MTI AND PULSE DOPPLER RADAR

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Introduction

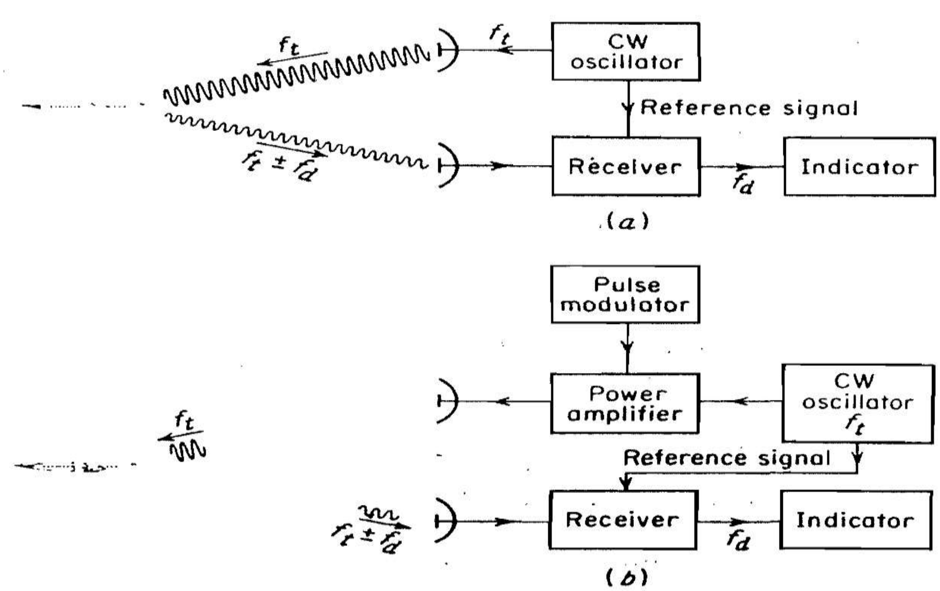
- The Doppler frequency shift [$f_d = 2V_r / \lambda$] produced by a moving target also used in a pulse radar just as in the CW radar, to determine the relative velocity of a target or to separate desired moving targets from undesired stationary objects (clutter).
- Pulse radar that utilizes the Doppler 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 around echoes).
- 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 range ambiguities.
- The discussion in this chapter, mostly is based on the **MTI Radar**, but much of what applies to MTI can be extended to **Pulse Doppler Radar** as well.

- **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.
- The basic MTI concepts were introduced during World War 2, and most of the signal processing theory on which **MTI** (and **pulse Doppler**) radar depends was formulated during the mid-1950s.
- However, the implementation of theory to practice was speeded up only subsequently after the availability of the necessary signal-processing technology.
- 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)**.** It consists of a transmitter, receiver, indicator, and the necessary antennas.
- In principle, the CW radar 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.
- this CW signal also 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**.

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



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

Then the reference signal is: $\mathbf{V_{ref} = A_2 \sin 2\pi f_t t}$ **.......... (1)**

- And the Doppler-shifted echo-signal voltage is:

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

Where $\mathbf{A_2}$ = amplitude of reference signal

$\mathbf{A_3}$ = amplitude of signal received from a target at a range R_0

$\mathbf{f_d}$ = 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:

$$V_{diff} = A_4 \sin\left(2\pi f_d t - \frac{4\pi f_t R_0}{c}\right) \qquad ....(3)$$

- Note that the equations **(1) to (3)** above represent sine wave carriers upon which the pulse modulation is imposed.
- For stationary targets the Doppler frequency shift will be zero and hence $\mathbf{V_{diff}}$ will not vary with time and may take on any constant value from $\mathbf{+A_4}$ **to** $\mathbf{-A_4}$ including zero.
- However, when the target is in motion relative to the radar $\mathbf{f_d}$ 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 $\mathbf{f_d}$ is large compared with the reciprocal of the pulse width is shown in **Fig.2(b).**
- If, on the other hand $\mathbf{f_d}$ 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.

- The video signals shown in Fig.**2** are called **bipolar**, since they contain both positive and negative amplitudes.

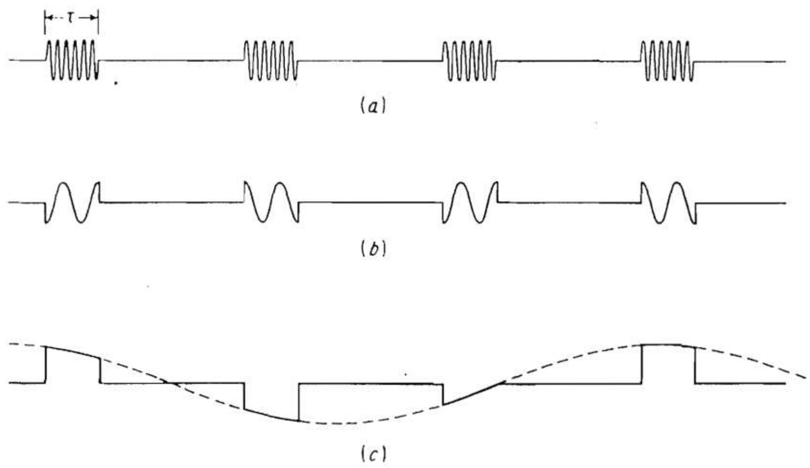


Figure 2 (a) RF or IFecho pulse train (b) video pulse train for Doppler frequency f_d>I/τ (c) video pulse train for Doppler frequency f_d< I/τ .

- 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.
- 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.

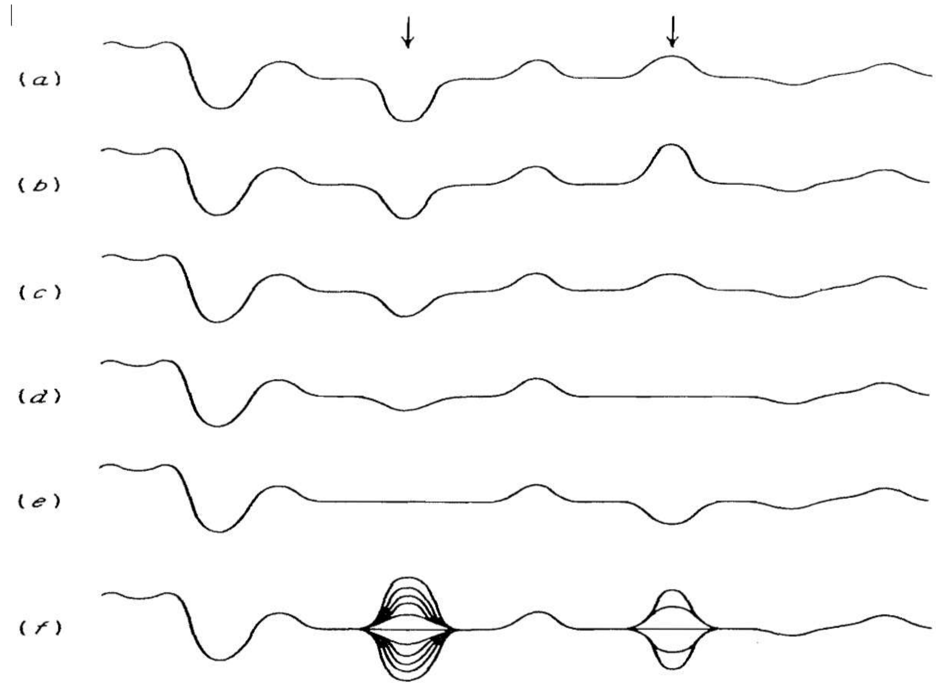


Figure 3 (a-e) Successive sweeps of a MTI radar A-scope display (echo amplitude as a function of time) (f) superposition of many sweeps : arrows indicate position of moving targets.

Delay-line canceler

- 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 canceler.
- The delay-line canceler 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 uncanceled 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 must be converted into unipotential voltages (unipolar video) by a full-wave rectifier.

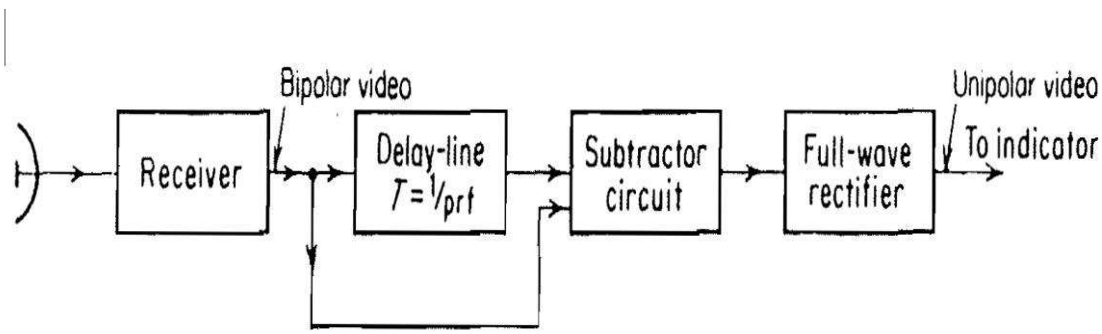
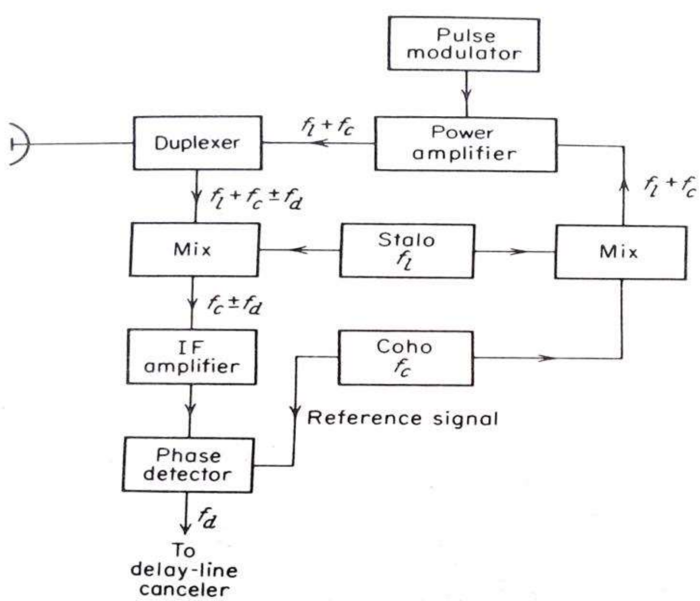


Figure 4 : MTI Receiver with delay-line canceler

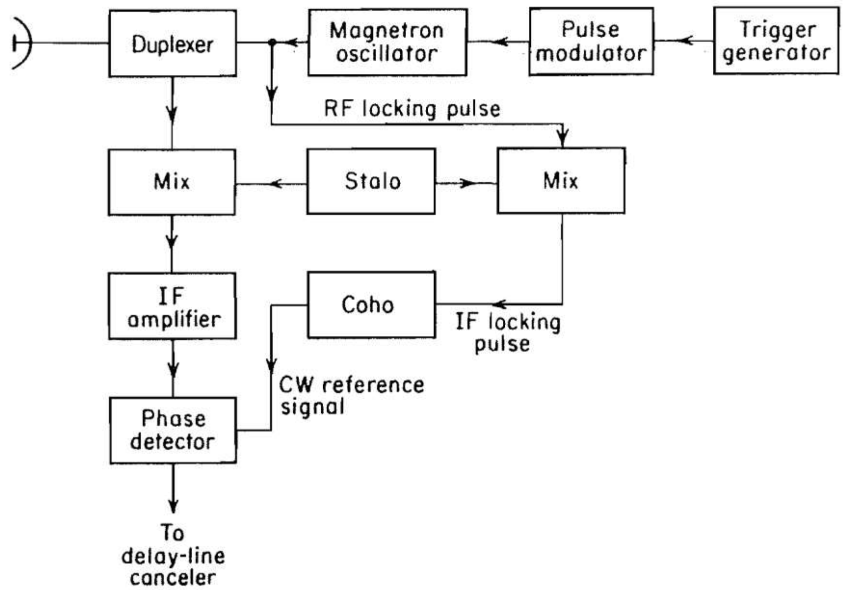
MTI Radar with Power Amplifier



- 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 above.
- The significant difference between this MTI configuration and that of **Fig. 1(b)** is the manner in which the reference signal is generated.
- In this diagram, 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 $\mathbf{f_l}$. This local oscillator also must be a stable oscillator and is called **stalo,** stands 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.

- 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 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.
- 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 available at microwave frequencies for radar application was the magnetron oscillator.
- In an 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.
- A block diagram of an MTI radar (with a power oscillator) is shown in below slide.
- **A** portion of the transmitted signal is mixed with the **stalo** output to produce an **IF** beat signal whose phase is directly related to the phase of the transmitter.
- This IF pulse is applied to the **coho** and causes the phase of the **coho** CW oscillation to "lock" in step with the phase of the IF reference pulse.
- The phase of the **coho** is then related to the phase of the transmitted phase and may be used as the reference signal for echoes received from that particular transmitted pulse.
- Upon the next transmission, another **IF** locking pulse is generated to relock the phase of the CW **coho** until the next locking pulse comes along.

Delay-line canceler

- The simple MTI delay-line canceller shown earlier is an example of a time-domain filter.
- The capability of this device depends on the quality of the medium used as the delay line. The 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 **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 themid-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.
- 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 canceler 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 R_0 is

$$V_1 = k \sin(2\pi f_d t - \emptyset_0) \qquad \text{.........................4}$$

where Ø_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

$$V_2 = k \sin [2\pi f_d(t - T) - \text{Ø}_0) \quad \text{---------------} \; 5$$

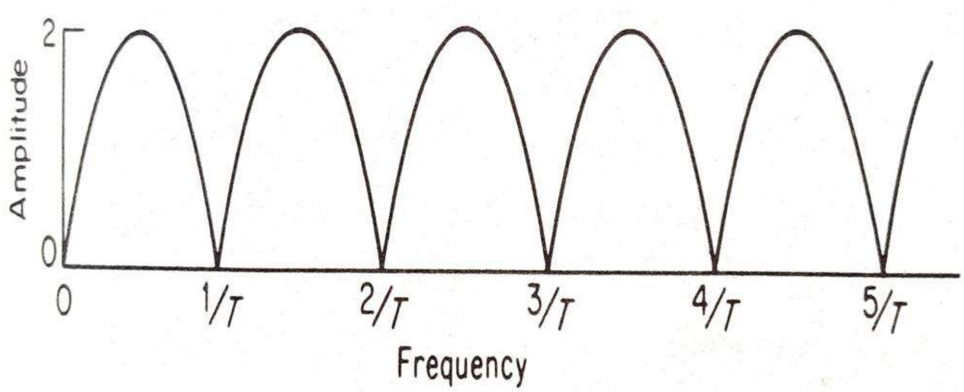
- The output from the subtractor is

$$V = V_1 - V_2 = 2k \sin(\pi f_d T) \cos [2 \pi f_d(t - T/2) - \text{Ø}o] \qquad \text{-------------} \; 6$$

$$\sin a \pm \sin b = 2 \sin \{1/2 (a \pm b)\} \cos \{1/2 (a \mp b)\}$$

- It is assumed that the gain through the delay-line canceller is unity. The output from the canceller consists of a cosine wave at the Doppler frequency & 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 below.

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

$$f_d = \frac{n}{T} = nf_p \qquad \text{.......... (7)}$$

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

$$v_n = \frac{n\lambda}{2T} = \frac{n\lambda f_p}{2} \qquad n = 1, 2, 3, \ldots \qquad \text{......... (8)}$$

- where v_n is the n^{th} blind speed. If λ is measured in meters, f_p in Hz, and the relative velocity in knots, the blind speeds are :

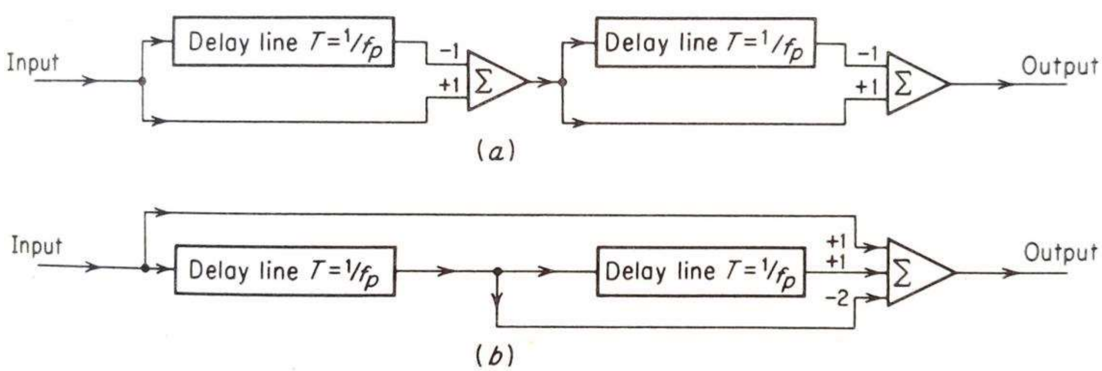
$$v_n = \frac{n\lambda f_p}{1.02} \approx n\lambda f_p \qquad \text{--------------(9)}$$

- 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.
- Based on eq **9** there are four methods for reducing the determental effects of blind speeds:
  1. Operate the radar at long wavelengths
  2. Operate with a high pulse repetition frequency
  3. Operate with more that one PRF (Staggered prf's)
  4. Operate with more than one RF frequency
- Unfortunately, there are usually constraints other than blind speeds which determine the wavelength and the pulse repetition frequency. Therefore, blind speeds might not be easy to avoid.
- The possible solution for the blind speed is keep the first blind speed out of the expected range of Doppler frequency

Double cancellation

- The frequency response of a single-delay-line canceller (Fig. **7)** 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. (9) 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 **(** $\mathbf{4 \sin^2 \pi f_d T}$ **)**.
- The configuration of **Fig. 9 (a)** 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. **10.**
- 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.**9 (b)** has the same frequency-response characteristic as the double-delay-line canceller.

Figure 9 : (a) Double-delay-line canceller (b) three-pulse canceller



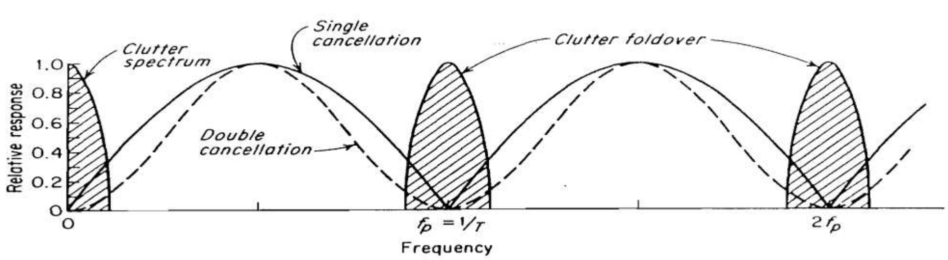


Figure (10): Relative frequency response of the single-delay-line canceller (solid curve) and the double delay-line canceller (dashed curve). Shaded area represents clutter spectrum.

- 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.

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 **,** but it also allows a sharper low-frequency cutoff in the frequency 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 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 below.

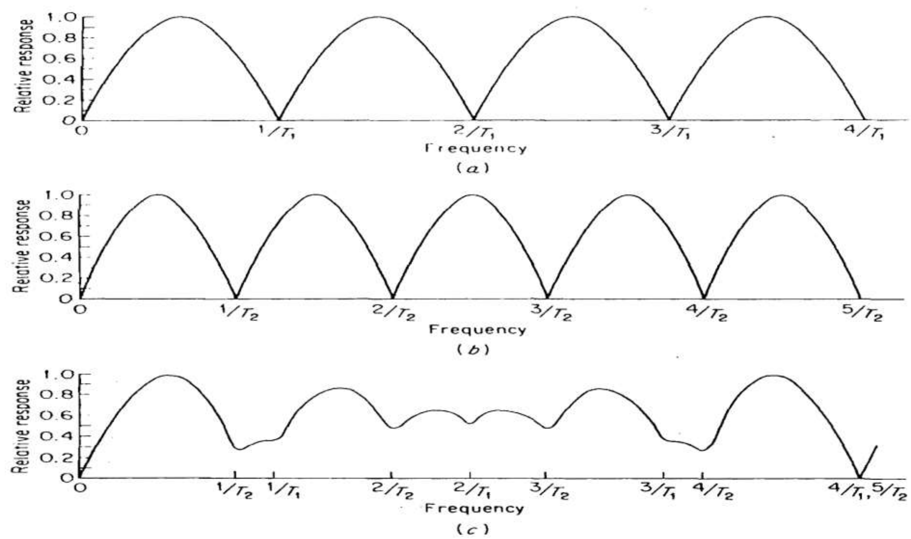
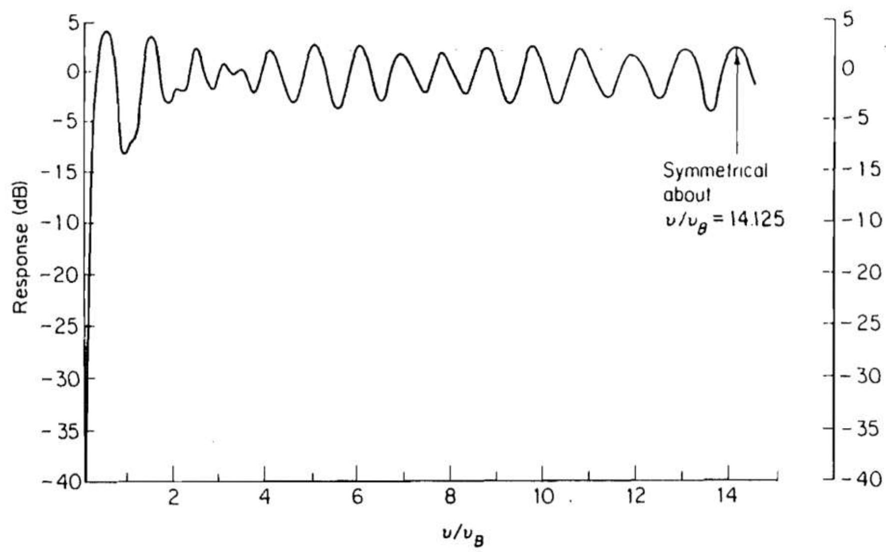


Figure : Frequency-response of a single-delay-line canceller for f_P= 1/T_1 (b) same for f_p= l/T_2 (c) Composite response with T_1/T_2= 4/5.

- Zero frequency response occurs only when the blind speeds of both radars coincides.
- The disadvantage is that the region of low sensitivity might appear. (that means may not detect the weak signals)
- As closer the ration of T1:T2 is unity, the lower the lower the value of the first blind speed.
- But first null in the vicinity of fd=1/T1 becomes deeper.

- Figure below shows the response of a five-pulse stagger (four periods) that might be used with a long-range air traffic control radar.

Figure 12: Frequency response of a five-pulse (four-period) stagger.



- If the periods of the staggered waveforms have the relationship $\mathbf{n_1/T_1 = n_2/T_2} =$ ……. $= \mathbf{n_N/T_N}$, where $\mathbf{n_1, n_2, ..., n_N}$ 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 $T_{av} = (T_1 + T_2 + ... T_N)/N$ then the first blind speed $\mathbf{v_1}$ is given by :

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

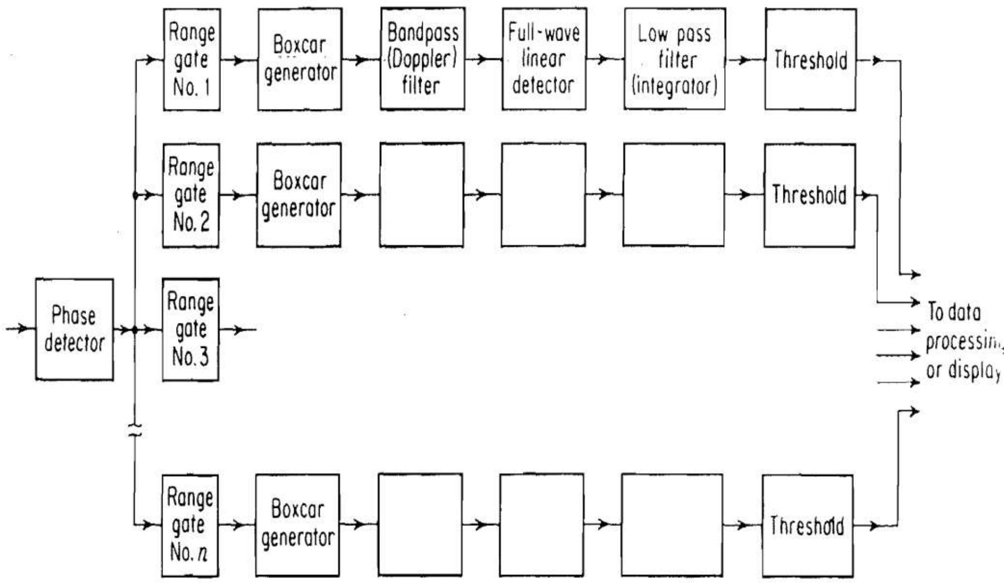
- A disadvantage of the staggered prf is its inability to cancel second-time-around clutter echoes. Such clutter does not appear at the same range from pulse to pulse and thus produces un canceled residue.
- Second-time-around clutter echoes can be removed by use of a constant prf, providing there is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

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.
- However the filter configuration would be more complex, than the single, narrow-band pass filter.
- 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. (This Loss Results When Radar Integrates Additional Noise Samples Along with Wanted (S/N) Pulses)

- 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.
- A collapsing loss does not take place since noise from the other range intervals is excluded.

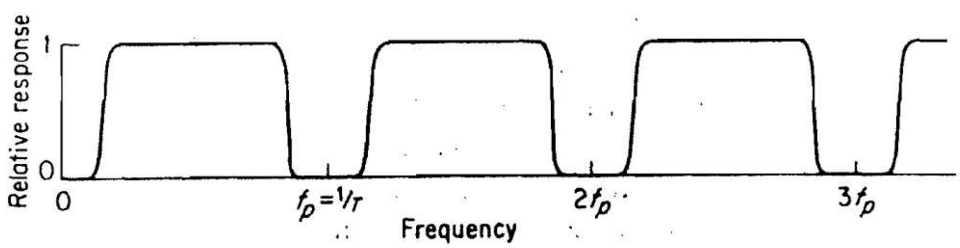
Figure 13: Block diagram of MTI radar using range gates and filters



- A block diagram of the video of an MTI radar with multiple range gates followed by clutter-rejection filters is shown 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 low.
- 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.
- 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.

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



The band pass filter can be designed with a variable low-frequency cutoff that can be selected to conform to the prevailing clutter conditions.

A variable lower cutoff might be advantageous when the width of the clutter spectrum changes with time as when the radar receives unwanted echoes from birds.

A relatively wide notch at zero frequency is needed to remove moving birds.

If the notch were set wide enough to remove the birds, it might be wider than necessary for ordinary clutter and desired targets might be removed.

Since the appearance of birds varies with the time of day and the season, it is important that the width of the notch be controlled according to the local conditions.

- MTI radar using range gates and filters is usually more complex than an MTI with a single-delay-line canceller.
- The additional complexity is justified in those applications where good MTI performance and the flexibility of the range gates and filter MTI are desired.
- The better MTI performance results from the better match between the clutter filter characteristic and the clutter spectrum.

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)
- And limiting in the receiver

- 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.

With respect to Doppler frequency, the Improvement factor can be expressed as:

$$I_f = (S/C)_{out} * (S/C)_{in} = \frac{C_{in}}{C_{out}} G_{av}$$

C_{in} = strength of clutter at clutter filter input
C_{out} = strength of clutter at clutter filter output
G_{av} = average filter gain for moving targets

Subclutter Visibility (SCV):

It describes the radar's ability to detect non-stationary targets embedded in a strong clutter background with a given signal-to-clutter ratio (SCR), for some specified probabilities of detection and false alarm. It is often used as a measure of the effectiveness of moving-target indicator radar, equal to the ratio of the signal from a fixed target that can be canceled to the signal from a just visible moving target.

The subclutter visibility is expressed as the ratio of the improvement factor to the minimum MTI output given signal-to-clutter ratio (SCR) required for proper detection for a given probability of detection.

$$SCV = \frac{I_f}{(SCR)_{out}}$$

SCV = Sub-Clutter Visibility SCR = Signal-to-Clutter Ratio

Interclutter visibility(ICV)

If a radar system can resolve the areas of strong and weak clutter within its field of view, then the phrase Interclutter visibility (ICV) describes the ability to recognize the moving target which occur in clear resolution cells between strong clutter patches.

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

Clutter attenuation: The ratio of clutter power at the canceller input to the clutter residue at the output, normalized to the attenuation of a single pulse passing through the unprocessed channel of the canceller. (The clutter residue is the clutter power remaining at the output of a MTI system.)

Cancellation ratio: The ratio of canceller voltage amplification for the fixed-target echoes received with a fixed antenna, to the gain for a single pulse passing through the unprocessed channel of the canceller.

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 fluctuate with time, and these fluctuations can limit the performance of MTI radar.

Antenna scanning modulation

- As the antenna scans by a target, it observes the target for a finite time equal to : $\mathbf{t_o=n_B/f_P = \theta_B / \theta_S}$ where $\mathbf{n_B}$= number of hits received, fp = pulse repetition frequency, $\mathbf{\theta_B}$,$\mathbf{\theta_S}$ = antenna beamwidth and antenna scanning rate.
- The received pulse train of finite duration $\mathbf{t_o}$ has a frequency spectrum (which can be found by taking the Fourier transform of the waveform) whose width is proportional to l/to.
- 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.

Limiting in MTI Radar:

- A limiter is usually employed in the IF amplifier just before the MTI processor to prevent the residue from large clutter echoes from saturating the display. Ideally a MTI radar should reduce the clutter to a level comparable to receiver noise.

- However, when the ***MTI improvement factor*** is not great enough to reduce the clutter sufficiently, the clutter residue will appear on the display and prevent the detection of aircraft targets whose cross sections are larger than the clutter residue. This condition may be prevented by setting the limit level L, relative to the noise N, equal to the MTI improvement factor I; or L/N = I.

- If the limit level relative to noise is set higher than the improvement factor. Clutter residue obscures part of the display. If it is set too low, there may be a “black hole" effect on the display. The limiter provides a constant false alarm rate (CFAR) and is essential to usable MTI Performance.

- Unfortunately, nonlinear devices such as limiters have side-effects that can degrade performance. Limiters cause the spectrum of strong clutter to spread into the canceller pass- band, and result in the generation of additional residue that can significantly degrade MTI performance as compared with a perfect linear system.

Benefits or advantages of MTI Radar

- MTI radar can distinguish between moving target and stationary target.
- It uses low PRF (Pulse Repetition Frequency) to avoid range ambiguities.
- MTI principle is used in air surveillance radar which operates in presence of clutter.
- It is simpler compare to pulse doppler radar.
- Antenna bandwidth is high.
- It is economical.
- It does not require waveforms with multiple PRF.
- It is preferred at UHF frequencies.

Drawbacks or disadvantages of MTI Radar

- Blind speed does not get detected by pulse MTI radar. Blind speed is defined as magnitude of radial component of velocity of target when moving target appears as stationary target.
- They can have doppler ambiguities.

MTI VS PULSE DOPPLER RADAR

- 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.
- The pulse Doppler radar, on the other hand, has a high pulse repetition frequency that avoids blind speeds, but it experiences ambiguities in range.
- The pulse Doppler radar is more likely to use range-gated Doppler filter-banks than delay-line cancellers. Also, a power amplifier such as a klystron is more likely to be used than a power oscillator like the magnetron.
- A pulse Doppler radar operates at a higher duty cycle than does an MTI.
- Although it is difficult to generalize, the MTI radar seems to be the more widely used of the two, but pulse Doppler radar is usually more capable of reducing clutter.