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REPORT DOCUMENTATION PAGE

AD-A191 583

1b. RESTRICTIVE MARKINGS

3. DISTRIBUTION/AVAILABILITY OF REPORT

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4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
Naval Ocean Systems Center	NOSC	Naval Ocean Systems Center

6c. ADDRESS (City, State and ZIP Code)

San Diego, California 92152-5000

7b. ADDRESS (City, State and ZIP Code)

San Diego, California 92152-5000

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State and ZIP Code)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	AGENCY ACCESSION NO.
RDDA	MP72	DCA	DN305 117

11. TITLE (Include Security Classification)

Meteor Burst Communication Buoy Relay Tests

12. PERSONAL AUTHOR(S)

J.E. Bickel

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Presentation/Speech	FROM Nov 1987 TO Nov 1987	January 1988	

16. SUPPLEMENTARY NOTATION

DTIC SELECTE MAR 2 3 1988 S E D

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

meteor trails ionize
relay function
battery-powered meteor
CONUS

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A meteor burst communications (MBC) link is limited to approximately 1000 nautical miles (nmi). This is due to the physical height at which meteor trails ionize, which is typically 100*km* - 120*km*, and to the curvature of the earth.

Longer range communications can be achieved by using meteor burst relays. Over the oceans, ships at sea can provide the relay function, but are generally not practical for long periods of time if the ship is required for other missions. Another alternative is the use of buoys, which are allowed to drift or are moored to seamounts or to the deep ocean bottom.

This paper describes a relatively large MBC relay buoy with remote and master station capability and presents the results of a buoy and ship relay test between San Diego, San Francisco, and Hawaii. The tests demonstrate the feasibility of mounting a battery-powered meteor burst master and remote station system in a buoy and operating it for 6 months. Smaller buoys are possible if needed for only a few short emergency messages or to act as a remote station only, operating within range of master stations so that a large battery is not necessary.

During these tests messages were successfully relayed between CONUS and Hawaii, and the relative performance of vertically and horizontally polarized antennas in the seawater environment was observed.

Presented at Meteor Burst Communications (MBC) Symposium, The Hague, Netherland, 4-5 Nov 1987.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT

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21. ABSTRACT SECURITY CLASSIFICATION

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22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
J.E. Bickel	(619) 553-3065	Code 542

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1. METEOR BURST COMMUNICATION BUOY RELAY TESTS

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1.1 INTRODUCTION

A meteor burst communications (MBC) link is limited to approximately 1000 nautical miles (nmi). This is due to the physical height at which meteor trails ionize, which is typically 100 km ± 20 km, and to the curvature of the earth.

Longer range communications can be achieved by using meteor burst relays. Over the oceans, ships at sea can provide the relay function, but are generally not practical for long periods of time if the ship is required for other missions. Another alternative is the use of buoys, which are allowed to drift or are moored to seamounts or to the deep ocean bottom.

This paper describes a relatively large MBC relay buoy with remote and master station capability and presents the results of a buoy and ship relay test between San Diego, San Francisco, and Hawaii[1]. The tests demonstrate the feasibility of mounting a battery-powered meteor burst master and remote station system in a buoy and operating it for 6 months. Smaller buoys are possible if needed for only a few short emergency messages or to act as a remote station only, operating within range of master stations so that a large battery is not necessary.

During these tests messages were successfully relayed between CONUS and Hawaii, and the relative performance of vertically and horizontally polarized antennas in the seawater environment was observed.

1.2 BUOY RELAY SYSTEM

An MBC relay buoy was developed and built for deployment in the open ocean that would survive at least 90 days and in sea states of six or more. The buoy system includes the meteor burst communications equipment capable of continuous remote station operation and 2 hours a day master station operation, its antenna, the battery power supply, a switching circuit for remotely selecting redundant MBC equipment and battery-charging circuits, and environmental sensors.

A comprehensive study of possible buoy designs, MBCS buoy antennas, and power supply systems was made before selecting the optimum design.[2]

A surface-following, pendulous spherical buoy, shown in Figure 1, was selected from among several classes of buoys as the most effective at maintaining the vertical stability of the MBCS antenna while providing the necessary reserve buoyancy to insure proper flotation. This buoy consists of a spherical float with a rigid "arm" extending downward to form a "ball-in-socket joint" where the float rotates in the ocean support. A ballast weight is suspended from the end of the arm, well below the effective depth of the surface wave motion, to provide a righting moment when the buoy is tilted. A design objective for the buoy was that it maintain the antenna within 10 degrees of vertical for conditions up to and including sea state six.

The antenna was a 15-foot-high "J", shown in Figure 2, with characteristics equivalent to a vertical half-wave dipole. Vertical polarization, omnidirectional coverage, and 2.1 dBi of gain were achieved.

The MBC equipment was manufactured by Meteor Communications Corp. (MCC) and had previously been used for various other MBC applications tests. MCC model 540A remote station transceivers and MCC 530 master station transceivers were deployed and used as illustrated in Figure 3. The transmitter of the MCC 540A provided 300 watts of peak RF power. The MCC 530 transmitter provided 500 watts of RF power. Their instantaneous data rates were 4 kbps. Software modifications by MCC for this buoy relay test demonstration were incorporated to provide an automatic message relay capability so that test and information messages were relayed automatically from an MBCS master to remote, to master, to a final remote station destination and acknowledgement returned to the originating master station.

A second MCC MBC system was also deployed which included an MCC model 512 remote station which had been modified to perform as a 33% duty cycle probe-and-listen master station for use on the buoy. However, because of weather and ship schedule problems, it was not tested.

The MBCS primary power supply selected was a zinc-air battery 16" x 16" x 62" weighing 450 lb and rated at 1200 ampere-hours. It was used to recharge a lead-acid secondary battery at a 0.7-ampere rate, which provided the short periods of high power drain required by the MBCS transmitter. Its expected voltage variation over a 16-hour test cycle, when powering the MCC 512 master station for 1 hour each day, is shown in Figure 4. The zinc-air battery was recently developed by the U.S. Coast Guard for use on their thousands of aids-to-navigation buoys for up to 2 years each and has proven to be very reliable and optimum for buoy applications.

1.3 TEST PLAN SYNOPSIS

The basic test configuration included the meteor burst stations indicated in Figure 3 and described as follows (the equipment in parentheses was for testing the relay system with the buoy performing as a master station but was not used):

1. One ground-based model MCC-530 (and MCC-510) MBCS master station, located at San Diego (NOSC). The antenna was a 5-element Yagi antenna oriented for vertical polarization and directed toward the buoy near San Francisco.

2. One ship-based MCC-530 (and 510) master station, located aboard USNS De Steiguer (T-AGOR-12) research ship. During the course of the test, the ship took two cruises to a mid-ocean point between Hawaii and CONUS, acting as a master station relay. The ship was also used to deploy and recover the buoy. Two 5-element vertically polarized Yagi antennas were mounted on the ship, one on the bow and one near its stern. They were operated simultaneously through a power splitter as shown in Figure 5.

3. Two buoy-mounted model MCC-540A remote station MBCS equipments. (An MCC 512 remote station transceiver, which had been modified to operate as a master station with its transmitter having a 33% duty cycle, was also on the buoy.) The buoy was moored off the California coast 45 nmi SW of San Francisco.

4. One ground-based MCC-540A remote station, located on Mauna Loa (11-,100 feet) on the island of Hawaii. This site elevation extended meteor burst range (100 - 150 nmi). A 5-element Yagi antenna was directed toward San Francisco.

5. One ground-based MCC-540A remote station, located at Stinson Beach, 12 nmi N of San Francisco. This station was originally located on top Mt. Tamalpais near San Francisco, but was moved to Stinson Beach because of rf interference from the entire San Francisco bay area on Mt. Tamalpais. A 3-element Yagi antenna was used at this site.

Photographs of the buoy and the installations at San Diego, on USNS De Steiguer, and at Stinson Beach, are shown in Figure 6.

The primary testing included two cruises of USNS De Steiguer. These cruises are summarized below:

1.3.1 CRUISE NUMBER ONE

During the first cruise, illustrated in Figure 7, the ship left from Oakland Naval Shipyard on 25 June 1986, and traveled to 37°22'N, 123°09'W, 45 nmi SW of the Golden Gate Bridge, where it deployed the buoy. It then sailed to 30°32'N, 138°09'W, almost midway between the buoy and Hawaii. During this time, the ship was in constant communication with the buoy through line-of-site (LOS) operation, meteor burst operation, and sporadic E operation, using the MCC 530/540A (master/remote) MBCS equipment; the San Diego master station was communicating with the buoy; and the ship was also listening for Hawaii, achieving the first communication at about 1300 nmi range.

While the ship was at mid-position, it sailed back and forth in a 100-nmi pattern, keeping its bow and stern MBCS Yagi antennas pointed to the buoy and Hawaii. Messages were transferred between the ship and Hawaii, and between the ship and buoy. Because of problems with the automatic message generator at San Diego, there were no messages sent from San Diego to Hawaii. Several messages were sent from Hawaii to San Diego. The ship was at mid-position for about three days, after which it sailed back to the buoy.

The plan was to remotely switch from the MCC 540A remote system to the MCC 512 remote system on the buoy to allow testing of the buoy battery power system while the buoy was operated as a master station. (The MCC 512 had been modified to function as either a remote station relay requiring as little as 1.5 watts of DC power or as a master station relay requiring as much as 600 watts of DC power.) Because of bad weather and heavy seas, the ship bypassed the buoy returning to Port Heuneme California on 8 July 1986.

1.3.2 CRUISE NUMBER TWO

On cruise number two, illustrated in Figure 8, the ship left Oakland Naval Shipyard on 8 August 1986 at 0300. The ship sailed to the buoy, which had been moored during cruise one. The plan was to recover the buoy and deploy it to a seamount 400 nmi closer to Hawaii, providing more optimum ranges for relay between San Diego, the buoy, the ship, and Hawaii.

Upon arrival at the buoy site, it was found that the buoy tether line had been cut by a passing ship and the MBCS buoy was gone. The crown (tether) buoy was still in place, but had a scrape mark on its side, indicating it had been hit by a green ship. Because of the loss of the buoy, the test plan was changed to allow relay of data from the station located at Stinson Beach near San Francisco to Hawaii via the ship.

During the cruise to mid-position, messages were transferred between the ship and Stinson Beach. Continuous ground wave connectivity (LOS) was measured out to 230 nmi. During the remainder of the cruise, communication was maintained using meteor burst and sporadic E operation. At about 1200 nmi from Hawaii, the first communications from Hawaii were received, apparently due to sporadic E.

The ship arrived at mid-position on August 12th, where it maintained a test pattern of back-and-forth operation over a 50-nmi path for about 3 days. During this period, numerous messages were transferred between Hawaii and Stinson Beach. Although the activity was sporadic, indicating a lot of sporadic E operation, there were periods of meteor activity, and the test did prove the relay concept. At mid-point, the transmission paths were at times in excess of 1000 nmi.

On 15 August 1986, the Yagi antennas on the bow of the USNS De Steiguer and at Stinson Beach were rotated to obtain performance data for horizontal polarization, the shipboard transmitter power delivered 800 watts to only the 5-element Yagi mounted on the bow of the ship, and the ship started its cruise back to Oakland, arriving 18 August. During the return cruise, good meteor activity was recorded between the ship and Stinson Beach.

The equipment buoy was later seen by a naval ship, but efforts to relocate and recover it failed; however MBCS communications between the buoy and San Diego were re-established, even though the location of the buoy was uncertain. This communication continued until 5 February 1987 as the buoy drifted from north of San Diego to about 1000 nmi south. Its fate is not known.

1.4 TEST RESULTS

All test data resulted from operating the MCC 530/540A (master/remote) equipment. The bulk of the MCC 530/540A data consisted of the number of good (verified) receptions of a 72 ms long test message from a remote station (buoy, Stinson Beach, or Hawaii) recorded by the ship's 530 as it sailed to and from the remote stations located in the buoy, at Stinson Beach, or at Hawaii. This provided valuable data on performance versus range over the ocean.

Figures 9 and 10 give the good receptions from the buoy as a function of range. The cyclic variation of good receptions is due to the diurnal variations in meteor rates. The peaks correspond to 0600 local time. Note the ground wave performance extended out to 130 nmi during cruise number one.

During cruise number two, the same data was obtained during communications with the shore-based station at Stinson Beach. This data is plotted in Figures 11 and 12. The ground wave extended to at least 230 nmi. This difference in ground wave range data correlates to the type of antennas used, dipole J-antenna on the buoy and a higher gain 3-element Yagi at Stinson Beach

At the same time, the shore-based MCC 530 at San Diego recorded the same data as it communicated with the buoy, giving information on performance versus time of day. Figure 13 gives the number of "good receptions" received from the buoy at San Diego. Note the diurnal variations in the data. The data was taken during cruise number one.

During the second ship cruise, Stinson Beach and Hawaii were entering messages for relay through the ship to each other. A list of the total number of characters relayed through and received at each remote station from the other remote station is summarized in Table 1. Note from this data that a large number of messages were transferred from Stinson Beach to Hawaii; however, a lot of these messages occurred in groups, indicating that sporadic E was the most common propagation medium. Because of the long range (near 1100 nmi), meteor activity was extremely slow, and waiting times were at times measured in hours instead of minutes. These results point to the need for additional relays in the San Francisco/Hawaii link.

1.5 ANALYSIS

A list of the average Rx good counts vs. range is given in Table 2. This data was taken from Figures 9, 10, 11, and 12. These values are from an imaginary curve that averages the diurnal variation which is evident but ignores the extreme values that are assumed to result from sporadic-E. Also listed in Table 2 is the system power factor (PF), which is a function of antenna gains (G_T and G_R), transmitter power (P_T), and receiver threshold (P_R). The differences between the four sets of data are due to the different PF used, i.e.:

Cruise 1 Out - VERTICAL POLARIZATION

Tx Power 250 watts, Omni Rx Ant PF = 176 dB

Cruise 1 In - VERTICAL POLARIZATION

Tx Power 500 watts, Omni Rx Ant PF = 179 dB

Cruise 2 Out - VERTICAL POLARIZATION

Tx Power 250 watts, 3EL Yagi Rx Antenna PF = 179 dB

Cruise 2 In - HORIZONTAL POLARIZATION

Tx Power 800 watts, 3EL Yagi Rx Antenna PF = 187 dB

The differences in count roughly follows the standard equation relating meteor count to system power factor or sensitivity, i.e.,

$$\frac{N_1}{N_2} = 10 \exp \left\{ \frac{PF_1 - PF_2}{20} \right\}$$

where:

N_1 = Meteor Rate for System 1

N_2 = Meteor Rate for System 2

PF_1 = Power Factor for System 1

PF_2 = Power Factor for System 2

As an example, the daily average Rx good count difference between the first and the fourth plot at 500 miles is about 4:1. This corresponds to a 12-dB difference in system sensitivity. The actual power difference was 11 dB.

Note from the data that the performance drops off with range beyond 700 to 750 nmi. This is especially true for the second half of the second cruise, which used horizontal polarization. This suggests that vertical polarization will perform best at these ranges, probably because the antenna cutback is less for the antenna heights used.

1.6 CONCLUSIONS

The San Francisco/Hawaii link provided marginal performance using one relay (the ship). Unfortunately, the loss of the buoy during the second cruise prevented placing the buoy 400 nmi closer to Hawaii. This would have allowed the test of a two-relay link, which would have undoubtedly improved performance. With this arrangement, message waiting times could be reduced to minutes.

Large, heavy fuel supplies or batteries of limited life are required to provide power for a buoy relay system operating as a master station. However, an MBCS emergency relay network operational concept that partially mitigates this limitation includes implementing combination master/remote station functions in the MBCS equipment operated at each buoy-supported transceiver relay node in the network. This is illustrated by the MBCS network diagrammed in Figure 14. Each of the nodes can function as either an MBCS master station, probing to establish connectivity with a remote station, or as the remote station.

Initially, all stations function continuously as remote stations, prepared to respond with a transmission acknowledging reception of a probing signal. When a message is injected into the network, the node responds by functioning as a master station, probing for a programmed number of minutes or until the message receipt is acknowledged by one or more of the remote stations addressed. The functioning master station may or may not continue to probe until all of the remote stations within range of its transmitted probing signal acknowledge reception of the message. Each station (node) to which the message is passed begins functioning as a master station, probing until the message is passed to yet another combination remote/master station functioning as a remote station closer to the intended final destination of the addressed message. Each station (node) returns to functioning as a remote station when it has no message to relay.

REFERENCES

1. NOSC TR 1171, Buoy Relay for a Meteor Burst Communication System - Test Report, by J.E. Bickel, T.L. Wright, G.L. Davis, E.A. Thowless, J.F. Theisen of NOSC, and T. Donich of MCC, April 1986.

2. NOSC TR 1150, Preliminary Design Options for Meteor Burst Communications Systems Buoy Relays, J.E. Bickel, T.L. Wright, E.A. Thowless, G.L. Davis, G. Pickins (CSC), December 1986.

Table 1. Number of characters relayed through USNS De Steiguer and received at Stinson Beach from Hawaii and at Hawaii from Stinson Beach.

DAY NUMBER	STINSON BEACH RX CHAR	HAWAII RX CHAR	RANGE FROM STINSON BEACH (nmi)
222	Off	4,544	343-603
223	Off	23,160	614-876
224	2,632 (7 hrs)	88,088	876-977
225	680	6,088	999-950
226	78,088	79,264	998-950
227	19,648	1,120 (8 hrs)	990-800
228	95,920	Off	800-550
229	94,054	Off	550-360

Table 2. List of the daily average (noon) Rx good receptions for 300, 600, 800 nmi ranges (values from Figures 9, 10, 11, and 12).

	RANGE, nmi				
CRUISE	300	600	800	POL.	PF**
1 Out	10	10	4	Vert.	176 dB
1 In	15	15	5	Vert.	179 dB
2 Out	15	15	5	Vert.	179 dB
2 In	40	40	10	Horz.	187 dB

**NOTE: PF (db) = $P_T + G_T + G_R - P_R$

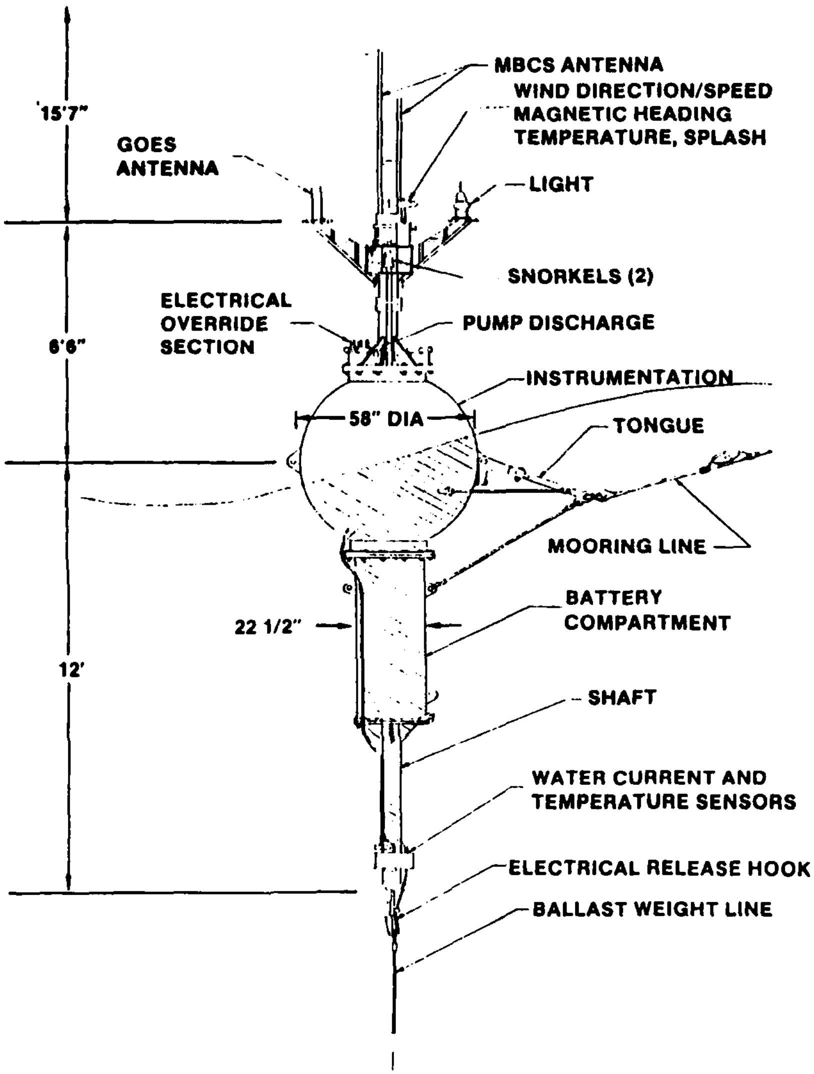


Figure 1. MBCS Relay Buoy

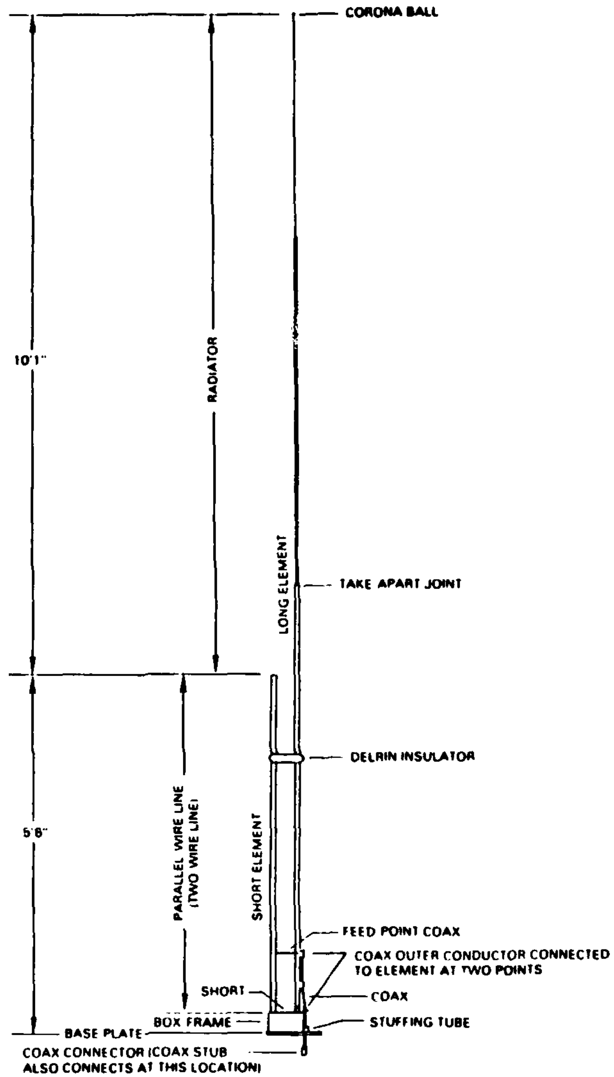


Figure 2. The J-antenna mounted on top of the buoy mast.

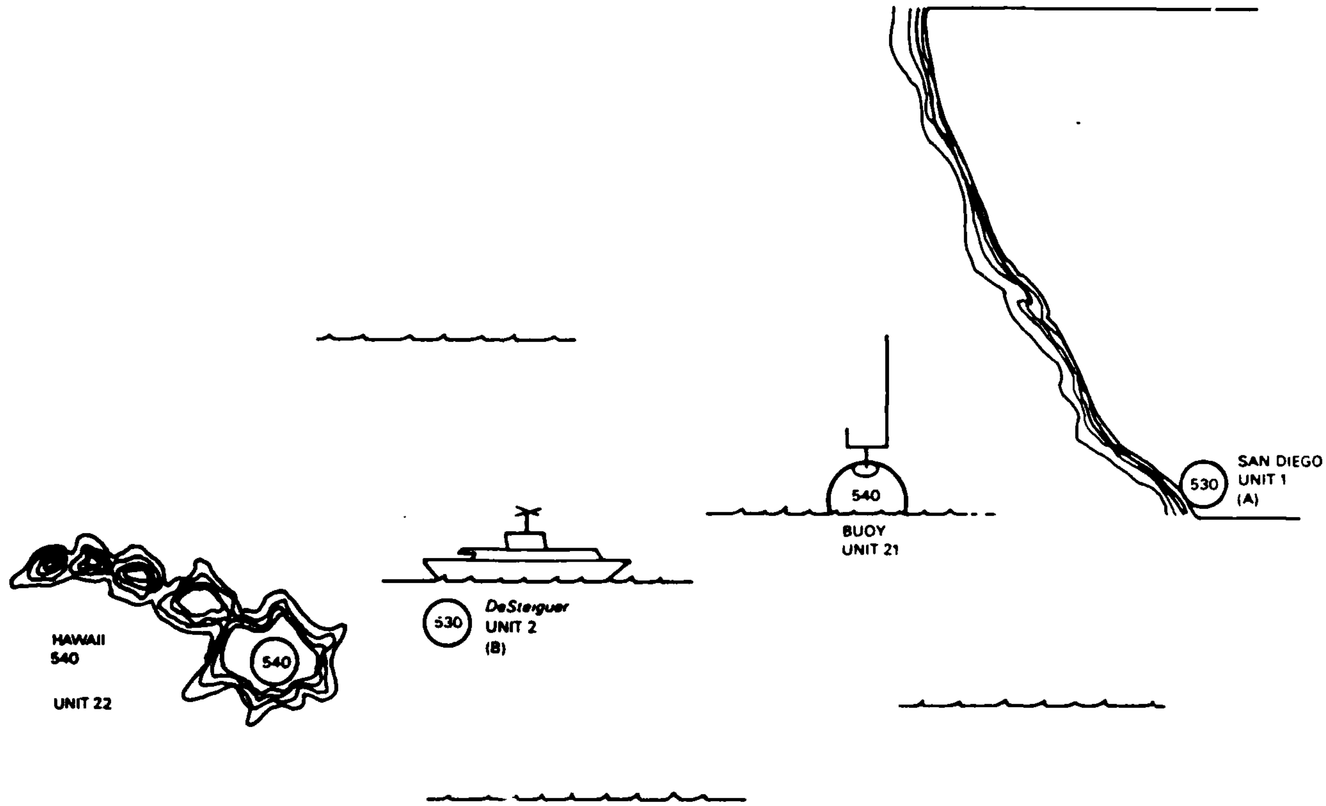


Figure 3. MBCS equipment deployment for relay tests.

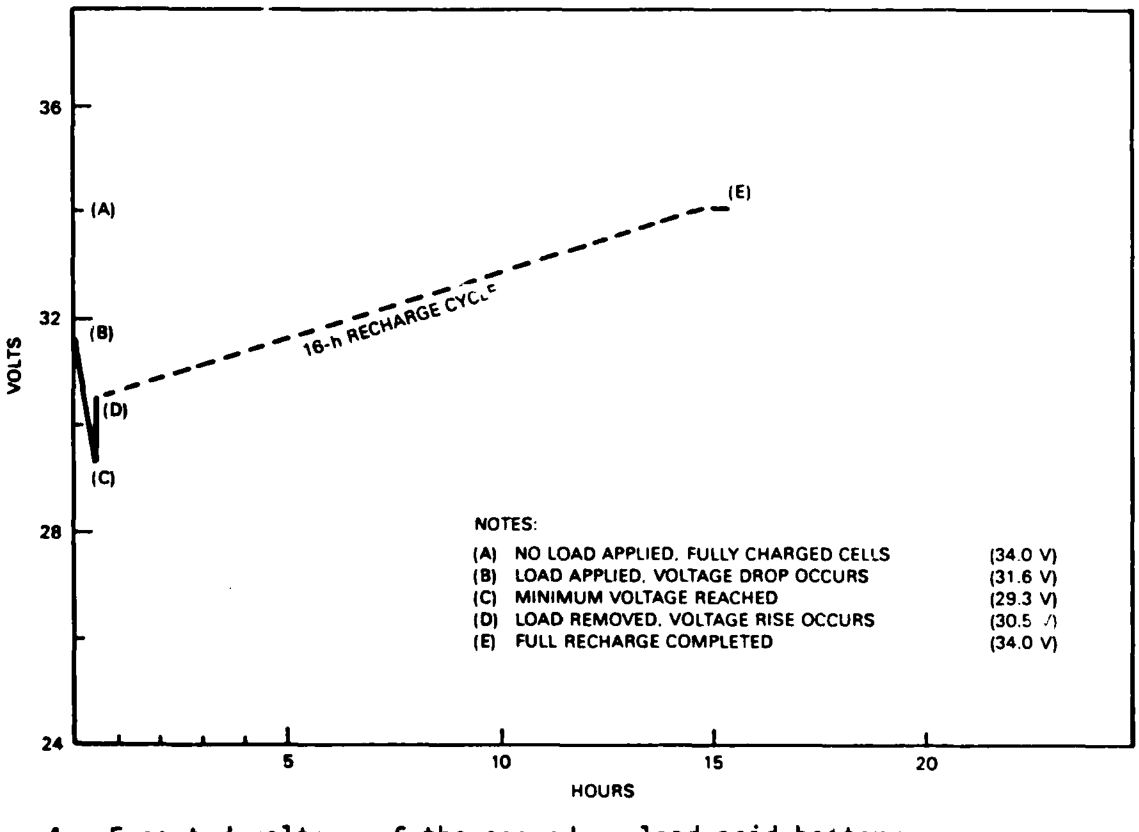


Figure 4. Expected voltage of the secondary lead-acid battery during a typical test cycle.

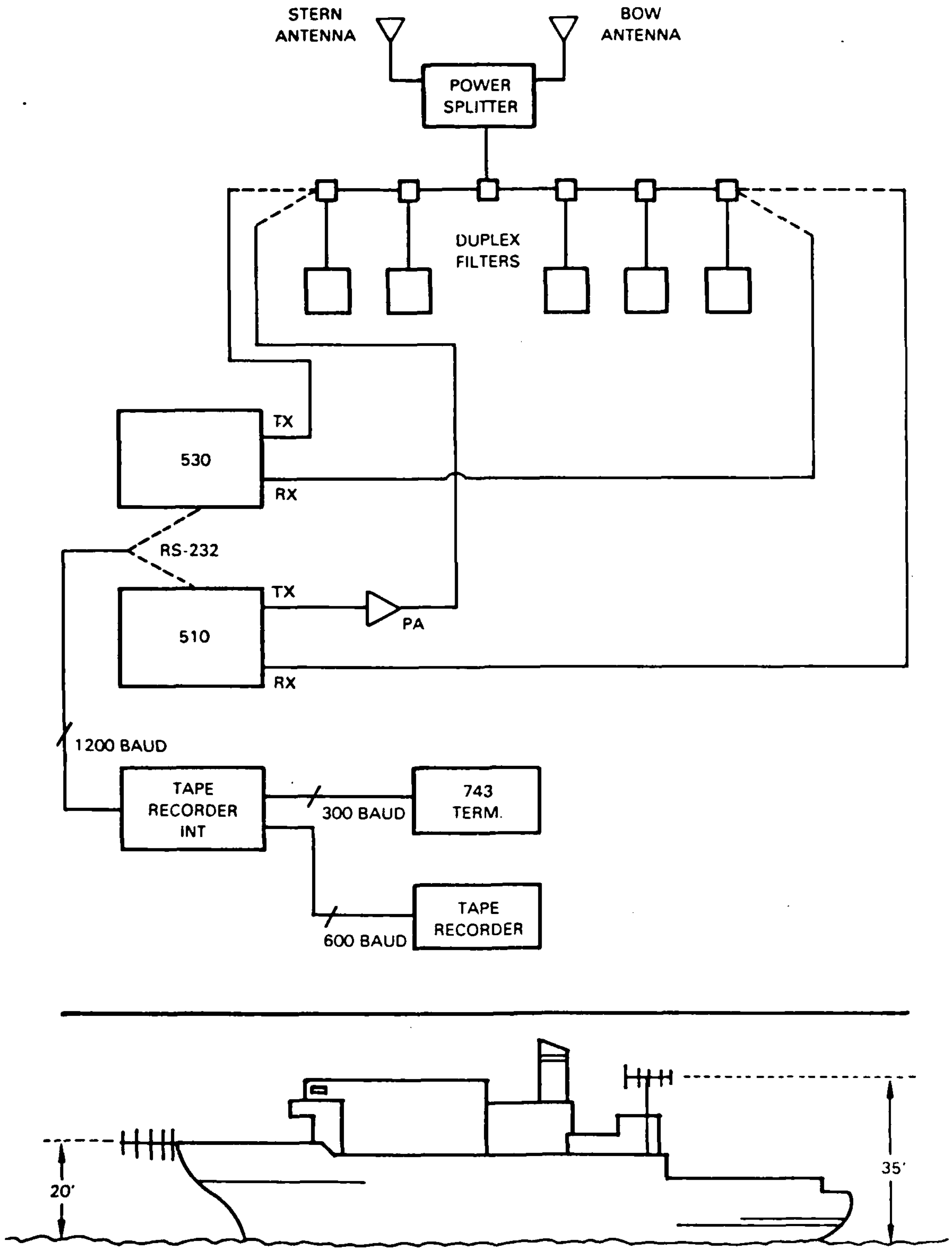
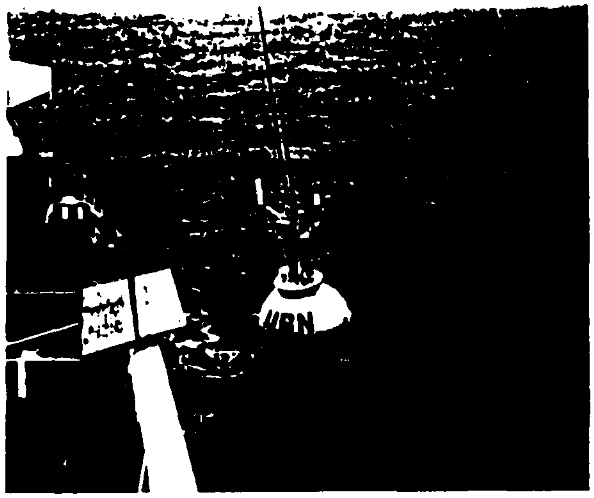


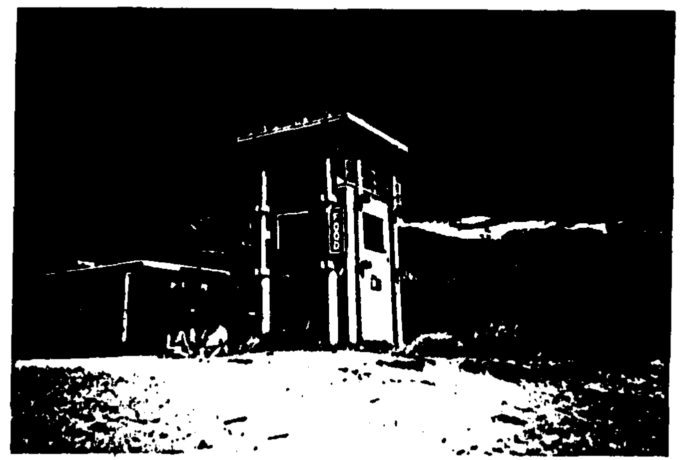
Figure 5. USNS De Steiguer MBCS Yagi antenna installation.



Buoy

San Diego

USNS De Steiguer



Stinson Beach

Figure 6. Photographs of the test installations.

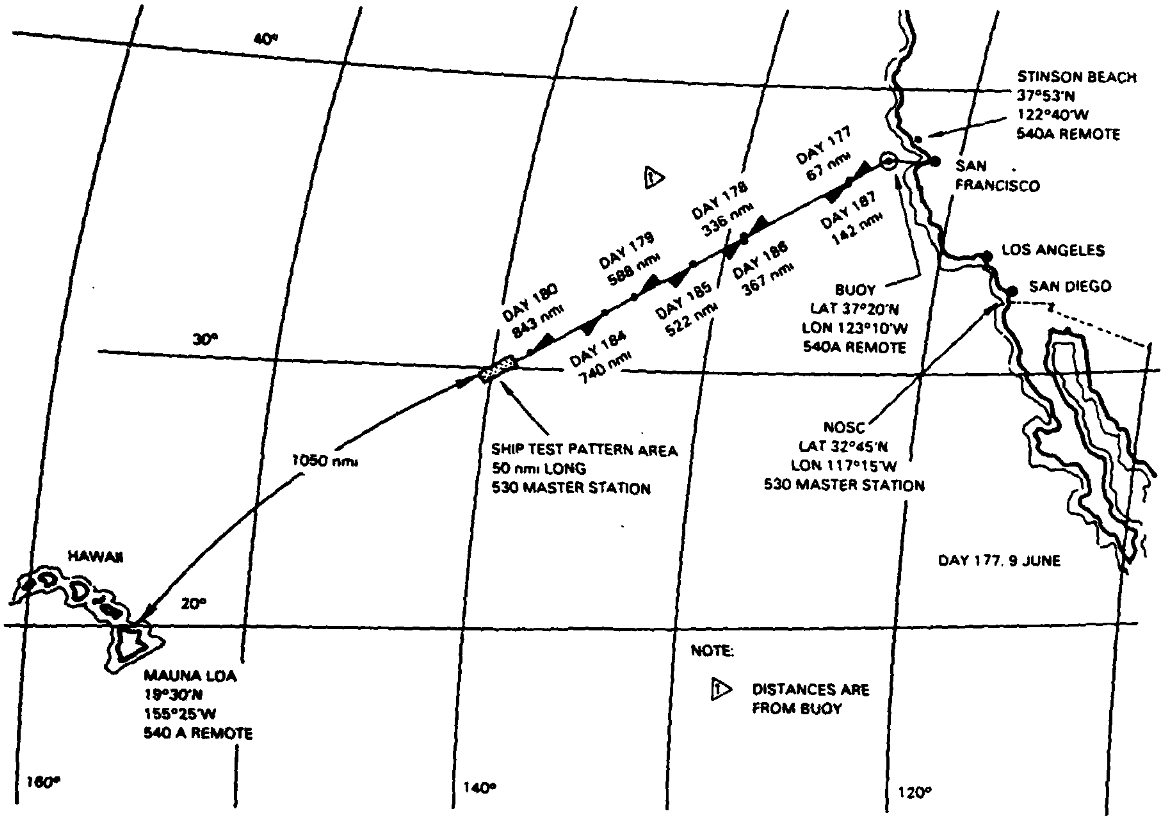


Figure 7. The first cruise of USNS De Steiguer from 25 June to 7 July 1986.

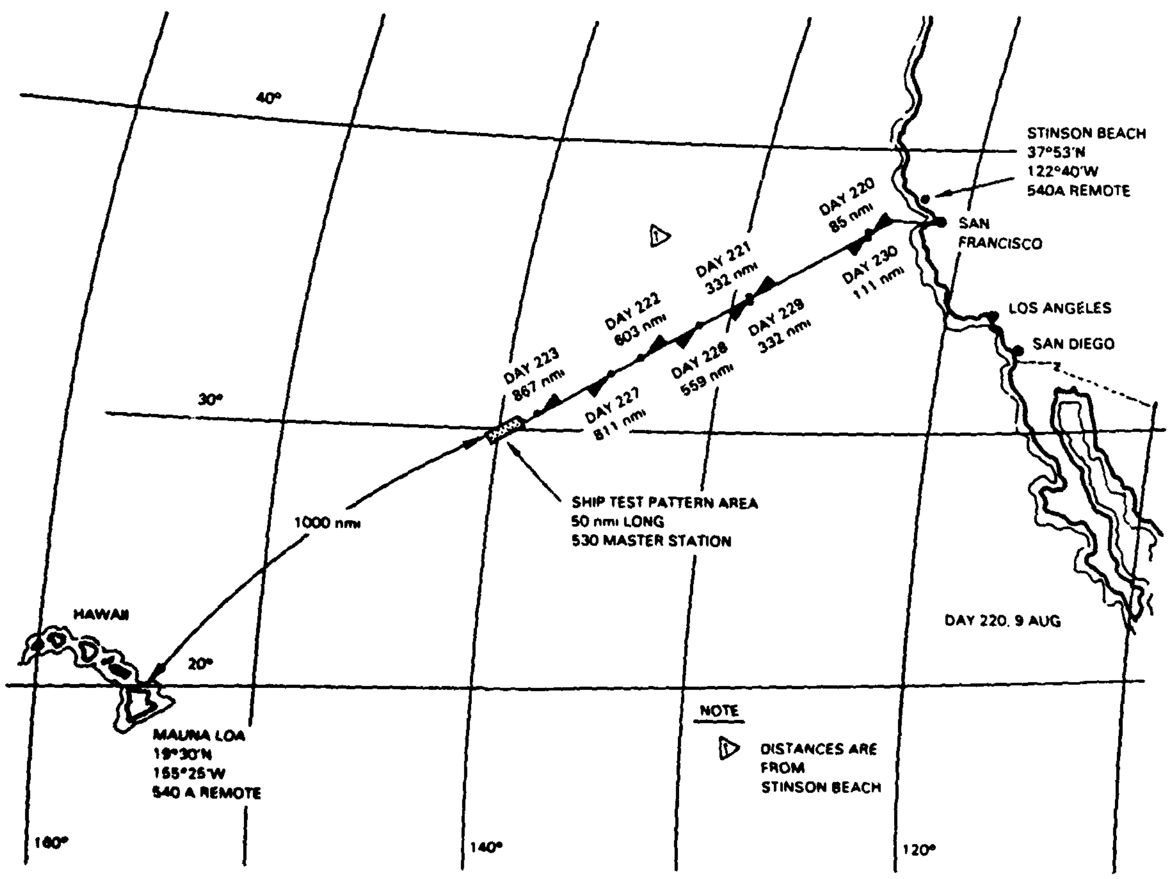


Figure 8. The second cruise of USNS De Steiguer from 8 to 18 August 1986.

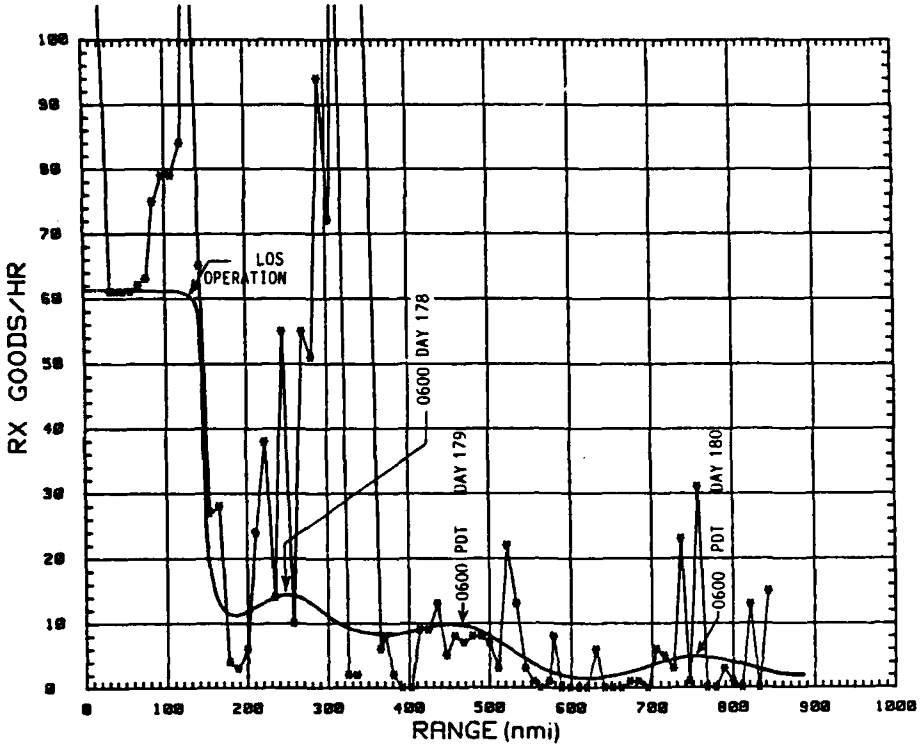


Figure 9. Number of good receptions per hour recorded aboard USNS De Steiguer from the buoy during the first half of the first cruise.

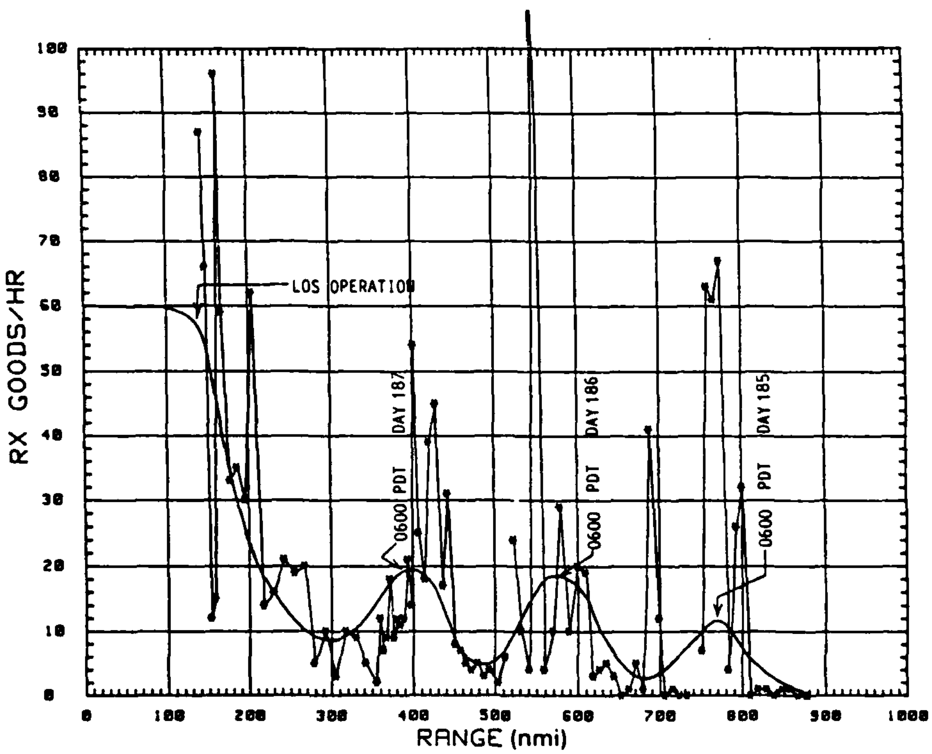


Figure 10. Number of good receptions per hour recorded aboard USNS De Steiguer from the buoy during the second half of the first cruise.

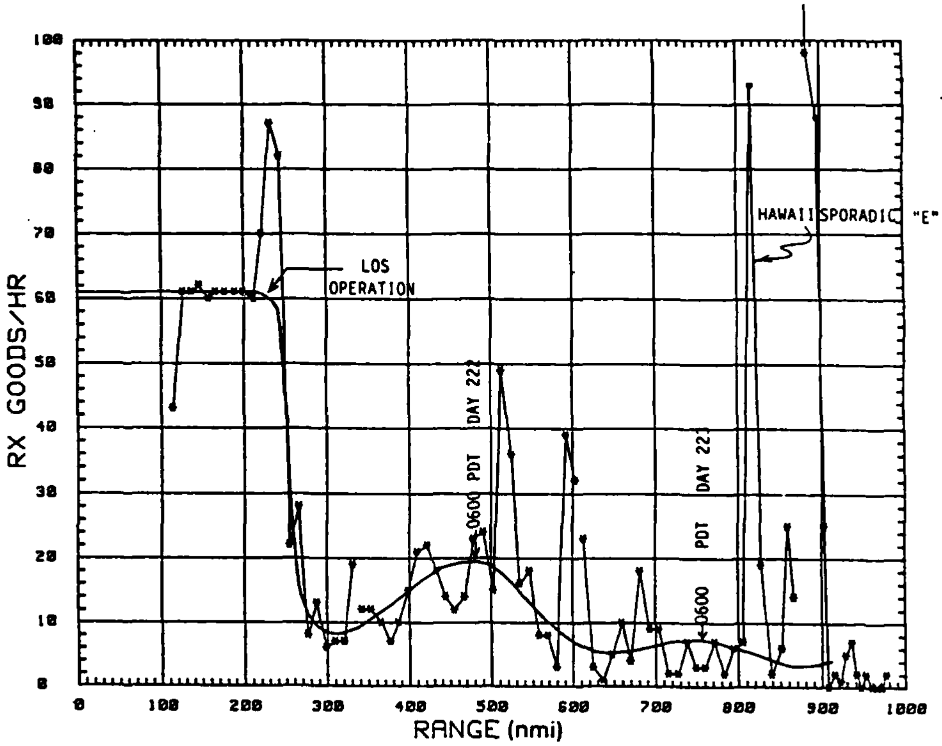


Figure 11. Number of good receptions per hour recorded aboard USNS De Steiguer from Stinson Beach during the first half of the second cruise.

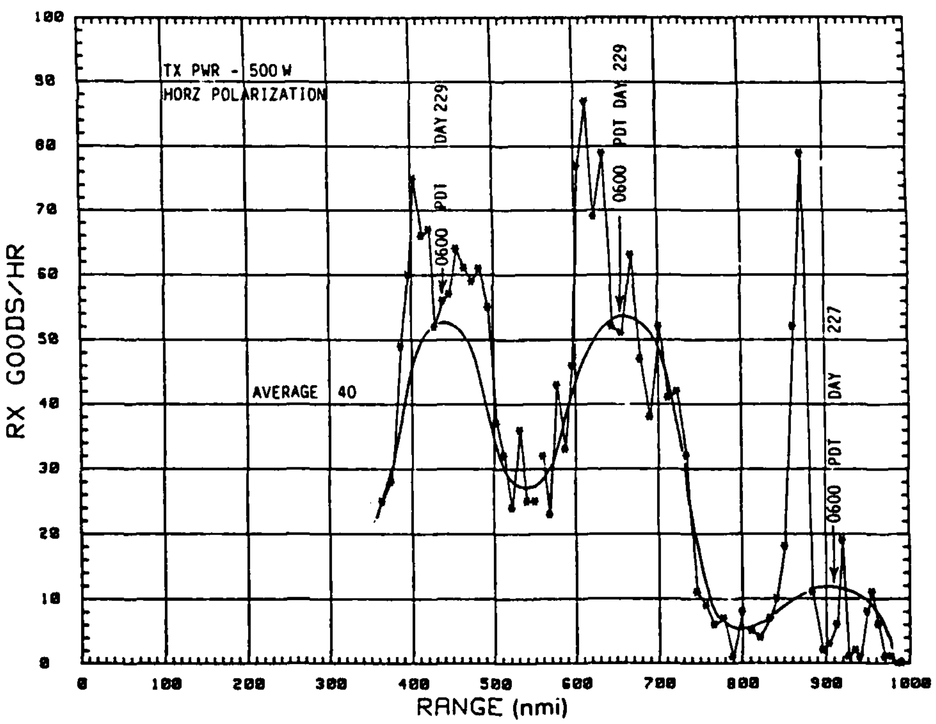


Figure 12. Number of good receptions per hour recorded aboard USNS De Steiguer from Stinson Beach during the second half of the second cruise. Horizontally polarized antennas were used.

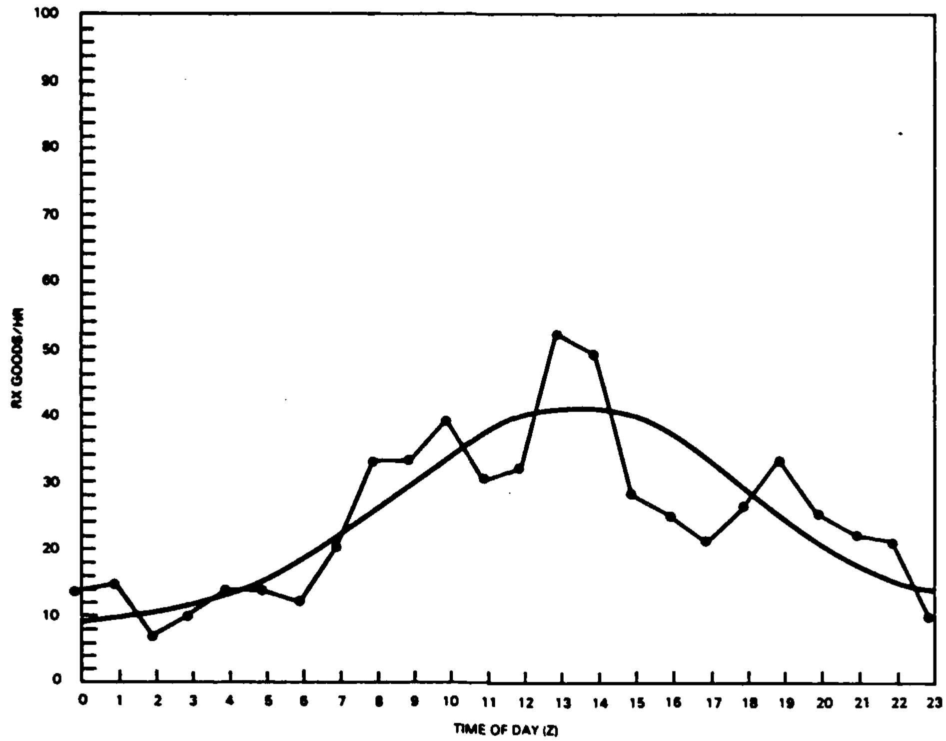


Figure 13. Typical diurnal variation of the number of good receptions received from the buoy at San Diego during cruise 1.

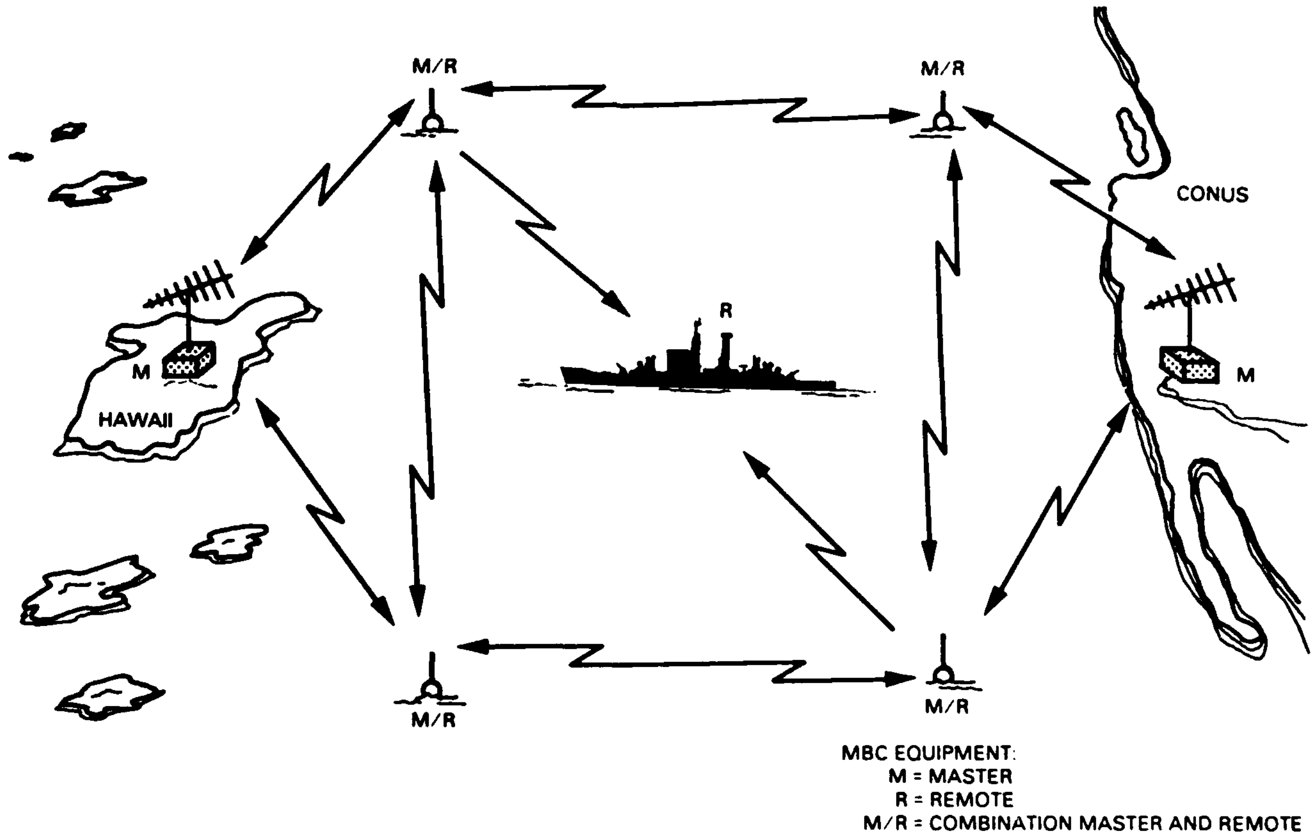


Figure 14. A proposed MBCS strategic connectivity network.