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CALIFORNIA INSTITUTE OF TECHNOLOGY

SEISMOLOGICAL LABORATORY

"DEVELOPMENT OF PERFORMANCE CRITERIA FOR ADVANCED VIKING SEISMIC EXPERIMENTS"

FINAL REPORT
AUGUST 31, 1972

NATIONAL AERONAUTICS AND
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California Institute of Technology

Seismological Laboratory

Pasadena, California

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Preface

This document discusses a study of the requirements of instrumentation appropriate for inclusion on post Viking '75 Mars missions for which a greater tolerance of weight, volume, power consumption and data transmissability is presumed to exist, and for which information gained by Viking '75 may be available as a guide.

The report consists of several sections as follows:

Figures

Tables

I. Summary of the Mars Viking Seismic Experiment

A. Scientific Objectives and Design Strategy

The main objective of the Advanced Viking Seismic Experiment will be to map the internal structure of the planet Mars. The Mariner missions have given us a strong indication that Mars is a recently tectonically active planet. Prior to Mariner we suspected that Mars might be intermediate to the Earth and the Moon in its geological and geophysical processes. The Moon is currently an essentially dead planet as far as seismic activity is concerned. This is consistent with its ancient surface, the age of its rocks and the mild stresses which are presently being supported by its interior. This state is also consistent with thermal history calculations. Mars, in addition to the evidence for recent volcanism and tectonism, has a very rough gravity field. This in turn implies high stresses in the interior. One could even make a case from the Mariner photographs that plate tectonics is beginning to develop on Mars. The line up of volcanoes near 110° occurs near a continental margin and exhibits the geometry of island arc areas on Earth. Nix Olympica seems to be the analog of the Hawaiian Islands and may be a Martian hot spot. The equatorial valley could be a rift zone, modified by erosion. Thermal history calculations indicate that the thermal evolution of Mars will start later than either the Earth or the Moon. There is also some evidence for polar wandering on Mars.

The first order questions regarding the internal structure of Mars are: 1) what is the thickness of the mantle, 2) what is the composition of the mantle, 3) what is the size and composition of the core and 4) what is the three dimensional distribution of Marsquakes? These can all be answered with a long-lived landed seismic experiment. If the seismometer has a long period capability, i.e. the ability to measure surface waves and free oscillations, a single large Marsquake can provide a comprehensive view of the interior. Because of the probable high wind noise on Mars and the probable high frequency background noise of the lander, including random high frequency pulses and because of the optomism we now have regarding the tectonic activity of the planet, we consider it essential that a long-period (low-frequency) capability be part of the Advanced Viking Seismic Experiment.

It should be stressed that a Marsquake large enough to excite free oscillations or globe encircling surface waves provides information about the internal structure and the density distribution and this information can be interpreted independently of knowledge regarding the location and time of the event. The fundamental spheroidal, radial, and toroidal modes of the Earth have periods of 54, 21, and 43 minutes respectively. These are excited only by the largest terrestrial earthquakes. These long periods are difficult to measure and require instruments such as quartz or laser strainmeters, gravimeters or displacement sensitive seismometers. The corresponding modes on Mars have periods of 20, 12, and 26 minutes. The shorter periods are due to the smaller size of the planet. Actually, the existence of a core and the structure of the mantle and crust can be established without measuring the gravest fundamental modes. A credible Martian free oscillation experiment could be performed with an instrument that is sensitive to periods shorter than 600 seconds.

We still have no information regarding the spectra of short period (body wave) signals or noise. Thus the design of the short period part of the seismometer must include provisions to change the response after landing. This can easily be accomplished.

In addition to increasing the bandwidth, the Advanced Viking Seismometer differs from the Viking Seismometer in having a larger dynamic range, a higher sensitivity and better timing. Wind and lander induced noises are still expected to be the major problem. In order to unambiguously identify these disturbances the seismic package should include a wind speed-direction sensor which records on the same time base as the seismometer, and strain gage or accelerometer devices which can identify lander related noises. Open questions at the moment are the deployment of the seismometer and the possiblity of impacts or explosion calibration events.

The other main objective of the seismic experiment is to map the seismicity of the planet and to correlate seismic activity with geology and topography. This can be adequately handled with two landers and Viking instrumentation with better timing, higher sensitivity and more positive techniques of isolating spurious signals.

B. Type of Signals that May Exist

Several types of signals can be expected to exist. First, there will be the microseismic background which is generated by wind and pressure variations and thermal effects. This is considered "noise" on the earth because it is of little intrinsic interest to the seismologist. On Mars the real "noise" will include, also, disturbances of, or in, the landed vehicle. The important signals will be caused by events such as faulting and volcanic activity, which write quite a different signature than the previous types of signals. Also, on Mars there may be a significant number of meteoritic impacts recorded. Some of these may be indistinguishable from quake events but, due to certain unique characteristics of impact signals, it may be possible to segregate some of these from quake signals. In any case, they will be useful sources to map the internal structure of Mars.

C. Requirements of the Instrumentation

To achieve the scientific goals it is necessary to have a system which indicates the relative amplitude and direction of ground motion in three axes. Ordinarily the instrument components are arranged in an orthogonal pattern (N,E,Z) though other configurations are sometimes used.

Since the event envelopes normally exhibit considerable amplitude modulation with the arrival of waves of different type and paths, and since these arrivals are used in interpretation, a time scale is necessary. It is desirable not to have excessive amplitude distortion or clipping, which might disguise the wave groups; thus a large dynamic range with reasonable linearity is a requirement.

The sensitivity of the system must be such that small events can be detected, since if Marsquakes occur in a distribution similar to earthquakes the number will be approximately in inverse proportion to their magnitude.

It is advantageous to have some means of scanning frequency content of both discrete events and the microseismic and noise signals.

Caltech has previously designed a system for Viking '75 which is adequate for a first sampling of the Martian seismic environment. It is hoped that this instrumentation will provide data which can help select the design parameters of more sophisticated instruments to extend this knowledge, and that experience gained in design of the previous experiment will benefit the development of more advanced seismic experiments for future missions. Recent advances in electronics make it possible to partially redesign the instrumental response on the surface of Mars without a prohibitive weight penalty, and at the same time extend the frequency range that can be observed.

The Viking '75 instrumentation includes a 3 component short period system of moderate sensitivity having provision for basic spectrum analysis of microseismic background by selectable filtering, a triggered mode at accelerated data rate for event registration, and data compaction to provide for full-time operation without exceeding the data bit allotment. (See Final Report for NASA Grant NGR-05-002-129, "Development of Performance Criteria and Functional Specifications for a Passive Seismic Experiment on Mars" Dec. 31, 1969.) Weight volume and power constraints are extreme. Presumably advanced Viking missions will permit weight, volume and power consumption in excess of the allowances on Viking '75. We can take advantage of this to design more sophisticated instrumentation. With knowledge of ground motion amplitudes and frequencies, noise signals, etc., expected to be derived from Viking '75, it will be possible to design systems having longer period and broad band response which will be compatible with the signal environment. Particular emphasis should be placed on detecting the long period waves associated with surface waves and free oscillations. Inclusion of an active experiment utilizing explosion or impact generated signals to derive information about the sub-surface would be an important supplement to the seismic experiment.

D. Advanced Viking Seismic Instrumentation

An advanced Viking seismic instrument package should include the following:

(1) A short-period vertical component system for observation of short and middle frequency phenomena such as local Marsquakes volcanic activity and meteoric impacts.

(2) A long-period or wide-band 3 component system for observation of periods in the range of 2 to 1200 seconds period from natural events.

(3) A high frequency vertical component system for registration of waves generated by explosion of grenades deployed in a linear array for a shallow refraction determination of the sub-surface structure.

(4) A system for detection and rejection of lander induced noises.

The capability of changing frequency pass band of (1) and (2) should be included.

The following are some instrumental characteristics and parameters which are suitable for an advanced Mars seismic experiment but which are not intended to be specifications for such instrumentation. Some methods which can be used in achievement of the goals are discussed. Final selection of characteristics may be influenced by Viking '75 data, if this becomes available, but much can be done in the way of preliminary planning.

II. Seismic Instrument Characteristics

A. Long-Period

Peak in sensitivity to ground displacement at several ground periods and fall off symmetrically on either side of peak. The response should be extended to as long a period as is consistent with the state of the art. (See Figure 1)

B. Wide-Band

Flat displacement response over various band widths up to 500 seconds ground period. (See Figure 1)

C. Short-Period

Response similar to Viking '75 but with added high frequency capability for performance of an 'active' experiment. (Figure 2)

The same short period seismometer could be used for natural events and explosions with switchable filtering.

D. Ground Motion Resolution (typical)

(1) Long-period (peaked) - - 10^{-5} mm at 50 seconds ground period.

(2) Wide-band - - 10^{-4} mm at 100 seconds ground period.

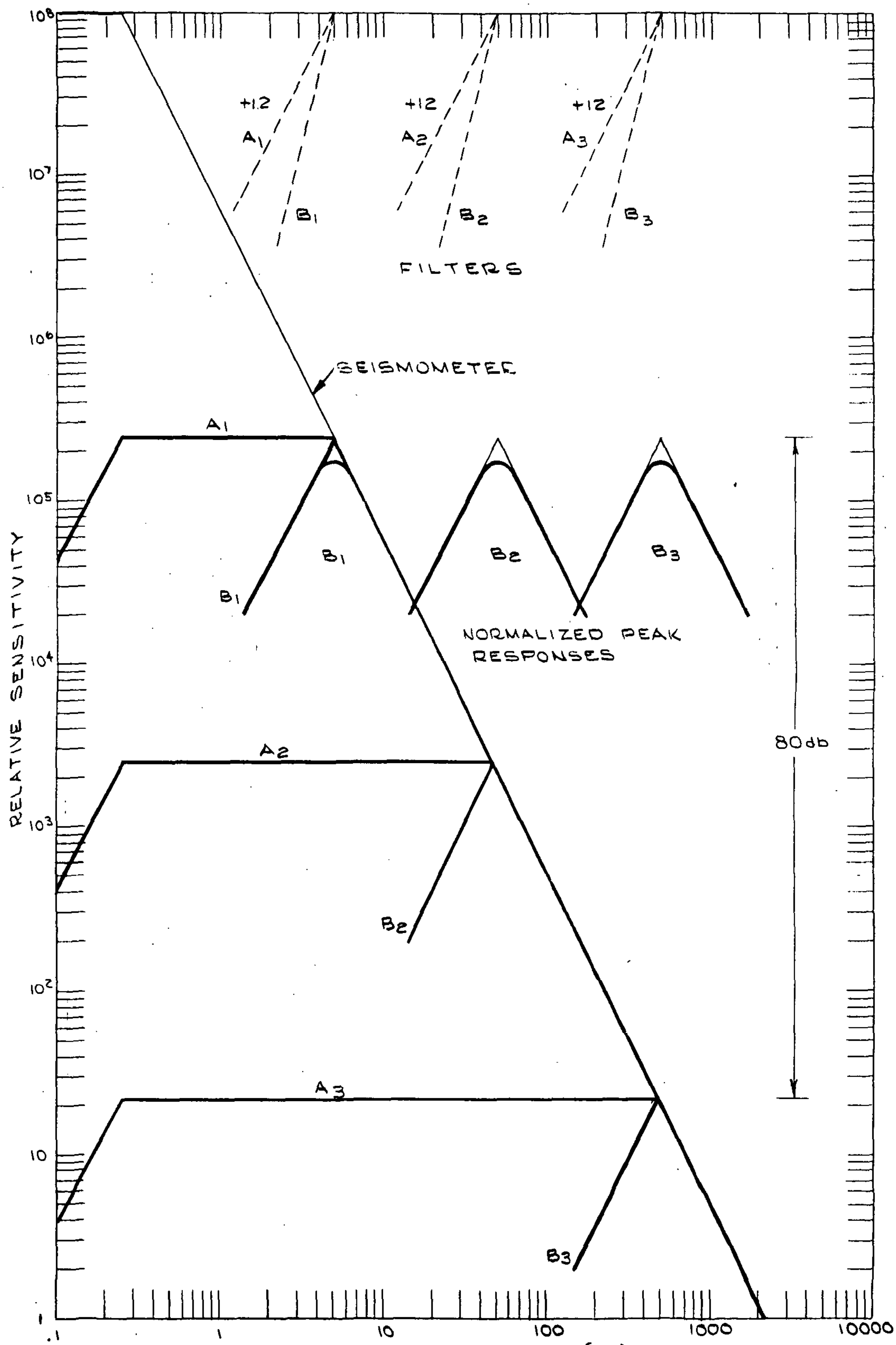

FIGURE 1
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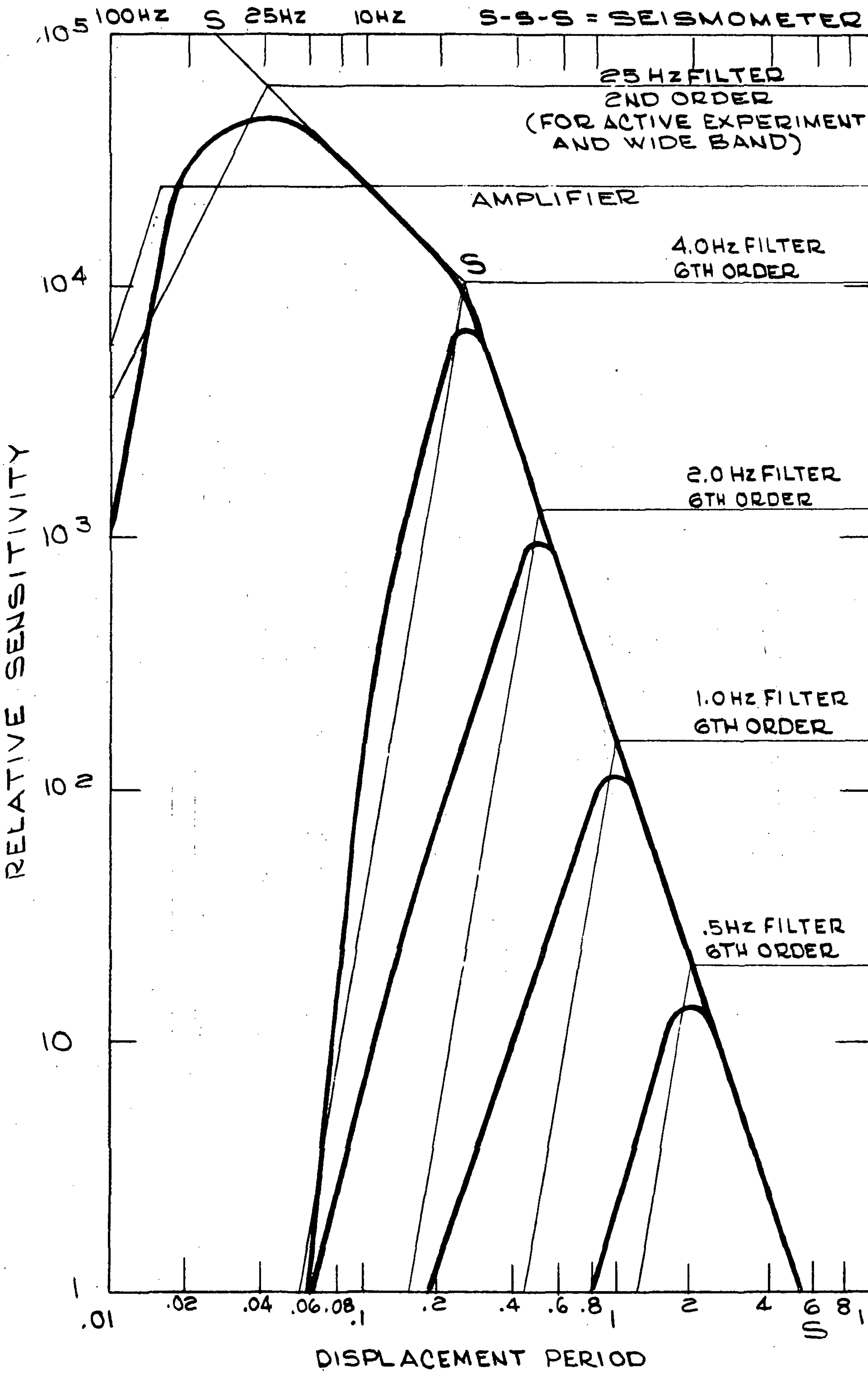


SHORT PERIOD SYSTEM RESPONSE

FIGURE 2

(3) Short-period.

(a) Passive experiment - - - 10^{-6} mm @ 0.2 seconds.

(b) Active experiment - - - 10^{-8} mm @ .04 second.

In general, the suggested short-period instrumentation resembles in characteristics that used for Ranger, Surveyor, Apollo or Viking with extensions and modifications made possible by new techniques. Sensitivities of the various systems is shown in Figure 3.

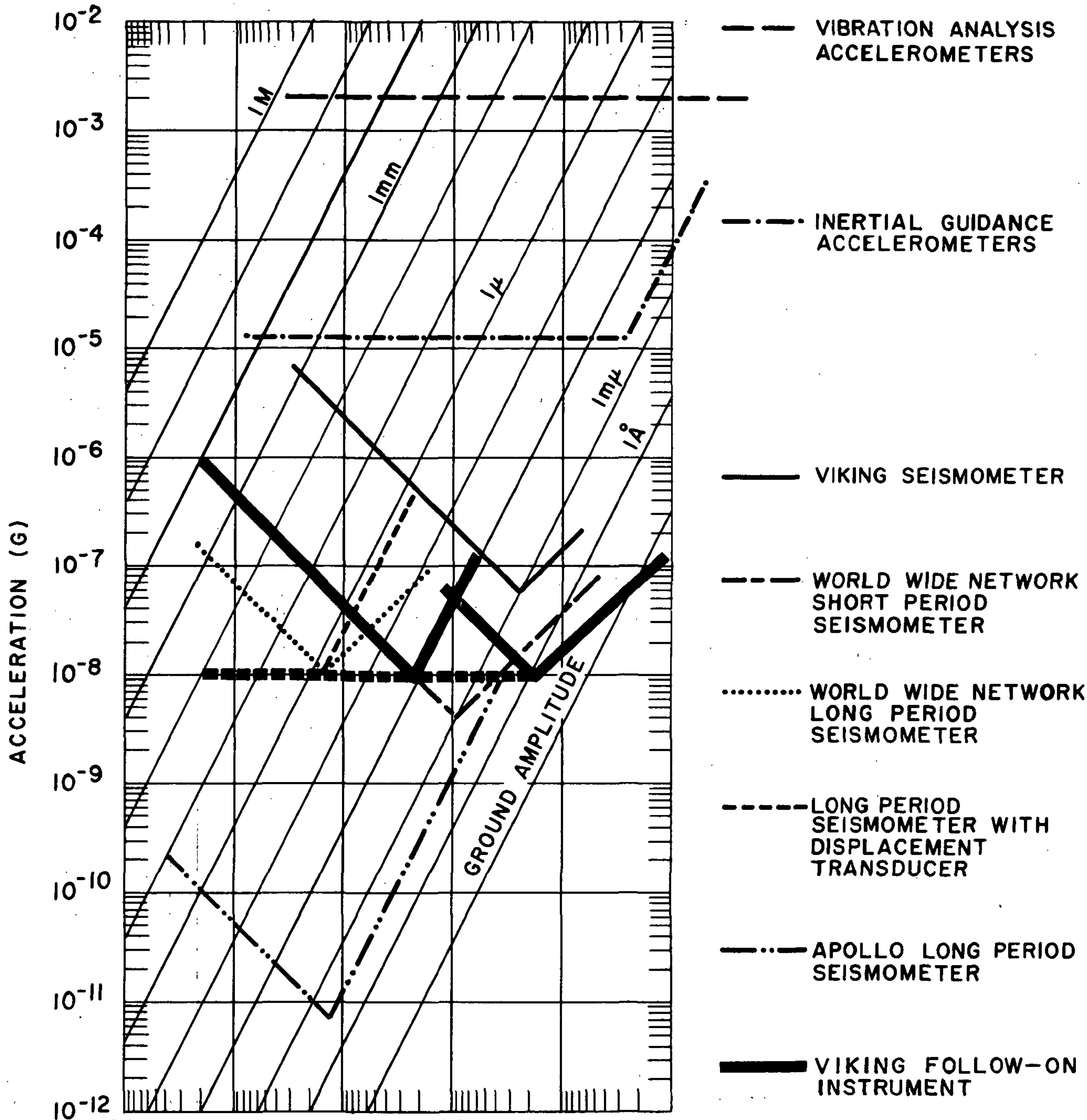
III. Implementation

Instrumentation for planetary emplacement must accommodate much in the way of an unfavorable environment. In launch, and on landing, high vibration and shock levels must be accommodated. Once landed, extremes of temperature, disturbance from within the landed craft, wind forces, etc., are to be expected. Constraints on power consumption, weight, volume and data transmission are always severe.

Following are brief descriptions of two already tested systems upon which design for advanced Viking systems might be based, and some non-space oriented instrumentation developments. These, and any other system suggested, should be thoroughly evaluated before a firm choice is made, preferably after Viking '75 data are studied.

A. Viking '75

The Viking '75 design combines ruggedness with small volume, light weight, low power consumption, and data compaction. At the same time, it achieves sensitivity in the short period area equal to an average



SENSITIVITIES OF ACCELEROMETERS AND SEISMIC INSTRUMENTS

FIGURE 3

earth-based seismic station. (See Final Report of NASA Grant NGR 05-002-129.) Having a natural period of only 0.25 seconds, the Viking seismometers can tolerate a considerable off-level attitude without becoming disabled. It is technically feasible to use this sensor coupled to a suitable displacement transducer to sense both long and short period signals, or with a velocity transducer for high sensitivity at short periods. Because of its unique and rugged design, it lends itself well to survival of the flight, landing and environment. Its short natural period and small dimension are advantages in packaging, leveling and servoing. It may be desirable to increase the period somewhat for use in a long-period application.

B. Surveyor and Apollo Systems

The Surveyor, Surveyor follow-on, and Apollo systems consisted of 3 components of relatively long period pendulums fitted with displacement transducers, leveling and mass position servomechanism, and response shaping filters. Response approximated that of the well known Press-Ewing seismograph widely used in observatory recording of teleseismic waves. Response of these is essentially flat to, or peaks near, 15 seconds ground period. Both the Apollo and Surveyor units used pendulums of 15 sec. period. The Caltech Surveyor follow-on (See Final Report of NASA Grant NSG 535) used 5 second pendulums and achieved the desired response by means of shaping filters. Considerable stability is gained by use of shorter period pendulums.

The following have been suggested for evaluation for the advanced Viking application; neither has been applied to planetary or lunar emplacement.

C. Block-Moore Accelerometer

The Block-Moore (UCSD-IGPP) quartz fiber suspended accelerometer having approximately 1 second period is an exceptionally stable device fitted with a capacity type displacement transducer. Its extreme stability and freedom from noise permits high fidelity recording of earth tides. However, these are of the same order of magnitude in acceleration as much smaller amplitude earthquake waves within the resolution capability of more conventional seismometers.

In its present form it is felt that this instrument is too fragile and complicated for planetary emplacement and that when operating with filtering which permits detection of seismic frequencies spurious responses might seriously affect the data.

D. Burke et al., Wide-Band System

Burke *et al*, have described a system in which a 1.5 second seismometer is used with filtering and amplifiers to give a *velocity* response useful to in excess of 40 seconds period. Separate amplified and filtered bands are adjusted in gain, combined,and applied to a digital recording system of large dynamic range. The system is essentially flat to *velocity* over a band of approximately .03 to 3 Hz. This is certainly an acceptable method which employs a rugged short period seismometer for good stability. Relatively high magnification over the wide band is possible due to the large dynamic range of the recording system. Some difficulty will be encountered in making the system flat to *displacement*.

E. Recommendation for Advanced Viking Instrumentation

It is our opinion that the initial approach to an advanced Viking long period system should be one of the following:

(1) 3 components of medium period (5 seconds) seismometers with a mass position and leveling servomechanism utilizing carrier type displacement transducers with phase sensitive detection. (Capacity bridge, differential transformer, etc.)

(2) Short period (.25 - 1 second) seismometers as above but perhaps with transducers having gauge factors greater than 1. (See appendix A, Figure 7).

(3) Same as (2) but using a capacity transducer and phase-sensitive detection, as in (1) (See Appendix A, Figure 8a, b).

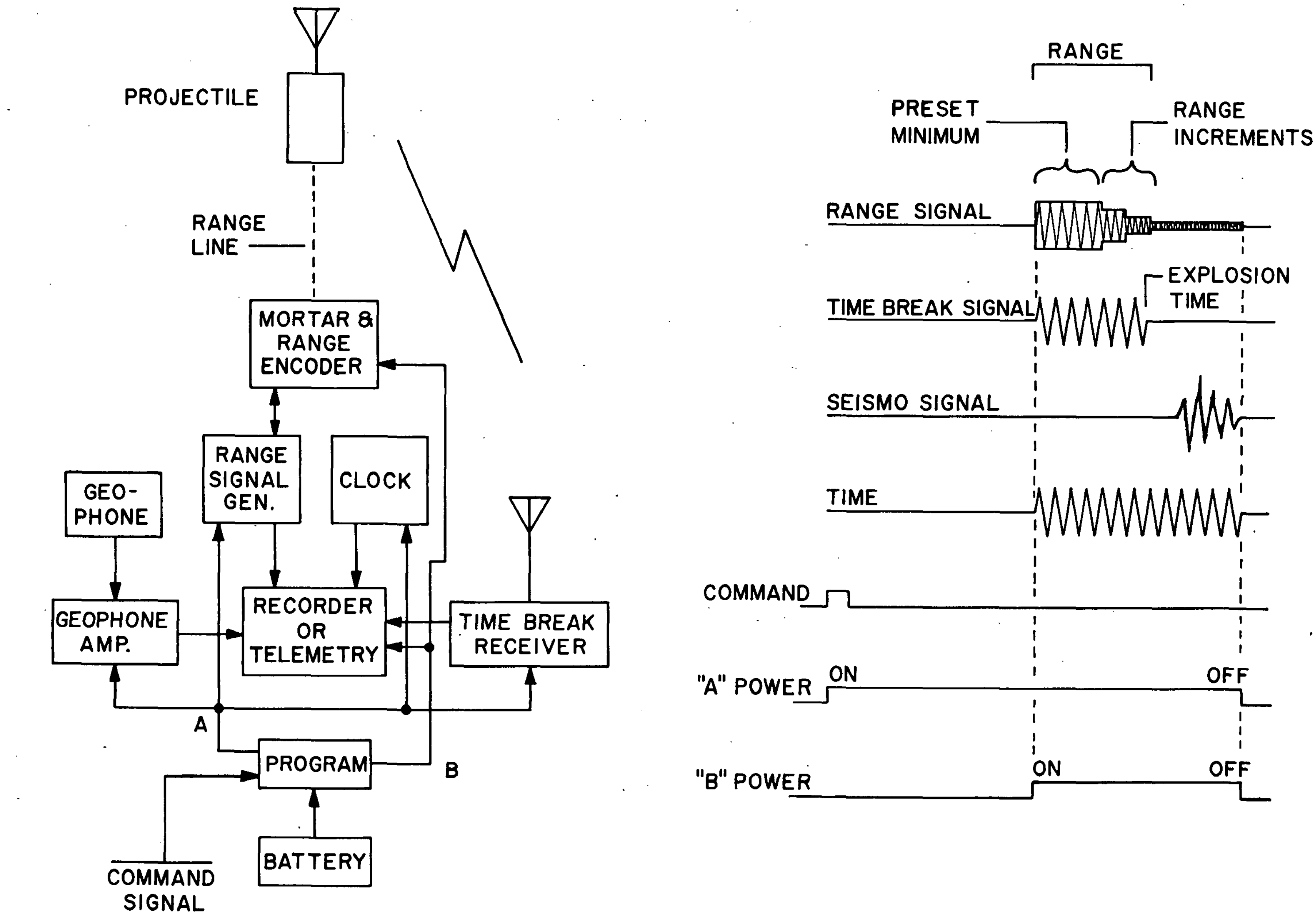
(4) Vertical component of sensor used in (2) and (3) with conventional amplification and filtering of velocity output from damping and servo coil to give .1 to 2 and .02 to .1 pass bands.

(5) Systems for (1), (2), and (3) would be for data in the period range of from 2 to 1200 second (4) would be for a period range of .1 to 2 second and .10 - .02 second for passive and active short-period applications respectively. See appendix B for computation of sensitivities achievable, and other information.

Regardless of the system chosen, provision should be made for all of the command capability associated with Viking '75 but with greater latitude in adjustment. Signal properties in the medium and long period range will be unknown even after Viking '75 data are available due to limitations imposed on the mission instrumentation. While the basic requirements of the instrumentation are similar to those for Viking '75, broadening of the scope of investigation, increasing of dynamic range, etc., must be included. Much of the technology developed for Viking '75 can be adapted to the new experiment. Modifications might include sensor redesign to include displacement transducers, and perhaps longer free period, and level and zero position control. Combining of functions in electronic elements may be possible with the large scale integration of circuitry (LSI) experience gained in the Viking '75 development.

(6) To initiate signals for reception by the active experiment system either a package of mortars to deploy explosive charges into a linear array, or a mechanical device to 'thump' the surface at various distances must be included. Devices for ranging of source distance and indication of time of initiation and time of reception are necessary. A mortar package similar to that included on Apollo lunar missions would be a practical method. Work relative to this is described in Caltech's report to NASA covering original development under Grant NSG 535 and follow-on finalization by Stanford University under Contract NAS 9-5632. (Figure 4)

It is mandatory that all seismometers proposed be deployed onto the Martian surface at as great a distance as is practical from the lander. Thermal control and shock protection such as was used on Apollo instrumentation must be included. Power and signal output connections will be



SCHEMATIC OF LUNAR SEISMIC REFRACTION SYSTEM

FIGURE 4

provided by cable to the lander. Rejection of disturbances occurring on the lander by techniques utilizing the nearly simultaneous detection by the seismometer and devices aboard would be desirable.

F. Data Processing and Control System

The Viking '75 seismic experiment was restricted in sensitivity, bandwidth and dynamic range to that of an average earth-based seismic observatory because of mission constraints and because little was known about the microseismic background on Mars. The Advanced Viking Seismic Experiment should be designed so that it can take advantage of the knowledge gained from Viking '75. It should be designed for a much wider bandwidth and increased sensitivity and dynamic range.

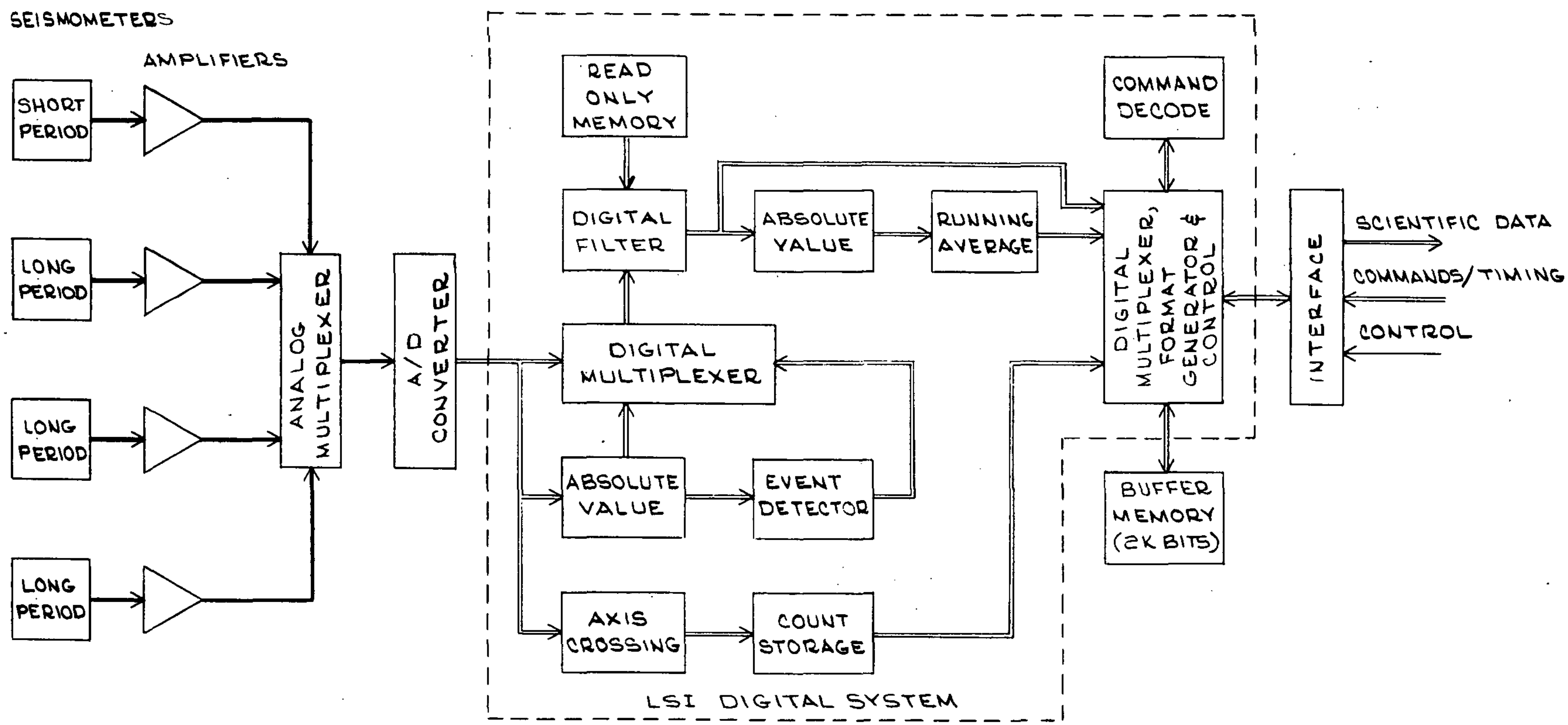
In addition, the advanced seismic experiment can build upon the experience gained in Viking '75 with the use of large scale integrated (LSI) digital circuitry. It is planned to make extensive use of LSI circuits to build a great deal of flexibility into the data handling and processing system. This flexibility is a necessity for several reasons. First, even though we will have some data on the seismic bakcground level and disturbance to be expected on Mars from Viking '75 this knowledge may well not be available before it is necessary to "firm up" the advanced experiment design. Secondly, an experiment as conceived for this advanced project would be difficult to conduct even on the earth without specific prior knowledge of the chosen site with its local disturbances (wind, heat profile, tilts, etc.), the pier (lander or rover), and the coupling of the seismometer to the surface. Thirdly, past planetary missions have shown that the equipment is designed, built and launched before the scientific investigations can gain experience with the actual flight hardware.

Finally, the design of an experiment to be integrated into an interplanetary vehicle is an iterative process within the ever changing constraints and ground rules. Unfortunately, what may be a good approach to a scientific investigation under one set of constraints may well fail to take full advantage of a new set of constraints particularly if the design becomes "frozen", in reality if not in fact, by the sheer inertia of the program. The flexibility designed into this advanced mission will allow for the experiment to essentially be designed on Mars. It will permit the investigators to look at the site and to optimize the experiment for that site (as is done on Earth) and to conceive of new experiments as further data are gathered.

(1) Viking '75 System

The Advanced Martian Seismic System is an expanded version of the Viking '75 system. Before describing the advanced system let us review briefly the Viking '75 system package upon which the data handling concept is based, Figure 5.

A rugged, lightweight, three-component seismometer and associated electronics were developed for the Viking '75 Lander payload. The instrumentation includes sensors, amplification, filtering, automatic event triggering, and data



VIKING '75 SEISMIC SYSTEM
SIMPLIFIED BLOCK DIAGRAM

FIGURE 5
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compaction. The frequency range is 0.1 to 4 Hz with a ground amplitude resolution of 50 x 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.

The electronics and data processing system include the following equipment and functions, see Figure 5.

a. A variable gain amplifier is provided for each seismometer unit.

b. A digital filter (pass-bands of 0.5, 1, 2, and 4 Hz) and a digital averaging circuit are provided per seismometer component for observing the microseismic level and spectrum; the filters are selectable or programmable. The averaging and sampling period is approximately 15 seconds.

c. An event detector, the trigger level of which is set to a command-selectable ratio relative to the averaged microseism level, monitors the output; which, on the occurrence of a discrete event which exceeds the ratio, causes the event envelope to be detected and presented to the lander for sampling at a rate of once per second. Simultaneously, a count of the positive axis crossings of the event is sampled at the same rate. This combination of sampling the envelope and axis crossings between samples results in a ten to one compression of the data required to encode the original signal. The signal may be reconstructed on Earth with reasonable fidelity by passing the seismic envelope through an inverse filter and convolving with the instrument response according to the axis crossing count within each sampling interval.

d. A commandable high data rate mode (20 samples/second) is included which utilizes the triggered mode pass-band. This is intended for initial surveys to establish correct operating adjustment, or for times when the lander can accept a larger data volume. Seismometer calibration is performed in the high data rate mode.

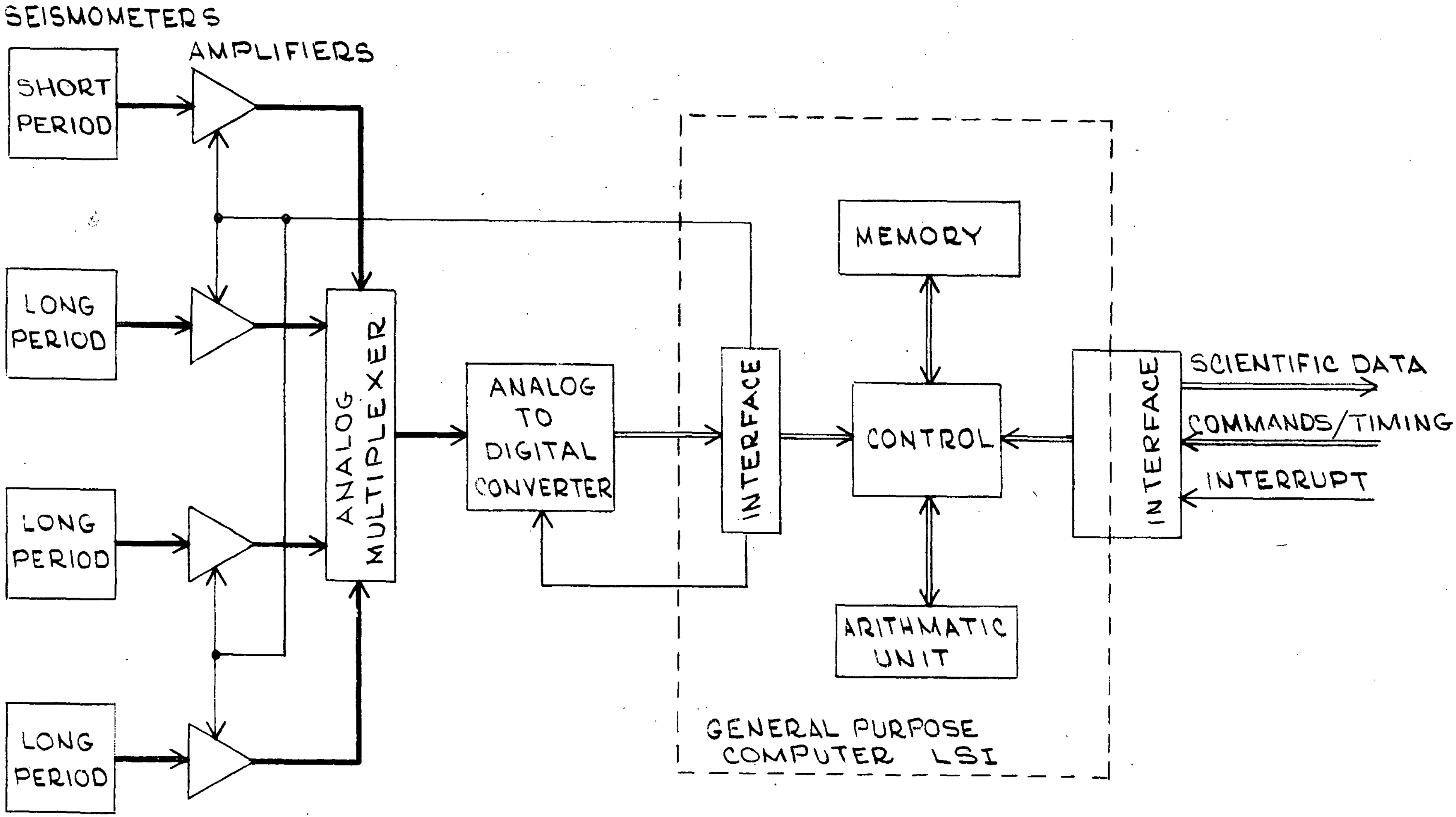
e. The digital data handling and control circuitry is built primarily of LSI (large scale integrated) circuitry and includes in addition to filtering, event detection and averaging, such necessary functions as analog to digital conversion, buffer memory storage, command decoding, timing and control.

Custom LSI circuits are used throughout the system where the proper function can be implemented. This greatly reduced the weight and volume over that required for conventional circuitry. For example, the programmable filters were reduced from three 4 x 5 inch circuit cards when implemented in analog fashion to four LSI circuits occupying roughly one-half of a 4 x 5 circuit card. The weight and volume were each reduced to approximately 10% of their former value.

(2) Description of the Advanced Seismic Data System

It is proposed that the Advanced Seismic System incorporate all of the functions of the Viking '75 system, but that they be implemented somewhat differently in order to take full advantage of the use of the LSI circuitry. Viking '75 contained a read-only-memory (ROM) for holding the coefficients of the programmable digital filter. The advanced system will use a random access memory (RAM) which will share, in addition to the digital filter coefficients, the values for the time constants of the various averaging circuits, the sensitivity and delay of the event detector and values for timekeeping and control timing. In addition, this same memory will serve as the buffer storage which will undoubtedly be necessary to interface with the lander system. The memory will be addressable through the Earth-Mars telemetry up-link. The presently available magnetic film memory would be a good candidate for this application because it is non-volatile, low power consuming and tolerant of environmental extremes.

The Viking '75 system contained more than 35 data and control registers as well as logic circuitry for controlling timing multiplexing and decoding of the digital data. It is proposed for this system that these registers and special purpose control circuits be replaced by an arithmatic unit and control circuit creating in fact a general purpose digital computer. A block diagram of the Data System is shown in Figure 6. It is not uncommon for a digital computer to be used in a guidance or control application, but it is perhaps



BLOCK DIAGRAM
ADVANCED SEISMIC DATA SYSTEM

FIGURE 6

unusual to propose its use in a remotely controlled planetary experiment. Nevertheless, there are many advantages to be gained by the use of a computer as the controller in this scientific equipment.

This proposed mission has stressed flexibility as of prime importance. A general purpose computer controller which may be programmed through the Earth-Mars up-link is the ultimate in flexibility. It will not be necessary to second-guess the mission constraints and expected signal amplitudes and spectrum months or even years in advance of the launch or to become frozen in design early in the program. New experiments may be conceived late in the program, and, in fact, during the mission as data are received and analyzed.

There will be a reduction in hardware through the substitution of one general purpose system for the multitude of special purpose circuits and registers. In fact the computer processing may be reconfigured for the active experiment and then converted back to the routine data processing,eliminating the need to carry special purpose hardware for this one short-lived portion of the mission.

A savings in power would be realized because circuitry which is used only infrequently, such as the command decoder, would not be idling with the associated non-functional power consumption.

The above methods will make for a far more useful data processing system. Specifically; Viking '75 contained a 6th order Butterworth lowpass filter with 4 filter break points. With the new system, the filter order and breakpoints and, in fact, the type of filter, may be changed. Changing from a Butterworth to a linear phase (Bessel) filter, for instance, is just a matter of changing the filter coefficients. The sensitivity, averaging time constants and delays of the event detector may be adjusted to optimize its ability to differentiate seismic events from the background. Data compaction schemes which would result in greater fidelity of the reconstructed signal may be incorporated. In fact, the computation of the power spectrum and/or the auto-correlation function would be possible.

In addition, the interaction between the scientific investigators, the prime contractor and the space-flight manufacture would be smoothed because each of them would understand the hardware and software functions of a general purpose digital computer as opposed to the unique character of special purpose equipment.

Finally, the problem of the investigators gaining experience with the hardware and the presentation of the data would be alleviated because it would not be necessary to work with flight hardware as one could use any number of readily available "mini" computers to model the flight system.

This system will expand the dynamic range of 40 db used in Viking '75 to 72.2 db by use of a 12 bit analog-to-digital converter. With an analog signal range of plus and minus 10 volts this requires the resolution of the least significant bit to be 2.44 mV. The dynamic range of the amplifiers will be extended by operating at a correspondingly lower gain. For instance, a voltage gain of 2440 with the 12 bit A/D converter is equivalent to the gain of 10^5 with the 8 bit A/D converter used in Viking '75. With the lower gain, the amplifiers' low frequency response may be extended to 0 Hz without suffering from excessive low frequency drift and noise. The dynamic range may be extended still further by having the control system detect an overflow and institute a gain change subroutine.

The uncertainty in the location of seismic events detected by the Viking '75 seismometer is roughly ±6 km due, in part, to the uncertainty in the location of the lander, but due equally to the granularity of the timekeeping of 1/2 second. It is hoped to obtain better accuracy in the location of events in this advanced system. This will require finer timing resolution. The computer would be capable of deriving whatever resolution is necessary from the lander timing. One of the data compaction schemes considered for this mission consists of recording the amplitude of positive and/or negative peaks of the seismic signal and the time of these peaks. This system would require timing resolution of the order of 25 milliseconds for a bandwidth of 20 Hz.

Table I is an estimate of the apportionment of memory locations based on a 1 K word (by 12 bit) memory.

Table II is an estimate of the weight and power required. Each of the functions shown in Table II may be packaged

Table I. 1 K Memory Apportionment

Multiply Subroutine	15
Filter Coefficients	48
Filter Subroutine	20
Event Detector Coefficients	5
Event Detector Subroutine	20
Background Monitor Coefficients	3
Background Monitor Subroutine	20
Data Compaction Coefficients	3
Data Compaction Subroutine	40
Timekeeping Coefficients	5
Timekeeping Subroutine	10
Interrupt Subroutine	30
Command Decode Subroutine	50
Calibration Coefficients	3
Calibration Subroutine	25
Amplifier Gain Coefficients	16
Signal Overflow Subroutine	15
Housekeeping Coefficients	14
Housekeeping Subroutine	30
Self-Check Coefficients	20
Self-Check Subroutine	20
Control Subroutine	50
Buffer Memory	300
Uncommitted	262
Total	1024

Table II. Data Handling System Weight and Power Estimate

	Power Required	Weight
Memory	6 w	5 lb
Control	4	
Interface	5	
A/D Converter	1	1
Amplifiers and Transducers	4	1
Power Conversion and Distribution (80% eff.)	5	1
Case	-	2
Total	25 w	10 lb

on a single 5 x 5 inch card for a total of six cards housed in a case approximately 5 x 5 x 5 inches with a total volume of 125 cubic inches.

G. Items Suggested for Continued Study

Future efforts in development of Advanced Viking Seismic Systems, should include the following:

(1) Effort should be expended in the development of super stable mechanical suspension systems for the sensors in order to fully utilize the capabilities of high-gain, ultra-low noise electronics. Special attention should be given to long period drift which would degrade the S/N for periods in the free-mode oscillation range.

(2) It would be desirable to make a study of applying servo-mechanism methods in general to seismic systems, and, in particular, with a view to preserving the long period sensitivity of the suspended system. Conventional continuous direct servo of the mass position results in an 18 db/octave sensitivity loss with increasing ground period. Incremental servo of the mass zero position by adjustment of level or the mass support retains the 12 db/octave characteristic inherent to a mass-spring system. Development of a fine-grained incremental system, and study of other methods should be included in future efforts.

(3) Experimentation in the development of low noise displacement transducers and associated electronics which are dimensionably feasible for inclusion in planetary emplacement packages should continue.

Work on the above will be preparatory to the design of complete systems for inclusion on future, more elaborate, Mars missions.

IV. Appendix A

Computation of sensitivity capabilities and suggested instrument responses.

(1) Variable Discriminator Transducer

The transducer shown in Figure 7 consists of a split-stator variable capacitor with the variable plate coupled to the seismometer mass. The two halves of the capacitor are included in two circuits, which, when the plate is centered, are resonant to the same frequency.

If a signal whose frequency is constant is applied at the inflection point of the resonance curve, an equal voltage is developed across each half of the transducer and no output results. If the movable plate is displaced, the two halves of the transducer move in opposite directions in resonant frequency. Thus the voltage across one will rise and across the other will fall. Operation over a small portion of the resonance curve at the inflection point gives a very nearly linear response.

The output voltage will be

$$E\ \text{out} = Qe_{\alpha} \frac{\Delta d}{d} \qquad \text{Eq. 1}$$

where d = plate spacing

$Q = \frac{\omega \ell}{R}$ of tuned circuits $= \frac{fr}{2(fr-fo)}$

e_o = applied voltage

Δd = change in plate spacing

Note that unlike other capacity transducers the output is multiplied by the Q of the resonant circuit which depends somewhat on its physical dimension; typically it may be near 100.

If we assume

$$d = 1 \text{ mm}$$

$$\Delta d = 10^{-6} \text{ mm}$$

$$Q = 100$$

$$e_o = 10$$

$$E_{out} = \frac{10^{-6} \times 10^2 \times 10}{1} = 10^{-3} \text{ volts}/10^{-6}\text{mm, or } \underline{1000 \text{ volts/mm}}.$$

If we assume a pendulum period of 0.25 second (as in Viking '75) and an applied ground signal of 100 seconds period

Response of the pendulum is

$$\frac{1}{1 + (\frac{Te}{To})^2} = \frac{1}{1 + (\frac{100}{.25})^2} = 6.25 \text{ X } 10^{-6} \text{ of ground motion} \quad \underline{\text{Eq. 2}}$$

where Te = ground period and To = instrument period

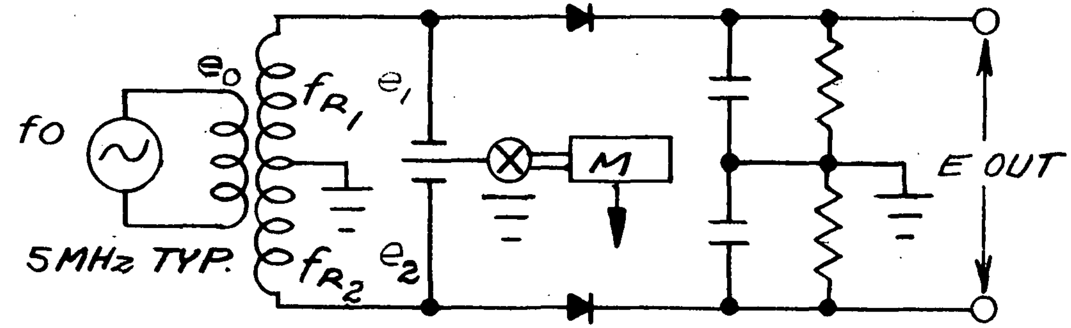
thus a ground amplitude of 10^{-4} mm at 100 second period will result in an output of

$$10^3 \text{ (v/mm)} \times 6.25 \times 10^{-6} \text{ (response)} \times 10^{-4} \text{ (ground amplitude)}$$

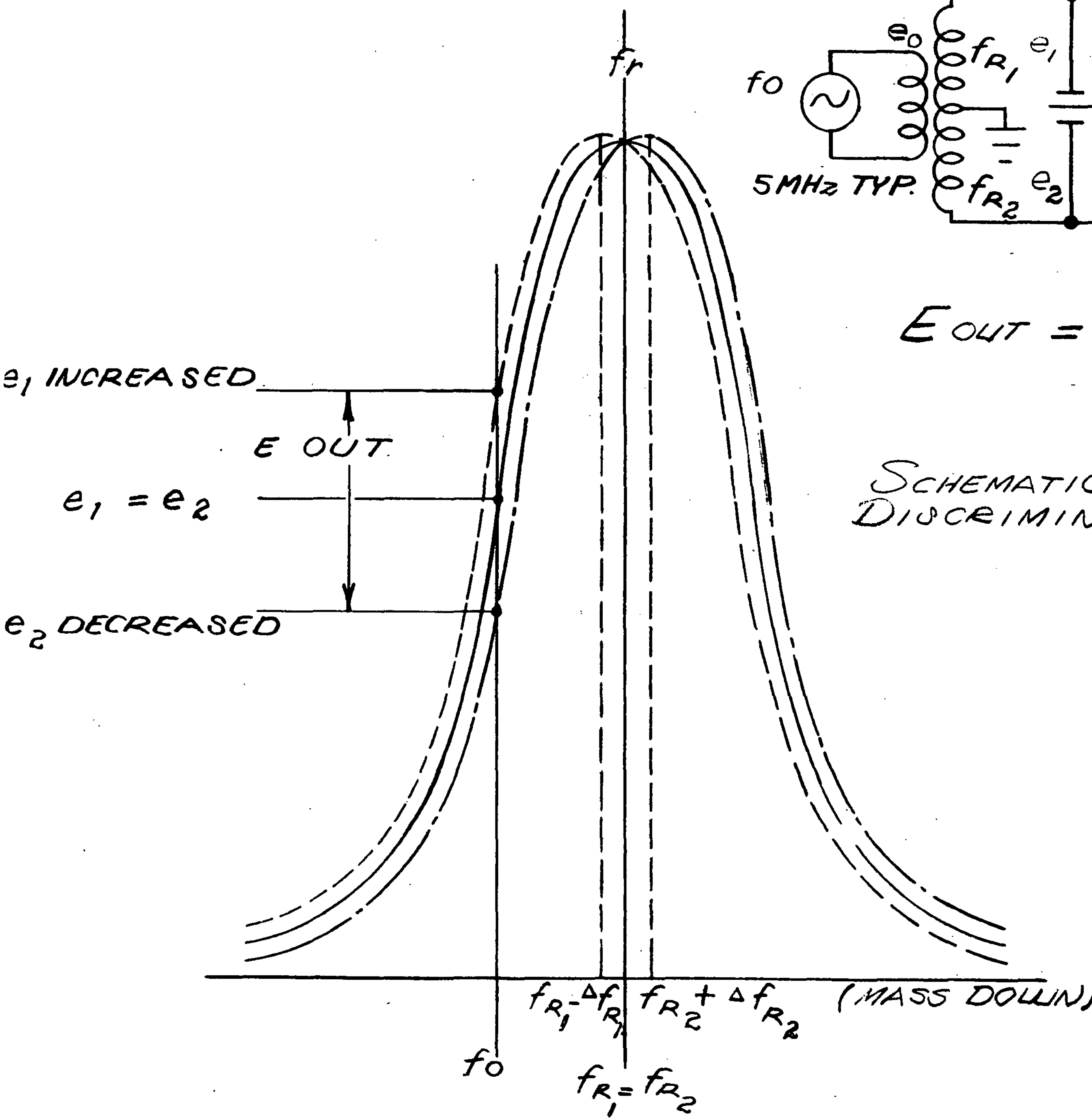
$$= 6.25 \times 10^{-7} \text{ volts or } \underline{.62\ \mu \text{ volts}}$$

At 1200 seconds ground period, a ground amplitude of approximately 1.5×10^{-2} mm would be required for the same output.

In this example, Equation 1 indicates that if the center plate assumes a displacement which produces resonance, a voltage of 1000 V will exist between the center plate and one of the outside plates. The corresponding voltage on the other plate would be 450 volts. These voltages produce unbalanced electostatic forces which add or substract from the spring rate depending upon which side of



$$E_{OUT} = \frac{\Delta d}{d} Q e_0$$



SCHEMATIC OF VARIABLE DISCRIMINATOR TRANSDUCER

FIGURE 7

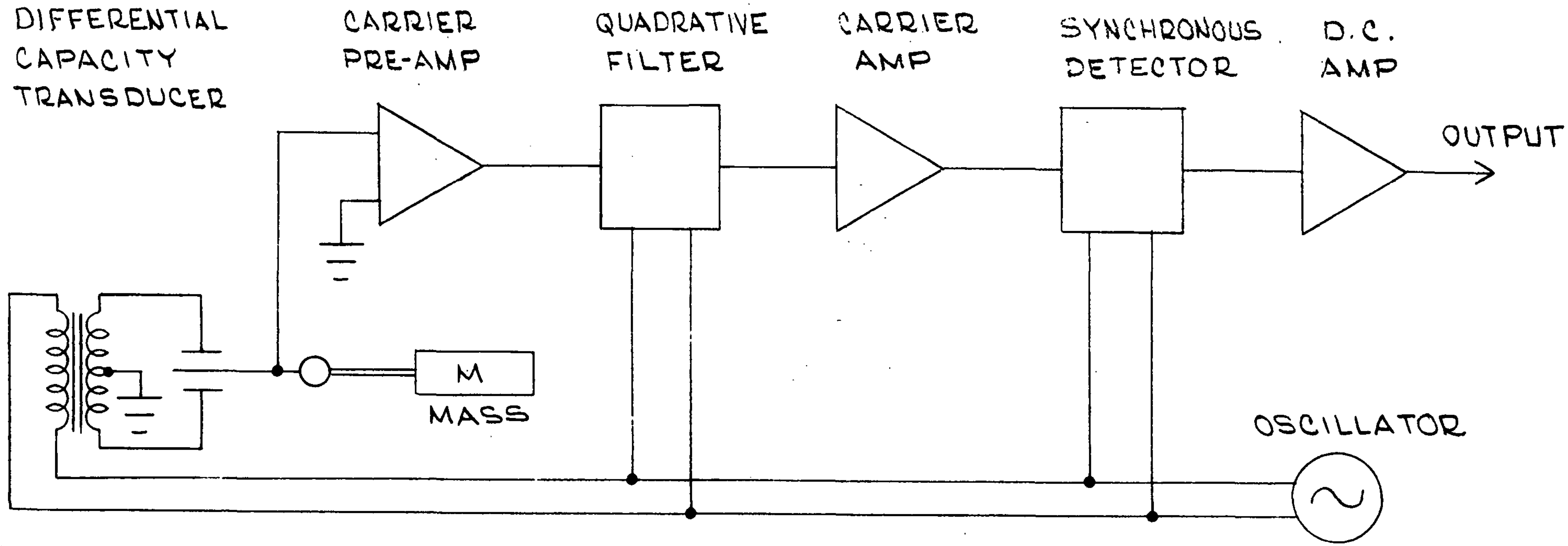
resonance the transducer is tuned. In the example, for capacitor plates of 4 square centimeters in area, the change in period would be approximately 0.1% and the change in extension 0.2%.

An item to be considered with this variable discriminator transducer is that if the Q is high, large off-center conditions may cause the individual resonant curves to cross to the opposite side of the applied frequency, reducing the output to near zero and thus confusing the automatic centering system. This can be corrected by one of several methods.

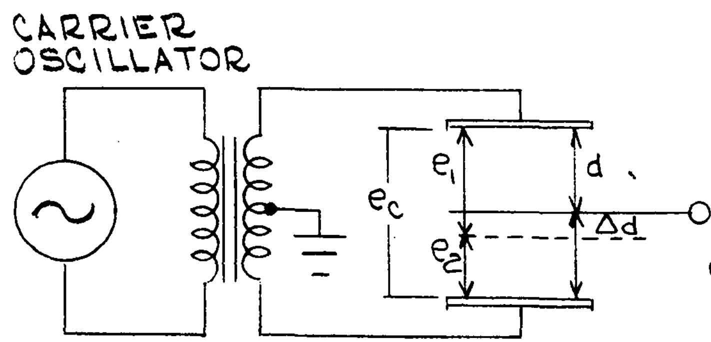
(2) Capacitance Divider Transducer with Synchronous Detector Amplifier

A capacitance divider is shown in Figure 8a and its application as a displacement transducer in a carrier system is shown in Figure 8b. In operation the carrier oscillator excites the transducer and synchronous detector. The transducer modulates the carrier signal in amplitude and phase according to the position of the movable center plate relative to the fixed outer plates.

The advantage of the carrier system is that it uses narrow bandwidth a.c. amplifiers (approaching twice the bandwidth of the information desired) which reduces the internal and external noise and the d.c. voltage drift. There is, in addition, a trade-off between low frequency drift and dynamic range. To minimize the low frequency drift the voltage gain of the carrier amplifiers should be large with little additional d.c. voltage gain required following the synchronous detector. However, for large dynamic range the carrier amplifier gain is kept relatively low to avoid overloading the synchronous detector with the quadrature signal at null. The



(8B)



$$C_1 = \frac{K\epsilon_0 a}{d + \Delta d}$$

$$C_2 = \frac{K\epsilon_0 a}{d - \Delta d}$$

ϵ_0 = DIELECTRIC CONSTANT OF FREE SPACE

K = RELATIVE DIELECTRIC CONSTANT

$$e_1 - e_2 = e_c\left[\frac{C_2 - C_1}{C_1 + C_2}\right] = e_c \frac{\Delta d}{d} \qquad \text{(Eg. 2)}$$

(8A)

CAPACITOR DISPLACEMENT TRANSDUCER AND CARRIER SYSTEM

FIGURE 8

quadrature signal is a function of the capacitance unbalance to ground in the transducer and its excitation transformer, and also due to the extraneous pickup of the carrier signal. Both of these must be kept to a minimum in the fitting of the transducer to the seismometer. The quadrature signal may be reduced by the inclusion of a quadrature filter as shown in Figure 8b.

Comparing Equation 2 for the capacitance divider transducer to Equation 1 for the previously discussed tuned capacitance transducer, it is seen that the output signal for equal displacements is less by a factor of Q for the capacitance divider. Therefore, for the example using the 0.25 second Viking '75 seismometer at 100 seconds, the output voltage would be .006 microvolts. Presently available commercial synchronous detection amplifiers have maximum resolutions of the order of .001 microvolts.

(3) Sensitivity of Viking Seismometer with Velocity Transducer

Output of the Viking seismometer for natural and explosion events at the peak of sensitivity curve shown in Figure 2 is as follows:

(a) Natural event characteristics.

1. Peak of response curve = 5 Hz
2. Pendulum response at 5 Hz = ground amplitude approx.
3. For 10^{-6} mm ground amplitude, ground velocity is 3×10^{-8} M/second.
4. Generator constant is approximately 180 V/M/second thus generated output is 5.4×10^{-6} volts.
5. Taking into account the filter attenuation shown in Figure 2, and the effect of the damping shunt, the

signal appearing at the amplifier input is approximately $.5 \times 10^{-6}$ volts per 10^{-6} mm ground displacement at 5 Hz. Thus with the Viking '75 amplifier a resolution at 1 mμ at 5 Hz is possible.

(b) Explosion sensing characteristics.

Frequencies expected from surface explosions might center about 25 Hz. At these frequencies response of the pendulum is near 100% and the generated voltage will be approximately 2.7×10^{-5}V/ 10^{-6} mm of ground displacement. Taking into account the filter attenuation shown in Figure 2 and the effect of the damping shunt, voltage appearing at the amplifier input will be of the order of 60×10^{-6} volts. Thus with the Viking '75 amplifier, resolution of ground motion will approach 10^{-8} mm.

Work performed in 1963 at Caltech under NASA Grant NAS w-81 related to a lunar active experiment, indicates that an explosion of 1 oz. of high explosive on an alluvium surface at 2000 ft range will give a ground amplitude of approximately 3×10^{-7} mm ("Experimental Ground Amplitudes from Small Surface Explosions", Kovach, Lehner, Miller, Geophysics, Oct. 1963).

V. Appendix B

Resolution and bandwidth capabilities of seismic instrumentation for planetary exploration depends greatly on weight, volume, and power limitations.

Without reasonable knowledge of the constraints which will be placed on advanced Viking instrumentation, it is not possible to accurately assign values to these items.

Figure 3 and Table III show approximate values for previously designed devices. It is felt that the instrumentation characteristics proposed herein for an Advanced Viking system can be easily met within the dimensions listed.

Appendix B

Table III. Comparison of Planetary Seismic Instrumentation.
. The following are approximate values.

	Ranger	Surveyor (Lamont)	Surveyor Follow-on (Caltech)	Apollo	Viking	Advanced Viking
Seismometer only Weight	8 lb	20 lb	8 lb	15 lb	10 oz.	2 lb.
Components	Z only	X,Y,Z	X,Y,Z	X,Y,Z	X,Y,Z	
Package Weight	50 lb.	40 lb.	10 lb.	20 lb.	3 lb.	12 lb.
Package Volume	1 ft^3	1 ft^3	1/2 ft^3	1/2 ft^3	1/8 ft^3	.5 ft^3
Power Requirement	200 mw		0.5 w	7 w	4 w	25 w
Ground Motion Resolution	10^{-6} mm	10^{-6} mm	10^{-6} mm	10^{-6} mm	10^{-6} mm	10^{-8} mm
Peak of Period Response	0.2 sec. 1.0 sec.	0.2 sec. to 15 sec.	0.2 sec. and 20 sec.	0.2 sec. to 15 sec.	.25 sec. .5 sec. 1 sec. 2 sec.	various .04 - 500 sec.
Usable Spectrum	.1 - 20 sec.	.1 to 100 sec.	.1 to 100 sec.	.1 to 100 sec.	.1 to 10 sec.	.01 to 1200 sec.