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.

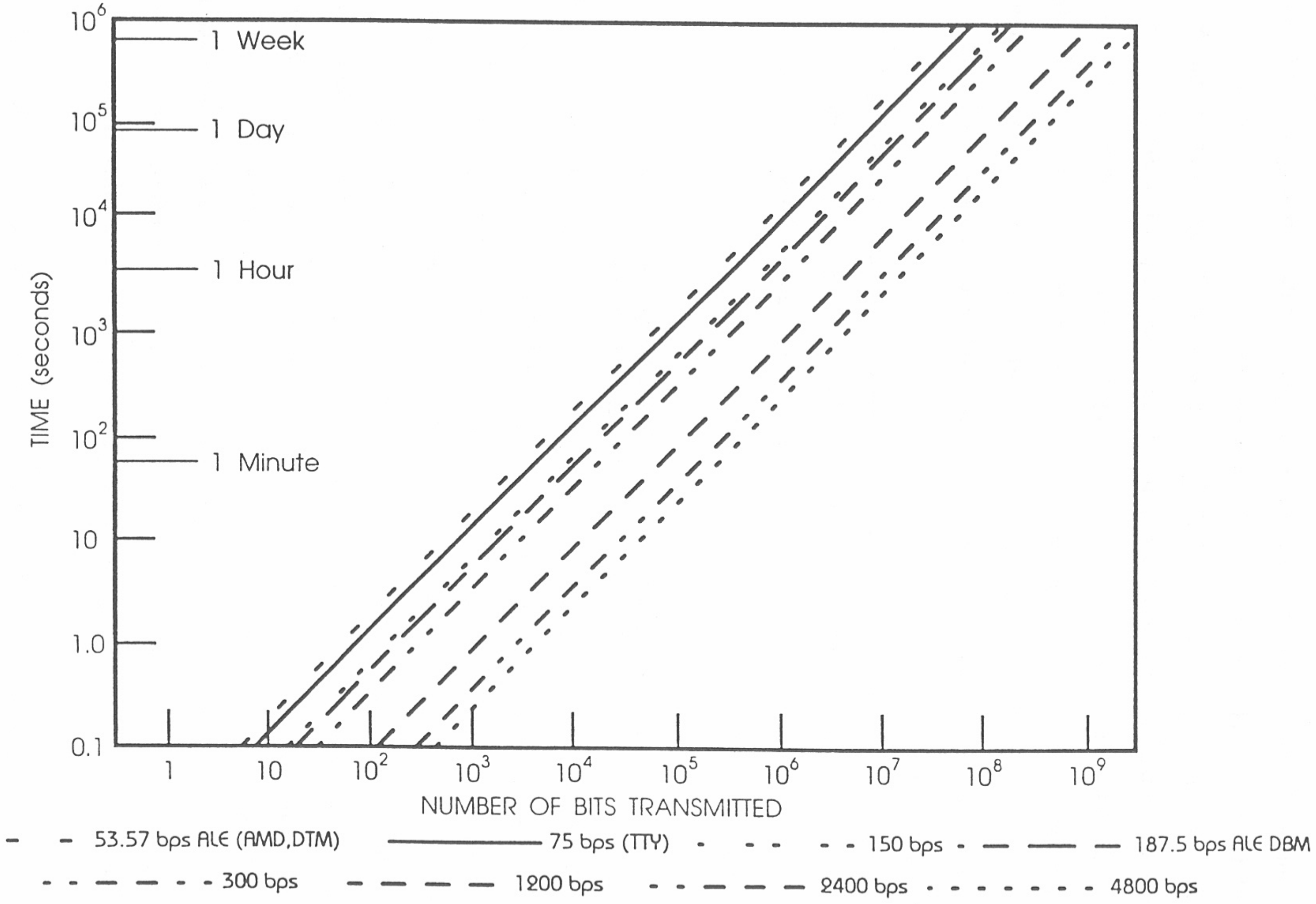

Figure 16. Time required for data transmission at selected rates of transmission.

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

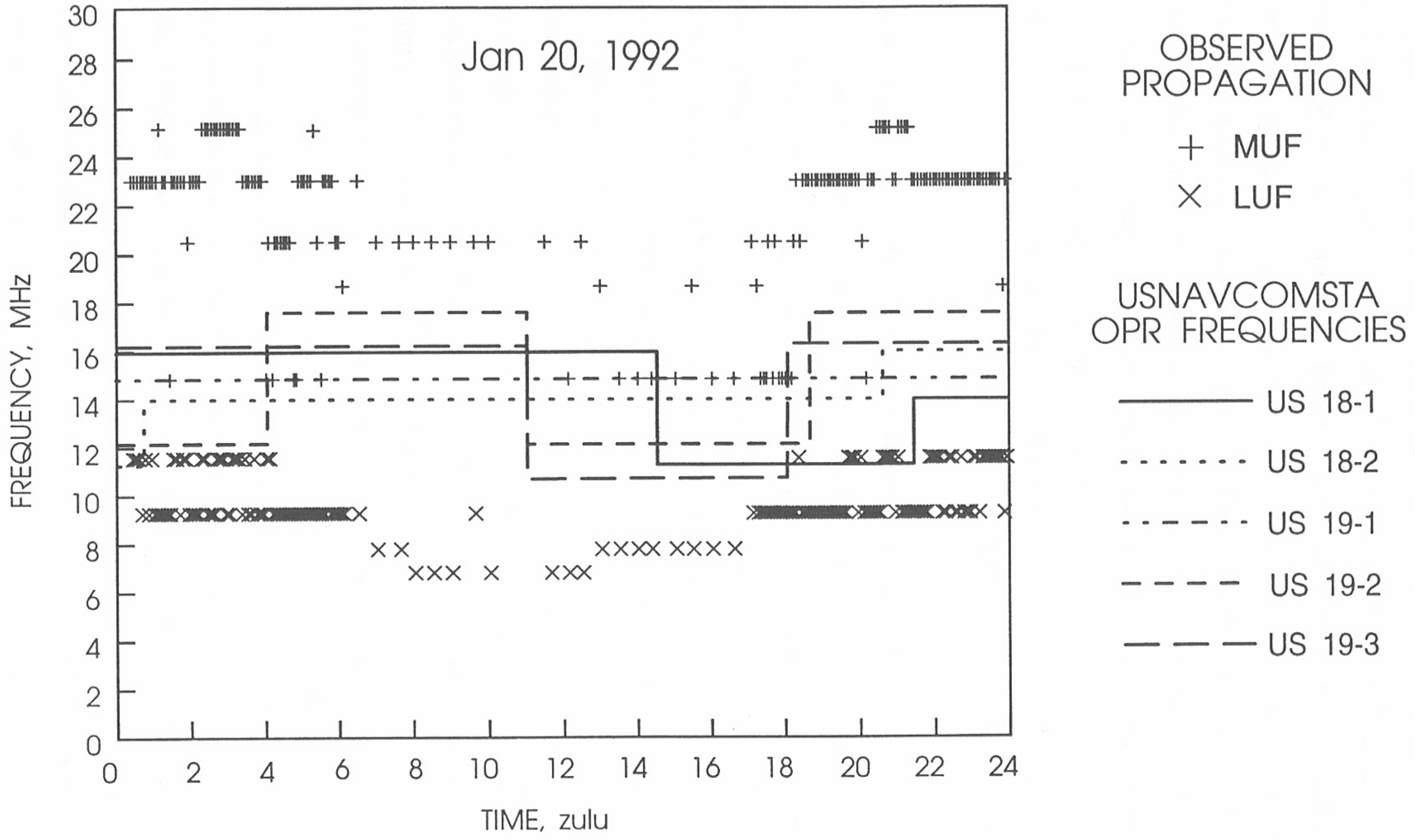

Figure 17. Comparison of observed propagation with Navy operational frequencies.

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 modem 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

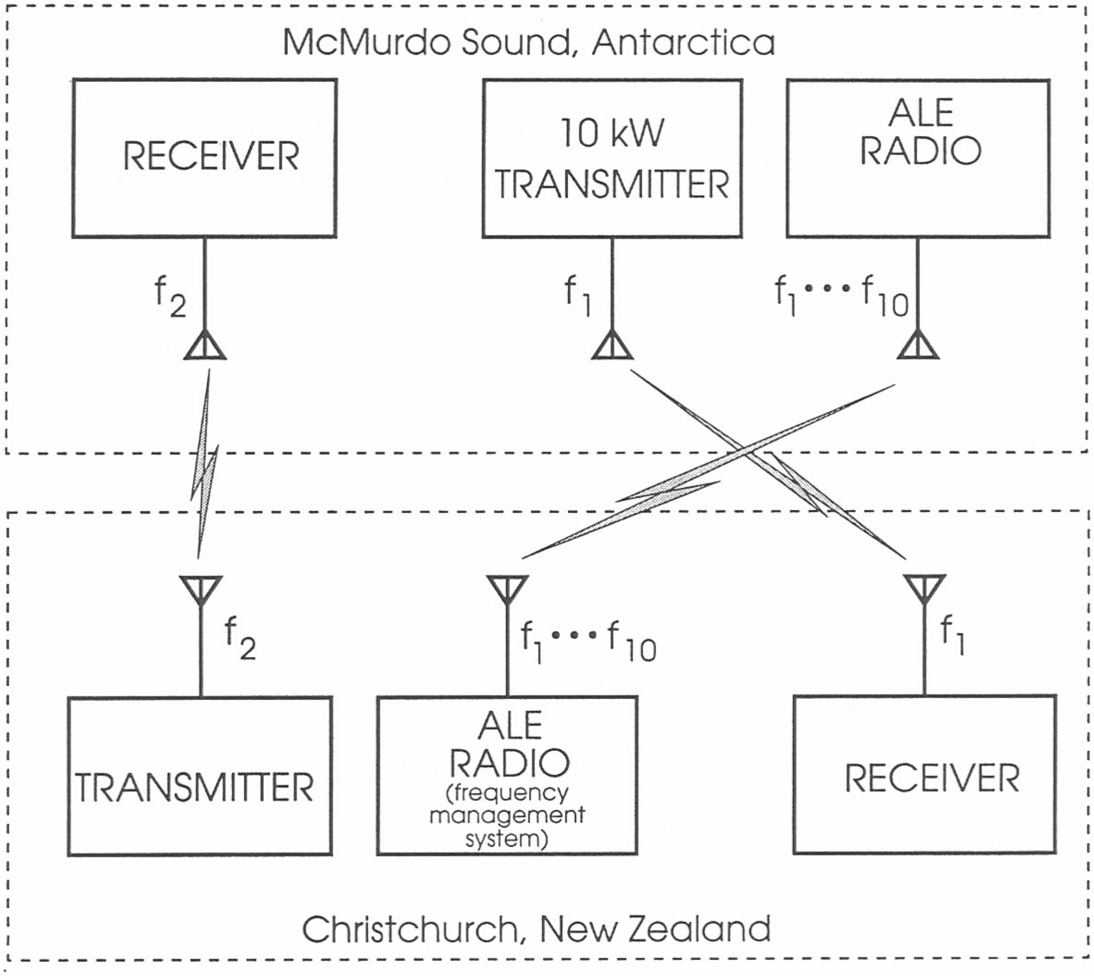

Figure 18. ALE equipment as real-time frequency management system.

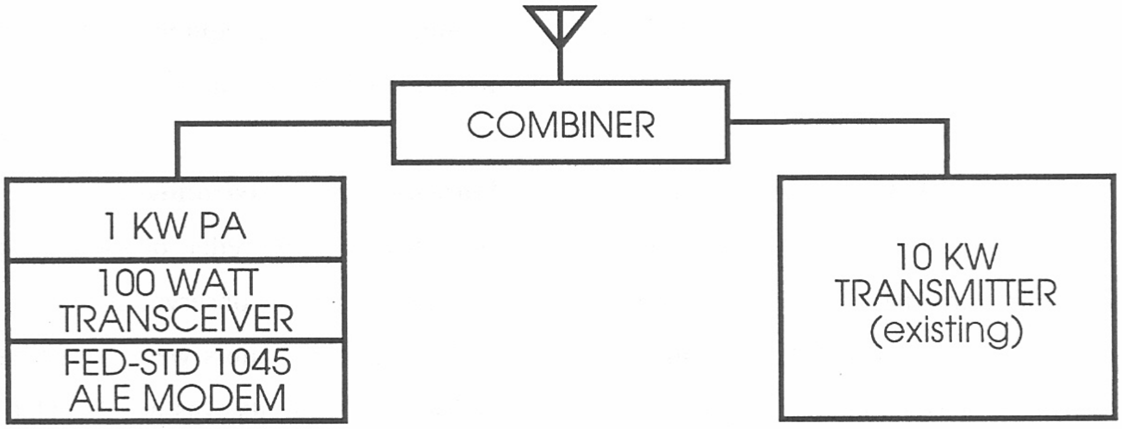

Figure 19. Recommended equipment configuration and specification for ALE real-time frequency management system.

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

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