

## NIT-3 MTI AND PULSE DOPPLER RADAR

### 3.1 INTRODUCTION

In the previous chapter we studied how doppler frequency shift can be used in continuous wave radars to determine relative velocity of a moving target or distinguish moving targets from stationary targets. In this chapter we shall show that the doppler frequency shift produced by a moving target may also be used in a pulse radar to determine the relative velocity of a target or to separate desired signals from moving targets and undesired signals from stationary objects (clutter).

Though the doppler frequency shift is sometimes used to measure relative velocity of a target using a pulse radar, its most interesting and widespread use has been in identifying small moving targets in the presence of large clutter. Such pulse radars which use the doppler frequency shift to distinguish (or discriminate) between moving and fixed targets are called MTI (Moving Target Indicators) and Pulse Doppler Radars. The physical principle of both these radars are the same but they differ in their mode of operation. For instance the MTI radar operates on low pulse repetition frequencies thus causing ambiguous Doppler measurements (blind speeds) but unambiguous range measurements (no second-time-around echoes). On the other hand the pulse doppler radar operates on high pulse repetition. frequency thus causing unambiguous doppler measurements (no blind speeds) but ambiguous range measurements (second-time-around echoes). The meaning of these terms will become clear later when we describe the actual operational principles of these radars.

Most of the discussion in this chapter will be restricted to MTI radars. These are high-quality air surveillance radars that operate in the presence of clutter.

### 3.2 DESCRIPTION OF OPERATION

In principle the CW radar can be converted to a pulse radar by providing a pulse modulator which turns on and off the amplifier to generate pulses. The output of this operation is shown in Fig..

The block diagram is almost self-explanatory. We need to note that there is no local oscillator here since the reference signal is supplied directly from the CW oscillator. Apart from this function the CW oscillator also supplies a coherent reference needed to detect the doppler frequency shift. By coherent we mean that the phase of the transmitted signal is preserved in the reference signal. This kind of reference signal is the distinguishing feature of a coherent MTI radar.

Let the CW oscillator voltage be

$$V_{osc} = A_1 \sin(2\pi f t)$$

The reference signal is

$$V_{ref} = A_2 \sin(2\pi f t)$$

The doppler-shifted echo-signal voltage is

$$V_{echo} = A_3 \sin \{ 2\pi(f \pm f_d)t - \frac{4\pi f_c t R_0}{c} \}$$

where,

$A_1$  = amplitude of oscillator voltage

$A_2$  = amplitude of reference signal

$A_3$  = amplitude of echo signal

$R_0$  = range (distance between radar and target)

$f_d$  = doppler frequency shift

$f_t$  = frequency of the transmitted carrier signal  $t$  = time

$c$  = velocity of propagation.

The reference signal and the target echo signal are heterodyned in the mixer stage. The difference frequency component is

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

For stationary targets the doppler frequency shift  $f_d$  will be zero; hence  $V_{diff}$  will not vary with time and may take on any constant value from  $+A_4$  to  $-A_4$ , including zero. But 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 will vary with time. Note that all these frequencies are with reference to the carrier waveform and has nothing to do with the pulse repetition frequency.

Fig.4.3(a) shows the reflected signal from the target. The frequency of this signal may have been changed due to the motion of the target. In Fig.4.3(b) the difference signal is shown in the presence of a moving target for the case when the resultant doppler frequency is such that  $f_d > 1/\tau$ , and in Fig. 4.3(c) for the case when  $f_d < 1/\tau$ , where  $\tau$  is the width of one pulse. When  $f_d > 1/\tau$ ,  $f_d$  can be easily found from the information contained in one pulse. whereas, when  $f_d < 1/\tau$  many pulses will be required to extract  $f_d$ . The difference signal is the output of the mixer and is also called the video output. If this video output is now displayed on an A-scope (amplitude vs. time or range) in successive sweeps. Note that the amplitude of the signals from stationary targets do not change with the number of sweeps. But the echo signals from moving targets will change in amplitude over successive sweeps according to Equation (4.4). When these sweeps are superposed over each other (Fig.4.4(f)), due to the effect of persistence of vision, the moving targets will produce signals which on the A-scope display will look like a butterfly opening and closing its wings. This kind of signal is not good enough for a PPI since the screen display will show bright patches for all stationary targets and spots of fluctuating brightness for moving targets. But what we actually require is doppler information regarding moving targets only. one method to extract this information is to employ delay-line cancellers. In this the current signal is delayed by one pulse time period (reciprocal of the pulse repetition frequency) and subtracted from the signal coming next. The effect is shown in Fig.4.5 below. Only the fluctuating signal from the moving target remains and the signals from the stationary targets are cancelled out. In the PPI, the positions of stationary targets will show dark patches and moving targets will show spots which periodically fluctuate in brightness. However, use of delay line cancellers cause problems of blind speeds. Note that the signal is delayed by one

pulse time period and then subtracted. Suppose the signal from the moving target fluctuates in such a way that the signal after this time delay is the same as the signal before this time delay. This will happen whenever  $f_d$  is a multiple of  $f_p$  (the pulse repetition frequency), that is,

$$f_d = nf_p, \quad n = 1, 2, \dots$$

When this happens the resultant signal after subtraction is Zero. Thus the radar fails to detect, or is blind to, the presence of such a moving target. Doppler frequency shifts  $f_d$  which cause this phenomenon are themselves caused by certain specific target velocities. Substituting the expression for doppler frequency in (4.5), we get,

$$f_d = nf_p = 2v_r / \lambda$$

From which we get

$$v_r = \frac{n\lambda f_p}{2} = \frac{n\lambda}{2T}, n = 1, 2, \dots$$

where, T is the pulse time period.

For a specific n this is called the n-th blind speed. Whenever the target relative velocity with respect to the radar along the line of sight matches with these speeds, an MTI radar fails to detect the moving target. Thus to avoid doppler ambiguities (due to blind speeds) the first blind speed must be larger than the maximum expected relative velocity of the target. This can be achieved by either making  $f_p$  large or by making  $\lambda$  large. So MTI radars should operate at long wavelengths (low carrier frequencies) or high pulse repetition frequencies, or both. But, unfortunately other constraint prevent this kind of choice. Too low radar frequencies make the beam-width wider and cause deterioration in angular resolution. Too high pulse repetition frequencies cause ambiguous range measurements.

As mentioned at the beginning of this chapter, MTI radars operate on low pulse repetition frequencies and thus are prone to blind speeds, but they do not have the problems of range ambiguities. On the other hand, pulse doppler radars operate at high pulse repetition frequencies and thus are affected by ambiguous range measurements. But they do not have the problem of blind speeds. MTI radars are usually used as high-resolution surveillance radars in airports. Pulse doppler radars are used for detection of high-speed extraterrestrial objects like satellites and astronomical bodies.

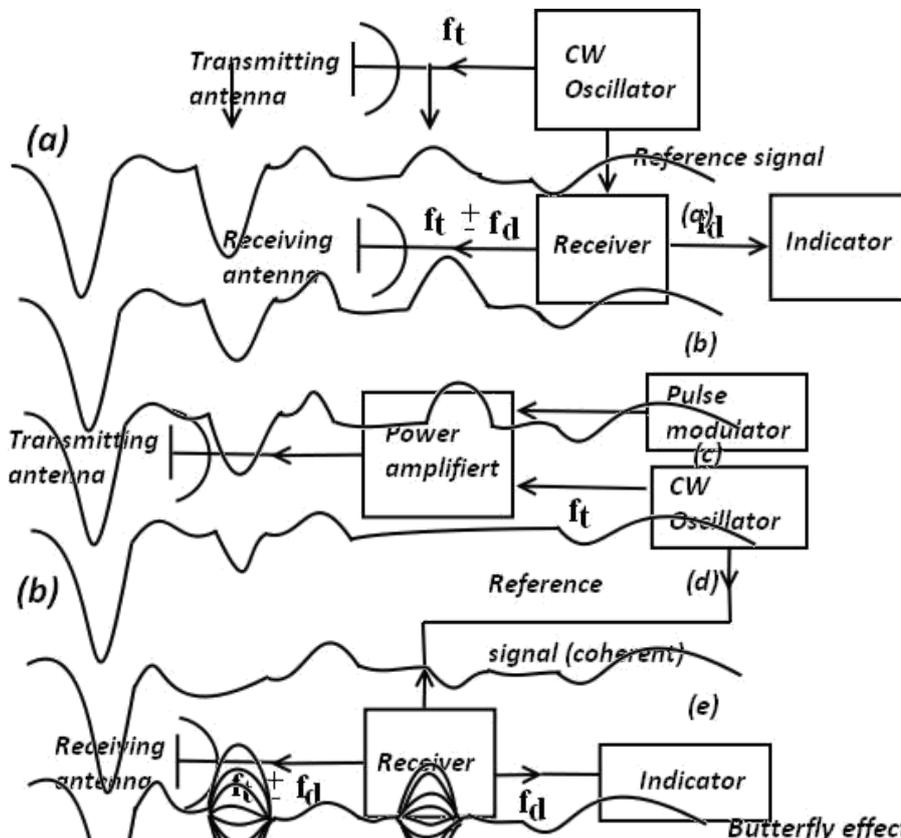


Figure: Block Diagram of (a) Simple CW Radar and (b) pulse radar using doppler information

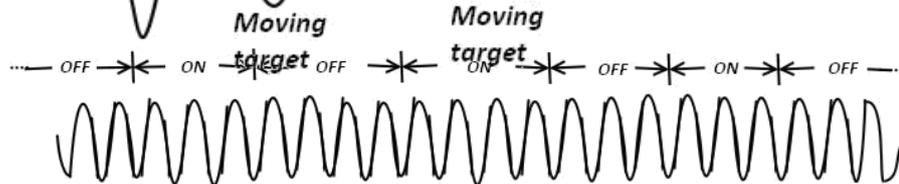


Figure: Pulse train generated from a continuous signal

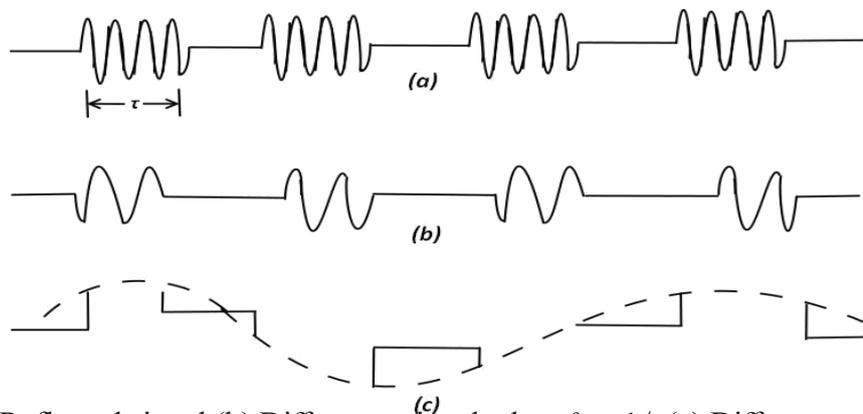


Figure: (a) Reflected signal (b) Difference signal when  $f_a > 1/\tau$  (c) Difference signal when  $f_a < 1/\tau$

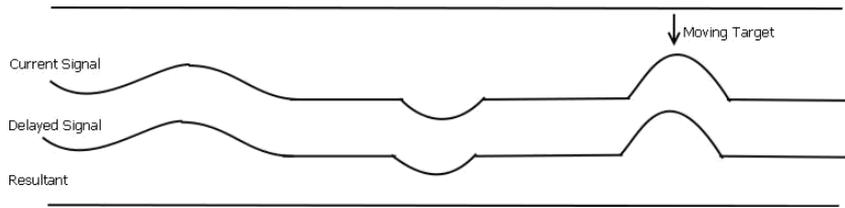


Figure: (a-e) Successive sweeps of an MTI Radar on an A-scope display and (f) supersposition of these signals (arrows indicate moving targets)

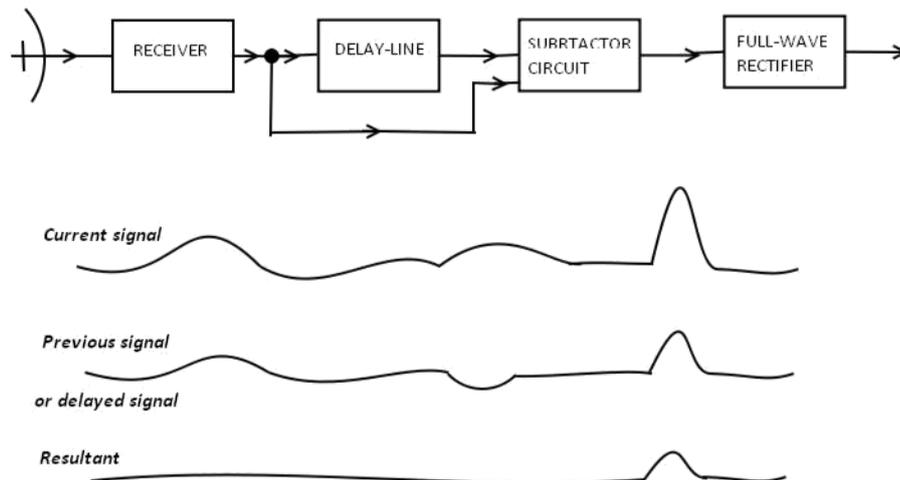
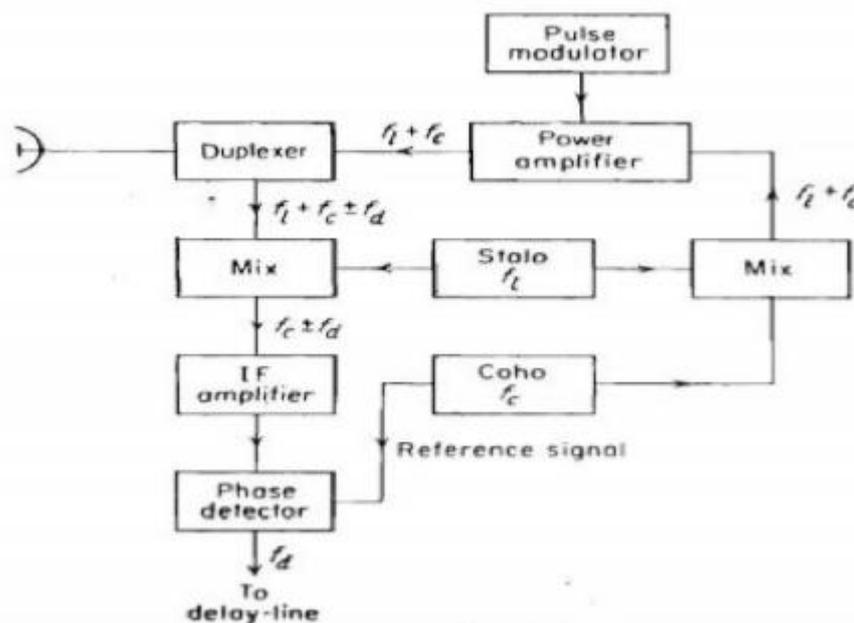


Figure: (a) Basic delay line canceller block diagram (b) Effect of delay line canceller on the signal

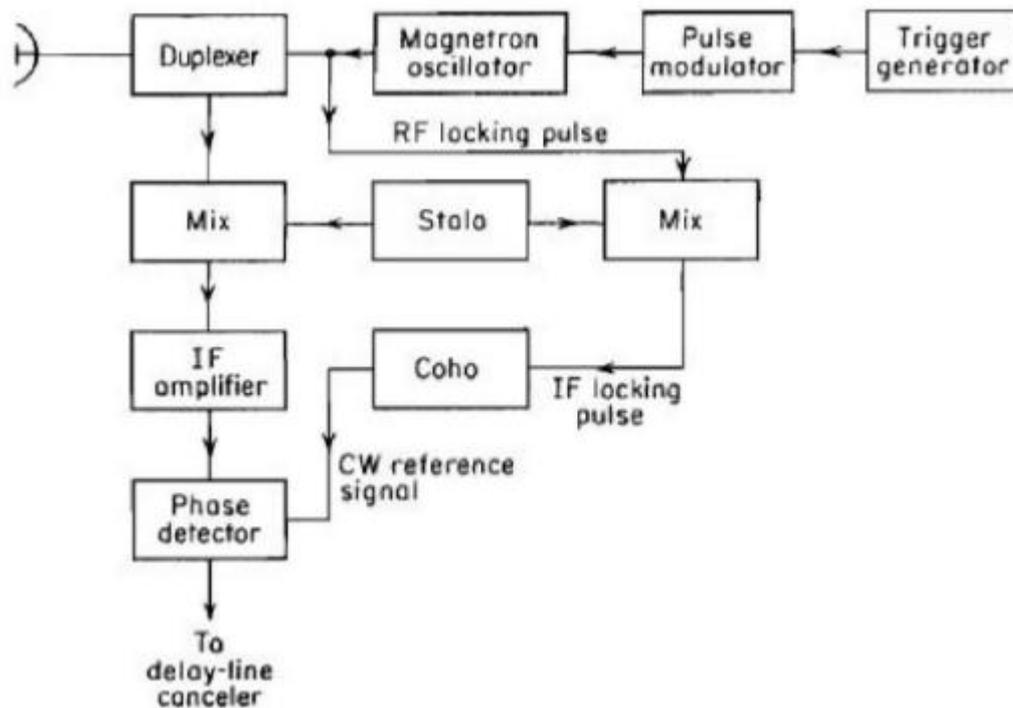
Figure: Effect of Blind speeds

### MTI RADAR WITH POWER AMPLIFIER TRANSMITTER

The block diagram of more common MTI radar employing a power amplifier is shown. The significant difference between this MTI configuration is the manner in which the reference signal is generated. The coherent reference is supplied by the 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. The local oscillator- must also have 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 conventional super heterodyne receiver.



Before the development of the klystron amplifier, the only high-power transmitter available at microwave frequencies for radar application was the magnetron oscillator. A block diagram of an MTI radar (with a power oscillator) is shown. 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 of the 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 pulse 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.



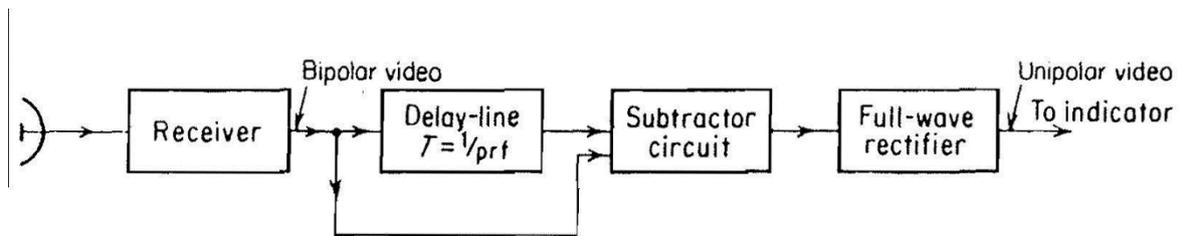
**DELAY-LINE CANCELERS** The simple MTI delay-line canceller The simple MTI delay-line canceller The capability of this device depends on the quality of the medium used in the delay line. The Pulse modulator delay line must introduce a time delay equal to the pulse repetition interval. For typical ground-based air-surveillance radars this 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 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 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 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 filterbanks 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.

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#### **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.  $V_1 = k \sin (2\pi f_d t - \phi_0)$

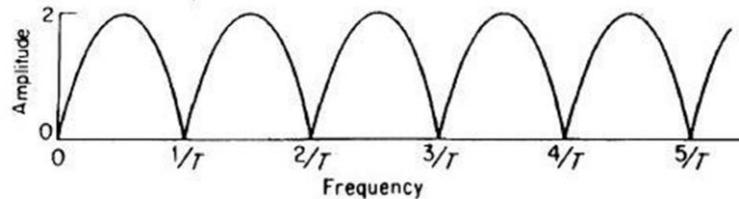
where  $\Phi_0$  = phase shift and k = amplitude of video signal. The signal from the previous transmission, which is delayed by a time T = pulse repetition interval, is

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

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

$$V = V_1 - V_2 = 2k \sin \pi f_d T \cos \left[ 2\pi f_d \left( t - \frac{T}{2} \right) - \phi_0 \right]$$

It is assumed that the gain through the delay-line canceller is unity. 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 canceler [ratio of the amplitude of the output from the delay-line canceler, to the amplitude of the normal radar video.



Frequency response of the single delay-line canceler;  $T = \text{delay time} = 1/f_p$

**Blind speeds:** The response of the single-delay-line canceller will be zero whenever the argument  $\pi f_d T$  in the amplitude factor. 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  $f_p R$  must be large. Thus the MTI radar must operate at long wavelengths (low frequencies) or with high pulse repetition frequencies, or both.

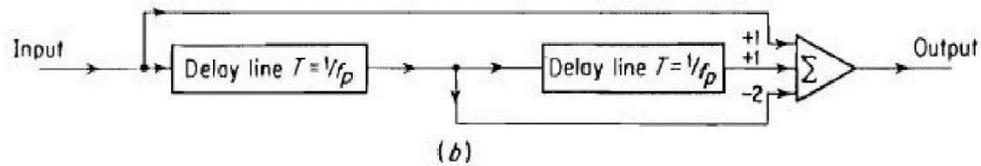
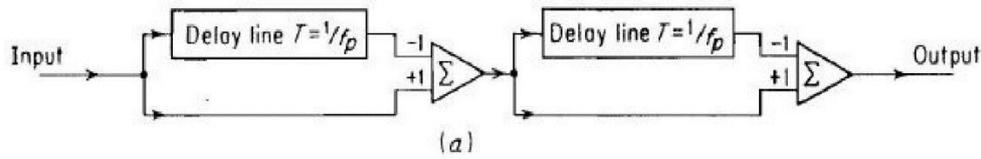
**Double cancellation:** The frequency response of a single-delay-line canceller does not always have as broad a clutter-rejection null as might be desired in the vicinity of d-c. The clutter-rejection notches may be widened by passing the output of the delay-line canceller through a second delay-line canceller. The output of the two single-delay line cancellers in cascade is the square of that from a single canceller.

The two-delay-line configuration 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  $f(t) - 2f(t + T) + f(t + 2T)$

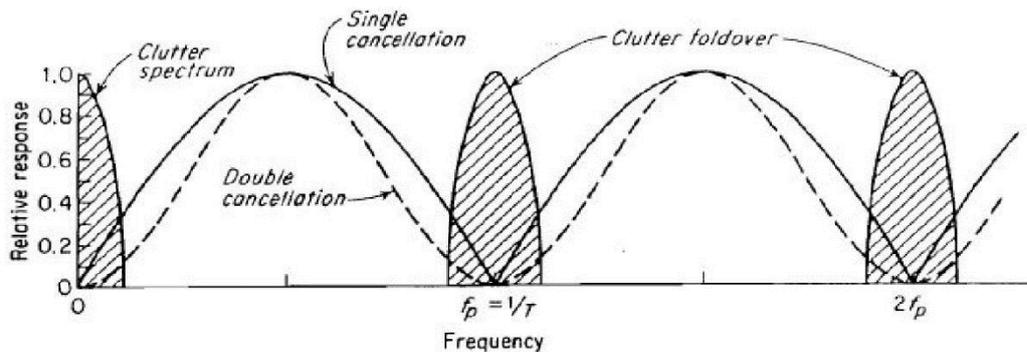
which is the same as the output from the double-delay-line canceller

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

This configuration is commonly called the **three-pulse canceller**.



(a) Double-delay-line canceler; (b) three-pulse canceler.



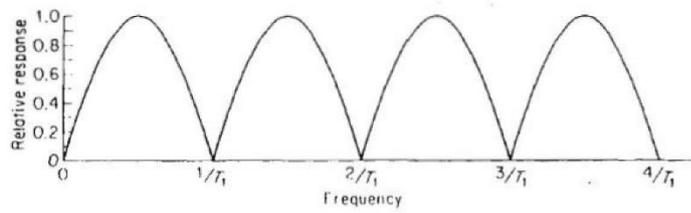
Relative frequency response of the single-delay-line canceler (solid curve) and the double-delay-line canceler (dashed curve). Shaded area represents clutter spectrum.

## MULTIPLE, OR STAGGERED, PULSE REPETITION FREQUENCY

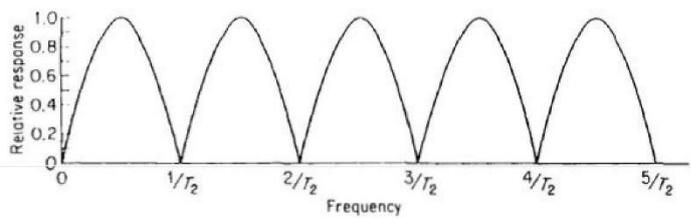
The use of more than one pulse repetition frequency offers additional flexibility in the design of MTI doppler filters. It not only reduces the effect of the blind speeds but it also allows a sharper low-frequency cutoff in the frequency response than might be obtained with a cascade of single-delay-line cancelers.

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 pulse RADAR frequency (PRF).

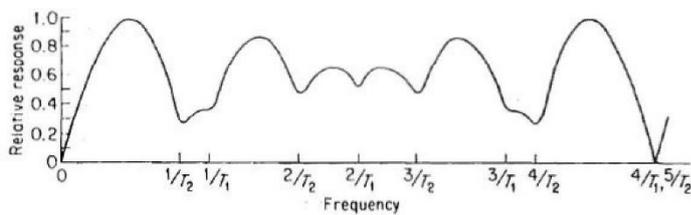
An example of the composite (average) response of an MTI radar operating with two separate pulse repetition frequencies on a time-shared basis is shown below



(a)



(b)



(c)

- (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  $T_1/T_2 = 3/2$ .