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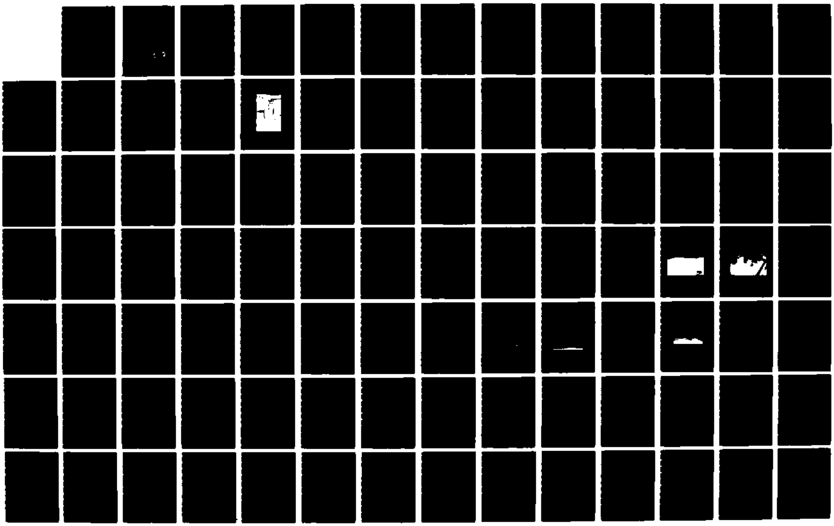

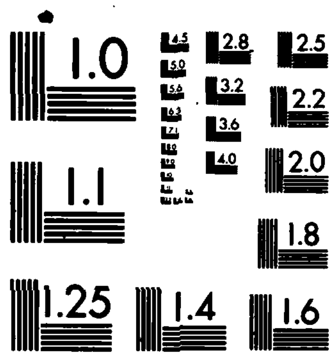

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An Automatic System for Global Monitoring of ELF and VLF Radio Noise Phenomena

AD-A161 148

by
Bruce R. Fortnam

Technical Report E450-1

June 1985

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Abstract

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Acknowledgements

This project was supervised by Professors Robert A. Helliwell and Antony C. Fraser-Smith. Evans Paschal performed the bulk of the circuit design, and Mike Dermedziew, John Billey, and John Green provided additional engineering support. Construction of the radiometer equipment would not have been possible without the efforts of Paul McGill, Kevin Smith, Sean Devin, Gordon Battaille, Brad Chen, Keith Donald, and Andrew Kalman.

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Chapter 1. Introduction

The Earth's radio environment in the very-low-frequency and extremely-low-frequency bands exhibits a rich variety of naturally occurring electromagnetic phenomena. The strongest signals consist of highly impulsive atmospheric noise emitted by lightning discharges, commonly referred to as "*sferics*". These large current impulses emit broad-band bursts of electromagnetic energy, which may propagate via several different modes, each giving rise to unique features when observed at some distance from the source. Since the frequency of these signals is in the audio range, an observer can listen to them with a simple antenna and an audio amplifier, which can convert varying electric or magnetic fields to sound waves, and it is most illustrative to describe them in terms of audible sounds. A lightning-produced impulse heard at short range sounds like a sharp click or crackle, since it contains a very broad range of frequency components occurring at nearly the same instant. When observed at a greater distance, these components begin to exhibit dispersion due to the low-frequency cutoff of the earth-ionospere waveguide. The dispersion causes the low-frequency components to arrive slightly later, producing at the receiver a chirping sound commonly called a "*tweek*". Perhaps the most dramatic natural signal is the "*whistler*", which occurs when a lightning-produced impulse travels upward through the ionosphere and into the magnetosphere, then propagates by means of the *whistler mode* along the earth's magnetic field lines out to an altitude of several earth radii, then back to the surface in the opposite hemisphere. This mode of propagation is highly dispersive, with a strong variation in travel time versus frequency. The received signal sounds like a whistle of descending tone lasting up to several seconds.

Other less intense but more complex signals can often be heard which are not the result of a lightning stimulus. Collectively referred to as "*VLF emissions*", these signals are not well understood and are currently a very active research topic. Some appear to be generated spontaneously, such as the "*dawn chorus*", which resembles the sound of a flock of birds singing in the morning. Others are clearly triggered by another signal such as a whistler or a VLF transmitter signal propagating through the magnetosphere in the whistler mode. These usually take the form of a free-running oscillation which, once triggered, may undergo wide excursions in frequency from that of the triggering signal before dying out. Other observed signals include various types of hiss—broadband, unstructured signals, often pulsating with a period of several seconds to several minutes.

This variety of signals, while interesting to scientists studying the processes occurring in the ionosphere and magnetosphere, constitutes an interfering signal to the engineer attempting to design a communication system to operate in the very-low and extremely-low frequency bands. Such a design requires a knowledge of the undesired signals present in the radio environment to determine the optimum frequencies and power levels required to establish reliable communications. Since the time of occurrence of most interfering signals cannot be known in advance, statistical methods are normally used to characterize the noise. Monitoring the natural radio noise can provide information on typical signal levels, diurnal and seasonal variations, and frequency distribution to aid in choosing the most reliable means of communication.

1.1. Previous Radio Noise Surveys

The most widely referenced atmospheric radio noise study for the last twenty years has been the C.C.I.R. Report 322, *Worldwide Distribution and Characteristics of Atmospheric Radio Noise*, published in 1963. Based on data from 16 stations with broad geographic distribution, worldwide predictions are made for the expected value of the noise level, as well as a measure of its impulsiveness, for frequencies between 10 KHz and 20 MHz.

Very little work was done below 10 KHz before the work of E. L. Maxwell and D. L. Stone during the 1960's (*Maxwell and Stone, 1963; Maxwell, 1966*). These reports presented data on the mean noise density, standard deviation, and amplitude-probability distribution for frequencies as low as 1 Hz, based primarily on vertical electric field measurements from a network of 12 stations, mostly distributed along a line through North and South America.

The VLF group of the STAR laboratory of Stanford University has been studying whistlers and related VLF phenomena since the 1950's. During this time, VLF receivers have been operated at diverse locations reaching from the South Pole to Alaska and northern Canada, but no attempt has yet been made to simultaneously map worldwide VLF noise. Data from Stanford's field sites have been predominantly in analog form, with data reduction performed at Stanford, largely by means of spectral analysis. The increasing availablity of computers for data analysis has spurred a need for on-site digital recording.

The current research was undertaken in response to the Office of Naval Research *Research Opportunities Announcement (1980)*, in the research area entitled *Environvental Factors Related to ELF/VLF/ULF Communications*. The system design and the bulk of the circuit design was performed by Evans Paschal of Stanford University. This report is intended to give an overview of the system and the goals of the experiment, and to provide a basic reference for those wishing to work with the resulting data. Readers desiring more thorough documentation of the radiometer system should consult the system manual provided with each field unit and the *ELF/VLF Noise Survey Software Reference Manual* by Evans Paschal.

1.2. Goals of the New Radiometer System

The goal of this project is to provide worldwide statistical information on the distribution of natural radio noise in the ELF and VLF frequency range. To help achieve this goal, a new system has been developed, which we call a *radiometer* to emphasize its quantitative analysis capabilities. The new system has three major enhancements over systems previously used by Stanford's VLF research group:

1. Increased geographic coverage with a series of stations widely spaced in both latitude and longitude.
2. Extended frequency coverage, from 10 Hz to 32 KHz.
3. On-site digital recording capability to facilitate analysis of the data.

In order to provide sufficient data to map the global distribution of ELF/VLF noise, eight widely spaced observing sites are being established. The proposed station locations are listed with their geographic coordinates in Table 1.1 and shown on a world map in Figure 1.1.

These locations are widely distributed in both latitude and longitude, covering low latitudes well equatorward of the nominal plasmapause position (Stanford, Dunedin, Japan, Italy), near the plasmapause region (New Hampshire, Arrival Heights), and the auroral zone (Thule and Sondre Stromfjord). On many occasions the Greenland sites will be well inside the polar cap region. Another major consideration in site selection is the availability of suitable facilities and personnel for routine operation.

The system's frequency range is divided into two overlapping ranges, covered by two independent receivers; a VLF unit covering the usual band from 300 Hz

TABLE 1.1. Site Locations and Coordinates for Radiometer Stations

Station	Coordinates
Arrival Heights, Antarctica	78°S, 167°E
Sondre Stromfjord, Greenland	67°N, 50°W
Thule, Greenland	80°N, 60°W
Dunedin, New Zealand	46°S, 170°E
Kochi, Japan	33°N, 134°E
Stanford, California	37°N, 122°W
New Hampshire	43°N, 72°W
L'Aquila, Italy	42°N, 13°E

to 32 KHz, and a new ELF receiver covering 10 Hz to 400 Hz. Each receiver has two channels with crossed loop antennas, oriented vertically in the East-West and North-South directions. The ELF receiver will provide broadband and statistical data for a band that has historically received little attention. Broadband recordings will be made from both receivers, nominally on a synoptic basis (i.e. 1 minute recording every 30 minutes), although this can be easily changed by the operator to continuous recording for periods of special interest. The VLF band will be recorded on standard 1/4" audio tape, while the ELF band will be sampled and recorded on standard 1/2" digital tape. The sampling rate for the broadband ELF will be 1000 samples per second, allowing complete reconstruction of signals up to 400 Hz.

In order to facilitate statistical analysis of the noise characteristics, a set of narrow-band filters has been added to the system. These 5% bandwidth filters are evenly distributed throughout the ELF and VLF bands. The envelope of the filter outputs is sampled continuously by the computer to allow computation of statistical averages.

The on-site digital recording consists of two major forms of data: the broadband ELF data, sampled at 1000 samples per second during scheduled recording periods, and the low-speed samples from the narrow-band filters, typically recorded at 1 sample per second for all 16 filters. Computed statistical averages, along with station status information and operator messages, complete the recorded information. Much of the radiometer data, therefore, arrives at the analysis lab already in digital form, eliminating the need for post-digitizing when digital processing is desired. The ELF broadband data can still be viewed in analog form by passing it through

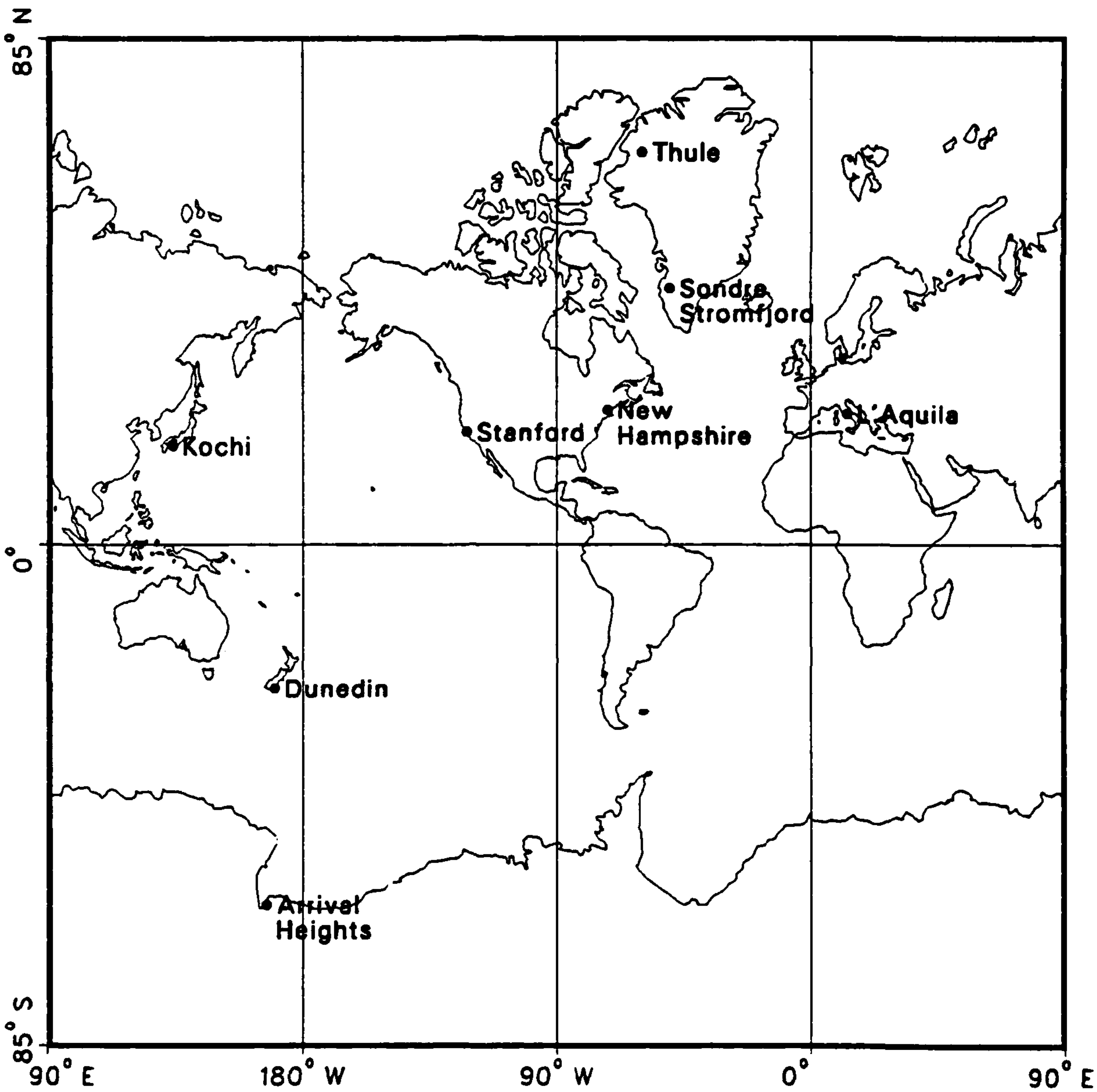

Figure 1.1. World map showing the locations of the eight radiometer installations.

a digital-to-analog converter. Statistical quantities, consisting of root-mean-square, maximum and minimum amplitudes, are maintained continuously and recorded at the end of every minute, independent of the noise filter sampling rate. This data can be read and listed directly from the tape with no further processing required. The unprocessed statistical samples are also recorded, normally at 1 sample per second, to allow additional digital processing at a later date.

Chapter 2. System Description

2.1. Overview

The radiometer system is shown in block diagram form in Figure 2.1. The primary data are provided by two radio receivers covering the ELF and VLF bands, each having two quadrature antennas and two receiving channels. For the purposes of this description, the term 'ELF' is used to refer to the band 10 Hz to 400 Hz, and 'VLF' to refer to the band 300 Hz to 32 KHz. For recording purposes, these are considered the nominal bandwidths of the two receivers, although both are capable of wider range operation.

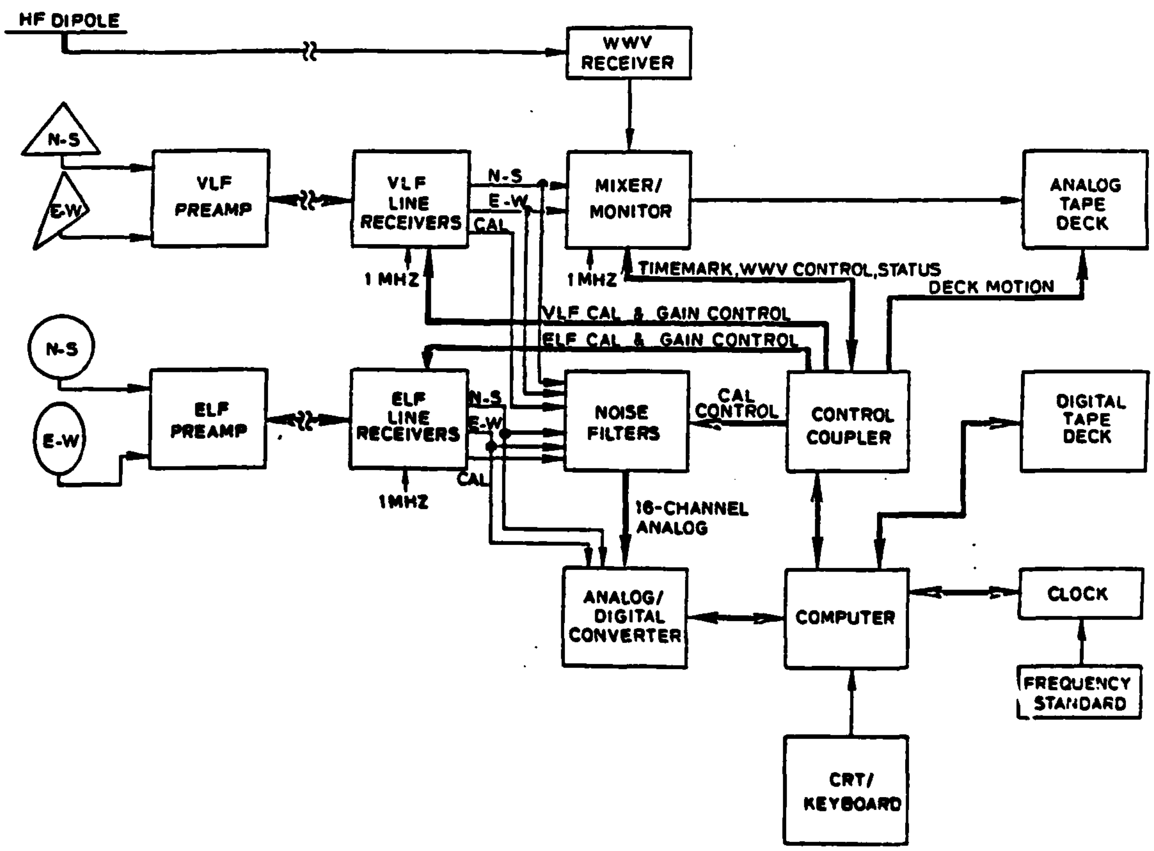

Figure 2.1. Block diagram of the Stanford ELF/VLF Radiometer.

A photograph of the laboratory portion of the radiometer is shown in Figure 2.2, and diagrams of the two antenna installations are shown in Figure 2.3 and Figure 2.4. The ELF antennas consist of 1-meter diameter multi-turn loops and are placed a maximum of 1000 feet from the lab enclosed in a vault to isolate them from air movement and vibrations. The VLF antennas consist of two single-turn loops mounted on a single 10-meter high tower placed a maximum of 3000 feet from the lab. The preamplifiers are located at the antenna sites, as close to the antenna terminals as possible. Multi-conductor cables return the preamplified signals to the lab and provide DC power and calibration signals to the preamps.

In the lab, the line receivers provide variable gain for both ELF and VLF signals before passing them on to the noise filters and the broadband recording system. The noise filters consist of narrowband (5% bandwidth) filter pairs at 16 different center frequencies, 6 in the ELF band, and 10 in the VLF band. The filter outputs are rectified and filtered to provide a measure of the signal envelope for statistical noise characterization. All the filters are sampled continuously at a rate of 10 samples per second, and recorded on digital tape at a rate determined by the operator; typically 1 sample per second. The broadband VLF signal is recorded on standard 1/4 inch audio tape, according to a schedule selected by the operator, typically 1 minute samples every 30 minutes. Similarly, the broadband ELF signal is recorded on digital tape, being sampled at 1000 samples per second for the duration of the broadband recording. A microcomputer controls all the automatic system functions, using schedule information set up by the operator with switches on the front panel of the control coupler. The control coupler also serves as an output device by displaying system status and error information and by passing control signals on to the receivers, mixer/monitor, and noise filter unit. The system clock maintains the date and time, derived from an oven-stabilized quartz frequency standard, and generates a timing interrupt for the computer and synchronization pulses for the analog-digital converter. A video terminal is provided for displaying signal statistics, system status, and to allow the operator to set up special recording schedules.

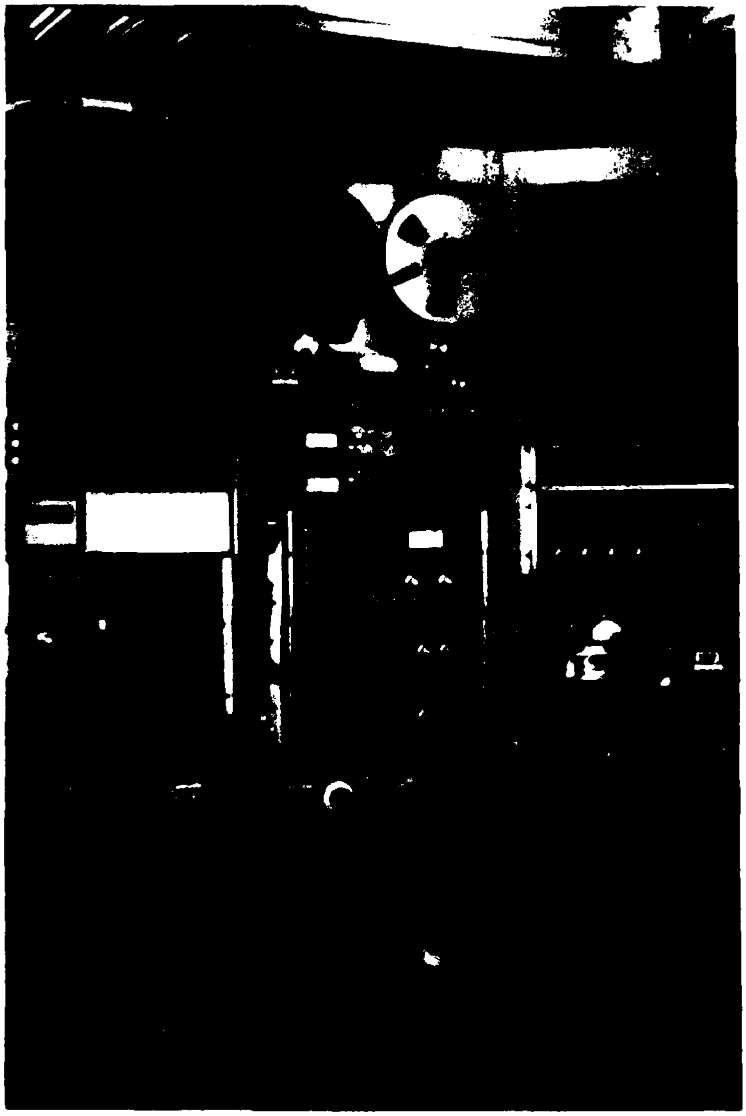

Figure 2.2. Photograph of the laboratory portion of the radiometer, as installed at Arrival Heights, Antarctica.

Physical Specifications:

Lab System: Resides in 2 standard 19" equipment racks

Floor space: 44" x 27"

Height: 78" (86" at some installations)

Weight: 800 lb.

Power: 2000 watts maximum, 1200 watts typical

50 or 60 Hz, 240–120 volt transformer will be provided where necessary

Outside access is required for 2 large cables.

VLF Receiving Site (1000'-3000' from lab):

10 meter tower with guy lines if necessary to accomodate local wind conditions

Appx. ground area required—60' x 60' square

Forested areas acceptable, must be remote from local power line interference sources

ELF Receiving Site (1000' from lab):

Buried or wind-tight above-ground vault

Size—appx. 2 meter cube

Antennas are 1 meter loops weighing 70 lb. each, and must be mounted with non-magnetic materials

Must be remote from roads and other vibration sources, including pedestrians, as well as power line interference sources.

Other: 10 MHz WWV antenna required.

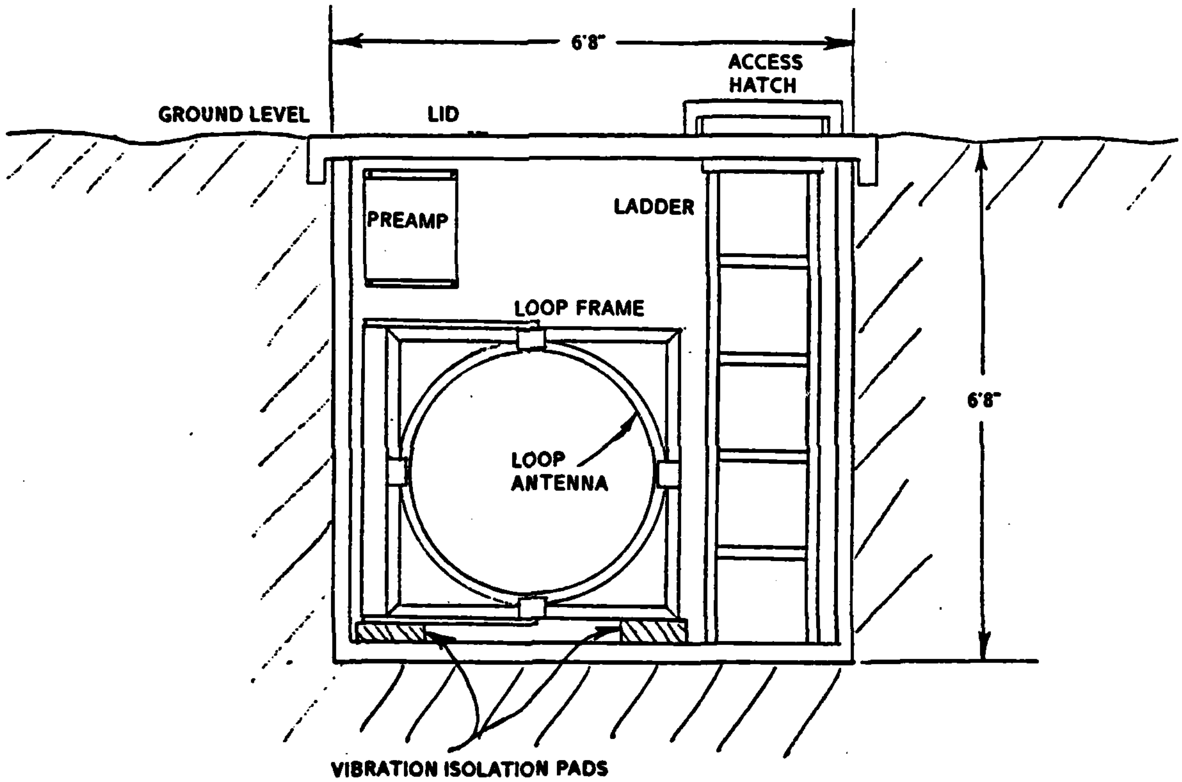

Figure 2.3. Diagram of the below-ground ELF antenna vault, showing the loops mounted in a wooden frame that holds them at 90° to each other.

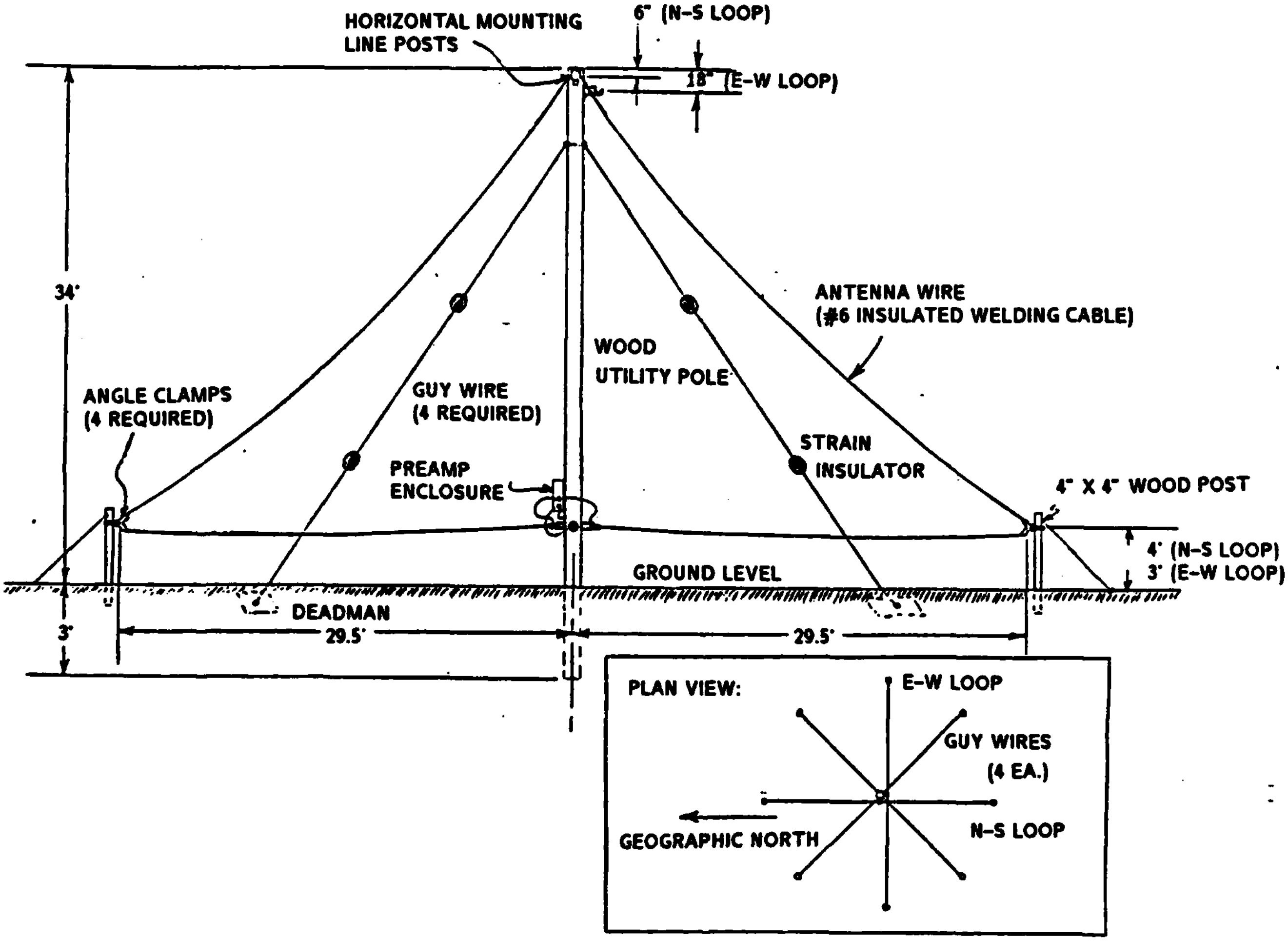

Figure 2.4. Diagram illustrating the construction of the VLF antenna.

2.2. VLF Receiver

The VLF receiver, shown in block diagram form in Figure 2.5, is designed to measure signals with frequencies ranging from 300 Hz to 32 KHz. A magnetic field antenna is used, consisting of a single loop of #6 AWG braided copper welding cable (chosen for low resistance and flexibility) erected on a steel tower in a triangular shape 18 meters along the base and 9 meters high, giving an area of 81 m^2. The antenna sensitivity, expressed as the equivalent field strength of the antenna noise is given in Figure 2.6, along with the equivalent field strength of the combined antenna and preamplifier front end noise. For comparison, typical background atmospheric noise levels are in the range 10^{-5} to 10^{-7} V/m in a 1 Hz bandwidth—well above the combined antenna and receiver noise levels.

The preamp input stage uses low-noise bipolar transistors in a common-base configuration to provide a low input impedance ($\sim 500\Omega$), easing the turns ratio requirement on the input matching transformer. This is followed by a differential amplifier stage, providing a fixed voltage gain before going to a pair of high power operational amplifiers that form a balanced line driver to drive up to 3000 feet of twisted pair to bring the signal into the laboratory.

Space has been provided in the preamp enclosure for a third channel, which can be used for a vertical antenna for direction finding as an added capability in the future. The preamp is housed in a weatherproof box mounted on the tower that supports the loop antennas, and is connected to the lab by means of a 6-pair shielded cable, with the twisted pair cables allocated as follows:

1. N/S Received Signal
2. E/W Received Signal
3. Phone
4. Calibration signal to preamp
5. DC power to preamp
6. Spare

The 'Phone' wire is provided for voice communications between the lab and antenna site, using an intercom or sound-powered telephone, when making calibration line loss measurements and when servicing the preamps.

The line receiver unit is a $5\frac{1}{4}$ inch-high rack-mounted module that resides in the lab with the recording system. The balanced signal lines coming from the preamp are fed to differential amplifiers to reject common-mode signals picked up by the

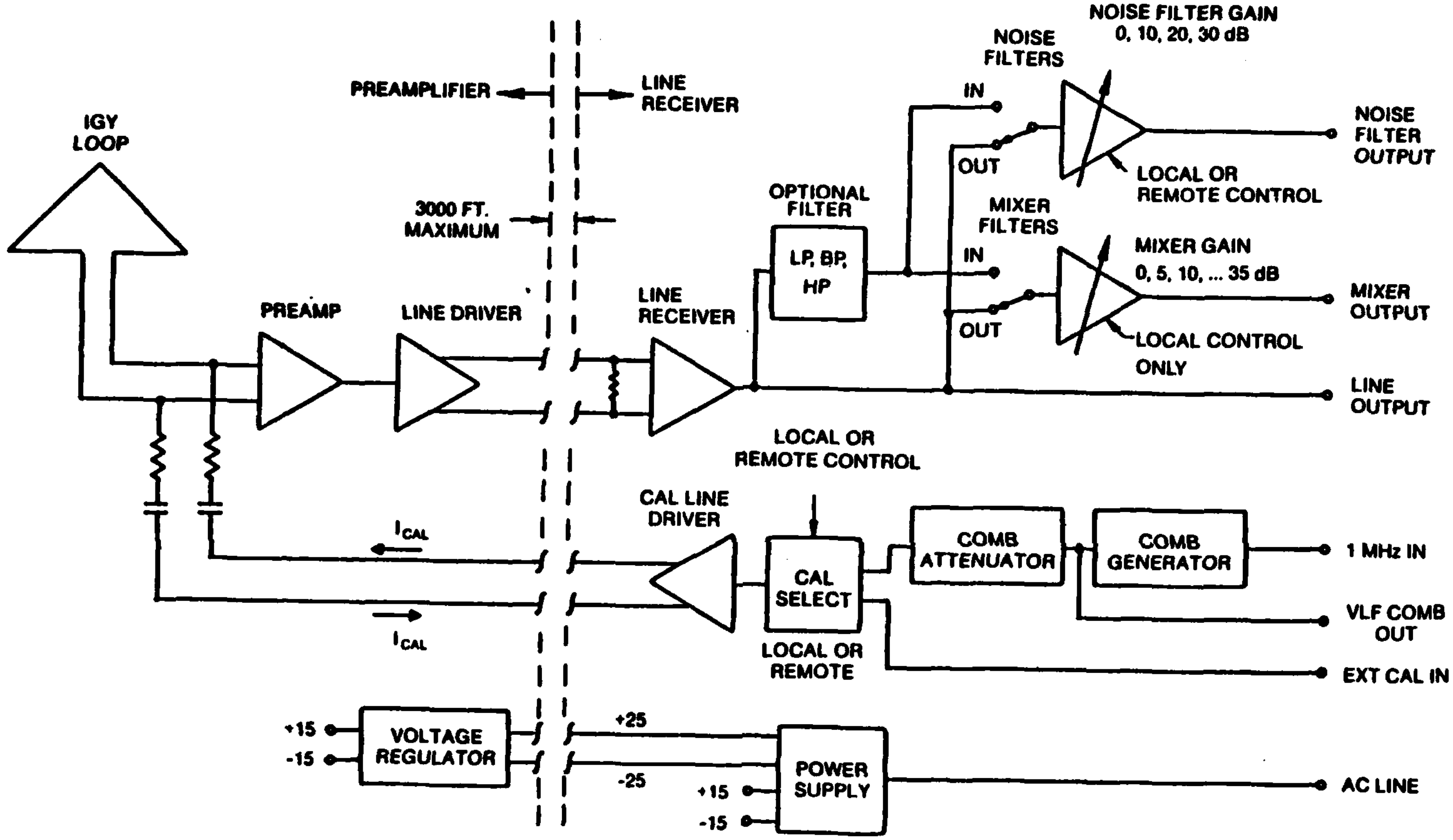

Figure 2.5. VLF preamplifier and line receiver block diagram. Shown is one channel of the two-channel receiver, and the calibration circuit and power supply, which are common to both channels.

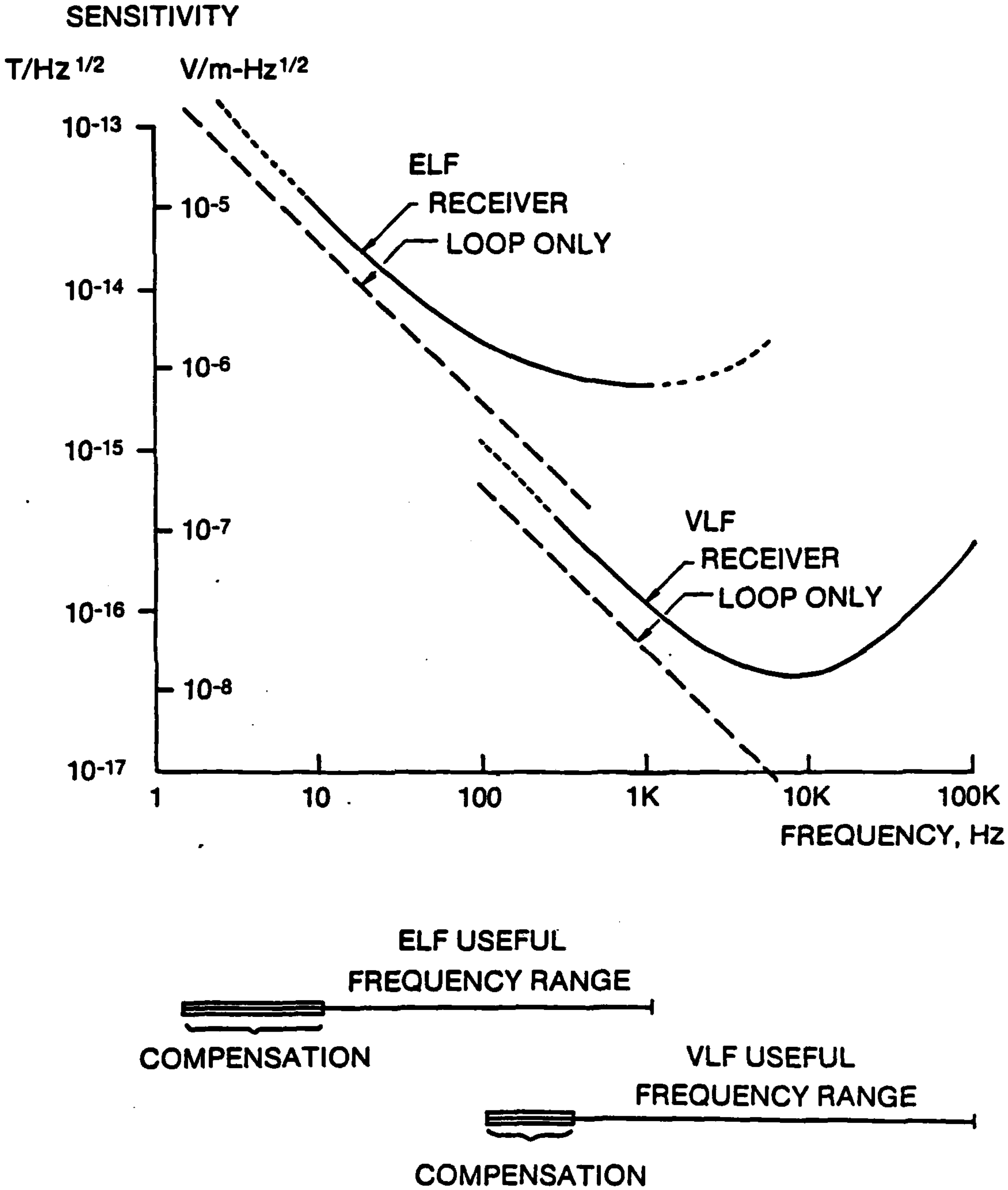

Figure 2.6. VLF and ELF loop antenna sensitivities, expressed as the equivalent field strength of the antenna noise in a 1 Hz bandwidth.

transmission lines. A card slot and wiring are provided to allow insertion of an interference filter in each channel, the nature and necessity of which is determined by individual site requirements. A typical filter might be a high-pass filter with a cutoff frequency of 1–2 kHz to remove strong power line harmonics. The interference filter is followed by a variable gain stage to provide additional gain for periods of low-level activity. The gain to the Mixer/Monitor outputs is selectable from 0 to 35 dB in 5 dB steps, and the gain to the noise filter outputs from 0 to 30 dB in 10 dB steps. The noise filter gain setting is normally controlled automatically by the computer, but can be overridden at the line receiver unit by the local mode switch. Two rear panel outputs are provided from each channel, for connection to the mixer/monitor and to the noise filters, and a front panel output for directly monitoring the receiver output. A calibration signal output is provided for the noise filter calibration, which is performed separately from the VLF and ELF receiver calibrations. A multiconductor cable connects the receiver to the control coupler, which passes all control and status information to and from the computer.

VLF Calibration circuit:

Balanced injection of a known current into the preamp input directly in parallel with the antenna is used to calibrate the receiving system for absolute measurements of VLF received signal strength. The calibration signal is generated in the lab, and can be either a comb signal generated within the line receiver unit or an external signal applied to the CAL input of the line receiver. The comb signal is normally used and consists of a sequence of equal-amplitude components spaced every 250 Hz to more than 32 KHz, derived from the station's 1 MHz frequency standard. An external sine wave source should be used during installation and periodic check-ups for measuring the system frequency response and determining the '*calibration constant*' that relates received signal strength to the receiver output voltage seen in the laboratory. The calibration signal is sent over a balanced line to the preamp unit at the antenna, where it is injected directly in parallel with the antenna when switched on by a DC calibration control signal. An attenuator with 10 dB steps from 0 to 70 dB is provided for checking the linearity of the receiver.

2.3. ELF Receiver

The ELF receiver preamp and line receiver block diagrams are shown in Figure 2.7. It is designed to receive signals in the frequency range 10 Hz to 400 Hz, although it has a usable response to more than 1000 Hz. As in the VLF receiver, 2 channels, for east/west- and north/south-oriented antennas, are provided. The magnetic-field-sensing antenna consists of 1164 turns of #18 AWG insulated wire in a layered bifilar winding on a 37 inch diameter core, giving a turns-area product of 863 m^2. Refer to Figure 2.6for the antenna sensitivity.

The ELF loops, when located in the Earth's magnetic field, are extremely sensitive to mechanical vibrations that can distort the area of the loop or change its orientation relative to the magnetic field lines, thus changing the number of flux lines enclosed by the loop. The sensitivity is such that footsteps can be heard on the receiver's monitor, and a light breeze (~5 knots) is enough to saturate the preamplifier. This requires that the loops be isolated from air movement by a wind-proof vault, normally buried in the ground, and isolated from ground vibrations such as vehicle traffic and footsteps by a damping suspension system. A simple wooden support structure has proven sufficient for this purpose. Heavy vehicle or personnel movement in the vicinity of the antennas will still create interference, and must be avoided. An electrostatic shield surrounds the coil to prevent electrostatic interference from local broadcast transmitters and power line fields.

The ELF preamplifier is similar to the VLF preamp, but the antenna is directly coupled into the input stage, which consists of 5 common-base transistors in parallel in both legs of the center-tapped antenna to provide the low input impedance necessary to match the antenna impedance. This is coupled to a differential amplifier stage, then to a line driver. Two shielded twisted pair cables bring the 2 channels of ELF broadband signal into the laboratory. DC power for the preamp is provided via another twisted pair. The ELF link to the laboratory is a 6-pair shielded cable identical to the VLF cable, with a maximum length of 1000 feet.

The ELF line receiver is a separate $5\frac{1}{4}$ inch-high rack-mount unit containing the line receivers for the two channels, the preamp DC power supply, the antenna calibration signal generator, and filters for removing unwanted components of the broadband signals, as described below. The gain to the noise filter and A/D con-

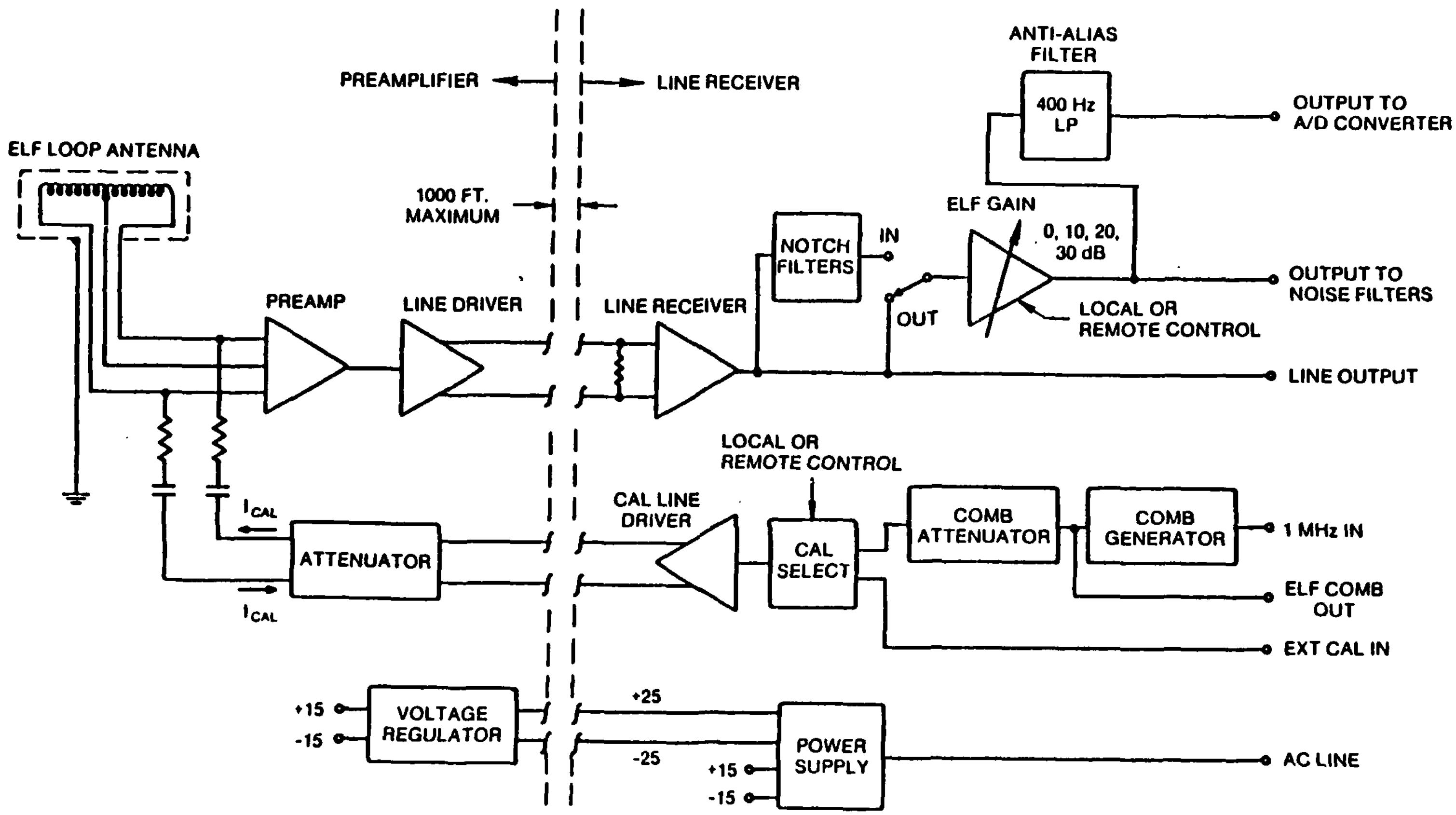

Figure 2.7. Block diagram of the ELF preamplifier and line receiver. Shown is one channel of the two-channel receiver, and the calibration circuit and power supply, which are common to both channels.

verter outputs can be varied from 0 to 30 dB in 10 dB steps, while the monitor output (Line Out) has a fixed gain.

ELF receiver filters

Four notch filters are provided for each ELF channel for removing the local power line frequency and several of the first few harmonics. In 60 Hz power line areas, these filters are centered at 60, 120, 180, and 300 Hz, while in 50 Hz areas, they are centered at 50, 100, 150, and 250 Hz. All four filters can be switched in or out according to filtering requirements for each individual site. If the local line frequency varies significantly, as it often does at remote sites like those in the Antarctic, short-term surges in interference levels will be present in the data. Tests at the South Pole showed that a 1 Hz departure from 60 Hz due to load transients on the generators resulted in a 20 dB increase in the noise level.

The ELF receiver has a useful bandwidth of approximately 1000 Hz, making low-pass filtering necessary to prevent aliasing when it is sampled at a rate of 1000 samples/second for digital recording. An anti-aliasing filter in the line receiver unit performs this function by removing all components above 400 Hz from the signal going to the A/D converter. The outputs for the noise filters and monitor are unfiltered.

ELF Calibration circuit

The ELF calibration method is identical to the VLF, except that the comb calibration signal has components spaced every 10 Hz. This ensures that at least one comb component will fall in the passband of each of the noise filters. An external calibration tone may be injected in place of the comb cal signal for frequency response measurements. The comb signal may be attenuated under program control before it is sent over a twisted pair to the preamp, to be injected in parallel with the antenna. An output is provided for calibrating the ELF section of the noise filters independently of the receiver calibration.

2.4. Noise Filters

The noise filter unit performs the 'radiometer' function of the ELF/VLF Radiometer. It consists of 32 bandpass filters arranged in pairs at 16 different frequencies, for observing selected narrow bands spaced throughout both the ELF and VLF bands. The filter frequencies are chosen to fall between 50 Hz and 60 Hz power line harmonics in the ELF band, and for observing specific natural phenomena in the VLF band, as listed in Table 2.1. The filter response is third-order Chebyshev with 0.5 dB passband ripple and a 3 dB bandwidth of 5% of the center frequency. The filters are implemented with an L-C ladder network, with the inductors simulated with operational amplifiers in a gyrator configuration. All filters have the same basic circuit, varying only in component values, to facilitate circuit layout and changes in the center frequency.

TABLE 2.1. Noise Filter Frequencies

	Channel	Frequency	Reason for Choice
ELF Receiver	1	10 Hz	Lower limit of system
	2	30 Hz	Geometric mean of 10 and 80
	3	80 Hz	Between 60 Hz and 100 Hz
	4	135 Hz	Between 120 Hz and 150 Hz
	5	275 Hz	Between 250 Hz and 300 Hz
	6	380 Hz	Between 360 Hz and 400 Hz
VLF Receiver	7	500 Hz	Lower edge, polar chorus band
	8	750 Hz	Upper edge, polar chorus band
	9	1.0 KHz	Active mid-latitude chorus band
	10	1.5 KHz	Active mid-latitude chorus band
	11	2.0 KHz	Active mid-latitude chorus band
	12	3.0 KHz	Active mid-latitude chorus band
	13	4.0 KHz	Active mid-latitude chorus band
	14	8.0 KHz	Prominent hiss band
	15	10.4 KHz	OMEGA frequency
	16	32.0 KHz	Upper limit of system

The overall block diagram of the noise filter unit is shown in Figure 2.8. The unit is housed in a 12.25 inch high rack-mount enclosure installed in the laboratory.

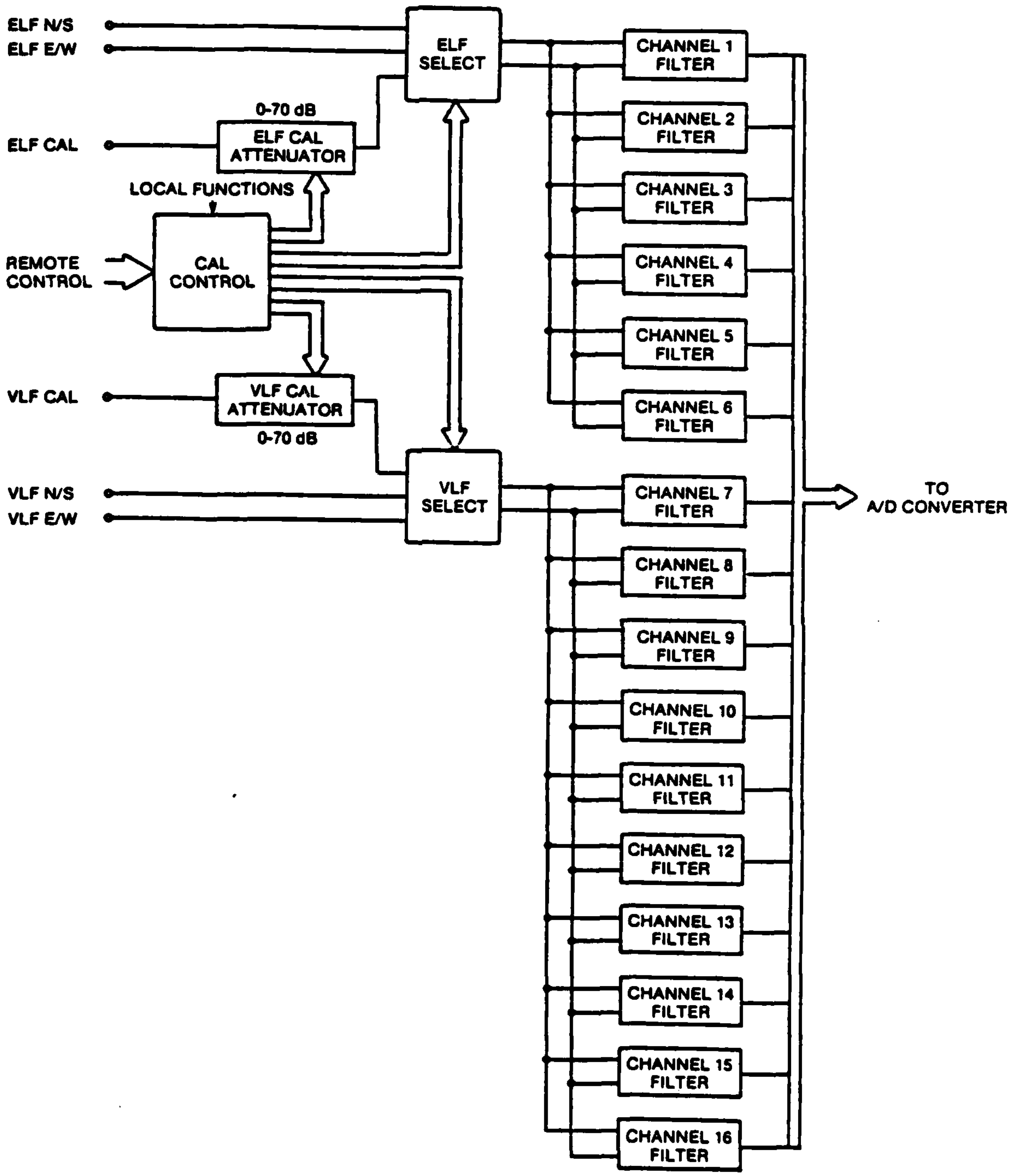

Figure 2.8. Block diagram of the noise filter unit.

The 32 filters are arranged in 2 banks, with filter frequencies from 10 Hz through 380 Hz taking their input from the ELF receiver, and 500 Hz through 32 KHz from the VLF receiver. Two filters are provided at each frequency, one for the N/S channel and one for the E/W channel. At the output of each filter is an rms detector and ripple filter with a rise time short compared to that of the bandpass filter, so that the output charateristics are determined primarily by the bandwidth of the given filter. All 32 filter outputs are brought out to a 37 pin connector on the rear panel for connection to the A/D converter, as well as to BNC connectors on the front panel.

Calibration signals can be switched in place of the input signals separately for the ELF and VLF filter banks. The calibration signals are normally the comb signals from the line receivers: 10 Hz-spaced components for ELF and 250 Hz-spaced components for VLF. The cal signals can be attenuated in 10 dB steps from 0 to 70 dB for checking the linearity of the filters. The calibration sequence is normally controlled by the computer by logic signals passed through the control coupler, but can be overridden manually by the operator.

2.5. Control and Recording System

All system control and recording functions are performed under software control by a Data General MicroNova microcomputer. The control program resides in 16K words of non-volatile EPROM memory, and starts up automatically when the computer is turned on or reset, thus eliminating the need for the operator to reload the software after a power outage. Another 16K words of volatile read/write memory is used for variable storage and magnetic tape data buffering.

Four I/O ports are used to communicate with the various system components, each with its own interface residing in the computer chassis. The clock and control coupler controllers, both built at Stanford, provide 16 bits of input or output using the standard Data General programmed I/O instructions. The digital tape controller is a Stanford-built interface with its own dedicated microprocessor to manage the tape data transfer and timing and control of the magnetic tape functions. This interface uses the *data channel* method of transfer, which allows a programmer to transfer a specified block of memory without having to handle each byte of data individually. The interface for the A/D converter is supplied as an accessory by the converter manufacturer.

2.6. System Clock

The system clock was designed and built at Stanford to provide precise time-of-day information and timing signals to synchronize the recording and control functions. The time base for the clock is an oven-stabilized quartz frequency standard. The 1 MHz signal from the frequency standard is divided down by the clock to 1 KHz, which is used as an interrupt signal to inform the computer that 1 millisecond has passed. It is further divided to generate the seconds, minutes, hours, day of year, and year information, which is displayed on the clock front panel and made available in binary-coded decimal format to the computer via a rear panel connector. Using the front panel controls, the operator may set any digit and synchronize the clock to within 1 millisecond of a timing signal from an HF WWV receiver. A 3000 pulse/second low-jitter synchronization signal is also provided for precise triggering of analog-to-digital conversion samples. Both the clock and the frequency standard are provided with battery back-up to maintain the time information for several hours during power failures. The clock's LED display is blanked at such times to conserve battery power. Should the frequency standard fail, the clock will automatically switch to a less stable internal crystal oscillator and continue to maintain the time, although with reduced accuracy.

2.7. Control Coupler

The control coupler manages the transfer of all control and status information between the computer and the rest of the system, except for the A/D subsystem, which contains its own control lines and occupies a separate I/O slot in the computer. The coupler connects to a general purpose I/O interface, through which the computer can read status information and issue control signals. Figure 2.9 shows the block diagram of the control coupler. It reads coupler data by first sending a '*Read Condition Code*' word to the coupler with a Data Output (DOC) instruction. The coupler then places the requested information on the DATA IN lines to the computer, to be read with a Data Input (DIA) instruction. When output data (for system control) is sent to the coupler with a DOB instruction, a 3-bit destination code is included in the data word, so only one CPU instruction is required. The destination code causes the control signals to be routed to the appropriate device or indicator.

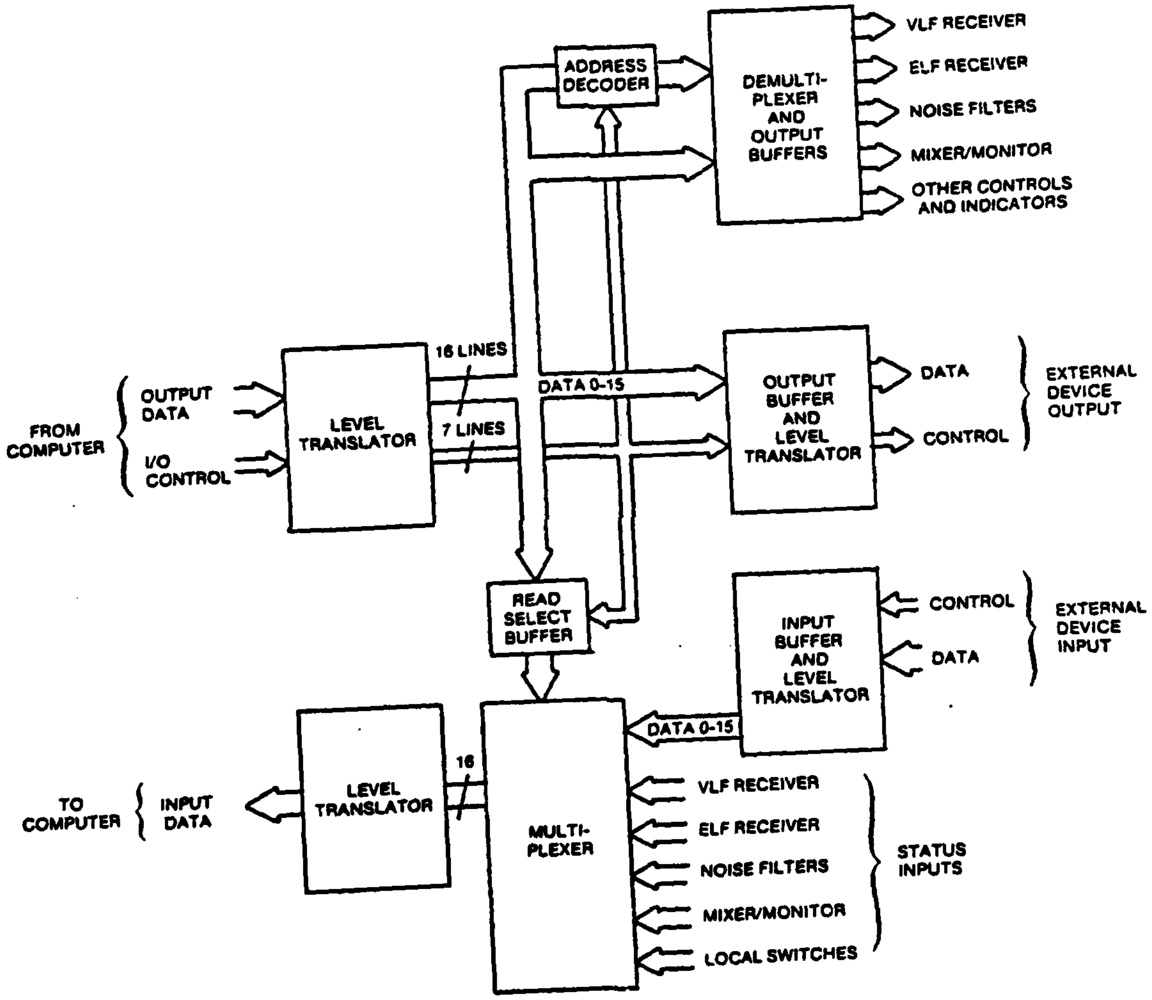

Figure 2.9. Control coupler block diagram.

The following devices send status information and/or receive control information by way of the coupler:

1. VLF Line Receiver	5. Recorder 1
2. ELF Line Receiver	6. Recorder 2
3. Mixer/Monitor	7. Chart Time Mark
4. Noise Filters	8. External Device

The external device port contains 16 input lines, 16 output lines, and I/O control lines for a TTL or CMOS auxiliary device such as a paper tape reader. This port was used during program development to download software from an Eclipse minicomputer development system into the Micronova.

Auxiliary relay closure outputs are provided for Relay 1, Relay 2, and Alarm. BNC inputs External Record 1 and External Record 2 provide a means of controlling the analog recorders independently of the computer. When enabled by the front panel switches, a continuous high logic level (TTL or CMOS) or a contact closure will put the appropriate recorder in record mode. Logic level or contact closure input is selected by a back panel switch.

Indicators and Output Data

All front panel indicators are controlled by the software, and all control signals going to other devices have a corresponding indicator. The coupler indicators show the state of the remote control lines going to any particular device, and are not valid if the device is in local mode.

VLF (ELF) Receiver Sections:

Error - indicates an abnormal condition exists in the VLF (ELF) receiver.
Recording - currently taking a synoptic broadband VLF (ELF) sample.
Gain - gain setting on the noise filter output of the VLF (ELF) receiver.
Cal Indicators:

Ext - External cal tone applied to cal line driver.
Comb - Comb signal applied to cal line driver.
Comb Enable - Comb generator enabled.

Noise Filter Section:

Error - abnormal condition in noise filters.

Recording - currently sampling the noise filter outputs.

Cal Indicators (VLF or ELF):

Sig Inh - Calibration circuit enabled.

NS, EW - cal signal applied to the NS and/or EW filter banks.

40 dB, 20 dB, 10 dB - cal signal attenuation setting (0-70 dB in 10 dB steps).

Analog Tape Deck Section:

Error - abnormal condition in either tape deck.

Record, Stop (Deck 1 or Deck 2) - indicates the last control pulse sent to the tape deck.

Digital Tape Deck Section:

Error - abnormal condition in digital tape deck.

On Line - tape deck is on line to the computer.

Ready - tape deck is ready to record data.

New Tape - system is waiting for a new tape to be mounted.

Data Lost - an error has occurred that allowed some data to be lost.

Write Lock - the write ring is missing from the current tape (no data can be written)

Write, Write EOF, Read, Erase, Space FWD, Space Rev, Rewind - current command being sent to the digital tape deck.

Mixer/Monitor Section:

Error - abnormal condition in mixer/monitor.

Time Mark - shows operation of the 1-sec time mark and station code.

WWV - received WWV signal applied to analog recorder outputs.

Program Lights (0–7): eight bits of output data to be used for debugging and auxiliary output information.

Program Status:

Error - a non-fatal software error has occurred.

Restart - a fatal software error has occurred, causing the program to restart itself.

Power Failure - a power failure has occurred.

Message Waiting - the computer is waiting to send a message to the CRT terminal.

Relay Outputs:

Relay 1, Relay 2 - auxiliary relay closure outputs.

Chart Time - relay closure output for the 1-min chart time mark.

Alarm - combined relay closure output, back panel Sonalert alarm, and red front panel LED used to alert the operator that the system needs attention.

Front Panel Controls and Computer Input Data

The control coupler front panel controls form the operator's primary control interface for the radiometer system. This is where the normal operating modes are set up — special schedules must be programmed at the CRT terminal. The controls and input signals going to the computer are as follows:

Front Panel Controls

VLF (ELF) Synoptic Rate - 6-position rotary switch to select the interval for synoptic recordings: 1-min in 5, 15, 30, or 60 min, continuous recording or off.

Noise Filter Sample Time - 7-position rotary switch to select the interval between noise filter samples: .2, .5, 1, 2, 5 or 10 secs, or off.

Analog Tape Deck Mode (Deck 1 or Deck 2):

Ext - selects the back panel external record control.

Local - coupler recorder controls disabled.

Auto - recording controlled by the computer.

First Deck - selects Deck 1 or Deck 2 as the first recorder of the sequence.

Transfer Time - 5-position rotary switch to select the transfer time between analog decks: 4, 8, 12, or 24 hours, or off (no transfer).

Digital Tape Deck-Change Tape Button - allows the operator to tell the computer he wishes to change a digital tape. The computer will perform an orderly termination of digital recording and rewind the tape, then turn on the "NEW TAPE" light.

Program Switches (0–3) - four bits of input data to be used for debugging and auxiliary input information.

Reset Errors Button - clears all error indicators whose error conditions no longer exist.

Alarm Disable - disables the Sonalert alarm (not the alarm relay output).

Computer Input Data

VLF Receiver (RDC = 1):

VM20DB, VM10DB, VM05DB - mix gain to Mixer/Monitor output.

VMFIL - Mixer Filters In.

VG20DB, VG10DB - actual gain to noise filter output (local or remote mode)

VGLOC - noise filter gain in local mode.

VGFIL - noise output filters In.

VCLOC - cal control in local mode.

VPWR - line receiver power on.

ELF Receiver (RDC = 2):

EG20DB, EG10DB - actual gain (local or remote mode).

EGLOC - gain in local mode.

EFIL - output filters In.

ECLOC - cal control in local mode.

EPWR - line receiver power on.

Noise Filters (RDC = 3):

FCLOC - cal control in local mode.

FPWR - Noise filter power on.

Mixer/Monitor (Channels A, B; RDC = 4, Channels C, D; RDC = 5)

x = Channel A, B, C, or D

MxSEL0, MxSEL1 - Input select; 00 = 1, 01 = 2, 10 = 3, 11 = 4

MxAUX1, MxAUX2 - Auxiliary Input 1 or 2 ON

MxWLOC - WWV control in local mode

MxTLOC - Time Mark Disabled Locally

MxMIC - Microphone input selected

MPWR (Mixer 1 only) - Mixer/Monitor Power On

Schedule (RDC = 6):

REC1LOC, REC2LOC - Analog Recorders in local or external mode

RFIRST - First Deck Switch; 0 = Deck 1, 1 = Deck 2

RTRN0, RTRN1, RTRN2 - Analog Deck Transfer Time Switch

VSYN0, VSYN1, VSYN2 - VLF Synoptic Rate Switch

ESYN0, ESYN1, ESYN2 - ELF Synoptic Rate Switch

FSYN0, FSYN1, FSYN2 - Noise Filter Sampling Rate Switch

Miscellaneous (RDC = 7):

PSW0–PSW3 - Program Switches

ALINH - Sonalert Alarm disabled

TLOAD - Digital Tape 'Change Tape' Button

ERESET - 'Reset Errors' Button

2.8. Mixer/Monitor and Analog Tape Recorders

The mixer/monitor provides analog signal selection, mixing and monitoring capability for the signals to be recorded on analog tape. As shown in Figure 2.10, it provides input channels for four data signals and outputs for four channels of recorded information. One of the four input signals may be selected for each output, and may be mixed with either or both of the auxiliary inputs and a 10KHz pilot tone/time mark signal. WWV voice announcements or the microphone input may be selected in place of the normal data output. The computer normally controls the time mark modulation (10 dB increase in amplitude corresponding to the time code) and the WWV voice announcements that are inserted at the start of every synoptic recording. The microphone input is selected by the combination of the front panel switch and the microphone 'Talk' button. The operator selects the input to be recorded on each output, along with any desired auxiliary signals, and he may override the automatic WWV announcements by local front panel switches. The gain of the two auxiliary inputs may be varied by front panel potentiometers, while the four data inputs have fixed gain.

A monitor amplifier is also provided to allow the operator to listen to any input or output, as well as the return signal from the tape recorder to verify the recording process. A front panel VU meter displays the level of the monitored signal, which can be heard on either headphones, a separate monitor speaker, or observed on an oscilloscope or other external instrument via a front panel BNC connector. The computer monitors the status of all signal selection switches via the control coupler.

The output signals from the mixer/monitor normally go to an analog tape deck—a studio-quality 1/4-inch 2-track audio tape recorder. Most stations will record only one track at a time of analog data, allowing both sides of the tape to be used, but the mixer/monitor is capable of providing up to four channels. The tape deck is remote-controlled by the computer, through relays in the control coupler, although the automatic control may be overridden by the operator using switches on the control coupler. The capstan is driven by a DC servo motor to provide a stable recording speed independently of the line frequency, which tends to vary widely at remote stations with small power plants. The record equalization has been adjusted on these recorders to give a constant record head current over the

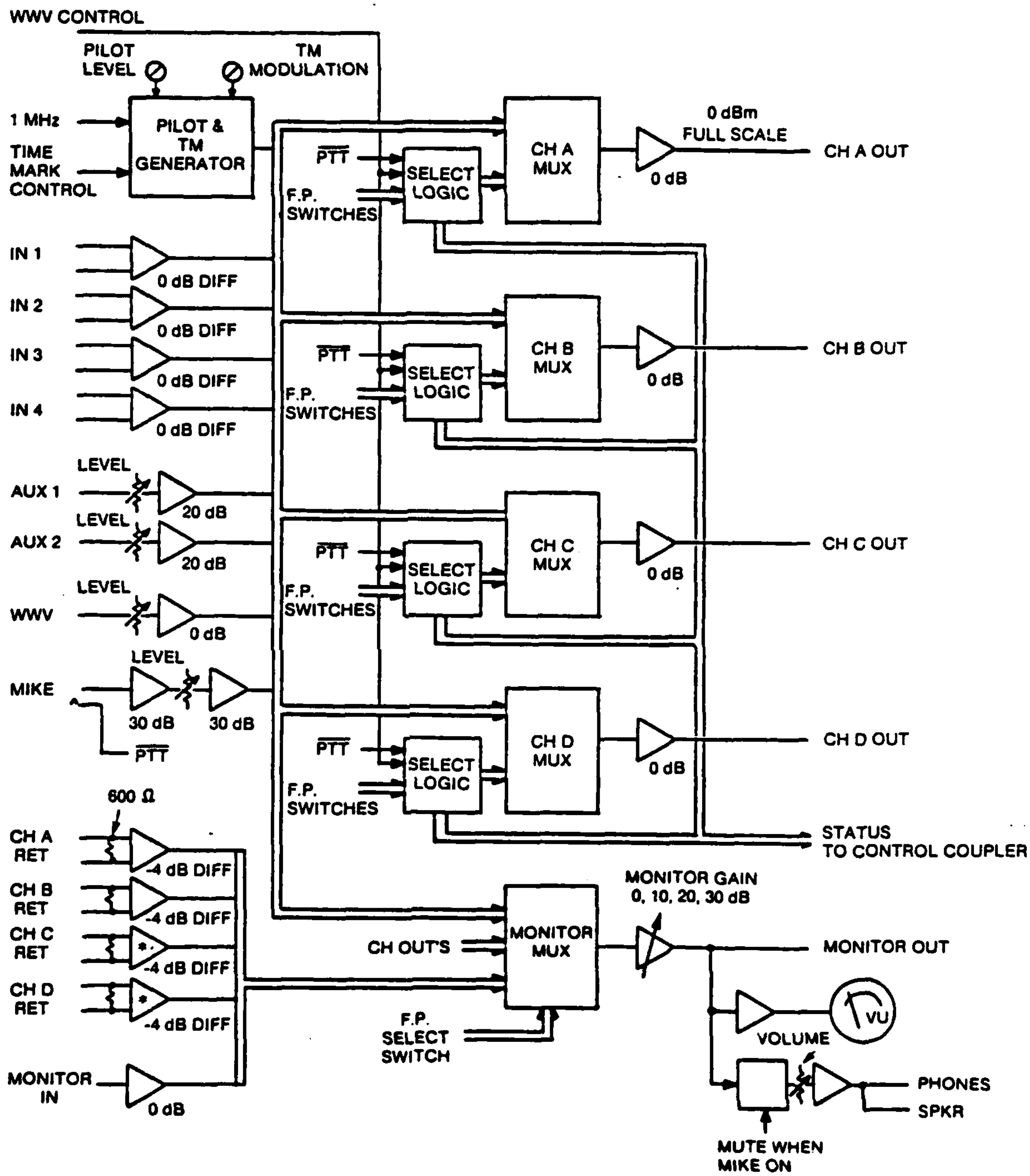

Figure 2.10. Block diagram of the mixer/monitor unit. This device is used to select the signal to be recorded on analog tape, and to add in the pilot tone/time mark and other desired signals, and to monitor the operation of both the receivers and the recording equipment.

full useful frequency range of the recorder—i.e. the high frequency peak usually used for audio recording is removed.

2.9. Analog/Digital Converter and Digital Tape Deck

The analog-to-digital (A/D) converter allows discrete samples of selected analog signals to be taken and recorded in digital form. A commercially built general-purpose A/D converter is used in the radiometer, with 3 plug-in analog input cards, each of which can be configured to provide either 8 balanced differential inputs or 16 single-ended inputs with a common ground. Although any input can be switched under program control between differential and single-ended mode, in this system 2 of the analog input cards are committed to single-ended operation by the chassis wiring to give 32 unbalanced inputs for the noise filters, and the third card is committed to differential operation by wiring the inputs to isolated BNC connectors, giving 8 balanced inputs. The computer can select any input one at a time to be sampled and digitized, with a range of ±10.24 volts and 14-bit resolution, giving 84 dB of dynamic range. The converter has a maximum conversion time of 29 microseconds, corresponding to a conversion rate of 34,000 samples per second. The computer has direct access to the converter through a dedicated I/O port and a bus converter to interface the computer I/O bus to the A/D converter internal bus.

In practice, all 32 single-ended inputs are used for sampling the narrowband noise filters at a rate of ten samples per second. A vector sum is taken of the two orthogonal channels for each filter frequency, and the result is further processed for statistical information, and selected values are recorded on digital tape, according to the sampling rate selected on the front panel of the control coupler (normally one sample per second). Two of the differential inputs are dedicated to the broadband east/west and north/south ELF signals, and are sampled 1000 times per second when ELF recordings are enabled. Six additional differential inputs are available for recording the output of other instruments that may be added at some radiometer installations. The use of the differential mode of operation for these inputs provides much greater common-mode rejection than would be available using single-ended inputs, and allows instruments with balanced outputs such as a bridge-type transducer to be connected. These optional inputs, labelled DIFF1 through DIFF6, are sampled continuously at 10 samples per second, and recorded on digital tape at the rate specified for the noise filters, normally 1 sample per second.

Digital recordings are made on a standard 1/2 inch, nine-track tape deck, with a recording density of 1600 bits per inch. $10\frac{1}{2}$-inch reels of tape are used, giving a capacity of approximately 40 megabytes of information per tape. The computer has direct access to the digital tape thru a dedicated I/O port. A custom-built controller installed in the computer chassis governs the actual data transfer and translates software commands into control signals for the tape deck. Tape data transfers are programmed using the 'data channel' method defined in the architecture of the computer, where the programmer need only specify a block of memory to be transferred and start the process, rather than handle each byte of data individually. The controller then takes over and manages the details of the transfer, and interrupts the CPU when complete. The controller also contains a built-in diagnostic routine for performing a self-check of the tape drive.

Chapter 3. Data Formats

The radiometer data are recorded in two basic forms — audio tape, used solely to record broadband VLF data, and digital magnetic tape, used to record broadband ELF data (high-speed digital samples), noise filter outputs (low-speed digital samples), noise filter statistical averages maintained by the computer, and station housekeeping information.

3.1. Analog Tape Format

The output of the VLF receiver is recorded on standard 1/4" audio tape, on a schedule that nominally consists of a 1-minute sample every 30 minutes. Using the selector switch on the front panel of the control coupler, the operator may change the frequency of these samples to one every 5, 15, 30, or 60 minutes, or to continuous recording for periods of special interest. Continuous recordings may also be scheduled using the *Schedule Control* function of the operator's console. The duration of synoptic recordings may not be changed.

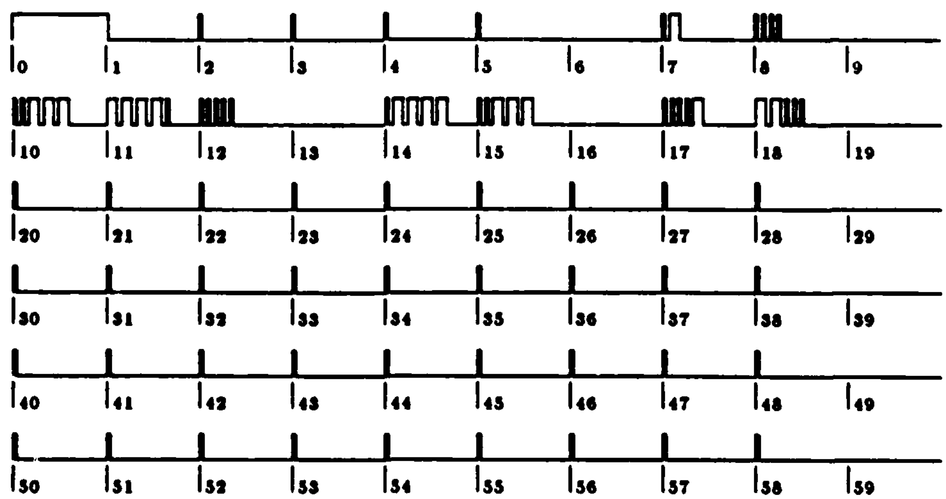

Figure 3.1. Time code format used to amplitude modulate the 10 KHz pilot tone for each minute. The minute begins with a 1040 ms pulse, and most seconds are marked by a 40 ms pulse, but the ninth of every ten seconds is omitted to facilitate counting tens of seconds. The two-character station ID is encoded during seconds 7–8, the day code during seconds 10–12, the hour during seconds 14–15, and the minute during seconds 17–18, all in Morse code. Shown is station AH (Arrival Heights), day 295, hour 12, and minute 47.

Mixed with the VLF at all times is a highly stable 10 KHz pilot tone at a level of 30 dB below the system 0 VU level, which can be used to detect and correct

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for tape flutter and speed variations. The pilot tone is modulated with a 10 dB increase in amplitude to encode the day, time, and station ID information in Morse code, as illustrated in Figure 3.1.

Each synoptic record begins 7 seconds before the scheduled minute, and is recorded with the following format:

xx:53–xx:00	WWV voice announcement
xx:00–xx:01	VLF + calibration signal
xx:01–xx:53	Broadband VLF

Continuous recordings will contain a WWV break and a calibration signal every five minutes, at the same time they would occur for synoptic recordings, unless defeated by the operator. A log of actual recordings made by the system will be maintained by the computer and recorded on digital tape. With a tape speed of $7\frac{1}{2}$ inches per second and a synoptic recording rate of 1 minute in 30, a 3600 foot tape will last 2 days per side. If 2 analog tape decks are present in the system, the computer will automatically switch to the alternate deck at a time scheduled by the *Transfer Time* switch on the control coupler — this must be selected by the operator according to the tape length and recording schedule, so that transfers will occur at the end of 96 minutes of recording.

3.2. Digital Tape Format

Digital recordings are made on industry-standard 1/2", 9-track magnetic tape, with a recording density of 1600 bits per inch. All data are organized into 8192 byte *tape records*, each containing 4096 16-bit words of data. An end-of-file (EOF) mark is written to the tape every hour, so a user reading the tape will find a sequence of *files*, each consisting of a one hour sequence of data. It should be noted here that the computer sends data to the tape interface in units of 16-bit words–each word is written to the tape as two 8-bit bytes, high-order byte first. Many computer systems (such as VAX/VMS) expect to find the low-order byte first when reading a tape, so the bytes must be swapped to form a correct 16-bit integer. Appendix B contains an example program illustrating this task.

Each tape record is sub-divided into variable-length *data records*, as shown in Figure 3.2. Each data record begins with a 5-word header consisting of a 1-word *data code*, a 1-word *block count*, a 1-word *day number*, and a 2-word *time code*. The data code word identifies the type of data contained in the block, as listed in Table 3.1. The block count is the number of words in the block, including the 5-word header. The day number is a 16-bit unsigned integer giving the number of days since January 0, 1900. The time-of-day code is a double-precision (32-bit) unsigned integer giving the time in milliseconds since the beginning of the day.

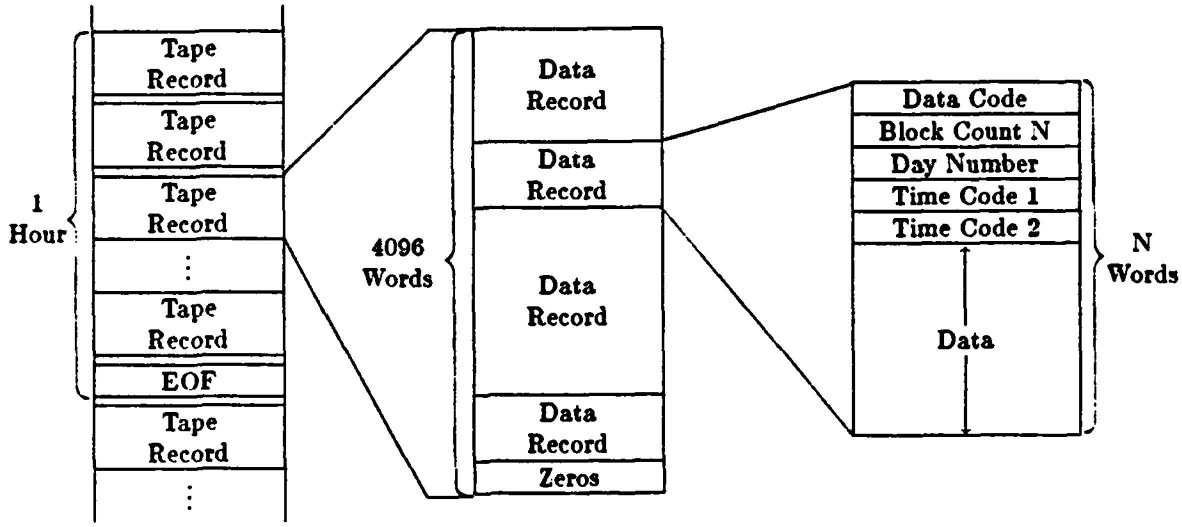

Figure 3.2. Digital tapes are broken down into a hierarchical structure consisting of tape files, tape records, data records, and the data itself.

Since tape records are always 4096 words long, any remaining space after the data records will be filled up with zeros. Therefore, when reading the tape, a data code of zero denotes the end of the tape record.

Table 3.1. Data Code words used to identify data blocks.

Data Code	Type of Data
1	Noise filter/differential input data
2	Noise filter/differential input statistics
3	Broadband ELF N/S data
4	Broadband ELF E/W data
5	System status data
6	Message log data (text)

Within each data block, the data following the header is encoded differently for each type of data, and must be decoded according the appropriate format. The details of the formats for each block type are given in Appendix A, and will be summarized here:

Noise Filter and Differential Input Data (Data Code 1)

The 32 noise filters and the 6 differential inputs are sampled continuously every 100 milliseconds. The vector sum (square root of the sum of the squares) is taken of the N/S and E/W channels for each noise filter frequency, and all the resulting values are included in the statistical calculations. Only a fraction of these raw data samples are recorded, however, at the rate selected by *Sample Time* switch on the control coupler. The possible interval between recorded samples is 0.2, 0.5, 1, 2, 5, or 10 seconds, but the setting will normally be 1 second, so that every tenth data sample will be recorded. The differential input data will be recorded at the same times, but only if the system has been specifically requested to do so — either at system start-up time or by a schedule control command.

The actual time that noise filter and differential input sampling occurs is precisely on the millisecond, in a sequence beginning with noise filter channel 1 N/S, noise filter channel 1 E/W, noise filter channel 2 N/S, etc., up through differential input 6, for a total of 38 milliseconds. The time between successive samples of any particular input is therefore precisely 100 milliseconds, with a jitter of no more than a few nanoseconds.

Noise Filter and Differential Input Statistics (Data Code 2)

A block with a data code of 2 is recorded at the start of every minute, containing the average, root-mean-square, maximum and minimum values over the previous minute for each noise filter frequency and differential input. Note that the time word recorded with data code 2 refers to the minute during which the samples were taken, not the time that the data block is recorded. Statistics are not computed for the noise filter channels during calibration periods, so the recorded values will reflect real data only, and not the calibration signals.

Broadband ELF Data (Data Codes 3 and 4)

The ELF receiver output is recorded on a schedule similar to, but independent from, the VLF analog recording schedule — a synoptic schedule of 1 minute in 5, 15, 30, or 60 minutes, continuous recording, or off. Each synoptic record is 1 minute long, beginning 7 seconds before the start of the minute, and ending 53 seconds into the minute. The preamp calibration signal is mixed with the ELF data during the first 8 seconds of the recording, and no WWV voice announcement is made. The time code words for this data type refer to the time of the first sample in the data record. The signal is low-pass filtered at 400 Hz to prevent aliasing, then sampled at 1000 samples per second. The actual sampling times are interleaved between noise filter and differential input samples, with N/S samples taken at 333 microseconds, and E/W samples at 666 microseconds after the start of each millisecond. Each sample is a 14-bit signed integer, between -8192 and +8191, corresponding to the range -10.24 to +10.24 volts. These values must be scaled using the receiver gains in effect at the time of the recording and the calibration constant for the system to determine the actual field strength at the ELF antennas. Broadband ELF data blocks always contain 500 words of data (505 words total block count), or 0.5 seconds worth of samples. These data constitute by far the greatest fraction of the total data on digital tapes, so serious consideration must be given to tape consumption when selecting the recording rate of broadband ELF.

System Status Data (Data Code 5)

The entire system status is recorded every 10 minutes in a block with data code = 5. The data in this block consists of 86 data words, containing the station ID code, a copy of the control coupler data, the A/D converter gains and zero offsets, the magnetic tape flags and status, and error status words. Included within the control coupler status is information such as the ELF and VLF receiver gains, which is required for interpreting data in the other block types and on the analog tape. Appendix A contains a detailed description of the information encoded in the system status blocks.

Message Log Data (Data Code 6)

The message log data blocks contain text in ASCII form, two characters per word, of the messages entered by the operator via the console terminal. The character string is packed left-to-right — that is, the first character is stored in the high (left) byte of the first data word, the second character in the low (right) byte, the third character in the high byte of the second data word, and so on. Since the high byte is written to the tape first, the character string is stored in the proper order on the tape itself. Therefore, when reading text messages one character at a time directly from the tape, it is not necessary to swap bytes, as must be done when reading 16-bit words.

3.3. Suggestions for Data Analysis

Appendix A, excerpted from the *ELF/VLF Noise Survey Software Reference Manual* by Evans Paschal, the architect of the radiometer software, contains a detailed description of the formats used to record digital data. Any user wishing to analyze radiometer tapes should consult Appendix A for exact data specifications.

Appendix B contains suggested low-level subroutines, written in C, for extracting data from the digital tapes using the STAR lab's VAX/VMS computer system.

The routine analysis of tapes arriving at Stanford from the eight stations should consist first of extracting the statistical average data blocks (data code 2), the system status data (data code 5), and any operator messages (data code 6) that may be present. The system status data is required to establish the receiver gain settings and to verify that no equipment errors that could affect the validity of the data were present. The statistical data may then be scaled and plotted in terms of absolute field strength, and added to a data base which will later be used to compute long-term averages, and to show comparisons between the eight stations.

Chapter 4.
The Arrival Heights Radiometer Installation

The first radiometer was installed at Arrival Heights, Antarctica during December, 1984 and January, 1985 in the new Upper Atmospheric Physics (U.A.P) building erected during the same period. Arrival Heights is approximately 2 miles by road from McMurdo Station, the primary U.S. Antarctic research base, located on the coast of the continent at 78° south, 167° east, or roughly straight south from New Zealand. An area at Arrival Heights approximately 1.5 km by .6 km has been designated by international agreement as a quiet radio receiving zone—no radio transmitters are allowed at the site, all non-essential activity is prohibited, and aircraft are not allowed to fly over the region. Refer to Figure 4.1 for the layout and topography of the area.

4.1. Antenna Construction

The VLF and ELF antennas are both located on the North side of the building, at the greatest distance allowed by the available feed lines, to place them as far as possible from the power line leading to McMurdo. Surveys of the potential sites with a portable VLF receiver exhibited spherics and Omega signals, and only very low level power line hum, with no apparent directional nulls, so both ELF and VLF antennas are oriented geographically north-south and east-west. Once the sites had been selected, a construction team from Antarctic Services, Inc., the support contractor to the National Science Foundation for its Antarctic operations, assisted with the task of building the antennas.

VLF Antenna

The VLF antenna is located on relatively flat terrain inside the Second Crater, just under 3000 feet from the building. The crater rim is highest on the eastern side where it provides considerable protection from the prevailing storm winds. A rock drill was required to drill holes in the permanently frozen ground of the crater, and a jack hammer to enlarge the hole for the telephone pole. A Caterpiller D8 was needed to haul the drill and its compressor as well as the telephone pole itself up the 40% grade to the crater rim. A team of three electrical linemen erected the pole, with 4 steel guy wires attached to 8-foot anchors drilled into the ground. Water from a nearby pond was poured around the pole and the anchors to form

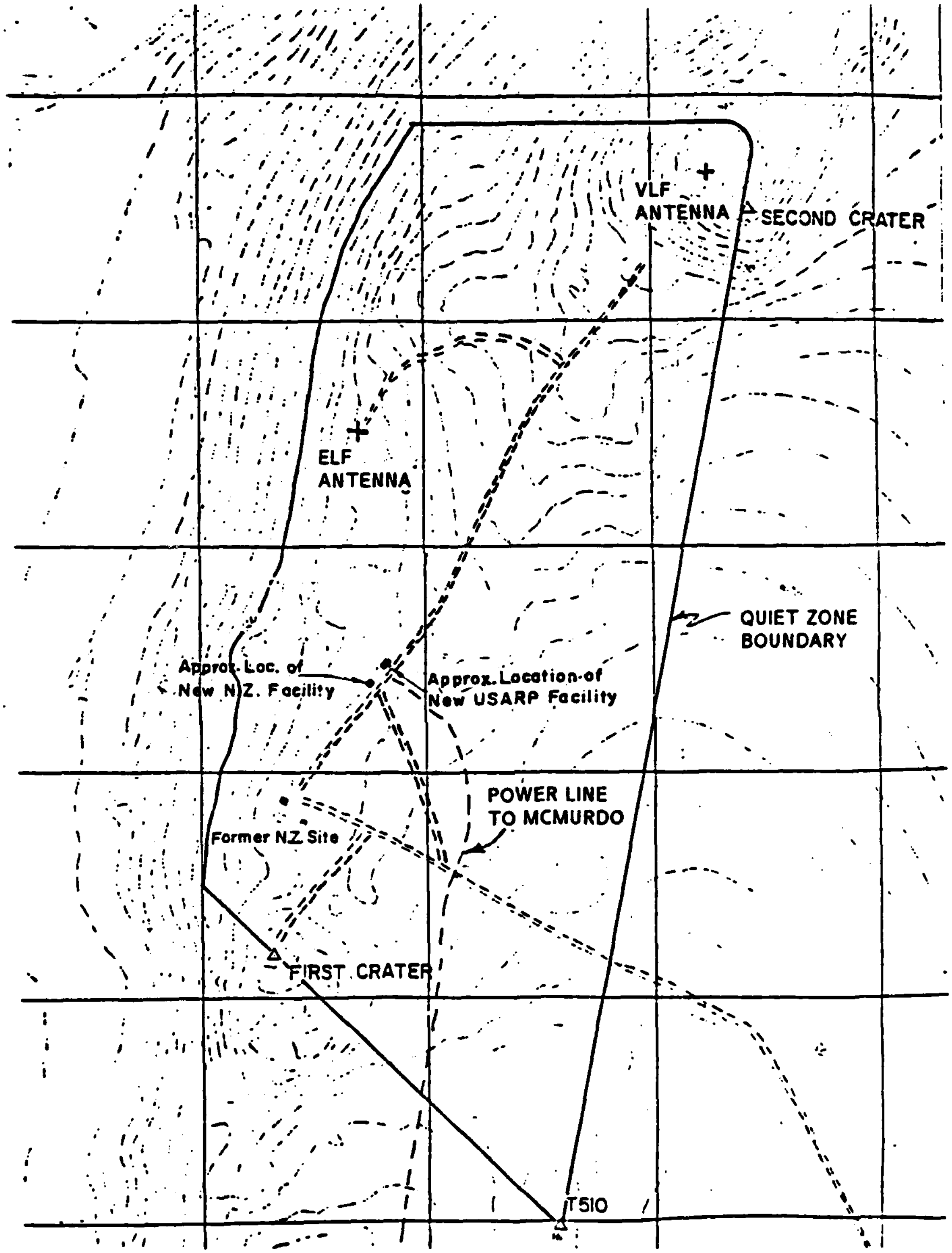

Figure 4.1. Map of the Arrival Heights area, showing the location of the U.A.P. building and the ELF and VLF receiving antennas. The grid spacing is 1000 feet and the contour interval is 20 feet.

'Antarctic concrete', which should enable the pole to withstand the strongest winds that are likely to occur. 4" by 4" wooden posts were also drilled and frozen into the ground to provide attachment points for the lower ends of the loops. The loop wires themselves were strung from insulators at the top of the pole and attached to the corner posts, and the preamp enclosure was bolted to the side of the pole. The completed antenna is shown in Figure 4.2.

The steel bracket and clevis insulators used at the top of the pole are vulnerable to wind vibration. The wind could be heard in the receiver at speeds of around 40 knots, and loosening the loops had no effect. The noise comes from two sources: vibrations in the steel bracket, and rolling motion of the clevis insulators on their steel spindles. A different mounting method is recommended for use at future installations.

ELF Antenna

The site chosen for the ELF antenna is on a flat spot at the top of the slope going down to the sea ice, 1000 feet north of the building. The ground consists of very large rocks that required blasting to make a hole big enough for the underground vault. The rock drill was used here also to drill 16 holes for the blasting charges. A backhoe was necessary to remove the debris from the dynamited crater.

The vault itself was built in the carpenters' shop and forklifted to the site. Crucial to the success of the vault design was the inclusion of double 2-by-6 'walers', spaced horizontally 12 inches apart at the top and 8 inches apart at the bottom, to provide reinforcement against the earth pressure when backfilled. The outside walls are sheeted with 1/2-inch plywood and a double vapor barrier lining keeps water out. The inside floor is 5 feet square, enough to rotate the loop frame to any orientation, and the inside height of just over 6 feet makes working inside very comfortable. The entire lid can be lifted off to place or remove the loops, and a covered hatch provides routine access. Figure 4.3 shows the completed ELF vault with the lid removed.

A wooden frame built in the carpenters' shop holds both ELF loops in a vertical position at right angles to each other. Foam rubber under the frame helped isolate the loops from floor vibrations set up by wind turbulence. It proved critical to make the top of the vault as flush as possible with the surface to prevent wind turbulence that can make the vault (and the loops) vibrate. The ELF preamplifier was mounted on the wall on the inside of the vault.

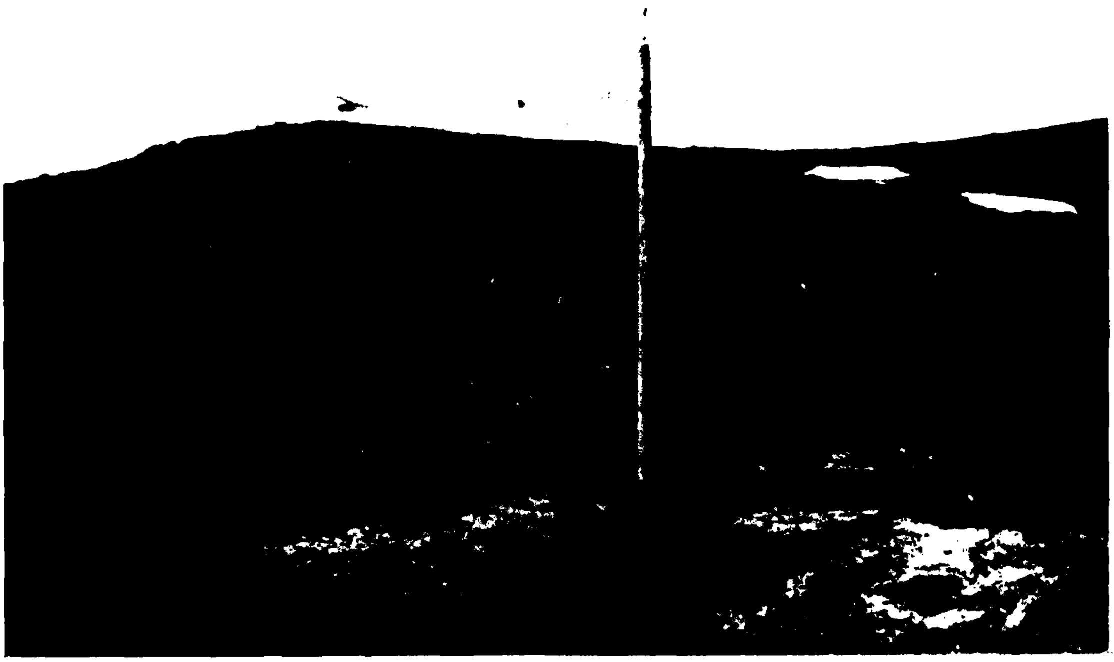

Figure 4.2. The VLF antenna as installed at the Second Crater near Arrival Heights, Antarctica. A telephone pole serves as the central support for the 2 triangular loops, whose lower ends are supported on 4" by 4" wooden posts. Four steel guy wires help the structure withstand the high winds encountered at this site. The preamp enclosure is mounted on the side of the pole and is connected to the laboratory by 3000 feet of 6-pair cable.

Figure 4.3. Photograph of the Arrival Heights ELF antenna vault, with the lid removed. The top of the vault is flush with the surface of the ground, and the floor approximately 6 feet below the surface. 2" by 6" 'walers' reinforce the vault to withstand the ground pressure on the walls. The wooden frame in the foreground holds the 2 loop antennas in a vertical position and maintains their relative orientation at 90 degrees.

4.2. Radiometer Lab System

The U.A.P. building had an ample supply of rack space, so three racks were used to house the line receivers and recording system. The Sanborn 8-channel chart recorder provided for this site occupies a fourth rack space. Other instruments installed in the U.A.P. building in 1985 are two riometers (30 MHz and 51.4 MHz), a 3-axis fluxgate magnetometer, a 3-axis micropulsation magnetometer, an all-sky camera, and a 2-channel photometer for auroral studies.

The radiometer system started up properly when first switched on, but several problems postponed the commencement of routine operations, the most serious being interference from the 10 KW HF communications transmitters less than 2 miles away.

HF Interference

Strong high frequency signals were able to produce a common-mode input signal to the preamplifier, whose common–mode rejection is not effective at high frequencies. The solution was to filter the HF signals before they get to the preamplifier, using 0.01 μf capacitors to ground on both sides of the loop antenna at the point it enters the preamp enclosure. This method proved effective for both the ELF and VLF receivers, reducing the interference to inaudible levels. This change will be made to all future preamplifiers before they are taken into the field.

Local Power Line Interference

The 4800 volt power line going from McMurdo to Arrival Heights proved to be a source of considerable interference in both receivers, with harmonics of 60 Hz present up to approximately 8 KHz. Examples of this interference are shown in the spectrograms in Section 4.4. The power line is a 2-conductor shielded cable directly wired into a single phase of the 3-phase system in McMurdo. It is stepped down from 4800 volts to 240 volts by a 100 KVA transformer close to the lab building. Induction fields from the cable are seriously degrading the background environment in the ELF/VLF frequency range in the Arrival Heights area, and efforts are underway to re-engineer the power line to reduce the problem. Until the power line is improved, considerable locally-generated noise will be present on our VLF broadband tapes. As of February, 1985, analog recordings are being made with a 2 KHz high-pass filter, located between the mixer output of the VLF line receiver and the input to the Mixer/Monitor. The filter is an Allison variable low pass/high pass filter that can be easily changed if necessary.

Noise Filter Oscillations

The output stage of the noise filters consists of an active ripple filter following the r.m.s. detector. The op amp used in this filter can be made to oscillate with a large (~8 volts pk-pk) amplitude at a frequency of 450—550 KHz with the addition of a fairly small capacitance on the output (i.e. 10 feet of coaxial cable). Since the oscillations are not perfectly symmetrical, it shows up on the Sanborn as a D.C. offset. On the A/D samples, which can be observed using the signal listing functions on the terminal, it shows up as a wildly jumping signal, and, should a calibration occur while the filters are oscillating, a large zero-signal offset will be stored in the computer—in most cases a sign of a malfunction.

The time-mark pen on the Sanborn chart recorder is the usual stimulus that starts the oscillations—once started, they will continue until the capacitance is removed from the output. At Arrival Heights, the Sanborn's time mark channel was disconnected from the control coupler output for that reason; the receiver calibrations every 5 minutes and noise filter calibrations every hour provide sufficient timing information on the charts. Subsequent communications from McMurdo have indicated that this is a continuing problem—other stimuli have been found to set the noise filter outputs in oscillation, and an effort is being made to make the output op-amps stable for any load conditions.

Other hardware problems

The pre-assembled D-connector cables we ordered from an outside vendor are proving to be troublesome. The [illegible] conductor computer-control coupler cable at Arrival Heights was defective, a[illegible]ng bits of the status and schedule words passed from the control coupler to the computer. Another cable was available that worked properly, but this is likely to be a problem at future installations, so the cables should be checked carefully before sending them into the field.

Failures occurred in both an op-amp and an rms detector in the noise filter unit. These have proven to be failure-prone as these are not the first failures of this type we have seen. There was no spare for the rms detector chip, so one channel (30Hz E/W) is currently inoperative. A spare will be sent do replace it, but until that time, the 30Hz filter statistics will reflect the N/S channel only.

The computer sometimes indicated a 'Clock Phase Error' for no apparent reason. It is probably caused either by noise on the lines connecting the clock to the computer or internal noise in the clock that falsely triggers the 'New Second' flip-flop. Either case is difficult to diagnose because it happens so infrequently and with no identifiable cause. It rarely occurred when no one was in the building, and happened mostly while someone was working on the equipment. A layer of anti-static matting in front of the racks reduced the problem considerably.

4.3. System Operation

The system was left operating with the default recording schedule of 1 minute in 30 synoptics for both VLF and ELF broadband recording, and 1 sample per second continuous noise filter sampling. The analog tapes will last 2 days per side, and the digital tapes just over 4 days, thus requiring the operator to visit the station every other day. In order not to miss any data, the analog tapes should be changed between 23:36 and 00:04 UT—this conveniently occurs at local noontime for Arrival Heights.

Five channels were functioning on the Sanborn recorder as of February, 1985, and 5 noise filter channels were selected for display on the chart records. The filters displayed and their calibrations are as follows:

Sanborn Channel	2	3	4	7	8
Filter Frequency	30 Hz	135 Hz	500 Hz	2 KHz	4 KHz
Full Scale B_w, pT, L.R. Gain = 0 dB	31.6	31.6	1.0	1.0	10
10 dB	10.0	10.0	0.316	0.316	3.16
20 dB	3.16	3.16	0.1	0.1	1.0
30 dB	1.0	1.0	.0316	.0316	0.316

The Sanborn amplifier gains were set as high as possible: the different calibrations reflect the different sensitivities of the ELF and VLF receivers. Channel 8 exhibited a weak amplifier, and was unable to achieve the same gain as the other VLF channels. Note that during quiet conditions such as those observed in February, the computer will set the line receiver gains at the maximum of 30 dB, but during periods of strong activity that would drive the pens off scale, the computer will automatically reduce the gain in 10 dB steps. The full scale calibration on the chart increases by a factor of 3.16 for each 10 dB step. Gain changes should be apparent on the chart records, but the exact history of the gain changes is recorded in the system status data on the digital tape, and should be consulted any time that absolute field strength measurements are to be made. When the 3 remaining channels on the Sanborn are repaired, other instruments such as the riometer, the magnetometer, and the micropulsation magnetometer will be displayed for correlations studies with the VLF channels.

The noise filter unit (Arrival Heights only) has an auxiliary output connector (9-pin type 'D') for connection to the University of Maryland data system. As of February, 1985, these outputs are wired internally to the following channels

Pin 1	10 Hz	Pin 5	1 KHz
Pin 2	30 Hz	Pin 6	4 KHz
Pin 3	135 Hz	Pin 7	10.2 KHz
Pin 4	500 Hz	Pin 8	32 KHz

Scott Base Ionosonde

Scott Base re-activated their ionosonde in early February, and it immediately showed up in our VLF receiver. The transmitter is approximately 4 km away from the VLF antenna, and is putting out 100 KW at 2.9 MHz. The schedule is repeated every hour, and consists of pulses spaced 1 second apart from 08:00 to 09:30 and 10:30 to 12:00 minutes, and a burst pattern repeated every six seconds from 46:00 to 58:00 minutes. It is heard in the VLF audio output as a clearly repetitive ticking pattern.

4.4. Sample Data

A power failure occurred in McMurdo while I was working at Arrival Heights on February 12, and I took the opportunity to make a continuous recording of both VLF and ELF receivers with near-minimum local power line interference. The uninterruptible power supply at the U.A.P. building made it possible to keep the entire radiometer running during the power failure. Figure 4.4 shows a spectrogram from this period, displayed both from 0 to 20 KHz and from 0 to 2 KHz to emphasize the absence of high-order power line harmonics. The ELF receiver was recorded on analog tape for this demonstration—some rolloff below 50 Hz due to the tape recording process should be expected. Two OMEGA stations, Australia and Hawaii, and two weaker stations show strongly on the 0–20 KHz record, along with seven Navy VLF transmitters. The line at 10 KHz is the station pilot tone modulated with time and station code information. Considerable wind noise can be seen up to about 300 Hz on the 0–2 KHz record, caused by approximately 40 knot winds during the recording period. The ELF recording made several minutes later shows no such wind-induced interference, and low-order power line harmonics can be seen at 60, 180, and 300 Hz. These are probably produced by the Williams Field power system, which was still operating at this time. The vertical lines on the record are atmospherics, the only natural activity seen during this very quiet period.

Figure 4.5, a spectrogram of a VLF recording made on 8 February, shows the local interference levels when the McMurdo power system is operating, with the same data displayed from 0–20 KHz, 0–2 KHz, and 0–500 Hz. The first half of the record, made while the power line to Arrival Heights was disconnected at the McMurdo end, shows approximately the same power line harmonic levels as the record shown in Figure 4.4, when McMurdo was completely dead. At the point indicated, the power line to Arrival Heights was re-energized by inserting a fuse into the line, and a dramatic increase in power line harmonics is evident. The secondary increase approximately 12 seconds later is probably due to increase in current when the uninterruptible power supply begins recharging its batteries. Figure 4.6 gives an example of the background spectrum present during normal conditions at Arrival Heights.

As mentioned previously, the VLF signal recorded on analog tape is high-pass filtered at 2 KHz to reduce the strong low-order power line harmonics. The VLF output going to the Noise Filters is unfiltered, so there is a possibility of some power line harmonics getting into the narrowband filters. Note that only the odd harmonics are present, so there are no harmonics within the passband of the 500 and 750 Hz filters, 1 each in the 1.0, 1.5, and 2.0 KHz filters, and 2 each in the 3.0 and 4.0 KHz filters. Figure 4.6 shows that the strength of the harmonics increases around 5 KHz, then disappears above 7 or 8 KHz.

There is a strong component at 420 Hz, which is clearly audible in the ELF receiver output when the notch filters are enabled for 60, 120, 180, and 300 Hz. This component is beyond the cutoff of the 400 Hz anti-aliasing filter, but is only attenuated a small amount, and we presently have no notch filter at this frequency, so it will be present on our digitized broadband ELF data. This component is not visible when the power line is de-energized, so a notch filter should not be necessary if the power line itself can be cleaned up.

Figure 4.7 through Figure 4.10 show Sanborn chart samples of all 16 noise filter frequencies, taken from the North/South channel in all cases. There is very little natural activity present, so most channels show typical quiet levels. There appears to be some hiss present on the 500 Hz channel, and two Omega stations (Australia and Hawaii) can clearly be seen on the 10.2 KHz channel, showing field strengths of approximately 0.075 pT (23 μV/m) and 0.02 pT (6 μV/m) respectively. The 1-second pulses appear to merge together into a continuous line at the chart speed used for these records. The periodic vertical lines on the chart are due to the comb calibration signal injected into the preamps at 5-minute intervals. Each comb component has an amplitude of 10 pT for ELF and 0.1 pT for VLF. The larger disruption seen at the start of every hour is the noise filter calibration sequence, which takes 19 seconds for VLF channels and 200 seconds for ELF channels.

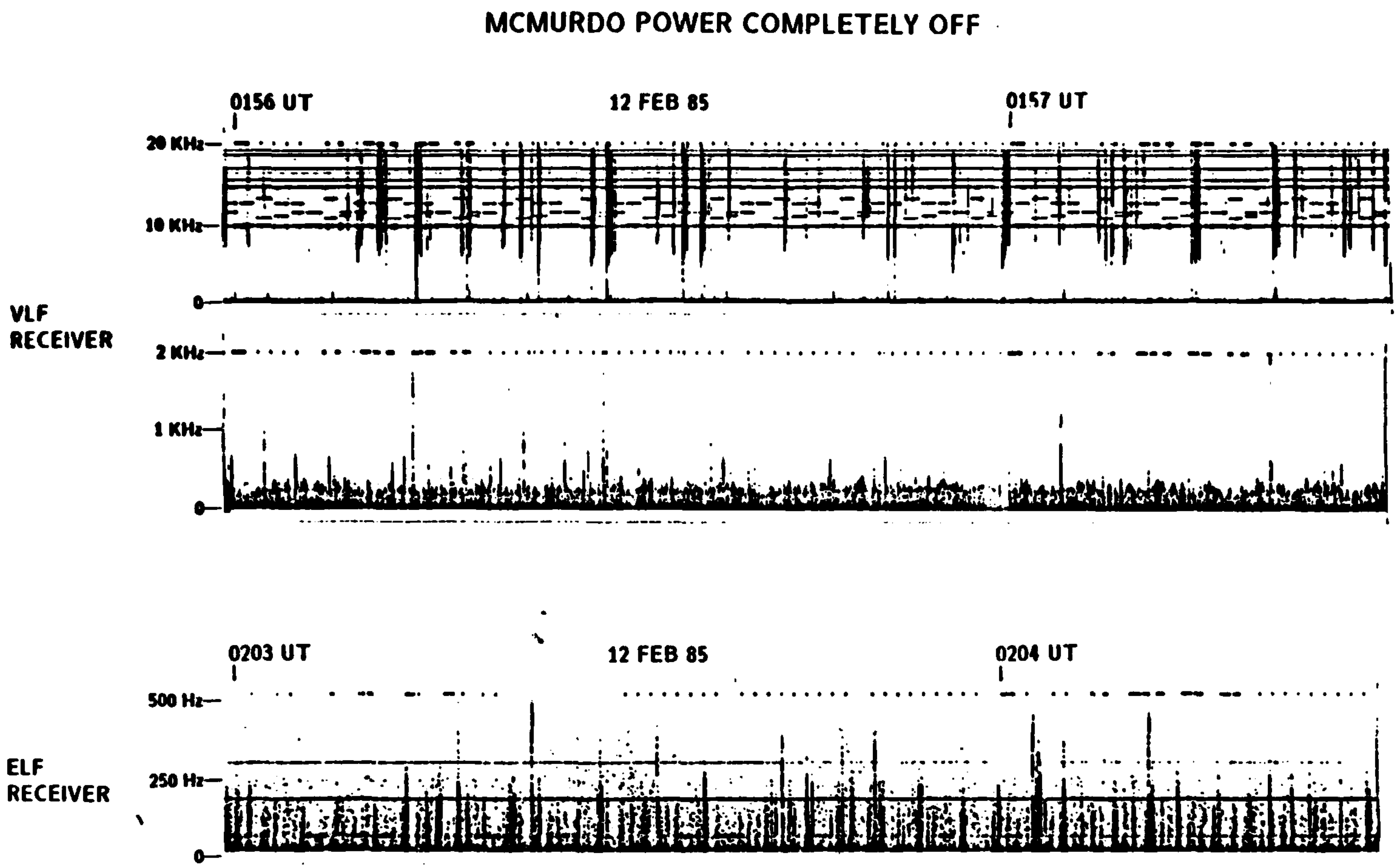

Figure 4.4. Spectrograms of recordings made while the McMurdo power system was completely shut down. The VLF records show the same time period displayed from 0 to 20 KHz and from 0 to 2 KHz. The ELF record shows a period 6 minutes later, displayed from 0 to 500 Hz. Two OMEGA stations and six Navy VLF stations can be clearly seen above 10 KHz on the 0—20 KHz record. The activity seen below 500 Hz on the 0—2 KHz record is due to wind-induced vibrations in the VLF loop. The apparent weak band in the wind noise is caused by a deficiency in reproduction.

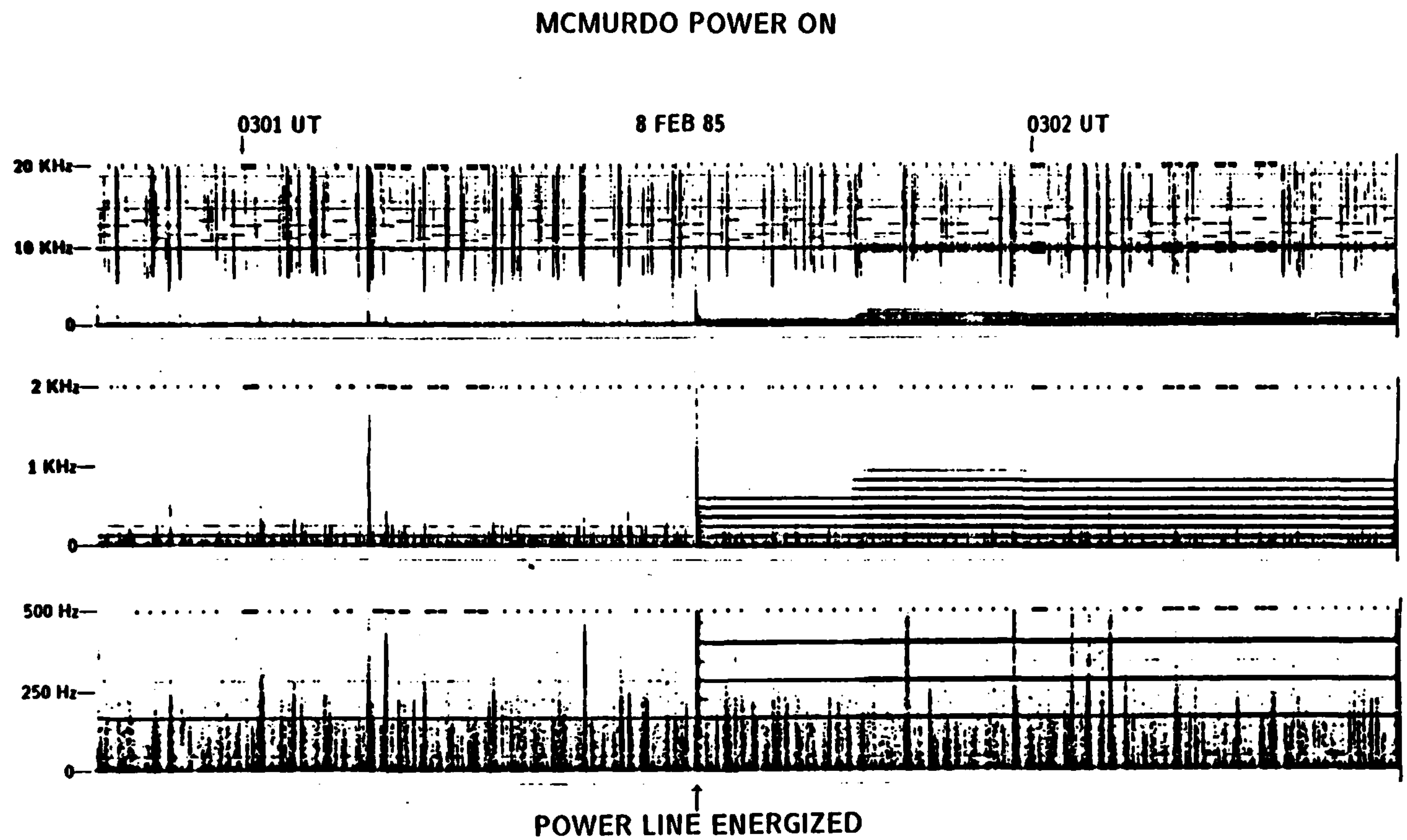

Figure 4.5. Spectrograms showing the increase in local interference when the Arrival Heights power line is energized. The McMurdo power system is operating through the entire record, and a fuse is inserted to energize the power line at the time indicated. The increase in power line harmonic levels 12 seconds later is caused by activation of the battery charger in the Arrival Heights uninterruptible power supply. The broadening of the 10 KHz pilot tone trace that also occurs at this time is due to overload in the analysis equipment, since the levels were set to best illustrate the relatively weak data.

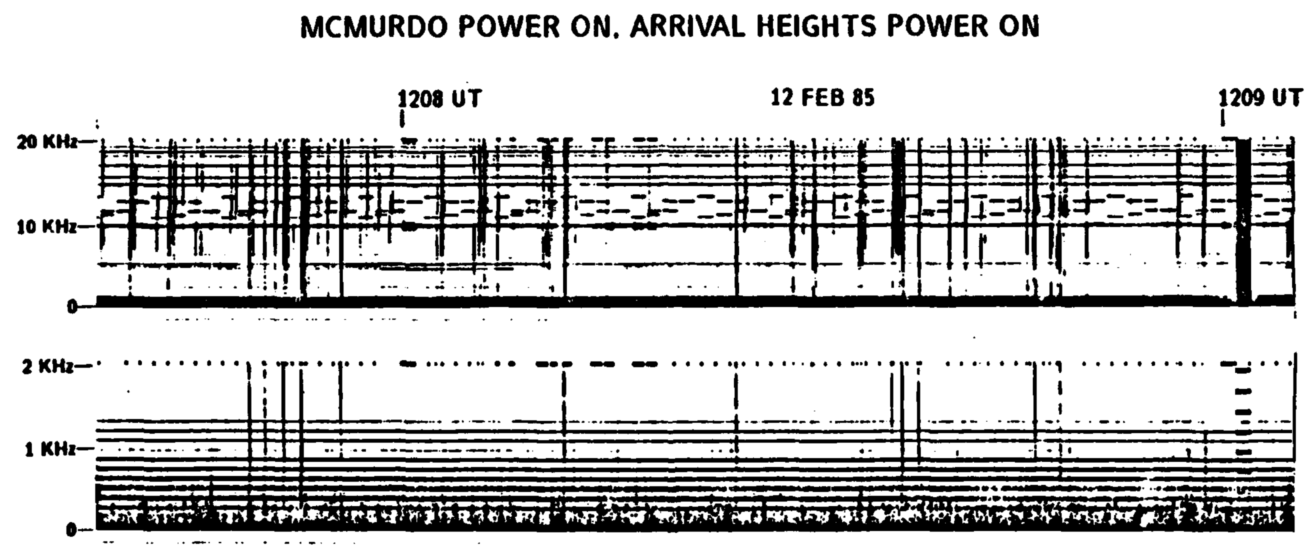

Figure 4.6. Spectrogram showing the harmonics of 60 Hz picked up by the VLF receiver during normal operation. The same time period is displayed from 0 to 20 KHz and from 0 to 2 KHz.

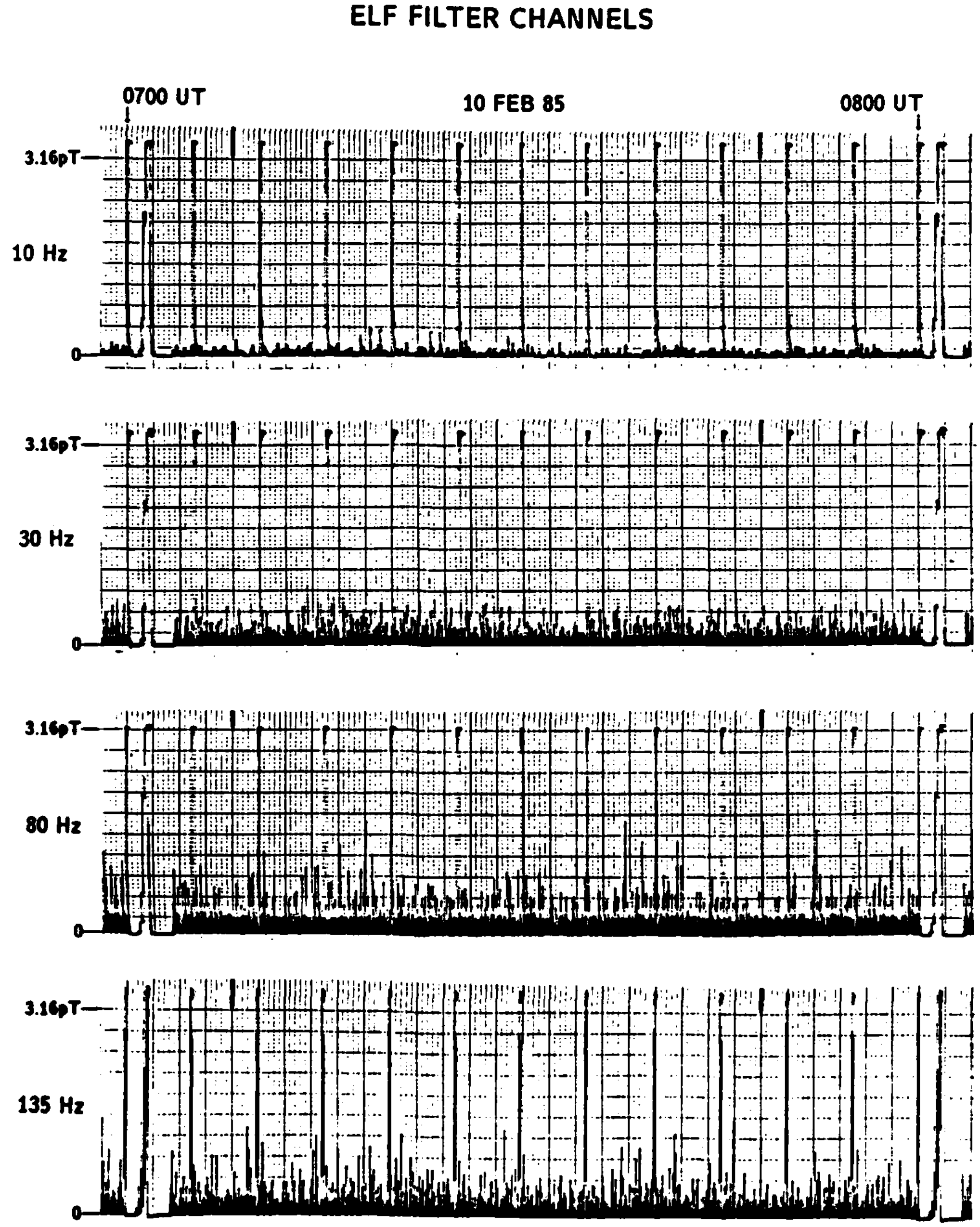

Figure 4.7. Chart records of the ELF noise filter channels at 10 Hz, 30 Hz, 80 Hz, and 135 Hz.

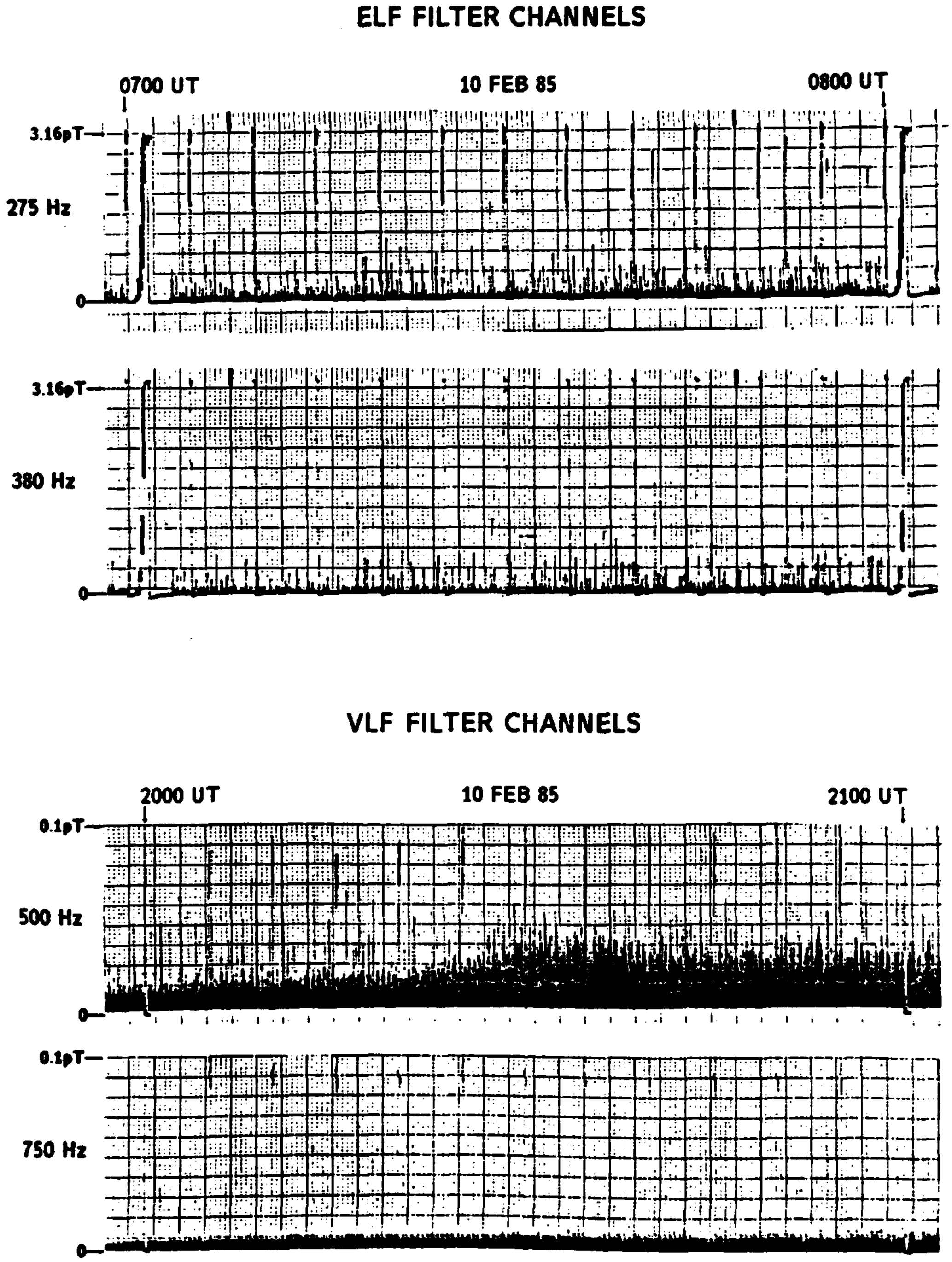

Figure 4.8. Chart records of the ELF noise filter channels at 275 Hz and 380 Hz, and the VLF channels at 500 Hz and 750 Hz.

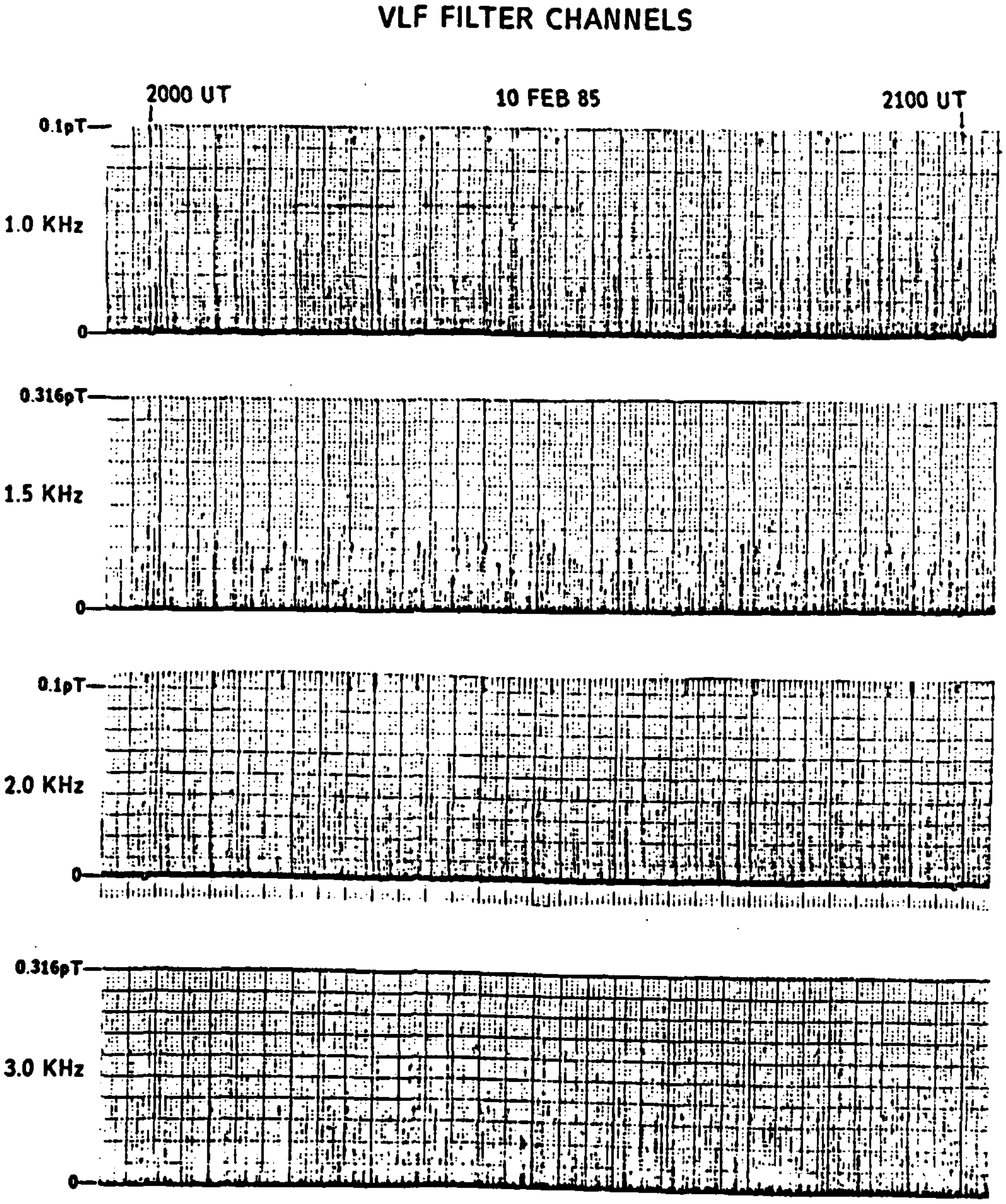

Figure 4.9. Chart records of the VLF noise filter channels at 1.0 KHz, 1.5 KHz, 2.0 KHz, and 3.0 KHz.

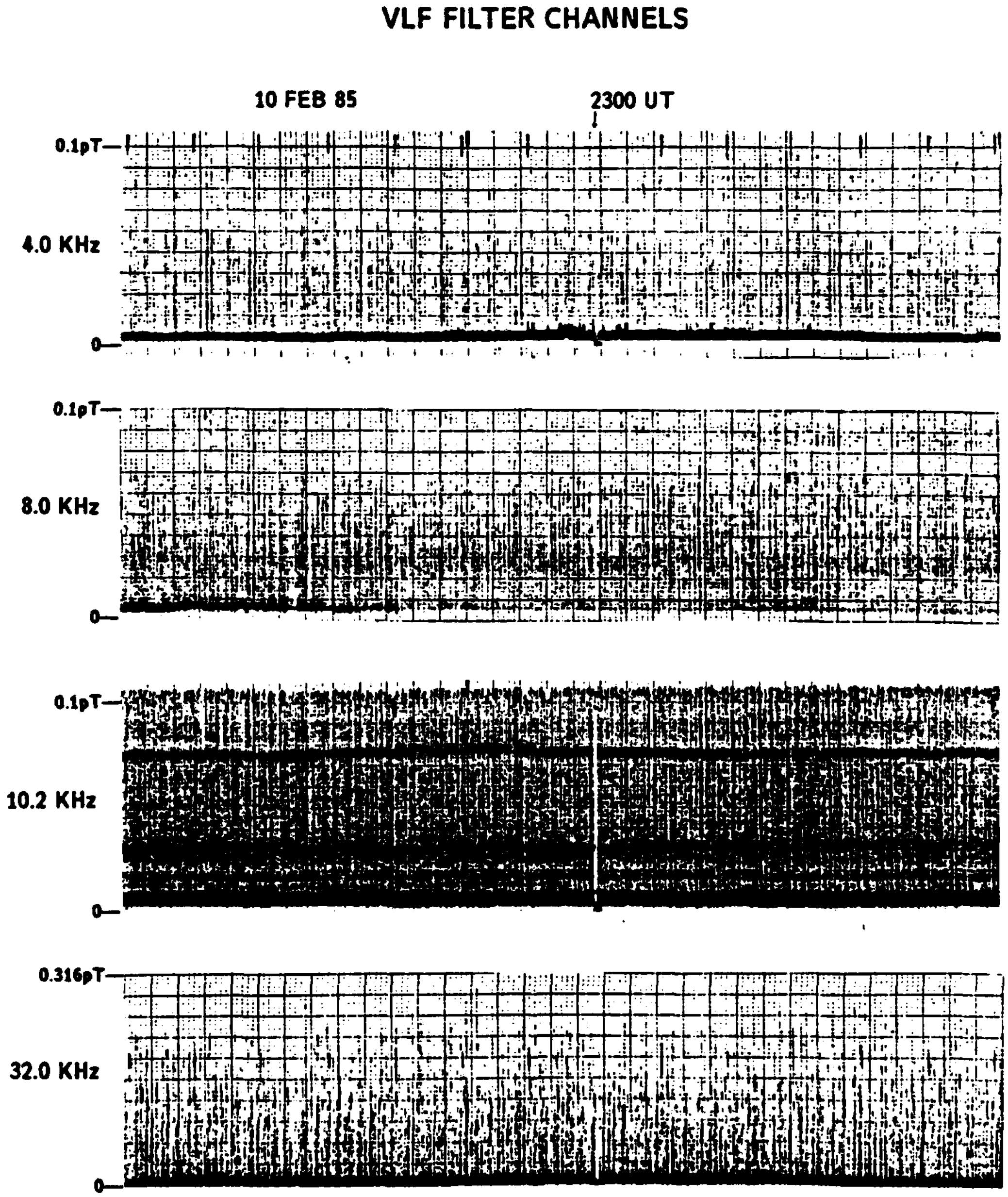

Figure 4.10. Chart records of the VLF noise filter channels at 4.0 KHz, 8.0 KHz, 10.2 KHz, and 32.0 KHz.

Appendix A. Data Format Reference Manual

This appendix is an excerpt from the *Noise Survey Software Reference Manual*, written by Evans Paschal of Stanford University. It contains complete specifications for the data recording formats of both analog and digital tapes, and should serve as the guide for anyone attempting to read and analyze radiometer data tapes.

The page numbers are those of the original document, going from 3.1 to 3.34.

3. DATA FORMATS AND RECORDING SCHEDULES

This chapter contains most of the information needed to interpret digital tape recordings made by the Noise Survey system. As such, it is intended primarily for data users.

3.1 ELF and VLF Receiver Calibrations

The VLF and ELF receivers are calibrated by injecting a calibration signal of known amplitude at the preamp antenna input terminals for both the NS and EW channels of each preamplifier. Each calibration signal has a comb spectrum, with equal amplitude components spaced evenly in frequency throughout the range of the respective receiver. The signals are generated by a comb generator in the respective line receiver, and use a pseudo-random waveform to maximize the signal power while minimizing signal peak amplitude. The VLF comb calibration signal has components every 250 Hz, from 250 Hz on up (down 0.09 dB at 32 kHz), where each component is equivalent to a received field strength of 0.100 pT (B field) or 30 uV/m (E field). The ELF signal has components every 10 Hz (down 0.05 dB at 500 Hz), each equivalent to a received field of 10.0 pT or 3.0 mV/m.

If the calibration signals are measured during data analysis, the gain and frequency response of each channel of both receivers can be determined, and thus absolute measurements of received signal strength can be made. A reference signal is especially important in the case of the broadband VLF recording, made on analog tape, where tape quality and recorder gain variations may cause the signal on playback to be at a different level than when recorded.

The comb calibration signals are applied as follows:

1. VLF preamp calibration: every 5 minutes starting at 00:00:01 for 1 second.

2. ELF preamp calibration: every 5 minutes starting at 00:04:53 for 8 seconds.

Note that the VLF cal signal occurs just after the WWV break (see Section 3.3 below), and the ELF cal occurs during the WWV break time. When either calibration signal is on (and for a short time thereafter - 1 s for VLF, 10 s for ELF) the noise filter data processing task is inhibited from generating statistical data from the respective bank of filters so cal tones will not be interpreted as received signals.

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3.2 Noise Filter Calibrations

Noise filter calibrations are used to measure the gain and rms detector linearity of the various filters in the noise filter unit, and also to measure any dc offset in the rms detectors and A/D converter input multiplexors. Noise filter calibrations are made by switching off the signals from the VLF/ELF receivers and inserting instead attenuated signals from the line receiver comb generators. The comb signals are applied separately to the VLF and ELF filter banks, first to the NS channels and then to the EW channels, with various attenuations over a 70 dB range.

Noise filter calibrations are performed as follows:

1. VLF NF filters: every hour on the hour for 19 seconds as follows:
   a. 1 second no signal, no cal (zero response check)
   b. 1 sec each NS bank only at -70, -60, ..., 0 dB atten.
   c. 1 second no signal, no cal
   d. 1 sec each EW bank only at -70, -60, ..., 0 dB atten.
   e. 1 second no signal, no cal

2. ELF NF filters: every hour on the hour for 200 seconds as follows:
   a. 20 seconds no signal, no cal (zero response check)
   b. 10 sec each NS bank only at -70, -60, ..., 0 dB atten.
   c. 10 seconds no signal, no cal
   d. 10 sec each EW bank only at -70, -60, ..., 0 dB atten.
   e. 10 seconds no signal, no cal

After segment a. (zero response check), the digitized input samples for each VLF or ELF filter are saved as zero offsets for the respective inputs, and are subtracted from subsequent input values to compensate for rms and A/D converter dc offset. If the noise filter power is off or the unit is in local cal mode, no calibration is attempted, since the zero offsets saved in that case would be erroneous. Also, if the noise filter power should fail or the unit be put in local cal mode after a cal sequence is started, the calibration is aborted for the same reason.

10 seconds after the system is first started, when recovering from a power failure, or after a fatal panic, the noise filter calibrations are also run to determine the zero offset values.

When a calibration signal is on (and for a short time thereafter - 1 s for VLF, 10 s for ELF) the noise filter data processing task is inhibited from generating statistical data from the respective bank of filters so cal tones will not be interpreted as received signals.

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3.3 Analog VLF Recording

Analog recordings are made of the broadband VLF data on a synoptic, continuous, or special-schedule basis as selected by the operator. The analog recorder is an Ampex 440C 2-channel recorder/reproducer that takes standard 1/4-inch analog tape on 10-1/2 inch reels. The recorder has half-track heads and can record 2 channels at once in one direction, but most often will be used to record a single channel only, with the operator swapping reels at the end of one side and then continuing to record the same channel on the other side of the tape. Recordings can be made from 3.75 to 30 ips, but most are made at either 3.75 or 7.5 ips, depending on the frequency response required. At 3.75 ips a 3600-foot reel will hold about 3 hours of data on each side, or 6 hours of single-channel data total. At 7.5 ips, it can contain 96 minutes each side, or 3 hours total.

The record electronics use constant-current equalization. That is, a signal of given amplitude will generate a constant rms current in the recording head regardless of frequency (at least over the frequency range of interest for a specified tape speed). The reproduce electronics are adjusted to play back constant-current recordings with maximum fidelity. Constant-current equalization is used instead of the more common NAB equalization for our data because it allows a reasonable dynamic range over a wider frequency range. (NAB and other common audio equalizations emphasize high-frequency components during recording and de-emphasize them during playback to eliminate tape noise. However, with VLF data this would cause high-frequency signals to saturate the tape.)

VLF synoptic recordings are normally made of only one receiver output, usually the NS signal (though the operator can record the VLF EW signal, either ELF signal, though with a limitation on low-frequency response, and add either of 2 auxiliary input signals). In addition to the signal, the tape contains WWV breaks for time checks, and a continuous time mark and pilot tone for time and phase reference. The beginning of each tape should include a short announcement by the operator giving the date, station, and various other particulars of the recording.

Synoptic recordings are made automatically 1, 2, 4, or 12 times an hour (every 6Ø, 3Ø, 15, or 5 minutes), depending on the setting of the SYNOPTIC RATE switch on the coupler. Each synoptic recording lasts either 59 or 6Ø seconds. (While a 36ØØ-foot tape would have exactly enough space on each side at 7.5 ips for 24 hours of 6Ø-second recordings made once every 15 minutes, we must leave room for a voice annotation at the beginning and allow for some tape length variation.) Synoptic recordings are made at the following times:

Synoptic Rate	Start Time	Stop Time (VLF Synoptic)
1/5 1/15 1/3Ø 1/6Ø	XX:Ø4:53	XX:Ø5:52
1/5	XX:Ø9:53	XX:1Ø:53
1/5	XX:14:53	XX:15:52
1/5 1/15	XX:19:53	XX:2Ø:53
1/5	XX:24:53	XX:25:52
1/5	XX:29:53	XX:3Ø:53
1/5 1/15 1/3Ø	XX:34:53	XX:35:52
1/5	XX:39:53	XX:4Ø:53
1/5	XX:44:53	XX:45:52
1/5 1/15	XX:49:53	XX:5Ø:53
1/5	XX:54:53	XX:55:52
1/5	XX:59:53	XX:ØØ:53

Each VLF synoptic recording starts with an 8-second WWV break, when the input signal is switched off and the output of the WWV receiver is recorded. 8 seconds is just long enough to catch the WWV station and time announcement ("Station WWV. At the tone, the time will be ...") and the 1-second tone on the minute. Following the WWV break, the VLF signal is turned back on. The first second of signal will include a VLF preamp calibration tone.

At stations equipped with two analog recorders, recordings can be made using both decks, with control transferring from one deck to the other at times determined by the FIRST DECK and TRANSFER TIME switches on the coupler. This allows longer periods of operation before the operator must swap tape reels or load a new tape. The following table lists the deck used versus time of day and transfer time switch setting, assuming the first deck switch is set to DECK 1. The other deck is used if the first deck switch is set to DECK 2. Note that the times listed are in whole hours. A recording on the hour actually starts 7 seconds before the hour, but is assigned a deck as if it started on the hour. (Even and and odd days refer to the parity of the day number, the number of days since Jan Ø, 19ØØ.)

Time of Day	Transfer Time Switch Setting				
	OFF	24	12	8	4
Even Days					
ØØ-Ø3 hours	1	1	1	1	1
Ø4-Ø7 hours	1	1	1	1	2
Ø8-11 hours	1	1	1	2	1
12-15 hours	1	1	2	2	2
16-19 hours	1	1	2	1	1
2Ø-23 hours	1	1	2	1	2
Odd Days					
ØØ-Ø3 hours	1	2	1	2	1
Ø4-Ø7 hours	1	2	1	2	2
Ø8-11 hours	1	2	1	1	1
12-15 hours	1	2	2	1	2
16-19 hours	1	2	2	2	1
2Ø-23 hours	1	2	2	2	2

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3.4 Tape Pilot Tone and Time Marks

The pilot and time mark tone is a 1Ø kHz amplitude modulated signal inserted along with the received signal in analog VLF recordings for two purposes:

1. to provide a phase reference to allow the reconstruction of received signal phases during data analysis (eliminating tape wow and flutter) and

2. to provide automatic station, day, and time identification in the tape record.

The pilot tone is normally recorded 3Ø db below normal maximum tape level (-3Ø VU), but is modulated up by 1Ø db (to -2Ø VU) to provide time mark ticks on the second, and station identification, day, and time of day information. No year information is encoded. The time mark modulation is as follows:

4Ø ms pulse on the second except

- a. 1.Ø4 second pulse on the minute
- b. no pulse on any second ending in 9 (Ø9s, 19s, ...)
- c. no pulse at Ø6s
- d. 2-letter station code in Morse code at Ø7s, Ø8s
- e. 3-digit day of year in Morse code at 1Øs, 11s, 12s
- f. no pulse at 13s
- g. 2-digit hour in Morse code at 14s, 15s
- h. no pulse at 16s
- i. 2-digit minute in Morse code at 17s, 18s

All Morse code characters are generated with dit = 4Ø ms, dah = 12Ø ms.

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3.5 Chart Time Marks

A relay contact output is provided at the coupler to drive chart time mark pens, with contact closure as follows:

1 second closure on the minute except

- a. no closure on minutes ending in 9 (Ø9m, 19m, ...)
- b. 3Ø sec closure at ØØm on the hour
- c. 3Ø sec closure at ØØ:Ø2 at the beginning of the day

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3.6 Digital Tape Recording Format

Digital data are recorded on 1Ø-inch reels of standard 1/2-inch wide digital tape. All recordings are 9-track (8 data tracks plus odd parity) at either 16ØØ bpi PE (phase-encoded or high density, the usual choice) or 8ØØ bpi NRZI (low density, an optional choice). Recording uses the industry-standard (ie, IBM compatible) format. Data on the tape are divided into FILES, TAPE RECORDS, and DATA RECORDS, as follows.

Each FILE is a section of tape terminated by and end-of-file or EOF mark. An EOF is normally written at the beginning of each hour, so each file contains one hour's worth of data. Files provide a convenient means for rapid data searches when reading a tape. However, it should be noted that the file mark does not cut the data stream always precisely at the hour. Data accumulated in a task buffer is usually not written to the tape until the buffer is full, so some data taken just before the hour may be written to the tape after the file mark. The last file on the tape is marked by two EOF marks in a row - the logical EOT or end-of-tape point. No valid data can be read past this point. (Note that the logical EOT usually occurs before the physical EOT mark, a reflective foil strip just before the end. Any data past the logical EOT is garbage left from some previous use.)

Within each file, data is written in TAPE RECORDS. Each tape record is a block of 8192 bytes of data followed by a small inter-record gap or IRG. The record also contains CRCC/LPCC check characters and/or synchronizing fields depending on the density used (PE or NRZI). When a tape is read back for processing, it is read one tape record at a time. Each pair of bytes should be interpreted as the high (first) and low (second) byte of a 16-bit word. Thus, each tape record contains exactly 4Ø96 words.

Within each tape record, data are written in DATA RECORDs. Each data record includes a 5-word data block header followed by a variable-length data block. (NF/DIFF data records further divide the data block into subblocks.) The data header contains a code word identifying the type of data, a block count indicating the total number of words in this data record, and three words of time information specifying the time of the first data sample. The maximum size of a data record is 1Ø24 words (though most are smaller), so each tape record can contain 4 or more data records. If the data records in a tape record do not add up to 4Ø96 words, the remaining words are made Ø's.

Each tape record is thus formatted like this (16-bit words are written in 2 bytes, high byte first):

```
word 1:          <data code 1>  --------
                 <block count N1>      |
                 <time word Ø>         |
                 <time word 1>         |-- Data Record 1
                 <time word 2>         |
                 <data ...             |
                   ...>         --------
                 ------------
word N1+1:       <data code 2>  --------
                 <block count N2>      |
                 <time word Ø>         |
                 <time word 1>         |-- Data Record 2
                 <time word 2>         |
                 <data ...             |
                   ...>         --------
                 ------------
word N1+N2+1:    <data code 3>  --------
                 <block count N3>      |-- Data Record 3
                   ...          --------
                 ------------
                   ...
                 ------------
                 <optional Ø's ...
                   ...
word 4Ø96:       Ø>
                 CRCC/LPCC/IRG  ----------- End of Tape Record
```

The data codes used in the Noise Survey system are defined as follows:

- Data code = 1 - Noise filter/differential input data
- Data code = 2 - Noise filter/differential input statistics
- Data code = 3 - Broad-band ELF NS data
- Data code = 4 - Broad-band ELF EW data
- Data code = 5 - System status data
- Data code = 6 - Message log (text) data

The block count N is the total number of words in the particular data record. When searching through digital tape data, the next tape record is read into a buffer. The data code and block count for the first data record are read from the first two words of the buffer. If the code is not of the type wanted the block count is added to the buffer pointer and the next data code and block count are retrieved and so on, until the desired data are found. If the end of a given tape record is reached (ie, data code = Ø), the next record must be read into the buffer and the search continues. Note that tape records are all of fixed size: 4Ø96 words. If data records do not completely fill a tape record, the remaining words in the tape record are zeros.

The time words specify the time of the data as follows:

Time word Ø - Day number. This is an unsigned 16-bit integer which ranges from 1 to 65535, giving the number of days since Jan Ø, 19ØØ. Note that Jan 1, 19ØØ = 1; Jan 1, 2ØØØ = 36525; and Jun 5, 2Ø79 = 65535. (Remember that 19ØØ is not a leap year, but 2ØØØ is.)

Time word 1 and Time word 2 - Time of day. The time of day is a 2-word unsigned double-precision integer giving the time in milliseconds since the beginning of the present day, high word first. The maximum value of the time of day is ØØ2446^Ø55777 = 86399999, or 23:59:59.999. In practice, the time of day is only given in increments of 1ØØ ms (snap time).

Data of a given type (data code) are always recorded in data records in time order (sequentially) as they are generated. However, different types of data records may be intermingled in each tape record, since the tape record represents the output of a number of concurrent processes. The format of the data recorded in each type of data record is detailed in the following sections.

****

3.7 Noise Filter Sampling and Recording

The 32 noise filter rms detector outputs (16 filter frequencies, each with a NS and an EW filter and detector) are sampled every 1ØØ ms, along with the 6 differential inputs. The total (non-directional) signal at each noise filter frequency is calculated by taking the square root of the sum of the squares of the NS and EW detector outputs, to give 16 noise filter magnitudes. Various other statistical measures are also calculated, as described in Section 3.8.

However, most of these data points are not recorded. The operator can select the number of data points recorded by the SAMPLE TIME switch on the coupler, and record samples at Ø.2, Ø.5, 1, 2, 5, or 1Ø-second intervals. Samples may also be recorded every Ø.1 second on a special-schedule basis only. In addition, the 6 differential inputs (signals from other optional experiments) may be recorded if desired at these times. Recorded samples are always taken at times starting on the minute, and at the specified intervals thereafter. The operator may also elect to inhibit the synoptic recording of noise filter/diff input data and/or to specify recording at special rates (from the list above) and times. In addition, the operator may specify that particular noise filter inputs not be included in the filter magnitude calculations, useful in cases where one signal (NS or EW) is heavily contaminated by local interference and is not to be sampled at a particular frequency. (This option may also be included in the built-in program at assembly.)

Noise filter/differential input data records on tape are formatted as follows:

```
1                   - NF/DIFF data code
<block count>       - total number of words in data record
<time word Ø>       - time of the first set of samples
<time word 1>
<time word 2>
<block recording flags>
<subblock size>
<data subblock 1> - first set of samples
<data subblock 2> - second set of samples
   ...
<data subblock n> - last set of samples
```

The block record flags word (6th word in the data block) gives the following information:

FLAGS:	B0	- 1 if DIFF1 is being recorded
	B1	- 1 if DIFF2 is being recorded
	...	
	B5	- 1 if DIFF6 is being recorded
	B6	- 1 if synoptic record has been inhibited for any time during this data record
	B7	- 1 if this record contains a synoptic recording
	B8	- 1 if this record contains a special-schedule recording
	B9	- always 1
	B10-12	- synoptic recording sample time
	B13-15	- special schedule recording sample time

The recording sample time flags (B10-12 and B13-15) give the recording rate as follows:

000	- off
001	- 10 seconds/sample
010	- 5 seconds/sample
011	- 2 seconds/sample
100	- 1 second/sample
101	- 0.5 second/sample
110	- 0.2 second/sample
111	- 0.1 second/sample (special-schedule only)

The subblock size word (7th word in the data block) gives the size in words of each subblock in the current record. In a given record, the subblock size (and which differential inputs are being recorded) is fixed.

Each data subblock contains 16 to 22 words representing the 16 noise filter magnitudes and (optionally) samples of the 6 differential inputs taken at one time (over an interval of 38 ms). Because differential inputs are optional, the subblock size is variable. Similarly, the data record size will also vary, depending on the number of subblocks that can be fit into one data record. The maximum data block size is currently 247 words (NRBBZ+7). (See NTSK5 for a discussion of the choice of this value.) For example, when no diff input data are being recorded, each subblock will contain 16 words (noise filter magnitudes), and each data record will contain 15 subblocks, giving a total record size of 247 words (5 header words, 2 flag and size words, and 240 data words). If one differential input were being recorded, each subblock would have 17 words, and each data record would contain 14 subblocks for a total of 245 words. Within each subblock, data are recorded in the following order:

Subblock: NF channel 1 magnitude
NF channel 2 magnitude
...
NF channel 16 magnitude
DIFF 1 (if recorded)
DIFF 2 (if recorded)
...
DIFF 6 (if recorded)

Each noise filter magnitude is the square root of the sum of the squares of the NS and EW filtered signals at that frequency (unless one is being ignored because of interference) and is an unsigned integer ranging from 0 to 46335 (= 132377 octal). The A/D converter gain used in taking each noise filter sample is compensated for by shifting the digitized samples before magnitude computation, and any converter zero offsets are subtracted, so these effects should not be apparent to the data user. However, the magnitudes recorded do depend directly on the VLF or ELF receiver gains (0, 10, 20, or 30 dB) and these gains must be taken into account when analyzing data. Receiver gains are recorded in the system status data. (See Section 6.8 for the receiver automatic gain algorithm.) The following table shows the rms received field in a properly calibrated system which gives a noise filter magnitude of 1 for various receiver gains:

Receiver Gain	ELF Mag = 1	VLF Mag = 1
0 dB	72.67E-15 Tesla	4.167E-15 Tesla
10 dB	22.98E-15 Tesla	1.318E-15 Tesla
20 dB	7.267E-15 Tesla	416.7E-18 Tesla
30 dB	2.298E-15 Tesla	131.8E-18 Tesla

Some cautions when interpreting noise filter magnitudes are in order here. First, the minimum useful output voltage from the rms detector in each noise filter channel is about 2.5 mV, corresponding to a magnitude of 8. Noise filter magnitudes of this order are near the system noise level. Second, the maximum useful output from the rms detector is about 7 V, corresponding to a magnitude of 22400. Magnitudes larger than this may be in error because of clipping in the system. The useful dynamic range of noise filter magnitudes is thus about 70 dB.

The differential input data (when recorded) are a bit different. Differential inputs may be defined as signed or unsigned. The choice for each input is fixed when a particular system is assembled (PARNC parameters ??DS1-??DS6). Signed inputs take on values from -32768 (100000 octal) to +32764 (077774 octal) representing voltages from -10.24 to +10.24 V. Unsigned inputs are limited by the data processing task to be always non-negative (that is, if an unsigned sample is taken and found to be less than 0, the value 0 is used instead). This feature is useful with certain instruments (such as rms detectors) whose outputs should always be positive voltages and where a negative voltage represents an error of some kind which should not be used when calculating the average, rms and minimum/maximum statistics. Unsigned sample values range from 0 to 32764 representing input voltages from 0 to +10.24 volts.

Also note that the particular A/D converter gain (1, 2, 4, or 8) used when sampling a particular differential input is compensated in the data correction task by shifting the sample (left 2 bits, left 1, no shift, right 1 bit) so all samples are normalized to the range +/- 10.24 V full scale. However, the precision of each sample is only 14 bits (13 with gain of 8). That is, with an A/D gain of 1, samples will range from -32768 (or 0 if unsigned) to +32764 in steps of 4 (= 1.25 mV). With an A/D gain of 4, samples will range from -8192 (or 0) to +8191 in steps of 1 (= 0.3125 mV). The interpretation of differential input data depends, of course, on what optional instruments have been connected at any given field station.

****

3.8 Noise Filter Statistics

The noise filter statistics data are recorded every minute at the start of a new minute and contain the rms, minimum, and maximum values of the noise filter and differential input samples taken during the previous 60 seconds. Each statistics data record looks like this:

```
2                 - Statistics data code
96.               - block count, always 96
<time word 0>     - time of the minute for this data
<time word 1>
<time word 2>
<ELF smpl cnt>    - number of ELF (NF Ch1-Ch6) samples
<VLF smpl cnt>    - number of VLF (NF Ch7-Ch16) samples
<DIFF smpl cnt>   - number of DIFF samples
<average values
  ...>            - 22 words
<rms values
  ...>            - 22 words
<minimum values
  ...>            - 22 words
<maximum values
  ...>            - 22 words
```

The ELF, VLF, and DIFF sample counts are the number of sample sets used in calculating the average, rms, minimum, and maximum values for noise filter channels 1-6 (ELF channels), noise filter channels 7-16 (VLF channels), and the 6 differential inputs (DIFF1-DIFF6), respectively. These inputs are sampled every 100 ms (every snap), so a minutes worth of data will normally contain the results of processing 600 samples (60 seconds at 10 samples/second). However, if either an ELF or a VLF calibration is in progress (either a preamp cal, taking 8 seconds for ELF and 1 second for VLF, or a noise filter cal, taking 200 seconds for ELF or 19 seconds for VLF), the respective noise filter samples are not processed as part of the statistics data. If the noise filter power or that of one of the receivers is off, or a unit is in local cal mode, the respective samples are not used to generate statistics. Also, following a calibration, power off status, or local cal status, the ELF filters are ignored for 10 seconds, and the VLF filters for 1 second, to allow time for the individual filters to settle back to their steady state response. The noise filter statistics data thus refer only to the values of received signals. (Differential input statistics are not inhibited by calibrations.) Finally, if the operator should correct the clock during a given minute, that minute's statistics data may contain greater or fewer than the usual number or samples. Sample counts are normally as follows:

Time	ELF count	VLF count	DIFF count
XX:X0	490	580	600
XX:X1	600	600	600
XX:X2	600	600	600
XX:X3	600	600	600
XX:X4	530	600	600
XX:X5	490	580	600
XX:X6	600	600	600
XX:X7	600	600	600
XX:X8	600	600	600
XX:X9	530	600	600

except on the hour, when noise filter calibrations are started, and the sample counts are:

XX:00	0	400	600
XX:01	0	600	600
XX:02	0	600	600
XX:03	300	600	600
XX:04	530	600	600
XX:05	490	580	600
XX:06	600	600	600
...			

The 22 average, rms, minimum, and maximum values are each written in the following order:

NF channel 1
NF channel 2
...
NF channel 16
DIFF 1
...
DIFF 6

Note that the differential input values are alwavs reported, even if no external instrument is connected to a particular input.

The average values are obtained by summing, during each minute, the corrected noise filter magnitudes and differential input values, and at the end of the minute dividing the (double-precision) sum by the number of samples included. The resulting average for a noise filter channel is an unsigned integer from 0 to 46335 (132377 octal). For a differential input the average is a signed integer from -32768 (100000 octal) to +32764 (077774 octal), though only signed differential inputs may be less than zero. Averages covering longer periods of time may be calculated during data analysis by averaging the averages in the obvious way.

The rms values are calculated by dividing the triple-precision sum of the squares of the noise filter magnitudes or differential input values by the number of samples accumulated in each minute, and taking the square root of the result. The resulting rms values are unsigned integers ranging from 0 to 46335 (132377 octal) for the noise filters, and 0 to 32768 (100000 octal) for the differential inputs. RMS values covering longer periods of time may be found by reversing this procedure to find the sums of the squared values, adding those results, and dividing by the sums of the sample counts and taking the square root.

The minimum and maximum values reported in the statistics data are the minimum and maximum values found for each input during the given minute. Since the noise filter data are magnitudes (unsigned integers from 0 to 46335) whereas the differential input data are voltage samples (signed integers from -32768 to +32764 or unsigned integers from 0 to +32764), the minima and maxima of noise filter and differential input data are interpreted differently, as follows:

1. The minima and maxima of noise filter magnitudes are unsigned integers, ranging from 0 to 46335. The minimum value for a given noise filter channel is that value closest to 0 found during the given minute. The maximum value is that closest to 46335.

2. The minima and maxima of signed differential input samples are signed integers, ranging from -32768 to +32764. The minimum value for a given signed input is that sample closest to -32768 found during the given minute. The maximum value is that closest to +32764.

3. The minima and maxima of unsigned differential input samples are non-negative integers, ranging from 0 to 32764. The minimum value is that sample closest to 0 (negative inputs are changed to 0). The maximum value is that closest to +32764.

If no samples of a given type were processed in a given minute (because of calibrations, for instance), the average and rms values reported will be 0, the minima will be high, and the maxima will be low (ie, the initial values used in processing the data). Also, if particular noise filter inputs are being ignored (because of local interference), the values reported reflect only that signal (NS or EW) that is processed.

Refer to Section 3.7 above to convert a given average, rms, minimum, or maximum value to a received field or an instrument output voltage.

****

3.9 Broad-Band ELF Recording

Broad-band ELF data are recorded on a synoptic schedule just like the analog VLF data described above, except that each ELF record on digital tape is exactly 60 seconds long. Synoptic ELF recordings start at xx:x4:53 or xx:x9:53 and end at xx:x5:53 or xx:x0:53, respectively. The first 8 seconds of an ELF record contain an ELF preamp calibration signal along with received signals. Broad-band ELF recordings can be made of either the NS signal, the EW signal, or both signals at the same time (the data code specifies which signal is contained in a particular data record). The broad-band ELF signal is low-pass filtered to 400 Hz and sampled at a rate of 1000 samples/second to preserve signal information from 10 Hz to 400 Hz, and eliminate aliasing above 400 Hz.

Each sample is digitized to 14 bits, and is a signed integer in 2's-complement form from -8192 to +8191, representing the receiver output voltage over a range of -10.24 to +10.24 volts (assuming an A/D converter gain of 1, the normal case). The field strength of a received signal that corresponds to a given sample depends on the ELF receiver gain used at the time. The following table gives the received field in a properly calibrated system versus sample value and receiver gain:

Receiver Gain	Sample = 1	Full-scale = 8192
0 dB	726.7E-15 Tesla	5.953E-09 Tesla
10 dB	229.8E-15 Tesla	1.883E-09 Tesla
20 dB	72.67E-15 Tesla	595.3E-12 Tesla
30 dB	22.98E-15 Tesla	188.3E-12 Tesla

The A/D converter is synchronized to a 3 kHz signal from the clock derived from the station frequency standard, and jitter in the sample times should be very low (a few nanoseconds). However, the NS and EW signals are not sampled simultaneously. Every NS sample is taken approximately 333 usec after the millisecond, and every EW sample is taken approximately 667 usec after the millisecond. This means that there is a time lag of 333 or 334 usec between corresponding NS and EW samples, which must be kept in mind during data analysis if the two signals are to be compared to each other. (See Section 5.12 for details of the sampling process.)

The format of each data record for BB ELF data is:

3 or 4	- data code for NS or EW, respectively
505.	- block count, always 505.
<time word 0>	- time of the first data sample
<time word 1>	
<time word 2>	
<500 words of data ...>	

Each data record thus contains 500 samples, or 0.500 seconds, of BB ELF data. (See NTSK5 for a discussion of the choice of the parameter ELFBK = 500.)

****

3.10 System Status Data

A system status data record is made every 10 minutes starting on the hour. It contains information needed during data analysis (such as the receiver gains) as well as information providing a record of system operation. Each system status data record is formatted as follows:

5	- System status data code
92.	- block count, always 92
<time word 0>	- time of status reporting
<time word 1>	
<time word 2>	
SYSID	- Station ID bytes
SYCPL	- Coupler data copy, 19 words
...	
SYADG	- A/D converter gains, 10 words
...	
SYADZ	- A/D zeros, 38 words
...	
SYMFL	- Mag tape flags, 8 words
...	
SYMST	- Mag tape transport status, 8 words
...	
SYER0	- Error status word 0
SYER1	- Error status word 1
SYER2	- Error status word 2

Coupler Data copy SYCPL and following:

These 19 words contain a snapshot of the coupler data as they were at the time of status reporting, arranged as follows (see Section 3.11 for a description of particular coupler data words):

Coupler Input Data:

SYCPL+Ø = CPLI1 - VLF receiver status in
SYCPL+1 = CPLI2 - ELF receiver status in
SYCPL+2 = CPLI3 - Noise filter status in
SYCPL+3 = CPLI4 - Mixer1 status in
SYCPL+4 = CPLI5 - Mixer2 status in
SYCPL+5 = CPLI6 - Schedule status in
SYCPL+6 = CPLI7 - Miscellaneous status in

Coupler Output Data:

SYCPL+7 = CPLOØ - Program lights out
SYCPL+8 = CPLO1 - VLF receiver out
SYCPL+9 = CPLO2 - ELf receiver out
SYCPL+1Ø = CPLO3 - Noise Filter out
SYCPL+11 = CPLO4 - Mixer out
SYCPL+12 = CPLO5 - Relay control out
SYCPL+13 = CPLO6 - Digital tape status out
SYCPL+14 = CPLO7 - Other indicator status out

Program Schedule Status Words:

SYCPL+15 = CPLSØ - VLF recording status
SYCPL+16 = CPLS1 - ELF recording status
SYCPL+18 = CPLS3 - Statistics recording status
SYCPL+17 = CPLS2 - Noise filter recording status

A/D Converter channel gains SYADG and following:

These 1Ø words contain the signed number flag (8Ø) and the low 3 bits (ignore flag and gain) of the A/D converter select words ASØ1N-ASBBE at the time of status reporting, arranged in 4-bit nibbles.

SYADG+Ø = <Ch 1 NS><Ch 1 EW><Ch 2 NS><Ch 2 EW>
SYADG+1 = <Ch 3 NS><Ch 3 EW><Ch 4 NS><Ch 4 EW>
SYADG+2 = <Ch 5 NS><Ch 5 EW><Ch 6 NS><Ch 6 EW>
SYADG+3 = <Ch 7 NS><Ch 7 EW><Ch 8 NS><Ch 8 EW>
SYADG+4 = <Ch 9 NS><Ch 9 EW><Ch1Ø NS><Ch1Ø EW>
SYADG+5 = <Ch11 NS><Ch11 EW><Ch12 NS><Ch12 EW>
SYADG+6 = <Ch13 NS><Ch13 EW><Ch14 NS><Ch14 EW>
SYADG+7 = <Ch15 NS><Ch15 EW><Ch16 NS><Ch16 EW>
SYADG+8 = <DIFF 1 ><DIFF 2 ><DIFF 3 ><DIFF 4 >
SYADG+9 = <DIFF 5 ><DIFF 6 ><ELF NS ><ELF EW >

Within each nibble, the bits are encoded as:

ØXXX - Statistics calculated for unsigned input
1XXX - Statistics calculated for signed input
XØXX - Don't ignore input
X1XX - Ignore input (NF inputs only)
XXØØ - A/D gain 1
XXØ1 - A/D gain 2
XX1Ø - A/D gain 4
XX11 - A/D gain 8

A/D converter noise filter/differential input zero offsets SYADZ and following:

These 38 words contan the signed zero offset sample values that are subtracted from each NF/DIFF input sample during data correction before the NF/DIFF data are processed. The 32 noise filter channel words are saved during noise filter calibrations and represent the zero-signal noise filter output voltages. They should be small numbers (-1Ø to +1Ø or so). The differential input zero offsets are not calculated (except in particular system implementations) and these 6 words should be all Ø.

The zero offsets are a copy of the A/D converter data table words AZØ1N through AZDF6, as follows:

```
SYADZ+Ø  = AZØ1N - NF Ch1 NS zero offset
SYADZ+1  = AZØ1E - NF Ch1 EW zero offset
SYADZ+2  = AZØ2N - NF Ch2 NS zero offset
...
SYADZ+31 = AZ16E - NF Ch16 EW zero offset
SYADZ+32 = AZDF1 - Differential input 1 zero offset
...
SYADZ+37 = AZDF6 - Differential input 6 zero offset
```

Mag tape flag words copy SYMFL and following:

These 8 words contain a copy of the flags (MSTFØ-MSTF7) for tape units MTØ-MT7, meaning as follows:

```
MFSYS  = BØ      - This unit is defined in the system
MFDRC  = B1      - Record data on this unit
MFDEN  = B2      - Data are high density (PE)
MFONL  = B3      - This unit is on-line
MFLOD  = B4      - Reload this unit
MFERC  = 3777B15 - Data error count for this unit
                   (Ø-3777 octal)
```

MFERC is incremented when a data late, bad tape, parity, corrected, or odd character error occurs. A large data error count signifies a low-quality tape or the need for tape head cleaning. MFERC is reset when a new tape is loaded.

Most Noise Survey systems will have only one digital tape unit, MTØ, and the flag words for the other units will be Ø.

Mag Tape transport status words copy SYMST and following:

These 8 words contain a copy of the transport status words (MSTSØ-MSTS7) for Tape units MTØ-MT7, meaning as follows:

```
MSERR  = BØ   - Error
              = B1+B3+B5+B6+B7+B8+B1Ø+(B11&/B4)+B12+B14
MSDTL  = B1   - Data late
MSREW  = B2   - Rewinding
MSILL  = B3   - Illegal command
MSPE   = B4   - PE/NRZI
MSPER  = B5   - Hard (parity) error
MSEOT  = B6   - End of tape
MSEOF  = B7   - End of file
MSBOT  = B8   - Load point
MSONL  = B9   - On-line
MSBTP  = B1Ø  - Bad tape
MSID   = B11  - PE only - ident burst
MSCER  = B12  - PE only - corrected error
MSWLK  = B13  - Write lock
MSODC  = B14  - Odd char
MSRDY  = B15  - Ready
```

Transport status words for undefined units will be Ø. See NMTAD for further details of the meanings of the various bits.

See Section 3.12 for a description of the various error word bits in the system error words SYERØ-SYER2.

****

3.11 System Status Data - Coupler Data

The coupler data table copy in the system status data record (words SYCPL and following) are particularly important in monitoring the operation of the system, and are described in some detail in this section. These tables list, for each word, the mnemonics for the various bits (strictly, for the bits of these words in the coupler data table), the bit positions, and their meanings.

VLF Receiver In (SYCPL+Ø = CPLI1 copy):

BØ-B5 - not used, always Ø

VM2ØD	= B6	- Mixer gain 2Ø dB
VM1ØD	= B7	- Mixer gain 1Ø dB
VMØ5D	= B8	- Mixer gain 5 dB
VMFIL	= B9	- Mixer filters in circuit

The mixer gain bits encode the VLF receiver mixer gain in steps of 5 dB from Ø to 35 dB. This is the gain used in the analog recording system. VMFIL is 1 if the mixer filters (in the line receiver) are in the circuit.

VG2ØD	= B1Ø	- Noise gain 2Ø dB
VG1ØD	= B11	- Noise gain 1Ø dB
VGLOC	= B12	- Noise gain in local mode

These bits encode the noise gain (the gain used before output to the noise filter unit) in steps of 1Ø dB from Ø to 3Ø dB. This information is important when reading NF records to determine the absolute level of any received signals in noise filter channels 7-16. If VGLOC = 1, the gain is the result of a manual setting of the line receiver front-panel switches. Otherwise, the gain is that selected by the system.

VGFIL = B13 - Noise filters in circuit

This bit, if set, indicates that the internal line receiver filters are in the circuit. These filters are used to attenuate certain frequency bands to help eliminate interference of various kinds, and will be different at different installations.

VCLOC = B14 - Cal in local mode

This bit indicates whether or not any of the manual calibration switches on the line receiver are on. They should be off for normal operation.

VPWR = B15 - VLF receiver power on

ELF Receiver In (SYCPL+1 = CPLI2 copy):

BØ-B9 - not used, always Ø

EG2ØD	= B1Ø	- Gain 2Ø dB
EG1ØD	= B11	- Gain 1Ø dB
EGLOC	= B12	- Gain in local mode

These bits encode the gain used before output to the A/D converter (for BB ELF sampling) and the noise filter unit in steps of 1Ø dB from Ø to 3Ø dB. This information is important when reading NF and broad-band ELF records to determine the absolute level of any received signals in noise filter channels 1-6 and in the BB ELF data. If EGLOC = 1, the gain is the result of a manual setting of the line receiver front-panel switches. Otherwise, the gain is that selected by the system.

EFIL = B13 - Filters in circuit

This bit, if set, indicates that the internal line receiver filters are in the circuit. These filters may be used to attenuate local power line interference. They will be set to harmonics of the local power line frequency (either 5Ø or 6Ø Hz.)

ECLOC = B14 - Cal in local mode

This bit indicates whether or not any of the manual calibration switches on the line receiver are on. They should be off for normal operation.

EPWR = B15 - ELF receiver power on

Noise Filters In (SYCPL+2 = CPLI3 copy):

BØ-B13 - not used, always Ø

FCLOC = B14 - Cal in local mode

If this bit is set, the noise filter front-panel cal switch is in local mode. This will prevent received signals from being analyzed. This switch should normally be off.

FPWR = B15 - Noise filter power on

Mixer In, First Word (SYCPL+3 = CPLI4 copy):

The mixer/monitor has four independent channels. In most systems with only one analog tape recorder, only channels A and B will be used. Most of the time recording will be of channel A only, on one side of the tape in one direction and, later, on the other side of the tape when the tape is reversed. If dual channel recordings are being made, channels A and B will both be used. Channels C and D are used only in multi-recorder installations. The various bits in the two mixer words are encoded similarly for all four channels. Only the channel A bits are described.

MBSLØ	= BØ	- Channel B select bit Ø
MBSL1	= B1	- Channel B select bit 1
MBAX1	= B2	- Channel B AUX 1 on
MBAX2	= B3	- Channel B AUX 2 on
MBWLC	= B4	- Channel B WWV local mode
MBTLC	= B5	- Channel B time mark local mode
MBMIC	= B6	- Channel B microphone on
	B7	- not used, always Ø

MASLØ = B8 - Channel A select bit Ø
MASL1 = B9 - Channel A select bit 1

These two bits encode the input select switch for the mixer/monitor channel A, as inputs 1 through 4 (normally VLF NS, VLF EW, ELF NS, and ELF EW, respectively). Input 1 (VLF NS) is the usual choice.

MAAX1 = B1Ø - Channel A AUX 1 on
MAAX2 = B11 - Channel A AUX 2 on

These two bits encode whether or not either of the auxilliary inputs AUX1 and AUX2 have been added to the selected signal for recording on channel A. Normally no auxilliary inputs are recorded.

MAWLC = B12 - Channel A WWV local mode

If this bit is 1, the WWV break function for this channel is not under program control. This bit should be Ø.

MATLC = B13 - Channel A time mark local mode

If this bit is 1, the analog time mark is not included in the channel A signal. This bit should be Ø.

MAMIC = B14 - Channel A microphone on

This bit will be 1 when the operator is making a voice annotation on channel A.

MPWR = B15 - Mixer/monitor power on

Mixer In, Second Word (SYCPL+4 = CPLI5 copy):

```
MDSLØ   = BØ    - Channel D select bit Ø
MDSL1   = B1    - Channel D select bit 1
MDAX1   = B2    - Channel D AUX 1 on
MDAX2   = B3    - Channel D AUX 2 on
MDWLC   = B4    - Channel D WWV local mode
MDTCL   = B5    - Channel D time mark local mode
MDMIC   = B6    - Channel D microphone on
          B7    - not used, always Ø
MCSLØ   = B8    - Channel C select bit Ø
MCSL1   = B9    - Channel C select bit 1
MCAX1   = B1Ø   - Channel C AUX 1 on
MCAX2   = B11   - Channel C AUX 2 on
MCWLC   = B12   - Channel C WWV local mode
MCTLC   = B13   - Channel C time mark local mode
MCMIC   = B14   - Channel C microphone on
          B15   - not used, always Ø
```

Schedule In (SYCPL+5 = CPLI6 copy):

These bits encode the various coupler front-panel switches that determine the synoptic program functions.

BØ - not used, always Ø

REC1L = B1 - Recorder 1 local mode
REC2L = B2 - Recorder 2 local mode

These bits are 1 if the respective analog deck switches are in LOCAL or EXTernal mode, and not in AUTO mode. If not in auto mode, the system does not have control over tape motion (recording and stopping). They should be Ø.

RFRST = B3 - First deck is recorder 2

This bit is Ø or 1 as the first deck for automatic deck transfer is deck 1 or deck 2. In single-deck systems this bit should be Ø.

RTRNØ = B4 - Recorder transfer time bit Ø
RTRN1 = B5 - Recorder transfer time bit 1
RTRN2 = B6 - Recorder transfer time bit 2

The recorder transfer time bits are encoded as follows:

```
ØØØ   - off
ØØ1   - 24 hours
Ø1Ø   - 12 hours
Ø11   - 8 hours
1ØØ   - 4 hours
```

In single-deck systems, any transfer time except off is illegal and these bits should be Ø in that case.

```
VSYNØ   = B7    - VLF synoptic rate bit Ø
VSYN1   = B8    - VLF synoptic rate bit 1
VSYN2   = B9    - VLF synoptic rate bit 2
ESYNØ   = B1Ø   - ELF synoptic rate bit Ø
ESYN1   = B11   - ELF synoptic rate bit 1
ESYN2   = B12   - ELF synoptic rate bit 2
```

The VLF and ELF synoptic rate bits are encoded as:

```
ØØØ     - off
ØØ1     - 1/6Ø
Ø1Ø     - 1/3Ø
Ø11     - 1/15
1ØØ     - 1/5
1Ø1     - continuous
```

```
FSYNØ   = B13   - Noise filter sample time bit Ø
FSYN1   = B14   - Noise filter sample time bit 1
FSYN2   = B15   - Noise filter sample time bit 2
```

The noise filter sample time bits are encoded as follows:

```
ØØØ     - off
ØØ1     - 1Ø seconds/sample
Ø1Ø     - 5 seconds/sample
Ø11     - 2 seconds/sample
1ØØ     - 1 second/sample
1Ø1     - Ø.5 second/sample
11Ø     - Ø.2 second/sample
```

Miscellaneous In (SYCPL+6 = CPLI7 copy):

BØ-B3 - not used, always Ø

```
PSWØ    = B4    - Program switch Ø
PSW1    = B5    - Program switch 1
PSW2    = B6    - Program switch 2
PSW3    = B7    - Program switch 3
```

The program switch bits are 1 if the associated front-panel switch is on. These bits are used at start-up to determine the BB ELF input used for BB ELF data records, and the number of differential inputs included in NF/DIFF data records as follows:

1. If the coupler power is off, the default words CPS1D and CPS2D are used for CPLS1 and CPLS2 (see NSTRT for details). This usually means the NS input for BB ELF records, and no diff inputs in NF/DIFF records.

2. If the coupler power is on and PSWØ is up, the bits CSENS and CSEEW in CPS1D are complemented. This means use the EW input in BB ELF records in the standard system.

3. If the coupler power is on, PSW1, PSW2, and PSW3 determine the bits CSND1-6 in CPLS2, and the differential inputs recorded in noise filter/diff input records as follows:

```
PSW1-3  CSND1-6

ØØØ     default value in CPS2D (usually none)
ØØ1     1ØØØØØ - record DIFF1 only
Ø1Ø     11ØØØØ - record DIFF1 and DIFF2
Ø11     111ØØØ - record DIFF1-DIFF3
1ØØ     1111ØØ - record DIFF1-DIFF4
1Ø1     11111Ø - record DIFF1-DIFF5
11Ø     111111 - record DIFF1-DIFF6
111     ØØØØØØ - don't record any diff inputs
```

B8-B11 - not used, always Ø

CPWR = B12 - Coupler power on

Note that if the coupler power is off, all of the coupler input words will be meaningless.

ALINH = B13 - Alarm inhibit on

This bit is 1 when the coupler alarm is inhibited. The front-panel ALARM light will come on but the audible alarm will not sound in this case.

TLOAD = B14 - Change tape button pressed
EREST = B15 - Reset errors button pressed

These bits are latched when the respective buttons are pressed. However, they are cleared by the status check task STSCK when detected, and will normally be Ø.

Program Lights Out (SYCPL+7 = CPLOØ copy):

BØ-B2 - Coupler output buffer address, always ØØØ
B3-B7 - not used, always Ø

PLØ	= B8	- Program light Ø
PL1	= B9	- Program light 1
PL2	= B1Ø	- Program light 2
PL3	= B11	- Program light 3
PL4	= B12	- Program light 4
PL5	= B13	- Program light 5
PL6	= B14	- Program light 6
PL7	= B15	- Program light 7

These bits turn on the 8 program lights on the coupler. These lights are not used by the system at present, but may be turned on and off by the operator with an SCB if desired, say, as a reminder of some other function.

VLF Receiver Out (SYCPL+8 = CPLO1 copy):

BØ-B2 - Coupler output buffer address, always ØØ1
B3-B7 - not used, always Ø

VPINH	= B8	- Pending gain inhibit
VP2ØD	= B9	- Pending gain 2Ø dB
VP1ØD	= B1Ø	- Pending gain 1Ø dB

These three bits control the VLF receiver auto-gain function. If VPINH is 1, automatic gain changes are inhibited; otherwise they are enabled. This bit will normally be Ø. VP2ØD and VP1ØD specify the pending gain in increments of 1Ø dB from Ø to 3Ø dB. They are set at XX:X9:ØØ by the statistics recording task, depending on average signal levels from the noise filter VLF channels during the previous 9 minutes, and (if not inhibited) are moved to the current gain bits one minute later at XX:XØ:ØØ minutes by the seconds programmer task PRGMR. Note that the coupler does not respond to these bits on output. They are merely stored here for the convenience of the program. See Section 6.8 for the auto-gain algorithm.

VR2ØD	= B11	- Gain 2Ø dB
VR1ØD	= B12	- Gain 1Ø dB

These bits encode the VLF receiver noise gain as set by the system. Unless the receiver gain is in local mode (bit VGLOC = 1) these bits should also be returned in bits VG2ØD and VG1ØD, the actual receiver gain.

```
VCEXT    = B13    - Turn external cal on

                  This bit is 1 when the external calibration circuit in
                  the line receiver is to be activated.  This function is
                  not implemented at this time and the bit should be Ø.

VCCOM    = B14    - Turn comb cal on

                  This bit is 1 when a VLF preamp calibration is in
                  progress.

VCCEN    = B15    - Enable comb generator

                  This bit is 1 when the line receiver comb generator is on
                  to generate the comb signal for a VLF noise filter
                  calibration.
```

ELF Receiver Out (SYCPL+9 = CPLO2 copy):

The bits in the following word are used similarly to those in the VLF receiver output word, except they control ELF receiver functions. Refer to the discussion above for their significance.

```
           BØ-B2 - Coupler output buffer address, always Ø1Ø
           B3-B7 - not used, always Ø
EPINH    = B8    - Pending gain inhibit
EP2ØD    = B9    - Pending gain 2Ø dB
EP1ØD    = B1Ø   - Pending gain 1Ø dB
ER2ØD    = B11   - Gain 2Ø dB
ER1ØD    = B12   - Gain 1Ø dB
ECEXT    = B13   - Turn external cal on
ECCOM    = B14   - Turn comb cal on
ECCEN    = B15   - Enable comb generator
```

Noise Filters Out (SYCPL+1Ø = CPLO3 copy):

The following word controls the calibration circuitry in the noise filter unit. Note that these bits are only functional when the noise filter is not in local mode (bit FCLOC = Ø). The control bits for the ELF and VLF sections of the noise filter are similar, and only the ELF functions are described.

```
           BØ-B2 - Coupler output buffer address, always Ø11
           B3    - not used, always Ø

FESIN    = B4    - ELF signal inhibit

                  This bit is on during an ELF noise filter calibration
                  sequence to switch off the input signals from the ELF
                  line receiver.  It will be Ø during normal operation.

FEC4Ø    = B5    - ELF cal attenuation 4Ø dB
FEC2Ø    = B6    - ELF cal attenuation 2Ø dB
FEC1Ø    = B7    - ELF cal attenuation 1Ø dB

                  These three bits encode the attenuation of the comb
                  signal from the line receiver before it is applied to the
                  ELF filter banks, in 1Ø dB steps from Ø to 7Ø dB.

FECNS    = B8    - ELF cal to NS filters
FECEW    = B9    - ELF cal to EW filters

                  These two bits control which (if any) bank of filters the
                  calibration signal is applied to.
```

FVSIN = B10 - VLF signal inhibit
FVC40 = B11 - VLF cal attenuation 40 dB
FVC20 = B12 - VLF cal attenuation 20 dB
FVC10 = B13 - VLF cal attenuation 10 dB
FVCNS = B14 - VLF cal to NS filters
FVCEW = B15 - VLF cal to EW filters

Mixer Out (SYCPL+11 = CPLO4 copy):

B0-B2 - Coupler output buffer address, always 100
B3-B13 - not used, always 0

MWWV = B14 - Turn WWV break on

This bit is turned on every five minutes for 8 seconds by the WWV break task WWVBK to record the output of the WWV receiver at the beginning of analog VLF synoptic recordings. It will normally be 1 since system status is recorded every 10 minutes near the end of a WWV break.

MTM = B15 - Turn tape time mark on

This bit is set and cleared by the tape time mark tasks to modulate the time mark pilot tone with station ID, day and time information, and time ticks. It will normally be 1 since system status is recorded during the 1-second pulse on the minute.

Relay Controls Out (SYCPL+12 = CPLO5 copy):

B0-B2 - Coupler output buffer address, always 101
B3-B7 - not used, always 0

RLY1 = B8 - Relay 1 on
RLY2 = B9 - Relay 2 on

These two bits are 1 when the associated relays are on. The function of the relay outputs depends on the particular installation.

ALARM = B10 - Alarm on

This bit turns on the coupler alarm. It is usually 0.

CTM = B11 - Chart time mark relay on

This bit turns on the chart time mark relay. It is set and cleared by the tasks CT1S and CT30S. It will normally be 1 since system status is recorded during the closure at the beginning of a minute.

REC1R = B12 - Recorder 1 record
REC1S = B13 - Recorder 1 stop
REC2R = B14 - Recorder 2 record
REC2S = B15 - Recorder 2 stop

These four bits control the motion of the analog tape recorder(s). If the recorders are in auto mode, they start and stop synoptic and special-schedule recordings. Note that these relays are pulsed on for only 1 second at the beginning and end of a recording, so they will normally be 0.

Digital Tape Status Out (SYCPL+13 = CPL06 copy):

B∅-B2 - Coupler output buffer address, always 11∅
B3-B4 - not used, always ∅

CTLOD = B5 - Clear TLOAD latch

This bit is set briefly to clear the CHANGE TAPE button latch TLOAD when the button has been pressed. This bit is usually ∅.

TLNEW = B6 - Load new tape light

This bit activates the NEW TAPE light. It is set when a digital tape transport is off-line and needs to be reloaded.

TDLOS = B7 - Data lost light

This bit controls the DATA LOST light, and is set when an error has prevented data from being stored in the mag tape buffer for writing to the tape (panic XRCDD).

TDERR = B8 - Error light

This bit controls the tape error light and is on when a digital tape error (panic XMTAP) has occurred.

TWLCK = B9 - Write lock light

This bit is on when the digital tape transport has been loaded with a tape missing a write ring. Without a write ring installed, data cannot be written on that tape. It should be ∅.

TONLN = B1∅ - On-line light

This bit is on when the digital tape is on-line. It should normally be 1.

TRDY = B11 - Ready light

This bit is on when the digital tape is ready for a command. It will be 1 unless a tape command is in progress.

TCMDE = B12 - Command display enable
TCMD∅ = B13 - Command display bit ∅
TCMD1 = B14 - Command display bit 1
TCMD2 = B15 - Command display bit 2

These bits control the digital tape command display lights on the coupler. Commands are encoded as follows:

∅XXX - lights off
1∅∅∅ - READ
1∅∅1 - REWIND
1∅1∅ - not used
1∅11 - SPACE FORWARD
11∅∅ - SPACE REVERSE
11∅1 - WRITE
111∅ - WRITE EOF
1111 - ERASE

Other Indicators Out (SYCPL+14 = CPL07 copy):

The error light bits in the following word control the error lights on the coupler. These lights come on as errors are detected and are turned off by pressing the RESET ERRORS button. For error monitoring, the error words SVERØ-SVER2 in the system status data should be used (see Section 3.12 below).

BØ-B2 - Coupler output buffer address, always 111

CREST = B3 - Clear EREST latch

This bit is turned on momentarily to clear the RESET ERRORS latch EREST when it is detected. It will normally be Ø.

VRCRD = B4 - VLF recording light

This bit is 1 when a synoptic or special-schedule analog VLF recording is taking place.

ERCRD = B5 - ELF recording light

This bit is 1 when a synoptic or special-schedule broadband ELF recording to the digital tape is taking place.

FRCRD = B6 - Noise filters recording light

This bit is 1 momentarily when noise filter/differential input data are being written into the NF record buffer for recording to the digital tape. The NF RECORDING light should flash at a rate depending on the NF synoptic sampling time. This bit may be Ø or 1 in the system status data depending on program timing.

ERVLF = B7 - VLF error light

This bit is one when a VLF receiver error has occurred (panics XVLFP, XVLFG, XVLFC).

ERELF = B8 - ELF error light

This bit is on when an ELF receiver error has occurred (panics XELFP, XELFG, XELFC, XBBDO).

ERFIL = B9 - Noise filters error light

This bit is on when a noise filter error or associated data error has occurred (panics XNFLP, XNFLC, XNFSO, XNFDO, XNFPU).

ERMIX = B1Ø - Mixer error light

This bit is on when the mixer/monitor power is off (panic XMIXP).

ERREC = B11 - Analog tape deck error light

This bit is on when an analog deck error has occurred (panics XDKFX, XDFTX, XDK1L, XDK2L, XDK1X, XDK2X).

ERPRG = B12 - Program error light

This bit is on when various program errors have occurred, not covered by the bits above (panics XGARB, XSYSF, XUDVI, XCLKX, XCLKS, XCKLF, XCLKR, XCLKP, XADCP, XCPLP, XNTLT, XTASK, XSKED, XSKEX, XSYCE, XUNKN).

PFAIL = B13 - Power fail light

This bit is on after recovery from a system power failure (panic XPWRF).

```
RSTRT    = B14   - Program restart light

                 This bit is one following a program restart (panics
                 XGARB, XSYSF, XPWRF, XRSTR, XUNKN).

MWAIT    = B15   - Message waiting light

                 This bit is on when any new (unlisted) panic has
                 occurred.  It is cleared when errors have been listed by
                 the error listing task ERRLS.
```

VLF Recording Status (SYCPL+15 = CPLSØ copy):

```
CSVPD    = BØ    - Present synoptic deck

                 This bit indicates the analog deck (Ø for deck 1, 1 for
                 deck 2) to be used for synoptic recording.  It is set by
                 task SYNOP according to the settings of the first deck
                 switch and transfer time switch.

CSVX1    = B1    - Deck 1 in system

                 This is a system configuration bit, set during program
                 installation.  It indicates that analog deck 1 exists and
                 is connected to the coupler.  It is checked by various
                 system tasks for error detection.  This bit will be 1 in
                 all systems with analog recorders.

                   B2-B3 - not used, always Ø

CSVI1    = B4    - Inhibit synoptic deck 1

                 This bit is set by an SCB to inhibit all automatic
                 synoptic recording on deck 1, possibly to preserve the
                 tape for special-schedule recordings.  When set, CSVI1
                 keeps CSVS1 clear.

CSVS1    = B5    - VLF synoptic deck 1

                 This bit is set by the synoptic task SYNOP, depending on
                 the synoptic rate switch, the transfer time switch, and
                 bit CSVPD, to record synoptic VLF data.

CSVP1    = B6    - VLF special-schedule deck 1

                 This bit is set by an SCB to record on deck 1 at special
                 operator-specified times.

CSVR1    = B7    - Deck 1 running

                 This bit is the inclusive-OR of bits CSVS1 and CSVP1, set
                 by task PSNAP.

                   B8    - not used, always Ø

The following bits pertain to deck 2, and function just like
those above.

CSVX2    = B9    - Deck 2 in system
           B1Ø-B11 - not used, always Ø
CSVI2    = B12   - Inhibit synoptic deck 2
CSVS2    = B13   - VLF synoptic deck 2
CSVP2    = B14   - VLF special-schedule deck 2
CSVR2    = B15   - Deck 2 running
```

Broad-band ELF Recording Status (SYCPL+16 = CPLS1 copy):

BØ-B9 - not used, always Ø

CSENS = B1Ø - Record BB ELF NS
CSEEW = B11 - Record BB ELF EW

These two bits are used by the BB ELF data recording task BBDRC to determine which broad-band signals to record on the digital tape. Default operation is normally NS only, but EW only or both may be specified by an SCB if needed. These bits are determined on start-up by the default value CPS1D and the setting of program switch PSWØ.

CSEIN = B12 - Inhibit BB ELF synoptic

This bit is set by an SCB to inhibit all automatic synoptic recording of BB ELF data. When set, CSEIN keeps CSESY clear.

CSESY = B13 - BB ELF synoptic

This bit is set by the synoptic task SYNOP, depending on the synoptic rate switch, to record synoptic ELF data.

CSESP = B14 - BB ELF special-schedule

This bit is set by an SCB to record BB ELF at special operator-specified times.

CSERN = B15 - BB ELF running

This bit is the inclusive-OR of bits CSESY and CSESP, on whenever BB ELF data are being sampled and recorded. It is set be PSNAP.

Noise Filter Recording Status (SYCPL+17 = CPLS2 copy):

CSND1 = BØ - Record DIFF1
CSND2 = B1 - Record DIFF2
CSND3 = B2 - Record DIFF3
CSND4 = B3 - Record DIFF4
CSND5 = B4 - Record DIFF5
CSND6 = B5 - Record DIFF6

These bits are used by the noise filter data processing task NFDPR to determine which differential input signals (if any) to record on the digital tape along with noise filter data. Default operation is normally noise filter data only (all bits Ø), but any of the above can be selected by an SCB if desired. These bits are determined on start-up by the default value CPS2D and the settings of program switches PSW1-PSW3.

CSNIN = B6 - Inhibit NF synoptic

This bit is set by an SCB to inhibit all automatic synoptic recording of noise filter and diff input data.

CSNSY = B7 - NF synoptic

This bit is generated by PSNAP and is just the complement of bit CSNIN.

CSNSP = B8 - NF special-schedule

This bit is set by an SCB to record noise filter data at operator-specified times and rates.

CSNRN = B9 - NF running

This bit is set by PSNAP when CSNSY is 1 and the NF synoptic rate is non-zero (not "OFF"), or when CSNSP is 1 and the NF special-schedule rate is non-zero. That is, it is on whenever noise filter data are being recorded. It will normally be 1.

CSNSØ = B1Ø - NF synoptic rate bit Ø (FSYNØ)
CSNS1 = B11 - NF synoptic rate bit 1 (FSYN1)
CSNS2 = B12 - NF synoptic rate bit 2 (FSYN2)
CSNPØ = B13 - NF special-schedule rate bit Ø
CSNP1 = B14 - NF special-schedule rate bit 1
CSNP2 = B15 - NF special-schedule rate bit 2

Rate bits (CSNSØ-CSNS2 and CSNPØ-CSNP2) encode the sample time thus:

ØØØ	- off (no recording)
ØØ1	- 1Ø seconds/sample
Ø1Ø	- 5 seconds/sample
Ø11	- 2 seconds/sample
1ØØ	- 1 second/sample
1Ø1	- Ø.5 second/sample
11Ø	- Ø.2 second/sample
111	- Ø.1 second/sample (CSNPØ-CSNP2 only)

If both synoptic (CSNSY) [ie CSNIN = Ø] and special-schedule (CSNSP) bits are set, data are recorded at the higher of the two rates specified.

Statistics Recording Status (SYCPL+18 = CPLS3 copy):

CSSVX = BØ - Don't generate VLF statistics

This bit is set by NFDCR as the inclusive-OR of bits CSSVR, CSSVF, CSSVP, and CSSVN. It indicates that a VLF calibration tone is being applied either at the VLF receiver or in the VLF channels of the noise filter, or that the vlf receiver or noise filter power is off or in local cal mode. CSSVX set causes NFDPR to ignore inputs from noise filter channels 7-16 (VLF channels) when calculating statistics data. When calibrations are done or normal hardware status is restored, NFDCR will hold CSSVX on for 1 additional second to allow time for the transient to die away.

CSSEX = B1 - Don't generate ELF statistics

This bit is set as the inclusive-OR of bits CSSER, CSSEF, CSSEP, and CSSEN. It is used like CSSVX above to ignore inputs from noise filter channels 1-6 (ELF channels) when generating statistics data. When calibrations are done or normal hardware status is restored, NFDCR will hold CSSEX on for 1Ø additional seconds to allow time for the transient to die away.

B2-B5 - not used, always Ø

CSSVQ = B6 - Abort VLF noise filter calibration
CSSEQ = B7 - Abort ELF noise filter calibration

These bits are set by NFDCR whenever the noise filter unit power is off or the cal switch is in local mode. (However, they are not cleared by NFDCR when status is ok.) A bit set will cause the noise filter calibration task VNCAL or ENCAL to abort. This is done so as not to save A/D converter zero offsets when the noise filter unit is not under program control. VNCAL/ENCAL will reset the respective bit at the start of a calibration (if status is ok) and check it periodically thereafter.

```
CSSVR   = B8    - VLF receiver off or in local cal mode
CSSER   = B9    - ELF receiver off or in local cal mode
```

These bits are set by NFDCR whenever the respective line receiver power is off or a cal switch is in local mode to inhibit statistics generation.

```
CSSVF   = B1Ø   - VLF noise filter off or in local cal mode
CSSEF   = B11   - ELF noise filter off or in local cal mode
```

These bits are set (together) by NFDCR whenever the noise filter unit power is off or the cal switch is in local mode to inhibit VLF/ELF statistics generation.

```
CSSVP   = B12   - VLF preamp cal in progress
CSSEP   = B13   - ELF preamp cal in progress
```

These bits are set by the preamp calibration tasks VPCAL and EPCAL to inhibit the respective statistics while a cal tone is applied to the preamp.

```
CSSVN   = B14   - VLF noise filter cal in progress
CSSEN   = B15   - ELF noise filter cal in progress
```

These bits are set by the noise filter calibration tasks VNCAL and ENCAL to inhibit statistics generation when the respective calibration sequence is in progress.

****

3.12 System Status Data - Error Words

The system error words SYERØ, SYER1, and SYER2 in the system status data contain a bit for every possible panic. The bit will be set if the corresponding panic has occurred during the status reporting interval, that is, during the previous 1Ø minutes. These bits are cleared every 1Ø minutes after the status record is written, and allowed to accumulate new errors during the next interval. Note that the errors reported here may not correspond exactly to the error lights in coupler word CPLO7 and its copy in the status data, since those bits will stay set until cleared when the operator presses the RESET ERRORS button on the coupler.

The following tables give, for each word, the bit number, the associated panic mnemonic and title, and a description of the conditions which can cause the error:

SYERØ, System Status Error Word Ø:

BØ   XGARB - Garbage panic - FATAL

A garbage panic is triggered by trying to execute memory location Ø as an instruction. Except during interrupt handling, location Ø contains a trap for this purpose. Location Ø is executed by a JMP Ø instruction, whose code is ØØØØØØ (octal), that is, a null word. A garbage panic thus indicates that the program has tried to execute a null word as an instruction. This is a serious error and shows a bug in the stored program. The garbage panic is a fatal panic, meaning that the system will reinitialize RAM memory and restart (also causing panic XRSTR).

B1   XSYSF - System failure - FATAL

The system failure panic means that inconsistent system data has been found somewhere in the program. For example, the task return call .SYSTM/.RTN causes the system to search through the pending task chain to find the task control block belonging to the calling task. If the TCB is not found a system fail panic is generated, since the TCB chain has been damaged in some way. This panic is fatal and will cause a system restart.

B2 XUDVI - Undefined device interrupt

The undefined device interrupt panic is detected by the external device interrupt service routine INTSV when it is unable to identify the device requesting service. This may be a sign of noise on the interrupt bus, but it can also occur when some external devices (such as the A/D converter chassis) are first turned on. Repeated errors of this kind indicate a hardware failure.

B3 XPWRF - Power fail

The power fail panic is detected when the system is first turned on, or when it comes back on after a power failure. The clock controller card has a latch that senses power fail status and is tested at restart.

B4 XRSTR - Program restart

This panic is generated by the system initialization and start-up routine NSTRT during an initial start-up, during a restart from a power failure, and during an error restart following a fatal panic.

B5 XCLKX - Clock stopped

This panic is generated by the internal real-time clock when it times out, and means that no external clock pulses have occurred for at least 4Ø ms. This most likely happened because the operator pressed the STOP button on the clock in preparation for setting it. System operation is disrupted when the external clock is stopped and data sampling and digitizing is halted.

B6 XCLKS - Clock manual time set

This panic records the fact that the SET ENABLE switch on the clock is on, allowing the operator to stop, advance, and retard the clock, and to change individual digits in the day and time. This switch is normally left off to prevent altering the time accidently.

B7 XCLKF - Clock external standard fail

This panic is generated when the external frequency standard connected to the clock is turned off, or runs out of battery power during an extended power failure. When this happens the clock switches to its internal oscillator and keeps running, though with reduced long-term accuracy. The operator must manually reset the standard fail logic in the clock by pressing the clock CLEAR button to use the external standard again.

B8 XCLKR - Clock read error

A clock read error indicates that the system has failed to respond to at least one tick from the clock. This error may occur during system start-up, but it should not occur during normal operation.

B9 XCLKP - Clock phase error

A clock phase error indicates that the previous interval between new second pulses from the clock did not contain exactly 1ØØØ 1-millisecond ticks. This error will occur on start-up, as the system synchronizes itself to the clock, and it will also occur after the clock has been stopped for setting purposes and then restarted.

B1Ø XADCP - A/D converter power off

This panic is trapped by the status check task STSCK when the A/D chassis power is off. This condition will also cause a noise filter sampling start overrun panic XNFSO.

B11 XCPLP - Coupler power off

This panic is trapped by STSCK when the coupler is turned off. When this occurs, coupler input data are invalid.

B12 XVLFP - VLF receiver power off
B13 XVLFG - VLF receiver gain local mode
B14 XVLFC - VLF receiver cal local mode

These three panics are trapped by STSCK. Receiver power off means that no signals are available for processing and recording. Gain in local mode means that the line receiver noise gain switch is in one of the manual positions and the system does not have control over the gain (though the gain is known from the coupler input data). Calibration in local mode means that one or more of the line receiver calibration switches are not in their normal position. The system may or may not be able to make preamp or noise filter calibrations. No VLF statistics will be collected if the VLF receiver power is off or the unit is in local cal mode.

B15 XELFP - ELF receiver power off

SYER1, System Status Error Word 1:

BØ XELFG - ELF receiver gain local mode
B1 XELFC - ELF receiver cal local mode

The preceeding three panics are similar to those for the VLF receiver described above.

B2 XNFLP - Noise filter power off
B3 XNFLC - Noise filter cal local mode

These two panics are trapped by STSCK. Power off means that the noise filter data are invalid. Cal in local mode means that the front-panel calibration switch is not in its normal position - signal data are inhibited and the calibrator attenuation in use is unknown. No noise filter statistics data are collected in either of these two conditions. Turning the power off or switching the cal to local mode will also abort a noise filter calibration sequence already in progress.

B4 XMIXP - Mixer/monitor power off

This panic is trapped by STSCK. The mixer/monitor power is off and analog recordings cannot be made. Note that no other mixer/monitor status bits are checked by the system (ie, which input is being recorded or whether or not the time mark signal is added to the analog record).

B5 XDKFX - Illegal first deck
B6 XDFTX - Illegal transfer time

These panics are generated by STSCK in systems that do not have two analog recorders (that is, in the usual system). An illegal first deck means that the coupler FIRST DECK switch specifies an analog deck not defined in the system. Unless two analog decks are defined, any TRANSFER TIME switch setting other than OFF generates an illegal transfer time panic.

B7 XDK1L - Analog deck 1 not auto mode
B8 XDK2L - Analog deck 2 not auto mode

These two panics are trapped by STSCK only for decks that are defined in the system, and mean that the system does not have control over analog tape recording because the coupler deck control switch for the respective recorder is not in the AUTO position.

B9 XDK1X - Analog deck 1 not in system
B1Ø XDK2X - Analog deck 2 not in system

These two panics are trapped by the analog recorder control tasks TDK1R, TDK1S, TDK2R, and TDK2S, when trying to start or stop an analog deck not defined in the system. The record or stop relays are activated as specified, but the panic signals that an attempt was made to control a non-existent tape deck.

B11 XMTAP - Digital mag tape error

This panic is generated by the digital tape tasks DATRC, NTLOD, and NTFIL when a digital tape error occurs. The system status data does not record the type of error (though it is saved in the variable trap data for examination by the operator). Typical errors are caused by the tape unit being off-line, a missing write ring, or an unrecoverable data error due to dirty or low-quality tape.

B12 XRCDD - Error recording digital data

This error occurs when a task is unable to write data into the mag tape buffer via a .SYSTM/.RCDD call. This usually happens because the buffer is full and has not been dumped to the tape, perhaps because the tape is off-line or because of multiple tape data errors.

B13 XNTLT - No task lead time

The no task lead time panic is generated by the task monitor TKMON when, at the start of a new frame, the monitor finds that a priority Ø, 1, or 2 task is still executing. These tasks must finish in the frame in which they are started for normal operation. A XNTLT panic means that there may be some temporary loss in program task synchronization. This error is usually caused by stopping and restarting the clock, though clock hardware problems may also cause it by making frames occur too quickly. It may occasionally occur when excessive processor time is used correcting digital tape data errors.

B14 XTASK - Error when creating TCB for task

This panic is trapped by various tasks when they are unable to pend some new task over which they have control, usually because that task is already running. This error usually occurs when the seconds programmer PRGMR tries to pend a task already running, such as a noise filter calibration task when the system is started up just before the beginning of an hour, or occasionally when the clock time is changed. (Since NF cal tasks are run both on system start-up and on the hour, one pended on start-up may not have finished before the hour is up.)

B15 XSKED - Error when creating SCB

This panic is not used at present, since no tasks except the console schedule command task SCCMD create SCB's, and that task handles errors by alerting the operator directly.

AD-A161 148 AN AUTOMATIC SYSTEM FOR GLOBAL MONITORING OF ELF AND 2/2
VLF RADIO NOISE PHEN (U) STANFORD UNIV CA SPACE
TELECOMMUNICATIONS AND RADIOSCIENCE LA B R FORTNAM
UNCLASSIFIED JUN 85 E450-1 N00014-81-K-0382 F/G 17/2 1 NL

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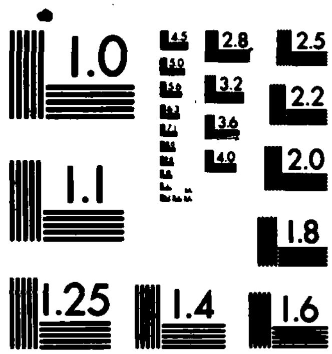

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SYER2, System Status Error Word 2:

BØ XSKEX - Error when executing SCB

This panic is trapped by PRGMR when an illegal action is detected in an SCB to be executed. This usually occurs when trying to pend an alarm or calibration task which is already running.

B1 XNFSO - Noise filter sampling start overrun

This panic is generated by the snap programmer PSNAP when it initiates noise filter and differential input data sampling and finds that the corrected data table start count is greater than the block count. This means that data are not being sampled and corrected by the data correction task NFDCR. This error usually means that the A/D converter is not working. Either it is off or the 3 kHz sync pulse it needs from the clock is missing. If this error occurs, PSNAP calls the A/D converter reset routine RTPRS to try to resynchronize the conversion process.

B2 XNFDO - Noise filter data overflow

This panic is trapped by the data correction task NFDCR when it finds that a new set of NF/DIFF samples has been started before it has had time to correct the previous set. Some of the samples will be lost.

B3 XNFPU - Noise filter data processing underrun

This panic is trapped by NFDCR when the corrected data buffer overflows because the data processing task NFDPR has been unable to process it fast enough. Some noise filter and differential data are lost.

B4 XBBDO - BB ELF data overflow

This error is trapped by the broad-band ELF data recording task BBDRC when the broad-band ELF buffers overflow because data are not being written out to the tape buffer as fast as they are coming in. Some data are lost.

B5 XSYCE - System call error

This panic is trapped at various places in the program to report an error return of unspecified kind from a system call. The most common occurrence will be trapped in STSCK due to a digital tape timeout error when the system is trying to correct tape data errors and denies tape access to STSCK. This error is not very important.

B6 XUNKN - Unknown panic - FATAL

This panic occurs when a call is made to the trap handler with an unknown panic code. This is a serious error and may indicate a severe hardware problem or the erasure of some of the program in EPROM. This panic is fatal, and causes the system to try to restart itself.

B7-B15 - not used, always Ø

****

3.13 Operator Message Logs

Operator message logs are text strings that the operator has typed into the system on the terminal and caused to be recorded on digital tape. The format of an operator message log is as follows:

```
6                 - Message log data code
<block count>     - total number of words in this record
<time word 0>     - time of message recording
<time word 1>
<time word 2>
<text
  ...>
```

The text is composed of ASCII characters, two characters per word, packed left-right (that is, in serial order in the tape record). Each line in the text contains at most 80 characters and is terminated by a carriage-return and a line-feed (82 bytes max total per line). The record contains at most 21 lines of text (1722 characters). The end of the message is terminated by a null byte.

****

3.14 Analog Tape Use Versus VLF Synoptic Rate

A 10-1/2 inch reel of tape contains 3600 feet of analog tape. At 7.5 ips the tape can record 96 minutes of data on each side (ie, edge), assuming only one channel is being recorded. (If two channels are being recorded with half-track heads, the full width of the tape is used and it can be recorded in one direction only.) At 3.75 ips the tape can hold twice as much, or 192 minutes per side. The following table lists the number of days of single-channel recording that can be made on one side of a tape versus the VLF synoptic rate and the tape speed.

Tape Use in Days/Side - Single-Channel Recording

Speed \ Rate	1/60	1/30	1/15	1/5
7.5	4.0	2.0	1.0	0.33 (8 hours)
3.75	8.0	4.0	2.0	0.67 (16 hours)

This table can be used to determine the intervals between tape changes. Note that when one side of a tape is finished, the operator must manually swap the reels to record on the other side. Tape consumption can be estimated by noting that a tape for single-channel recording has two sides, and so a new tape will need to be mounted every second interval.

****

3.15 Digital Tape Use Versus Recording Rates

The following discussion should enable investigators to estimate the recording time per tape and the tape consumption for the digital tape recorder. This discussion assumes that data are recorded in high density (1600 bpi PE). At low density (800 bpi NRZI) tape consumption will be twice that given below, and tapes will only last half as long.

The calculation of tape consumption involves several factors:

1. At high density, each 10-inch reel of tape (2400 feet) can hold about 4900 records, each containing 4096 16-bit words.

2. Every minute, an NF/DIFF statistics data record is written to the tape, which requires 36 words.

3. Every 1Ø minutes, a system status record is written to the tape, requiring 92 words.

4. NF/DIFF data is sampled at a rate depending on the sampling time (1Ø, 5, 2, 1, Ø.5, Ø.2, or Ø.1 seconds/sample). The number of inputs recorded in each sample set ranges from 16 if no differential inputs are included, to 22 if all 6 differential inputs are used. The size of an NF/DIFF data record, and the number of sample sets it contains, also depends on the number of diff inputs used. The following table gives the number of sample sets per record, the size of the data record, and the number of data records per tape record (plus the amount of blank space left at the end) for the different possible numbers of differential inputs recorded:

Number of Diff's	Sets/Record	Data Record Size	Data R's/Tape R (+ Unused Words)
Ø	15	247 words	16 (+144)
1	14	245	16 (+176)
2	13	241	16 (+24Ø)
3	12	235	17 (+1Ø1)
4	12	247	16 (+144)
5	11	238	17 (+5Ø)
6	1Ø	227	18 (+1Ø)

5. Broad-band ELF records each contain 5Ø5 words, representing one-half second of data. For each BB ELF input (NS or EW) being recorded, one tape record is generated every 4 seconds. The total amount of BB ELF data recorded depends on the ELF synoptic rate (1, 2, 4, or 12 minutes per hour) and the number of inputs recorded (1 or 2).

6. The size of message log data records varies depending on the amount of text the operator wishes to write. However, unless we find some very prolific authors, message logs will have only an insignificant effect on tape consumption.

7. The efficiency of recording, that is, the ratio of space in tape records used for data compared to that left as zeros at the end of each record, depends on how well these different-sized data records can be packed into a tape record. Note that tape records are fixed in size, all 4Ø96 words long. If we were only recording NF/DIFF data records with 16 NF magnitudes and no DIFF inputs, each data record would be 247 words long, and we could pack 16 data records in each tape record. But there would be 144 words left at the end of the tape record which would be filled with zeros and would represent wasted space. However, some of the time this extra space could be used for an NF/DIFF statistics or a system status record, with an increase in efficiency.

Based on the considerations outlined above, we can make some estimates of the tape used for different recording schedules. The following tables give consumption in tapes per day for the various types of data records. Note that the figures in these tables are not exact, since the packing efficiency is a non-linear function of the various possible schedules, but the errors will be only a few percent.

1. NF/DIFF statistics data and system status recordings require Ø.ØØ75 tapes/day.

2. NF/DIFF data recording consumes tape as shown below in tapes/day depending on the number of differential inputs recorded and the

sampling time:

Nr of Diff's	Sampling Time (seconds/sample) 10	5	2	1	0.5	0.2	0.1
0	.00735	.0147	.0367	.0735	.147	.367	.735
1	.00787	.0157	.0396	.0787	.157	.396	.787
2	.00848	.0170	.0424	.0848	.170	.424	.848
3	.00864	.0173	.0432	.0864	.173	.432	.864
4	.00918	.0184	.0459	.0918	.184	.459	.918
5	.00943	.0189	.0471	.0943	.189	.471	.943
6	.00980	.0196	.0490	.0980	.196	.490	.980

3. Each BB ELF input recorded (NS or EW) consumes tape as shown below in tapes/day versus the synoptic rate:

Synoptic Rate	1/60	1/30	1/15	1/5	Continuous
	.0735	.147	.294	.882	4.41

From these tables we can calculate the length of time between tape changes as 1/(sum of consumptions). For example, when recording NF/DIFF data with no differential inputs and a sampling time of 1 second/sample, plus the BB ELF NS input with a synoptic rate of 1/30, the consumption is:

```
  0.0075   - statistics and system status
+ 0.0735   - NF/DIFF data
+ 0.147    - BB ELF
---------
  0.2280   - Total consumption, tapes/day
```

so each tape will last 1/0.2280 = 4.39 days, approximately.

The following tables list recording time per digital tape from some common recording schedules.

Tape Use in Days/Tape - 1 BB ELF Input, NF/DIFF at 2 Seconds/Sample

BB ELF Synoptic Time / Nr of Diff Inputs	off	1/60	1/30	1/15	1/5
0	22.6	8.50	5.23	2.96	1.08
1	21.2	8.29	5.15	2.93	1.08
2	20.0	8.10	5.08	2.91	1.07
3	19.7	8.05	5.06	2.90	1.07
4	18.7	7.88	4.99	2.88	1.07
5	18.3	7.81	4.96	2.87	1.07
6	17.7	7.69	4.91	2.85	1.07

(tables continued overleaf -->)

Tape Use in Days/Tape - 1 BB ELF Input, NF/DIFF at 1 Second/Sample

BB ELF Synoptic Time / Nr of Diff Inputs	off	1/60	1/30	1/15	1/5.
0	12.3	6.47	4.39	2.67	1.04
1	11.6	6.26	4.29	2.63	1.03
2	10.8	6.03	4.18	2.59	1.03
3	10.6	5.97	4.15	2.58	1.02
4	10.1	5.79	4.06	2.54	1.02
5	9.82	5.70	4.02	2.53	1.02
6	9.48	5.59	3.96	2.50	1.01

Tape Use in Days/Tape - 1 BB ELF Input, NF/DIFF at 0.5 Second/Sample

BB ELF Synoptic Time / Nr of Diff Inputs	off	1/60	1/30	1/15	1/5
0	6.47	4.39	3.32	2.23	0.96
1	6.08	4.20	3.21	2.18	0.96
2	5.63	3.98	3.08	2.12	0.94
3	5.54	3.94	3.05	2.11	0.94
4	5.22	3.77	2.95	2.06	0.93
5	5.09	3.70	2.91	2.04	0.93
6	4.91	3.61	2.85	2.01	0.92

Appendix B. Data Processing Examples

This appendix contains several subroutines written in C for the STAR lab VAX/VMS computer to read data from digital tapes. The subroutines **getuword** and **getsword** can be incorporated into any program to extract data from the tapes. It is important that the correct subroutine be used for reading any particular data word, since the tapes contain a mixture of signed and unsigned integers. **getuword** will interpret the incoming 16-bit word as an unsigned integer when converting it to a 32-bit integer for the VAX, while **getsword** will interpret the incoming word as a signed 16-bit integer. The only way to tell the difference while reading the tapes is to keep track of the current block type and word count.

```
/* TAPEREAD.C

    This program contains subroutines to read data tapes
    written by the ELF/VLF Radiometer system in
    Data General format.

    The main program scans the tape, reading the data code
    and block length from each data block, and printing them
    on the terminal.  If a block with data code 6 (Operator
    Messages) is found, the entire block is read and
    displayed on the terminal.

    After the tape is mounted on the tape drive,
    issue the commands:

        $ all mfa0:
        $ mount/block=8192/record=8192/foreign mfa0:

    This will allocate the tape drive to your process, then
    inform the computer that the tape is organized in 8 Kbyte
    blocks, and that it is not ANSI-labelled.

        Bruce Fortnam,  November '84                       */
```

```
#include stdio

        /* Data code definitions: */

#define DKEOB 0     /* Data code 0 means end of tape block  */
#define DKNFD 1     /* Noise filter/diff input data         */
#define DKNFS 2     /* Noise filter/diff input statistics   */
#define DKELN 3     /* Broadband ELF NS data                */
#define DKELE 4     /* Broadband ELF EW data                */
#define DKSTS 5     /* System status data                   */
#define DKLOG 6     /* Message log data                     */

main()
{
    FILE *tapefile;
    int blocknum, timecode, i;
    unsigned short dcode, count, daynum, getuword();

    if ((tapefile = fopen("MFAO:", "r")) == NULL)
        error("Unable to open MFAO: for input");
    else
        blocknum = 1;
        dcode = getuword(tapefile);  /* Get first data code */
        while (feof(tapefile) == 0)  /* While not end-of-file */
        {
            if (dcode != DKEOB)      /* Check for end-of-block */
            {
                count = getuword(tapefile);
                daynum = getuword(tapefile);
                timecode = (getuword(tapefile)<<16)
                    + getuword(tapefile);

                printf("Data block %d: dcode = %d, count = %3d, ",
                        blocknum++, dcode, count);
                printf("day = %d, time = %d\n", daynum, timecode);

                if (dcode == DKLOG)  /* Print message on terminal */
                    printlog(tapefile, (count - 5));
                else                 /* Skip rest of data block   */
                    for (count -= 5; count > 0; count--)
                        getuword(tapefile);
                dcode = getuword(tapefile);  /* Get next data code */
            }
            else        /* End of tape block */
            {
                printf("Data code = %d; End of tape block\n\n", dcode);
                while ((feof(tapefile) == 0) & (dcode == 0))
                    dcode = getuword(tapefile); /* Skip zeroes */
            }

        }       /* Continue Loop */

    fclose(tapefile);
}
```

```
/*****************************************************************/

error(errstring)        /* Print error message and die */
char *errstring;
{
    printf(errstring);
    printf("\n");
    exit(1);
}

/*****************************************************************/

unsigned short getuword(fp)
                    /* Get an unsigned 16-bit word from file fp */
FILE *fp;
{
    unsigned char c1,c2;  /* Interpret incoming bytes as unsigned */
                          /* Swap bytes and return unsigned short */
    return(((c1 = getc(fp))<<8) + (c2 = getc(fp)));
}

/*****************************************************************/

short getsword(fp)    /* Get a signed 16-bit word from file fp */
FILE *fp;
{
    unsigned char c1,c2;  /* Interpret incoming bytes as unsigned */
                        /* Swap bytes and convert to signed short */
    return((short) (((c1 = getc(fp))<<8) + (c2 = getc(fp))));
}

/*****************************************************************/

printlog(fp, wcount)
              /* Print a message log data block on the terminal */
FILE *fp;
int wcount;
{
    char c;
    putchar('\n');       /* Start a new line */
    for (; wcount-- > 0;)
    {
        if ((c = getc(fp)) != 0) putchar(c);  /* Print left char  */
        if ((c = getc(fp)) != 0) putchar(c);  /* Print right char */
    }
    printf("\n\n");      /* Skip a line */
}

/*****************************************************************/
```

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