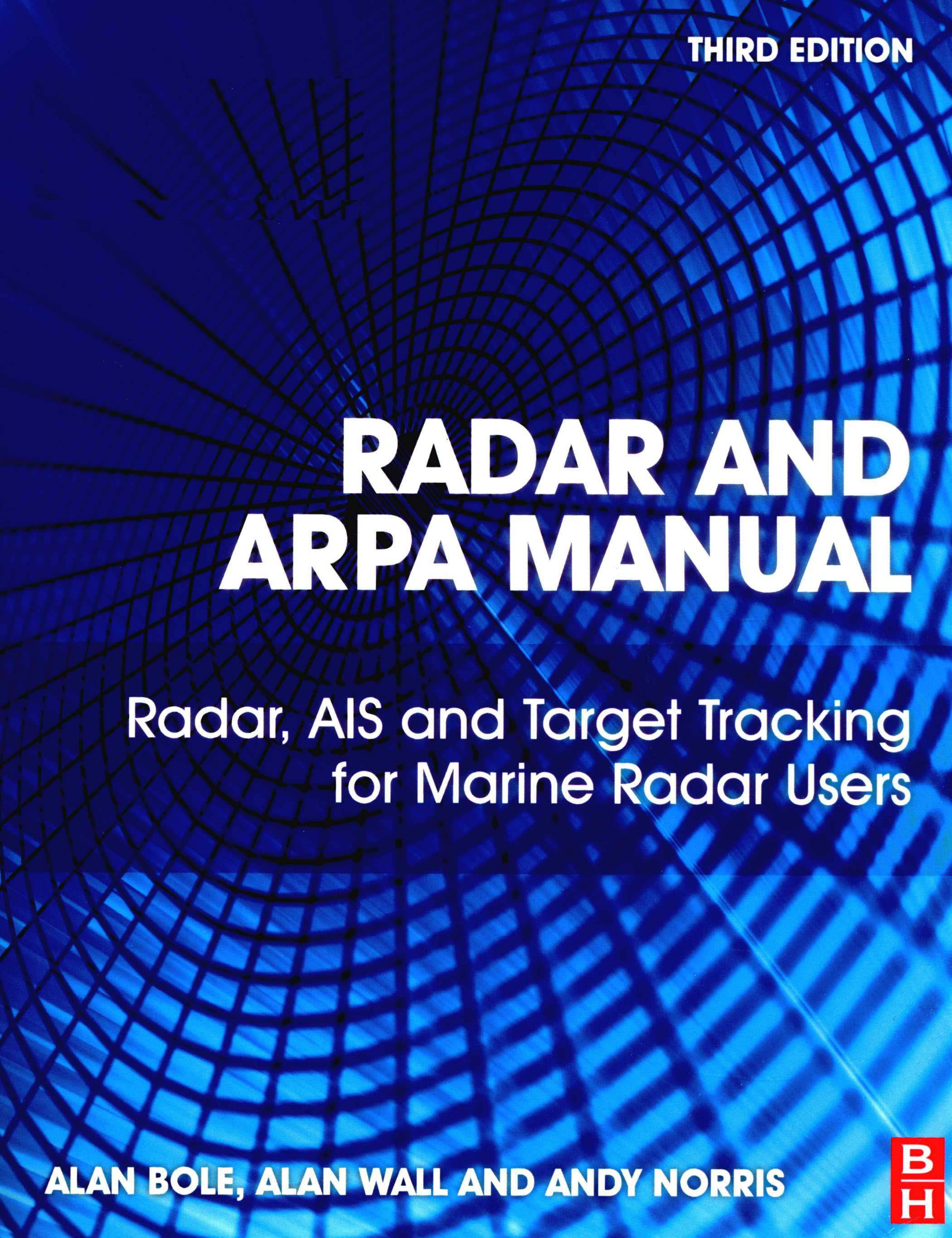

THIRD EDITION

RADAR AND ARPA MANUAL

Radar, AIS and Target Tracking for Marine Radar Users

ALAN BOLE, ALAN WALL AND ANDY NORRIS

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Preface to the Third Edition

There have been considerable advances in technology in recent years which has meant that a major revision has been necessary.

In the past, much of the work of the navigator involved the correct use of the controls in setting up the display and the correct interpretation of the displayed data – in particular, radar plotting to determine risk of collision. These problems have been largely solved by the development of digital techniques which have allowed the data to be electronically processed resulting, among other facilities, in auto-clutter suppression and target tracking (ARPA).

Unfortunately, the advances in technology have brought with them their own problems. The move from analogue to digital techniques has opened up considerable possibilities, in particular, to integrate the displayed outputs from what were independent instruments on to a common display monitor. This can give rise to information overload and/or display congestion if used indiscriminately.

A common failing now is for operators not to input, update or regularly check the data being fed to the systems upon which the output depends (courses, speeds, ship's data, etc.). As a result, for the navigator, the displayed data can be erroneous/misleading. The behaviour of an observer on another vessel will depend on the information being received (e.g. from AIS) and from information determined (e.g. from radar/ARPA). Serious confusion can arise when there are inconsistencies in what the instruments are telling the observer.

In recent years, there have been considerable changes and increases in the technical specifications of all navigational equipment (although rarely retrospective), and also, the Carriage Requirements. These have, to a large extent, been taken into account in this treatment. Also, the basic ideas behind solid-state coherent radars have been included within Chapter 2, as these are being increasingly fitted to vessels.

IMO and national advice on matters of safety and good practice is still included where applicable. The correct use of the equipment is paramount and it is in this area that we have continued to stress the importance of 'good practice' which has been built up over the years.

Although small vessels and pleasure craft are not specifically required to carry this equipment, many of them do and in their interest; it is hoped that many aspects of the material covered here will prove of value for them.

Some material relating to the development of radar has been retained in order to provide a background to understand where today's equipment is coming from and to underpin the theory upon which present-day radars are based. Most of the descriptions which related to specific earlier equipment has been removed, in spite of the fact some of that equipment may still be in use today.

Another significant change is that the latest IMO performance standards for radar on ships no longer refer to the term ARPA and instead use the term Target Tracker, as the equipment now has to integrate and present AIS (Automatic Identification System) data with radar tracked data. This new edition has therefore included a much larger discussion of AIS with the inclusion of the new Chapter 5. This trend away from independent to integrated equipment has meant that, for completeness, the inter-relationship between radar/ARPA, AIS, GPS and ECDIS has had to be included, but not to the same technical depth as the radar and ARPA.

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First edition

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Captain C. E. Nicholls of Liverpool Polytechnic for his major contribution to Chapter 8.

Second edition

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In this edition we are grateful for the considerable assistance of June Bole and Alison Wall in proofreading the manuscript and for their help, support and encouragement in our completion of this book.

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Third edition

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CHAPTER

1

Basic Radar Principles

1.1 INTRODUCTION

Radar forms an important component of the navigational equipment fitted on virtually all vessels apart from the very smallest. Its display of critical information is easily assimilated by a trained user and has acted as a focus for the presentation of other navigational data, giving it a deserved prominence on the bridge of a vessel. It is poised to retain its central electronic navigational role into the foreseeable future, equalled only in display significance by the rather more recent development, the electronic chart. Together, they will provide the basis of the major displays for marine navigation into an increasingly integrated navigational world.

The word RADAR is an acronym derived from the words *Radio Detection and Ranging*. The scientist Heinrich Hertz, after whom the basic unit of frequency is named, demonstrated in 1886 that radio waves could be reflected from metallic objects. In 1904 a German engineer, Christian Hülsmeyer, obtained a patent in several countries for a radio wave device capable of detecting ships, but it aroused little enthusiasm because of its very limited range. Marconi, delivering a lecture in 1922, drew attention to the work of Hertz and proposed in principle what we know today as marine radar. Although radar was used to determine the height of the ionosphere in the mid-1920s, it was not until 1935 that radar pulses were successfully used to detect and measure the range of an aircraft. In the 1930s there was much simultaneous but independent development of radar techniques in Britain, Germany, France and America. Radar first went to sea in a warship in 1937 and by 1939 considerable improvement in performance had been achieved. By 1944 naval radar had made an appearance on merchant ships and from about the end of the Second World War the growth of civil marine radar began. Progressively it was refined to meet the needs of peacetime navigation and collision avoidance.

The civil marine radars in use today differ markedly from their ancestors of the 1940s in size, appearance and versatility, but the basic data that they offer, namely target range and bearing, are determined by exploiting the same fundamental principles unveiled so long ago. An understanding of such principles is an essential starting point in any study of marine radar, even though recent developments in the use of a technology known as *coherent radar* have somewhat complicated the picture. This latter technology is explained in some detail in Section 2.9, but first it is useful to gain an understanding of the basic principles behind radar.

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1.2 PRINCIPLES OF RANGE AND BEARING MEASUREMENT

1.2.1 The Echo Principle

An object (normally referred to as a target) is detected by the transmission of radio energy as a pulse or otherwise, and the subsequent reception of a fraction of such energy (the echo) which is reflected by the target in the direction of the transmitter. The phenomenon is analogous to the reflection of sound waves from land formations and large buildings. Imagine somebody giving a short sharp shout through cupped hands to focus the sound energy. The sound wave travels outwards and some of it may strike, for example, a cliff. Some of the energy which is intercepted will be reflected by the cliff. If the reflected energy returns in the direction of the caller, and is of sufficient strength, it will be heard as an audible echo, resembling the original shout. In considering this analogy, the following points can usefully assist in gaining a preliminary understanding of pulse radar detection:

A. The echo is never as loud as the original shout.
B. The chance of detecting an echo depends on the loudness and duration of the shout.
C. Short shouts are required if echoes from close targets are not to be drowned by the original shout.
D. A sufficiently long interval between shouts is required to allow time for echoes from distant targets to return.
E. It can be more effective to cup one's hands over the mouth when shouting and put a hand to the ear when listening for the echo.

Now considering radar, its basic building blocks are illustrated diagrammatically in Figure 1.1. The antenna is used both to transmit the signal and to receive its reflection. On transmit, the antenna is acting very much like the cupped hand, focussing the energy in a particular direction. On receive it is acting more like a hand to the ear, collecting more received energy from that direction. The transmitter has a similar role to that of the mouth and vocal chords of the shouter, and the radar receiver acts as the ear. The processor clarifies the received signal and judges its distance, perhaps somewhat similar to what a trained human brain can do in identifying and assessing a received sound wave. Finally the radar displays the information to a human operator, perhaps analogous to a human writing down the estimated range and direction of the object producing the echo.

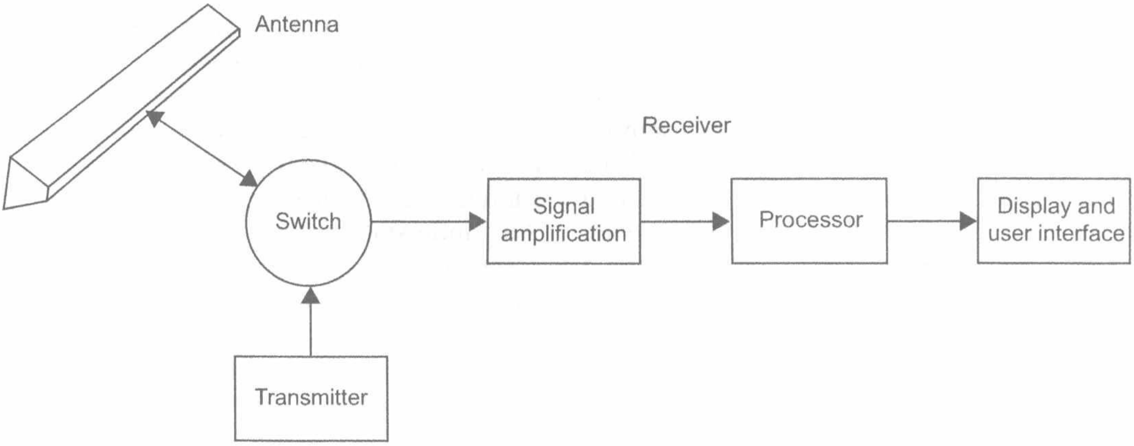

FIGURE 1.1 The basic radar system.

The antenna of a marine radar rotates steadily in the horizontal plane giving a complete rotation about every 2 s. This means that radar pulses consecutively cover all directions over 360° at each rotation of the antenna. The speed of radio waves is so high, about one million times greater than sound waves, that the antenna receives all the reflected energy from a particular transmitted pulse before it has appreciably rotated.

1.2.2 Range as a Function of Time

It is self-evident that the time which elapses between the transmission of a pulse and the reception of the corresponding echo depends on the speed of the pulse and the distance which it has travelled in making its two-way journey. If the speed of the pulse is known and the elapsed time can be measured, the range of the target producing the echo can be calculated.

The velocity of radio waves is dependent on the nature of the medium through which they travel. In fact, within the Earth's atmosphere it is hardly different to that within a space-type vacuum, that is 299,792,458 m/s. In our own minds this is easiest to be considered to be almost precisely 300,000,000 (three hundred million) metres per second, or as 300 metres per microsecond (μs), where 1 μs represents one millionth part of a second (i.e. 10^{-6} s). Using this value it is possible to produce a simple general relationship between target range and the elapsed time which separates the transmission of the pulse and the reception of an echo in any particular case (Figure 1.2).

Let D = the distance travelled by the pulse to and from the target (metres)

R = the range of the target (m)
T = the elapsed time (μs)
S = the speed of radio waves (m/μs)

Then $D = S \times T$
and $R = (S \times T)/2$
hence $R = (300 \times T)/2$
thus $R = 150T$

The application of this relationship can be illustrated by the following example.

EXAMPLE 1.1

Calculate the elapsed time for a pulse to travel to and return from a radar target whose range is (a) 40 m (b) 12 nautical miles (NM).

a. $R = 150T$
thus $40 = 150T$
hence $T = 40/150 \approx 0.27\,\mu\text{s}$

This value is of particular interest because 40 m represents the minimum detection range that must be achieved to ensure compliance with IMO Performance Standards for Radar Equipment (see Section 11.2.1). While this topic will be fully explored in Section 3.2.4, it is useful at this stage to note the extremely short

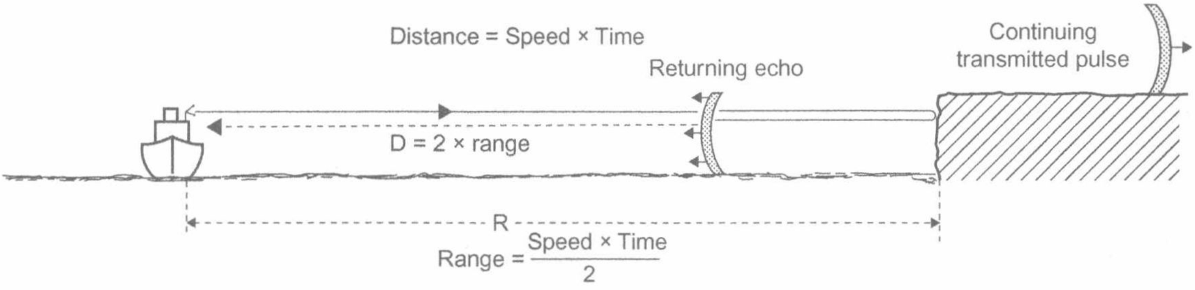

FIGURE 1.2 The echo principle.

time interval within which transmission and reception must be accomplished.

b. $R = 150T$

$$\text{Since } 1\ \text{NM} = 1852\ \text{m},$$
$$12 \times 1852 = 150T$$
$$\text{hence } T = 12 \times 1852/150 = 148.16\ \mu\text{s}$$

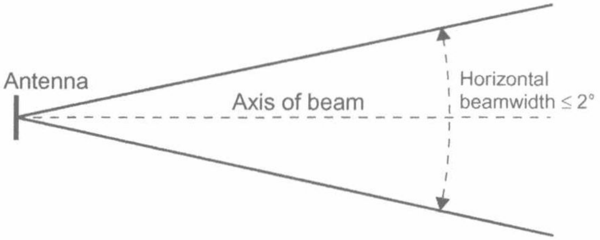

FIGURE 1.3 The horizontal beam width.

This result is noteworthy as it represents the elapsed time for a commonly used marine radar range scale. The elapsed times established in this section are of the order of millionths of a second and therefore need special instrumentation to be able to measure them accurately. In the early days of radar this was cutting-edge technology, but with the advent of quartz timing technology, and fast microelectronics it is no longer a major issue. Such technology is low cost, accurate and ubiquitous, with most humans owning multiple examples of precision timing in their watches, mobile phones, computers, TVs and cars.

1.2.3 Directional Transmission and Reception

In a marine radar system it is cost and space effective to use a single antenna for both transmission and reception. It is designed in such a way (see Section 2.5) as to focus the transmitted energy into a beam which is very narrow in the horizontal plane. The angle within which the energy is constrained is called the *horizontal beamwidth* (Figure 1.3). It must have a value of not more than 2.0° if it is to comply with the international regulations which govern marine radar. Civil marine radars for large ships are available with horizontal beamwidths as narrow as 0.75°. The equivalent reception property of the antenna is such that it will detect energy which has returned from within the angular limits of the horizontal beamwidth; that is from those targets that have been illuminated by the corresponding radar transmission. Its insensitivity to picking up unwanted noise from other directions effectively increases its ability to detect the reflected echoes.

An essential feature of a marine radar is that it should provide continuous coverage over the full 360° of azimuth angle. To achieve this the antenna has to rotate and no part of the vessel should obscure the radar beam, such as masts and other superstructure. Typical antenna rotation rates are 24–45 revolutions per minute, resulting in a complete rotation occurring every 1.3–2.5 s, depending on the system.

The interval between successive transmitted pulses has to at least allow the transmitted signal to travel out to the furthest target of interest and back again, although there are other considerations, which are discussed in Section 2.3.3.2. This interval is normally considered as a pulse repetition frequency (PRF), that is the number of pulses transmitted in 1 s. If we take, as an example, a value of 1500 pulses per second (1500 Hz); this is equivalent to one pulse every 667 μs. Taking a representative time for one revolution of the scanner to be 2 s, it is seen that 3000 pulses are transmitted during one revolution and that the scanner rotates through 0.12° between pulses. The picture is thus 'built up' of approximately 3000 radial lines of reflected echoes.

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