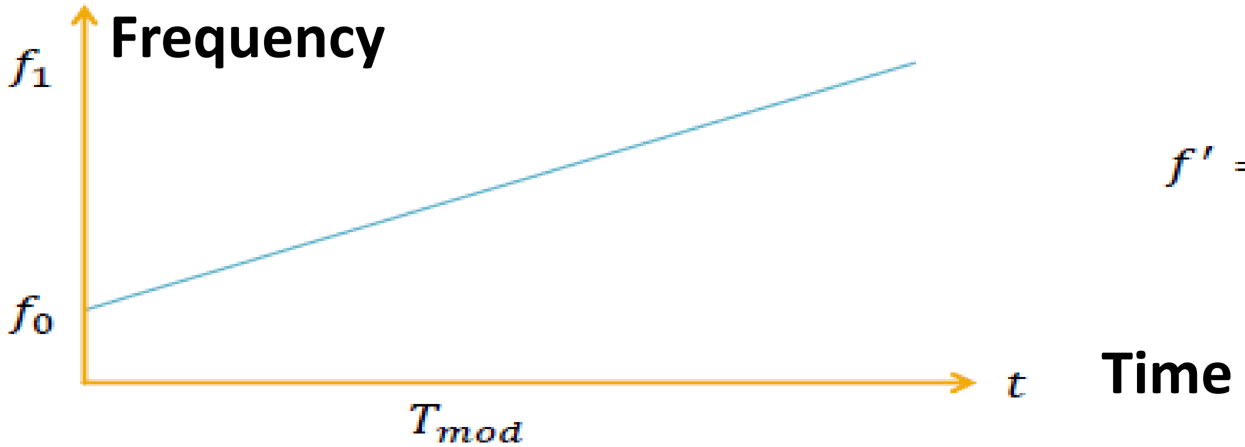
RANGE AND DOPPLER MEASUREMENT

FREQUENCY MODULATED CW RADAR (CONTD..)

- **Types of Frequency Modulation for CW:**
  1. Pulse Modulated CW(Pulse radar)
  2. Linear Frequency Modulation
  3. Saw tooth Frequency Modulation
  4. Triangular Frequency Modulation
  5. Sinesoidal Frequency Modulation

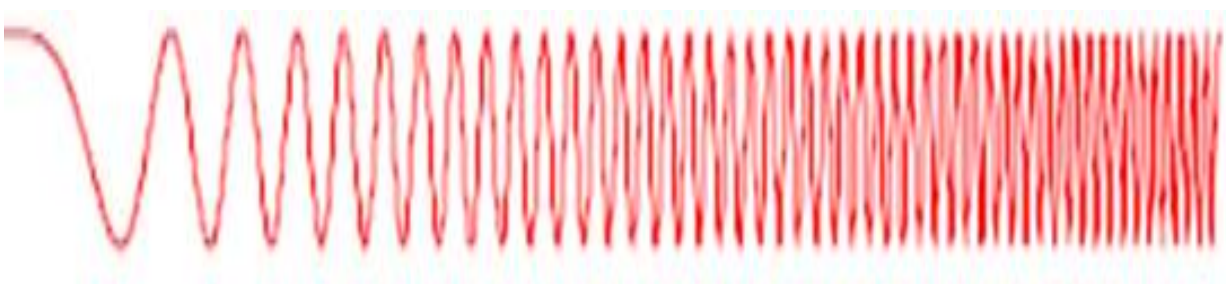
LINEAR FREQUENCY MODULATION

- In frequency domain it is a Linear Ramp



$$f' = \frac{f_1 - f_0}{T_{mod}}$$

In Time Domain it is called Chirp



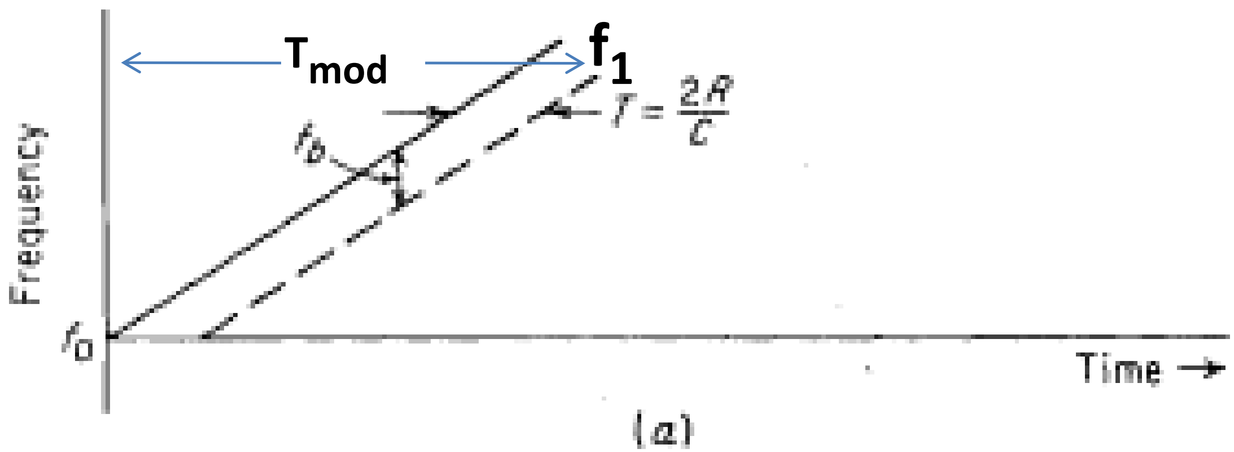
QUESTIONS

1. Derive an expression for range & doppler measurment for a FM CW Radar (for doppler derivation see earlier slides)

2. Explain the operation of FM-CW Radar when modulation is linear and triangular and target is assumed to be stationary with the help of neat sketches

3. Derive an expression for range frequency in case of FM CW radar

LINEAR FREQUENCY MODULATION (CONTD…)



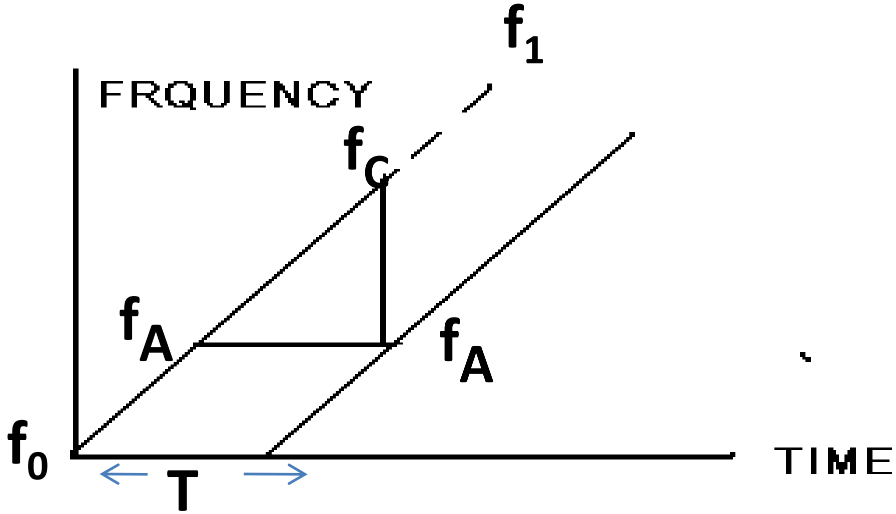
Rate of change of carrier frequency =

$$\dot{f}_o = \frac{f_1 - f_o}{T_{mod}}$$

LINEAR FREQUENCY MODULATION (CONTD…)

- R_X is mixed with T_X and passed through a low pass filter , to obtain beat frequency f_b
- f_b is the difference between f_d (Doppler frequency) and f_r (frequency due to the target's range)
- If the target is stationary ($f_d = 0$) then $f_b = f_r$
- f_r is the difference in frequency between T_X and R_X signals due to range
- T = Time difference between T_X and R_X ramps
- $f_r = \dot{f}_o T = \dot{f}_o \frac{2R}{C} = \frac{f_1 - f_0}{T_{mod}} \times \frac{2R}{C}$

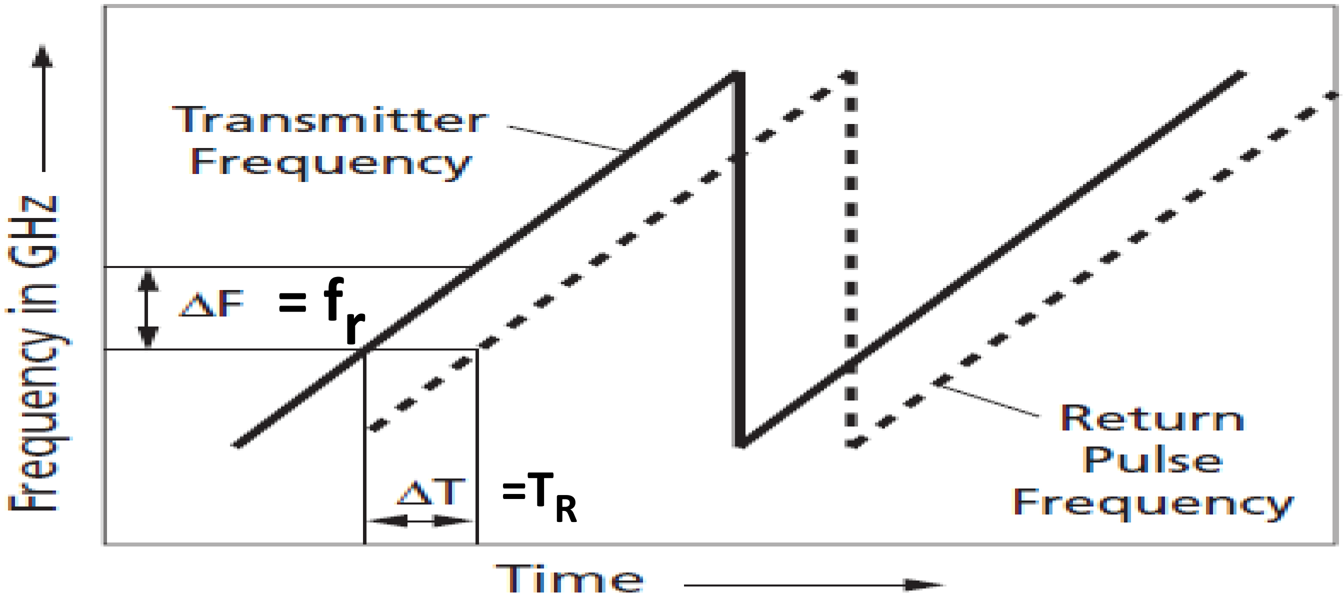
LINEAR FREQUENCY MODULATION (CONTD…)

- 

- $(f_C - f_A) = f_r$ = Beat frequency because of Range
- But $\dfrac{(f_C - f_A)}{T} = \dot{f}_0$
- Where $f_r = (f_C - f_A) = \dot{f}_0 T = \dot{f}_0 \dfrac{2R}{C}$

SAW TOOTH FREQUENCY MODULATION

- In practice , frequency cannot be continually changed indefinitely. Periodicity in modulation is necessary.
- **Saw tooth modulation**



TRIANGULAR FREQUENCY MODULATION

- Triangular modulation is more popular and easy to implement
- 4 distinct cases arise in measurement of range and radial velocity

4 Cases:

(i) Target at Range R ($f_r \neq 0$) but not moving ($f_d = 0$)

(ii) Target at Range R =0 (hypothetical) ($f_r = 0$) but moving ($f_d \neq 0$)

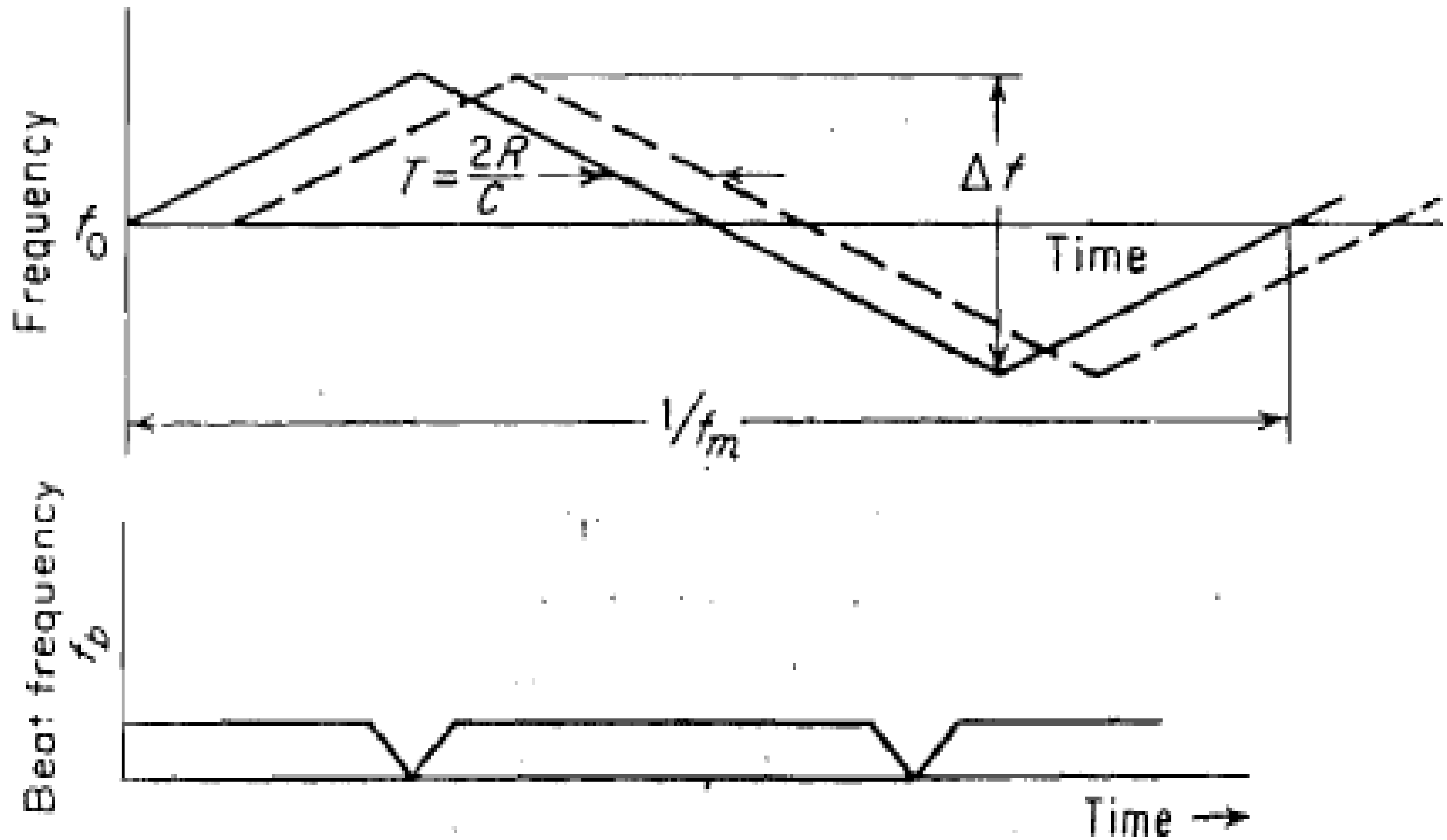
(iii) Target at Range R ($f_r \neq 0$) ,moving ($f_d \neq 0$) target approaching but $f_r > f_d$

(iv) Target at Range R ($f_r \neq 0$) ,moving ($f_d \neq 0$) target approaching but $f_r < f_d$ (high speed at short range)

TRIANGULAR FREQUENCY MODULATION (CONTD..)

- **Case (i)**

Target at Range R ($f_r \neq 0$), not moving ($f_d = 0$)



TRIANGULAR FREQUENCY MODULATION (CONTD..)

- Since $f_r = \frac{2R}{C}\dot{f_o}$

- Rate of change of frequency $= \dot{f_o} = \frac{\Delta f}{\frac{1}{2 f_m}}$

  Where Δf = Maximum frequency – Minimum frequency

- $\frac{1}{f_m}$ = period of one cycle of triangular wave

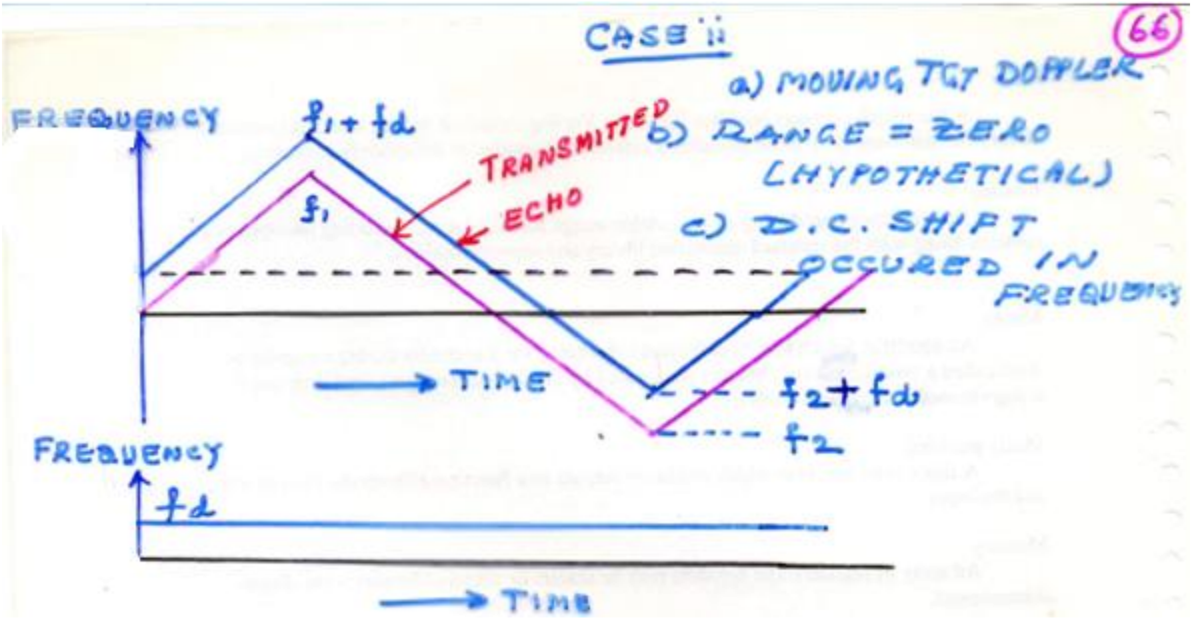
- Substituting $\dot{f_o}$ in f_r

- $f_r = \frac{2R}{C}\dot{f_o} = \frac{2R}{C}\frac{\Delta f}{[\frac{1}{2 f_m}]} = \frac{4 R f_m \Delta f}{C}$

- **Inference: Echo wave is shifted in Time Axis**

Triangular Frequency Modulation (Contd..)

- **Case (ii):Target Range R= 0 (f_r=0); moving ($f_d \neq 0$)**
- The above is a hypothetical target. Does not exist in practice.

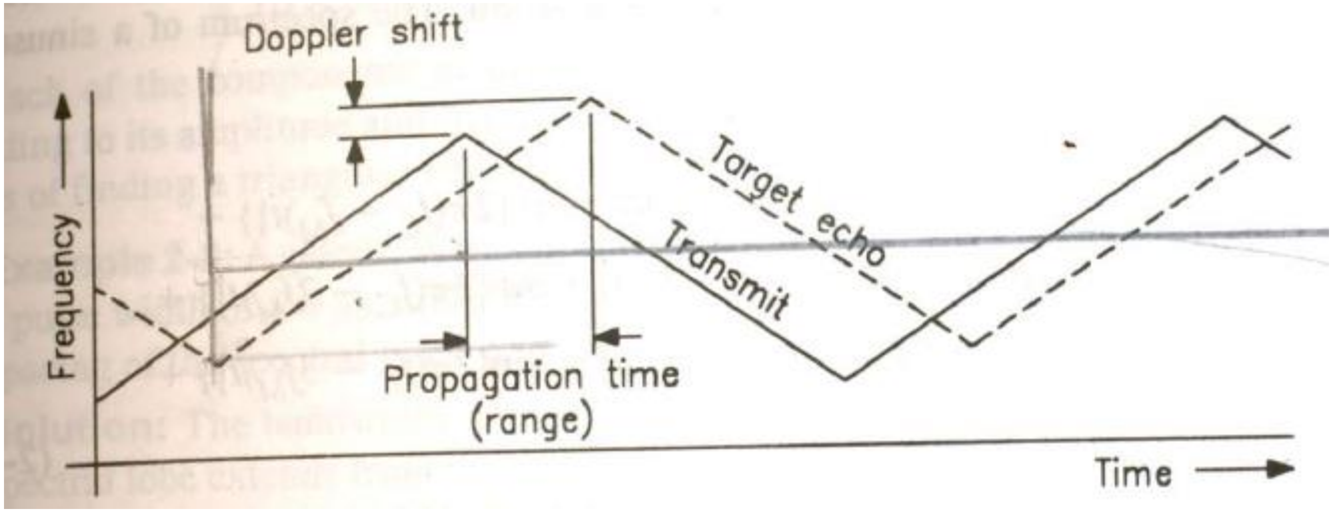


- **Inference: Echo wave is shifted in frequency Axis.**

TRIANGULAR FREQUENCY MODULATION (CONTD..)

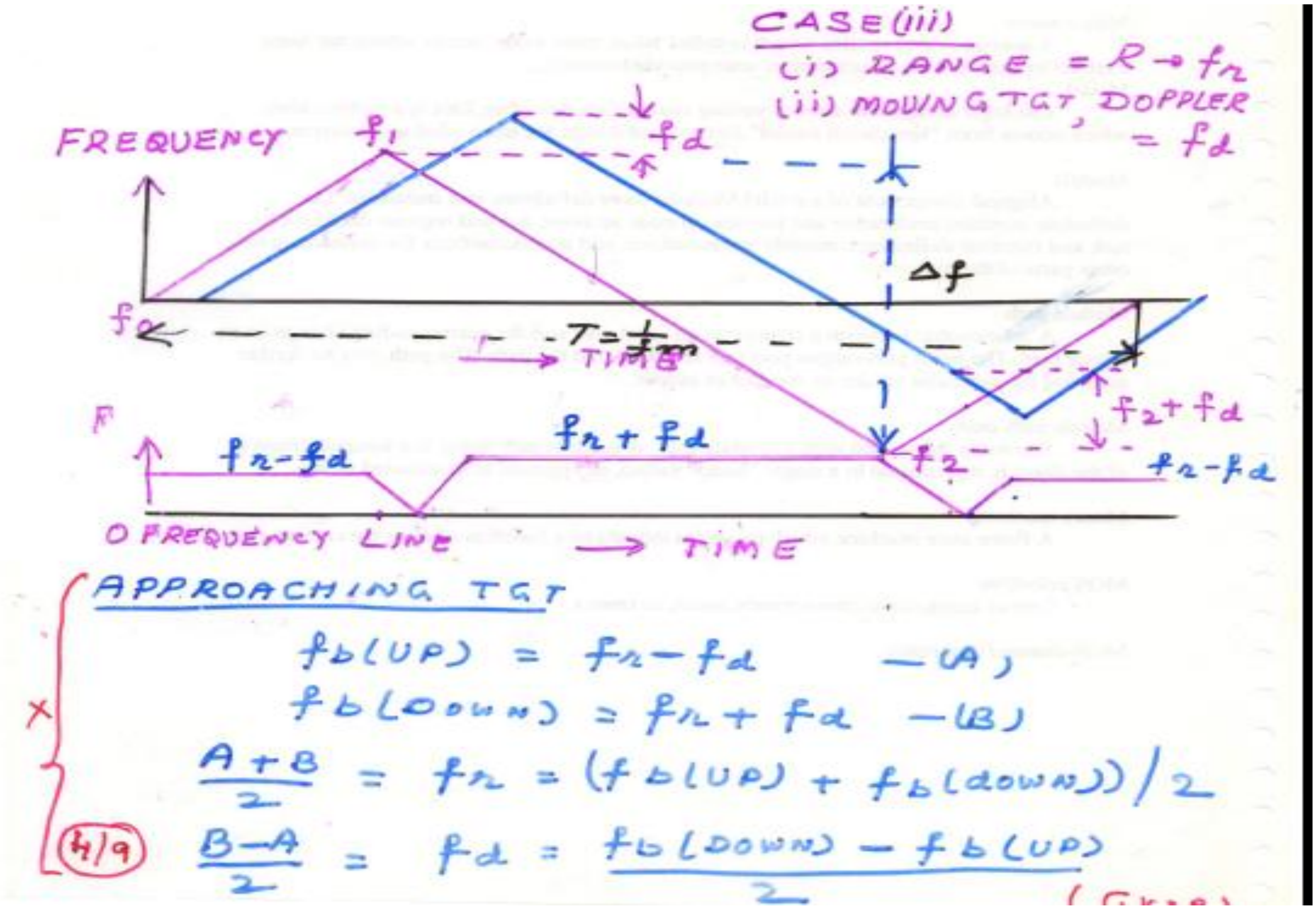
- **Case (iii) Target at Range R ($f_r \neq 0$), moving ($f_d \neq 0$), approaching target, but $f_r > f_d$**

- f_r beat frequency for Range shifts the curve laterally sideways (time axis)
- f_d beat frequency for Doppler shifts the curve up vertically (frequency axis).



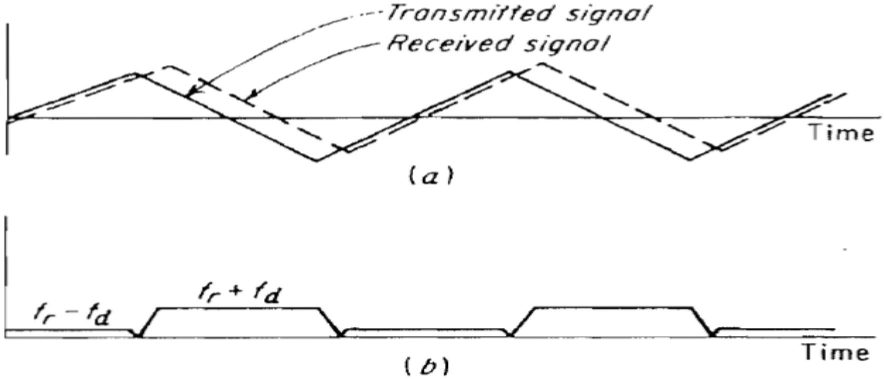
TARGET AT RANGE R ($f_R \neq 0$) , APPROACHING TARGET

- .



TARGET AT RANGE R ($f_R \neq 0$) , APPROACHING TARGET

- f_b (Up) = $f_r - f_d$
- f_b (down) = $f_r + f_d$



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

- f_b (up) and f_b (down) are measured separately by switching frequency counter every half modulation cycle

TRIANGULAR FREQUENCY MODULATION (CONTD..)

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

- Roles of Averaging & Difference measurements are reversed
- Average meter measures Doppler velocity
- $f_d = \dfrac{f_b(up) + f_b(down)}{2}$
- Difference meter measures Range
- $f_r = \dfrac{f_b(down) - f_b(up)}{2}$

PROBLEMS

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

PROBLEMS

- $fr = \dfrac{4\ R\ f_m\ \Delta f}{C}$
- $25\ \times\ 10^3\ = \dfrac{4\ R \times\ 1 \times\ 10^6\ \times\ 1 \times 10^3}{3 \times 10^8}$
- R = 1875 meters
- $f_d = \dfrac{f_b(\text{down}) -\ f_b\ (\text{up})}{2} = \dfrac{30\ \times 10^3 -\ 20 \times\ 10^3}{2}$
- = 5000Hz

PROBLEMS

Problem 2: A CW Radar has center frequency of 10.0 GHZ and triangularly sweeps a bandwidth of 2.0 MHZ at 200 HZ rate. The frequency difference between transmit and receive in the up swing is 65510 and on downswing 82650 HZ. What is the target range and radial velocity.

- Solution: Approaching target is assumed.

$$f_r = \frac{f_b\,(up) + f_b\,(Down)}{2}$$

$$f_r = \frac{(65510 + 82650)}{2} = 74080\ Hz$$

$$R = \frac{f_r\ C}{4\ \Delta f\ f_m} = \frac{74080 \times 3 \times 10^8}{4\ \times 2\ \times\ 10^6 \times 200} =$$

13890 mts =13.89 Kms

PROBLEMS

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

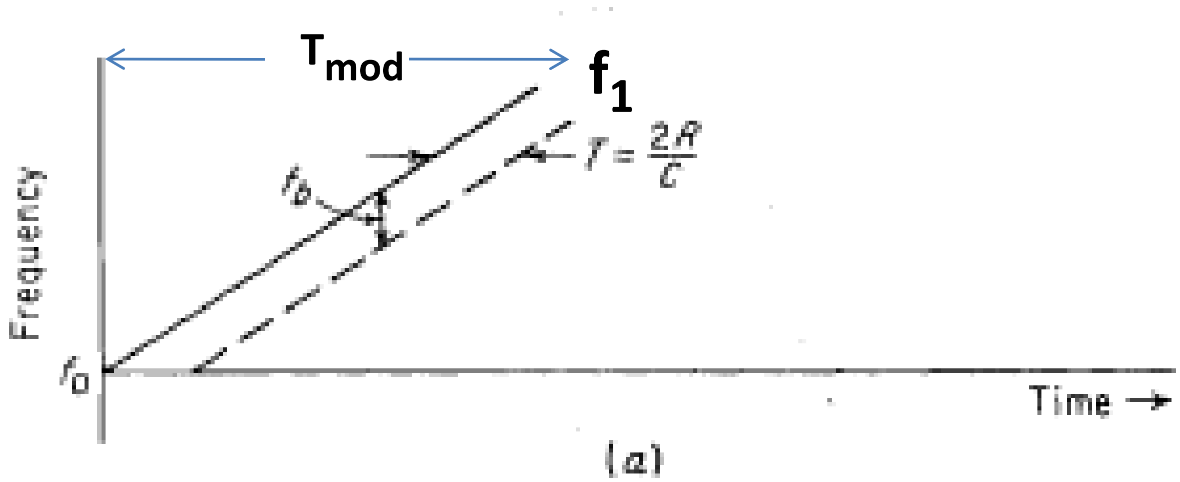
$f_d = \frac{82650 - 65510}{2} = 8570$

$f_d = \frac{2\ V_r}{\lambda} = \frac{2\ V_r\ f}{C}$

So $V_r = \frac{C\ f_d}{2\ f} = \frac{3 \times 10^8 \times 8570}{2 \times 10 \times 10^9}$

V_r = 128.55 Mt/sec

LINEAR FREQUENCY MODULATION



Rate of change of carrier frequency =

$$\dot{f_0} = \frac{f_1 - f_0}{T_{mod}}$$

$$f_b = f_r = \dot{f_0}\,T = \dot{f_0}\,\frac{2R}{C} = \frac{f_1 - f_0}{T_{mod}} \times \frac{2R}{C}$$

PROBLEMS

Problem 3: In an FM CW Radar the frequency changes by 2000 Hz every micro second. What will be the beat frequency if a target is at 8000 ft away from a radar.

Rate of change of frequency = $\dot{f}_0 = \frac{f_1 - f_0}{T_{mod}}$

Rate of change of frequency = $\frac{2000}{1 \times 10^{-6}} = 2 \times 10^{9}$ Hz/sec

R = $8000 \times \frac{12 \times 2.54}{100} = 2438.4$

$f_r = \dot{f}_0 \, T = \dot{f}_0 \, \frac{2R}{C}$

$f_r = \frac{2 \times 10^{9} \times 2 \times 2438.4}{3 \times 10^{8}} = 32512 \text{ Hz}$

PROBLEMS

Problem 4: An FM CW Radar transmits a triangular frequency modulation in which the frequency changes 1000 Hz every micro second. Show how a filter bank can be included in the radar to produce a range resolution of 1000 ft. What should be band width of each filter be

- Solution:

R = 1000 ft = $\frac{1000 \times 12 \times 2.54}{100}$ = 304.8 Mt =

$T_R = \frac{2\ R}{C} = \frac{2 \times 304.8}{3 \times\ 10^8} = 2.034 \times 10^{-6}$ sec

f_r = rate of change of frequency $\times T_R$

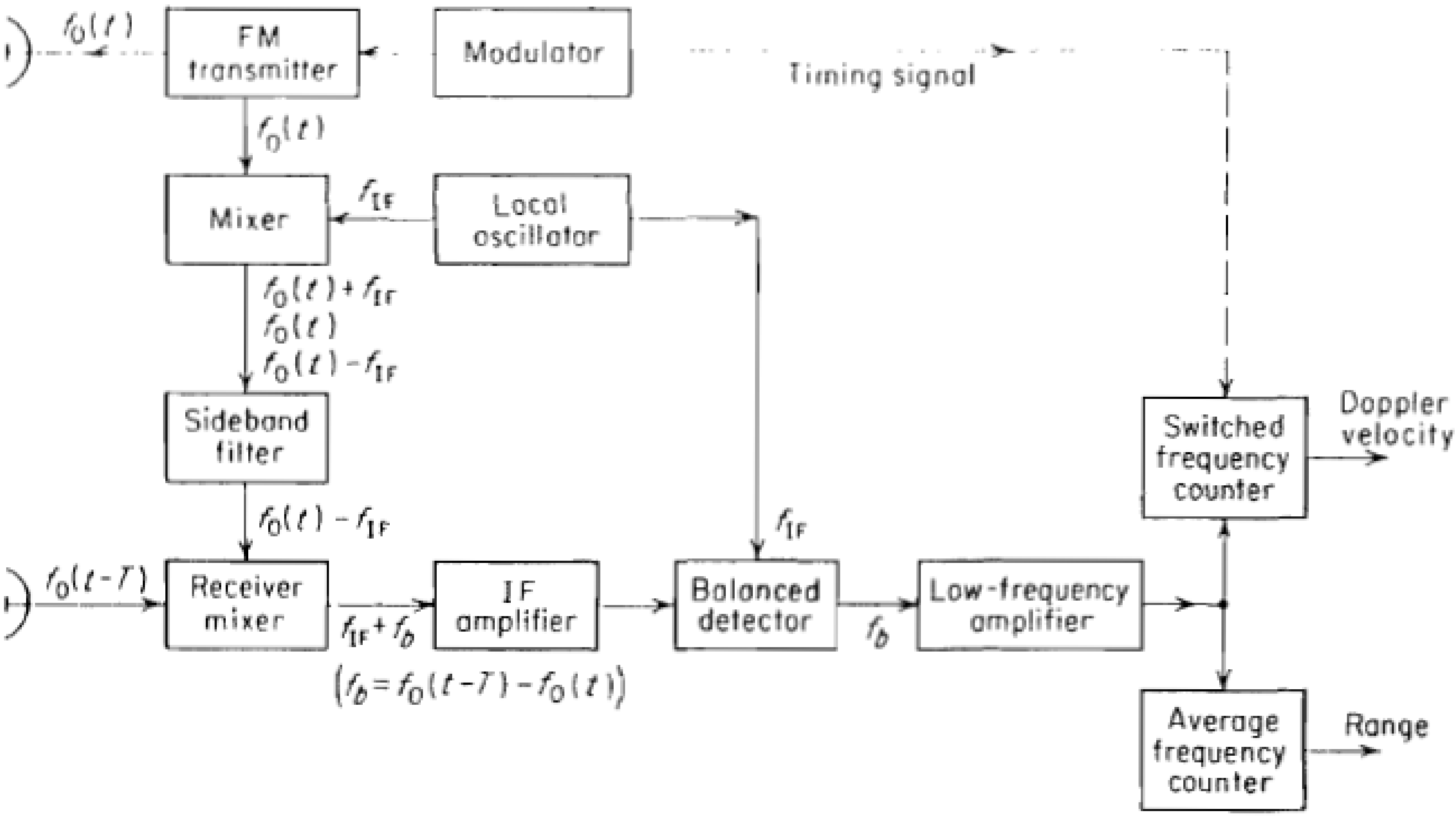
$f_r = \frac{1000}{10^{-6}} \times\ 2.034 \times 10^{-6} = 2034$ Hz

Band width of filter = 2000 Hz

FM-CW RADAR

BLOCK DIAGRAM OF FM-CW RADAR

- **FM CW RADAR:**



BLOCK DIAGRAM OF FM-CW RADAR

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

CONTINUED IN RADAR 2 D

RADAR SYSTEMS
(EC 812)
(ELECTIVE V)
UNIT – 2D
B.TECH IV YEAR II SEMESTER
BY

Prof.G.KUMARASWAMY RAO
(Former Director DLRL Ministry of Defense)
BIET

Acknowledgements

The contents , figures , graphs etc., are taken from the following Text book & others

“ INTRODUCTION TO RADAR SYSTEMS “

Merill I.Skolnik

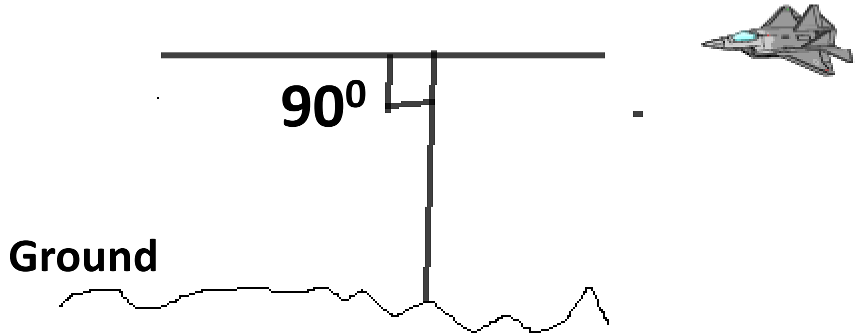
Second Edition

Tata McGraw – Hill publishing company

Special Indian edition

FM-CW ALTIMETER

PRINCIPLE OF FM-CW ALTIMETER



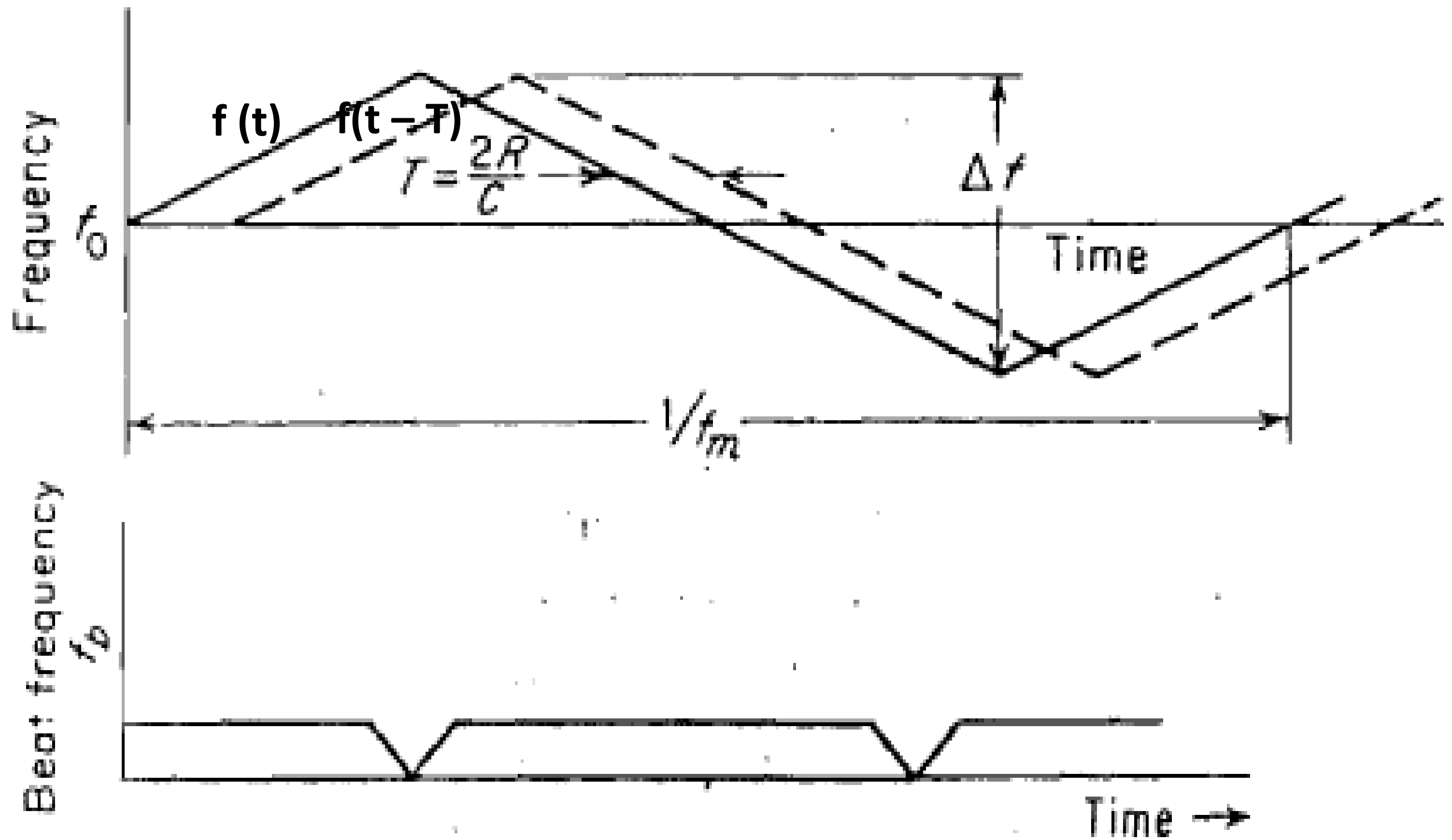
- ➢ Radio (FM-CW) Altimeter measures the height of the aircraft above the surface of Earth.
- Earth is a large scatter . Its RCS is very high.
- Relatively short (heights) ranges are required to be measured by aircraft(say max 25 Kms). So low power transmitter can be used. Antenna size also can be small(low gain)

PRINCIPLE OF FM-CW ALTIMETER

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

TRIANGULAR FREQUENCY MODULATION

Height of aircraft/ Helicopter h = R and f_d=0

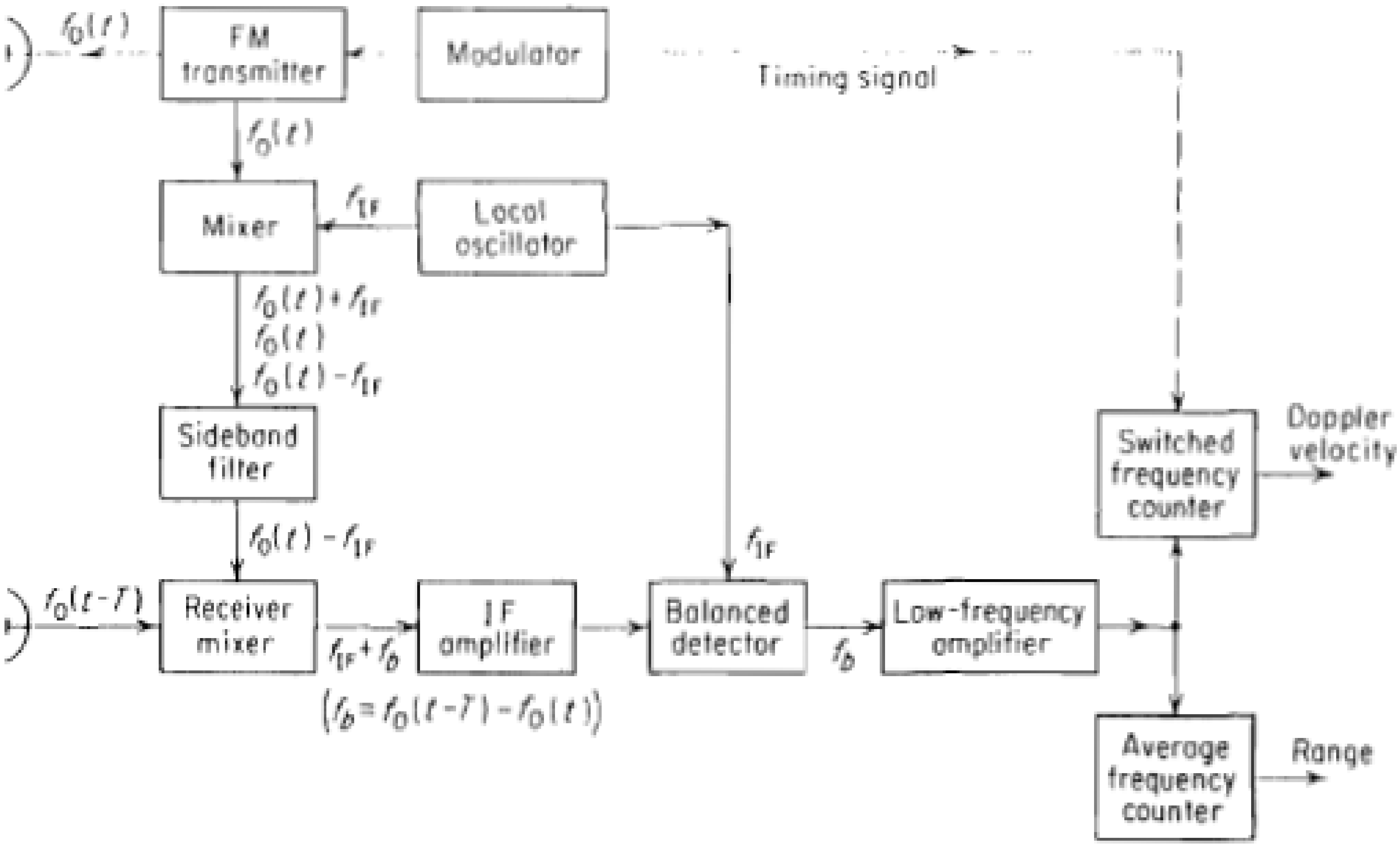


FM-CW ALTIMETER (CONTD..)

- Frequency Band reserved for Radio Altimeter is 4.2 to 4.4 GHZ
- T_X power is low (Max.height 25kms)
  - CW Magnetron
  - Back ward – wave oscillator
  - Reflex Klystron
  - Solid state Amplifier
- Radio Altimeter uses either

  (i) Homodyne R_X or(ii) Super heterodyne R_X
- For better sensitivity & stability super heterodyne R_X is preferred

BLOCK DIAGRAM OF RADIO ALTIMETER



BLOCKS OF RADIO ALTIMETER

- (i) FM TX & Modulator:
- High power FM-CW is generated and applied to TX antenna.
- (ii) Antenna :
- Separate antennas are used for

  (i) Transmission and

  (ii) Reception of Echo
- (iii) Local Oscillator :
- Fixed frequency f_{IF} generated and applied to (a) Mixer & (b) Balanced detector. This is the IF frequency used in the system.

BLOCKS OF RADIO ALTIMETER (CONTD ..)

- (iv) Mixer :

  Inputs

  (a) $f_0(t)$ portion of FM transmitted signal
  (frequency varying with time)

  (b) f_{IF} fixed frequency from L O

  outputs

  (a) $f_0(t) + f_{IF}$ upper side band

  (b) $f_0(t)$ transmitted frequency

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

- (V) Sideband Filter :

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

BLOCKS OF RADIO ALTIMETER (CONTD ..)

➢ (VI) Receiver Mixer

- Inputs a) $f_0\ (t - T)$
  b) $f_0\ (t) – f_{IF}$
- Outputs : $f_{IF} + f_b$ where $f_b = f_0((t - T) – f_0\ (t)$
  Where f_b is composed of f_r (range frequency) and f_d (Doppler frequency)

➢ (VII) IF Amplifier:

- $f_{IF} + f_b$ is amplified

➢ (VIII) Balanced Detector:

- Inputs (a) f_{IF}
- (b) $f_{IF} + f_b$
- Output: f_b

BLOCKS OF RADIO ALTIMETER (CONTD ..)

- (IX) Low-Frequency Amplifier:
  - Low frequency f_b is amplified to match the level of indicator
- (X) Average Frequency Counter:
  - The input is the amplified f_b
  - Frequency counter is calibrated in terms height
  - $h = \frac{f_r C}{4 f_m \Delta f}$ since $f_b = f_r$
- (X I) Switched Frequency Counter
- The input is the amplified f_b
- since $f_d = 0$, this counter reads zero

QUESTION

1. Explain how the noise signals are limiting the performance of FM altimeter

BLOCKS OF RADIO ALTIMETER (CONTD ..)

➢Necessity for shaping of Gain of Low Frequency Amplifier:

- The swing of echo signal is large. It depends on height
- It is desirable to shape the gain characteristics such that the output of the amplifier remains constant inspite of large swing in input echo power.
- The variation in echo power occurs due to
  (i) Change of height (Range)

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

  (ii) Change in area of ground scattering σ (RCS) due to change in height of Antenna.

GAIN CHARACTERISTICS OF AMPLIFIER

➢ (i) Change of height (range)

$$\text{Echo Power} \propto \frac{1}{\text{Height}^4}$$

- Doubling (Octave) of height decreases echo power by

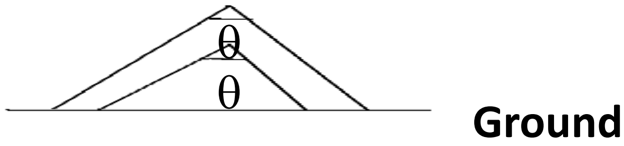
  16 times (10 log 16 = 12dB) $f_r = \frac{4\,h\,f_m\,\Delta f}{C}$
- At low height, beat frequency f_r is low

  but echo power is high. So gain should be low.
- At larger height beat frequency f_r is high but echo

  power is low. So gain should be high.
- The Echo power has a negative slope of 12dB/octave. The Gain characteristic should have a positive slope of 12 dB/octave, to keep the output of the Amplifier constant.

GAIN CHARACTERISTICS OF AMPLIFIER (CONTD ..)

➢ Change in height of Antenna:

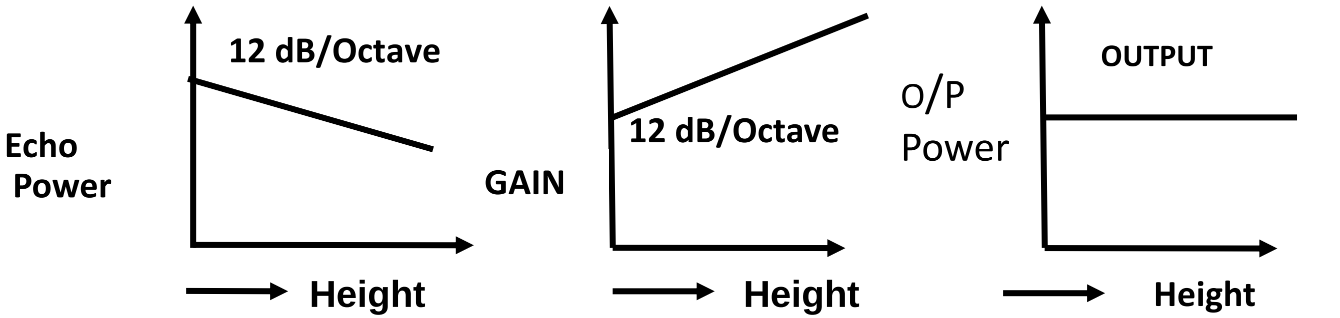


- As the height of transmitter Antenna is increased, the echo area illuminated by the antenna increases. As such RCS increases
- Echo Power α area α height ^{2}
- Doubling (octave) of height increases power by 4 times (10 log 4 = 6dB). Echo power has a positive slope of 6 dB/octave.
- At low height fr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

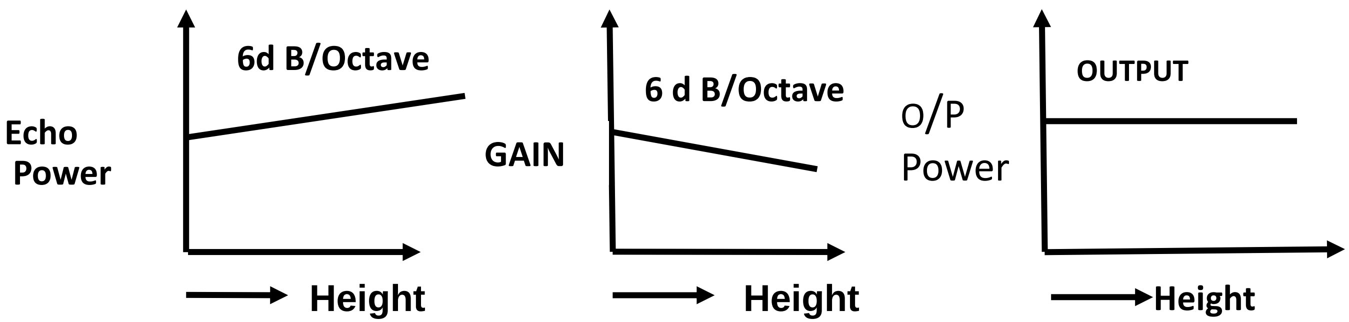
GAIN CHARACTERISTICS OF AMPLIFIER (CONTD ..)

➢ Combined Gain Characteristics:

(i) Due to height in Radar Equation



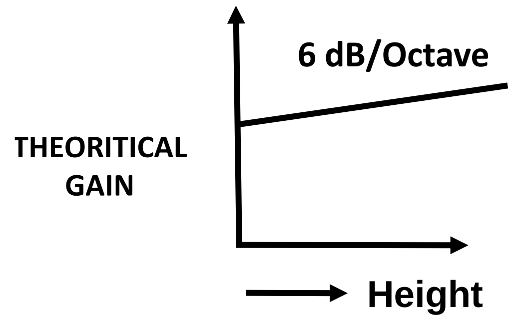
(ii) Due to Antenna Height:

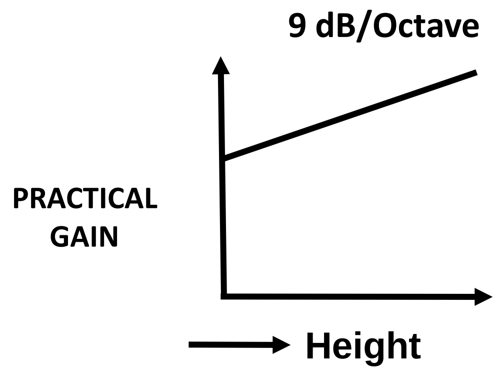


GAIN CHARACTERISTICS OF AMPLIFIER (CONTD ..)

(iii) Combined Gain Characteristics:

- Combined theoretical Gain characteristic has (12−6) = 6dB/octave with positive slope





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

BLOCKS OF RADIO ALTIMETER (CONTD ..)

➢ Low-Frequency Amplifier (Contd ..)

- **Advantages of Gain shaping :**

(i) Gain shaping makes the output of Amplifier constant , Thus lowers the dynamic range.

(ii) Flicker noise is high at low frequencies. Since the gain of Amplifier is small at low frequencies , the overall S/N is better

(iii) At low heights, the signal from unwanted reflections is large. But Gain of Amplifier is small at low frequencies (low height). The overall S/N is better.

BLOCKS OF RADIO ALTIMETER (CONTD ..)

➢ Low-Frequency Amplifier (Contd ..)

- **Method to reduce noise by using a narrow band filter**
- $f_r = \dfrac{4\,h\,f_m\,\Delta f}{C}$

  f_r will have a band of frequencies because of minimum and maximum heights
- Noise is more for a large band of frequencies (N =KTB)
- f_r is maintained constant by varying Δf (excursion of minimum and maximum frequencies) by a servo loop.

This reduces 'B' and there by Noise.

- The value of Δf is a measure of altitude.

MEASUREMENT ERRORS

MEASUREMENT OF ERRORS IN RADIO ALTIMETER

- At low altitudes the absolute accuracy is of more importance than at high altitudes

Example: Error of 5 mts. is not of much concern when the aircraft is flying at a height of 10 kmts compared to when it is cruising at low altitude especially when it is blind landing.

- Theoretical accuracy depends on
  (i) Band width of transmitted signal
  (ii) S/N ratio
  (iii) Measurement accuracy

MEASUREMENT ERRORS

- Measurement Errors occur due to practical restrictions like

i) Accuracy of measuring device

ii) Residual path length error caused by transmission lines and circuit delays

iii) Errors caused by multiple reflections

iv) Transmitter leakage

v) Frequency error due to turn-around of frequency modulation

MEASUREMENT ERROR (CONTD ..)

➢ (i) Frequency Measuring Device Error:

- Cycle counter measures only integral cycles and not fraction of a cycle. This is called Quantization error.
- N = Average No. of cycles of f_r in one period of modulation cycle = $\frac{\text{Average } f_r}{f_m}$
- But $f_r = \frac{4\,h\,f_m\,\Delta f}{C}$
- $\frac{f_r}{f_m} = N = \frac{4\,h\,\Delta f}{C}$

Therefore $h = \frac{C\,N}{4\,\Delta f}$

FREQUENCY MEASURING DEVICE ERROR (CONTD ..)

- **Since N is an integral number**

Quantization error $\delta R = \frac{\mathbf{C}}{\mathbf{4\,\Delta f}}$

$$\delta R\ (\text{mts}) = \frac{75}{\Delta f(\text{MHz})}$$

- Quantization error is not a function of altitude or carrier frequency but depends on Δf (Frequency Excursion)
- So for quantization error (δR) to be low Δf should be large.

FREQUENCY MEASURING DEVICE ERROR (CONTD ..)

➢ Method to reduce Quantization Error :

- δR is reduced by wobbling the modulation frequency or phase of transmission.
- The cycle counter reads the average of N and N+1 given by each cycle of modulation.
- Averaging reduces δR in cases of Normal fluctuations in altitude due to

  i) Uneven ground terrain

  ii) Waves on water

  iii) Turbulent air

MEASUREMENT ERRORS (CONTD ..)

- **Other causes for measurement Errors**

  i) Variation in Transmitter frequency

  ii) Variation in Modulation frequency

  iii) Variation in frequency excursion.

  iv) Target motion

  Error in height = $v_r \; T_0$

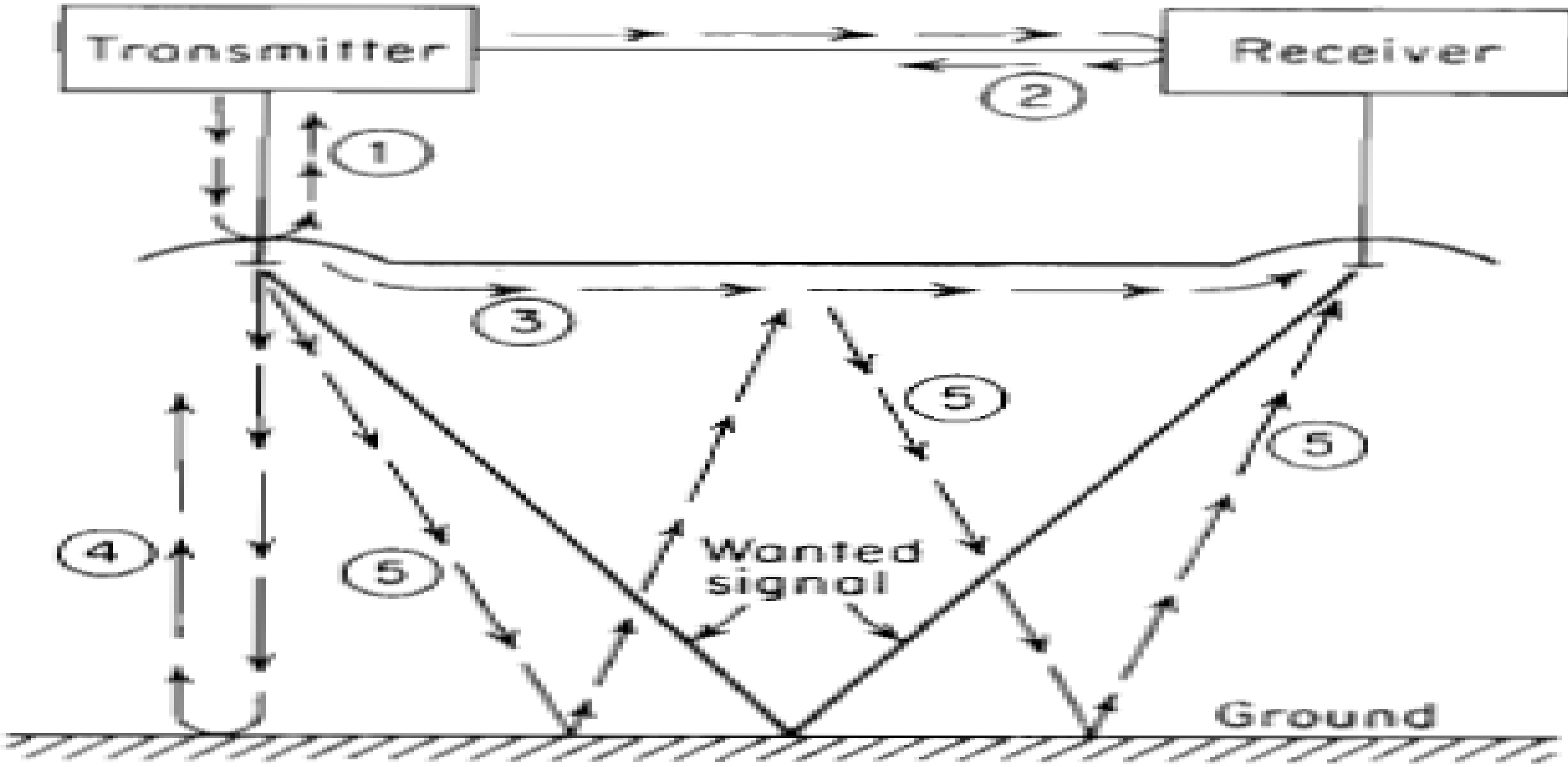
  Where T_0 = observation Time and

  v_r = relative velocity

  v) Residual path errors due to delays in the circuitry and transmission time. This becomes significant percentage at low altitudes.

MEASUREMENT ERRORS (CONTD ..)

➢ vi) Multi path error



- **Wanted signal is shown by solid line**

MULTIPATH ERROR (CONTD ..)

- **The unwanted Multipath Signals are**

  (a) Reflection of transmitted signal at the antenna caused by impendence mismatch

  (b) Standing wave pattern on the cable feeding the reference signal to R_x , due to poor mismatch

  (c) Leakage signal entering R_x via coupling between T_x and R_x antennas

  (d) Interference due to power being reflected back to T_x causing a change in impedance. applicable at low altitudes.

  (e) Double bounce signal

MEASUREMENT ERRORS (CONTD ..)

➢ **vii) Transmitter Leakage:**

- Sensitivity is limited by the noise leaked into Rx from the Tx
- Techniques used to overcome are

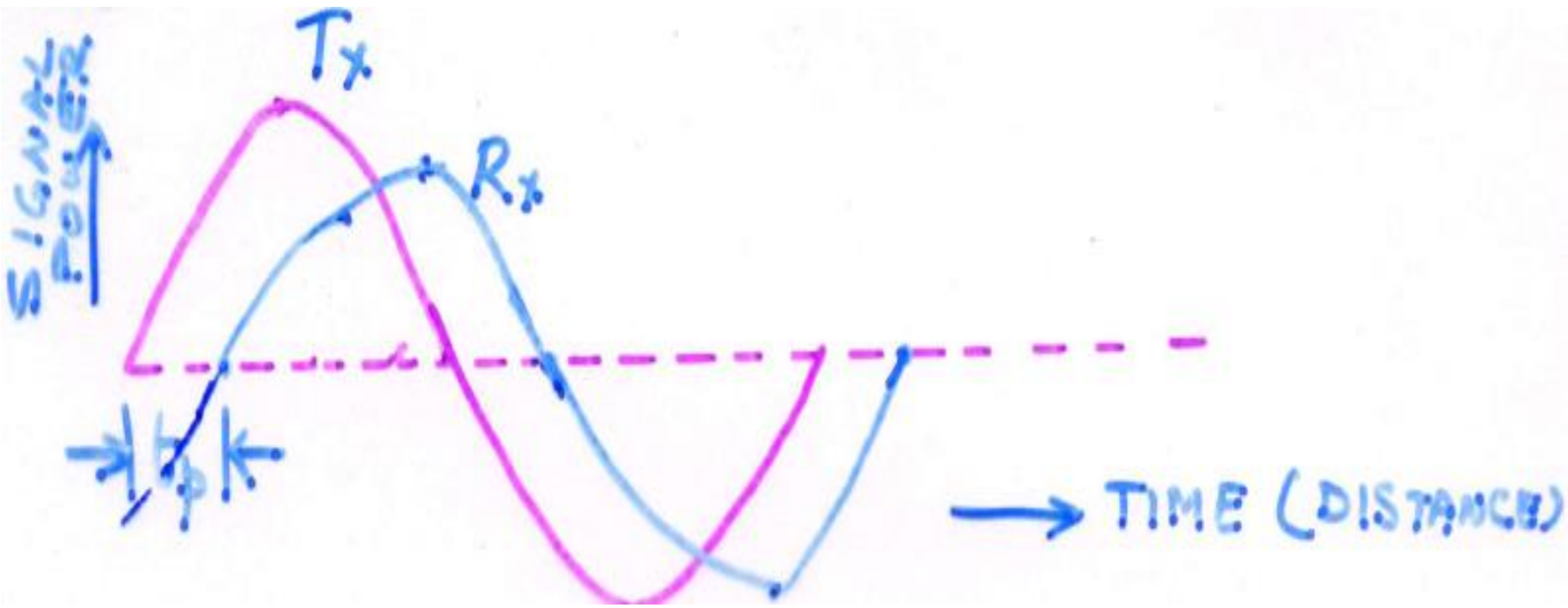
  i) Use of separate antennas for Tx and Rx

  ii) Direct cancellation of leakage signal

MULTIPLE FREQUENCY CW RADAR

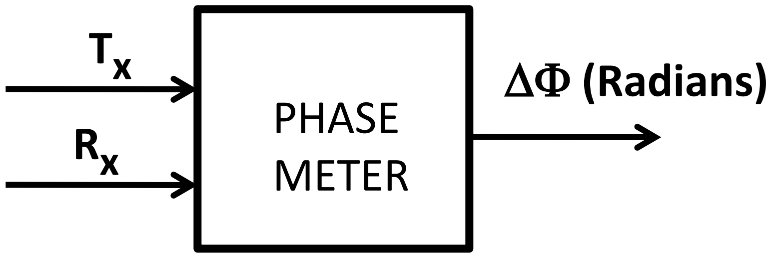
MULTIPLE FREQUENCY CW RADAR

- Simple CW Radar cannot measure Range.
- Under certain circumstances it is possible to measure range by measuring the phase of echo signal.



MULTIPLE FREQUENCY CW RADAR (CONTD ..)

- .



$$\emptyset(\text{rad}) = w(\text{rad/sec}) \times t(\text{sec})$$

- $\Delta\phi = 2\,\pi\, f_0\, t_p$
- $\Delta\phi = \frac{4\,\pi\, R}{C}\, f_0 = \frac{4\,\pi\, R}{\lambda}$
- $R = \frac{C}{4}\;\frac{\Delta\emptyset}{\pi\;f_0}$

$$t_p = \frac{2R}{C}$$

$$\frac{c}{f_o} = \lambda$$

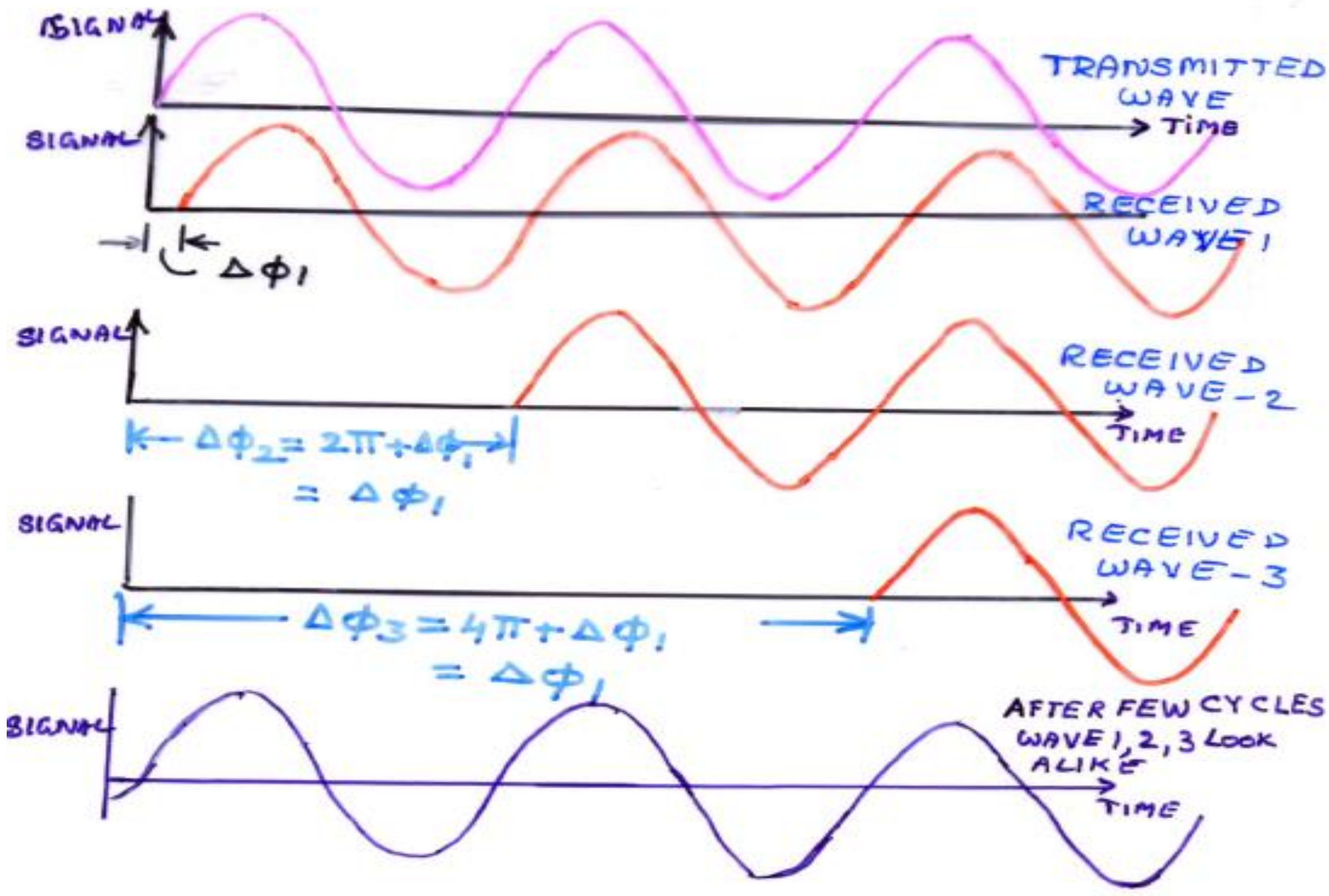
MULTIPLE FREQUENCY CW RADAR (CONTD ..)

Unambigous Range :

- $\Delta\emptyset = \Delta\emptyset + 2\pi = \Delta\emptyset + 4\pi$ ....
- $\Delta\phi$ is unambiguous, only if $\Delta\phi$ does not exceed 2π radians
- Maximum $\Delta\phi = 2\pi$ radians
- $\Delta\emptyset = \frac{4\pi R}{C} \times f_0 = 2\pi$
- $R = \frac{2\pi C}{4\pi f_0} = \frac{C}{2 f_0} = \frac{\lambda}{2}$
- Example : $f_0 = 1 \times 10^9$ HZ, $\lambda = \frac{C}{f_0} = \frac{3\times 10^8}{10^9} = 30$ cms
- So maximum range without ambiguity $\frac{\lambda}{2} = 15$ cms
- This range is not much of practical use

MULTIPLE FREQUENCY CW RADAR (CONTD ..)

- **Ambiguous Range**



MULTIPLE FREQUENCY CW RADAR (CONTD ..)

➢ RANGE AMBIGUITY

RANGE AMBIGUITY

$f_0 = 1\,GHz$, $\lambda = 30\,cms$

$$\Delta\phi = \frac{R \times 4\pi}{\lambda}$$

$$R = \frac{\lambda}{4\pi} \times \Delta\phi$$

RANGE	ACTUAL PHASE	MEASURED PHASE	MEASURED RANGE	AMBIGIOUS RANGE
7.5 cms $(\frac{\lambda}{4})$	π	π	7.5 cms	
$\frac{\lambda}{2} = 15$ cms	2π	0	0	0 OR 15 cms
$\frac{3}{4}\lambda = 22.5$ cm	3π	π	7.5 cms	7.5 OR 22.5 cms
$\lambda = 30$ cms	4π	0, 2π	0	0 OR 15 OR 30 cms
$1\frac{1}{4}\lambda = 37.5$ cms	5π	π	7.5	7.5, 22.5, 37.5 cms
$1\frac{1}{2}\lambda = 45$	6π	0	0	0, 15, 30, 45, 22.5 cms

QUESTION

1. Derive an expression for unambiguous range of two frequency CW radar

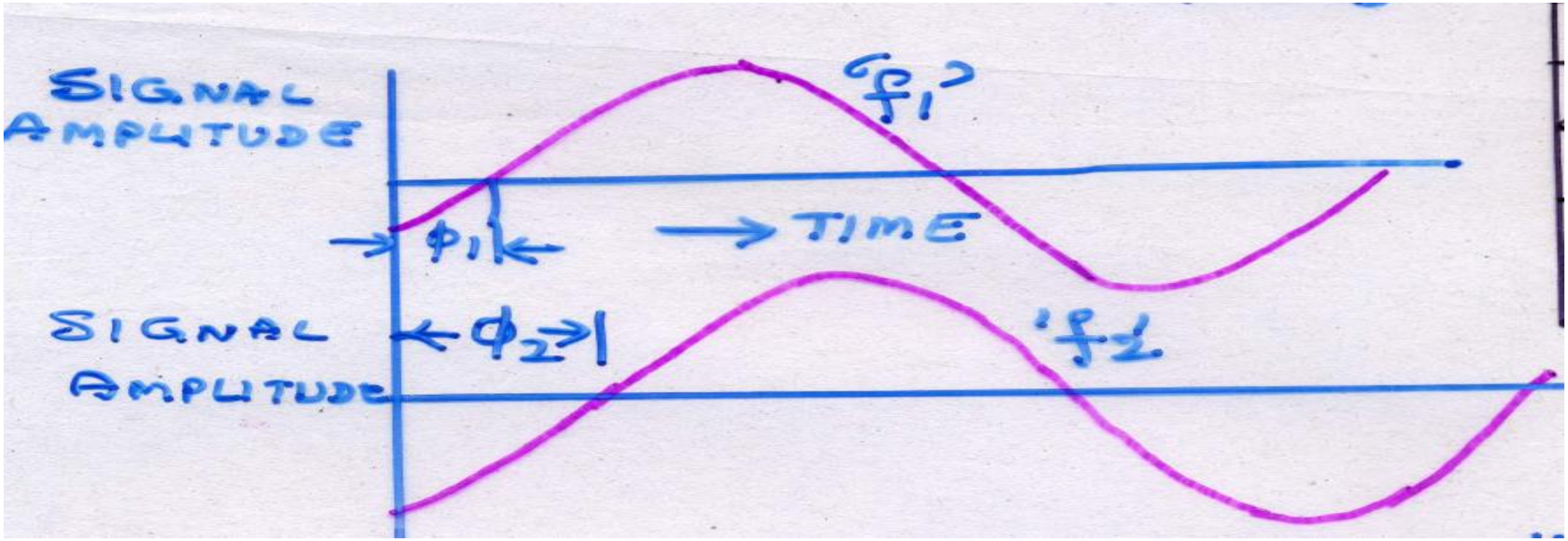
TWO FREQUENCY CW RADAR

- Range is extended considerably by utilizing 2 separate CW signals differing slightly in frequency.
- Unambiguous range corresponds to $\frac{\lambda}{2}$ of Difference frequency
- Example : Difference in frequency = 1 KHZ
- $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{1 \times 10^3} = 3 \times 10^5 = 300 \text{ Kms}$
- Unambiguous Range $= \frac{\lambda}{2} = \frac{300}{2} = 150 Kms$

Δf	100KHz	10 KHz	1 KHz
R	1.5kms	15kms	150kms

TWO FREQUENCY CW RADAR (CONTD ..)

- V_1T and V_2T are the two transmitted sine waves with frequencies f_1 and f_2. separated by Δf.
- $V_1T = \sin(2\pi f_1 t + \emptyset_1)$
- $V_2T = \sin(2\pi f_2 t + \emptyset_2)$
- $\emptyset_1$ and $\emptyset_2$ are arbitrary constant phase angles.



TWO FREQUENCY CW RADAR (CONTD ..)

- Echoes of V_1T and V_2T changes due (i) Doppler fd (ii) Range computed from $\Delta\emptyset = \frac{4\pi R f}{C}$
- $V_1 R = \sin\left[2\pi(f_1 \pm f_{d1})t - \frac{4\pi f_1 R_0}{C}\right] - \emptyset_1$
- $V_2 R = \sin\left[2\pi(f_2 \pm f_{d2})t - \frac{4\pi f_2 R_0}{C}\right] - \emptyset_2$
- $f_2 = f_1 + \Delta f$ where $\Delta f = f_2 - f_1$
- Δf is a very small compared to f_1
- so $f_2 \approx f_1$
- $f_{d1} = f_{d2} = f_d$

TWO FREQUENCY CW RADAR (CONTD ..)

- V_1T heterodyned with V1R
- V_2T heterodyned with V2R

$$\mathbf{Sin\,A \cdot Sin\,B = \frac{cos(A-B) - cos(A+B)}{2}}$$

- $$V_1\,D = \cos\left(\pm 2\pi f_d t - \frac{4\pi f_1 R_0}{C}\right)$$
- $$V_2\,D = \cos\left(\pm 2\pi f_d t - \frac{4\pi f_2 R_0}{C}\right)$$
- V_1 D and V_2 D applied to Phase Detector

TWO FREQUENCY CW RADAR (CONTD ..)

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

- R_0 =Range= $\frac{C\ \Delta\phi}{4\ \pi\ \Delta f}$
- (Note: For a single frequency f_1
- R_0=Range= $\frac{C\ \Delta\phi}{4\ \pi\ f_1}$)
- Both equations above are same except that f_1 is replaced by Δf.

TWO FREQUENCY CW RADAR (CONTD ..)

➢ Method of Transmission:

- f_1 and f_2 are transmitted simultaneously

OR

- f_1 and f_2 transmitted sequentially by rapidly switching RF sources
- Two frequencies CW radar is essentially a single target radar since only one phase difference is measured

TWO FREQUENCY CW RADAR (CONTD ..)

➢ Maximum Unambiguous Range :

- $R_0 = \frac{C \; \Delta\phi}{4 \; \pi \; \Delta f}$
- Maximum Unambiguous range (Runamb) occurs when $\Delta\phi = 2\pi$ Radians

- R unamb $= \frac{C \; 2 \; \pi}{4 \; \pi \; \Delta f} = \frac{C}{2 \; \Delta f}$

- R unamb is large when Δf is small

MULTIPLE FREQUENCY CW RADAR

➢ Necessity for Multiple frequency CW Radar

- Theoretical RMS Range error (formula assumed)
- $$\delta R = \frac{C}{4\ \pi\ \Delta f\ \left(\frac{2E}{N_0}\right)^{\frac{1}{2}}}$$
- To get δR small , Δf should be large
- But from $R_{unamb} = \frac{C}{2\ \Delta f}$
- Δf should be small to get large R_{unamb}.
- For small range Error (δR) Δf should be large.
- For large unambiguous range (R_{unamb}) Δf should be small.
- This controversial requirement is solved by going to multiple - frequency Radar.

MULTIPLE FREQUENCY CW RADAR

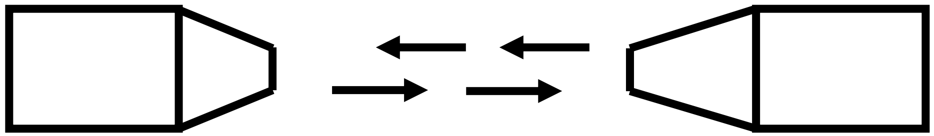
- One more frequency f_3 is transmitted in air along with f_1 and f_2.
- However $(f_3 - f_1) = \Delta f$ is made large to obtain high accuracy ie., small range error. This gives raise to less unambiguous range.
- $(f_2 - f_1) = \Delta f$ is made small to obtain large unambiguous range . This resolves the range ambiguity because of $(f_3 - f_1)$ being large.
- $(f_3 - f_1) = K \quad (f_2 - f_1)$
- K lies between 10 to 20.

TELLURO METER

- A portable electronic surveying instrument.
- Measures accurate distance in surveying.
- Uses multiple frequency CW principle.
- **Type MRB 201** measures from 200 Mts to 250Kms Accuracy $\pm$ 0.5 m $\pm$ 3x10^{-6} d
  where d = distance
- Tx power = 200mws, Antenna small paraboloid Polarization between T_x and R_x is orthogonal
- **Type MRAS** Accuracy $\pm$ 0.05 m $\pm$ 3x10^{-5} d Range 100mts to 50 kms Frequency 10 to 10.5 GHZ band

TELLURO METER

➢ Principle



- Carrier Frequency – 3GHZ
- 4 single sideband modulating frequencies separated by 10 , 9.99 , 9.9 and 9 MHZ are used
- Example: Let Δf = 10 MHZ
- $$R_{unamb} = \frac{C \ \Delta\phi}{4 \ \pi \ \Delta f} = \frac{C \times 2\,\pi}{4 \ \pi \ \times 10 \times 10^{6}} = 15mt$$

10 MHZ provides the basic accuracy measurement, while 1MHZ, (10-9),100KHZ (10-9.9),10 KHZ (10-9.99) permit resolution of ambiguities.

TELLURO METER

- **Accuracy:**

- $$R = \frac{C \ \Delta \emptyset}{4 \ \pi \ \Delta f}$$
- When phase meter resolution = 1^0 ($\frac{2\pi}{360}$ Radians)
- For 10 MHZ Range Accuracy
- $$\Delta R = C \times \frac{2 \ \pi}{360} \times \frac{1}{4 \ \pi \times 10 \times 10^6}$$

Δf	R_{unamb}	Accuracy ΔR
10 MHZ	15 Mts	0.042 Mt
1 MHZ	150 Mts	0.4166 Mt
100 KHZ	1.5 Kms	4.166 Mt
10 KHZ	15 Kms	41.66 Mt

Question

1.Differentiate the operation of Pulsed Radar from simple CW Radar

2. Explain how do you distinguish between CW Radar and Pulsed Radar

3. What are the advantages and disadvantages for CW Radar

4. Explain the limitations of CW Radar

COMPARISON OF CW & PULSE RADAR

CW Radar	Pulse Radar
1. A simple CW radar cannot measure range. (However with FM modulations , Range measurement is possible.)	1. A Conventional pulse Radar cannot measure velocity of target. (However with Pulse Doppler/MTI Radars can measure velocity of target)
2. Rx Bandwidth is low Hzs. (Difference between maximum & minimum f_d)	2. Rx Bandwidth is in Mega Hzs (1/ Pulse width)
3. Duty cycle is unity and hence peak power is less	3. Duty cycle is low therefore peak power is high

COMPARISON OF CW & PULSE RADAR

CW Radar	Pulse Radar
4. No High voltage modulator needed	4. High voltage modulator needed to pulse the power tube. Electrical breakdown due to high voltage is a problem
5. Transmitters are smaller in size and weight.	5. Pulse T_x is 25 to 50 percent heavy compared to CW T_x
6. FM CW Radars operate to almost zero range.	6. Minimum Range depends on pulse width and duplexer recovery time.
7. Permits clutter to be rejected since it works on Doppler principle.	7. Conventional Pulse Radar cannot Reject clutter , (However Pulse Doppler/ MTI Radar can reject clutter)

COMPARISON OF CW & PULSE RADAR

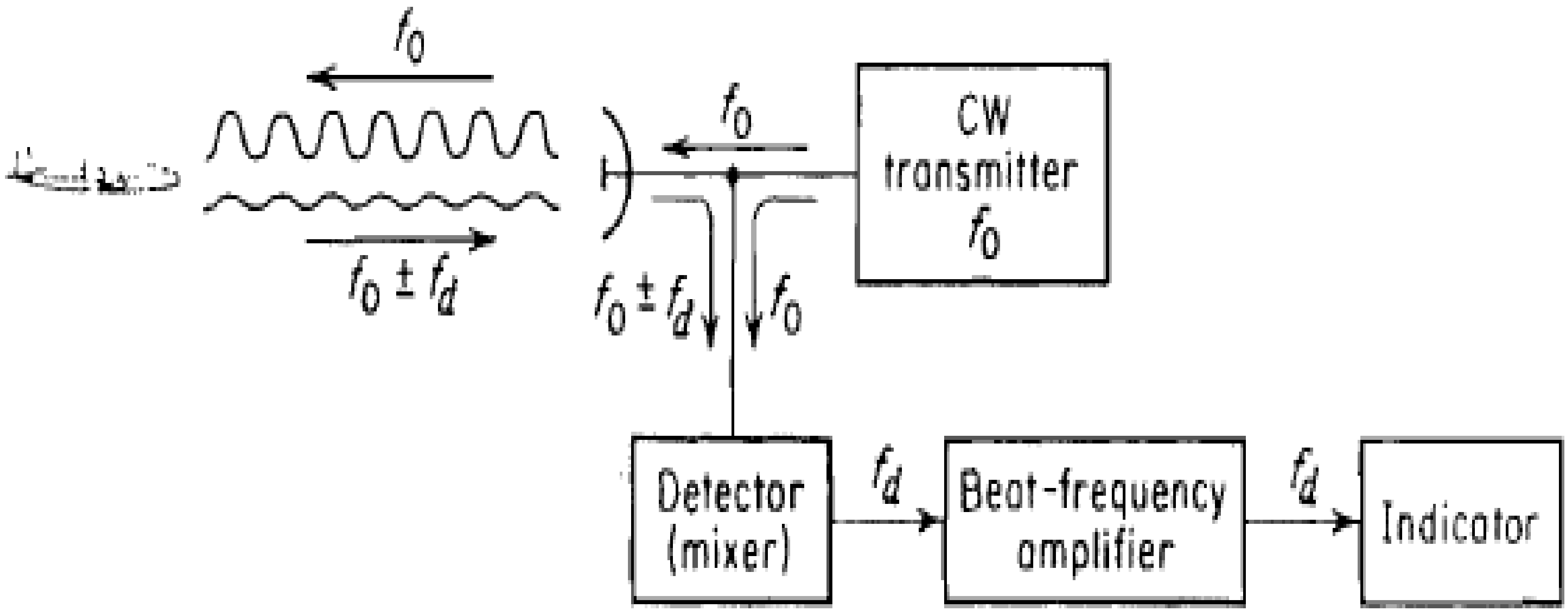
CW Radar	Pulse Radar
8. Tangent or crossing trajectories whose paths are perpendicular to Radar beam have zero relative velocities.	8. Conventional Pulse Radar measures r velocity. Pulse Doppler/MTI Radar which measures Range behave the same way as in the CW Radar.
9. Number of targets that can be resolved at one time depends on the number of Doppler filters.	9. If delay line canceller is used, there is no restrictions on number of targets as Delay Line Canceller is a time Domain Filter.
10. Practical limit to the maximum power employed; This depends on the amount of isolation and TX noise leaking into the R_x.	10. No such Limit , as the Duplexer switches off the Rx during transmission.
11. Used as (i) Police Radar (ii) Proximity fuze (iii) Altimeter (iv) Rate of Climb meter Etc.;	11. Used as (i) Surveillance Radar (ii) Airborne Radar

Question

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

CW RADAR

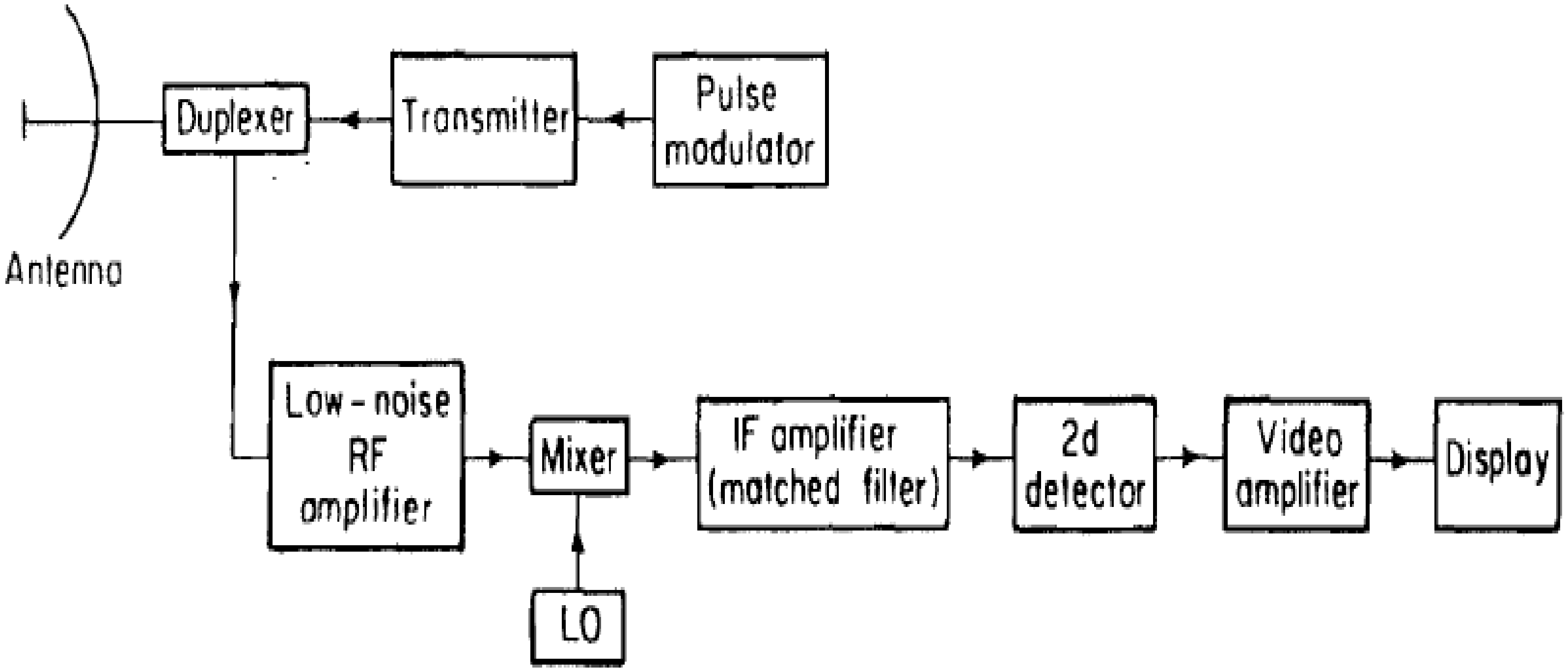
- **CW Radar block diagram**



For description of each block See earlier slides

PULSE RADAR

- **Pulse Radar block diagram**



For description of each block See earlier slides

PROBLEMS

Problem 1. An X-band CW-Radar of 10.4 GHZ uses a sinsoidal FM for ranging. Its modulation frequency is 90 MHZ. The phase difference between the received modulation and that transmitted is 3.5degrees. Find the target range.

- Solution : $R = \frac{C \ T_m \ \Delta\emptyset}{2 \ \pi}$
- T_m = Period of modulation = $\frac{1}{90 \times 10^6}$ =0.01111sec
- $\Delta\emptyset = 3.5^0$ or $\frac{2 \ \pi}{360} \times 3.5$ radians

Range R = $\frac{3 \times 10^8 \times 0.01111 \times 2 \ \pi \times 3.5}{360 \times 2 \ \pi}$ = 16200mts

= 16.2 Kmts

PROBLEMS

Problem 2: A CW Radar has center frequency of 10.0 GHZ and triangularly sweeps a bandwidth of 2.0 MHZ at 200 HZ rate. The frequency difference between transmit and receive in the up swing is 65510 and on downswing 82650 HZ. What is the target range and radial velocity.

- Solution: Approaching target is assumed.

$$f_r = \frac{f_b\,(up) + f_b\,(Down)}{2}$$

$$f_r = \frac{(65510 + 82650)}{2} = 74080\ Hz$$

$$R = \frac{f_r\ C}{4\ \Delta f\ f_m} = \frac{74080 \times 3 \times 10^8}{4 \times 2 \times 10^6 \times 200} =$$

13890 mts =13.89 Kms

PROBLEMS

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

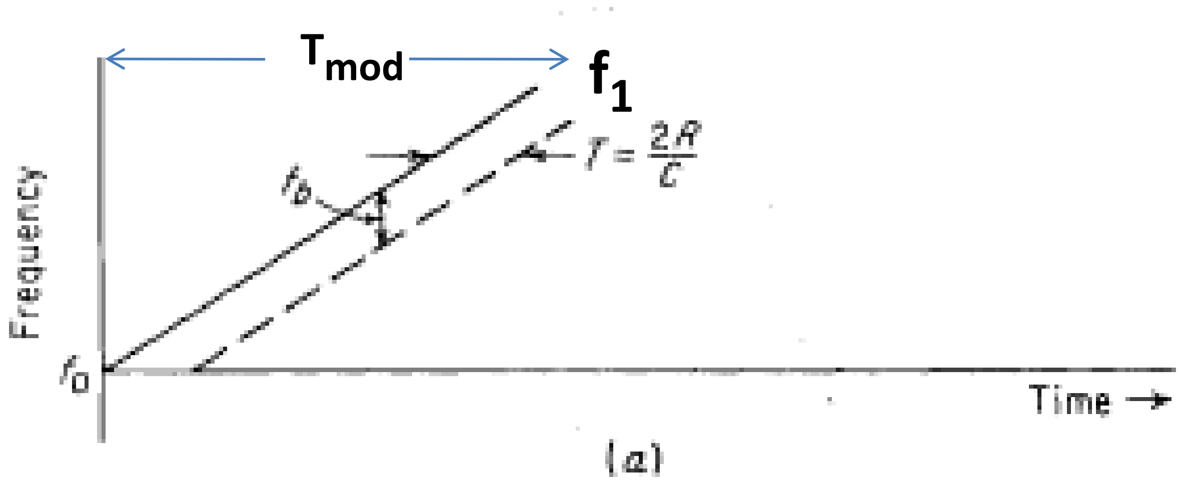
$f_d = \frac{82650 - 65510}{2} = 8570$

$f_d = \frac{2\ V_r}{\lambda} = \frac{2\ V_r\ f}{C}$

So $V_r = \frac{C\ f_d}{2\ f} = \frac{3 \times 10^8 \times 8570}{2 \times 10 \times 10^9}$

$V_r = 128.55$ Mt/sec

LINEAR FREQUENCY MODULATION (CONTD…)



Rate of change of carrier frequency =

$$\dot{f_0} = \frac{f_1 - f_0}{T_{mod}}$$

$$f_b = f_r = \dot{f_0}\, T = \dot{f_0}\, \frac{2R}{C} = \frac{\dot{f_1} - f_0}{T_{mod}} \times \frac{2R}{C}$$

PROBLEMS

Problem 3: In an FM CW Radar the frequency changes by 2000 Hz every micro second. What will be the beat frequency if a target is at 8000 ft away from a radar.

Rate of change of frequency = $\dot{f}_0 = \dfrac{f_1 - f_0}{T_{mod}}$

Rate of change of frequency = $\dfrac{2000}{1 \times 10^{-6}} = 2 \times 10^9$ Hz/sec

$R = 8000 \times \dfrac{12 \times 2.54}{100} = 2438.4$

$f_r = \dot{f}_0 \; T = \dot{f}_0 \; \dfrac{2R}{C}$

$f_r = \dfrac{2 \times 10^9 \times 2 \times 2438.4}{3 \times 10^8} = 32512 \text{ Hz}$

PROBLEMS

Problem 4: An FM CW Radar transmits a triangular frequency modulation in which the frequency changes 1000 Hz every micro second. Show how a filter bank can be included in the radar to produce a range resolution of 1000 ft. What should be band width of each filter be

- Solution:

R = 1000 ft = $\frac{1000 \times 12 \times 2.54}{100}$ = 304.8 Mt =

$T_R = \frac{2 R}{C} = \frac{2 \times 304.8}{3 \times 10^8} = 2.034 \times 10^{-6}$ sec

f_r = rate of change of frequency $\times T_R$

$f_r = \frac{1000}{10^{-6}} \times 2.034 \times 10^{-6} = 2034$ Hz

Band width of filter = 2000 Hz

END OF UNIT 2