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

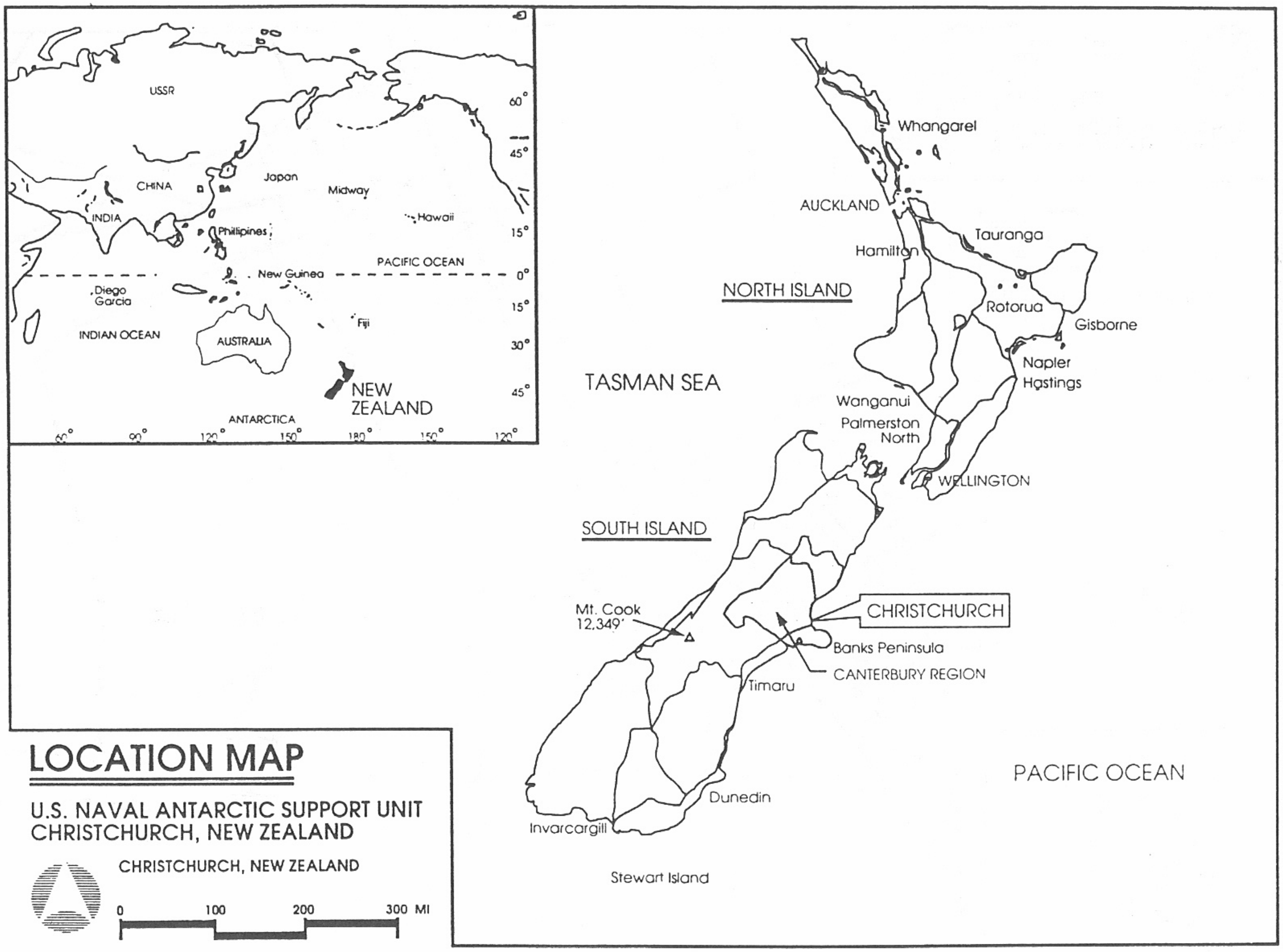


Figure 1. Location map, U.S. Naval Antarctic Support Unit, Christchurch, New Zealand.

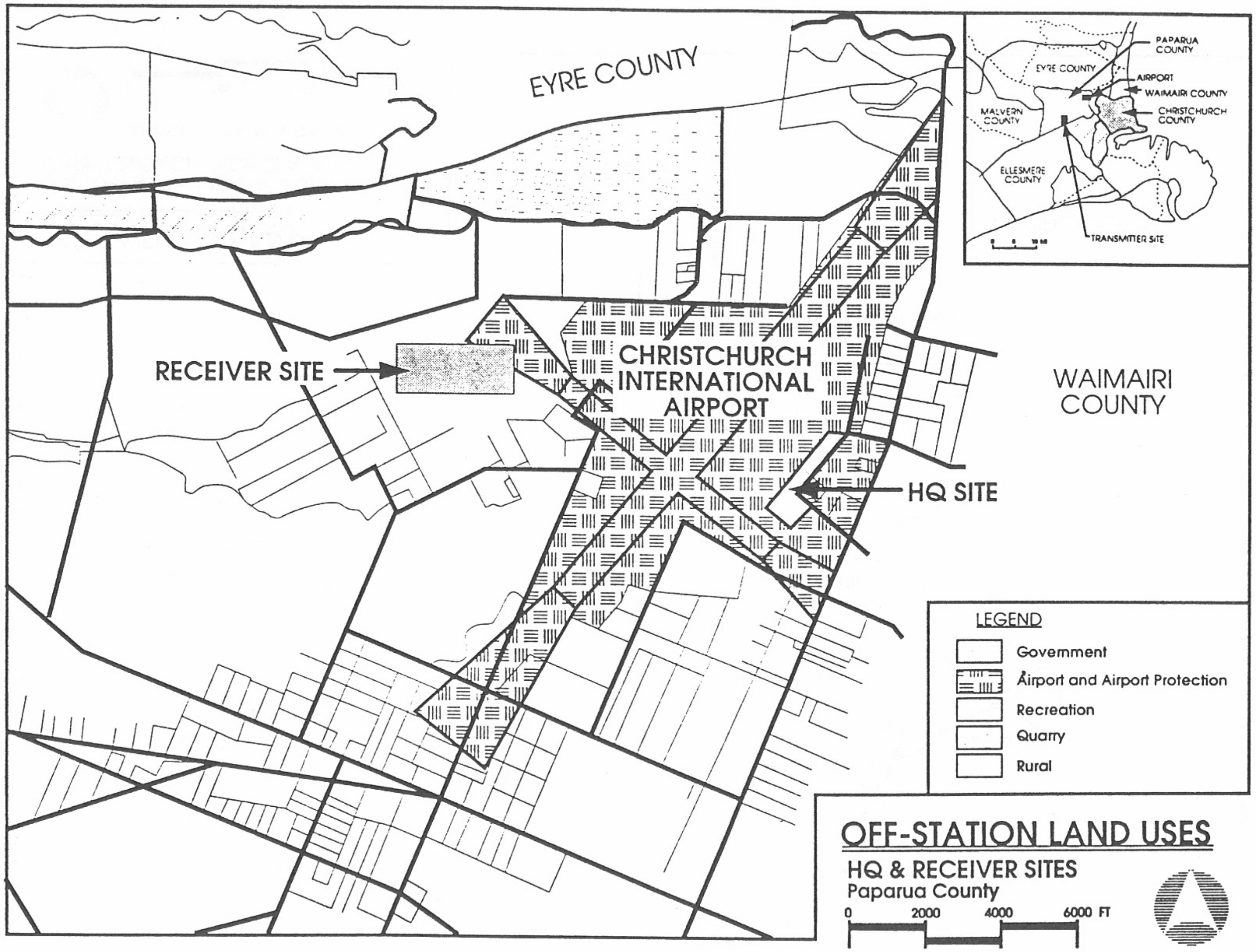


Figure 2. Location map, HQ and receiver sites.

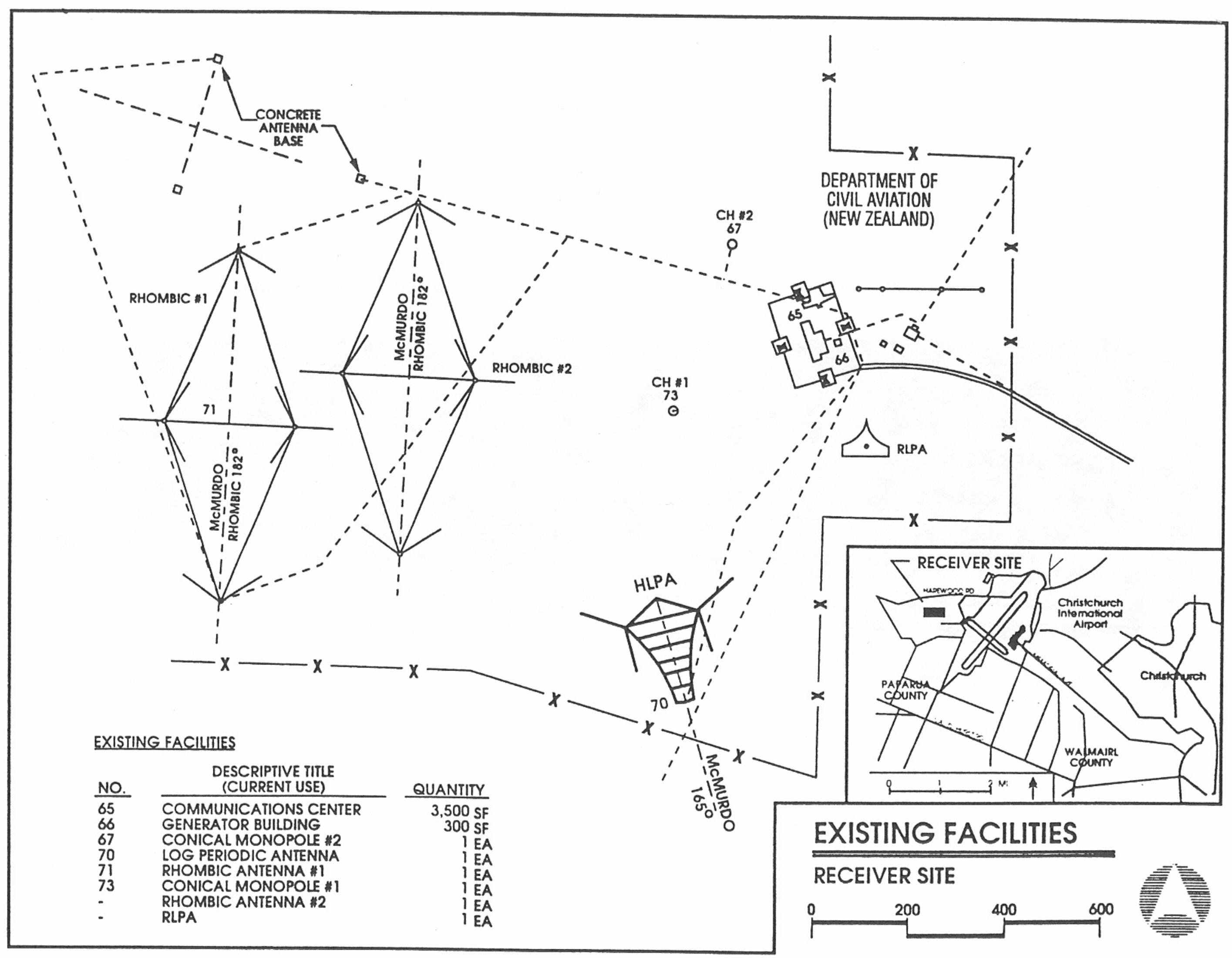


Figure 3. Site plan - receiver site.

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.

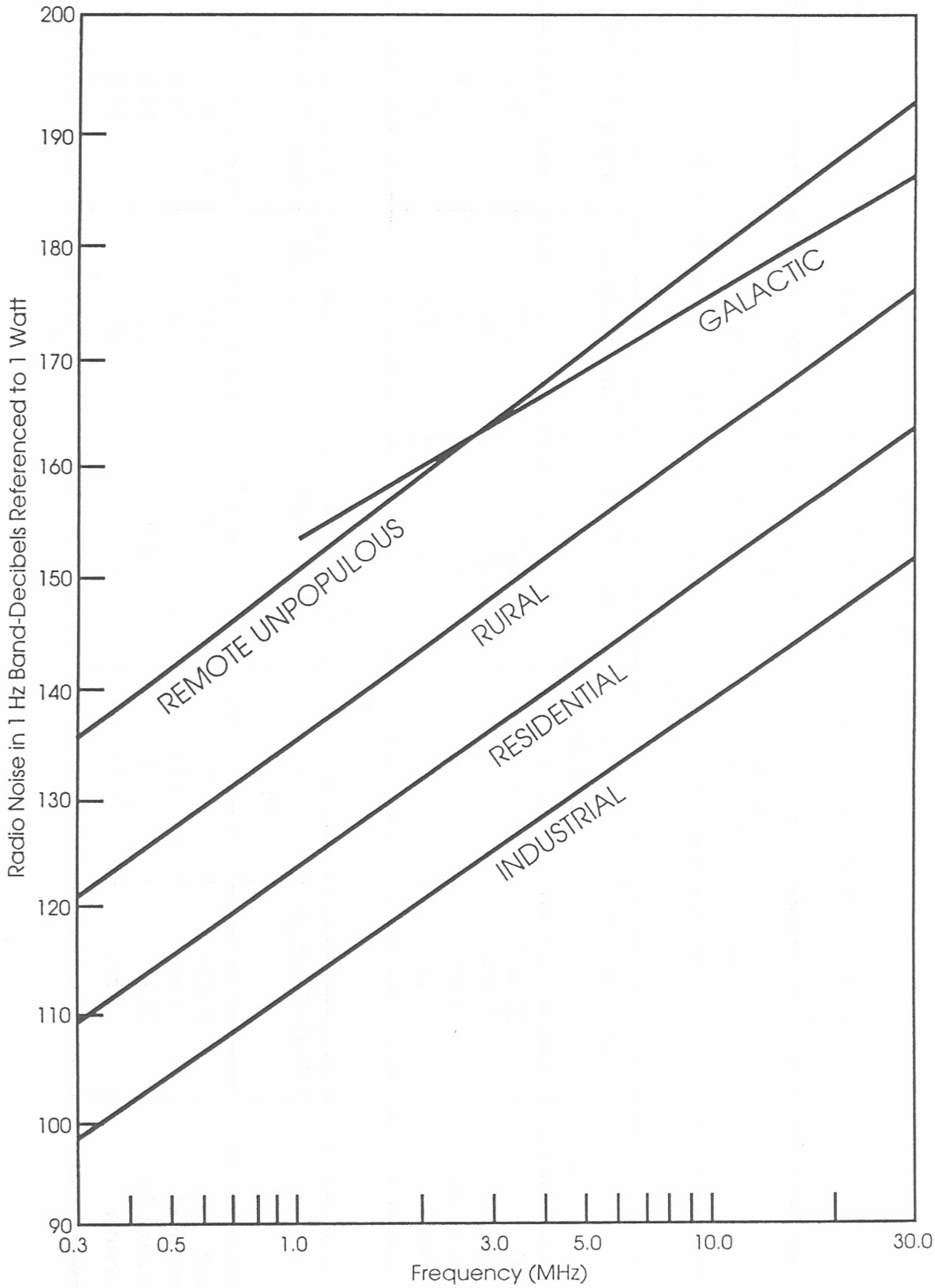


Figure 5. Levels of manmade noise in the HF spectrum (USA, 1972).

Table 1. Predicted Circuit Availability Versus Manmade Noise Levels

McMurdo (T) to Christchurch (R)
Pwr = 4 kW, BW = 3 kHz, Ant = rhombic, S/N req = 13.0 dB

	Daily Coverage	Rx Noise, dBm/Hz	dBm (2.7 kHz)	Noise < Sig, dB	Avg S/N @ FOT
SSN = 10					
Rural	23 hrs	-148	-113.7	-34.2	37.2
Residential	21 hrs	-136	-101.7	-23.3	26.9
Receiver Site	18 hrs	-130	-95.7	-17.5	21.7
Industrial	11 hrs	-125	-90.7	-12.5	17.0
SSN = 150					
	Daily Coverage	Rx Noise, dBm/Hz	dBm (2.7 kHz)	Noise < Sig, dB	Avg S/N @ FOT
Rural	23 hrs	-148	-113.7	-31.7	45.0
Residential	23 hrs	-136	-101.7	-23.5	29.3
Receiver Site	22 hrs	-130	-95.7	-18.0	24.2
Industrial	15 hrs	-125	-90.7	-13.6	21.4

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

Time (local)	dB > KT_oB (1 MHz)	dB > KT_oB (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_oB (1 MHz)	dB > KT_oB (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

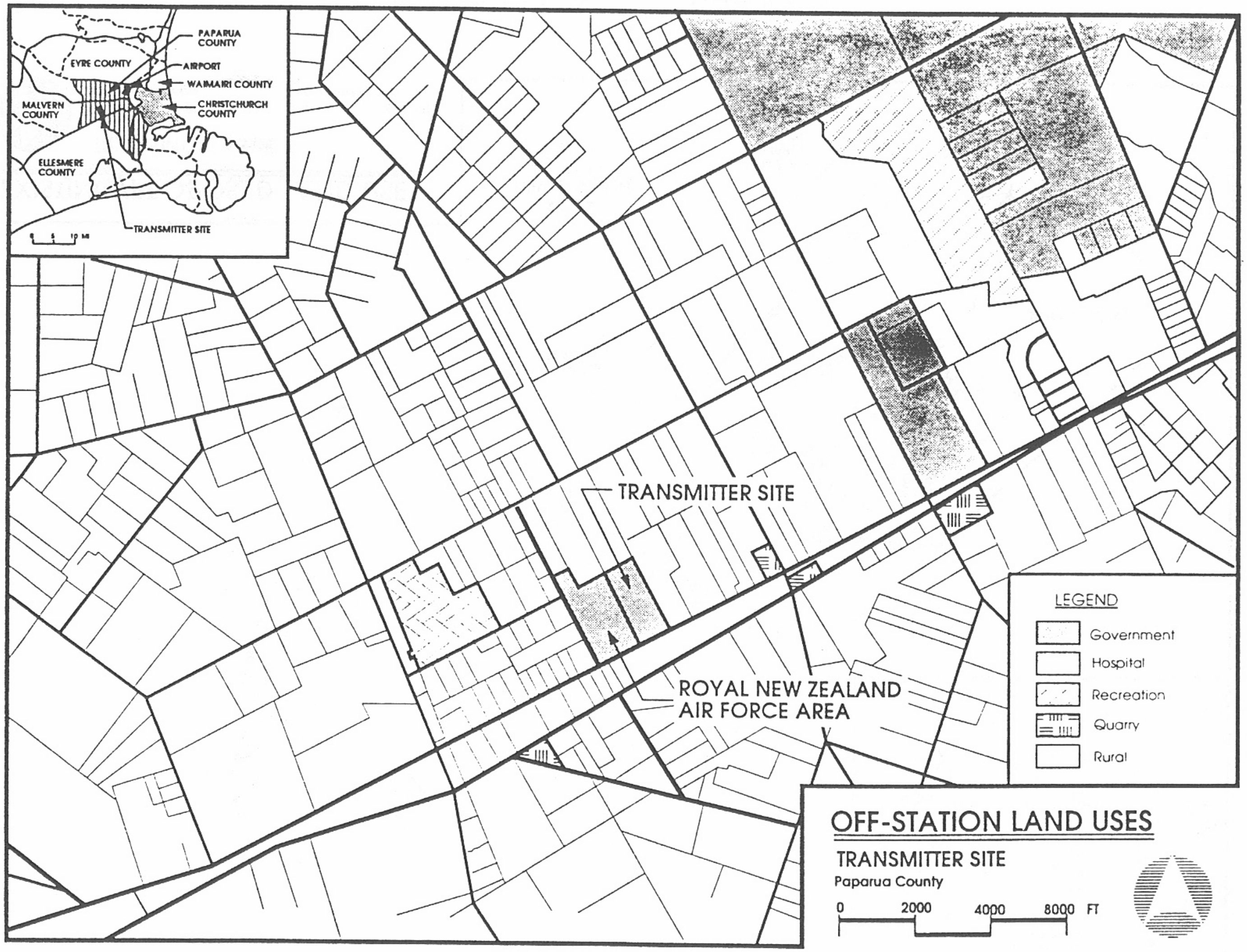


Figure 6. Location map - transmitter site.

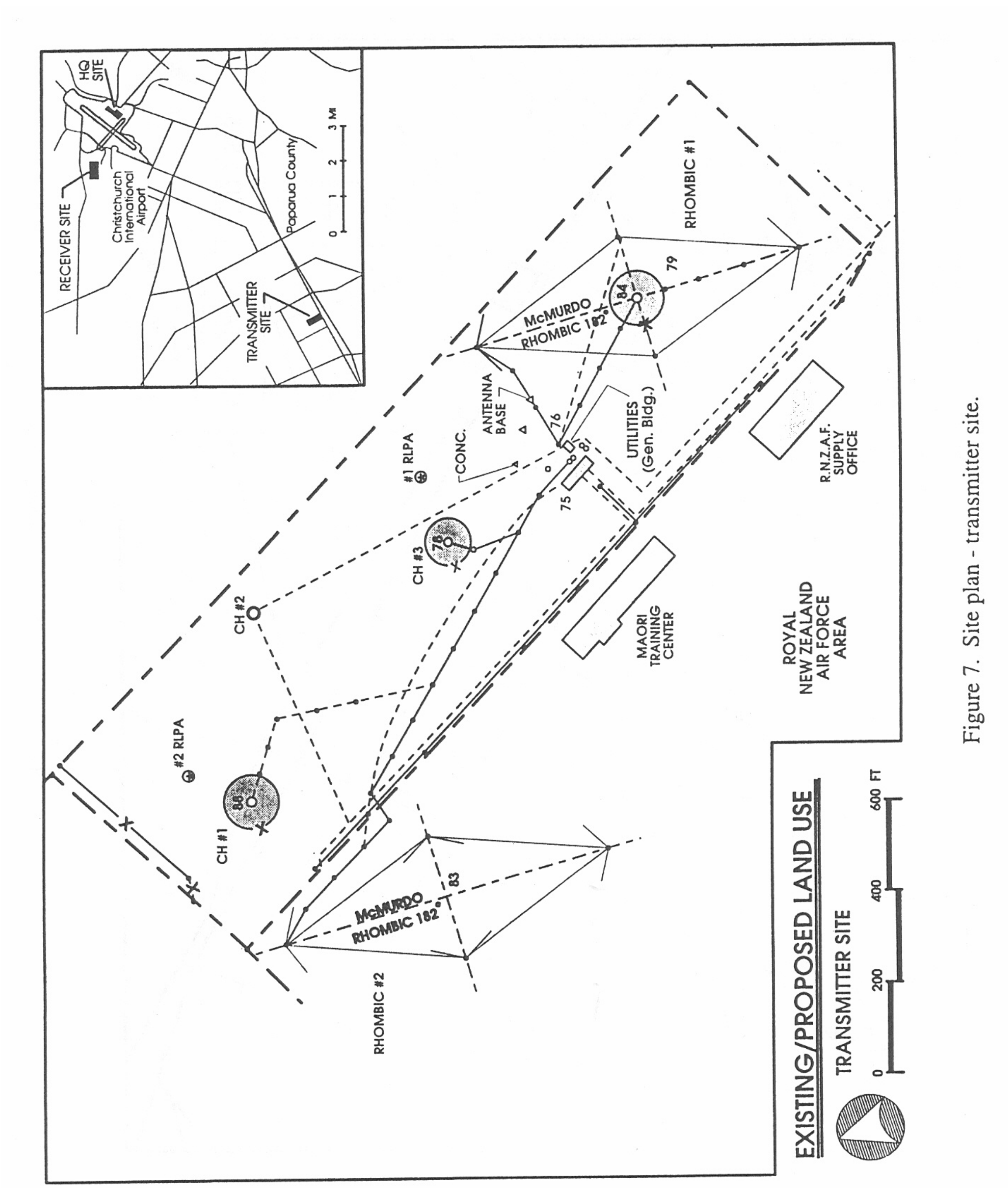
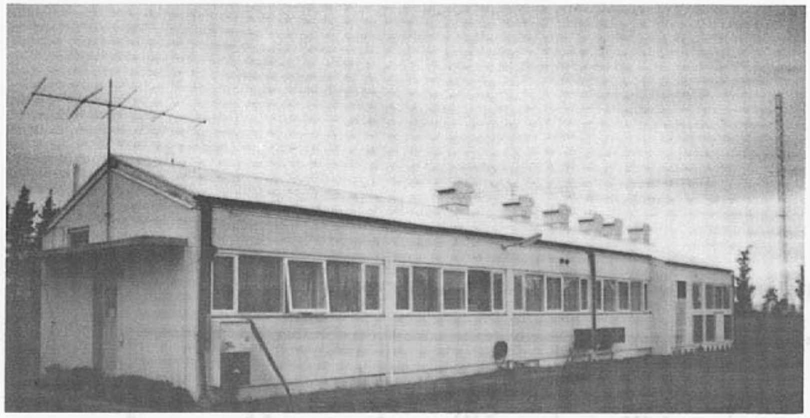
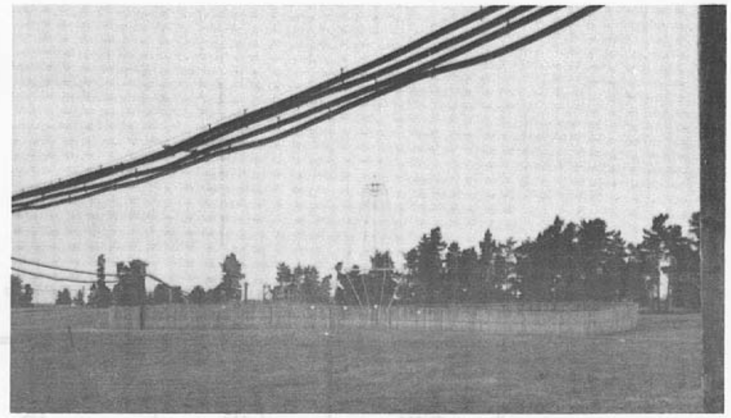


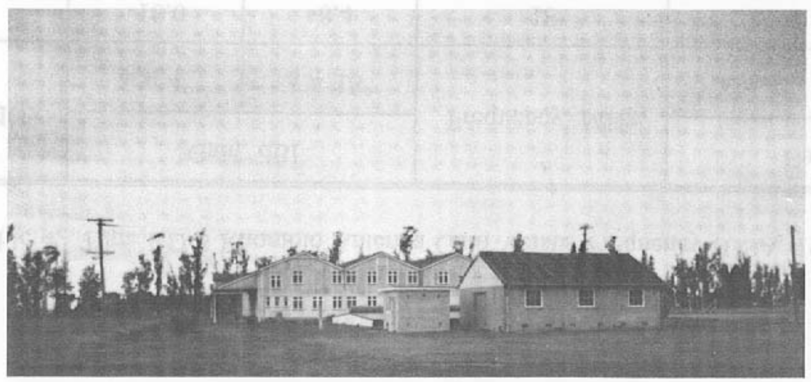
Figure 7. Site plan - transmitter site.



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	
	$\Delta = 4°$	$\Delta = 18°$		$\Delta = 4°$	$\Delta = 18°$
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