CALIFORNIA INSTITUTE OF TECHNOLOGY

SEISMOLOGICAL LABORATORY

DEVELOPMENT OF PERFORMANCE CRITERIA AND FUNCTIONAL SPECIFICATIONS FOR A PASSIVE SEISMIC EXPERIMENT ON MARS

FINAL REPORT
DECEMBER 31, 1969

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California Institute of Technology
Seismological Laboratory
Pasadena, California

Final Report

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NASA GRANT NO.: NGR 05-002-129

PROJECT TITLE: Development of Performance Criteria and Functional Specifications for a Passive Seismic Experiment on Mars

PRINCIPAL INVESTIGATOR: Don L. Anderson

Preface

This report summarizes the accomplishments under NASA Grant NGR 05-002-129, for work entitled "Development of Performance Criteria and Functional Specifications for a Passive Seismic Experiment on Mars," and is divided into two Sections as follows:

Section I - Introduction, including a resume of the science goals, a discussion of the nature of the seismic data necessary to accomplish them, and a brief discussion of permissible modification of data to accommodate the telemetry without serious degradation of its usefulness.

Section II - Describes an instrumentation system for sensing the seismic signals and converting them into a data form compatible with the information sought, and with the data bit volume allotted for telemetry transmission. Photographs, blueprints, circuit schematics, and results of various tests performed are included as part of this section, as is an outline of areas where work is required to finalize the design.

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I. Introduction

A. Scientific Objectives

In planetary exploration, structural features, thermal status, and the nature of other geophysical activity can be best indicated by inclusion of seismographic instrumentation aboard landing craft.

Questions of interest concerning Mars which might well be answered by seismic data are:

1. What are the amplitude, spectrum, polarization, and sources of the continuous background microseism activity?
2. Is Mars a tectonically active planet and what is the level, nature, and location of tectonic activity?
3. What is the internal structure and composition of Mars; and specifically, does Mars have a crust and a core, and is the mantle of Mars similar in composition to the mantle of Earth?
4. What is the influx rate of meteorites?
5. What are the mechanical properties of the material near the lander?

Complete answers to these questions can be achieved from seismic data provided the instrumentation can indicate three orthogonal components of motion, polarity of the waves sensed, and frequency content and amplitude modulation of the signal envelope. However, valuable data can be obtained from less than all three axes of detection in the event of failure of one or even two channels.

Registration of events by more than one seismic station can greatly enchance the value of the data, and this prospect is anticipated with subsequent Mars landings.

In addition to seismic information, seismograph instrumentation can provide knowledge of meteorological events, and serve as a monitor for other lander activities by sensing the disturbance created by their functions and thus aid in future spacecraft designs.

Ordinarily, seismic data are studied in its entirety; however, in the Mars experiment data-bit quantity dictates that compression or compaction be used in order to make continuous operation of the experiment possible. If the signal envelope can be preserved, and an indication of frequency content and relative time of various envelope amplitude modulation features is clear, adequate information is furnished for answering the above questions. A data processing system which can accomplish this using 10% of the data-bits normally required is included in the system developed at the Seismological Laboratory of the California Institute of Technology, and described below.

B. Design Concept

The weight, volume, and power restrictions imposed on the Viking lander, together with considerations of ruggedness, simplicity, and reliability have dictated the design philosophy for a Martian seismometer. The seismometer must be of a type requiring a minimum number of adjustments, controls, servo-systems, leveling mechanisms, and thermal controls. These constraints lead to a sensor having a short natural period with a small suspended mass and output adequate to sense the desired minimum threshold signal. Employment of a velocity transducer in such a sensor eliminates any requirement for precise mass centering and the short natural period permits operation in relatively severe off-level attitudes without disabling the unit due to mass position shift.

A rugged, lightweight, three-component seismometer and associated electronics has been developed for the Viking Lander payload. The instrumentation includes sensors, amplification, filtering, triggering, and data compaction within the frequency range 0.1 to 4 Hz with a ground amplitude resolution of 50×10^{-6} mm at 1 Hz. Variable gain and filter characteristics are provided. Weight, volume, and power consumption are held to a minimum and the design has taken account of lander and environmental constraints.

A breadboard model has been built which has recorded both local and teleseismic events. Data compression and triggering schemes have been successfully tested on real seismic data both in computer simulations and with the proposed analog circuitry.

C. Data Compaction

One of the requirements of the Viking seismic experiment is to provide the maximum information about the seismic background and transient events on Mars with a limited data transmission rate. The seismometer package will have a useful response up to 10.0 Hz. The lower limit is determined by the free period of the instrument, and the upper limit by available data rates, attenuation of high frequency seismic waves in geological materials, and by the high frequency filter cutoffs which are designed to minimize the effect of lander vibrations. Thus, for full recovery of data from teleseismic events a sampling rate of twenty (20) per second is adequate. At this rate, a three-component instrument would generate 28.8×10^3 bits of information every minute. Not all this data can be transmitted to Earth with the available storage and transmission rates; thus, a priority system and a data compacting scheme must be employed to return the most valuable information.

We have carried out a number of experiments of compaction and reconstruction of seismic data utilizing different bit rates. In the light of these experiments we have found that an optimum scheme requires three separate modes of data acquisition.

1. High sampling rate. Each component is sampled at twenty (20) samples per second when instructed by an earth command. During a six-minute operation this would generate about 1.7×10^5 bits of information. To determine the character of seismic signals in a totally new environment, and to calibrate the seismic instrument response, this mode is desirable. Under this mode data will be acquired for a fixed period of time or until the allocated storage quota is filled. This mode would probably

only be used when direct transmission via the orbiter or to Earth is possible.

2. <u>Seismic Background Monitoring</u>. To determine the seismic background level (i.e. microseismic activity), its nature, variation with time, and correlation with meteorologic phenomena, a continuous monitoring scheme is incorporated in the experiment. The output of each seismometer is filtered, rectified, and averaged over a given time period ΔT

$$\text{i.e.} \qquad P = \frac{1}{\Delta T} \int_{T_1}^{T_2} \left| U(t) \right| dt$$

A trade off between reducing the bit rates and increasing ΔT, determines the time resolution of the background variation. We propose T = 15 seconds under the present bit rate constraints. With T = 15 seconds, the background monitor also acts as an event counter for small events which fall below the trigger threshold level or for events which occur after the storage allocated to the triggered mode is filled.

To determine the frequency content of the background noise, a variable low-pass filter with four cutoff frequencies is incorporated into the experiment and the power level is determined successively through each filter setting. Thus, the spectral information is obtained at four frequencies, although each is sampled for a T_o once over a time period of $4T_o$. This consecutive mode is required in order to conserve bits and weight.

3. Triggered Mode. The seismic activity due to Marsquakes or meteorite impacts are transient phenomena. On the Earth, for example, there are about ten events per day which can be recorded at teleseismic distances. When such transient events occur it is necessary to record data at some faster rate so that various phases can be identified and analyzed. With restricted bit rates, some compaction is necessary even when a trigger occurs. The trigger mechanism and data compaction function is included in the analog circuitry of the seismometer electronics.

The data compaction technique consists of detecting the envelope and counting the axis crossings of the seismic signature. Sampling both these functions at the rate of 1 sample/sec results in a bit reduction of 90% over the high sampling rate, while preserving frequency content and envelope amplitude and modulation information.

II. Instrumentation System

A. Sensor

Because of the severe constraints of weight, volume, and environmental survival, the seismometer design selected is of the 'boom' type of short period. In this configuration the desired period is easily attained with a rugged suspension and the magnet volume required for the specified output is held to a minimum.

A ground motion sensing seismometer unit such as shown in Figures 1 and 2, has been developed and tested to a point which we believe is acceptable for integration into the Viking Seismic System flight hardware design. The seismometer transfer function is given by

$$E_o(s) = \frac{US^3\ Y(s)}{S^2 + 2\ \zeta\omega_n\ S + \omega_n^2}$$

$E_o(s)$ = Laplace transform of the voltage across the total damping resistance

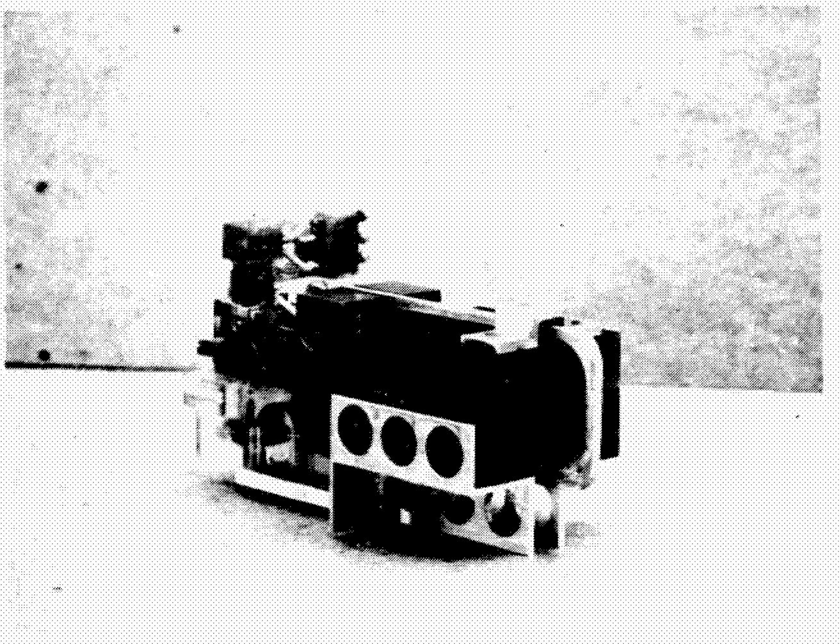
$Y(s)$ = Laplace transform of the frame displacement

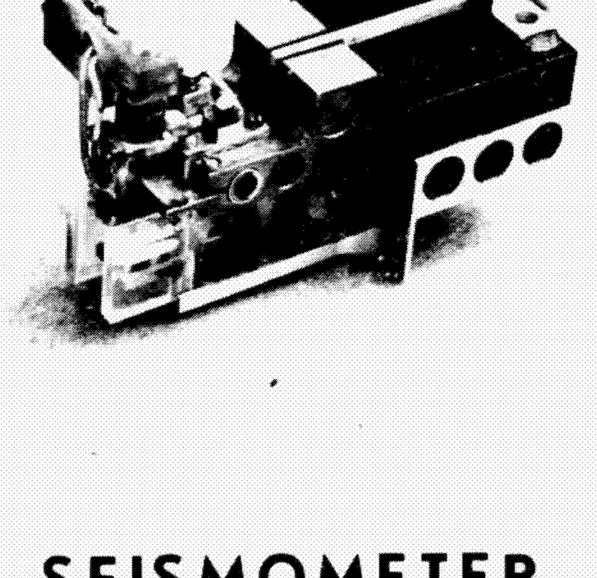
ζ = fraction of critical damping

ω_n = natural resonant angular frequency of the suspended system

U = generator constant

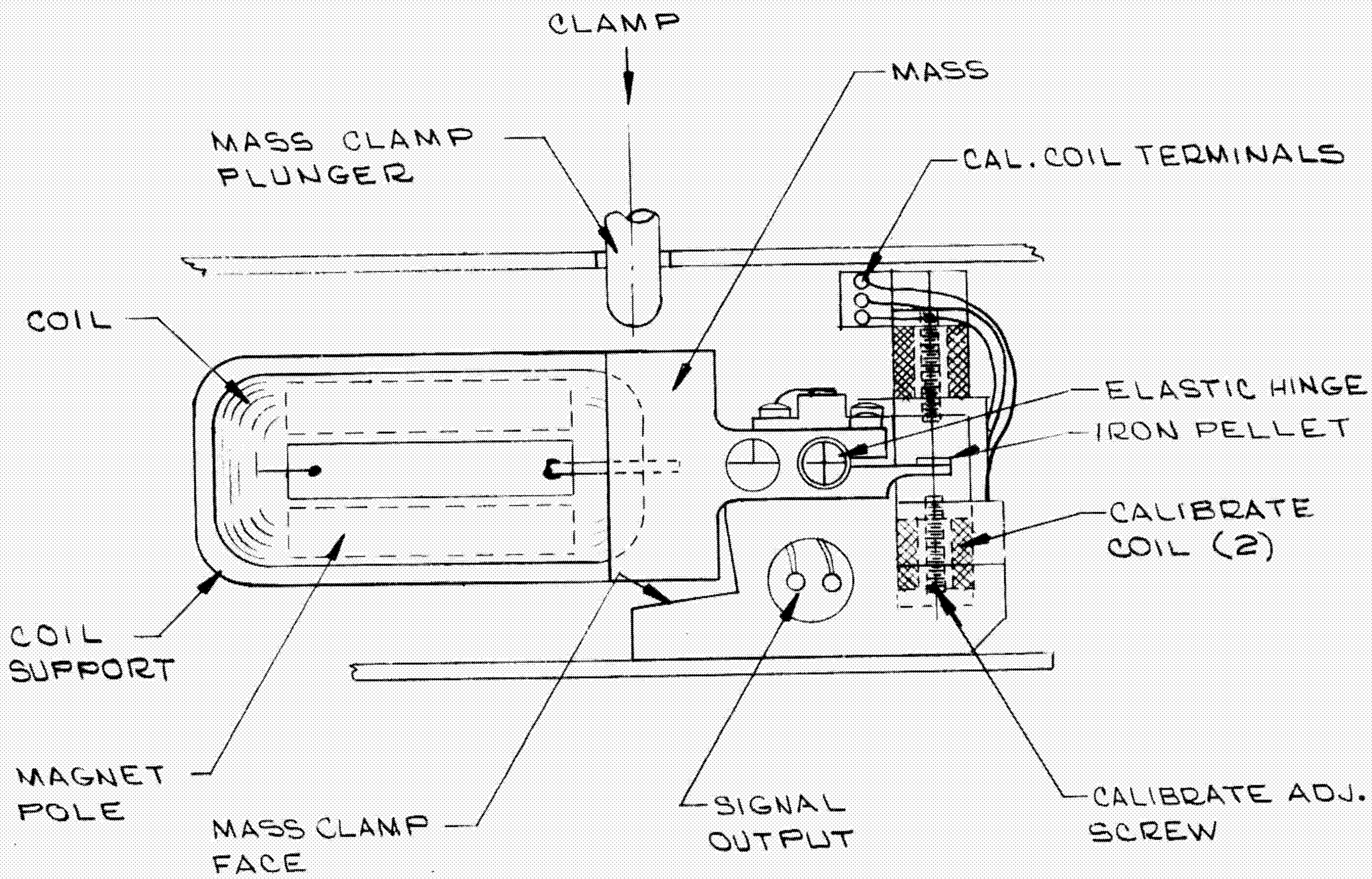
The same unit may be used both as a horizontal or vertical component sensor except for minor details such as terminal position. Several packages of three seismometers in orthogonal arrangement are under





SEISMOMETER
SHOWN ACTUAL SIZE

FIGURE 1



SEISMOMETER SCHEMATIC FIGURE 2

assembly; the development package is shown in Figure 3.

In these instruments a 28 gram mass-coil assembly is supported on twin booms by two Bendix Free Flex pivots so that the flat transducer coil is poised between facing poles of two channel magnets. Motion of the frame (as in ground motion) causes the transducer coil to move in the field of the channel magnets and to generate a signal proportional to the relative velocity of coil and magnets. Damping is achieved by power loss in the resistive component of the output circuit (amplifier-input and transducer coil resistance). Design free period, $\frac{2\pi}{\omega_n}$, and damping constant, ζ, are .25 sec and 0.5, respectively.

Rearward extensions of the boom support an insulating bridge carrying a soft iron pellet to which the calibration coils apply a magnetic force when they are energized. Position of the iron cores of these coils is variable so that equality and magnitude of the force applied can be adjusted.

Lever magnification of center-of-percussion motion at the coil center is approximately 2. This magnification reduces the actual generator constant needed to achieve the proper degree of damping, by this ratio, and thus also reduces the magnet weight.

Using the parameters of the transducer, the calculated generator constant (U) is approximately 94 v/meter/sec. Including the lever magnification, the "effective" U as it affects the center of percussion is approximately 188 v/meter/sec. This closely agrees with the required

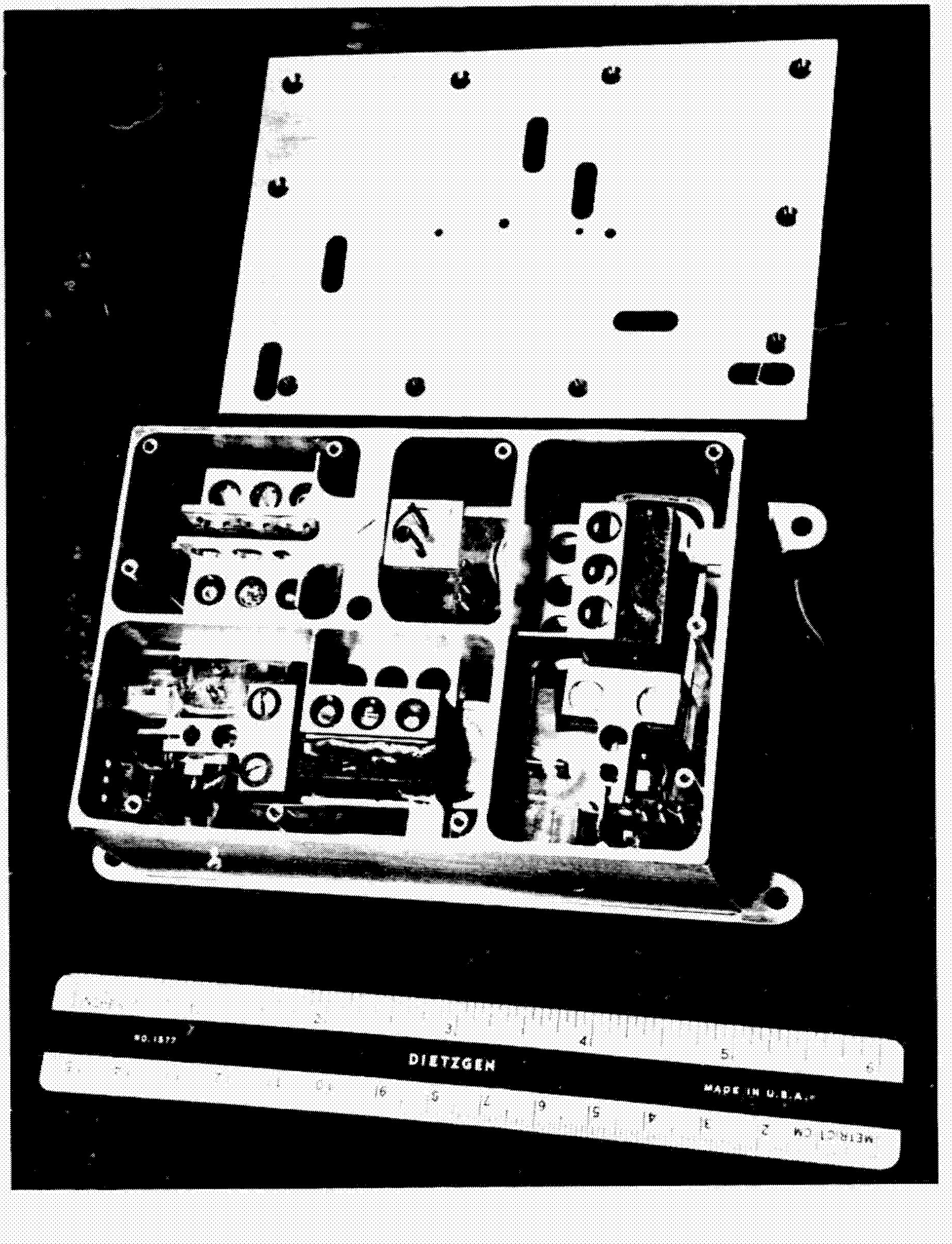


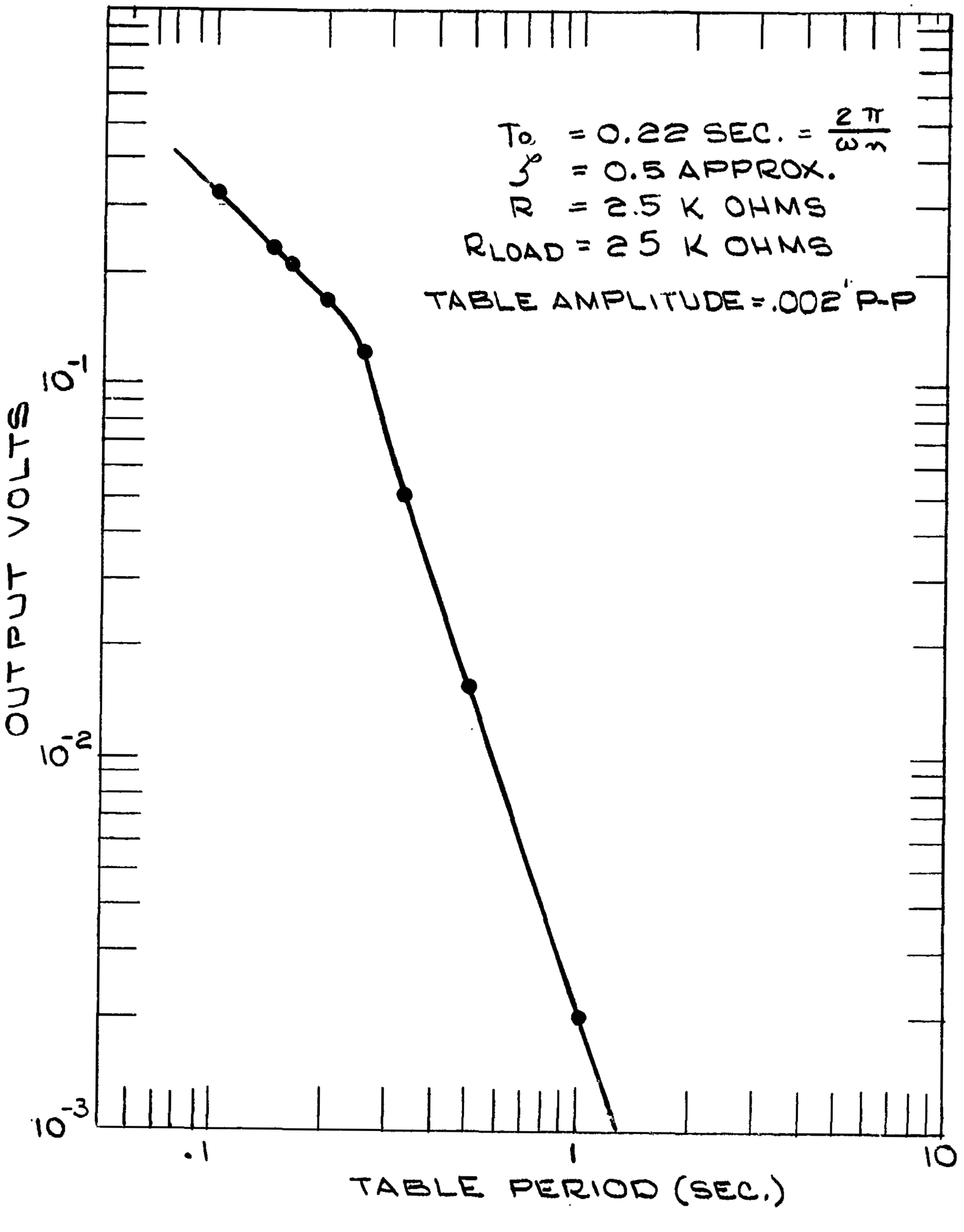
Figure 3

value to give the same damping constant to a similar mass-spring system without the lever magnification (see Appendix A).

A basic shake table was constructed and an instrument of .22 sec period and 28 gm mass, fitted with a 25000 ohm coil of 10,500 turns and damped to .5 of critical by a 25000 ohm shunt has been tested. Figure 4 shows the p-p voltage developed across the load for a p-p table amplitude of .002". The measurement agrees well with the calculated values, for example, the measured output at 10 cps is .32 volts whereas the calculated value is .32 volts (see Appendix A).

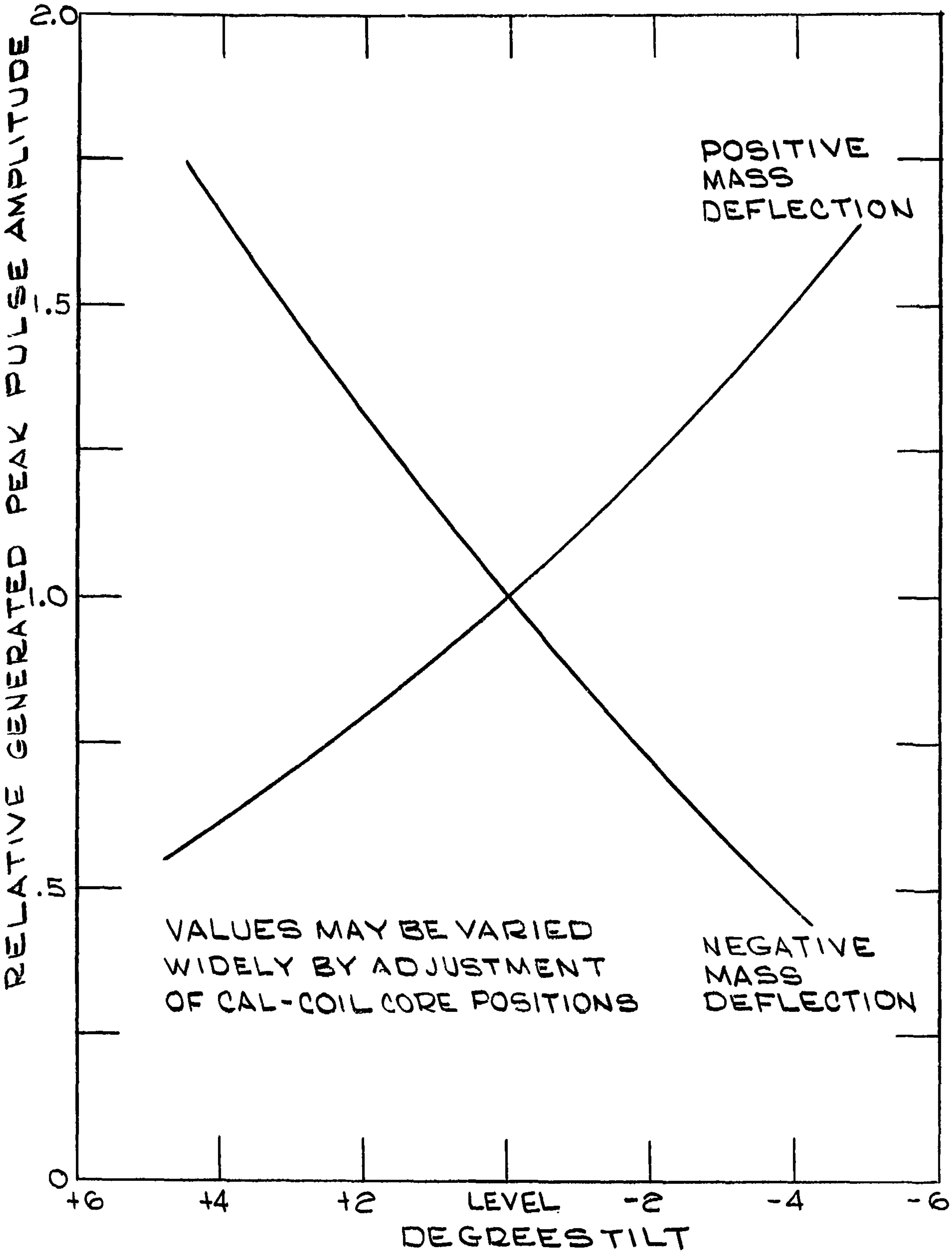
Two coils are included to provide force applications of opposite polarity to the suspended system for generation of calibration pulse output. Typical peak value of a calibration pulse generated by application of a step of voltage to either cal-coil is 10^{-4} volts output for 10 ma cal-coil current. This is highly adjustable and will be optimized in flight hardware production. Probably some calibration signal other than a step will be used to eliminate the need for use of a high data rate to transmit the pulse with fidelity. This may be a ramp, sine wave, or some other low rate function. Response to the calibration signal will be used as a verification of the instrument performance, and must be referenced to system performance in preflight calibration.

Because the spacing between the calibration coil and the iron pellet varies with mass position, with known calibration, instrument tilt may be determined by the relative magnitude of opposite-going pulses. Figure 5 shows one such test of pulse magnitude vs instrument tilt.



SHAKE TABLE TEST OF DEVELOPMENT MODEL VIKING SEISMOMETER

FIGURE 4



TYPICAL SEISMOMETER PULSE OUTPUT Vs TILT AT EARTH G.

FIGURE 5

Early specification of performance indicated a maximum of 15° off-level might be expected on the Martian surface. An instrument period of 0.25 sec was selected so that the seismometers would not require zero adjustment for this angle at Mars G. Also, the seismometer characteristic effectively becomes one side of the filtered channels roll-off for the desired data periods. In the event that larger tilts are experienced, the horizontal units will continue to operate with lessened sensitivity up to 23°. The vertical instrument can operate with tilts as great as 35° off-level.

The estimated temperature coefficient of mass displacement vs temperature at Mars G for the vertical seismometer is $.6 \times 10^{-4}$ cm/°C. An experimental Earth vertical component seismometer continued to function properly when exposed for several hours to temperatures of + 80°C and - 110°C. At Mars G the sensitivity to drift will be .4 of that on earth; thus, it appears that no difficulty will be encountered in constructing a seismometer package for survival of Martian surface temperatures. The horizontal component units will be relatively immune to temperature changes.

The mechanical dynamic range limit is approximately ± 2 mm, the mass migration of the horizontal units is approximately 1 mm for the 15° tilt, at Mars G, in the most sensitive roll axis, and of the vertical unit about 1 mm for 35° off-level. Off-level by the same angle in the longitudinal direction results in slight period change due to the contribution of gravity to the restoring force, however, this may be neglected in this system at this instrument period and at Mars G.

While no shock or vibration tests have been performed on the prototype instruments, it is believed that the survival of 50 G forces can easily be achieved. Specified strength of the flexures is such that accelerations of this magnitude acting on the mass assembly in any axis will not cause them to fail.

Mass caging to prevent "slamming" is provided by spring loaded plungers which firmly hold the mass against a stop seat. In the present design, release is accomplished by nonexplosive alloying of a palladium-aluminum fuse wire securing device by heating with the passage of current, allowing the plungers to be expelled by a strong spring.

Weight of the individual development sensor is 110 gm and total weight of a package of three units is 550 grams. Rework to thin sections and substitution of materials will reduce this to within the specified weight of 450 grams. Dimensions of the sensor case are 3¼" x 5" x 1-3/4".

B. Seismic Analog Data Processor-General Description

The seismic data processor amplifies and conditions the analog seismic signal for presentation to the lander interface. This report is concerned only with the handling of the seismic signal in analog form. The design of the commutation, digitization, storage, and transmission is not discussed.

The seismic data processor is designed to allow for three modes of operation:

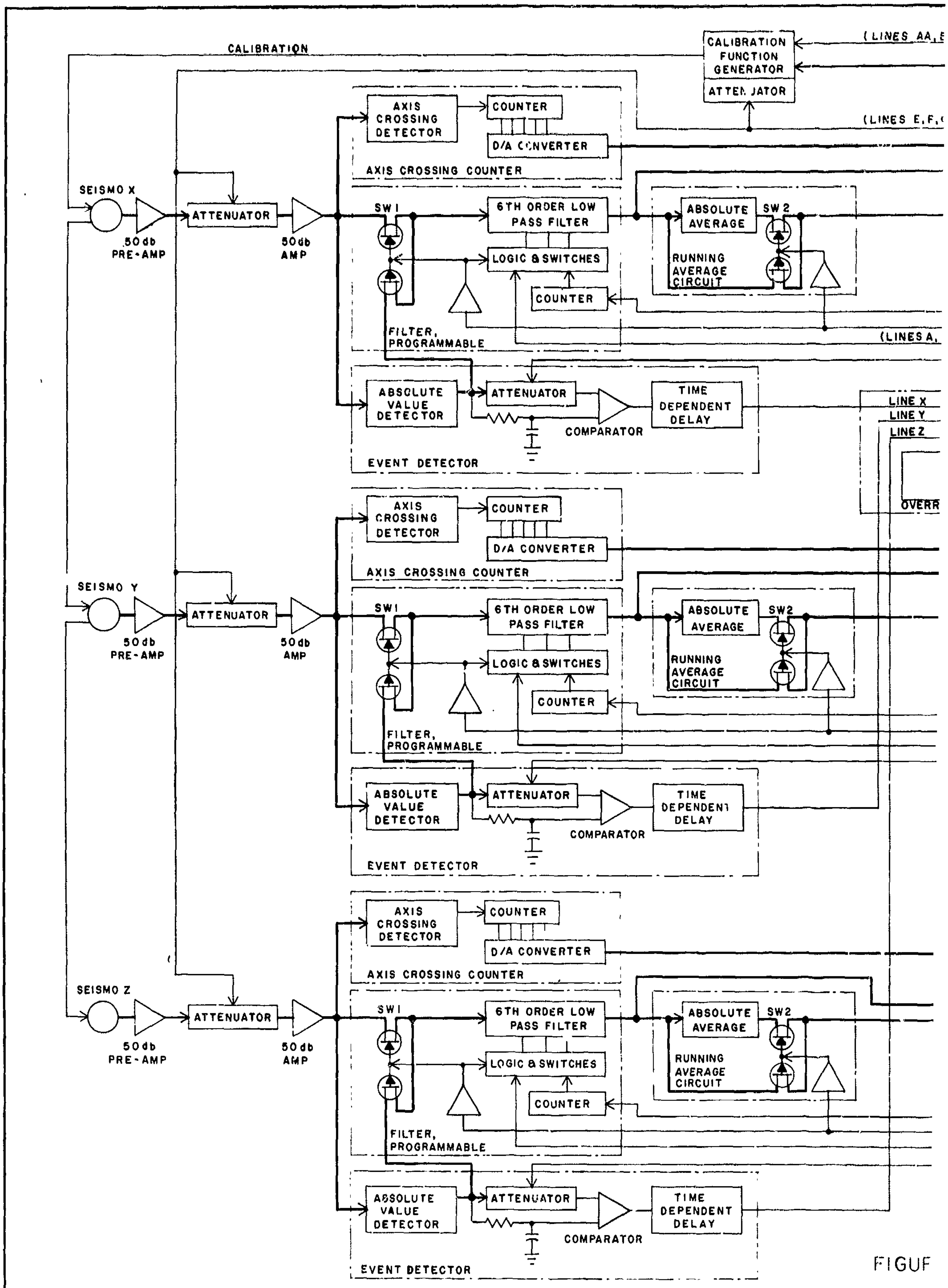
1. High data rate, 20 samples/sec/channel. three data channels. This mode is intended to be initiated by earth command at times when the telemetry can accommodate the bit rate.

2. Low data rate, 4 samples/min/channel, three data channels. This is the normal operating mode where the microseism background is sampled within narrow frequency bands.

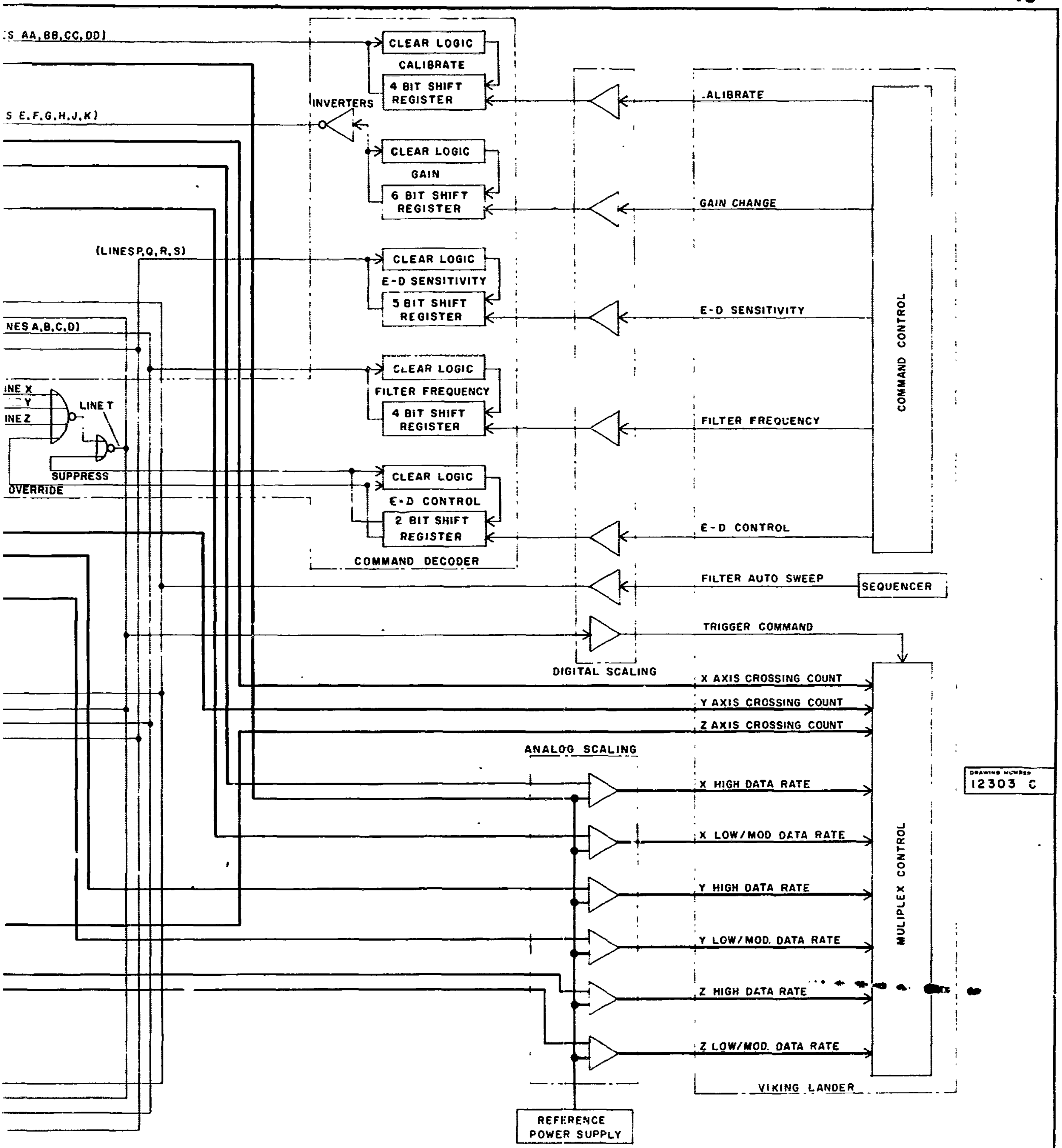
3. Moderate data rate, 1 sample/sec/channel, six data channels. This mode is initiated either by Earth command or automatically upon the detection of a seismic event by the event trigger. In this model some form of data compression must be used to preserve the wideband seismic information while consuming a minimum number of bits.

All of the data are presented to the lander in analog form for subsequent digitization, storage, and transmission.

Figure 6 is a block diagram of the three-axis seismic data


CALIBRATION
CALIBRATION FUNCTION GENERATOR
ATTEN JATOR
(LINES AA, E
(LINES E, F, (
SEISMO X
SEISMO Y
SEISMO Z
50 db PRE-AMP
ATTENUATOR
50 db AMP
AXIS CROSSING DETECTOR
COUNTER
D/A CONVERTER
AXIS CROSSING COUNTER
SW 1
6TH ORDER LOW PASS FILTER
LOGIC & SWITCHES
COUNTER
FILTER, PROGRAMMABLE
ABSOLUTE AVERAGE
SW 2
RUNNING AVERAGE CIRCUIT
(LINES A,
ABSOLUTE VALUE DETECTOR
ATTENUATOR
COMPARATOR
TIME DEPENDENT DELAY
EVENT DETECTOR
LINE X
LINE Y
LINE Z
OVERR

FIGUF



GURE 6

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VIKING SEISMIC DATA PROCESSOR BLOCK DIAGRAM

D 12303 C

FOLDOUT FRAME 2

processor; the three axes are identical and each consists of the following:

a. A variable gain amplifier with a bandwidth from 0.1 to 10 Hz and gain selectable upon Earth command from 1.59×10^3 to 10^5.

b. A programmable low-pass filter with selectable cutoff frequencies of 0.5, 1.0, 2.0, and 4 Hz. Each of which may be selected by Earth command or the filter may be commanded to automatically step through each of the bandwidths provided.

c. A circuit for detecting the absolute average of the seismic signal.

d. An event trigger with selectable sensitivity and an ON-time dependent upon the nature of the event.

e. An axis crossing counter which produces a running count of the positive going axis crossings of the seismic signal.

f. Electronic switches for changing the modes of operation from simple absolute averaging to envelope detection.

A brief description of the three modes of operation is as follows:

1. High Data Rate Mode - Wideband Transmission of the Seismic Data.

This mode is used when telemetry conditions are such that the lander can transmit high (20 samples/sec/channel) data rates. Three analog data signals are presented to the lander after filtering. The amplifier gain and filter settings can be selected to optimize this transmission.

2. Normal Mode - Spectral Filtering and Averaging of Microseisms.

To investigate the average level of the microseism noise, "comb filtering" of the microseisms will be performed by using a programmable low-pass filter in conjunction with the frequency roll-off of the seismometer. The signal data is then passed through an absolute value detector and low-pass filter to obtain the running (15 sec) average of the microseism level in each band.

The programmable filter is a 6th order low-pass Butterworth type with the cutoff frequency selectable by Earth command. The bandwidths available are 0.5, 1.0, 2.0, and 4.0 Hz. The response of this system, including the seismometer, is shown in Figure 7.

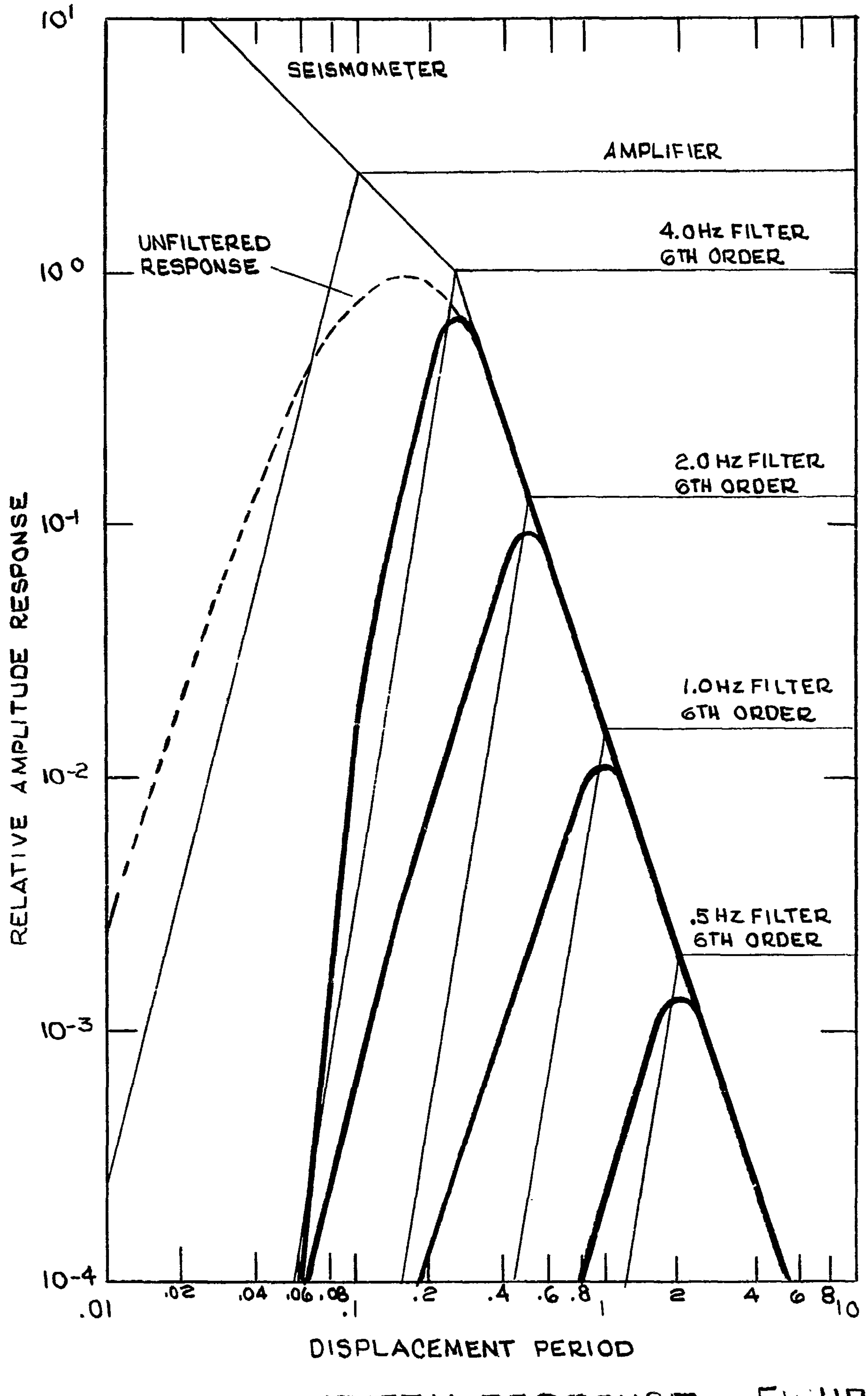
Upon Earth command the filter may automatically be stepped through its filter settings so that a spectral analysis of the background is obtained. Timing for this automatic mode is obtained from the lander sequencer, multiplexing timing, or other suitable source.

The gain of the seismic amplifier is selectable by Earth command in 6 db increments from 64 db to 100 db.

The filtered and averaged seismic signal is presented to the lander, in analog form, on one channel per axis.

3. Triggered Mode - Data Compression of Seismic Events.

The limited number of bits available precludes high speed (20 samples/sec) sampling of the seismic channels except for a few occasions. It is unlikely that a Marsquake will occur during



SYSTEM RESPONSE FIGURE 7

these rare intervals. It is very desirable, however, to observe the signatures of Marsquakes and so a mode of operation with a moderate sampling rate and data compression is automatically initiated upon the detection of a large amplitude event by an event detector.

This data compression scheme consists of a seismic event envelope detector and an axis crossing counter for each seismic axis. Two data words per sample are required which when sampled at one sample/second results in a 10 to 1 data compression.

Reconstruction, on Earth, of the original seismogram may be performed by passing the seismic envelope signal through an inverse filter and convolving with the instrument response according to the axis crossing count within each sampling interval.

Implementing this system makes multiple use of existing hardware in that the seismic envelope detector is constructed, with suitable switching, utilizing the low-pass filter and absolute value circuit already required. The addition of the axis crossing counter and some electronic switches complete the data compression system. The seismic event trigger controls the position of the switches which in turn changes the system from one channel of filtered and averaged data to one channel for the seismic envelope and one for the axis crossing count.

The seismic event trigger is designed to detect an event when its amplitude exceeds a predetermined multiple of the average background level. It allows for an unknown or varying background by adjusting the trigger point so that it remains a fixed multiple of the average background. The multiple is selected by Earth command.

The trigger has an ON-time which varies from approximately 2 sec for a false trigger (a seismic noise impulse) to about four minutes for the longest event.

After the occurrence of an event of sufficient magnitude to cause triggering of the event detector, the following functions are performed by the event detector output:

a. The lander is commanded to go to the moderate (1 sample/sec) sampling rate on six channels.

b. The programmable filter is switched to the 0.5 Hz break point to provide proper smoothing of the seismic envelope.

c. The electronic switch presents to the programmable filter, the absolute value of the signal (obtained from the event detector) forming the seismic envelope detector, and the averaging circuit is by-passed.

When the level of the seismic event falls below the average background level, the event trigger will reset, putting the system back into the normal mode of operation.

C. Electronics - Detailed Description

1. Amplifier

The seismic amplifier (Figure 8) consists of a pre-amplifier and an amplifier separated by a variable attenuator for adjusting the total gain. For simplicity, the transfer functions of the pre-amplifier and the amplifier were made identical.

A block diagram of a pre-amplifier or amplifier section is also shown in Figure 8, along with a Bode plot of its frequency response. The shape of the Bode plot on the high frequency side, is dictated by the fact that the signal must be filtered to prevent aliasing and on the low frequency side by the requirement that the offset voltage of the pre-amplifier must be attenuated such that the total amplifier offset voltage at the output with the maximum gain of 10^5 remains below the worst case design goal (62 mv). The mid-frequency gain is simply $(10^5)^{\frac{1}{2}}$ and the mid-frequency corner breakpoints are selected to give a bandwidth of .1 Hz (ω = .628) to 10 Hz (ω = 62.8).

High-pass filters for shaping the transfer function were avoided at these low frequencies because of their tendency to accumulate a charge upon a large signal overload, and to produce an excessively long amplifier recovery time. Instead, the Bode plot was synthesized, using only low-pass filters in the feed-forward and feed-back loops. The result is that the amplifier can accommodate a 100 times overload within the bandwidth of 0.1 H_z to

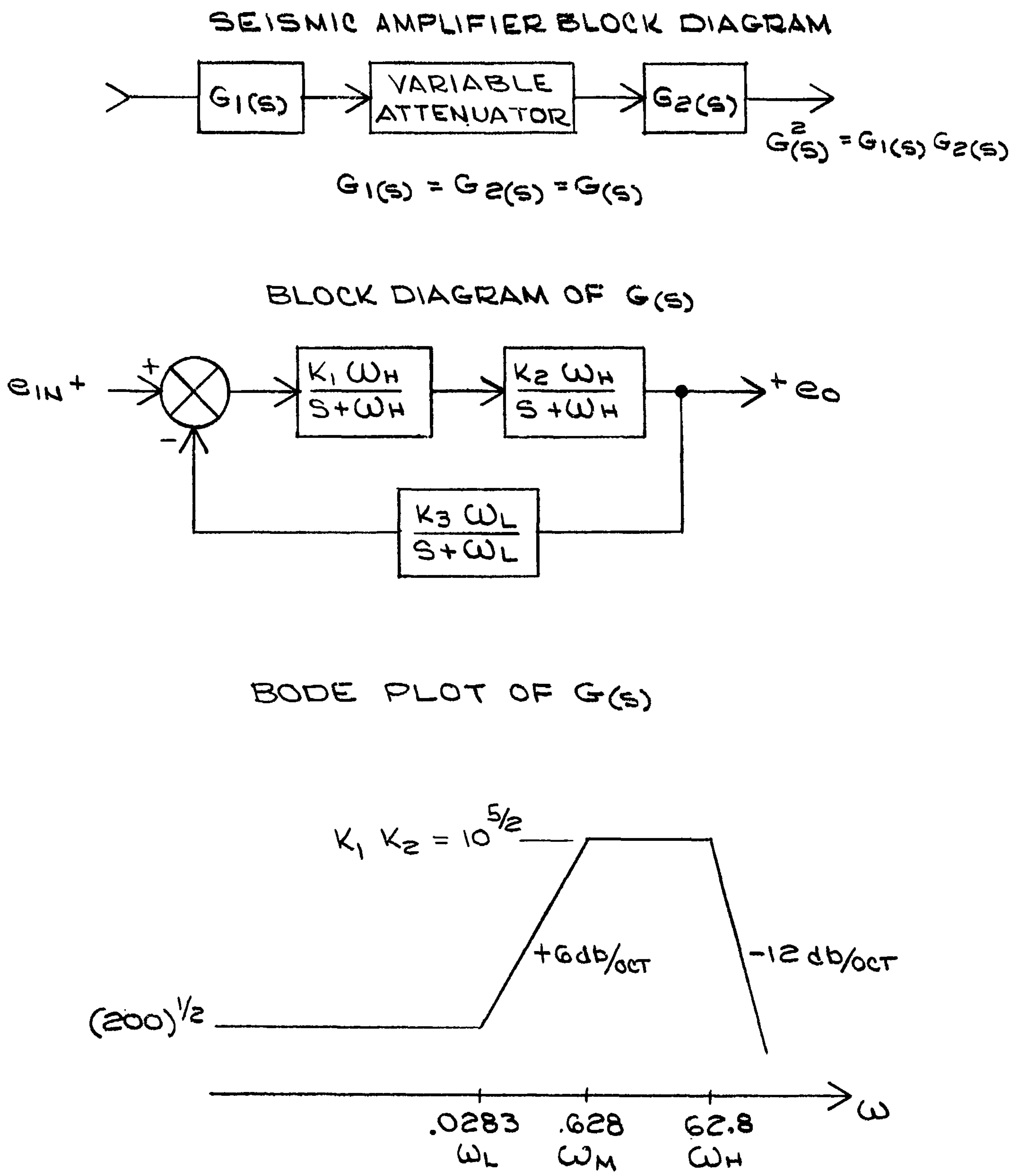

SEISMIC AMPLIFIER BLOCK DIAGRAM
G1(S)
VARIABLE ATTENUATOR
G2(S)
G²(S) = G1(S) G2(S)
G1(S) = G2(S) = G(S)
BLOCK DIAGRAM OF G(S)
eIN +
+
−
K1 ωH / S+ωH
K2 ωH / S+ωH
+ eo
K3 ωL / S+ωL
BODE PLOT OF G(S)
K1 K2 = 10^5/2
+6db/OCT
−12 db/OCT
(200)^1/2
.0283
ωL
.628
ωM
62.8
ωH
ω

FIGURE 8

10 Hz, and its recovery will be that which is described simply by its amplitude and frequency response characteristics, with symmetrical clipping above the plus and minus 10 volt full-scale output.

The input of the amplifier is protected by diodes against the high voltage that is generated if the seismometer is subjected to a large acceleration (a 50 g step of acceleration will produce approximately 40 volts from the transducer).

Each section consists of two stages. Although a single stage would have sufficient voltage gain, it is desirable that the feedback factor be greater than 50 db which a single stage cannot satisfy. Two stages also make it convenient to construct the aliasing filter by making each stage into a first order low-pass filter.

Deriving the transfer function from the block diagram in Figure 8 gives:

$$G(s) = \frac{K_1K_2\omega_H^2 \left(S + \omega_L\right)}{S^3 + S^2 \left(2\omega_H + \omega_L\right) + S\omega_H \left(\omega_H + 2\omega_L\right) + \omega_H^2 \, \omega_L \left(1 + K_1K_2K_3\right)}$$

which for $K_1K_2 = 10^{5/2}$

$K_1K_2K_3 = 21.2$

$\omega_H = 62.8$

$\omega_L = .0283$ and $\omega_L << \omega_H$

becomes

$$G(s) = \frac{(316)(62.8)^2 \ (S + .0283)}{S^3 + 126S \ + 3950S + 2480}$$

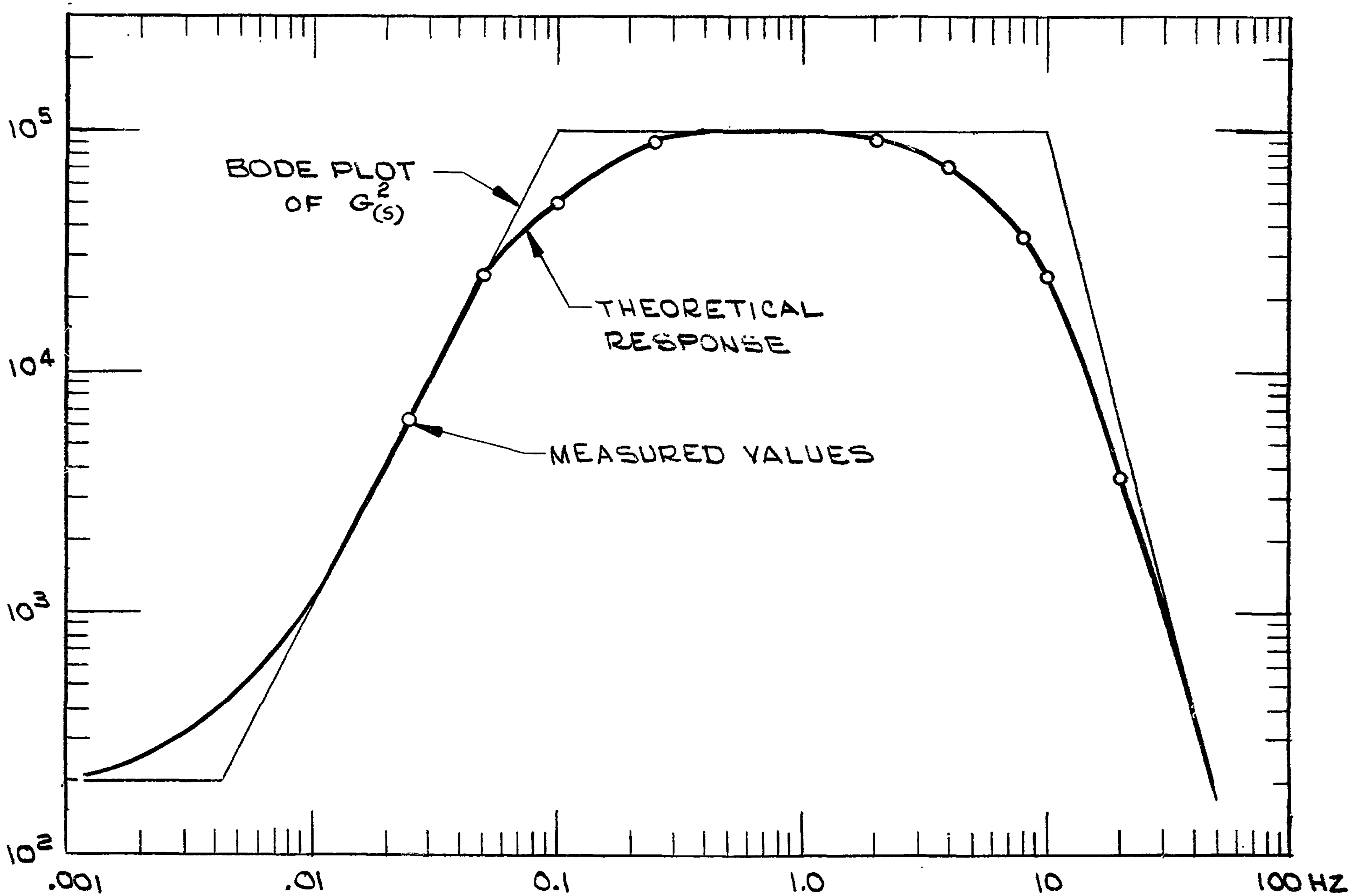
Factoring the denominator gives:

$$G(s) = \frac{(316)(62.8)^2 \ (S + .0283)}{(S + .628)(S + 62.8)^2}$$

Combining the pre-amplifier and amplifier (with 0 db attenuation) gives an overall transfer function of:

$$G\ (s) = \frac{10^5 \ (62.8)^4 \ (S + .0283)^2}{(S + .628)^2 \ (S + 62.8)^4}$$

The Bode plot for the combination is shown in Figure 9, along with the actual theoretical response and measured points from a breadboard model. Although this may not be the most desirable transfer function in that the response is a little low at each of the mid-frequency breakpoints, the ease with which it is synthesized and the simplicity of the resulting design makes it quite acceptable.



PRE-AMPLIFIER, AMPLIFIER FREQUENCY RESPONSE AT MAXIMUM GAIN

FIGURE 9

Figure 10 shows the phase response of a single section, and of the combination, and indicates that the phase margin and gain margins are sufficient for unconditional stability.

The noise referred to the input of the seismic amplifier is primarily a function of the noise figure of the first stage of the pre-amplifier (assuming that low noise components are used, the power supply is well decoupled, and that good construction practices are used to prevent external sources from being coupled or induced into the pre-amplifier). An operational amplifier, Model 153K, manufactured by Analog Devices, Inc., was chosen for the first stage based upon its specifications and noise tests performed in a prototype pre-amplifier. The minimum low-frequency gain was then determined from the offset voltage specification for the 153K and the shape of the required Bode plot, and finally, the transfer function developed. Because of the large amount of feedback used, the overall amplifier characteristics are independent of the specifications, except for minimum voltage gain, of the other stages. The low-frequency and mid-frequency gains and the Bode breakpoints are as accurate as the components (resistors and capacitors) used.

It is often the practice with seismic amplifiers to use negative feedback to adjust the input impedance of the amplifier to that required to damp the seismometer. This results in the maximum power transfer and minimizes the noise figure. This practice was not followed in this case, however, because of the added complexity of synthesizing the transfer function and the

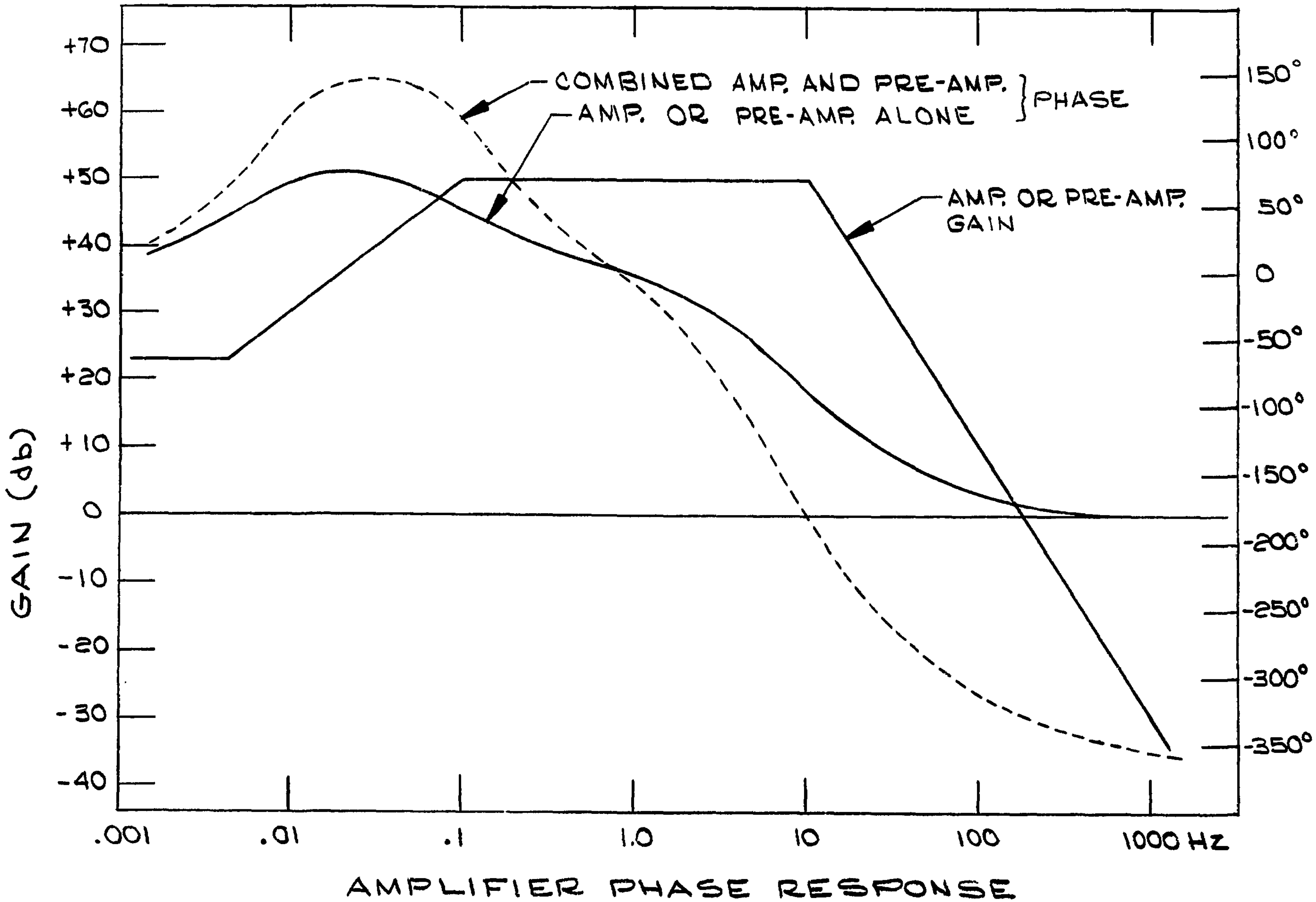

COMBINED AMP. AND PRE-AMP.
AMP. OR PRE-AMP. ALONE
PHASE
AMP. OR PRE-AMP. GAIN
GAIN (db)
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
PHASE SHIFT (DEGREE
150°
100°
50°
0
-50°
-100°
-150°
-200°
-250°
-300°
-350°
.001
.01
.1
1.0
10
100
1000 HZ
AMPLIFIER PHASE RESPONSE

FIGURE 10

Table 1

Seismometer Amplifier Specifications

Voltage Amplification	10^5(100 db) max. (adjustable in 6 db increments to 64 db)
Bandwidth	0.1 to 10 Hz (Bode breakpoints) .15 to 4 Hz (-3 db points)
Input impedance	2 x 10^8 ohms, nominal (shunted by diodes)
Output	± 10 volts at 5 ma
Noise RTI	Less than .75 microvolt peak-to-peak
Offset voltage	50 mv, nominal 62 mv, worst-case -55°C to + 55°C
Overload recovery time	Negligible
Quiescent power	10 milliwatts at ± 15 volts.

fact that it is difficult to simultaneously stabilize the input impedance and the voltage gain resulting in a very complex worst-case analysis. Rather, the input impedance was made very large (approaching the common mode input impedance of the 153 K or 2×10^8 ohms) by operating the first stage in a non-inverting configuration with seismometer damping achieved by shunting the velocity transducer with the appropriate resistance. Tests of this technique verified that the noise referred to the input was sufficiently low to allow operation at an amplifier gain of 10^5, which is about an order of magnitude greater than is practical with this seismic system at the Caltech Seismological Laboratory in Pasadena, California, where the limit is determined by the microseismic level. The quiescent power consumption of the combined pre-amplifier, attenuator, and amplifier is nominally 10 mw.

2. Programmable Filter

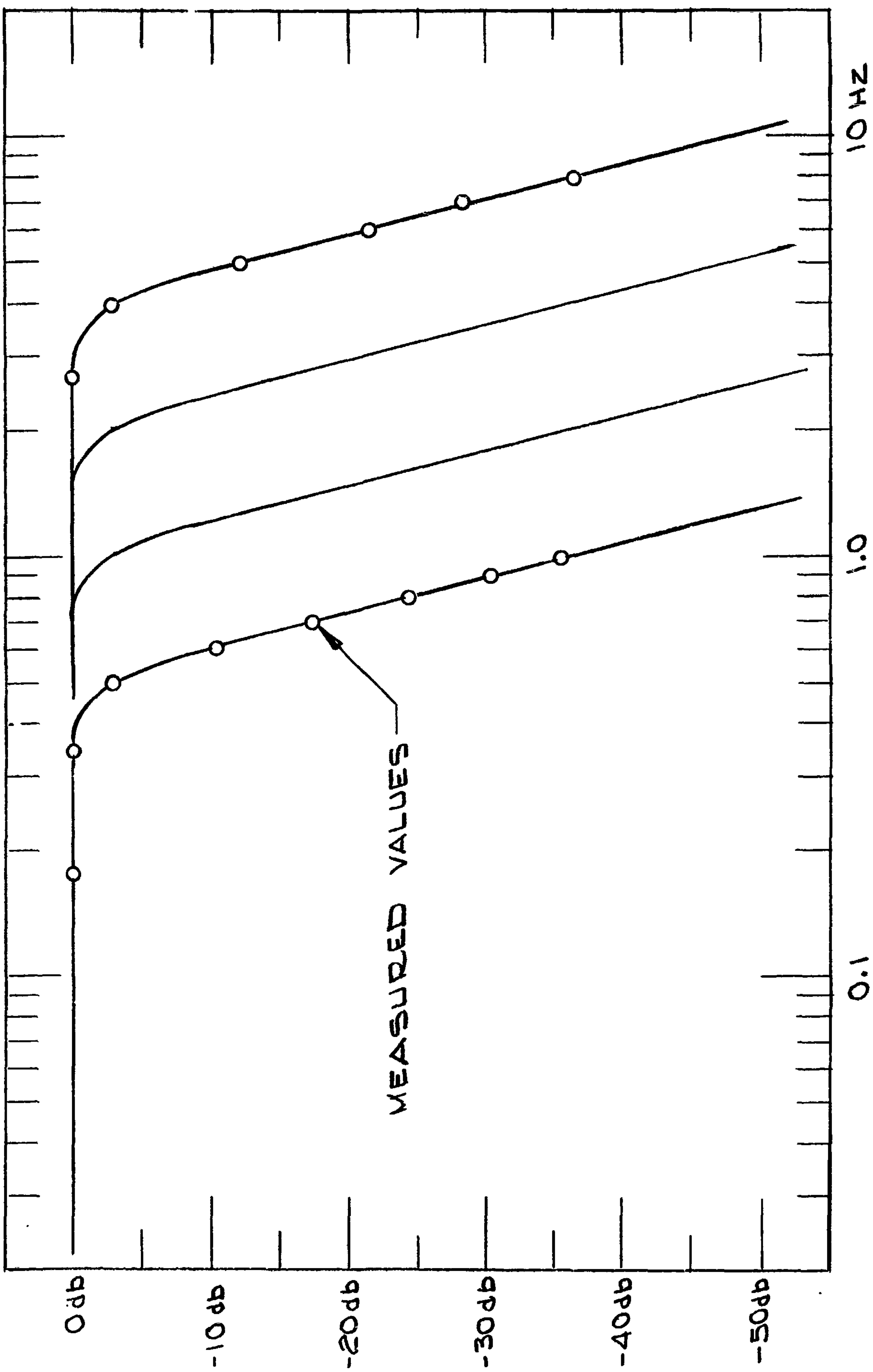
The programmable filter is a 6th order low-pass Butterworth filter with the normalized transfer function:

$$G_B(s) = \frac{1}{S^6 + 3.86\ S^5 + 7.46\ S^4 + 9.14\ S^3 + 7.46\ S^2 + 3.86\ S + 1}$$

The basic filter has a cutoff frequency of 0.5 Hz. It is synthesized using active RC networks. The cutoff frequency is raised in octave steps by progressively shorting one-half of the resistance in each RC time constant with field-effect transistors.

The cutoff frequencies available are 0.5, 1.0, 2.0, and 4.0 Hz. Figure 11 shows the theoretical and measured response of a prototype filter. To keep the weight and volume of the filter to a minimum, the capacitor values were kept as small as the design would allow. The lower limit on capacitor value is determined by the maximum resistance values which may be used and, in turn, the maximum resistance is determined by the maximum allowable output-offset voltage that may be tolerated. The product of the input-offset current of the operational amplifier and the total resistance in the time constant which appears at the input of the amplifier is the output-offset voltage. The filter was originally designed around National NH0001 operational amplifiers because of their low quiescent power consumption (2 mw). The sum total of the capacitance in this design was approximately 13 mfd. For accuracy and stability a high quality metallized polycarbonate capacitor was chosen. Such capacitors are not as small as might be desired and the programmable filter constituted more than one-half of the weight and volume of the entire data processor.

The introduction of the LM108 operational amplifier by National Semi-Conductor Corporation with its greatly reduced input-offset current allowed the filter to be redesigned with a reduction in total capacitance to 1 mfd and a reduction in worst-case offset voltage from 156 mv to 33 mv at 55°C. At the maximum temperature of 55°C, approximately 40% of the remaining offset voltage is contributed by the Igss leakage of the FET switches used for changing the cutoff frequency.



PROGRAMMABLE FILTER RESPONSE

FIGURE 11

The LM 108 amplifier, however, consumes more power than the NH0001; consequently, the power consumption of the filter was increased by about a factor of four to 34 mw.

In addition to the basic low-pass filter and the electronic switches, the programmable filter also contains logic to allow the cutoff frequency to be determined by three modes of operation:

a. Earth Command Mode - Any one of the cutoff frequencies may be selected by Earth command.

b. Auto Sequencing Mode - In the absence of an Earth command, the filter will be automatically stepped through each of the filter positions by timing provided by the lander. This is the "comb filtering" mode of operation where the seismic background level is sampled.

To allow for an as yet unspecified timing interval, a binary divider is provided so that the timing frequency may be divided by 2^0 to 2^5. For example, if a pulse is received in synchronism with the sampling of the data in the normal mode (4 samples/sec), a division of 2^3 would give a 2 min interval between changes of the filter frequency. The timing should be synchronized to the sampling and it is assumed that the lander will provide timing identification.

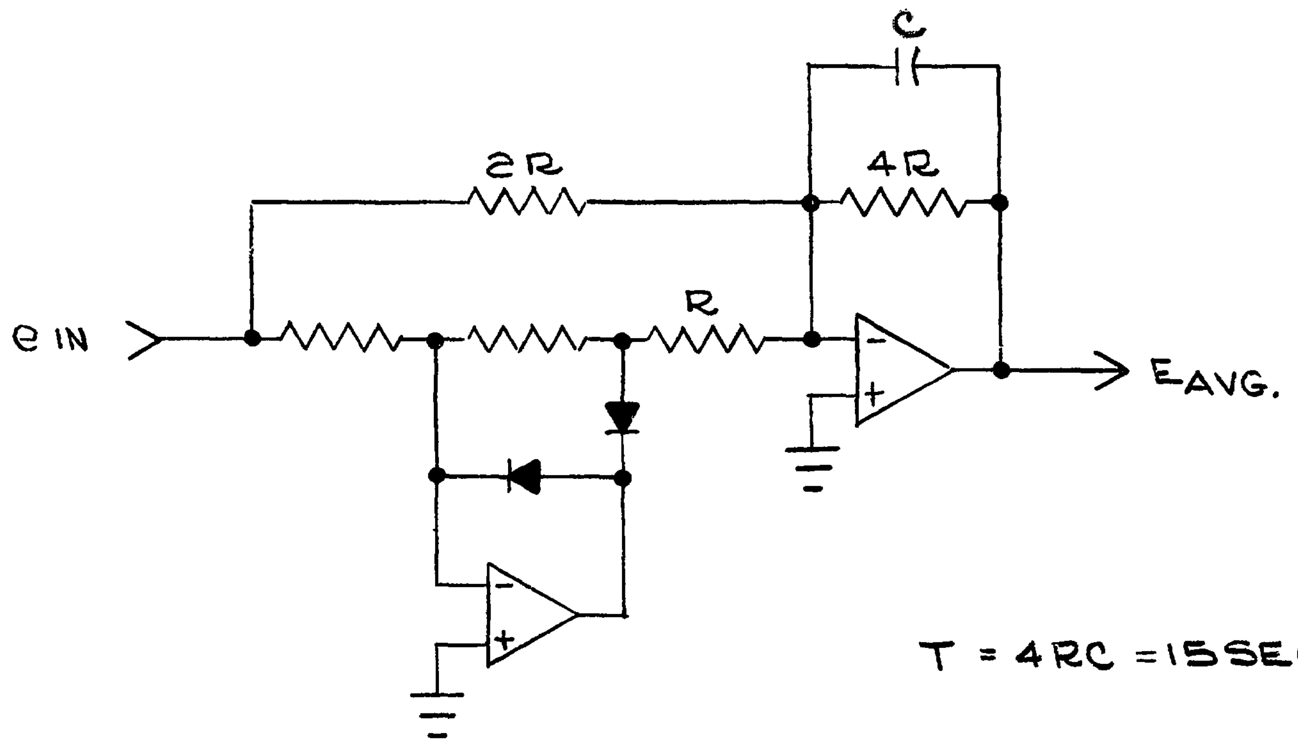
c. Trigger Override Mode - When the event detector detects a seismic event, a command is provided to the programmable filter to switch it to the 0.5 Hz position for proper iltering of the seismic envelope; this mode always overrides the others. When the signal from the event detector is removed, the logic returns the filter to its former mode, and if this was the auto-sequencing mode, the first filter position will be 0.5 Hz.

Since the input to the filter in this mode must be switched from the seismic amplifier to an absolute value circuit, a single-pole, double-throw electronic switch is provided and also controlled by the event detector command.

3. Absolute Average Circuit

During the normal mode of operation, the absolute average of the seismic background is sampled at the rate of 4 samples/min. To detect the absolute average the seismic signal is first full-wave rectified and then low-pass filtered. Actually, both functions are combined in what is commonly called a "precision rectifier," Figure 12, where the diodes are placed in the feedback loop of an operational amplifier to reduce their forward voltage drop by an amount equal to the gain of the amplifier. The addition of a capacitor to the second stage of this circuit provides the filtering and a running average of the absolute value. The averaging time constant is 15 sec.

Because the absolute average value of the seismic signal will always be less than the peak value (and often much less), the circuit is designed with a voltage amplification of two to make better use of the dynamic range available. The expression for the output of this circuit is



$T = 4RC = 15 \text{ SEC.}$

$$E_{AVG} = \frac{2|e_{IN}|}{1 + Ts}$$

ABSOLUTE VALUE CIRCUIT

FIGURE 12

$$E_{avg} = \frac{2 \mid e_{in} \mid}{1 + \tau S} \qquad \tau = 15 \text{ sec.}$$

In addition, the circuit contains a single-pole, double-throw electronic switch which is controlled by the event detector. Since the analog signal for both the normal mode and the triggered mode appears on the same output channel, this switch provides the needed commutation by by-passing the absolute average circuit during the triggered mode.

The power consumption of the absolute average circuit is nominally 5 mw.

4. Seismic Event Detector

Fundamental to the triggered mode of operation and data compression is the seismic event detector. Its function is to detect seismic (or other) events which produce a signal exceeding the average seismic background level by a multiple which can be selected by Earth command. The event detector continuously adjusts its trigger point to allow for the unknown and probably varying background level by making it a fixed multiple above the average. The multiples available are x 4, x 8, x 12, x 16, and x 20. The signal from the event detector is used to perform the switching necessary to form the envelope detector and to command the lander multiplexing and digitizing systems to sample at 1 sample/sec. on 6 channels.

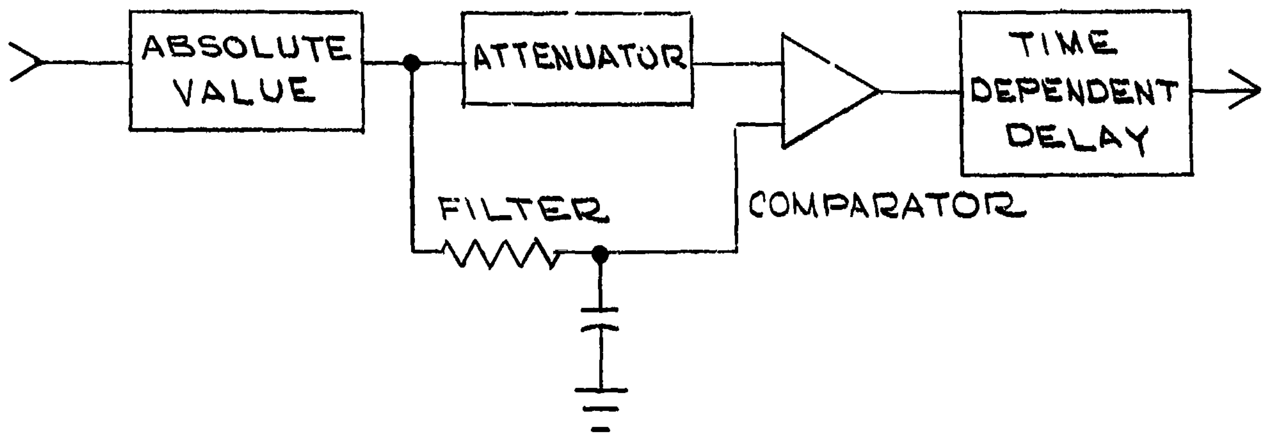
A block diagram of the event detector is shown in Figure 13. It consists of an absolute value circuit, a comparator and a delay. The absolute value circuit is identical to the one used in the absolute average circuitry except that the filtering is eliminated.

The absolute value of the seismic signal is passed into one input of a comparator through an attenuator. This attenuator sets the trigger point multipl' and is adjustable by Earth command. The same absolute value is passed into the other input of the comparator through a low-pass filter. The comparator is thus comparing a fraction of the seismic background with the average background. When an event exceeds the average by an amount equal to the attenuation factor, the comparator will change state, producing an output. When the attenuated level of the event falls below the average level of the background (which now includes the event), the comparator will reset to its original state. The time constant of the filter is selected to allow for gradual changes in the background level which, in effect, continuously readjusts the trigger point.

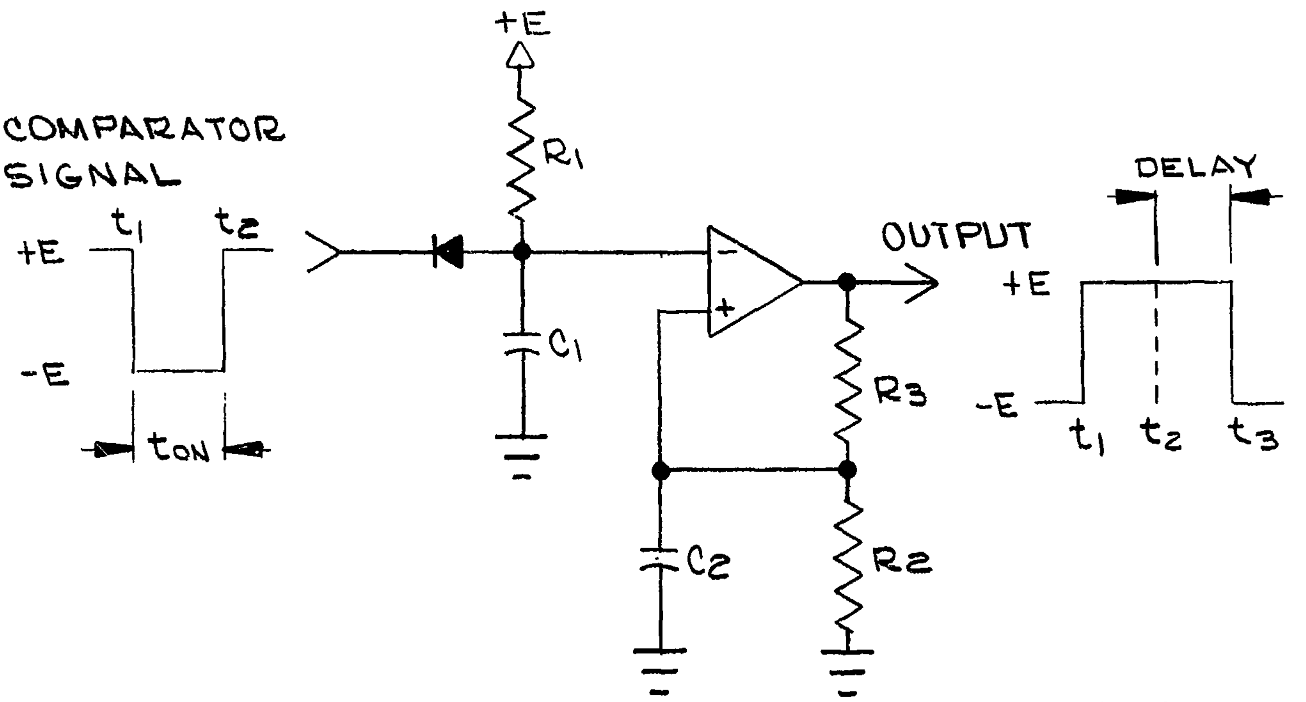
Tests of the circuitry so far described revealed two problems;

a. the level between the P and S waves of many small seismic events drops to such a value that the comparator would reset before the S wave arrival and then retrigger on the S wave, and

b. since the average background during an event contains the event, the comparator was often reset before the level of the event had dropped to a value close to the average background



EVENT DETECTOR BLOCK DIAGRAM



$$T_1 = R_1 C_1$$

$$\text{DELAY} = t_d = T_d \, L_N \, \frac{2(R_2+R_3)}{R_3 + 2R_2 \, e^{-\frac{t_{ON}}{T_2}}}$$

$$T_2 = \frac{R_2 R_3}{R_2+R_3} C_2$$

t_{ON} = COMPARATOR "ON" TIME

VARIABLE DELAY

FIGURE 13

prior to the event. A fixed delay of about 15 sec following the reset of the comparator would solve both of these problems, but it would also mean that 15 sec of moderate sampling on six channels would be performed even if a short duration impulse caused the triggering.

To circumvent this problem a time-dependent delay circuit was developed which produces a delay proportional to the trigger time duration of the comparator. The delay sets coincident with the triggering of the comparator and resets following the reset of the comparator with a delay which is close to zero for negligibly small comparator ON-times but becomes increasingly longer as the ON-time of the comparator increases.

A simplified schematic of the delay is shown in Figure 13. It consists of another comparator with one of the inputs driven directly by the previous stage and the other referenced to its own output. The expression for the delay time as given in Figure 13 is:

$$td = \tau_1 \ln \frac{2(R_2 + R_3)}{R_3 + 2R_2 e^{-\frac{t_{on}}{t_2}}}$$

$$\tau_1 = R_1 C_1 \approx 15 \text{ sec.}$$

$$\tau_2 = \frac{R_2 R_3}{R_2 + R_3} C_2 \approx 60 \text{ sec.}$$

t_{on} = Comparator ON-time

It is desirable to maximize the ratio:

$$\frac{\text{Delay (max.)}}{\text{Delay (min.)}}$$

where

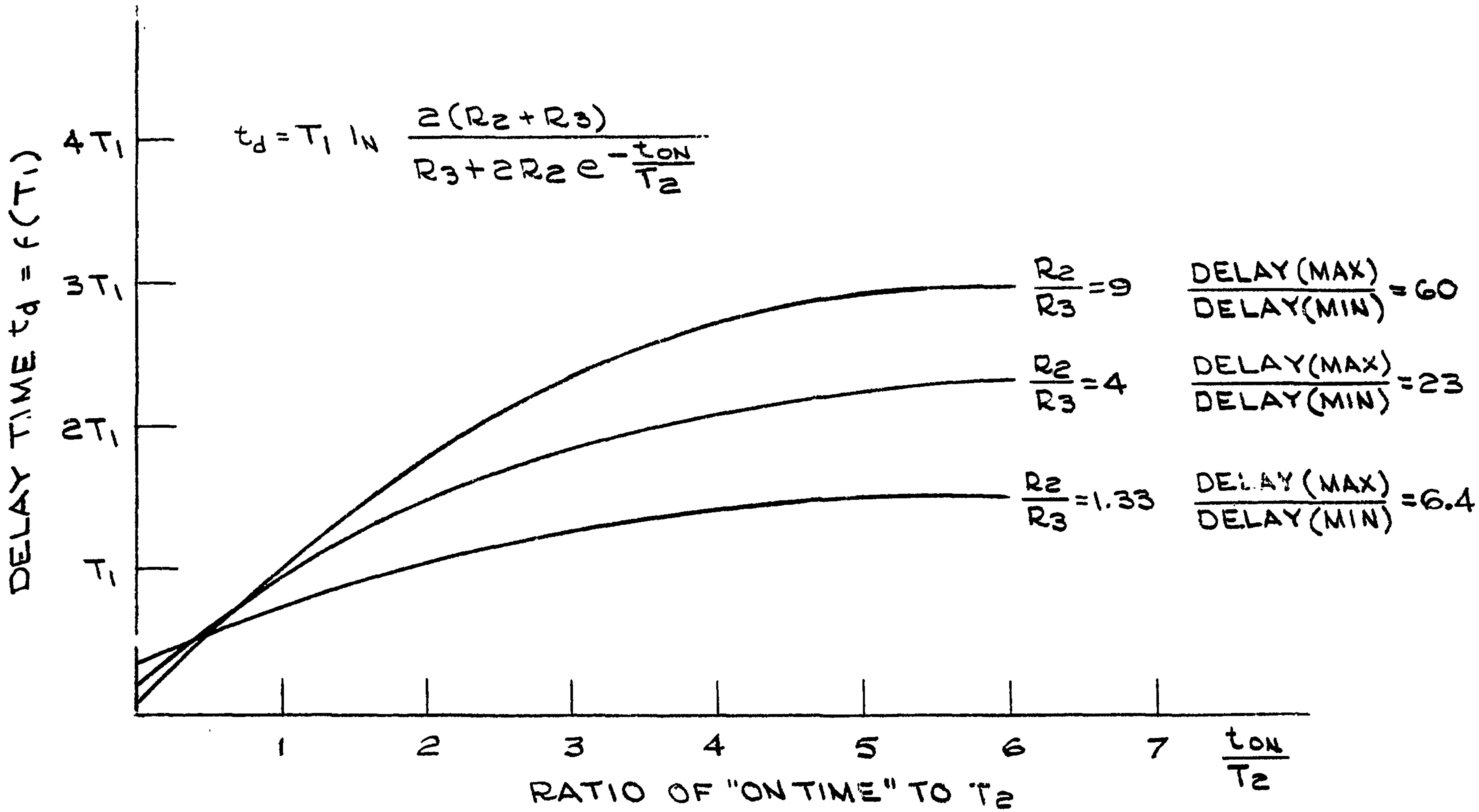
$$\text{Delay (max.)} = t_d(\text{mx}) = \tau_1 \ell n \left. \frac{2(R_2 + R_3)}{R_3} \right|_{t_{on} = \infty}$$

$$\text{Delay (min.)} = t_d(\text{mn}) = \tau_1 \ell n \left. \frac{2(R_2 + R_3)}{2R_2 + R_3} \right|_{t_{on} = 0}$$

Figure 14 is a plot of delay time (t_d) versus the ratio t_{on}/τ_2 for various ratios of R_2 to R_3.

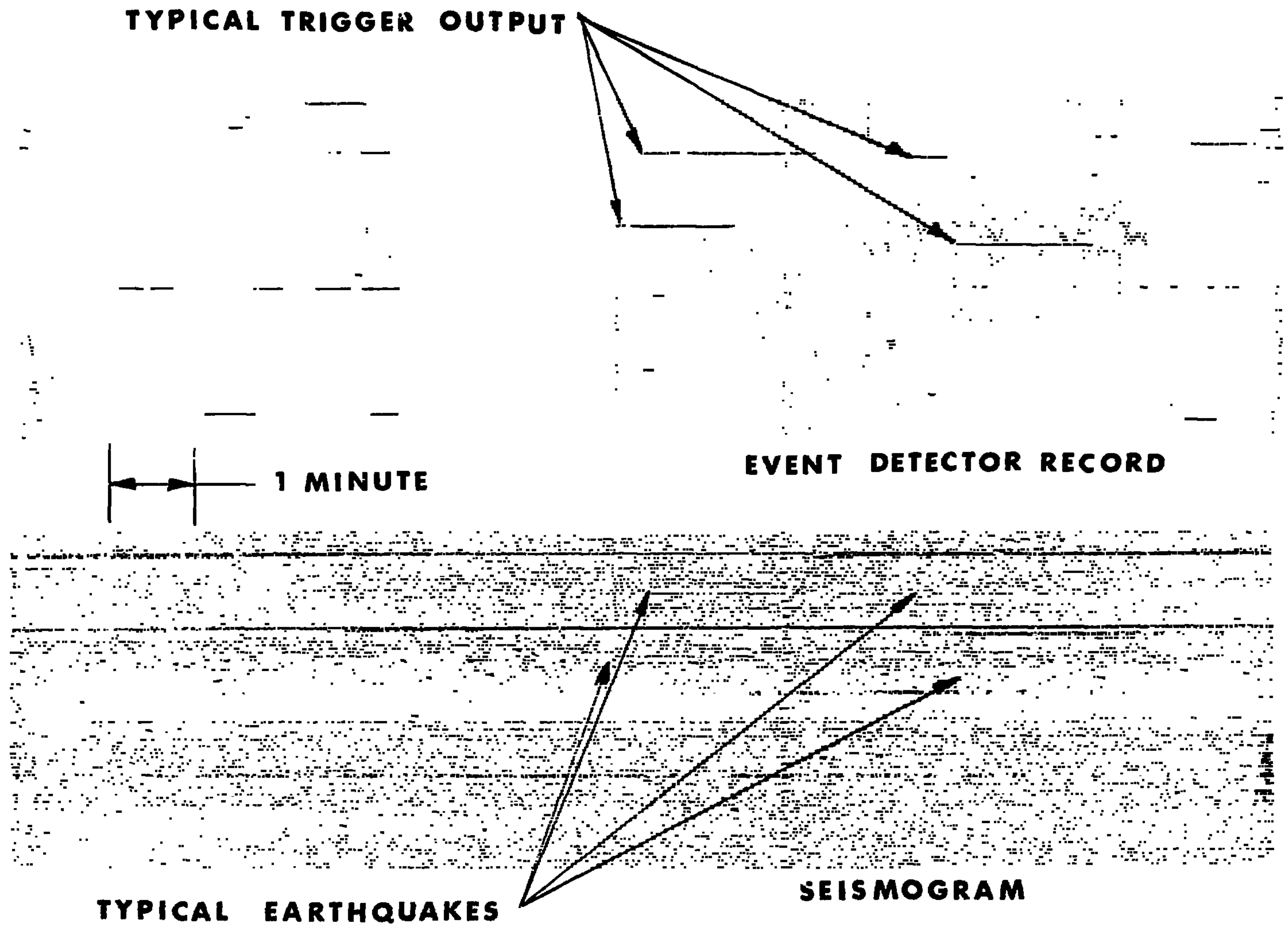
This circuit was designed around the NH0001 operational amplifier and to accommodate its low differential voltage breakdown (5 volts), the maximum reliable ratio of R_2 to R_3 was 1.33. This gives a ratio of $t_d(\text{mx})/t_d(\text{mn})$ of 6.4 so that for a 3 sec minimum delay, the maximum delay is 20 sec. The introduction of the RM 4132 low power operational amplifier by the Raytheon Company with a 30 V differential voltage breakdown allowed the circuit to be redesigned around this device with a ratio $R_2/R_3 = 4$ which increases $t_d(\text{mx})/t_d(\text{mn})$ by about a factor of four. The schematic given with this report, however, does not reflect this new design for reasons given in the section on parts selection.

Testing of the event detector has shown its ability to detect seismic events, while accommodating variations in the microseism background level, is excellent. Figure 15 compares a 24-hour



TIME DEPENDENT DELAY Vs "ON TIME"

FIGURE 14



SEISMIC EVENT DETECTOR TEST

FIGURE 15

Table 2

EVENT DETECTOR TEST RESULTS

Date	Trig. Level	Hours of Recording	Earthquakes			Glitchs*			Comments
			Number	Total Time (Seconds)	% Time	Number	Total Time (Seconds)	% Time	
7/10-11/69	13.5 x	22	22	529	85%	21	97	15%	
7/13-14/69	13.5 x	22	15	744	19%	801	3204	81%	Trig. level set low
7/15-16/69	10 x	23	26	1406	89%	60	180	11%	5 x Δ
7/16-17/69	10 x	23	12	598	81%	39	137	19%	5 x Δ
7/18-19/69	10 x	24	25	1313	86%	79	215	14%	Little Δ
7/22-23/69	10 x	25	19	641	78%	29	180	22%	6 x Δ
7/23-24/69	10 x	24	18	737	84%	42	142	16%	Little Δ

Δ = change in average background level during the recording interval.

*Glitchs are events of seismic or other origin which were not considered of much seismic interest.

seismogram* with the event detector output. For this period, nineteen earthquakes were detected, during which time the background level varied by a factor of six. Table 2 summarizes the results of such tests. Although the number of false triggers (seismic impulses, noise, etc.) is often one to three times the number of triggers on events of seismic interest, the amount of time attributed to these events is only about 15% of the total time. An examination of the test records included in this report which show the event detector in conjunction with the seismic signal and the detected envelope of the seismic signal will disclose its operation.

The nominal power consumption of the event detector is 10 mw.

5. <u>Axis Crossing Counter</u>

The data compression scheme requires, in addition to the detection of the envelope of the seismic signal, a count of the number of zero axis crossings of the seismic signature during each sampling interval. The axis crossing counter circuitry performs this function by keeping a running binary count of the number of positive zero axis crossings in a register and converting this digital number to an analog voltage to be sampled at a 1 sample/sec rate during the triggered mode of operation.

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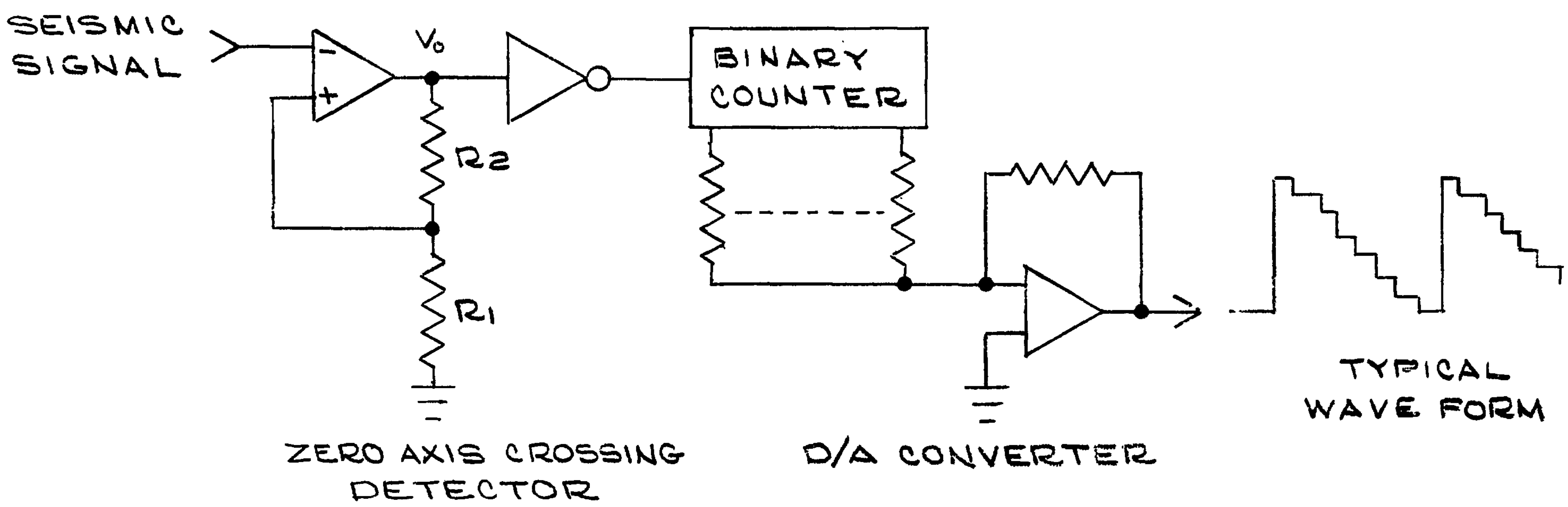
*Seismic signal telemetered from Glamis, California to the Seismological Laboratory in Pasadena. The seismometer is a 1 sec. instrument with the velocity response peaking at 4Hz.



$$V_H = \frac{2 R_1 V_o}{R_1 + R_2}$$

V_H = HYSTERESIS VOLTAGE
V_o = PEAK OUTPUT VOLTAGE

AXIS CROSSING COUNTER

FIGURE 16

Figure 16 is a block diagram of the system. The zero-axis-crossing detector is a comparator with positive feedback to produce a hysteresis about zero volts equal to approximately two least-significant bits. This is to insure that zero axis crossings less than the system resolution will not be detected.

The output from the comparator is passed through an inverter to increase its rise time and then into the binary counter. The counter will count the axis crossings up to a maximum of 2^5, reset to zero and continue counting. Binary weighted resistors from the first five bits in the binary counter are used in conjunction with a current summing operational amplifier to convert the binary number to an analog voltage. Scaling of the D/A converter is such that the output level is 0 to + 5 v and it is anticipated that no further scaling is necessary.

The axis crossing counter circuitry has an average power consumption of 8 mw.

6. Command Decoder

The command decoder is designed to accept discrete command pulses on five command lines. It produces quantitative commands on 19 lines with the ability of performing 25 quantitative controls. The command decoder consists of shift registers with set-up logic so that only one stage of the register may contain a true state. Sequential pulses on the command line control the position of this true state in the register. The number of quantitative output control lines is equal to the number of stages in the register. Since one of the legitimate register states is with no stages true, each register may perform one more control function than the number of stages it contains.

After initial power turn on, each of the register stages will be in a random state. Therefore it is necessary to pulse each discrete command line a sufficient number of times to insure proper set-up of the registers and then to follow an orderly procedure of giving a command and observing the system response to determine the state of each of the registers. An alternative to this approach is for the lander to supply a "clear" pulse which will set all the registers to zero.

Table 3 lists the discrete and quantitative command lines.

For convenience, the command decoder also contains the logic for OR-ing the outputs of the event detectors. These outputs along with the suppress/override command create line T, the trigger line used for controlling the operation in the normal and moderate data sampling modes.

The command decoder is designed around complementary MOS logic. Its quiescent power consumption is negligible.

Table 3

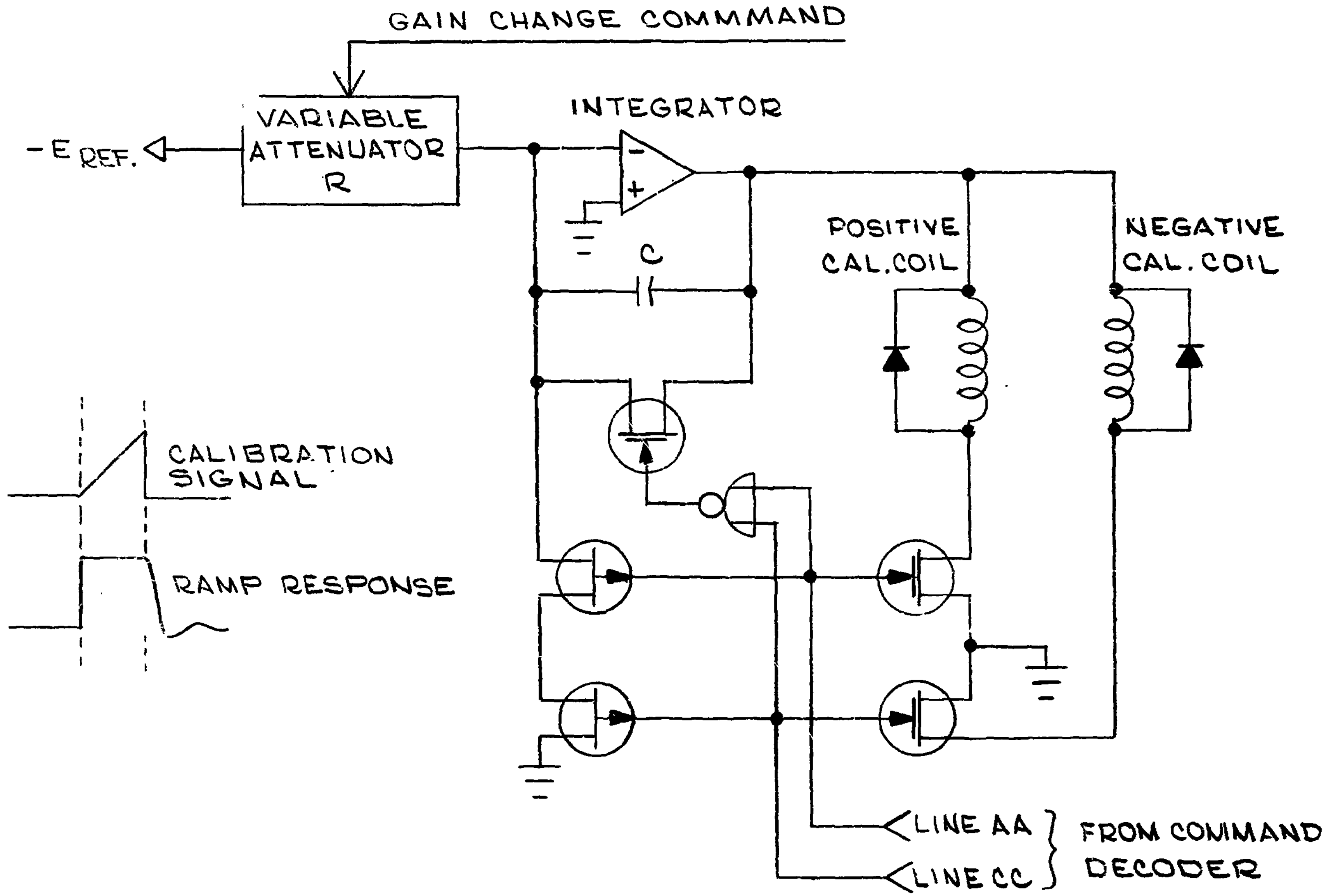
Command Decoder Lines

Discrete Command Line	Quantitative Command Line	Function	
Filter Frequency	A	4 H_3	Filter Frequency
	B	2 H_3	
	C	1 H_3	
	D	.5 H_3	
Gain Change	E	-6 db	Amp. Gain
	F	-12 db	
	G	-18 db	
	H	-24 db	
	J	-30 db	
	K	-36 db	
Event Detector Sens.	P	X8	Event Detector Sensitive
	Q	X12	
	R	X16	
	S	X20	
Event-Detector Control	T	Trigger Line	
Calibrate	AA	To be specified	
	BB		
	CC		
	DD		

7. Calibration Function Generator

Each sensor contains two calibration coils which, by application of a voltage, are capable of applying forces in opposite directions to the suspended system for the generation of calibration output signals. These signals are used as a verification of the instrument performance and a measure of instrument tilt. A convenient method of calibration is to apply a step of voltage to the cal-coil, producing a pulse output which is the step response of the instrument. Because of the 0.25 second natural period of the suspended mass, however, the harmonic content of the step response is such that it can only be observed during the high data rate mode of operation, precluding calibration by this means during the normal or triggered modes.

To circumvent this problem other means of calibration have been studied. One which appears promising is the application of a linearly increasing voltage ramp to the cal-coils. The output (ramp response) of the system will be a voltage step proportional to the slope of the ramp, and the position of the suspended system relative to the cal-coils. The duration of the output step is determined by the dynamic range of the ramp generator, and may be made sufficiently long so as to be observed in the triggered mode of operation. If the calibration signal is applied during the normal, averaging mode, the event detector will sense the output and switch the system to the triggered mode. When the ramp is terminated by resetting it to zero, the output will display the step response of the instrument, and this may be observed in the high data rate mode.



CALIBRATION CIRCUIT

FIGURE 17

A proposed calibration circuit is shown in Figure 17. It consists of an integrator for generating the ramp, and FET switches for controlling the duration of the ramp and its application to either cal-coil. The slope is a function of the integrator input resistor which is adjusted by the gain change command to keep the calibration signal scaled to the amplifier gain. The ramp would be initiated and terminated by Earth command. If the ramp is allowed to continue until it peaks out at the maximum output of the integrator, the slope of the ramp may be ascertained, and the amplifier gain selection verified.

8. Analog Scaling

The seismic data processor is designed to have a 40 db dynamic range with a bipolar signal of plus and minus 10 v peak. This gives a system resolution of .01 x 10 v = .1 v peak. Scaling circuitry for the interface with the lander systems has not been designed; however, it would consist of one operational amplifier for each analog channel. If the lander system is a conventional 0 to + 5 v design this operational amplifier must have an output:

$$e_o = -.25\ (e_{in} - 10\ v)$$

assuming that operational amplifier is in the inverting configuration.

The -10 v constant must be obtained from a reference supply. As determined from the analysis of the voltage offset of the system, this circuitry must have an offset voltage no greater than 15 mv. If 5 mv of this is attributed to the operational amplifier, then the reference power supply must contribute no more than 10 mv to the output. The reference voltage must therefore be -10 v ± 20 Mv (± .04%) nominally. Similar analysis for the worst-case gives the result that the reference power supply must be -10 v ± .2 v (± .1%) over the temperature range of -55°C to +55°C.

9. Digital Scaling

The seismic data processor digital system is designed around complementary MOS logic operating from the plus 14 volt power supply. The logic levels are:

Logic true - + 14 V

Logic false - 0 V

Scaling to mate with the lander system has not been designed. It is necessary to scale five command lines and one timing line received from the lander, and to scale the trigger line going to the lander. Because the propagation time of these functions need not be very short, it is anticipated that scaling circuitry requiring a power consumption of only about 1 milliwatt per line may be designed.

D. Parts Selection

1. Design Philosophy

The system is designed for an operating temperature range of -55°C to + 55°C using hermetically sealed components with controlled specifications over the temperature range of -55°C to + 125°C. The exception is the preamplifier first stage, a commercially available operational amplifier with its specifications controlled from -25°C to + 85°C.

The two parameters most affecting dynamic range are system noise and output offset voltage. Both of these are at a maximum when the system amplification is at a maximum (attenuator at 0 db). The noise is a function of the preamplifier first stage and accounts for the selection of the Analog Devices, Inc., Model 153K operational amplifier. The output offset voltage is a function of the offset voltage and current of the operational amplifier and Igss leakage of the FET switches used in the system. It is kept within bounds by careful design.

The basic design guideline was to keep the sum of nominal system noise and offset voltage appearing at the output of any analog channel to less than -40 db below the full scale output of plus and minus 10 volts (or less than 100 mv before system scaling at 25°C). In addition it was hoped to keep the worst-case sum of system noise and offset voltage to less than -34 db below full scale output (200 mv) over the temperature range of -55°C to + 55°C. The nominal design was based on the manufacturer's published specifications using the worst-case data at 25°C.
The worst-case design was based on the worst case data specified at -55°C and + 55°C. If the +55°C worst-case value was

not given or easily computed, the + 125°C worst-case value was used.

For a digitizer with a resolution of one part in 2^7 (i.e. seven bits), the least-significant bit (LSB) would have a value of 78 mv (before scaling). Since the maximum worst-case data at 25°C was used instead of the typical data, and because of the conservative worst-case design over the full temperature range of -55°C to + 55°C, it is felt that the system will have a nominal sum of noise and offset voltage less than 1 LSB (78 mv or -42 db below full scale), and a worst-case sum of noise and offset voltage less than 2 LSB (-36 db). Our tests have verified this for the nominal values.

2. Parts Selection Rationale

The following is a list of the electronic parts used in the seismic data processor, the manufacturer, and critical specifications or rationale for using each:

Operational Amplifier

153K - Analog Devices	Selected for its very low noise (RTI) over the bandwidth of .1 to 10 Hz. Very low power consumption, .5 mw at 2.7 v.
NH0001 - National Semi-conductor	Low noise (RTI) and low power consumption, 2 mw at ± 14 v.
RM 4132 - Raytheon	Discussed in separate section.
LM108 - National Semi-Conductor	Low noise (RTI), low power consumption, 9 mw at ± 14v, improved offset current over the NH0001, 0.4 na -55°C to + 125°C.

Junction FET

2N5116, P Channel Union Carbide	4 v maximum pinchoff voltage. 150 ohm, maximum R_{on}.
2N4393, N Channel Union Carbide	3 v maximum pinchoff voltage. 100 ohm, maximum R_{on}.

Junction Bipolar Transistors

2N2484, NPN	h_{FE} = 100 (min) at I_c = 10 μa
2N2605, PNP	h_{FE} = 100 (min) at I_c = 10 μa

M O S FET

MFE3002, N. Channel Motorola	Low threshold voltage, 3 v maximum. 100 ohm R_{on} maximum.

M O S Logic

CD 4000 Series - RCA	Low static power consumption, high noise rejection, 6 v typical. Operation directly from ± 14 volts; high voltage swing, capable of driving the FET switches directly without additional switch drivers.

Diodes

1N3605 - G.E.	Not critical, any good silicon planar will suffice.
LVA5.6A - TRW	A zener diode with a sharp knee at low voltage.

Tantalum Capacitors ... All values greater than 8 mfd.

350D series - Sprague	Stability and good low temperature operation.

Filter Capacitors...Values between .0047 and .56 mfd.

X483 Series - TRW	Very stable metallized polycarbonate, hermetically sealed, very low volume and weight.

Frequency Compensating Capacitors...100, 39, 22, and 10 pfd.

VY Series - Vitramon	Not critical.

Resistors...less than 2 Megohm

RN55, RN60, RN65	1% tolerance, hermetically sealed.

Resistors...Greater than 2 Megohm

TS Series - Allen Bradley	2% tolerance, hermetically sealed.

Resistors...Wirewound

100 Series - Micro-ohm	Low noise, low temperature coefficient, small size.

Substitution of RM 4132

The data processor was originally designed totally around the NH0001 operational amplifier (with the exception of the pre-amp first stage) because of its low power consumption, low noise and wide dynamic range. The introduction of the LM108 operational amplifier with several improved specifications, particularly input-offset current, allowed one of the critical functions, the programmable filter, to be redesigned resulting in a reduction in size, weight, and output-offset voltage at a slight sacrifice in power consumption.

The specifications of the RM4132 operational amplifier, introduced late in 1969, indicate that a still further reduction in power consumption, size, weight, and parts count, may be achieved by directly substituting it for all the remaining NH0001 amplifiers.

This unit has improved input-offset current over the NH0001, is internally frequency compensated, and is available in a flat package. The result will be an elimination of approximately 100 components, a weight savings of about 5 oz., and lower output-offset voltage in the absolute value circuits. In addition, a slight redesign of the variable delay in the event detector may take advantage of the 30 volt differential voltage of RM4132 to improve the ratio of the maximum to minimum delay.

The schematics supplied with this report do not reflect the incorporation of the RM4132 into the design because of its unavailability until early 1970.

3. Special Testing

153K Operational Amplifier

These units were tested in a prototype preamplifier for noise referred-to-the-input. Most units had a noise level of 0.4 microvolts peak-to-peak or less; of six units, all were acceptable.

NH0001 Operational Amplifier

These units were tested for noise (RTI) in the same manner as the 153K operational amplifier. Out of 50 units tested the results were as follows:

15% ≈ 1 microvolt peak-to-peak

78% ≈ a few microvolts peak-to-peak

8% ≈ 100 microvolts peak-to-peak

The units with the lowest noise were used in the preamplifier and amplifier stages. The units with the greatest noise were used in the absolute value circuits.

2N4393 FET

An analysis of the worst-case contribution to the output-offset voltage by the Igss leakage of the 2N4393 field-effect transistors used as switches in the programmable filter indicates that they must be selected. The manufacturer's specifications give a maximum Igss at 25°C of 100 pa. The design requires a maximum Igss at 25°C of 40 pa. The typical data given for the 2N4393 indicate, however, that this selection should not be a problem.

E. Instrument Specifications

1. Sensor Specifications (nominal)

Mass (weight at earth G)------------------------25 gm ± 1 gm

Period--0.25 sec ± 10%

3 components must be matched to ± 1%

Damping --.5 - .7 of critical

when shunted by load equal to internal resistance.

Three components must be matched to ± 1%. Open circuit damping must not exceed 1% of critical.

Transducer Coil

Must have maximum packing density of wire; 11000T ± 1%, #50 wire, 30,000 ohms.

Generator Constant

To conform to above.

Earth G Operation

Both horizontal and vertical components must be operable at Earth gravity. The vertical component suspension must be capable of supporting the mass assembly when the sensitive axis is parallel to the local gravity vector, and when so operated the characteristics must not deviate from the nominal by more than 5%.

Spurious Modes of Vibration

There shall be no vibratory modes, other than the principle response mode, of less than 100 Hz.

Cross Response

Individual sensor components must be oriented in the package so that cross-response is less than 2% when the suspended systems are mechanically centered, and the response plane of the horizontal unit is normal to the local gravity vector.

Temperature Environment Operation Capability

The sensors shall be capable of operation in the temperature range of -100°C to + 100°C, with mass displacement not to exceed ±1/4 mm.

Electrical Circuit

Must be as nearly as possible all copper. Where dissimilar junctions occur they must be in opposing pairs, and as nearly as possible located for minimum temperature differences. All insulation must be of highest quality.

Mechanical Materials

Select materials for compatible coefficients of thermal expansion, light weight, and strength. Use of isoelastic suspension materials will reduce mass migration of the vertical component due to temperature change.

Dimension and Weight

Minimal.

Electronic Specifications

Dynamic Range------------------------------- 40 db

± 10 V signal 'efore scaling

System overload recovery time---------------- negligible

Thermal Control---------------------------- -55°C to + 55°C

Power required------------------------------ 225 mw nominal

404 mw worst-case

Data Outputs

(a) Normal mode

3 channels of filtered and averaged data
4 samples/minute/channel

(b) Triggered mode

6 channels of compressed data
1 sample/sec/channel

Table 4

System Noise and Offset Specification*

	Nominal	Worst Case	Measured
Amplifier Noise (RTI)	0.4 μVP-P	--	0.4 μVP-P
Offset Voltage			
Amplifier at 10^5 gain	50 mv	62 mv at +55°C	20 mv
Filter	10 mv	33 mv at +55°C	10 mv
Absolute Avg. Crt.	4 mv	10 mv at +125°C	
		100 mv at -55°C	
	(7 mv)**	(8 mv at ±55°C)**	
High data rate channel			
Amp. and Filter	60 mv	95 mv at +55°C	30 mv
		80 mv at -55°C	
Normal or triggered channel			
Amp., Filter, Abs. Crt.	64 mv	105 mv at +55°C	35 mv
		195 mv at -55°C	
	(67 mv)**	(103 mv at ±55°C)**	

*For the analog system prior to scaling (± 10 V bipolar signal)

**Value with the RM 4131 substituted for the NH0001

Table 5

Electronics Power Requirements

	Function Nominal	System Nominal	System Worst Case
Pre-amp, Amplifier	10 mw	30 mw	72 mw
Programmable Filter	34	104	104
Event Detector	10	30	90
Absolute Value Circuit	5	15	45
Axis Crossing Counter	8	24	36
Command Decoder	--	--	--
Analog Scaling	15	15	50
Digital Scaling	7	7	7
		225 mw	404 mw

(c) High data rate mode

3 channels with 0.1 to 4 Hz bandwidth
20 samples/sec/channel

F. Summary of Test Results

Various design models of the Viking Seismometer were constructed and tested for period, damping, generator constant, tilt sensitivity, etc. The mass caging system was tested and found to function properly. A vertical unit was operated successfully over the temperature range of -110°C to + 80°C. Results of shake table and calibration system tests are shown in Figures 4 and 5.

The construction and testing of electronic functions proceeded at two levels. Breadboards, using readily available components and convenient construction techniques, were built to verify the proper operation of each function. Prototypes, using flight selected components mounted on 4 x 5 inch printed circuit boards, were constructed of as many of the functions as time would allow and were tested for nominal accuracy, noise, voltage offset, and dynamic range.

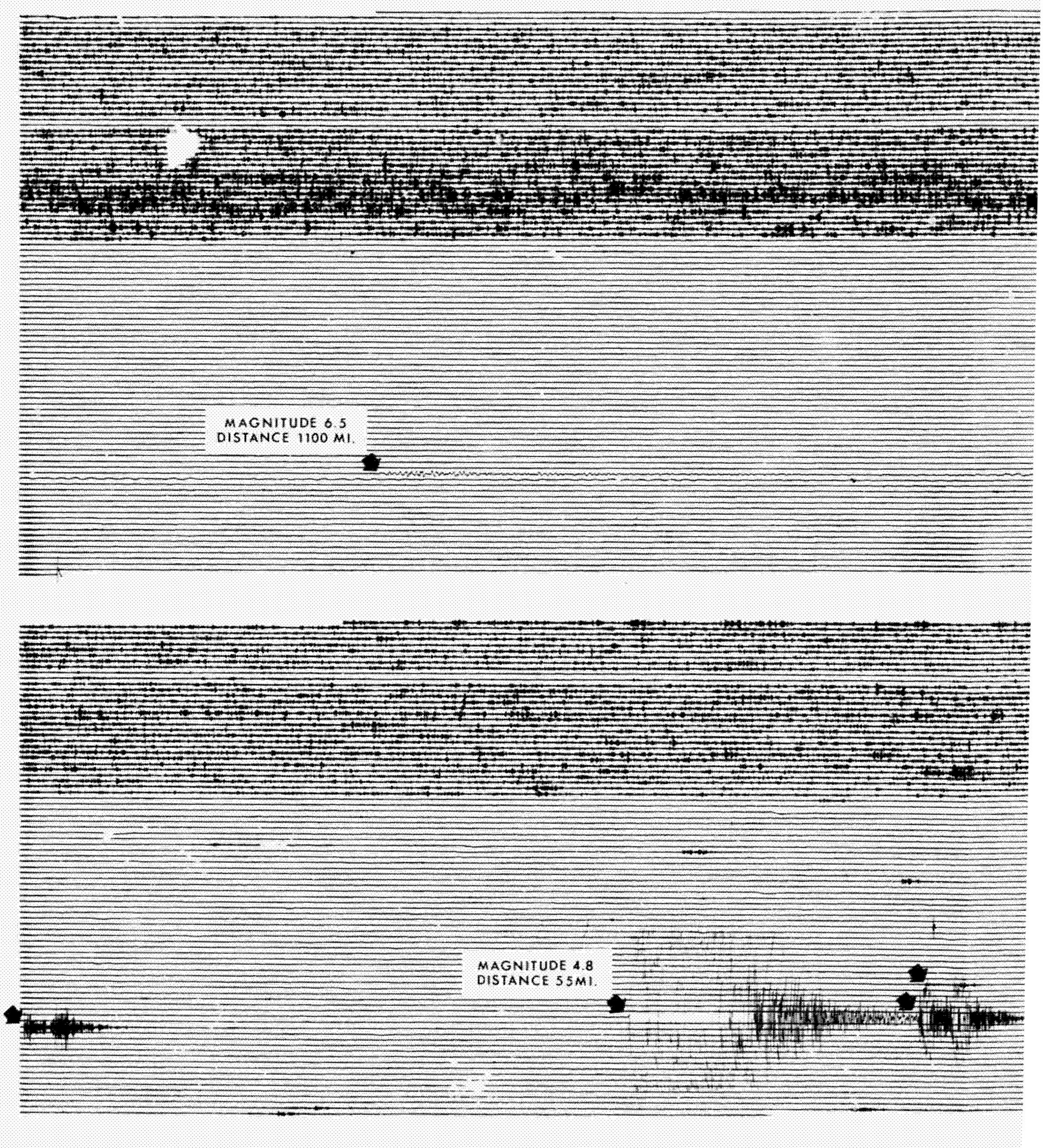
A breadboard pre-amplifier was operated continuously for more than 8000 hours. The only observed change in its characteristics was that the noise, referred to the input, improved somewhat.

The results of measurements on prototype functions are shown in Table 4. A prototype combination of pre-amp, amplifier, and 4 Hz filter was operated with the Viking seismometer for approximately 1500 hrs. Figure 18 shows typical seismograms from this test.

A breadboard system consisting of the event detector, envelope detector, filter, and axis crossing counter was operated for approximately 1500 hours with a standard seismometer (1 sec period with the velocity response peaked at 4 Hz); typical results from these tests are shown in Table 2, Figure 15, and Figures 19 through 23.

A short discussion of plates A though O shown in Figures 19 through 23 is in order. Displayed in each of these plates is the seismic signal, its detected envelope, the running positive axis crossing count and the signal from the event detector showing (by a positive step, with the exception of plate A) that portion of the record which caused it to be triggered. A variety of local events are shown (plates A, B, D, M, and others) along with some teleseisms (plates G and O). Plates E and F are simulated surface waves demonstrating the operation of the envelope detector and event detector on this type of signal.

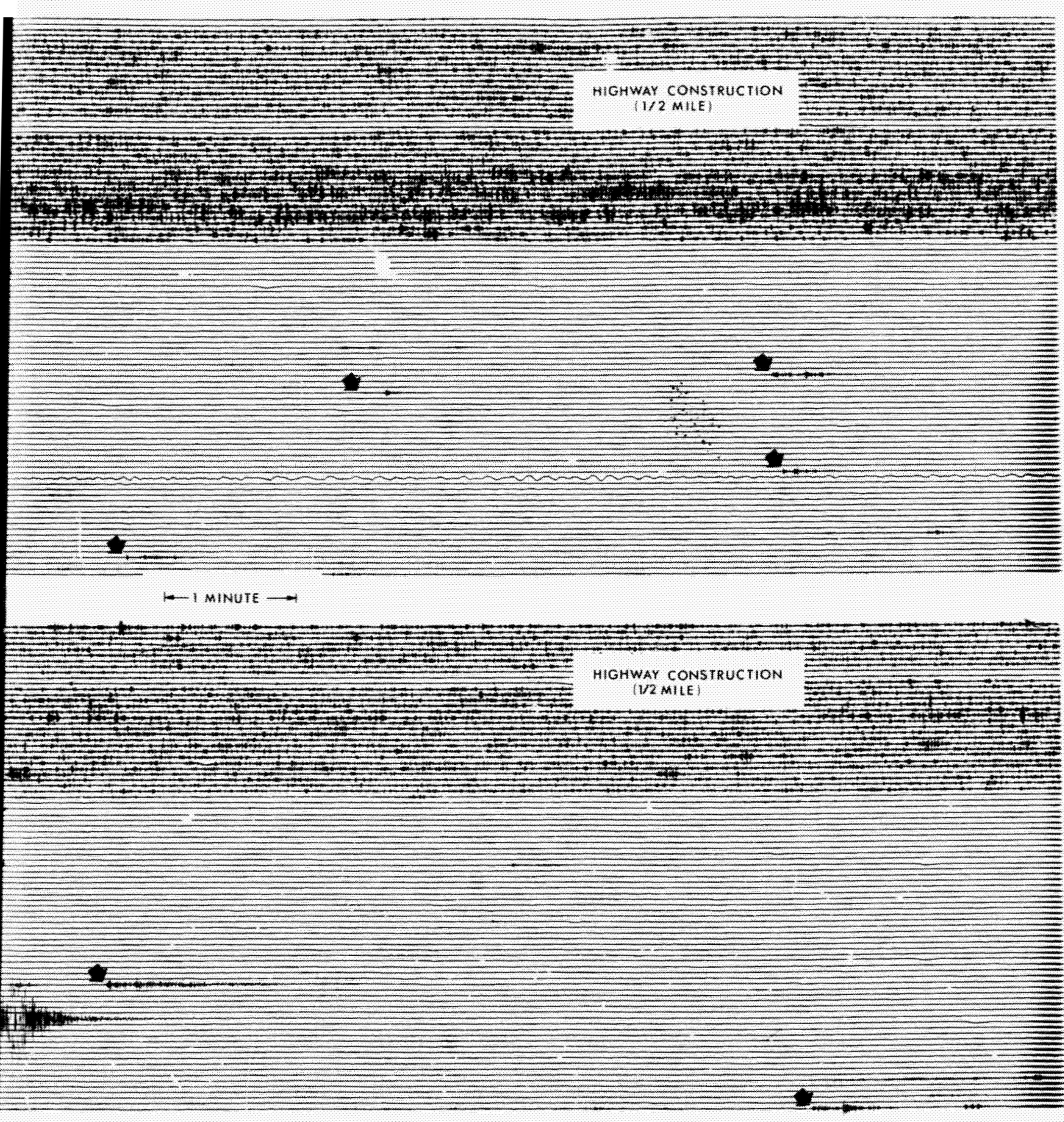
An examination of the running axis crossing count will disclose that its average slope is a measure of the prevailing harmonic content of the seismic signal. For instance, the microseisms of plate O are predominately of 1 second period; those of plate N, 0.5 second period, and the irregular nature of the slope in plate M is due to the presence of large six-second microseisms. In addition, an abrupt change in the slope at the onset of an earthquake is apparent in most of the plates. For this system the slope of the P and S waves of local events is generally



= EARTHQUAKE

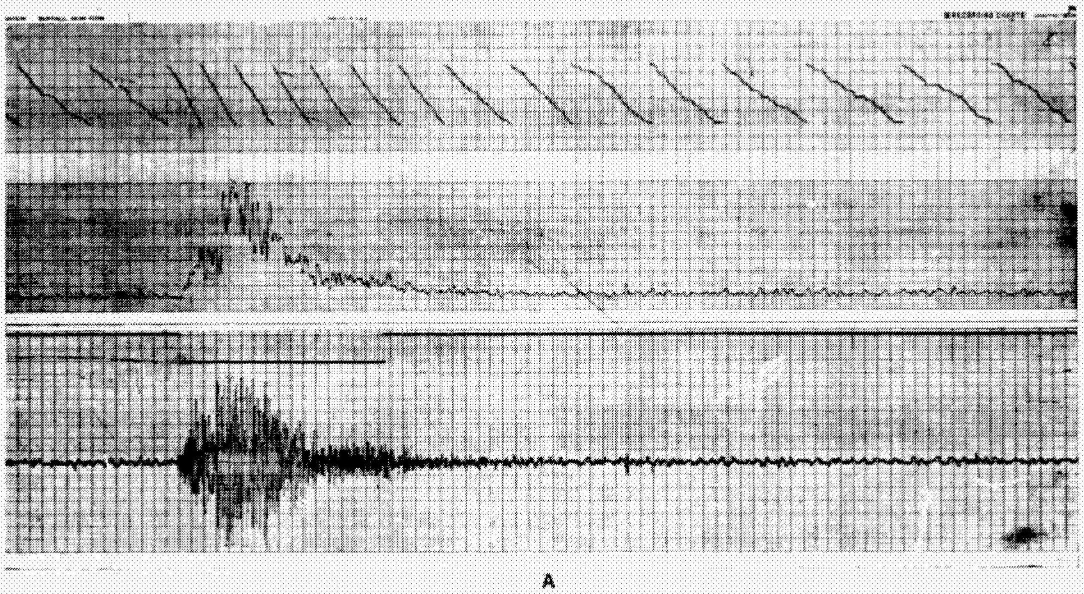
FOLDOUT FRAME

TYPICAL SEISMOGR

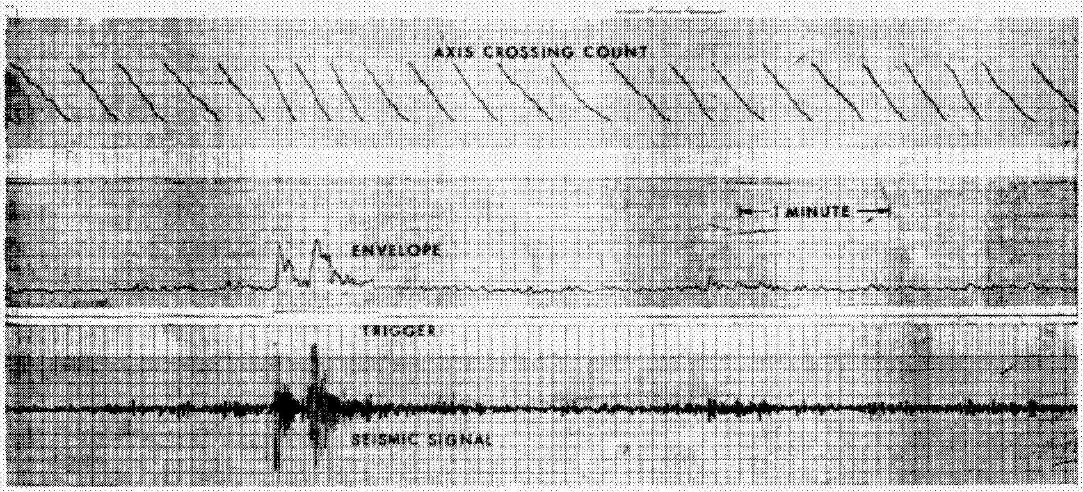


SMOGRAMS

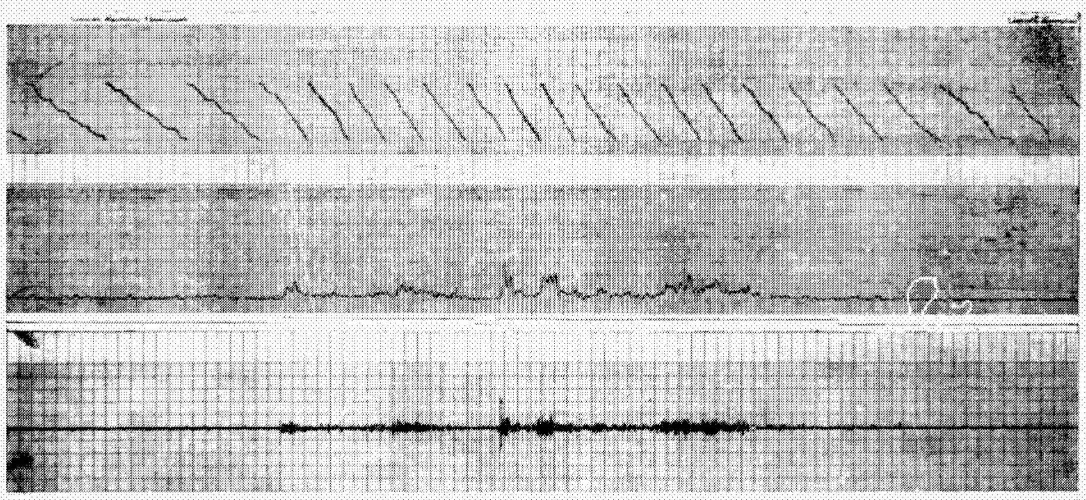
FOLDOUT FRAME 2



A

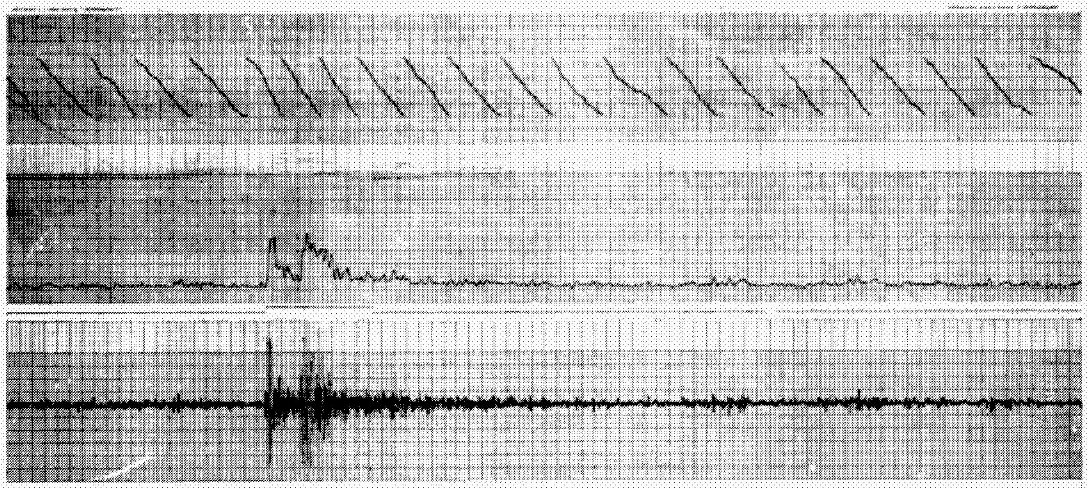


B

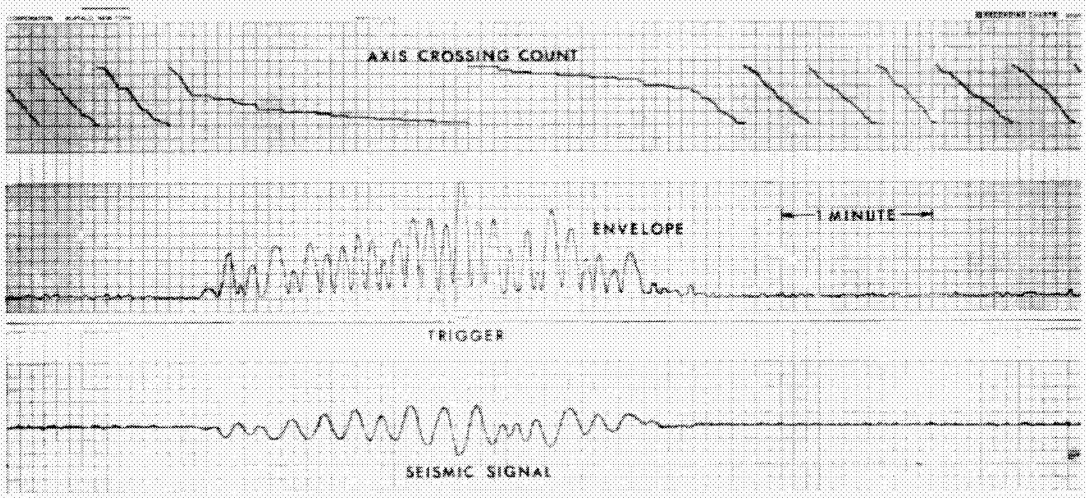


C

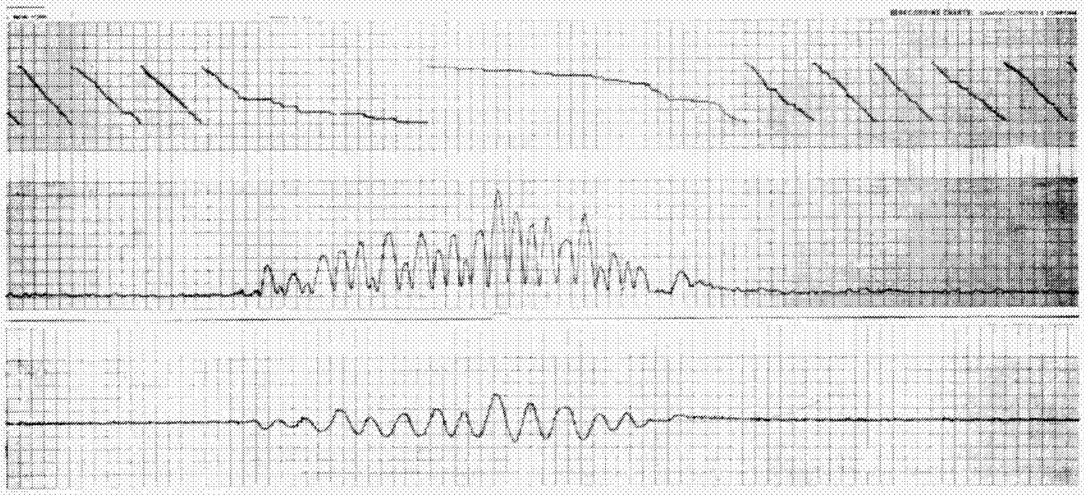
FIGURE 19



D

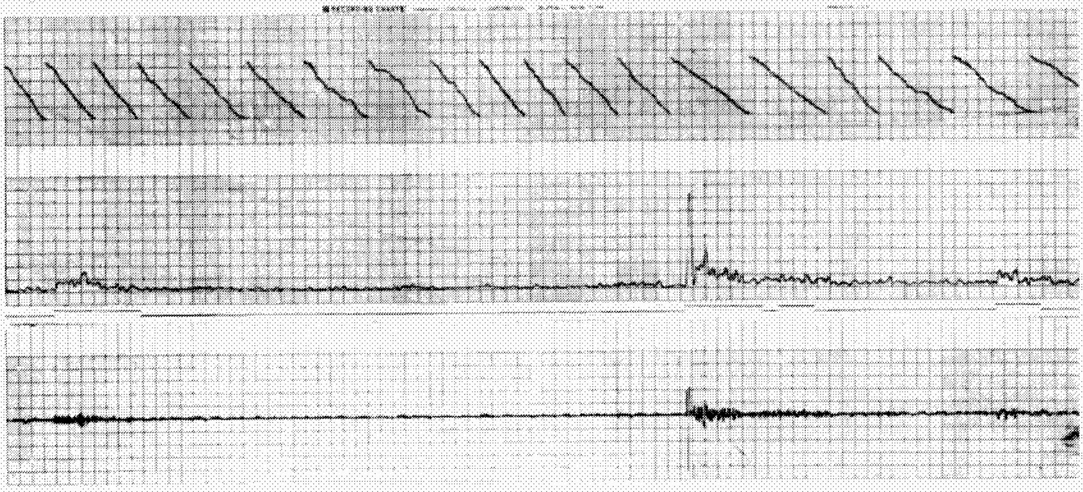


E

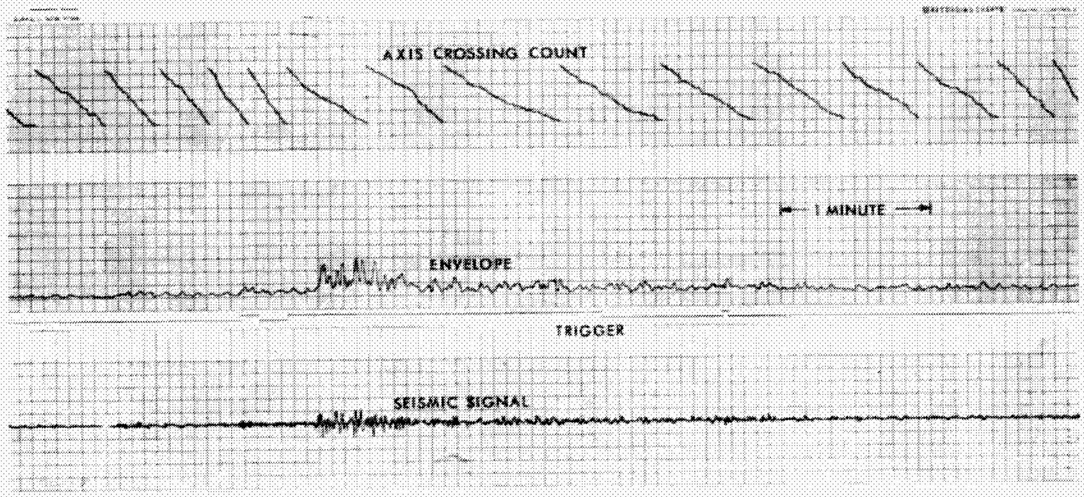


F

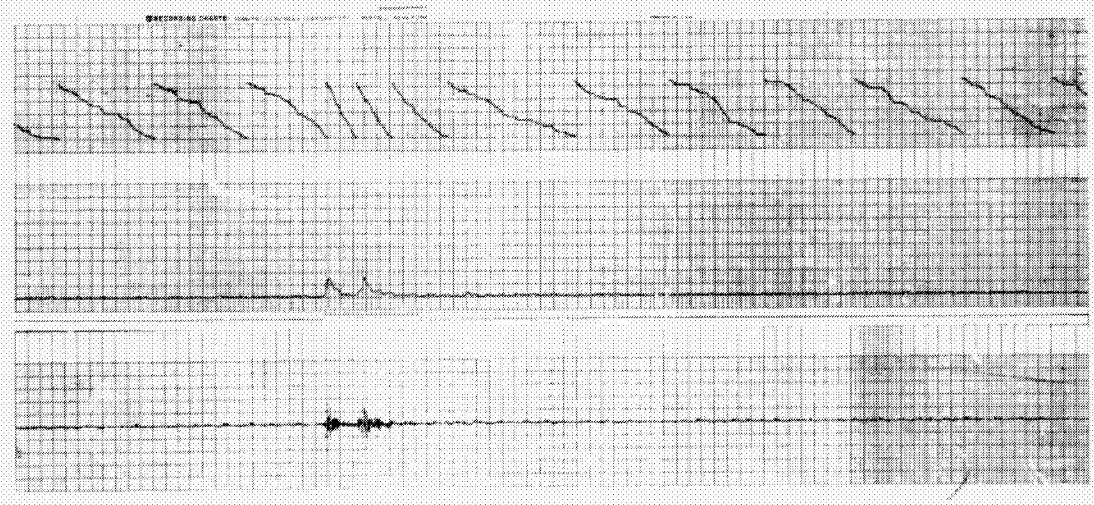
FIGURE 20



G

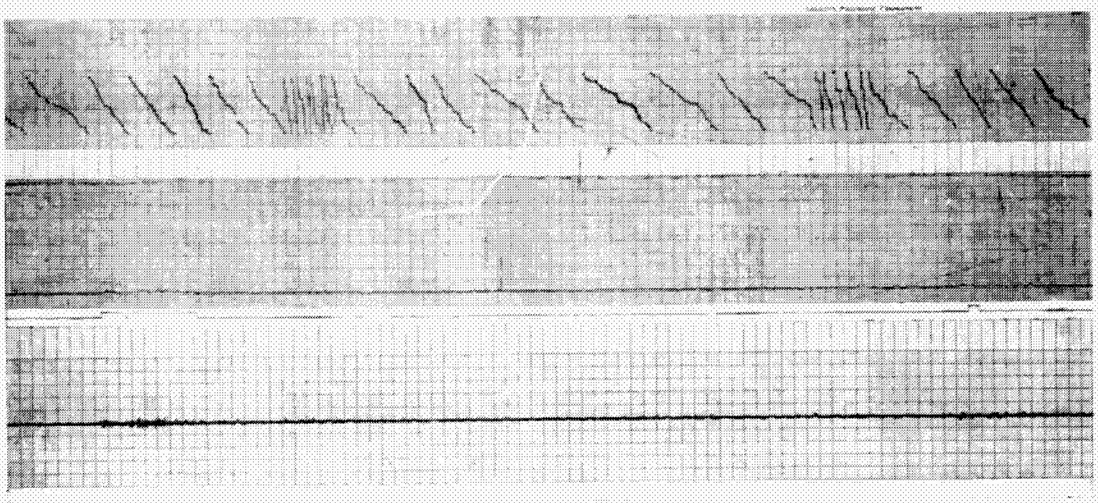


H

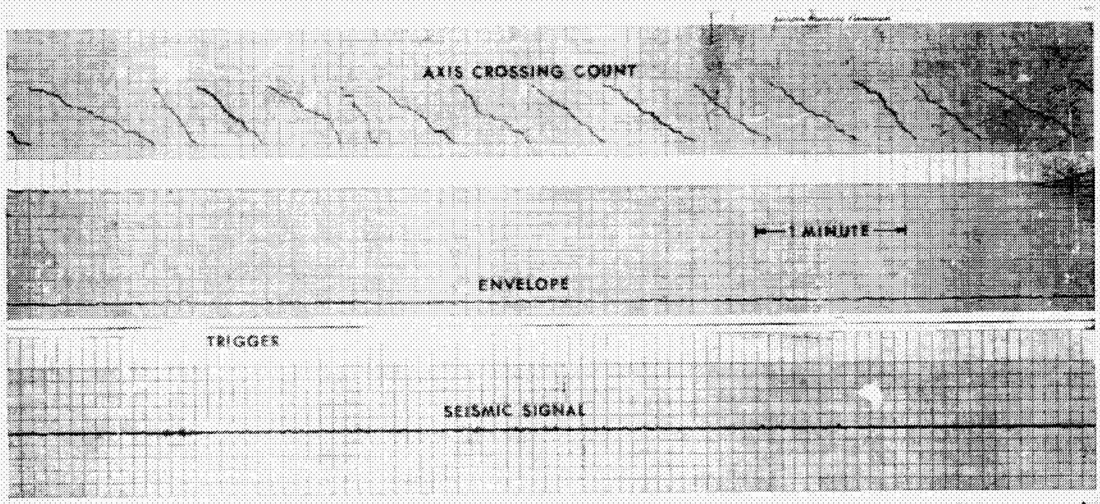


I

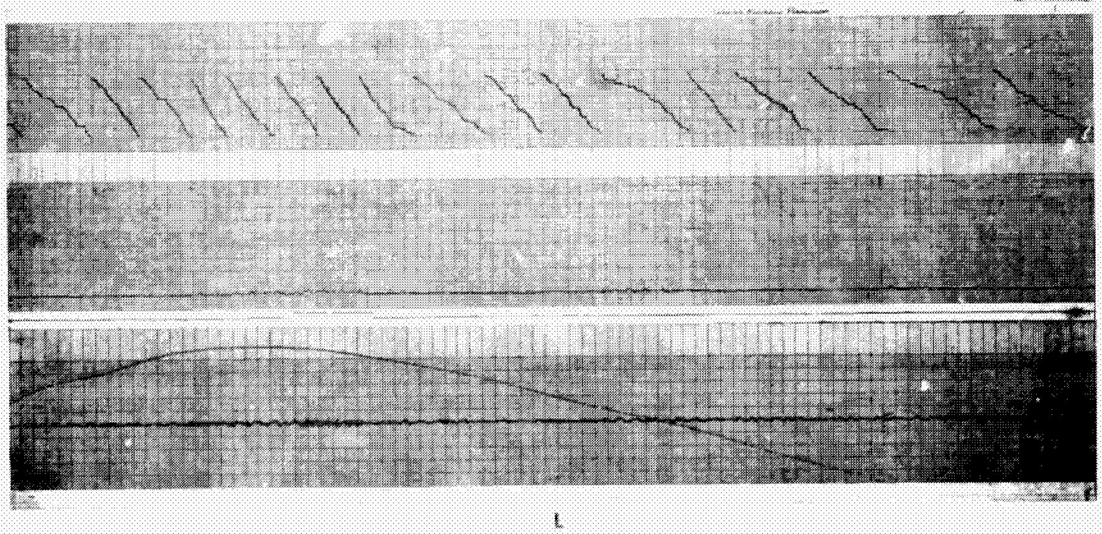
FIGURE 21



J

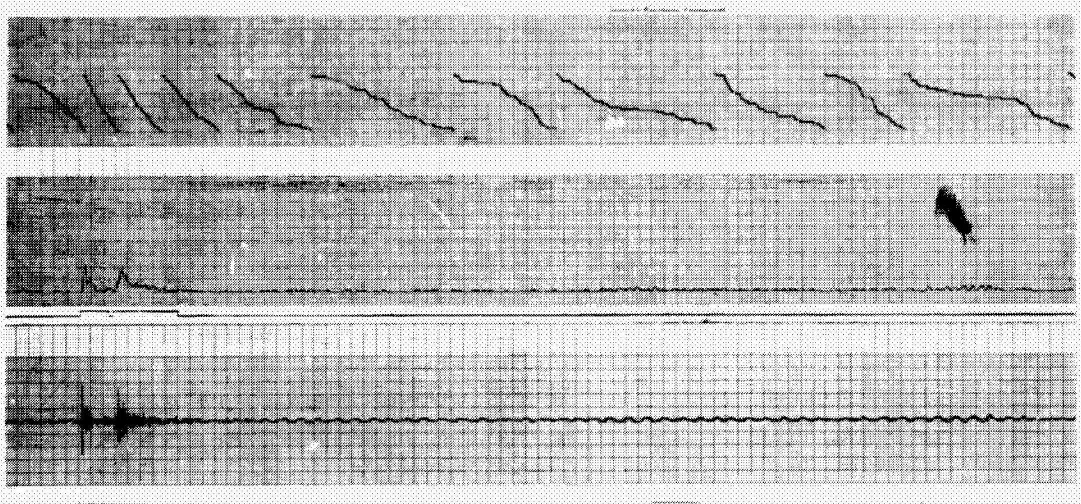


K

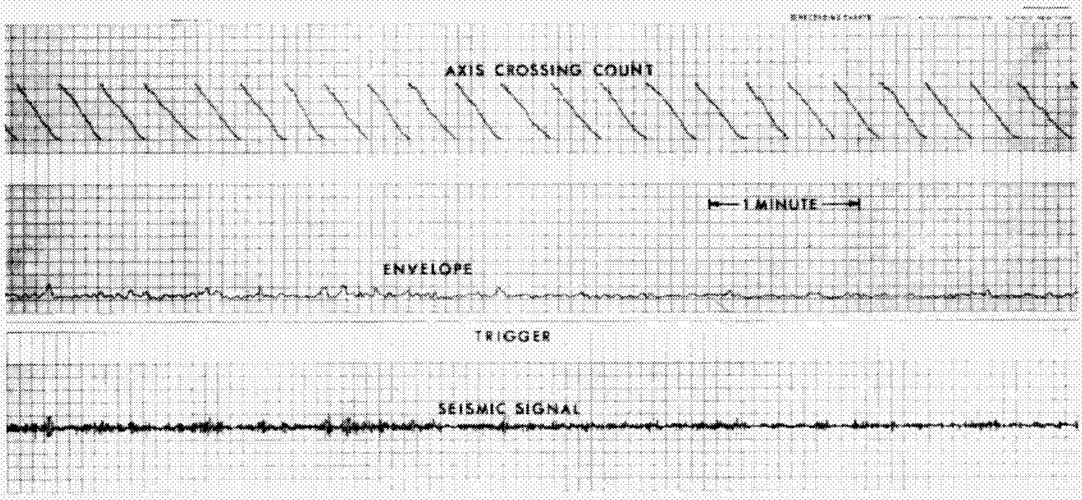


L

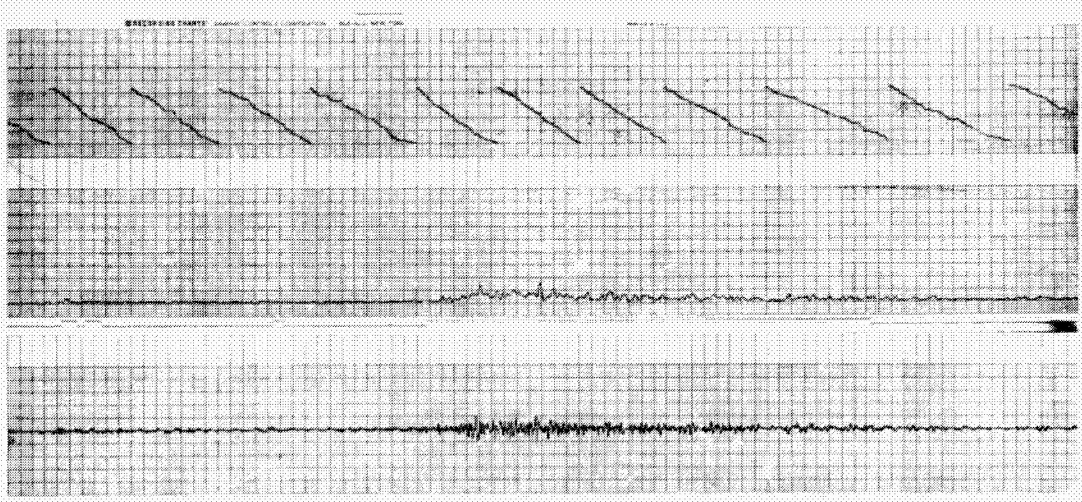
FIGURE 22



M



N



O

FIGURE 23

greater than that of the background because they contain higher frequency harmonics. It then gradually lessens as longer period waves arrive (Plates A and B). Teleseisms, however, produce an abrupt decrease in the slope relative to the background (Plates G and H).

The event detector in all of these tests was set to trigger at a signal ten times the average background level. This corresponds to 3 to 5 times the peak microseism level. The ability of the event detector to detect very small events is demonstrated in plates J, K, and L. Comparing the large difference in microseism level between plates K and L demonstrates the event detector's ability to accommodate such changes without excessive triggering.

G. Areas for Further Development

1. Sensor

Note that easily procurable parts and materials were used to expedite the system design philosophy; some of these must be replaced by more efficient elements in flight hardware.

a. Select material to reduce weight, increase rigidity, and for compatible temperature coefficients, etc.

b. Select Free-Flex pivots for uniformity and proper torsional constant to give correct period.

c. Study magnet selection - any increase in field strength would be an advantage.

d. Investigate possibility of increasing coil resistance to 10^5 ohms.

e. Increase coil width, decrease coil thickness and magnet gap to maintain G, while increasing mechanical dynamic range with uniform output.

f. Study seismometer output for low-rate calibration signal.

g. Improve magnetic material in cal-coil cores.

h. Increase cal-coil resistance and turns.

i. Study repeatable caging mechanism.

j. Perform vibration and shock tests when caged.

k. Study deployable case designs and cabling.

l. Further calibration tests, cross coupling tests, etc.

2. Electronics

Because the design of the electronic data processor was conducted concurrently with the design of the Lander, much of the information relative to the Lander interfacing, data acquisition, mandatory parts, etc., was not available, or was released too late to be incorporated into this design. The following is a partial list of areas requiring investigation, redesign, etc., based on the latest information available.

a. Design of the analog and digital circuitry for interfacing the data processor to the Lander.

b. Design of the calibration function generator.

c. Redesign of the command decoder based upon the qualitative commands which will be available from the Lander.

d. For improved resolution in determining the wave-arrival vector, the signal from each of the zero-axis-crossing detectors may be summed into a binary-weighted, eight-level analog voltage which is a running indication of the quadrant of the vector. This would require an additional analog channel to be sampled during the triggered mode and an increase of approximately 15% in the total number of bits required during this mode.

e. Parts approval from the prime contractor of parts not presently on the mandatory parts list, or substitution of parts from the mandatory parts list with appropriate redesign where this will not sacrifice the system performance, weight, or power requirements.

f. Packaging to meet the constraints of flight, i.e., weight, volume, environment, etc.

g. Testing to verify operation within the environmental extremes.

Appendix A

Computations and Derivations

A. Design values for the seismometer units are as follows:

Period (T_o) = 0.25 seconds = $\frac{2\pi}{\omega_n}$

Damping (ζ) = 0.5 of critical

Transducer Resistance = 25000 ohms

Circuit resistance for critical damping = 25000 ohms

Mass = 25 grams (weight at earth G)

1. Generator constant U; with 75% of the coil immersed in the magnet gap

$E = Bl\ V \times 10^{-8}$

where E = generated voltage

B = field strength in Gauss

V = velocity in cm/sec

$E = 2.5 \times 10^{3} \times 3.75 \times 10^{4} \times 10^{2} \times 10^{-8}$ = 94 volts/meter/sec.

Since V is lever magnified x 2, effective U as related to the center of percussion of the mass is 188 v/meter/sec.

For comparison, a mass-spring system having similar characteristics but without lever magnification requires a U of $\sqrt{4\pi\ fM\ CDR}$ = 178 v/meter/sec. where f is the natural frequency, M the mass in Kg and CDR the total circuit resistance for critical damping.

2. Comparison of calculated output with measured output of development instrument tested.

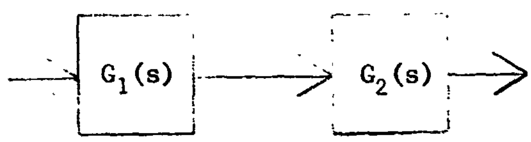
If ground amplitude is .002" p-p
ground frequency is 10 Hz
ground velocity will be 3.18×10^{-3} M/sec.

Since response of a .22 sec pendulum with 0.5 damping at 10 Hz frame excitation will be approximately 1.1 of frame amplitude, velocity of the coil in the field will be 3.5×10^{-3} M/sec. Therefore the generated signal will be $3.5 \times 10^{-3} \times 188 = 6.5 \times 10^{-1}$ volts or voltage across the amplifier input resistor (25000 ohms) will be 3.25×10^{-1} volts.

The measured value shown in Curve 1 is 3.2×10^{-1} volts. For the originally specified minimum surface amplitude resolution of 50×10^{-6} mm p-p, the output will be 3.2×10^{-4} volts at 10 Hz and 2×10^{-6} volts at 1 Hz. Thus with suitable amplifier input noise figure and gain adjustments, the minimum specification is easily met at 1 Hz or below, and exceeded for higher frequencies.

B. Synthesis of the Amplifier Transfer Function.

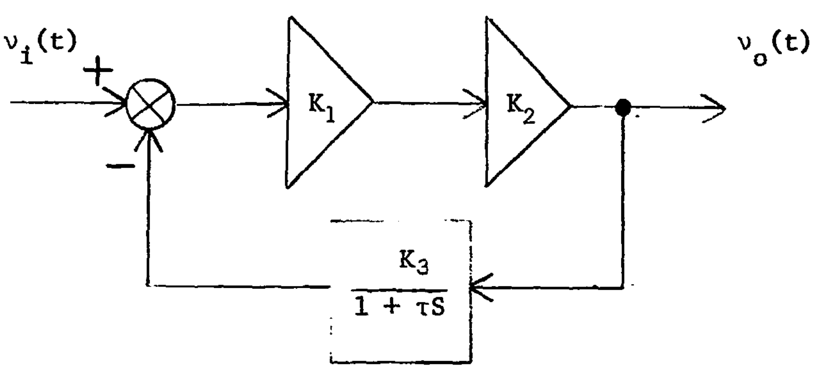
The amplifier consists of a pre-amp and an amplifier with the same transfer function



$G_T(s) = G^2(s)$

where $\quad G_1(s) = G_2(s) = G(s)$

The transfer function is most easily synthesized by considering the low-frequency and high-frequency portions separately. The low-frequency block diagram of G(s) is:



$$G(s) = \frac{K_1K_2}{1 + \frac{K_1K_2K_3}{1 + \tau S}} = \frac{K_1K_2\,(1 + \tau S)}{1 + K_1K_2K_3 + \tau S} \tag{1}$$

The maximum overall low-frequency gain, $G^2(s)$, as determined by the offset voltage of the first stage of the pre-amplifier is 200; therefore, the maximum low-frequency gain of G(s) is $(200)^{\frac{1}{2}}$.

For $S \to 0$

$$G(s) \to \frac{K_1K_2}{1 + K_1K_2K_3} = (200)^{\frac{1}{2}} \qquad (2)$$

The desired total mid-frequency gain is 10^5.

For $\tau S >> 1 + K_1K_2K_3$

$$G(s) \to K_1K_2 = (10^5)^{\frac{1}{2}} \qquad (3)$$

Solving for K_3, Equation 3 into Equation 2

$$K_3 = \frac{1}{14.8} \qquad (4)$$

Then

$$K_1K_2K_3 = 21.2 \qquad (5)$$

The mid-frequency gain breakpoint is at 0.1 Hz (ω_m = .628)

From equation (1)

$$G(s) = \frac{10^{5/2}\left(S + \frac{1}{\tau}\right)}{S + \frac{21.2}{\tau} + \frac{1}{\tau}} \tag{6}$$

The corner frequency breakpoint occurs at

$$S = \frac{21.2}{\tau} + \frac{1}{\tau}$$

Therefore,

$$\frac{21.2}{\tau} + \frac{1}{\tau} = \omega_m = 2\pi(0.1) = .628$$

$$\frac{1}{\tau} = \omega_L = 0.0283 \tag{7}$$

$$\tau = 35.4 \text{ sec}$$

The low-frequency transfer function is, therefore,

$$G(s) = \frac{10^{5/2}\ (S + .0283)}{S + .628} \tag{8}$$

The high frequency portion of the transfer function is synthesized by replacing the K_1 and K_2 amplifiers with first order low-pass filters of the form:

$$G_f(s) = \frac{K\omega_H}{S+\omega_H} \qquad \omega_H = 63.8 \tag{9}$$

The complete transfer function becomes

$$G(s) = \frac{(62.8)^2 \ 10^{5/2} \ (S+.0283)}{(S+62.8)^2(S+.628)} \tag{10}$$

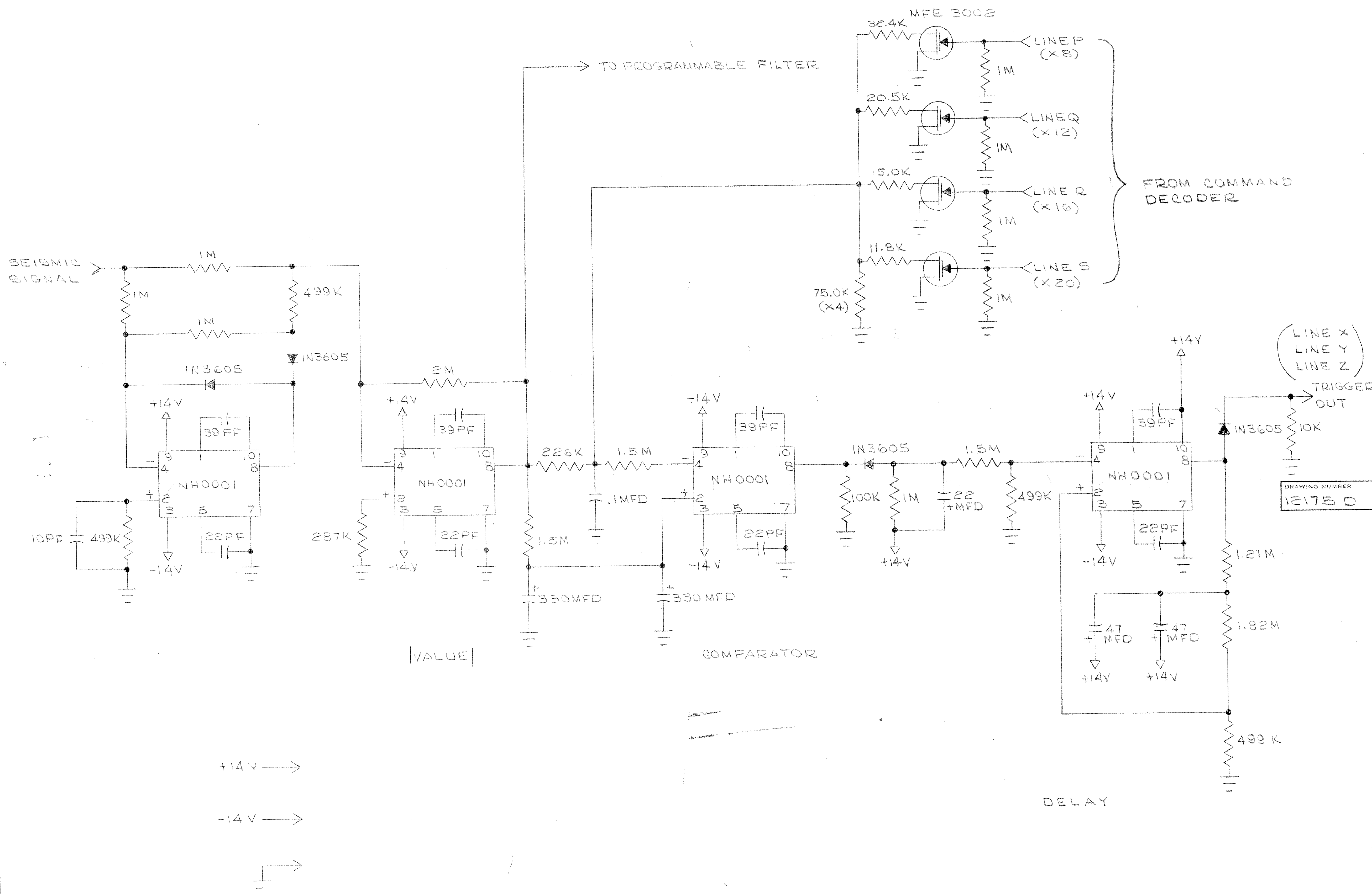
The transfer function of the pre-amp, amplifier combination is therefore

$$G^2(s) = \frac{(62.8)^4 \ 10^5 \ (S+.0283)^2}{(S+62.8)^4(S+.628)^2} \tag{11}$$

Appendix B

Drawings and Schematics Included with this Report

C12319	Viking Seismometer Horizontal Unit Assembly
C12320	Viking Seismometer Vertical Unit Assembly
C12321	Viking Seismometer Final Assembly
D12303C	Viking Seismic Data Processor Block Diagram
C12175D	Viking Seismic Event Trigger
D12300C	Viking Seismic System Programmable Filter
C12301C	Viking Seismic Axis Crossing Counter
B12304	Viking Seismic Amplifier
B12305A	Viking Seismic Absolute Average
B12306A	Viking Seismic Pre-amplifier
B12307A	Viking Seismic Amplifier Attenuator
C12308A	Viking Command Decoder



DRAWING NUMBER 12175 D

LTR	REVISION		DATE
D	CLAMP DELETED	BB	1-5-70
C	REVISED & REDRAWN	BB	12-1-69

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± ½°
CONCENTRICITY .005 T.I.R.
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY

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ENGINEER — DATE
APPROVED — DATE
CONTRACT

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE: VIKING SEISMIC EVENT TRIGGER

FINISH — SCALE — C — DRAWING NUMBER 12175 D

K+E ALBANENE® LA 1030 TRACING PAPER

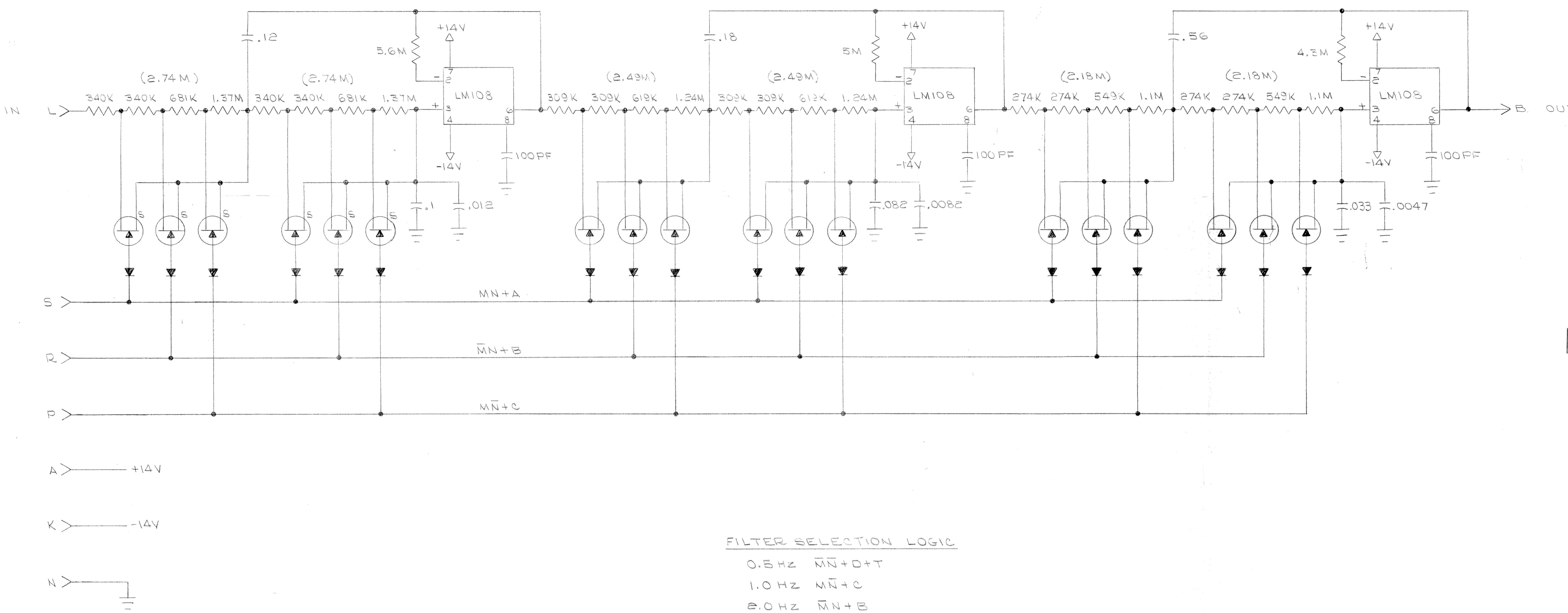
NOTES:

UNLESS OTHERWISE NOTED:

1. ALL CAPACITOR VALUES IN MFD.

2. ALL DIODES IN3605.

3. ALL TRANSISTORS 2N4393
   $R_{DS(ON)}$ = 100 Ω (MAX.).



DRAWING NUMBER 12300 C

FILTER SELECTION LOGIC

0.5 Hz	M̄N̄+D+T
1.0 Hz	MN̄+C
2.0 Hz	M̄N+B
4.0 Hz	MN+A

LTR	REVISION	DATE
C	REVISED & REDRAWN BB	2-9-70

UNLESS OTHERWISE SPECIFIED TOLERANCES: .000 ± .002; .00 ± .01; FRACTIONS ± 1/64; ANGLES ± ½°; CONCENTRICITY .005 T.I.R.; BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY

DRAWN DATE | ENGINEER DATE | APPROVED DATE | CONTRACT

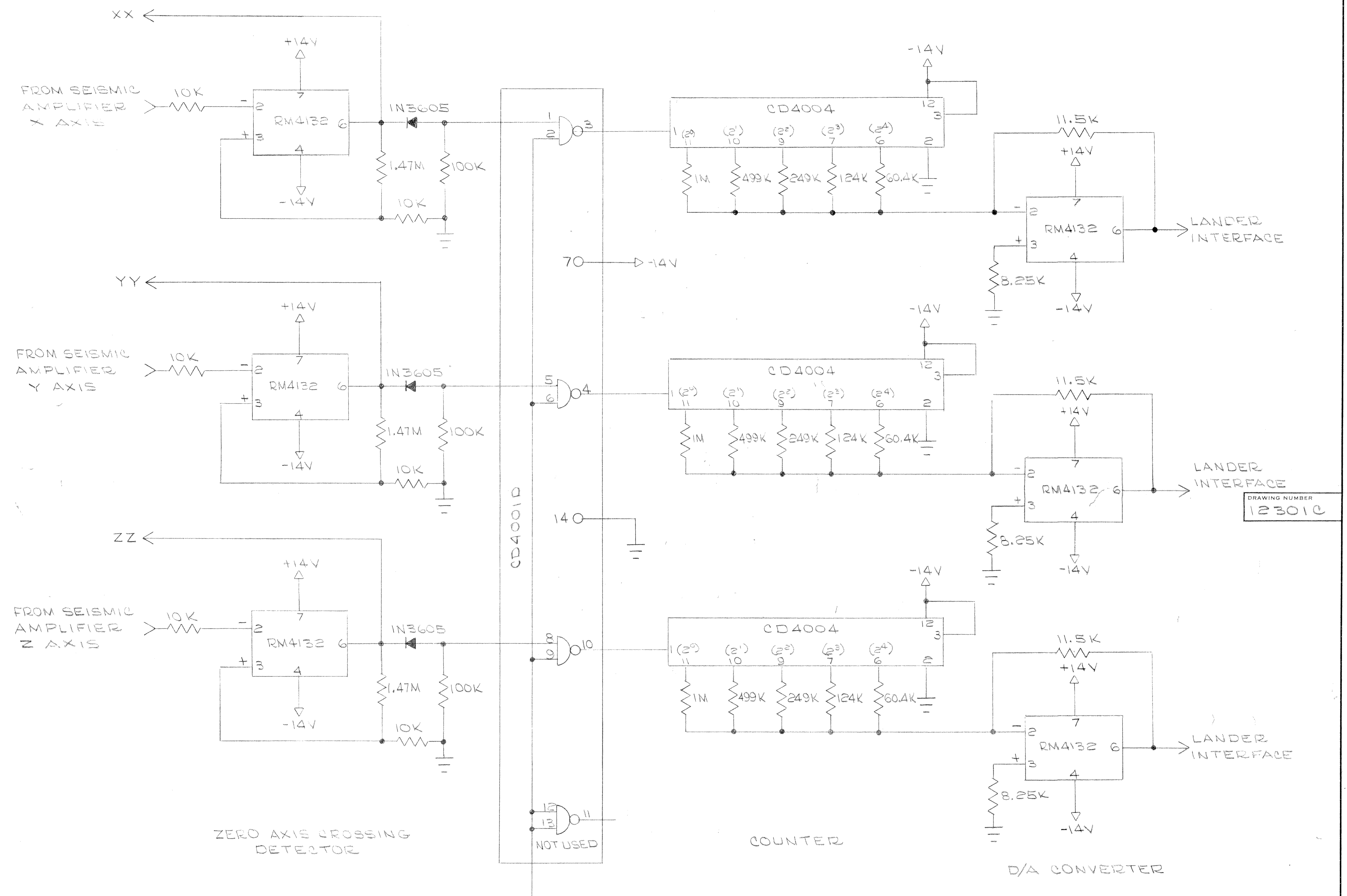
CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE VIKING SEISMIC SYSTEM PROGRAMMABLE FILTER

FINISH | SCALE | D | DRAWING NUMBER 12300 C

UNLESS OTHERWISE SPECIFIED TOLERANCES: .000 ± .002 .00 ± .01 FRACTIONS ± 1/64 ANGLES ± ½° CONCENTRICITY .005 T.I.R. BREAK SHARP EDGES AND REMOVE BURRS	DRAWN Barber	DATE 10-27-69	CALIFORNIA INSTITUTE OF TECHNOLOGY SEISMOLOGICAL LABORATORY	
	ENGINEER	DATE	TITLE VIKING SEISMIC SYSTEM PROGRAMMABLE FILTER	
	APPROVED	DATE		
NEXT ASSEMBLY	CONTRACT		FINISH	SCALE
LTR	REVISION	DATE	D	DRAWING NUMBER 123002

K+E ALBANENE 1957 TRACING PAPER



LTR	REVISION	DATE
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.00 ± .01
FRACTIONS ± 1/64
ANGLES ± 1/2°
CONCENTRICITY .005 T.I.R.
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APPROVED	DATE
CONTRACT	

CALIFORNIA INSTITUTE OF TECHNOLOGY
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TITLE VIKING SEISMIC AXIS CROSSING COUNTER (3 CHANNEL)

FINISH | SCALE | C | DRAWING NUMBER 12301C

K+E ALBANENE® LA 1030 TRACING PAPER


CALIBRATION
CALIBRATION FUNCTION GENERATOR
ATTENUATOR
(LINES AA, BB, CC, DD)
(LINES E, F, G, H, J, K)
(LINES P, Q, R, S)
(LINES A, B, C, D)
SEISMO X
SEISMO Y
SEISMO Z
50 db PRE-AMP
50 db AMP
ATTENUATOR
AXIS CROSSING DETECTOR
COUNTER
D/A CONVERTER
AXIS CROSSING COUNTER
SW 1
6TH ORDER LOW PASS FILTER
LOGIC & SWITCHES
COUNTER
FILTER, PROGRAMMABLE
ABSOLUTE AVERAGE
SW 2
RUNNING AVERAGE CIRCUIT
ABSOLUTE VALUE DETECTOR
COMPARATOR
TIME DEPENDENT DELAY
EVENT DETECTOR
LINE X
LINE Y
LINE Z
LINE T
SUPPRESS
OVERRIDE
INVERTERS
CLEAR LOGIC
CALIBRATE
4 BIT SHIFT REGISTER
GAIN
6 BIT SHIFT REGISTER
E-D SENSITIVITY
5 BIT SHIFT REGISTER
FILTER FREQUENCY
E-D CONTROL
2 BIT SHIFT REGISTER
COMMAND DECODER
DIGITAL SCALING
CALIBRATE
GAIN CHANGE
E-D SENSITIVITY
FILTER FREQUENCY
E-D CONTROL
COMMAND CONTROL
FILTER AUTO SWEEP
SEQUENCER
TRIGGER COMMAND
X AXIS CROSSING COUNT
Y AXIS CROSSING COUNT
Z AXIS CROSSING COUNT
ANALOG SCALING
X HIGH DATA RATE
X LOW/MOD. DATA RATE
Y HIGH DATA RATE
Y LOW/MOD. DATA RATE
Z HIGH DATA RATE
Z LOW/MOD. DATA RATE
MULIPLEX CONTROL
VIKING LANDER
REFERENCE POWER SUPPLY
ANALOG SIGNAL LINES
CONTROL LINES
DRAWING NUMBER 12303 C
C REDRAWN BB 1-23-70
LTR REVISION DATE
DRAWN BARBER DATE 11-23-69
CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY
TITLE VIKING SEISMIC DATA PROCESSOR BLOCK DIAGRAM
D 12303 C

FIGURE 6

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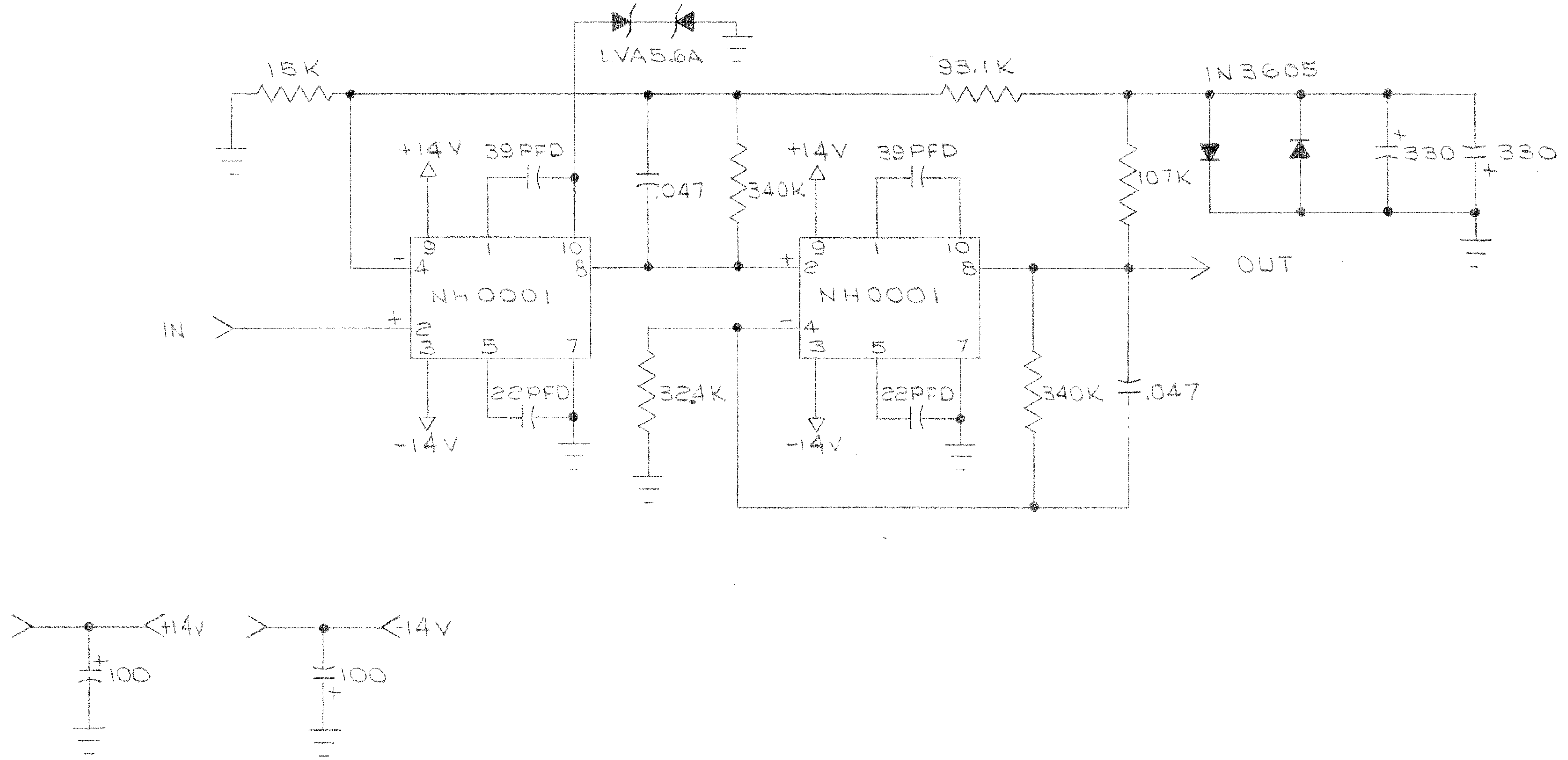

LTR	REVISION	DATE

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± ½°
CONCENTRICITY .005 T.I.R.
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY

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BARBER	12-1-69
ENGINEER	DATE
APPROVED	DATE

CONTRACT

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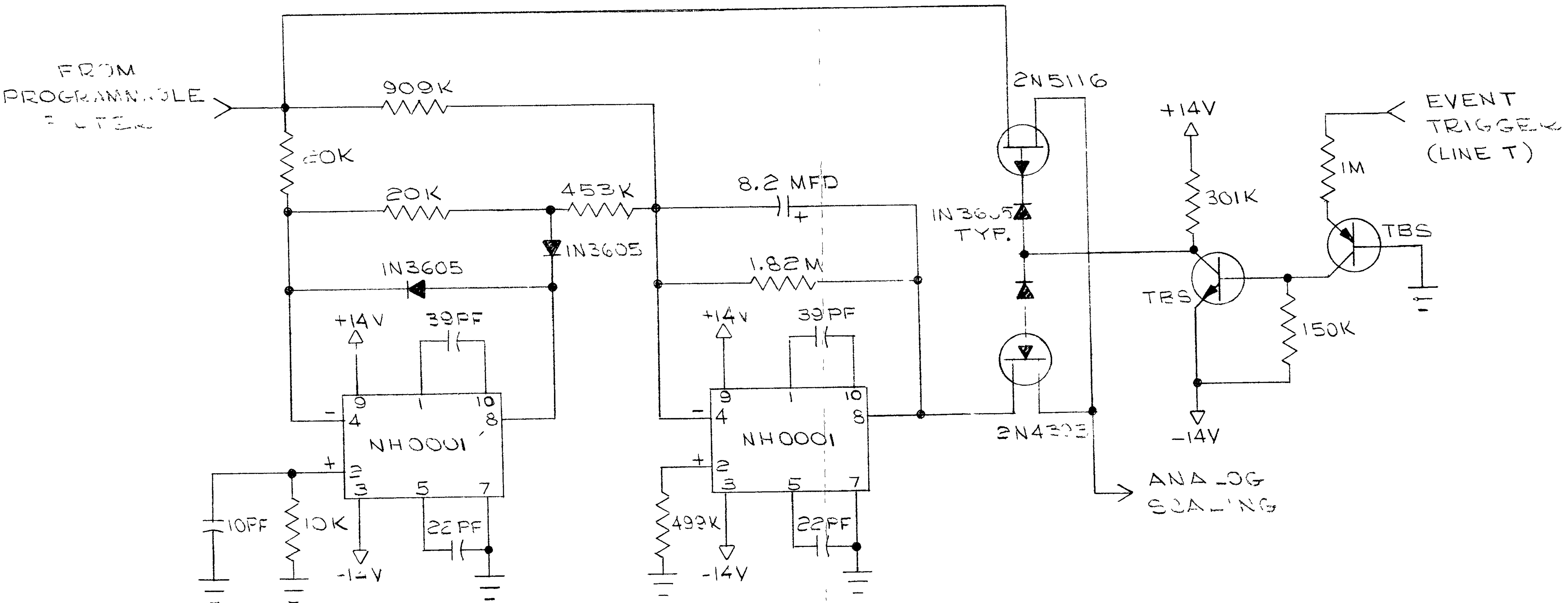
SEISMOLOGICAL LABORATORY

TITLE VIKING SEISMIC AMPLIFIER

FINISH
SCALE
B
DRAWING NUMBER 12304

DRAWING NUMBER 12305 A



LTR	REVISION	DATE
A	DRIVER ADDED	1-5-70

UNLESS OTHERWISE SPECIFIED
TOLERANCES
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± ½°
CONCENTRICITY .005 T I R.
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY

DRAWN Barse DATE 12-1-69
ENGINEER DATE
APPROVED DATE
CONTRACT

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE VIKING SEISMIC ABSOLUTE AVERAGE

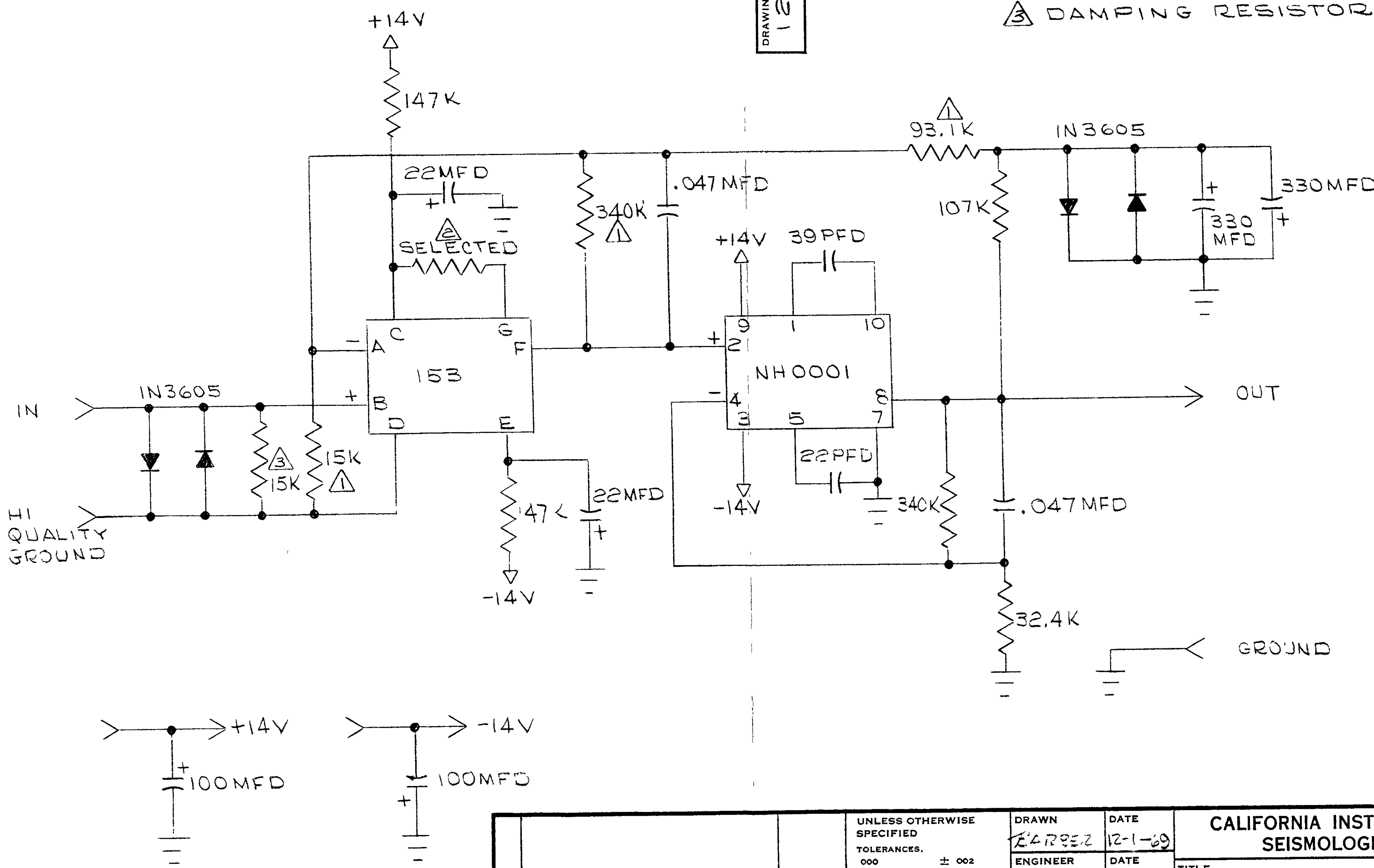
FINISH
SCALE
B DRAWING NUMBER 12305 A

K+E ALBANENE® LA 1035 TRACING PAPER

DRAWING NUMBER 12306 A

NOTES:

1. (△1) WIREWOUND RESISTOR
2. (△2) SUPPLIED BY "ANALOG DEVICES"
3. (△3) DAMPING RESISTOR



A	VALUE CHANGE	BB	1-5-70
LTR	REVISION		DATE

UNLESS OTHERWISE SPECIFIED
TOLERANCES.
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± ½°
CONCENTRICITY .005 T I R
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY

DRAWN: E. ARREZ	DATE: 12-1-69
ENGINEER	DATE
APPROVED	DATE
CONTRACT	

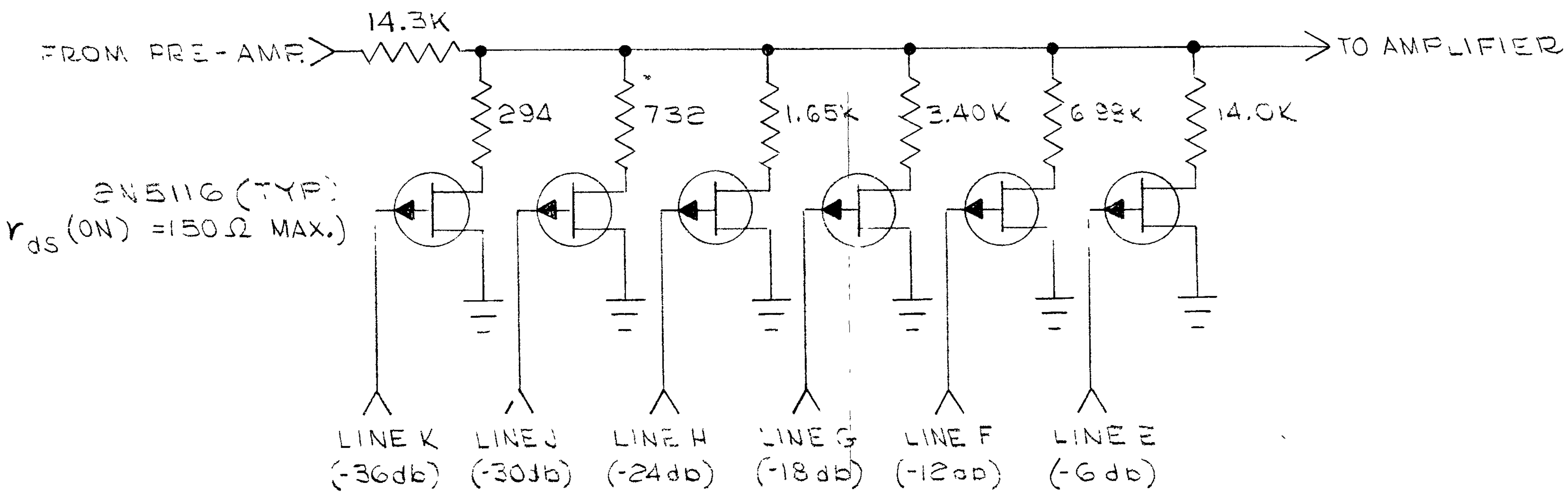
CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE: VIKING SEISMIC PRE-AMPLIFIER

FINISH | SCALE | B | DRAWING NUMBER 12306 A

K+E ALBANENE® LA 1035 TRACING PAPER

DRAWING NUMBER 12307 A



LTR	REVISION		DATE
A	VALUE CHANGE	B/3	1-5-70

UNLESS OTHERWISE SPECIFIED
TOLERANCES.
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± 1/2°
CONCENTRICITY .005 T I R.
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY

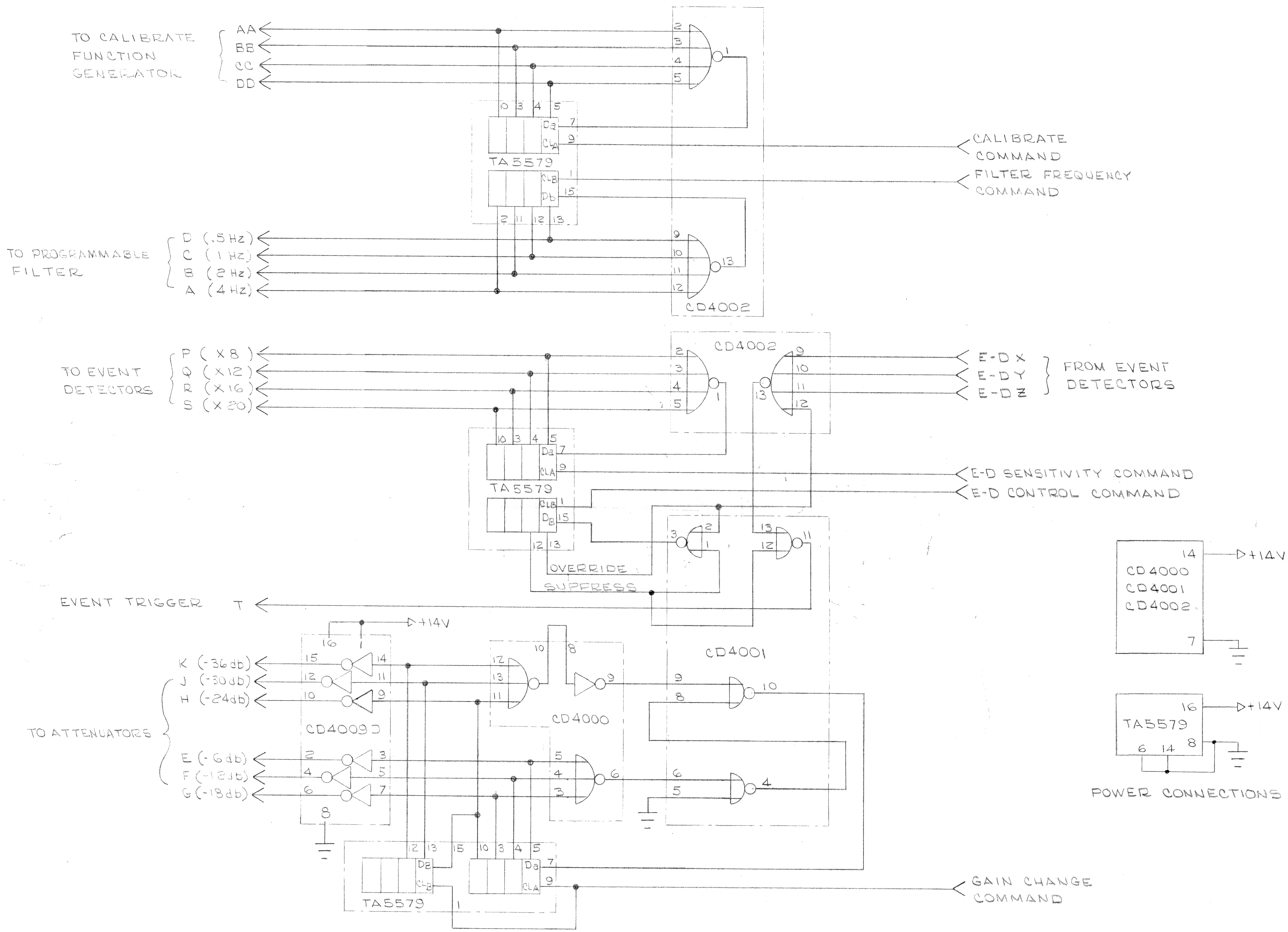
DRAWN	DATE
BARBER	12-1-69
ENGINEER	DATE
APPROVED	DATE

CONTRACT

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE
VIKING SEISMIC AMPLIFIER ATTENUATOR

FINISH | SCALE | B | DRAWING NUMBER 12307 A



DRAWING NUMBER 12308 A

LTR	REVISION		DATE
A	LABELED LINES	BB	1-5-70

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± ½°
CONCENTRICITY .005 T.I.R.
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY

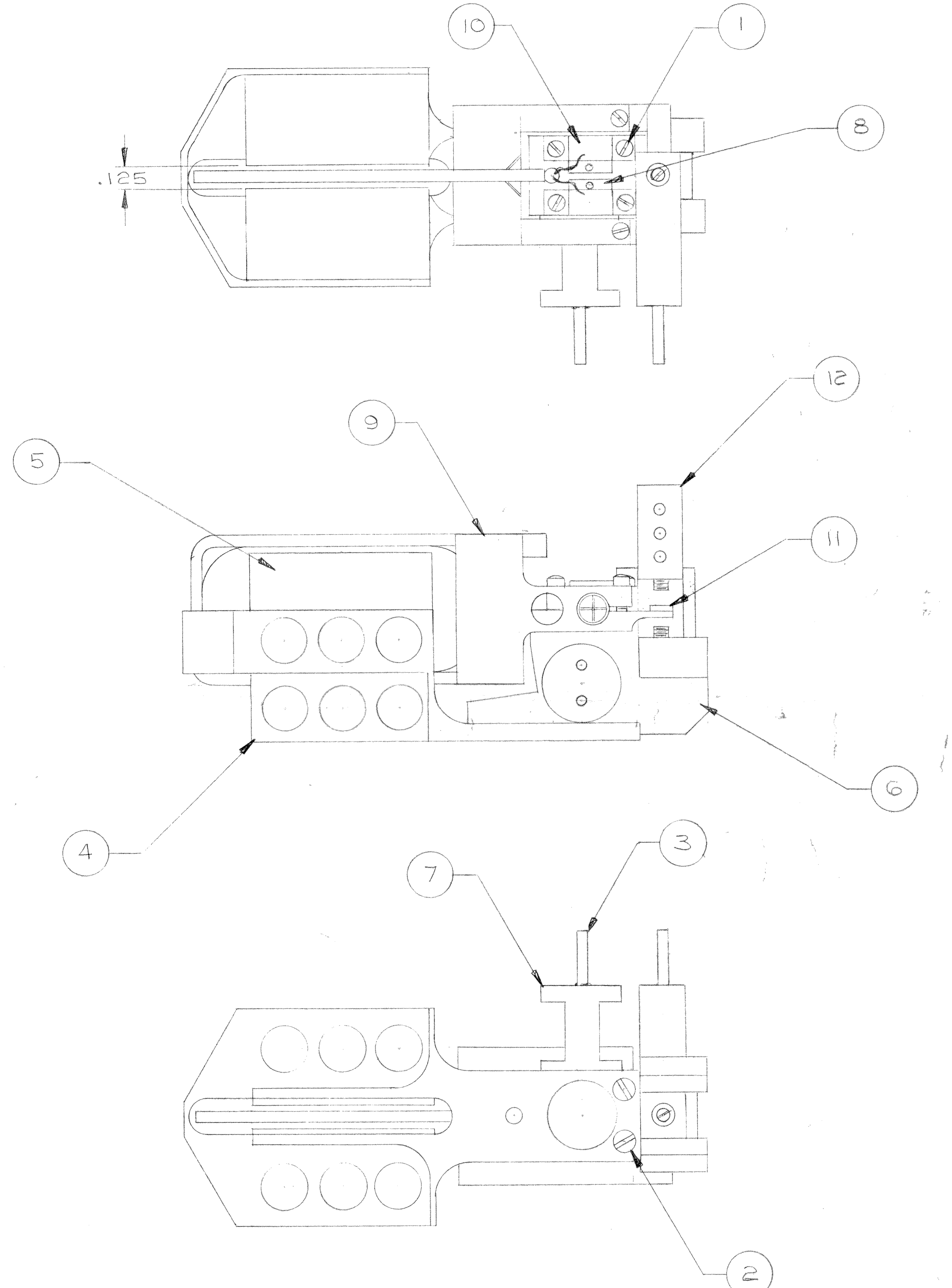
DRAWN	DATE
BARBER	12-1-69
ENGINEER	DATE
APPROVED	DATE
CONTRACT	

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE: VIKING SEISMIC COMMAND DECODER

FINISH | SCALE | C | DRAWING NUMBER 12308 A

K+E ALBANENE® LA 1030 TRACING PAPER



NOTES:

1. CEMENT ITEMS 5 INTO POSITION IN ITEM 4, USE SPACER TO MAINTAIN REQUIRED SPACING.
2. CEMENT ITEM 7 INTO ITEM 6, ORIENT AS SHOWN.
3. CEMENT ITEM 11 ONTO ITEM 9.
4. CEMENT ITEM 12 INTO ITEM 6.
5. ALL CEMENT USED TO BE EPOXY.
6. CEMENT ITEMS 3 INTO ITEM 7.

DRAWING NUMBER 12319

REQ'D	PART NO.	NOMENCLATURE	ITEM
1	12317	HORIZONTAL PULSER ASS'Y	12
1	12297	PULSER BAR	11
2	12289	PIVOT CLAMP	10
1	12298	MASS-COIL ASSEMBLY	9
2	12293	PIVOT SHELL	8
1	12299	OUTPUT TERMINAL	7
1	12284	BODY	6
2	12318	MAGNET	5.
1	12285	SUPPORT FRAME	4
2	NO.14X1	TINNED COPPER WIRE	3
2	2-56X3/16	FLAT HD SCREW (BRASS)	2
4	0-80X1/4	FILLISTER HD SCREW (BRASS)	1

LTR	REVISION	DATE

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± 1/2°
CONCENTRICITY .005 T.I.R.
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY 12321

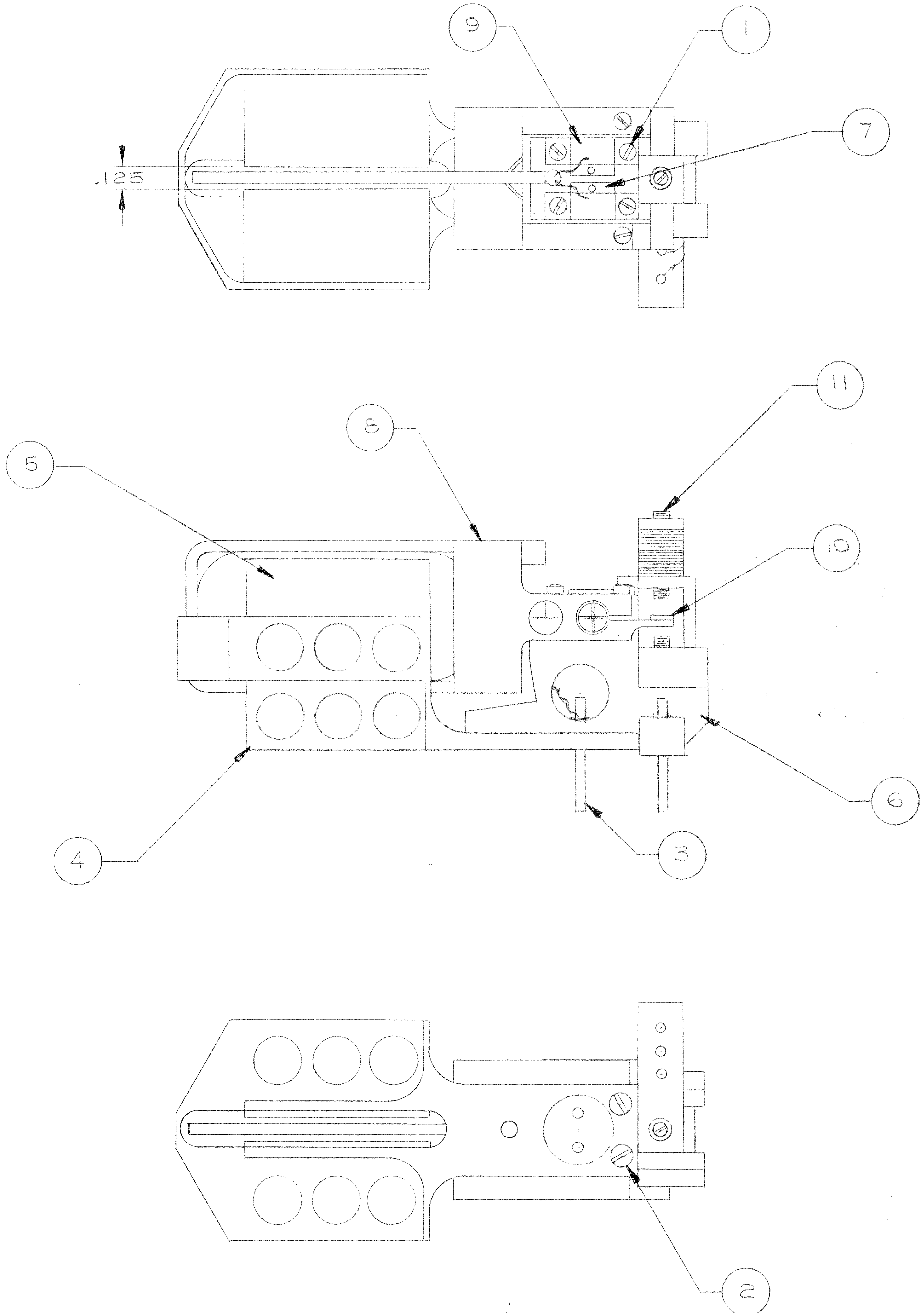
DRAWN: BARBER — DATE: 12-18-69
ENGINEER — DATE
APPROVED — DATE
CONTRACT

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE: VIKING SEISMOMETER HORIZONTAL UNIT ASSEMBLY

FINISH
SCALE 2/1
C
DRAWING NUMBER 12319

K+E ALBANENE® LA 1030 TRACING PAPER



NOTES:

1. CEMENT ITEMS 5 INTO POSITION IN ITEM 4, USE SPACER TO MAINTAIN REQUIRED SPACING.
2. CEMENT ITEM 10 ONTO ITEM 8.
3. CEMENT ITEM 11 INTO ITEM 6.
4. ALL CEMENT USED TO BE EPOXY.
5. CEMENT ITEMS 3 INTO ITEM 6.

DRAWING NUMBER 12320

REQ'D	PART NO.	NOMENCLATURE	ITEM
	12316	VERTICAL PULSER ASS'Y	11
1	12297	PULSER BAR	10
2	12289	PIVOT CLAMP	9
1	12298	MASS-COIL ASSEMBLY	8
2	12293	PIVOT SHELL	7
1	12284	BODY	6
2	12318	MAGNET	5
1	12285	SUPPORT FRAME	4
2	NO.14 X 5/8	TINNED COPPER WIRE	3
2	2-56 X 3/16	FLAT HD SCREW (BRASS)	2
4	0-80 X 1/4	FILLISTER HD. SCREW (BRASS)	1

LTR	REVISION	DATE

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± ½°
CONCENTRICITY .005 T.I.R.
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY 12321

DRAWN	DATE
BARBER	12-18-69
ENGINEER	DATE
APPROVED	DATE
CONTRACT	

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

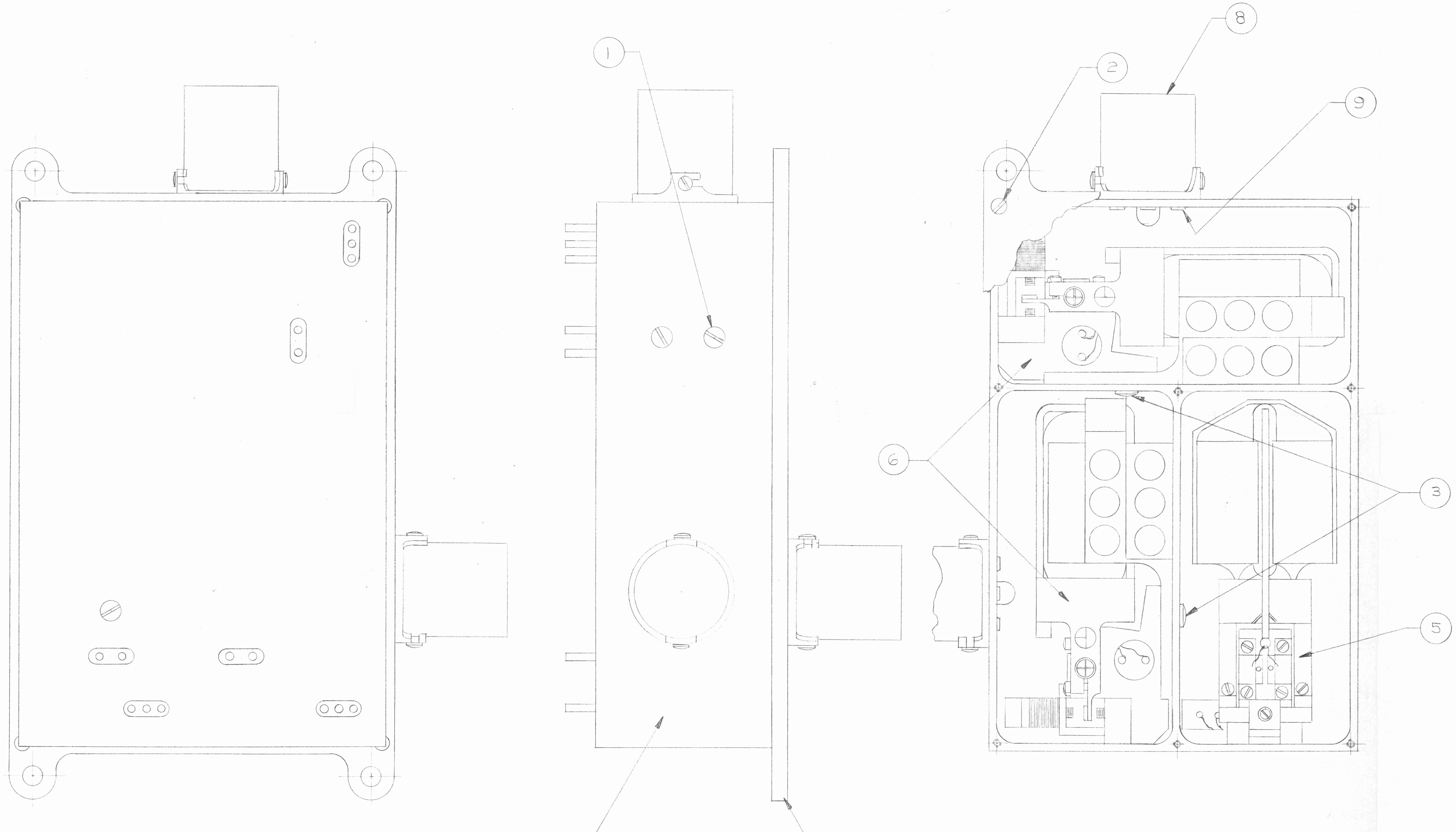
TITLE VIKING SEISMOMETER VERTICAL UNIT ASSEMBLY

FINISH | SCALE 2/1 | C | DRAWING NUMBER 12320

K+E ALBANENE® LA 1030 TRACING PAPER

NOTES:

1. CALIBRATION COIL - 4000 TURNS #46 WIRE, 850 OHMS.
2. TRANSDUCER COIL - 11000 TURNS #50 WIRE; 30000 OHMS.
3. MAGNET - CRUCIBLE STEEL NO. C-152, PA1061



BOTTOM VIEW
MOUNTING PLATE CUTAWAY

REQ'D	PART NO.	NOMENCLATURE	ITEM
12	1/16 X 1/8	RIVET - ALUMINUM	9
3	12330	CLAMP ASSEMBLY	8
1	12311	MOUNTING PLATE	7
2	12319	HORIZONTAL UNIT ASSEMBLY	6
1	12320	VERTICAL UNIT ASSEMBLY	5
1	12296	MAIN FRAME	4
2	2-56 X 1/4	BINDING HEAD SCREW	3
8	0-80 X 1/4	FLAT HEAD SCREW	2
7	2-56 X 1/4	FLAT HEAD SCREW	1

LTR	REVISION		DATE
A	ADDED NOTES	BB	1-23-70

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
.000 ± .002
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± 1/2°
CONCENTRICITY .005 T.I.R.
BREAK SHARP EDGES AND REMOVE BURRS

NEXT ASSEMBLY

DRAWN: BARBER DATE: 12-22-69
ENGINEER DATE
APPROVED DATE
CONTRACT

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE: VIKING SEISMOMETER FINAL ASSEMBLY

FINISH
SCALE: 2/1
D
DRAWING NUMBER: 12321A

DRAWING NUMBER 12321A