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An Investigation of Federal Standard 1045 High-Frequency ALE Radio Performance in the Southern Trans-Auroral Zone

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PREFACE

The Naval Undersea Warfare Center (NUWC) Military Interdepartmental Purchase Request (MIPR) N6660492MP25003 dated 8 November 1991, tasked the Institute for Telecommunication Sciences (ITS) to conduct an assessment of the National Science Foundation Office of Polar Programs' (NSF/OPP) primary high-frequency (HF) radio link between Christchurch, New Zealand, and McMurdo Station, Antarctica, and to provide specific recommendations to improve the voice and data transmission quality, as well as increase the circuit time availability. These recommendations include equipment configuration and specification.

This NTIA Report presents the professional opinions and recommendations of the ITS authors. However, the report does not reflect NTIA, NUWC, or any other Federal agency position, policy, or decision unless otherwise designated by other official documentation, and it does not constitute product endorsement by any agency of the U.S. Department of Commerce nor the sponsor of this project.

The technical and administrative monitoring of this project was performed by Mr. Joseph Katan of the Naval Undersea Warfare Center. Technical leadership and administrative supervision of the project at ITS were provided by Mr. David F. Peach, P.E.

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ACRONYMS AND ABBREVIATIONS

AEA	Advanced Electronic Applications, Inc. A manufacturer of HF data modems designed primarily for the amateur radio market.
ALE	Automatic link establishment. The capability of an HF radio station to make contact, or initiate a circuit, between itself and another specified radio station, without operator assistance and usually under processor control. Note: ALE techniques include automatic signaling, selective calling, and automatic handshaking. Other automatic techniques that are related to ALE are channel scanning and selection, link quality analysis (LQA), polling, sounding, message store and forward, address protection, and anti-spoofing.
AMAF	A manufacturer of the Lincompex™ voice compandors. The corporate name of this company changed to Link-Plus in 1992.
AMTOR	Amateur teleprinting over radio. An error-free radio-teletype system developed by amateur radio experimenters from a maritime mobile service protocol (CCIR Recs. 476, 625).
ASA	Antarctic Support Associates. A contractor supporting the NSF and the U.S. Antarctic Program.
ASAPS	Advanced stand alone prediction system. A computer HF radio propagation system developed by the Australian IPS Radio and Space Services, Department of Administrative Services (1992).
BER	Bit error ratio. The number of erroneous bits divided by the total number of bits transmitted, received, or processed over some stipulated period of time.
Bit	Binary digit. A signal having two states, represented by a "1" or "0".
BW	Bandwidth. The difference between the limiting frequencies within which performance of a device, in respect to some characteristic, falls within specified limits.
CCIR	The International Radio Consultative Committee. An international standards making body that develops radio standards.
COMSTA	A U.S. Navy communications station.
cw	Continuous wave. Used for manual Morse code telegraphy.

ACRONYMS AND ABBREVIATIONS (cont.)

dBi	Decibels referenced to an isotropic antenna.
dBW	Decibels referenced to one watt.
EIRP	Equivalent isotropic radiated power. The rf power radiated from an antenna, in a specified direction, referenced to that of an isotropic antenna.
FEC	Forward error correction. A coding technique that detects and automatically corrects some or all of the errors in a data transmission.
FOT	Optimum traffic frequency. A frequency below the maximum frequency that will propagate, and that is relatively immune to minor changes in the ionosphere.
FSK	Frequency shift keying. A form of frequency modulation in which the modulating signal shifts the output frequency between predetermined values.
HF	High frequency. A band of radio frequencies from 3-30 MHz, that is used for world-wide communications.
HLPA	Horizontal log periodic antenna.
IONCAP	Ionospheric communications analysis and prediction. An HF radio propagation program developed by ITS and widely used throughout the Federal Government.
ISB	Independent-sideband. A method of transmission in which the information carried by each sideband is different.
ITS	The Institute for Telecommunication Sciences, an engineering element of NTIA.
LEO	Low earth orbit, as applied to satellites in circular, near-earth orbits (700-900 km height above mean sea level).
LQA	Link quality analysis. A composite score, defined by FED-STD-1045, representing the received SINAD and pseudo-bit error ratio (PBER) of an ALE signal.
LUF	Lowest usable frequency. For sky-wave signals in the MF/HF spectrum, the lowest frequency effective under specified conditions for ionospheric propagation of radio waves between two specified points on a planetary surface.

ACRONYMS AND ABBREVIATIONS (cont.)

MUF	Maximum usable frequency. The highest frequency of radio waves that can be used between two points under specified conditions for reliable transmission by reflection from the regular layers of the ionosphere.
NASU	Naval Antarctic Support Unit, Christchurch, NZ.
NIST	The National Institute of Standards and Technology (formerly the National Bureau of Standards).
NSF	The National Science Foundation.
NTIA	The National Telecommunications and Information Administration. An agency of the U.S. Department of Commerce, responsible for setting telecommunications policy for the U.S. Government.
NUWC	Naval Undersea Warfare Center.
PBER	Pseudo-bit error ratio (see BER). A measure of the BER produced by the Harris RF-7210 ALE modem.
PCA	Polar cap absorption. The result of infrequent but major disturbances of the ionosphere, caused by high-energy solar protons. Guided by the earth's magnetic field, these protons increase the ionization level of the D region causing total absorption of radio signals from HF into the VHF spectrum. PCAs may last for several days.
PM	Preventive maintenance. Tests, measurement, replacements, adjustments, repairs and similar activities, carried out with the intention of preventing faults or malfunctions from occurring during subsequent operation. Preventive maintenance is designed to keep equipment and programs in proper operating condition and is performed on a scheduled basis.
PSK	Phase-shift keying. A method of modulation used for digital transmission wherein the phase of the carrier is discretely varied in relation to a reference phase, or the phase of the previous signal element, in accordance with the data to be transmitted.
RATT	See RTTY.
RF	Radio frequency. Those frequencies of the electromagnetic spectrum normally associated with radio wave propagation.

ACRONYMS AND ABBREVIATIONS (cont.)

RLPA	Rotatable Log Periodic Antenna.
RTTY	Radio teletypewriter. A teletypewriter employed in a communication system using radio circuits. Note: Such systems are spoken of as RATT systems.
SATCOM	Satellite communications.
SID	Sudden ionospheric disturbance. Abnormally high ionization densities in the D region caused by an occasional sudden outburst of ultraviolet light on the Sun (solar flare). This results in a sudden increase in radio-wave absorption, which is most severe in the upper MF and lower HF frequencies.
SINAD	An acronym for "signal plus noise plus distortion to noise plus distortion ratio" expressed in decibels (dB), where the "signal plus noise plus distortion" is the audio power recovered from a modulated radio frequency carrier, and the "noise plus distortion" is the residual audio power present after the audio signal is removed. This ratio is a measure of audio output signal quality for a given receiver audio power output level.
SITOR	Simplex telex over radio. A form of radio teletype protocol used in the Maritime Mobile Service, that incorporates error detection and automatic repeat request in a selective calling mode or forward error correction in a broadcast mode.
SNR	Signal-to-noise ratio. The ratio of the amplitude of the desired signal to the amplitude of noise signals at a given point in time. Usually expressed in decibels, and in terms of peak values for impulse noise and root-mean-square values for random noise. Both the signal and noise should be defined to avoid ambiguity; e.g., peak-signal to peak-noise ratio.
SOP	Standing (or Standard) operating procedures.
SSN	Sunspot number. A physical count of the number of sunspots on the solar disk. This number has been shown to be correlated with ionospheric behavior. A daily or monthly average count may be obtained from the Space Environment Service Center (SESC), Boulder, CO, or from other sources around the world.
VHF	Very high frequency. Frequencies from 30 to 300 MHz.
Z	Zulu Time. Synonym for Coordinated Universal Time (UTC, Z Time). Formerly a synonym for Greenwich Mean Time

AN INVESTIGATION OF FEDERAL STANDARD 1045 HIGH-FREQUENCY ALE RADIO PERFORMANCE IN THE SOUTHERN TRANS-AURORAL ZONE

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This report presents the results of two weeks of bi-directional high-frequency radio path soundings in a trans-auroral environment between Christchurch, New Zealand, and the U.S. station, McMurdo (Black Island), Antarctica, during mid-January, 1992. The work was commissioned by the Naval Undersea Warfare Center, New London, CT, for the National Science Foundation. This investigation demonstrated the value of ALE adaptive radio systems as a real-time frequency management tool. Based on the results observed, the authors recommended that NSF consider the acquisition of a 1-kW ALE radio system to be used, primarily as an oblique ionospheric channel sounder, with their existing communications system. This addition would provide significant improvement to the NSF frequency management capability.

Key words: adaptive radio; ALE; Antarctica; automatic link establishment; communications; frequency management; high frequency; high latitude; radio

1. INTRODUCTION

1.1 Background

High-frequency (HF) radio circuits are a primary means of communications for the National Science Foundation (NSF) between their base at McMurdo Station, Antarctica, and the communications gateway in Christchurch, New Zealand. These HF links provide both voice and data circuits to and from the scientific and support personnel stationed in Antarctica. The day-to-day operation of these communications circuits is handled by the U.S. Navy [U.S. Naval Antarctic Support Unit (NASU), Christchurch, New Zealand, and the U.S. Naval Support Force Antarctica, McMurdo Station, Antarctica].

Despite the importance of these HF radio circuits, much of the electronic equipment is antiquated, dating to the late 60's or early 70's. In addition to the mechanical failures due to the age of the equipment, the radio circuits are affected by the harsh radio propagation environment

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of the high (those latitudes above 60° N or below 60° S) and trans-auroral (communications between points inside and outside the auroral oval) latitudes. Near the Polar regions, HF communications links are subject to both temporary blackouts due to Sudden Ionospheric Disturbances (SID) and magnetic storms, and longer blackouts lasting several days due to Polar Cap Absorption (PCA) events.

Satellite elevation angles are very low at these high latitudes. McMurdo Station currently is operating one voice frequency channel to support the transmission of bulk data collected by scientific teams. Satellite service to the camps and stations nearer to the South Pole can only be provided by satellites in low earth orbit (LEO) with short time durations of visibility. At present this option is not available.

1.2 Plan of Assessment

During the fall of 1991, the Naval Undersea Warfare Center (NUWC) contacted ITS to secure assistance in helping the NSF to study and recommend improvements to the reliability of their HF radio communications. It was thought that the use of the emerging adaptive HF technologies might provide better reliabilities over these difficult circuits. Because of ITS' extensive experience in developing Federal Standards for adaptive HF radio systems and experience in the testing of these equipments, ITS was asked to participate in a test of the new FED-STD-1045 (GSA, 1990) Automatic Link Establishment (ALE) adaptive radio equipment on a circuit between New Zealand and Antarctica. The test was designed to demonstrate the utility of ALE systems in the difficult high-latitude trans-auroral environment.

As the tasking from NUWC to ITS requested recommendations for improving HF communications between McMurdo Station, Antarctica, and Christchurch, New Zealand, a site survey of both the transmitter and receiver sites at Christchurch, New Zealand, was required. During the over-the-air portion of the experiment, a careful review of the U.S. Navy's operational and blackout Standard Operating Procedures (SOP) was made. All McMurdo operations were conducted from the new (partially complete--receive site planned to be separated from the transmit site at McMurdo) receiver site on Black Island, some 20 miles south of McMurdo Station (and the main radio site).

1.2.1 Christchurch, NZ, Site Surveys

A limited site survey of the U.S. Navy's Antarctic support communications facilities at Christchurch, New Zealand was completed, and site plots were obtained from files at the Christchurch communications facility.

The U.S. Navy communicators, following accepted practice for high-powered HF communications systems, operated a split communications site, locating the receivers and their antennas to the northwest of the city of Christchurch, near the international airport, and the transmitters and their antennas at the Royal Air Force Base at Weedons, approximately 7.5 miles to the southwest.

The site surveys included review of the receiver and transmitter sites, their associated antenna fields, and the operations of the communications center including the repair and maintenance shop.

1.2.2 McMurdo Station, Antarctica, Site Survey

An on-site survey of the McMurdo Station communications station was not possible. The McMurdo Sound end of the radio link for this investigation was placed at the new Black Island receiver site facilities (not yet operational). The present McMurdo transmitter and receiver sites are located at the McMurdo Station compound some 20 miles north of Black Island. A review of the Christchurch transmit and receive sites provided enough data for a clear picture of the U.S. Antarctic Program HF communications capabilities. Information concerning the McMurdo receive and transmit sites was gathered from the NSF support contractor (Antarctic Support Associates) but not verified by ITS. Any information concerning communications equipment, antennas, and operating procedures, gathered on the New Zealand end of the communications link was assumed to be the same for the McMurdo end.

1.2.3 HF ALE Linking Experiment

The assessment of the ability of an ALE HF adaptive radio system, conforming to FED-STD-1045 (GSA, 1990), to perform in a high-latitude trans-auroral zone environment was central to developing a recommendation to assist the NSF to improve the reliability of its HF radio communications. The automatic, bi-directional sounding capabilities of these ALE radios were used to collect as much data as possible during the period of the test (January 12-24, 1992). These results were compared with the Navy's communications links, operating concurrently with the ALE equipment. A secondary experiment was to test the AMAF Lincompex™ compandors on the voice circuits established by ALE, and subjectively evaluate several different data modems, to include PSK serial tone, AX.25, packet radio, FSK radio teletype (RTTY) and Simplex Telex Over Radio (SITOR). The object was to evaluate the performance of these data modems on the best channel available, as selected by the ALE radio, and on channels with progressively lower link quality analysis (LQA) scores (i.e., 2nd best, 3rd best, etc.).

2. U.S. NAVY SUPPORT FACILITY - NEW ZEALAND COMMUNICATIONS SITE SURVEYS

A survey of the NSF communications sites, daily operations, and blackout procedures provided data, along with information gathered during the ALE experiments, to form the basis for making recommendations to the NSF on ways to improve their New Zealand - Antarctica HF communications reliability.

2.1 Receiver Site - Christchurch, New Zealand

Figure 1 shows the location of the U.S. Navy communications facility near Christchurch, New Zealand, on the South Island. Figure 2 indicates the position of the receiver site located off the west end of the Christchurch International Airport and to the northwest of Christchurch. Figure 3 shows the plan of the receiver site and the locations of the existing receive antennas. During the period of the experiment, NASU used two rhombic antennas for their operations. Conical monopole #2, located to the north of the communications building, was available and used to physically support the sloping Vee antenna used by the investigation team. The final figure in this series, Figure 4, shows a view from the front gate of the receiver site compound and the major buildings at the site. The communications building is on the left, the small building in the center foreground houses the site's emergency generator, and the small building on the right is the calibration laboratory.

The actual survey of the receiver site was conducted during the period of the ALE experiment, and was based on observations of the site personnel and equipment, examinations

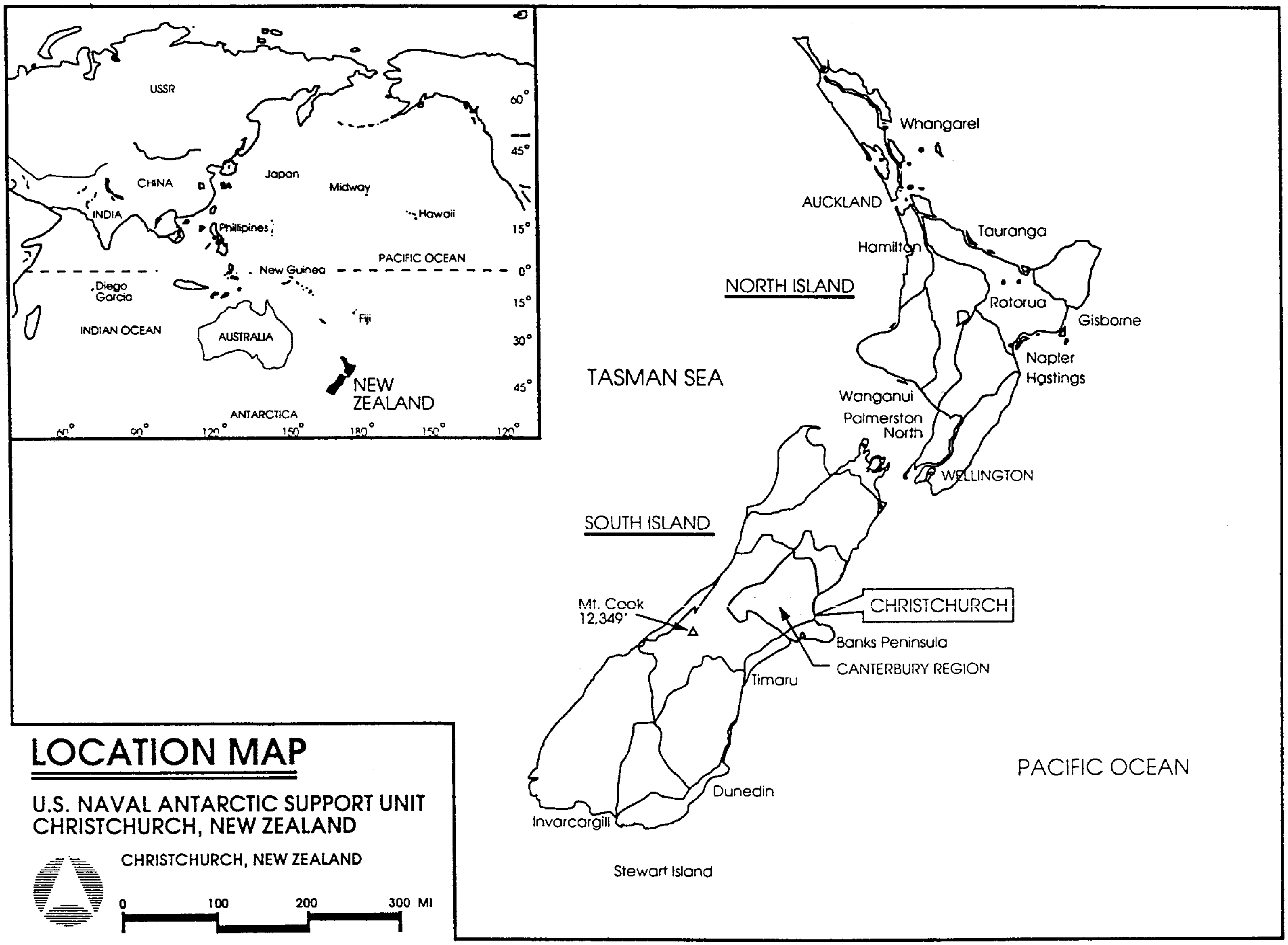


Figure 1. Location map, U.S. Naval Antarctic Support Unit, Christchurch, New Zealand.

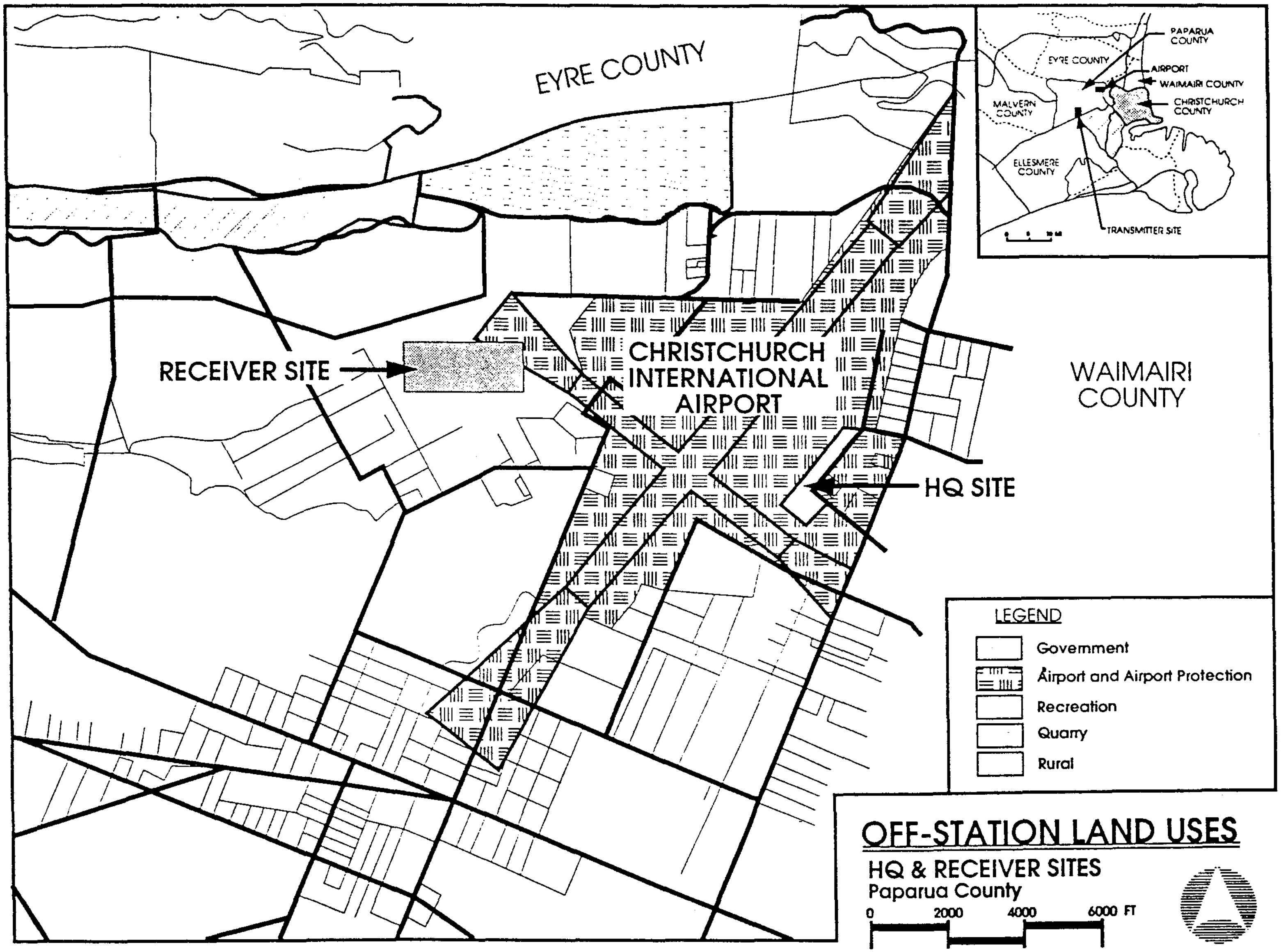
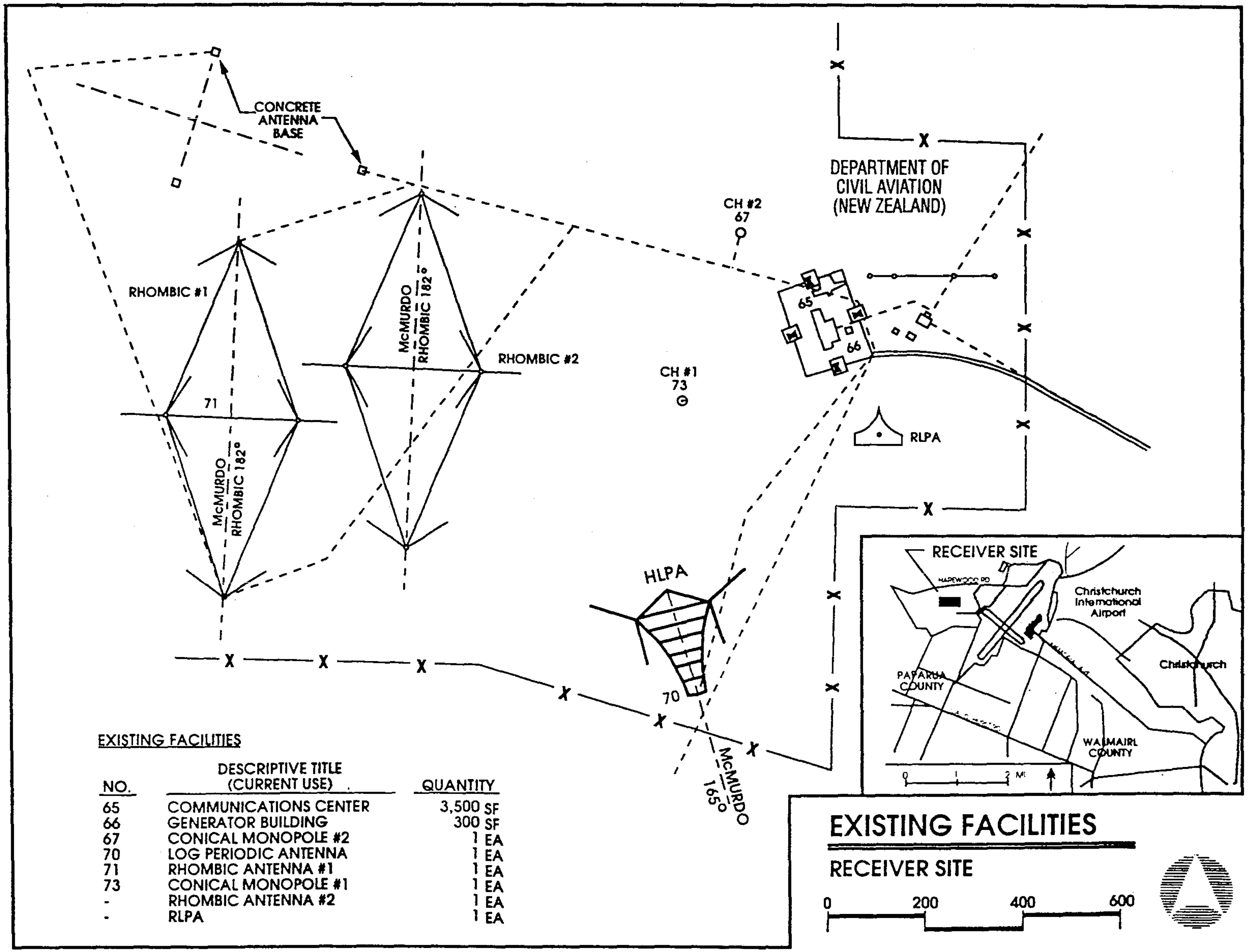


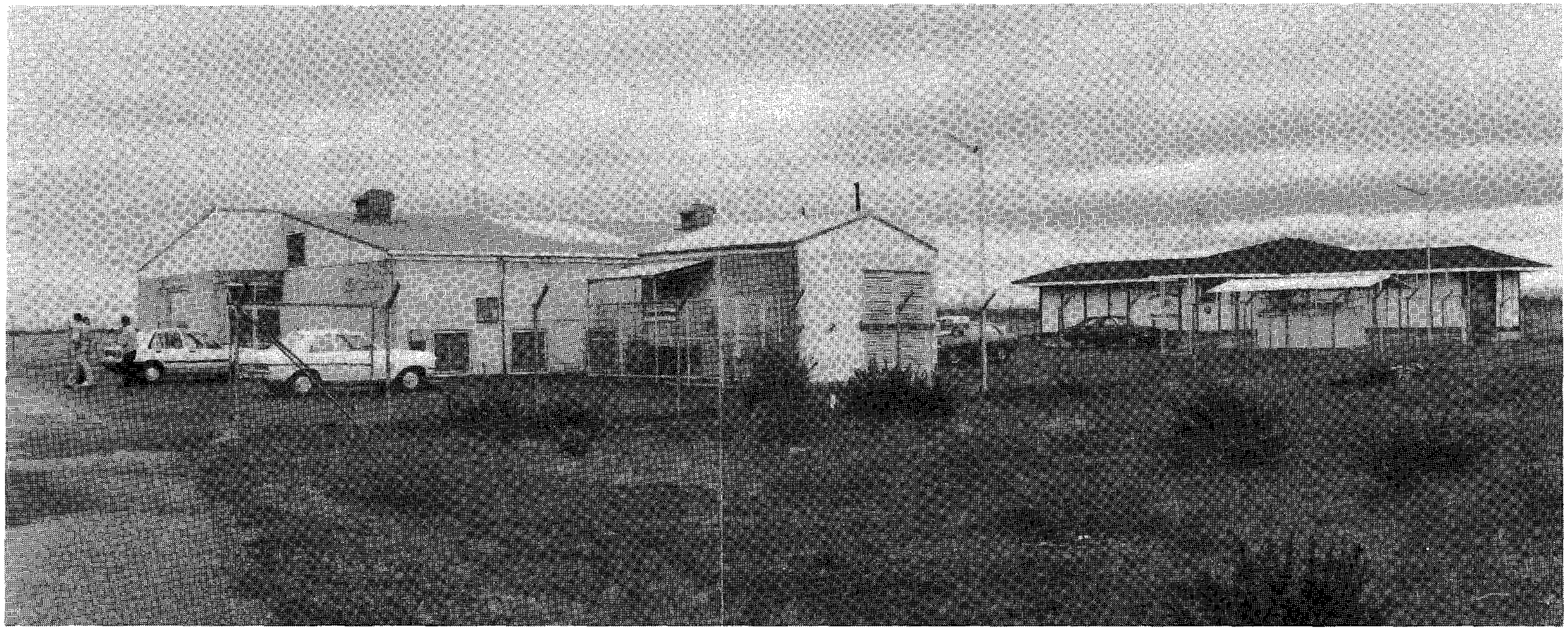
Figure 2. Location map, HQ and receiver sites.



EXISTING FACILITIES

NO.	DESCRIPTIVE TITLE (CURRENT USE)	QUANTITY
65	COMMUNICATIONS CENTER	3,500 SF
66	GENERATOR BUILDING	300 SF
67	CONICAL MONOPOLE #2	1 EA
70	LOG PERIODIC ANTENNA	1 EA
71	RHOMBIC ANTENNA #1	1 EA
73	CONICAL MONOPOLE #1	1 EA
-	RHOMBIC ANTENNA #2	1 EA
-	RLPA	1 EA

Figure 3. Site plan - receiver site.



Receiver Site. Communications Center (left), Calibration Lab (right).

Figure 4. Communications center.

of maintenance records and schedules, reading SOPs, and conversations with various site personnel.

2.1.1 Personnel

The Christchurch Communications detachment is commanded by a U.S. Navy Lieutenant and assisted by a Chief Petty Officer as his senior enlisted advisor. At the time, there were sufficient detachment personnel to adequately staff four duty shifts to provide continuous coverage 24 hours per day (in two duty shifts of 12 hours per shift). The skill mix includes radiomen (operators), electronics technicians (repairmen), and record keepers (repair parts clerks). The rank structure includes rates from E-3 (Seaman 1st class) through E-6 (lead Petty Officer), and appeared adequate in training and experience to carry out the station's mission.

2.1.2 Training

During the period of the ALE experiment (2 weeks) members of the NUWC/NTIA team had the opportunity to observe the daily routine of the site. Operators learned their jobs from the more experienced operators. Proficiency was developed by repetition; on-the-job training. ITS observed no other training program.

2.1.3 Maintenance

The receiver site maintenance program consisted of emergency or on-the-spot repairs (parts permitting) and a preventive maintenance (PM) program. Several electronics technicians varying in grade from novices (E-3) through journeymen (E-6), repair parts clerks, and a New Zealand civilian teletype repairman were on site.

Equipment breakdowns were repaired on-the-spot if possible, or placed on-the-shelf to await parts. The extreme age (20 to 30 years) of the equipment and the low priority of the NASU versus other Navy units made spare parts difficult to obtain. Very few parts were stocked locally. Most had to be ordered from California. Several teletypewriters were on-the-shelf, awaiting parts.

The preventive maintenance program followed standard U.S. Navy procedure. A small percentage of the site's equipment was selected to receive preventive maintenance inspection, calibration, etc. in accordance with the appropriate equipment technical manuals on a periodic basis. Members of the ITS team noted that scheduled PM was not completed for some pieces of equipment.

2.1.4 Operations

The day-to-day HF communications between Christchurch, New Zealand, and McMurdo Station, Antarctica, are conducted on five HF frequencies. Each of these frequencies can be changed as propagation conditions change. They are called US-18 (2 ea) transmitted from McMurdo and US-19 (3 ea) transmitted from Christchurch.

Each 24-hour day is divided into two watches of 12 hours. Two additional watch crews provide for time off and rotation of the shift schedule. Adequate numbers of radiomen and electronics technicians are on each watch to operate and maintain the equipment, and to provide for messenger service between the communications center and the headquarters buildings at the airport.

The daily traffic (based on the December 1991 message count) is approximately 100 messages per day sent to McMurdo and 60 messages per day received from McMurdo. (The message traffic to and from Australia and Hawaii were not included in this study.)

Reaction to temporary communications blackouts due to severe fading or complete loss of signals due to Polar Cap Absorption, or solar particle-induced magnetic storms, is outlined in the site's "blackout procedures for US-18/US-19" (CNSFA OPORD ZYR annex APP VIII TABA). This SOP states that the watch supervisor has the overall responsibility for the restoration of communications. Site personnel must aggressively work to restore communications during blackouts that can last from several hours to several days. The watch supervisor will resort to the blackout SOP when all communications have been lost for a period exceeding 30 minutes. Attempts to coordinate restoration will be made via HF voice, SATCOM, and the Commercial/INMARSAT. If these methods of coordination prove unsuccessful, each station will transmit in the blind, announcing that they are changing to the established blackout frequencies (primary, secondary, and four tertiary frequencies). Each station will remain on the primary and secondary frequencies throughout the blackout period, but will change the tertiary frequencies every 30 minutes (on the hour and half-hour). The SOP specified that, if sufficient receivers are available, the last good frequency used should be monitored throughout the blackout period.

2.1.5 Equipment

The receiving equipment consisted of R-1051 receivers and several Rockwell-Collins MD-2002 high-speed data modems. The R-1051 is a triple-conversion, superheterodyne, independent sideband (ISB) receiver designed for use by the Navy in shipboard or fixed station installations. This receiver design dates to the late 60's or early 70's and is currently in its 7th major revision (R-1051 G/URR, circa 1981). Its seven major operating modes provide reception on voice (AM, USB, and LSB), teletype (RATT) and ISB (voice and RATT). The R-1051 features a built-in preselector for minimum degradation from nearby transmitters operating at frequencies near the receive frequency.

The Rockwell MD-2002 HF data modem is a multimode data modem (singletone, 16 tone, 39 tone PSK, and 2 and 4 tone FSK); it is also capable of serving as a wireline modem. The MD-2002 modem provides data rates between 75 and 2400 bit/s, and employs forward error correction and variable interleaving.

Figure 3 shows the physical layout of the receive site. Rhombic antennas 1 and 2 are the primary receive antennas at the Christchurch site for the signals from McMurdo. These antennas appear to be type RD-3 rhombics, with leg length of 400 feet, height of 130 feet, and tilt angle with the side support of 69 degrees, providing a receive gain of 13.5 to 22.5 dBi in the frequency range from 6 to 26 MHz (USA, 1972).

Several broadband conical monopoles and one rotatable log periodic antenna (RLP) are used, according to site personnel, in a flight-following mode, whenever aircraft are enroute between Christchurch and McMurdo. These antennas were not used for routine traffic.

2.1.6 Receiver Noise Environment

As shown in Figure 2, the Christchurch receiver site is located adjacent to the Christchurch International Airport and near the outskirts of the suburbs of Christchurch, New Zealand. While no electrical noise measurements were made, there were indications that the receiver site was in a high noise environment. The authors estimated that the manmade noise levels were somewhere between residential (-136 dBW/Hz @ 3 MHz) and industrial (-125 dBW/Hz @ 3 MHz). Figure 5 (USA, 1972) shows levels of manmade noise in the HF spectrum. To use this figure to determine noise power, enter the figure along the horizontal axis at the frequency of interest moving vertically until the noise level of interest is reached (rural, industrial, etc.) then move horizontally to the vertical axis and extract the noise power (to compute noise power in terms of dBm, add 30 to the value previously obtained). Table 1 shows estimated hours of circuit availability, and signal-to-noise ratios at low (10) and high (150) sunspot numbers. This table was developed from an analysis using the Advanced Stand Alone Prediction System (ASAPS) propagation prediction program. This IONCAP-like (Ionospheric Communications Analysis and Prediction) program is extremely user friendly, permitting the rapid entry of site variables, and provides output in both tabular as well as graphic formats. It can be seen from the table that the receiver noise environment can greatly affect the circuit availability for the case of sunspot number = 10, an estimate of worst case. The difference in circuit availability between our best estimate for the noise level of the Christchurch receiver site and a residential area is 12.5 percent. If the receiver site were located in a rural area, the improvement in circuit connectivity would be almost 21 percent better.

Tables 2 and 3 show values of atmospheric noise for local summer time, as computed from the most recent CCIR noise model (CCIR, 1988). A comparison of Tables 2 and 3 with Figure 5 shows that manmade noise is the predominate noise source during the day and shortly after dark (10 pm local time). The manmade noise, measured at 3 MHz, in a 2.7-kHz receiver bandwidth is greater than atmospheric noise for the average industrial location and for the estimated value at the Christchurch receiver site. The predominate nighttime noise source is atmospheric, with worst case predicted to be about -98 dBm in a 2.7-kHz bandwidth. (Note: manmade noise and atmospheric noise have equivalent affects on receiver sensitivity degradation. The manmade noise disappears around 10 pm, local time, when the Christchurch Airport shuts down operations for the night).

Table 3 lists the computed values of atmospheric noise for the McMurdo Sound Station, Antarctica. In general, the atmospheric noise is 10 dB lower than in Christchurch. No estimate was made of the manmade noise environment, although operations conducted from the new Black Island site were expected to produce "rural" noise levels.

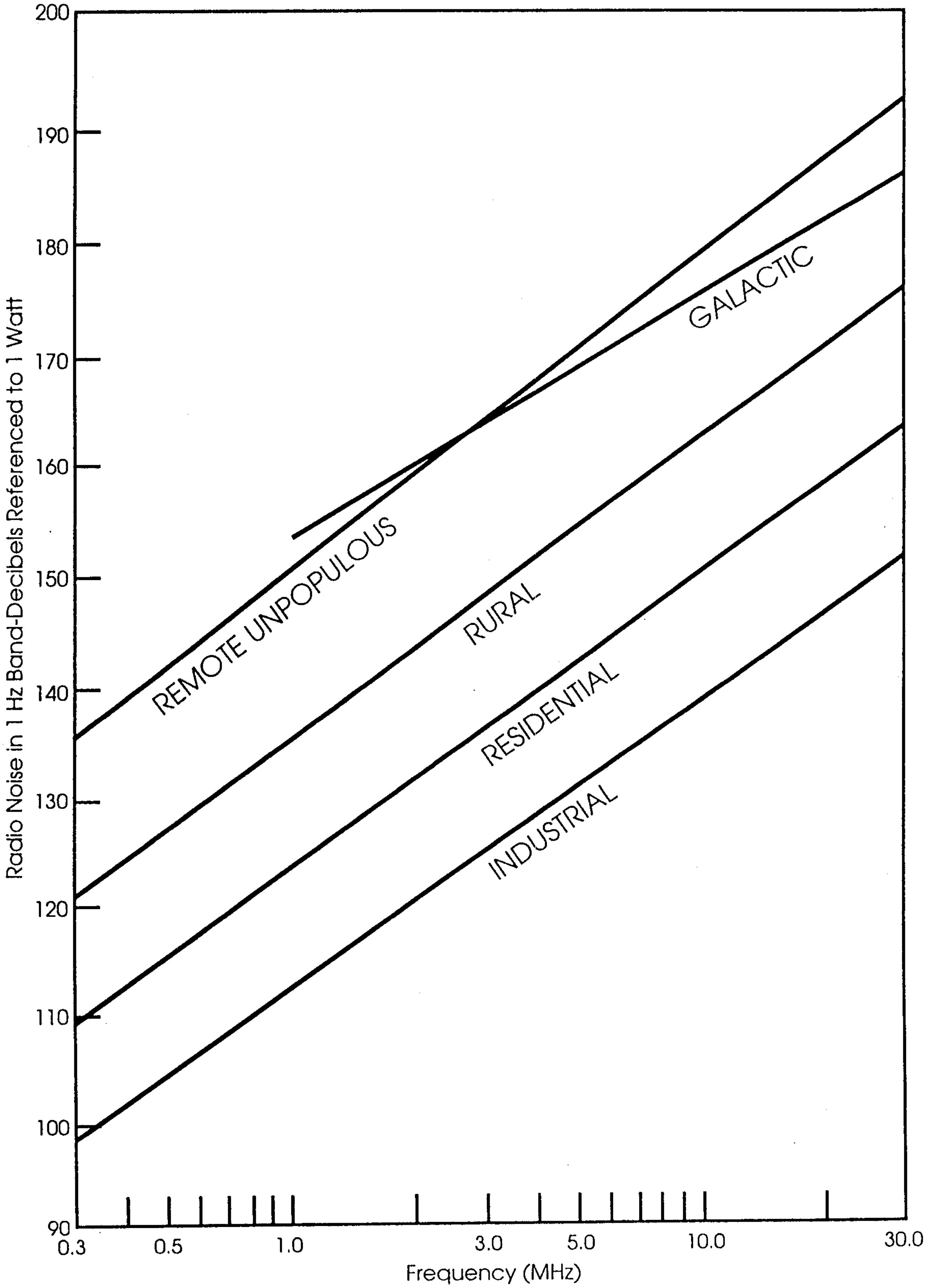


Figure 5. Levels of manmade noise in the HF spectrum (USA, 1972).

Table 1. Predicted Circuit Availability Versus Manmade Noise Levels

<table>
<tr><th colspan="6">McMurdo (T) to Christchurch (R)
Pwr = 4 kW, BW = 3 kHz, Ant = rhombic, S/N req = 13.0 dB</th></tr>
<tr><th colspan="6">SSN = 10</th></tr>
<tr><th></th><th>Daily Coverage</th><th>Rx Noise, dBm/Hz</th><th>dBm (2.7 kHz)</th><th>Noise < Sig, dB</th><th>Avg S/N @ FOT</th></tr>
<tr><td>Rural</td><td>23 hrs</td><td>-148</td><td>-113.7</td><td>-34.2</td><td>37.2</td></tr>
<tr><td>Residential</td><td>21 hrs</td><td>-136</td><td>-101.7</td><td>-23.3</td><td>26.9</td></tr>
<tr><td>Receiver Site</td><td>18 hrs</td><td>-130</td><td>-95.7</td><td>-17.5</td><td>21.7</td></tr>
<tr><td>Industrial</td><td>11 hrs</td><td>-125</td><td>-90.7</td><td>-12.5</td><td>17.0</td></tr>
<tr><th colspan="6">SSN = 150</th></tr>
<tr><th></th><th>Daily Coverage</th><th>Rx Noise, dBm/Hz</th><th>dBm (2.7 kHz)</th><th>Noise < Sig, dB</th><th>Avg S/N @ FOT</th></tr>
<tr><td>Rural</td><td>23 hrs</td><td>-148</td><td>-113.7</td><td>-31.7</td><td>45.0</td></tr>
<tr><td>Residential</td><td>23 hrs</td><td>-136</td><td>-101.7</td><td>-23.5</td><td>29.3</td></tr>
<tr><td>Receiver Site</td><td>22 hrs</td><td>-130</td><td>-95.7</td><td>-18.0</td><td>24.2</td></tr>
<tr><td>Industrial</td><td>15 hrs</td><td>-125</td><td>-90.7</td><td>-13.6</td><td>21.4</td></tr>
</table>

Table 2. Atmospheric Noise, Christchurch, New Zealand, Summer

Time (local)	dB > KT_0B (1 MHz)	dB > KT_0B (10 MHz)	dBm (1 Hz)	dBm (2.7 kHz)
0-4	72.5	45	-129	-94.7
4-8	53	50	-134	-99.7
8-12	55	28	-146	-111.7
12-16	40	30	-144	-111.7
16-20	68	44	-130	-95.7
20-24	72	42	-132	-97.7

From CCIR Rpt. 322-3, 1988.

Table 3. Atmospheric Noise, McMurdo Station, Antarctica, Summer

Time (local)	dB > KT_0B (1 MHz)	dB > KT_0B (10 MHz)	dBm (1 Hz)	dBm (2.7 kHz)
0-4	32	25	-149	-114.7
4-8	18	30	-144	-109.7
8-12	17	25	-149	-114.7
12-16	13	25	-149	-114.7
16-20	28	35	-139	-104.7
20-24	33	30	-144	-109.7

From CCIR Rpt. 322-3, 1988.

If the assumption that the Christchurch receiver site is located in a high manmade noise environment is valid, then the relocation of the receiver site to a quieter area would improve the number of hours of daily connectivity. The ASAPS analysis, resulting in Table 1, shows that a relocation to an area of "rural" levels of manmade radio noise could result in several more hours of connectivity each day.

2.2 Transmitter Site - Weedons, New Zealand

The transmitter site supporting the Naval Antarctic Support Unit is located on the Royal New Zealand Air Force Base, at Weedons, New Zealand, approximately 7.5 air miles from the receiver site. Figure 6 shows the location of the site, with respect to Christchurch. Figure 7 is a plan of the transmitter site, indicating the locations of the various site antennas. Figure 8 shows various views of the transmitter building and site.

2.2.1 Transmit Antennas

The main transmitting antennas at the Weedons site are rhombics. From the information gained during site personnel interviews and from study of the site plan, the rhombics appear to be of RD-3 design. Table 4 presents calculated gains of these antennas across their useable frequency range. The rhombic antenna develops the highest gain possible and represents the best choice for both a broadband transmit and receive antenna on this circuit path. The gain figures presented for the transmit rhombic are listed for take-off angles of 4 and 18 degrees. These angles are averages of the take-off angles required for one-hop F and two-hop F propagation modes. The rhombic antennas at the new McMurdo receive site (Black Island) appear to be of the F type from the data supplied by Antarctic Support Associates (ASA) personnel. Table 5 presents the calculated gains of this type of antenna (USA, 1972).

2.2.2 Transmitting Equipment

The site visit to the transmitter building revealed the transmitting equipment to be AN/FRT-77 type equipment of a late 1960's or early 1970's vintage. While nominally rated at 10 kW, site personnel stated that the transmitters were normally loaded to about 4 kW to preserve the life of the equipment (a loss of 4 dB in power capability). Computer modeling of this

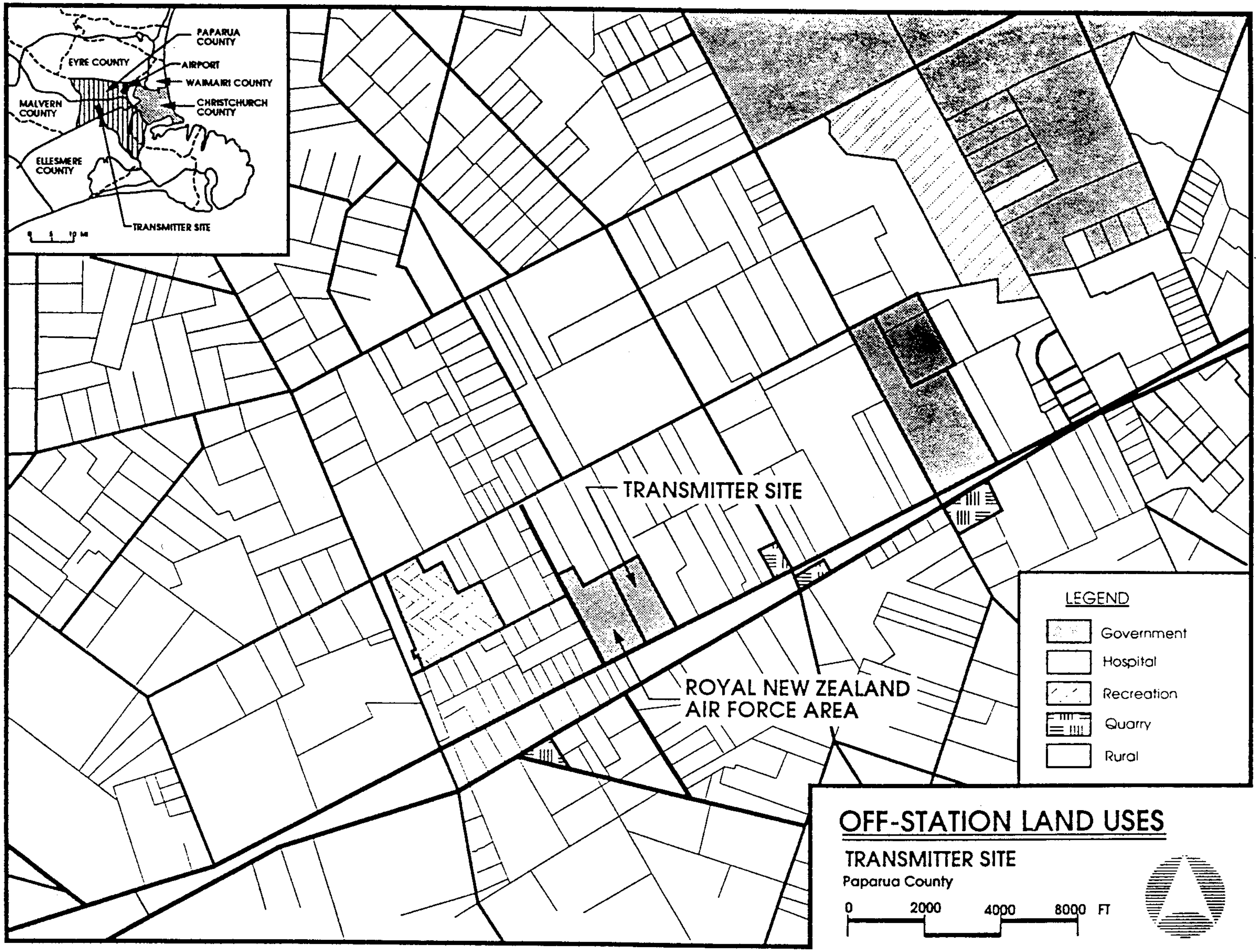


Figure 6. Location map - transmitter site.

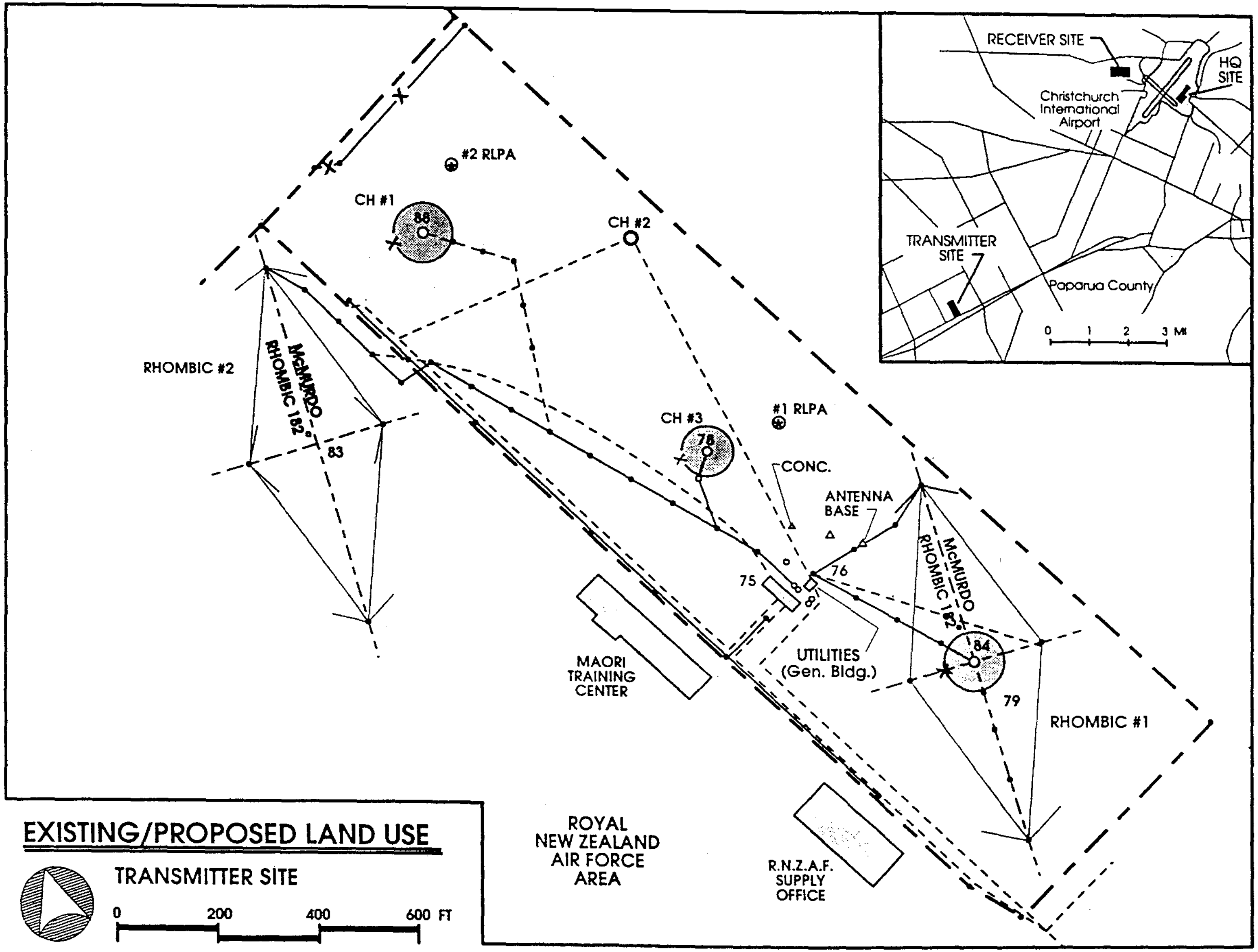
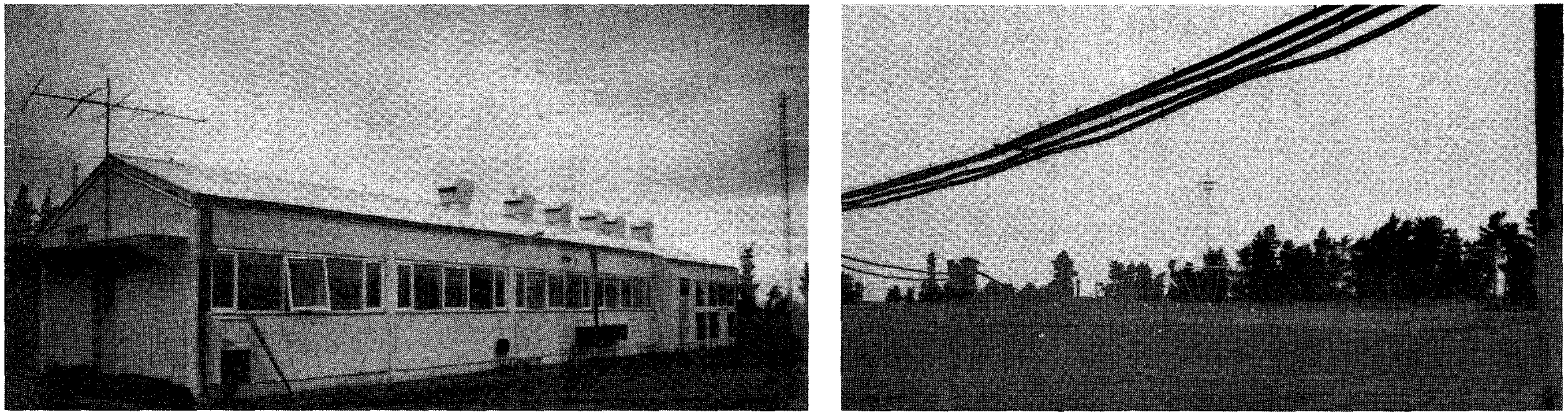
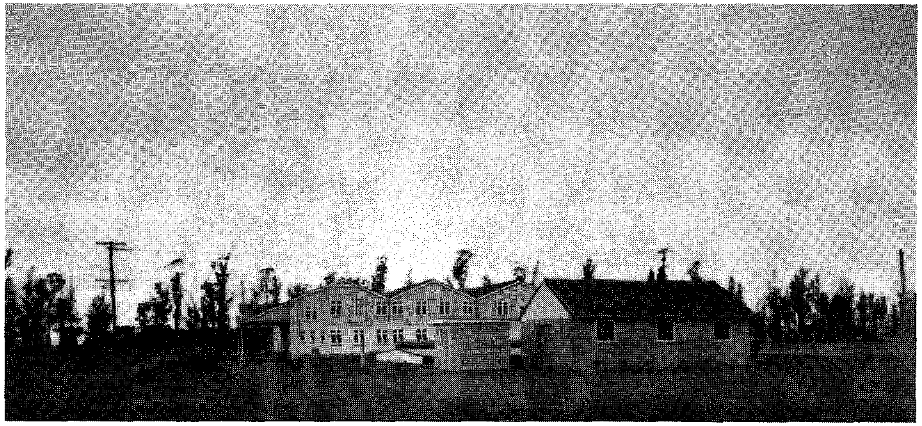


Figure 7. Site plan - transmitter site.



Transmitter - Building 75

Transmitter Antenna - Conical Monopole



Transmitter Site - RNZAF Area

Figure 8. Views of the transmitter site.

Table 4. Type RD-3 Rhombic Antenna Gain Versus Frequency (USA, 1972)

Frequency, MHz	Gain, dBi		Frequency, MHz	Gain, dBi	
	Δ = 4°	Δ = 18°		Δ = 4°	Δ = 18°
2	-10.0	-8.4	18	22.1	7.2
4	-7.3	6.8	20	22.3	-5.3
6	2.5	13.5	22	21.9	-10.0
8	9.0	15.4	24	20.6	-10.0
10	13.8	12.4	26	18.5	0.3
12	17.2	2.3	28	15.4	11.5
14	19.6	10.2	30	10.7	16.4
16	21.3	11.7			

Antenna Dimensions: Length = 400 ft., Height = 130 ft., Tilt Angle (ϕ) = 69°.

Table 5. Type F Rhombic Antenna Gain Versus Frequency (USA, 1972)

Frequency, MHz	Gain, dBi		Frequency, MHz	Gain, dBi	
	$\Delta = 4°$	$\Delta = 18°$		$\Delta = 4°$	$\Delta = 18°$
2	-10.0	-10.0	18	13.2	13.4
4	-10.0	-2.0	20	13.6	8.7
6	-6.7	6.6	22	13.3	0.9
8	-0.3	11.9	24	12.2	-10.0
10	4.4	15.2	26	10.3	-10.0
12	7.9	16.9	28	7.2	-10.0
14	10.4	17.2	30	2.2	-8.4
16	12.2	16.1			

Antenna Dimensions: Length = 258 ft., Height = 80 ft., Tilt Angle (ϕ) = 67°.

communications circuit using the ASAPS program indicated there are situations requiring the full 10 kW to maintain the link. There are also times when even 10 kW will not be enough to establish and maintain the link. This subject is covered in more detail later in this report.

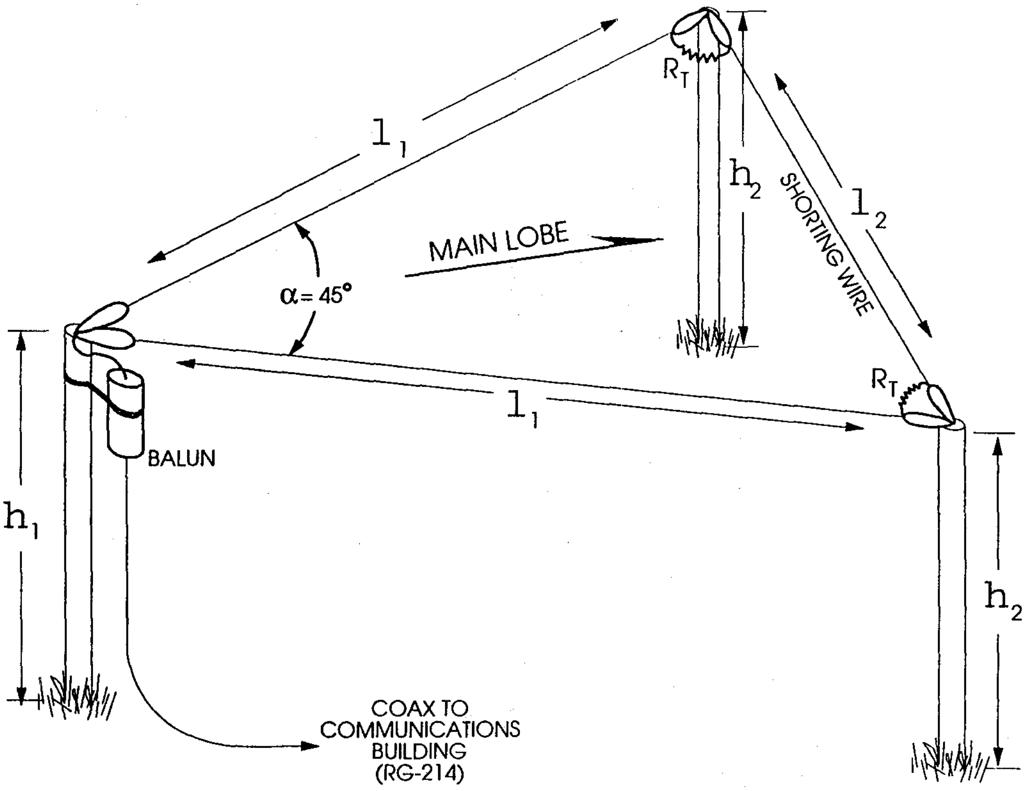
3. FEDERAL STANDARD 1045 AUTOMATIC LINK ESTABLISHMENT (ALE) CIRCUIT PERFORMANCE

Naval Undersea Warfare Center personnel arrived at the Christchurch receiver site on January 6, 1992, and began the process of retrieving and unpacking their equipment, previously shipped to New Zealand in preparation for testing and check-out. An ITS representative arrived in Christchurch on the afternoon of January 7, 1992, and joined the NUWC personnel on January 8, 1992. A large shipping container that contained the a NUWC-designed sloping Vee antenna had not arrived. This box was finally delivered during the afternoon of the 8th. The construction of the sloping Vee receiving and transmitting antenna began on the 9th of January. Figure 9 and Table 6 show the dimensions, parameters, and gains of the sloping Vee antenna used during the ALE experiments. During the pre-visit coordination ITS learned that both of the receiver-site rhombic antennas were in constant use and would not be available for use by the test team. The sloping Vee antenna was then selected and constructed because it provided the highest gain and directivity coupled with ease of on-site assembly and installation.

The antenna was constructed from materials shipped from the United States. The 55-foot mast used to raise the apex/feed point was strengthened by lashing it to the center support of an unused conical monopole (#2). Figure 3 shows the location of conical monopole #2.

January 10, 1992, was spent reviewing the programming procedures for both of the Harris ALE radios, and practice on each piece of auxiliary test or measurement equipment and software packages to be used during the investigation. Table 7 lists the equipment and software used during the tests. Figure 10 shows the physical and electrical HF link parameters for the Christchurch, New Zealand, to Black Island, Antarctica, radio link.

Personnel programmed the Harris RF-350/RF-7210 ALE radio system with the 10 HF frequencies authorized for the tests. Table 8 lists the ALE test frequencies assigned to the Navy frequency manager for use during the tests. The ALE identifiers (call signs) used were CHC for the Christchurch station and BLI (NBLI was also used) for Black Island. Christchurch began



Design Parameters

$h_1 = 55$ ft.
$h_2 = 20$ ft.
$l_1 = 250$ ft.
$l_2 = 191$ ft.
$R_T = 300\ \Omega$, 50W
BALUN 12:1

Figure 9. Christchurch ALE sloping Vee transmit antenna.

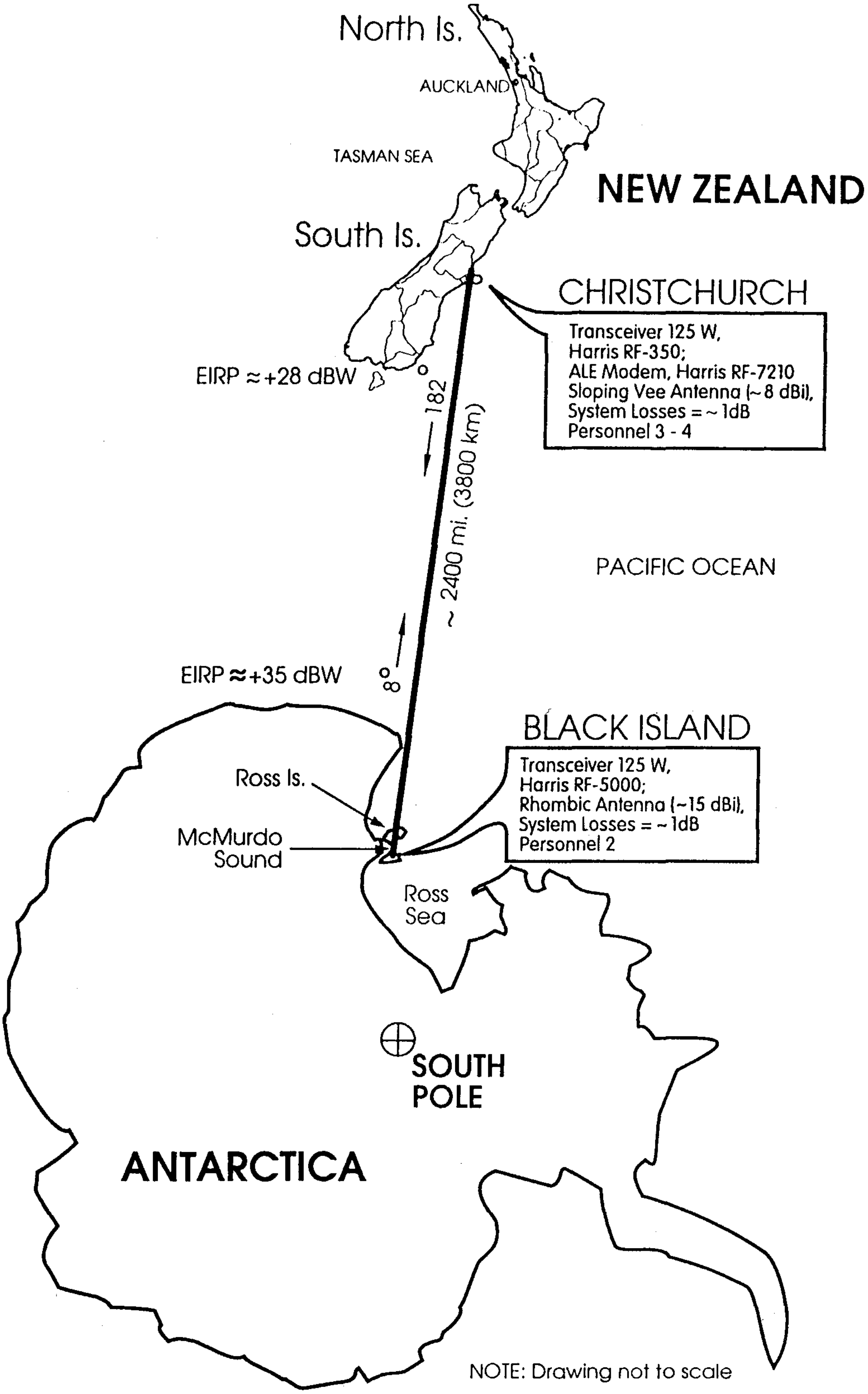
Table 6. Gain of Sloping Vee ALE Transmit/Receive Antenna (USA, 1972)

Frequency, MHz	Gain, dBi		Frequency, MHz	Gain, dBi	
	Δ = 4°	Δ = 18°		Δ = 4°	Δ = 18°
6	-9.2	1.6	18	3.6	4.1
8	-5.3	4.5	20	4.2	1.9
10	-2.4	6.2	22	4.5	0.9
12	0.2	7.0	24	4.5	1.6
14	1.4	6.9	26	4.5	2.4
16	2.7	5.9	28	4.5	2.1
			30	4.6	0.6

Length = 400 ft., Height = 6 ft., Apex Angle = 45°, Feed Height = 50 ft.

Table 7. High-Latitude ALE Test Equipment List

Christchurch Receiver Site, Christchurch, New Zealand		
		Owner
1 ea Harris RF-350 HF Transceiver, 125 W		(ITS)
1 ea Harris RF-7210 ALE modem		(ITS)
1 ea AEA PK-232 Multimode HF data modem		(ITS)
1 ea Frederick Model 1102 high-speed PSK data modem		(NUWC)
1 ea Compaq portable computer (80386)		(NUWC)
1 ea NUWC-fabricated sloping Vee antenna		(NUWC)
1 ea AMAF Lincompex Model 1100 voice compandor		(NUWC)
Black Island Receiver Site, McMurdo, Antarctica		
1 ea Harris RF-5000 HF transceiver, 125 W		(NUWC)
1 ea AEA PK-232 Multimode HF data modem		(ITS)
1 ea Frederick Model 1102 high-speed PSK data modem		(NUWC)
1 ea Toshiba T1000SE laptop computer		(NUWC)
1 ea Type F rhombic antenna		(NSFA)
1 ea AMAF Lincompex Model 1100 voice compandor		(NUWC)
Computer Software		
DOS 3.3	Operating System	(NUWC)
WordPerfect 5.1®	Word Processing	(NUWC)
Procomm Plus®	Communications	(NUWC)
AEASOFT™	Terminal/comm for PK-232	(ITS)



NOTE: Drawing not to scale

Figure 10. HF ALE communication link parameters.

sounding on the hour at 1200 (local) and at 15-minute intervals. The Christchurch staff did not known when the McMurdo station would become operational, but hoped that a link would be established as soon as that station was placed on the air. The first link was initiated from McMurdo and not Christchurch as planned. Due to a programming error in the RF-5000 radio at the McMurdo site, a Christchurch-initiated link was not possible. After some time on the air and not establishing contact with Christchurch, the NUSC engineer initiated a link from Antarctica that was immediately successful. After some discussion of the possible problem, the Black Island radio was reprogrammed. After reprogramming, it was possible to initiate links from either station. The test plan called for the Christchurch station to initiate links with the McMurdo station with the Link Quality Analysis (LQA) feature enabled. The information recorded with each sounding was the date and time of the sound, the channel number and operating frequency of the sound, the call sign or ALE address of the called station, and, if the link was successful, the signal-plus-noise-plus-distortion to noise-plus-distortion ratio (SINAD) and a pseudo-bit error ratio (PBER). Table 9 shows a sample of this data.

Table 8. Assigned ALE Test Frequencies, MHz

Primary	Alt 1	Alt 2
1. 6.767		
2. 7.730		
3. 9.110	9.215	
4. 11.508		
5. 13.490		
6. 16.065	15.899	14.777
7. 18.610		
8. 20.439		
9. 22.950		
10. 25.110		

All LQA scores were recorded with frequency and date-time data, by the Christchurch ALE radio. The Black Island radio, designed as a tactical-vehicular radio set, was not able to

Table 9. Sample ALE LQA Received Data

LQA Data from Harris Radio Soundings at a:logchc

Sound	Date	Time -13 hrs	From	Ch	Freq MHz	SINAD		PBER		Score
						Rcv	Mea	Rcvd	Measrd	
1	92-015	04:36:06	101/NBLI	10						
2	92-015	04:36:23	101/NBLI	09						
3	92-015	04:36:40	101/NBLI	08						
4	92-015	04:37:00	101/NBLI	07	18.610000	16	16	0.0000	0.0000	078
5	92-015	04:37:19	101/NBLI	06	15.899000	17	16	0.0000	0.0000	079
6	92-015	04:37:37	101/NBLI	05						
7	92-015	04:37:56	101/NBLI	04	11.508000	17	16	0.0000	0.0000	079
8	92-015	04:38:16	101/NBLI	03	09.215000	12	12	0.0141	0.0000	065
9	92-015	04:38:33	101/NBLI	02						
10	92-015	04:38:51	101/NBLI	01						
11	92-015	04:41:34	101/NBLI	06	15.899000	17	15	0.0070	0.0000	077
12	92-015	04:54:40	101/NBLI	10						
13	92-015	04:55:15	101/NBLI	09						
14	92-015	04:55:35	101/NBLI	08	20.439000	14	15	0.0000	0.0000	073
15	92-015	04:55:54	101/NBLI	07	18.610000	16	15	0.0070	0.0000	076
16	92-015	04:56:14	101/NBLI	06	15.899000	17	15	0.0000	0.0000	078
17	92-015	04:56:31	101/NBLI	05						
18	92-015	04:56:51	101/NBLI	04	11.508000	16	16	0.0070	0.0000	077
19	92-015	04:57:10	101/NBLI	03	09.215000	12	10	0.0141	0.0286	060
20	92-015	04:57:28	101/NBLI	02						
21	92-015	04:57:45	101/NBLI	01						
22	92-015	05:00:00	101/NBLI	10						
23	92-015	05:00:35	101/NBLI	09						
24	92-015	05:00:52	101/NBLI	08						
25	92-015	05:01:12	101/NBLI	07	18.610000	17	16	0.0000	0.0000	079
26	92-015	05:01:32	101/NBLI	06	15.899000	17	16	0.0000	0.0000	079
27	92-015	05:01:49	101/NBLI	05						
28	92-015	05:02:09	101/NBLI	04	11.508000	16	16	0.0070	0.0000	077
29	92-015	05:02:29	101/NBLI	03	09.215000	13	12	0.0070	0.0070	066
30	92-015	05:02:46	101/NBLI	02						
31	92-015	05:03:03	101/NBLI	01						
32	92-015	05:05:33	101/NBLI	07	18.610000	16	16	0.0000	0.0000	078
33	92-015	05:07:19	101/NBLI	04						
34	92-015	05:10:26	101/NBLI	04						
35	92-015	05:12:15	101/NBLI	06	15.899000	18	16	0.0070	0.0000	080
36	92-015	05:22:53	101/NBLI	07	18.610000	17	16	0.0000	0.0000	079
37	92-015	05:30:00	101/NBLI	10						
38	92-015	05:30:35	101/NBLI	09						
39	92-015	05:30:54	101/NBLI	08	20.439000	13	14	0.0070	0.0070	069
40	92-015	05:31:14	101/NBLI	07	18.610000	16	16	0.0000	0.0000	078
41	92-015	05:31:34	101/NBLI	06	15.899000	16	15	0.0070	0.0213	074
42	92-015	05:31:51	101/NBLI	05						
43	92-015	05:32:10	101/NBLI	04	11.508000	18	16	0.0000	0.0000	081
44	92-015	05:32:30	101/NBLI	03	09.215000	15	13	0.0070	0.0000	071
45	92-015	05:32:48	101/NBLI	02						
46	92-015	05:33:05	101/NBLI	01						
47	92-015	05:35:00	101/NBLI	10						
48	92-015	05:35:35	101/NBLI	09						
49	92-015	05:35:52	101/NBLI	08						
50	92-015	05:36:09	101/NBLI	07						
51	92-015	05:36:29	101/NBLI	06	15.899000	15	15	0.0000	0.0000	075
52	92-015	05:36:46	101/NBLI	05						
53	92-015	05:37:06	101/NBLI	04	11.508000	18	15	0.0000	0.0000	079
54	92-015	05:37:25	101/NBLI	03	09.215000	15	14	0.0070	0.0070	072
55	92-015	05:37:40	101/NBLI	02						
56	92-015	05:37:57	101/NBLI	01						
57	92-015	05:40:00	101/NBLI	10						
58	92-015	05:40:35	101/NBLI	09						

record or display LQA scores. However, the Black Island radio was able to exchange LQA scores with the Christchurch site using the bi-directional LQA exchange protocol built into FED-STD-1045. Each time the Christchurch radio conducted a ten-channel sounding, the test computer recorded the LQA scores computed from the received Black Island signal, and the LQA scores computed from the Black Island signal received from the Christchurch station and sent back to the Christchurch station. The scores for both ends of the link were recorded on a portable computer connected to the data logger port of the ALE radio's ALE modem (RF-7210 as shown in Figure 11).

3.1 Computer-Predicted Daily Maximum and Minimum Working Frequencies

During the planning stage of this experiment, several well-known computer propagation prediction models were used to predict the performance of the ALE linking experiments and to assist in the application for test frequencies from both the New Zealand military and the U.S. Navy. Table 10 presents a list of the models used and their sources. Except for ICEPAC (developed by ITS and derived from the older IONCAP prediction model) all of these models were developed based on mid-latitude data. The ICEPAC model that was designed specifically for high latitudes was not based on measured data, nor has it ever been checked against any measured data. Figure 12 is a comparison of predictions from the various computer models. The majority of these models are derived from either the MINIMUF 3.5 model (Navy/NOSC) or the IONCAP model (ITS). The usefulness of these models at high latitudes may be judged from an inspection of Figures 13 and 14. In any event, these models provided a "best estimate" of what range of frequencies to request for the tests (3-30 MHz).

The actual sunspot numbers and geomagnetic and particle data, as recorded by NOAA's Space Environment Service Center, Boulder, Colorado, are presented in Appendix A. Evaluation of this data indicates that during the period of the test the sunspot numbers and 10.7-cm solar flux were at relatively high levels and the planetary A and K indexes remained low, indicating the geomagnetic conditions were "quiet," thus there were no magnetic storms to interfere with communications. All conclusions were drawn from the data which was collected during testing that was done under very favorable conditions.

Table 10. List of Computer Prediction Models

	VERSION	SOURCE
IONCAP	PC 26	NTIA/ITS
ICEPAC	IC.11	NTIA/ITS
Bandaid		amateur shareware
MINIMUF	3.5	US Navy NOSC
MINIPROP	2.2	amateur shareware
ASAPS	2.0	Australian IPS and Space Services

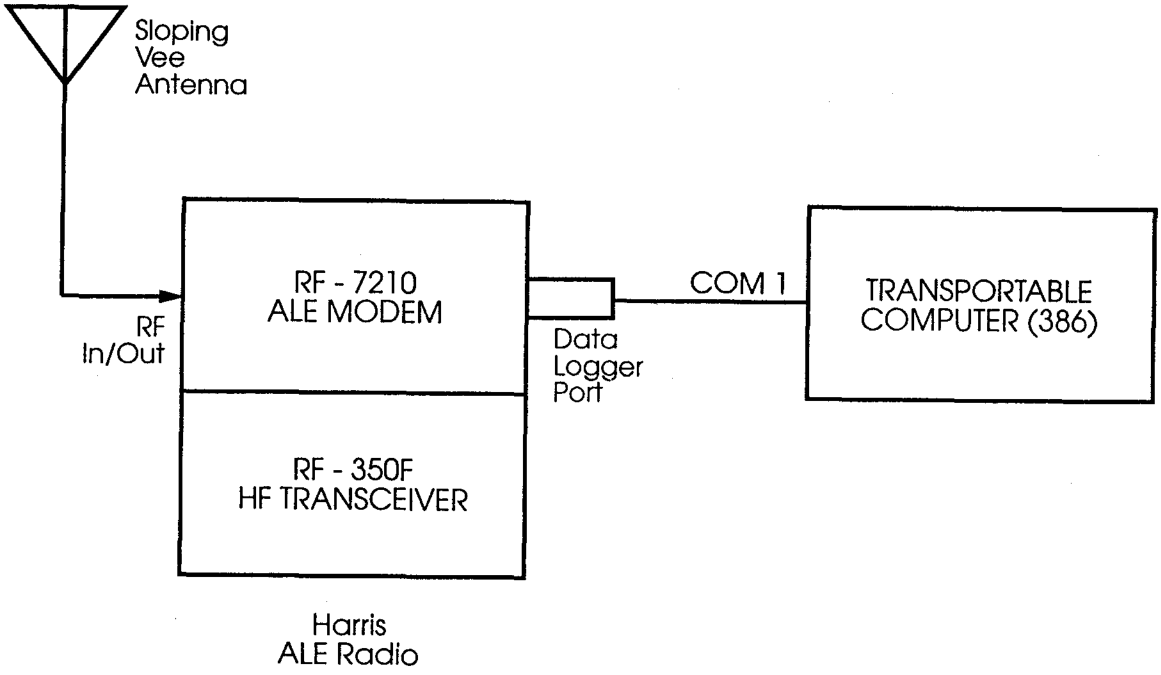


Figure 11. LQA data collection equipment interconnections.

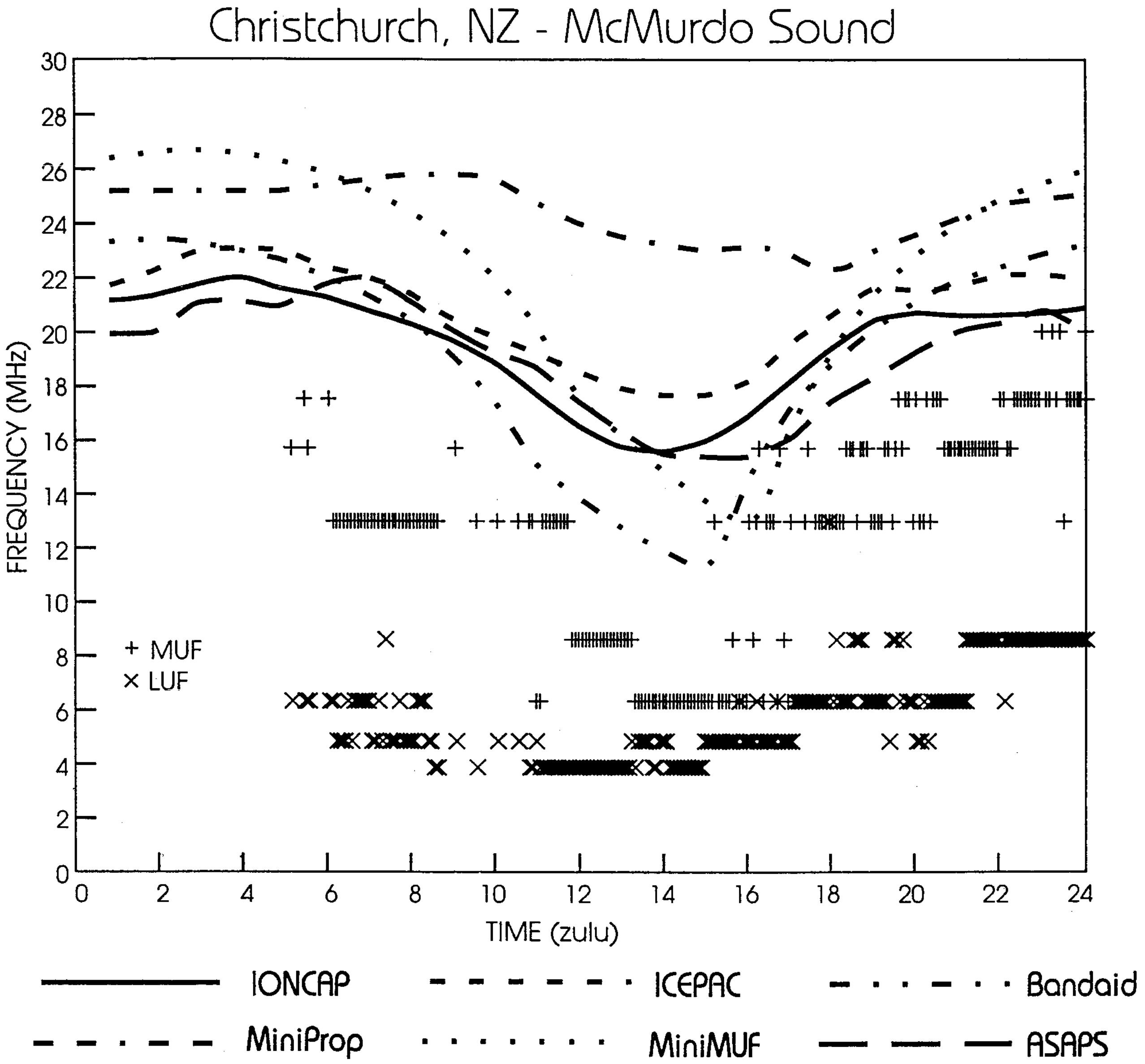


Figure 12. Comparison of predicted MUF with observed MUF, Jan. 15, 1992

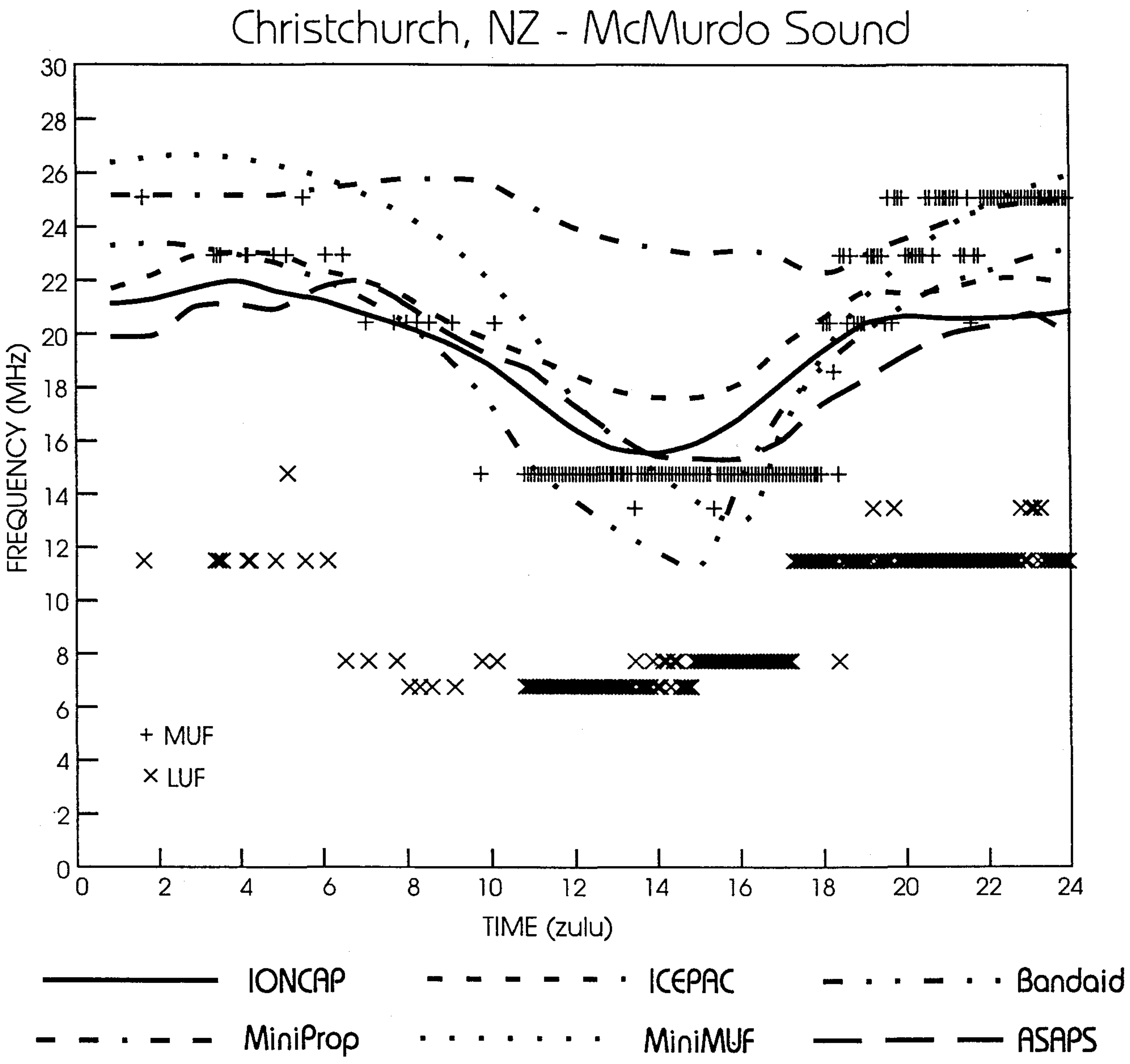


Figure 13. Comparison of predicted MUF with observed MUF, Jan 16, 1992.

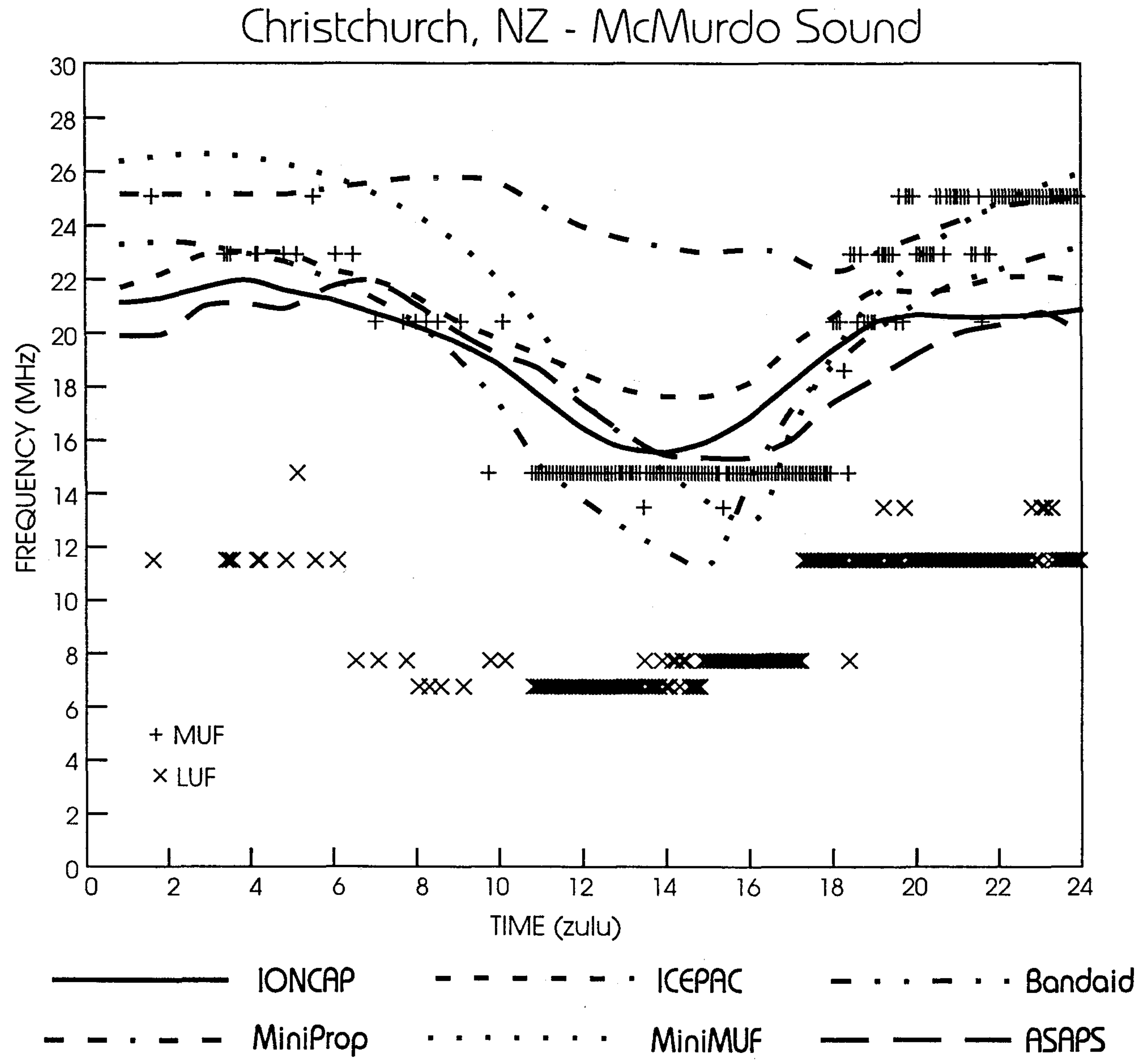


Figure 14. Comparison of predicted MUF with observed MUF, Jan 16, 1992.

3.2 Bi-Directional ALE Sounding With LQA

The actual testing phase of the operation began on the 12th of January. Following a review of the test objectives by all the Christchurch team members, the LQA sounding interval was changed from fifteen minutes to five minutes. The NUWC program manager wished to maximize the amount of data collected and the five-minute interval was the shortest interval that would allow for a bi-directional sounding of all ten test frequencies and an exchange of LQA data between the two stations. This sounding interval remained in effect throughout the period of testing and was interrupted only by the tests of the various modems (see Table 7 for a list of test equipment).

Figure 11 shows the physical connection of the Harris RF-350/RF-7210 HF transceiver to the 386 PC used to collect the LQA data. Table 11 lists the parameters that were set on the radio equipment and the software program used to communicate with the radio. The measurement team determined that, with a sounding interval of five minutes, a 1.2-MByte, 5-1/4" floppy diskette could store 24 hours of LQA data. Each day at approximately noon local time a new diskette was placed into the PC and a new file opened in the communications program to log the data. Each of these files was identified as CHC (for Christchurch), followed by two figures representing the local calendar date (i.e., CHC12), and the extension DAT. Data was collected from 12 noon January 13, 1992, through 6 am on January 25, 1992. Appendix B, Figures B-1 through B-13, displays the daily data collected. The local times that tagged each data entry were changed to Universal Coordinated Time (UTC or Zulu) during the data reduction phase of the experiment. The output from the radio's ALE modem, as shown in Table 9, was put into Lotus 1-2-3® spreadsheets and the graphical displays (Figures B-1 ... B-13) were generated using the Lotus 1-2-3® graphing package.

Table 11. Radio System Parameters for Bi-directional LQA Sounding

Harris Rf-7210

program set of ten frequencies
program self and individual IDs (addresses
set LQA interval - 5 minutes

enable LQA exchange
enable data logger

Compac Computer

initiate Procomm Plus communications program
open file (to collect LQA data to disk file

Analysis of the data recorded during the tests indicated that of a possible 282 hours, data was recorded during only 191 hours, leaving 91 hours unaccounted for. Table 12 lists the periods when the computer logged the output of the Christchurch ALE modem. In order to estimate the amount of time the radios simply would not link with each other due to propagation conditions, one must subtract the time when there was known equipment (or software) failure. Equipment failures were caused by several factors:

1. on two separate occasions the Harris radio system at the Christchurch end of the circuit "locked up" for more than 6 hours, during unmanned periods of operation, and would not scan or initiate sounds to the Black Island station. On each of these occasions, turning off the power to the radio and reinitializing the radio system restored the system to normal operation;

2. six and a half hours of data were lost when a low-density (360 Byte) floppy diskette was inadvertently used to collect the day's data;

3. an outage of over 6 hours was recorded due to a storm at Black Island that caused the electrical power generating plant to shut down (dust or ice crystals in the voltage regulator).

4. some of the holes in the daily graphs are caused by a failure of the signal to propagate on any of the frequencies used for the test.

Table 12. Daily Periods of Data Collection

DATE	TIMES (Z or UTC)	MISSING TIME	KNOWN PROPAGATION OUTAGES
Jan. 12, 1992	23:00:17 -- 23:59:59	00:00:00	
Jan. 13, 1992	00:00:00 -- 12:47:20 23:31:13 -- 23:59:59	10:53:53	01:38
Jan. 14, 1992	00:00:00 -- 04:21:37	19:38:22	
Jan. 15, 1992	04:36:06 -- 23:52:54 23:55:18 -- 23:59:59	04:40:46	00:21
Jan. 16, 1992	00:00:00 -- 19:13:07 19:15:18 -- 23:59:59	00:02:11	01:48
Jan. 17, 1992	00:00:00 -- 10:23:05 19:20:18 -- 23:59:59	08:57:13	01:42
Jan. 18, 1992	00:00:00 -- 07:32:54 10:25:18 -- 10:28:05 21:00:20 -- 23:59:59	13:24:39	
Jan. 19, 1992	00:00:00 -- 00:19:11 07:40:18 -- 19:33:12	11:47:54	00:21
Jan. 20, 1992	00:25:18 -- 06:09:23 06:31:24 -- 10:13:10 11:30:41 -- 14:03:04 14:23:01 -- 23:59:59	02:24:47	
Jan. 21, 1992	00:00:00 -- 10:14:15 10:30:18 -- 19:26:53	04:49:09	
Jan. 22, 1992	17:10:00 -- 23:59:59	06:49:59	01:42
Jan. 23, 1992	00:00:00 -- 03:02:54 10:40:18 -- 23:59:59	07:37:24	03:02
Jan. 24, 1992	00:00:00 -- 16:53:37	00:00:00	00:27
	Totals	91:06:17	11:06

From inspection of the data files, the ITS engineer estimated that propagation outages accounted for approximately 11.1 hours during the periods recorded. This leaves approximately 65 hours during the 11 3/4-day test period where no data was recorded and no recorded reason for outage (RFO) was available. Since this time period represents approximately 5.5 hours per day, we can reasonably assign some of this time to other associated testing being conducted each day (modems, Lincompex™, etc.). If we now subtract the known and unknown RFOs from the total possible test hours (keeping the 11.1 hours due to propagation) we are left with 191 hours. The probability of linking or P(L) with the ALE system is 94.2% [1 - 11.1/191]. This means that, on the average, ALE links between Christchurch and McMurdo were not possible for only 1 hour and 24 minutes each day.

Each of the daily Observed Propagation figures presents the highest and lowest frequencies that were received by the ALE equipment. These frequencies are an approximation to the Maximum Usable Frequency (MUF) and the Lowest Usable Frequency (LUF). All frequencies higher than the MUF are not refracted back to earth, and all frequencies lower than the LUF are completely absorbed by the ionosphere to the point where the received signal is below the SNR required to link. In some cases, the LUF is actually higher than the predicted MUF and no record of propagation was received.

During a portion of each working day the bi-directional sounding was set to 15-minute intervals to allow the test team to make subjective evaluations of the voice companding equipment and HF data modems (Table 7). The first of these devices to be tested was the Lincompex™ voice companders on loan to NUWC from the AMAF Corporation. Audio input/outputs to and from each radio were run through the Lincompex™ demonstration kits. Once a link was established using ALE, a subjective voice quality assessment was made by both stations. A quality rating of 1 (unusable) to 5 (excellent) was assigned. Each frequency in the set was checked in this manner, going from the frequency with the highest LQA score to the frequency with the lowest LQA score. The assessment of the Lincompex™ devices was outside the scope of the ITS tasking, so no listing of the subjective scores is presented. The Lincompex™ was able to remove most of the background noise or hiss from channels rated from good to marginal. However, it was not able to improve unusable channels.

The second device to be subjectively evaluated was the PK-232 Multimode data modem from AEA. This device is a low-cost item marketed to the amateur radio hobbyist (the U.S. Army has also purchased several hundred of these units for their backbone data traffic networks). This unit, when installed between an HF transceiver and a video display terminal or microcomputer, enables the operator to send and receive the following communications: Morse code (continuous wave-cw), radio teletype (frequency shift keying-FSK), AMTOR/SITOR (teletype with error correction), and packet radio (using the amateur AX.25 error-detection protocol). This device will also receive and print HF FAX broadcasts. Approximately four hours total were devoted to the evaluation of the PK-232 in the FSK radio teletype mode. A baud rate of 45.45 (60 wpm) and a frequency shift of 200 Hz were used. The bandwidth (BW) of the channel is assumed to be 3 kHz. A link was established using the ALE feature of the radio. Teletype messages were sent back and forth between the two stations and a subjective rating for the quality of the communications assigned. This test was repeated on successive channels with lower LQA scores until communications using this mode (285H0F2B) became impossible.

Similarly, the PK-232 was tested in the SITOR/AMTOR mode A (FEC) and AX.25 Packet modes. To make an assessment of the Bit Error Ratio (BER), a simple test message, consisting of ten lines of "thequickbrownfoxjumpedoverthelazydogsback1234567890.,;:'/"\+=" was sent between each station. This message made counting character errors relatively easy to accomplish. From this count, an estimate of the BER was calculated (errors/characters sent). Messages received in Christchurch were saved on floppy diskettes for later analysis by NUWC personnel.

NUWC was primarily interested in the performance of the Frederick Model 1102, serial tone, high-speed PSK data modems. This modem, built to the MIL-STD-188-110A standard, had error detection and correction algorithms incorporated within the protocol. The same sort of data communications tests were made using the Model 1102. Data rates were varied from 300 to 2400 baud. The NUWC engineers gathered data on the performance of the Model 1102 on progressively worse channels, until the BER became excessive and the test was stopped.

3.3 Frequency Management

The inherent capability of the ALE radio system to function as a real-time frequency management system was demonstrated during these tests. Each sounding produced an ordering of the frequency channels from the highest LQA score to the lowest. The LQA score is a composite score (the exact algorithm varies from vendor to vendor) consisting of a measurement of the SINAD and a measurement of the BER. Figure 15 shows the relationship between the LQA score and the received SINAD score (for the Harris ALE radios only). As was mentioned earlier, the highest propagating frequency is an approximation of the MUF, while the lowest propagating frequency approximates the LUF. The ALE modem continuously stores the information gained from the sounding operations, in a matrix. When a communication link is desired, the ALE equipment will begin to establish a link by starting the call on the frequency with the highest (matrix-stored) LQA score. If a link is not achieved on the channel with the highest LQA score, then the call is made on the channel with the next highest score, and so on. Normally, unless propagation conditions are changing rapidly or considerable time has elapsed since the last sounding, a link can be accomplished on the channel with the highest measured LQA score.

By examining the score table stored in the matrix in the memory of the ALE modem, it becomes very easy to predict the best operating frequency before commencing a call to a distant station. At one point during the testing, the Navy COMSTA operating concurrently with the ALE station experienced a total communications blackout. Following the published U.S. Navy blackout procedures provided no restoration of the circuits. The lead radioman requested help from the test team in selecting a frequency that might restore the communications between Christchurch and McMurdo. He was given a frequency that scored the highest LQA score on the most recent sounding. Selecting a Navy operational frequency close to the "best" ALE frequency immediately restored the Navy communications, providing a demonstration that the low-power (125 W) ALE system outperformed the experienced operators using higher-power (4 kW) transmitters and their Blackout SOPs.

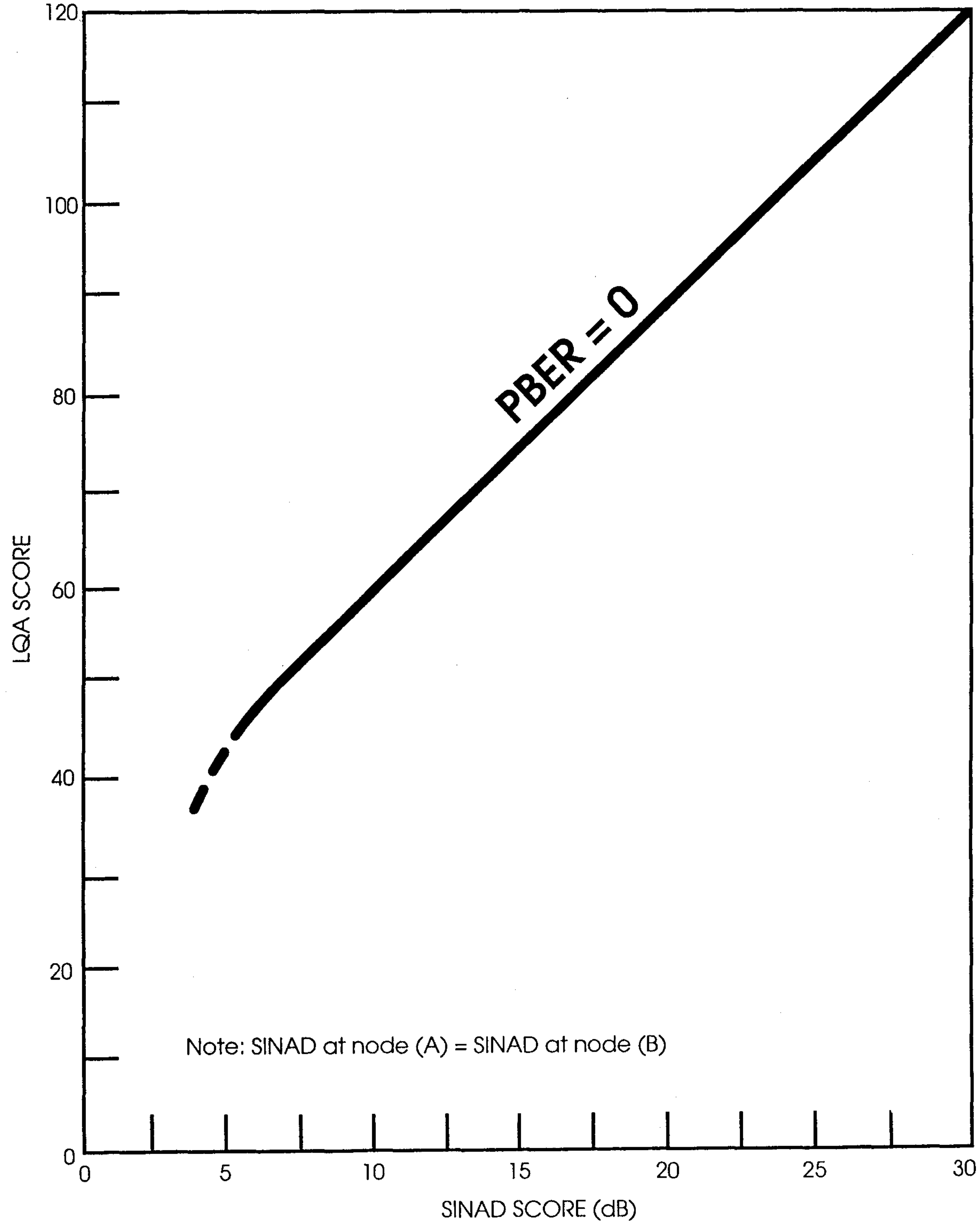


Figure 15. FED-STD 1045 ALE LQA vs SINAD.

4. SUMMARY

4.1 Analysis of Transmitter Power Requirements

One of the significant questions to be answered by this ALE test was what RF power level could be used to achieve reliable and consistent communications between Christchurch, New Zealand, and McMurdo Station, Antarctica. The transmitter power level requirement depends on the bandwidth of the signal being transmitted, and the required signal-to-noise ratio for the grade of service (orderwire, marginal commercial, good commercial) specified. It also depends on the season of the year and time of day (sunspot number and atmospheric noise level) as well as the gains of the respective receive and transmit antennas. Tables 13, 14, and 15 depict the results of an analysis (using ASAPS) of the expected daily circuit availability (in hours per day) for high (200), medium (100) and low (10) sunspot numbers. The daily circuit availability is tabulated for the various types (modes) of modulation that could be used by the communicators on the New Zealand - Antarctica link. The total hours available for each mode varies due to different bandwidths and signal-to-noise ratios.

The improvement in availability as the sunspot number decreases from 200 to 100 is due to a change in the mode of propagation. At the higher sunspot number the principal mode of propagation is via one hop from the F layer, whereas when the sunspot number is 100 or 10 the principal mode is via two F layer hops. It also should be noted that there is a point above which further increases in transmitter power will not provide any increase in the number of available hours.

Analysis of this link, using computer models such as IONCAP and ASAPS, shows that the link may often be maintained with power levels of 100 W or less. Also, there are conditions of atmospheric and manmade noise, sunspot numbers, and propagation take-off angles that require power levels of more than 10 kW to maintain desired signal-to-noise levels.

4.2 Analysis of Data Transmission Requirements

Taking the figures of an average of 100 messages per day to McMurdo and 60 messages per day from McMurdo, and making the assumption of one page per message (or approximately 15.5 bits/message), we can arrive at an approximate figure for required daily connectivity by using the nomograph presented in Figure 16. If 75 baud radio teletype (RTTY) is used it will

Table 13. Transmitter Power Versus Hourly Circuit Availability

Smoothed Sunspot Number = 200					
Power (watts)	Voice[1]	FSK[2]	FS-1045 ALE[3]	Serial Tone[4]	39 Tone[5]
	Circuit Availability, Hours/Day				
10	3	0	5	0	0
20	4	0	6	0	1
50	5	0	8	0	3
100	6	0	18	1	4
500	14	4	24	4	6
1000	21	4	24	5	7
2500	24	5	24	6	14
5000	24	6	24	7	21
10 K	24	8	24	11	24
50 K	24	23	24	24	24
100 K	24	24	24	24	24
500 K	24	24	24	24	24
900 K	24	24	24	24	24

1. SSB, voice (2K70J3E), BW = 2.7 kHz, SNR = 13 dB, fading conditions.

2. FSK Teletype, 60 wpm, 45.5 Baud, 850 Hz Shift, (1K10F1B), SNR = 33 dB, fading conditions.

3. BW = 3 kHz, SNR = 5 dB, 53.6 bps, P(L) = 25%, fading conditions.

4. PSK 4800 baud, BW = 3 kHz, SNR = 27 dB, BER = 10E-3, fading path, Frederick Model 1102, Harris Model RF-5254.

5. 39 tone parallel, asynchronous, BW = 3 kHz, SNR = 20 dB, Harris Model RF-3466.

Table 14. Transmitter Power Versus Hourly Circuit Availability

Smoothed Sunspot Number = 100					
Power (watts)	Voice[1]	FSK[2]	FS-1045 ALE[3]	Serial Tone[4]	39 Tone[5]
	Circuit Availability, Hours/Day				
10	0	0	12	0	0
20	4	0	13	0	0
50	11	0	18	0	0
100	12	0	20	0	4
500	20	1	20	3	12
1000	20	7	20	9	14
2500	20	12	20	12	20
5000	20	13	20	14	20
10 K	20	17	20	20	20
50 K	20	20	20	20	20
100 K	20	20	20	20	20
500 K	20	20	20	20	20
900 K	20	20	20	20	20

1. SSB, voice (2K70J3E), BW = 2.7 kHz, SNR = 13 dB, fading conditions.

2. FSK Teletype, 60 wpm, 45.5 Baud, 850 Hz Shift, (1K10F1B), SNR = 33 dB, fading conditions.

3. BW = 3 kHz, SNR = 5 dB, 53.6 bps, P(L) = 25%, fading conditions.

4. PSK 4800 baud, BW = 3 kHz, SNR = 27 dB, BER = 10E-3, fading path, Frederick Model 1102, Harris Model RF-5254.

5. 39 tone parallel, asynchronous, BW = 3 kHz, SNR = 20 dB, Harris Model RF-3466.

Table 15. Transmitter Power Versus Hourly Circuit Availability

Smoothed Sunspot Number = 10					
Power (watts)	Voice[1]	FSK[2]	FS-1045 ALE[3]	Serial Tone[4]	39 Tone[5]
	Circuit Availability, Hours/Day				
10	0	0	3	0	0
20	1	0	3	0	0
50	2	0	4	0	0
100	3	0	4	0	1
500	5	0	6	1	3
1000	5	3	6	3	4
2500	6	3	9	3	5
5000	6	3	11	4	5
10 K	9	4	11	5	6
50 K	11	5	11	6	9
100 K	11	6	11	6	11
500 K	11	9	11	11	11
900 K	11	11	11	11	11

1. SSB, voice (2K70J3E), BW = 2.7 kHz, SNR = 13 dB, fading conditions.

2. FSK Teletype, 60 wpm, 45.5 Baud, 850 Hz Shift, (1K10F1B), SNR = 33 dB, fading conditions.

3. BW = 3 kHz, SNR = 5 dB, 53.6 bps, P(L) = 25%, fading conditions.

4. PSK 4800 baud, BW = 3 kHz, SNR = 27 dB, BER = 10E-3, fading path, Frederick Model 1102, Harris Model RF-5254.

5. 39 tone parallel, asynchronous, BW = 3 kHz, SNR = 20 dB, Harris Model RF-3466.

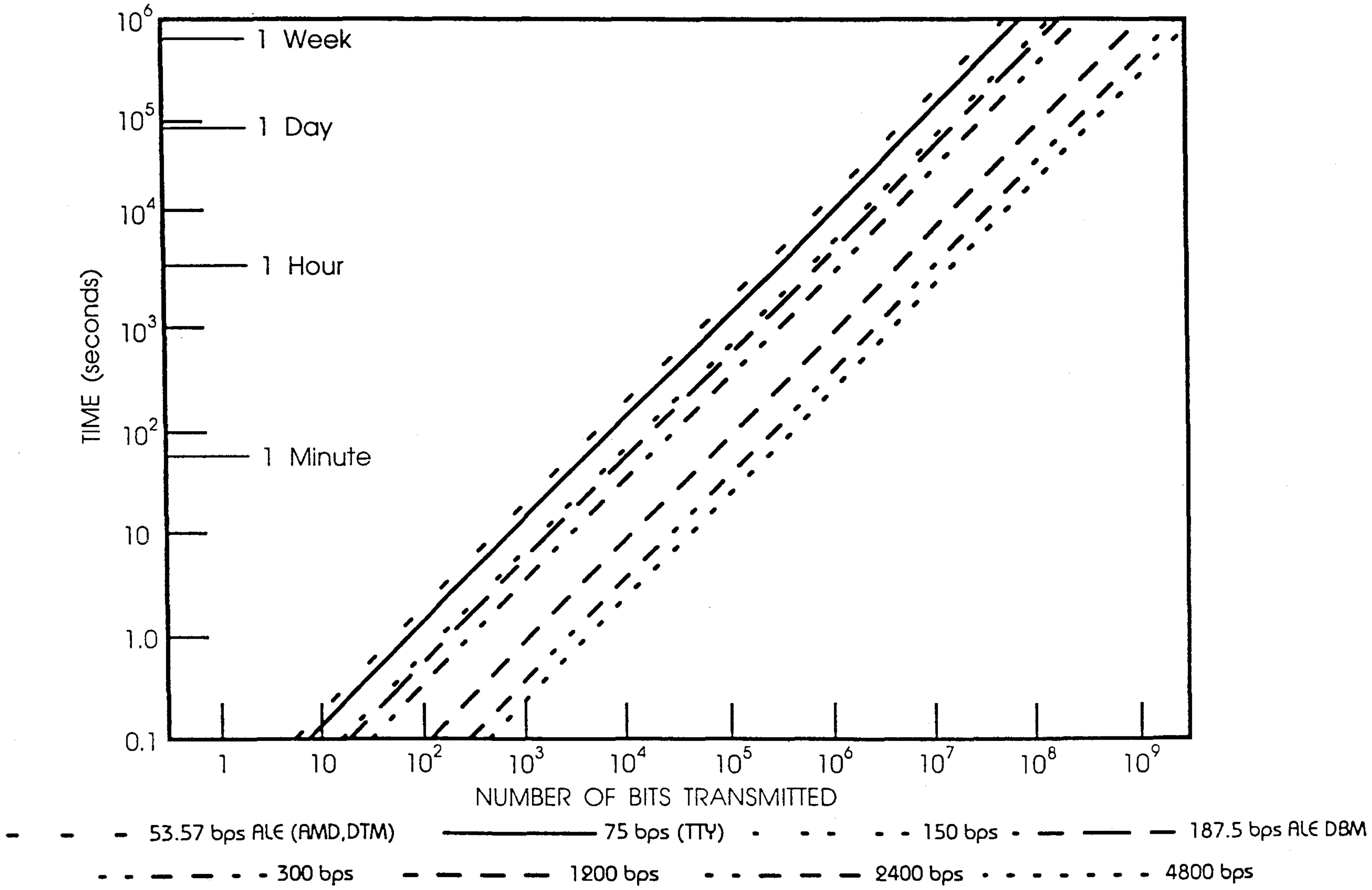


Figure 16. Time required for data transmission at selected rates of transmission.

require almost 6 hours of transmission time to pass the 100 daily messages from Christchurch to McMurdo (3.5 hours for messages from McMurdo). Figure 16 also includes the data rate for ALE data block message (DBM) and ALE data text message (DTM) modes. Table 15 indicates that even with a transmitter power level of 10 kW it may not be possible to achieve the required 6 hours of connectivity at the bottom of the solar cycle (low sunspot numbers). By using high-speed HF data modems of the serial tone or parallel tone variety, at speeds of 300 to 2400 baud, it should be possible to pass the daily required traffic, error free, within the limited time permitted by the physics of the propagation medium (300 baud = 1.4 hrs, 1200 baud = 22 min., 2400 baud = 11 min.).

High-speed error-detecting and correcting modems will greatly speed up the process of passing the current amount of record traffic and will provide excess capability. At a data rate of 4800 baud and a circuit availability of 5 hours, more than 13 times the current amount of traffic could be passed.

4.3 Analysis of Navy COMSTA Frequency Selection Versus ALE Frequency Selection

An analysis of the frequencies used for transmitting messages was performed. A log of the frequencies used, and for how long, was created and plotted as shown in Appendix C.

Figures C-1 through C-10 show the pattern of frequency usage on each of the five operational channels, taken from official U.S. Navy station logs. A review of the official Christchurch station logs for the period of January 12-21, 1992, indicates that each outage recorded was due to either equipment failure or some form of maintenance operation. In no case were any of the outages assigned to a failure of the ionosphere to support propagation. It was not possible to compare known periods of propagation outage from each system. Each frequency change occurred as a result of an attempt to either pass operational traffic or to make required communications checks. When communications could not be established on the last usable frequency, operators would attempt to reestablish the link, on another frequency following established procedures.

The pattern of Navy COMSTA frequency usage is consistent with the MUF-LUF data collected during the ALE experiments, as displayed in Figures B-1 through B-13. ITS noted, however, that the U.S. Navy's choice of frequencies seemed to always be a compromise. They tried a frequency and if it supported communications they used it until it no longer worked. Some of the frequencies choosen were close to the LUF and had poor SNRs, while others were significantly below the MUF and would be subjected to multipath fading. Without some form of real-time frequency management, the U.S. Navy's radio operators must spend a great deal of time hunting for frequencies on which to operate, a process that can easily be automated with the ALE equipment. Figure 17 shows an example of the pattern of COMSTA frequency selection, compared to the MUF-LUF data collected by the ALE system on January 20, 1992. It should be noted that in no case was the selected operating frequency near the observed MUF or optimum working frequency (FOT).

5. RECOMMENDATIONS FOR IMPROVING HF LINK RELIABILITY

5.1 ALE as a Real-Time, Frequency Management Tool

The results of the brief ALE test over the Christchurch-to-McMurdo HF radio link have demonstrated the usefulness of this new technology. If propagation was possible, ALE quickly provided the link. Some of the Navy's permanent staff even remarked that the ALE radio system was like placing a telephone call; one push of a button and the distant end was quickly on the line (with near-toll quality). At one point, the experimenters were approached by the COMSTA's senior radioman who stated that the crew was unable to establish communications with the station in McMurdo and requested help in selecting a workable frequency. The Navy operators were provided with the information from the LQA database (high LQA scoring frequencies, and bit error ratios) and were soon able to re-establish communications with their manually operated, high-power equipment. This clearly demonstrates the effectiveness of the ALE system as a real-time frequency management tool.

As a result of these experiments, the researchers believe it has been conclusively demonstrated that the effectiveness of the NSF HF communications between the support base in Christchurch, New Zealand, and McMurdo Station in Antarctica would be significantly improved by the use of an ALE HF radio system as a real-time frequency management tool. This could definitely enhance communications using the existing transmitting and receiving equipment. Computer modeling has indicated there will be times that require 10 kW or more of transmit

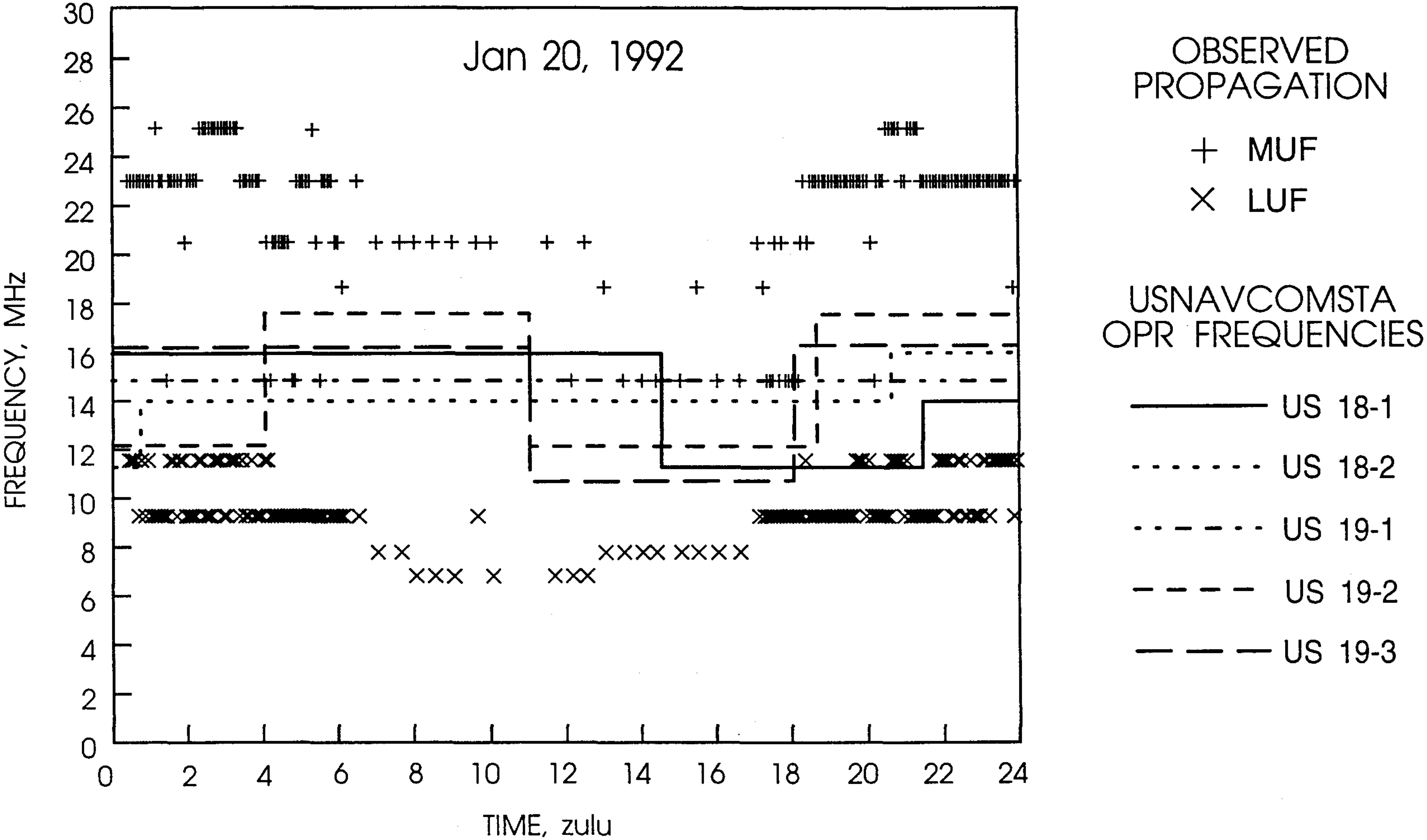


Figure 17. Comparison of observed propagation with Navy operational frequencies.

power to ensure successful communications. Since ALE equipment will achieve link-ups at SNRs 10 dB below those required for passing voice traffic (GSA, 1990), the minimum recommended size for the ALE system is 1 kW, or 10 dB below the existing 10 kW equipment.

As was stated earlier, the solar and geomagnetic conditions during the period of the investigation were rather benign. The investigators feel that there is merit in continuing to gather similar data during different seasons of the year and at different parts of the solar sun spot cycle. This continuing study would provide validation for the computer predictions included in this report.

Figure 18 shows the ALE system operating as a real-time frequency management system. Figure 19 shows the recommended components of the ALE frequency management system. The use of a combiner would allow the ALE system to use the same transmitting antenna as the station's high-power transmitter. The same configuration should be used on both ends of the link.

5.2 Replacement of Older Transmitting Equipment

Interviews with site personnel have indicated that the transmitters used in the New Zealand - Antarctica link are being operated at reduced output power (4 kW versus 10 kW) either to maximize the time between equipment failures or because that is the most power that can be generated by the equipment. Computer modeling has shown that there will be times throughout the 11-year solar sunspot cycle that will require the full 10 kW (or more) to establish and maintain the link. The older-generation transmitters should be replaced with modern equipment that is capable of producing the full 10 kW when required. The new equipment will be easier and more economical to maintain than the transmitters in current operation.

5.3 Evaluation of Receiver Site Manmade Noise Environment

The location of the Christchurch receiver site adjacent to the edge of the city and the Christchurch International Airport, coupled with the high noise floor observed in the ALE test receivers, indicates a high level of manmade noise. The ALE evaluators were not prepared to make noise measurements (a spectrum analyzer of sufficient sensitivity was not included in the suite of test equipment). It is recommended that a study of the ambient manmade noise

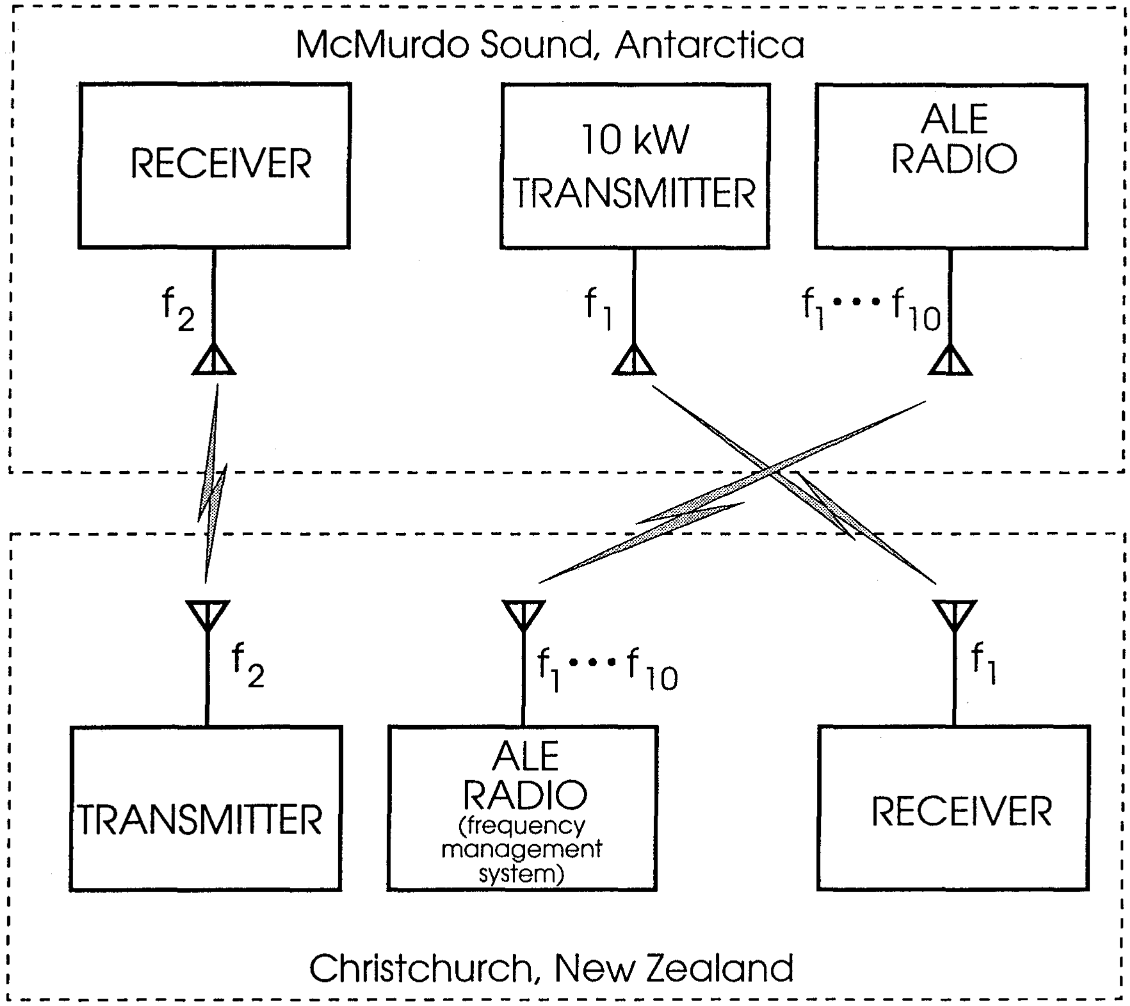


Figure 18. ALE equipment as real-time frequency management system.

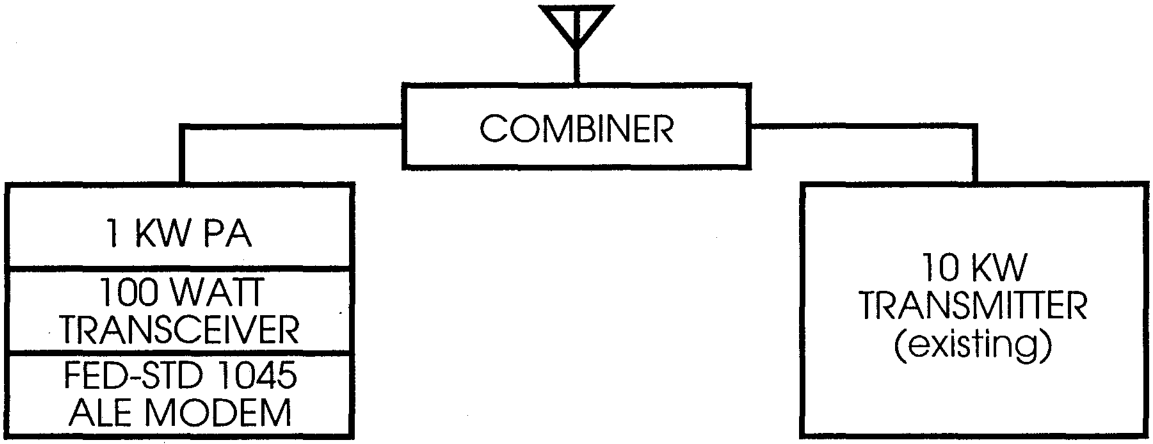


Figure 19. Recommended equipment configuration and specification for ALE real-time frequency management system.

environment in the vicinity of the Christchurch receiver site be made. If, as expected, the noise environment of the receive site is at an "industrial" level, then a relocation of the receive site to a "rural" area should be considered. Such a relocation could improve the SNR by up to 23 dB, thereby ensuring several more hours of circuit connectivity per operating day.

6. CONCLUSIONS

The solar and geomagnetic conditions that were present during the period of testing were benign. It is suggested that a series of similar experiments be planned to continue the evaluation of this new technology during periods of lower solar flux and during periods of severe geomagnetic activity.

HF radio systems employing adaptive ALE technology are still largely untested in practical service. Experiments with this new technology, such as the one described in this report, go a long way in documenting the successes that these systems can produce. ALE technology is living up to the projections, made only a few years ago, that through automation and adaptive techniques HF radio will take its place as a practical and reliable means of long-distance communications.

7. ACKNOWLEDGMENTS

The authors wish to thank Dr. David R. Wortendyke for helping to make the task of reducing the large amount of data collected during this experiment manageable and Mr. John M. Harman for his assistance in producing clear graphics and tables.

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APPENDIX A: JANUARY 1992 SOLAR AND GEOMAGNETIC DATA

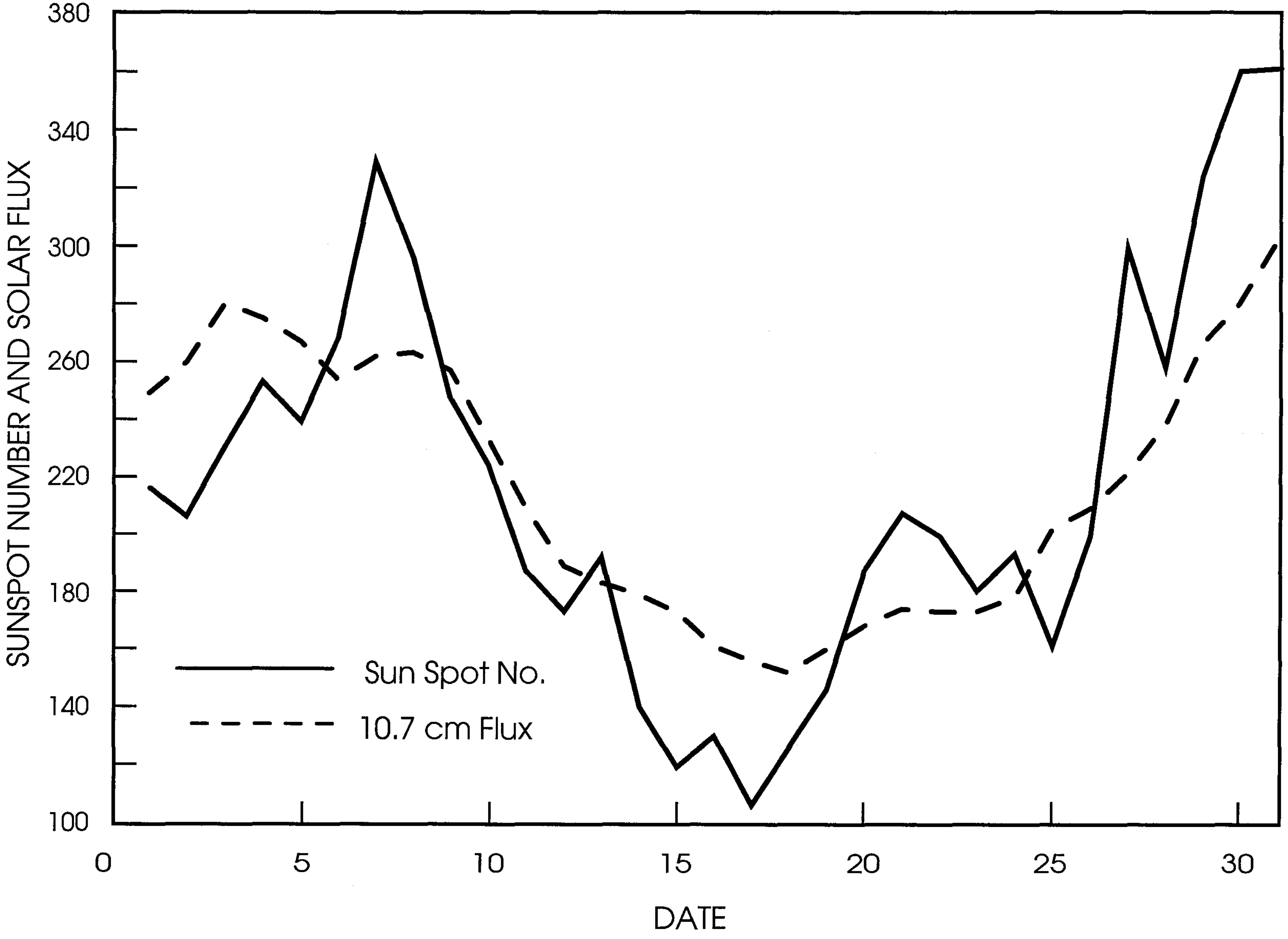


Figure A-1. Daily solar data, January 1992

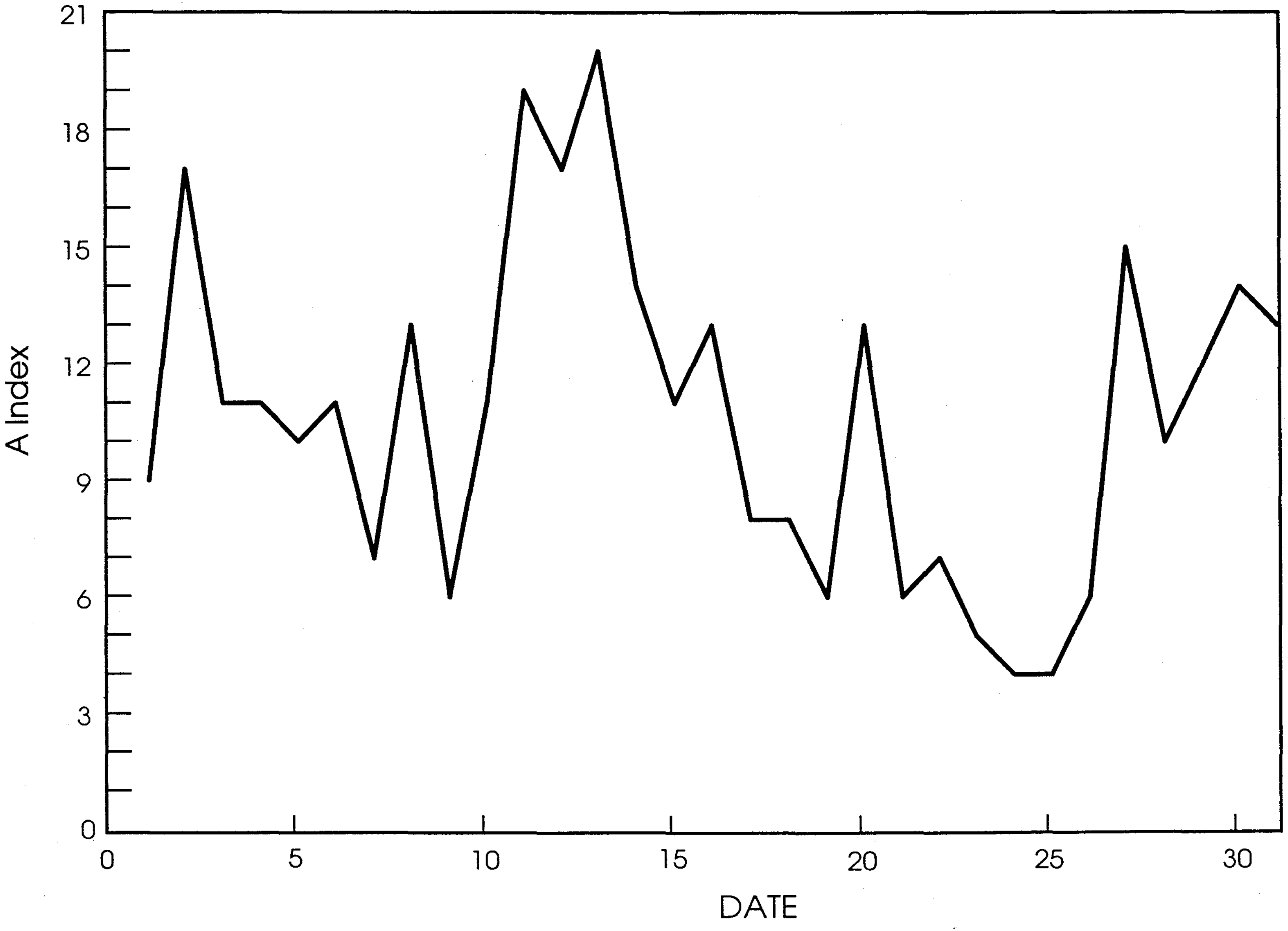


Figure A-2. Planetary - A index, January 1992.

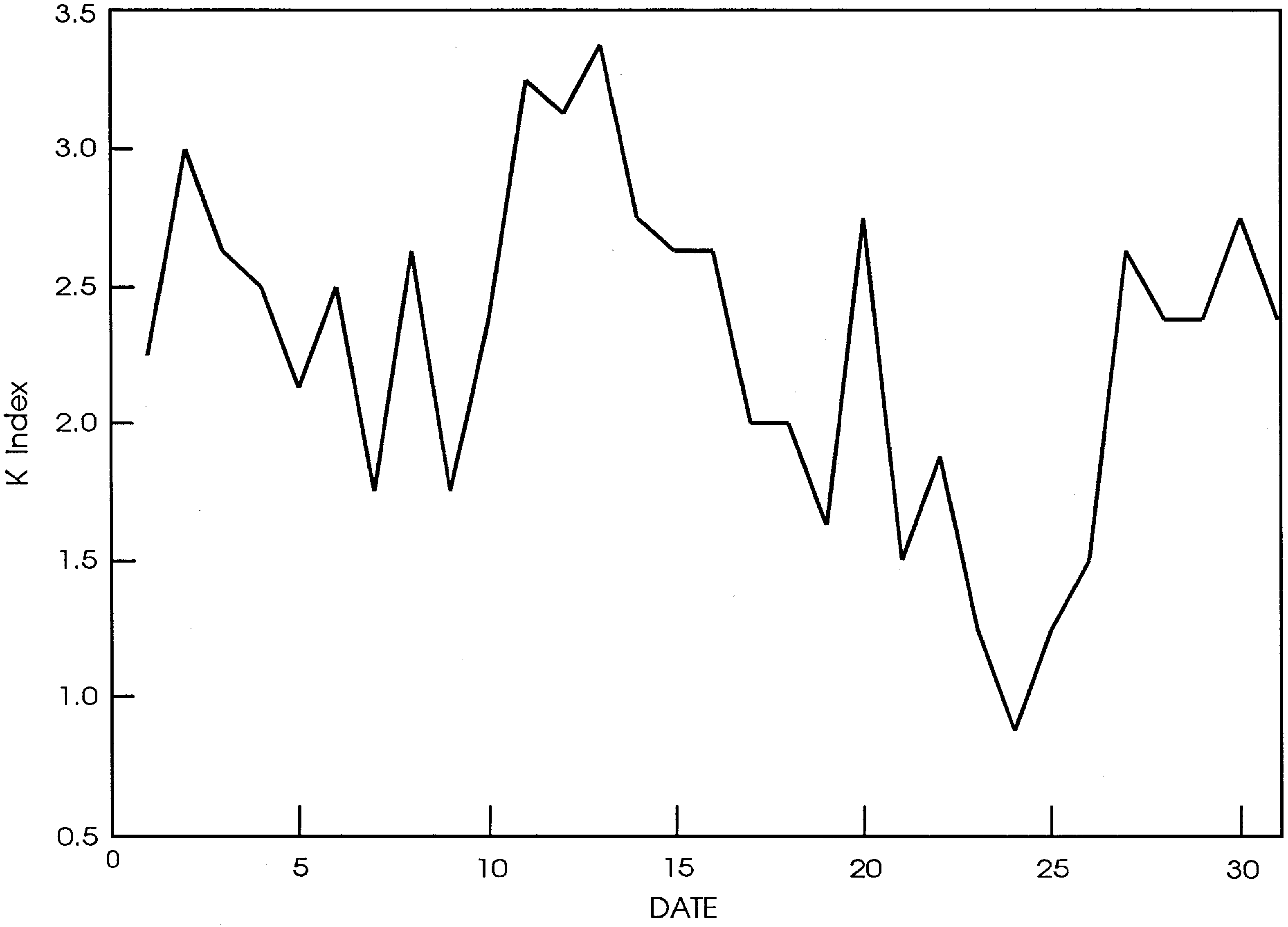


Figure A-3. Planetary - K index, January 1992.

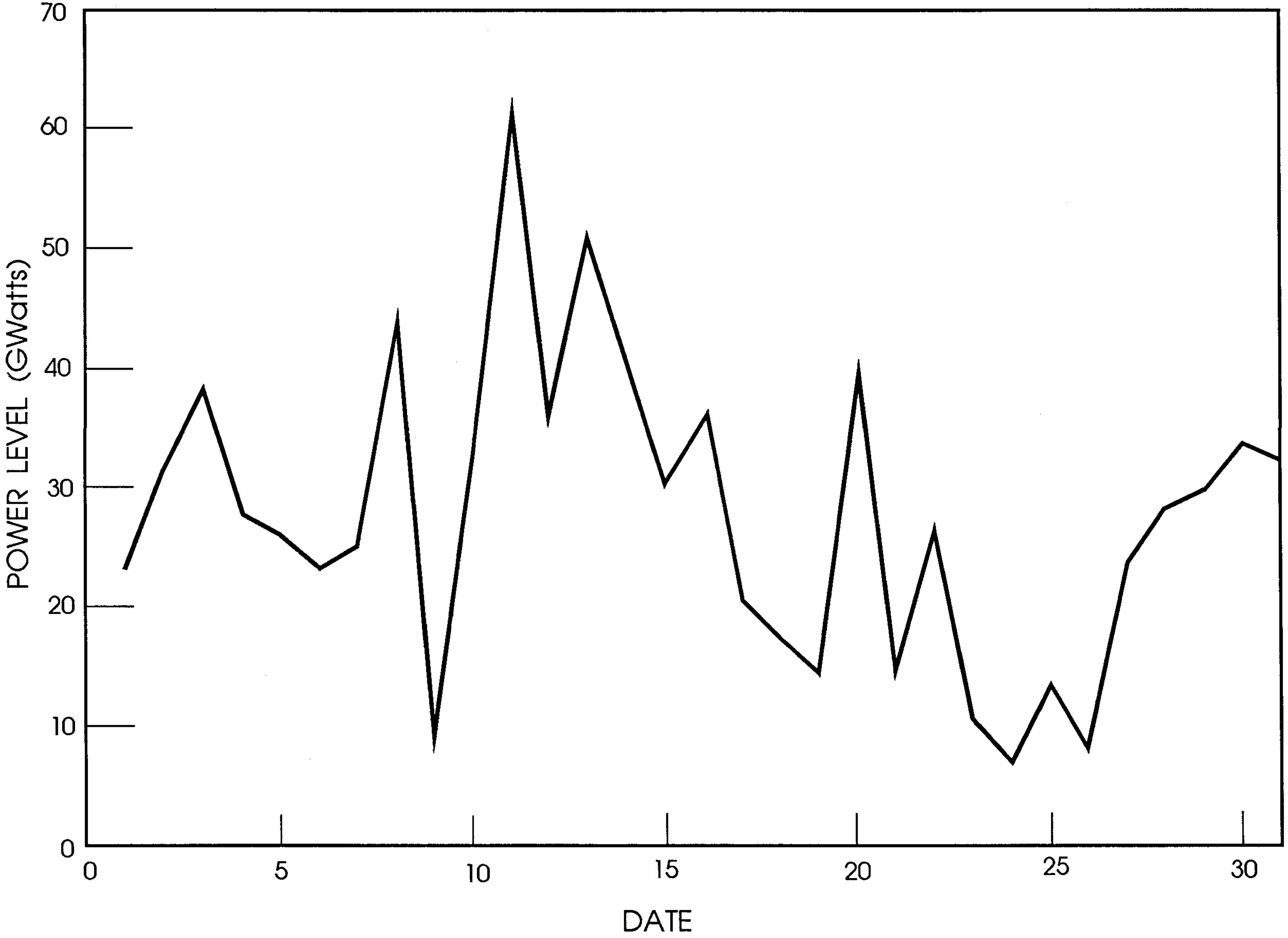


Figure A-4. South auroral zone particle activity January, 1992 (NOAA-12 satellite).

APPENDIX B: RESULTS OF DAILY ALE SOUNDINGS

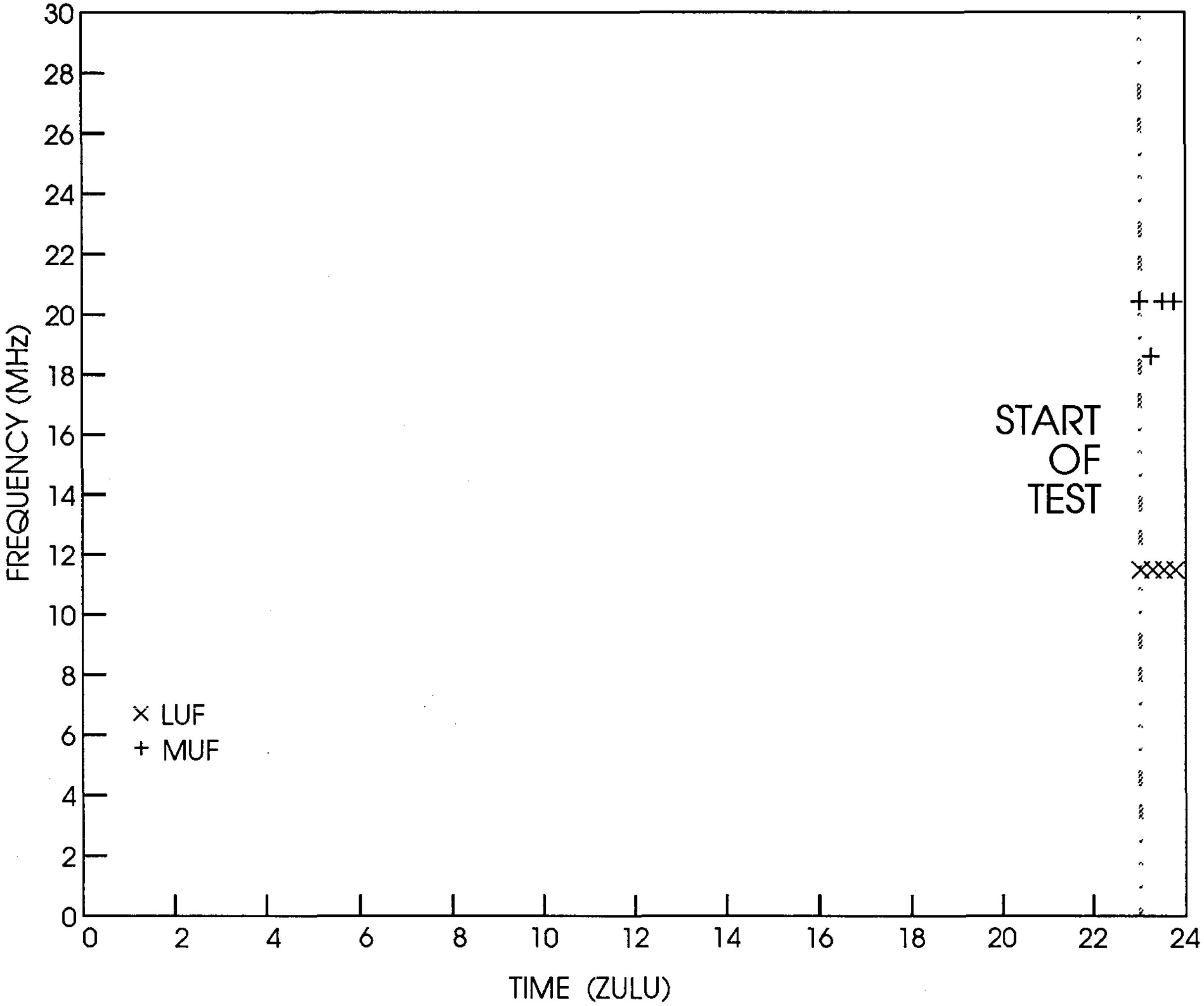


Figure B-1. Observed propagation January 12, 1992.

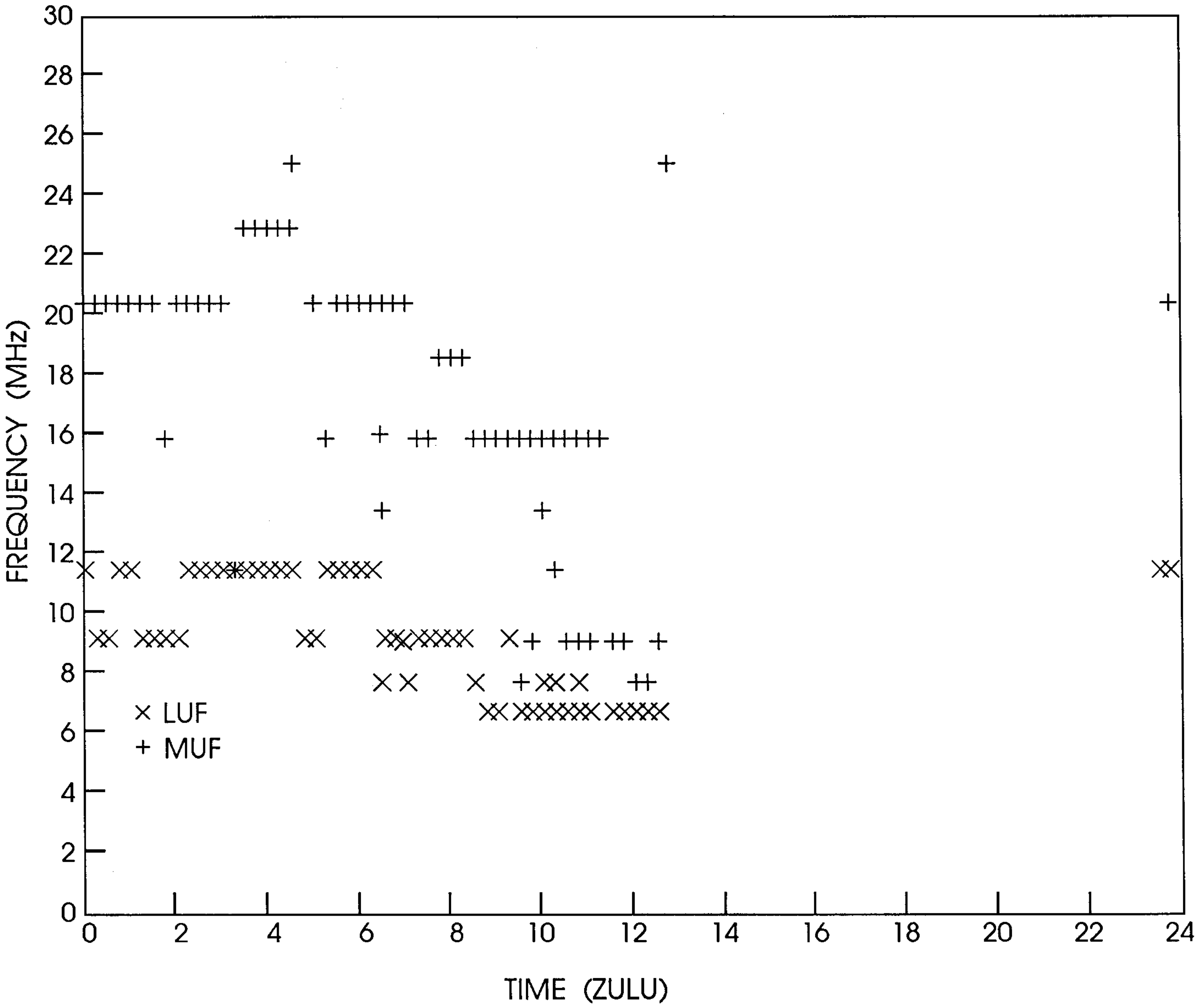


Figure B-2. Observed propagation January 13, 1992.

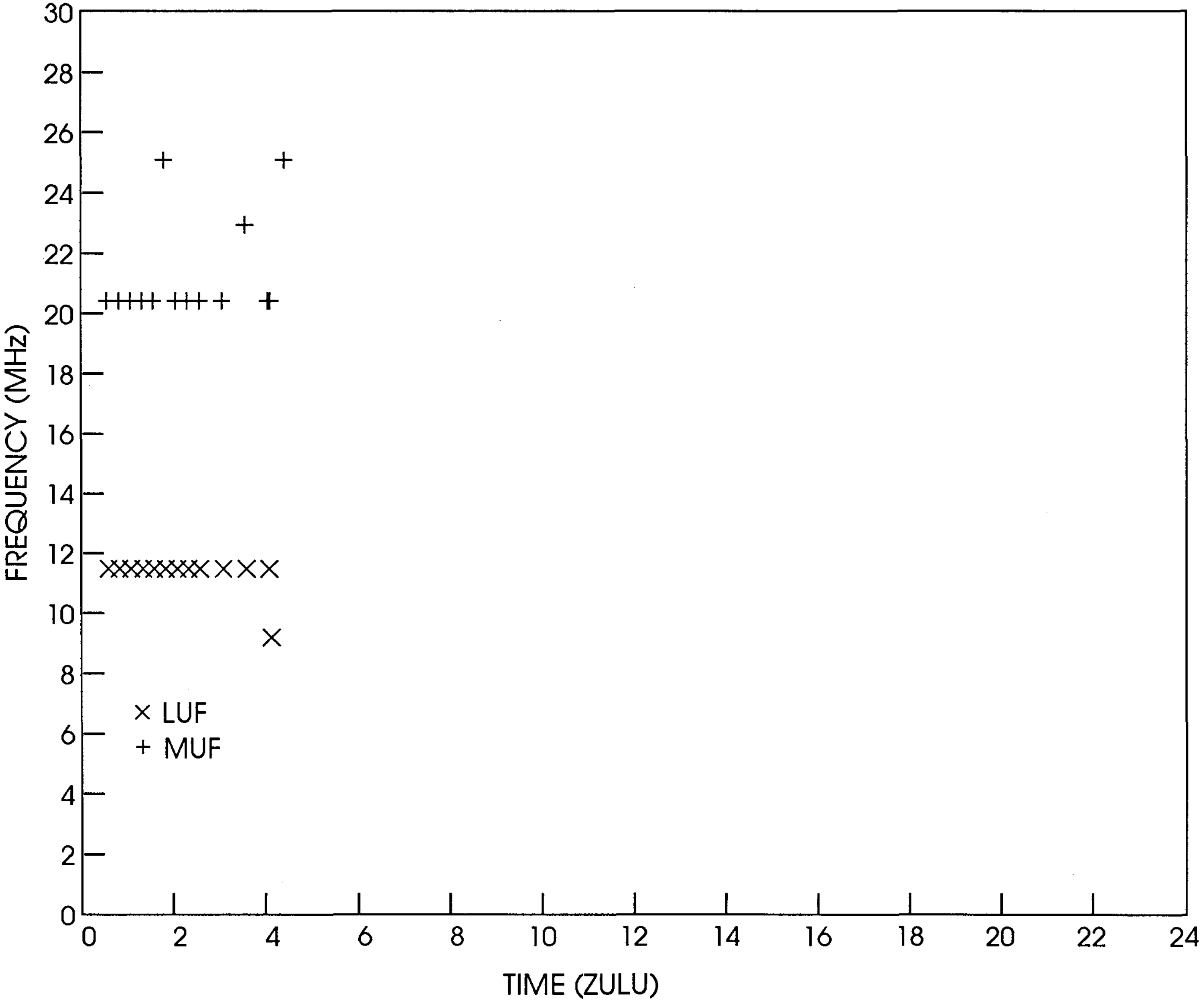


Figure B-3. Observed propagation January 14, 1992.

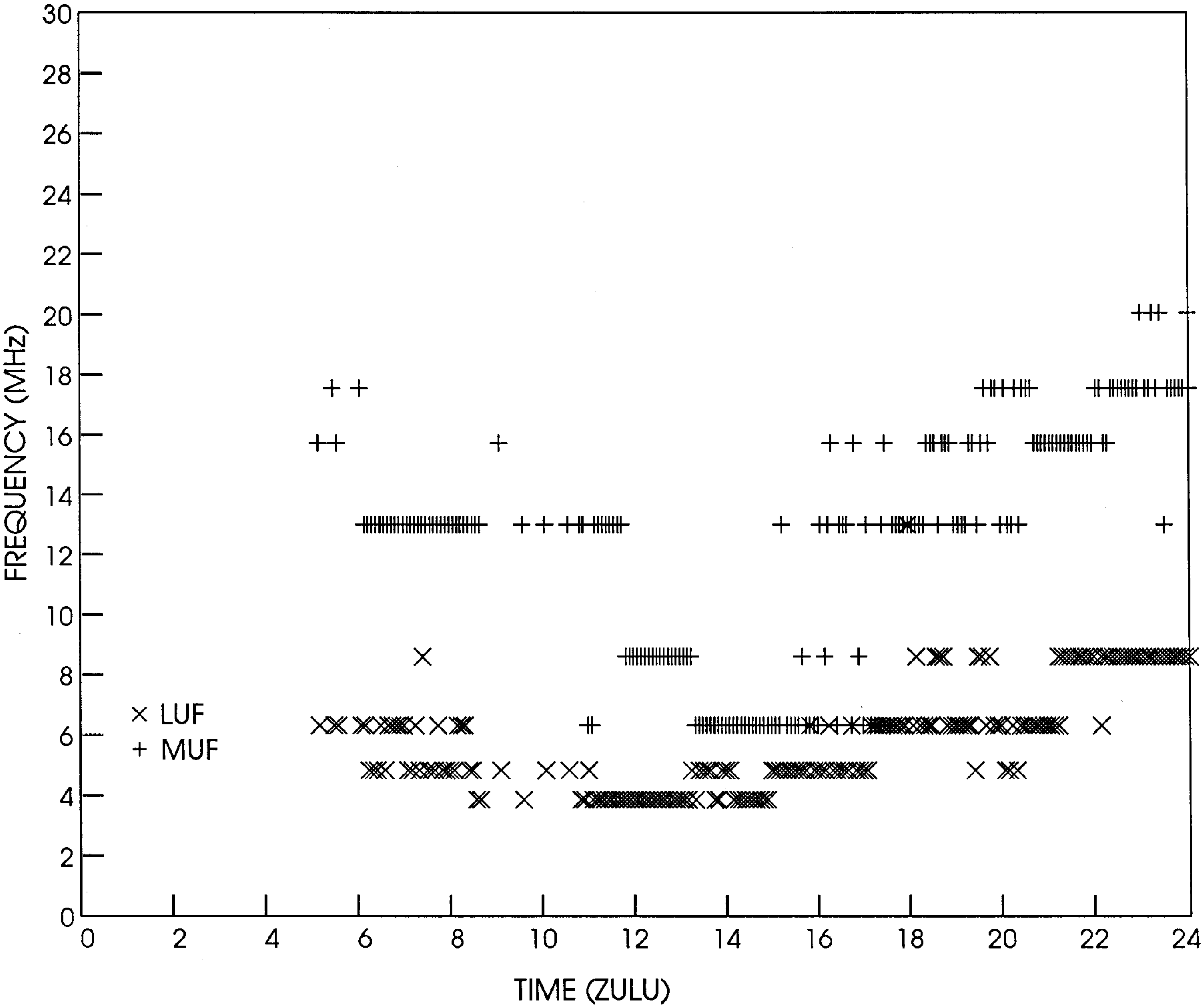


Figure B-4. Observed propagation January 15, 1992.

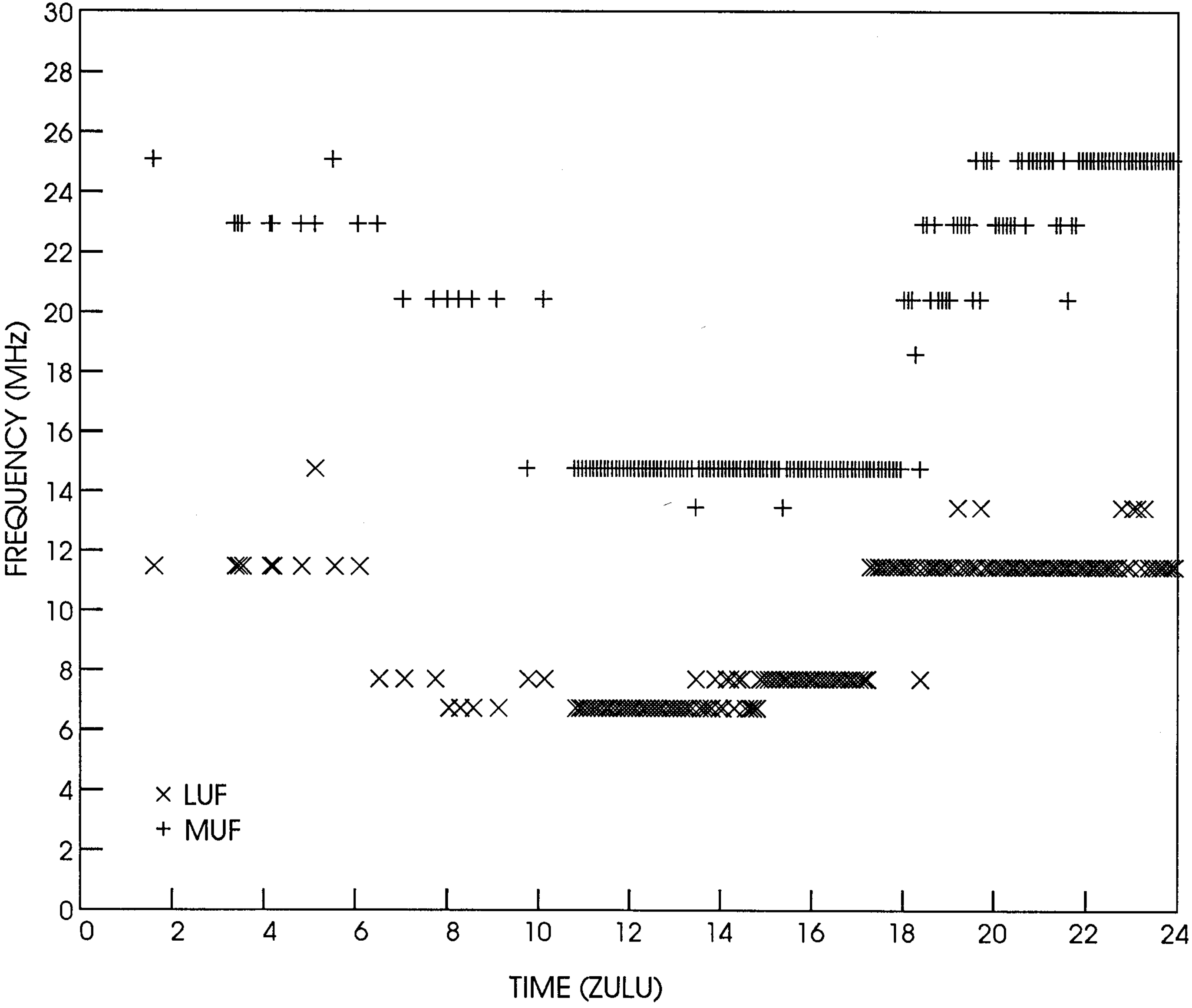


Figure B-5. Observed propagation January 16, 1992.

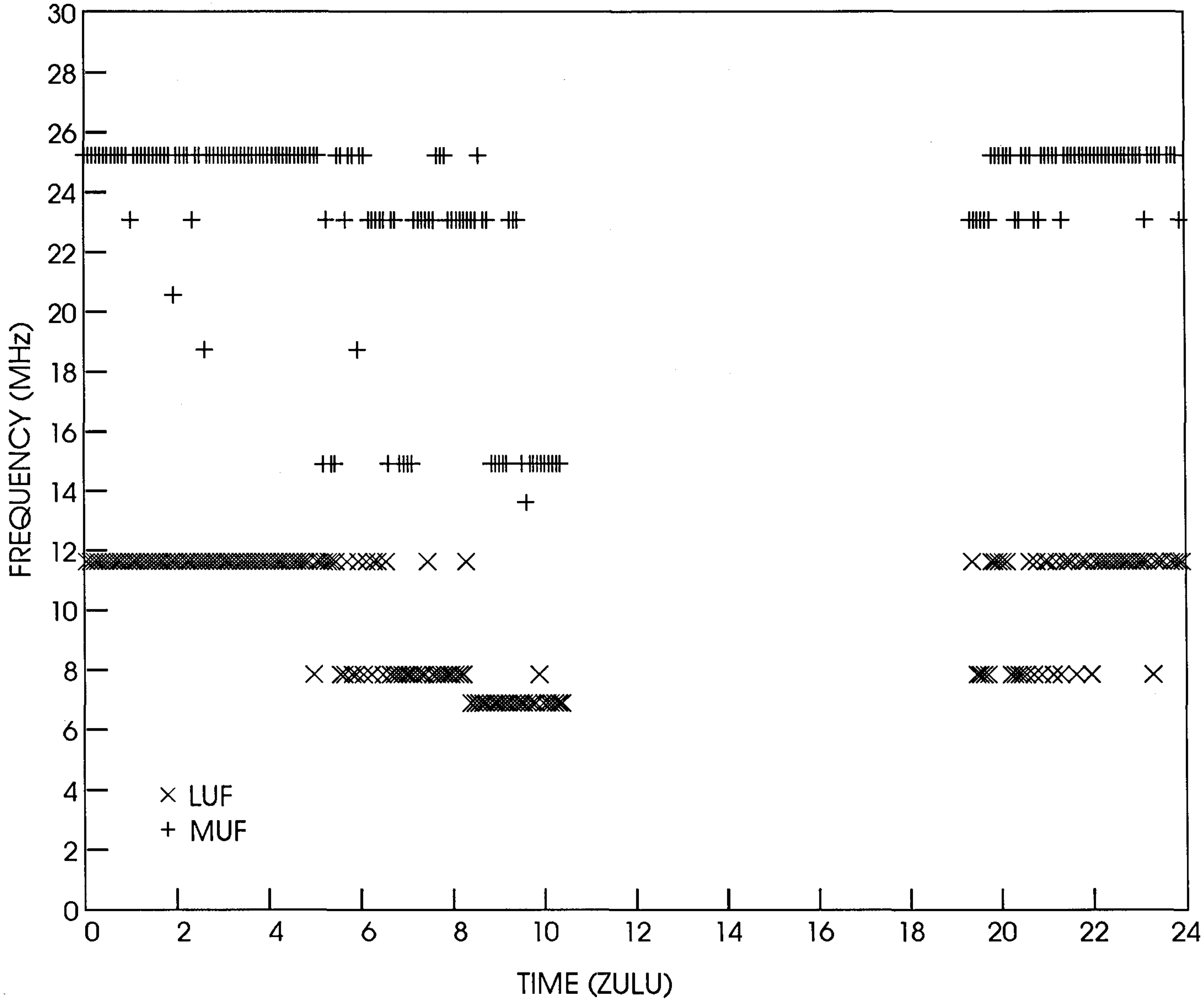


Figure B-6. Observed propagation January 17, 1992.

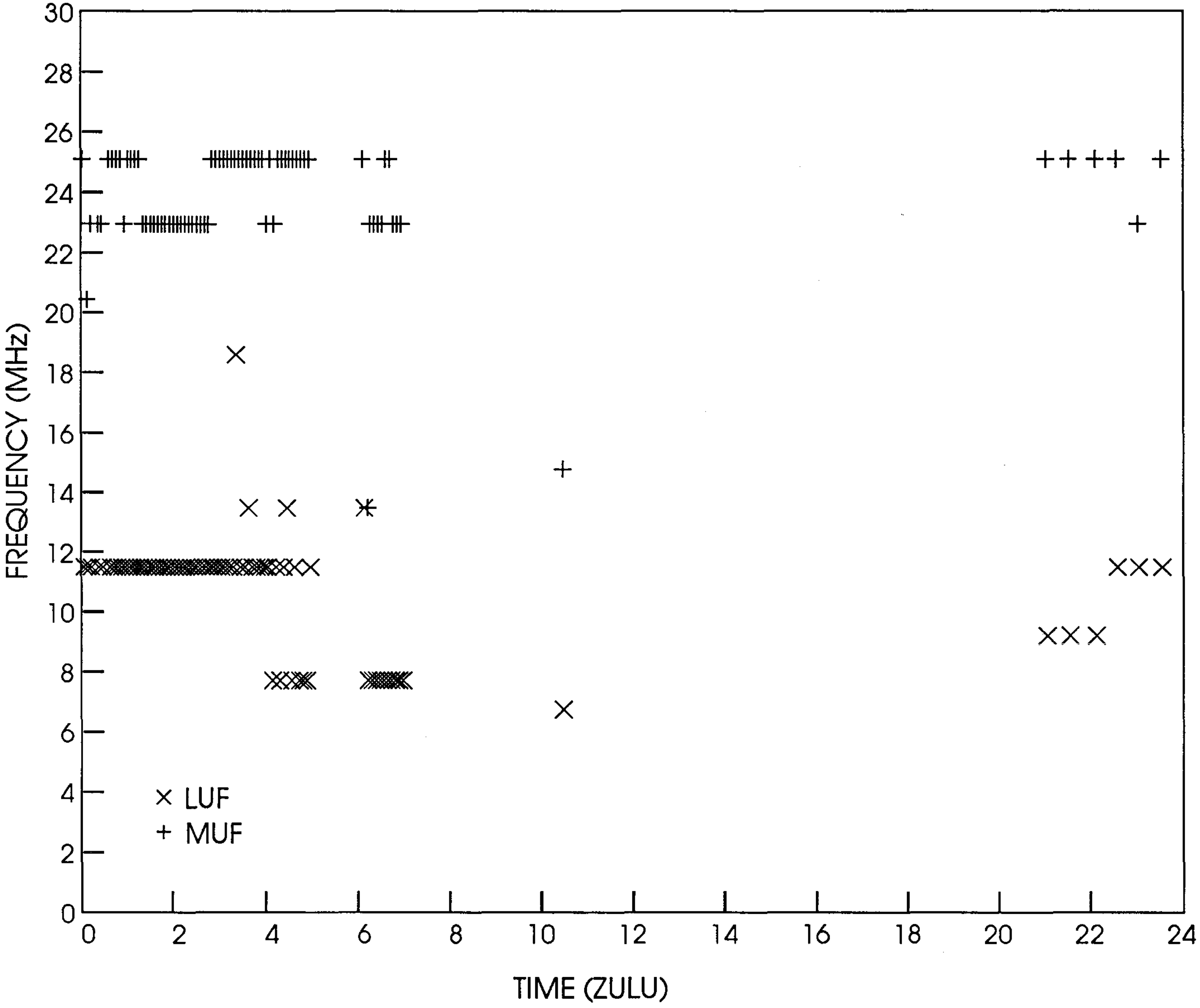


Figure B-7. Observed propagation January 18, 1992.

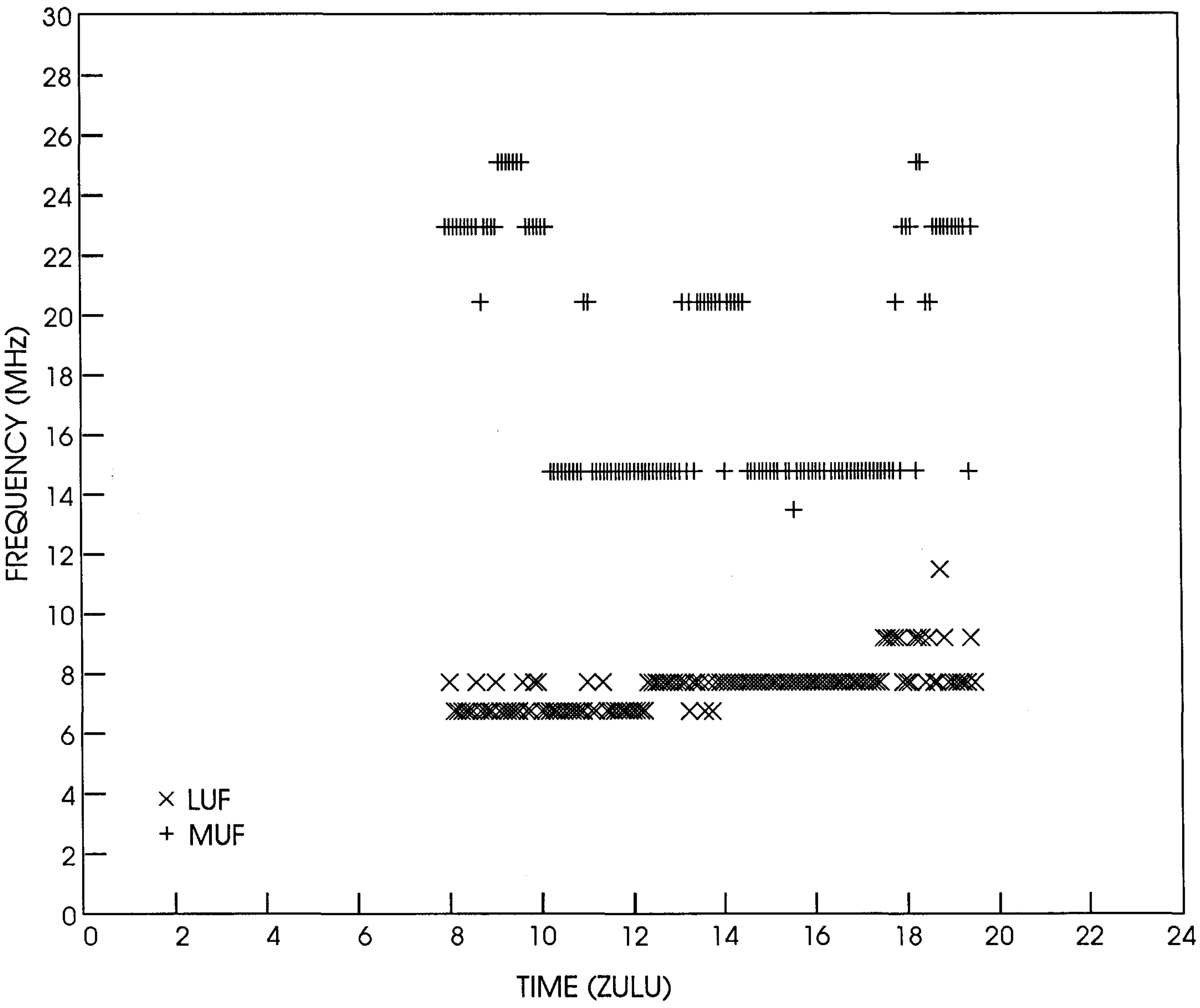


Figure B-8. Observed propagation January 19, 1992.

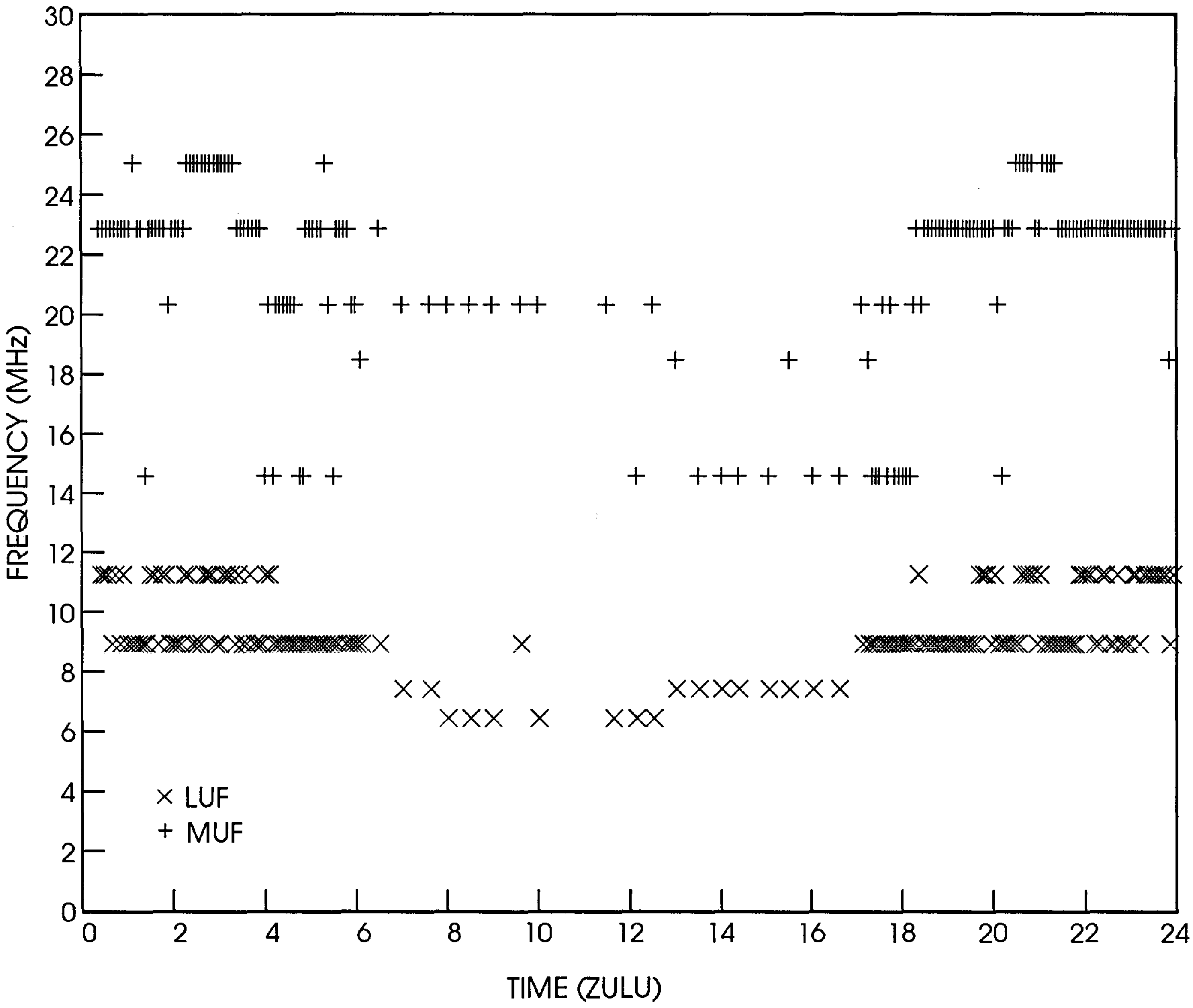


Figure B-9. Observed propagation January 20, 1992.

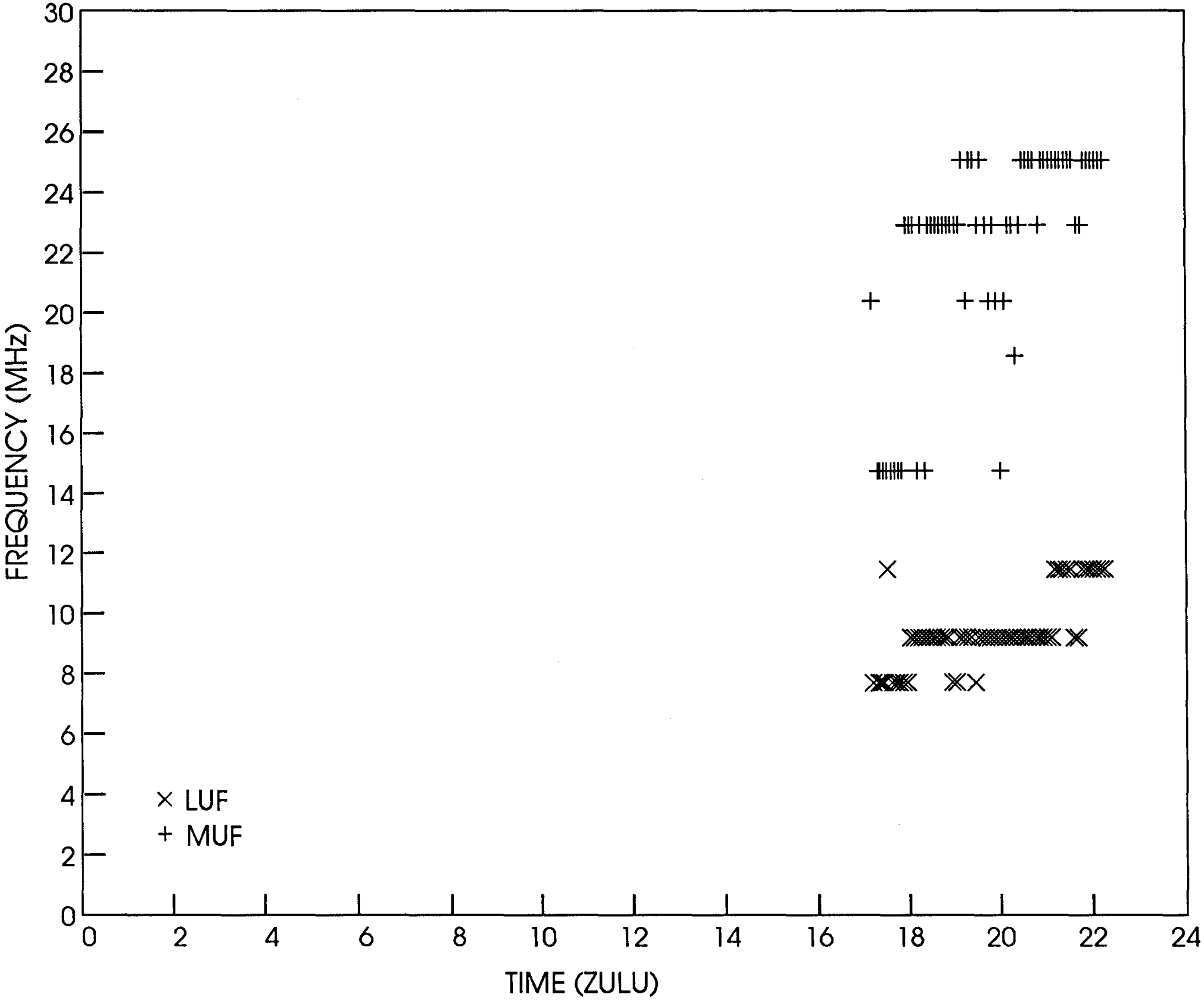


Figure B-10. Observed propagation January 21, 1992.

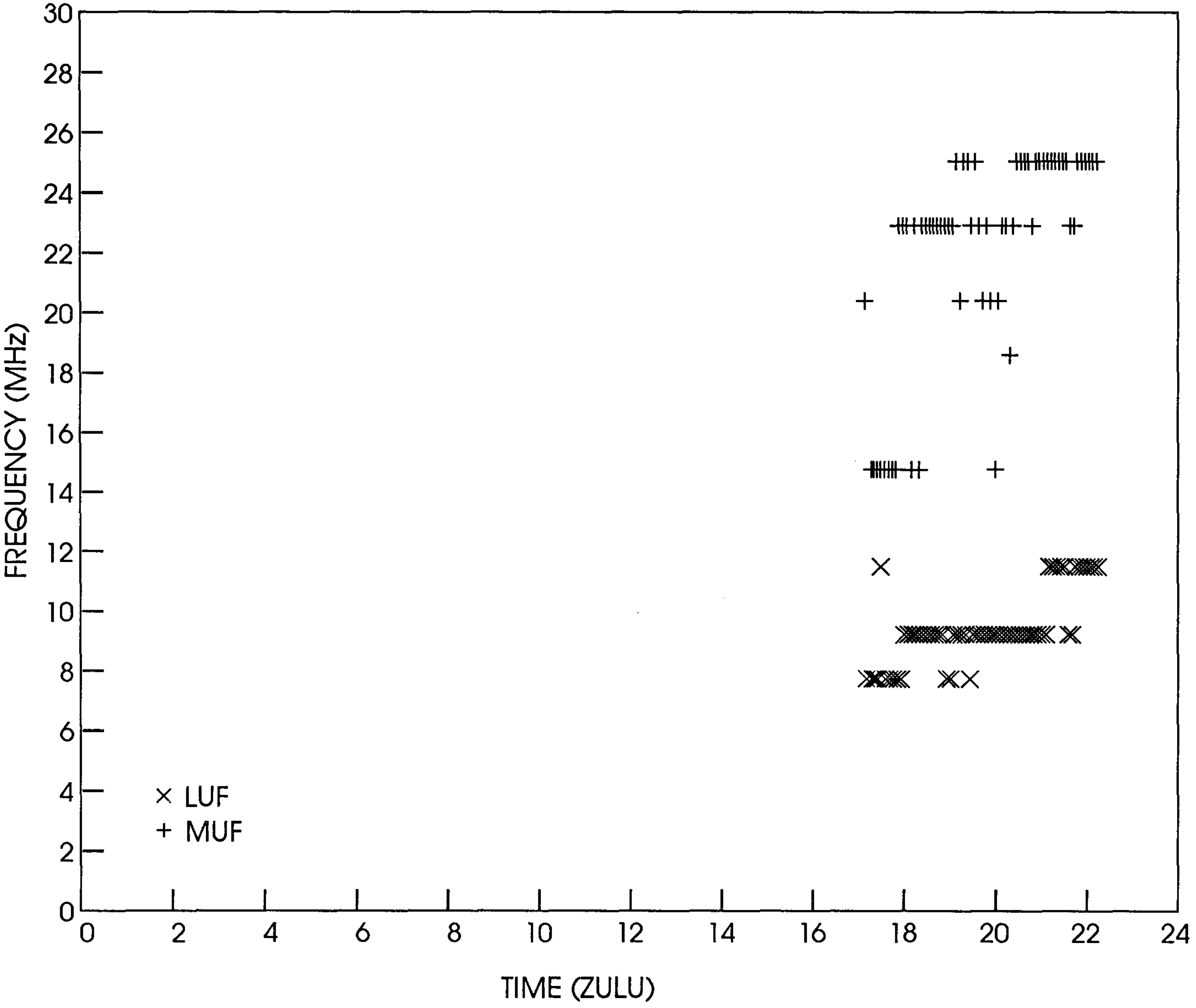
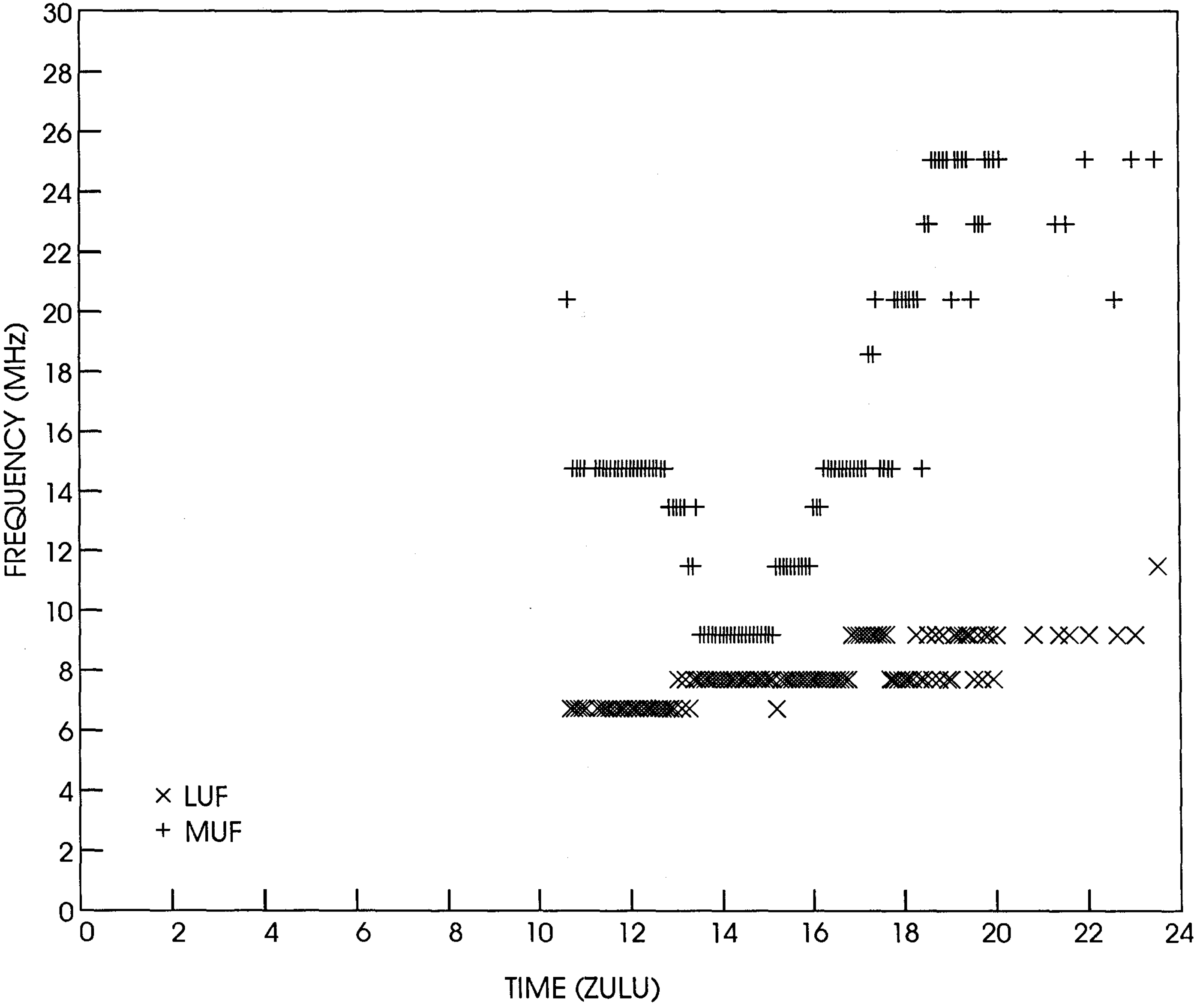


Figure B-11. Observed propagation January 22, 1992.



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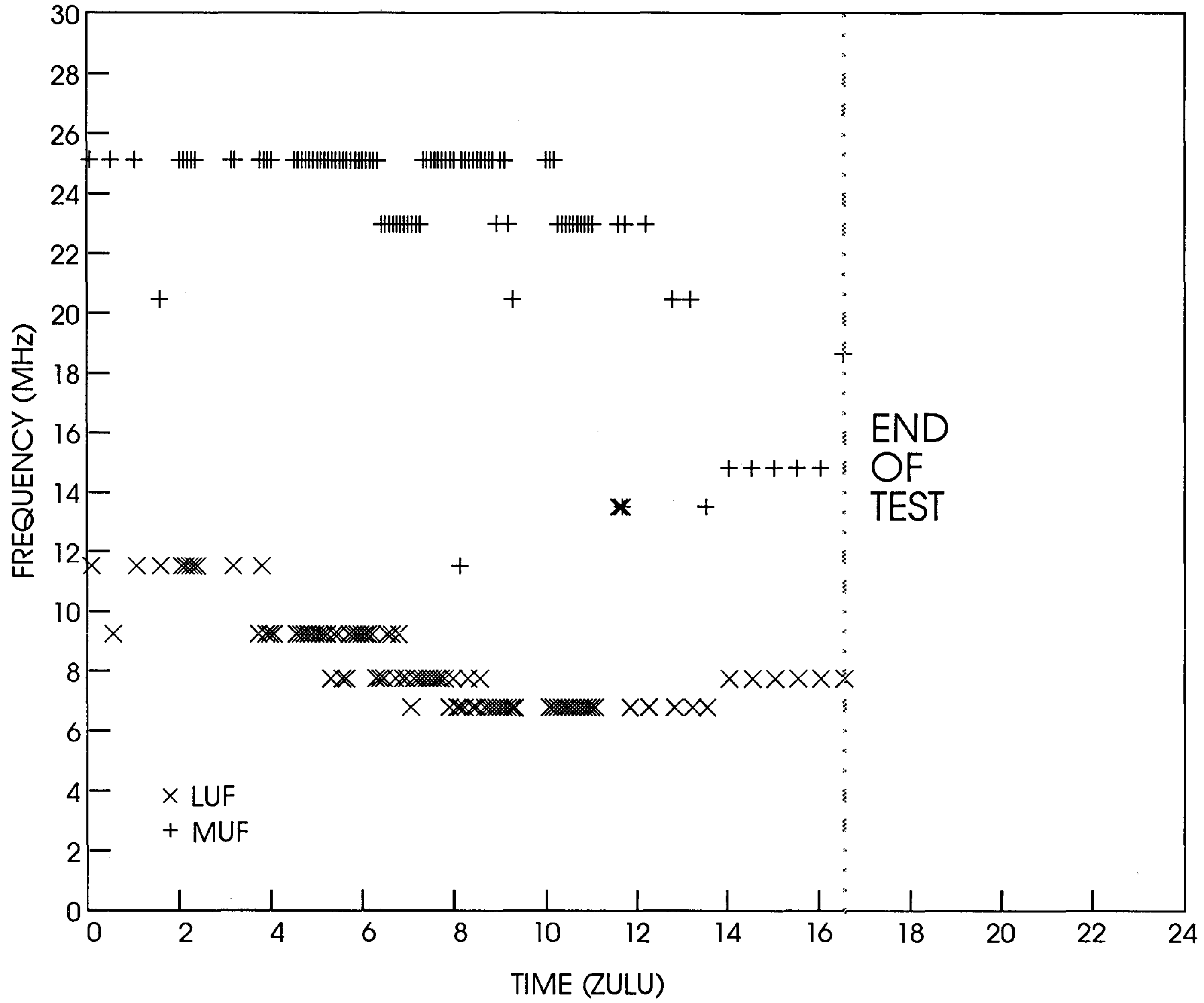

Figure B-13. Observed propagation January 24, 1992.

APPENDIX C: PATTERN OF U.S. NAVY COMSTA FREQUENCY SELECTION

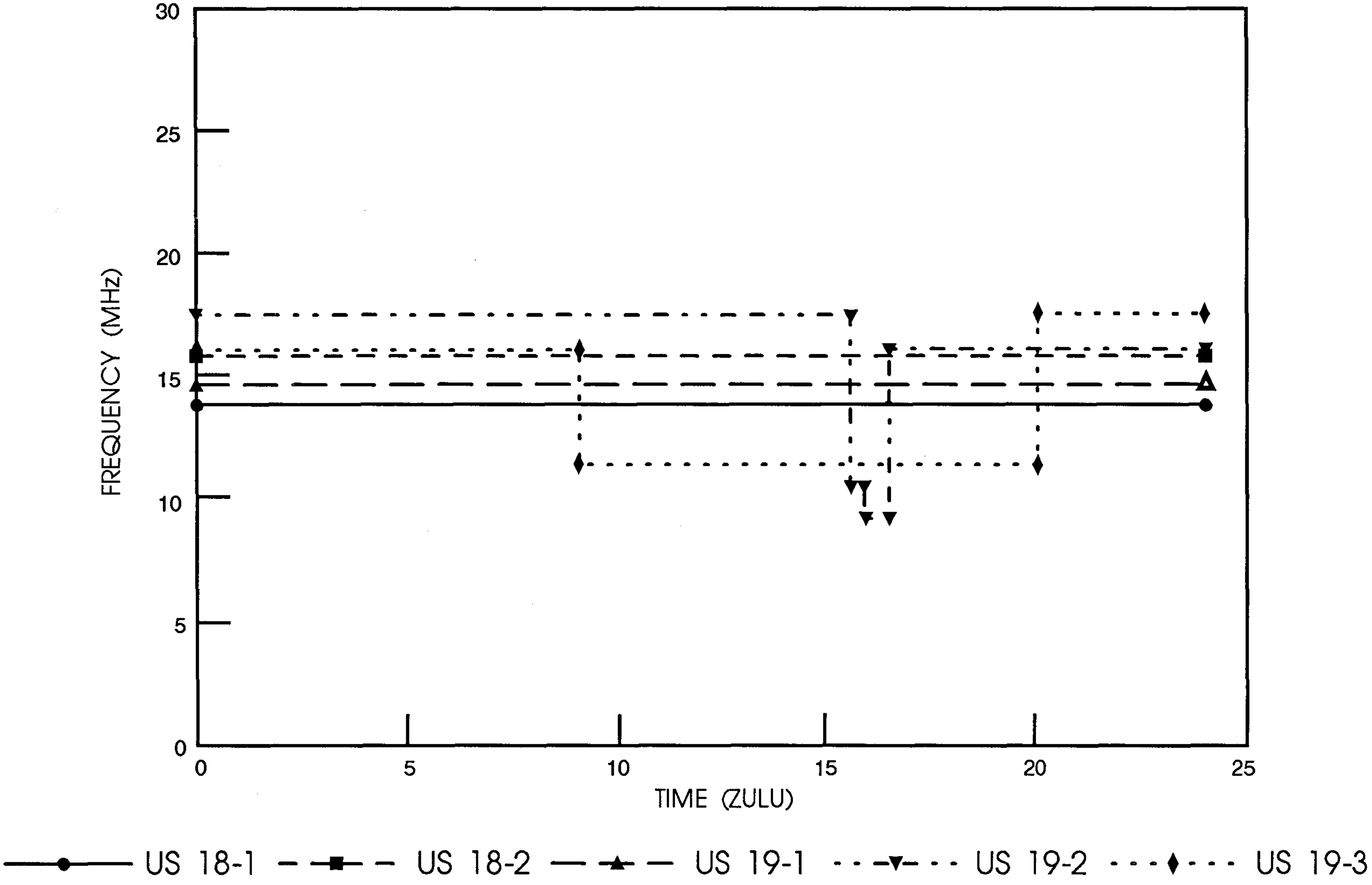

Figure C-1. U.S. Navy operational frequencies, January 12, 1992.

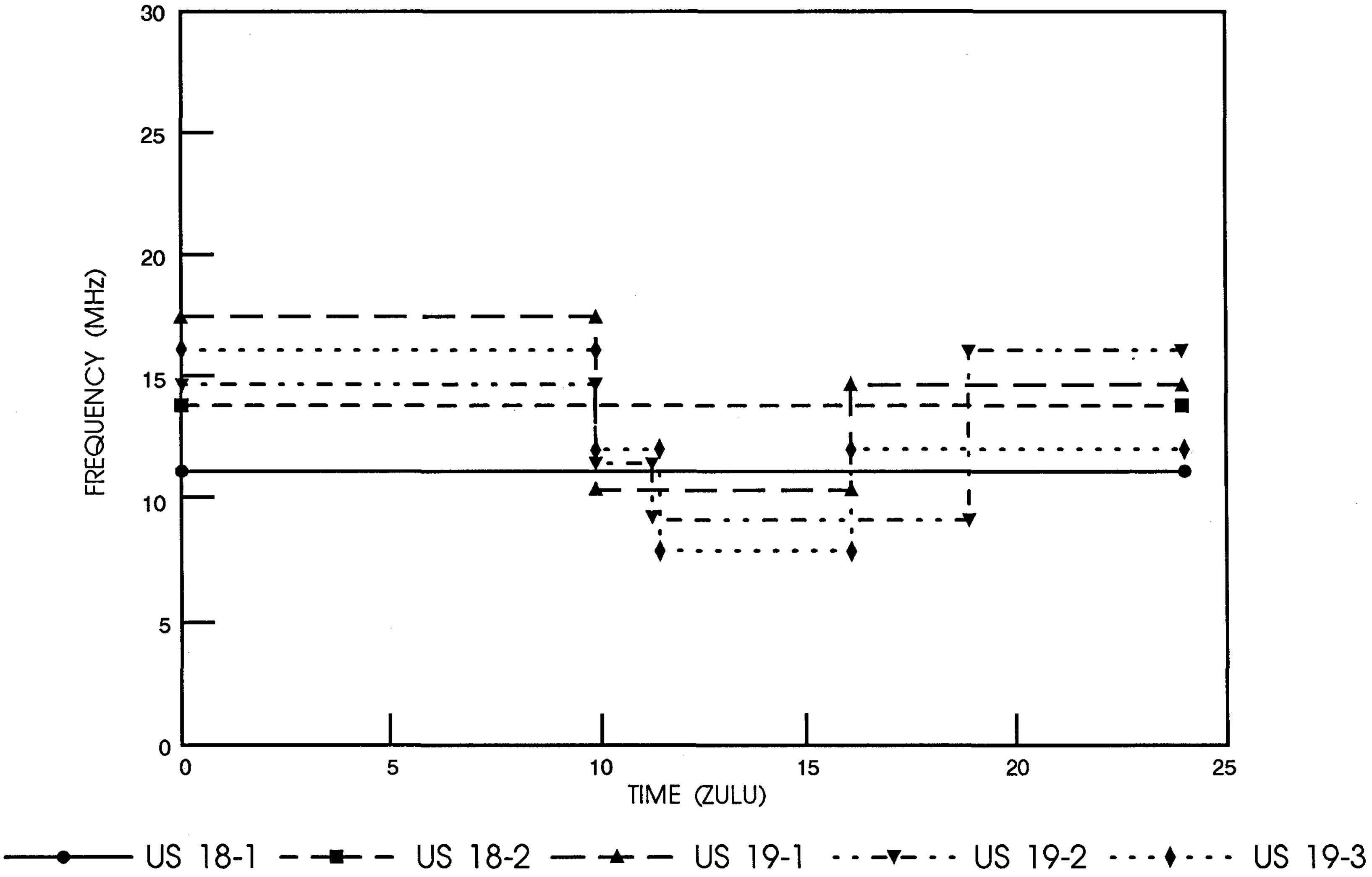

Figure C-2. U.S. Navy operational frequencies, January 13, 1992.

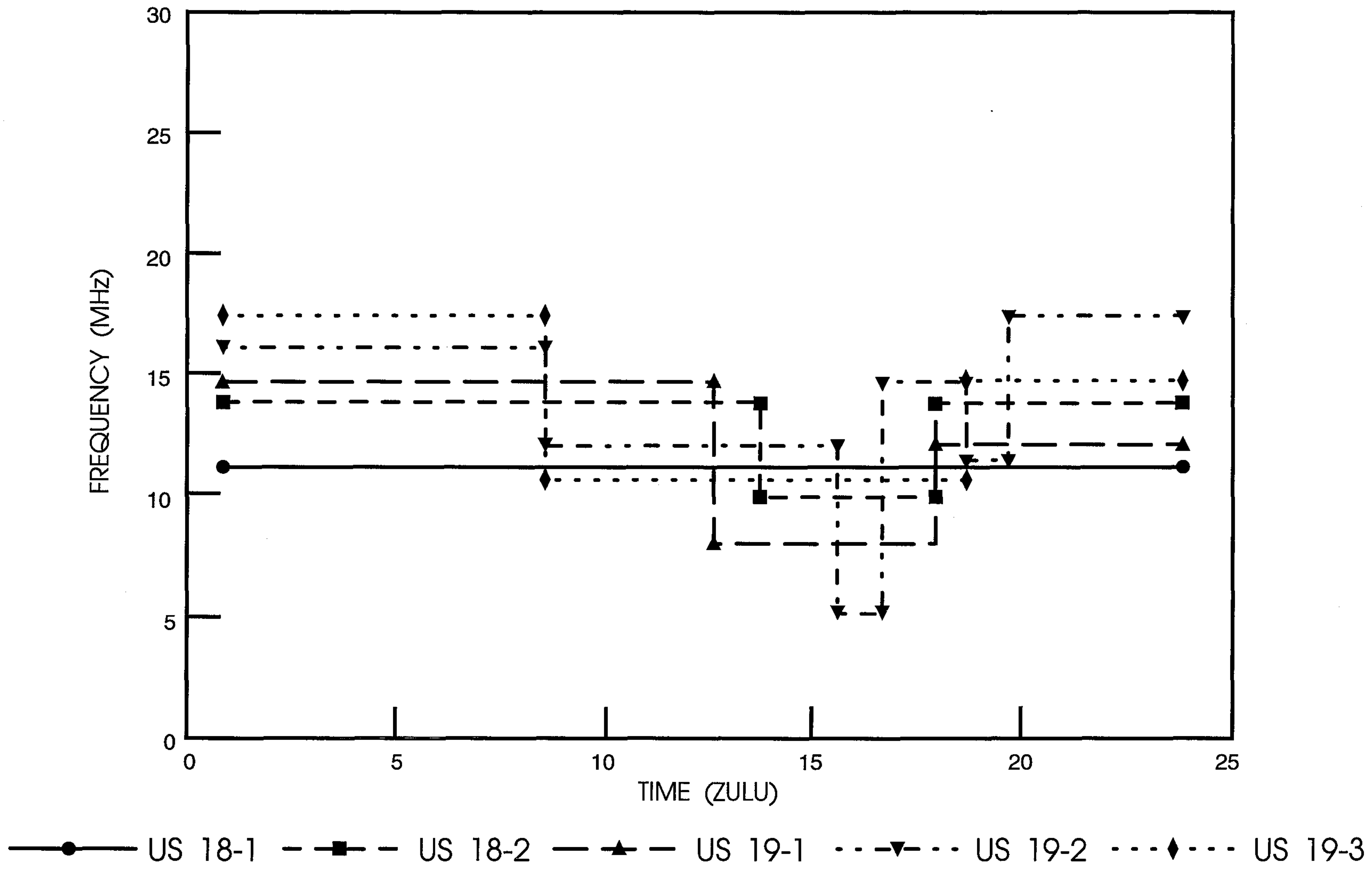

Figure C-3. U.S. Navy operational frequencies, January 14, 1992.

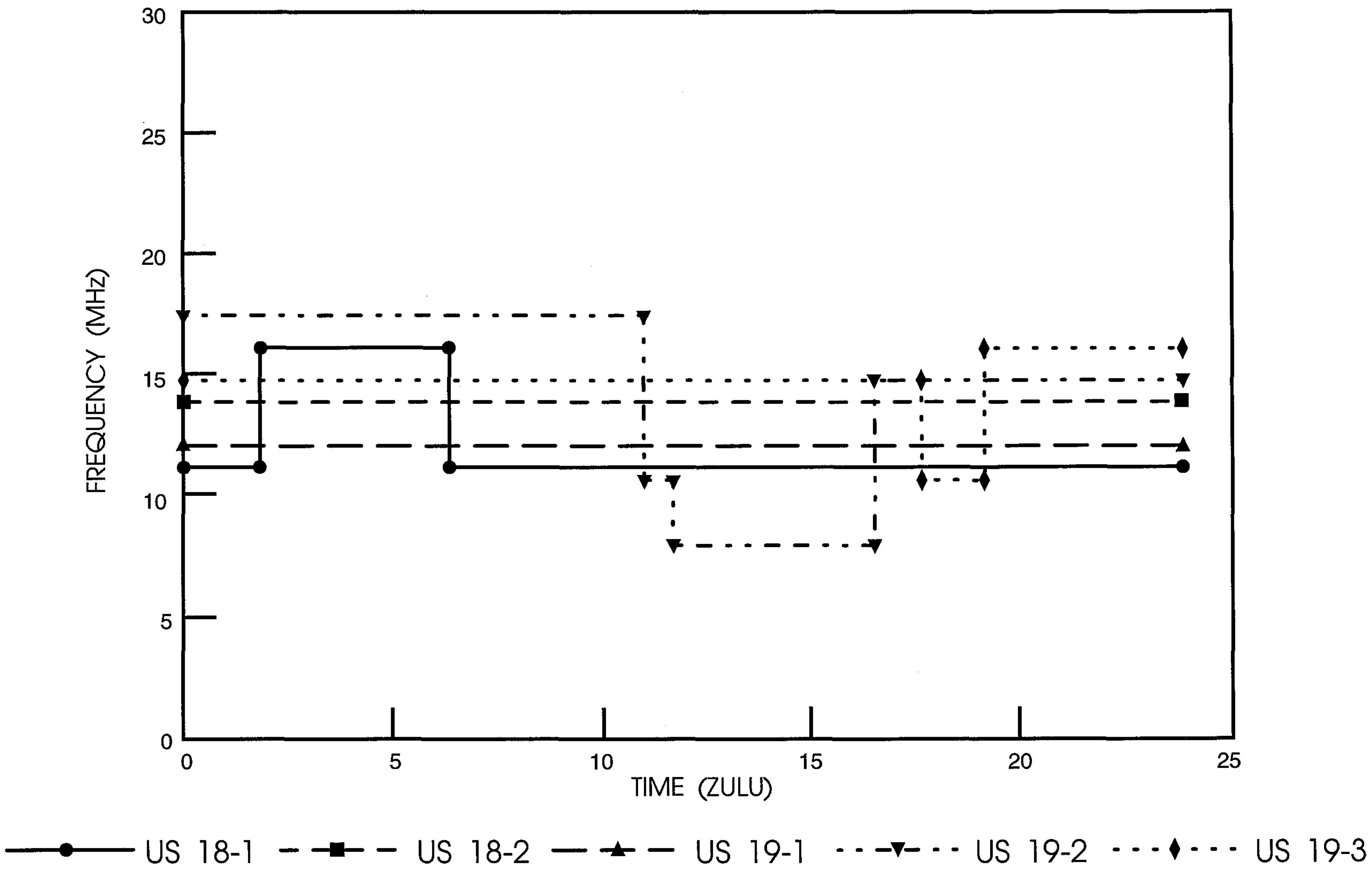

Figure C-4. U.S. Navy operational frequencies, January 15, 1992.

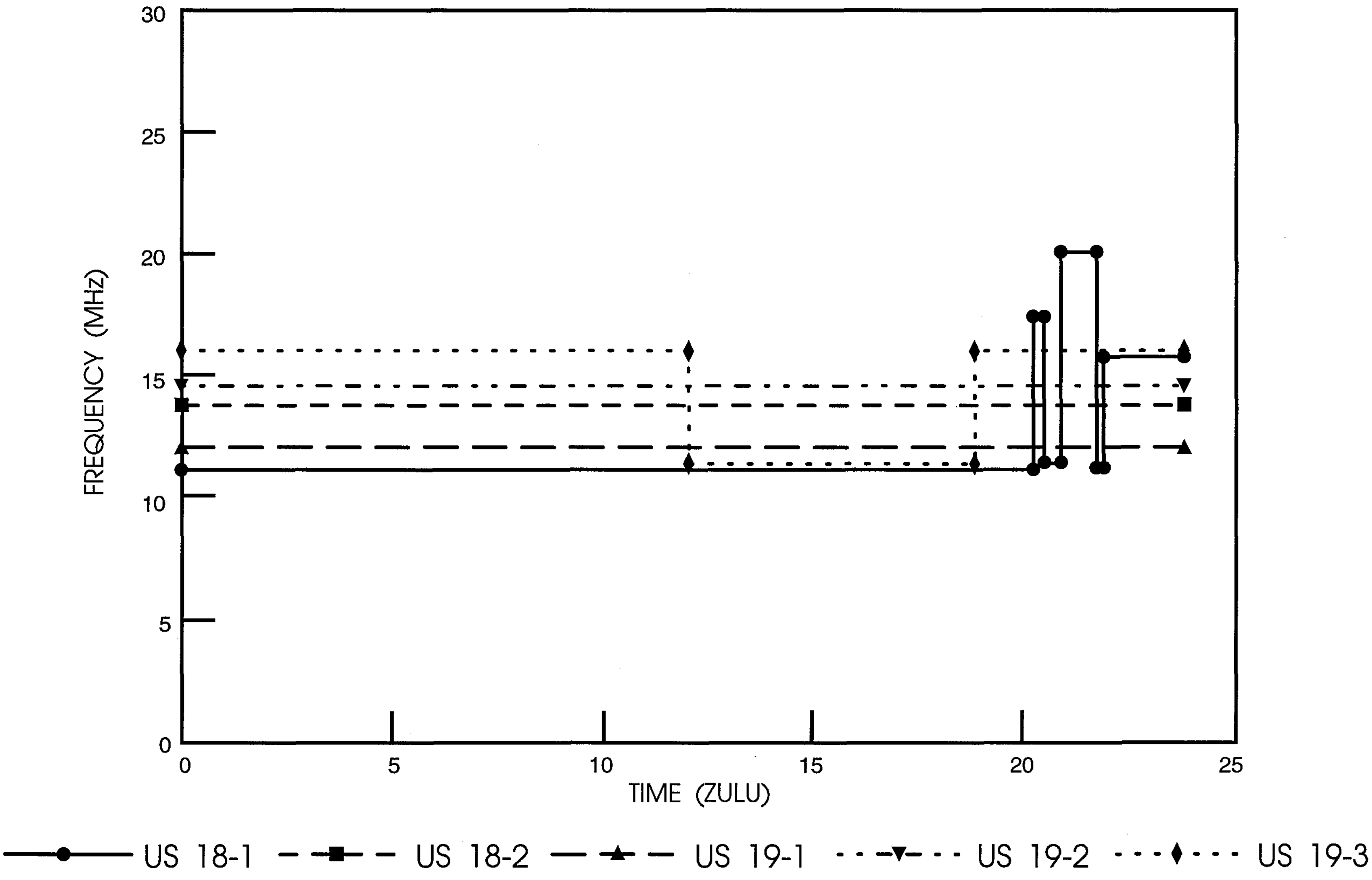

Figure C-5. U.S. Navy operational frequencies, January 16, 1992.

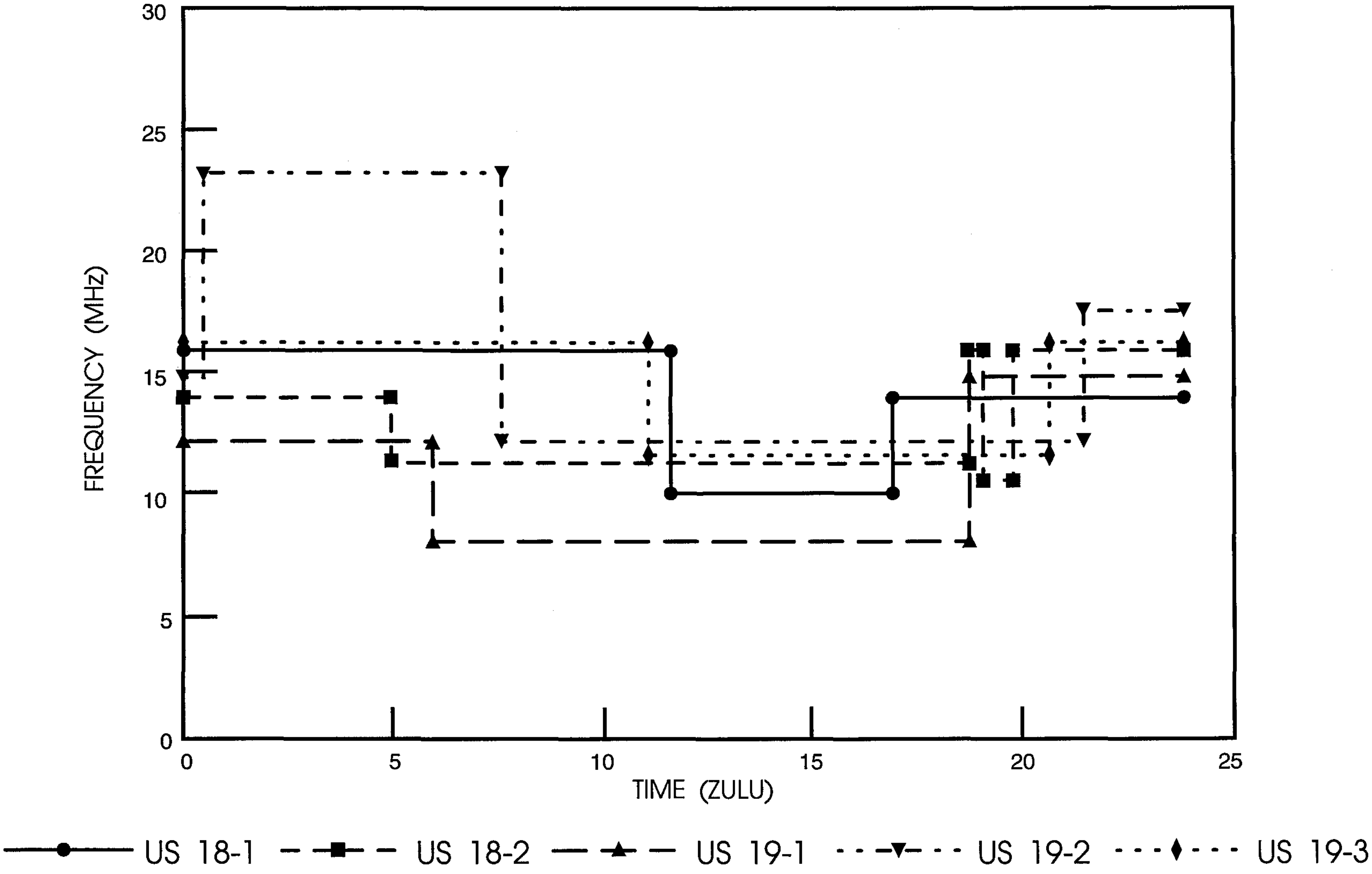

Figure C-6. U.S. Navy operational frequencies, January 17, 1992.

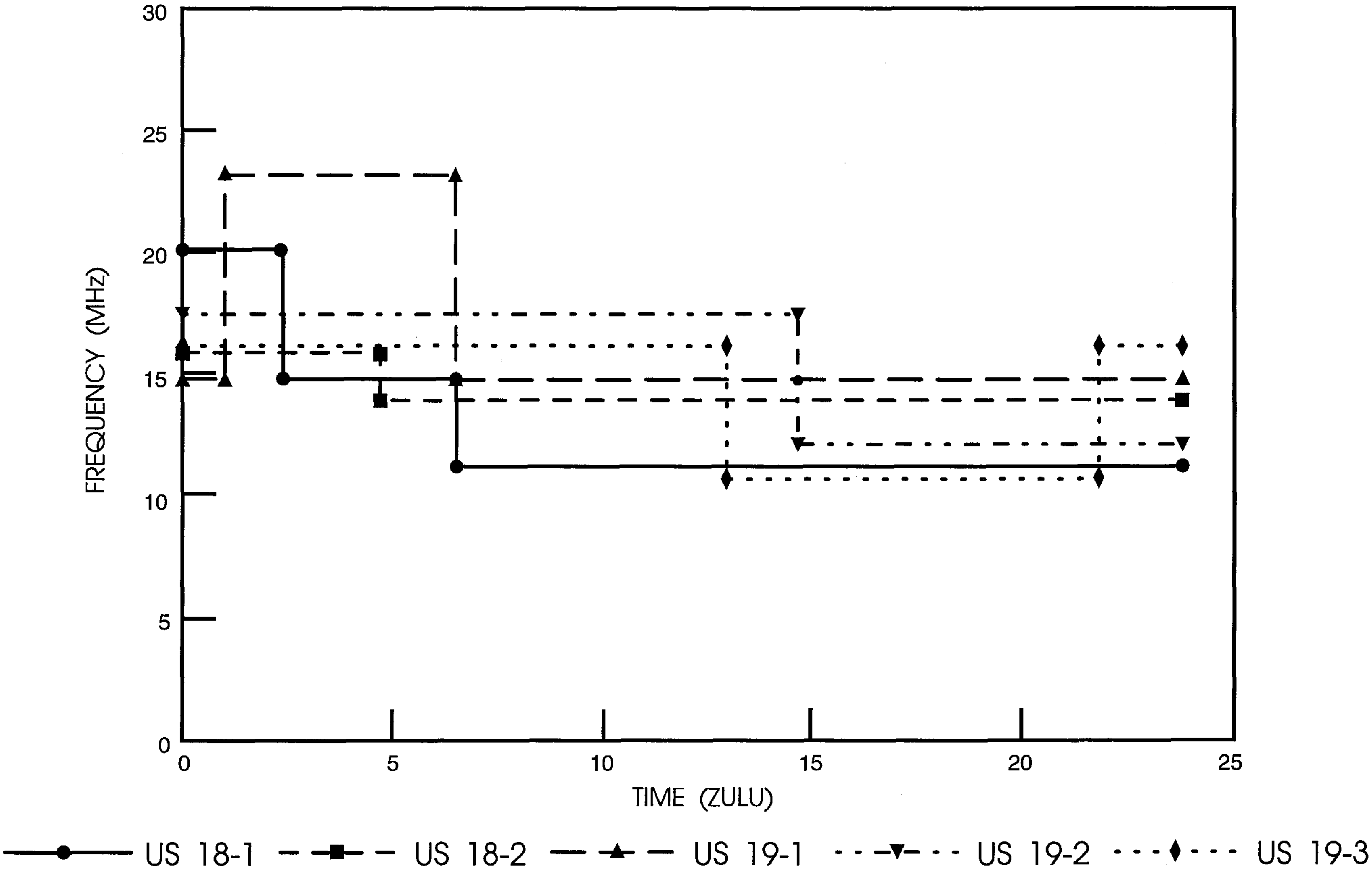

Figure C-7. U.S. Navy operational frequencies, January 18, 1992.

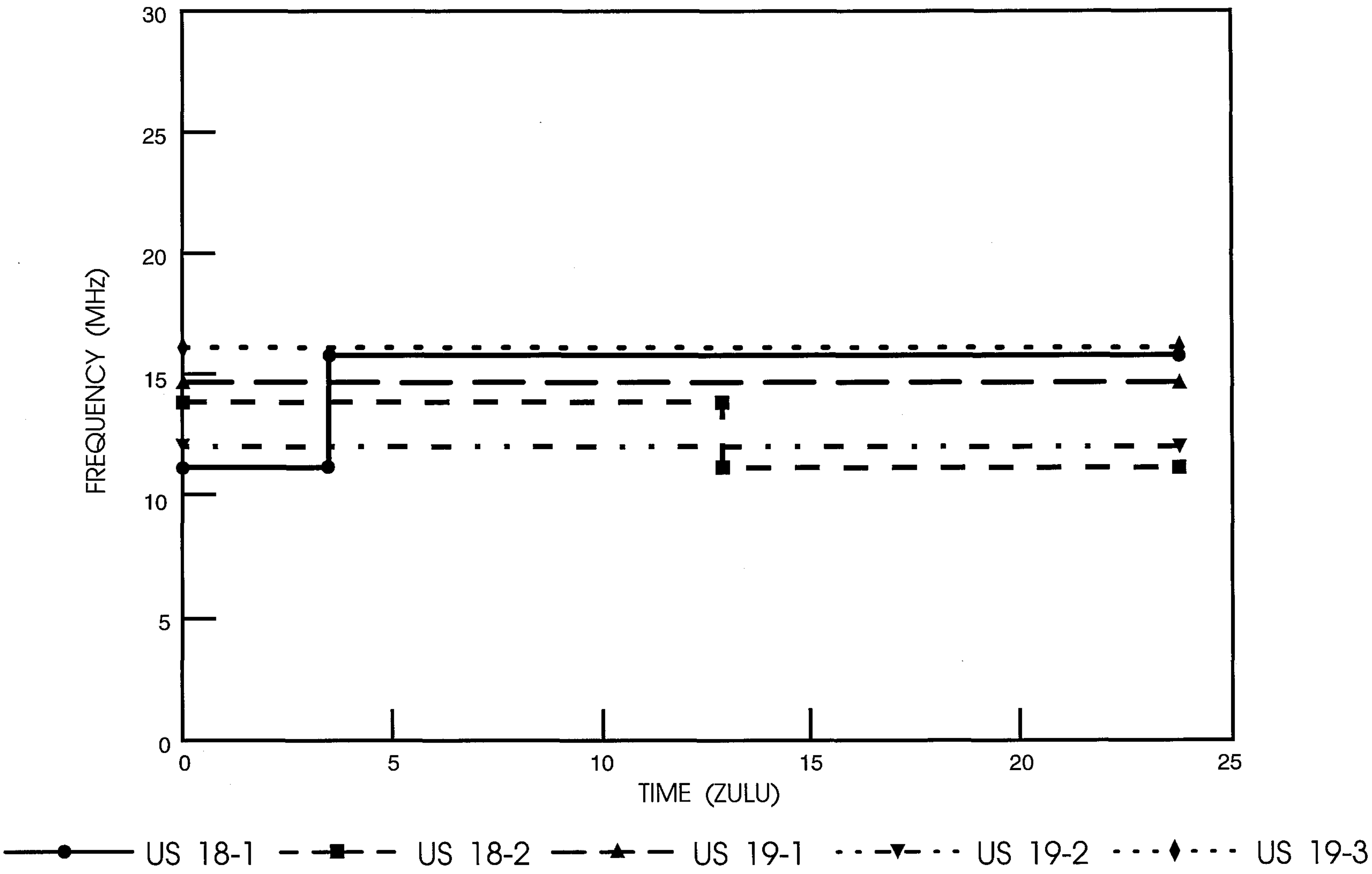

Figure C-8. U.S. Navy operational frequencies, January 19, 1992.

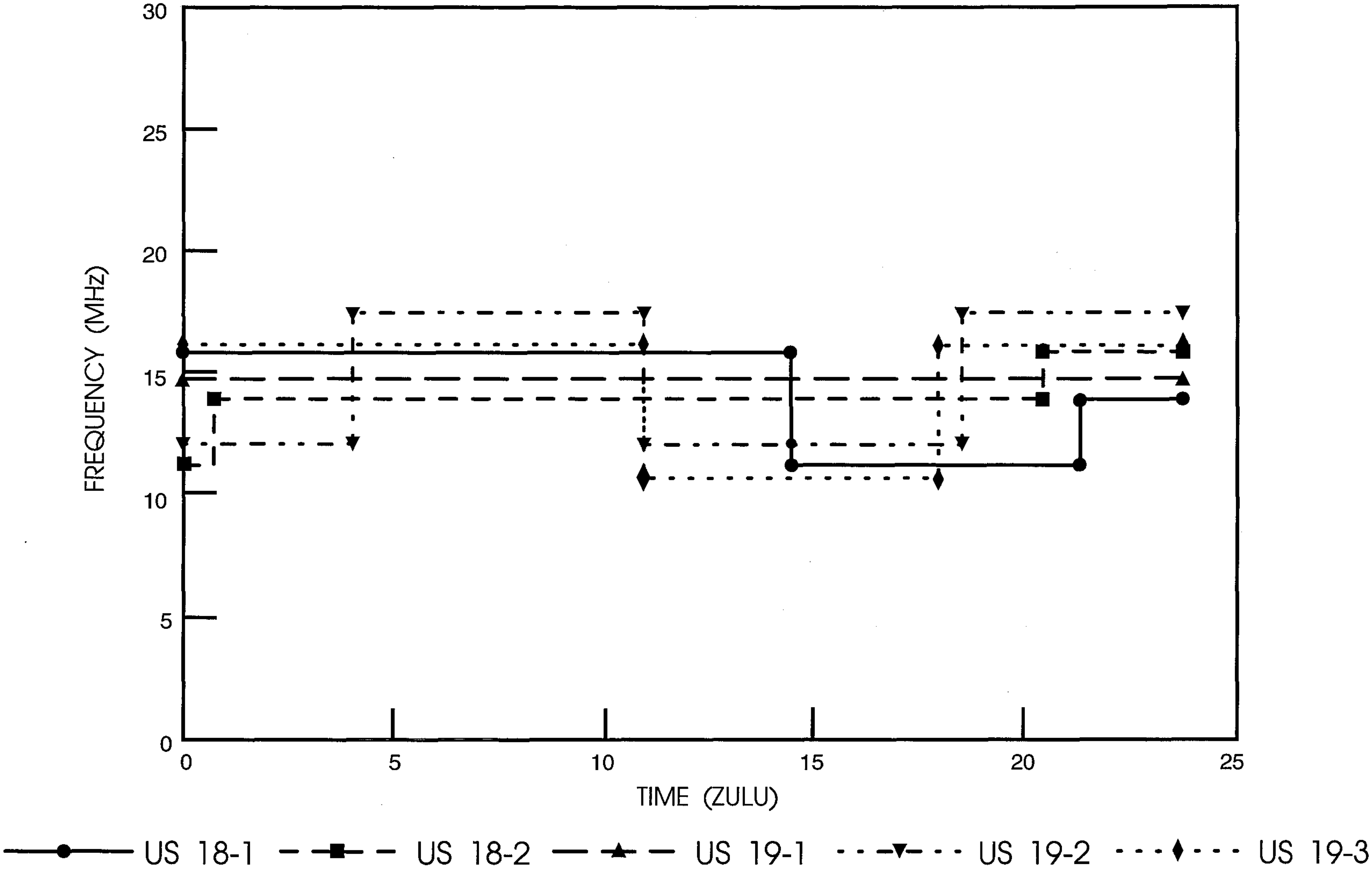

Figure C-9. U.S. Navy operational frequencies, January 20, 1992.

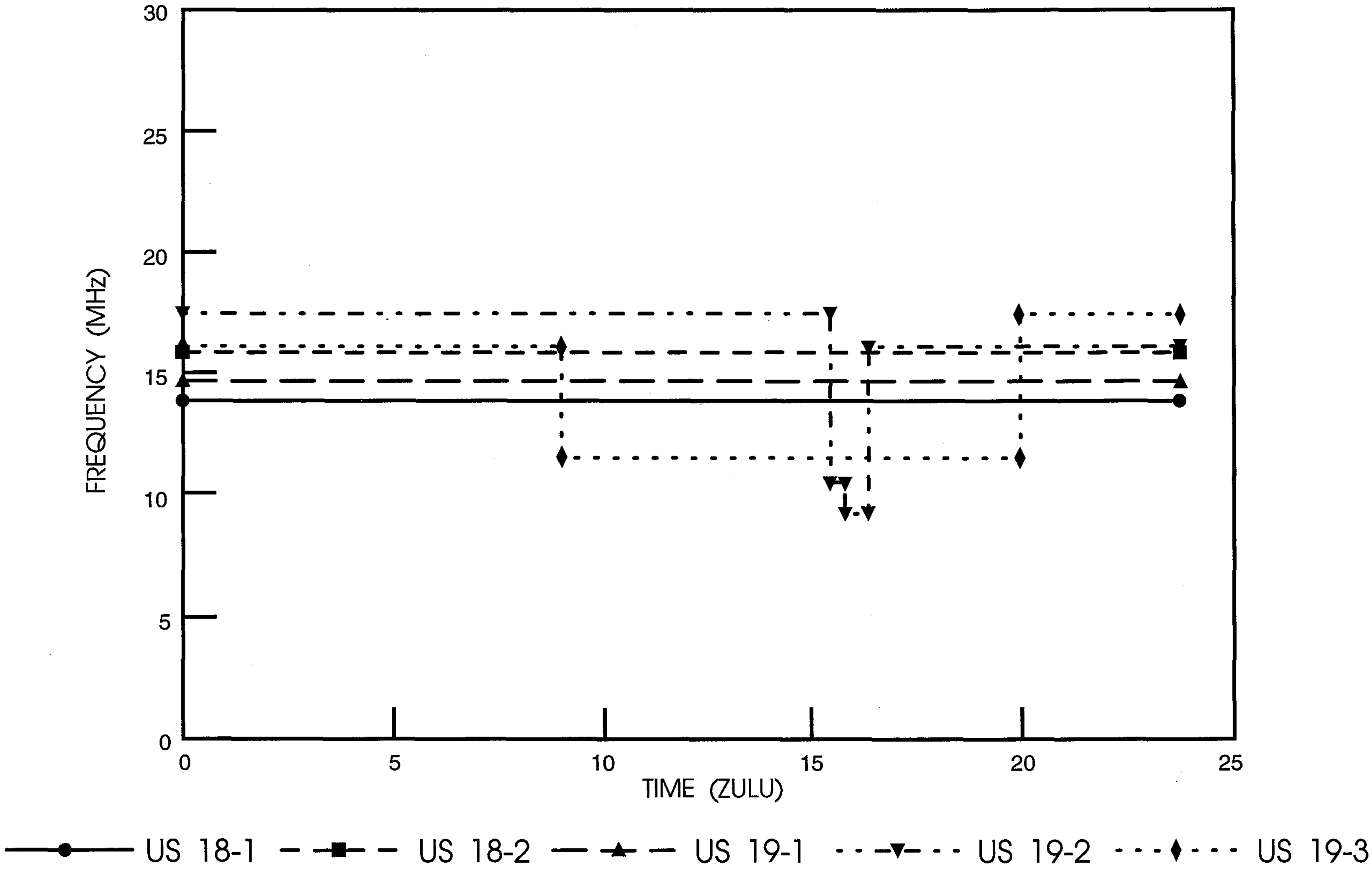

Figure C-10. U.S. Navy operational frequencies, January 21, 1992.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report presents the results of two weeks of bi-directional high-frequency radio path soundings in a trans-auroral environment between Christchurch, New Zealand, and the U.S. station, McMurdo (Black Island), Antarctica, during mid-January, 1992. The work was commissioned by the Naval Undersea Warfare Center, New London, CT, for the National Science Foundation. This investigation demonstrated the value of ALE adaptive radio systems as a real-time frequency management tool. Based on the results observed, the authors recommended that NSF consider the acquisition of a 1-kW ALE radio system to be used, primarily as an oblique ionospheric channel sounder, with their existing communications system. This addition would provide significant improvement to the NSF frequency management capability.

16. Key Words *(Alphabetical order, separated by semicolons)*

adaptive radio; ALE; Antarctica; automatic link establishment; communications; frequency management; high frequency; high latitude; radio

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