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# RESEARCH DIRECTED TOWARD THE STUDY OF RAPID FLUCTUATIONS OF THE GEOMAGNETIC FIELD

By

Rev. Daniel Linehan, S.J.

Contract No. AF19(628)211



FINAL REPORT

PROJECT 8601
TASK 860103



31 October 1962

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Prepared

for

GEOPHYSICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

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# FOREWORD

This report represents contractor efforts expended following the expiration of contract AF19(604)5569, of which this type of work was a part. The major part of the work effort of the previous contract was continued under contract AF19(628)236 by the same contractor, while this portion was segregated into the present contract. With the expiration of the present contract, the contractor will continue his other efforts in the field of geomagnetism but will not continue this line of research in the same fashion. Since the inception of this contract certain types of magnetometers have become available which suggest to the contractor that equipment already in place at his facility should provide interesting information of the same type as was available from the different approach described in this report. In any case, the contractor feels that research in this area of investigation should be continued.

## ABSTRACT

Research was directed toward the study of rapid fluctuations of the geomagnetic field. An investigation was made of the characteristics and origins of the natural magnetic field fluctuations in the frequency range of approximately 0.01 to 50 cps with particular emphasis on frequencies from about 0.1 to 3 cps. Field records were made of the fluctuations. Early records obtained for analysis and a study into the relationship of the results to magnetic disturbances and other geological phenomena were provided to Air Force Research Cambridge, Terrestrial Science Group.

The work described in this report covers the hardware phase of the installation of the measurement facilities at Strawberry Hill Field site Concord, Massachusetts. A description of the instrumentation and early measurements taken are given. Full time data gathering of the 0.01 to 3 cps geomagnetic fluctuations is in progress at the conclusion of this contract.

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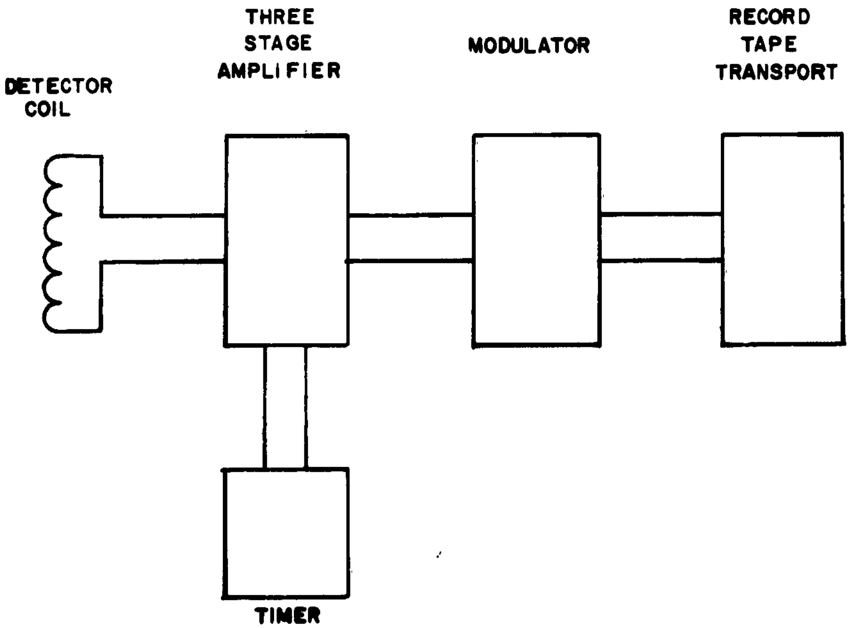
## INTRODUCTION

The basic instrumentation for the investigation of the characteristics and origins of the natural magnetic field fluctuations was designed and implemented at the Fort Devens facility. This has been detailed in the report AFCRL #62-1143 "Final Report Contract AF19(604)5569. The sub audio and RLF system diagrams electronics, detector coils and recording system is briefly reviewed in Figure I through 6. Due to the noisy environment of Ft. Devens and the hazards of military training activities, uninterrupted scientific data collection was a difficult process. The whole installation was then moved to Strawberry Hill, Concord, Mass. where a quieter and a controlled scientific environment was possible.

This report discusses the relocation of the scientific site, the installation and calibration of the new site and reviews preliminary records obtained. The primary goal of preparing and installing a new site was achieved. The system is producing records, data from which are compressed in this report for cursory evaluation.




SUB-AUDIO SYSTEM BLOCK DIAGRAM

figure No. 1

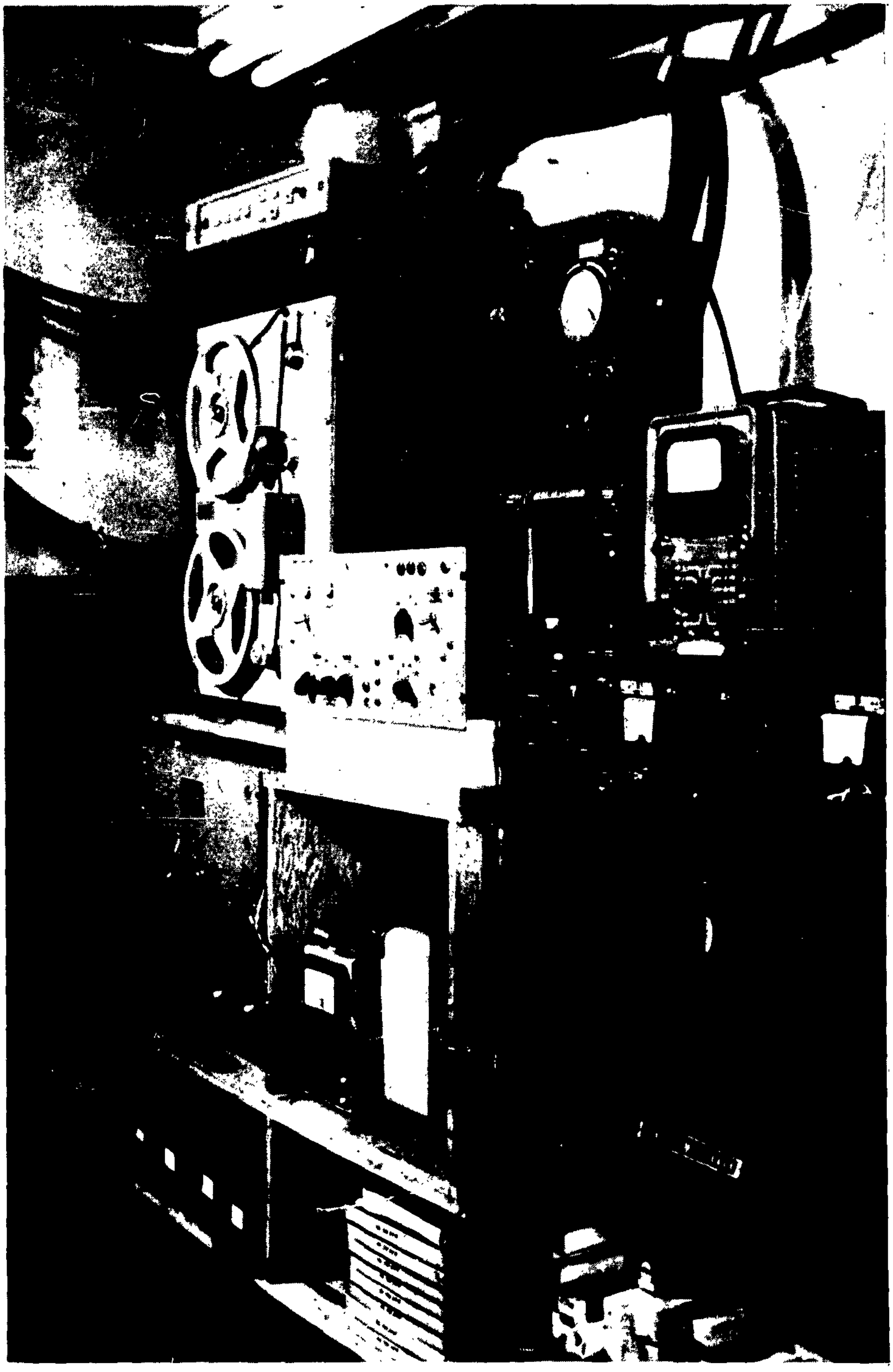


Figure 2 Sub-Audio System Electronics - Ft. Devens

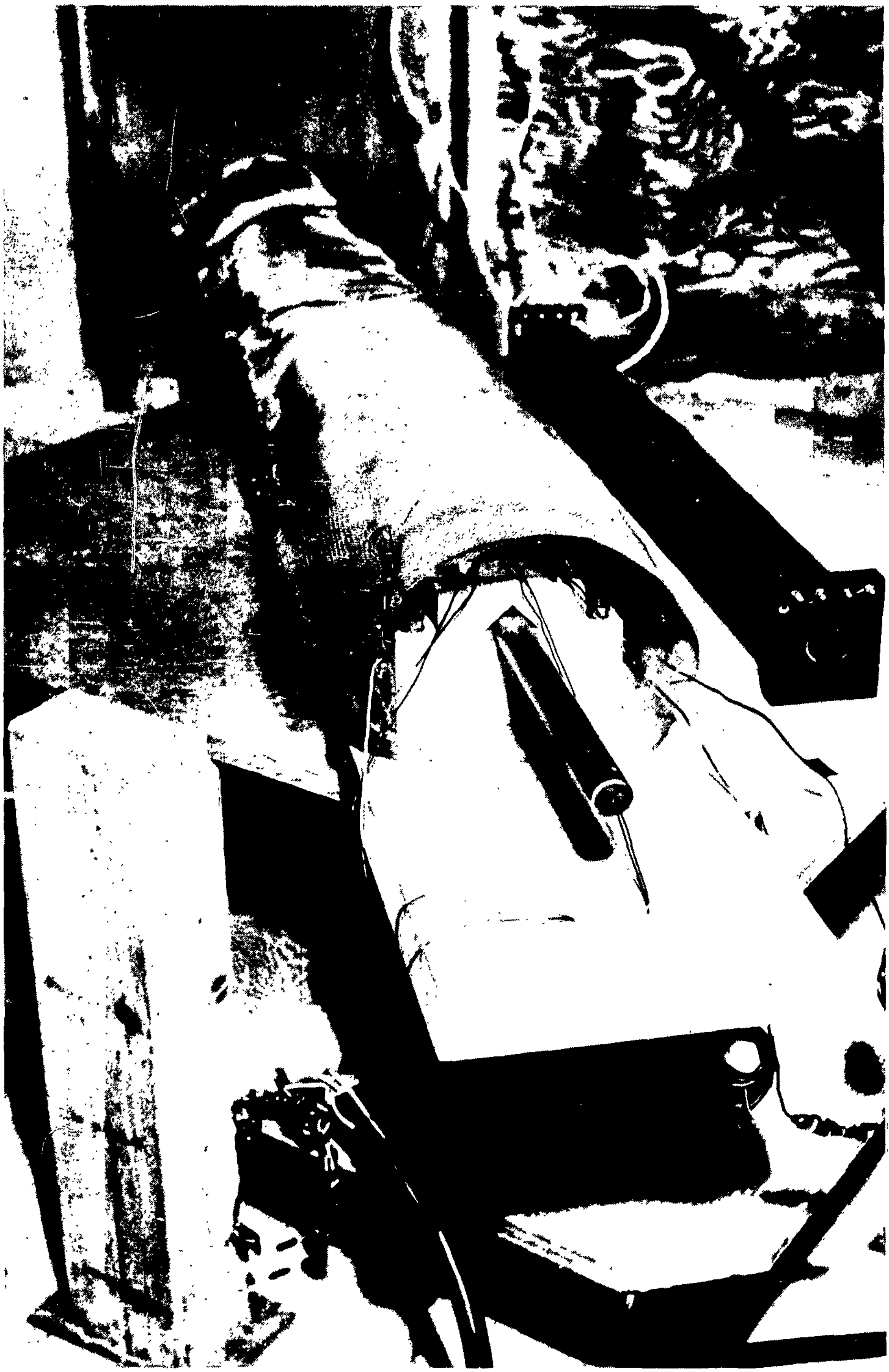


Figure 3 Core Type Low Frequency Variation Detector Coils - Ft. Devens

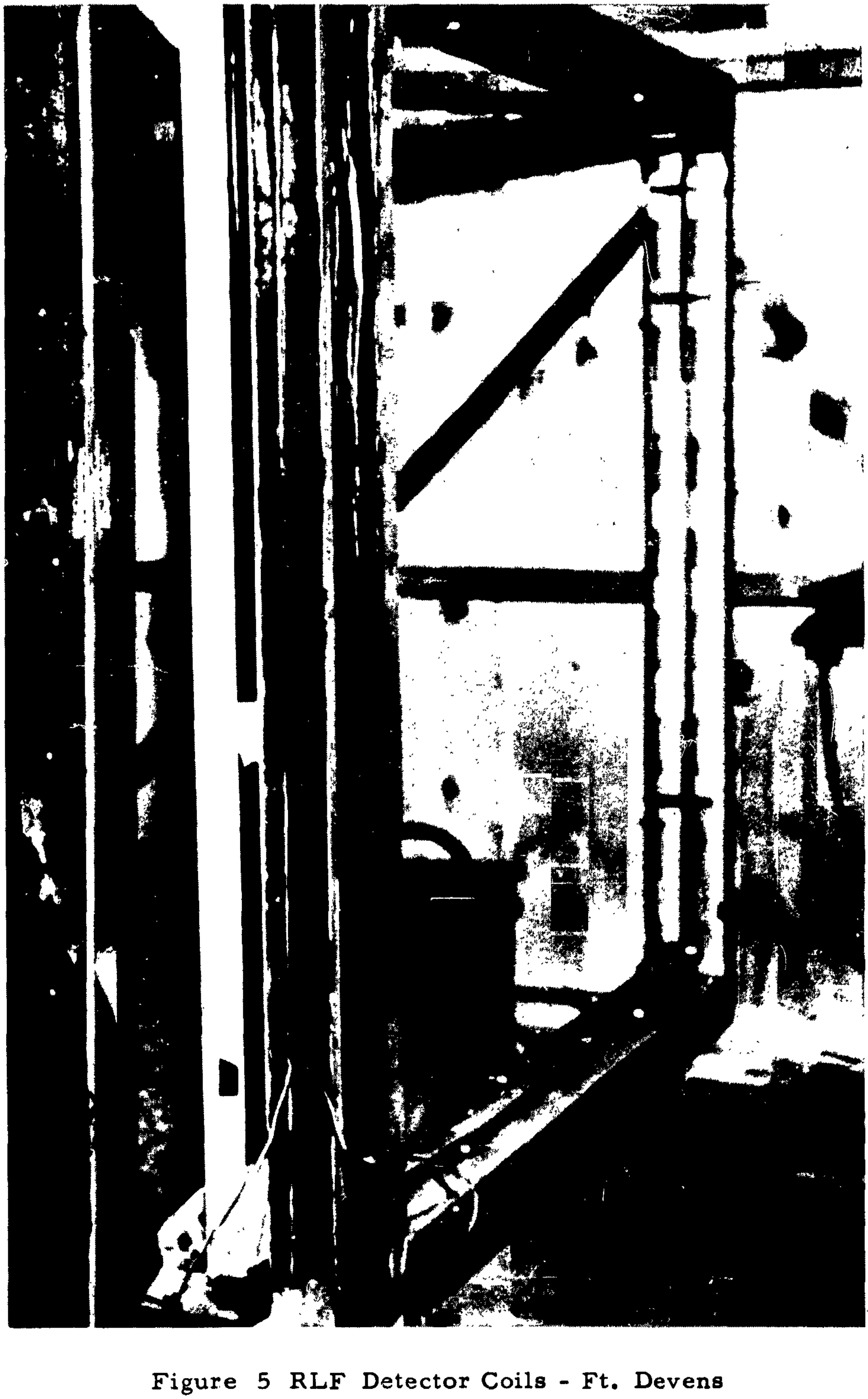


Figure 5 RLF Detector Coils - Ft. Devens

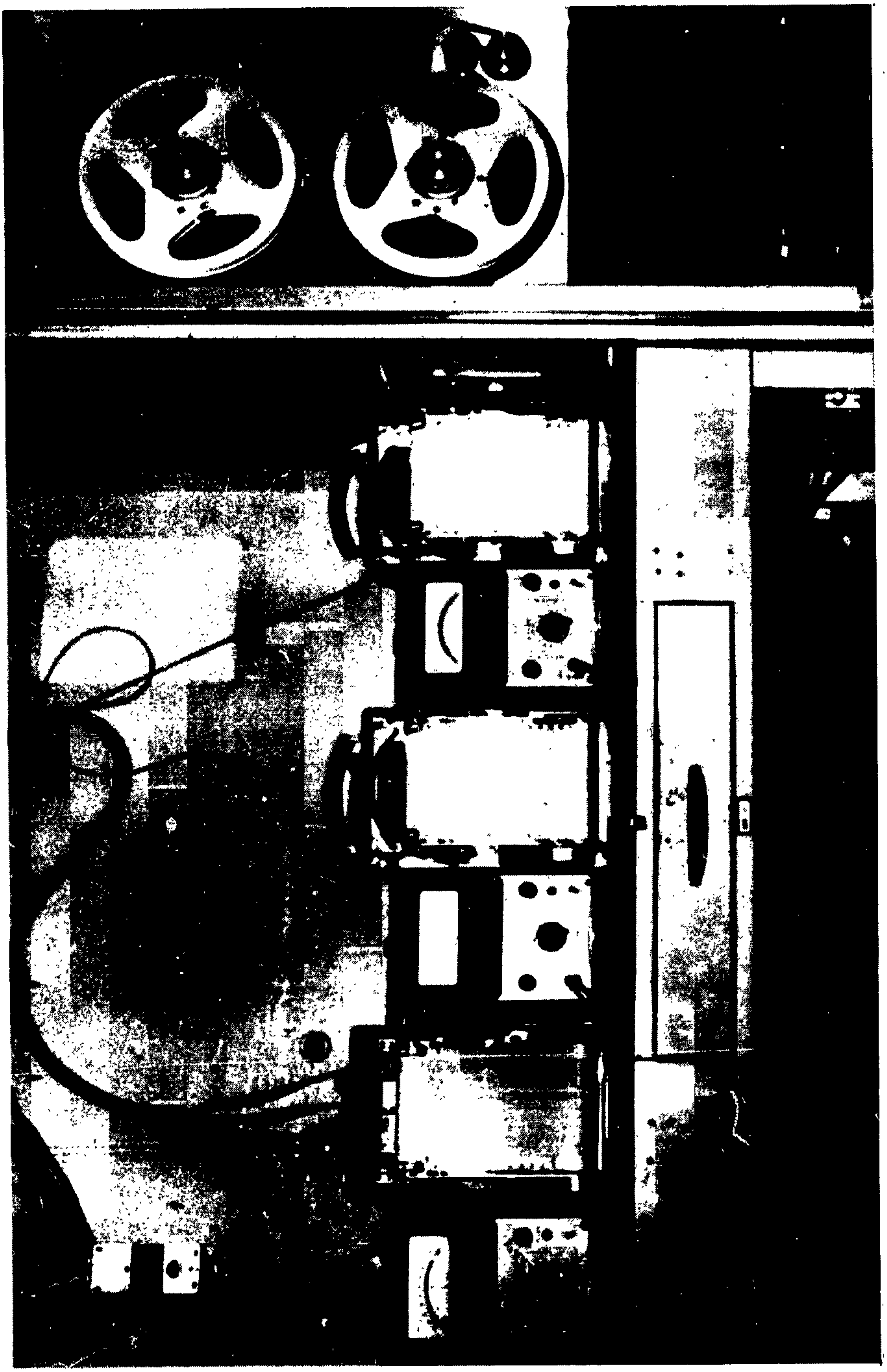
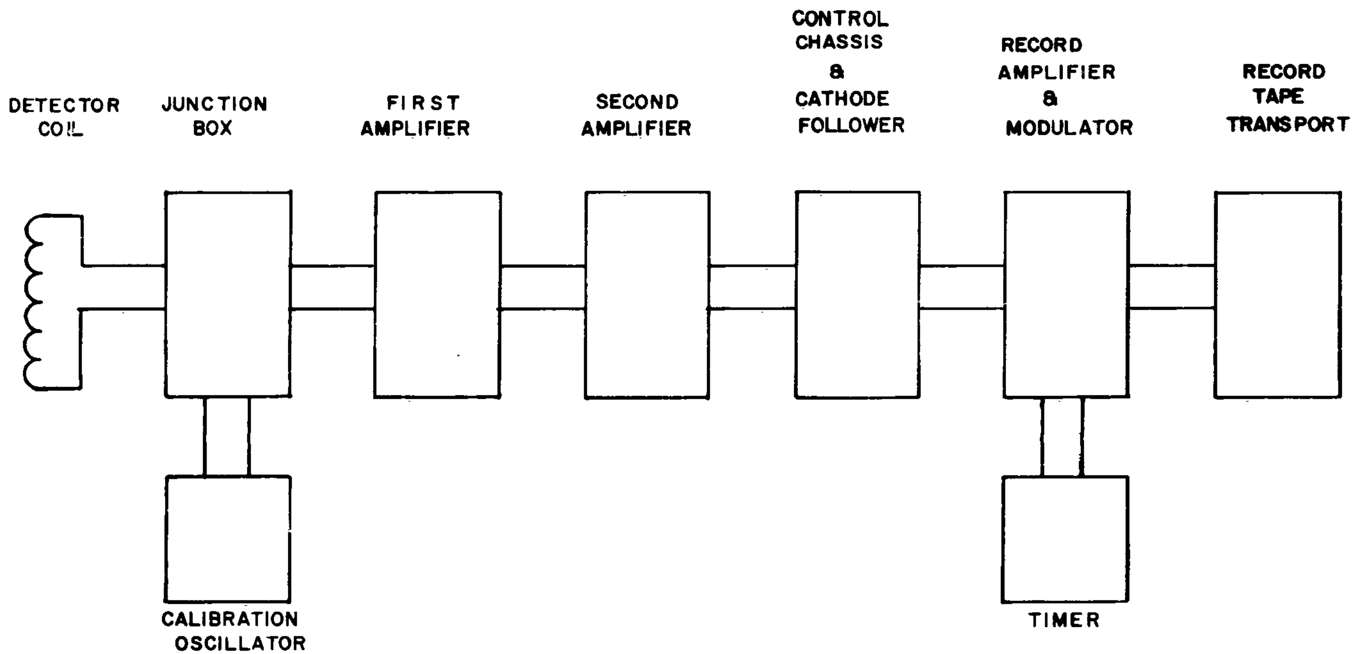


Figure 6 Low Frequency Variation Electronics - Ft. Devens




RLF SYSTEM DIAGRAM

figure No. 4

## DISCUSSION

### 1.0 Establishment of the Field Installation

A field installation was established at Strawberry Hill, Concord, Massachusetts, for the measurement of natural geomagnetic field fluctuations in the RLF range i. e., the frequency range from approximately 0.01 to 3 cycles per second.

Two square areas 100 yards apart were cleared; one, about 125 feet on a side, to accommodate five detector installations (two north-south, two east-west, and one vertical); and another, about 60 feet on a side, to accommodate two instrument vans. The detector area is large enough for a 10,000 feet square ground loop to be installed also.

It is essential that the detectors be located as far as possible from man-made noise and protected from natural noise. Therefore, the AC power was brought into the instrument vans underground to keep the 60 cycle noise low. In addition, the five detector installations were arranged so the mutual inductances among the detectors are satisfactorily low and interaction among detectors, therefore, negligible.

Motion of the detectors in the earth's magnetic field also produces noise. Extremely small rotations in a field of 60,000 gammas or so can be equivalent to signals of several milligammas. Consequently the detector installations were designed to minimize vibrational motion due to microseisms of both natural and man-made origins.

Four concrete piers 6.5 feet long, 3 feet wide and 7 feet deep were poured to support the horizontal component detectors, and one pier 6.5 feet long, 4.5 feet wide and 7 feet deep, to support the vertical detector. Loose fill was placed around the piers from the bottom of the excavation up to a level about 3 feet below the ground surface. On this back fill, concrete footings about 2 feet wide and 4 inches thick were poured around the piers, but separated from them by 6 inches. Concrete block foundations were erected on the footings to extend 2 feet above ground level. The spaces between piers and foundation were back-filled to ground level with sand as were the remaining excavations outside the foundation.

Two low profile detector sheds were built on two of the foundations, one to cover a north-south detector and the other to cover an east-west detector. The remaining foundations for horizontal components were capped temporarily to protect them from the weather. A larger prefabricated shed, to cover the vertical component detector, was placed on its foundation. Thus the detector sheds and their foundations are not in direct physical contact with the pier. The lack of contact greatly reduces the mechanical vibration transmitted to the detectors. Of course, all building materials and hardware in the detector installations are nonmagnetic.

## 2.0 The RLF Recording System

The RLF recording system provides magnetic tape recordings of three mutually perpendicular components (north-south, east-west, and vertical) of the naturally occurring geomagnetic field fluctuations in the frequency range from approximately 0.01 to 3 cycles per second. Six channels are recorded, two sensitivities on each of the horizontal components, one sensitivity on the vertical component, and one timing information channel. A block diagram of the RLF recording system is shown in Figure No. I.

The detectors are induction coils which have an instantaneous voltage induced in them which is proportional to the time rate of change of the ambient geomagnetic field. The induced voltages are of the order of a few microvolts or less because the rate of change of the field is small, i. e., generally less than one gamma per second.

Two different types of detectors have been used in the RLF System; one type for the horizontal component detectors and another for the vertical. Both types are protected against thermo-electric and chemoelectric voltages by being tightly sealed in epoxy resin. The horizontal detectors are electrostatically shielded by a copper screen and placed in well insulated wooden boxes. The vertical detector has its metal frame grounded but has no insulated box surrounding it because of its size and shape.

2.1 Horizontal

The horizontal detectors are cylindrical mu-metal core coils consisting of three sections of 60,000 turns each connected in series. Thus each horizontal detector has 180,000 turns of No. 25 formvar magnet wire. The mu-metal cores are 7/8 inches in diameter and 58 inches long providing an effective permeability, u, of 900, which is about as high as can be used without saturation in the earth's field.

The effective area of the core (uA) is 3450 $cm^2$. The effective area of the detector coil (NuA) is then $6.21 \times 10^8$ $cm^2$. This corresponds to a sensitivity of approximately 450 $uv/\gamma/cps$ expressed in terms of sinusoidal field changes; that is, a sinusoidal signal having an amplitude of one gamma and a frequency of one cycle per second would induce a sinusoidal emf having an amplitude of 450 microvolts. At a frequency of 0.01 cps, the same amplitude signal would induce an emf one hundred times smaller. These sensitivities give the emf induced in the detector. They also give the potential difference which is observed at the detector terminals if the detector is terminated in a sufficiently high impedance.

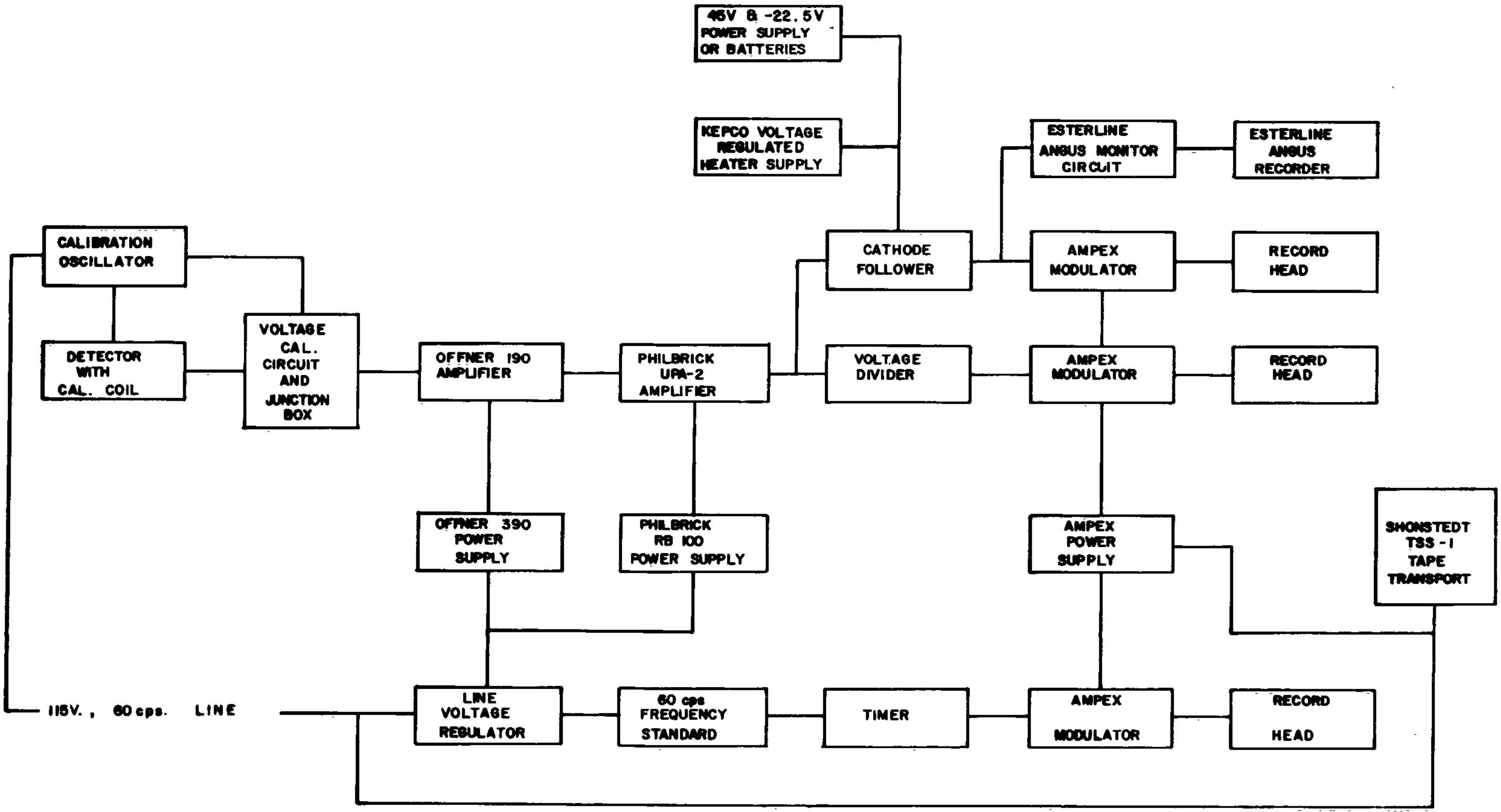
A few turns of wire are wound around the plastic spacers of the detector coil forms for calibration coils. The detectors and cover are mounted together rigidly, but not in direct contact with one another, before they are placed in their insulated boxes.

## 2.2 Vertical

The vertical detector is an air core coil 49.7 inches square consisting of five sections of 5000 turns each of No. 26 formvar magnet wire connected in series. The effective area of this 25000 turn detector is 3.984 X $10^8 cm^2$ which corresponds to a sensitivity of about 250 u v/γ/cps in terms of sinusoidal field change i.e., a one gamma signal gives 250 microvolts at one cycle per second.

The five sections of the detector are bolted together to form a rigid unit weighing nearly 600 pounds. The calibration coil for this detector is mounted on the detector shed and is coaxial with the detector.

The detectors are separated from the instrument vans by 300 feet long electrostatically shielded cables. The cables terminate in a thermally insulated junction box which contains a tuning capacitor and a voltage calibration circuit for each component. See Figures 7 and 8. The tuning capacitors reduce the 60 cps noise picked up by the detectors despite precautions taken against this source of noise. The cable capacitance is not negligible and must




BLOCK DIAGRAM OF RLF RECORDING SYSTEM

figure No. 7

be considered when the tuning capacitors are selected. The voltage calibration network enables a signal of known voltage to be introduced ahead of the first amplifier for comparison with natural signal, noise, or current calibration.

## 2.3 Amplification

The first stage amplifier for each component is a low noise, Offner 190 DC chopper amplifier which has a flat frequency response and a maximum gain of about 1200. The Offner input impedance is around 100,000 ohms. Slight loading of the detectors by the amplifiers does occur, especially in the horizontal components.

There is an LC filter in the Offner output which has no significant effect upon the frequency response of the RLF System but does contribute to the source impedance seen by the second stage amplifier. The DC resistance of the filter inductance L, which is 2000 ohms, must be included in the gain determination for the second stage amplifier because its gain depends upon the ratio of the feedback impedance to the source impedance.

The Offner amplifiers are sensitive to line voltage fluctuations beyond the regulated range of their own Model 390 power supply. Therefore, this power supply is operated from a Sorensen Voltage Regulator to realize the low noise characteristics of the amplifiers. The Offner amplifiers are operated in a separate van away from the rest of the

RLF System and all other instruments except the Sorensen Voltage Regulator. Once again the reason for such isolation is to reduce 60 cps pickup ahead of the Offner.

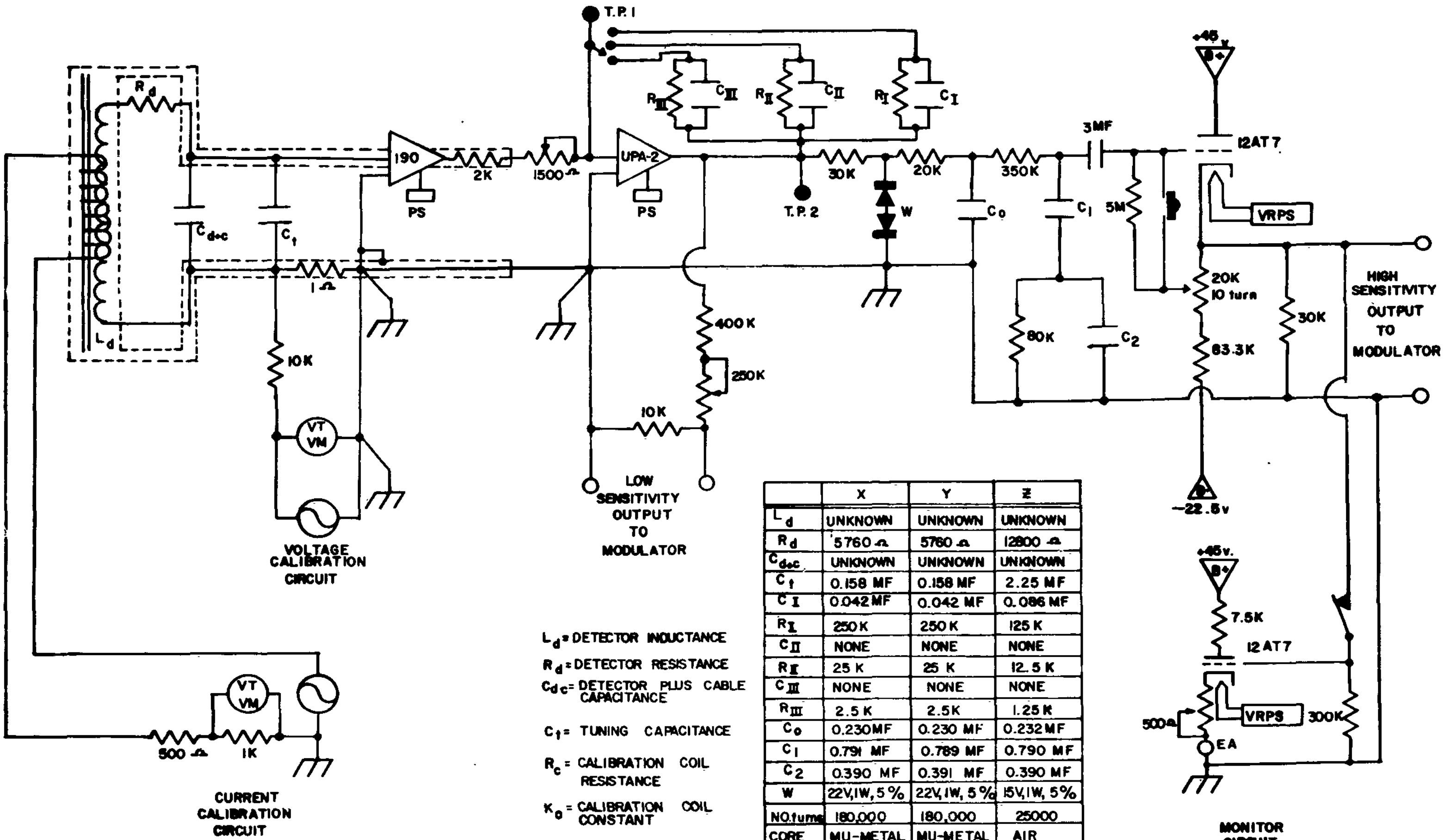
The importance of keeping noise from all possible sources to a minimum ahead of the first stage of amplification cannot be overemphasized if a suitable signal to noise ratio is to be achieved. The usual sources of noise such as bad tubes, bad components, and poor connections must be guarded against throughout the system as well. The thermo-electric voltages generated by temperature differences between contacts of dissimilar metals in the systems circuitry are inevitable because of the soldered joints. But by thermally insulating these soldered connections, especially ahead of the Offners, the external temperature changes can be made to produce only very slow changes in the temperature of the joints and then the corresponding voltages will not have appreciable components in the RLF range.

Electrostatically shielded cables about 30 feet long separate the first and second stage amplifiers.

The second stage amplifier for each component is a Philbrick Utility Packaged Amplifier Model UPA-2 which embodies a USA-3 operational, chopper stabilized, DC amplifier. The overall characteristics of the second stage of amplification are determined by an external feedback network entirely. The UPA-2 activates this network. As previously mentioned, the dynamic gain of the amplifier is simply the ratio of the feedback impedence to the source impedance.

In the RLF System the UPA-2 is used as an amplifier-attenuator with an RC filter which acts like a low pass filter, i.e., the signal amplitude decreases as the signal frequency increases (see Fig. No. 8). Continuous gain control is obtained by adding a 1500 ohm variable resistance in series with the 2000 ohm source impedance mentioned above. With minimum attenuation, the range of gain for the horizontal component channels is from 70 to 125, and for the vertical, from 35 to 62. These ranges can be reduced by increasing the attenuation by factors of 0.1 and 0.01. The RC filter in the feedback of the UPA-2 is present to reduce the 60 cps voltage out of the UPA-2.

The low sensitivity horizontal component channels are taken directly from the UPA-2 output. They consist of




| | X | Y | Z |
|---|---|---|---|
| $L_d$ | UNKNOWN | UNKNOWN | UNKNOWN |
| $R_d$ | 5760 Ω | 5760 Ω | 12800 Ω |
| $C_{d+c}$ | UNKNOWN | UNKNOWN | UNKNOWN |
| $C_t$ | 0.158 MF | 0.158 MF | 2.25 MF |
| $C_I$ | 0.042 MF | 0.042 MF | 0.086 MF |
| $R_I$ | 250 K | 250 K | 125 K |
| $C_{II}$ | NONE | NONE | NONE |
| $R_{II}$ | 25 K | 25 K | 12.5 K |
| $C_{III}$ | NONE | NONE | NONE |
| $R_{III}$ | 2.5 K | 2.5K | 1.25 K |
| $C_0$ | 0.230 MF | 0.230 MF | 0.232 MF |
| $C_1$ | 0.791 MF | 0.789 MF | 0.790 MF |
| $C_2$ | 0.390 MF | 0.391 MF | 0.390 MF |
| W | 22V, 1W, 5% | 22V, 1W, 5% | 15V, 1W, 5% |
| NO. turns | 180,000 | 180,000 | 25000 |
| CORE | MU-METAL | MU-METAL | AIR |
| $R_c$ | 4 Ω | 4 Ω | 10 Ω |
| $K_c$ | 7.25 $^{\mu}$/ma ±2% | 7.25 $^{\mu}$/ma ±2% | 9.13 $^{\mu}$/ma ±4% |
| | | | |
| | | | |

$L_d$ = DETECTOR INDUCTANCE

$R_d$ = DETECTOR RESISTANCE

$C_{dc}$ = DETECTOR PLUS CABLE CAPACITANCE

$C_t$ = TUNING CAPACITANCE

$R_c$ = CALIBRATION COIL RESISTANCE

$K_c$ = CALIBRATION COIL CONSTANT

## RLF SYSTEM

figure No. 8

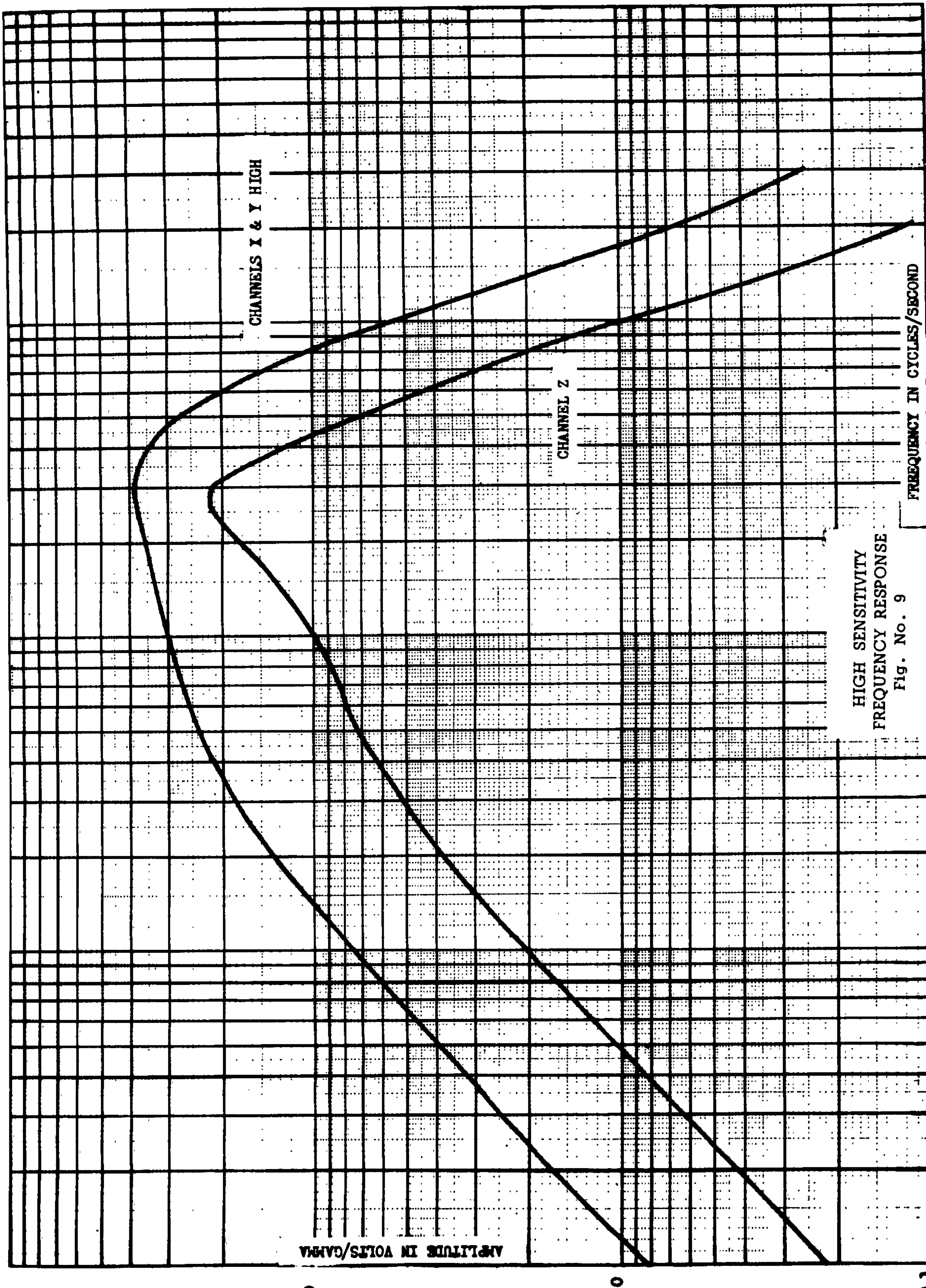
a variable voltage divider which permits limited continuous gain control ranging from 0.015 to 0.025 times the UPA-2 output voltage.

The high sensitivity horizontal component channels and the vertical component channel feed into a current limiting resistor and voltage limiting zener diodes. The resistor-diode circuit has the configuration of a voltage divider with the output taken across the zener diodes. The zener voltages are selected sufficiently high so 1 volt RMS signals will be passed without distortion. This means that the back resistance of the zener will be a factor of ten or higher than the current limiting resistor.

The current limiting resistor also serves as part of each of the following two RC low-pass filters. One additional resistor in series with the current limiting resistor completes the resistance of the first simple RC. The second low-pass RC filter is compound. Its upper half includes the first two resistors mentioned above plus a third one. But the capacitor, instead of being connected directly between the high side of the circuit and ground, as in the first RC, has a lower half consisting of a resistor and capacitor in parallel between it and ground.

After the low-pass filters are a high-pass filter and a cathode follower circuit in that order. The time constant of the high pass filter depends upon the input impedance of the cathode follower circuit, which is extremely high, and the capacitor. The high-pass filter is present, not to throw away signals below 0.01 cps, but to block DC coming through the system which might either overload the cathode follower and subsequently the record amplifier-modulator, or at least distort natural signals passing through them. The time constant of this filter has been made as long as seems practical.

The overall frequency responses of the high sensitivity channels and the vertical component channel are shaped chiefly by the two low-pass and one high-pass filters in each, see Fig. 9. The filters have been designed to pass natural signals from 0.01 to 3 cps with maximum efficiency. The effect of the low-pass filters upon the response of the horizontal channels can be observed by comparing the frequency response curves of the unfiltered low sensitivity channels with the filtered high sensitivity

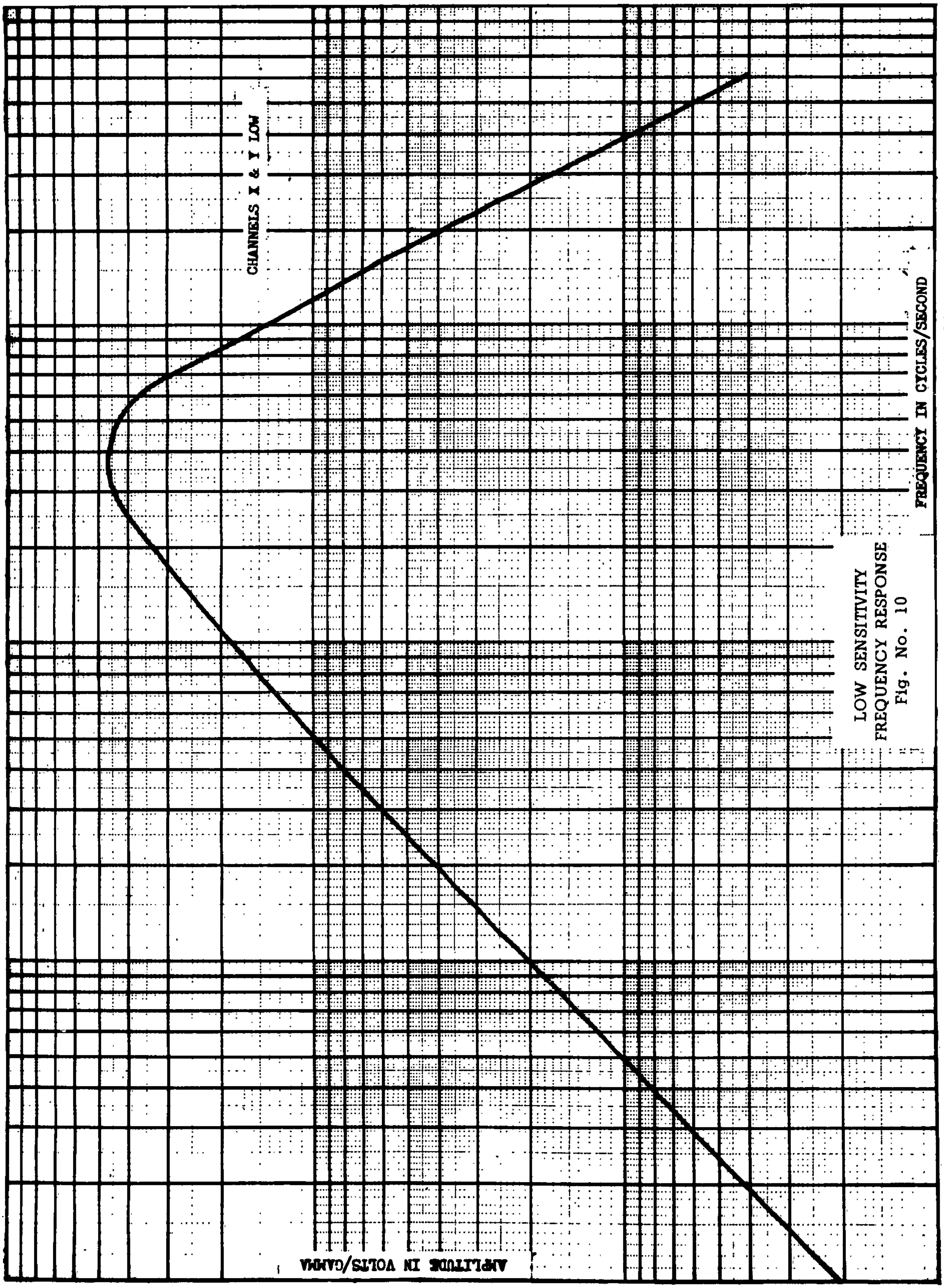



HIGH SENSITIVITY
FREQUENCY RESPONSE
Fig. No. 9

channels, Figs. 9 and 10.

The purpose of the low sensitivity channels is to observe only signals which overload the high sensitivity. Most overloading at times of magnetic disturbance will be below 1 cps, hence, the response of the RLF system up through the UPA-2's (Fig. 4) is adequate without additional filtering as long as all signal amplitudes are sufficiently reduced to effectively eliminate any unwanted signals above 3 cps, natural or artificial. Thus in the low sensitivity channels a large portion of the signal voltage is divided away at all frequencies in order that only signal enhancement below 2 or 3 cps of geomagnetic origin will produce large enough voltages to be distinctly observed at playback.

The reasons for having one sensitivity for the vertical component channel are largely practical. First, there were not enough record amplifier-modulators available to record seven channels. Second, more external noise is present on the vertical component, especially from 60 cps sources. Hence a lower maximum sensitivity than the horizontal channels is necessary on the vertical to maintain a satisfactory signal-to-noise ratio. Finally, the vertical




LOW SENSITIVITY
FREQUENCY RESPONSE
Fig. No. 10

component detector has roughly one-half the sensitivity of the horizontal component detectors. In order to raise the vertical channel sensitivity to that of the horizontal ones would require more gain in its second stage amplifier and would result in a less satisfactory signal-to-noise ratio. Thus, a single vertical channel with a sensitivity about one-half that of the high sensitivity horizontal was chosen as the best compromise.

The cathode follower circuits used in the high sensitivity horizontal and vertical channels have been designed to operate with zero volts DC out when the input is shorted and with minimum DC drift. The drift is kept at approximately $\pm$ 0.01 volts by using a voltage regulated Kepco DC power supply for the cathode follower tube filiaments, by using batteries for the B+ and B- supplies, and by placing a 30,000 ohm shunt resistor at the cathode follower output.

The cathode follower zero is set by adjusting the bias on the grid using a 10 turn 20,000 ohm potentiometer. A shorting switch permits the 5M resistor between the variable cathode resistor center tap and the grid to be shorted out to facilitate the zeroing process. An experimentally predetermined voltage with the 5M resistor shorted is set and then the short is removed allowing the voltage to drift back to zero.

One of the primary considerations in the RLF System design has been to make the System compatible with the Ampex Record Amplifier-Modulators since all six channels feed into them. The fm modulators have a center frequency of 90 cps. A ± 1.0 volt RMS signal into them produces a ± 40% frequency deviation, which is considered to be full modulation. This is the maximum signal level for which the modulator is linear, but there is no sharp cut-off at this level, and somewhat larger peak signals may be used although they are slightly distorted.

From the Ampex Record Amplifier-Modulators the signal goes to the record heads of the Schonstedt TSS-1 Tape Transport. This transport uses 1/2" magnetic tape, operates at a speed of 0.1 inches per second, and has a dynamic range of 40 db.

The overall dynamic range of the combined RLF record and playback system is 40 db per track. Between the high and low sensitivity horizontal channels there is a maximum potential dynamic range of 80 db. Although the maximum dynamic range possible is normally desirable, overlap between the high and low sensitivities is more exigent here because an overloaded signal on the high sensitivity should be sufficiently large on the low to be visible at playback. Accordingly, the total dynamic range of the combined channels was reduced to 65 db by adjusting the gains properly.

Of course, there is an underlying assumption that 65 db is an adequate dynamic range for both the largest and smallest geomagnetic signals expected to be encountered in the RLF range. Should 65 db prove to be inadequate, then the dynamic range can be increased at the expense of overlap.

The overall gain for the high sensitivity channels, then, is limited chiefly by noise. The gain may be increased until a maximum of $\pm$ 0.02 volt noise level at the record amplifier-modulator input is present. Further increase in gain, which would increase the noise level at this point, would result in reducing the effective dynamic range of that channel because the additional noise would obscure natural signals of the same order of magnitude as itself.

A spring-powered Esterline-Angus recording milliammeter is used to monitor the performance of the RLF System during recording intervals. It is operated at a speed of 3 inches per hour normally. A four pole rotary switch at the cathode follower outputs is used to select one channel at a time or to turn the monitor off. The Esterline-Angus drive circuit uses the other half of the channel X cathode follower tube which is a 12AT7, twin triode. The same B+ and filiament supplies are used for both halves of the 12AT7, but the Esterline-Angus is connected between the cathode and ground so no B- is used in its half. Centering of the EA stylus is accomplished by adjusting a 500 ohm potentiometer located between its high side and the cathode.

2.4 Time Signal Generator

Pending the completion of a Time Signal Generator, to be described Appendix I, a temporary timing device has been employed to put one minute and 15 minute indicator marks on the magnetic tape. The marks are supplied by batteries which provide DC voltages to the Amplifier-modulator when normally open microswitches are closed by cams driven by synchronous AC motors. The motor for the minute timer is driven by a tuning fork frequency standard which has an accuracy of 1 part in $10^5$. The 15 minute timer is operated directly from the line voltage since its accuracy is less critical.

3.0 Recording Procedure

Magnetic tapes of three different lengths have been used for recording the RLF signals, 2400 ft., 3600 ft., and 4800 ft. At 0.1 in/sec, they last approximately 3 1/3, 5, and 6 2/3 days respectively under normal continuous recording conditions. Thus, the normal frequency with which the RLF Recording System must be serviced depends upon the magnetic tape length used.

When the RLF System is serviced, a regular routine is followed which yields maximum information about its performance during the reel just recorded and some control over its future performance. All pertinent information regarding circuit changes and system performance are noted on a performance data sheet which accompanies each reel. The data sheet also provides a chronological log of the tape contents.

3.1 Calibration

Calibration signals are recorded at the beginning and end of each reel of magnetic tape by applying a known sinusoidal current at a known frequency to the calibration coils whose constants are known. The effective constnat of each calibration coil in gamma/maRMS represents the amplitude, in gamma, of a uniform, sinusoidal magnetic field which would induce the same emf in the detector coil that is induced when a 1maRMS (2.82 ma peak-to-peak) sinusoidal current of the same frequency is passed through the calibration coil. The horizontal coil constants are approximately 7.25 $\gamma/^{ma}$ the vertical, 9.13 $\gamma/^{ma}$ .

During the calibration the gain of each channel is reduced by a factor of 100, as previously described, in order to reduce the natural signals so they will not interfere with the much larger calibration signal. Specifically, 1 maRMS at 0.1 cps is applied to calibrate the high sensitivity horizontal and the vertical component channels at the beginning of each reel and again at the end of each reel. A second calibration ranging from 4 to 6 maRMS at 0.1 cps is applied to calibrate the low sensitivity horizontal channels at the end of each reel also. The calibration at the start runs for 30 minutes, those at the end, for 15 minutes each. Voltages at the record amplifier-modulator inputs are observed during the calibrations.

3.2 Preparation of Data Collection

Prior to the start of each reel the cathode followers are set at 0 $\pm$ 0.005v.DC, with gains reduced by a factor of 100 as during calibration; the modulator center frequencies are set at 90 cps if they are not already there; the minute timer is set to coincide with the minute tone of WWV $\pm$ 0.2 sec.; and the Esterline-Angus meter is rewound and reloaded (when required). At a speed of 3in./hr. the 100 ft. EA chart lasts for approximately 16 days.

3.3 Monitoring

At the completion of each reel the performance of the EA monitored channel is observed to ascertain if there has been any malfunction during the recording interval; the DC level of each cathode follower is observed and noted after the final calibration is completed; the minute timer accuracy is checked against WWV and any discrepancy noted; finally, the channel monitor selector is rotated cyclically to the next channel to be monitored.

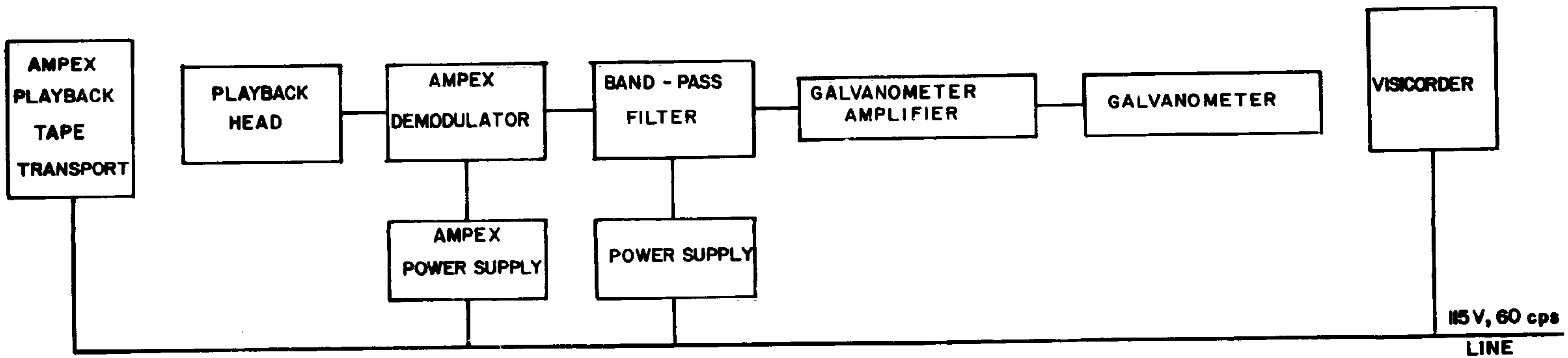
3.4 Maintenance

On the average of once per month, the following checks are made; each record modulator level is checked to insure that it is giving ± 40% modulation for ± 1.41v.DC and if not it is adjusted to do so; all B and filiament voltages are checked; the Sorensen line voltage regulator outputs are checked; and the noise level of each channel is checked.

4.0 RLF Playback System

The recorded reels of magnetic tape are played back on an Ampex tape transport at a speed of 30 in./sec., which is 300 times greater than the recording speed. Thus, the frequency range at playback is from 3 to 900 cps.

The signal from the playback head is fed into the Ampex playback amplifier-demodulator (see Fig. 11). From the demodulator the signal is either passed through a Krohn-Hite




BLOCK DIAGRAM OF RLF PLAYBACK SYSTEM

figure No. 11

band-pass filter into a Minneapolis-Honeywell galvanometer amplifier or it is passed directly into the galvanometer amplifier. In either case the signal from the galvanometer amplifier feeds into the galvanometer of a Minneapolis-Honeywell Visicorder oscillograph. There are six playback channels available. The playback sensitivity of each channel is set by a continuous gain control on each galvanometer amplifier.

4.1 RLF Playback Procedure

Since the Esterline-Angus record monitor has been in use the general level of signal activity over the recording interval is known prior to the playback of the reel. This information helps to determine how much of a particular reel should be played back on the Visicorder. The portion or portions of the reel selected for playback are physically identified on the magnetic tape by playing the reel while monitoring the galvanometer amplifier output on an oscilloscope. The reel is stopped at the beginning and end of each selected section and marked on the back with small coded bits of masking tape. Thus each selected section of a reel is located for future reference.

Prior to the introduction of the Esterline-Angus monitor, each reel was first observed on the oscilloscope playback monitor in order to judge its contents and then it was marked in the manner described above.

Visicorder direct print linograph photographic paper comes in 100 ft. rolls. The paper drive speed is adjustable in steps of 0.2, 1.0, 5 and 25 in./sec. A high paper speed is required to resolve the higher frequencies recorded. However, the speed most frequently used is 5 in./sec. because it gives optimum representation of the signal content for a reasonable amount of Visicorder paper. The 25 in/sec speed is used only for relatively short sections of tape containing higher frequency signals; while the 1.0 and 0.2 in/sec speeds are normally used in association with the band-pass filter set to eliminate higher frequency signals.

When a 2400 ft. reel of magnetic tape is played back in its entirety at 5 in/sec, approximately five 100 ft. rolls of Visicorder paper are required to accommodate it if overlap is taken into account. Obviously, more rolls of Visicorder paper are required to accommodate 3600 ft. and

4800 ft. than the 2400 ft. reels played back at the same speed. The spots on the magnetic tape corresponding to the beginnings and endings of the 100 ft. rolls of Visicorder paper are marked with coded masking tape as are the specially selected sections of tape.

The band-pass filter permits selected portions of the frequency range at playback, 3 to 900 cps, to be observed. The frequency range of the filter is 0.02 to 2000 cps for both high and low cut-off frequencies.

The playback sensitivity, which is controlled at the galvanometer amplifier, depends upon the overall noise level and signal level of the particular channel for the reel being played back. The mechanical positioning of the galvanometer spot on the Visicorder paper, controlled at the Visicorder, in turn, depends upon the number of channels being played back simultaneously, and their relative sensitivities.

Only three signal channels are played back on the Visicorder at once to allow optimum playback sensitivity with minimum confusion of traces. A fourth channel is always included at playback for the timing information.

Thus far, the general procedure has been first to play back the two high sensitivity horizontal channels and the vertical channel of each reel completely, without filtering, and at a Visicorder speed of 5 in/sec. The playback sensitivity of each of these channels is set at the maximum consistent with the channel's signal to-noise ratio for the particular reel. The galvanometer traces are spaced to permit maximum motion to the high sensitivity horizontal channels. The vertical channel has a lower record sensitivity and a worse overall signal-to-noise ratio; therefore, its playback sensitivity is maintained at approximately one-half that of the high sensitivity horizontal channels. This lower sensitivity requires lower amplitude motion of the trace; therefore, it may be placed quite close to the timing trace, which is at one edge of the paper.

Preliminary analysis of the initial playback records determines whether filtering or different Visicorder speed, or both are desirable. It also determines whether any of the low sensitivity horizontal channels should be played back or not.

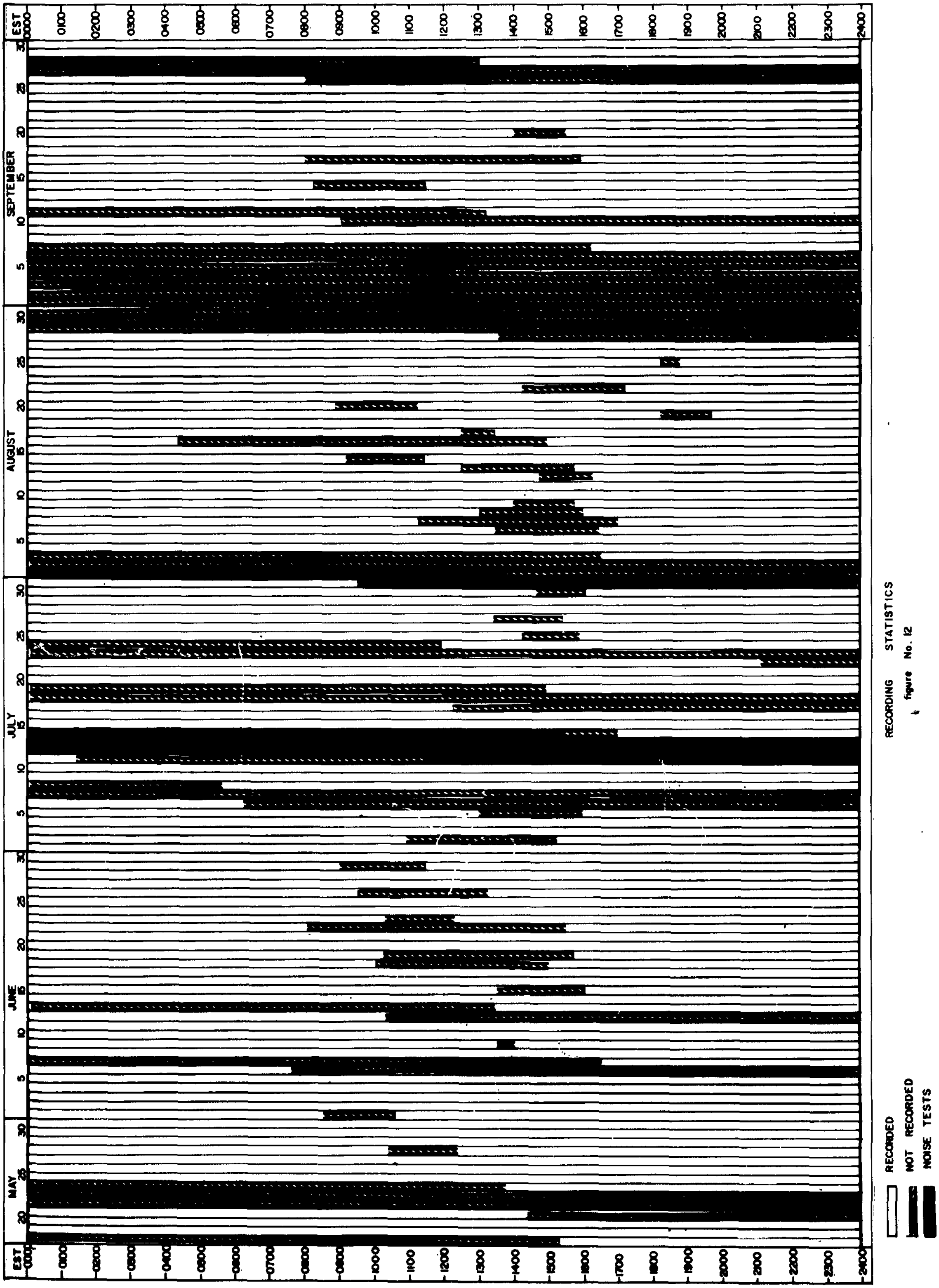
A playback log is kept as diligently as is the recording log so the exact conditions of playback and the performance of the playback system are known relative to each particular playback of a reel. This information is entered on the recording log sheet.

4.2 RLF Visicorder Records

The Visicorder records are permitted to latensify until a sharp trace is visible. Next the records are numbered, dated and labeled to indicate what each trace represents, and scaled for time by writing the time on the record at 15 minute intervals. After the identification procedure is completed, the records are accordian folded into lengths corresponding to 15 minutes of record time. Finally, the records are separated into 24 hour units, each starting at zero hours EST. One unit represents one calendar day of recording. Days only partially recorded are separated from the complete daily units also. The records are stored in a cool dark place.

5.0 RLF Recording Statistics

The recording interval ran from May 18 through September 30, 1962, a total of 136 days (3264 hours) (See Fig. 12). During this interval 33 reels of magnetic tape of several lengths previously noted were recorded, which




RECORDING STATISTICS
figure No. 12

represent 2376 hours of recorded signal.

Geomagnetic micropulsations were recorded without any interruption for 63 of the 136 days, about 47% of the total interval; 55 days were interrupted for various periods of time; and 18 days were not recorded at all. Altogether, 888 hours (27% of the total interval, were lost.

Four of the days partially recorded were interrupted intentionally by noise recording; 15, by circuit modification and/or repairs; 3, by power or system failure; and the remainder by the changing and calibration of reels. Days interrupted only by changing and calibrating reels rarely resulted in the loss of more than 3 hours of recording time. Of the days on which no signals were recorded at all, 2 were devoted to intentional noise recording and 8, to circuit modifications.

There is a bias on the time of interruption of recording on the partially recorded days. Approximately 75% of the interruptions occur between 0800 and 1700 EST; that is, during normal working hours.

The RLF system proved to be highly reliable under continuous operation and, as it approached final development, very little recording time was lost due to system modification or failure. However, some interruption of recording is inevitable in order to change and calibrate reels. The number of these interruptions can be minimized without sacrificing the reliability of the data by using the 4800 ft. reels of magnetic tape exclusively. When fewer interruptions are necessary the biasing of the time of such interruptions can be virtually eliminated by staggering them.

## 6.0 Appendix I

### Time Signal Generator

During the contract a time signal generator was designed and drafted for fabrication by the AFCRL shop. The final design will depend upon the outcome of performance tests to be conducted after fabrication has been completed.

The time signal generator is intended to produce a series of voltage pulses to be recorded on one channel of a multi-channel magnetic tape recording. In this way time on the recorded reel may be easily and accurately identified when the tape is played back. Timing accuracy of 0.1 second or better is desired. This generator is intended for a slow speed tape transport, 0.1 in/sec., which records geomagnetic fluctuations having frequencies of 50 cps of less. One reel of magnetic tape may cover as much as five days of recording time. The tapes are played back at a speed of 30 in/sec., which increases the recorded frequencies by a factor of 300. One hour of recording time equals 12 seconds of playback time.

The generator consists, essentially, of two voltage sources which are connected by means of switches and photoconductors to the input of the recording amplifier. The specific recording amplifier in the case is an f-m modulator with an input impedance of 100,000 ohms.

Four AC motors with gear-reduction to produce drive-shaft speeds of 10 rpm, 0.1 rpm, 1/6 rph, and 1 rpd are used to operate micro-switches or to rotate slotted disks which control the illumination of photoconductive cells. The switches and photoconductors vary the resistance in series with the voltage sources and the recording amplifier and, thus, vary the voltages at the amplifier input to produce the desired sequence of voltage pulses. Either batteries or oscillators of suitable frequency may be used as the voltage sources.

The time mark code operates as follows: except for the 30-second interval immediately preceding the start of each hour, voltage pulses are recorded at each second and minute. A motor driven at 10 rpm (one revolution in six seconds) produces one pulse per second (six per revolution) with the pulse indicating the start of each hour and each sixth pulse thereafter being accented, i.e., of larger duration than the intervening five.

A motor driven at 0.1 rpm produces one pulse per minute (ten per revolution). The minute pulses are longer than the second pulses with the pulse indicating the start of each hour, and each tenth pulse thereafter, being heavily accented; the pulse indicating the fifth minute after each hour, and each tenth pulse thereafter, are less heavily accented.

Photoconductors, rather than microswitches, are used in the time mark code circuits because of their longer lifetimes measured in terms of the number of operations (the seconds pulse photoconductor, for example, must be cycled 86,400 times per day; a microswitch would last only a few days). The resistance of the photoconductors is controlled by slotted disks which are placed between the photoconductors and the neon lamps which serve as the light sources.

The accuracy of the slots in the disk to be driven by the 10 rpm motor should be 0.01 second ($0.6^{\circ}$ of arc), while in the disk controlled by the 1/10 rpm motor the accuracy should be better than 1 second ($0.6^{\circ}$ of arc). The motors are set for approximately the correct time by turning on the AC power at the proper time. Fine adjustment is obtained by rotating the running motor and its disk with respect to the fixed photocells and lamps and then locking the motor in the proper position; 180° of adjustment is provided.

Since the accuracy of the time mark code (to within the 0.01 second limit noted above) will be determined by the accuracy of the two motors controlling the seconds and minutes pulses, they must be operated by a frequency-regulated source of power for attainment of the desired timing accuracy. Use of the 60 cps power lines in urban areas could result in errors of the order of ten seconds at times; these errors would later be corrected and would not be cumulative over intervals of more than a day. Many sources of AC power may, of course, be less accurate.

The hour mark code is a two-digit code which indicates the hour of the day from 1 to 24 and is recorded during the 30-second interval immediately preceding the start of each hour. The time mark code is interrupted during this interval.

The first digit of the hour mark code indicates the six-hour interval of the day (1 to 6, 7 to 12, 13 to 18, or 19 to 24 hours) by means of 1, 2, 3, or 4 successive voltage pulses which are recorded during the six-second rotation of the 10 rpm motor occurring from 24 to 18 seconds preceding the start of the hour. The six-second interval from 30 to 24 seconds before the hour, which has no timing pulses, is an aid for distinguishing the hour mark code from the time mark code. Similarly, the six-second interval from 18 to 12 seconds before the hour has no timing pulses and separates the two digits of the hour mark code.

The second digit of the hour mark code indicates the hour within the six-hour interval of the day (e. g., the 7th, 8th, 9th, 10th, 11th, or 12th hour of the day) by means of 1, 2, 3, 4, 5 or 6 successive voltage pulses which are recorded during the six-second rotation of the 10 rpm motor occurring from 12 to 6 seconds preceding the start of the hour. After a six-second interval with no timing pulses, the regular time mark code is resumed at the start of the hour.

The 1 rpd motor operates microswitches to control the number of pulses in the first digit of the hour mark code.

The operation needs to be accurate only to $\pm$ 20 minutes ($\pm$ 5° of rotation).

The 1/6 rph motor operates microswitches to control the number of pulses in the second digit of the hour mark code. It also operates a microswitch which serves as part of the control to turn off the time mark code and turn on the hour mark code at the proper time.

In effect, the 1/6 rph motor selects the particular rotation of the 0.1 rpm motor during which the hour mark will be applied. The 0.1 rpm motor next selects the two particular rotations of the 10 rpm motor during which the two digits of the hour mark code will be applied. The 10 rpm motor then operates a system of photoconductors and relays which assure that the selected digit of the hour code (the number of pulses in the digit having been pre-selected by the 1 rpd motor or the 1/6 rph motor) will be applied once and only once on a signal from the 0.1 rpm motor.

The operation of the 1/6 rph motor needs to be accurate to $\pm$ 3 minutes ($\pm$ 3° of rotation). Both the 1/6 rph and the 1 rpd motors may be operated on the regular AC power in most locations.

When more than one day of data are recorded on a single reel of magnetic tape, it is a simple matter to determine at playback to which day a particular hour, as indicated by the code above, belongs from the information on the timer of beginning and ending of the recording and the location of the hour on the reel. No code for indicating days has, therefore, been included.

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Contract # AF19(604) 5569

Final Report # AFCRL 62-1143

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Weston Observatory

Contract AF19(628) 236

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# ASTIA CARD

ABSTRACT

Research was directed toward the study of rapid fluctuations of the geomagnetic field. An investigation was made of the characteristics and origins of the natural magnetic field fluctuations in the frequency range of approximately 0.01 cps with particular emphasis on frequencies from about 0.1 to 3 cps. Field records were made of the fluctuations. Early records obtained for analysis and a study into the relationship of the results to magnetic disturbances and other geological phenomena were provided to Air Force Cambridge, Terrestrial Science Group.

The work described in this report covers the hardware phase of the installation of the measurement facilities at Strawberry Hill Field site Concord, Massachusetts. A description of the instrumentation and early measurements taken are given. Full time data gathering of the 0.01 to 3 cps geomagnetic fluctuations is in progress at the conclusion of this contract.