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.

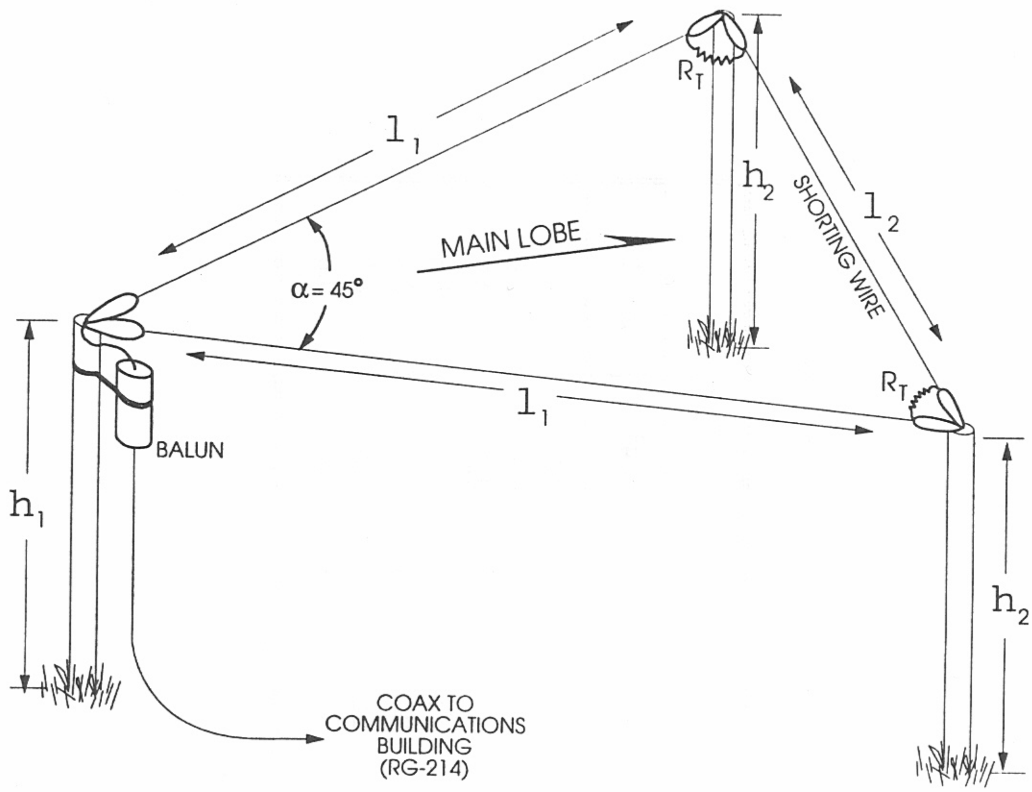
3. FEDERAL STANDARD 1045 AUTOMATIC LINK ESTABLISHMENT (ALE) CIRCUIT PERFORMANCE

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-721O 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.	l_1 = 250 ft.	R_T = 300 Ω 50W
h_2 = 20 ft.	l_2 = 191 ft.	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	
	$\Delta = 4°$	$\Delta = 18°$		$\Delta = 4°$	$\Delta = 18°$
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)

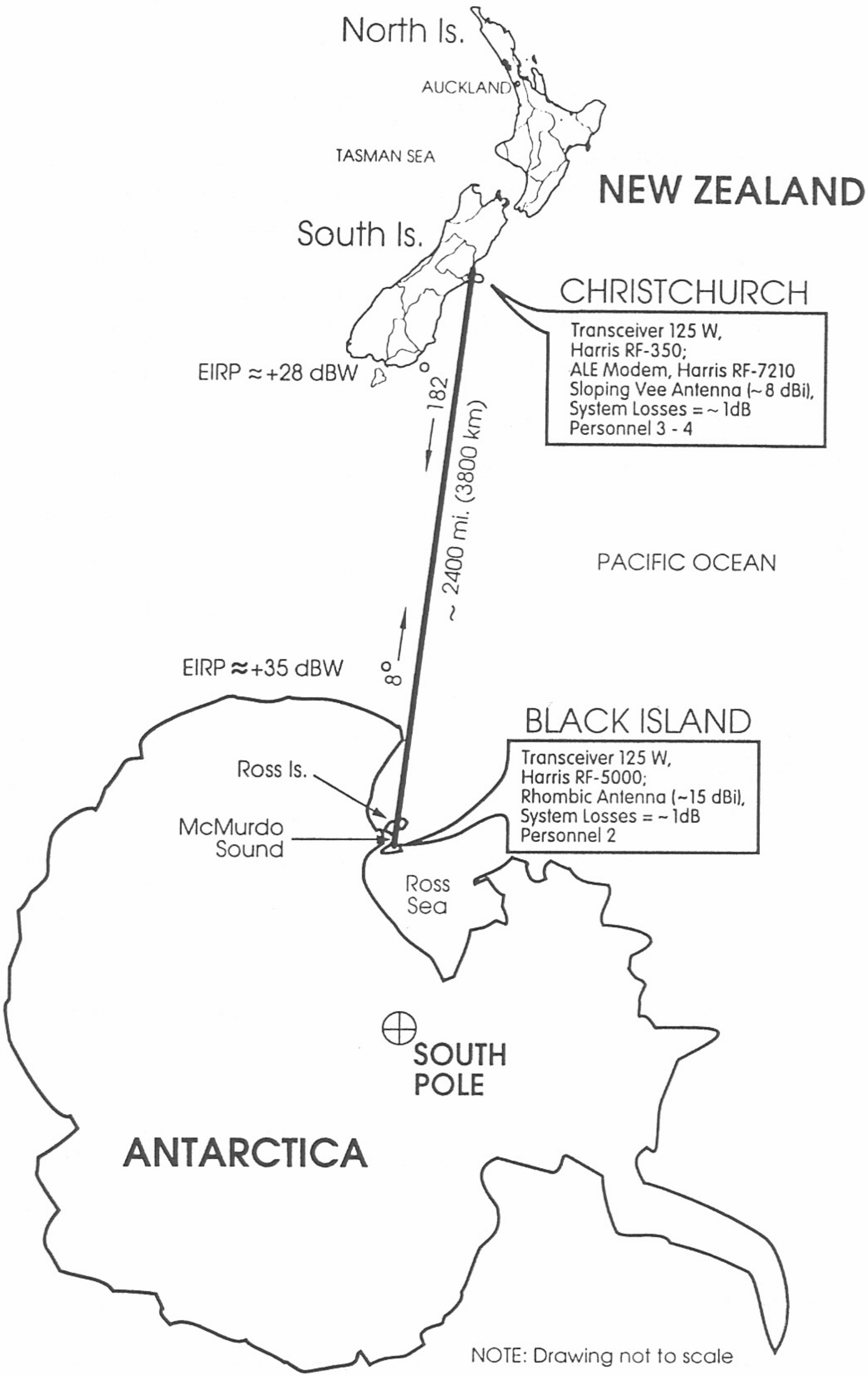


Figure 10. HF ALE communication link parameters.

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 Rcv	Mea	PBER Rcvd	Measrd	Score
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

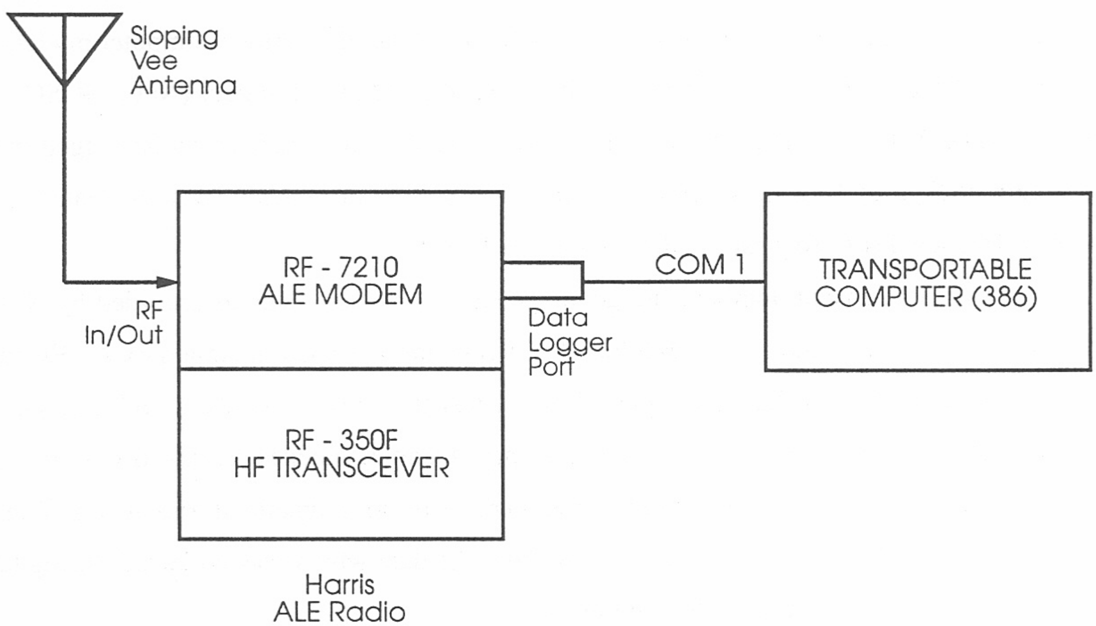


Figure 11. LQA data collection equipment interconnections.

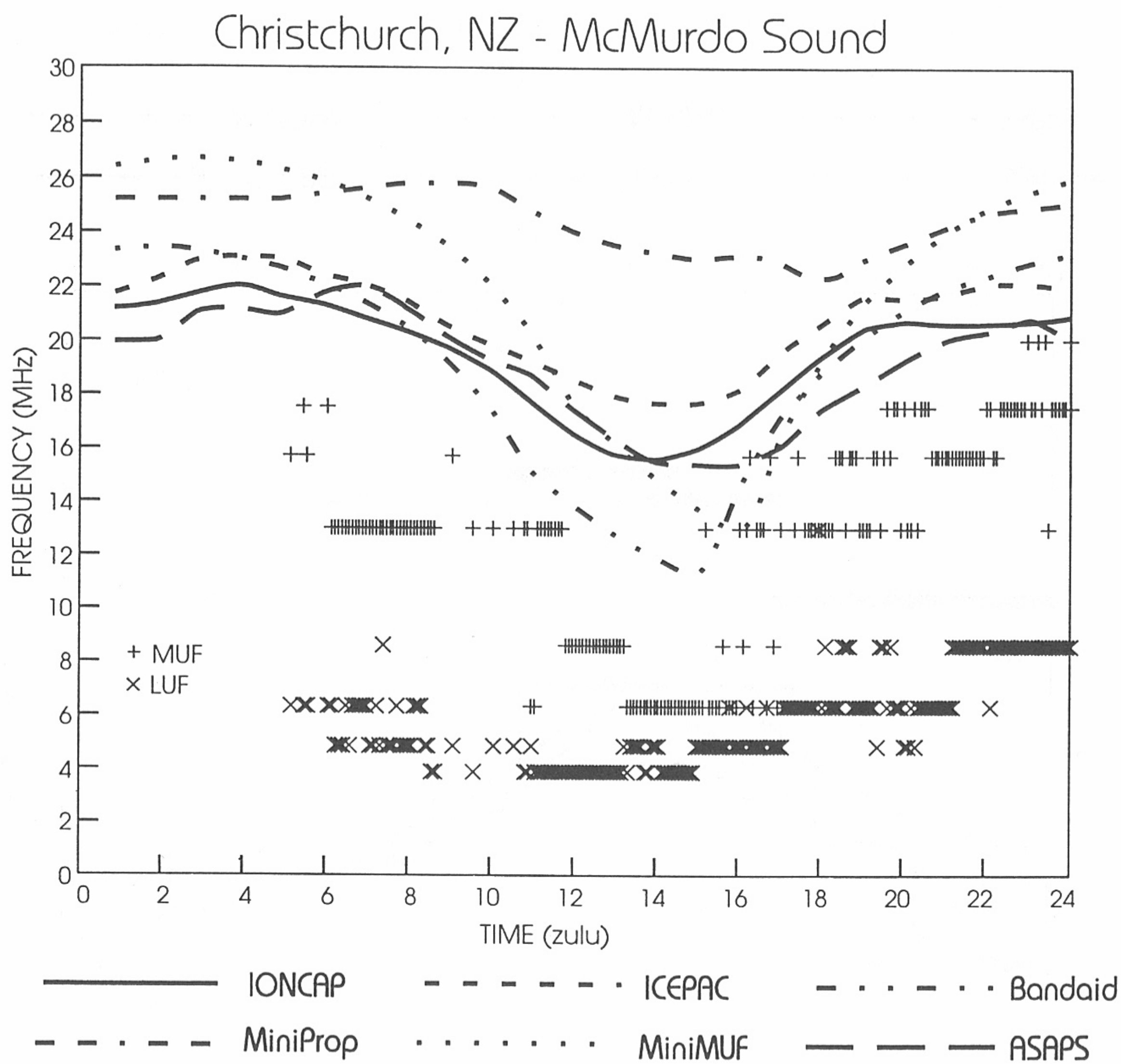


Figure 12. Comparison of predicted MUF with observed MUF, Jan. 15, 1992

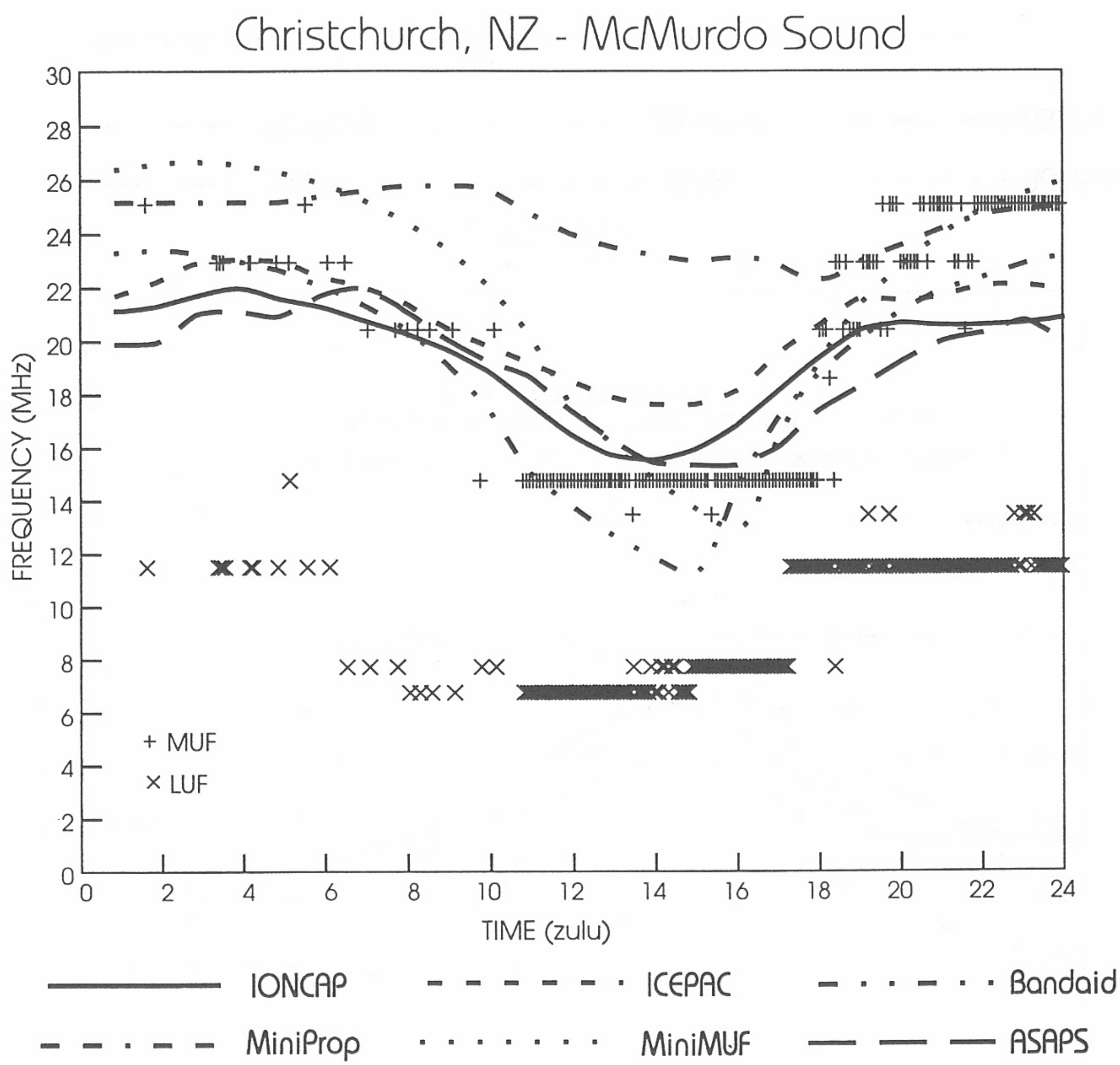


Figure 13. Comparison of predicted MUF with observed MUF, Jan 16, 1992.

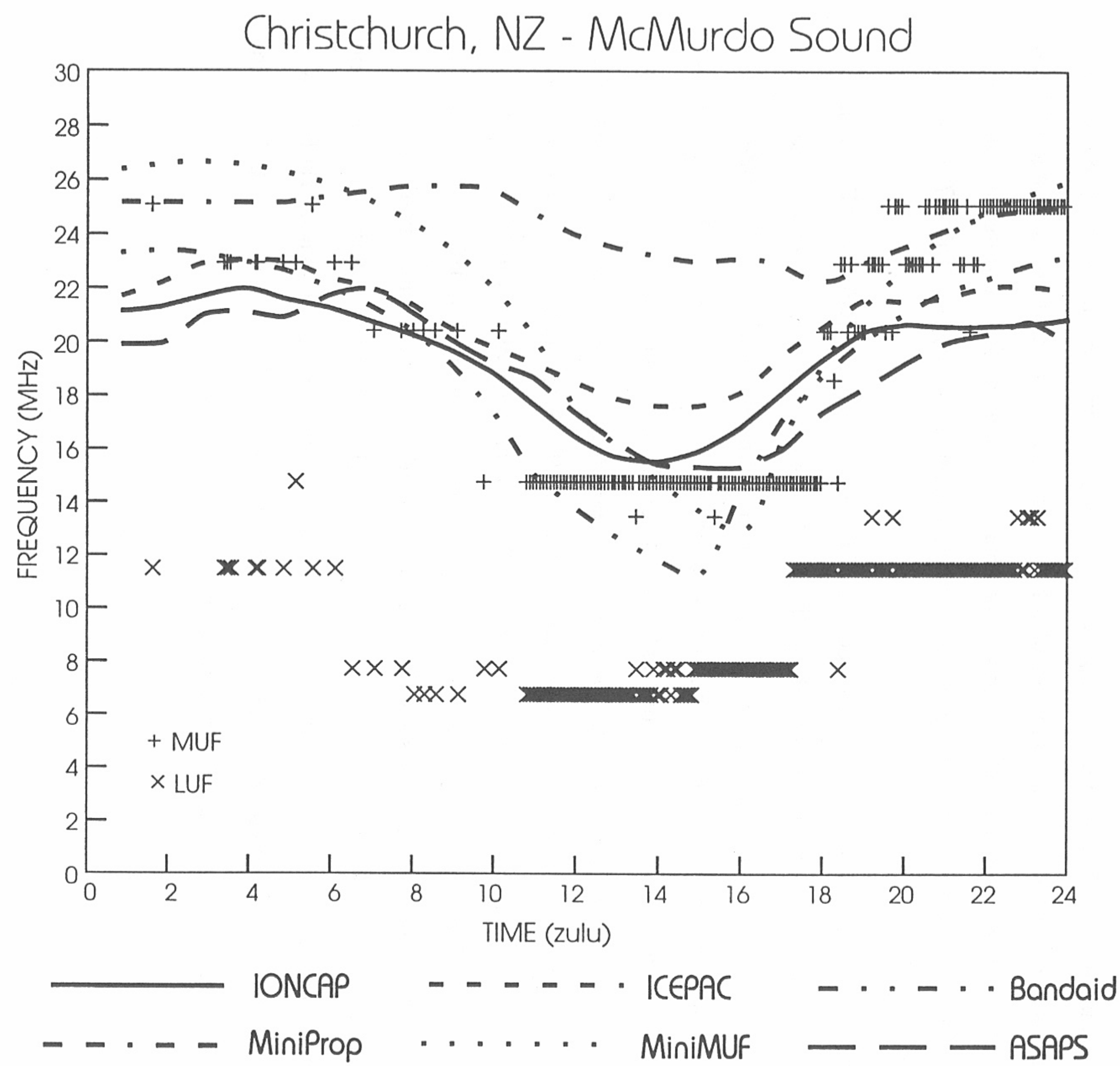


Figure 14. Comparison of predicted MUF with observed MUF, Jan 16, 1992.

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 ABA. 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.

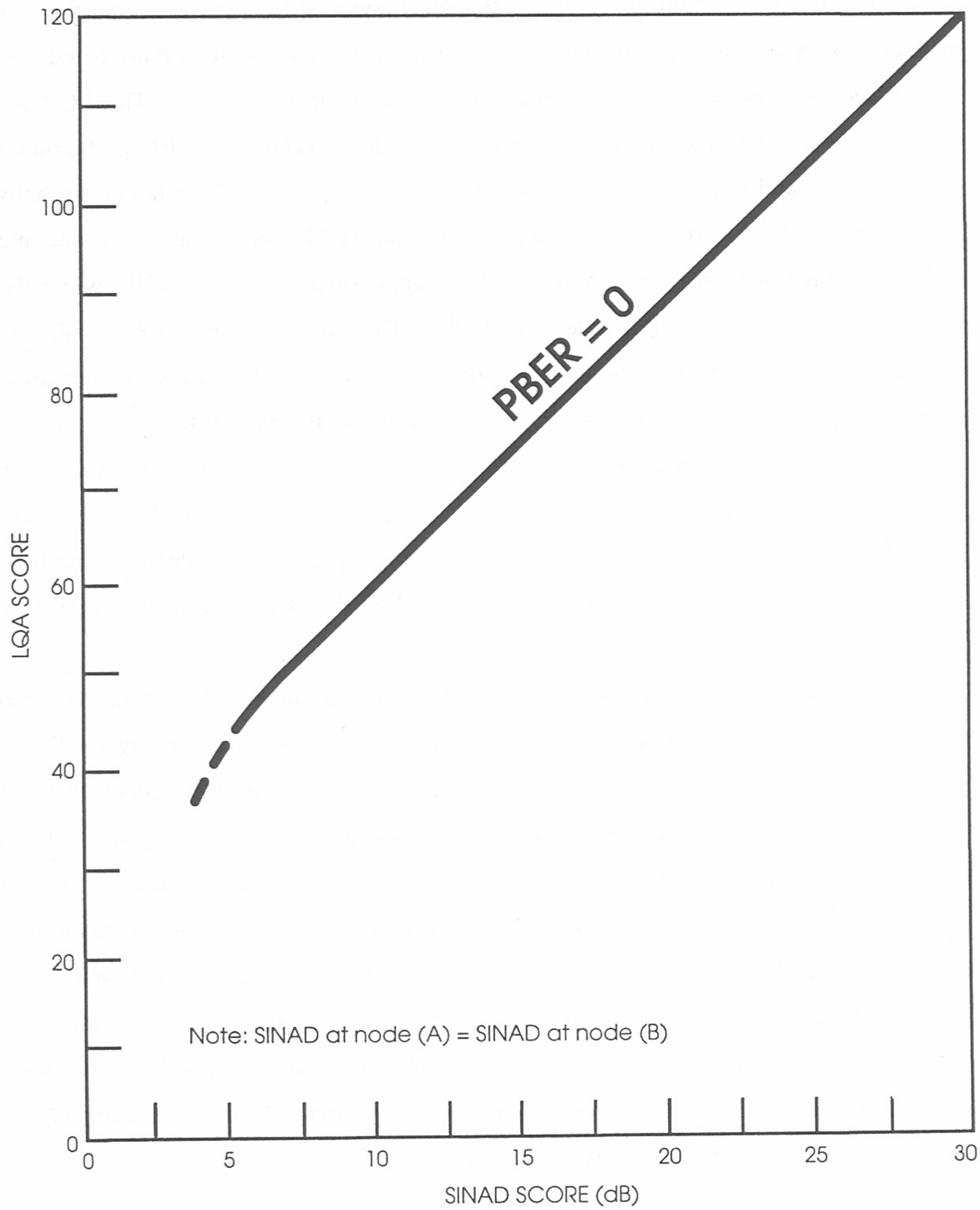


Figure 15. FED-STD 1045 ALE LQA vs SINAD.