

AD-785 482

ULF MEASUREMENTS

David L. Reasoner

Rice University

Prepared for:

Army Missile Command
Advanced Research Projects Agency

20 August 1974

DISTRIBUTED BY:

NTIS

**National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151**

AD785482

Final Technical Report

"ULF MEASUREMENTS"

ARPA Order Number: 2225

Program Code Number: W31P4Q

Title: "ULF Measurements"

Contractor: Rice University

Amount: \$23,633

Contract No.: DAA-H01-74-C-0131

Effective Date: September 5, 1973

Expiration Date: February 29, 1974

Project Scientist: David L. Reasoner

Phone: A/C 713 528-4141, Ext. 1135

D D C
RECEIVED
AUG 23 1974
RECEIVED

August 20, 1974

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

David L. Reasoner

David L. Reasoner

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

Summary

This report describes the results of an experiment to investigate the possibility of artificially stimulating ultra-low-frequency (ULF) signals in the earth's magnetosphere by means of signals from a very-low-frequency (VLF) transmitter.

A VLF transmitter system was operated by The Aerospace Corporation near Anchorage, Alaska, in August and September, 1973. This investigator operated a low-frequency (0.1 - 45 Hz) portable magnetometer station at a site adjacent to the VLF transmitter, and also designed a schedule of modulation modes and transmission frequencies for the VLF transmitter in an effort to cause stimulation of ULF signals which would in turn be detected by the magnetometer.

Approximately 40 hours of VLF transmissions over an 8-day period in August, 1973, were devoted to the artificial stimulation experiment. An examination of the data by both visual inspection of chart records and by power spectral density analysis failed to show any monochromatic ULF signals which could be unambiguously related to the VLF transmissions. An upper limit on the intensity of such emissions can be placed at 15 milligammas.

ULF data in a lower frequency range (below 0.1 Hz) was obtained from observations at College, Alaska, and Dunedin,

New Zealand, and were examined for evidence of artificially stimulated activity. It was found that a significantly larger number of ULF emission events occurred during VLF transmission periods than during off periods. However, these events could not be correlated on a 1:1 basis with the VLF transmissions.

TABLE OF CONTENTS

I	Introduction	1
II	Description of the Magnetometer-Detector System	4
III	Field Operation	7
IV	Data Analysis and Results	8
V	Conclusions	11
VI	References	12
	Appendix A Glossary of Terms	
	Appendix B Description of the TVLF System	
	Appendix C TVLF System Transmission Logs	

I Introduction

It has been known for some years that very-low-frequency (VLF) signals in the magnetosphere, either naturally occurring or artificially-induced, are capable of triggering other VLF emissions. For example, VLF transmitting stations such as NAA regularly trigger discrete VLF emissions which are received by ground-based and satellite receivers. A natural extension of this was to inquire whether ultra-low-frequency (ULF) signals in the frequency range 0.01 - 100 Hz could also be triggered by VLF signals. Interest centered not only around the basic physical processes involved but also because of the potential of ULF signals as a communications medium. ULF signals possess a distinct advantage in that their attenuation in propagating through conducting media such as the ionosphere, water, or earth is much less than that of higher frequency signals. However, direct generation of ULF signals is rather impractical because of the extremely low efficiencies associated with antenna arrays of any reasonable size. For electric dipole antennas the radiated power is a function of $(\lambda/r)^2$ and for magnetic dipole antennas the radiated power is a function of $(\lambda/r)^4$. Here λ is the wavelength and r is the antenna dimension (Ramo and Whinney, 1962).

The possibility exists, however, of utilizing the magnetosphere and the energy stored therein in the form of magnetic

fields and charged particles as a ULF "transmitter" and "antenna", and a controlled VLF transmitter as a means of artificially stimulating ULF emissions. There are various candidate physical processes through which this might be accomplished. For example, the VLF transmissions may cause enhancement of precipitation of trapped electrons, which would in turn modify the ionosphere conductivity in a periodic manner leading to ULF wave generation. A second is to transmit two VLF frequencies with a frequency difference equal to the desired ULF frequency, and then the ULF signal would be produced by non-linear mixing followed by natural amplification. These mechanisms have been discussed theoretically by Davis et al. [1973] and by Harker and Crawford [1969].

The Aerospace Corporation of El Segundo, California, has conducted a program of VLF transmission experiments using a transportable very-low-frequency system (TVLF) which was originally built for the United States Navy. Briefly, the system consists of a balloon-supported vertical wire antenna of approximately 1500 meters in length and a 150 kilowatt transmitter. The available transmitted power ranges from a few hundred watts at 6.0 kHz to 9 kilowatts at 21.0 kHz. A complete description of the TVLF system may be found in Appendix B, an extract from the proposal to Rice University from the Aerospace Corporation for VLF transmitter operation in support of this research. The

Aerospace program involved an extensive schedule of operations near Anchorage, Alaska, in the summer of 1973. Accordingly, Rice University proposed a program of an experimental search for artificially-stimulated ULF emissions using the Aerospace TVLF system as an exciter and a portable low-frequency magnetometer system as a detector.

II Description of the Magnetometer-Detector System

The variable- μ magnetometer instrument used for this investigation was originally developed by Electro-Mechanics, Inc. as a flight prototype unit for a proposed Rice University ULF/VLF research satellite.

The magnetometer operates on the principle of variation of the incremental permeability, or μ , of a ferrite material with applied magnetic field. Since the B-H curve of a ferrite material is a non-linear function, the instantaneous slope of the B-H curve, $\mu = \partial B / \partial H$, is a function of the external magnetic field H. The ferrite material forms the core of an oscillator inductance, and hence the oscillator frequency is a function of the applied magnetic field. The basic oscillator frequency of 3.3 mHz is multiplied by a factor of 9 to 29.7 mHz, and this signal is converted to an intermediate frequency of 100 kHz. Standard F-M detection is then used to translate the magnetic-field-induced frequency changes to an analog signal.

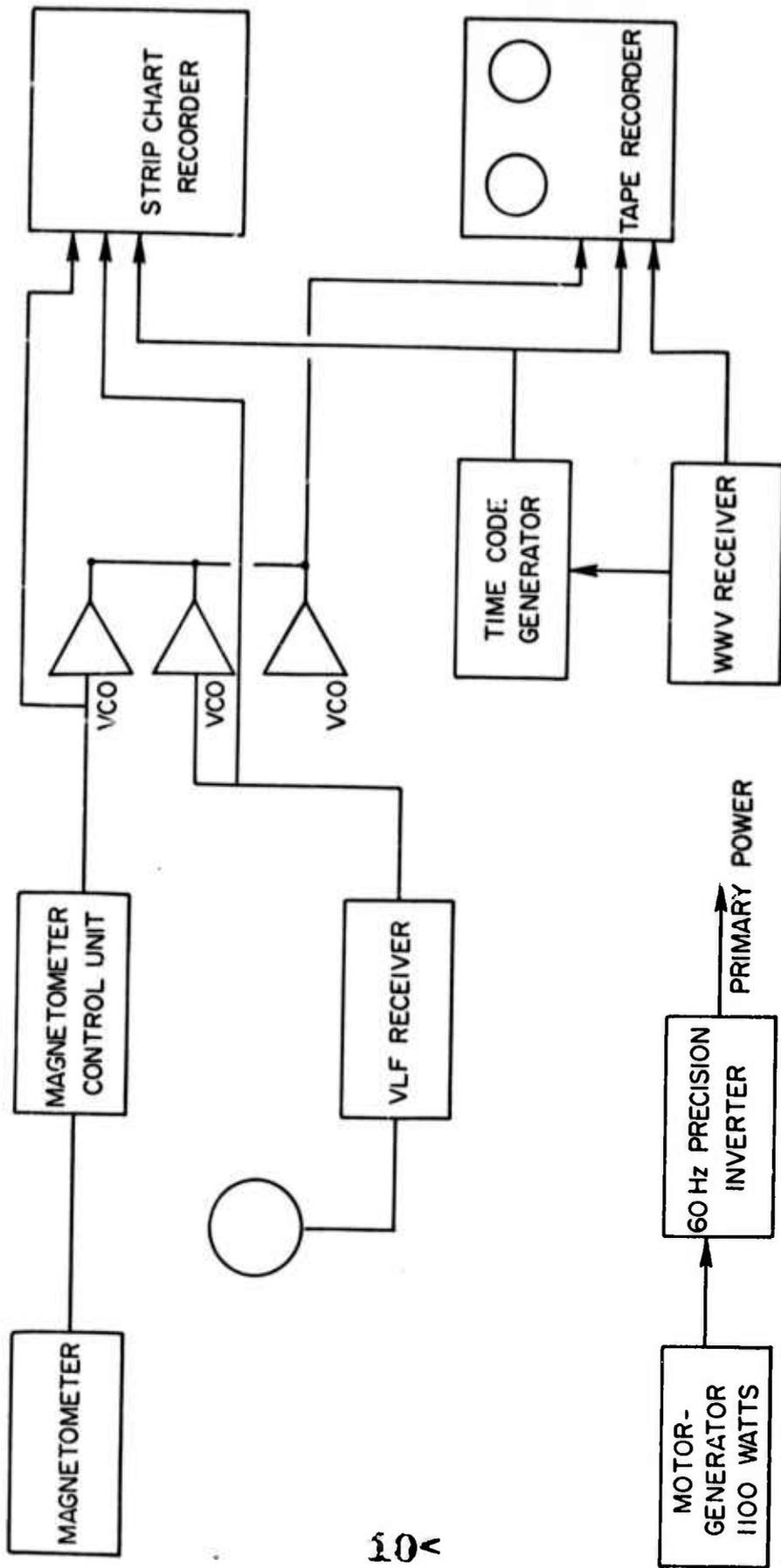
The magnetometer has its greatest sensitivity and linearity over a range of ± 500 gammas (1 gamma = 10^{-5} Gauss = 10^{-9} Tesla), and hence an analog servo loop system driving a bias coil is used to maintain the ambient field at the sensor within a prescribed range. The low frequency response limit of the magnetometer can thus be selected by selecting the time constant of the integrator in the servo loop.

In the configuration used in 1973 at Fort Richardson, the low-frequency cut-off was set at 0.1 Hz, and the high frequency response was limited by an 18 db/octave rolloff at 45 Hz in order to guard against interference from power sources. The instrument noise level is 160 milligammas p-p, or 60 milligammas R.M.S. integrated over the above frequency range.

The data recording and signal flow system is shown in the block diagram of Figure 1. The primary power source was an 1100 watt motor-generator set followed by a precision inverter to stabilize the line frequency and voltage. This was necessary to assure constant running speed of a strip chart recorder and tape recorder. The magnetometer data was recorded on a strip-chart recorder for real-time display and also on a tape recorder for future analysis. Because of low-frequency limitations of the tape-recorder, the magnetometer data was impressed upon a voltage-controlled oscillator (VCO) and the VCO signal was in turn recorded on tape.

In order to have real-time data available on the ULF transmitter operation mode, a simple VLF receiver was constructed. The rectified receiver output, which was the transmitter modulation envelope, was recorded on both the strip-chart recorder and the tape-recorder.

Timing information was provided by a time-code generator synchronized to a WWV receiver. A reference VCO signal was



104

also recorded on the tape in order to provide tape speed compensation in playback for data analysis.

III Field Operation

The TVLF system was situated approximately 20 kilometers northeast of Anchorage, Alaska, on the training range of Fort Richardson, United States Army, Alaska. The area was within restricted airspace R-2203B. The magnetometer station was emplaced approximately 1.6 kilometers distant from the TVLF site. Field tests of the magnetometer system in conjunction with the TVLF system at Port Heiden, Alaska, in August, 1972, showed that this distance was sufficient to guard against local interference of the magnetometer from the various noise sources at the TVLF site. Other factors affecting the magnetometer site location were range safety and access by road.

Requirements imposed by the Federal Aviation Administration and the United States Army, Alaska, upon the use of the airspace R-2203B limited operation of the TVLF system to hours of local night on weekdays. Coordinated operations with the TVLF system and the magnetometer receiving station were conducted on August 9, 10, 14, 15, 17, 20, 22, and 23, 1973. For the purposes of the artificially-stimulated ULF emissions experiment, various modulation modes were transmitted including continuous waves, square waves, pulse trains, and two-frequency mixing. The carrier frequencies used were 21.0, 13.275, 8.0, and 6.6 kHz. Appendix C of this report contains a listing of the TVLF transmission log. In all approximately 40 hours of TVLF time were devoted to the artificially-stimulated ULF emission experiment.

IV Data Analysis and Results

The complete set of strip chart-recorder records was first examined for evidence of ULF transmissions which showed a direct correlation with the TVLF transmitter operation. In effect, we were looking for evidence of periodic signals which were related in an obvious way to the modulation frequency or mode of the TVLF transmitter. A careful search of the recordings failed to show any such events, although there were periods when there was naturally occurring ULF activity. It was thought that these periods would be prime candidates for more intensive analysis on the theory that during periods of naturally-occurring activity the conditions would be most favorable for artificially-stimulated activity.

Twenty-five hours of data were selected for analysis by Fourier transform techniques. The data were first low-pass filtered with a cutoff frequency of 12 Hz and then digitized with a 30 Hz sampling rate. The data were then divided into 2.5 minute intervals, and for each of these intervals the power spectral density (PSD) function was computed using a Fast Fourier Transform computer routine. The parameters of the PSD computation process were:

Number of points	= 4096
Effective Band Width	= 0.059 Hz
Normalized Standard Error	= 0.33

Figures 2 and 3 show examples of the power spectral density plots obtained from the data. Figure 2 is from a quiet period when no activity was present, and therefore illustrates the inherent magnetometer noise level. Figure 3 represents a period of natural ULF activity, showing a strong band in the frequency range 0.2 - 1.0 Hz.

Each of the power spectral density plots (a total of approximately 600) was searched for evidence of discrete peaks in the PSD function at frequencies either equal to or harmonically related to the TVLF transmitter modulation frequency. No evidence of such peaks was found. The noise level of the magnetometer is about 10^{-4} gammas²/Hz (see Figure 1) and hence the smallest monochromatic signal that would result in a 1:1 signal-to-noise ratio is 3 milligammas. Thus as a practical matter an upper limit of 15 milligammas can be placed on the intensity of any possible monochromatic ULF signals artificially stimulated by the TVLF system.

There does remain the possibility that broadband ULF signals in a different frequency range were triggered by the TVLF system. In a cooperative effort with H. C. Koons of the Aerospace Corporation, ULF data in the frequency range below 0.1 Hz was obtained from stations at College, Alaska, and Dunedin, New Zealand. These data were analyzed for statistical correlation between TVLF transmitter operation and the onset of micropulsation activity.

ULF PSD

235/10/45/0

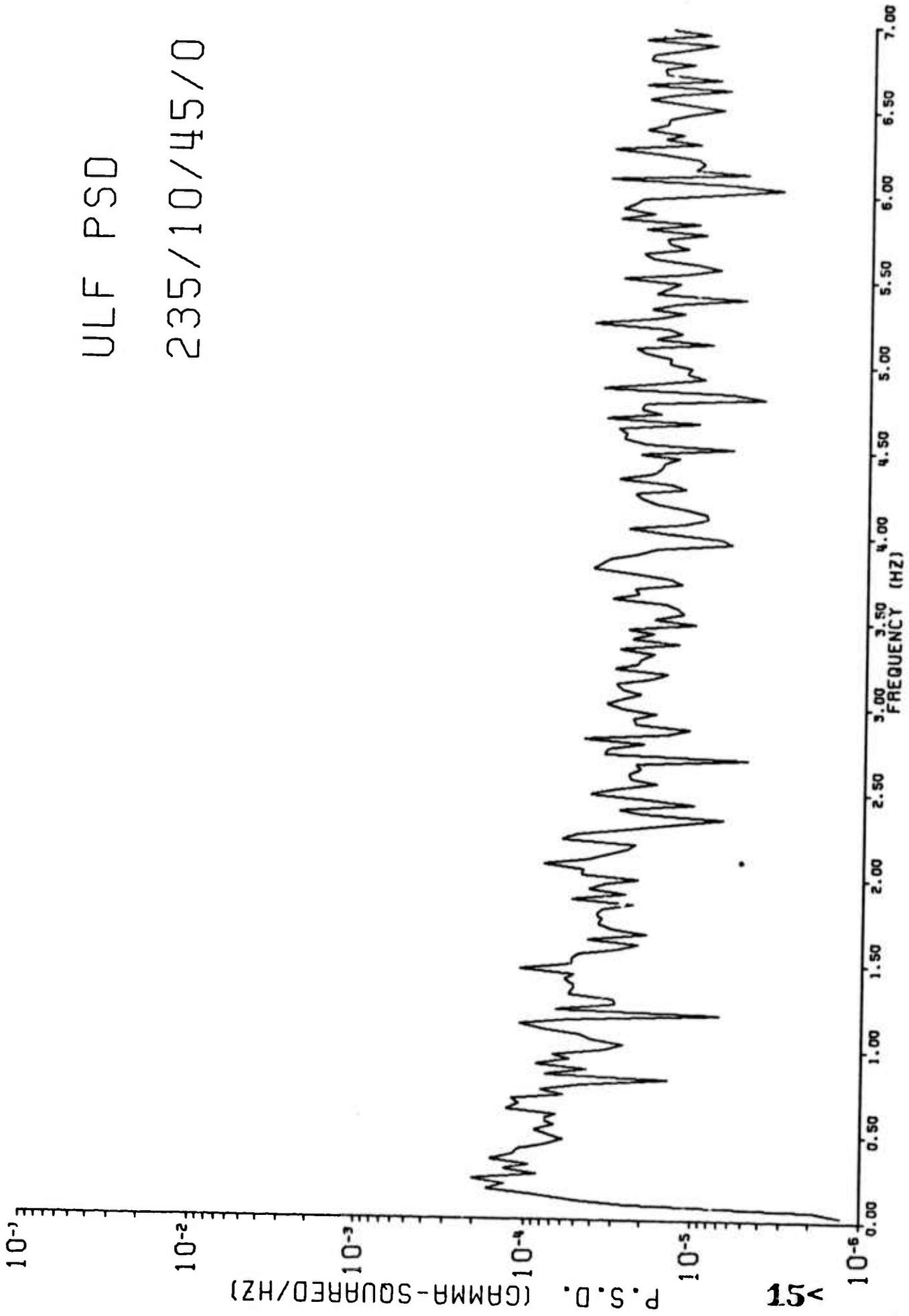
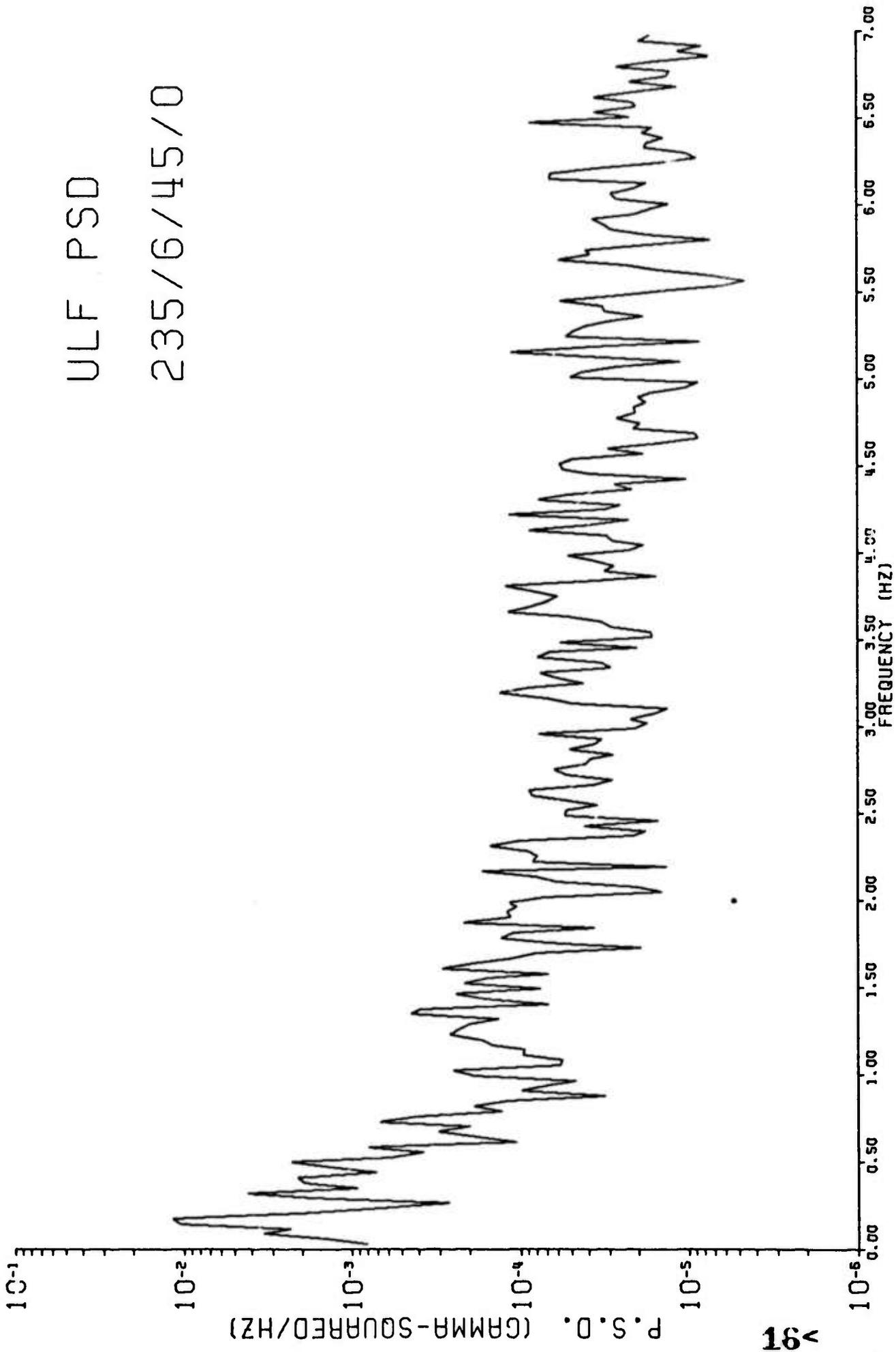


FIGURE 2

ULF PSD

235/6/45/0



>91

FIGURE 3

It was found that there was a statistically significant larger number of micropulsation onsets during pulsed transmission operations of the TVLF system (Koons et al., 1974).

V Conclusions

The artificially-stimulated ULF emission experiment had as its objective to search for ULF emissions triggered by a VLF transmitter. A sensitive, low-frequency magnetometer station was established in proximity to the VLF transmitter whose primary objective was to search for monochromatic ULF signals which could be positively correlated with the modulation frequencies and modes of the VLF transmitter. No such monochromatic signals were detected, and an upper limit of 15 milligammas can be placed upon the intensity of any such emissions.

ULF micropulsation data from other stations were examined for a statistical correlation between ULF activity and VLF transmitter operation. It was found that there was a significantly larger number of micropulsation onsets when the VLF transmitter was operating. However, a 1:1 correspondence between VLF transmissions and micropulsation events could not be established.

References

1. Davis, John R., J. W. Willis, and Edwin L. Althouse, "Magic Mode: Investigations of Artificial Stimulation of ULF Waves in the Ionosphere and Magnetosphere", NRL Report 7552, March, 1973.
2. Harker, K. S., and F. W. Crawford, "Non-linear Interaction between Whistlers", J. Geophys. Res., 74, 5029, 1969.
3. Koons, H. C., M. H. Dazey, and D. A. McPherson, "Micropulsations Triggered by VLF Wave Transmissions into the Magnetosphere", EOS, Trans. Am. Geophys. Union, 55, 400, 1974.
4. Ramo, Simon, and John R. Whinney, "Fields and Waves in Modern Radio", 2nd edition, John Wiley, New York, 1962.

Appendix A

Glossary of Terms

ELF - Extremely Low Frequency - the frequency range 100-1000 Hz

Magnetosphere - The region of space beginning at the ionosphere and extending outward for 10-20 earth radius distance units.

PSD - Power Spectral Density - the square of the Fourier transform of a signal. This function is the power per unit bandwidth as a function of frequency.

TVLF - Transportable Very-Low-Frequency System - a transportable VLF antenna, transmitter, and generator unit used as a VLF excitation system in this experiment.

ULF - Ultra-Low-Frequency - the frequency range up to 100 Hz.

VCO - Voltage Controlled Oscillator - A device for producing a sinusoidal signal whose frequency is a linear function of the applied voltage. Used to convert low-frequency analog data to a form suitable for transmission or tape-recording.

VLF - Very-Low-Frequency - The frequency range of 1000-100,000 Hz.

WWV/WWVH - The National Bureau of Standards standard time and frequency stations located at Fort Collins, Colorado, and Kekaha, Kauai, Hawaii, respectively.

Appendix B

Description of the TVLF System

PROPOSAL TO RICE UNIVERSITY

ULF MODULATION OF A VLF TRANSMITTER

H. C. Koons
M. H. Dazey

Space Physics Laboratory
The Aerospace Corporation

18 May 1973

Principal Investigator:

H. C. Koons
Space Physics Laboratory
The Aerospace Corporation
Post Office Box 92957
Bldg., 120/ Room 1823 A
Los Angeles, California 90009

Phone: (213) 648-6519

SUMMARY

Title: ULF Modulation of a VLF Transmitter

Principal Investigator: Dr. Harry C. Koons

Co-Investigator: Mr. M. H. Dazey

Investigation: A very-low-frequency (VLF) transmitter will be operated at a site near Anchorage, Alaska in August and September 1973. Appropriate modulation patterns might trigger ULF emissions which have potential as a communication signal which readily penetrates earth and seawater. In this investigation the transmitter will be operated in modes expected to have a high probability of triggering ULF emissions. Transmissions will also be made to interact (resonate) with naturally occurring ULF emissions in progress.

Technique (including Instruments):

The transmitter will be the transportable very-low-frequency (TVLF) system. The antenna will be a 5000 foot vertical monopole supported by a tethered balloon. This system can radiate a power in excess of 20 kW at 20 kHz. The carrier frequency can be set at assigned frequencies between 6 and 30 kHz. The carrier will be 100% modulated with a square wave at frequencies between .01 and 20 Hz.

Duration of Proposed Work:

Six (6) months commencing 1 July 1973.

CONTENTS

	PAGE
1.0 INTRODUCTION	1
2.0 JUSTIFICATION	2
3.0 EXPERIMENT OPERATION	3
3.1 Site	3
3.2 Transmitter	3
3.3 Supporting Instrumentation	5
4.0 STATEMENT OF WORK	7
5.0 SCHEDULE	8
6.0 PERSONNEL	9
7.0 FIGURE CAPTIONS	13

1.0 INTRODUCTION

The proposed research will be a controlled wave-particle interaction experiment. The technique consists of transmitting very-low-frequency waves from a ground-based transmitter in Alaska to VLF receivers in Campbell Island and in Dunedin, New Zealand near the transmitters conjugate point in the southern hemisphere. The signals propagate at speeds near the velocity of light c in the earth-ionosphere waveguide and at roughly $c/20$ along ducts formed by geomagnetic field-aligned, plasma-density enhancements in the magnetosphere. The latter signals, propagating in the whistler-mode, interact resonantly with energetic electrons in the outer radiation belt. This specific proposed task is directed at triggering or amplifying ultra-low-frequency (ULF) waves in the 0.01 to 20 Hz frequency range. Control of the experiment is achieved by variation of the transmitter frequency, modulation pattern, power, and time of operation.

The equipment consists of the transportable very-low frequency (TVLF) transmitter with a tuning helix designed to cover frequencies between 6.0 and 30.0 kHz. The antenna is a vertical monopole consisting of a conducting cable lofted to an altitude of 5,000 ft by a 27,000 cu ft helium balloon. The antenna cable is also used as the balloon tether.

This system was successfully operated at Port Heiden, Alaska, in August, 1972. The basic facilities, equipment, and procedures were developed, fabricated, and tested in field operation. The proposed experiment is a more extensive program based on the experience gained in 1972.

The proposed work includes transmitting appropriate modulation patterns in the 0.01 to 20 Hz range to stimulate or trigger ULF waves in this frequency range.

2.0 JUSTIFICATION

1. The TVLF system represents a unique asset to conduct ULF/VLF research in the magnetosphere. The transmitter is dedicated to research and experimentation rather than communication operations. Hence, it is under the control of scientists and is an extremely flexible tool for wave injections into the magnetosphere.
2. Much of the nonproductive exploratory work necessary to start the experiment were performed in the field at Port Heiden, Alaska in August 1972. The support requested is to continue the ULF experiments in a manner based on the preliminary results and experience gained at Port Heiden.

3.0 EXPERIMENT OPERATION

3.1 Site

The TVLF operations will take place in the Restricted Air Space (R-2203) at Fort Richardson, Alaska. The site is located at $61^{\circ} 21' 11''$ N. Lat., $149^{\circ} 37' 30''$ W. Long.

This site was chosen on the basis of weather data. The most serious difficulty encountered at Port Heiden was balloon damage sustained during two storms with wind speeds exceeding 35 k. With the minor changes in balloon design, it is believed that the new balloons will survive ground winds of 35 k. Winds are not expected to exceed 28 k at Fort Richardson.

Dunedin is 1229 km from the conjugate point of Fort Richardson while Campbell Island is 403 km from the conjugate point of Fort Richardson. For reference, Port Heiden is 348 km from the conjugate point of Dunedin. The conjugate relations are shown in Figure 1.

Fort Richardson is at an L value of 4.1. The minimum electron gyrofrequency along the field line at the longitude of Fort Richardson is 11.9 kHz. Therefore, half the minimum gyrofrequency is 5.95 kHz which is very close to the lower limit of the tuner. The transmitter will couple to field lines south of Anchorage so that the range 6 to 21 kHz should provide magnetospheric propagation.

3.2 Transmitter

One of the unique features of this experiment is the transmitter. This equipment, called the transportable VLF (TVLF) system, was developed by the Navy as a mobile VLF transmitter for shore to submarine communications. The TVLF system is contained in three vans, with a fourth van

28<

out-fitted as a maintenance and machine shop facility. In Figure 2, the four trailers comprising the TVLF system are shown prior to their shipment to Port Heiden. In Figure 3, the balloon, helix, and variometer are shown setup for operation at Port Heiden, Alaska in 1972.

The block diagram of the transmitter system is shown in Figure 4. The transmitter consists of a 150 kW amplifier and a balloon-supported antenna that is deployed and retrieved by the winch. The antenna winch and cable are designed to operate at a maximum height of 10,000 ft. and a tension of 7,000 lb. force. The operating height of the present system is limited to 5,000 ft. by the lift of the 27,000 cu. ft. balloon.

Being self-sufficient, the TVLF system can be moved to any location accessible by truck (including barge which was the mode of transportation used in 1972). It is an extremely valuable asset for wave-particle studies because it is mobile and can be operated at various sites in conjunction with the location requirements of other experiments.

The antenna tuning system, consisting of a helix and variometer, fabricated in 1972, operated successfully at Port Heiden. The minimum useable frequency was measured to be 6.2 kHz with the balloon at approximately 3,200 ft. The minimum useable frequency is reduced by increasing the height of the antenna.

The radiated power is limited by either a maximum base voltage of 100 kV rms or a maximum antenna current of 100 A rms. The system has been hi-potted to 100 kV rms.

The maximum base voltage used at Port Heiden was 44 kV at 21.0 kHz. The resulting antenna current was 49.3 A. The theoretical power radiated for the antenna (assumed to be at a height of 4,500 ft. = 0.9 x 5,000 ft. of cable out) was then 9.5 kW. At that time, the field strength reported in New Zealand was 30 $\mu\text{V}/\text{m}$ and at Stanford University, 200 $\mu\text{V}/\text{m}$. Approximately twice this power level can be achieved at maximum current.

The programmer, fabricated in 1972 to provide very flexible modulation patterns to the transmitted signals, has been improved for operation at Fort Richardson. The unit provides 20 on-off functions for the transmitter,

with variable duration from 50 ms to 10 sec for each function. A program of ten different pulse lengths with ten different pulse separations can be transmitted repetitively. The accuracy for each period is 1%. This can be improved to 0.1% by measurement of each period at test points provided. Timing will be provided by a Datatron 3000 Generator/Translator that will be synchronized to the time-code generator.

Professor Dowden has fabricated a FM modulator for the TVLF transmitter. This modulator varies the transmission frequency ± 46.56 Hz about the allocated frequency in a ramp mode. The frequency rate of change is derived from the crystal oscillator in the HP 3320A frequency synthesizer. An identical unit will drive the receiver in New Zealand. These modulators will be used to obtain the group dispersion and total path delay of the whistler.

The modulator unit also provides 12 fixed pulse synthesis programs.

3.3 Supporting Instrumentation

Supporting Instrumentation is summarized in Table 1.

TABLE 1. Supporting Instrumentation

Instrument	Investigator	Location	Objective
VLF field strength meter	Naval Electronics Center	San Diego	TVLF-radiated power
VLF field strength meter	NOAA	Boulder	TVLF-radiated power
Narrowband VLF receivers	Aerospace	Ft. Richardson	Earth ionosphere duct perturbation
Wideband VLF receivers	Dartmouth	Farewell, Ak	Whistler-mode echoes VLF hiss mechanism
Riometer	University of Otago	Dunedin	D-region perturbation
Photometer	University of Otago	Dunedin	3914 A light emission
Magnetometer	University of Otago	Dunedin	Micropulsations
Micropulsation detectors	NOAA	College, Ak	Micropulsations

7.0 FIGURE CAPTIONS

- Figure 1: MAGNETIC CONJUGATE MAP. Northern land masses and city names are shown conjugately superimposed on a map of Australia, New Zealand, and Antarctica. The Southern geographic grid and the invariant latitude grid (common to local and conjugate areas) are also shown.
- Figure 2: TRANSPORTABLE VLF SYSTEM. From left to right: (1) antenna winch, (2) maintenance shop, (3) control and transmitter van, and primary power.
- Figure 3: BALLOON AND TUNING HELIX - - used by personnel of The Aerospace Corporation for whistler-mode propagation tests between Port Heiden, Alaska and Dunedin, New Zealand in August 1972.
- Figure 4: BLOCK DIAGRAM OF TVLF SYSTEM.

Pages 7 thru 12 intentionally deleted

CONJUGATE SUPERPOSITION

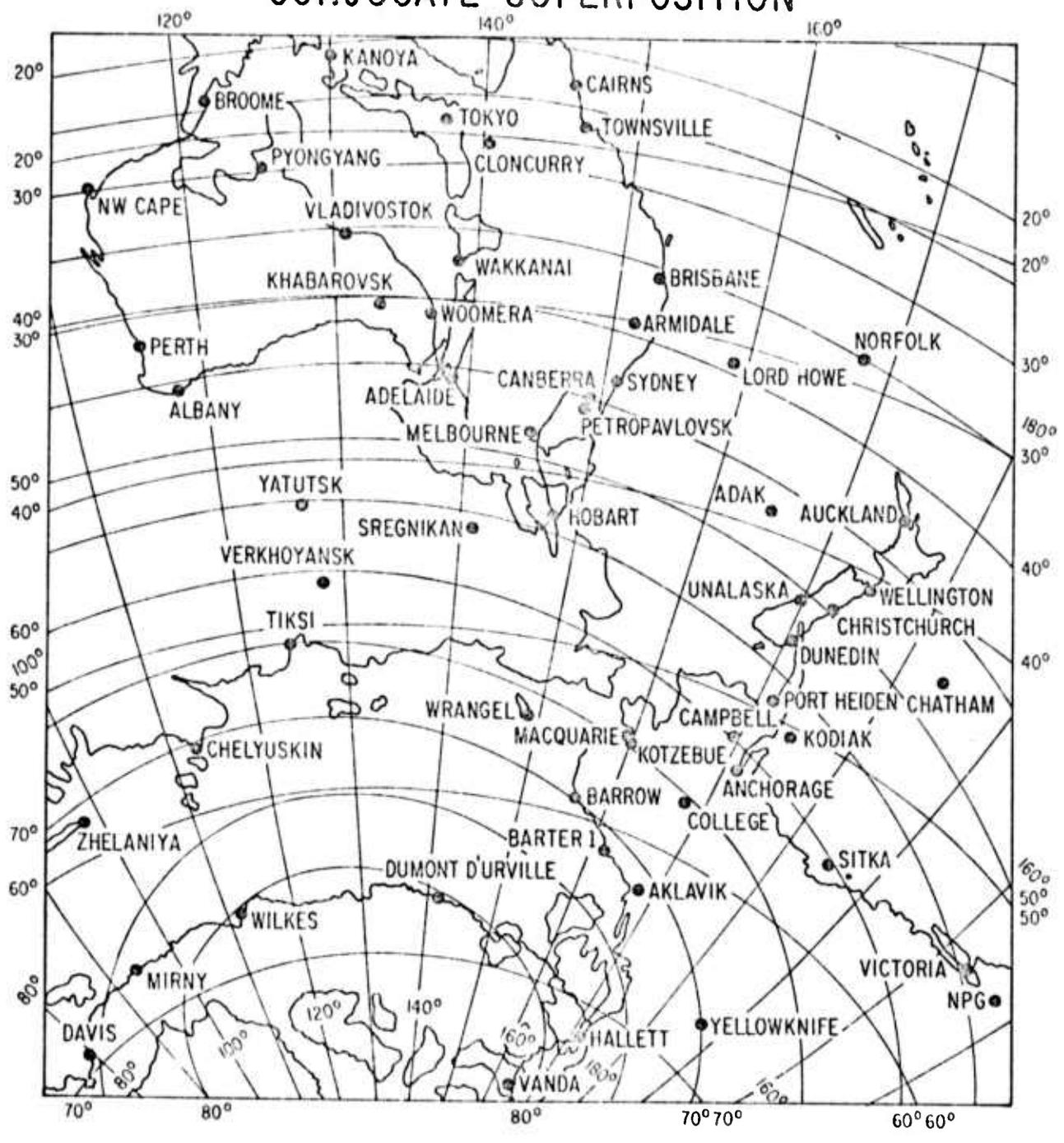


Figure 1

Reproduced from
best available copy.

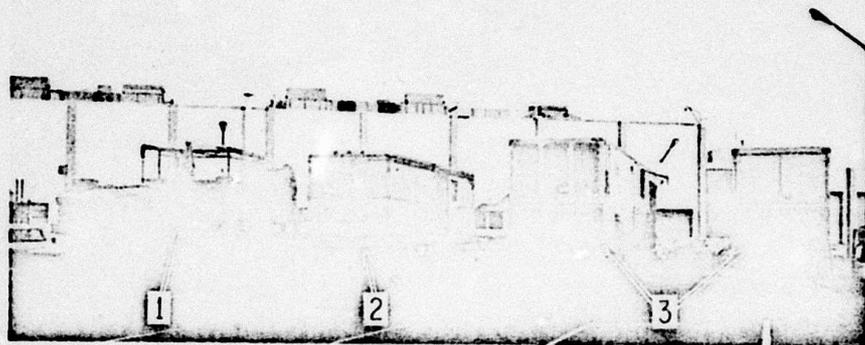
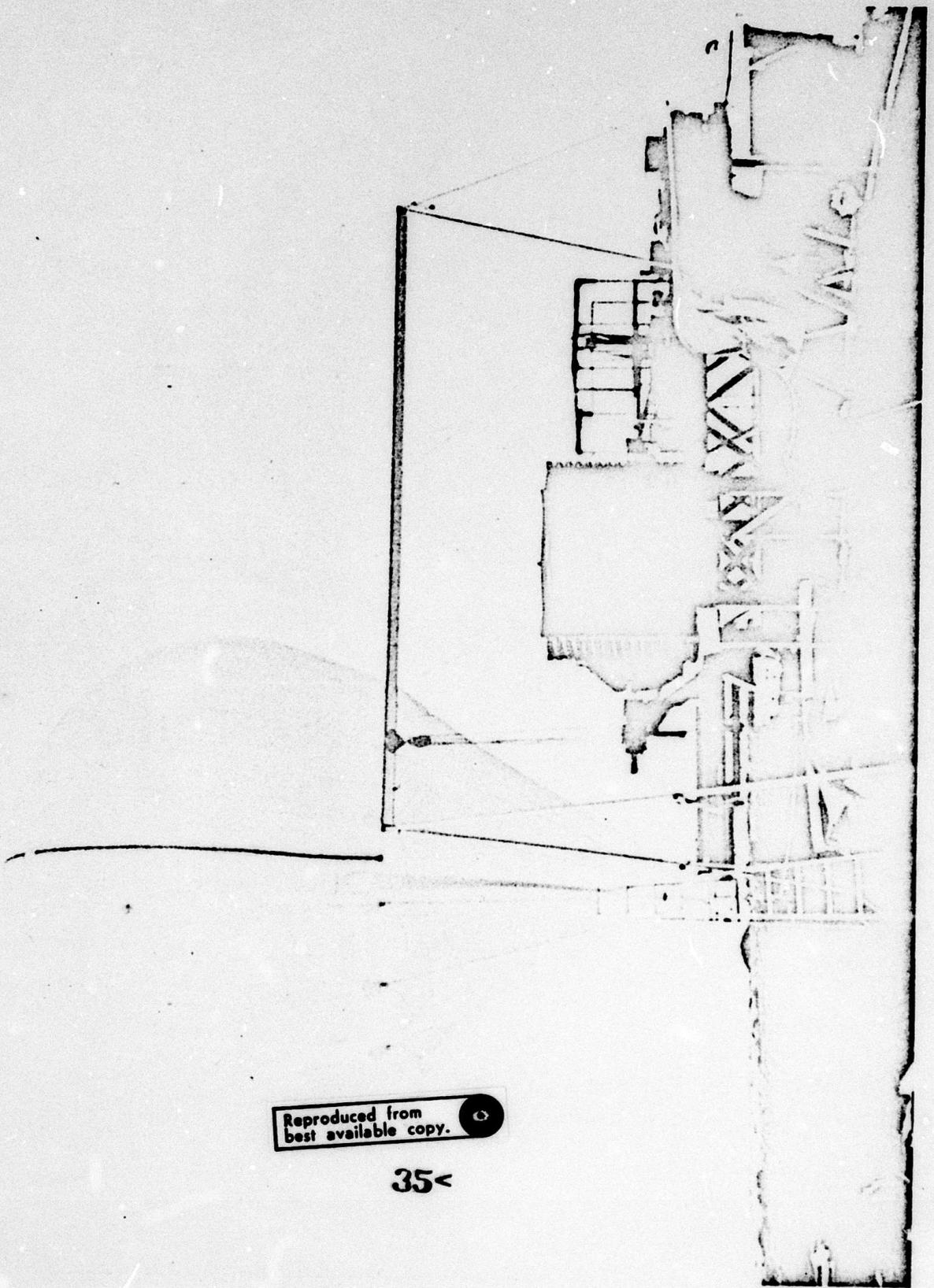


Figure 2



Reproduced from
best available copy.

35<

Figure 3

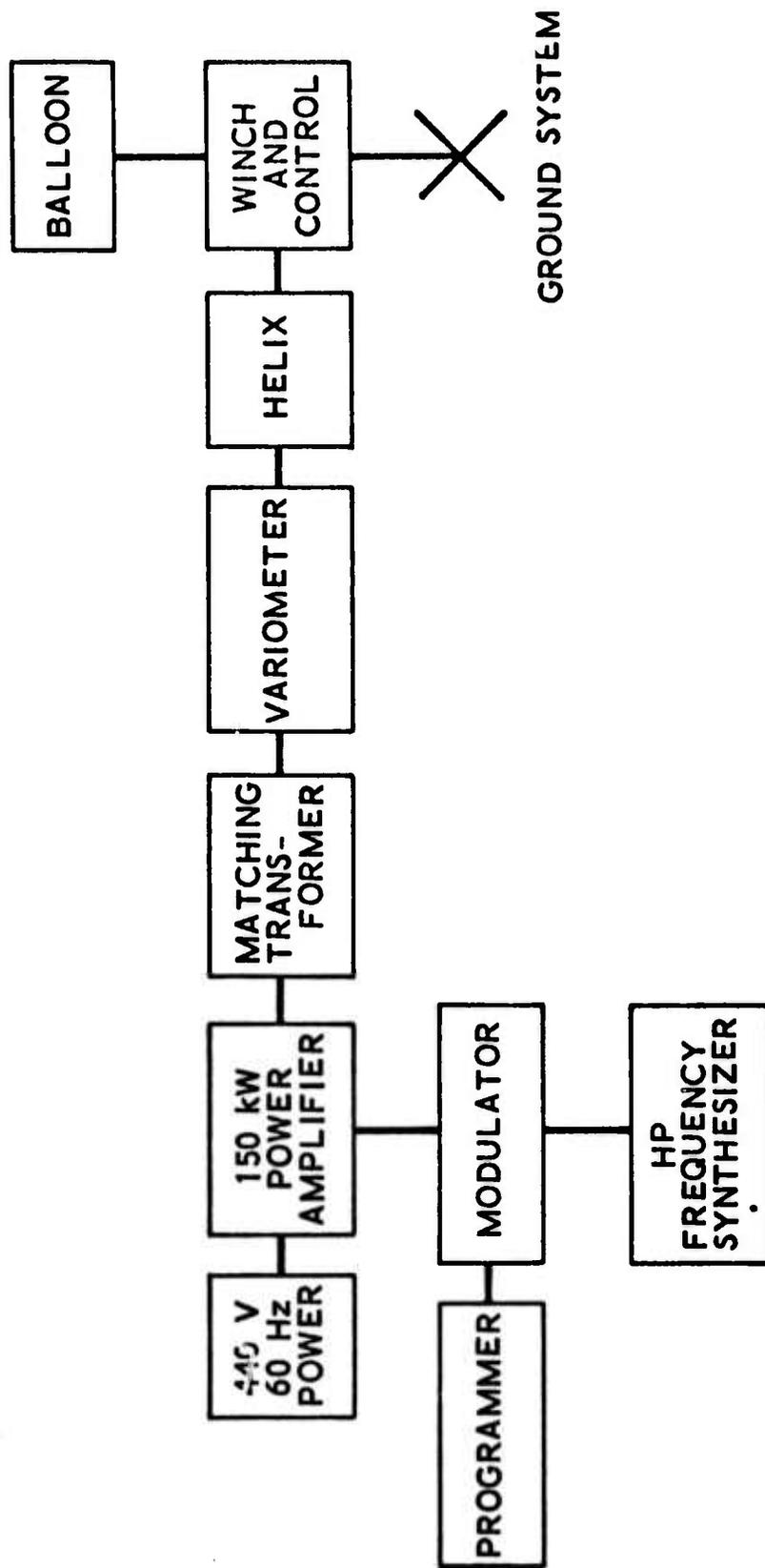


Figure 4

Appendix C

TVLF System Transmission Logs

Schedule 1 - Square Wave Modulation

.1 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
.5 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
1.0 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
2.0 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
4.0 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
8.0 Hz	1 on, 0 off, 2 on, 2 off, 2 on, 2 off

Schedule 2 - Two Frequency Mixing

ΔF

1.0 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
2.0 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
4.0 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
6.0 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off
8.0 Hz	1 on, 1 off, 2 on, 2 off, 2 on, 2 off

Schedule 3 - Pulse Modulation

	Length (sec)	Repetition Period (sec)	# Cycle	Time
1.	1	10	25	5 on 2 off
2.	2	10	25	5 on 2 off
3.	5	30	30	15 on 2 off
4.	10	30	30	15 on 2 off
5.	30	60	30	• <u>30 on</u> 2 off

1 h 20 m

Schedule 1A - Square Wave Modulation

.1 Hz	5 on, 5 off
.5 Hz	5 on, 5 off
1.0 Hz	5 on, 5 off
2.0 Hz	5 on, 5 off
4.0 Hz	5 on, 5 off

Schedule 1B - Square Wave Modulation

1.0 Hz	5 on, 5 off
2.0 Hz	5 on, 5 off
4.0 Hz	5 on, 5 off
8.0 Hz	5 on, 5 off
16.0 Hz	5 on, 5 off

Schedule 2A - 2 Frequency Mixing

ΔF	1.0 Hz	5 on, 5 off
	2.0 Hz	5 on, 5 off
	4.0 Hz	5 on, 5 off
	6.0 Hz	5 on, 5 off
	8.0 Hz	5 on, 5 off

Schedule 3A - Pulse

length	Rep Rate	
1	10	3 on, 2 off
2	10	3 on, 2 off
5	30	13 on, 2 off
10	30	13 on, 2 off
30	60	8 on, 2 off

TRANSMISSION SCHEDULE

DAY 221 - August 9, 1973

0830 Sweep at 13.275 kHz
0900 PGM 1
0905 PGM 2
0910 PGM 3
0915 PGM 4
0920 PGM 5
0925 PGM 6
0930 PGM 8
0935 PGM 10
0940 .25 sec on; 2 sec rep.
0950 .25 sec on; 5 sec rep.
1000 .5 sec on; 2 sec rep.
1010 .5 sec on; 5 sec rep.
1020 Aerospace PGM 1
1030 Aerospace PGM 2
1040 Rice Schedule 1
1150 Rice Schedule 2
1250 Sweep
1310 "N"
1320 5 sec on; 30 sec rep.
1333 OFF
1335 10 sec on; 30 sec rep.
1348 OFF
1350 Fast D
1351 Slow D
1355 OFF - End 13.275 kHz

DAY 221

1430 Sweep at 8.0 kHz
1440 4 Hz sq
1442 XMTR Power Loss
1501 .5 Hz sq
1606 .5 sec on; 5 sec rep.
1620 1.0 sec on; 5 sec rep.
1640 Sweep
1700 OFF

DAY 222 - August 10

21 kHz

10/05 .5 Hz sq
10/10 1 sec on; 10 sec rep.
1015 OFF
1017 2 sec on; 10 sec rep.
1022 OFF
1024 5 sec on; 30 sec rep.
1039 OFF - CORONA PROBLEMS
1120 10 sec on; 30 sec rep.
1135 OFF
1137 30 sec on; 60 sec rep.
1207 OFF - END 21 kHz

8.0 kHz

1235 .5 Hz sq
1249 5 sec on; 10 sec rep.
1300 PGM 1
1305 PGM 2
1310 PGM 3
1315 PGM 4
1320 PGM 5
1325 PGM 6
1330 PGM 8
1335 PGM 10
1340 .5 sec on; 2 sec rep.
1350 .5 sec on; 5 sec rep.
1400 Sweep
1410 1 sec on; 5 sec rep.
1420 Aerospace PGM 1
1430 Aerospace PGM 2
1440 Sweep

DAY 222

1450 .5 Hz sq 1 on, 1 off, 2 on, 2 off, 2 on, 2 off
1500 1.0 Hz sq
1510 2.0 Hz sq
1520 4.0 Hz sq
1530 8.0 Hz sq
1540 16.0 Hz sq
1550 Sweep
1600 D
1602 RT

6.7 kHz

1630 PGM 1
1635 PGM 2
1640 PGM 3
1645 PGM 4
1650 PGM 5
1655 PGM 6
1700 PGM 8
1705 PGM 10
1710 .5 sec on; 2 sec rep.
1720 .5 sec on; 5 sec rep.
1730 Sweep
1740 1 sec on; 5 sec rep.
1750 Aerospace PGM 1
1800 Aerospace PGM 2
1810 Sweep
1820 .5 sq
1830 1.0 sq
1840 2.0 sq
1850 4.0 sq
1900 8.0 sq

DAY 222

6.7 kHz cont'd.

1910 16.0 sq

1920 Sweep

1930 30 sec on; 60 sec rep.

1940 .1 sq

1945 CW

2000 OFF

Transmission Schedule - Day 226 August 14, 1973

21 kHz

226/08/00	1 Hz sq
226/03/05	OFF
226/08/10	Rice Schedule 3A
226/09/00	.5 Hz sq
226/09/05	OFF
226/09/10	1.0 Hz sq
226/09/15	OFF
226/09/20	2.0 Hz sq
226/09/25	OFF
226/09/30	Aerospace PGM 1
226/09/40	Aerospace PGM 2
226/09/46	CW
226/09/54	1.0 Hz sq
226/10/00	Sweep
226/10/15	OFF - End 21 kHz

13.275

10/20	Tuning to 13.275
10/40	CW - Antenna being blown down
11/00	Start Schedule 3A - Through 5; 30
11/25	.5 Hz sq
11/30	OFF
11/35	1.0 Hz
11/40	OFF

TRANSMISSION SCHEDULE

DAY 227 - August 15, 1973

227/06/48	CW
227/07/10	Rice Schedule 3A
227/07/40	CW momentarily for retuning
227/08/01	CW
227/08/25	OFF - Variometer Burned Up

TRANSMISSION SCHEDULE

DAY 229 - August 17, 1973

229/06/48	CW and Tuning - 13.275 kHz
229/07/01	OFF to replace ball gap
229/07/03	Sweep
229/07/30/20	End Sweep
229/07/45	CW
229/08/00	Sweep
229/08/10	Rice Schedule 1A - 40 amps antenna current
229/09/00	Sweep
229/09/10	Dowden Programs
229/09/10	PGM 1
229/09/15	PGM 2
229/09/20	PGM 3
229/09/25	PGM 4
229/09/30	PGM 5
229/09/35	PGM 6
229/09/40	PGM 8
229/09/50	PGM 10
229/09/55	PGM 12
229/10/00	Sweep
229/10/10	Rice Schedule 3A
229/11/00	.5 Hz sq for satellite pass - field strength in mag?
229/11/20	Sweep
229/11/30	\overline{RT}
229/11/32	OFF - End 13.275 kHz

TRANSMISSION SCHEDULE

DAY 229 - August 17, 1973

11/43	CW at 6.6 kHz
12/00	.5 Hz sq
12/20	Sweep
12/30	Dowden Programs
12/30	PGM 1
12/35	PGM 2
12/40	PGM 3
12/45	PGM 4
12/50	PGM 5
12/55	PGM 6
13/00	Sweep
13/10	PGM 8
13/15	PGM 10
13/20	.5 sec on; 2 sec rep.
13/25	4 Hz sq
13/30	CW
13/35	2 Hz sq
13/40	CW
13/45	1 Hz sq
13/50	CW
13/55	.5 Hz
14/15	1.0 Hz - Decreasing power levels
14/20	Sweep
14/30	Aerospace #1
14/45	Aerospace #2
15/00	Sweep
15/10	Rice Schedule 3A

DAY 229 - August 17, 1973

16/00	Sweep
16/10	Rice Schedule 2A
17/00	Sweep
17/10	Schedule 1
18/00	Sweep
18/10	Aerospace PGM 1
18/20	Aerospace PGM 2
18/30	CW
18/45	.5 Hz sq
19/00	Sweep
19/10	PGM 12
19/20	5 sec on; 30 sec rep.
19/30	CW
19/40	1.0 Hz
19/45	OFF
19/50	2.0 Hz sq
19/55	OFF
20/00	Sweep
20/10	OFF

TRANSMISSION LOG - DAY 232 - August 20, 1973

09/40 Tuning to 13.275 kHz
09/45 OFF
10/00 CW - 30 amps antenna current
10/05 Increasing Power
10/06 CW - 40 amps antenna current
10/15 .1 Hz square waves
10/20 OFF
10/25 .5 Hz square waves
10/30 OFF
10/35 1.0 Hz square waves
10/40 OFF
10/45 2.0 Hz square waves
10/50 OFF
10/55 4.0 Hz square waves
11/00 Sweep
11/10 OFF

11/15 Tuning to 6.6 kHz
11/21 CW - 20 amps antenna current
11/30 Sweep
11/40 PGM 12
11/50 .2 Hz square waves
12/00 .5 Hz square waves
12/15 PGM 1
12/20 PGM 3
12/25 PGM 5
12/30 1.0 Hz square waves
12/40 .5 Hz square waves
12/50 1.0 Hz square waves
12/55 .2 Hz square waves

TRANSMISSION LOG - DAY 232 - August 20, 1973

13/00 Sweep
13/10 Aerospace PGM 1
13/20 Aerospace PGM 2
13/30 CW
13/40 1.0 Hz square waves
13/45 2.0 Hz square waves
13/50 .5 Hz square waves
13/55 .2 Hz square waves
14/00 .5 Hz square waves
14/10^{14/05} Sweep^{.2 Hz}
14/20 .5 Hz square waves
14/25 PGM 1
14/30 CW
14/35 .5 Hz square waves
14/40 PGM 2
14/45 PGM 3
14/50 PGM 4
15/00 Sweep
15/10 PGM 5
15/15 PGM 6
15/20 PGM 8
15/25 .5 Hz square waves
15/30 CW
15/40 .5 Hz square waves
15/45 1.0 Hz square waves
15/50 2 Hz square waves
15/55 .5 Hz square waves
16/00 Sweep
16/10 1.0 Hz square waves
16/15 2.0 Hz square waves
16/20 .5 Hz square waves
16/25 1.0 Hz square waves

TRANSMISSION LOG - DAY 232 - August 20, 1973

16/30	CW
16/40	2 Hz square waves
16/45	5 sec; 30 sec
17/00	Sweep
17/10	END

TRANSMISSION LOG - DAY 234 - August 22, 1973

07/15 Tuning to 13.275 kHz
07/17 Sweep
07/19 CW
07/21 OFF
07/24 CW Antenna Current = 25 amps
07/30 .5 Hz square waves
07/35 1.0 Hz square waves
07/40 2.0 Hz square waves
07/45 .5 Hz square waves
07/50 1.0 Hz square waves
07/55 2.0 Hz square waves
08/00 Sweep
08/07 OFF

08/30 6.6 kHz
08/30 16.0 Hz square waves
08/35 OFF

09/30 CW at 7.4 kHz
10/00 Sweep
10/10 .5 sec pulses, 5 sec rep period
10/15 1.0 sec pulses, 5 sec rep period
10/20 Aerospace PGM 2
10/30 CW
10/35 .5 Hz square waves
10/40 1.0 Hz square waves
10/45 2.0 Hz square waves
10/50 .5 Hz
11/05 Sweep
11/15 CW
11/20 .2 Hz square waves
11/25 .5 Hz square waves

TRANSMISSION LOG - DAY 234 - August 22, 1973

11/40	PGM 1
11/45	PGM 2
11/50	PGM 3
11/55	PGM 4
12/00	Sweep
12/10	PGM 5
12/15	PGM 6
12/20	PGM 8
12/30	CW
12/35	OFF
12/45	PGM 10
12/50	PGM 12
12/55	.5 sec pulses 5 sec rep. period
13/00	Sweep
13/10	1.0 Hz square waves
13/15	.5 Hz square waves
13/35	Aerospace PGM 1
13/45	Aerospace PGM 2
13/55	1 sec pulses 5 sec rep. period
14/00	Sweep
14/10	1; 10
14/13	OFF
14/15	2; 10
14/18	OFF
14/20	5; 30
14/33	OFF
14/35	10; 30
14/48	OFF
14/50	30; 60
15/00	Sweep
15/10	.5 Hz square waves

TRANSMISSION LOG - DAY 234 - August 22, 1973

15/15	1.0 Hz square waves
15/20	CW
15/30	OFF

TRANSMISSION LOG - DAY 235 - August 23, 1973

06/54 CW at 13.275 kHz, 40 amps antenna current
07/00 Sweep
07/10 .5 Hz square waves
07/15 1.0 Hz square waves
07/20 2.0 Hz square waves
07/25 .5 Hz square waves
07/30 CW
07/35 2 sec pulses, 10 sec rep period
07/40 .5 Hz square waves
07/50 5 sec pulses, 30 sec rep period
08/00 Sweep
08/10 16.0 Hz square waves
08/15 8.0 Hz square waves
08/20 4.0 Hz square waves
08/25 2.0 Hz square waves
08/30 CW
08/35 1.0 Hz square waves
08/40 .5 Hz square waves
08/45 .2 Hz square waves
08/50 .1 Hz square waves
09/00 Sweep
09/10 PGM 1
09/15 PGM 2
09/20 PGM 3
09/25 PGM 4
09/30 PGM 5
09/35 PGM 6
09/40 PGM 8
09/45 PGM 10
09/50 .5 sec pulses, 2 sec rep period
10/00 Sweep
10/10 END 13.275 kHz

TRANSMISSION LOG - DAY 235 - August 23, 1973

10/25 on at 6.6 kHz 20 amps antenna current
10/27 .5 Hz square waves
10/35 1 sec pulses, 10 sec rep period
10/40 2 sec pulses, 10 sec rep period
10/45 5 sec pulses, 30 sec rep period
11/00 Sweep
11/10 16.0 Hz square waves
11/15 8.0 Hz square waves
11/20 4.0 Hz square waves
11/25 2.0 Hz square waves
11/30 CW
11/35 1.0 Hz square waves
11/40 .5 Hz square waves
11/45 .2 Hz square waves
11/50 .1 Hz square waves
12/00 .5 Hz square waves
12/15 PGM 2
12/20 PGM 3
12/25 PGM 4
12/30 PGM 5
12/35 PGM 6
12/40 PGM 8
12/45 PGM 10
12/50 .5 sec pulses, 2 sec rep rate
12/55 .2 Hz square waves
13/00 .5 Hz square waves
13/15 1.0 Hz square waves
13/20 2.0 Hz square waves
13/25 .5 Hz square
31/30 CW