Chapter 2
MTI Radar

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2.1 PREFACE

This chapter addresses surface-based radars; e.g., radars sited on land or installed onboard ships. For airborne radar, rapid platform motion has a significant effect on design and performance as discussed in Chapters 3, 4, and 5 of this *Handbook*.

The fundamental theory of moving target indication (MTI) radar, as presented in the previous editions of the *Radar Handbook*, has not materially changed. The performance of MTI radar, however, has been greatly improved, due primarily to four advances: (1) increased stability of radar subsystems such as transmitters, oscillators, and receivers; (2) increased dynamic range of receivers and analog-to-digital converters (A/D); (3) faster and more powerful digital processing; and (4) better awareness of the limitations, and therefore requisite solutions, of adapting MTI systems to the environment. These four advances have made it practical to use sophisticated techniques that were considered, and sometimes tried, many years ago but were impractical to implement. Examples of early concepts that were well ahead of the available technology were the velocity indicating coherent integrator (VICI)[1] and the coherent memory filter (CMF).[2,54]

Although these improvements have enabled much improved MTI capabilities, there are still no perfect solutions to all MTI radar problems, and the design of an MTI system is still as much of an art as it is a science. Examples of current problems include the fact that when receivers are built with increased dynamic range, system instability limitations will cause increased clutter residue (relative to system noise) that can cause false detections. Clutter maps, which are used to prevent false detections from clutter residue, work quite well on fixed radar systems, but are difficult to implement on, for example, shipboard radars, because as the ship moves, the aspect and range to each clutter patch changes, creating increased residues after the clutter map. A decrease in the resolution of the clutter map to counter the rapidly changing clutter residue will preclude much of the interclutter visibility (see later in this chapter), which is one of the least appreciated secrets of successful MTI operation.

MTI radar must work in the environment that contains strong fixed clutter, birds, bats and insects, weather, automobiles, and ducting. The ducting, also referred to as *anomalous propagation*, causes radar returns from clutter on the surface of the Earth to appear at greatly extended ranges, which exacerbates the problems with birds and automobiles, and can also cause the detection of fixed clutter hundreds of kilometers away.

The clutter models contained in this chapter are approximations of the types of clutter that must be addressed. The exact quantitative data, such as precise spectrum and amplitude of each type of clutter, or the exact number of birds or point reflectors (e.g., water towers or oil-well derricks) per unit area, is not important, because the MTI radar designer must create a robust system that will function well no matter the actual deviation from the clutter models of real clutter encountered.

MTI radars may use rotating antennas or fixed apertures with electronic beam scanning (phased arrays). The rotating antenna may use a continuous waveform processed through either a finite-impulse-response (FIR) filter or an infinite-impulse-response (IIR) filter, or may use a batch waveform consisting of coherent processing intervals (CPIs) that are processed in FIR filters in groups of N pulses. (The term *MTI filter*, used often in this chapter, is a generic nomenclature that includes both FIR and IIR filters.) The finite time-on-target dictates the need for a batch processing approach.

There are many different combinations of successful MTI techniques, but any specific MTI radar system must be a total concept based on the parameters of the antenna, transmitter, waveform, signal processing, and the operational environment.

A number of plan-position-indicator (PPI) photographs, taken years ago, are included in this chapter to provide a better understanding of the environment that is difficult to appreciate with many modern radars. These photographs show MTI operation, birds, insects, and ducting better than can be described in words.

Attention is especially directed to the final section in this chapter, "Considerations Applicable to MTI Radar Systems," which provides insight into both hardware and environmental lessons learned during many decades of MTI system development.

2.2 INTRODUCTION TO MTI RADAR

The purpose of MTI radar is to reject returns from fixed or slow-moving unwanted targets, such as buildings, hills, trees, sea, and rain, and retain for detection or display signals from moving targets such as aircraft. Figure 2.1 shows a pair of photographs of a PPI, which illustrates the effectiveness of such an MTI system. The distance from the center to the edge of the PPI is 40 nmi. The range marks are at 10-nmi intervals. The picture on the left is the normal video display, showing mainly the fixed-target returns. The picture on the right shows the effectiveness of the MTI clutter rejection. The camera shutter was left open for three scans of the antenna; thus, aircraft show up as a succession of three returns. MTI radar utilizes the doppler shift imparted on the reflected signal by a moving target to distinguish moving targets from fixed targets. In a pulse radar system, this doppler shift appears as a change of phase of received signals between consecutive radar pulses. Consider a radar that transmits a pulse of radio frequency (RF) energy that is reflected by both a building (fixed target) and an airplane (moving target) approaching the radar. The reflected pulses return to the radar a certain time later. The radar then transmits a second pulse. The reflection from the building occurs in exactly the same amount of time, but the reflection from the moving aircraft occurs in less time because the aircraft has moved closer to the radar in the interval between transmitted pulses. The precise time that it takes the reflected signal to reach the radar is not of fundamental importance. What is significant is whether the time changes between pulses. The time change, which is of the order of a few nanoseconds for an aircraft target, is determined by comparing the phase of the received signal with

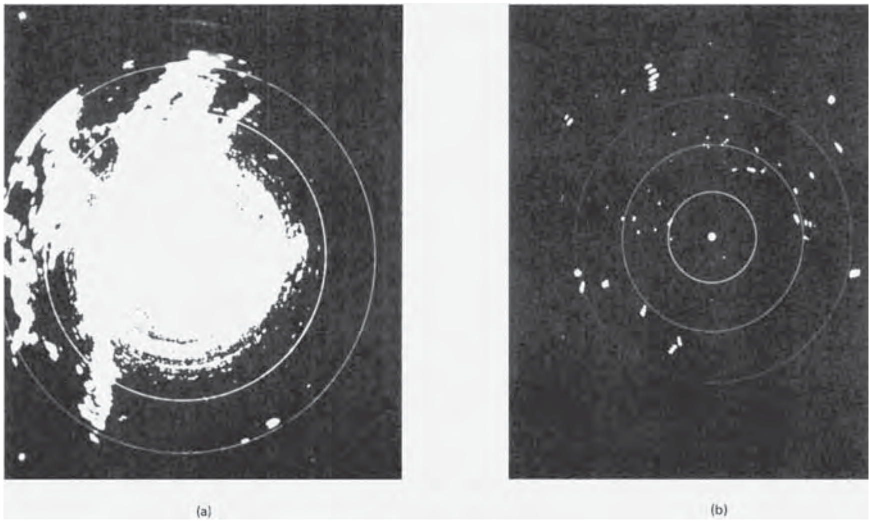

FIGURE 2.1 (*a*) Normal video and (*b*) MTI video: These PPI photographs show how effective an MTI system can be. Aircraft appear as three consecutive blips in the right-hand picture because the camera shutter was open for three revolutions of the antenna. The PPI range is 40 nmi.

the phase of a reference oscillator in the radar. If the target moves between pulses, the phase of the received pulse changes.

Figure 2.2 shows a simplified block diagram of a coherent MTI system. The RF oscillator feeds the pulsed amplifier, which transmits the pulses. The RF oscillator

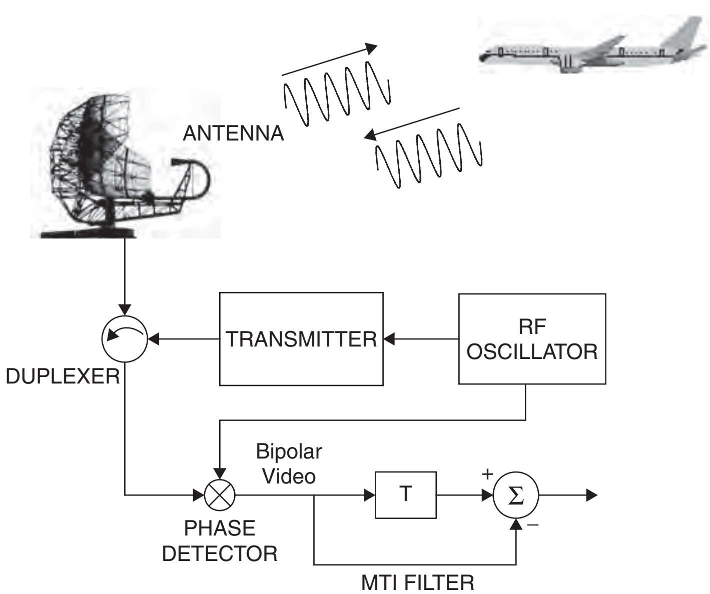

FIGURE 2.2 Simplified block diagram of a coherent MTI system

is also used as a phase reference for determining the phase of reflected signals. The phase information is stored in a pulse repetition interval (PRI)) memory for the period, *T,* between transmitted pulses, and is subtracted from the phase information from the current received pulse. There is an output from the subtractor only when a reflection has occurred from a moving target.