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LEVEL II

Characteristics of Electrical Discharges on the P78-2 Satellite (SCATHA)

ADA087249

H. C. KOONS
Laboratory Operations
The Aerospace Corporation
El Segundo, Calif. 90245

15 July 1980

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THE AEROSPACE CORPORATION

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This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report ~~has~~ been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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The P78-2 (SCATHA) satellite was launched on 30 January 1979 to measure the characteristics of the spacecraft charging process near synchronous orbit. A Charging Electrical Effects Analyzer onboard measures the characteristics of electrical discharges in both the frequency and time domain. Pulses are detected in response to commands, during electron and ion beam operations and during natural charging events.

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FIGURES

FIGURES (Continued)

TABLES

I. Introduction

The Charging Electrical Effects Analyzer (CEEA) was provided for the P78-2 (SCATHA) satellite payload to verify that electrical discharges are occurring when other instruments measure large differential potentials between surface materials on the vehicle.

The CEEA consists of three instruments: the Pulse Analyzer, the VLF Analyzer, and the RF Analyzer. The Pulse Analyzer measures the number of pulses, their amplitudes and shapes on four sensors. The VLF Analyzer measures the electric and magnetic field spectra of waves in the frequency range from ~100 Hz to 300 kHz. The RF Analyzer measures the electric field intensity on a 1.8-m monopole antenna in the frequency range from 2 to 30 MHz.

In this paper I present results from ten days between 12 February and 24 April 1979. This period covers quiet and active days, eclipse and electron and ion beam operations. The CEEA instruments are described in the next section. That is followed by a presentation of the statistics of pulses detected. Individual time periods of special interest are described in detail in the final sections.

II. Instrument Description

Pulse Analyzer

The Pulse Analyzer measures the shape of electro magnetic pulses in the time domain from 7 ns to 3.7 ms. The pulse analyses are made on four sensors: (1) a loop antenna around one of the two redundant space vehicle Command Distribution Units, (2) a wire along the outside of a "typical" space vehicle cable bundle, (3) an external short dipole antenna at the end of a 2-m boom, and (4) a digital command line from the Command Distribution Unit to the Pulse Analyzer.

The signal processor may be switched by command to any of the four sensors. It then steps automatically through the selected sensors monitoring each in turn for 16 s. The functional block diagram is shown in Fig. 1. When a signal exceeds a commandable threshold, its amplitude is sampled at 16 points to measure the pulse shape. The 16 samples may be spaced logarithmically or linearly in time. The logarithmic spacing covers the range from 7 ns to 492 μs. The linear spacing is commandable with the following options: 0.015, 0.06, 0.24, 1.0, 3.8, 30, and 250 μsec. The amplitude is measured by a bank of 20 discriminators, 10 positive and 10 negative. The total range of the discriminator bank is 3 mV to 1.8 V. The signal from each sensor can be attenuated by command to place it within this range. There are six attenuation settings that select measurement ranges from 3 mV to 1.84 V at minimum attenuation to 3.46 V to 1910 V at maximum attenuation. The threshold is coupled to the attenuation setting. The attenuation, threshold, and sampling interval can be independently commanded for each sensor. The number of pulses per second above four selectable thresholds is also measured. Three of the thresholds are determined by the attenuation selection; the fourth is the pulse analysis threshold.

The instrument is commanded by a 22-bit serial magnitude command of which only the seven least significant bits are used.

In its normal mode of operation the instrument steps through each of the four sensors monitoring each for 16 s in sequence. The threshold and attenuations for each sensor are determined by experience on orbit. Initial measurements have been made with the logarithmic sample spacing. Linear spacing will be used since typical pulses prove to be short (200 ns).

Inflight verification of the calibration is accomplished by sending serial magnitude commands from the Command Distribution Unit to the serial magnitude command sensor.

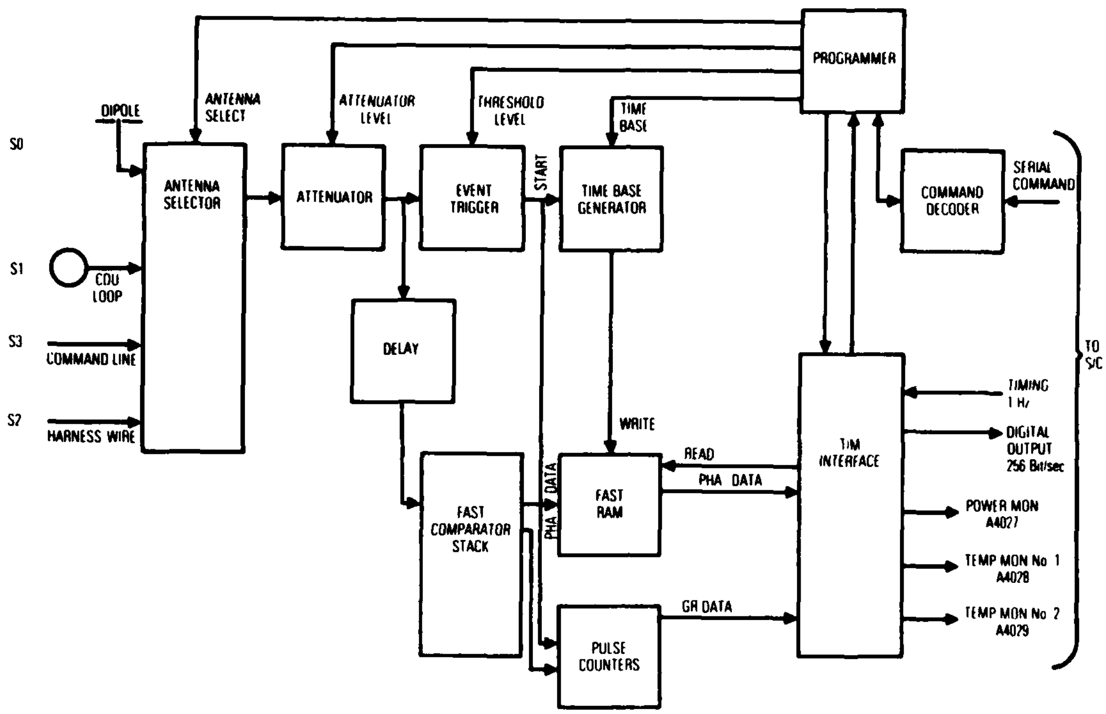

Fig. 1 Simplified block diagram of Pulse Analyzer

VLF Analyzer

The VLF Analyzer measures electromagnetic emissions in the ELF, VLF, and LF ranges.

The experiment employs two antennas to detect the electromagnetic and electrostatic emissions. An air-core loop antenna detects the magnetic components of the waves and a 100-m tip-to-tip dipole antenna, provided by the Goddard Space Flight Center for the DC Electric Field Experiment, detects the electric component. The over-all sensitivity of the electric field receiver is 5×10^{-7} V/m Hz at 1.3 kHz and 10^{-7} V/m Hz at 10.5 kHz.

The air-core loop is electrostatically shielded and has an effective area of 575 m^2 at 1.3 kHz. It is constructed of 1530 turns of 36 AWG copper wire on a form 50 cm in diameter. The antenna is a boom mounted loop 2 m from the spacecraft. The overall sensitivity of the receiver is 3×10^{-6} γ/ Hz at 1.3 kHz. The dynamic range is 60 db.

The VLF Analyzer has eight pulsed commands to control the operation of the experiment as follows: (1) Selection of the broadband output mode-OFF/3 kHz/5 kHz (2) Selection of the antenna signal to be analyzed-ELECTRIC/MAGNETIC/AUTOMATIC SWITCHING AT 16s INTERVALS (3) Selection of the calibrate mode-ON/OFF, and (4) Selection of the narrowband filter mode-ON/OFF.

The primary on-orbit operation will be the narrowband filter mode providing tape recorded data with the antennas switching. There are eight narrowband channels at 0.4, 1.3, 2.3, 3.0, 10, 30, 100, and 300 kHz. Broadband data can only be collected in realtime.

RF Analyzer

The RF Analyzer measures electromagnetic emissions in the frequency range from 2 MHz to 30 MHz. It measures the number of pulses and the spectral envelope in the RF frequency range (integrated over many pulses).

The RF analyzer employs two antennas for the measurements: an extendible 100-m tip-to-tip dipole provided by the Goddard Space Flight Center for the DC field experiment and a 1.8-m monopole along a boom that is deployed perpendicular to the spin axis of the vehicle.

The analyzer can be operated in both a swept or a fixed frequency mode. The design includes five frequency bands, two sweep rates for each band, and two detection bandwidths. The amplitude (peak detection) is sampled 400 times per second, converted to an 8-bit digital format (one bit is a sync bit) and telemetered on a special purpose 3 kHz broadband data channel. During tape recorder only operations, the amplitude is sampled eight times per second. Only fixed frequency operation will take place in this mode.

III. DATA

The Pulse Analyzer was turned on and successfully checked out on February 5, 1979. Initial operations began with the pulse analysis threshold set at 0.651 V and the countrate thresholds set as shown in Table 1, column 1. At this setting only ten pulses were detected during the 168 hours of data available from February 10-16. All of these pulses occurred during SC4-2 ion beam operations. The pulses had a width at half maximum of 200-500 μs and an amplitude of 0.7 V.

Because it was apparent that very few pulses were being detected, the threshold was lowered on February 18 to 0.165 V with the associated countrate thresholds listed in Table 1, column 2.

At this threshold the analyzer occasionally responds to pulses generated when commands are sent to the vehicle. Pulses occurring within one second of a command are attributed to a vehicle or payload response to the command and are identified as Command Pulses in Table 2. An interesting variation to this is a pulse which occurs approximately 20 s after the vehicle transmitter is turned off. This is about the time that the ground station command transmitter ceases sending s-tones to the vehicle. Twenty-eight such pulses have been detected. They are identified as Command Pulses in Table 2.

A second source of pulses is the antenna switch in the VLF Analyzer. This experiment is housed in the same package as the Pulse Analyzer. When the VLF antenna switches from the magnetic antenna to the electric antenna a pulse is detected on the Pulse Analyzer Command Line Sensor. This pulse occurs once every 64 seconds. Since pulses are synchronized to the vehicle clock they can be readily identified and they have been eliminated from the distributions in Table 2.

The majority of the remaining pulses listed in Table 2 occur during the SC4-1 electron beam operations and the SC4-2 ion beam operations. These time periods will be described in more detail below.

Only 12 of the 561 pulses have not been associated with an identifiable source. The location of the satellite at the time these 12 pulses occurred is shown in Fig. 2 as a function of local time and radial distance. This distribution is certainly consistent with the local time dependence of circuit upsets on DOD and commercial satellites.[1] It is, however, premature to attribute these pulses to discharges. All occurred when a Range Tracking Station was operating the satellite in real time. Until it can be clearly established that they are not the response due to normal payload operations their source is simply unknown.

The amplitudes of the 12 pulses vary from 180 mV to 690 mV. The peak amplitude typically occurs at the 0.097 μs sample. The width to half-maximum is less than 0.2 μs. Six of the 12 pulses occurred on the Command Line Sensor. The pulse shapes are shown in Fig. 3, a-b (with calibration in Table 3). It is interesting to note that the shapes are essentially identical even though the pulses occurred on three different days. Pulses that occurred when s-tones to the vehicle ceased are shown in Figs. 3c, -e and -f. A pulse due to a command is shown in Fig. 3d. Pulses

[1] McPherson, D. A., Cauffman, D. P., and Schober, W. R., "Spacecraft Charging at High Altitudes: SCATHA Satellite Program," Journal of Spacecraft and Rockets, Vol. 12, Oct. 1975, p. 621.

Table 1 Pulse Analyzer Settings

Function	Time Period 2/5 - 2/17	2/18 - 4/26	4/27 - 10/13
Pulse Analysis Threshold	0.651 V	0.165 V	0.327 V
Countrate Threshold CR0	0.117	0.030	0.117
Countrate Threshold CR1	1.85	0.469	1.85
Countrate Threshold CR2	28.3	7.18	28.3
Countrate Threshold CR3	0.651	0.165	0.327
Pulse Analysis Range	0.05 - 29.2	0.014 - 7.43	0.05 - 29.2
Time State	Log	Log	Log

Table 2 Distribution of pulses detected by the Pulse Analyzer

Date	*Threshold*	Total Pulses	Command Pulses	Electron Beam Pulses	Ion Beam Pulses	Unattributed Pulses	RTS Active
10 Feb	0.65	0	0	-	-	0	-
11 Feb	0.65	1	1	-	-	0	-
12 Feb	0.65	0	0	-	-	0	-
13 Feb	0.65	0	0	-	0	0	-
14 Feb	0.65	2	0	-	2	0	-
15 Feb	0.65	5	0	0	5	0	-
16 Feb	0.65	2	0	-	2	0	-
20 Feb	0.17	8	8	-	-	0	-
22 Feb	0.17	8	5	-	-	3	3
5 Mar	0.17	11	11	-	-	0	-
17 Mar	0.17	12	8	-	-	4	4
22 Mar	0.17	13	13	-	-	0	-
23 Mar	0.17	7	7	-	-	0	-
26 Mar	0.17	11	11	-	-	0	-
27 Mar	0.17	7	7	-	-	0	-
28 Mar	0.17	9	7	-	-	2	2
29 Mar	0.17	17	17	-	-	0	-
30 Mar	0.17	171	6	165	-	0	-
31 Mar	0.17	120	14	61	45	0	-
4 Apr	0.17	62	12	0	50	0	-
5 Apr	0.17	55	17	-	36	2	2
24 Apr	0.17	40	17	10	12	1	1
		561	158	236	152	12	12

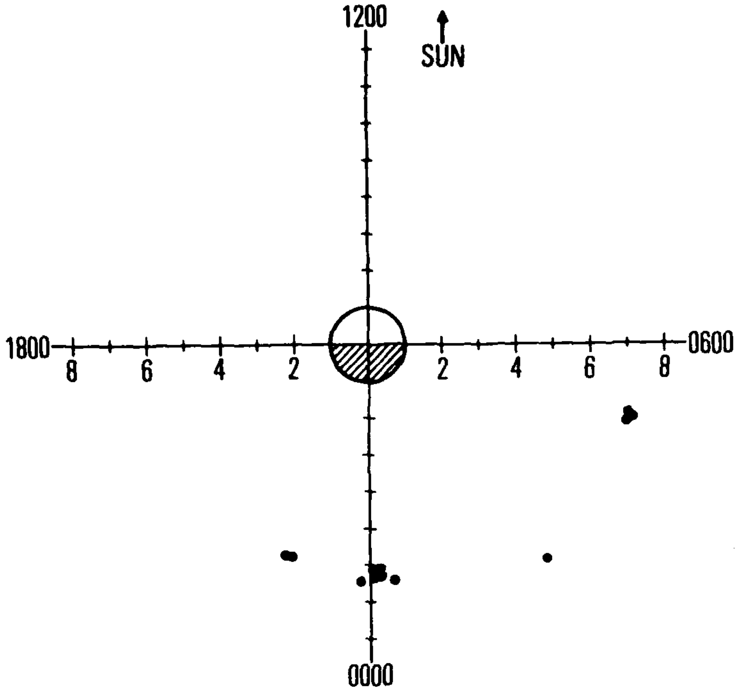

Fig. 2 P78-2 satellite location in radial distance and local time when discharges of unknown source are detected.

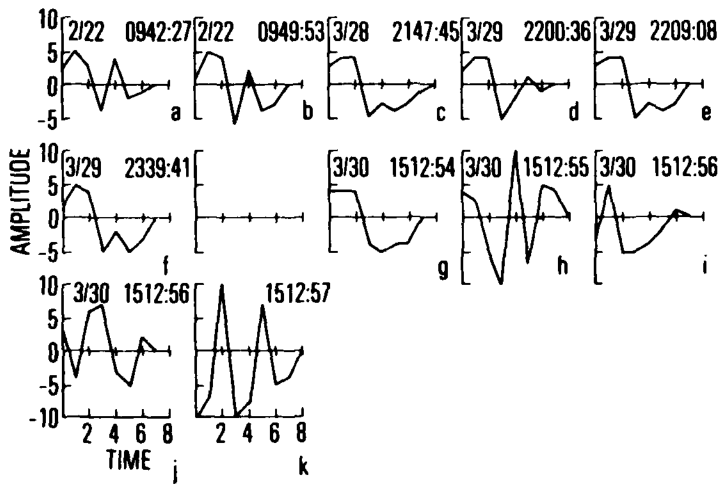

Fig. 3 Pulse shapes measured on the command line sensor. The sources of a and b are not known. c, e and f occur when the s-tones to the vehicle command receiver cease. d is a response to a payload command. g-k occurred during electron beam operations. Table 3 gives the amplitude and time calibration for this figure.

that occurred during the electron beam operations on 30 March are shown in Fig. 3, g-k. These pulses show a variety of different shapes. This is a good indication that the nearly identical shape of the other pulses is related to the source of these pulses and is not instrumental.

Table 3 Amplitude (y axis) and Time (x axis) calibrations for the data in Fig. 3.

	Amplitude, V	Time, μs
0	0.014	-0.008
1	0.023	0.007
2	0.045	0.037
3	0.089	0.097
4	0.176	0.217
5	0.350	0.457
6	0.693	0.937
7	1.39	1.91
8	2.80	3.83
9	5.59	7.67
10	7.43	15.3

IV. Electron Beam Operations

During the SC4-1 electron beam operations on 30 March 1979 the SC2-1 and SC2-2 Plasma Potential Sensors failed. Data obtained from the Pulse Analyzer and the RF Analyzer show that discharges were occurring on the vehicle at the time of the failure. Two of the largest pulses occurred at the times of the SC2-1 and SC2-2 failures.

Table 4 shows the order of events during the electron beam experiments on 30 March. Pulses exceeding the 0.165 V analysis threshold abruptly onset at 1512:08 UT at the time the electron beam was commanded to a -3 kV potential at 6 ma current. Pulses above threshold continued until 1551:24 UT.

Table 4 Time line of events on March 30, 1979 during electron gun operations at the time of the SC2-1,2 Plasma Potential Sensor Failures

Time	Event
prior to 1512:08	Electron gun at -1.5 kV and 6 ma with no discharges observed.
1512:08	Electron gun commanded to -3 kV. Pulse Analyzer begins detecting pulses above 0.165 V threshold.
1512:09	Pulse Analyzer detects a pulse greater than 7.4 V on the Harness Wire Sensor.
1512:10	SC2-1 Plasma Potential Sensor fails.
1512:16	Space vehicle data system begins scrambled operation.
1512:29	Data system corrects itself at Main Frame 0.
1512:40	SC2-2 Plasma Potential Sensor Fails
1512:08 to 23:29	Pulse Analyzer and TPM detect numerous pulses on all sensors.
1513:29	Electron gun commanded to -1.5 kV. Pulse amplitudes drop to 1.4 to 2.8 V.
1517:36	Electron gun current lowered to 0.01 ma. Pulses cease on Pulse Analyzer.

Pulses of comparable magnitude occurred on each of the four Pulse Analyzer sensors. The largest count rate threshold was 7.18 V. The number of pulses above this threshold is shown in Fig. 4 as a function of time. Only once did two pulses occur in one second. The number of pulses above the threshold of 0.469 V is shown in Fig. 5. Typical pulse shapes on each of the four sensors are shown in Figs. 6-9. The pulses on the same sensor tend to have the same shape. This suggests that the larger discharges are occurring at the same point on the vehicle. Pulses of differing shapes are seen sufficiently often to rule out an instrumental effect in the shapes. The pulses that occurred at the time of the SC2 Probe failures are identified on the figures.

Since the highest discriminator level was exceeded by about ten percent of the pulses, the thresholds were reset to the values shown in Table 1, column 3 on 27 April 1979.

At the time these pulses occurred the RF Analyzer was operating on the 1.8-m monopole antenna at a fixed frequency of 20 MHz with a bandwidth of 4 kHz.

The data from the RF Analyzer is shown in Fig. 10. The pulses began at 1512:08 UT. The amplitude distribution of the pulses above -90 dbm is shown in Fig. 11. The hole at -86 dbm is an artifact of the quantization of the calibration. The SC2-1 and SC2-2 Probes failed during two of the larger pulses detected by the RF Analyzer.

The peak power of -83 dbm in a 4 kHz bandwidth at 20 MHz cannot be considered very large at that frequency.

The VLF Analyzer shows pulses during SC4-1 electron beam operations. Broadband data is available from the beam operations on 24 April 1979. A sample spectrogram is shown in Fig. 12. The single pulse at 0741:56 UT was also detected by the Pulse Analyzer on the Loop Sensor (S1) around the Command Distribution Unit. On that sensor its amplitude was 0.7 V and its duration was 0.9 μs. Obviously the VLF Analyzer is responding to a long tail to the pulse.

The VLF Analyzer detects many low level pulses that do not cross the Pulse Analyzer threshold. An example from the electron beam operations on 24 April is shown in Fig. 13. In the center of the spectrogram the antenna switches from electric to magnetic antenna. The horizontal lines are magnetospheric emissions spontaneously generated by the radiation belt electrons.

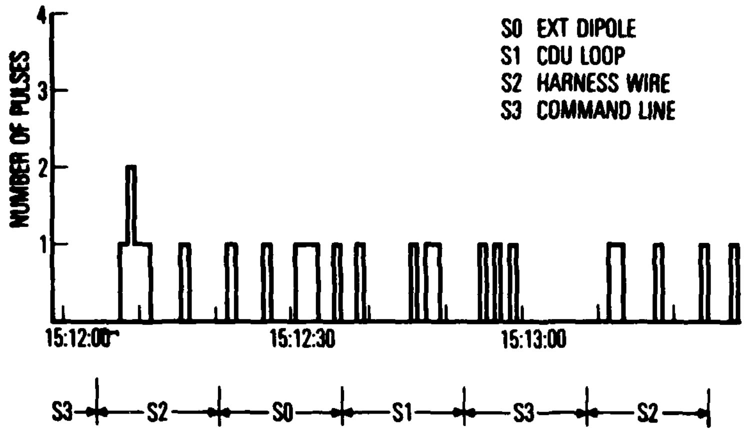

Fig. 4 Number of pulses exceeding a threshold of 7.18 V as a function of time during electron beam operations on 30 March 1979.

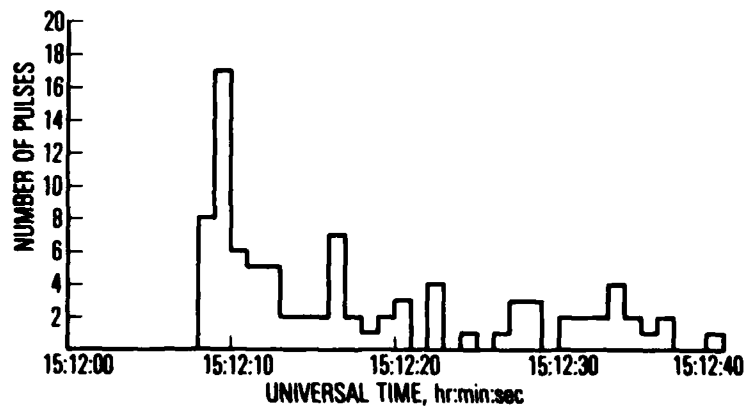

Fig. 5 Number of pulses exceeding a threshold of 0.469 V as a function of time during electron beam operations on 30 March 1979.

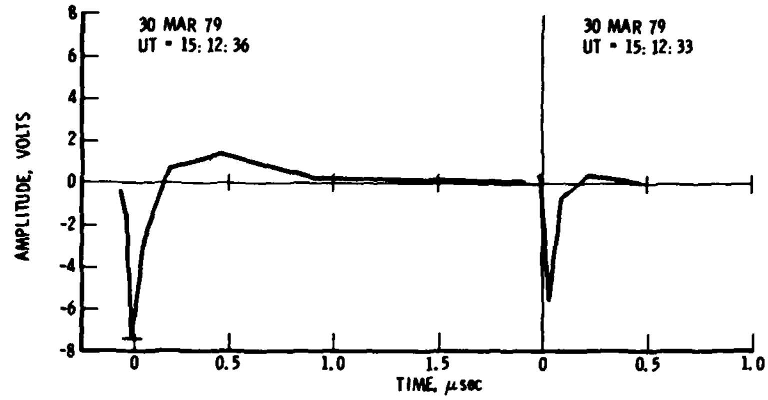

Fig. 6 Pulse shapes measured on the External Dipole Sensor.

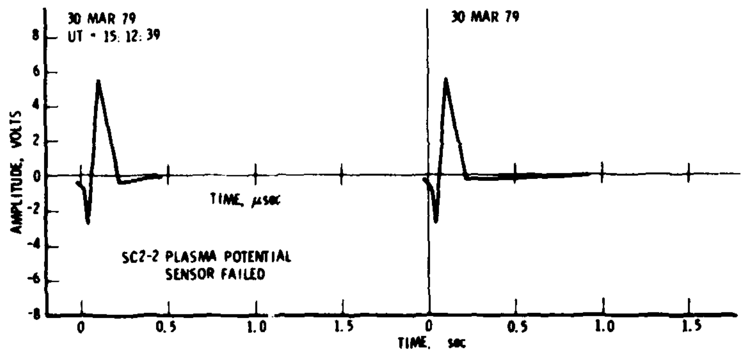

Fig. 7 Pulse shapes measured on the Loop Sensor around the space vehicle Command Distribution Unit.

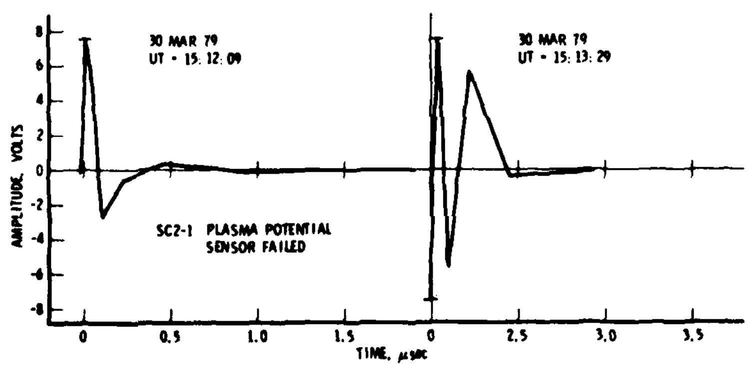

Fig. 8 Pulse shapes measured on the Harness Wire Sensor.

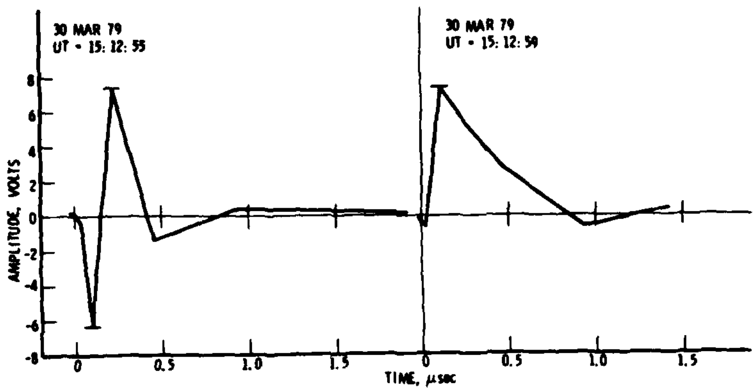

Fig. 9 Pulse shapes measured on the Command Line Sensor.

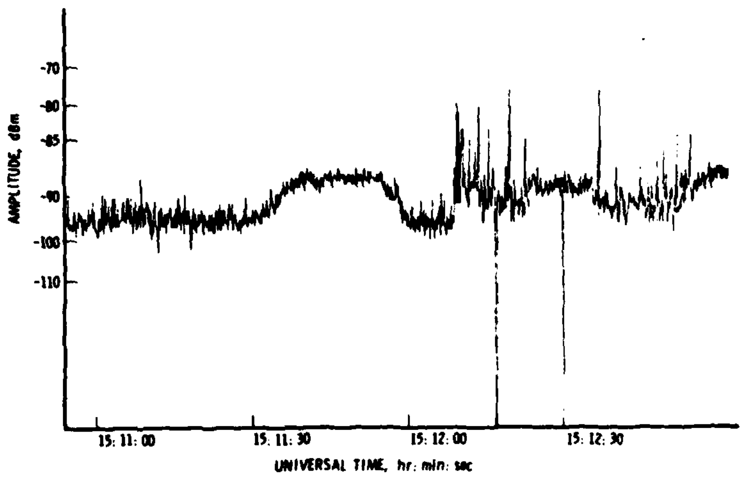

Fig. 10 Amplitude of the signal detected on the 1.8-m monopole antenna by the RF Analyzer on 30 March 1979 as a function of time. The analyzer was fixed tuned to a frequency of 20 MHz with a detection bandwidth of 4 kHz. Discharges due to electron beam operations began at 15: 12: 08 UT.

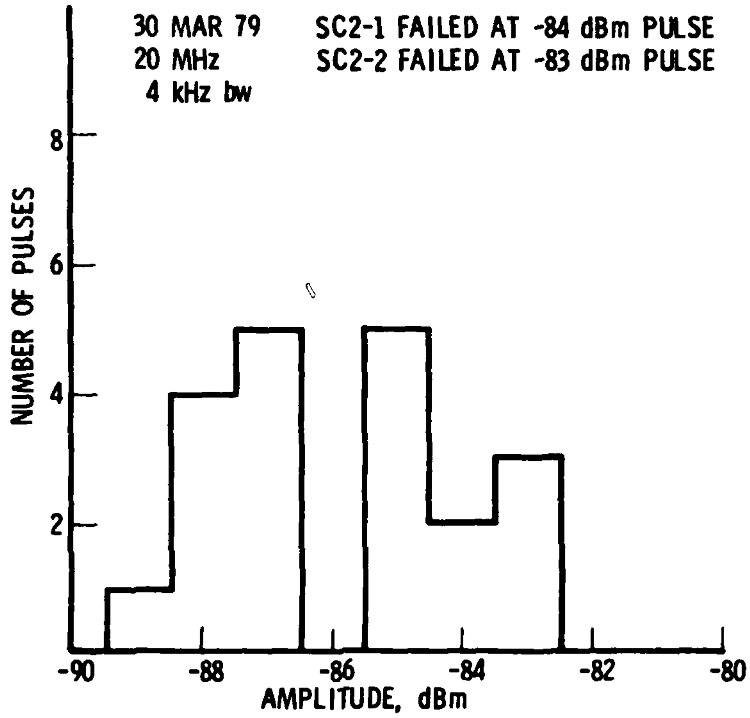

Fig. 11 Histogram of pulse occurrence as a function of amplitude as measured by the RF Analyzer during electron beam operations on 30 March 1979.

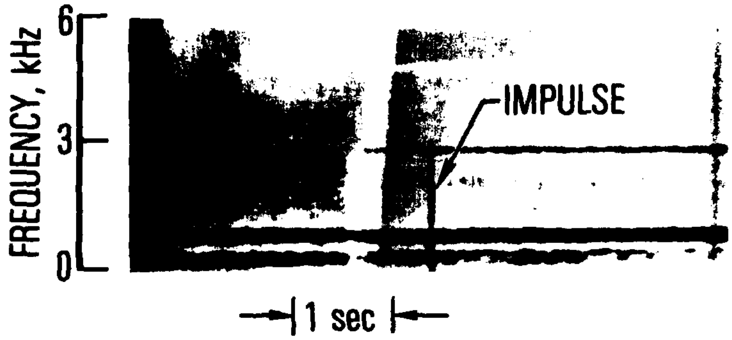

Fig. 12 VLF Analyzer spectrogram during electron beam operations at 0741:54 UT on 24 April 1979. The single impulse shown was also detected by the Pulse Analyzer.

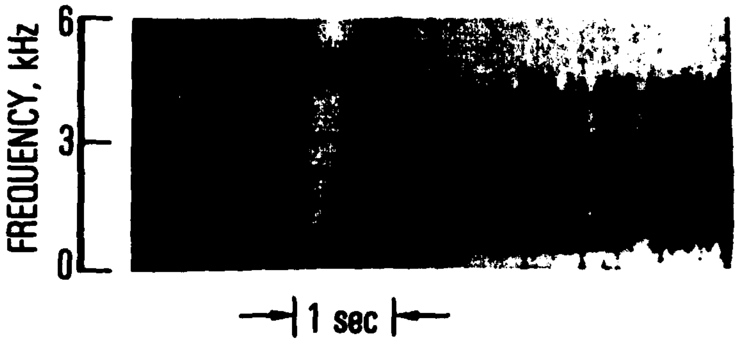

Fig. 13 VLF Analyzer spectrogram during electron beam operations at 0743:13 UT on 24 April 1979. Pulses are detected on only the magnetic antenna at this time.

V. Ion Beam Operations

On 14 February, 5 April and 24 April pulses were detected by the Pulse Analyzer during an SC4-2 ion beam induced charging event.

The VLF spectrogram shown in Fig. 14 shows the SC4-2 ion beam turn on at 0105:02 UT on 5 April. Impulses appear in the spectrum essentially continuously after turn-on. Few of these are detected by the Pulse Analyzer. Fig. 15 shows a spectrogram from 0108:50 on 5 April. At 0108:47 UT a 1.39 V pulse was detected by the Pulse Analyzer on the External Dipole Sensor. Obviously many lower level pulses are occurring.

As with the electron beam it has not yet been possible to determine if the pulses are external or internal to the beam hardware.

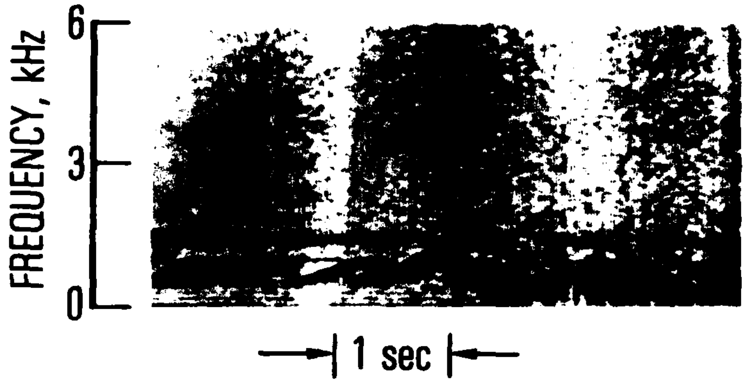

Fig. 14 VLF Analyzer spectrogram during ion beam operations at 0105:00 UT on 5 April 1979. The pulses began when the ion beam was turned on.

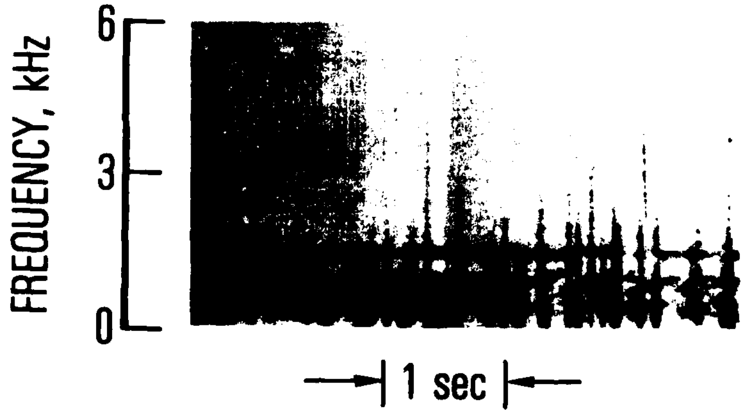

Fig. 15 VLF Analyzer spectrogram during ion beam operations at 0108:47 UT on 5 April 1979.

VI. Natural Charging Events

On 28 March, a natural charging event occurred during eclipse. The maximum potential of the vehicle with respect to the plasma reached approximately 4 kV. Only two pulses were detected by the Pulse Analyzer. The first pulse was detected at 1637:31 UT approximately five minutes after the energetic electron spectrum hardened. The second pulse was detected at 1714:48 UT as the vehicle exited from the eclipse.

The VLF Analyzer was in its broadband mode from 1635 to 1645 UT. Impulses were detected throughout this time period. Two of the larger pulses were measured on the electric antenna near the time of the pulse detected by the Pulse Analyzer at 1637:31 UT. The broadband spectrum at this time is shown in Fig. 16. The amplitudes of these pulses were also measured by the VLF Analyzer. The spectral density of several of the larger pulses is shown in Fig. 17.

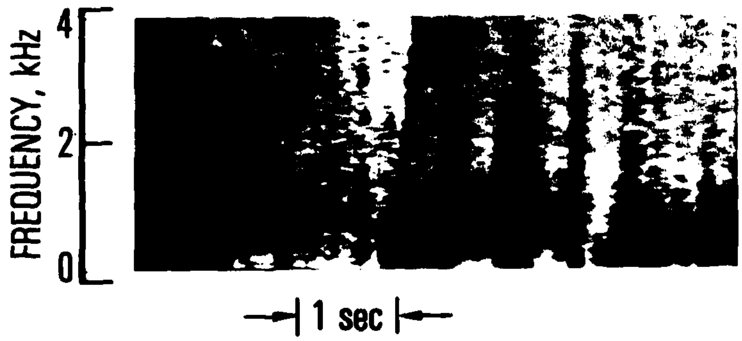

Fig. 16 VLF Analyzer spectrogram during a natural charging event in eclipse at 1637:29 UT on 28 March 1979.

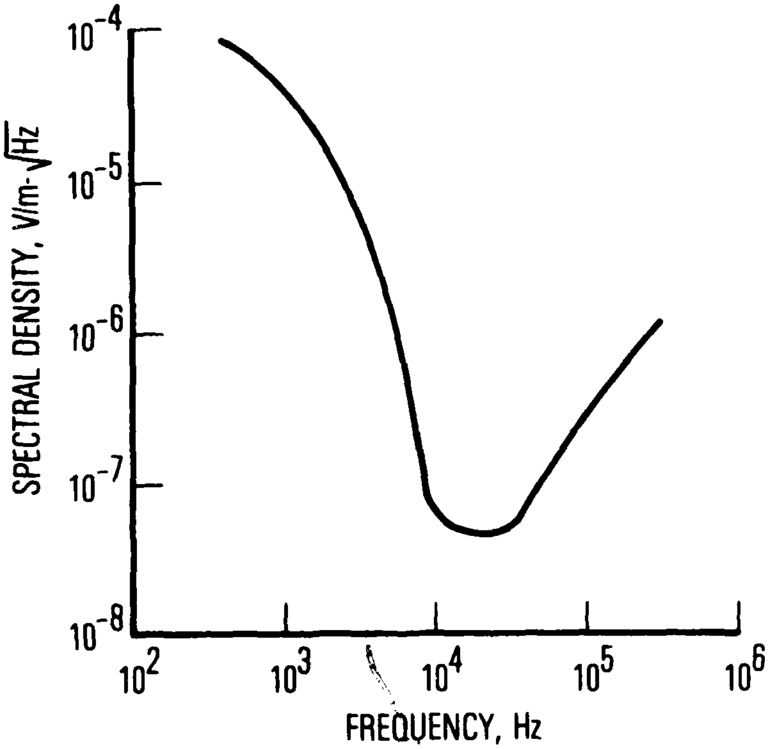

Fig. 17 Spectrum of a typical discharge measured during a natural charging event on 28 March 1979.

VII. Conclusions

Impulses are detected by the three Charging Electrical Effects Analyzer experiments on the P78-2 satellite in response to vehicle or payload commands, during electron and ion beam experiments and during natural charging events.

Very few large pulses are detected by the Pulse Analyzer. Only two have occurred during a charging event confirmed the Satellite Surface Potential Monitors and the energetic electron detectors. Those pulses had an amplitude of 0.2 to 0.7 V and a width at half maximum of 50 to 100 μs. The VLF spectrum shows several low level pulses occurring each second during the same charging event.

LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military concepts and systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space and missile systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch and reentry aerodynamics, heat transfer, reentry physics, chemical kinetics, structural mechanics, flight dynamics, atmospheric pollution, and high-power gas lasers.

Chemistry and Physics Laboratory: Atmospheric reactions and atmospheric optics, chemical reactions in polluted atmospheres, chemical reactions of excited species in rocket plumes, chemical thermodynamics, plasma and laser-induced reactions, laser chemistry, propulsion chemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, photosensitive materials and sensors, high precision laser ranging, and the application of physics and chemistry to problems of law enforcement and biomedicine.

Electronics Research Laboratory: Electromagnetic theory, devices, and propagation phenomena, including plasma electromagnetics; quantum electronics, lasers, and electro-optics; communication sciences, applied electronics, semiconducting, superconducting, and crystal device physics, optical and acoustical imaging; atmospheric pollution; millimeter wave and far-infrared technology.

Materials Sciences Laboratory: Development of new materials; metal matrix composites and new forms of carbon; test and evaluation of graphite and ceramics in reentry; spacecraft materials and electronic components in nuclear weapons environment; application of fracture mechanics to stress corrosion and fatigue-induced fractures in structural metals.

Space Sciences Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, studies of solar magnetic fields; space astronomy, x-ray astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.

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