1. What is the principle of MTI radar?

The radar which uses the concept of Doppler frequency shift for distinguishing desired moving targets from stationary objects i.e., clutter is called as MTI radar (Moving Target Indicator).

The block diagram of MTI radar employing a power amplifier is shown in Fig. 5.1. The significant difference between this MTI configuration and that of Pulse Doppler radar is the manner in which the reference signal is generated. In Fig. 5.1, 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 $f_c$ is also mixed with the local-oscillator frequency $f_l$. The local oscillator must also 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 signal, just as in the conventional superheterodyne receiver. The stalo, coho, and the mixer in which they are combined plus any low-level amplification are called the receiver-exciter because of the dual role they serve in both the receiver and the transmitter.

Fig 5.1 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 diagramed in Fig. 4.5 by generating the transmitted signal from the cohø 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 cohø and the IF echo signal are both fed into a mixer called the pulse 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 a number of transmitting-tube types might be used as the power amplifier. These include the triode, tetrode, klystron, traveling-wave tube, and the crossed-field amplifier.

2. Explain the Butterfly effect that is produced by MTI.

![Butterfly effect diagram](image)

Fig. 5.2 (a-e) Successive sweeps of an MTI radar A-scope display (echo amplitude as a function of time); (f) superposition of many sweeps; arrows indicate position of moving targets.

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. 5.2(a). 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. (It may be possible to distinguish extended ground targets from point targets by the stretching of the echo pulse. However, this is not a reliable means of discriminating moving from fixed targets since some fixed targets can look like point targets, e.g., a water tower. Also, some moving targets such as aircraft flying in formation can look like extended targets.) Successive A-scope sweeps (pulse-repetition intervals) are shown in Fig. 5.2(b) 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. 5.2(J). The moving targets produce, with time, a butterfly effect on the A-scope.

3. Write about delay line canceler.

The simple MTI delay-line canceler shown in Fig. 5.3 is an example of a time-domain filter. The capability of this device depends on the quality of the medium used is 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 might 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 $10^{-5}$ 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.

![Fig 5.3 MTI receiver with delay-line canceler](image)

The early acoustic delay lines developed during World War II 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 supplanted in the early 1970’s 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.

4. **Explain in detail the Filter characteristics of the delay-line canceller.**

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 received from a particular target at a range \( R_0 \) is

\[
V_1 = k \sin(2\pi f_d t - \phi_0)
\]

Where, \( \phi_0 \) = phase shift

\( k \) = amplitude of video signal.

The signal from the previous transmission, which is delayed by a time \( T = \text{pulse repetition interval} \), is

\[
V_2 = k \sin(2\pi f_d (t - T) - \phi_0)
\]

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

\[
V = V_1 - V_2 = 2k \sin(\pi f_d T \cos[2\pi f_d (t - T / 2) - \phi_0])
\]

It is assumed that the gain through the delay-line canceller is unity. The output from the canceller \( V \) consists of a cosine wave at the doppler frequency \( f_d \) with an amplitude \( 2k \sin(\pi f_d T) \). 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, \( 2k \sin(\pi f_d T) \), to the amplitude of the normal radar video \( k \) is shown in Fig. 5.4.

![Fig 5.4 Frequency response of the single delay-line canceler; \( T = \text{delay time} = 1 / f_p \)](image)

GRIET-ECE
5. Write about 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 \( V = V_1 - V_2 = 2k \sin \pi f_d T \cos [2\pi f_d (t - T / 2) - \phi_0] \) is 0, \( \pi \), 2\( \pi \), .., etc., or when

\[
\frac{f_d}{T} = n = n f_p
\]

where,

\( n = 0, 1, 2, \ldots \),

\( f_p = \) 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

\[
v_n = \frac{n\lambda}{2T} = \frac{n\lambda f_p}{2} \quad n = 1, 2, 3, \ldots
\]

where

\( v_n \) is the \( n \)th blind speed.

If \( \lambda \) is measured in meters, \( f_p \) in Hz, and the relative velocity in knots, the blind speeds are

\[
v_n = \frac{n\lambda f_p}{1.02} \approx n\lambda f_p
\]

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 \( \lambda f_p \) must be large. Thus the MTI radar must operate at long wavelengths (low frequencies) or with high pulse repetition frequencies.

In Fig. 5.5, the first blind speed \( v_1 \) is plotted as a function of the maximum unambiguous range \( R_{\text{unamb}} = cT / 2 \), with radar frequency as the parameter. If the first blind speed were 600 knots, the maximum unambiguous range would be 130 nautical miles at a frequency of 300 MHz (UHF).
6. Explain about Double delay line canceller and three pulse canceller.

The frequency response of a single-delay-line canceller does not always have as broad a clutter-rejection null as might be 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. 5.6.1. 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 $4 \sin^2 \frac{\pi f}{T}$. The configuration of Fig. 5.6.1 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. 5.6.2. The finite width of the clutter spectrum is also shown in this figure so as to illustrate the additional cancellation of clutter offered by the double canceller.

The two-delay-line configuration of Fig. 5.6.1 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 two pulse periods previous. The output of the adder is therefore

$$f(t) - 2f(t + T) + f(t + 2T)$$
7. Explain about Transversal filters.

The three-pulse canceller is an example of a transversal filter. Its general form with \( N \) pulses and \( N - 1 \) delay lines is shown in Fig. 5.7. It is also sometimes known as a feed forward filter, a non recursive filter, a finite memory filter or a tapped delay-line filter. The weights \( w_i \) for a three-pulse canceller utilizing two delay lines arranged as a transversal filter are 1, -2, 1. The frequency response function is proportional to \( \sin^2 \left( \frac{\pi f_d}{T} \right) \). A transversal filter with three delay lines whose weights are 1, -3, 3, -1 gives a \( \sin^3 \left( \frac{\pi f_d}{T} \right) \) response. This is a four-pulse canceller. Its response is equivalent to a triple canceller consisting of a cascade of three single delay-line cancelers. Note the potentially confusing nomenclature. A cascade
configuration of three delay line's, each connected as a single canceler, is called a triple canceler, but when connected as a transversal filter it is called a four-pulse canceler.

The weights for a transversal filter with n delay lines that gives a response \( \sin^n \pi f_d T \) are the coefficients of the expansion of \((1 - x)^n\), which are the binomial coefficients with alternating signs

\[
w_i = (-1)^{i-1} \frac{n!}{(n - i + 1)! (i - 1)!}, \quad i = 1, 2, \ldots, n + 1
\]

Fig 5.7 General form of a transversal (or non recursive) filter for MTI signal processing

8. Draw the block diagram of MTI radar using range gates and filters and explain.

The block diagram of the video of an MTI radar with multiple range gates followed by clutter-rejection filters is shown in Fig. 5.8. 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 bandpass filter whose bandwidth depends upon the extent of the expected clutter spectrum.
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 might appear as in Fig. 5.8.1. The shape of the rejection band is determined primarily by the shape of the bandpass filter of Fig. 5.8.
9. Draw the block diagram of a non coherent MTI radar and explain.

The composite echo signal from a moving target and clutter fluctuates in both phase and amplitude. The coherent MTI and the pulse-doppler radar make use of the phase fluctuations in the echo signal to recognize the doppler component produced by a moving target. In these systems, amplitude fluctuations are removed by the phase detector. The operation of this type of radar, which may be called coherent MTI, depends upon a reference signal at the radar receiver that is coherent with the transmitted signal.

It is also possible to use the amplitude fluctuations to recognize the doppler component produced by a moving target. MTI radar which uses amplitude instead of phase fluctuations is called noncoherent. It has also been called externally coherent, which is a more descriptive name. The noncoherent MTI radar does not require an internal coherent reference signal or a phase detector as does the coherent form of MTI. Amplitude limiting cannot be employed in the noncoherent MTI receiver, else the desired amplitude fluctuations would be lost. Therefore the IF amplifier must be linear, or if a large dynamic range is required, it can be logarithmic.

The detector following the IF amplifier is a conventional amplitude detector. The phase detector is not used since phase information is of no interest to the noncoherent radar. The local oscillator of the noncoherent radar does not have to be as frequency-stable as in the coherent MTI.
The output of the amplitude detector is followed by an MTI processor such as a delay-line canceler. The doppler component contained in the amplitude fluctuations may also be detected by applying the output of the amplitude detector to an A-scope.

The advantage of the noncoherent MTI is its simplicity; hence it is attractive for those applications where space and weight are limited. Its chief limitation is that the target must be in the presence of relatively large clutter signals if moving-target detection is to take place. Clutter echoes may not always be present over the range at which detection is desired.

10. Explain the following limitations of MTI radar.

1. Equipment instabilities.
2. Scanning modulation.

1. Equipment instabilities:

Pulse-to-pulse changes in the amplitude, frequency, or phase of the transmitted 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 an MTI radar must be considerably better than that of an ordinary radar. It can limit the performance of the MTI radar if sufficient care is not taken in design, construction, and maintenance.

Consider the effect of phase variations in an oscillator. If the echo from stationary clutter on the first pulse is represented by $A \cos \omega t$ and from the second pulse is $A \cos (\omega t + \Delta \phi)$ where $\Delta \phi$ is the change in oscillator phase between the two, then the difference between the two after subtraction is

$$A \cos \omega t - A \cos (\omega t + \Delta \phi) = 2A \sin (\Delta \phi/2) \sin (\omega t + \Delta \phi/2).$$

For small phase errors, the amplitude of the resultant difference is $2A \sin \Delta \phi/2 \approx A \Delta \phi$.

Therefore the limitation on the improvement factor due to oscillator instability is

$$I = 1 / \Delta \phi^2$$

2. Scanning modulation:

As the antenna scans by a target, it observes the target for a finite time equal to

$$t_0 = n_B / f_p = \theta_B / \theta_S$$

where,
$$n_B = \text{number of hits received},$$

$$f_p = \text{pulse repetition frequency},$$

$$\theta_B = \text{antenna beamwidth and}$$

$$\theta_S = \text{antenna scanning rate.}$$

The received pulse train of finite duration to has a frequency spectrum (which can be found by taking the Fourier transform of the waveform) whose width is proportional to $1/t_0$. 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.

11. Explain about staggered pulse repetition frequencies.

The pulse repetition frequency in which the switching is pulse to pulse is known as staggered PRF.

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 but it also allows a sharper low-frequency cutoff in the frequency response than might be obtained with a cascade of single-delay-line cancelers 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 would be 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 beamwidth, 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. 5.11. 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. 5.11, the blind speeds are coincident for

$$4/T_1 = 5/T_2.$$
Fig 5.11 (a) Frequency-response of a single-delay-line canceler for \( f_p = 1/T_1 \); (b) same for \( f_p = 1/T_2 \) (c) composite response with \( 4/T_1 = 5/T_2 \).

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 \( f_d = l/T_1 \) 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 pass band. The depth of the nulls can be reduced and the first blind speed increased by operating with more than two interpulse periods.

A disadvantage of the staggered prf is its inability to cancel second-time-around clutter echoes. Such clutter does not appear at the same range from pulse to pulse and thus produces uncanceled residue. Second-time-around clutter echoes can be removed by use of a constant prf, providing there is pulse-to-pulse coherence as in the power amplifier form of MTI.