THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Atmospheric, Oceanic and Space Sciences
Space Physics Research Laboratory

Solar Extreme Ultraviolet Sensor and
Advanced Langmuir Probe

PROGRESS REPORT
December 14, 1992

Prepared on behalf of the project by:

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G. R. Carignan

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1.0 Introduction

For more than two decades, the staff of the Space Physics Research Laboratory (SPRL) has collaborated with the Goddard Space Flight Center (GSFC) in the design and implementation of Langmuir probes (LP). This program of probe development under the direction of Larry Brace of GSFC has evolved methodically with innovations to: improve measurement precision, increase the speed of measurement, and reduce the weight, size, power consumption and data rate of the instrument. Under contract NAG5-419 these improvements were implemented and are what characterize the Advanced Langmuir Probe (ALP).

Using data from the Langmuir Probe on the Pioneer Venus Orbiter, Brace and Walter Hoegy of GSFC demonstrated a novel method of monitoring the solar extreme ultraviolet (EUV) flux. This led to the idea of developing a sensor similar to a Langmuir probe specifically designed to measure solar EUV (SEUV) that uses a similar electronics package. Under this contract, a combined instrument package of the ALP and SEUV sensor was to be designed, constructed, and laboratory tested. Finally the instrument was to be flight tested as part of a sounding rocket experiment to acquire the necessary data to validate this method for possible use in future earth and planetary aeronomy missions.

2.0 Summary of Project Activities

The primary purpose of this contract was to develop the electronics hardware and software for this instrument, since the actual sensors were supplied by GSFC. Due to budget constraints, only a flight model was constructed. These electronics were tested and calibrated in the laboratory, and then the instrument was integrated into the rocket payload at Wallops Flight Facility where it underwent environmental testing. After instrument recalibration at SPRL, the payload was reintegrated and launched from the Poker Flat Research Range near Fairbanks Alaska. The payload was successfully recovered and after refurbishment underwent further testing and development to improve its performance for future use.

2.1 Project Hardware

The SEUV/ALP hardware was designed for the sounding rocket mission but also with the intention of allowing it to be easily upgradable to a flight qualified instrument with minimal effort. The entire instrument consisted of a Flight Computer with Telemetry Interface, a Grid Voltage Generator Board and two VA Generator/Electrometer Boards. In addition, ground support equipment was designed that would allow the instrument to
operate in a laboratory setting as well as support the instrument once it was integrated into the rocket payload.

2.1.1 Flight Computer

The processor chosen for the flight computer was Intel's 80C916 12MHz microcontroller which was specifically designed to be used in embedded systems such as this one. The advantages of using this processor were that it has two timers, an eight channel A/D converter, and a serial port. The additional functionality of this processor provided for a smaller and more power efficient flight computer.

The flight computer has an address space of 64K: 8K was used for the boot ROM, 32K was used for the program EEPROM (electrically-erasable PROM), 8K was used for battery-backed RAM, and 4K was used for memory mapped I/O. A watchdog timer was also integrated into the flight computer, which would reset the flight computer should the flight program crash. The flight computer also had some signal conditioning hardware to allow the eight A/D channels to be used for housekeeping purposes.

The programming of the flight computer was done via the serial port. Once the flight program was compiled, it was uploaded to the flight computers EEPROM using the ground support computer communicating over a RS-422 link.

2.1.2 Grid Voltage Generator

The solar EUV sensor has three grids which must be biased with varying potentials ranging from approximately -50V to +50V. The Grid Voltage Generator Board has a quadruple 12-bit digital to analog converter (DAC) which produces voltages in the -10V to +10V range. Three high voltage amplifiers were used to amplify these signals to the required levels. The fourth DAC was not used for the rocket mission, but its output signal is available externally should it be required in the future. The Grid Voltage Generator Board also has a programmable timer which generates two shift clocks (one each for the SEUV and the ALP) for the optocoupled electrometers in the VA Generator/Electrometer Boards. In addition, there are buffers which were used to condition the grid voltage signals so that the rocket's telemetry system could monitor these signals during the flight.

2.1.3 VA Generator/Electrometer

The VA Generator/Electrometer Board is a result of extensive work done at SPRL to improve the accuracy and speed of the Langmuir Probe instrument. The VA Generator is constructed similarly to the Grid Voltage Generators except that a single 16-bit DAC is used to allow the VA to have a -65V to +65V ranges with 2mV resolution. The
electrometer makes its measurements while floating on the applied potential. Data signals are optically coupled from the flight computer to the electrometer gain registers and the 12-bit A/D converter. There is also a relay circuit which is used to apply +125V to the sensor to clean the sensor by electron bombardment using ionospheric electrons.

2.1.4 Ground Support Equipment

The ground support equipment for this instrument is contained in a single suitcase with the addition of a notebook sized IBM PC compatible computer. The suitcase contains a power supply and RS-422 to RS-232 interface hardware. The ground support computer is used to develop, compile, and upload object code to the flight computer. In addition, there exists software that allows one to operate the instrument in a laboratory environment where one sends commands to the instrument and receives data back from the instrument via the RS-422 link. This software has the capability of displaying the resulting I-V curves in real-time as well as saving them to disk for later analysis.

2.2 Project Software

The following paragraphs describe the real-time flight control software of the SEUV/ALP instrument. This software was designed to operate the instrument at the highest sampling rate possible without sacrificing instrument reliability, accuracy, and the portability of the flight code. The instrument can operate either in flight mode or test/laboratory mode without reprogramming the flight computer. In flight mode, the instrument steps through a sequence of pre-programmed measurement modes and telemeters the acquired data. In test/laboratory mode, the instrument requires a ground support computer to control the instrument and record measured data.

2.2.1 Overview

The majority of the software was written in a high level language, ANSI C, and was compiled with the Archimedes 80C196 cross-compiler. A high level language was used to reduce software development time. ANSI C was chosen because it is a high level language that is well suited for real-time embedded systems programming. Some assembly language programming was necessary and the Archimedes 80C196 cross-assembler was used to produce object code.

In early development phases of the software, it was decided that the use of a real-time kernel and operating system was not necessary, because it would produce overhead that would reduce the temporal resolution of the instrument. Instead, the instrument was to perform its tasks within a predefined measurement interval. In that interval, current was to
be measured, voltages were to be adjusted, telemetry was to be sent and housekeeping information gathered. This concept allowed the instrument to have temporal resolution that was dictated by the analog hardware and not by the speed of the flight computer.

The flight software was designed in modules or processes (see drawing in Appendix A). Each process or module is a collection of functionally similar tasks or routines, and these processes are described below.

2.2.2 Module Descriptions

MAIN -- This is the highest level control process of the flight software system. This process is initiated upon reset of the system -- either powerup, manual or watchdog timer reset. This process can operate in two modes: flight or bench mode.

After performing all necessary initialization, this process goes into bench mode. In this mode the process awaits for commands from the serial port continuously until a launch signal is detected. The commands are processed and executed by the COMPROC process and can be used to configure or test the instrument during pre-launch operations or to operate the instrument in a laboratory setting for measurements or testing. After the launch signal is detected, this process is in flight mode and measurement sequencing is initiated and controlled by the MODES process. To insure that measurements are made at regular time intervals in flight mode, after the necessary tasks are done, the CPU is placed into a power-conserving sleep mode and wakes up by an interrupt generated by the TIMER process.

COMPROC -- This process parses, limit checks and executes all commands received from the serial port from the SERIAL process. The commands are executed by referencing a function pointer in a lookup table allowing a very flexible and expandable command processor. Currently, there are commands for testing, calibration, hardware debugging, mode debugging, and laboratory measurement programmed in the command processor. The results from these commands are either sent via the SERIAL process to the ground support computer or via the TM process to the telemetry interface.

MODES -- The MODES process executes a pre-programmed sequence of modes. There are two tables (one for the SEUV and one for the ALP) of ordered mode names which are used to control this sequence. These tables can be either compiled in, or programmed by commands in the COMPROC process. This process controls measurement sequencing by communicating to the MODES2 process which step of which mode is to be executed. The current measurement mode and step are stored in zero-powered RAM to allow the instrument to continue operation where it left off after a power failure or a watchdog timer reset.
The mode names are stored in a table also, along with function pointers and other information, to facilitate the addition of new modes.

**MODES2** -- This module is not a single process but a collection of processes that control the activities necessary to perform scientific measurements (adjusting gains, setting applied voltages, measuring currents) by executing I/O routines. Each measurement mode process is controlled by a mode step number that is received from the MODES process. The modes that are programmed in this module are specified by the *Modes of Operation* document (see Appendix B).

**TM** -- The process generates and transmits telemetry either over the dedicated telemetry channel or via the serial port. The SEUV/ALP instrument uses packet telemetry conforming to the Consultative Committee's on Space Data Systems (CCSDS) packet telemetry standard as specified in the CCSDS 102.0-B-2 Blue Book. This telemetry system uses packet error control as specified in the CCSDS 100.0-G-1 Green book. This process assembles data into packets and when completed, copies the assembled packets into the telemetry system interface hardware.

**SERIAL** -- This is an Interrupt Service Routine (ISR) module whose task is to receive data from the serial command port and transmit it to the COMPROC process, and to send data back to the ground support equipment during testing and laboratory measurement setups. To maximize the throughput and efficiency, this process was programmed in 80C916 assembly language.

**TIMER** -- This ISR module initializes the CPU's timers and acknowledges interrupts from the CPU. The timers are used to provide an instrument clock which ensures that current measurements are made at regular time intervals, and to provide a start time for all measurement modes which simplifies the data analysis process. This module was programmed in assembly language also.

**I/O** -- This module is a collection of routines that communicate directly with the instrument hardware (VA generators, A/D converters, registers, timers, etc.). The purpose of this module was to keep all device dependent programming together to reduce the effort necessary to modify the flight code for various hardware configurations. Any calibration information used in the instrument is also contained in this module.

### 2.3 Flight Experiment Details

The combined SEUV/ALP instrument was part of Dr. William Sharp's sounding rocket mission 27.133 UE. The instrument was piggybacked onto Dr. Sharp's payload and was launched by a Nike-Black Brant VC from Poker Flat Research Range (65°07'N 147°28'W) at 206:13:36:00 UT 1992. The payload achieved an apogee of 233.36 km,
and was successfully recovered with the SEUV/ALP instrument not sustaining any damage.

The instrument was partially successful in achieving its objectives which were twofold: to acquire SEUV data to verify the measurement model, and to perform an engineering test of the combined SEUV/ALP electronics. A satisfactory number of SEUV measurements were made, and are currently being processed. Due to a component failure, the ALP channel failed and no measurements were made. However this does not constitute a failure to meet the second objective since an identical unit which was used to measure SEUV currents did not fail.
APPENDIX A

System Specifications and Block Diagrams
Langmuir Probe/Solar EUV Electronics Data Sheet

- **Applied Voltage Generators:**
  2 Generators with 16 bits of resolution
  Range: -65.536V to 65.534V in 2mV increments

- **Grid Voltage Generators:**
  3 Generators with 12 bits of resolution
  Range: -51.200V to 51.175V in 25mV increments

- **Electrometers:**
  2 Electrometers sampled with 12 bits resolution
  Range 1: -66μA to +66μA
  Range 2: -4μA to +4μA
  Range 3: -200nA to +200nA
  Range 4: -15nA to +15nA

- **Flight Computer:**
  Custom Computer based on Intel 80C196 12MHz processor w/watchdog timer
  32K of EEPROM Program Memory
  8K of Boot/Loader ROM
  8K of Battery Backed RAM

- **Telemetry/Command Interface:**
  Serial TM Interface to PCM stack at 1250 bytes/sec
  (Packet TM conforming to CCSDS 102.0-B-2 standard)
  Serial RS-422 Command/TM Interface at 9600 baud

- **Size of Electronics:**
  10.180" (L) x 5.930"(W) x 5.610"(H)

- **Mass of Electronics:**
  3.75 kg

- **Power Consumption:**
  (2) V_a Generator/Electrometers 2.10 W
  Grid Voltage Generators 2.94 W
  CPU/Telemetry 2.23 W
<table>
<thead>
<tr>
<th>Process Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN</td>
<td>High Level Control</td>
</tr>
<tr>
<td>COMPROC</td>
<td>Terminal Command Processing</td>
</tr>
<tr>
<td>MODES</td>
<td>Mode Sequeencer</td>
</tr>
<tr>
<td>MODES2</td>
<td>Measurement Mode Execution</td>
</tr>
<tr>
<td>TM</td>
<td>Telemetry Processing</td>
</tr>
<tr>
<td>SERIAL</td>
<td>Serial Port ISRs</td>
</tr>
<tr>
<td>TIMER</td>
<td>Timer ISRs</td>
</tr>
<tr>
<td>I/O</td>
<td>Hardware Interface Library</td>
</tr>
</tbody>
</table>

Space Physics Research Laboratory
College of Engineering
University of Michigan

SFM/ALP Flight Software Overview

RELEASE 1.0
January 1, 1992

SFM/ALP A-E
Notes:
1. The above format conforms to the CCSDS Packet Telemetry format as specified in the CCSDS 102.0-B-2 Blue Book (January 1987).
2. The Frame Synchronization Marker when NOT using Reed-Solomon Encoding is 0x1ACFFC1D.
3. The error control word is a cyclic redundancy code generated using the generator polynomial specified in the CCSDS Telemetry 100.0-G-1 Green Book (December 1987.)
APPENDIX B

SEUV/ALP Electrical Drawings
Probe Cleaning Control Signals

To write to:

<table>
<thead>
<tr>
<th>Data must be of the form</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Programmable Timer</strong></td>
</tr>
<tr>
<td>00XXXXXXXXXXXXXXXXX</td>
</tr>
<tr>
<td><strong>Quadruple DAC</strong></td>
</tr>
<tr>
<td>01XXXXXXXXXXXXXXXXX</td>
</tr>
<tr>
<td><strong>Octal Latch</strong></td>
</tr>
<tr>
<td>10XXXXXXXXXXXXXXXXX</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Unless otherwise specified, all resistors are type RNC55 and all capacitors are type CK105.
NOTES:

1. Devices F1 and F2 are PolySwitch current limiting devices. They were required by NASA/WPP for the 27-133 rocket flight experiment. They will sustain a maximum of 1.85 amperes without tripping.
APPENDIX C

SEUV/ALP Mechanical Drawings
SOLAR FLUX MONITOR & ADVANCED LANGMUIR PROBE

LAYOUT FOR AFT EXPERIMENT SECTION 27.133

4/2/92 BL-BRANT
LANGMUIR PROBE

LAYOUT FOR AFT EXPERIMENT SECTION
**DASH NO.** | **NAME** | **A DIM.** | **B DIM.** | **# REQ'D.**
---|---|---|---|---
-1 | DECK POST | 5.00 | 3.950 | 6
-2 | P.C. POST-LONG | 3.12 | 5.929 | 1
-3 | P.C. POST-SHORT | 3.12 | 3.762 | 1

**Space Physics Research Laboratory**  
**College of Engineering**  
The University of Michigan  
Ann Arbor, Michigan

**Threaded Deck Rod**  
**Electronic Housing Assy, Flight**  
**SMF/AlP**
NOTE:
1. ALL HOLE DIM 0.02
2. FINISH CHROMATE CONVERSION
3. BLACK ANODIZE - 2 TOP PLATE
#10-32 NF-2 TAP THRU

1.25 DIAM. THRU 4 HOLES

-1.000
-1.875
-1.312
-350

NOTE: BLACK ANODize MILL. PARS. 250 TIPS

#4-40 NC-2 TAP X .312 DP, 5 HOLES

-0.125
-0.250

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THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN
1.25 Dia. thru & slot for 1000 max dia. #3 places.

Note: Black anodize Mil. Al 8056C Type 2.
APPENDIX D

Measurement Mode Specifications
Modes of Operation
(revised October 7, 1992)

I. Solar Flux Monitor

1) **Standard EUV Measurement Mode:**
   G1 = -25V
   G2 = +25V
   G3 = -15V
   Target = sweep from +20V to -36V in 1V steps (57 total)
   **Telemetry:** 1 reading of Decade & Vernier settings, 57 A/D values
   = 1 word + 57 words = 58 words = 116 bytes

2) **High Resolution EUV Measurement Mode:**
   G1 = -25V
   G2 = +25V
   G3 = -15V
   Target = sweep from +20V to -36V in 0.25V steps (225 total)
   **Telemetry:** 1 reading of Decade & Vernier settings, 225 A/D values
   = 1 word + 225 words = 226 words = 452 bytes

3) **Grid 1 Test Mode:**
   G1 = -35V, -30V, -25V, -20V, -15V
   G2 = +25V
   G3 = -15V
   Target = sweep from +20V to -36V in 2V steps (29 total)
   **Telemetry:** 5 * (1 reading of Decade & Vernier settings, 29 A/D values)
   = 5 * (1 word + 29 words) = 150 words = 300 bytes

4) **Grid 2 Test Mode:**
   G1 = -25V
   G2 = +15V, +20V, +25V, +30V, +35V
   G3 = -15V
   Target = sweep from +20V to -36V in 2V steps (29 total)
   **Telemetry:** 5 * (1 reading of Decade & Vernier settings, 29 A/D values)
   = 5 * (1 word + 29 words) = 150 words = 300 bytes

5) **Grid 3 Test Mode:**
   G1 = -25V
   G2 = +25V
   G3 = -25V, -20V, -15V, -10V, -5V
   Target = sweep from +20V to -36V in 2V steps (29 total)
   **Telemetry:** 5 * (1 reading of Decade & Vernier settings, 29 A/D values)
   = 5 * (1 word + 29 words) = 150 words = 300 bytes

6) **EUV Ion Retarding Potential Analyzer Mode:**
   G1 = -10 V
   G2 = sweep from -5V to +5V in 0.2V steps (51 total)
   G3 = 0V
   Target = 0V
   **Telemetry:** 1 reading of Decade & Vernier settings, 51 A/D values
   = 1 word + 51 words = 52 words = 104 bytes
7) **EUV Electron Retarding Potential Analyzer Mode:**
G1 = +10 V
G2 = sweep from -5V to +5V in 0.2V steps (51 total)
G3 = 0V
Target = 0V
Telemetry: 1 reading of Decade & Vernier settings, 51 A/D values
= 1 word + 51 words = 52 words = 104 bytes

8) **EUV Cleaning Mode 1 (5 seconds):**
G1 = + 50V
G2 = + 30V
G3 = + 15V
Target = +125V
Telemetry: None.

II. Advanced Langmuir Probe

1) **Fast (5-point) ALP Mode:**
   Probe \( V_a \) = values determined by algorithm (5 total)
   Telemetry: 1 reading of Decade & Vernier settings, 1 reading of \( kTe \),
   5 A/D & D/A values
   = 1 word + 1 word + 2 * 5 words = 12 words = 24 bytes

2) **Standard ALP Sweep Mode:**
   Probe \( V_a \) = sweep from -5 V to +5 V in 0.1V steps (101 total)
   Telemetry: 1 reading of Decade & Vernier settings, 101 A/D values
   = 1 (16-bit) word + 101 words = 102 words = 204 bytes

3) **High Resolution ALP Sweep Mode:**
   Probe \( V_a \) = sweep from -1.7V to +1.7V in 0.04V steps (86 total)
   Telemetry: 1 reading of Decade & Vernier settings, 86 A/D values
   = 1 word + 86 words = 87 words = 174 bytes

4) **Medium Resolution ALP Sweep Mode:**
   Probe \( V_a \) = sweep from -9kTe to +1kTe in \( kTe/8 \) steps (81 total), and a
   single reading at 2V above \( 1kTe \)
   Telemetry: 1 reading of Decade & Vernier settings, 1 reading of \( kTe \),
   81 A/D values
   = 1 word + 1 word + 81 words = 83 words
   = 166 bytes

5) **ALP Cleaning Mode 1 (5 seconds):**
   Probe \( V_a \) = +125 V
   Telemetry: None.

**Notes:**
1) All data will be transmitted in packet form. The telemetry requirements above
do not include packet headers & terminators (start codes, mode ID, packet
length, timestamp, checksum).

2) To avoid unnecessary redundancy, the housekeeping information will be sent
   in a separate packet.
**Langmuir Probe Five-Point Algorithm**

1. Set $V_a = V_1$ (initial value = -5.0 V)
2. Set preamp and vernier so that A/D measures $I_1 = -3.3 V$
3. Set $V_a = V_3$ so that A/D measures $I_3 = -0.4715 * I_1$
4. Set $V_a = V_4$ so that A/D measures $I_4 = -4.0 * I_1$ (max. +5.0V)
5. Set $V_a = V_2 = V_1 + 2 * (V_4 - V_3)$ & measure $I_2$
6. Set $V_a = V_5 = V_4 + 7 * (V_4 - V_3)$ & measure $I_5$
7. Compute new $V_1 = -9 * (V_4 - V_3)$
8. Telemeter $V_1, I_1, V_2, I_2, V_3, I_3, V_4, I_4, V_5, I_5$

(For mode which sweeps from -9kTe to +1kTe, kTe = $V_4 - V_3$)
APPENDIX E

Representative Data from Sounding Rocket Flight
Solar Flux Monitor / Advanced Langmuir Probe

Process ID: ALP_PROC
Mode: ALP_HR
Grid 1 (V)
Grid 2 (V)
Grid 3 (V)

Mode Start Time: 10.305 = 2061
Altitude (m): 2061
Pre/Vern Gain: 0x1AFF
Target (V): 2061

Telemetry Source: GOODTM_ALP
Solar Flux Monitor / Advanced Langmuir Probe

Process ID
ALP_PROC
Grid 1 (V)

Mode
ALP_HR
Grid 2 (V)

Start Time
7.730 = 1546

Altitude (m)

Pre/Vern Gain
0x1000
Target (V)

Telemetry Source - GOODTM_ALP
Solar Flux Monitor / Advanced Langmuir Probe

Process ID
SFM_PROC
Grid 1 (V) -25.0

Mode
SFM_HR
Grid 2 (V) +25.0

Mode Start Time
116.585 = 23317

Altitude (m)
149387

Pre/Vern Gain
0x1000
Target (V)
SWEEP

Telemetry Source - GOODTM.SFM
Solar Flux Monitor / Advanced Langmuir Probe

Process ID
SFH_PROC
Grid 1 (V) -25.0

Mode
SFH_STD
Grid 2 (V) +25.0

Mode Start Time
304.950

Altitude (m)
60890
219322

Pre/Vern Gain
0x3000
Target (V)
Sweep

Telemetry Source - GOODTM.SFM