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VEHICLE CHARGING ON STS-3 MISSION*

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In the Vehicle Charging and Potential experiment on the STS-3 mission, a pulsed electron gun was used to eject known charges and currents from the Shuttle Orbiter, and the resulting perturbations of the surface charge and current densities were studied with appropriate instruments. An ejected current of 100 mA, if maintained for a time sufficiently long for equilibrium to be established, could change the vehicle potential by 50 V or more when the ambient plasma density was low. In general, the observed perturbations could be ordered qualitatively in terms of the plasma density and of the attitude of the shuttle relative to its orbital velocity vector.

1. Introduction

The Vehicle Charging and Potential (VCAP) experiment flown on the STS-3 mission was designed to study the electrical interaction of the shuttle orbiter with the low earth orbit environment. The interaction of a large, orbiting body with the low earth space environment is not well known. With the initiation of an operational era in space, it is necessary that we understand (1) the perturbations produced by the orbiter as it moves through the near earth environment, (2) the environment as provided to instrumentation operating in the payload bay of the orbiter and (3) the effects that the environment exerts upon the orbiter itself. Future missions which depend upon knowledge of the electrical interaction of the orbiter with the space environment include those with high power charged particle beam experiments and others with long antennas operating at high voltages in the VLF frequency range. Also, when operations begin with orbit inclinations above about 50 degrees, large fluxes of energetic electrons (and protons) will bombard the orbiter when the vehicle is at high magnetic latitudes. In the past, satellites have

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been adversely affected by electrical discharges induced by energetic particle bombardment and these problems present similar concerns for the dielectric-covered orbiter. The VCAP experiment on STS-3 was designed to study the interactions between the orbiter and the environment which are of importance to understanding these problems.

2. INSTRUMENTATION

An electron gun with fast pulse capability was used in the VCAP experiment to actively perturb the vehicle potential in order to study dielectric charging, return current mechanisms and the techniques required to manage the electrical charging of the orbiter. Return currents and charging of the dielectrics were measured during electron beam emission, and plasma characteristics in the payload bay were determined in the absence of electron beam emission.

The VCAP instrumentation as flown on the OSS-1 pallet during STS-3 includes five separate pieces of hardware:

1. Fast Pulse Electron Generator (FPEG) - The FPEG consists of two independent electron guns which are of the diode configuration with a directly heated tungsten filament and a tantalum anode. The two guns, designated as FPEG 1 and FPEG 2, emit electrons with an energy of 1000 eV at currents of 100 mA and 50 mA respectively. The electron beams are collimated to a beam width of about 5 degrees by focus coils mounted just beyond the anodes. Each gun is controlled by a 37-bit serial command word which selects the gun to be used, controls filament and high voltage power supplies, and determines the on time, off time and number of pulses of the beam. The times are controllable in 32 logarithmic steps from 600 nanoseconds to 107 seconds and the number of pulses is controllable in powers of two from 1 to 32,768. The rise and fall times for the electron beam are 100 nanoseconds so that very short pulses (and therefore small increments of charge) can be emitted.
2. Charge Current Probes (CCP1 and CCP2) - Each Charge Current Probe (CCP) consists of two adjacent sensors — one metallic and one dielectric — as shown in figure 1. The current flowing to the metallic sensor is used as an indication of the return current to exposed metal surfaces on the orbiter. The dielectric sensor provides a measurement of the charge accumulation on the dielectric-covered surfaces of the orbiter; the material used for the charge probe dielectric is from the same batch of Flexible Reusable Surface Insulation (FRSI) that was used on the Columbia (OV-102) and covers the payload bay doors and upper wing surfaces (fig. 2). Both of the CCP sensors respond rapidly to changes in the orbiter potential. Measurement rates were set at 60 samples per second but peak hold measurements of both current and charge were made which allowed spikes longer than 100 nanoseconds to be captured.

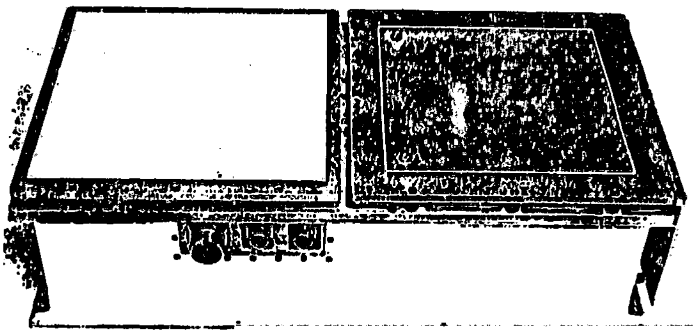
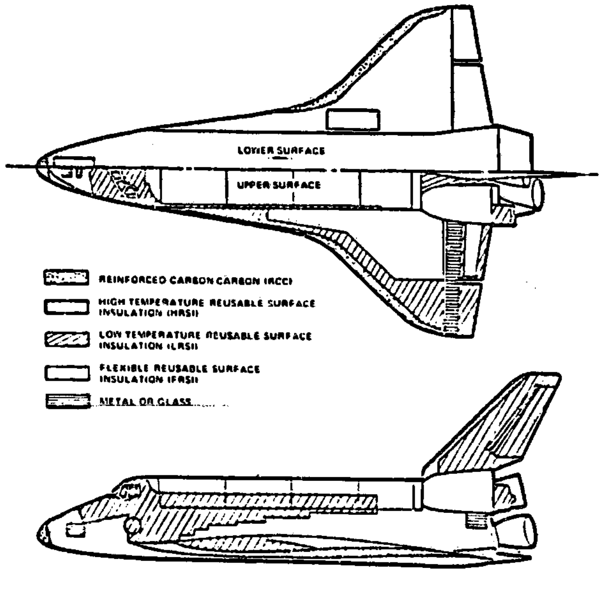


Figure 1. VCAP charge probe (left) and current probe (right). The experiment involved two such units, one on each side of the payload bay.



Insulation	Temperature limits	Area, m² (ft²)	Weight, kg (lb)
Flexible reusable surface insulation	Below 644 K (371° C or 700° F)	319 (3 436)	499 (1 099)
Low-temperature reusable surface insulation	644 to 922 K (371° to 649° C or 700° to 1200° F)	268 (2 881)	917 (2 022)
High temperature reusable surface insulation	922 to 978 K (649° to 704° C or 1200° to 1300° F)	477 (5 134)	3826 (8 434)
Reinforced carbon-carbon	Above 1533 K (1260° C or 2300° F)	38 (409)	1371 (3 023)
Miscellaneous			632 (1 394)
Total		1102 (11 860)	7245 (15 972)

Figure 2. - Distribution of insulating material over the outer surface of the Orbiter.

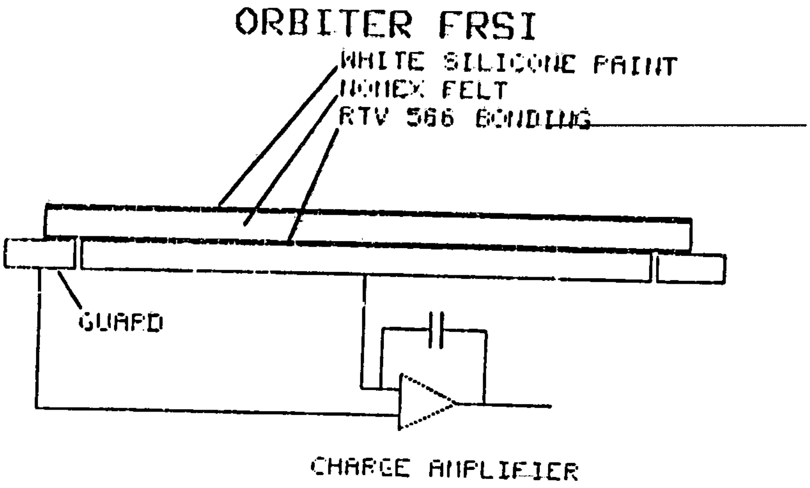


Figure 3. - Schematic of charge probe.

The Charge Probe measures directly the charging of a metal plate covered by a piece of FRSI. Since this is the same material as covers the payload bay doors and upper wing surfaces, we assume that measurements made on the FRSI in the payload bay are indicative of the behavior of this same material on the orbiter. The metal plate is connected to the input of a charge amplifier (fig. 3). When the vehicle potential changes, so does the charge induced on the metal plate: the charge increment is equal to the change in potential multiplied by the capacity between the plate and the ambient plasma. The charge amplifier converts this increment to a voltage. Assuming a theoretical value for the capacity, the change in vehicle potential can be calculated by scaling the output voltage appropriately. This is shown from the CCP measurement of vehicle potential. However, two reservations should be made with regard to these data: firstly, the probe can only measure changes in the vehicle potential, and not its absolute value; secondly, the actual capacity of the probe depends on the state of the ambient plasma so it may depart significantly from the assumed value. Hence, although the charge increments are measured precisely, the inferred changes in vehicle potential are only approximate, and may differ for two Charge Probes mounted at different places on the same spacecraft.

On STS-3, two sets of the CCP (designated CCP1 and CCP2) were used with CCP1 mounted adjacent to the FPEG and CCP2 mounted on the opposite corner of the pallet as far away from the FPEG as possible. These probes provide measurements of vehicle potential changes and return currents induced by operation of the FPEG with high time resolution at voltages up to 1000 volts and currents up to 4 mA.

3. Spherical Retarding Potential Analyzer (SRPA) - The Spherical Retarding Potential Analyzer measures the density and energy of ions and provides an absolute value for the vehicle potential as well as a measurement of the plasma environment in the payload bay. The SRPA has a 19 cm diameter spherical collector surrounded

by a 20 cm diameter spherical grid. The biasing voltages applied to these electrodes result in the collection of positive ions by the collector. In the frame of reference of the orbiter the dominant ambient ion O^+ will have a drift energy of approximately 5 eV. This energy is related to the orbiter velocity, which is well known, so any deviation of the O^+ drift energy from the expected value gives a measure of the electrical potential of the orbiter structure relative to the ionosphere. A Langmuir probe is attached to the SRPA. This probe is a small, spherical probe which measures the density and temperature of electrons and provides a cross check on the vehicle potential. The SRPA/Langmuir probe instrument is mounted on a corner of the pallet as far from other surfaces as possible to give the best opportunity to acquire data uncontaminated by wake effects.

4. Digital Control Interface Unit (DCIU) - The Digital Control Interface Unit provided all signal, command and power interfaces between the VCAP instrument and the pallet. Power switching and command decoding were done in the DCIU. Three microprocessors (1802 type) were used in the DCIU. The control microprocessor stored sequences of time-tagged serial commands in both ROM and RAM. These sequences of commands could be initiated in response to a single command sent from a source external to the DCIU and perform a series of operations such as FPEG pulsing, gain changing and resets. A second microprocessor was used to control the offset of the SRPA sweep voltage. The third microprocessor was used to monitor temperatures, voltages and currents and to set out of limit flags passed as bi-level signals to the orbiter GPC for display and alarm signaling.

3. MEASUREMENTS

Passive and active operations were performed during OSS-1. The SRPA and CCP's were operating throughout the mission and data obtained when the electron gun was not being operated determine the characteristics of the orbiter and the payload bay environment in the absence of perturbations from active experiments.

The electromagnetic interference (emi) levels during the mission were the lowest experienced during the project and were unmeasurably low on orbit. The thrusters produced disturbances which were variable in character and magnitude. Strong ram/wake effects were seen in the ion densities in the payload bay. Measurements of the vehicle potential offset indicate that the main engine nozzles provide a reference potential to the ionospheric plasma surrounding the vehicle. Because the orbiter is 97% covered with dielectric materials, the main engine nozzles provide the primary contact between the orbiter metallic structure and the plasma. Vehicle potentials were variable with respect to the plasma and depended upon location on the vehicle relative to

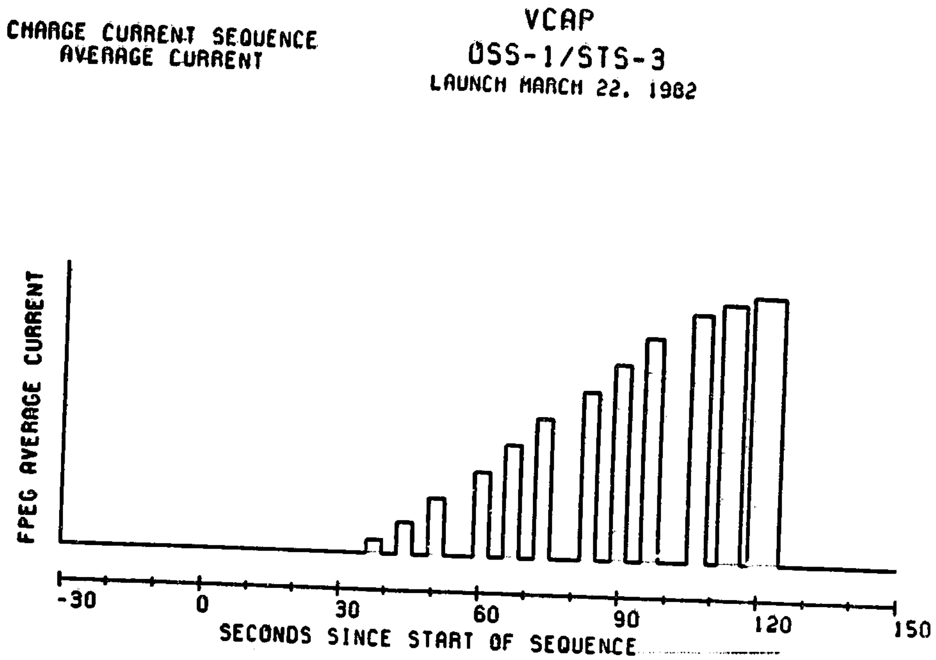


Figure 4. - Sequence of electron current pulses emitted by the Fast Pulse Electron Generator.

the main engine nozzles, the vehicle attitude and the direction of the geomagnetic field; their variations are consistent with the expected effects of the $\mathbf{V} \times \mathbf{B}$ electric field.

Active experiments were performed by emitting a series of electron beam pulses, as illustrated in figure 4 for instance. Inside each of the positive-going pulses shown in this figure there are 16 narrower rectangular pulses of 100 mA peak current, increasing in width from each group of 16 to the next. Thus the amplitude of the wider pulses, which is equal to the average of the current over the repetition period of the narrower pulses, increases throughout the sequence. The wider pulses are arranged in groups of three, and between each group and the next the Charge Probes are reset to zero so as to eliminate long-term drift.

Data taken during one such sequence, designed to study vehicle charging and return current mechanisms and labeled Charge Current (CC), are shown in figure 5; see table 1 for the meanings of the symbols. The sequence begins with one microsecond pulses (which show no measurable perturbation). When the pulse widths are increased to more than a millisecond in duration, significant charging of the orbiter occurs with induced potentials of tens of volts. The potentials measured close to the FPEG are higher than those on the far side of the pallet and may indicate that a sheath developed around the vehicle. The currents at the two locations (CCP1 and CCP2) are also different, with the larger current near the electron gun as might be expected since the beam produces locally enhanced ionization levels.

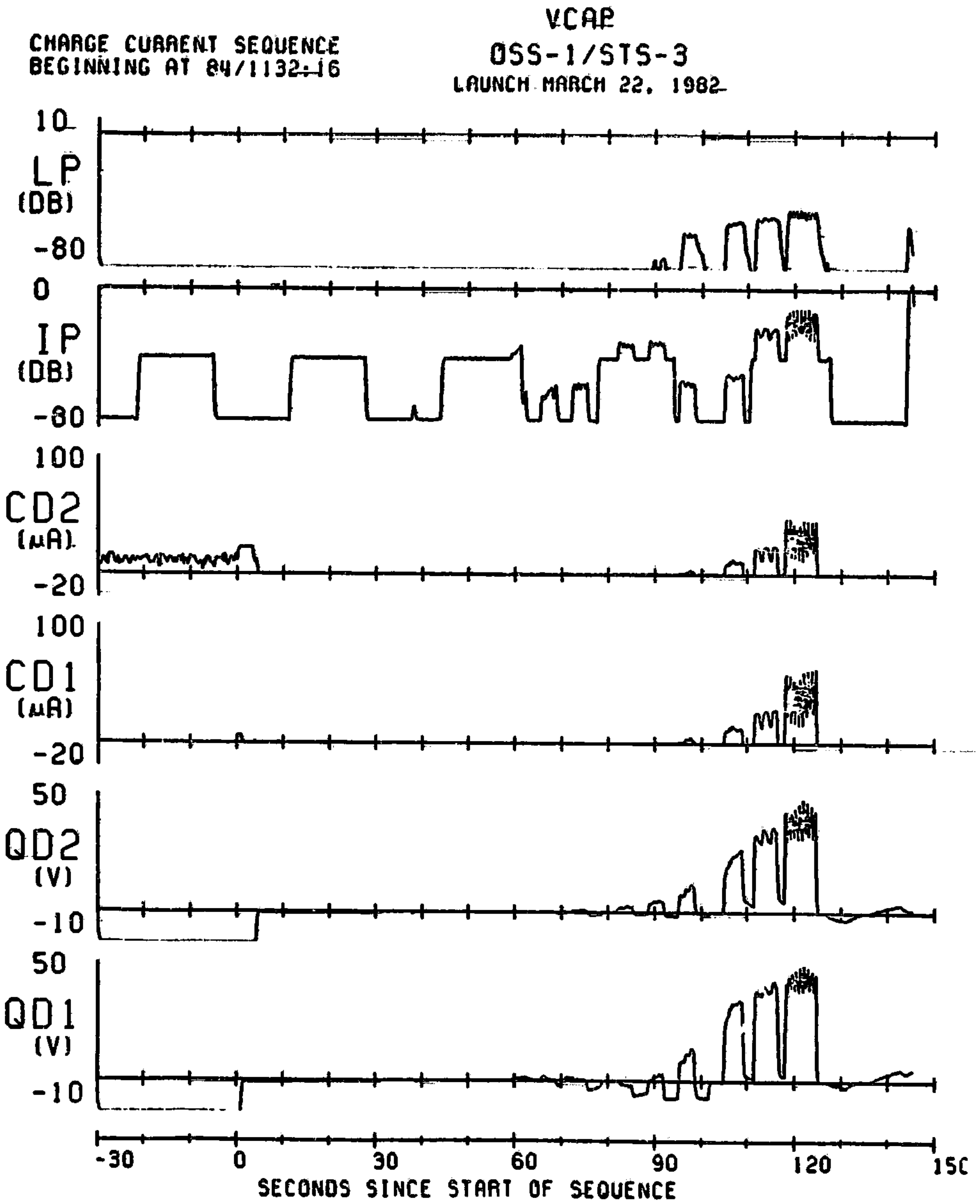


Figure 5. - Representative charge current sequence (1132 GMT on 25 March 1982). In data from SRPA (graph labeled IP), no ion current is observed until about 34 s after start of pulse sequence: rectangular waveform seen at earlier times is due to automatic switching of electronics between two ranges with different sensitivities.

In a higher time resolution plot of a portion of the same CC sequence (not shown) it appears that the measured currents recover to their normal non-emission levels in the short time between pulses, but the charge on the dielectric is retained and decays much more slowly. Time constants for the vehicle potential (or dielectric charging) to return to non-emission levels vary from less than one second up to minutes. Thus, in the two lowermost graphs of fig. 5, more marked fluctuations appear on the later groups of pulses than on the earlier groups; this difference is probably due to the reduction in the time constant as the vehicle potential increases.

One of the most distinctive features of the STS-3 flight results is the variety in the measurements of charging and return current. Virtually any combination of results can be found in the 52 Charge Current sequences that were performed during this mission. In some cases the charging is negligible, in other cases charging is significant and more than 50 volts for the same sequence. Return currents can be small or large and either the same on both probes or with either one large and the other negligible. In the following series of figures we show examples of this panoply of measurements.

Figure 6 shows some data taken during local daytime, with the nose of the shuttle pointing towards the sun and with the instruments looking into the wake. The latter circumstance explains the low charging currents and also the failure of the Langmuir probe to measure an electron current. The fact that the SRPA nevertheless measured a substantial ion current is unexplained. On this occasion, operation of the electron gun led to large positive excursions of the vehicle potential.

The data shown in figure 7 were also acquired in the daytime, with the shuttle in the same attitude relative to the sun but in a different attitude relative to the orbital velocity vector. The instruments, though still somewhat in the wake, were less well shielded from the plasma than on the occasion represented in figure 6. The attitude was such that the main engine nozzles were pointed more or less along the orbit, i.e., in the ram direction. Hence, the vehicle was in better electrical contact with the plasma, which explains why its potential was relatively unaffected by the gun operations.

In the data of figure 8, the electron and ion currents are comparable with those noted in figure 7. No attitude data are available for this case at the time of writing, but since the vehicle potential did not vary much, again there must have been good contact with the plasma. Even during the most intense FPEG emissions, neither of the current probes registers much current, which means that the return current must have been flowing elsewhere.

Figure 9, like figure 7, presents data acquired during the day with the shuttle in the nose-to-sun attitude and with the instruments partly in the wake. The electron and ion densities are greater this time, however. The changes in vehicle potential are even less than in the case of figure 8, but contrariwise the current probes both register large currents; their data are unusual in that the probe further from the FPEG collects the larger current.

The data of the final figure 10 show large electron and ion densitities, with the output from the ion probe even going off scale. The sizeable current on CD2 during the period from -30 s to 0 s suggests that this current probe was then facing towards the ram direction; the drop in current at 0 s may be due to the probe having been taken out of this orientation by vehicle roll. The FPEG pulse sequence had almost no effect on any of the six instruments in the VCAP package.

Figures 6-10 have been presented in the order of increasing ambient plasma density, at least as indicated by the Langmuir probe and the SRPA. Qualitatively, increased density leads to greater stability of the vehicle potential, as one would expect.

Although, as mentioned earlier, the 52 recorded Charge Current sequences show a wide variety of behavior, this proves to be reproducible if the sequences are ordered in terms of two parameters, namely the plasma density and the attitude of the shuttle relative to its orbital velocity vector. For a given density and attitude, qualitatively similar behavior has been observed on different occasions. Other parameters, such as the attitude relative to the earth's magnetic field and the presence or absence of sunlight, are less influential but not neglible.

4. CONCLUSIONS

The VCAP experiment on STS-3 has shown that active, controlled experiments on shuttle charging can be successfully performed from the payload bay of the orbiter. Electron beams have been used to perform a series of experiments to study the electrical interaction of the orbiter with the surrounding environment and the environment provided to the payload. A preliminary analysis of the data has shown that, qualitatively, they are reproducible and understandable, which strengthens our confidence that it will be possible to model them quantitatively in the long run.

Table 1

In each of the figures 5-10, the following quantities are plotted as the ordinates of the six graphs (from top to bottom):

LP	Langmuir Probe. Current on a logarithmic scale.
IP	Ion Probe (Spherical Retarding Potential Analyzer). Current on a logarithmic scale.
CD2	Current Probe on the starboard side of the payload bay. Current (μA) on a linear scale. Increased current corresponds to increased electron collection.
CD1	Current Probe on the port side of the payload bay. Current (μA) on a linear scale.
QD2	Charge Probe on the starboard side. Voltage on a linear scale. Increased voltage corresponds to the vehicle becoming more positive with respect to the plasma.
QD1	Charge Probe on the port side. Voltage on a linear scale.

Note: The instruments on the port side of the payload are close to the Fast Pulse Electron Generator.

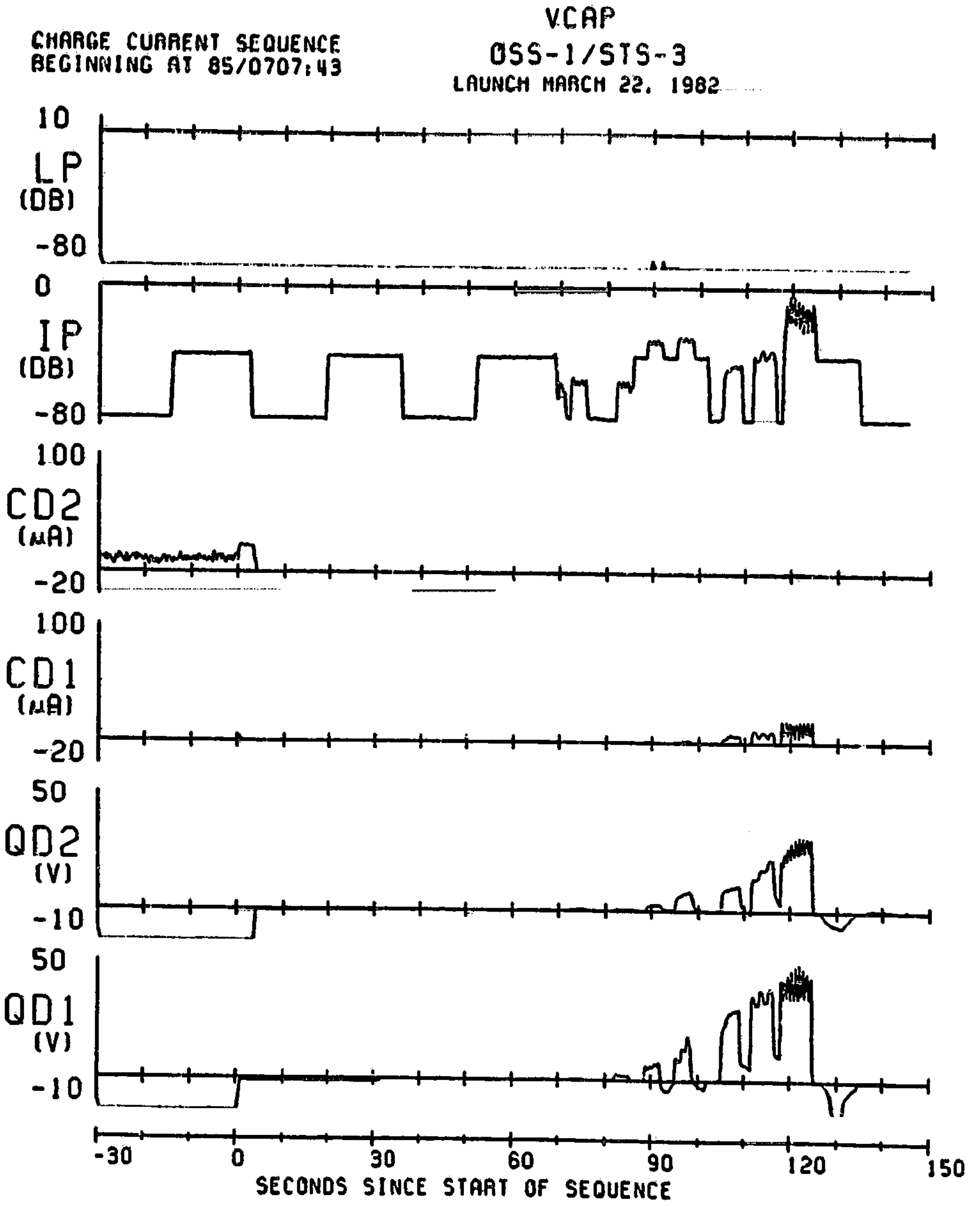


Figure 6. - Charge current sequence (0707 GMT on 26 March 1982).

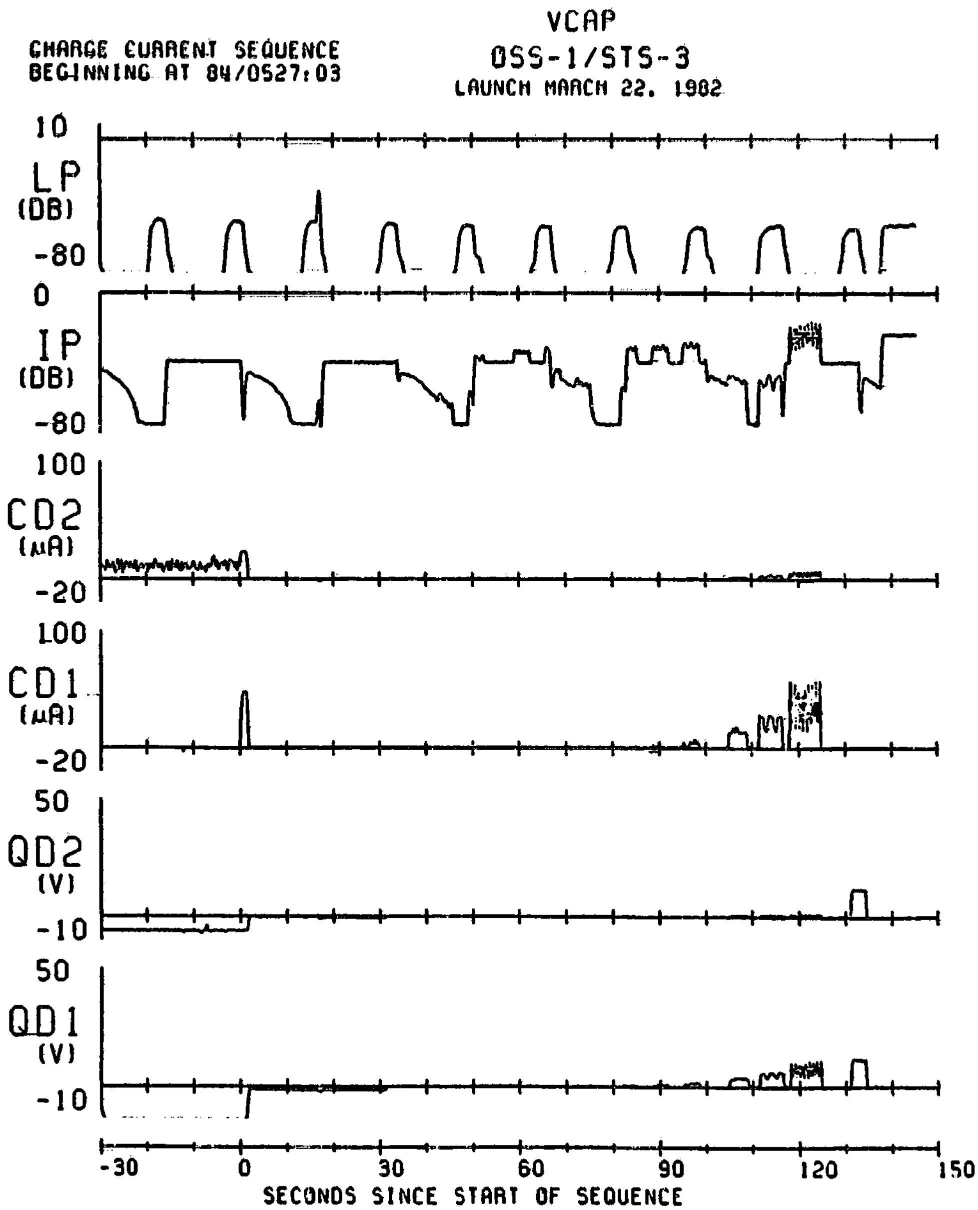


Figure 7. - Charge current sequence (0527 GMT on 25 March 1982).

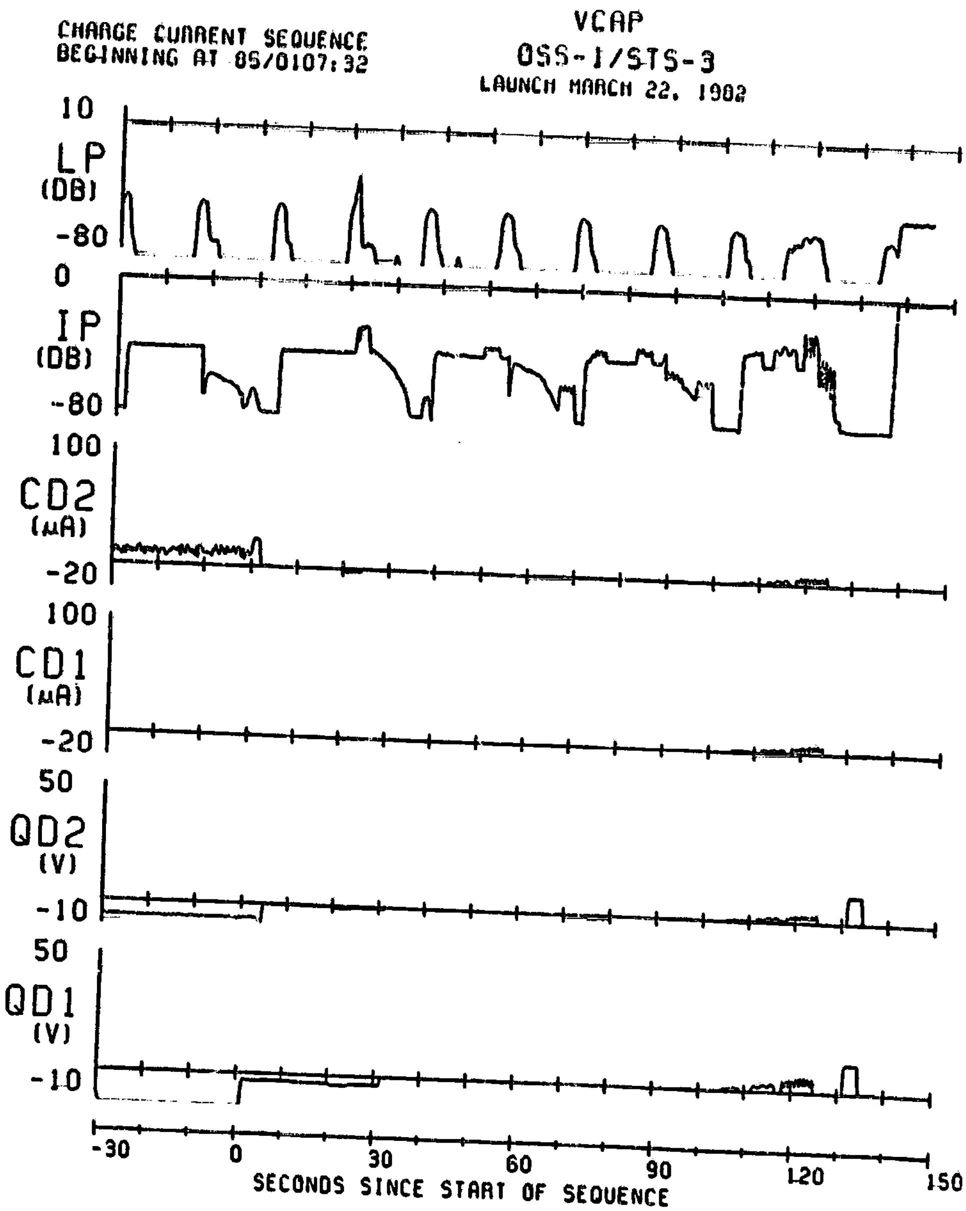


Figure 8. - Charge current sequence (0107 GMT on 26 March 1982).

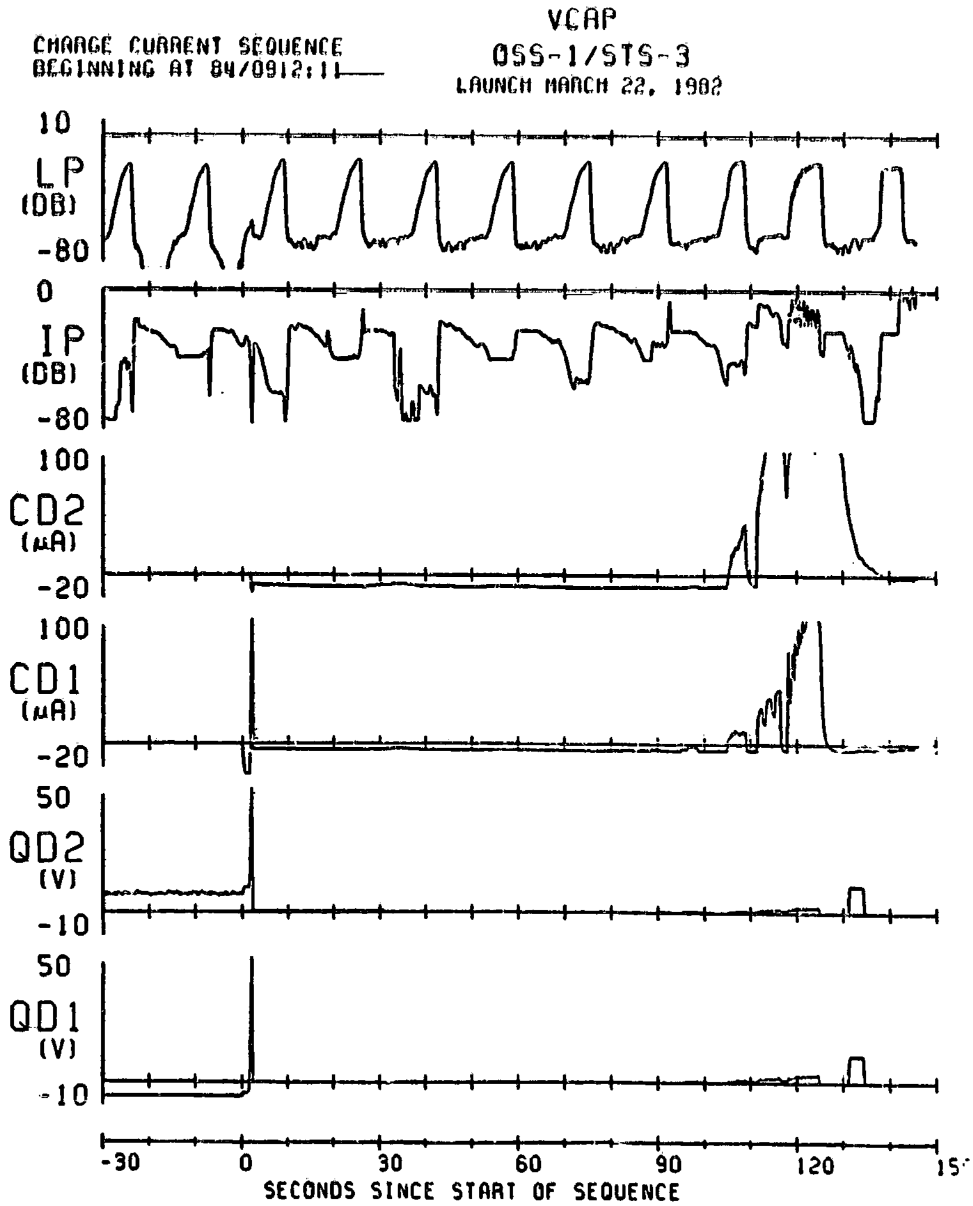


Figure 9. - Charge current sequenee (0912 GMT on 25 March 1982).

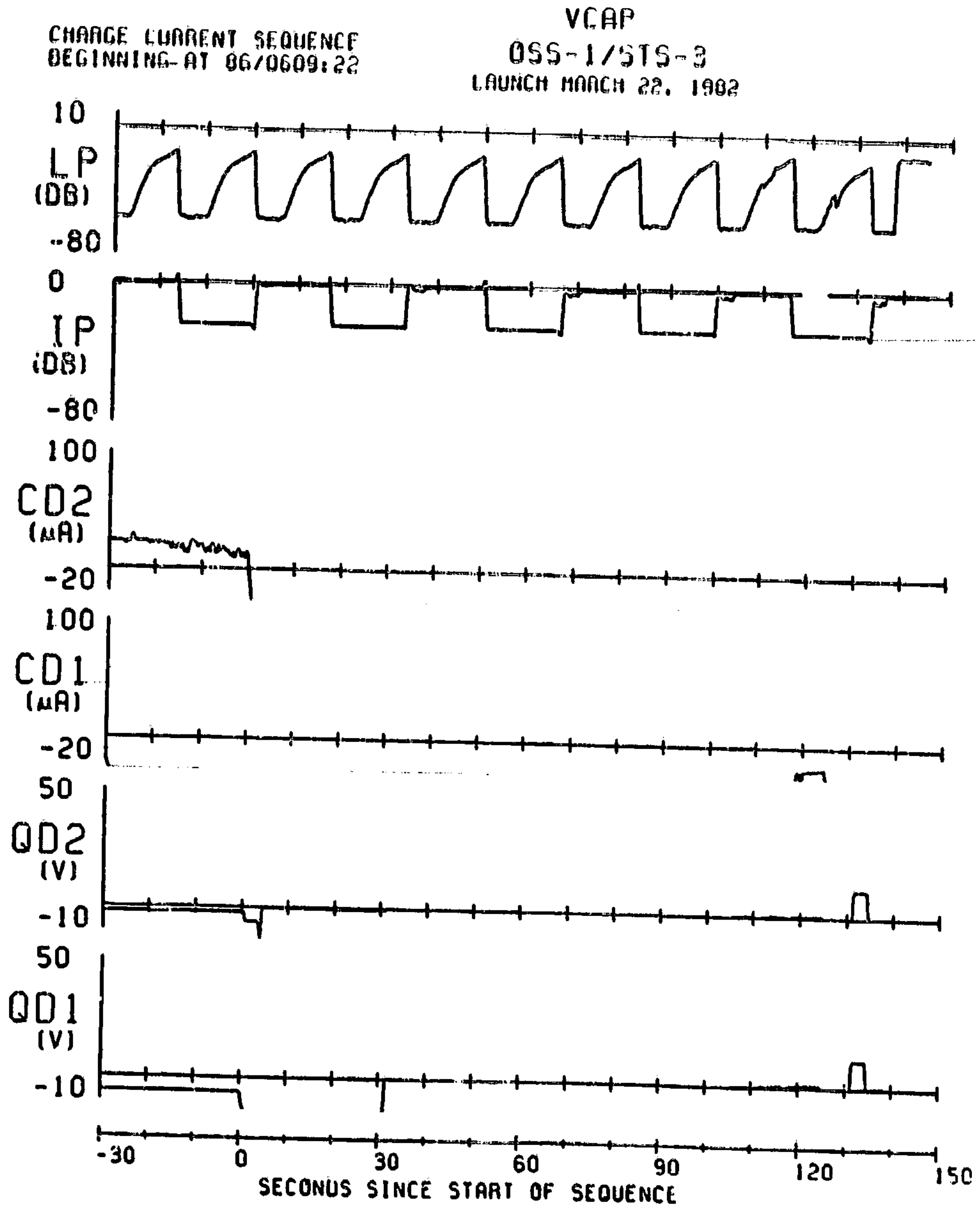


Figure 10. - Charge current sequence (0609 GMT on 27 March 1982).