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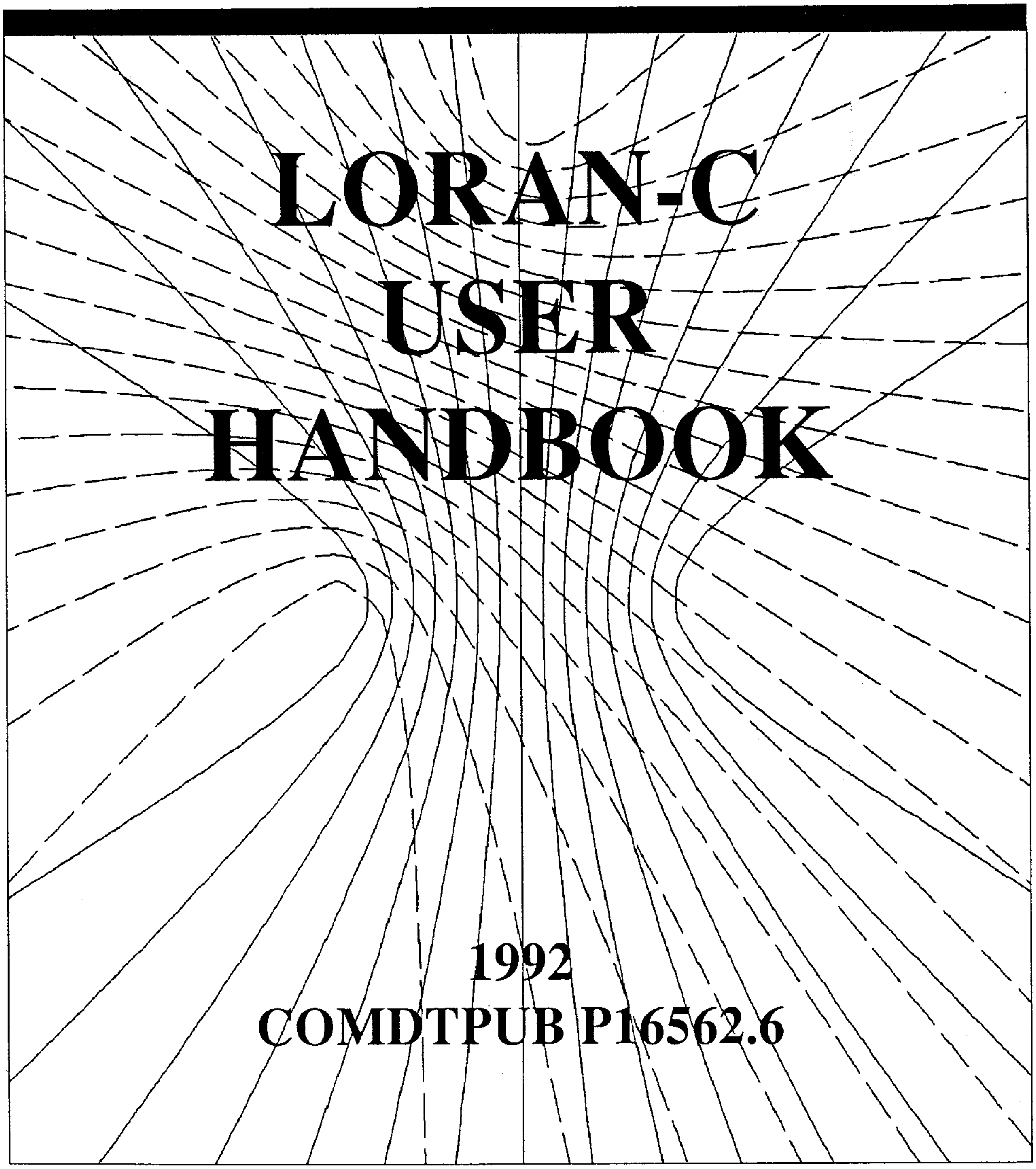

LORAN-C USER HANDBOOK

1992
COMDTPUB P16562.6

U.S. Department of Transportation
United States Coast Guard

Commandant (G-NRN)
United States Coast Guard

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Subj: Loran-C User Handbook

1. PURPOSE. To provide a general description of the LORAN-C Navigation System and an introduction to its use.

2. DIRECTIVES AFFECTED. The Loran-C User Handbook, COMDTINST M16562.3, dated May 1980 is cancelled.

3. DISCUSSION. The new Loran-C User Handbook is a much more comprehensive edition than the previous one. A Loran-C system description, use of Loran-C receivers, interference to Loran-C and its effects, nautical charts and tables containing Loran-C information, and updated information on available Loran-C coverage are only some of the topics covered in the handbook.

W. J. ECKER
Chief, Office of Navigation Safety
and Waterway Services

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FORWARD

The purpose of this book is to provide general information about the Loran-C Radionavigation System and to present an introduction to its use. This revision reflects major changes in: the Loran-C system, Coast Guard operational technology, and Loran receivers. The book also includes information for aviators and terrestrial users.

Navigators are cautioned never to place total reliance on any single aid to navigation. Because no system is reliable 100% of the time, navigators should use all available navigation information, and be knowledgeable with the capabilities and limitations of each.

This revised publication was made possible through the efforts of the U. S. Coast Guard Auxiliary and specifically, Mr. L. Daniel Maxim, DVC-ED, Auxiliary Department of Education. The work conducted by the Coast Guard Auxiliary was instrumental in the completion of this publication and is greatly appreciated.

For more information on Loran-C, write or call:

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Introduction and Overview

Background: The *"Green Book"*

It is now more than ten years since the *United States Coast Guard* (USCG) issued COMDINST M16562.3, *Loran-C User Handbook* (the so-called *Green Book* because of the original color of its cover) in May of 1980. This handbook soon proved very popular and went through several printings. For several years, it stood virtually alone among "accessible" (semi-technical) discussions of the Loran-C system. Over the years, strong consumer demand caused available stocks of this handbook to be depleted, and finally exhausted.

In the intervening years since this handbook was first written, there have been substantial changes to the loran system from both the "hardware" and "software" perspectives. *Loran-A* (as the original loran system came to be called) was phased out in the United States in favor of the more accurate and longer range *Loran-C* system. There were many changes and expansions of the Loran-C chains such as the recent expansion of loran coverage to plug the "mid-continent gap". New components have been added (e.g., solid-state transmitters, remote operating systems, etc.). Verification surveys to increase system accuracy were completed and new Loran-C charts have been prepared. The identity and location of sources of loran interference have changed substantially. These are just a few of the many changes and other relevant loran developments over the past ten years.

Nor were changes confined to the design and operation of the loran system. There were near-revolutionary advances in the state-of-the-art of loran receiver design (e.g., automated coordinate converters, addition of navigation computers, ability to store and display waypoints, ability to interface with other shipboard electronics, advances in display technology, etc.) that have resulted in the commercial availability of more powerful, easy-to-use, and relatively inexpensive receivers. Taken together, these changes were so substantial as to require a complete rewrite (rather than mere reprinting) of the original USCG *"Green Book."*

The New Handbook Edition: More Than Just the Cover Has Changed

This new edition retains many of the useful tables, figures, and charts of the original edition (updated as necessary), but has been considerably expanded in scope to cover the major developments of the past decade. In particular, much more material has been added on how to use loran for navigation to complement the systems information presented in this and the earlier *Green Book*. Although this handbook is not intended to be an academic treatise on loran navigation, parts of this text, particularly Chapters II and III, are quite technical. Most of the chapters, however, do not presume any extensive technical background on the part of the reader. A comprehensive glossary (Appendix C) and much expanded bibliography (Appendix E) are also included.

To facilitate quick reading and to simplify some of the more technical sections of this handbook, capsule summaries are found throughout the text, set apart in shaded insets. Readers lacking interest in the technical details of these specialized sections can skim these capsule summaries and skip ahead to more interesting topics.

The focus of this handbook is on marine applications of Loran-C. However, aviators may find this handbook useful as well—mentally replace the word "mariner" with "aviator" and the vessel icons with aircraft. Lastly, terrestrial users may also find this handbook of interest—particularly the discussions of the system and the technical material in the appendices.

Comments on this handbook are welcome, and should be directed to Commandant (G-NRN), United States Coast Guard, Washington, DC 20593–0001.

Introduction

This introductory chapter provides a brief overview of the loran system and shows how this system compares with other radionavigation systems used in the United States. A simplified discussion of the principle of operation is presented, along with an identification of the components of the loran system. The chapter concludes with a brief history of loran.

Subsequent chapters build upon this basic treatment, detailing the Loran-C system in greater depth (Chapters II and III), Loran-C receivers (Chapter IV), practical aspects of Loran-C navigation (Chapter V), relevant charts (Chapter VI), and installation and related matters (Chapter VII). Numerous appendices provide additional material of a more technical nature.

Readers without any background in loran are advised to read Chapter I, then skip ahead to Chapters IV through VII. Chapters II and III can be deferred for later study and/or skimmed. Readers more familiar with loran and wishing to learn the technical details of this system should read the various chapters in numerical sequence.

What is Loran?

The name, "*loran*", is an acronym for **lo**ng-**ra**nge **n**avigation.[1] It is a radionavigation system using land-based radio transmitters (operated in the United States by the USCG) and receivers to allow mariners, aviators, and (more recently) those interested in terrestrial navigation to determine their position. *Loran-C* is the federally provided radionavigation system for the U.S. *Coastal Confluence Zone* (CCZ). (The CCZ is defined as the area seaward of a harbor entrance to 50 nautical miles offshore or the edge of the Continental Shelf—100 fathom curve—whichever is greater. The CCZ does not include the harbor, however. See the glossary in Appendix C for the definitions of specialized terms of art.) Loran-C is also approved as a supplemental air navigation system.

[1]When the word loran is used in a generic sense, it is not capitalized. Specific loran systems, such as Loran-C are capitalized in this handbook.

The Federal Aviation Administration (FAA) is presently in the process of certifying Loran-C for non-precision approaches (NPA) conducted under Instrument Flight Rules (IFR). As of this writing only a few such approaches have been established and certified, but the pace of certification is expected to increase substantially in the next few years.

A discussion of the details of the Loran-C system is presented later in this chapter and elsewhere in this handbook. In general terms, however, Loran-C can be characterized as a highly accurate (better than 0.25 nautical mile (NM) absolute accuracy in the defined coverage area), available (99.7% availability), 24-hour-a-day, all-weather[2] radionavigation system. Loran-C (the present version of this system) coverage extends over the conterminous United States, portions of Alaska, and many other areas of the world.

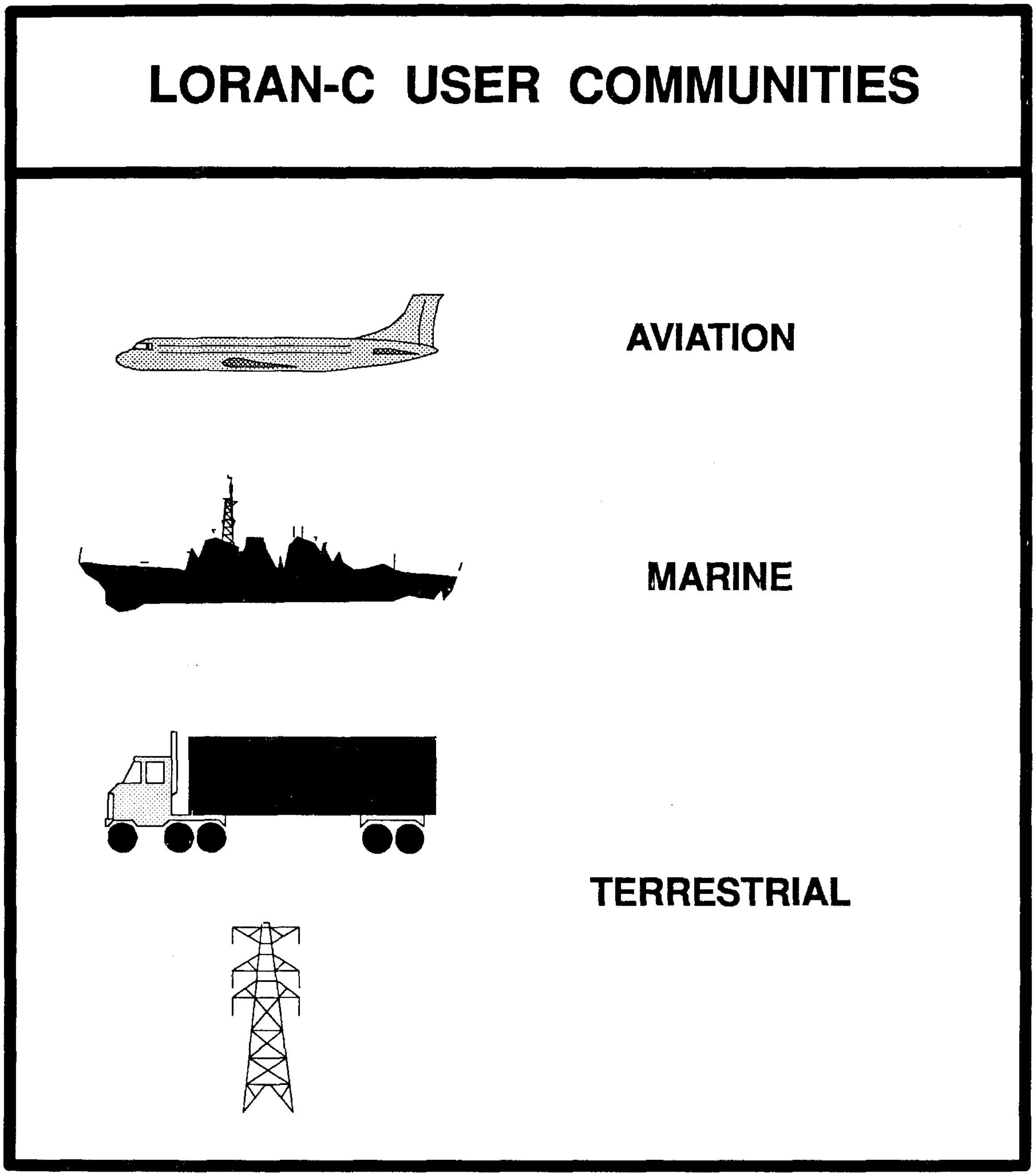
Loran is also used extensively to establish a precise time reference. Power companies, telephone companies, and many others use Loran-C as a source of timing information for such pur–poses as controlling and monitoring cesium clocks.

> **. . . Loran-C is the federally provided radionavigation system for the U.S. Coastal Confluence Zone. . . . . It is a highly accurate, highly available, 24-hour-a-day, all-weather, radionavigation system.**

From the perspective of the mariner, Loran-C is designed to be used in several phases of marine navigation, including ocean navigation and coastal navigation. Loran-C is also a useful *supplemental* system for harbor and harbor approach navigation. It can also be a valuable supplemental navigation system for inland navigation of recreational vessels. Table I–1 provides brief definitions of these phases of navigation and identifies the navigation techniques and systems commonly in use for each phase.

According to estimates given in the *1990 Federal Radionavigation Plan* (FRP), in 1991 there are expected to be more than 572,000 users of the Loran-C system, the second largest "user community" to employ a single radionavigation system. (According to other estimates, the number of loran users is much larger, perhaps one million or more.) The majority (82%) of Loran-C users are marine users (both domestic and international). Other Loran-C users include U.S. civil aviation users (14%), U.S. civil land users (3.8%), and a small number of *Department of Defense* (DOD) users. With the exception of DOD applications, which are scheduled to cease as of 31 December 1994, these numbers of Loran-C users are projected to continue to grow in number. Aviation uses of Loran-C, in particular, are expected to increase substantially in the years ahead. Accurate projections of the future number of users depend upon several factors, such as the upcoming (1994) decision by the U.S. *Department of Transportation* (DOT) whether to continue the Loran-C system, or to begin to phase this system out in favor of other alternatives, such as the *Global Positioning System* (GPS). Although the outcome of DOT's

[2]Weather, in particular thunderstorms, does degrade the performance of Loran-C (see Chapters II and III). However, usable navigation information can often be obtained during these circumstances.



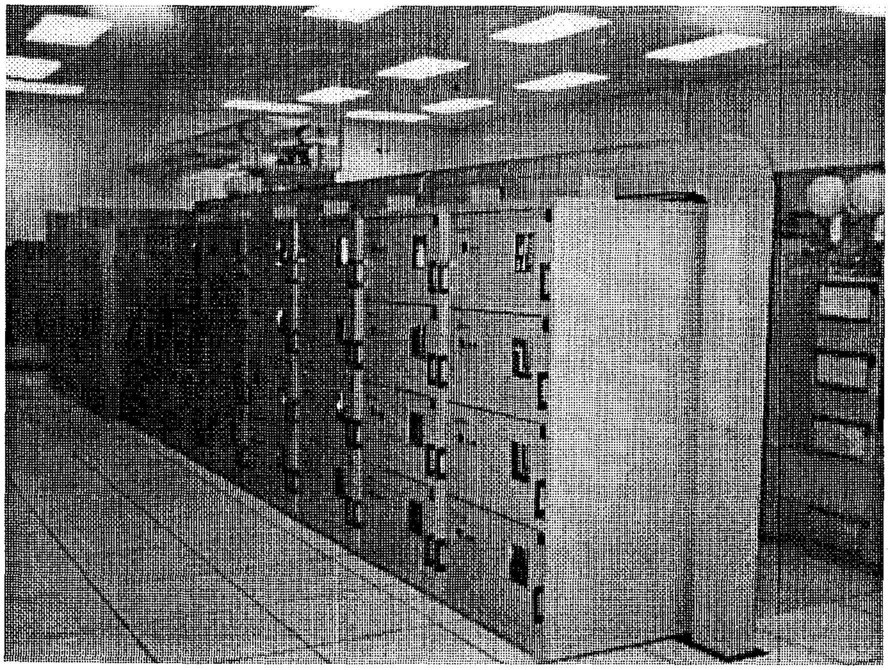
deliberations cannot be forecast with any certainty, many believe that the Loran-C system will remain in operation well into the next century.

Comparison of and Relationship of Loran-C to Other Marine Radionavigation Systems

Before discussing the details of loran, it is useful to understand the role, limitations, and capabilities of the Loran-C system in the context of the overall U.S. radionavigation systems mix. That is, loran should be compared with other competing and complementary radionavigation systems. Table I–2 provides relevant data on the Loran-C system and several other marine radionavigation systems in use throughout the United States and elsewhere. Radionavigation systems included in this comparison include Omega, GPS, marine radiobeacons, and Transit, together accounting for the principal radionavigation systems in use by U.S. mariners. Several key system characteristics of each system, including accuracy, availability, coverage, reliability, fix rate, fix dimension, system capacity and ambiguity potential are summarized in this table. (Recall that definitions of these and other specialized technical terms can be found in the glossary provided in Appendix C of this handbook.)

–Omega

The Omega system was originally developed and implemented by the Department of the Navy, and now operated by seven nations under the operational control of the USCG. Omega is a very low frequency (VLF 10.2–13.6 kHz) hyperbolic[3] radionavigation system used chiefly for ocean navigation. Table I–3 summarizes the various radio frequency bands, provides a capsule description of the relevant characteristics of each, and identifies past and present radionavigation systems using each band. Position information is obtained by measuring relative phase differences of received Omega signals. There are now eight Omega transmitters. These are located in Norway (at the arctic circle); Monrovia, Liberia; La Reunion Island (in the Indian Ocean); Golfo Nuevo, Argentina; Victoria, Australia; Tsushima, Japan; and in the United States at La Moure, North Dakota, and Oahu, Hawaii. The Omega user community was estimated to number approximately 26,500 in 1991. Under present plans, Omega will remain in operation past the year 2000.



Interior of LORSTA, showing solid-state transmitters.
(Photograph from USCG.)

In broad terms (see Table I–2), Loran-C offers superior fix accuracy compared to Omega, but lacks Omega's worldwide coverage. Fix accuracy (more on this in Chapter III) for the Loran-C system within the designated coverage area is no worse than 0.25 NM compared to 2–4 NM for Omega. (Omega's accuracy constraints limit its use to ocean navigation.) Approximate areas of Loran-C coverage can be found in Appendix B. Although Loran-C coverage exists for many areas of the world, there are also broad expanses of ocean (such as the South Pacific and South Atlantic

[3]Hyperbolic systems, including loran, are discussed later in this and subsequent chapters and defined in the Glossary.

TABLE I-1. PHASES OF MARINE NAVIGATION AND SYSTEMS OR TECHNIQUES IN USE IN EACH PHASE.		
Phase	**Brief Description**	**Techniques and Systems in Use**
Ocean Navigation	Vessel beyond Continental Shelf, and more than 50nm from land, where position fixing by pilotage impractical.	Loran-C, Omega, Transit, RDF, GPS, Inertial Navigation, Dead Reckoning and Celestial Fixes.
Coastal Navigation	Vessel within 50nm from shore or the limit of the Continental Shelf, whichever is more distant. Also applies to other waters where traffic separation schemes have been established.	Loran-C, RDF, and GPS.
Harbor and Harbor Approach Navigation	Vessel generally inland from coastal waters. The harbor approach phase begins with a transition zone between the relatively unrestricted coastal waters and narrowly restricted waters and/or within the entrance to a bay, river, or harbor where the harbor phase begins.	RDF, DGPS,[1] fixed and floating ATONs, audible warning signals, and radar. Loran-C may also be useful, but as a supplemental navigation system.
Inland Navigation	Conducted in restricted waters similar to harbors or harbor approaches. For inland navigation, however, the focus is on nonseagoing vessels, including most recreational craft.	Fixed and floating ATONs, and radar. Loran-C may also be useful, depending upon the waters, but not as a primary navigation system.

[1]Under study

SOURCE: Abstracted from *1990 Federal Radionavigation Plan.*

Oceans) where Loran-C coverage is not available. In contrast, the Omega system offers virtually worldwide coverage. Although not listed among the characteristics given in Table I–2, Loran-C receivers are substantially less expensive than corresponding equipment for Omega— and likely to remain so in view of the relative size of the two user communities.

–Global Positioning System (GPS)

GPS is a space-based military and civilian radio positioning system operated by DOD that will provide three-dimensional position, velocity, and time information to users on or near the surface of the earth. The space component consists of 21 satellites plus three operational spares operating in high altitude (10,900 NM) orbits, and transmitting navigational signals on 1575.42 and 1227.6 MHz. There were an estimated 15,000 GPS users in 1991, a figure projected to grow substantially in the coming years.

GPS is an emerging system that offers improved coverage and accuracy compared to Loran-C, and is the likely successor to the loran (and Omega) system. However, as of this writing, the entire constellation of satellites necessary for continuous worldwide GPS coverage has not been deployed. (According to present plans, the GPS will be fully operation as of 1993.

TABLE I-2. RELEVANT CHARACTERISTICS OF SEVERAL NAVIGATION SYSTEMS

System	Accuracy: Predictable	Accuracy: Repeatable	Accuracy: Relative	Unit Availability	Coverage	System Availability	Fix Rate	Fix Dimension	System Capacity	Ambiguity Potential
Loran-C	At least 0.25nm (460m) 1:3 SNR	60-300 ft. (18-90m)	60-300 ft. (18-90m)	99+% Transmitting station signal availability greater than 99.9%	Coastal continental U.S. and selected overseas areas	99.7%[1]	10-20 fixes/ minute	Two dimensions	Unlimited number of simulta- neous uses	Yes, easily resolved
Omega	2-4nm (3.7-7.4km)	2-4nm (3.7-7.4km)	0.25-0.5nm (463-926m)	99+%	Worldwide continuous	97%[2]	1 fix every 10 seconds	Two dimensions	Unlimited	Requires knowledge to ± 36nm[3]
GPS	PPS[4] Horz-17.8m Vert-27.7m Time-90ns	Horz-17.8m Vert-27.7m	Horz-7.6m Vert-11.7m	Expected to approach 100%	Worldwide continuous	98% probability that a 21-satellite constellation will be operating	Essentially continuous	Three dimensions plus, velocity and time	Unlimited	None
	SPS[5] Horz-100m Vert-156m Time-175ns	Horz-100m Vert-156m	Horz-28.4m Vert-44.5m							
Marine RDF	Marine ± 3°	NA	NA	99%	Out to 50 nm or 100 fathom curve	99%	Function of the type of beacon continuous or sequenced	One LOP per beacon	Unlimited	Potential is high for reciprocal bearing without sense antenna
Transit	Dual frequency 25m[6]	15m	Under 10m with trans- location techniques	99% when satellite is in view	Worldwide non- continuous	99%	Every[7] 30 seconds	Two dimensions	Unlimited	None
	Single frequency 500m	50m								

SOURCE: Adapted from the *1990 Federal Radionavigation Plan* (FRP).

NOTES:

[1] Triad reliability; individual station availability normally exceeds 99.9%. Note also that many areas of the United States are served by more than one loran chain, increasing the availability.

[2] Three station joint signal availability.

[3] Three frequency receiver (10.2, 11.33, 13.6kHz).

[4] Precise position service for U.S. and Allied military, U.S. government, and selected civil users specifically approved by the U.S. government. PPS is specified as spherical error probable. Multiply this quantity by 2.5 to ensure comparability with other entries in this column. SPS numbers do not need to be adjusted.

[5] Standard positioning service for other uses.

[6] 2 sigma, position accuracy is highly dependent on the user's knowledge of his velocity.

[7] Maximum satellite waiting time varies with latitude. (30 minutes at 80°, 110 minutes at equator)

TABLE I-3. FREQUENCY BANDS AND RADIONAVIGATION SYSTEMS

Frequency Range	Name	Abbrevia-tion	Brief Description	Line of Sight Limitation	Navigation and Other Systems Operating in This Range
3 kHz - 30 kHz	Very low frequency	VLF	VLF signals propagate between the bounds of the ionosphere and the earth. Signals follow the curvature of the earth to great distances with excellent stability.	No	Omega Delrac*
30 kHz - 300 kHz	Low frequency	LF	Compared to VLF there is greater signal attenuation with distance, and range for a given power output decreases substantially. Some skywave interference possible.	No	Loran-C Decca* Consol* Radiobeacons
300 kHz - 3,000 kHz	Medium frequency	MF	Groundwaves provide reliable service, but the range for a given power output falls off rapidly. Skywaves begin to penetrate the ionosphere at the upper end of the frequency range.	No	Radiobeacons Consol* Standard radio broadcast band* Loran-A
3 MHz - 30 MHz	High frequency	HF	Groundwave range is limited to a few miles, but long-range communications still possible.	Variable	Ship-to-ship and ship-to shore communications*
30 MHz - 300 MHz	Very high frequency	VHF	Transmission limited by direct wave and/or ground-reflected wave.	Yes	Short- and medium-range communications* VOR*, ILS* Transit Hi-Fix* Gee
300 MHz - 3,000 MHz	Ultra high frequency	UHF	Skywaves cannot be used in this band. Reception of signals is virtually free of fading and interference by atmospheric noise.	Yes	Some communications DME* TACAN* Transit GPS
3,000 MHz - 30,000 MHz	Super high frequency	SHF	Also called microwave band. No skywave reception possible. Interference virtually nonexistent.	Yes	Radar*

* Not discussed in this handbook.

However this schedule may slip.) Additionally, GPS receivers are substantially more expensive than Loran-C receivers, although this price differential will undoubtedly narrow in the future as the market expands for GPS receivers.

–Marine Radiobeacons

Marine radiobeacons are nondirectional low power radio transmitting stations which operate in the low- and medium-frequency bands (285-325 kHz) to provide ground wave signals to a shipboard receiver equipped with a directional antenna. The receiver, termed a *radiodirection finder* (RDF) or (typically in aircraft installations) an *automatic direction finder* (ADF), is used to measure the relative bearing of the transmitter with respect to the user. The *line of position* (LOP) so determined can be crossed with another derived from a second radiobeacon to determine a fix. (As well an RDF LOP can be advanced or retired and crossed with an earlier or later LOP from the same or another station to determine a running fix.) Currently, there are approximately 200 marine radiobeacons (operated by USCG), located on or near the coasts of the United States.[4] The area of reliable signal reception from these radiobeacons varies with location, but generally includes coastal waters within 200 NM from the shore.

Marine radiobeacons and RDFs provide a redundant or backup system to more sophisticated radionavigation systems. RDF is a popular low-cost, medium-accuracy system for vessels equipped with only minimal radionavigation equipment. Some RDF receivers are powered with self-contained batteries, and can be used in applications where electrical power is at a premium (e.g., sailboats) and/or an independently powered backup navigation system is desired. According to some estimates, the size of the present RDF user community is the largest among U.S. radionavigation systems. It was estimated to number 675,000 users in 1991, but this figure is projected to decrease in the coming years. (Additionally, the present network of RDF stations is being rationalized, and some reductions in their number are being planned.) Under present plans, marine radiobeacons will remain in operation past the year 2000.

Marine radiobeacons are presently under consideration as a component of a differential global positioning system (DGPS). Using this concept, the DGPS signal would be transmitted in concert with a digital GPS correction to increase the accuracy of the GPS. A prototype system at Montauk Point, Long Island, has enabled a position-fixing accuracy of 30 ft (10 meters) to be achieved.

In contrast to Loran-C, marine radiobeacons do not provide sufficient accuracy or coverage to be used as a primary aid to navigation for large vessels in U.S. coastal waters. Although RDF receivers are still being manufactured, there are far fewer makes and models to choose from, compared to the wide variety of commercial Loran-C receivers. The price differential between RDF and Loran-C receivers, once substantially in favor of RDF, has now become almost nonexistent. Moreover, most Loran-C receivers are integrated with special-purpose computers that provide the user with a wealth of additional information of navigational relevance (e.g., ground speed, estimated time enroute, etc.). In contrast, marine radiobeacon receivers offer only the capability to fix the vessel's position, and track or home towards or away from the transmitter.

[4]Additionally, there are many more aeronautical radiobeacons that are located at or near to major airports in the United States.

–Transit

As with GPS, the *Transit* system is another DOD operated military and civilian satellite-based system consisting of satellites in approximately 600 NM polar orbits. These satellites transmit information continuously on 150 and 400 MHz. (Only one frequency is required to determine a position. However, accuracy is increased by using two frequencies.)

Transit offers slightly improved fix accuracy compared to Loran-C, and offers worldwide, but noncontinuous coverage. (Fix rates range from an average of once every 30 minutes at 80 degrees latitude to an average of once every 100 minutes near the equator. Under realistic worst-case conditions (5% of the time) a user must wait as many as six hours between fixes. Dead reckoning is used in the periods between fixes.) Transit receivers are presently much more expensive than corresponding Loran-C receivers and likely to remain so. There were an estimated 95,599 users of the Transit system in 1991. It is anticipated that the Transit system will be phased out in favor of GPS. Under present schedules, operation of the Transit system will be discontinued in 1996.

–Summary

The foregoing discussion, coupled with the material in Tables I–1 and I–2 shows the role and utility of the various radionavigation systems. Loran-C fills an important place in the mix of radionavigation systems and, moreover, has found wide acceptance; Loran-C has at least the second largest number of users of the major radionavigation systems, a point highlighted in Figure I–1. From the perspective of the user, Loran-C offers a proven, easy-to-use, accurate, all-weather radionavigation system applicable (as either a primary or complementary system) to nearly all phases of navigation within designated areas of coverage.

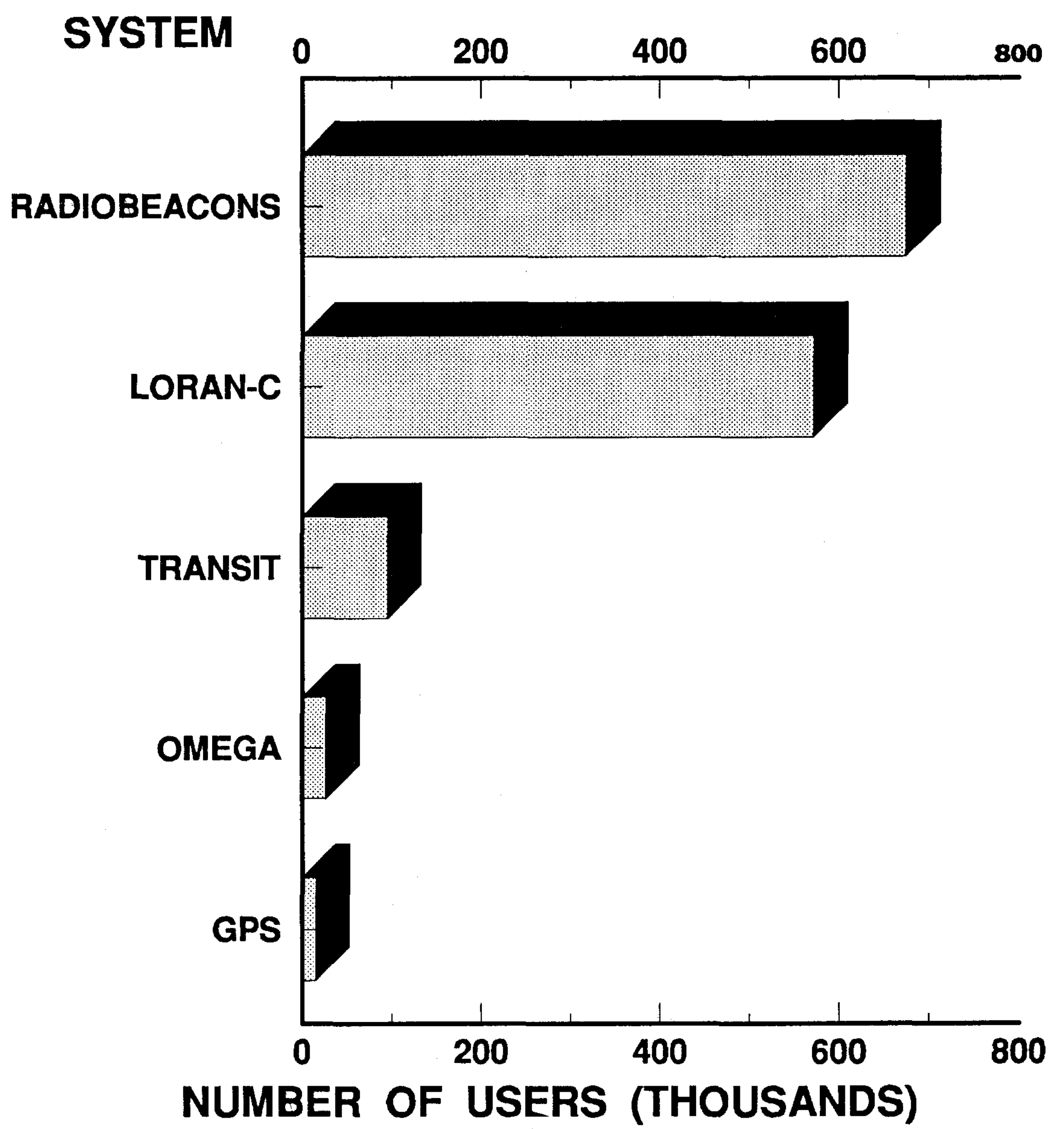
From the perspective of the user, Loran-C offers a proven, easy-to-use, accurate, all-weather radionavigation system applicable (as either a primary or complementary system) to nearly all phases of navigation within designated areas of coverage.

Simplified Principle of Loran-C Operation[5]

A more comprehensive technical discussion of the Loran-C system can be found in Chapters II and III. But briefly, the basic Loran-C system consists of a *chain* of three or more land-based transmitting stations, each separated by several hundred miles. Within the loran chain, one station is designated as a *master station* (M), and the other transmitters as *secondary stations,* conventionally designated Victor (V), Whiskey (W), Xray (X), Yankee (Y), and Zulu (Z). For example, the loran chain that serves the northeast United States (NEUS), consists of a master station located in Seneca, New York, with a Whiskey secondary located in Caribou, Maine, an Xray secondary in Nantucket, Massachusetts, a Yankee secondary in Carolina Beach, North Carolina, and a Zulu secondary in Dana, Indiana.

[5]This explanation is confined to use of loran as a hyperbolic system. Specially equipped receivers, costing much more than conventional receivers, can measure the range to the master or secondary stations. This *range – range* or RHO-RHO mode of operation is not discussed in this handbook.

FIGURE I-1. 1991 ESTIMATES OF THE NUMBER OF USERS OF THE MAJOR RADIONAVIGATION SYSTEMS.*



SOURCE: 1990 FEDERAL RADIONAVIGATION PLAN

* OTHER ESTIMATES FOR THE NUMBER OF LORAN USERS HIGHER.

Figure I–2 illustrates the simplest possible loran chain, called a *triad,* with a master (denoted M) and two secondary transmitters; Xray (X) and Yankee (Y).

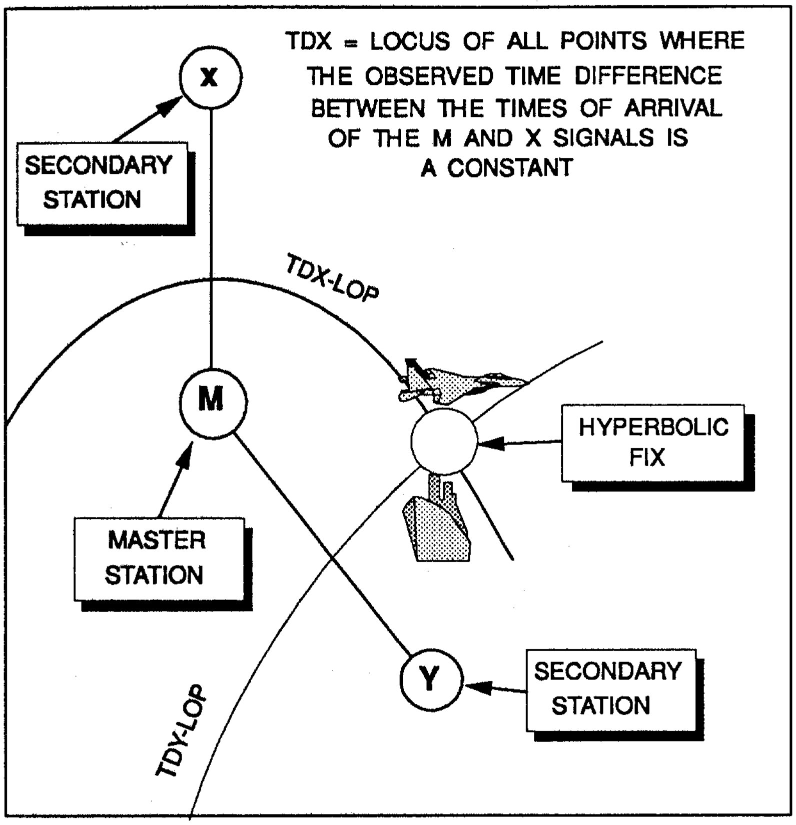
The master station and the secondaries transmit radio pulses at precise time intervals. An onboard Loran-C receiver (depicted by the vessel and aircraft icons in Figure I–2) measures the slight difference in the time that it takes for these pulsed signals to reach the ship or aircraft from both master-secondary pairs. These *time differences* (TDs) are quite small, and are measured in millionths of a second, *microseconds* (usec or us). Time differences for each master-secondary pair, denoted (TDX and TDY in Figure I–2) are displayed by the mobile loran receiver.

The difference in the time of arrival of signals from a given master-secondary pair, observed at a point in the coverage area, is a measure of the difference in distance from the vessel to each of the two stations. The locus of points having the same TD from a specific master-secondary pair is a curved line of position (LOP). (Mathematically, these curved LOPs are hyperbolas—or, more accurately, spherical or spheroidal hyperbolas on the curved surface of the earth. This is why Loran-C and related systems are termed *hyperbolic systems.*) The intersection of two or more LOPs from the TDs (shown as TDX-LOP and TDY-LOP in Figure I–2) determine the position of the user (a hyperbolic fix). (This is shown as a circle in Figure I–2, but one course charting convention specifies plotting all electronically determined fixes with a triangular symbol. Using this convention the loran fix would be plotted as a triangle, with the fix time and the word "loran" written next to the fix parallel to one of the chart axes.)

In practice, the operator simply reads the observed time differences from the Loran-C receiver display, and converts these TD readings to more commonly-used coordinates, such as latitude and longitude, using special charts (termed loran overprinted charts) that display the lattice of possible loran LOPs spaced in convenient units (e.g., every 5 or 10 usec for large-scale charts and at greater intervals for small-scale charts, see Chapter VI for details). Alternatively, most modern loran receivers employ computer algorithms for this coordinate conversion process, and when this feature is selected, an estimate of the user's latitude and longitude can be read directly from the loran receiver. (Aviation users deal exclusively in latitude/longitude coordinates.)

Basic marine Loran-C receivers merely displayed measured TDs, so that the navigator was required to fix the vessel's position from these TDs and suitable loran charts. Other necessary or useful navigational tasks (e.g., estimating current set and drift, determining course to steer, estimating speeds and times of arrival, etc.) had to be done manually using the fix information supplied by the loran receiver. However, in the past decade, there have been major advances in the state-of-the-art of loran receivers. Most loran receivers now have the ability to determine the vessel's (or aircraft's) speed and course over the ground, to define *waypoints* (points of specified position, such as entrance buoys, turnpoints, wrecks, prime fishing locations, shoals or other hazards to navigation, etc.) and monitor the progress of the vessel or aircraft towards these waypoints, providing such useful information as course corrections, estimated times of arrival, etc. Many loran receivers can interface with other shipboard electronic systems, including radar, autopilots, gyroscopes, fluxgate compasses, speed sensors, and electronic charting systems. These and other useful features of Loran-C receivers are discussed in Chapter IV.

FIGURE I-2. HYPERBOLIC FIX GEOMETRY FOR LORAN-C SYSTEM ILLUSTRATED



. . . In practice, the user simply reads the observed time differences from the Loran-C receiver display, and converts these TD readings to more commonly-used coordinates, such as latitude and longitude, using special charts or the coordinate converter of the receiver (if so equipped).

Components of the Loran System

Simply put, the components of the loran system include the land-based facilities, receiver (and associated equipment), and appropriate loran overprinted charts.

Land-based facilities are highlighted in Figure I–3. These include a master transmitter, at least two secondary transmitters, a control station, a monitor site and time reference. The function of the transmitters are to transmit the loran signals at precise instants in time. The *control station* and associated Loran Monitor Sites (LORMONSITES)[6] continually measure the characteristics of the loran signal as received, detect any anomalies or out-of-tolerance conditions (see Chapter II), and relay this information so that any necessary corrective action can be taken (e.g., to maintain TDs within specified tolerances). Although Loran-C transmitters incorporate extremely accurate cesium clocks as standard equipment, these signals need to be synchronized with standard time references. The U.S. Naval Observatory (USNO) supplies this time reference for the various loran chains.

[6]Simply put, a "station" is manned, a "site" is not. For aviation users, *Loran Aviation Monitors* (LAM) are presently installed at 192 facilities.

The second basic component of the loran system is the receiver (and associated antenna, antenna coupler, and ground). This receives the loran signals and converts these into useful navigational information. (Receivers are discussed in Chapter IV.)

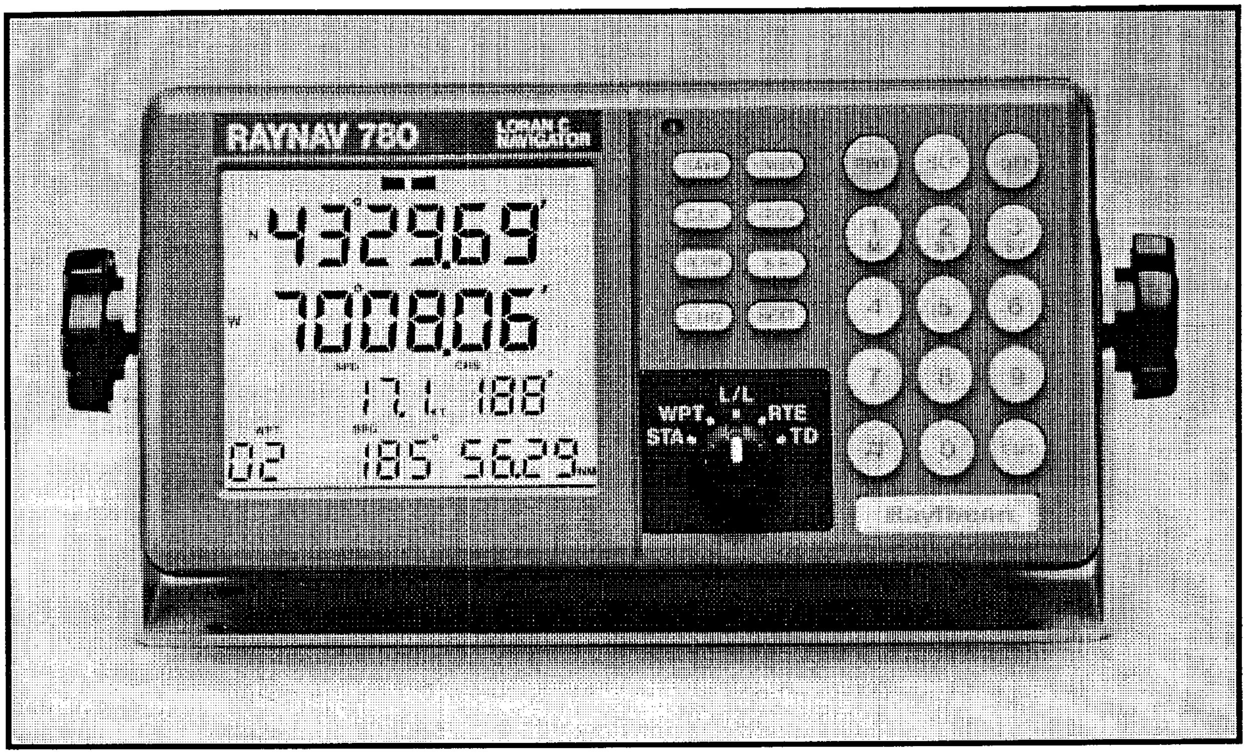
The third basic component of the system consists of a set of loran overprinted nautical charts that enable the mariner to convert the time differences into latitude and longitude. (Loran-C charts are discussed in Chapter VI.) As noted, aviation users work in latitude and longitude terms, so aeronautical charts are not overprinted with loran TDs.

A Brief History of Loran

The first "loranlike" hyperbolic radionavigation system was proposed by R. J. Dippy in 1937, and later implemented as the British *Gee* system in early 1942 (Pierce and Woodward 1971, Pierce 1989, Watson-Watt 1957, Johnson 1978, Webster and Frankland 1961).[7] Gee was a hyperbolic system operated at frequencies from 30 MHz to 80 MHz consisting of master and "slave" transmitters located approximately 100 miles apart. The choice of the frequency simplified the problem of dealing with the irregular variation of radio signal propagation, but limited the system to nearly a "line-of-sight" basis. (There is some bending of radio waves, so the distance to the radio horizon is slightly greater than the distance to the visual horizon.) This limitation was of lesser consequence to Gee, because Gee was intended as a system to assist bomber navigation in World War II. Obviously a line-of-sight constraint would severely limit the range of a marine navigation system.

The same principles of hyperbolic radio–navigation systems were also recognized in the United States, where a far-reaching project was initiated at the MIT Radiation Laboratory. John Alvin Pierce is generally credited as being the "father of loran" (and, for that matter, Omega) in the United States. Credit for the name "loran" apparently goes to LCDR L. M. Harding, USCG, who coined the name in response to security concerns that the name of the so-called "LRN Project" (as it was known at the time) was too obvious. Development of loran in the United States proceeded rapidly, spurred by urgent wartime needs, and soon (1943) a chain of transmitters (later called the *standard loran* or the *Loran-A* system) was being operated by the USCG. By the close of the war, at least 75,000 receivers had been distributed, as well as 2.5 million loran charts. Some 70 transmitters were in operation offering nighttime coverage over 30% of the earth's surface.

[7]Names and dates inserted in parentheses refer to references in the bibliography given in Appendix E of this handbook.

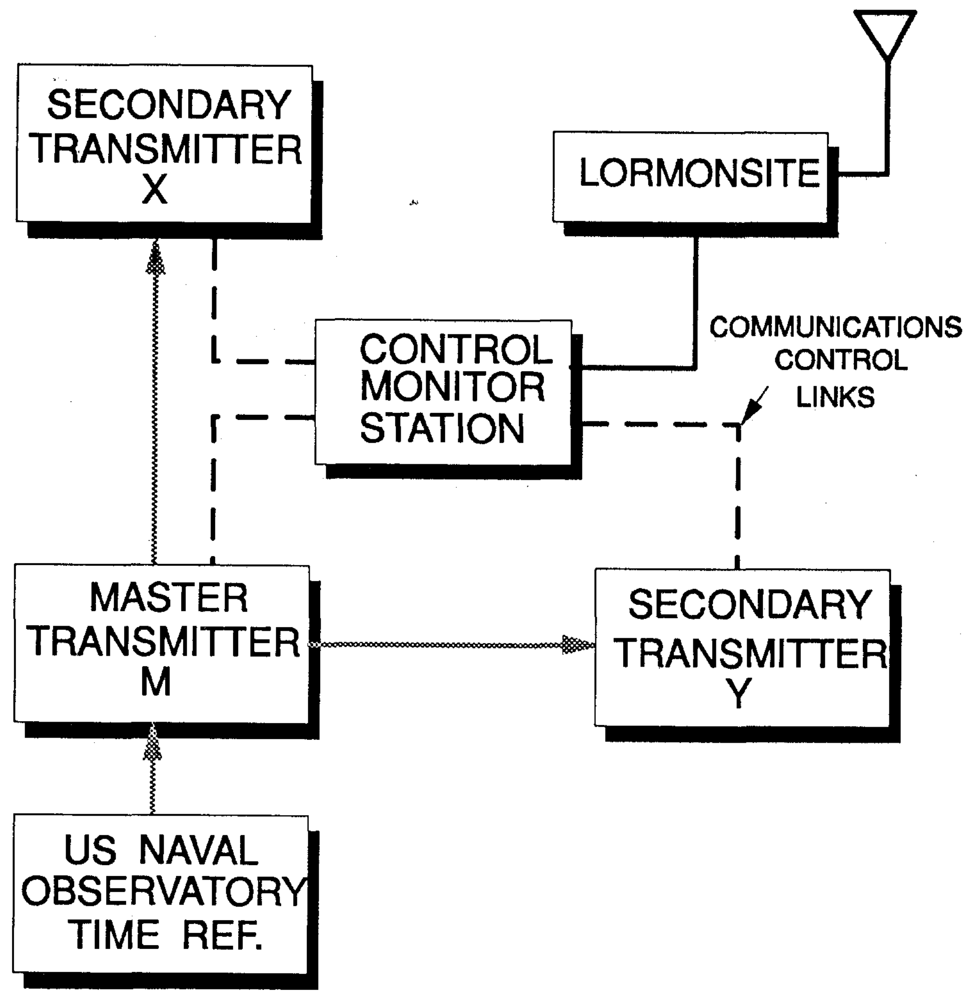


A Modern Loran-C Receiver Displaying Position (Latitude, Longitude), and Navigation Information.
(Photograph courtesy of Raytheon Marine Company)

Loran-A operated at frequencies between 1,850 and 1,950 kHz, and featured groundwave coverage (see Chapter II) of some 400 to 800 miles from the transmitting stations during the daytime, and skywave coverage at greater distances, as much as 1,400 NM at night. The accuracy of Loran-A fixes was approximately 1 NM for groundwave reception (explained in Chapter II) and as poor as 6 NM for skywave reception. Loran-A continued to operate after the war, serving both military and civilian users, as researchers sought to develop more reliable and accurate systems. Indeed, Loran-A continued to be operated in the United States until 1980, when this system was finally phased out in favor of Loran-C. (Some stations in a Canadian Loran-A chain continued operation until 1983and the system is still in operation in Japan as of this writing.)

Although the accuracy figures presented above can reasonably be thought of as typical for the Loran-A system, it is interesting to note that, with care, more accurate results could be obtained (Pierce and Woodward 1971, Pierce 1989). As an historical aside, it is interesting to mention that during the closing days of World War II, Pierce was in Bermuda taking field measurements. He noted (Pierce and Woodward 1971) that "...the measurements showed a probable

FIGURE I-3. MINIMUM ELEMENTS OF A LORAN CHAIN MASTER AND SECONDARY TRANSMITTERS, CONTROL STATION, LORMONSITE, AND TIME REFERENCE.



NOTE: CONTROL MONITOR STATIONS ARE TYPICALLY LOCATED IN THE SAME FACILITY AS TRANSMITTERS.

error in the position of the receiver of only 130 feet, although it must be admitted that the indicated position was about 1200 feet from the [charted] position." Pierce later continued (1989):

> "It was disappointing that the average error was about a quarter of a mile, and that there was no time to determine what might have caused so big an error. I was, however, somewhat relieved a year or two later, when the Hydrographic Office decided to 'move' Bermuda about 1200 ft on its charts. ...I never cared to inquire in what direction they moved it!"

Obviously this navigation system brought new standards of accuracy to marine navigation.

Postwar research sponsored by DOD and other agencies was directed at developing a more accurate and longer range version of loran. Various improvements, with names such as *Loran-B, Cyclan, Cytac,* ultimately culminated in the creation of the Loran-C system, which was made operational in 1957 and placed under USCG control in 1958. Loran-C offered greater accuracy and longer range than Loran-A. Nonetheless, both loran systems were operated in parallel for many years to ease the financial burdens on mariners equipped with Loran-A receivers. By 1974, however, the decision was made to phase out the Loran-A system, and to designate Loran-C the primary navigation system for Alaska and the Coastal Confluence Zone of the United States.

As of this writing, the USCG operates 49 Loran-C stations worldwide (including those in Italy, Japan, Spain, and Turkey) and yet other loran chains are operated by several other countries of the world, including China (Guoqiang, 1991), the Soviet Union (Funtikov, 1991), South Korea, Germany, Egypt, France, Denmark, Norway, Iceland, Canada, and Saudi Arabia. Additional loran chains are being considered to extend coverage to other areas in Europe, India, South Africa, and off the northern coast of South America.

CHAPTER II

The Loran-C System: A More Detailed View

Introduction

This chapter provides a more detailed exposition of the Loran-C system. In particular, a more technical presentation of the logic of hyperbolic systems is given, along with additional details on chains, signal propagation, ASF corrections, chain coverage, and salient characteristics of the transmitted signal. Chapter III extends this discussion to loran accuracy and its determinants, and methods for plotting positions.

Loran Transmitters, Chains, and Some Basic Definitions

As noted in Chapter I, a basic element of the Loran-C system is the loran chain. This chain consists of three or more stations (generally abbreviated LORSTAs for <u>lor</u>an <u>sta</u>tions), including a master and at least two secondary transmitters. (Each master-secondary pair enables determination of one LOP, and two LOPs are required to determine a position.) Each Loran-C chain provides signals suitable for accurate navigation over a designated geographic area termed a *coverage area*. (The limits of each chain's coverage area are given in Appendix B, and discussed in conceptual terms in this chapter and in Chapter III.) The coverage areas of the various Loran-C chains overlap somewhat, and there are many areas in the United States and nearby coastal waters where two (or more) chains can be received and used for navigation.[1] Criteria for selection of the most appropriate chain for navigation in areas covered by more than one chain are discussed in Chapter III.

Table II–1 identifies the ten Loran-C chains that provide coverage of the United States and contiguous areas, along with their common abbreviations, GRI designators (defined and discussed below), and the year that each chain was first completed. Closure of the so-called *mid-continent gap*[2] was completed with the commissioning of the NOCUS and SOCUS chains in 1991—an event marked with much pageantry as a sort of navigational equivalent of the completion of transcontinental railway of yesteryear.

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[1]For reasons that will be apparent in Chapter III, overlapping coverage areas are desirable. Redundant coverage not only increases the likelihood that the user can receive critical navigation information, but also offers the possibility of increased fix accuracy.

[2]This was an area of the United States where Loran-C coverage was missing. Closure of this gap benefits mariners who boat in the central states, but is of particular interest to aviation and terrestrial users of the Loran-C system.

TABLE II–1. LORAN-C CHAINS PROVIDING COVERAGE OF THE UNITED STATES AND CONTIGUOUS AREAS

Chain[1]	Common Abbreviation	GRI[2] Designator	Year Completed[3]
North Pacific Chain	NORPAC	9990	1981
Gulf of Alaska Chain	GOA	7960	1977
Canadian West Coast Chain	CWC	5990	1980
U. S. West Coast Chain	USWC	9940	1977
North Central U. S. Chain	NOCUS	8290	1991
South Central U. S. Chain	SOCUS	9610	1991
Great Lakes Chain	GL	8970	1980
South East U. S. Chain	SEUS	7980	1979
North East U. S. Chain	NEUS	9960	1979
Canadian East Coast Chain	CEC	5930	1983

[1]Relevant data on each of these chains, including the location of the master and secondary stations and the coverage diagram for the chain, can be found in Appendix B.

[2]Group repetition interval designator, discussed later in this chapter and defined in Appendix C.

[3]Portions of the chain may have been completed earlier. The date given in this table is the first year that the entire chain was operational.

Loran-C transmitters vary in radiated power from less than 200 kW (kilowatts) to over 2 MW (megawatts). To lend some perspective, the radiated power output of a typical AM station in the United States might be 5 kW. For FM transmissions the typical output would be larger, say 50 kW. Exact comparisons of power output are difficult to make, because the loran transmits only pulses. Nonetheless, in semi-quantitative terms at least, loran transmitters are quite powerful. Among other factors, the radiated power controls the range at which a usable signal can be received and, therefore, the coverage area of the chain.

Some transmitters have only one function (i.e., to serve as a master or secondary in a particular chain), but many transmitters are "dual rated," meaning that these can serve one function in one chain, and yet another in a neighboring chain. For example, the Dana, IN, transmitter serves as the Zulu secondary in the NEUS (9960) chain, and also as the master transmitter for the Great Lakes (8970) chain. Dual rating is desirable because, other things being equal, land acquisition costs and siting difficulties are reduced.

–Signal Characteristics and Some Important Definitions

Characteristics of the transmitted Loran-C signal are discussed in some detail below, but briefly, the transmitted signal consists of a series or group of *pulses* (each of a defined waveform discussed later). For the master signal, a series of *nine* pulses are transmitted (eight spaced 1,000 usec apart, followed by a ninth 2,000 usec later). (Pulsed transmission reduces the power requirements for system operation, assists signal identification, and enables precise timing of the signals.) Secondaries transmit a series of only *eight* pulses, each spaced 1,000 usec apart. This difference in the number of pulses, among other properties of the signal, enables some loran receivers to distinguish the signals from the master from those of the secondary stations. (Most receivers use phase codes, discussed below, for this purpose, however.) The master and each secondary in the chain transmit in a specified and precisely timed sequence. First, the master station transmits. Then, after an interval sufficient to allow the master signal to propagate throughout the coverage area, the first secondary in sequence transmits,[3] and so forth. Normally, the secondary stations transmit in the alphabetical order of their letter designator—e.g., Whiskey before Xray before Yankee, etc. The secondary transmission is timed as follows: after the master signal reaches the next secondary in sequence, this secondary waits an interval, termed the *secondary coding delay* (SCD) or simply *coding delay* (CD), to transmit. The total elapsed time from the master transmission until the secondary transmission is termed the *emission delay* (ED). The ED is equal to the sum of the time for the master signal to travel to the secondary (termed the *baseline travel time* or *baseline length* (BLL)) and the CD. Next, other secondaries (each with a specified CD/ED) transmit in sequence. The sequence is completed when the master again transmits the nine pulse group.

The length of time between successive transmissions of the master's pulse groups is termed the *group repetition interval* (GRI), and is expressed in microseconds (usec). The *GRI designator* is the GRI divided by ten, and is used as a symbol to identify and designate the loran chain.[4] Thus, the interval between successive transmissions (GRI) of the master pulse group for the Northeast US (NEUS) chain is 99,600 usec (about 0.1 sec), so the GRI designator for this chain is 9960. The GRI is chosen for each chain to be sufficiently large so that the signals from the master and each secondary in the chain have sufficient time to propagate throughout the chain's coverage area before the next cycle of pulsed transmissions begins.[5]

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[3]This scheme ensures that the first signal received by an observer in the coverage area is from the master. Reception of the master "starts the clock" in the loran receiver to measure the time difference.

[4]The terms GRI and GRI designator are often used interchangeably—it is clear from the number of digits which term is being referred to. GRIs are five-digit numbers, GRI designators are four-digit numbers.

[5]Setting a GRI for a chain involves the consideration of several factors. On the one hand, signal-to-noise considerations argue for relatively small GRIs. The Group Repetition Rate (reciprocal of the GRI) will be largest for short GRIs, and the increased duty cycle will provide an (cont'd.....)

Continuing the example of the NEUS (9960) chain, the CDs and BLLs for the various secondary stations in this chain are: Whiskey (CD 11,000 usec/BLL 2,797.20 usec), Xray (CD 25,000 usec/BLL 1,969.93 usec), Yankee (CD 39,000 usec/BLL 3,221.64 usec), and Zulu (CD 54,000 usec/BLL 3,162.06 usec). This information is essential for computation of theoretical *time differences* (TDs) or loran LOPs, as illustrated below.

As a point of interest, dual-rated stations are periodically faced with an impossible task of radiating two overlapping pulse groups at the same (or nearly the same) time. To resolve this difficulty, one of the signals is blanked or suppressed during this time period. *Priority blanking* occurs when the same signal is always blanked, whereas *alternate blanking* occurs when blanking alternates between the two rates. The type of blanking used for dual-rated stations is shown in the data sheets given in Appendix B.

The stations in the loran chain transmit in a fixed sequence which ensures that TDs can be measured throughout the coverage area. The length of time in usec over which this sequence of transmissions from the master and the secondaries takes place is termed the Group Repetition Interval (GRI) of the chain.

All Loran-C chains operate on the same frequency (100 kHz), but are distinguished by the GRI of the pulsed transmissions. GRIs for each chain, together with CDs and EDs for each secondary in the chain are also given in Appendix B.

–Chain Configuration

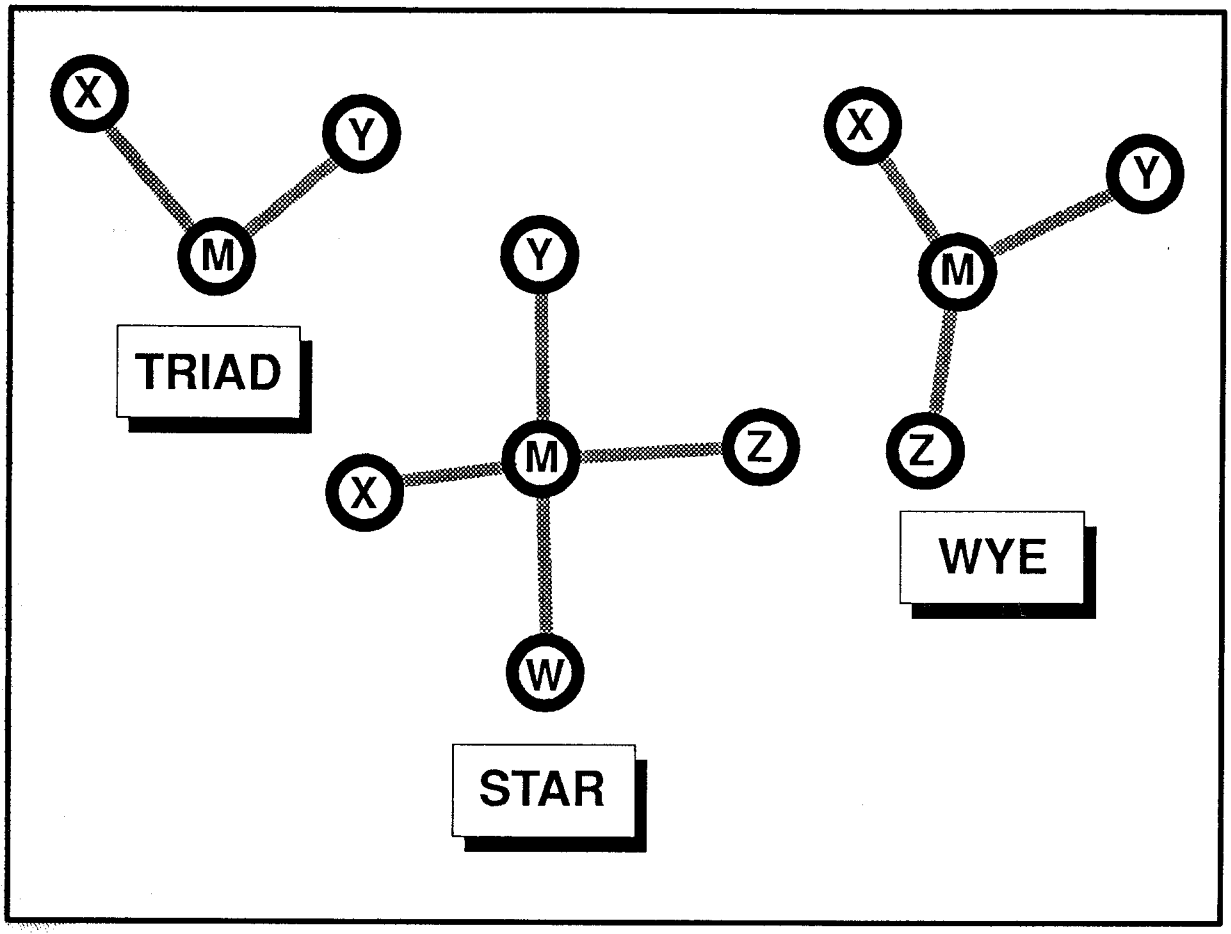
The physical locations of the master and secondary transmitters (among other factors) is an important determinant of both the accuracy and coverage area of the Loran-C chain. Although the *configuration* (site pattern of the transmitters) of each loran chain differs, it is convenient to group these configurations into three generic categories; the *Triad* (master and two secondaries), the *Wye* (master and three secondaries in a spatial arrangement roughly resembling the letter "Y"), and the *Star* (master and four or more secondaries roughly resembling a star in appearance), as illustrated in Figure II–1. For example, the Icelandic (9980) and Labrador (7930) chains are illustrations of Triads, the North Pacific (9990) is a Wye, and the NEUS (9960) is in a Star configuration.

These generic configuration categories are only approximate descriptions—the NEUS (9960) chain, for example, would be classified as a star in this taxonomy but, as can be seen from Figure II–2,[6] the resemblance is not literal. Interestingly enough, each transmitter in the 9960 chain is dual rated; the Zulu secondary is

[5](...cont'd.) improvement in the ratio of signal-to-noise. On the other hand, the pulse spacing, receiver recovery time, necessity for coding delays, baseline lengths, the distances between secondaries, and the number of secondaries impose constraints that collectively argue for longer GRIs. As with many technical parameters of the Loran-C system, practical compromises and trade offs need to be made. In the end, however, these considerations are of much greater relevance to the system designer than to the user.

[6]This figure also contains a great deal of other useful information. This figure is referred to later in the chapter, and again in Chapter III.

FIGURE II-1. TYPICAL CONFIGURATIONS FOR LORAN-C CHAINS

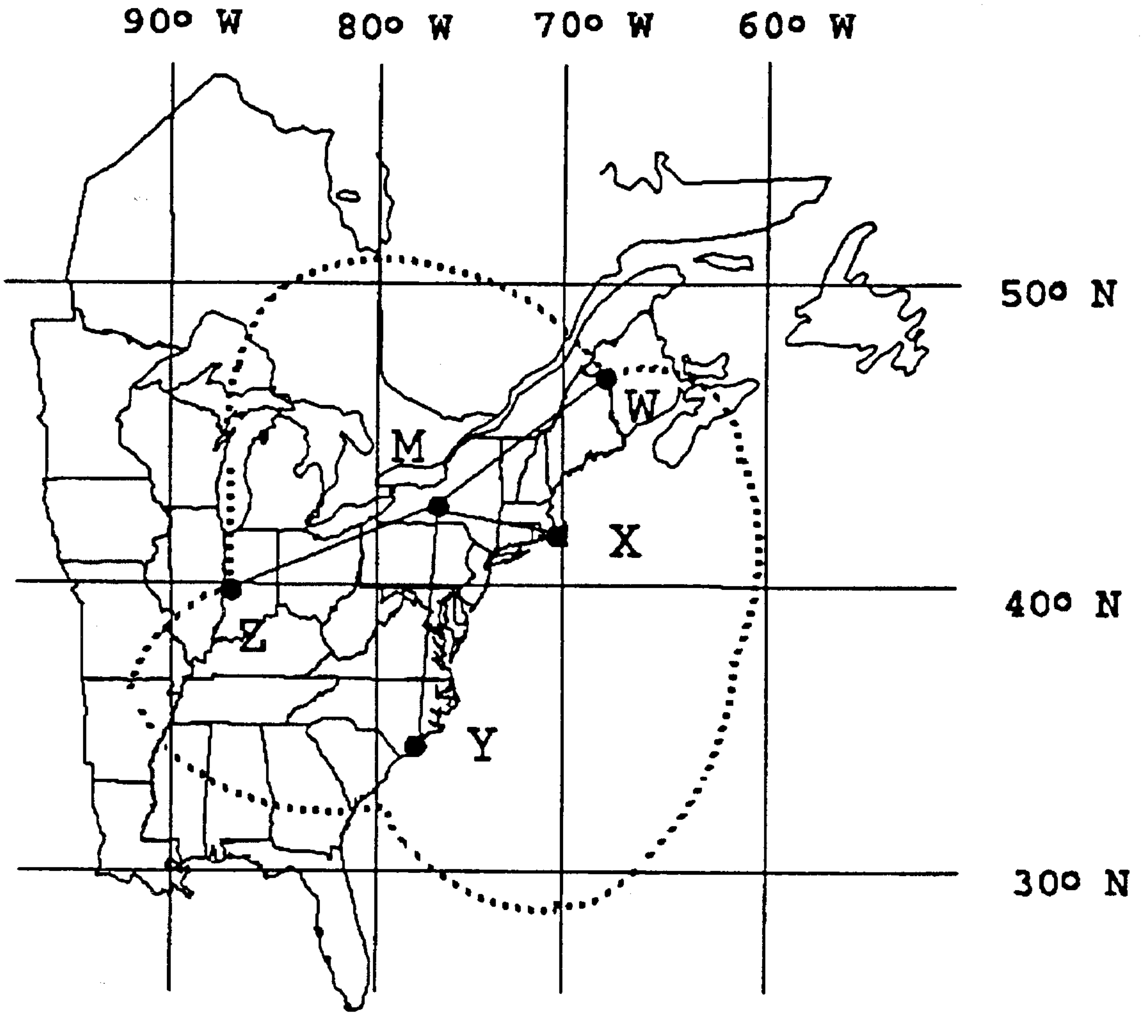


discussed above, the master, located in Seneca, NY, also serves as the Xray secondary for the Great Lakes (8970) chain, the Yankee secondary, located in Carolina Beach, NC, also serves as the Zulu secondary for the SEUS (7980) chain, the Xray secondary, located in Nantucket, MA, also serves as Xray secondary for the Canadian East Coast (5930) chain, and finally, the Whiskey secondary, located in Caribou, ME, also serves as the master station for the Canadian East Coast (5930) chain.

The chain configuration is an important determinant of the coverage and navigational accuracy of the chain. Three common configurations in use are the Triad, Wye, and Star.

The coverage area (discussed in Chapter III) for the NEUS (9960) chain is also shown in Figure II–2 enclosed by the long dashed lines. In this chain the dimensions of the coverage area

FIGURE II-2. AN ACTUAL LORAN-C CHAIN SHOWING TRANSMITTER AND MONITOR LOCATIONS FOR THE NEUS CHAIN (GRI 9960).



Transmitter	Coordinates		CD (uS)	Power (kW)
M Seneca, NY	42 42 50.71 N	76 49 33.31 W		800
W Caribou, ME	46 48 27.31 N	67 55 37.16 W	11000	800
X Nantucket, MA	41 15 12.05 N	69 58 38.54 W	25000	350
Y Carolina Beach, NC	34 03 46.21 N	77 54 46.10 W	39000	600
Z Dana, IN	39 51 07.66 N	87 29 11.59 W	54000	400

NOTE: *Estimated* Groundwave Coverage, actual coverage will vary.

are each nearly 1,000 NM in length—an area several hundred thousand square miles in extent. Off-shore coverage extends several hundred miles.

–Other Definitions

The geographic line (technically the arc segment of the great circle) connecting the master and each secondary is termed the *baseline* for the master-secondary pair. The length of the baseline (in nautical miles) varies with the chain and the individual master-secondary pair, but is typically several hundred miles. Other points on this same great circle containing the baseline (i.e., on the extension of the baseline beyond the two stations joined) are part of what is termed the *baseline extension.* As noted below, navigational use of a particular master-secondary pair in the area of the baseline extension is problematic. (Baseline extensions are shown on nautical charts, as discussed in Chapter VI.)

Key technical terms defined in this section include GRI, ED, CD, baseline, baseline travel time, and baseline extension.

Hyperbolic Systems: A Second Look

As noted in Chapter I, hyperbolic navigation systems function by measuring the time differences in reception of signals from the master and secondary transmitters.This chapter expands upon the basic idea of the hyperbolic system—with particular emphasis on the Loran-C system. This section is fairly technical, and may be skipped by the reader uninterested in such detail. Overall, the key technical points are simple enough. First, the locus of points of constant difference in distance from two stations is described by a mathematical function termed a *hyperbola.* Second, the same is true for time differences (assuming a constant propagation velocity). Therefore, LOPs of constant TDs are likewise hyperbolas. Finally, the real world is slightly more complex than the assumption of a constant propagation velocity would indicate. Precise calculations of the physical location of loran LOPs require a series of correction factors to be applied to account for the fact that loran waves slow down over seawater or land (compared to propagation through the atmosphere).

–Hyperbolic Geometry On a Plane

To be concrete, suppose that (as some ancients did) the earth were a flat plane, defined by the usual rectangular (X, Y) coordinate system, where the units of the X and Y axis are in nautical miles from an origin located at the point (0,0). Now suppose that two loran stations are located on this lattice, a master station located at the point M = $(x_m, y_m) = (-200, 0)$ along the X axis, and an Xray secondary station at the point S = (x_s, y_s) (200, 0)—some 400 NM to the right along the X axis. Consider an arbitrary point A = (x_a, y_a) on the lattice. From elementary plane geometry, the distance (in nautical miles) from point A to the master M, denoted d_{am}, is:

$$d_{am} = ((x_a - x_m)^2 + (y_a - y_m)^2),^{0.5} \qquad \text{(II-1)}$$

or, in terms of the defined location of the master station, equation (II–1) reduces to:

$$d_{am} = ((x_a + 200)^2 + y_a^2).^{0.5} \qquad \text{(II-2)}$$

Likewise, the distance from point A to the secondary, denoted d_{as}, is given by:

$$d_{as} = ((x_a - 200)^2 + y_a^2)^{.0.5} \qquad \text{(II-3)}$$

Finally, the difference between these distances, denoted Z, is given by:

$$Z = d_{am} - d_{as} \qquad \text{(II-4)}$$

$$Z = ((x_a + 200)^2 + y_a^2)^{0.5} -$$

$$((x_a - 200)^2 + y_a^2).^{0.5} \qquad \text{(II-5)}$$

FIGURE II-3. THE DIFFERENCE IN DISTANCE BETWEEN ANY POINT AND THE MASTER AND SECONDARY STATIONS FOR THE EXAMPLE IN THE TEXT

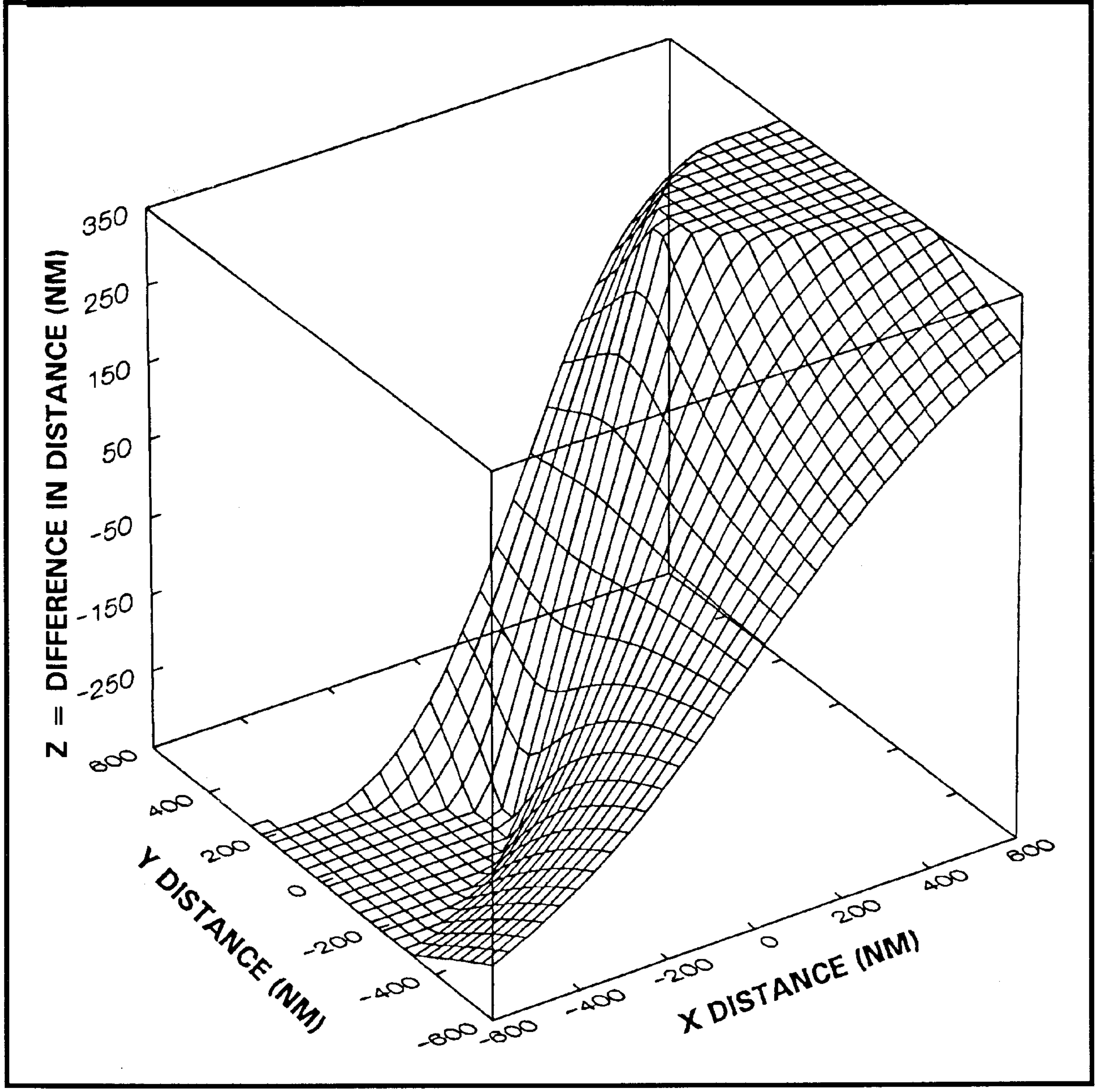
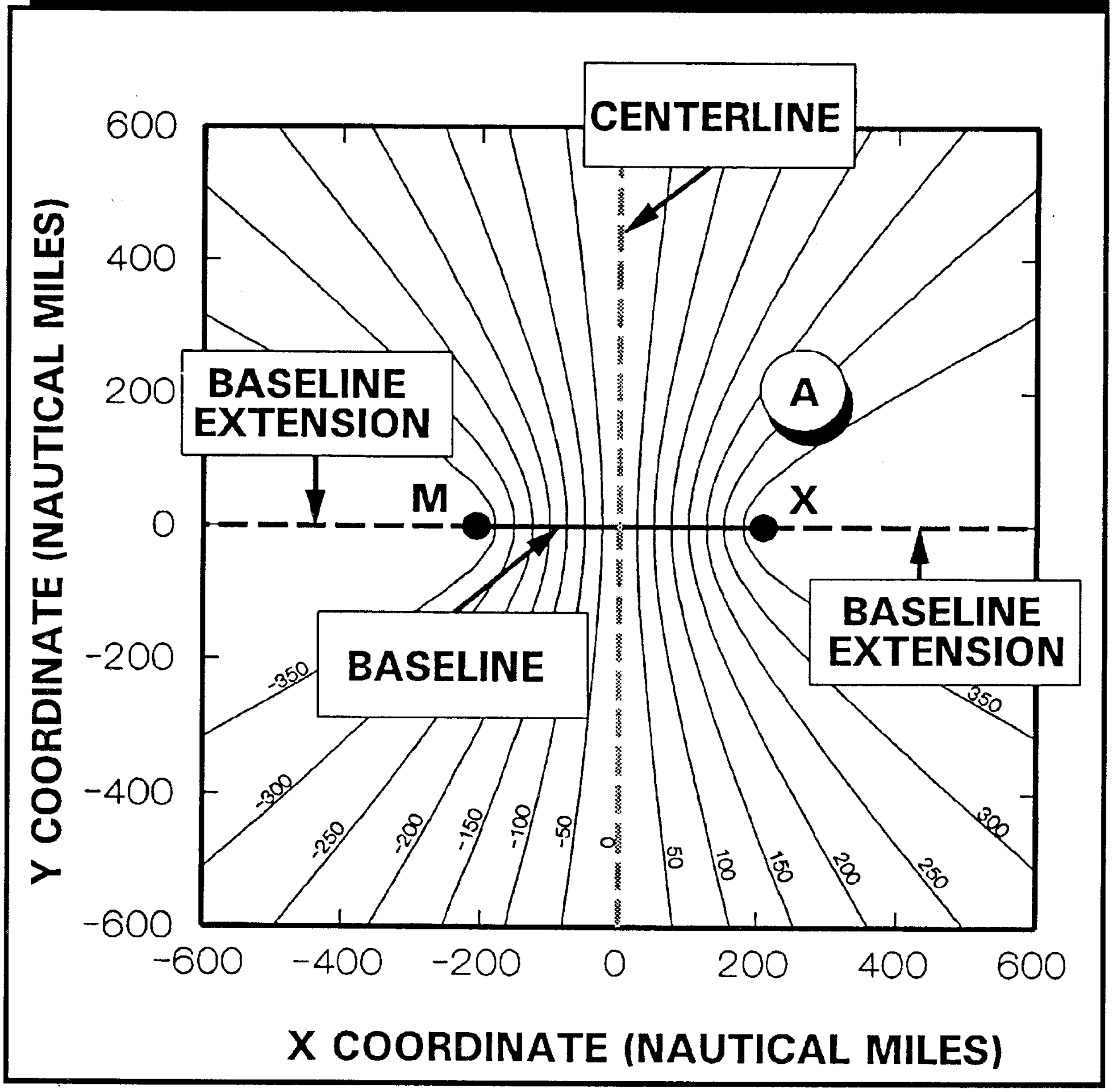


Figure II–3 shows how this distance difference function, Z, varies with the location of the point A in the plane. (This figure is truncated at Z = -350 (point A 350 miles chosen to the master than to the secondary) and at Z = 350 (point A 350 miles closer to the secondary than to the master).

A more typical presentation of this difference function is to take slices of this surface at various values for Z. These slices (referred to as level curves, or constant differential distance contours) are shown in Figure II–4. Mathematically, these curves are *hyperbolas*. On a sphere (rather than the plane used in Figures II–3 and

FIGURE II-4. A MORE CONVENTIONAL DEPICTION OF LORAN LOPs--SECTIONS OF THE DIFFERENCE FUNCTION GIVEN IN FIGURE II-3 ARE HYPERBOLAS.



II–4) these would be *spherical hyperbolas*, while on the slightly nonspherical earth these would be *spheroidal hyperbolas*. (Readers accustomed to looking at relatively large-scale loran overprinted nautical charts may be surprised at the curvature of the LOPs shown in Figure II–4. Over the short distances covered by a large-scale charts the curvature of the loran LOPs is much less apparent.)

The locus of points that have a constant difference in distance from a master and secondary station describes a mathematical curve termed a hyperbola.

To illustrate, suppose that point A were located at the point shown in Figure II–4, A = (271.9, 200). From equation (II–3), the distance from point A to the secondary would be approximately 212.5 nautical miles. And, from equation (II–2), the distance from point A to the master would be approximately 512.5 nautical miles. Point A, therefore, is 300 miles closer to the Xray secondary than to the master. Figure II–4 also shows the locus of all such points 300 miles closer to the secondary than to the master—this contour is a hyperbola labeled with the number 300. Thus, if we could determine that we were 300 miles closer to the secondary than to the master, we would be located somewhere along this hyperbolic LOP (300).

These hyperbolic LOPs are all curved, with the exception of the LOP where the difference in distance is exactly zero. This is termed the *centerline* of the system, and is a "straight" line (rather than a curve) that bisects the baseline. On the curved surface of the earth the centerline is actually a great circle oriented at right angles to the baseline. The baseline extension is also shown in Figure II–4.

–Equivalence Between Distance and Time

The contours in Figure II–4 are labeled in terms of distance, but (assuming a constant speed of signal propagation) could equally well be labeled in terms of *time difference* (TD). All that is necessary to calculate the theoretical time difference for any point in Figure II–4 is the speed of signal propagation and the CD of the Xray secondary. To a first approximation,[7] loran signals travel at the speed of light—it takes approximately 6.18 usec for the signal to travel one nautical mile.

TABLE II–2.
THEORETICAL CALCULATION OF TIME DELAY AT POINT "A"

Propogation	**Time (usec)**
Master to Secondary (400NM)—baseline travel time	2,472
Secondary Coding Delay (CD)	11,000
Secondary to Vessel (212.5NM)	1,313
Master to Vessel (512.5NM)	– 3,167
Measured Time Difference at Vessel	11,618

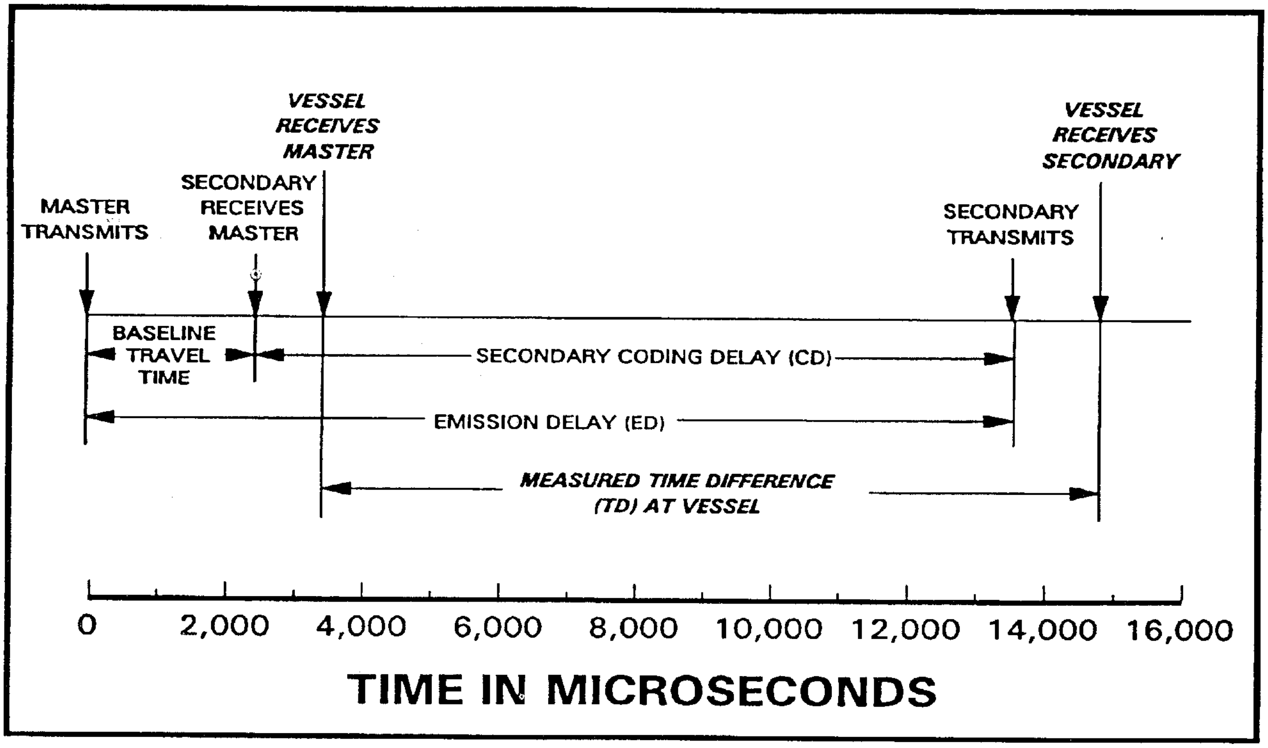
ALTERNATIVE CALCULATION

Baseline Travel Time (400NM)	2,472
Secondary Coding Delay (CD)	11,000
Difference in Distance (300) Between Master and Secondary Stations and Vessel	– 1,854
Measured Time Difference at Vessel	11,618

NOTE: Calculations shown here are only approximate, SFs and ASFs, for example, are not included here.

[7] This assumption is refined below as various corrections are introduced.

FIGURE II-5. GRAPHICAL DEPICTION OF TIME AXIS FOR COMPUTING LORAN-C TD FOR POINT "A."



Now consider point A again in Figure II–4. The distance from the master to point A is 512.5 NM, so the signal from the master would take approximately 6.18 (512.5) = 3,167 usec to reach a vessel at point A. The arrival of this signal starts the TD measurement in the vessel's loran receiver. When will the signal from the secondary arrive? Recall that the secondary transmits after an emission delay, equal to the baseline travel time plus the secondary coding delay. The master and Xray secondary are 400 miles apart in this illustration, so the baseline travel time (or baseline length in usec) is approximately 6.18 (400) = 2,472 usec. Assuming a CD for this secondary of 11,000 usec,[8] the Xray secondary would transmit 2,472 + 11,000 = 13,472 usec after the master. This signal must travel approximately 212.5 NM to reach the vessel at point A, a travel time of 6.18 (212.5) = 1,313 usec. Thus, in this example, the signal from Xray would arrive 13,472 + 1,313 = 14,785 usec after the master transmission. The observed TD at the vessel is this time, 14,785 usec, minus the time that the master signal arrives at the vessel, previously calculated as 3,167 usec. The theoretical TD (based upon these assumptions) at the vessel is 14,785 - 3,167 = 11,618 usec. This calculation is summarized in Table II–2 and the time lines are shown diagrammatically in Figure II–5.

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[8]Recall that EDs and CDs for each secondary in each chain are given in Appendix B.

TABLE II–3. PHASE FACTOR CORRECTIONS NECESSARY TO ENSURE LORAN-C ACCURACY SPECIFICATIONS ARE MET

Quantity	Primary Phase Factor	Secondary Phase Factor	Additional Secondary Phase Factor
Abbreviation	PF	SF	ASF
Brief Description	A correction to a Loran-C reading due to signal propagation through the atmosphere as opposed to propagation through free space.	The amount, in usec, by which the predicted time difference of a pair of Loran-C signals that travel over all-seawater paths differs from that of signals that travel through the atmosphere.	The amount, in usec, by which the time difference of an actual pair of Loran-C signals that travel over terrain of various conductivities differs from that of signals which have been predicted on the basis of travel over all-seawater paths.
Function of	Atmospheric Index of Refraction	Conductivity and permittivity of seawater—time delay a function of distance.	Specific paths between master, secondary, and vessel.
Included on Loran-overprinted Charts	Yes	Yes	Yes, on nearly all charts, see chart legend for details
Included in Lat/Long Conversions on Loran-C Receivers	Yes	Yes	Yes, on most modern receivers, check owner's manual for individual set.
Additional Information Available From	See Glossary for details	See Glossary for details	See DMAHTC *Loran-C Correction Tables*, for various chains and secondaries.

Other sources of system error remain, but these corrections are usually sufficient to ensure 0.25 NM absolute accuracy.

> **Loran LOPs can be displayed as distance differences or equivalently as TDs. Because TDs are measured on the receiver, these are shown on loran overprinted charts.**

Returning now to Figure II–4, the LOP on which point A is located could be labeled as 300 NM or equivalently as 11,618 usec. Any point on this LOP is 300 miles closer to the Xray secondary. Likewise (given the assumed CD), at any point on this same line, the theoretical TD would also be 11,618 usec. Because it is the TD rather than the difference in distance that is measured, it is much more convenient to label the loran overprinted nautical chart with the TD. More typically the LOPs shown on a loran overprinted chart would be evenly spaced every 5 or 10 usec. (See Chapter VI.)

With a few added complexities (discussed below) to account for a nonconstant speed of signal propagation, this is the exact procedure used for calculation of the theoretical location of the TDs on the nautical chart.

> **Though tedious, calculation of the location of lines of constant time difference is a straightforward exercise in geometry. To a first approximation, lines of constant difference in distance from two stations are also lines of constant TD.**

–More Exact Calculations

The foregoing calculations assume a constant speed of propagation of the Loran-C signal. This simplifying approximation is very nearly correct, but would result in position inaccuracies that exceed the designed accuracy limits of the Loran-C system. Therefore, it is necessary to refine this approximation.

Conventionally, this refinement process amounts to applying various corrections to either the speed of propagation of the loran signal or equivalently the predicted time required for the signal to traverse a specified distance. Typically three correction factors, termed *phase factors,* are applied. These are defined and summarized in Table II–3.

–Primary Phase Factor (PF)

The first of these factors is termed the *primary phase factor* (PF), and accounts for the fact that the speed of propagation of the signal in the atmosphere is slightly slower than in free space (vacuum). According to Bowditch, the speed of light in vacuum is 161,875 NM/sec (equivalent to 6.17761 usec/NM), whereas in the atmosphere the speed is slowed slightly to 161,829 NM/sec (equivalent to 6.17936 usec/NM). This speed difference is related to the fact that the atmospheric index of refraction is slightly greater than unity. All Loran-C overprinted charts and loran receivers incorporate the PF correction.

–Secondary Phase Factor

The second correction factor, termed the *secondary phase factor* (SF), reflects the fact that the loran groundwave is further retarded when traveling over seawater as opposed to through the atmosphere. When the Loran-C signals are transmitted, part of the electromagnetic wave is in the air, and part penetrates the earth's surface. Seawater is not as good a electrical conductor as air, so the signals are slowed as they travel over seawater. The amount of time required for travel over a specified distance will *exceed* that calculated using the PF by an amount equal to the SF. SF is applied as a correction term to the required travel time rather than as an adjustment to the propagation speed of the signals. Several equations for SF have been proposed, such as the so-called Harris polynomials shown below which relate the SF to the distance traveled, d (in statute miles):

$$SF = \begin{cases} -0.01142 + 0.00176d + 0.510483/d \text{ for } d \leq 100 \text{ SM} & \text{(II-6)} \\ -0.40758 + 0.00346776d + 24.0305/d \text{ for } d \geq 100 \text{ SM} & \text{(II-7)} \end{cases}$$

Table II–4 shows the PFs and SFs (from equation II–7)) applied to the approximate calculation given in Table II–4. For this example, the more exact calculation differs little from the approximate calculation, but (depending on the position within the coverage area) these differences could be numerically larger. As with PFs, SFs are incorporated into all Loran-C overprinted charts and commercial receivers.

–Additional Secondary Phase Factor (ASF)

Application of the PF and SF enables calculation or loran TDs over an all-seawater path. In practice (see, e.g., Figure II–2), loran signals travel over a mixed path; partially over land of various conductivities, and partially over seawater. The correction arising from the additional retardation of the signal is termed the *additional secondary factor* (ASF). ASF is the least predictable of the phase factors. Many things affect the value of ASF along a signal transmission path, including conductivity of the soil (which itself varies with the temperature and water content of the soil), distance traveled over land, etc. The accuracy of a conversion from Loran-C TDs to latitude/longitude (discussed in Chapters III and IV) depends critically on the value of ASF used in the mathematical signal propagation model.

ASF is generally calculated by considering the overall path as separate segments, each having a uniform conductivity value. The ASF of each segment can be computed and then the composite ASF is derived. A popular method of doing this is called *Millington's method*, reviewed in Appendix F. Another method of determining ASF is to measure the TDs at a point, compute the TDs at the same point using a mathematical model which assumes an all seawater propagation path, and then determine the difference between the measured and computed TDs. A finite number of such measurements can be made and extrapolated to cover the areas between measurements. ASFs "measured" in this fashion tend to be more accurate than those computed by Millington's method. ASFs at a fixed point in the coverage area actually vary with time. To achieve optimum accuracy these temporal ASF changes must be taken into ac-

TABLE II–4. THEORETICAL CALCULATION OF TIME DELAY AT POINT "A" USING PFs AND SFs

Propogation	PF (usec)	SF (usec)	Time (usec)
Master to Secondary (400NM)—baseline travel time	2,471.74	1.25	2,472.99
Secondary Coding Delay	NA	N/A	11,000.00
Secondary to Vessel (212.5NM)	1,313.11	0.55	1,313.67
Master to Vessel (512.5NM)	3,166.92	1.68	– 3,168.61
Measured Time Difference at Vessel			11,618.05

count. ASF variations with time are chiefly caused by changes in soil conductivity due to seasonal weather variations, day/night temperature variations, and local weather activity (thunderstorms, droughts, etc.).

In summary, speed and phase of Loran-C signals are affected by several physical parameters. The primary, secondary, and additional secondary phase factors (PF, SF, and ASF) account for changes due to air, seawater, and land paths, respectively.

–ASF Tables

As can be seen from Appendix F, computation of even *average* (let alone time varying) ASFs is quite tedious, and requires a substantial data base describing the relevant conductivity of land or mixed land/water paths. Fortunately these ASFs are incorporated into most Loran-C overprinted charts and also many Loran-C receivers.

Although ASF corrections are incorporated into most (but not all) modern Loran-C receivers, the user should remember that the government is responsible for the accuracy of the ASFs incorporated into ASF tables (see below) and loran overprinted charts. The government is not responsible and cannot guarantee the quality of the ASF data bases used in Loran-C receivers, these are strictly the responsibility of the manufacturer.

Additionally, ASFs can be found in a set of tables, called *Loran-C Correction Tables,* prepared and published by the Defense Mapping Agency, Hydrographic/Topographic Center (DMAHTC). These tables are published in a series of volumes, one for each loran chain. Each volume is organized into a set of pages for each *station pair* (master and secondary) or *rate* within the chain. Further, each page of corrections in the table covers an area three degrees in latitude by one degree of longitude. An index permits rapid determination of the appropriate page in the table to find ASFs of interest.

Table II–5 provides an excerpt of a *Loran-C Correction Table* for the NEUS (9960) chain and master-Whiskey station pair. This page covers an area off the mouth of the Delaware Bay between latitudes of 36° 0' N and 39° 0' N, and longitudes 74° 0' W and 75° 0' W. Large land bodies and areas outside the CCZ are represented by blank spaces on the pages (see Table II–5).

ASF corrections given in this table are to be applied to the measured TDs, and can be positive or negative. Negative values are prefixed with a minus (–) sign, while positive values are shown without sign. In some cases, a negative sign precedes a zero value; this results from rounding off a value slightly less than zero and indicates the trend of the correction.

–Use of Tables

According to DMAHTC, "ASF tables are published primarily for precision navigators who utilize electronic computers to convert Loran-C time differences to geographic coordinates." These tables can also be used by navigators using manual plotting methods for Loran-C navigation.

ASF corrections are typically small (no more than ± 4 usec), but can be significant for precise navigation, a point illustrated below.

The ASF correction table can be entered by using the vessel's *dead reckoning* (DR) position, indicated loran position, or position determined by other means. ASFs are added algebraically to the measured (observed) TD of the station pair. For example, suppose that the vessel were located at the approximate position 39° 0' N and 74° 30' W, and that the ASF for the Whiskey

TABLE II-5
EXCERPT FROM LORAN-C CORRECTION TABLES FOR 9960 CHAIN FOR AREA OFF DELAWARE BAY

9960–W **33W**

LONGITUDE WEST

LATITUDE NORTH	75° 0'	55	50	45	40	35	30	25	20	15	10	5	74° 0'
39°0'				-0.9	-1.0	-0.9	-0.9	-0.8	-0.7	-0.6	-0.6	-0.6	-0.5
55	-1.4	-1.2	-1.1	-0.9	-0.9	-0.9	-0.8	-0.7	-0.7	-0.6	-0.6	-0.6	-0.5
50	-1.3	-1.1	-1.0	-0.9	-0.8	-0.8	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.5
45	-1.3	-1.0	-1.0	-0.9	-0.9	-0.7	-0.6	-0.7	-0.6	-0.6	-0.6	-0.6	-0.5
40	-1.3	-1.1	-1.0	-0.9	-0.8	-0.7	-0.6	-0.7	-0.7	-0.6	-0.6	-0.5	-0.6
35	-1.1	-1.0	-1.0	-0.9	-0.8	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
30	-1.0	-1.0	-1.0	-0.8	-0.7	-0.6	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6
25	-1.0	-1.1	-0.9	-0.8	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
20	-0.9	-0.9	-0.8	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
15	-0.8	-0.8	-0.8	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
10	-0.6	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
5	-0.5	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
38°0'	-0.3	-0.6	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
55	-0.4	-0.5	-0.6	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	
50	-0.3	-0.3	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6		
45	-0.3	-0.4	-0.6	-0.6	-0.6	-0.6	-0.7	-0.6	-0.6	-0.6	-0.6		
40	-0.3	-0.3	-0.4	-0.5	-0.6	-0.7	-0.7	-0.6	-0.6	-0.6			
35	-0.2	-0.3	-0.3	-0.5	-0.7	-0.6	-0.7	-0.6	-0.6				
30	-0.2	-0.2	-0.3	-0.4	-0.6	-0.6	-0.7	-0.6					
25	-0.2	-0.2	-0.3	-0.4	-0.6	-0.5	-0.7						
20	-0.2	-0.2	-0.3	-0.4	-0.6	-0.5	-0.6						
15	-0.2	-0.2	-0.3	-0.3	-0.5	-0.4	-0.6						
10	-0.2	-0.2	-0.2	-0.3	-0.4	-0.4							
5	-0.2	-0.3	-0.2	-0.3	-0.4	-0.4			**Area Outside of CCZ**				
37°0'	-0.2	-0.2	-0.2	-0.2	-0.4								
55	-0.2	-0.2	-0.2	-0.2	-0.3								
50	-0.2	-0.2	-0.2	-0.2	-0.2								
45	-0.2	-0.2	-0.2	-0.2									
40	-0.2	-0.2	-0.2	-0.2									
35	-0.2	-0.2	-0.2	-0.2									
30	-0.2	-0.2	-0.2	-0.1									
25	-0.2	-0.2	-0.2	-0.0									
20	-0.2	-0.2	-0.2	-0.0									
15	-0.2	-0.2	-0.1	-0.0	0.0								
10	-0.2	-0.1	-0.1	-0.0	0.0	0.1							
5	-0.1	-0.0	-0.0	-0.0	0.1	0.1							
36°0'	-0.1	-0.0	-0.0	-0.1	0.1	0.2	0.3						

SOURCE: Defense Mapping Agency, Hydrographic/Topographic Center. *Loran-C Correction Table, Northeast USA 9960,* DMA Stock No. LCPUB 2211200-C, 1983.

station pair were desired. From Table II–5 it can be seen that the ASF is –0.9 usec. Thus, in this instance 0.9 usec should be subtracted from the observed TD to obtain a corrected TD.

> **ASF corrections should be used with caution for areas within ten nautical miles of land (coastline effect) and should not be used with charts that provide a corrected lattice.**

Care should be taken to ensure that the correct table (hence chain) is used, and that the correction station pair is considered. Table II–6, for example, shows how the ASF correction (for the same latitude and longitude used in the above illustration) varies with the secondary station and chain. Assuming the location given, the correction appropriate for the Xray secondary in the 9960 chain would be 2.9 usec, compared to only 0.3 usec if the 8970 chain were used. It is particularly important to use the right table (correct chain and station pair) when determining ASF corrections.

Lest the reader conclude that all this emphasis on refined calculations is much ado about nothing, the accuracy of the predicted LOP is a key determinant of the accuracy of the loran position. Loran-C accuracy and its determinants are explored in some detail in Chapter III. One important determinant of accuracy is the *gradient* of the LOP. Technically, the gradient is the number of ft (meters, yds, etc.) position difference divided by the number of microseconds. As shown in Chapter III, these gradients are smallest on the Loran-C baseline, and increase throughout the coverage area. Even for positions located on the baseline, however, the gradient is nearly 492 ft/usec. So an ASF correction of 3 usec, for example, corresponds to a position difference of *at least* 1,476 ft in position—and perhaps several times greater. Concern over appropriate ASF corrections is not merely a technical quibble.

TABLE II–6
ASFs DEPEND UPON THE OBSERVER'S LOCATION, CHAIN, AND SECONDARIES USED

Approximate Position L: 39° 00' N, Lo: 74° 30' W

	SECONDARY			
Chain	X	W	Y	Z
9960	2.9	-0.9	1.9	-0.3
8970	0.3	0.0	Not given	N/A

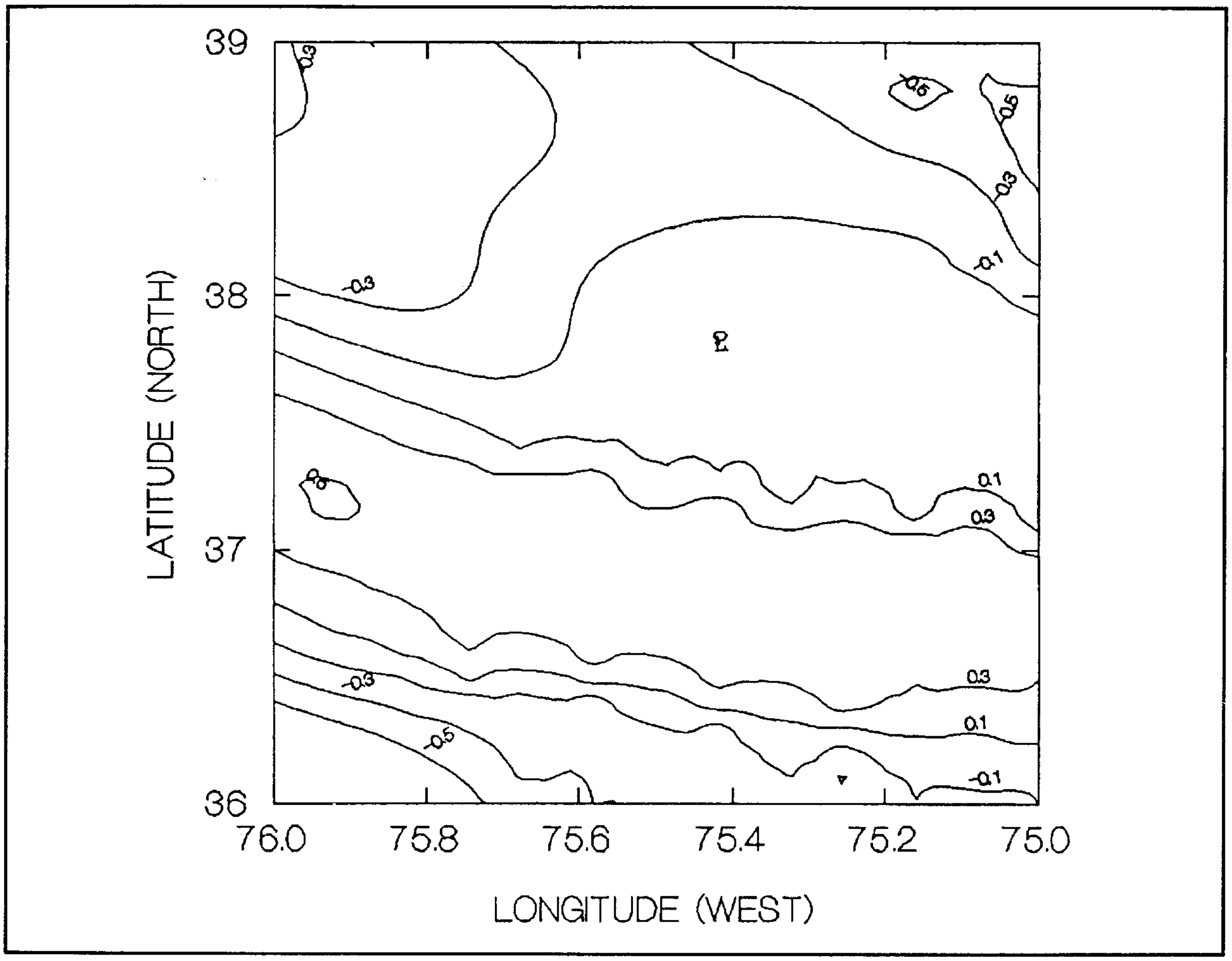
SOURCE: *Loran-C Correction Tables.*

ASF tables are typically not interpolated, as the ASF functions are generally not linear. Figure II–6, for example, shows smoothed contours of equal ASF for the data displayed in Table II–5. As can be seen, there are numerous ridges, saddle points, and local maxima and minima in the surface described by the data. Simple linear interpolation would not offer any meaningful increase in accuracy for such a complex surface. Rather, the correction nearest to the vessel's approximate latitude and longitude should be applied to the appropriate time difference.

ASF corrections may change over time, as new and more accurate corrections are determined, so the latest volume should be consulted. According to some observers (Melton, 1986) the *average* ASFs are changing in such areas as Florida's west coast, due to the construction of high-rise buildings there.

ASFs (and loran accuracy in general) are much less certain in the vicinity of the coastline (coastline effect). DMAHTC recommends that ASF corrections be used with caution for areas within 10 NM of a coastline.

FIGURE II-6. CONTOURS OF CONSTANT ASF CORRECTION FOR A PORTION OF THE AREA COVERED BY THE 9960 CHAIN.



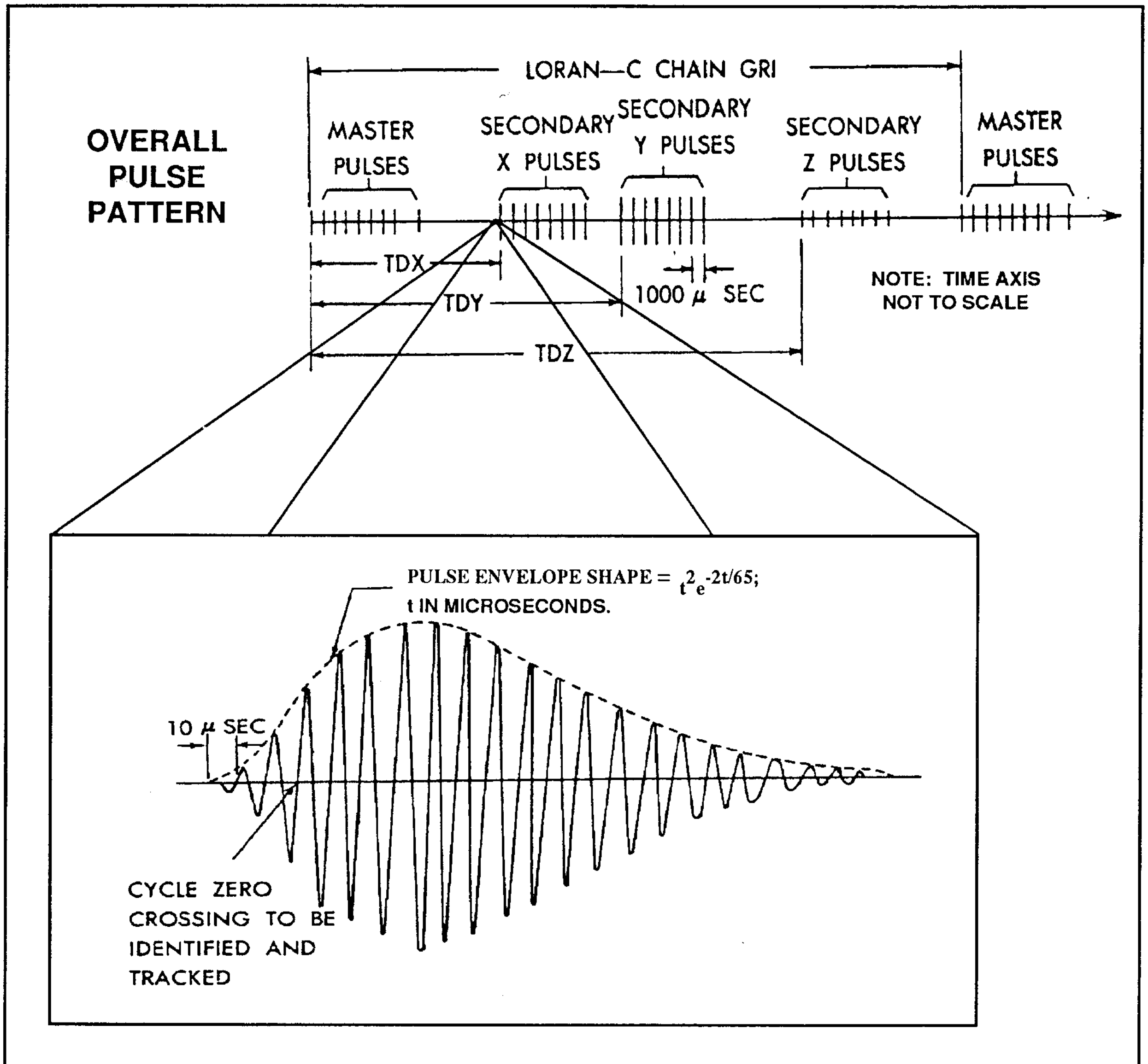
Groundwave versus Skywave Propagation

Radio energy from a Loran-C transmitter emanates in all directions. The pulsed Loran-C signal, therefore, may reach the observer by many propagation paths. These paths are conveniently grouped into two major categories: (i) *groundwave,* and (ii) *skywave.*

The groundwave signal propagates in the atmospheric medium below the ionosphere (an electrified layer of the atmosphere) and is relatively well understood and quite predictable. However, the signal strength of the groundwave is attenuated as it follows the contour of the earth. At great distances from the transmitter, the groundwave signal is substantially attenuated.

Skywaves consist of that component of the Loran-C signal which travels to the observer via reflection from the ionosphere which is actually comprised of several reflecting layers, assigned letter symbols in conventional nomenclature. For the 100 kHz frequency of the Loran-C, this

FIGURE II-7. PULSE PATTERN AND DETAILED PULSE SHAPE FOR LORAN-C TRANSMISSION.



DETAILED VIEW OF INDIVIDUAL PULSE SHAPE

reflection will take place in the lower E or D region of the ionosphere. The reflection height will vary from approximately 60 kilometers during daylight, to approximately 90 kilometers at night. From the geometry of the reflection, it is obvious that the skywave signal must travel a longer distance to reach an observer and will arrive after the corresponding groundwave—generally after a time lapse of from 35 usec to 1000 usec after the groundwave (depending upon the height of the reflecting layer in the ionosphere). Because skywaves do not travel over the surface of the earth, these are not attenuated to the same extent as the groundwave. In consequence, at long distances, the skywave signal may be very much stronger than the groundwave signal. The skywave can cause distortion of the received groundwave signal in the form of fading and pulse shape changes—generally given the name "skywave contamination."

Although it is possible to develop position information from skywave signals (and, indeed, skywaves were used in early loran), the most accurate navigation requires the use of the loran groundwave. (Use of skywaves for navigation is discussed briefly in Appendix H.)

The reason why groundwaves are preferred over skywaves for accurate navigation is that the propagation conditions (in the ionosphere) are not stable, but change from day-to-day and even hour-to-hour, which vastly complicates the problem of prediction of arrival times for skywaves. The skywave, therefore, is generally regarded as a "nuisance," and the Loran-C system has been designed in part to minimize the possible influence of skywaves on groundwave reception and tracking.

Pulse Architecture and Related Technical Matters

It is noted above that the Loran-C system uses pulsed transmission—nine pulses for the master and eight pulses for the secondary transmissions. Figure II–7 shows this overall pulse pattern for the master and three secondary transmitters (Xray, Yankee, and Zulu). Shown also in Figure II–7 is an "exploded" view of the Loran-C pulse shape. It consists of sine waves within an envelope that might loosely be described as

FIGURE II-8. LORAN-C PHASE CODES FOR MASTER AND SECONDARY TRANSMITTERS

GRI INTERVAL	MASTER TRANSMITTER	SECONDARY TRANSMITTER
A	++--+-+-+	+++++--+
B	+--+++++-	+-+-++--

NOTE: (+) INDICATES ZERO DEGREES CARRIER PHASE
(-) INDICATES 180 DEGREES CARRIER PHASE
LORAN-C INTERVALS A & B ALTERNATE IN TIME

TABLE II–7. TECHNICAL AND OTHER REASONS FOR SEVERAL KEY LORAN ATTRIBUTES

Feature	Reason for Inclusion
Pulsed Transmission	To save on prime power required for transmission and to facilitate signal identification and precise timing. Multiple pulses were selected over single pulses to increase the average power.
Different Number of Pulses on Master versus Secondary	Facilitate identification of master. On modern commercial receivers phase coding is now used for this purpose.
Phase Coding	Reduce the effects of skywaves on the loran groundwave. Also assists in identifying master from among secondaries.
Pulse Shape	Selected so that 99% of the radiated power is contained within the allocated frequency band of 90–110 kHz. Fine structure in pulse shape enables *cycle matching* to be used, increasing accuracy of timing relative to *envelope matching*.
Standard Zero Crossing	Compromise made; selected to be early enough in the pulse to lessen effects of skywave contamination. Selected as 30 usec in normal use (without cycle step).
Blink Codes	To provide users with indications of loran system accuracy and reliability. Secondary blink is detectable by the majority of users to indicate low power, improper TDs, ECD out of tolerance, and/or improper phase code or GRI.
90–110 kHz Frequency	Avoid interference with other users of the frequency spectrum and ensure adequate (relatively long) range. The spacing between each cycle of 100 kHz is approximately 10 usec, and technologically it was easier to design equipment to measure time in tenths of a microsecond.
Relative Time Measurements	Simplify and reduce costs of receivers (no absolute time reference required). Eliminate the need to account for all variances in propagation time (e.g., those arising from use of notch filters) in order to have accurate system.

Overall, a complex system at a detailed level. But these complexities are essential to create highly accurate, reliable, long-range system that is easy to use.

"teardrop shaped," and is referred to technically as a t-squared pulse. (The equation for the envelope is also included in Figure II–7.) This pulse will rise from zero amplitude to maximum amplitude within the first 65 usec and then slowly trails off or decays over a 200–300 usec interval. The pulse shape is designed so that 99% of the radiated power is contained within the allocated frequency band for Loran-C of 90 kHz to 110 kHz.

The rapid rise of the pulse allows a receiver to identify one particular cycle of the 100 kHz carrier. Cycles are spaced approximately 10 usec apart. The third cycle of this carrier within the envelope is used when the receiver matches the cycles. The third zero crossing (termed the *positive 3rd zero crossing*) occurs at 30 usec into the pulse. This time is both late enough in the pulse to ensure an appreciable signal strength and early enough in the pulse to avoid skywave contamination from those skywaves arriving close after the corresponding groundwave.

-Phase Coding

Within each pulse group from the master and secondary stations, the phase of the *radio frequency* (RF) carrier is changed systematically from pulse-to-pulse in the pattern shown in Figure II–8. This procedure is known as *phase coding*. The patterns "A" and "B" alternate in sequence. The pattern of phase coding differs for the master and secondary transmitters. Thus, the exact sequence of pulses is actually matched every two GRIs—an interval known as a *phase code interval* (PCI).[9]

Phase coding enables the identification of the pulses in one GRI from those in an earlier or subsequent GRI. Just as selection of the pulse shape and standard zero crossing enable rejection of certain skywaves, phase coding enables rejection of others; late airway skywaves will have a different phase code from the groundwave. Because the master and secondary signals have different phase codes, these can be distinguished by the loran receiver. Phase coding also offers other technical benefits.

–Blink Coding

The Loran-C system also permits the secondary transmissions (more specifically the first two pulses of the secondary pulse group) to "blink." This secondary blink can be detected by the loran receiver, and is used to warn users that the loran signal is unreliable and should not be used for navigation. (The specifics of the blink display differ from receiver-to-receiver—in some cases a blink alarm on the receiver will light, in others the displayed TDs simply blink on and off.) Blink alarms warn that the signal power, TD, or ECD is out-of-tolerance (OOT) and/or that an improper phase code or GRI is being transmitted. The blink coding contributes significantly to the *integrity* of the loran system.

When secondary blink is enabled, the first two pulses of the affected secondary are blinked at a four-second cycle; about 3.6 seconds off and about 0.4 seconds on. Secondary blink is used to advise users of potential problems. The loran system also has the capability to blink the master signal. Master blink is used for internal communications, and does not indicate a system malfunction. Most modern user receivers are not programmed to detect master blink.

Concluding Comments

Table II–7 summarizes some of the key technical features of the Loran-C system and reasons for their inclusion. At a detailed level, this system is highly complex, but these complexities are essential to create a highly accurate, reliable, and easy to use long-range system.

[9]Technically speaking, the exact sequence of loran pulses does not repeat every GRI, but rather every PCI.

CHAPTER III

Position Determination and Accuracy

Introduction

This chapter shows how positions are identified using Loran-C, examines the important topic of Loran-C accuracy and its determinants, and briefly notes how range limits and coverage diagrams are developed for this system. (Actual plotting of positions, including the use of loran linear interpolators, is addressed more fully in Chapter VI.) Although some of the material in this chapter is unavoidably technical, the information presented here is very important to mariners and other users who need to know the capabilities of the loran system, and how to exploit these capabilities in full measure. Coast Guard and Coast Guard Auxiliary experience in dealing with thousands of search and rescue cases annually indicate that many mariners use loran without full knowledge of its capabilities or limitations. Some mariners have excessively optimistic expectations for the accuracy of the system and little knowledge of how accuracy varies throughout the coverage area—thereby facing increased risk of grounding or other navigational mishaps (see Humber, 1991 for an illustrative sea story). Yet others realize some of these limitations, but are unaware of techniques to take full advantage of the system—thereby sacrificing efficiency and utility.

The principal reason for including the material in this chapter is that this information is important. A subsidiary reason is that the subject of accuracy and its determinants is generally either omitted entirely or treated in only a sketchy manner in many texts and/or the owners' manuals that accompany loran receivers—including those manufactured by some of the leading companies. It can be argued rightly that the loran user need not be a scientist or engineer in order to operate a loran set, but it is equally true that a knowledge of the basic technical principles of this system is essential to safe and efficient navigation.

Position Determination Using TDs

As noted in Chapter II, differential distances or TDs from a station pair determine a "family" or set of hyperbolic LOPs (see, for example, Figure II–4). Knowledge of even one loran TD can be useful[1] (e.g., by crossing it with a visual or radar bearing or range to determine a fix) but, more typically, TDs from two station pairs are

[1]Although use of two LOPs is certainly preferred, it sometimes happens that only one station pair is available (e.g., because of a scheduled or unscheduled outage). Users should be alert to opportunities to exploit whatever information is available.

used for fixing a user's position. Figure III–1, for example, shows the same geographic plane and master station used for illustration in Figure II–4. This figure shows the differential distances from the master station, assumed to be located at the point (-200, 0), and the Yankee secondary, assumed to be located at the point (0, 500) in the rectangular grid. Again the familiar pattern of hyperbolic LOPs is shown in Figure III–1, except that this figure presents the difference in distance of the LOPs for the *master-Yankee station pair* rather than the master-Xray pair.

If *both* the master-Xray and master-Yankee station pair time differences are considered, the individual sets of loran LOPs (shown in Figure II–4 and Figure III–1) can be superimposed to determine the *hyperbolic lattice* illustrated in

FIGURE III-1. ANOTHER SET OF HYPERBOLIC LOPs FROM A MASTER, LOCATED AT (-200,0), AND A YANKEE SECONDARY, LOCATED AT (0,500).

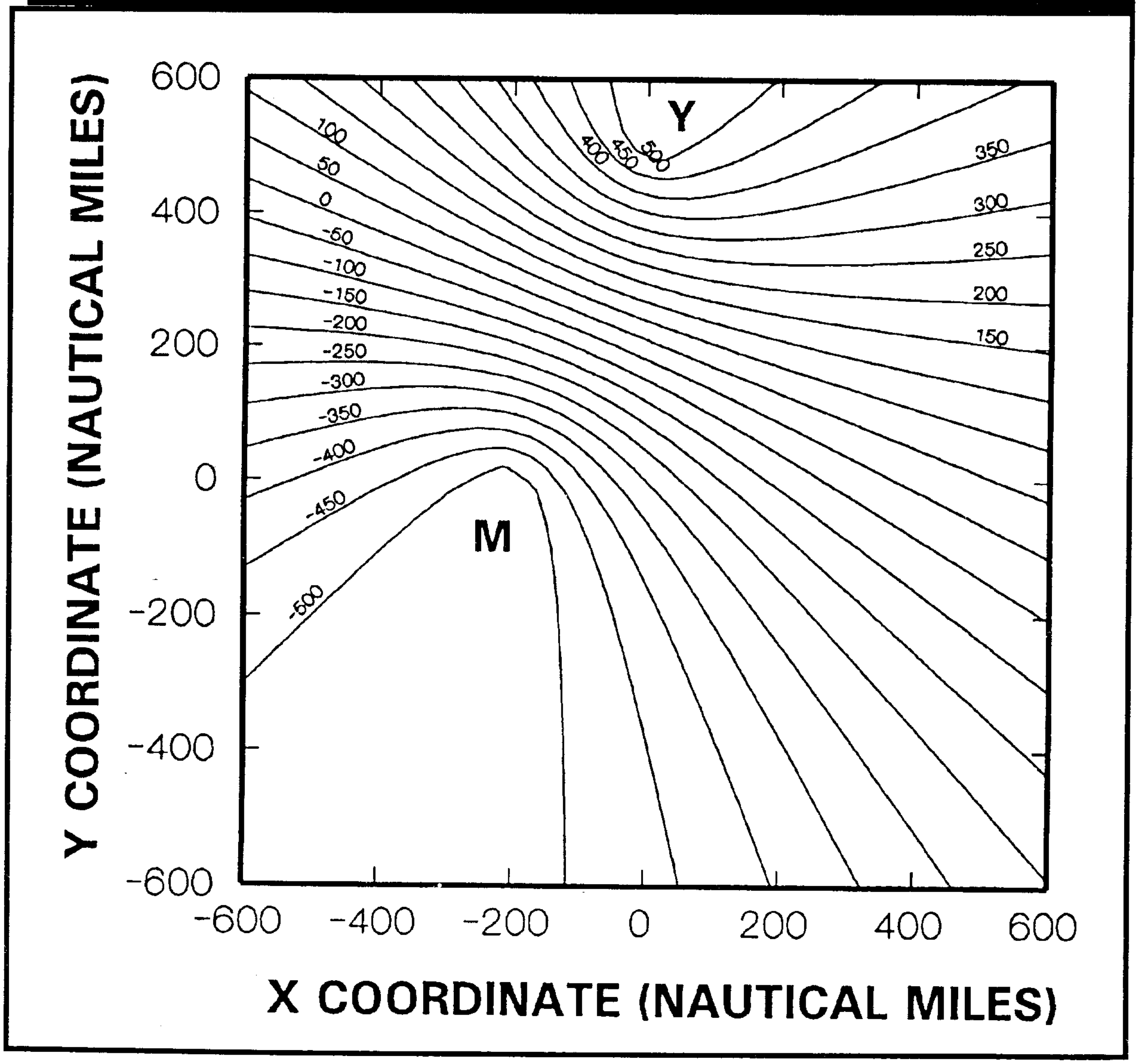
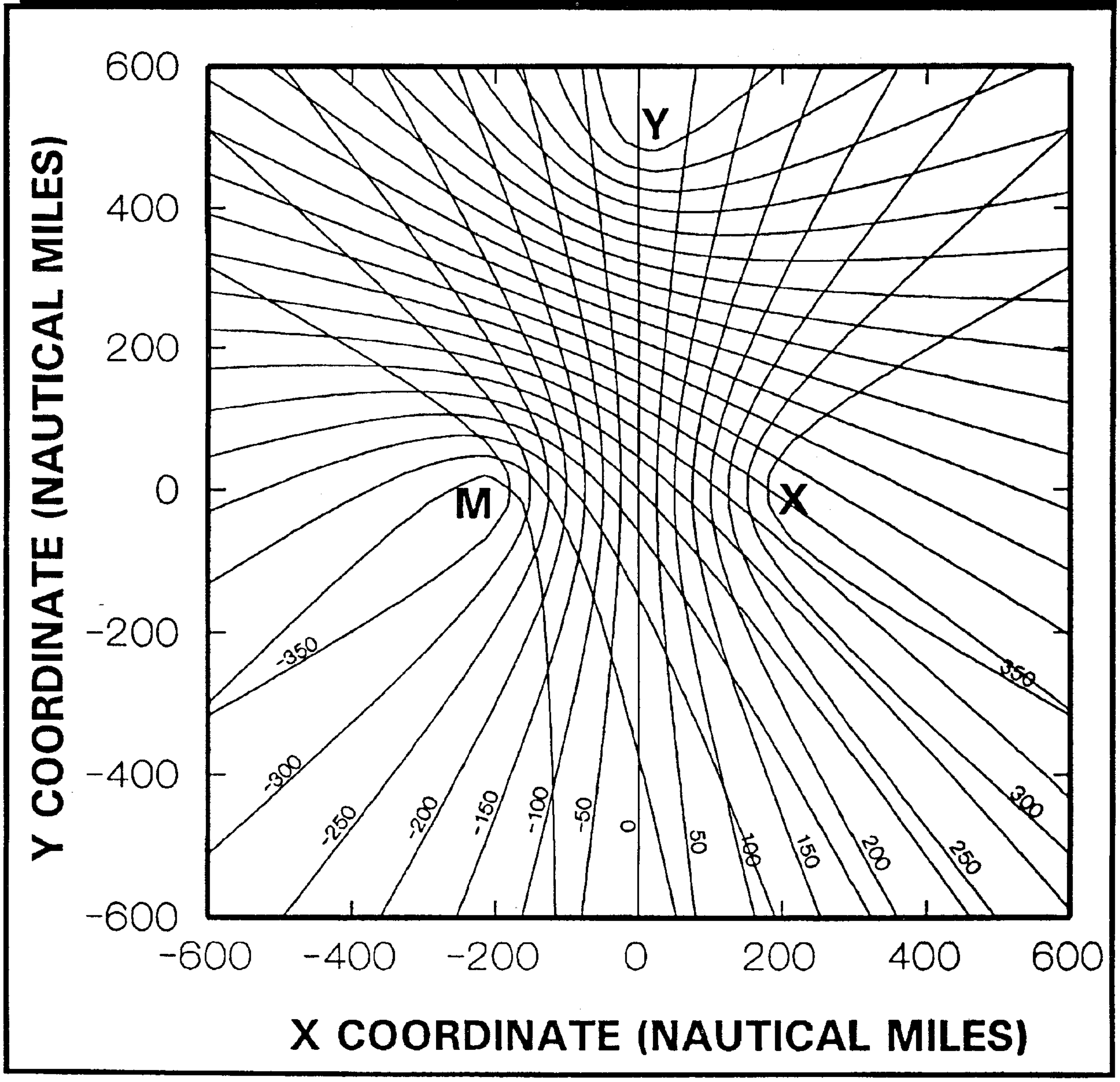


Figure III–2. (The term *hyperbolic grid* is also commonly used, but because the axes of a grid are typically at right angles, the word "lattice" is preferable.) As can be seen clearly in Figure III–2, the LOPs from the two station pairs do not always cross at right angles. As shown below, the *crossing angle* of the LOPs is an important determinant of fix accuracy.) Position determination is simply a matter of locating the LOPs represented by each measured time difference (i.e., those from each of two master–secondary pairs) and fixing the user's position at the intersection of these two LOPs on the hyperbolic lattice, as illustrated in Figure III–3.

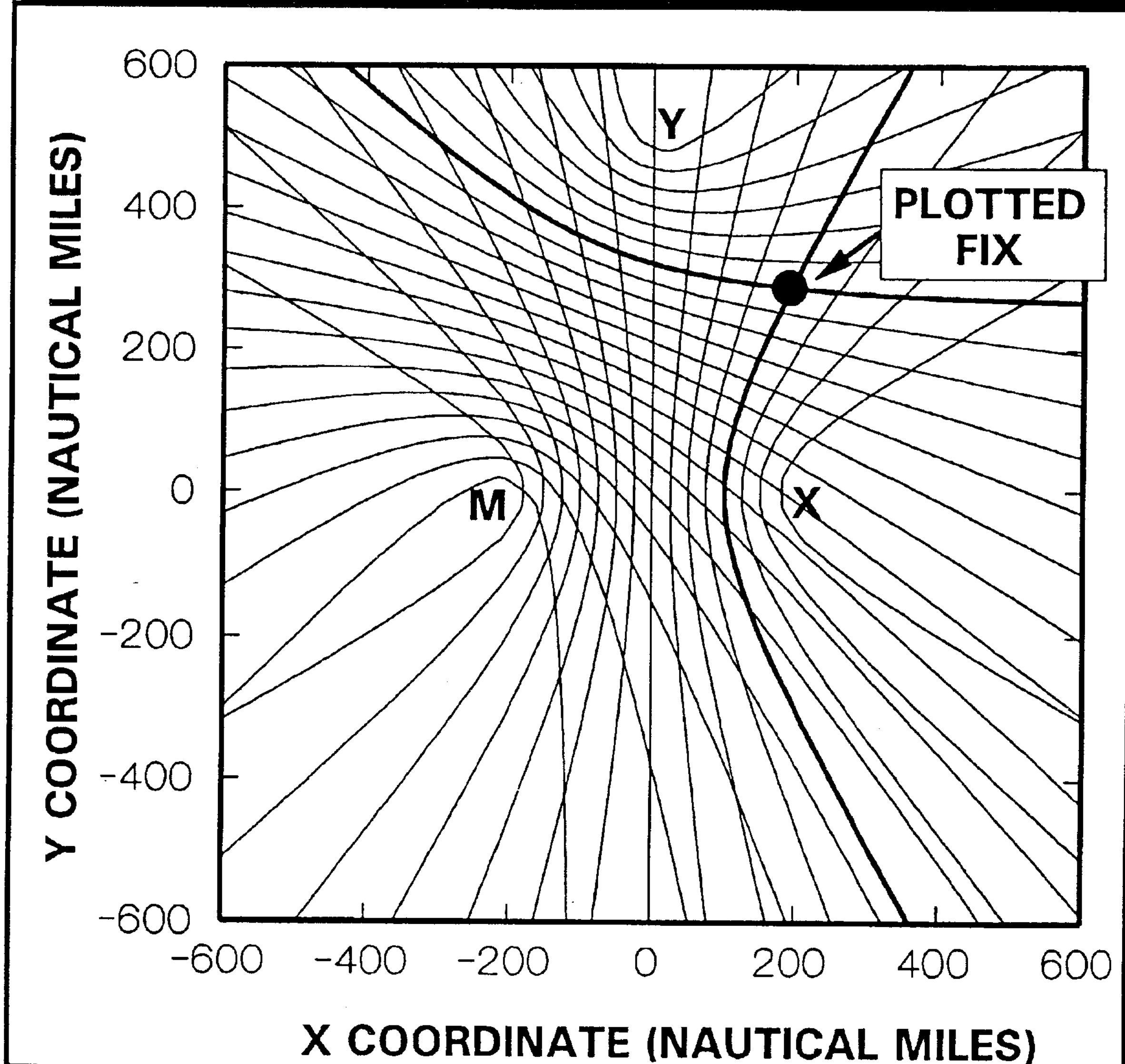
FIGURE III-2. A HYPERBOLIC LATTICE FORMED BY THE PATTERN OF INTERSECTING LOPs FROM THE STATION-PAIRS M-X, AND M-Y.



> **Loran-C TDs for various chains are displayed on special charts, termed *loran overprinted charts.* Loran fixes can be converted from TD units to latitude and longitude using these charts, or plotted directly.**

Were the LOPs straight lines (on the plane), two LOPs (not parallel) would intersect at only one point. However, two hyperbolic LOPs can, in certain circumstances, intersect at two points in the coverage area of the chain. This phenomenon is illustrated in Figure III–2. Look carefully at where the "350" Xray LOP crosses the Yankee LOP near the Xray secondary in Figure III–2. One crossing is

FIGURE III-3. A FIX PLOTTED IN THE HYPERBOLIC PATTERN OF INTERSECTING LOPs FROM THE STATION-PAIRS M-X, AND M-Y.



evident just northwest of the Xray secondary, and another is shown some distance southeast of this secondary at the edge of the diagram—so there are two possible positions on this chart with exactly these same TDs. Absent other information, a mariner would not know which of these positions is correct. This problem, termed *fix ambiguity,* occurs only in the vicinity of the baseline extension of any master-secondary pair. Although some Loran-C receivers can warn the user of this problem with an *ambiguity alarm* (and yet other, more sophisticated receivers, are programmed to track three secondaries and automatically resolve this ambiguity), the safest course of action is to avoid use of any secondary station in the vicinity of its baseline extension. In practice, the navigator would switch to another secondary in lieu of Xray in this illustration, and the ambiguity would be resolved.

Referring to Figure III–2, note also that the crossing angle of the two sets of TDs is very small in the area south of the Xray secondary. (In fact, the two sets of LOPs are very nearly parallel in this area.) Such small crossing angles are incompatible with accurate fixes. This important characteristic of LOPs is discussed at some length below. For the present, however, suffice it to say that the accuracy of a loran fix depends (among other things) upon the user's position with respect to the transmitters.

Avoid use of loran stations in the vicinity of their baseline extensions. Fix accuracies are substantially degraded, and ambiguous positions may result.

Loran-C TD LOPs for various chains and secondaries are printed on special nautical charts, termed *loran overprinted charts,* as discussed in Chapter VI. Each of the sets of LOPs (often termed *rates,* although technically a rate refers to both the GRI and the secondary) is given a distinct color (e.g., on US nautical charts, the color blue is used to print TDs for the Whiskey secondary, magenta for the Xray, black for the Yankee, and green for the Zulu) and denoted by a characteristic set of symbols or label to depict the LOP.[2] For example, a magenta Loran-C overprinted LOP might be labeled 9960–X–25750 on the nautical chart. Decoded, this particular label means that the chain GRI designator is 9960, the TD for the master-Xray station pair is being plotted, and the estimated time difference along this LOP is 25,750 microseconds.

If each and every LOP from this station pair were shown on the chart, a very cluttered (indeed, virtually unusable) chart would result. For this reason, only selected LOPs are printed, e.g., 25750, 25760, 25770 microseconds, etc. (the interval varies with the station pair and the scale of the chart), and the GRI designator and station pair are shown only on selected (e.g., every fifth) LOPs. In the typical case where the measured TD is not shown exactly on the chart—for example, if the TD displayed on the loran receiver were 25,755.5—it would be necessary to *interpolate* between the charted LOPs. This interpolation process is explained and illustrated in Chapter VI and is quite simple in practice, using the "Mark I human eyeball" or, for greater accuracy, the loran interpolator printed on the chart, or a special purpose interpolator (made of plastic or cardboard) available from commercial sources or the Coast Guard.

[2]Users should be careful to note the GRI designator as well as the color of the overprinted LOP. This is because some charts (in areas of overlapping chain coverage) may have more than one family of LOPs printed in the same color if the same secondary (e.g., the Zulu secondary) from more than one chain can be received.

A given loran overprinted chart may have three or more secondaries (from one or more chains) displayed if usable signals can be received from several station pairs in the area covered by the chart. The user has the option of selecting from among several TDs (station pairs) for position determination. In this situation, chains and master-secondary pairs should be selected to provide reliable signal reception and to maximize the accuracy of the resulting fix. Criteria for selection of chains and station pairs are presented in this chapter, following the discussion of loran accuracy.

Because of overlapping coverage of Loran-C chains and/or secondaries within a chain, the user often has a choice among rates (TDs). Criteria for selection of the "best" secondaries are presented later in this chapter.

Incidentally, the displays of most loran receivers *do not* use letter designators to identify the TDs for each station pair. Rather these receivers use numerals to display the particular TDs, e.g., "TD1," "TD2," etc. Because of the manner in which CDs are selected, the identification of the specific station pairs is generally obvious from the magnitude of the TDs. However, the owners' manuals accompanying the receiver typically provide a code to indicate the correspondence between the TD's displayed and the letter designation for the secondaries. For example, Raytheon's RAYNAV 570 receiver uses the code "1 = Whiskey," "2 = Xray," etc. to denote the secondaries of the 9960 chain. Be careful to consult the correct entry in the correspondence table, as different codes may be appropriate for each chain.

Loran Accuracy

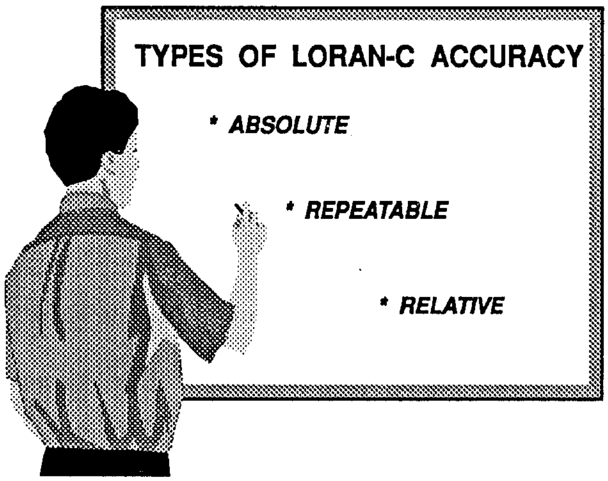
Accuracy is one of the least understood attributes of the Loran-C system. To begin, there are three major types of accuracy relevant to a navigation system, (i) predictable accuracy, (ii) repeatable accuracy, and (iii) relative accuracy.

There are three types of accuracy relevant to the Loran-C system; absolute accuracy, repeatable accuracy, and relative accuracy. Absolute and repeatable accuracy are most relevant to the majority of users.

Predictable (also called absolute or geodetic) accuracy is the accuracy of a position with respect to the geographic or geodetic coordinates of the earth. For example, if a mariner were to note the TDs corresponding to a charted object (e.g., a light house on a "Texas tower") and travel to the point indicated by these time references only, the difference between the vessel's loran-determined position and the actual location of the lighthouse would be a measure of the absolute accuracy of the system.

Repeatable accuracy is the accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigational system. Continuing the above example, if the mariner were to travel to the light tower referenced above, note the Loran-C TDs corresponding to the actual position of the structure, and later return to these same TDs (rather than the TDs corresponding to the coordinates shown on the loran overprinted chart), the resulting position difference would be a measure of repeatable accuracy. Note that TDs for many locations of interest to the mariner (e.g., light structures, day markers, channel turnpoints or centerlines, wrecks, etc.) are sometimes published by the Coast Guard and/or commercial sources. If these TDs are developed from actual survey data (as in the case for those published by the Coast Guard) rather than simply read from a chart, the accuracy of these coordinates approaches the repeatable accuracy, rather than the absolute accuracy, of the system (see below). To many users, repeatable accuracy is more important than absolute accuracy—exploitation of the great repeatable accuracy of Loran-C enables the user to take full advantage of the capabilities of this navigation system.

Finally, *relative accuracy* is the accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time. Applications where relative accuracy is important (e.g., search and rescue) are more specialized and not addressed in this handbook.



Of these three types of accuracy, most users are concerned with either absolute or repeatable accuracy. Loosely stated, the absolute accuracy of the system includes both the precision (random errors) and the bias (systematic errors) of the system, whereas the repeatable accuracy of the system includes only the random errors of the system. Both types of accuracy (i.e., absolute and repeatable) are important to loran users, but for different purposes. For example, a mariner entering an unfamiliar harbor and trying to locate the sea buoy marking this initial approach fix to this harbor would be concerned with the *absolute accuracy* of the Loran-C system. However, if the mariner had visited the harbor (on previous occasions) and recorded the actual TDs corresponding to the sea buoy, *repeatable accuracy* would be at issue. Likewise, repeatable accuracy is relevant to a fisherman returning to a previously visited area and seeking to locate a productive wreck, to avoid "hangs" or other bottom obstructions that could foul nets, or to find lobster pots in poor visibility.

This distinction between absolute and repeatable accuracies is quite important, because the system accuracy differs depending upon how accuracy is defined. The absolute accuracy of the Loran-C system varies from approximately 0.1 to 0.25 nautical miles, depending upon the mariner's location in the coverage area. (This assumes that overland propagation delays, ASFs, are employed for correcting observed TDs.) The official specification of the Loran-C system is that absolute accuracy should be no less than 0.25 nautical mile within the defined coverage area of the chain. There is no explicit specification for the repeatable accuracy of Loran-C, although a range of from 60 ft to 300 ft is noted in the *Federal Radionavigation Plan.* Repeatable accuracy also depends upon the mariner's location in the coverage area (see Blizard, *et al.*, 1986; Taggart and Slagle, 1986; Wenzel and Slagle, 1983; McCullough, *et al.*, 1983 for details).

The absolute accuracy of Loran-C varies from 0.1 NM to 0.25 NM. Repeatable accuracy is much greater, typically from 60 ft to 300 ft.

The high repeatable accuracy of Loran-C enables advantageous use of this system for selected harbors and harbor approaches (HHA) (also termed *harbors and harbor entrances,* HHE) where TD data have previously been collected and recorded. When the repeatable capabilities of Loran-C are exploited, this system can be employed as a secondary system in HHA navigation. Mariners are cautioned, however, never to rely solely on any one navigation system—particularly in areas where precision navigation is important.

The repeatable accuracy of Loran-C can be used to advantage in HHA navigation to supplement other systems for fixing a vessel's position. Mariners are cautioned never to rely solely on one system.

Determinants of Loran-C Accuracy

Several factors collectively determine the overall accuracy (repeatable or absolute) of the Loran-C system. For example, transmitters, transmitter controls, the medium through and over which the signals travel, receivers, charts, and the user determine the overall accuracy of the system. Each component contributes to the system error—these sum statistically to yield the overall system error.

Table III–1 identifies the most important sources of error (absolute or repeatable) in the operation and use of the Loran-C system. Some factors affect both absolute and repeatable accu-

TABLE III-1

SELECTED FACTORS LIMITING THE ACCURACY OF LORAN-C POSITION DETERMINATION

Factor	Effect On	
	Geodetic Accuracy	Repeatable Accuracy
Crossing Angles and gradients of the Loran-C LOPs	Yes	Yes
Stability of the transmitted signal (e.g., transmitter effect)	Yes	Yes
Loran-C chain control parameters	Yes	Yes
Atmospheric and man-made noise	Yes	Yes
Factors with temporal variations in signal propagation spread (e.g., weather, seasonal effects, diurnal variation, etc.)	Yes	Yes
Accuracy with which LOPs are printed on nautical charts	Yes	No
Sudden Ionic Disturbances	Yes	Yes
Accuracy of computer algorithms for coordinate conversation	Yes	No
Shipboard noise	Yes	Yes
Receiver quality and sensitivity	Yes	Yes
Operator error	Yes	Yes

SOURCES: Numerous, but particularly, *Radionavigation Bulletin,* No. 15, September 1984, and Blizard and Slagle, 1987.

racy, while others affect only absolute accuracy. All of these factors, save operator error, are included in the accuracy specifications noted above. (Human error includes a myriad of errors and blunders, such as misreading charts, receiver displays, transposing digits in copying positions, applying ASF corrections with the wrong sign, misreading tables, etc. Because of the diversity of these errors and their inherent unpredictability, human errors are typically not quantified in the system accuracy specifications. This does not mean that these errors are unimportant or that the user should not take pains to minimize these errors.)

The first entry in Table III–1 (crossing angles and gradients of the Loran-C LOPs) includes a variety of terms usually grouped under the rubric of "Geometric Factors." These important determinants of accuracy are discussed in some detail later in this chapter. The balance of the error sources shown in this table are summarized briefly below.

–Stability of the Transmitted Signal

This term refers to the errors of the system associated with loran transmissions. Although the loran transmitters produce highly accurate pulsed signals, there is a small variability from this source, termed *transmitter effects*. At some LORSTAs equipped with tube-type transmitters, redundant transmitters are switched in and out as part of routine maintenance activities, resulting in small signal perturbations. (This error will decline in importance as solid-state transmitters are employed throughout the chains. As of this writing, only the West Coast Chains, LORSTAs Dana, IN, and Cape Race, NFLD employ tube-type transmitters.) Additionally, LORSTA operators make routine *manual phase adjustments* (MPAs) to the signal in order to maintain the signal within preestablished tolerances. Additionally, Local Phase Adjustments (LPAs) are made to compensate for differences in cesium oscillator drift.

Another signal perturbation (termed *chain control effect*) results when a control monitor station becomes inoperative, and alternative control schemes are used (e.g., a switch from one monitor location to another). This shift "warps" the loran lattice slightly, and contributes to variability of the loran signal.

–Atmospheric and Man-Made Effects on Propagation

Atmospheric conditions can significantly affect the propagation of the Loran-C signal, and derivatively of the accuracy of the fix. (Noise also affects the *signal-to-noise ratio* (SNR) and the maximum distance at which a usable signal can be received, as discussed below.) Atmospheric noise is the dominant form of noise in the loran band. It is produced by lightning all over the earth. Atmospheric noise is always present, because thunderstorms are always present. Each lightning strike produces a point noise source—the effects of this noise depend upon the distance from the storm to the receiver. Atmospheric noise is generally greater in the summer than the winter, and in the tropics compared to the higher latitudes.

–Factors Causing Temporal Variability

There are several factors that can cause temporal variation in signal propagation throughout the system coverage area. Recall (from Chapter II) that ASFs vary with the characteristics of the mixed land-sea path that loran signals travel to the observer. Terrain moisture and temperature, for example, exhibit seasonal variability which, in turn, affects signal propagation *(seasonal effect)*. Figure III–4, for example, shows a plot of the variability of the Xray TD for the NEUS (9960) chain at Massena, NY, (Blizard and Slagle, 1987) versus (Julian) day of the year. A pronounced seasonal effect is evident at this location. Xray TDs at this location are nearly 1 usec higher in the summer months than in December and January. Seasonal effects vary in

FIGURE III-4. SEASONAL VARIABILITY ILLUSTRATED FOR THE 9960 XRAY STATION PAIR AT MASSENA, NY

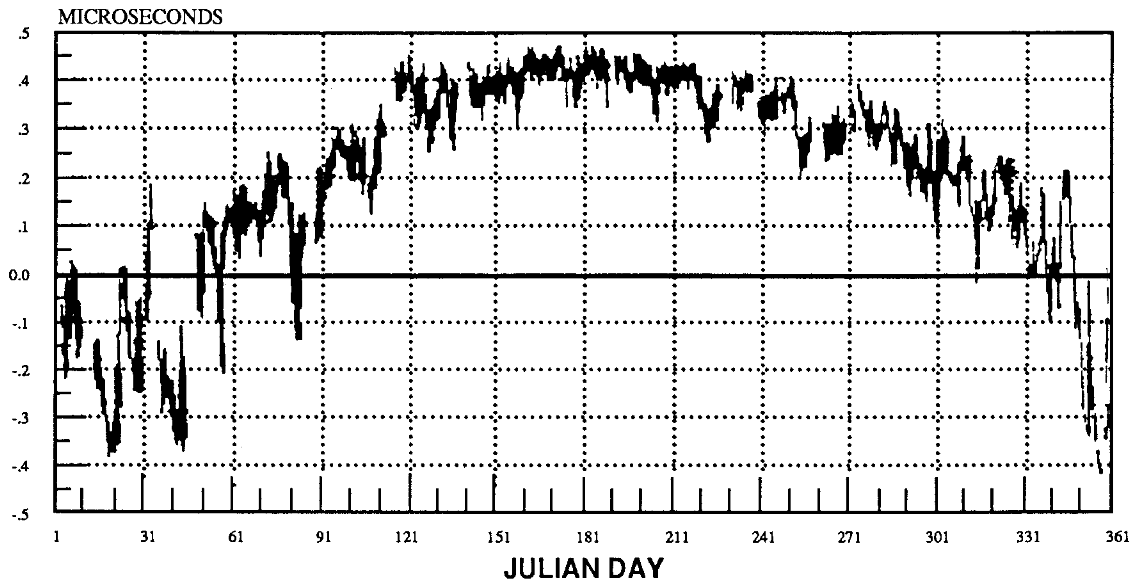
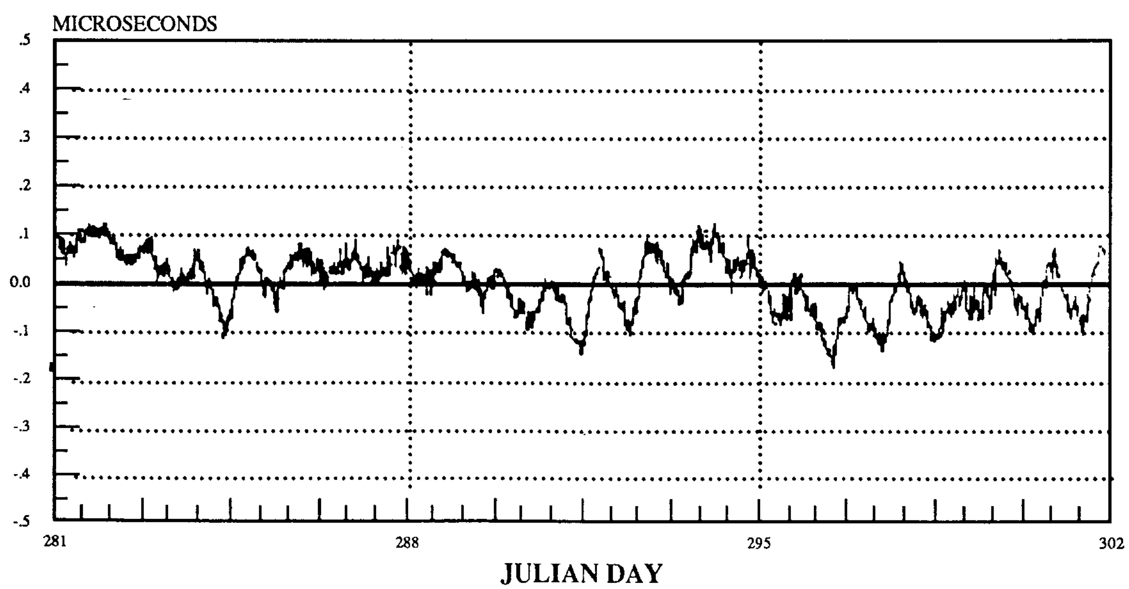


FIGURE III-5. VARIATION SEEN AT MASSENA, NY FOR 9960 XRAY TD



magnitude with the season, chain, station pair, and the location of the observer. For example, there is almost no seasonal effect observed for this rate at Sandy Hook, NJ (Blizard and Slagle, 1987). The explanation for this phenomenon is that Sandy Hook is a LORMONSITE for the 9960 chain, and the monitor provides information that, among other purposes, is used to maintain a standard time difference at this location.

Diurnal (hourly within a day) variability is another form of temporal variability, as is illustrated in Figure III–5 for the Xray secondary of the NEUS (9960) chain at Massena, NY. In this illustration, daily shifts in this TD of as much as 0.1 usec can be seen—smaller than the seasonal component at this location, but potentially significant nonetheless. As with seasonal variability, the magnitude of this effect varies with chain, station pair, and observer location.

Weather affects signal propagation, and the effects of the "Alberta Clipper" or "Siberian Express" (cold fronts with associated cold spells lasting from hours to days) sweeping across the Northeast can readily be detected in TD shifts as far south as South Carolina. In cold weather the speed of propagation of the signal is greater. Both temperature and humidity affect signal propagation. For a comprehensive discussion on weather effects on signal propagation, the reader is referred to citations provided in Appendix E (e.g., Samaddar, 1979, 1980).

The reader may ask the question: "If seasonal, weather related, and diurnal factors can be quantified, why can't this information be used to reduce the overall uncertainty of the loran TDs?" The answer to this astute question is that, in fact, *it is possible* to measure and quantify these factors, and (in principle) to broadcast a series of corrections to loran readings (similar to ASFs) for use by the mariner. Such a system, termed the *differential Loran-C system* (DLCS), has been extensively studied (Blizard and Slagle, 1987) by the Coast Guard and proven to be feasible. Indeed, absolute accuracy of 30 meters or better in a local area has been demonstrated using differential Loran-C. However, DLCS has not been implemented to date. For most purposes (and in most locations), the accuracy of conventional loran is adequate, and any decision to increase this accuracy must be carefully evaluated on the basis of cost benefit calculations.

–Factors Associated With Spatial Variability

Another group of factors highlighted in Table III–1 are those included under the rubric of factors that change from place to place, such as mountains, deserts, and structures. Although these factors are considered in the determination of the ASFs (see Chapter II), not all the "microstructure" can be reflected in the estimated ASFs. To illustrate, near shore effects, bridges, powerlines, and other large structures (e.g. petroleum refineries, steel mills) affect loran signal propagation but are not accounted for in published ASFs. In extreme cases Loran-C TDs measured near such structures could result in navigational errors which exceed the absolute accuracy specifications. For example, the Verrazano-Narrows Bridge is a large suspension bridge arching over the entrance to New York Harbor. When transiting between way–points (see Chapter V for a discussion of waypoint navigation) in the centerline of the channel near this bridge, a calculation of the vessel's position based upon Loran-C TDs may indicate that the vessel is several tens or even hundreds of yards outside the channel. The effect is greatest directly under the structure, and diminishes with distance. The distance where Loran-C TDs become unusable varies among structures, as does the amount of the TD shift. In Coast Guard trackline surveys (see: *Radionavigation Bulletin,* No. 11), it was noted that some powerlines affected Loran-C TDs as much as 500 yards distant, and caused distance errors up to 200 yards when directly under the powerlines. Although no method has yet been developed to predict and correct for these particular effects, the Coast Guard periodically identifies and publishes *(Radionavigation Bulletin)* a list of structures with the potential for adversely affecting the accuracy of loran navigation. Mariners are well advised to exercise caution when in the vicinity of these structures and not to rely solely on Loran-C for navigation in these areas.

Recall also that ASFs are less accurate within 10 NM of the coast *(coast effect)*. (For interesting data relative to this effect, see McCullough, *et al.,* 1983.) Although fixes determined by Loran-C may satisfy the 0.25 NM accuracy specification in these areas, such accuracy is not "guaranteed" for the system.

–Other Factors

The accuracy with which loran LOPs are printed on charts is discussed in Chapter VI, and the accuracy of computer latitude/longitude conversions (imbedded into the Loran-C receiver logic) is discussed in Chapter IV. Constraints on the length and scope of this handbook do not permit a complete discussion of all the sources of error in the loran system, and the interested reader should consult the many sources given in the bibliography (Appendix E) for a more complete discussion.

System Geometry

Perhaps the most important determinants of loran accuracy are those grouped under the classification of system geometry. Of particular relevance here are the *crossing angles* and the *gradient* of the Loran-C LOPs. These are discussed below, and in Appendix G, where the important concept of *geometric dilution of position* (GDOP) is explained and illustrated.

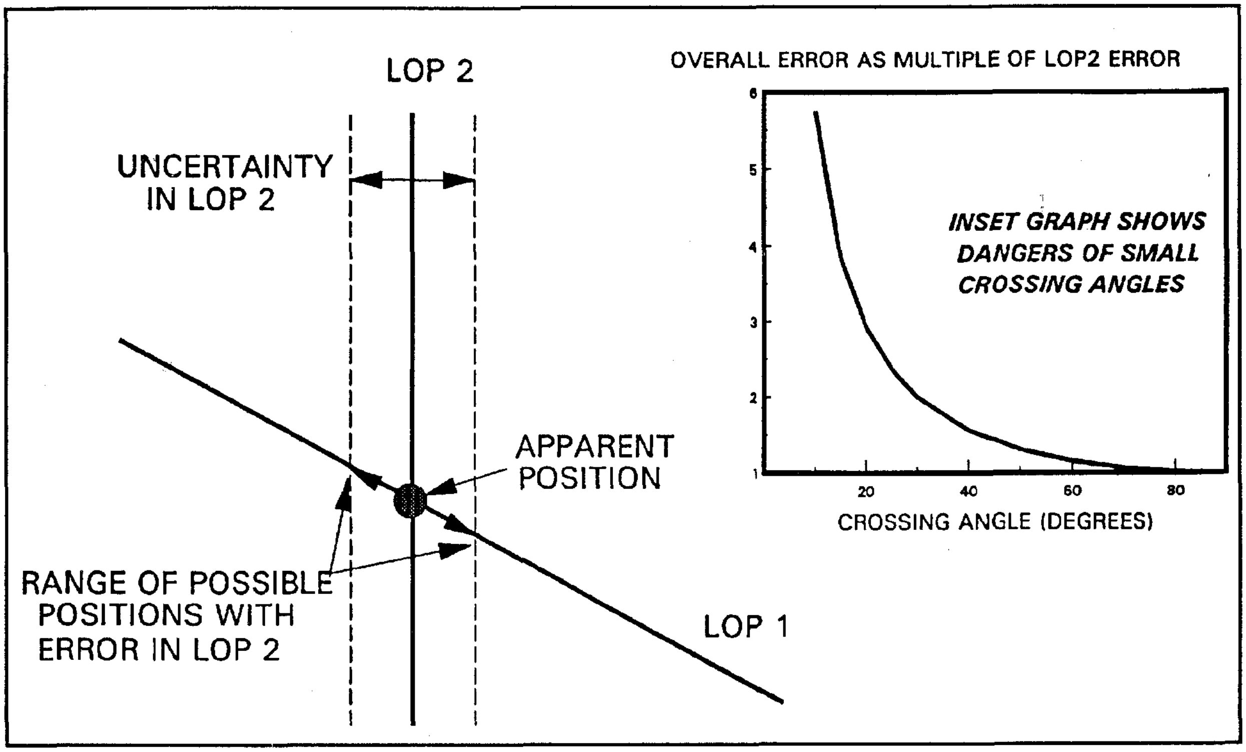
Geometric factors are among the most important determinants of Loran-C navigation accuracy. Geometric factors include the crossing angle and gradient, both of which vary throughout the coverage area.

–Crossing Angles

The *crossing angle* is the angle (more accurately the smaller of the two angles) between two LOPs that determine a fix. Most navigators are very familiar with the fact that the accuracy of a two-bearing fix varies with the crossing angle of the LOPs and that the optimal crossing angle for two LOPs is 90 degrees. The effects of large and small crossing angles are illustrated in Figure III–6. In this figure LOP 1 is assumed to be known without error, and LOP 2 to within an error shown by the dashed lines parallel to LOP 2. It is also assumed, for illustrative purposes, that the variability of LOP 2 is +/- 0.1 microseconds.[3] The best estimate of the observer's position is where the two LOPs cross (denoted by the circle in Figure III–5), but the possible (one dimensional) uncertainty in this position along LOP 1 depends not only on the uncertainty of LOP 2, but also on the crossing angle of the two LOPs. More specifically, the length of the interval of uncertainty is a function of the reciprocal of the trigonometric sin function of the crossing angle. As the inset graph in this figure shows, the length of this projection on LOP 1 is smallest at

[3]Recall (from the discussion in Chapter II) that either time or distance units may be used interchangeably.

FIGURE III-6. AN ERROR IN ONE TD IS MAGNIFIED IF THE CROSSING ANGLE OF THE LOPs IS LESS THAN 90 DEGREES--HERE'S HOW IT LOOKS.



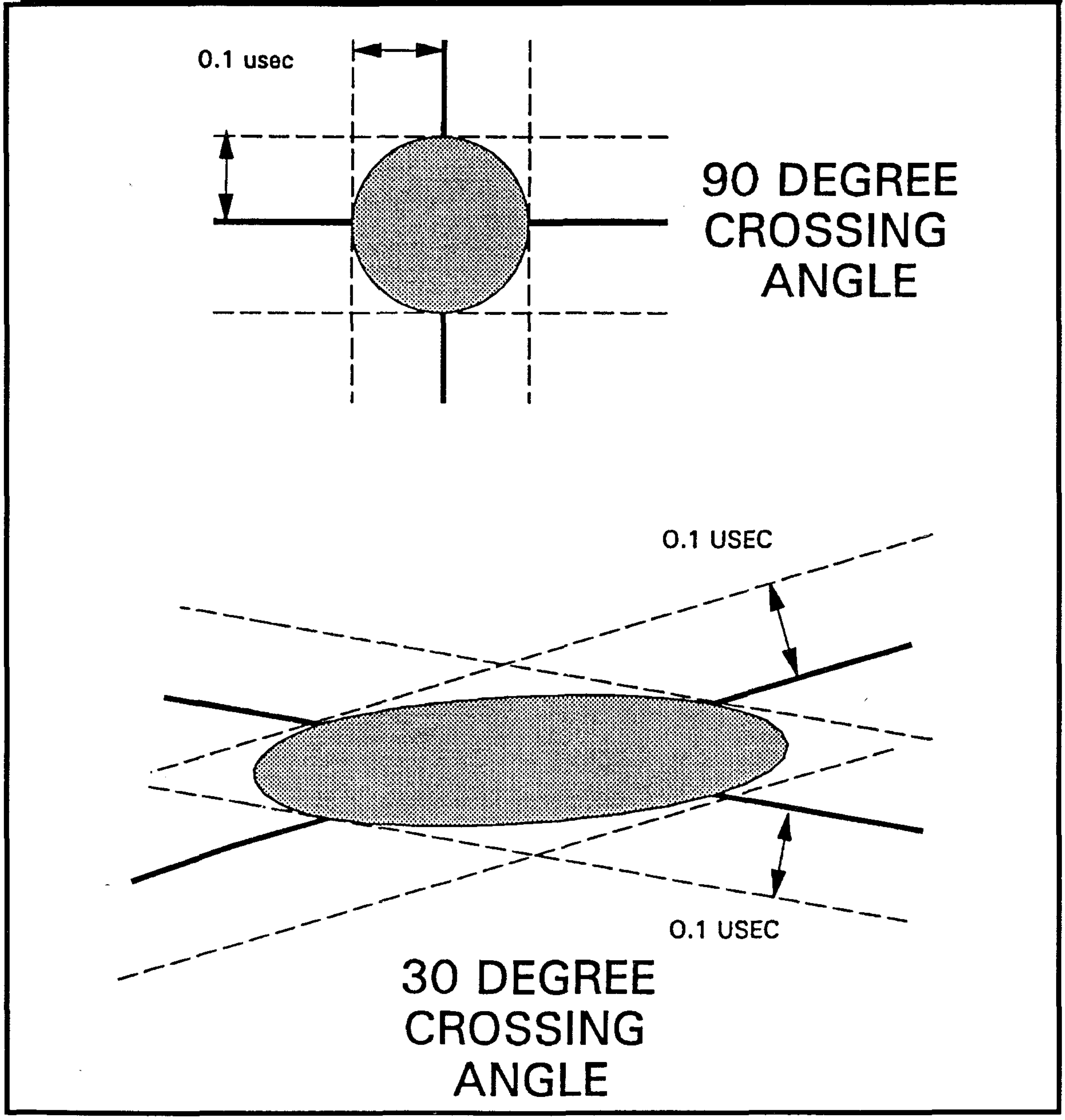
a crossing angle of 90 degrees and becomes very large for crossing angles of 30 degrees or less. Indeed, the length of the interval of uncertainty becomes infinite for a zero degree crossing angle.

To illustrate, if the crossing angle were 90 degrees, the projection of the +/- 0.1 usec uncertainty in LOP 2 on LOP 1 would be 0.1/(sin 90) = +/- 0.1 microseconds. However, if the crossing angle were as small as 15 degrees, the projection on LOP 1 would be 0.1/(sin 15) = nearly +/- 0.4 microseconds. Such small crossing angles are generally incompatible with the absolute accuracy specifications of the Loran-C system.

Other things being equal, the user should select those TDs with crossing angles closest to 90 degrees.

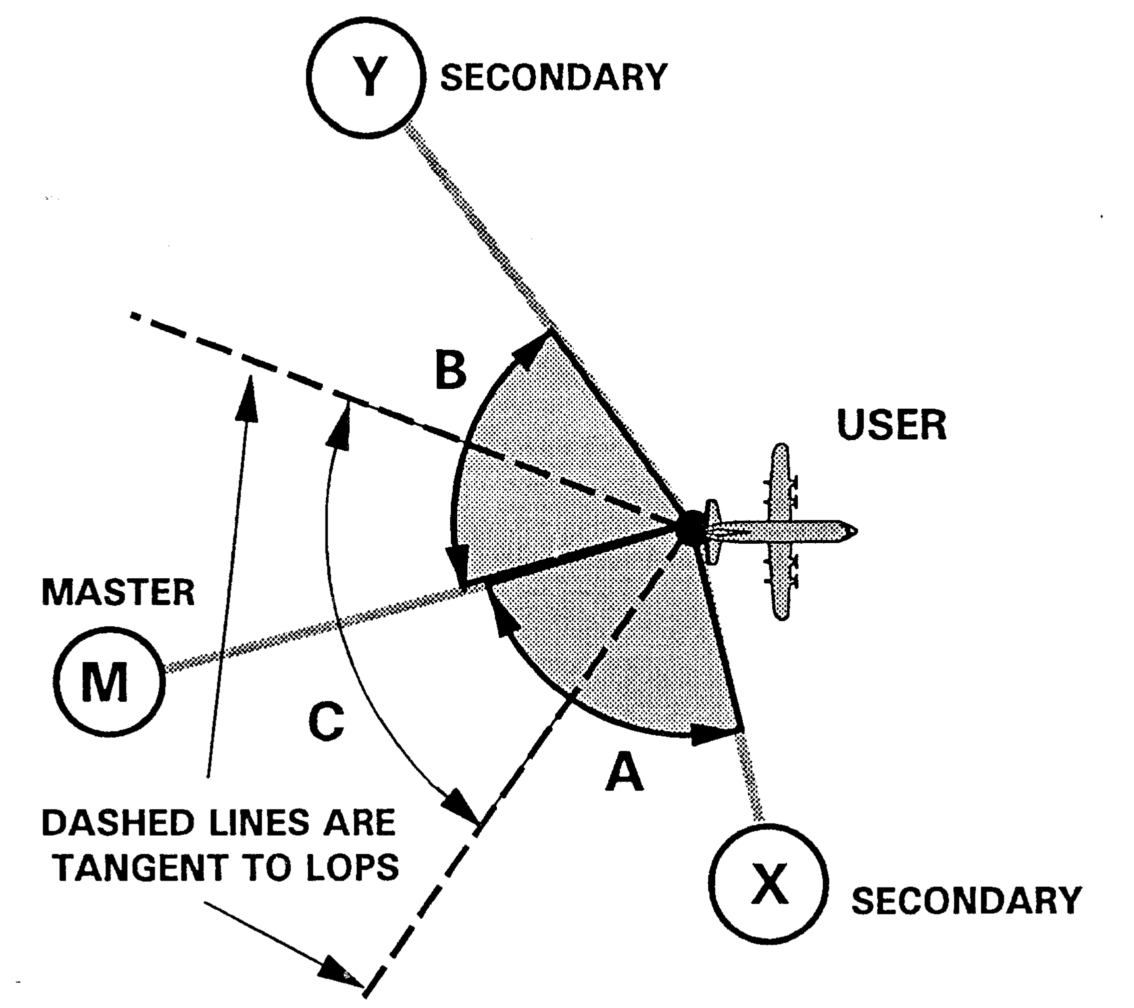
Figure III–6 is simplified for illustrative purposes. In fact, there is uncertainty in both LOPs, not just one. In this more general case, the resulting uncertainty of the fix is not a one dimensional line, but rather a two dimensional area. Provided that the LOPs are at right angles, and the uncertainty in each LOP is the same (0.1 usec in this illustration), and that the possible errors in each TD are uncorrelated, this two

FIGURE III-7. CROSSING ANGLES AND AREAS OF FIX UNCERTAINTY SHOW BENEFITS OF 90 DEGREE CUTS. NOTE DISPARITY IN SIZE OF SHADED AREAS.



dimensional area is a circle, as shown in Figure III–7 (top). In the top illustration (which satisfies the above assumptions) the vessel's position would be known (in probabilistic terms) to be within the shaded circle of uncertainty. (The probability that the vessel would be in this area depends upon the probability content of each of the LOP bounds—more later.) However, assuming everything else were held constant but the crossing angle, the area of uncertainty would become distorted (into an ellipse) and very much larger if the crossing angle were decreased.

FIGURE III-8. ILLUSTRATION OF CROSSING ANGLE GEOMETRY FOR LORAN TRIAD.



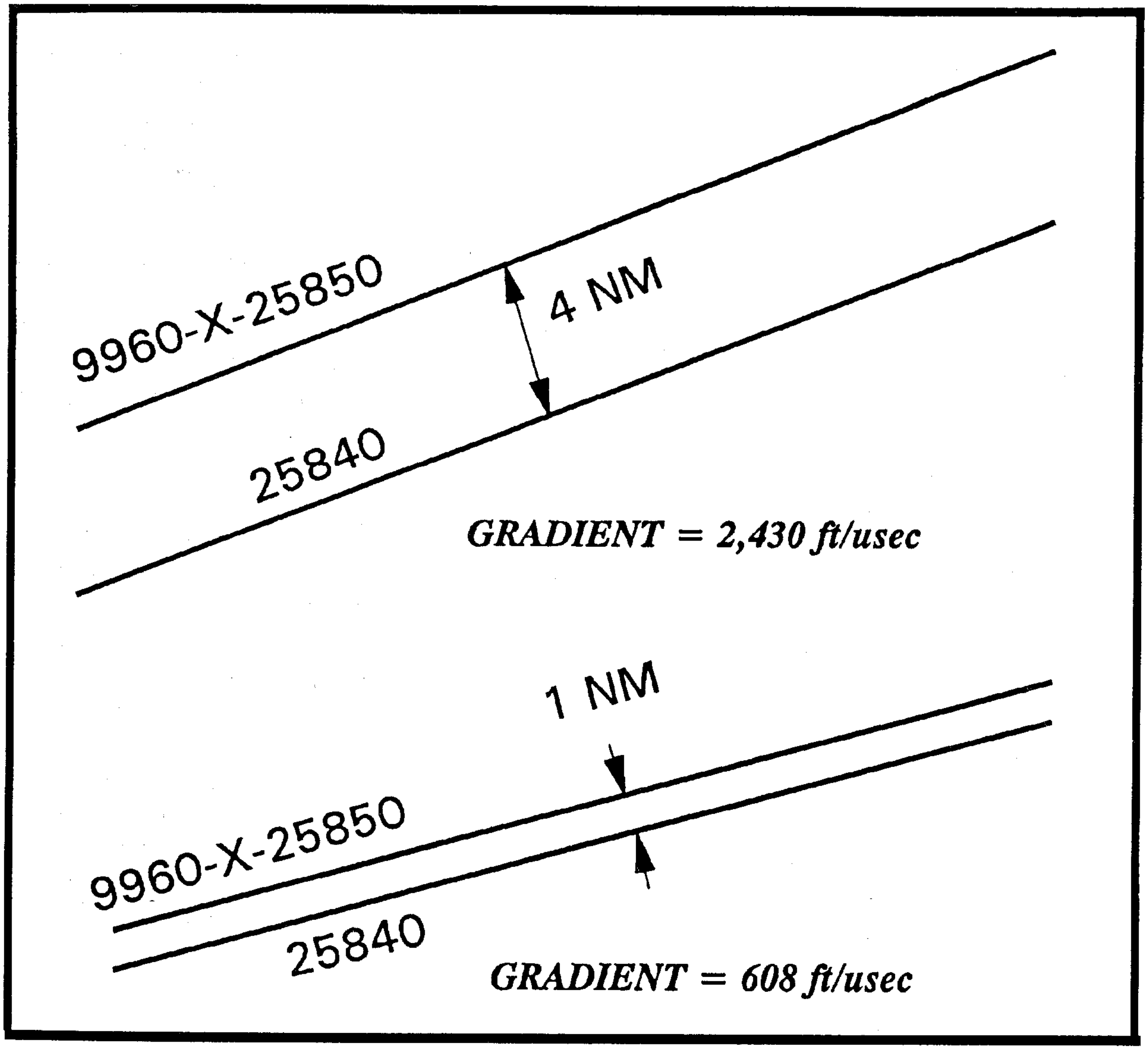
C = A/2 + B/2

C = CROSSING ANGLE

Figure III–7 (bottom) shows how this circle is distorted and enlarged as the crossing angle is decreased from 90 degrees to 30 degrees. This distortion and enlargement becomes even more pronounced as the crossing angle is further decreased.

The crossing angle of Loran-C TDs can be shown (see Taylor 1961, Swanson 1978) to be related simply to the location of the vessel in the coverage area and to the location of the master and secondary stations. Figure III–8 shows the geometry of the crossing angle for a loran Triad.

FIGURE III-9. LARGE GRADIENTS TRANSLATE INTO LARGE POSITION UNCERTAINTY, SMALL GRADIENTS INTO SMALL POSITION UNCERTAINTY.



Specifically, if angle A is the angle between the great circles drawn from the user to the master and the Xray secondary, and angle B is similarly defined with respect to the master and the Yankee secondary, then the crossing angle (angle C in Figure III–8 bounded by the dashed sector) is equal to A/2 + B/2. (This follows from the so-called "optical" property of the hyperbola—the tangent to a hyperbola (i.e., to the LOP) at a point P bisects the angle between the lines joining P to the two foci of the hyperbola.)

Figure III–8 enables the reader to visualize how the crossing angle varies throughout the coverage area of the loran Triad. As drawn, the crossing angle is approximately 79 degrees. If the aircraft or vessel were to move in a "north-easterly" direction (north being the top of the page), the crossing angle would decrease, implying a less accurate fix. If the user were to move toward the master, the crossing angle would first increase and then decrease again, as the user draws close to the master. (Remember that the crossing angle is the smaller of the two angles formed by the intersection of two LOPs.) Crossing angles for positions along the baselines are not as close to 90 degrees as at certain interior points of the triangle formed by the master and two secondaries.

In practice, the crossing angles of the Loran-C LOPs are easy to measure from the loran overprinted chart, so that the determination of the secondaries with crossing angles nearest to 90 degrees at any position on the chart, is likewise easy.

–Gradient

The *gradient* is calculated as the ratio of the spacing between adjacent loran TDs (measured in ft, yards, nautical miles) and the number of microseconds difference between these adjacent LOPs.[4] Most commonly, the gradient is expressed as ft/usec or meters/usec. Figure III–9 illustrates the computation of gradients for two hypothetical sets of loran LOPs such as would be found on a loran overprinted chart. In the illustration at the top of this figure, loran LOPs are spaced 10 usec apart (i.e., 25850 - 25840) and 4 nautical miles apart. The gradient in this case would be 4(6,076)/10 = 2,430 ft/usec. In the bottom illustration, this gradient is 608 ft/usec. If it is assumed that there is a constant error of the TD (as measured in usec) throughout the coverage area, it follows that (other factors held constant) loran LOPs with smaller gradients will result in a fix with greater accuracy. Note that computation of the gradient of a given rate at a given location is a simple task of measuring the distance (in nautical miles or other convenient units) between adjacent Loran-C TDs as printed on the appropriate chart and dividing this distance by the spacing (in usec) between the LOPs.

As with crossing angles, gradients vary throughout the coverage area. Figure III–10 shows how the gradient of a single TD varies with location for the example originally given in Chapter II. As can be seen, the gradient is smallest in the vicinity of the baseline (e.g., point "A" in Figure III–10). *In fact, the gradient is constant anywhere alone the baseline and numerically equal to 491.62 ft/usec.* It can also be shown that if the gradient exceeds 2,000 ft/usec, the 0.25 NM absolute accuracy requirement for Loran-C system accuracy will not be satisfied.

Note from Figure III–10 that the gradient grows larger as you move away from the baseline, from point "A" to point "B." The increase in gradient with increases in distance from the baseline is not constant—increases are very much larger in the vicinity of the baseline extension. Note that the gradient at point "C" in Figure III–10 is even larger than at "B". (Had other LOPs been shown in Figure III–10 even closer to the baseline, the increase in gradient would have been more dramatic.) This is one of the major reasons why it is not recommended to use secondaries in the vicinity of their baseline extensions.[5] Users at or near position "C" in Figure III–10 would be well advised to select another secondary—in lieu of the Xray secondary—for more accurate navigation.

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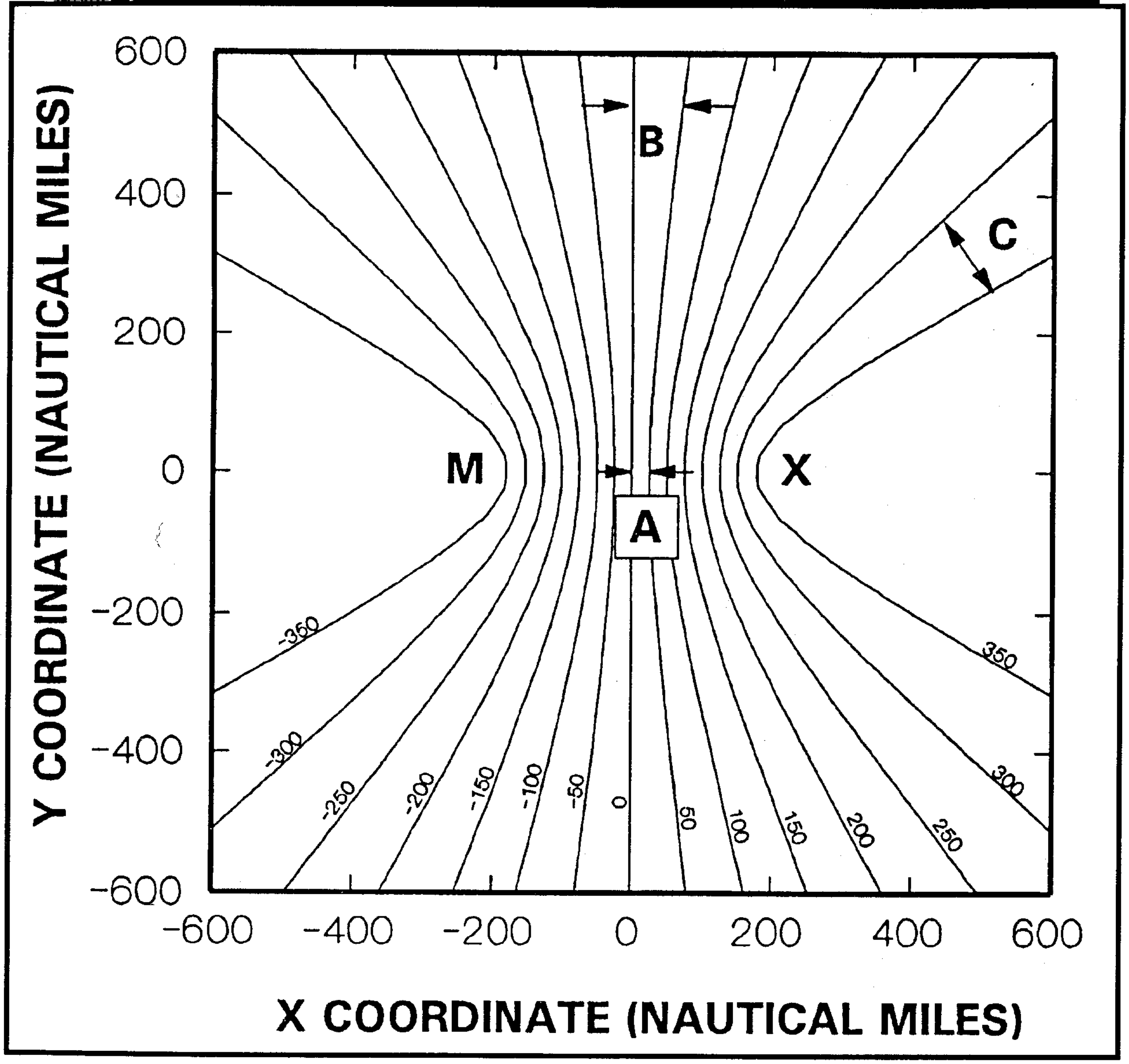
[4]Technically, the gradient is defined as the rate of change of distance with respect to TD, i.e., is the *derivative* of this function. It is calculated from charts in terms of numerical differences. Some authors use the word "lane" interchangeably with gradient.

[5]Recall from the discussion in the beginning of this chapter that ambiguous positions are associated with baseline extensions.

FIGURE III-10. GRADIENTS ARE SMALLEST ALONG THE BASELINE, INCREASE EVERYWHERE ELSE, AND ARE VERY LARGE NEAR BASELINE EXTENSIONS.



> **Small gradients are associated with most accurate fixes. For a given master-secondary pair, gradients are smallest near the baseline. Gradients are very large in the vicinity of a baseline extension. Other things being equal, the user should select those TDs with the smallest gradients.**

The explosive expansion of the gradient near the baseline extension is the reason why secondary stations should not be used in the vicinity of the baseline extensions, and why these lines are shown on nautical charts. Important areas of baseline extension in the United States include the area east of the Xray secondary of the NEUS chain located on Nantucket, MA, the area south of the Yankee secondary in Carolina Beach NC for this same chain, the area southeast of the Yankee secondary of the SEUS (7980) chain, located in Jupiter, FL, etc. (These areas can be clearly seen from inspection of the coverage diagrams presented in Appendix B.)

Brief Remarks on Station Placement

Careful examination of Figure III–10 suggests that the gradients in a loran coverage area could be reduced and the crossing angles improved if the master and Xray secondary were placed a greater distance apart. This conjecture is, indeed, correct. Long baseline lengths serve to increase the accuracy of loran fixes in the coverage area. This is a well-known principle in the design of loran chains. Other things being equal, the fix accuracy of the Triad shown in Figure III–2 would improve if either of the baseline lengths were extended. As well, the crossing angles of many of the LOPs would improve if the two baselines were more nearly at right angles. Figure III–11 shows the LOPs that would result if the Xray secondary were relocated on the original grid from (200, 0) to (400, -300)—that is if the crossing angle of the two baselines were changed to 94 degrees (86 degrees, when subtracted from 180) rather than the 70 degrees in the original Triad, and the length of the Xray secondary were lengthened to 671 miles from the original 400 miles. In this illustration the spacing of the Xray LOPs is still 50 miles (or its equivalent in TD units), and the TD spacing of the Yankee LOPs is likewise unaltered. But note how the crossing angles have improved throughout the "northeast" part of the coverage area (compare Figures III–2 and III–11), as have the gradients. Although the lattice is still obviously distorted, it is much more nearly rectangular than the original. This chain configuration is decidedly superior to that assumed initially. From a geometric perspective alone, further lengthening of either baseline would help, as well as shifting the angle between the two baselines. (Incidentally, Figure III–11 shows clearly the position ambiguities in the vicinities of the baseline extensions of the two master-secondary pairs.)

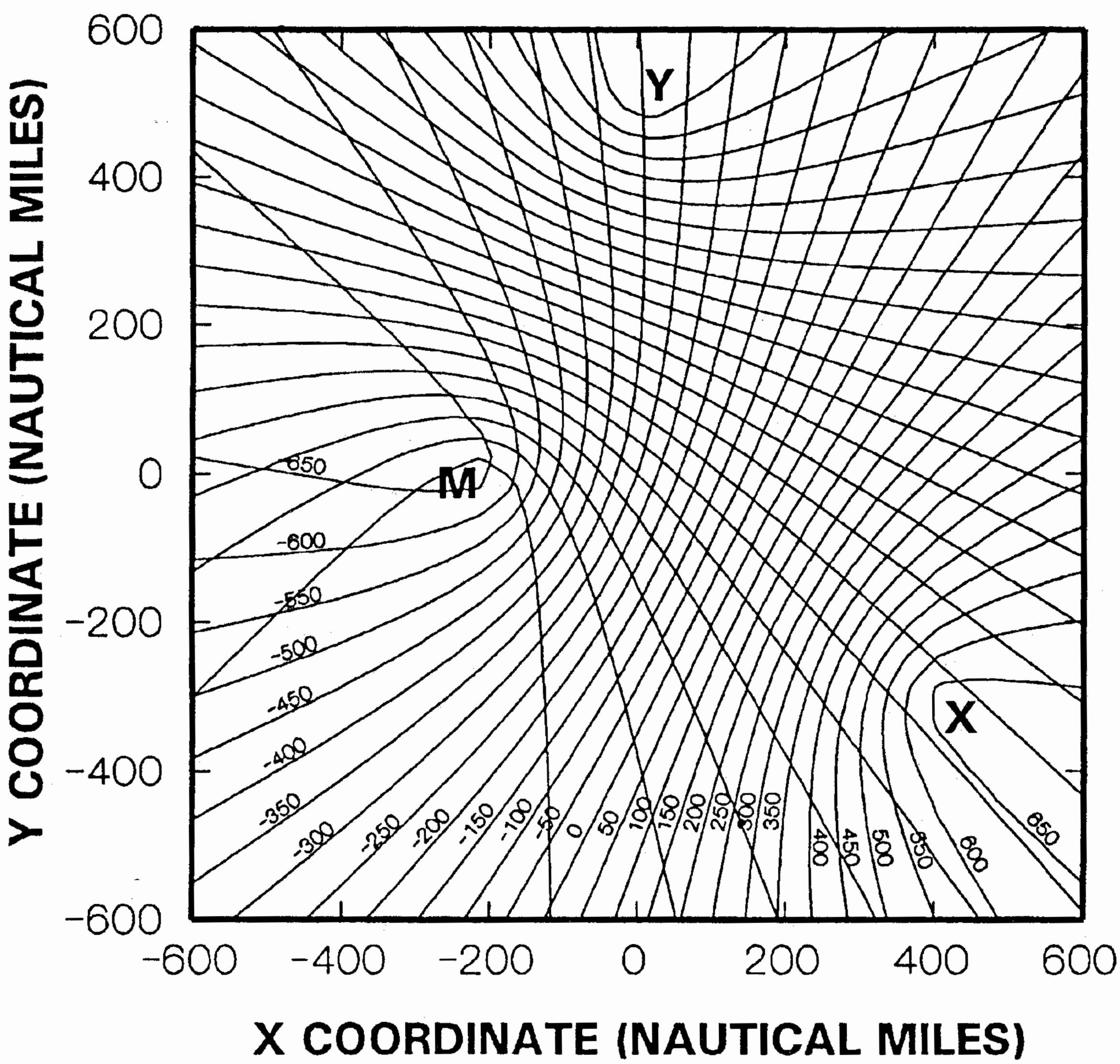
However, there are practical limits that need to be considered in selecting locations for loran stations. First, there are numerous physical and political constraints which limit the placement of these stations. These stations need to be located on land, and in friendly or cooperating countries. Physical and political constraints limit baseline lengths and crossing angles. Second, there are technical constraints which also impose limits on the length of baselines. The selection of long baseline lengths to obtain high accuracy often is not compatible with optimum coverage area because distance limitations on signal propagation prevent simultaneous reception of signals from the most distant stations. Of course, the useable baseline distance can be increased by increasing the transmitter power, but a diminishing returns situation prevails—substantial power increases are required as the master and secondary stations are located farther apart.

Putting it Together: drms

The advice to select secondaries with 90 degree crossing angles and small gradients is fundamentally sound, but occasionally there is a tension between these objectives.[6] Therefore, it

[6]As noted, gradients of individual rates are smallest near their respective baselines, while optimal crossing angles are found in interior points. Moreover, the gradients of both sets of LOPs need to be considered. Unless some aggregate measure of accuracy is at hand, it is not obvious how to make tradeoffs among these measures so as to maximize fix accuracy. Use of the 2 drms accuracy measure resolves these difficulties.

FIGURE III-11. SYSTEM GEOMETRY WITH THE XRAY SECONDARY RELOCATED TO (400,-300) SHOWS MUCH IMPROVED CROSSING ANGLES AND GRADIENTS.



is very useful to have an accuracy measure which includes the effects of both these geometric variables. Although several such measures can be defined, the quantity "2 drms" is most commonly used. *This quantity, 2 drms, is the radius of a circle about the vessel's apparent position such that, in at least 95% of the fixes, the vessel's actual position would be located somewhere within this circle.* Mathematically, 2 drms is given by the equation:

$$2 \text{ drms} = \frac{2 K \sigma}{\sin C} \left[\frac{1}{\sin^2\left(\frac{A}{2}\right)} + \frac{1}{\sin^2\left(\frac{B}{2}\right)} + \frac{2 \rho \cos(C)}{\sin\left(\frac{A}{2}\right) \sin\left(\frac{B}{2}\right)} \right]^{0.5} \quad \text{(III-1)}$$

where

A,B,C = angles defined in Figure III–8.

ρ = correlation coefficient between the measured TDs, generally taken to be 0.5 for purposes of calculation,

K = baseline gradient, 491.62 ft/usec, and

σ = common value of the standard deviation of each TD, generally taken to be 0.1 usec for 2 drms absolute accuracy calculations.

The Loran-C accuracy specification is expressed in terms of 2 drms; 2 drms plus ASF error must be less than or equal to 0.25 NM throughout the coverage area. Indeed, the accuracy limits on the range of coverage of loran triads (and, derivatively, loran chains) are determined as the largest range such that 2 drms is less than or equal to 0.25 NM throughout the coverage area.

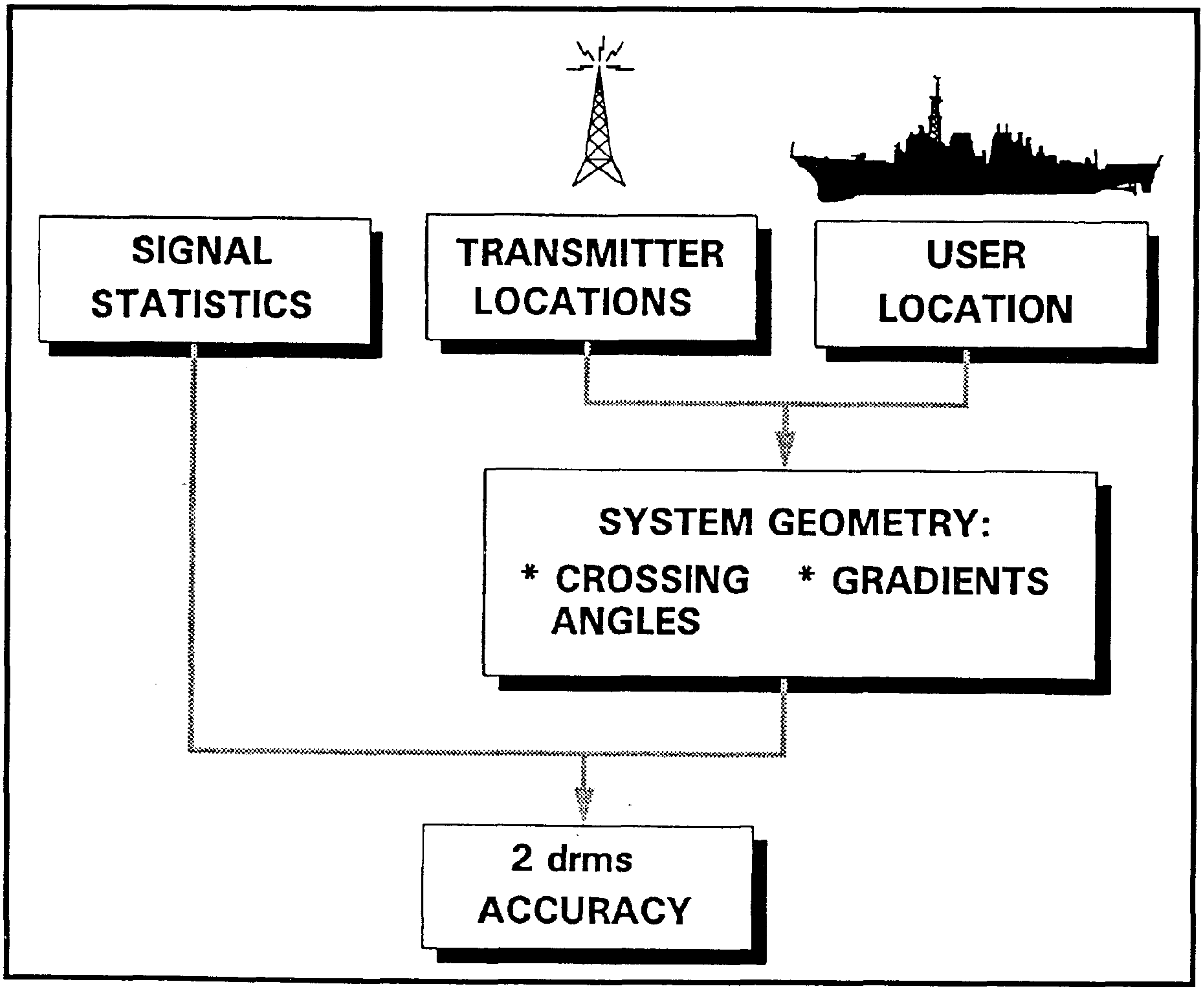
Equation (III–1) can be used to calculate how accuracy varies throughout the coverage area. The various terms in this equation identify the key parameters and variables affecting the 2 drms accuracy measure. Figure III–12 shows these schematically. In broad terms, there are three sets of variables that determine 2 drms. These include the statistical characteristics of the transmitted signal, the locations of the transmitters, and the position of the user. Key statistical parameters include the standard deviation of the TDs (generally taken as 0.1 usec for each TD), and the correlation coefficient between the measured TDs (which varies throughout the coverage area, but often set equal to 0.5 for calculation of 2 drms). The transmitter locations and the user's position determine the angles A, B, and C shown in Figure III–8. The location of the transmitters and that of the user jointly determine the crossing angles and gradients referred to earlier. Collectively, all these factors determine 2 drms. The user has no control over the signal characteristics of the Loran-C transmissions, nor the locations of the transmitters. However, for many locations, the user does have a choice among chains, and secondaries within these chains. (In portions of the eastern United States, for example, the user can choose among three chains. West Coast users are less fortunate.) For best results, the user should select the secondaries so as to minimize 2 drms, or equivalently, to maximize the accuracy of any fixes. This choice is described below.

–Accuracy* vs. *Location in the Coverage Area

From the point of view of the user, the significance of the above equation is that the *absolute accuracy* of fixes derived from any two station pairs can be calculated, and the "best" station pairs can be selected from among the available alternatives. Although these calculations are not conceptually difficult, a computer is required for rapid and numerically accurate solution. In any event, it would be very tedious if the user had to make these calculations for each station pair of each chain in order to select the best station pairs—particularly as these calculations would have to be replicated for every possible position in the coverage area.

> **The quantity 2 drms is the radius of a circle within which 95% of the possible fixes lie. Secondaries should be selected to minimize the value 2 drms for most accurate navigation.**

FIGURE III-12. 2 drms ACCURACY IS DETERMINED BY STATISTICAL SIGNAL CHARACTERISTICS AND THE USER'S LOCATION RELATIVE TO THE TRANSMITTERS.



Fortunately, these calculations have already been made, and are given in Appendix B. Figure III–13 (taken from COMDINST M16562.4, *Specification of the Transmitted Loran-C Signal*), shows results of these calculations for the various station pairs in the NEUS (9960) chain. For example, diagram "C" in Figure III–13 shows accuracy contours for the master-Xray and master-Yankee station pairs. The *solid* line in this diagram shows the 2 drms contour of 1,500 ft. absolute accuracy, the *dashed* line 1,000 ft., and the *dotted* line 500 ft. Imagine, for example, that a vessel were located off Cape May, NJ. As can be seen, this location is well within the limits of the 500 ft. 2 drms contour, indicating that the absolute accuracy of the Loran-C system using these master-secondary pairs is quite high, and significantly better than the 0.25 NM absolute accuracy specification. Note from this illustration that these contours are well clear of the baseline extensions south of the Yankee secondary, or east of the Xray secondary.

Similarly, diagram "B" in Figure III–13 shows the same information for the master-Whiskey and master-Xray station pairs. These station pairs provide accurate coverage north of Massachusetts, but offer accuracy little better than 1,500 ft in the area off Cape May, NJ. A careful examination of all the diagrams within Figure III–13 indicates that the master-Xray and master-Yankee station pairs provide the most accurate Loran-C coverage over a broad ocean area stretching southward from Nantucket, MA, to the Yankee secondary in North Carolina. Therefore, a mariner using the NEUS (9960) chain anywhere within this area should select these secondaries for navigation.

Coverage Diagrams

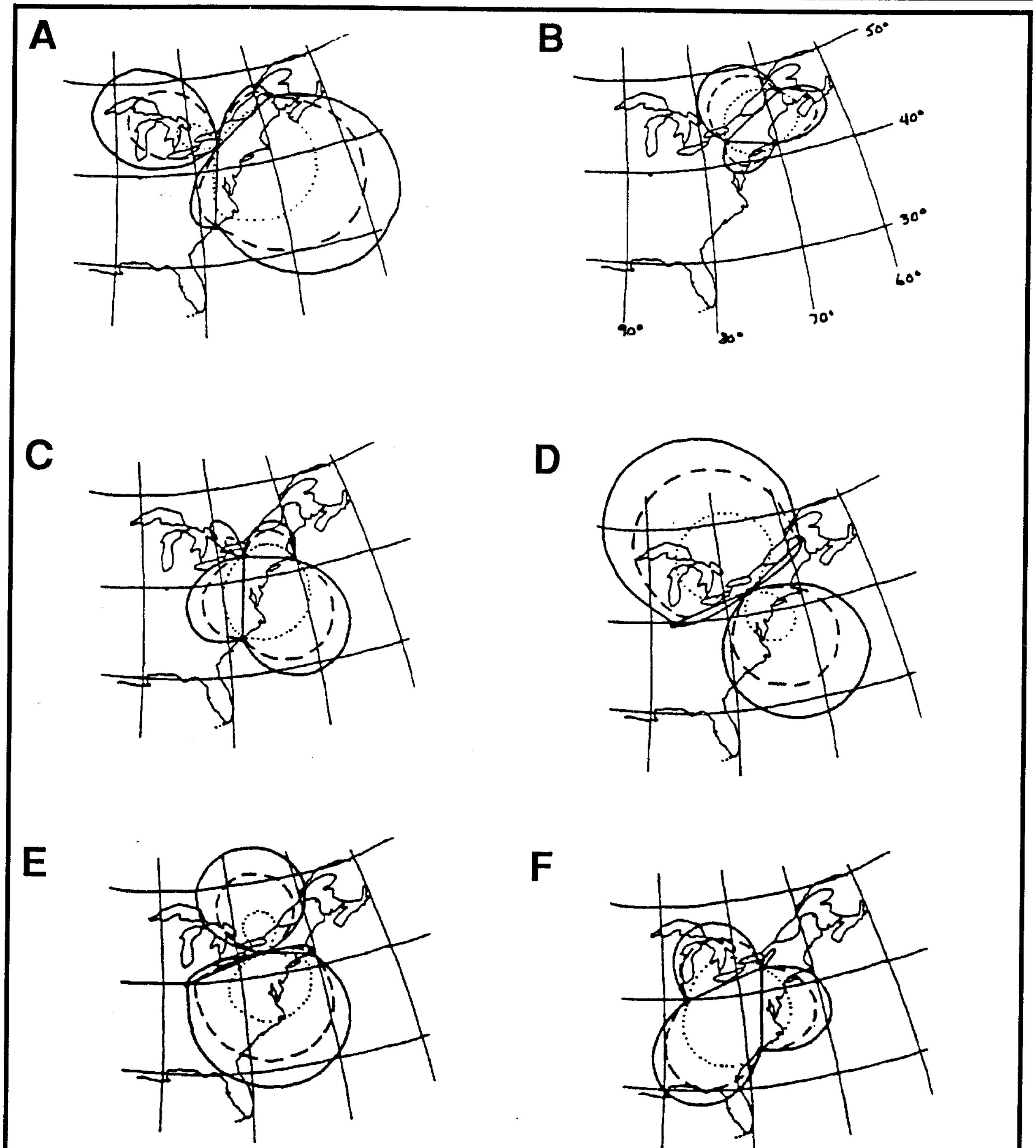
The range limits of the coverage diagram are selected to ensure that the *absolute accuracy* of a Loran-C fix (expressed as 2 drms) is at least 0.25 NM.

However, potential fix accuracy is only one criterion used in the determination of the coverage area of each Loran-C chain. It is also important to have *reliable* Loran-C reception. The Loran-C receiver has to be able to acquire and track a transmitted signal imbedded in "noise." This noise arises principally from atmospheric sources (noted above), and typically has a strength which exceeds that of the signal. The key measure of the relation between the signal strength and that of the noise is the signal-to-noise ratio (SNR). It is expressed as a ratio of the average signal strength to the root mean square noise strength.[7] The loran receiver's tasks of acquiring and tracking the signal are reliably accomplished when the SNR is high, but become more difficult as the SNR is lowered, and virtually impossible beneath a critical value. (The critical value varies among receivers.)

Signal strength as measured at a receiver location depends upon the transmitter power, antenna type, conductivity of the mixed land sea path over which the ground wave travels, and upon the range from the transmitter to the observer. In particular, the signal is attenuated as it travels from the transmitter to the receiver; the signal strength decreases as range increases. The strength of the noise is a function of many factors, but is typically dominated by atmospheric noise.

Mathematical models have been developed to calculate signal attenuation as a function of the distance from a loran transmitter, as well as to estimate noise. Using these models (typically imbedded in computer routines) it is possible to estimate the SNR of a signal as a function of range from the master station and associated secondaries in the loran chain. (For range planning purposes, it is assumed that the loran re-

FIGURE III-13. CONTOURS OF EQUAL 2 drms FOR VARIOUS TRIADS IN THE 9960 CHAIN.



2 drms fix accuracy; $\sigma = 0.1\ \mu s$

···················	500 ft.
— — — —	1000 ft.
————————	1500 ft.

Note: These contours are based on geometry only and *do not* include range limits.

ceiver requires a SNR of 1/3 or greater to provide reliable reception. In fact this SNR limit is conservative, many loran receivers can track signals adequately with SNRs of 1/10 or even less.) Therefore, it is possible to calculate the range limit for each set of station pairs in the loran chain.

Figure III-14 displays the results of an illustrative set of SNR calculations. This illustration shows the variation of SNR (from 0 to a maximum of 5) with range (in hundreds of nautical miles) for signals of various power (275 kW and 800 kW, representative of a secondary and master station power respectively) in two noise environments. The "average noise" environment (200 uv/meter) is representative of good weather conditions, and the "high noise" value (800 uv/meter) is typical of what might be expected during a thunderstorm. (Other assumptions in this calculation are summarized in Culver, 1987 and relate to "fair soil" ground path. This is one of the simpler models from among several that can be used for SNR calculations.) Note from Figure III-14 that the SNR decreases with distance, and that the SNR at the receiver is dependent upon the distance from the transmitter, the power of the transmitter, and the atmospheric noise level. For any combination of transmitter power and noise, the range at which the SNR falls beneath the assumed limit of 1/3 (0.333) can be calculated. In this set of calculations, this range limit varies between approximately 600 and 1100 miles, depending upon the transmitter power and the atmospheric noise level. Other things being equal, a doubling of the transmitter power results in only a 41% increase in the SNR, a point that underscores the practical difficulties of increasing the baseline lengths by increasing the transmitter power.

Remember also that each station in the Triad in use must be received with a minimum SNR for acceptable navigation, so the range coverage limit is calculated based upon the signals from the master and both secondaries.

The maximum range of the Loran-C system is defined as that range which satisfies both accuracy and SNR criteria. This is the limit of coverage shown in the Loran-C coverage diagrams. Adequate Loran-C navigation may be possible at ranges exceeding this maximum range (operation in so-called "fringe areas"), but adequate reception of a navigationally accurate signal is assured within the published coverage limits of the system.

Chain Selection

As noted, many loran receivers will automatically select both the loran chain and secondaries for use. As receiver design has advanced, these selection algorithms have become quite sophisticated, at least for some makes and models of receiver. However, the criteria used for automatic selection of chains and secondaries may be inappropriate in some instances. For example, some earlier loran receivers selected secondaries principally on the basis of the SNR. Although signal strength is certainly relevant to the selection of secondaries, it is not the only appropriate criterion. Moreover, there are circumstances where selection of the strongest signals would be contraindicated. (See Doyle, 1990, for an example relevant to the West Coast chain.)

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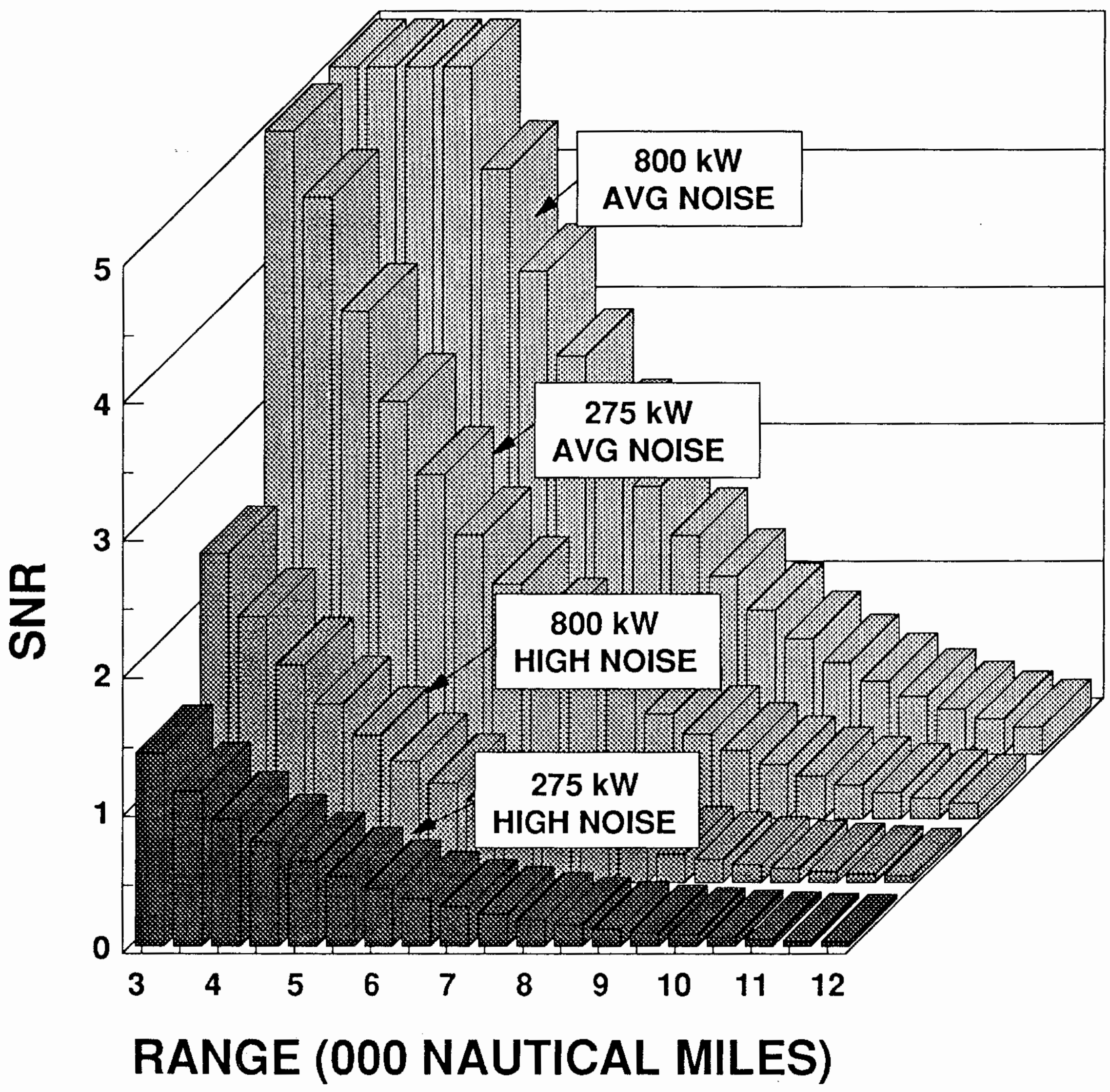
[7]For noise estimation purposes, the upper 95% one-sided confidence limit is used as averaged over each 4-hour period of the day, for each season of the year. This computation is made for a selected point in the middle of the coverage area.

FIGURE III-14. RELATIONSHIP BETWEEN SNR AND RANGE FOR VARIOUS ATMOSPHERIC CONDITIONS AND TRANSMITTER POWER LEVELS.



BASED UPON EQUATIONS PRESENTED IN CULVER 1987.

TABLE III-2
CHAIN SELECTION CRITERIA[1]

Criterion	Brief Description
Route/Destination Coverage	Whenever possible, select a chain that can be used throughout the entire voyage. This allows you to "lock on" your receiver prior to departure and maintain track throughout the trip without having to change chains.
Adequacy of Secondary Stations	Chain selection also depends upon the associated secondary stations. Select a chain that includes secondaries having the greatest potential for accurate navigation.
Availability of Service	Avoid using chains that have scheduled outages during the period of the planned voyage. Scheduled outages are published in the *Local Notices to Mariners,* and *Notices to Airmen,* and announced on Coast Guard radio broadcasts.[2]

[1]These criteria apply when manually selecting a Loran-C chain. Commercial receivers use a variety of criteria for *automatic* chain selection.

[2]Obviously *unscheduled* outages are also relevant to chain selection, but these are infrequent and (by definition) cannot be anticipated in prevoyage planning.

All Loran-C receivers have the capability for *manual* chain and secondary selection, and users should know how to select these chains and secondaries for optimal reception. Table III–2 provides three useful criteria for selection of the appropriate chain and secondaries. Assuming that there are no scheduled outages, and that one chain can be used for the entire voyage route, these criteria reduce to selection of the optimal secondaries shown in the coverage diagrams (e.g., Figure II–2).

Practical Pointers

Chapter V presents practical pointers on the use of loran. However, it is useful to consider the practical implications of the above discussion of system accuracy. At the most basic level, no navigation system should be used without a clear understanding of its limitations. Some of the key limitations for Loran-C are those on system absolute and repeatable accuracy. Unless the user has completed a survey (however informal) and determined actual TDs for important locations (e.g., entrance buoys, channel centerlines, channel turnpoints, rocks, shoals, and other obstructions to safe passage) or has access to such survey data, passages should be planned to keep the vessel well clear (considering the *absolute* *accuracy* of the system) of potential hazards to navigation. As well, the navigator should remember that loran accuracy is degraded (possibly beneath the stated 0.25 NM accuracy) in areas within 10 NM of shore and, in any event, when in close proximity of bridges, powerlines, and other large structures.

The mariner should also pay close attention to the selection of chains and secondaries to use, so as to maximize the absolute accuracy of the system. Receivers may select stations based on other criteria (e.g., SNR) that, while relevant, are not directly related to system accuracy. The loran user should not passively accept the "default" selection criteria of the receiver, without at least noting which secondaries are chosen and manually overriding the automatic selection when appropriate.

Users should try, whenever possible, to exploit the repeatable accuracy of the system, by deliberately recording locations of interest and navigational relevance. Each voyage presents the opportunity to record the TDs of navigationally relevant locations, and to check the repeatable accuracy of the system, including the receiver, by other methods (e.g., horizontal sextant angles, buoys, etc.). These activities can be integrated into a recreational voyage without consuming undue amounts of time. Cumulatively over several voyages, a very useful "personal data bank" of information can be developed. The utility of this information will be apparent on the first occasion that weather deteriorates to such a degree that a true "instrument approach" is needed to return safely to home port.

Incidentally, TDs of navigationally relevant locations can be stored in the Loran-C receivers (as waypoints), but should also be recorded in a separate hard-copy *log*. The utility of a written record is not only because receivers may not be able to store enough waypoints, but also because electronically stored waypoints can be accidentally erased.

Finally, it is worth repeating here that no one system of position fixing should be used exclusively. The prudent mariner or aviator is one who appreciates both the capabilities and limitations of the system, and uses all relevant information (e.g., DR plots, soundings, visual observations, radar, etc.) for navigation.

...No one system of position fixing should be used exclusively. The prudent mariner uses *all* available information (e.g. soundings, visual observations, of landmarks, fixed and floating ATONs, radar) for navigation.

CHAPTER IV

Receiver Features and Their Use

Introduction

Earlier chapters have addressed the theory of the Loran-C system. This chapter narrows the focus to the shipboard component of the system—Loran-C receivers. Specifically, this chapter provides an overview of the key features and characteristics of Loran-C receivers relevant to the navigator. Readers wishing to learn about the operating instructions for a specific make and model of loran receiver are advised to consult the appropriate owner's manual for details. As of this writing, there are at least 25 brand names of marine Loran-C units, (and several manufacturers of aircraft lorans)[1] and most manufacturers produce several models—so the user has a wide array of choices. Available Loran-C receivers differ substantially in design, type of displays, and operating instructions, making it impractical to cover this information in requisite depth in a chapter of reasonable length. Moreover, any such discussion would rapidly become obsolete because new models are continually being introduced.

This chapter serves as a supplement to the owner's manual, providing perspective, rationale, and theory to explain the features of modern Loran-C receivers. Prospective purchasers of a loran receiver may also find this chapter useful to identify the potentially desirable features of loran sets. Readers should be aware, however, that neither the Coast Guard nor any other agency of the U.S. government has the responsibility of performance evaluation or publication of comparative performance statistics of recreational vessel loran receivers although marine lorans used on certain types of vessels and aircraft lorans must meet technical performance criteria. (There are private sector publications that do present technical data and frank evaluations of Loran-C receivers.) It is also worth reminding the reader that receiver photo-

[1]Some of these are undoubtedly made by the same manufacturers, with only minor changes in the size or shape of housing or other "cosmetic" differences to distinguish "private label."

graphs included in this handbook are for illustrative purposes only and should not be construed as endorsements of any particular make or model.

As with this handbook generally, the focus of this chapter is on marine users. Where appropriate, supplemental material relevant to other users is included.

Read Your Owner's Manual

Although all Loran-C receivers operate on the same general principles, there are important differences among these receivers in features, methods of operation, and even in the definitions of terms used in the operating instructions. For example, one manufacturer uses the term "velocity along route" (VAR) to describe the component of the aircraft's or ship's speed over the ground in the direction of the course (more below), while other manufacturers use terms such as "velocity made good" (VMG) or "speed of advance" (SOA) to describe the same term. As a second example, one manufacturer calculates the "time-to-go" (TTG) to the next waypoint as the distance to the waypoint (distance-to-go, DTG) divided by the speed over the ground, another as the DTG divided by the component of the ground speed in the direction of the waypoint.

The control buttons of different receivers have different names (or alphanumeric designators), and operating procedures likewise differ.

The only way to master a particular make and model of Loran-C receiver is to read the accompanying manual, and call the manufacturer (or dealer) if you have any questions.[2] The old saw: "when all else fails, read the directions," is simply not good advice when it comes to today's sophisticated marine electronics or avionics. There is no substitute for careful study of the owner's manual.

Owner's manuals differ significantly in the amount of detail presented, and in their clarity and accuracy. The prospective purchaser is well advised to read this document and include the quality of the manual among the attributes to be considered in the purchase decision.

The old saw: "when all else fails, read the directions," is simply not good advice when it comes to today's sophisticated marine electronics. There is no substitute for careful study of the owner's manual.

Generations of Loran-C Receivers

Although the earliest Loran-C receivers were a substantial improvement over Loran-A receivers, these early (so-called *first generation*) Loran-C receivers were extremely primitive by today's standards. The first Loran-C models were difficult to operate (similar to the Loran-A sets), and provided only TD information. Later (so-called second generation) models offered little more than a display of measured TDs from two secondaries in a Triad. Users would need to specify the GRI and secondaries to be tracked, and take the measured TDs, convert these to latitude and longitude if desired, and otherwise do the time-honored navigator's "days work" of plotting, determining course to steer, estimated time enroute (ETE), estimated time of arrival (ETA), and the many other tasks common to the practice of navigation.

[2]Commercial videotapes are available to supplement the owner's manual for many makes and models.

Example of a "hand held" loran powered by 6 AA batteries. The antenna is telescoping and no external ground is required.
(Photograph courtesy of Micrologic Inc.)

The advent of microchips and miniaturization of computers over the years since the Loran-C system has been in place has created a "revolution" in the design and features of the modern receiver. Loran-C receivers now select chains and secondaries, automatically convert TDs to latitude/longitude, warn of any lack of system integrity, do many of the typical calculations made by navigators, and "talk" to other on-board electronic systems, such as radar, electronic charts, autopilots, and other marine electronics. If the early receivers could be called "radios" in some sense, the later receivers should really be termed "navigation computers." Additionally, the price of full-feature lorans has decreased substantially over the years, as manufacturers amortized research and development expenditures, captured economies of scale, and responded to competitive pressures. Receivers have, therefore, become much more affordable for owners of recreational vessels and aircraft.

Considering the sophistication of most modern receivers, these are remarkably "user friendly" (i.e., easy to operate). Nonetheless, it requires time and some diligence to master the use of a given receiver—not unlike that required to use a computer. Although some lorans are much easier to operate than others, all require a modicum of user sophistication.

Features

This section describes the relevant features of various Loran-C receivers now available commercially. Not all receivers include all of the features discussed below, but all of these features can be found among commercial loran sets. Some manufacturers use company-unique or trade names—different from those in this handbook—to describe these features.

Receivers differ widely in the number and type of features offered. The features discussed here provide a useful sample for the prospective purchaser.

–Basic Function: Reception and Display of Position Information

In broad terms, the functions of the Loran-C receiver are to acquire and lock on the appropriate transmissions and, at a minimum, to display the TDs associated with the selected master-secondary station pairs. Additionally, all receivers now being marketed have the capability to convert from TDs to latitude and longitude, termed a *coordinate conversion* capability. All modern receivers also have a "navigation mode" that enables the user to monitor the progress of a flight or voyage, and make necessary corrections to stay on course.

Receiver circuit designs are generally proprietary and, in any event, beyond the scope of this handbook. Nonetheless, receivers do employ different hardware and software,[3] and differ substantially in their ability to acquire and process signals. These differences can be important to the mariner—particularly a mariner who frequents "fringe areas" near the limits of the coverage area or areas where interference is high. With some older receivers, it is necessary to select the chain and the station pairs as part of the *setup* process. Newer receivers incorporate *automatic transmitter selection* (ATS) or *automatic initialization,* as it is sometimes called. If the receiver has this capability, all the user need do to initialize the set is to enter the user's latitude/longitude, and the set automatically selects the "best"[4] GRI and station pairs. This feature is convenient, but (as noted in Chapter III) it is sometimes necessary to override this automatic selection.

Once the GRI and the secondaries are selected, the receiver goes through a sequence of steps to search for, acquire, settle, and "lock-on" to the transmissions from the desired secondaries. Table IV–1 identifies the "generic" steps in signal acquisition and lock. The time for receivers to complete these steps varies with the receiver and the SNR of the master and the secondaries. Typically, this time varies from less than a minute for very strong signals to 15 minutes or more for signals with low SNRs. Most receivers display an alphanumeric code to identify the stage of the setup procedure. As noted in earlier chapters, the requisite SNR for reception differs with the receiver. The SNR required for acquisition is generally greater than that for tracking. This is why it sometimes occurs in an out-and-back trip that the loran receiver can continue to track a previously acquired signal in circumstances where the same receiver could not acquire the signal.

Some receivers can acquire and track only a master and two secondaries, while others can acquire and track all usable secondaries in a chain. Although two loran LOPs are sufficient to determine a fix, reception of additional second-

[3]It is convenient to distinguish between the receiver's "front end," or ability to acquire and lock-on to signals, and the "software" or computer programs that are used to process and interpret these signals. Sensitivity, dynamic range, and minimum SNRs necessary for acquisition and lock are largely (but not entirely) determined by the front end. Navigation features, latitude/longitude conversions, and ease of use are more a function of the software.

[4]"Best" is placed in quotation marks for the reasons discussed in Chapter III.

TABLE IV-1.
GENERIC STAGES FOR SIGNAL RECEPTION

Stage (Search Status)	Description
Search and Acquisition	Looking for signals of selected GRI, i.e., establishing the approximate location in time of the master and each of the selected secondaries with sufficient accuracy to permit subsequent settling and tracking.
Settling	Detecting the front edge of Loran-C pulse. Selecting the correct cycle (3rd) to be tracked.
Tracking (Lock)	Tracking 3rd cycle, i.e., maintaining the synchronization of the receiver with the selected signals. Lock on is the state of the receiver in which acquisition and settle have been completed and the receiver is tracking the selected signals.

SOURCE: *Report of the Special Committee No. 70, Minimum Performance Standards, Marine Loran-C Receiving Equipment,* Radio Technical Commission for Marine Services (RTCM), Washington, DC, 1977.

NOTES:

Different receiver manufacturers use slightly different terminology for these stages.

Some receivers display numeric codes to identify the various stages.

The time required to complete each stage depends upon the SNR of the signal at the receiver.

aries is desirable. As noted, the availability of an additional secondary can be used to resolve ambiguous positions when operating near areas of baseline extension. Moreover, statistical techniques can be used (Kalman filtering) to derive more precise position information if three or more LOPs can be measured. The receiver's computer automatically determines the position which minimizes the weighted mean square error of all the LOPs. At least one receiver manufacturer has designed a Loran-C unit with the capability to use signals from two chains simultaneously—a so-called *dual-chain receiver*. Statistically optimal positions can be derived from LOPs from many station pairs from the two chains. An advantage claimed for the dual chain receiver is that it can provide accurate positions at greater distances than single-chain counterparts.

It is important to note, however, that simply because a Loran-C receiver tracks all secondaries does not mean that it is capable of using information from more than two master secondary pairs in the manner noted above. Prospective purchasers are cautioned to read the user's manual carefully on this point.

Users should consult their owner's manuals to determine exactly which chains can be received by the set—some are capable of tracking all extant GRIs (including the USSR system), while others are more limited. The introduction of new chains (e.g., the recent SOCUS and NOCUS chains) may require software revisions for adequate reception on older models.

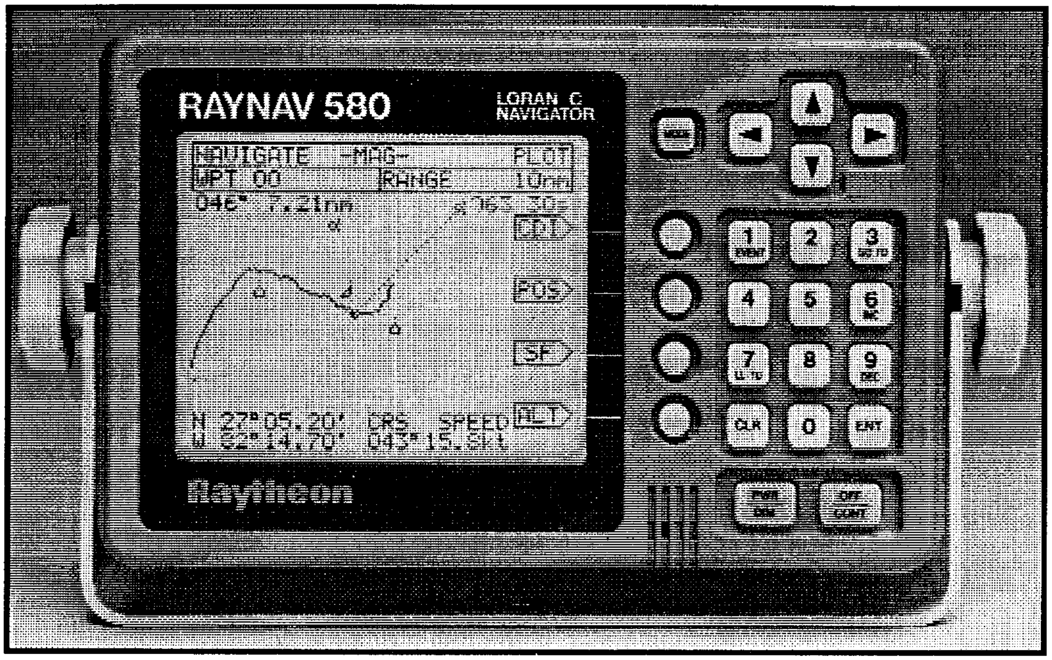


Illustration of a Loran-C receiver integrated into a plotter. Other display sizes include signal status, course deviation indicator, and route information. (Photograph courtesy of Raytheon Marine Company.)

–Displays

Nearly all modern marine loran receivers use a *liquid crystal display* (LCD), which is energy efficient and easy to read in daylight as well as darkness.[5] Dimmer switches are handy to control nighttime cockpit or nav-station light levels. These displays indicate position information (TDs or latitude/longitude) as well as many other ancillary quantities (stations in use, signal characteristics, navigational information, etc.). The size of the display screen varies among models. Some models feature "paged displays" in which different information is displayed on different "pages" of the display. By pressing a mode or other key, the user can page through the available information. Some lorans can interface with voice synthesizers, so that the user does not have to look at a display to acquire necessary information—a mechanical voice continually broadcasts data from the receiver. Some users find lorans equipped with voice synthesizers to be very convenient; to others this feature is an irritating distraction.

Prospective receiver purchasers are well advised to pay particular attention to the type of display screen of the set. This may seem an odd point to emphasize, but it is absolutely true that the most sophisticated Loran-C receiver in the world is of little use, unless the navigator can quickly read and interpret the available information. As with many other features of the loran receiver, the design of the display reflects numerous compromises and tradeoffs. A large screen, for example, is more costly, consumes more power, and may be incompatible with the overall size of the receiver. The available information from a Loran-C receiver (see below) includes status indicators and warning information, identification of the GRI and secondaries in use, SNRs of the master and secondaries chosen, alarm settings, position information (in latitude/longitude or TDs), and navigational information (e.g., waypoint descriptors, bearing and distance to waypoint, ETE/ETA information, cross-track errors, speeds, and courses, to cite just a few elements). In total, a modern Loran-C re-

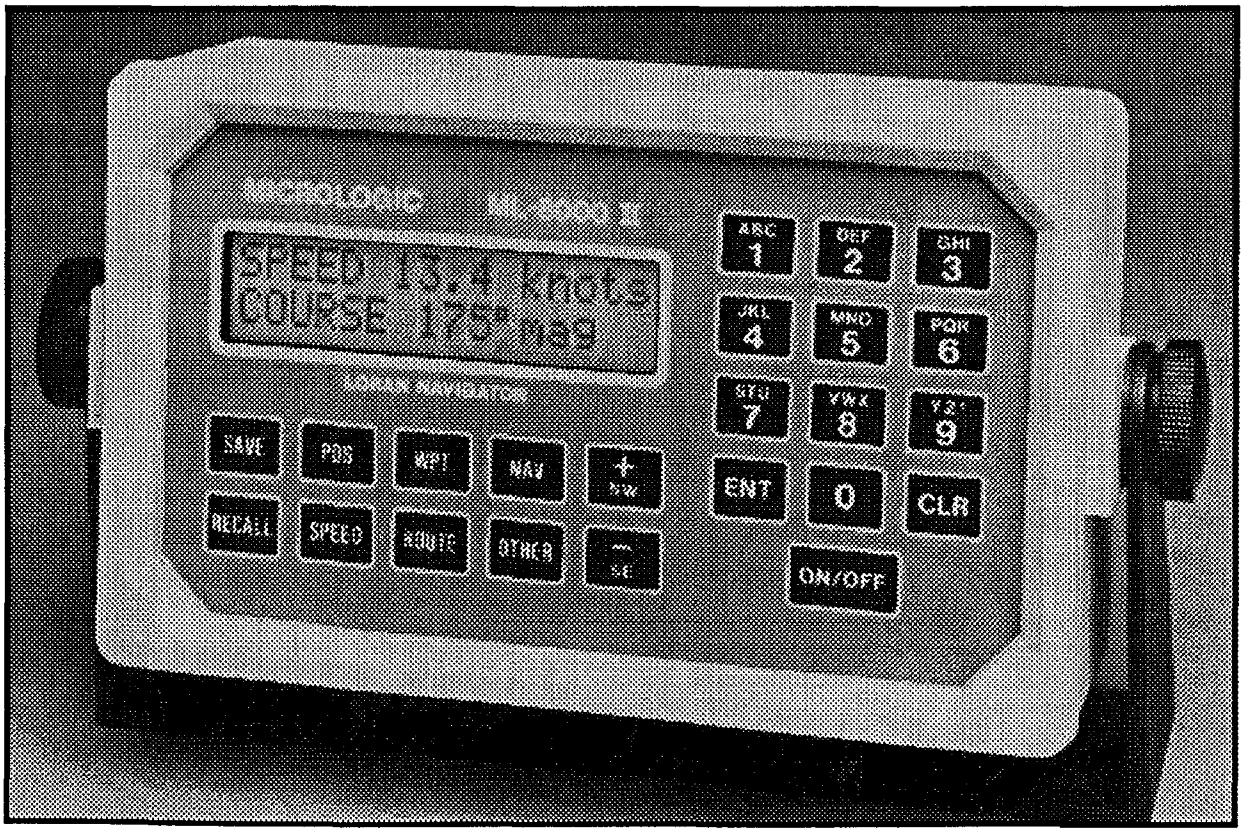
[5]Some earlier marine lorans used light emitting diodes (LED) which draw more power and are more difficult to read in strong light conditions. Aircraft lorans use LED displays more frequently.

ceiver may have the capability of displaying hundreds of pieces of potentially relevant data. Practical constraints limit the overall size of display screens, and size of lettering/numbering, so that it would be impossible (let alone confusing) to present all this information on one display. Segmenting the display into "pages," each with defined and logically grouped contents is a viable design alternative. However, paged displays do not solve all problems. For example, a user cannot simultaneously examine the contents of more than one page—so that not all information is rapidly accessible.

Large clear numerals or letters (without distracting and hard-to-read letters made from numerals) are easiest to read. It is also helpful if the screen can display several items at once (perhaps in different sizes) so that the user does not continually have to switch pages to find related information. Some information is more easily and rapidly understood in analog (e.g., pointers, arrows, etc.) rather than digital form. Arrows, symbols, or mini-charts, if well designed and logically grouped, can also enhance the interpretability of a display. So-called "menu" screens (i.e., those with self-prompting inputs) can ease the task of entering data.

Display screens differ in the "viewing angle," through which the numbers can be clearly read. Some displays are quite difficult to read when not standing directly in front of the set.

Finally, the display should be evaluated in terms of where the loran receiver will be mounted in the vessel. Mounting directly in front of the helm station (e.g., on a power vessel) may not



A "paged" two line display showing course and speed information.

(Photograph courtesy of Micrologic Inc.)

require a display as large as if the set were mounted at some distance from the navigator's eye, as might be required on a sailboat. Aircraft lorans are generally rack mounted on the instrument panel.

Receiver displays are a very important feature. Ideally, the display should be large and easy-to-read, keeping key information readily in view.

–Keypad

The keypads used on loran receivers differ. Some use "membrane" or flat keypads, others use raised keys. In general, raised keys (as on a computer keyboard) have a better feel, and are easier to use. Membrane keypads are easier to make waterproof or water-resistant, however.

Some receivers emit a "beep" when a key is depressed and the information is entered. This feature compensates, to some degree, for the lack of tactile sensation when using a membrane keyboard.

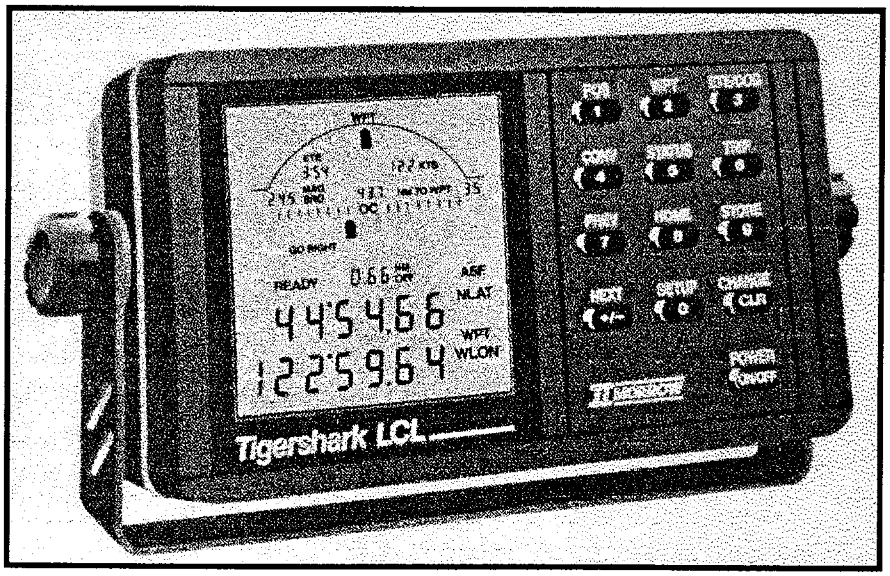
The size of the keys likewise differs among receivers. Closely spaced keys invite entry errors, particularly when on the bridge of a pitching or rolling vessel, or in the cockpit of an aircraft encountering turbulence.

Nearly all receivers have a numeric keypad (in addition to function keys). On some models, however, it is necessary to push "+" or "–" buttons to increase or decrease an entry—an inconvenience when entering waypoint coordinates.

Some marine lorans have "calculator style" numeric keyboards—i.e., with the keys 7-8-9 on the top row. Other marine lorans have "telephone style" numeric keyboards—i.e., with the keys 1-2-3 on the top row. There is no "best choice" for the keyboard type,but a matter of individual preference.

–Remote Readout

Some receivers offer the option of a remote readout or display to be used instead of, or in addition to, the principal readout. Receivers with this feature can be used to provide navigational information in two locations, such as at the bridge and at a separate navigator's station. Of course, the same effect can be achieved by using two lorans—one at each station—but the remote



This Loran-C receiver features an "artificial horizon" display that facilitates understanding of navigation information.
(Photograph courtesy of II Morrow Inc.)

readout ensures that both stations display the same navigational information, and at a cost somewhat less than that for a second loran.

–Coordinate Conversion

All modern *marine* Loran-C receivers have the capability of displaying position information as TDs or as latitude/longitude. (Aircraft lorans use latitude/longitude exclusively.) TDs are what is measured by the receiver in all cases, and these are converted to latitude/longitude by mathematical algorithms using ASF information (e.g., the tables shown in Chapter II) stored in computer memory.[6] Some manufacturers have gone to great lengths to ensure that ASFs are as accurate as possible.

Although the ASFs stored in the internal memory of the Loran-C receiver are highly accurate for many makes and models, this is not true uniformly. Studies conducted at the Coast Guard Research and Development Center in Groton, CT (see Frazier, 1988), indicated that the internal ASF tables in some models were very inaccurate for some locations. Indeed, for some makes and models, the internal ASF corrections resulted in greater latitude/longitude errors than if no corrections were applied at all. As of this writing, there is no industry standard for coordinate conversion,[7] and each manufacturer uses a slightly different variant. It is possible, therefore, for two Loran-C receivers located next to each other to register exactly the same TDs, but slightly different positions in latitude and longitude terms.

Because of this lack of standardization, and because ASFs are only approximate in any event, use of TDs is preferred for most accurate navigation—although accuracy differences may not be large for "top-of-the-line" Loran-C receivers.

(As noted above, aircraft loran receivers provide latitude/longitude information only. The width of a typical airway ["highway" in the sky] is 4 nautical miles either side of a centerline, so precise position information is less important in the enroute mode. When making instrument approaches to airports, standard ASFs appropriate to each airport are entered into the loran from the published instrument approach procedure.)

When prestored ASFs are being applied, there is generally some indication on the display (e.g., the code sequence "ASF") to indicate that this is the case. (Most lorans also enable the user to input a predefined ASF, latitude/longitude offset, or *bias* as an alternative to the stored values.)

Experienced navigators needing optimal Loran-C accuracy are well advised to use TDs rather than latitude and longitude. Published waypoints are often given in TDs as measured.

–Notch Filters

Loran-C signal reception can be impaired by interference from other signals, broadcast on

[6]A few loran receivers being marketed as of this writing do not have internal ASF tables or the capability of manually entering these factors.

[7]RTCM is presently working on such a standard. Interested readers should contact RTCM for details and current information.

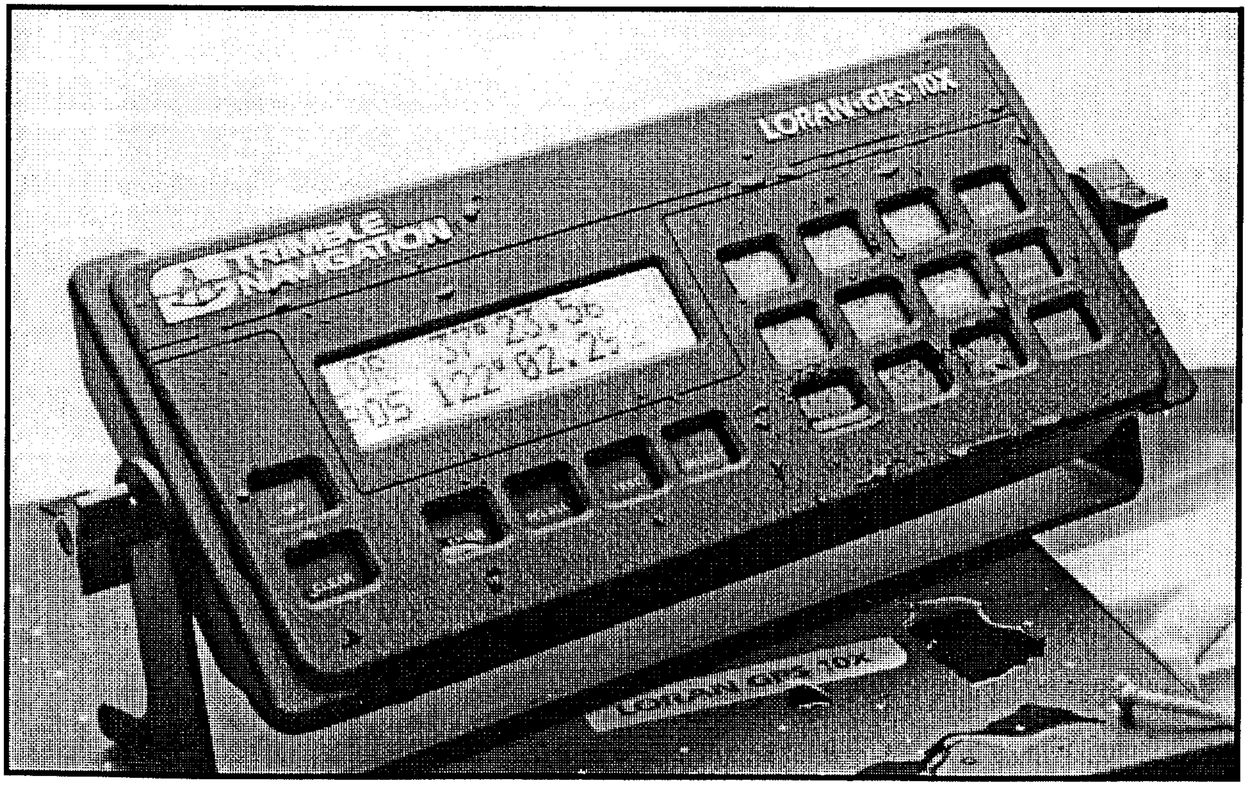
slightly different frequencies (e.g., radio broadcast stations, military radio transmitters, and other navigation equipment). Appendix A provides a list of known sources of interference in the United States, Canada, and Mexico.. The severity of the effects of interfering signals is a function of many factors, but interfering signals can reduce the SNR of the loran signal and degrade the accuracy of the position determined.

To avoid the degradation in SNR associated with these interfering sources, loran sets are equipped with so-called *notch filters* that can be used to attenuate or "notch out" the interfering signal. Some receivers contain built-in *spectrum analyzers* to display levels of interfering signals, a useful feature when setting adjustable notch filters. Some receivers are equipped with preset notch filters, others with adjustable notch filters, and yet others with so-called "Pac-man" or "seek and destroy" filters. These latter filters automatically search for interfering signals near the loran band and dynamically notch out this interference. Refer to the owner's manual for instructions on how to use the notch filters for a particular make and model of receiver.

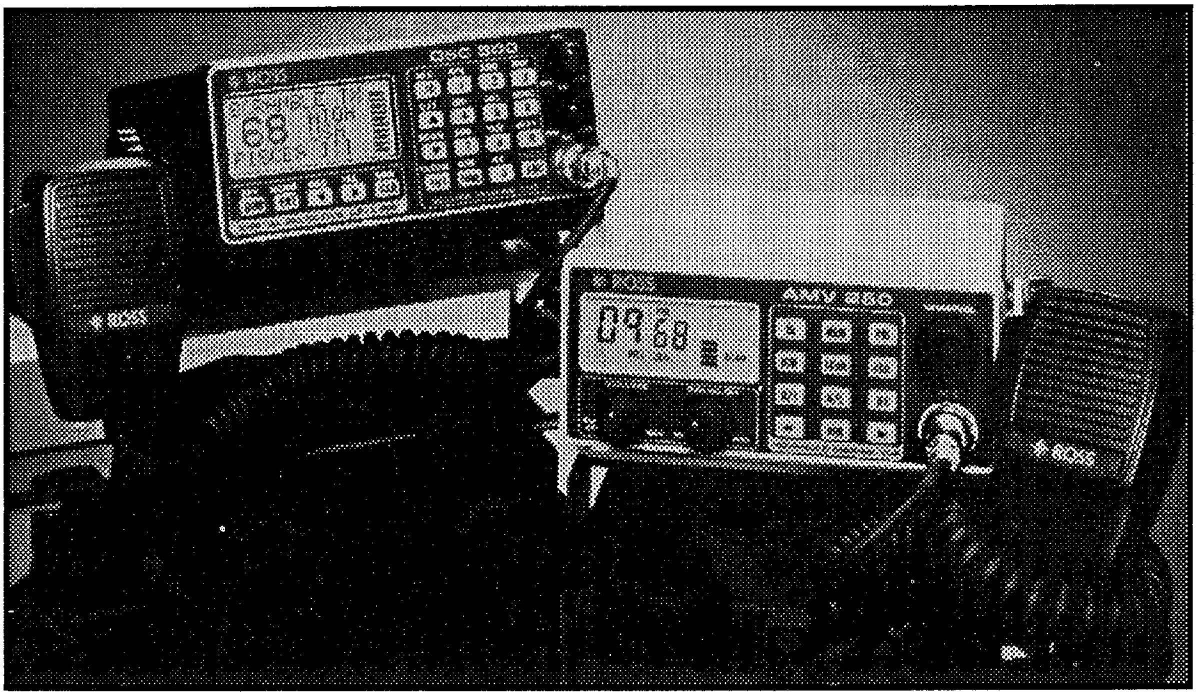
It should be noted that the purpose of notch filters is to control the effects of interfering signals, not any noise or interference associated with shipboard equipment. Control of *internal* noise sources is addressed in more detail in Chapter VII.

–Integration with Other Systems

Loran-C receivers can be integrated with



This receiver can process Loran-C or GPS inputs, and couples not only to shipboard electronics, but also personal computers.
(Photograph courtesy of Trimble Navigation.)



The Digital Selective Calling (DSC) radio pictured at left interfaces with a marine loran receiver so that the vessel's position can be transmitted. This is particularly helpful in the event of distress.
(Photograph courtesy of Ross Engineering)

other shipboard systems in two ways. Some Loran-C receivers are actually "built into" another piece of electronic gear, e.g., a depth sounder, fish finder, or plotter. Some receivers are integrated with GPS, offering additional flexibility and redundancy. As well, most receivers have output jacks with a standardized output (three common protocols are the *National Marine Electronics Association,* NMEA 0180, 0182, and 0183 formats) that enables interconnection with plotters, video charts, autopilots, and radars. Some models can also be interconnected with a gyrocompass or fluxgate compass and speed log—enabling the electronic determination of the set and drift of the current. This interface capability can be a considerable help to the navigator. Prospective purchasers should ensure that the correct output formats are available to tie into ancillary equipment.

–Data Bases

Some Loran-C receivers, typically those intended for use on aircraft, but also some marine models, incorporate a self-contained "data base." On an aircraft loran, for example, this data base would contain the locations of the thousands of airports throughout the country. The user can call up attributes of the airport (e.g., the longest hard surfaced runway) with only a few keystrokes, and navigate to this airport. In the event of an in-flight emergency, the loran receiver can display the distance and bearing of the nearest airfield having the requisite runway characteristics. Likewise, marine loran receivers with data bases contain the locations of buoys and other features of navigational interest. One marine loran comes with a data base of approximately 8,000 lights and 6,000 buoys, along the coast of the continental United States, Great Lakes, Hawaii, and Alaska.

A data base can be very convenient, but it is also necessary to have some means to update the data base as the locations of the entries or other

TABLE IV-2. CURRENT DRAW FOR SEVERAL TYPES OF MARINE ELECTRONIC EQUIPMENT: TURNING OFF THE LORAN-C IS UNLIKELY TO FEATURE IN ANY LOAD-SHEDDING STRATEGY.		
Equipment Type	**Typical Current Draw (Amperes)**	**Remarks**
RDF/ADF	0.5 - 3.0	Older units likely to be less efficient. ADFs (aircraft type) are at the upper-end of this range.
Loran-C	0.07 - 1.75	More complex Loran-C, including integrated loran/GPS navigation systems draw more current.
VHF-Radio	1.0 - 5.5	Varies depending upon whether transmitting or operating in receive only.
Video Charts	0.8 - 2.5	Based upon sample of 10 makes and models.
Video Plotter	1.1 - 8.3	Based upon sample of 11 makes and models.
Weather Fax	2.0 - 3.3	Depends upon whether receiving or only in standby mode.
Radar	3.0 - 18.0	Based upon sample of 62 makes and models. Power required a function of maximum range of the radar.
Depth Sounder	0.3 - 5.0	Depends upon whether indicator only or video or paper chart type.
Autopilot	8	NA
Navigation Lights	3	Based upon three 12-watt lights, this number could be larger.
Tape Deck	1.25	Based upon sample of 8 makes and models.
Bilge Pump	1 - 15	Unlikely to run continuously.
Cabin Lights	1 - 4	Varies with number and wattage.
Single-Side Band Radio	1 Receive 12 Xmit	Not needed within VHF range of shore.

NOTE: The above table is furnished for illustrative purposes only. Consult the owner's manual for each piece of equipment for details.

information changes. With aircraft lorans, a cartridge is shipped periodically to update the original factory supplied data.

–Magnetic Variation

Most Loran-C receivers are equipped with a chip that provides magnetic variation data throughout the areas of the world covered by the loran chains that can be used by the receiver. On some models, this data base includes average annual changes in variation. Once the user enters the date and year, the receiver can compute the variation at any relevant location. In practice, therefore, the user can do all navigation with reference to either true or magnetic north. (Deviation is not accounted for on any production loran as of this writing.) When directions are referenced to magnetic north, the loran receiver displays a "flag," such as "MAG" or other abbreviation to indicate that directions are referenced to magnetic, rather than true, north.

–Power Requirements

Nearly all Loran-C receivers used by recreational vessels or aircraft operate on DC power. In most cases, these receivers are designed to use on board power. Consult the specifications for each receiver for the acceptable voltage range (e.g., 10–15 volts or 7–40 volts). However, some receivers are portable, and use self-contained batteries (e.g., 6 AA cells). (Power batteries should not be confused with those lithium batteries required to maintain the receiver's waypoint memory.)[8]

If the voltage drops outside of the acceptable range (because the batteries are run down, or as a result of starting the engine), the loran receiver may "crash," and have to begin the entire acquisition-to-lock cycle anew. This could cause a problem if, for example, the engine(s) were shut down to increase the likelihood of hearing a sound signal from a critical buoy in circumstances of restricted visibility. If, on restarting the engine(s), the loran were to crash, the navigator would lose critical navigational data at an inopportune time. Where possible, it is desirable to use a different battery to power marine electronics from that used to start the engine(s).

Power requirements for Loran-C receivers are typically quite modest. As Table IV–1 shows, Loran-C receivers do not draw much current (e.g., 0.15 to 1.75 amperes among a sample of 20 receivers), at least in comparison to many other types of marine electronics found on board a recreational vessel. Thus, to operate a Loran-C receiver for a 24-hour period would require from 3.6 to 42 ampere-hours.

Power requirements for Loran-C receivers are typically quite modest compared to other marine electronics. This enables Loran-C receivers to be operated almost continuously on sailboats, power vessels or aircraft experiencing alternator failure.

[8]These memory batteries need to be replaced periodically to ensure that memory contents are not lost. A battery lifetime of from 3 to 7 years is typical for lithium batteries used for this application.

TABLE IV-3. AUTOMATIC ALARMS, STATUS, AND WARNING INDICATORS.[1]	
Name[2]	**Brief Description**
Accuracy	Alphanumeric display to warn that accuracy of displayed position may be poor.
Ambiguity	Alarm to note that ambiguous position information is being received—probably as result of operating in area of baseline extension.
No Solution	Receiver unable to compute latitude/longitude from available information—may be provided in lieu of "ambiguity" alarm.
SNR	Warns that SNR of master or secondaries is poor.
Cycle Select	Warns that receiver may not be tracking correct cycle in Loran-C pulse.
Blink	Warns whenever blink code is received. Latitude/longitude or TDs will blink on and off as well on some receivers.
Battery	Feature on portable loran sets to warn that batteries used as power supply are low and need to be replaced. May also present remaining battery life in hours.
Power Failure	Warns that battery voltage (shipboard) batteries has dropped below usable voltage (e.g., 10 volts) and that restart procedures must be used.
Memory Battery	Warning on some lorans that internal battery is weak or has failed and memory contents may be lost.
ASF	Indicates that ASFs permanently stored in memory or manually entered are in use for latitude/longitude conversion.
MAG	Indicates that course and bearing displays are reference to magnetic, rather than true north. Variation may be input manually or stored on memory chip.
Manual Offset	Indicates that user-supplied offsets (ASFs) are being applied for latitude/longitude conversions.
ECD	Warns that envelope-to-cycle difference is out of specification and that the receiver may be tracking the wrong signal. Display may be integrated with cycle alarm.

[1]Above list is illustrative, not all receivers are able to display each warning or status message.

[2]Names given in this list are illustrative. Actual designations vary from receiver to receiver.

Power requirements for marine electronics are relevant not only for selecting the storage batteries and sizing the generator (alternator), but also for designing a "load shedding" strategy in the event of alternator failure. A heavy-duty marine battery of 100 ampere-hour rating, for example, could supply current to service the ship's electronics load at the rate of 100 amperes for one hour, 50 amperes for two hours, 25 amperes for three hours, etc., without being recharged. In the event of alternator failure, all nonessential electrical equipment would be shut off to conserve the battery. Mariners are left to decide exactly what is "nonessential," depending upon the circumstances of the voyage. As Table IV–2 indicates, the current drain for most lorans is sufficiently small that the loran receiver would probably not have to be shut down in the event of alternator failure. Even this small draw could be reduced by the simple expedient of shutting off the display lights and using a small flashlight for illumination if necessary.

–Automatic Alarms and/or Status Indicators

Most Loran-C receivers have the capability to display a variety of automatic alarms and/or status and warning indicators. Table IV–3 provides a sample of these alarms and status and warning indicators for marine lorans. These alarms and the names and display codes vary from receiver to receiver, so the owner's manual should be consulted for details. For example, one receiver model combines all of these alarms into one warning flag, *"wait,"* to indicate that positions displayed by the loran may be unreliable. On this model "wait" is displayed if there is a low SNR, cycle error, blink code, etc. Other models are capable of displaying much more detailed information. In general, it is desirable to have more detailed information, because the user can often intervene (e.g., by switching secondaries) to remediate the problem.

With one exception, the definitions of the alarms and status indicators in Table IV–3 are clear and do not need elaboration. It is appropriate, however, to say a few words more about SNR indications on Loran-C receivers. SNRs are very important to the user. "Low" SNRs warn the user of possible acquisition or tracking difficulties, the need to switch secondaries, and/or that on-board electrical interference problems exist. "High" SNRs are generally desirable—but "abnormally high" SNR values in what would otherwise be fringe areas could warn of skywave contamination (see Chapter II). For these and other reasons, SNR values are important to the mariner.

Some Loran-C receivers display SNR information only in qualitative terms, e.g., by letter codes (e.g., "A" = excellent, "B" = very good, etc.) or word descriptors such as "very low" or "very high." Other sets display a two or three digit numerical code—e.g., ranging from 00 to 99, where 00 is worst and 99 is best. Pay particular attention to the text in the owner's manual to interpret the SNR values provided by a particular make and model.

A measure of the signal-to-noise ratio favored by electrical engineers is the SNR in decibels, abbreviated dB. The SNR in dB is numerically equal to 20 log (SNR). Thus, for example, an SNR of 0.5 would be equal to -6.02 dB. Equivalently, the SNR corresponding to a particular dB reading is SNR = $10^{0.05dB}$. Table IV–4 shows the relationship between the SNR (as a fraction) and the equivalent in decibels. As can be seen from inspection of this table, the SNR in dB will change by approximately six units whenever the actual SNR is either doubled or halved. Some Loran-C receivers have the capability of displaying SNR values in dB. This display is preferable because, alone among the

TABLE IV-4. RELATION BETWEEN SNR AND DECIBEL SNR MEASUREMENT.

SNR	Decibels (dB)
5.00	13.98
4.00	12.04
3.00	9.54
2.00	6.02
1.00	0.00
0.90	-0.92
0.80	-1.94
0.70	-3.10
0.60	-4.44
0.50	-6.02
0.40	-7.96
0.33	-9.54
0.30	-10.46
0.25	-12.04
0.20	-13.98
0.15	-16.48
0.10	-20.00
0.05	-26.02

various methods of indicating SNR, the actual SNR value can be calculated from the dB figure.[9]

SNR displays are useful for setting notch filters, determining the sources and significance of shipboard electrical interference, detecting skywave contamination, and selecting secondaries for use. Quantitative displays showing the actual SNR (as a ratio or in decibels) are best.

–Recording SNR Data in the Navigation Log

Navigators should make it a practice to record the SNR for various stations as a *memo item* in the navigation log for each trip. Over time, a data base can be assembled that will provide the navigator with a series of "norms" for comparison. It is only by this method that the navigator has the information to determine that something is amiss. Perhaps there are storms between the LORSTAs and the vessel, perhaps a newly installed piece of shipboard equipment needs noise suppression, or the receiver's ground has been impaired, etc. These phenomena or problems can only be detected by a systematic comparison of SNR values with historical norms which depend upon the make and model of receiver, installation technique, and vessel location.

Navigation Features

The above features of loran receivers would be, in themselves, more than satisfactory for navigational purposes. However, all modern lorans also incorporate a wide variety of navigational functions that, taken together, transform loran from simply an instrument to determine position (such as a hand bearing compass or a sextant) into a complete navigational system. Navigational information and functions of modern Loran-C receivers are next discussed.

The Loran-C receiver "knows" the user's position (in TD and/or latitude/longitude terms) at any instant in time. As well, the receiver has a very precise "clock." Knowledge of position and time information enable the calculation of the user's speed, course, and other relevant information for navigation.

[9] In principle, SNR values could also be calculated from a two-digit or three-digit code. However, a survey of 20 owner's manuals for different sets has failed to find one example where this correspondence has been provided.

–Waypoints

As noted in earlier chapters, all Loran-C receivers in current production have the capability of entering and storing "waypoints." These waypoints are simply sets of coordinates which describe a location of navigational interest. Waypoints could include a dockside location where the vessel is berthed, fixed and floating aids to navigation, channel centerlines, turnpoints, productive fishing areas, wrecks, shoals, etc.

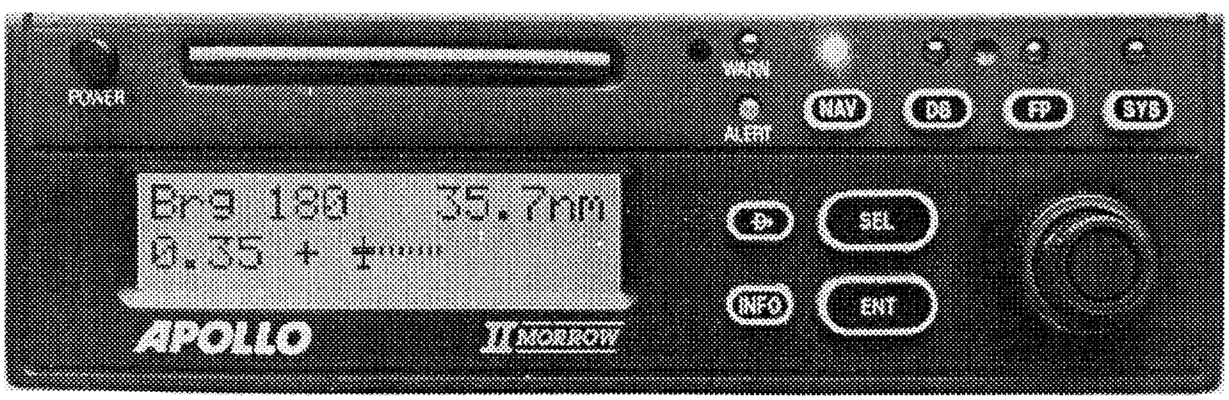
Aviators would typically define different types of waypoints from those given above. Possible waypoints relevant to aviation uses of loran could include airports, locations of the initial approach fix, locations of radionavigation aids, airway intersections, locations of published holding fixes, turnpoints, and other relevant information. Note that aviation lorans equipped with a data base may have many of these locations preprogrammed in the loran. (A subscription service is available to update these locations.)

Waypoints can generally be entered into (and stored by) the loran either by visiting the area and pressing the appropriate control button on the set, or can be entered as coordinates (typically as TDs, latitude, longitude, or as distance and either true or magnetic bearing from another waypoint). The number of waypoints that can be stored in the receiver's memory varies by make and model, but most receivers can store 100 or more waypoints. Waypoints are stored as a waypoint number and set of coordinates. Some receivers permit an alphanumeric waypoint designator (e.g., "home," "buoy 01," etc.) to be used.

In use, waypoints are either places to be *visited* (e.g., checkpoints along a route) or places to be *avoided* (e.g., shoals, rocks, or other obstructions to navigation). Often a navigator will lay out a sequence of waypoints, linked into an overall "route" for the voyage. The Loran-C receiver keeps track of the user's progress from waypoint to waypoint. At all times, the user can determine the "distance-to-go" (DTG) and "bearing" (BRG) to the next waypoint in sequence, an angular course direction to the next waypoint, and the "time-to-go" (TTG) to reach the next waypoint. (These functions are discussed in more detail below.)

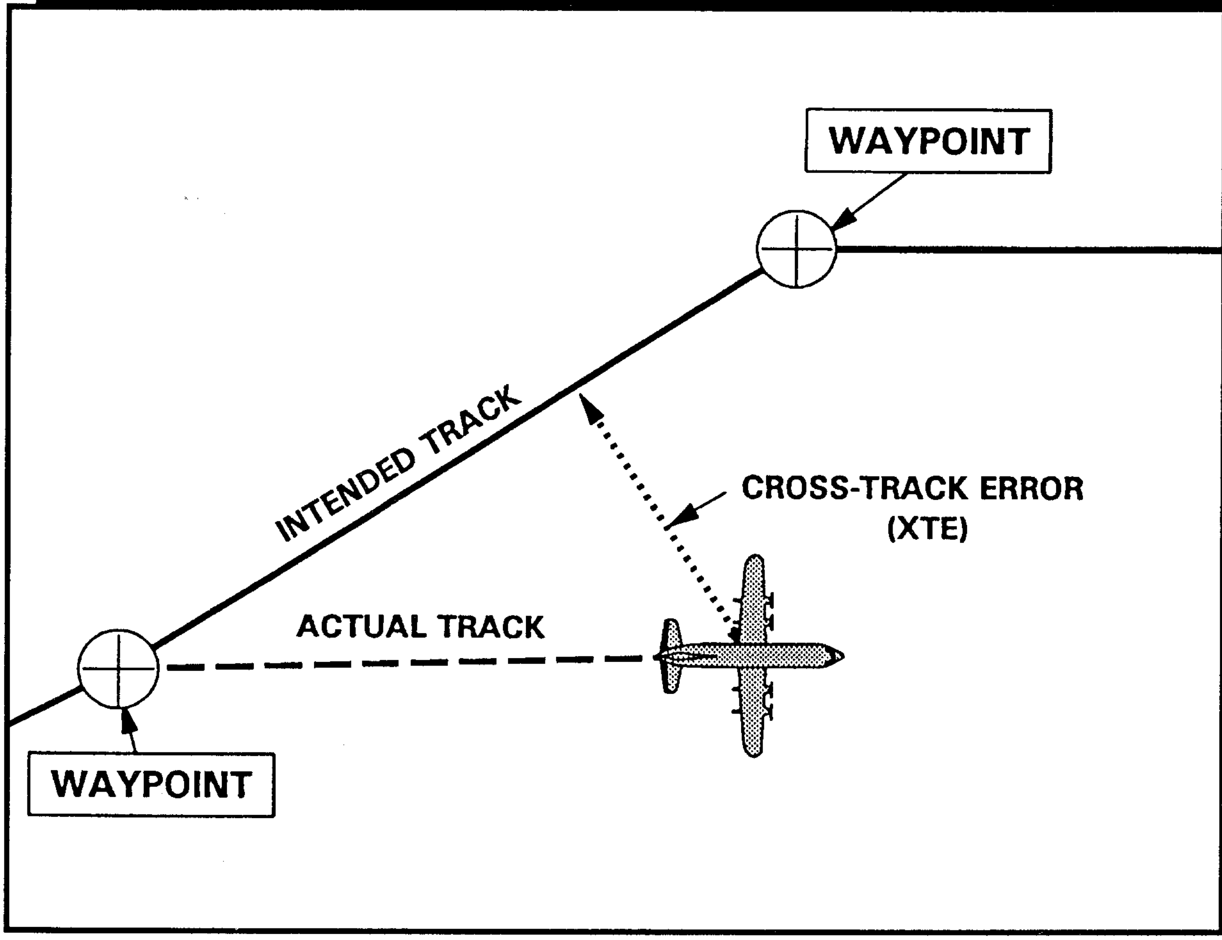
–Cross Track Error

The *cross track error,* often abbreviated XTE on loran displays, is the perpendicular distance from the user's present position to the intended track between waypoints. Nearly all



Aircraft loran displaying bearing and distance to waypoint.
The second line shows the magnitude (0.35NM) and direction of the XTE.
(Photograph courtesy of II Morrow Inc.)

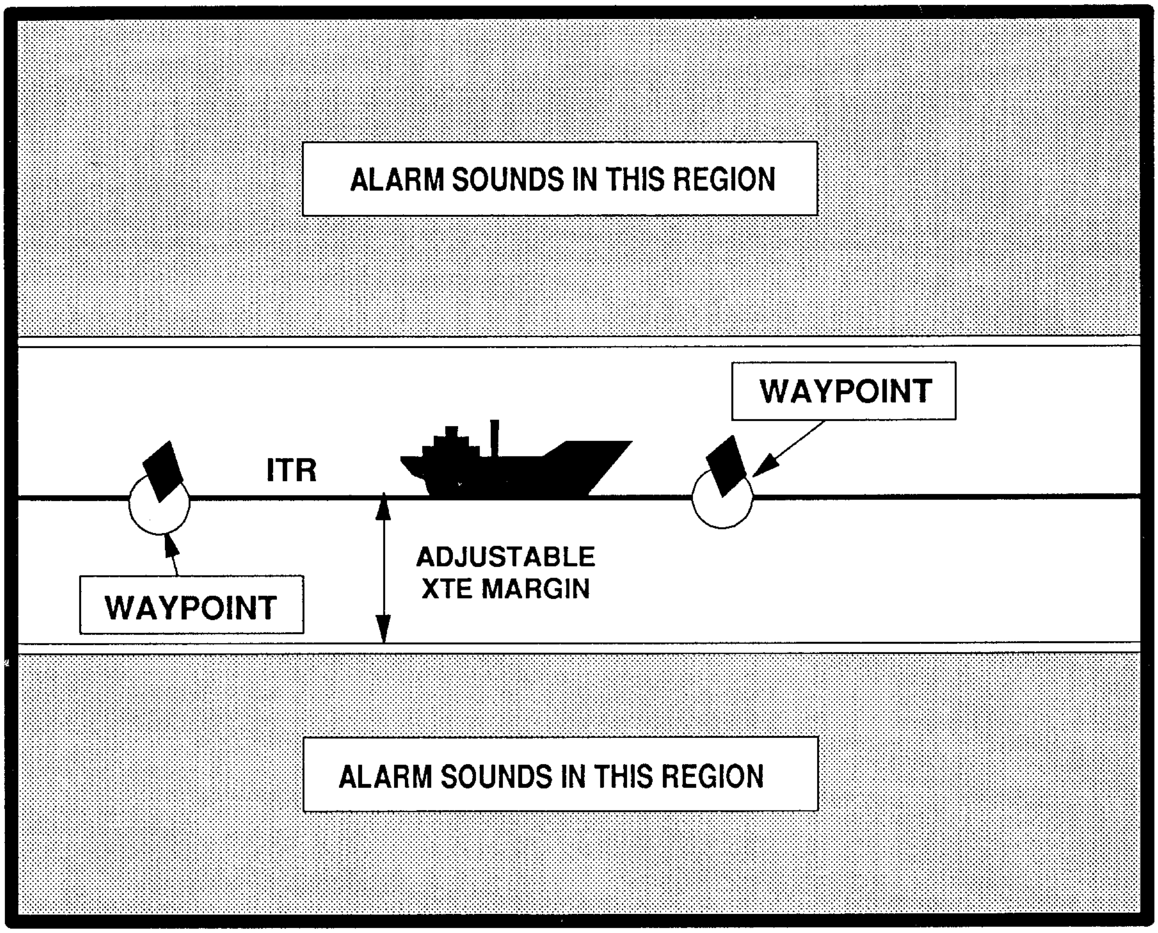
FIGURE IV-1. CROSS-TRACK ERROR (XTE) IS THE PERPENDICULAR DISTANCE FROM THE USER'S POSITION TO THE INTENDED TRACK.



modern Loran-C receivers can display the XTE— optionally in nautical or statute miles. Cross-track error is illustrated in Figure IV–1, which shows the aircraft's intended track (the solid line) between two waypoints and the actual track, denoted by the dashed line. In this illustration, the aircraft has drifted to the right (south) of course. The "bearing" (BRG sometimes called *course-to-steer* [CTS]) would be the angle from the aircraft's present position, and the DTG, the distance (great circle) from the user's present position to the next waypoint in sequence.

Knowledge of the XTE enables the user to alter the vessel's or aircraft's course to compensate for the observed drift, effects of maneuvering to avoid traffic, and/or inattention at the helm. Additionally, many receivers display a *course deviation indicator* (CDI), often by an arrow, that indicates the appropriate angular correction to return to course. It is important to remember that the mere fact that the loran indicates the XTE does not imply that there is safe water or airspace between the vessel and the waypoint. It is the navigator's responsibility to

FIGURE IV-2. THE CROSS-TRACK ERROR (XTE) ALARM SOUNDS WHENEVER THE PRESCRIBED XTE HAS BEEN EXCEEDED.



check the appropriate charts to determine if a course alteration can be made safely. If an autopilot is coupled to the loran receiver, the autopilot will maintain a correct course to the next waypoint.

To simplify navigation, many receivers enable an adjustable *XTE alarm* to be set, so as to warn the user when a pre-defined XTE tolerance is exceeded. Figure IV–2 shows this graphically. As in the first illustration, the vessel is assumed to be in transit between two waypoints. The XTE alarm is an audible alarm that can be set to warn the mariner of any excursions outside of a "lane" of adjustable width between the waypoints. In Figure IV–2, for example, the XTE alarm would sound whenever the vessel strays into the shaded area.

An XTE alarm would typically be set for voyage legs where navigational hazards (e.g., shoals, rocks, heavily traveled shipping lanes, fish trap areas) lie to one side or the other of the intended track. The XTE alarm should be set so as to enable the vessel to return to course in ample time to avoid the navigational hazard.

TABLE IV-5. ADJUSTABLE ALARMS OR TYPICAL LORAN-C SETS

Name	Description
Arrival	Alarm to indicate that vessel has penetrated to within an adjustable radius of the next waypoint.
Passing	Alarm to indicate that vessel has passed a waypoint and is enroute to the next waypoint in a route sequence. (Sometimes termed "*arrival off course alarm*" or "*perpendicular crossing alarm.*")
Off Course (Cross Track Error)	Alarm to indicate that vessel has cross track error larger than preset amount.
Boundary (Border)	Alarm to indicate that vessel has penetrated a defined exclusion zone parallel to the track between two waypoints.
Anchor Watch	Alarm to indicate that vessel has departed from within a predefined swing circle about waypoint.

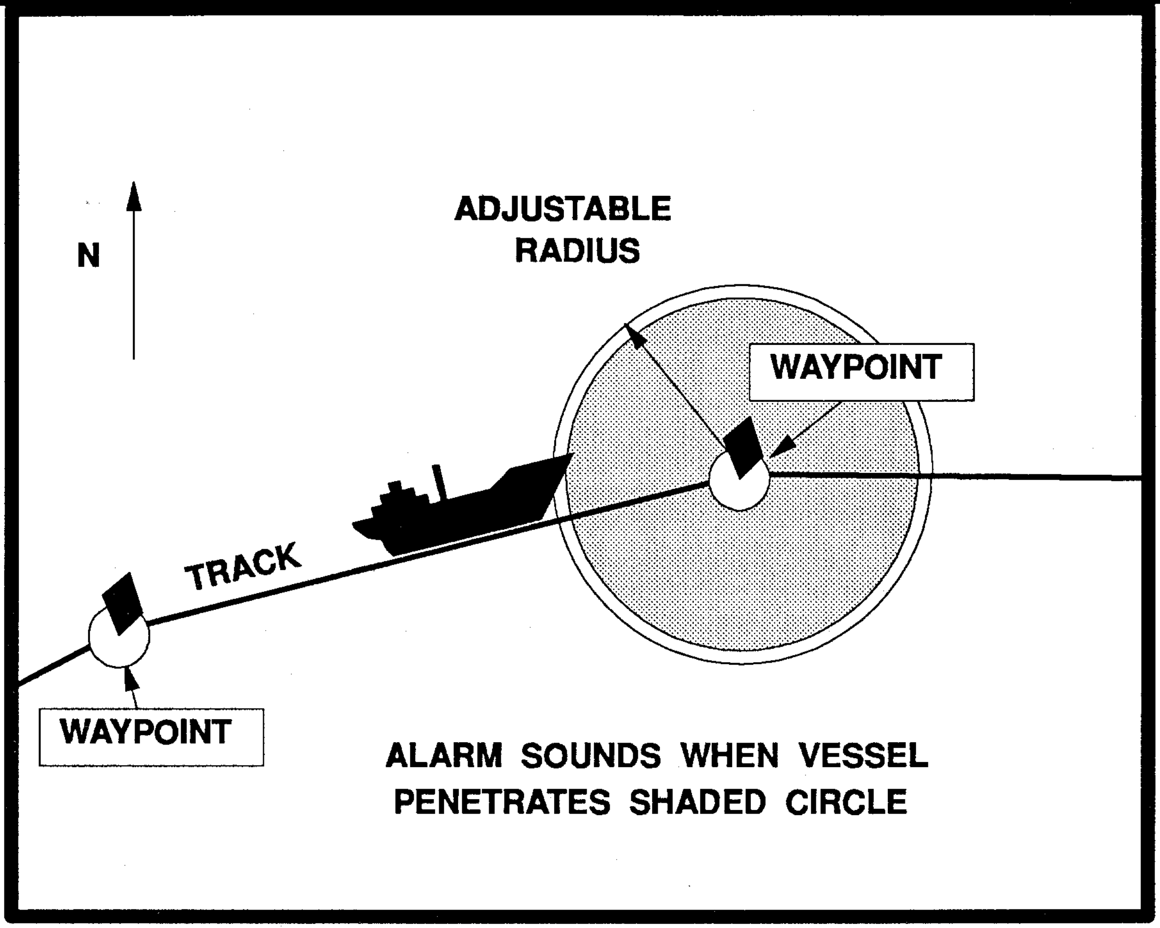
Therefore, the navigator should allow an adequate margin of safety to ensure safe passage. This safety margin should reflect, among other things, an allowance for the accuracy of the loran system, the "reaction time" of a distracted helmsman, and the speed and reaction capability of the vessel. Although vessel are generally thought of as being comparatively slow, these can still cover a surprising distance in a short span of time. A sport fisherman on plane at 30 knots, for example, will cover more than 1,500 ft in 30 seconds.

Incidentally, it is noted above that the distance to go (DTG) to the next waypoint is the great circle distance between the vessel (or aircraft's) present position and the waypoint. In circumstances where the vessel's intended course differs from this great circle, e.g., because the vessel is following a meandering river, this DTG could be a significant understatement of the actual distance remaining. In turn, other navigationally relevant information based upon this quantity, such as the time to go, would also be in error. To minimize this error, the navigator should (within the memory limitations of the receiver) enter as many waypoints as necessary to represent the vessel's meandering course to destination. Failing this, the navigator should recognize that the distance to go may understate the actual miles over the route to be followed.

Other Alarms

The XTE (sometimes called *off-course)* alarm is only one of several adjustable alarms that can be set by the user to assist in navigation. Table IV–5 provides a list of several other alarms commonly incorporated into Loran-C receivers. These are next discussed. (Although these are described as "audible alarms" in the manufacturer's literature, the sound of the alarm may not carry very far—particularly in a noisy

FIGURE IV-3. ARRIVAL ALARMS INFORM THE USER WHEN THE VESSEL PENETRATES AN ADJUSTABLE RING SURROUNDING A WAYPOINT.

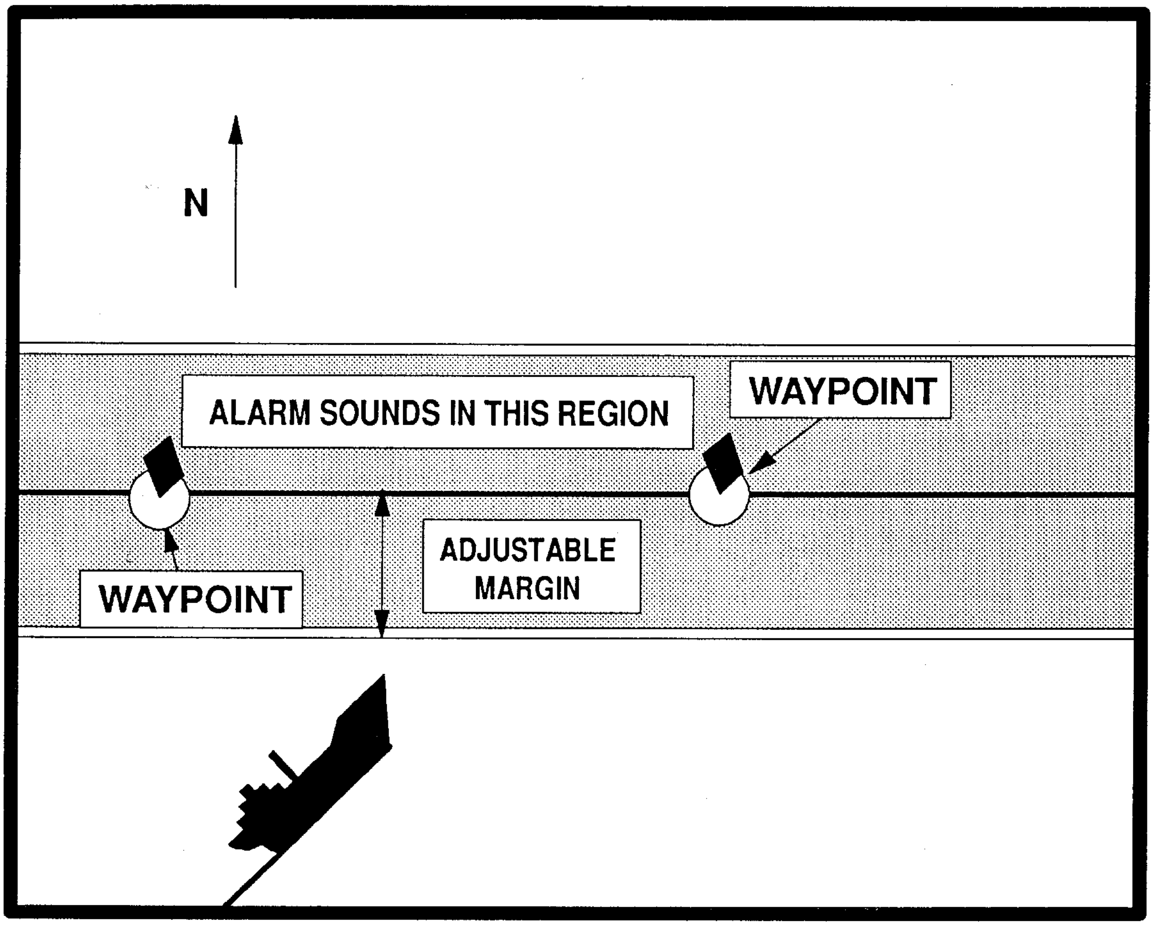


environment—and some manufacturers provide for an external connection to a loud alarm.)[10]

Although alarms can be used to great advantage, these should be used judiciously. Many types of modern marine electronics are fitted with alarms—those described below for the loran, depth alarms on the sonar, intrusion alarms on radar sets, etc. The sound of numerous alarms going off simultaneously may actually complicate decision making in a hazardous situation. So, while it is nice to have the *capability* to set various alarms, these should be used with some discretion. Moreover, the navigator should be fully familiar with the sound or tone patterns of the various alarms lest valuable time be wasted in identifying which alarm has tripped.

[10]An external connection to a loud alarm could be particularly useful if an anchor alarm is being set. While at anchor crew might not be near the helm, and might even be sleeping.

FIGURE IV-4. THE BOUNDARY (BORDER) ALARM IS SIMILAR TO THE XTE ALARM, EXCEPT FOR THE REGION WHERE THE ALARM SOUNDS.

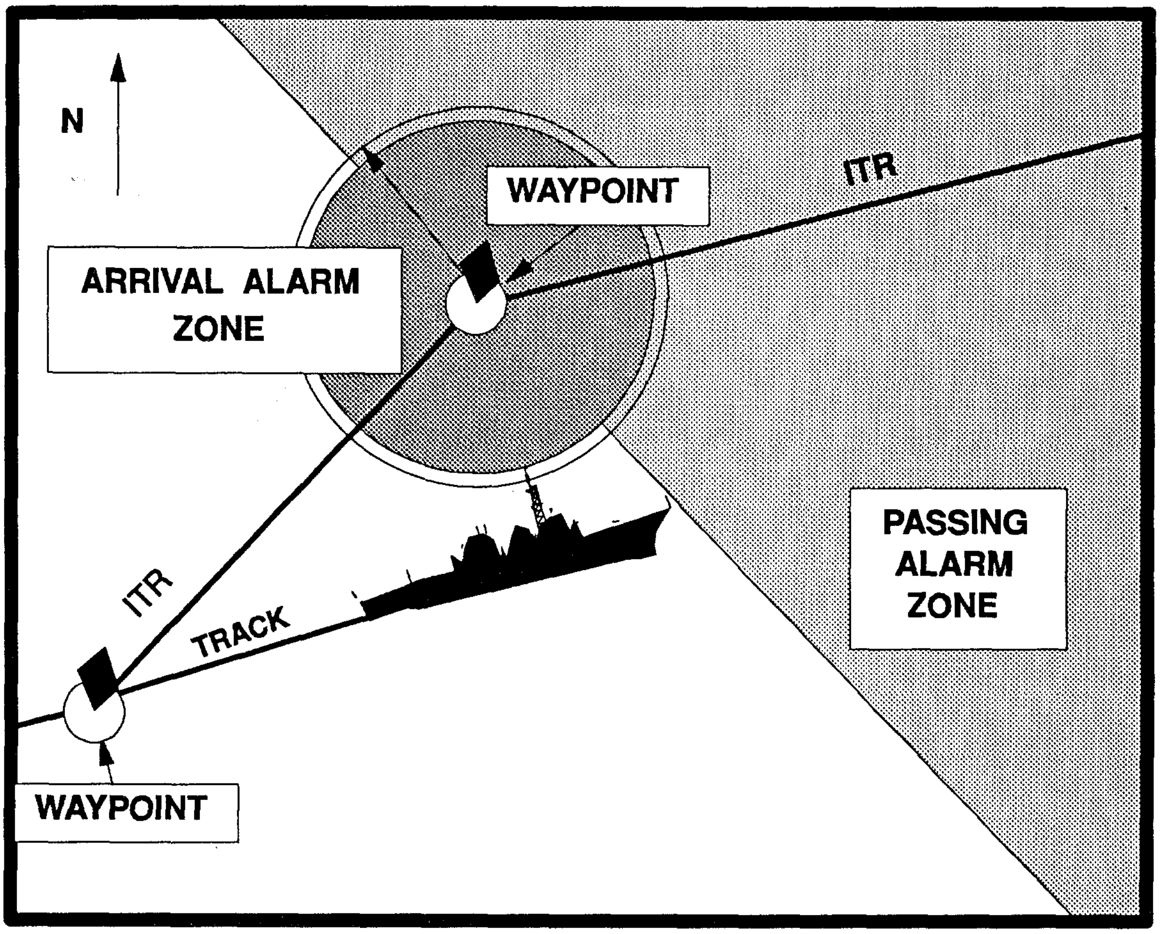


–Arrival Alarm

An *arrival alarm* can be programmed to sound whenever the vessel passes within a user-defined distance of the next waypoint in sequence. Figure IV–3 illustrates the arrival alarm. The arrival alarm will sound whenever the vessel penetrates the shaded area. The alarm can be turned off manually and, on some models, will automatically shut off whenever the vessel exits the shaded area in Figure IV-3. Arrival alarms are useful in circumstances of bad weather or otherwise restricted visibility to alert watch–standers to be particularly vigilant in searching for an entrance buoy, for example. The arrival alarm may also signal the helm to reduce speed to avoid overrunning or running into the waypoint (if a physical object such as a buoy or a light structure). Incidentally, many lorans use different tones or tone patterns for the different alarms. One manufacturer, for example, uses the Morse code "A" (• —) for the arrival alarm.

Generally speaking, an arrival alarm would be set only for those waypoints where some action is required by the operator or crew, such as a course or speed change. When traveling

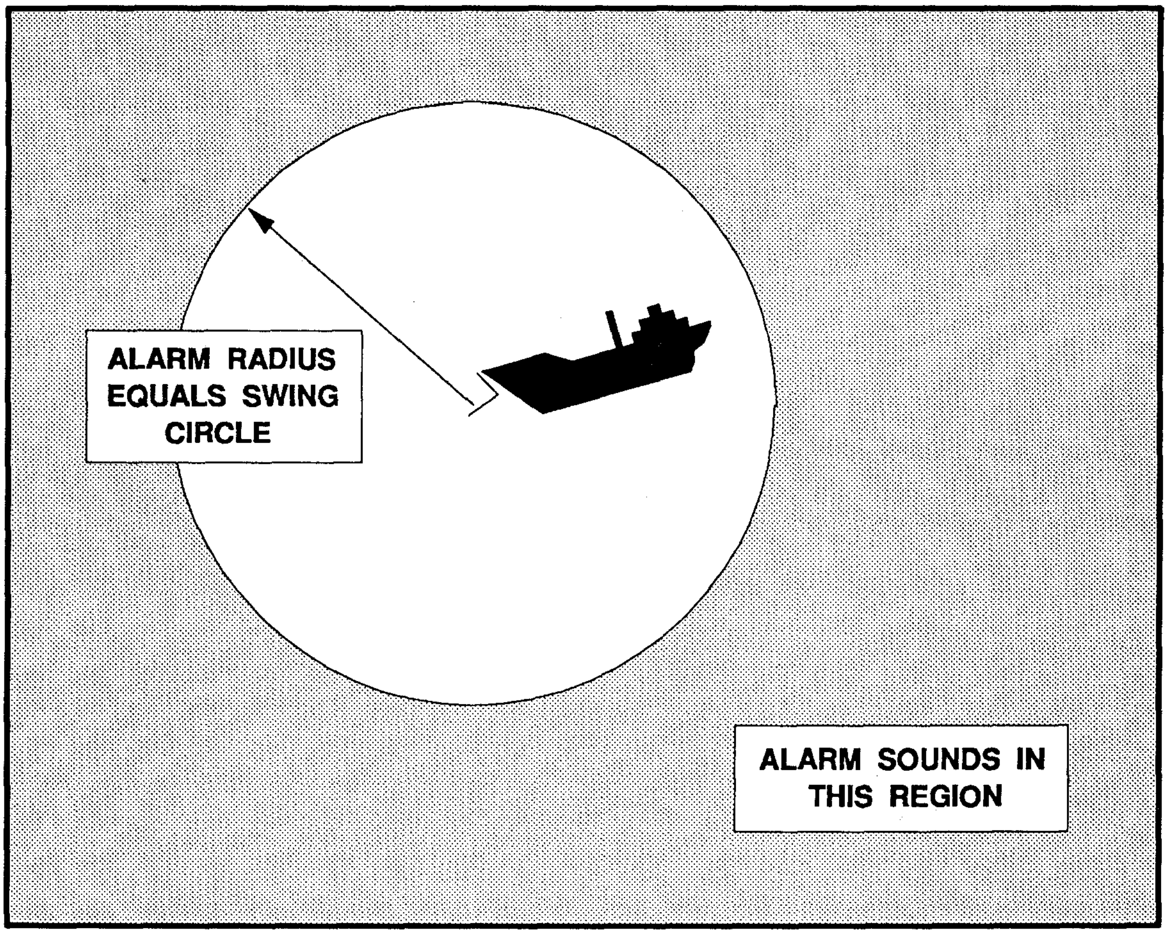
FIGURE IV-5. PASSING ALARMS INFORM THE USER THAT THE VESSEL/AIRCRAFT HAS PASSED THE WAYPOINT BUT HAS NOT SATISFIED THE ARRIVAL CRITERION.



towards waypoints where no operator action is required, the alarm can be disabled. This practice is desirable because it reinforces the idea that, when an alarm sounds, some action *must be taken* by the operator. Alarms that sound routinely have a desensitizing effect ("the cry wolf syndrome") which could mean that a genuinely significant alarm would be overlooked or that alarms will not be set in the first place.

Arrival alarms are particularly useful in cases where a waypoint must be reached exactly, and in circumstances (e.g., reduced visibility) with a high potential for distraction. As with the XTE alarm, the arrival alarm should be set at a sufficient distance to avoid overrunning the waypoint. Upon hearing the arrival alarm, the vessel operator would normally slow down and carefully monitor the DTG and BRG indications to steer to the waypoint. A prudent navigator should use all available means (e.g., depth sounder, radar) to help locate the waypoint. If the waypoint were an entrance buoy, for example, and visibility were impaired (e.g., by fog or darkness) the operator might wish to initiate a systematic *search pattern* to ensure that the

FIGURE IV-6. AN ANCHOR WATCH CAN BE SET TO ALERT THE MARINER THAT THE VESSEL HAS DRIFTED OUTSIDE A DEFINED SWING CIRCLE.



buoy was located *prior* to proceeding to the next waypoint.

–Boundary (Border) Alarm

Figure IV–4 illustrates the *border alarm.* It may be thought of as the "mirror image" of the XTE alarm, warning the user that the vessel is about to penetrate a "lane" of defined width between two waypoints. This could be used to warn the mariner that the vessel has entered a traffic separation lane. As a second illustration, this feature might be used by a commercial fisherman to avoid fishing in "illegal" fishing areas of defined dimension. These illegal areas are separated from legal zones by an imaginary line between two points of latitude/longitude or TDs. Penalties for fishing within illegal areas can be very substantial, so many commercial fishing vessels find these alarms particularly useful.

–Passing Alarm

Figure IV–5 illustrates the *passing* (sometimes termed the *arrival off-course) alarm.* As the name implies, this alarm warns the mariner that a waypoint has been passed (technically that the vessel has passed a line perpendicular to the intended track at the waypoint) without triggering the arrival alarm.

–Anchor Watch

Figure IV–6 shows an *anchor watch alarm,* which might be thought of as the mirror image of the arrival alarm. The mariner defines a waypoint where the anchor is dropped, and an alarm circle sufficient to accommodate the swing circle of the vessel. (Directions for how to do this vary by make and model—for some models the swing circle is preset, in other models it is adjustable.) The alarm will sound whenever the vessel penetrates the shaded area—in other words whenever the anchor drags and the vessel drifts outside of a user-defined swing circle. The low power consumption of the loran ensures that the ship's battery won't be run down excessively if the generator is not running or not available and the loran is left on overnight so as to use the anchor watch.

Overall, an anchor watch is a desirable feature. But, it is important to have a realistic appreciation of the limitations of this feature. First, an anchor watch probably won't be of much help in a very crowded anchorage, where the swing circles of other vessels are just boat lengths away. The repeatable accuracy of a loran may not be sufficient for this purpose. Second, unless an external land alarm is fitted, the noise of the anchor alarm may not be sufficient to wake crew sleeping some distance from the loran receiver.

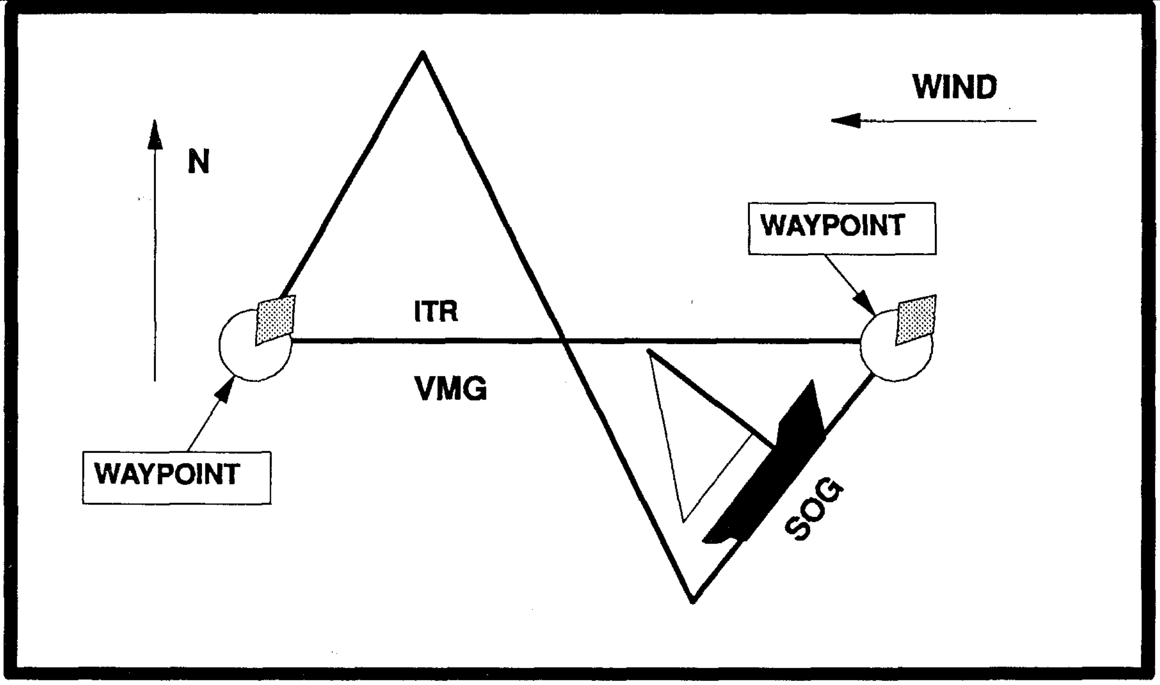
Course and Speed Information

As noted above, position and time data in the loran receiver enable the computation of course and speed estimates. In the case of loran, all course and speed estimates are referenced to *motion over the ground, rather than motion relative to the water.* Thus, for example, the course and speed estimates are really *course-over-the ground* (COG) and *speed-over-the-ground* (SOG). COG and SOG information are particularly useful to the navigator, because these quantities reflect the combined effect of the vessel's motion through the water, and the current set and drift. When navigating to a destination, the user simply alters the heading of the vessel to maintain a zero XTE, or to maintain the COG equal to the intended track, and the vessel will arrive at the chosen waypoint. Navigators should remember that the vessel's heading (per standard compass) will generally differ from the COG, because of compass deviation and the correction or "crab" angle necessary to compensate for current (or winds aloft in the case of aircraft).

Reference to numerous owner's manuals indicates that there is little-or-no uniformity in the nomenclature employed by various manufacturers to describe course and speed information. Moreover, the apparent definitions of these terms are generally at variance with accepted navigational nomenclature. For a summary of the traditional definitions of many course and speed terms, please refer to Appendix C. In what follows, the course and speed features of a sample of modern lorans are summarized.

All modern lorans have the capability to display COG and SOG—or some reasonable facsimile of these quantities. (According to definitions used by some manufacturers, these are incorrectly termed *course-made-good* (CMG) and *speed-made-good* (SMG) respectively—consult the owner's manual for your set.) According to traditional definitions, the COG and SOG are *instantaneous* values. In the case of loran receivers, these quantities are in fact *short-term average values,* where the averaging period (e.g., from seconds to minutes) is adjustable by the user. Because of this time averaging, the

FIGURE IV-7. AN ILLUSTRATION OF VELOCITY-MADE-GOOD COMPARED TO SOG. VMG IS LIKELY TO BE MORE RELEVANT TO SAIL CRAFT THAN POWER VESSELS.



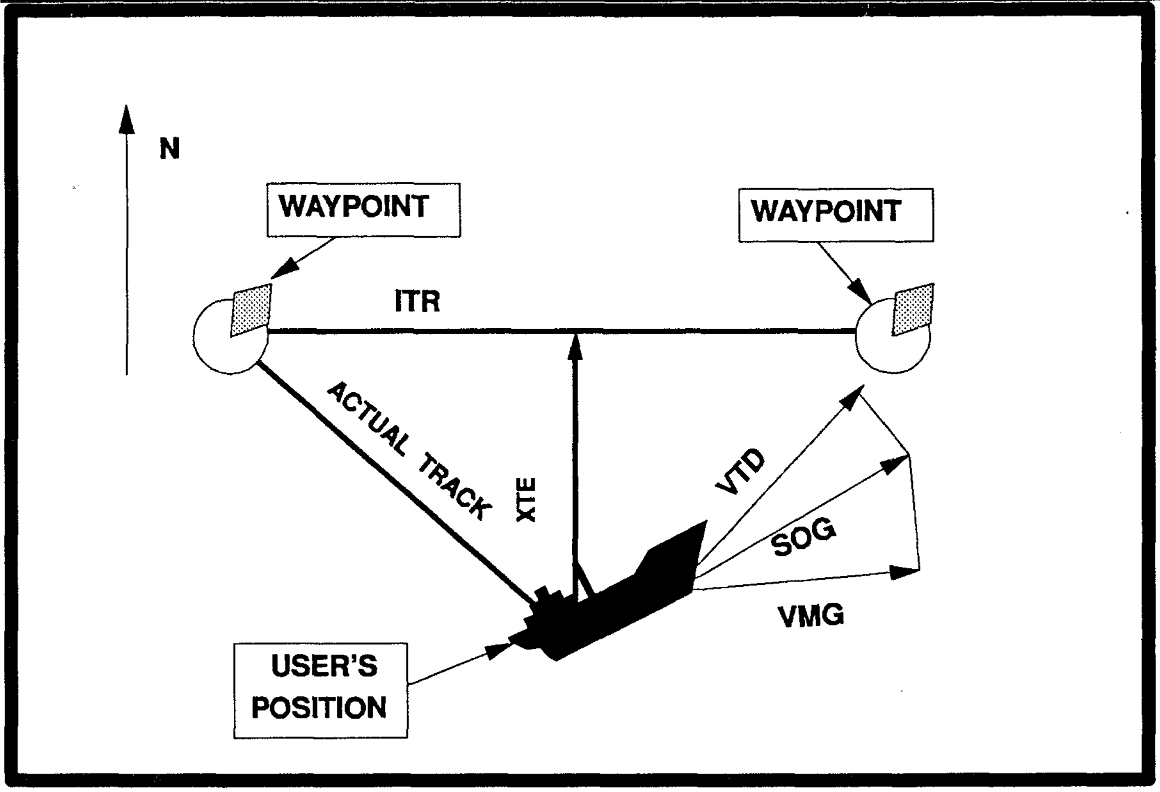
values displayed by the receiver will lag the vessel's actual direction and speed—e.g., the speed indication for a decelerating vessel will be *overstated.* "Long" averaging times (e.g., as many as 7 minutes for some models) will tend to be quite stable and accurate, provided the vessel does not alter speed. "Short" averaging times (e.g., 30 seconds) will track changes in the user's speed more readily, but at the expense of stability.

Some receivers have the capability of determining the average course and speed (with respect to the ground) since the last waypoint—i.e., arguably the true CMG and SMG values.

–Velocity Made Good (VMG)

Illustrated in slightly exaggerated form in Figure IV–7, *velocity made good* (VMG)—also called *velocity along route* (VAR) by at least one major manufacturer, and *speed of advance* (SOA) by another—is a term very familiar to sailors. *VMG represents the component of a vessel's speed over the ground in the direction of the waypoint.* In Figure IV–7, a sailing vessel is travelling from the waypoint to the west to the one to the east. The bearing of this second waypoint is 090 degrees from the first. However, in this example, because the wind is assumed to be coming from the east, the vessel's actual track must consist of a series of tacks, with the result that the actual path over the ground is a series of zig-zags shown by the dotted line. Obviously, the distance along the dotted line between the two waypoints is larger than the great circle distance shown by the solid straight line. As a consequence, the overall VMG—as measured along the solid line—would be substantially smaller than the vessel's SOG. In general, it can be shown that the relation be-

FIGURE IV-8. THREE SPEED/VELOCITY TERMS THAT CAN BE DISPLAYED ON SOME LORAN-C RECEIVERS ARE SOG, VMG, AND VTD. ONLY THE COORDINATES DIFFER.



tween the average SOG and the VMG is equal to the cosine (cos) of the angle that the vessel's course makes with the intended track. If, for example, the angle between the actual track and the direct course between the two waypoints were 50 degrees, and the vessel's SOG were 6 knots, the VMG would equal 6 knots times cos(50), or approximately 3.9 knots. The sailor has a practical optimization problem to solve. Generally speaking, a sailing vessel is faster off the wind than when sailing close to the wind. (The specific relation between the wind direction and the sailboat is termed a *polar diagram,* and differs from vessel to vessel.) But, sailing further off the wind increases the distance to be covered. The optimal course is one that maximizes the VMG. A Loran-C receiver that has the capability to display VMG could be very handy in determining the optimal course to steer. The mariner would make multiple minor adjustments on course, watching the loran closely (and allowing for averaging lags) finally setting on the course that maximizes the VMG.[11]

–Velocity Towards Destination (VTD)

The *velocity towards destination* (VTD) is

[11]The situation is a little more complicated than this simplified discussion suggests. See Alexander (1988) for more details.

the average component of the vessel's SOG along the direct course to the destination. The VTD will equal the SOG provided that the vessel's COG is exactly equal to the bearing to the next waypoint. If not, the VTD is equal to the SOG multiplied by the cosine of the angle between the COG and the bearing to the waypoint. Figure IV–8 illustrates the definitions of SOG, VMG, and VTD. The scale has been exaggerated for clarity. In this instance, a vessel has drifted off course to the south (right) of the track between two waypoints. The operator is attempting to correct for this deviation, but the correction is insufficient because the SOG vector is not directly aligned with the bearing to the next waypoint. The VTD is the projection of the SOG vector on an axis directly oriented with the bearing to the next waypoint. The VMG is the projection of the SOG vector on an axis parallel to the original track.

In general, both VMG and VTD are less than or equal to SOG. The relation between VTD and VMG depends upon the geometry.

Time Information

Many Loran-C receivers have a built in calendar and time display. Additionally, most lorans can be used to calculate either or both of the *estimated time enroute* (ETE—also called TTG) or the *estimated time of arrival* (ETA) at the next waypoint. These quantities can be found in one of the pages of the navigational display. The TTG or ETE display will change throughout the voyage as the vessel nears the next waypoint. If the vessel slows down, the TTG or ETA will increase, if it speeds up the TTG or ETA will decrease.

Incidentally, receivers differ in how the TTG is calculated. Most receivers calculate the

Datacard being inserted into aviation laser receiver. Datacards can be periodically replaced to ensure the database is current.
(Photograph courtesy of II Morrow Inc.)

TTG as the distance-to-go (DTG) divided by the vessel's SOG. This calculation will be correct only if the vessel is headed directly toward the waypoint. At least one model loran calculates the TTG as the DTG divided by the VMG, arguably a more realistic estimate.

Routes

The *route* capabilities of Loran-C receivers are discussed in more detail in the next chapter. However, it should be noted here that most lorans have the capability to store a route as a sequence of waypoints. Once a route is assembled and entered into memory, the waypoints appear in sequence, a new waypoint becomes the destination waypoint whenever the current destination waypoint is passed. With some models, only one route can be stored, with others several (in some models even hundreds of) routes can be stored. The number of possible waypoints in each route may also be limited.

Voyage Planning

Most receivers can be used in a mode that facilitates voyage planning. For example, when a sequence of waypoints is assembled into a route, the loran will display the bearing and distance from each waypoint to the next, and (on some models) the entire route distance.

Interface With Electronic Charts

As noted above, many Loran-C receivers either have "built-in" plotters or can interface with electronic charts and/or plotters. In either case, the vessel's actual ground track can be displayed, and the waypoints along a route can be superimposed on the electronic chart of the area. This feature is convenient for many reasons. But it is particularly convenient because it facilitates the detection of "blunders" in entering waypoint coordinates in the loran. The actual waypoints are displayed on the electronic chart and it is easy to see if the waypoint is grossly in error.

Aviation Lorans

In conceptual terms, aviation lorans are very similar to marine lorans. However, there are also some important differences in features and method of operation. (See Connes, 1990, for additional details on aircraft receivers.) Aviation Loran-C receivers are considerably more complex than marine counterparts. This added complexity is found chiefly in the "computational" and data base functions of the aviation receiver. Partially because of this additional complexity, and partially because of the respective sizes of the aviation and marine markets, aviation lorans are considerably more expensive (by as much as a factor of 10 for some makes and models) than their marine counterparts. Moreover, the annual cost of operation of the aviation is larger, because the databases (see below) have to be periodically replaced to ensure that vital navigational information is kept current.

As of this writing, only a few marine loran receivers have prestored data bases, while this feature is common on aviation loran receivers. Data available from an aircraft loran includes airport information (location, runway lengths, radio frequencies for communications, etc.), airspace information (restricted areas, terminal control areas, etc.), airway information, altitude information (e.g., minimum safe altitudes, minimum enroute altitudes, etc.) and a host of other data. Greater computer "power" is required to access and rapidly process this information—particularly when the aircraft's greater speed is considered. For example, it is no small task to find (quickly) and display the bearing and distance to the nearest airport—information that could be critical in the event that a precautionary or emergency landing were necessary. As a second example, aviation receivers need to keep track (dynamically) of the aircraft's position in relation to restricted or special-use airspace. Of course, these functions are being undertaken along with the usual signal-processing and navigation functions.

Some aviation lorans can make special purpose calculations unique to aviation (e.g., computation of density altitude, true airspeed, etc.), others compute estimates of winds aloft (the aviation equivalent of "current sailing" computations), and yet others are integrated with fuel management systems, so that the aviator can compute and update fuel reserves along with the other routine navigational bookkeeping.

There are circuitry differences between aviation and marine lorans as well, but these are less significant than the computer and software differences.

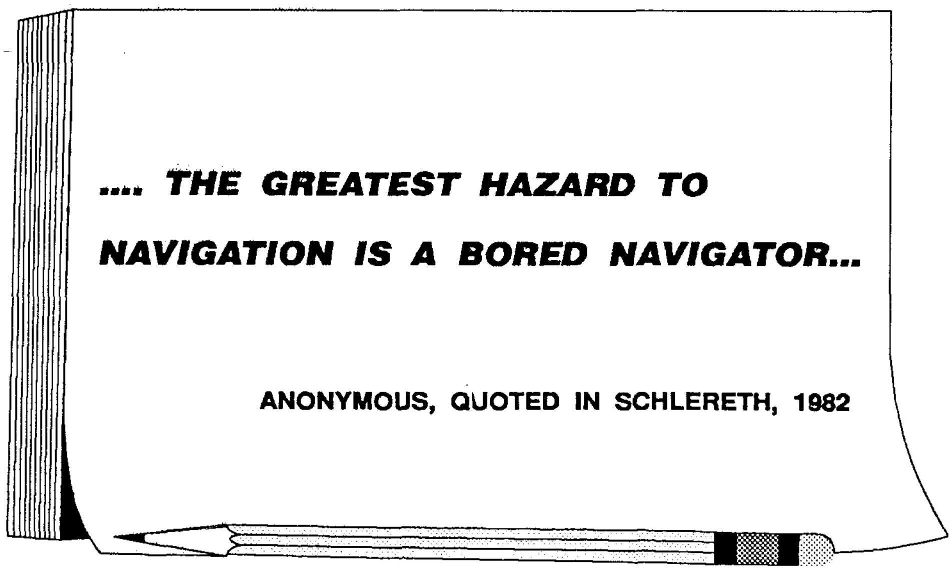
Detailed specifications for aviation loran receivers are provided in Radio Technical Commission for Aeronautics (RTCA) Document Number DO-194, as amended by the Federal Aviation Administration (FAA) Technical Standard Order TSO-C60b. This latter document contains minimum standards that must be satisfied if the loran is used for instrument flight.

Pitfalls

The capabilities of the modern Loran-C receiver are almost astounding. It is literally possible (with the right equipment) to move the vessel from the dock, enter in the required waypoints and route sequence, engage the autopilot, and do nothing thereafter until the vessel reaches the final waypoint. However, such a voyage could be very foolhardy. Built into every electronic system is the possibility of error—arising from the inherent limitations of the system, human error in programming, reliability errors, etc. These technological marvels can encourage laziness among the unwary. It is important to remember that the vessel operator or pilot in command has the ultimate responsibility for the safe passage of the vessel or aircraft.

The above caution is not intended to be a Luddite epistle. Used properly, and in conjunction with all available information, and "the ordinary practice of good seamanship," this system offers tremendous capabilities.

The wide array of features of modern Loran-C receivers and other marine electronics greatly simplifies the job of the navigator. However, these do not relieve the navigator of the burden of systematically fixing the vessel by all available means, nor of the "ordinary practice of good seamanship."



CHAPTER V

Practical Aspects of Loran Navigation

Introduction

This chapter draws upon the material presented in other chapters as a foundation for practical advice on the use of the Loran-C system. It presents additional information on the choice of coordinate systems, use of "bias" or "home port" corrections, use of Loran-C for HHA navigation, maintenance of navigation and performance logs, waypoint navigation, route selection and routing, and operation in fringe areas. Technical material is included, in this as well as other chapters, to impart "know why" as well as "know how."

As with Chapter IV, the emphasis in this chapter is on marine users. Additional comments relevant to aviation users are also included.

TDs Versus Latitude/Longitude: Reprise

As noted in Chapter IV, current marine Loran-C receivers have a coordinate conversion capability, so that either TDs or latitude and longitude can be used without having to refer to nautical charts for conversion. The use of the latitude and longitude coordinate system is familiar to most navigators, and many sources (e.g., the *Light List* and the *US Coast Pilot*) report the coordinates of navigationally important objects only in this coordinate system. For this reason, many navigators prefer to use latitude and longitude exclusively. Provided that the mariner is prepared to accept the stated absolute accuracy of the Loran-C system or operates in waters where the absolute accuracy is greater than the system specification, there is nothing wrong with this practice. Indeed, this is undoubtedly how many mariners (and all aviators) use loran on a day-to-day basis. Nonetheless, there are some instances when greater accuracy—tens rather than potentially hundreds of yards—may be necessary or appropriate for safe passage. In these circumstances, TDs are to be preferred rather than latitude and longitude for marine applications. Guidance is offered below.

The process of automatic conversion from TDs to latitude and longitude is discussed in earlier chapters. Basically this involves the use of mathematical models (imbedded in the loran receiver's logic) for estimating the latitude and longitude corresponding to an observed set of TDs. This model includes allowance for PF, SF, and ASFs (refer to Chapter II) on most receivers. As noted in Chapter III, however, there is presently no industry standard for this conversion process (though one is reportedly under development), and some receivers are much better than others in this regard. For applications requiring the greatest navigational accuracy, TDs are to be preferred to latitude and longitude. This section provides additional detail on this important topic.

The reader might be puzzled at the advice to use TDs in preference to latitude and longitude. Specifically, the reader might pose the following question: I understand that the latitude and longitude of a position as calculated by the receiver might be in error (compared to "ground truth" or the vessel's true geographic position), but if I use the same receiver to return to the same *indicated* position (in latitude and longitude coordinates) wouldn't I be exploiting the repeatable accuracy of the system regardless of the coordinate system used? And if the loran is always used so as to take advantage of its repeatable accuracy, what is the reason for preferring one system of coordinates over another?

These are astute questions and deserve a careful answer. To begin, note that the receiver measures a set of TDs, and then calculates a latitude and longitude from these measured TDs using the ASFs stored in the memory (assuming that the receiver is programmed to include ASFs, as most are, and that the Auto ASF function is in use). Provided that the vessel (equipped with the same loran receiver) returns to a spot with the same indicated TDs (and is using the same secondaries), it is indeed true (if the Auto ASF function is engaged) that the displayed latitude and longitude will also be approximately the same. In this event, it would be solely a matter of convenience which coordinate system were used for the purpose of returning to a presurveyed waypoint.

However, remember that the ASF corrections are not only a function of the indicated position, but also (refer to Chapter II) a function of the chain and secondaries in use. If, for whatever reason, the receiver were tracking *different* secondaries on the second visit, the ASFs would also be different, and so would the calculated latitude and longitude of a specific position. The problem arises if the assumption of the same rates is in error (Brogdon, 1991)—recall that receivers will sometimes use different secondaries at the same position (depending upon, *inter alia,* the respective signal strengths of the received signals from the various secondaries). Assuming that the same receiver is used, it is only if the same chain, the same secondaries, and the same ASFs are also used, that the mariner can assume that the latitude and longitude will be within the repeatable accuracy of the Loran-C system. Moreover, there are two other circumstances where the correspondence between latitude and longitude and TDs will differ. Suppose first that the Auto ASF function is not enabled in the receiver. In this event, no ASFs will be applied to the observed TDs, and the latitude and longitude will differ from that determined if the ASF corrections were in use. Second, the mariner may be using a "home port," "bias," or "offset" correction (explained below) which also effectively alters the ASFs applied. In this instance as well, the correspondence between TD and latitude/longitude will be changed. Of course, the indicated latitude and longitude would also be slightly different if another receiver with different ASFs were used. For this reason, published waypoints are typically given in TD, rather than latitude and longitude, coordinates.

For greatest repeatable accuracy, ensure that the receiver is tuned into the same GRI and same secondaries as were used when "saving" the waypoint originally. Also ensure that the same ASFs are being used.

It is important to note that most loran receivers store waypoints in memory as latitude and longitude coordinates regardless of how these coordinates were actually entered into the receiver. In the process of storing these coordinates, ASFs then in use will be applied to the TDs to calculate the latitude and longitude to be stored in the receiver's memory. If on a later visit, the same ASFs are applied to the same TDs, the latitude and longitude will also be the same. If, however, the Auto ASF is disabled or another chain and/or secondaries are in use, the positions may differ. Normally these differences will be small and within the published absolute accuracy of the system, but could nonetheless be substantially less accurate than the repeatable accuracy of this system.

The simplest way to deal with this situation (Brogdon, 1991) is to record the observed TDs corresponding to any waypoint of interest. In particular, it is useful to record *all* TDs—not just the two TDs in use[1]—so that, on a later visit, if the preferred secondaries are unavailable or unusable, the mariner can still find the waypoint using other TDs. When using the loran in navigation mode—i.e., when navigating to a waypoint using range and bearing information, the user should be careful to check that the same secondaries are in use and that the ASF correction function in use is the same as when the waypoint was originally entered in memory. Otherwise the accuracy of the system will be degraded.

Record TDs of all usable signals in the waypoint log, not just those in use by the receiver at the time.

Another aspect of ASFs and latitude/longitude conversion that should be noted is the receiver's ASF logic when using the loran in a planning mode. The receiver can be used to convert the coordinates of a waypoint from latitude/longitude to TDs. In principle, the receiver should use the ASFs appropriate to the latitude and longitude of each waypoint for this conversion. However, published reports (Jones, 1989), indicate that at least one well-known receiver *uses the ASFs corresponding to the vessel's current position and not the ASFs corresponding to the actual waypoint location for the conversion*. This difference could be of little consequence if the waypoint were close to the vessel's location, but could be quite significant if the waypoint were a long distance away. This difficulty is not inherent in the Loran-C system, but rather an artifact of the software used in at least one particular make. (Incidentally, this peculiar feature was not covered in the owner's manual.) In the case related by Jones, the waypoints being converted were along the Maine coast and the vessel's location at the time of conversion was in Massachusetts. Because ASFs change appreciably in this region, the converted positions were up to 0.5 miles in error—a figure in excess of the absolute accuracy specifications of the system. The point of this illustration is that the user should become familiar with the specific features of the particular loran. Although Jones (1989) raised this point in connection with only one make and model of receiver, the above point is more general.

Whether or not the gain in accuracy achieved by using TDs or bias corrections (see below) is worth the effort depends very much upon the circumstances. Finding a fairway buoy marking the approximate centerline a "wide"[2] channel in

[1]Recall, however, that some receivers use more than two TDs to determine a position.
[2]The word "wide" is put in quotation marks to indicate that it may have different meanings for different classes of vessels. The effective width of a "channel" would be substantially different for a tanker drawing 30 ft of water than a sailing vessel drawing 6 ft or a jet drive vessel drawing 1 ft.

excellent visibility does not require pinpoint accuracy, nor are the consequences great if this buoy is missed. However, finding a lateral buoy marking the edge of a narrow channel with surrounding hazards on a fog-shrouded day requires very careful navigation and operation of the Loran-C receiver so as to maximize accuracy.

Bias Corrections

Most modern Loran-C receiver can accommodate ASF corrections in two ways. The Auto ASF function can be enabled or disabled. That is, prestored ASFs can be included or excluded. Most Loran-C receivers also have an additional feature, variously called a "bias," "offset," or "home port" correction by receiver manufacturers. To use this feature, the mariner travels to an accurately known location—often a dock at the marina—and manually enters these known coordinates into the loran, either directly, or as differences (called *"deltas"* in some owner's manuals) or offsets to the known latitude and longitude. In this way, the observed position (in latitude and longitude coordinates) error will be *forced* to equal zero at this location.

This seems a simple and elegant way of "calibrating" the receiver in the local area and increasing the accuracy of the latitude and longitude readouts. Useful as this procedure is, the mariner should be aware of some limitations of this technique. In effect, the user is entering an "ASF-like" correction into the receiver's memory to replace (or supplement) the prestored values.[3] At best, this correction includes all the factors normally considered in ASF corrections, but also reflects a compensation for season, diurnal, and secular trends in signal propagation. In effect this represents a crude differential Loran-C adjustment. However, this correction is only exact for the particular calibration point used, and not necessarily for other, more distant, locations. Were this procedure repeated in another location, the correction would be slightly different.

Within what range is this "local area correction" valid? Table V–1 provides a sampling of published estimates, ranging from approximately 10 miles to 100 miles from the point of calibration. Although these values are given for perspective, the mariner should determine empirically the limits in waters frequently cruised. The mariner should also give some consideration to the calibration point. For example, the mariner's home port could be a marina near a metal bridge, overhead power lines, or other natural or man-made obstructions. In this event, the home port correction might be quite inappropriate for locations only a few hundred yards away.[4] Even if the mariner's home port is not affected by anomalies caused by bridges, powerlines, or other objects that produce localized distortions in the loran grid, the areal extent over which this bias correction is applicable is a function of how

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[3]On some models the "bias" correction replaces the ASF corrections, on others it is *in addition to* the prestored values. The ASF status indicator may display the same indication if either a bias or regular ASF is being used.

[4]For example, there are several marinas located along the Delaware River in close proximity to bridges and one located *directly under* the Ben Franklin Bridge in Philadelphia, PA. A home port correction developed in this location could be seriously in error outside the zone of influence of the bridge.

TABLE V-1. APPROXIMATE LIMITS OF APPLICABILITY OF "HOME PORT" OR "BIAS CORRECTIONS" AS GIVEN BY VARIOUS SOURCES

Maximum Distance From Original Reference Point Where "Home Port" Correction is Applicable (NM)	Source
10	*Practical Sailor,* 1990
10	*Marinteck Owner's Manual*
20	Melton, 1986
25	*Voyager Loran-C Owner's Manual*
"Fairly Broad Area"	*Raynav 570 Owner's Manual*
100	Gait, 1990
100	*Dutton's,* Thirteenth Edition

Remember, these are only *estimates,* designed to be representative over a broad area. Mariners are cautioned to verify these estimates for frequently traveled waters.

much the ASFs vary over the region of interest. And, as even a casual examination of DMAHTC's ASF tables will show, the variation in ASF can differ significantly, depending upon the chain, secondary, and location. Therefore, none of the estimates given in Table V–1 should be accepted uncritically.

Bias or "home port" corrections can be useful. However, the mariner should determine experimentally the area over which a fixed bias correction should be used.

Those who elect to use an offset correction should also be aware that the entry of this correction effectively *alters the apparent locations of any waypoints stored prior to establishing this home port correction.* Finally, users should refer to the owner's manual for directions on how to enter this correction and for other relevant particulars. For example, on some lorans, the home port correction is automatically deleted if the set is turned off, on others, the correction is retained in memory until it is deliberately erased.

Even if the vessel remains in the same waters, there is some benefit to reentering home port corrections from time to time. Recall from material presented in Chapter III that TDs have seasonal, diurnal, weather-related, and possibly secular components. Periodic recalibration can, in principle, remove some of this variability and increase accuracy in a local area.

If the vessel strays from the local area, the bias should be changed when the opportunity presents itself for an accurate fix. DePree (1987), for example, claims that daily site-specific bias corrections enabled Loran-C position accuracies of 0.5 miles or better when cruising in the Bahamas. This area is not included in the coverage diagrams for the 7980 chain, and uncorrected fix errors of five miles or more are common in these same waters. This "poor man's dynamic differential Loran-C' is sound in principle, but the mariner should allow an extra safety margin when entering waypoints to guard against the possibility of degraded accuracy. Moreover, every opportunity should be taken to verify Loran-C position information by other means—a point emphasized below and throughout this *Loran-C Handbook.* The United States Coast Guard does not encourage the sole use of any one navigation system in any potentially hazardous waters, much less when operating in areas outside the defined coverage area of a navigational system.

Finally, the mariner should be aware that a bias or home port correction will cease to be appropriate if the loran receiver switches secondaries or chains. May (1987) recounts just such an experience which occurred off Monomoy Island near Cape Cod, MA. According to this account, the vessel operator just happened to be looking at the loran when it switched secondaries[5] and noticed that the indicated position "jumped" out of the channel and moved to a nearby shoal! The mariner had entered a bias correction which was no longer appropriate when the receiver changed secondaries. There are two lessons to be learned from this cautionary tale. First, bias corrections should not be used in or near areas where chain or secondary switches may occur—such as in the vicinity of a baseline extension. The second lesson to be learned is that the mariner should systematically record the secondaries in use whenever a fix is taken (see below). May's account does not mention that this procedure was used—rather, it gives the impression that the observation of a rate switch was entirely fortuitous. If, however, the mariner noted the rates in use whenever a fix was recorded, the rate switch would have been detected and the bias correction could have been removed.

The bias or offset should be removed whenever the GRI or secondaries are changed. Otherwise the correction may *decrease,* rather than increase the accuracy.

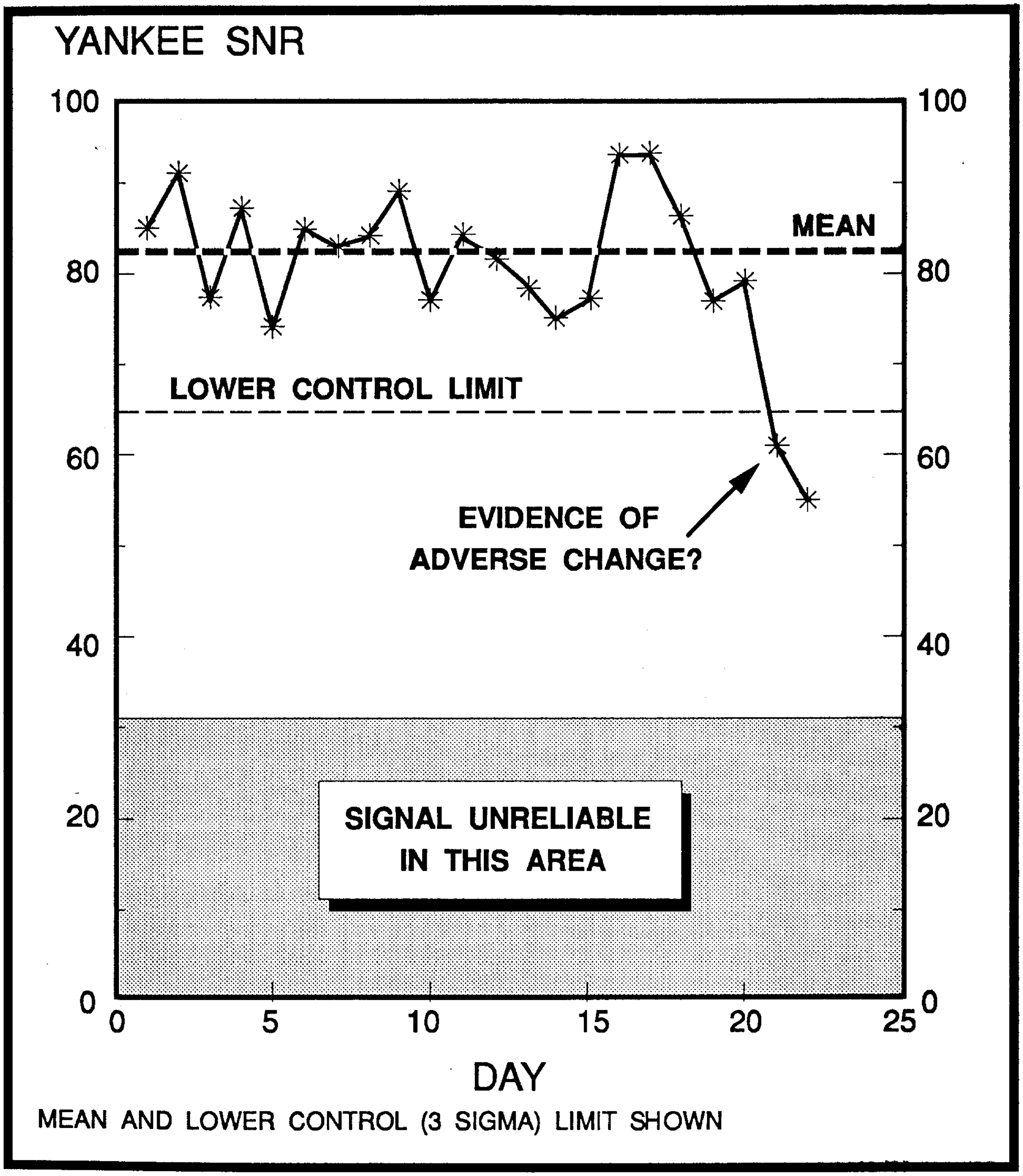
Practice Often and in Good Weather

Mariners should become thoroughly familiar with the operation and performance characteristics of their loran receivers. The best way to ensure the required familiarity is by frequent practice. As noted in other chapters, loran manuals are not always well written, and many loran sets have idiosyncracies that are not thoroughly documented in the owner's manual. The only way to learn about a particular receiver is to practice in "benign" conditions (e.g., in good weather and in an area relatively free of hazards to navigation) when errors are not critical, and there is time to read (and reread) the owner's manual while underway. This practice can be put to good use when weather or other conditions deteriorate and there is no time for such a deliberate approach.

Part of the reason for this practice is to become familiar with the purely "mechanical"

[5]This probably occurred because the vessel was in the vicinity of the Xray baseline extension of the NEUS (9960) chain.

FIGURE V-1. CONTROL CHART FOR YANKEE SNR DATA ON FACILITY 223971 DOCKSIDE AT THE BORDENTOWN, NJ, SARDET WITH HANDHELD LORAN RECEIVER.



aspects of operation of the loran receiver. But another important reason is to gather useful data on such elements as loran accuracy (both repeatable and absolute), typical SNRs, waypoint coordinates, etc., in areas frequently traveled. The material on these topics in this *Loran-C Handbook* is as complete as possible, but cannot reflect all relevant site-specific information. For example, SNRs measured at the receiver are a function of the distance from the various transmitters (as noted in Chapter III). In principle, these distances could be used to calculate contours of constant SNR on generalized charts. But SNRs are also a function of the receiver make and model, adequacy of grounding (see Chapter VII), local interference aboard ship, receiver placement on the vessel, weather, and other factors that cannot easily be generalized or presented as "typical" values. Therefore, it makes sense for the vessel operator to maintain a "performance log" which summarizes these data for the particular installation. Even a procedure as simple as noting in a performance log the SNRs of the various TDs when the vessel is tied at the dock can be useful. Figure V–1 shows such data in the form of a *statistical control chart*[6] for the Yankee secondary of the NEUS (996) chain for 22 days during the summer of 1991. (Data plotted are in units of the two-digit SNR codes displayed by the receiver, rather than the actual SNR.) These data were taken with a hand-held loran receiver (without an external ground) on an aluminum patrol facility in the upper Delaware River, docked at a fixed Search and Rescue Detachment (SARDET). The dashed line in this figure represents the average of the SNR readings of the Yankee secondary over the first 20 of the 22 days, and the dotted line the lower control limit. (Although statistical techniques beyond the scope of this handbook were used to compute the lower control limit, it should be clear from visual inspection of the plot given in Figure V–1 that "something happened" after day 20 in the sequence.) Note that the SNR exceeded the manufacturer's minimum SNR for reliable signal reception (denoted by the shaded area in Figure V–1) throughout this period, but the trend evident in these data points to some adverse development that should be investigated. Such a drop in SNR could have been caused by a failed alternator filter, the installation of new equipment aboard the vessel, weather in the last 2 days or other factors—see Chapter VII—but the point of this example is that these data can be used to advantage.

Entries in the performance log should indicate the vessel's position, SNR, an accuracy measure (if provided by the receiver), known weather (e.g., a thunderstorm at the location), a listing of the status indications or alarms at the time, and a list of other electronics (e.g., radar, depth sounder) in operation. The important thing is to record these data systematically so that performance norms can be established. Later, actual readings can be compared with these performance norms to detect anomalous conditions and begin a search for an "assignable cause." For ease of exposition, the performance graph shown in Figure V–1 was deliberately simplified. In practice, SNRs from the master and all usable secondaries would be recorded and plotted, not just data for the Yankee secondary.

[6]Readers unfamiliar with statistical control charts will find details in any elementary textbook on statistical quality control, for example, Duncan, A. J. *Quality Control and Industrial Statistics,* Third Ed., Richard D. Irwin, Homewood, IL, 1972, or Grant, E. L., *Statistical Quality Control,* Third Ed., McGraw-Hill Book Company, New York, NY, 1964.

Maintain a receiver "performance log" to record SNRs, status indications, and fix accuracy estimates. These data can be used to detect shifts, trends, etc.

Yet another reason for noting SNR measurements is to help detect "cycle slips" that can occur in fringe areas, high noise environments, or if the receiver is not installed properly (see Doyle, 1986). In these circumstances, the receiver may fail to track the appropriate point (3rd positive zero crossing in the pulse, see Chapter II) and instead track another zero crossing which differs by an integer multiple of 10 usec (e.g., 10 usec, 20 usec, 30 usec) from the correct tracking point. If this occurs, the measured TD(s) (and thus the vessel's apparent position) would be in error by an equivalent amount. Therefore, it is important to detect this condition should it occur. Most receivers are programmed to automatically *detect* (normally by comparing the amplitude ratio of the peaks on either side of the tracking point), *display* (via a cycle alarm or status indicator), and ultimately *correct* this condition. For most (but not all) makes and models these alarms and status indicators work well. However, the user should also be alert to the potential for this problem to arise—particularly in fringe areas or in other circumstances where cycle slip is more likely. It is mentioned in this context because when cycle slip occurs, so too does the SNR. Referring to the pulse envelope shape discussed in Chapter II, note that the signal amplitude increases as the tracking point is "slipped" further into the pulse. Cycle slips, therefore, will be associated with a change in the SNR of the received signal. (Other methods for detecting these slips are reviewed below.) If the mariner systematically records the SNR when the vessel's position is fixed, cycle slips may be evident in changes from these preestablished norms.

SNR measurements can also be used to determine if a secondary is "off-the-air."

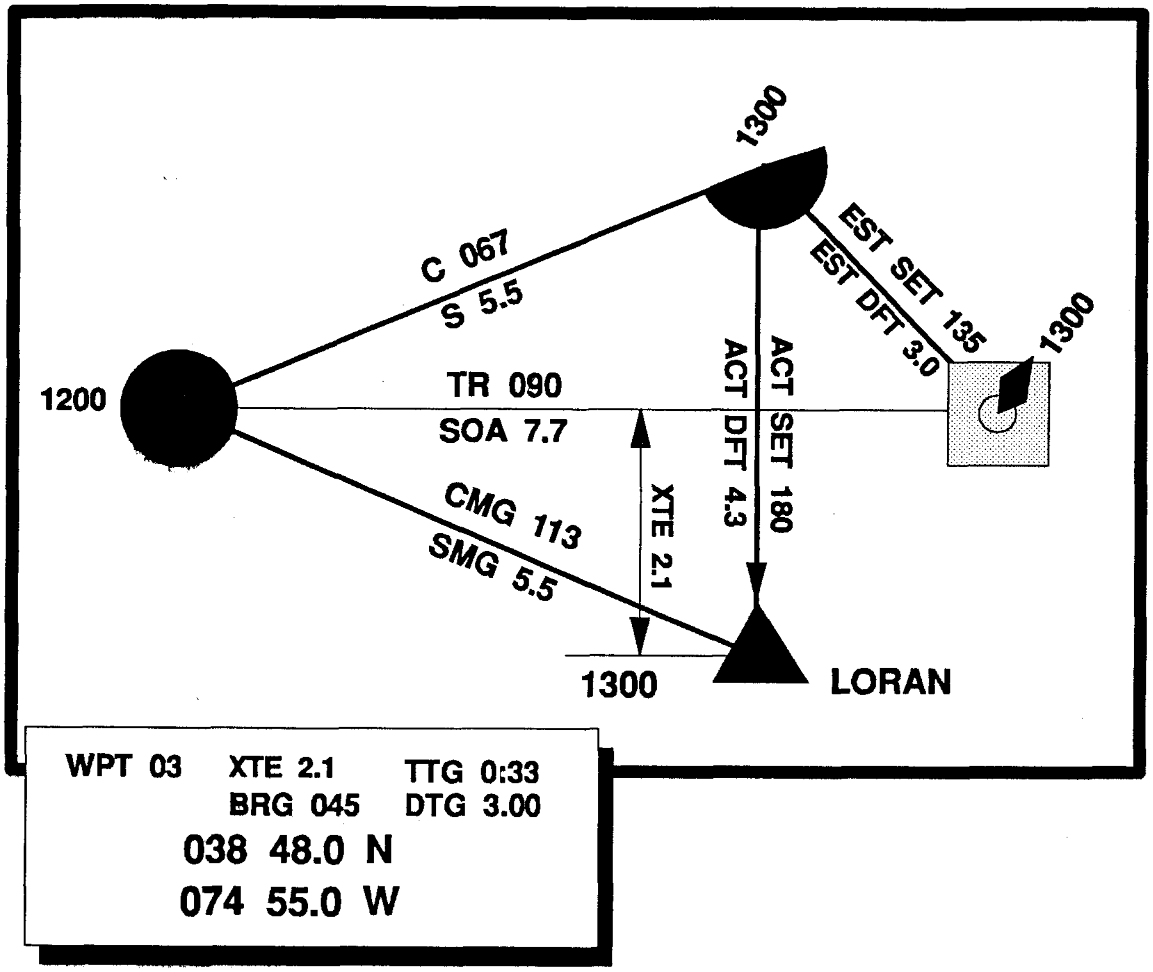
Practice sessions with the loran can also be used to record the coordinates of desired waypoints (entered in the receiver and in a separate waypoint log) so that the loran's repeatable accuracy can be used when in "instrument" conditions. The vessel operator can practice "blind" approaches (of course with competent lookouts aboard to avoid collisions and ensure that the vessel does not stray from safe water) to key harbors or anchorages to gain familiarity with the waypoint sequencing options and confidence in the capability of the loran system. The mariner might also wish to evaluate the utility of "home port" corrections (discussed above) and the likely accuracy to be attained with these corrections.

Maintain a DR Plot and Cross-Check Fixes

It is physically possible to navigate a vessel entirely by electronic means, but this is not a prudent course of action. In particular, navigators should never abandon the practice of maintaining a DR plot. (Methods and graphical conventions for construction of a DR plot are beyond the scope of this handbook, but can be found in any text on coastal piloting or navigation.) Absent sophisticated interfaces between the loran, fluxgate compass, and a speed sensor, the only way the navigator can estimate the *set* and *drift* of the current is by comparing the vessel's DR position with a contemporaneous fix. Therefore, one major purpose of the DR plot is to enable estimation of set and drift—and derivatively determining a course to steer to compensate for the current.

Another purpose of the use of the DR plot is to provide at least a gross "reality check" on the positions determined by the loran. Figure V–2 illustrates how this might be done. The figure

FIGURE V-2. HYPOTHETICAL VOYAGE WITH ESTIMATED AND ACTUAL CURRENTS, AS IT WOULD BE CHARTED



itself shows the DR plot, estimated position after one hour, intended track and loran fix. The inset shows a stylized replica of the loran display at the time of the fix. In this example, a mariner estimates the current set and drift to be 135 degrees and 3.0 knots respectively. Assuming a speed through the water of 5.5 knots and a desired track of 090 degrees to the waypoint indicated by the buoy, the navigator determines that an appropriate course to steer would be 067 degrees, and that the estimated speed of advance would be approximately 7.7 knots. After one hour in this example (in actual practice fixes would be more frequent) the navigator notes the loran fix (denoted by the triangle in Figure V–2) and calculates the actual set and drift to be 180 degrees and 4.3 knots respectively. The mariner can use this information to help assess the plausibility of the loran position. Cycle slip, for example, might be detected by this method. If cycle slip were suspected, several possible loran positions could be plotted by sequentially assuming that one or both of the TDs were +/– 10 usec in error. If any of these alternative positions were much more consistent with the estimated set and drift, the hypothesis of cycle slip might be supported.

The navigator should also maintain a DR plot because the loran may become inoperative. As noted in Chapter I, the Loran-C system availability is excellent—better than 99.7% availability for any given triad. However, the availability of the onboard receiver may not attain these levels—particularly if it is subject to direct contact with seawater, varying input voltages, and other environmental challenges to reliable operation. A DR plot would be invaluable if the loran became inoperative.

Along with maintaining a DR plot, the navigator should establish a definite interval for recording fixes. The loran receiver is continually updating the vessel's position (every few seconds or so), but the advice here is to record the loran fixes in the voyage log or navigator's workbook and to plot the fixes on the nautical chart. (Before the advent of coordinate converters, mariners had to plot the TDs to determine a position on the chart, but automatic converters eliminated this requirement.) The fix information should include the coordinates, secondaries in use, SNRs, and a notation describing any pertinent status indicators (e.g., SNR or cycle flags). Not only is this fix information necessary for computing current set and drift (from a comparison with the DR position) but also writing down and plotting the fix information could be quite useful in the event that the loran fails. The appropriate interval between fixes is a function of the vessel's speed, frequency of course and/or speed changes, and the navigational hazards posed by the route. Appropriate fix intervals could range from every 3 minutes or so (for a fast moving vessel or one in a narrow channel) to once per hour for a sailboat or power vessel in the open waters well removed from HHAs.

Finally, the mariner should attempt to confirm any loran fix by other methods—particularly if the fix is "critical." One obvious method for checking a fix is to note the water depth at the time of the fix. When the fix is plotted, the observed depth can be compared (after adjustment for the tide height if necessary) with the charted depth at the fix to verify the fix. Of course, if the water depth does not vary apprecia-

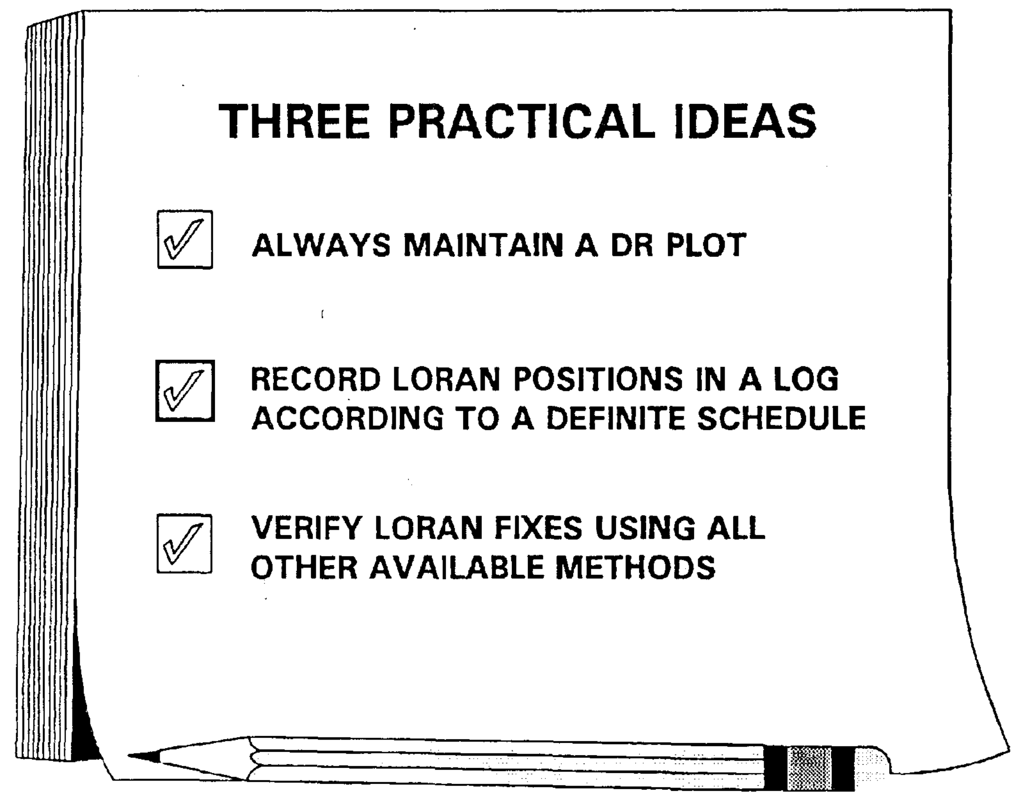
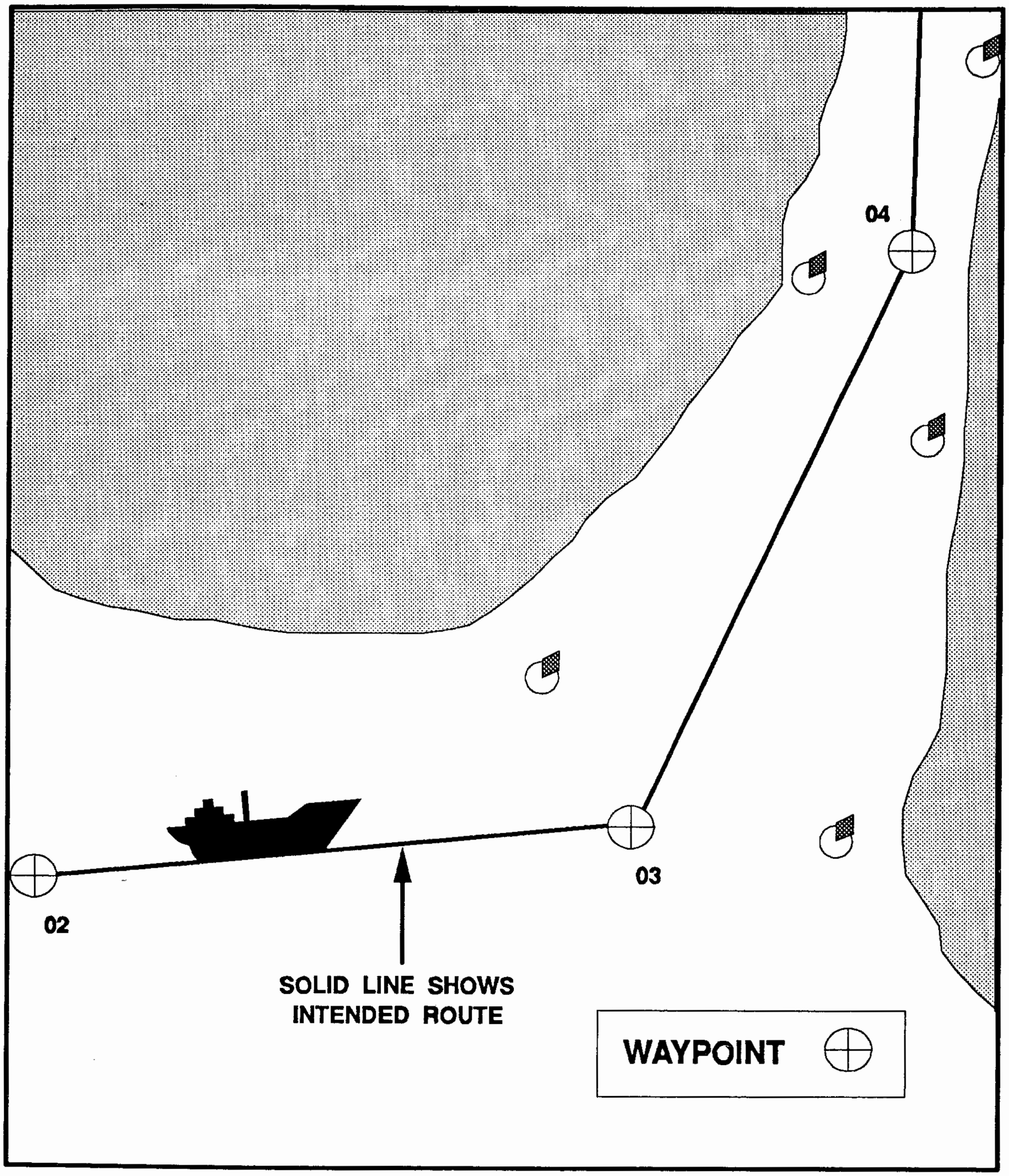


FIGURE V-3. A ROUTE IS A SEQUENCE OF WAYPOINTS WHICH DESCRIBES THE VOYAGE.



bly over a broad area, this validation method would not be useful. Visual bearings can also be taken in pilot waters, and buoys are also helpful in verifying positions. Certainly, spotting a buoy in the wrong position (Humber, 1991) ought to alert the navigator to the need for special vigilance.

Exploiting Partial Information

Normally, a loran receiver is either working satisfactorily or it is not. However, it sometimes happens (see Dahl, 1986 or Gait, 1990 for examples) that *partial* loran information is available. For example, the receiver may be able to display TDs, but the latitude/longitude conversion and navigation functions may be inoperative. Alternatively, only one TD may be available or usable. Although only one TD would not be sufficient to provide a fix, it does determine an LOP which could be crossed with a visual or RDF bearing or by some other means (e.g., a depth contour or a celestial sight) to determine a fix. Alternatively, depending upon the angle of the TD to the intended track, the TD might be "followed" to a point closer to the shore where visual bearings could be used. Obviously, limited information should be regarded with healthy suspicion, but should not be disregarded entirely.

Another example of the use of limited information is as follows. It frequently happens in the HHE/HHA phase of navigation that loran cannot be used as a primary navigation system (say because either absolute or repeatable accuracy is insufficient to navigate a narrow channel), but that loran information can be a valuable supplement. In the narrow channel example above, it may well be the case that loran could not be used to determine whether or not the vessel were in the channel, but the loran readout (in conjunction with the observed position in the channel) could be used to determine a fix. In essence visual observation would determine one coordinate of a fix, while the other coordinate would be supplied by the loran. Moreover, even in this circumstance the loran's ground speed readout would be usable.

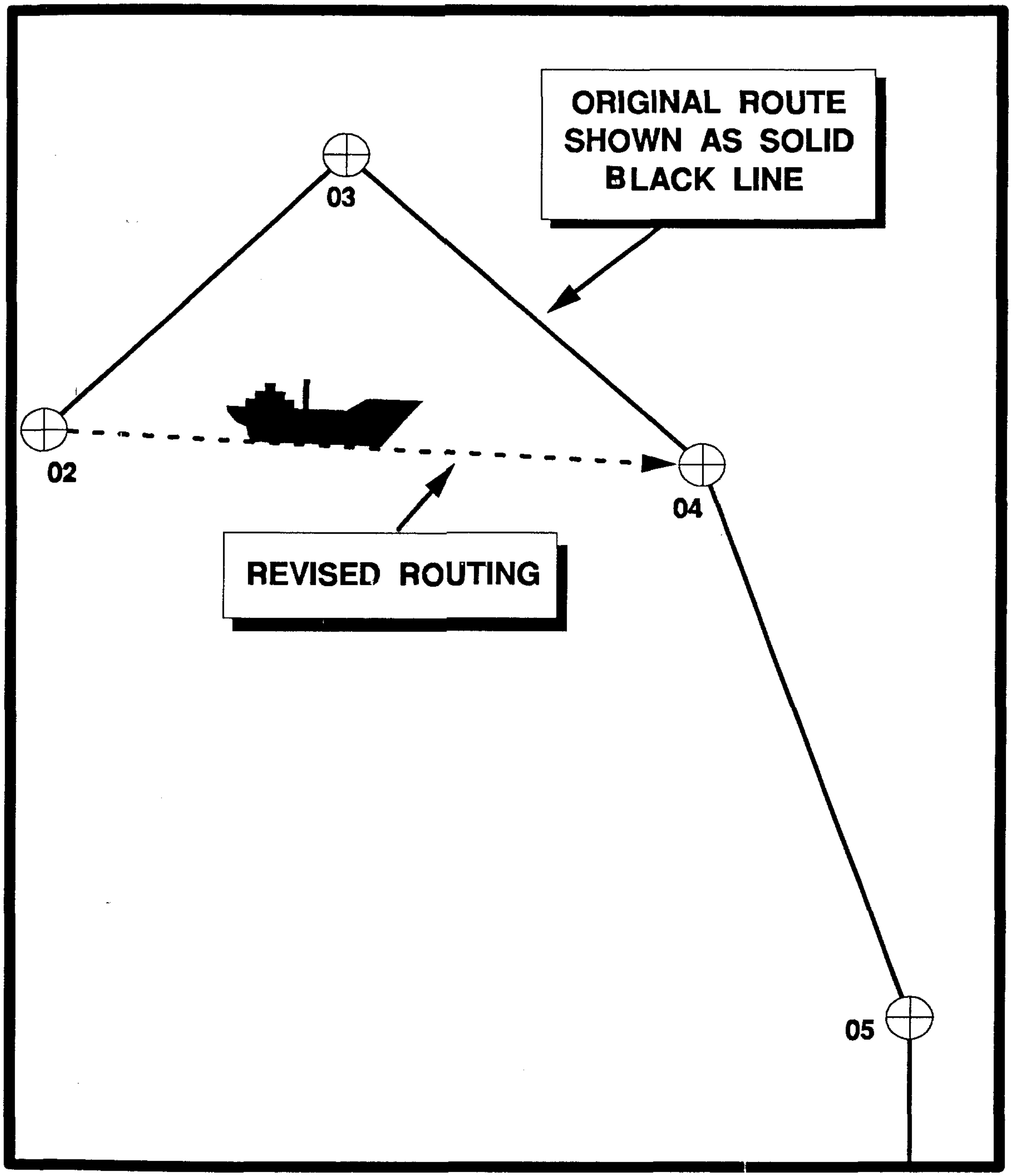
Use of the Route Function

As noted in Chapter IV, many loran receivers have a route function that enables the navigator to link waypoints together into an overall route. (Operating details vary by make and model of receiver, so these points are omitted here. Refer to the owner's manual for this information.) Waypoints used can be entered by actually visiting each and using the receiver's "save" capability (this has the advantage of exploiting repeatable accuracy), entered directly as latitude/longitude or TDs, or selected from among the available waypoints previously stored in the receiver's memory. Routes are stored in memory, as are waypoints, and must be planned with applicable memory limitations in mind.

Usually, the waypoints in a route are arranged so that these correspond to points where the vessel's course or speed needs to be changed. Figure V–3 illustrates a route consisting of several waypoints (denoted by circles with crosshairs and a waypoint number in this diagram) for traversing a harbor entrance. (If the channel were narrow, it might be necessary to have visited the waypoints earlier to ensure that the repeatable accuracy of the loran was attained.) Of course, the same effect could be achieved by sequentially entering waypoints as the vessel proceeds along the route, but the advantage of using a route function is that the receiver will automatically switch from waypoint to waypoint as the vessel passes each in sequence. Moreover (see below), it is good practice to minimize the number of keystroke entries that have to be made while the vessel is underway.

It sometimes happens that the navigator wishes to by-pass any individual waypoint in the

FIGURE V-4. WAYPOINTS IN A ROUTE CAN BE BYPASSED AND A MORE DIRECT ROUTE SELECTED.



route sequence. Figure V–4 illustrates this situation. The route originally planned consisted of the waypoints 02, 03, 04, 05, etc. But, after reaching waypoint 02, the mariner decides to travel directly from 02 to 04 (along the track indicated by the dotted line) rather than visiting waypoint 03 as programmed in the original route sequence. The route function of most receivers enables this to be done without having to enter in an entirely new sequence of waypoints—a handy feature. However, this feature must be used with care, and only after the navigator has determined that the direct leg between waypoint 02 and 04 (in this example) can be traversed safely. Remember, the loran receiver has no idea of the hazards to navigation or water depths along any route. There may, in fact, be an island between waypoints 02 and 04! It is the mariner's responsibility to lay out each route on the nautical chart and assess whatever hazards lie along the route. Although this would almost seem too obvious a point to mention, groundings have occurred for this very reason. Automatic features are intended to facilitate navigation, not to eliminate the need for common sense.

In some cases a route may have been defined but, for one reason or another, the navigator may have permitted the vessel to drift off the intended track. The vessel operator has two choices, (i) steer a course to return to the original track, or (ii) *restart* the route and travel directly to the next waypoint in sequence after "zeroing out" the cross-track error. Most loran receivers enable the route to be restarted from any point, eliminating the need to return to the original track to obtain useful navigational information.

Most receivers with a route function enable any route stored in memory to be traversed in either direction. For example, a mariner departing a harbor in good weather can save waypoints along the way to define a route and merely run this route in reverse waypoint order to return safely to harbor.

Cycle Stepping

In Chapter II, and elsewhere in this handbook, it is noted that the Loran-C receiver is programmed to track on the third positive zero crossing of the loran pulse—30 usec into the pulse. This tracking point has been selected based upon an engineering compromise. On the one hand, the further into the pulse (on the leading edge) the sampling or tracking point is placed, the greater the signal strength—until a point approximately 60 usec from the start of the pulse. Therefore, setting the tracking point further into the pulse will (other things being equal) increase the SNR. On the other hand, "advancing" the tracking point increases the likelihood of skywave contamination—and consequently of incorrect TDs. The 30 usec tracking point strikes a practical compromise—the SNR at this point is sufficiently good for most navigational purposes, and the likelihood of skywave contamination is small.

However, navigators who venture into "fringe areas"—areas near the limits of Loran-C coverage—may find that the SNR at the normal tracking point is insufficient for reliable navigation. (Popular cruising areas which could be termed "fringe areas" include the Bahamas, Bermuda, portions of the Gulf of Mexico, and the area south of San Diego, CA, on the West Coast, particularly the Baja Peninsula.) Although skywave contamination is a threat, mariners who cruise in these fringe areas may wish to take a *calculated risk* and alter the tracking point in order to have a sufficiently strong signal for navigation. USCG cannot assume the responsibility for Loran-C fix accuracy if cycle-stepping is used.

Many receivers permit this tracking point to be altered by a technique known as *cycle stepping*. Simply put, cycle stepping advances the tracking point of the pulses received by the master and the secondaries so as to provide a greater SNR. (Deliberate use of skywaves is another approach to navigation in fringe areas discussed in Appendix H.) Again, the owner's manual for the specific make and model of receiver should be consulted for the specific "mechanical" steps (i.e., the sequence of buttons to push) necessary for cycle stepping.

IMPORTANT DISCLAIMER!
Use of cycle stepping can enable the usable range of Loran-C coverage to be extended. However, this procedure entails the risks of fixes of reduced and possibly unknown accuracy. The USCG cannot guarantee fix accuracy if this technique is used.

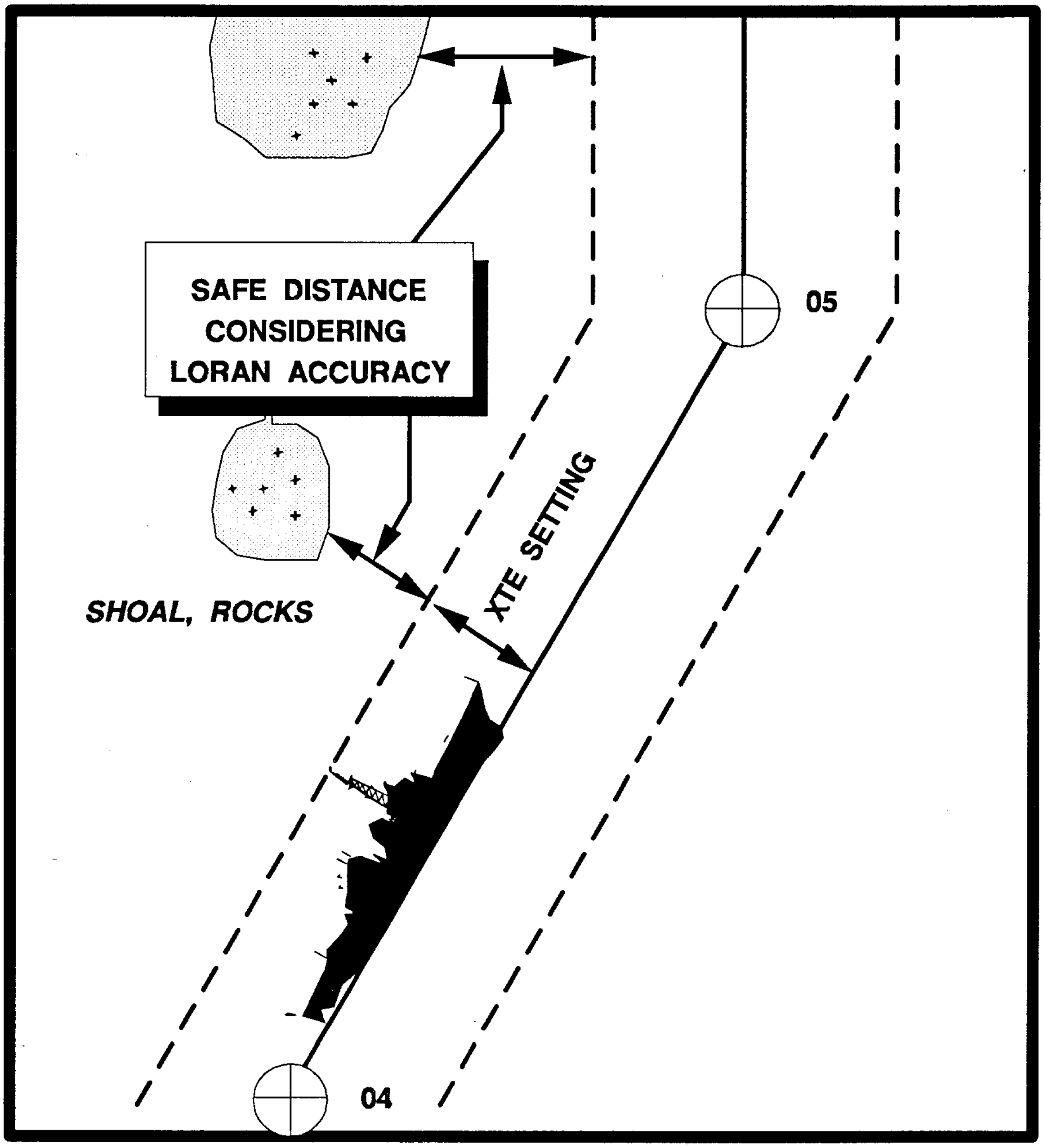
The conceptual procedure for cycle stepping is straightforward. First, it is necessary to determine the vessel's position as accurately as possible, noting the correct TDs (from a loran overprinted chart) corresponding to the vessel's position. Second, it is necessary to disable the ATS function of the receiver and manually select the GRI and secondaries for use. Next, it is necessary to *override the automatic tracking function*. Once these three steps have been completed, the tracking point on the master and secondaries can be advanced (in 10 usec increments) until an acceptable SNR results. Usually, the master signal is cycle stepped first (by, say, 10 usec or 20 usec), and then the secondaries are stepped the same number of cycles. If both the master and the two secondaries are advanced by the same number of cycles, the observed TDs will not be changed. (Advancing only the master will *decrease* the measured TDs, while advancing only the secondaries will *increase* the measured TDs.) If the master and the two secondaries are cycle stepped by the same amount, the vessel's indicated position will return to the position originally noted, or to the vessel's "actual" position (give or take the basic loran accuracy). If the master and secondaries are not stepped by the same amount, the difference must be applied as a correction to the observed TDs. For example, if the tracking point of the master were advanced by 20 usec, while those for the two secondaries were advanced by 10 usec, 10 usec would have to be *added* to each TD to determine the vessel's correction position.

Users should bear in mind that the limits of loran coverage are calculated based upon both SNR and accuracy criteria. Operating outside the limits of the published coverage diagram not only increases SNR problems, but also operates the vessel in areas of decreased loran accuracy. Recall from Chapter III that the absolute (and repeatable) accuracy of the loran is a function of geometry (i.e., gradients and crossing angles). Areas of low SNR (for which cycle stepping may be required) are also likely to be areas of "poor" geometry where the accuracy of the system is degraded.

Cycle stepping may be appropriate if there is no viable alternative, but operation in areas of low SNR must be done cautiously—and with due allowance for the fact that accuracy may be considerably degraded or compromised by either geometry or skywave contamination. Obviously, positions so determined must be regarded with particular suspicion, and should be verified by all other available means.

Cycle stepping is an advanced technique that can increase the usable range of the loran system. Use of cycle stepping increases the risk of skywave contamination, and positions so determined must be treated with skepticism.

FIGURE V-5. LAY OUT COURSES AND SET XTE ALARMS TO PROVIDE AN ADEQUATE MARGIN OF SAFETY WHEN POSSIBLE LORAN POSITION ERRORS ARE CONSIDERED.



Plan Courses and Waypoints Considering Loran-C Accuracy

As noted in many places in this document, the absolute accuracy of the Loran-C system within the defined areas of coverage is between approximately 0.1 and 0.25 nautical miles—repeatable accuracies are significantly better. One obvious consequence of these accuracy limitations is that courses should be planned with these limits in mind. Where possible, survey the waypoints to take advantage of the repeatable accuracy of the loran. If visiting an area for the first time, ensure that courses (and alarms) are set with due regard for the limitations of this system. In many cases this is quite easy to do, and amounts to nothing more than laying out courses and waypoints that provide an adequate margin of safety and allow the vessel to remain well clear of charted hazards to navigation. If this cannot be done, because the channels are too narrow or for other reasons, the loran should be assigned a supporting role, and other methods of position fixing (e.g., optical bearings and ranges, or radar) should be used as the primary means of navigation.

Arrival alarms (if utilized) should be set at a distance which enables the lookouts to have sufficient advance warning of an approaching waypoint in cases where this waypoint is a physical object, such as a buoy or light tower. Cross-track error alarms should be set if hazards to navigation require more precise navigation. But these alarms should be set with a safety margin to allow for Loran-C error.

Figure V–5 illustrates this point. Here the waypoints, route, and cross-track error alarm distance are laid out so that the vessel will have ample clearance from the two shoal areas. The appropriate amount of safety margin is a matter of judgment, and should consider whether or not waypoints 04 and 05 are known to within the repeatable or absolute accuracy of the system. If physical constraints (e.g., shoals to the east) do not permit a sufficient safety margin, then use of buoys, range markers, danger bearings, radar fixes, etc., should be planned.

Preplan Dockside and Cross-Check Data Entry

Operator error accounts for the majority of accidents or incidents caused by faulty navigation. This holds true for use of all navigation systems, including loran. Human errors associated with loran use include conceptual errors, such as a failure to understand the accuracy limitations of the system or the use of bias corrections in an area far removed from the point of calibration, and operational errors, such as entering the wrong coordinates for a waypoint, and allowing this error to go undetected because of insufficient cross-checks among various navigational systems. Such errors underscore the need for *constant vigilance* in navigation. The following ideas may prove useful to reduce the likelihood or consequences of human error.

Entering data into a loran receiver (e.g., waypoint coordinates, routes, adjusting the ASF corrections, etc.) is much easier at dockside, when the vessel is not rolling or pitching and the operator is not distracted by other duties, than while underway. This is particularly important in small craft where the operator is also the navigator. Indeed, the vast majority of the data entry (aside from storing waypoints underway or switching "pages" in the receiver display) can be completed well before the mooring lines are cast off at the beginning of a voyage.

Where possible, have someone else cross-check data entries, such as waypoint coordinates. Often the person entering the data will miss certain types of errors (particularly transposition errors, as latitude 41 04.6 in place of latitude 41 40.6) that are more easily detected by a second person. Commercial aviators do this when loading coordinates into inertial navigation systems as a matter of routine—the co-pilot checks entries made by the captain. Distances and bearings from waypoint to waypoint taken from the nautical chart can be matched against the receiver display as an added check on data entries.

Carrying a second loran receiver (independently programmed) furnishes another check on the vessel's position and also reduces the likelihood of both receiver's being inoperative. Prices of lorans have fallen to levels so low that carrying a second receiver as a backup is a very cheap form of insurance. (Carrying an entirely independent navigation receiver, such as GPS, would protect the mariner against system failures of either system. This would be a costly option given present prices for GPS receivers, but these prices will decrease in the future.)

CHAPTER VI

Loran-C Charts and Related Information

Introduction

This chapter discusses Loran-C overprinted charts and related Loran-C information available from the various agencies of the U.S. government. Relevant information includes the Loran-C charts, DMA published manuals on ASF corrections (discussed in Chapter II), and material furnished by USCG, including the *Local Notice to Mariners* and related information. This chapter is principally of interest to mariners.

Loran-C Charts: Third Vital Component of the System

As noted in Chapter I, the Loran-C system consists of land based transmission and control systems, a receiver to measure TDs, and Loran-C overprinted charts, used for navigation and for plotting and converting the measured TD data into latitude and longitude. (These charts are not used by aviators. As noted, aviation users work in latitude and longitude units exclusively.) For U.S. waters, these charts are prepared and published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS). For other parts of the world, the Department of Defense (DOD), Defense Mapping Agency, Hydrographic/Topographic Center (DMAHTC), publishes nautical charts, many overprinted with Loran-C TDs. Additionally, several other countries of the world publish Loran-C overprinted nautical charts. Canada, for example, publishes excellent Loran-C charts of both Canadian and adjoining U.S. waters.

The focus of this discussion is upon charts of U.S. waters, therefore, the charting conventions of NOS will be emphasized. Chart conventions generally agree among the various countries, although there are some minor differences. Readers wishing information on chart conventions employed in other countries should write directly to the NOS counterpart in the country of interest. Useful material on NOS conventions can be found in Stuart (1986, 1991) or obtained directly from NOS.

Loran-C Overprinted Charts

Charts available from NOS are identified in the *NOS Chart Catalog,* issued in five volumes, including: the *Atlantic and Gulf Coasts* (Volume 1); the *Pacific Coast, including Hawaiian, Mariana and Samoa Islands* (Volume 2); *Alaska, including the Aleutian Islands* (Volume 3); the *Great Lakes and Adjacent Waterways* (Volume 4); and finally a fifth volume covering *Bathymetric and Fishing Maps, including Topographic/Bathymetric Maps.* These chart catalogs are available at no charge from authorized

NOS sales agents, or directly from NOS at 6501 Lafayette Avenue, Riverdale, Maryland 20737. The catalogs contain a small scale chart of the applicable areas of U.S. CCZ waters with coded rectangles (outlining the area covered by each NOS chart) superimposed. These rectangles contain the chart number, and are also color coded to reflect the scale of the chart. Harbor charts, for example, at a scale of 1:50,000 and larger are printed in a purple outline, while coast charts, with scales of from 1:150,000 to 1:50,000 are outlined in blue. Inset panels provide more information on the various charts, including the chart number, title, and scale. Charts prefixed with a "C" inside a circle (similar in appearance to a copyright mark) are overprinted with Loran-C TDs. Although the catalog enables the identification of which charts are overprinted with Loran-C TDs, this catalog does not identify which rates are shown on these charts. Loran-C overprinted charts are available for the entire CCZ and many other areas as well. Loran-C overprinted *bathymetric maps*[1] are also available for selected areas, and loran overprinted transparent mylar overlays can be obtained upon special request (and at additional cost) from NOS. These loran overprinted bathymetric maps are much used by fishing vessels.

With very few exceptions, Loran-C TDs are not printed on any chart with a scale larger than 1:80,000 (1:75,000 in Canada). For the present, this is a deliberate NOS (also USCG and DMAHTC) policy, made because the ASF data presently available are not accurate enough for presentation at larger scales. Other navigational systems (e.g., radar, visual fixes, depth information) are available for inshore piloting and are almost always adequate.

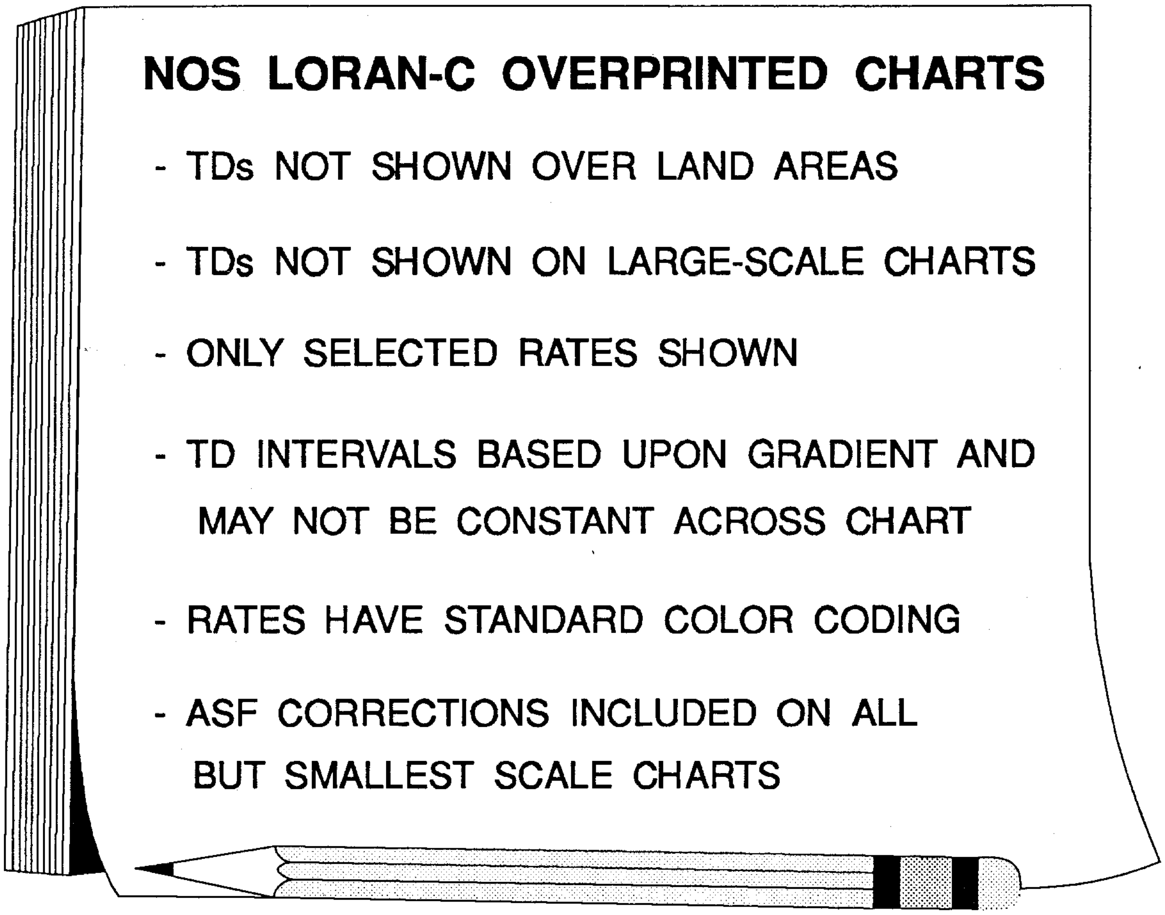
Absolute (geodetic) accuracy limitations of Loran-C in near shore and harbor areas are explained in Chapters II and III and arise from the sometimes unpredictable effects that land has on loran signals. To some degree, this limitation could be removed by gathering extensive and costly survey data. However, the ready availability of satisfactory alternatives to the use of Loran-C for navigation in these waters and the high cost of such surveys have resulted in the policy decision not to print loran LOPs on large-scale charts.

As well, it is NOS policy not to show Loran-C TDs for inshore waters, bays, rivers, protected harbors (nor over land areas) on smaller scale charts which include these areas. As a point of interest, these LOPs are actually calculated throughout the area covered by the chart by the computer programs used by NOS, but "painted out" over these regions on the photographic negatives prior to printing the chart.

Rates Printed on NOS Charts

Rates (GRI and secondaries) shown on each overprinted chart are specifically identified in the Loran-C notes on each chart (see below). NOS loran overprinted charts include at least the recommended rates shown in the coverage diagram, but not necessarily all rates that can be received in the waters covered by the chart. If the spacing between LOPs is excessive (poor gradient), or the crossing angle is too small (see Chapter III), a rate may be not be shown on the chart. In particular, LOPs in the fringe area of ground wave coverage, or in the baseline extension area for a specific rate, are usually deleted from the chart. The decision to omit a rate depends upon several factors, including chart

[1]Maps that show enhanced bottom detail. By convention, these are called maps rather than charts.



clutter, and is made jointly by USCG and NOS. However, if a particular rate is shown on the coastal series charts in an area, it will also be shown on smaller scale charts of the same waters.

Intervals Between Adjacent TDs and Spacing

As noted in earlier chapters, it would be impractical to print LOPs on nautical charts corresponding to each possible TD. Therefore, only selected TDs are printed. The interval spacing (in microseconds) between the adjacent TDs printed on the nautical chart depends upon the gradient (see Chapter III) and the chart scale. The overall objective of the cartographer is to select an interval (difference in microseconds between adjacent TD lines) that will result in lines of position spaced approximately 3/4" to 1 1/4" apart—in any event not closer than 1/2", nor farther apart than 2". Table VI–1 shows the interval between adjacent charted TDs (in usec) and the chart scale and gradient (ft/usec) necessary to achieve a chart spacing of 0.5 in, 1.0 in, or 2.0 inches. For example, charting an LOP near the baseline (gradient approximately 500 ft per usec) at a 1:80,000 scale (typical of coastal charts) would require an interval of 6.7 usec to achieve a spacing of 0.5 in or 27 usec to achieve a spacing of 2 in between adjacent TDs. An interval of 10 or 20 usec might be used. However, if the gradient were as large as 2,500 ft/ usec, a smaller interval, such as 2, 4, or 5 usec

TABLE VI-1. CHART INTERVAL (usec) BETWEEN ADJACENT LOPs TO SATISFY NOS CONSTRAINTS ON LOP SPACING AS A FUNCTION OF GRADIENT AND CHART SCALE.

Gradient (ft/usec)	Chart Scale	Interval Between Adjacent Overprinted LOPs to Obtain the Following Line Spacing (Inches)		
		0.5	1.0	2.0
500	1:80,000	6.7	13.3	26.7
1,000	1:80,000	3.3	6.7	13.3
1,500	1:80,000	2.2	4.4	8.9
2,000	1:80,000	1.7	3.3	6.7
2,500	1,80,000	1.3	2.7	5.3
500	1:200,000	16.7	33.3	66.7
1,000	1:200,000	8.3	16.7	33.3
1,500	1:200,000	5.6	11.1	22.2
2,000	1:200,000	4.2	8.3	16.7
2,500	1:200,000	3.3	6.7	13.3
500	1:500,000	41.7	83.3	166.7
1,000	1:500,000	20.8	41.7	83.3
1,500	1:500,000	13.9	27.8	55.5
2,000	1:500,000	10.4	20.8	41.7
2,500	1:500,000	8.3	16.7	33.3
500	1:1,000,000	83.3	166.7	333.3
1,000	1:1,000,000	41.7	83.3	166.7
1,500	1:1,000,000	27.8	55.5	111.1
2,000	1:1,000,000	20.8	41.7	83.3
2,500	1:1,000,000	16.7	33.3	66.7

would be appropriate. Too small an interval results in a cluttered and unusable chart, while too large an interval complicates the task of interpolation using a plotter (see below).

Microsecond intervals between adjacent TDs are usually selected as multiples of 5 or factors of 100 (e.g., 5, 10, 20, 25, or 50). On larger scale charts, smaller intervals of 1, 2, or 4 microseconds may be employed. On smaller scale charts, intervals of 200, 250, or 500 microseconds are necessary to ensure the desired spacing between adjacent LOPs. Normally, the interval will be constant for a rate throughout the chart, but in some cases it is necessary to vary the spacing for the same rate in different areas of the chart.[2] In this event, the larger interval is selected as an integer multiple of the smaller. For example, if the TDs spaced at a 10 microsecond interval begin to "spread" such that the spacing is not within tolerances, a 5 microsecond interval would be used for a portion of the chart to maintain the desired spacing of LOPs. The microsecond interval between adjacent TDs may differ among the rates shown on the chart.

These conventions on line spacing are quite reasonable, and undoubtedly result in a chart of greater utility. However, users should note carefully the interval between adjacent TDs when plotting a position and not make the assumption that the interval is constant throughout the chart for a given rate, or the same for all rates shown on the chart.

[2]This would occur, for example, if the gradient varies substantially over the area covered by the chart.

Users should note carefully the interval between adjacent TDs when plotting a position and not make the assumption that the interval is constant throughout the chart for a given rate, or the same for all rates shown on the chart.

Rate Designators on NOS Charts

Rate designators are the coded sequence of numbers or index that identify a rate. Thus, for example, the rate designator for a loran TD printed with the index "9960–W–14500" would be "9960–W." These rate designators are shown every fifth TD on Loran-C overprinted charts produced by NOS unless the microsecond interval is 25, 50, or 250 microseconds. In this latter event, rate designators can be shown on every fourth line, such that the indexed lines will be at 100, 200, or 1,000 microsecond intervals.

ASF Compensation on NOS Loran-C Charts

As noted in Chapter II, the location of the Loran-C LOP on a chart depends upon the speed of propagation of the loran radio waves from the transmitter(s) to the user's position. In particular, it is often necessary to include an allowance for landpath delays in computing the location of a Loran-C LOP on the nautical chart. These delays, termed ASFs, can be computed from theoretical propagation models (see Appendix F) or a combination of theoretical models and actual survey data. (Where actual survey data of acceptable quality are available, ASFs are calculated by statistical procedures that force fit the TD lattice so as to reflect the theoretical estimates and provide good fits to the survey data as well.) The surveys are conducted by various agencies of the U.S. Government and provided to DMAHTC for ASF calculation.[3] In turn, DMAHTC provides computer tapes containing the ASF corrections to NOS for use in chart compilation. The format and "fineness" of the ASF grid varies from chart to chart. For example, for charts with a scale smaller than 1:875,000, ASF corrections are probably unnecessary. (This is because the differences between corrected and uncorrected LOPs would appear very small when plotted on such a small-scale chart. Recall from Chapter II that ASF corrections are generally within +/- 4 usec.) For charts with a scale between 1:250,000 and 1:875,000, DMAHTC may provide a single ASF lattice shift (in microseconds) for each rate to be charted. This shift represents an average correction for overland signal delay and is constant over the entire area of chart coverage. Alternatively, for coastal charts with a scale larger than 1:250,000, DMAHTC furnishes NOS with a data tape containing ASF corrected Loran-C coordinate values for each rate at every 5 minutes of latitude and longitude in the area of chart coverage. On these charts, if the hyperbolic curvature of the TDs is clearly noticeable (e.g., in areas near baseline extensions) a finer grid (e.g., at 1 minute intervals) is provided.

[3]For a useful discussion of DMAHTC's role, activities, and methods, see Speight, (1982).

TABLE VI-2. GENERAL NOTES FOUND ON RELEVANT EDITIONS OF LORAN-C OVERPRINTED CHARTS[a]

Note	Remarks
"The Loran-C correction tables published by the Defense Mapping Agency or others should not be used with this chart. The lines of position shown have been adjusted based on survey data. Every effort has been made to meet the 1/4 nautical miles accuracy criteria established by the U. S. Coast Guard. Mariners, however, are cautioned not to rely solely on the lattices in inshore waters."	Most common and recent note, found particularly on coastal charts. Indicates that ASF corrections have been applied and updated with current survey data.
"The Loran-C correction tables published by the Defense Mapping Agency or others should not be used with this chart. The lines of position shown have been adjusted based on theoretically determined overland signal propagation delays. They have **not** been verified by comparison with survey data. Every effort has been made to meet the 1/4 nautical mile accuracy criteria established by the U. S. Coast Guard. Mariners, however, are cautioned not to rely solely on the lattices in inshore waters."	This indicates that theoretical ASF corrections have been applied — and, therefore, that the mariner should not make these adjustments — but that survey data have not been considered in determining the location of the overprinted TDs.
"The Loran-C correction tables published by the Defense Mapping Agency or others should be used with this chart. The lines of position shown are based on assumed all seawater signal paths. Uncorrected positions may not meet the 1/4 nautical mile accuracy criteria established by the U. S. Coast Guard. Mariners, however, are cautioned not to rely solely on the lattices in inshore waters."[b] **Or alternatively,** "The Loran-C lines of position on this chart are based on assumed all sea water signal paths. They are not adjusted for overland signal transmission delay."	Normally applies only on very small scale charts where ASF corrections are unlikely to be important.

[a] Older charts may contain other text, but all are being revised to include one of the above notes. Read the note on your chart carefully, however, to determine whether or not to use the ASF tables for adjustment.
[b] This note is being phased out on new charts.

The available survey data varies by area, and is described on each chart with a specific chart note found as part of the Title Block or in the Supplemental Notes where the other general loran information is presented. Table VI–2 provides the text of the three standard chart notes now being printed on NOS Loran-C overprinted charts. Older charts may contain different text, depending upon how the chart was compiled.[4] Users should read this note carefully to determine whether or not it is appropriate to use the DMA ASF tables to adjust the printed TDs on a chart, or whether these corrections have already been incorporated into the chart.

Provided the user's Loran-C receiver is programmed to include ASFs, the latitude and longitude read from the receiver should be nearly the same as that determined from the TDs when these are plotted directly on nautical charts corrected for ASF. Some differences may result, however, because the ASFs incorporated into the receiver may differ from those provided by DMAHTC to NOS. Additionally these tables can be used by users to correct TDs prior to automatic conversion on receivers not programmed to include ASFs.

Standard Color Coding for Loran-C TDs

Loran-C rates plotted on NOS (and DMA) charts employ a standard color coding, noted in earlier chapters and in the Glossary. As of this writing, no color code has yet been assigned to the Victor secondary, although gold or brown are options under consideration.

The standard color coding for loran TDs serves as an additional check to ensure that the correct line is used to plot a position. Normally, this is not an issue, because the CDs are selected to ensure that there is a wide variation in the numerical values of the various TDs throughout a region. Additionally, the rate designators (noted above) are shown on selected (every fourth or fifth) TDs. Finally, the color coding serves as yet another check.

Users should pay special attention to identifying the correct family of loran LOPs if these are plotted for two GRIs on the same chart, otherwise substantial position errors could result.

Plotting and Interpolation

As noted, only selected TDs are overprinted on the charts, so it is generally necessary to *interpolate* between printed TDs to plot an exact position. For example, suppose the vessel were cruising in the northern areas of Rhode Island Sound. In this location the TDs for best accuracy (refer to coverage diagrams) would be the Xray and Yankee secondaries of the 9960 NEUS chain. Suppose the TD readings on the receiver were 25,744 and 43,952 microseconds. (Normally, a receiver would display these numbers with one or two figures to the right of the decimal point for the Xray and Yankee secondaries respectively, but these are omitted here for simplicity.) Reference to the appropriate chart indicates that the TDs for the Xray secondary are spaced 10 microseconds apart, so that 25,744 would be located between the 25,740 and 25,750 TDs. On this same chart, the interval between adjacent TDs on the Yankee secondary is 5 microseconds, so the 43,952 TD line would be located between the 43,950 and 43,955 overprinted TDs.

As shown in Figure VI–1, without interpolation all that can be said is that the user's position is in the shaded polygon bounded by the overprinted TDs. For many purposes, this approximate position would be entirely satisfactory, but for more accurate navigation it would be necessary to determine exactly where the vessel is located within this polygon.

Although loran LOPs are really hyperbolas, it is convenient to treat these as parallel straight lines within a small area and to use linear interpolation. Thus, the 25,744 TD would be parallel to and approximately 4/10ths of the distance between the 25,740 and 25,750 lines. There are several techniques for locating this 25,744 TD. Perhaps the simplest is to use one of the many loran linear interpolators on the market, or those

[4] Some of the original coastal charts did not include even theoretical ASF corrections, but these have since been updated.

FIGURE VI-1. PLOTTING A LORAN POSITION IN RHODE ISLAND SOUND--DETERMINING AN APPROXIMATE POSITION WITHOUT INTERPOLATION.

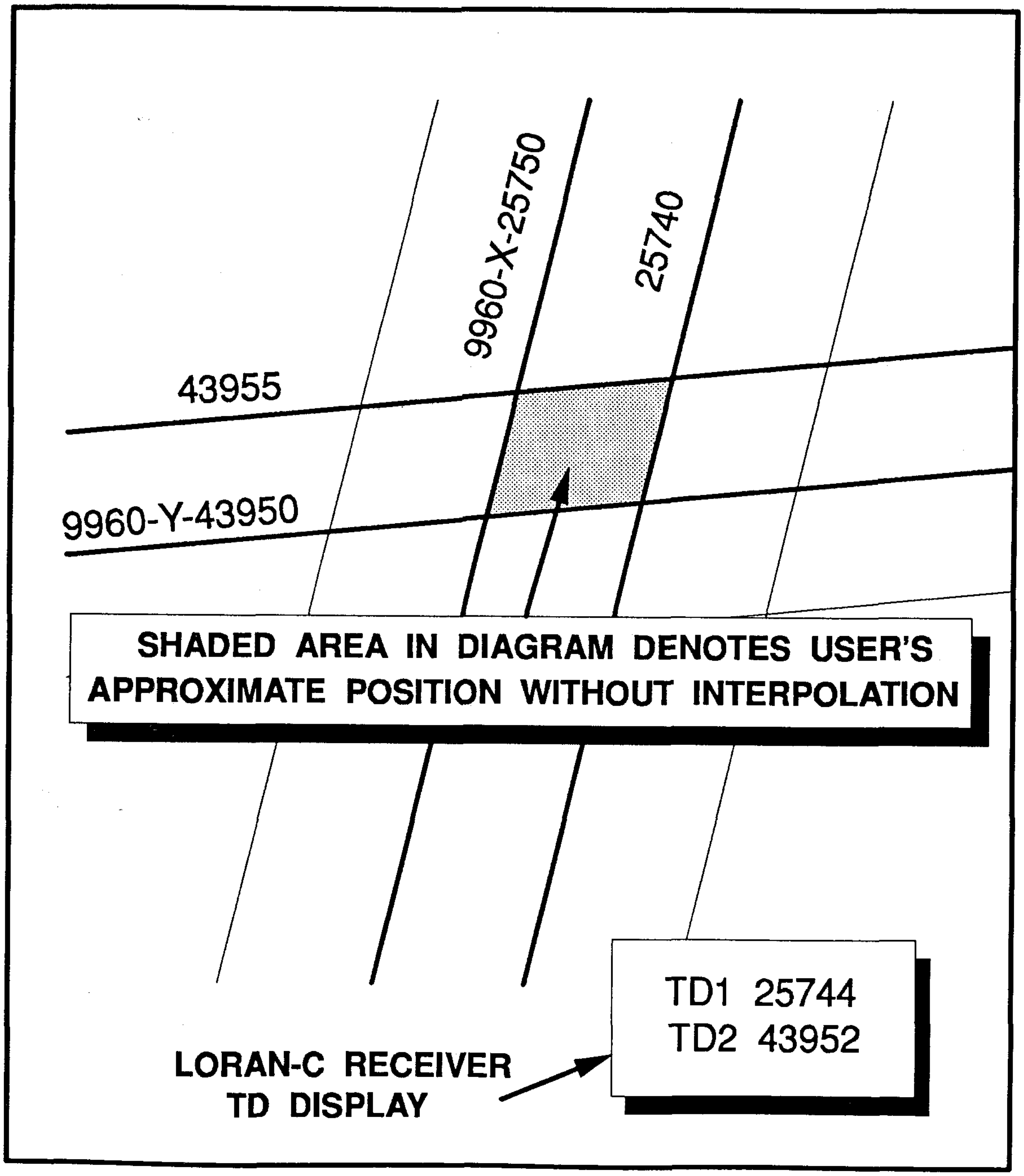
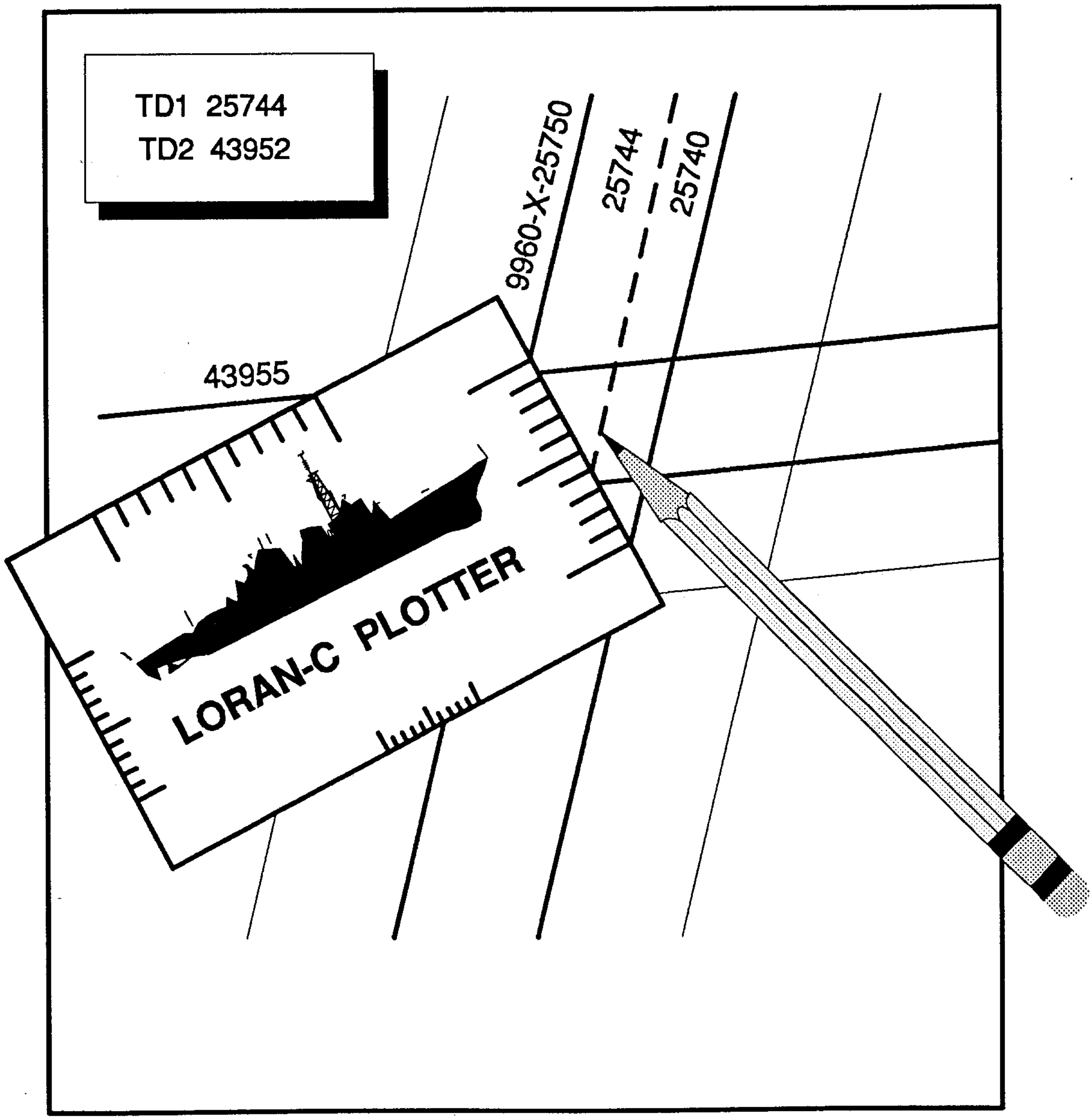


FIGURE VI-2. USING A LORAN PLOTTER AND PENCIL TO INTERPOLATE THE XRAY SECONDARY TD COORDINATE GIVEN IN FIGURE VI-1.



provided by NOS or the U.S. Coast Guard. These interpolators are made of plastic or stiff cardboard and have several uniform scales with either 5 or 10 equally spaced divisions. All that is necessary is to fix one of the scales with one end at the lower TD, and the other end at the upper TD, much as is shown in Figure VI–2. The desired TD for the Xray TD is located 4 units along the 10 unit scale of the interpolator. Using a pencil, simply make a mark next to the 4th mark out of ten and draw in a 24,744 TD parallel to the adjacent TDs printed on the chart. A similar procedure would be followed for the other TD and the vessel's location fixed at the intersection of the dotted TDs. In the case of the Yankee secondary, adjacent overprinted TDs are only 5 units apart, so either a 5 unit scale must be used or the difference must be prorated on a 10 unit scale of the plotter.

Depending upon the plotting convention used, the mariner would normally plot the resulting fix as a dot within a circle or dot within a triangle (to denote an electronic fix) and write "LORAN" next to the symbol. The fix time (four-digit 24-hour time) is recorded and written next to the fix symbol and parallel to one of the chart axes.

Each Loran-C overprinted chart contains an interpolator printed on the chart, as shown in Figure VI–2. All that is required to use this interpolator is a set of dividers. The procedure is quite simple. First, the dividers are placed on the chart in the vessel's approximate position and set to the spacing between adjacent overprinted TDs. Next, one end of the dividers is placed on the bottom of the chart interpolator—while holding the dividers perpendicular to the bottom—and the dividers moved along the bottom axis until the other end of the dividers intersects the line for the appropriate spacing, e.g., 10 microseconds. The user simply puts a faint pencil mark at the bottom axis at this point. Next, the spacing of the dividers is reduced, while holding one end on the bottom axis, until the other end intersects the desired spacing. This length is then transferred to the chart. In practice, this procedure is easier to do than to describe, and works quite well. Whether to use a separate interpolator or that provided on the chart is a matter of personal preference. Moreover, as noted, it may not be necessary to interpolate at all if the area of the shaded polygon illustrated in Figure VI–1 is sufficiently small for the navigator's purpose.

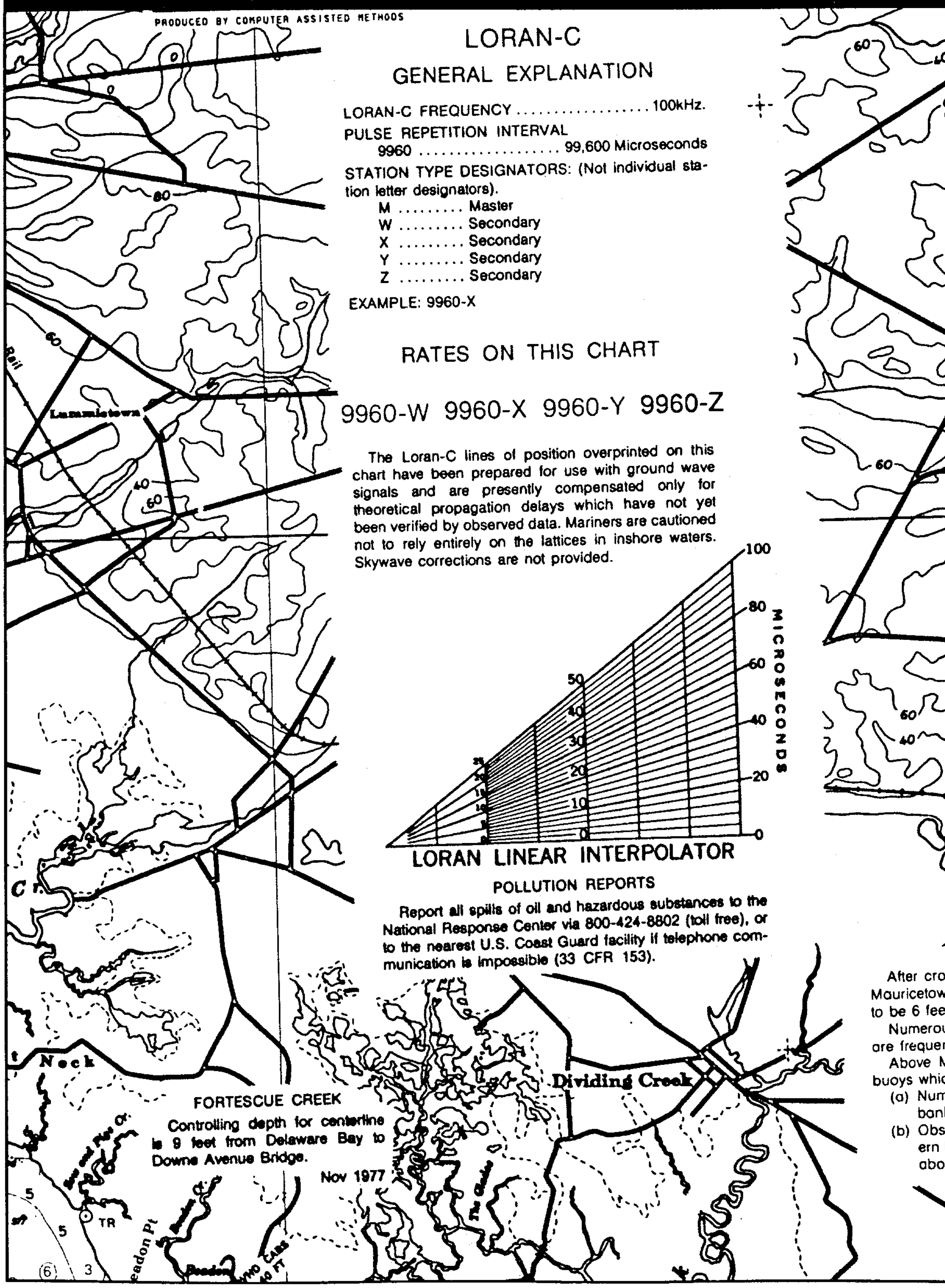
Finally, the user may elect to use the automatic coordinate converter in the loran receiver (if so equipped) and simply plot latitude and longitude directly. Recall, however, that the receiver's ASF corrections are not subject to any industry standard, and may not ensure that the system accuracy limits are satisfied.

Use of Loran-C Without Loran-C Overprinted Charts

As noted above, USCG, NOS, and DMAHTC have developed a clear policy about which rates to show on a loran overprinted chart, which charts to overprint, and which areas of the charts to overprint with LOPs. Omission of loran overprinting generally means that the absolute accuracy standards of the Loran-C system cannot be guaranteed in the area covered by the chart.

Loran-C can, however, be used in areas where overprinted charts are not available. If the user has previously transited the area and entered waypoints in the receiver memory (or noted these in hard copy form), the user can generally exploit the receiver's high repeatable accuracy for navigation. Even if previously recorded TDs are not available, the mariner can still use the coordinate conversion capability of the receiver (if so equipped) to determine an approximate position. However, the accuracy of this approximate position cannot be guaranteed, and loran should only be used to provide a

FIGURE VI-3. PORTION OF LORAN OVERPRINTED CHART WITH INTERPOLATOR.



general indication of position. Most mariners will encounter this situation (within the CCZ) only in harbors and harbor entrances where other aids to navigation are abundant, and should serve as the primary method for navigation.

Although loran can sometimes be used to great advantage in areas where charts do not provide TDs, the omission of overprinted LOPs generally means that system absolute accuracy specifications cannot be guaranteed in these locations.

Local Notice to Mariners

Another important source of Loran-C information relevant to coastal waters available from the U.S. Government is the *Local Notice to Mariners,* published by the U.S. Coast Guard, and available from each District office of the U.S. Coast Guard. Experienced mariners rely on the information contained in this publication for chart corrections and other information. It is mentioned here to indicate that loran related information is also presented in this publication.

Table VI–3 provides a sample of such information pertinent to loran extracted from the *Local Notice to Mariners* for the Fifth Coast Guard District. In general, this publication is used to disseminate information on such topics as the availability of new chains, additional secondaries, scheduled maintenance downtime, reported interference, test efforts, and a host of other time-critical information. The illustrations furnished in Table VI–3 provide examples of the types of information and data given in this publication.

The *Local Notice to Mariners* also provides contact information (names and telephone numbers) for U.S. Coast Guard personnel from whom additional information can be obtained on the status of Loran-C chains.

DMA Publications

As noted earlier, DMAHTC publishes Loran-C overprinted charts, tables of ASF information, and other relevant material. Readers are also advised of the availability of DMA Chart 5133, which provides information on loran coverage worldwide.

TABLE VI-3. SAMPLE LORAN-RELATED INFORMATION FOUND IN *LOCAL NOTICE TO MARINERS.*

LORAN-C OPERATIONS: GREAT LAKES CHAIN (GLKS 8970)

At 1201 on 14 May 1991 the 8970 MZ baseline; i.e., from the master, located in Dana, IN; to the Zulu secondary, located in Boise City, OK, will be considered fully operational and available to users. This new baseline will expand GLKS Loran-C coverage. The expanded 8970 MWXYZ chain coverage area was approximated based on conservative estimates of station range limits, atmospheric noise, and grid geometry limitations. Our calculations indicate 8970 MWXYZ will provide good Loran-C coverage as follows: states fully covered: all of Kansas, Oklahoma, Missouri, Arkansas, Tennessee, South and North Carolina, Kentucky, Virginia, Maryland, Delaware, West Virginia, Ohio, Indiana, Illinois, Iowa, Wisconsin, Michigan, including coastal offshore coverage from Brunswick, GA, north to Cape May, NJ. Great Lakes coverage: all of Lakes Superior, Michigan, Huron, including the Georgian Bay and all of Lake Erie less the northern quarter. States partially covered: all of Minnesota less the northwestern tip, southeastern corner of North Dakota, eastern half of South Dakota, all of Nebraska less the extreme western end, eastern quarter of Colorado, eastern third of Texas, northwestern half of Louisiana, all of Mississippi, Alabama, and Georgia less the extreme southern regions, and the western half of Pennsylvania. Canadian coverage: coverage extends into the southeastern parts of Canada approximately along a curve from north of International Falls, WI, into Ontario short of the James Bay, over into Quebec and down to Toronto, Canada. Users should address inquiries concerning the Great Lakes Chain, to the coordinator of chain operations, LCDR Piccioni, at (507) 869-1334. Information is also available on the recorded status number, (607) 869-5395. For timing users: USNO will continue to monitor GLKS timing and provide recommended frequency adjustments to the Coast Guard. We trust you will find this new, expanded version of the GLKS chain useful in meeting your navigation or timing needs.

SOUTH CENTRAL U. S. (SOCUS 9610) LORAN-C CHAIN OPERATIONAL

At 1500Z on 17 January 1991 the fourth SOCUS baseline—Boise City — Gillette (9610 MV) — will be considered fully operational and available to users. The remaining SOCUS baseline — Boise City — Las Cruces (9610 MX) — is not yet ready for use. Baseline 9610 MX will not be operational until April 1991.

This baseline will be added to those SOCUS baselines declared operational in December. Status of each SOCUS baseline is provided below:

BOISE CITY, OK (Master) — GILLETTE, WY (Victor) — 9610 MV (AVAILABLE 17 JANUARY 1991)

(Continued Next Page)

TABLE VI-3. SAMPLE LORAN-RELATED INFORMATION FOUND IN *LOCAL NOTICE TO MARINERS. (cont'd.)*

BOISE CITY, OK (Master) — SEARCHLIGHT, NV (Whiskey) — 9610 MV (AVAILABLE 25 DECEMBER 1991)

BOISE CITY, OK (Master) — LAS CRUCES, NM (Xray) — 9610 MX (AVAILABLE APRIL 1991)

BOISE CITY, OK (Master) —RAYMONDVILLE, TX (Yankee) — 9610 MY (AVAILABLE 25 DECEMBER 1991)

BOISE CITY, OK (Master) — GRANGEVILLE, LA (Zulu) — 9610 MZ (AVAILABLE 25 DECEMBER 1991)

Coverage area:

All of Iowa, Utah, Colorado, Kansas, New Mexico, Texas, Oklahoma, Louisiana, Arkansas, and off shore of the Texas/Louisiana coast to a line between Brownsville, TX, and New Orleans, LA.

Southwestern quarter of Montana, all of Idaho less the northern panhandle, all of Nevada less the western third of state, western half of Mississippi, southwestern corner of Tennessee, all of Missouri less southeastern corner, western third of Illinois, southwestern quarter of Wisconsin, eastern and western thirds of Nebraska, southwestern corner of South Dakota and all of Wyoming less northeastern corner.

Mexican coverage: less the area south of Arizona and the Baja Peninsula, most of northern Mexico from a line between Brownsville, TX, and the southern tip of the Baja Peninsula.

LORAN

Lorsta Boise City (Great Lakes Only) Off-Air.
Lorsta Boise City's test transmissions as a new secondary on the Great Lakes Loran Chain (8970 GLKS) are causing 8970 acquisition problems on some receivers. To minimize the impact on users and give the receiver manufacturers time to correct receiver software, we ceased all 8970 Zulu transmissions from Lorsta Boise City, OK, at 17427, 28 September 90.

Unfortunately, we must, on at least a daily basis, obtain Loran-C test data concerning the new 8970 Master-Zulu baseline. Further, precise timing measurements to establish emissions delays remain to be done. To meet our daily data needs and minimize interference to users, we will permit Boise City to transmit 8970 Zulu signals during the hours of 1500 to 1700Z each day. Daily transmissions from 1500 to 1700Z will commence on 03 October

(Continued Next Page)

TABLE VI-3. SAMPLE LORAN-RELATED INFORMATION FOUND IN *LOCAL NOTICE TO MARINERS.* (*cont'd.*)

1990 and end on 29 October 1990; on 30 October 1990 Lorsta Boise City, OK, will resume continuous 8970 Zulu transmissions.

During the measurement of emission delays, Boise City will be authorized sufficient additional on-air time to accomplish the measurement. When the dates for the emission delay measurement are known, we will advise all concerned.

If you object to this procedure or are experiencing unusual problems with the Great Lakes Chain, please contact the coordinator of chain operations, LCDR Piccioni, at (607) 869-1334. Information concerning this problem will also be available on the recorded status number, (607) 869-5395.

Control of chain timing; southeast US (SEUS 7980) and Great Lakes (GLKS 8970) Loran-C chains. The following information will not repeat nor affect most navigation users; timing, as used in this message, relates to the time relationship of the loran chain master's signal to the naval observatory's master clock. Those navigation receivers dependent on measuring a master-secondary time difference will be unaffected by the control changes described.

As part of our compliance with legislated reductions in timing tolerances, we have been experimenting with procedural attempts to meet the demands of the law. With SEUS, we have been allowing the USCG coordinator of chain operations (COCO) to calculate and enter timing/frequency adjustments; in this procedure, all previous limitations, e.g., advance notification to users, minimum times between adjustments, etc., were removed; adjustment size, however, was limited to (per day) 300 nanosecond time steps and 12 parts in 10 to the thirteenth in frequency. With GLKS, we used daily small time steps (always less than 300 nanoseconds and usually 100 nanoseconds or less).

On 29 Oct 90 we will change the above-mentioned SEUS/GLKS control methods to that now being used with the Northeast U.S. (NEUS 9960) Chain, i.e., steering each master's cesium frequency by daily insertion of naval observatory recommended frequency adjustments.

Loran-C Operations: South Central U.S. Chain (9610 V) and North Central U.S. Chain (8290 X). During the week of 15 Oct 90 Lorsta Gillette, WY, will commence transmissions as a SOCUS 9610 Victor secondary and NOCUS 8290—secondary. Transmissions will be intermittent and are test signals only. Do not, repeat, do not use these signals for any navigation or timing purposes.

Installation and Related Matters

Introduction

The final chapter of this *Loran-C Handbook* covers the important topics of receiver installation and related matters. Proper installation of a loran receiver and associated equipment is essential in order to realize the maximum utility from the system. As the following discussion shows, installation is far more than simply wiring up the receiver, turning it on, and getting the vessel underway. An otherwise excellent receiver, if improperly installed, may not perform as well as an inexpensive receiver calibrated and installed with care.

An otherwise excellent receiver, if improperly installed, may not perform as well as an inexpensive receiver installed with care.

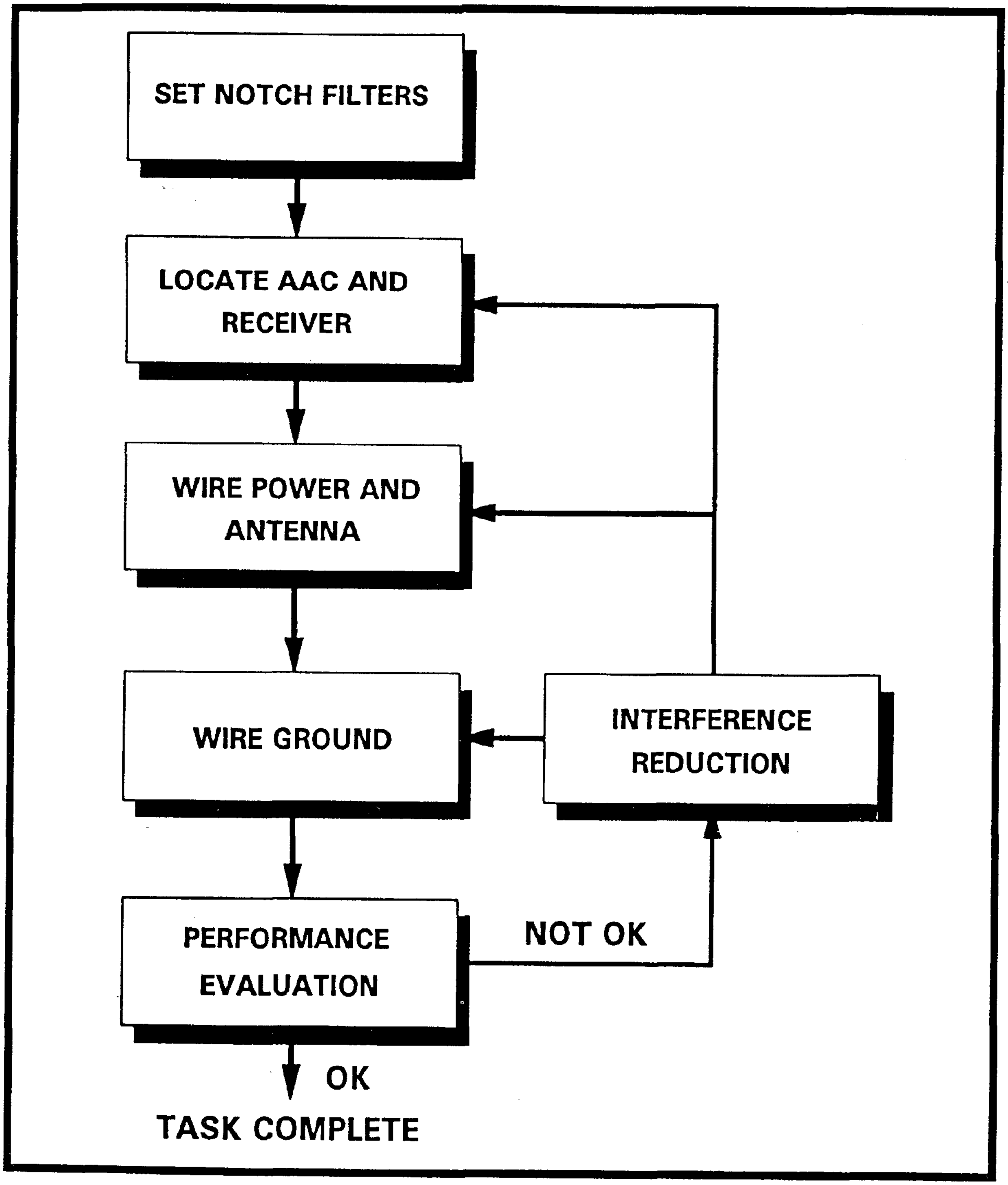
The chief consequence of installation errors is that the SNR of the received signal will be lower than it would have been with proper installation. In areas where the signal is very strong and in good weather conditions, it is possible that (aside from lower-than-expected SNRs) the improperly installed receiver will perform quite well. However, in areas where the SNR is normally lower, the added losses as a result of poor installation may cause the receiver to take longer to initialize, or to "crash" more often. Additionally, cycle slip errors may occur with greater frequency, and the effective range of the system at which usable loran signals can be acquired will be substantially reduced.

As with other chapters, the material presented here is designed to supplement, but not replace, the instructions contained in the receiver owner's manual. Users should carefully read the specific installation instructions contained in the owner's manual.

Overall Sequence of Installation Steps

The overall job of installation and calibration involves several steps shown schematically in Figure VII–1. These include; (i) setting the receiver's notch filters (if adjustable), (ii) locating, fastening, and wiring the receiver's antenna and antenna coupler, (iii) finding a suitable location for and mounting the receiver, (iv) connecting the antenna lead and supplying power to the receiver, (v) grounding the receiver, (vi) performance evaluation, (vii) interference reduction (if necessary), and (viii) connecting the receiver's interface (if any) to other on-board navigation systems. With the exception of items (i) and (viii), these steps are addressed in this chapter.

FIGURE VII-1. STEPS IN LORAN-C RECEIVER INSTALLATION AND PERFORMANCE EVALUATION



Setting adjustable notch filters is a specialized task and beyond the scope of this handbook. (Ideally, these notch filters should be "optimized" for the intended cruising area considering the known sources of interference.) Likewise, connecting the Loran-C receiver interface to other shipboard electronics is straightforward, but depends upon many application-specific factors (e.g., the particular communication protocol required) and is not discussed here.

The material given here is designed to supplement the owner's manual for those users who elect to install the receiver and associated equipment. Although installation is not especially difficult, it needs to be done properly. Therefore, the user may wish to consider having this installation done by an electronics technician. The cost of professional installation is usually not great, and the user can generally be assured that the job will be done correctly. For those on a tight budget, do-it-yourself installation not only saves money but also permits the user to learn more about the receiver. (Aviation users should check applicable Federal Aviation Administration (FAA) regulations to determine the personnel qualifications necessary to install loran receivers and antennas.)

The material presented in this chapter applies chiefly to marine users. Other users may find elements of this discussion of interest.

> **Do-it-yourself loran installation can save money and enable the user to learn more about loran, but professional assistance is sometimes necessary. Aviation users should check FAA regulations to determine exactly what maintenance and installation activities need to be done by licensed personnel.**

Antenna/Antenna Coupler (AAC) Location

As received from the factory, the Loran-C typically includes the receiver itself, an antenna, an antenna coupler, a coaxial cable for the connection from the coupler to the receiver, a power cord, and miscellaneous installation hardware (e.g., yoke mount, nuts, bolts, screws). Use only the antenna supplied with the receiver or an alternate recommended by the manufacturer.

Antenna/antenna coupler (AAC) location is a prime determinant of the performance of the loran receiver, and careful thought must be given to this choice. Guidelines for location of the AAC unit on vessels are as follows:[1]

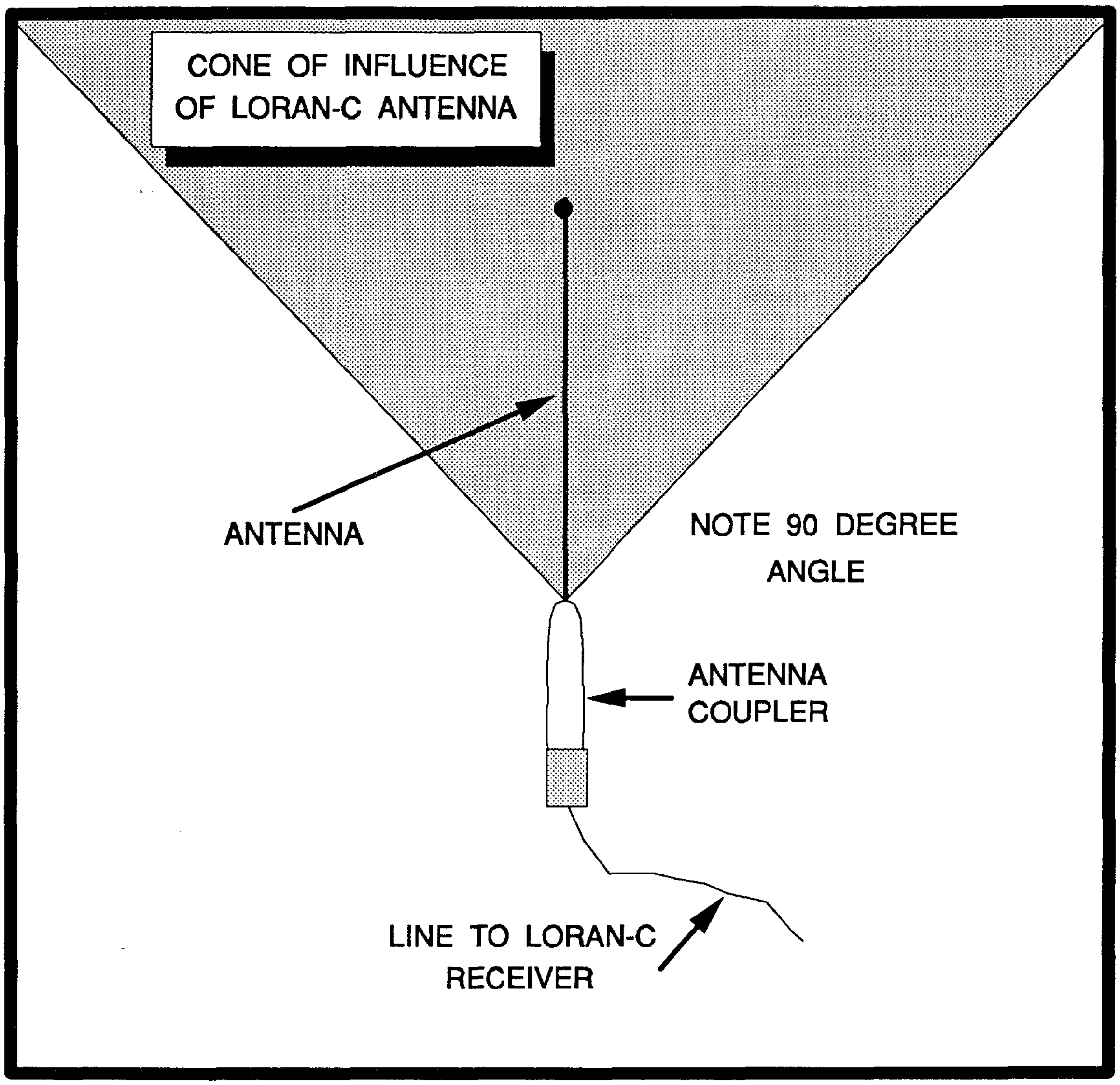
(i) The AAC should be located several feet away from the loran receiver, or other potential sources of on-board noise (see below).

(ii) The AAC should be mounted vertically, or as near to vertical as possible. In some installations (see below) it may prove advantageous to tilt the antenna *slightly.*

(iii) Unlike a VHF-FM radiotelephone, Loran-C reception is not limited by line-of-sight constraints, so the loran antenna height, *per se,* is not that important. However, masts, other metal structures (e.g., tuna towers, cargo booms, outriggers, "flopper stoppers"), shrouds, stays, and other antennas (radar, RDF, VHF-DF, VHF-FM, etc.) can interfere with loran reception and degrade the SNR. The easiest way to visualize the potential for this interference is to imagine a "cone of interference" (COI) as shown schematically in Figure VII–2.

[1]Location of aviation receivers and antennas is not discussed in this chapter.

FIGURE VII-2. "CONE OF INFLUENCE" OF LORAN-C ANTENNA. FOR BEST RESULTS, METAL OBJECTS OR OTHER ANTENNAS SHOULD REMAIN CLEAR OF THIS COI.



This COI originates at the base of the loran antenna and emanates outward and upward at a 45 degree angle to the antenna. Ideally, the loran antenna should be mounted at a location such that no "foreign object" penetrates this COI. This may not always be possible, particularly in the case where the vessel has an "antenna farm." However, the loran antenna should be located as far from the other antennas as possible; preferably at least 1 to 2 meters (3–6 ft) from other antennas. The antenna can sometimes be tilted slightly to ensure that the COI is free of metal objects.

(iv) Mounting the loran antenna on the mainmast of a sailboat or atop the flying bridge of a cabin cruiser will usually satisfy the COI constraint. However, there are often competing requirements for this location. Radar and VHF-FM, for example, are limited by line-of-sight constraints and, for this reason, require the highest possible location to ensure maximum range. On a sailboat with two masts, a practical alternative is to locate the VHF-FM antenna atop the mainmast and the loran antenna atop the mizzen mast. On sailboats with only one mast the loran antenna is often mounted on a stern rail (always *above* the stern rail). On powerboats the loran antenna should be separated as much as possible from other antennas.

(v) Coaxial cable is used to connect the antenna coupler to the receiver. Where possible, the length of this cable should be minimized. However, it can be lengthened (special connectors are available from marine electronics dealers). Likewise fiberglass extension "masts" can be used to increase the height of the loran antenna. (Ensure that these extensions are well braced.)

(vi) The coaxial cable should be routed so as to avoid contact with wires supplying power to the receiver or other equipment. As well the coaxial cable should be loosely clamped, and not in any area where standing water can be found, nor where it could be exposed to high temperatures.

One useful idea is to mount the antenna temporarily, pending completion of performance checks on the receiver (see below). The best spot may then be determined by a "trial-and-error" process of evaluating several alternative antenna locations.

The antenna and antenna coupler should be securely mounted and located so as to minimize the signal attenuation effects of masts, shrouds, stays, tuna towers, outriggers, and other antennas (e.g., radar, VHF-FM, SSB, and RDF). The loran antenna should also be located well away from the loran receiver, and other sources of on-board noise.

Receiver Location and Mounting

After (provisionally) mounting the antenna and antenna coupler, the next step is to select a location for and mount the Loran-C receiver. Generally speaking, the most important consideration in placing the receiver is to locate it at either the navigation station or the helm. If the steering and course correction features of the receiver are to be used, it is preferable to locate the receiver where it can be easily seen from the helm. There are several other factors that should be considered in selecting a location for the receiver. These include:

(i) The display of the receiver should not be located where it would be exposed to direct sunlight. Strong light makes it more difficult to read the display and, moreover, may actually damage the display.

(ii) The receiver should be located at least 1 meter (3 ft) away from the vessel's magnetic compass to minimize possible deviation errors. Additionally, the receiver should not be mounted close to radar, radios, echo sounders, and other electronic equipment capable of causing on-board interference (see below).

(iii) The receiver should be located in a vibration-free environment that will not get excessively (e.g., over 50° centigrade) hot. (It should be in a well-ventilated area.) Users who elect flush mounting should ensure that there is adequate ventilation behind the bulkhead. Small fans can be used to increase ventilation, but these may need to be filtered (see below) to suppress electrical noise. The receiver should not be placed where it will get wet (salt spray, rain, condensation, wash water). Although some receivers are more water resistant than others, salt spray does not improve the performance of any receiver.

Most receivers can be mounted in several ways, for example, flush-mounted through a bulkhead or yoke mounted from below or above. It is sometimes convenient to mount the receiver on an overhead near the windshield at the helm, but remember that windshield wiper motors cause electrical noise that can interfere with the receiver.

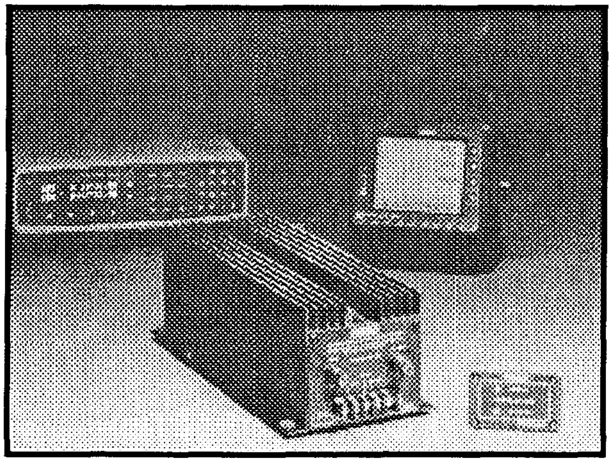
The loran receiver should be placed in a convenient, cool, vibration-free, and dry location. It should be at least 1 meter (3 ft) away from the vessel's compass and other electronic instruments.

Power

Most Loran-C receivers are designed to operate on 12-volt direct current (DC) power. (Some receiver can be powered from a 24-volt system.) It is recommended that the vessel's electrical system be wired so that the battery supplying power to the loran is different from the starter battery. The benefit of this arrangement is that the loran is less likely to crash if the vessel's engine(s) need to be restarted. Devices are commercially available that supply backup power or supplemental voltage to a loran during engine start. These units (which also contain noise filters as well as a supplemental battery) function as a buffer between the vessel's fluctuating input voltage and the loran receiver. These backup power units and voltage "conditioners" are cheap insurance against inopportune receiver crashes.

As noted in Chapter IV, loran receivers do not draw a great deal of current, so the power cables do not need to be large. many manufacturers recommend that the loran receiver be wired directly to the battery, by-passing any power "bus" or terminal strip supplying power to other devices to lower the likelihood of interference. (At a minimum, ensure that the loran is not wired through the ignition system.) Check to see if the receiver is internally fused, otherwise it is necessary to provide an external fuse of appropriate current rating. Check that the polarity of the power line is correct, otherwise the receiver may be damaged. Route the power line to the loran so that it is as far as possible from other electrical cables.

It is recommended that the loran be powered by a battery separate from that used for starting the engine, and/or that a backup power voltage conditioner unit be used.



This unit is a combination back-up power pack and voltage "conditioner" which ensures continuous and well-regulated DC power for electronic navigation systems.
(Photograph courtesy of Newmar, Inc.)

Ground

With the exception of portable units, all loran receivers need an external ground. If the vessel has a steel hull, the loran receiver can be grounded directly to the hull. For wood or fiberglass vessels, the receiver can be grounded to the engine block or the negative side of the vessel's battery (if this is grounded to the engine block). The best ground connection is to a ground plate or ground shoe that is attached to the hull. These plates are manufactured by several companies for exactly this purpose. Ground connections can be made with copper wire, but braided copper strap provides improved grounding.

Proper grounding is important to ensure high SNRs.

Preliminary Performance Evaluation

The next step in the installation procedure is to turn on the loran receiver, and measure the SNRs of the master and secondary stations. This should be done first with all other electronics (or other possible interference sources) turned off. SNRs will fluctuate, and several values can be averaged for best estimates. These "baseline" SNRs should be compared with values suggested by the manufacturer. If the vessel's dock is located near to cliffs, bridges, or other "difficult" reception areas, it may be necessary to move to a better location to obtain valid performance data.

Next, each piece of gear should be turned on one-by-one and the engine started. The resulting SNRs should be checked to determine if there is any appreciable reduction in SNR. The one-at-a-time approach enables interference sources to be identified. If SNRs remain high and within the manufacturer's recommended limits (e.g., no more than a 20% drop in SNR), the installation is complete, and provisional connections can be finished. If not, on-board sources of interference will have to be controlled.

Sources of Interference

Table VII–1 provides a list of common sources of on-board electrical interference that can affect loran reception. The list is organized into four major classes:

(i) engine and drive, including engine ignition systems, the voltage regulator, engine alternator (frequently a major noise source), and the propeller shaft (when turning),

(ii) auxiliary and related, including DC motors on water and bilge pumps, windshield wiper motors, power generators, and DC motors and blowers,

(iii) marine electronics of various types, shown in Table VII–1, and

(iv) items grouped under the rubric of "amenities," including microwave ovens, refrigerators, TV sets (another bad offender), and fluorescent lighting.

In broad terms, electrical noise may reach the loran receiver by one or both of two pathways, *radiation* or *conduction*. Radiated noise is picked up by the loran antenna, while conducted noise enters the receiver through the power cable and/or ground.

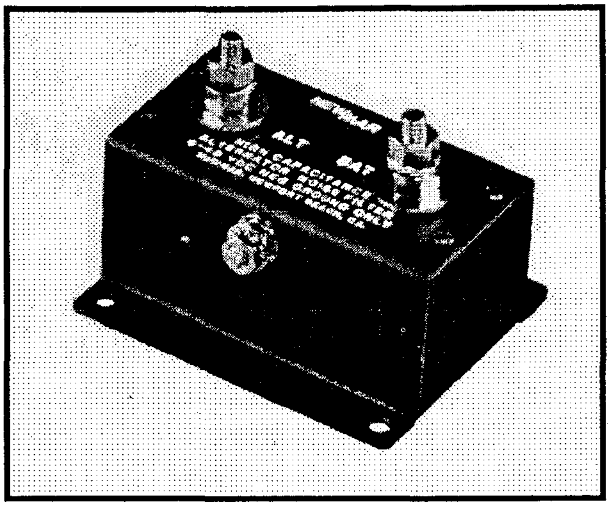
Some sources of on-board interference affect the loran principally through conduction, others through radiation, and some through both pathways. For example, the alternator (used to charge the vessel's batteries) is often a major source of radio frequency (RF) noise. Alternator diodes switch on and off with each cycle of output voltage at a rate depending upon the engine revolutions per minute (RPM). This switching causes "spikes" of energy at radio frequencies and produces the RF noise. The RF noise travels

TABLE VII-1. AN ILLUSTRATIVE LIST OF ON-BOARD SOURCES OF ELECTRICAL INTERFERENCE

Category	Item
Engine and Drive	Gasoline Engine Ignition Systems Voltage Regulator Engine Alternator Propeller Shafts (when turning)
Auxiliary & Related	DC Motors on Water and Bilge Pumps Windshield Wiper Motors Power Generator DC Motors on Blowers
Marine Electronics	Inverters on Marine Radars Other Loran Units Single-Side Band Radios When Transmitting Fish Finders Echo Sounders Autopilots Tachometers Wind Speed Indicators Water Speed Indicators
Amenities	Microwave Ovens Refrigerators TV Sets Fluorescent Lighting

NOTE: All of these sources are *capable* of interfering with loran reception. Depending upon many factors (e.g., distance from receiver and antenna) these may not produce interference in each installation. Generally, these noise sources will not produce interference unless in actual operation.

throughout the vessel along the power wiring (conductive noise) and also radiates into space (radiation noise). The Loran-C receiver picks up the RF noise, along with the loran signal—resulting in a lower SNR. As engine RPMs are increased, the rate at which these spikes are generated likewise increases. As more current is drawn by the electrical equipment in use, larger spikes result. RF noise from an alternator is generally at a maximum when the engine is started, particularly if the batteries are in a low state of charge. Although the alternator can create substantial interference problems, these can often be eliminated by the installation of a noise filter (see below) installed on the alternator.



High-capacitance alternator noise filter. This filter should be well grounded and mounted as close to the alternator as possible

(Photograph courtesy of Newmar, Inc.)

Strategies for Noise Reduction

If the performance checks indicate that noise reduction is required, there are several strategies that can be employed to mitigate or eliminate this shipboard noise. (Notch filters are designed to eliminate external noise sources, and normally should not be used to control on-board noise sources.) These are shown schematically in Figure VII–3. In brief, these include:

(i) ***Shield the noise source.*** In some cases it may be possible and desirable to shield the noise source. Shielding can be done with aluminum foil, "noise tape," and/or copper screen available from marine supply houses. Outboard motors, principally those with high-voltage capacitor discharge ignition, can sometimes be a troublesome noise source. Some manufacturers sell noise reduction kits for these engines. But, failing this, household aluminum foil (Dahl, 1986, Miller and Malone, 1988), cemented to the inside of the fiberglass engine cover and grounded, can serve as an effective shield. Plastic-cased ignition coils sometimes radiate excessively and should be replaced or shielded.

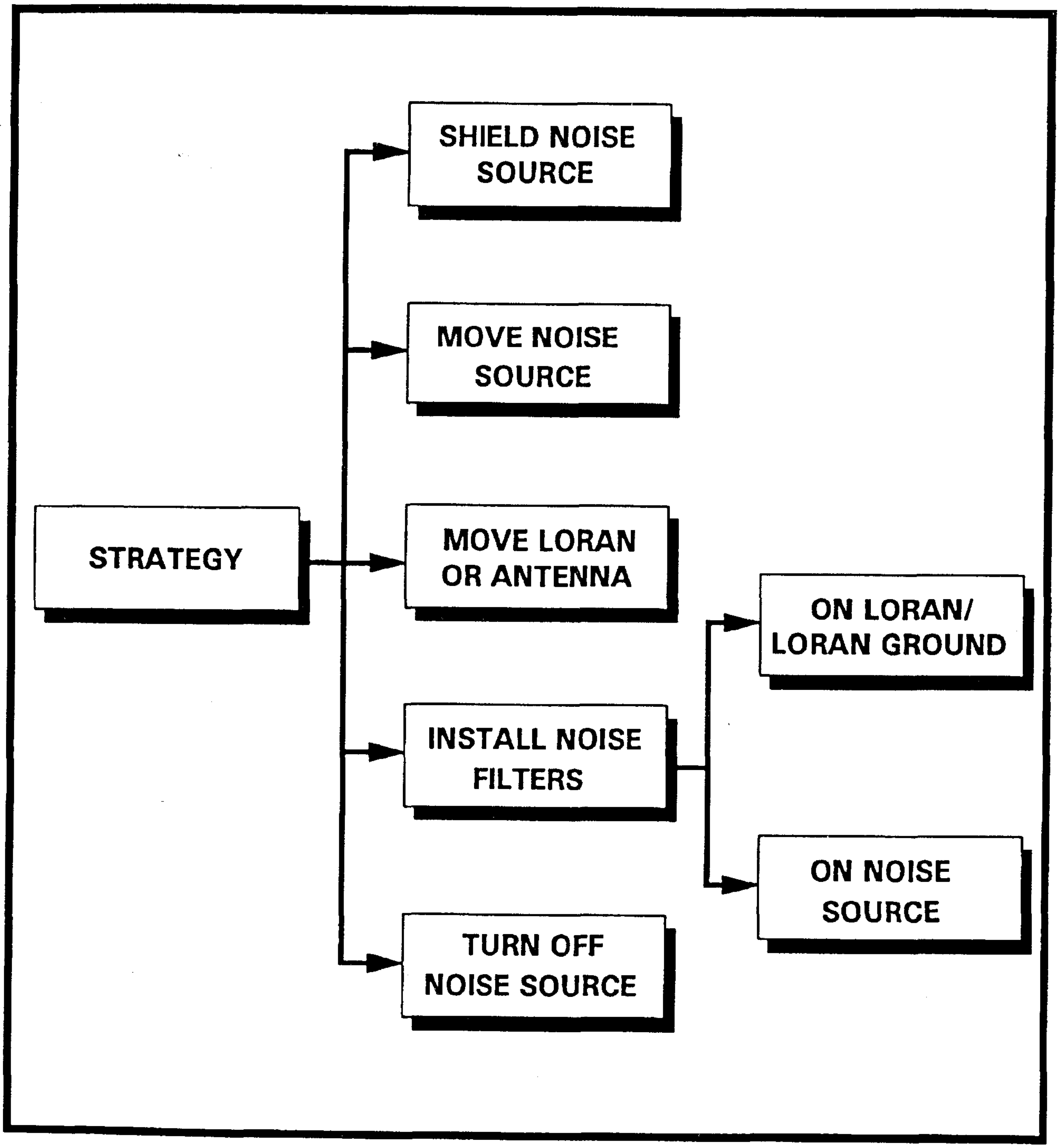
(ii) ***Increase the distance between the noise source and the loran receiver and/or AAC and the offending noise source.*** (This is why provisional mounting is recommended.) In some cases, moving the antenna or the loran receiver only a few feet will substantially reduce the noise.

(iii) ***Turn off the noise source.*** For many items in the "amenity" group, such as television sets or microwave units, a simple policy of refraining from use of the amenity while the loran is in use will be the easiest solution to an on-board noise problem.

(iv) Finally, ***electronic filters (resister capacitor circuits) can be used.*** These filters (illustrated in several of the photographs of this chapter) can be installed on the noise source directly and/or on the loran receiver and/or ground. Manufacturers produce an integrated family of these filters, each designed for a specific purpose. Noise filters can often be used to great effect on the vessel's alternator. For best results, follow the manu–facturer's recommendations. Installation directions are also provided by the manufacturer of the filters.

Generally, changing the placement of the receiver and/or converter will solve a noise problem. Failing this, filters are a good choice. For the special case of noise caused by the rotation of the propeller shaft(s), it is often sufficient (Miller and Maloney, 1988) to attach a grounded bronze "finger" or brush that wipes and maintains electrical contact with the shaft(s).

FIGURE VII-3. BASIC STRATEGIES FOR REDUCING THE EFFECTS OF ON-BOARD NOISE SOURCES ON LORAN-C



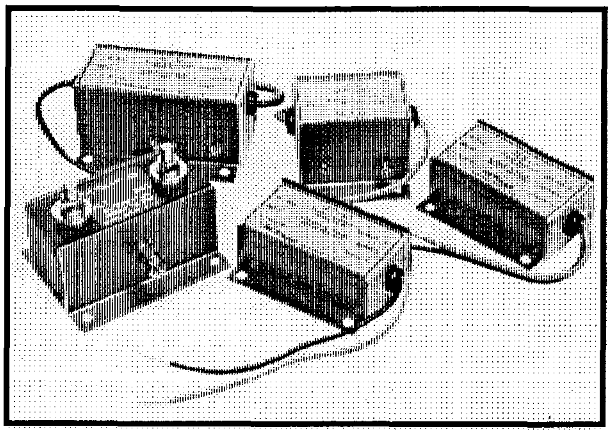
If all of the above ideas fail, either an electronics technician or the manufacturer should be consulted.

The noise-reduction steps given here will not only improve loran reception, but also will reduce noise levels in other on-board electronic equipment.

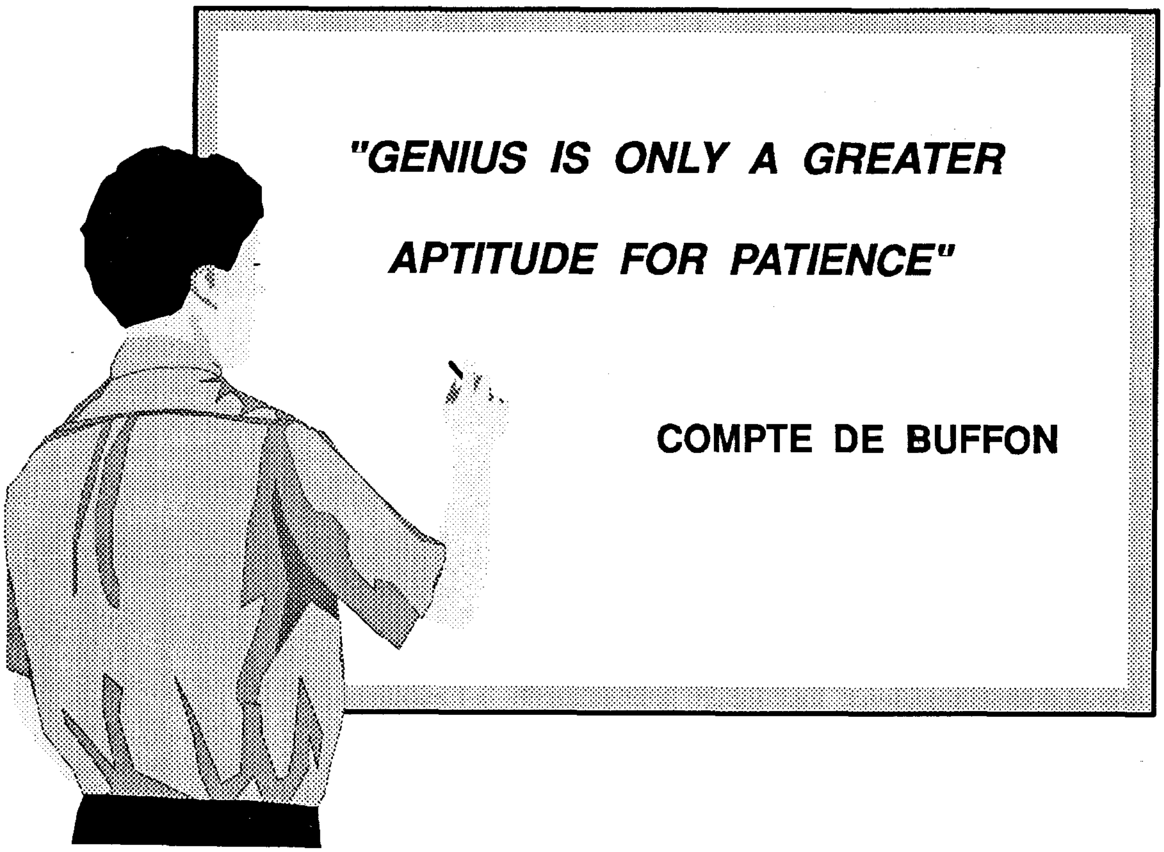
Final Performance Checks

After completing the installation and noise reduction steps, another series of performance checks should be made to verify the satisfactory operation of the loran receiver.

Finally, those who elect to install a loran receiver should remember the remark of the Compte De Buffon (1707-1788) that "Genius is only a greater aptitude for patience."



A selection of noise filters for various applications. Although these are simple from an electronic standpoint, mariners often find it convenient to purchase (rather than make) these units.
(Photograph courtesy of Newmar, Inc.)



APPENDIX A

SOURCES OF INTERFERENCE

FREQUENCY LISTINGS

Frequency kHz	Location: Country	Location: City	Location: State or Province	Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
16.625	USA	ANNAPOLIS	MD	3859N	07637W	1000.000	33.250	49.875
17.800	USA	CUTLER	ME	4439N	06717W	1000.000	35.600	53.400
17.800	USA	WASHINGTON	DC	3859N	07627W	1000.000	35.600	53.400
18.200	USA	ANNAPOLIS	MD	3859N	07627W	1000.000	36.400	54.600
18.200	USA	NEW YORK	NY	4055N	07256W	200.000	36.400	54.600
18.400	USA	ANNAPOLIS	MD	3859N	07627W	200.000	36.800	55.200
18.400	USA	BOSTON	MA	4223N	07115W	200.000	36.800	55.200
18.400	USA	NEW YORK	NY	3934N	07422W	250.000	36.800	55.200
18.500	USA	CUTLER	ME	4439N	06717W	1000.000	37.000	55.500
18.600	USA	CUTLER	ME	4439N	06717W	1000.000	37.200	55.800
18.800	USA	ANNAPOLIS	MD	3859N	07628W	200.000	37.600	56.400
18.800	USA	BOSTON	MA	4223N	07115W	200.000	37.600	56.400
18.800	USA	NEW YORK	NY	3934N	07422W	200.000	37.600	56.400
19.000	USA	WASHINGTON	DC	3859N	07627W	1000.000	38.000	57.000
20.000	USA	BOULDER	CO	4002N	10527W	40.000	40.000	60.000
20.600	MEX	MERIDA	YUC	2059N	08939W	1.000	41.200	61.800
20.600	MEX	MEXICO CITY	DF	1926N	09908W	1.000	41.200	61.800
20.600	MEX	MONTERREY	NL	2540N	10018W	1.000	41.200	61.800
21.400	USA	CUTLER	ME	4439N	06717W	1000.000	42.800	64.200
21.400	USA	WASHINGTON	DC	3845N	07651W	1000.000	42.800	64.200
21.425	USA	CUTLER	ME	4438N	06717W	1000.000	42.850	64.275
22.100	USA	ANNAPOLIS	MD	3859N	07627W	200.000	44.200	66.300
22.100	USA	BOSTON	MA	4223N	07115W	200.000	44.200	66.300
22.100	USA	NEW YORK	NY	4055N	07256W	200.000	44.200	66.300
22.100	USA	NEW YORK	NY	3934N	07422W	200.000	44.200	66.300
22.300	USA	CUTLER	ME	4439N	06717W	2000.000	44.600	66.900
22.300	USA	WASHINGTON	DC	3859N	07627W	1000.000	44.600	66.900
22.350	USA	ANNAPOLIS	MD	3859N	07627W	200.000	44.700	67.050

FREQUENCY LISTINGS (cont'd.)

Frequency kHz	Location: Country	Location: City	Location: State or Province	Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
22.350	USA	BOSTON	MA	4223N	07115W	200.000	44.700	67.050
22.350	USA	CUTLER	ME	4439N	06717W	1000.000	44.700	67.050
22.350	USA	NEW YORK	NY	3934N	07422W	250.000	44.700	67.050
24.000	USA	ANNAPOLIS	MD	3859N	07637W	1000.000	48.000	72.000
24.025	USA	ANNAPOLIS	MD	3859N	07637W	1000.000	48.050	72.075
25.300	USA	CUTLER	ME	4439N	06717W	1000.000	50.600	75.900
25.820	USA	ANNAPOLIS	MD	3859N	07627W	1000.000	51.640	77.460
25.820	USA	CUTLER	ME	4439N	06717W	1000.000	51.640	77.460
25.820	USA	NEW YORK	NY	4035N	07354W	200.000	51.640	77.460
25.820	USA	WASHINGTON	DC	3859N	07627W	1000.000	51.640	77.460
30.600	USA	NEWPORT	RI	4127N	07123W	50.000	61.200	91.800
31.850	MEX	MERIDA	YUC	2059N	08939W	1.000	63.700	95.550
31.850	MEX	MEXICO CITY	DF	1926N	09908W	1.000	63.700	95.550
31.850	MEX	MONTERREY	NL	2540N	10018W	1.000	63.700	95.550
40.000	MEX	MERIDA	YUC	2059N	08939W	1.000	80.000	120.000
40.000	MEX	MEXICO CITY	DF	1926N	09908W	1.000	80.000	120.000
40.000	MEX	MONTERREY	NL	2540N	10018W	1.000	80.000	120.000
40.750	USA	NORFOLK	VA	3648N	07630W	100.000	81.500	122.250
40.750	USA	NORFOLK	VA	3648N	07630W	50.000	81.500	122.250
40.750	USA	NORFOLK	VA	3648N	07630W	25.000	81.500	122.250
40.750	USA	WASHINGTON	DC	3859N	07637W	5.000	81.500	122.250
40.750	CAN	HALIFAX	NS	4440N	06336W	20.000	91.500	137.250
47.450	USA	NORFOLK	VA	3656N	07618W	50.000	94.900	142.350
58.000	MEX	MERIDA	YUC	2059N	08939W	1.000	116.000	174.000
58.000	MEX	MEXICO CITY	DF	1926N	09908W	1.000	116.000	174.000
58.200	MEX	MONTERREY	NL	2540N	10018W	1.000	116.400	174.600
60.000	USA	BOULDER	CO	3959N	10515W	3.000	120.000	180.000
64.200	USA	NORFOLK	VA	3648N	07630W	50.000	128.400	192.600
64.200	USA	NORFOLK	VA	3648N	07630W	100.000	128.400	192.600
64.200	USA	WASHINGTON	DC	3859N	07628W	50.000	128.400	192.600
64.200	USA	WASHINGTON	DC	3859N	07628W	200.000	128.400	192.600
70.000	MEX	MERIDA	YUC	2059N	08939W	1.000	140.000	210.000
70.000	MEX	MEXICO CITY	DF	1926N	09908W	1.000	140.000	210.000
70.000	MEX	MONTERREY	NL	2540N	10018W	1.000	140.000	210.000
70.387	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	140.774	211.161
70.387	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	140.774	211.161
70.387	CAN	S LAWRENCE	NFLD	4655N	05523W	1.200	140.774	211.161
70.387	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	140.774	211.161
70.983	CAN	ANTIGONISH	NS	4544N	06154W	1.200	141.966	212.949
70.983	CAN	GRINDSTONE	QUE	4721N	06156W	1.200	141.966	212.949

FREQUENCY LISTINGS (cont'd.)

Frequency kHz	Location: Country	City	State or Province	Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
70.930	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	141.860	212.790
71.142	CAN	CHESTER	NS	4434N	06416W	2.400	142.284	213.426
71.142	CAN	ECUM SECUM	NS	4458N	06209W	2.400	142.284	222.426
71.433	USA	ELGIN AFB	FL	3029N	08623W	1.200	142.866	214.299
71.433	USA	ELBA	AL	3125N	08610W	1.200	142.866	214.299
71.433	USA	TYNDALL	FL	3001N	08538W	1.200	142.866	214.299
71.437	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	142.874	214.311
71.437	CAN	PORT MENIER	QUE	4951N	06427W	1.200	142.874	214.311
71.437	CAN	SEPT ILES	QUE	5009N	06637W	1.200	142.874	214.311
71.437	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	142.874	214.311
73.600	CAN	HALIFAX	NS	4440N	06336W	250.000	147.200	220.800
77.150	USA	NORFOLK	VA	3648N	07630W	50.000	154.300	231.450
77.150	USA	NORFOLK	VA	3649N	07630W	100.000	154.300	231.450
79.000	MEX	MERIDA	YUC	2059N	08939W	1.000	158.000	237.000
79.000	MEX	MEXICO CITY	DF	1926N	09908W	1.000	158.000	237.000
79.000	MEX	MONTERREY	NL	2540N	10018W	1.000	158.000	237.000
84.465	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	168.930	253.395
84.465	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	168.930	253.395
84.465	CAN	S LAWRENCE	NFLD	4655N	05523W	1.200	168.930	253.395
84.465	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	168.930	253.395
84.730	CAN	POINT HILL	QUE	5713N	07859W	0.900	169.460	254.190
85.180	CAN	ANTIGONISH	NS	4544N	06154W	1.200	170.360	255.540
85.180	CAN	GRINDSTONE	QUE	4721N	06156W	1.200	170.360	255.540
85.180	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	170.360	255.540
85.370	CAN	CHESTER	NS	4434N	06416W	2.400	170.740	256.110
85.725	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	171.450	257.175
85.725	CAN	PORT MENIER	QUE	4951N	06427W	1.200	171.450	257.175
85.725	CAN	SEPT ILES	QUE	5009N	06637W	1.200	171.450	257.175
85.725	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	171.450	257.175
88.000	USA	WASHINGTON	DC	3859N	07628W	50.000	176.000	264.000
89.000	USA	WASHINGTON	DC	3859N	07628W	50.000	176.000	264.000
102.000	USA	WASHINGTON	DC	3859N	07628W	50.000	204.000	306.000
109.700	USA	CHARLESTON	SC	3254N	08005W	2.000	219.400	329.100
109.700	USA	NEWPORT	RI	4129N	07115W	2.000	219.400	329.100
109.700	USA	NORFOLK	VA	3657N	07617W	2.000	219.400	329.100
109.700	USA	WASHINGTON	DC	3859N	07628W	10.000	219.400	329.100
110.050	USA	NEW ORLEANS	LA	3001N	09004W	1.000	220.100	330.150
110.804	CAN	BLACK POINT	NFLD	4732N	05239W	0.450	221.608	332.412
110.804	CAN	ST ANTHONY	NFLD	5121N	05534W	0.450	221.608	332.412
111.100	USA	NORFOLK	VA	3657N	07616W	2.000	222.200	333.300

FREQUENCY LISTINGS (cont'd.)

Frequency kHz	Location			Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
	Country	City	State or Province					
112.150	CAN	SHILO	MAN	4952N	09932W	3.000	224.300	336.450
112.620	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	225.240	337.860
112.620	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	225.240	337.860
112.620	CAN	ST LAWRENCE	NFLD	4655N	05523W	1.200	225.240	337.860
112.620	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	225.240	337.860
112.850	USA	AMAGANSETT	NY	4100N	07203W	15.000	225.700	338.550
112.973	CAN	TENT ISLAND	QUE	5438N	07943W	0.900	225.946	338.919
113.200	CAN	OTTAWA	ONT	4456N	07608W	3.000	226.400	339.600
113.573	CAN	ANTIGONISH	NS	4544N	06154W	1.200	227.146	370.719
113.573	CAN	GRINDSTONE	QUE	4721N	06156W	1.200	227.146	340.719
113.573	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	227.146	340.719
113.827	CAN	ALMA	NB	4539N	06456W	2.400	227.654	341.481
113.827	CAN	ECUM SECUM	NS	4458N	06209W	2.400	227.654	341.481
113.827	CAN	JORDAN BAY	NS	4342N	06514W	2.400	227.654	341.481
114.300	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	228.600	342.900
114.300	CAN	PORT MENIER	QUE	4951N	06427W	1.200	228.600	342.900
114.300	CAN	SEPT ILES	QUE	5009N	06637W	1.200	228.600	342.900
114.300	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	228.600	342.900
114.950	USA	ANNAPOLIS	MD	3859N	07627W	10.000	229.900	344.850
114.950	USA	ANNAPOLIS	MD	3859N	07627W	20.000	229.900	344.850
115.435	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	230.870	346.305
115.435	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	230.870	346.305
115.435	CAN	ST LAWRENCE	NFLD	4566N	05523W	1.200	230.870	346.305
115.435	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	230.870	346.305
115.490	CAN	MABERLY	NFLD	4837N	05301W	0.900	230.980	346.470
115.490	CAN	QUIRPON	NFLD	5135N	05526W	0.900	230.980	346.470
116.412	CAN	ANTIGONISH	NS	4544N	06154W	1.200	232.824	349.236
116.412	CAN	GRINDSTONE	QUE	4712N	06156W	1.200	232.824	349.236
116.412	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	232.824	349.236
117.157	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	234.314	351.471
117.157	CAN	PORT MENIER	QUE	4951N	06427W	1.200	234.314	351.471
117.157	CAN	SEPT ILES	QUE	5009N	06637W	1.200	234.314	351.471
117.157	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	234.314	351.471
119.150	CAN	SHILO	MAN	4952N	09932W	3.000	238.300	357.450
119.150	USA	KEY WEST	FL	2434N	08148W	2.000	238.300	357.450
119.150	USA	NORFOLK	VA	3656N	07618W	2.000	238.300	357.450
119.150	USA	NORFOLK	VA	3656N	07618W	4.000	238.300	357.450
119.150	USA	NEWPORT	RI	4129N	07115W	2.000	238.300	357.450
119.850	USA	NORFOLK	VA	3657N	07617W	2.000	239.700	359.550
119.850	USA	WASHINGTON	DC	3859N	07628W	2.000	239.700	359.550

FREQUENCY LISTINGS (cont'd.)

Frequency kHz	Location			Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
	Country	City	State or Province					
121.950	USA	WASHINGTON	DC	3859N	07628W	200.000	243.900	365.850
122.300	CAN	CP BORDEN	ONT	4226N	07958W	3.000	244.600	366.900
122.500	CAN	HALIFAX	NS	4458N	06359W	10.000	245.000	367.500
124.050	USA	TUCKERTON	NJ	3938N	07418W	6.000	248.100	372.150
124.654	CAN	BLACK POINT	NFLD	4732N	05239W	0.450	249.308	373.962
124.654	CAN	ST ANTHONY	NFLD	5121N	05534W	0.450	249.308	373.962
124.654	CAN	SHASAMU	ONT	5552N	08647W	0.900	249.308	373.962
126.698	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	253.396	380.094
126.698	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	253.396	380.094
126.698	CAN	S LAWRENCE	NFLD	4655N	05523W	1.200	253.396	380.094
126.698	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	253.396	380.094
127.095	CAN	C JONES	QUE	5149N	07906W	0.900	254.190	381.285
127.200	CAN	MONTREAL	QUE	4527N	07347W	10.000	254.400	381.600
127.770	CAN	ANTIGONISH	NS	4544N	06154W	1.200	255.540	383.310
127.770	CAN	GRINDSTONE	QUE	4721N	06156W	1.200	255.540	383.310
127.770	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	255.540	383.310
128.055	CAN	ALMA	NB	4539N	06456W	2.400	256.110	384.165
128.055	CAN	ECUM SECUM	NS	4458N	06209W	2.400	256.110	384.165
128.055	CAN	JORDAN BAY	NS	4342N	06514W	2.400	256.110	384.165
128.250	USA	NEW LONDON	CT	4124N	07205W	1.000	256.500	384.750
128.250	USA	NEW YORK	NY	4035N	07354W	1.000	256.500	384.750
128.250	USA	NEW YORK	NY	4124N	07354W	1.000	256.500	384.750
128.250	USA	NEWPORT	RI	4127N	07123W	2.000	256.500	384.750
128.250	USA	NORFOLK	VA	3633N	07616W	2.000	256.500	384.750
128.300	CAN	DEBERT	NS	4525N	06334W	3.000	256.600	384.900
128.587	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	257.174	385.761
128.587	CAN	PORT MENIER	QUE	4951N	06427W	1.200	257.174	385.761
128.587	CAN	SEPT ILES	QUE	5009N	06637W	1.200	257.174	385.761
128.587	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	257.174	385.761
129.500	USA	NEWPORT	RI	4127N	07123W	50.000	259.000	388.500
129.500	USA	NEWPORT	RI	4127N	07123W	25.000	259.000	388.500
129.926	CAN	MABERLY	NFLD	4837N	05301W	0.900	259.852	389.778
129.926	CAN	QUIRPON	NFLD	5135N	05526W	0.900	259.852	389.778
130.350	USA	SO CHATHAM	MA	4140N	07002W	15.000	260.700	391.050
130.250	USA	SO CHATHAM	MA	4140N	07002W	7.500	260.500	390.750
131.400	CAN	VALCARTIER	QUE	4651N	07150W	3.000	262.800	394.200
131.750	USA	KEY WEST	FL	2434N	08148W	1.000	263.500	395.250
131.050	USA	WASHINGTON	DC	3859N	07627W	25.000	262.100	393.150
131.050	USA	WASHINGTON	DC	3859N	07627W	50.000	262.100	393.150
132.100	USA	NEW YORK	NY	4049N	07315W	2.000	264.200	396.300

FREQUENCY LISTINGS (cont'd.)

Frequency kHz	Location			Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
	Country	City	State or Province					
133.150	CAN	HALIFAX	NS	4525N	06334W	25.000	266.300	399.450
133.850	CAN	SHILO	MAN	4952N	09933W	10.000	267.700	401.550
134.900	USA	ANNAPOLIS	MD	3859N	07627W	100.000	269.800	404.700
134.950	USA	ANNAPOLIS	MD	3859N	07627W	50.000	269.800	404.700
134.950	USA	ANNAPOLIS	MD	3859N	07627W	25.000	269.800	404.700
136.300	CAN	VALCARTIER	QUE	4651N	07150W	3.000	272.600	408.900
137.000	USA	TUCKERTON	NJ	3938N	07418W	20.000	274.000	411.000
139.100	USA	BOSTON	MA	4223N	07059W	3.000	278.200	417.300
139.100	USA	CHARLESTON	SC	3254N	08005W	3.000	278.200	417.300
139.100	USA	GREAT LAKES	IL	4222N	08750W	3.000	278.200	417.300
139.100	USA	JACKSONVILLE	FL	3014N	08140W	2.000	278.200	417.300
139.100	USA	KEY WEST	FL	2434N	08148W	2.000	278.200	417.300
139.100	USA	MIAMI	FL	2553N	08015W	3.000	278.200	417.300
139.100	USA	NEW LONDON	CT	4124N	07205W	2.000	278.200	417.300
139.100	USA	NEW ORLEANS	LA	3001N	09004W	3.000	278.200	417.300
139.100	USA	NEW YORK	NY	4035N	07354W	3.000	278.200	417.300
139.100	USA	NEWPORT	RI	4129N	07115W	2.000	278.200	417.300
139.100	USA	NORFOLK	VA	3657N	07617W	3.000	278.200	417.300
139.100	USA	PENSACOLA	FL	3021N	08716W	2.000	278.200	417.300
139.100	USA	PHILADELPHIA	PA	3953N	07510W	3.000	278.200	417.300
139.100	USA	WASHINGTON	DC	3859N	07628W	2.000	278.200	417.300
139.800	USA	NEWPORT	RI	4127N	07123W	20.000	279.600	419.400
139.800	USA	NORFOLK	VA	3640N	07630W	100.000	279.600	419.400
139.800	USA	NORFOLK	VA	3640N	07630W	50.000	279.600	419.400
139.800	USA	NORFOLK	VA	3640N	07630W	1.000	279.600	419.400
140.850	USA	NEWPORT	RI	4127N	07123W	15.000	281.700	422.550
140.850	USA	NEWPORT	RI	4127N	07123W	30.000	281.700	422.550
142.250	USA	WASHINGTON	DC	3859N	07627W	100.000	284.500	426.750
142.250	USA	WASHINGTON	DC	3859N	07627W	50.000	284.500	426.750
142.250	USA	WASHINGTON	DC	3859N	07627W	25.000	284.500	426.750
143.000	USA	SO CHATHAM	MA	4140N	07002W	20.000	286.000	429.000
146.100	CAN	GOOSE BAY	NFLD	5317N	06018W	10.000	292.200	438.300
146.100	USA	NEWPORT	RI	4127N	07123W	50.000	292.200	438.300
146.100	USA	NEWPORT	RI	4127N	07123W	100.000	292.200	438.300
146.800	USA	TUCKERTON	NJ	3938N	07418W	6.000	293.600	440.400
147.500	USA	SO CHATHAM	MA	4140N	07002W	15.000	295.000	442.500
147.500	USA	SO CHATHAM	MA	4140N	07002W	7.500	295.000	442.500
148.200	USA	CHARLESTON	SC	3254N	08005W	1.000	296.400	444.600
148.200	USA	NORFOLK	VA	3657N	07617W	55.000	296.400	444.600
148.550	CAN	OTTAWA	ONT	4456N	07608W	3.000	297.100	445.650
149.250	USA	NEW YORK	NY	4041N	07403W	5.000	298.500	447.750

ALPHABETICAL LISTINGS

Frequency kHz	Location: Country	Location: City	Location: State or Province	Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
113.827	CAN	ALMA	NB	4539N	06456W	2.400	227.654	341.481
128.055	CAN	ALMA	NB	4539N	06456W	2.400	256.110	384.165
70.983	CAN	ANTIGONISH	NS	4544N	06154W	1.200	141.966	212.949
85.180	CAN	ANTIGONISH	NS	4544N	06154W	1.200	170.360	255.540
113.573	CAN	ANTIGONISH	NS	4544N	06154W	1.200	227.146	370.719
116.412	CAN	ANTIGONISH	NS	4544N	06154W	1.200	232.824	349.236
127.770	CAN	ANTIGONISH	NS	4544N	06154W	1.200	255.540	383.310
110.804	CAN	BLACK POINT	NFLD	4732N	05239W	0.450	221.608	332.412
124.654	CAN	BLACK POINT	NFLD	4732N	05239W	0.450	249.308	373.962
122.300	CAN	CP BORDEN	ONT	4226N	07958W	3.000	244.600	366.900
127.095	CAN	C JONES	QUE	5149N	07906W	0.900	254.190	381.285
71.142	CAN	CHESTER	NS	4434N	06416W	2.400	142.284	213.426
85.370	CAN	CHESTER	NS	4434N	06416W	2.400	170.740	256.110
70.387	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	140.774	211.161
84.465	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	168.930	253.395
112.620	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	225.240	337.860
115.435	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	230.870	346.305
126.698	CAN	COMFORT COVE	NFLD	4921N	05452W	1.200	253.396	380.094
128.300	CAN	DEBERT	NS	4525N	06334W	3.000	256.600	384.900
71.142	CAN	ECUM SECUM	NS	4458N	06209W	2.400	142.284	222.426
113.827	CAN	ECUM SECUM	NS	4458N	06209W	2.400	227.654	341.481
128.055	CAN	ECUM SECUM	NS	4458N	06209W	2.400	256.110	384.165
146.100	CAN	GOOSE BAY	NFLD	5317N	06018W	10.000	292.200	438.300
70.983	CAN	GRINDSTONE	QUE	4721N	06156W	1.200	141.966	212.949
85.180	CAN	GRINDSTONE	QUE	4721N	06156W	1.200	170.360	255.540
113.573	CAN	GRINDSTONE	QUE	4721N	06156W	1.200	227.146	340.719
116.412	CAN	GRINDSTONE	QUE	4712N	06156W	1.200	232.824	349.236
127.770	CAN	GRINDSTONE	QUE	4721N	06156W	1.200	255.540	383.310
40.750	CAN	HALIFAX	NS	4440N	06336W	20.000	91.500	137.250
73.600	CAN	HALIFAX	NS	4440N	06336W	250.000	147.200	220.800
122.500	CAN	HALIFAX	NS	4458N	06359W	10.000	245.000	367.500
133.150	CAN	HALIFAX	NS	4525N	06334W	25.000	266.300	399.450
113.827	CAN	JORDAN BAY	NS	4342N	06514W	2.400	227.654	341.481
128.055	CAN	JORDAN BAY	NS	4342N	06514W	2.400	256.110	384.165
115.490	CAN	MABERLY	NFLD	4837N	05301W	0.900	230.980	346.470
129.926	CAN	MABERLY	NFLD	4837N	05301W	0.900	259.852	389.778

ALPHABETICAL LISTINGS (cont'd.)

Frequency kHz	Location: Country	Location: City	Location: State or Province	Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
127.200	CAN	MONTREAL	QUE	4527N	07347W	10.000	254.400	381.600
71.437	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	142.874	214.311
85.725	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	171.450	257.175
114.300	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	228.600	342.900
117.157	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	234.314	351.471
128.587	CAN	NATASHQUAN	QUE	5011N	06149W	1.200	257.174	385.761
113.200	CAN	OTTAWA	ONT	4456N	07608W	3.000	226.400	339.600
148.550	CAN	OTTAWA	ONT	4456N	07608W	3.000	297.100	445.650
70.930	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	141.860	212.790
85.180	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	170.360	255.540
113.573	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	227.146	340.719
116.412	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	232.824	349.236
127.770	CAN	PORT BASQUES	NFLD	4738N	05914W	1.200	255.540	383.310
70.387	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	140.774	211.161
84.465	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	168.930	253.395
112.620	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	225.240	337.860
115.435	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	230.870	346.305
126.698	CAN	PT BLANDFRD	NFLD	4821N	05410W	1.200	253.396	380.094
84.730	CAN	POINT HILL	QUE	5713N	07859W	0.900	169.460	254.190
71.437	CAN	PORT MENIER	QUE	4951N	06427W	1.200	142.874	214.311
85.725	CAN	PORT MENIER	QUE	4951N	06427W	1.200	171.450	257.175
114.300	CAN	PORT MENIER	QUE	4951N	06427W	1.200	228.600	342.900
117.157	CAN	PORT MENIER	QUE	4951N	06427W	1.200	234.314	351.471
128.587	CAN	PORT MENIER	QUE	4951N	06427W	1.200	257.174	385.761
115.490	CAN	QUIRPON	NFLD	5135N	05526W	0.900	230.980	346.470
129.926	CAN	QUIRPON	NFLD	5135N	05526W	0.900	259.852	389.778
110.804	CAN	ST ANTHONY	NFLD	5121N	05534W	0.450	221.608	332.412
124.654	CAN	ST ANTHONY	NFLD	5121N	05534W	0.450	249.308	373.962
70.387	CAN	ST LAWRENCE	NFLD	4655N	05523W	1.200	140.774	211.161
84.465	CAN	ST LAWRENCE	NFLD	4655N	05523W	1.200	168.930	253.395
112.620	CAN	ST LAWRENCE	NFLD	4655N	05523W	1.200	225.240	337.860
115.435	CAN	ST LAWRENCE	NFLD	4566N	05523W	1.200	230.870	346.305
126.698	CAN	ST LAWRENCE	NFLD	4655N	05523W	1.200	253.396	380.094
71.437	CAN	SEPT ILES	QUE	5009N	06637W	1.200	142.874	214.311
85.725	CAN	SEPT ILES	QUE	5009N	06637W	1.200	171.450	257.175
114.300	CAN	SEPT ILES	QUE	5009N	06637W	1.200	228.600	342.900
117.157	CAN	SEPT ILES	QUE	5009N	06637W	1.200	234.314	351.471
128.587	CAN	SEPT ILES	QUE	5009N	06637W	1.200	257.174	385.761
124.654	CAN	SHASAMU	ONT	5552N	08647W	0.900	249.308	373.962

ALPHABETICAL LISTINGS (cont'd.)

Frequency kHz	Location			Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
	Country	City	State or Province					
112.150	CAN	SHILO	MAN	4952N	09932W	3.000	224.300	336.450
119.150	CAN	SHILO	MAN	4952N	09932W	3.000	238.300	357.450
133.850	CAN	SHILO	MAN	4952N	09933W	10.000	267.700	401.550
71.437	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	142.874	214.311
85.725	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	171.450	257.175
114.300	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	228.600	342.900
117.157	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	234.314	351.471
128.587	CAN	SHIPPEGAN I	NB	4751N	06441W	1.200	257.174	385.761
70.387	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	140.774	211.161
84.465	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	168.930	253.395
112.620	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	225.240	337.860
115.435	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	230.870	346.305
126.698	CAN	SHOE COVE	NFLD	4744N	05244W	1.200	253.396	380.094
112.973	CAN	TENT ISLAND	QUE	5438N	07943W	0.900	225.946	338.919
131.400	CAN	VALCARTIER	QUE	4651N	07150W	3.000	262.800	394.200
136.300	CAN	VALCARTIER	QUE	4651N	07150W	3.000	272.600	408.900
20.600	MEX	MERIDA	YUC	2059N	08939W	1.000	41.200	61.800
31.850	MEX	MERIDA	YUC	2059N	08939W	1.000	63.700	95.550
40.000	MEX	MERIDA	YUC	2059N	08939W	1.000	80.000	120.000
58.000	MEX	MERIDA	YUC	2059N	08939W	1.000	116.000	174.000
70.000	MEX	MERIDA	YUC	2059N	08939W	1.000	140.000	210.000
79.000	MEX	MERIDA	YUC	2059N	08939W	1.000	158.000	237.000
20.600	MEX	MEXICO CITY	DF	1926N	09908W	1.000	41.200	61.800
31.850	MEX	MEXICO CITY	DF	1926N	09908W	1.000	63.700	95.550
40.000	MEX	MEXICO CITY	DF	1926N	09908W	1.000	80.000	120.000
58.000	MEX	MEXICO CITY	DF	1926N	09908W	1.000	116.000	174.000
70.000	MEX	MEXICO CITY	DF	1926N	09908W	1.000	140.000	210.000
79.000	MEX	MEXICO CITY	DF	1926N	09908W	1.000	158.000	237.000
20.600	MEX	MONTERREY	NL	2540N	10018W	1.000	41.200	61.800
31.850	MEX	MONTERREY	NL	2540N	10018W	1.000	63.700	95.550
40.000	MEX	MONTERREY	NL	2540N	10018W	1.000	80.000	120.000
58.200	MEX	MONTERREY	NL	2540N	10018W	1.000	116.400	174.600
70.000	MEX	MONTERREY	NL	2540N	10018W	1.000	140.000	210.000
79.000	MEX	MONTERREY	NL	2540N	10018W	1.000	158.000	237.000
112.850	USA	AMAGANSETT	NY	4100N	07203W	15.000	225.700	338.550
16.625	USA	ANNAPOLIS	MD	3859N	07637W	1000.000	33.250	49.875
18.200	USA	ANNAPOLIS	MD	3859N	07627W	1000.000	36.400	54.600
18.400	USA	ANNAPOLIS	MD	3859N	07627W	200.000	36.800	55.200
18.800	USA	ANNAPOLIS	MD	3859N	07628W	200.000	37.600	56.400
22.100	USA	ANNAPOLIS	MD	3859N	07627W	200.000	44.200	66.300
22.350	USA	ANNAPOLIS	MD	3859N	07627W	200.000	44.700	67.050

ALPHABETICAL LISTINGS (cont'd.)

Frequency kHz	Location: Country	City	State or Province	Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
24.000	USA	ANNAPOLIS	MD	3859N	07637W	1000.000	48.000	72.000
24.025	USA	ANNAPOLIS	MD	3859N	07637W	1000.000	48.050	72.075
25.820	USA	ANNAPOLIS	MD	3859N	07627W	1000.000	51.640	77.460
114.950	USA	ANNAPOLIS	MD	3859N	07627W	10.000	229.900	344.850
114.950	USA	ANNAPOLIS	MD	3859N	07627W	20.000	229.900	344.850
134.900	USA	ANNAPOLIS	MD	3859N	07627W	100.000	269.800	404.700
134.950	USA	ANNAPOLIS	MD	3859N	07627W	50.000	269.800	404.700
134.950	USA	ANNAPOLIS	MD	3859N	07627W	25.000	269.800	404.700
18.400	USA	BOSTON	MA	4223N	07115W	200.000	36.800	55.200
18.800	USA	BOSTON	MA	4223N	07115W	200.000	37.600	56.400
22.100	USA	BOSTON	MA	4223N	07115W	200.000	44.200	66.300
22.350	USA	BOSTON	MA	4223N	07115W	200.000	44.700	67.050
139.100	USA	BOSTON	MA	4223N	07059W	3.000	278.200	417.300
20.000	USA	BOULDER	CO	4002N	010527W	40.000	40.000	60.000
60.000	USA	BOULDER	CO	3959N	010515W	3.000	120.000	180.000
109.700	USA	CHARLESTON	SC	3254N	08005W	2.000	219.400	329.100
139.100	USA	CHARLESTON	SC	3254N	08005W	3.000	278.200	417.300
148.200	USA	CHARLESTON	SC	3254N	08005W	1.000	296.400	444.600
17.800	USA	CUTLER	ME	4439N	06717W	1000.000	35.600	53.400
18.500	USA	CUTLER	ME	4439N	06717W	1000.000	37.000	55.500
18.600	USA	CUTLER	ME	4439N	06717W	1000.000	37.200	55.800
21.400	USA	CUTLER	ME	4439N	06717W	1000.000	42.800	64.200
21.425	USA	CUTLER	ME	4438N	06717W	1000.000	42.850	64.275
22.300	USA	CUTLER	ME	4439N	06717W	2000.000	44.600	66.900
22.350	USA	CUTLER	ME	4439N	06717W	1000.000	44.700	67.050
25.300	USA	CUTLER	ME	4439N	06717W	1000.000	50.600	75.900
25.820	USA	CUTLER	ME	4439N	06717W	1000.000	51.640	77.460
71.433	USA	ELBA	AL	3125N	08610W	1.200	142.866	214.299
71.433	USA	ELGIN AFB	FL	3029N	08623W	1.200	142.866	214.299
139.100	USA	GREAT LAKES	IL	4222N	08750W	3.000	278.200	417.300
139.100	USA	JACKSONVILLE	FL	3014N	08140W	2.000	278.200	417.300
119.150	USA	KEY WEST	FL	2434N	08148W	2.000	238.300	357.450
131.750	USA	KEY WEST	FL	2434N	08148W	1.000	263.500	395.250
139.100	USA	KEY WEST	FL	2434N	08148W	2.000	278.200	417.300
139.100	USA	MIAMI	FL	2553N	08015W	3.000	278.200	417.300
128.250	USA	NEW LONDON	CT	4124N	07205W	1.000	256.500	384.750
139.100	USA	NEW LONDON	CT	4124N	07205W	2.000	278.200	417.300
110.050	USA	NEW ORLEANS	LA	3001N	09004W	1.000	220.100	330.150
139.100	USA	NEW ORLEANS	LA	3001N	09004W	3.000	278.200	417.300

ALPHABETICAL LISTINGS (cont'd.)

Frequency kHz	Location			Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
	Country	City	State or Province					
18.200	USA	NEW YORK	NY	4055N	07256W	200.000	36.400	54.600
18.400	USA	NEW YORK	NY	3934N	07422W	250.000	36.800	55.200
18.800	USA	NEW YORK	NY	3934N	07422W	200.000	37.600	56.400
22.100	USA	NEW YORK	NY	4055N	07256W	200.000	44.200	66.300
22.100	USA	NEW YORK	NY	3934N	07422W	200.000	44.200	66.300
22.350	USA	NEW YORK	NY	3934N	07422W	250.000	44.700	67.050
25.820	USA	NEW YORK	NY	4035N	07354W	200.000	51.640	77.460
128.250	USA	NEW YORK	NY	4035N	07354W	1.000	256.500	384.750
128.250	USA	NEW YORK	NY	4124N	07354W	1.000	256.500	384.750
132.100	USA	NEW YORK	NY	4049N	07315W	2.000	264.200	396.300
139.100	USA	NEW YORK	NY	4035N	07354W	3.000	278.200	417.300
149.250	USA	NEW YORK	NY	4041N	07403W	5.000	298.500	447.750
30.600	USA	NEWPORT	RI	4127N	07123W	50.000	61.200	91.800
109.700	USA	NEWPORT	RI	4129N	07115W	2.000	219.400	329.100
119.150	USA	NEWPORT	RI	4129N	07115W	2.000	238.300	357.450
128.250	USA	NEWPORT	RI	4127N	07123W	2.000	256.500	384.750
129.500	USA	NEWPORT	RI	4127N	07123W	50.000	259.000	388.500
129.500	USA	NEWPORT	RI	4127N	07123W	25.000	259.000	388.500
139.100	USA	NEWPORT	RI	4129N	07115W	2.000	278.200	417.300
139.800	USA	NEWPORT	RI	4127N	07123W	20.000	279.600	419.400
140.850	USA	NEWPORT	RI	4127N	07123W	15.000	281.700	422.550
140.850	USA	NEWPORT	RI	4127N	07123W	30.000	281.700	422.550
146.100	USA	NEWPORT	RI	4127N	07123W	50.000	292.200	438.300
146.100	USA	NEWPORT	RI	4127N	07123W	100.000	292.200	438.300
40.750	USA	NORFOLK	VA	3648N	07630W	100.000	81.500	122.250
40.750	USA	NORFOLK	VA	3648N	07630W	50.000	81.500	122.250
40.750	USA	NORFOLK	VA	3648N	07630W	25.000	81.500	122.250
47.450	USA	NORFOLK	VA	3656N	07618W	50.000	94.900	142.350
64.200	USA	NORFOLK	VA	3648N	07630W	50.000	128.400	192.600
64.200	USA	NORFOLK	VA	3648N	07630W	100.000	128.400	192.600
77.150	USA	NORFOLK	VA	3648N	07630W	50.000	154.300	231.450
77.150	USA	NORFOLK	VA	3649N	07630W	100.000	154.300	231.450
109.700	USA	NORFOLK	VA	3657N	07617W	2.000	219.400	329.100
111.100	USA	NORFOLK	VA	3657N	07616W	2.000	222.200	333.300
119.150	USA	NORFOLK	VA	3656N	07618W	2.000	238.300	357.450
119.150	USA	NORFOLK	VA	3656N	07618W	4.000	238.300	357.450
119.850	USA	NORFOLK	VA	3657N	07617W	2.000	239.700	359.550
128.250	USA	NORFOLK	VA	3633N	07616W	2.000	256.500	384.750
139.100	USA	NORFOLK	VA	3657N	07617W	3.000	278.200	417.300
139.800	USA	NORFOLK	VA	3640N	07630W	100.000	279.600	419.400
139.800	USA	NORFOLK	VA	3640N	07630W	50.000	279.600	419.400
139.800	USA	NORFOLK	VA	3640N	07630W	1.000	279.600	419.400
148.200	USA	NORFOLK	VA	3657N	07617W	55.000	296.400	444.600
139.100	USA	PENSACOLA	FL	3021N	08716W	2.000	278.200	417.300
139.100	USA	PHILADELPHIA	PA	3953N	07510W	3.000	278.200	417.300

ALPHABETICAL LISTINGS (cont'd.)

Frequency kHz	Location: Country	City	State or Province	Latitude	Longitude	Radiated Power kW	2nd Harmonic kHz	3rd Harmonic kHz
130.350	USA	SO CHATHAM	MA	4140N	07002W	15.000	260.700	391.050
130.250	USA	SO CHATHAM	MA	4140N	07002W	7.500	260.500	390.750
143.000	USA	SO CHATHAM	MA	4140N	07002W	20.000	286.000	429.000
147.500	USA	SO CHATHAM	MA	4140N	07002W	15.000	295.000	442.500
147.500	USA	SO CHATHAM	MA	4140N	07002W	7.500	295.000	442.500
124.050	USA	TUCKERTON	NJ	3938N	07418W	6.000	248.100	372.150
137.000	USA	TUCKERTON	NJ	3938N	07418W	20.000	274.000	411.000
146.800	USA	TUCKERTON	NJ	3938N	07418W	6.000	293.600	440.400
71.433	USA	TYNDALL	FL	3001N	08538W	1.200	142.866	214.299
17.800	USA	WASHINGTON	DC	3859N	07627W	1000.000	35.600	53.400
19.000	USA	WASHINGTON	DC	3859N	07627W	1000.000	38.000	57.000
21.400	USA	WASHINGTON	DC	3845N	07651W	1000.000	42.800	64.200
22.300	USA	WASHINGTON	DC	3859N	07627W	1000.000	44.600	66.900
25.820	USA	WASHINGTON	DC	3859N	07627W	1000.000	51.640	77.460
40.750	USA	WASHINGTON	DC	3859N	07637W	5.000	81.500	122.250
64.200	USA	WASHINGTON	DC	3859N	07628W	50.000	128.400	192.600
64.200	USA	WASHINGTON	DC	3859N	07628W	200.000	128.400	192.600
88.000	USA	WASHINGTON	DC	3859N	07628W	50.000	176.000	264.000
89.000	USA	WASHINGTON	DC	3859N	07628W	50.000	176.000	264.000
102.000	USA	WASHINGTON	DC	3859N	07628W	50.000	204.000	306.000
109.700	USA	WASHINGTON	DC	3859N	07628W	10.000	219.400	329.100
119.850	USA	WASHINGTON	DC	3859N	07628W	2.000	239.700	359.550
121.950	USA	WASHINGTON	DC	3859N	07628W	200.000	243.900	365.850
131.050	USA	WASHINGTON	DC	3859N	07627W	25.000	262.100	393.150
131.050	USA	WASHINGTON	DC	3859N	07627W	50.000	262.100	393.150
139.100	USA	WASHINGTON	DC	3859N	07628W	2.000	278.200	417.300
142.250	USA	WASHINGTON	DC	3859N	07627W	100.000	284.500	426.750
142.250	USA	WASHINGTON	DC	3859N	07627W	50.000	284.500	426.750
142.250	USA	WASHINGTON	DC	3859N	07627W	25.000	284.500	426.750

DATA SHEETS and COVERAGE DIAGRAMS

This appendix contains the latest and best information available as of the publication date of this *Loran-C User Handbook.* Users should consult the *Radionavigation Bulletin, Local Notice to Mariners, Notices to Airmen (NOTAMs),* and other sources for updated information. Recommended secondaries (shown in the figures of this appendix) and limits of coverage are only approximate, and may be revised as a result of ongoing studies.

Finally, users are again cautioned not to rely on any one system of navigation, but rather to use all available information.

TABLE B-1. POSITIONS OF LORAN-C TRANSMITTERS IN WGS 84 COORDINATES.

Chain		Latitude	Longitude	Emission Delay	Coding Delay	Power kW[1]
5930	CANADIAN EAST COAST CHAIN					
M	Caribou, ME	46° 48' 27.305"N	67° 55' 37.159"W			800
X	Nantucket, MA	41° 15' 12.046"N	69° 58' 38.536"W	13131.88	11000	350
Y	Cape Race, Canada	46° 46' 32.286"N	53° 10' 27.606"W	28755.02	25000	1000
Z	Fox Harbour, Canada	52° 22' 35.252"N	55° 42' 27.862"W	41594.59	38000	900
5990	CANADIAN WEST COAST CHAIN					
M	Williams Lake, Canada	51° 57' 58.876"N	122° 22' 01.686"W			400
X	Shoal Cove, AK	55° 26' 20.940"N	131° 15' 19.094"W	13343.60	11000	560
Y	George, WA	47° 03' 48.096"N	119° 44' 38.976"W	28927.36	27000	1400
Z	Port Hardy, Canada	50° 36' 29.830"N	127° 21' 28.489"W	42266.63	41000	350
7930	LABRADOR SEA CHAIN					
M	Fox Harbour, Canada	52° 22' 35.252"N	55° 42' 27.862"W			900
W	Cape Race, Canada	46° 46' 32.286"N	53° 10' 27.606"W	13167.31	11000	1000
X	Angissoq, Greenland	59° 59' 17.348"N	45° 10' 26.916"W	29565.39	26000	760

[1]Nominal value, radiated power may vary from printed value by ± 20%.

TABLE B-1. POSITIONS OF LORAN-C TRANSMITTERS IN WGS 84 COORDINATES. (Cont'd.)

Chain		Latitude	Longitude	Emission Delay	Coding Delay	Power kW
7960	GULF OF ALASKA CHAIN					
M	Tok, AK	63° 19' 42.884"N	142° 48' 31.346"W			560
X	Kodiak, AK	57° 26' 20.301"N	152° 22' 10.708"W	13804.45	11000	400
Y	Shoal Cove, AK	55° 26' 20.940"N	131° 15' 19.094"W	29651.14	26000	560
Z	Port Clarence, AK	65° 14' 40.372"N	166° 53' 11.996"W	47932.52	45000	1000
7970	NORWEGIAN SEA CHAIN					
M	Ejde, Denmark	62° 17' 59.713"N	07° 04' 25.984"W			325
X	BØ, Norway	68° 38' 06.207"N	14° 27' 47.554"E	15048.10	11000	165
W	Sylt, Germany	54° 48' 29.962"N	08° 17' 36.866"E	30065.64	26000	325
Y	Sandur, Iceland	64° 54' 26.647"N	23° 55' 21.196"W	48944.53	46000	1500
Z	Jan Mayen, Norway	70° 54' 52.662"N	08° 43' 58.136"W	63216.30	60000	165
7980	SOUTHEAST U.S. CHAIN					
M	Malone, FL	30° 59' 38.870"N	85° 10' 08.751"W			800
W	Grangeville, LA	30° 43' 33.149"N	90° 49' 43.046"W	12809.54	11000	800
X	Raymondville, TX	26° 31' 55.141"N	97° 49' 59.539"W	27443.38	23000	540
Y	Jupiter, FL	27° 01' 58.528"N	80° 06' 52.875"W	45201.88	43000	350
Z	Carolina Beach, NC	34° 03' 46.208"N	77° 54' 46.100"W	61542.72	59000	600
7990	MEDITERRANEAN SEA CHAIN					
M	Sellia Marina, Italy	38° 52' 20.707"N	16° 43' 06.713"E			165
X	Lampedusa, Italy	35° 31' 20.912"N	12° 31' 30.799"E	12755.98	11000	325
Y	Kargabarun, Turkey	40° 58' 21.066"N	27° 52' 02.074"E	32273.29	29000	165
Z	Estartit, Spain	42° 03' 36.629"N	03° 12' 16.066"E	50999.71	47000	165
8290	NORTH CENTRAL U.S. CHAIN					
M	Havre, MT	48° 44' 38.589"N	109° 58' 53.613"W			400
W	Baudette, MN	48° 36' 49.947"N	94° 33' 17.915"W	14786.56	11000	800
X	Gillette, WY	44° 00' 11.305"N	105° 37' 23.895"W	29084.44	27000	400
Y	Williams Lake, Canada	51° 57' 58.876"N	122° 22' 01.686"W	45171.62	42000	400
8970	GREAT LAKES CHAIN					
M	Dana, IN	39° 51' 07.658"N	87° 29' 11.586"W			400
W	Malone, FL	30° 59' 38.870"N	85° 10' 08.751"W	14355.11	11000	800
X	Seneca, NY	42° 42' 50.716"N	76° 49' 33.308"W	31162.06	28000	800
Y	Baudette, MN	48° 36' 49.947"N	94° 33' 17.915"W	47753.74	44000	800
Z	Boise City, OK	36° 30' 20.783"N	102° 53' 59.487"W	63669.46	59000	900
9610	SOUTH CENTRAL U.S. CHAIN					
M	Boise City, OK	36° 30' 20.783"N	102° 53' 59.487"W			800
V	Gillette, WY	44° 00' 11.305"N	105° 37' 23.895"W	13884.48	11000	540
W	Searchlight, NV	35° 19' 18.305"N	114° 48' 16.881"W	28611.81	25000	560
X	Las Cruces, NM	32° 04' 18.130"N	106° 52' 04.388"W	42044.93	40000	540
Y	Raymondville, TX	26° 31' 55.141"N	97° 49' 59.539"W	56024.80	52000	540
Z	Grangeville, LA	30° 43' 33.149"N	90° 49' 43.046"W	69304.00	65000	800
9940	U.S. WEST COAST CHAIN					
M	Fallon, NV	39° 33' 06.740"N	118° 49' 55.816"W			400
W	George, WA	47° 03' 48.096"N	119° 44' 38.976"W	13796.90	11000	1400
X	Middletown, CA	38° 46' 57.110"N	122° 29' 43.975"W	28094.50	27000	400
Y	Searchlight, NV	35° 19' 18.305"N	114° 48' 16.881"W	41967.30	40000	560

TABLE B-1. POSITIONS OF LORAN-C TRANSMITTERS IN WGS 84 COORDINATES. (Cont'd.)

Chain		Latitude	Longitude	Emission Delay	Coding Delay	Power kW
9960	NORTHEAST U.S. CHAIN					
M	Seneca, NY	42° 42' 50.716"N	76° 49' 33.308"W			800
W	Caribou, ME	46° 48' 27.305"N	67° 55' 37.159"W	13797.20	11000	800
X	Nantucket, MA	41° 15' 12.046"N	69° 58' 38.536"W	26969.93	25000	350
Y	Carolina Beach, NC	34° 03' 46.208"N	77° 54' 46.100"W	42221.64	39000	600
Z	Dana, IN	39° 51' 07.658"N	87° 29' 11.586"W	57162.06	54000	400
9970	NORTHWEST PACIFIC CHAIN					
M	Iwo Jima, Japan	24° 48' 03.734"N	141° 19' 30.857"E			1815
W	Marcus Island, Japan	24° 17' 08.026"N	153° 58' 53.786"E	15283.94	11000	1000
X	Hokkaido, Japan	42° 44' 37.217"N	143° 43' 09.799"E	36685.12	30000	600
Y	Gesashi, Japan	26° 36' 25.110"N	128° 08' 56.999"E	59463.18	55000	600
Z	Barrigada, Guam	13° 27' 50.092"N	144° 49' 32.987"E	85365.84	81000	600
9980	ICELANDIC CHAIN					
M	Sandur, Iceland	64° 54' 26.647"N	23° 55' 21.196"W			1500
W	Angissoq, Greenland	59° 59' 17.348"N	45° 10' 26.916"W	15068.03	11000	760
X	Ejde, Denmark	62° 17' 59.713"N	07° 04' 25.984"W	32944.54	30000	325
9990	NORTH PACIFIC CHAIN					
M	Saint Paul, AK	57° 09' 12.350"N	170° 15' 06.245"W			275
X	Attu Island, AK	52° 49' 44.134"N	173° 10' 49.528"E	14848.23	11000	275
Y	Port Clarence, AK	65° 14' 40.372"N	166° 53' 11.996"W	32068.95	29000	1000
Z	Kodiak, AK	57° 26' 20.301"N	152° 22' 10.708"W	46590.45	43000	400

OTHER LORAN-C/LORAN-C-LIKE SYSTEMS

Chain		Latitude	Longitude	Emission Delay	Coding Delay	Power kW
7950	EASTERN RUSSIA "Chayka" (Pulse-Phase System; geodetic datum unknown)					
M	Aleksandrovsk	51° 04' 42.8"N	142° 42' 04.9"E			700
1	Petropavlovsk	53° 07' 47.5"N	157° 41' 42.9"E	14508.1	11000	700
2	Ussuriysk	44° 31' 59.7"N	131° 38' 23.4"E	33678.0	30000	700
8000	WESTERN CIS (Commonwealth of Independent States) "Chayka" (Pulse-Phase System; geodetic datum unknown)					
M	Bryansk	53° 07' 50.6"N	34° 54' 44.8"E			650
1	Petrozavodsk	61° 45' 32.4"N	33° 41' 40.4"E	13217.21	10000	700
2	Solnim	53° 07' 55.2"N	25° 23' 46.0"E	27125.00	25000	450
3	Simferopol'	44° 53' 20.6"N	33° 52' 32.1"E	53070.25	50000	550
4	Syzran'	53° 17' 17.6"N	48° 06' 53.4"E	67941.60	65000	700
8990	SAUDI ARABIA NORTH CHAIN					
M	Afif	23° 48' 36.96"N	42° 51' 18.18"E			800
V	Salwa	24° 50' 01.64"N	50° 34' 12.57"E	13641.09	11000	800
W	Ar Ruqi	29° 01' 04.74"N	46° 37' 22.50"E	27298.51	25000	200
X	Ash Shaykh Humayd	28° 09' 16.00"N	34° 45' 40.54"E	43145.53	40000	400
Y	Al Lith	20° 13' 58.45"N	40° 12' 31.57"E	57606.26	56000	200
Z	Al Muwassam	16° 25' 56.03"N	42° 48' 04.88"E	71726.94	69000	800

TABLE B-1. POSITIONS OF LORAN-C TRANSMITTERS IN WGS 84 COORDINATES. (Cont'd.)

Chain		Latitude	Longitude	Emission Delay	Coding Delay	Power kW
7170	SAUDI ARABIA SOUTH CHAIN					
M	Al Khamasin	20° 28' 02.03"N	44° 34' 52.89"E	13612.55	11000	800
W	Salwa	24° 50' 01.64"N	50° 34' 12.57"E	27371.23	26000	800
X	Afif	23° 48' 36.96"N	42° 51' 18.18"E	40526.50	39000	800
Y	Al Lith	20° 13' 58.45"N	40° 12' 31.57"E	53617.59	52000	200
Z	Al Muwassam	16° 25' 56.03"N	42° 48' 04.88"E			800
6930	CHINESE CHAIN					
M	Xindu	23° 58.1'N	111° 43.1'E			1000
1	Xinhe	22° 25.0'N	107° 21.0'E			1000
2	Zhangxi	23° 43.7'N	116° 53.8'E			1000

TABLE B-2. POSITIONS OF LORAN-C TRANSMITTERS IN WGS 72 COORDINATES.

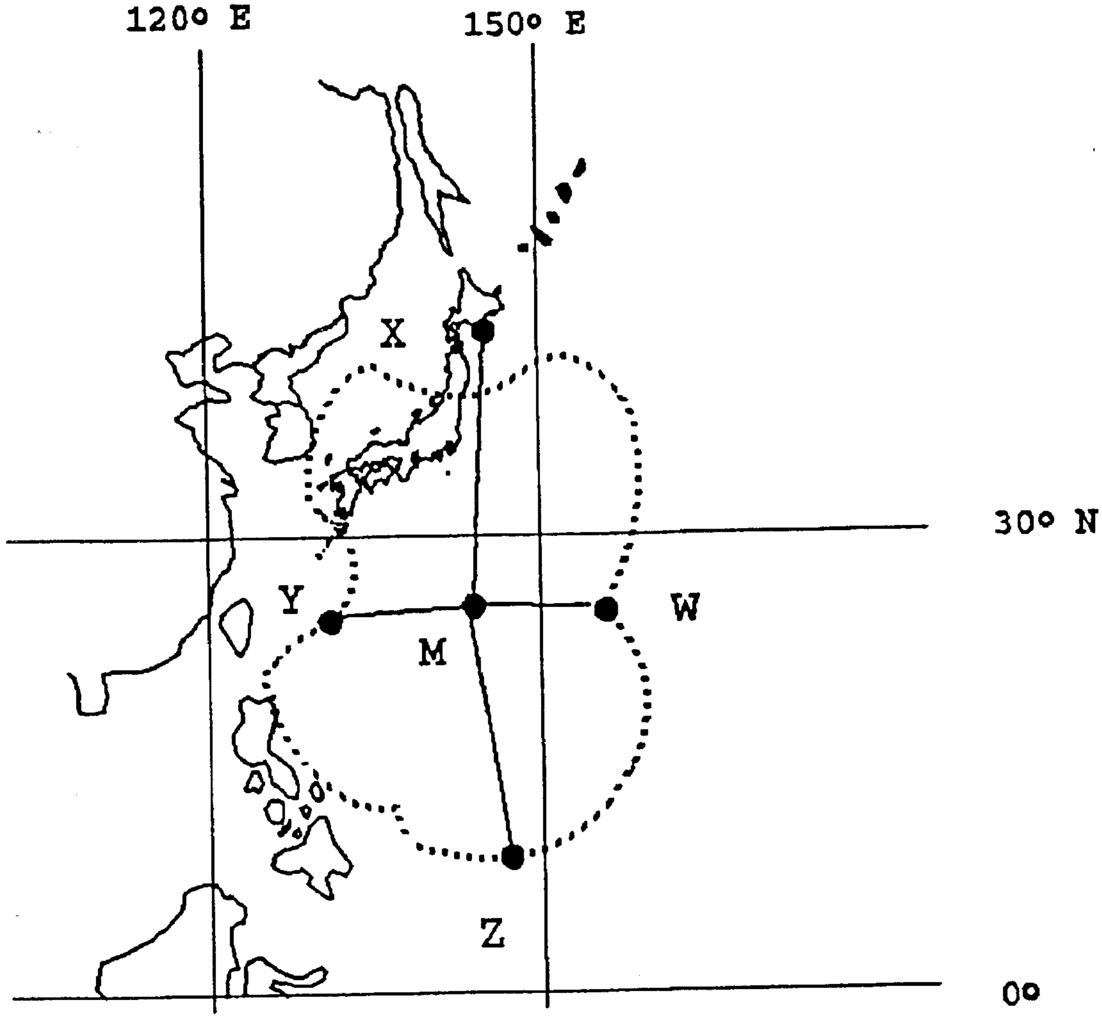
Chain		Latitude	Longitude	Emission Delay	Coding Delay	Power kW
5930	CANADIAN EAST COAST CHAIN					
M	Caribou, ME	46° 48' 27.199"N	67° 55' 37.713"W			800
X	Nantucket, MA	41° 15' 11.930"N	69° 58' 39.090"W	13131.88	11000	350
Y	Cape Race, Canada	46° 46' 32.180"N	53° 10' 28.160"W	28755.02	25000	1000
Z	Fox Harbour, Canada	52° 22' 35.157"N	55° 42' 28.416"W	41594.59	38000	900
5990	CANADIAN WEST COAST CHAIN					
M	Williams Lake, Canada	51° 57' 58.780"N	122° 22' 02.240"W			400
X	Shoal Cove, AK	55° 26' 20.851"N	131° 15' 19.648"W	13343.60	11000	560
Y	George, WA	47° 03' 47.990"N	119° 44' 39.530"W	28927.36	27000	1400
Z	Port Hardy, Canada	50° 36' 29.731"N	127° 21' 29.043"W	42266.63	41000	350
7930	LABRADOR SEA CHAIN					
M	Fox Harbour, Canada	52° 22' 35.157"N	55° 42' 28.416"W			900
W	Cape Race, Canada	46° 46' 32.180"N	53° 10' 28.160"W	13167.31	11000	1000
X	Angissoq, Greenland	59° 59' 17.270"N	45° 10' 27.470"W	29565.39	26000	760
7960	GULF OF ALASKA CHAIN					
M	Tok, AK	63° 19' 42.814"N	142° 48' 31.900"W			560
X	Kodiak, AK	57° 26' 20.217"N	152° 22' 11.262"W	13804.45	11000	400
Y	Shoal Cove. AK	55° 26' 20.851"N	131° 15' 19.648"W	29651.14	26000	560
Z	Port Clarence, AK	65° 14' 40.306"N	166° 53' 12.550"W	47932.52	45000	1000
7970	NORWEGIAN SEA CHAIN					
M	Ejde, Denmark	62° 17' 59.640"N	07° 04' 26.538"W			325
X	BØ, Norway	68° 38' 06.150"N	14° 27' 47.000"E	15048.10	11000	165
W	Sylt, Germany	54° 48' 29.872"N	08° 17' 36.312"E	30065.64	26000	325
Y	Sandur, Iceland	64° 54' 26.580"N	23° 55' 21.750"W	48944.53	46000	1500
Z	Jan Mayen, Norway	70° 54' 52.610"N	08° 43' 58.690"W	63216.30	60000	165
7980	SOUTHEAST U.S. CHAIN					
M	Malone, FL	30° 59' 38.740"N	85° 10' 09.305"W			800
W	Grangeville, LA	30° 43' 33.018"N	90° 49' 43.600"W	12809.54	11000	800
X	Raymondville, TX	26° 31' 55.006"N	97° 50' 00.093"W	27443.38	23000	540
Y	Jupiter, FL	27° 01' 58.393"N	80° 06' 53.429"W	45201.88	43000	350
Z	Carolina Beach, NC	34° 03' 46.081"N	77° 54' 46.654"W	61542.72	59000	600
7990	MEDITERRANEAN SEA CHAIN					
M	Sellia Marina, Italy	38° 52' 20.587"N	16° 43' 06.159"E			165
X	Lampedusa, Italy	35° 31' 20.787"N	12° 31' 30.245"E	12755.98	11000	325
Y	Kargabarun, Turkey	40° 58' 20.950"N	27° 52' 01.520"E	32273.29	29000	165
Z	Estartit, Spain	42° 03' 36.515"N	03° 12' 15.512"E	50999.71	47000	165
8970	GREAT LAKES CHAIN					
M	Dana, IN	39° 51' 07.540"N	87° 29' 12.140"W			400
W	Malone, FL	30° 59' 38.740"N	85° 10' 09.305"W	14355.11	11000	800
X	Seneca, NY	42° 42' 50.603"N	76° 49' 33.862"W	31162.06	28000	800
Y	Baudette, MN	48° 36' 49.844"N	94° 33' 18.469"W	47753.74	44000	800
Z	Boise City, OK	Coordinates not available in WGS 72				
9940	U.S. WEST COAST CHAIN					
M	Fallon, NV	39° 33' 06.621"N	118° 49' 56.370"W			400
W	George, WA	47° 03' 47.990"N	119° 44' 39.530"W	13796.90	11000	1400
X	Middletown, CA	38° 46' 56.990"N	122° 29' 44.529"W	28094.50	27000	400
Y	Searchlight, NV	35° 19' 18.180"N	114° 48' 17.435"W	41967.30	40000	560

TABLE B-2. POSITIONS OF LORAN-C TRANSMITTERS IN WGS 72 COORDINATES (Cont'd.)

Chain		Latitude	Longitude	Emission Delay	Coding Delay	Power kW
9960	NORTHEAST U.S. CHAIN					
M	Seneca, NY	42° 42' 50.603"N	76° 49' 33.862"W			800
W	Caribou, ME	46° 48' 27.199"N	67° 55' 37.713"W	13797.20	11000	800
X	Nantucket, MA	41° 15' 11.930"N	69° 58' 39.090"W	26969.93	25000	350
Y	Carolina Beach, NC	34° 03' 46.081"N	77° 54' 46.654"W	42221.65	39000	600
Z	Dana, IN	39° 51' 07.540"N	87° 29' 12.140"W	57162.06	54000	400
9970	NORTHWEST PACIFIC CHAIN					
M	Iwo Jima. Japan	24° 48' 03.597"N	141° 19' 30.303"E			1815
W	Marcus Island, Japan	24° 17' 07.888"N	153° 58' 53.232"E	15283.94	11000	1000
X	Hokkaido, Japan	42° 44' 37.104"N	143° 43' 09.245"E	36685.12	30000	600
Y	Gesashi, Japan	26° 36' 24.975"N	128° 08' 56.445"E	59463.18	55000	600
Z	Barrigada, Guam	Coordinates not available in WGS 72		85365.84	81000	600
9980	ICELANDIC CHAIN					
M	Sandur, Iceland	64° 54' 26.580"N	23° 55' 21.750"W			1500
W	Angissoq, Greenland	59° 59' 17.270"N	45° 10' 27.470"W	15068.03	11000	760
X	Ejde, Denmark	62° 17' 59.640"N	07° 04' 26.538"W	32944.54	30000	325
9990	NORTH PACIFIC CHAIN					
M	Saint Paul, AK	57° 09' 12.265"N	170° 15' 06.799"W			275
X	Attu, AK	52° 49' 44.040"N	173° 10' 49.974"E	14875.25	11000	275
Y	Port Clarence, AK	65° 14' 40.306"N	166° 53' 12.550"W	32068.95	29000	1000
Z	Kodiak, AK	57° 26' 20.217"N	152° 22' 11.262"W	46590.45	43000	400

Positions are based on U.S. Defense Mapping Agency survey data (positions of Loran systems operated by other governments were provided by those governments). Power shown is transmitter peak rated power.

FIGURE B-1. LORAN-C GRI 9970 NORTHWEST PACIFIC CHAIN



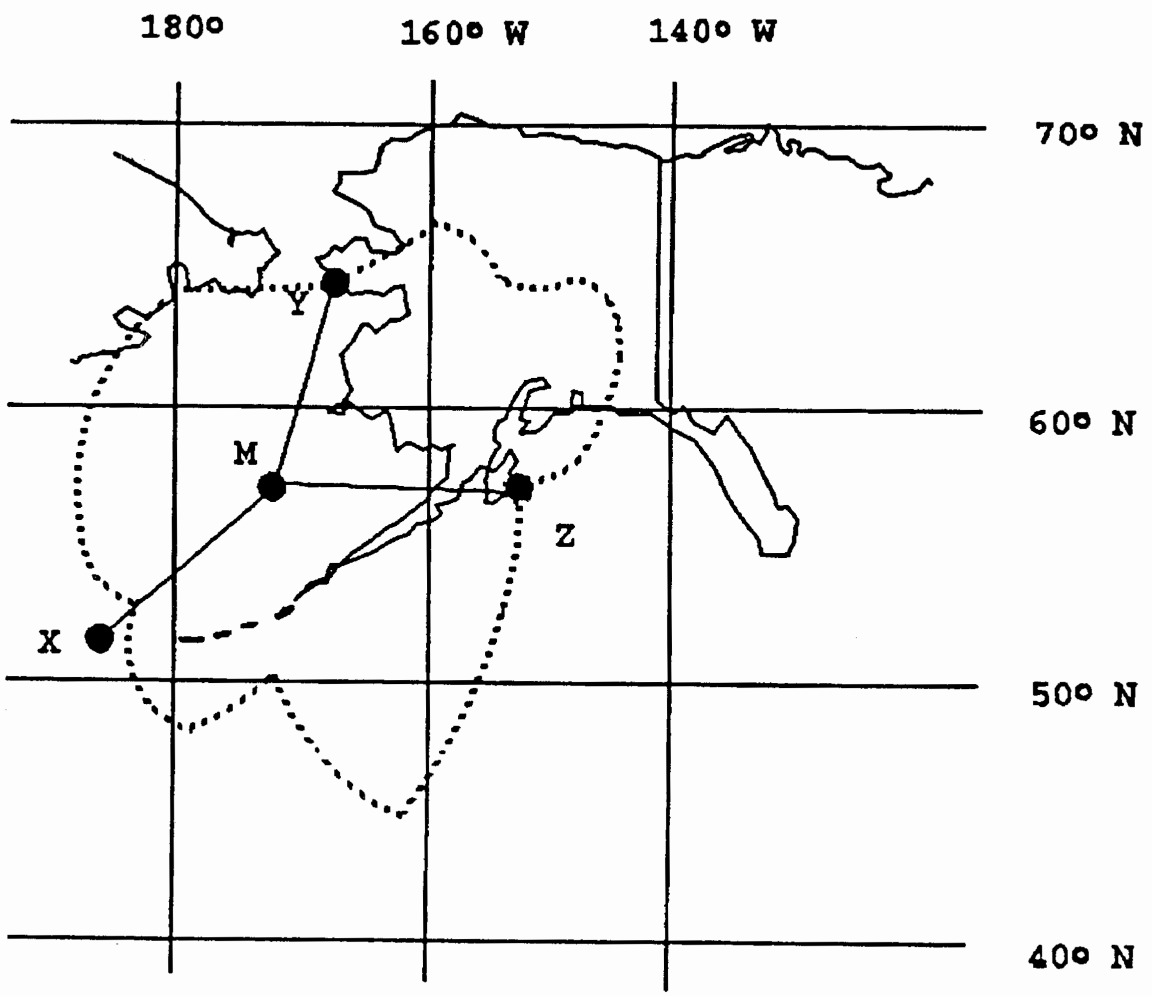
Transmitter

M Iwo Jima, Japan
W Marcus Island, Japan
X Hokkaido, Japan
Y Gesashi, Japan
Z Barrigada, Guam

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 58.1 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-2. LORAN-C GRI 9990 NORTH PACIFIC CHAIN



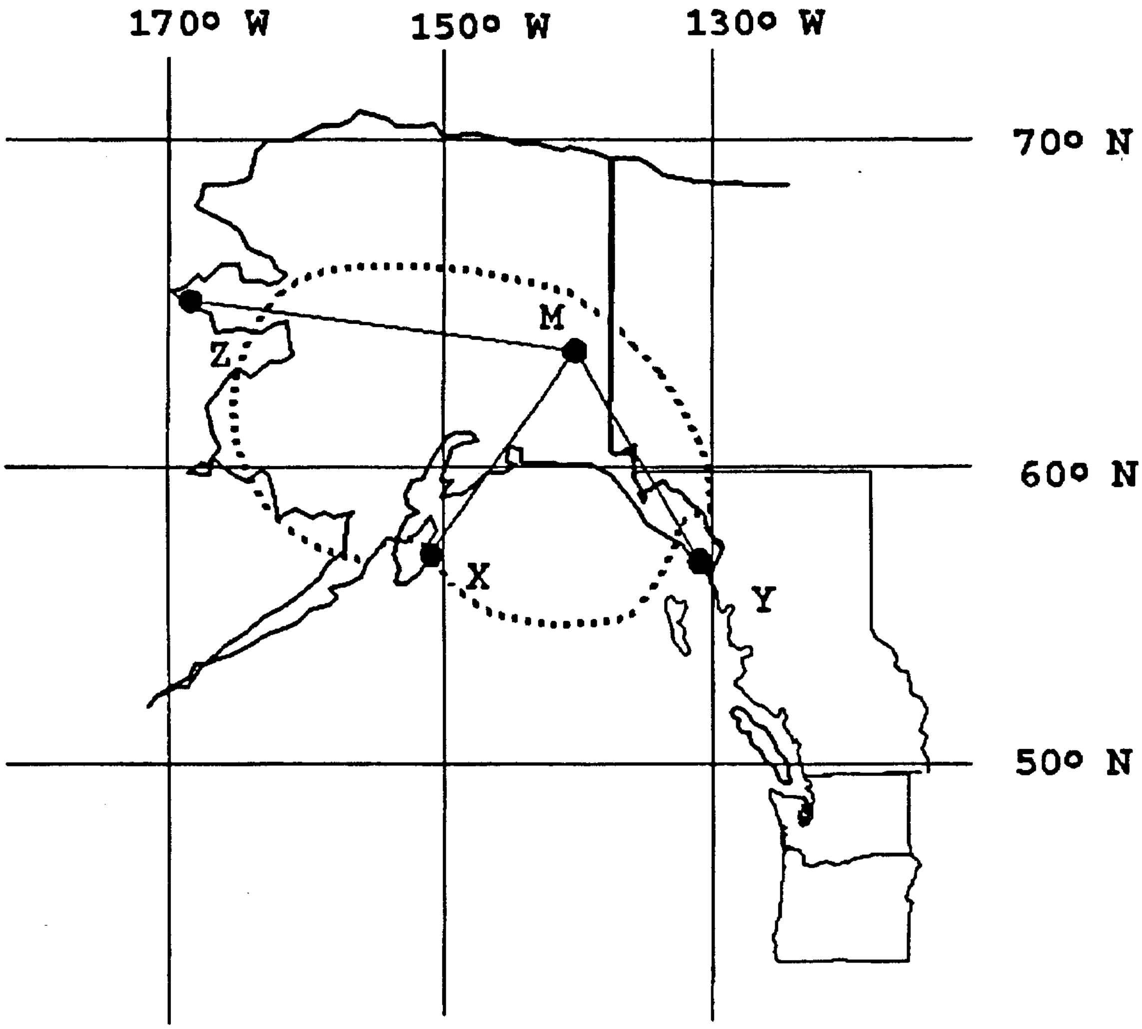
Transmitter

M St. Paul, AK
X Attu, AK
Y Port Clarence, AK
Z Kodiak, AK

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 48.2 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-3. LORAN-C GRI 7960
GULF OF ALASKA CHAIN



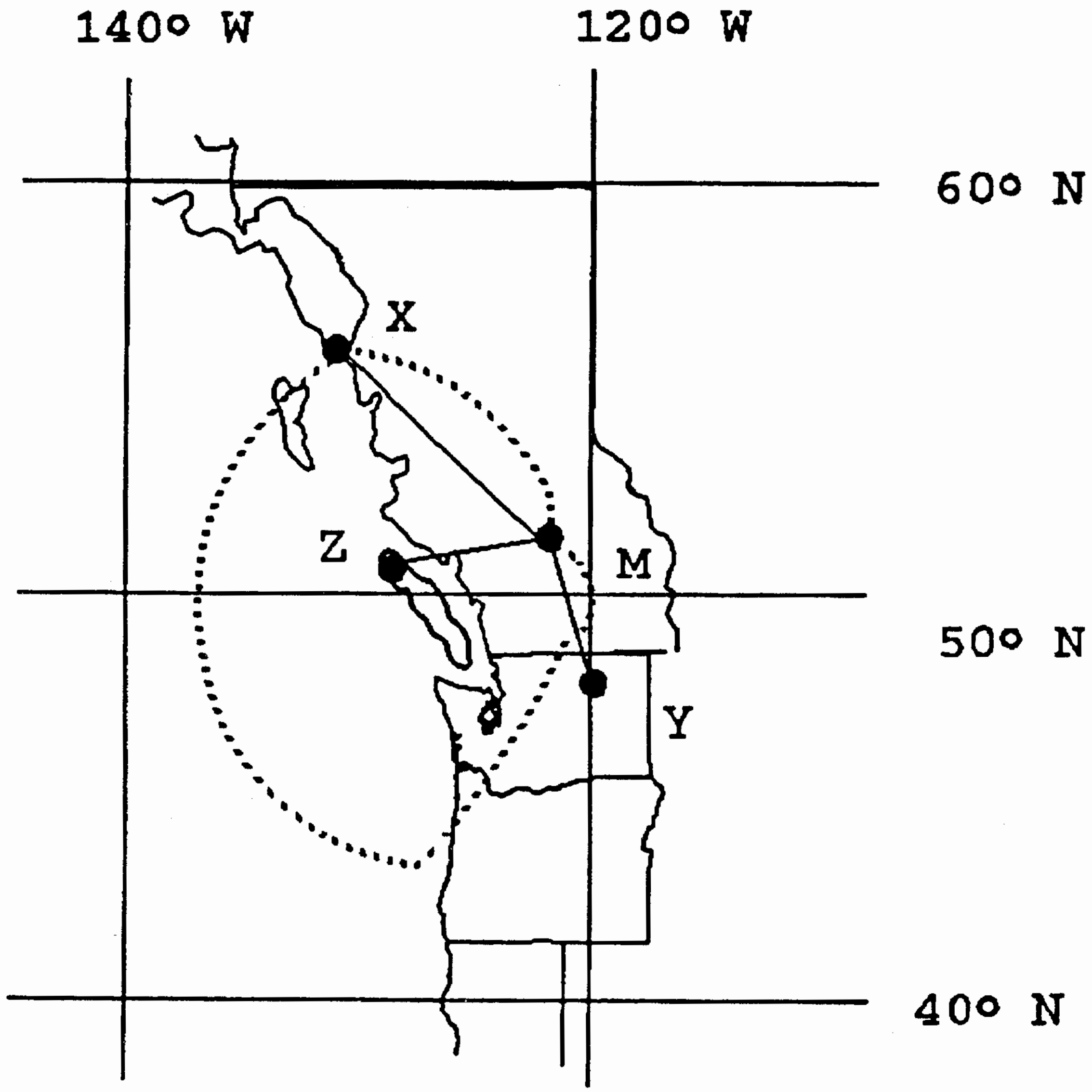
Transmitter

M Tok, AK
X Kodiak, AK
Y Shoal Cove, AK
Z Port Clarence, AK

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 49.0 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-4. LORAN-C GRI 5990 CANADIAN WEST COAST CHAIN



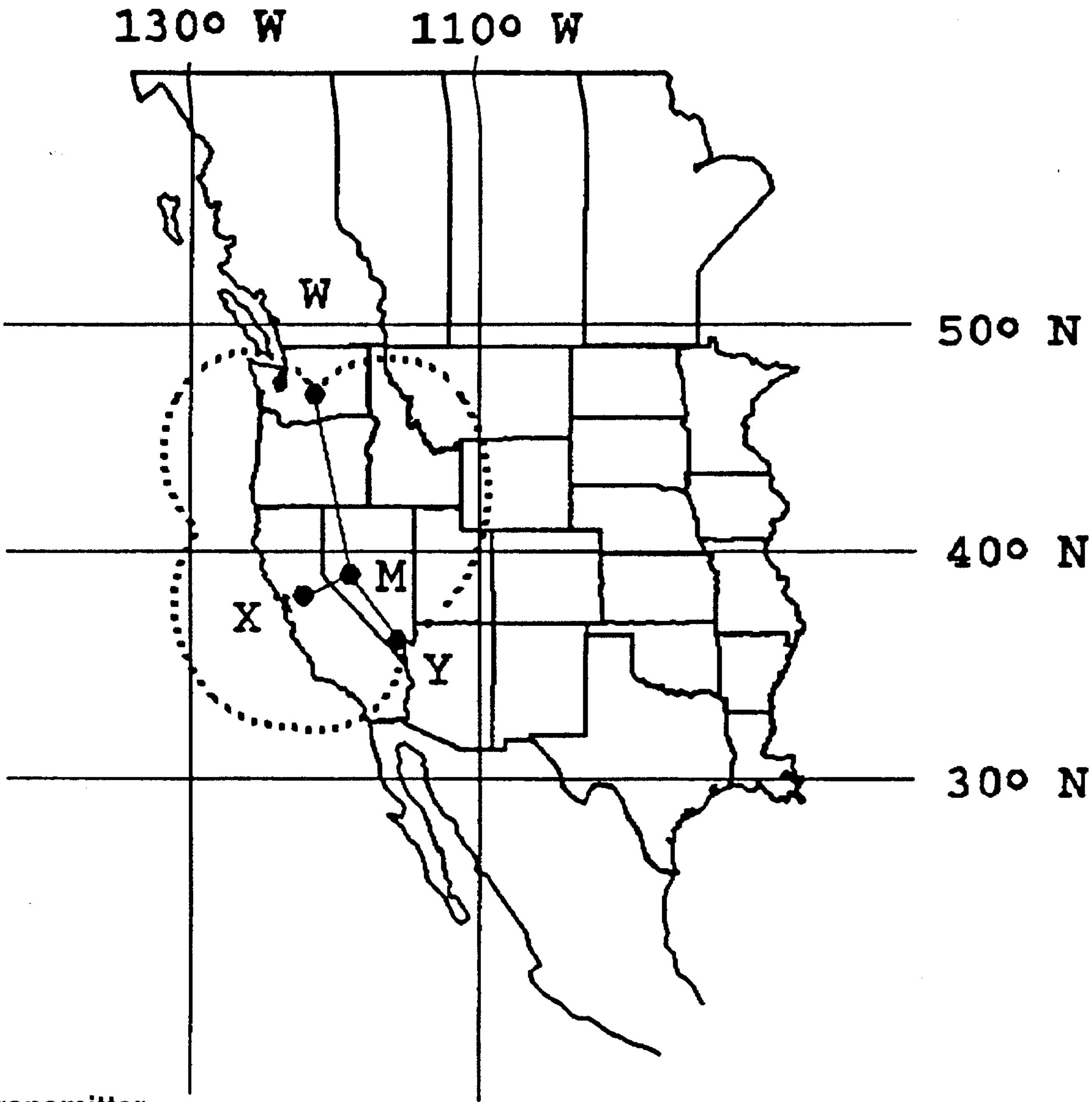
Transmitter

M Williams Lake, Canada
X Shoal Cove, AK
Y George, WA
Z Port Hardy, Canada

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 46.4 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-5. LORAN-C GRI 9940
U. S. WEST COAST CHAIN



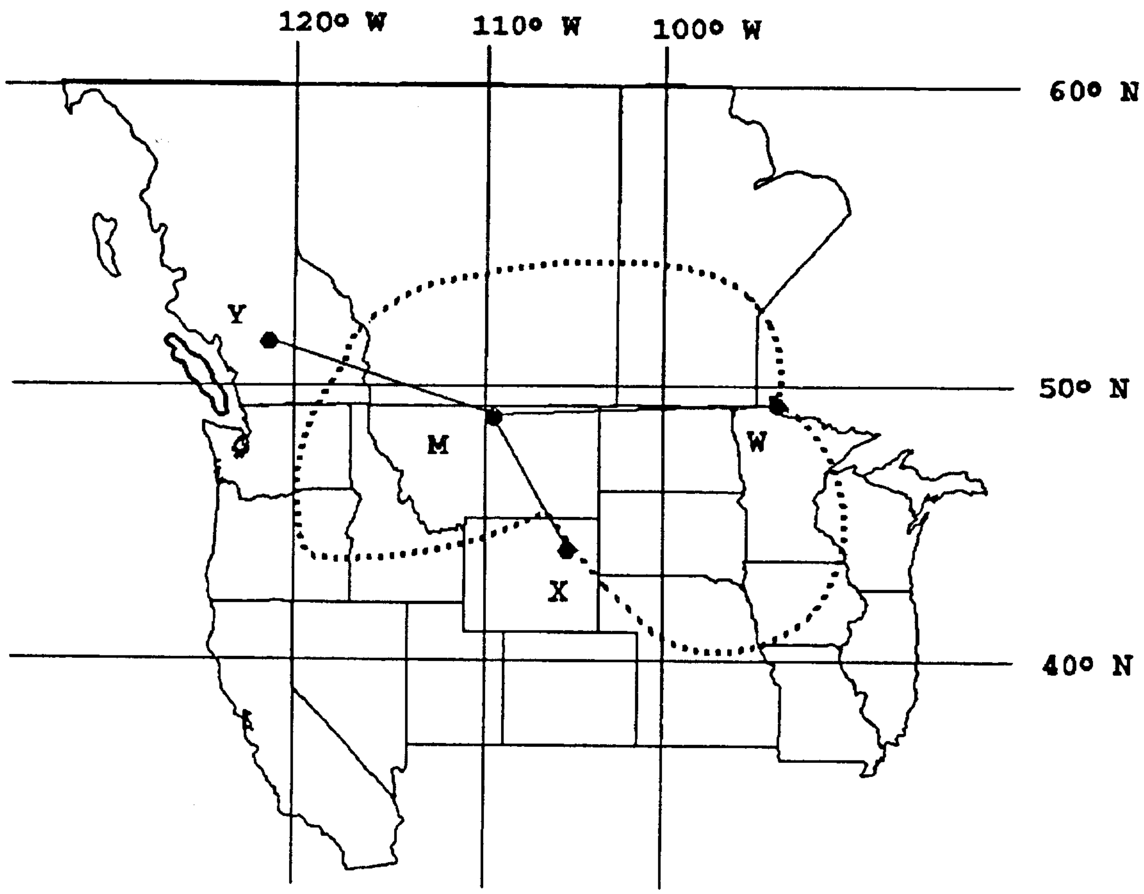
Transmitter

M Fallon, NV
W George, WA
X Middletown, CA
Y Searchlight, NV

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 52.4 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-6. LORAN-C GRI 8290 NORTH CENTRAL U. S. CHAIN



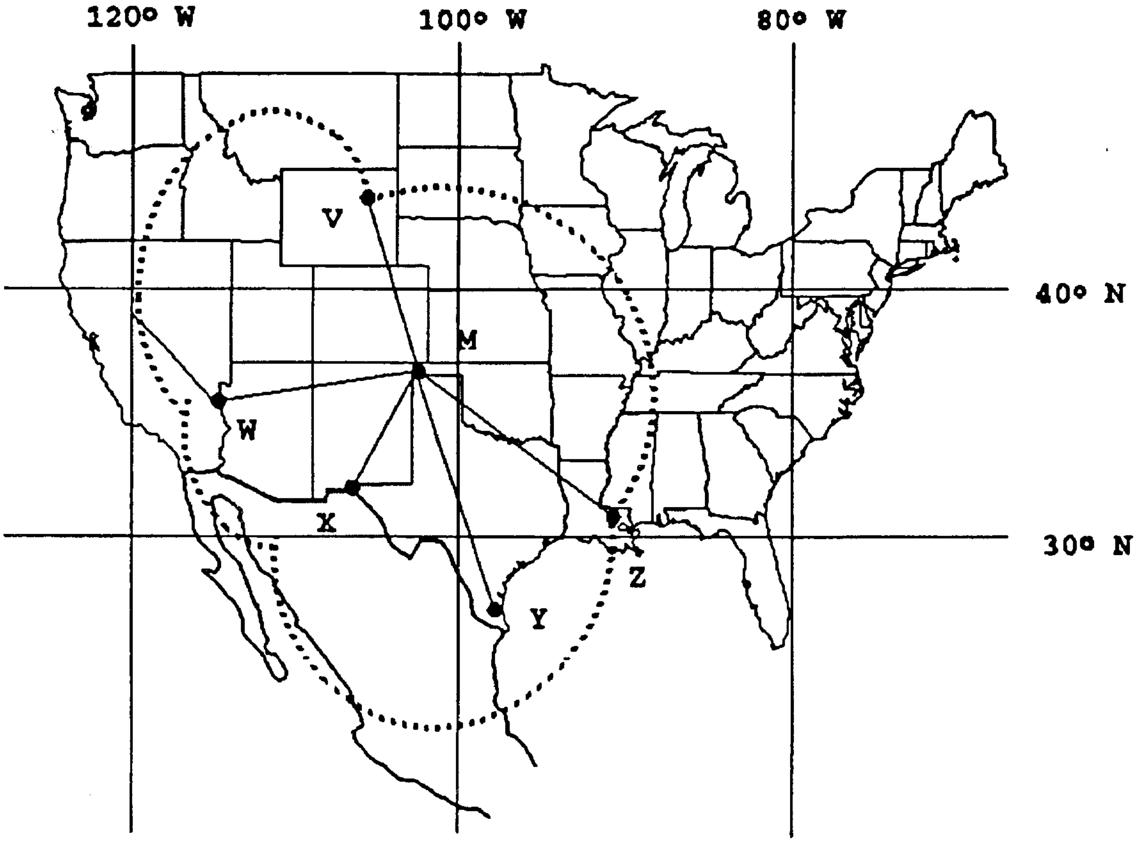
Transmitter

- M Havre, MT
- W Baudette, MN
- X Gillette, WY
- Y Williams Lake, Canada

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 57.8 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-7. LORAN-C GRI 9610 SOUTH CENTRAL U. S. CHAIN



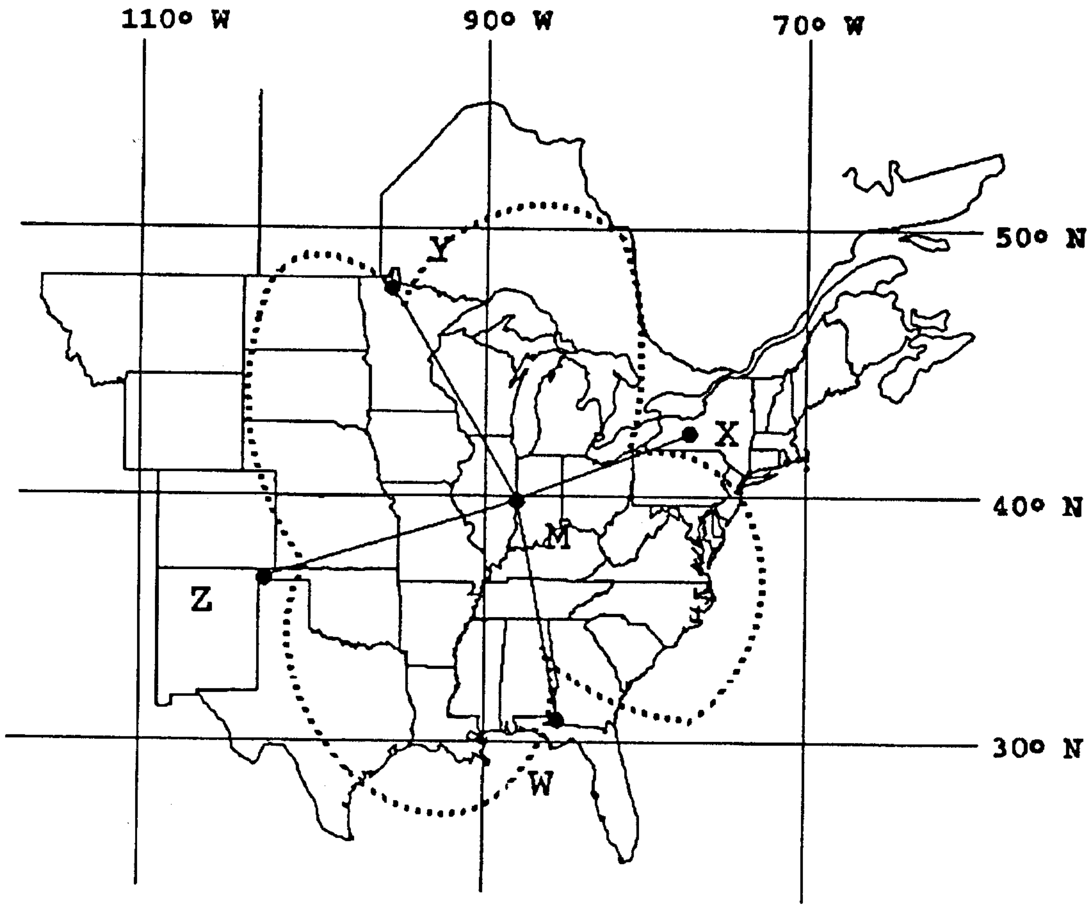
Transmitter

M Boise City, OK
V Gillette, WY
W Searchlight, NV
X Las Cruces, NM
Y Raymondville, TX
Z Grangeville, LA

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 57.8 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-8. LORAN-C GRI 8970
GREAT LAKES CHAIN



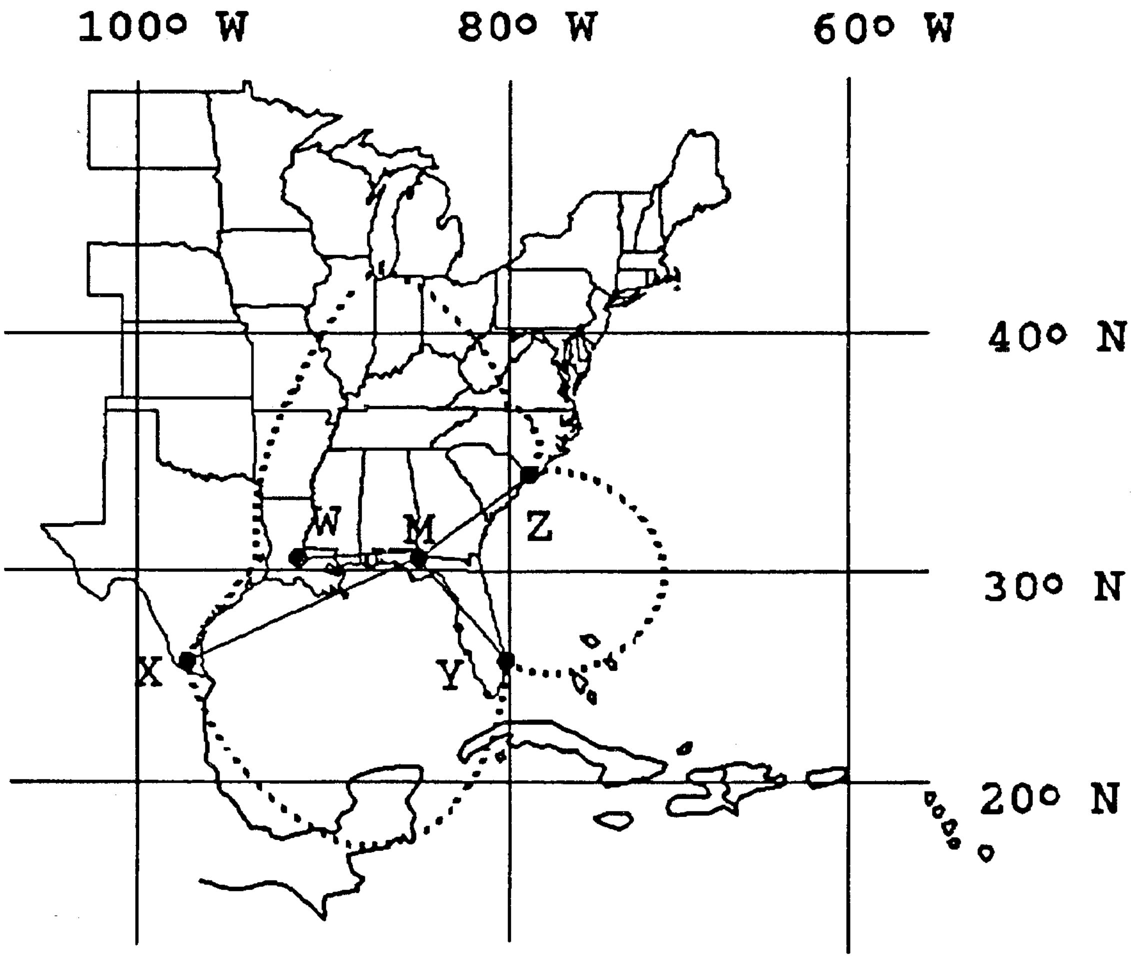
Transmitter

M	Dana, IN
W	Malone, FL
X	Seneca, NY
Y	Baudette, MN
Z	Boise City, OK

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise .... 58.1 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-9. LORAN-C GRI 7980 SOUTHEAST U. S. CHAIN



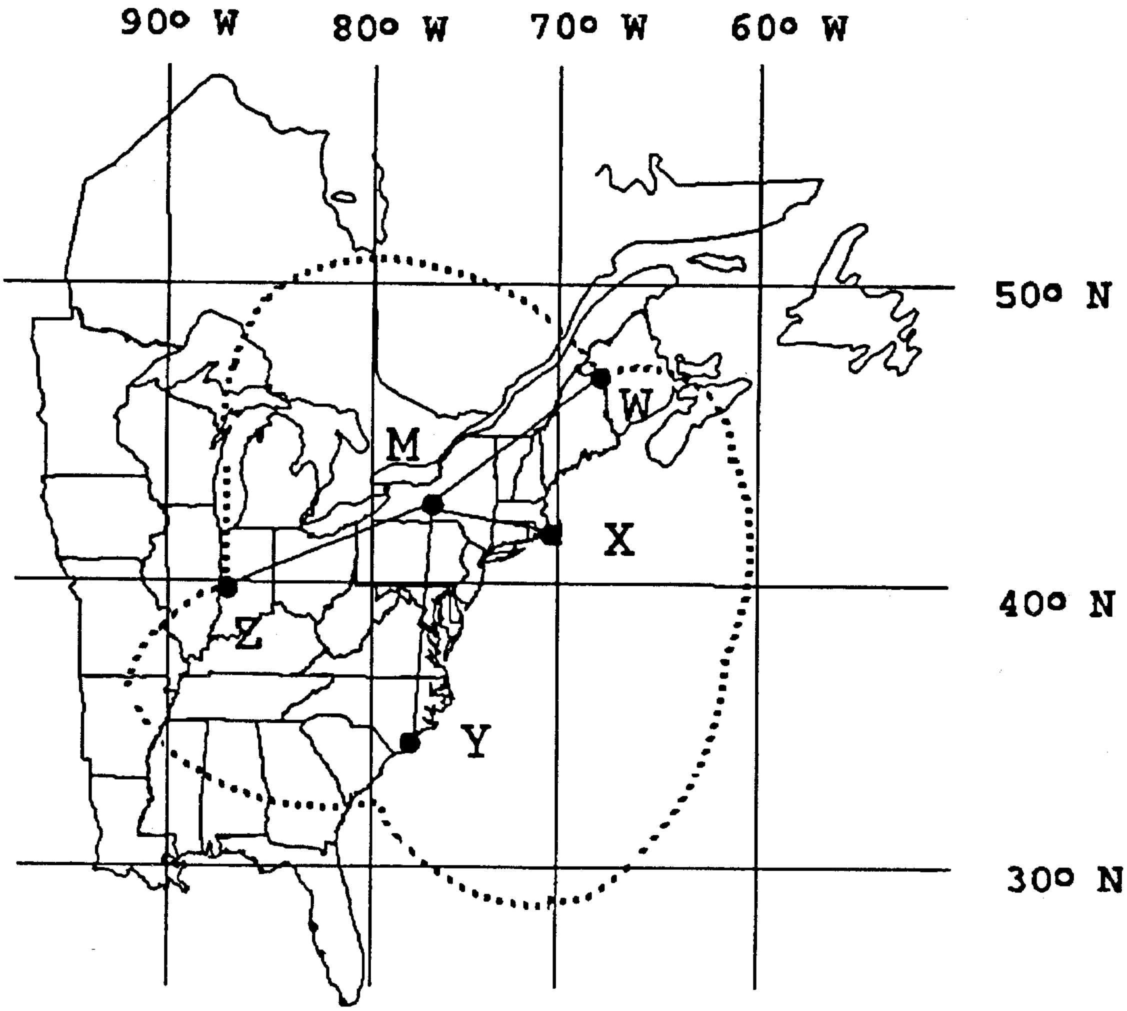
Transmitter

M Malone, FL
W Grangeville, LA
X Raymondville, TX
Y Jupiter, FL
Z Carolina Beach, NC

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 60.5 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-10. LORAN-C GRI 9960 NORTHEAST U. S. CHAIN



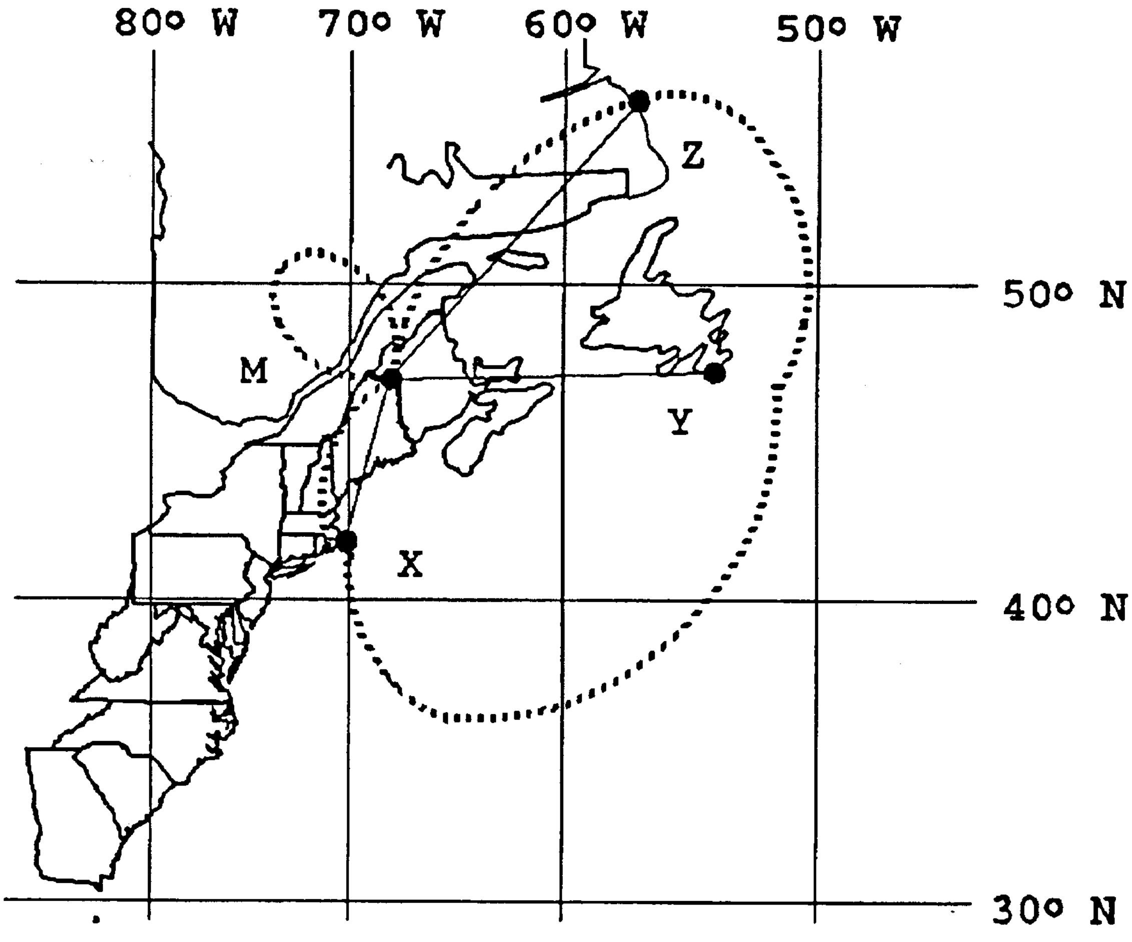
Transmitter

M Seneca, NY
W Caribou, ME
X Nantucket, MA
Y Carolina Beach, NC
Z Dana, IN

SNR 1:3
Fix Accuracy ....1/4 NM (95% 2dRMS)
Atmospheric Noise .....58.1 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-11. LORAN-C GRI 5930 CANADIAN EAST COAST CHAIN



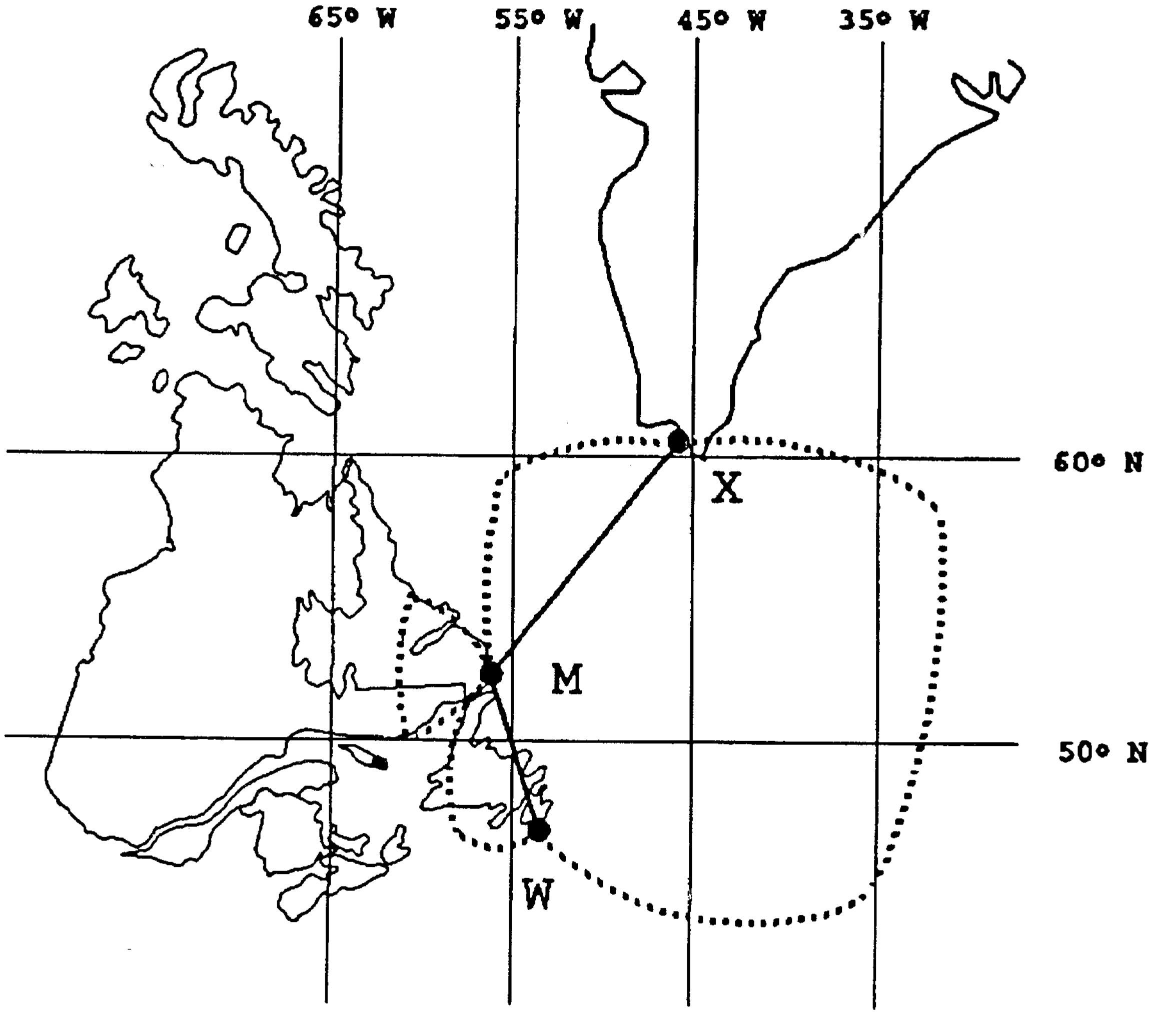
Transmitter

M Caribou, ME
X Nantucket, MA
Y Cape Race, Canada
Z Fox Harbor, Canada

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 47.6 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-12. LORAN-C GRI 7930
LABRADOR SEA CHAIN



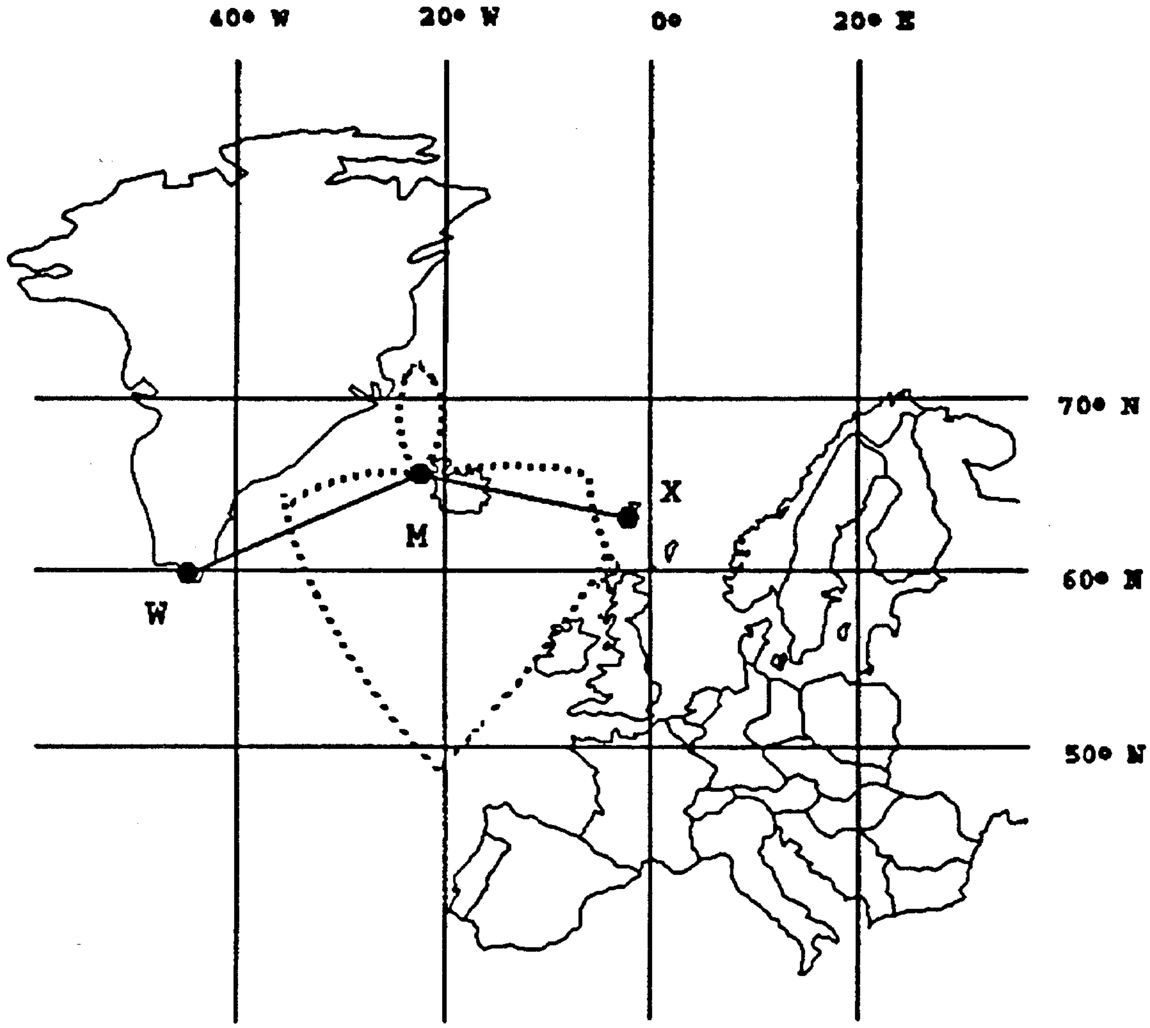
Transmitter

M Fox Harbor, Canada
W Cape Race, Canada
X Angissoq, Greenland

SNR 1:3
Fix Accuracy ....1/4 NM (95% 2dRMS)
Atmospheric Noise ....43.1 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-13. LORAN-C GRI 9980 ICELANDIC SEA CHAIN



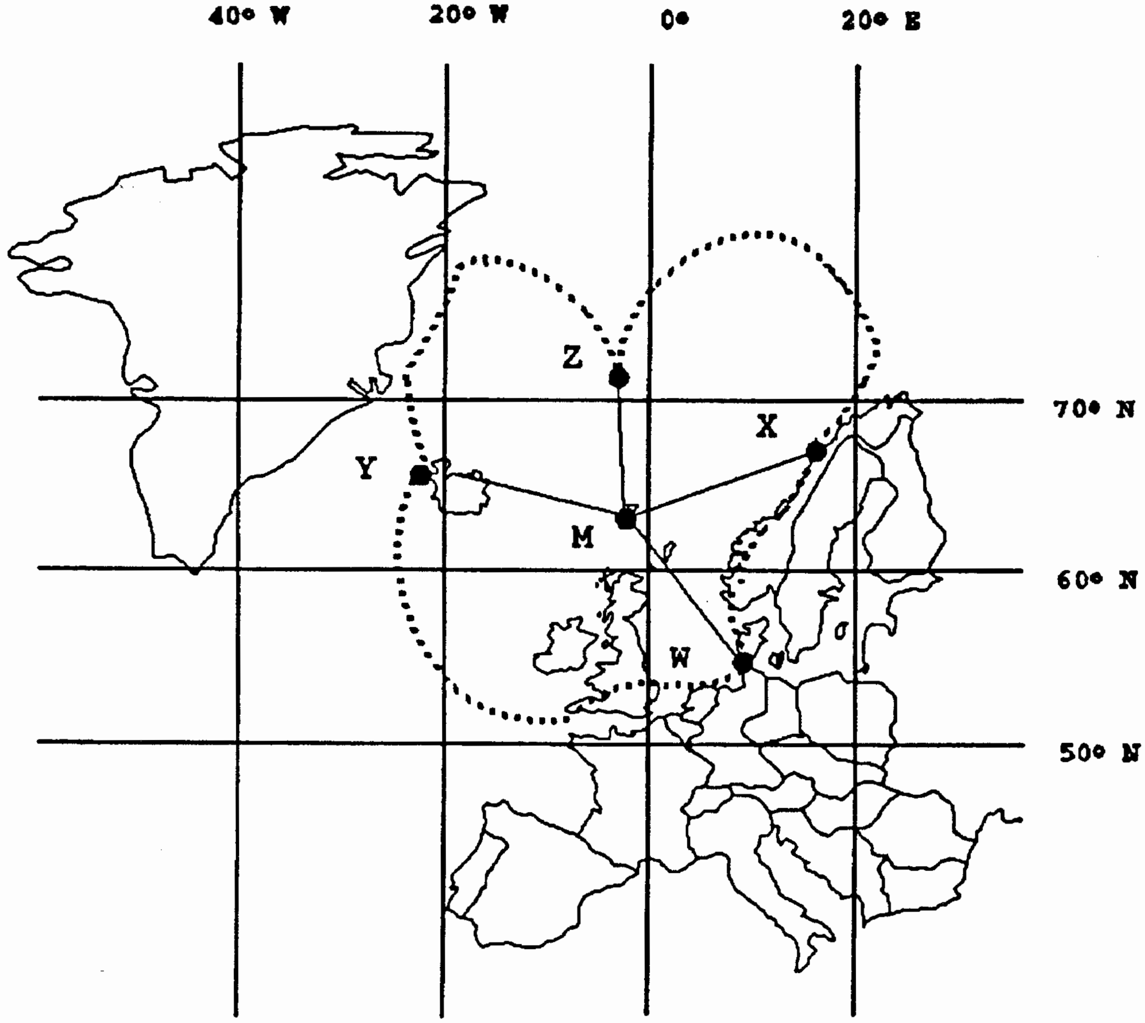
Transmitter

M Sandur, Iceland
W Angissoq, Greenland
X Ejde, Denmark

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 50.0 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-14. LORAN-C GRI 7970 NORWEGIAN SEA CHAIN



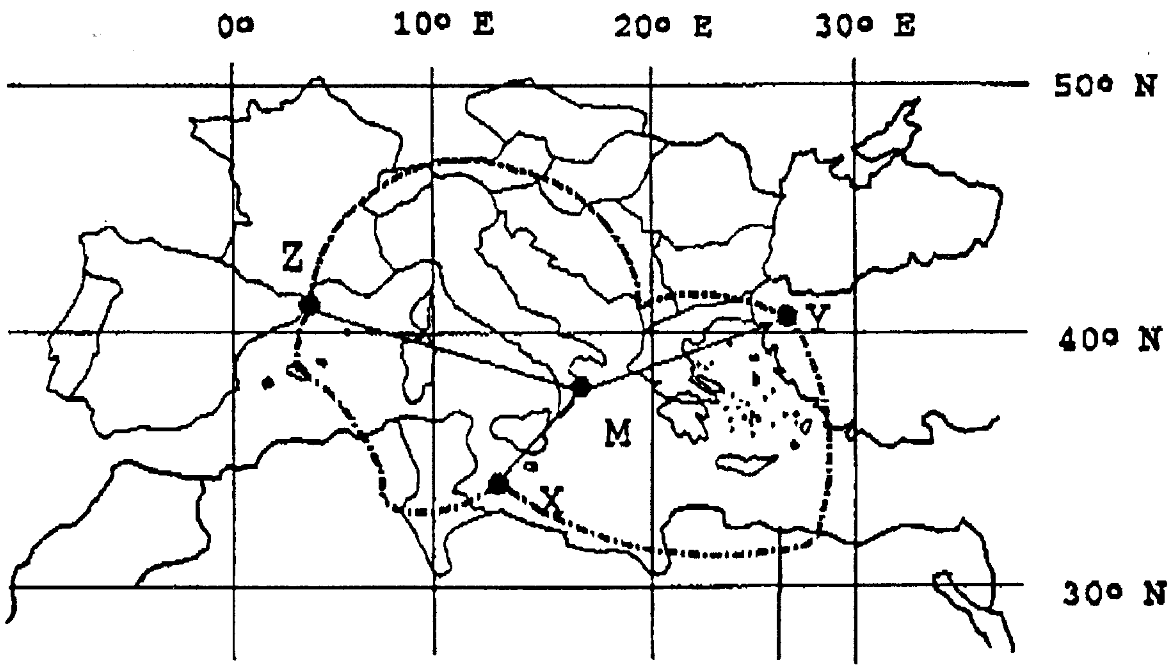
Transmitter

M	Ejde. Demark
X	Bo, Norway
W	Sylt, Germany
Y	Sandur, Iceland
Z	Jan Mayen, Norway

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 43.1 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

FIGURE B-15. LORAN-C GRI 7990 MEDITERRANEAN SEA CHAIN



Transmitter

M Sellia Marina, Italy
X Lampedusa, Italy
Y Kargabarun, Turkey
Z Estartit, Spain

SNR 1:3
Fix Accuracy .... 1/4 NM (95% 2dRMS)
Atmospheric Noise ... 51.2 dB above 1 uV/m

NOTE: *Estimated* Groundwave coverage, actual coverage will vary.

APPENDIX C

GLOSSARY OF TERMS

This appendix contains a glossary of terms relevant to loran and loran radionavigation. Sources from which these definitions were taken include *Bowditch*, the *United States Coast Guard Auxiliary* text, *Advanced Coastal Navigation*, the *Federal Radionavigation Plan*, *Specification of the Transmitted Loran-C Signal*, *Radionavigation Systems* (1988), *Radionavigation Bulletin*, and from course notes for the Loran-C course taught at the United States Coast Guard Academy (USCGA).

Terms included all relate to loran and/or navigation. Some arguably relevant terms, such as CALOC, TINO, COCO, PGEN and the like have been deliberately excluded as this a publication intended for a more general audience. Additional system-related terms can be found in the USCGA course notes.

Accuracy. In navigation, the accuracy of an estimated or measured position of a craft (vehicle, aircraft, or vessel) at a given time is the degree of conformance of the position with the true position of the craft at that time. Since accuracy is a statistical measure of performance, a statement of the accuracy of a navigation system is meaningless unless is includes a statement of the associated statistical confidence. See also *Accuracy: Types*.

Accuracy: Statistical Measures. Navigation system errors generally follow a known error distribution. Therefore, the uncertainty in position can be expressed as the probability that the error will not exceed a certain amount. A thorough treatment of errors is complicated by the fact that the total error is comprised of errors caused by instability of the transmitted signal, effects of weather and other physical changes in the propagation medium, errors in the receiving equipment, and errors introduced by the human navigator. In specifying or describing the accuracy of a system, the human errors are usually excluded.

When specifying linear accuracy, or when it is necessary to specify requirements in terms of orthogonal axes (e.g., along-track or cross-track), the 95 percent confidence level is normally used. Vertical or bearing accuracies will be specified in one-dimensional terms (2 sigma), 95 percent confidence level.

When two-dimensional accuracies are used, as in the case of Loran-C, the 2 drms (distance root mean square) uncertainty estimate will be used. Two drms is twice the radial error, drms. The radial error is defined as the root-mean-square value of the distances from the true location point of the position fixes in a collection of measurement. It is often found by first defining an arbitrarily-oriented set of perpendicular axes, with the origin at the true location point. The variances around each axis are then found, summed, and the square root computed. When the distribution of errors is elliptical, as it often is for stationary, ground-based systems (including Loran-C), these axes can be taken for convenience as the major and minor axes of the error ellipse. Then the confidence level depends on the elongation of the error ellipse. As the error ellipse collapses to a line, the confidence level of the 2 drms measurement approaches 95 percent; as the error ellipse becomes circular, the confidence level approaches 98 percent.

DOD specifies horizontal accuracy in terms of *circular error probable* (CEP—the radius of a circle containing 50 percent of all possible fixes) or spherical error probable (SEP) the radius of a sphere containing 50% of all possible fixes.

Accuracy: Types. Specifications of radionavigation system accuracy generally refer to one or more of the following definitions:

(a) *predictable accuracy:* the accuracy of a position with respect to the geographic, or geodetic, coordinates of the earth. (Also called absolute or geodetic accuracy.)

(b) *repeatable accuracy:* the accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.

(c) *relative accuracy:* the accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time. This may be expressed also as a function of the distance between the two users. Relative accuracy may also refer to the accuracy with which users can measure position relative to their own positions in the recent past. For example, the present position of a craft whose desired track forms a specific geometric pattern in search operations or hydrographic survey, will be measured generally with respect to a previously determined datum.

Acquisition. The reception and identification of transmitted Loran-C signals from master and selected secondaries to permit reliable measurement of TDs. The requisite signal-to-noise ratio for original signal acquisition is generally greater than for tracking.

Additional Secondary Factors (ASFs). Land path factors due to variation in the conductivity of the earth's surface that alter the speed of propagation of loran signals over land compared to over water. Variation of propagation velocities over land degrade the absolute accuracy of a loran system (unless compensated for) but do not affect the repeatable accuracy.

Aid to Navigation (ATON or NAVAID). Any device external to a vessel or aircraft specifically intended to assist navigators in determining their position or safe course, or to warn them of dangers or obstructions to navigation.

Allowable GRIs. As published in the *Federal Register* (40 *Federal Register* 29, 11 February 1975), permissible GRIs are multiples of 10 microseconds from 40,000 through 99,990 microseconds.

Ambiguity. In certain areas, particularly in the vicinity of loran baseline extensions, there is the possibility that two positions will satisfy two observed loran TDs.

Anchor Alarm. Feature of many Loran-C receivers that can be set to warn the user that the vessel has moved outside the swing circle of the anchor. This is also termed *an anchor watch.*

Angle of Cut. The smaller angular difference between two bearings or lines of position. See also *Crossing Angle.*

Antenna. Any structure or device used to collect or radiate electromagnetic waves; specifically, that part of a transmitter or receiver that contains, or itself consists of, the apparatus that radiates or receives electromagnetic waves.

Antenna Coupler. A radio frequency transformer and other electronic circuit(s) used to connect an antenna to a transmission line or to connect a transmission line to a radio receiver. The purpose of an antenna coupler is to match the impedance of the antenna with the receiver. In practical terms, an antenna coupler enables the use of physically short antennas.

Arrival Alarm. Feature of many Loran-C receivers that provides an aural warning when the vessel is within a certain distance of a specified waypoint along a route. The distance at which the alarm is activated is typically adjustable.

Attenuation. A lessening in amount, particularly the reduction in amplitude of an electromagnetic wave with distance from the origin.

Automated Notices to Mariners System (ANMS). Computer system that can be accessed by authorized users to obtain chart corrections and notices to mariners. Users need a teletype, computer terminal, or other device, and an access code available from DMA.

Automatic Secondary Selection (ASS). See Automatic Transmitter Selection.

Automatic Transmitter Selection (ATS). Feature on some Loran-C receivers that automatically selects the master and secondaries to use for position determination. Criteria for selection of secondaries differ among makes and models of receivers, and involve crossing angles, gradients, and SNR. When a receiver equipped with this feature is initialized or set up, the user enters an approximate position (in latitude and longitude) and the receiver selects the chain and secondaries associated with this approximate position and the SNRs of the secondaries.

Autopilot. Device for automatic steering of a vessel. Depending upon the Sophistication of the autopilot, these can be used to maintain a heading, or to interface with a loran or other electronic navigation system. Sometimes informally called "George" or "Iron Mike."

Availability. The availability of a navigation system is the percentage of time that a signal within preestablished tolerances is being broadcast throughout the coverage area. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities. For example, the measured availability of the Loran-C chain in the eastern U. S. and Canada have averaged 99.8786% availability over the last decade.

Baseline. The shortest-distance segment of a great circle that joins the master and a secondary station in a loran chain. Also used to describe a master secondary pair.

Baseline Delay. Same as *baseline travel time.*

Baseline Extension. The extension of the baseline beyond the two joined stations. Loran positions in baseline extension areas are problematic and ambiguous.

Baseline Length. Same as *baseline travel time* when expressed in usec.

Baseline Travel Time. The length of time, in microseconds, that it takes for a loran signal to travel along the baseline from the master to a secondary station.

Blink. An indication that the master or secondary signals in a loran chain are out of tolerance and not be used. Loran receivers have a blink alarm that warns the user that the indicated positions may not be reliable. Blink conditions warn that the signal power or TD is out-of-tolerance (OOT) and/or that an improper phase code or GRI is being transmitted. Physically (see Chapter II) the first two pulses of the secondary pulse group are blinked on and off. In turn, the receiver displays this blink code by flashing the display. Blink contributes to the integrity of the Loran-C system. According to some sources, this code is the origin of the common english phrase "on the blink." There are actually *two* types of blink, secondary and master blink. See the main text.

Centerline. Perpendicular bisector (great circle) of the baseline. This represents the locus of points equidistant from both master and secondary.

Chart Reference Systems—Nautical Charts. Most nautical charts are based on regional horizontal datums which have been defined over the years independently of each other. These include charts published by the Defense Mapping Agency and the National Ocean Service of NOAA. In addition, in many parts of the world, the positional accuracy of chart features (such as hazards to navigation) sometimes varies from chart to chart and in some cases, within a chart. Certain charts for waters in the Southern Hemisphere, for example, do not show islands in their correct geodetic positions, absolute or relative. Therefore, datums and limited chart accuracy must be considered when a navigational fix is plotted by a navigator on a nautical chart.

Modern navigational positioning is based on satellite systems which are geocentric by definition, and these satellite coordinate systems differ significantly in many cases with the local or regional datums of nautical charts. In addition to this difference, the plotted details such as soundings and navigational aids, contain a minimum plottable error that ranges between 0.5 mm to 1.0 mm on paper.

Virtually all radionavigation equipment incorporating coordinate converters (automated computation of geodetic latitude and longitude from data received from a radionavigation system) are programmed with the World Geodetic System 1972 (WGS 72) description of the earth. In January 1987, GPS began using WGS 84, an improvement over WGS 72. There are significant variations between WGS 72 and WGS 84 coordinates and coordinates referenced to local datums. These differences range from a few meters in the central US to 160 meters in Alaska and the Caribbean, and almost 450 meters in Hawaii.

The large majority (86 percent) of the nautical charts published by NOS have been compiled on a regional horizontal datum, specifically, the North American Datum of 1927 (NAD 27). The remaining 14 percent of the charts in the NOS nautical chart suite have been published on eight other local or regional datums. NOS has adopted a geocentric datum, NAD 83, and is beginning to convert its suite of nautical charts to that datum. The charts of the Pacific Islands published by NOS will be compiled on WGS 84. For charting purposes, however, NAD 83 is equivalent to WGS 84. As charts are converted, datum transformation notes will be added which report the extent of the shift from NAD 27 coordinates.

Improvements in worldwide navigational accuracy, which are anticipated with the implementation of GPS in the early 1990s, will be significant. However, the ability to safely navigation along the coastlines of the world and on the high seas will remain limited where accurate, up-to-date hydrography and associated topographic features are not all positioned on the same satellite-based WGS reference system.

Chart Reference Systems. Geodetic datums are basic control networks used to establish the precise geographic position and elevation of features on the surface of the earth. They are established at all levels of government (international, national, and local) and form the legal basis for all positioning and navigation. Within the last 20 years, there have been great advances in our knowledge of the shape and size of the earth (i.e., our geodetic knowledge). The old datums are no longer scientifically relevant (although otherwise still relevant). In recent years, geodesy and navigation trended toward *earth centered body fixed* (ECBF) coordinate systems. These are cartesian coordinate systems with origins at the center of mass of the earth, whereas the old datums have generally been based on localized surface monumentations (and associated agreements) and defined by a reference ellipsoid that was not earth centered.

The DOD Global Positioning System is based on the World Geodetic System of 1984 (WGS 84). WGS 84 is an ECBF coordinate system upon which all US military and much civilian navigation, geodesy, and survey will be based. Within the US, the National Geodetic Survey (NGS) is the legal authority for the establishment of US datums. The datum presently used throughout most of the US and Canada is the North American Datum of 1927 (NAD 27). This is a surface (or horizontal) datum. There is a vertical datum as well (i.e., the National Geodetic Vertical Datum [NGVD 29]). Practically all nautical charts, aeronautical charts, federal surveys, and associated data provided by the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) are legally established with respect to NAD 27. Recently, NGS has developed a new datum known as the North American Datum of 1983 (NAD 83) which, for purposes of navigation and relative survey, is generally the same as WGS 84. NAD 83 is based on the internationally adopted earth model GRS 80; the WGS 84 earth model differs slightly from GRS 80. The NGS is presently completing a new vertical datum (NGVD 88).

Circular Error Probable (CEP). In a circular normal distribution (the magnitudes of the two one-dimensional input errors are equal and the angle of cut is 90°), circular error probable is the radius of the circle containing 50 percent of the individual measurements being made, or the radius of the circle inside of which there is a 50 percent probability of being located.

Coastal Confluence Zone (CCZ). Harbor entrance to 50 nautical miles offshore or the edge of the Continental Shelf (100 fathom curve), whichever is greater.

Common-use Systems. Systems used by both civil and military sectors.

Conterminous U.S. Forty-eight adjoining states and the District of Columbia.

Control Station. Station to record information sent by LORMONSITES, determine whether or not any signals are out-of-tolerance, insert corrections to the transmitting stations, and notify the user of any abnormalities via blink. Out-of-tolerance conditions are relayed from the control station to the transmitting stations. In most cases control stations are located in the same facility as the LORSTA.

Coordinate Conversion. The process of changing the coordinate values from one system to another; e.g., from geodetic coordinates (latitude and longitude) to Universal Transverse Mercator grid coordinates, or in the case of Loran-C, from Time Differences to geodetic coordinates. In the case of Loran-C, conversion can be a manual process, by interpolation of LOPs printed on nautical or aeronautical charts, or accomplished automatically in the Loran-C receiver.

Course (C). Course is the average heading and the horizontal direction in which a vessel is intended to be steered, expressed as the angular distance relative to north, usually from 000° at north, clockwise through 359° from the point of departure or start of the course to the point of arrival or other point of intended location.

Course Deviation Indicator (CDI). An indicator, shown on some lorans, that graphically displays whether or not the vessel is on the designated track between waypoints and, if not, the direction to return to this track.

Course LOP. An LOP situated approximately directly ahead or behind the vessel, so named because the LOP provides a good indication of the vessel's CMG.

Course Made Good (CMG). This indicates the single resultant direction from a point of departure to a point of arrival at a given time. (Synonym: Track Made Good)

Course of Advance (COA). This indicates the direction of the *intended* path to be made good *over the ground.*

Course Over the Ground (COG). This indicates the direction of the path *actually followed* by the vessel *over the ground,* usually an irregular line.

Coverage Area. The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the navigator to determine position to a specified level of accuracy and at a specified SNR. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal propagation.

Coverage Diagram. A diagram showing the area where a given loran chain enables reliable reception (at an acceptable SNR) and satisfies specified accuracy criteria. Coverage diagrams are provided for each Loran-C chain elsewhere in this document.

Cross Rate (Cross Chain) Interference. Interference in the reception of radio signals from one loran chain caused by signals from another loran chain.

Cross Track Error. Distance between the vessel's actual position and the direct course between two waypoints. Abbreviated XTE on some receiver displays.

Cross Track Error Alarm. Alarm that can be set on many Loran-C receivers that warns the navigator if the vessel's cross track error exceeds some prespecified value.

Crossing Angle. Generally, the smaller of the angles between two LOPs which determine a fix. The closer this angle is to 90 degrees, the better the fix. Also used with loran LOPs.

Current. Term used in two senses. It is used to refer either to the horizontal motion over the ground, including ocean current, tidal, and river currents, or more generally to these factors together with the effect of wind and seas, steering error of the helmsman, compass error, speed curve error, and other factors.

Current (alternate definition). Generally, a horizontal movement of water. Currents may be classified as *tidal* and *nontidal*. Tidal currents are caused by gravitational interactions between the sun, moon, and earth and are a part of the same general movement of the sea that is manifested in the vertical rise and fall, called *tide*. Nontidal currents include the permanent currents in the general circulatory systems of the sea as well as temporary currents arising from more pronounced meteorological variability.

Cyclan. The designation of Loran-C in the earliest stage of development, later superseded by the term *Cytac*.

Cycle Match. In Loran-C, the comparison, in time difference, between corresponding carrier cycles contained in the times of a master and secondary station pulse. The comparison is refined to a determination of the phase difference between these two cycles. Cycle matching provides superior performance over envelope matching.

Cycle Slip. Failure of the Loran-C receiver to lock on the proper sampling or tracking point. In cases of cycle slip, the receiver will lock on to another sampling point that differs from the proper sampling point by integer multiples of 10 microseconds. This is most likely to occur in fringe areas outside the normal Loran-C coverage area, but can occur elsewhere in the coverage area. Unless recognized and compensated for, cycle slip will result in additional errors of position. If position errors are detected and are the result of cycle slip, these can be compensated for by manual cycle selection or cycle step. Cycle slip can be detected by cross-checking loran positions with other methods, and also by noting the SNR for the signal. Cycle slippage further into the loran pulse will increase the SNR.

Cycle Step. A manual mode of altering the sampling point of the signal, in 10 microsecond increments. This may need to be done to attempt to correct cycle slip and/or to find a stronger portion of the signal for fringe area operations. Stepping further into the loran signal will increase the signal strength, but also increases the likelihood of skywave contamination.

Cytac. The designation of Loran-C in an earlier stage of development.

Dead Reckoning (DR). The practice of estimating position by advancing a known position for courses and distances run. The effects of wind and current are not considered in determining a position by dead reckoning.

Dead Reckoning (DR) Plot. A DR plot is the charted movement of a vessel as determined by dead reckoning.

Dead Reckoning (DR) Position. A position determined by dead reckoning.

Differential. A technique used to improve radionavigation system accuracy by determining positioning error at a known location and subsequently transmitting the determined error, or correction factors, to users of the same radionavigation system, operating in the same area.

Differential Loran. A system to increase the accuracy of loran which operates by broadcasting a correction signal to users in a fixed geographic area to adjust measured TDs to compensate for seasonal, diurnal, chain control, transmitter, and other effects. Differential loran has proven feasible in tests by the Coast Guard (see bibliography), but has not been implemented.

Direction (True). The angle between the local true meridian and a line from the observer's position to an object or another location.

Distance-to-Go (DTG). Quantity displayed on some loran receivers representing the distance from the vessel's (or aircraft's) present position to the next waypoint.

Dividers. An instrument consisting of two pointed legs joined by a pivot, and used principally for measuring distances or coordinates. An instrument having one pointed leg and the other carrying a pen or pencil is called a *drafting compass.*

Drift. The speed in knots at which the current is moving. Drift may also be indicated in statute miles per hour in some areas, the Great Lakes, for example. This term is also commonly used to mean the speed at which a vessel deviates from the course steered due to the combined effects of external forces such as wind and current. With external inputs, such as a fluxgate compass and a device to measure speed through the water, some Loran-C receivers can determine current set and drift.

Dual Rate Blanking. To provide continuous service from one Loran-C chain to the next, some stations are dual rated (see *dual rated station*). A dual-rated station is faced periodically with an impossible requirement to radiate two overlapping pulse groups at the same time. During the time of overlap, the subordinate signal is blanked or suppressed. Priority blanking occurs when the same rate is always blanked, whereas alternate blanking occurs whenever the two rates are blanked in an alternate manner.

Dual Rated Station. Term used to describe a master or secondary station in one Loran-C chain that is also used as a master or secondary in another chain. The Dana, Indiana, loran transmitter is one example, serving as the zulu secondary in the 9960 (Northeast US) chain as well as the master in the 8970 (Great lakes) chain.

ECBF. See definition of *chart reference systems.*

Electronic Chart. A device that can display a chartlike representation on a screen. Some electronic charts are very elaborate and allow the user to "zoom in" to examine an area at a larger scale. Depth contours, NAVAIDS, and other chart features can be displayed—even down to individual docks at certain locations. Electronic charts can interface with other shipboard electronics, such as a loran and display the vessel's current position, waypoints, and related information.

Electronic Navigation Digital Data System (ENDDS). Computer system used by DMAHTC which, *inter alia*, computes ASFs.

Emission Delay (ED). The time difference, in microseconds, between when a master loran station transmits and a given secondary station transmits. The emissions delay (ED) is equal to the sum of the baseline travel time plus the secondary coding delay.

Envelope Match. In Loran-C, the comparison, in time difference, between the leading edges of the demodulated and filtered pulses from a master and secondary station. The pulses are superimposed and matched manually or automatically. This may be done preliminary to a cycle match. The Loran-A system employed envelope matching, but not cycle matching..

Envelope to Cycle Difference (ECD). The time relationship between the phase of the Loran-C carrier and the time origin of the envelope waveform. Zero envelope to cycle difference is defined as the signal condition occurring when the 30 microsecond point of the Loran-C pulse envelope is in time coincidence with the third positive zero crossing of the 100 kHz carrier.

Envelope to Cycle Discrepancy. An error in a Loran-C TD measurement which results from disturbing the precise relationship between the shape of the pulse envelope and the phase of the carrier wave necessary for an accurate measurement.

Estimated Position (EP). An improved position based upon the DR position and which may include, among other things, factoring in the effects of current (wind, water currents, etc.), a single line of position, or both of the above.

Estimated Time Enroute. (ETE) The estimated time for the vessel to travel from its present position to the next waypoint in sequence. Same as TTG.

Estimated Time of Arrival. (ETA) The estimated time that the vessel will arrive at the next waypoint. It is calculated by the loran receiver as present clock time plus the distance to go divided by the vessel's speed (speed over the ground on some models, or velocity made good on other models).

Fix. A known position determined by passing close aboard an object of known position or determined by the intersection of two or more lines of position (LOPs) adjusted to a common time, determined from terrestrial, electronic, and/or celestial data. The accuracy, or quality of a fix, is of great importance, especially in coastal waters, and is dependent on a number of factors.

Fix Dimensions. This characteristic of a navigation system defines whether the navigation system provides a linear, one-dimensional line-of-position, or a two- or three-dimensional position fix. The ability of the system to derive a fourth dimension (e.g., time) from the navigational signals is also included.

Fix Rate. The fix rate is defined as the number of independent position fixes or data points available from the system per unit time.

Fluxgate Compass. A compass that senses the earth's magnetic field electronically, rather than with magnets. Fluxgate compasses can interface with other shipboard electronics such as radar or loran.

Fringe Area. Region at or beyond the published range and accuracy limits for a loran chain. Attainment of published accuracy limits may be difficult or impossible because of geometric limits or noise. Reception of ground wave signals may be compromised by skywave contamination in this region. Finally, specialized operating techniques may be required in fringe areas.

Gee. British hyperbolic system used for air navigation during World War II. Gee, proposed by R. J. Dippy in 1937 and implemented in early 1942, was a pulsed system operating at frequencies from 30 to 80 megahertz, with separation between transmitters of the order of 100 miles. Gee was named for the hyperbolic grid of TDs.

Geocentric. Relative to the earth as a center, measured from the center of the earth.

Geodesy. The science related to the determination of the size and shape of the earth (geoid) by such direct measurements as triangulation, leveling, and gravimetric observations; which determines the external gravitational field of the earth and, to a limited degree, the internal structure.

Geodetic Accuracy. Term meaning the same as absolute or predictable accuracy.

Geometric Dilution of Precision (GDOP). Term used to include all geometric factors (gradient, crossing angle) that degrade the accuracy of position fixes from externally referenced navigation systems, such as Loran-C. GDOP can be calculated from an equation which summarizes these effects in one single measure.

Global Positioning System (GPS). GPS is a spaced-based positioning, velocity, and time system that uses satellites for world-wide coverage. (See Chapter I.)

Gradient. Mathematically the rate of change of distance with respect to time difference. It is measured as the ratio of the spacing between adjacent loran TDs, as measured in nautical miles, yards, or feet, and the number of microseconds difference between these lines. Most commonly this is expressed as ft/usec or meters/usec. Generally speaking, the smaller the gradient, the better the fix. The loran gradient is smallest along the baseline, where it is numerically equal to 491.62 ft/usec.

Great Circle. The intersection of a sphere and a plane through its center.

Great-Circle Distance. The length of the shorter arc of the great circle joining two points on a sphere. It is usually expressed in nautical miles (NM).

Grid. A series of lines, usually (but not always) straight and parallel, superimposed on a chart or plotting sheet to serve as a directional reference for navigation. Although the term *grid* could be used to refer to any two or more families of intersecting lines (as in the hyperbolic lines for Gee), a preferred term for hyperbolic systems is *lattice*.

Groundwave. A radio wave that travels near or along the earth's surface.

Group Repetition Interval (GRI). Length of time (in microseconds) between the start of one transmission from the master station in a Loran-C chain and the start of the next.

GRI Designator. This is the GRI of the chain with the last zero omitted. Thus, a chain with a GRI of 99,600 usec would have a GRI designator of 9960. The GRI designator is used to identify a loran chain. The terms GRI and GRI designator are often used interchangeably in casual conversation.

Gyrocompass. A compass having one or more gyroscopes as the directive element(s), and which is north seeking. Its operation depends upon four natural phenomena, including gyroscopic inertia, gyroscopic precession, the earth's rotation, and gravity.

Heading (HDG). The instantaneous direction of a vessel's bow. It is expressed as the angular distance relative to north, usually 000° at north, clockwise through 359°. Heading should not be confused with course. Heading is a constantly changing value as a vessel yaws back and forth across the course due to the effects of sea, wind, and steering error. Heading is expressed in degrees of either true, magnetic, or compass direction.

Hertz (Hz). Name for a derived unit of frequency in the international system of units. One Hertz is equal to one cycle per second.

HF. See Chapter I, Table I-3.

Homing. Process of moving towards a location by continually pointing the bow of the vessel or nose of the aircraft in the direction of the station. In the absence of wind or current, homing will lead to a ground track that is a straight line. With any current, however, the ground track will become curved, bowed in the direction of the prevailing current.

Hyperbolic Grid. Lattice of curved (hyperbolic) lines of position produced by a hyperbolic system.

Hyperbolic System. Navigation systems, such as Loran-C or Omega, that operate by measuring the time difference between signals transmitted by two or more transmitters.

Integrity. Integrity is the ability of a navigation system to provide timely warnings to users when the system should not be used for navigation. For the Loran-C system, integrity is effected by secondary blink.

Ionosphere. The region of the atmosphere extending from about 40 to 250 statute miles above the earth's surface, in which there is appreciable ionization. The presence of charged particles in this region affects the propagation of certain electromagnetic radiation.

Jitter. A term used to describe the short term instability of a signal. This instability may be in amplitude, phase, or both. Used in connection with loran, this is the variation of the last digits (in either TD or latitude/longitude mode) displayed on the loran receiver caused by changing propagation of the signal or other sources.

Kilo. Prefix meaning 1,000.

Latitude (L, Lat). Angular measure north or south of the equator (typically expressed in degrees from zero to ninety), north or south, e.g., L 073N or as degrees, minutes, and seconds.

Lattice. A pattern formed by two or more families of intersecting lines, such as that pattern formed by two or more families of hyperbolas representing curves of equal time difference associated with a hyperbolic radionavigation system. Similar to grid.

LCD—Liquid Crystal Display. Type of display screen used with loran receivers and other electronic equipment. This display typically shows black (or dark colored) numbers or letters on a white or grey screen. This display is typically easy to see during bright daylight. Most modern loran receivers use this type of display.

LED—Light Emitting Diode. Type of display screen used with earlier loran receivers and other electronic equipment. This display typically shows red (orange) numbers or letters on a dark background. This display is sometimes difficult to see in bright daylight.

Legend. A title or explanation on a chart, diagram, illustration.

Line of Position (LOP). A line of bearing to a known origin or reference, upon which a vessel is assumed to be located. An LOP is determined by observation (visual bearing) or measurement (RDF, loran, radar, etc.). An LOP is assumed to be a straight line for visual bearings, or an arc of a circle (radar range), or part of some other curve such as hyperbola (loran).

Line of Sight. The straight line between two points. This line is in the direction of a great circle, but does not follow the curvature of the earth. Used also to describe certain radio waves where minimal beveling occurs.

Local Notice to Mariners. A written document issued by each U.S. Coast Guard district to disseminate important information affecting aids to navigation, dredging, marine construction, special marine activities, and bridge construction on the waterways within that district. Scheduled Loran-C system outages are published in *Local Notice to Mariners*.

Locus. All possible positions of a point or curve satisfying stated conditions.

Longitude (Lo). Distance east or west of the prime meridian expressed in degrees from zero to 180 east or west; e.g., Lo 123W, or as degrees, minutes, and seconds.

Loran. A contraction of long-range navigation, used to describe an electronic navigation system using a chain of transmitting stations that allows mariners (or aviators) to determine their position. When used in a generic sense, the word "loran" is not capitalized (except at the beginning of a sentence). When used to denote a specific system (e.g. Loran-C) the word loran is capitalized.

Loran-A. Also called *standard loran*, a forerunner to the present Loran-C system operating in the medium frequency band (1850 – 1950 kHz) phased out in 1980 in the United States.

Loran-C LOP. Line of position as determined from reception of the loran master signal and that of one secondary. Loran-C LOPs at convenient intervals are printed on NOS charts. See also *Rate*.

Loran-C Overprinted Chart. Nautical chart with Loran-C TD LOPs superimposed, used for navigation and coordinate conversion.

Loran-C Plotter. A device (typically made of cardboard or plastic) that enables interpolation between charted loran LOPs. Another method of interpolation is printed on loran overprinted charts. See also *Loran Linear Interpolator*.

Loran-C Signal Availability. The design minimum availability for a Loran-C triad is 99.7%, computed on an approximately monthly basis. For purposes of computing availability, a baseline (station pair) is considered unavailable when any of the following conditions exist:

(i) TD out of tolerance,

(ii) ECD out of tolerance,

(iii) improper phase code or GRI, or

(iv) master or secondary station off-air or operating at less than 50% of specified power output.

Loran Chain. Series of three to six transmitting stations consisting of a master station and two to five secondary stations used in the loran system.

Loran Linear Interpolator. A small inset diagram shown on loran overprinted charts that enables interpolation of time differences. Alternatively, a cardboard or plastic card with several overprinted scales used for this same purpose.

Loran Monitor Site (LORMONSITE). Monitor site to observe transmitted signal (signal strength, time difference, LOP, and pulse shape) as received in the coverage area. Formerly termed System Area Monitor (SAM).

Loran Pulse. Basic "building block" of the transmitted loran signal. The loran pulse exhibits a characteristic (and well controlled) waveform which can be identified and timed by a receiver. The loran signal from a master station actually consists of nine pulses. The first eight pulses are spaced 1,000 microseconds apart, followed at an interval of 2,000 microseconds by the ninth pulse. Secondary stations transmit only eight pulses, each separated by 1,000 microseconds. Pulsed transmission saves on the power required for signal transmission and facilitates signal identification. Multiple-pulse transmission is used rather than single-pulse transmission to increase the average power of the loran signal. The appearance of the pulse is discussed elsewhere in this handbook.

Loran Station (LORSTA). Facility housing master or secondary transmitter.

Low Frequency. Radio transmissions in the range of 30 to 300 kHz. The Loran-C system is a low-frequency system.

Magnetic Compass. A magnet, balanced so that it can pivot freely in a horizontal plane; a sailor's most common and most reliable direction-indicating aid.

Magnetic Direction (M). A direction relative to the earth's magnetic field and magnetic north. Magnetic courses are labeled with an "M" to signify "magnetic."

Magnetic Meridian. A system of "meridians" passing through the earth's magnetic poles. A compass aligns with these "meridians" if there is no local magnetic field on the vessel to cause deviation.

Master Station. Essential component of a Loran-C chain. This station broadcasts the signal that is used to identify the chain (the GRI) and is the common base against which all time differences are calculated.

Mega-. Prefix meaning 1 million.

Mercator Projection. The projection technique most commonly used in navigational charts; shapes and distances are increasingly distorted as you move into extreme northern and southern areas. This is a cylindrical projection ingeniously modified by expanding the scale at increase latitudes to preserve ship's direction, and angular relationships.

Meridian (Geographic Meridian). A great circle of the earth passing through both the geographic poles and any given point on the earth's surface.

MF. See Chapter I, Table I-3.

Micro-. Prefix meaning one millionth.

Microsecond (us or usec). One millionth of a second.

Most Probable Position. Vessel's probable position considering all available navigational information. Term is generally used when there is position uncertainty as a result of conflicting or ambiguous information.

Nano-. Prefix meaning one billionth.

Nanosecond (ns or nsec). One billionth of a second.

Nautical Mile (nm). A unit of distance used principally in navigation. The international nautical mile is 1,852 meters long.

Nautical Slide Rule. Analog device for solving time-speed-distance calculations. In present manufacture these are typically circular slide rules with three separate scales graduated in units of time, speed, and distance.

Navigation. The art and science of conducting a vessel or aircraft safely from one point to another.

North Geographic Pole. A reference for specifying a position on the earth's surface, at the north end of the earth's axis. Also called *True North Pole.*

North Magnetic Pole. The central point of the north end of the earth's magnetic core to which a compass points when it is free of other influences.

Notch Filters. Filters in a loran receiver that are either fixed or capable of being tuned to reduce ("notch out") the effects of interfering signals. Some filters (termed *Pac-Man* filters) can automatically seek and notch out interfering signals. Typical signals that can cause loran interference are listed in this *Loran-C Handbook.* The notch filters on a loran should be adjusted for the area of intended cruising to minimize the interference caused by the competing signal.

Out of Tolerance (OOT). A condition in which a Loran-C signal or time difference exceeds established tolerances. An out-of-tolerance (OOT) condition causes the secondary transmitter to blink.

Paraline Plotter. Plotter that has a set of rollers attached to enable the device to be moved parallel to itself, and used for the same purpose as parallel rules.

Parallel of Latitude. Any of the imaginary small circles parallel to the equator and representing latitude.

Phase Code Interval (PCI). That interval over which the phase code repeats itself. For the Loran-C system, phase codes repeat every two GRIs.

Phase Coding. This is a scheme of changing the phase of the pulses in a transmitted loran signal to minimize pulse-to-pulse skywave interference and to reject synchronous interfering signals. Master and secondary transmitters use different phase codes for signal identification. These codes are shown in Chapter II of this handbook.

Phase Velocity. Term used to describe the velocity of the leading edge of the Loran-C wave at its point of contact with the earth's surface. This velocity is affected by conductivity and atmospheric effects.

Plotter. Device for drawing straight lines on a nautical chart, and measuring courses, bearings, and (with some plotters) distances. Term is also used for any electromechanical device that shows the track of a vessel or aircraft on a chart.

Plotting Sheet. A blank chart, usually on the Mercator projection, showing only the graticule and a compass rose. The meridians are usually unlabeled by the publisher so that these can be appropriate labeled when the chart is used in any longitude. Plotting sheets are often used in-lieu of charts when the vessel is "off-soundings" (in deep water). By using special tables, Loran-C LOPs can be drawn on plotting sheets.

Position. On the earth this refers to the actual geographic location of a vessel defined by two parameters called coordinates. Those customarily used are latitude and longitude. Position may also be expressed as a bearing and distance from an *object,* the position of which is known, or by loran TDs.

Position Line. See *Line of Position.*

Predictable Accuracy. Term meaning the same as absolute or geodetic accuracy.

Primary Phase Factor (PF). A correction to a Loran-C reading due to signal propagation through the atmosphere as opposed to propagation through free space. The speed of Loran-C signals through the atmosphere is equal to the speed through free space divided by the atmospheric index of refraction. This speed is taken as 2.99691162 times 10^8 meters per second.

Prime Meridian. The meridian from which longitude is measured both east and west; 0 longitude. It passes through Greenwich, England, and divides the earth into Eastern and Western Hemispheres.

Protractor. An instrument for measuring angles on a surface, such as a chart. Typically a protractor is constructed of transparent plastic and has a semicircular scale measured in degrees.

Pulse Leading Edge. That portion of the Loran-C pulse between the beginning and peak.

Pulse Repetition Frequency or Rate (PRF, PRR). The average number of pulses per unit of time. For the Loran-C system, the PRF or PRR is the reciprocal of the GRI. Thus, a chain with a GRI of 50,000 usec would have a PRR of 20 Hertz.

Pulse Trailing Edge. That portion of the Loran-C pulse following the peak.

Radionavigation. The determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of the propagation properties of radio waves.

Radionavigation System Parameters. Navigation systems described are defined in terms of system parameters which determine the use and limitations of the individual navigation system's signal in space. These parameters are:

- Ambiguity
- Accuracy
- Availability
- Capacity
- Coverage
- Fix Dimension
- Fix Rate
- Integrity
- Reliability
- Signal Characteristics

(See separate definitions of each term.)

Rate. Generic term sometimes used to describe a Loran-C LOP or family of LOPs from a given station pair. Nautical charts, for example, will identify the "rates" shown, e.g., 9960-W, 9960-X, 9960-Y, 9960-Z, 7980-W, etc.

Reciprocal Bearing or Course. A bearing or course that differs from the original by 180 degrees.

Reciprocal Direction. Corresponding but reversed direction obtained by adding or subtracting 180 degrees to the reference direction.

Relative (R). See *Relative Direction.*

Relative Direction (Bearing). A direction relative to the fore-and-aft line of a vessel, expressed in degrees and labeled "R."

Reliability. The reliability of a navigation system is a function of the frequency with which failures occur within the system. It is the probability that a system will perform its function within defined performance limits for a specified period of time under given operating conditions. Formally, reliability is one minus the probability of system failure.

Remote Operating System (ROS). System developed by the U.S. Coast Guard to permit remote-control of loran stations and reduce the manning requirements. ROS consists of two individual sets of equipment:

(i) the local station operating set (LSOS) which is located at the transmitting station, and

(ii) the remote site operating set (RSOS) which is located at the remote (or control) station.

ROS permits the operation of a transmitting station to be controlled from a remotely located station.

RHO-RHO (ranging mode). A mode of operation of a radionavigation system in which the times for the radio signals to travel from each transmitting station to the receiver are measured rather than their differences (as in the hyperbolic mode). This is based upon the known correspondence of the transmission time to UTC. In principle, Loran-C can be used in the RHO–RHO mode (see attached references), but this requires special equipment not used by the typical user.

Root Mean Square (RMS). The square root of the arithmetical mean of the squares of a group of numbers.

Secondary Coding Delay (SCD or CD). Interval in microseconds between the reception of a loran signal at the secondary station and the time when the secondary station transmits a signal in the loran navigation system. Secondary coding delays are published for each secondary station. Sometimes referred to simply as coding delay (CD).

Secondary Phase Factor (SF). The amount, in microseconds, by which the predicted time difference of a pair of Loran-C signals that travel over an all seawater path differs from that of signals that travel through the atmosphere. For distances, denoted D, of less than or equal to 100 NM this SF is approximately:

$$SF = (0.00176)D + 0.510483/D - 0.011402,$$

for distances greater than or equal to 100 NM, this SF is approximately:

$$SF = (0.00346776)D + 24.0305/D - 0.40758.$$

Secondary Station. One of the two to five other transmitters in the Loran-C chain (designated V, W, X, Y, and Z) that transmits a signal, keyed in time to that of the master, used to compute a time difference. At one time, the secondary transmitter would transmit (after an interval known as the secondary coding delay) only on receipt of the master signal. These station's transmissions were *controlled* by the master station and were called *slave* stations. Now, the secondary transmitters maintain their own time standard, but the time of transmission relative to the master signal is designed to be the same as before. Technically speaking the transmissions of secondary stations are now *referenced* to the master.

Service Area. See *Coverage Area.*

Set. The direction *towards* which the current is flowing expressed in degrees. This term is also commonly used to mean the direction towards which a vessel is being deviated from an intended course by the combined effects of external force such as wind and current.

Settling. Second step in the Loran-C receiver sequence of signal acquisition, settling, and tracking. In this step the Loran-C receiver automatically aligns the phase codes and identifies the standard zero crossing point to establish ground wave tracking. See *Acquisition, Tracking*.

SHF. See Chapter I, Table I-3.

SIGMA. See *Standard Deviation.*

Signal Characteristics. Signals in space are characterized by power levels, frequencies, signal formats, data rates, and any other information sufficient to completely define the means by which a user derives navigational information.

Signal-to-Noise Ratio (SNR). The ratio of the signal strength to that of the electronic noise (background) in a defined frequency spectrum. Loran coverage diagrams are calculated so that the SNR is at least 1:3, even though many receivers are capable of processing weaker signals. Signal-to-noise is sometimes expressed in decibels (dB). The SNR in decibels is mathematically equal to 20 log (SNR), so that an SNR of 1:3 works out to approximately -9.54 -- often rounded to -10.

Skywave. Skywave is an indirect radio wave that reflects off the ionosphere, rather than traveling a direct path from transmitter to receiver. Because these waves travel a different distance (in particular a longer distance), skywaves will give an erroneous TD reading in a loran receiver. The shape of the loran pulse and phase coding are used to attempt to minimize or eliminate the effects of skywave contamination.

Skywave Delay. The time interval between the arrival of the groundwave and the various skywave reflections. Typically, skywaves can arrive as early as 35 microseconds, or as late as 1,000 microseconds after the groundwave.

Slave Station. Term used with standard loran. See *Secondary Station.*

Small Circle. Any plane passing through the earth, but not through its center, produces a small circle at its intersection with the earth's surface.

South Geographic Pole. A reference for specifying a position on the earth's surface, at the south end of the earth's axis. Also called *True South Pole.*

South Magnetic Pole. The end of the earth's magnetic core opposite the North Magnetic Pole. (Located in Antarctica.)

Spectrum Specification. The spectrum specification relates to the amount of energy allowed outside the authorized 90 to 110 kHz band. The maximum out of band energy is constrained to be no more than 1% of the total radiated energy, with subsidiary constraints than no more than 0.5% of the total radiated energy be less than 90 kHz nor greater than 110 kHz.

Speed (S). The rate at which a vessel advances relative to the water over a horizontal distance. When expressed in terms of nautical miles per hour, it is referred to as knots (kn or kt). One knot equals approximately 1.15 statute miles per hour.

Speed Curve. A curve relating the vessel's speed through the water to the engine's throttle setting expressed in revolutions per minute (RPM).

Speed LOP. An LOP situated at approximately right angles to the intended track, so named because the EP derived from this LOP provides a good indication of the vessel's SMG.

Speed Made Good (SMG). Indicates the overall speed actually accomplished relative to the ground along the course line.

Speed of Advance (SOA). Indicates the speed *intended* to be made relative to the ground along the track line.

Speed Over the Ground (SOG). The *actual* speed made good at any instant in time with respect to the ground along the course being steered.

Speed Through the Water (STW). The *apparent* speed indicated by log-type instruments or determined by use of tachometer and speed curve or table, at a particular point in time, along the course line.

Speed–Time–Distance. A formula to calculate speed, time, or distance.

Spherical Coordinate System. The system used to define positions on the earth's surface.

Standard Deviation (SIGMA). A measure of the dispersion of random errors about the mean value. If a large number of measurements or observations of the same quantity are made, the standard deviation is the square root of the sum of the squares of deviations from the mean value divided by the number of observations less one.

Standard Sampling Point (SSP). In the calculation or measurement of Loran-C field strength it is necessary to specify the point on the pulse to which the calculation or measurement relates. This point is termed the standard sampling point and is the point on the Loran-C pulse envelope 25 microseconds after the beginning of the pulse. For the standard Loran-C pulse with zero ECD, the amplitude at the standard sampling point is 0.506 of the peak amplitude.

Standard Zero Crossing. The positive zero crossing at 30 microseconds of a positively phase coded pulse on the antenna-current waveform. This zero crossing is phase-locked to the Loran-C station's cesium reference. The standard zero crossing is used as a timing reference for measurement of Loran-C signal specifications.

Standardized Color Coding (Charts). Standardized colors used to show Loran-C lines of position on nautical charts. These color codes for the various secondaries in the loran chain are W=blue, X=magenta, Y=black, and Z=green.

Station-Pair. A master and secondary station in a Loran-C chain from which it is possible to derive an LOP.

System Ambiguity. System ambiguity exists when the navigation system identifies two or more possible positions of the vehicle, with the same set of measurements, with no indication of which is the most nearly correct position. See also *Ambiguity.*

System Area Monitor (SAM). See LORMONSITE.

System Capacity. System capacity is the number of users that a system can accommodate simultaneously. The Loran-C system could theoretically allocate an infinite number of users.

Tachometer. An instrument that indicates the speed of the engine measured in revolutions per minute (RPMs).

Theta. Bearing or direction to a fixed point to define a line of position.

Time Difference (TD). In the loran system, the time difference (in microseconds) between the receipt of the master and secondary signals.

Time To Go (TTG). Calculated time until the next waypoint is reached, obtained by dividing the distance to go by the groundspeed.

Timing of Secondary Pulse Groups. The emission delays of secondary stations are selected to ensure that the following criteria are met within each chain wherever signals can be received:

(i) The minimum time difference between any secondary and master is 10,900 microseconds.

(ii) The minimum difference of any two time differences is 9,900 microseconds.

(iii) The maximum time difference is the GRI minus 9,900 microseconds.

Track (TR). The intended or desired horizontal direction of travel *with respect to the ground.* (Synonym: Intended Track, Trackline.)

Tracking. Process of moving towards a location by adjusting the heading to compensate for prevailing current so as to travel to the station in a straight line.

Tracking (Loran). The process of measuring time differences from an acquired master-secondary Loran-C pair. The signal-to-noise ratio required for tracking of a preidentified signal is generally less than that required for signal is acquisition. For this reason it is sometimes the case that a vessel that has already acquired a loran signal can continue to navigate with this signal although an identical receiver turned on may be unable to acquire the signal. This is the terminal phase in the sequence acquisition—settling—tracking.

True North Pole. The north end of the earth's axis. Also called *North Geographic Pole.* The direction indicated by 000° or (360°) on the true compass rose.

True Rose. The resulting figure when the complete 360° direction system is developed as a circle with each degree graduated upon it, and with the 000° indicated as true north. Also called compass rose.

True South Pole. A reference for specifying a position on the earth's surface, at the sound end of the earth's axis. Also called *South Geographic Pole.*

Turning Bearing. A bearing on a charted object, measured in advance by the navigator, at which the vessel should turn to reach the next leg of the course.

Uncorrecting (A Magnetic Direction). Converting a true direction to equivalent magnetic or compass direction.

VHF. See Chapter I, Table I-3.

Variation. The angular difference between the magnetic meridian and the geographic meridian at a particular location.

Velocity Along Route (VAR). Alternate name for velocity made good.

Velocity Towards Destination (VTD). Component of vessel's velocity in the direction of the waypoint. (See Chapter IV.)

Velocity Made Good (VMG). Component of vessel's ground speed in the direction of the waypoint in use. In general, VMG is less than or equal to the vessel's ground speed. This will equal the ground speed, in the absence of current, whenever the vessel is on course and heading directly toward the waypoint. Many Loran-C receivers can display VMG.

Verification Survey. In order to ensure that Loran-C lattices printed on nautical charts are as accurate as possible, the Coast Guard, with assistance from the National Ocean Survey, has been conducting Loran-C verification surveys. The purpose of these surveys is to collect TD data. These data are then used to update and improve the accuracy of Loran-C lattices printed on previous editions of nautical charts.

Very High Frequency Radio (VHF). Radio frequency of 30 MHz to 300 MHz. The VHF system is essentially a line-of-sight system limited in range to only a little beyond the horizon. Early hyperbolic systems e.g., Gee, operated at these frequencies.

VLF. See Chapter I, Table I-3.

Waypoint (WPT or WYPT). Arbitrary geographic point entered into a loran set as a reference point for navigational calculations. Typically voyages are organized into a series of waypoints marking the legs of the trip. Most modern Loran-C receivers have provision for storing and recalling numerous waypoints.

Waypoint Sequencing (Route Option). A feature incorporated into many loran receivers that allows an operator to store a sequence of waypoints in the loran receiver's memory to describe a route. In this mode, whenever the vessel arrives at a waypoint the next waypoint in a prestored route sequence automatically appears on the display screen.

World Geodetic System (WGS). A consistent set of parameters describing the size and shape of the earth, the positions of a network of points with respect to the center of mass of the earth, transformations from major geodetic datums, and the potential of the earth (usually in terms of harmonic coefficients).

APPENDIX D

ABBREVIATIONS and ACRONYMS

This appendix contains a summary of the abbreviations and acronyms used in this *Loran-C User Handbook.* Relevant definitions of many of these terms can be found in the main text and also in Appendix C.

AAC .... Antenna/Antenna Coupler
AC .... Antenna Coupler
AC .... Alternating Current
ADF .... Automatic Direction Finder
AM .... Amplitude Modulation
ANMS .... Automated Notice to Mariners System
ASF .... Additional Secondary Factor
ASS .... Automatic Secondary Selection
ATON .... Aid to Navigation
ATS .... Automatic Transmitter Selection

BLL .... Baseline Length
BRG .... Bearing

CCZ .... Coastal Confluence Zone
CD .... Coding Delay
CDI .... Course Deviation Indicator
CDR .... Commander
CEC .... Canadian East Coast
CEP .... Circular Error Probable
CMG .... Course Made Good
COCO .... Coordinator of Chain Operations
COG .... Course Over the Ground
COI .... Cone of Influence
COMDTINST ... Commandant Instruction
CTS .... Course To Steer
CWC .... Canadian West Coast

dB .... Decibels
DC .... Direct Current
DGPS .... Differential Global Positioning System
DLCS .... Differential Loran-C System
DMA .... Defense Mapping Agency
DMAHTC .... Defense Mapping Agency/ Hydrographic and Topographic Center
DOD .... Department of Defense
DOT .... Department of Transportation
DR .... Dead Reckoning
DSC .... Digital Selective Calling
DTG .... Distance To Go

ECBF .... Earth Centered Body Fixed
ECD .... Envelope to Cycle Difference
ED .... Emission Delay
ENDDS .... Electronic Navigation Digital Data System
ENS .... Ensign
EP .... Estimated Position
ETA .... Estimated Time of Arrival
ETE .... Estimated Time Enroute

FAA .... Federal Aviation Administration
FM .... Frequency Modulation
FRP .... Federal Radionavigation Plan

GDOP .... Geometric Dilution of Position
GL .... Great Lakes
GLKS .... Great Lakes
GOA .... Gulf of Alaska
GPS .... Global Positioning System
GRI .... Group Repetition Internal
GS .... Groundwave Skywave
G–NRN .... Radionavigation Division

HDG .... Heading
HF .... High Frequency
HHA .... Harbor and Harbor Approach
HHE .... Harbor and Harbor Entrance
Hz .... Hertz

IFR .... Instrument Flying Rules

kHz .... Kilohertz
kW .... Kilowatt

LAM .... Loran Aviation Monitors
LCD .... Liquid Crystal Display
LCDR .... Lieutenant Commander
LED .... Light Emitting Diode
LF .... Low Frequency
LNM .... Local Notice to Mariners
LOP .... Line of Position
LORAN .... Long Range Navigation
LORMONSITE . Loran Monitor Site
LORSTA .... Loran Station
LPA .... Local Phase Adjustment
LT .... Lieutenant

MAG .... Magnetic
MF .... Medium Frequency
MHz .... Megahertz
MIT .... Massachusetts Institute of Technology
MPA .... Manual Phase Adjustments
MPP .... Most Probable Position

NAD .... North American Datum
NAV .... Navigation
NAVAID .... Navigation Aid
NBS .... National Bureau of Standards
NEUS .... Northeast US
NGS .... National Geodetic Survey
NM .... Nautical Mile
NMEA .... National Marine Electronics Association
NOAA .... National Oceanic and Atmospheric Administration
NOCUS .... North Central US
NORPAC .... North Pacific
NOS .... National Ocean Service
NOTAM .... Notice to Airmen
NPA .... Non-Precision Approach

OOT .... Out of Tolerance

PCI .... Phase Code Interval
PF .... Primary Phase Factor
PRF .... Pulse Repetition Frequency
PRR .... Pulse Repetition Rate

RADAR .... Radio Direction and Ranging
RDF .... Radio Direction Finding
RF .... Radio Frequency
RHO–RHO .... Range-Range Mode

RMS .... Root Mean Square
ROS .... Remote Operating System
RPM .... Revolutions Per Minute
RTCM .... Radio Technical Commission for Marine Electronics

SAM .... System Area Monitor
SARDET........... Search and Rescue Detachment
SCD .... Secondary Coding Delay
SEUS .... Southeast US
SF .... Secondary Factor
SG .... Skywave Groundwave
SHF .... Super High Frequency
SM .... Statute Miles
SMG .... Speed Made Good
SNR .... Signal-to-Noise Ratio
SOA .... Speed of Advance
SOCUS .... South Central US
SOG .... Speed Over the Ground
SSB .... Single-Side Band
SSP .... Standard Sampling Point
STW .... Speed Through the Water

TD .... Time Difference
TOA .... Time Of Arrival
TR .... Track
TTG .... Time To Go
TV .... Television

UHF .... Ultra High Frequency
USCG .... United States Coast Guard
USCGA .... United States Coast Guard Academy
USCGAUX .... United States Coast Guard Auxiliary
usec .... Microsecond
USNO .... United States Naval Observatory
USWC .... US West Coast
UTC .... Universal Coordinated Time

V .... Victor
VAR .... Velocity Along Route
VAR .... Variation
VHF .... Very High Frequency
VLF .... Very Low Frequency
VMG .... Velocity Made Good
VOR .... Very high frequency Omni-directional Radio range
VTD .... Velocity Toward Destination

W .... Whiskey
WGA .... Wild Goose Association
WGS .... World Geodetic System
WPT .... Waypoint
WYPT .... Waypoint

X .... Xray
XTE .... Cross-track Error

Y .... Yankee

Z .... Zulu

ABBREVIATED LORAN-C BIBLIOGRAPHY

This appendix presents an abbreviated Loran-C bibliography for those who wish to learn more about the history, design, operation, or use of the Loran-C system or progenitors. No claim is made that this list is complete—a complete bibliography would undoubtedly include several thousand references.

In-lieu of completeness, a representative selection of articles and texts on relevant loran-related topics is included in this bibliography. Just as there is a wide diversity of topics covered in these references, there is a substantial variation in the level of technical difficulty of the articles and texts included. Some of these references are highly technical, and of interest principally to specialists in the field. Others are written for a more general readership and are taken from the popular boating literature. This mix is quite deliberate and reflects the diverse interests of potential readers of this *Loran-C Handbook.*

No attempt has been made to refer to videotapes in this bibliography. The reader should be aware, however, that numerous videotapes on Loran-C are sold commercially, some of excellent quality.

Likewise, no owner's manuals for individual sets are included in this list. (The proliferation of makes and models would make such a list impractical to compile and rapidly out-of-date.) As well, material contained in these manuals is usually quite specific to the particular make and model, although some manuals offer excellent general discussions. Readers are advised to consult the manual for the particular set to be used.

Finally, inclusion of a particular reference in this list does not imply that the United States Coast Guard has peer-reviewed or otherwise endorsed the contents and/or any specific products mentioned therein.

Some of the articles/texts included here include information that is no longer correct and/or applicable—these are included for historical interest. Others may present alternative viewpoints to those expressed herein, and are included to lend balance and perspective.

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APPENDIX F

MILLINGTON'S METHOD

Introduction

Calculation of the propagation behavior of radio waves over mixed paths (including various types of terrain and seawater) to estimate ASFs is both theoretically complex and numerically tedious. This appendix presents a simplified description of one commonly used empirical approach for ASF calculation known as *Millington's Method.*

Chapter II discussed the overall approach for calculating the time required for a loran groundwave signal to propagate from a transmitter to the vessel or aircraft over a distance, d. To a first approximation, the time to propagate this distance is simply the distance divided by the speed of light through the atmosphere (Primary Phase Factor). Although this simple calculation is nearly correct, it is not sufficiently accurate to satisfy the absolute accuracy requirements of the Loran-C system. Two additional corrections are usually applied to this simple formula for calculation of TDs. The first, termed *secondary phase factor* (SF), corrects for signal propagation delays over seawater compared to propagation through the atmosphere. The second, termed *additional secondary factor* (ASF), corrects for the additional signal propagation delay over a mixed land/seawater path compared to an all-seawater path. Traditionally, these corrections are calculated as *increments* to be added algebraically (i.e., with regard to sign) to the time computed from the "simple" model (PF). That is, the propagation time required to traverse a distance, d, is first calculated based upon propagation through the atmosphere. Next, increments to this time (SF) and (ASF) are calculated and added to the propagation time.

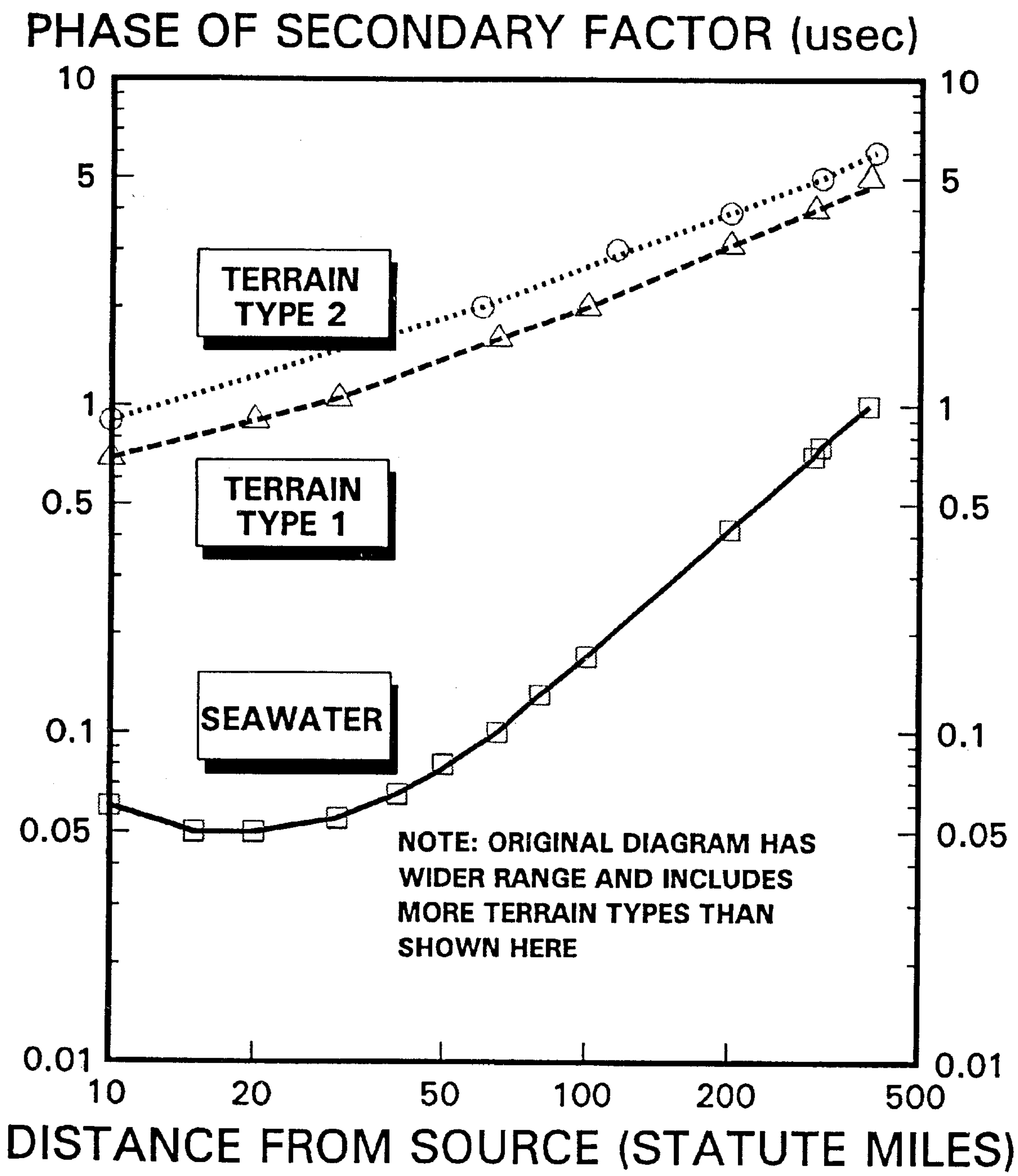
Conductivity — A Key Parameter

The conductivity, denoted by the symbol σ, is a key determinant of the magnitude of the SF and ASF corrections. Conductivity is measured in units of mhos/meter or in millimhos/meter (1,000 millimhos is equal to 1 mho). (The unit "mho," is ohm spelt backwards and captures the reciprocal relationship between resistivity and conductivity.) Table F–1 provides a sample of conductivity values for seawater and various types of terrain.

Calculation of Propagation Delays From Conductivity Data

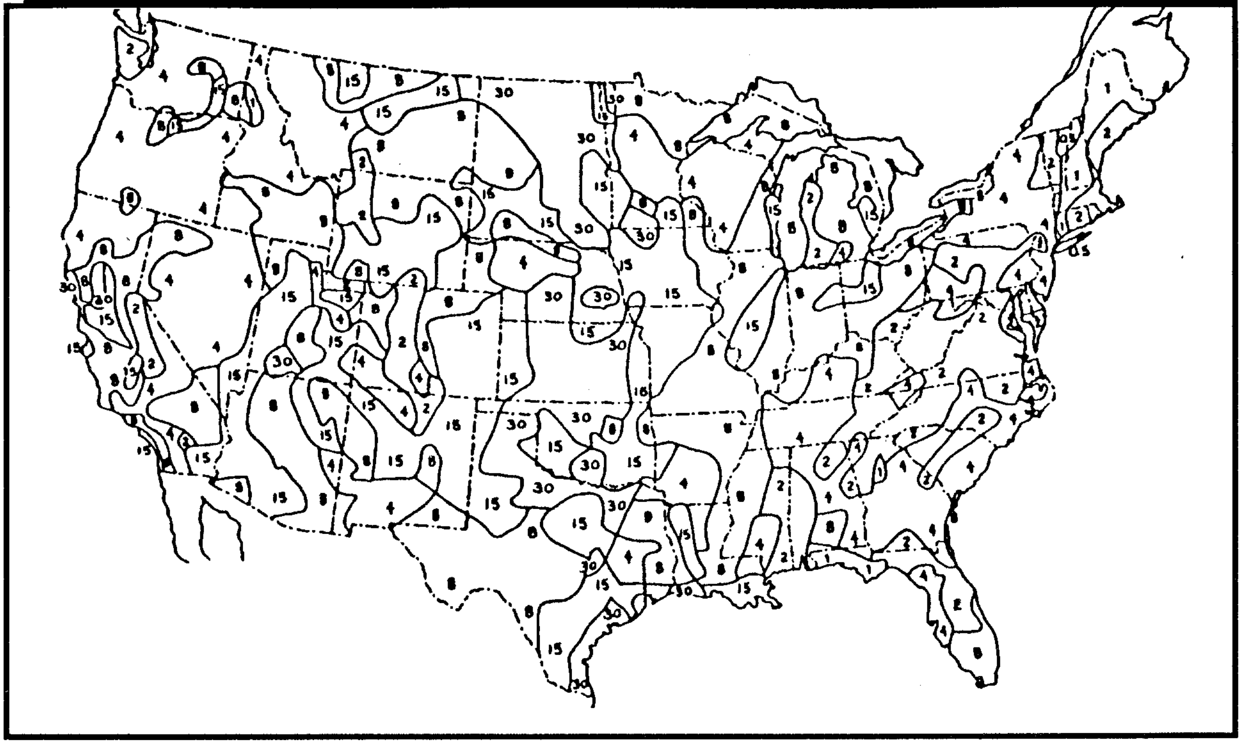
The incremental propagation time (compared to the travel time through the atmosphere) for *homogeneous* paths is a function of distance and can be determined using generalized curves found in National Bureau of Standards (NBS)

FIGURE F-1. VARIATION OF PHASE OF SECONDARY FACTOR WITH DISTANCE FROM SOURCE



PORTION OF CHART GIVEN IN NBS CIRCULAR 573

FIGURE F-2. ESTIMATED EFFECTIVE GROUND CONDUCTIVITY IN THE UNITED STATES. NUMBERS SHOWN ARE EFFECTIVE CONDUCTIVITY IN MILLIMHOS/METER.



Circular 573. An extract from these curves is reproduced in Figure F–1.[1] This figure shows the additional propagation time (phase of the secondary factor) in usec as a function of the distance of the receiver from the transmitter. This illustration includes estimates for an all-seawater path, and also homogeneous paths across two different types of terrain with lower conductivity.

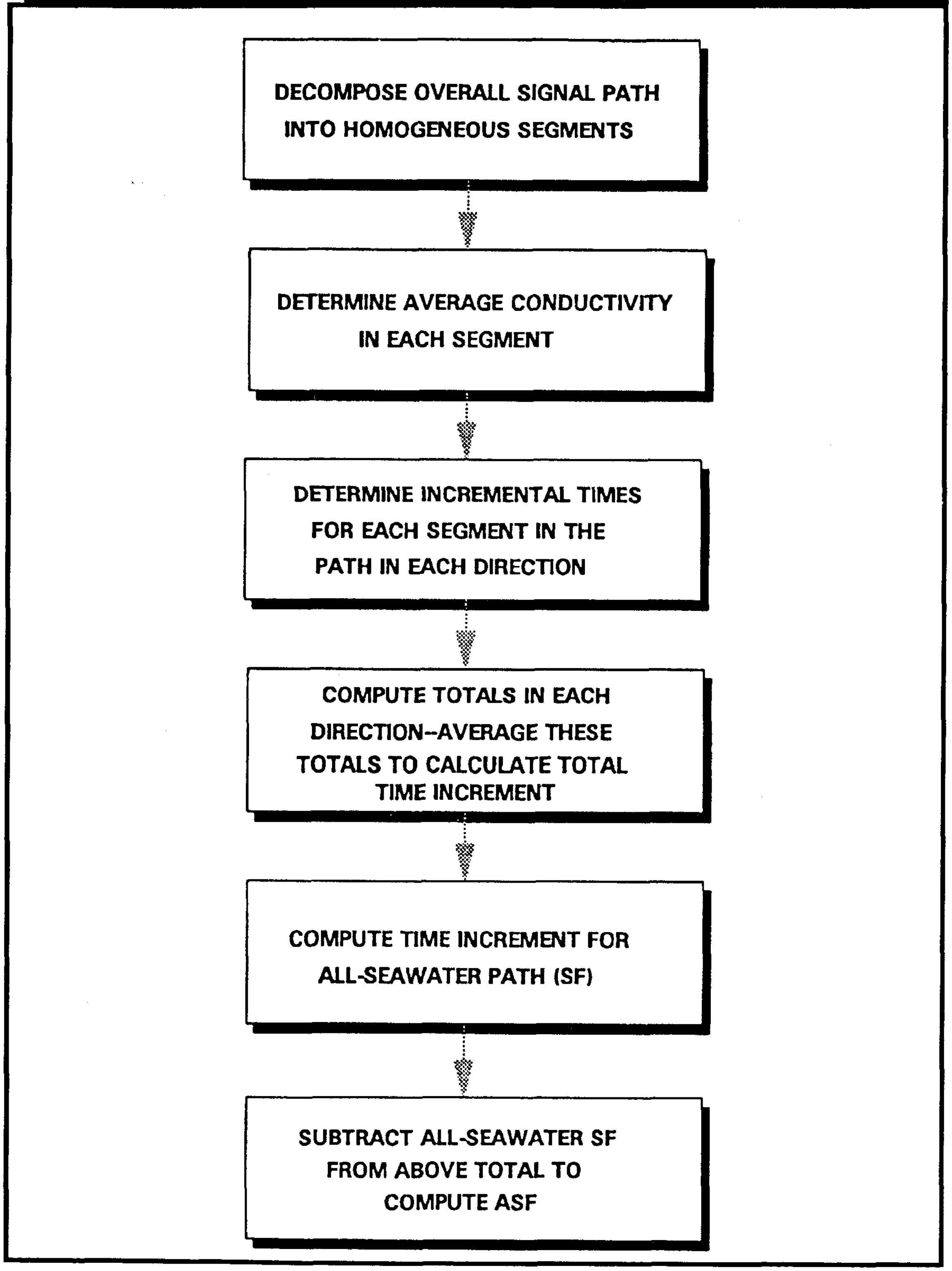
To illustrate, the incremental propagation time (over that calculated employing the velocity of light through the atmosphere) for a signal to propagate a distance of 390 statute miles (SM) over an all-seawater path would be approximately 1 usec, referring to the "seawater" path curve in Figure F–1.[2]

–Conductivity Data

Calculation of these time increments requires a data base of conductivity estimates across all possible land and seawater paths. Figure F–2 shows these estimates (in millimhos/meter) for the continental United States.

[1]This set of curves has been simplified for reproduction purposes. Only three types of propagation surface are included. The actual NBS diagram has data for numerous conductivity values included.
[2]The SFs for the seawater path can also be calculated from equations (II–6) and (II–7) given in the main text.

FIGURE F-3. FLOWCHART FOR COMPUTATION OF ASFs USING MILLINGTON'S METHOD



–Use of Conductivity Data in Millington's Method

Figure F–3 shows the computational steps in the use of Millington's Method. This procedure will be illustrated with a numerical example.

The first step is to decompose the overall path from transmitter to receiver into a series of homogeneous segments—each with the same conductivity value. Figure F–4 shows an illustrative path from a loran transmitter over seawater and two islands, each with a different terrain type. In this case there are a total of five segments in the path, three over seawater, and two over islands of different terrain type.

The second step shown in Figure F–3 is to determine the average conductivity in each segment. The average conductivity for the seawater segments is 5,000 millimhos/meter. Average conductivities for the various terrain types can be found in tables similar to Table F–1 or generalized diagrams similar to Figure F–2.

The third step shown in Figure F–3 is to compute the propagation time increments for each segment of the path in each direction. Consider first the direction from the transmitter to the vessel in Figure F–4. Table F–2 shows the equations necessary for computation of these time increments in both directions for a five-segment path.

(i) The first segment is over seawater, a distance of 65 statute miles (SM). Reference to Figure F–1 (or exact computations using the seawater equations in Chapter II) indicates that the time increment for this segment is approximately 0.1 usec.

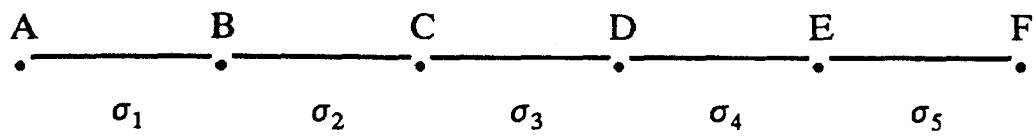
(ii) The second segment is over land of terrain type 2 from 65 miles (at the left endpoint) to 100 miles (at the right endpoint). To calculate the time increment, read from Figure F–2 (Type 2 terrain) the time increments associated with the

TABLE F-1.

Terrain Description	Conductivity in Milli mhos/meter σ
Seawater	5,000
Rich agricultural land	10 — 30
Forested land	8
Fresh water	8
Pastoral land, medium hills and forestation	4 — 5
Rocky land, dry sandy coastal land	2
Mountainous land, cities	1
Snow-covered mountains	0.5

SOURCE: USCG Loran-C Lecture Notes.

TABLE F-2.
NOTATION FOR COMPOSITE BASELINE ANALYSIS.



$$t_{(A-F)} = t_{(A-B)\sigma_1} + \left[t_{(A-C)\sigma_2} - t_{(A-B)\sigma_2}\right] + \left[t_{(A-D)\sigma_3} - t_{(A-C)\sigma_3}\right] \cdots + \left[t_{(A-F)\sigma_5} - t_{(A-E)\sigma_5}\right]$$

$$t_{(F-A)} = t_{(F-E)\sigma_5} + \left[t_{(F-D)\sigma_4} - t_{(F-E)\sigma_4}\right] + \left[t_{(F-C)\sigma_3} - t_{(F-D)\sigma_3}\right] \cdots + \left[t_{(F-A)\sigma_1} - t_{(F-B)\sigma_1}\right]$$

$$t = \frac{t_{(A-F)} + t_{(F-A)}}{2}$$

left endpoint (1.6 usec) and the right endpoint (2 usec). The time increment, 0.4 usec in this example, is the difference between these two values.

(iii) The third segment in Figure F–4 is an all-seawater path 100 statute miles in extent, with a left endpoint of 100 miles and a right endpoint of 200 miles. The propagation time increments (Figure F–1) are 0.18 usec and 0.41 usec, respectively, an increment for this segment of 0.23 usec.

(iv) The fourth segment is over terrain Type 1, with a left endpoint of 200 miles and a right endpoint of 310 miles. The corresponding time increments are approximately 3.2 usec and 4.3 usec, a difference of 1.1 usec.

(v) The final segment is over seawater, from 310 to 390 statute miles. The time increment for this seawater segment is approximately 1.01 usec (at 390 statute miles) less 0.74 usec (at 310 statute miles), a difference of 0.27 usec.

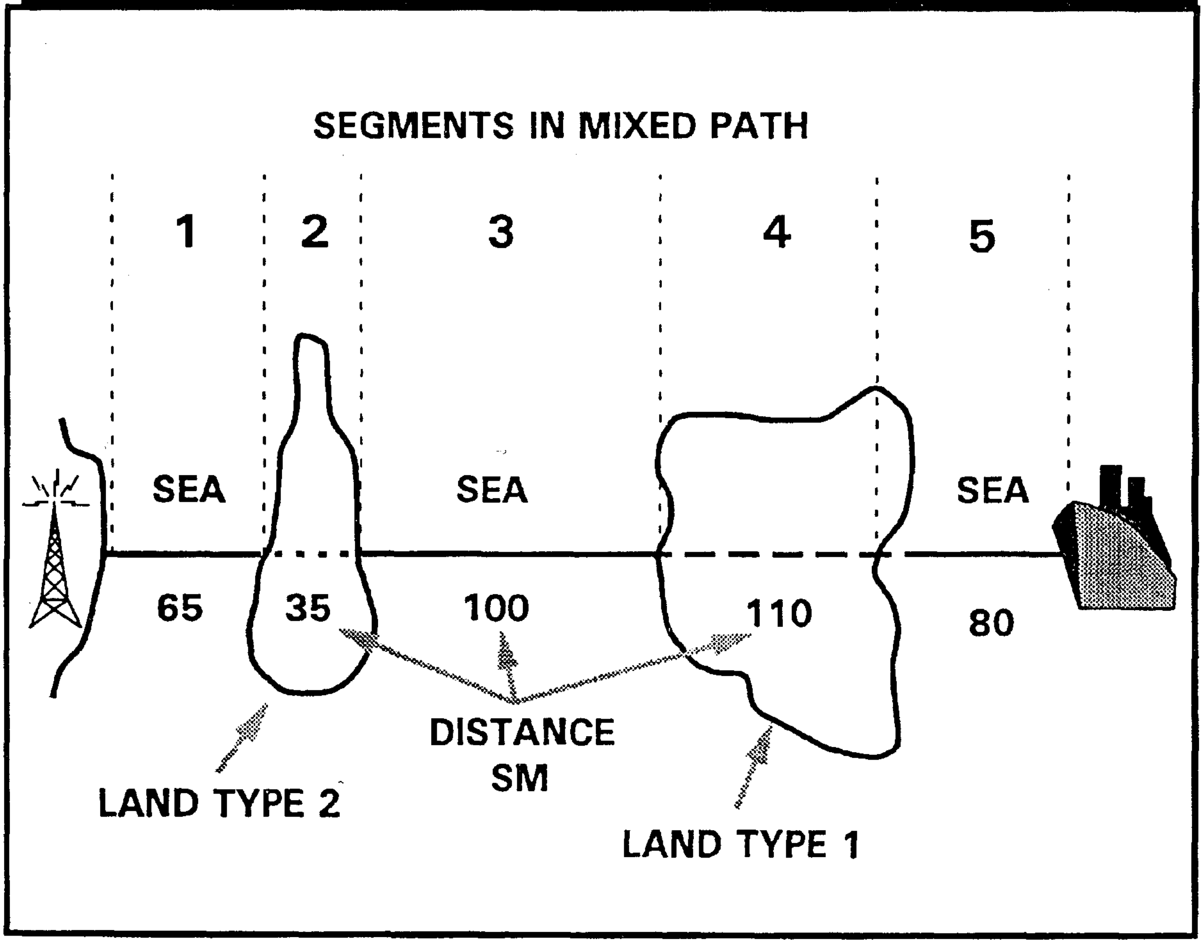
The fourth step in Figure F–3 is to compute the total time increments in each direction. The total time increment from left to right is 0.1 + 0.4 + 0.23 + 1.1 + 0.27 = 2.1 usec. If the direction of calculation were reversed, an identical series of computations would lead to a total time increment of approximately 2.3 usec. The computational procedure is to *average* these calculations to estimate the time increment.

(The need to consider propagation along both directions of the pathway relates to the principle of reciprocity. This principle states that in a linear uniform propagation medium, the response of the medium to a source is unchanged when the source and the receiver are interchanged. The direction of a path from a source across a medium does not affect the response of the medium. As shown above, Millington's method predicts a phase delay by computing a correction from source to transmitter and a reciprocal correction. The values of these corrections are averaged. Except in the unlikely case where the path and its reciprocal are identical, the two time increments calculated in each direction are not identical, because the conductivity segments are biased, depending upon their proximity to the source. For more details, consult references given in Appendix E.)

This average, 2.2 usec in this example, is the total increment to propagation time compared to an atmospheric signal path. Recall that the additional secondary factor is defined as the incremental time *over and above* an all-seawater path.

The fifth step in Figure F–3 is to compute the SF for the entire path. Using either Figure F–1 or the equations given in Chapter II, the SF for the

FIGURE F-4. A NUMERICAL EXAMPLE OF A MIXED PATH FOR ADDITIONAL SECONDARY FACTOR CALCULATIONS BY MILLINGTON'S METHOD



signal to propagate 390 statute miles over seawater would be 1.01 usec.

The final step shown in Figure F–3 is to subtract the time increment for an all-seawater path from the average total increment to calculate an ASF. The ASF in this case would be 2.20 – 1.01 = 1.19 usec.

The ASF calculated above applies to the propagation path from one transmitter to one location in the coverage area. The ASF appropriate to a loran TD LOP involves two propagation paths, one from the master to the user's location, the other from a secondary to the user's location. Therefore, to calculate the ASF corresponding to a particular master station pair, it is necessary to make the above calculations for both paths, and subtract the individual ASFs to calculate an ASF for a TD at that point in the coverage area. Careful examination of Figure F-1 (or the original curve from which this extract was taken) indicates that the curves of propagation delays for various types of terrain are generally above that for seawater—that is, land slows loran waves even more than water. The ASF calculated for a single path will generally be either zero (if the path is an all seawater path) or positive (if the path involves segments over both water and land). However, the ASF for a master-secondary pair could be either positive or negative, depending upon the propagation characteristics for the paths from the user's location to the master and secondary. This is why the ASF correction tables contain both positive and negative quantities—to a first approximation entries will either be positive or negative depending upon the relative portion of the paths from secondary or master that are over land versus seawater.

Reference to Figure F-4 shows why ASFs sometimes appear to change in a discontinuous manner. Imagine, for example, that the path between the transmitter and the user were swung through an arc. As soon as the path were clear of the islands, the ASFs would go abruptly to zero. Lack of smoothness of the ASF curves (and the reason why these curves are not easily interpolated) relates (among other things) to lack of smoothness of terrain features.

In practice, these predictions would be validated with survey data, and ASF tables and loran overprinted charts adjusted based upon survey data.

Computer Implementation

In order to produce ASF tables, it is necessary to replicate the computational procedure used here many times over a latitude–longitude grid. As these computations are numerically tedious, computers are used to produce the tables of ASF values. Readers interested in details of these computer programs can refer to Speight (1982).

APPENDIX G

GDOP EXPLAINED and ILLUSTRATED

Introduction

Equation (III–1) in Chapter III of the main text enables calculation of the fix accuracy (2 drms) in terms of the bearings from the user to the master and two secondary stations, the common standard deviation of each TD, the correlation coefficient between the two TDs, and the gradient of the LOPs along the baseline.

To recapitulate, 2 drms is the radius of the fix area with probability content of at least 95%. That is, at the given point in the coverage area, at least 95% of the apparent fixes would be within a circular area of radius 2 drms. It is given by the equation:

$$2\ \text{drms} = \frac{2K\sigma}{\sin C}\left[\frac{1}{\sin^2(\frac{A}{2})} + \frac{1}{\sin^2(\frac{B}{2})} + \frac{2\rho\ \text{Cos}\ C}{\sin(\frac{A}{2})\ \sin(\frac{B}{2})}\right]^{0.5} \qquad \text{(G-1)}$$

where:

A, B, C = angles defined in Figure G–1,

ρ = correlation coefficient between the measured TDs, generally taken to be 0.5,

K = baseline gradient, 491.62 ft/usec, and

σ = common value for the standard deviation of each TD, generally taken to be 0.1 usec for accuracy calculations.

Referring to Figure G–1, angle A is the angle between the first secondary and the master station (viewed from the user's position) and angle B is that subtended by the master and the other secondary. The actual TDs are shown by the dashed lines which are bisectors of angles A and B. The crossing angle, C, for the three station fix is:

$$C = A/2 + B/2. \qquad \text{(G-2)}$$

The parameter ρ in equation (G–1) is the correlation coefficient between the two TDs. The three individual signals from the master and two secondaries are assumed to be independent and uncorrelated because the timing of each signal is derived from separate cesium oscillators. However, the two TDs are correlated to some degree because both are based upon a common master signal. The correlation coefficient varies throughout the coverage area, but is typically given the value 0.5 in chain coverage calculations.

Numerical Examples

In the illustration, angle A is approximately 89 degrees, and angle B is approximately 70 degrees and angle C = 89/2 + 70/2 = 79.5 degrees. Because the crossing angle is quite large, it is to be expected that the value of 2 drms at this location in the coverage area would be relatively small. This conjecture is shown to be correct: substitution of these angles and other constants given results in a value of 2 drms of approximately 235 ft—quite accurate indeed.

FIGURE G-1. ILLUSTRATION OF CROSSING ANGLE GEOMETRY FOR A LORAN-C TRIAD.

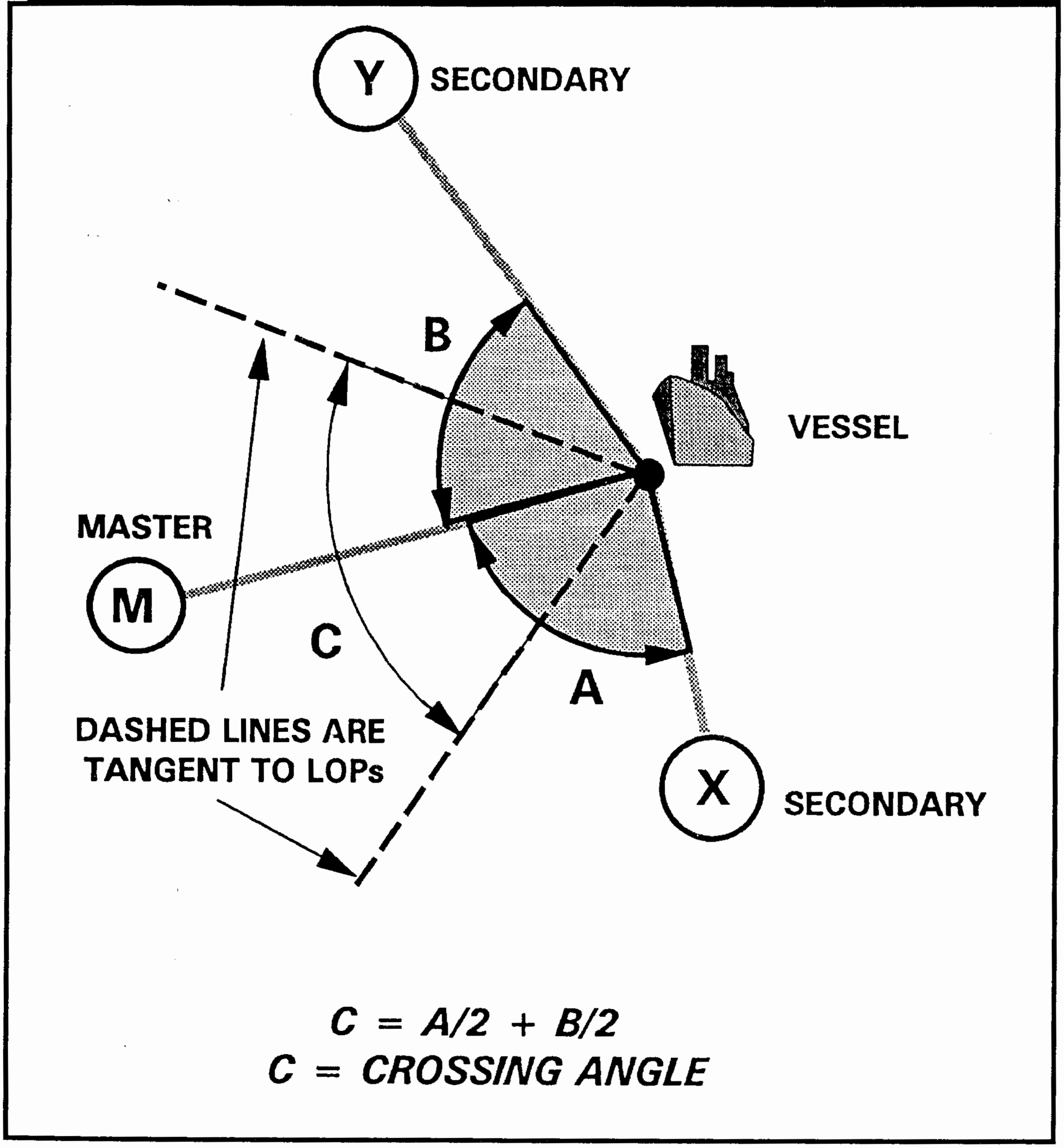
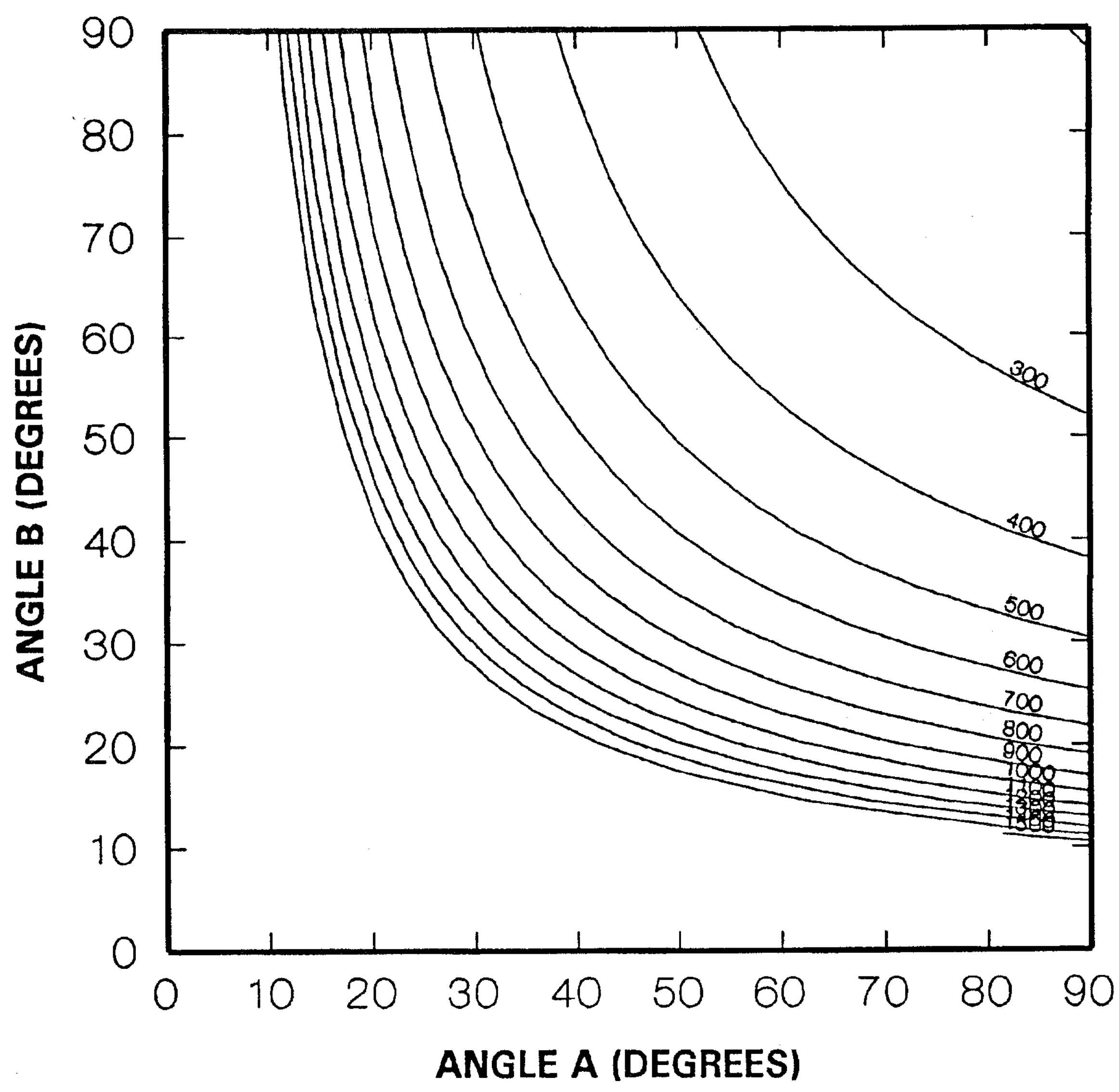


FIGURE G-2. CONTOURS OF EQUAL 2 drms IN TERMS OF ANGLES A AND B.



If the vessel (or aircraft) in the illustration were to move away from the master in a generally northeast direction until angle B were 20 degrees and angle A were 30 degrees (thus, angle C = 25 degrees), then the value of 2 drms would increase to approximately 1,922 ft.

Equation (G–1) can be used to calculate 2 drms for a three-station loran fix anywhere within the coverage area. Table G–1 shows how 2 drms varies with angles A and B. This quantity grows quite large whenever either or both of these angles are small. Figure G–2 shows contours of equal value of 2 drms. In general, as shown in Figure G–2, the value of 2 drms is a function of the placement of the master and secondary stations, the user's location relative to these stations, and the common standard deviation of the TDs.

According to Swanson (1978), the greatest possible accuracy (minimum value of 2 drms) will occur with *four* stations, each subtending a 90 degree angle with the adjacent station so as to form two orthogonal (at right angles) and uncorrelated LOPs. The optimal accuracy for this configuration, 2 drms*, is given by the equation:

$$2 \text{ drms}^* = 2\sqrt{2}\, K\, \sigma = 139.1 \text{ ft}, \qquad \text{(G-3)}$$

given the assumed values for each of these parameters.

The *geometric dilution of position* (GDOP) is defined as the ratio of the actual value of 2 drms corresponding to equation (G–1) divided by this "best" value, or:

$$\text{GDOP} = \frac{2 \text{ drms}}{2\, K\, \sigma \sqrt{2}}. \qquad \text{(G-4)}$$

TABLE G-1. 2 drms AS A FUNCTION OF ANGLES A AND B.

ANGLE B (Degrees)	ANGLE A (Degrees) 10	15	20	25	30	40	50	60	70	80	90
10	11,212	7,541	5,738	4,660	3,940	3,035	2,491	2,128	1,871	1,682	1,539
15	7,541	5,007	3,780	3,057	2,579	1,985	1,631	1,396	1,230	1,108	1,015
20	5,738	3,780	2,835	2,282	1,920	1,474	1,210	1,036	914	824	757
25	4,660	3,057	2,282	1,830	1,535	1,175	963	824	727	657	603
30	3,940	2,579	1,920	1,535	1,285	980	802	686	605	547	503
40	3,035	1,985	1,474	1,175	980	743	606	518	457	413	380
50	2,491	1,631	1,210	963	802	606	493	421	371	335	309
60	2,128	1,396	1,036	824	686	518	421	359	316	286	264
70	1,871	1,230	914	727	605	457	371	316	279	252	233
80	1,682	1,108	824	657	547	413	335	286	252	229	212
90	1,539	1,015	757	603	503	380	309	264	233	212	196

FIGURE G-3. 2 drms ACCURACY IS DETERMINED BY STATISTICAL SIGNAL CHARACTERISTICS AND THE USER'S LOCATION RELATIVE TO THE TRANSMITTERS.

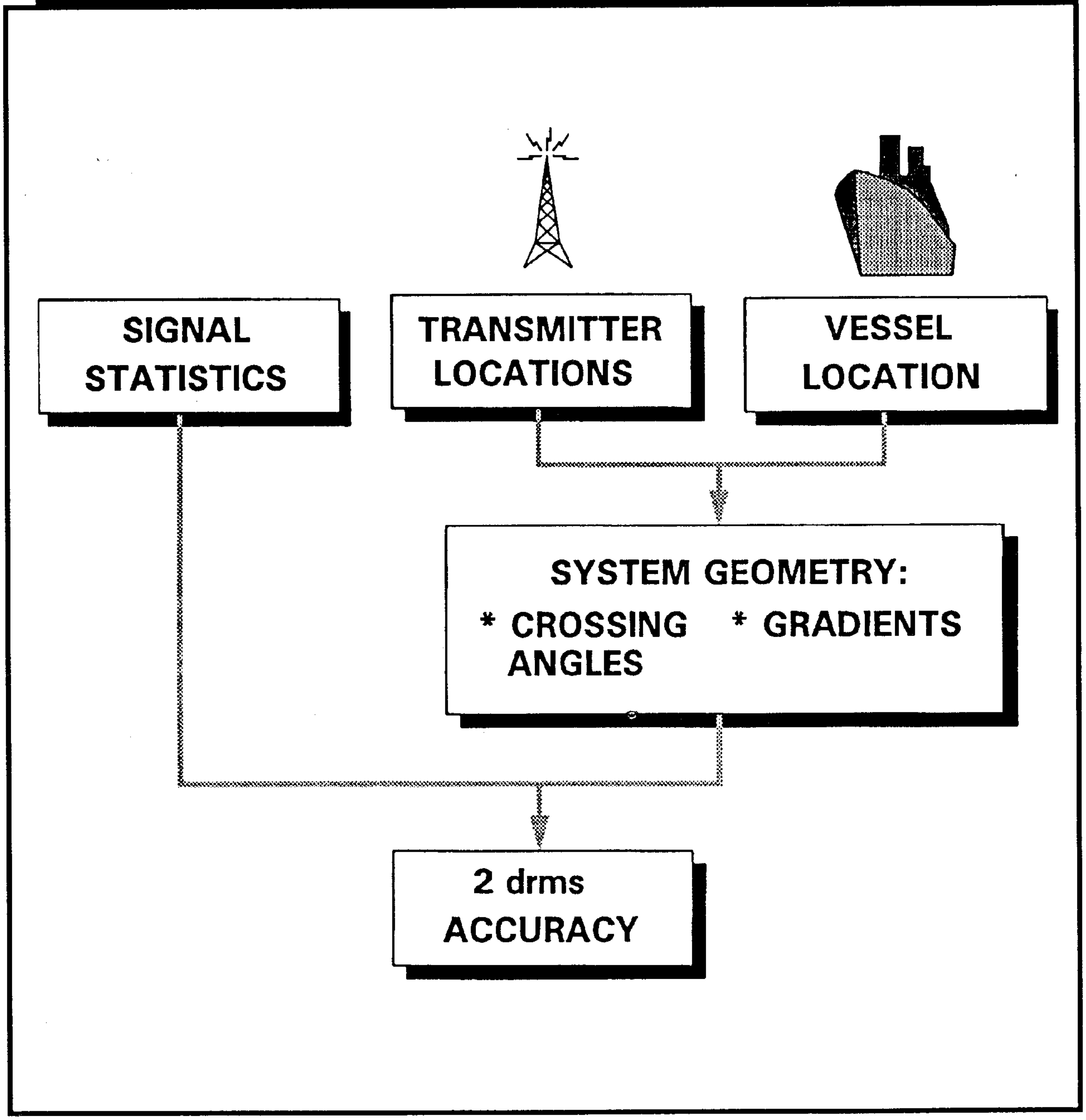


TABLE G-2. CORRESPONDENCE BETWEEN 2 drms AND GDOP.

GDOP	2 drms
1.0	139
1.5	209
2.0	278
2.5	348
3.0	417
3.5	487
4.0	556
4.5	626
5.0	695
6.0	834
7.0	973
8.0	1112
9.0	1251
10.0	1390
12.0	1668
14.0	1946
16.0	2224
18.0	2503
20.0	2781

In essence, GDOP measures the ratio of the *actual* value of 2 drms corresponding to the user's location in the coverage area of a loran *triad* to the *best possible accuracy* of the best possible loran stations. GDOP is a *normalized* 2 drms, which takes into account the effects of the system geometry and the user's location. Table G–1 shows the correspondence between GDOP and 2 drms. The specified absolute accuracy of Loran-C is 0.25 NM (1,519 ft), which is equivalent to a GDOP of 10.92.

APPENDIX H

USE OF SKYWAVES FOR NAVIGATION

Introduction—Skywaves A Boon or a Bane?

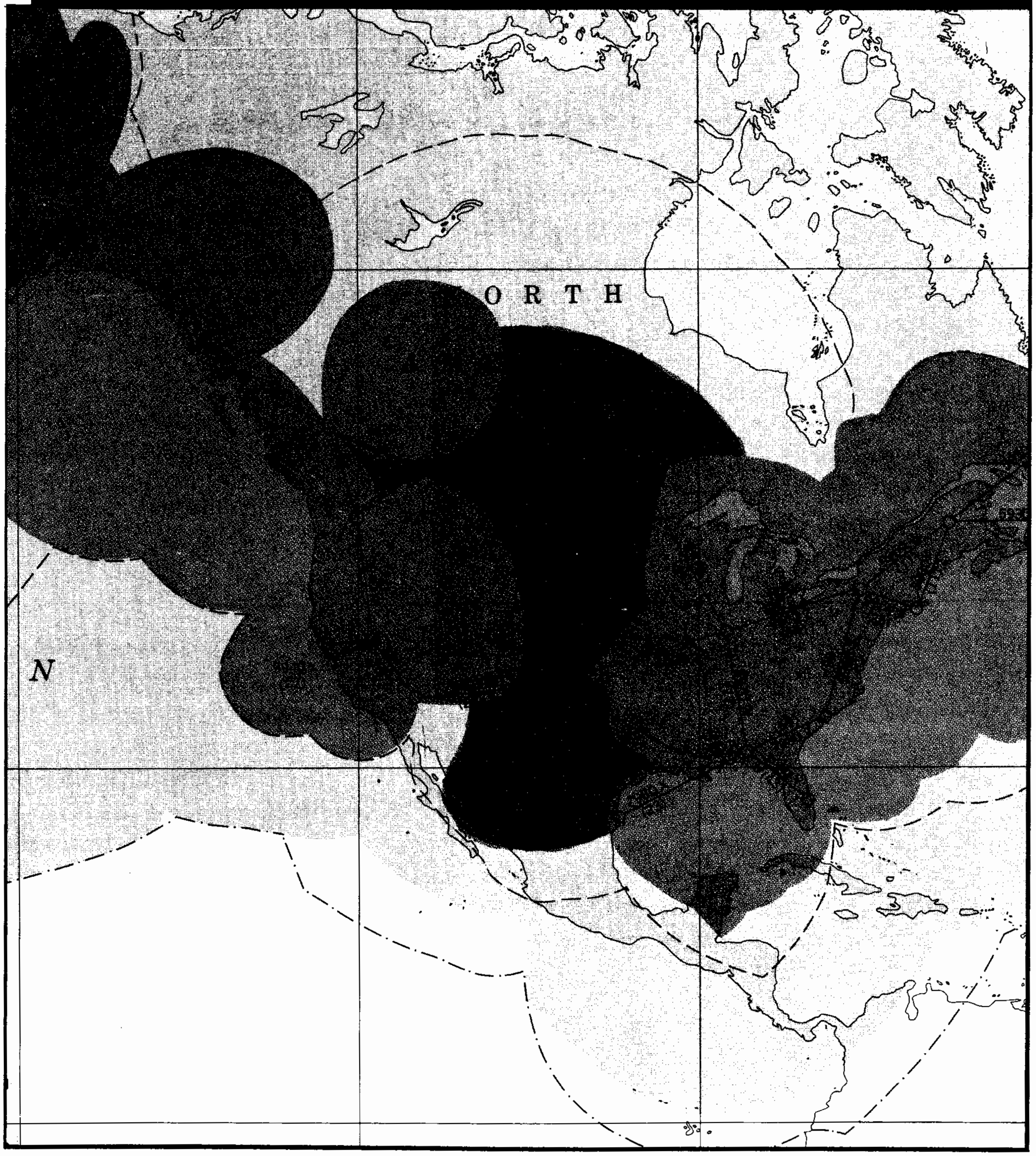
Skywave propagation of Loran-C signals is discussed in the main body of this handbook. As noted there, a portion of the Loran-C signal radiates upward and is reflected off the ionosphere before reaching the receiver—this is the skywave. Compared to the groundwave, the skywave differs in two key respects. First, from simple geometry it can be seen that the skywave signal travels a longer and less constant (because the height of the various layers of the ionosphere exhibits diurnal variability) distance to the receiver than the groundwave. Second, the skywave is attenuated to a lower degree than the groundwave, because it passes through the atmosphere rather than directly over terrain and seawater. If the skywave signal is received rather than the groundwave—and this goes unrecognized—then the loran positions determined from the loran overprinted charts or the receiver's coordinate conversion logic will be in error, because the correspondence between geodetic position and apparent TD differs, depending upon whether a groundwave or skywave signal is received.

Because the propagation characteristics (and, therefore, the geographic location of TDs) of skywaves are less predictable, the Loran-C system was designed to exploit groundwaves. In the normal Loran-C context, skywaves are principally a "nuisance" and various technical means, such as the location of the sampling or tracking point in the pulse and phase coding, have been devised to lessen the likelihood of skywave "contamination."

Still, these measures are imperfect, particularly at long distances (i.e., areas outside of these depicted in the coverage diagram) from the transmitter and secondaries. At these extreme ranges, groundwaves are severely attenuated, but skywaves suffer less attenuation, with the result that skywave reception may be the only option. Moreover, exploitation of skywaves can substantially increase the usable range of Loran-C. Although skywave propagation is less predictable than for groundwaves, the Loran-C system can still be used with skywaves. Indeed, the earliest versions of the loran system were based upon skywave reception only.

Figure H–1 shows a portion of DMA Chart 5133. This figure shows the limits or loran groundwave reception (2 drms of <1,500 ft and an SNR of at least 1:10), denoted by the dashed

FIGURE H-1. SKYWAVE AND GROUNDWAVE COVERAGE COMPARED



line, and of *skywave reception*[1] (minimum SNR of 1:10, minimum crossing angle of 15 degrees and gradient of line position of less than 2 NM per usec), denoted by the combination dashed-dotted line. As can be seen, use of skywaves can substantially extend the limits of coverage of the Loran-C system.

In order to use skywaves, however, it is necessary to (i) recognize that the receiver is tracking skywaves and (ii) apply appropriate corrections to the measured TDs (to account for propagation differences) to obtain *corrected* TDs that are used to determine position on a loran overprinted chart.

Indications of Skywave Reception

It is first necessary to determine exactly which signals (master or any of the secondary) are skywaves rather than groundwaves. Consult the owner's manual for the particular loran receiver for detailed guidance. (The owner's manuals for many makes and models do not address skywaves for navigation, but this is the first place to look.) The following general criteria are useful for this purpose.

(i) Skywave reception is much more likely outside the limits of conventional groundwave reception. Therefore, the vessel's location should be considered. Anytime the vessel is outside the limits of the chain's published coverage diagram, skywave reception is likely.

(ii) A few older Loran-C receivers are equipped with a "sky" alarm or status indicator that alerts the user to skywave reception.

(iii) Skywave reception is likely when the SNR is much larger than would be expected for groundwaves. (This serves as another example of the utility of recording the SNRs of master and secondary whenever a fix is determined. Without such data it is impossible to determine norms for comparison.)

(iv) Skywave reception is indicated when SNRs vary more than "normal." (Again, this indicates the utility of maintaining a performance log.)

(v) Skywave reception is likely if TDs vary more than normal.

(vi) Skywave reception is likely if there are large apparent position errors.

The user should determine exactly which stations (master and secondary) exhibit these indications. This is important, because it is necessary to determine which TDs to correct if skywave data are to be used.

Options

Faced with the possibility (probability) of skywave reception, the user has two alternatives.

(i) Temporarily discontinue the use of Loran-C for navigation purposes until the vessel or aircraft has returned to the area of reliable groundwave coverage.

(ii) "Correct" the apparent TDs of the signals, using correction factors explained below, and use the skywaves for position fixing.

[1]As defined by DMA.

Undoubtedly, option (i) is the "conservative" choice—and that recommended here if there are other suitable means of navigation at hand. Option (ii) may be attractive if other methods of position fixing are unavailable or likewise unreliable. If option (ii) is selected, the mariner or aviator must use loran position information with much more caution, for the following reasons.

(i) The navigator may "misdiagnose" skywave indications, and misclassify a groundwave as a skywave, or *vice versa*. In this event, the user would apply the wrong corrections to the measured TD. The "corrected" TD could be further in error than the uncorrected TD.

(ii) The published correction factors are only *average* values. Propagation conditions vary over time, and these corrections do not reflect these temporal changes.

(iii) Gradients and crossing angles of the loran LOPs may be "poor" in areas where skywave reception is likely. Therefore, the accuracy of the resulting fix may be much less than for groundwave reception in the chain's groundwave coverage area.

In consequence, the Loran-C "fix" uncertainty is much greater in areas where skywave reception is likely. Confine this method of position fixing in "safe water" where larger fix uncertainties are more tolerable. Finally, cross-check any skywave "fixes" with those determined by other methods, such as observation of celestial bodies or use of GPS.

Published DMAHTC Skywave Corrections

Figure H–2 reproduces an extract from DMAHTC Chart 28001 that shows a portion of the Gulf of Mexico near the Honduras/Nicaragua border. Reference to Figure H–1 (or the coverage diagrams provided in Appendix B) indicates that this area is outside of the coverage diagram for the 7980 chain, yet still within the area of possible skywave coverage. And, as can be seen from examination of the actual chart legend, loran LOPs are printed for the Xray, Whiskey, Yankee, and Zulu secondaries of the 7980 chain. The locations of the Loran-C TDs overprinted on this chart have been calculated on the assumption of groundwave propagation only. This convention is adopted not because groundwave reception is most likely in this area, but rather to provide a basis for applying skywave corrections to the measured TDs. Simply put, published adjustments are used to correct the observed TD to what it would be if only groundwave signals were received.

The chart section shown in Figure H–2 is of conventional appearance except for the "data blocks" inserted at regular intervals of the intersections of meridians of longitude and parallels of latitude. On this chart, the data blocks are shown at each degree of latitude and for every two degrees of longitude. These data blocks provide the adjustments necessary for correcting measured TDs prior to plotting a position.

In areas where skywave reception is possible, there are four logical reception possibilities for each station pair. These are shown in Table H–1; both signals groundwave, both signals skywave and two possibilities of mixed groundwave—skywave reception. However, at a particular point on the earth, not all of these combinations are equally likely. At some locations far removed from both master and secondary, only skywave reception for both master and secondary is possible. At other locations, groundwave reception is also possible for either the master or secondary signal. Likely combinations of groundwave and skywave reception are identified in the data blocks.

FIGURE H-2. EXTRACT FROM DMA CHART 28001, SHOWING PORTION OF GULF OF MEXICO NEAR HONDURAN/NICARAGUA BORDER

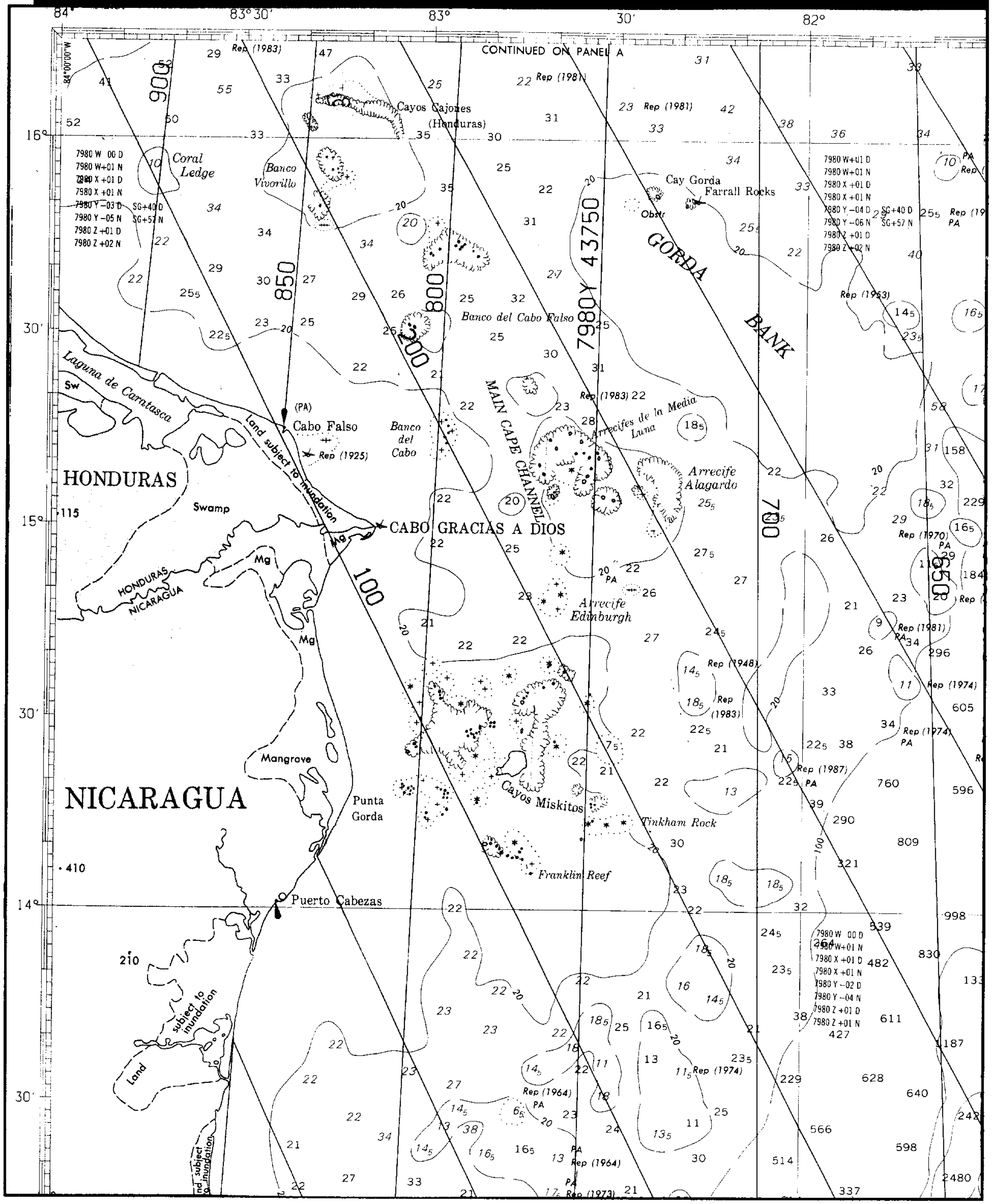


TABLE H-1. LOGICAL POSSIBILITIES FOR GROUNDWAVE SKYWAVE RECEPTION FROM MASTER AND SECONDARY

	Type of Signal	Master Signal	
		Groundwave	**Skywave**
Secondary Signal	Groundwave	Use loran LOPs as printed on chart	Use corrections prefixed with "SG."
	Skywave	Use corrections prefixed with "GS."	Use special correction shown immediately to right of printed rate.

A Numerical Example

Observed TD readings do not need to be corrected if both signals are determined to be groundwaves. However, if one or both of the master secondary signals involve skywaves, then corrections are necessary. These skywave corrections to the observed TDs are best illustrated by a numerical example. Consider first the data block found in the vicinity of latitude 16 degrees north and 82 degrees west, a position slightly northeast of Gorda Bank on the chart. For ease of reading, Table H–2 reproduces the data block found at this location in Figure H–2. The first line, "7980 W +01D" signifies that, if the 7980 W rate is being used (7980 W), the observation is taken during daylight hours ("D") and both the master and Whiskey secondary signals are skywaves, then 1 microsecond (+01) should be *added* (+) to the observed TD for this station pair to obtain a corrected TD for position plotting. The second line, "7980 W +01N," indicates that if, the observation is taken at night ("N") i.e., between the hours of sunset and sunrise and both the master and secondary signals are skywaves, then 1 microsecond should also be added to the observed TD to provide a corrected TD for position plotting. These "skywave-skywave" corrections are typically not large.

Skip down to the fifth and sixth lines in the data block. The entry, "7980 Y -04D," signifies that if both the master and Yankee secondary are skywaves and the time of observation is from sunrise to sunset (day, or "D"), 4 microseconds are to be *subtracted* (-04) from the observed TD to produce a corrected TD for this rate. Were this observation taken at night, 6 microseconds would have to be *subtracted* ("-06N") from the observed TD. Now, notice the entry "SG+40D" to the right of "7980 Y -04D." This entry signifies that *if the master is a skywave signal, and that for the Yankee secondary is a groundwave (SG),* and the observation is taken during the day ("D"), then a 40 microsecond correction is to be *added* ("+40D") to the observed TD. If the observation were taken at night, a 57 microsecond correction would be necessary. These "mixed corrections" are substantial in this example. The gradient of the Yankee secondary in this area is approximately 12 NM per 50 usec (1,500 ft/usec), so the +57 usec nighttime correction would shift the vessel's (or aircraft's) position approximately 13.7 miles further west.

Note that the largest corrections always occur when there is mixed skywave-groundwave reception. This is initiatively reasonable, because of differences in the propagation path between skywaves and groundwaves.

Questions and Answers About This Example

The careful reader may have a few questions about the numerical example at this point. Possible questions and answers are summarized below.

Question: Referring to the information given in the fifth line of the data block, what if the secondary were a skywave and the master a groundwave?

Answer: In this case the correction would be identified as "GS," rather than "SG." And, indeed, depending upon the relative locations of the master and the secondary, "GS" corrections are provided on these charts. Figure H–3, for example, shows another excerpt from the same chart as Figure H–2. The area detailed is in the general vicinity of the Cayman Islands. Note the number of "GS" corrections shown in the surrounding data blocks.

TABLE H-2. SKYWAVE CORRECTION EXTRACT FROM L: 16° 00.0 N, Lo: 82° 00.0 W (NORTHEAST OF GORDA BANK) ON DMA CHART 28001 SCALE 1:1,300,000 AT L: 16° 00	
7980 W +01 D	
7980 W +01 N	
7980 X +01 D	
7980 X +01 N	
7980 Y -04 D	SG +40 D
7980 Y -06 N	SG +57 N
7980 Z -01 D	
7980 Z -02 N	

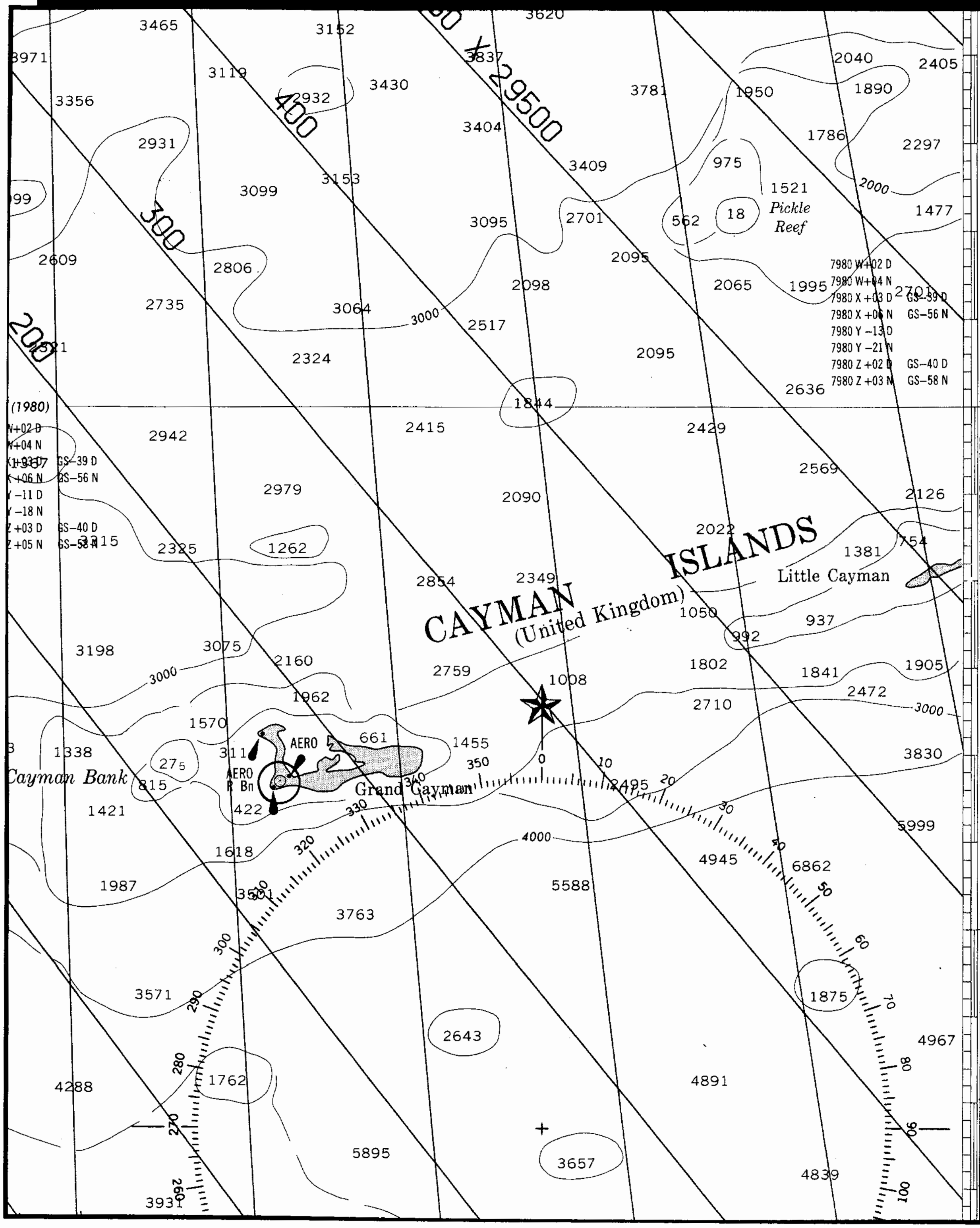
Question: Fair enough, but why isn't a "GS" correction included in the data block for the Gorda Bank location?

Answer: The TD corrections are only given for the likely reception possibilities. At this location, it is not likely that the receiver would pickup a groundwave from the master and a skywave from the Yankee secondary. To see why this is true, consider the relative distances from this point to the master (located in Malone, FL) and the Yankee secondary (located in Jupiter, FL). The Yankee secondary is closer to this point than the master, and therefore, it is more likely that any groundwave would be received from the Yankee secondary than from the master. In contrast, in the vicinity of the Cayman Islands, it is more likely that groundwaves would be received from the master. Finally, it should be noted that skywave correction data blocks are omitted entirely in areas where only groundwave reception is likely.

Question: Why isn't there an "SG" correction given in the skywave data block near the Gorda Bank shown in Table H–2 for any rate other than the master Yankee station pair?

Answer: Reception of a skywave from the master and groundwave signals from these other secondaries (Whiskey, Xray, and Zulu) is very unlikely at this location. Therefore, no corrections are provided. Refer to the data block immediately south of that used in this numerical example, i.e., that at latitude 14 degrees north and longitude 82 degrees west. Note that no "SG" corrections are given for any of the rates shown in this block. This location is approximately 60 miles farther south and

FIGURE H-3. ANOTHER EXCERPT FROM THE CHART SHOWN IN FIGURE H-2.



groundwave reception of the Yankee secondary is unlikely at this location. You simply "run out of groundwave" as you go farther from the station.

Question: This is clear now, but suppose that (in the location of the first example), notwithstanding the likelihood of this combination, my receiver indications suggested that the master signal were groundwave, and the secondary skywave?

Answer: Check these indications more carefully. This is an unlikely reception combination at this location. In any event, no correction is published for this combination, so the mariner or aviator should regard any position information as tentative. Referring to the chart in this general location, note also that the gradients are relatively large, at least for some secondaries (for example, although the gradient of the Xray secondary is approximately 700 ft/usec, that for the Whiskey secondary is approximately 1,700 ft/usec). As well, the crossing angles are much less than in the designated coverage area. The best crossing angle among these station pairs, Xray and Zulu, is only 30 degrees, and others are less. The LOPs of the Yankee and Zulu secondaries, for example, are nearly parallel!

Summary

Skywaves can be used for navigation. For this purpose it is necessary to correct the observed TDs prior to plotting. Corrections can be found on DMAHTC charts in areas where skywaves can be used.

Use of skywaves considerably extends the Loran-C coverage area. However, positions so determined are less accurate, partially because skywave propagation is more difficult to predict, and partially because of the "poor geometry" of LOPs in the skywave coverage area.

Skywave corrections shown here must be used with core, and only in circumstances where larger position errors are tolerable. Cross check any skywave fixes with those determined by other methods.

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