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DEVELOPMENT OF A REFLECTANCE SPECTROMETER
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CENTER FOR SPACE RESEARCH
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Final Report to the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

for the

Preliminary Design and Development of a Reflectance Spectrometer Instrument

Contract # NASW-3008 January 19, 1979

FINAL REPORT

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Submitted by the

CENTER FOR SPACE RESEARCH

of the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

January 19, 1979

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I. INTRODUCTION

In July of 1975, MIT submitted a proposal to NASA for a Surface Mineralogy Experiment for the Lunar Polar Orbiter (LPO). This experiment measures the reflected solar spectra of surface soils to determine the presence of absorption bands that are diagnostic of the types and amounts of the constituent minerals and glasses. The MIT proposal was accepted in the spring of 1976, but flight instrument development was delayed pending Project approval by NASA.

In July of 1976, MIT submitted an independent proposal to NASA for SR&T support for the preliminary design and development of a Reflectance Spectrometer Instrument (RSI) for use on spacecraft orbiting terrestial bodies such as the Moon, Mars, Jupiter, etc. This proposal was accepted by NASA and a contract (#NASW-3008) negotiated with MIT. This report constitutes the Final Report as required by Article XIII of that contract.

II. CONTRACT HISTORY

Since the work completed by MIT was affected by the contract itself, a short history of the contract is necessary to understand the direction of the work performed. As mentioned above, MIT submitted in July 1976 a proposal for the preliminary design and development of a reflectance spectrometer in the amount of $260,000 for a twelve-month period. This proposal was subsequently negotiated at $238,850. Some difficulties were incurred at NASA in issuing a definitive contract. Hence, precontractural coverage was negotiated each month to cover the months of November and December, 1976, and January and February of 1977. On February 25, 1977, NASA Headquarters directed the termination of LPO studies and the phase-out of SR&T support for related instrumental development. On March 16, MIT submitted a revised proposal in the amount of $90,000 to complete the phase-out of the RSI work. The contract with MIT was negotiated at $89,800 and signed by NASA on April 14, 1977, with an expiration date of May 31, 1977.

Two points should be noted in this history. First, the total period of time from the start of funding (Nov. 15) to the notification of termination (Feb. 25) was only 3½ months compared to the twelve month period anticipated in the proposal. Secondly, the tentative nature of the contract, as evidenced by the monthly pre-contractural funding, caused MIT to concentrate its resources on design personnel rather than breadboard development and equipment. These two points resulted in a focusing of effort on the design aspects of the instrument, with only limited laboratory testing of some hardware components.

Laboratory verification of the design concepts has not yet been accomplished.

III. TECHNICAL RESULTS

The work performed under contract NASW-3008 for the preliminary design of a Reflectance Spectrometer Instrument (RSI) has, in general, fallen into a few broad categories: a) Review and verification of the basic concepts and designs presented in the original (July 75) reflectance spectrometer proposal for the Lunar Polar Orbiter mission (Figure 1); b) Preliminary instrument design and trade off analyses; c) Investigation of the minimum modifications to the basic instrument in view of the significant parameter changes required for application of the instrument to other terrestial bodies; and d) Specification preparation and, in some cases, procurement of subsystems for a breadboard version of the RSI and laboratory equipment for its testing.

A. Optical Design

The main area of work in the optical design was related to the investigation of the changes in the instrument if it were to be applied to other missions. In particular, NASA had indicated preliminary plans for Jupiter orbiter, Mars orbiter, and comet flyby Missions. An RSI type experiment would be well-suited to each of these missions, as well as the original LPO. The need for a larger input mirror to compensate for the reduction in solar flux at Mars or Jupiter was obvious. In addition, however, scientific inputs from planetary astronomers indicated that the bandwidth of the RSI had to be extended to 5.0 μm (from 2.5 μm) to permit, for

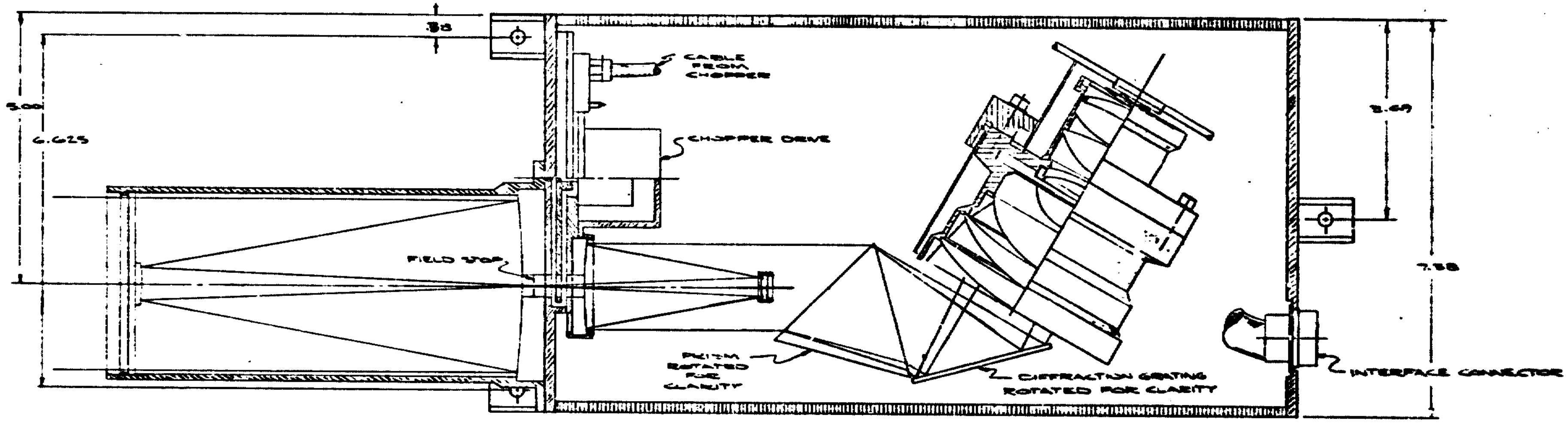
.38
5.00
6.625
CABLE FROM CHOPPER
CHOPPER DRIVE
FIELD STOP
3.69
7.38
PRISM ROTATED FOR CLARITY
DIFFRACTION GRATING ROTATED FOR CLARITY
INTERFACE CONNECTOR

FIGURE 1

example, measurements of water ice in the Jovian satellite system.

Two optical designs were explored to obtain this extended bandwidth. The first design was to respecify the grating and prism and thereby obtain the entire 0.35-5.0 µm spectrum in one optical path. Although this approach results in low weight and volume, it was technically unfeasible due to the requirements it put on the refocussing lens. The second approach involved using a beam splitter (dichroic filter) to separate wavelengths above 2.5 µm and use a separate optical train and detector array to measure this radiation. The main optical path remained unchanged from the earlier design, with the addition of the beam splitter.

Subsequent work on this design has resulted in further changes. We discovered that a dichroic filter with 2.5 µm transition wavelength will begin to absorb radiation below about 1 µm. In addition, as discussed in the original proposal, the design of a refocussing lens with an f number = 1 over the 0.35-2.5 µm bandwidth proved to be very difficult. We then converged on a basic design whereby the two optical paths contain radiation in the range 0.35-1.0 µm and 1.0-5.0 µm. This reduces the constraints on the refocussing lens and has additional advantage that the two detector arrays are now more logically separated, in that one array consists only of Si detectors while the second (cooled) array consists of PbS and PbSe detectors.

At this point in the design, further scientific inputs were received which indicated a requirement for simultaneous spatial and spectral information for some missions. Since the echelle-type spectrometer cannot be modified to obtain spatial information, we changed the basic optical design to one which uses multiple optical beams, each containing one octave of spectral information, with a separate refocussing lens and detector array for each beam. The multiple beams are formed via a series of dichroic filters and beam splitters. Since each beam is only one octave, there is no longer any problem with multiple orders from the diffraction grating and, hence, the prisms can be eliminated. If the circular entrance aperture of LPO is changed to a rectangular aperture, the second dimension of each detector array corresponds to different spatial elements of the observed target region. Hence, each detector array now provides spectral information along one dimension, and spatial information along the other.

There are no technical limits to spectral or spatial resolution. However, if 20 spatial resolution elements are assumed, the total number of detectors (and associated electronics) for a 250 spectral channel instrument is 5000. Therefore, it is assumed that for any given mission, only a small subset of possible spatial-spectral channels will be implemented. The mechanical layout for this design is shown in Figure 2.

After this basic instrument concept was finalized, we began the selection of materials and components for the laboratory evaluation. For example, the material used for the lens in the 2.5-5.0 μm band must not only have a high transmission but also a high resistance to the radiation enviroment encountered at Jupiter. While fused quartz does have a high radiation resistance, it begins to absorb for wavelengths above 3.5 μm. A search was initiated for data on the radiation properties of materials which have a high transmission in the infra-red, such as calcium fluoride, barium floride and magnesium oxide. Also, considerable effort was expended to find laboratory equipment (in particular the monochrometer) which is suitable to our wide bandwidth, low resolution application. The equipment selection was completed by the end of the contract but not purchased.

Finally, it was realized early in the program that the light chopper subsystem is independent of the other changes in the basic optical design described above. Therefore, this subsystem was studied in more detail and a Bulova tuning fork light chopper was selected and purchased. Laboratory tests of this unit have been successfully carried out.

B. Electrical Design

Work was performed in three separate areas of electrical circuit design: signal detection, signal processing, and interface/control. Furthermore preliminary

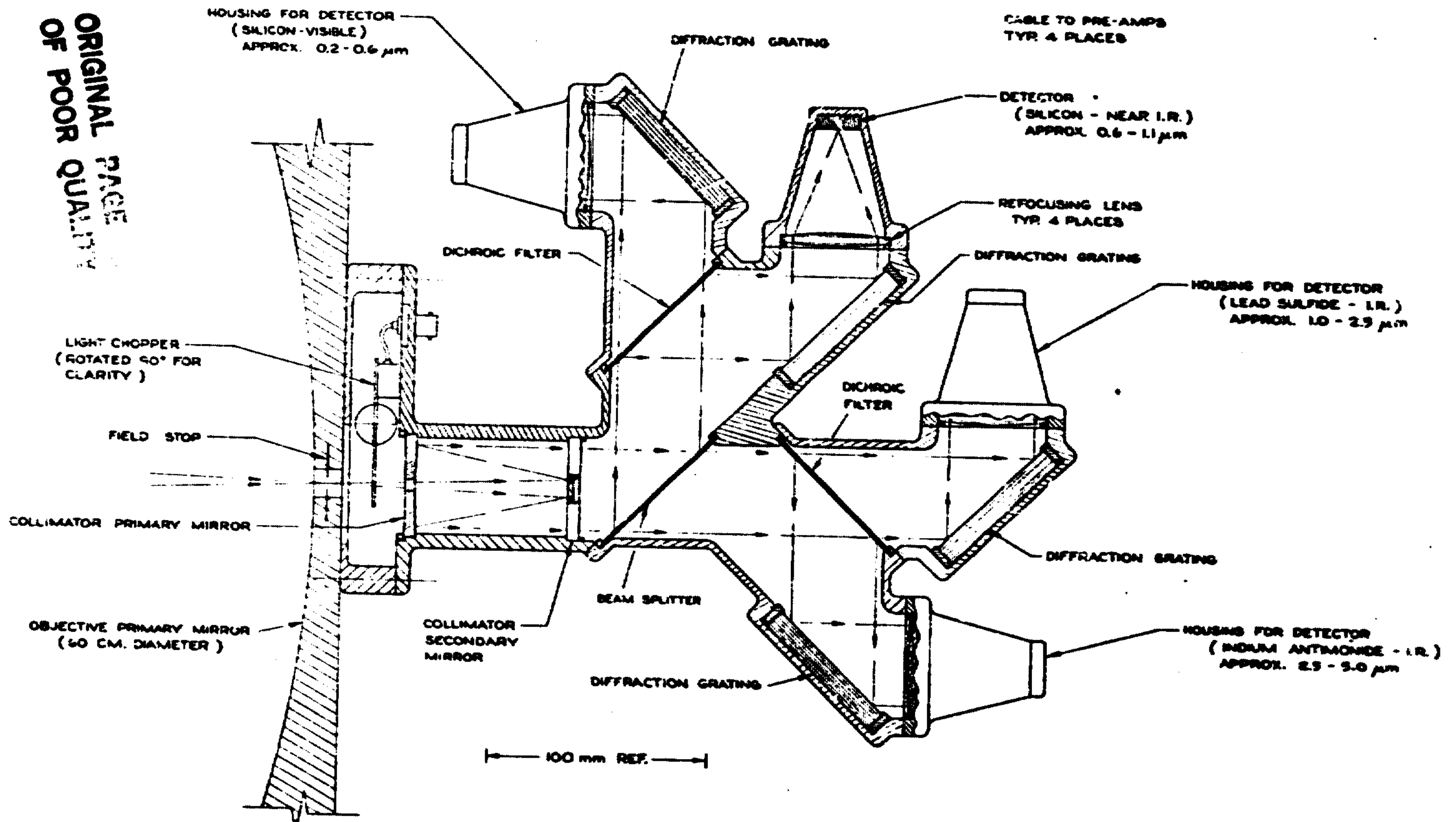
HOUSING FOR DETECTOR (SILICON-VISIBLE) APPROX. 0.2 - 0.6 μm
DIFFRACTION GRATING
CABLE TO PRE-AMPS TYP. 4 PLACES
DETECTOR (SILICON - NEAR I.R.) APPROX. 0.6 - 1.1 μm
REFOCUSING LENS TYP. 4 PLACES
DIFFRACTION GRATING
HOUSING FOR DETECTOR (LEAD SULFIDE - I.R.) APPROX. 1.0 - 2.5 μm
DICHROIC FILTER
LIGHT CHOPPER (ROTATED 90° FOR CLARITY)
DICHROIC FILTER
FIELD STOP
COLLIMATOR PRIMARY MIRROR
DIFFRACTION GRATING
BEAM SPLITTER
OBJECTIVE PRIMARY MIRROR (60 CM. DIAMETER)
COLLIMATOR SECONDARY MIRROR
HOUSING FOR DETECTOR (INDIUM ANTIMONIDE - I.R.) APPROX. 2.5 - 5.0 μm
DIFFRACTION GRATING
100 mm REF.

FIGURE 2

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DETECTOR ASS'Y
REFLECTANCE SPECTROMETER
D
80230

specifications of the silicon and lead sulfide detector have been made. Units of each type have been procured, with NBS-traceable spectral calibration data supplied for one of the silicon detectors.

Two separate preamplifier designs for signal detection have been carried forward. The first is a transconductance approach which is quite common in IR work. Biasing may or may not be incorporated into the resistive feedback network which determines the preamplifier gain. The second approach shown in Figure 3 involves a charge-amplifier configuration which offers the possibility of some minor improvements in both noise and packaging. (The noise improvement comes from the substitution of an imaginary gain impedence -- the charge integrating capacitor -- for the real gain impedence of the first approach. If the detector bias problem is complicated as a result, however, the improvements in system performance may similarly turn out to be imaginary.) Both designs are optimized for the lead sulfide detectors, since the common optical design results in an overabundance of signal for the silicon detectors ($\lambda < 1\,\mu m$).

The preamplifier design is, in any event, prejudiced by the need to hybridize the final product. One would like to use biasing and gain resistors in the megohm range. Thick film resistors of this value develop excess noise related to the voltage stress across them while thin film resistors become unsuitably large. Similarly, capacitors tend to be large to start with, and for stable types this is especially ture. Power consumption is not a problem since impedence matching for minimum noise figure dictates low bias currents. The final choice of basic configuration, not to mention final parts selection, must await electro-optical testing since we have often discovered that system considerations tend to dominate the theoretical.

The signal processing design has also proceeded through initial specification. A single hybrid package is required to amplify (adjustable, but typically by a gain like 10), synchronously demodulate at 400 Hz, integrate for 1 second, and hold for 100 milliseconds. It must have a dynamic range of 96 dB while consuming no more

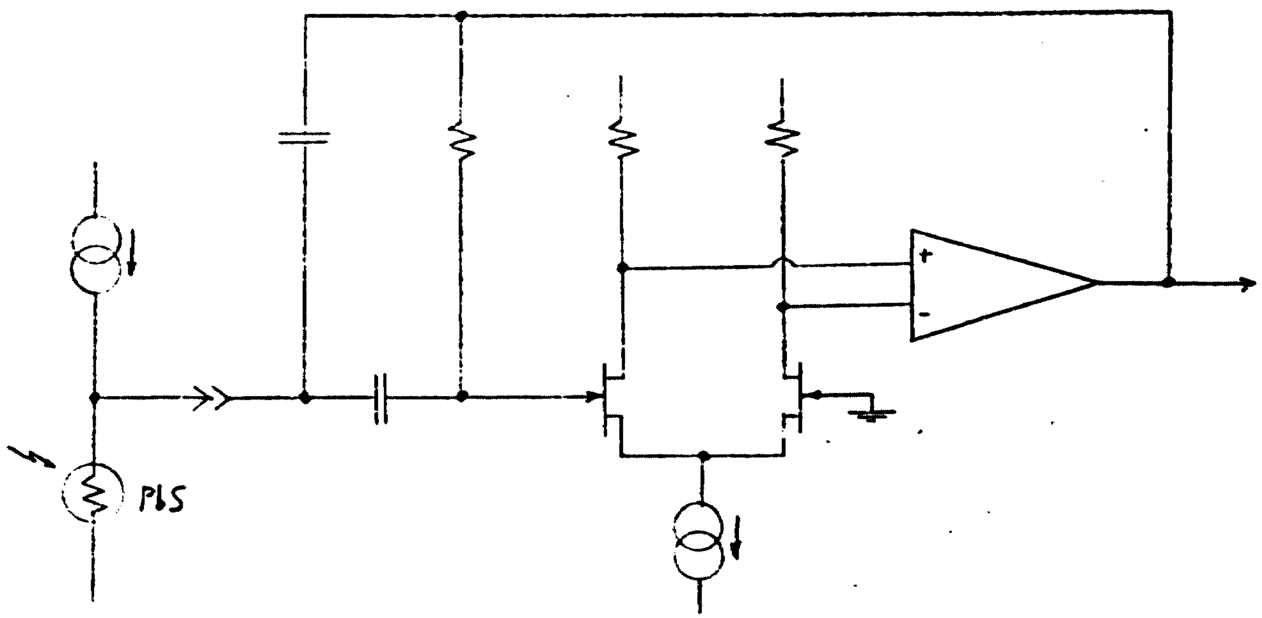

FIGURE 3

CHARGE AMPLIFIER

than 10 mW of power. We have breadboarded one and designed a second circuit to meet these criteria. The difference between the two designs lies in the integrate-and-hold functions. The breadboarded version (see Figure 4) uses a standard analog operational-amplifier-with-a-big-capacitor approach. The capacitor -- a polycarbonate, currently, though polystyrene might ultimately prove a better choice -- must reside outside the hybrid creating both physical and electrical (noise) problems; the power budget is well in hand. Although one can easily conceive of automatic drift compensation circuitry which would allow use of much smaller integrating capacitors, the circuit complexity rapidly exceeds prudent limits for hybrid manufacture.

In parallel with this lab effort we have developed a numerical analysis program on our HP 9820 calculator to investigate the problems of component variations. The driving concern here is the 96 db dynamic range requirement. At these accuracies it is far easier to separate out the different error sources by simulation than it is to do so in the lab.

The computational model used for this analysis is shown in Figure 5. Only first order error terms are dealt with, but those are many and varied. The operational amplifier model includes input bias current, the input offset voltage, and the frequency dependent open loop gain. With the exception of the offset voltage, these parameters are (fairly) linear functions of the amplifier quiescent current which, in turn, is constrained by our power budget. Another interesting trade-off is present in the reverse capacitance of the demodulation FET. A switch with low "ON" resistance, hence lower DC demodulation errors, has a higher reverse channel capacitance (in the OFF state) than a less perfect switch. The channel capacitance (in parallel with the input capacitance of the operational amplifier) causes phase shift errors in the demodulation process which are non-linear. The analysis program is now available as a tool to be used in conjunction with a breadboard to optimize the design for specific operational parameters.

It was in an attempt to alleviate potential packaging problems that the second

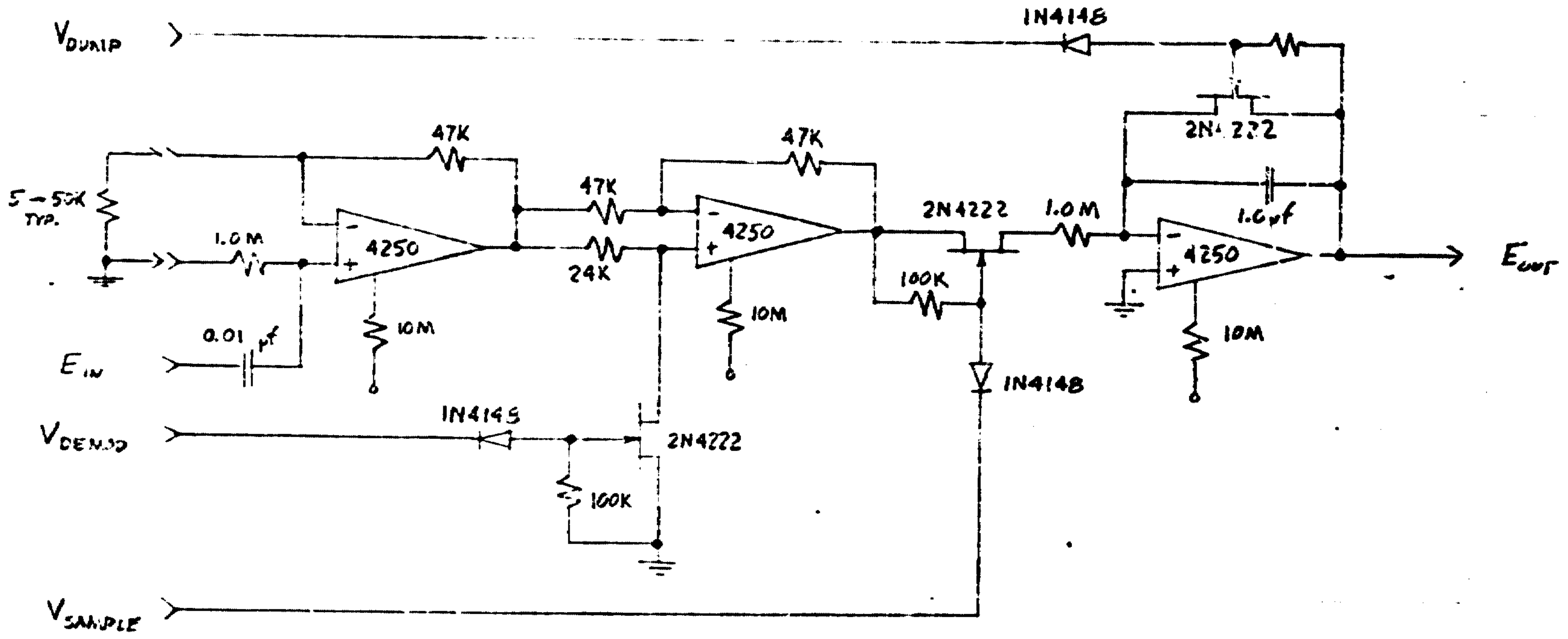

Figure 4

Amplifier/Demod/Integrator

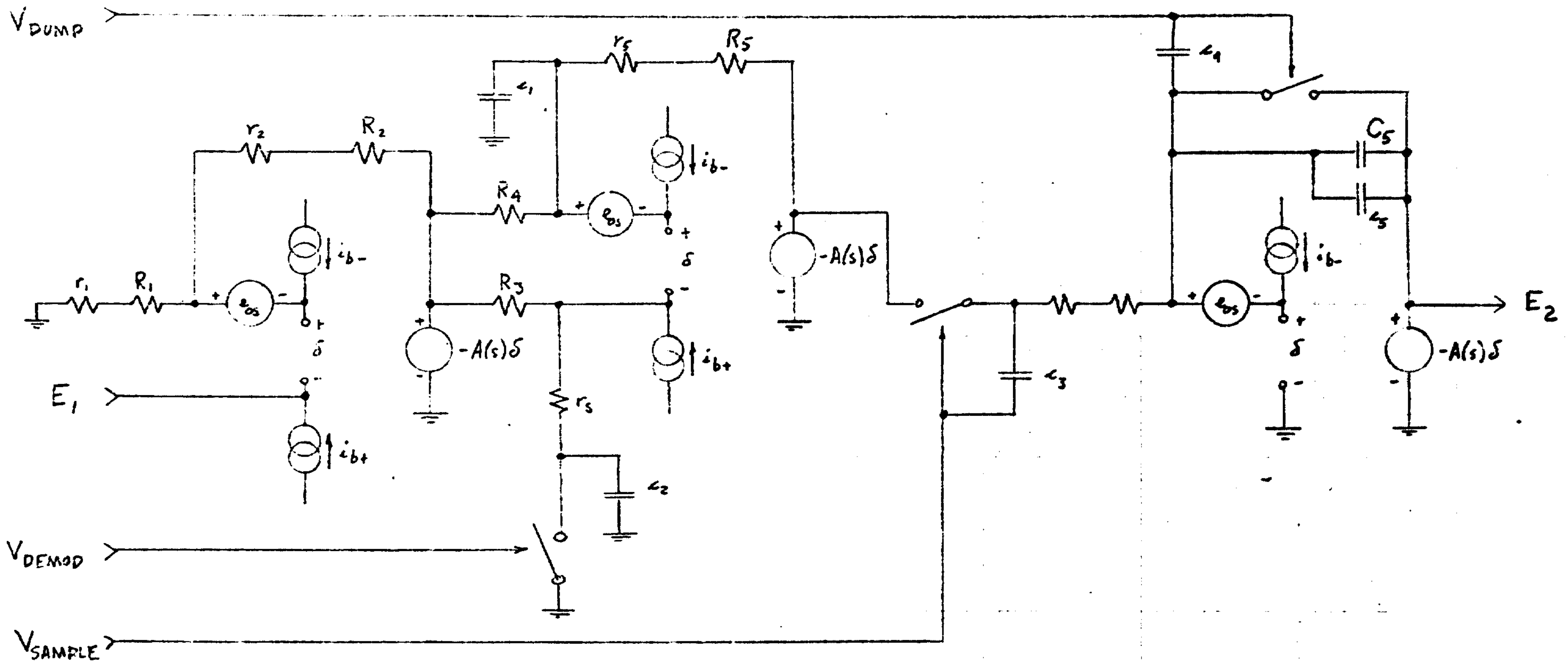

FIGURE 5

COMPUTATIONAL MODEL OF
AMPLIFIER/DEMOD/INTEGRATOR

design was undertaken. This design uses a voltage-to-frequency converter inside the hybrid, with the required 16 bit counter needed to complete the integrate-and-hold function located elsewhere. The design was not entirely successful, since the unit power came out at 20 mW. Nevertheless, the approach is not yet rejected in that factors of 2 are often attainable on a second iteration. Much of the numerical analysis work done for the first approach will also be applicable here.

It was not our intention originally to concern ourselves with interface and control problems, since these are highly mission dependent. In the course of designing a test facility for use with various detectors and associated electronics, however, it became clear that we were going to have some data accumulation and number-crunching problems. The most obvious example is the need to normalize the detector response to account for temporal changes in the illumination source. To establish detector noise performance, furthermore, one would like to combine many samples taken over some reasonable period of time. Our solution to this was to begin bringing on line a micro-processor controlled test system to make reference measurements, take test data, and print our normalized averages and deviations. Since we could use an RCA 1802 processor which was already available, and since this is one of the candidates for use in the JPL Unified Data System, the experience is providing a solid basis for evaluating the effects of particular mission requirements upon the hardware under design.

In work done in the CSR Man-Vehicle Laboratory an interactive computer language called STOIC (A Stack Oriented Interactive Compiler) was written for Nova minicomputers and the Intel 8080 microprocessor. STOIC is an extensive language, permitting the user to create high level instructions based upon user generated word definitions of arbitrary sophistication. In its most basic form these word definitions are written in the machine language of the host processor. It is at this level that input-output routines, elementry mathematics, and timing loops are generated. Since STOIC acts as an interpreter in response to operator commands in real time, it is an excellent tool for running a laboratory test facility. We have written the language onto our 1802 processor and verified its input-output performance.

IV. SUMMARY

The work performed under contract NASW-3008 was related mainly to the design of an RSI which could be used on various terrestial body missions. Considerable improvements over the original LPO design were incorporated into the final system. These include a larger entrance minor, rectangular aperture, multiple optical beams, spatial resolution, and a bandwidth extension to 5 μm. In addition, detailed electronic designs were produced for a charge amplifier and an amplifier/demodulator/integrator. Design of a micro-processor driven test system was begun. Laboratory tests were performed on a tuning-fork chopper and prototype detectors were purchased, although not received before the termination of the contract.

V. RECOMMENDATIONS

Further work is clearly necessary to verify and complete the optical and electrical designs. We recommend that additional support be provided to permit the construction and testing of a laboratory breadboard.