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Proton magnetometer coherence

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PROTON MAGNETOMETER COHERENCE

ROBERT A. ANDERSON

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by

Robert A. Anderson

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
ENGINEERING ELECTRONICS

United States Naval Postgraduate School
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ABSTRACT

The results of coherence measurements of three free precession proton magnetometers are discussed. The measuring and data processing instrumentation is described. The noise associated with the instrumentation has been measured and presented in statistical form. The results of measurements with elementary local perturbations are included to illustrate the target detection problem. The limitations of the instrument for target detection are discussed and imporvements suggested.

The writer wishes to express appreciation to Professor Carl E. Menneken for suggesting the problem, and Professor Harold A. Titus for encouragement and assistance in the preparation of this thesis.

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1. Introduction

The use of magnetometers for target detection requires identification of signals in the presence of the noise associated with the earth's magnetic field. The signal, in many cases, will be smaller in magnitude than the normal diurnal variation of the field, local fixed perturbations and geomagnetic pulsations. The system noise is of major concern in a detection scheme using magnetometers. This paper presents the preliminary results of a study of three proton free precession magnetometers operated under non laboratory conditions at Naval Postgraduate School La Mesa Village site.

The free precession magnetometer consists of a coil of wire in which a source of protons is placed. A strong field is applied to orientate the proton spins in a direction approximately normal to the earth's field. The polarizing field is then removed in a manner such that the spins cannot follow the field. The earth's field then causes the protons to precess about the lines of magnetic force at the Lamour frequency given by:

$$\omega = \gamma_p H$$

where γ_p = gyro magnetic ratio

= magnetic moment/angular momentum (1)

and H = magnitude of external field (earth's field)

The net precessing magnetic moment causes a voltage to be induced in a coil surrounding the sample. Since the precessional frequency is dependent only on the external magnetic field, the measurement of H consists of measuring the frequency of the induced emf. The inherent

accuracy of the free precession magnetometer is determined by the spectral line width (1), which is related to the relaxation time T_2, and is given by:

$$\Delta H \cong \frac{1}{\gamma_p T_2} \qquad (2)$$

where

$$= 3.6\ \gamma$$

$H \cong$ Half intensity width

$T_2 \cong 1$ sec (meas)

$\cong 10^{-5}$ GAUSS

The gyromagnetic ratio has been measured by the NBS to better than 1 part in 10^5. Full advantage of this inherent accuracy has not been utilized because of the problems associated with the frequency measurement. The frequency measurement is complicated by the fact that only a limited time is available for measurement. The signal received from the magnetometer is in the few microvolt range; hence locally generated electronic noise and transients from the polarizing operation cause the signal to noise ratio to be small. Standard counting techniques are used for measurement. To get the required accuracy, the frequency must be obtained from period or multiple period average measurements. The process is digital in nature and lends itself very nicely to computer processing of the data.

The main disadvantage is that any reasonable attempt to obtain an analog signal proportional to the measurement is an analog of period rather than frequency; therefore, the analog is the inverse of the quantity of interest. This does not present serious problems for target detection since the absolute magnitude of field is not of interest.

2. Instrumentation

2.1 Measurement

The engineering aspect of the measurement problem can be stated simply as follows:

Given: Three transient type signals of frequency approximately two kc/s occuring at the same time, with usable duration of about 3/4 sec. The signals are in the microvolt range. The recurrance rate is to be 2 sec. The measurements must be conducted in the presense of high electronic noise such as relay transients, contact noise and transients from the collapsing polarizing field.

Find: The frequency of the oscillations accurate to 1 part in 10^5 or better, and suitable means of data aquisition and processing.

The funds available excluded the possibility of using commercially constructed instruments or components. Also, modifications and interfacing would have to be done if components were used. Hence, the basic measuring instrumentation was constructed at NPGS. No detailed circuit design is presented; however the circuit diagrams are included in Appendix IV.

Assume the precession signal has been amplified in a suitable, low noise, narrow band preamplifier, and converted to a signal having fast waveform. Referring to the simplified block diagram of Fig. 1, the basic counter operation is as follows: Let the slow and fast counters consist of flip-flop counting units, connected to form a binary counter. The gate control flip-flop is capable of being triggered into either state. The multiplier converts the clock frequency to a harmonic of the precision 100 kc/s oscillator.

BASIC COUNTER UNIT

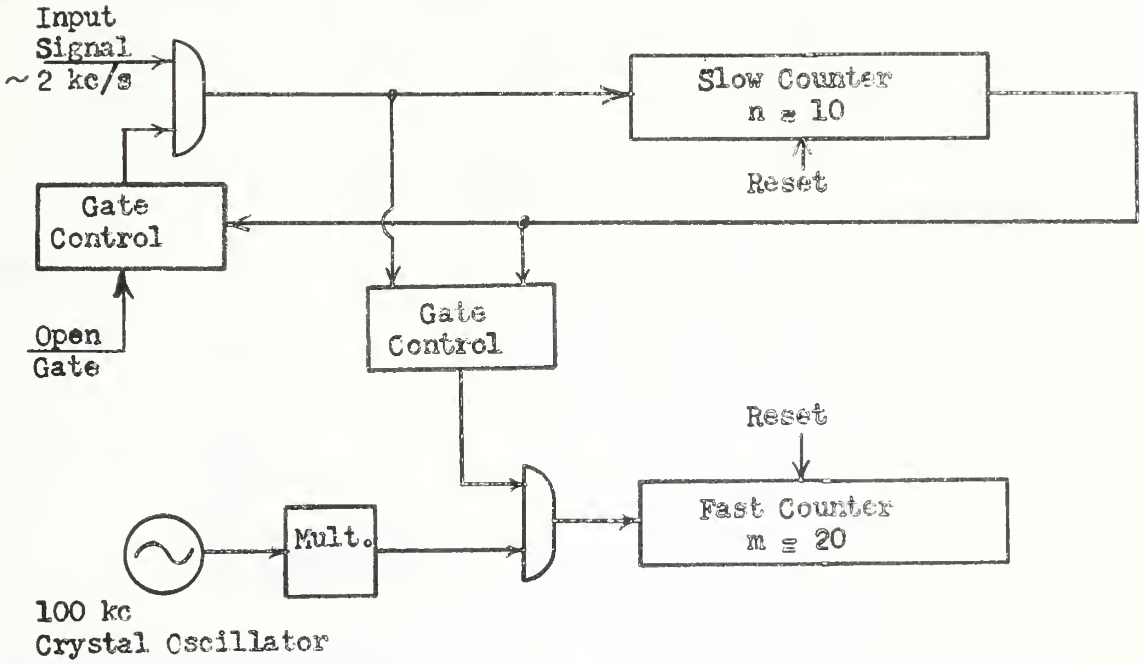


Figure 1

Let all counters be reset and ready for operation. The unknown input signal is applied to the gate. After a delay of approximately 150 ms, an external signal triggers the gate control to open the signal gate. The long delay is necessary to allow for damping the polarizing field and relay transients. The first pulse through the signal gate opens the clock gate. The fast counter then counts the number of clock pulses occuring during the time interval determined by the slow counter. The slow counter is increased one for each cycle of unknown input signal. After the slow counter has reached a predetermined number, both signal and clock gates are closed, and the number in the fast counter is a value of the time interval of 2^n cycles of unknown input signal, or can be reduced to the average period of the signal.

Let us define

N = number in fast counter

2^n = number of cycles of unknown signal

t_p = period of clock (μsec.)

t_n = period of unknown signal

Then we have

$$T_m = N t_p$$

$$t_m = \frac{T_m}{2^m}$$

$$= N t_p / 2^m$$

Substituting in (1) gives

$$H = \frac{2\pi \cdot 2^m}{\gamma_p N t_p} \tag{3}$$

and with n = 10,

$$H = \frac{2348400 \times 1024}{N} \tag{4}$$

The accuracy of such a scheme depends on:

a. The accuracy in determining the zero crossing of the unknown signal.

b. Propagation delay in the slow counter.

c. Gating speed.

d. Accuracy of the clock.

e. Plus or minus the las bit, due to noncoherent gating as illustrated in Fig. 2.

EFFECT OF NONCOHERENT GATING

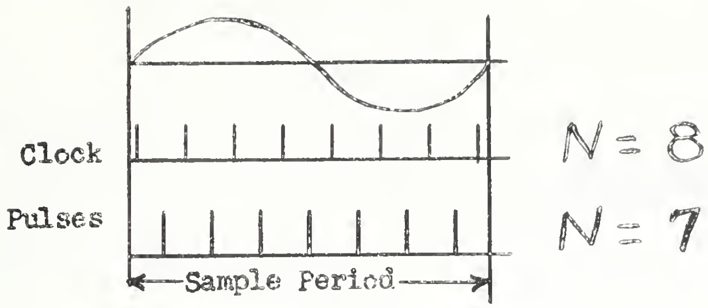


Figure 2

The errors due to determining the zero crossing are usually the dominant error in using this technique; however when averaged over 1024 cycles they become small and the largest error is the plus or minus last bit, as shown. The accuracy in determining the zero crossing in the presence of noise (2) is:

$$t_n = \frac{V_n}{S}$$

where:

t_n = maximum error in trigger time in sec.

V_n = peak to peak noise in volts.

S = slope of ideal signal at point of trigger level.

For a sinusoidal input:

$$S = \frac{d}{dt}(V_s \sin wt)\Big|_{wt = n\pi}$$

$$= V_s W$$

Assume a signal to noise ratio $2\,V_s/V_n$ = 20 db, and

$$W \cong 2\pi \times 2 \text{ kc/s}$$

then:

$$t_n = 0.318 \times 10^{-4}$$

For 1024 periods:

$$t_m \cong 0.3 \times 10^{-7} \text{ sec}$$

$$= 0.03 \,\mu\text{sec}$$

The plus or minus last bit error if the clock is 100 kc, is ± 10 sec., and the other errors mentioned are negligible compared to the 10 μsec. error.

Consider the ± 1 bit limitation in detail for the earth's field 50950 γ, which is the approximate value at Monterey, California.

let:

$N = 00134051_8 \pm 1$ bit

1 bit ± 10 μsec.

then:

$$\Delta H = \pm 1.1 \gamma$$

This becomes the sensitivity of the instrument. If the clock is increased to 1 mc/sec, 1 bit = μsec., and:

$\Delta H = \pm 0.11 \gamma$; however other noise becomes appreciable and cannot be neglected. The circuits were designed for 1 mc/sec operation, but the measurements to date were conducted at 100 kc/s and 300 kc/s clock rates. The added complication is to construct 3 meters that will read identical, the input circuitry and slow counters must have identical characteristics. This is impossible from a practical point of view. The result is that the three counters with an ideal signal input can vary ± 1 bit in comparing their readings.

A simplified block diagram and photo of the magnetometer is shown in Figs. 3, 4 and 5. It must be remembered that operation

is to be in remote locations where extremes of temperature, line voltage fluctuations, poor grounds, etc. will be found; hence circuits that are sensitive to these variations must be carefully compensated.

For the experiments under consideration, locating the sensing coils approximately 500' apart would be sufficient; however for further experiments a distance of greater than 500' might be necessary. Therefore, a provision to place the preamps in the line nearer the sensing coils for improved signal to noise ratio was included. Bias for the preamps is applied to the signal line, from the console to eliminate the need for battery replacement. The relays that provide the two to three amps of polarizing current, and provide for dissapation of the stored energy when polarizing current is turned off, must precede the preamp. Since this unit is placed near the sense coil, it must be magnetically clean.

Referring to the block diagram the components that are common to the three units are the clock, timer, recorders and the power supplies.

COUNTER INSTRUMENT

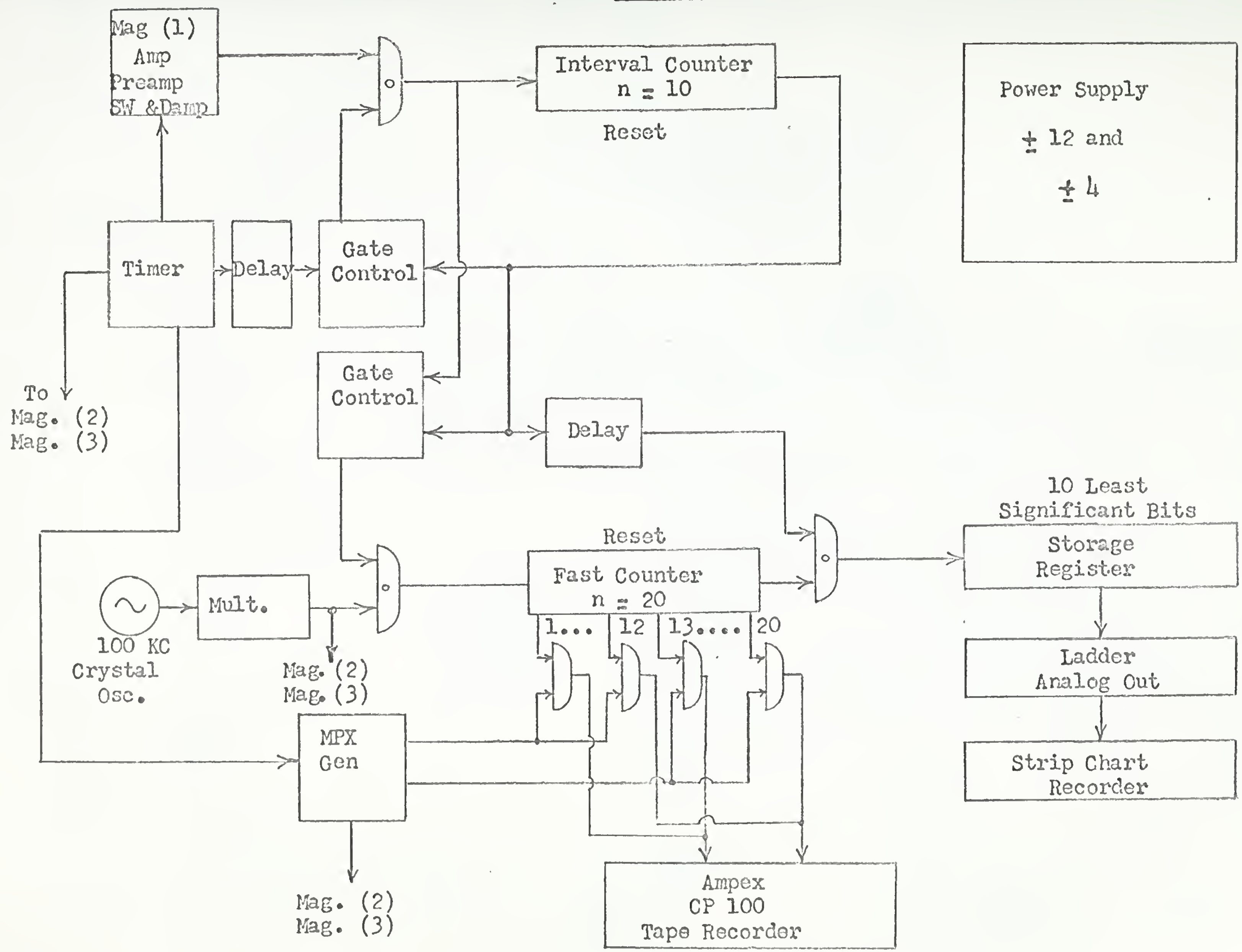


Figure 3

MAGNETOMETER INPUT SECTION

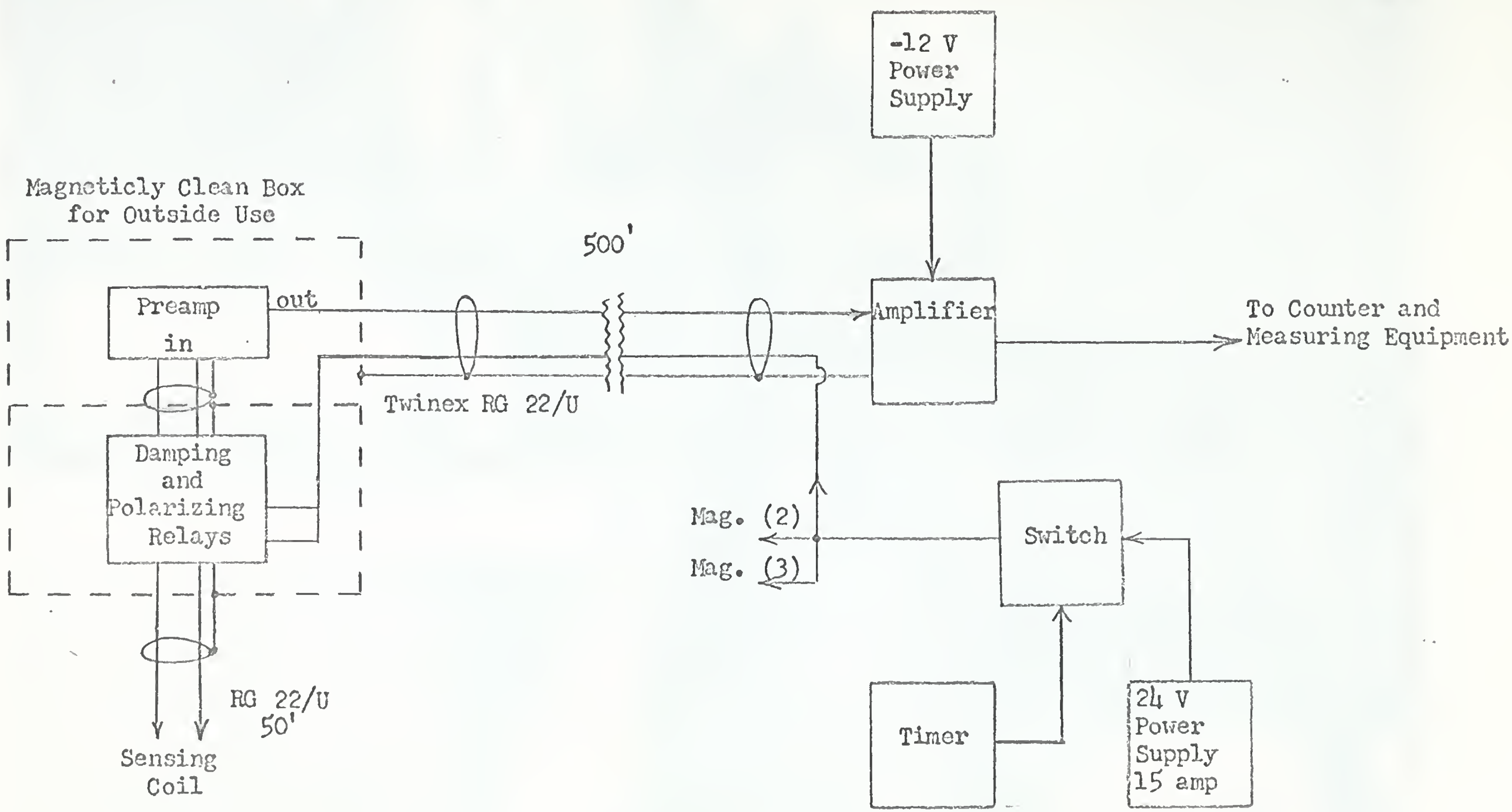


Figure 4

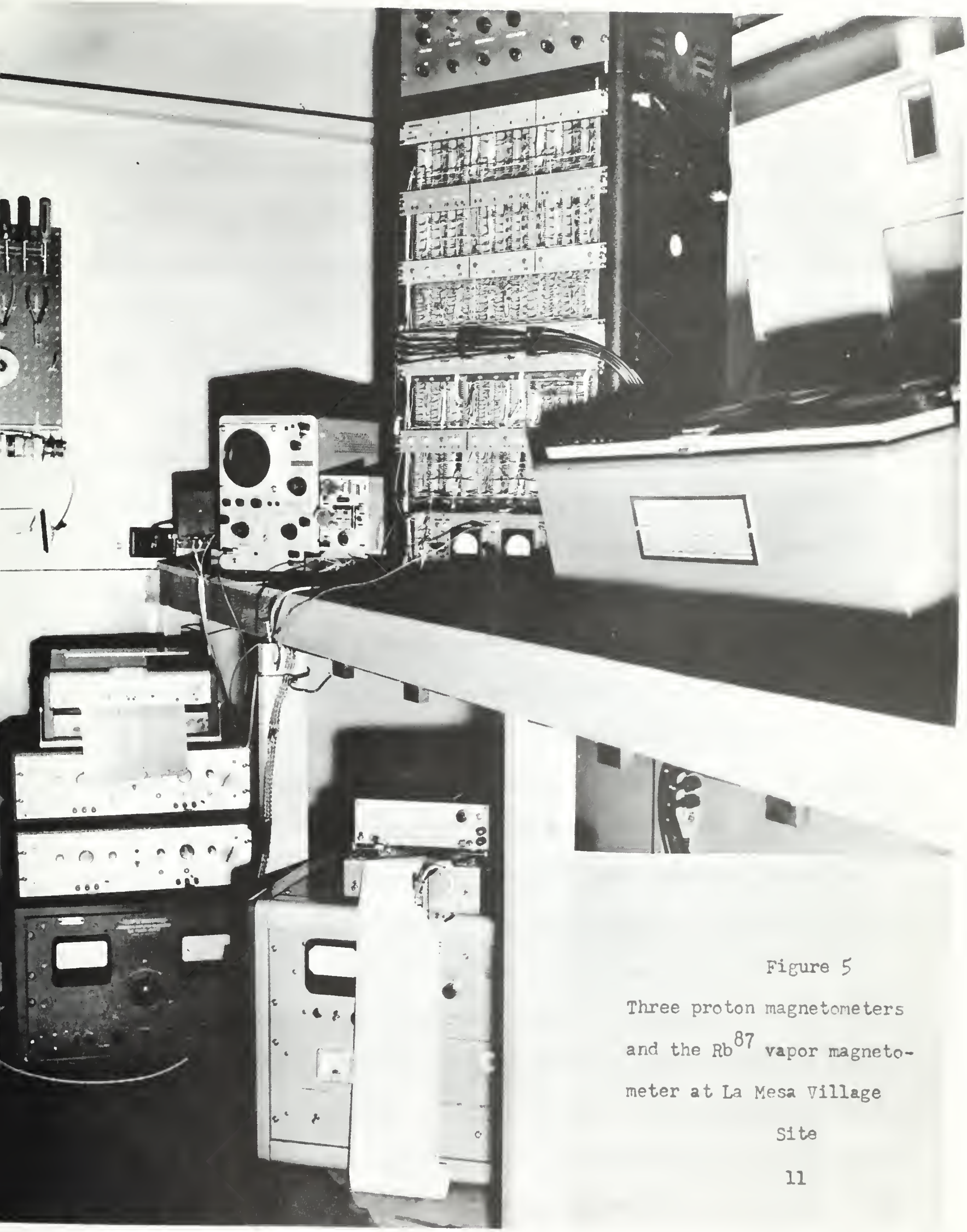


Figure 5

Three proton magnetometers and the Rb^{87} vapor magnetometer at La Mesa Village Site

2.2 Data Aquisition and Processing

Figure 6 shows a block diagram of the data collection and reproduction system.

The scheme used for data handling is certainly not optimum in the sense of tape utilization and ease of operation, but an Ampex CP100 was available and required no additional expenditure for tape recorder. Also with minor modifications a data recorder can be utilized at a later date if funds become available.

Consider the form of the data. The sensing coils are polarized for one second, at the end of this time the polarizing current is turned off, the transients are damped; and the signal is fed to the counting units. After 1024 cycles of the input signal (about 1/2 sec.) the measurement is complete. In the fast counters, there are three binary numbers to be processed. The magnitude of the binary numbers, for $H = 50950\ \gamma$ with clock frequency = 100 kc/s, is about 00134146_8 or 16 bits. With the clock increased to 300 kc/s, the number is 00425260_8 or 18 bits. Hence, at the end of the counting interval, there are 48 bits to be recorded in a format for computer input. The Ampex CP100 is a "portable" instrumentation recorder with 14 parallel inputs and capable of speeds from 1 7/8 ips to 60 ips. All of the record and reproduce amplifiers that were on hand were not capable of recording D.C. levels; therefore, the information was put on tape in the form of pulses. Also, for reasonable speed in reproduction, the data was recorded at 1 7/8 ips and reproduced at 60 ips. A record of approximately 6.5 hours can be reproduced in 10 minutes. The machine used to read the raw data is a CDC160 com-

DATA AQUISITION AND PROCESSING

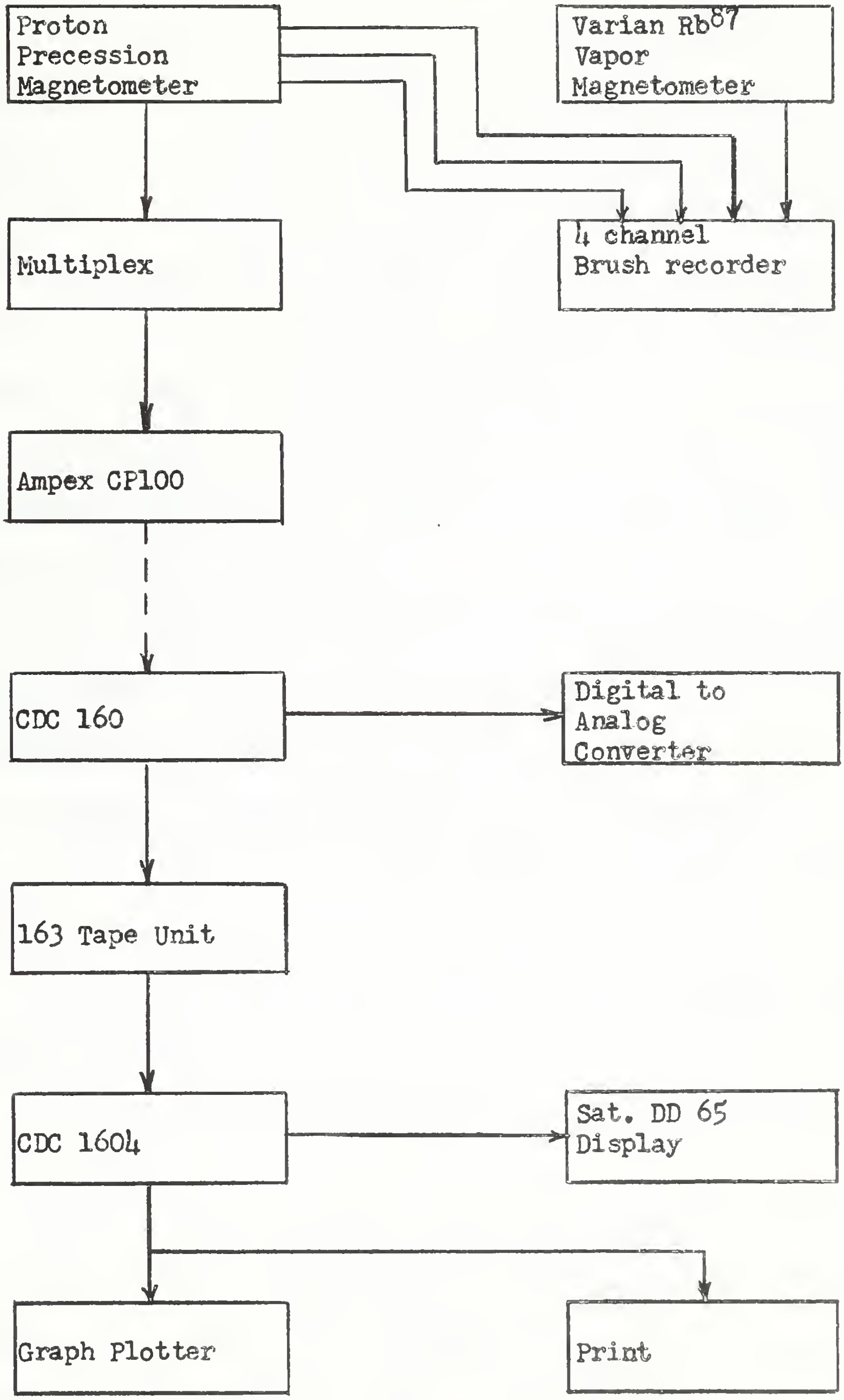


Figure 6

puter capable of reading words of up to 12 parallel bits. The magnetometer words are broken into two, 12 bit words and time multiplexed on tape to satisfy the computer input conditions. Hence, for each sample, there are six 12 bit words to be processed. Even with the time speed up in reproduction the CDC 160 is operating below its capabilities. In an effort to utilize the 160 time, the data was put on tape, so that when it occured, the 160 would read at its maximum rate and use the "no data time" to continue with preliminary processing. Channels 13 and 14 on the tape are input ready and disconnect signals used to control the 160. And of course, for reasonable machine time efficiency, there is on hand enough tape to allow continuous recording for one week.

The Ampex CP100 was not designed specifically for this type of operation; hence the need for an interface to mate it with the 160. The interface must provide the following functions:

a. Convert the pulse type data to D.C. level signals.

b. Put the data on line when a request is supplied from the computer.

c. Effectively disconnect itself from the lines when other equipment is called.

d. Provide control information, i.e. input ready and disconnect for the 160.

e. Effectively isolate the computer from spurious transients from the tape machine. These normally occur during start - stop operations, but the recorder is somewhat susceptible to power line transients and they sometimes appear in its output.

Figures 8, 9 and 10 shows the block diagram of the interface provided. Fig. 11 is a photo of the preliminary processing setup. The cards were assembled and mounted as a component on a laboratory cart, the tape unit is placed on the top of the cart and computer cable connectors provided. This eliminates the need for a permanent rack in the computer laboratory.

The preliminary processing consists of the following:

a. Reading the raw data.

b. Checking the data and keeping a record of the errors.

c. Writing the storage tape.

d. Providing identifying blocks on the storage tape.

e. Searching the storage tape for any particular record or the end of the data so that one storage tape may be used for many week's records.

f. Direct display of the raw data.

The data storage format used is illustrated in Fig. 7.

STORAGE TAPE FORMAT

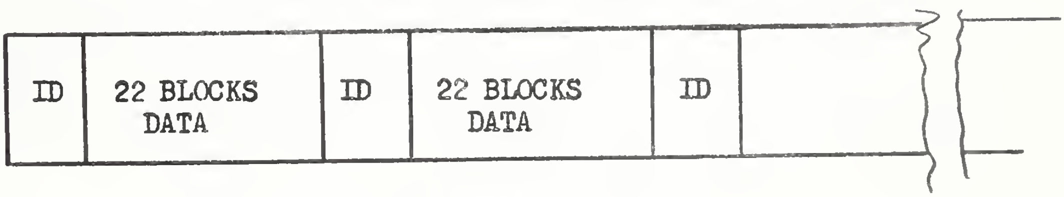


Figure 7

With the time base used there are nearly 38040 twelve bit words per 6.5 hours record. The 6.5 hours record is one 3600 roll of instrumentation tape at 1 7/8 ips. Since the operation is stopped to change tape, it is convenient to put the identifying block at the

TAPE DECK OUTPUT REGISTER

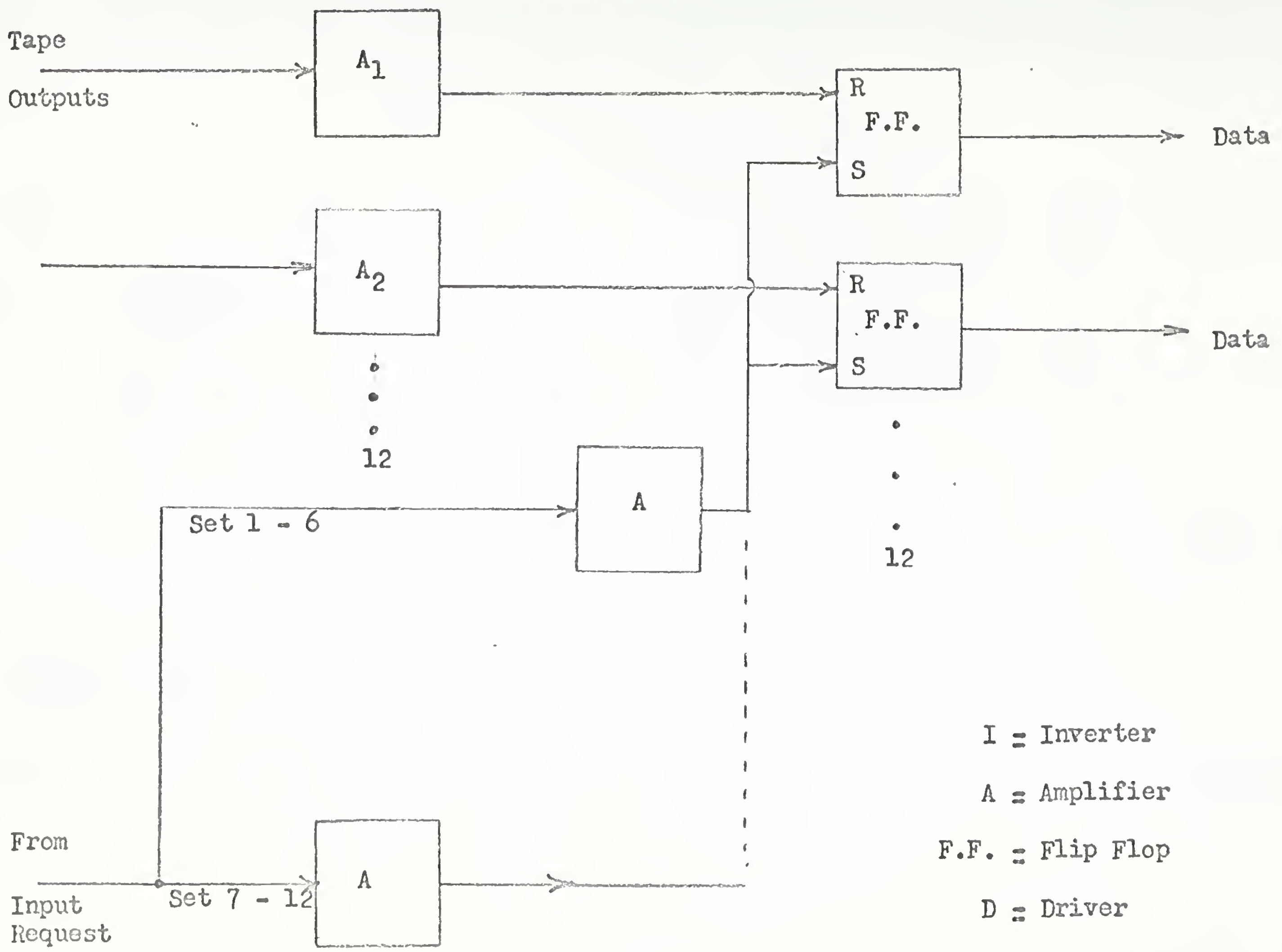


Figure 8

INTERFACE INPUT SECTION

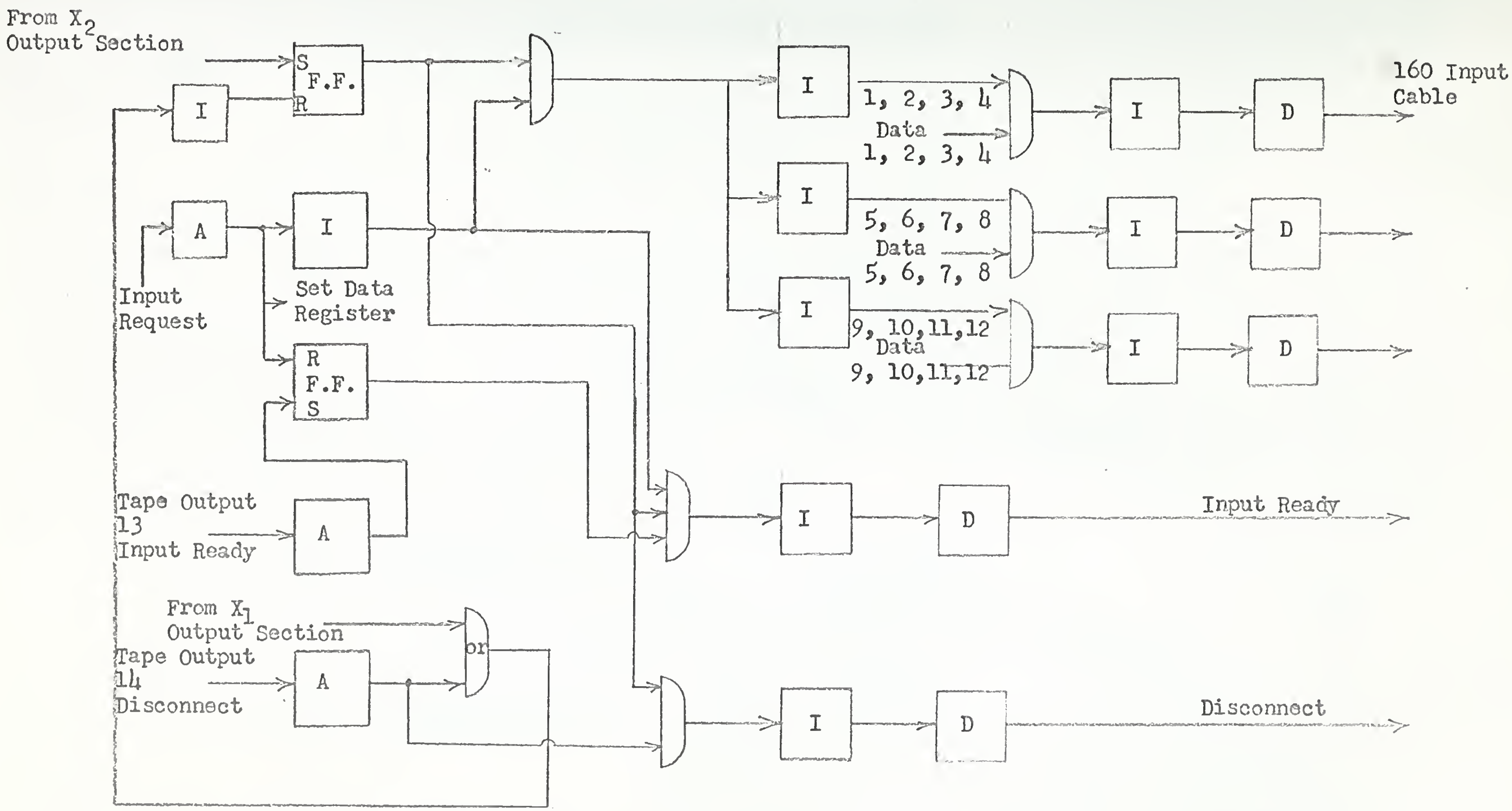


Figure 9

OUTPUT SECTION DECODEING AND RESUME

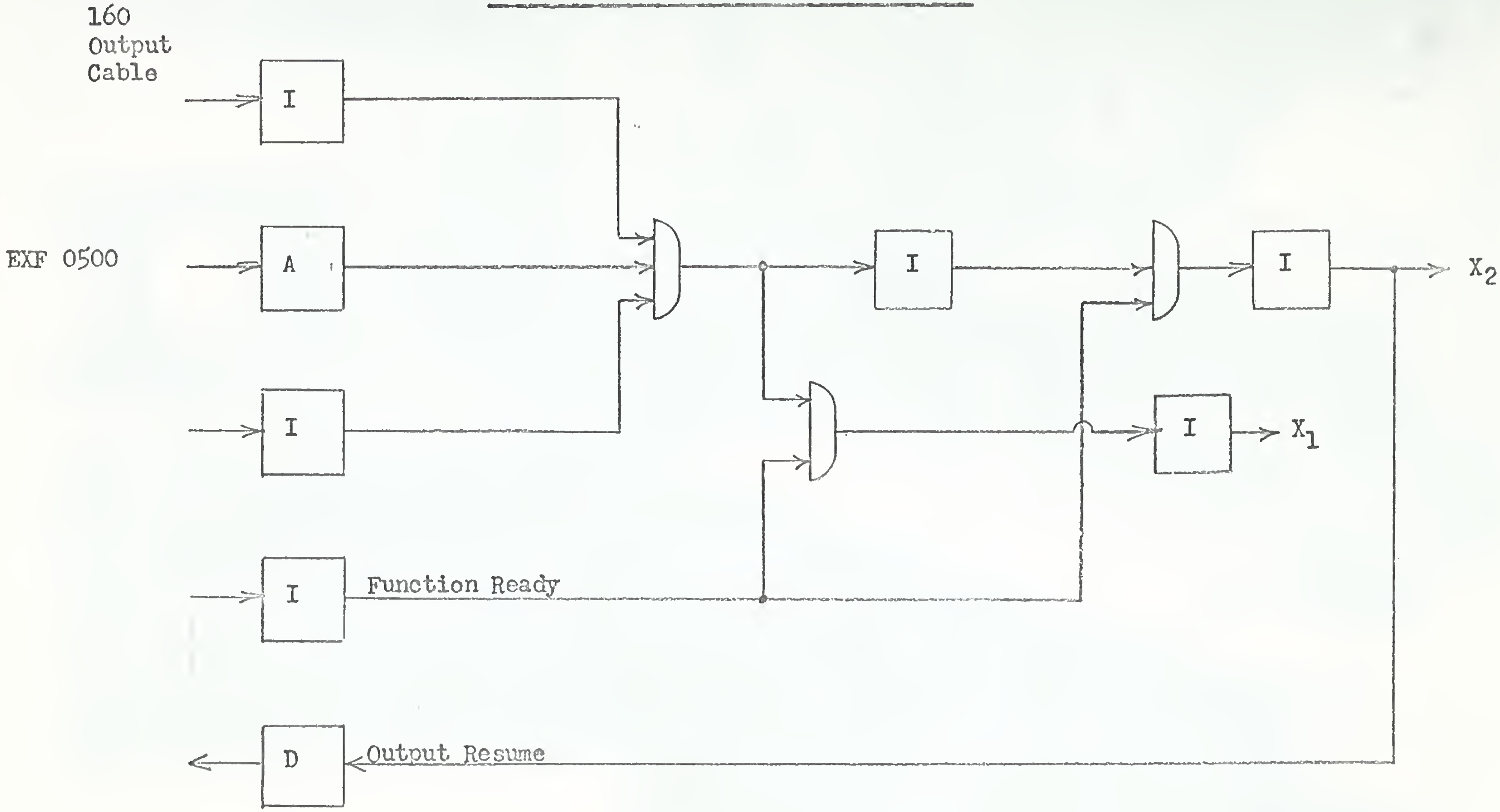


Figure 10

Figure 11

Preliminary Processing Setup

end of this record. Also, this number of data words can be processed in the order of minutes by the CDC1604 so that if the computer is needed for other jobs; it can be stopped at the identifying blocks and return later to the same point with the proper index setting. The block length was set somewhat arbitrarily. The memory storage limit of the 160, write time of the 163 tape unit and suitable records for handling in the 1604, are the factors to be considered when chosing the block length. The instrumentation recorder cannot conveniently be stopped when writing the storage tape; hence one data point is lost when transferring data. This represents 22 points per 6.5 hours record or less than a minute in real time. The block length was chosen to be 3456_{10} twelve bit words per block, the figure being compatable with the above conditions.

The identifying record consists of writing the month, day and year in flex code. The remaining cells of the block are loaded with zeros. It is then easy to separate the data from the identifying blocks since none of the data words will be all zeros.

The fact that the data had to be reconstructed in the 1604 was also considered in chosing the block length. The information is buffered into the 1604 in 48 bit words. The blocks consist of an even number of data points, i.e. six 12 bit or two 48 bit words. After a block is read into the machine and loaded into the A register, the magnetometer readings can be stored sequentially in memory with a loop of a few machine language instructions. The data analysis is then done using Fortran, allowing easy and versatile manipulation of the data. The 160 and 1604 input programs are included in Appendices II and III.

Reassembly is illustrated below.

1604 WORDS

Mag 1 (24 bits)	Mag 2 (24 bits)
Mag 3 (24 bits)	Mag 1 (24 bits)
Mag 2 (24 bits)	Mag 3 (24 bits)

Briefly, the operation is as follows: Magnetometer readings are recorded for long periods of time at a remote site on a protable magnetic tape unit. The tape unit is then returned to the processing site, and using a time speed up of X 32, the intermediate processing is performed and the data stored.

The storage tape along with suitable programs is then placed on file for processing by the computer facility at their convenience. The tape unit is then returned to magnetometer site for more records. The new data obtained is added to the storage tape so as not to destroy the existing data.

3. Data Analysis

The experimental measurement program was set up to study the coherence between the magnetometers, i.e. the comparison of simultaneous samples of the field, with the sensors located at different spatial locations. The coherence was to be examined with various local perturbations in the field. With the target detection objective in mind, the least complicated method of obtaining the target signal will result in the best instrumentation for field use. The problem is somewhat analogous to the radar problem where decisions must be made in the presence of noise, with associated probabilities of error in detection.

There are several types of geomagnetic noise that occur. The most dominant is the diurnal variations. Superimposed on this are smaller variations known as micropulsations and noise caused by local disturbances. Sudden eruptions on the sun sometimes cause large fluctuations in the field. Several studies of the various noises have been made (3), (4) and (5). For the proton precession magnetometer, the instrument produces noise of major contribution to the spectra of small geomagnetic pulsations. For target detection, the signal of interest will most likely be of the same order of magnitude as the small micropulsations and local distrubances. For geophysical prospecting and mapping, the signals will be much larger.

As with any raw data, there will be some points that are obviously in error. The cause of errors is usually uncertain, but some provision must be made in the processing to eliminate these errors so as not to distort the data. Care must be taken when performing

these operations so the target signals are not masked. Records of the errors should be kept in order that decisions about the usefulness of the set of data can be made.

The problem of coherence between the spatial samples requires that the instrument noise be determined, with an ideal signal, then measurements be conducted with no local perturbations in the field, and the samples compared. The simplest comparison is to plot the difference signal vs. time. With no local perturbation, this means essentially a plot of the system noise vs. time; hence the need for filtering is obvious. To use this method for target detection will require serious consideration of the filter time constants.

The types of filtering

1. A clipping filter (on the raw data) that clipped at $\pm 200\ \gamma$. The number of points outside of this range are recorded. This range was about twice the expected diurnal variation. The filter removes the errors from lost high order bits and other instrument sources. The typical error rate was about 1/50000.

2. A simple three point average for display of the raw data on the DD 65 display unit was used. This gives an operator a fast visual display of the raw data. Decisions can then be made about the quality of the data.

3. Eighteen point averaging, i.e. 36 seconds real time, gave partially smoothed 6.5 hours graph records.

4. A simple single section low pass filter was used of the form $1/(s - a)$. The time constant was set at 100 sec. and 20 min. in real time. The implementation was done using Z transform (6).

The filter design was done by Professor Harold A. Titus.

We have

$$\frac{X_o(S)}{X_{in}(S)} = \frac{a}{s - a}$$

which has a Z transform

$$\frac{X_o(Z)}{X_{in}(Z)} = \frac{\beta}{1 - e^{-aT} Z^{-1}}$$

In block diagram form this is seen in Fig. 29

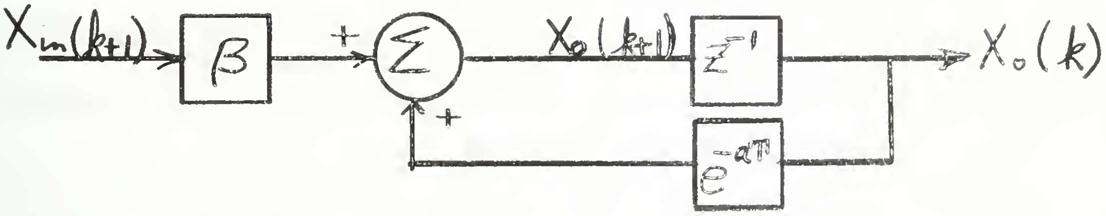


Figure 29

In terms of the discrete time samples we have

$$X_o(k+1) = \beta \sum_{n=0}^{k} e^{-anT} x_{in}(k+1-n)$$

$$\beta = 1 \Big/ \sum_{n=0}^{k} e^{-anT}$$

T = sample period

a = time constant

The function was trunkated at n = 20 for values of k > 20. The contribution to the filtered value from the terms multiplied by e^{-anT} for n > 20 is negligible.

The coherency is a statistical parameter, and must be represented as such.

Let:

$$\Delta_1 = H_1 - H_2$$

$$\Delta_2 = H_1 - H_3$$

$$\Delta_3 = H_2 - H_3$$

The differences of the unfiltered values were grouped in a frequency distribution which approximates the continuous density function for large sample size. Since the process is digital, the allowable differences, in bits are: 0, ± 1, ± 2, ± .... Therefore, the frequency distribution is not a smooth curve. Since the instrument noise is randomly distributed, the envelope of the distribution is a normal density function. The mean was removed before plotting, and the statistic representing the standard deviation was computed according to:

$$S = \frac{1}{N}\sqrt{\sum_{i=1}^{N}(\Delta_i - \bar{\Delta})^2}$$

where: N = the number of samples in a 6.5 hour record.

Comparison of the density function curve with an ideal signal input to that of magnetometer input gives a measure of the noise produced by the device.

To further define the coherence, the auto and cross correlation functions were computed and the coherency computed as defined:

$$\mathrm{coh}_{11} = \frac{\phi_{12}}{\sqrt{\phi_{11}\,\phi_{22}}}$$

where:

$$\phi_{12}(\tau) = \lim_{T \to \infty} \int_{-T/2}^{T/2} x(t)\, y(t+\tau)\, dt$$

and

$$\phi_{11}(\tau) = \lim_{T \to \infty} \int_{-T/2}^{T/2} x(t)\, x(t+\tau)\, dt$$

This discrete computational form is

$$C_{xy}(\tau) = \frac{1}{N-m} \sum_{p=1}^{N-m} x_p\, y_{p+r}$$

and

$$C_{xx}(\tau) = \frac{1}{N-m} \sum_{p=1}^{N-m} x_p\, x_{p+r}$$

where:

N = number of data values

n = number of lags

$\tau = n \Delta t$

Since the functions are from finite time series n_{max} can only be made about 0.1 N. The 6.5 hour records will vary in form depending upon the time of day the records were made. Therefore, the correlation

functions will not be the same shape for each record; however the coherence function as defined will be the same, and for perfectly coherent records is unity. The programs are included in Appendix III.

It should be pointed out that when perturbations are placed in the field, the basic assumptions regarding correlation; i.e. a stationary random process, are no longer applicable.

Experimental data was taken to determine typical signatures for elementary perturbations. Fig. 12 shows the geometry of the detector centered coordinate system.

PERTURBATION EXPERIMENT GEOMETRY

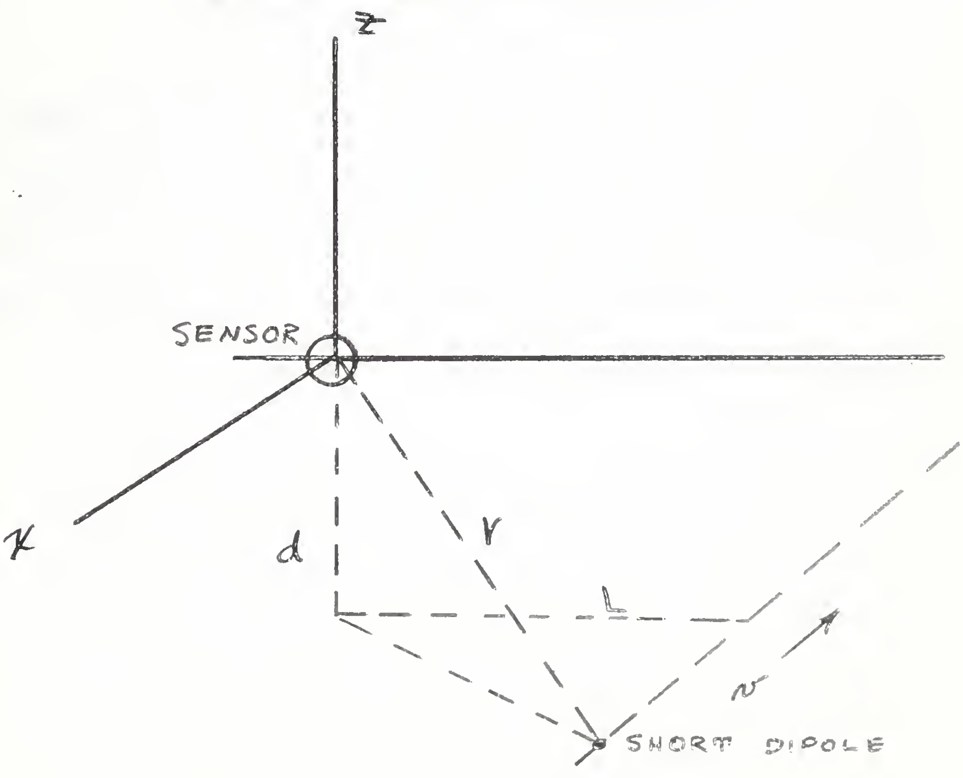


Figure 12

The dipole moment was orientated parallel to the earth's field and its motion was in the x direction such that $dx/dt = \text{constant}$. The approximation $r \gg 1$ is valid.

At the detector:

$$H = \sqrt{Ho^2 - Hp^2}$$

And:

$$Hp = \frac{K\,M}{r^3}$$

where:

M = dipole moment

r = function of time and the geometry

K = constant

No attempt was made at this time to compare the measured values with the theoretical values, because the terrain does not lend itself keeping L, d, and v constant. The results are representative of typical signatures that would be found in practice.

4. Results

4.1 Instrumentation:

An ideal signal was substituted for the procession signal and set of records were made, as shown in Figs. 13 through 25. The graph scales were left unchanged because it was desired to show the instrument errors on the same scale as the magnetic field scales. The magnetic field vs. time graphs were not included because the input signal was an audio oscillator and only a small drift puts it off the graph scale. The clock was 300 kc/s which makes 1 bit = 0.36 γ.

Figure 28 shows the precesion signal from the various sensors. Figs. 26 and 27 are typical plots made from the analog section of the instrument. For comparison, the Rb^{87} magnetometer output was adjusted to the same scale and plotted on the same graph. The Rb^{87} magnetometer output is an analog of frequency, while the proton magnetometer the analog is of period; hence the reason for the opposite drift on the chart. Figure 27 is an analog record of the differences. The filter was a single section RC filter with time constant = 10 sec. On the multiple curve plots showing coherence, the curves are identical and cannot be distinguished from each other. These curves can be compared with the curves obtained from the sensor with no local perturbations in the field, for the contribution of the measuring instrument noise to the total noise.

Difficulties with both instrumentation and computer tape have been encountered. The use of new computer tape for data storage and scratch tapes, and frequent head cleaning of the instrumentation recorder reduced the difficulties to a minimum.

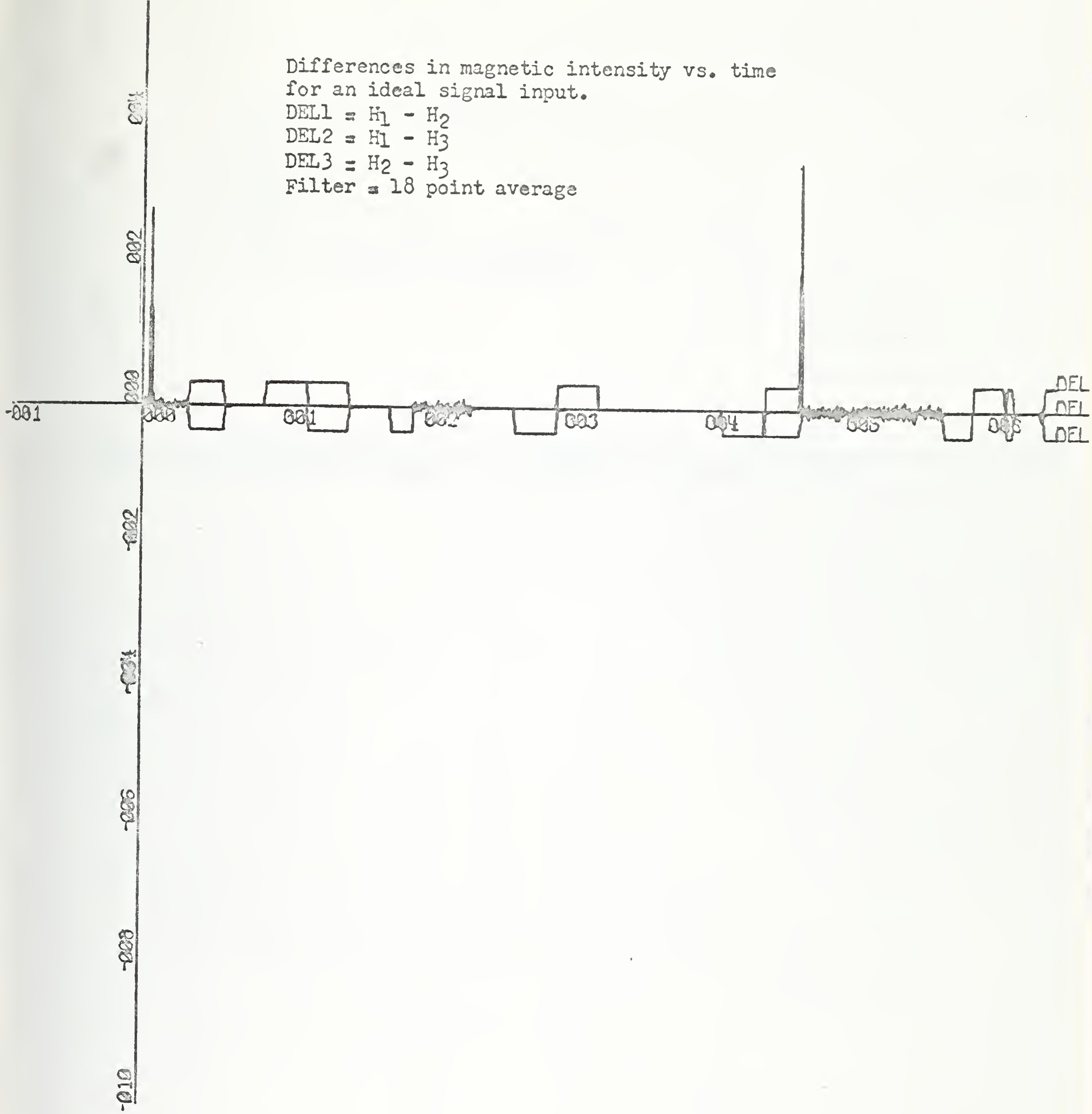


Figure 13

X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.
ANDERSON BOX 263
FIRST DIFFERENCE IN MAG FIELD T IN HRS H GAMMA

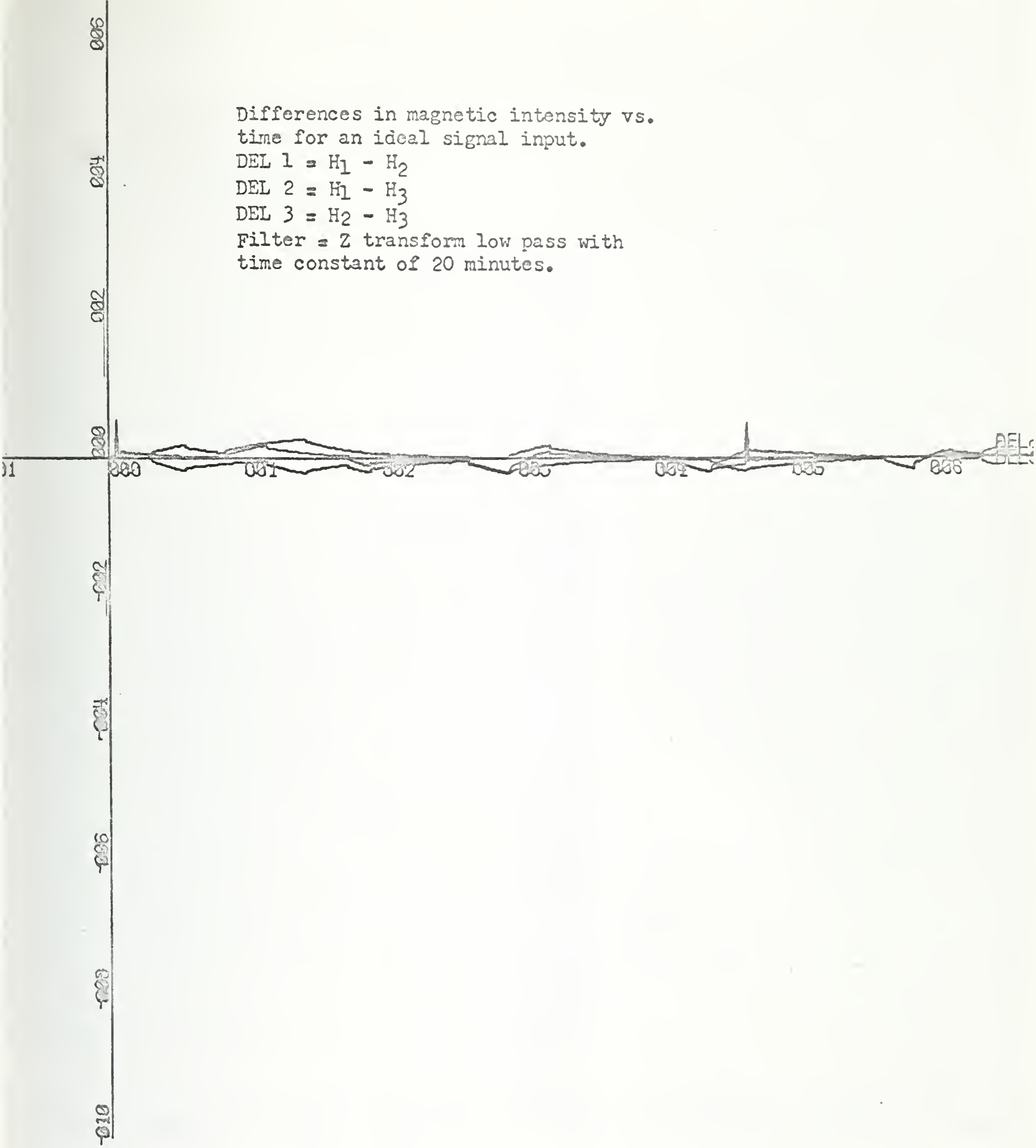


Figure 14

X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.
ANDERSON FILTER
FILTEREDDIFFERENCE IN MAG FIELD T IN HRS H GAMMA

Normalized density function for the difference $H_1 - H_2 - \text{mean}\,(H_1 - H_2)$, with an ideal signal input.
Mean = 0.061 gamma
Standard deviation = 0.21

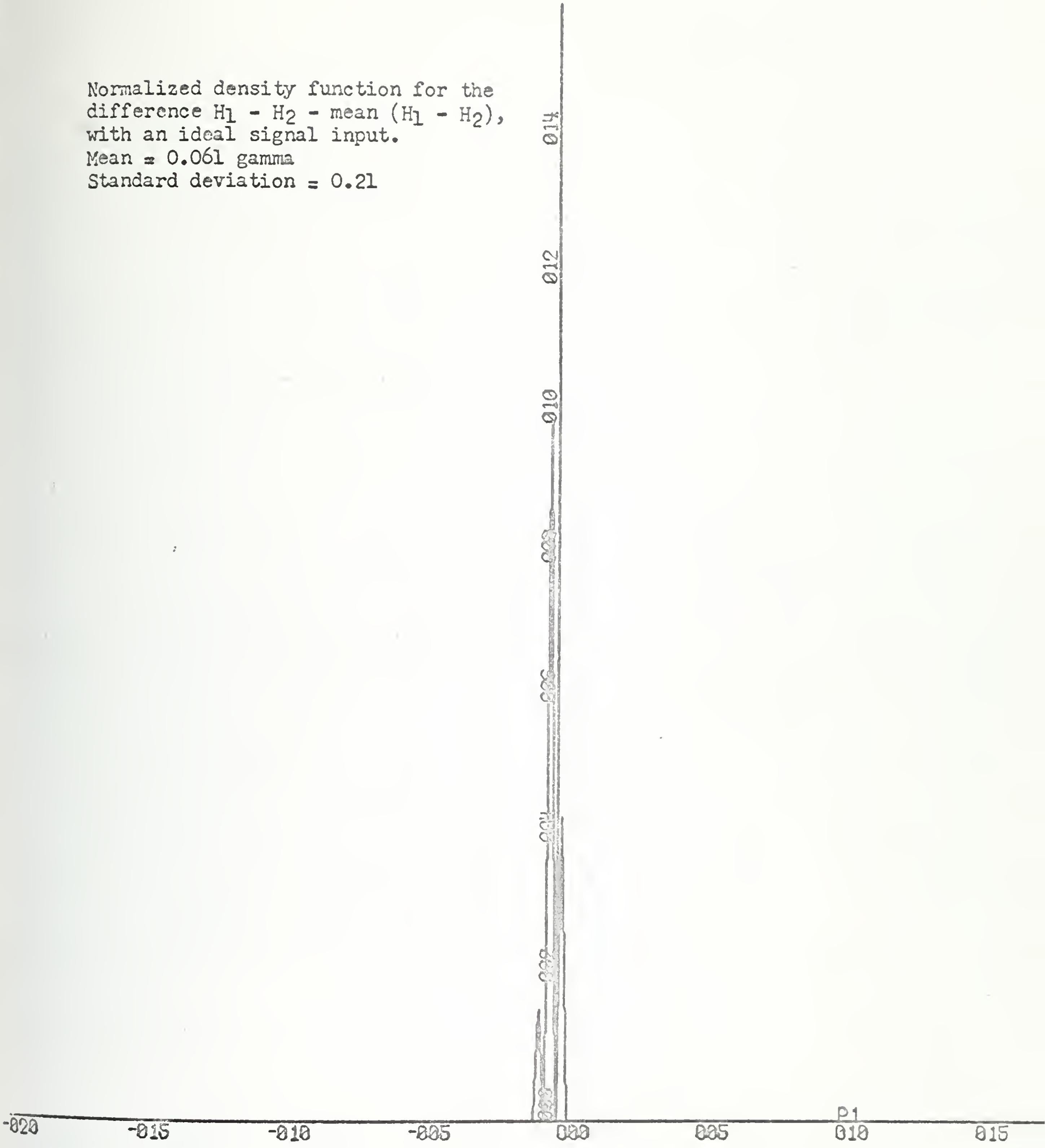


Figure 15

X-SCALE = 5.00E+00 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.
ANDERSON BOX 263
DENSITY FUNCTION X IN GAMMA Y IN FREQ

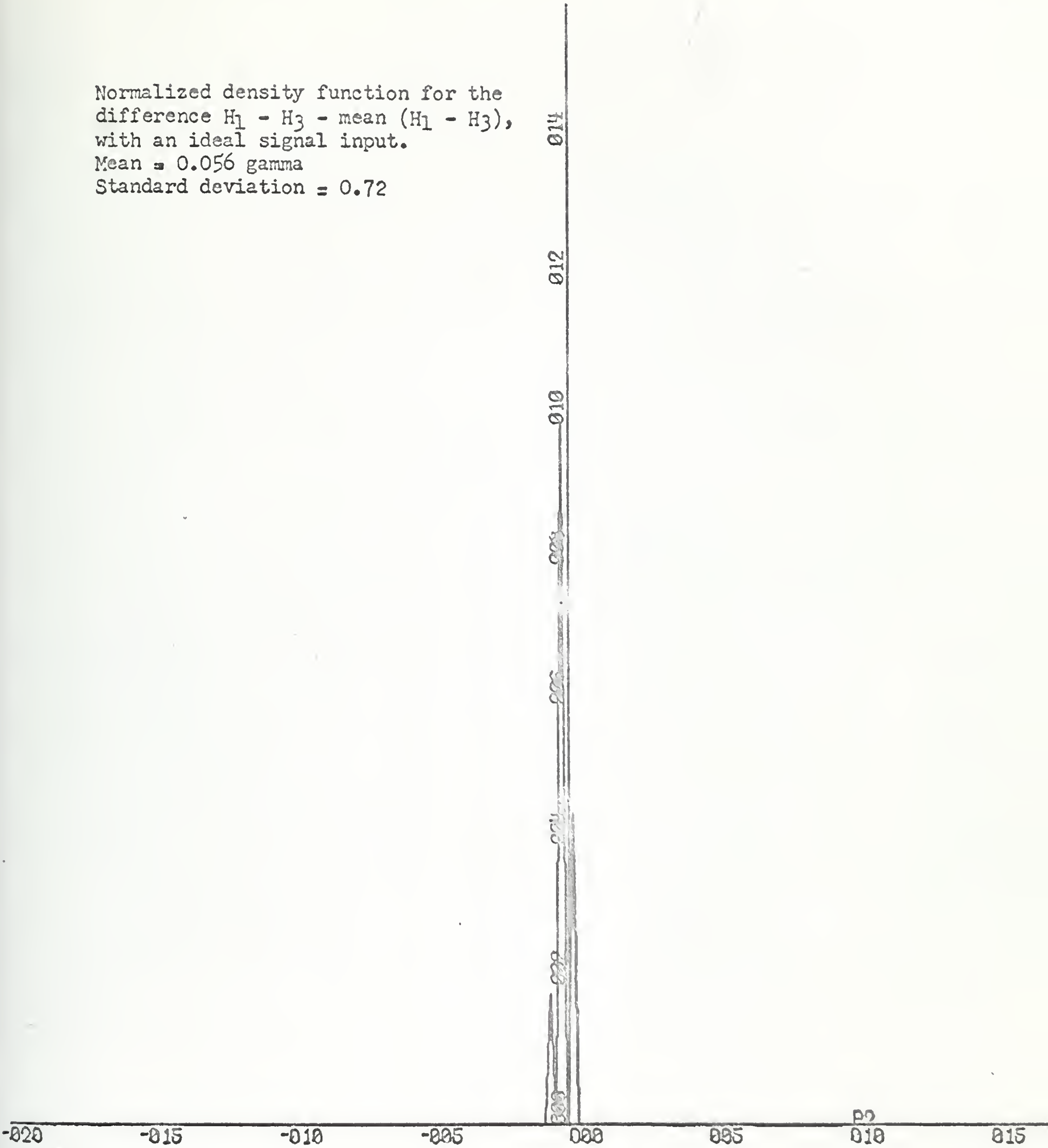


Figure 16

X-SCALE = 5.00E+00 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.
ANDERSON BOX 263
DENSITY FUNCTION X IN GAMMA Y IN FREQ

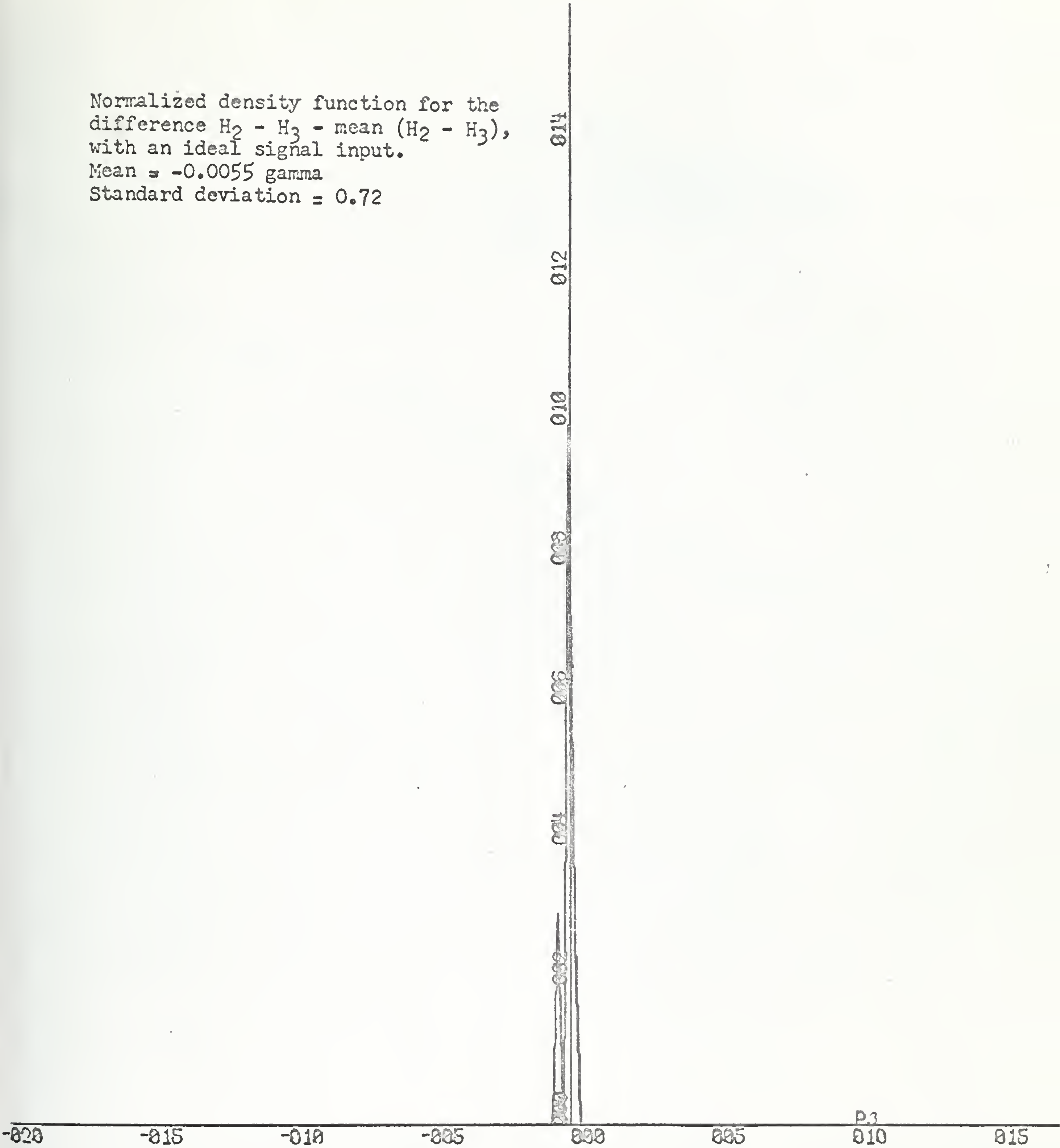


Figure 17

X-SCALE = 5.00E+00 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.
ANDERSON BOX 263
DENSITY FUNCTION X IN GAMMA Y IN FREQ

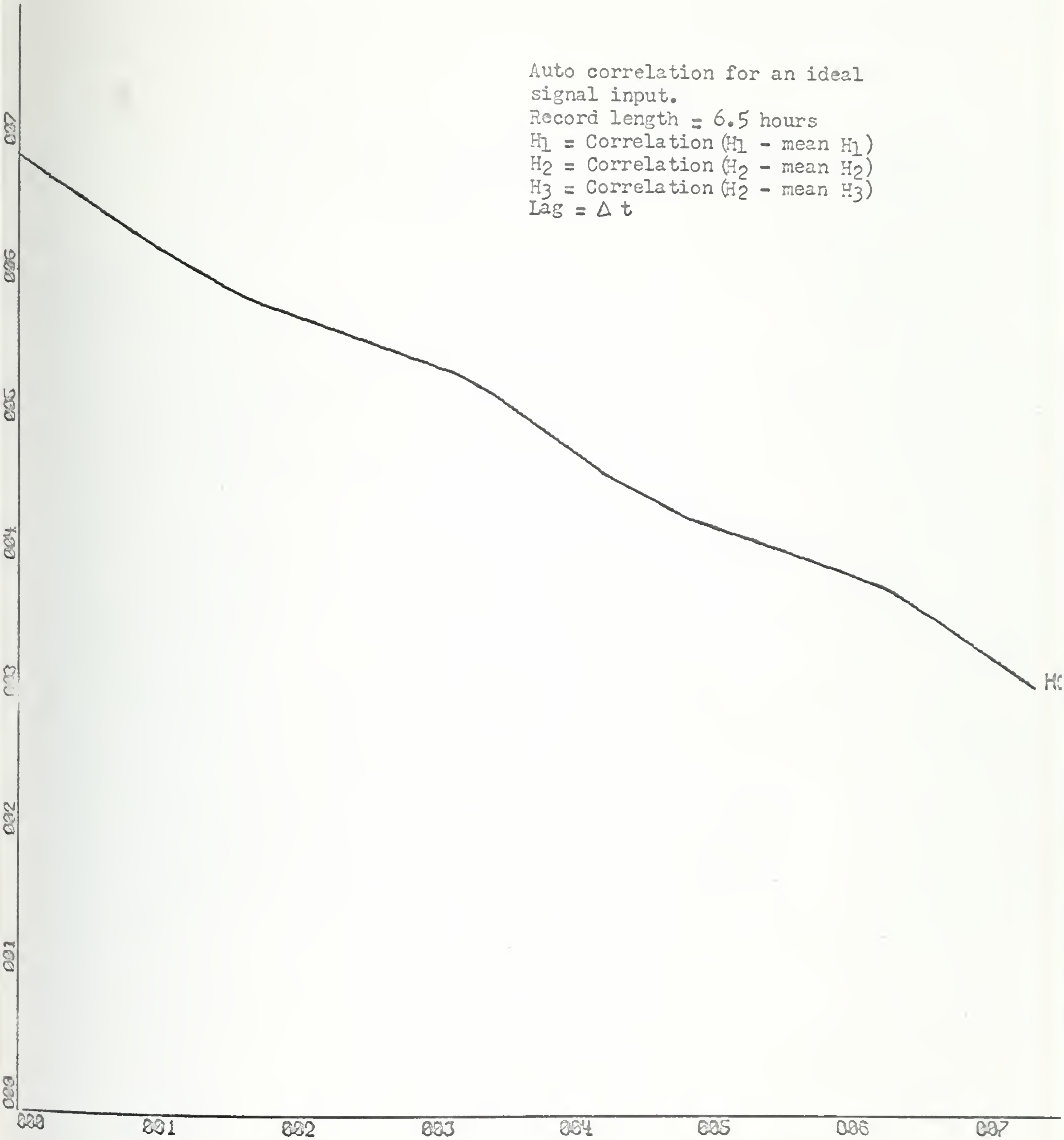


Figure 18

X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 1.00E+04 UNITS/INCH.
ANDERSON BOX 263
AUTOCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS

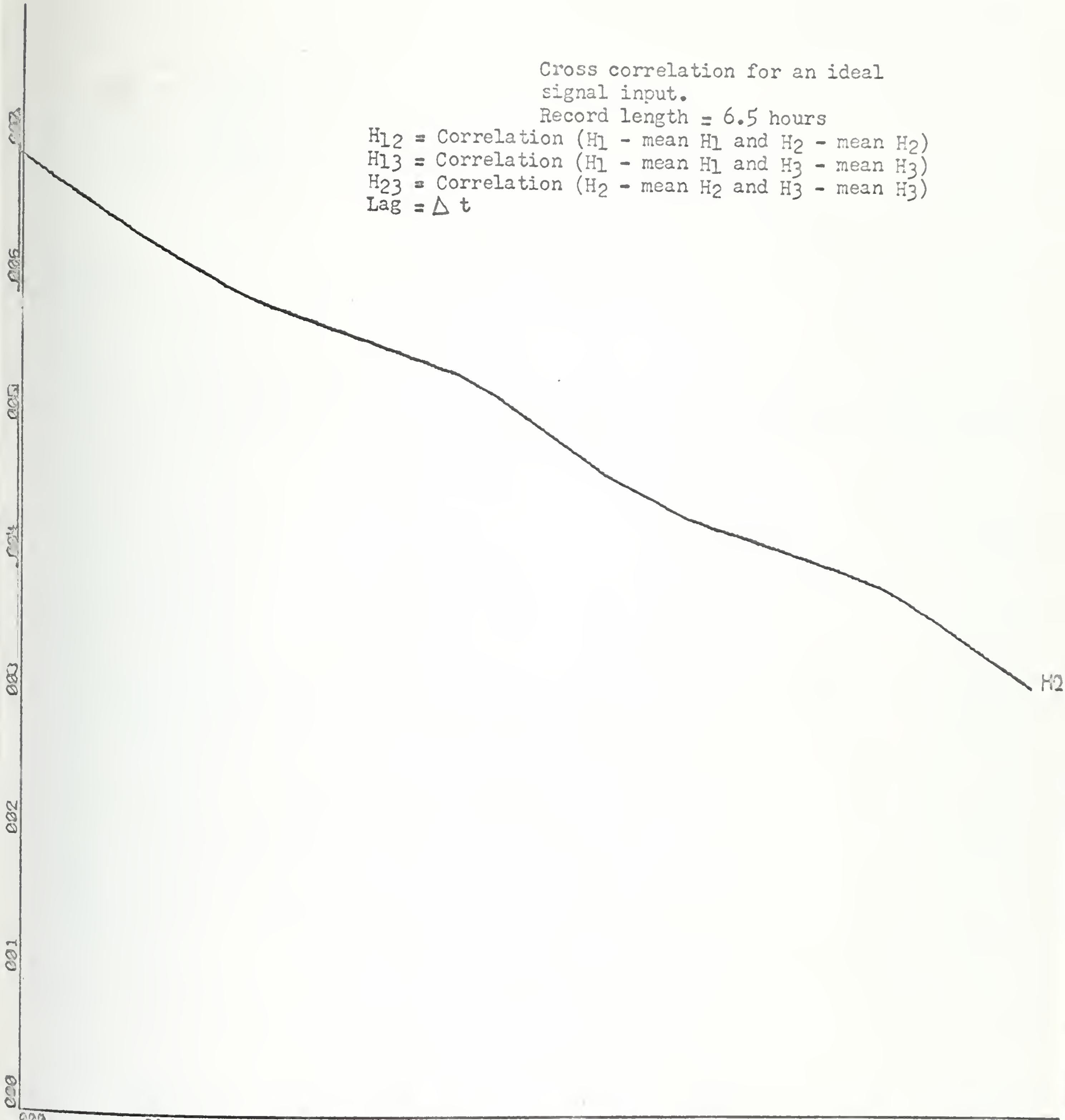


Figure 19

X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 1.00E+04 UNITS/INCH.
ANDERSON BOX 263
CROSCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS

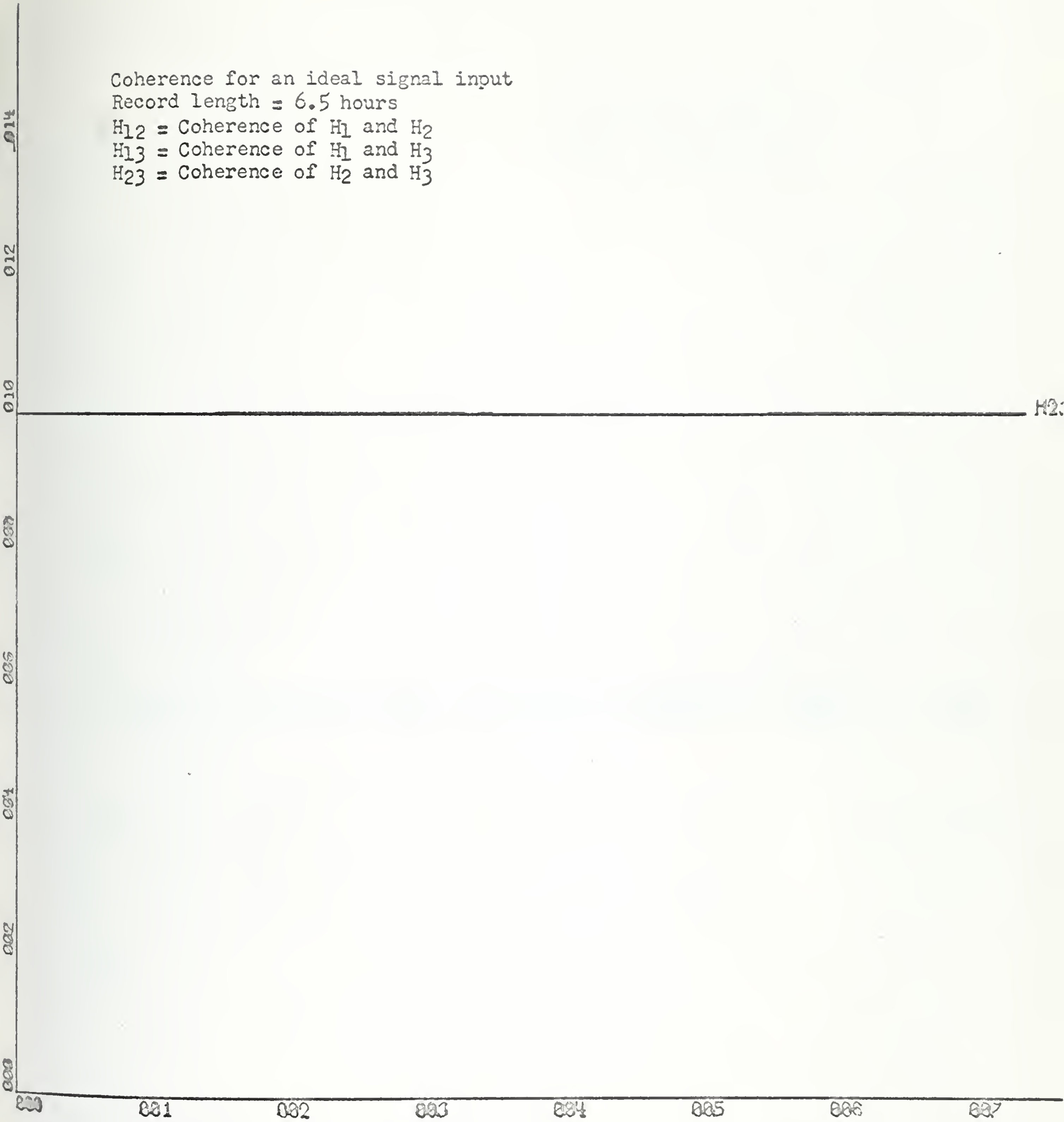
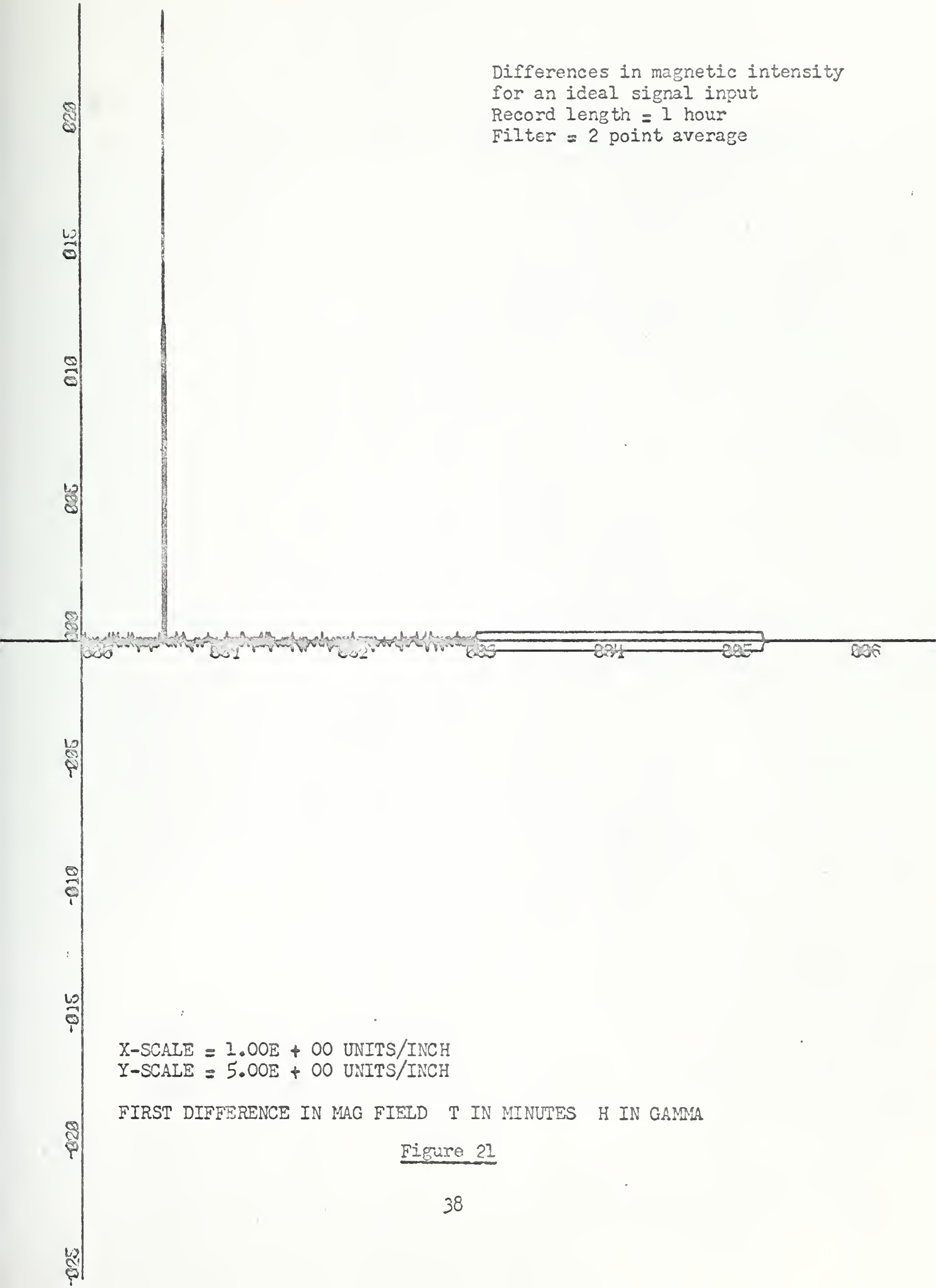


Figure 20

X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.
ANDERSON BOX 263
COHERENCE FUNCTION Y IN COH X IN LAGS



FIRST DIFFERENCE IN MAG FIELD   T IN MINUTES   H IN GAMMA

Figure 21

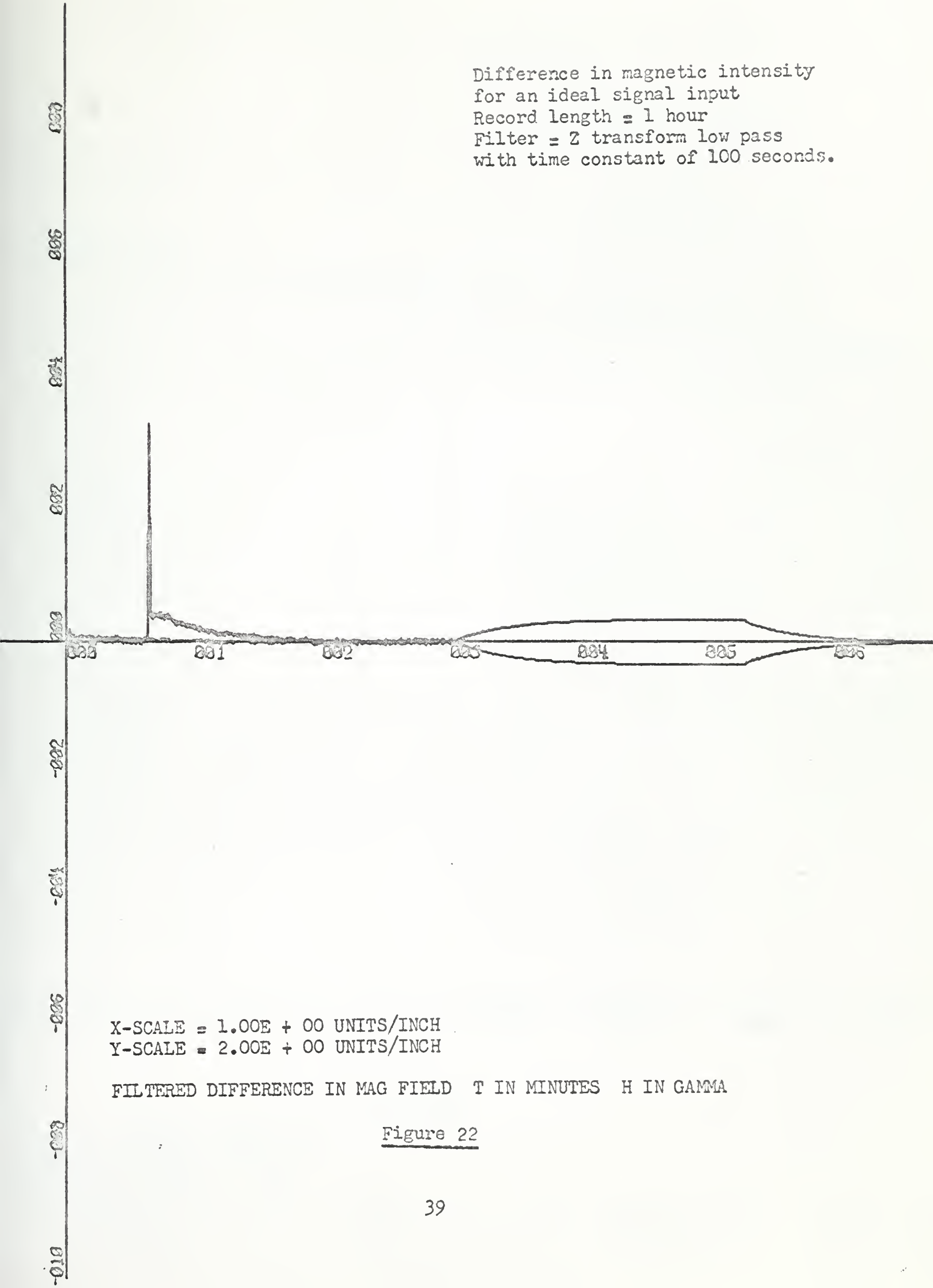

Difference in magnetic intensity
for an ideal signal input
Record length = 1 hour
Filter = Z transform low pass
with time constant of 100 seconds.
008
006
004
002
000
-002
-004
-006
-008
-010
000
001
002
003
004
005
006
X-SCALE = 1.00E + 00 UNITS/INCH
Y-SCALE = 2.00E + 00 UNITS/INCH
FILTERED DIFFERENCE IN MAG FIELD T IN MINUTES H IN GAMMA

Figure 22

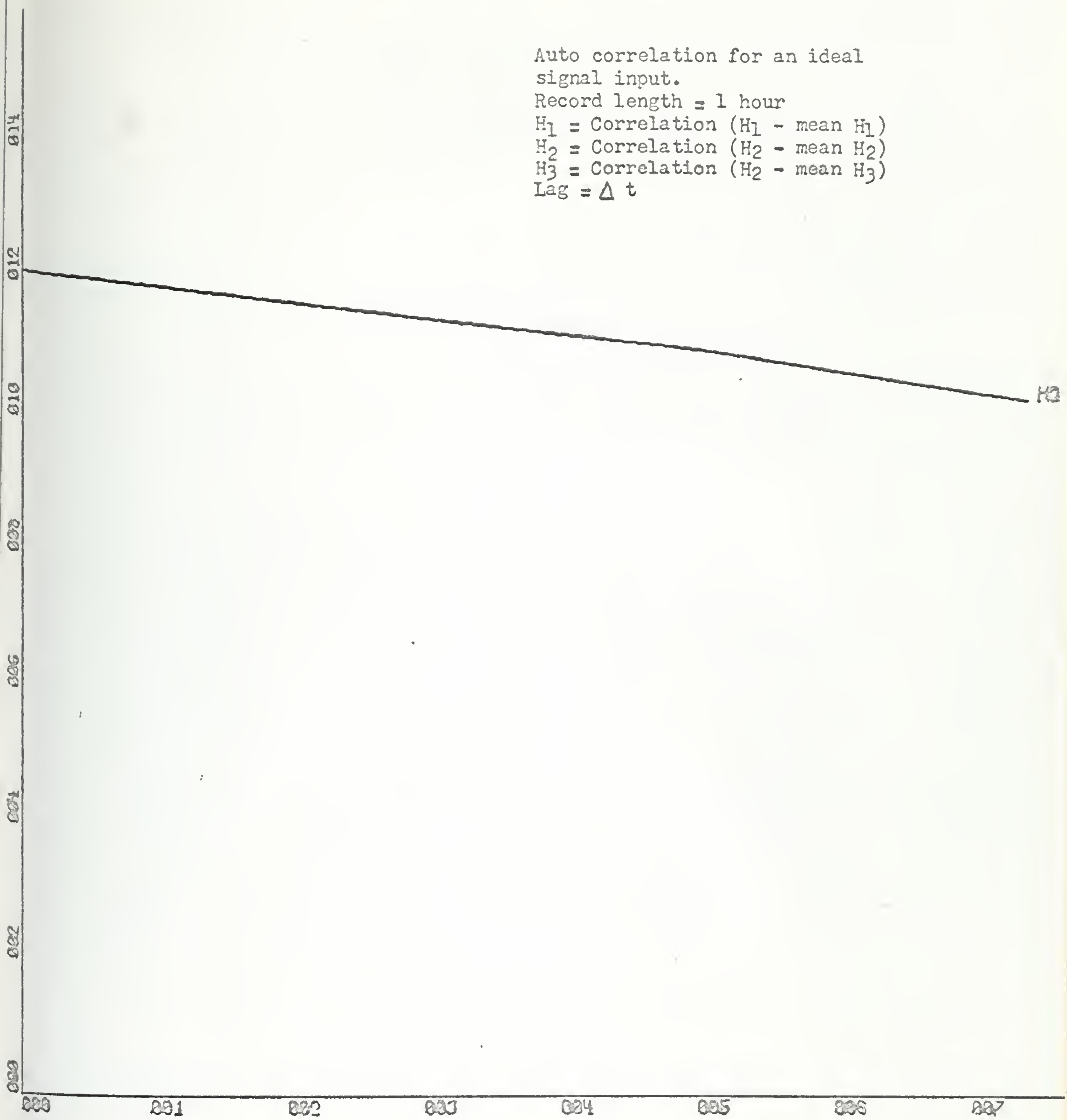


Figure 23

X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+03 UNITS/INCH.

ANDERSON BOX 263
AUTOCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS

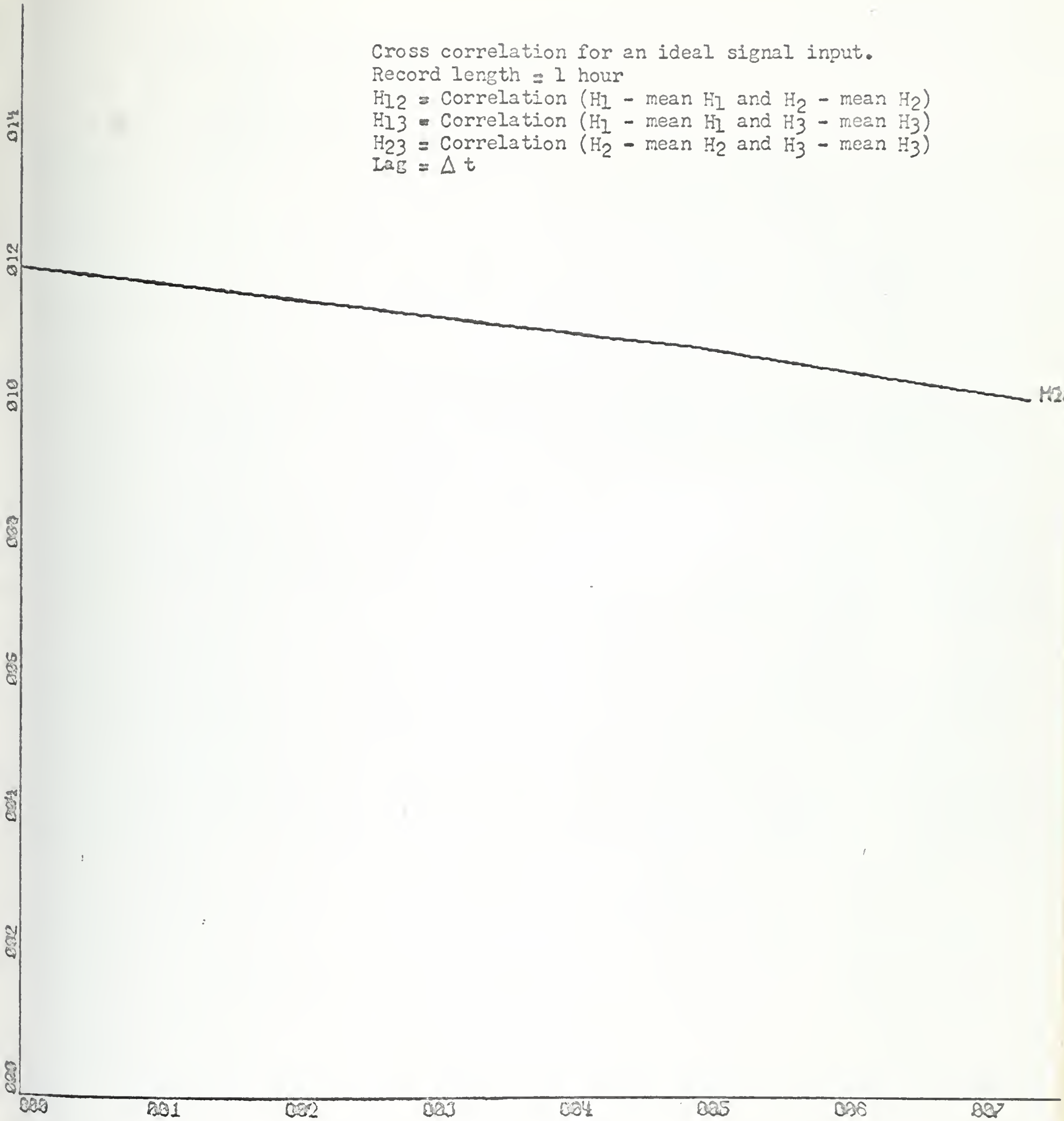


Figure 24

X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+03 UNITS/INCH.

ANDERSON BOX 263
CROSCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS

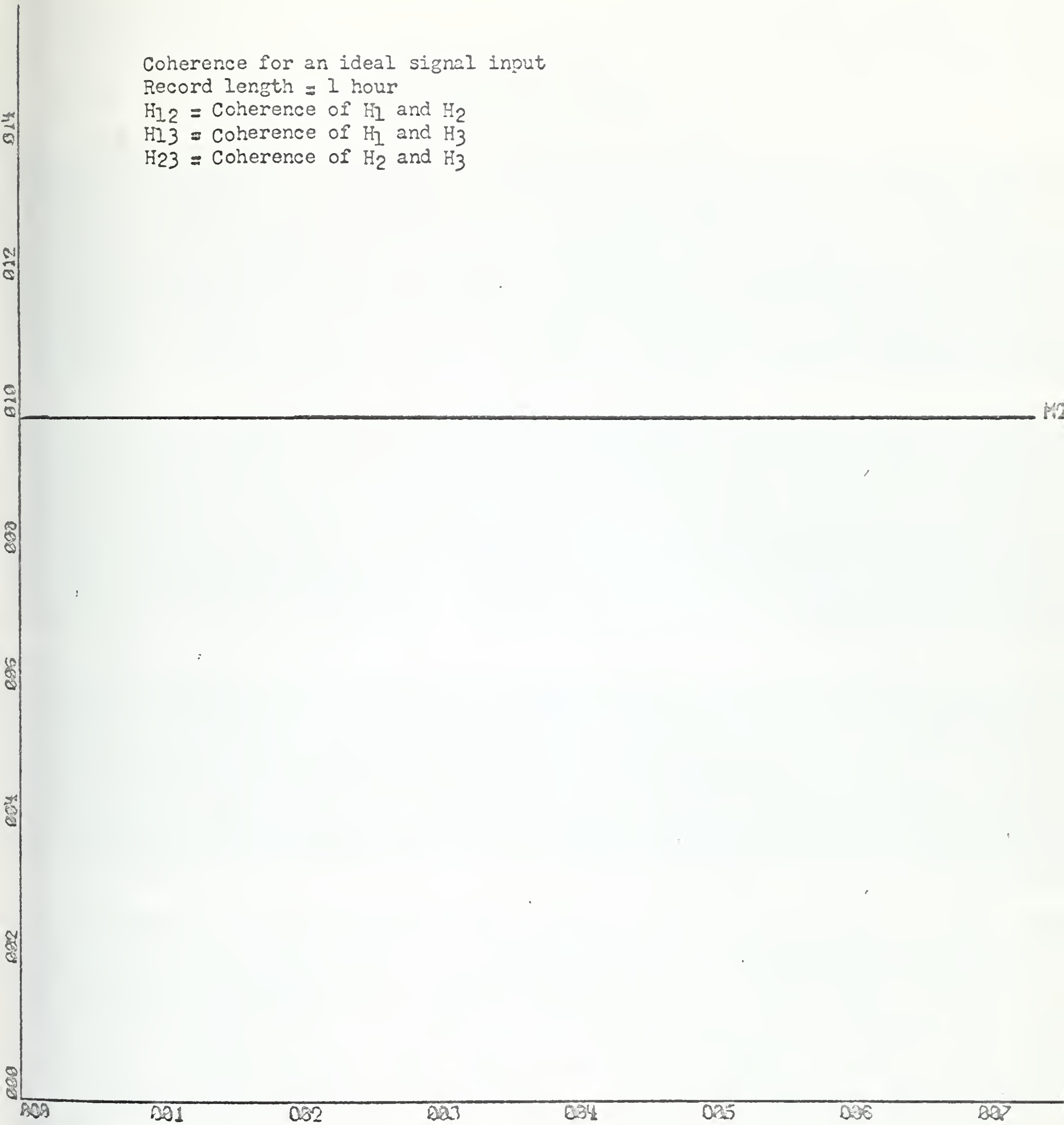


Figure 25

X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.
ANDERSON BOX 263
COHERENCE FUNCTION Y IN COH X IN LAGS

TYPICAL ANALOG PLOT OF
MAGNETIC INTENSITY VS. TIME
FILTER = RC WITH TIME CONSTANT OF 6 SECONDS

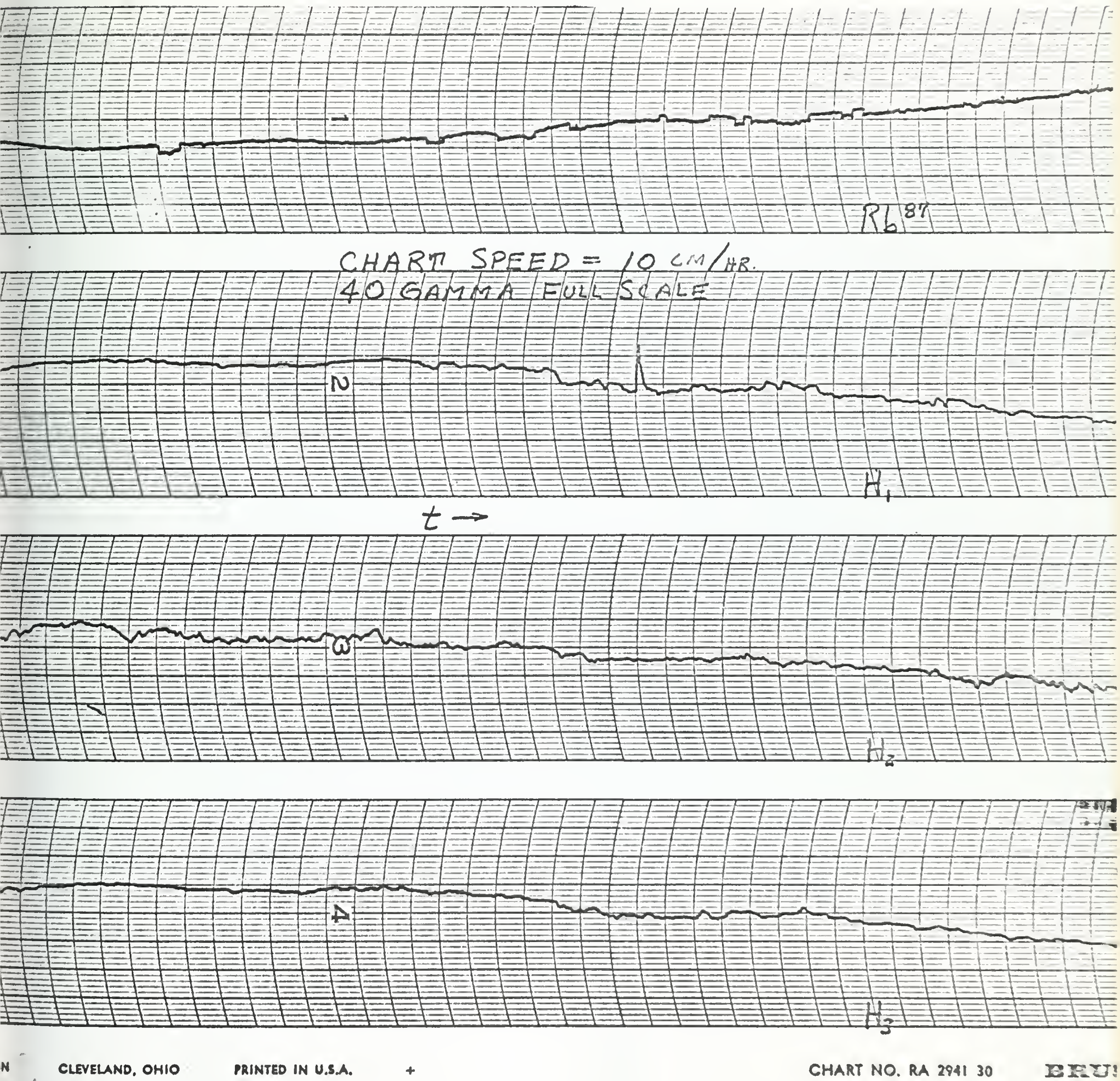


FIGURE 26

TYPICAL ANALOG PLOT OF
THE DIFFERENCES VS. TIME
FILTER = RC WITH TIME CONSTANT OF 6 SECONDS

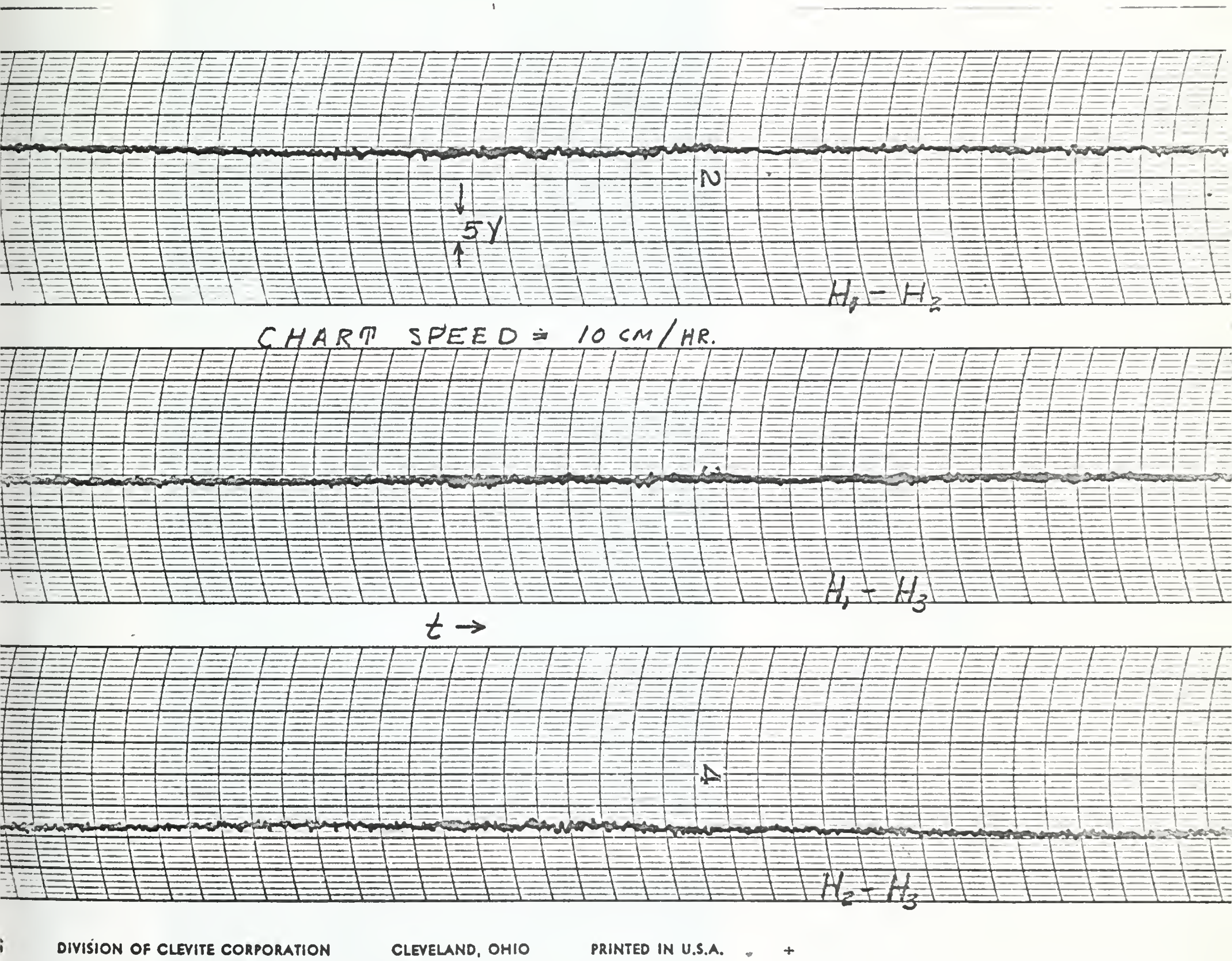
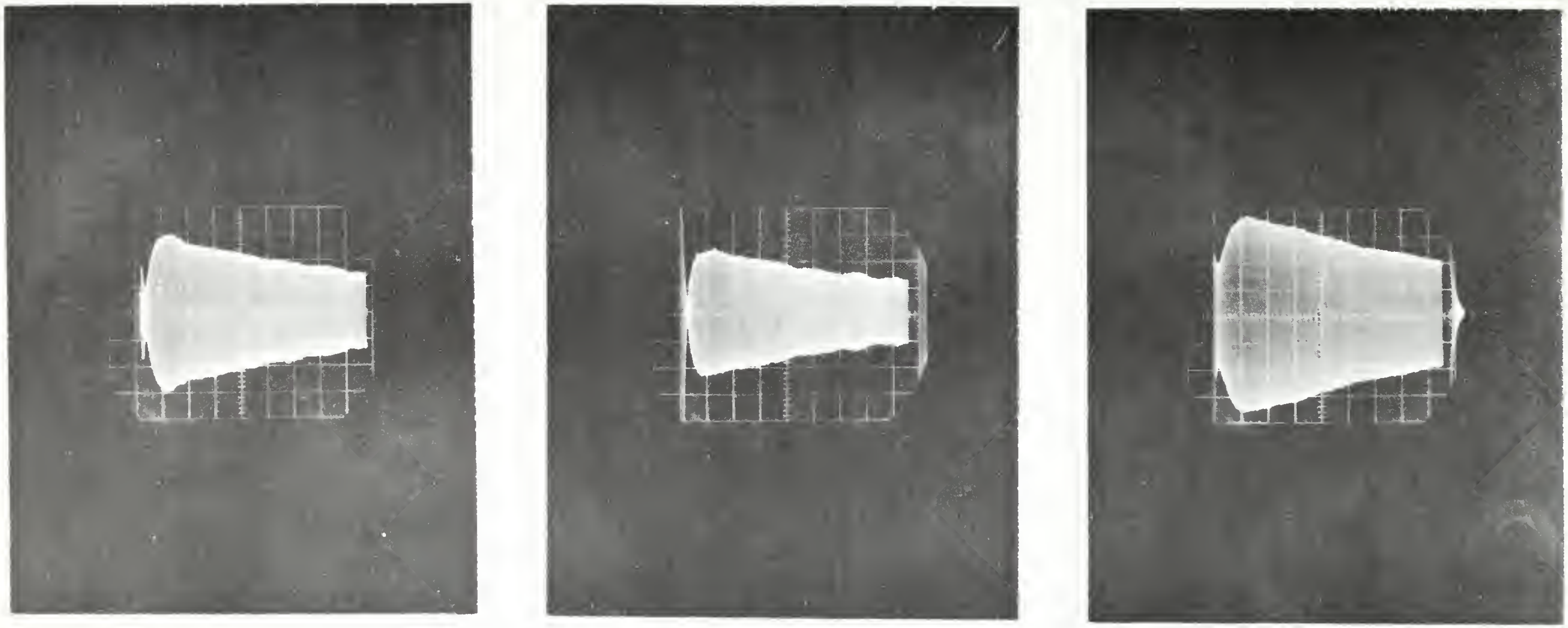


FIGURE 27



H_1 H_2 H_3

PRECESSION SIGNALS FROM THE THREE SENSORS AFTER PREAMPLIFICATION
HORIZONTAL = 0.1 SEC/CM
VERTICAL = 0.1 VOLT/CM

FIGURE 28

4.2 Magnetic field measurements

Only representative results of the magnetic field measurements are presented, since the measurements are not complete at this time. Samples of plots made with the clock at 100 kc/s are included to illustrate the effect of the clock frequency on the results. For the associated density function of the differences, the allowable values are $0 \pm 1.1, \pm 2.2, \pm \ldots$ in gamma, with the clock at 100 kc/s. The expanded difference vs. time shows clearly the $\pm$ last bit limitation. Comparing the density functions with the plots for the clock at 300 kc, shows that most of the noise associated with the measurement is due to the last bit and can be reduced by increasing the clock frequency. The perturbation experiments were conducted with the clock at 300 kc/s. The results of the perturbation experiments show clearly the effect of the digital filtering, and the importance of time constant consideration for target detection. The oscillator is to be run 1 mc/s for further experiments. Also, many of the errors that appear in the data were the direct result of the instrumentation tape. New tape has been purchased and should eliminate most of these errors, in future records.

As pointed out previously, the basic assumptions regarding correlation are not valid, when the noise is not stationary; however, since correlation detectors can be instrumented and may prove useful in the detection problem. Some of the correlation function plots are included to illustrate the effect of local perturbations on the functions.

5. Conclusions

For target detection, where the signals under consideration are in the $\frac{1}{2}$ gamma, or less range, it will be difficult to detect the target without resorting to sophisticated signal processing. In this range of signals, consideration should be given to other instruments; such as the Rubidium optically pumped magnetometer, whose theoretical sensitivity is 0.001 gamma, especially where the detector is stationary, and orientation is not a problem. It can be demonstrated that when using the same measurement technique as for the proton magnetometer, the instrument and processing noise will be an order of magnitude less than the theoretical limits imposed by the sensitivity of the instrument.

For signals in the $\frac{1}{2}$ to $1\frac{1}{2}$ gamma range, detection could be accomplished with analog type correlation detectors. These could be implemented with operational amplifiers.

Signals above this range could be detected with the simple differencing technique, and the associated R.C. filters.

Increasing the clock frequency and averaging the period over more than 1024 cycles would reduce the measurement noise to a smaller part of the total noise. The target signals could then be reduced by a factor of three, with no change in the instrumentation.

Full utilization of the inherently narrow line width of proton magnetometer cannot be achieved using the standard measuring technique. Other techniques have been suggested by Professor Carl I. Menneken; such as utilizing a rapid coherent polarization in a phase-lock loop arrangement. Further development work needs to be done to explore these possibilities.

BIBLIOGRAPHY

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3. Alexander Hoffman, Geophysical Interpretations of Power Spectral Analysis of Low Frequency Fluctuations in the Magnetotelluric Field, University of Texas, Ph.D. Thesis, 1962.

4. A. W. Green, Jr., B. H. List and J.F.P. Zengel, Theory, Measurement and Applications of Very-Low-Frequency Magnetotelluric Variations, Proceedings of the I. R. E., Vol. 50, No. 11, pp. 2347 - 2363, Nov., 1962.

5. J. A. Jacobs and K. Sinno, Occurrence Frequency of Geomagnetic Micropulsations, Journal of Geophysical Research, Vol. 65, No. 1, pp. 107 - 113, Jan., 1960.

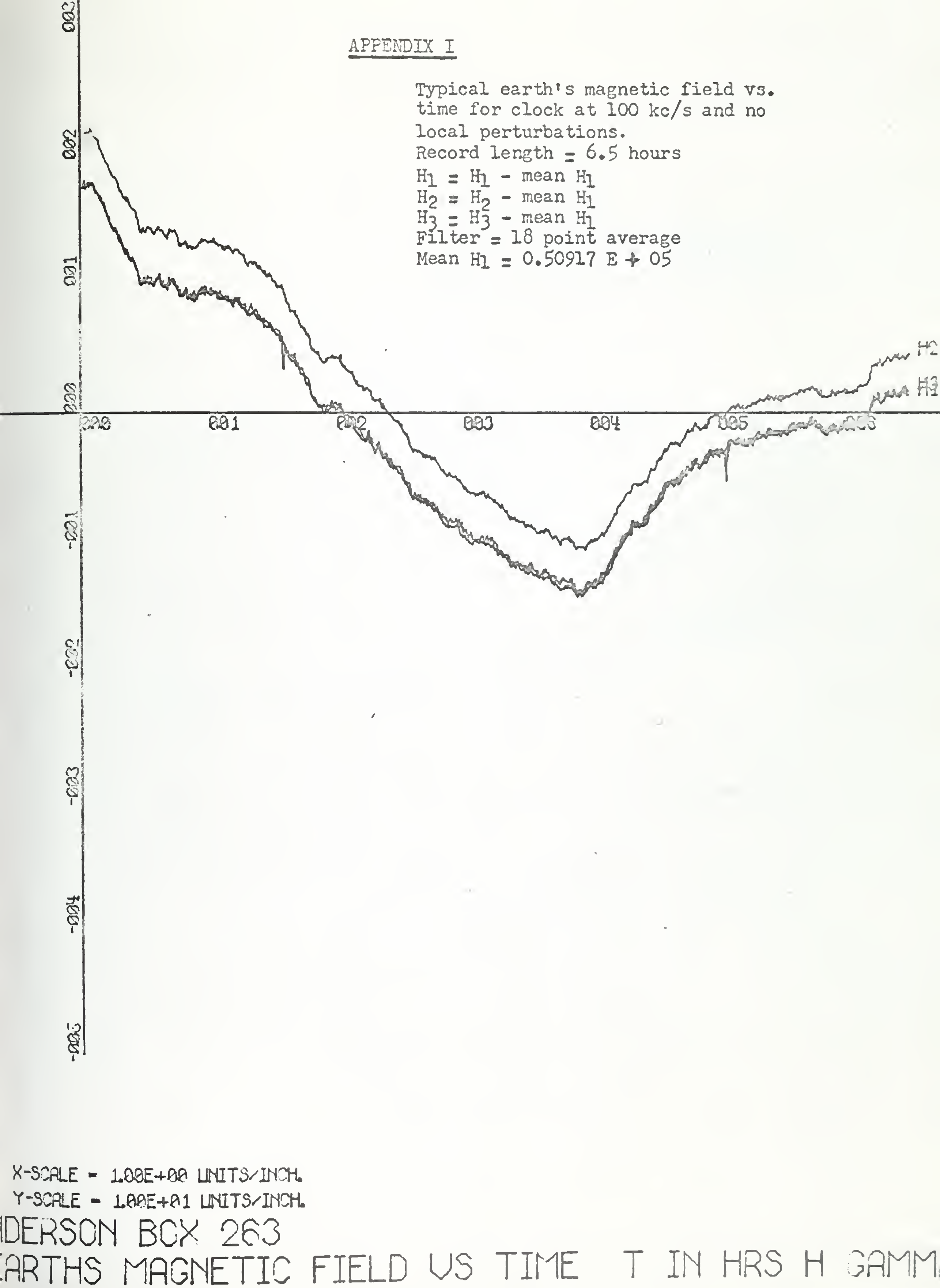
6. Ragazzini and Franklin, Sampled Data Control Systems, McGraw Hill, 1958.

A P P E N D I C E S

APPENDIX I

RESULTS OF
MAGNETIC FIELD
AND PERTURBATION
EXPERIMENTS

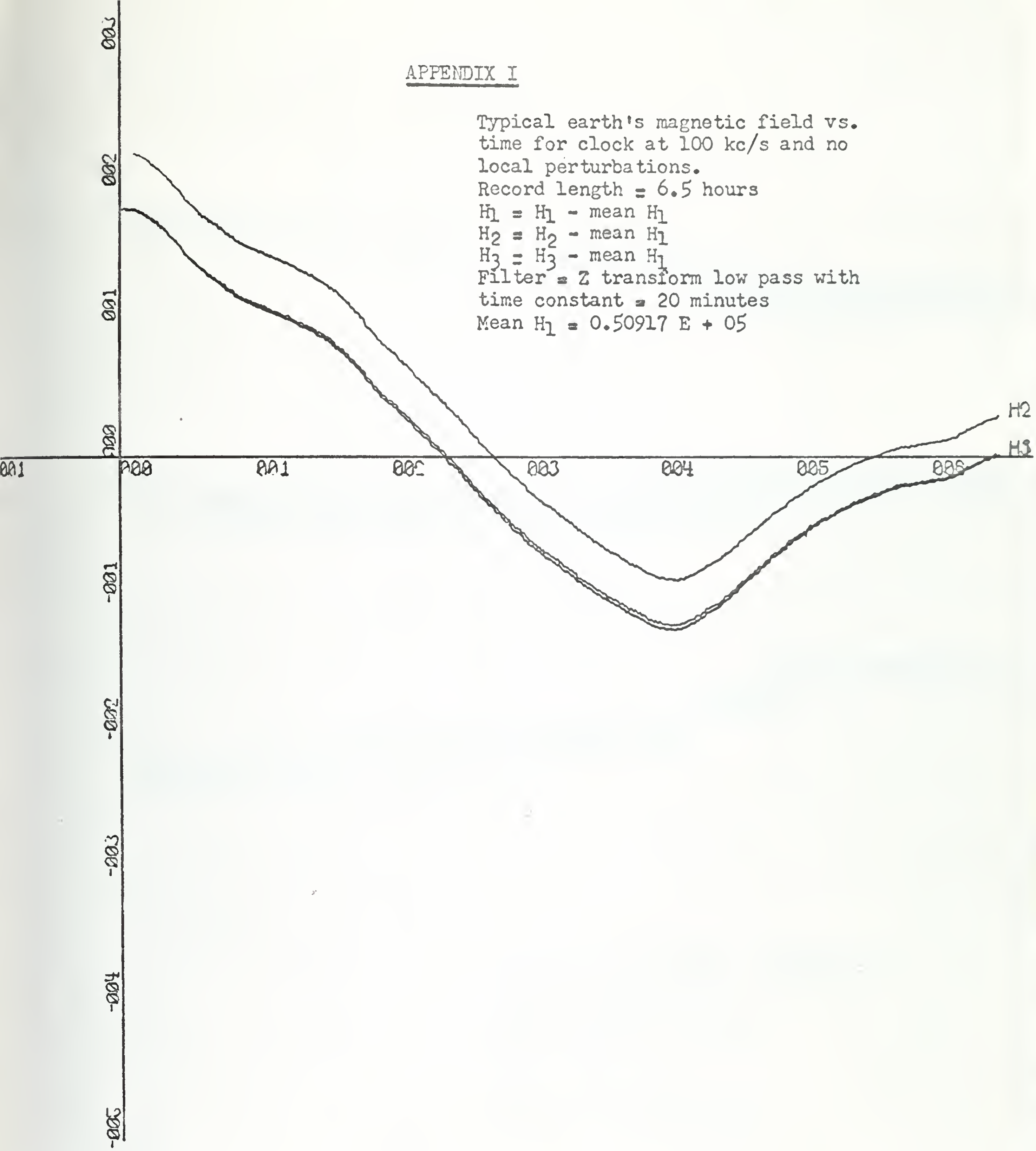
APPENDIX I



Typical earth's magnetic field vs. time for clock at 100 kc/s and no local perturbations.
Record length = 6.5 hours
$H_1 = H_1$ - mean H_1
$H_2 = H_2$ - mean H_1
$H_3 = H_3$ - mean H_1
Filter = 18 point average
Mean H_1 = 0.50917 E + 05

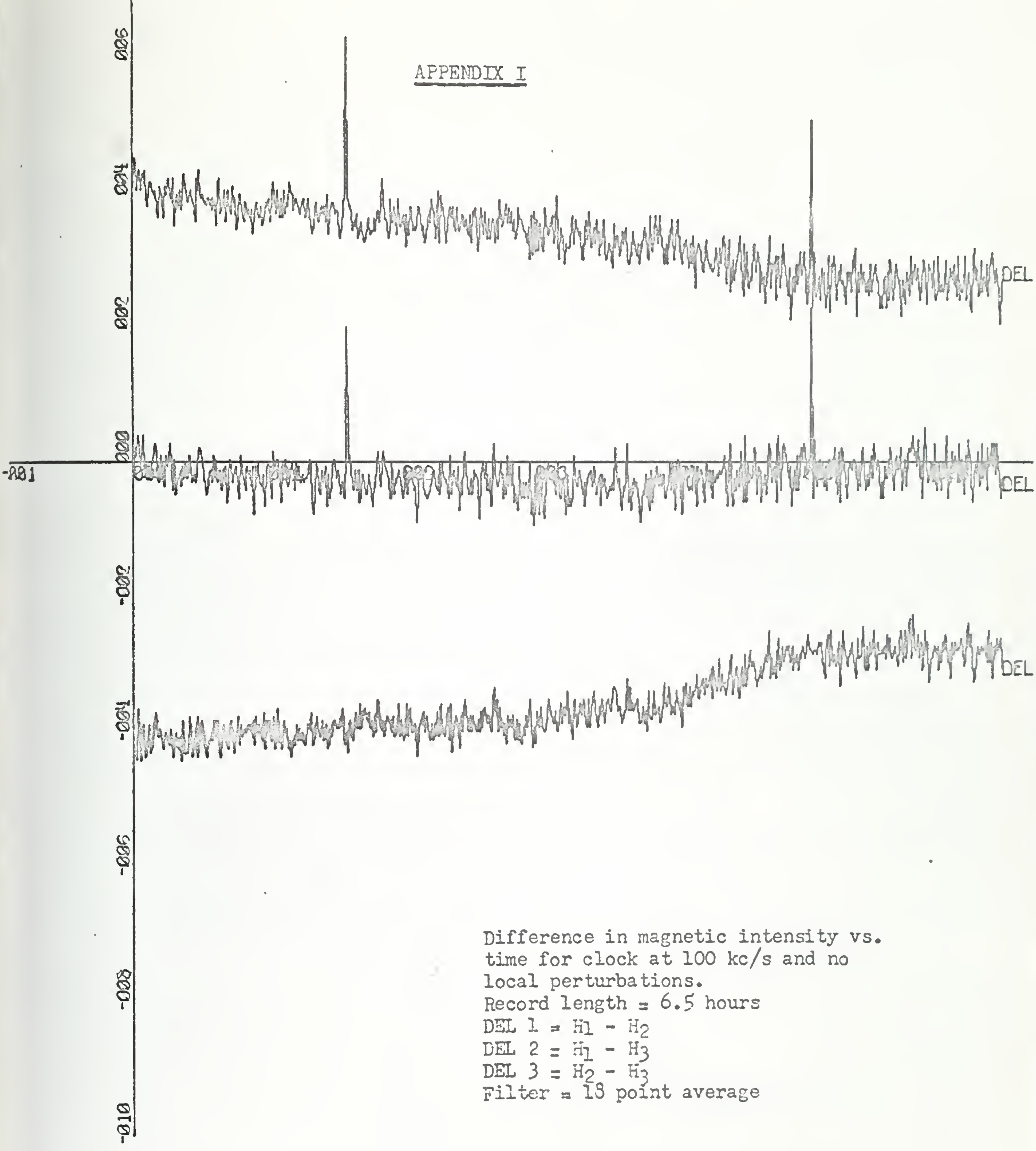
APPENDIX I

Typical earth's magnetic field vs. time for clock at 100 kc/s and no local perturbations.
Record length = 6.5 hours
$H_1 = H_1$ - mean H_1
$H_2 = H_2$ - mean H_1
$H_3 = H_3$ - mean H_1
Filter = Z transform low pass with time constant = 20 minutes
Mean H_1 = 0.50917 E + 05



X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 1.00E+01 UNITS/INCH.
ANDERSON FILTER
EARTHS MAGNETIC FIELD VS TIME T IN HRS H GAMMA

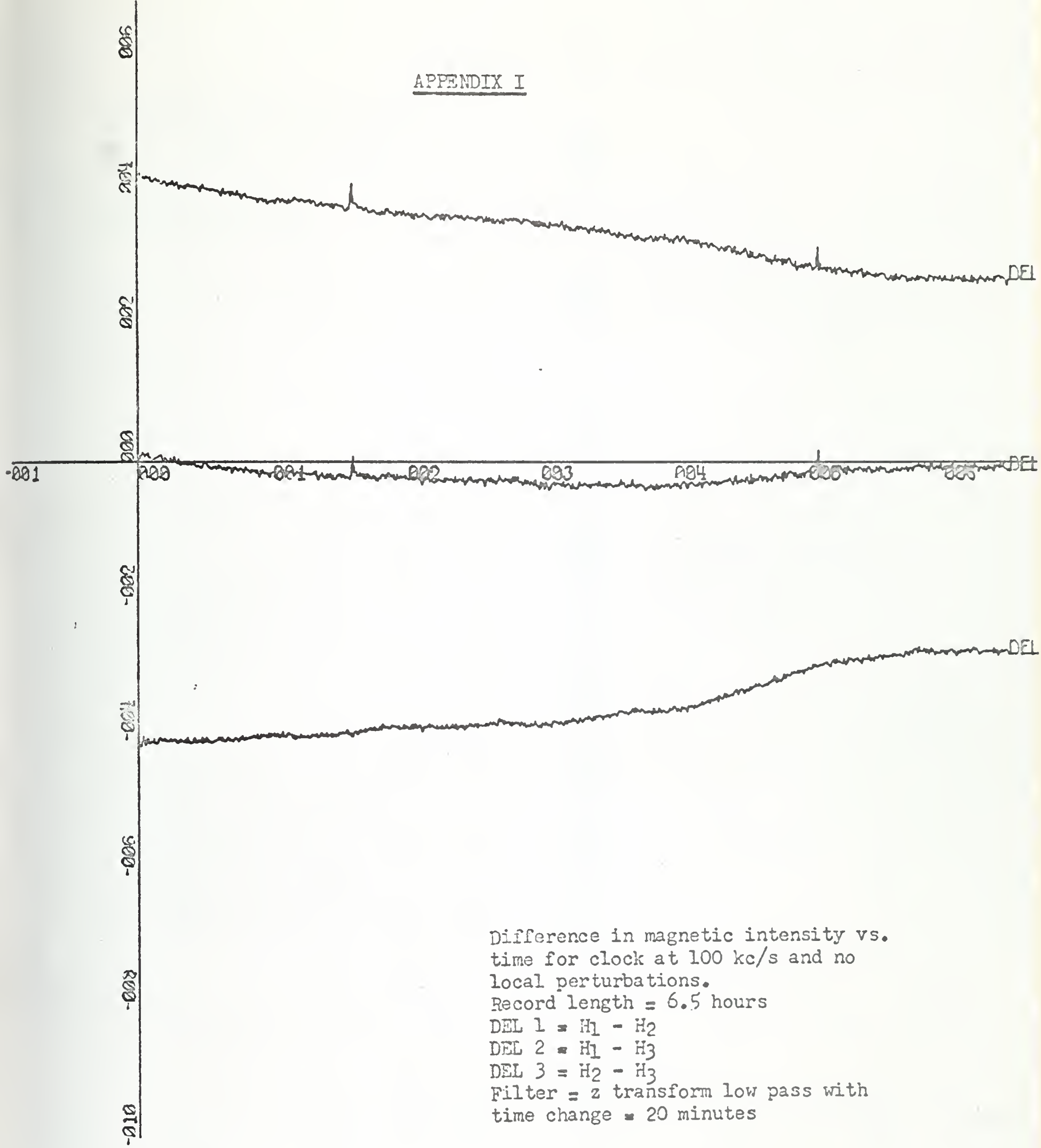
APPENDIX I



Difference in magnetic intensity vs.
time for clock at 100 kc/s and no
local perturbations.
Record length = 6.5 hours
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$
Filter = 18 point average

X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.
ANDERSON BOX 263
FIRST DIFFERENCE IN MAG FIELD T IN HRS H GAMMA

APPENDIX I



Difference in magnetic intensity vs. time for clock at 100 kc/s and no local perturbations.
Record length = 6.5 hours
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$
Filter = z transform low pass with time change = 20 minutes

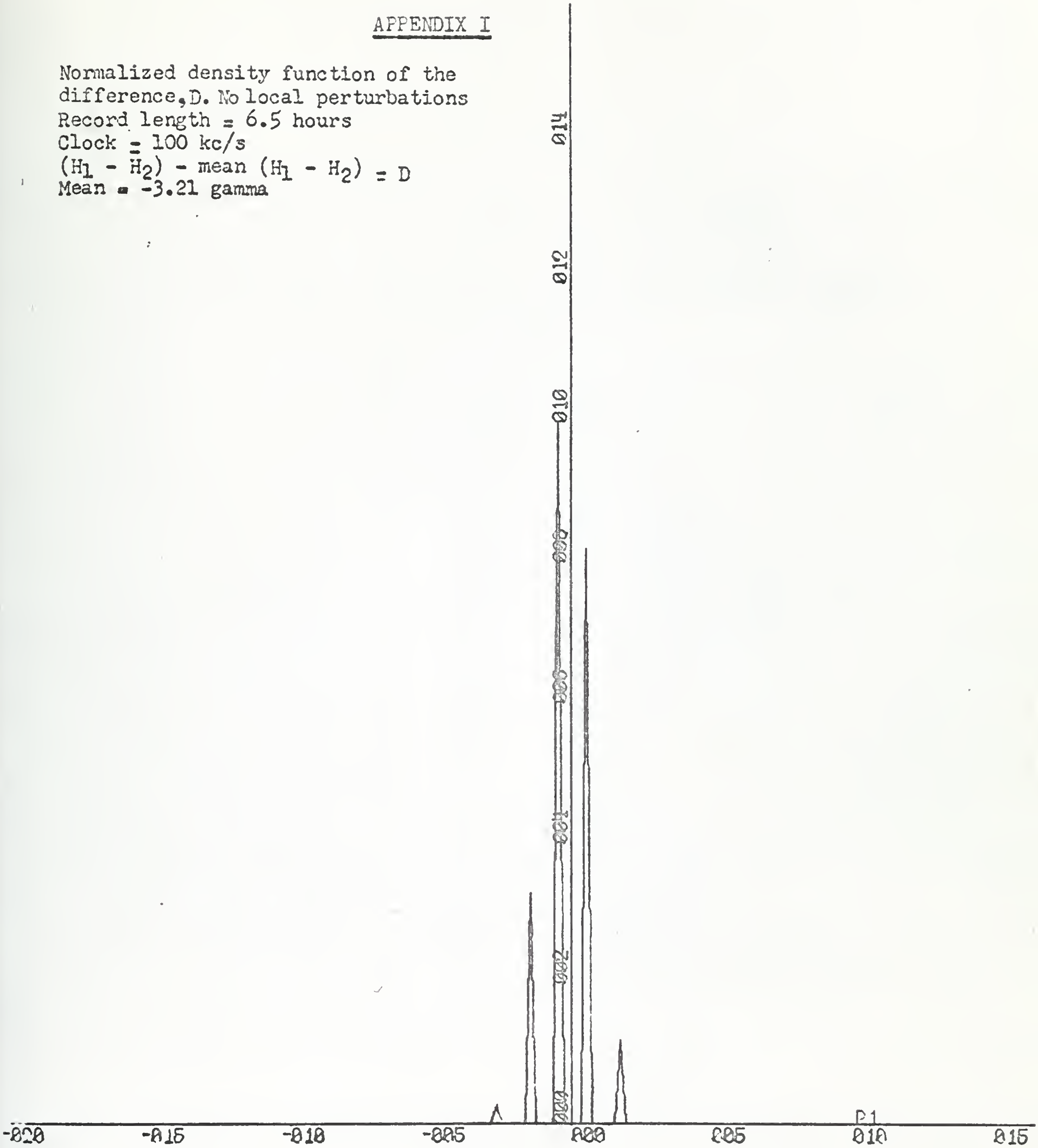
X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.

ANDERSON FILTER

FILTEREDDIFFERENCE IN MAG FIELD T IN HRS H GAMMA

APPENDIX I

Normalized density function of the difference, D. No local perturbations
Record length = 6.5 hours
Clock = 100 kc/s
$(H_1 - H_2)$ - mean $(H_1 - H_2)$ = D
Mean = -3.21 gamma

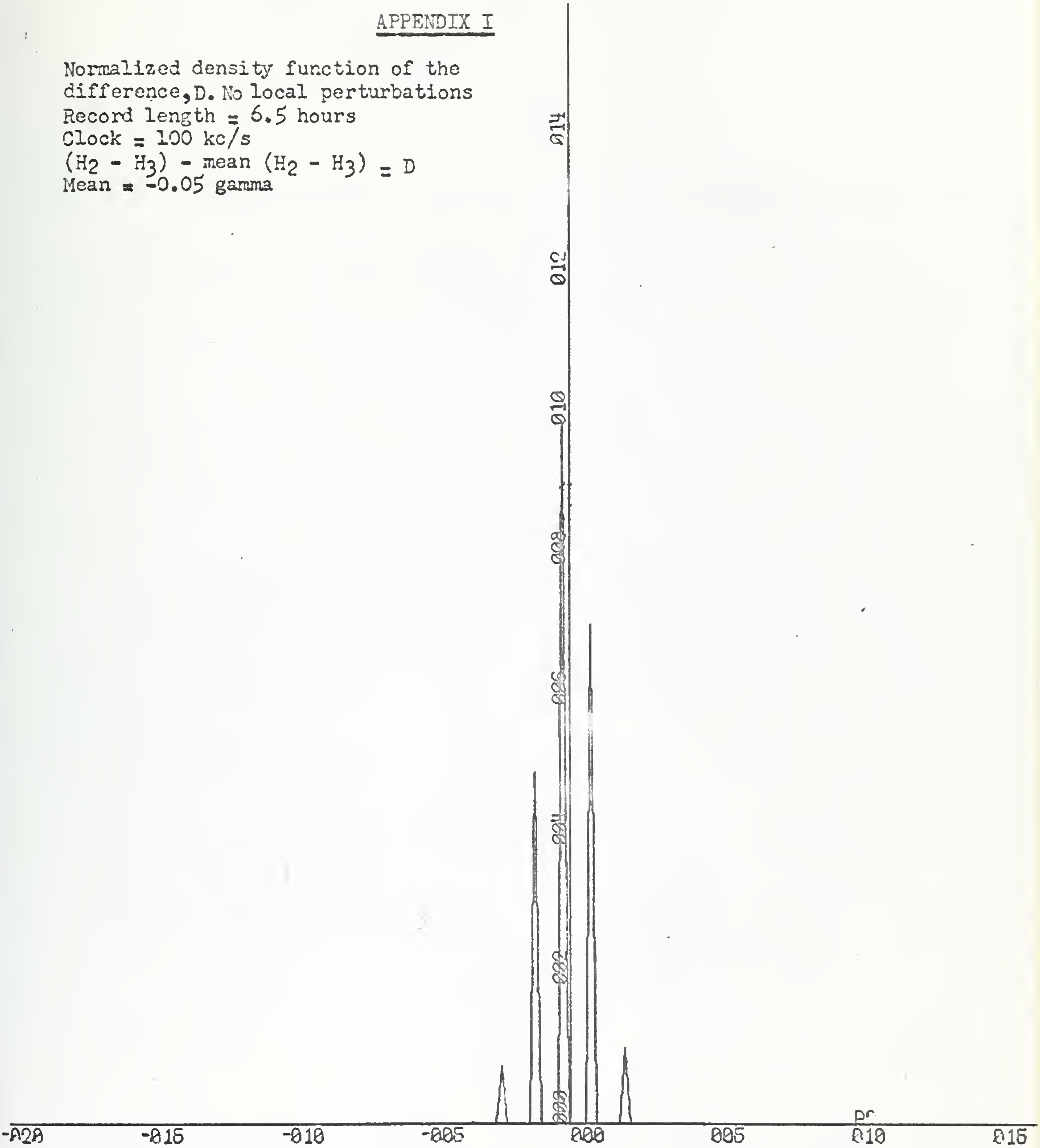


Y-SCALE = 5.00E+00 UNITS/INCH.
X-SCALE = 5.00E-01 UNITS/INCH.

ANDERSON BOX 263
DENSITY FUNCTION X IN GAMMA Y IN FREQ

APPENDIX I

Normalized density function of the difference, D. No local perturbations
Record length = 6.5 hours
Clock = 100 kc/s
$(H_2 - H_3)$ - mean $(H_2 - H_3) = D$
Mean = -0.05 gamma

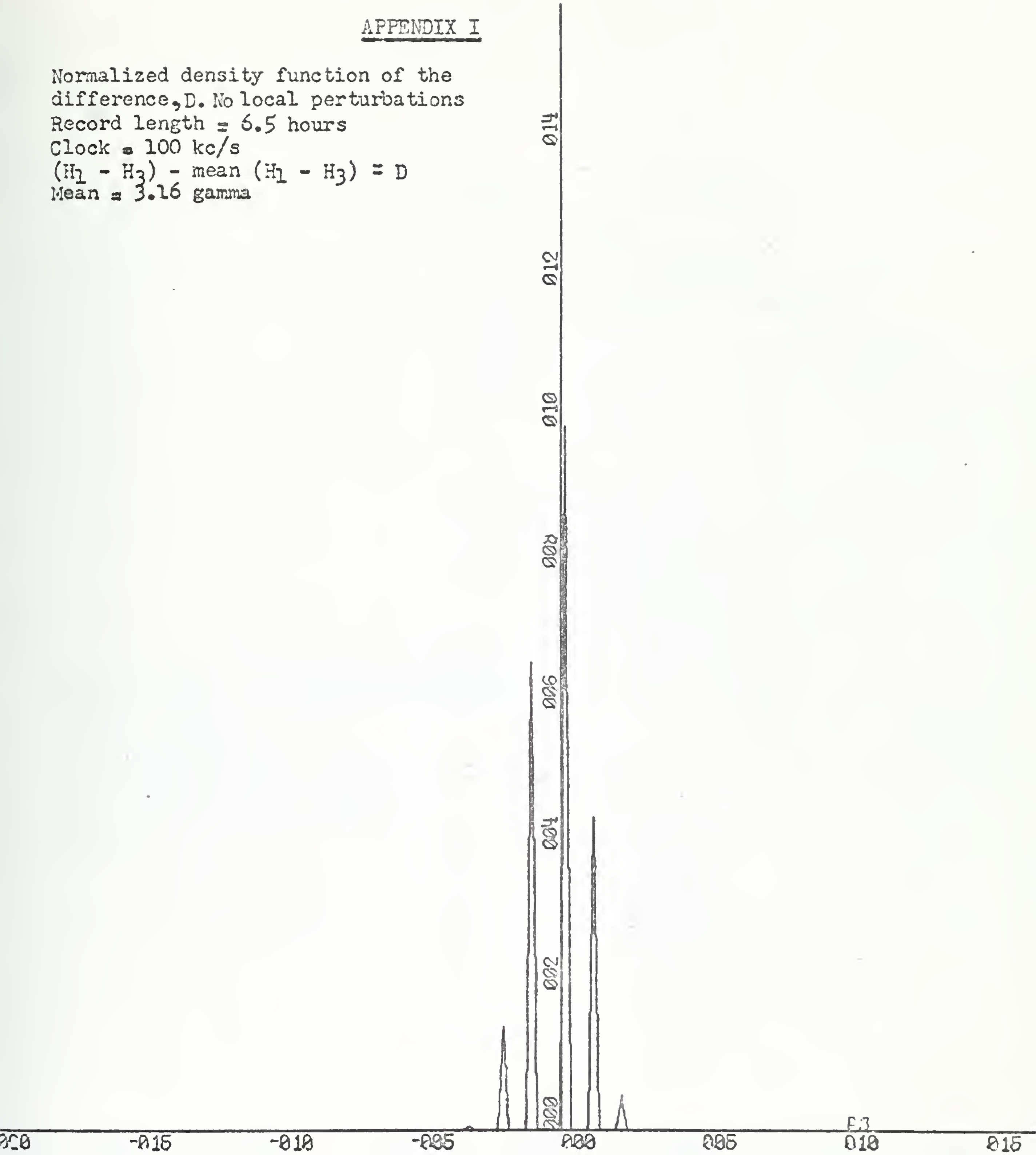


X-SCALE = 5.00E+00 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.

ANDERSON BOX 263
DENSITY FUNCTION X IN GAMMA Y IN FREQ

APPENDIX I

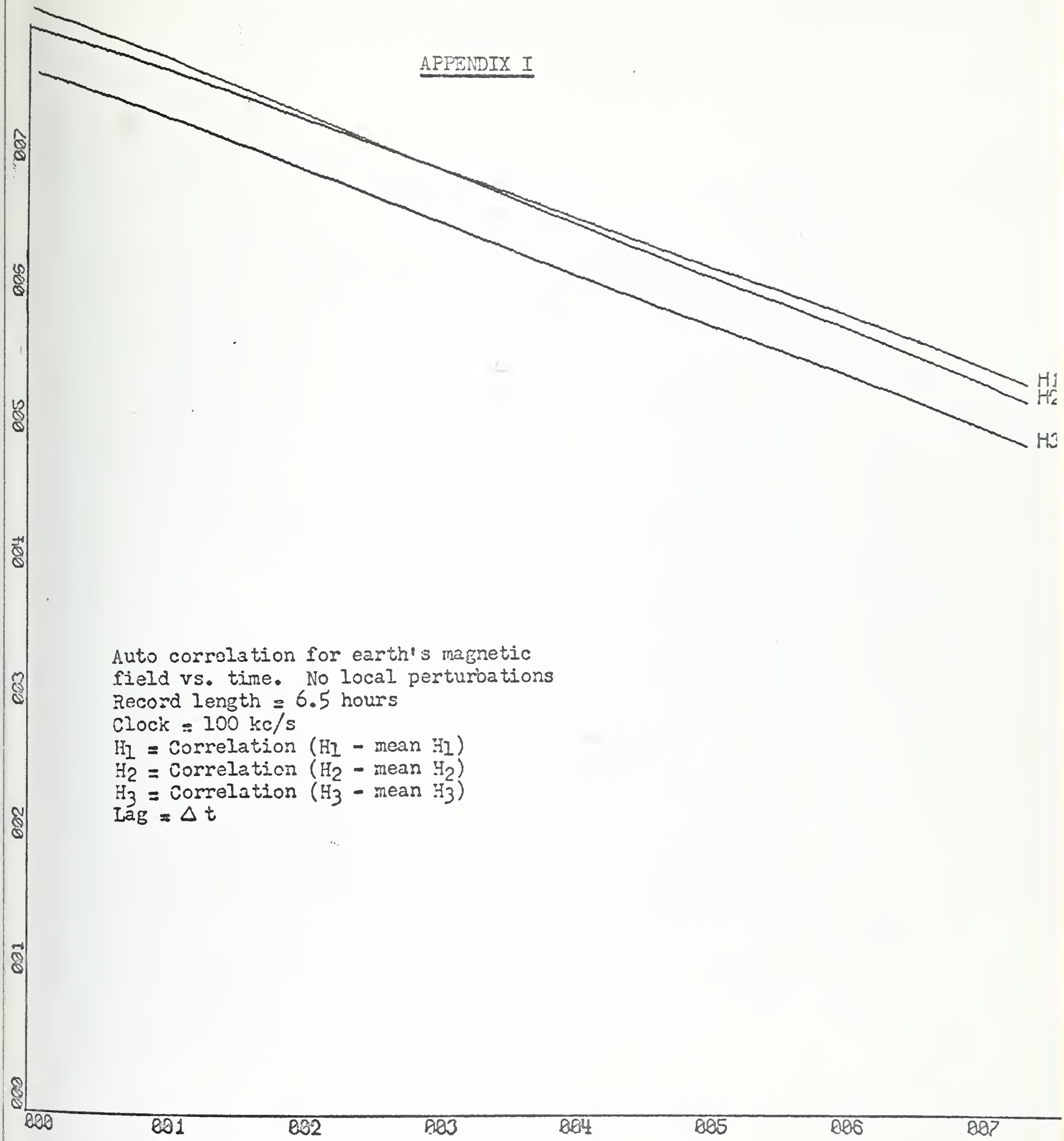
Normalized density function of the difference, D. No local perturbations
Record length = 6.5 hours
Clock = 100 kc/s
$(H_1 - H_3)$ - mean $(H_1 - H_3)$ = D
Mean = 3.16 gamma



X-SCALE = 5.00E+00 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.

ANDERSON BOX 263
DENSITY FUNCTION X IN GAMMA Y IN FREQ

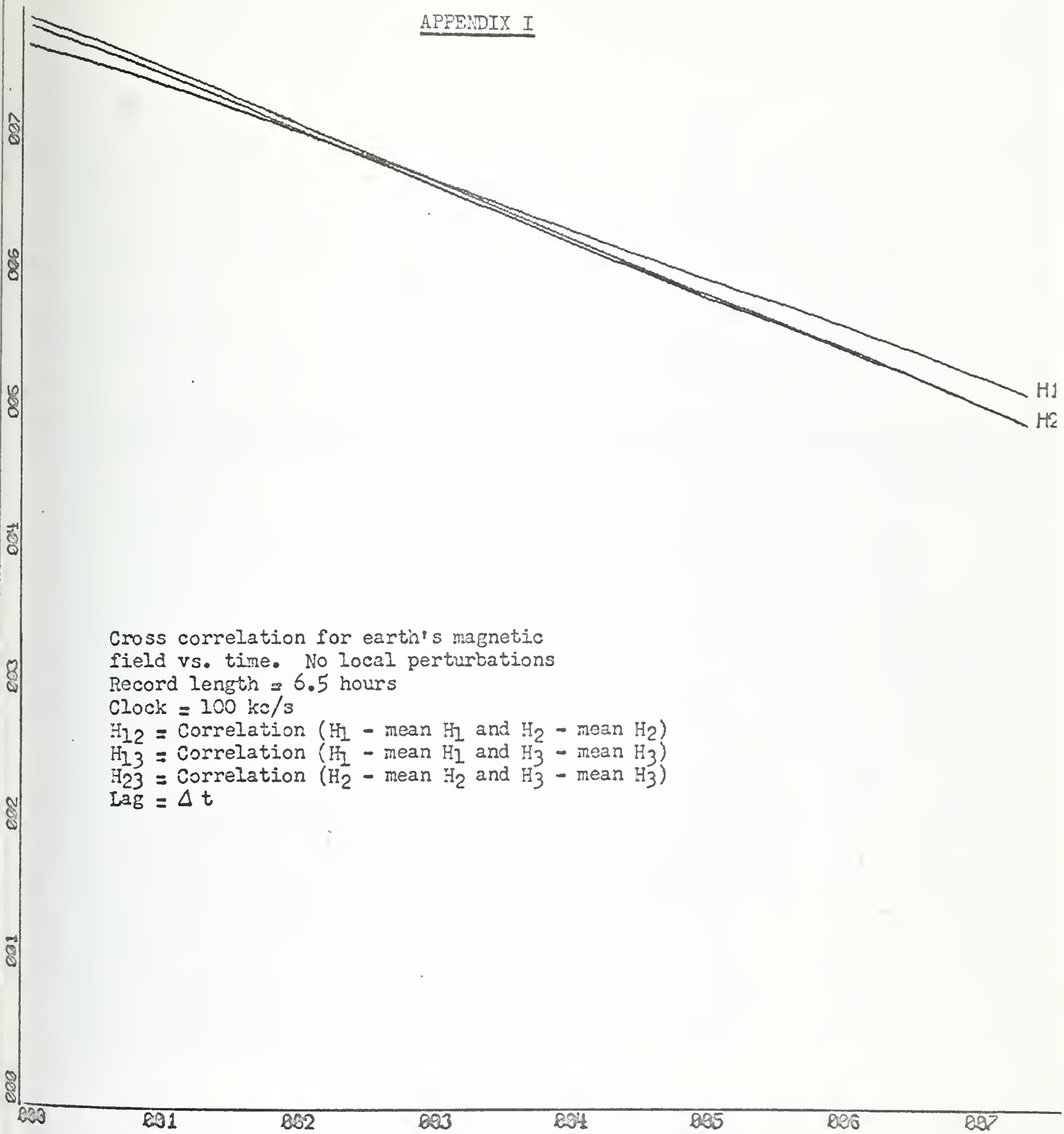
APPENDIX I



X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 1.00E+01 UNITS/INCH.

ANDERSON BOX 263

AUTOCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS

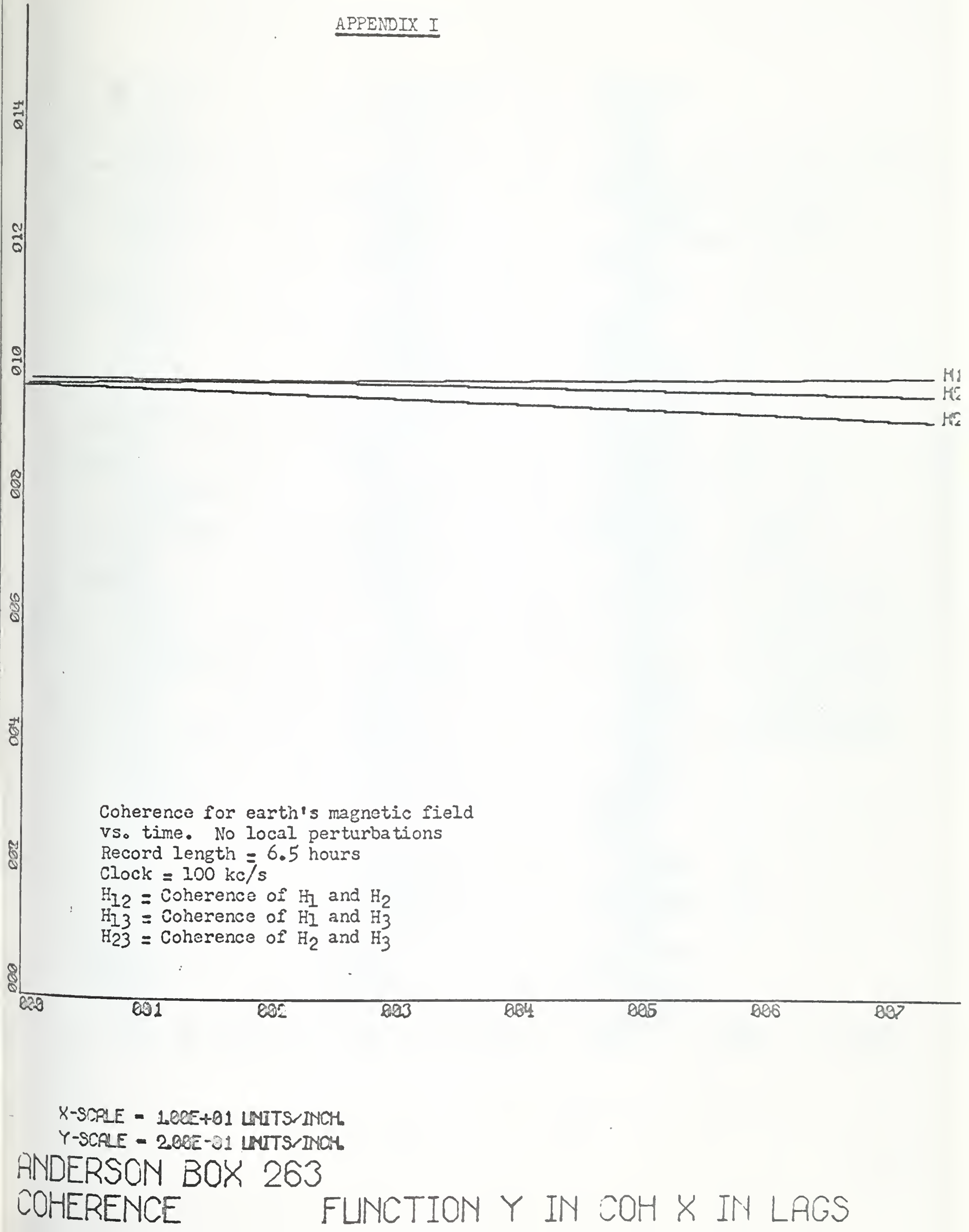


X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 1.00E+01 UNITS/INCH.

ANDERSON BOX 263

CROSCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS

APPENDIX I



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003
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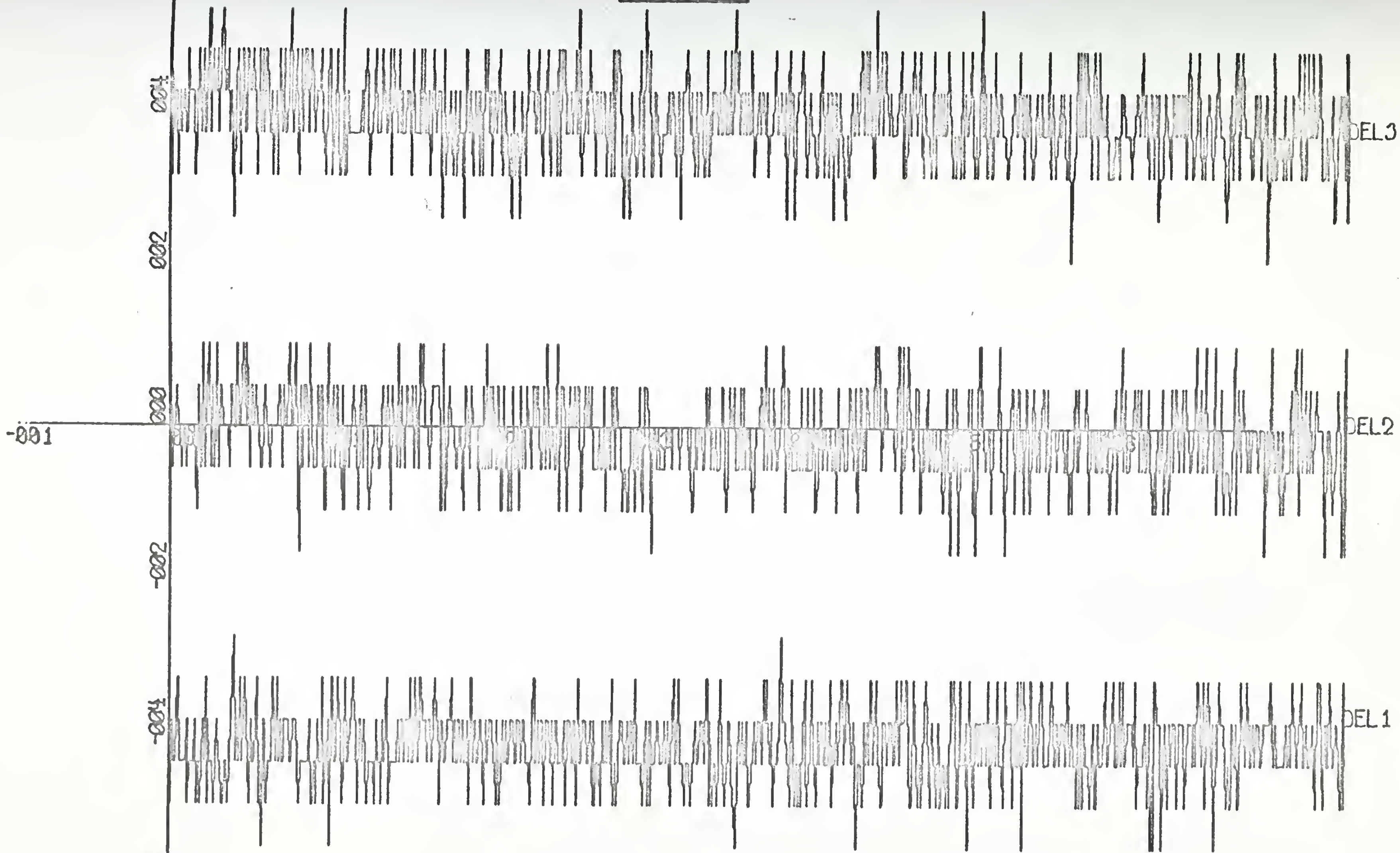
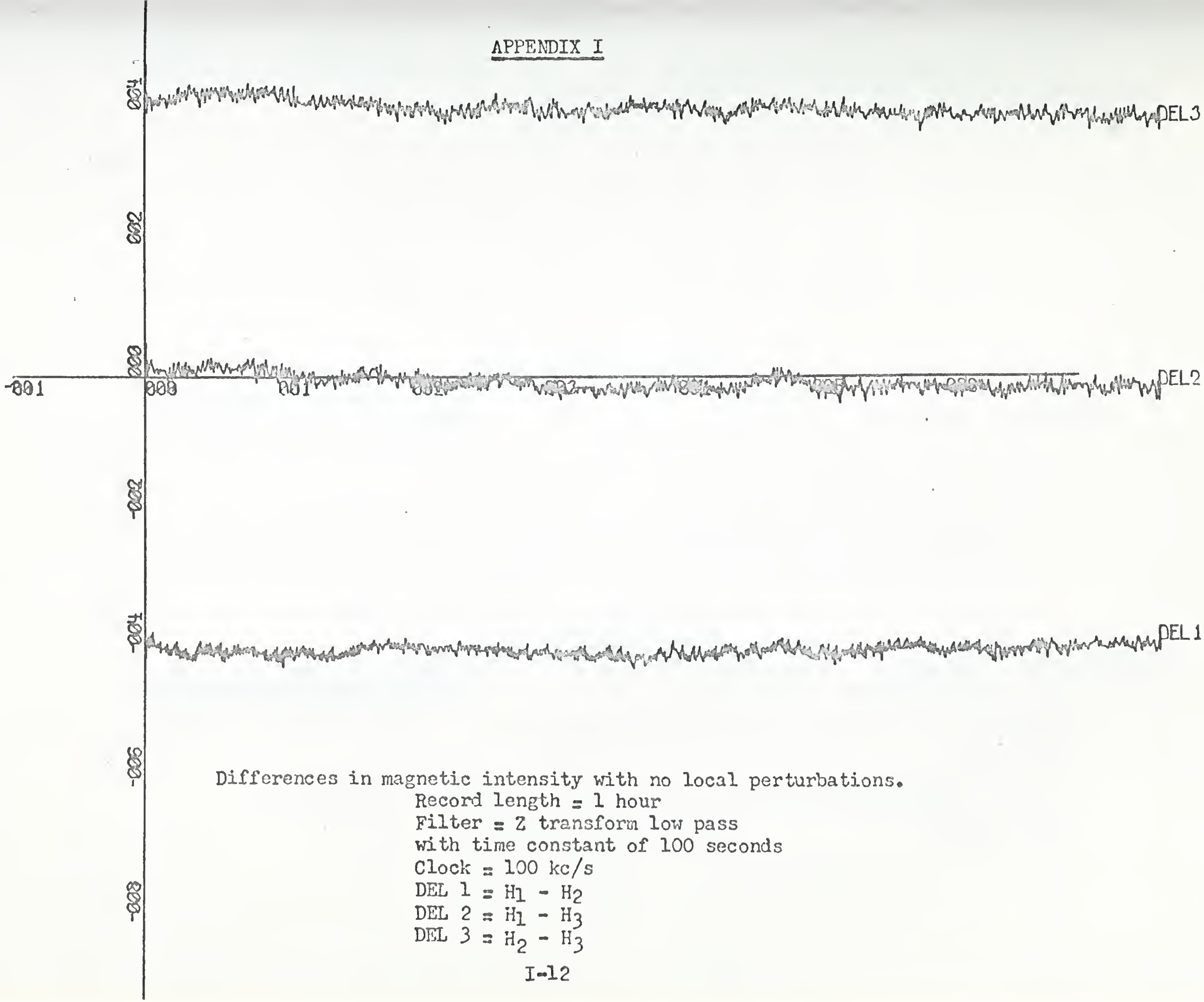
006
007
H1
H2
H2
Coherence for earth's magnetic field
vs. time. No local perturbations
Record length = 6.5 hours
Clock = 100 kc/s
H12 = Coherence of H1 and H2
H13 = Coherence of H1 and H3
H23 = Coherence of H2 and H3
X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.
ANDERSON BOX 263
COHERENCE
FUNCTION Y IN COH X IN LAGS

APPENDIX I

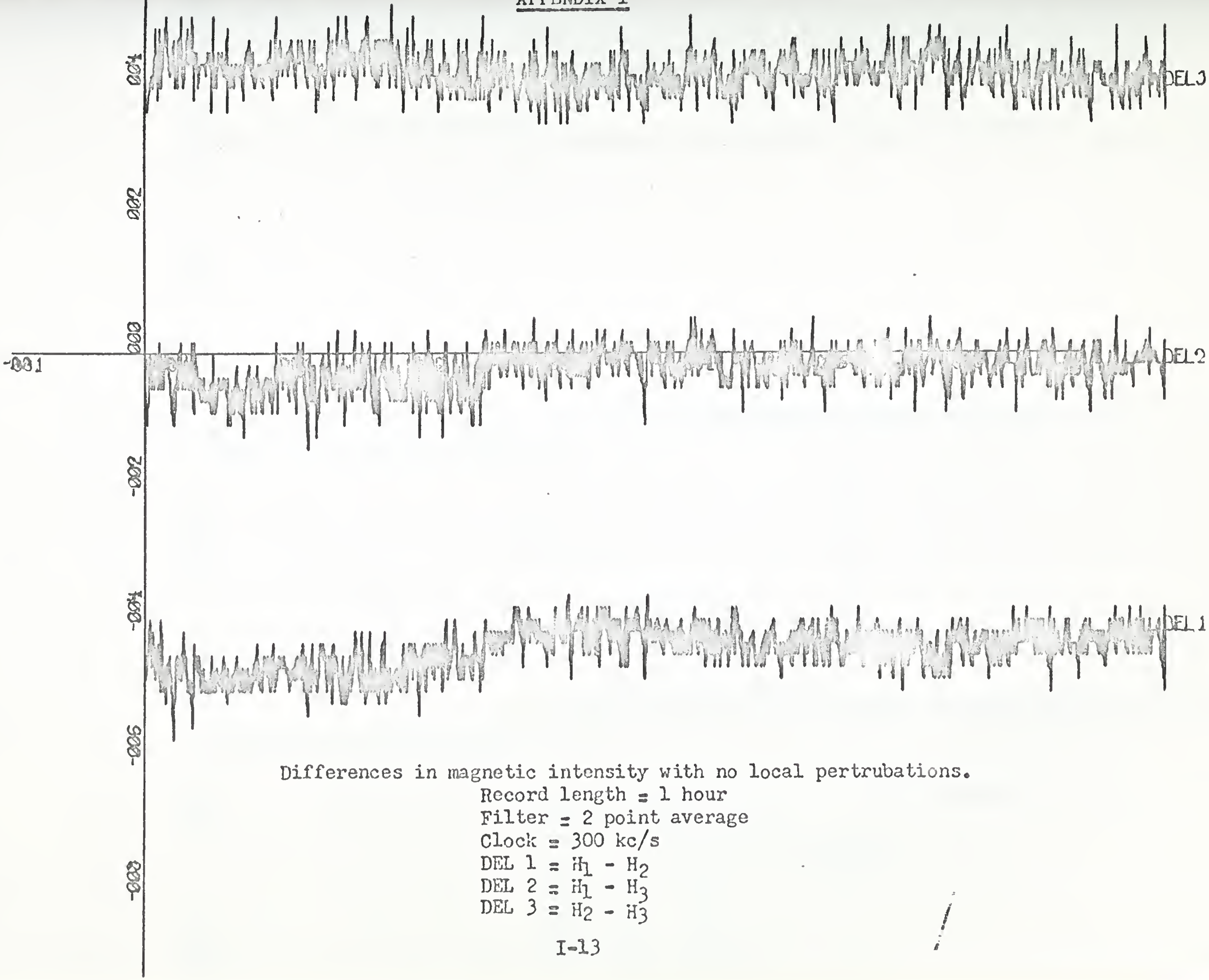


Differences in magnetic intensity with no local perturbations.

Record length = 1 hour
Filter = 2 point average
Clock = 100 kc/s
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$

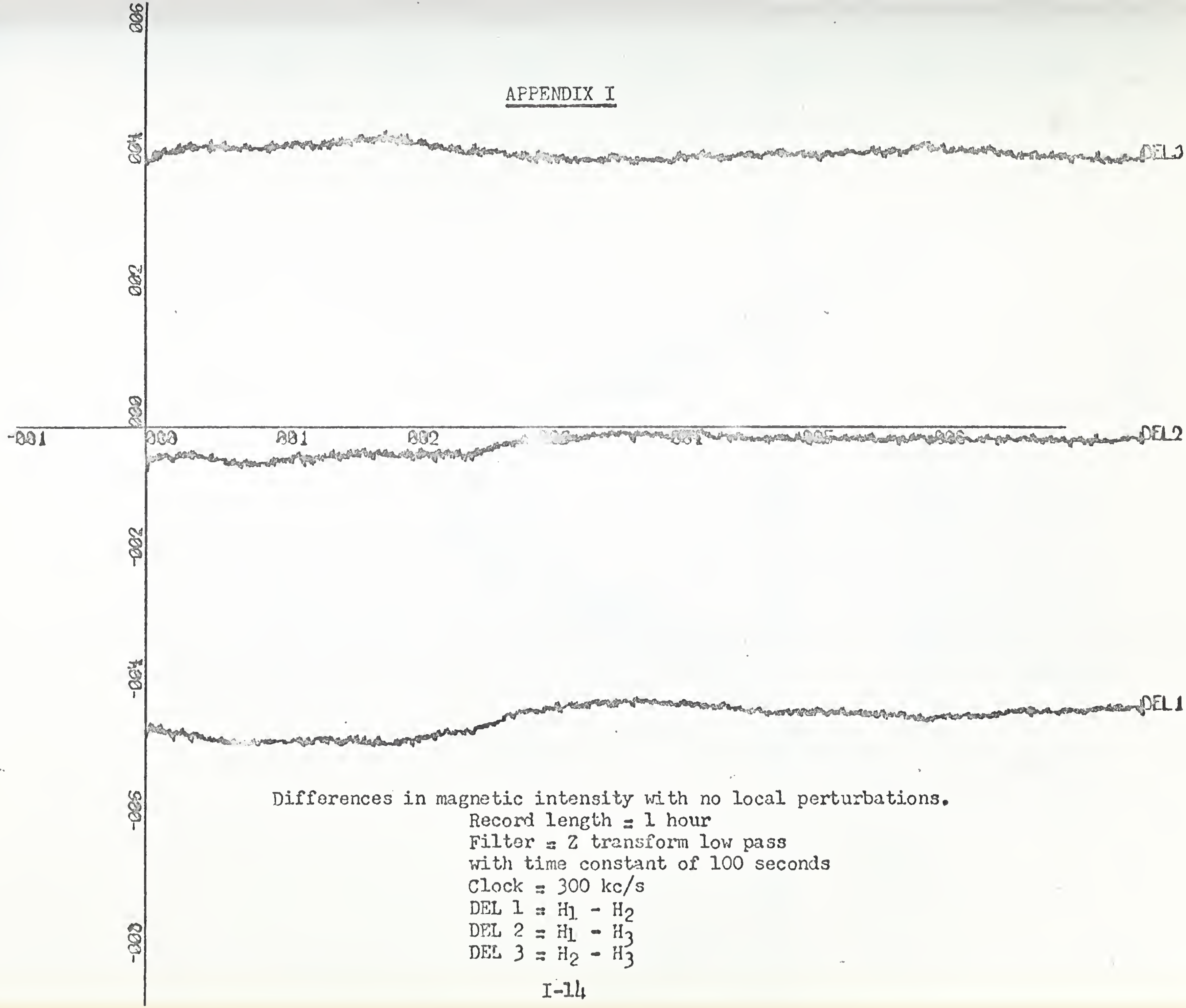


Differences in magnetic intensity with no local perturbations.
Record length = 1 hour
Filter = Z transform low pass
with time constant of 100 seconds
Clock = 100 kc/s
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$



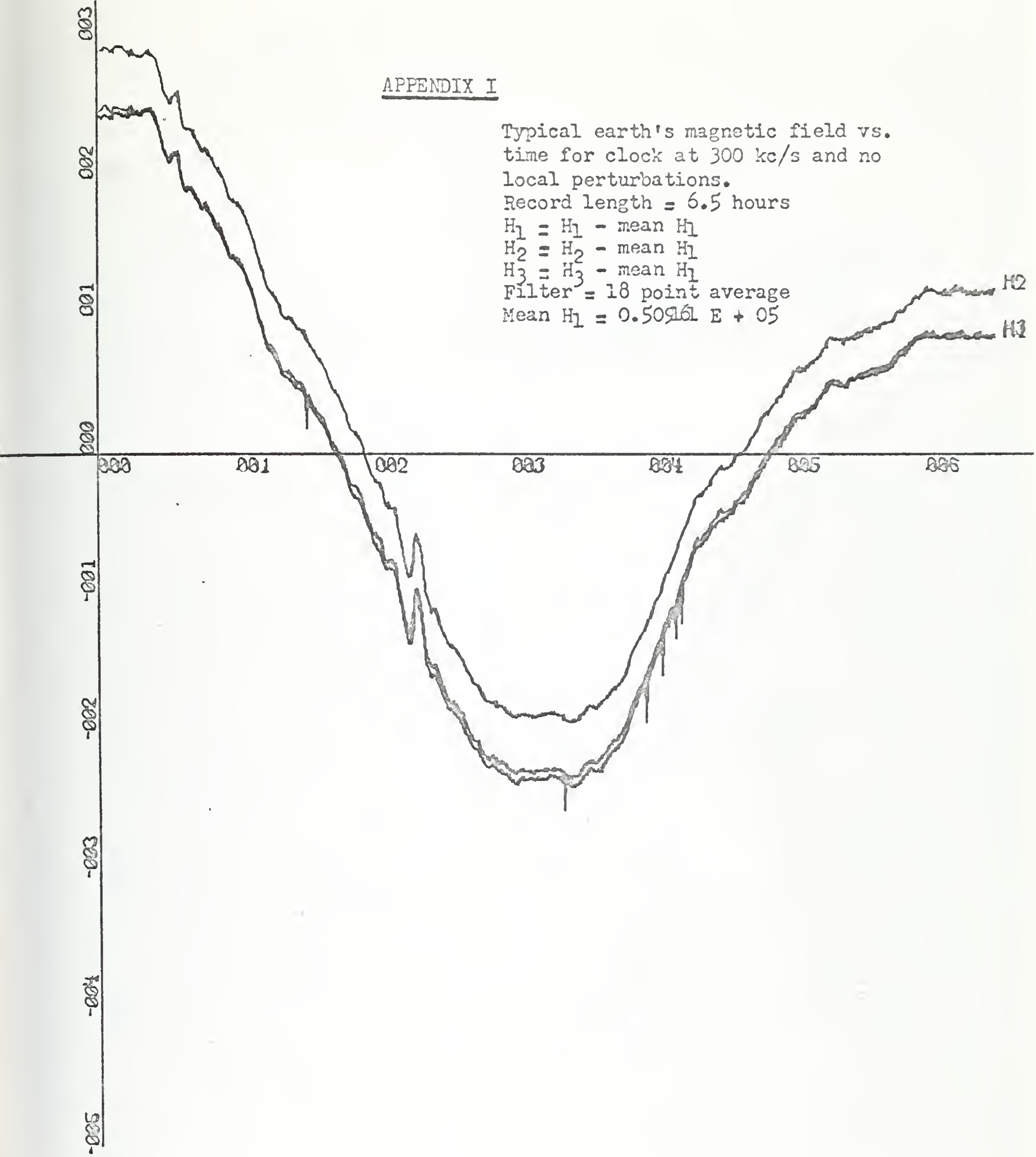
Differences in magnetic intensity with no local pertrubations.
Record length = 1 hour
Filter = 2 point average
Clock = 300 kc/s
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$

APPENDIX I



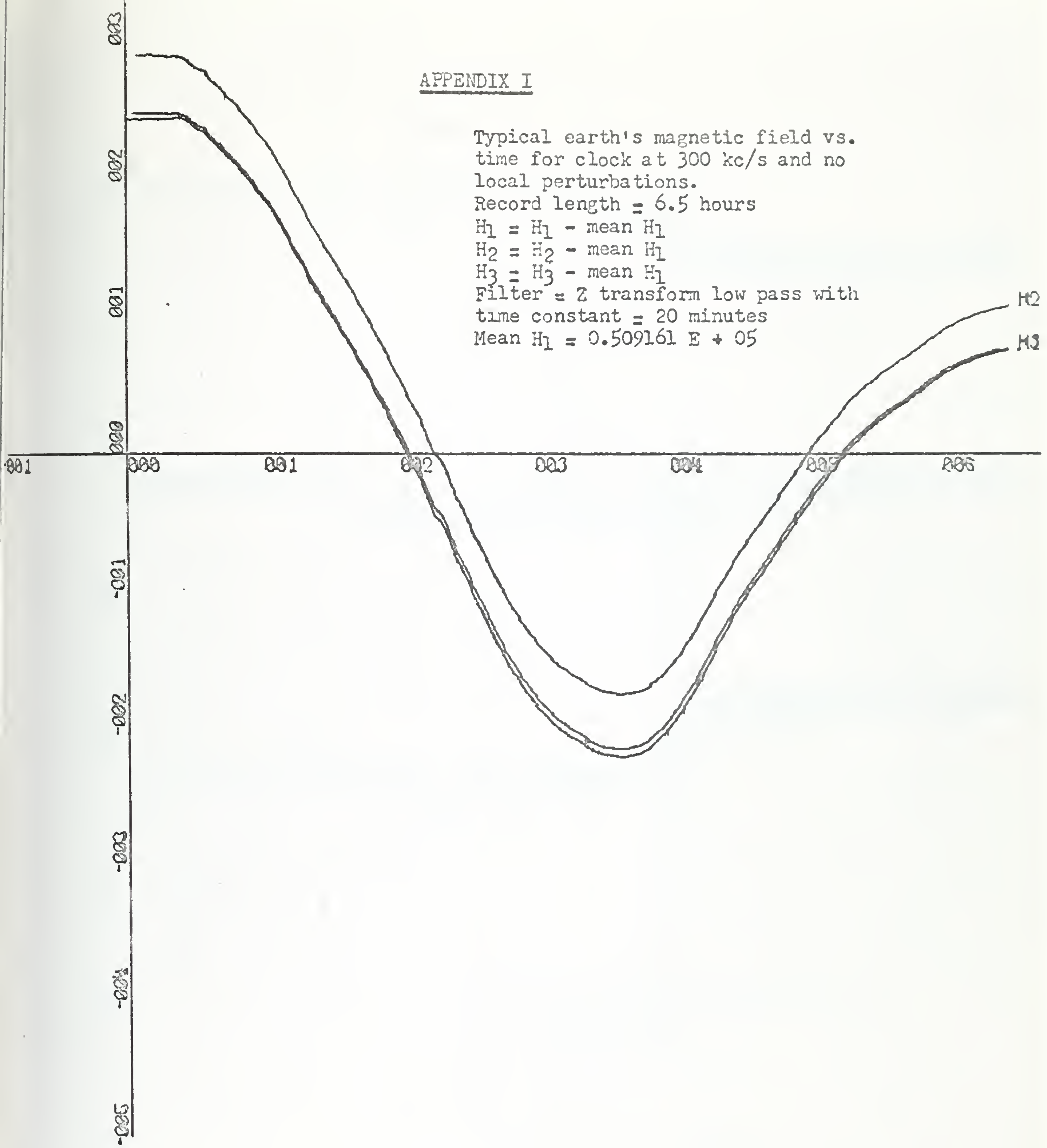
Differences in magnetic intensity with no local perturbations.
Record length = 1 hour
Filter = Z transform low pass
with time constant of 100 seconds
Clock = 300 kc/s
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$

APPENDIX I



X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 1.00E+01 UNITS/INCH.
NDERSON BOX 263
EARTHS MAGNETIC FIELD VS TIME T IN HRS H GAMMA

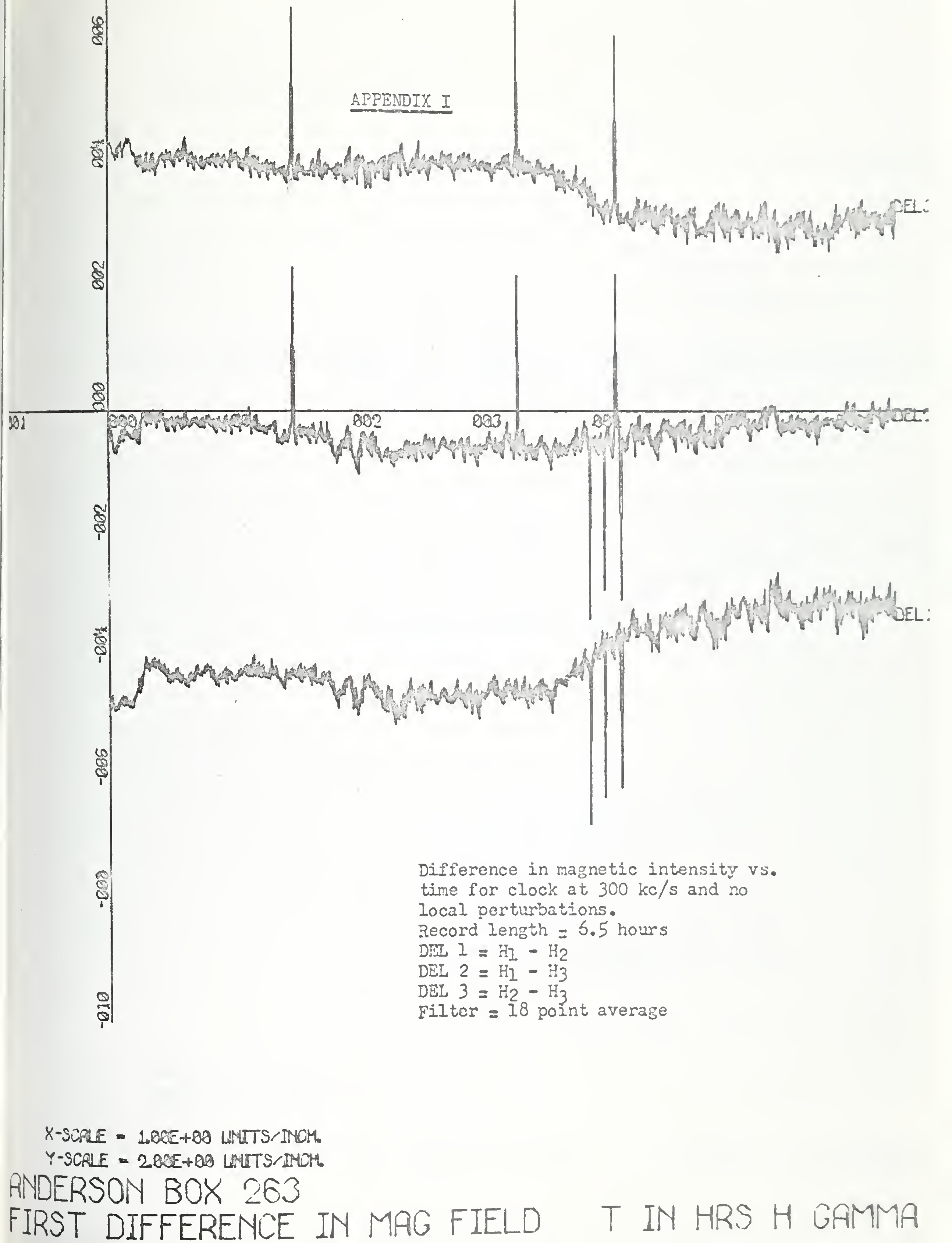
APPENDIX I



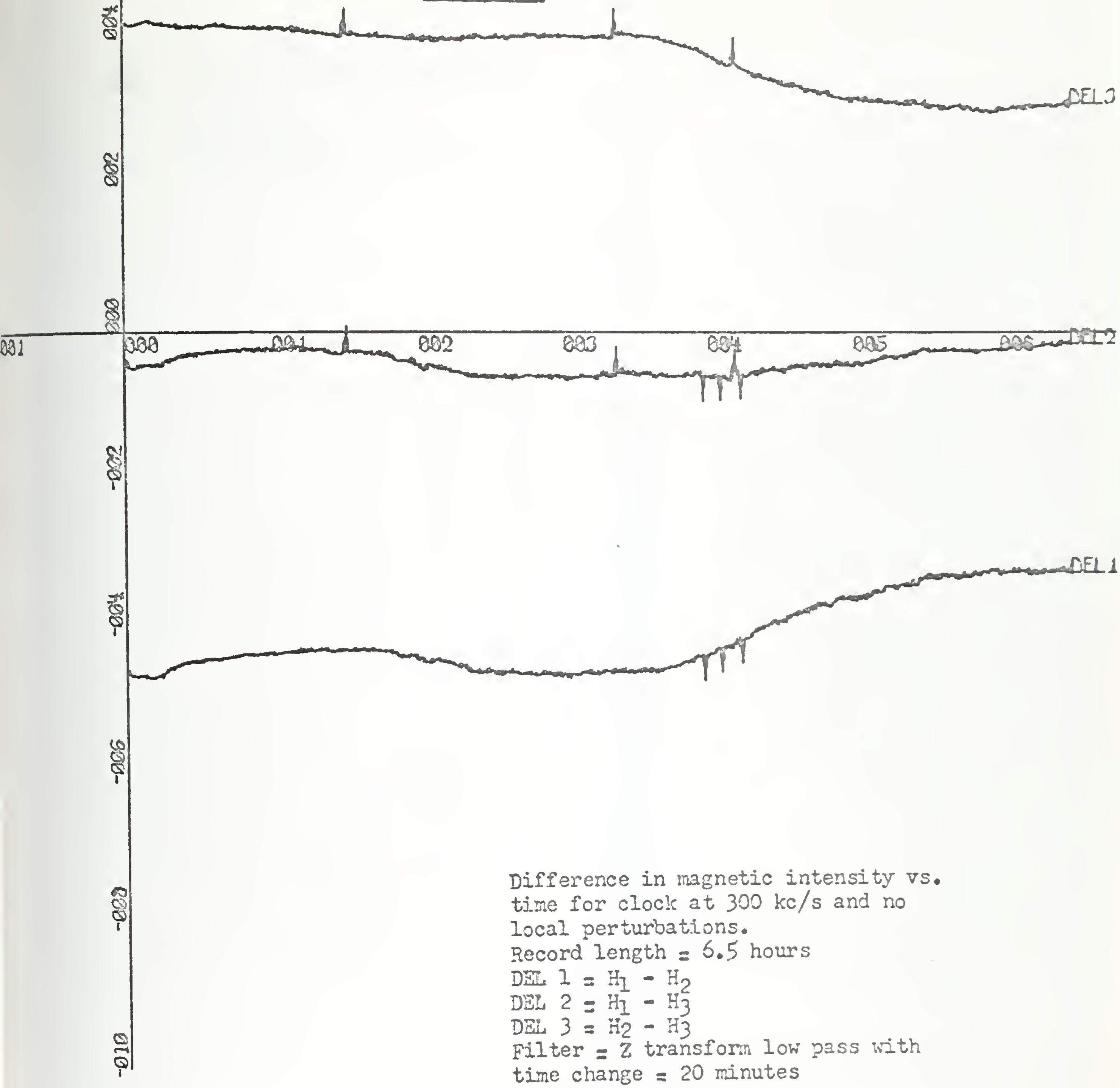
X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 1.00E+01 UNITS/INCH.

ANDERSON FILTER
EARTHS MAGNETIC FIELD VS TIME T IN HRS H GAMMA

APPENDIX I



Difference in magnetic intensity vs. time for clock at 300 kc/s and no local perturbations.
Record length = 6.5 hours
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$
Filter = 18 point average



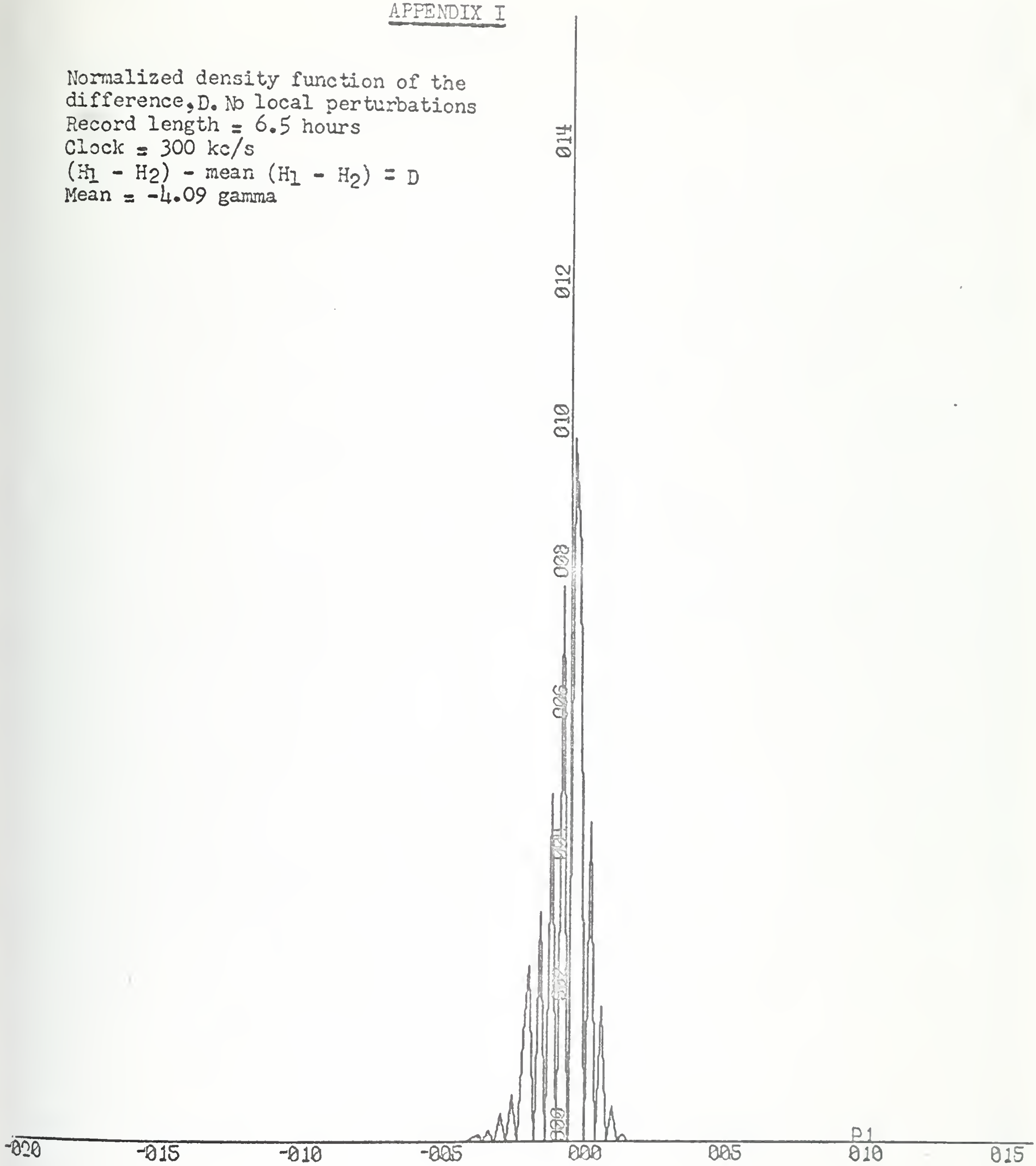
Difference in magnetic intensity vs. time for clock at 300 kc/s and no local perturbations.
Record length = 6.5 hours
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$
Filter = Z transform low pass with time change = 20 minutes

X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.

ANDERSON FILTER
FILTEREDDIFFERENCE IN MAG FIELD T IN HRS H GAMMA

APPENDIX I

Normalized density function of the difference, D. No local perturbations
Record length = 6.5 hours
Clock = 300 kc/s
$(H_1 - H_2) - \text{mean }(H_1 - H_2) = D$
Mean = -4.09 gamma

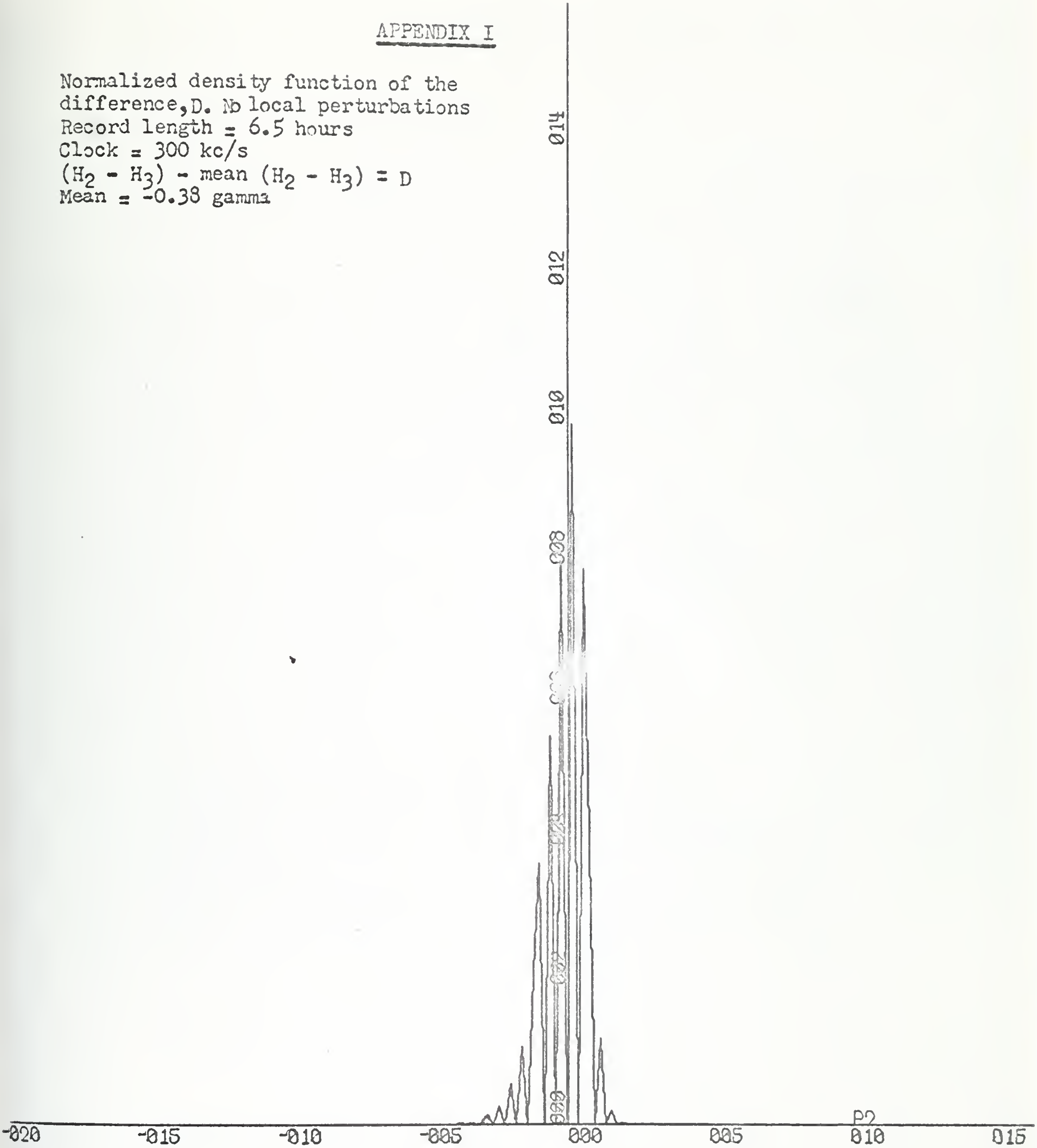


X-SCALE = 5.00E+00 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.

ANDERSON BOX 263
DENSITY FUNCTION X IN GAMMA Y IN FREQ

APPENDIX I

Normalized density function of the difference, D. No local perturbations
Record length = 6.5 hours
Clock = 300 kc/s
$(H_2 - H_3)$ - mean $(H_2 - H_3)$ = D
Mean = -0.38 gamma

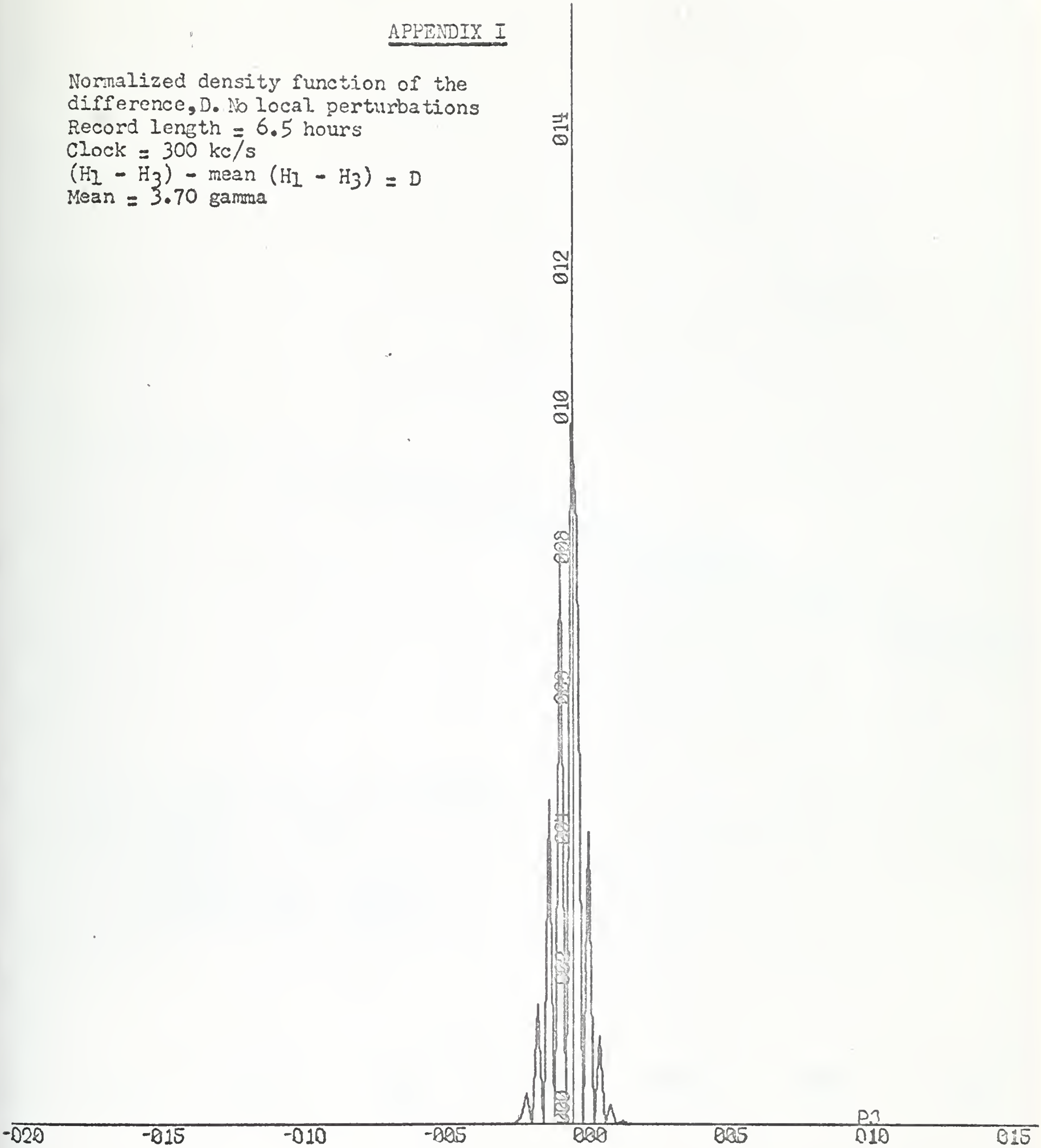


-SCALE = 5.00E+00 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.

ANDERSON BOX 263
DENSITY FUNCTION X IN GAMMA Y IN FREQ

APPENDIX I

Normalized density function of the difference, D. No local perturbations
Record length = 6.5 hours
Clock = 300 kc/s
$(H_1 - H_3)$ - mean $(H_1 - H_3) = D$
Mean = 3.70 gamma

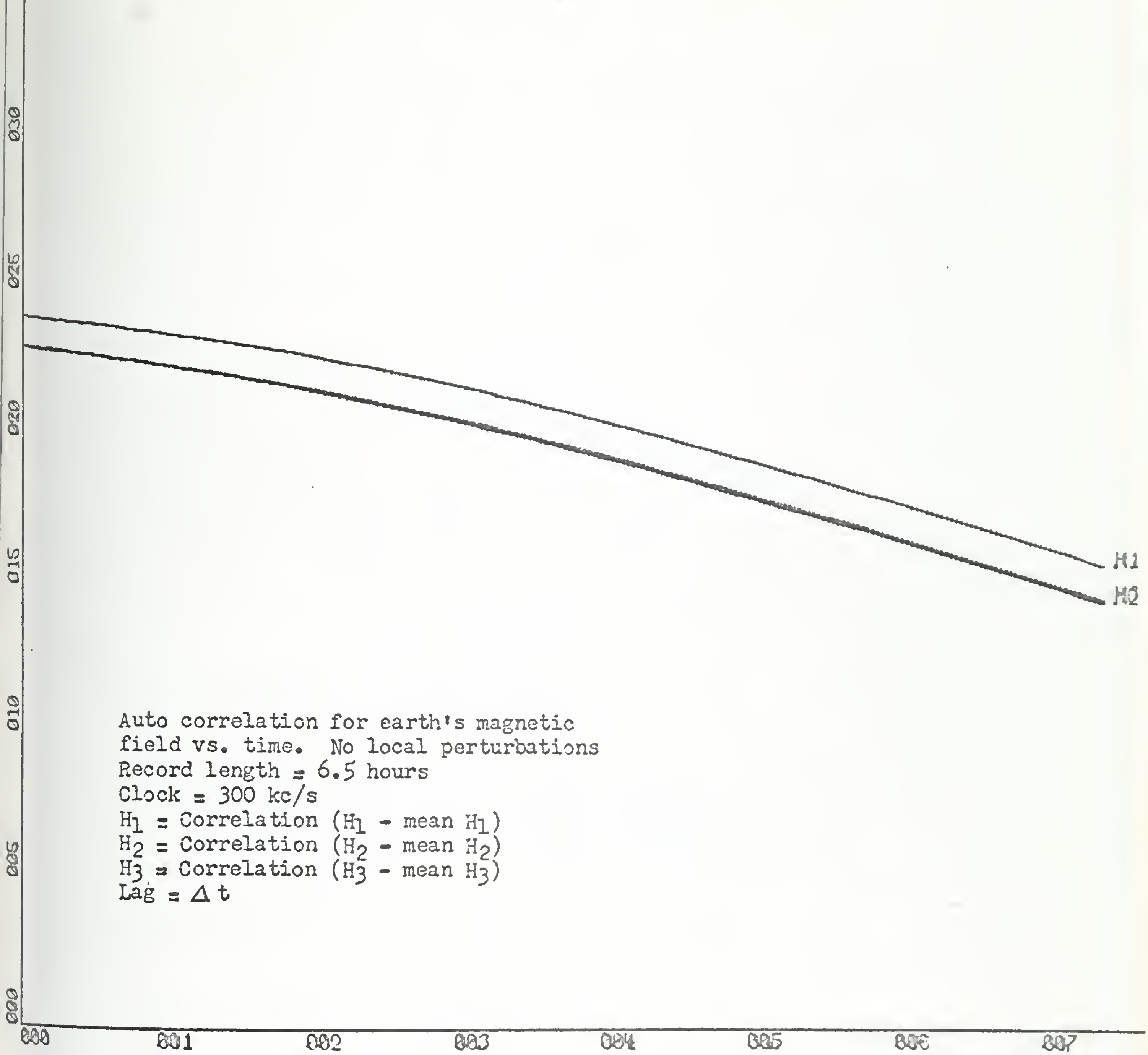


X-SCALE = 5.00E+00 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.

ANDERSON BOX 263

DENSITY FUNCTION X IN GAMMA Y IN FREQ

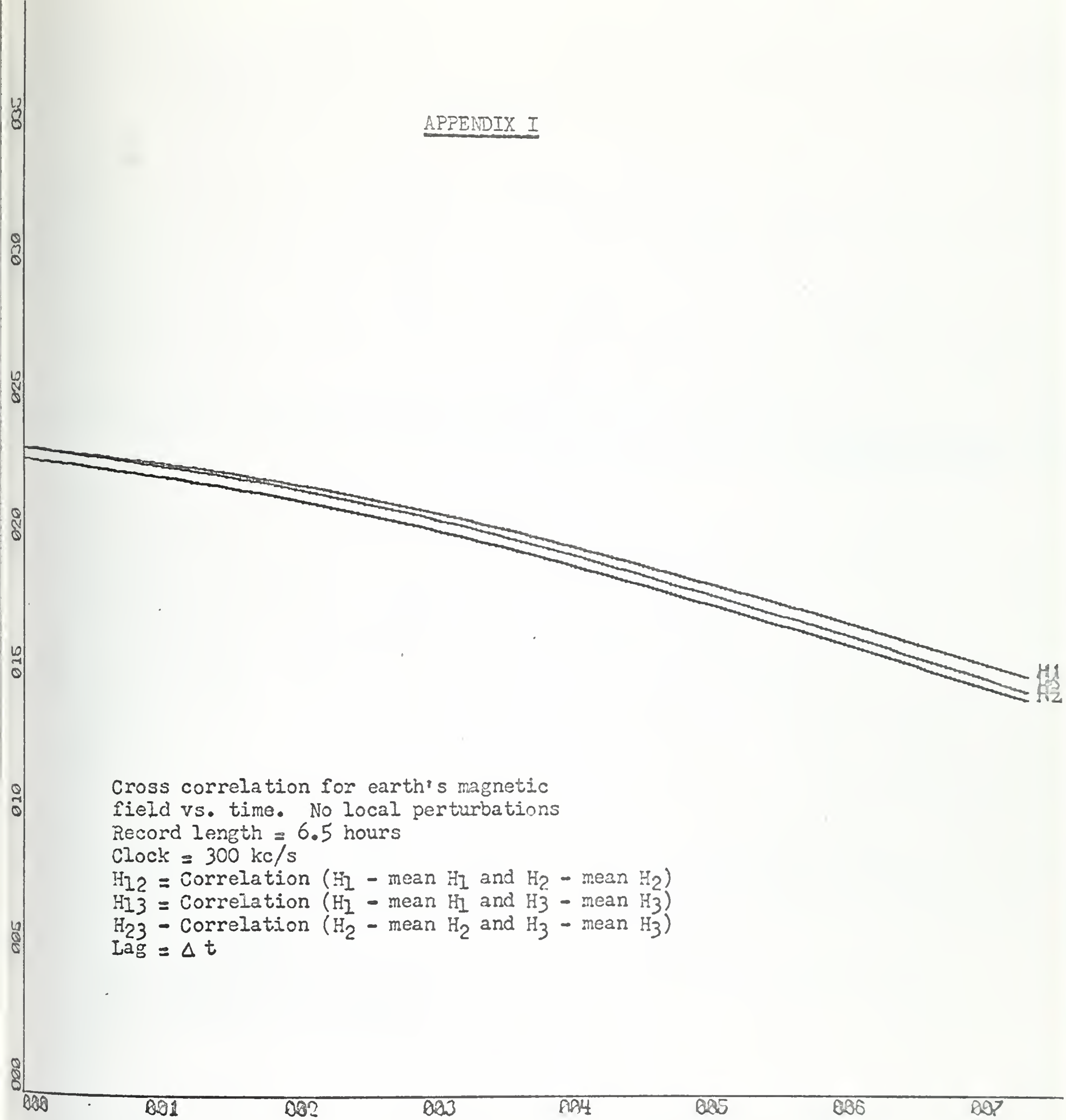
APPENDIX I



X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 5.00E+01 UNITS/INCH.

ANDERSON BOX 263
AUTOCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS

APPENDIX I

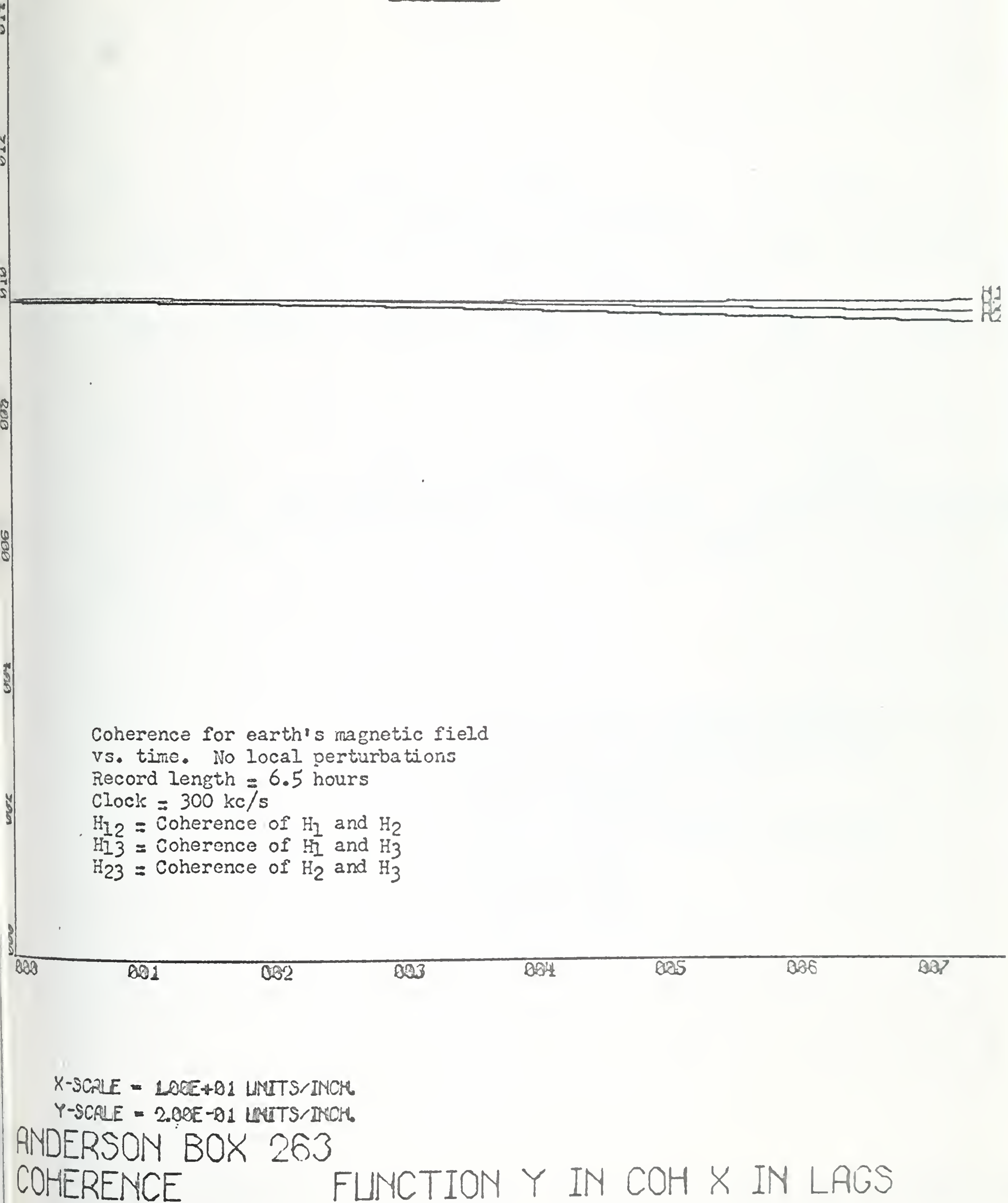


X-SCALE = 1.00E+01 UNITS/INCH.

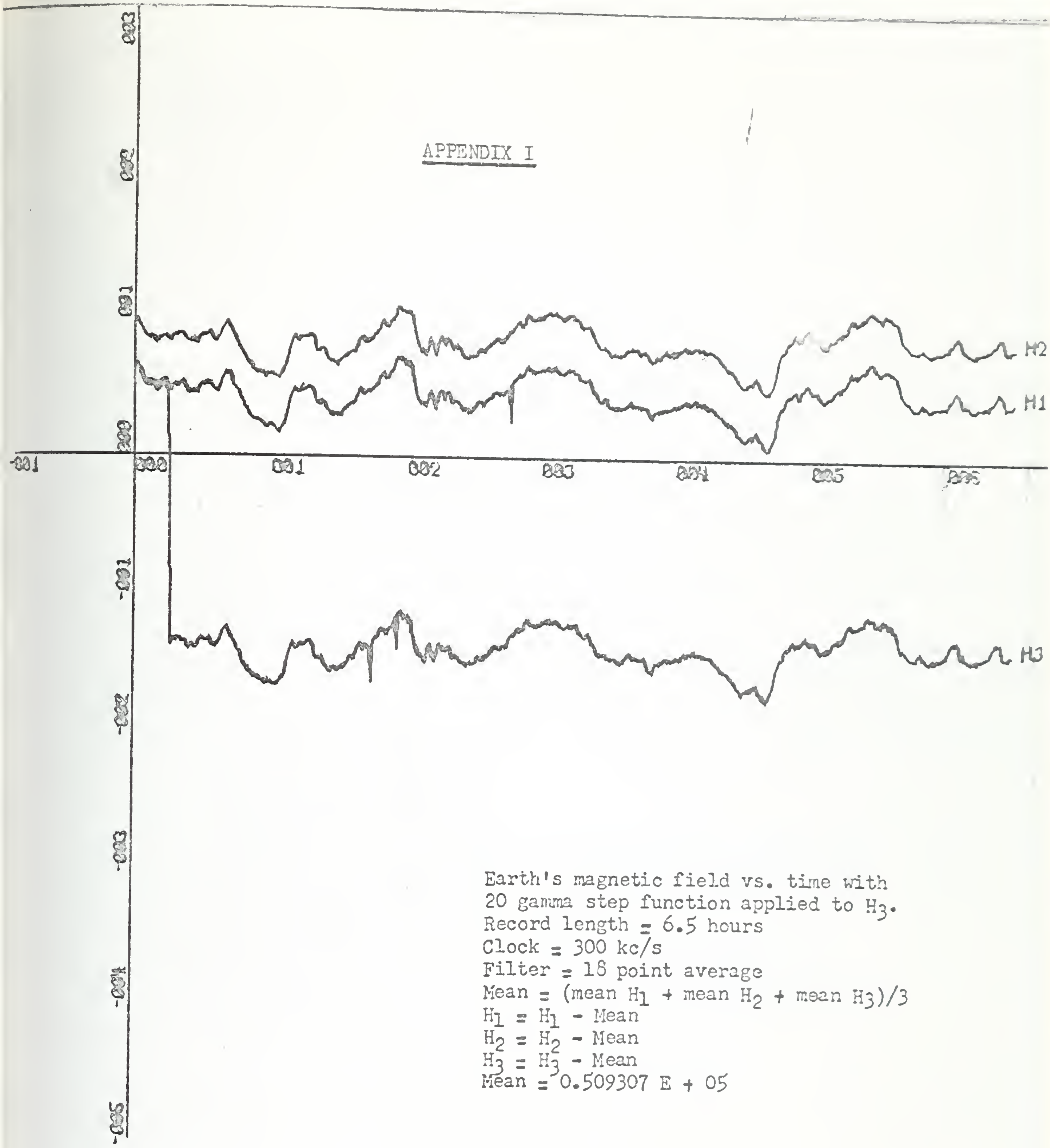
Y-SCALE = 5.00E+01 UNITS/INCH.

ANDERSON BOX 263

CROSCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS


Coherence for earth's magnetic field
vs. time. No local perturbations
Record length = 6.5 hours
Clock = 300 kc/s
H_{12} = Coherence of H_1 and H_2
H_{13} = Coherence of H_1 and H_3
H_{23} = Coherence of H_2 and H_3
000
001
002
003
004
005
006
007
X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 2.00E-01 UNITS/INCH.
ANDERSON BOX 263
COHERENCE
FUNCTION Y IN COH X IN LAGS

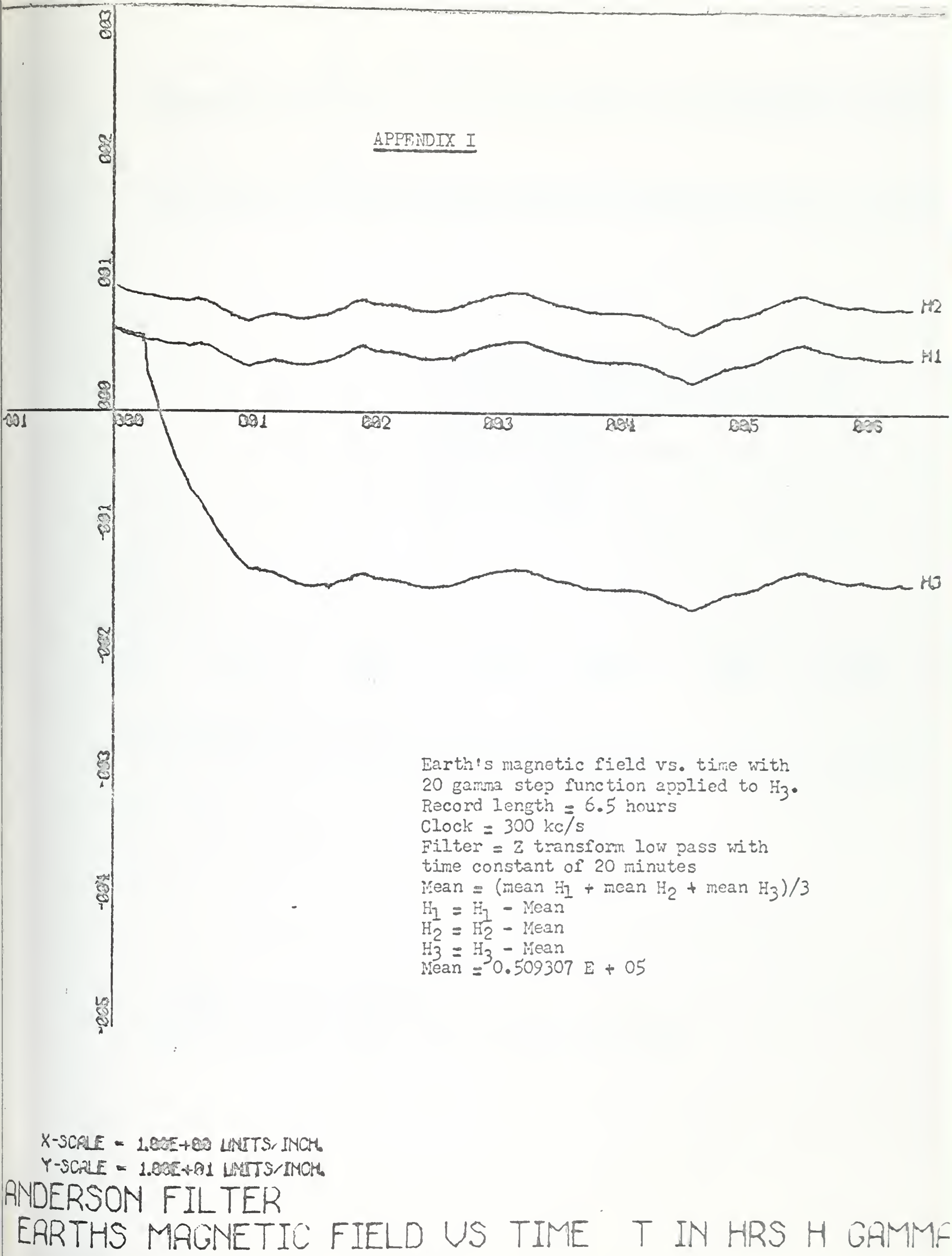
APPENDIX I



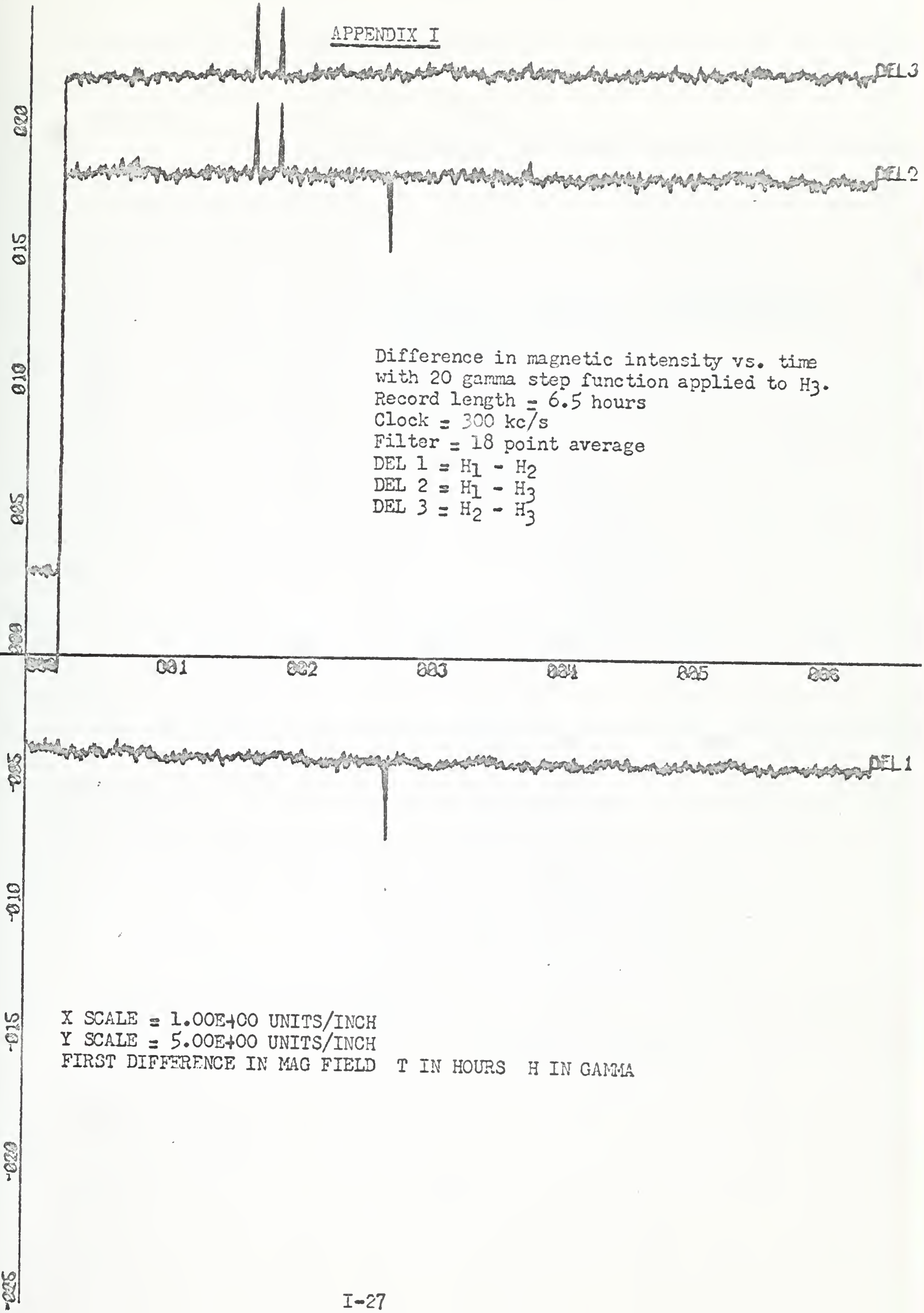
Earth's magnetic field vs. time with
20 gamma step function applied to H_3.
Record length = 6.5 hours
Clock = 300 kc/s
Filter = 18 point average
Mean = (mean H_1 + mean H_2 + mean H_3)/3
$H_1 = H_1$ - Mean
$H_2 = H_2$ - Mean
$H_3 = H_3$ - Mean
Mean = 0.509307 E + 05

X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 1.00E+01 UNITS/INCH.
ANDERSON BOX 263
EARTHS MAGNETIC FIELD VS TIME T IN HRS H GAMMA

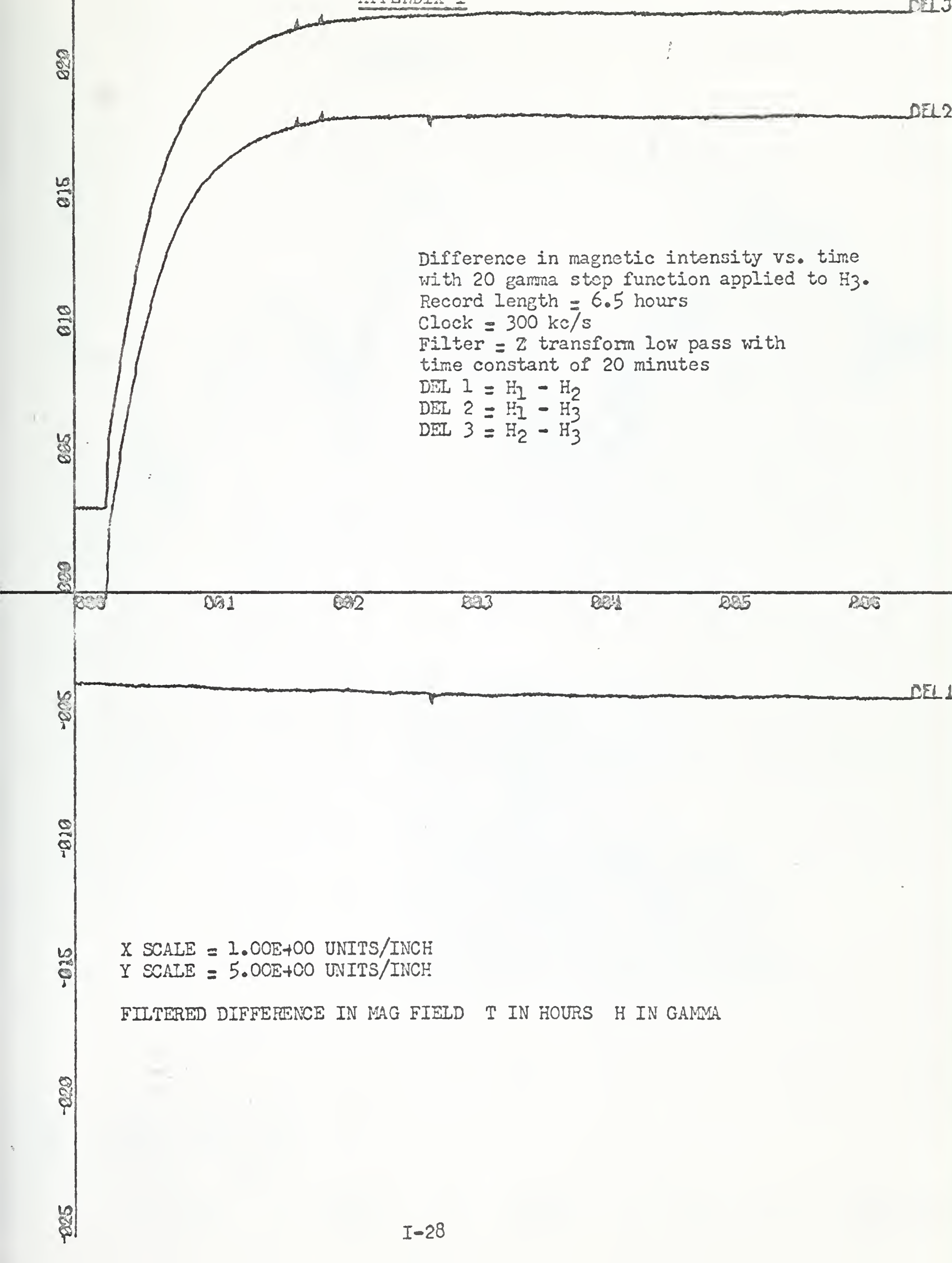
APPENDIX I



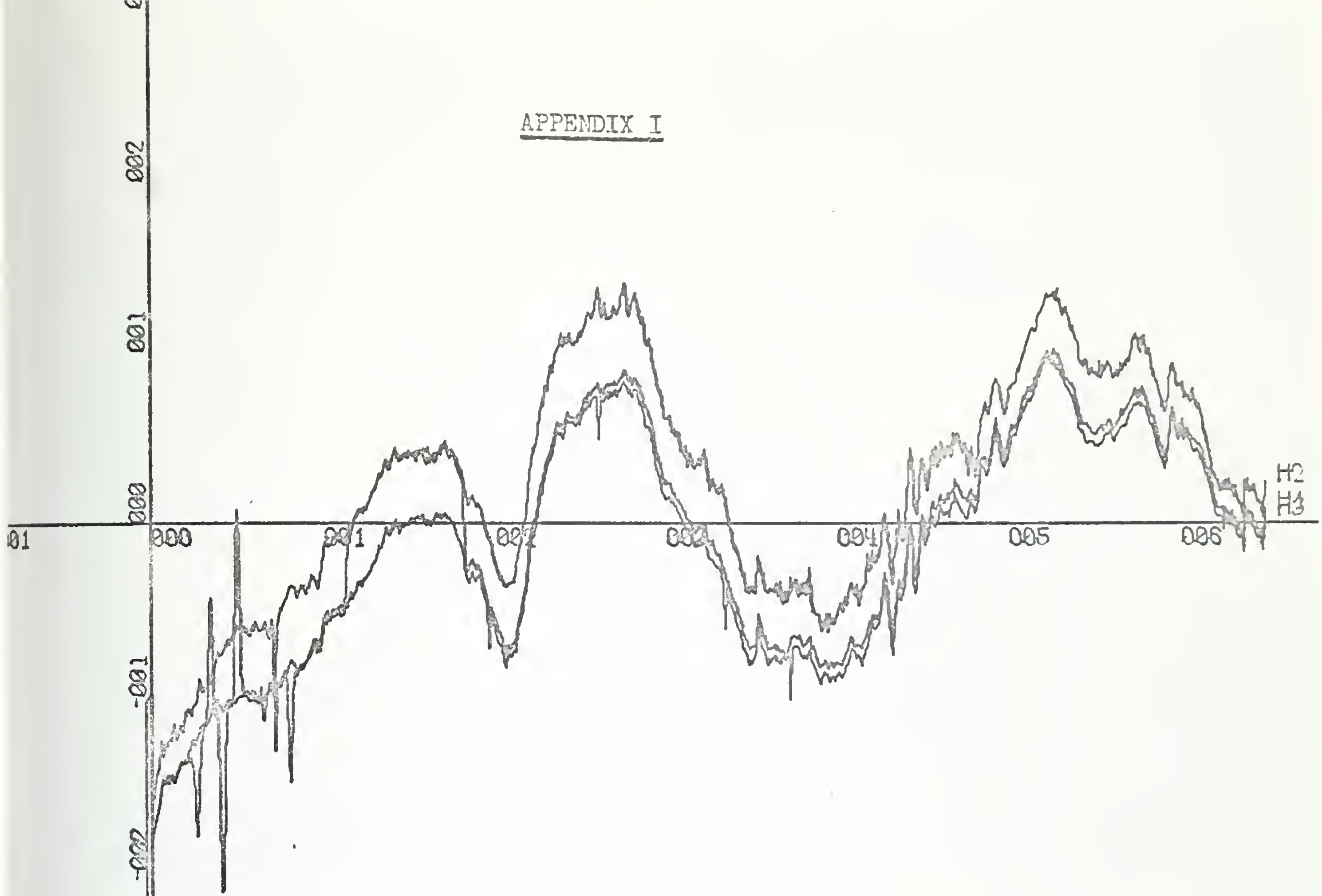
Earth's magnetic field vs. time with
20 gamma step function applied to H_3.
Record length = 6.5 hours
Clock = 300 kc/s
Filter = Z transform low pass with
time constant of 20 minutes
Mean = (mean H_1 + mean H_2 + mean H_3)/3
$H_1 = H_1$ - Mean
$H_2 = H_2$ - Mean
$H_3 = H_3$ - Mean
Mean = 0.509307 E + 05



DEL 3
DEL 2
DEL 1
020
015
010
005
000
-005
-010
-015
-020
-025
001
002
003
004
005
006
Difference in magnetic intensity vs. time with 20 gamma step function applied to H3.
Record length = 6.5 hours
Clock = 300 kc/s
Filter = 18 point average
DEL 1 = H1 - H2
DEL 2 = H1 - H3
DEL 3 = H2 - H3
X SCALE = 1.00E+00 UNITS/INCH
Y SCALE = 5.00E+00 UNITS/INCH
FIRST DIFFERENCE IN MAG FIELD   T IN HOURS   H IN GAMMA


DEL 3
DEL 2
DEL 1
020
015
010
005
000
-005
-010
-015
-020
-025
000
001
002
003
004
005
006
Difference in magnetic intensity vs. time
with 20 gamma step function applied to H3.
Record length = 6.5 hours
Clock = 300 kc/s
Filter = Z transform low pass with
time constant of 20 minutes
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$
X SCALE = 1.00E+00 UNITS/INCH
Y SCALE = 5.00E+00 UNITS/INCH
FILTERED DIFFERENCE IN MAG FIELD T IN HOURS H IN GAMMA

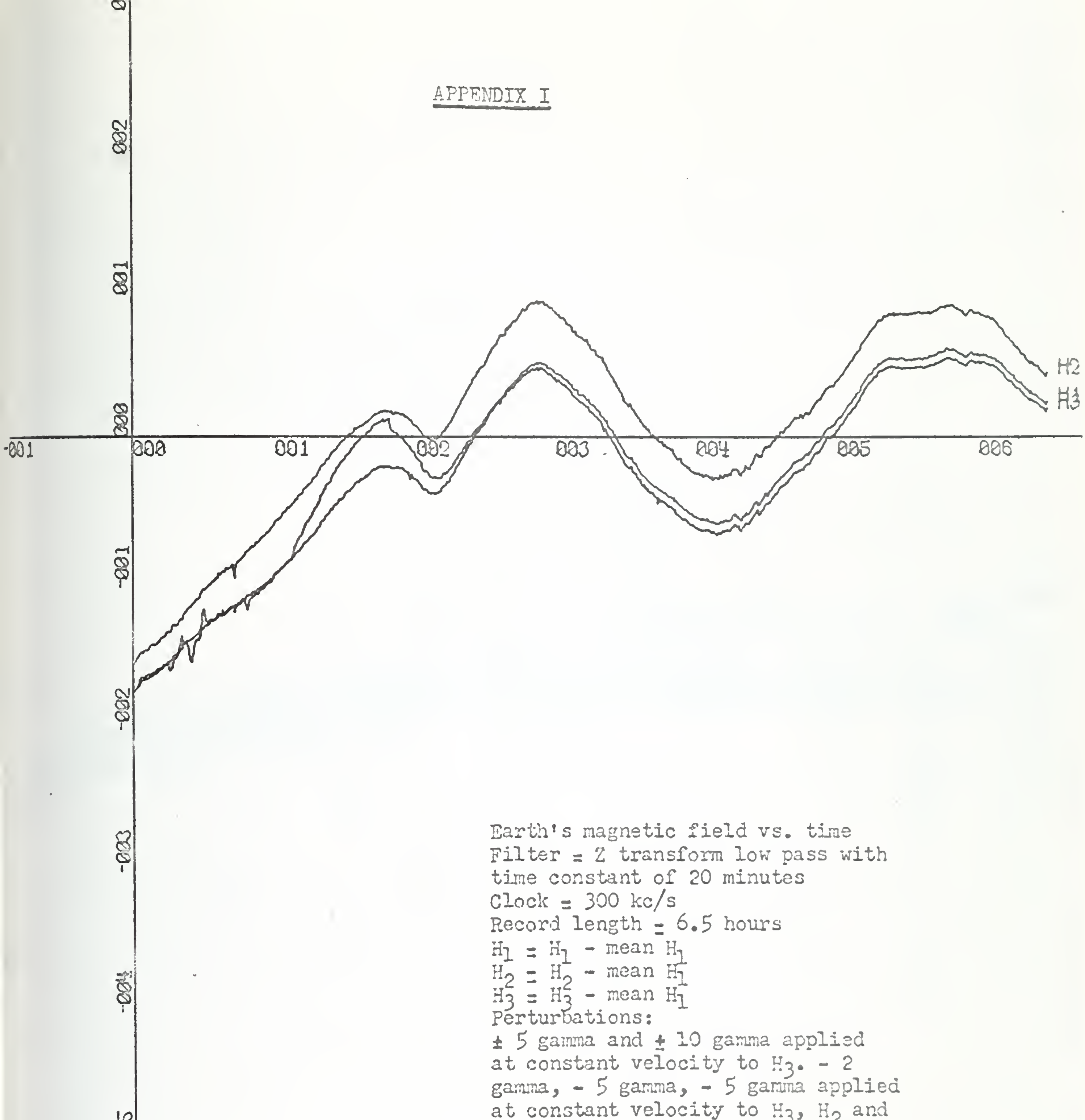
APPENDIX I



Earth's magnetic field vs. time
Filter = 18 point average
Clock = 300 kc/s
Record length = 6.5 hours
$H_1 = H_1$ - mean H_1
$H_2 = H_2$ - mean H_1
$H_3 = H_3$ - mean H_1
Perturbations:
± 5 gamma and ± 10 gamma applied at constant velocity to H_3. - 2 gamma, - 5 gamma, - 5 gamma applied at constant velocity to H_3, H_2 and H_1 during first hour. A 5 gamma step applied to H_3 at t = 1 hour and removed at t = 1 3/4 hours.

X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 1.00E+01 UNITS/INCH.
ANDERSON BOX 263
EARTHS MAGNETIC FIELD VS TIME T IN HRS H GAMMA

APPENDIX I



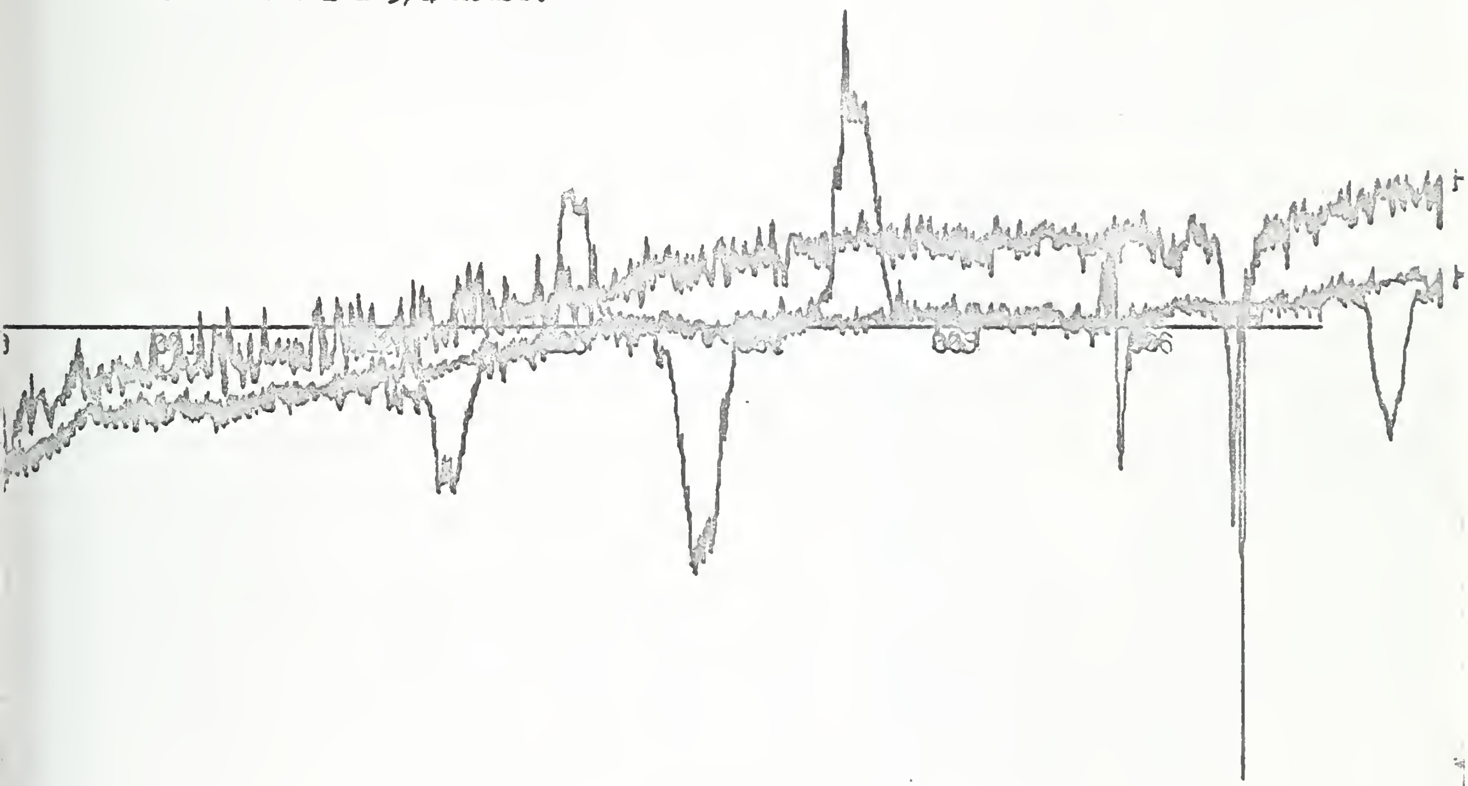
Earth's magnetic field vs. time
Filter = Z transform low pass with time constant of 20 minutes
Clock = 300 kc/s
Record length = 6.5 hours
$H_1 = H_1$ - mean H_1
$H_2 = H_2$ - mean H_1
$H_3 = H_3$ - mean H_1
Perturbations:
± 5 gamma and ± 10 gamma applied at constant velocity to H_3. - 2 gamma, - 5 gamma, - 5 gamma applied at constant velocity to H_3, H_2 and H_1 during first hour. A 5 gamma step applied to H_3 at t = 1 hour and removed at t = 1 3/4 hours.

X-SCALE = 1.00E+00 UNITS/INCH.
Y-SCALE = 1.00E+01 UNITS/INCH.

ANDERSON FILTER
EARTHS MAGNETIC FIELD VS TIME T IN HRS H GAMM

APPENDIX I

Earth's magnetic field vs. time
Filter = 2 point average
Clock = 300 kc/s
Record length = 1 hour
$H_1 = H_1$ - mean H_1
$H_2 = H_2$ - mean H_1
$H_3 = H_3$ - mean H_1
Perturbations:
$\pm$ 5 gamma and $\pm$ 10 gamma applied at constant velocity to H_3. -2 gamma, -5 gamma, -5 gamma applied at constant velocity to H_3, H_2 and H_1 during first hour. A 5 gamma step applied to H_3 at t = 1 hour and removed at t = 1 3/4 hours.

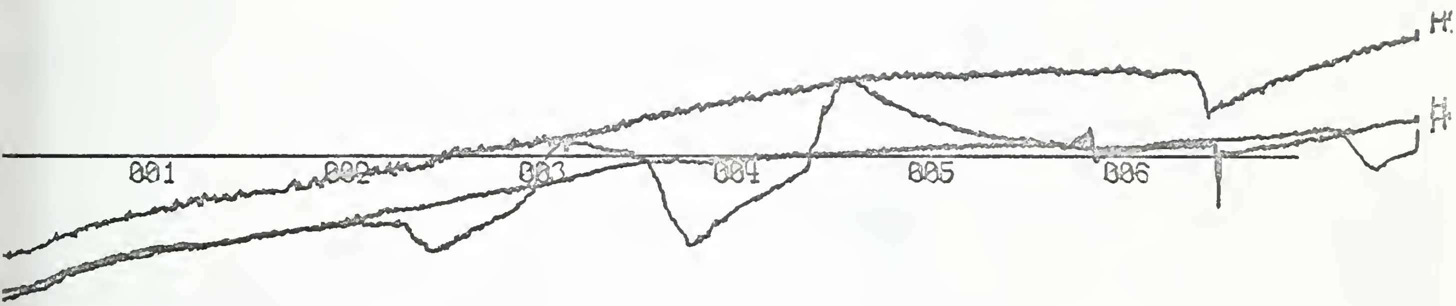


X SCALE = 1.00E+00 UNITS/INCH
Y SCALE = 1.00E+01 UNITS/INCH

EARTHS MAGNETIC FIELD VS TIME T IN MINUTES H IN GAMMA

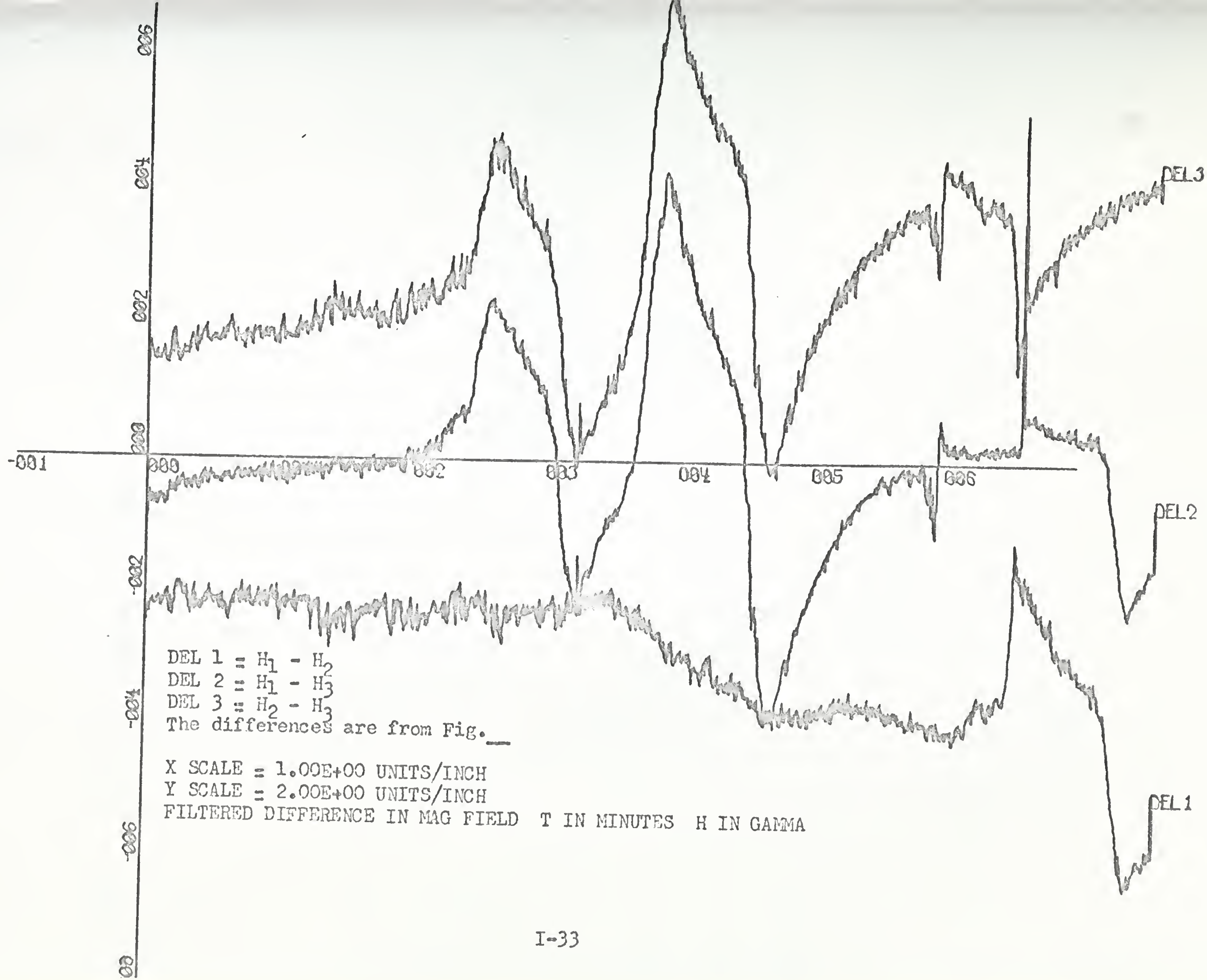
APPENDIX I

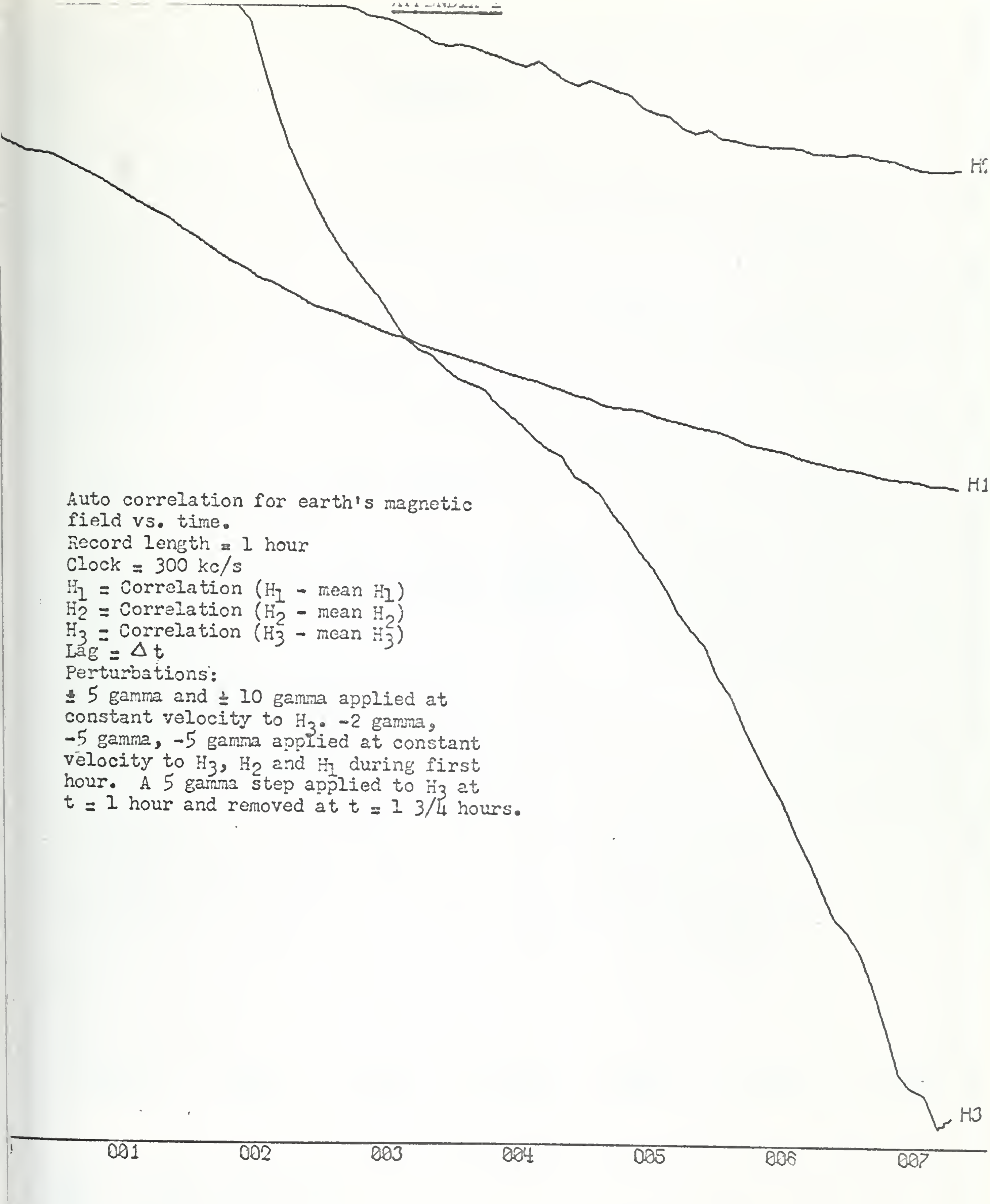
Earth's magnetic field vs. time
Filter = Z transform low pass with
time constant of 100 seconds.
Clock = 300 kc/s
Record length = 1 hour
$H_1 = H_1$ - mean H_1
$H_2 = H_2$ - mean H_1
$H_3 = H_3$ - mean H_1
Perturbations:
= 5 gamma and = 10 gamma applied
at constant velocity to H_3. - 2
gamma, - 5 gamma, - 5 gamma applied
at constant velocity to H_3, H_2 and
H_1 during first hour. A 5 gamma
step applied to H_3 at t = 1 hour
and removed at t = 1 3/4 hours.



X SCALE = 1.00E-00 UNITS/INCH
Y SCALE = 1.00E-01 UNITS/INCH

EARTHS MAGNETIC FIELD VS TIME T IN MINUTES H IN GAMMA

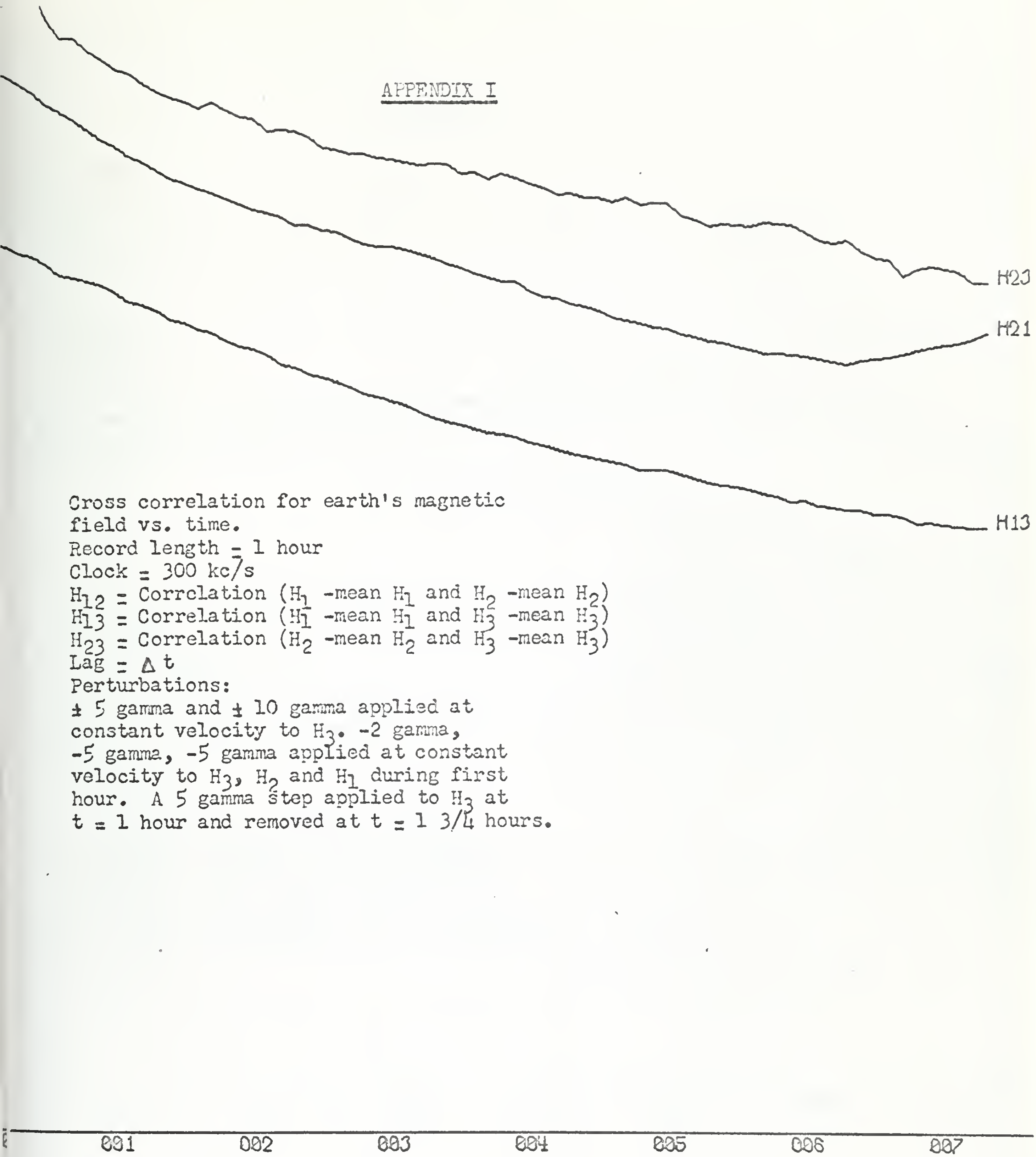

DEL3
DEL2
DEL1
000
002
003
004
005
006
-001
-002
-004
-006
DEL 1 = $H_1 - H_2$
DEL 2 = $H_1 - H_3$
DEL 3 = $H_2 - H_3$
The differences are from Fig.__
X SCALE = 1.00E+00 UNITS/INCH
Y SCALE = 2.00E+00 UNITS/INCH
FILTERED DIFFERENCE IN MAG FIELD T IN MINUTES H IN GAMMA



X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 1.00E+00 UNITS/INCH.

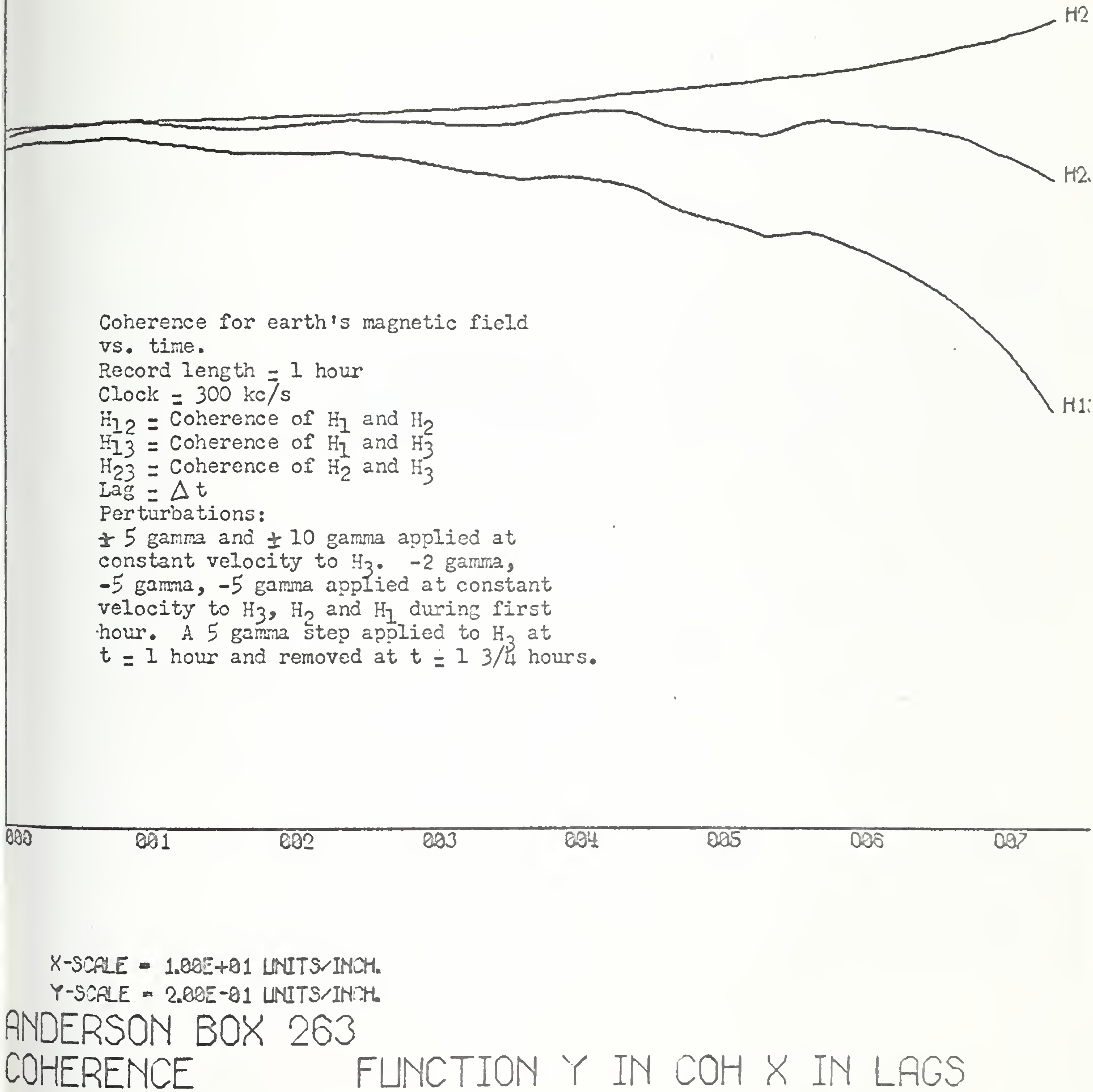
IDERSON BOX 263

ITOCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS



Cross correlation for earth's magnetic field vs. time.
Record length = 1 hour
Clock = 300 kc/s
H_{12} = Correlation (H_1 -mean H_1 and H_2 -mean H_2)
H_{13} = Correlation (H_1 -mean H_1 and H_3 -mean H_3)
H_{23} = Correlation (H_2 -mean H_2 and H_3 -mean H_3)
Lag = Δt
Perturbations:
$\pm$ 5 gamma and $\pm$ 10 gamma applied at constant velocity to H_3. -2 gamma, -5 gamma, -5 gamma applied at constant velocity to H_3, H_2 and H_1 during first hour. A 5 gamma step applied to H_3 at t = 1 hour and removed at t = 1 3/4 hours.

X-SCALE = 1.00E+01 UNITS/INCH.
Y-SCALE = 1.00E+00 UNITS/INCH.
DERSON BOX 263
OSCORRELATION FUNCTION Y IN PRODUCTS X IN LAGS



Coherence for earth's magnetic field vs. time.
Record length = 1 hour
Clock = 300 kc/s
H_{12} = Coherence of H_1 and H_2
H_{13} = Coherence of H_1 and H_3
H_{23} = Coherence of H_2 and H_3
Lag = Δt
Perturbations:
$\pm$ 5 gamma and $\pm$ 10 gamma applied at constant velocity to H_3. -2 gamma, -5 gamma, -5 gamma applied at constant velocity to H_3, H_2 and H_1 during first hour. A 5 gamma step applied to H_3 at t = 1 hour and removed at t = 1 3/4 hours.

APPENDIX II

160 PROGRAMS AND OPERATOR INSTRUCTIONS

APPENDIX II

160 PROGRAMS AND OPERATOR INSTRUCTIONS

Starting Addresses	Function
0000	Rewind
0002	Read
0004	Search
0006	Write
0010	Write identification Block
0100	Main Input Program

Error Stops	Cause
ERR01	77_8 of current input in error
ERR02	Memory storage not complete
ERR04	End of storage tape
ERR03	163 not ready

Addresses of Important Counters	Information
0057	Number of blocks written on storage tape
0045	Current storage location in memory
0046	Number of zero words in memory

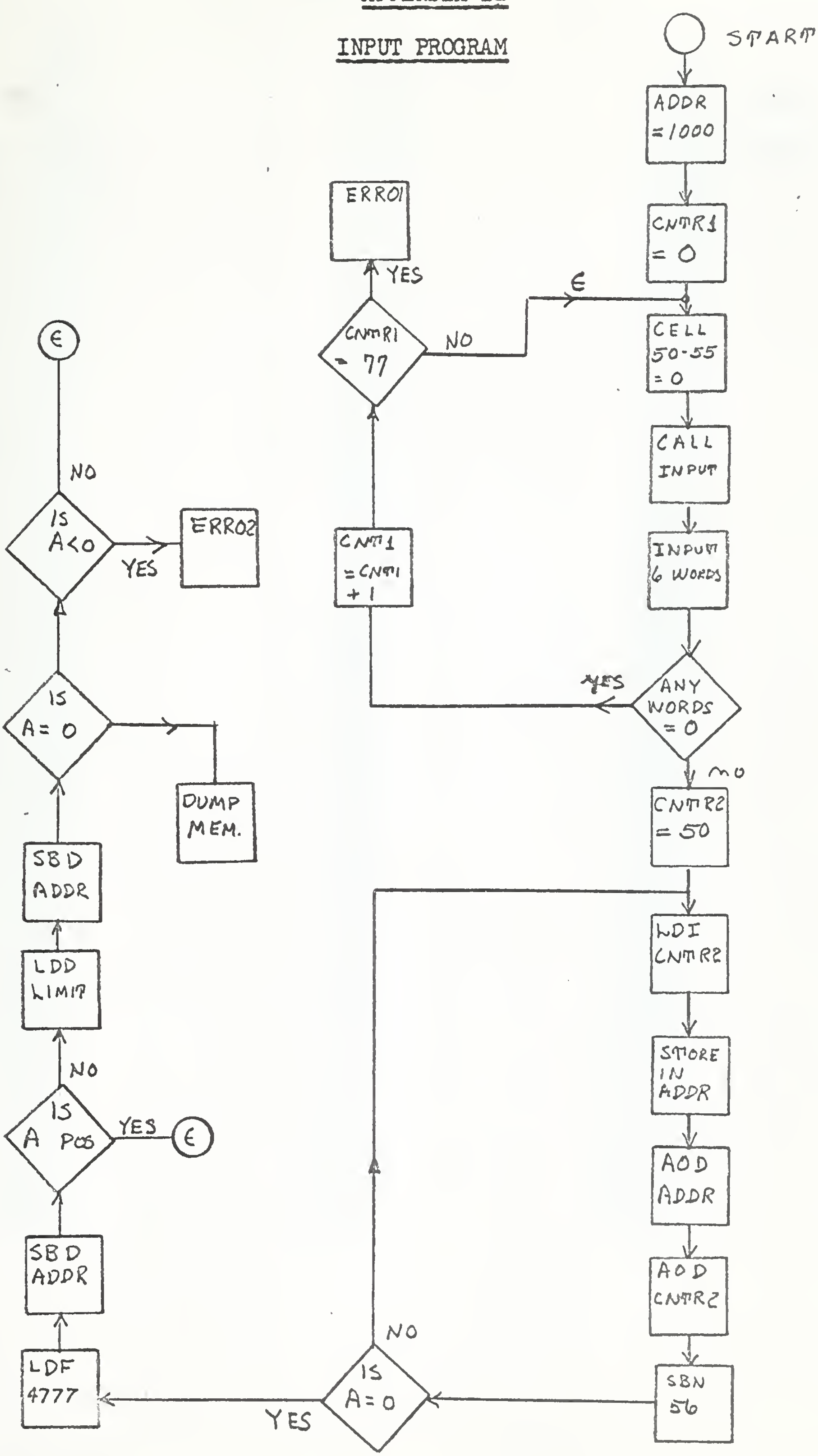
Operator Instructions

1. Load program and make the necessary cable connections.
2. Set identifying records in cells 30_8 to 37_8.
3. Write identifying block (run from P = 010). Stop at P = 100.
4. Set cell 100 = 2200

   57 = 0
5. Start Ampex C.P. 100 and run from P = 100. Stop when tape is finished or ERR stop.

APPENDIX II

INPUT PROGRAM



APPENDIX II

0100	2200	LDF00	
0101	1000	1000	
0102	4045	STD45	(ADDR)
0103	0400	LDN00	
0104	4046	STD46	(CNTR1)
0105	0400	LDN00	
0106	4150	STI50	
0107	4151	STI51	
0110	4152	STI52	
0111	4153	STI53	
0112	4154	STI54	
0113	4155	STI55	
0114	7500	EXF00	
0115	0500	0500	
0116	7203	INP03	
0117	0620	0620	
0120	6102	NZF02	
0121	0600	0600	
0122	1600	LSF00	
0123	0607	ADN07	
0124	6115	NZF15	
0125	2150	LDI50	
0126	6013	ZJF13	
0127	2151	LDI51	
0130	6011	ZJF11	
0131	2152	LDI52	
0132	6007	ZJF07	
0133	2153	LDI53	
0134	6005	ZJF05	
0135	2154	LDI54	
0136	6003	ZJF03	
0137	2155	LDI55	
0140	6105	NZF05	
0141	5446	AOD46	
0142	0777	SBN77	
0143	6536	NZB36	
0144	0001	ERR01	
0145	2050	LBD50	
0146	4047	STD47	
0147	2147	LDI47	
0150	4145	STI45	
0151	5445	AOD45	
0152	5447	AOD47	
0153	3456	SBD56	
0154	6505	NZB05	
0155	2200	LDF00	
0156	4777	4777	

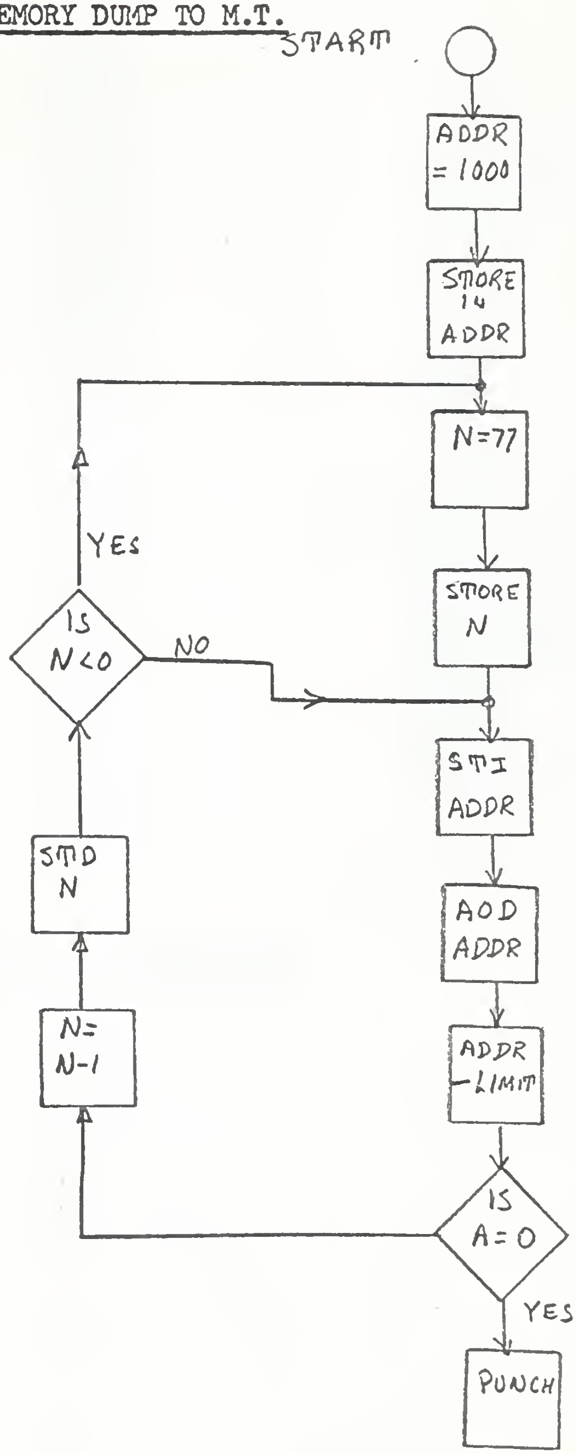
0157	3445	SBD45
0160	6653	PJB53
0161	2044	LDD44
0162	3445	SBD45
0163	6003	ZJF03
0164	6657	PJB57
0165	0002	ERR02
0166	7101	JFI01
0167	0172	WRITE
0170	1000	
0171	7700	HLT00

ADDITIONAL CELLS USED

0044	LIMIT	(PUT IN LIMIT)
0045	ADDR	7600
0046	CNTR 1	
0047	CNTR 2	
0050	BUFFER STORAGE	
0051	BUFFER STORAGE	
0052	BUFFER STORAGE	
0053	BUFFER STORAGE	
0054	BUFFER STORAGE	
0055	BUFFER STORAGE	
0057	NUMBER OF MEMORY DUMPS	

APPENDIX II

MEMORY DUMP TO M.T.



APPENDIX II

0172	5457	AOD57
0173	2600	LCF00
0174	7776	
0175	4060	STD60
0176	7500	EXF00
0177	1141	REQ STAT
0200	7600	INA00
0201	0202	LPN02
0202	6004	ZJF04
0203	5460	AOD60
0204	6506	NZB06
0205	0003	ERR03
0206	7500	EXF00
0207	2111	2111
0210	7303	OUT03
0211	7600	TERM OUT (LIMIT + 1)
0212	6102	NZF02
0213	1000	INIT WRIT
0214	7500	EXF00
0215	1141	REQ STAT
0216	7600	INA00
0217	0240	LPN40
0220	6103	NZF03
0221	7101	JFI01
0222	0100	00
0223	7700	HLT00

DUMP TO PAPER TAPE

0163	7500
0164	4104
0165	7303
0166	7600
0167	6102
0170	1000
0171	7700

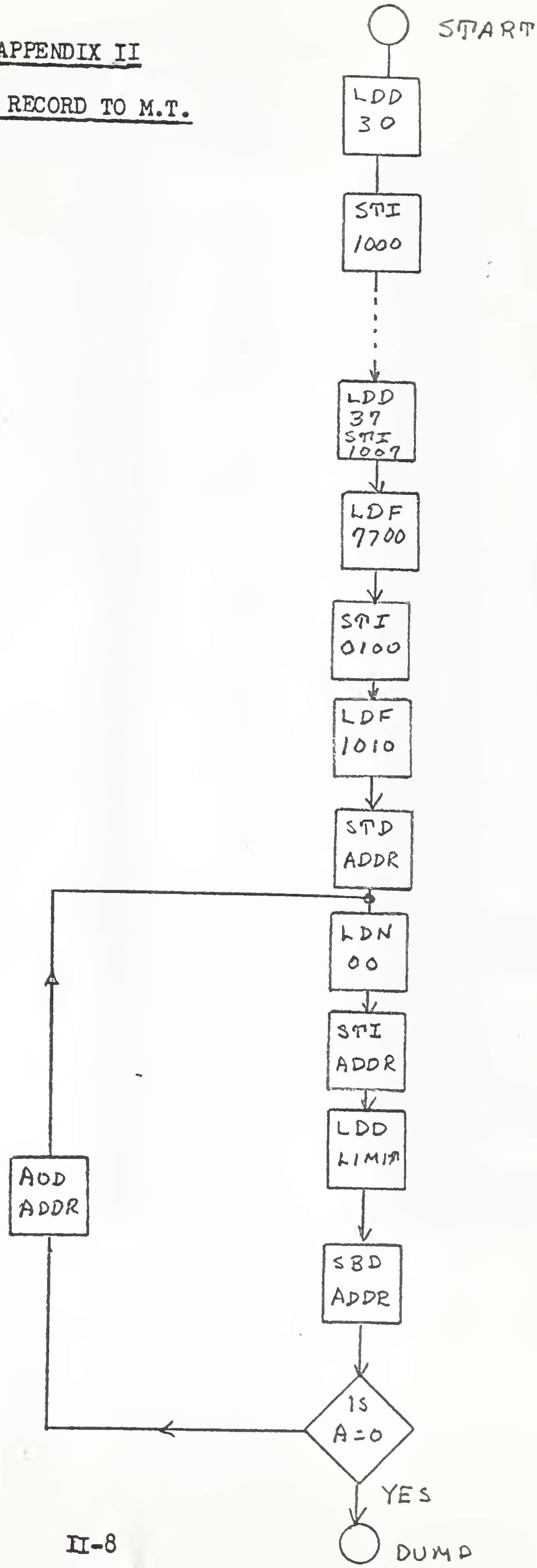
APPENDIX II

DAILY IDENTIFICATION

USE 8 CELLS		EXAMPLE
0030	0070	2 day
0031	0064	3
0032	0032	J
0033	0030	A month
0034	0060	N
0035	0072	6 year
0036	0062	4
0037	0045	CAR RET

APPENDIX II

DAILY RECORD TO M.T.



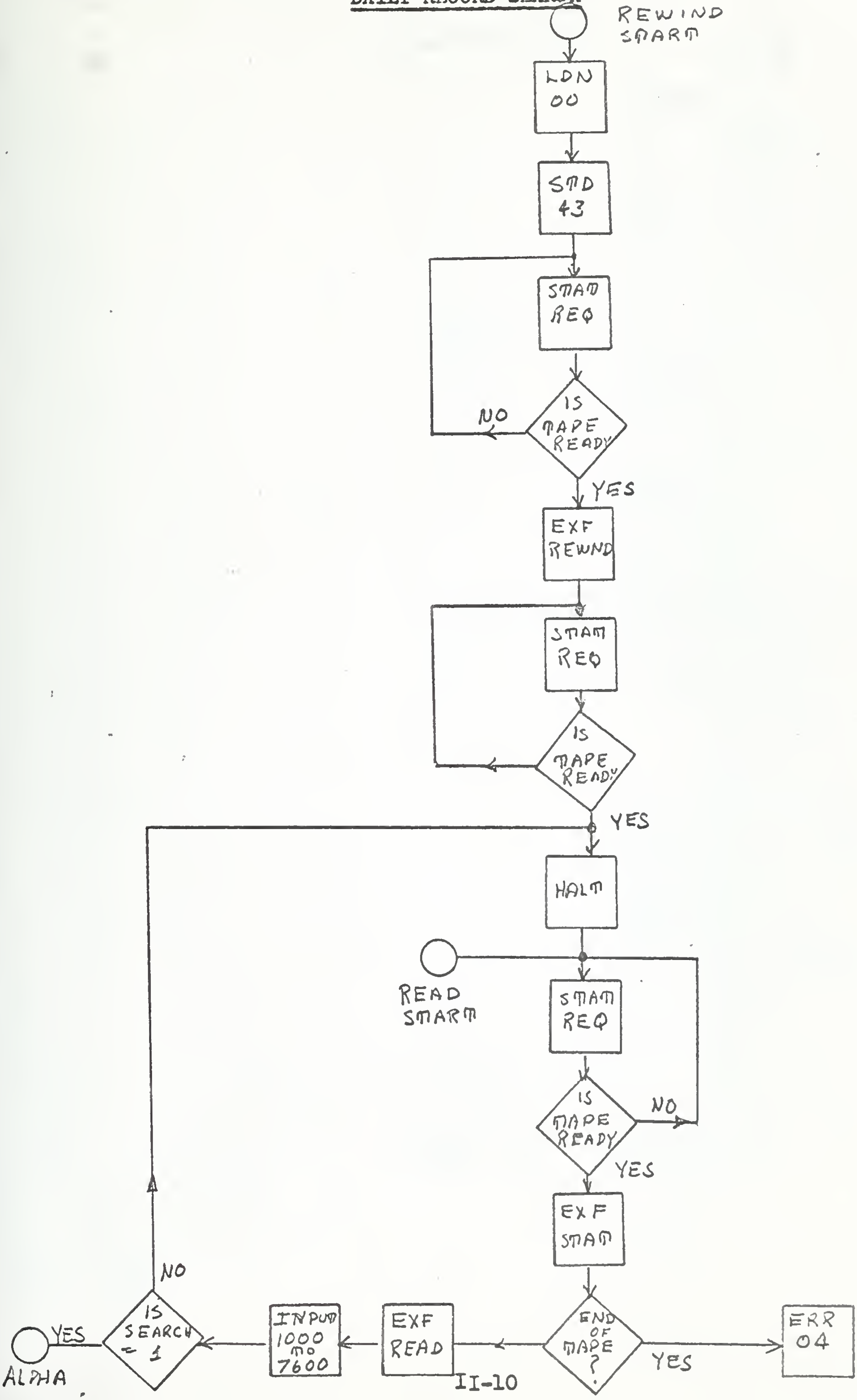
APPENDIX II

DAILY RECORD TO M.T.

0224	2030	LDD30
0225	4100	STI00
0226	1000	1000
0227	2031	LDD31
0230	4100	STI00
0231	1001	1001
0232	2032	LDD32
0233	4100	STI00
0234	1002	1002
0235	2033	LDD33
0236	4100	STI00
0237	1003	1003
0240	2034	LDD34
0241	4100	STI00
0242	1004	1004
0243	2035	LDD35
0244	4100	STI00
0245	1005	1005
0246	2036	LDD36
0247	4100	STI00
0250	1006	1006
0251	2037	LDD37
0252	4100	STI00
0253	1007	1007
0254	2200	LDF00
0255	7700	7700
0256	4100	STI00
0257	0100	0100
0260	2200	LDF00
0261	1010	1010
0262	4045	STD45 (ADDR)
0263	0400	LDN00
0264	4145	STI45
0265	2044	LDD44
0266	3445	SBD45
0267	6003	ZJF03
0270	5445	AOD45 (ADDR)
0271	6506	NZB06
0272	7101	JFI01
0273	0172	0172 (DUMP)
0274	7700	NORMAL STOP

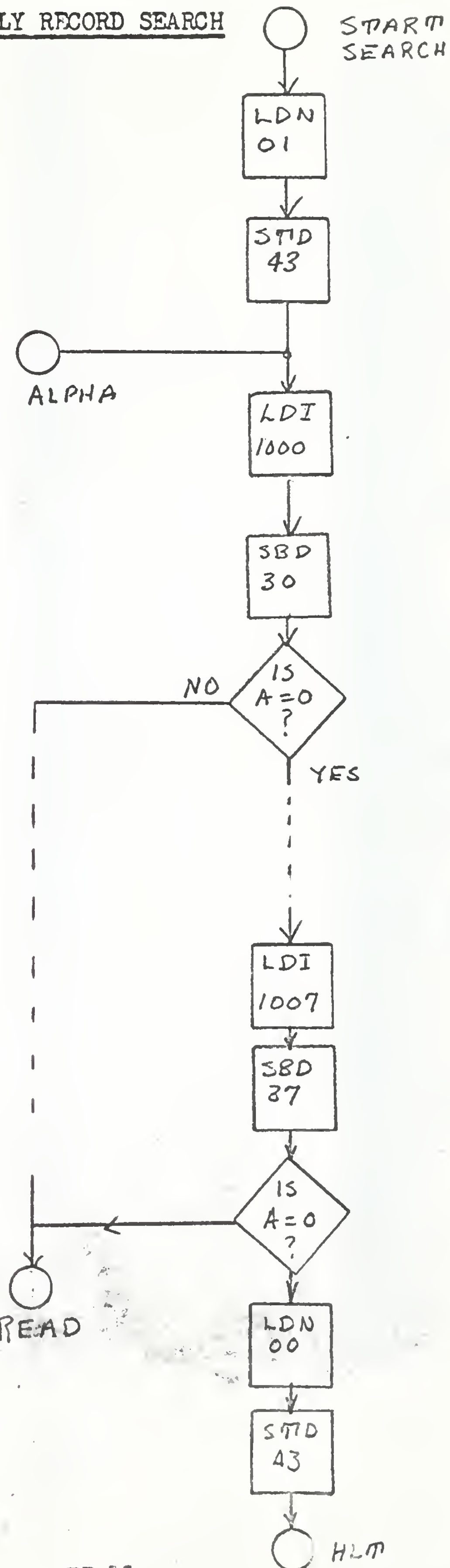
REWIND, READ AND

DAILY RECORD SEARCH



REWIND, READ AND

DAILY RECORD SEARCH



Start Rewind	0275	0400	LDN00
	0276	4043	STD43
	0277	7500	EXF00
	0300	1141	REQ STAT
	0301	7600	INA00
	0302	0202	LPN02
	0303	6504	NZB04
	0304	7500	EXF00
	0305	1161	REWIND
	0306	7500	EXF00
	0307	1141	REQ STAT
	0310	7600	INA00
	0311	0202	LPN02
	0312	6504	NZB04
Read	0313	7700	HLT00
Start	0314	7500	EXF00
	0315	1141	REQ STAT
	0316	7600	INA0C
	0317	0202	LPN02
	0320	6504	NZB04
	0321	7500	EXF00
	0322	2111	EXF11 READ
	0323	7203	OUT03
	0324	7600	TERM READ
	0325	6102	NZF02
	0326	1000	INIT READ
	0327	7500	EXF00
	0330	1141	REQ STAT
	0331	7600	INA00
	0332	0240	LPN40
	0333	6002	ZJF02
	0334	0004	ERR04 (END OF
	0335	2043	LDD43 TAPE)
	0336	0701	SBN01
	0337	6004	ZJF04
	0340	6525	NZB25
Search	0341	0401	LDN01
Start	0342	4043	STD43 (SEARCH)
	0343	2100	LDI00
	0344	1000	1000
	0345	3430	SBD30
	0346	6532	NZB32
	0347	2100	LDI00
	0350	1001	1001
	0351	3431	SBD31
	0352	6536	NZB36
	0353	2100	LDI00

0354	1002	1002
0355	3432	SBD32
0356	6542	NZB42
0357	2100	LDI00
0360	1003	1003
0361	3433	SBD33
0362	6546	NZB46
0363	2100	LDI00
0364	1004	1004
0365	3434	SBD34
0366	6552	NZB52
0367	2100	LDI00
0370	1005	1005
0371	3435	SBD35
0372	6556	NZB56
0373	2100	LDI00
0374	1006	1006
0375	3436	SBD36
0376	6114	NZF14
0377	2100	LDI00
0400	1007	1007
0401	3437	SBD37
0402	6110	NZF10
0403	2100	LDI00
0404	1010	1010
0405	6105	NZF05
0406	0400	LDN00
0407	4043	STD43
0410	7101	JFI01
0411	0077	0077
0412	7101	JFI01
0413	0314	

TEST TAPE 22 BLOCKS DATA

$M = 47145_{10}$

$= \underset{N_2}{0013} \quad \underset{N_1}{4051_8}$

LIMIT CELL 44 = 7600
ADDR CELL 45
CNTR 2 CELL 21
N_1 CELL 22
N_2 CELL 23
CNTR 1 CELL 20

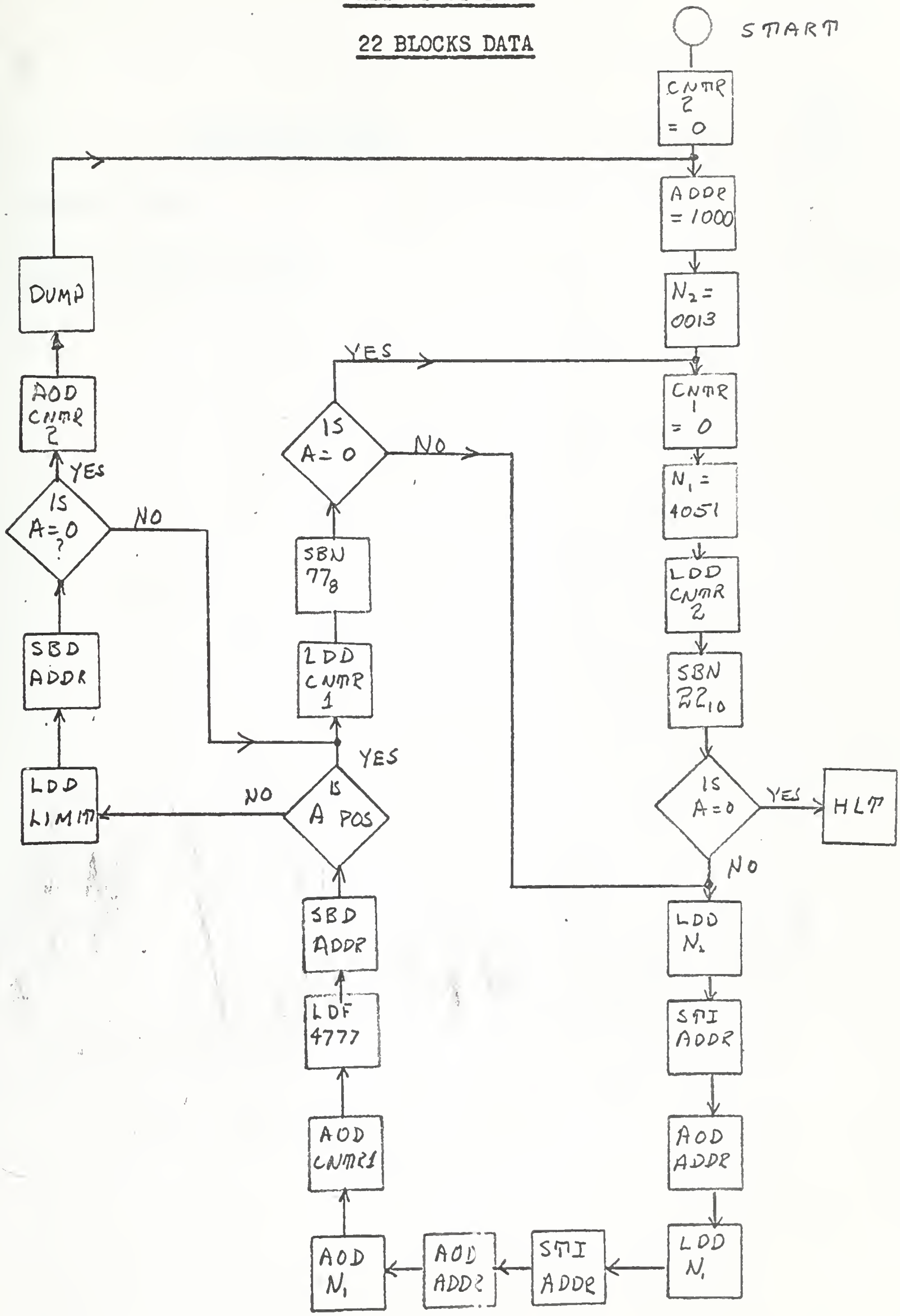
0526	7700	HLT00
0527	0400	LDN00
0530	4021	STD21
0531	2200	LDF00
0532	1000	1000

0533	4045	STD45
0534	0413	LDN13
0535	4023	STD23
0536	0400	LDN00
0537	4020	STD20
0540	2200	LDF00
0541	4051	4051
0542	4022	STD22
0543	2021	LDD21
0544	0726	SBN26
0545	6417	ZJB17
0546	2023	LDD23
0547	4145	STI45
0550	5445	AOD45
0551	2022	LDD22
0552	4145	STI45
0553	5445	AOD45
0554	5422	AOD22
0555	5420	AOD20
0556	2200	LDF00
0557	4777	4777
0560	3445	SBD45
0561	6207	PJF07
0562	2044	LDD44
0563	3445	SBD45
0564	6104	NZF04
0565	5421	AOD21
0566	7101	JFI01
0567	0172	0172
0570	2020	LDD20
0571	0777	SBN77
0572	6434	ZJB34
0573	6525	NZB25

APPENDIX II

WRITE TEST TAPE

22 BLOCKS DATA



APPENDIX III

FORTRAN PROGRAMS	PAGE
ANALYSIS PROGRAM	1
SATELLITE DISPLAY PROGRAM	7

```
      DIMENSION NDATA(864),DATE(100),H(1728),HONE(900),ITITLE(12),
     1HTWO(900),HTHRE(900),T(900),BIN1(100),BIN2(100),BIN3(100),X(100)
      DO 5 J = 1,14
      READ 5,DATE(J)
    5 FORMAT(O16)
      CON(MASK = 00000000777777778)
      ENA(NDATA),INA(1).
      STA(INIT),INA(864).
      STA(ITERM),ENI(0).
    6 CALL READ(3,INIT,ITERM,1)
      DO 70 I=3,3
      SLS1(7)
    7 ADATE = DATE(I)
      BDATE = DATE(I+1)
      LDA(ADATE),SUB(NDATA +1),AJP1(6),
      LDA(BDATE),SUB(NDATA +2),AJP1(6).
      NBLOC = 0
   30 CALL READ(3,INIT,ITERM,1)
      NZRO = 0
      DO 81 J=1,864
      IF(NDATA(J)) 82,82,81
   82 NZRO = NZRO+1
   81 CONTINUE
      ND = NDATA(3)
      LDA(ND),AJP0(10).
      K=0
      DO 40 J=1,864
      K=K+1
      INDATA = NDATA(J)
      LDA(INDATA),LDQ(MASK),ARS(24),STL(INLIST).
      H(K)=INLIST
      K=K+1
      LDA(INDATA),LDQ(MASK),STL(INLIST).
      SLS1(40).
   40 H(K)=INLIST
      AVE=0.
      DO 50 J =1,1728
      H(J) = H(J)/3.
      H(J)=1024./H(J)*2348400.0
   50 AVE = H(J) + AVE


      PRINT 26, AVE
C ZAPP FILTER
      NERR =  0
      AVE = 0.
      HBAR = 50950.0
      DO 51 J=1,1728
      DEV = ABSF(H(J)-HBAR)
      IF(DEV-200.) 51,52,52
      JCOUNT = J
   52 NERR = NERR + 1
      IF(J-3) 53,53,54
   53 H(J) = H(J+3)
      GO TO 51
   54 H(J) = H(J-3)
   51 AVE = AVE + H(J)
      AVE = AVE/1728.
      PRINT 26, AVE
      PRINT 97,NERR,NZRO,JCOUNT
      NBLOC = NBLOC + 1
      WRITE TAPE 2, H
      GO TO 30
   10 REWIND 2
C THIS SECTION COMPUTES H VS TIME
C 18 PT AVE N IS TOTAL NUMBER OF POINTS PER DAY
      TIME = - 6.5/704.
      DO 60 L=1,NBLOC
      READ TAPE 2,H
      DO 62 J=1,32
      H1BAR = 0.
      H2BAR = 0.
      H3BAR = 0.
      DO 61 K=1,18
      M = 3*K - 2 + (J - 1)*54
      H1BAR = H(M) + H1BAR
      H2BAR = H(M+1) + H2BAR
   61 H3BAR = H(M+2) + H3BAR
      N = J + (L-1)*32
      HONE(N) = H1BAR/18.
      HTWC(N) = H2BAR/18.
      HTHRE(N) = H3BAR/18.
      TIME = TIME + 6.5/704.
   62 T(N) = TIME
   60 CONTINUE
```

APPENDIX III

```
      REWIND 2
      PRINT 27,N
      PRINT 27,M
      NPTS=N
C MEAN VALUE OF DIFFERENCES
      JERR = 0
      IERR = 0
      NERR = 0
      DEL1 = 0.
      DEL2 = 0.
      DEL3 = 0.
      DO 64 J = 1,NBLOC
      READ TAPE 2,H
      DO 64 L = 1,576
      M = 3*L-2
      DEL = H(M + 1) - H(M)
      IF(ABSF(DEL)- 40.) 65,66,66
   65 DEL1 = DEL1 + DEL
      GO TO 67
   66 NERR = NERR + 1
   67 DEL = H(M + 1) -H(M + 2)
      IF(ABSF(DEL) - 40.) 68,69,69
   68 DEL2 = DEL2 + DEL
      GO TO 71
   69 IERR = IERR + 1
   71 DEL = H(M) - H(M + 2)
      IF(ABSF(DEL) - 40.) 72,73,73
   72 DEL3 = DEL3 + DEL
      GO TO 64
   73 JERR = JERR + 1
   64 CONTINUE
      REWIND 2
      PRINT 97,NERR,IERR,JERR
   97 FORMAT(3I20)
      ABLOC = NBLOC
      DEL1 = DEL1/(576.*ABLOC)
      DEL2 = DEL2/(576.*ABLOC)
      DEL3 = DEL3/(576.*ABLOC)
      PRINT 49,DEL1,DEL2,DEL3
C DENSITY FUNCTION
      STDEV1=0.
      STDEV2=0.
      STDEV3=0.
      NERR = 0
      IERR = 0
      JERR = 0
      XL=-25.
      DO 45 K=1,100
      BIN1(K)=0.
      BIN2(K)=0.
      BIN3(K)=0.
      X(K)=XL
   45 XL= XL+0.5
      DO 74 J=1,NBLOC
      READ TAPE 2,H
      DO 74 L = 1,576
      M = 3*L-2
      STDEV1= (H(M+1)-H(M)-DEL1)**2 +STDEV1
      STDEV2= (H(M+1)-H(M+2)-DEL2)**2 + STDEV2
      STDEV3= (H(M)-H(M+2)-DEL3)**2 +STDEV3
      DEL = H(M+1) - H(M)
      IF(ABSF(DEL-DEL1)-25.)75,75,76
   76 NERR = NERR + 1
   75 DEL = H(M+1) -H(M+2)
      IF(ABSF(DEL-DEL2)-25.)77,77,78
   78 IERR = IERR + 1
   77 DEL = H(M) - H(M+2)
      IF(ABSF(DEL-DEL3)-25.)29,29,80
   80 JERR = JERR + 1
   29 DO 31 K=1,3
      IF(K-2)32,33,34
   32 DEL=H(M+1)-H(M)-DEL1
      GO TO 35
   33 DEL=H(M+1)-H(M+2)-DEL2
      GO TO 35
   34 DEL=H(M)-H(M+2)-DEL3
   35 XL= -25.
      DO 36 N=1,100
      IF(DEL-XL) 37,37,38
   38 IF(DEL-(XL+0.5))39,39,37
   39 IF(K-2) 42,43,44
   42 BIN1(N)=BIN1(N)+1.
      GO TO 31
   43 BIN2(N) = BIN2(N)+1.
      GO TO 31
```

```
 30 CONTINUE
 31 CONTINUE
 74 CONTINUE
    STDEV1 =SQRTF(STDEV1/(576.*ABLOC))
    STDEV2 =SQRTF(STDEV2/(576.*ABLOC))
    STDEV3 =SQRTF(STDEV3/(576.*ABLOC))
    PRINT 49,STDEV1,STDEV2,STDEV3
    PRINT 97,NERR,IERR,JERR
    REWIND 2
C NORMALIZED  DENSITY FUNCTION
    AMAX=BIN1(1)
    BMAX=BIN2(1)
    CMAX=BIN3(1)
    DO 200 J=1,100
    IF(AMAX-BIN1(J))201,202,202
201 AMAX=BIN1(J)
202 IF(BMAX-BIN2(J))203,204,204
203 BM+XOBIM2(-)‡‡‡‡‡‡‡‡/‡/‡‡‡‡‡‡‡S‡‡S‡‡‡‡‡‡‡//‡‡‡‡‡‡‡‡‡‡S          //
204 IF(CMAX-BIN3(J))205,200,200
205 CMAX=BIN3(J)
200 CONTINUN
    PRINT 49,AMAX,BMAX,CMAX
    DO 206 J=1,100
    BIN1(J)=BIN1(J)/AMAX
    BIN2(J)=BIN2(J)/BMAX
206 BIN3(J)=BIN3(J)/CMAX
    DO 46 K=1,12
 46 ITITLE(K)=8H
    ITITLE(1)=8HANDERSON
    ITITLE(2)=8H BOX 263
    ITITLE(7)=8H DENSITY
    ITITLE(8)=8H FUNCTIO
    ITITLE(9)=8HN X IN G
    ITITLE(10)=8HAMMA Y
    ITITLE(11)=8HIN FREQ
    LABA=4H P1
    LABB=4H P2
    LABC=4H P3
    CALL DRAW(100,X,BIN1,0,C,LABA,ITITLE,0,0,0,4,0,2,8,8,0,LAST)
    CALL DRAW(100,X,BIN2,0,C,LABB,ITITLE,0,0,0,4,0,2,8,8,0,LAST)
    CALL DRAW(100,X,BIN3,0,C,LABC,ITITLE,0,0,0,4,0,2,8,8,0,LAST)
506 N=NPTS
    HONEAV=0.
    HTWOAV=0.
    HTHREAV=0.
    DO 48 L=1,N
    HONEAV=HONEAV+HONE(L)
    HTWOAV=HTWOAV+HTWO(L)
 48 HTHREAV=HTHREAV+HTHRE(L)
    SV04 = N
    HONEAV = HONEAV/SV04
    HTWOAV = HTWOAV/SV04
    HTHREAV = HTHREAV/SV04
    PRINT 49,HONEAV,HTWOAV,HTHREAV
 49 FORMAT(3E20.7)
    PRINT 27,NBLOC
 27 FORMAT(I7)
    HONEAV= (HONEAV +HTWOAV +HTHREAV)/3.
    PRINT 26,HONEAV
 26 FORMAT(E20.7)
    WRITE TAPE 2, HONE
    WRITE TAPE 2, HTWO
    WRITE TAPE 2, HTHRE
    REWIND 2
    DO 90 L = 1,N
    HONE(L) = HONE(L) - HONEAV
    HTWO(L) = HTWO(L) - HONEAV
 90 HTHRE(L) = HTHRE(L) - HONEAV
    DO 1 L=1,12
  1 ITITLE(L) = 8H
    ITITLE(1)=8HANDERSON
    ITITLE(2)=8H BOX 263
    ITITLE(7)=8H EARTHS
    ITITLE(8)=8HMAGNETIC
    ITITLE(9)=8H FIELD V
    ITITLE(10)=8HS TIME
    ITITLE(11)=8HT IN HRS
    ITITLE(12)=8H H GAMMA
    LABA=4H H1
    LABB=4H H2
    LABC=4H H3
    CALL DRAW(N,T,HONE,1,0,LABA,ITITLE,1.0,10.0,5,1,2,2,8,10,0,LAST)
    CALL DRAW(N,T,HTWO,2,0,LABB,ITITLE,1.0,10.0,5,1,2,2,8,10,0,LAST)
    CALL DRAW(N,T,HTHRE,3,0,LABC,ITITLE,1.0,10.,5,1,2,2,8,10,0,LAST)
C Z TRANSFORM LOW PASS FILTER N EQUAL 20 TITUS
    AT= 4.*3.14116/100.
```

APPENDIX III

```
      IF(J-20) 302,303,303
  302 M=J
      GO TO 304
  303 M=20
  304 DO 301 K=1,M
      L= K-1
      BL=L
      ASUM = EXPF(-AT*BL)+ASUM
      BSUM =EXPF(-AT*BL)*HONE(J-L)+BSUM
      CSUM =EXPF(-AT*BL)*HTWO(J-L) + CSUM
  301 DSUM = EXPF(-AT*BL)*HTHRE(J-L)+DSUM
      HONE(J)=BSUM/ASUM
      HTWO(J)= CSUM/ASUM
  300 HTHRE(J)= DSUM/ASUM
      ITITLE(2)=8H FILTER
      CALL DRAW(N,T,HONE,1,0,LABA,ITITLE,1.0,10.0,5,1,2,2,8,10,0,LAST)
      CALL DRAW(N,T,HTWO,2,0,LABB,ITITLE,1.0,10.0,5,1,2,2,8,10,0,LAST)
      CALL DRAW(N,T,HTHRE,3,0,LABC,ITITLE,1.0,10.,5,1,2,2,8,10,0,LAST)
C DIFFERENCES OF FILTERED VALVES
      DO 306 J = 1,N
      H(J)= HONE(J)
      HONE(J)= H(J)- HTWO(J)
      STORE = HTWO(J)
      HTWO(J)= H(J)-HTHRE(J)
  306 HTHRE(J)= STORE- HTHRE(J)
      ITITLE(7)=8HFILTERED
      ITITLE(8)=8HDIFFEREN
      ITITLE(9)=8HCE IN MA
      ITITLE(10)=8HG FIELD
      LABA=4HDEL1
      LABB=4HDEL2
      LABC=4HDEL3
      CALL DRAW(N,T,HONE,1,0,LABA,ITITLE,1.0,5.00,5,1,2,2,8,10,0,LAST)
      CALL DRAW(N,T,HTWO,2,0,LABB,ITITLE,1.0,5.00,5,1,2,2,8,10,0,LAST)
      CALL DRAW(N,T,HTHRE,3,0,LABC,ITITLE,1.0,5.0,5,1,2,2,8,10,0,LAST)
C THIS SECTION COMPUTES SIMPLE DIFF
      READ TAPE 2, HONE
      READ TAPE 2, HTWO
      READ TAPE 2, HTHRE
      REWIND 2
      DO 15 L=1,900
      H(L)=HONE(L)
      HONE(L)=H(L)-HTWO(L)
      STORE=HTWO(L)
      HTWO(L)=H(L)-HTHRE(L)
   15 HTHRE(L)=STORE-HTHRE(L)
      DO 16 L=1,12
   16 ITITLE(L)=8H
      ITITLE(1)=8HANDERSON
      ITITLE(2)=8H BOX 263
      ITITLE(7)=8HFIRST DI
      ITITLE(8)=8HFFERENCE
      ITITLE(9)=8H IN MAG
      ITITLE(10)=8HFIELD
      ITITLE(11)=8HT IN HRS
      ITITLE(12)=8H H GAMMA
      LABA=4HDEL1
      LABB=4HDEL2
      LABC=4HDEL3
      CALL DRAW(N,T,HONE,1,0,LABA,ITITLE,1.0,5.00,5,1,2,2,8,10,0,LAST)
      CALL DRAW(N,T,HTWO,2,0,LABB,ITITLE,1.0,5.00,5,1,2,2,8,10,0,LAST)
      CALL DRAW(N,T,HTHRE,3,0,LABC,ITITLE,1.0,5.0,5,1,2,2,8,10,0,LAST)
C AUTOCORRELATION FUNCTION 75LAGS
      NLAGS=75
      MPTS= N-NLAGS
      PTS= MPTS
      XL=0.
      DO 9 J=1,100
      BIN1(J)=0.
      BIN2(J)=0.
      BIN3(J)=0.
      X(J)=XL
    9 XL = XL+1.
      READ TAPE 2,HONE
      READ TAPE 2,HTWO
      READ TAPE 2,HTHRE
      REWIND 2
      DO 11 J=1,N
      HONE(J) = HONE(J)- HONEAV
      HTWO(J) = HTWO(J) - HTWOAV
   11 HTHRE(J)=HTHRE(J)-HTHREAV
      DO 12 J=1,NLAGS
      DO 14 K=1,MPTS
      L=K-1
```

```
      BIN2(J)= BIN2(J) + HTWO(K)*HTWO(L+J)
   14 BIN3(J)=BIN3(J) + HTHRE(K)*HTHRE(L+J)
      BIN1(J)=BIN1(J)/PTS
      BIN2(J)= BIN2(J)/PTS
   12 BIN3(J)= BIN3(J)/PTS
C SAVE AUTOCORRELATION  FUNCTION
      DO 105 J=1,100
      H(J)=BIN1(J)
      H(J+100)=BIN2(J)
  105 H(J+200)=BIN3(J)
      DO 100 J=1,12
  100 ITITLE(J)=8H
      ITITLE(1)=8HANDERSON
      ITITLE(2)=8H BOX 263
      ITITLE(7)=8HAUTOCORR
      ITITLE(8)=8HELATION
      ITITLE(9)=8HFUNCTION
      ITITLE(10)=8H Y IN PR
      ITITLE(11)=8HODUCTS X
      ITITLE(12)=8H IN LAGS
      LABA=4H H1
      LABB=4H H2
      LABC=4H H3
      CALL DRAW(NLAGS,X,BIN1,1,0,LABA,ITITLE,0,0,0,0,0,0,8,8,0,LAST)
      CALL DRAW(NLAGS,X,BIN2,2,0,LABB,ITITLE,0,0,0,0,0,0,8,8,0,LAST)
      CALL DRAW(NLAGS,X,BIN3,3,0,LABC,ITITLE,0,0,0,0,0,0,8,8,0,LAST)
C CROSS CORRELATION FUNCTION 75 LAGS
      DO 101 J=1,100
      BIN1(J)=0.
      BIN2(J)=0.
  101 BIN3(J)=0.
      DO 102 J=1,NLAGS
      DO 103 K=1,MPTS
      L= K-1
      BIN1(J)=BIN1(J)+ HTWO(K)*HONE(L+J)
      BIN2(J)=BIN2(J)+HTWO(K)*HTHRE(L+J)
  103 BIN3(J)=BIN3(J)+ HONE(K)*HTHRE(L+J)
      BIN1(J)=BIN1(J)/PTS
      BIN2(J)= BIN2(J)/PTS
  102 BIN3(J)= BIN3(J)/PTS
      DO 104 J=1,12
  104 ITITLE(J)=8H
      ITITLE(1)=8HANDERSON
      ITITLE(2) =8H BOX 263
      ITITLE(7) =8HCROSCORR
      ITITLE(8) =8HELATION
      ITITLE(9) =8HFUNCTION
      ITITLE(10)=8H Y IN PR
      ITITLE(11)=8HODUCTS X
      ITITLE(12)=8H IN LAGS
      LABA = 4H H21
      LABB = 4H H23
      LABC = 4H H13
      CALL DRAW(NLAGS,X,BIN1,1,0,LABA,ITITLE,0,0,0,0,0,0,8,8,0,LAST)
      CALL DRAW(NLAGS,X,BIN2,2,0,LABB,ITITLE,0,0,0,0,0,0,8,8,0,LAST)
      CALL DRAW(NLAGS,X,BIN3,3,0,LABC,ITITLE,0,0,0,0,0,0,8,8,0,LAST)
C COHERENCY  COMPUTATION 75 LAGS
      DO 106 J = 1,NLAGS
      BIN1(J)=(BIN1(J)**2)/(H(J+100)*H(J))
      IF(BIN1(J)) 107,108,108
  107 BIN1(J)=-BIN1(J)
  108 BIN1(J)= SQRTF(BIN1(J))
      BIN2(J)=(BIN2(J)**2)/(H(J+100)*H(J+200))
      IF(BIN2(J)) 109,110,110
  109 BIN2(J)=-BIN2(J)
  110 BIN2(J)= SQRTF(BIN2(J))
      BIN3(J)=(BIN3(J)**2)/(H(J)*H(J+200))
      IF(BIN3(J)) 111,106,106
  111 BIN3(J)=-BIN3(J)
  106 BIN3(J)= SQRTF(BIN3(J))
      ITITLE(7)=8HCOHERENC
      ITITLE(8)=8HE
      ITITLE(10)=8H Y IN CO
      ITITLE(11)=8HH X IN L
      ITITLE(12)=8HAGS
      CALL DRAW(NLAGS,X,BIN1,1,0,LABA,ITITLE,0,.2,0,0,0,0,8,8,0,LAST)
      CALL DRAW(NLAGS,X,BIN2,2,0,LABB,ITITLE,0,.2,0,0,0,0,8,8,0,LAST)
      CALL DRAW(NLAGS,X,BIN3,3,0,LABC,ITITLE,0,.2,0,0,0,0,8,8,0,LAST)
   70 CONTINUE
      REWIND 3
      STOP
      END
      MACHINE READ(1ARG,2ARG,3ARG,4ARG)
```

```
* TYPEWRITER MESSAGE CODE TABLE

      CON(T6 =4504041220302204B,    T7 =1120061301050420B,
     *    T8 =1212031200000000B,    T9 =4504041220302204B,
     *    T10=1530121401250420B,    T11=1212031200000000B)
      CON(T12=4504041220302204B,    T13=2006220403260426B,
     *    T14=1411200000000000B,    T15=4504043112140120B,
     *    T40=4504040130152004B,    T41=3406140104060301B,
     *    T42=0414062214163001B,    T43=2022420000000000B)

* TAPE UNIT ASSIGNMENT TABLE
*     ASSIGNMENTS FOR CHANNEL 3/4 LIBRARY TAPE

      CON(K0 =0       ,  K1 =332010B,  K2 =332020B,
     *    K3 =332030B,   K4 =332040B,  K5 =552010B,
     *    K6 =552020B,   K7 =552030B,  K8 =552040B)

* ASSORTED CONSTANTS

      CON(R4 =7373737373737373B,  R16=0070000000000000B)

* TAPE READING ROUTINE

1X    SLJ(N)           SLJ(L+5)       . EXIT/ENTRY
1ARG  ZRO(0)           ZRO(0)         . TAPE UNIT NUMBER ARG.
2ARG  ZRO(0)           ZRO(0)         . INITIAL ADDRESS
3ARG  ZRO(0)           ZRO(0)         . TERMINAL ADDRESS
4ARG  ZRO(0)           ZRO(0)         . MODE, 1 = BINARY, 2 = BCD
      LDA7(1ARG)       INA(-11B)      .
      SIU1(19X)        AJP3(L+3)      . CHECK FOR TU ASSIGNMENT
      ENA(T40)         SLJ4( G)       . GO PRINT ERROR
      SLJ( P)          ZRO(0)         .
      INA(11B)         STA(K0)        .
      LIL1(K0)         LDA1(K0)       .
      ADD7(4ARG)       SAU(4X)        . SET TU CONTROL CODES
      SCL(777B)        SAL(4X)        . INITIALIZE
      SAL(5X)          SAL(11X)       .
      INA(3)           SAU(8X)        .
      INA(2)           SAU(9X)        .
      INA(1)           SAU(11X)       .
      INA(1)           SAU(7X)        .
      LRS(18)          ENA(0)         .
      LLS(3)           SAL(2X)        .
      SAL(3X)          SAU(12X)       .
      LLS(39)          LDQ(R16)       .
      STA(K0)          LDA(5X)        .
      SSU(K0)          STA(5X)        .
      LDA7(2ARG)       SAU(5X)        .
      LDA(6X)          SSU(K0)        .
      STA(6X)          ENI(0)         .
2X    LDA7(3ARG)       SAL(N)         .
      SAU(6X)          SIL2(19X)      .
3X    ENI2(4)          LIL1(N)        .
4X    EXF(N)           EXF7(N)        . SELECT UNIT
5X    EXF(N)           EXF7(N)        . ACTIVATE CHANNEL
6X    EXF(N)           LDA7(2ARG)     .
      SUB(R4)          LLS(48)        .
      INI1(-1)         LDA1(Z)        .
      INI1(1)          SUB(R4)        .
7X    EXF7(N)          SLJ(15X)       . SENSE ENDFILE
8X    EXF7(N)          SLJ(L+4)       . SENSE PARITY ERROR
9X    EXF7(N)          SLJ(10X)       . SENSE LENGTH ERROR
      QJP1(19X)        AJP(3X)        . SENSE FOR BAD RECORD
      SLJ(19X)         ZRO(0)         . EXIT
      IJP2(L+2)        SLJ(14X)       . SENSE FIVE PARITY ERRORS
10X   IJP2(L+1)        SLJ(13X)       . SENSE FIVE LENGTH ERRORS
      AJP(3X)          QJP(3X)        . SENSE FOR BAD RECORD
11X   EXF(N)           EXF7(N)        . BACKSPACE
12X   LIL1(N)          SLJ(4X)        . RETURN TO REREAD
13X   ENA(T6)          SLJ(17X)       . SET TO INDICATE TROUBLE
14X   ENA(T9)          SLJ(17X)       .
15X   ENA(T12)         SLJ(18X)       .
17X   SLJ4( G)         ZRO(0)         . TROUBLE EXIT
      AJP(19X)         AJP3(3X)       . SENSE ACTION TO TAKE
      SLJ(11X)         ZRO(0)         .
18X   SLJ4( G)         ZRO(0)         . TROUBLE EXIT
      AJP(3X)          AJP3(3X)       . SENSE ACTION TO TAKE
      SLJ(11X)         ZRO(0)         .
19X   ENI1(N)          ENI2(N)        . RE-STORE INDEXES
      SLJ(1X)          ZRO(0)         .
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```
      PROGRAM PROMAG
      DIMENSION NDATA(864),DATE(100),H(1728),HONE(900),ITITLE(12),
     1HTWO(900),HTHRE(900),T(900)
      DO 5 J = 1,14
      READ 5,DATE(J)
    5 FORMAT(O16)
      CON(MASK = 00000000777777778)
      ENA(NDATA),INA(1).
      STA(INIT),INA(864).
      STA(ITERM),ENI(0).
    6 CALL READ(3,INIT,ITERM,1)
      DO 70 I = 1,11,2
      ADATE = DATE(I)
      BDATE = DATE(I+1)
      LDA(ADATE),SUB(NDATA +1),AJP1(6),
      LDA(BDATE),SUB(NDATA +2),AJP1(6).
      NBLOC = 0
   30 CALL READ(3,INIT,ITERM,1)
      ND = NDATA(3)
      LDA(ND),AJP0(10).
      K=0
      DO 40 J=1,864
      K=K+1
      INDATA = NDATA(J)
      LDA(INDATA),LDQ(MASK),ARS(24),STL(INLIST).
      H(K)=INLIST
      K=K+1
      LDA(INDATA),LDQ(MASK),STL(INLIST).
      SLS1(40).
   40 H(K)=INLIST
      AVE=0.
      DO 50 J =1,1728
      H(J)=(1024./H(J))*2348400.0
   50 AVE=H(J)+AVE
      AVE=AVE/1728.
      PRINT 26, AVE
C ZAPP FILTER
      NERR =  0
      AVE = 0.
      HBAR = 50950.0
      DO 51 J=1,1728
      DEV = ABSF(H(J)-HBAR)
      IF(DEV-200.) 51,52,52
   52 NERR = NERR + 1
      IF(J-3) 53,53,54
   53 H(J) = H(J+3)
      GO TO 51
   54 H(J) = H(J-3)
   51 AVE = AVE + H(J)
      AVE = AVE/1728.
      PRINT 26, AVE
      PRINT 27, NERR
      NBLOC = NBLOC + 1
      WRITE TAPE 2, H
      GO TO 30
   10 REWIND 2
      NPTS = (1728*NBLOC)/2700
      PRINT 27,NPTS
      READ TAPE 2, H
      K = 1
      TIME = -6.5/900.
      M=1
C THIS SECTION COMPUTES H VS TIME
      DO 60 L=1,900
      HONE(L)=(H(K)+H(K+3)+H(K+6))/3.
      HTWO(L)=(H(K+1)+H(K+4)+H(K+7))/3.
      LCOUNT=L
      HTHRE(L)=(H(K+2)+H(K+5)+H(K+8))/3.
      TIME = TIME + 6.5/900.
      T(L) = TIME
      K = K + 3*NPTS
      MAX = K+8
      IF(MAX - 1728) 60,60,80
   80 K=1
      IF(M-NBLOC) 85,95,95
   85 READ TAPE 2,H
      M=M+1
   60 CONTINUE
   95 PRINT 97,LCOUNT
      PRINT 97,M
      AT = 4.*3.1416/100.
      REWIND 2
      WRITE TAPE 2, HONE
      WRITE TAPE 2, HTWO
      WRITE TAPE 2, HTHRE
```

```
      HONEAV=0.
      HTWOAV=0.
      HTHREAV=0.
      DO 48 L=1,900
      HONEAV=HONEAV+HONE(L)
      HTWOAV=HTWOAV+HTWO(L)
   48 HTHREAV=HTHREAV+HTHRE(L)
      HONEAV=HONEAV/900.
      HTWOAV=HTWOAV/900.
      HTHREAV=HTHREAV/900.
      PRINT 49,HONEAV,HTWOAV,HTHREAV
   49 FORMAT(3E20.7)
      PRINT 27,NBLOC
   27 FORMAT(I7)
      HONEAV= (HONEAV +HTWOAV +HTHREAV)/3.
      PRINT 26,HONEAV
   26 FORMAT(E20.7)
      DO 90 L=1,900
      HONE(L) = HONE(L) - HONEAV
      HTWO(L) = HTWO(L) - HONEAV
   90 HTHRE(L) = HTHRE(L) - HONEAV
      DO 1 L=1,12
    1 ITITLE(L) = 8H
      ITITLE(1)=8HANDERSON
      ITITLE(2)=8H BOX 263
      ITITLE(7)=8H EARTHS
      ITITLE(8)=8HMAGNETIC
      ITITLE(9)=8H FIELD V
      ITITLE(10)=8HS TIME
      ITITLE(11)=8HT IN HRS
      ITITLE(12)=8H H GAMMA
      LABA=4H H1
      LABB=4H H2
      LABC=4H H3
      CALL DRAW(900,T,HONE,1,0,LABA,ITITLE,1.0,10.0,5,1,2,2,8,10,0,LAST)
      CALL DRAW(900,T,HTWO,2,0,LABB,ITITLE,1.0,10.0,5,1,2,2,8,10,0,LAST)
      CALL DRAW(900,T,HTHRE,3,0,LABC,ITITLE,1.0,10.,5,1,2,2,8,10,0,LAST)
      CALL SATGRAF(0,900,T,HONE,0,0,0,0)
      CALL SATGRAF(0,900,T,HTWO,0,0,0,0)
      CALL SATGRAF(0,900,T,HTHRE,0,0,0,0)
C THIS SECTION COMPUTES SIMPLE DIFF
      READ TAPE 2, HONE
      READ TAPE 2, HTWO
      READ TAPE 2, HTHRE
      REWIND 2
      DO 15 L=1,900
      H(L)=HONE(L)
      HONE(L)=H(L)-HTWO(L)
      STORE=HTWO(L)
      HTWO(L)=H(L)-HTHRE(L)
   15 HTHRE(L)=STORE-HTHRE(L)
      DO 16 L=1,12
   16 ITITLE(L)=8H
      ITITLE(1)=8HANDERSON
      ITITLE(2)=8H BOX 263
      ITITLE(7)=8HFIRST DI
      ITITLE(8)=8HFFERENCE
      ITITLE(9)=8H IN MAG
      ITITLE(10)=8HFIELD
      ITITLE(11)=8HT IN HRS
      ITITLE(12)=8H H GAMMA
      LABA=4HDEL1
      LABB=4HDEL2
      LABC=4HDEL3
      CALL DRAW(900,T,HONE,1,0,LABA,ITITLE,1.0,2.00,5,1,2,2,8,10,0,LAST)
      CALL DRAW(900,T,HTWO,2,0,LABB,ITITLE,1.0,2.00,5,1,2,2,8,10,0,LAST)
      CALL DRAW(900,T,HTHRE,3,0,LABC,ITITLE,1.0,2.0,5,1,2,2,8,10,0,LAST)
      CALL SATGRAF(0,900,T,HONE,0,0,0,0)
      CALL SATGRAF(0,900,T,HTWO,0,0,0,0)
      CALL SATGRAF(0,900,T,HTHRE,0,0,0,0)
   70 CONTINUE
      REWIND 3
      STOP
      END
      MACHINE READ(1ARG,2ARG,3ARG,4ARG)

* NOTE  G = ADDRESS OF ENTRY TO TYPEWRITER SENSE ROUTINE
*       P = ADDRESS OF PROGRAM CONTROL ROUTINE JUMP  ENTRY
* THIS ROUTINE IS FOR PROGRAM CALL

      LOC(G=31,  P=10)

* TYPEWRITER MESSAGE CODE TABLE
```

```
      CON(T12=4504041220302204B,   T13=2006220403260426B,
     *     T14=1411200000000000B,   T15=4504043112140120B,
     *     T40=4504040130152004B,   T41=3406140104060301B,
     *     T42=0414062214163001B,   T43=2022420000000000B)

* TAPE UNIT ASSIGNMENT TABLE
*     ASSIGNMENTS FOR CHANNEL 3/4 LIBRARY TAPE

      CON(K0 =0      ,  K1 =332010B,  K2 =332020B,
     *     K3 =332030B,  K4 =332040B,  K5 =552010B,
     *     K6 =552020B,  K7 =552030B,  K8 =552040B)

* ASSORTED CONSTANTS

      CON(R4 =7373737373737373B,  R16=0070000000000000B)

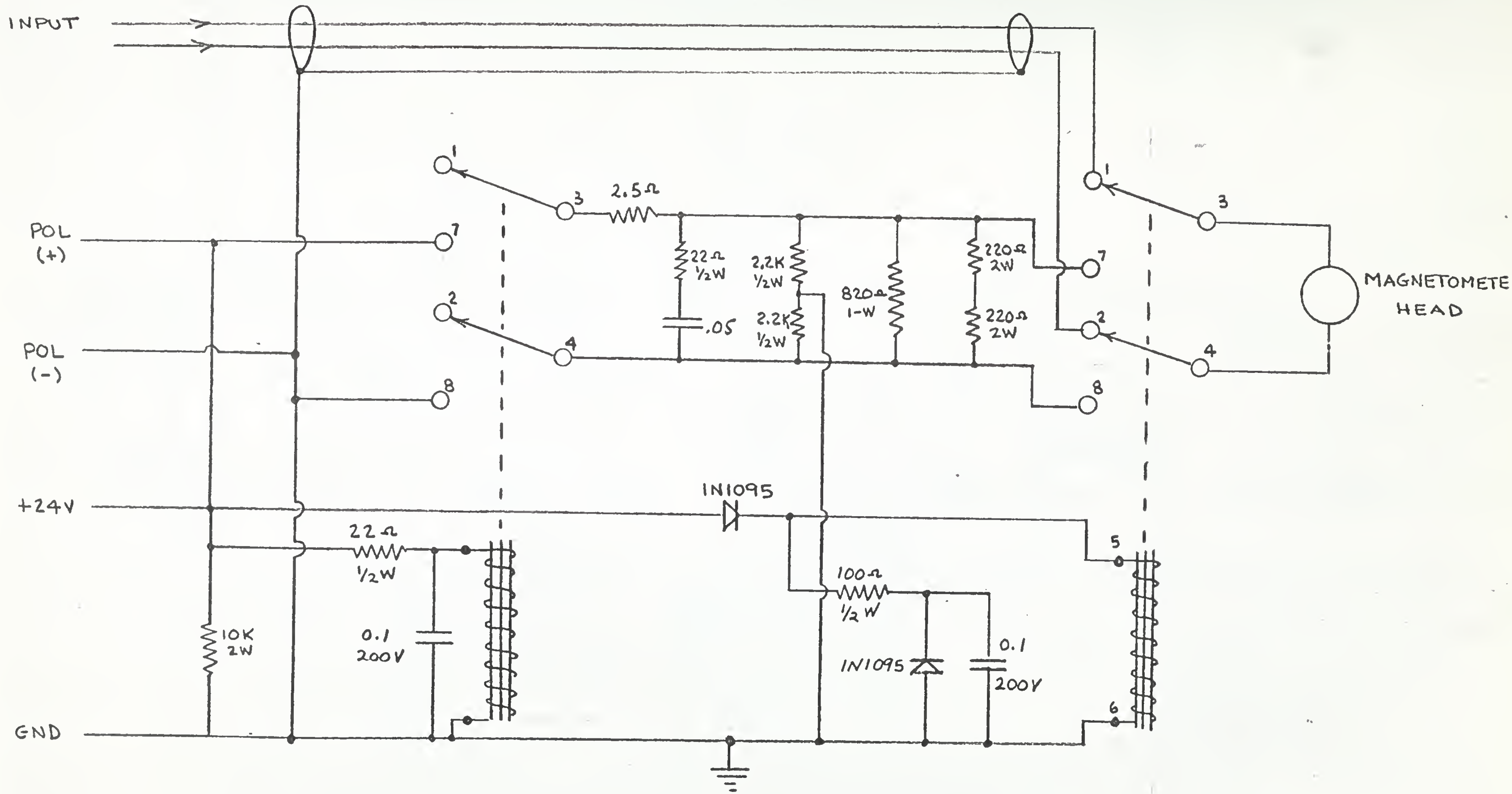
* TAPE READING ROUTINE

1X    SLJ(N)            SLJ(L+5)          . EXIT/ENTRY
1ARG  ZRO(0)            ZRO(0)            . TAPE UNIT NUMBER ARG.
2ARG  ZRO(0)            ZRO(0)            . INITIAL ADDRESS
3ARG  ZRO(0)            ZRO(0)            . TERMINAL ADDRESS
4ARG  ZRO(0)            ZRO(0)            . MODE, 1 = BINARY, 2 = BCD
      LDA7(1ARG)        INA(-11B)         .
      SIU1(19X)         AJP3(L+3)         . CHECK FOR TU ASSIGNMENT
      ENA(T40)          SLJ4( G)          . GO PRINT ERROR
      SLJ( P)           ZRO(0)            .
      INA(11B)          STA(K0)           .
      LIL1(K0)          LDA1(K0)          .
      ADD7(4ARG)        SAU(4X)           . SET TU CONTROL CODES
      SCL(777B)         SAL(4X)           . INITIALIZE
      SAL(5X)           SAL(11X)          .
      INA(3)            SAU(8X)           .
      INA(2)            SAU(9X)           .
      INA(1)            SAU(11X)          .
      INA(1)            SAU(7X)           .
      LRS(18)           ENA(0)            .
      LLS(3)            SAL(2X)           .
      SAL(3X)           SAU(12X)          .
      LLS(39)           LDQ(R16)          .
      STA(K0)           LDA(5X)           .
      SSU(K0)           STA(5X)           .
      LDA7(2ARG)        SAU(5X)           .
      LDA(6X)           SSU(K0)           .
      STA(6X)           ENI(0)            .
2X    LDA7(3ARG)        SAL(N)            .
      SAU(6X)           SIL2(19X)         .
3X    ENI2(4)           LIL1(N)           .
4X    EXF(N)            EXF7(N)           . SELECT UNIT
5X    EXF(N)            EXF7(N)           . ACTIVATE CHANNEL
6X    EXF(N)            LDA7(2ARG)        .
      SUB(R4)           LLS(48)           .
      INI1(-1)          LDA1(Z)           .
      INI1(1)           SUB(R4)           .
7X    EXF7(N)           SLJ(15X)          . SENSE ENDFILE
8X    EXF7(N)           SLJ(L+4)          . SENSE PARITY ERROR
9X    EXF7(N)           SLJ(10X)          . SENSE LENGTH ERROR
      QJP1(19X)         AJP(3X)           . SENSE FOR BAD RECORD
      SLJ(19X)          ZRO(0)            . EXIT
      IJP2(L+2)         SLJ(14X)          . SENSE FIVE PARITY ERRORS
10X   IJP2(L+1)         SLJ(13X)          . SENSE FIVE LENGTH ERRORS
      AJP(3X)           QJP(3X)           . SENSE FOR BAD RECORD
11X   EXF(N)            EXF7(N)           . BACKSPACE
12X   LIL1(N)           SLJ(4X)           . RETURN TO REREAD
13X   ENA(T6)           SLJ(17X)          . SET TO INDICATE TROUBLE
14X   ENA(T9)           SLJ(17X)          .
15X   ENA(T12)          SLJ(18X)          .
17X   SLJ4( G)          ZRO(0)            . TROUBLE EXIT
      AJP(19X)          AJP3(3X)          . SENSE ACTION TO TAKE
      SLJ(11X)          ZRO(0)            .
18X   SLJ4( G)          ZRO(0)            . TROUBLE EXIT
      AJP(3X)           AJP3(3X)          . SENSE ACTION TO TAKE
      SLJ(11X)          ZRO(0)            .
19X   ENI1(N)           ENI2(N)           . RE-STORE INDEXES
      SLJ(1X)           ZRO(0)            .
      END
      END
       .5143083E+05
       .5093095E+05
    29
       .5097462E+05
```

APPENDIX IV

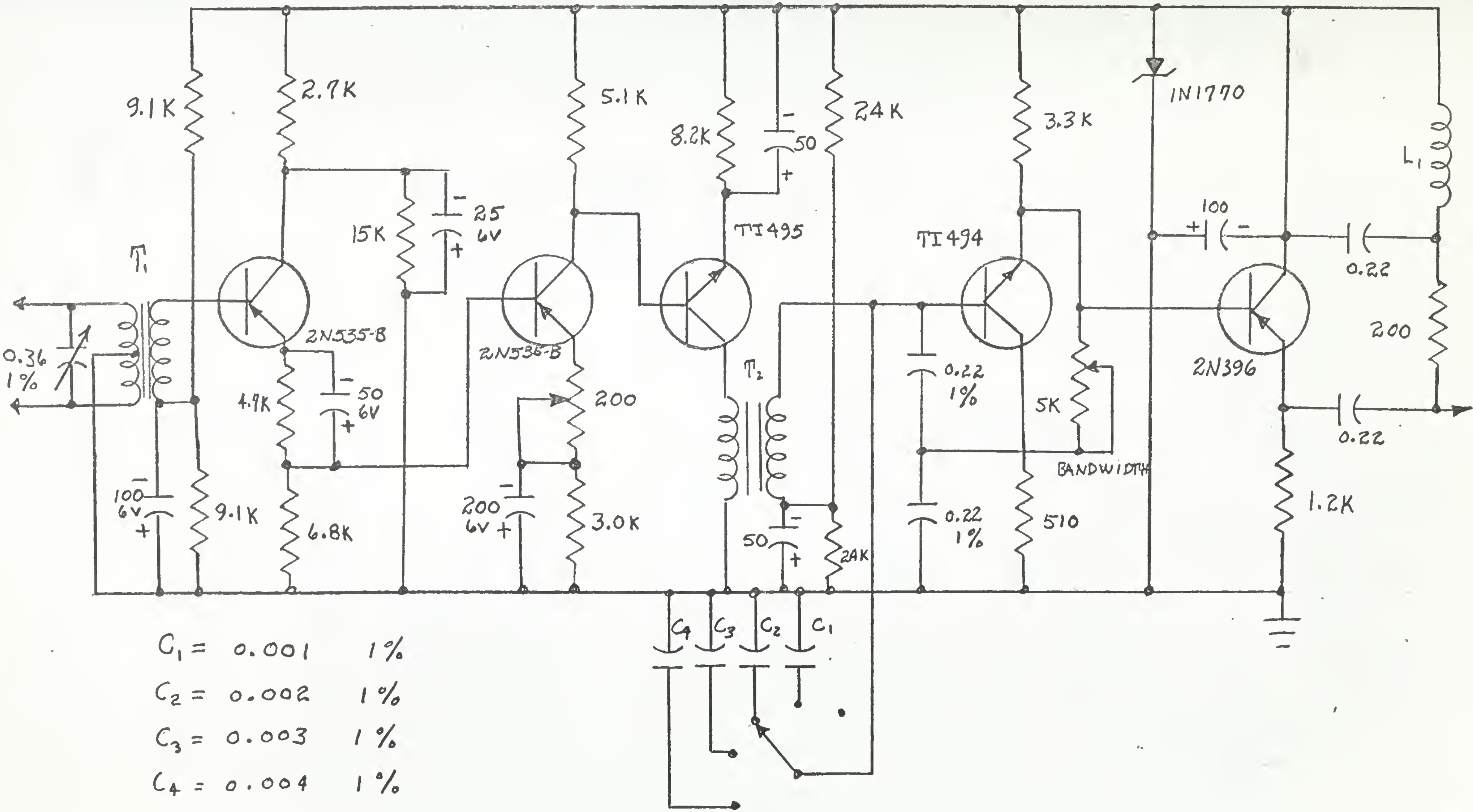
CIRCUIT DIAGRAMS	PAGE
POLARIZING AND DAMPING NETWORK	1
MAGNETOMETER PREAMP	2
MAGNETOMETER AMPLIFIER	3
RADAR GATE	4
CLOCK GATE AND GATE CONTROL	5
STORAGE RESET AND GATE DRIVER	6
TIMER	7
COUNTER START AND RESET	8
SIGNAL GATE AND GATE CONTROL	9
CLOCK FREQUENCY MULTIPLIER	10
COUNTER FLIP-FLOP AND GATE	11
MULTIPLEX PULSE GENERATOR	12
MULTIPLEX BLOCK DIAGRAM	13
ANALOG LADDER	14
OUTPUT AMPLIFIERS	15
PLUS AND MINUS 12 VOLT POWER SUPPLY	16
PLUS AND MINUS 4 VOLT POWER SUPPLY	17
PLUS 28 VOLT OSCILLATOR AND TIMER POWER SUPPLY	18
INTERFACE DRIVER AND AMPLIFIER	19
INTERFACE AND/OR GATES	20
INTERFACE FLIP-FLOP AND INVERTER	21

APPENDIX IV



IV-1

APPENDIX IV



$C_1 = 0.001 \quad 1\%$

$C_2 = 0.002 \quad 1\%$

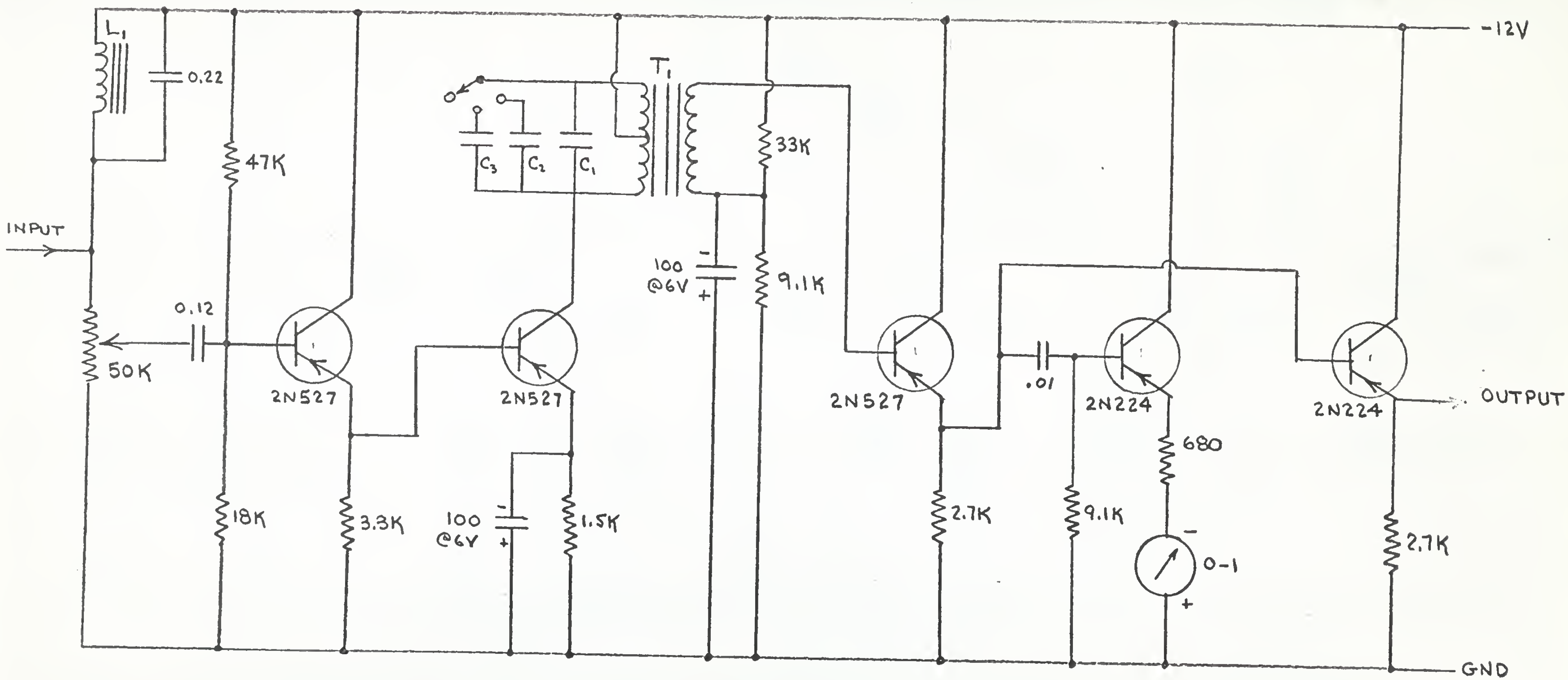
$C_3 = 0.003 \quad 1\%$

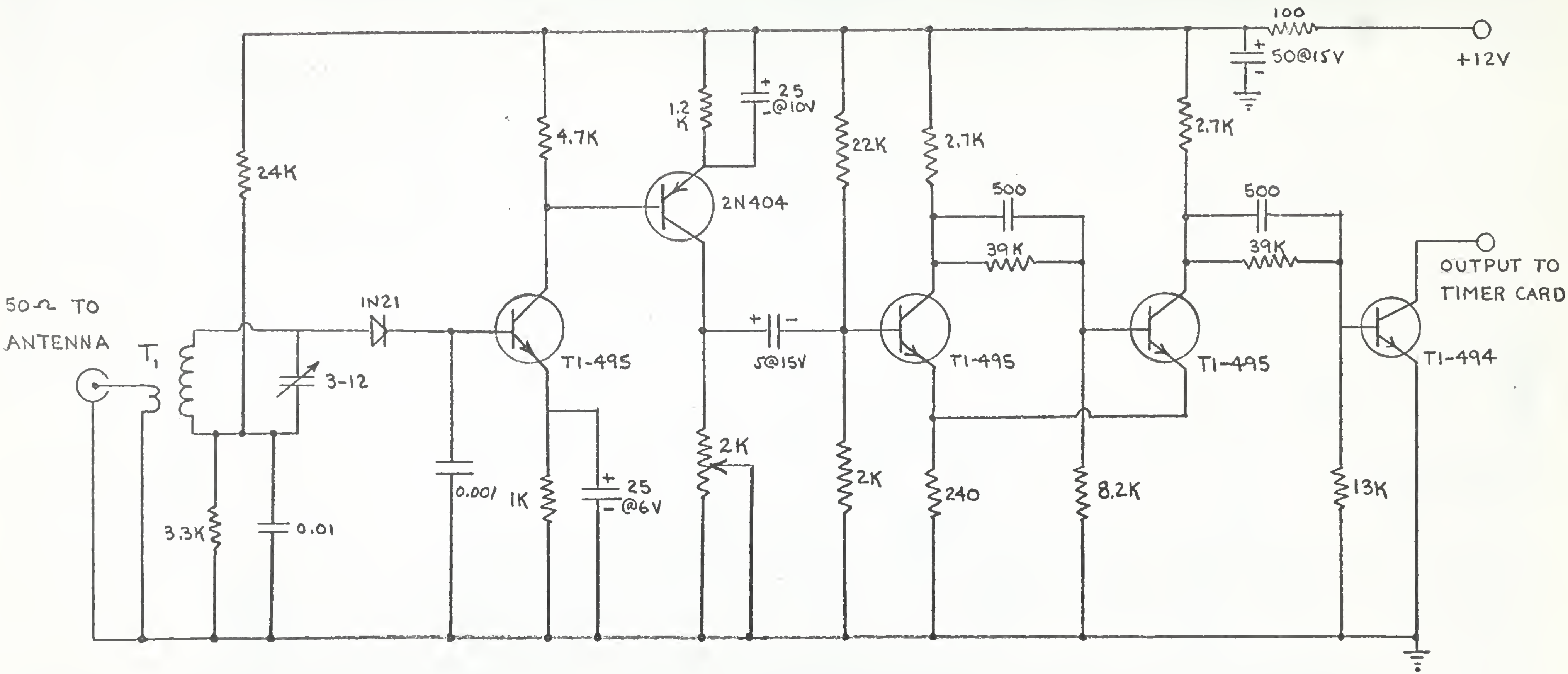
$C_4 = 0.004 \quad 1\%$

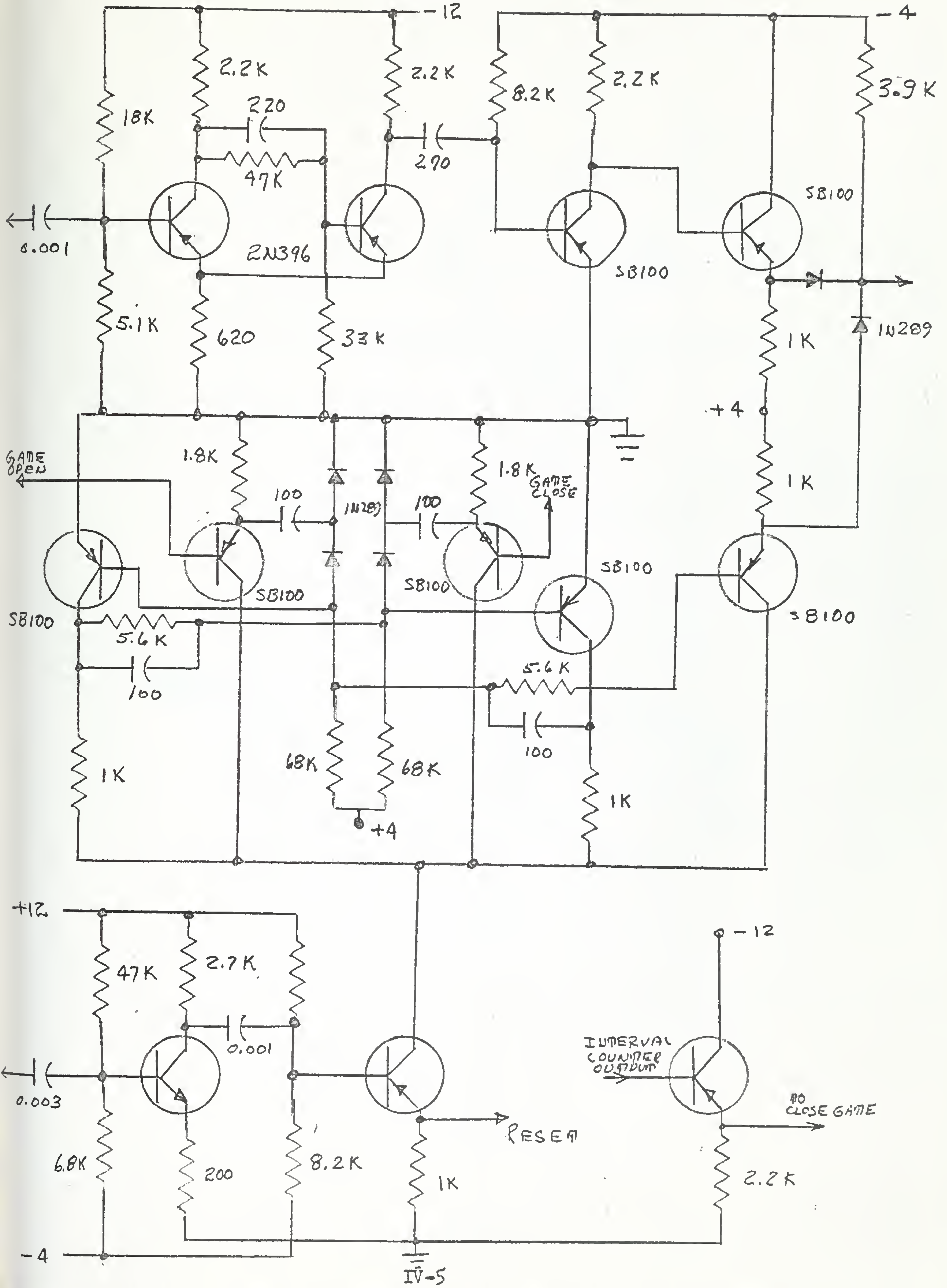
$L_1 = 24.4$ mh

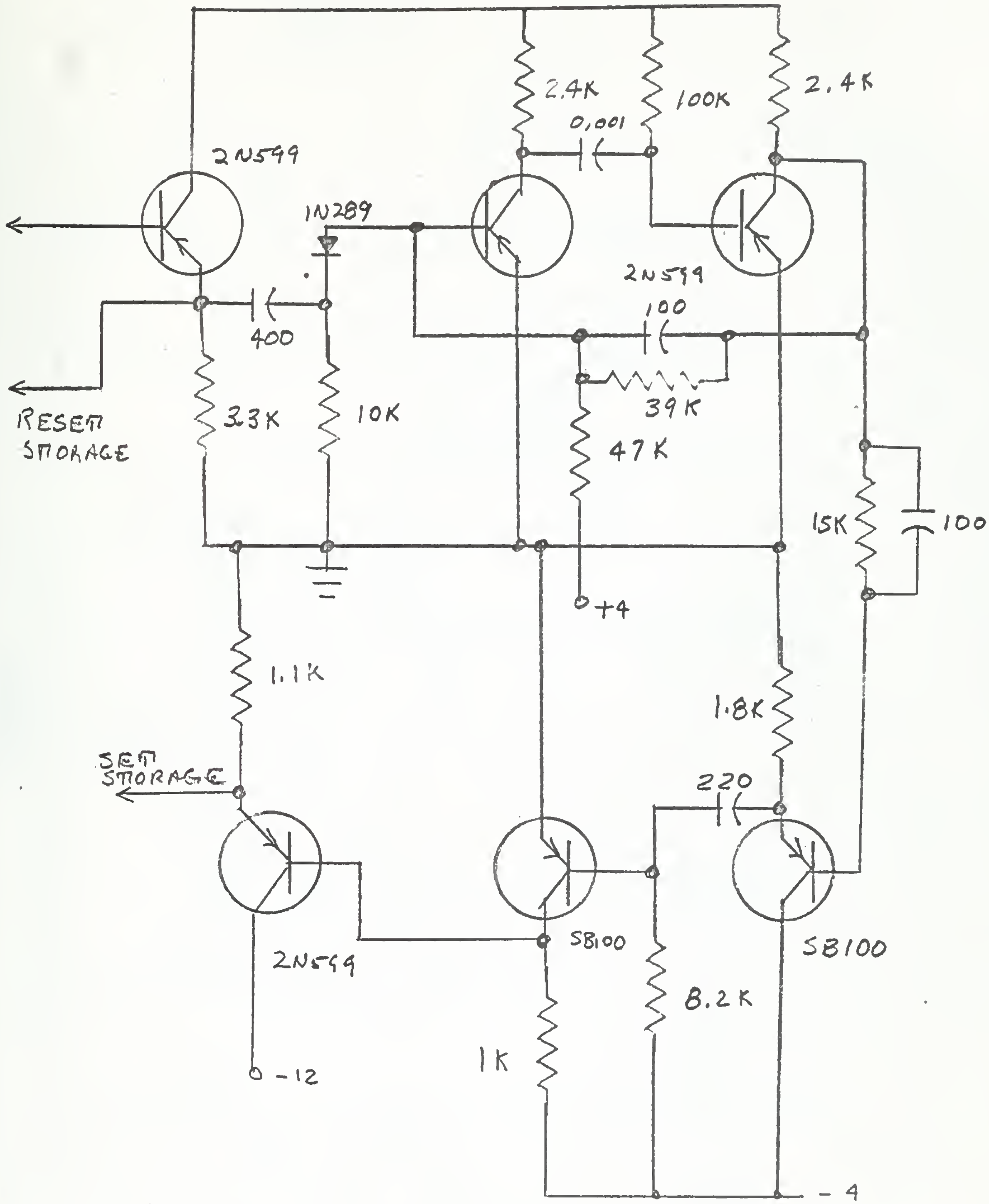
$T_1 =$ 400T (PRIMARY)
1400T (SECONDARY)

$T_2 =$ 120T (PRIMARY)
570T (SECONDARY)

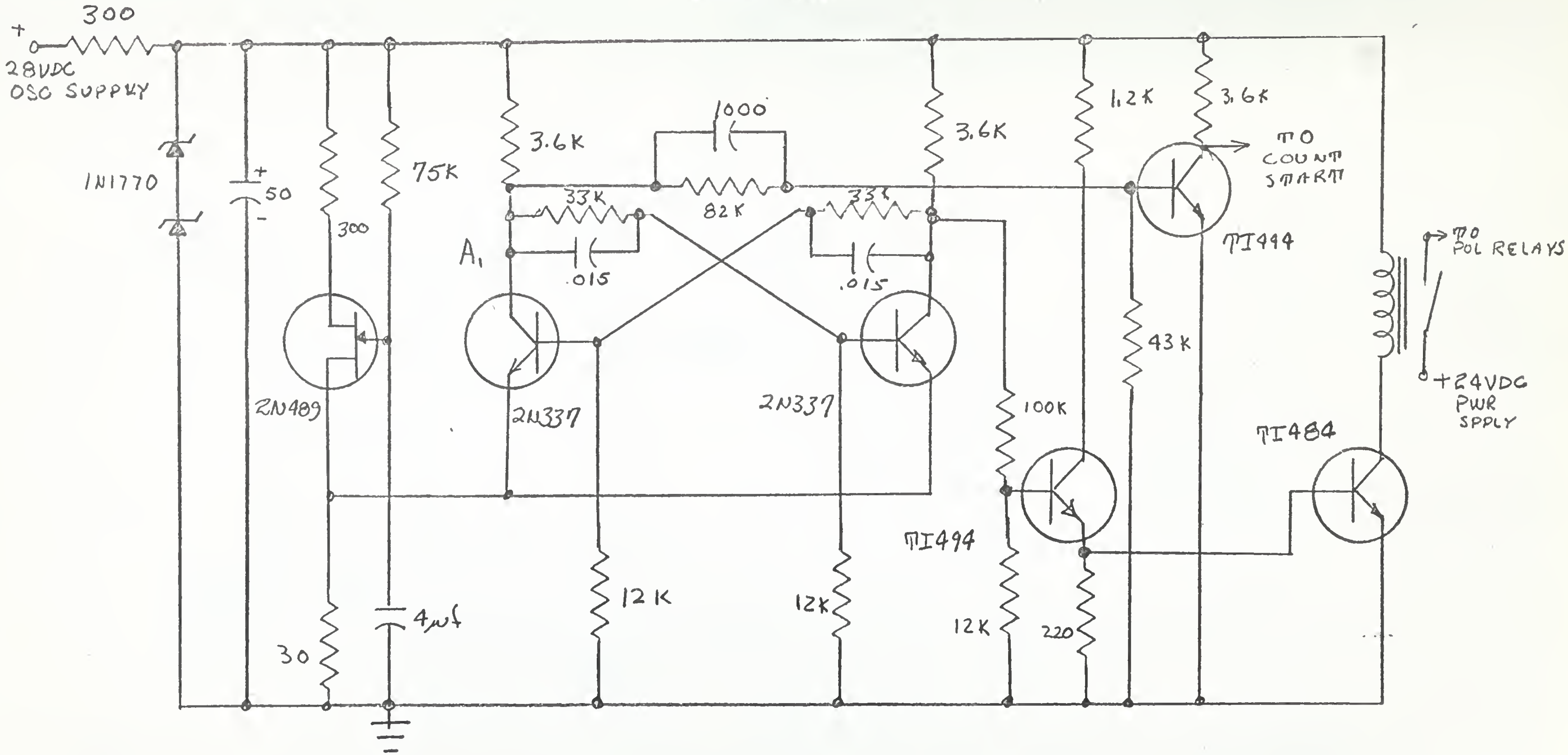

L1
0.22
47K
INPUT
0.12
50K
2N527
18K
3.3K
C3
C2
C1
T1
100
@6V
1.5K
33K
9.1K
2N527
.01
2N224
680
9.1K
0-1
2N224
2.7K
2.7K
-12V
OUTPUT
GND


50Ω TO
ANTENNA
T_1
24K
3.3K
0.01
3-12
IN21
0.001
1K
4.7K
TI-495
+ 25
- @6V
1.2
K
+ 25
- @10V
2N404
2K
+ -
5@15V
22K
2K
2.7K
500
39K
TI-495
240
8.2K
2.7K
500
39K
TI-495
13K
100
+
50@15V
-
+12V
OUTPUT TO
TIMER CARD
TI-494

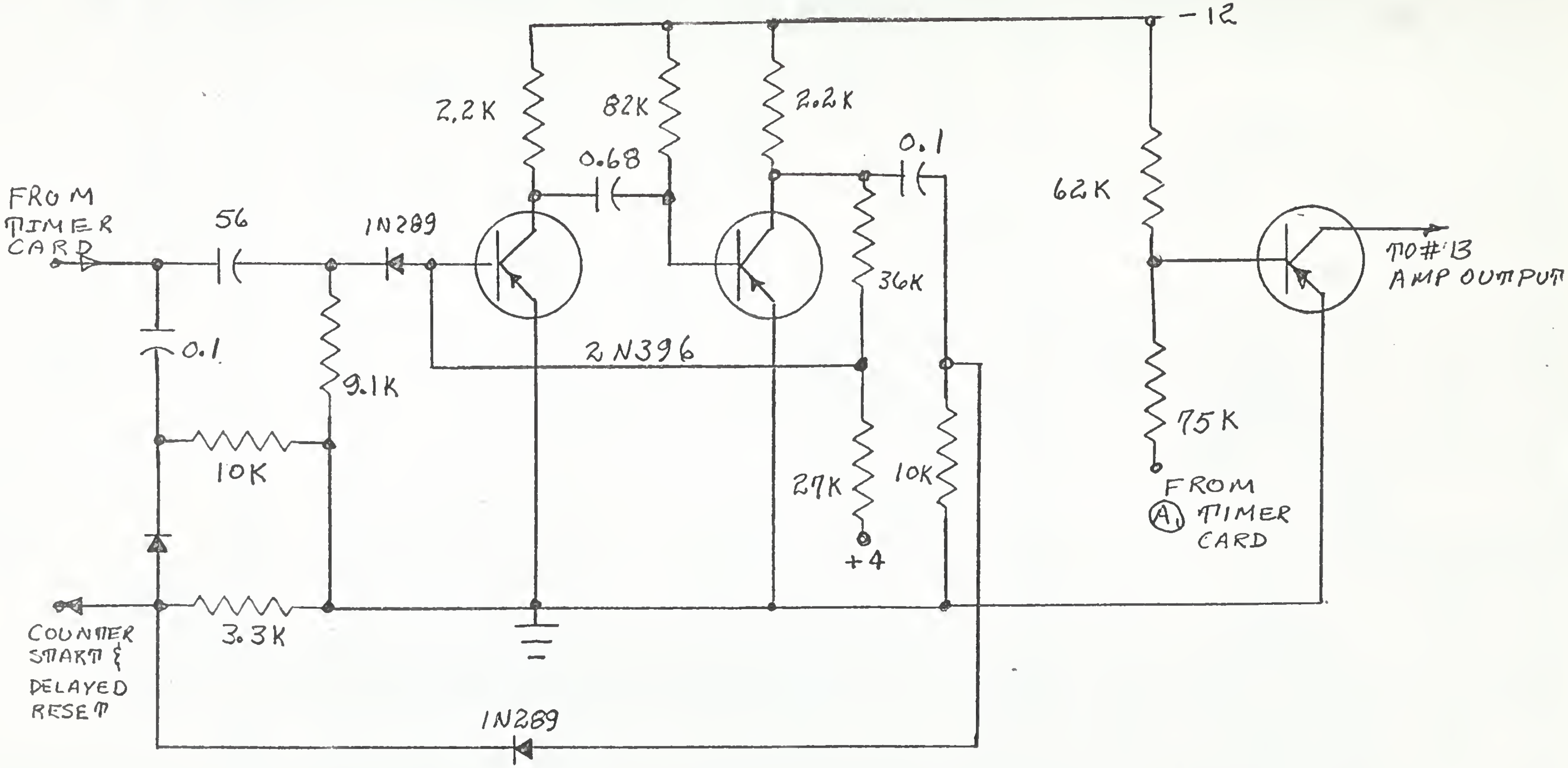

-12
-4
2.2K
2.2K
2.2K
8.2K
3.9K
18K
220
47K
270
0.001
2N396
SB100
5.1K
620
33K
1K
1N289
+4
GAME OPEN
1.8K
100
1N289
100
1.8K
GAME CLOSE
SB100
SB100
SB100
SB100
SB100
5.6K
100
5.6K
100
1K
68K
68K
+4
1K
+12
47K
2.7K
0.001
0.003
6.8K
200
8.2K
1K
RESET
-12
INTERVAL COUNTER OUTPUT
TO CLOSE GAME
2.2K
-4

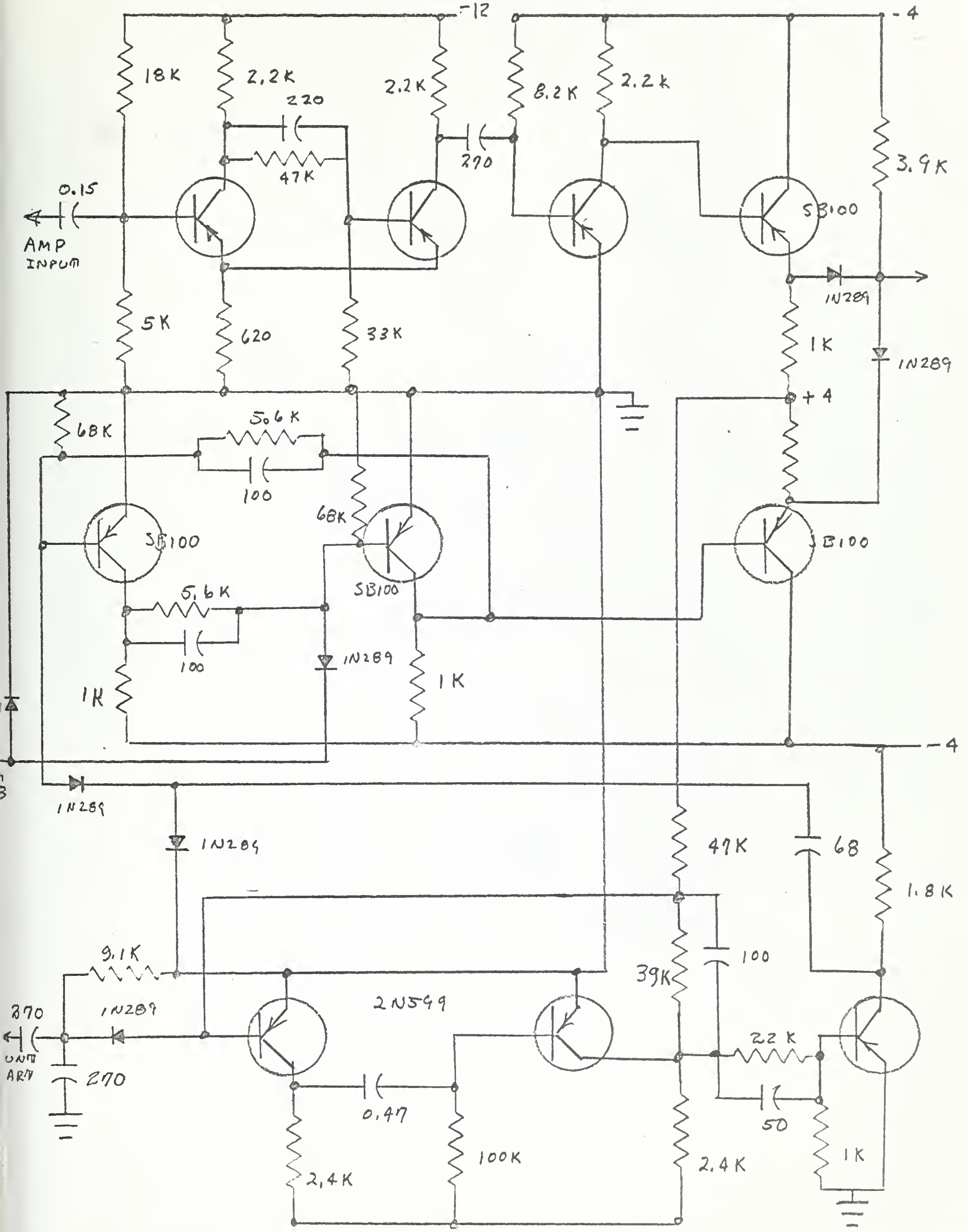

2N599
1N289
2.4K
100K
2.4K
0.001
2N599
100
400
39K
33K
10K
47K
RESET
STORAGE
15K
100
+4
1.1K
1.8K
SET
STORAGE
220
SB100
SB100
2N599
8.2K
1K
-12
-4

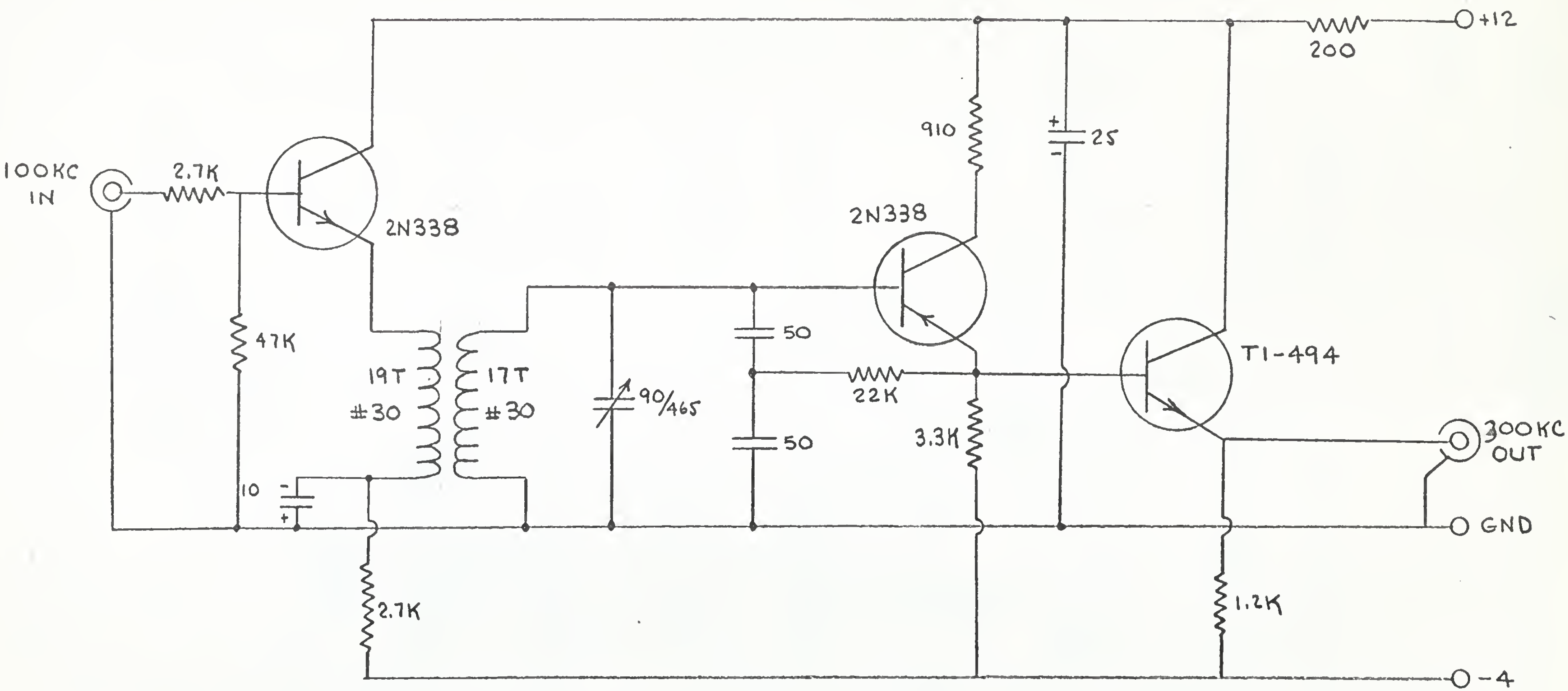
APPENDIX IV

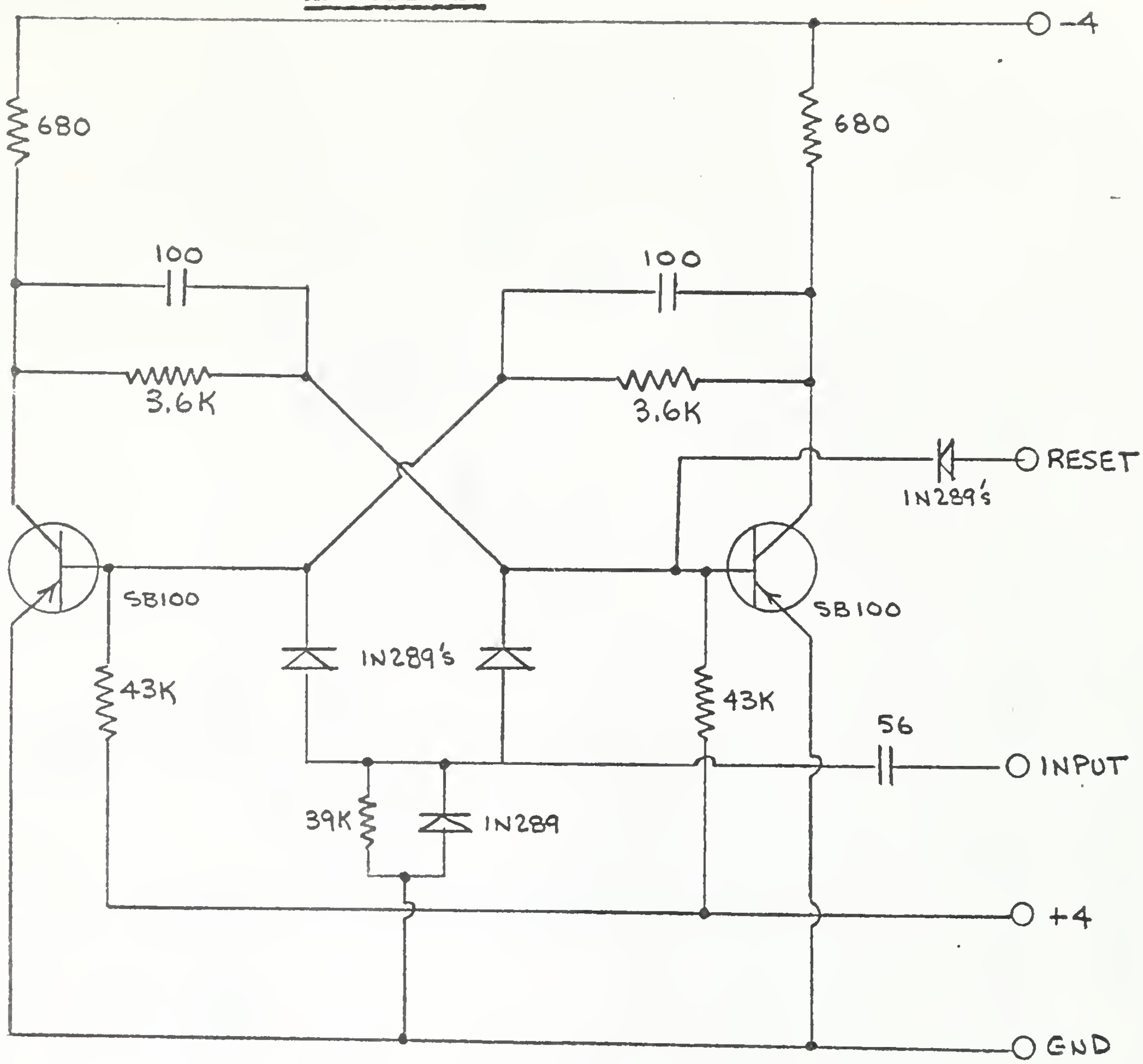


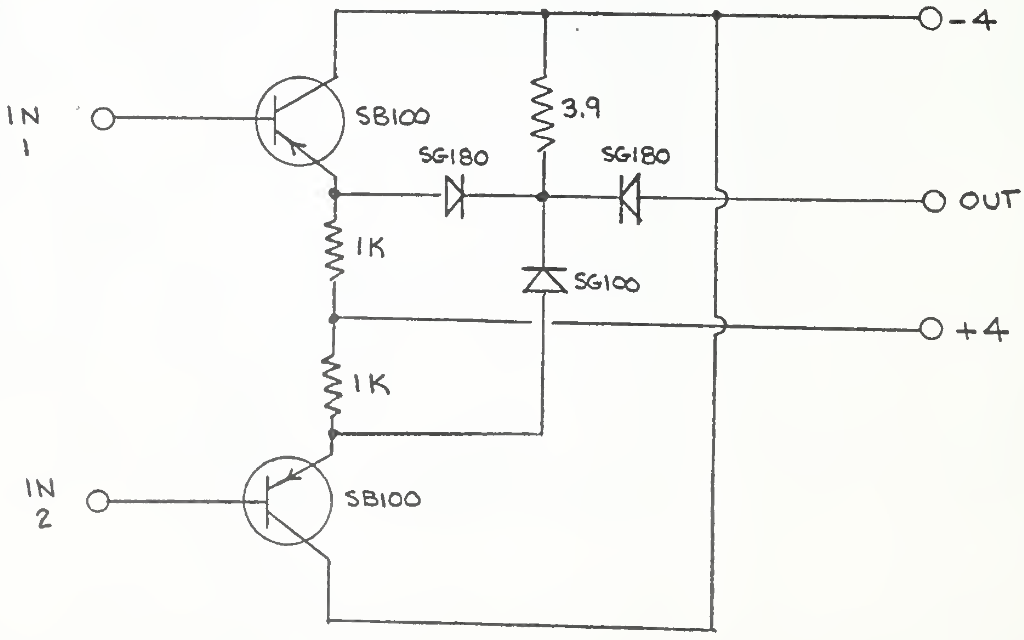
+
300
28VDC
OSC SUPPLY
1N1770
50
300
75K
2N489
30
4μf
3.6K
A1
33K
.015
1000
82K
2N337
12 K
12K
3.6K
100K
TI494
12K
220
1.2K
43K
3.6K
TO COUNT START
TI494
TO POL RELAYS
+24VDC PWR SPPLY
TI484

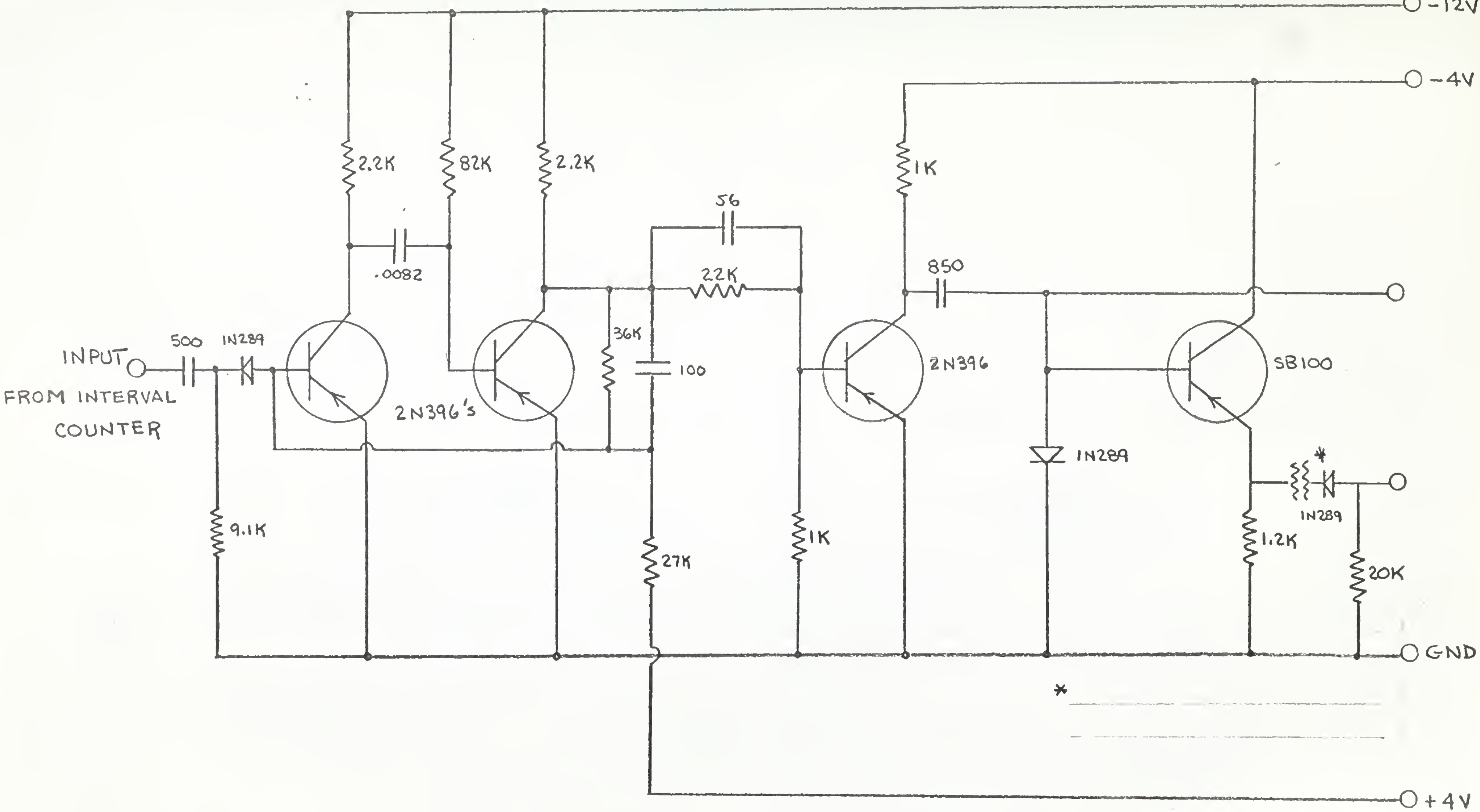

-12
2.2K
82K
2.2K
0.68
0.1
62K
FROM
TIMER
CARD
56
1N289
TO #13
AMP OUTPUT
36K
0.1
2N396
9.1K
10K
27K
10K
75K
FROM
A1 TIMER
CARD
+4
3.3K
COUNTER
START &
DELAYED
RESET
1N289


-12
-4
18K
2.2K
220
2.2K
8.2K
2.2k
47K
270
3.9K
0.15
AMP
INPUT
SB100
1N289
5K
620
33K
1K
1N289
+4
68K
5.6K
100
SB100
68K
SB100
SB100
5.6K
100
1N289
1K
1K
-4
1N289
1N289
47K
68
1.8K
9.1K
100
39K
270
1N289
2N549
22K
270
0.47
50
2.4K
100K
2.4K
1K

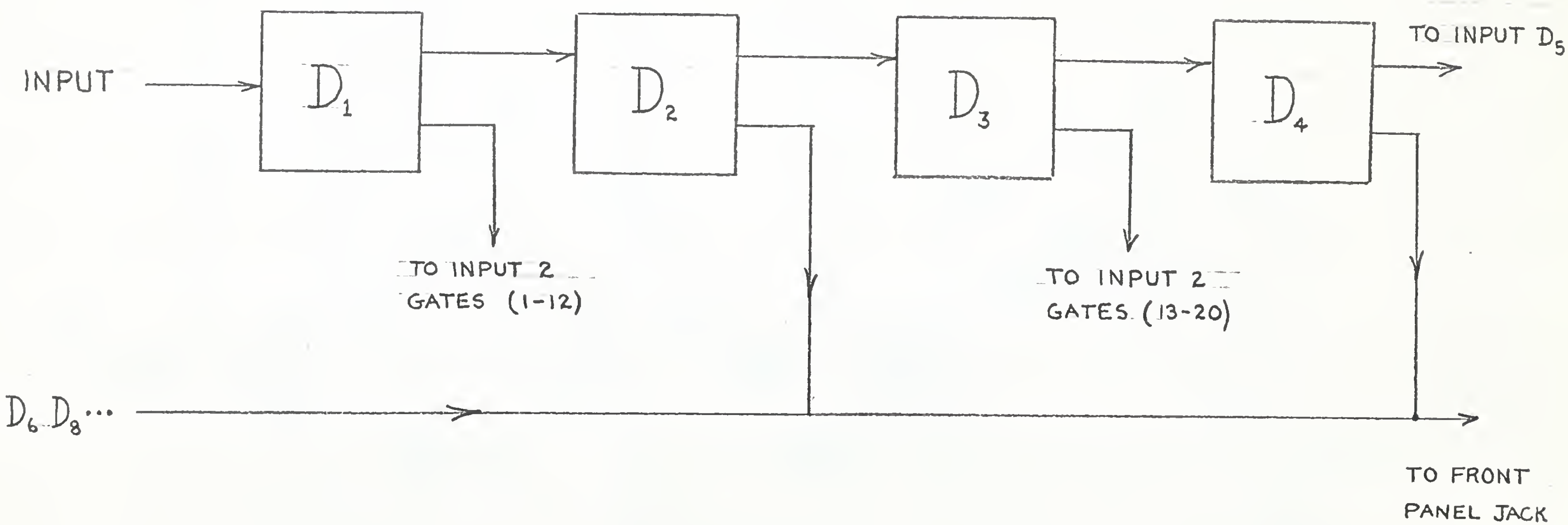

100KC
IN
2.7K
2N338
47K
19T
#30
17T
#30
10
2.7K
90/465
50
50
22K
2N338
910
3.3K
25
TI-494
200
+12
300KC
OUT
GND
1.2K
-4

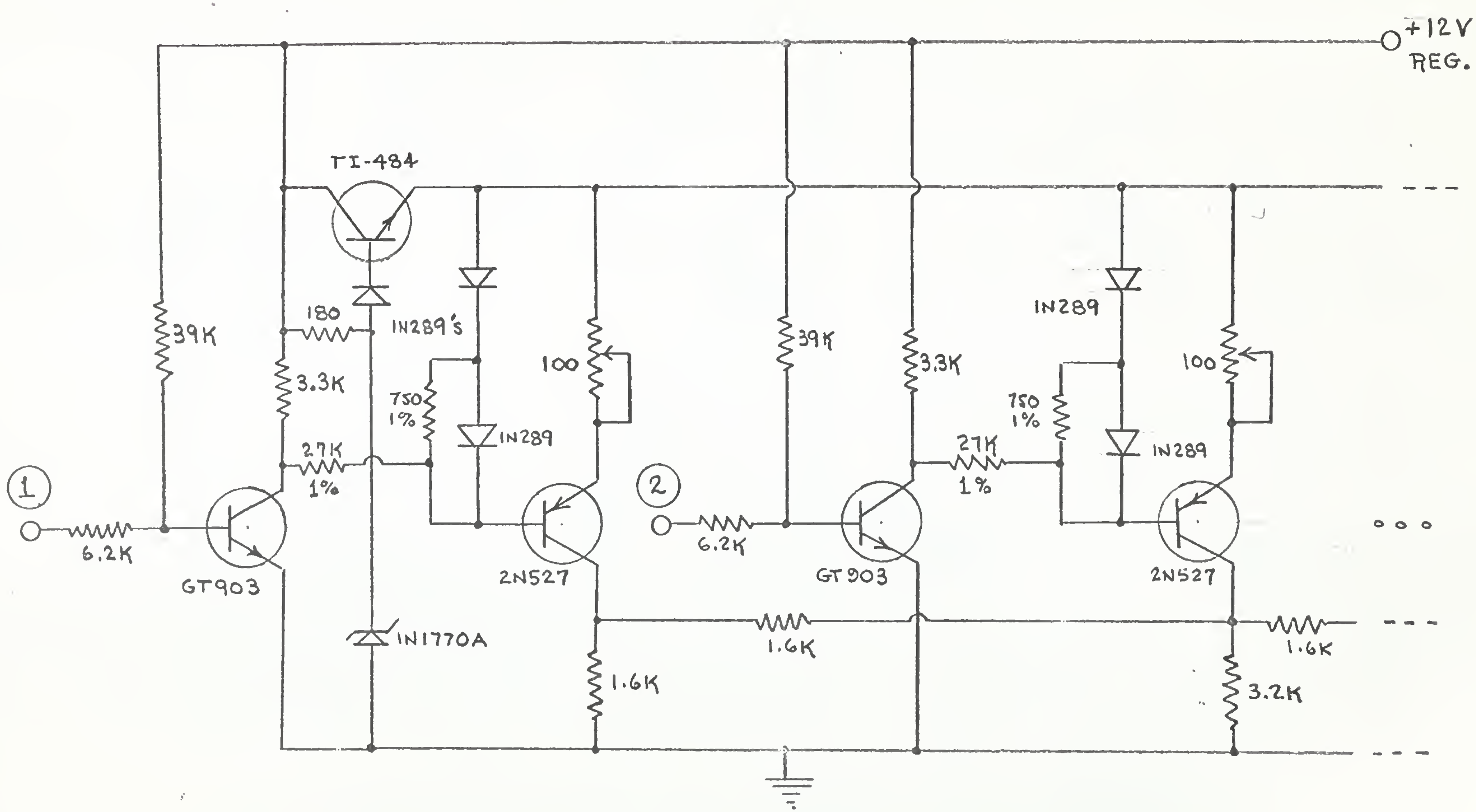

-4
680
680
100
100
3.6K
3.6K
RESET
IN289's
SB100
SB100
IN289's
43K
43K
56
INPUT
39K
IN289
+4
GND

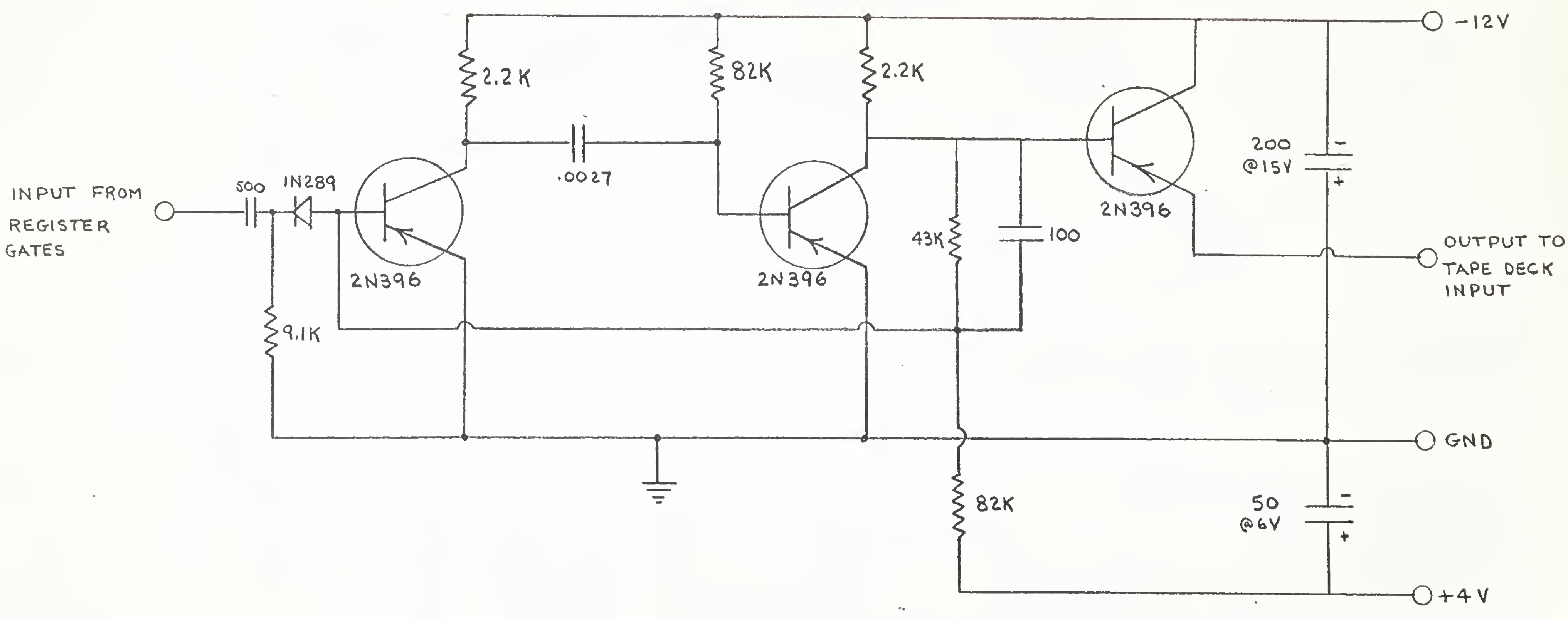

-4
IN
1
SB100
3.9
SG180
SG180
OUT
1K
SG100
+4
1K
IN
2
SB100

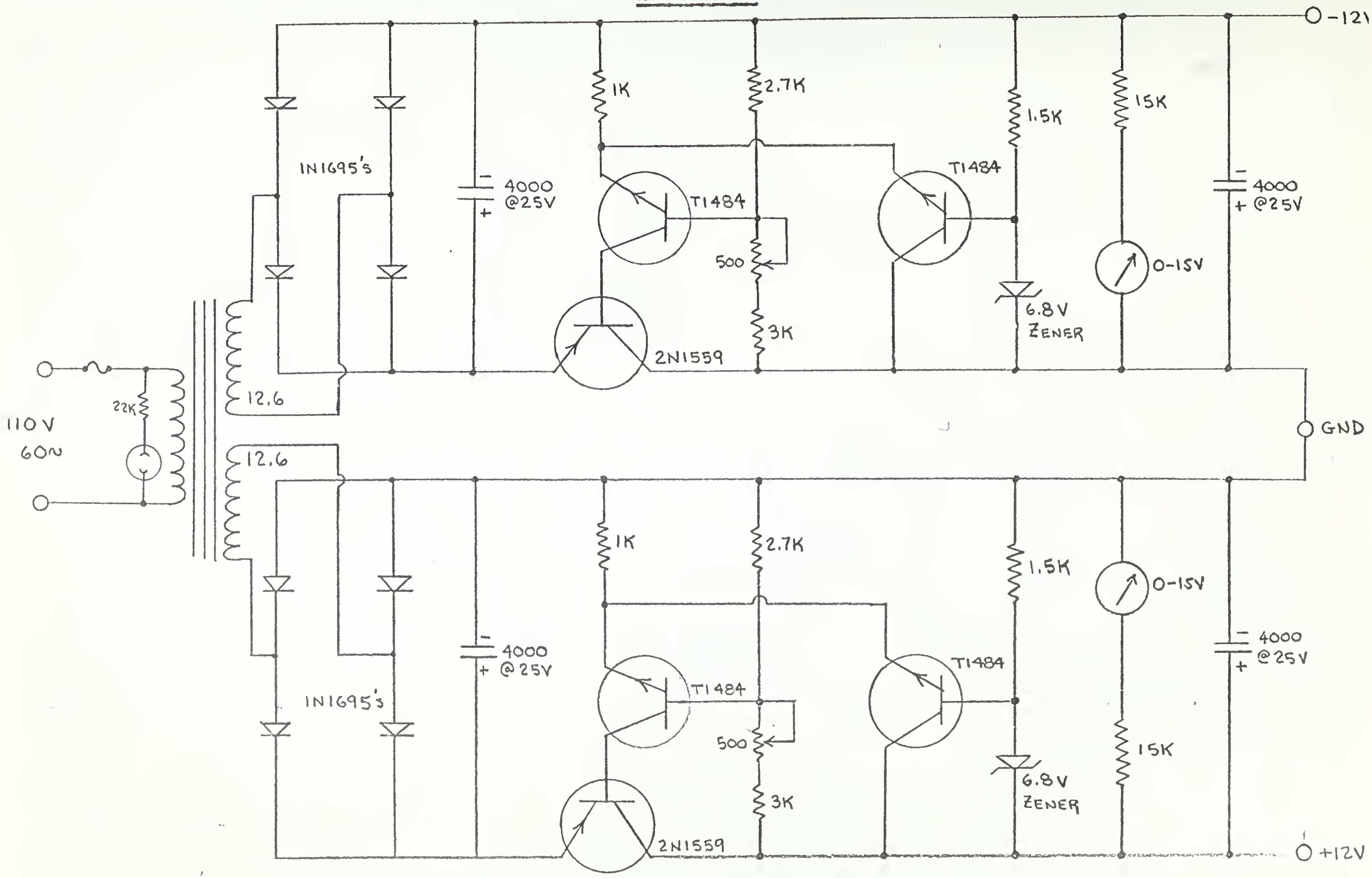

-12V
-4V
2.2K
82K
2.2K
.0082
56
22K
1K
850
36K
100
INPUT
FROM INTERVAL
COUNTER
500
1N289
2N396's
2N396
SB100
1N289
*
1N289
1.2K
20K
9.1K
27K
1K
GND
+4V

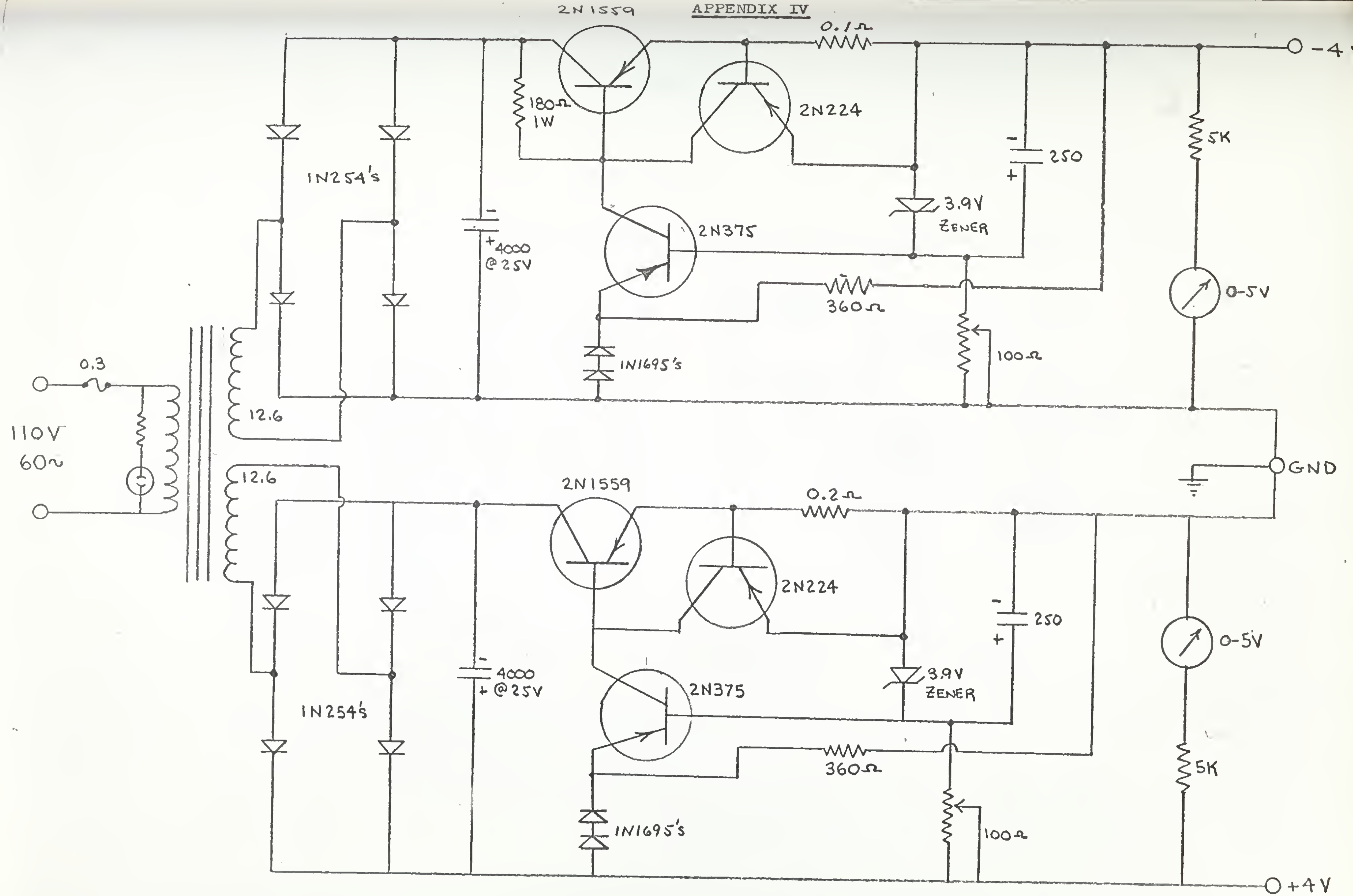
*

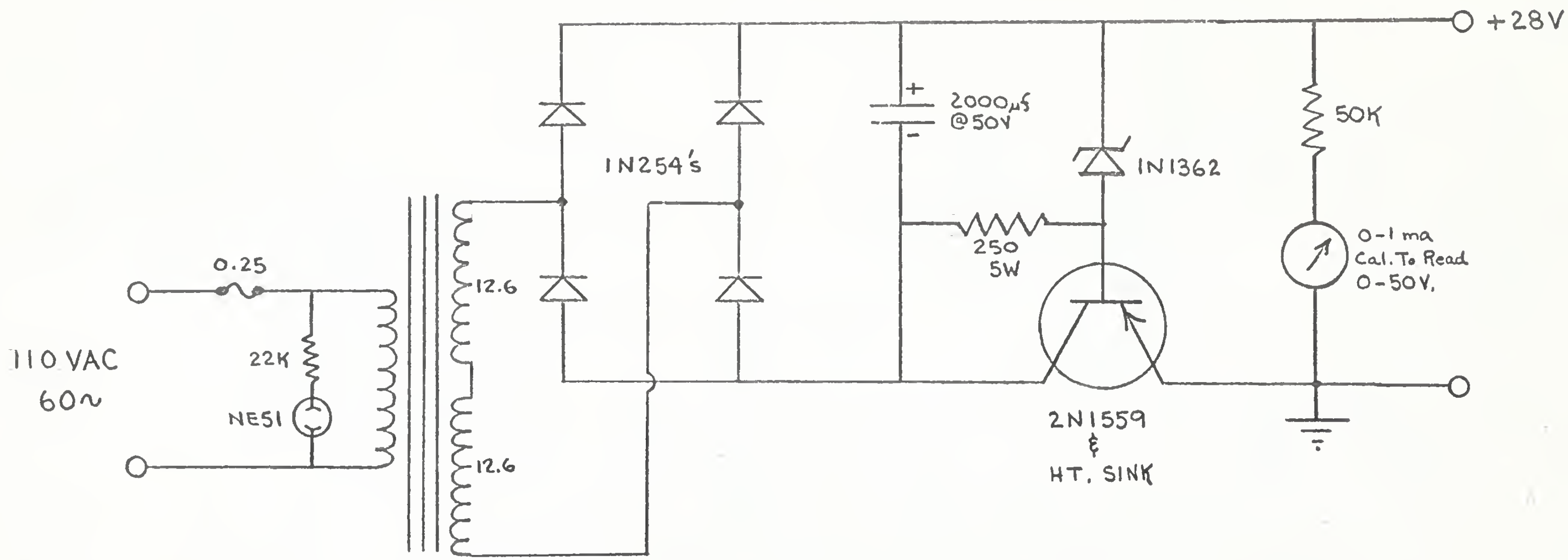

INPUT
D1
D2
D3
D4
TO INPUT D5
TO INPUT 2
GATES (1-12)
TO INPUT 2
GATES (13-20)
D6 D8 ...
TO FRONT
PANEL JACK

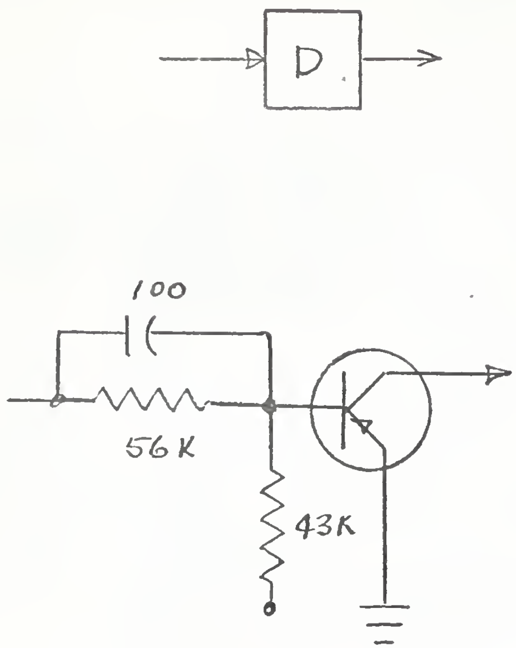

+12V
REG.
TI-484
180
IN289's
39K
3.3K
27K
1%
750
1%
IN289
100
1
6.2K
GT903
2N527
IN1770A
1.6K
2
6.2K
39K
3.3K
27K
1%
750
1%
IN289
IN289
100
GT903
2N527
1.6K
1.6K
3.2K

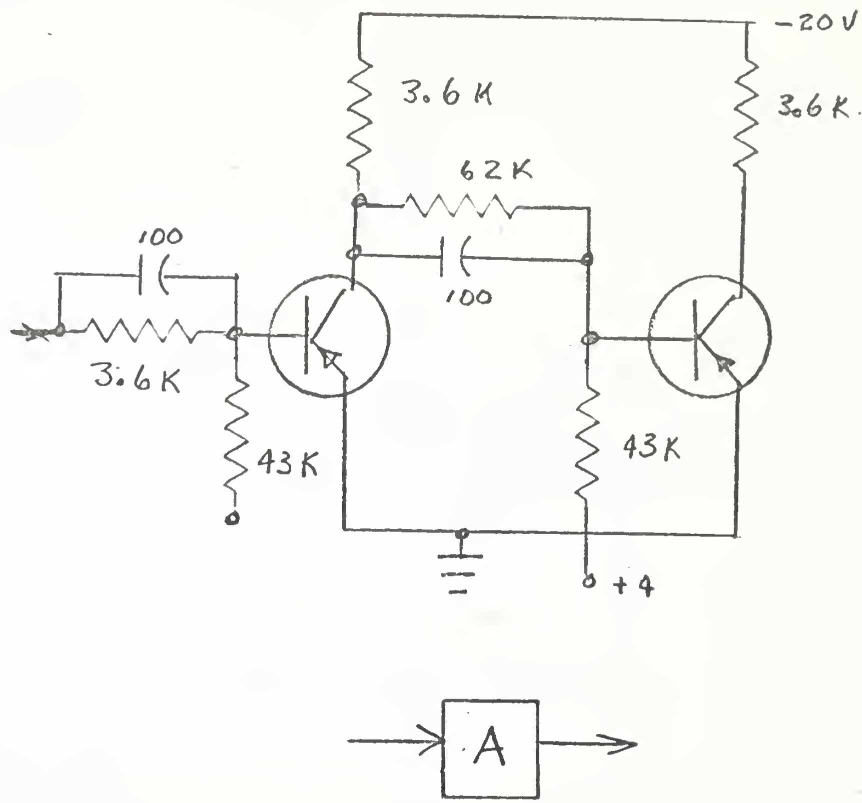

INPUT FROM
REGISTER
GATES
500
1N289
2N396
9.1K
2.2 K
.0027
82K
2.2K
2N396
43K
100
2N396
82K
200
@15V
50
@6V
−12V
OUTPUT TO
TAPE DECK
INPUT
GND
+4 V

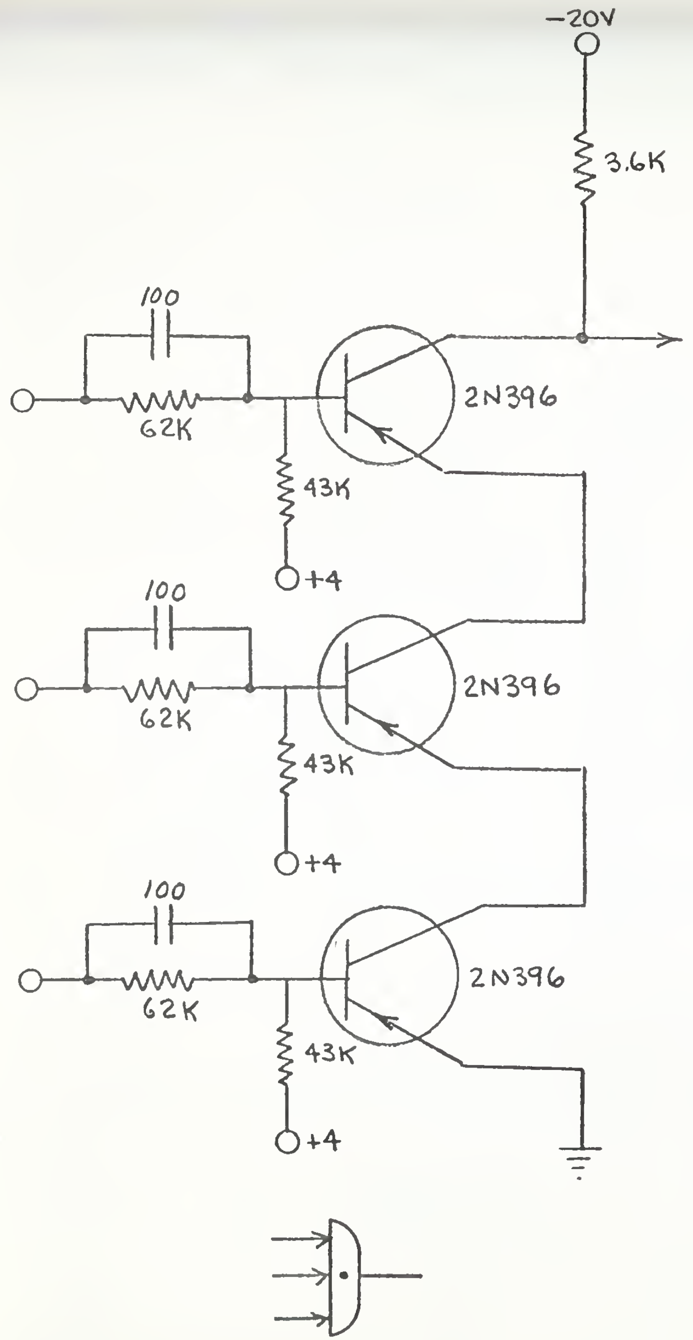

-12V
GND
+12V
110V
60~
22K
12.6
12.6
1N1695's
1N1695's
4000 @25V
4000 @25V
4000 @25V
4000 @25V
1K
1K
2.7K
2.7K
T1484
T1484
T1484
T1484
500
500
3K
3K
2N1559
2N1559
1.5K
1.5K
6.8V ZENER
6.8V ZENER
15K
15K
0-15V
0-15V

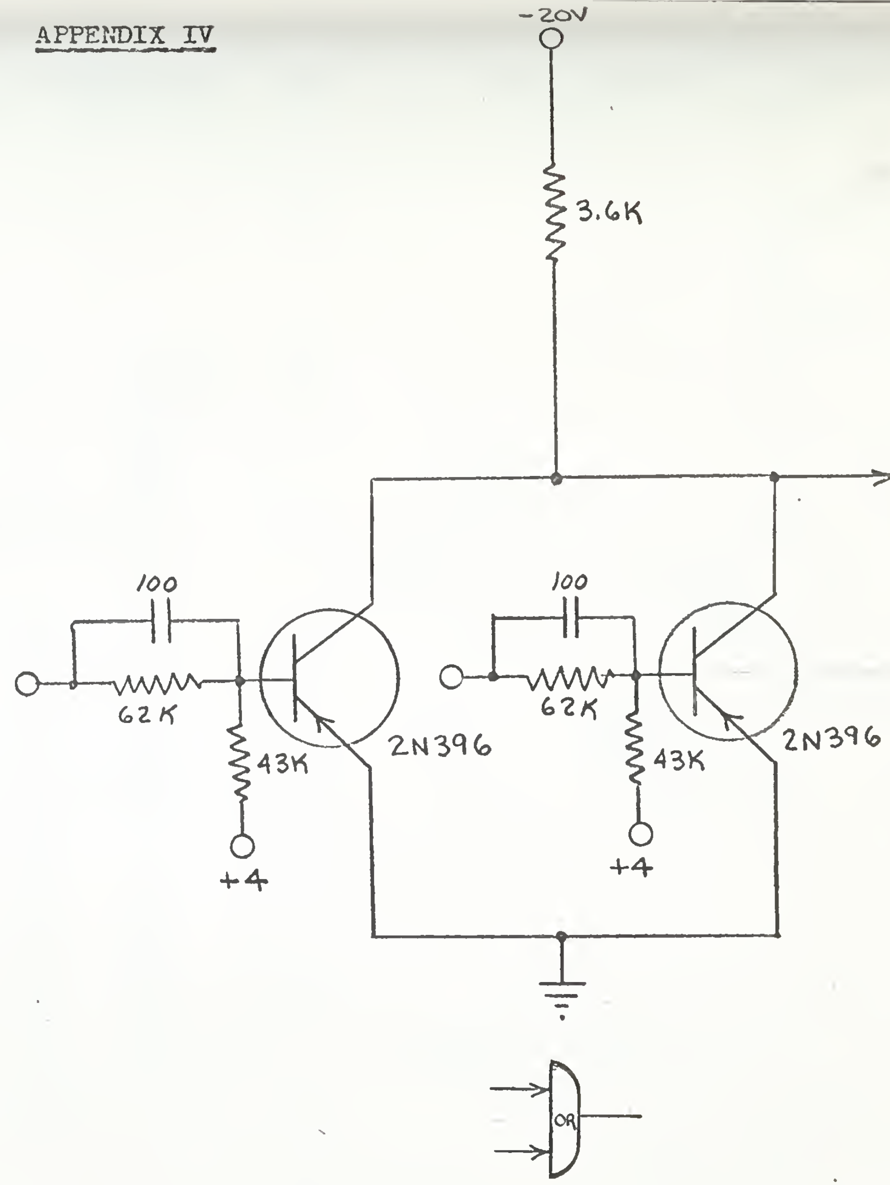

2N1559
0.1Ω
180Ω
1W
2N224
5K
250
1N254's
3.9V
ZENER
2N375
+4000
@25V
360Ω
0-5V
1N1695's
100Ω
0.3
12.6
110V
60~
12.6
GND
2N1559
0.2Ω
2N224
250
0-5V
4000
+@25V
3.9V
ZENER
2N375
1N254's
360Ω
5K
1N1695's
100Ω
-4V
+4V

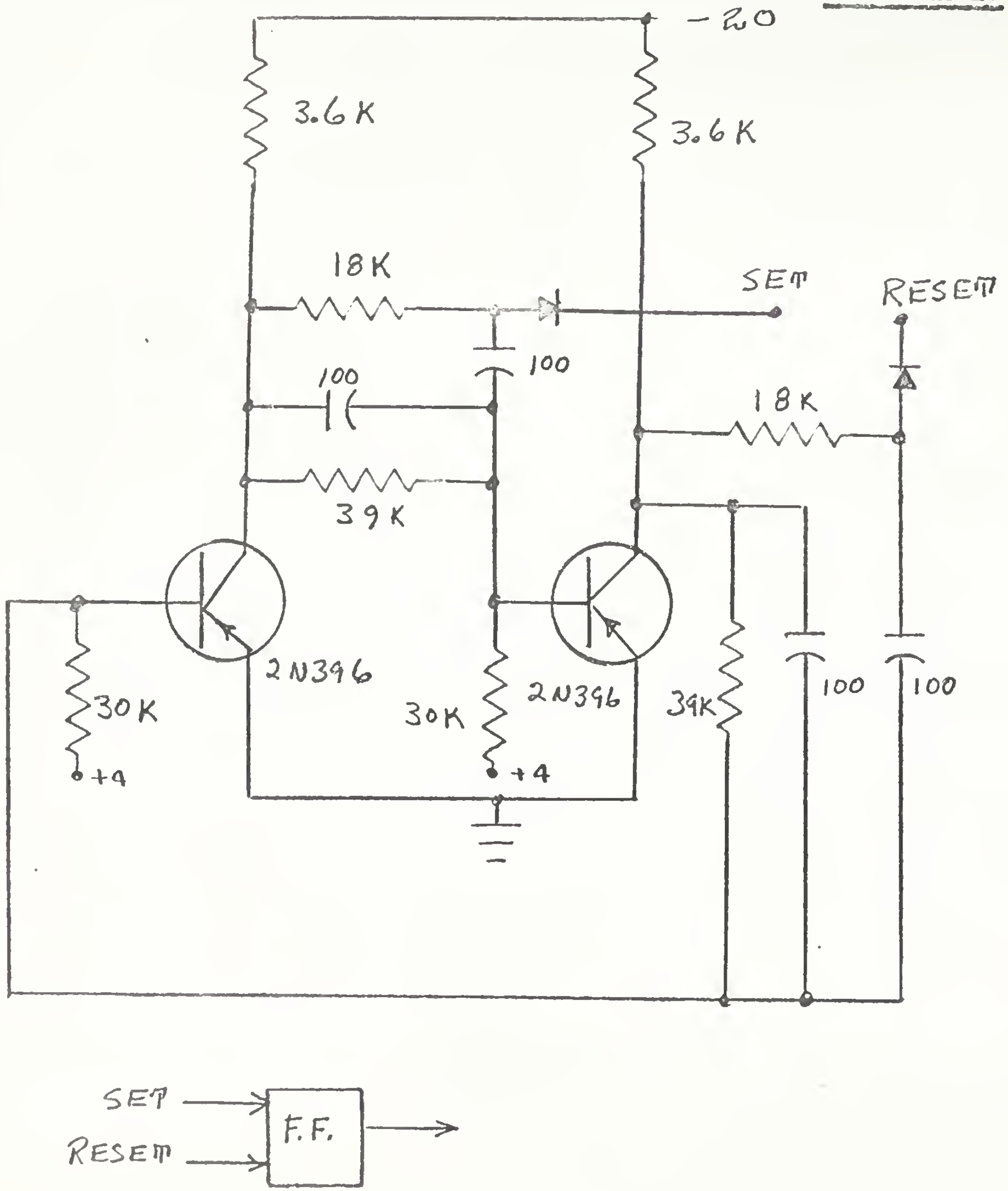

110 VAC
60~
0.25
22K
NE51
12.6
12.6
1N254's
2000µf
@50V
250
5W
1N1362
2N1559
&
HT. SINK
50K
0-1 ma
Cal. To Read
0-50V.
+28V

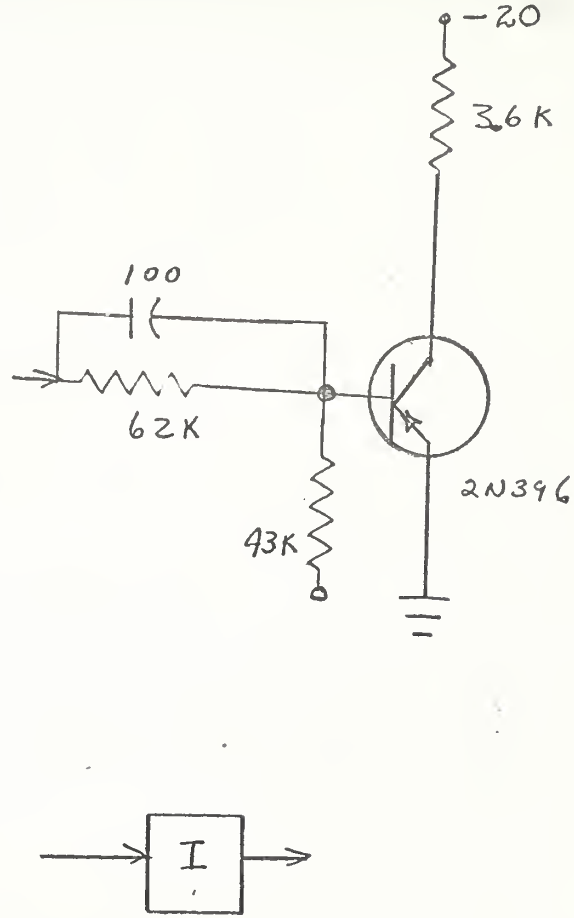

D
100
56K
43K


-20V
3.6K
3.6K
62K
100
100
3.6K
43K
43K
+4
A


-20V
3.6K
100
62K
43K
+4
2N396
100
62K
43K
+4
2N396
100
62K
43K
+4
2N396


-20V
3.6K
100
62K
43K
+4
2N396
100
62K
43K
+4
2N396
OR


-20
3.6 K
3.6 K
18 K
SET
RESET
100
100
18 K
39 K
2N396
2N396
30 K
30 K
+4
+4
39K
100
100
SET
RESET
F.F.


-20
3.6 K
100
62 K
43K
2N396
I