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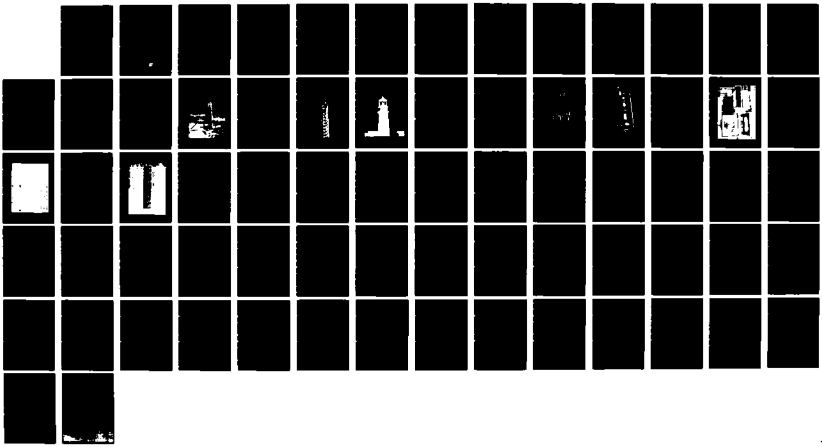

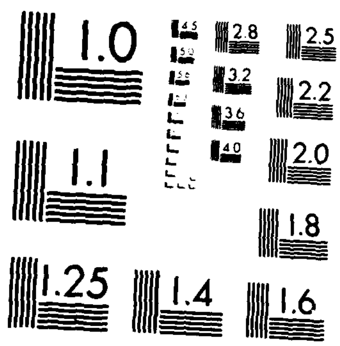


MICROCOPY RESOLUTION TEST CHART
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DOT-TSC-CG-83-2

# Evaluation of VHF-FM Shore-Based Direction Finding Triangulation System in Massachusetts Bay Area



Charles J. Murphy
LTJG James C. Preisig

Transportation Systems Center
Cambridge MA 02142

June 1983
Final Report



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U.S. Department of Transportation
United States Coast Guard

Office of Research and Development
Washington DC 20593

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16. Abstract


This report describes the evaluation of a VHF-FM Direction Finding Triangulation System in the Massachusetts Bay Area of the First Coast Guard District during the 1982 boating season. The evaluation consisted of the following phases:

(1) System definition and site selection;

(2) System calibration;

(3) Operational evaluation;

(4) Cost/benefit analysis.

It was concluded that properly implemented shore-based direction finding systems in either single line-of-bearing or triangulation configurations are valuable potential tools in accomplishment of SAR mission requirements.


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# PREFACE

As an element of the program to develop concepts and technology applicable to improved emergency distress location, the U.S. Coast Guard (USCG) directed the Transportation Systems Center (TSC) to procure, install and evaluate a VHF-FM direction finding (DF) triangulation system in the Massachusetts Bay Area during the 1982 boating season. This document describes an operational evaluation (OPEVAL) of the technical performance and cost-effectiveness of that system. Based on the results of the OPEVAL, as described in this report, TSC will prepare a technical specification for use by the Coast Guard in procurement of additional VHF-FM DF triangulation systems. This specification will be published as a separate document.

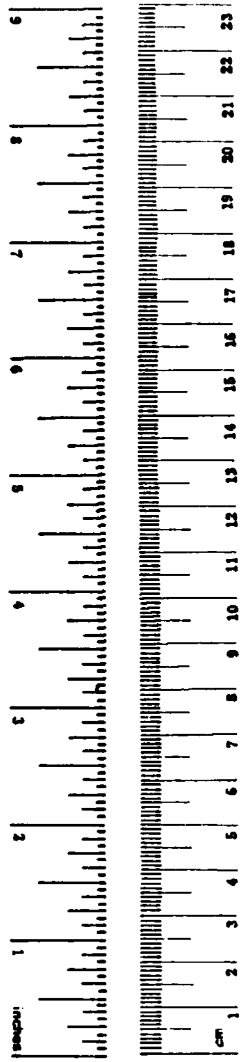
The authors wish to acknowledge the contribution of Dr. William Guion of Southwest Research Institute, producer of the DF system, and Mr. William O'Halloran and Dr. Eugene Mallove of JAYCOR, INC., test support contractor. Excellent guidance was provided by LCDR Larry Parkin and LT Jerry Lentz of the U.S. Coast Guard, Office of Research & Development and Mr. Robert Wisleder of TSC. Excellent support was received throughout the OPEVAL from personnel of the First Coast Guard District, in particular, LT Joseph Donovan and CWO Dennis Monroe. Invaluable assistance was also received from Mrs. Elly Paulos (G-OSR-3), the personnel of the Search & Rescue Division in the Fifth CG District, and Mr. Robert Wilmarth and Mr. William Murphy of TSC.

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

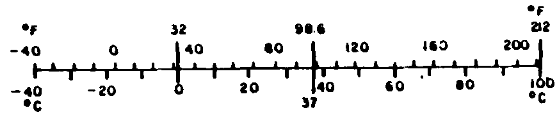
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# EXECUTIVE SUMMARY

As an element of the program to develop concepts and technology applicable to improved emergency distress location, the U.S. Coast Guard (USCG) directed the Transportation Systems Center (TSC) to procure, install, and evaluate a VHF-FM direction finding (DF) triangulation system in the Massachusetts Bay Area during the 1982 boating season. This document describes an operational evaluation (OPEVAL) of the technical performance and cost-effectiveness of that system.

The desired system was required to provide position determination for VHF-FM transmissions originating anywhere in the Massachusetts Bay/Cape Cod Bay Area utilizing remote DF receiving antennas to be located on existing Coast Guard structures.

The system chosen for the evaluation consists of three remotely located DF receiving systems connected by communication links to a Control/Display Unit at the Group Boston Communications Center. The three remote receiving sites are located at Cape Ann Light on Thacher Island, COMMSTA Boston in Marshfield, MA and Highland Light in North Truro, MA. Upon receiving a VHF-FM transmission at a minimum of two of the three receiving sites, the system presents an estimate of the transmitter's position along with an estimate of the accuracy of the position calculation.

Following system installation, a system calibration was performed utilizing test transmissions from SAR vessels and Class-C EPIRBs from known locations throughout the area of coverage. It was determined that the system provided position determination coverage for the entire Massachusetts Bay/Cape Cod Bay Area with an accuracy of 1-2 nautical miles for 25-watt ship transmissions. Due to the lower transmitted power, only line-of-bearing coverage was obtained for Class-C EPIRB transmissions.

The system has been in operational service since July 1982, and has been used successfully on several SAR cases. Operational personnel have found the system easy to use and reliable.

To determine the potential cost-effectiveness of such equipment to the Coast Guard, cost/benefit analyses were performed for the system as installed, and for two hypothetical installations located in the Woods Hole, MA area and in Chesapeake Bay. It was concluded that properly sited and operationally integrated systems will prove cost effective in regions of high SAR density.

# 1. INTRODUCTION

As an element of the program to develop concepts and technology applicable to improved emergency distress location, the U.S. Coast Guard (USCG) directed the Transportation Systems Center (TSC) to procure, install, and evaluate a VHF-FM direction finding (DF) triangulation system in the Massachusetts Bay Area during the 1982 boating season. This document describes an operational evaluation (OPEVAL) of the technical performance and cost-effectiveness of that system.

The desired system was required to provide position determination for VHF-FM transmissions originating anywhere in the Massachusetts Bay/Cape Cod Bay Area utilizing remote DF receiving antennas to be located on existing Coast Guard structures.

The system chosen for the evaluation consists of three remotely located DF receiving antennas with associated receiver-processors, connected by communication links to a Control/Display Unit at the Group Boston Communications Center. The system was designed and manufactured by Southwest Research Institute (SwRI) of San Antonio, TX, and is described in detail in reference 1. The three remote receiving sites are located at Cape Ann Light on Thacher Island, COMMSTA Boston in Marshfield, MA and Highland Light in North Truro, MA and are shown in Figure 1-1. The five channel system receives on channels 6, 12, 15, 16 and 22A of the VHF-FM band with channel selection controlled from Group Boston. Upon receiving a VHF-FM transmission at a minimum of two of the three receiving sites, the system presents an estimate of the transmitter's position along with an estimate of the accuracy of the position calculation.

During a three-week period following system installation, a system calibration was performed utilizing test transmissions from SAR vessels and Class-C EPIRBs from known locations throughout the area of coverage. During this calibration, personnel of the

Group Boston Communications Center were trained in the operation of the system and began using the system on actual SAR cases. A demonstration of the system for Headquarters personnel was conducted on September 27, 1982. The OPEVAL period ended November 30, 1982.

Section 2 presents a description of system design considerations while Section 3 describes the chosen system. The system calibration and technical results are presented in Section 4. Section 5 contains a summary of operational use of the system during the OPEVAL. Section 6 contains an overview of system operating costs and projected benefits. The conclusions and recommendations presented in Section 7 will be used in the formulation of a specification for follow-on systems to be presented in a separate document.

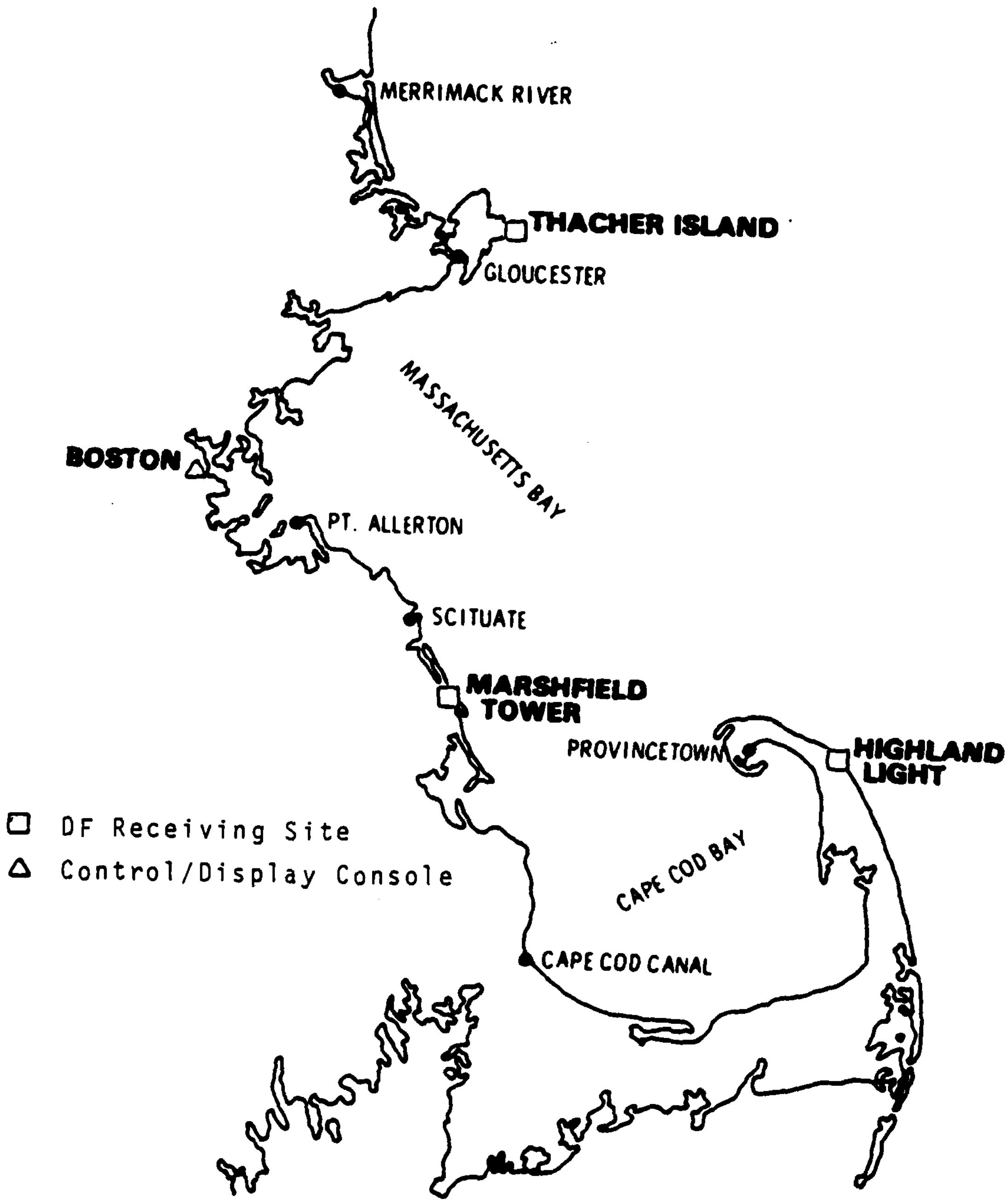


FIGURE I-1. DF SITE LOCATIONS

## 2. PRELIMINARY SYSTEM DESIGN AND SITE SELECTION

In designing a position locating system based on inputs from remotely located (bearing only) direction finding equipment, receiving antenna locations and heights must be chosen so that:

1. transmission from any point in the coverage area is received with adequate signal strength from at least two remote sites;

2. the resulting bearings to the transmitter from the sites should be no closer than 30° from being parallel.

The second requirement is necessary since each DF bearing is subject to such inaccuracies as site reflections and received noise, and a given bearing error translates into a larger position error as the intersection angle with the remaining LOP approaches the parallel alignment (at which point the position error becomes infinitely large). Thus the relative locations and heights of the DF sites and the relative location of the target transmitter influence the accuracy of location estimation. With any chosen set of antenna locations, the system accuracy over the required coverage area will be a constantly changing function of the number of LOPs obtained, the signal strengths and accuracy of the bearings, and the bearing intersection angles.

A study of triangulation geometry for the Massachusetts Bay/ Cape Cod Bay Area indicated that DF receivers should be located in the following areas: Gloucester/Cape Ann, MA; Scituate/ Marshfield, MA; and Provincetown, MA and that antenna heights of at least 200 feet ASL would be required.

Two possible sites were identified in the Gloucester/Cape Ann region: Eastern Point Light (57 feet ASL) and the Cape Ann Light on Thacher Island (166 feet ASL). Because of its superior height and offshore location the Cape Ann light was the clear choice from DF signal considerations alone (Figure 2-1). However, telephone service to the island, provided by a submarine cable, was in poor condition and considered unsuitable for use in the

FIGURE 2-1. CAPE ANN LIGHT ON THACHER ISLAND

DF system. To overcome this problem a decision was made to purchase and install a full duplex UHF link between the Cape Ann Light and Group Boston for the experiment.

In the Scituate/Marshfield area an ideal antenna site was available at the top of the microwave relay tower at COMMSTA Boston. The top of the tower (240 feet ASL) is free of antennas and affords a clear view to sea (Figure 2-2).

For the third site two possible locations were identified; the Pilgrim Monument in Provincetown, MA (348 feet ASL) on which a USCG high site is installed, and the Highland Light in North Truro, MA (183 feet ASL). The Pilgrim Monument, although the clear choice from signal reception considerations, is privately owned and was not available for the experiment. Thus the third site is the Highland Light, located approximately ten miles south of Provincetown (Figure 2-3). This site and the Marshfield site are connected to the control unit by dedicated, voice-grade telephone lines.

Upon consideration of the distances between the sites and the antenna heights offered by the available sites, it was determined that sensitivity was a critical system parameter and that basic system r.f. sensitivity should be enhanced by a system of averaging successive bearings from the same transmission. The bearing standard deviation for a fixed signal-to-noise ratio is improved by a factor of $\sqrt{N}$ when N independent bearings are averaged. Therefore the system is designed to compute independent bearings at a rate of 10 bearings per 200-millisecond time period. The ten bearings are averaged; bearings outside a predetermined limit are thrown out, and the resulting average bearing and average signal strength are transmitted in a frequency-shift keyed (FSK) format to the Control/Display Unit, where additional averaging is performed prior to calculation of position.

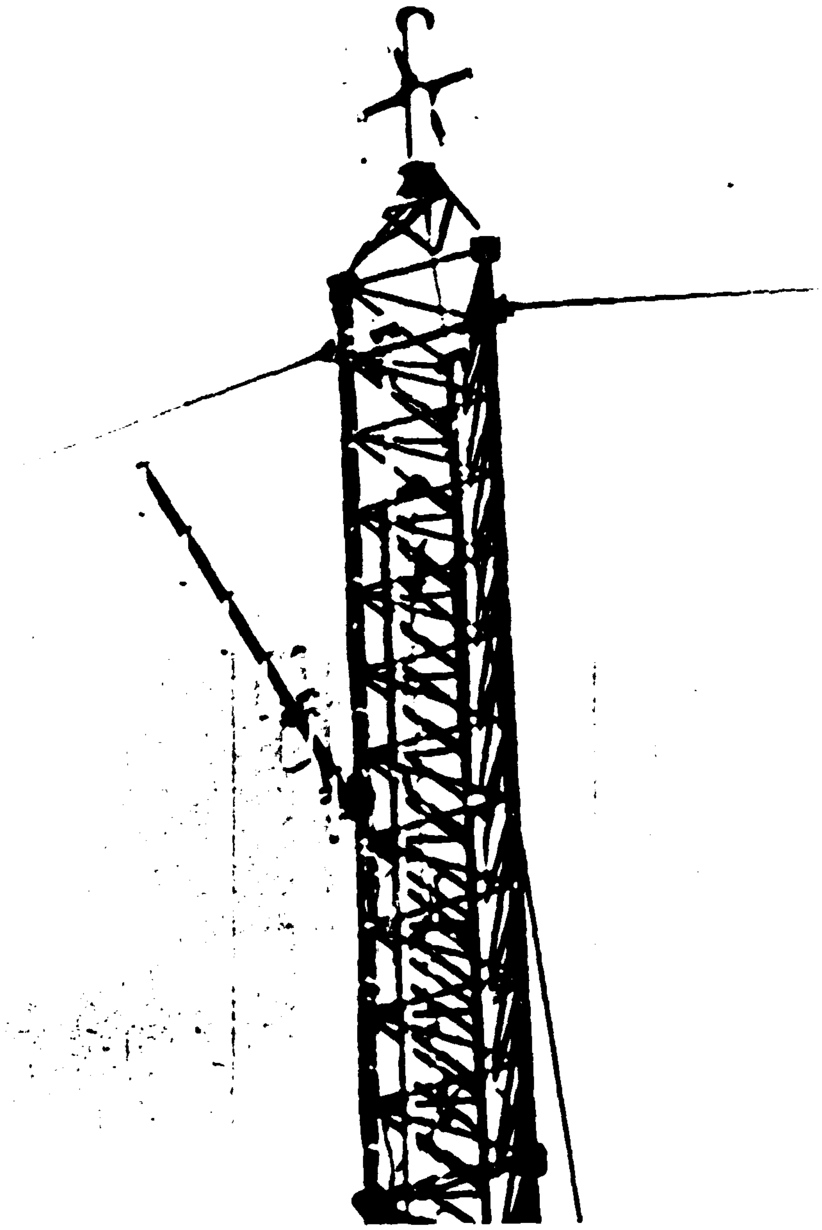

FIGURE 2-2. MICROWAVE TOWER AT MARSHFIELD, MA

FIGURE 2-3. HIGHLAND LIGHT AT NORTH TRURO, MA

# 3. SYSTEM DESCRIPTION

## 3.1 SYSTEM OVERVIEW

This chapter presents a system description of moderate detail following the system block diagram presented in Figure 3-1. For a more detailed description, see references 1 and 5.

## 3.2 DF ANTENNA

The DF antenna is a fixed four-element dipole Adcock, designed for center frequency operation of 160 MHz. The antenna is designed to allow the mounting of a separate symmetrical antenna above it and includes a hollow mast to carry the cables to the upper antenna. This would allow installation at a Coast Guard high site with the communications antenna on top. A photograph of the antenna is shown in Figure 3-2. A hybrid electronics package in the DF antenna provides simultaneous signals proportional to $\sin\phi$, $\cos\phi$, and omnidirectional with respect to the azimuth angle($\phi$) of the incident signal. The three antenna outputs are routed by phase-matched cables to the DF processor unit.

## 3.3 DF PROCESSOR UNIT

A DF Processor Unit (Figure 3-3) is located at each remote site and performs the following functions:

1. five-channel VHF-FM receiver;
2. bearing determination;
3. bearing averaging;
4. signal strength measurement;
5. communications link interface.

The DF Processor Unit provides full local control of the remote site with three digit bearing readout, channel select switch, readout, and audio headphone output.

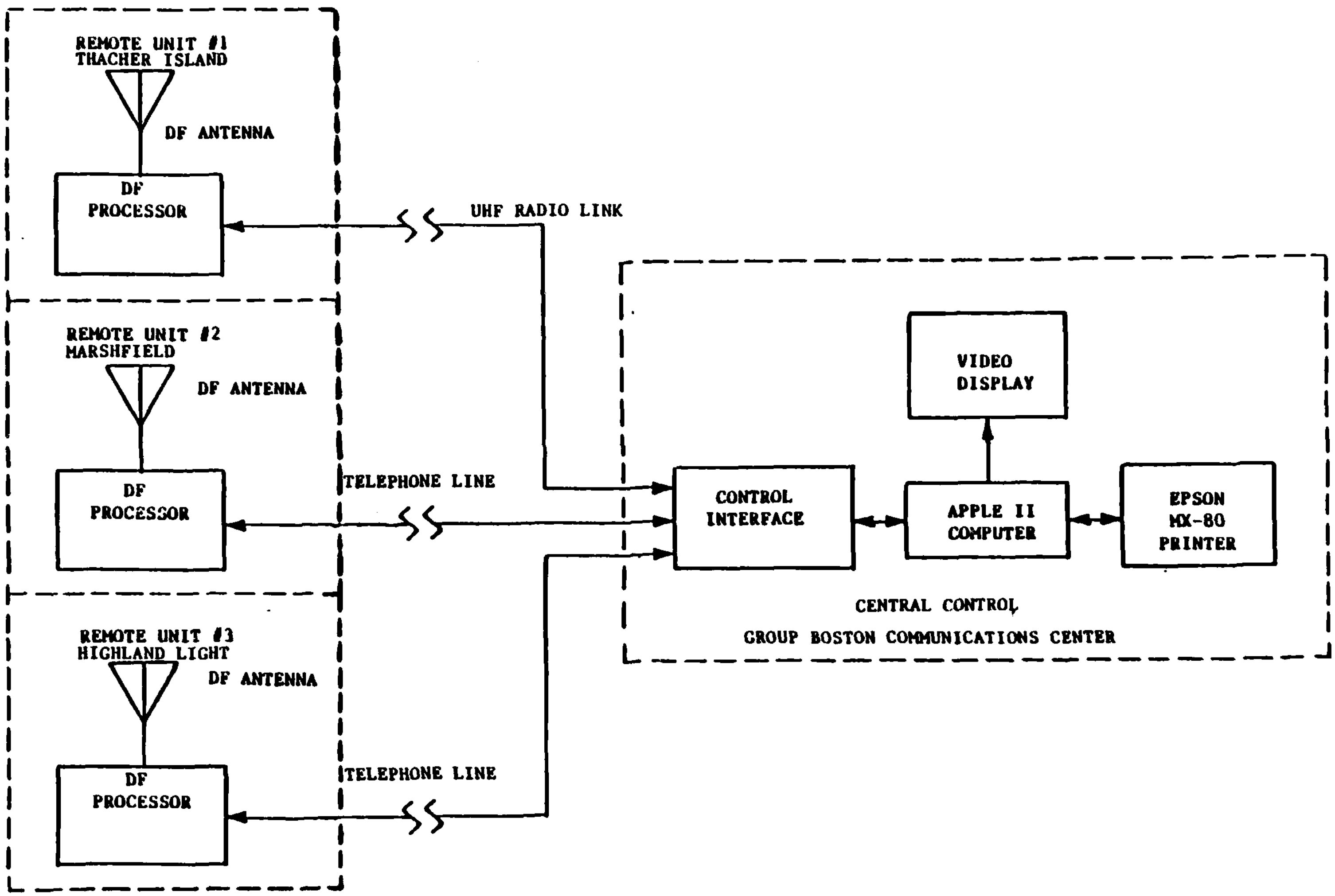


FIGURE 3-1. VFH RADIO DIRECTION FINDING AND RADIOLOCATION SYSTEM BLOCK DIAGRAM (from Ref 1)

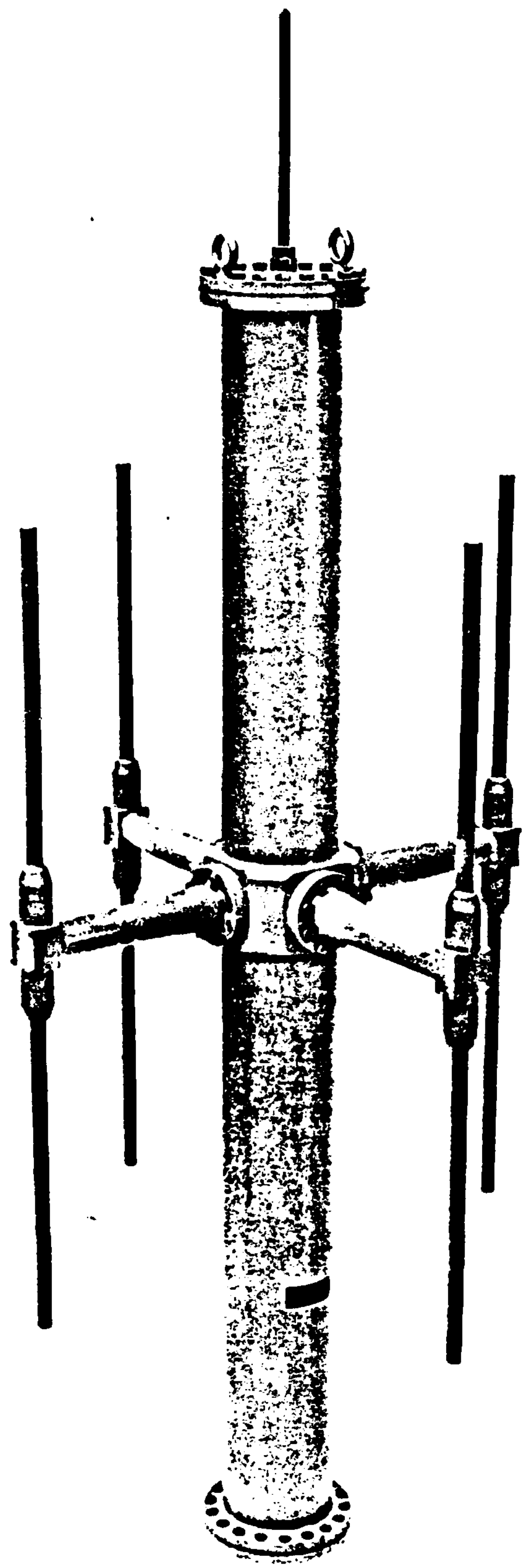

FIGURE 3-2. ANTENNA ASSEMBLY (from Ref 1)

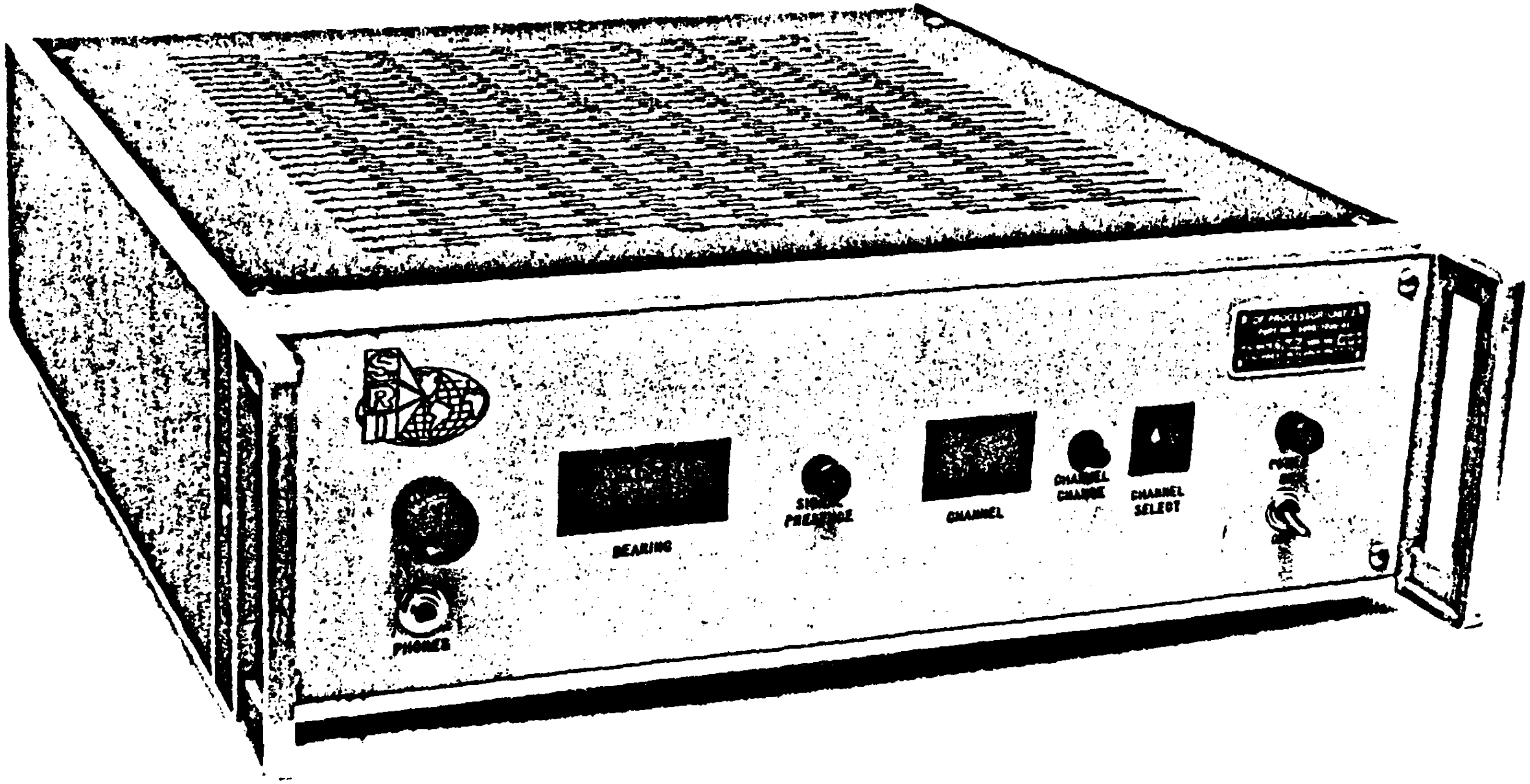


FIGURE 3-3. DF PROCESSOR (from Ref 1)

However, its primary mode of operation is as a slave receiver for the control console, and as such it receives and carries out channel change commands received on the communications link. The three antenna inputs to the DF Processor are used to compute the angle of arrival (bearing) of the signal using an electronic goniometer and a power (sense) combiner. Bearings are computed at a rate of 10 per 200-ms period and averaged in a microprocessor. Individual bearings differing substantially from the computed average are thrown out. The resulting average bearing, and the average received signal strength are encoded in a frequency-shift keyed (FSK) format and combined with the demodulated audio. The resultant signal is transmitted over a single dedicated voice-grade telephone line (or equivalent communication channel) to the Control/Display Unit.

## 3.4 CONTROL/DISPLAY UNIT

The Control/Display Unit, shown in Figure 3-4, provides operator control of the remote DF sites, as well as processing and display of the received bearing information and derived position information. The Control/Display Unit is composed of the following subunits:

1. Control Interface Unit;
2. Apple II Plus Computer;
3. SMD Color Video Display;
4. Epson MX-80 Printer.

The Control Interface Unit receives simultaneous inputs from the three remote sites containing audio and digital data. Notch filters are used to separate the audio and digital data and the audio can be selected from a single site, or any combination of sites, for monitoring through a loudspeaker. The data stream is then monitored and sampled in real time by the Apple computer.

The only data transmitted to the remote sites is the receiver channel select command which is encoded in an FSK format and transmitted simultaneously to the three remote DF sites. The sites,

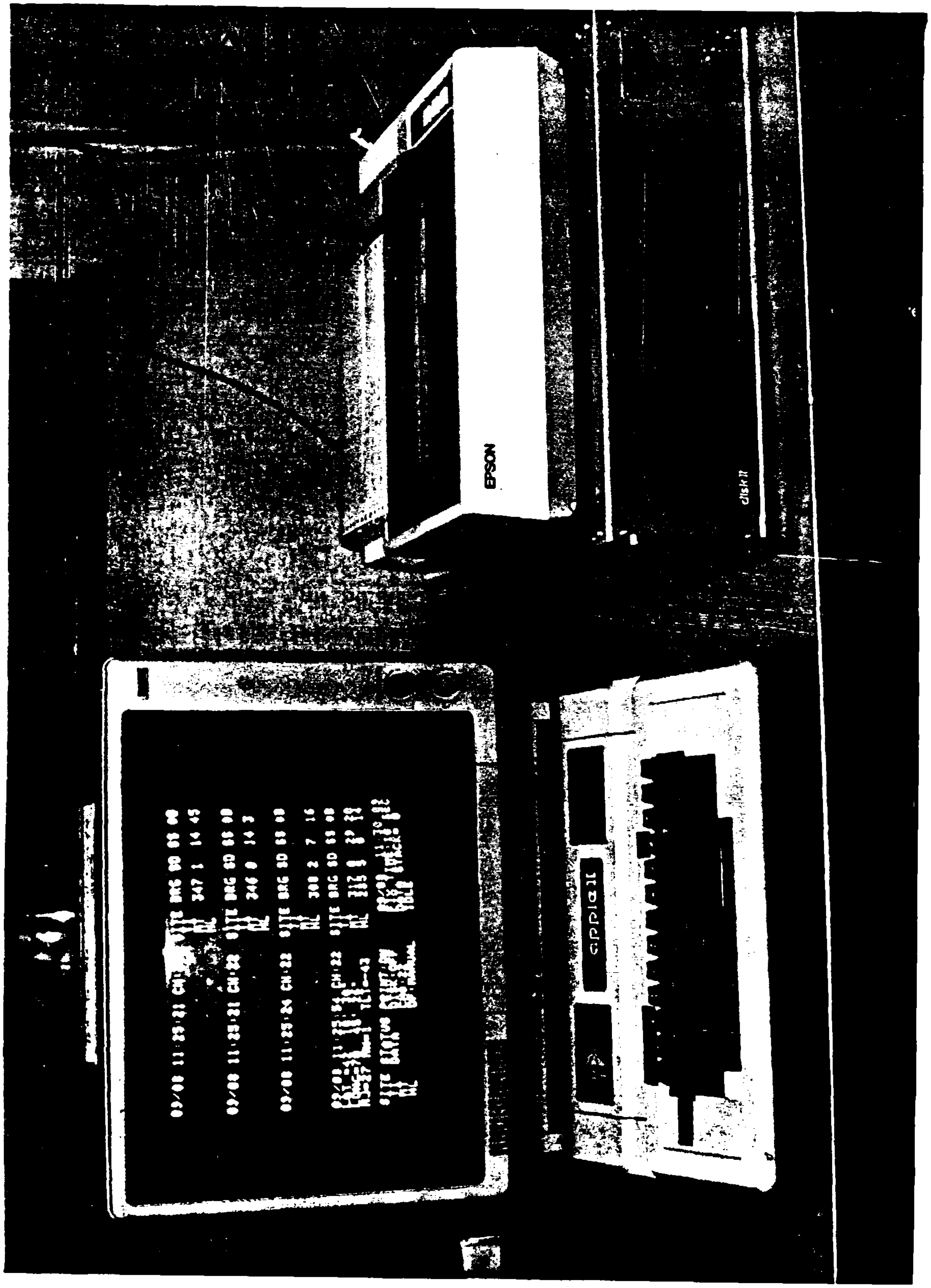


FIGURE 3-4. DF CONTROL/DISPLAY UNIT

upon complying with the "channel select" command, transmit an "acknowledge" signal back to the control console.

The FSK encoded bearing and signal strength data from each remote site is individually time tagged and input to the computer. The computer compares the arrival times of the bearing data from the three channels via the time tags and if two or all three of the inputs fall within a 60-millisecond time window, the signals are considered to have originated from the same transmitter. Signals thus qualified are used to compute a position which is presented to the operator. Bearings from signals falling outside of the 60-ms window are presented to the operator as bearing only information.

Due to the fact that each bearing received from a remote site has errors associated with it, the lines-of-position (LOPs) from three sites will not intersect in a single point but will intersect in three points, forming a triangle. In determining a statistical best point estimate to be used as the target position, the contractor utilized a least squares method, first described by Stansfield (ref. 6). The position is calculated by selecting the point that minimizes the weighted distance to each LOB. The weighting emphasizes bearing data from DF sites that are nearer the estimated position and those having the smallest bearing standard deviations.

Typical system operation will now be described. The operator first configures the system utilizing a display on the video monitor called the "OPTION MENU" which is shown in Figure 3-5. The operator makes the following choices:

1. <u>Channel Selected: 6, 12, 15, 16, 22</u>

2. <u>Fix Time: 2, 5, 10 or 15 seconds</u>. The computer will collect bearing data for the selected fix time or until the end of transmission, whichever occurs first, before presenting an averaged bearing.

3. <u>Printer: ON/OFF</u>. If the printer is selected "ON", all data appearing on the video monitor will be printed. If

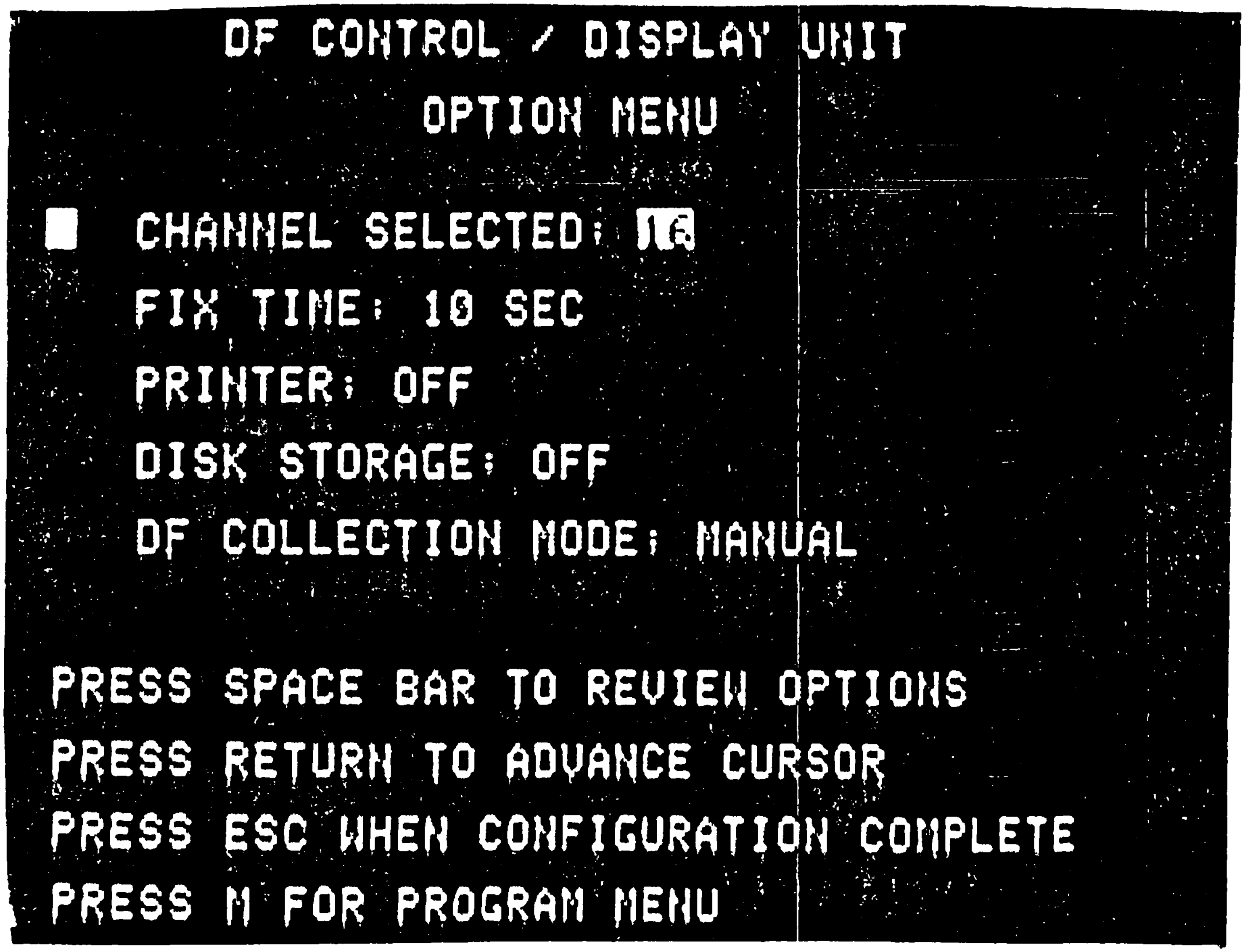


FIGURE 3-5. DF CONTROL/DISPLAY UNIT OPTION MENU (from Ref 5)

the printer is selected "OFF", the contents of the screen can be printed via a "PRINT SCREEN" key.

4. Disk Storage. Allows data to be stored on disk. Not normally used.

5. DF Collection Mode: MANUAL/AUTO. In "MANUAL," the computer will display position and bearing information on a transmission only if a "MANUAL DF" key is pressed prior to or during a transmission. In "AUTO", data will be displayed for all received transmissions.

Once the configuration is complete, the operator receives data on the video monitor (and printer, if selected) in the format shown in Figure 3-6.

Referring to the upper left hand corner of Figure 3-6, the date, time, and channel number are presented for a typical transmission. Below this the latitude and longitude of the calculated position are presented along with the major axis (MJ), minor axis (MN) and the orientation to true north (TLT in degrees) of a 95 percent confidence error ellipse. Opposite this information is presented the average bearings from the sites (TI = Thacher Island; MT = Marshfield; HL = Highland Light) used in the position calculation. Also presented for each bearing (BRG) are the standard deviation (SD) of the average bearing, the average received signal strength (SS), and the number of bearings used to compute the average (#B). Note that the overall number of bearings averaged is ten times greater than indicated due to the previous averaging before transmission from the remote site.

System status information is presented in the bottom four lines of the display. Status of the communications links to the three sites is presented under the "ERROR" column. If the link is operating properly, bearing information from the sites is presented in real time in this column before being processed. The remaining columns contain, in addition to confirmation of the system configuration, date, time of day, and the number of transmissions the computer has received but has not had time to process yet (DATA STACK).

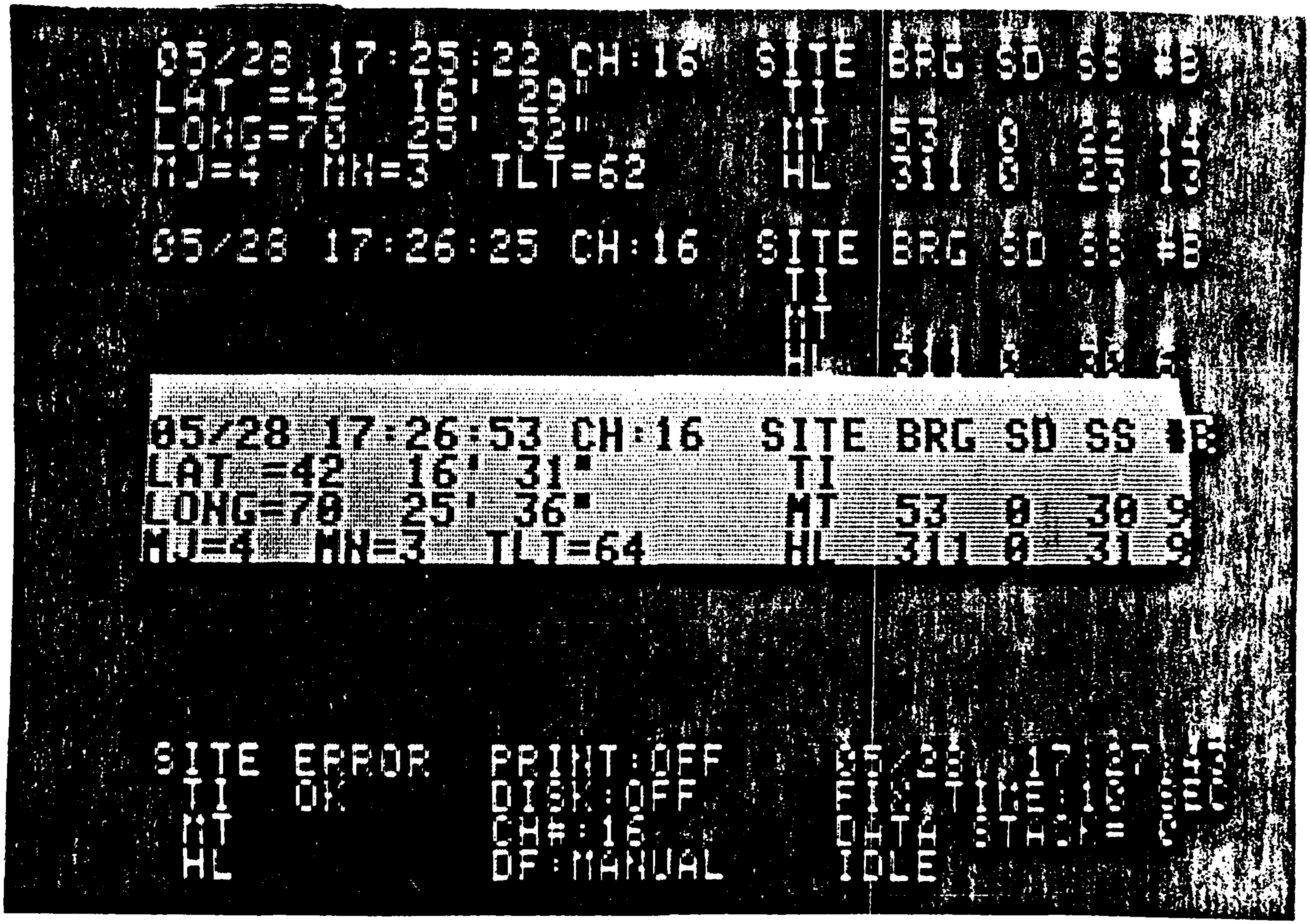


FIGURE 3-6. DF BEARING AND FIX VIDEO DISPLAY

# 4. SYSTEM CALIBRATION

## 4.1 INSTALLATION AND CHECKOUT

During the week of May 24 the DF receivers were installed at the three remote sites (antennas having been previously installed). Each site was individually aligned to true north and checked out via test transmissions from local Coast Guard shore-based transmitters. These adjustments were made by the SwRI system engineer at the remote sites, before the units were connected to the communication links. After all three receiving sites were determined to be working properly, they were tied into the Control/Display Unit and exercised individually from Group Boston. Finally the position computation system was exercised for all local shore-based transmitters, and found to be working properly.

## 4.2 CALIBRATION PROCEDURES

Figure 4-1 presents the predicted coverage areas for the three sites, indicating that there are areas of coverage by all receiving sites and areas covered by only two sites. In addition, there are areas such as north of Plum Island and east of Cape Cod where single site coverage will be provided resulting in determination of a bearing only to the transmitter. All testing was supported by 41-foot utility boats from local SAR sations except for the eastern part of Massachusetts which required support more than 10 miles offshore. For these tests, a 95-foot cutter was utilized. The test schedule is presented in Table 4-1 and test vessel routes are shown in Figure 4-2.

On all tests, vessel position was determined by a calibrated LORAN-C receiver provided and operated by a TSC test engineer. The LORAN-C receiver was checked before and after each series of test transmissions by reference to known locations such as buoys and the dockside position. Test transmissions were of 1, 10 and 15 seconds duration to determine system accuracy dependence on length of transmission. All tests transmissions were or channel 22A.

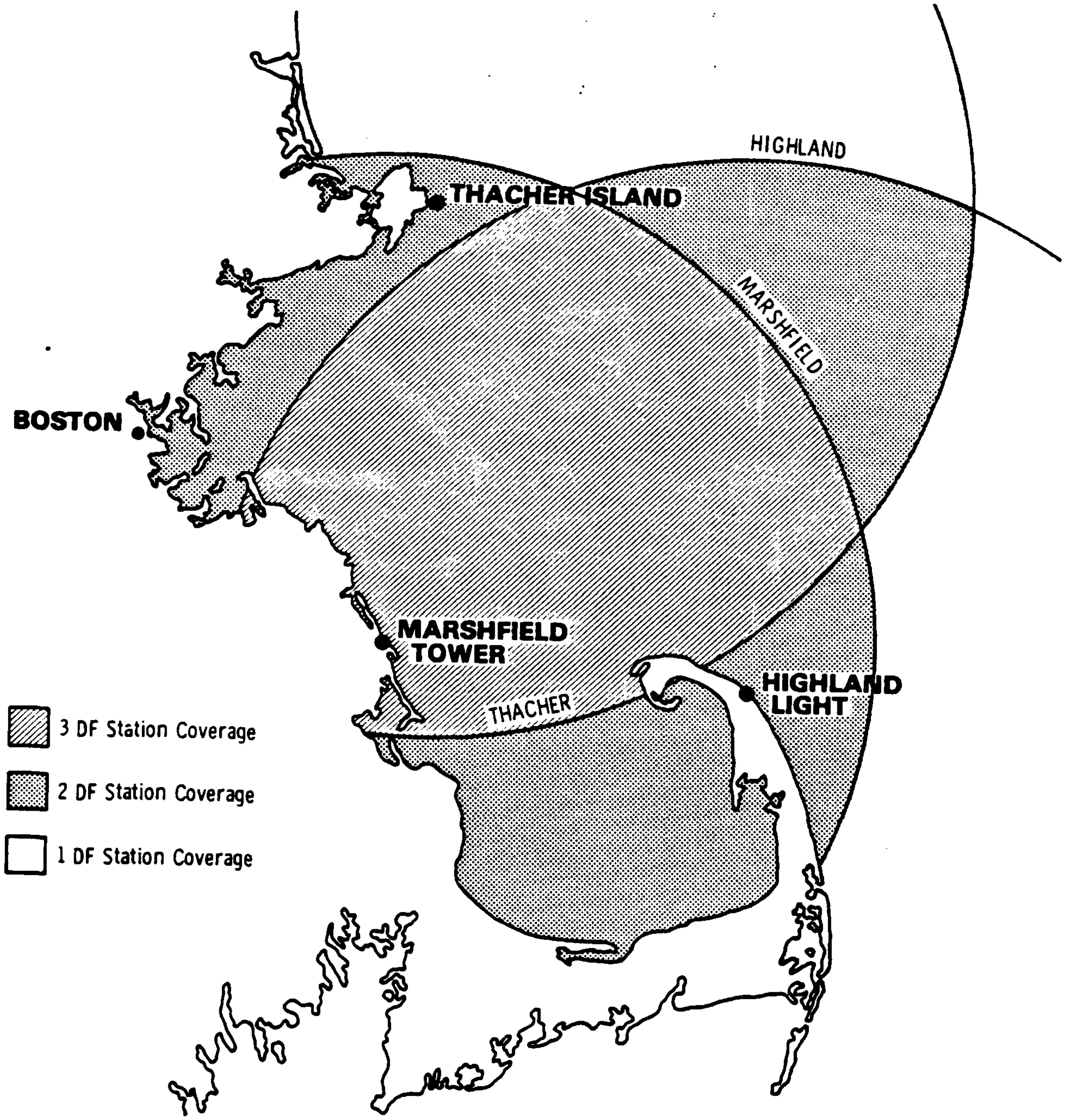


FIGURE 4-1. PREDICTED DF SYSTEM COVERAGE-MASSACHUSETTS BAY AREA (From Ref. 1)

TABLE 4-1. SYSTEM CALIBRATION TEST SCHEDULE

| Test Sequence No. | Test Support | Date | Region Covered |
|---|---|---|---|
| 1 | STA Gloucester, 41' utility boat | 7-13-82 | Cape Ann to Nahant; to LNB, to Gloucester |
| 2 | STA Point Allerton, 41' utility boat | 7-15-82 | Nahant to Cohasset Harbor |
| 3 | STA Scituate, 41'utility boat | 7-16-82 | Scituate Harbor to Plymouth Harbor |
| 4,5 | STA Provincetown, 41' utility boat | 7-30-82<br>7-21-82 | Provincetown Harbor to Orleans |
| 6 | STA Cape Cod Canal, 41' utility boat | 7-22-92 | Plymouth Harbor to Orleans |
| 7 | STA Gloucester 41' utility boat | 7-27-82 | Newburyport Harbor to Cape Ann |
| 8 | STA Gloucester, 95' cutter | 8-3-82 | From Gloucester 40 nm at 135°M, south to latitude of Provincetown, to Gloucester |

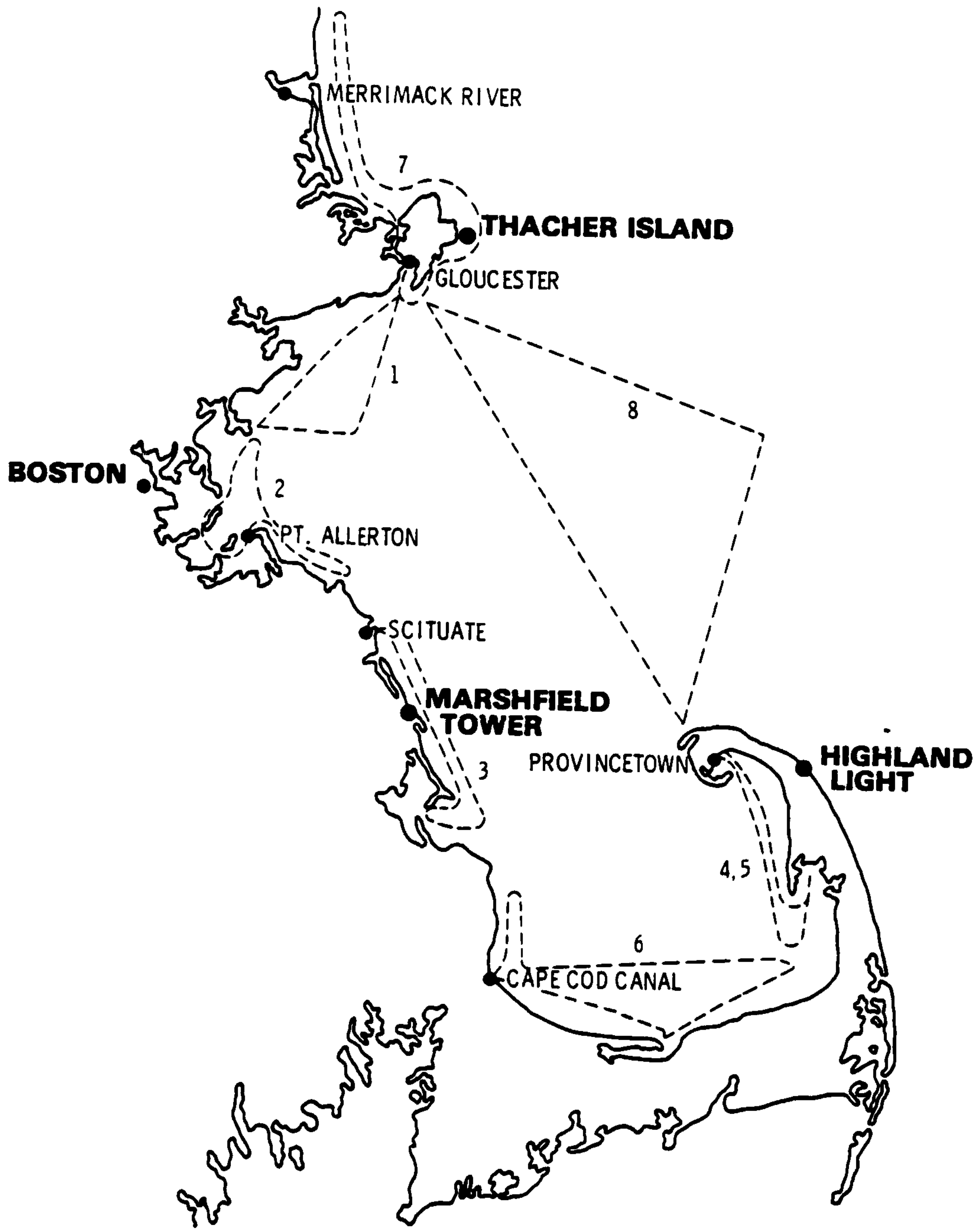


FIGURE 4-2. SYSTEM CALIBRATION TEST SEQUENCE DIAGRAM

Additionally, at selected locations in each test sequence, the DF receiving channel was changed to Channel 15, and a Class-C EPIRB was used as the signal source.

Each test transmission resulted in a printout of bearings and position of the test vessel at the Group Boston Communications Center. The format of this printout is shown in Table 4-2. A test engineer annotated each printout with vessel position and determined that the DF system and communication links were functioning properly.

Detailed test procedures for each day were prepared in consultation with Coast Guard operational personnel. These procedures included course of vessel, transmission coordinates, length and number of transmissions at each location, and calibration points for the LORAN-C receiver.

## 4.3 CALIBRATION RESULTS

Detailed test results (tabulations from ref. 2) are included in Appendix A. This data is summarized below.

### 4.3.1 Tests Conducted with 25-Watt Transmitter

With the standard 25-watt VHF-FM transmitter as a test source, position location was possible throughout the intended coverage area with the exception of the extreme southeastern region of Cape Cod Bay, where a bearing only was obtainable. The average position error was approximately one nautical mile. Average received signal strengths for the test positions are indicated in Figures 4-3 through 4-5 (from ref.2). Towards the conclusion of the test program the sensitivities of the Marshfield Tower and Highland Light DF receivers were increased by 6 dB. Thus system coverage and accuracy is somewhat better than the test results indicate (the receiver sensitivity had been reduced to mitigate the decorrelation problem).

### 4.3.2 Tests Conducted with Class-C EPIRB

A limited number of tests were conducted utilizing a Class-C EPIRB deployed in the water as the signal source. The Class-EPIRB

TABLE 4-2. CRT/PRINTER FORMAT FOR CONTROL/DISPLAY CONSOLE

```
01/10 11:24:30 CH:22  SITE BRG SD SS #B
LAT=42    22' 16"      TI  231 1  53 46
LONG=71  1'  45"       MT  315 1  28 45
MJ=5  MN=3  TLT=-60    HL  296 0  30 38
```

TI = Thacher Island

MT = Marshfield

HL = Highland Light

BRG = Bearing

SS = Signal Strength (dB) above threshold

SD = Bearing Standard Deviation (degrees)

#B = Number of Bearings Averaged

MJ = Major Axis of 95% Error Ellipse (nm)

MN = Minor Axis of 95% Error Ellipse (nm)

TLT = Tilt of Major Axis from True North (degrees)

CH = Channel

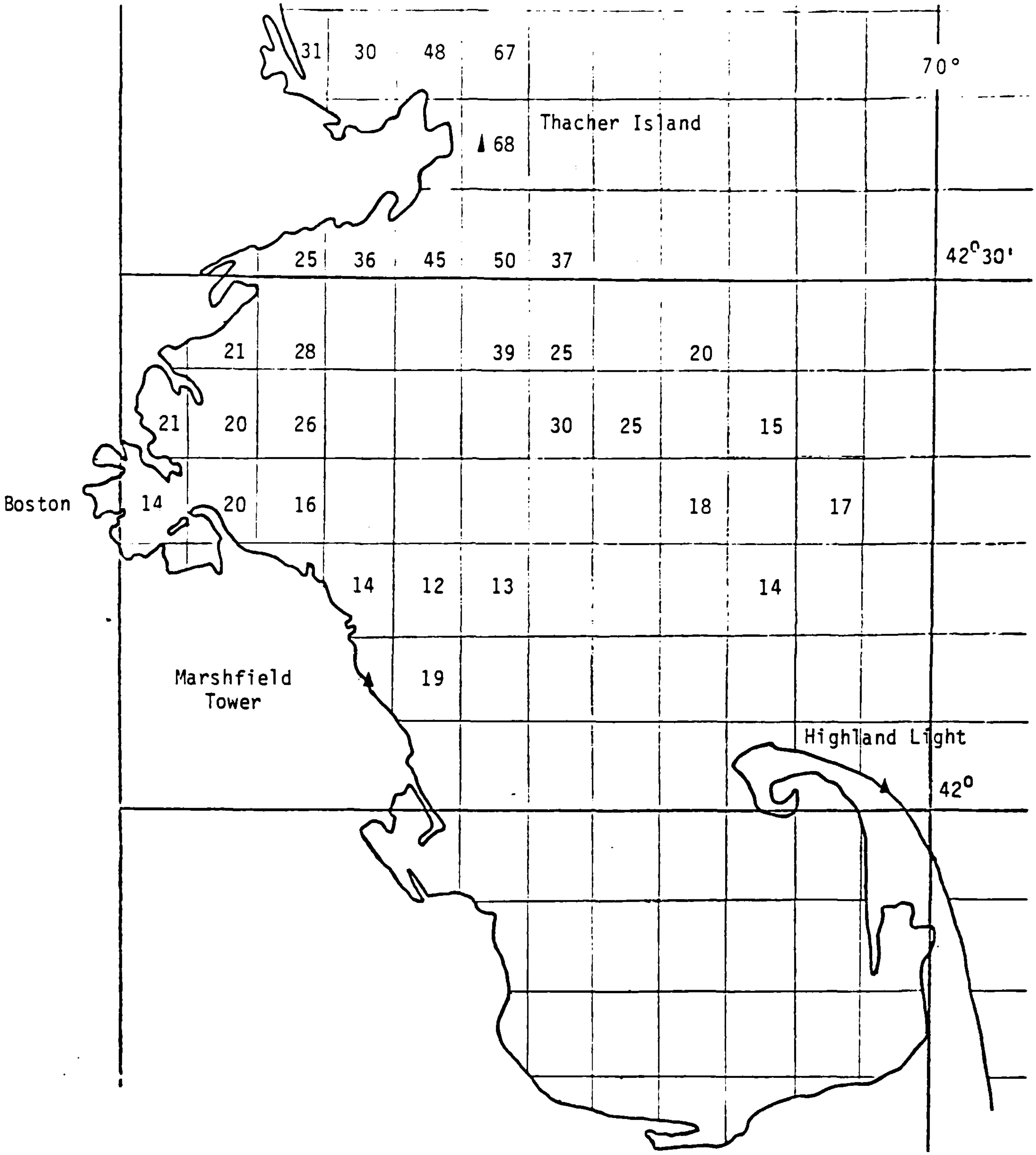


FIGURE 4-3. SIGNAL STRENGTH AVERAGES FROM TEST POSITIONS AT THACHER ISLAND (from Ref 2)

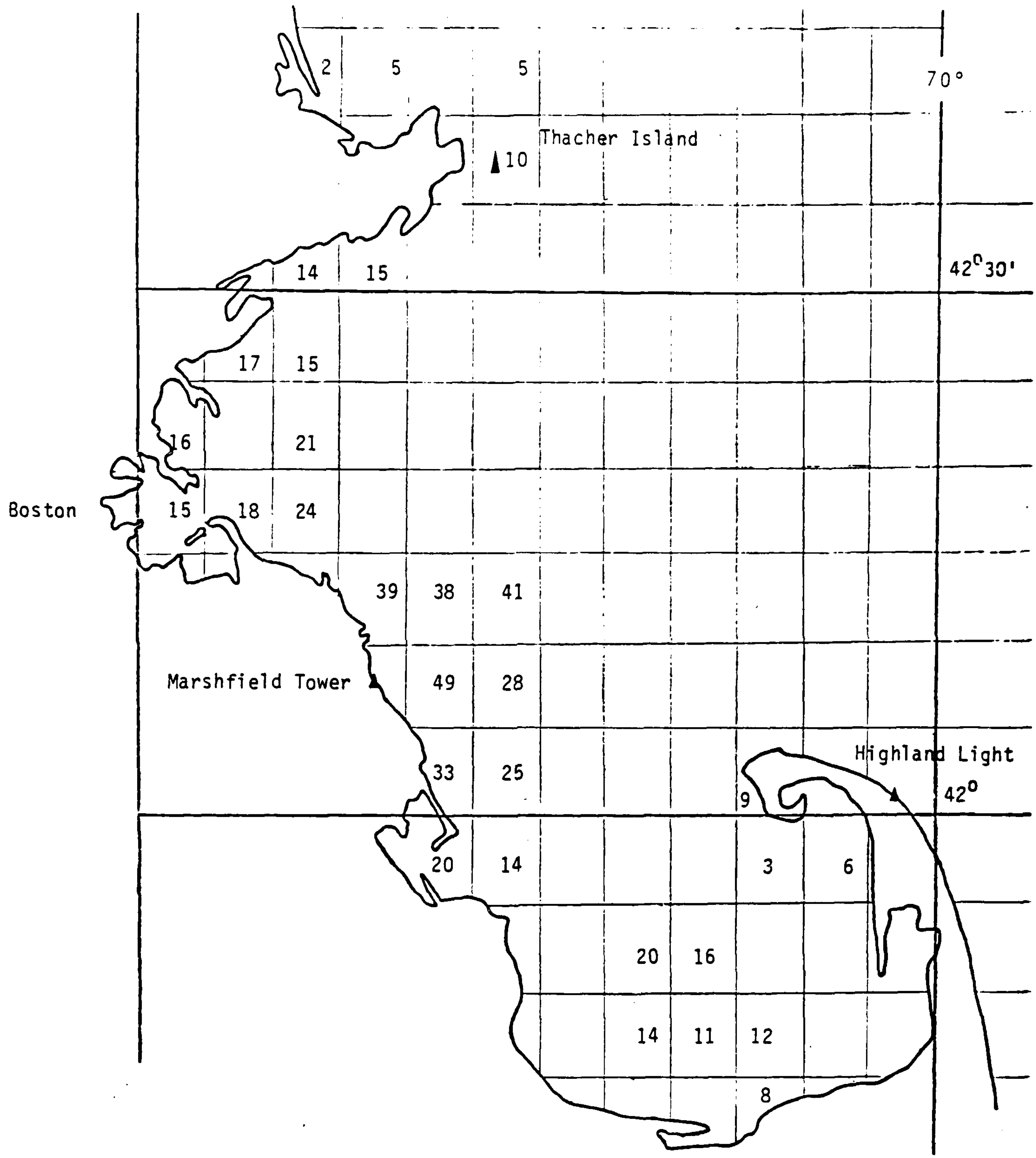


FIGURE 4-4. SIGNAL STRENGTH AVERAGES FROM TEST POSITIONS AT MARSHFIELD TOWER (from Ref 2)

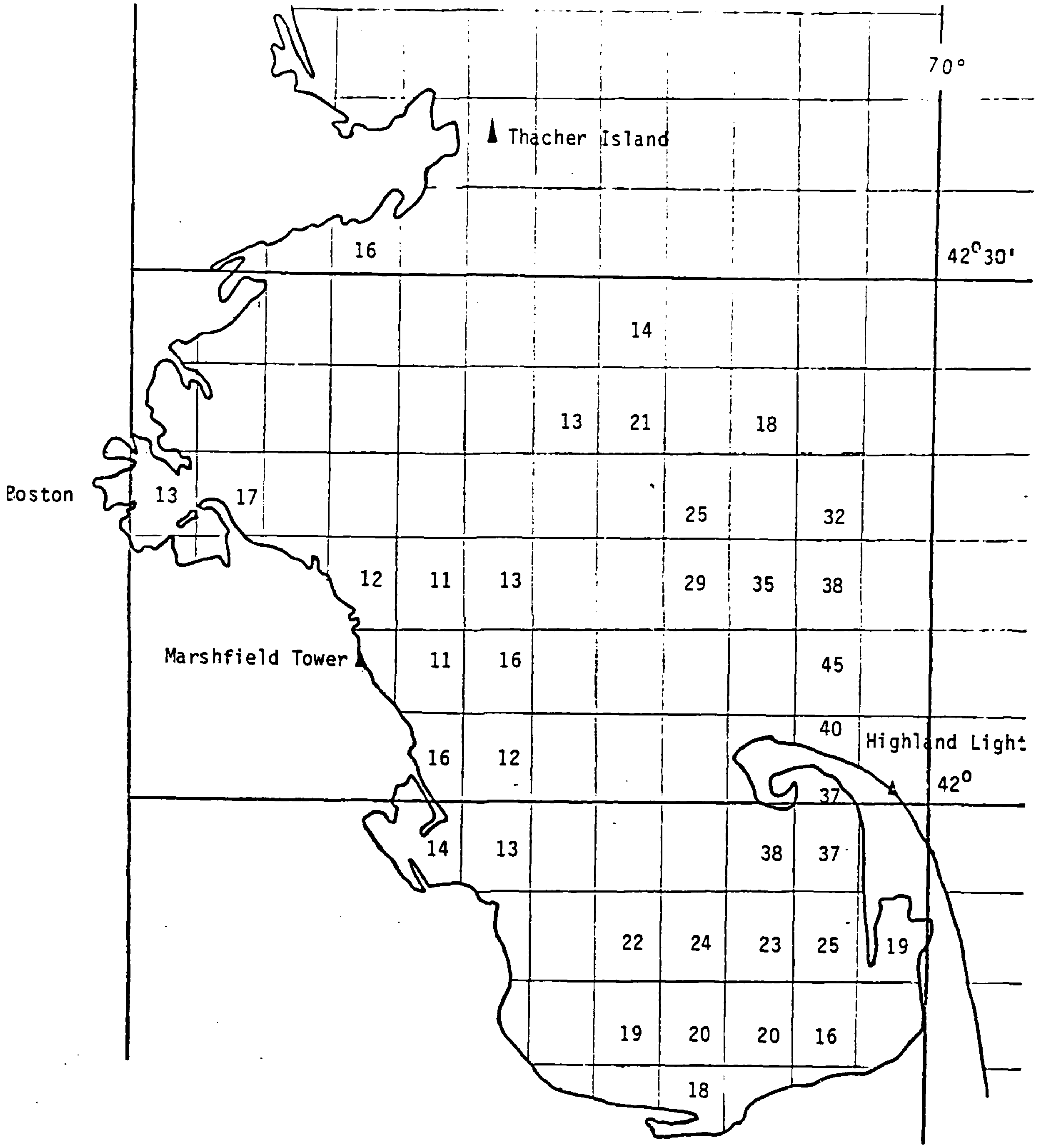


FIGURE 4-5. SIGNAL STRENGTH AVERAGES FROM TEST POSITIONS AT HIGHLAND LIGHT (from Ref 2)

| DATE | LAT | LON | Average Bearing Error Degrees | | | Average Signal Strength in dB Above Microwave/M | | | Distance from EPIRB to Receiver (nm) | | | RECEIVER SENSITIVITY (1μV - 0dB) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Deg-Min-Sec | Deg-Min-Sec | TI | MT | HL | TI | MT | HL | TI | MT | HL | TI | MT | HL |
| 7-13 Gloucester | 42 35 04<br>42 31 43 | 70 40 47<br>70 49 45 | -.45<br>1.83 | -.76 | | 31<br>19 | 10 | -- | 5.6<br>13.0 | 27.6 | | -6 | -6 | -6 |
| 7-15 Pt. Allerton | 42 18 47<br>42 17 59 | 70 55 15<br>70 49 22 | | | 11.46 | | | 11 | | | 41.7 | -6 | -6 | -6 |
| 7-15 Scituate | 42 7 2<br>41 59 41 | 70 37 52<br>70 36 35 | | 4.88<br>-1.49 | 0.14 | | 43<br>19 | 7 | | 2.8<br>8.6 | 24.7 | -6 | -6 | -6 |
| 7-20 P'town | 42 0 42<br>41 48 2 | 70 9 40<br>70 9 58 | | | -2.56<br>0.82 | | | 29<br>11 | | | 4.8<br>15.1 | -6 | -6 | -6 |
| 7-21 P'town | 42 1 14<br>41 54 49 | 70 9 39<br>70 9 47 | | 4.38 | -1.11<br>2.31 | | 4 | 27<br>14 | | 24.5 | 4.7<br>8.9 | -6 | 0 | -6 |
| 7-22 Cape Cod Canal | 41 53 20 | 70 29 22 | | 1.76 | 1.18 | | 3 | 8 | | 16.8 | 21.2 | -6 | 0 | -6 |
| 7-27 Gloucester/ Merrimack | 42 40 46<br>42 44 49 | 70 41 1<br>70 45 24 | -0.54<br>-0.01 | | | 24<br>20 | | | 5.4<br>10.4 | | | -6 | 0 | -6 |
| 8-3 USCG Cutter Cape Morgan | 42 28 12 | 70 24 0 | -0.32 | | | 18 | | | 12.6 | | | -6 | 0 | -6 |

FIGURE 4-6. EPIRB TEST RESULTS

transmits a short VHF-FM signal format on channels 15 and 16 at one-watt output power. Since this is an operational EPIRB, precautions were taken to inform the boating public and other Coast Guard units before and after each test was run. Because of this only 15 EPIRB tests points were taken vs. approximately 100 total test points during the calibration. The test results indicated the expected lower reception range for the one-watt signal as compared to the 25-watt transmissions. The system was able to produce only line of bearing information for the EPIRB transmissions due to their lower power. EPIRB test results are tabulated in Figure 4-6.

### 4.3.3 Site Dependent Bearing Errors

Prior to acceptance testing,each DF antenna is tested on a near-ideal site and bearing errors due to the antenna pattern are corrected. When the antenna is installed on a typically imperfect receiving site, repeatable bearing errors due to nearby reflectors will usually be observed. These errors can then be reduced or eliminated by storing error information in a look-up memory table in the DF processor, thus increasing system accuracy. Examples of site induced error patterns are seen in Figures 4-7 through 4-9 (from ref. 2) for the three receiving sites. The Thacher Island and Marshfield sites show a sinusoidal pattern, whereas Highland Light shows a constant offset at all bearing angles, which was corrected by changing the north adjustment.

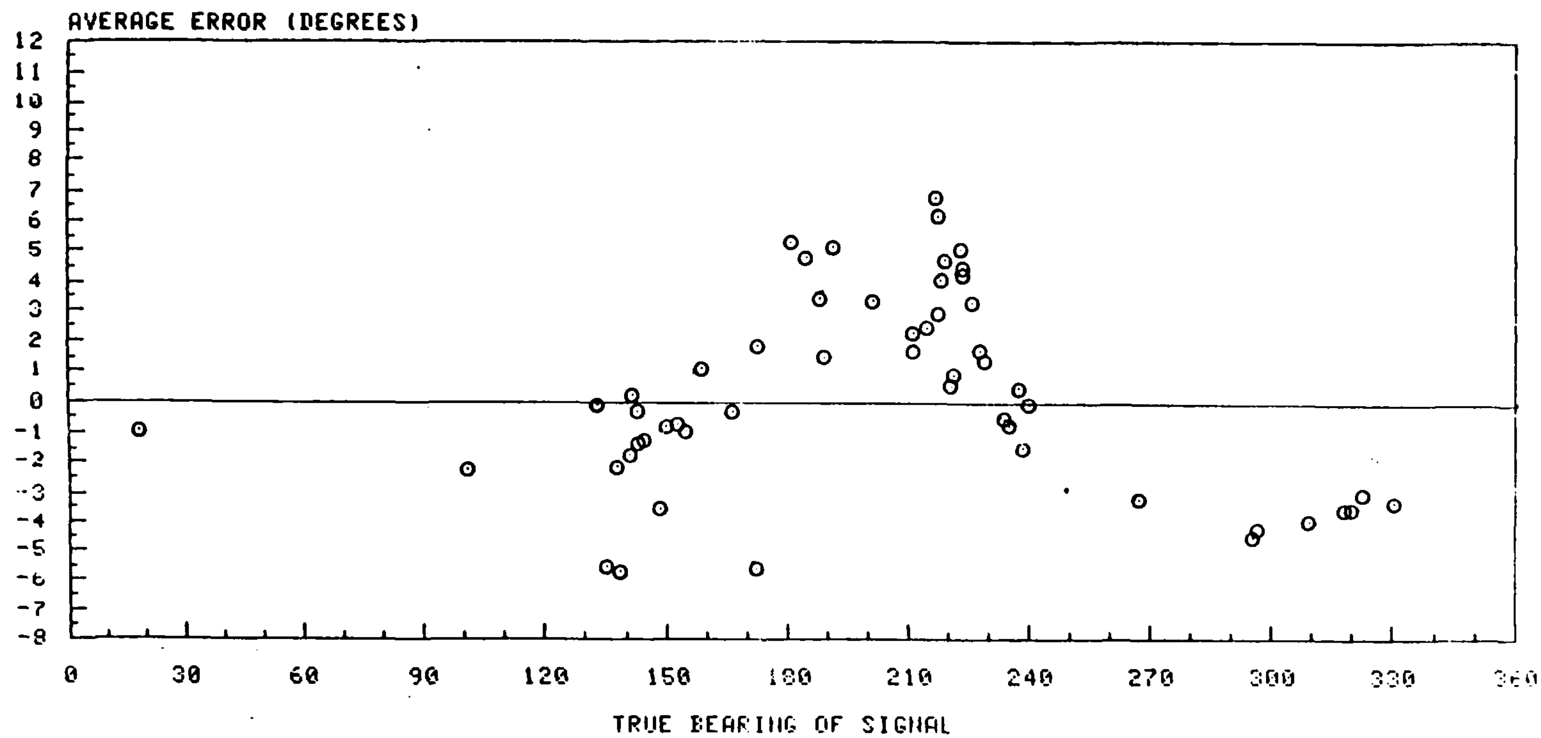


FIGURE 4-7. DF TRIANGULATION BEARING ERROR AVERAGES THACHER ISLAND DATA (CHANNEL 22) (from Ref 2)

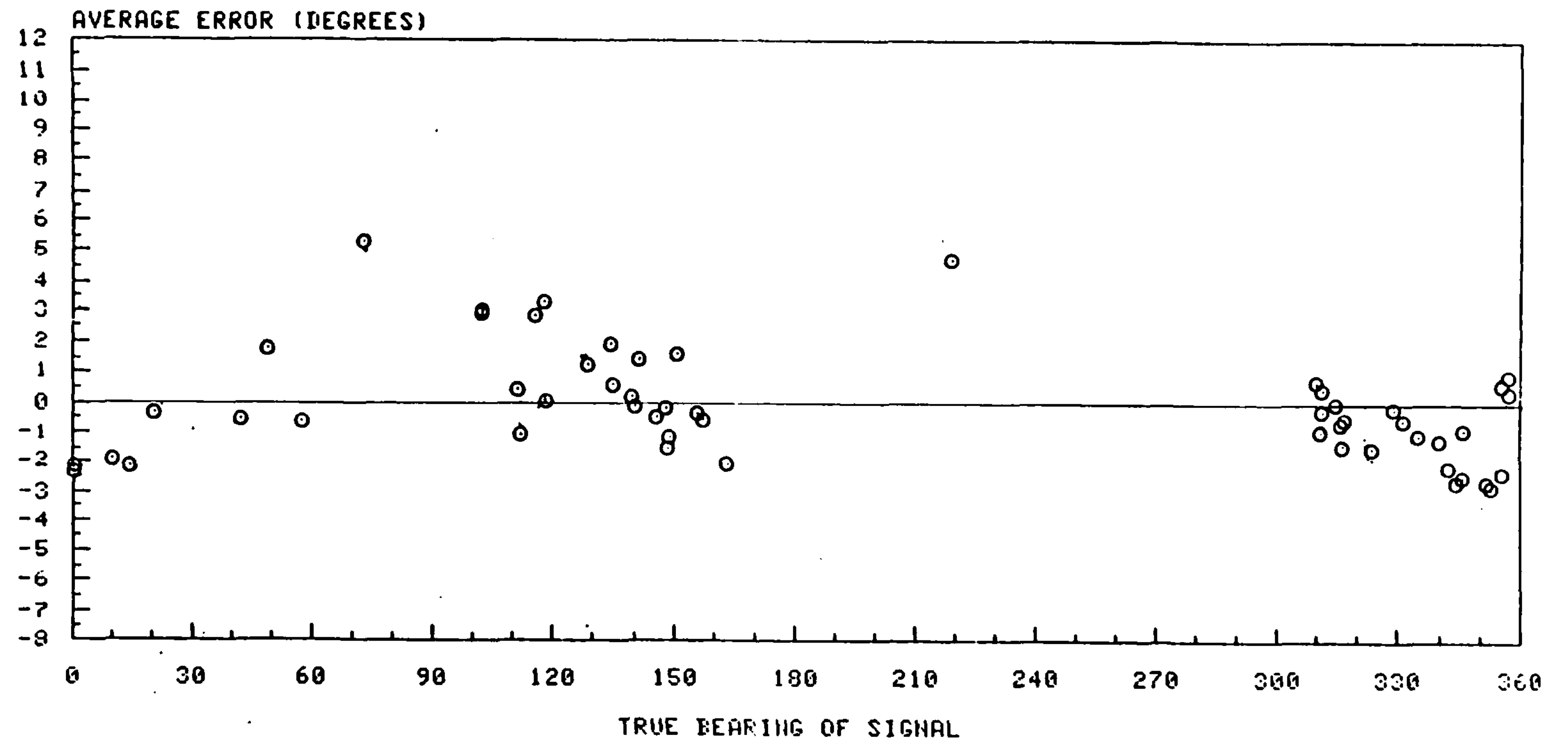


FIGURE 4-8. DF TRIANGULATION BEARING ERROR AVERAGES MARSHFIELD TOWER (CHANNEL 22) (from Ref 2)

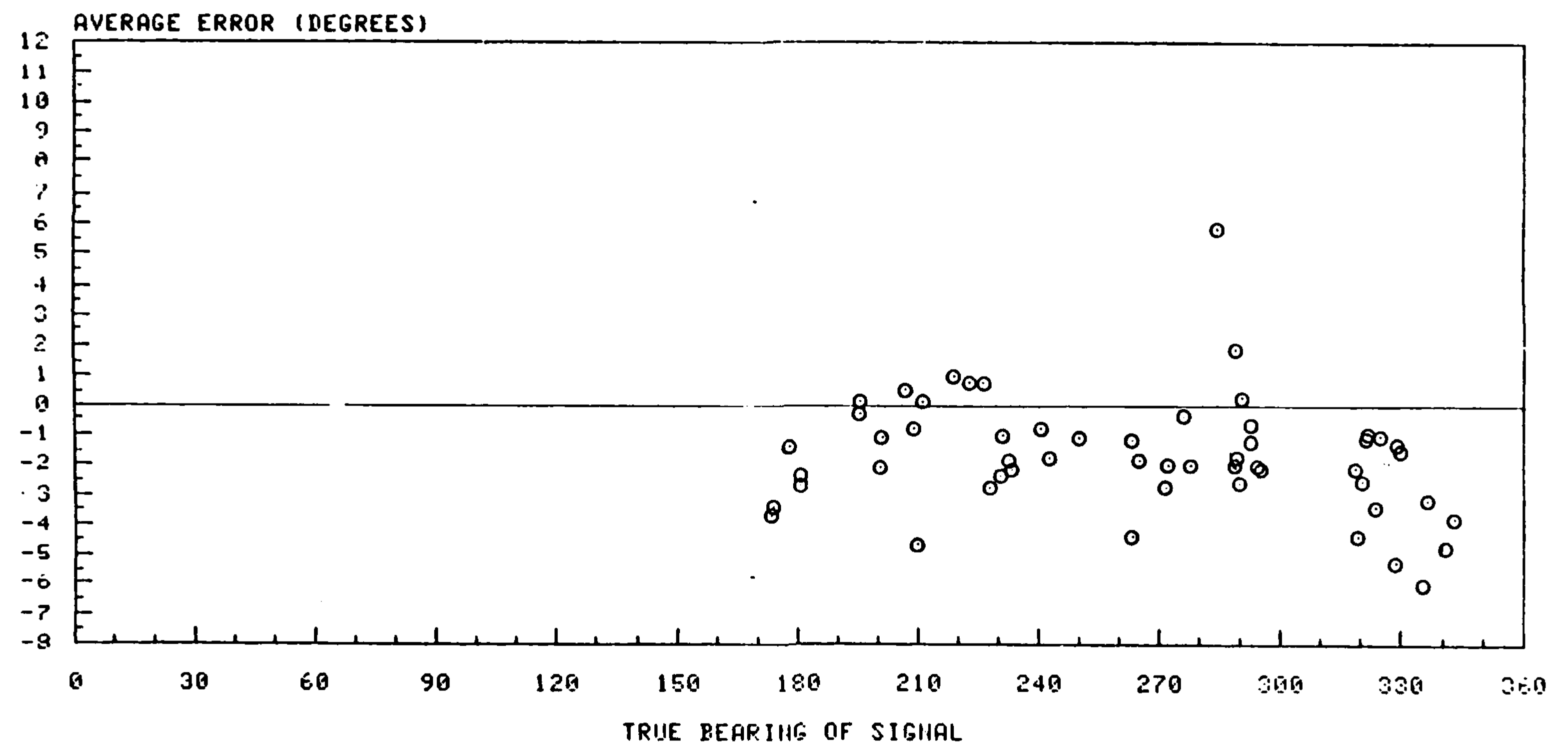


FIGURE 4-9. DF TRIANGULATION BEARING ERROR AVERAGES HIGHLAND LIGHT DATA (CHANNEL 22) (from Ref 2)

# 5. SUMMARY OF OPERATIONAL USE

Having shown via the calibration that the system meets requirements for coverage and accuracy, the present section will describe the remaining aspects of system performance as determined during the OPEVAL. These aspects fall into the categories of ease of use, reliability, and maintainability. Discussion of these categories will be preceded by a brief description of typical cases the system has been used on.

## 5.1 OVERVIEW OF OPERATIONAL USE

The system was used on several types of cases, such as, boat lost, injured seaman, sinking, and hoax.

On several occasions, the system was used to determine the position of a lost vessel. As an example, a pleasure vessel became lost in heavy fog in Salem Harbor. The approximate position was determined by the DF system and a Coast Guard vessel was directed to the vessel without a search.

A seaman was seriously injured on a fishing vessel off Cape Ann. The vessel's radio operator did not speak English but was able to convey the seriousness of the problem. The vessel's approximate position was determined on the initial transmission and a Medical Evacuation was carried out. In this case the DF position was backed up by a LORAN-C position from an assisting fishing vessel.

A fishing vessel off Cape Ann reported it was sinking and the crew was being rescued by another vessel which then left the scene. A utility boat was dispatched from Station Gloucester to the scene but could not locate the vessel due to poor visibility and the fact that the vessel was low in the water. The Staff Duty Officer was able to vector the utility boat to the sinking vessel by using the DF in a differential mode. In this mode the vector difference in DF positions of the distress and rescuing vessel is derived and used to direct the rescuing vessel.

## 5.2 EASE OF USE

### 5.2.1 Correlation

The method by which the system determines whether signals arriving at a particular time from two or more remote receiving sites are actually from the same transmitting source has been described in Section 3. The scheme, based on time of arrival, is simple, inexpensive and should perform well on uncrowded channels. However, on very crowded channels, where transmissions are frequently overlapping, the present algorithm is not optimum due to its inability to detect the start time of the second of two overlapping transmissions. In this case the bearing data from the overlapped transmission is presented in a separate data block and is not used in a position calculation. As a way around this problem, additional software was incorporated to allow the operator to manually enter the decorrelated bearings to obtain position calculations. If this does not prove sufficient, the system could be modified so that in the event of a decorrelation, the system would look for significant bearing or signal strength changes in the overlapped transmission. This, however, would require hardware modifications in the DF processor units and is not considered necessary.

### 5.2.2 Manual vs Automatic Operation

As described in Section 3, the operator has a choice between manual or automatic operation. In manual mode, the operator, upon pressing the "MANUAL DF" key, receives position information on the ongoing transmission only, or if the channel is quiet, on the next transmission only. This mode has the advantage of eliminating confusion between position readouts and transmissions, but has the disadvantage that a short transmission of interest can easily be missed if the key is not pressed before the end of transmission. The alternative automatic mode eliminates this disadvantage. However, on a busy channel,since the computer takes several seconds to compute and display each transmission, backlogs of up to 50 transmissions can occur, making it very difficult to identify the correct position calculation when it eventually is presented.

To resolve the above problem a third mode of operation, the "MODIFIED MANUAL" mode will be incorporated which is similar to the present manual mode except that calls occurring up to 15 seconds before the "MANUAL" button is pressed will also be displayed. With this feature a call will not be lost with the system in manual mode as long as the "MANUAL" button is pressed within 15 seconds after the transmission ended. It is recommended, based on operator's comments, that future systems be operated in the "MODIFIED MANUAL" mode.

### 5.2.3 Control Convenience

In the original configuration, the method of changing channels, which required calling the menu, selecting the channel and deselecting the menu, is time consuming in comparison to conventional channel selection methods. As a solution to this problem, a software modification will be incorporated which will allow the operator to change DF receiving channels without having to leave the DF mode.

### 5.2.4 Vector Calculation

Since the predominant error source in most position calculations is a repeatable site induced bearing error, and since these errors have been shown to be fairly constant in 5-10$^{\circ}$ bearing sectors, positions calculated on targets located within 2-3 nm of each other tend to have the same repeatable error segment. The vector difference becomes more accurate as the targets approach each other. A software routine will be incorporated allowing automatic calculation of this vector.

### 5.2.5 Graphical Display

A software routine will be incorporated to allow the LAT/LONG and error ellipse of a selected transmission to be presented on the video monitor against a map of the Massachusetts/Cape Cod Bay area.

5.2.6 Channel Usage

Experience has indicated that five channels are more than adequate for SAR requirements, but that all channel capability will be necessary for the system to be useful in a Law Enforcement mode. Incorporation of all-channel capability is not expected to be a major cost factor and is recommended for future systems.

5.2.7 System Calibration

A single-point system calibration based on reception of a transmission from the Boston High Site will be incorporated. Upon reception of the transmission, depression of a calibration key will provide a go/no-go decision based on the calculated position and received signal strengths.

## 5.3 RELIABILITY AND MAINTAINABILITY

5.3.1 System Reliability

Total system reliability is composed of DF system reliability, over which the designer has some control, and communication link reliability over which he has virtually no control in the case of telephone lines.

5.3.1.1 DF System Reliability - In five months of operation only two failures were encountered, both of which affected only one remote site, leaving the system operable on two remaining sites. In one case the audio output of one site became disabled but the site still provided bearings. In the remaining case one site produced random bearings and the DF processor was returned for warranty repair. In each case two trips to the site were required. If a spare DF processor had been available, necessary site trips would have been reduced to one per failure.

5.3.1.2 Communication Link Reliability - UHF Link to Thacher Island: Intermittent outages were experienced on several occasions in July and September, possibly due to interference. This problem has not recurred in the last several months, and link reliability is considered excellent. Phone Lines: The dedicated voice-grade phone lines to Marshfield and Highland Light suffered three outages, all of which were repaired within 24 hours. This performance was better than anticipated.

5.3.2 System Maintainability

Early indications are that the system will be quite reliable with the major maintenance problem being the DF processors, due to their remote location and specialized circuitry. Due to the small number of these units at the group or district level it does not appear cost effective to train personnel to repair them locally. However, the alternative, returning them to the factory, results in approximately one week down time per site per failure. A spare processor could be obtained for approximately $30,000 but would not be efficiently utilized with only three field units installed. However, if more than one system were installed in a district the provision of a spare processor would probably be cost effective, eliminating the need to return to the site with the repaired unit and reducing down time.

# 6. COST/BENEFIT ANALYSIS

One measure of the desirability of the VHF-DF System is the difference between the cost of installing, operating and maintaining the system and the value of the benefits derived from the system. The cost/benefit analysis is a vehicle for looking at these quantities. A cost benefit analysis was performed for the system as installed as well as for theoretical systems which could be installed in the Nantucket Island-Block Island-Woods Hole Area and the Chesapeake Bay Area.

## 6.1 BENEFIT ANALYSIS

The most difficult of the two quantities to determine is the economic value of the benefits which might be derived from the system. The benefits can be split into two groups. The first group contains benefits to the Coast Guard in the form of resources saved as a result of reduced search requirements. The second group consists of benefits to society in the form of additional property and lives which might be saved. Because of the small amount of time available to collect Search and Rescue (SAR) data while the VHF-DF System was operational, it was decided to use the SAR Data Base for fiscal years 1979, 1980, and 1981, which is maintained at Coast Guard Headquarters, as the data base for this analysis. There was insufficient reliable data for fiscal years 1977 and 1978 to justify including this data in the analysis. The benefit of the system can be determined by analyzing each case in the file to determine the extent to which the use of the VHF-DF system would have impacted on resources expended, lives lost, or property lost.

It is recommended that the procedures described in this document be utilized to determine the cost effectiveness of potential sites for VHF-DF Triangulation Systems throughout the Coast Guard. Initial identification of areas of possible interest can be accomplished using a special computer program written by LT. J. Lentz (G-DST-3). This program, utilizing FY 1982 SAR data, identifies for a chosen VHF-FM high site all cases in which a fatality occurred and notification was by VHF-FM directly from the distressed vessel. Using this program, the following areas were identified as handling high fatality rates and are suggested for analysis as possible sites for VHF-DF Triangulation Systems:

| | |
|---|---|
| Third District: | Long Island Sound<br>New Jersey Coast<br>Delaware Bay |
| Seventh District: | Station Tybee-Base Charleston-Station St. Simons Area |
| Ninth District: | Western End of Lake Erie<br>Southern End of Lake Michigan |
| Eleventh District: | Long Beach Area |
| Thirteenth District: | Straits of Juan de Fuca. |

Additional candidate sites can be identified by district personnel.

In addition to areas which are identified as potential sites for triangulation systems, the locations of current VHF-FM high sites should be considered as candidates for single-bearing-only DF installations. Any areas identified as possible candidate sites for bearing-only systems can be analyzed using a methodology similar to that used in this analysis for triangulation systems.

### 6.1.1 Methodology

The methodology used to determine the benefits which could potentially be derived from a given VHF-DF Triangulation system utilized a case by case analysis of potential savings.

The first step was to select cases for consideration based on the following criteria:

a. The case had to involve a search for the distressed party.

b. The case had to be reported directly from the distressed party to the Coast Guard via VHF-FM.

c. The case had to fall within the coverage area of the triangulation system.

Once the applicable cases were identified, they were analyzed to determine the potential savings to the Coast Guard in resources which might have been realized if a VHF-DF Triangulation System had been available and used. For cases involving a loss of life or property, the individual case files were examined to determine if the use of a triangulation system might have prevented the loss. A detailed description of the benefit analysis methodology is contained in Appendix A.

6.1.2 Results

The preceding methodology was applied to three geographical areas of interest to the Coast Guard. The first area was the coverage area of the existing VHF-DF Triangulation System, which includes Cape Cod Bay and Massachusetts Bay. The specified latitude boundaries used were 41 degrees 43 minutes North to 42 degrees 41 minutes North; and the longitude boundaries were 70 degrees West to 71 degrees West. The data for fiscal years 1979 through 1981 was analyzed. Table B-1 of Appendix B summarizes the expected savings to the Coast Guard in resources spent grouped by resource type and year. Table B-1 also summarizes the total benefit to the Coast Guard and to society for all three years. There were no cases in which it was determined that additional lives or property might have been saved if the VHF-DF system had been available and used.

The second area analyzed is covered by a theoretical five site VHF-DF system. The system covers the Nantucket Island, Block Island and Woods Hole areas. The latitude and longitude boundaries used were 41 degrees 05 minutes North to 41 degrees 40 minutes North and 69 degrees 40 minutes West to 71 degrees 30 minutes West. Table B-2 of Appendix B summarizes the benefits which might be derived from the theoretical system. There was one case in which it was determined that the use of a VHF-DF system might have enabled the Coast Guard to save two lives which were lost. The total benefit to society if those two lives had been saved would have been $560,000. The case in question took place in fiscal year 1979 and also accounted for an expenditure of approximately $34,000 in resources which could have been saved if a VHF-DF system had been available.

The final area analyzed was the Chesapeake Bay area, which could be covered by a four-site system. The boundaries used were 36 degrees 35 minutes North to 39 degrees North, and 75 degrees 33 minutes West to 76 degrees 18 minutes West. Table B-3 of Appendix B summarizes the results of this analysis. There were no cases in which additional lives or property might have been saved by using a VHF-DF system.

## 6.2 COST ANALYSIS

The costs associated with a VHF-DF System are broken down into the following three categories:

1. Initial Acquisition and Installation Cost
2. Operating Cost
3. Maintenance Cost

The initial system acquisition and installation cost of a single system is $45,000 per DF site. Cost savings which would be associated with a larger quantity buy are discussed later. Additionally, it cost $15,000 to acquire and install each required UHF data link for communications between the system computer and the DF receivers. These initial acquisition and installation costs are divided by fifteen (assuming a fifteen year life expectancy for the system) to arrive at an initial acquisition and installation cost per year.

The operating cost of the system is made up of the rental cost for the telephone lines needed for communications between the system computer and the DF receivers. The cost for each required telephone line is estimated to be $3600 per year.

The final cost associated with the system is the maintenance cost. The maintenance program assumed is that Coast Guard personnel will perform on site board level repair with defective boards shipped to a contractor facility for repair.

The cost of Coast Guard manpower for routine system maintenance plus a service contract is estimated to be approximately $10,000 per year. There is an additional estimated cost of $1000 per year to maintain each required UHF data link.

Table C-1 of Appendix C summarizes the costs for each of the three systems which were analyzed. These costs assume that no UHF data links will be required for either of the two theoretical systems.

If a large number of complete systems were purchased at one time (on the order of twenty to twenty-five systems) the price for each receiver site would drop to approximately $33,000. A further overall cost reduction can be realized if UHF data links rather than telephone lines are used for all communications. However, this requires line of site communications capability between the central computer and each DF receiver site. Table C-2 of Appendix C shows the resultant system costs if these cost reductions are incorporated.

## 6.3 OTHER CONSIDERATIONS

Several assumptions of note were made in determining the benefits which could be derived from using the VHF-DF System. The first assumption is that the system will be used to fix the position of the distressed vessel at the outset of all cases where there is VHF-FM communications with the distressed vessel. This insures that an accurate distress vessel position will be known so that the assisting vessel will not be sent to an erroneous position, and that hoax cases will be spotted quickly rather than after several hours of fruitless search. If the system operators wait until the assisting unit has discovered that the position given by the distress vessel is in error before they use the system to fix the distress vessel's position, part of the value of the system will be lost.

The second assumption made is that the system will be used on all cases which occur in its coverage area. This requires that the personnel at the unit possessing the system be aggressive in using the system to fix the position of distressed vessels whose cases are being handled by other units and in passing the position information obtained on to the unit handling the case. Any unit whose operating area includes a portion of the coverage area of the VHF-DF system should be encouraged to contact the unit possessing the system in order to get distress vessel position information whenever that particular unit is handling a case via VHF-FM. Without the personnel taking these steps to ensure that the system is used in the largest possible number of cases, the benefit derived from the system will be less than that indicated in this analysis.

The authors feel that there is some question as to the reliability of the data contained in the SAR Data Base. This could possibly be due to the fact that the SAR Data System is a fairly new system and that personnel in the field are either unsure or careless in filling out the SAR Assistance Reports. Some examples of discrepancies found are:

1. The METHOD OF LOCATING (field B08) information indicates that the exact position of the vessel in distress was known and that there was no problem in locating the vessel while the TIME SPENT SEARCHING (field C08) and ASSISTANCE RENDERED-TYPE OF SORTIE (C15a) information indicated that quite an extensive search was required in order to locate the vessel.

2. The LIVES LOST AFTER COAST GUARD NOTIFICATION (field B17) indicates that no lives were lost in the case while the individual case file indicates that there were lives lost in the cases after the Coast Guard was notified of the case.

3. The TIME SPENT SEARCHING (field C08) is greater than or equal to the total TIME ON SORTIE (field C11).

4. Sortie records for sorties involving the same case contain different information on the facts of the case.

5. The ASSISTING RESOURCE TYPE (field C04) field contains data codes not listed in the SAR Data System Manual.

As can be seen from the fiscal year 1979 results for the Woods Hole area, the occurrence of a single case involving a loss of life or property or a large expenditure of resources can severely affect the results of the analysis. In general, these cases occur quite infrequently. The authors feel that the three years of data available in the SAR data base is inadequate to statistically reflect the value of a VHF-DF system in prosecuting these major cases. The occurrence of one or two of these cases during the life of the system would be more than enough to justify the cost of the system.

As the use of EPIRBs becomes more widespread among the boating public, the possible benefit to be derived from a VHF-DF system will increase. There are several reasons for this. First, the number of cases reported via VHF-FM will increase. Second, the system will be able to locate more people in the water and in life rafts. Finally, the number of false alarms and hoaxes is likely to increase as the use of EPIRBs increases, which will make a VHF-DF system more valuable in detecting these cases.

The analysis as it was done does not take into account the fact that the system coverage area is smaller when trying to detect an EPIRB than it is when trying to detect a transmission from a vessel. This was done because of the extremely small number of cases analyzed involving the use of EPIRBs. If an analysis was done involving larger numbers of EPIRBs, this difference would have to be considered.

The VHF-DF system has been analyzed strictly from the point of view of the Coast Guard's Search and Rescue mission. If the system were modified by adding channel synthesis and scanning capability, it could also be used to increase the Coast Guard's capabilities in carrying out its Law Enforcement Mission. This would increase both the cost of and the benefits derived from the system. The magnitude of the changes have not been analyzed.

## 6.4 CONCLUSIONS

When we compare the benefits derived from each system which was analyzed, with the cost of each system, we can see that only the Nantucket Island/Block Island/Woods Hole system shows a favorable cost/benefit ratio. This is entirely due to the effect of a single large SAR case which took place in fiscal year 1979. Without the contribution which that case made to the possible benefits of the system ($34,000 in resources and 2 lives saved), the annual benefit which could be derived from the system would have been approximately $13,000. This is of the same magnitude as the benefits which could be derived from the other systems. Because of this, it is obvious that it is the large but infrequent cases and not the day-to-day cases which justify the expenditure to setup and maintain a VHF-DF system.

Keeping the above in mind, and the limitations of this analysis discussed above, the authors feel that the installation of VHF-DF systems in areas of concentrated boating activity is justifiable from a cost/benefit point of view.

# 7. CONCLUSIONS AND RECOMMENDATIONS

1. The Direction Finding Triangulation System satisfied all program objectives.

2. Accuracy of position location on the order of 1-2 nautical miles was typically obtained and was considered very useful by operational personnel. Somewhat greater accuracy could be obtained through reduction of site reflection errors. All DF equipment should include capability for programmed bearing corrections.

3. Coverage requirement for the Class-C EPIRB should be limited to single line-of-position only because its power output is significantly lower than standard transceivers. Failure to do this would result in significantly higher system costs due to requirements for higher antenna heights and/or closer spacing of remote sites.

4. Cost effectiveness of the triangulation system depends on geography and SAR density. Based on the analysis presented in Section 6, it is concluded that properly sited and operationally integrated systems will prove cost effective. The procedures defined in Section 6 and Appendix A should be utilized to analyze candidate sites.

5. To assure cost-effective utilization of any DF system with centralized control, operational procedures should be developed to assure its use in each applicable case. Particular attention should be given to installations crossing group boundaries.

6. Based on Lentz's study (ref 4), cost-effectiveness of bearing-only single DF remoted to high site should be considered for high SAR density regions with little overlap on high site coverage.

7. The use of UHF radio links should be considered on links that would result in phone line costs of $2000/yr or more, or where the reliability of phone service is questionable.

8. DF control and display units should be designed to be incorporated into existing radio consoles at group communication centers.

## APPENDIX A

## BENEFIT ANALYSIS METHODOLOGY

The following is the methodology used to determine the benefits derived from the VHF-DF system. By changing the latitude and longitude boundaries of the coverage area, this same methodology can be used to determine the potential benefits which could be derived from a system in any given area of interest.

The Information Systems Staff of the Search and Rescue Division of the Office of Operations (G-OSR-3) maintains the SAR Data Base. Mrs. Elly Paulos (FTS 426-1951) should be contacted in order to receive data from the SAR Data Base. The Search and Rescue Data System Manual (COMDTINST M5230.10 dtd 17 FEB 1982) contains a description of the organization and meaning of the information contained in the SAR Data Base and must be consulted in order to complete the analysis.

The SAR Data Base contains many pieces of information on all SAR cases handled by the Coast Guard. The information is organized into records with a separate record for each sortie. The information in each record is broken into fields, and is entered using alphanumeric codes. By specifying the desired codes of a few selected fields, the data on sorties which meet the case selection criteria can be retrieved.

The first fields of interest are those which specify the location of the particular SAR case in question. Field B06 contains the latitude of the case and field B07 contains the longitude. By specifying minimum and maximum values for both fields which correspond to the boundaries of the coverage area of the system, cases which fall outside the coverage area are eliminated from consideration. If the coverage area of the system cannot be closely approximated by such a rectangle, specify boundaries which loosely approximate the coverage area and eliminate by hand the cases which fall outside of the coverage area.

The second task is to select the class of cases in which the use of the system would enable the Coast Guard to either save additional lives or property or use fewer resources in prosecuting the case. There are two criteria which a case must meet in order to fall into this category. They are:

1. The VHF-DF system must be able to receive a signal directly from the distressed vessel or an EPIRB.
2. The Coast Guard must not know the true location of the distressed vessel and therefore must have had to conduct a search for the vessel.

By selecting for consideration only those cases which meet these criteria, the cases on which the VHF-DF System would have no effect are eliminated from consideration.

There are two fields which are of interest in determining which cases meet the selection criteria. The first is field B03 which contains the information on the method by which the Coast Guard received the notification of distress. The cases desired are those in which notification was direct from the distressed vessel to the Coast Guard via VHF-FM or by a Class-C EPIRB. The codes corresponding to these criteria are 05, 06, and 12. By specifying these codes for field B03, the applicable cases can be selected.

The second field of interset is C15a, which contains the information on the type of sortie which was conducted in response to the request for assistance. We are interested in sorties in which the assisting unit had to search for the distressed vessel. The codes corresponding to this criteria are 1 and 2. By specifying these codes for field C15a, the sorties involving searches will be selected. A sortie requiring a search is defined as one in which the assisting vessel had to search for the distressed vessel for more than three minutes after arriving at the distressed vessel's assumed or reported position.

By specifying the proper values for fields B06, B07, B03 and C15a, a listing of the applicable sorties will be obtained. In order for the listing to be of use, the information desired on each sortie must be specified. The following fields of information were requested.

| FIELD | DESCRIPTION |
|---|---|
| A01 | OPFAC NUMBER |
| A02 | UNIT CASE NUMBER |
| A03 | MULTI-UNIT CASE NUMBER |
| B03 | METHOD OF NOTIFICATION |
| B04 | NATURE OF INCIDENT |
| B06 | CASE LOCATION-LATITUDE |
| B07 | CASE LOCATION-LONGITUDE |
| B08 | METHOD OF LOCATING |
| B17 | LIVES LOST AFTER C.G. NOTIFICATION |
| B20 | PROPERTY LOST (THOUSANDS OF DOLLARS) |
| C03 | SORTIE NUMBER |
| C04 | ASSISTING RESOURCE TYPE |
| C08 | TIME SPENT SEARCHING (TENTHS OF HOURS) |
| C11 | TIME ON SORTIE (TENTHS OF HOURS) |
| C15a | ASSISTANCE RENDERED-TYPE OF SORTIE |

When specifying field B17, it must be specified that LIVES LOST AFTER COAST GUARD NOTIFICATION is the data desired. The reason is that field B17 lists both LIVES LOST BEFORE COAST GUARD NOTIFICATION as well as LIVES LOST AFTER COAST GUARD NOTIFICATION.

Once a sortie-by-sortie listing of the above information on the desired sorties is obtained, it is necessary to eliminate sorties which for any reason are not applicable to the analysis. First, as mentioned earlier, it is necessary to eliminate sorties involving distressed vessels which are included in the boundaries specified for latitude and longitude but which fall outside of the actual coverage area of the VHF-DF system.

The second step is to eliminate sorties based on the nature of the incident (field B04). With current SAR conditions, there are several types of incidents whose outcome could not be affected by the use of the VHF-DF system. Among these are personnel in the water (code 71), man overboard (72), swimmer in danger (73), diver missing/failed to surface (75), overdue/missing vessel (91), or any incident involving aircraft in distress (21-29). The cases involving personnel in the water in one form or another (71, 72, 73, 75) are eliminated because these people generally do not have any sort of VHF transmitter with them in the water and could not be located using the system. However, if the person in the water is carrying an activated EPIRB (METHOD OF NOTIFICATION (field B03) = 12), then the sortie need not be eliminated. The overdue or missing vessel sorties are eliminated because by nature these types of cases imply no direct VHF communications between the Coast Guard and the overdue vessel as required in order for the VHF-DF system to be used. Aircraft incidents are eliminated because the aircraft VHF frequencies are different from those covered by the current system.

Once all non-applicable sorties have been eliminated, the remaining sorties should be grouped by case by comparing OPFAC NUMBERS (field A01), UNIT CASE NUMBERS (A02) and MULTI-UNIT CASE NUMBERS (A03). After this is done, multiple listings of the same sortie (which has occurred) can be eliminated by checking for duplicate SORTIE NUMBERS (field C03) by the same unit on the same case.

It is now possible to analyze the potential benefits to society which could be realized by using the VHF-DF system. These benefits take the form of additional lives or property which might have been saved by using the system. All cases involving a LOSS OF LIFE AFTER COAST GUARD NOTIFICATION (field B17) or a LOSS OF PROPERTY (B20) should be singled out. The individual case files (usually held at district offices or individual units for a period of three years) should be consulted to determine in each case whether the use of the VHF-DF system might have resulted in saving the lives or property which was lost. In general, if a delay in locating the party in distress due to position uncertainty resulted in the loss of life or property and if the VHF-DF system would have enabled the assisting unit to locate the distressed party before the life or property were lost then the system might have enabled the Coast Guard to save the lives or property which were lost. This determination relies on the judgement of the individuals performing the analysis.

The total benefit to society is computed by multiplying $280,000 by the number of lives which might have been saved (the $280,000 figure was taken from the Operating Program Plan for the Search and Rescue Program FY 1983-1992), to which was added the total value of the property which might have been saved.

If on examining the individual case files, it is evident that the use of the VHF-DF system would not have affected the expenditure of resources in prosecuting the case (the collision involving the USCGC Cuyahoga is one such case), then that case should be eliminated from consideration before proceeding with the resource savings analysis.

The final measure of the benefit of the system is the value of the resources which would not have been expended if the VHF-DF system were in use. This savings in resources is a benefit directly to the Coast Guard. In determining the amount of resources which could be saved, the assumption made is that if the system were in operation and used in the differential mode, no search time would be required by the assisting vessel in order to locate the distress vessel and the system operator would be able to spot a case as a hoax prior to large amounts of resources being committed to a search. It is also assumed that an assisting vessel would have to respond to all cases whether or not the system were in use; therefore, on single sortie cases, the system could eliminate only the TIME SPENT SEARCHING (field C08) by the assisting unit. On multiple sortie cases, the entire TIME ON SORTIE (field C11) can be saved for all units with the exception of one of the assisting units. This unit must respond to the case, but will still be able to save the amount of time equal to the TIME SPENT SEARCHING. The decision as to which assisting unit would be required to respond is left to the judgement of the individuals performing the analysis.

For each case, the total resource savings in hours is computed for each resource type expended. These totals are multiplied by the cost/hour figures for each resource type. The cost/hour figures are taken from the Marine Safety Manual Vol. VI, Tables for Hourly Standard Rates for Cutters, Small Boats, Aircraft and Personnel (COMDTINST M16000.3, CH. 7 dtd 3 DEC 1980). The cost/hour figures used in this analysis were multiplied by 1.18 in order to bring the operating cost figures into 1982 dollars. No cost/hour figure is assigned to time saved by Coast Guard Auxiliary units. The total savings in resources can be summed and expressed as savings per year.

## APPENDIX B

## CAPE COD BAY/MASSACHUSETTS BAY

Fiscal Year 1979

Table B-1

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HH52A | 1 | 0.1 | $ 794.55 | $ 79.46 |
| HH3F | 1 | 0.2 | $1,552.01 | $ 310.40 |
| UTB | 159 | 164.5 | $ 83.10 | $13,669.96 |
| UTL | 2 | 1.9 | $ 36.36 | $ 69.08 |
| MLB | 16 | 15.7 | $ 92.48 | $ 1,451.94 |
| Skiff | 2 | 1.0 | $ 14.54 | $ 14.54 |
| WPB | 2 | 1.5 | $ 199.75 | $ 299.63 |
| WLB | 1 | 0.1 | $ 564.42 | $ 56.44 |
| Misc. Boats | 2 | 1.2 | $ 14.54 | $ 17.45 |
| Personnel | 1 | 0.3 | $ 8.26 | $ 2.48 |
| Auxiliary | 16 | 11.0 | | |
| Total | | | | $15,971.38 |

Fiscal Year 1980

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HU16 | 1 | 0.1 | $1,356.24 | $ 135.62 |
| HH52A | 1 | 0.1 | $ 794.55 | $ 79.46 |
| HH3F | 5 | 6.0 | $1,552.01 | $ 9,312.06 |
| UTB | 88 | 64.7 | $ 83.10 | $ 5,376.57 |
| UTL | 5 | 2.9 | $ 36.36 | $ 105.44 |
| MLB | 7 | 8.6 | $ 92.48 | $ 795.33 |
| Skiff | 2 | 1.9 | $ 14.54 | $ 27.63 |
| Misc. Boats | 1 | 0.5 | $ 14.54 | $ 7.27 |
| WHEC | 1 | 2.3 | $1,969.68 | $ 4,530.26 |
| WPB | 3 | 3.6 | $ 199.75 | $ 719.10 |
| Personnel | 1 | 1.2 | $ 8.26 | $ 9.91 |
| Auxiliary | 19 | 13.5 | | |
| Total | | | | $20,098.65 |

Fiscal Year 1981

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HH52A | 3 | 2.8 | $ 794.55 | $ 2,224.74 |
| UTB | 60 | 67.1 | $ 83.10 | $ 5,576.01 |
| UTL | 4 | 5.8 | $ 36.36 | $ 210.89 |
| MLB | 5 | 7.7 | $ 92.48 | $ 712.10 |
| Skiff | 1 | 0.1 | $ 14.54 | $ 1.46 |
| WHEC | 1 | 2.0 | $1,969.68 | $ 3,939.36 |
| Auxiliary | 16 | 9.6 | | |
| Total | | | | $12,664.56 |

Total Benefits From System

| Type of Benefit | Total Benefits | Benefits/Year |
|---|---|---|
| Resources Saved | $48,734.59 | $16,244.86 |
| Auxiliary Hours Saved | 34.1 Hours | 11.4 Hours |
| Benefit to Society | none | none |

NANTUCKET ISLAND/BLOCK ISLAND/WOODS HOLE

Fiscal Year 1979 Table B-2

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HU16 | 3 | 5.7 | $1,356.24 | $ 7,730.57 |
| HH52A | 15 | 25.7 | $ 794.55 | $20,419.94 |
| HH3F | 2 | 1.7 | $1,552.01 | $ 2,638.42 |
| UTB | 81 | 84.6 | $ 83.10 | $ 7,030.26 |
| UTM | 2 | 0.6 | $ 58.40 | $ 35.04 |
| UTL | 2 | 2.5 | $ 36.36 | $ 90.90 |
| MLB | 31 | 34.3 | $ 92.48 | $ 3,172.06 |
| Skiff | 7 | 6.5 | $ 14.54 | $ 94.51 |
| ANB | 1 | 1.8 | $ 104.06 | $ 187.31 |
| WPB | 4 | 33.0 | $ 199.75 | $ 6,591.75 |
| Personnel | 1 | 8.0 | $ 8.26 | $ 66.08 |
| Auxiliary | 8 | 6.1 | | |
| Total | | | | $48,056.84 |

Fiscal Year 1980

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HH52A | 4 | 5.5 | $ 794.55 | $ 4,370.03 |
| HH3F | 1 | 0.4 | $1,552.01 | $ 620.80 |
| UTB | 71 | 65.7 | $ 83.10 | $ 5,459.67 |
| UTM | 3 | 5.5 | $ 58.40 | $ 321.20 |
| UTL | 2 | 0.3 | $ 36.36 | $ 10.91 |
| MLB | 34 | 24.9 | $ 92.48 | $ 2,302.75 |
| Skiff | 4 | 4.0 | $ 14.54 | $ 58.16 |
| ANB | 1 | 0.4 | $ 104.06 | $ 41.62 |
| WPB | 1 | 0.1 | $ 199.75 | $ 19.98 |
| WLB | 1 | 0.2 | $ 564.42 | $ 112.88 |
| Auxiliary | 20 | 4.5 | | |
| Total | | | | $13,318.00 |

Fiscal Year 1981

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HH52A | 3 | 1.9 | $ 794.55 | $ 1,509.65 |
| HH3F | 5 | 4.5 | $1,552.01 | $ 6,984.05 |
| UTB | 62 | 32.1 | $ 83.10 | $ 2,667.51 |
| UTL | 2 | 1.1 | $ 36.36 | $ 40.00 |
| MLB | 12 | 17.9 | $ 92.48 | $ 1,655.39 |
| Skiff | 2 | 1.2 | $ 14.54 | $ 17.45 |
| Auxiliary | 23 | 9.3 | | |
| Total | | | | $12,874.05 |

Total Benefits From System

| Type of Benefit | Total Benefits | Benefits/Year |
|---|---|---|
| Resources Saved | $74,248.89 | $24,749.63 |
| Auxiliary Hours Saved | 19.9 Hours | 6.6 Hours |
| Benefit to Society | $560,000.00 | $186,666.67 |

CHESAPEAKE BAY

TABLE B-3

Fiscal Year 1979

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HH3F | 10 | 9.4 | $1,552.01 | $14,588.89 |
| UTB | 45 | 31.4 | $ 83.10 | $ 2,609.34 |
| UTM | 16 | 14.0 | $ 58.40 | $ 817.60 |
| UTL | 5 | 1.5 | $ 36.36 | $ 54.54 |
| MLB | 4 | 5.2 | $ 92.48 | $ 480.90 |
| TICWAN/TANB | 1 | 1.0 | $ 54.61 | $ 54.61 |
| Skiff | 4 | 3.1 | $ 14.54 | $ 45.07 |
| Misc. Boats | 1 | 0.1 | $ 14.54 | $ 1.45 |
| WPB | 8 | 18.3 | $ 199.75 | $ 3,688.42 |
| WYTM | 1 | 4.7 | $ 324.03 | $ 1,522.94 |
| Auxiliary | 108 | 66.6 | | |
| Total | | | | $23,697.69 |

Fiscal Year 1980

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HH3F | 1 | 1.7 | $1,552.01 | $ 2,638.42 |
| UTB | 20 | 22.5 | $ 83.10 | $ 1,869.75 |
| UTM | 14 | 4.1 | $ 58.40 | $ 239.44 |
| UTL | 3 | 3.5 | $ 36.36 | $ 127.26 |
| MLB | 4 | 24.1 | $ 92.48 | $ 2,228.77 |
| Skiff | 1 | 0.5 | $ 14.54 | $ 7.27 |
| Misc. Boats | 1 | 0.2 | $ 14.54 | $ 2.91 |
| WPB | 3 | 1.3 | $ 199.75 | $ 259.68 |
| WLB | 1 | 2.6 | $ 564.42 | $ 1,467.49 |
| Auxiliary | 96 | 52.1 | | |
| Total | | | | $ 8,840.99 |

Fiscal Year 1981

| Resource Type | # of Sorties | Hours Saved | Cost/Hour | Dollars Saved |
|---|---|---|---|---|
| HH3F | 7 | 8.1 | $1,552.01 | $12,571.28 |
| UTB | 37 | 23.4 | $ 83.10 | $ 1,944.54 |
| UTM | 6 | 3.4 | $ 58.40 | $ 198.56 |
| MLB | 3 | 0.7 | $ 92.48 | $ 67.74 |
| Skiff | 2 | 1.1 | $ 14.54 | $ 15.99 |
| ANB | 4 | 6.3 | $ 104.06 | $ 655.58 |
| Misc. Boats | 2 | 7.5 | $ 14.54 | $ 109.05 |
| WMEC | 1 | 5.1 | $ 789.03 | $ 4,024.05 |
| WPB | 2 | 2.3 | $ 199.75 | $ 459.43 |
| Auxiliary | 3 | 1.3 | | |
| Total | | | | $20,043.22 |

Total Benefits From System

| Type of Benefit | Total Benefits | Benefits/Year |
|---|---|---|
| Resources Saved | $52,581.90 | $17,527.30 |
| Auxiliary Hours Saved | 120.0 Hours | 40.0 Hours |
| Benefit to Society | none | none |

# APPENDIX C

## SYSTEM COSTS ASSUMING PURCHASE OF A SINGLE SYSTEM AND THE USE OF PHONE LINKS

### Table C-1

### CAPE COD BAY/MASSACHUSETTS BAY

System Costs

| Type of Cost | Total Cost* | Cost/Year |
|---|---|---|
| Initial Acquisition and Installation | $150,000 | $10,000 |
| Operation | | $ 7,200 |
| Maintenance | | $11,000 |
| Total | | $28.200 |

### NANTUCKET ISLAND/BLOCK ISLAND/WOODS HOLE

System Costs

| Type of Cost | Total Cost | Cost/Year |
|---|---|---|
| Initial Acquisition and Installation | $225,000 | $15,000 |
| Maintenance | | $18,000 |
| Total | | $10,000 |
| | | $43,000 |

### CHESAPEAKE BAY

System Costs

| Type of Cost | Total Cost | Cost/Year |
|---|---|---|
| Initial Acquisition and Installation | $180,000 | $12,000 |
| Operation | | $14,400 |
| Maintenance | | $10,000 |
| Total | | $36,400 |

*Includes one UHF Link

SYSTEM COSTS ASSUMING VOLUME DISCOUNT ON PURCHASE OF SYSTEM AND USE OF UHF DATA LINKS FOR COMMUNICATIONS

## CAPE COD BAY/MASSACHUSETTS BAY

System Costs

| Type of Cost | Total Cost | Cost/Year |
|---|---|---|
| Initial Acquisition and Installation | $145,000 | $ 9,667 |
| Operation | | $ 0 |
| Maintenance | | $13,000 |
| Total | | $22,667 |

## NANTUCKET ISLAND/BLOCK ISLAND/WOODS HOLE

System Costs

| Type of Cost | Total Cost | Cost/Year |
|---|---|---|
| Initial Acquisition and Installation | $241,667 | $16,111 |
| Operation | | $ 0 |
| Maintenance | | $15,000 |
| Total | | $31,111 |

## CHESAPEAKE BAY

System Costs

| Type of Cost | Total Cost | Cost/Year |
|---|---|---|
| Initial Acquisition and Installation | $193,333 | $12,889 |
| Operation | | $ 0 |
| Maintenance | | $14,000 |
| Total | | $26,889 |

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