N73-11396

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Development and Testing of the Ultraviolet Spectrometer for the Mariner Mars 1971 Spacecraft

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PREFACE

The work described in this memorandum was performed by the University of Colorado's Laboratory for Atmospheric and Space Physics under the cognizance of the Project Engineering Division of the Jet Propulsion Laboratory.

CONTENTS

ABSTRACT

The Mariner Mars 1971 ultraviolet spectrometer is an Ebert-Fastie type of the same basic design as the Mariner Mars 1969 instrument. Light enters the instrument and is split into component wavelengths by a scanning reflection diffraction grating. Two monochrometer exit slits allow the use of two independent photomultiplier tube sensors. Channel 1 has a spectral range of 1100 to 1692 Å with a fixed gain, while Channel 2 has a spectral range of 1450 to 3528 Å with an automatic step gain control, providing a dynamic range over the expected atmosphere and surface brightness of Mars.

The scientific objectives, basic operation, design, testing, and calibration for the Mariner Mars 1971 ultraviolet spectrometer are described in this memorandum. The design discussion includes those modifications that were necessary to extend the lifetime of the instrument in order to accomplish the Mariner Mars 1971 mission objectives.

I. INTRODUCTION

The primary objective of the Mariner Mars 1971 Project was to study the dynamic characteristics of the planet Mars from orbit for a minimum of 90 days. The spacecraft carried a complement of scientific instruments that included a scanning ultraviolet spectrometer (UVS). The Mariner Mars 1971 UVS was basically the same as the instrument carried on the Mariner Mars 1969 spacecraft; however, some modifications were necessary since the earlier project's experiment was designed to determine the atmospheric composition of the planet during flyby (Refs. 1 and 2), whereas the Mariner Mars 1971 UVS experiment was designed to produce a spectrographic map of Mars and thus required a longer lifetime for the instrument.

II. SCIENTIFIC OBJECTIVES

The Mariner Mars 1971 UVS scientific objectives (Ref. 3) fell into two categories:

(1) Ultraviolet cartography, i.e., the mapping of the surface and lower atmosphere in the ultraviolet spectral region, in order to:

- (a) Measure the local atmospheric pressure over the major portion of the planet.
- (b) Measure the local ozone concentration.
- (c) Measure the wave of darkening in the ultraviolet.
- (d) Measure the variability of the surface features in the ultraviolet.
- (e) Measure the yellow clouds, blue haze, and blue clearing in the ultraviolet.

(f) Search for evidence of biological activity by measuring local variations in the oxygen-ozone abundances.

(2) Ultraviolet aeronomy, i. e., the study of the composition and structure of the upper atmosphere using the techniques of ultraviolet spectroscopy, in order to:

(a) Determine the composition and structure of the upper atmosphere as a function of latitude, longitude, and time.

(b) Measure the variability of the ionospheric composition.

(c) Measure the variability of the rate of escape of atomic hydrogen from the exosphere.

(d) Measure the distribution and variability of the ultraviolet aurora and determine the induced planetary magnetic field.

III. FUNCTIONAL DESCRIPTION

The Mariner Mars 1971 UVS is an Ebert-Fastie-type spectrometer with an occulting slit telescope. Its physical configuration and optical path are shown in Figs. 1 and 2, respectively; Fig. 3 is a functional block diagram of the instrument.

Extensive baffling is incorporated to eliminate "off-axis" stray light. The telescope provides the required spatial resolution and focuses the incident light onto the monochrometer entrance slit. The monochrometer separates the light into its component wavelengths. The configuration consists of an entrance slit, a concave spherical mirror, a scanning plane diffraction grating, and two exit slits. As the grating is rotated, the different monochromatic spectral features are swept across the exit slits.

A rotating cam and pin follower are used to provide the angular motion of the grating. The total grating excursion of 16.25 deg requires 2.82 s of the 3-s scan period. The remaining 0.18 s is used for the grating flyback (the return of the grating to the short-wavelength start of the next scan). The cam is driven by a 300-Hz, 9000-rpm, synchronous motor. The speed of 9000 rpm is reduced to a 3-s period by an 18:1 spur gear reduction assembly followed by a sealed planocentric drive that provides another 25:1 reduction.

Two independent photomultiplier tubes (PMTs) are used as sensors to convert ultraviolet light from the two monochrometer exit slits into anode currents proportional to the light intensity. The output of each PMT is integrated, sampled, stored, amplified, and converted into a pulsewidth every 5 ms in response to the UVS "read" pulse from the Data Automation Subsystem. Both channels, separate but identical, have provisions for switching signals other than sensor outputs into the data stream.

Engineering and calibration reference measurements are switched into the data stream produced by each channel just prior to and during grating flyback. The sequence is controller by a fiducial pulse from a magnetic pickup mechanically referenced to the cam. The sequence starts in both channels with "zero check," a true-zero signal to both channels produced by energizing a clamp across the input. During the next period, a known amount of current is injected into the input to provide electronic "gain calibration" information. The high voltage for this period is at a low level, representing negligible gain on the PMTs.

The high voltage returns to its operating level, and the following measurements are switched into the data stream: On Channel 1, the secondary-optics cavity temperature T_1 is measured by a voltage proportional to the resistance change of a thermister. This is followed by the "15-V monitor," a signal taken from a voltage divider in the 15-V portion of the low-voltage power supply (LVPS). The final measurement on Channel 1 is the "high-voltage monitor." This signal is taken from a resistance network on the high voltage of the Channel 1 PMT.

After the "gain calibration" on Channel 2, the F-PMT temperature T_2 is measured from a thermistor located on the PMT mount. This measurement is followed by the F-channel "gain indicator," a signal from the up-down counter indicative of the F-PMT gain level. The final engineering measurement on Channel 2 is the "high-voltage monitor," which is obtained the same way as that for Channel 1.

The only engineering measurement not in the spectral data stream is that of a platinum-wire resistance temperature sensor, whose output is presented on Flight Telemetry Subsystem Channel 416.

IV. DESIGN

The Mariner Mars 1971 UVS is mounted on the spacecraft scan platform in such a way that its optical axis is aligned with the optical axis of the television camera to allow complete coordination of the two experiments. Because of the emphasis on UV cartography, specifically, the measurement of Hartley-band ozone absorption between 2000 and 3000 Å, it was necessary to decrease the detector sensitivity to longer-wavelength scattered light beyond 3500 Å. This was accomplished by replacing the EMR 541-N PMT with its bi-alkali (antimony sodium-potassium) photocathode with an EMR 541-F PMT with a cesium telluride photocathode.

The wavelength, or spectral scanning range, was reduced from 1050-4300 Å to 1100-3528 Å commensurate with the PMT change. This reduction was accomplished by changing the cam follower arm configuration while keeping the cam profile the same. These changes resulted in the Mariner Mars 1971 instrument having the same spectral resolution, but a longer deadband, in the 3-s scan. Specifically, the G-channel (UVS-1) views the spectrum in the first order from 1100 to 3383 Å and in the second order from 1100 to 1692 Å. The F-channel (UVS-2) views the spectrum in the first order from 1450 to 3528 Å and in the second order from 1450 to 1764 Å.

Both the entrance and exit slits of the monochrometer were changed to achieve the spatial resolution required on the planet. The G-channel (UVS-1) field-of-view is 0.19×1.9 deg, while the F-channel (UVS-2) field-of-view is 0.19×0.55 deg.

The Mariner Mars 1969 planet limb sensors were removed, and an automatic gain control system was incorporated to maintain an on-scale reading during the entire orbital phase. This system consists of two voltage level detectors and a 3-bit up-down counter. The automatic gain control system was incorporated in the F-channel only; the gain of the G-channel remains constant. The gain change is accomplished by varying the voltage on the PMT. Eight gain ranges are available. These ranges increase by integral factors of 3, making the highest gain 2187 times the lowest gain. The gain change is accomplished by the circuit shown in Fig. 4. The output of the F-channel is averaged over a 40-ms period in the 2890-Å region. The integration of the output signal is controlled by a magnetic pickup on a code wheel attached to the cam shaft. This pickup generates a pulse that starts a one-shot multivibrator. The output drives a switch that controlls the integration period.

The integrated output voltage of the F-channel is applied to the voltage comparators, one set at 5.5 and the other at 1 V. If the sampled voltage is above 5.5 V, flip-flop A is set; flip-flop B is set if the voltage is below 1 V. If the voltage is between 1 and 5.5 V, neither flip-flop is set.

At the beginning of the cam flyback, a second strobe signal (UVS fiducial pulse) is initiated. This strobe produces a pulse to the up-down counter. If the A signal is true, the counter will count up 1 bit; if the B signal is true, it will count down 1 bit. The output of the counter is gated by seven gates, which control analog switches and connect an accurate reference voltage to one of the seven resistors. These resistors form the upper leg of a divider network, the buffered output of which is applied to the control input of the high-voltage power supply (HVPS). Each resistor changes the control voltage of the HVPS such that a difference of approximately 200 V will occur for successive gain changes. These resistors are selected such that the gain of the PMT changes by a factor of 3 for each successive count.

The Mariner Mars 1969 HVPS (one for each UVS channel) was a 2.4-kHz step-up type with a voltage quadrupler. Only a slight modification was made to this design to enable the acceptance of the F-channel automatic gain control. During systems tests, however, it was found that the 2.4-kHz spacecraft voltage supplied to the UVS was not as stable as that for the Mariner Mars 1969 spacecraft. This instability resulted from a Data Automation Subsystem memory dump each 60-ms, which caused interference on the UVS analog output through the HVPS. Several filtering schemes were tried, both on the spacecraft and the UVS, but none were successful. This problem led to the redesign of the UVS HVPS.

The new HVPS is a standard Cochroft-Walton-type voltage multiplier. The inverter used is a standard magnetically coupled multivibrator type. A schematic diagram of the HVPS is shown in Fig. 5. The control signal from the gain change logic is applied to point A. A voltage change at this point results in a variation of the reference voltage. The output of the HVPS is returned through a high-voltage resistor to the inverting input of an operational amplifier. This amplifier controlls the base current of a series pass regulator that powers the magnetically coupled multivibrator. The output of the HVPS may be reduced to its minimum level by simply pulling point A to ground. The response of the HVPS to the programming input is such that, when making a zero-level calibration, negligible capacitive coupling effects will be noted in the output data. One advantage of the Cochroft-Walton-type circuits for this application is a lower potential across the capacitors as compared to that in the parallel filtered configuration (Ref. 4).

The duration of the engineering pedestal data was increased to 380 ± 5 ms by taking advantage of the shorter wavelength scan, thus allowing an increased time for reading out engineering data. In addition, the HVPS has a longer period to stabilize prior to gain calibration and high-voltage monitor. Figure 6 is a simplified diagram showing the UVS engineering parameters monitored, while Fig. 7 shows the sequencing of each parameter. Tables 1 and 2 show the value and number of samples for each engineering status measurement.

Because of the additional operating time required by the Mariner Mars 1971 orbiter mission, the gear train in the planocentric drive assembly is completely sealed in order to maintain better lubrication. (The Mariner Mars 1969 gear housing was vented rather than sealed.) Furthermore, a new motor with improved torque characteristics was designed for the scan drive mechanism. Again, this change was made to extend the lifetime of the instrument due to the additional operating time required by the mission.

V. TESTING AND CALIBRATION

The test program for the UVS began with screening and margin testing of individual electronic component parts. These tests were performed in accordance with JPL specifications both at JPL and at vendors' facilities.

After assembly into modular packages but prior to conformal coating, each module underwent a series of performance tests over a temperature range of -55 to 55°C at atmospheric pressure. Following conformal coating and encapsulation, each test was repeated. After integration of the modules into a complete electronics package, another series of performance tests was made on the integrated package over the temperature range of -40 to 40°C.

At the University of Colorado, the electronics package was mated with the optics case and scan drive mechanism. A complete instrument calibration sequence was performed for both wavelength and photometric sensitivity. These calibrations were performed in vacuum as well as at atmospheric pressure.

The units were then delivered to JPL and subjected to flight-acceptance and type-approval subsystem environmental tests in accordance with the JPL project test specifications. In addition, the instrument engineering functions were calibrated in 10°C increments over the temperature range at pressures less than 1.33×10^{-3} N/m^2 (10^{-5} mm Hg). Following calibration verification at the University of Colorado, the units were returned to JPL for spacecraft assembly and systems testing, including systems-level environmental tests.

While the spacecraft was enroute to the Air Force Eastern Test Range (AFETR), the UVS underwent final calibration verification at the University of Colorado. It was then delivered to the AFETR for incorporation on the spacecraft and final systems testing prior to launch.

Table 3 summarizes the test and calibration program and shows the distribution of problems with respect to the unit and test involved. Of the 32 significant problems reported, 22 required fixes, 9 required minor engineering changes, and 1 (in the HVPS) required the major design change described previously.

REFERENCES

1. Mariner Mars 1969 Final Project Report: Development, Design, and Test, Technical Report 32-1460, Vol. I. Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1, 1970.

2. Pearce, J. B., Gause, K. A., Mackey, E. F., Kelly, K. K., Fastie, W. G., and Barth, C. A., Appl. Opt., Vol. 10, No. 4, Apr. 1971.

3. Proposal for Mariner Mars 1971 Ultraviolet Spectrometer: Vol. 1, Technical Section. Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Feb. 29, 1969 (Prepared for JPL).

4. Proposal for Mariner Mars 1971 Ultraviolet Spectrometer Sensor Electronics Package: Vol. 1, Technical Section, Document No. 8031. Space and Systems Division of Packard-Bell Electronics Corp., Newbury Park, Calif., Feb. 2, 1969 (Prepared for University of Colorado).

Table 1. UVS-1 engineering pedestal data

Measurement	Normal magnitude, DN[a]	Number of samples	High voltage, V	Temperature, °C
Zero check	7 ± 2	32 ± 1	-961	---
Gain calibration	194 ± 3	22 ± 1	-961	---
Temperature T_1	106 ± 2	13 ± 1	-3004	-20
	130 ± 2			-10
	151 ± 2			0
	172 ± 2			10
	187 ± 2			20
	200 ± 2			30
	208 ± 2	13 ± 1		40
15-V monitor	206 ± 1	4 ± 1		---
High-voltage monitor	179 ± 1	4 ± 1	-3004	---

[a]255 DN (data numbers) represent 6-V analog output.

Table 2. UVS-2 engineering pedestal data

Measurement	Normal magnitude, DN	Number of samples	High voltage, V	Temperature, °C
Zero check	4 ± 2	32 ± 1	-614	---
Gain calibration	185 ± 3	22 ± 1	-614	---
Temperature T_2	108 ± 2	13 ± 1	-1076	-20
	128 ± 2			-10
	147 ± 2			0
	165 ± 2			10
	179 ± 2			20
	189 ± 2			30
	200 ± 2	13 ± 1		40
Gain indicator 0	30 ± 2	4 ± 1	-1076	---
1	56 ± 2		-1270	---
2	85 ± 2		-1499	---
3	111 ± 2		-1731	---
4	137 ± 2		-2009	---
5	163 ± 2		-2312	---
6	189 ± 2		-2672	---
7	215 ± 2		-3126	---
High-voltage monitor 0	70 ± 2		-1076	---
1	81 ± 2		-1270	---
2	92 ± 2		-1499	---
3	104 ± 2		-1731	---
4	119 ± 2		-2009	---
5	135 ± 2		-2312	---
6	153 ± 2		-2672	---
7	176 ± 2	4 ± 1	-3126	---

Table 3. UVS test and calibration program

Test	Location	Number of problems		
		SN003	SN004[a]	SN005
Component parts screening and margin tests	JPL and vendors	---	---	---
Module pre- and post encapsulation tests	JPL and vendors	1	3	3
Electronics package integration tests	JPL and vendors	2	2	1
Instrument calibration	University of Colorado	2	1	1
Flight-acceptance and type-approval environmental tests	JPL	---	11	---
Calibration verification	University of Colorado	---	---	---
Systems tests	JPL	1	2	1
Final calibration verification	University of Colorado	---	---	---
Final systems tests	AFETR	1	---	---

[a]Proof test model, as well as flight spare.

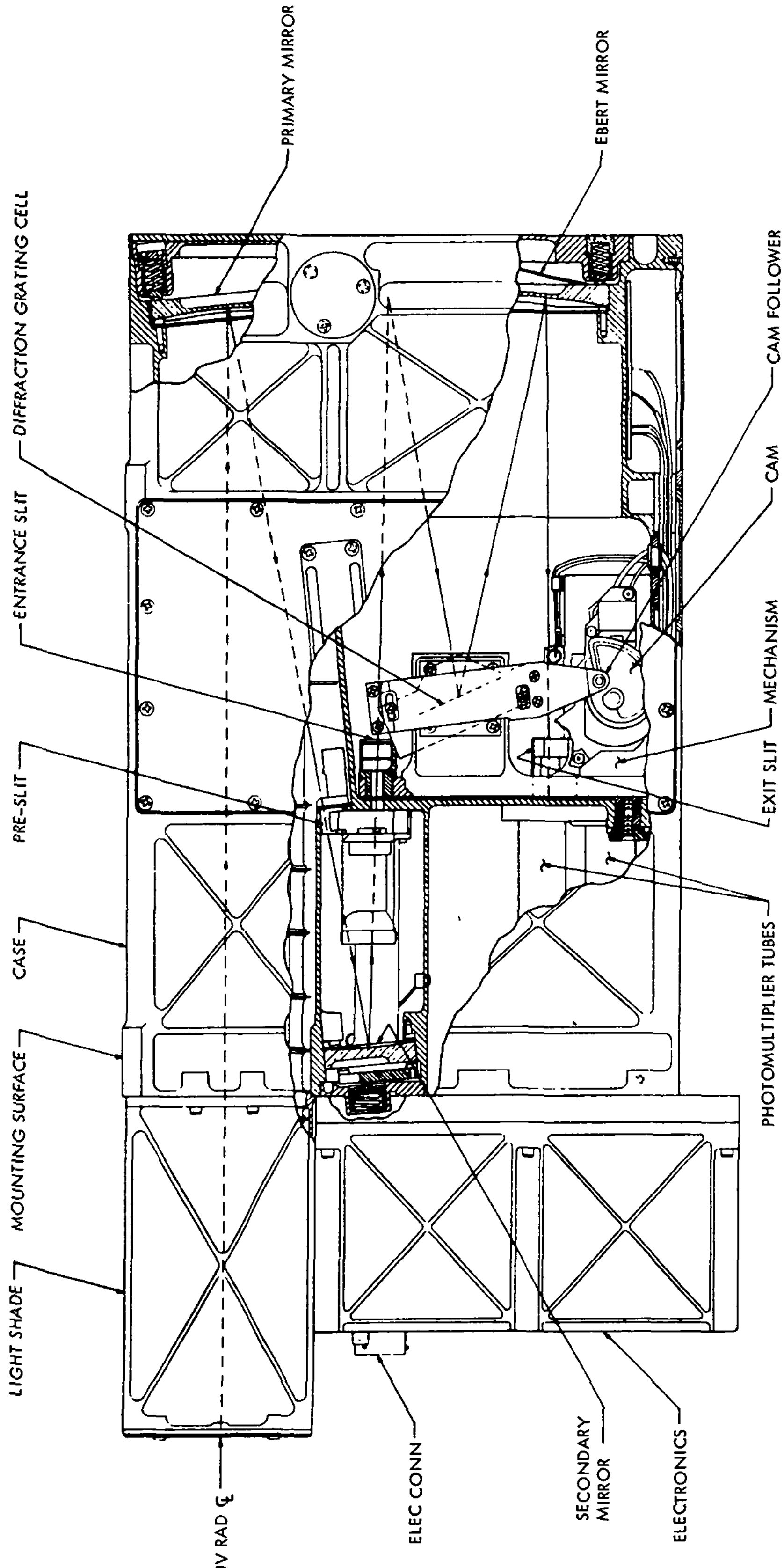


Fig. 1. UVS physical configuration

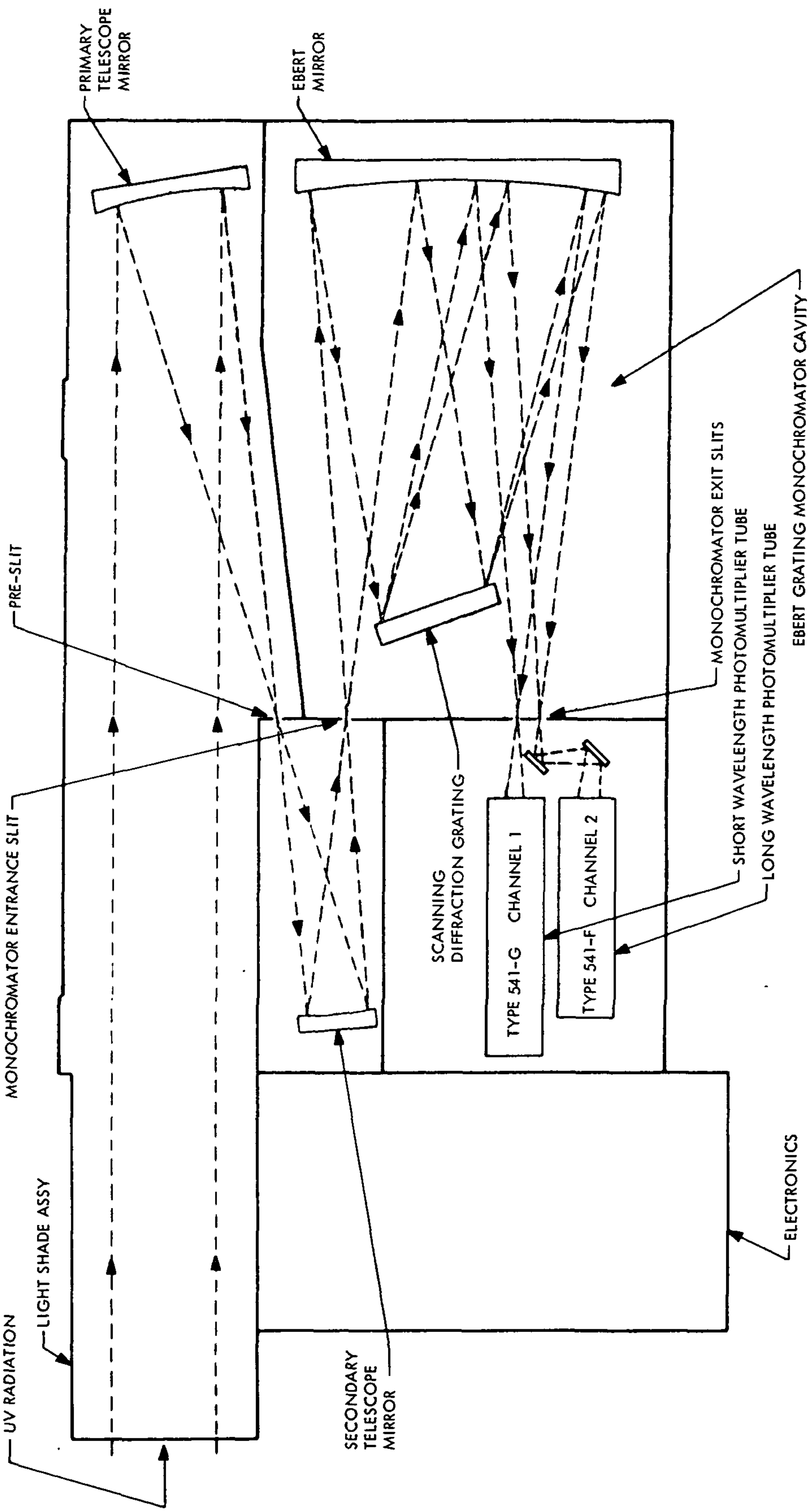


Fig. 2. UVS optical path

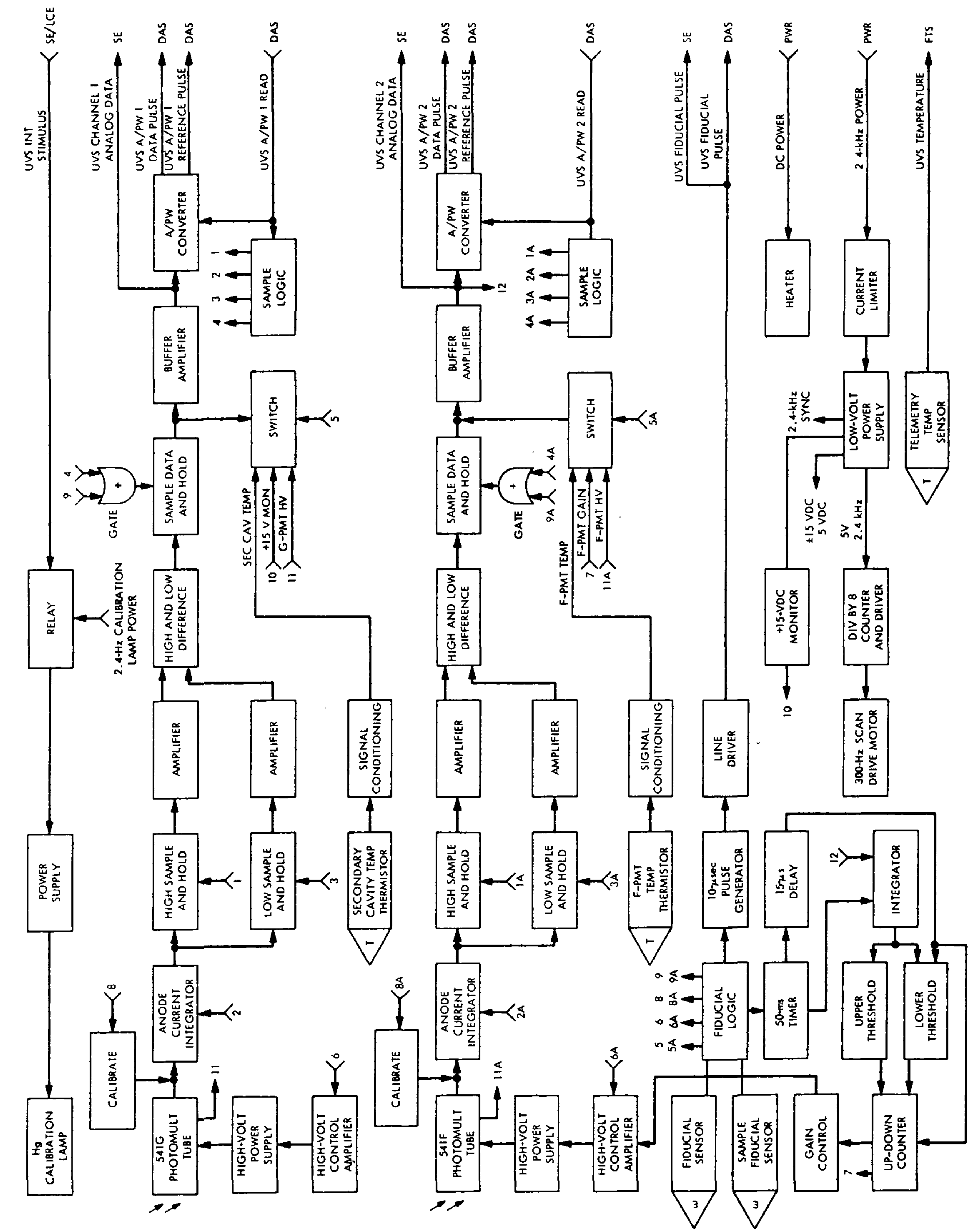


Fig. 3. UVS functional block diagram

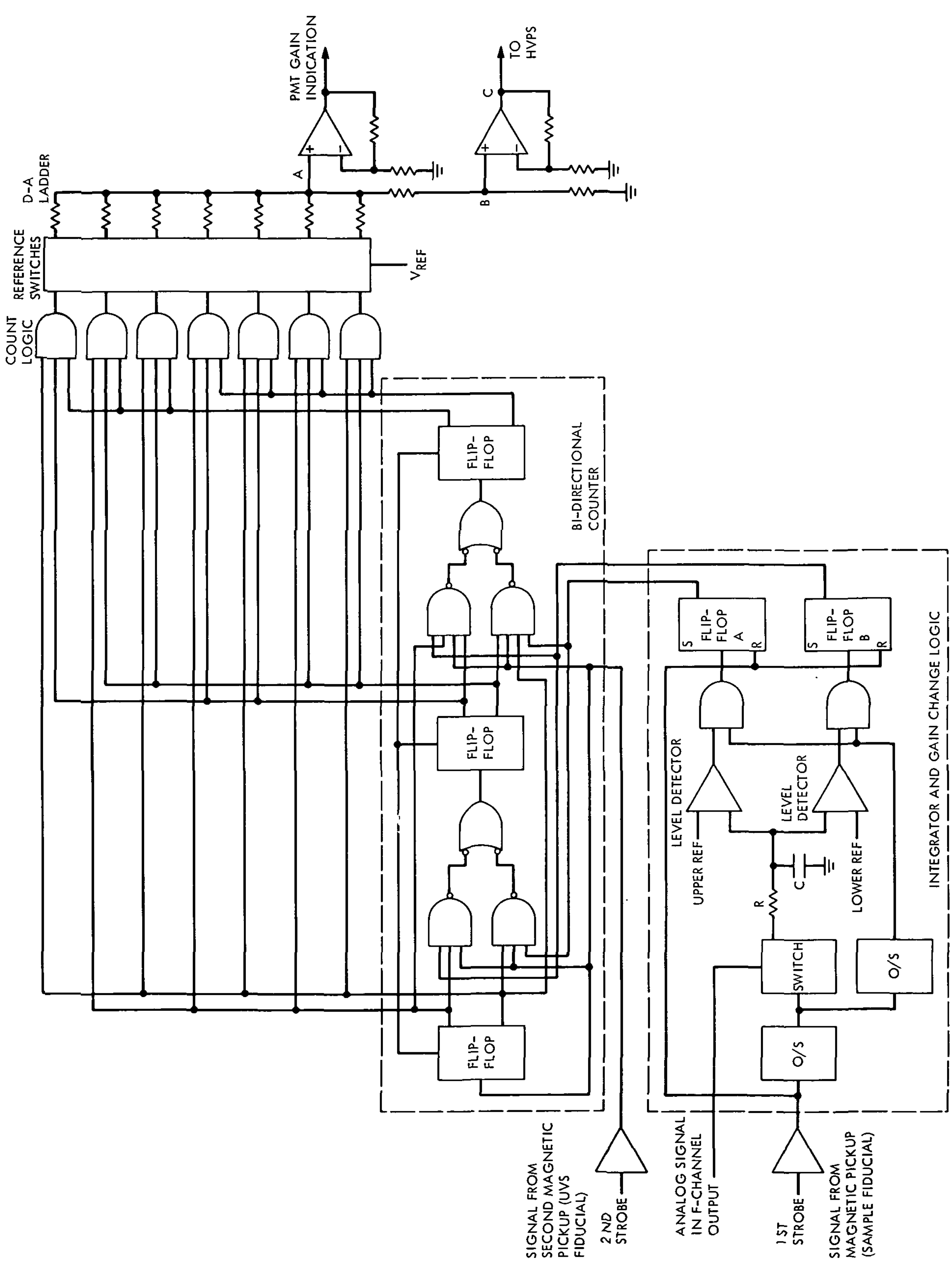


Fig. 4. F-channel gain change circuitry

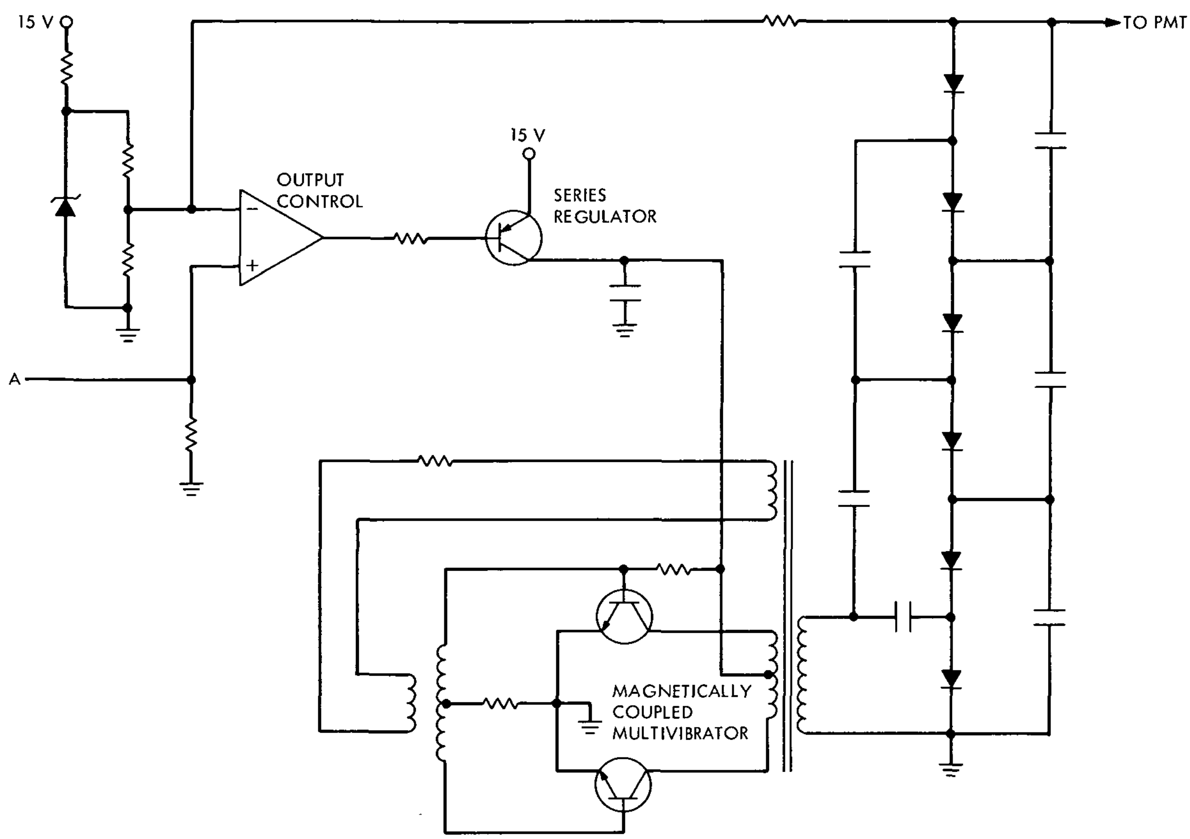


Fig. 5. High-voltage power supply

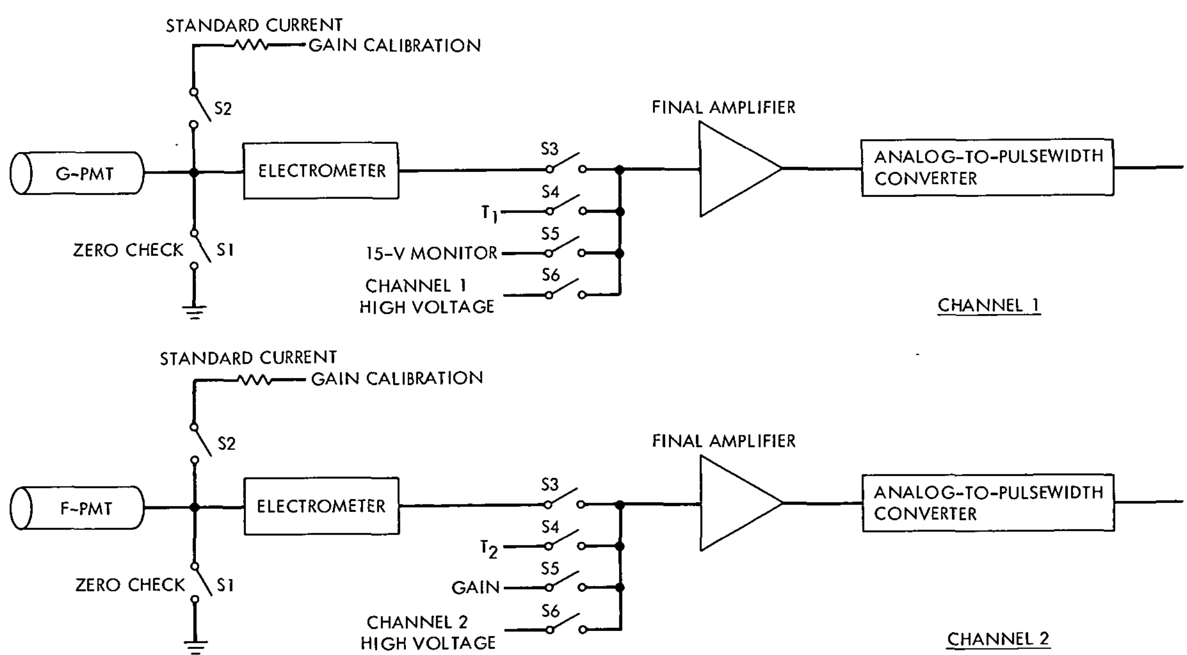
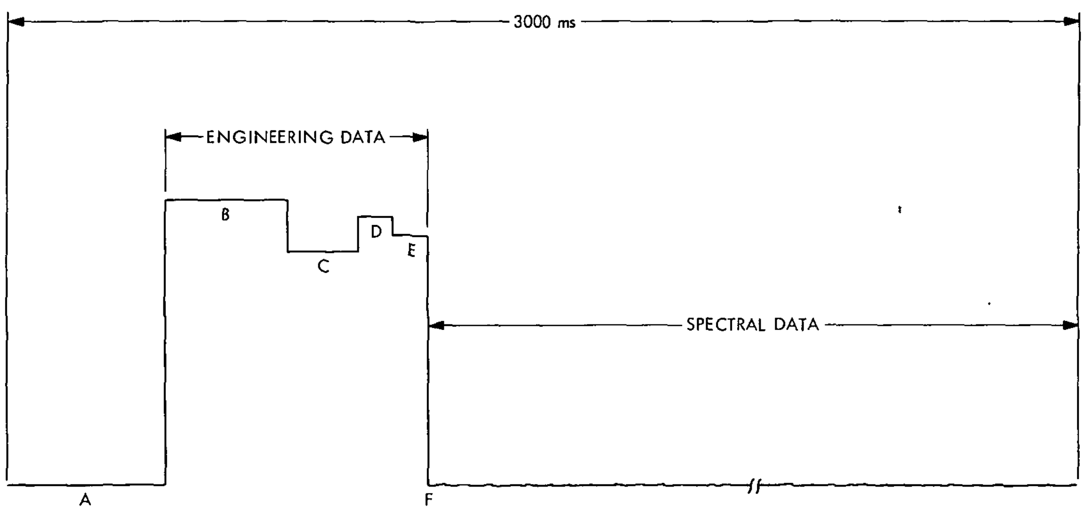


Fig. 6. Engineering parameters monitored during UVS scan



STEP	SWITCHES ON S1	S2	S3	S4	S5	S6	DURATION, ms	HIGH VOLTAGE	FUNCTION CHANNEL 1	CHANNEL 2
A	✓		✓				160	DOWN	ZERO CHECK	ZERO CHECK
B		✓	✓				110	DOWN	GAIN CALIBRATION	GAIN CALIBRATION
C				✓			65	UP	TEMPERATURE T_1	TEMPERATURE T_2
D					✓		20	UP	15-V MONITOR	GAIN INDICATOR
E						✓	20	UP	HIGH VOLTAGE	HIGH VOLTAGE
F			✓				2620	UP	SPECTRAL SCAN	SPECTRAL SCAN

Fig. 7. UVS scan sequence