Severe Spacecraft-Charging Event on SCATHA in September 1982

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Large amplitude electrostatic discharges were detected by the engineering instruments aboard the SCATHA satellite on September 22, 1982. The Pulse Analyzer detected 29 pulses on that date. Seventeen of the pulses exceeded the maximum voltage discrimination level which was set to 7.4 V. This is the worst instance of electrostatic discharges encountered to date by the SCATHA satellite. Three different spacecraft anomalies occurred on SCATHA on September 22, 1982. The most serious was a two-minute loss of data. Data from the Satellite Surface Potential Monitor confirmed that these electrostatic discharges occurred during one of the largest spacecraft charging events recorded by the instruments aboard the SCATHA satellite.

I. Introduction

THE P78-2 (SCATHA) satellite was launched on January 30, 1979. The primary objective of the satellite was to obtain environmental and engineering data that could be used to provide guidelines and material, process and test specifications to ensure that future spacecraft will operate satisfactorily in a spacecraft charging environment. The experiments on the satellite are described by Stevens and Vampola[1] and Fennell.[2]

II. Pulse Analyzer Data

A large number of intense electrostatic discharges were detected by the engineering instruments aboard the SCATHA satellite on September 22, 1982. The satellite was located at dawn very near the geosynchronous altitude. The Pulse Analyzer detected 29 pulses on that date. A summary of the pulses is given in Table 1. Seventeen of the pulses exceeded the maximum voltage discrimination level which was set to 7.4 V. The Transient Pulse Monitor also detected 29 pulses as shown in Table 1. Most of these were coincident in time with those detected by the Pulse Analyzer. This is the worst instance of electrostatic discharges encountered to date by the SCATHA satellite. During this same time period the Satellite Surface Potential Monitor (SSPM) experiment measured the largest differential surface charging observed in the data analyzed since launch.

The Pulse Analyzer has been operating continuously since it was turned on in February 1979. Since that time, data from 822 days (about 1/3 of the total) have been analyzed.[3-5] A total of 147 pulses attributed to electrostatic discharges on the vehicle have been detected. The 29 discharges detected on September 22, 1982 represent almost 20 percent of the total number of pulses detected in over two and one-half years of analyzed data.

The amplitude distribution of the discharge pulses is shown in Fig. 1. The voltage plotted along the x axis is the highest discriminator voltage level exceeded by each pulse. The discriminator levels are spaced by factors of approximately two. The pulse amplitude distribution is unusual in that it shows a large number of pulses at the high voltage end of the distribution. Almost all of the pulses above one volt occurred on only one day, September 22, 1982. The amplitude distribution for September 22, 1982 is shown together with the total distribution in Fig. 1.

In Fig. 2 the time of the discharges (plotted as circles near the top of the figure) is compared with the absolute value of the differential potential of the gold sample on the SSPM with respect to the spacecraft ground. The discharges occurred when the potential of the gold sample was greater than 300 V negative with respect to the reference ground. Although there is no evidence that this particular sample was responsible for the discharges, this is the most direct evidence available that discharges on SCATHA were due to differential potentials on the vehicle.

In Fig. 3 the amplitude distribution for the September 22 discharges is compared with the amplitude distribution for the factory test pulses measured during the systems level electrostatic discharge tests. The system level tests were conducted in accordance with MIL-STD-1541. Almost all of the pulses on September 22 exceeded the factory test pulses. We conclude that the factory test pulses are not large enough in amplitude to represent a worst-case on-orbit environment.

III. Surface Potential Monitor Data

Figure 4a shows the time plot of the absolute value of the gold sample voltage beginning at 02 UT (universal time) and ending at 08 UT on September 22, 1982. The voltage is negative with respect to the satellite ground. The gold sample experienced low level differential charging between 02 and 03 UT. The SCATHA satellite entered the eclipse of the Earth shortly after 02:30 UT. The differential potential of gold remained relatively constant before and during the eclipse at values between -100 to -200 V. As the satellite proceeded into the postmidnight local time sector, the differential voltage exceeded -300 V near 04:15 UT (note: local time = universal time -3 h). The charging decreased over the next two hours and then again increased around 06:30 UT. The gold sample reached voltages greater than -300 V on four separate occasions. Each time the voltage exceeded this value, electrostatic discharges were recorded by the pulse analyzer.

Figure 4b shows the logarithm of the 18.4 keV electron intensity recorded by the Energetic Ion Composition Experiment. There is qualitative agreement between increases in the electron flux and the differential charging levels.

Figure 5a shows the time history of the Teflon and the quartz fabric sample voltages plotted with the logarithm of the 140 keV electron intensity in Figure 5b. Electrons with energies > 60 keV were measured by the High Energy Particle Spectrometer experiment. Electrons of these high energies do not provide the majority of the charging current to the samples,

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but they do play a role in modifying the charging properties of dielectrics such as Teflon.[6] Therefore, the magnitude of the differential charging may well depend on the high energy tail of the electron distribution.

The quartz fabric has a tendency to charge more frequently and to larger values than the Teflon sample. A differential potential of nearly 10,000 V measured on the quartz sample is the largest value recorded by the SSPM instrument. The potentials of the Teflon and quartz fabric samples are the maximum values reached during one satellite rotation, which took 1 min. The SSPM-3 instrument containing the Teflon and quartz fabric samples was positioned so that the samples pointed along the spin axis, which was maintained perpendicular to the satellite-sun direction to within 5 deg. In contrast, the gold sample on the SSPM-1 instrument rotated into and out of sunlight every 30 s, causing it to discharge before reaching its maximum value in shadow.

Figure 2 shows an expanded time plot of the gold sample from 6.5 to 7.7 h UT. The circle symbols represent times when

Table 1 Summary of discharges on September 22, 1982

			Pulse Analyzer		TPM	
UT	LT	Re	Sensor[a]	Volts	+Amp	−Amp
5109	22.7	7.3	3	0.12		
24059	3.8	5.8	3	7.4	2.82	3.40
24118	3.8	5.8	3	7.4	4.27	5.35
24177	3.8	5.8	3	7.4	5.16	5.56
24235	3.8	5.8			5.77	6.47
24238	3.8	5.8	3	7.4	5.16	6.00
24297	3.8	5.8	1	1.9	6.47	7.52
24356	4.0	5.8	1	1.9	5.16	5.56
24360	4.0	5.8	1	1.9	3.96	5.77
24419	4.0	5.8	1	3.8	6.97	7.18
24479	4.0	5.8	1	3.8	6.47	6.97
24539	4.0	5.8	1	1.9	6.23	6.71
24596	4.0	5.8	0	7.4	4.97	5.35
24600	4.0	5.8	0	7.4	6.47	7.52
24658	4.0	5.8	0	7.4	6.47	8.42
24716	4.0	5.8	0	7.4	5.56	8.42
24778	4.0	5.8	2	7.4	3.67	4.11
24837	4.0	5.8	2	7.4	2.61	3.28
24900	4.2	5.7	2	7.4	3.40	3.28
25381	4.2	5.7	1	1.9	5.56	5.77
25498	4.2	5.7	0	7.4	5.35	6.23
25558	4.4	5.7	0	7.4	4.97	5.16
25616	4.4	5.7	0	7.4	5.77	6.47
25620	4.4	5.7	0	7.4	4.27	5.35
25678	4.4	5.7	0	7.4	5.77	6.71
25738	4.4	5.7	2	7.4	3.40	4.78
26000	4.4	5.7			6.00	6.71
27238	4.9	5.6	1	1.9	7.24	7.52
27244	4.9	5.6	3	0.7		
27300	5.1	5.6	1	3.8	6.23	7.81
27358	5.1	5.6	1	1.9	6.23	7.81

[a]Sensors: 0, external dipole; 1, loop around the Command Distribution Unit; 2, harness wire; and 3, command line.

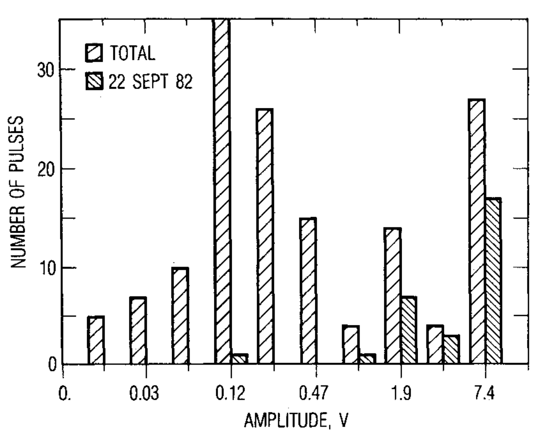

Fig. 1 Amplitude distribution of pulses caused by electrostatic discharges with pulses detected on September 22, 1982, shown separately.

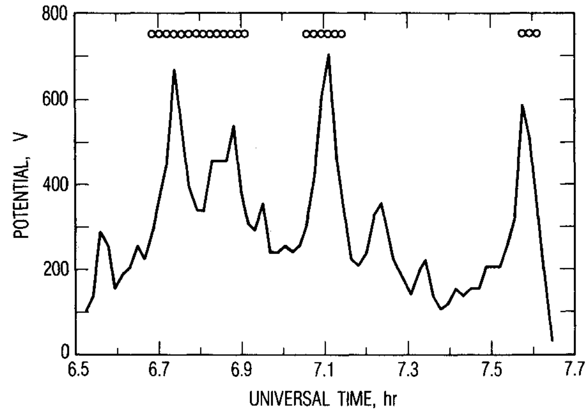

Fig. 2 The absolute value of the potential of the gold sample on the Satellite Surface Potential Monitor with respect to the space vehicle ground reference point. The potential of the sample is negative with respect to the ground reference. The circles plotted near the top of the figure identify the times when the Pulse Analyzer detected discharges.

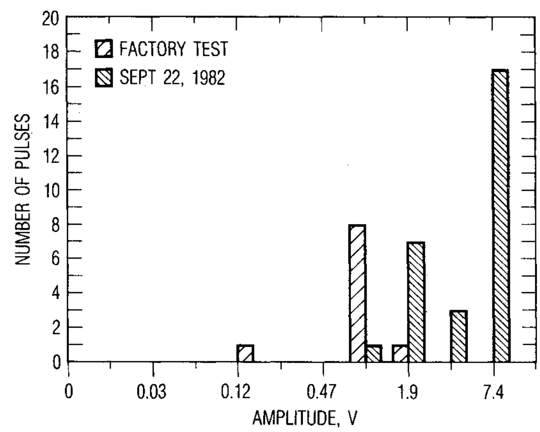

Fig. 3 The amplitude distribution of the pulses detected on September 22, 1982 is compared with the amplitude of the pulses measured during the system level factory electrostatic discharge tests.

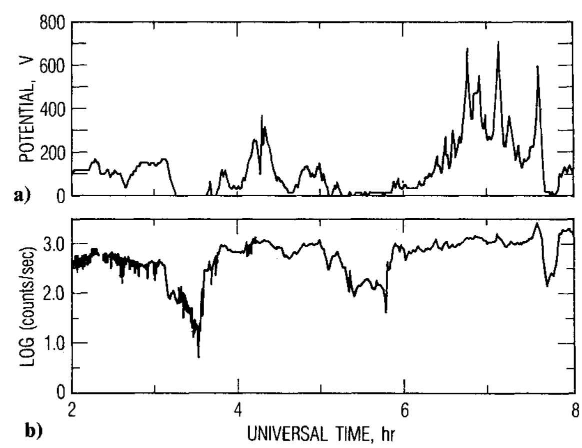

Fig. 4 a) The absolute value of the voltage on the Satellite Surface Potential Monitor gold sample as a function of time. The potential of the sample is negative with respect to the ground reference; b) the count rate for 18.4 keV electrons as a function of time.

discharges were recorded by the pulse analyzer. The discharges occurred with time differences very near the satellite rotation period of 60 s. The data in Fig. 2 suggest that a threshold of −300 V must be exceeded on the gold sample before discharges occurred somewhere on the satellite. There is a good correlation of the onset of the three charging periods (6.75, 7.12, and 7.58 h UT) with the onset of the electrostatic discharge pulses.

Table 2 shows a list of selected sample voltages measured by the SSPM on April 24, 1979 and September 22, 1982. The earlier time was selected to represent the worst case environment as reported by the Air Force Geophysics Laboratory (AFGL).[7] For all samples except the Kapton sample on the SSPM-3 instrument on the end of the spacecraft the September 22, 1982 voltages were larger than for the April 24, 1979 event. Since the conductivity of the Kapton samples on the SSPM-1 and -2 instruments on the side of the vehicle changed over a period of months due to solar exposure, we would expect a similar effect for the Kapton sample located on the end of the spacecraft to occur but over a longer period of time. This increase in the conductivity of the Kapton may account for the lower voltages observed during the 1982 event.

IV. Spacecraft Anomalies

Three different spacecraft anomalies occurred on SCATHA on September 22, 1982. The most serious was a two min loss of data. The other two were uncommanded mode changes in two experiments.

Two min are missing from the tape-recorded data from the satellite from 26159 to 26271 s UT. Although no pulse was recorded near that time by the pulse detectors, the signature of a pulse appears in the data from the Very-Low-Frequency (VLF) Wave Analyzer experiment. Each pulse detected by the Pulse Analyzer also produced an anomalous output from the VLF experiment. The pulses appear in the VLF data as 99 dB while the actual calibrated values are all less than 0 dB. At 26158.6 s, a 99 appears in the VLF data. Apparently a discharge occurred at approximately 26158 s. We believe that the discharge caused the PCM system to lose synchronization. The pulse shape as measured by the Pulse Analyzer would have been read out during the next second of data. Since this data could not be recovered, the pulse does not appear in the data from the Pulse Analyzer.

Two experiments on SCATHA experienced anomalies that coincided with discharges detected by both the Pulse Analyzer and the Transient Pulse Monitor.

An anomalous reconfiguration of the Magnetic Field Monitor experiment occurred and anomalous timing errors occurred in the VLF Plasma Wave Analyzer.

A filter select relay in the Magnetic Field Monitor experiment occasionally changes state. This occurs during time periods when discharges are occurring on the vehicle. One such filter change occurred on September 22.

The VLF experiment collects data from two sensors, an electric antenna and a magnetic antenna. The experiment contains a counter that counts the Main Frame sync pulses from the telemetry system. These occur at the rate of one per second. Every 16 sync pulses (seconds) the antenna is switched. The anomaly that occurred on September 22 was a failure of the experiment to switch properly after virtually every discharge. The observed and expected switching sequences for one time period are shown in Fig. 6. The switching failures in the figure coincided with four of the discharge pulses between 27238 and 27359 s UT.

V. Aspect Dependence

The 28 discharges detected on September 22 between 24059 and 27359 UT occurred at very nearly the same rotational phase of the vehicle. A histogram of the period between two consecutive discharges is shown in Fig. 7. The peak at 60 s coincides with the spin period of the satellite. Since the satellite was in sunlight (the local time was 04 h), the locking of the discharges to the spin rate suggests that only one location on the vehicle was arcing. A similar phenomena occurred on May 26, 1979 when six discharges occurred with a periodicity equal to the spin period.

VI. The Environment

Dst Values

Three large magnetospheric storms occurred during September 1982. Figure 8 shows the hourly equatorial ring-current index (Dst) values for this month. The first storm occurred on September 6. Dst reached a minimum value of −303 gamma at 12 h UT on September 6. One pulse was detected by the Pulse Analyzer at 19294 s (05:21) during the onset of the storm on

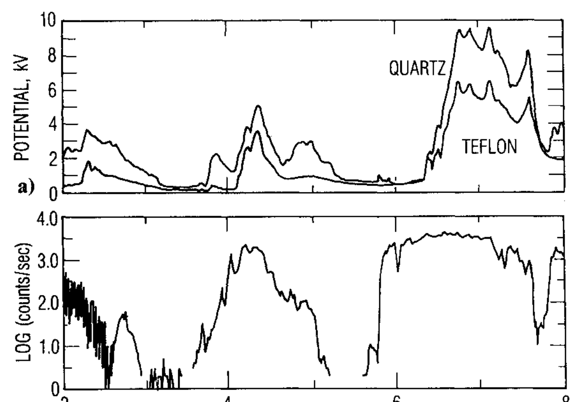

Fig. 5 a) The absolute value of the voltage on the Satellite Surface Potential Monitor quartz and teflon samples as a function of time. The potential of the sample is negative with respect to the ground reference; b) the count rate for 140 keV electrons as a function of time.

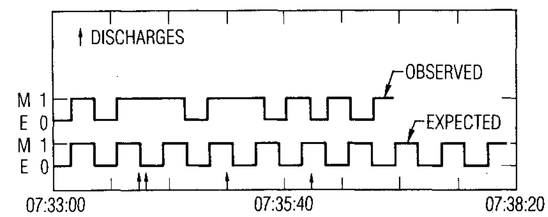

Fig. 6 The timing sequence of the antenna switch on the VLF Analyzer experiment during one time period when anomalous behavior occurred on September 22, 1982.

Table 2 Differential Voltages

Date	UT	Au	OSR	Kapton	Teflon	Quartz fabric
22 Sept. 1982	06:44	−650	−150	−250	−6250	−9400
22 Sept. 1982	07:06	−680	−150	−285	−6350	−9550
22 Sept. 1982	07:34	−570	−210	−250	−5500	−8260
24 April 1979	06:52	−400	−150	−1550	−3400	−1700

that date. Five more pulses were detected on September 7 during the recovery phase.

The second storm occurred on September 22. The minimum value for Dst was −228 gamma reached at 08 h on the 22nd. Although this storm was not so severe as the storm on September 6th, the discharges generated by the interaction with the plasma were much more severe. This was the case even though the satellite was in the same dawn local-time sector during both storms. Small discharges were detected on the 23rd, 24th, and 25th during the recovery phase of this storm. The pulses on the 24th and 25th occurred on the day side of the Earth where surface charging has not been observed. These discharges were most likely bulk discharges in a cable bundle.

The third storm occurred on September 26. The minimum value for Dst was −205 gamma reached at 19 h on the 26th. The Pulse Analyzer detected only one pulse on that day at 18570 s. This was well before the beginning of the storm.

Electrons

Figure 9 shows the distribution function for electrons from 80 eV to 300 keV on September 22 at 06:44 UT. These measurements were made perpendicular to the magnetic field line during a time period with peak charging levels. A similar curve of a time period with peak charging levels on April 24, 1979 from Fig. 21a of Ref. 7 is shown for comparison. The charging event on April 24, 1979 was the most severe charging event encountered by the SCATHA satellite prior to September 22, 1982. The distribution functions for the two dates are remarkably similar. However, the distribution function measured on September 22 is significantly higher in the energy range from 1 to 10 keV.

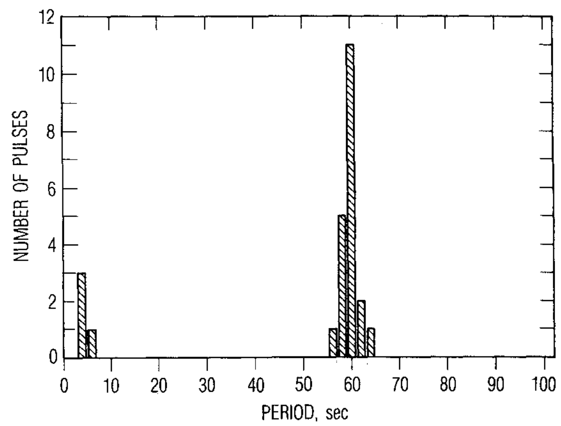

Fig. 7 Histogram of the repetition rate of the discharges detected by the Pulse Analyzer between 24059 and 27359 s on September 22, 1982.

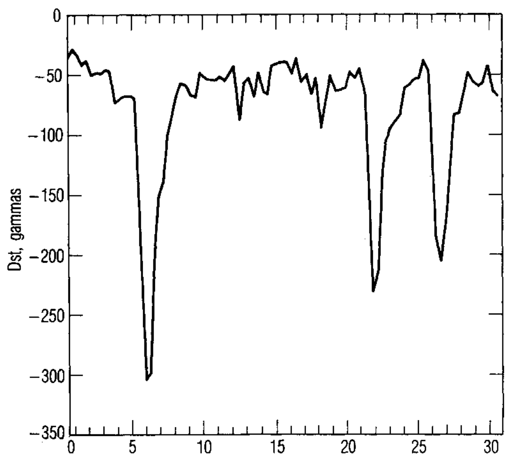

Fig. 8 Hourly equatorial Dst values for September 1982.

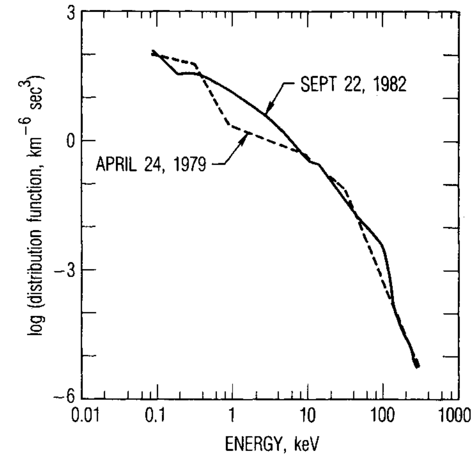

Fig. 9 Distribution functions of electrons measured perpendicular to the magnetic field—(solid) September 22, 1986 at 06:44 UT, (dashed) April 24, 1979 at 06:50 UT.

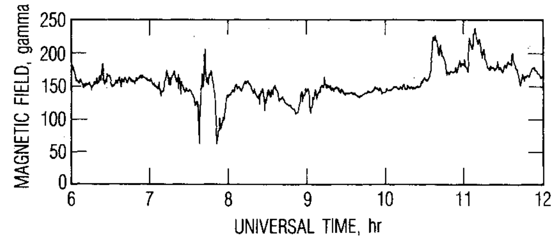

Fig. 10 The magnetic field at the SCATHA satellite on September 22, 1982.

Magnetic Field

Figure 10 shows the magnetic field measured by the Magnetic Field Monitor experiment aboard SCATHA during the time period of interest on September 22. The measurements show evidence for a large current sheet in the vicinity of the spacecraft just after 07:30 UT.

VII. Summary

The space plasma environment encountered by the SCATHA satellite on September 22, 1982, caused the highest charging levels and the largest electrostatic discharge pulses detected since the vehicle was launched in 1979. The discharges produced serious anomalies in the operation of some of the scientific instruments and a two-min loss of data from the vehicle.

The amplitude of the pulses were significantly larger than those measured during the preflight system level tests which were conducted according to MIL-STD-1541.

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