UNIT- 3
MTI AND PULSE DOPPLER RADAR

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MTI AND PULSE DOPPLER RADAR

Introduction:

The Doppler frequency shift [$f_d = 2V_r / \lambda$] produced by a moving target may be used in a pulse radar just as in the CW radar**,** to determine the relative velocity of a target or to separate desired moving targets from undesired stationary objects (clutter). Although there are applications of pulse radar where a determination of the target's relative velocity is made from the Doppler frequency shift, the use of Doppler to separate small moving targets in the presence of large clutter has been of greater interest. Such a pulse radar that utilizes the Doppler frequency shift as a means of discriminating moving targets from fixed targets is called a **MTI**(moving target indication) or a **pulse Doppler radar**. The two are based on the same physical principle, but in practice there are differences between **MTI** and **Pulse Doppler** radar.

- The MTI radar usually operates with ambiguous Doppler measurement (so-called **blind speeds**) but with unambiguous range measurement (no second-time aroundechoes).
- A pulse Doppler radar operates with ambiguous range measurement but with unambiguous Doppler measurement. Its pulse repetition frequency is usually high enough to operate with unambiguous Doppler (no Blind speeds) but at the expense of rangeambiguities.

Salient Features of MTI:

- **MTI** is a necessity in high-quality air-surveillance radars that operate in the presence of clutter.
- Its design is more challenging than that of a simple pulse radar or a simple CW radar.
- A **MTI** capability adds to a radar's cost and complexity and often system designers must accept compromises they might not wish to**.**
- It took almost twenty years for the full capabilities offered by MTI signal-processing theory to be converted into practical and economical Radar equipment. The chief factor that made this possible was the development of reliable, small, and inexpensive digital processing hardware.

Principle of operation:

A simple CW radar studied earlier is shown in Fig.1 (a)**.** In principle, the CW radar may be converted into a pulse radar as shown in Fig.1(b) by providing a power amplifier and a modulator to turn the amplifier on and off for the purpose of generating pulses. The chief difference between the pulse radar of Fig. 1(b) and the one studied earlier is that a small portion of the CW oscillator power that generates the transmitted pulses is diverted to the receiver to take the place of the local oscillator. However, this CW signal does more than the job of the local oscillator. It acts as the **coherent reference** needed to detect the Doppler frequency shift. By **coherent** it means that the phase of the transmitted signal is preserved in the reference signal. The reference signal is the distinguishing feature of **coherent MTI radar**.

If the CW oscillator voltage is represented as $A_1 \sin 2\pi f_t t$ where A_1 = amplitude and f_t the carrier frequency

- Then the reference signal is: $V_{ref} = A_2 \sin 2\pi f_t t$.. **(1)**
- And the Doppler-shifted echo-signal voltage is

$$V_{echo} = A_3 \sin\left[2\pi(f_t \pm f_d)t - \frac{4\pi f_t R_0}{c}\right]$$

………..(2)

Where A2 = **amplitude** of reference signal
A_3 = amplitude of signal received from a target at a range R_0
f_d = Doppler frequency shift
t = time
c = velocity of propagation

- The reference signal and the target echo signal are heterodyned in the mixer stage of the receiver. Only the low-frequency (difference-frequency) component from the mixer is of interest and is a voltage given by:

$$V_{diff} = A_4 \sin\left(2\pi f_d t - \frac{4\pi f_t R_0}{c}\right)$$

…………(3)

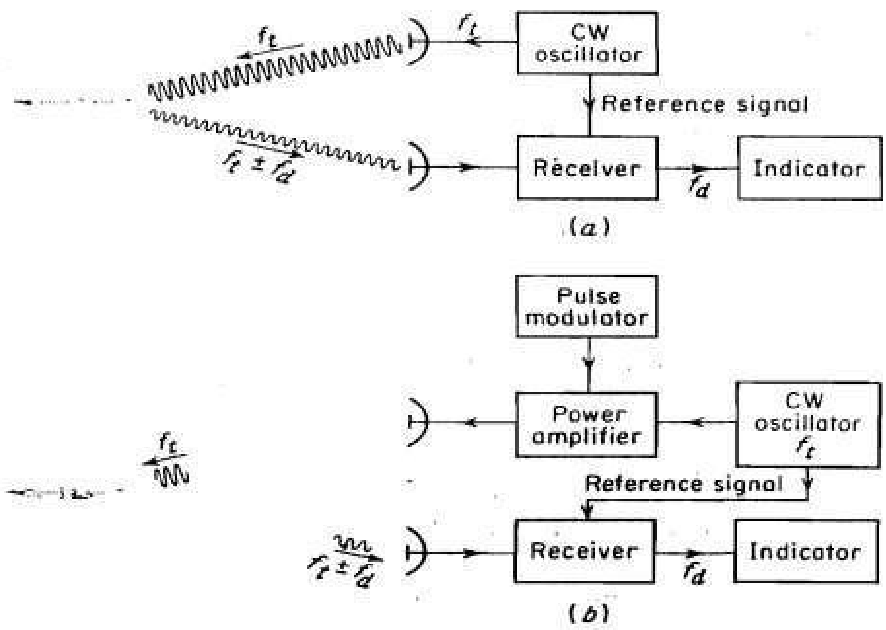

Figure 1: (a) Simple CW Radar (b) Pulse Radar using Doppler Information

Note that the equations **(1) to (3)** above represent sine wave carriers upon which the pulse modulation is imposed. The difference frequency is equal to the Doppler frequency **f_d**. For stationary targets the Doppler frequency shift will be zero and hence **V_{diff}** will not vary with time and may take on any constant value from **$+A_4$ to $-A_4$** including zero. However, when the target is in motion relative to the radar **f_d** has a value other than zero and the voltage corresponding to the difference frequency from the mixer **[Eq. (3)]** will be a function of time.

- An example of the output from the mixer when the Doppler frequency f_d is large compared with the reciprocal of the pulse width is shown in **Fig.2 (b).** The Doppler signal may be readily discerned from the information contained in a single pulse.
- If, on the other hand f_d is small compared with the reciprocal of the pulse duration, the pulses will be modulated with an amplitude given by Eq. **(3) [Fig. 2(c)]** and many pulses will be needed to extract the Doppler information.
- The case illustrated in **Fig. 2(c)** is more typical of aircraft-detection radar, while the waveform of **Fig. 2(b)** might be more applicable to a radar used for the detection of extraterrestrial targets such as ballistic missiles or satellites.
- Ambiguities in the measurement of Doppler frequency can occur in the case of the discontinuous measurement of **Fig. 2(c)** but not when the measurement is made on the basis of a single pulse.
- The video signals shown in Fig.**2**are called **bipolar***,* since they contain both positive and negative amplitudes.

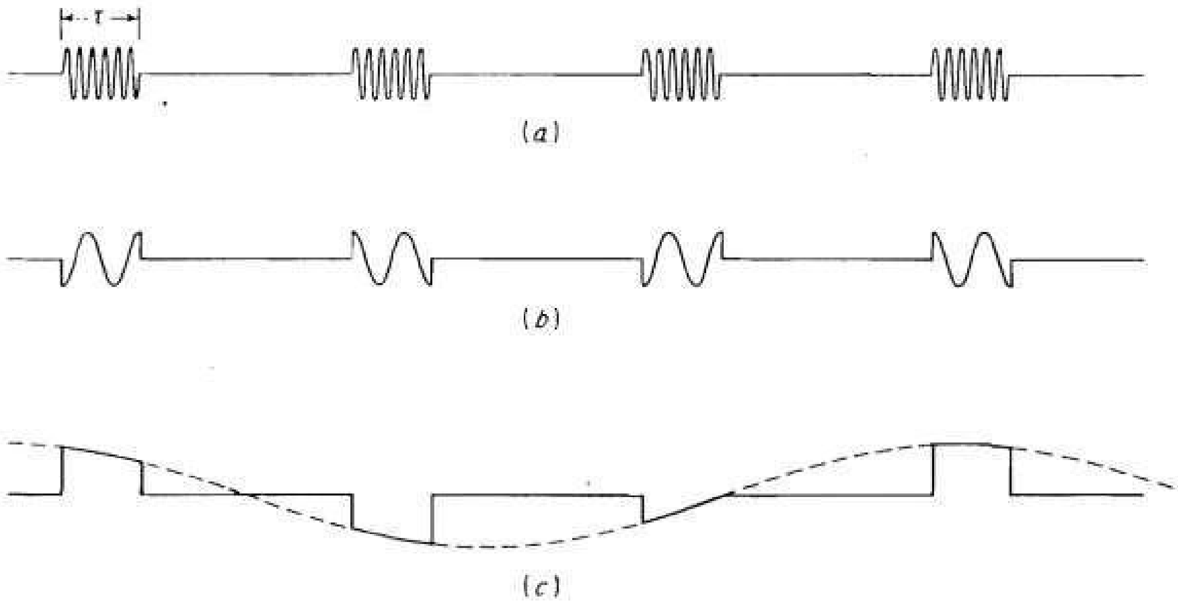

Figure 2 (a) RF echo pulse train (b) video pulse train for Doppler frequency f_d>I/τ (c) video pulse train for Doppler frequency f_d<I/τ .

Moving targets may be distinguished from stationary targets by observing the video output on an A-scope (amplitude vs. range). A single sweep on an A-scope might appear as in **Fig. 3 (a)** shown below. This sweep shows several fixed targets and two moving targets indicated by the two arrows. On the basis of a single sweep, moving targets cannot be distinguished from fixed targets.

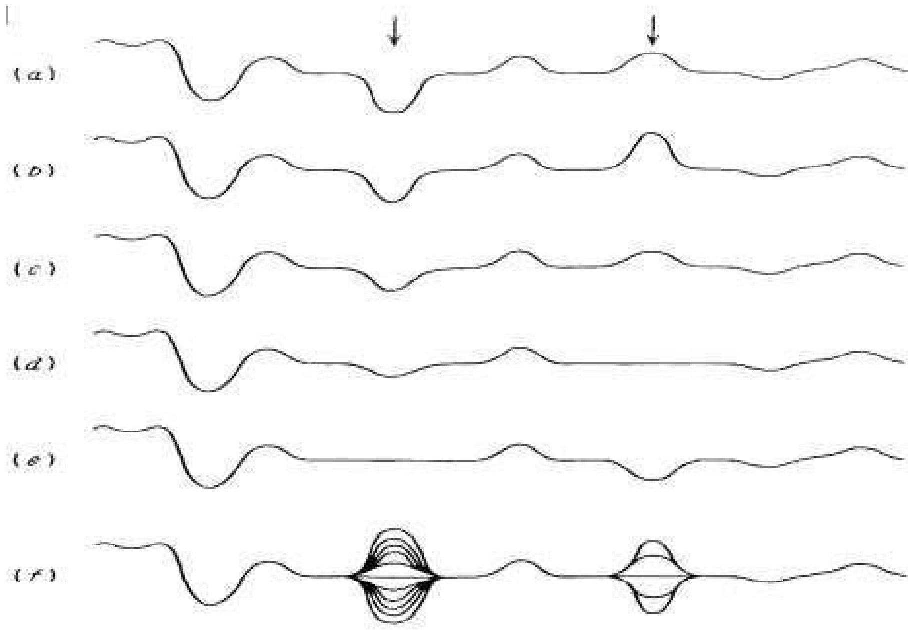

Figure 3 (a-e) Successive sweeps of a MTI radar A-scope display (echo amplitude as a function of time) (f) superposition of many sweeps: arrows indicate position of moving targets.

Successive A-scope sweeps (pulse-repetition intervals) are shown in Fig. 3 (a) to (e). Echoes from fixed targets remain constant throughout, but echoes from moving targets vary in amplitude from sweep to sweep at a rate corresponding to the Doppler frequency. The superposition of the successive A-scope sweeps is shown in Fig. 3(f). The moving targets produce, with time, a" **butterfly"** effect on the A-scope.

Concept of delay-line canceller:

Although the butterfly effect is suitable for recognizing moving targets on an A-scope, it is not appropriate for display on the PPI. One method commonly employed to extract Doppler information in a form suitable for display on the PPI scope is with a delay-line canceller as shown in the Fig. 4 below.

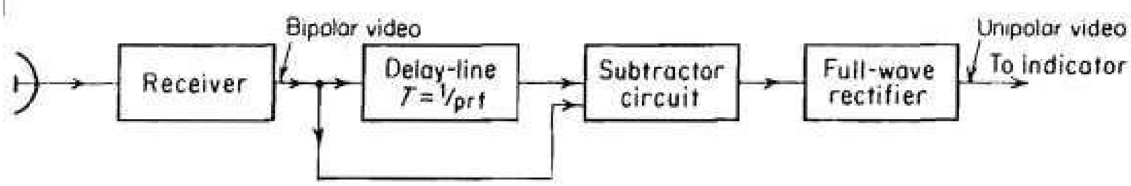

Figure 4: MTI Receiver with delay-line canceller

The delay-line canceller acts as a filter to eliminate the d-c component of fixed targets and to pass the a-c components of moving targets. The video portion of the receiver is divided into two channels. One is a normal video channel. In the other, the video signal experiences a time delay equal to one pulse-repetition period (equal to the reciprocal of the pulse repetition frequency). The outputs from the two channels are subtracted from one another. The fixed targets with unchanging amplitudes from pulse to pulse are canceled on subtraction. However, the amplitudes of the moving-target echoes are not constant from pulse to pulse and subtraction results in an un canceled residue. The output of the subtraction circuit is a bipolar video just as was the input. Before bipolar video can intensity-modulate a PPI display it is converted into unipotential voltages (unipolar video) by a full-wave rectifier.

MTI Radar with Power Amplifier Transmitter:

The simple MTI radar shown in **Fig. 1(b)** is not the most typical. The block diagram of a more common MTI radar employing a power amplifier is shown in the **Fig. 5 below.** The significant difference between this MTI configuration and that of **Fig. 1(b)** is the manner in which the reference signal is generated. In **Fig. 5**, the coherent reference is supplied by an oscillator called the **coho**, which stands for coherent oscillator. The **coho** is a stable oscillator whose frequency is the same as the intermediate frequency used in the receiver. In addition to providing the reference signal, the output of the **coho** is also mixed with the local-oscillator frequency f_l .The local oscillator also must be a stable oscillator and is called **stalo,** for stable local oscillator. The RF echo signal is heterodyned with the stalo signal to produce the IF just as in the conventional super heterodyne receiver. The **stalo, coho** and the mixer in which they are mixed are called Receiver- Exciter because of the dual role they serve both the receiver and the transmitter.

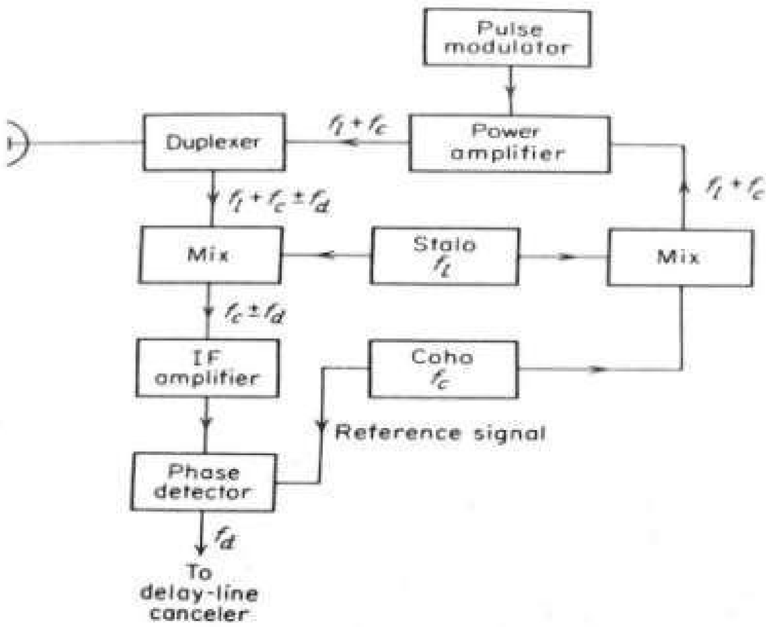

Figure 5: Block diagram of MTI radar with power-amplifier transmitter.

The characteristic feature of coherent MTI radar is that the transmitted signal must be coherent (in phase) with the reference signal in the receiver. This is accomplished in the radar system shown in **Fig. 5** by generating the transmitted signal from the **coho** reference signal. The function of the **stalo** is to provide the necessary frequency translation from the **IF** to the transmitted **(RF)** frequency. Although the phase of the **stalo** influences the phase of the transmitted signal, any **stalo** phase shift is canceled on reception because the **stalo** that generates the transmitted signal also acts as the local oscillator in the receiver. The reference signal from the **coho** and the IF echo signal are both fed into a mixer called the **Phase detector.** The phase detector differs from the normal amplitude detector since its output is proportional to the phase difference between the two input signals.

Any one of the transmitting-tubes like Triode, Tetrode, Klystron, Traveling-Wave Tube (TWT), and the Crossed-Field Amplifier ICFA) might be used as the power amplifier.

A transmitter which consists of a stable low-power oscillator followed by a power amplifier is sometimes called **MOPA**, which stands for **M**aster-**O**scillator **P**ower **A**mplifier.

MTI radar with power-oscillator transmitter:

Before the development of the Klystron amplifier, the only high-power transmitter tube available at microwave frequencies for radar application was the Magnetron. In a Magnetron oscillator, the phase of the RF bears no relationship from pulse to pulse. For this reason, the reference signal cannot be generated by a continuously running oscillator. However, a coherent reference signal may be readily obtained with the power oscillator by readjusting the phase of the **coho** at the beginning of each sweep according to the phase of the transmitted pulse. The phase of the **coho** is locked to the phase of the transmitted pulse each time a pulse is generated.

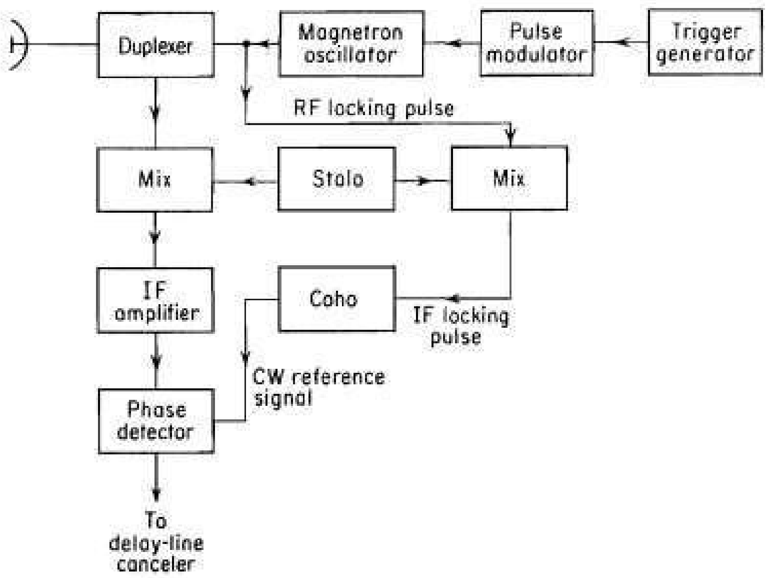

Figure 6: Block diagram of MTI radar with power-oscillator transmitter

Delay Line Cancellers:

The simple MTI delay-line canceller showed in **Fig. 4** is an example of a time-domain filter. The capability of this device depends on the quality of the medium used in the delay line. The Pulse modulator delay line must introduce a time delay equal to the pulse repetition interval. For typical ground-based air surveillance radars this will be several milliseconds. Delay times of this magnitude cannot be achieved with practical electromagnetic transmission lines. By converting the electromagnetic signal to an acoustic signal, it is possible to utilize delay lines of a reasonable physical length since the velocity of propagation of acoustic waves is about $\mathbf{10^{-5}}$ that of electromagnetic waves. After the necessary delay is introduced by the acoustic line, the signal is converted back to an electromagnetic signal for further processing. The early acoustic delay lines developed during World War 2 used liquid delay lines filled with either water or mercury. Liquid delay lines were large and inconvenient to use. They were replaced in the mid-1950s by the solid fused-quartz delay line that used multiple internal reflections to obtain a compact device. These analog acoustic delay lines were, in turn replaced in the early 1970s by storage devices based on digital computer technology. The use of digital delay lines requires that the output of the MTI receiver phase-detector be quantized into a sequence of digital words. The compactness and convenience of digital processing allows the implementation of more complex delay-line cancellers with filter characteristics not practical with analog methods. One of the advantages of a time-domain delay-line canceller as compared to the more conventional frequency-domain filter is that a single network operates at all ranges and does not require a separate filter for each range resolution cell. Frequency-domain Doppler filter banks are of interest in some forms of MTI and Pulse-Doppler radar.

Filter Characteristics of the Delay Line Canceller:

The delay-line canceller acts as a filter which rejects the d-c component of clutter. Because of its periodic nature, the filter also rejects energy in the vicinity of the pulse repetition frequency and its harmonics. The video signal of Eq.**(3)**received from a particular target at a range $\mathbf{R_0}$is

$$V_1 = k \sin (2\pi f_d t - \emptyset_0) \quad \ldots\ldots (4)$$

Where $\mathbf{\emptyset_0}$ = phase shift and **k** = amplitude of video signal. The signal from the previous transmission, which is delayed by a time **T** = pulse repetition interval, is

$$V_2 = k \sin [2\pi f_d (t - T) - \emptyset_0) \quad \ldots\ldots (5)$$

Everything else is assumed to remain essentially constant over the interval **T** so that **k** is the same for both pulses. The output from the subtractor is

$$V = V_1 - V_2 = 2k \sin \pi f_d T \cos [2\,\pi f_d(t - T/2) - \emptyset o] \quad \ldots\ldots (6)$$

It is assumed that the gain through the delay-line canceller is unity. The output from the canceller Eq. (6) consists of a cosine wave at the Doppler frequency & with an amplitude $\mathbf{2k \sin \pi f_d T}$: Thus, the amplitude of the canceled video output is a function of the Doppler frequency shift and the pulse-repetition interval, or prf. The magnitude of the relative frequency-response of the delay-line canceller **[**ratio of the amplitude of the output from the delay-line canceller, $\mathbf{2k \sin (\pi f_d T)}$ to the amplitude of the normal radar video **k] is** shown in the **Fig. 7** below.

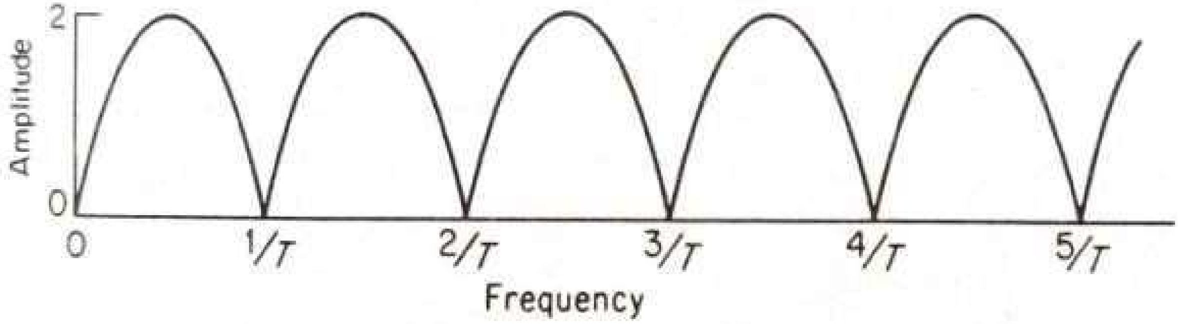

Figure (7): Frequency response of the single delay-line canceller: T = delay time =1/f_P.

Blind speeds:

The response of the single-delay-line canceller will be zero whenever the argument **($\pi f_d T$)** in the amplitude factor of **Eq. (6)** is 0, π, 2π, . .., etc., or when

$$f_d = \frac{n}{T} = nf_p$$

……………. **(7)**

where ***n*** = 0, **1,** 2, . . . , and **f_p**= pulse repetition frequency. The delay-line canceller not only eliminates the d-c component caused by clutter **(n = 0),**but unfortunately it also rejects any moving target whose Doppler frequency happens to be the same as the prf or a multiple thereof. Those relative target velocities which result in zero MTI response are called **blind speeds** and are given by

$$v_n = \frac{n\lambda}{2T} = \frac{n\lambda f_p}{2} \qquad n = 1, 2, 3, \ldots$$

……………… (8)

where **v_n** is the n^{th} blind speed.

The blind speeds are one of the limitations of pulse MTI radar which do not occur with CW radar. They are present in pulse radar because Doppler is measured by discrete samples (pulses) at the prf rather than continuously. If the first blind speed is to be greater than the maximum radial velocity expected from the target, the product, **λf_P** must be large. Thus, the MTI radar must operate at long wavelengths (low frequencies) or with high pulse repetition frequencies, or both. Unfortunately, there are usually constraints other than blind speeds which determine the wavelength and the pulse repetition frequency. Therefore, blind speeds are not easy to avoid. Low radar frequencies have the disadvantage that antenna beam widths, for a given-size antenna, are wider than at the higher frequencies and would not be satisfactory in applications where angular accuracy or angular resolution is important. The pulse repetition frequency cannot always be varied over wide limits since it is primarily determined by the unambiguous range requirement.

Double cancellation:

The frequency response of a single-delay-line canceller (Fig. **7)** does not always have as broad a clutter-rejection null as desired in the vicinity of d-c. The clutter-rejection notches may be widened by passing the output of the delay-line canceller through a second delay-line canceller as shown in **Fig. 8** below. The output of the two single-delay line cancellers in cascade is the square of that from a single canceller. Thus the frequency response is **($4 \sin^2 \pi f_d T$)**. The configuration of **Fig. 8** is called a double-delay-line canceller, or simply a ***double canceller.*** The relative response of the double canceller compared with that of a single-delay-line canceller is shown in Fig. **9.** The finite width of the clutter spectrum is also shown (hatched) in this figure so as to illustrate the additional cancellation of clutter offered by the double canceller.
The two-delay-line configuration of Fig.**8 (b)** has the same frequency-response characteristic as the double-delay-line canceller. The operation of the device is as follows. **A** signal **f (t)** is inserted into the adder along with the signal from the preceding pulse period, with its amplitude weighted by the factor -2, plus the signal from the previous two pulse periods. The output of the adder is therefore

f(t) - 2f(t + T) +f (t + 2T)

which is the same as the output from the double-delay-line canceller.

f (t) - f (t + T) -f (t + T) +f (t + 2T)

This configuration is commonly called the three-pulse canceller.

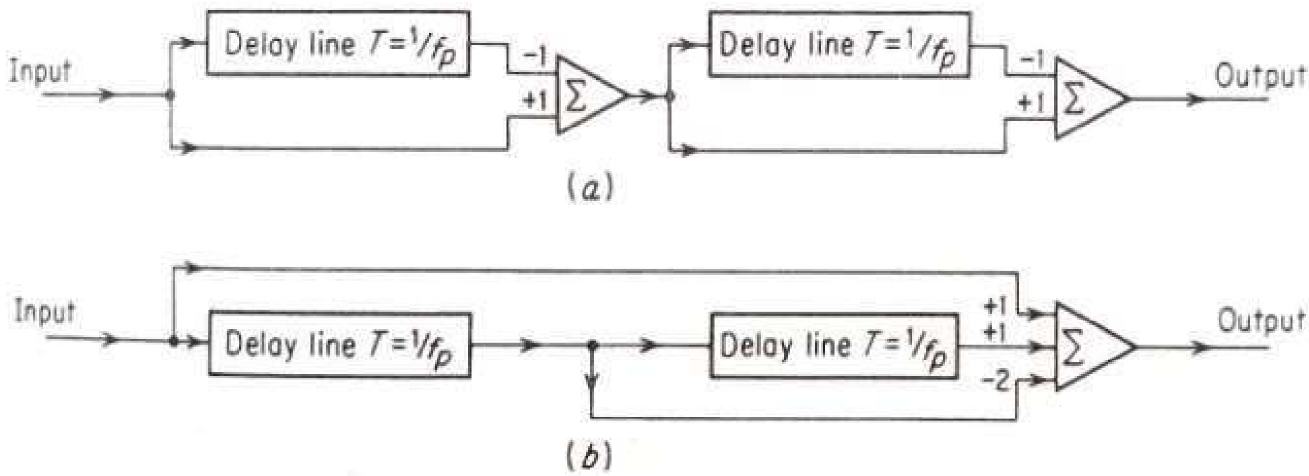

Figure 8 : (a) Double-delay-line canceller (b)Three-pulse canceller.

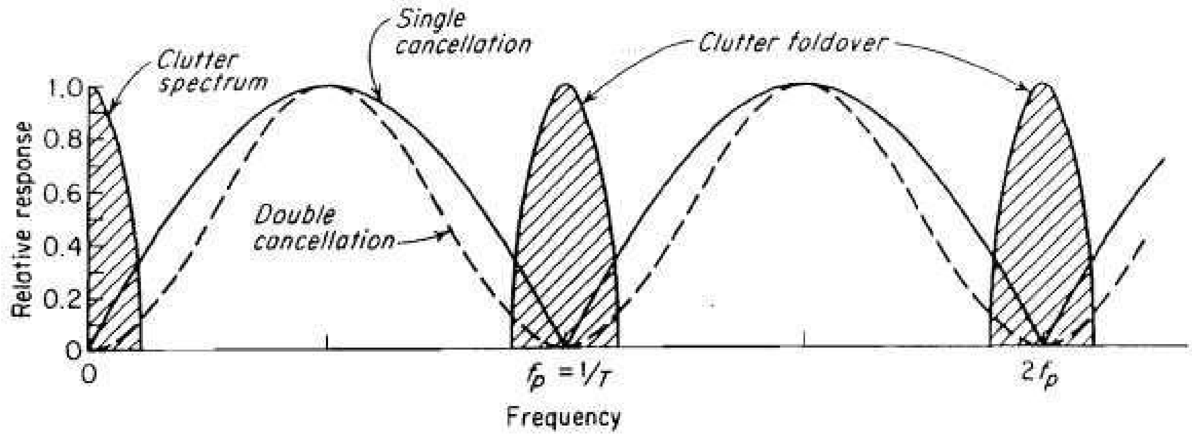

Figure (9): Relative frequency response of the single-delay-line canceller (solid curve) and the double delay-line canceller (dashed curve). Shaded area represents clutter spectrum.

Multiple or staggered Pulse Repetition Frequencies:

The use of more than one pulse repetition frequency offers additional flexibility in the design of MTI Doppler filters. It not only reduces the effect of the blind speeds of Eq. **8,** but it also allows a sharper low-frequency cutoff in the frequency response than might be obtained with a cascade of single-delay-line cancellers with $\sin^n \pi f_d T$ response. The blind speeds of two independent radars operating at the same frequency will be different if their pulse repetition frequencies are different. Therefore, if one radar were ***"blind*** "to moving targets, it is unlikely that the other radar would be" ***blind"*** also. Instead of using two separate radars, the same result can be obtained with one radar which time-shares its pulse repetition frequency between two or more different values (multiple PRF's). The pulse repetition frequency might be switched every other scan or every time the antenna is scanned a half beam width, or the period might be alternated on every other pulse. When the switching is pulse to pulse, it is known as a **staggered PRF**. An example of the composite (average) response of an MTI radar operating with two separate pulse repetition frequencies on a time-shared basis is shown in **Fig.10.** The pulse repetition frequencies are in the ratio of ***5:***4. Note that the first blind speed of the composite response is increased several times over what it would be for a radar operating on only a single pulse repetition frequency. Zero response occurs only when the blind speeds of each prf coincide. In the example of **Fig.10**, the blind speeds are coincident for $4/T_1 = 5/T_2$. Although the first blind speed may be extended by using more than one prf, regions of low sensitivity might appear within the composite pass band. The closer the ratio $T_1 : T_2$ approaches unity, the greater will be the value of the first blind speed. However, the first null in the vicinity of $f_d = 1/T_1$ becomes deeper. Thus, the choice of T_1/T_2 is a compromise between the value of the first blind speed and the depth of the nulls within the filter passband.

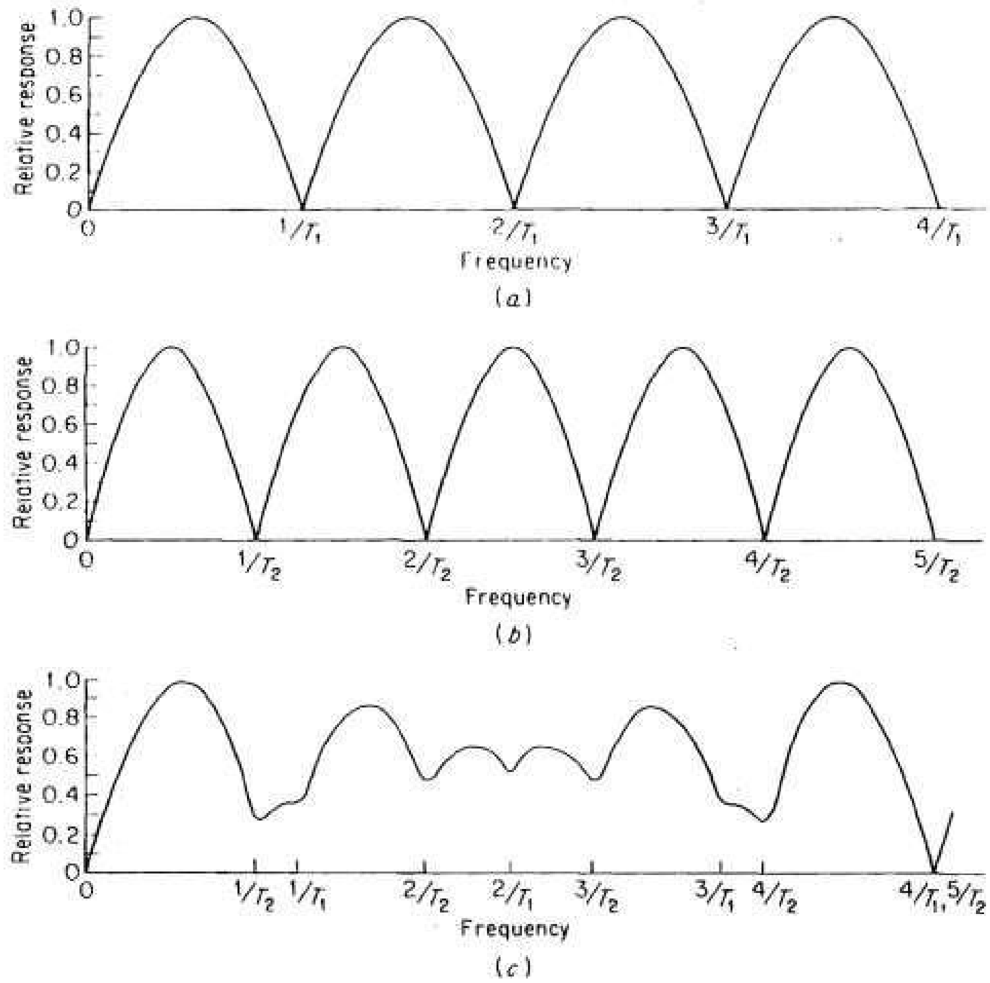

Figure 10 (a) Frequency-response of a single-delay-line canceller for f_P= $1/T_1$ (b) same for f_p= l/T_2 (c) Composite response with T_1/T_2= 4/5.

The depth of the nulls can be reduced and the first blind speeds increased by operating with more than two inter pulse periods. **Figure 11** below shows the response of a five-pulse stagger (four periods) that might be used with a long-range air traffic control radar. In this example the periods are in the ratio 25 : 30 : 27 : 31 and the first blind speed is **28.25** times that of a constant **prf** waveform with the same average period. If the periods of the staggered waveforms have the relationship $n_1/T_1 = n_2/T_2 = \ldots\ldots = n_N/T_N$, where $n_1, n_2, \ldots, n_N$ are integers, and if v_B is equal to the first blind speed of a non-staggered waveform with a constant period equal to the average period $T_{av} = (T_l + T_2 + \ldots T_N)/N$ then the first blind speed v_1 is given by :

$$\frac{v_1}{v_B} = \frac{n_1 + n_2 + \cdots + n_N}{N}$$

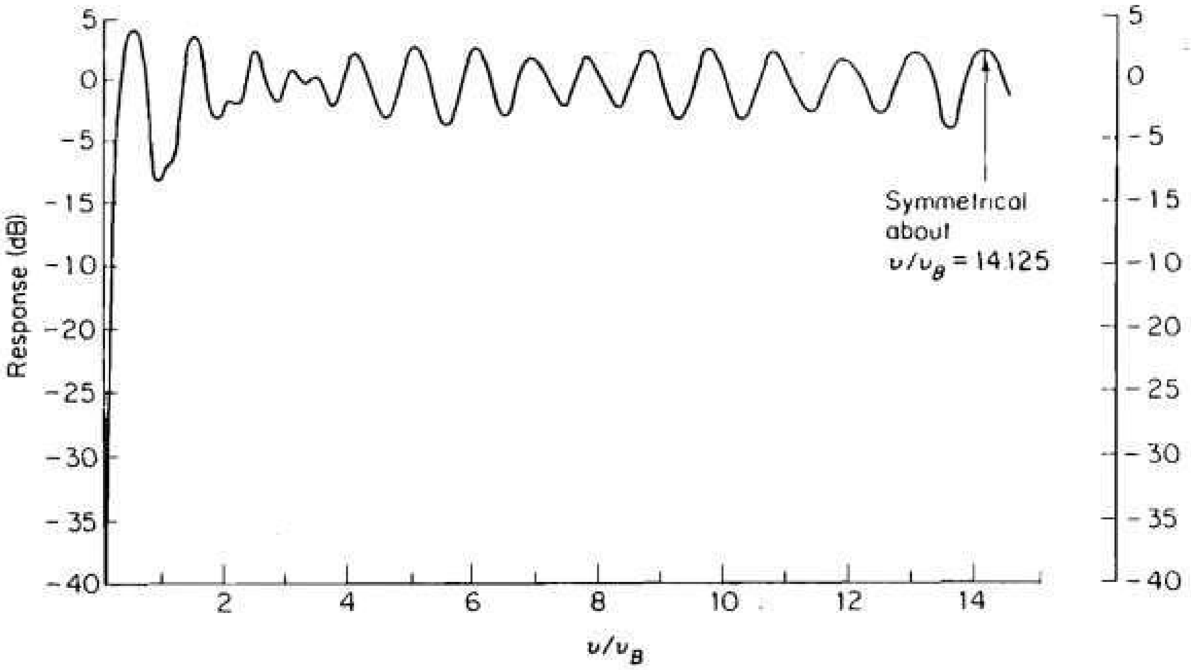

Figure 11: Frequency response of a five-pulse (four-period) stagger.

Range-gated Doppler filters:

The delay-line canceller, which can be considered as a time-domain filter, is widely used in MTI radar to separate moving targets from stationary clutter. It is also possible to employ the more common frequency-domain band pass filters of conventional design in MTI radar to separate the Doppler-frequency-shifted targets. The filter configuration however would be more complex, than the single, narrow-band pass filter. A narrowband filter with a pass band designed to pass the Doppler frequency components of moving targets will “ring" when excited by the usual short radar pulse. That is, its pass band is much narrower than the reciprocal of the input pulse width so that the output will be of much greater duration than the input. The narrowband filter ***"smears"*** the input pulse since the impulse response is approximately the reciprocal of the filter bandwidth. This smearing destroys the range resolution. If more than one target is present they cannot be resolved. Even if only one target is present, the noise from the other range cells that do not contain the target will interfere with the desired target signal. The result is a reduction in sensitivity due to a ***collapsing loss.***
The loss of the range information and the *collapsing loss* may be eliminated by first quantizing the range (time) into small intervals. This process is called ***range gating.*** The width of the range gates depends upon the range accuracy desired and the complexity which can be tolerated, but they are usually of the order of the pulse width. Range resolution is established by gating. Once the radar return is quantized into range intervals, the output from each gate may be applied to a narrowband filter since the pulse shape need no longer be preserved for range resolution. A collapsing loss does not take place since noise from the other range intervals is excluded.

A block diagram of the video of an MTI radar with multiple range gates followed by clutter-rejection filters is shown in **Fig. 12** below. The output of the phase detector is sampled sequentially by the range gates. Each range gate opens in sequence just long enough to sample the voltage of the video waveform corresponding to a different range interval in space. The range gate acts as a switch or a gate which opens and closes at the proper time. The range gates are activated once each pulse-repetition interval. The output for a stationary target is a series of pulses of constant amplitude. An echo from a moving target produces a series of pulses which vary in amplitude according to the Doppler frequency. The output of the range gates is stretched in a circuit called the ***boxcar generator,*** or ***sample-and-hold*** circuit, whose purpose is to aid in the filtering and detection process by emphasizing the fundamental of the modulation frequency and eliminating harmonics of the pulse repetition frequency. The clutter rejection filter is a band pass filter whose bandwidth depends upon the extent of the expected clutter spectrum.

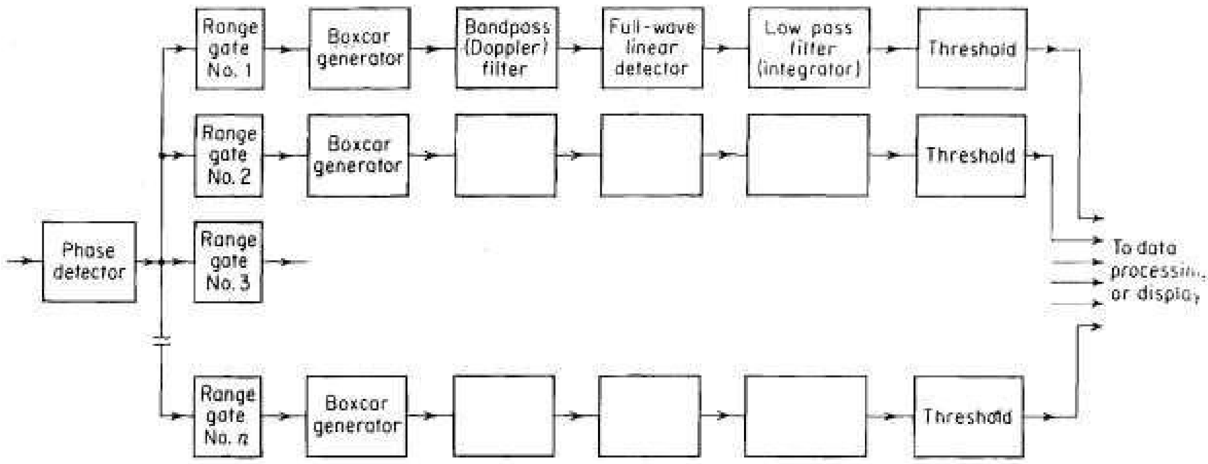

Figure 12: Block diagram of MTI radar using range gates and filters.

Following the Doppler filter is a full-wave linear detector and an integrator (a low-pass filter). The purpose of the detector is to convert the bipolar video to unipolar video. **The** output of the integrator is applied to a threshold-detection circuit. Only those signals which cross the threshold are reported as targets. Following the threshold detector, the outputs from each of the range channels must be properly combined for display on the PPI or A-scope or for any other appropriate indicating or data-processing device. The CRT display from this type of MTI radar appears "cleaner" than the display from a normal MTI radar, not only because of better clutter rejection, but also because the threshold device eliminates many of the unwanted false alarms due to noise. The frequency-response characteristic of the range-gated **MTI** appears as in Fig. 13. The shape of the rejection band is determined primarily by the shape of the band pass filter of **Fig. 12**.

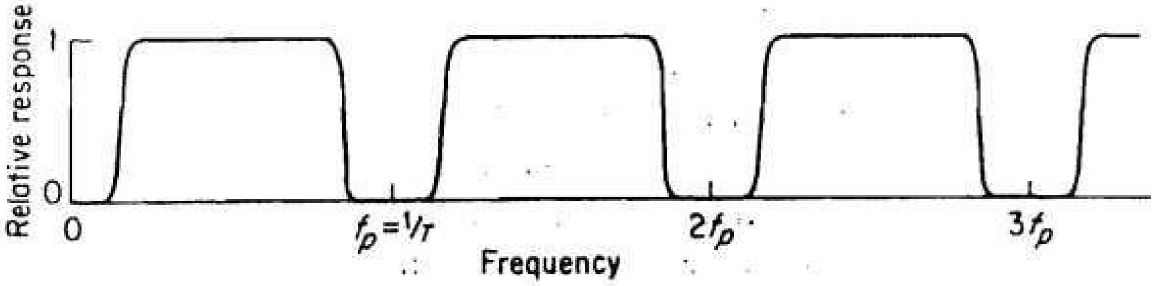

Figure 13: Frequency-response characteristic of an MTI using range gates and filters.

Limitations to MTI Performance:

The improvement in signal-to-clutter ratio of an MTI is affected by factors other than the design of the Doppler signal processor such as:

- Instabilities of the transmitter and receiver
- physical motions of the clutter
- Finite time on target (or scanning modulation)

Before discussing these limitations, we shall study the related definitions.

Definitions related to MTI Performance:

MTI improvement factor: The signal-to-clutter ratio at the output of the MTI system divided by the signal-to-clutter ratio at the input, averaged uniformly over all target radial velocities of interest.

Sub clutter visibility: The ratio by which the target echo power may be weaker than the coincident clutter echo power and still be detected with specified detection and false alarm probabilities.A sub clutter visibility of, for example, 30 dB implies that a moving target can be detected in the presence of clutter even though the clutter echo power is 1000 times the target echo power. Two radars with the same sub clutter visibility might not have the same ability to detect targets in clutter if the resolution cell of one is greater than the other and accepts a greater clutter signal power. i.e., both radars might reduce the clutter power equally, but one starts with greater clutter power because its resolution cell is greater and "sees" more clutter targets.

Clutter visibility factor: The signal-to-clutter ratio, after cancellation or Doppler filtering that provides stated probabilities of detection and false alarm.

The improvement factor (I): Is equal to the sub clutter visibility **(SCV)** times the clutter visibility factor **(V_{OC}).** In decibels, **I(dB) = SCV(dB) + Voc(dB).** When the MTI is limited by noise like system instabilities, the clutter visibility factor should be chosen as is the signal to noise ratio as defined in Radar Equation.

Limitations:

Equipment instabilities: Pulse-to-pulse changes in the amplitude, frequency, or phase of the transmitter signal, changes in the ***Stalo*** or ***Coho*** oscillators in the receiver, jitter in the timing of the pulse transmission, variations in the time delay through the delay lines, and changes in the pulse width can cause the apparent frequency spectrum from perfectly stationary clutter to broaden and thereby lower the improvement factor of an MTI radar. The stability of the equipment in MTI radar must be considerably better than that of an ordinary radar. It can limit the performance of MTI radar if sufficient care is not taken in design, construction, and maintenance.

Internal fluctuation of clutter: Although clutter targets such as buildings, water towers, bare hills or mountains produce echo signals that are constant in both phase and amplitude as a function of time, there are many types of clutter that cannot be considered as absolutely stationary. Echoes from trees, vegetation, sea, rain, and chaff fluctuate with time, and these fluctuations can limit the performance of MTI radar. Because of its varied nature, it is difficult to describe precisely the clutter echo signal.

Antenna scanning modulation: As the antenna scans by a target, it observes the target for a finite time equal to : $t_o = n_B / f_P = \theta_B / \theta'_S$ where n_B = number of hits received, f_p = pulse repetition frequency, θ_B = antenna beam width and θ'_S = antenna scanning rate. The received pulse train of finite duration t_o has a frequency spectrum (which can be found by taking the Fourier transform of the waveform) whose width is proportional to $1/t_o$. Therefore, even if the clutter were perfectly stationary, there will still be a finite width to the clutter spectrum because of the finite time on target. If the clutter spectrum is too wide because the observation time is too short, it will affect the improvement factor. This limitation has sometimes been called ***scanning fluctuations or scanning modulation*****.**

Pulse Doppler Radar Vs MTI :

A Pulse radar that extracts the Doppler frequency shift for the purpose of detecting moving targets in the presence of clutter is either a **MTI Radar** or a **Pulse Doppler Radar.** The distinction between them is based on the fact that in a sampled measurement system like a pulse Radar, ambiguities arise in measuring both the Doppler frequency (relative velocity) and the Range (time delay). Range ambiguities are avoided with a **low** sampling rate (low pulse repetition frequency), and Doppler frequency ambiguities are avoided with a **high** sampling rate. However, in most radar applications the sampling rate, or pulse repetition frequency, cannot be selected to avoid both types of measurement ambiguities. Therefore, a compromise must be made and the nature of the compromise generally determines whether the radar is called an **MTI** or a **Pulse Doppler Radar**.

- MTI usually refers to a Radar in which the pulse repetition frequency is chosen low enough to avoid ambiguities in range (no multiple-time-around echoes) but with the consequence that the frequency measurement is ambiguous and results in blind speeds, **Eq.** (4.8).
- The pulse Doppler radar, on the other hand, has a high pulse repetition frequency that avoids blind speeds, but it experiences ambiguities in range.

Previous Years' Examination Questions:

1. Explain the following limitations of MTI radar.
   (a) Equipment instabilities.
   (b) Scanning modulation.
   (c) Internal fluctuation of clutter.
2. (a) Explain the function of time domain filter in a MTI Radar with an example.
   (b) A MTI radar operates at 10GHz with a PRF of 300 pps. Calculate the lowest blind speed?
3. (a) An MTI radar is operated at 9GHz with a PRF of 3000 pps. Calculate the first two lowest blind speeds for this radar. Derive the formula used.
   (b) Discuss the limitations of non-coherent MTI Radar systems. [12+4]
4. (a) Write the description of Range gated Doppler filters.
   (b) Explain the operation of MTI radar with 2 pulse repetition frequencies. [8+8]
5. (a) Draw and explain the frequency response characteristics of a MTI using Range gates and filters.
   (b) A MTI Radar operates at frequency of 6Ghz with a PRF of 800 PPS . Calculate the lowest blind speeds of this Radar.
6. (a) Compare and contrast the situations with a Power amplifier and Power oscillator in the transmitter of a MTI system.
   (b) Calculate the blind speed for a Radar with the following specifications: Wave length: 0.1 mtr and PRF : 200 Hz
7. (a) Description of Range gated Doppler filters.
   (b) Differentiate blind phases from blind speeds.
   (c) Discuss the application of electrostatic storage tubes in MTI radar. [6+5+5]
8. (a) Briefly explain about range – gated Doppler filters.

   (b) Describe the importance of double cancellation.

9. (a) Compare MTI Radar with Pulse Doppler radar

   (b) Explain the function of a single delay line canceller and derive an expression for the frequency response function.
10. (a) What is an MTI Radar and how does it operate.
    (b) Define blind speed. A MTI radar operates at 5 Ghz with a PRF of 100PPS. Find the three lowest blind speeds of this Radar. Explain the importance of Staggered PRF. (8+7)