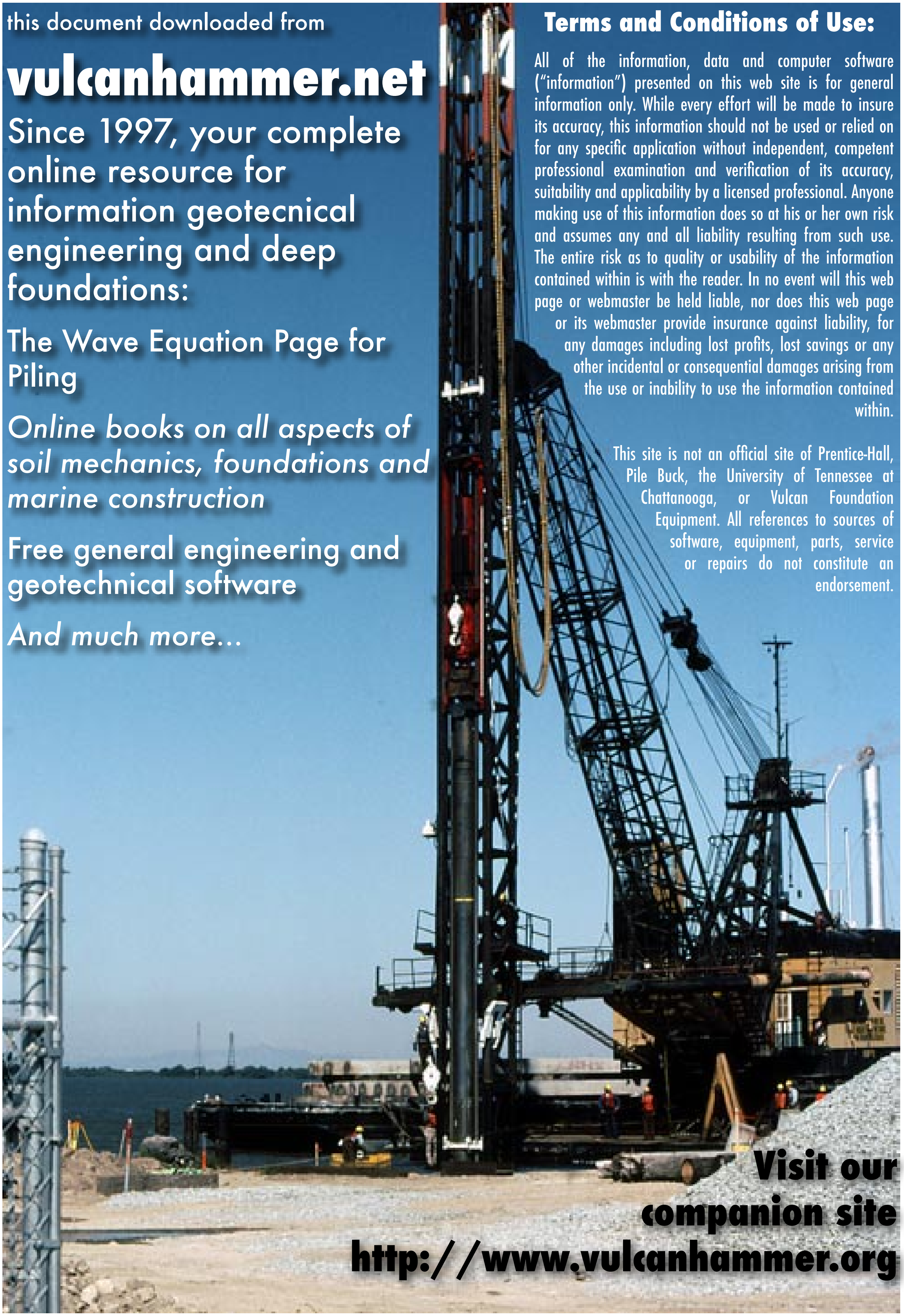


COMMANDANT PUBLICATION P16562.5

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 decription, 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

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:
(202) 267-0990
COMMANDANT (G-NRN-1)
2100 SECOND ST SW
WASHINGTON, DC 20593-0001

Table of Contents

Chapter I: Introduction and Overview

Background: The "Green Book" I-1
The New Handbook Edition: More Than Just the Cover Has Changed...I-1
Introdution...I-2
What is Loran?..I-2
Comparison of and Relationship of Loran-C to
Other Radionavigation Systems...............................I-4
--Omega..I-5
--Global Positioning System (GPS)...........................I-6
--Marine Radiobeacons......................................I-9
--Transit..I-10
--Summary..I-10
Simplified Principle of Loran-C Operation.....................I-10
Components of the Loran System................................I-13
A Brief History of Loran......................................I-14

Chapter II: The Loran-C System: A More Detailed View

Introduction...II-1
Loran Transmitters, Chains, and Some Basic Definitions........II-1
--Signal Characteristics and Some Important Definitions....II-3
--Chain Configuration.....................................II-4
--Other Definitions.......................................II-7
Hyperbolic System: A Second Look.............................II-7
--Hyperbolic Geometry On a Plane..........................II-7
--Equivalence Between Distance and Time....................II-10
--More Exact Calculations.................................II-13
--Primary Phase Factor (PF)...............................II-13
--Secondary Phase Factor II-13
--Additional Secondary Phase Factor (ASF).................II-14
--ASF Tables..II-15
--Use of Tables...II-15

Groundwave versus Skywave Propagation.........................II-18
Pulse Architecture and Related Technical Matters.............II-20
--Phase Coding...II-22
--Blink Coding...II-22
Concluding Comments...II-22

Chapter III: Position Determination and Accuracy

Introduction..III-1
Position Determination Using TDs............................III-1
Loran Accuracy...III-6
Determinants of Loran-C Accuracy.............................III-8
--Stability of the Transmitted Signal....................III-9
--Atmospheric and Man-Made Effects on Propagation.........III-9
--Factors Causing Temporal Variability...................III-9
--Factors Associated With Spatial Variability............III-11
--Other Factors...III-12
System Geometry..III-12
--Crossing Angles.......................................III-12
--Gradient..III-17
Brief Remarks on Station Placement..........................III-19
Putting it Together: drms..................................III-19
--Accuracy vs. Location in the Coverage Area.............III-22
Coverage Diagrams..III-23
Chain Selection..III-25
Practical Pointers..III-27

Chapter IV: Receiver Features and Their Use

Introduction..IV-1
Read Your Owner's Manual....................................IV-2
Generations of Loran-C Receivers.............................IV-2
Features..IV-3
--Basic Function:Reception and Display of Position Information..IV-4
--Displays...IV-6
--Keypad...IV-8
--Remote Readout...IV-8
--Coordinate Conversion..................................IV-9
--Notch Filters..IV-9
--Integration with Other Systems..........................IV-10
--Data Bases...IV-11
--Magnetic Variation......................................IV-13
--Power Variation..IV-13
--Automatic Alarms and/or Status Indicators................IV-15
--Recording SNR Data in the Navigation Log................IV-16

Navigation Features..IV-16
--Waypoints..IV-17
--Cross Track Error.......................................IV-17
Other Alarms..IV-20
--Arrival Alarm...IV-22
--Boundary (Border) Alarm.................................IV-24
--Passing Alarm...IV-24
--Anchor Watch..IV-25
Course and Speed Information.................................IV-25
--Velocity Made Good (VMG)................................IV-26
--Velocity Towards Destination (VTD).......................IV-27
Time Information...IV-28
Routes...IV-29
Voyage Planning...IV-29
Interface With Electronic Charts.............................IV-29
Aviation Lorans..IV-29
Pitfalls...IV-30

Chapter V: Practical Aspects of Loran Navigation

Introduction..V-1
TD's Versus Latitude/Longitude: Reprise........................V-1
Bias Corrections..V-4
Practice Often and in Good Weather.............................V-6
Maintain a DR Plot and Cross-Check Fixes.......................V-9
Exploiting Partial Information.................................V-13
Use of the Route Function.....................................V-13
Cycle Stepping..V-15
Plan Courses and Waypoints Considering Loran-C Accuracy........V-18
Preplan Dockside and Cross-Check Data Entry....................V-18

Chapter VI: Loran-C Charts and Related Information

Introduction...VI-1
Loran-C Charts: Third Vital Component of the System...........VI-1
Loran-C Overprinted Charts..................................VI-1
Rates Printed on NOS Charts..................................VI-2
Intervals Between Adjacent TDs and Spacing....................VI-3
Rate Designators on NOS Charts...............................VI-5
ASF Compensation on NOS Loran-C Charts........................VI-5
Standard Color Coding for Loran-C TDs.........................VI-7
Plotting and Interpolation...................................VI-7
Use of Loran-C Without Loran-C Overprinted Charts.............VI-10
Local Notice to Mariners.....................................VI-12

DMA Publications..VI-12

Chapter VII: Installation and Related Matters

Introduction...VII-1
Overall Sequence of Installation Steps.......................VII-1
Antenna/Antenna Coupler (AAC) Location.......................VII-3
Receiver Location and Mounting..............................VII-5
Power...VII-6
Ground..VII-7
Preliminary Performance Evaluation..........................VII-7
Sources of Interference.....................................VII-7
Strategies for Noise Reduction..............................VII-9
Final Performance Checks....................................VII-11

Appendix A: Sources of Interference

Frequency Listings..A-1
Alphabetical Listings...A-7

Appendix B: Data Sheets and Coverage Diagrams

Table B-1. Positions of Loran-C Transmitters in WGS 84 Coordinates..B-1
Table B-2. Positions of Loran-C Transmitters in WGS 72 Coordinates..B-5
Figure B-1. GRI 9970 Northwest Pacific Chain..................B-7
Figure B-2. GRI 9990 North Pacific Chain......................B-8
Figure B-3. GRI 7960 Gulf of Alaska Chain.....................B-9
Figure B-4. GRI 5990 Canadian West Coast Chain................B-10
Figure B-5. GRI 9940 U.S. West Coast Chain....................B-11
Figure B-6. GRI 8290 North Central U.S. Chain.................B-12
Figure B-7. GRI 9610 South Central U.S. Chain.................B-13
Figure B-8. GRI 8970 Great Lakes Chain........................B-14
Figure B-9. GRI 7980 Southeast U.S. Chain.....................B-15
Figure B-10. GRI 9960 Northeast U.S. Chain....................B-16
Figure B-11. GRI 5930 Canadian East Coast Chain...............B-17
Figure B-12. GRI 7930 Labrador Sea Chain......................B-18
Figure B-13. GRI 9980 Icelandic Sea Chain.....................B-19
Figure B-14. GRI 7970 Norwegian Sea Chain.....................B-20
Figure B-15. GRI 7990 Mediterranean Sea Chain.................B-21

Appendix C: Glossary of Terms....................................C-1

Appendix D: Abbreviations and Acronyms...........................D-1

Appendix E: Abbreviated Loran-C Bibliography......................E-1

Appendix F: Millington's Method

Introduction..F-1
Conductivity - A Key Parameter................................F-1
Calculation of Propagation Delays From Conductivity Data.......F-1
--Conductivity Data...F-3
--Use of Conductivity Data in Millington's Method...........F-5
Computer Implementation.......................................F-8

Appendix G: GDOP Explained and Illustrated

Introduction..G-1
Numerical Examples..G-1

Appendix H: Use of Skywaves for Navigation

Introduction - Skywaves A Boon or a Bane?......................H-1
Indications of Skywave Reception...............................H-3
Options...H-3
Published DMAHTC Skywave Corrections...........................H-4
A Numerical Example...H-6
Questions and Answers About This Example.......................H-7
Summary...H-9

Appendix I: Acknowledgements.....................................I-1

F1

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 wellmentally replace the word
mariner with aviator and the vessel icons with aircraft. Lastly, terrestrial users may also find this handbook of interestparticularly the discussions of the system and the technical material in the appendices.

Comments on this handbook are welcome, and should be directed to Commandant (GNRN), 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 Stats. 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 long-range navigation.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 Shelf100 fathom curvewhichever 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.

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-weather2 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 dmestic 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 DOTs 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) hyperbolic3 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.

In broad terms (see Table I
2), Loran-C offers superior fix accuracy compared to Omega, but lacks Omegas 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. (Omegas 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 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 Omegaand 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 tie 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. 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 vessels position, and track or home towards or away from the transmitter.

Transit

As with GPS, the Transitsystem 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 Operation5

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.

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 on-board 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 hyperbolasor, more accurately, sphercal 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 users 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 vessels 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 vessels (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.

. . . 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.

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

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 loran stations), 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 chains 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.

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 _he 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 X-ray 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 masters 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 chains coverage area before the next cycle of pulsed transmissions begins.

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), X-ray (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 discussed above, the master, located in Seneca, NY, also serves as the X-ray 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 X-ray secondary, located in Nantucket, MA, also serves as X-ray 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 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=(Xm, Ym) = (-200, 0) along the X-axis, and an X-ray secondary station at the point S = (Xs, Ys) (200, 0)-some 400 NM to the right along the X-axis. Consider an arbitrary point A = (Xa, Ya) on the lattice. From elementary plane geometry, the distance (in nautical miles) from point A to the master M, denoted d_{am}, is:

$$d_{am} = ((Xa - Xm)^2 + (Ya - Ym)^2),^{0.5} \qquad \text{(II-1)}$$

Or, in terms of the defined location of the master station, equation (II_1) reduces to:

$$d_{am} = ((Xa + 200)^2 + Y^2a).^{0.5} \qquad \text{(II-2)}$$

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

$$d_{as} = ((x \quad a -200)^2 + y^2a).^{0.5} \qquad \text{(II-3)}$$

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

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

$Z = ((Xa + 200)^2 + Y^2_a)^{.0.5}$ -

$((X_a - 200)^2 + y^2a)^{.0.5}$ (II-5)

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 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 X-ray 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 X-ray 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.

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 vessels 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 X-ray 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 X-ray 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 X-ray 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.

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 X-ray 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):

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 Millingtons 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 Millingtons 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 account. 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 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 databases 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 vessels 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 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 X-ray 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 _OP. 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.

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 vessels 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.

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 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 (X-ray, 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 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.

F1

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 areathereby 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 systemthereby 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 receiversincluding 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 usefull (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 used for fixing a users 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
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 users position at the intersection of these two LOPs on the hyperbolic lattice, as illustrated in Figure III
3.

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 hese 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 evident just northwest of the Xray secondary, and another is shown some distance southeast of this secondary at the edge of the diagramso 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 users 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 chartfor example, if the TD displayed on the loran receiver were 25,755.5it 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.

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 seected 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 TDs displayed and the letter designation for the secondaries. For example, Raytheons 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 vessels 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 accuracyexploitation 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 th 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 mariners 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 mariners 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 systemparticularly 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 vessels 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 errorthese 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 accuracy, 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 theerror 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 sourcethe 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 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 main
tain 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 seensmaller 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 temperatureand 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 cant 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 micro-structure 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 vessels 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, nd 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 observers 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 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 dimensional area is a circle, as shown in Figure III
7 (top). In the top illustration (which satisfies the above assumptions) the vessels 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 boundsmore 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
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. 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 th hyperbolathe 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
northeasterly 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 constantincreases 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 secondaryin lieu of the Xray secondaryfor more accurate navigation.

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 baselne 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 prevailssubstantial 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 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 vessels apparent position such that, in at least 95% of the fixes, the vessels actual position would be located somewhere within this circle. Mathematically, 2 drms is given by the equation:

where

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

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

K =baseline gradient, 491.62 ft/usec, and

s=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 users 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 pairsparticularly 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.

Fortunately, these calculations have already been made, and are given in Appendix B. Figure III
13 (taken from COMDINST M16562.4, Specification of the Tranmitted 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 receivers 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 receiver 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.)

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

F1

Introduction

Earlier chapters have addressed the theory of the Loran-C system. This chapter narrows the focus to the shipboard component of the systemLoran-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 owners 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 modelsso 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 owners 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 photographs 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 Owners 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 ships 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 todays sophisticated marine electronics or avionics. There is no substitute for careful study of the owners manual.

Owners 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 oldsaw:
when all else fails, read the directions, is simply not good advice when it comes to todays sophisticated marine electronics. There is no substitute for careful study of the owners 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 todays 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 navigators
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.

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 receivernot 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 namesdifferent from those in this handbookto 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 marinerparticularly 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 th 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 secondaries 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 receivers 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 simultaneouslya 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 owners manuals to determine exactly which chains can be received by the setsome 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.

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 informationa mechanical voice continually broadcasts data from the reeiver. 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 receiver 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 pageso 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 require a display as large as if the set were mounted at some distance from the navigators 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 entryan inconvenience when entering waypoint coordinates.

Some marine lorans have
calculatorstyle numeric keyboardsi.e., with the keys 7-8-9 on the top row. Other marine lorans have
telephone style numeric keyboardsi.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 navigators station. Of course, the same effect can be achieved by using two loransone at each stationbut the remote 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 navigationalthough 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 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 interferingsignal. 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 owners 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 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 logenabling 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 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 receivers waypoint memory.)8

If he 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.

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 ships 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 owners 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 desirablebut 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 o three digit numerical codee.g., ranging from 00 to 99, where 00 is worst and 99 is best. Pay particular attention to the text in the owners 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 = 100.05dB. 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 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 receivers 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 users 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 users speed, course, and other relevant information for navigation.

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 wapoint). The number of waypoints that can be stored in the receivers 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 users 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 users present position to the intended track between waypoints. Nearly all modern Loran-C receivers can display the XTEoptionally in nautical or statute miles. Cross-track error is illustrated in Figure IV 1, which shows the aircrafts 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 aircrafts present position, and the DTG, the distance (great circle) from the users present position to the next waypoint in sequence.

Knowledge of the XTE enables the user to alter the vessels 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 navigators responsibility to 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. 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 meandeing 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 manufacturers literature, the sound of the alarm may not carry very farparticularly in a noisy environmentand 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 alarmsthose 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.

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 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 buoy was located prior to proceeding to the next waypoint.

Boundary (Border) Alarm

Figure IV
4 illustrates the border alarm. It my 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 modelfor some models the swing circle is preset, in other models it is adjustable.) The alarm will sound whenever the vessel penetrates the shaded areain 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 ships battery wont 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 wont 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 vessels 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 vessels 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 owners 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 SOGor 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) respectivelyconsult the owners manual fo 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 values displayed by the receiver will lag the vessels actual direction and speede.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 users 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 waypointi.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 anotheris a term very familiar to sailors. VMG represents the component of a vessels 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 vessels 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 VMGas measured along the solid linewould be substantially smaller than the vessels SOG. In general, it can be shown that the relation between 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 vessels 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 the average component of the vessels SOG along the direct course to the destination. The VTD will equal the SOG provided that the vessels 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

F1

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 accuracytens rather than potentially hundreds of yardsmay 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 receivers 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 vessels true geographic position), but if I use the same receiver to return to the same indicated position (in latitude and longitude coordinates) wouldnt 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 indee 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 receivers 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 TDsnot just the two TDs in use1so 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 modei.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 receivers ASF logic when using the loran in a planning mode. The receiver can be used to convert the coordinates of a waypoint fom 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 vessels 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 vessels 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 owners manual.) In the case related by Jones, the waypoints being converted were along the Maine coast and the vessels 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 errora 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 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 locationoften a dock at the marinaand manually enters these known coordinates into the loran, either directly, or as differences (called deltas in some owners 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 receivers 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 mariners 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 mariners home port is not affected by anoalies 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 much the ASFs vary over the region of interest. And, as even a casual examination of DMAHTCs 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 owners 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 mans 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 meansa 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 secondaries5 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 occursuch 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). Mays account does not mention that this procedure was usedrather, 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 thooughly 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 owners 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 owners 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 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 chart6 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 manufacturers 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 factorssee Chapter VIIbut the point of this example is that these data can be used to advantage.

Entries in the performance log should indicate the vessels 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.

Maintain a receiver
performance log to record SNRs, status ndications, 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 vessels 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 ariseparticularly 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 vessels 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 lorans 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 vessels DR position with a contemporaneous fix. Therefore, one major purpose of the DR plot is to enable estimation of set and driftand 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 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 exampe (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 excellentbetter than 99.7% availability for any given triad. However, the availability of the onboard receiver may not attain these levelsparticularly 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 vessels 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 vessels 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 methodsparticularly 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 appreciably 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 systm (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 owners manual for this information.) Waypoints used can be entered by actually visiting each and using the receivers 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 receivers 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 vessels course or speed needs to be changed. Figure V 3 illustrates a route consisting of several waypoints (denoted by circles with cross-hairs 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 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 waypointsa 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 mariners 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 ths 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 pulse30 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 strengthuntil 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 contaminationand consequently of incorrect TDs. The 30 usec tracking point strikes a practical compromisethe 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 coveragemay 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 owners 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 vessels position as accurately as possible, noting the correct TDs (from a loran overprinted chart) corresponding to the vessels 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 vessels indicated position will return to the position originally noted, or to the vessels
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 vessels correction position.

Users should bear in mind tht 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 cautiouslyand 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.

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 milesrepeatable 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

F1

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 ientify 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 maps1 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 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" apartin 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 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).

Mcrosecond 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.

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 users 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.
The available survey data varies by area, and is dscribed 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 users 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 users 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 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 ne 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 vessels 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 vessels 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 interpolatorwhile holding the dividers perpendicular to the bottomand 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 navigators 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 receivers 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 receivers 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 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 ource 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

F1

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 owners manual. Users should carefully read the specific installation instructions contained in the owners 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 receivers notch filters (if adjustable), (ii) locating, fastening, and wiring the receivers 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 receivers interface (if any) to other on-board navigation systems. With the exception of items (i) and (viii), these steps are addressed in this chapter.
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 owners 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 enble 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. 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 vessels 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 mout 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 vessels 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 vessels 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 vessels 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 vessels 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.

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 vessels 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 vessels 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 manufacturers 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 elctrical 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 vessels 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 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 signalresulting 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.

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 fr 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 vessels alternator. For best results, follow the manu

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
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
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								
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
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								
133.150	CAN	HALIFAX	NS	4525N	06334W	25.000	266.300	
399.450								
133.850	AN	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	427N	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

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
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
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	408.00
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
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	0627W	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
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
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 appendixcontains 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-l. 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-l. 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-l. 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					
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" ılse-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-l. 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	2737 1.23	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.

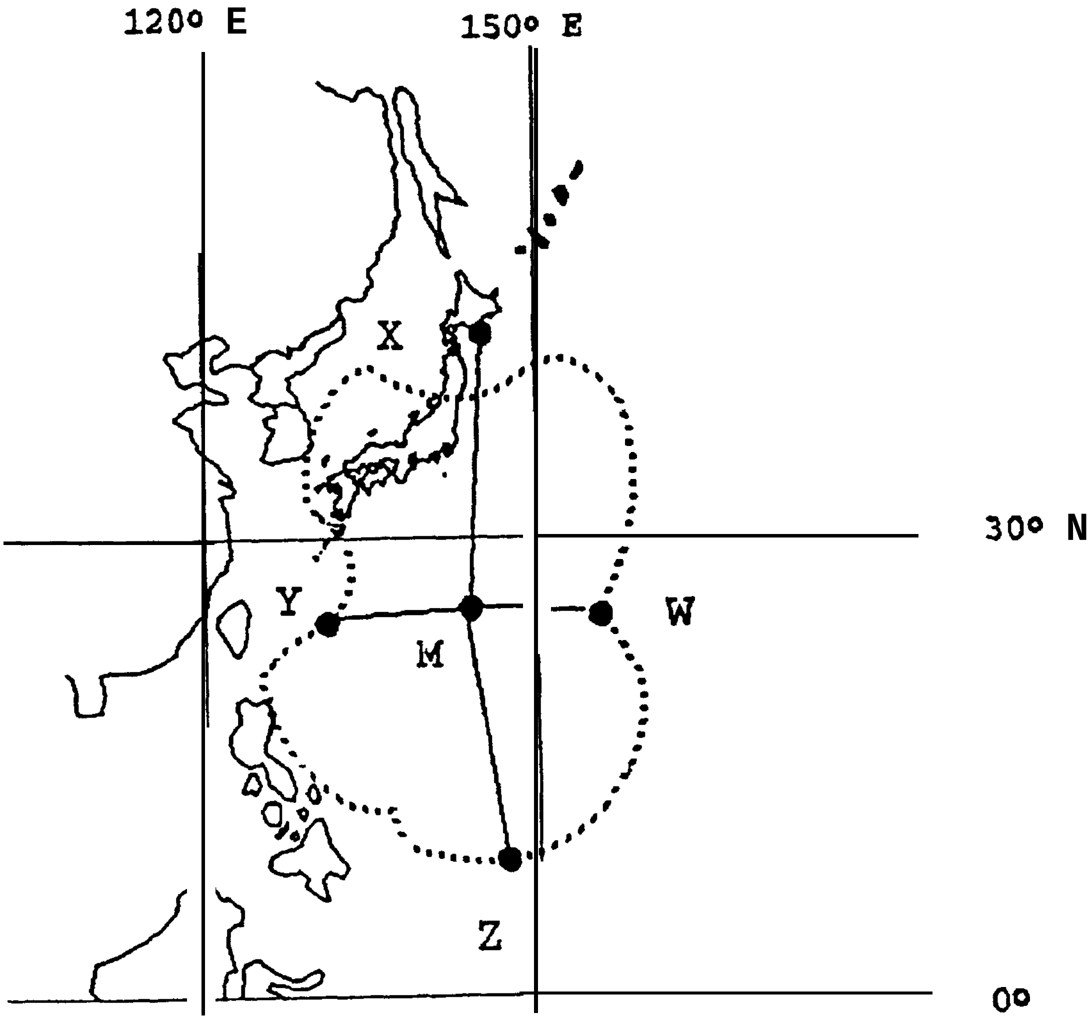
Chain	Latitude	Longitude	Emission Delay	Coding Delay	Power kW
5930 CANADIAN EAST COAST CHAIN					
M Caribou, ME	46° 48' 27.199"N	67° 55' 37.713"W			800
X Nantucket, MA	41° 15' 11.930"N	69° 58' 39.090"W	13131.88	11000	350
Y Cape Race, Canada	46° 46' 32.180"N	53° 10' 28.160"W	28755.02	25000	1000
Z Fox 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	4 1967.30	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-I. LORAN-C GRI 9970 NORTHWEST PACIFIC CHAIN



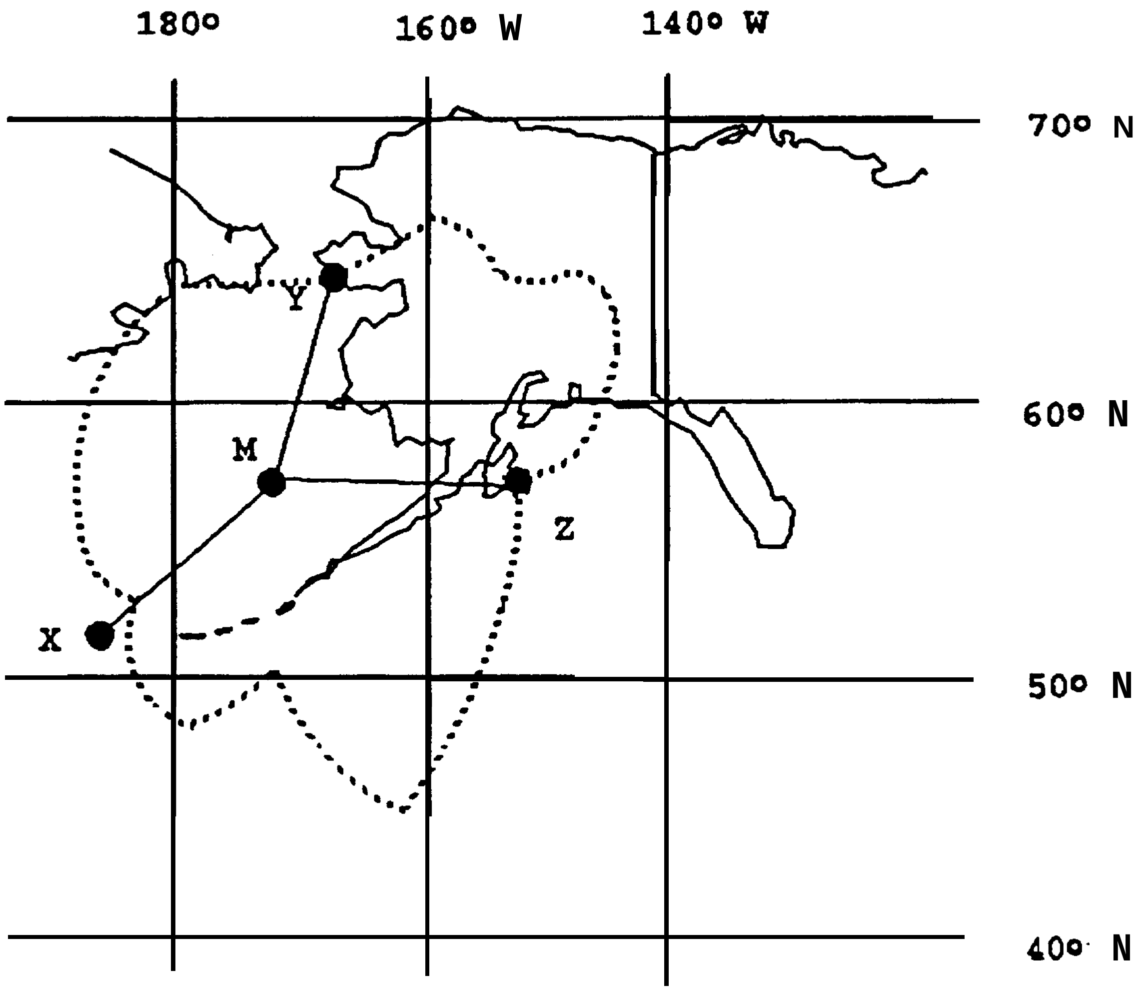
Transmitter

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



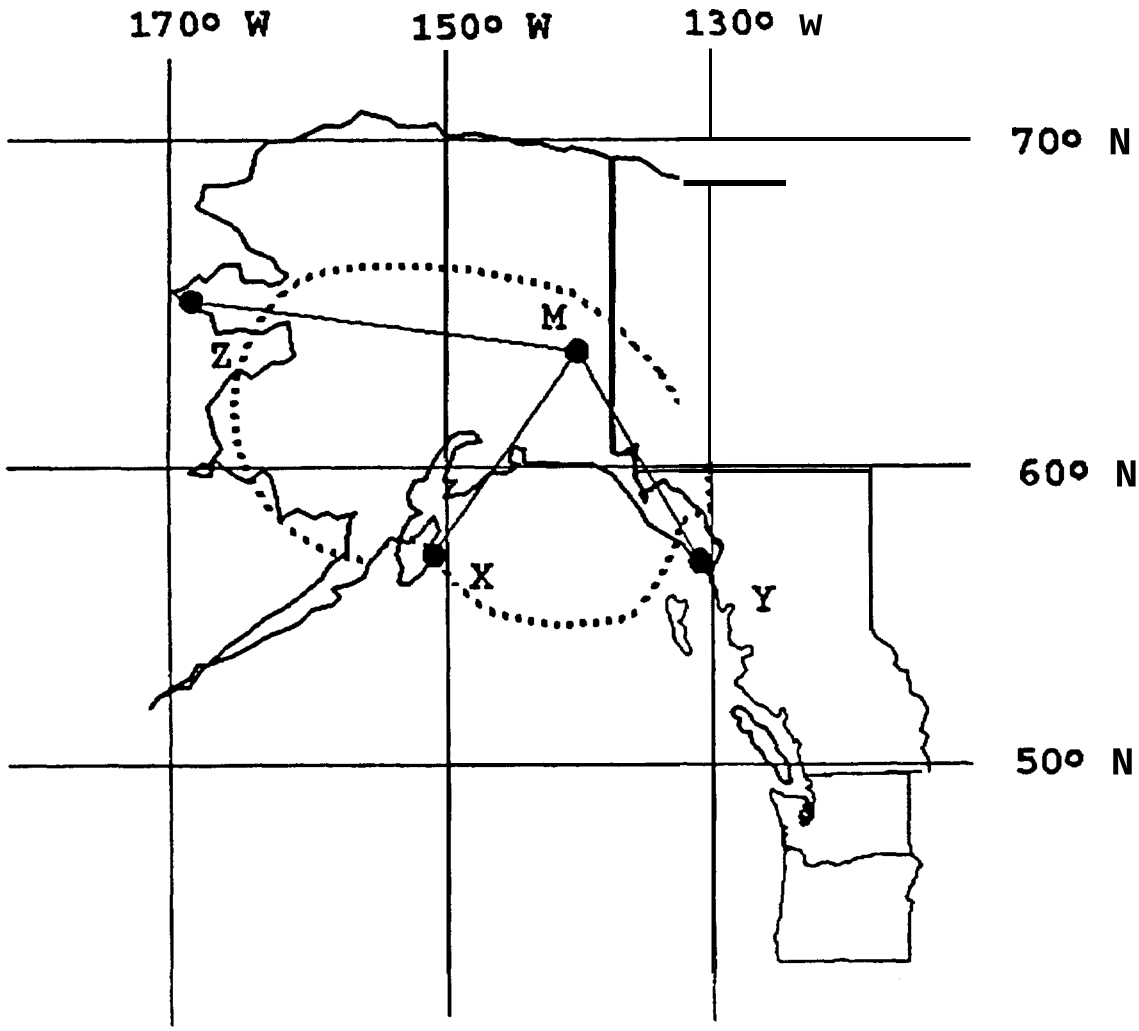
Transmitter

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



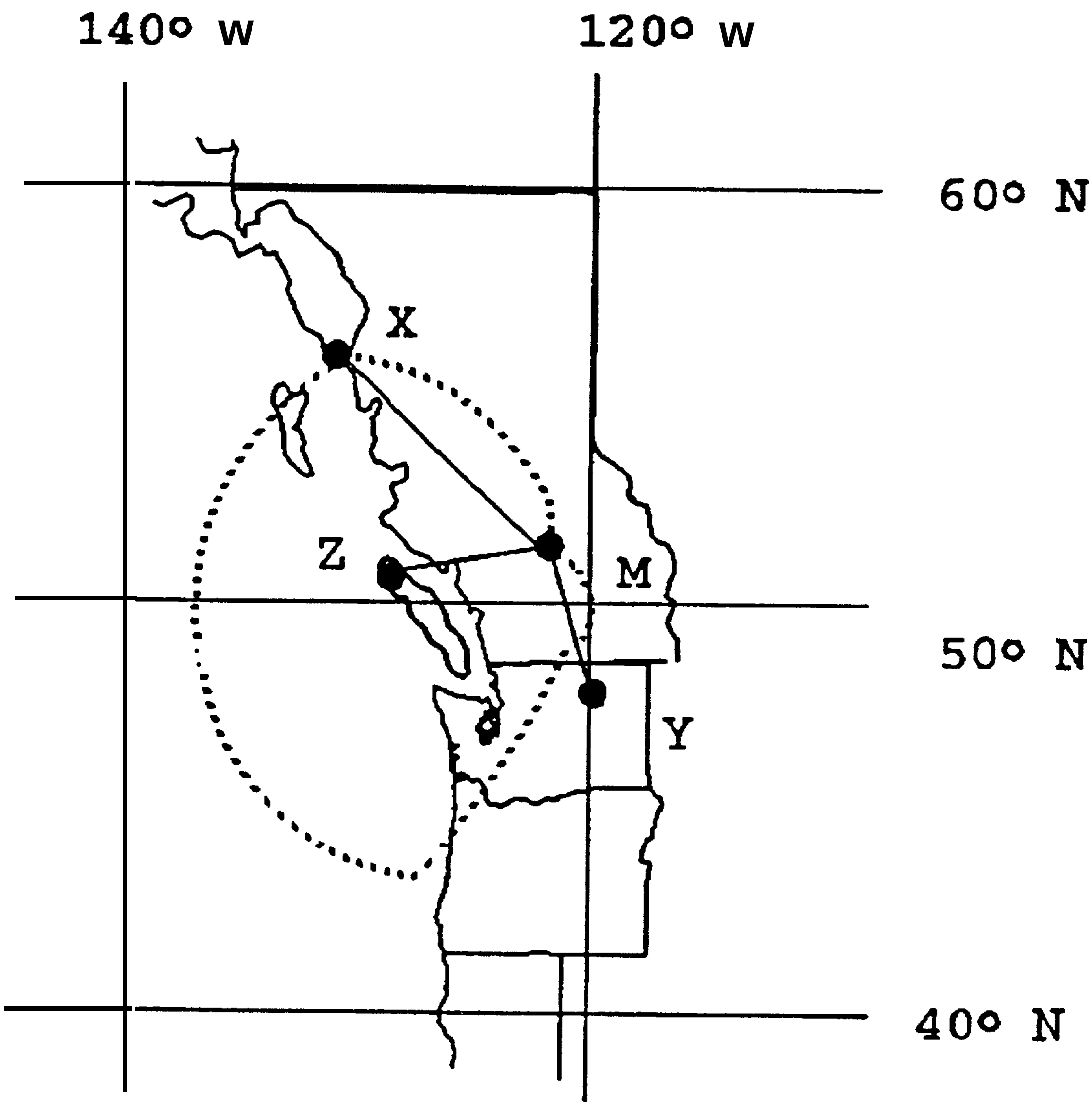
Transmitter

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



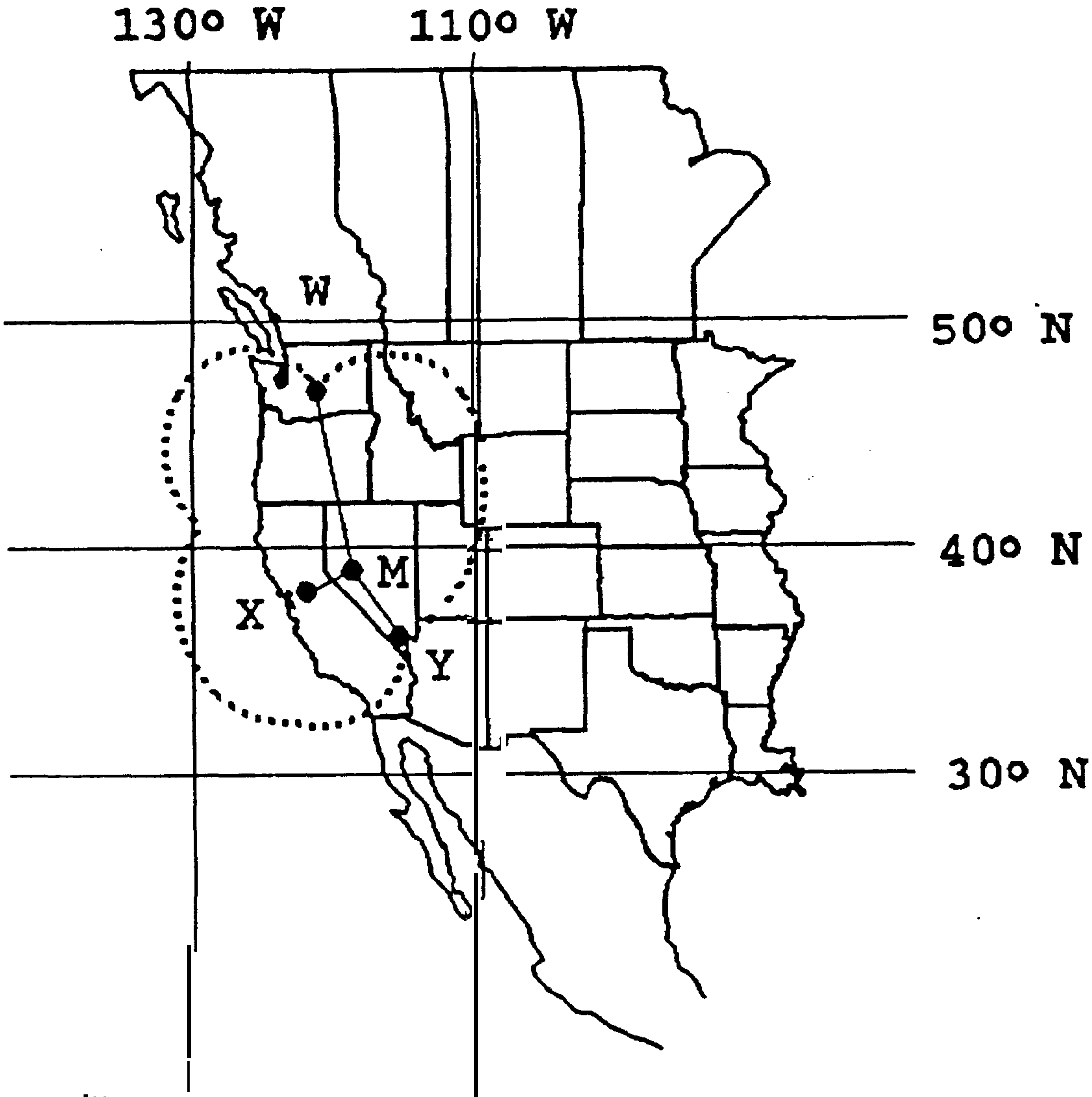
Transmitter

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



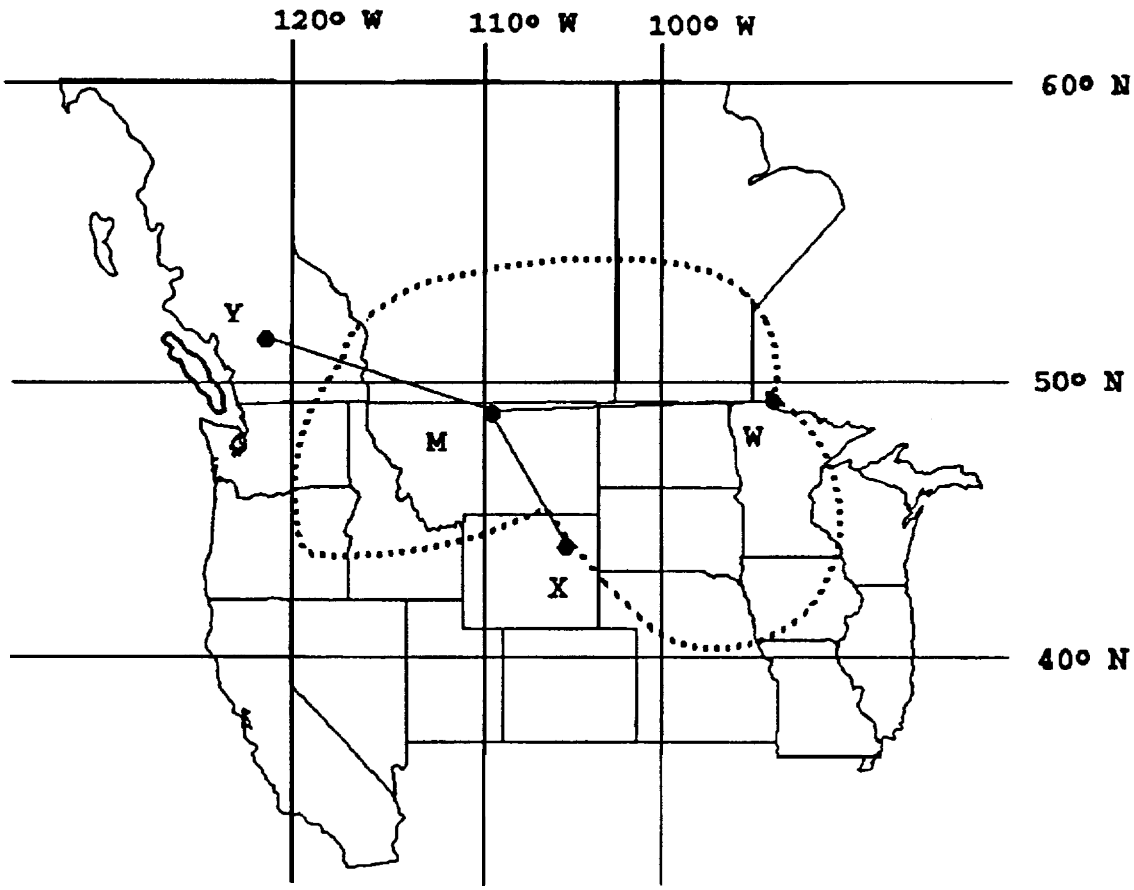
Transmitter

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: *Esfimafed* Groundwave coverage, actual coverage will vary.

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



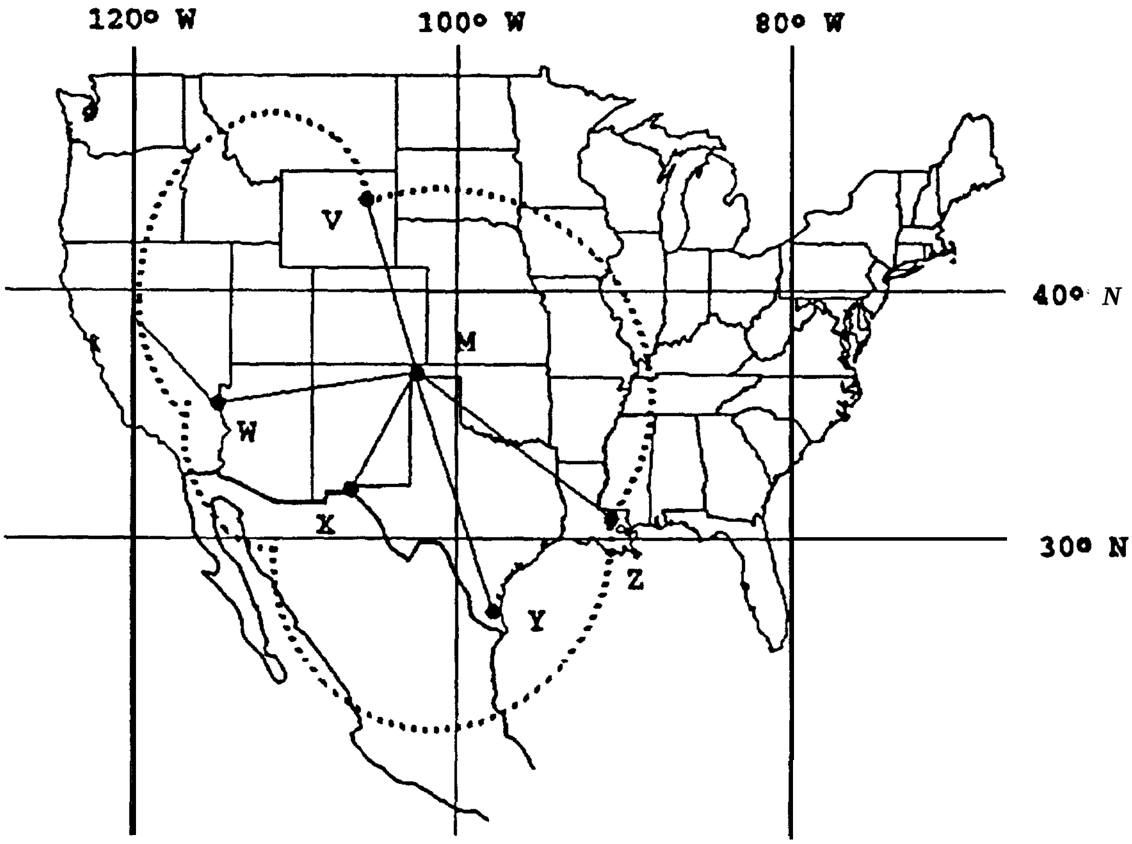
Transmitter

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



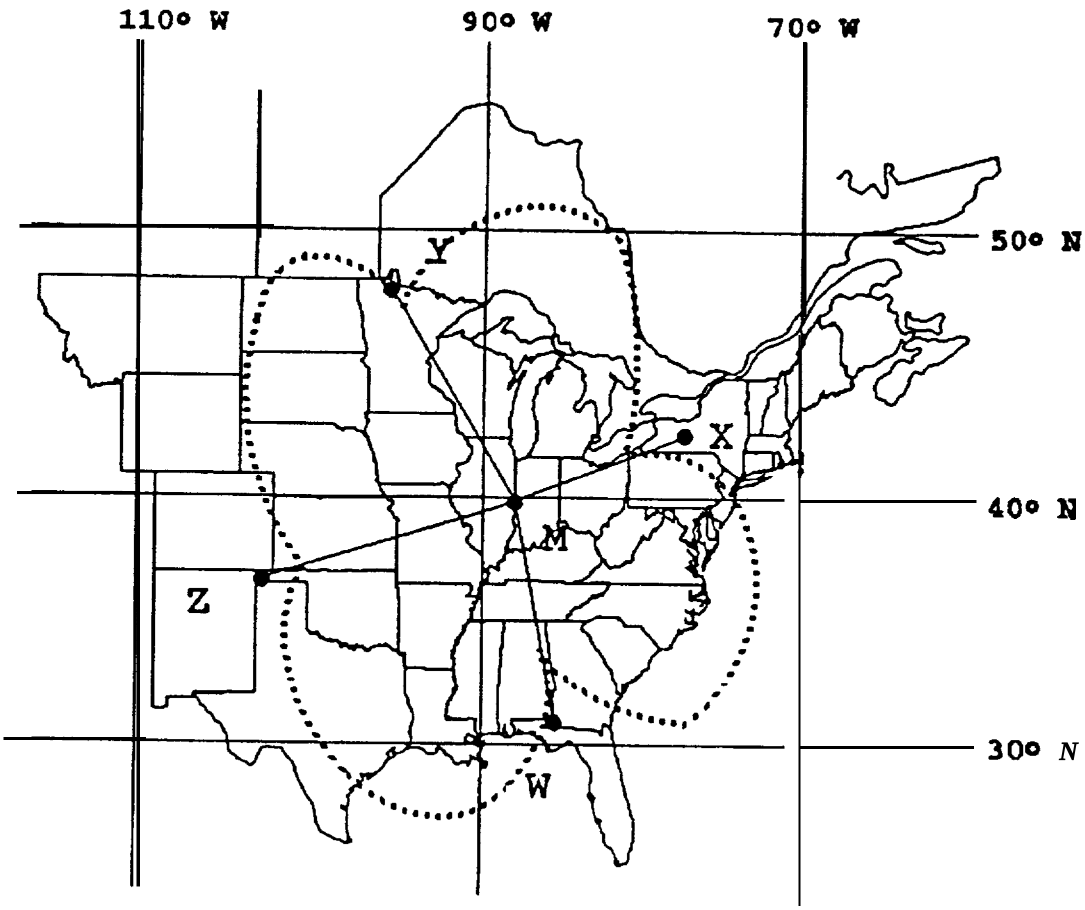
Transmitter

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: ***Esfimafed*** Groundwave coverage, actual coverage will vary.

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



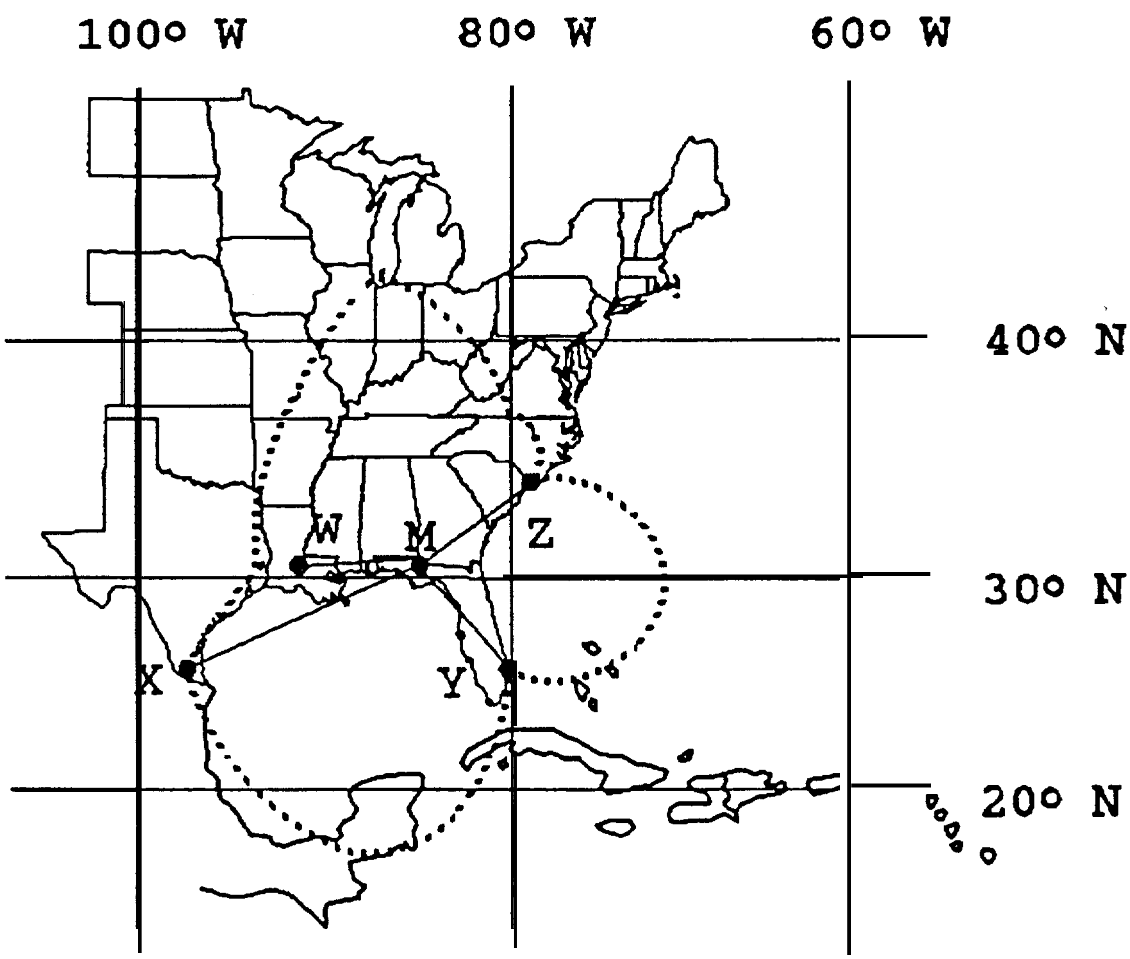
Transmitter

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



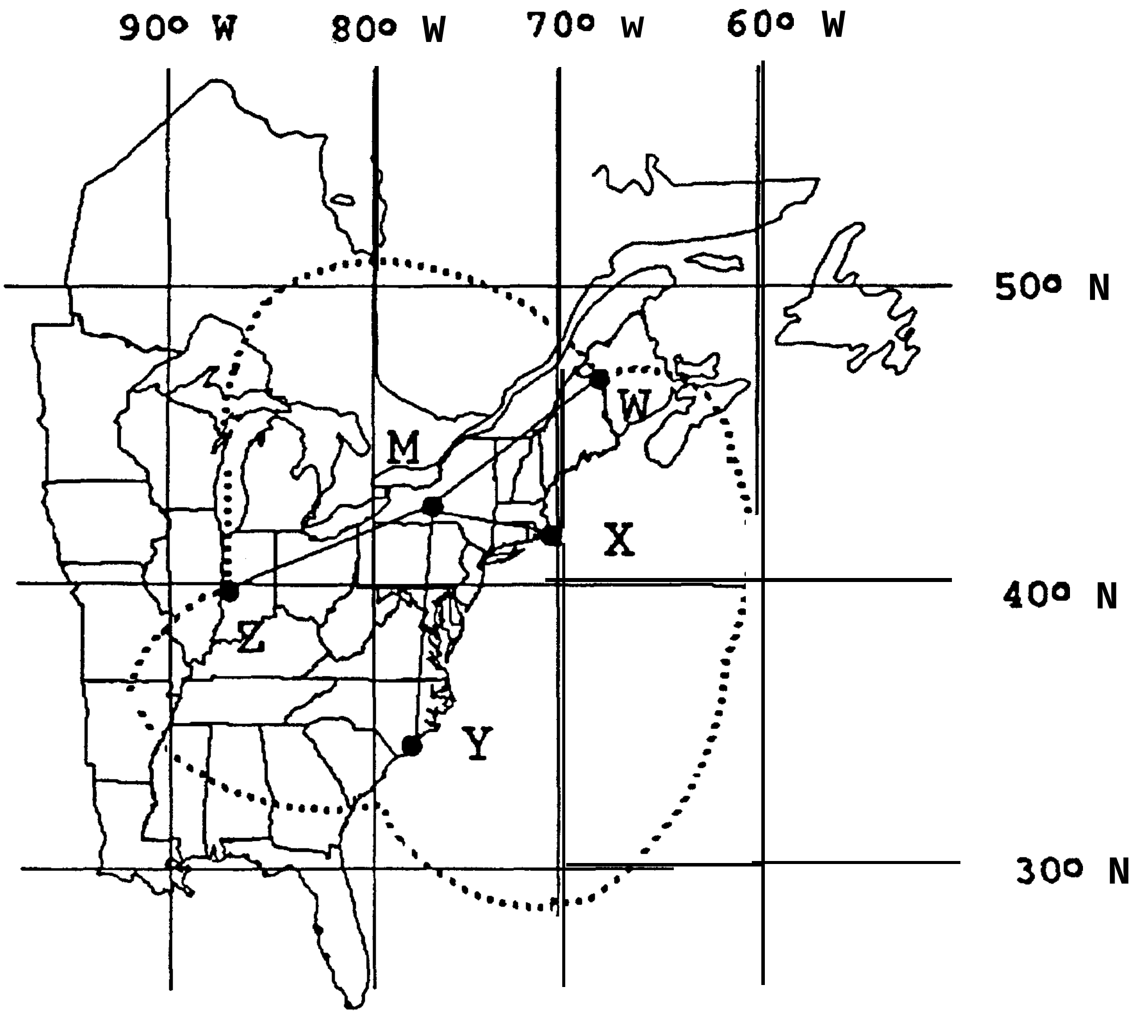
Transmitter

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

SNR ....a.......... **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



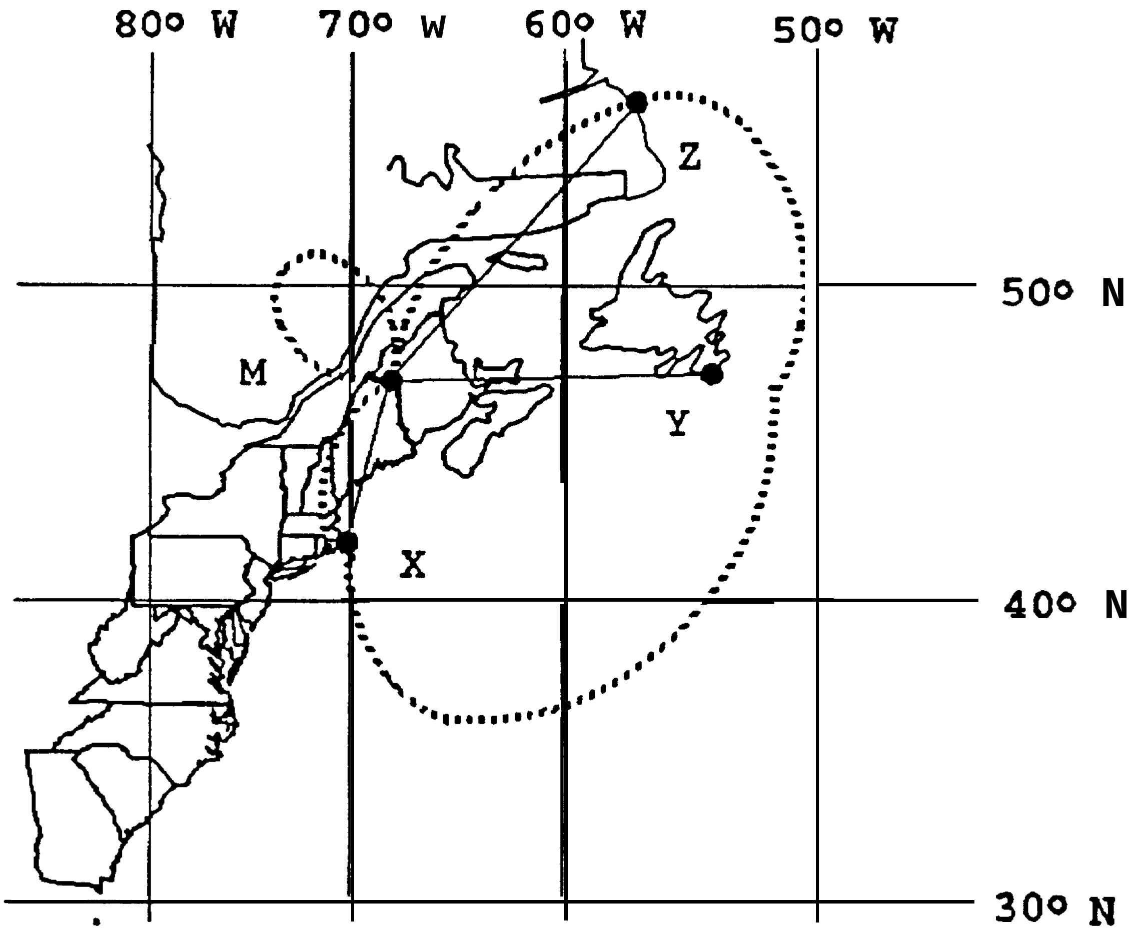
Transmitter

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



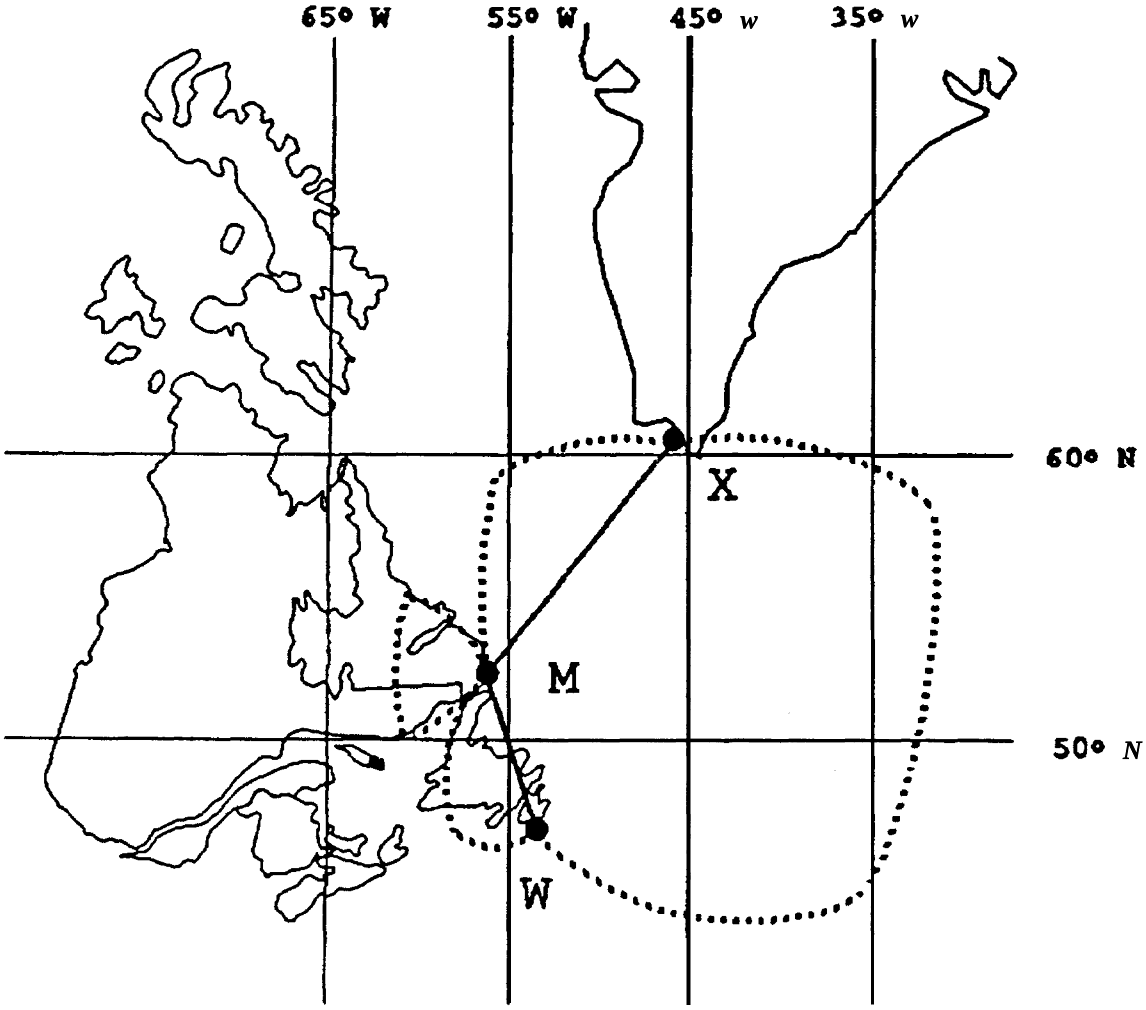
Transmitter

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



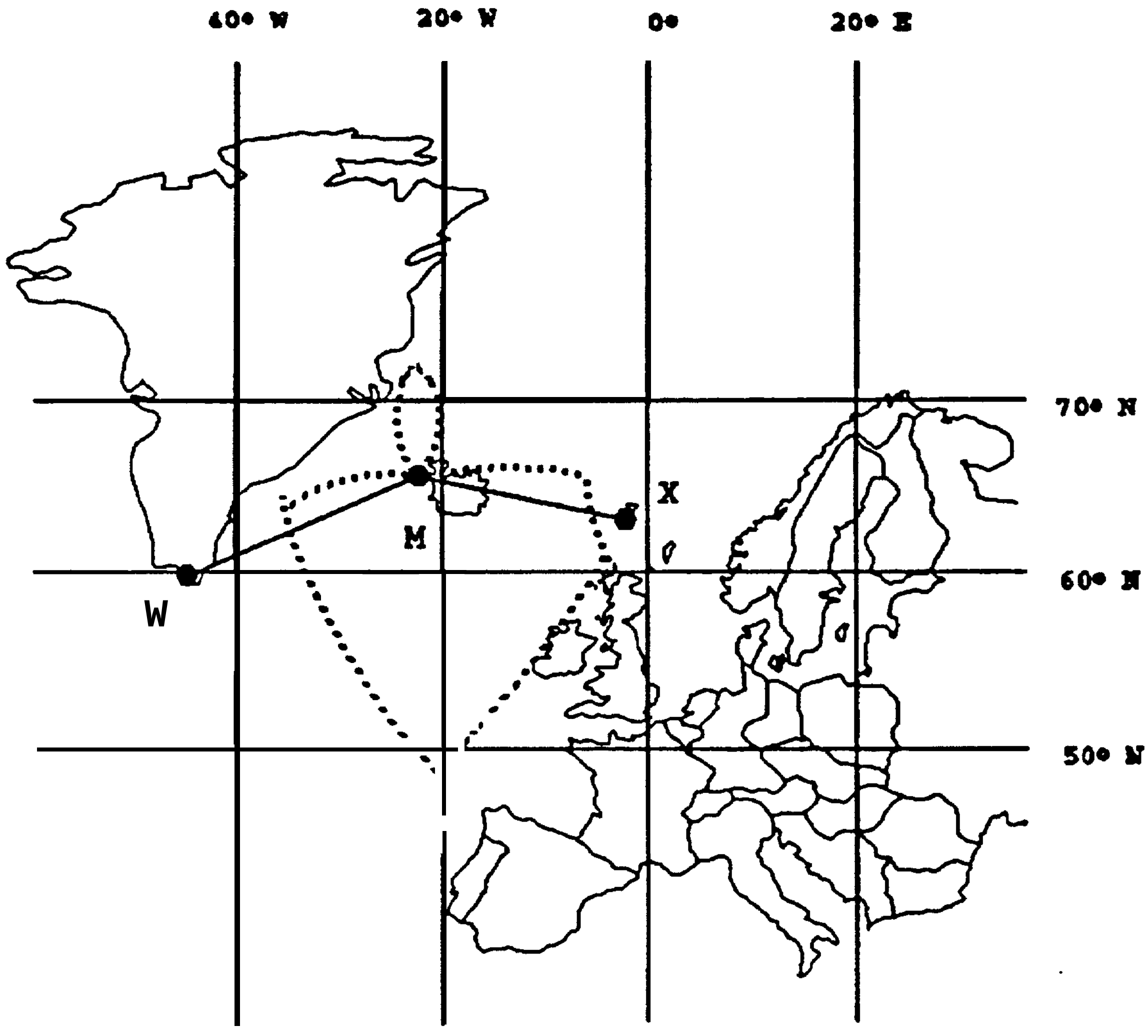
Transmitter

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



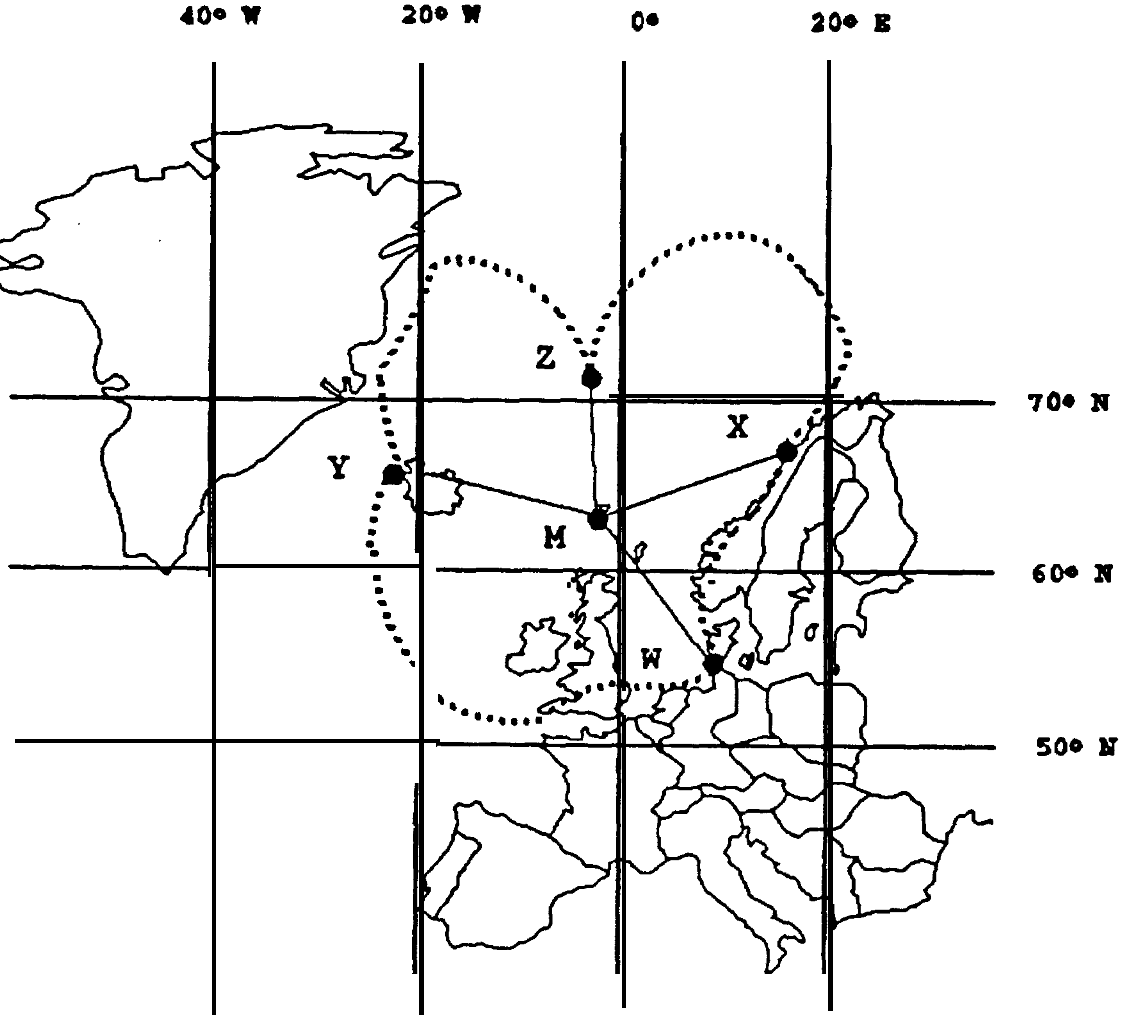
Transmitter

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-l 4. LORAN-C GRI 7970 NORWEGIAN SEA CHAIN



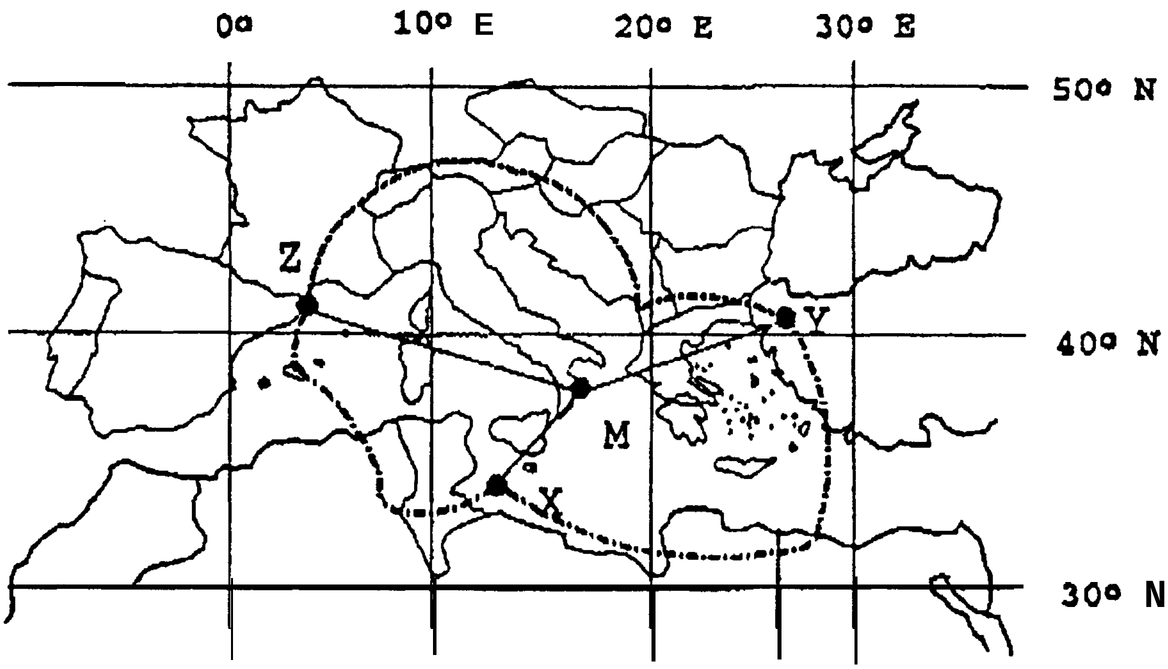
Transmitter

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 doverage, 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 Estattit, 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

This appendix contains a glossary of terms relevant to loran and loran radio navigation. 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), Radio navigation 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 radio navigation system accuracy generally refer to one or more of the following definitions:

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

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.

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 (40Federal 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 vessels 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 vessels 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 vessels 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 gravitation¬al 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, calledtide. 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 correspond¬ing carrier cycles contained in the times of a master and secondary station pulse. The comparison is refined to a determi¬nation of the phase difference between these two cycles. Cycle matching provides superior performance over enve¬lope 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. F 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 radio navigation 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 chart like 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 vessels 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.

Ground wave.
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 vessels 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 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 f 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 earths 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 sailors 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 earths 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 ships 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.
Vessels 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 earths 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 systems 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 micro-seconds 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), sky waves 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 ground wave 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 vessels speed through the water to the engines 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 vessels 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 earths 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 stations 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 vessels ground speed in the direction of the waypoint in use. In general, VMG is less than or equal to the vessels 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 receivers 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).

F1

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.

AACAntenna/Antenna Coupler
ACAntenna Coupler
ACAlternating Current
ADFAutomatic Direction Finder
AMAmplitude Modulation
ANMSAutomated Notice to Mariners System
ASFAdditional Secondary Factor
ASSAutomatic Secondary Selection
ATONAid to Navigation
ATSAutomatic Transmitter Selection

BLLBaseline Length
BRGBearing

CCZCoastal Confluence Zone
CDCoding Delay
CDICourse Deviation Indicator
CDRCommander
CECCanadian East Coast
CEPCircular Error Probable
CMGCourse Made Good
COCOCoordinator of Chain Operations
COGCourse Over the Ground
COICone of Influence
COMDTINSTCommandant Instruction
CTSCourse To Steer
CWCCanadian West Coast

dBDecibels
DCDirect Current
DGPSDifferential Global Positioning System
DLCSDifferential Loran-C System
DMADefense Mapping Agency
DMAHTCDefense Mapping Agency/Hydrographic and Topographic Center
DODDepartment of Defense
DOTDepartment of Transportation
DRDead Reckoning
DSCDigital Selective Calling
DTGDistance To Go

ECBFEarth Centered Body Fixed
ECDEnvelope to Cycle Difference
EDEmission Delay
ENDDSElectronic Navigation Digital Data System
ENSEnsign
EPEstimated Position
ETAEstimated Time of Arrival
ETEEstimated Time Enroute

FAAFederal Aviation Administration
FMFrequency Modulation
FRPFederal Radionavigation Plan

GDOPGeometric Dilution of Position
GLGreat Lakes
GLKSGreat Lakes
GOAGulf of Alaska
GPSGlobal Positioning System
GRIGroup Repetition Internal

GSGroundwave Skywave
G
NRNRadionavigation Division

HDGHeading
HFHigh Frequency
HHAHarbor and Harbor Approach
HHEHarbor and Harbor Entrance
HzHertz

IFRInstrument Flying Rules

HzKilohertz
kWKilowatt

LAMLoran Aviation Monitors
LCDLiquid Crystal Display
LCDRLieutenant Commander
LEDLight Emitting Diode
LFLow Frequency
LNMLocal Notice to Mariners
LOPLine of Position
LORANLong Range Navigation
LORMONSITELoran Monitor Site
LORSTALoran Station
LPALocal Phase Adjustment
LTLieutenant

MAGMagnetic
MFMedium Frequency
MHzMegahertz
MITMassachusetts Institute of Technology
MPAManual Phase Adjustments
MPPMost Probable Position

NADNorth American Datum
NAVNavigation
NAVAIDNavigation Aid
NBSNational Bureau of Standards
NEUSNortheast US
NGSNational Geodetic Survey
NMNautical Mile
NMEANational Marine Electronics Association
NOAANational Oceanic and Atmospheric Administration
NOCUSNorth Central US
NORPACNorth Pacific
NOSNational Ocean Service
NOTAMNotice to Airmen
NPANon-Precision Approach

OOTOut of Tolerance

PCIPhase Code Interval
PFPrimary Phase Factor
PRFPulse Repetition Frequency
PRRPulse Repetition Rate

RADARRadio Direction and Ranging
RDFRadio Direction Finding
RFRadio Frequency
RHO

F1
APPENDIX E

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 completea 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 owners 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 applicablethese are included for historical interest. Others may present alternative viewpoints to those expressed herein, and are included to lend balance and perspective.

Abramowitz, M., et al.
Approximate Method for Rapid Loran Computation, Navigation; Journal of the Institute of Navigation, Vol. 4, No. 1, March 1954, pp. 24
27.

Alexander, G.
The Premier Racing Tool, Ocean Navigator, Issue No. 20, Jul/Aug 1988, pp. 37, et seq.

Anonymous.
Loran: Installation Pitfalls, and How Fiendly Should Your Loran Be?
Practical Sailor, Vol. 11, No. 24, December 15, 1985, pp. 1, et seq.

Anonymous. Manual on Radio Aids to Navigation, International Association of Lighthouse Authorities, Nouvelle Adresse, 13 Rue Yvon-Villarceau 75116, Paris, 1979.

Appleyard, S. F. Marine Electronic Navigation. Routledge and Kegan Paul Ltd., Boston, MA, 02108, 1980.

Ashwell, G. E., B. G. Pressey, and C. S. Fowler. The Measurement of the Phase Velocity of Ground Wave Propagation at Low Frequencies Over a Land Path. Proceedings of the Institute of Electrical Engineering (London) 100 Part III, 1953.

Bedford Institute of Oceanography. Loran-C Receiver Performance Tests, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, Canada, B2Y 4A2.

Blizard, M. M. et al. Harbor Monitor System Final Report, CG-D-17-87, ADA 183 477, Dec. 1986, Available through the National Technical Information Service, Springfield, VA, 22161

Blizard, M. M., Lt. and CWO 3 D. C. Slagle. Differential Loran-C System Final Letter, Draft, United States Coast Guard, January 1987.

Blizard, M. M. and D. C. Slagle,
Loran-C West Coast Stability Study, Proceedings of the Fourteenth Wild Goose Technical Symposium, Wild Goose Association, Bedford, MA, 1985.

Brogdon, B.,
Loran Expansion, Ocean Navigator, Issue No. 42, Sept/Oct 1991, pp. 87, et seq.

Brogdon, W.
Loran Hook, a Little Known Foible Explained, Boating, August 1991, p.42.

Brogdon, W.
Electronic Errors, Ocean Navigator, Issue No. 40, June 1991, pp. 70, et seq.

Brogdon, W.
Pathfinders, American Hunter, Vol. 19, No. 7, July 1991.

Burt, W. A., et al. Mathematical Considerations Pertaining to the Accuracy of Position, Location, and Navigation Systems, Part I, Stanford Research Institute, 1966. Available from National Technical Information Service, AD 629609, US Department of Commerce, 5825 Port Royal Road, Springfield, VA 22151.

Canadian Coast Guard, Aids and Waterways Branch. A Primer on Loran-C, Ottowa, Ontario, Canada, 1981.

Connes, K. The Loran, GPS & NAV/COMM Guide, Butterfield Press, 1990.

Culver, C.
A New High Performance Loran Receiver, Proceedings of the Sixteenth Annual Technical Symposium, The Wild Goose Association, 20
27 October 1987, pp. 282, et seq.

Dahl, B.
Adopting Loran-C to Everyday Navigation, Cruising World, May 1983, pp. 40
45.

Dahl, B.
Loran-C for the Great Lakes, Lakeland Boating, March 1983, pp. 34
37.

Dahl, B. The Loran-C Users Guide for Cruisers, Racers and Fishermen, Richardsons Marine Publishing Inc., Streamwood, IL, 1986.

Dahl, B.
RadionavigationThe Big Three, Cruising World, Vol. 17, No. 5, May 1991, pp. 70 et seq.

Davis, C. W.
Recent Developments in the Use of Loran, Navigation; Journal of the Institute of Navigation, Vol. 3, No. 8, June 1953, pp. 289
295.

Defense Mapping Agency. Radio Navigational Aids, Publication 117, DMA Stock No. RAPUB117, Washington, DC, Various Years.

Defense Mapping Agency Hydrographic/Topographic Center. American Practical Navigator, An Epitome of Navigation, (Bowditch) Vol. 1, Pub. No. 9, DMA Stock No. NVPUB9VI, 1984, also NVPUB9V2, Vol. 2, 1981.

Defense Mapping Agency Hydrographic/Topographic Center. Loran-C Correction Tables, Northeast, USA, 9960, DMA Stock No. LCPUB2211200
C, 1983. See also these same tables for other chains.

DeGroot, L. E.
Navigation and Control from Loran-C, Navigation; Journal of the Institute of Navigation, Vol. 11, No. 3, Autumn 1964, pp. 213
227.

Delorme, J. F. and A. R. Tuppen
Low Cost Navigation Processing for Loran-C and Omega, Navigation; Journal of the Institute of Navigation, Vol. 22, No. 2, Summer 1975, pp.112-127.

Department of Defense and Department of Transportation. 1990 Federal Radionavigation Plan, DOT
VNTSC
RSPA
90
3/DOD
4650.4, 1990 and earlier editions.

Department of Transportation, United States Coast Guard, Coast Guard Aids To Navigation, COMDTPUB P16502.8, May 1988.

Department of Transportation, United States Coast Guard, Loran-C User Handbook, COMDTINST M16562.3, May 1980.

Department of Transportation, United States Coast Guard, Radionavigation Bulletin, Various Issues.

Department of Transportation, United States Coast Guard, Radionavigation Systems, G
NRN, September 1988.

Department of Transportation, United States Coast Guard, Specification of the Transmitted Loran-C Signal, COMDTINST M16562.4, July 1981.

Department of Transportation, United States Coast Guard, United States Coast Guard Annotated Bibliography, June 1982.

De Pree, K.
Using Your Loran in the Bahamas, A Technique for Figuring Differential Loran Corrections, Ocean Navigator, No. 15, Sept/Oct 1987, pp 43 et seq.

Dippy, R. J.
Gee, a Radio Navigational Aid, Journal I.E.E., Vol. 93, Part IIIA, No. 2, 1946, pp. 468
480.

Dishal, M.
Basic Design Procedure for Loran Transmitters Using High Power Half Cycle

Generators, Navigation; Journal of the Institute of Navigation, Vol. 23, No. 2, Summer 1976, pp. 136, et seq.

Doherty, R. H. Discussion of Real and Apparent Loran-C Propagation Limitations, paper for Advisory Group of Aerospace Research and Development meeting on
Propagation Limitations of Navigation and Positioning Systems, Istanbul, Turkey, October 1976.

Doherty, R. H. and J. R. Johler.
Meterological Influences on Loran-C Groundwave Propagation, Journal Atmospheric and Terrestrial Physics, Vol. 37, 1975, pp. 117
1124.

Doherty, R. H. and J. R. Johler.
Unexploited Potential of Loran-C, Navigation; Journal of the Institute of Navigation, Vol. 22, No. 4, 1975, p. 343.

Doxie, K.
A Navigators First Experience With Loran A, Ocean Navigator, Issue No. 6, Mar/April 1986, pp. 28, et seq.

Doyle, R. C.
Cycle SlippageHow to Detect and Correct It, Ocean Navigator, Issue No. 6, Mar/April 1986, pp. 31, et seq.

Doyle, R. C.
Selecting Secondaries: In Some Cases Youll Get Better Results By Manually Choosing Loran Stations, Ocean Navigator, Issue No. 34, Jul/Aug 1990, pp. 74, et seq.

Dresser, H.
First Experience Installing a Loran, Ocean Navigator, Issue No. 27, July/Aug 1989, pp. 76, et seq.

Dwelle, R.
Cutting Through the Fog: Demystifying Loran Terminology, Practical Sailors 1990 Gear Buying Guide, Belvoir Publications, Greenwich, CT, 1990, p. 6. See also in this issue by the same author,
Understanding the Loran Industry: A Case of Inbreeding, pp. 7
9, and
Cheap Electronic Navigation: New Low-Priced Lorans, pp. 10
15.

Dwelle, R.
Precise Loran Navigation: The ASF/TD/Lat/Lon Problem, Practical Sailor, Vol. 12, No. 2, January 15, 1986, pp. 3, et seq.

Enge, P. K. and J. R. McCullough.
Aiding GPS with Calibrated Loran-C, Navigation; Journal of the Institute of Navigation, Vol. 35, No. 4, Winter 1988
1989, pp. 469
482.

Enge, P. K. and G. Noseworthy.
Cross-Rate Synchronization of Loran-C Using GPS, Navigation; Journal of the Institute of Navigation, Vol. 35, No. 3, Fall 1988, pp. 335
346.

Englert, K. Loran Users Guide, Technical Information Services, Los Angeles, CA, 1986.

Ewing, G.,
Clearing the Record on Loran Outages, Ocean Navigator, No. 42, Sept/Oct 1991,

p. 29.

Fehlner, L. F., et al. Experimental Research on the Propagation of Loran-C Signals, Volumes A
D, APL/JHU TG 1298A, Applied Physics Laboratory, Johns Hopkins University, 1976.

Fehlner, L. F., et al. Loran-C Signal Specification, Applied Physics Laboratory, Johns Hopkins University, 1978.

Fehlner, L. F. and T. A. McCarty.
How to Harvest the Full Potential of Loran-C, Navigation; Journal of the Institute of Navigation, Vol. 21, No. 3, Fall 1974, pp. 223
233.

Feldman, D. A., M. A. Letts and R. J. Wenzel.
The Coast Guard Two Pulse Loran-C Communications System, Navigation; Journal of the Institute of Navigation, Vol. 23, No. 4, Winter, 1976, pp. 276, et seq.

Fell, H.
Comments on Loran Conversion Algorithms, Navigation; Journal of the Institute of Navigation, Vol. 22, No. 2, 1975, pp. 184, et seq.

Fontikov, A. G.
Review of Long-Range Radionavigation Systems Development in the USSR: Long-Range Radionavigation Systems, The Spheres of Employment, Proceedingf of the 20th Convention and Technical Symposum, Wild Goose Association, Williamsburg, VA, October 1991.

Frank, R. L.
Current Developments in Loran-C, Proc I. E. E. E., Vol. 71, No. 10, October 1983, pp. 1127 et seq.

Frank, R. L.
Multiple Pulse and Phase Code Modulation in the Loran-C System, IRE Trans. on Aeronautical and Navigational Electronics, 1986.

Frantz, W. P., W. N. Dean, and R. L. Frank.
A Precision Multi-Purpose Radio Navigation System, I. R. E. National Convention Record, Vol. 5, Part 8, March 1957, pp. 79
98.

Frazer, R.
Loran Accuracy, Ocean Navigator, Issue No. 20, July/Aug 1988, pp. 43, et seq.

Friedlander, B. and F. Hutton.
New Algorithms for Converting Loran Time Differences to Positions, Navigation; Journal of the Institute of Navigation, Vol. 20, No. 3, 1973, pp. 178, et seq.

Gait, M. A.
More on Fine Tuning Your Loran Receiver, Ocean Navigator, Issue No. 30, Jan/Feb 1990, pp. 16, et seq.

Government of Canada, Department of Fisheries and the Environment, Canadian Hydrographic Service. Fishermans Guide to the New Loran-C, Dominion Hydrographer, Canadian Hydrographic Service, 615 Booth Street, Ottawa, Ontario, K1A 0E6.

Government of Canada, Department of Fisheries and Oceans, Ocean Science and Surveys, Canadian Hydrographic Service. Cartographic Standing Orders, Loran-C Latticing, CSO 80
28, 20 February 1980.

Government of Canada, Department of Fisheries and Oceans, Ocean Science and

Surveys, Canadian Hydrographic Service. Notes on the Use of Loran-C Charts, Second Edition, 1983.

Guoqiang, G., et al.
The Chinese Loran-C System: Achievement and Prospect, Proceedings of the 20th Convention and Technical Symposium, Wild Goose Association, Williamsburg, VA, October 1991.

Hafley, G. The Development of Loran-C Navigation and Timing, NBS Monograph 129, Washington, DC, 1972.

Haislip, D. T.
Jan Mayen Island Revisited, US Coast Guard Academy Alumni Association Bulletin, Jan
Feb 1967.

Haislip, D. T.
Loran
C: A Precision Radionavigation System, Navigation; Journal of the Institute of Navigation, Vol. 9, No. 1, Spring 1962, pp. 14
20.

Hall, G. E.
The Correct Use of Corrections, Ocean Navigator, Issue No. 23, Jan/Feb 1989, pp. 15, et seq.

Hobbs, R. R. Marine Navigation 2: Celestial and Electronic, Second Edition, Naval Institute Press, Annapolis, MD, 1985.

Horowitz, L.
Direct Ranging Loran, Navigation; Journal of the Institute of Navigation, Vol. 17, No. 2, 1970, pp. 200
204.

Humber, J.
Following the Loran Onto the Rocks, Ocean Navigator, Issue No. 37, Jan/Feb 1991, p. 16.

International Telecommunication Union. World Distribution and Characteristics of Atmospheric Radio Noise. International Radio Consultive Committee, CCIR Report 322.2, Documents of the Xth Plenary Assembly, Geneva, 1963.

Jansky and Bailey, Inc. The Loran-C System of Navigation, National Technical Information Service, AD
281804, 1962.

Jeffrey, C. B.
Loran-C on the Lower Great Lakes, Navigation; Journal of the Institute of Navigation, Vol. 20, No. 1, Spring 1973, pp. 17
28.

Jeffrey,N. and K. Jeffrey.
Alternate Energy Sources, Ocean Voyager, Issue 17, No. 2, 1988, pp. 76, et seq.

Johler, J. R.
The Impact of the Choice of Frequency and Modulation on Radionavigation Systems, Navigation; Journal of the Institute of Navigation, Vol. 21, No. 3, Fall 1974, pp. 185, et seq.

Johnson, B. The Secret War, Methuen, New York, NY, 1978.

Jones, D. O.
Loran Technicalities, Ocean Navigator, Issue No. 24, March/Apr 1989, p. 16.

Kaczor, B. The Loran-C Handbook For Power and Sailboats, Sea Dog Marine Publishing, Cleveland, OH, 1986.

Keeler, N. H.
Maritime Future Navigation Needs and Plans, Navigation; Journal of the Institute of Navigation, Vol. 34, No. 4, Winter 1987
1988, pp. 290
298.

Kelley, C. T.
Use of Loran in the RangeRange Mode, Navigation; Journal of the Institute of Navigation, Vol. 16, No. 4, Winter 1969
70, pp. 390
400.

Kennedy, G. Electronics Communication Systems, McGraw-Hill, New York, 1977.

Kutik, W. M.
New Trends in Loran, Ocean Navigator, Issue No. 20, Jul/Aug 1988, pp. 31, et seq.

Last, D. and N. Ward.
Loran-C Measurement Trials in Ireland and UK: Interference, Noise, and Field Strength Results, Navigation; Journal of the Institute of Navigation, Vol. 37, No. 3, Fall 19980, pp. 233
248.

Lukac, C. F. and L. G. Charron.
Timing a Loran-C Chain, Navigation; Journal of the Institute of Navigation, Vol. 29, No. 3, Fall 1982, pp. 235
245.

Malloy, F. J.
Loran: A Long Distance Electronic Navigation System, Signal, Nov/Dec 1954, pp. 10
13.

Maloney, E. S. Duttons Navigation and Piloting, Fourteenth Edition, Naval Institute Press, Annapolis, MD, 1985.

May, J. M.
Chain Switch Fools Loran Set, Ocean Navigator, Issue No. 11, Jan/Feb 1987, p. 7.

Maxim, L. D. Advanced Coastal Navigation, Second Edition, United States Coast Guard Auxiliary, 86
51655, ISBN 0
930028
0
5, 1990.

McCullough, J. R.
A First Look at Loran-C Calibration Data in the Gulf of Mexico, Proceedings of the Sixteenth Annual Technical Symposium, The Wild Goose Association, 12
14 October 1983, pp. 25
67.

McCullough, J. R., B. J. Irwin, and R. M. Bowles. Loran-C Latitude-Longitude Conversion at Sea: Program Considerations. Woods Hole Oceanographic Institution, Woods Hole, MA.

McGann, E. L.
Evolution of Loran-C Coverage, Navigation; Journal of the Institute of

Navigation, Vol. 29, No. 1, Spring 1982, pp. 89, et seq.

Melton, L. The Complete Loran-C Handbook, International Marine Publishing Co., Camden, MA, 1986.

Melton, L. Piloting With Electronics, International Marine Publishing Co., Camden, ME, 1987.

Miller, A. R.
Some Suggestions for More Precise Loran Navigation, Navigation; Journal of the Institute of Navigation, Vol. 3, No. 1/2, September/December 1951, pp. 23
29.

Miller, C. and E. S. Maloney. Your Boat's Electrical System, Heast Marine Books, New York, NY, 1988.

Millington, G.
Ground Wave Propagation Over an Inhomogeneous Smooth Earth, Proceedings Institute of Electrical Engineering, London, UK, 1949 (96 Part III, p. 53).

Ministry of Defense (Navy) BR 45(1). Admiralty Manual of Navigation, Vol. I (General Navigation, Coastal Navigation and Pilotage) and Vol. III (Radio Aids to Navigation) Her Majestys Stationery Office, London, UK, 1987.

Moody, A. B. Navigation Afloat, Van Nostrand Reinhold Company, New York, NY, 1980.

Mooney, F. W.
Loran-C on Florida's Southwest Coast, Proceedings of the 20th Convention and Technical Symposium, Wild Goose Association, Williamsburg, VA, October 1991.

National Marine Electronics Association. Guide to Loran-C, NEMA, Accord, MA, 1987.

Nuzzi, S. F., and J. C. Sturm,
From Russia With Loran, Proceedings of 19th Convention and Technical Symposium, Wild Goose Association, Long Beach, CA, October 1990.

Olsen, D. L. et al. Precision Loran-C Navigation for the Harbor and Harbor Entrance Area, CG
D
34
80, ADA 086001, May 1980. Available through the National Technical Information Service, Springfield, VA 22161.

Olsen, D. L. and J. R. Stoltz.
Precision Loran-C Navigation on the St. Marys River, Navigation; Journal of the Institute of Navigation, Vol. 25, No. 3, pp. 290, et seq.

Oswitt, R. P.
The SST is Here!!! The Solid State Loran-C Transmitter, The Coast Guard Engineers Digest, Vol. 20, No. 199, Summer 1978.

Pierce, J. A.
An Introduction to Loran, Proc I. R. E., Vol. 34, May 1946, pp. 216
234.

Pierce, J. A.
Memoirs of John Alvin Pierce: Development of Loran, Navigation; Journal of the Institute of Navigation, Vol. 36, No. 1, Spring 1989, pp. 1
8.

Pierce, J. A., A. A. McKenzie, and R. H. Woodward. Loran, McGraw-Hill Book Company, New York, NY, 1948.

Pierce, J. A. and R. H. Woodward.
The Development of Long-Range Hyperbolic Navigation in the US, Navigation; Journal of the Institute of Navigation, Vol. 18, No. 1, Spring 1971, pp. 51
62.

Pike, D.
More Loran For Europe, Ocean Navigator, Issue No. 15, Sept/Oct 1987, pp. 39, et seq.

Poppe, M. C., Jr.
The Loran-C Receiver: A Functional Description, Navigation; Journal of the Institute of Navigation, Vol. 29, No. 1, Spring 1982, pp. 56
58.

Price, A. Instruments of Darkness, The History of Electronic Warfare, MacDonald and Janes, London, UK, 1977.

Queeney, T.
Marine Technology Notes: Staying in Control, Ocean Navigator, Issue No. 42, Sept/Oct 1991, pp. 5, et seq.

Queeney, T.
Time Differences Deciphered, Ocean Navigator, Issue No. 41, July/August 1991, pp. 5, et seq.

Queeney, T. E.
Loran for Voyaging, Ocean Voyager 1988 Handbook of Offshore Sailing, Issue 17, Vol. II, 1988, p. 30.
Queeney, T. E.
Loran: Its History and Its Future, Ocean Navigator, Issue No. 6, Mar/April 1986, pp. 24, et seq.

Queeney, T. E.
Navigating With Differential Loran, Ocean Navigator, Issue No. 10, Nov/Dec 1986, pp. 3, et seq.

Razin, S.
Explicit (Noniterative) Loran Solution, Navigation; Journal of the Institute of Navigation, Vol. 14, No. 3, Fall 1967, pp. 265
269.

Reymond, R. D.
Benefit/Cost Analysis Applied to Loran-C Expansion, Navigation; Journal of the Institute of Navigation, Vol. 29, No. 1, Spring 1982, pp. 40
55.

Rogoff, M. Calculator Navigation, W. W. Norton & Co., New York, 1979.

Ryerson, J. L.
Derivation of Circular Fixes in Hyperbolic Navigation Systems, Navigation; Journal of the Institute of Navigation, Vol. 16, No. 4, Winter 1969
70, pp. 382
389.

Samaddar, S. N.
The Theory of Loran-C Ground Wave PropagationA Review, Navigation; Journal of the Institute of Navigation, Vol. 26, No. 3, Fall 1979, pp. 173
187.

Samaddar, S. N.
Weather Effects on Loran-C Propagation, Navigation; Journal of the Institute of Navigation, Vol. 27, No. 1, Spring 1980, pp. 39
53.

Sandretto, P. C. Electronic Aviation Engineering, International Telephone and Telegraph Corporation, 1958.

Schlereth, H. Common Sense Coastal Navigation, W. W. Norton & Company, New York, NY, 1982.

Sexton, J.
Using Your New Loran Set for Celestial Navigation, Ocean Navigator, Issue No. 5, Jan/Feb 1986, pp. 49, et seq.

Sherman, H. T. and V. L. Johnson.
The Loran-C Ground Station, Navigation; Journal of the Institute of Navigation, Vol. 23, No. 4, 1976, pp. 349, et seq.

Shudde, R. H.
A Non-Iterative Algorithm for Loran-C Position Determination, Navigation; Journal of the Institute of Navigation, Vol. 31, No. 3, Fall 1984, pp. 179
199.

Smith, R. A. Radio Aids to Navigation, MacMillan (London), 1948.

Sonnenberg, G. J. Radar and Electronic Navigation, Sixth Edition, Butterworths, London, UK, 1988.

Speight, J. J.
DMAHTC Support to National Ocean Survey Loran-C Charting, Navigation; Journal of the Institute of Navigation, Vol. 29, No. 1, Spring 1982, pp. 22
39.

Stearns, R.
Who's Smarter, You or Your Loran?, Boating, August 1991, pp.98, et seq.

Stebbins, R. J. and K. S. Stebbins. Coastal Loran Coordinates, Volume 1: Texas to Maine, International Marine Publishing Company, Camden, ME, 1990.

Stuart, J. S. Loran and Omega Plotting Procedures and Specifications, NOS, 29 May 1991.

Stuart, J. S. The Status of National Ocean Service Loran-C Charting, NOS, Fall 1986.

Sullivan, J. E.
Hyperbolic History: Remembering Englands Gee System and Loran A, Ocean Navigator, Issue No. 6, Mar/April 1986, pp. 26, et seq.

Swanson, E. R.
Geometric Dilution of Precision, Navigation; Journal of the Institute of Navigation, Vol. 25, No. 4, Winter 1978
1979, pp. 425, et seq.

Taggart, D. S.
USCG R&D Differential Loran-C Study, Proceedings of the Thirteenth Wild Gooe Technical Symposium, Wild Goose Association, Bedford, MA, 1984.

Tagggart, D. S. and D. C. Slagle. Loran-C Signal Stability Study: West Coast, Final Report, CG
D
4
87, AD-A-183080. Available through the National Technical Information Service, Springfield, VA 22161.

Taylor, A. E. Calculus With Analytic Geometry, Prentice-Hall, Inc., Englewood Cliffs, NJ, Sixth Printing 1961.

Tetley, L. and D. Calcutt. Electronic Aids to Navigation, Edward Arnold, Baltimore, MD, 1986.

Transport Canada, Coast Guard, Aids and Waterways. A Primer on Loran-C, TP 2659, 1981.

Transport Canada, Coast Guard, Aids and Waterways. Loran-C Bulletins, TP 4574E.

Trow, G. H. and A. H. Jessel.
The Presentation of the Fixing Accuracy of Navigation Systems, Journal of the Institute of Navigation (London), Vol. 1, Issue No. 4, 1948, pp. 313
337.

Tucker, B.
At the Source, Correspondent Tours A US Loran Station, Ocean Navigator, Issue No. 9, Sept/Oct 1986, pp. 6, et seq.

Tucker, B.
The Electrical Needs of a Voyaging Yacht, Ocean Voyager, Issue 17, No. 2, 1988, pp. 82, et seq.

Tuttle, R. A.
Practical Experiences in the Use of Standard Loran in Ocean Navigation Since the End of the War, Navigation; Journal of the Institute of Navigation, Vol. 1, No. 2, December 1948, pp. 268
271.

United States Coast Guard Academy. Loran-C Engineering Course Notes, New London, CT, 1990.

Uttam, B. J., Editor.
Loran-C Special Issue, Navigation; Journal of the Institute of Navigation, Vol. 29, No. 1, Spring 1982.

Van Etten, J. P.
Navigation Systems: Fundamentals of Low- and Very-Low-Frequency Hyperbolic Techniques, Electrical Communication, Vol. 45, No. 3, 1970, pp. 192 et seq.

Van Hooff, RADM J. F. Aids to Marine Navigation, Vol. I, Netherlands Maritime Institute/Maritime Research Institute Netherlands (MARIN) 198, No. 2, pp. VI
23
25.

Watson, F. G. and H. H. Swope.
Loran, Navigation; Journal of the Institute of Navigation, Vol. 1, No. 1, March 1946, pp. 11
16.

Watson-Watt, R. Three Steps to Victory, Odhams Press Ltd., London, UK, 1957.

Webster, C. and N. Frankland. The Strategic Air Offensive Against Germany, Vol. IV, Her Majestys Stationery Office, London, UK, 1961.

Welch, Bill. Airborne Loran-C Navigation, Waypoint Press, Waterford, CT, 06385, 1984.

Wenzel, R. J. and D. S. Slagle. Loran-C Signal Stability Study: NEUS/SEUS, CG
D
28
83, August 1983.

Weseman, J. F.

Loran-C: Past, Present, and Future, Navigation; Journal of the Institute of Navigation, Vol. 29, No. 1, Spring 1982, pp. 7
21.

Wild Goose Association. Bibliography, (list of titles and all authors of papers presented at all Wild Goose Association conventions), Wild Goose Association, Bedford, MA.

Wild Goose Association. The Goose Gazette, Quarterly Newsletter of the Wild Goose Association (original 1972), Bedford, MA, Various Issues.

Wong, G. A. Loran-C System Configuration Analysis for Civil Aviation, Report No. DO/FAA/R
81/110 (MTR
82W10), The Mitre Corporation, McLean, VA, prepared for the FAA, Washington,DC, 1982.

Wood, T., and K. Barron,
Accurate GPS Still Requires Monitoring, Ocean Navigator, No. 42, Sept/Oct 1991, pp. 24, et seq.

Yonezawa, Y., et al.
Evaluation of Loran-C System By A Manual Receiver-Indicator Accuracy of Time Difference Reading and Its Position Lines, Navigation; Journal of the Institute of Navigation, Vol. 16, No. 1, Spring 1969, pp. 61

F1

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 Millingtons 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 s, 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) 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.

Use of Conductivity Data in Millingtons Method

Figure F
3 shows the computational steps in the use of Millingtons 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 segmentseach with the same conductivity value. Figure F
4 shows an illustrative path frm 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 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 he 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 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 seawaterthat 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 quantitiesto 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

F1

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 K s11
 2 drms =     ++
                  sin C    A B
   sin2 ()sin2 ()  2 2


2 r     Cos C0.5
(G-1)
  A  B
   sin     ()sin()
  2            2
```

where:
A, B, C=angles defined in Figure G
1,
r=correlation coefficient between the measured TDs, generally taken to be 0.5,
K =bseline gradient, 491.62 ft/usec, and
s=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 users 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:

$C = A/2 + B/2$.(G-2)

The parameter r 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 ftquite accurate indeed.

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 users 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:

given the assumed alues 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:

In essence, GDOP measures the ratio of the actual value of 2 drms corresponding to the users 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 users location. Table G

F1

IntroductionSkywaves 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 receiverthis 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 groundwaveand this goes unrecognizedthen the loran positions determined from the loran overprinted charts or the receivers 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 line, and of skywave reception1 (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 owners manual for the particular loran receiver for detailed guidance. (The owners 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 vessels location should be considered. Anytime the vessel is outside the limits of the chains published coverage diagram, skywave recepton 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.

Undoubtedly, option (i) is the conservative choiceand 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 chains 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 groundwaveskywave 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.

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 forposition 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 vessels (or aircrafts) 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.

Question: Fair enough, but why isnt 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 maser. Finally, it should be noted that skywave correction data blocks are omitted entirely in areas where only groundwave reception is likely.

Question: Why isnt there an
SG correction given in the skywave data block near the Gorda Bank shown in Table H