AD-A123 377 THE PLASMA EXPERIMENT ON BOARD METEOSAT-F2(U) EMMANUEL COLL BOSTON MA A HUBER ET AL. AUG 82 SCIENTIFIC-1 AFGL-TR-82-0276 F19628-82-K-0039 1/1

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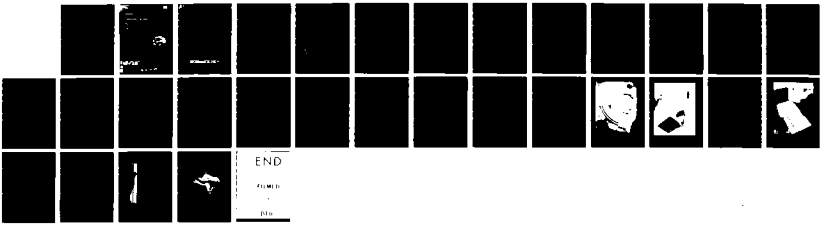

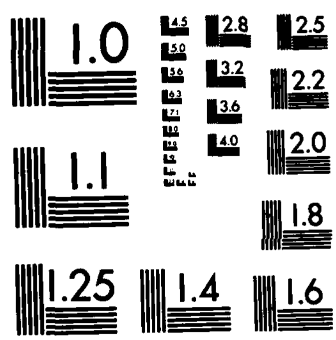

MICROCOPY RESOLUTION TEST CHART
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An electron spectrometer has been designed to aid in the study of spacecraft charging on METEOSAT-F2.

Differential energy analysis is performed by a pair of electrostatic analyzers (ESA) in which a time-sequenced variable electrostatic field deflects electrons of selected energies toward an exit aperture where they are counted by Channeltron (continued)

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20. Abstract

Electron Multipliers (CEM). The small ESA covers energies ranging from 50 eV to 1 keV; the larger, 1 keV to 20 keV. The dwell time at each energy level is 98 ms, with both analyzers operating simultaneously. A complete 16 point spectrum is produced once per second and the 16 data words are transferred to the satellite on command.

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INTRODUCTION

The surface potentials of geosynchronous satellites are known to vary according to the geomagnetic environment[1]. Excess negative charges build up on different parts of a satellite leading to possible breakdowns between two or more regions on the surface of the vehicle leading to unexpected status changes or anomalies.

The European geosynchronous satellite METEOSAT-F1 encountered spacecraft charging. The spacecraft did not suffer permanent damage, but the charging resulted in loss of data. It was suggested to the European Space Agency (ESA) that diagnostic instrumentation should be carried onboard the next satellite of the series, METEOSAT-F2. For that purpose, METEOSAT-F2 was equipped with an internal antenna sensitive to certain electrical transients resulting from discharges, and with an electrostatic analyzer to monitor plasma electron fluxes in the 50eV-20keV energy range.

The electrostatic analyzer represents a collaborative effort between Emmanuel College, the Air Force Geophysics Laboratory and the Mullard Space Science Laboratory. The purpose of this report is to document this instrumentation and to present data obtained during the first month of operation.

METEOSAT-F2 has shown only a small number of anomalies compared with METEOSAT-F1, and only two such events could possibly be attributed to spacecraft charging[2].

THE SPACECRAFT

METEOSAT-F2 was launched into a geosynchronous orbit on June 19, 1981. After about one month of programmed drift and orbit maneuvers, the spacecraft reached its final position on July 21, at 0 degree of longitude and latitude. The satellite is spin stabilized at 100 rpm, with its spin axis roughly parallel to the earth's spin axis. The spin rate is much too fast to obtain pitch angle distributions; it is ideal for spin-averaged-fluxes.

The first of the two instruments, the Electrostatic Event Monitor (EEM), was turned on a few days after launch, on June 21. The Electrostatic Spectrometer (SSJ/3) was commissioned on July 28, 1981. Quick look data taken with this instrument between July 28-31 showed that it was performing as planned. Production data up to July 1982 indicate that the SSJ/3 is performing with no detectable degradation.

THE ELECTROSTATIC ANALYZER (SSJ/3)

a) Physical Principle

An electric field established between two metallic plates which are in the shape of concentric cylindrical segments selects charged particles within a narrow energy band. Let R_i and R_o be the radii of curvature of the inner and outer plates respectively, to which electric potentials of +V and -V are applied. Using Gauss's theorem and the definition of potential, we calculate the electric field E between the plates to be

$$E = \frac{1}{r\ \ell n(R_o/R_i)} V \qquad (R_i \le r \le R_o)$$

where fringing of the electric field has been neglected. To a first order approximation, the trajectories of non-relativistic particles passing between the set of plates are circular arcs concentric with the plates. The energy E (expressed in electron volts) of a non-relativistic particle of charge q with a circular trajectory of radius r is then related to V by

$$E = \frac{V}{2\ \ell n(R_o/R_i)} \quad \text{(ev)}$$

which to a good level of accuracy, for $R_o - R_i \ll R_i$, can be reduced after expansion of the ℓn function to

$$E \simeq \frac{V\overline{R}}{2\delta}$$

where the mean radius $\overline{R} = 2R_oR_i/(R_i+R_o)$, and $\delta = R_o - R_i$.

The formula above thus indicates a linear relationship between the electric potential applied to the plates and an average energy of the particles which will be transmitted through the field, from an entrance aperture at one end of the cylindrical segments to the exit aperture at the other end.

The proportionality constant, known as the analyzer constant, is equal to $\overline{R}/2\delta$ and is equal to 1.96 eV/V and 20.0 eV/V for the low and high energy analyzers respectively.

It can be shown that the energy resolution, $\Delta E/E$, of the instrument is to a good approximation equal to $\delta'/\overline{R}$, where δ' is the width of the entrance aperture. The angular aperture of the system is approximately δ'/R radians (FWHM) in the plane of the trajectory. Such an instrument could be used for the analysis of either electrons or protons by the choice of the polarities of the applied potentials. Discrimination between protons and electrons is thus inherently excellent. In the present application only electrons are measured.

b) Physical Description

The SSJ/3 consists of 2 sets of plates, one set for each of the two electron energy ranges (51 - 1045 eV and 1.06 - 20 keV). Schematics of the small plates geometry (Low energy range), and large plates geometry (High energy range) are shown in Figure 1.

The plates are made of aluminum with a sand-blasted finish to minimize the amount of XUV reaching the channeltrons (see

"Detectors" below) which are extremely sensitive at these wavelengths. Further reduction of the XUV scattering from the small plates is achieved through closely spaced serrations on the plate's inner surfaces.

Dielectric materials between the plates and in the vicinity of their edges were carefully avoided to prevent charge buildup in these areas which in turn would affect the electron trajectories.

Figure 2 shows a picture of the complete SSJ/3 plate assembly together with the collimation system and the channeltrons in their housing.

The operating voltages are between $\pm$25V and $\pm$500V and $\pm$12.5V and $\pm$250V for the high and low energy analyzers. The use of a balanced $\pm$ (volts) configuration results in a zero potential surface midway between the plates. Since this surface passes through the narrow apertures, electrons undergo negligible acceleration upon entering and leaving the analyzer.

The field-of-view of the spectrometer is oriented at 45 degrees with respect to the spin axis of the satellite (see Figure 3). Thus the electron pitch angles sampled are between 30 and 60 degrees under quiescent magnetic conditions.

The integration time for each of the 16 channels (8 channels in the "high" and "low" energy range) is 12.583 seconds. Since the spectrometer records the electron fluxes in 2 energy channels (one in the "high" and one in the "low" energy range) simultaneously, a complete sixteen point spectrum is obtained in

100.7 seconds.

c) The Detectors

Immediately following the exit aperture of each set of plates are a pair of Channeltron Electron Multipliers*. The high energy range uses two CEM 4019-C/WL-SC (10 mm funnel), while the low energy range uses two CEM 4013-C/WL-SC (3 mm funnel). Each device has a gain of $\sim 10^7$-10^8. The anodes of the Channeltrons operate at +3 kV and their funnels are at ground potential. The critical dose for each Channeltron is in excess of 10^{11} counts.

Special care was taken to avoid potentially contaminating materials in the instrument which may have resulted in a long-term gain degradation of the detectors.

* Galileo Electro-Optics, Sturbridge, MA

THE ELECTRONICS

Figure 4 is a block diagram of the instrument. The Channeltron outputs from each ESA are capacitively coupled to a preamplifier-discriminator. These units produce logic-compatible outputs which are counted by log accumulators. Timing and control logic steps the energy levels, resets and enables the log accumulators, and loads the data words in the shi' registers. Upon receipt of a gate pulse from the spacecr t, the data word in the corresponding shift register is seri y shifted out on a data line. Figure 5 shows the SSJ/3 wit s analog and digital cards exposed. Please note that the housing of the instrument in this picture is not the actual one which was used in this experiment (see Figure 3). Brief descriptions of the functional block follow.

a) The Preamplifiers

The preamplifiers used in this instrument are of the charge sensitive type and have an inherent discrimination level of about .5 picocoulomb, corresponding to an electron gain of $3x10^6$. They include pulse forming circuitry which produces CMOS-compatible output pulses about 0.5μs in duration.

An externally accessible test input is provided to verify operation of the preamps, counters, and logic. This input couples an external pulse generator through a 2 pf capacitor to the preamp inputs. A fast-rising pulse of about .5 volt amplitude transfers enough charge into the preamps to produce output pulses.

b) <u>The Logarithmic Counters</u>

The electron count from each analyzer is accumulated in a log counter following the preamp. These units produce an 11-bit logarithmic representation of the actual count. The seven least significant bits represent the mantissa and are the contents of a 7-bit binary counter. The remaining four bits, the exponent, represent the final prescale factor by which the input to the 7-bit counter is divided. The unit operates as follows: Initially, the 7-bit counter counts all incoming pulses, up to a count of 128, or 0000000; at this point the input begins to be divided by two, so that only alternate pulses increment the counter. When the counter again reaches the 0000000 state, the prescale factor doubles, up to a maximum value of 2^{15}. The actual count represented by the 11-bit word is given by:

$$\text{COUNT} = 2^{y}(x+128)-129.$$

$$\underbrace{0000}_{y}\underbrace{0000000}_{x}$$

The value 129 rather than 128 appears here because a 1 count is preset into each log accumulator at the beginning of every data interval to aid in readout verification. This count must be subtracted to get actual count.

The maximum capacity of these accumulators is 8,355,711 counts, which is well in excess of the maximum expected count for the 12.5 seconds integration time period.

c) <u>The Control Logic and Data Output</u>

To establish timing for plate voltage stepping and data accumulation the control logic section uses two of three gate pulses provided by the spacecraft (see Figure 6). These pulses, which read out data words A and B, are spaced 12.53 sec, or 1/2 data frame apart, to simplify instrument timing. At each occurrence of pulse A or B, the plate voltage is stepped, and the log counters are disabled and their contents latched into shift registers. Then the contents of the corresponding 16-bit shift register, either A or B, is transferred across the interface. Since 16 bits are not adequate to read out the two 11-bit counts (plus sync bits), the 7-bit mantissas of the high energy counts are stored in a third shift register and read out by Gate C later in the frame.

In each 25 second data frame, 4 counts, representing four energies, are read out, producing a complete 16 point spectrum in 100 seconds.

All logic elements in the SSJ/3 are C-MOS. Radiation hardened devices were used where possible.

d) <u>The Power Supply</u>

The SSJ/3 package utilizes a 50 kHz sine wave inverter type DC-DC Converter to provide all required power. This supply is built in-house. It supplies four regulated voltage levels: +5V; ±750V; and +3000V. +5V operates all analog and digital circuitry. ±750, which are derived from voltage doublers, supply the plate stepper. +3000V is the bias voltage for the Channeltrons.

e) The High Voltage Stepping Circuit

The plate voltages are controlled by a shunt regulator using a chain of 4 high voltage field effect transistors as the shunt element. Employing only a single reference and error amplifier, this circuit produces balanced positive and negative outputs. The voltage levels are determined by fixed programming resistors which feed known currents into the error amplifier. These resistors are sequentially placed in the circuit by a Johnson-type C-MOS counter.

The settling time for this circuit is about 3 ms for the negative-going steps. This represents a negligible dead time for the instrument. Figure 6 is the wave form at the inner high energy plate.

THE DATA

Table I lists the mean energy (in eV) of each of the 16 energy channels together with the corresponding geometrical factor (cm^2-ster-eV). The energy resolution for each channel is ∿10%, and the acceptance angles of the low energy and high energy analyzer are 3.7x4.6 degrees (FWHM) and 1.9x9.6 degrees respectively.

Because of a tight schedule for the delivery of the SSJ/3, only a preliminary calibration was performed on the instrument. The parameters shown in Table I were obtained for 2 other similar instruments flown in connection with the Defense Meteorological Satellite Program (DMSP) of the U.S. Air Force[3,4]. These instruments were calibrated using an electron beam system at Rice University in Houston, Texas. Our experience has shown that there is a remarkable consistency from instrument to instrument in the mean energies and normalization constants. Thus, we estimate the certainties in the energies to be of the order of ±4%, and that of the normalization constants ±20% approximately.

TABLE I

Channel Number	Center Energy(eV)	Normalization Constant(cm^2-ster-eV)
1	49	1.72×10^{-3}
2	75	3.54 "
3	116	5.65 "
4	177	8.42 "
5	274	1.30×10^{-2}
6	418	2.00 "
7	664	3.17 "
8	990	4.71 "
9	984	6.94 "
10	1508	9.55 "
11	2316	1.29×10^{-1}
12	3540	1.80 "
13	5480	2.39 "
14	8360	3.20 "
15	12880	4.25 "
16	19800	5.26 "

Presentation of the Data

The SSJ/3 electron data are written onto magnetic tapes at the European Satellite Operations Center (ESOC), from where they are sent monthly to Mullard Space Science Laboratory (MSSL) and to Emmanuel College for processing.

MSSL presents the data in the output format shown in Figures 7 (daily summaries), and 8 (monthly summaries).

The Daily Summaries - The Daily Summaries are presented according to the following format. The channels are interpreted over 12 formats (5 min 02 sec) giving 286 points in a 24-hour period - Note that UT and local time are identical for METEOSAT-F2.

1) High Energy Spectrum (HI) For each of the 8 energy channels (i=9 to 16), the electron intensity (cm^{-2}-sr^{-1}-s^{-1}-eV^{-1})

$$J(i) = C(i)/N(i)/T$$

where C(i) is the accumulated number of counts in the time T (T=37.5 sec).

Successive pairs of fluxes are then averaged and grey-scaled logarithmically for the display within the range of 10^2 (white) to 10^6 (black) cm^{-2}-sr^{-1}-s^{-1}-eV^{-1}.

2) Low Energy Spectrum (LO) The same procedure as for the High Energy Spectrum is followed for the 8 energy channels (i=1 to 8) of the low energy detector.

3) Total Flux The total number flux (cm^{-2}-ser^{-1}-s^{-1}) for the 16 energy channels is calculated according to the following summation

$$NF = \frac{1}{2} \sum [J(i) + J(i+1)][E(i+1) - E(i)]$$

i=1 to 7 and i= 9 to 15

giving the total number flux which varies between 10^6 and 10^9.

4) Mean Energy A mean energy (eV) for the electron spectrum is calculated starting with the total energy flux ($eV\text{-}cm^{-2}\text{-}sr^{-1}\text{-}s^{-1}$)

$$EF = \frac{1}{2}\ \Sigma\ [J(i)E(i) + J(i+1)E(i+1)][E(i+1) - E(i)],$$
$$i = 1 \text{ to } 7 \text{ and } 9 \text{ to } 15.$$

The mean energy, EF/NF, is then calculated and is plotted between 0.1 and 20 keV.

5) Maximum and Minimum Counts for the High Energy Detector (HI max + min) - For each integration period the maximum and minimum values of 12.5*C(i)/T(i) with i=9 to 16 are determined and plotted between the limits 10^2 and 10^6.

6) Maximum and Minimum Counts for the Low Energy Detector (LO max + min) - Same as 5), but with i=1 to 8.

7) EEM Discharge Event Counter - Every 12.5 seconds a read out of the event counter gives the number of times that the threshold has been exceeded. The accumulation of this counter over 24 hours with a point plotted every 5 minutes on a scale of 0 to 5. Whenever the count exceeds 5 then 5 is subtracted. Note that the count is not integer due to the analogue nature of the output.

8) EEM Threshold Voltage - The average threshold voltage during each 5 minute period is plotted on a scale from 1.5 to 2.0 volts.

9) Eclipse Flag - On days when the spacecraft enters the

shadow of the Earth a hatched panel indicates the eclipse time.

10) Geomagnetic Index Kp - The three hour planetary index is calculated from the magnetic field excursions measured at eleven stations spread around the Earth. It is plotted on a scale from 0 to 9. (Note $2_- = 1.7$, $2_+ = 2.3$)

The Monthly Summaries - Data for a whole month is plotted using the same format as the Daily Summaries but using a basic integration period of 432 formats (3 hours) instead of 12 formats. Although the grey-scaled panels are of limited value, the total flux curve does give a good monitoring of the long term changes in the diurnal variation and their association with Kp.

The Energy Spectra - Figure 9 shows a sequence of energy spectra recorded on September 1, 1981, from 1200 UT until 2400 UT. The reader should compare these spectra to the grey plot scale of Figure 8. The low energy plasma injection from the plasma sheet is clearly visible toward ∿2330 UT.

ACKNOWLEDGEMENT

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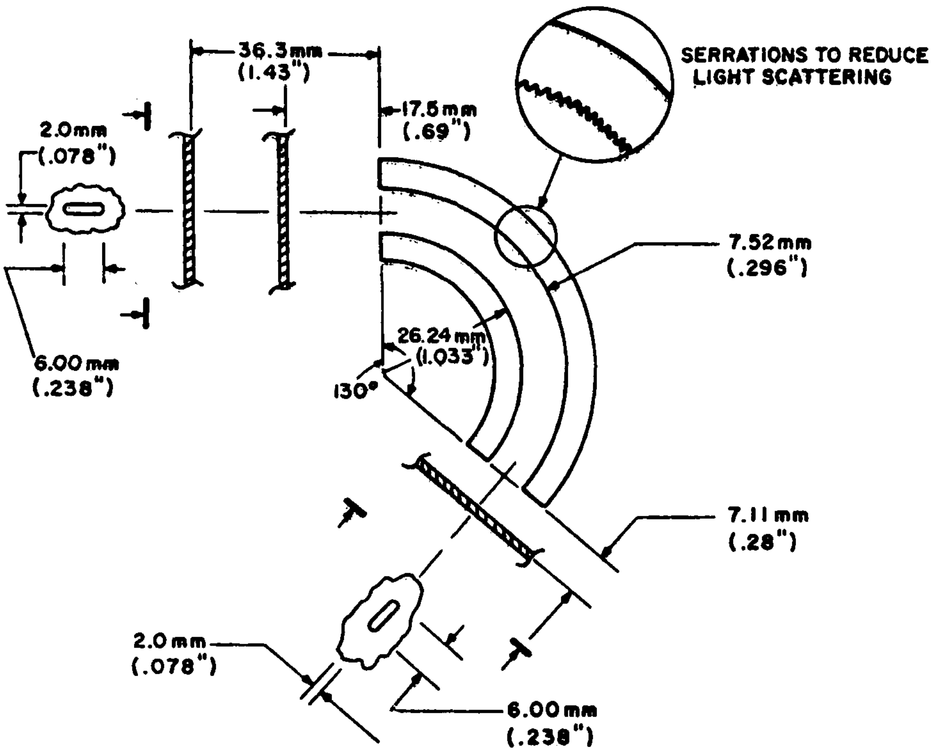
2) Johnstone, A.D., G.L. Wrenn, A. Huber, and D. Hoge, "First Results from Meteosat-2 Discharge Experiments", ESA Bulletin, No. 29, Feb. 1982.

3) Huber, A., J. Pantazis, A.L. Besse, and P.L. Rothwell, "Calibration of the SSJ/3 Sensor on the DMSP Satellites", AFGL-TR-77-0202, 1977.

4) Hardy, D.A., M.S. Gussenhoven, and A. Huber, "The Precipitating Electron Detectors (SSJ/3) for the Block 5D/Flights 2-5 DMSP Satellites: Calibration and Data Presentation", AFGL-TR-79-0210, 1979.

SSJ/3 - SMALL PLATES GEOMETRY



SSJ/3 - LARGE PLATES GEOMETRY

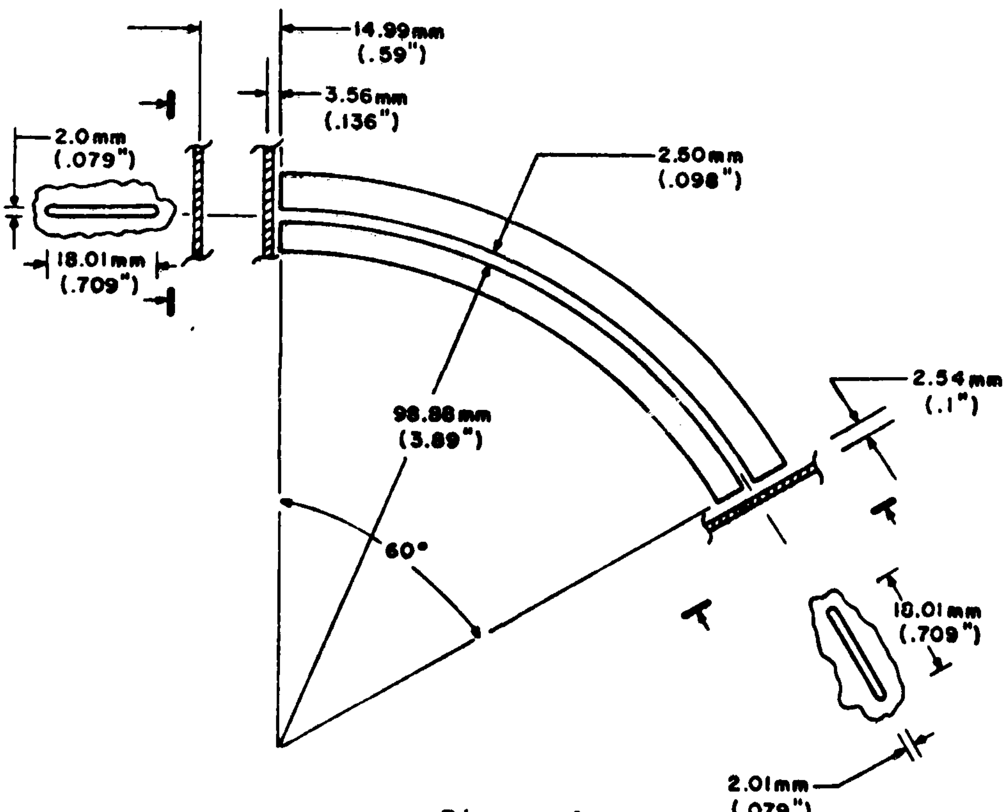


Figure 1

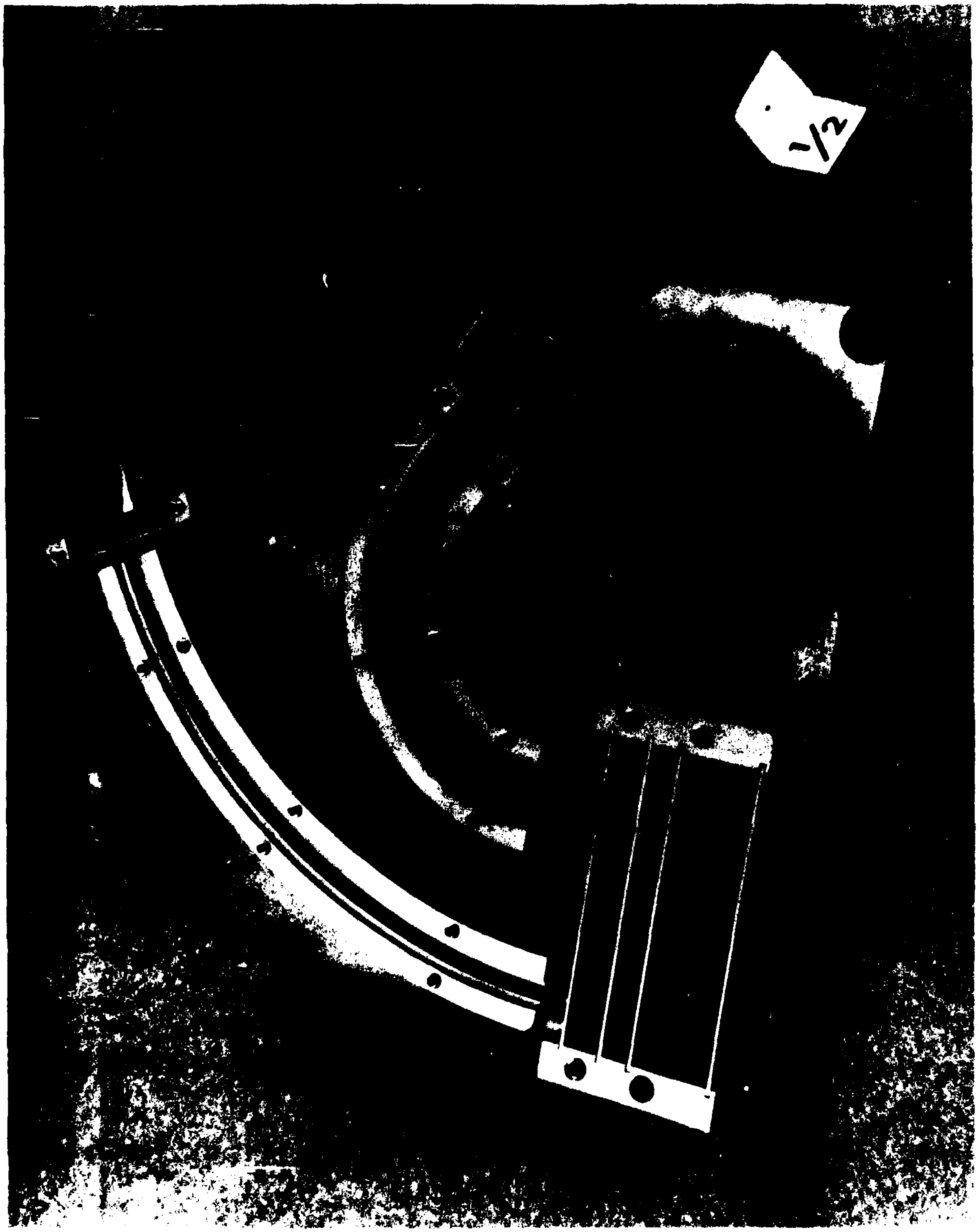


Figure 2

Figure 3

SSJ/3 BLOCK DIAGRAM

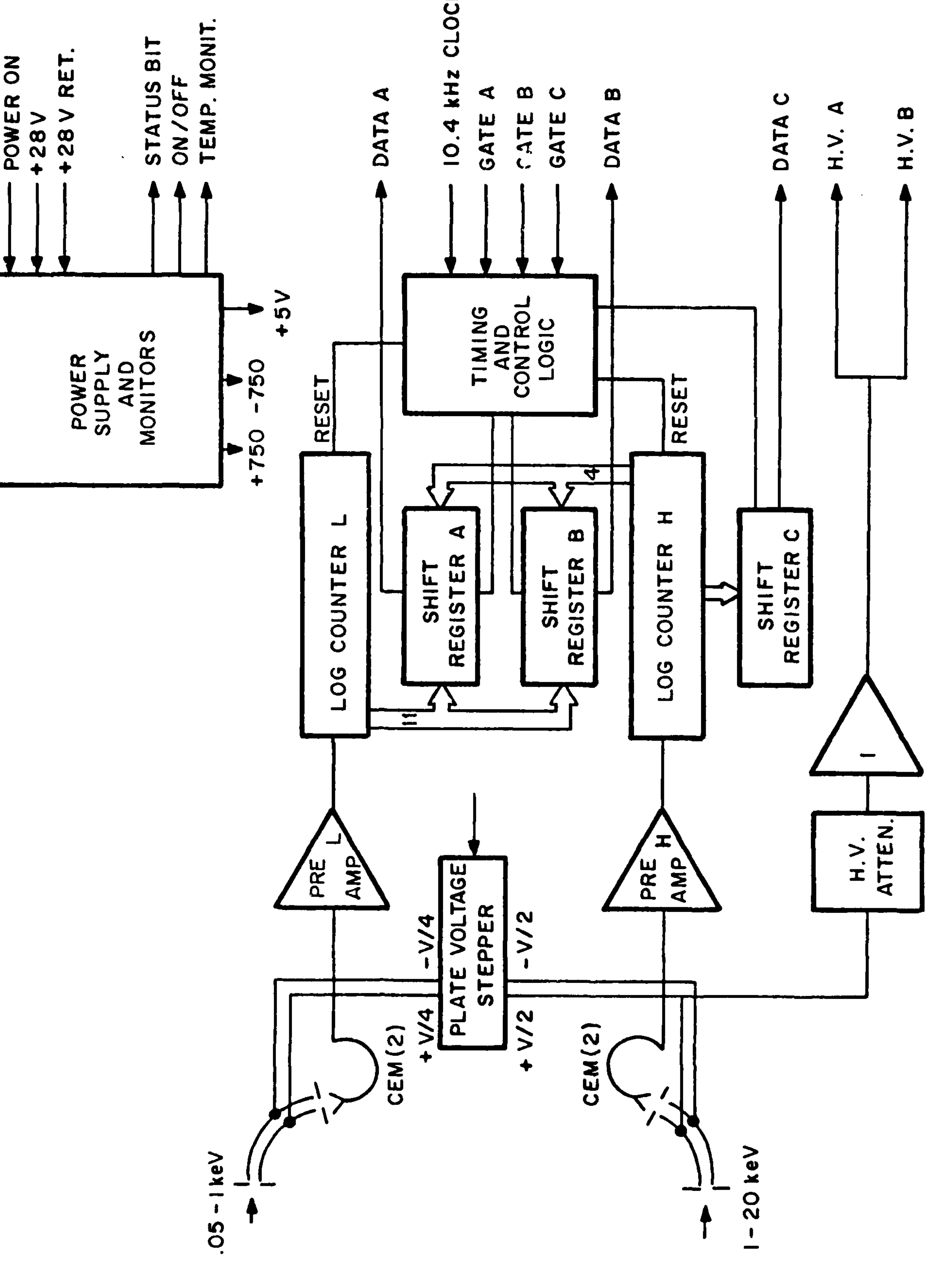


Figure 4

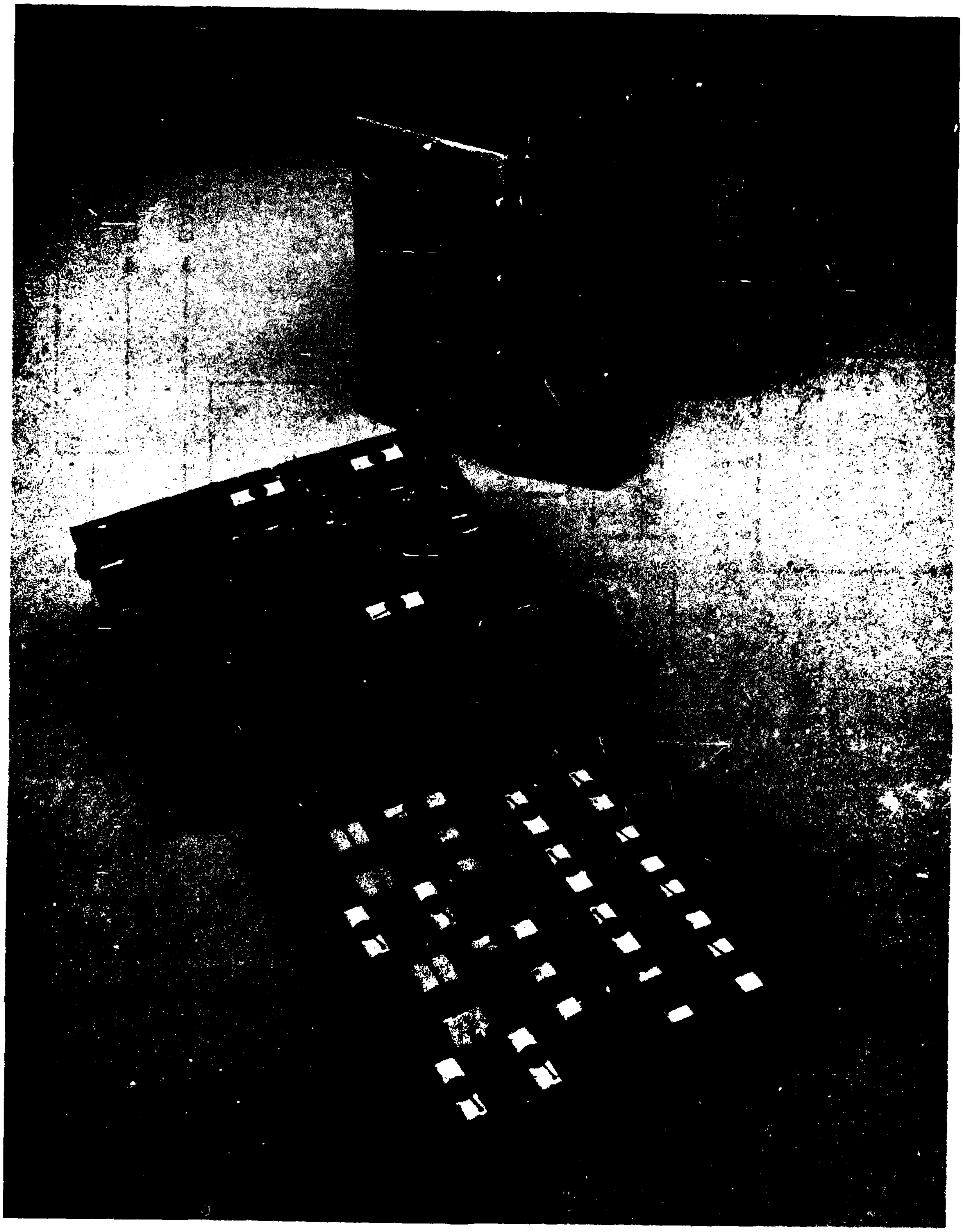


Figure 5

PLATE VOLTAGE SEQUENCE AND TIMING DIAGRAM

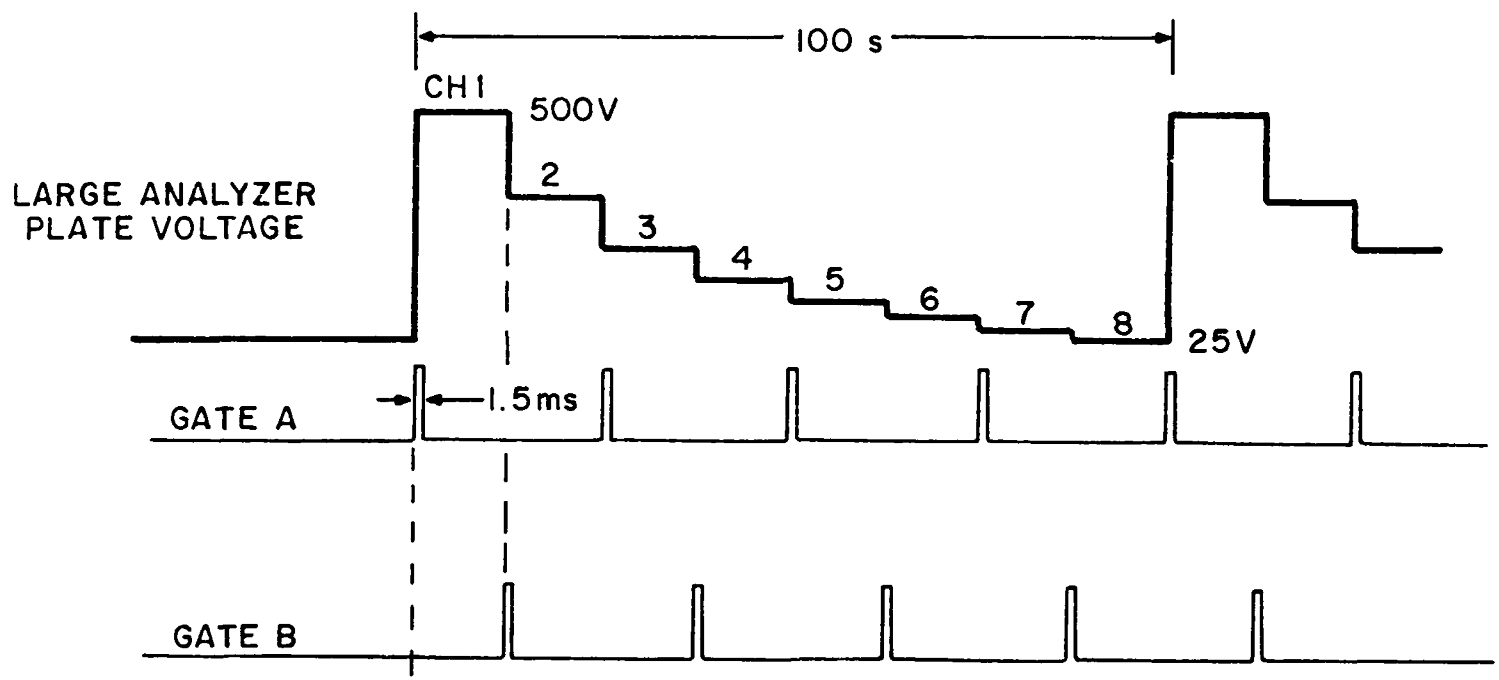
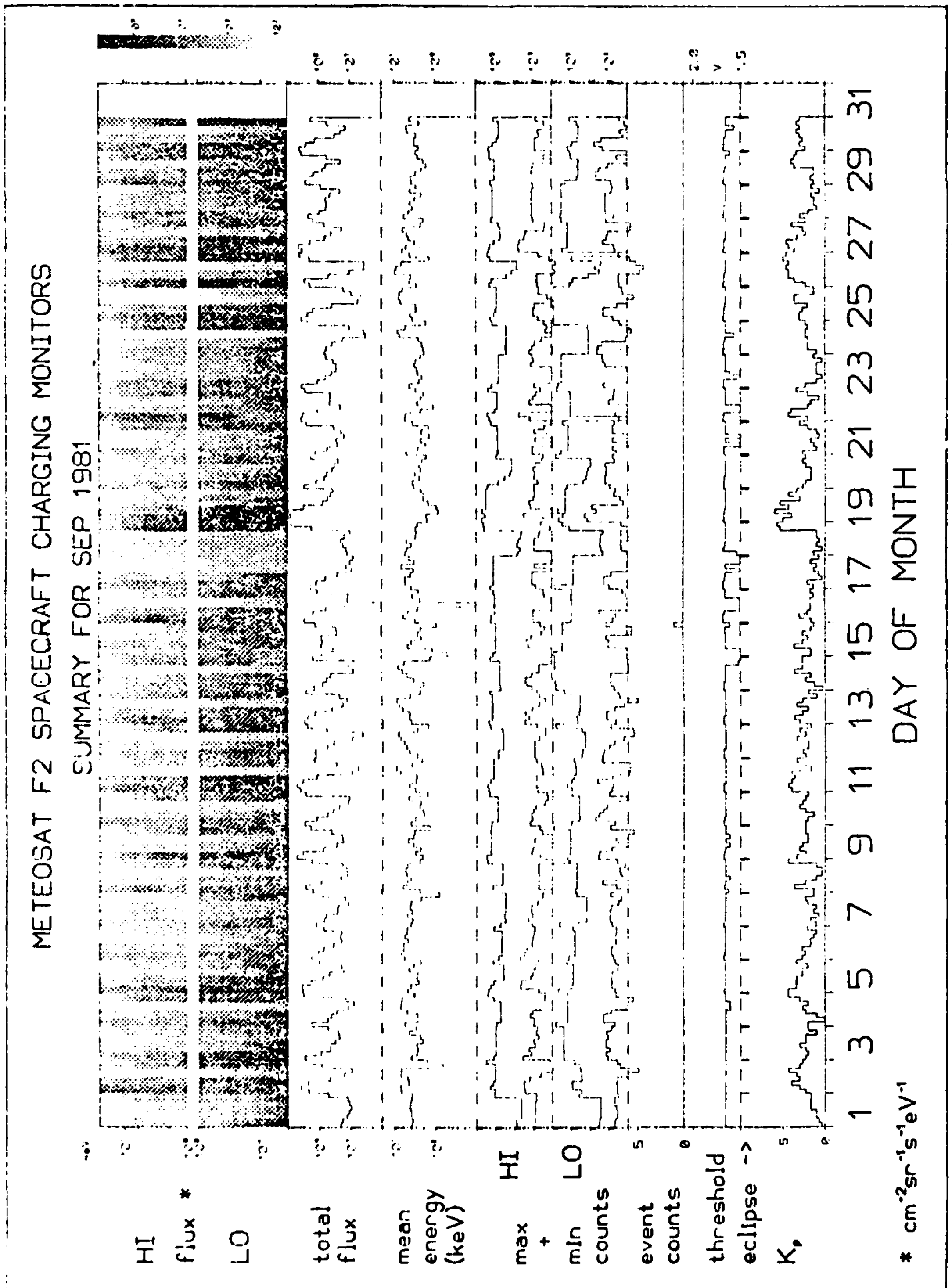


Figure 6



METEOSAT F2 SPACECRAFT CHARGING MONITORS
SUMMARY FOR SEP 1981
HI
flux *
LO
total flux
mean energy (keV)
max + min counts
HI
LO
event counts
threshold
eclipse ->
K_p
* cm^-2 sr^-1 s^-1 eV^-1
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
DAY OF MONTH

Figure 7

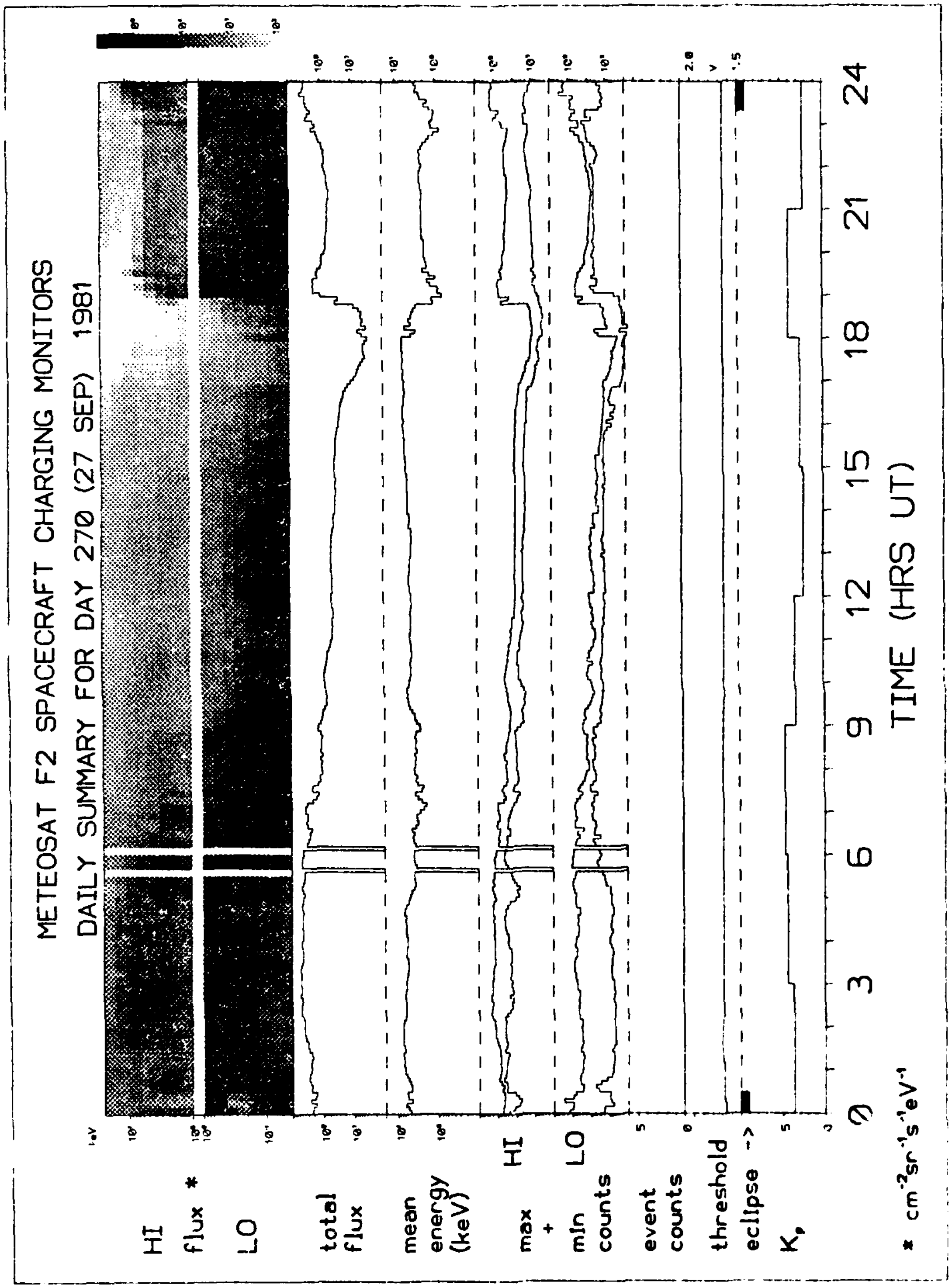

METEOSAT F2 SPACECRAFT CHARGING MONITORS
DAILY SUMMARY FOR DAY 270 (27 SEP) 1981
HI
flux *
LO
total flux
mean energy (keV)
max + min counts
HI
LO
event counts
threshold
eclipse ->
K
* cm⁻²sr⁻¹s⁻¹eV⁻¹
0
3
6
9
12
15
18
21
24
TIME (HRS UT)

Figure 8

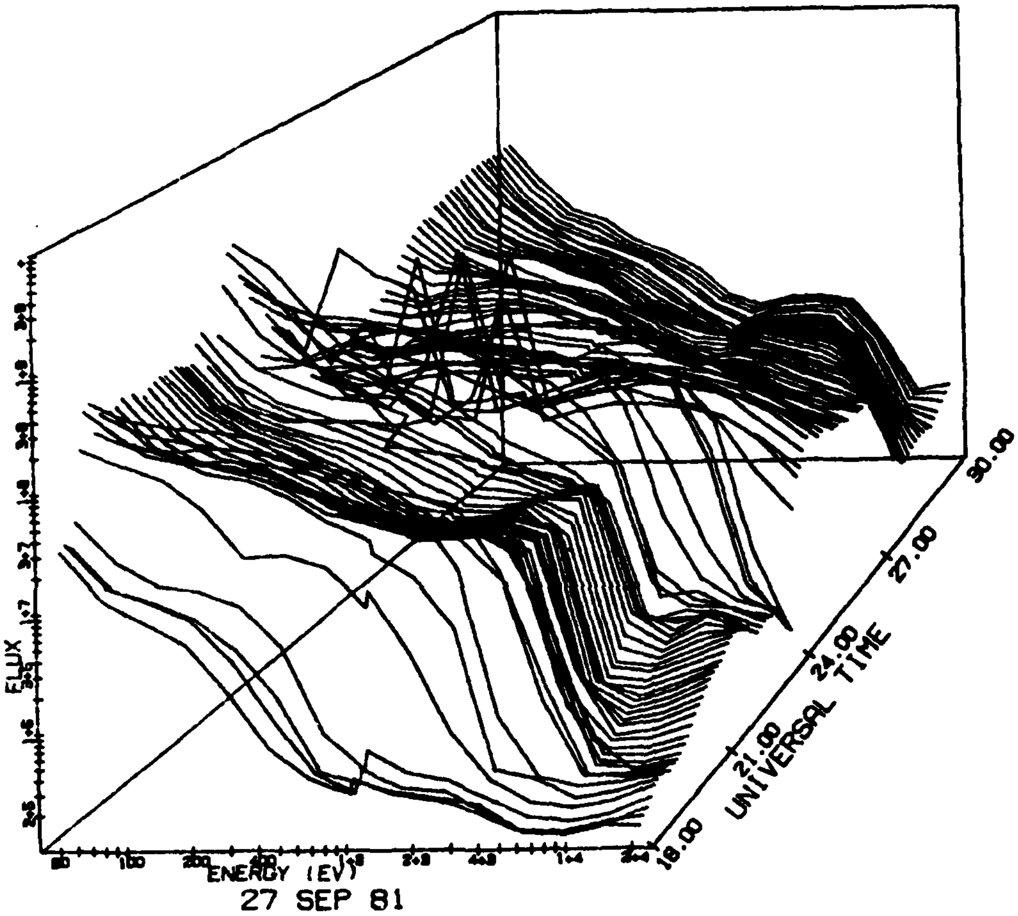

FLUX
100
ENERGY (EV)
27 SEP 81
18.00
21.00
24.00
27.00
30.00
UNIVERSAL TIME

Figure 9