FINAL TECHNICAL REPORT

for

National Aeronautical and Space Administration

Grant NGR 14-001-103

Entitled

"Advanced Technical Developments in Support of Scientific Experiments in Space."

Submitted by

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Headquarters
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Washington, D. C. 20546

Attention: Dr. Albert G. Opp, Code S.G.

Dear Dr. Opp:

I would like to take this opportunity to follow up on our conversation concerning some of the technological developments which have been carried out at the University of Chicago under NASA sponsorship and particularly those which were supported by Grant Number NGR-14-001-103, our so-called "Technology for Science" Grant.

First, let me summarize those developments which were a direct outgrowth of the Technology grant. They include:

A. A technique for preparing solid state lithium drifted silicon detectors (Figure 1) in the form of spherical segments. Detectors in this form were initially designed to provide improved energy loss resolution for separating nuclear species of charged particles. Results of this investigation have been published in Nuclear Instruments and Methods 68 (1969) 149-152, M.A. Perkins, J. J. Kristoff, G.M. Mason and J.D. Sullivan. These detectors were first used in our Imp 6 Main telescope and subsystem telescope. Their responses have been evaluated using particle accelerators at Chicago, Langley and the Princeton-Penn facilities and the predicted responses verified.

A further development of these detectors has led to the small fission detector system incorporated in the Pioneer 10 for detection of energetic ($\geq$ 30 MeV) protons in the Jovian radiation belts and in the Imp 6 subsystem as a prototype evaluation in the earth's belts.

The curved detectors are being used in the telescope systems of IMP H and J, Pioneer F/G and the Mariner Mercury '73 instruments.

B. Hollow cylindrical lithium-drifted silicon detectors such as that shown in Figure 2 have been built and tested for possible use as anti-coincidence shields to replace the conventional plastic scintillator and photomultiplier. However, the supply of silicon of sufficient diameter having the proper physical characteristics has become extremely limited. A new "low energy telescope" whose design was a result of investigations of RTG radiation interference for the Pioneer program, is being built to include a smaller cylindrical detector than those first investigated. These telescopes will be flown on IMP's H and J, Pioneer and Mariner '73.

C. A "Fission cell" system has been developed which is being flown in the Pioneer F/G instruments and in the IMP-I subsystem. These cells utilize a thorium foil sandwiched between a pair of spherical segment lithium drifted silicon detectors. The radius of curvature of the detectors is selected such that a proton whose path lies within the active region of the detectors cannot traverse a distance great enough to deposit energy equivalent to a fission fragment emitted from the foil. This arrangement makes it possible to discriminate fission fragments from an intense background of lighter charged particles. The system for Pioneer is designed to respond to fission fragments resulting from protons of energies greater than 50MeV in the radiation belts of Jupiter.

D. An "Electron Current Detector," formerly called the "Egg" was developed for Jovian belt measurements of the electron flux. A prototype was included in the IMP I subsystem. This detector system is designed to provide measurement of fluxes of particles which are in excess of those which may be evaluated by discrete event counting techniques. The system is composed of a solid state detector surrounded by a berrylium shell to provide secondary radiation. In a flux of electrons, the detector has induced in it ionization currents which are proportional to the electron flux. It provides for an analog measurement of fluxes over a dynamic range of 6 to 8 orders of magnitude. The system is operated at low temperature by passive thermal control techniques, preferably between -50 and -10°C. At the low end of its dynamic range, it overlaps digital counting capability by 1 to 2 orders of magnitude to allow a smooth transition of measurement such as in the Jovian belt passage.

A number of new circuits and devices were developed under this grant for purposes of improving instrumentation performance and for further miniaturization. These are described below.

A. A molecular oxide-silicon (MOS) block containing a four binary bit counter and four bit shift register was developed in conjunction with American Microsystems, Inc. of Santa Clara, California. This device was to be compatible with a series of devices under development by the Goddard Space Flight Center for the IMP spacecraft. The device was developed as a modular unit in which one could utilize from 1 to 4 bits per device in an add-on approach to construct instrument data words. This device has been flown in the IMP G and IMP I, and is being used in the IMP's H and J.

B. A "Count-shift register," American Microsystems, Inc., part No. S1694 or S1646, (depending upon their packaging), was developed for compact, low power data accumulation and temporary storage. These devices, like the four bit devices (A above) were designed to be cascaded in an add-on fashion, with the capability of serial or parallel input and output, thus providing a highly flexible data accumulation system. These devices are being used in the Pioneer F/G program and in Mariner '73. They provide a comparatively economical binary system (about 1/8 the cost of comparable discrete component designs of equivalent performance capability), with a significant miniaturization factor (about 10/1). This device is being commercially marketed by American Microsystems. One of their data sheets is attached.

C. An electronic circuit (preprint attached) has been developed which provides overall dynamic signal handling capability exceeding 10,000 to 1. The system is so designed that the overall gain is adjustable in a series of ramps of the desired slope to accommodate the necessary signal resolution at each level of input signal. This design allows a more complete capability of exploiting the linear response range of silicon particle detectors to particles of high nuclear charge (Z of 50 or more). The circuit design has been adapted to thick-film microcircuit techniques as well as discrete component applications. In the thick film version, selected component attachment points are provided to allow trim of the gain and knee points. These circuits have been flown successfully in the IMP V and VI and are being employed in IMP's H and J, Pioneer F/G and Mariner '73. Further, the designs have been made available to other experimenters on request, namely, the Bendix Corporation for possible use in the HEAO program.

D. A crystal stabilized, free running clock has been developed which is capable of providing the necessary timing to one or more pulse height analyzers simultaneously. The clock is designed for operation at frequencies of from 0.5 megahertz to several megahertz. This clock is stable to 0.2% over a temperature range from -20°C to +50°C. It is described in detail in the attached preprint. This circuit design also is available in thick film or discrete form.

E. A height to time converter (htc) system was developed in thick film microcircuit form. This system is provided with a dynamic range comparable to the multiramp amplifier system described under C. above. The htc, and clock, together with suitable binary counters such as the American Microsystems 8 bit count/shift register compose the pulse height analyzer systems used in our IMP I, H and J, Pioneer F/G and Mariner '73 cosmic ray instruments.

F. A quasi-logarithmic binary counting system was developed (LASR Preprint attached) for purposes of data compression. This system has been extensively evaluated in laboratory breadboard form for possible use in future missions.

G. A height to time conversion system was developed which provides a digital equivalent to the multi-ramp amplifiers and linear HTC described above. The principal advantage of this system lies in the fact that the ramp functions are digital and therefore not subject to the same drifts as might be encountered in analog circuits. This system has been laboratory evaluated and had been seriously considered for use in the Pioneer F/G instruments. However, the question of long term reliability of COSMOS devices which were to be used in the digital scaling and gating system precluded use of this design at the time the instrument designs were frozen. The system does have highly attractive potential for future applications.

H. A thick film dual output pulse height discriminator was developed in conjunction with Circuit Technology Inc. These devices are being used in the IMP, Pioneer and Mariner projects, since they require less space and weight than their discrete component counterparts.

I. A thick film, 4 element nand gate was developed for general use in cooperation with Circuit Technology, Inc. This device is intended for uses where its compactness is an advantage.

J. Time of Flight measurement techniques to be used in high energy electron experiments was begun under this grant. The time of flight system is designed to discriminate between relativistic electrons and heavier particles of comparable energy travelling at lower velocities.

The following general developments and investigations were also carried out under the Technology grant.

A. In conjunction with the LASR Data Systems and Analysis Group, a study was undertaken to determine the feasibility of using a small computer as the main component of an instrument ground support equipment system. A survey of available small computers resulted in the selection of the Varian 620i. This computer, together with suitable interface circuity and input-output devices such as a teletypewriter and incremental tape recorder could provide a more flexible, complete and rapid evaluation of complex instrument performance than the usual system tailored to each instrument. Further, the computer itself could be reused in future programs, thus reducing the overall outlay of funds and effort over the long run.

Two such systems have now been built, one for the IMP I, H and J program and the other for Pioneer F/G. In both cases, the systems have more than fulfilled expectations concerning their utility.

In one instance, one of these systems was used to verify the complex logic functions to be incorporated in the Pioneer instruments. It demonstrated a capability of performing tests on some 2^{15} logical combinations in approximately 30 seconds, a job which would have required several days, if performed by hand.

In other uses, these systems have significantly reduced the time required to perform cyclotron calibrations of the instruments, eliminating the need to collect data on magnetic or punched paper tape to be later reduced by a larger and less accessible computer.

Other applications to be performed by these systems remain to be explored at a time when they are not completely occupied in instrument test activities.

B. A detailed investigation of the interference effects to be encountered by cosmic ray instruments in the presence of Radioisotope thermal generators was undertaken in anticipation of the use of RTG's on Pioneer F/G and the outer planets missions. While this study was primarily aimed at a determination of the methods and quantities of shielding required to reduce interference to an acceptable level, the ultimate outcome was a new telescope design concept which required no shielding. This telescope design is the one which utilizes the small cylindrical detector described in the first section of the report.

C. The use of RTG's aboard Pioneer F/G and the anticipated flux levels in the Jovian radiation belts led to concern for the survival of electronic components to be used in such environments. This concern particularly centered around the use of MOS circuity which was reputed to be considerably more susceptible than most bipolar or passive components, with the possible exception of quartz oscillator crystals. The crystals reportedly were highly susceptible to damage. A series of tests were arranged in cooperation with the

Hughes Aircraft Corporation in Fullerton, California, in which representative circuits and devices were exposed to intense radiation in a Co^{60} source. The irradiations were carried to levels of 10^7 Rad (silicon) while the test specimens were in operation and their performance being monitored.

The tests revealed that the MOS circuits developed under this grant withstood up to 3×10^5 rads dosage before failure. This is approximately 2 orders of magnitude greater susceptibility than that exhibited by most bipolar devices but is considered adequate for the Pioneer mission. The quartz crystals were determined to remain stable to within 0.01% over 10^7 rads. COSMOS devices, on the other hand showed significant damage between 10^3 and 10^4 rads, thus further mitigating against their use in Pioneer.

In addition to the above summary of developments specifically related to NASA Grant NGR-14-001-103, a number of other developments, which have resulted from NASA support of the Laboratory, should be mentioned. These include:

A. The first all solid state silicon range-energy loss telescope was flown aboard Discoverer XXXVI in 1961. This instrument was a precursor to systems subsequently used in the Imps 1, 2, 3, 5, 6, OGO's 1, 2, 3, 4 and 5, Mariner IV, Pioneers 6, 7, 10, and to be used in Pioneer G, Imps H and J and Mariner '73.

B. The development of solid state detector, and electronics technology in support of our cosmic-ray programs made possible the development of the Alpha Scattering Instruments flown on Surveyors 5, 6 and 7, which provided the first detailed chemical analysis of the lunar surface.

C. The development of solid state silicon photodiodes used in conjunction with cesium iodide scintillators as a replacement for photomultiplier tubes. This arrangement not only allows a more compact telescope design, but it provides a significant improvement in the long term and thermal stability of total energy and energy loss elements over that which might be obtained using photomultipliers.

D. A low power complementary digital binary circuit was developed in the early 1960's which became a widely used design in all of our digital counting applications. This circuit was redeveloped in thick film form by Circuit Technology Inc., to afford a miniaturization factor of 4/1. By agreement with CTI these devices may be manufactured for any user who may have applications. While some interest has been shown by Cal Tech and others, their main uses have been by Chicago in the Imp, OGO 5 and Pioneer programs.

E. Solid state silicon detectors have been made available to Professor A. V. Crewe, Dean of the Physical Sciences Division of the University for use in the scanning electron microscope systems which he is developing. These detectors, approximately, 1 cm in diameter, have a small hole in the center through which the electron beam passes to illuminate the sample. The detector is then used to monitor the intensity of electron backscatter from the sample and to measure the energy of the backscattered electrons.

F. The techniques of solid-state detector manufacture have been taught to personnel from the University of Maryland to enable them to fabricate detectors for their own needs.

The above summarizes many of the developments in technology which have occurred at Chicago during our participation in space-flight and balloon flight programs under the sponsorship of NASA.

Very truly yours,

James E. Lamport

James E. Lamport
Technical Services Manager

Enclosures