*Detection, Estimation, and Modulation Theory, Part III:*
*Radar–Sonar Signal Processing and Gaussian Signals in Noise.* Harry L. Van Trees
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# 8

# *The Radar-sonar Problem*

In the second half of this book, we apply the detection and estimation theory results that we have derived to problems encountered in the analysis and design of modern radar and sonar systems. We shall confine our discussion to the signal-processing aspects of the problem. There are a number of books dealing with the practical and theoretical aspects of the design of the overall system (e.g., for radar [1]–[6], and for sonar [7]–[9].†

In this Chapter we discuss the problem qualitatively and outline the organization of the remainder of the book.

A simple model of an *active* radar system is shown in Fig. 8.1. A narrow-band signal centered around some carrier frequency $\omega_c$ is transmitted. If a target is present, the transmitted signal is reflected. The properties of the reflected signal depend on the target characteristics (e.g., shape and motion). An attenuated and possibly distorted version of the reflected signal is returned to the receiver. In the simplest case, the only source of interference is an additive Gaussian receiver noise. In more general cases, there is interference due to external noise sources or reflections from other targets. In the detection problem the receiver processes the signal to decide whether or not a target is present at a particular location. In the estimation problem the receiver processes the signal to measure some characteristics of the target, such as range and velocity.

As we pointed out in Chapter 1, there are several issues that arise in the signal processing problem.

1. The reflective characteristics of the target.
2. Transmission characteristics of the channel.
3. Characteristics of the interference.
4. Optimum and suboptimum receiver design and performance.

† We strongly suggest that readers who have no familiarity with the basic ideas of radar or sonar read at least the first chapter of one of the above references.

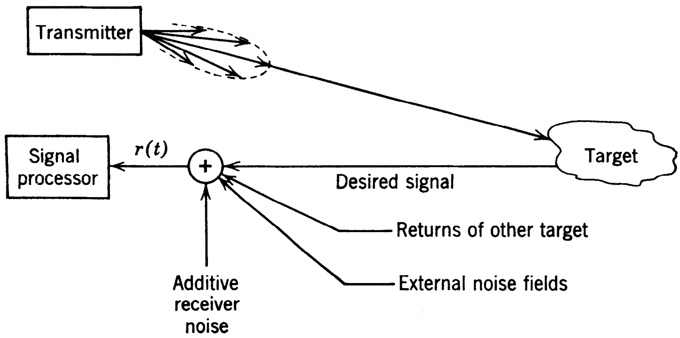


**Fig. 8.1 Model of an active radar or sonar system.**

We study these issues in detail in Chapters 9–13. Before beginning our detailed discussion, it is worthwhile outlining the hierarchy of the target models that we shall discuss.

The simplest model of the target is one that assumes that the target characteristics are fixed during the time it is illuminated by the transmitted pulse. If we further assume that its depth (measured in seconds) is negligible compared to the pulse length, we may consider it as a point reflector (with respect to the envelope of the pulse). Thus, the only effect of the target on the envelope is to attenuate and delay it. The carrier acquires a random phase shift. For this case, the attenuation and phase shift will be essentially constant over the pulse length, and we can model them as random variables. We refer to this type of target as a slowly fluctuating point target.

In Chapter 9 we discuss the problem of detecting a slowly fluctuating point target at a particular range and velocity. First, we assume that the only interference is additive white Gaussian noise and develop the optimum receiver and evaluate its performance. We then consider nonwhite Gaussian noise and find the optimum receiver and its performance. We use complex state-variable theory to obtain complete solutions for the nonwhite noise case. The final topic in the chapter is a brief discussion of signal design.

In Chapter 10 we consider the problem of *estimating* target parameters. Initially, we consider the problem of estimating the range and velocity of a single target when the interference is additive white Gaussian noise. Starting with the likelihood function, we develop the structure of the optimum receiver. We then investigate the performance of the receiver and see how the signal characteristics affect the estimation accuracy. We find that the signal enters into the analysis through a function called the *ambiguity function*; we therefore develop various properties of the ambiguity function and discuss how to design signals with desirable ambiguity functions. The final topic is the detection of a target in the presence of other interfering targets (the discrete resolution problem).

Although the material in Chapters 9 and 10 deals with the simplest type of target model it enables the reader to understand the signal processing aspects of most modern radar and sonar systems. The only background needed for these two chapters is the material in Chapter I-4.

In the remaining three chapters we study more complicated target models. Except for the reverberation discussion in Section 13.2, they assume familiarity with the material in Chapter III-2–III-4. The work in Chapters 11–13 is more advanced than that in Chapter 10 but is essential for readers doing research or development of more sophisticated signal-processing systems.

In Chapter 11, we consider a point target that fluctuates during the time the transmitted pulse is being reflected. This fluctuation causes time-selective fading, and we must model the received signal as a sample function of a random process.

In Chapter 12, we consider a slowly fluctuating point target that is distributed in range. We shall find that this type of target causes frequency-selective fading and, once again, we must model the received signal as a sample function of a random process.

In Chapter 13, we consider fluctuating, distributed targets. This model is useful in the study of reverberation in sonar systems and clutter in radar systems. It is also appropriate in radar astronomy and scatter communications problems. In the first part of the chapter we study the problems of signal and receiver design for systems operating in reverberation and clutter. This discussion will complete the resolution problem development that we begin in Chapter 10. In the second part of the chapter we study the detection of fluctuating, distributed targets and communication over fluctuating distributed channels. Finally, we study the problem of estimating the parameters of a fluctuating, distributed target.

In Chapter 14, we summarize the major results of the radar-sonar discussion. Throughout our discussion we emphasize the similarity between the radar problem and the digital communications problem. In several sections we digress from the radar-sonar development and consider specific digital communications problems.

All of our discussion in Chapters 9–13 describes the signals, systems, and processes with a complex envelope notation. In the Appendix we develop this complex representation in detail. The idea is familiar to electrical engineers in the context of phasor diagrams. Most of the results concerning signals, bandpass systems, and stationary processes will serve as a review for many readers, and our discussion merely serves to establish our notation. The material dealing with nonstationary processes, eigenfunctions, and complex state variables may be new, and so we include more examples in these parts. The purpose of the entire discussion is to develop an efficient notation for the problems of interest. The time expended in developing this notation is warranted, in view of the significant simplifications it allows in the remainder of the book. Those readers who are not familiar with the complex envelope notation should read the Appendix before starting Chapter 9.

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