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PROTOTYPE INSTRUMENTATION AND DESIGN STUDIES

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13. ABSTRACT *(Maximum 200 words)*
A flight prototype electrostatic analyzer (ESA) system has been constructed and is scheduled for a shuttle (TSS-1) mission in July 1992. The sensor system consists of two ESAs using nested spherical section deflection plates. The detectors measure ions and electron fluxes over a 100°x10° angular fan using 32 discrete energy steps ranging from 10 eV to 10 keV. The sensors are mounted on rotary tables which sweep their field of view. A microprocessor particle correlator system analyzes counts from the sensors to identity wave-particle interactions. Two space rated digital tape recorders record the data. A real time charging detection algorithm operates to display the potential difference between the ambient plasma and the shuttle structure.

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CONTENTS

INTRODUCTION

The fourth year of the Prototype Instrumentation and Design contract focused much of its attention on the completion of the Shuttle Potential and Return Electron Experiment (SPREE). The flight hardware was delivered for integration at Kennedy Spaceflight Center (KSC). Prior to delivery, the hardware was rigorously tested and the software was likewise exercised and evaluated. The software and documentation proved to be as large of a task as the design and physical construction of the SPREE experiment.

Most of this report concerns the SPREE system. This has been by far the principle product of this contract. We have included an outline of the GSE software that is used to operate SPREE and interpret the SPREE data. A discussion of the SPREE charging algorithm is included since this real-time approach to a charging event interpretation is unique, so far as we know.

Previous reports have discussed various engineering details of the SPREE diagnostics. The final engineering change was the installation and calibration of the aperture sizes to be used for the flight. We have included a tabulation of that final configuration for the record. Another small change was made in the Flight Data Recorder (FDR) status words. For the record, the flight configuration of the status word specification is included in this report.

Three papers are being written describing the SPREE experiment. One paper will be submitted to the Review of Scientific Instruments. This paper describes the triquadrispheric electrostatic analyzer. Another paper will be prepared for submission to the IEEE Transactions on Nuclear Science which describes the entire experiment including the Data Processing Unit, Software, Flight Data Recorders, and Rotary Tables. A third paper will discuss the scientific objectives and methodology of the SPREE. It will be submitted to an AIAA journal. Copies of these papers will be provided for the fifth and final report on the Prototype Instrumentation and Design Study Contract.

Finally a few subjects relative to the original Statement of Work for this contract are addressed. Some Time Of Flight (TOF) electronics have been developed by Amptek funds and are appropriate for the TOF investigations proposed for this contract. The preliminary designs for a set of orthogonally viewing triquadrispheres to provide a crossed "S" solid angle of view has been completed. The discussion for an Electrostatic Analyzer with Reverse S (EARS) is included with this report. This design can provide pitch angle coverage comparable to the capped hemisphere type ESA.

SPREE GSE SOFTWARE OUTLINE

1. Introduction

The SPREE Ground Support Equipment (GSE) includes an IBM PC compatible computer equipped with a custom driver card. The driver card, called the 'GSE board', includes a Smartflex MDM (SFMDM) emulator, a Flight Data Recorder (FDR) data bus, and a Greenwich Mean Time (GMT) encoder. Software running on this computer enables personnel to control and monitor many features of the SPREE experiment through the GSE board.

GSE software is written in assembly language for speed. Control of the software is through the standard input/output (keyboard and screen) of the GSE computer.

2. Assembly Routines

Assembly routines are built as a procedures. They perform handshake, search, display, and data storage functions, etc.

2.1 Message-In Phase

The SFMDM defines data acquisition as a 'message in'. For SPREE, each message contains nineteen 16-bit words. Every 31 milliseconds, the SFMDM sets a discrete high to signal the data transfer and direction. Then every word is clocked by a second discrete line.

2.2 Message-Out Phase

Following a 'message in' phase, the SFMDM sets a 'message out' phase and transmits the code for the next expected minor frame of data.

2.3 Synchronization

Each 'message in' phase is checked for validity by examining the minor frame byte. The value must match the previously requested minor frame address. A failure to synchronize invalidates the data for the entire major frame.

2.4 Tasks

The process of decommutating, displaying, and storing data cannot be performed after receiving a major frame. The time involved would interfere with the reception of the next major frame. Instead, the above processes are scheduled as tasks to be performed at predetermined intervals in the data processing. The SFMDM communicates with SPREE through 64 minor frames per major frame. Task 0 would be scheduled after minor frame 0 and so on.

SPREE CHARGING ALGORITHM BASIC CONCEPTS

Introduction

One of the objectives of the Shuttle Potential and Return Electron Experiment (SPREE) is to determine the shuttle's potential relative to the surrounding plasma during TSS-1 experiments.

A charged body will attract ions or electrons, depending on its polarity, in an attempt to neutralize its charge. An Electrostatic Analyzer (ESA) that measures the energies of the attracted particles can yield a determination of the body's relative potential. An algorithm developed with PL/GPSP personnel attempts to calculate in real-time the shuttle's potential from data collected by the forty detector zones in the SPREE ESAs.

A negative charging event should produce a peak in the ion energy spectrum. (Because of the TSS-1 electrodynamic configuration, only a negative potential is expected during TSS-1 deployed operations.) A simple algorithm could search for the energy with the greatest count among all the elevation zones and assume it to represent the potential. Multiple peaks, background noise, and saturation could, however, fool such a simple routine. A complete program must be able to ignore data and patterns that do not indicate charging. The SPREE algorithm uses several functions at three levels to process data and produce an estimated potential with indicated confidence.

Peak Search

Perform the following on each spectrum:

Set all elements to zero if any element is greater than the maximum expected count.

Make a working copy of the spectrum.

Set those elements to zero that are not enabled by a status bit.

Add elements to running sum spectrum.

Set those elements to zero that have a larger adjacent element. For equivalents size elements, the element representing the lesser energy is set to zero.

Set those elements to zero that have values greater than the saturation level.

Set those elements to zero that have values less than the threshold level.

Set those elements to zero that correspond to the maximum and minimum energies.

Declare the element with the greatest value as the primary peak, then set the element to zero. If the FWHM of the peak exceeds its limit, then find another primary peak.

Add location of peak to primary frequency data.

Compare primary peak to record high peak and replace its data set if larger. Declare the element with the greatest remaining value as the secondary peak. If the FWHM of the peak exceeds its limit, then find another peak.

Add location of peak to secondary frequency data.

Repeat for additional spectra.

After one second, report energy, count, width, zone, and azimuth of peak with the record high count along with the sum count of the peak and adjacent energies. Report energy of peak with most frequent occurrence along with the sum count of the peak and adjacent energies. Report on the sum counts of all ions and electrons.

Confidence Factor

The reported data is rated and the sum total of weighting factors is given as a confidence factor.

Level I

Input variables used:

MAXJ maximum allowed count, default = 13 (2^13-1 count)
LGC logic vector to control satellite report (8 bit)
TH1(i) set of 32 threshold exponents for central six zones, default = 3 (8 counts)
ITH1(i) actual threshold ITH1(i)=2^TH1(i)
TH2(i) set of 32 threshold exponents for four wing zones, default = 3 (8 counts)
ITH2(i) actual threshold ITH2(i)=2^TH2(i)
STAT set of 128 bits, 40 zones x 32 energies, default = 0

Local variables for each zone:

PKP primary peak has highest count.
LRPP nearest energy above primary peak with counts less than half of the primary.
LEGP energy of the primary peak.
LLPP nearest energy below primary peak with counts less than half of the primary.
NPP number of counts in primary peak.
WPP full width of peak at half maximum. WPP=LRPP-LLPP

PKS	secondary peak has second highest count.
LRPS	nearest energy above secondary peak with counts less than half of the secondary.
LEGS	energy of the secondary peak.
LLPS	nearest energy below secondary peak with counts less than half of the secondary.
NPS	number of counts in secondary peak.
WPS	full width of peak at half maximum. WPS=LRPS-LLPS
IFGP	bit 0 set if primary found, total=1. bit 1 set if secondary found, total=3. bit 2 set if saturated, total 7.
IFGS	bit 0 set if secondary peak found.

Procedure: For each zone,

Discard all energies with counts less than ITH(i).

Discard all energies with counts greater than MAXJ. If more than one energy has counts greater than MAXJ, then discard entire spectrum.

Calculate local variables.

Level II

Local variables:

PK2	maximum of the 20 ion PKPs.
LEG2	energy with the greatest primary peak (PK2).
LEL2	zone of PK2.
NP2	count of PK2.
WP2	width of PK2.
DP1	32 value distribution of the Legs.
DP2	32 value distribution of the LEGSs.
LEF2	energy most frequently a primary peak.
ICP2	sum of peak distribution above and below. (DP1) ICP2=DP1(LEG2-1)+DP1(LEG2)+DP1(LEG2+1) +DP2(LEG2-1)+DP2(LEG2)+DP1(LEG2+1)
ICF2	sum of frequency distribution above and below. (DP2) ICP2=DP1(LEF2-1)+DP1(LEF2)+DP1(LEF2+1) +DP2(LEF2-1)+DP2(LEF2)+DP2(LEF2+1)
NIT2	sum of the ion counts.
NET2	sum of the electron counts.

Level III

PK3	maximum of the PK2s.
LEG3	energy with the greatest primary peak (PK3).
LEL3	zone of PK3.
LAZ3	azimuth of PK3.
NP3	count of PK3.
WP3	width of PK3.
DP3	array sum of 16 DP1s
DP4	array sum of 16 DP2s
LEF3	energy most frequently a primary peak.
ICP3	sum of peak distribution above and below. (DP3) ICP3=DP3(LEG3-1)+DP3(LEG3)+DP3(LEG3+1) +DP4(LEG3-1)+DP4(LEG3)+DP4(LEG3+1)
ICF3	sum of frequency distribution above and below. (DP4) ICP4=DP3(LEF3-1)+DP3(LEF3)+DP3(LEF3+1) +DP4(LEF3-1)+DP4(LEF3)+DP4(LEF3+1)
NIT3	sum of ion counts.
NET3	sum of electron counts.

SPREE Charging Algorithm Commands

R02K004S	ACQUIRE DEFLECTION VOLTAGE	02D0 041F
R02K005S	ACQUIRE STORED DATA	02D0 051E
R02K006S	ACQUIRE ANALYZER DATA	02D0 061D
R02K007S	ALGORITHM DEFAULT PARAMS	02E0 0013
R02K008S	ALGORITHM MAXIMUM COUNT	027V VVVV
R02K009S	ALGORITHM ESA A SATURATION	022V VVVV
R02K010S	ALGORITHM ESA B SATURATION	023V VVVV
R02K011S	ALGORITHM ESA A THRESHOLD	024V VVVV
R02K012S	ALGORITHM ESA B THRESHOLD	025V VVVV
R02K013S	ALGORITHM MASK	02VV VVVV
R02K016S	ALGORITHM COUNT MODE	02D0 160D
R02K017S	ALGORITHM FREQUENCY MODE	02D0 170C

Variable fields for R02K008s through R02K012S are as follows: The first four bits are the exponent, the second eight bits are the mantissa, and the last eight bits are the check sum.

Variable fields for R02K013S are as previously described except that the electron commands disable (mask) ion array elements, while ion commands enable the ion array elements.

SPREE CHARGING ALGORITHM SOURCE CODE

1. Define the variables.
2. Acquire 20 spectra.
3. Make working copies of the data.
4. Record saturation conditions.
5. Filter the data.
5.1 Set all elements in a spectrum to zero if any element within is greater than the maximum expected count.
5.2 Set those elements to zero that are not enabled by a mask bit.
6. Find the peaks.
6.1 Set those elements to zero that have a larger adjacent element. For equivalent size elements, the element representing the lesser energy is set to zero.
6.2 Set those elements to zero that have values greater than the saturation level.
6.3 Set those elements to zero that have values less than the threshold level.
6.4 Set those elements to zero that correspond to the maximum and minimum energies.
6.5 Declare the element with the greatest value in each spectrum as a primary peak, then set the element to zero.
6.5.1 Add location of peak to frequency data.
6.5.2 Declare the element with the greatest remaining value in each spectrum zero as a secondary peak.
6.5.2.1 Add location of peak to frequency data.
7. Determine if current sweep contains maximum peak.
7.1 Update AI & BI.
7.2 Update AS & BS.
7.3 Update UCNT & LCNT.
7.4 Determine FWHM.
8. Repeat for additional sweeps up to one second.
9. Calculate confidence factor. Weighting factors are assigned to characteristics occurring in the data. The confidence factor is the sum of these weighting factors. Each of the following major categories contributes one weighting factor. Only the first valid condition in the category is computed.
10. Health of ESAs
10.1 Both ESAs operating (10)
10.2 One ESA operating (5)
10.3 Neither ESA operating (0 & quit)
11. Health of RTMDs
11.1 Full azimuthal scan for both RTMDs (10)
11.2 One parked RTMD and full scan for other RTMD (5)
11.3 Two parked RTMDs (3)
12. Spectrum selection
12.1 No peak detected (45)
12.2 Potential determined by peak with highest counts
12.2.1 Primary at least 10 times secondary
12.2.1.1 Energy less than 3.5 keV (25)

12.2.1.2 Energy at least 3.5 keV (5)
12.2.2 Primary less than 10 times secondary
12.2.2.1 Energy less than 3.5 keV (10)
12.2.2.2 Energy at least 3.5 keV (2)
12.2.3 Primary at least 100 times threshold
12.2.3.1 Energy less than 3.5 kEV (40)
12.2.3.2 Energy at least 3.5 kEV (15)
12.2.4 Primary at least 10 times threshold
12.2.4.1 Energy less than 3.5 kEV (30)
12.2.4.2 Energy at least 3.5 kEV (10)
12.2.5 Primary less than 10 times threshold
12.2.5.1 Energy less than 3.5 kEV (20)
12.2.5.2 Energy at least 3.5 kEV (5)
12.3 Potential determined by peak seen most frequently
12.3.1 Energy peak is seen at least 10 times
12.3.1.1 Energy less than 3.5 kEV (40)
12.3.1.2 Energy at least 3.5 kEV (10)
12.3.2 Energy peak is seen at least 5 times
12.3.2.1 Energy less than 3.5 kEV (30)
12.3.2.2 Energy at least 3.5 kEV (5)
12.3.3 Energy peak is seen at least once
12.3.3.1 Energy less than 3.5 kEV (20)
12.3.3.2 Energy at least 3.5 kEV (3)
13. Full width half maximum in high count rate spectrum
13.1 High energy side of peak is a continuum (3)
13.2 Low energy side of peak is a continuum (5)
13.3 FWHM contained in more than one energy step (7)
13.4 FWHM contained in one energy step (10)
13.5 No peak found (0)
14. Saturation points for selected ESA
14.1 Fast sweep mode
14.1.1 No spectra saturated in peak zone (10)
14.1.2 Up to 2 spectra saturated in peak zone (7)
14.1.3 Up to 4 spectra saturated in peak zone (5)
14.1.4 More than 4 spectra saturated (0)
14.2 Slow sweep mode
14.2.1 No spectra saturated in sector (10)
14.2.2 Up to 2 spectra saturated in sector (6)
14.2.3 Up to 5 spectra saturated in sector (3)
14.2.4 More than 5 spectra saturated in sector (0)
15. Grid blocking status
15.1 More than 2 central zones are excluded (4)
15.2 More than 2 wing zones are excluded (5)
15.3 Exactly 2 central zones are excluded (5)
15.4 Exactly 1 central zone is excluded (7)

15.5 Exactly 2 of the wing zones are excluded (7)
15.6 Exactly 1 of the wing zones is excluded (8)
15.7 None of the wing zones are excluded (10)
16. Additional blocking status
16.1 At least 1 mid-range energy is excluded (5)
16.2 At least 6 low and 5 high energies are excluded (6)
16.3 At least 5 high energies are excluded (8)
16.4 At least 6 low energies are excluded (8)
16.5 No part of the energy band is excluded (10)
17. Make data available to primary CPU.

SPREE ESA FINAL CONFIGURATION

New anodes with reduced collection area were fabricated from FR-4 fiberglass. A gold plated leaf spring assembly was installed on the anodes to make electrical contact with the microchannel plates. Previous ESAs for SPREE had used "zebra" connectors for this purpose. New screens were installed. The entire assembly was carefully cleaned and reassembled. This process was performed on both ESA-A and ESA-B. New aperture holes were mounted on both units. The new arrangement is:

ESA	Ion Aperture	Electron Aperture
-A	600 micron	400 micron
-B	50 micron	40 micron

SPREE FLIGHT DATA RECORDER STATUS WORD SPECIFICATION

This document defines the use and meaning of the SDIO Status Word for FDR1 and FDR2.

Description:

00h Nominal sense occurs when recording or waiting for a command.

02h The tape drive is not ready while performing an unexpected function. A discharge near the experiment has probably crashed the mechanism and it is about to record over the beginning of the tape. The operator should stop the recorder and toggle power. A *Rewind* and *Append* will be needed to resume recording.

03h Medium Error. A defect in the tape or excessive EMI has produced too many errors. An *Append* may be able to skip over bad tape.

04h Hardware Error. The tape drive mechanism is unable to control to tape within defined limits. The drum may be sticking to the tape. If the error persists, cycle the power to attempt recovery.

05h Illegal Request. Probably from an attempt to append immediately after recording. A *Rewind* or continued *Recording* should be permissible.

06h Unit attention may indicate a partial reset from a noise spike. Cycling power is recommended.

0Fh A Busy status indicates that the drive is temporarily unavailable for further commands. This occurs during transitions between states.

10h After the drive has initialized, a power fault bit is set. A *Rewind* command must be sent to clear this bit and load the tape.

12h Not Ready. The tape has not been loaded. Execute the *Rewind* command to load.

40h After rewinding, the tape is positioned at the beginning of the tape. An *Append* or *Record* may be performed at this time. This code also occurs when the tape is full, then only a *Rewind* command is allowed.

43h The physical end of tape is reached after *Appending* without finding a file mark.

80h File mark detect occurs when the drive successfully locates a file mark. A *Rewind*, *Write*, or another *Append* may be performed from here.

89h This file mark detect indicates a possible problem due to a past power failure. Splicing to this mark may not be possible. If in doubt, *Append* to the next valid file mark before further recording.

Hardware Specific Information:

The LSB of the Status Word contains the LSB of the read/write error count. The MSB of the status word contains the sense byte returned by the most recent Request Sense command.

MSB definitions:

Bit 7 - FMK (File mark). The current command encountered a file mark.
Bit 6 - EOM (End of Medium). The LBOT or LEOT has been reached.
Bit 5 - CTS (Cartridge Tape Subsystem Failure). An unrecoverable failure has occurred. Power may have to be toggled to recover.
Bit 4 - PWR (Power Failure). Power has been interrupted and subsequent recording has been disabled. A command containing an rewind or append is required to allow recording.
Bit 3 through 0 - Sense Key

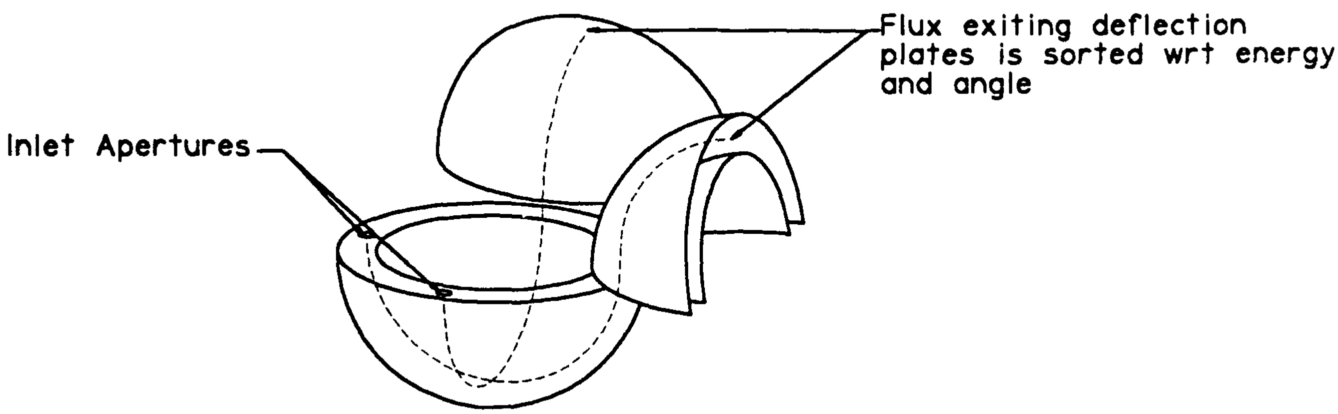
Sense Key Value Definitions:

0h	Nominal
1h	Not Used
2h	Not Ready
3h	Medium Error
4h	Hardware Error
5h	Illegal Request
6h	Unit Attention
7h	Data Protect
8h	Blank Check
9h	Reserved
Ah	Reserved
Bh	Aborted Command
Ch	Reserved
Dh	Volume Overflow
Eh	Reserved
Fh	Busy

EARS - ELECTROSTATIC ANALYZER WITH REVERSED S

Some possible variations in the spherical plate ESAs have been studied this quarter. In particular, a sensor with a field of view comparable to the capped toroidal hemisphere detector would be useful for space research. A capped toroidal can view nearly a 2π region but has problems with distortion and limitations in energy. The SPREE system achieves a similar view by rotating on a platform. A pair of SPREE type sensors with their viewing fans orthogonal to each other would also accomplish this wide field of view.

A design has been studied that forms a hemispheric ESA with pairs of quadrispheres located 90 degrees from each other placed at the output of the hemispheres. The input to the hemisphere is defined by two apertures spaced 90 degrees apart on the hemispheres. This results in orthogonal fans of views that occur simultaneously eliminating the need to rotate the units.

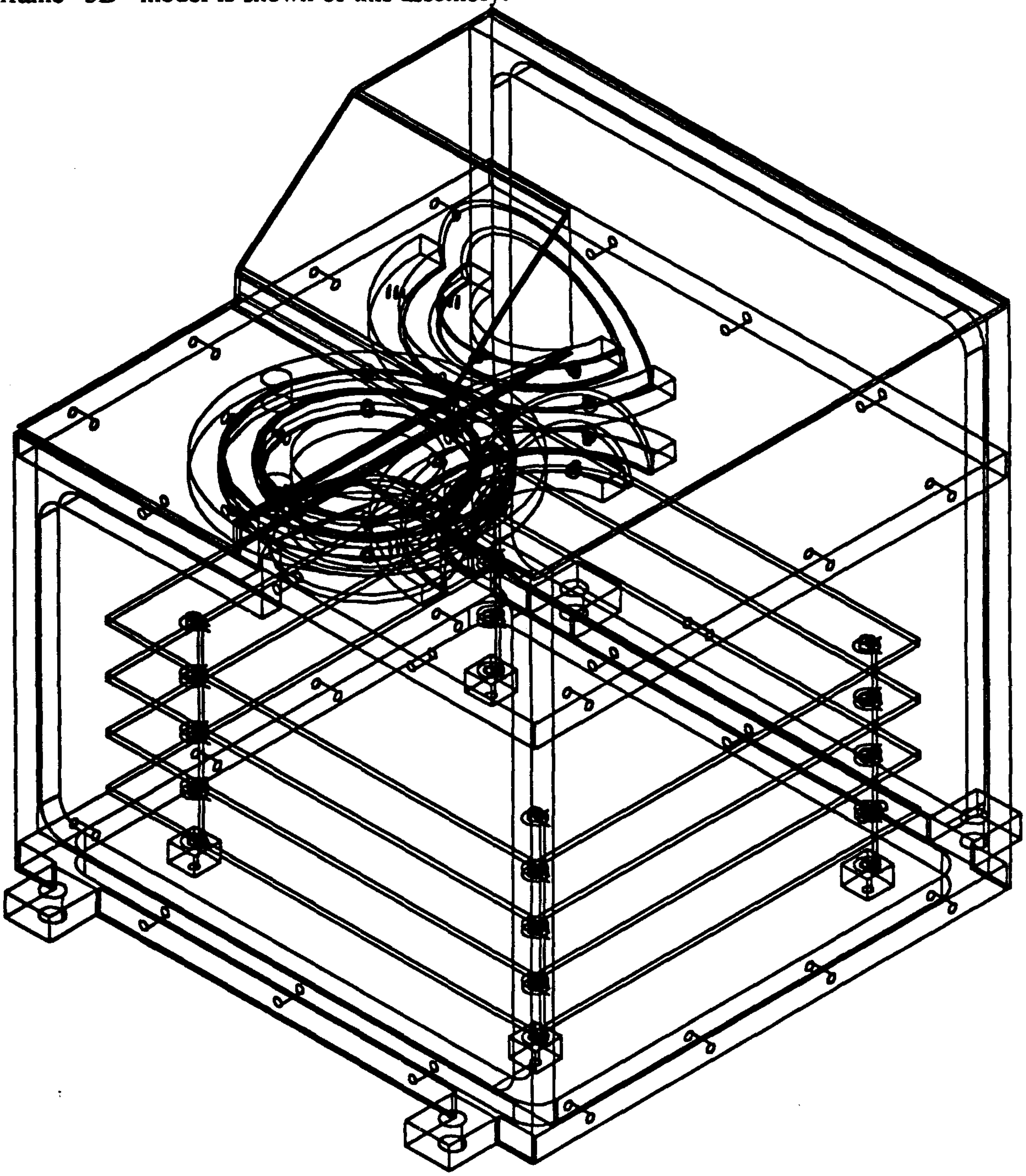


Sketch Showing Electron-Optics of Crossed S Geometry

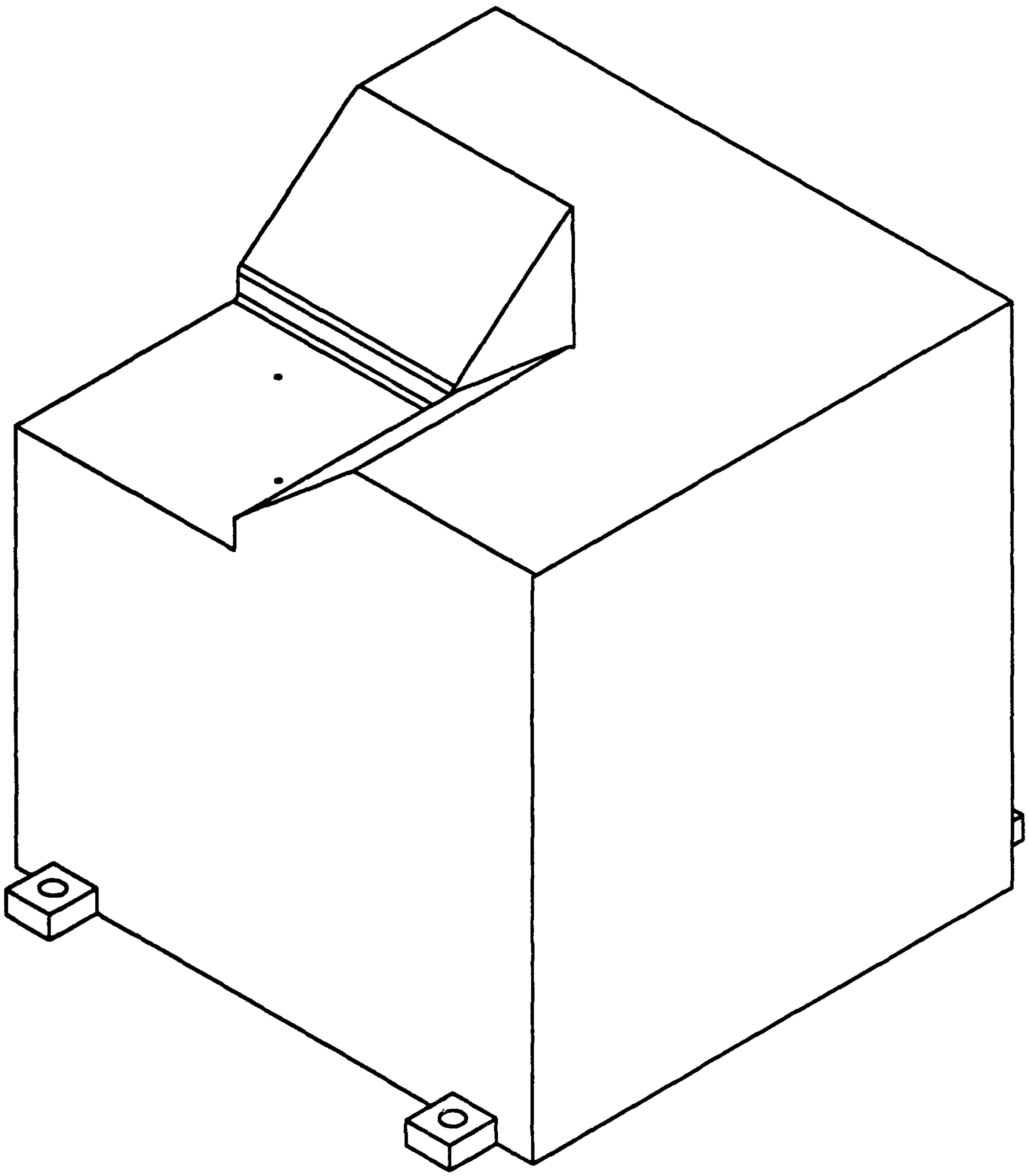
Particles captured in the electric fields created between the deflection plates fly half of a great circle and then experience a field reversal which forces them into the final 90 degrees of a "S" shaped path. If the transition region between reverse biased plates is treated properly, the particles' energy and incidence angles are preserved through the ESA and may be registered via a MCP/Anode detector at the exit region of the quadrispheres.

Spare parts from the SPREE sensor development could be used to demonstrate this detector geometry. The following two drawings show this configuration mounted on the SPREE base plate. The deflection plates are spare electron sensor plates that are mounted on a Kel-F surface to support, position and isolate the plates. A grounded screen would be positioned midway between the hemisphere and the adjoining quadrispheres. The screen would serve as a field line termination for the oppositely charged sectors.

Using SPREE parts, this geometry could be built by manufacturing the mounting surface, new MCP/Anode mounts, and some cover structure. The existing high voltage supply and amplifier card would be quite suitable for the test. A wire frame "3D" model is shown of this assembly.



Wire Frame of the EARS geometry created from SPREE Parts



View of the EARS
This geometry could prove to be useful in many space applications.

TIME OF FLIGHT ELECTRONICS

Part of the research effort originally planned for this PRDA contract had been the development of front end electronics suitable for Time-of-Flight (TOF) experiments. Charge sensitive amplifiers with good sensitivity and high speed characteristics are necessary for TOF used on spaceflight instruments. Weight and space requirements encourage short path lengths for the time of flight measurement. As the particle energy increases, the frequency requirements of a short path length TOF instrument get very demanding. And, as the frequency bandwidth of the amplifier increases, the power consumption must be kept moderate to be practical aboard spaceflight instruments. At the onset of this PRDA contract there were no commercial solutions to this design problem. Only custom unique designs (expensive in terms of time and money) had been flown.

Amptek, Inc. has just introduced a new pre-amplifier, the A121 which provides a commercial solution to the spaceflight TOF requirements. This amplifier was developed independently by Amptek in response to many customer requests. No government funds were used in its design or production. It has a 5 nano-second or less jitter, a frequency of operation of 12 MHz and consumes around 20 milliwatts operating power. It also has a voltage controlled threshold adjustment that allows remote control of the charge amplifier threshold, a feature that greatly simplifies the calibration and optimization of a TOF instrument. Control of the amplifier threshold allows customizing the start/stop detectors to minimize noise and maximize pulse detection under dynamic conditions.