RADAR SYSTEMS
(EC812 PE –V)
(ELECTIVE V)
UNIT – 3A
B.TECH IV YEAR II SEMESTER

(Jntuh)

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
(EC 815 PE-V)
ELECTIVE-V
B.TECH IV YEAR II SEMESTER
UNIT 3

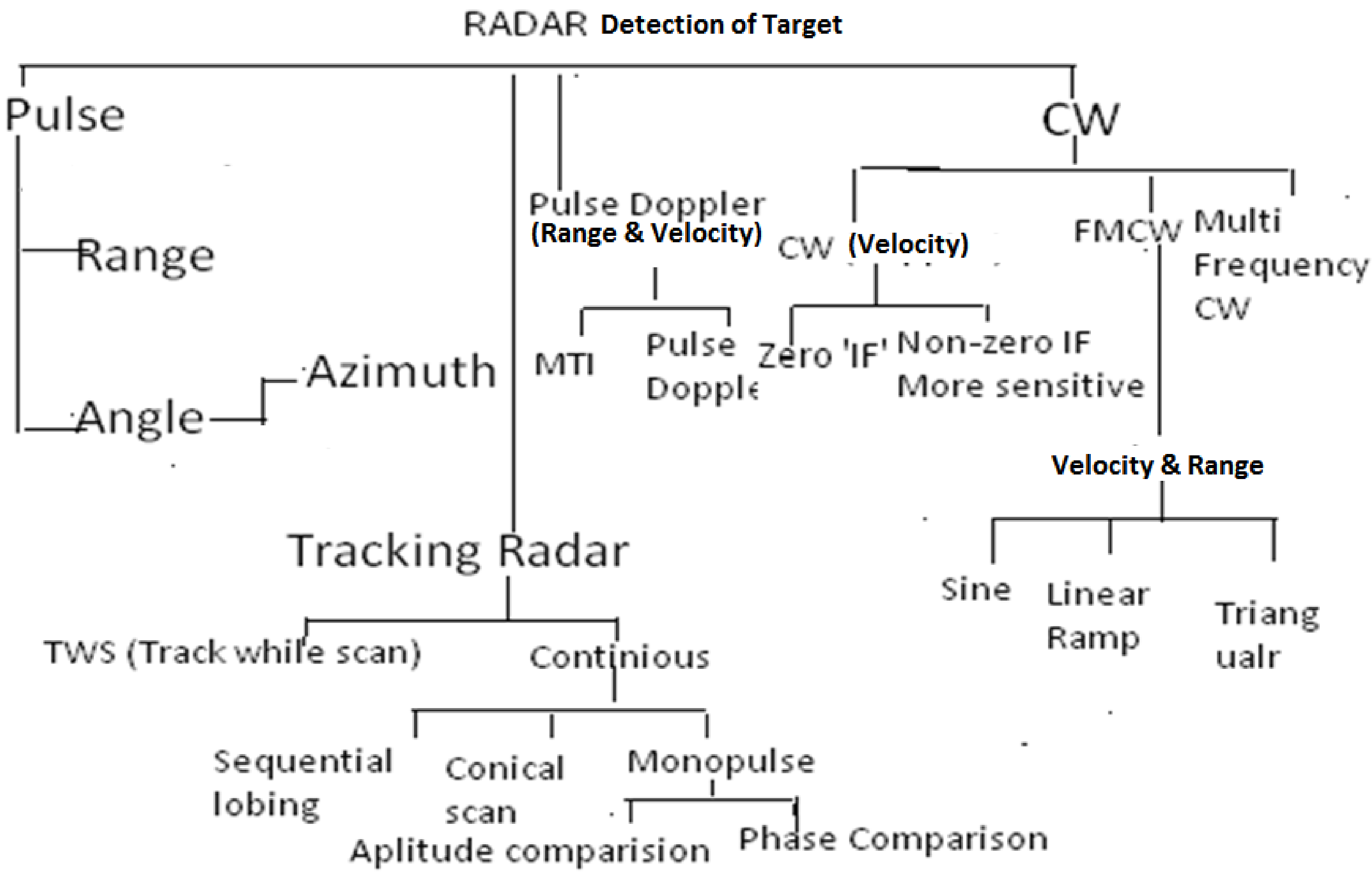
MTI AND PULSE DOPPLER RADAR:

Introduction, Principle, MTI Radar with Power Amplifier Transmitter and Power Oscillator Transmitter, Delay Line Cancellors – Filter characteristics, Blind speeds, Double cancellation, Staggered PRF, Range Gated Doppler Filters, MTI Radar Parameters Limitations to MTI performance, Non Coherent MTI, MTI versus Pulse Doppler Radar.

INTRODUCTION

RADAR

- Classification of Radars



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. CW Radars do not give range (However FM CW operates almost from 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 can not measures 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. There is no restrictions on number of targets as long as the range difference between targets is greater than C ζ / 2**
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**

TYPE OF RADAR	RANGE	VELOCITY
PULSE RADAR	YES MEASURES TIME BETWEEN T_x & ECHO PULSE (TIME MEASUREMENT) $R = C\ T_R/2$	NO
CW	NO	MEASURES DOPPLER FREQUENCY f_d $f_d = 2\ V_r / \lambda$
FM CW (TRIANGULAR WAVE)	YES MEASURES f_b UP AND f_b DOWN (FREQUENCY COUNTER) $f_r = ½ [\ f_b\ UP\ + f_b\ DOWN]$ $f_r = (4R\ f_m\ \Delta f\ ) / C$	YES $f_d = ½ [\ f_b\ UP - f_b\ DOWN]$ (DIFFERENCE FREQUENCY COUNTER $f_d = 2\ V_r / \lambda$
TWO FREQUENCY RADAR	YES MEASURES PHASE DIFFERENCE (PHASE METER) $R = (C\ \Delta\phi) / (4\ \pi \Delta f\ )$	YES $f_d = 2\ V_r / \lambda$

TYPE OF RADAR	RANGE	VELOCITY
PULSE DOPPLER RADAR	YES MEASURES TIME BETWEEN T_x & ECHO PULSE (TIME MEASUREMENT) $R = C\ T_R/2$	YES MEASURES PHASE w.r.t. fc AND USES DLC TO GET dϕ/dt OUTPUT OF DLC IS GIVEN TO FREQUENCY COUNTER $f_d = 2\ V_r / \lambda$

INTRODUCTION (CONTD..)

Christian Doppler

PULSE DOPPLER RADAR

PULSE DOPPLER RADAR

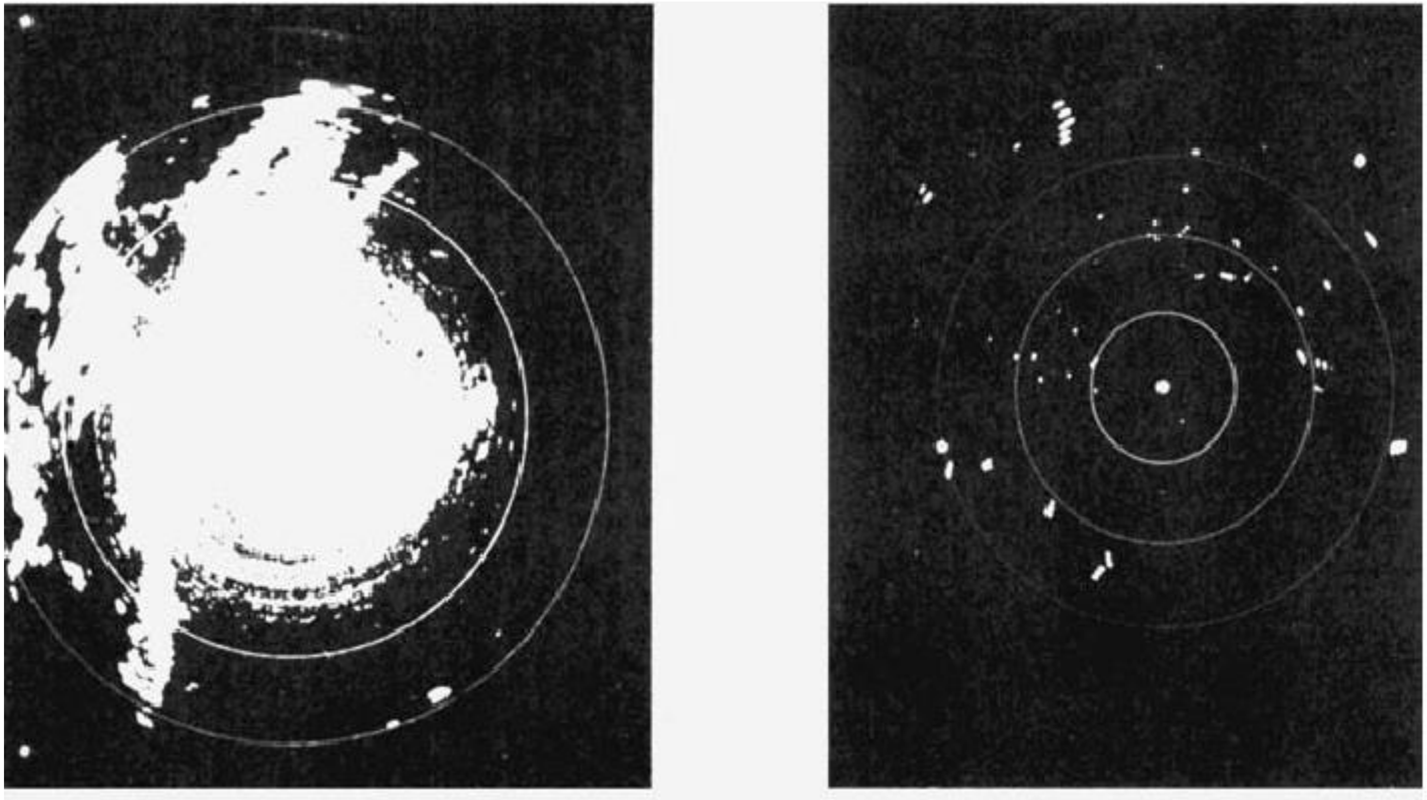
INTRODUCTION

- **CW Radar** provides the radial velocity by measuring the Doppler frequency shift.
- **FM CW Radar** provides the radial velocity and also the range of the target.
- **Pulse Radar** provides the range information.
- **Pulse Doppler Radar** provides velocity information (relative velocity) in addition to the range information.
- Another great advantage of **Pulse Doppler Radar** is the rejection of clutter which is not possible in pulse radar
- Clutter is the large amount of Echo signals that are received on account of reflections from stationary targets Ex: Tall Building , Water Tanks,hills,trees etc.,

INTRODUCTION (CONTD ..)

- Difference between Clutter & Noise :
- Clutter is not noise. Clutter is the echo signal that is because of reflections from stationary surroundings like tall buildings, transmission towers, water tanks, surrounding hills, trees etc. It clutters the Display and camouflages the moving targets. It is unwanted signal which need to be removed.
- A Pulse Radar that utilizes the Doppler frequency shift as a means of discriminating moving from fixed targets is called a MTI (Moving Target Indication) or a Pulse Doppler Radar

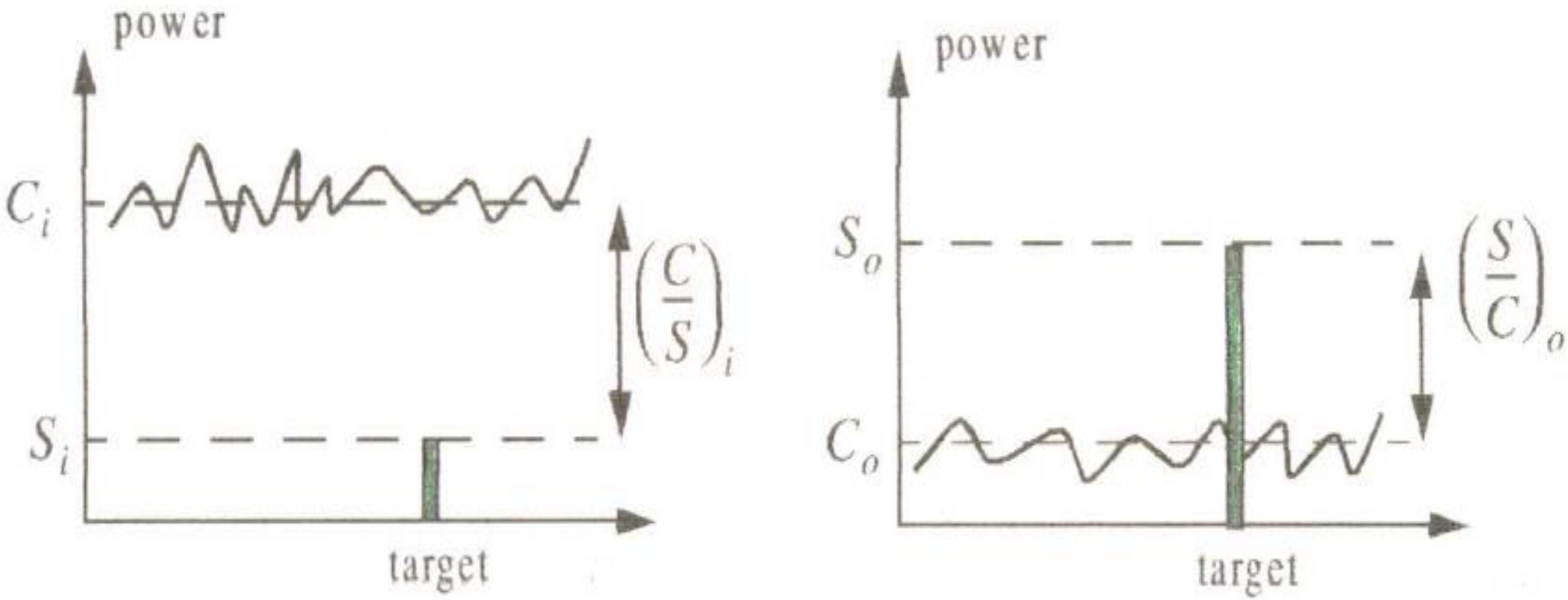
NECESSITY FOR CLUTTER REJECTION



•MTI Radar is complex ,expensive and occupies more space. However with developments in VLSI technology size and cost has come down

CLUTTER POWER VS TARGET ECHO POWER

- **c/s v_s s/c**



(Jntuh) **Distinguish between MTI radar and Pulse doppler radar**

MTI VS PULSE DOPPLER RADAR

➢ MTI Radar :

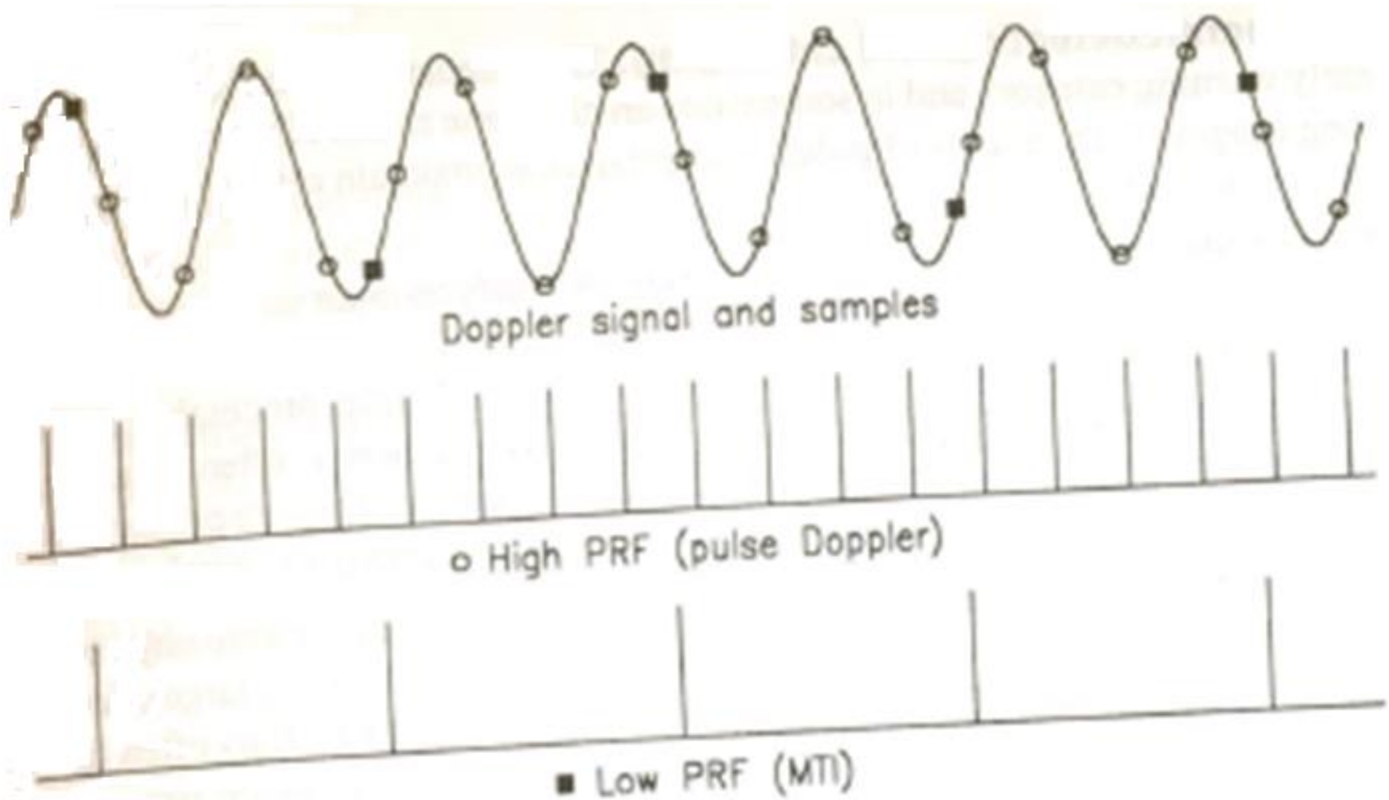
- Operates with ambiguous Doppler measurements (velocities) and blind speeds
- Range measurements are unambiguous (no second time around Echoes) $R_{unamb} \frac{T_p\, C}{2}$
- PRF is low $f_P = (1 / T_p)$ ie Time between pulses large

➢ Pulse Doppler Radar :

- Operates with unambiguous Doppler measurements and no blind speeds
- Range measurements are ambiguous
- PRF is high ie. Time between pulses small

MTI VS PULSE DOPPLER RADAR

- Pulse Doppler VS MTI

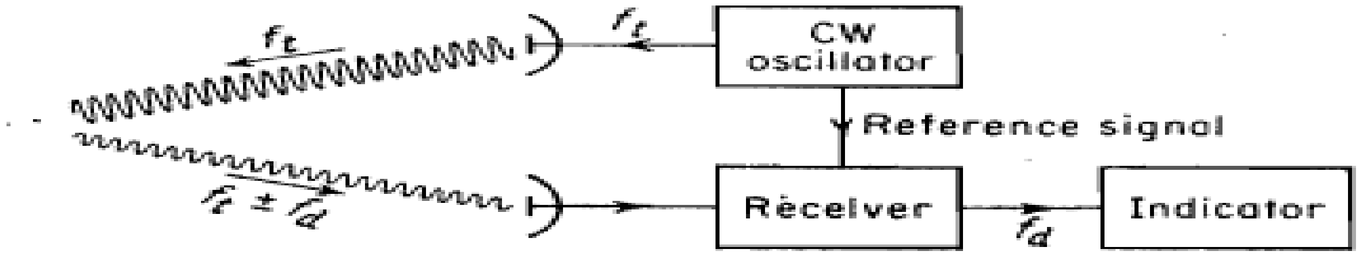


(Jntuh) 1. How does a MTI/Pulse doppler radar differ from CW radar

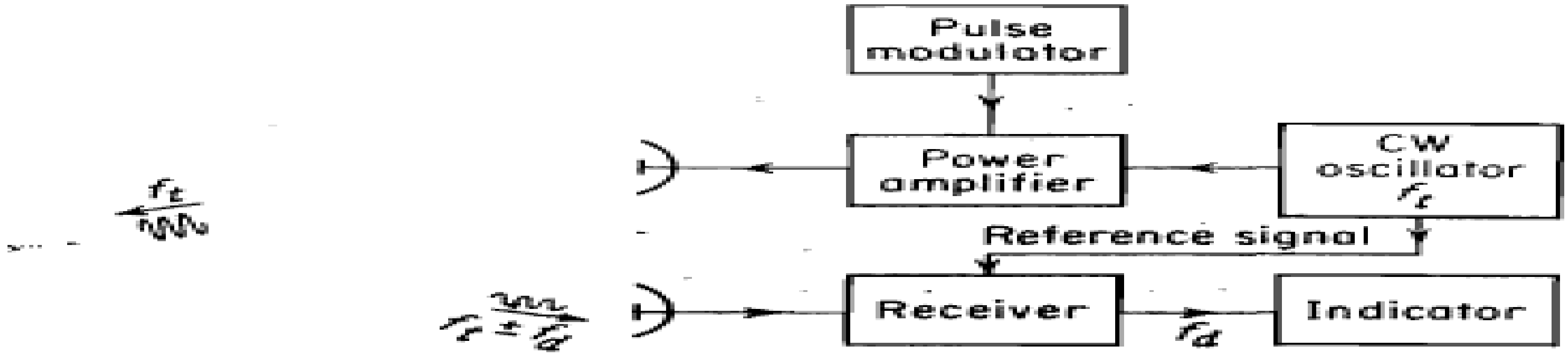
(Jntuh) 2. What is the principle of MTI radar

(Jntuh) 3. With an MTI radar we can get the radial velocity as well as the distance of the moving target. Justify this.

CONVERSION OF CW RADAR TO PULSE DOPPLER RADAR



SIMPLE CW RADAR

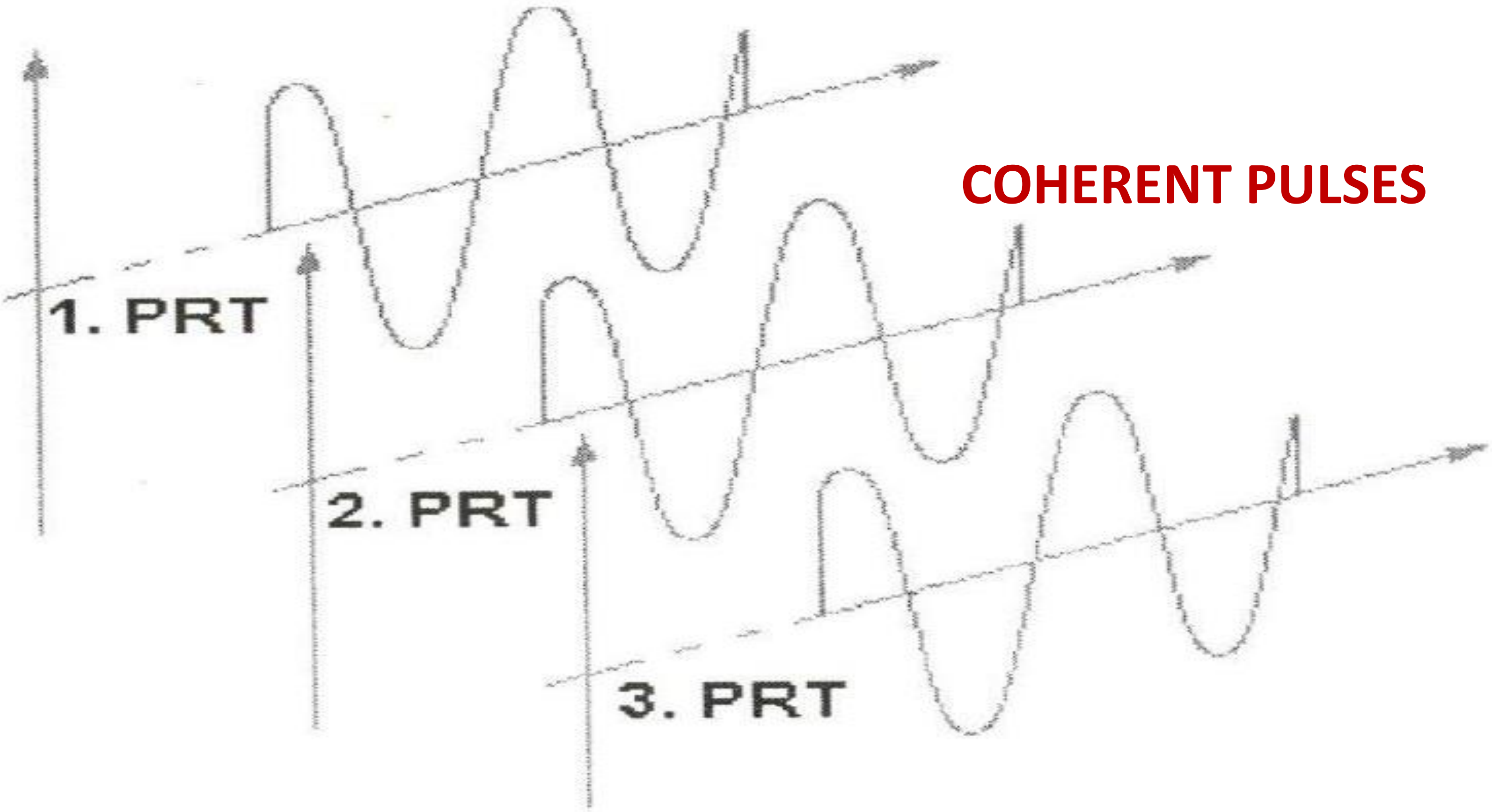


PULSE DOPPLER RADAR

CONVERSION OF CW RADAR TO PULSE DOPPLER RADAR (CONTD ..)

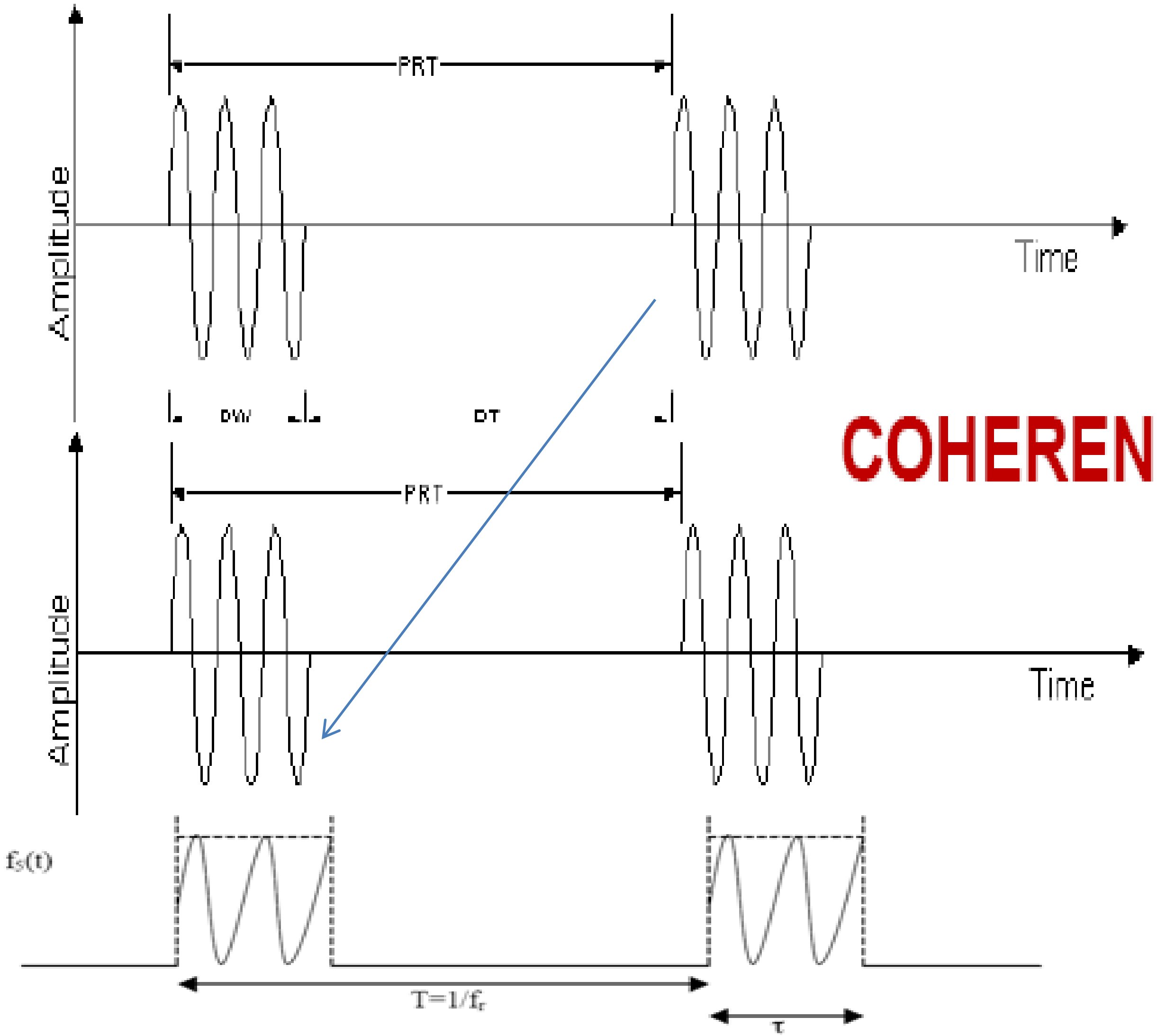
- Power amplifier and modulator are added to CW Radar.
- In Pulse Doppler Radar, a small portion of the CW oscillator power is diverted ro R_X in place of local oscillator . This replaces the function of LO.
- This also acts as the coherent reference needed to detect the Doppler frequency shift.
- COHERENCY MEANS that the phase of T_X signal is preserved in the reference signal

COHERENCY OF PULSES



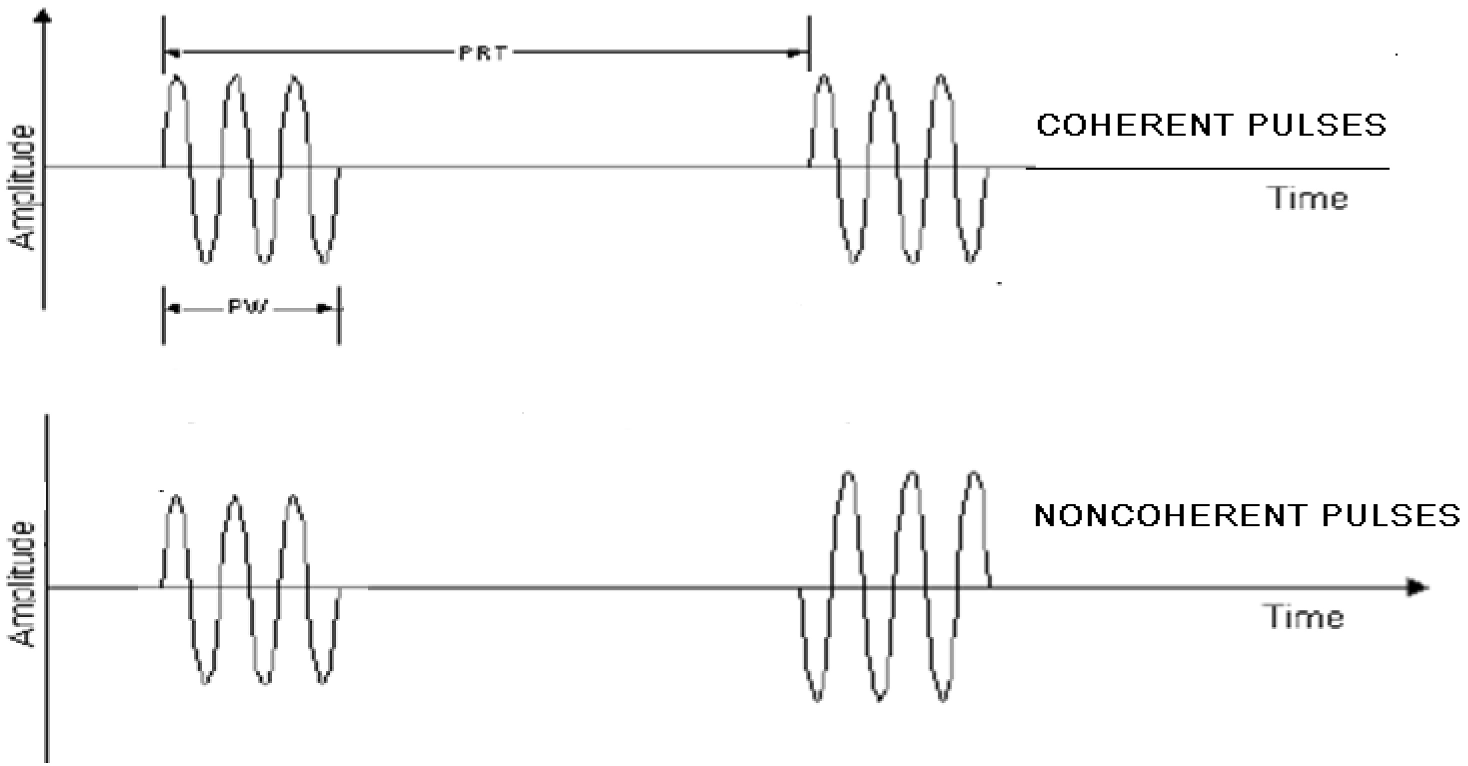
COHERENT PULSES

COHERENCY OF PULSES (CONTD…)



COHERENT PULSES

COHERENCY / NON COHERENCY OF PULSES



PRINCIPLE OF OPERATION

- $V_{osc} = A_1 \sin 2 \pi f_t t$
- Reference Signal $V_{ref} = A_2 \sin 2 \pi f_t t$
- Echo Signal = V_{echo}

$$= A_3 \text{ Sin} \left[2 \pi (f_t \pm f_d) t - \frac{4 \pi f_t R_0}{C} \right]$$

where A_1,A_2,A_3 are peak amplitudes of Sine Wave.

f_t = Transmitted Frequency

f_d = Doppler frequency shift

- V_{echo} & V_{ref} are heterodyned.

PRINCIPLE OF OPERATION (CONTD ..)

$$\text{Sin A} \times \text{Sin B} = \frac{1}{2}\left[\text{Cos}\,(A - B) - \text{Cos}\,(A + B)\right]$$

$$\text{Cos}\,(A - B) = \text{Cos}\left[2\pi f_t t + 2\pi f_d t - \frac{4\pi f_t R_0}{C} - 2\pi f_t t\right]$$

$$= \text{Cos}\left[2\pi f_d t - \frac{4\pi f_t R_0}{C}\right]$$

PRINCIPLE OF OPERATION (CONTD ..)

$$\text{Cos}\,(A + B) = \text{Cos}\left[4\pi f_t t + 2\pi f_d t - \frac{4\pi f_t R_0}{C}\right]$$

$$= \text{Cos}\left[2\pi f_d t - \frac{4\pi f_t R_0}{C}\right]$$

Sum is filtered out by low pass filter

Output of Mixer $V_d = A_d$

Principle Of Operation (Contd ..)

- $V_{diff} = A_d \operatorname{Sin}\left[2\pi f_d t - \frac{4\pi f_t R_0}{C}\right]$
  .

- V_{diff} has 2 components . Sine wave at Doppler frequency and the other is a phase shift which depends on the range of the target (R_o).

- For stationary targets R_0 is constant, (fd $= \frac{2 V_r}{\lambda}$), Doppler frequency shift $f_d = 0$ and so V_{diff} is constant.

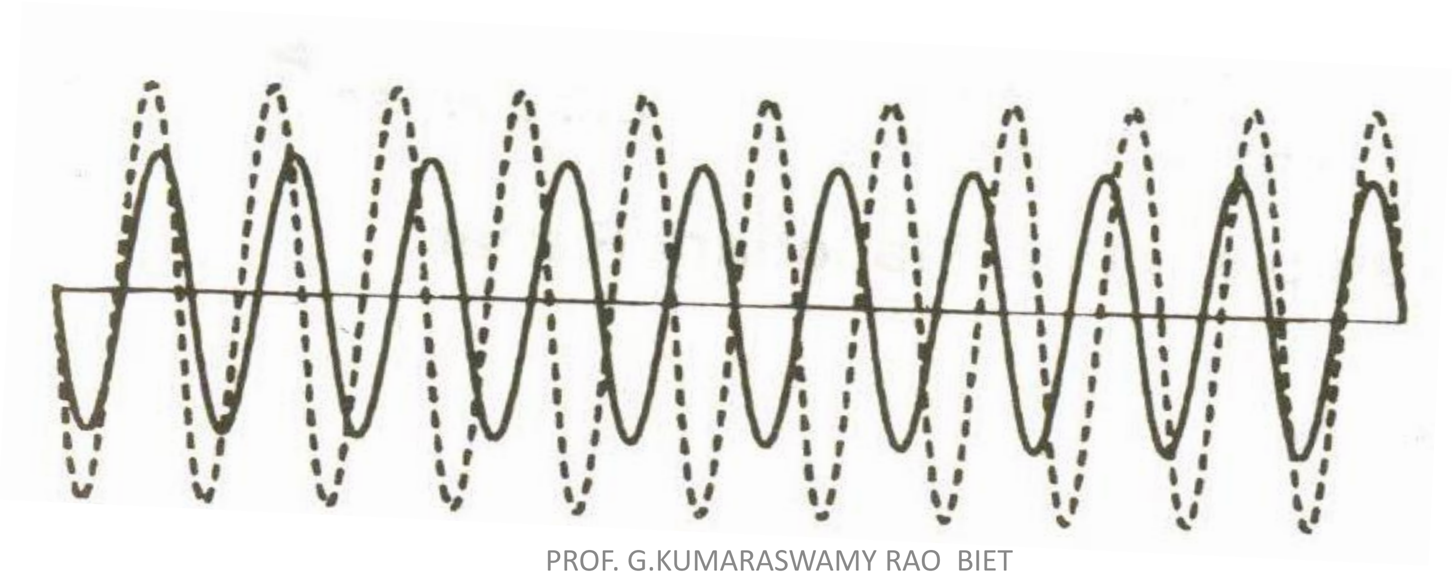
- For moving targets, f_d has a value, V_{diff} will be a function of time.

MEASUREMENT OF DOPPLER FREQUENCY

- Doppler frequency can be determined by

  i) measuring the frequency with frequency counter

  ii) measuring the phase with Phase meter at PRF intervals since Frequency = Rate of change of phase $\frac{d\,\emptyset}{dt}$



DOPPLER FREQUENCY DETERMINATION

➢ Why is phase measured instead of Doppler Frequency?

- Typical period of Doppler frequency = $\frac{1}{f_d}$

  (For 150 mt/sec velocity target , Radar transmitting at 1 GHz , f_d computed is 1000Hz which means period of f_d is 1/1000 =1000 microsecs.

- If transmitted pulse duration is 1 micro second only a very small fraction of a complete one Doppler frequency cycle is contained with in the pulse of 1microsec.

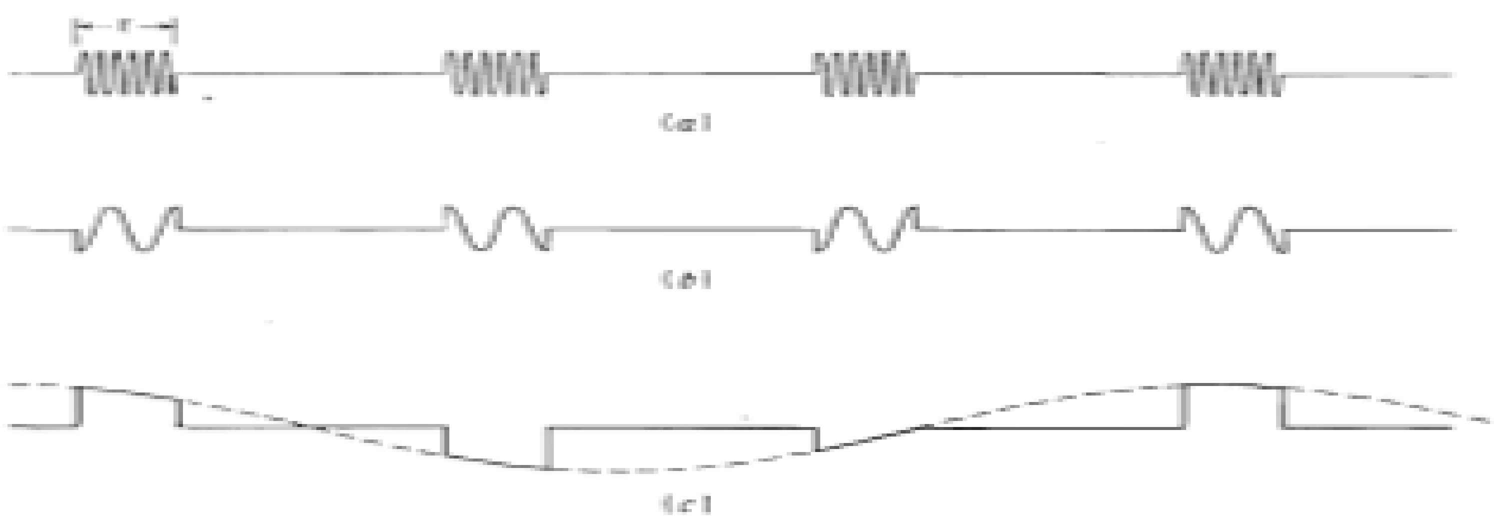
- If PRT of pulses transmitted is 200 μsec we need 5 pulses to construct one cycle of f_d. This is done by observing the phase changes that occur between pulses.

PRINCIPLE OF OPERATION (CONTD ..)

- Depending upon f_d , 2 cases will arise (τ = Pulse Width).

   i. $f_d > 1/\tau$ ⟶ f_d can be found quickly.

   ii. $f_d < 1/\tau$ ⟶ many pulses need to be observed to find f_d



MAGNITUDE OF DOPPLER SHIFT

- Doppler frequency gives the velocity of target along the beam forward or away from the Radar.

Radial Velocity	X Band 9.37 GHZ	C Band 5.61 GHZ	S Band 3.0 GHZ
1 mt/s	62.5 HZ **16000 microsecs**	37.5 HZ	20.0 HZ
10 mt/s	625 HZ **1600 microsecs**	375 HZ	200 HZ
50 mt/s	3125 HZ **320 microsecs**	1876 HZ	1000 HZ
200 mt/s	12KHZ (83micro secs)	7504 HZ	4000 HZ
2000 mt/s (High speed)	120 KHZ (8 .3micro secs)	75 KHZ (13.3 micro secs)	40 KHZ (25 micro secs)

PRINCIPLE OF OPERATION (CONTD ..)

- **$f_d > 1/\tau$** applicable to Radars which are meant to detect ballistic missiles or satellites whose velocity is very high.
- **$f_d < 1/\tau$** is applicable to common Radars which are utilized for detection of aircrafts EX : ATC Radar
- The video signals are called bi - polar, since their amplitudes are both positive and negative.
-

PRINCIPLE OF OPERATION (CONTD ..)

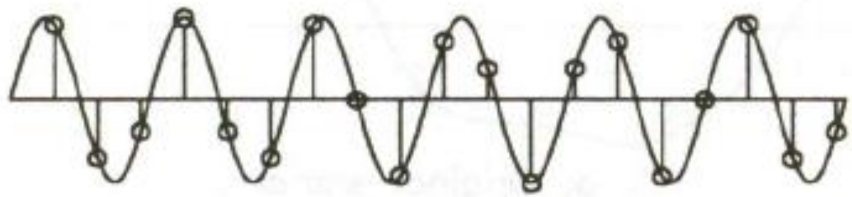
- Ambiguity in measurement of f_d is a problem

a. Does not occur in case where **$f_d > 1/\tau$** (Integral cycles are available for measurement)

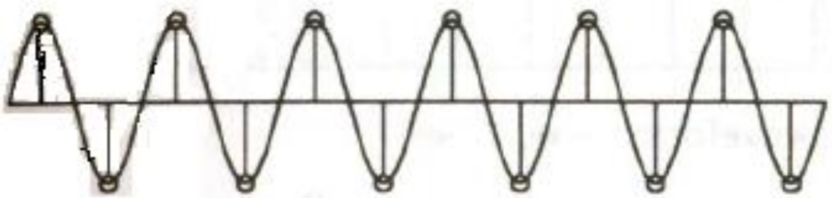
b. Ambiguity in measurement of f_d can occur in case where **$fd < 1/\tau$** Phase is measured in this case. Here sampling and Nyquist criterion applies.

NYQUIST SAMPLING PRINCIPLE

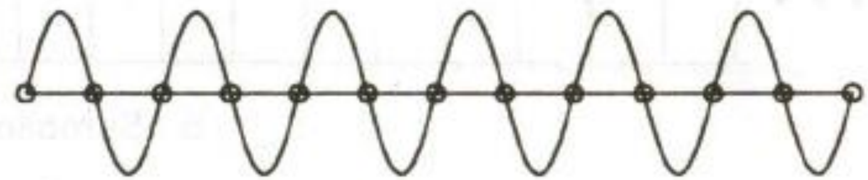
- **Sampling At different frequencies:**



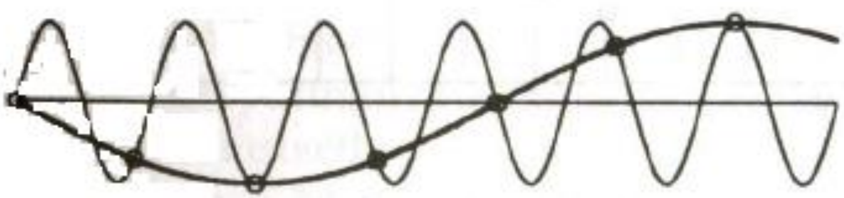
a. Sample rate > Nyquist



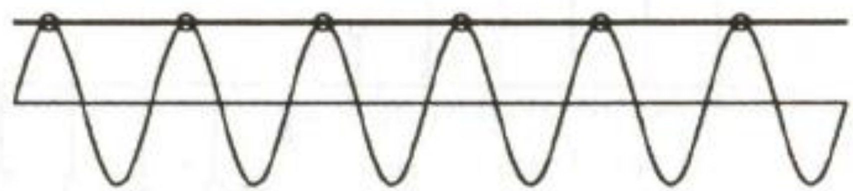
b. Sample rate = 2f



c. Sample rate = 2f

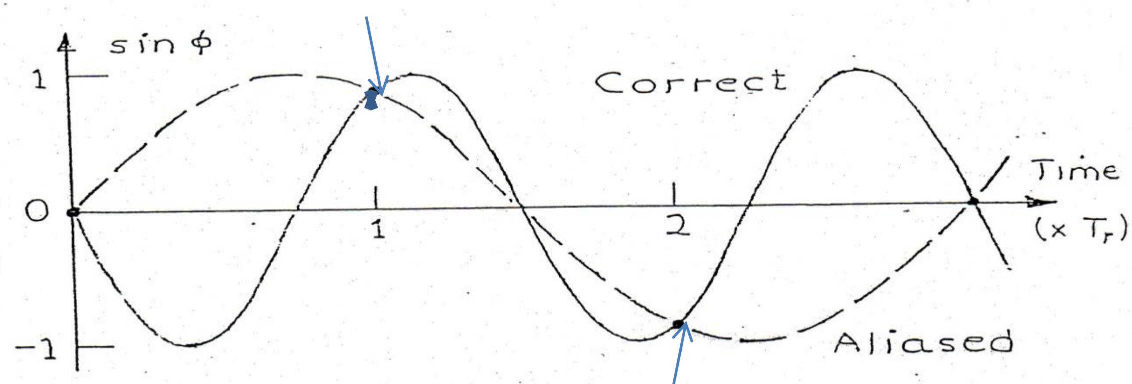


d. Sample rate < 2f

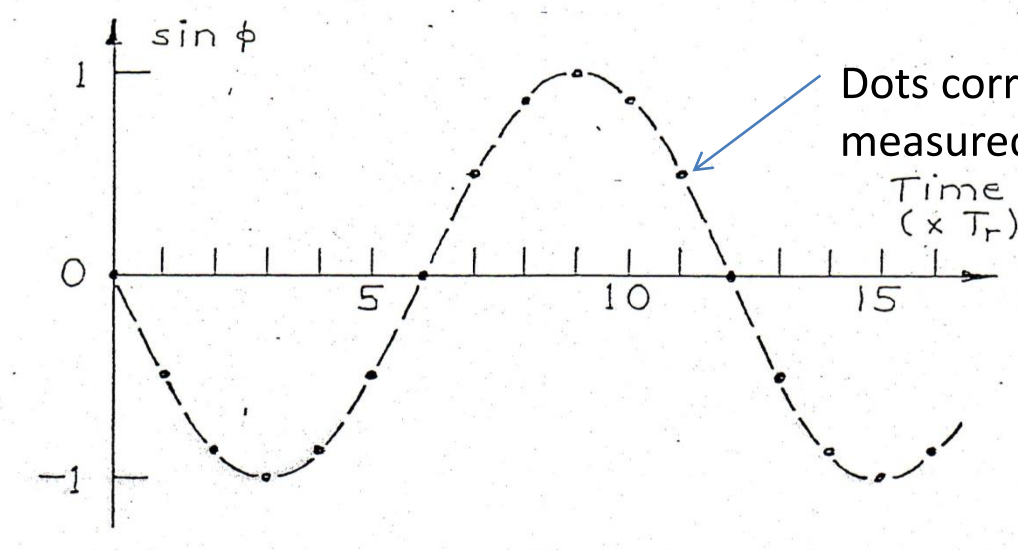


e. Sample rate = f

DOPPLER AMBIGUITIES



More than one doppler frequency will always exit that can fit a finite sample of phase values



Dots corresponds to the measured samples of phase

AMBIGUOUS DOPPLER & BLIND DOPPLER

- **Ambiguous Velocity :**

- If Nyquist sampling criterion is not met Doppler shift frequency measured becomes ambiguous and therefore radial velocity of target computed

  ($f_d = 2\, v_r / \lambda$) is not unique and it becomes ambiguous

- $f_P > 2\, f_d$ ie., $f_d < (f_P /2)$

AMBIGUOUS DOPPLER & BLIND DOPPLER

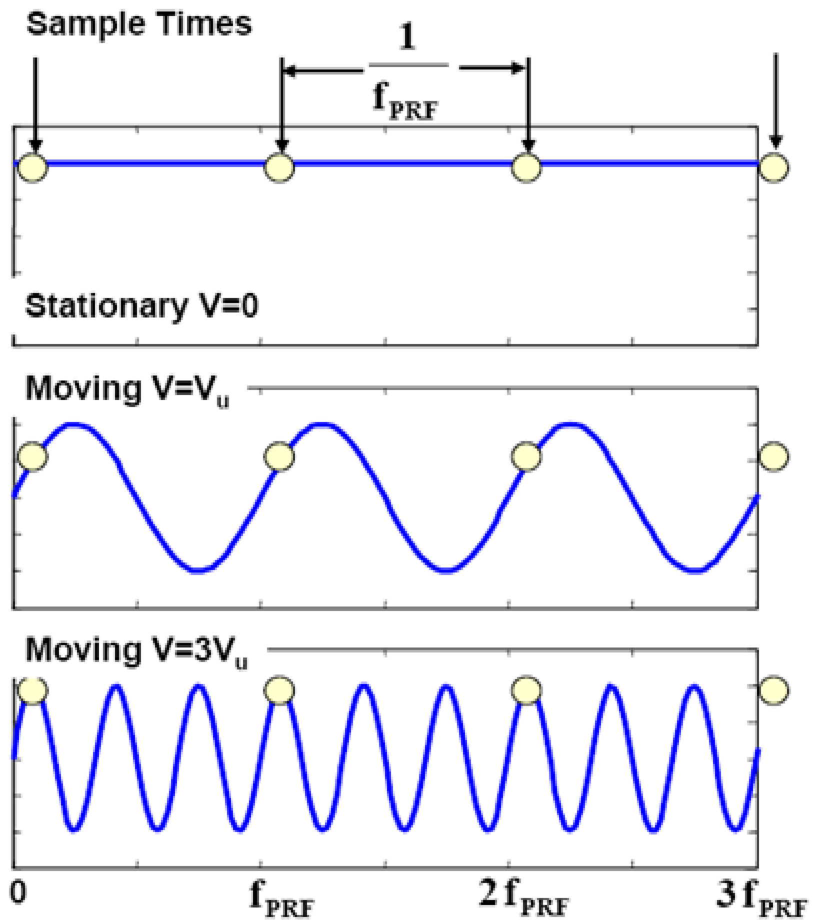
- **Blind Velocity :** When $\mathbf{f_d = n\, f_P}$ (n is an integer)

  $f_d = 0$ which means the Rx output is zero. This gives an erroneous result that there is no target where in reality there is a moving target (Blind speeds are not acceptable in some cases like in airborne radar)

BLIND DOPPLER SHIFT

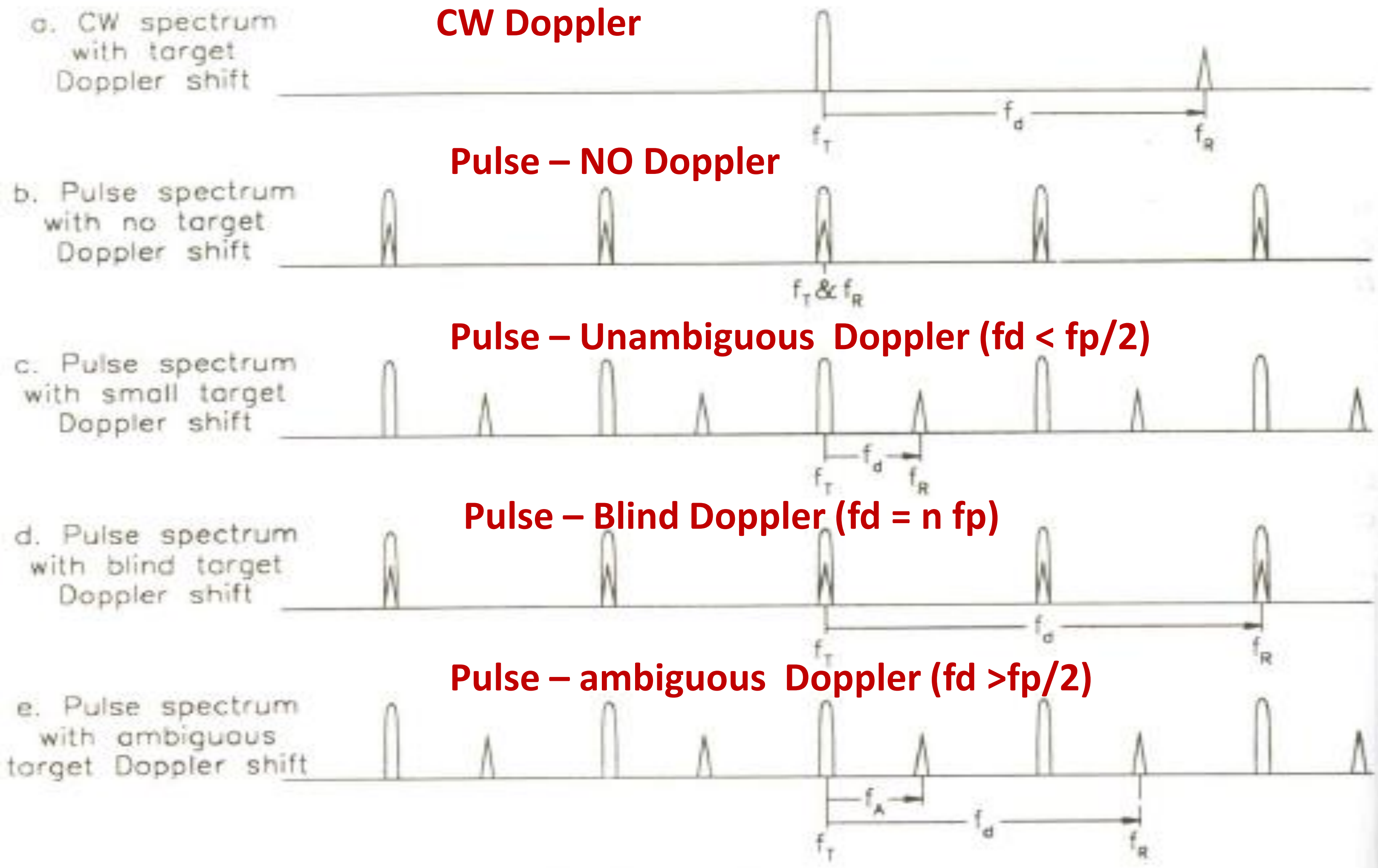
- Pulse Doppler waveform samples target with sampling rate = PRF
- Sampling causes aliasing at multiples of PRF
- Two targets with Doppler frequencies separated by an integer multiple of the PRF are indistinguishable
- Unambiguous velocity is given by:

$$V_U = \frac{\lambda f_d}{2}$$



DOPPLER SHIFT CONDITIONS

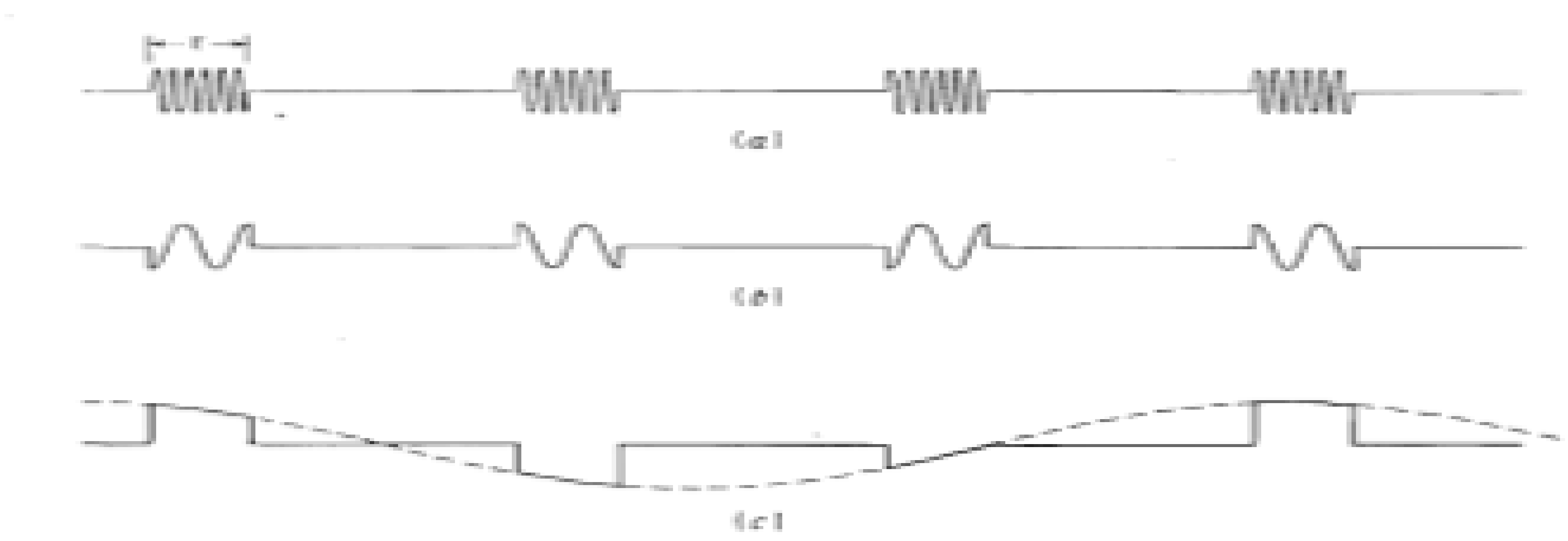
- **Frequency Spectrum:**



1. (Jntuh) Explain the Butterfly effect that is produced by MTI
2. (Jntuh) Draw the different sweeps of MTI radar in a A scope display

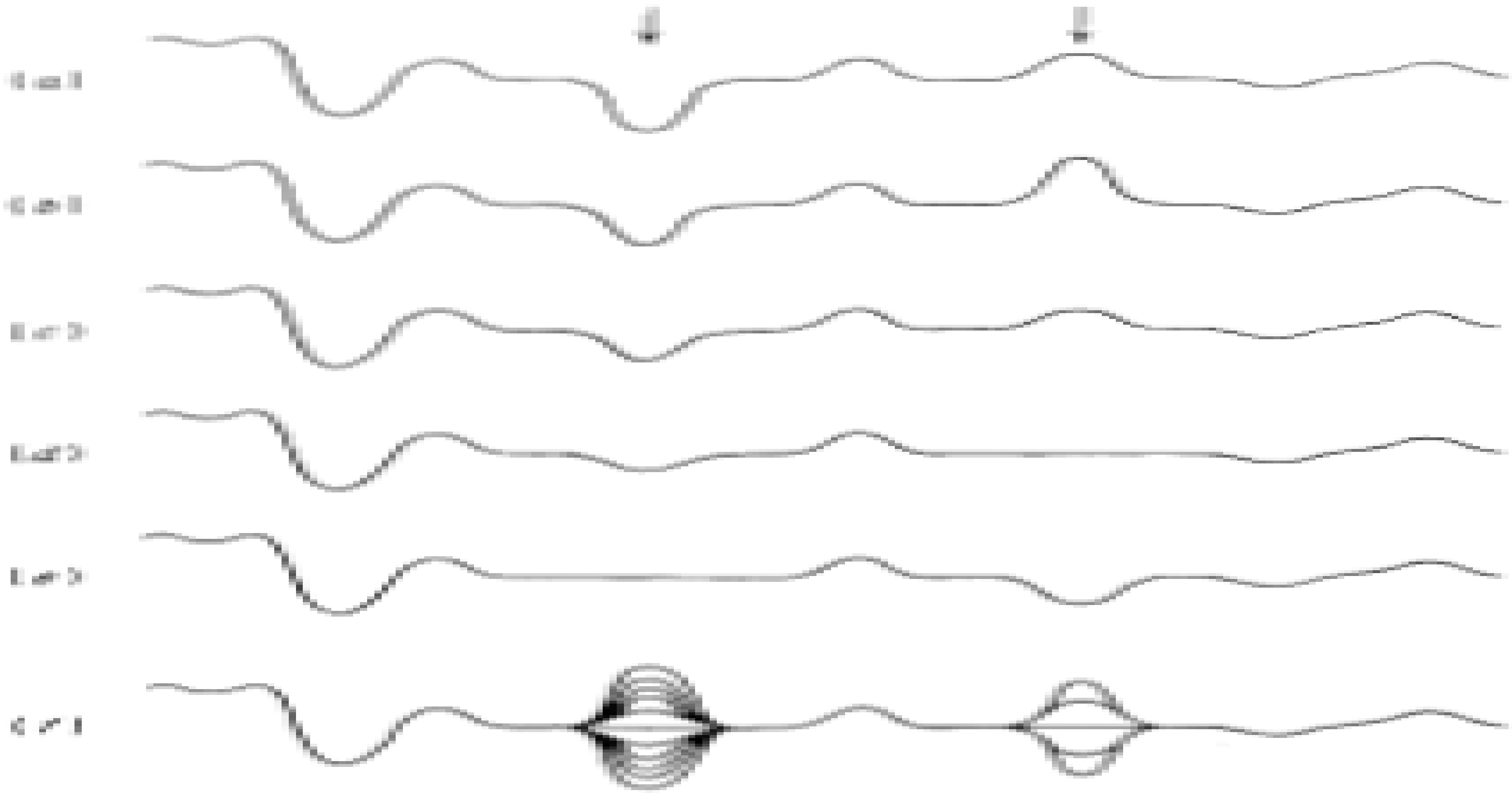
PRINCIPLE OF OPERATION

- Depending upon f_d , 2 cases will arise (τ = Pulse Width).
  i. $f_d > 1/\tau$ ⟶ f_d can be found quickly.
  ii. $f_d < 1/\tau$ ⟶ many pulses need to be sent to find f_d



MOVING TARGETS AND BUTTERFLY EFFECT

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



MOVING TARGETS AND BUTTERFLY EFFECT (CONTD ..)

•Several successive sweeps are required to distinguish a moving target.

•Echoes (phases) from fixed targets remain constant throughout.

•Echoes (phases) from moving targets varies in magnitude from sweep to sweep.

MOVING TARGETS AND BUTTERFLY EFFECT (CONTD ..)

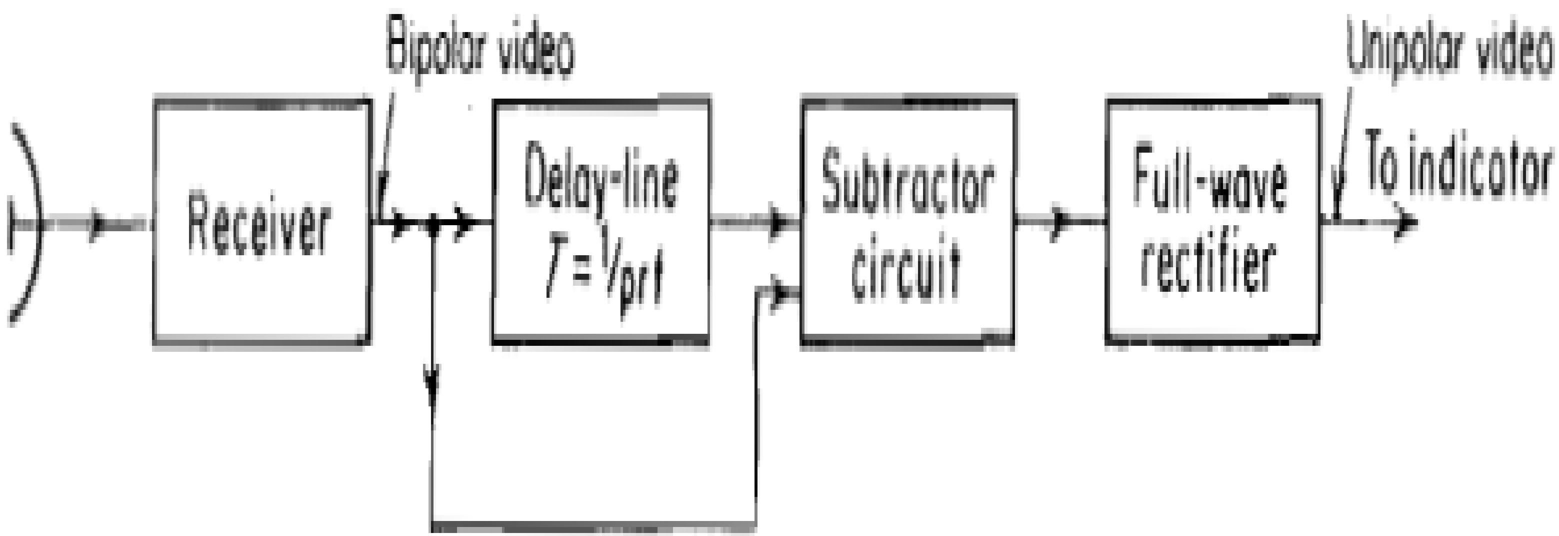
•Rate of change of phases corresponds to Doppler frequency.

•Super position of successive sweeps is shown at the bottom trace.

•The moving targets are distinguishable by the Butterfly Effect on the A Scope.

MTI R_X WITH A DELAY LINE CANCELER

- Delay Line Canceller is employed.
- Butterfly effect is not suitable for PPI (Plan Position Indicator) Display. Z input (intensity of spot) of PPI requires only positive pulses. So full-wave rectifier is used.



MTI R_X WITH A DELAY LINE CANCELLER (CONTD ..)

- Bipolar video is divided into 2 channels
    1. Normal video channel
    2. Delayed video channel. Time Delay is equal to one PRT (=PRI).

- Output from channels (i) and (ii) are subtracted
- Fixed Targets (clutter) do not change their phases. As such they are cancelled out.
- Moving targets change their phases . Subtraction results in an uncancelled residue.
- Bipolar video is converted to unipolar video by full wave rectifier and applied to PPI.

MAGNITUDE OF DOPPLER SHIFT

- DOPPLER Radars are only sensitive to the motion of objects.
- It measures the motion of target along the Radar beam .

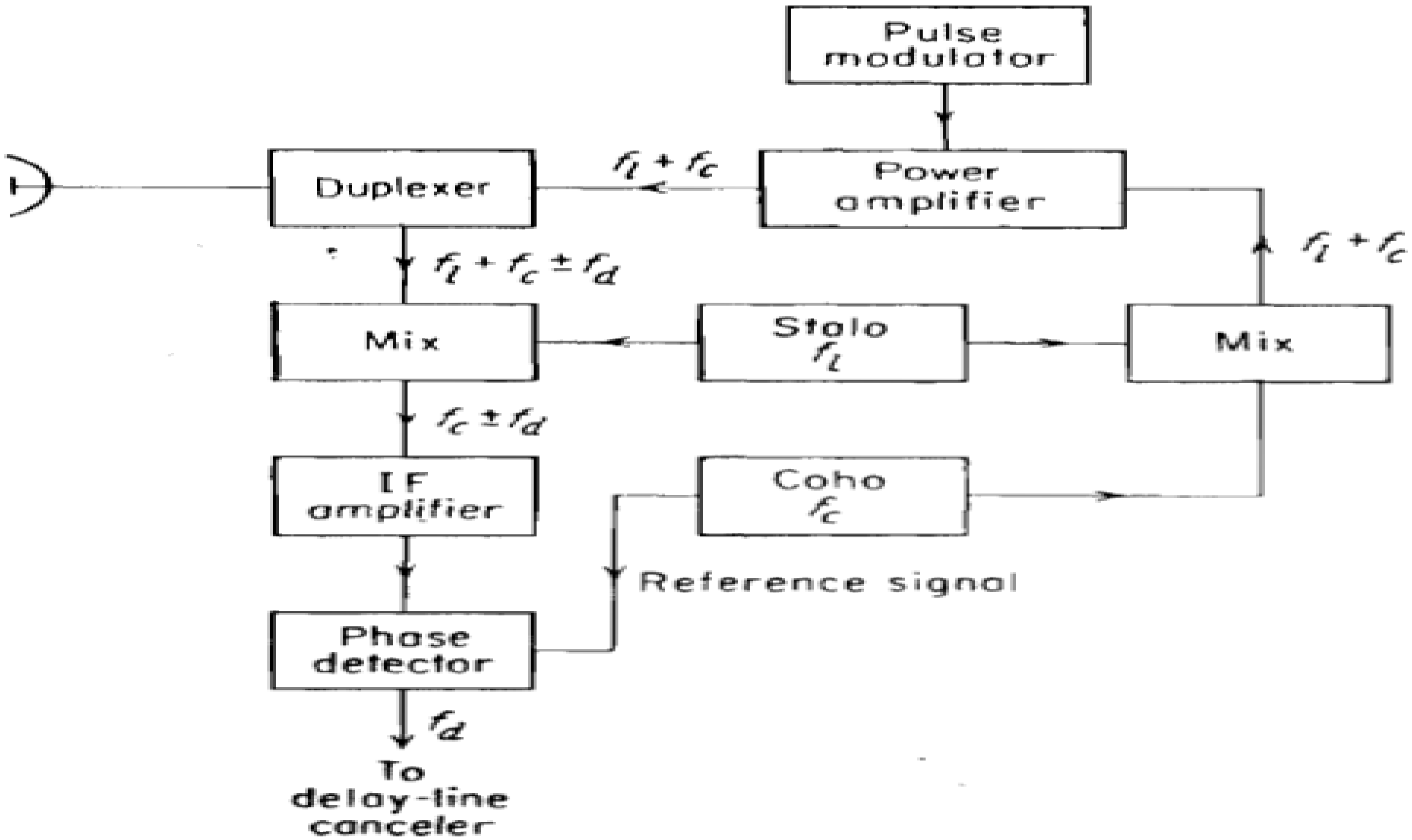
Radial Velocity	X Band 9.37 GHZ	C Band 5.61 GHZ	S Band 3.0 GHZ
1 m/s	62.5 HZ	37.5 HZ	20.0 HZ
10 m/s	625 HZ	375 HZ	200 HZ
50 m/s	3125 HZ	1876 HZ	1000 HZ
200 m/s	12KHZ (80micro secs)	7504 HZ	4000 HZ

- These Doppler frequency shifts are very small. For this reason, Doppler Radar must employ every stable oscillators in transmitters and receivers.

(Jntuh) **What is MOPA ? Write a technical note on it**

MTI RADAR WITH POWER AMPLIFIER

- 2 types of T_x are possible
  i. Power Amplifier   ii. Power Oscillator



MTI RADAR WITH POWER AMPLIFIER (CONTD ..)

- Stable reference signal is required for comparing the phases of transmitted pulse and the Echo pulse.

- Coherent reference is supplied by the coherent oscillator (COHO).

- COHO is a stable oscillator and its frequency should be the IF frequency used in the R_x.

- COHO frequency f_C (usually 30 or 60 MHZ) is mixed with local oscillator frequency f_L (say 1 GHZ, 2 GHZ,10 GHZ etc.)

MTI RADAR WITH POWER AMPLIFIER (CONTD ..)

- Local oscillator frequency also should be stable(STALO).
- The function of STALO is to provide the frequency translation from IF to T_x frequency. However the reference signal for comparison of phase is the COHO.
- Phase of STALO influences the phase of T_x signal but this shift does not matter, as the STALO is cancelled out in the Mixer.

MTI RADAR WITH POWER AMPLIFIER (CONTD ..)

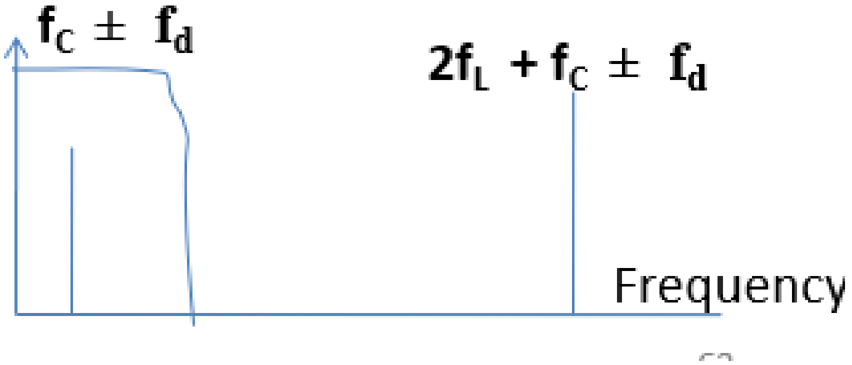
- T_x Frequency = $f_L + f_{C.}$
- Echo frequency = $f_L + f_C \pm f_{d.}$
- 2nd mixer output (i) $2f_L + 2f_C \pm f_d$ (Sum)

  (ii) $2f_C \pm f_d$ (Difference).
- $2f_L + f_C \pm f_d$ suppressed by low pass filter.
-

MTI RADAR WITH POWER AMPLIFIER (CONTD ..)

- Inputs to phase detector are i) $f_C \pm f_d$ and ii) f_c .

- Output of phase detector is f_d.



MTI RADAR WITH POWER AMPLIFIER (CONTD ..)

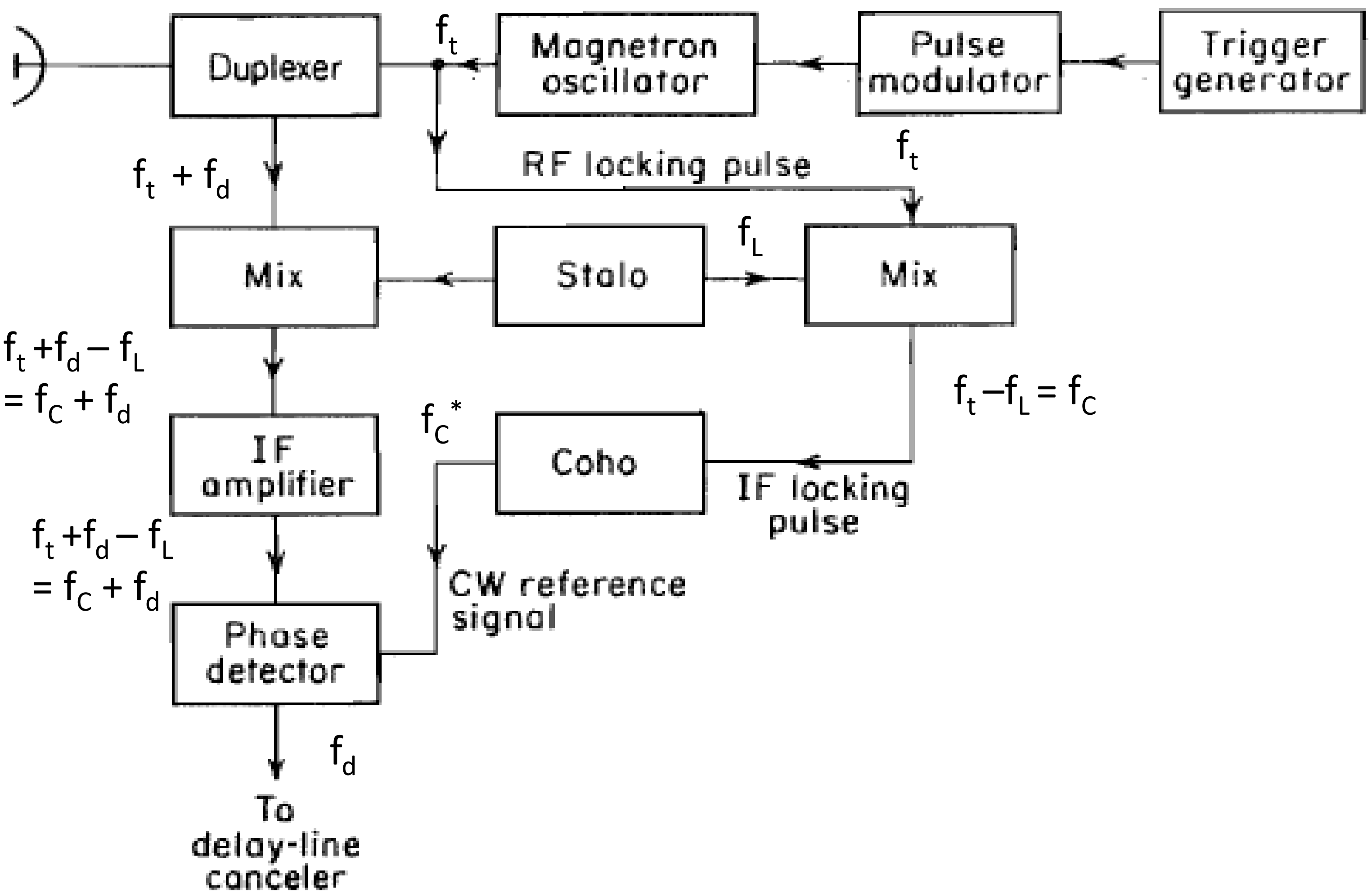
➢ Types of Power Amplifiers available:

(i) Triode
(ii) Tetrode
(iii) Klystron
(iv) Travelling wave tube
(v) Crossed – field amplifier.

- The portion of Radar which has low-power source followed by the power amplifier is called **MOPA** chain (Master Oscillator Power Amplifier).

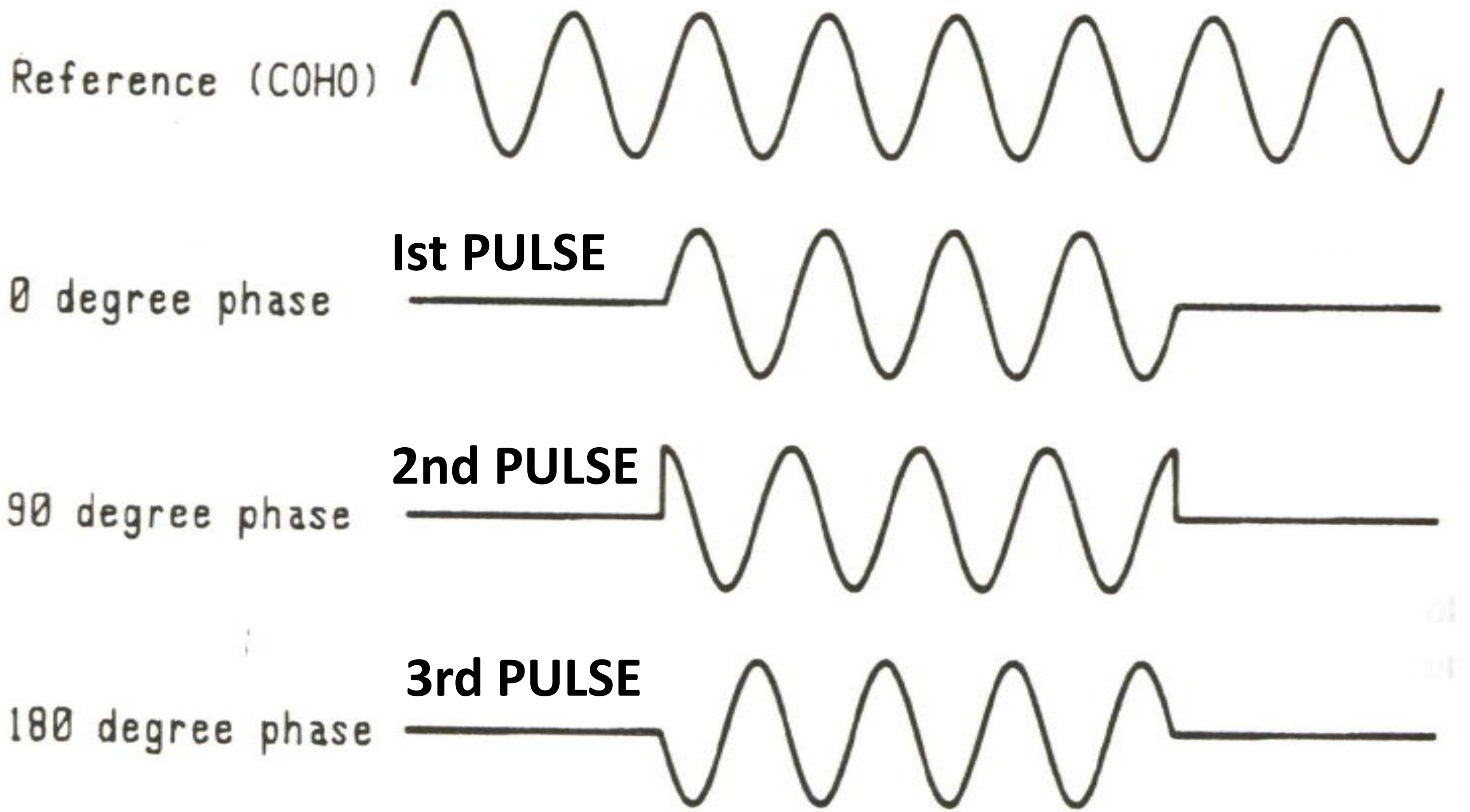
MTI RADAR WITH POWER OSCILLATOR

- Magnetron which is a high power oscillator is used.



MAGNETRON PULSES

- In a magnetron phase of sine wave with respect to a reference changes randomly from pulse to pulse



MTI RADAR WITH POWER OSCILLATOR (CONTD ..)

- Magnetrons are ON/OFF devices.
- When Magnetron is pulsed it starts up with a phase whose value is random from pulse to pulse. No coherence of phase is possible.
- COHO is used as a reference signal. However its phase is locked to magnetron using (phase lock loop)PLL. The phase of COHO is readjusted at the beginning of every transmitted pulse.

MTI RADAR WITH POWER OSCILLATOR (CONTD ..)

- **How to relate the phase of COHO with phase of transmitted pulse.**

- A portion of T_x signal is mixed with STALO to produce IF signal. The phase of IF signal is directly related to phase of the transmitter.
- The IF signal and COHO signal are phase locked using phase lock loop.

MTI RADAR WITH POWER OSCILLATOR (CONTD ..)

- Now the phase of COHO is related to the phase of transmitted signal and forms as the reference signal (f_c).
- The reference signal forms as one of the inputs of the phase detection. The other input to phase detector is $f_c \pm f_d$
- The output of the phase detector is applied to Delay Line Canceller.

CONTINUED IN RADAR 3B

👉 (Jntuh)

RADAR SYSTEMS
EC812 PE V)
(ELECTIVE V)
UNIT – 3B
B.TECH IV YEAR II SEMESTER
BY
Prof.G.KUMARASWAMY RAO
(Former Director DLRL Ministry of Defence)
BIET

Acknowledgements

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

“ INTRODUCTION TO RADAR SYSTEMS “

Merill I.Skolnik

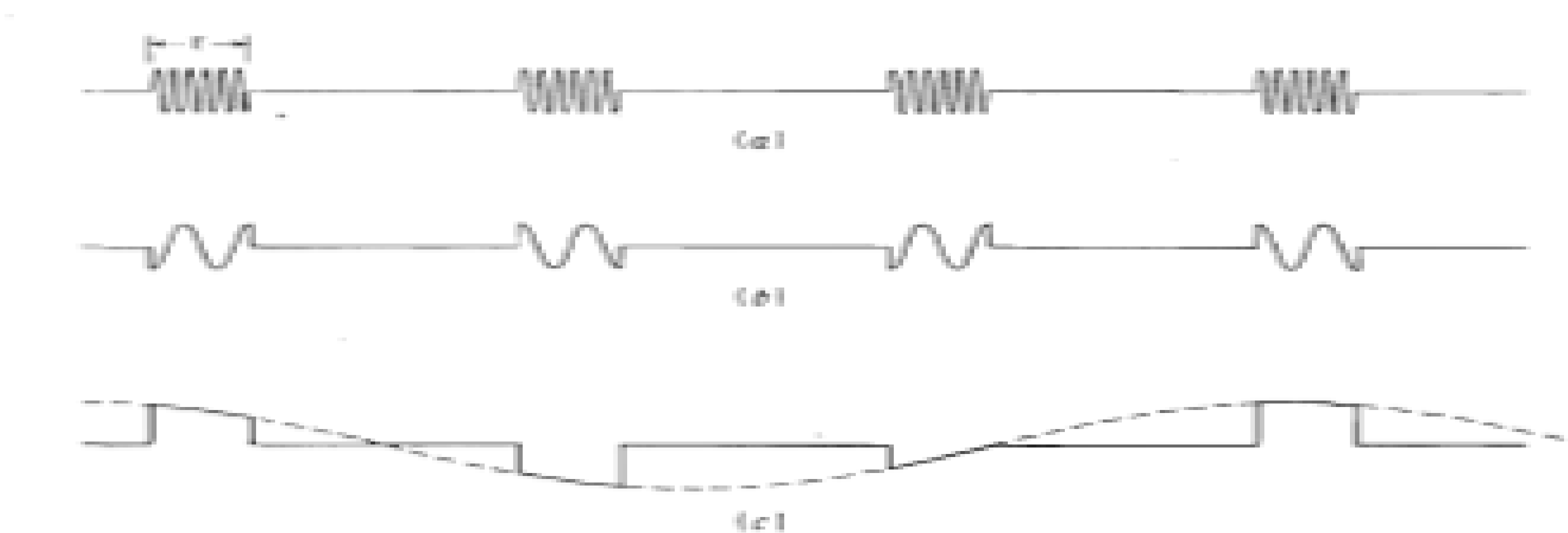
Second Edition

Tata McGraw – Hill publishing company

Special Indian edition

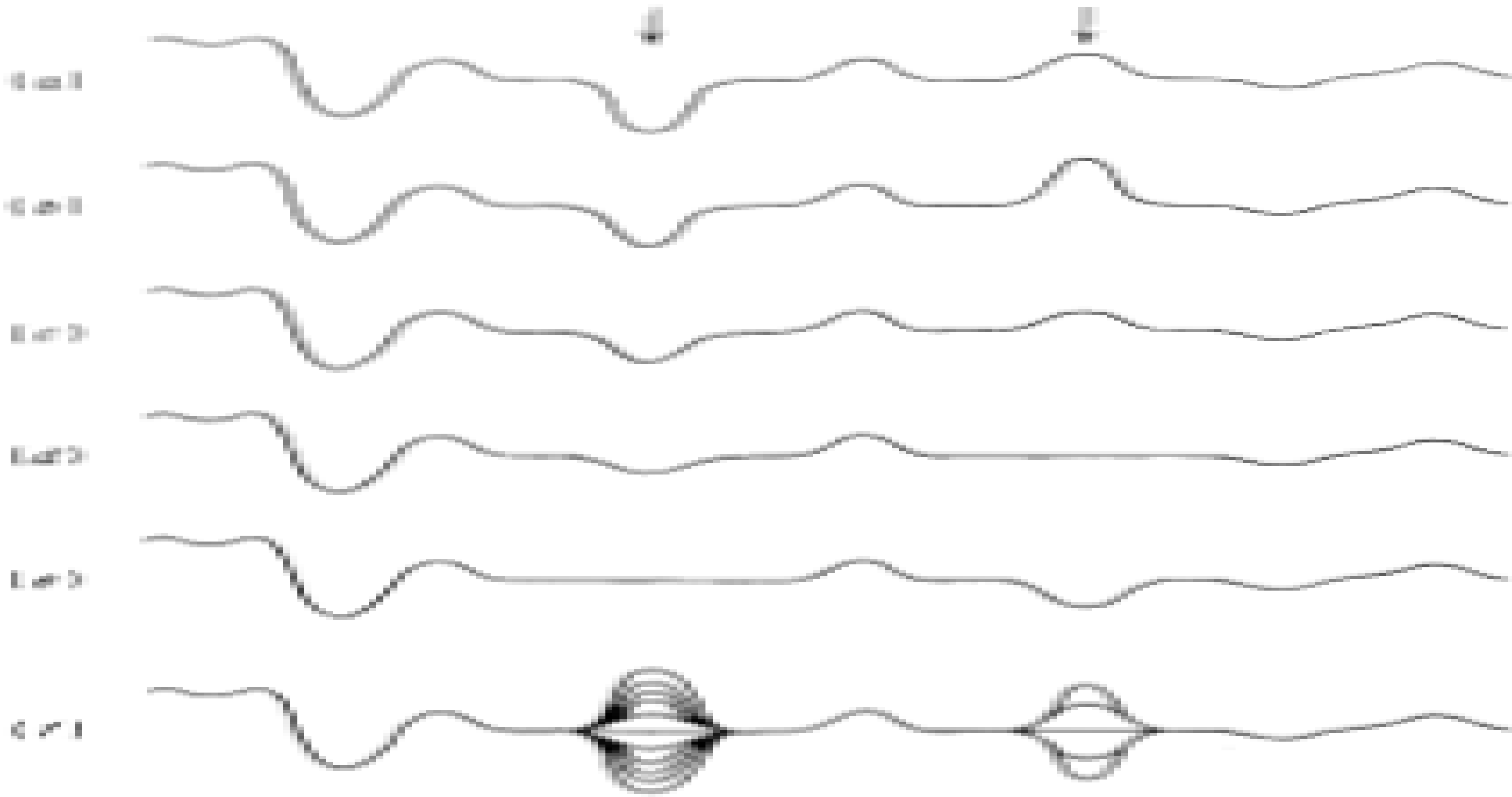
PRINCIPLE OF OPERATION (CONTD ..)

- Depending upon f_d , 2 cases will arise (τ = Pulse Width).
  i. $f_d > 1/\tau$ ⟶ f_d can be found quickly.
  ii. $f_d < 1/\tau$ ⟶ many pulses need to be sent to find f_d

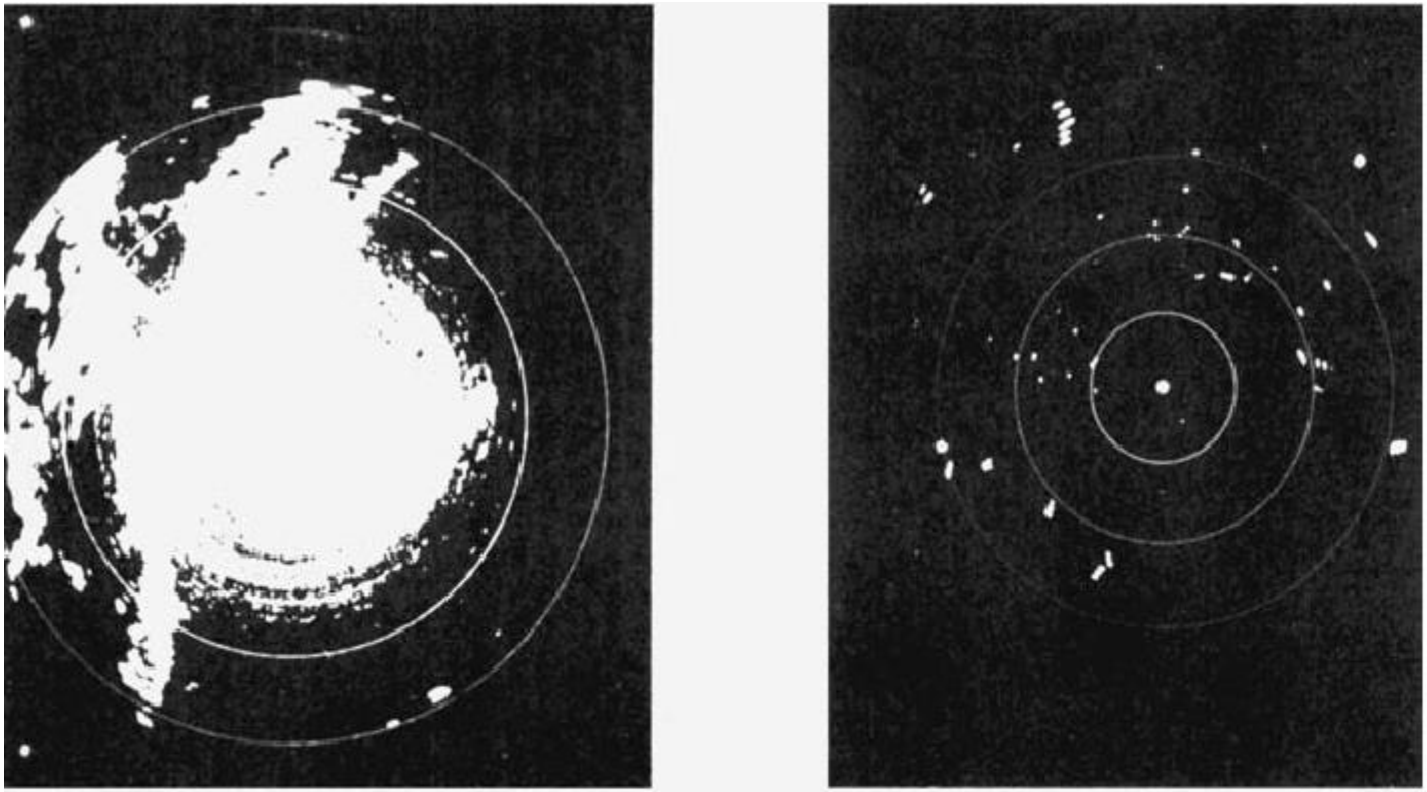


MOVING TARGETS AND BUTTERFLY EFFECT

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

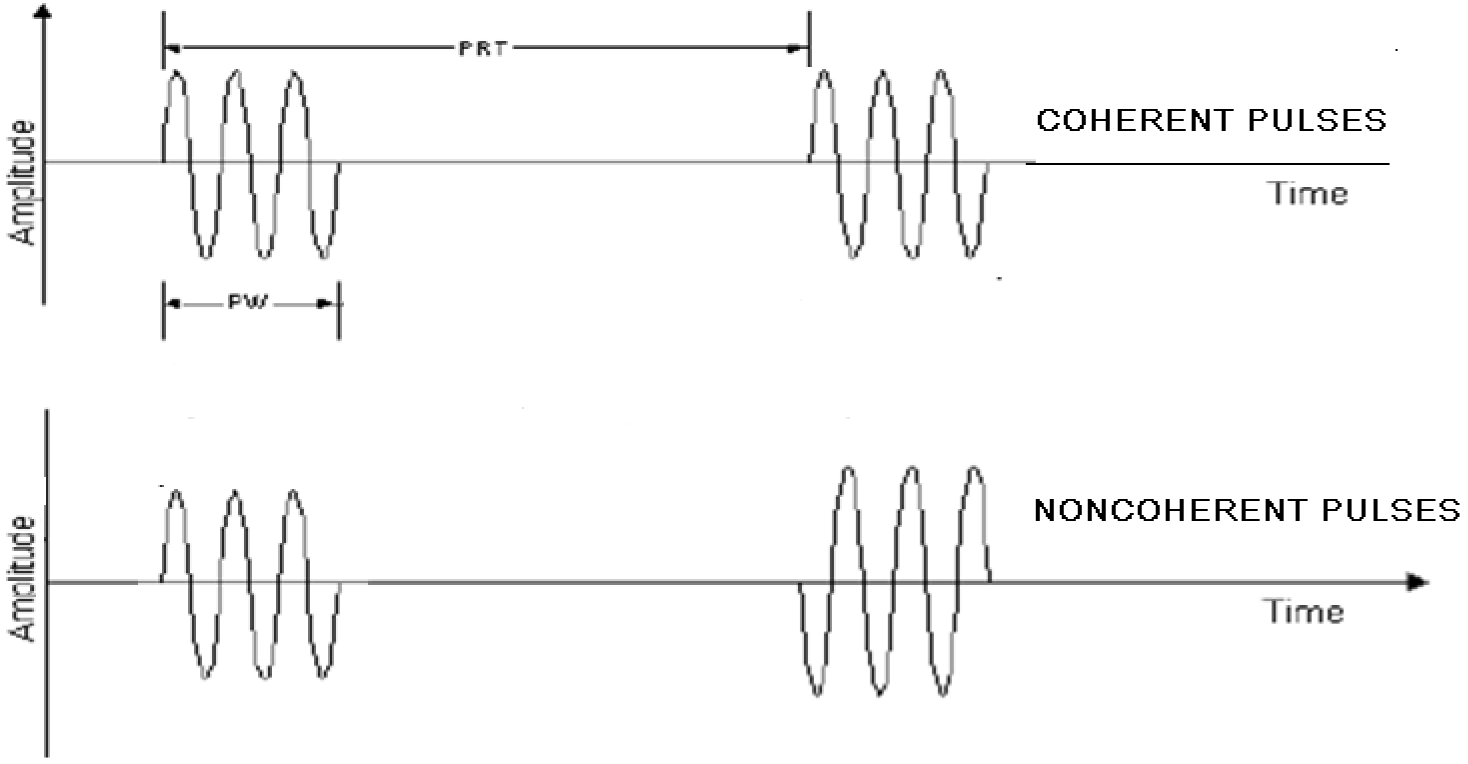


NECESSITY FOR CLUTTER REJECTION



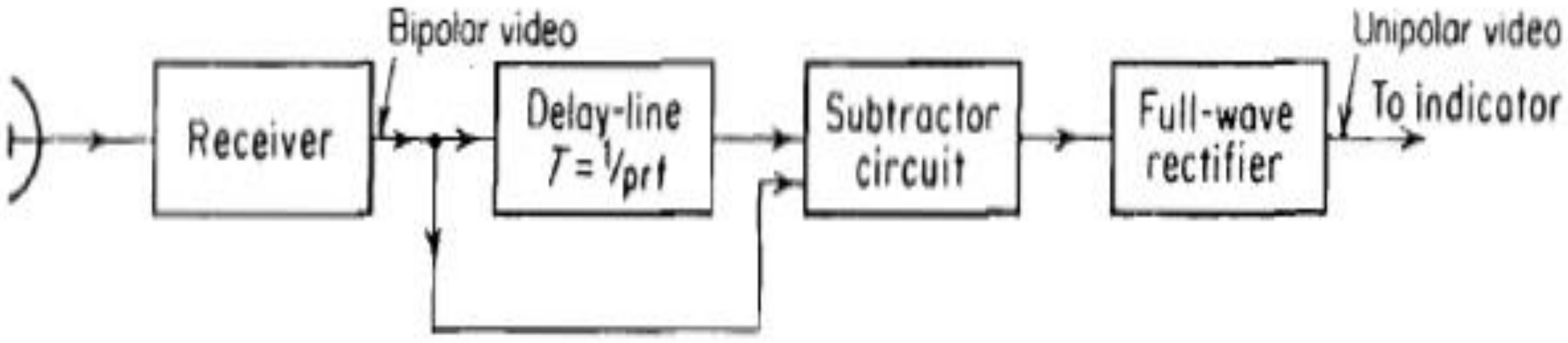
•MTI Radar is complex ,expensive and occupies more space. However with developments in VLSI technology size and cost has come down

COHERENCY / NON COHERENCY OF PULSES



DELAY LINE CANCELLERS

DELAY LINE CANCELLERS



- There are two ways to determine the Doppler Frequency. (i) Delay Line Cancellers (ii) Range gated Doppler Filters

REALIZATION OF DELAY LINE CANCELLERS

- Delay Line Cancellers is a time-domain filter.
- Advantage of DLC is that it operates at all ranges unlike Range Gated Frequency Filter.
- The delay line introduces a time delay equal to pulse repetition interval. This may be several milliseconds.
- To achieve a typical delay of 10milli.secs (Pulse Repetition Interval) the length of transmission line required is 3000 kms which is not practical to be implemented (length of cable = C x delay time

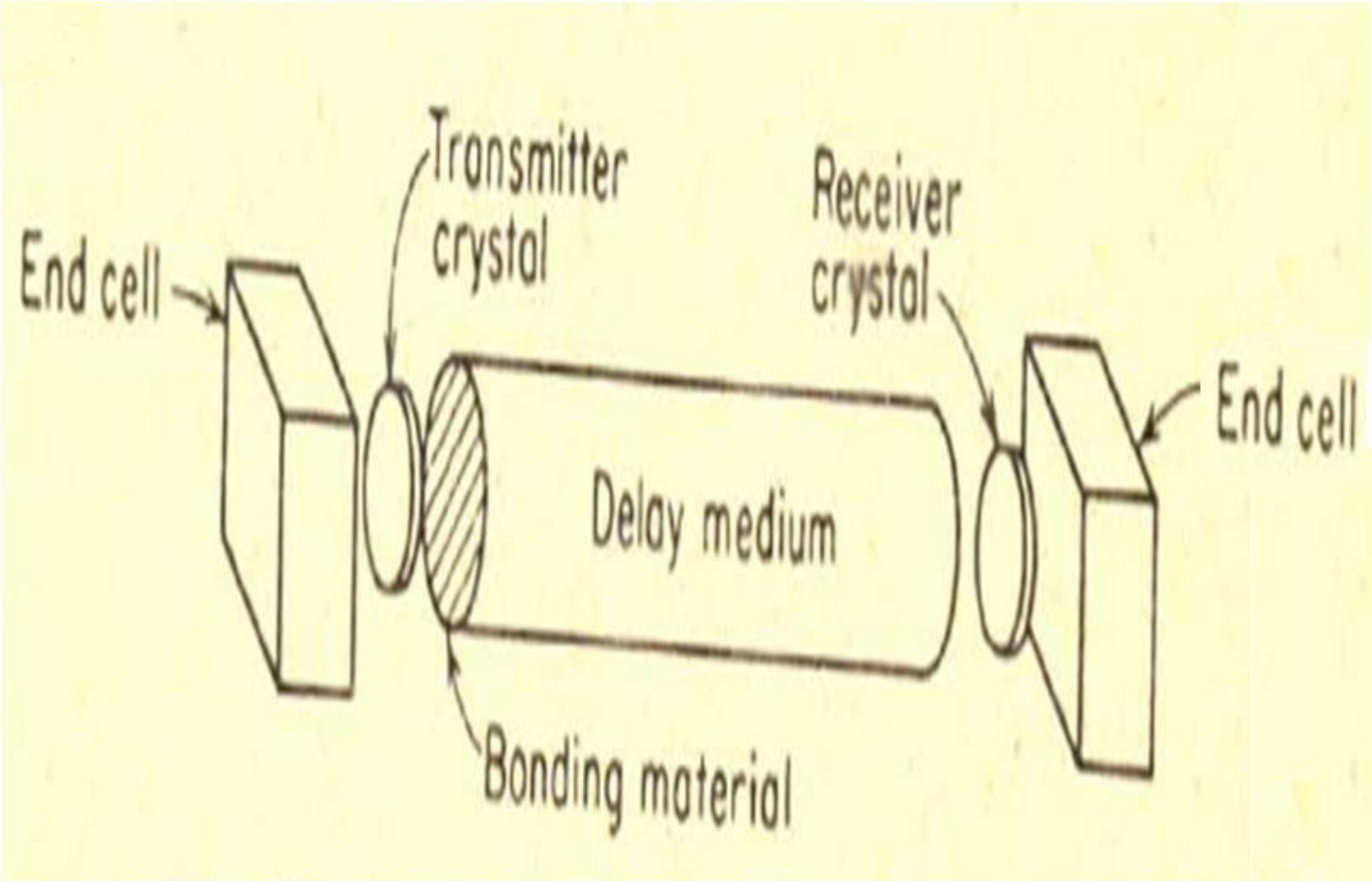
$$= 3x\ 10^{8}\ x\ 10\ x\ 10^{-3}$$

$$=3000Kms$$

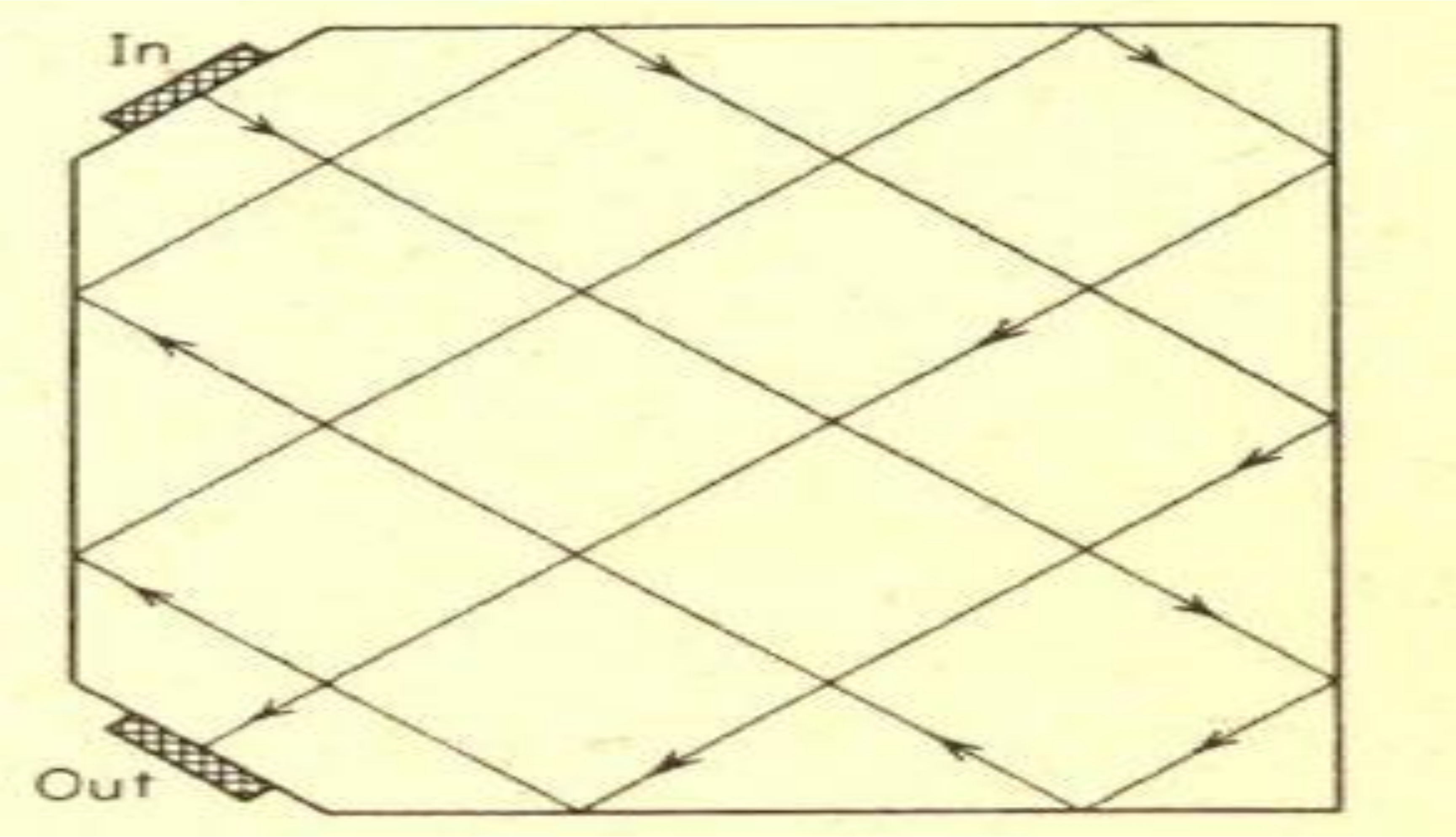
REALIZATION OF DELAY LINE CANCELLERS (CONTD ..)

- 1950 Technology - EM waves are converted into acoustic waves (Velocity of acoustic waves of 10^{-5} that of EM waves) to reduce the path length of transmission.
- Water, mercury later Quartz were used as a medium for Acoustic waves.
- Present day technology uses A/Ds, digital memory and processes.

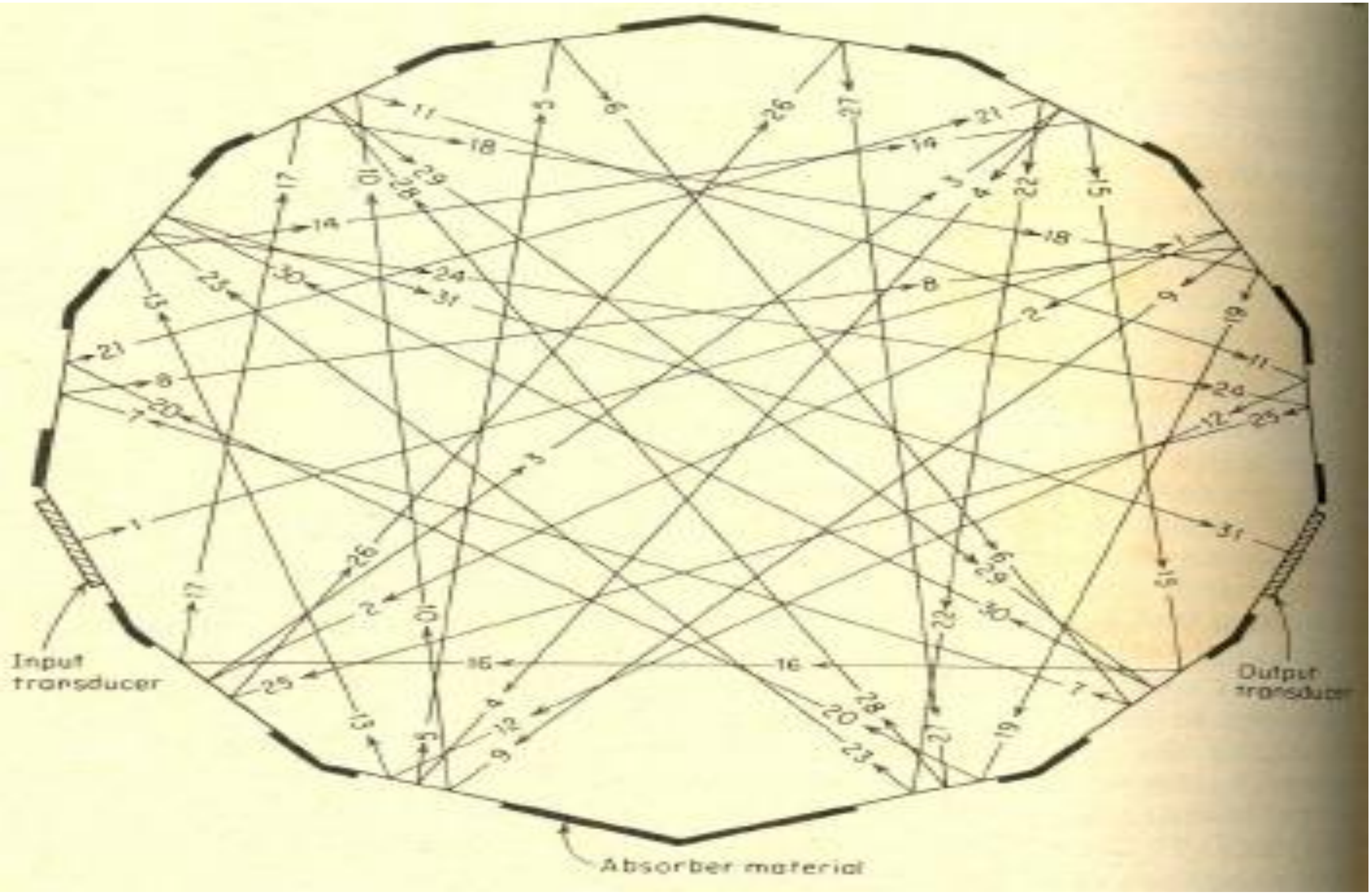
REALIZATION OF DELAY LINE CANCELLERS (CONTD ..)



REALIZATION OF DELAY LINE CANCELLERS (CONTD ..)



REALIZATION OF DELAY LINE CANCELLERS (CONTD ..)



ACOUSTIC DELAY LINES

- EM waves are converted into Acoustic waves.
- EM waves velocity is $\frac{1}{10,0000}$ of velocity of EM waves.
- To obtain a particular delay the path length of acoustic waves is less.
- After the necessary delay in acoustic line, the signal is converted back to EM waves for further processing.
- Acoustic delay lines implemented during world war II used (i) Water or (ii) Mercury as the medium
- 1950 - Delay lines using solid fused Quartz came into existence Principle of multiple reflections are used to reduce the size.

DIGITAL DELAY LINES

- SINCE 1970, Delay lines using digital technology came into existence.
- The output of phase detector is converted to digital value using A/D.
- More complex delay line cancellers with filter characteristics not possible with analog methods

METHODS TO EXTRACT DOPPLER FREQUENCY

- f_d can be determined by using

  (i) Delay line canceller (Time Domain Filter)

  (ii) Range gated Doppler filters

- **Advantages of DLC:**

- Single DLC is sufficient for all target ranges
- Does not require a separate DLC for each single resolution cell.
- Single DLC is enough for multiple targets.

FILTER CHARACTERISTICS OF DLC

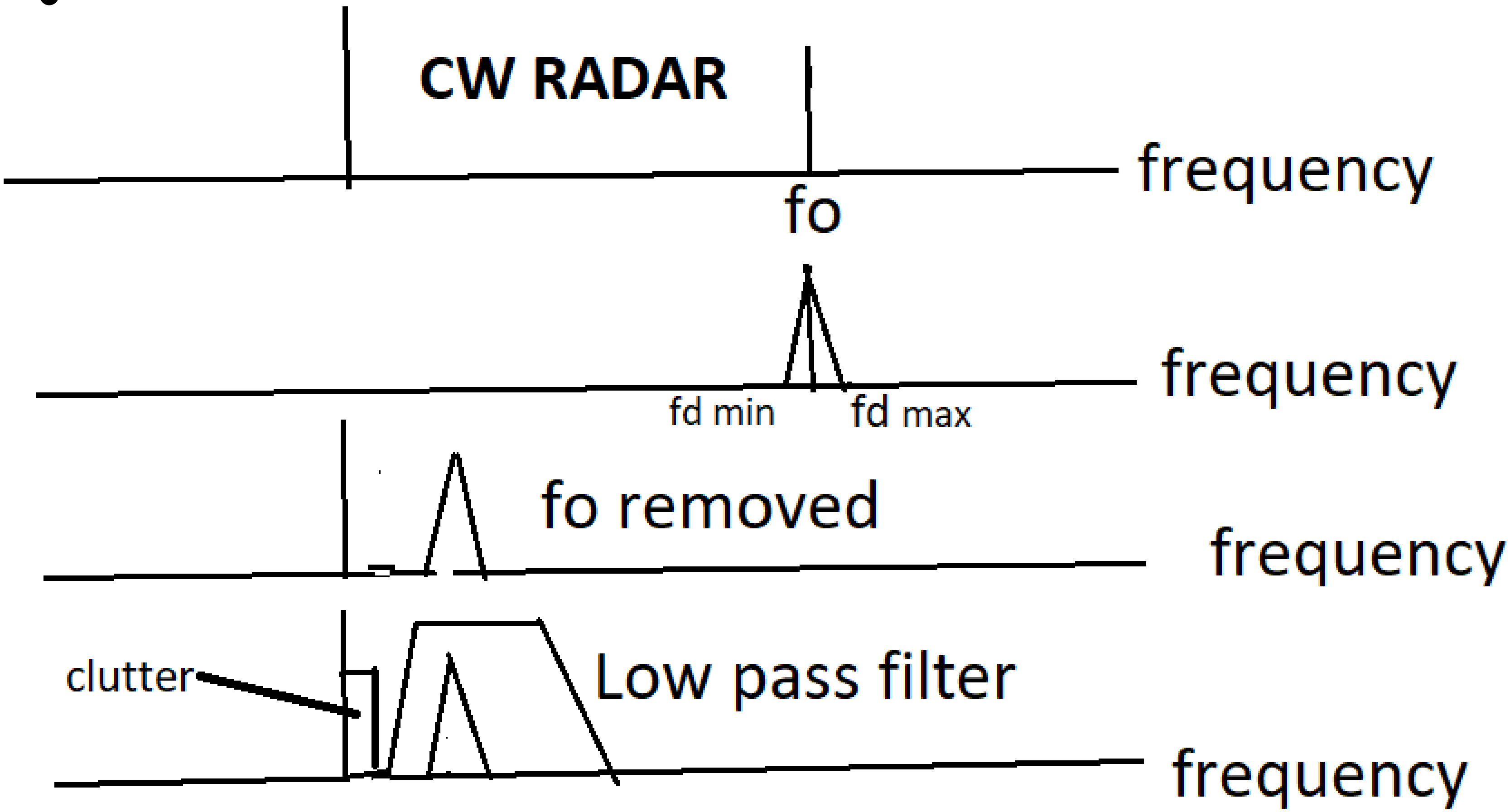
CHARACTERISTICS OF CLUTTER

- Function of DLC is to remove the clutter.
- Clutter is echo from

  (i) stationary targets Ex: Tall buildings, Water tanks ,Concrete structures, Hilly terrain etc.,

  (ii) Very slow moving targets Ex: Trees, Vegetation Moving clouds etc.,
- Clutter spectrum is concentrated around zero (DC) frequency in case of CW Radars and around multiple integers of Radar PRF (f_P) in MTI Radars
- In CW Radars clutter is suppressed by a high pass filter. In MTI Radar MTI filter is used.

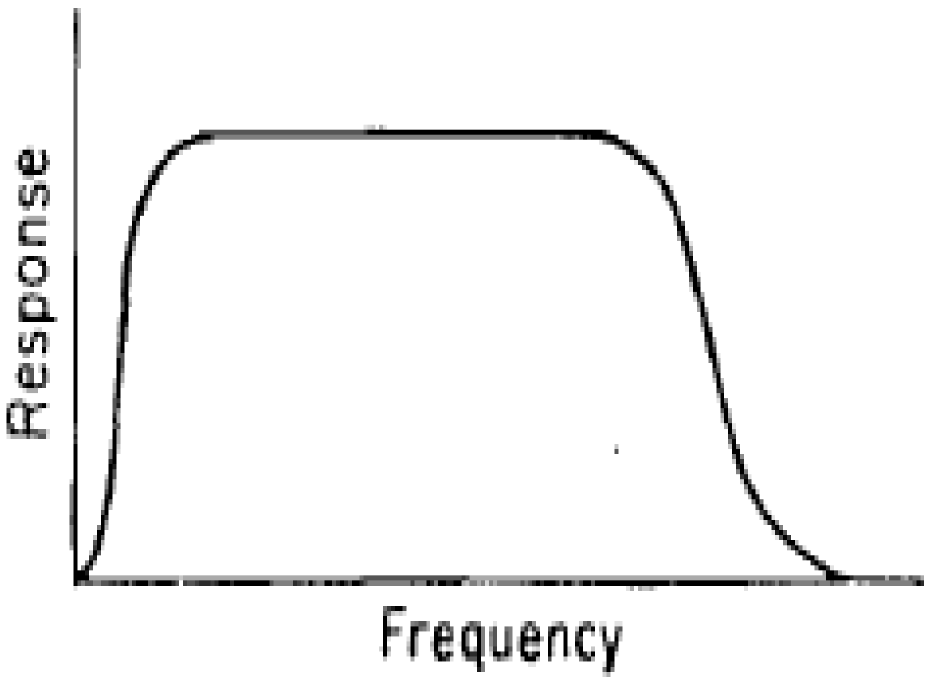
HOW CLUTTER REMOVED IN CW RADAR

- 

CW Radar

➢ Doppler Amplifier:

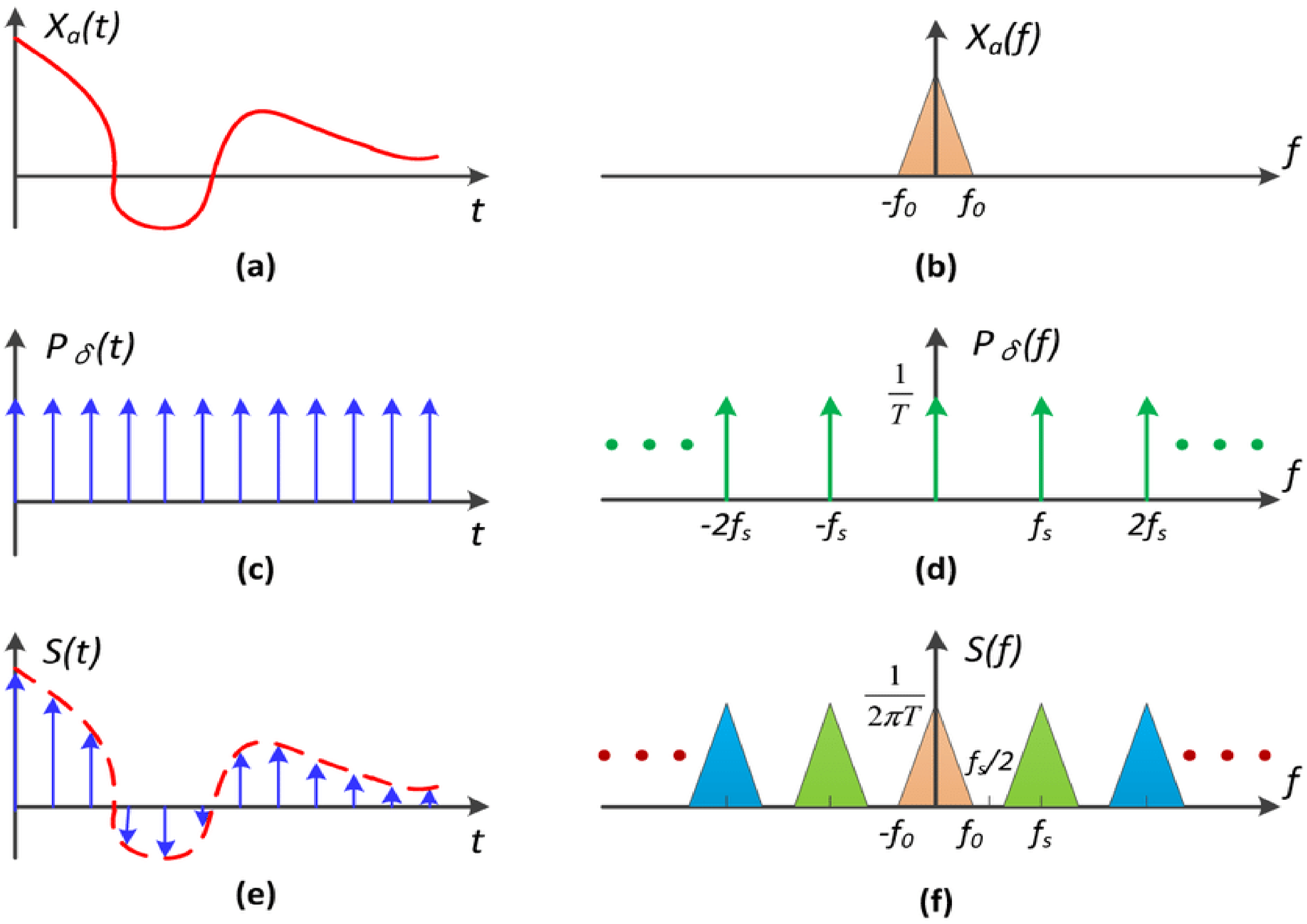
- O/P from Mixer is amplified and filtered. Amplifier level should be sufficient to operate the indicator.



Beat Frequency Amplifier Response

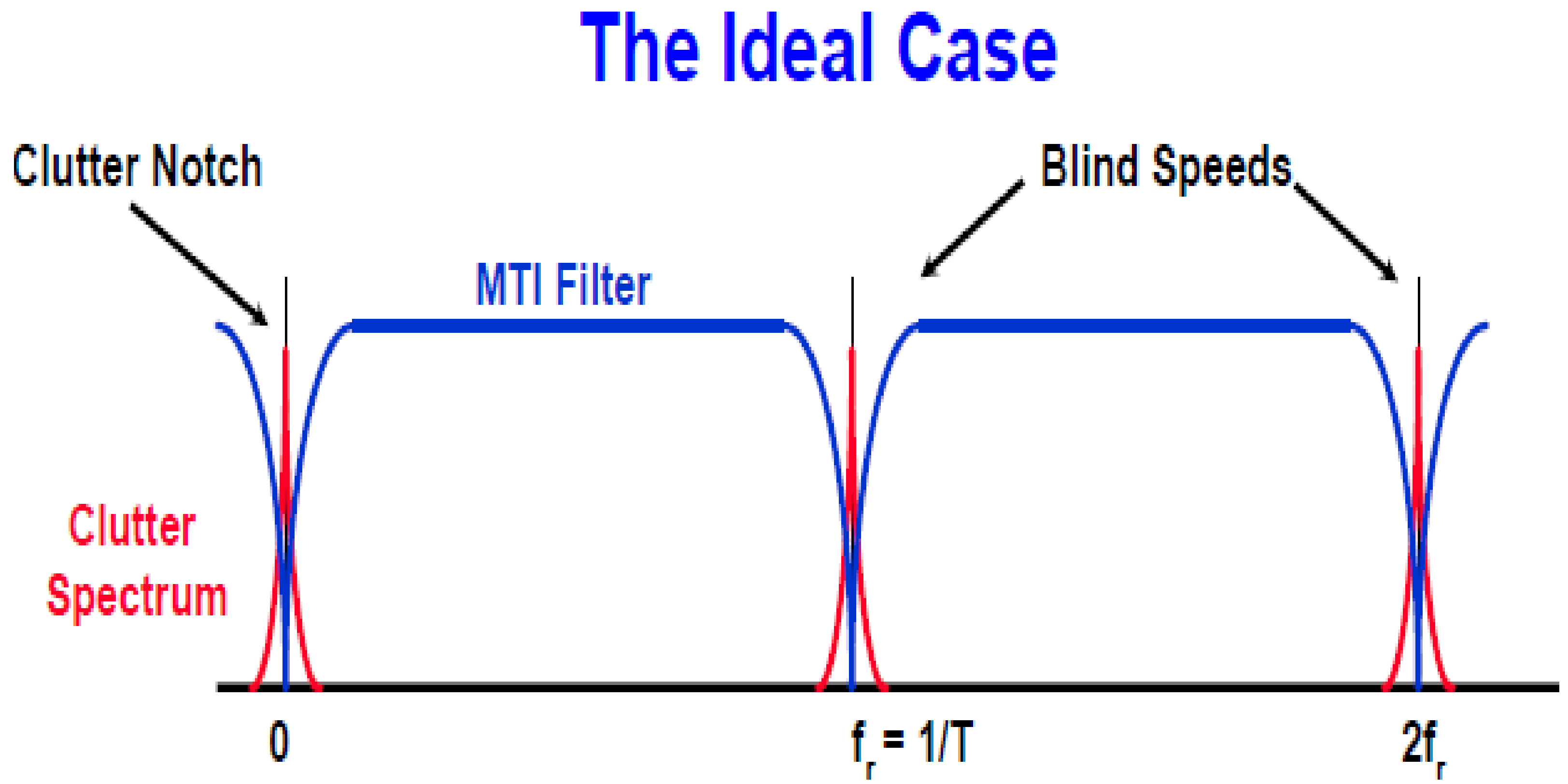
SAMPLING ANALOG SIGNAL

- .

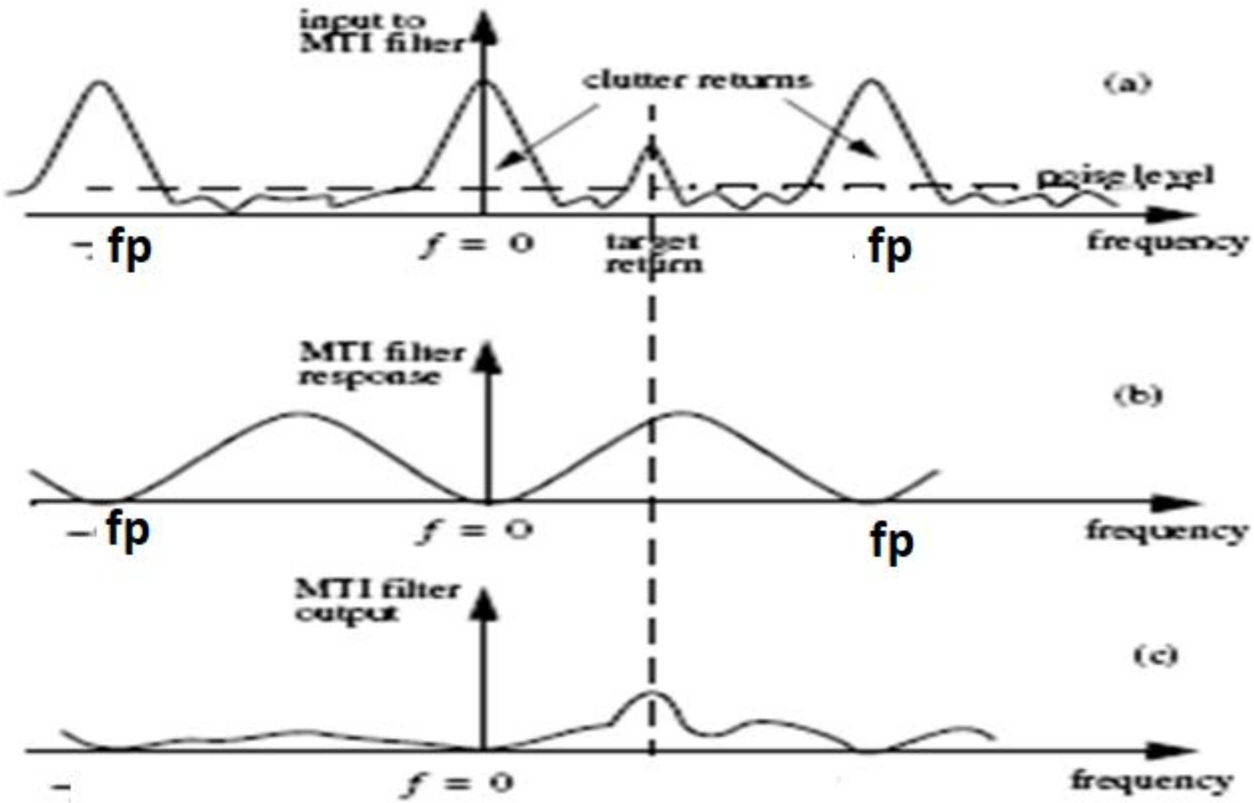


IDEAL DLC

- The frequency response of single DLC does not have the clutter – rejection null in the vicinity of DC

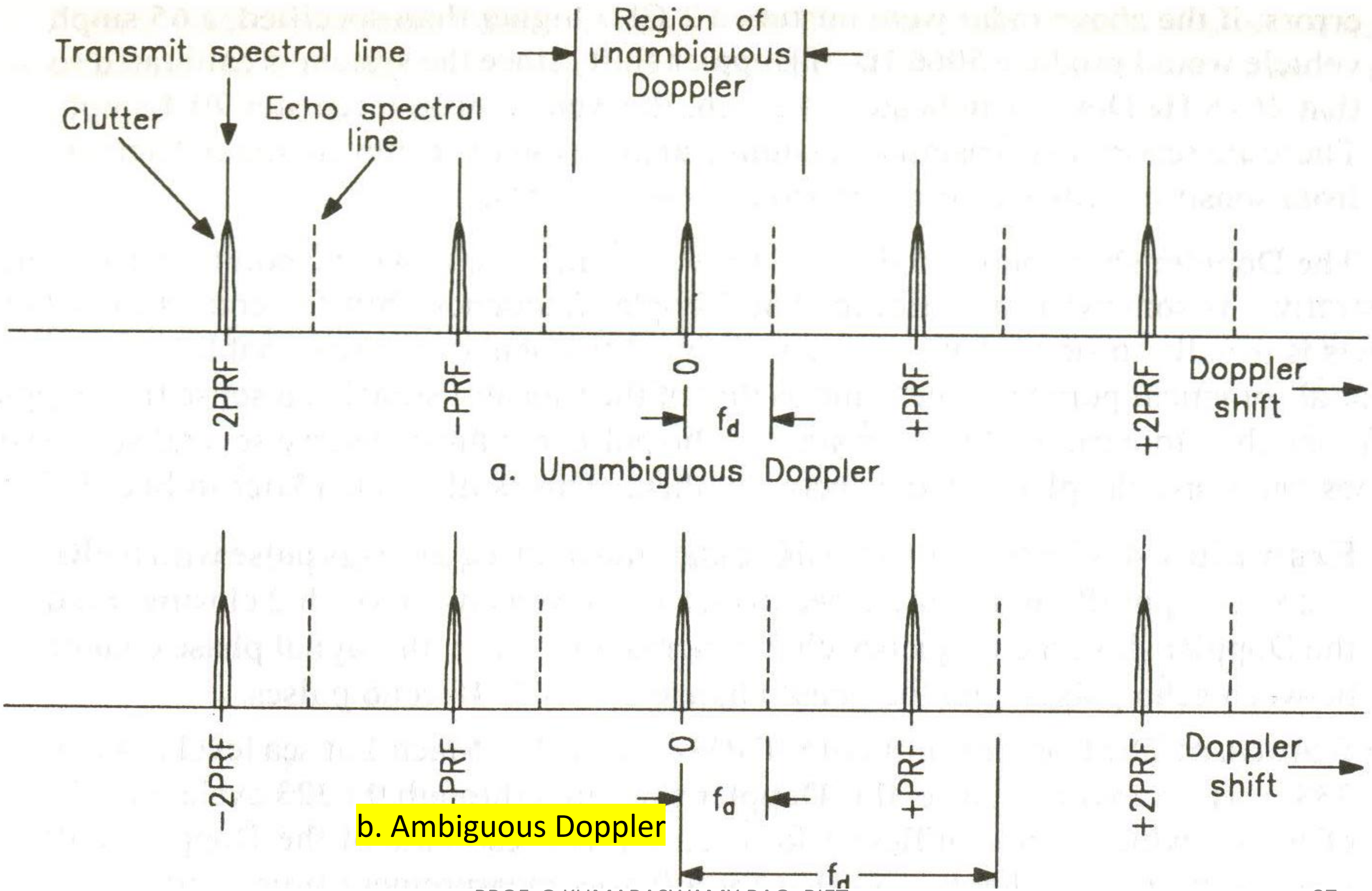


FREQUENCY CHARACTERSTICS OF CLUTTER



- Clutter need to be suppressed at frequencies around $0, f_P, 2f_P, \ldots, nf_P$ where n is an integer.
- MTI filter can be realized by using a Delay Line

FREQUENCY CHARACTERSTICS OF CLUTTER



b. Ambiguous Doppler

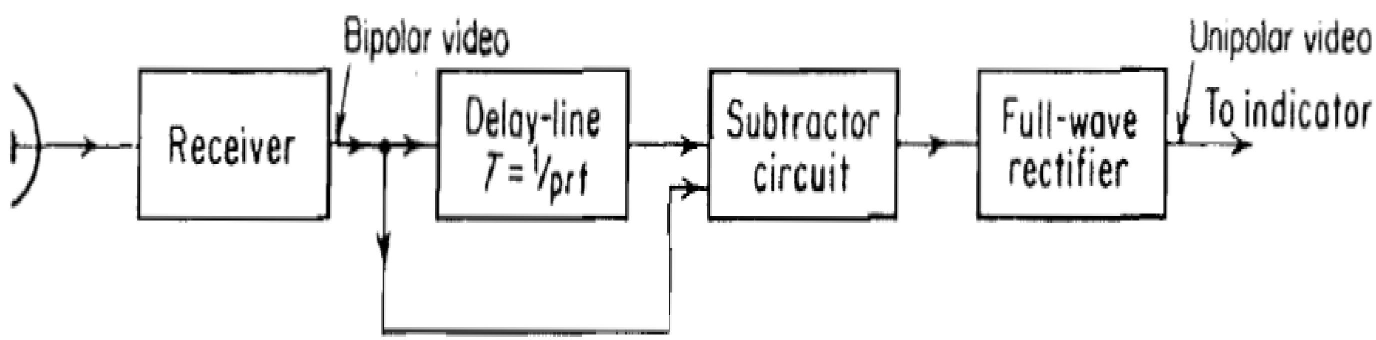
1. (Jntuh) **Explain in detail the filter characteristics of delay Line canceller**

2. (Jntuh) **A simple MTI delay canceller is an example of time of domain filter. Why ? Explain**

FILTER CHARACTERISTICS OF DLC

- DLC rejects the DC component of Clutter
- Because of periodic nature, clutter appears at

  0x PRF, 1x PRF , 2x PRF ......nx PRF
- DLC rejects the clutter at not only at zero frequency (DC) but also at 1 PRF, 2PRF, ..n PRF
- The 2 Inputs to the subtractor are i) Current Echo ii) Previous Echo delayed by one PRT



FILTER CHARACTERISTICS OF DLC (CONTD..)

- Echo received from a particular target $= V_1$
- $V_1 = K \sin[2\pi f_d t - \varphi_0] = K \operatorname{Sin} A$

φ_0 = Phase shift due to range R_0 $\quad \varphi_o = \dfrac{4\pi f_0 R_0}{C}$

- K = Amplitude of the Video signal
- Echo from the previous transmission delayed by one PRT $= V_2$
- $V_2 = K \sin[2\pi f_d (t - T) - \varphi_0] = K \operatorname{Sin} B$
- $V = (V_1 - V_2) = K(\operatorname{Sin} A - \operatorname{Sin} B)$
- $V = K \sin\left(\dfrac{A-B}{2}\right) \times \operatorname{Cos}\left(\dfrac{A+B}{2}\right)$

FILTER CHARACTERISTICS OF DLC (CONTD..)

- $V_1 = K \sin[2\pi f_d t - \varphi_0] = K \sin A$
- $V_2 = K \sin[2\pi f_d (t - T) - \varphi_0] = K \sin B$
- $\sin\left[\frac{A - B}{2}\right]$

$$= \sin\left[\frac{2\pi f_d t - \varphi_0 - 2\pi f_d t + 2\pi f_d T + \varphi_0}{2}\right]$$

$$= \sin \pi f_d T$$

FILTER CHARACTERISTICS OF DLC (CONTD..)

- $V_1 = K \sin[2\pi f_d t - \varphi_0] = K \text{ Sin } A$
- $V_2 = K \sin[2\pi f_d (t - T) - \varphi_0] = K \text{ Sin } B$
- $\text{Cos} \left[\frac{A + B}{2}\right]$
- $=$

$$\text{Cos}\left[\frac{2\pi f_d t - \varphi_0 + 2\pi f_d t - 2\pi f_d t - \varphi_0}{2}\right]$$

- $\text{Cos}\ [2\pi f_d t - \pi f_d t - \varphi_0]$
- $\text{Cos}\ \left[2\pi f_d (t - \frac{T}{2}) - \varphi_0\right]$

FILTER CHARACTERISTICS OF DLC (CONTD..)

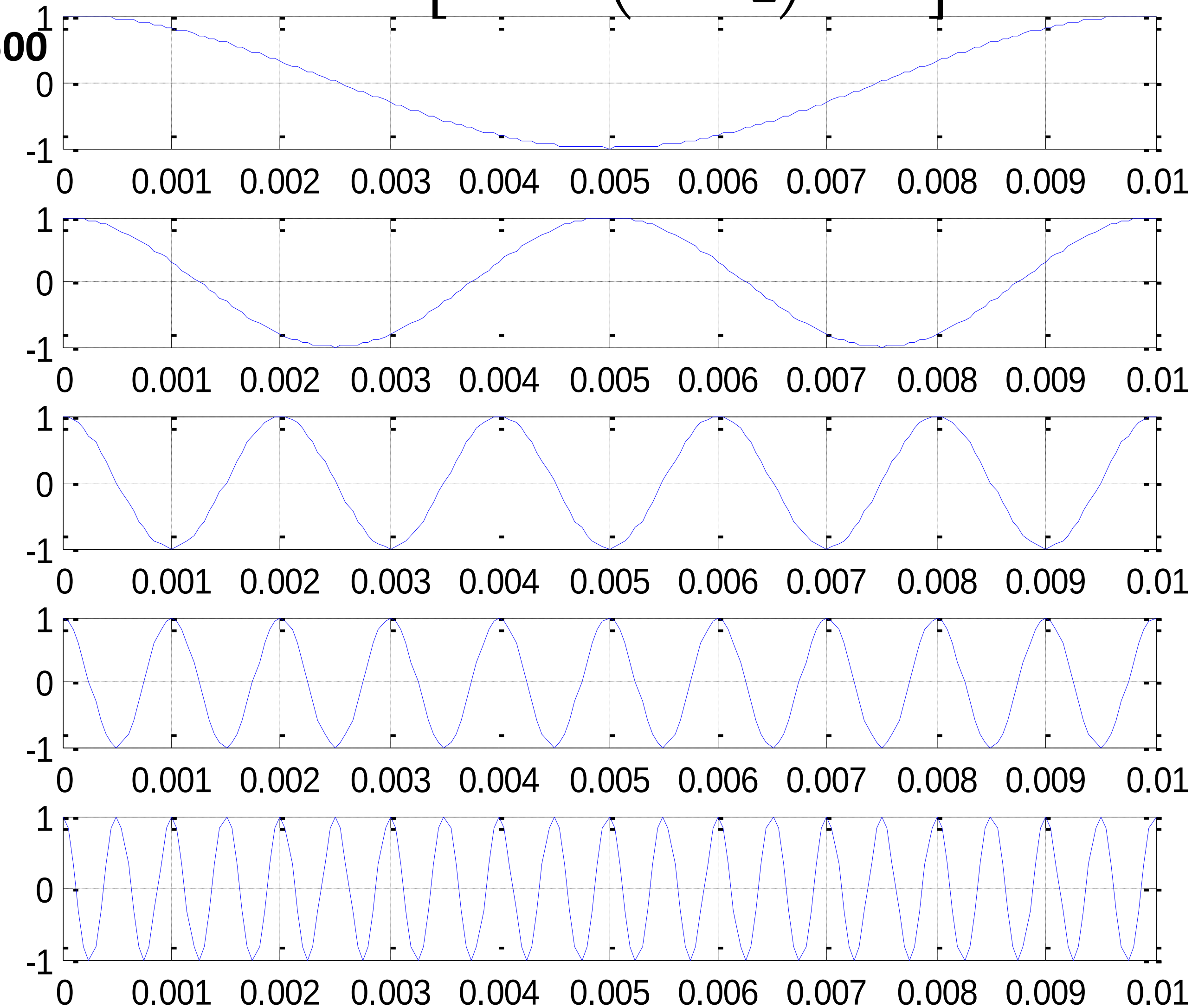
- Since
- $V = K\ 2\ \text{Sin}\left[\frac{A\ - B}{2}\right] \times \text{Cos}\left[\frac{A + B}{2}\right]$
- $V = \left[2\ K\ \text{Sin}\,\pi\ f_d\ T\right] \times \text{Cos}\left[2\ \pi\, f_d\left(t - \frac{T}{2}\right) - \varphi_0\right]$
- Above is a Cosine function like $\{A_{max}\ \text{Cos}\ (2\ \pi\ f\ t)\}$ varying with time "t'"

  Its peak amplitude A_{max} is $2K\ \text{Sin}\ \pi\ f_d\ T$
- For a fixed values of f_d and T peak amplitude of Cosine wave is $2K\ \text{Sin}\ \pi\ f_d\ T$ is fixed
- So $2K\ \text{Sin}\ \pi\ f_d\ T$ is the characteristics of DLC. It is a Sine function whose value depends on f_d and T

(Jntuh)**Draw the output waveforms from mixer for the different range of doppler frequencies**

$$V = \cos\left[2\pi f_d\left(t - \frac{T}{2}\right) - \psi_0\right]$$

T = .0005sec(500 microsec)



f_d = 100 Hz

f_d = 200Hz

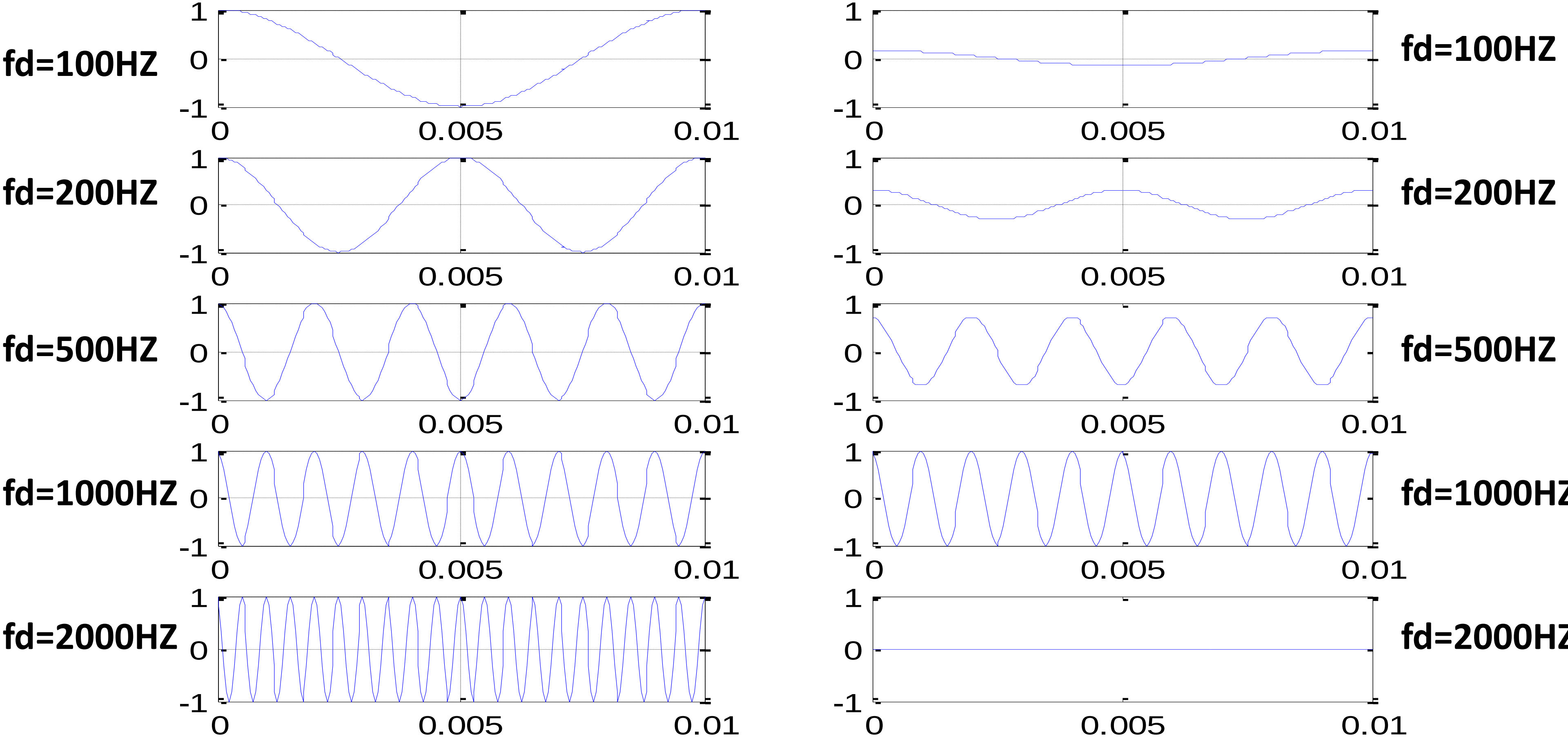
f_d = 500Hz

f_d = 1000Hz

f_d = 2000Hz

$$V = \cos\left[2\pi f_d\left[t - \frac{T}{2}\right] - \varphi_0\right]$$

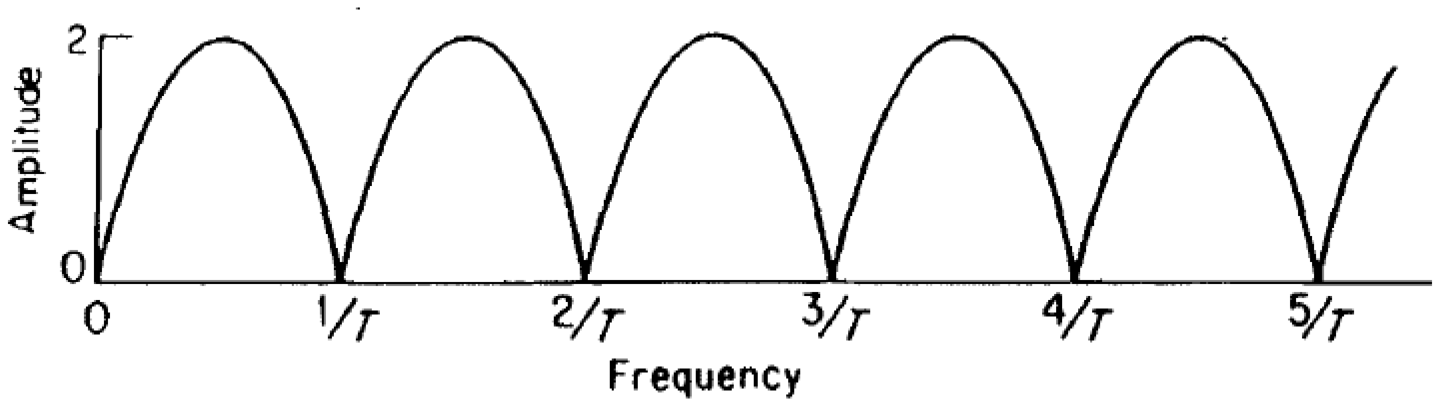
$$V = \sin \pi f_d T \times \cos\left[2\pi f_d\left[t - \frac{T}{2}\right] - \varphi_0\right]$$



T = .0005sec(500 microsec)

FILTER CHARACTERISTICS OF DLC (CONTD..)

- Frequency Response is the filter characteristic of DLC
- 2K Sin π f_d T varies as per f_d and is shown in the figure below. Sin π f_d T will have only positive values since the angle does not extend beyond π



FREQUENCY RESPONSE OF SINGLE DLC

BLIND SPEEDS

What are Blind speeds? Explain

BLIND SPEEDS

- **Interpretation:**
- i) Output of DLC is a Cosine function whose amplitude is varying with time
- Ii) Peak value of cosine function Amax = 2K sin π f_d T

BLIND SPEED

- The value of sin π f_d T (response of DLC) is zero when $\pi f_d T$ is 0 , π , 2π , ….etc.
- $\pi f_d T = n \pi$
- $f_d = \frac{n}{T} \quad = \quad nf_p$ where f_p = PRF

  n= integer number
- This means the amplitude of cosine function
- $\text{Cos}\left[2\pi f_d\left(t - \frac{T}{2}\right) - \phi_0\right]$ is zero whenever
- $f_d = \frac{n}{T}$

BLIND SPEED (CONTD ..)

Blind Speeds:

When $f_d = f_p$ (ie $f_d = \frac{2\,V_r}{\lambda}$ ie $V_r = \frac{f_p\,\lambda}{2}$)

the following happens

i. $\text{Sin}\ \pi f_d T = \text{Sin}\ \frac{\pi\ f_d}{f_p} = 0$

ii. Peak Amplitude of cosine function

- $\text{Cos}\left[2\ \pi f_d\left(t - \frac{T}{2}\right) - \varphi_0\right] = 0$
- So DLC output = 0. The output disappears.
- Velocity V_r under this condition is called blind speed.
- Same happens when n = 2,3,4,... etc. since

$\sin\pi = \sin 2\pi = \sin 3\pi \ldots\ldots = 0$

BLIND SPEEDS (CONTD ..)

- DLC eliminates DC component caused by clutter
- But it fails to record the moving target whose $f_d = f_p$ or $f_d = nf_p$ (multiple of f_p)
- $f_d = \frac{2 V_r}{\lambda}$ therefore $V_r = \frac{\lambda f_d}{2}$
- The relative target velocities which results in zero DLC response are called blind speeds.
- Blind speeds are those speed of targets which give no output from DLC.
- Targets at these speeds fail to be detected or recorded.

BLIND SPEEDS (CONTD ..)

- Targets at these speeds fail to be detected or recorded.
- So first blind speed $= \dfrac{\lambda \ f_p}{2}$
- Second blind speed $= \dfrac{2 \ \lambda \ f_p}{2}$
- nth blind speed $= \dfrac{n \lambda \ f_p}{2}$

BLIND SPEED (CONTD ..)

➢ Example : Let Frequency of Tx = 1 GHZ

- So $\lambda = \frac{C}{f} = \frac{3 \times 10^8}{1 \times 10^9} = 0.3\, mt$
- Let T = 1000 Micro Sec. $f_p = \frac{1}{1000 \times 10^{-6}} = 1000\text{Hz}$
- First Blind Speed : $f_{d1} = f_p = 1000$ Hz
- $V_{r1} = \frac{\lambda\ f_p}{2} = \frac{0.3 \times 1000}{2}$
- V_{r1} = 150Mt/Sec (540 KM/Hr)

BLIND SPEED (CONTD ..)

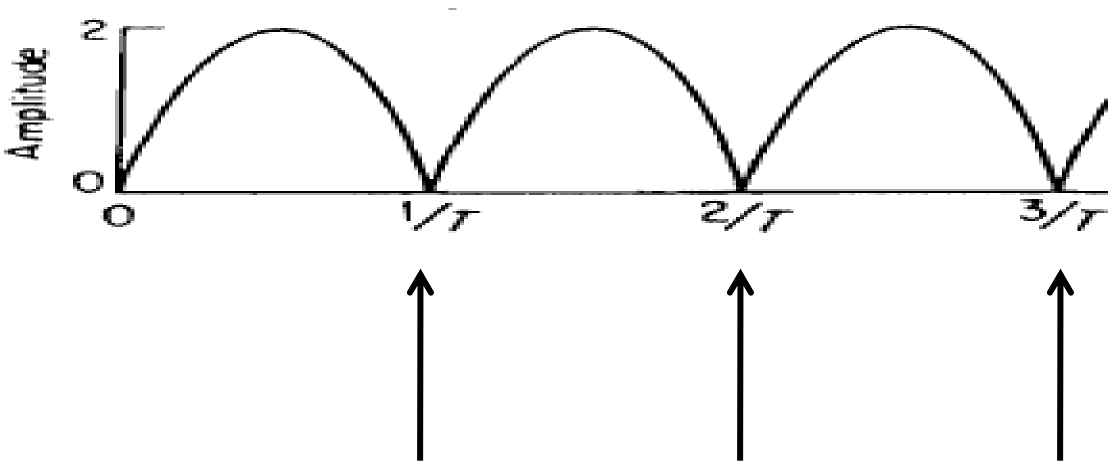
- Second Blind Speed : f_{d2} =2 f_p = 2000 Hz

$$V_{r2} = \frac{2\ \lambda\ f_p}{2}$$ = 300 mt/sec = (1080Km/hr)

- Third blind Speed : f_{d3} = 3 f_P = 3000 Hz
- $V_{r3} = \frac{3\ \lambda\ f_p}{2}$ = 450 mt/sec = (1620Km/hr)

BLIND SPEEDS (CONTD ..)

- **Example (Contd ..)**

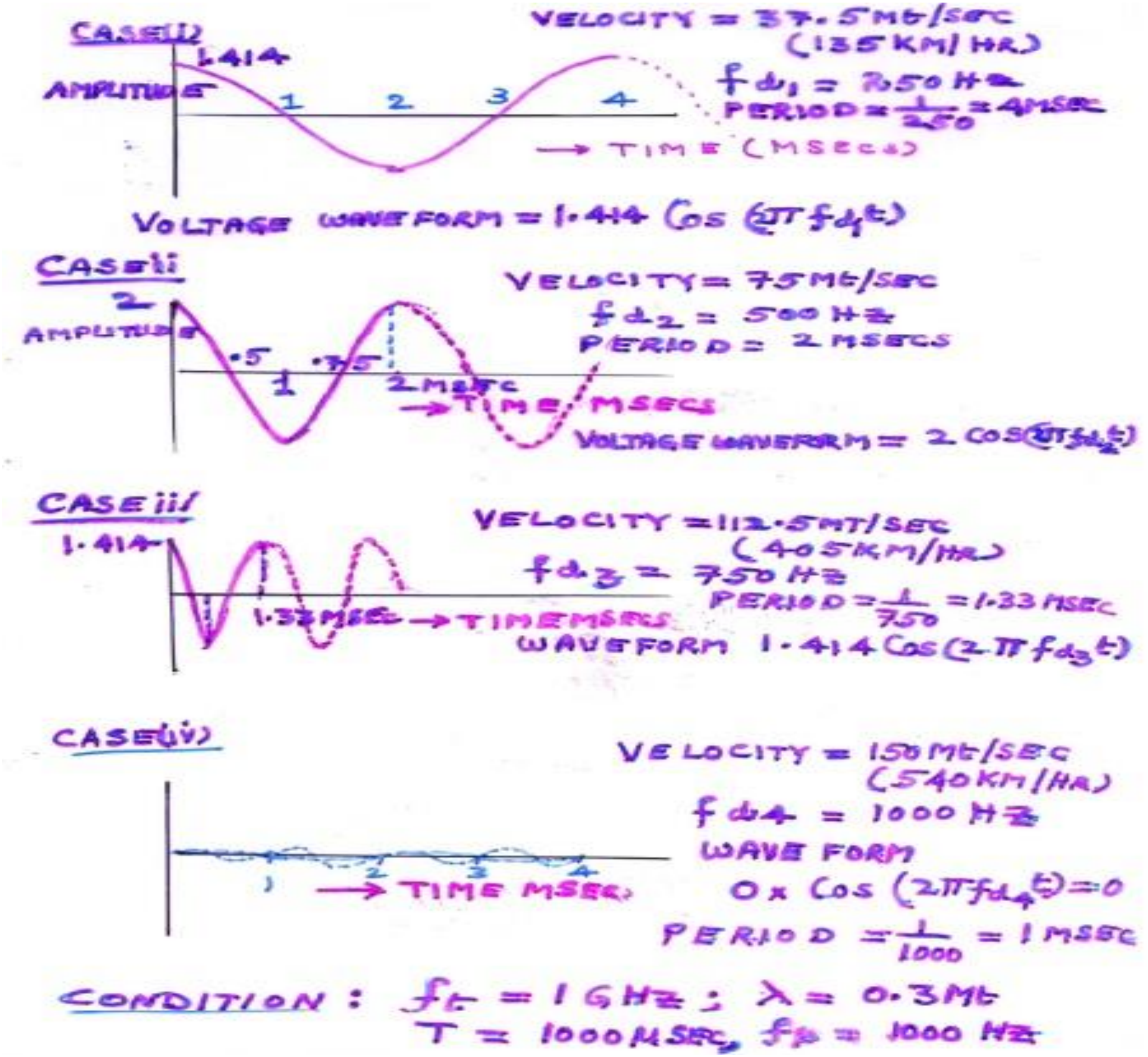


1000 Hz
150Mt/Sec

2000 Hz
300 Mt/Sec

3000 Hz
450Mt/Sec.

OUTPUT OF DLC

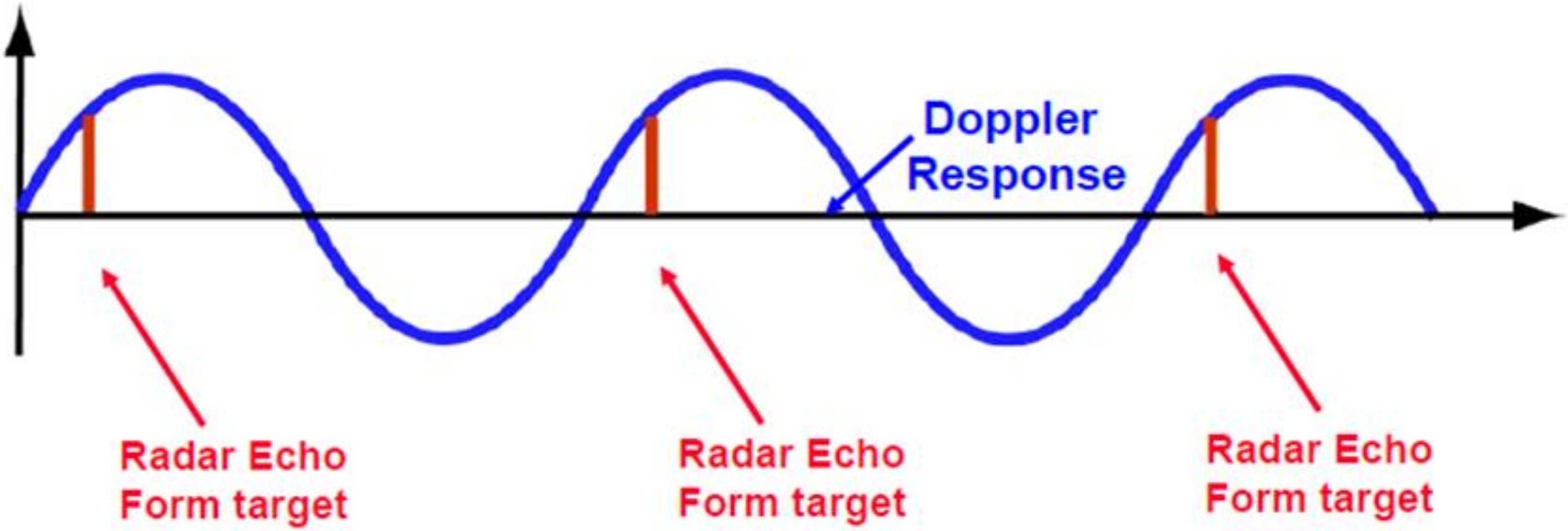


BLIND SPEEDS (CONTD ..)

- Blind speeds are the limitations of MTI Radar.
- Blind speeds do not occur in CW Radar.
- They occur in MTI because Doppler is measured by discrete samples (pulses) at PRF rather than continuously.

BLIND SPEED

➢ **Examples: Sampling at 1PRF , 3 PRF**



- Blind Speeds, V_B , result when the PRF (f_P) is equal to the target's Doppler Frequency (or a multiple of it)

- Doppler Velocity related to the Doppler Frequency by:

$$V_r = \frac{\lambda f_D}{2} \qquad V_B = \frac{\lambda f_P}{2} \qquad n = \text{integers}$$

$$V_{Bn} = \lambda\, n\, f_P /2 = n\, V_B$$

BLIND SPEED Vs UNAMBIGUOUS RANGE

- IF first Blind Speed is required to be large
- $$V_r = \frac{\lambda \; f_p}{2}$$

  $\lambda \, f_p$ must be large.
- λ large means , operating radar frequency small
- $\lambda = \frac{c}{f}$
- Low frequency radar for a given Antenna size will have a large Beam width and therefore less angular accuracy.
- f_p large means Maximum unambiguous Range is less

$$R_{unamb} = \frac{C}{2 \, f_p}$$

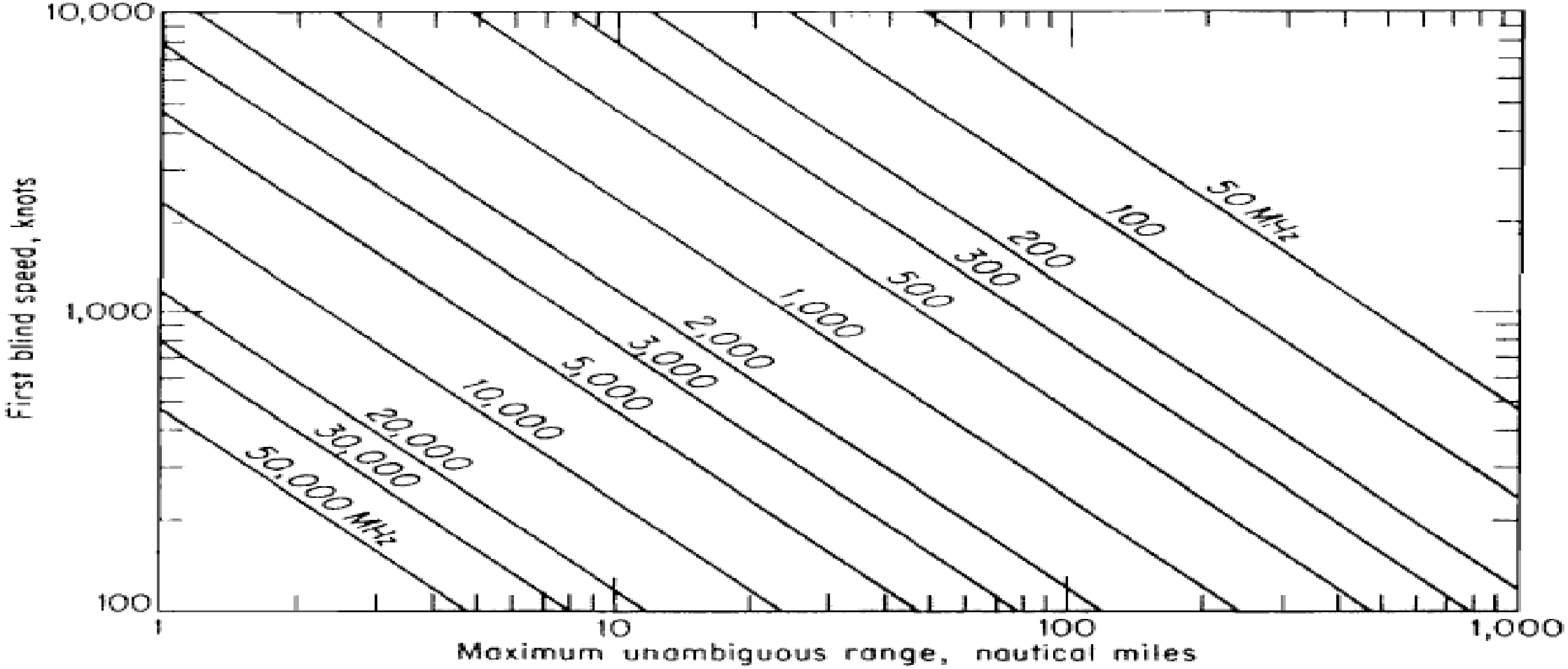
BLIND SPEED VS UNAMBIGUOUS RANGE

Blind Speed	Frequency of Radar	Unambiguous Range
600 Knots (1110 Km/Hr)	300 MHZ (UHF)	130 n miles (240 Kms)
600 Knots	3000 MHZ (S Band)	13 n miles (24 Kms)
600 Knots	10 GHZ (X Band)	4 n miles (7.4 Kms)

(1 nautical Mile = 1.85 Km)

- MTI Radar meant for detection of military aircraft(speeds > 600 Knots) will have number of blind speeds with in the maximum detection speed and this is a serious limitation.

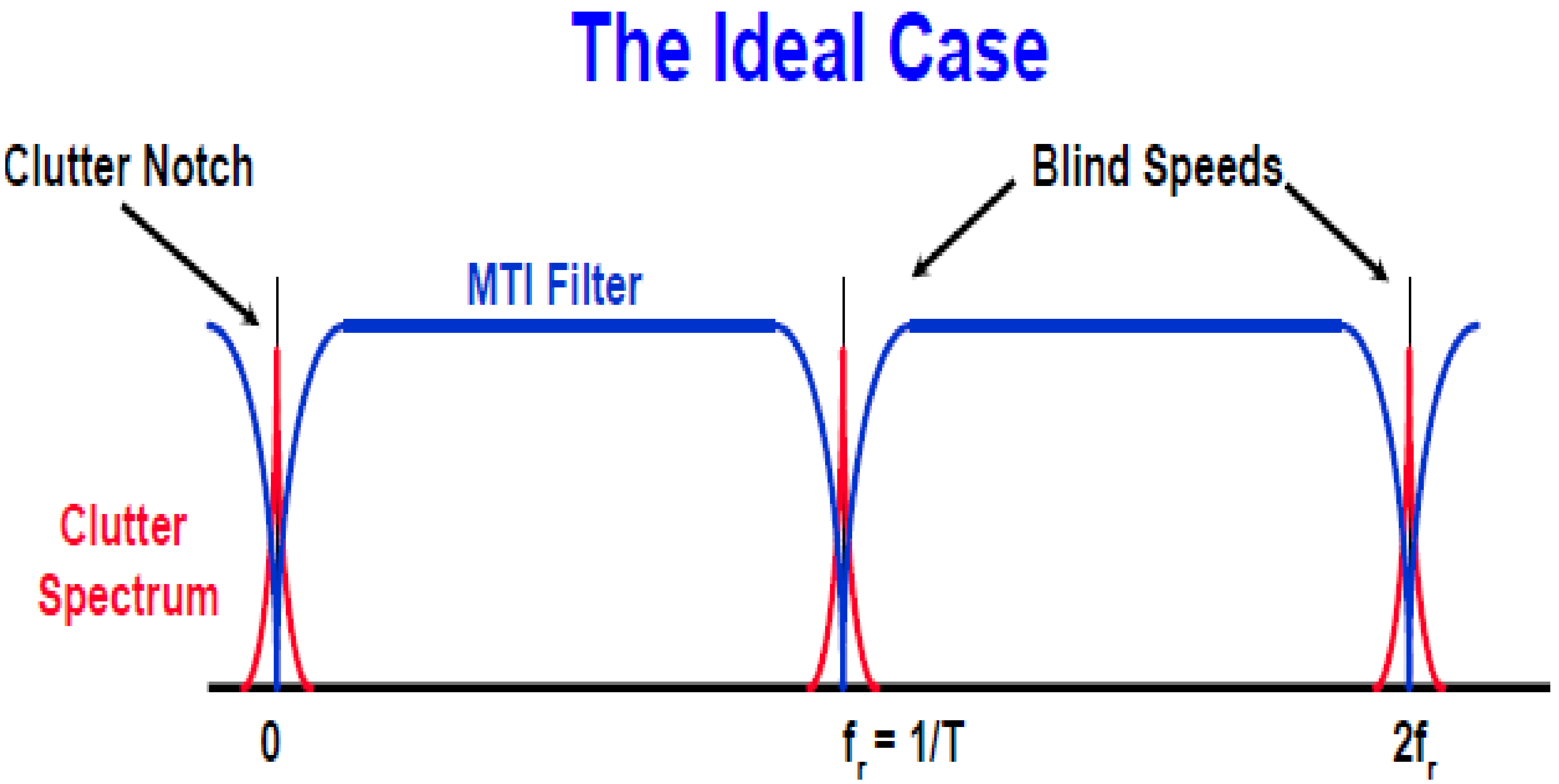
BLIND SPEED VS UNAMBIGUOUS RANGE (CONTD ..)



- Long Range MTI Radars will usually operate with (ambiguous velocities) small first blind speed.
- The presence of blind speeds with in the Doppler frequency band reduces the detection capability of Radar

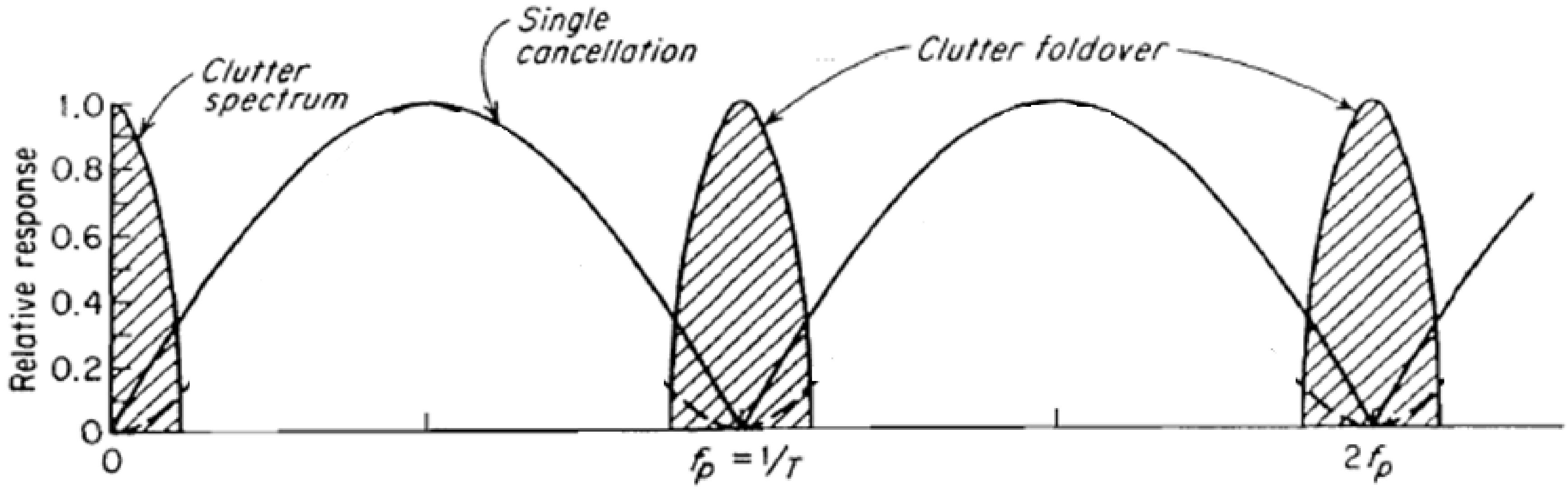
IDEAL DLC

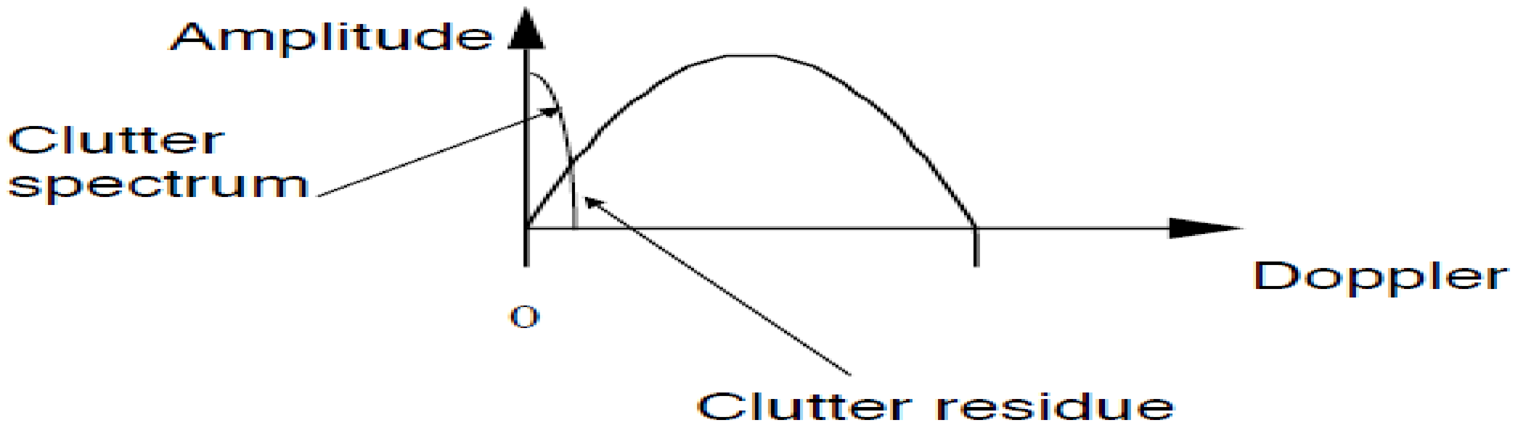
- The frequency response of single DLC does not have the clutter – rejection null in the vicinity of DC



PRACTICAL DLC

- Practical single DLC has the frequency response as shown



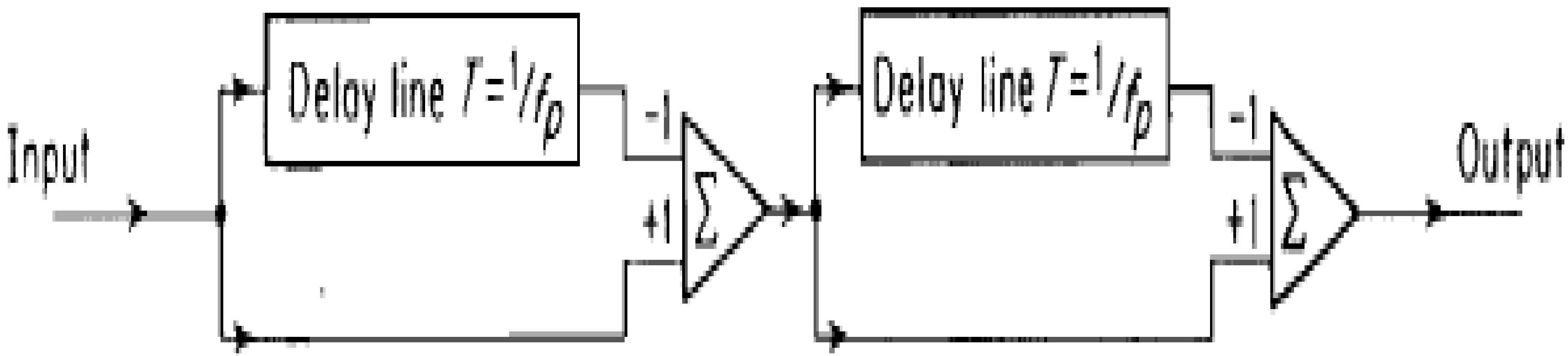


(Jntuh) **What is the difference between single cancellation and double in a delay line canceller?**

DOUBLE CANCELLATION

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

$$f(t) - f(t+T) - f(t+T) + f(t +$$



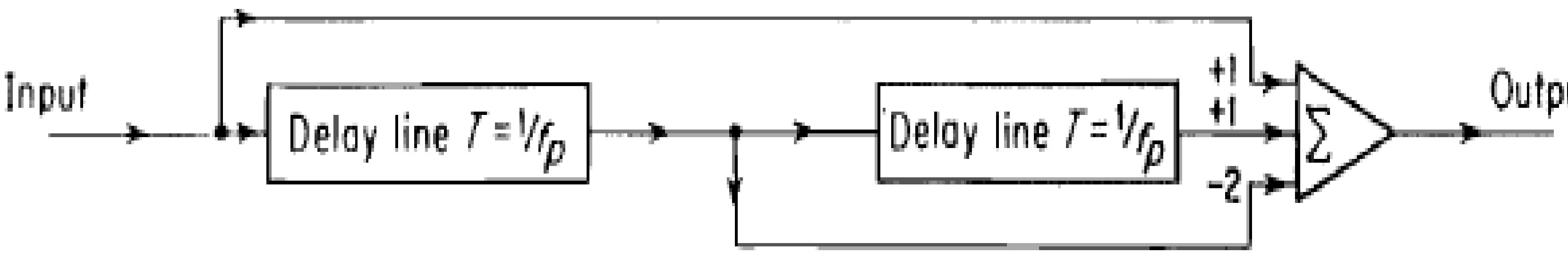
Output = f(t) – f(t + T) – f(t +T) + f(t+ 2T)

= f(t) – 2 f(t + T) + f(t + 2T)

DOUBLE CANCELLATION (CONTD ..)

➢ 3 Pulse Canceller

- Has the same response as Double DLC

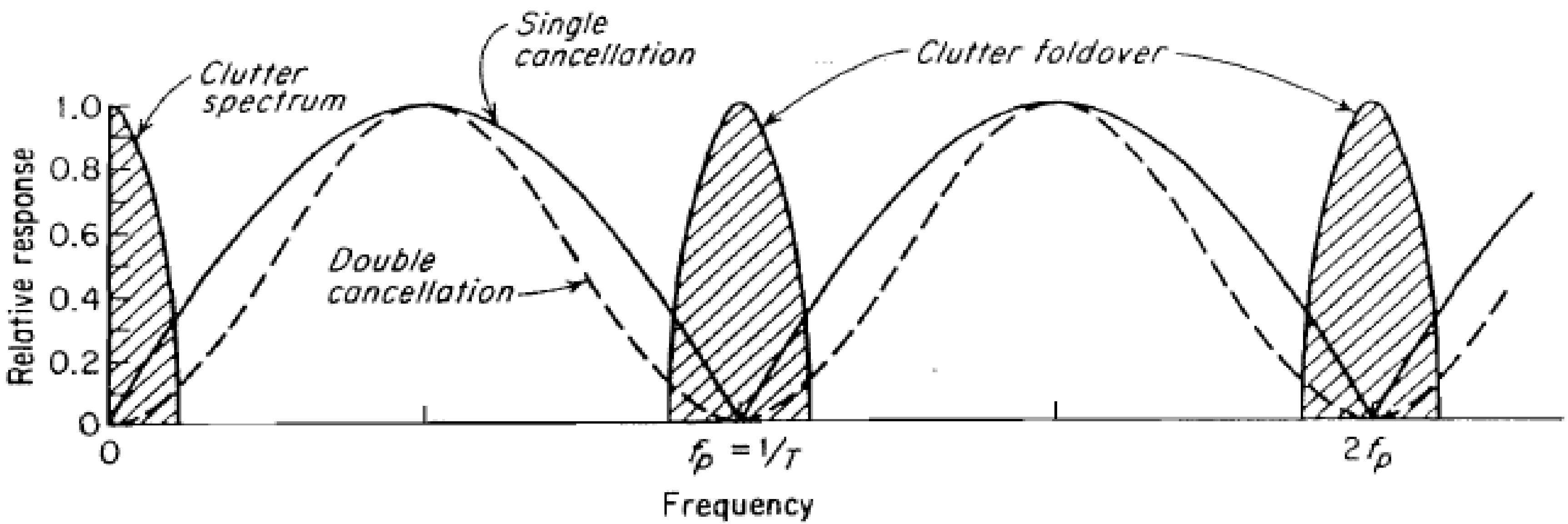


Output = f(t) – 2 f(t + T) + f(t + 2T)

(Jntuh) **Show that the percentage of clutter rejection is better in case of double cancellation as compared to single cancellation**

FREQUENCY RESPONSE OF DOUBLE CANCELLER

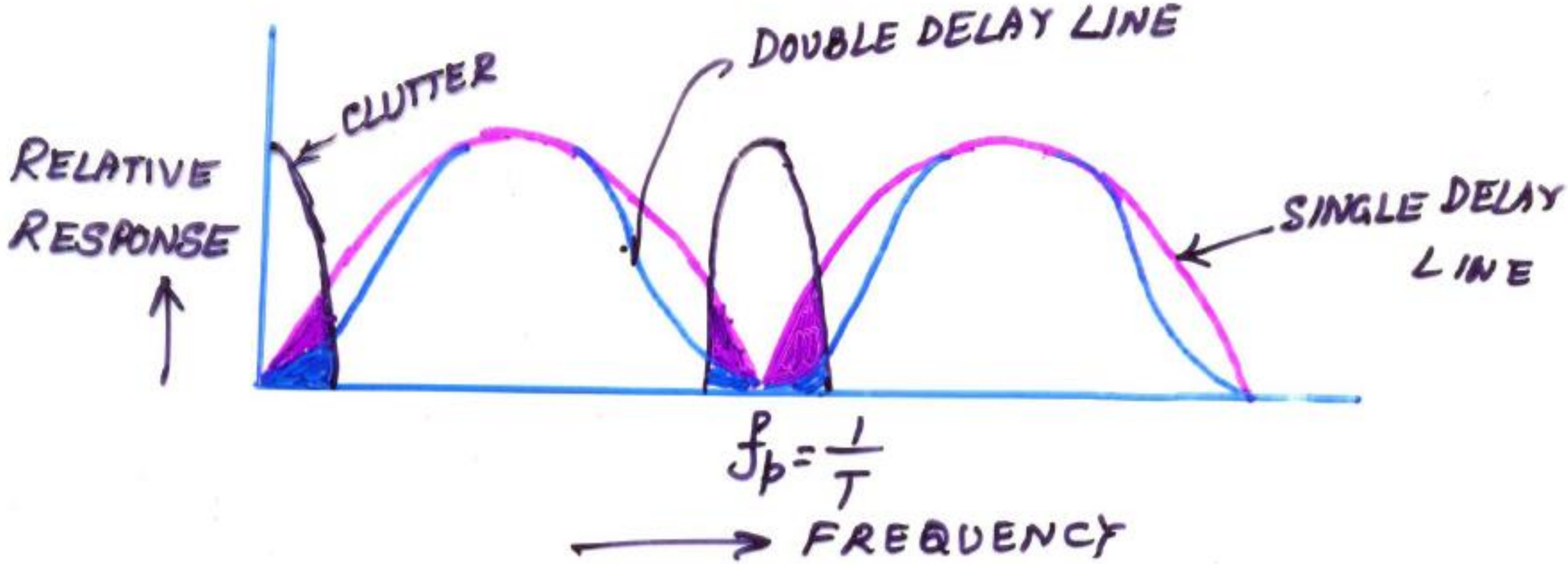
- Frequency response of both (i) Double DLC and (ii) 3 pulse Canceller is same i.e. $\sin^2 \pi f_d T$
- More clutter noise attenuated by using a Double Delay Line canceller.



ADVANTAGE OF DOUBLE CANCELLER

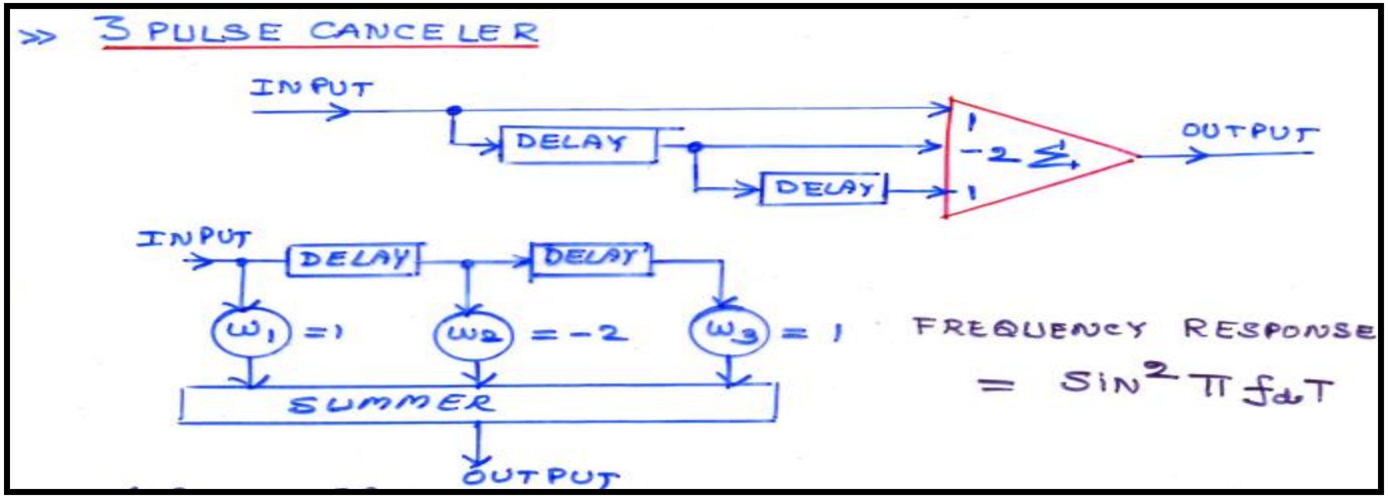
➢ Limitation of Single DLC:

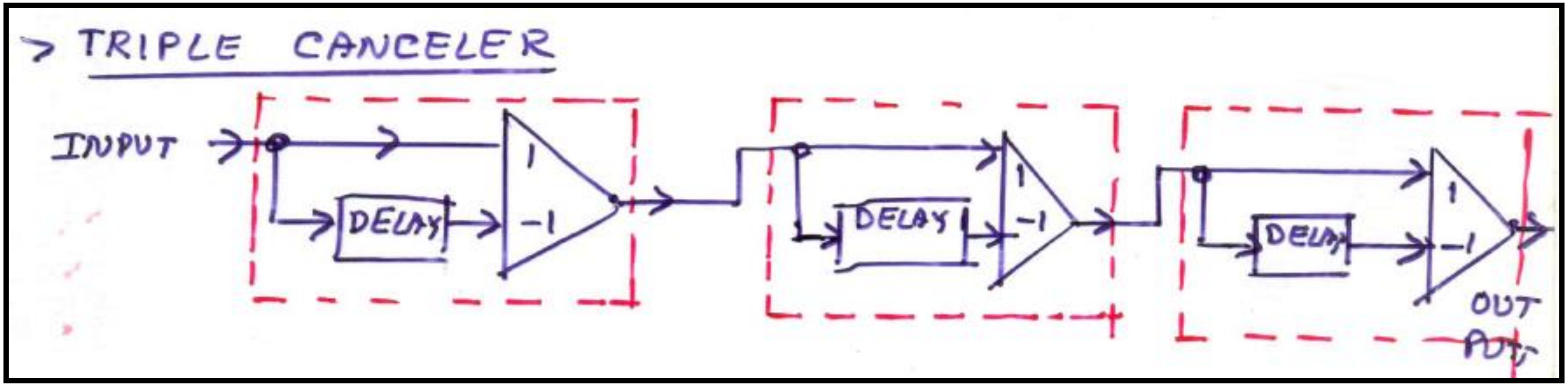
- Insufficient attenuation of Clutter



- Double DLC attenuates more clutter and residue clutter is less

COMPARISON OF CANCELLERS





FREQUENCY RESPONSE IS $SIN^3 \pi F_D T$

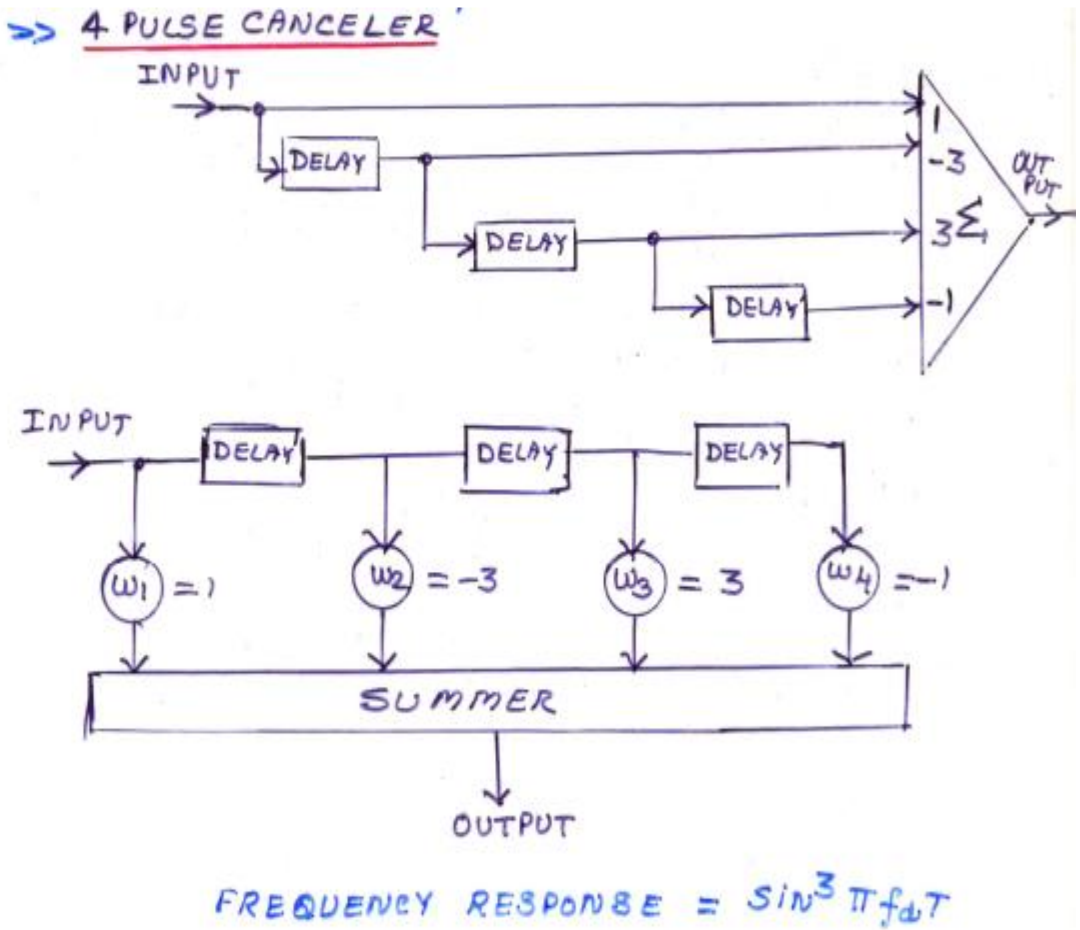
COMPARISON OF CANCELLERS (CONTD ..)

→ NOMENCLATURE :

FREQUENCY RESPONSE	SINGLE DELAY LINES IN CASCADE	TRAVERSAL FILTER
$\sin^2 \pi f_d T$	TWO IN CASCADE CALLED DOUBLE CANCELER	3 PULSES CALLED 3 PULSE CANCELER
$\sin^3 \pi f_d T$	THREE IN CASCADE CALLED TRIPLE CANCELER	4 PULSES CALLED 4 PULSE CANCELLER

4 PULSE CANCELLER (Contd ..)

- **4 Pulse canceller**



TRAVERSAL FILTER (N PULSE CANCELLER)

- **Traversal Filter:**

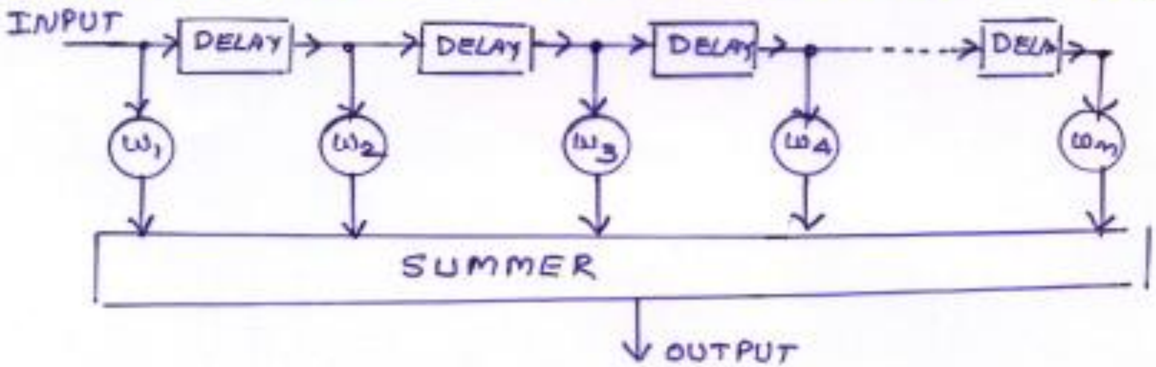
» N PULSE CANCELER : TRAVERSAL FILTER

→ THIS HAS N PULSES AND N-1 DELAY LINES

→ OTHER NAMES GIVEN TO THIS FILTER ARE

(1) FEED BACK FILTER (2) NON RECURSIVE FILTER

(3) FINITE MEMORY FILTER (4) TAPPED DELAY LINE FILTER



→ WEIGHTS FOR 'm' DELAY LINE TRAVERSAL FILTER ARE COEFFICIENTS OF EXPANSION OF $[1-x]^m$. THESE ARE BINOMIAL COEFFIENTS WITH ALTERNATING SIGNS.

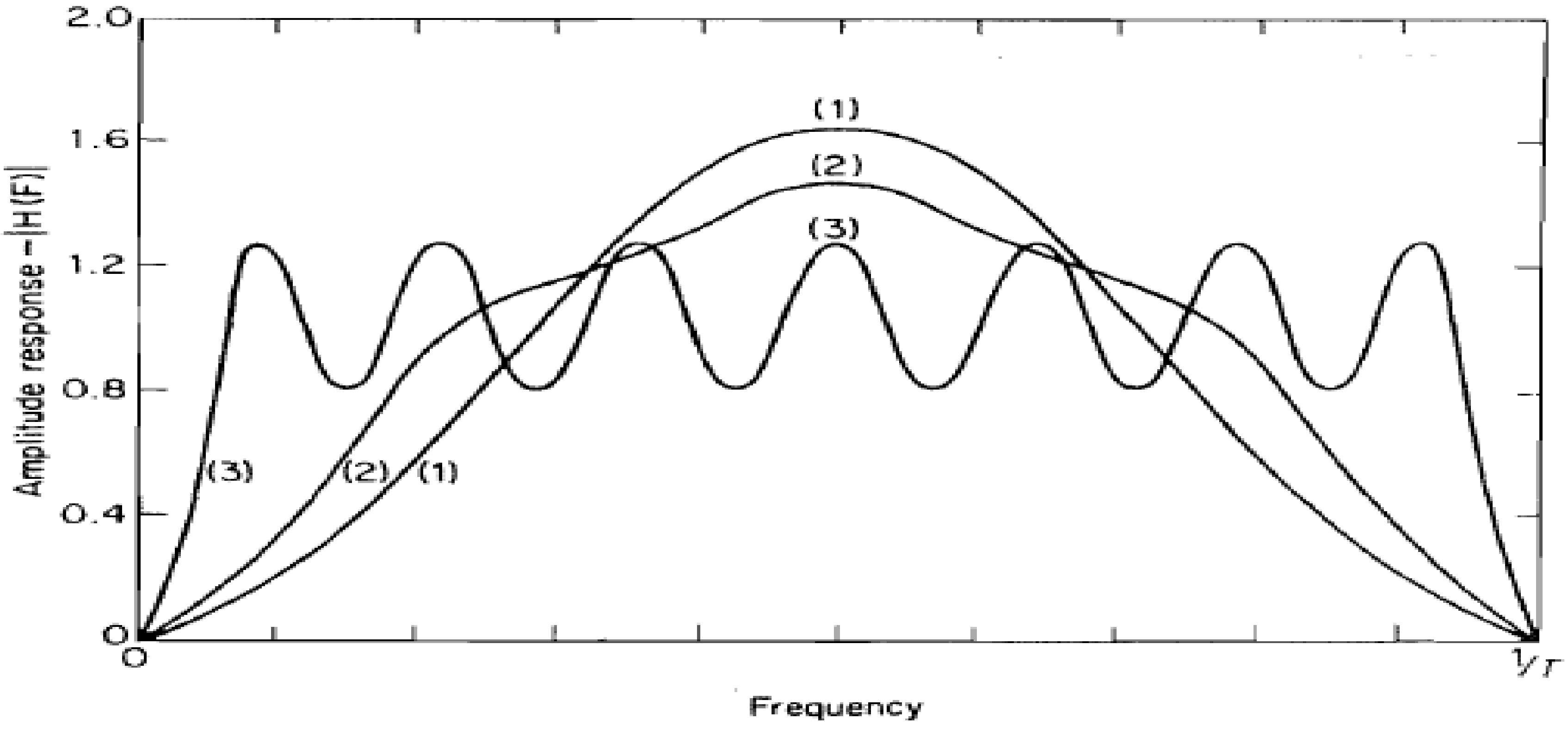
$$w_i = [-1]^{i-1} \frac{m!}{(m-i+1)!\,(i-1)!} \quad \text{WHERE } i = 1, 2, 3, \ldots, m+1$$

COMPARISON OF DELAY LINE CANCELLERS

1) Classical 3 pulse canceller with $\sin^2 \pi f_d T$ response

2)5 pulse canceller

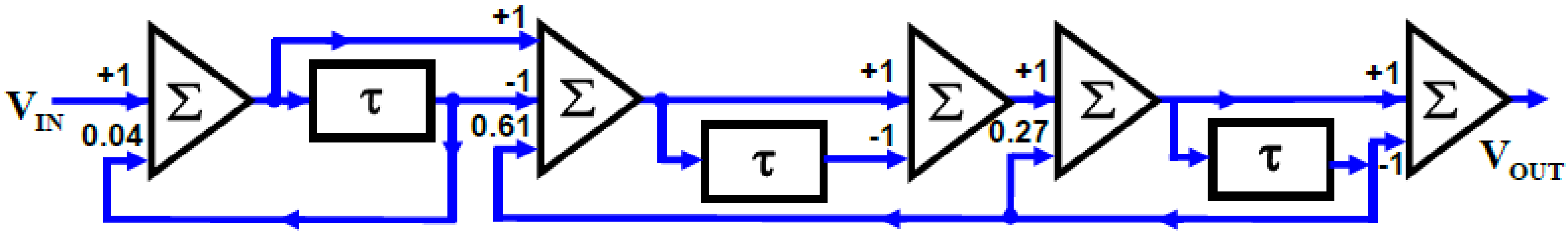
3)15 pulse canceller with chebyschev filter characteristics



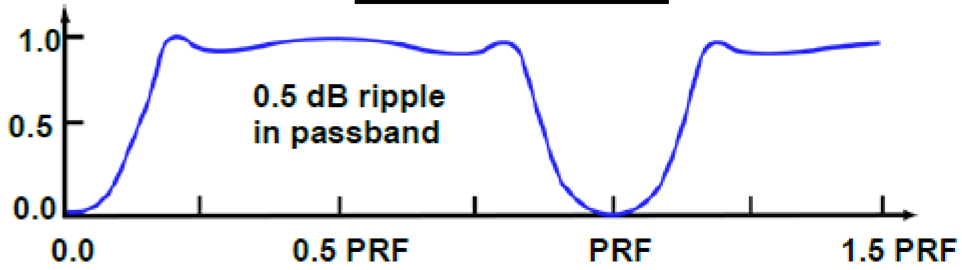
CANCELLERS EMPLOYING FEED BACK

- To obtain a rectangular shape with a few pulses, Feedback is employed. These are called Recursive filters.
  - **With few pulses it is very difficult to develop a filter, which has a rectangular shape without employing feedback in the MTI canceller**

Recursive MTI Filter Based on a Three Pole Chebyshev Design



Filter Response



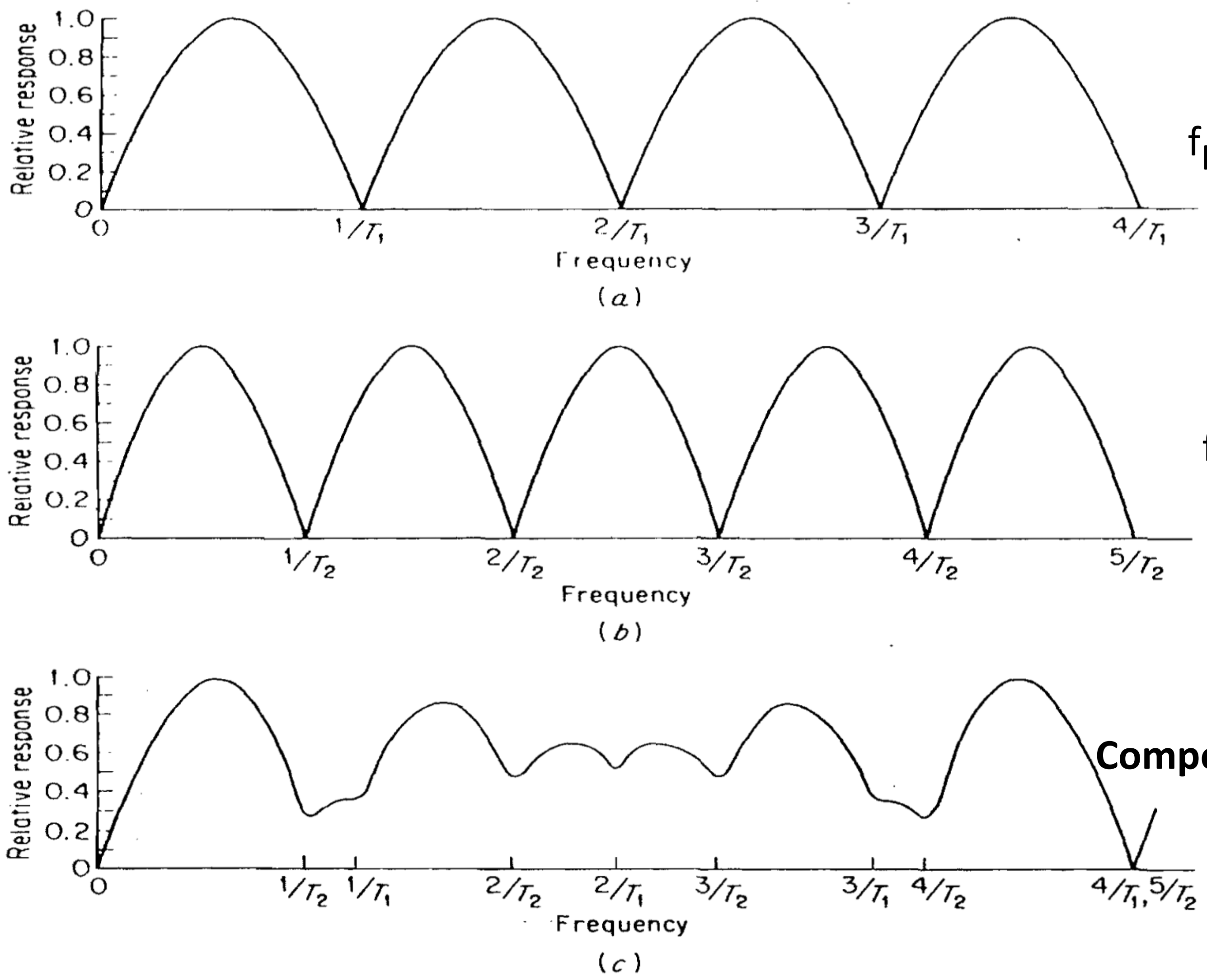
1. (Jntuh) **Explain how the effect of blind speed reduced by operating at more than one PRF**
2. (Jntuh) **What is staggered PRF ? Where and why is it used in a radar system**
3. (Jntuh) **Explain the operation of a MTI radar with 2 PRFs**

STAGGERED PRF

STAGGERED PRF

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

STAGGERED PRF



$f_P = 1/T_1$

$f_P = 1/T_2$

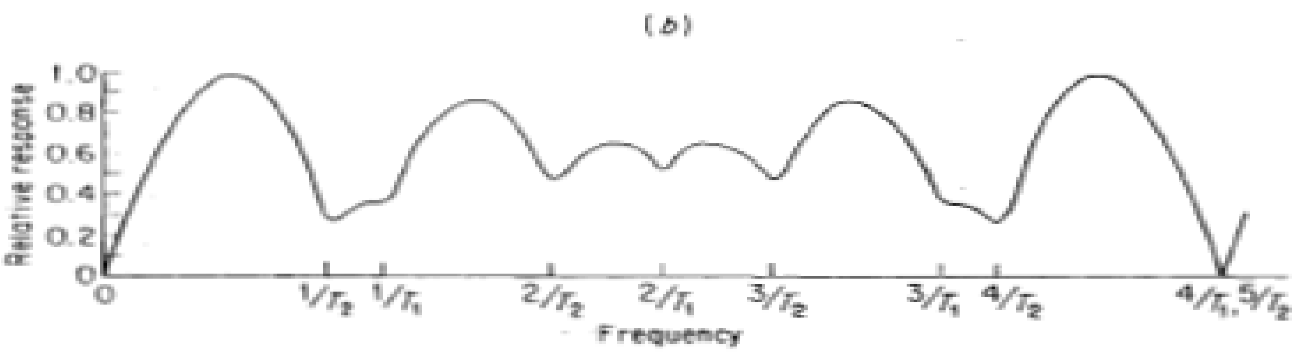
Composite Responce

STAGGERED PRF (CONTD ..)

- The PRFs are in the ratio 5:4

- The first blind speed of composite response is increased several times over the blind speed of single PRF

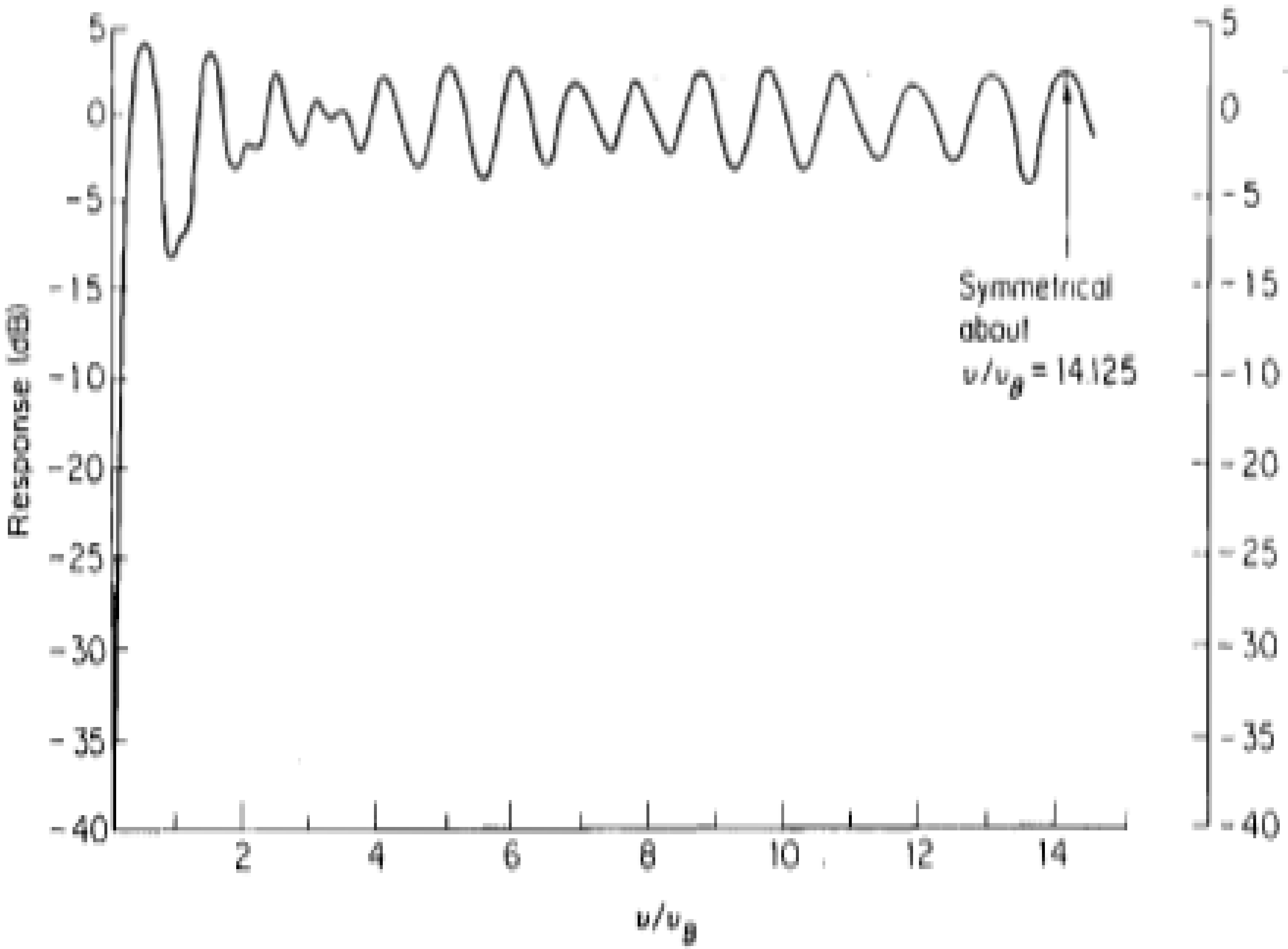
- The blind speeds are coincident for $\frac{4}{T_1} = \frac{5}{T_1}$



STAGGERED PRF (CONTD ..)

- Ratio $T_1 : T_2$ when it is near unity, the first blind speed value is increased.
- However first null in vicinity of $f_d = \frac{1}{T_1}$ becomes deeper.
- The depth of first null can be reduced and the first blind speed increased by using more than 2 PRFs.
- Five pulses will have a periods in the ratio
  25 : 30 : 27 :31
- The first blind speed is 28.25 times that of constant PRF waveform.

STAGGERED PRF (CONTD ..)



FREQUENCY RESPONSE OF 5 PULSE (4 PERIOD) STAGGER

STAGGERED PRF (CONTD ..)

- $\frac{n_1}{T_1} = = \frac{n_2}{T_2} = \ldots\ldots \frac{n_n}{T_n}$ are periods of staggered PRF
- n_1 , n_2 , …n_n are integers.

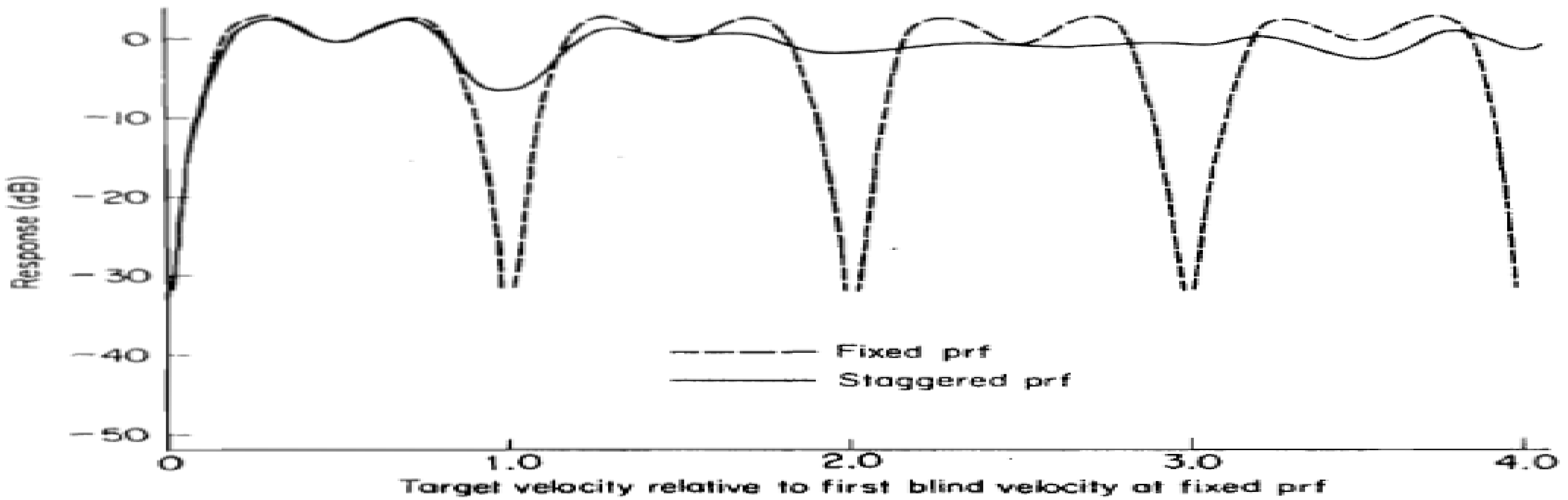
- V_B= First blind speed of non staggered wave form
- T_{av} = Average period = $\frac{T_1 + T_2 + \ldots\ldots T_n}{N}$

- V_1 = first blind speed of staggered wave form

$$\frac{V_1}{V_B} = \frac{n_1 + n_2 + \ldots\ldots n_n}{N}$$

STAGGERED WAVE FORM (CONTD ..)

- Weighting is applied to the Echo pulses.
- Dashed curve is response of 5 pulse canceller with fixed PRF with weighting $\frac{7}{8}$, 1, −3, $\frac{3}{4}$, 1, $\frac{7}{8}$
- Solid curve is staggered PRF with interpulse period of -15 , −5 , +5 , +15 percent of fixed period.
- The first blind speed null is down only by 6.6 dB



BLIND SPEED SUMMARY 1

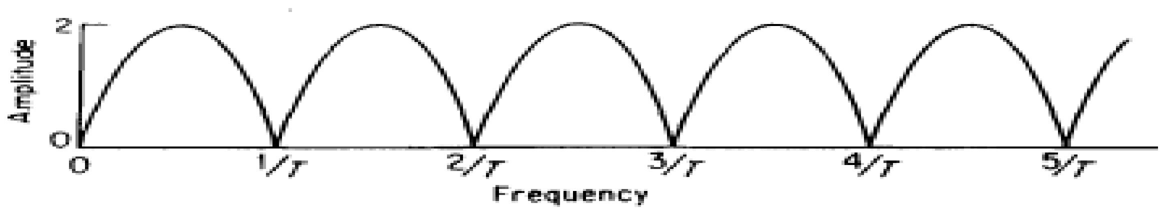
- WHY Blind speeds are not present in CW Radar but present in MTI Radar ?

- In CW Radar Doppler frequency is available continuously and measured continuously.

- In MTI Radar samples of Doppler frequency only are available rather than continuously. System follows the properties of sampled Data and Nyquist rules.

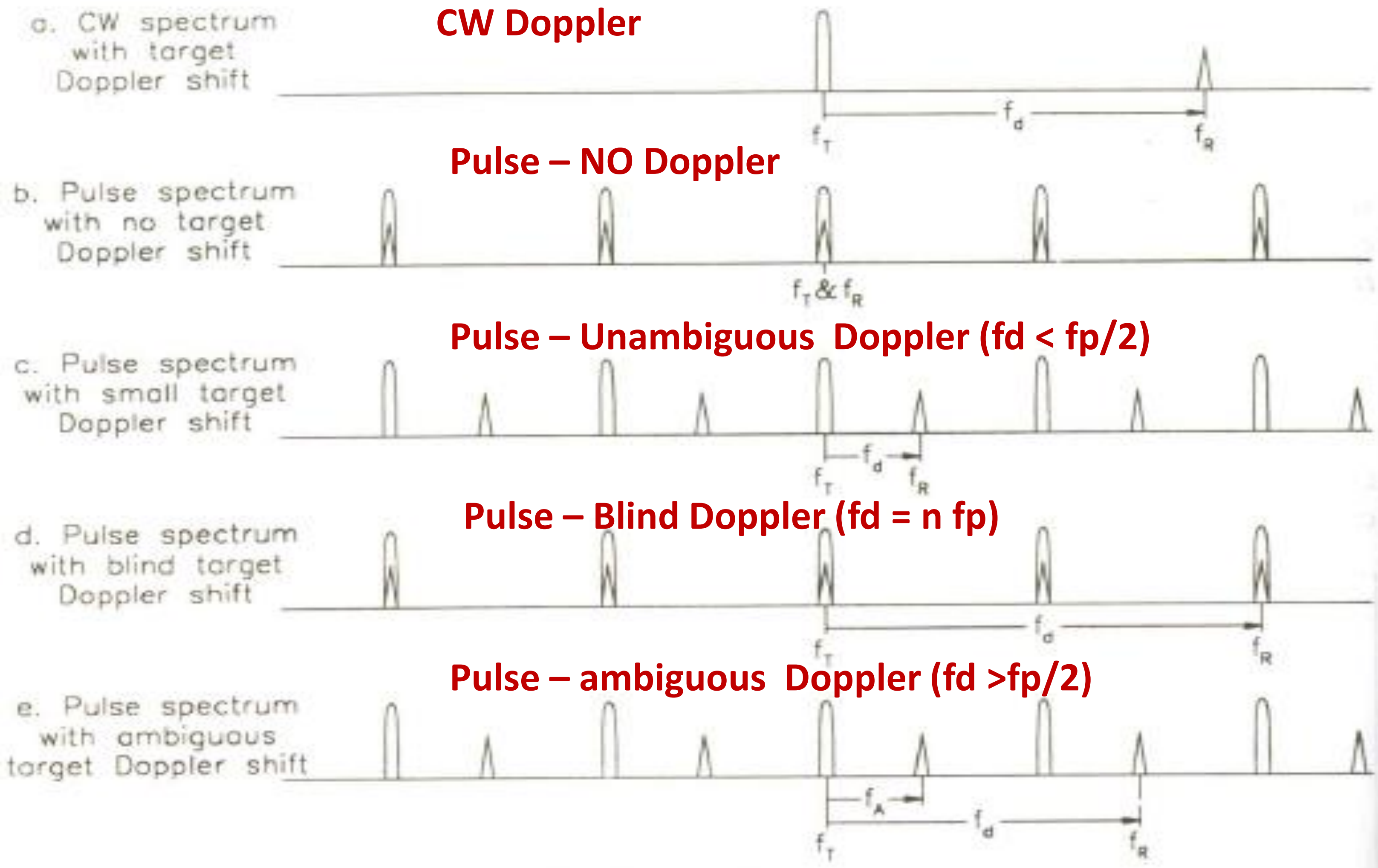
BLIND SPEED SUMMARY2

- As per Nyquist rule, sampling frequency f_P should be equal to or more than 2 x fd to avoid aliasing
- To avoid ambiguity in velocity $f_d = \frac{2\ V_r}{\lambda}$
- $f_d \leq \frac{1}{2}\ f_p$
- If f_d is greater than $\frac{f_p}{2}$, Velocity measurements become ambiguous.
- In addition in view of characteristics of DLC, blind speeds occur at 1 x f_p , 2 x f_p , 3 x f_p ….. , n x f_p



DOPPLER SHIFT CONDITIONS

- **Frequency Spectrum:**



BLIND SPEED SUMMARY 3

- What should be done to avoid the first blind speed with in the maximum speed of the target ?
- V_b (First blind speed) > V_{max}(Max speed of Target)

$$V_b = \frac{\lambda}{2\ T}$$

- λ should be large. Transmit at low frequency
- $\lambda = \frac{C}{f}$
- Disadvantage: 1) Antenna size large 2) Angular Accuracy suffers.

BLIND SPEED SUMMARY 3

- T should be small.
- Disadvantage: unambiguous Range becomes less
- $R = \frac{c\,T}{2}$
- Alternatives : 1) Staggered PRF 2) Multiple frequencies for transmission

CONTINUED IN RADAR 3C

(Jntuh)

RADAR SYSTEMS

EC812 PE 5

(ELECTIVE V)

UNIT – 3C

B.TECH IV YEAR II SEMESTER

BY

Prof.G.KUMARASWAMY RAO

(Former Director DLRL Ministry of Defence)

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

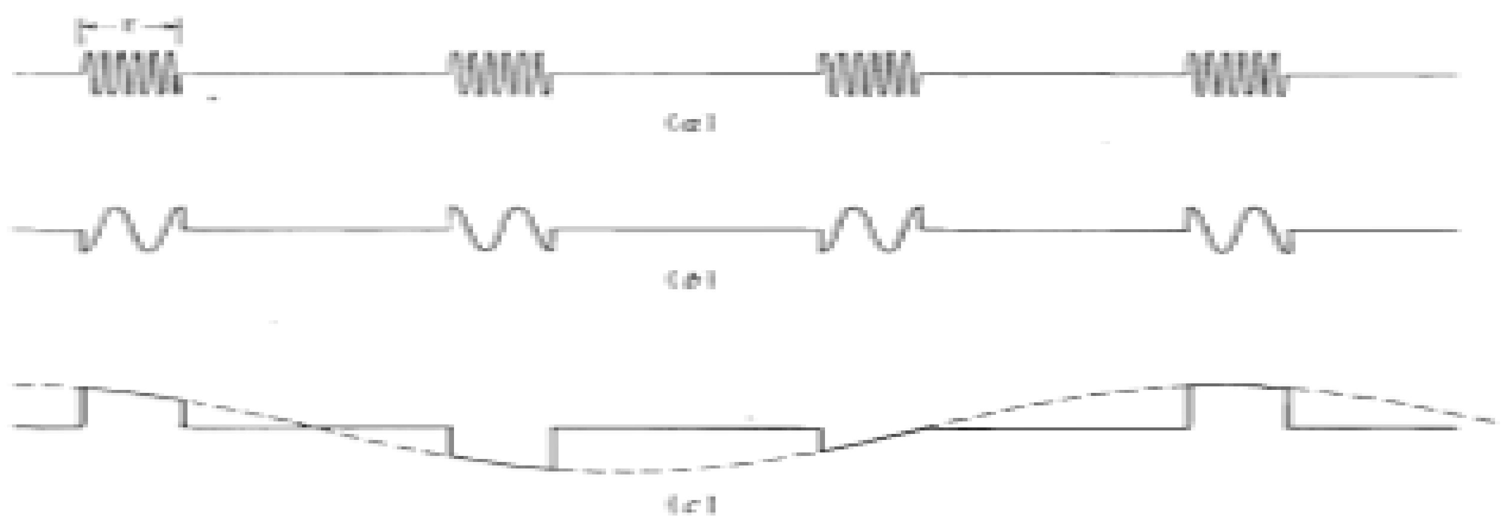
Special Indian edition

1. (Jntuh) **Draw the block diagram of Range-gated doppler filters and explain**

2. (Jntuh) **Draw and explain the frequency response characteristics of a MTI using gates and filters**

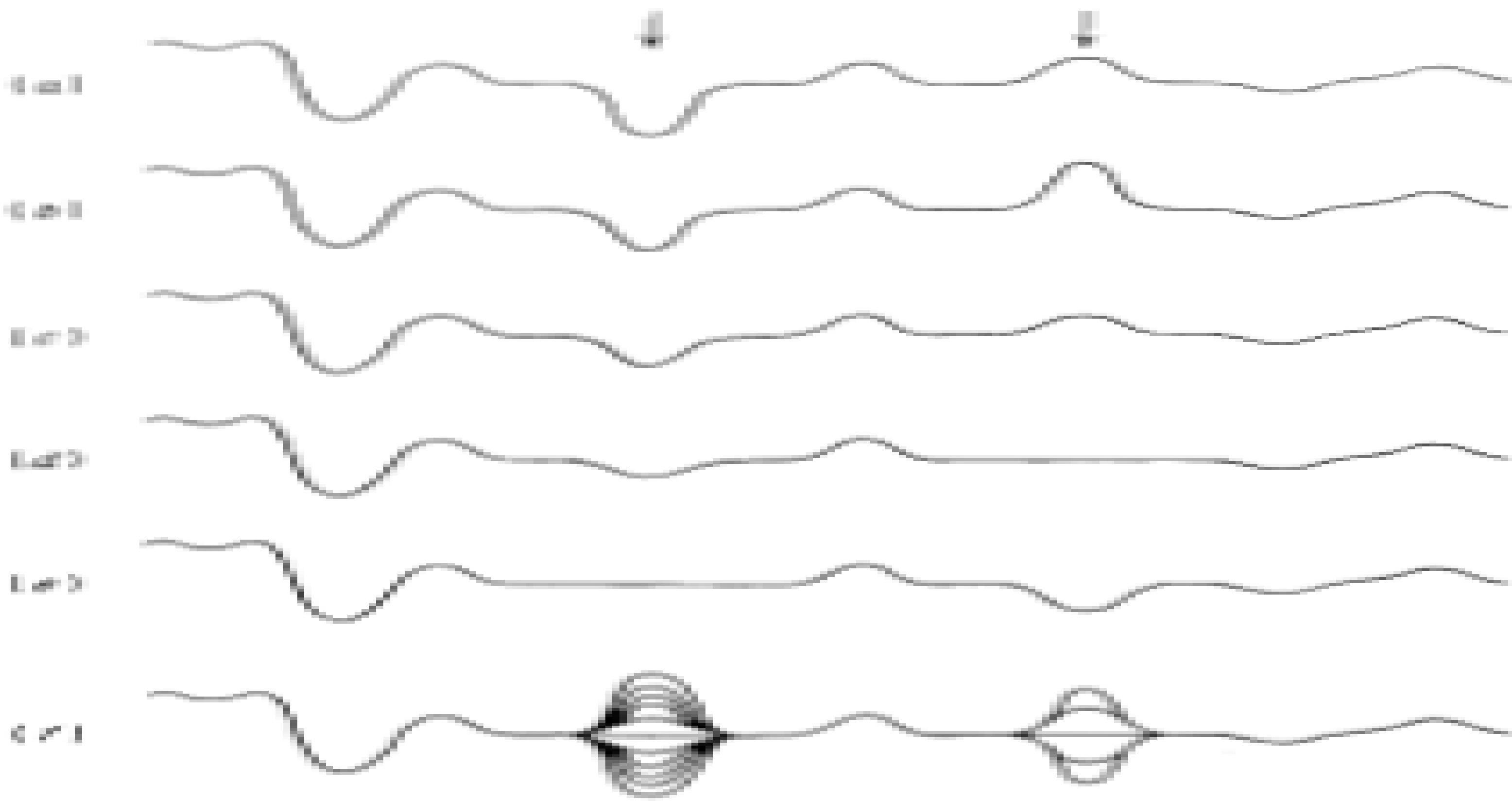
PRINCIPLE OF OPERATION (CONTD ..)

- Depending upon f_d , 2 cases will arise (τ = Pulse Width).
  i. $f_d > 1/\tau$ → f_d can be found quickly.
  ii. $f_d < 1/\tau$ → many pulses need to be sent to find f_d

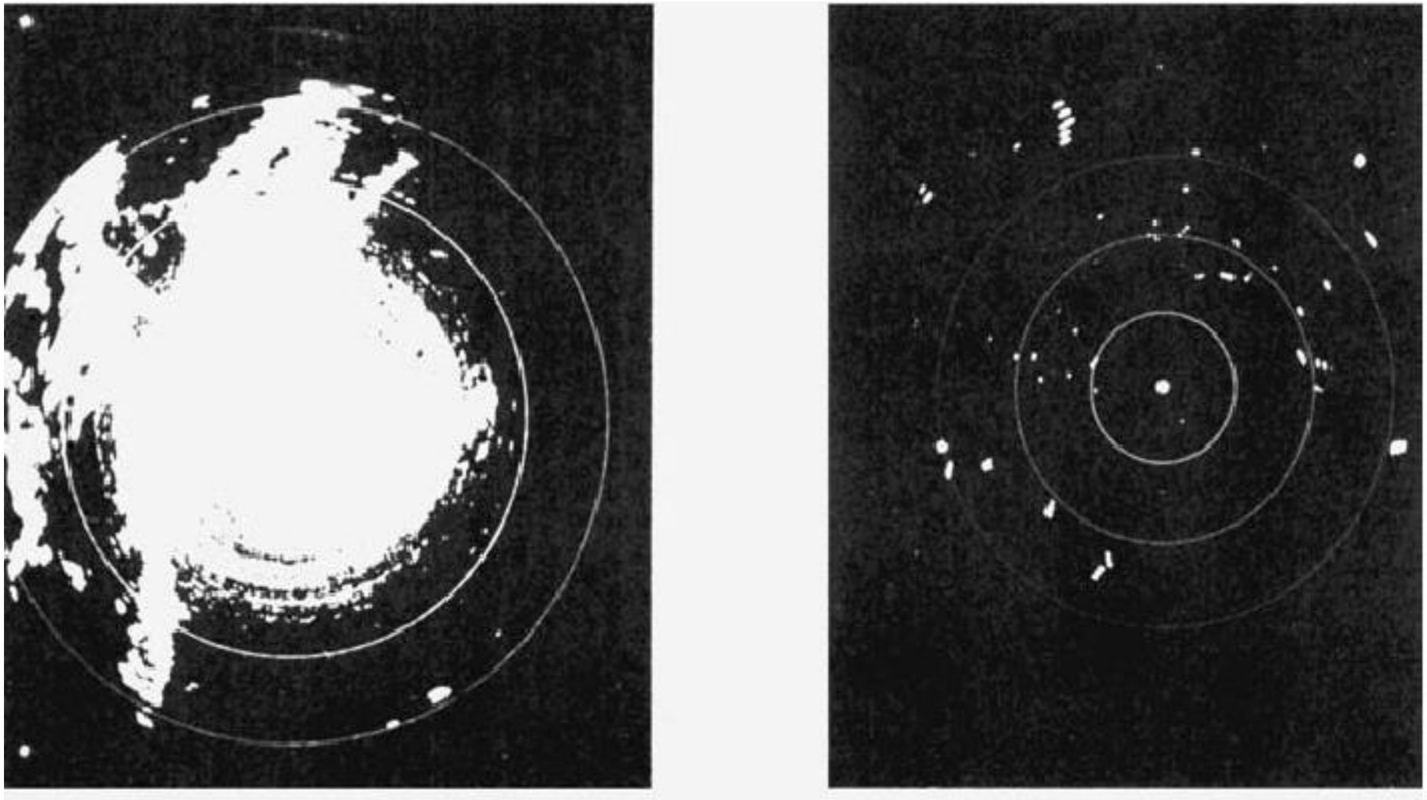


MOVING TARGETS AND BUTTERFLY EFFECT

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



NECESSITY FOR CLUTTER REJECTION

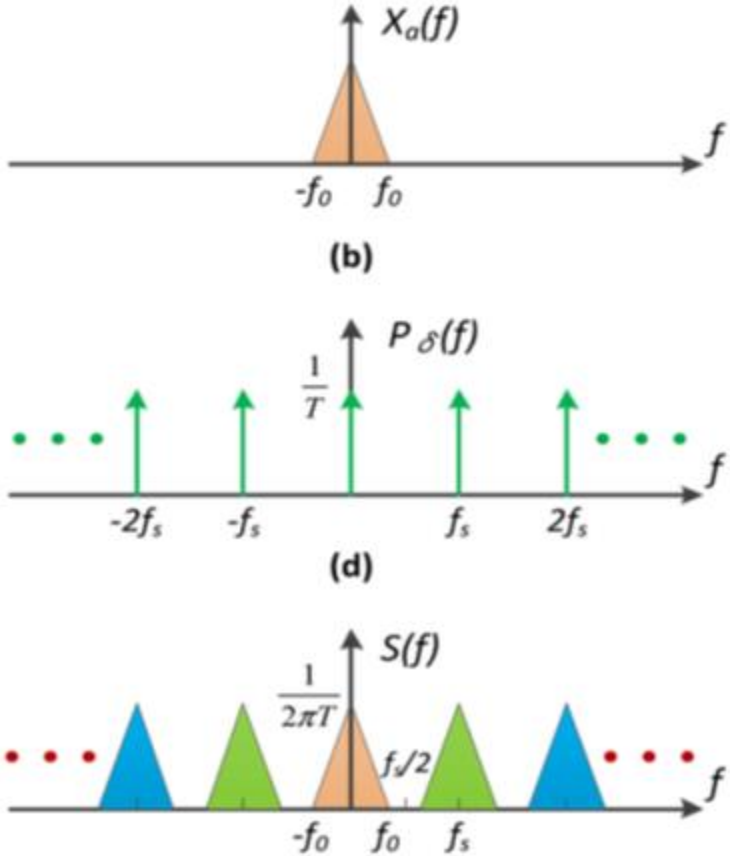


•MTI Radar is complex ,expensive and occupies more space. However with developments in VLSI technology size and cost has come down

RANGE GATED DOPPLER FILTERS

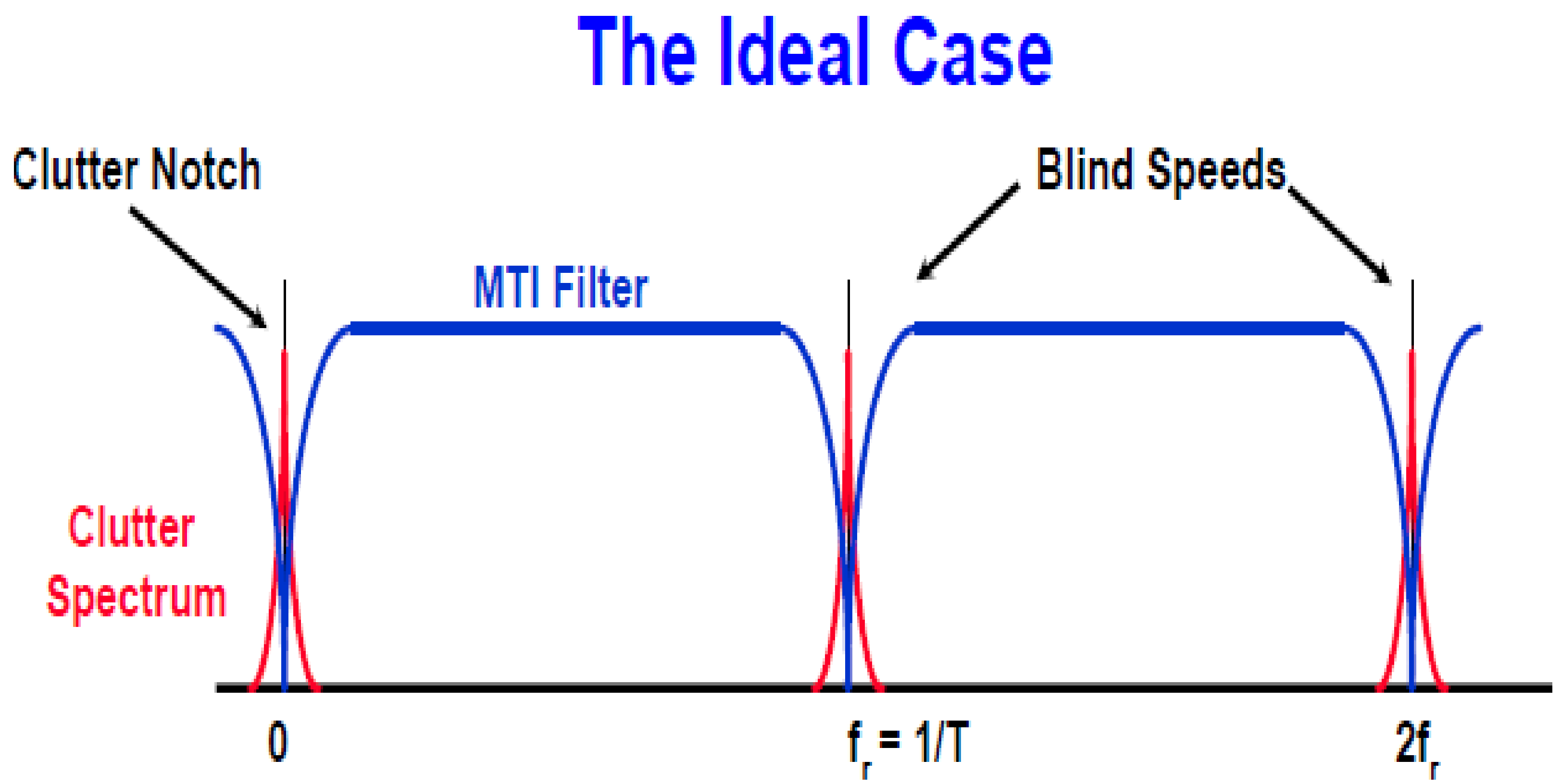
SAMPLING ANALOG SIGNAL

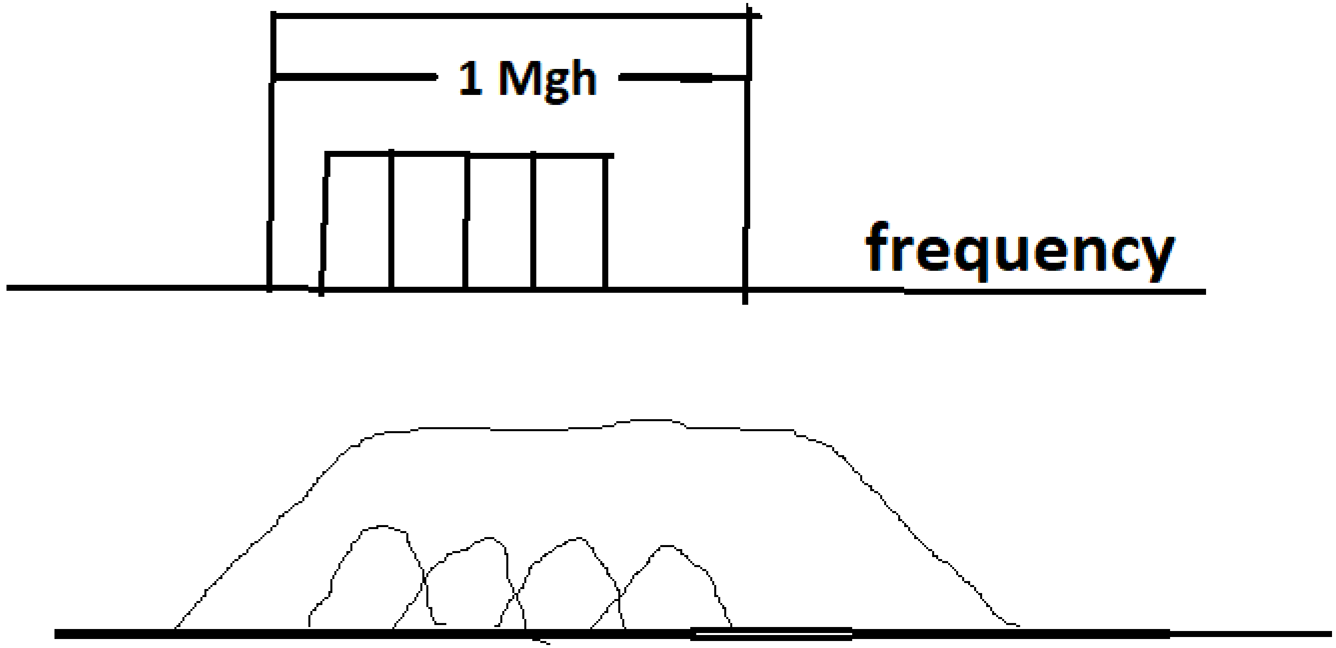
- .



IDEAL DLC

- The frequency response of single DLC does not have the clutter – rejection null in the vicinity of DC




1 Mgh
frequency

RANGE GATED DOPPLER FILTERS

- To separate moving targets from stationary targets following 2 methods adopted

  i. Time Domain Filter – DLC

  ii.Frequency Domain Band Pass Filter.

- **Frequency Domain Band Pass Filter:**

- This is a narrowband filter with a pass band to pass the Doppler frequencies

RANGE GATED DOPPLER FILTERS (CONTD ..)

➢ Reason for Range Gating:

- Pass Band for NB filter : Few KHZ
- Frequency of Radar pulse : $1 / \tau = 1$ MHZ

  (when $\tau = 1$ Micro sec)
- Since pass band is narrower few KHZ compared to 1 MHz, the output will be of much grater duration than the Radar pulse duration.

RANGE GATED DOPPLER FILTERS (CONTD ..)

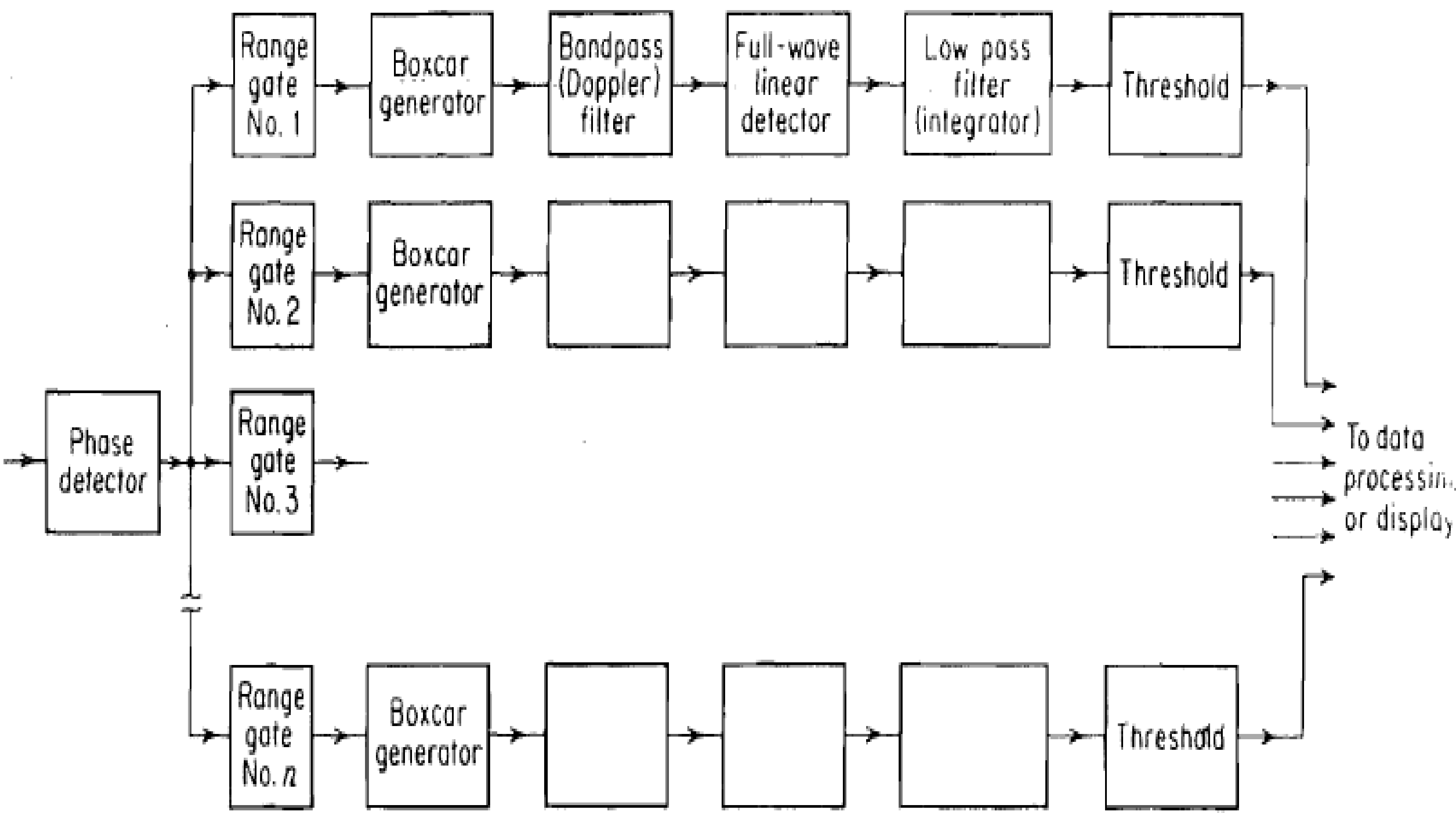
➢ Reason for Range Gating (contd)

- Ringing and smearing of pulse takes place, smearing destroys range information.
- Noise from other range cells will interfere with the target signal.
- if more than one target is present the problem is compounded.
- So Range Gated Doppler Filters are used.

RANGE GATED DOPPLER FILTERS (CONTD ..)

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

BLOCK DIAGRAM OF RANGE GATED FILTER

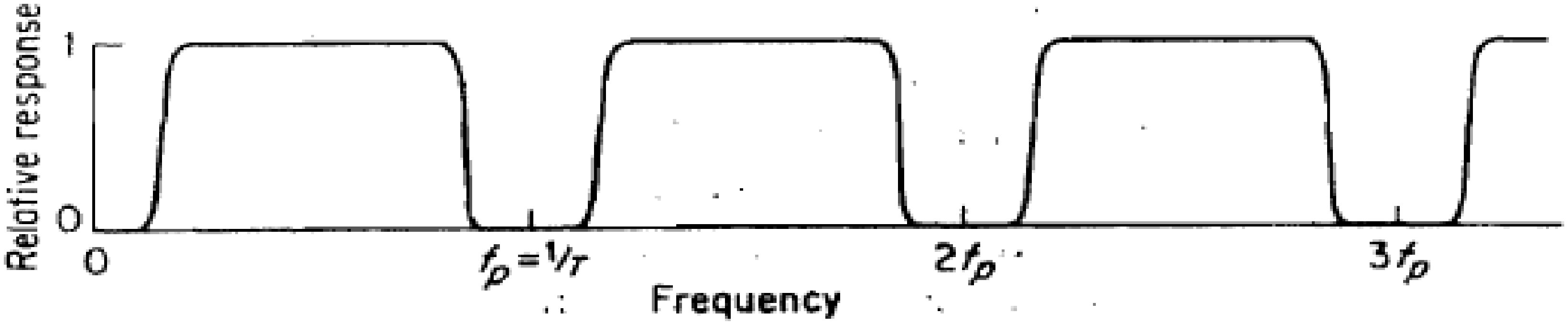


RANGE GATED DOPPLER FILTERS (CONTD ..)

- Output for a stationary target is a series of constant Amplitude pulses from the phase detector
- Output for moving target is a series of varying amplitude pulses according to Doppler frequency.
- Output from phase detector is passed sequentially through the range gates. Each range gate is switched in sequence at proper time for the duration of the sample.
- Output of each range gate is stretched in a Sample-and-hold circuit (Box car). This aids in eliminating harmonics of PRF.

RANGE GATED DOPPLER FILTERS (CONTD ..)

- **Band pass filter :** This is also called clutter rejection filter. The bandwidth is designed to conform to the clutter conditions.



- The lower cutoff can be adjusted by an operator to reject the unwanted spectrum from birds.
- Width of the notch is controlled manually to suit local conditions.

RANGE GATED DOPPLER FILTERS (CONTD ..)

- **Full Wave linear detector:**
  - Converts the Bipolar video into unipolar video
- **Low Pass Filter:**
  - Integrates the video.
- **Threshold:**
  - Allows those signals which cross the threshold are reported as targets.
- Outputs from each of the Range cells are combined for display on the PPI or ‘A’ scope.

(Jntuh) **Draw the block diagram of Non-coherent MTI radar and explain the function of each block in detail**

NON COHERENT MTI

NON COHERENT MTI

- **Echo consists of**

  i. Signal from moving target.

  ii.Clutter (stationary target).

- **Echo fluctuates in** i. Phase

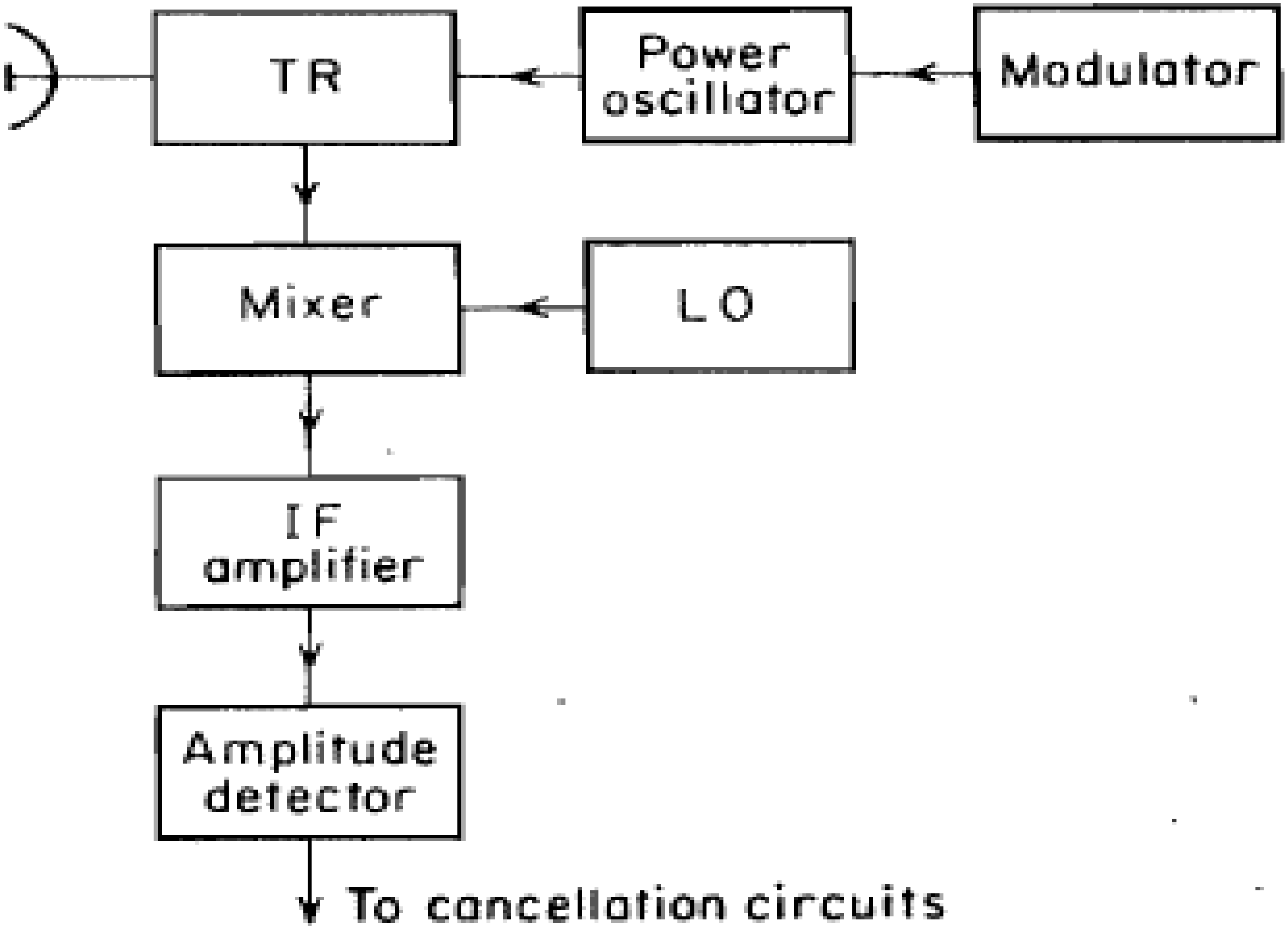
  ii. Amplitude

- COHERENT MTI Uses PHASE Fluctuations. Phase Detector removes Amplitude fluctuations. Reference signal is locked to transmitted signal
- Non coherent MTI uses Amplitude fluctuations this does not require internal reference as such no Phase Detector is used.

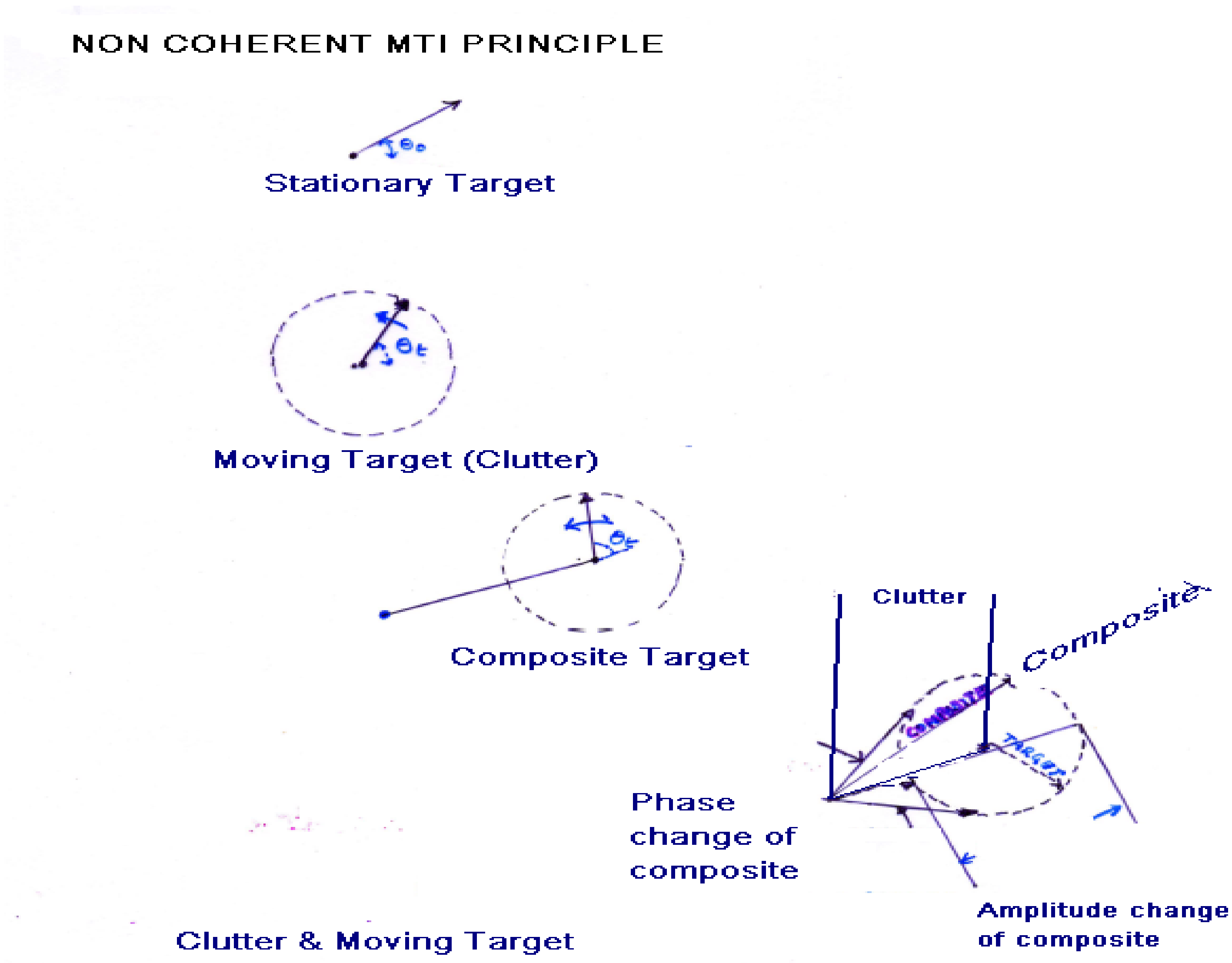
NONCOHERENT MTI (CONTD ..)

- Amplitude limiting should not be used . IF Amplifier should be linear. For large Dynamic range, logarithmic IF amplifier used. L.O. frequency need not be stable.
- As such complexity & cost of Noncoherent MTI is less.
- Output of IF Amplifier is given to an Envelope detector.
- Envelope detector is followed by DLC.
- Amplitude fluctuations due to Doppler produce Butterfly modulation. They ride on clutter.

BLOCK DIAGRAM OF NON COHERENT MTI

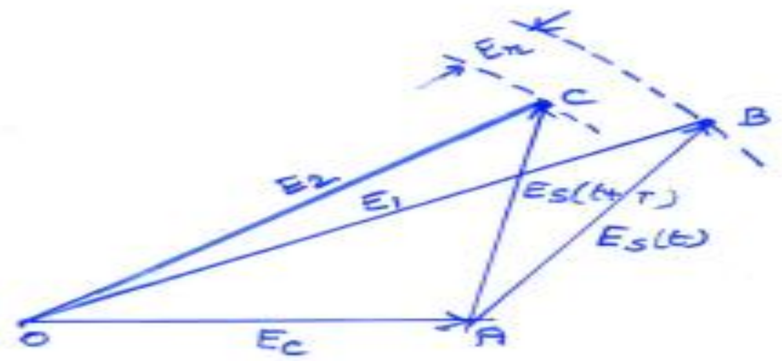


NON COHERENT MTI PRINCIPLE



NONCOHERENT MTI (CONTD ..)

PRINCIPLE OF OPERATION.



OA = CLUTTER VOLTAGE = E_c

$E_s(t)$ = AB = SIGNAL VOLTAGE at 't', AC = SIGNAL VOLTAGE (t+T)

OB = E1 SIGNAL + CLUTTER VOLTAGE FOR SECOND PULSE

OC = E2 —— DO ——

ψ = AVERAGE PHASE OF SIGNAL RELATIVE TO CLUTTER

$\Delta\psi$ = RELATIVE PHASE CHANGE OF SIGNAL DURING INTERPULSE PERIOD. $= 2\pi f_d / f_r$

SIGNAL OUTPUT $E_r^2 = 4 E_c E_s \left(\sin \frac{\pi f_d}{f_r} \right) \sin \psi$

→ BOTH BLIND SPEEDS & BLIND PHASES EXIST

→ POWER OUTPUT DEPENDS ON PRESENCE OF CLUTTER

(Jntuh) **Give the advantages of Non-coherent MTI radar**

NONCOHERENT MTI (CONTD ..)

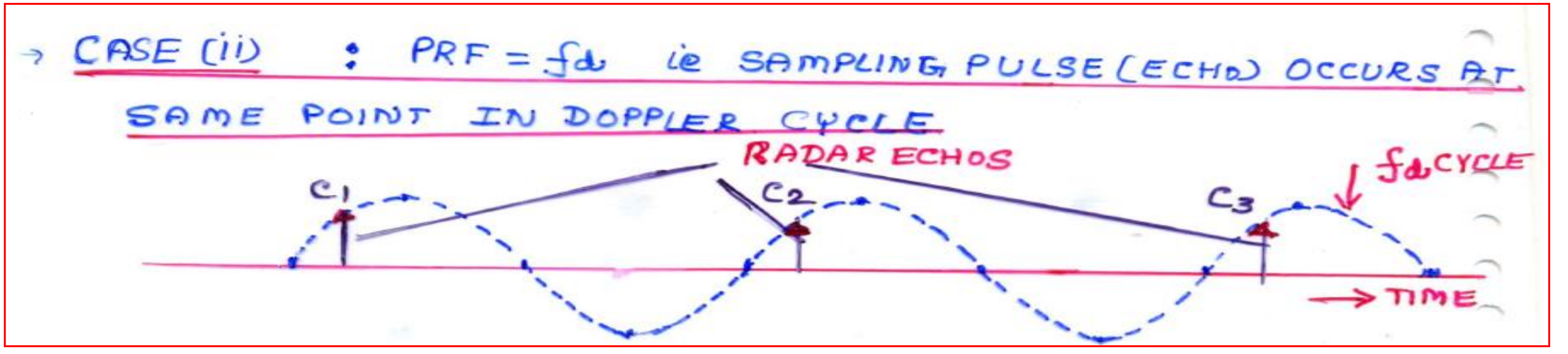
- **Advantage of Noncoherent MTI:**
  1. Simple, less expensive(stable LO not needed)
  2. Preferred for Airborne applications where space and weight are limited.
- **chief Limitations:**
  1. Moving target can be detected only when there is large clutter.
  2. But clutter may be present at sufficient level throughout the range cells. If clutter not present Doppler cannot be detected. Noncoherent Radar fails here.
  3. Improvement factor poor compared to coherent MTI since clutter not that stable as reference oscillator of coherent MTI.

(Jntuh) **Differentiate Blind phases from Blind speeds**

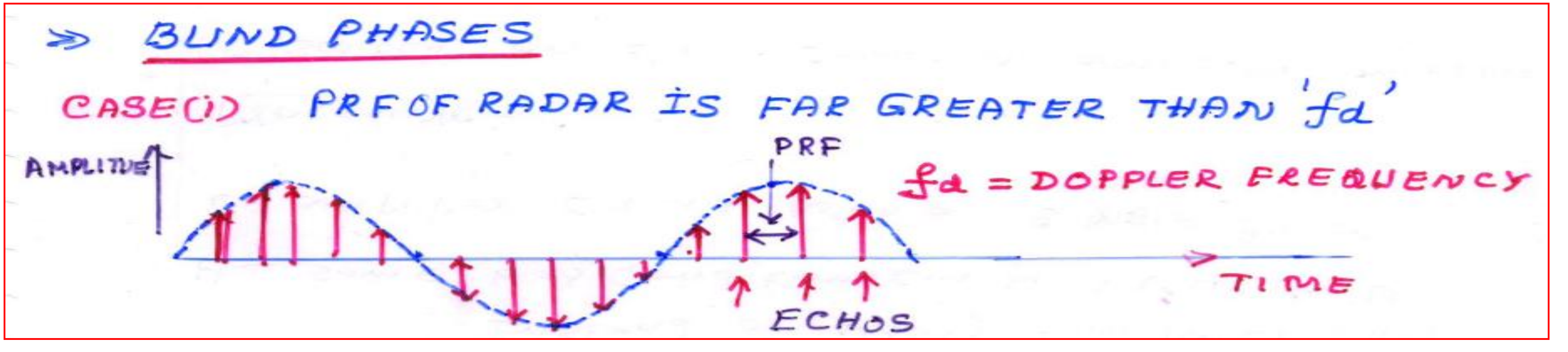
BLIND PHASES

BLIND PHASE

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

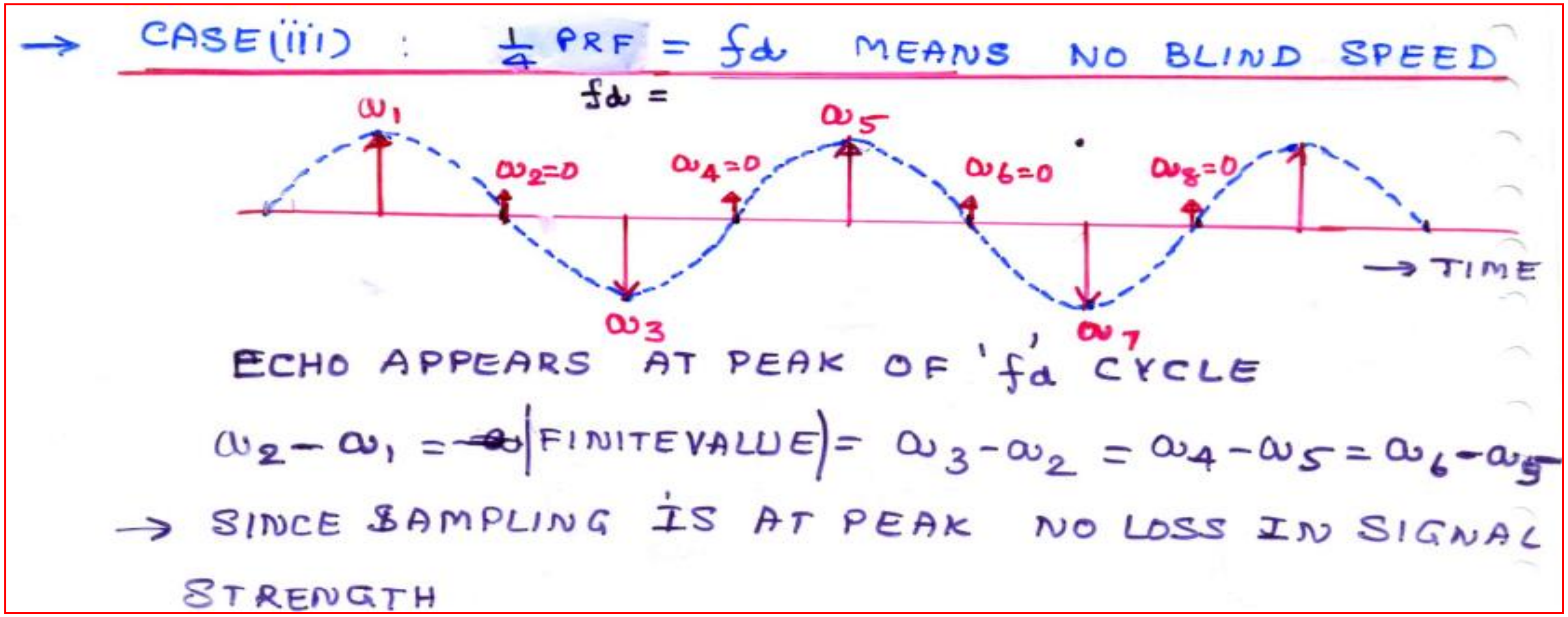


- When PRF > 2f_d (No Ambiguity occurs, But blind Phases likely to occur)



BLIND PHASE (CONTD ..)

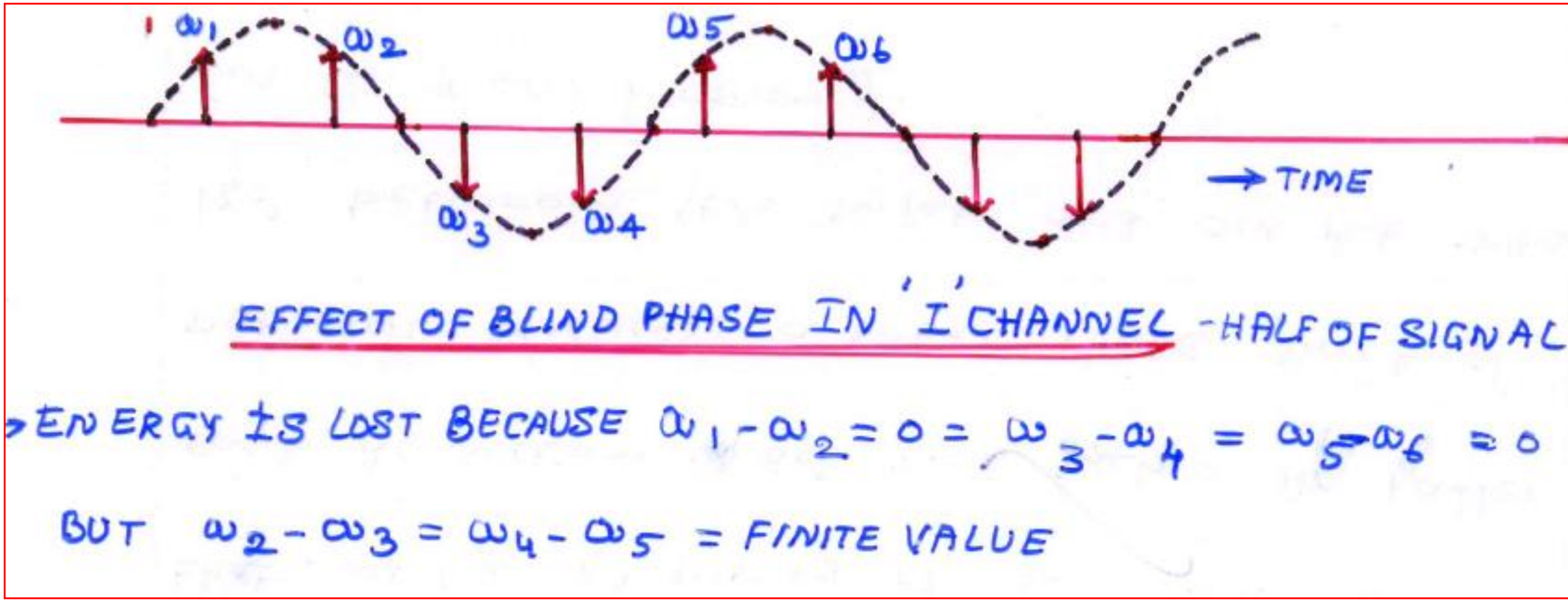
- When Phase between Doppler signal and sampling PRF results in loss, it is called Blind Phase.
- Blind Speed and Blind Phase are totally different.
- Example 1 f_p(PRF) = $4f_d$.



- No Blind Phase.

BLIND PHASE (CONTD ..)

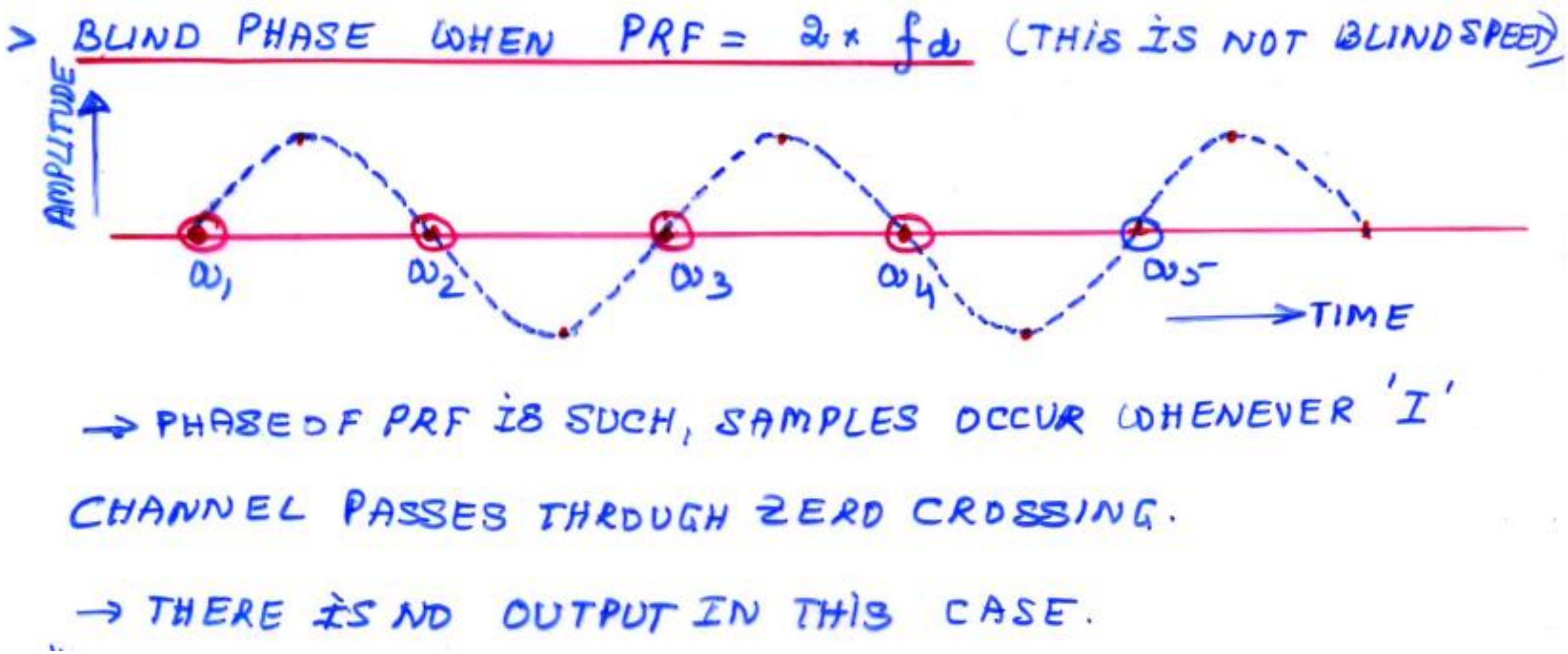
- Example 1: f_p(PRF) = $4f_d$.



- Blind Phase. Half the signal is lost.

BLIND PHASE (CONTD ..)

- Example 2: f_p(PRF) = $2f_d$.

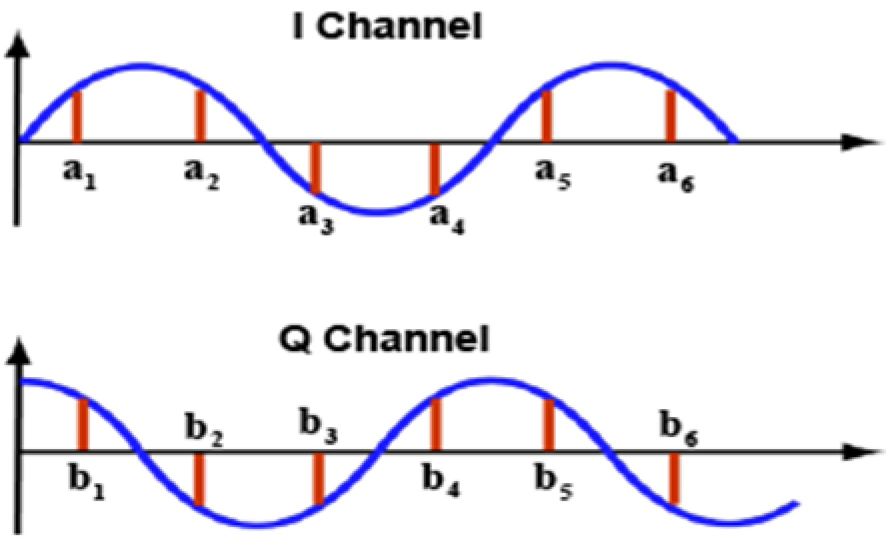


- Blind Phase. Whole signal is lost.

ELIMINATION OF BLIND PHASE

- **USING I & Q CHANNELS**
- Example 1 (revisited) f_p(PRF) = $4f_d$.

MTI Blind Phase Loss – Example 1



$a_1 - a_2 = 0$

$a_2 - a_3 \neq 0$

$a_3 - a_4 = 0$

$a_4 - a_5 \neq 0$

$b_1 - b_2 \neq 0$

$b_2 - b_3 = 0$

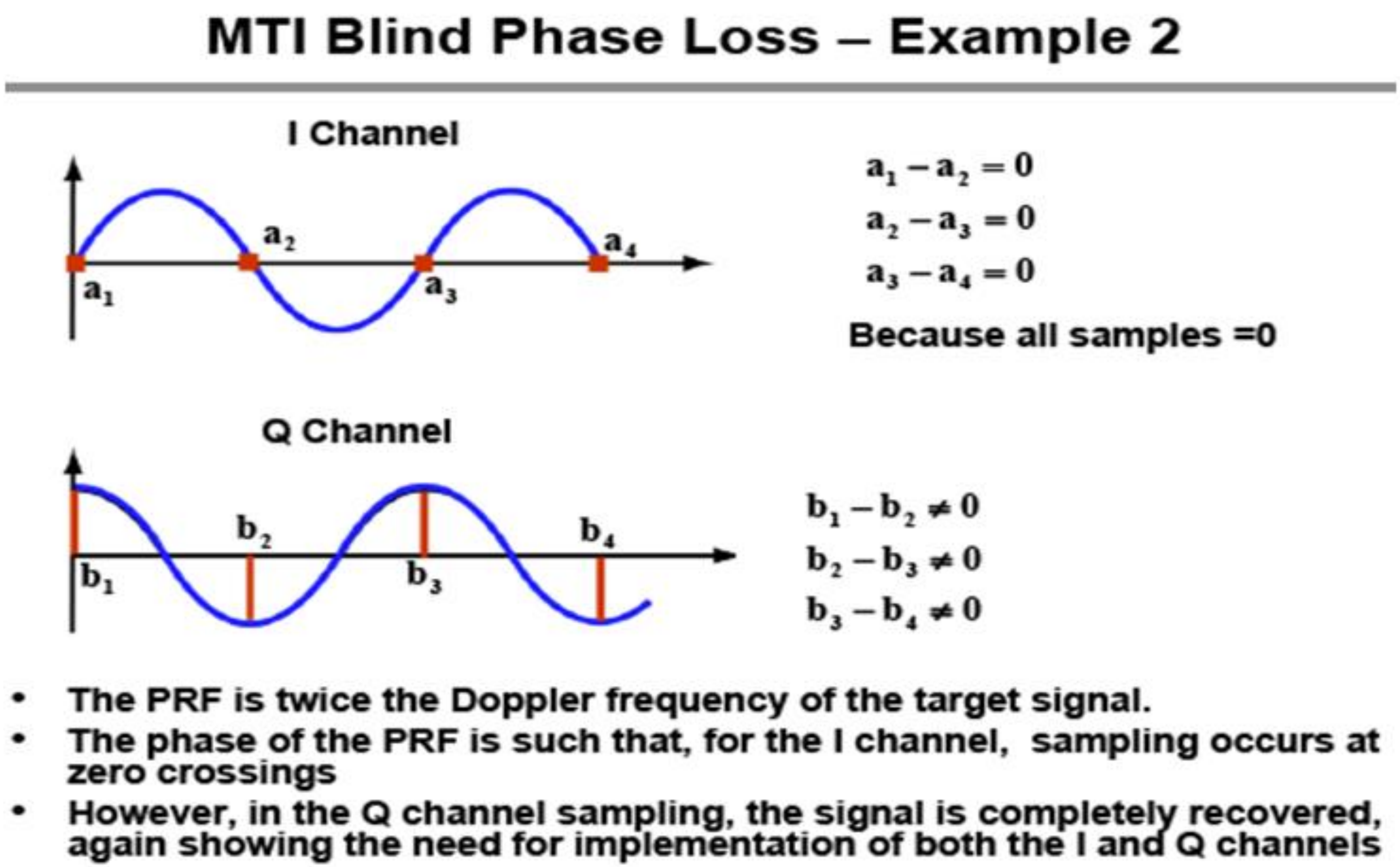
$b_3 - b_4 \neq 0$

$b_4 - b_5 = 0$

- In this case, after processing through a two pulse MTI, half of the signal energy is lost if only the I channel is used
- Use of both I and Q channels will solve this problem

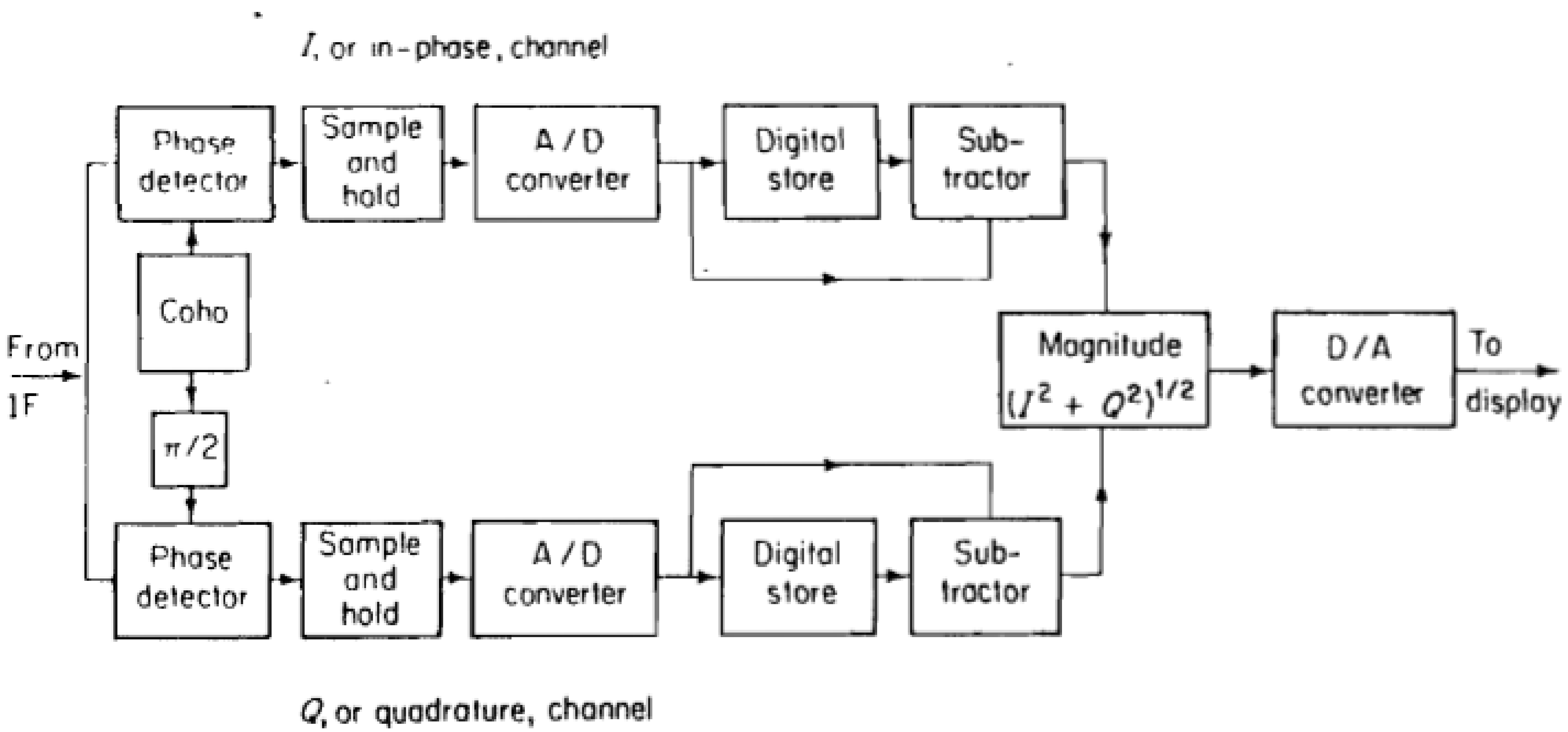
ELIMINATION OF BLIND PHASE

- **USING I & Q CHANNELS**
- Example 2 (revisited) f_p(PRF) = $2f_d$.



DIGITAL MTI

➢ Block Diagram:



DIGITAL SIGNAL PROCESSING

- Unlike in Analog Delay times, Delays can be obtained in storing Digital words for any length of time.
- **Advantages of Digital Processing:**

1. Multiple delay time cancellations easily achieved compared to analog. Multiple Delays increases clutter rejection.
2. Delay adjustment easier.
3. Delay does not change with temperature like in analog.
4. Delay time easily synchronized with PRF.
5. Reprogramming possible.
6. Compensation for Blind Phases achieved using I (Inphase) & Q (Quadrature) channels. I and Q processing difficult to achieve in analog processing.

1. (Jntuh) Explain the following limitations of MTI radar a) Equipment b) Scanning modulation C) internal fluctuation of clutter

2. (Jntuh) Mention the limitations of MTI radar related to clutter performance

3. (Jntuh) Mention the limitation of Improvement factor imposed by pulse to pulse instability

4. (Jntuh) write short notes on inter clutter visibility

LIMITATION OF MTI PERFORMANCE

LIMITATIONS TO MTI PERFORMANCE

- **Factors degrading MTI Performance:**

  i. instability in T_x and R_x

  ii.Physical motions of clutter

  iii.Finite time on target.(Scanning modulation)

  iv.Limiting in R_x

- **MTI IMPROVEMENT FACTOR :**

- $$\frac{\text{Signal to Clutter Ratio at MTI output}}{\text{Signal to Clutter ratio at Input of MTI}}$$

  averaged uniformly over all target velocities.

LIMITATIONS TO MTI PERFORMANCE (CONTD ..)

- **Sub Clutter Visibility:**
- $$\frac{\text{Target Echo Power}}{\text{Coicident clutter echo power}}$$

- **Example:** Sub clutter visibility = 30 dB (1000)

- Target is detected even though its power is less by 1000 times less than clutter power.
- While comparing Subclutter Visibility , resolution cell of both radars should be same.

- **Clutter Visibility Factor:**
- $$= \frac{\text{Signal}}{\text{Clutter}} \text{ after cacellation}$$

LIMITATIONS TO MTI PERFORMANCE (CONTD ..)

- I) Tx and Rx Instability:

i. Pulse to Pulse change in a) Amplitude
   b) Frequency c) Phase of Transmitted Pulse.

ii. Changes in stalo or Coho oscillator

iii. Jitter in timing of Pulse Transmission.

iv. Variations in Time delay in DLC.

v. Changes in Pulse width.

- Above causes, broaden Frequency Spectrum. This lowers Improvement factor.

- Effect of phase variation in an oscillator.
  - First Pulse = A cos ωt
  - Second Pulse = $A(\cos \omega t + \Delta\phi)$

  $\Delta\phi$ = Change in Phase.

  - Difference = A cos ωt – A cos (ωt + Δϕ)
  - $(\text{Cos A} - \text{Cos B}) = 2 \text{ Sin} \frac{A+B}{2} \text{ Sin} \frac{A-B}{2}$
  - $2 \text{ A Sin} \left(\omega\, t + \frac{\Delta\phi}{2}\right) \text{Sin} \frac{\Delta\phi}{2}$
  - $= 2 \text{ A Sin} \frac{\Delta\phi}{2} \approx A\,\Delta\phi$
  - Amplitude change

(for small $\Delta\phi$) so $I = \frac{1}{(\Delta\phi)^2}$

LIMITATIONS TO MTI PERFORMANCE (CONTD ..)

➢ II) FLUCTUATION OF CLUTTER:

- Echos from Buildings, water towers,Hills,Mountains produce constant Echoes.
- Echoes from trees,vegetation,Sea,rain,chaft fluctuates with time.
- This limits MTI performance.

LIMITATIONS TO MTI PERFORMANCE (CONTD ..)

III) FINITE TIME ON TARGET (SCANNING MODULATION):

- Antenna Beam width = θ_B
- Antenna Scanning Rate $= \dot{\theta}_S$
- Time of beam dwelling on target = t_0
- $t_0 = \dfrac{\theta_B}{\dot{\theta}_S} = \dfrac{n_B}{f_p}$
- Where n_B = Number of Pulse Hits.

$\dfrac{1}{f_P}$ = Pulse Interval Time.

LIMITATIONS TO MTI PERFORMANCE (CONTD ..)

- If t_0 is small , Frequency spectrum is large. This reduces Improvement factor.
- Limitation to Improvement factor
- $I_{st} = \frac{{n_B}^2}{1.388}$ (Single Canceller)
- $I_{2S} = \frac{{n_B}^4}{3.853}$ (Double Canceller)

LIMITATIONS TO MTI PERFORMANCE (CONTD ..)

- **V) LIMITING IN R_X :**

- Limiter is employed in IF amplifier.
- Limiter cause the spectrum of strong clutter to spread into the Canceller pass band. This generates additional residue. This significantly degrade MTI performance.

(Jntuh) **Distinguish between MTI Radar and Pulse doppler Radar**

DIFFERENCE BETWEEN MTI & PULSE DOPPLER RADAR

MTI RADAR	Pulse Doppler Radar
1. PRF is low (PRI is high) As such no range Ambiguities. Range measurement is unambiguous	1. PRF is high (PRI is low) As such range ambiguities occur.
2. Doppler Frequency is ambiguous. Blind speeds occur $f_d = \frac{n}{T}$ where n = 1,2,3,.... and T = PRI	2. No ambiguity in Doppler shift. No Blind speed.

DIFFERENCE BETWEEN MTI & PULSE DOPPLER RADAR

MTI Radar	Pulse Doppler Radar
3. Uses Delay Line Canceller to detect Doppler frequency	3. Doppler frequency filters are used.
4. Uses a high power magnetron which is a power oscillator	4. Uses a high power Amplifier like Klystron

CONCLUDED RADAR 3