Chapter 4

MTI AND PULSE DOPPLER RADARS

Keywords. MTI, Pulse Doppler radar, Blind speed

4.1 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.

4.2 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.4.2.

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

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

The reference signal is

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

The doppler-shifted echo-signal voltage is

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

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

$$V_{diff} = A_4 sin\left[2\pi f_d t - \frac{4\pi f_t R_0}{c}\right] \tag{4.1}$$

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 $f_d > 1/t$, and in Fig. 4.3(c) for the case when $f_d < 1/\tau$, where τ 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 cancelers. 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,

$$f_d = \mathrm{n} f_p, \quad n = 1, 2, \ldots$$

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,

$$f_d = n f_p = 2v_r/\lambda \tag{4.2}$$

From which we get

$$v_r = \frac{n\lambda f_p}{2} = \frac{n\lambda}{2T}, n = 1, 2, \ldots \tag{4.3}$$

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 λ 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.

EXAMPLE 4.1: In a MTI radar the pulse repetition frequency is 200 Hz and the carrier transmission frequency is 100 MHz. Find its first, second and third blind speeds.

ANSWER:

The pulse repetition frequency, $f_p = 200$ Hz

The carrier transmission frequency, $f_t = 100$ MHz.

The carrier wavelength,

$$= \frac{c}{f_t} = \frac{3 \times 10^8}{(100 \times 10^6)} = 3m \tag{4.4}$$

The n-th blind speed,

$$v_{rn} = \frac{n\lambda fp}{2} \tag{4.5}$$

So, the first blind speed =

$$\frac{1 \times 3 \times 200}{2} = 300 m/sec \tag{4.6}$$

The second blind speed =

$$\frac{2 \times 3 \times 200}{2} = 600 m/sec \tag{4.7}$$

The third blind speed =

$$\frac{3 \times 3 \times 200}{2} = 900 m/sec \tag{4.8}$$

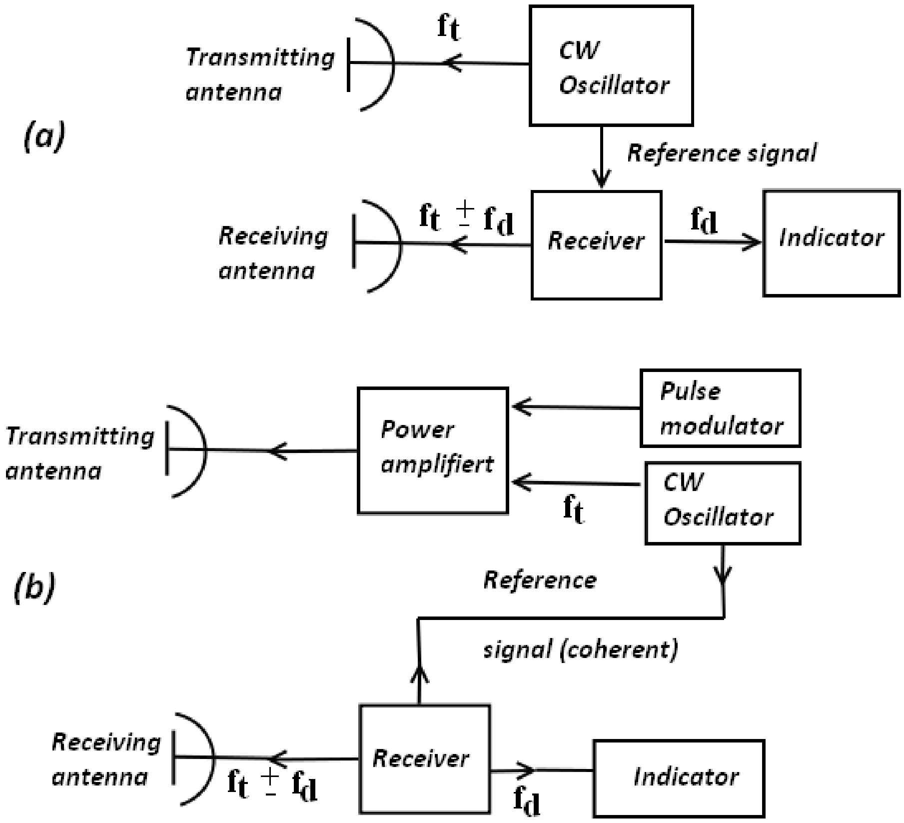

Figure 4.1: Block Diagram of (a) Simple CW Radar and (b) pulse radar using doppler information

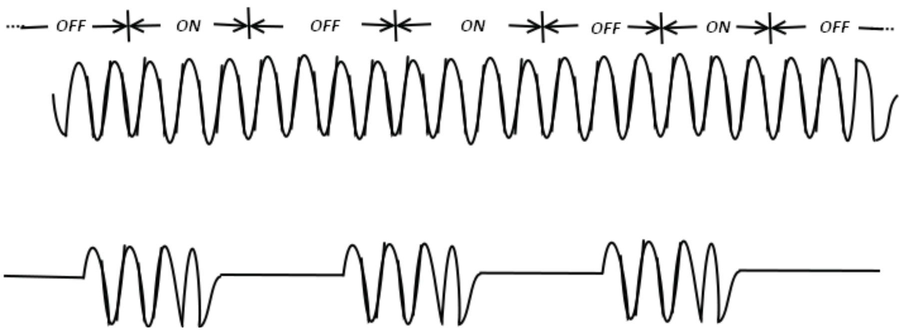

Figure 4.2: Pulse train generated from a continuous signal

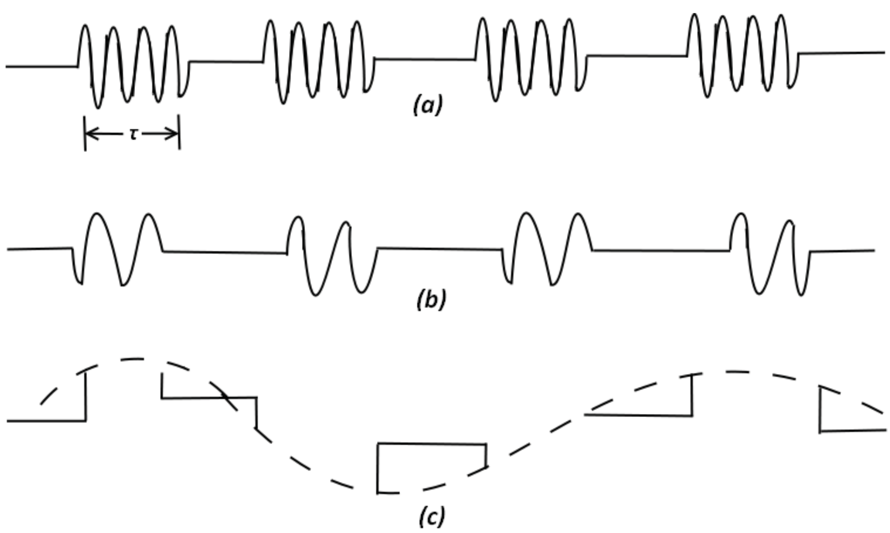

Figure 4.3: (a) Reflected signal (b) Difference signal when $f_d > 1/\tau$ (c) Difference signal when $f_d < 1/\tau$

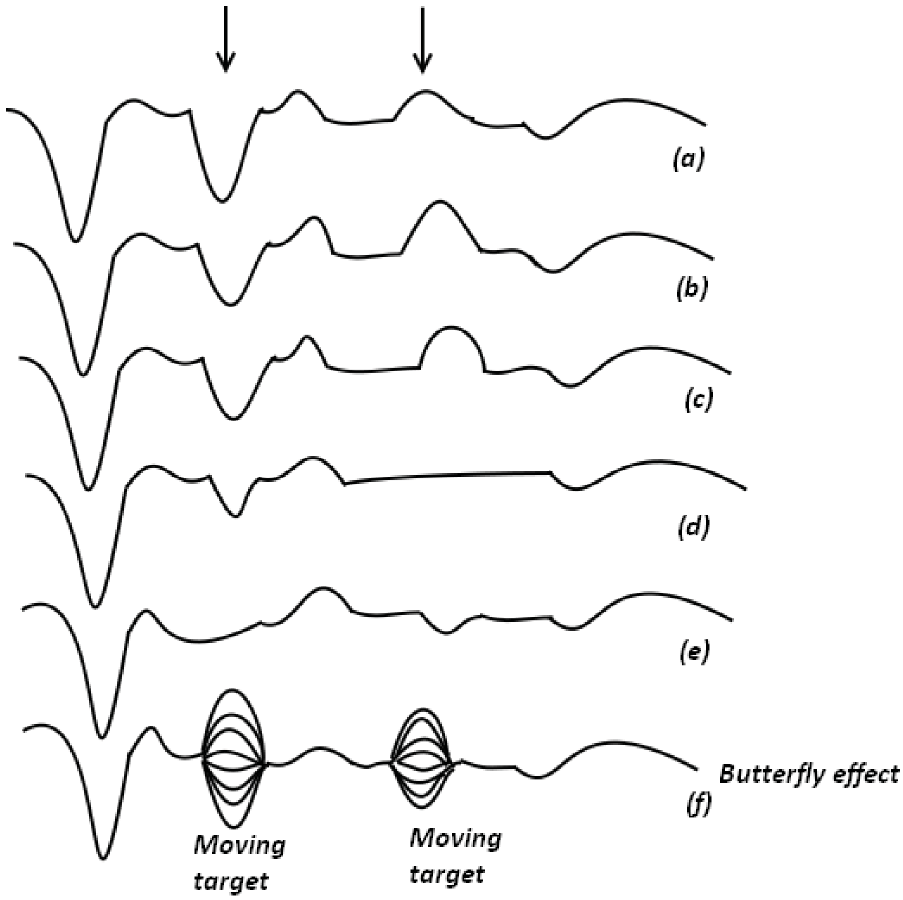

Figure 4.4: (a-e) Successive sweeps of an MTI Radar on an A-scope display and (f) supersposition of these signals (arrows indicate moving targets)

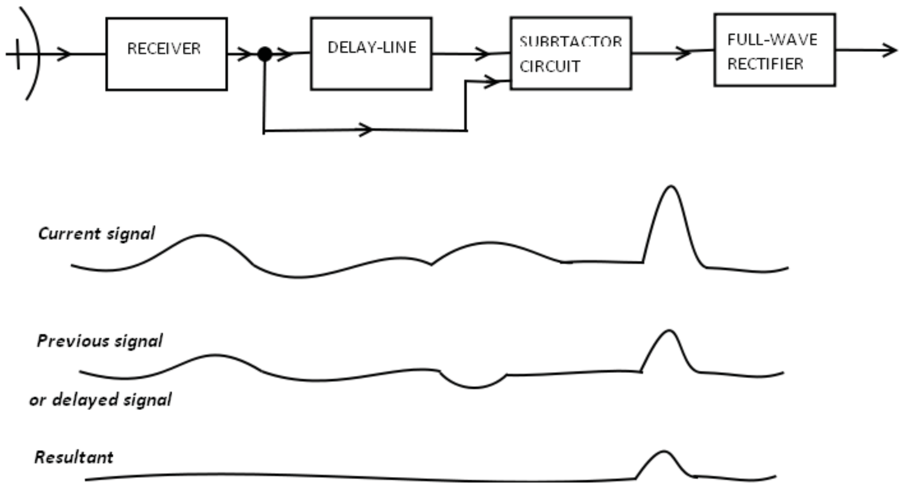

Figure 4.5: (a)Basic delay line canceller block diagram (b) Effect of delay line canceller on the signal

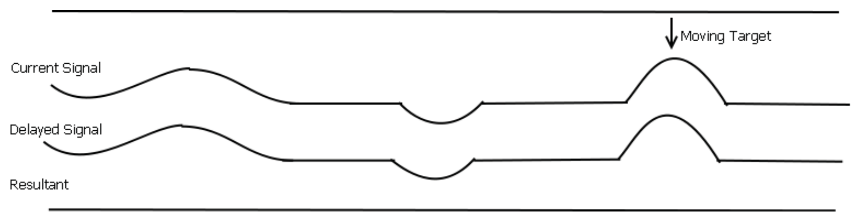

Figure 4.6: Effect of Blind speeds