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SPACECRAFT POTENTIAL CONTROL ON ISEE-1

A. Gonfalone and A. Pedersen
European Space Agency

U.V. Fahleson and C-G. Fälthammar
Royal Institute of Technology

F.S. Mozer and R.B. Torbert
University of California, Berkeley

ABSTRACT

The paper reports on the active control of the potential of the ISEE-1 satellite by the use of electron guns. The electron guns contain a special cathode capable of emitting an electron current selectable between 10^{-8} and 10^{-3}A at energies from approximately .6 to 41 eV.

Results obtained during flight show that the satellite potential can be stabilized at a value more positive than the normally positive floating potential. The electron guns also reduce the spin modulation of the spacecraft potential which is due to the aspect dependent photoemission of the long booms. Plasma parameters like electron temperature and density can be deduced from the variation of the spacecraft potential as a function of the gun current. The effects of electron beam emission on other experiments is briefly mentioned.

INTRODUCTION

The prime purpose of the electron guns mounted on the ISEE-1 spacecraft was to improve double probe electric field measurements. The scientific aim of the electric field experiment is to measure quasi-static fields in a range of about .1 to 200 mV/m (ref. 1). The spin plane component of the field is obtained from the spin modulation of the potential difference between a pair of 8 cm diameter vitreous carbon spheres separated by 73.5 m. The emission of beam of electrons parallel to the spin axis should have reduced the asymmetry in the potential produced by the photoelectrons. Several on orbit tests have shown that the electron guns have no significant influence on the electric field experiment. The interpretation of this unexpected result is that even without the electron beams the electric dipole moment of the photoelectron cloud is small enough for its effect on the double probe measurement to be negligible (ref. 2). The cloud symmetry is more favourable than expected from simplified model calculations (ref. 3).

The operation of the gun can still be a tool for the study of phenomena induced by the injection of a charged particle beam into a natural plasma. The intensity of the beam is far below intensities usually considered for active experiments (ref. 4) but can be sufficient to investigate active potential control of a body immersed in a plasma, plasma-beam instabilities, and waves.

Control of the spacecraft potential may also be a prerequisite for electric fields and low energy particle measurements in the vicinity of Jupiter (ref. 5) where the photoemission rate is 30 times less than at the Earth orbit or even at geosynchronous orbit to avoid negative charging during eclipses (ref. 6). Previous experiments have shown that thermoionic electron emission from a thruster could be used to reduce negative charging (ref. 7). It is shown in this paper that electron guns can be used to clamp the potential of a conductive spacecraft a few volts positive with respect to the plasma potential.

SYMBOLS

I	current
V	voltage
I_e	electron current collected by a conductive body in a plasma
I_o	value of I_e at the plasma potential
I_{pe}	photo electron current collected by a conductive body in sunlight
I_g	electron gun current
V_{sc}	potential of the spacecraft
V_{pl}	plasma potential
V_k	accelerating voltage of gun electrons with respect to the spacecraft potential

EXPERIMENTAL TECHNIQUE

Figure 1 illustrates the structure of the electron gun (ref. 8). The primary concern was in this case to reduce as much as possible the weight and the power needed for the emission of the electron beam. The cathode used in the gun is a tungsten impregnated cathode developed by Philips (ref. 9) from which a current of 500 µA at an energy of 41 eV could be drawn. Risks of contamination of the cathode were carefully studied and the following measures resulted in the safe operation of the guns. The two guns were opened at 600 km altitude where the concentration of oxygen is low, 15 days had elapsed since the launch so that the outgassing of the spacecraft was reduced, the opening system described in reference 8 was clean and finally a reactivating program was incorporated in the electronics of the experiment.

Tests were conducted before launch to simulate the effects of beam emission on spacecraft potential. The electron guns were attached to a metallic structure which could be biased (potential of the structure during the simulation is called V_{sc}) with respect to the walls (potential called V_{pl}) of a vacuum chamber (diameter 3 m, length 7 m). Figure 2 which summarizes the results shows that the beam current falls off with a slope of about 20 µA per volt and that at low energies ($V_k < 20$ V) spacecharge effects reduce the efficiency of the gun. The mechanism of formation of a virtual cathode in front of the gun at low energies may be invoked to explain the reduction in efficiency: at low energies the emission of electrons from the virtual cathode back to the anode of the gun is greater than the emission to the walls of the chamber at larger distances.

The configuration of the ISEE-1 spacecraft is illustrated in figure 3. In order to minimize potential disturbances originating at the spacecraft or in its vicinity an electrostatic cleanliness specification on the spacecraft surface was implemented at an early stage in the project with the result that the skin is essentially an equipotential surface (surface conductivity approximately $10^5 \Omega / \square$). Potentials can be measured between the satellite body and the probes at the end of the booms; the body of the spacecraft, as will be shown in the last section, can be considered as a large collecting probe.

On board, 13 instruments measure electron and ion populations, magnetic field, plasma waves and other plasma parameters (ref. 10). The orbit is highly elliptic with an apogee of 22.6 Earth radii and a perigee at about 300 km so that the plasmapause, the magnetopause and the bow shock are crossed successively. The measurements presented here were obtained on the 7th November 1977, starting at 17.00 hrs 49 min 40 sec UT when the spacecraft was in the solar wind at a distance of about 17.6 RE.

MEASUREMENTS

The current collection of a conductive body immersed in a space plasma is represented qualitatively as a function of potential in figure 4: the voltage reference is that of the undisturbed plasma at large distances from the body; I_e represents the current collected in shadow or when the photoemission rate is low, I_{pe} represents the contribution of the photoelectron current.

Plasma Potential Measurements

The vitreous carbon probes at the end of the wire booms can be used as conventional Langmuir probes with the difference that their current is swept rather than their voltage. The passage of the probe through the plasma potential has a clear signature indicated by a sudden change in the photoelectron current emitted by the probe. Biasing the probe with a negative current of about -60 nA maintains it within a fraction of a volt of the plasma potential for the data considered here.

Spacecraft Potential Control

The spacecraft potential is measured between the satellite body and one probe biased to be slightly positive relative to the plasma potential. Figure 5 a, b and c show the variations of the spacecraft potential and the electric field signals for 3 different values of the emitted gun current, as a function of the energy of the beam. The accelerating beam voltage V_k is maximum at the left of the figure and is stepped down automatically by steps of 1.6 Volt from 40.8 V to .58 V. The time necessary to step from one level of energy to the next may vary and the arrows indicate the times when the beam energy is equal to 8.6 eV and can be used as reference points. As mentioned earlier the sinusoidal signal representing the electric field is not affected by changes in beam energy or in gun current. (The spikes appearing regularly are due to the sudden change in potential of the probes as they pass in the shadow of the spacecraft).

When the gun current is set at 120 μA (fig. 5 a) the spacecraft potential follows closely the beam energy down to an energy of 8.6 eV where the gun looses its control of the potential. At this energy and lower, space charge effects limit the emission of the gun as was observed during the tests, and as is shown in figure 2 for $V_k < 20$ V. A detailed examination of the voltages indeed shows that decreasing the beam energy from 40 eV to 15 eV changes the spacecraft potential by only 23 V giving a ratio of .92 for V_{sc}/V_k. As will be shown in figure 6 this is due to the fact that beam electrons are not monoenergetic but have a spread in energy around a mean value. When the gun current is set at 60 μA (fig. 5 b) a modulation of the spacecraft potential at twice the spin frequency appears for high values of the beam energy; the modulation disappears betwen 24 V and 8.6 V where the modulation appears again. When the beam current is set at 30 μA the range where the control occurs is limited between 14 V and 8.6 V.
The modulation of the potential at twice the spin frequency is due to the changing photoemission of the shields of the long booms as they spin with the spacecraft. In the particular case of figure 5, the shields were biased at the potential of the probes minus 4 V which means that they are more negative than the plasma and consequently they are a source of photoelectrons. To compensate the changing photoelectron current of the booms the spacecraft potential adjusts to values where incoming and outgoing currents are equal.

The explanation for this behaviour is illustrated in figure 6 which shows current-voltage characteristics of the gun and of the spacecraft including the booms. The dotted line represents the emitted gun current at various energies, the fall off of the beam current has been assumed to be similar to the measured value of 20 μA/V (as shown in figure 2). The continuous lines represent the current collected by the spacecraft (similar to the current collected by a positive conductive body as was shown in the first quadrant of figure 4). The thick line corresponds to the minimum photoemission from the booms, the thinner line to the maximum photo emission. These two curves have been constructed from the data shown in figure 5 where the potential of the spacecraft can be measured for different values of the gun current.

The modulation of the spacecraft potential at twice the spin frequency occurs when the curve representing the current collected by the body cuts the gun current curve on the plateau, control of potential occurs when the gun current is larger than the current collected by the spacecraft body, the amount of gun current emitted into space is equal to the collected current. At voltages less than 8.6 V the modulation reappears with a smaller amplitude because the gun current ceases and the potential oscillates between 10 V and 5 V as is shown in fig. 6; as the slope of the collected current curves is larger at low energies the potential modulation decreases with the spacecraft potential.

DISCUSSION

As was shown in the previous section, the satellite potential can be stabilized at a specified value positive with respect to the plasma potential by operating electron guns at appropriate energies. The guns can be used to compensate for small variations in spacecraft potential due to the aspect dependent photoemission of the long booms which, in the case considered, were biased negatively and thus were a source of photoelectrons.
Limited possibilities to measure the ambient temperature exist in the experiment complement on board ISEE-1. In the following a method to determine the plasma density and temperature from the gun measurements is outlined.
A simple model for electron collection is assumed $I_e = I_o\ (1 + V_{sc}/V_e)$ where $I_o = n\ e\ v\ S/4$ with n the density, e the electron charge, v the thermal speed ($eV_e = mv^2/2$) and S the collecting surface of the entire spacecraft, approximately 10 m^2. The value of I_o is obtained by extrapolating towards low voltages the curve representing the electron saturation current.
As an indication the values obtained from figure 6 are $n \approx 30\ cm^{-3}$ and $V_e = 14.6$ V.

When the control of the spacecraft potential by the electron gun is effective a fraction of the gun current returns to the spacecraft. As noted by the particle experimenters on ISEE-1 this return flux increases considerably the countrate of particle detectors in the vicinity of the return area. The beam also excites plasma instabilities which have been observed in a frequency range around 20 kHz and detected by the other electric antenna on the spacecraft.

It therefore appears that in spite of their low electron beam intensities, some fundamental plasma physics phenomena can be investigated with the electron guns on board ISEE-1 in the future.

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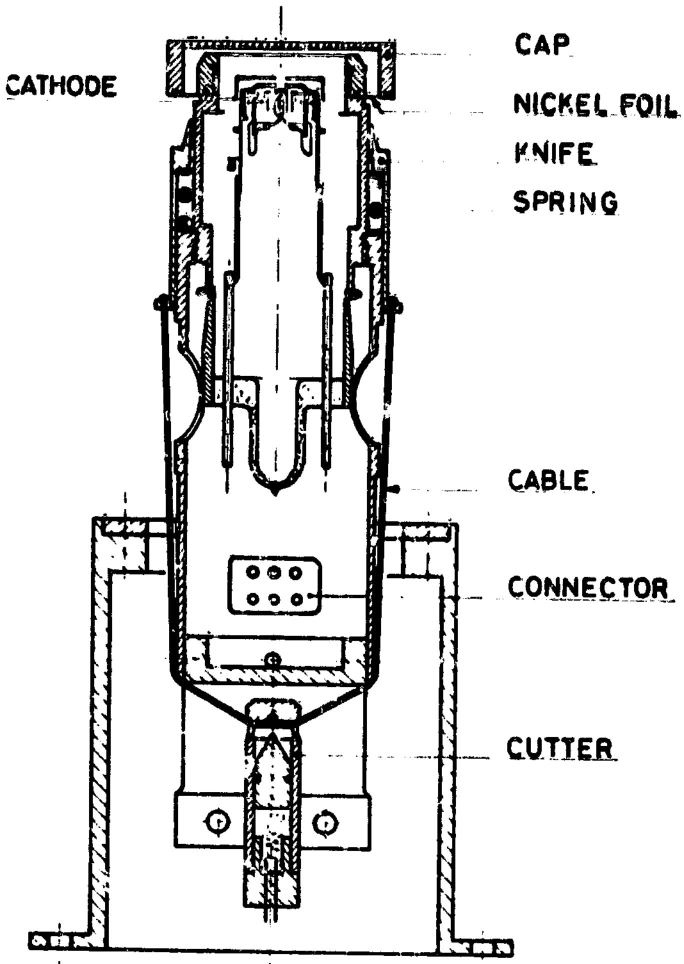

FIG.1 ELECTRON GUN STRUCTURE

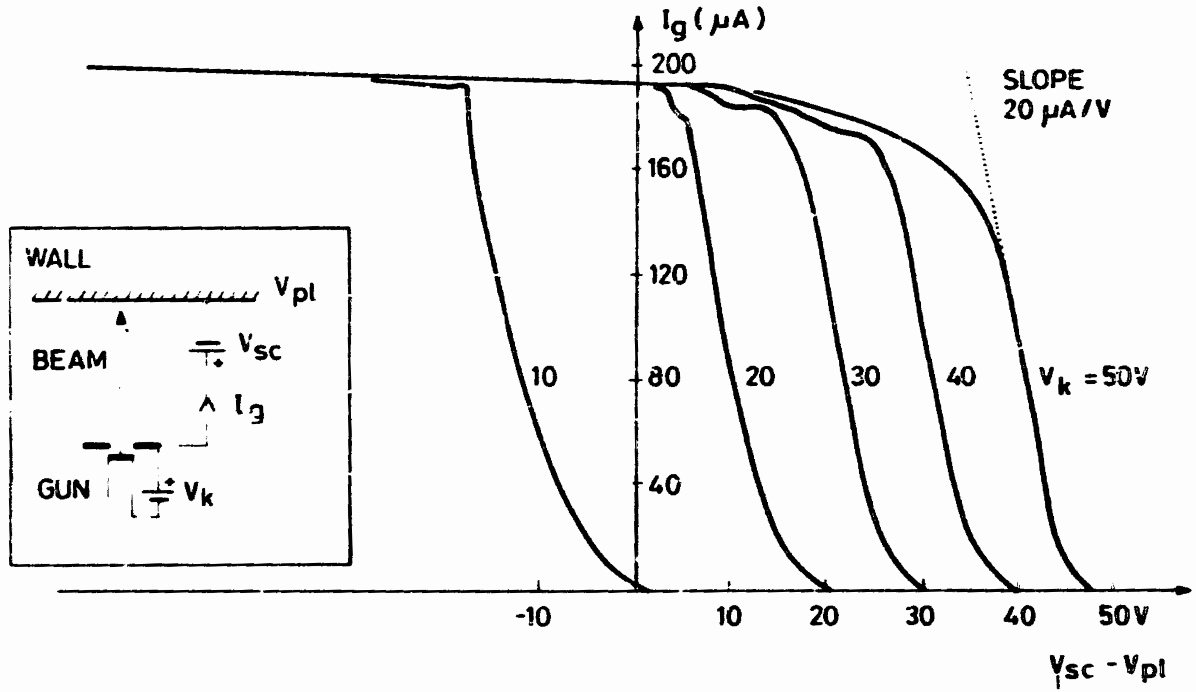

FIG.2 GUN TESTS

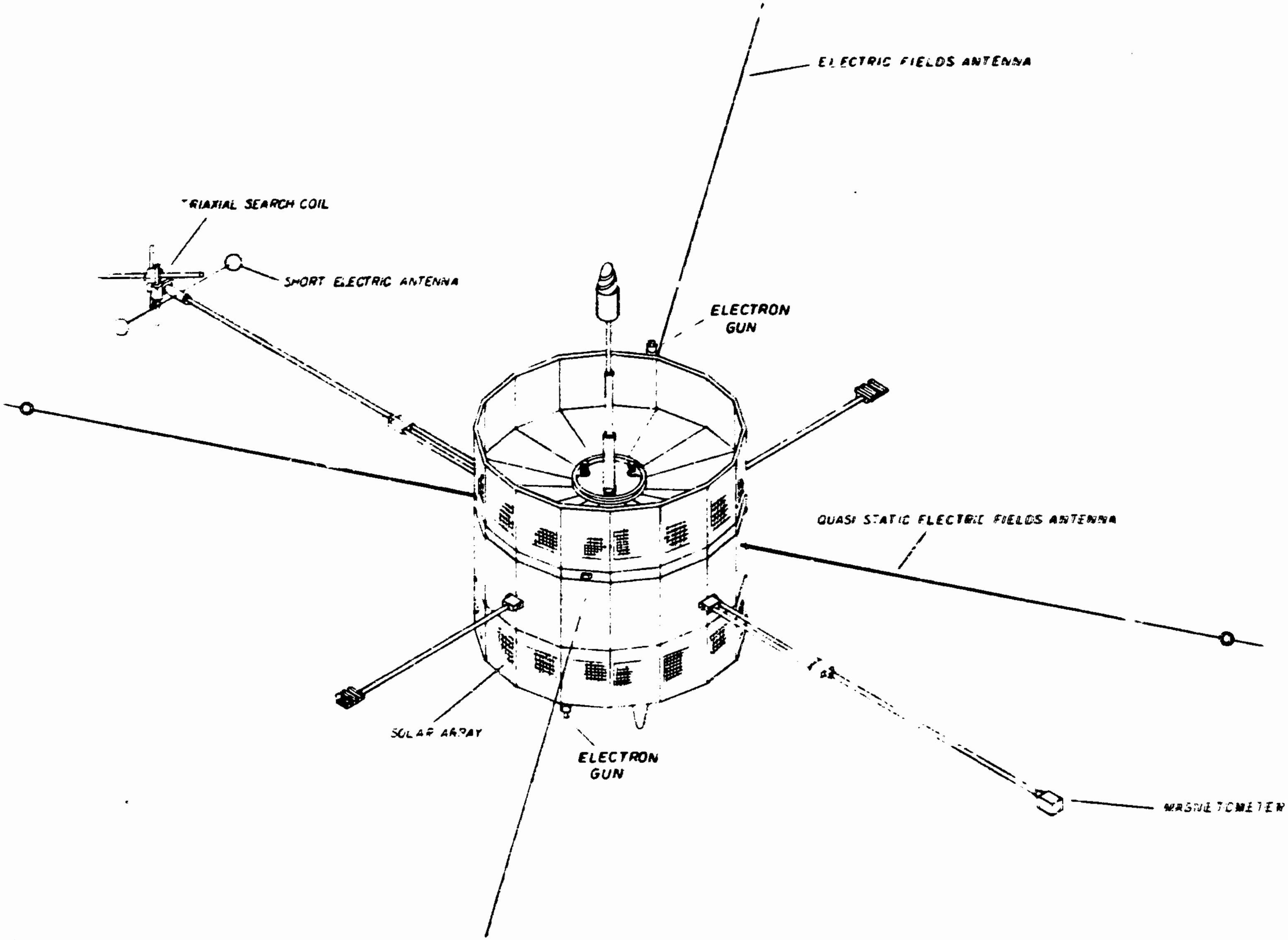

FIG. 3 ISEE-1 SPACECRAFT CONFIGURATION

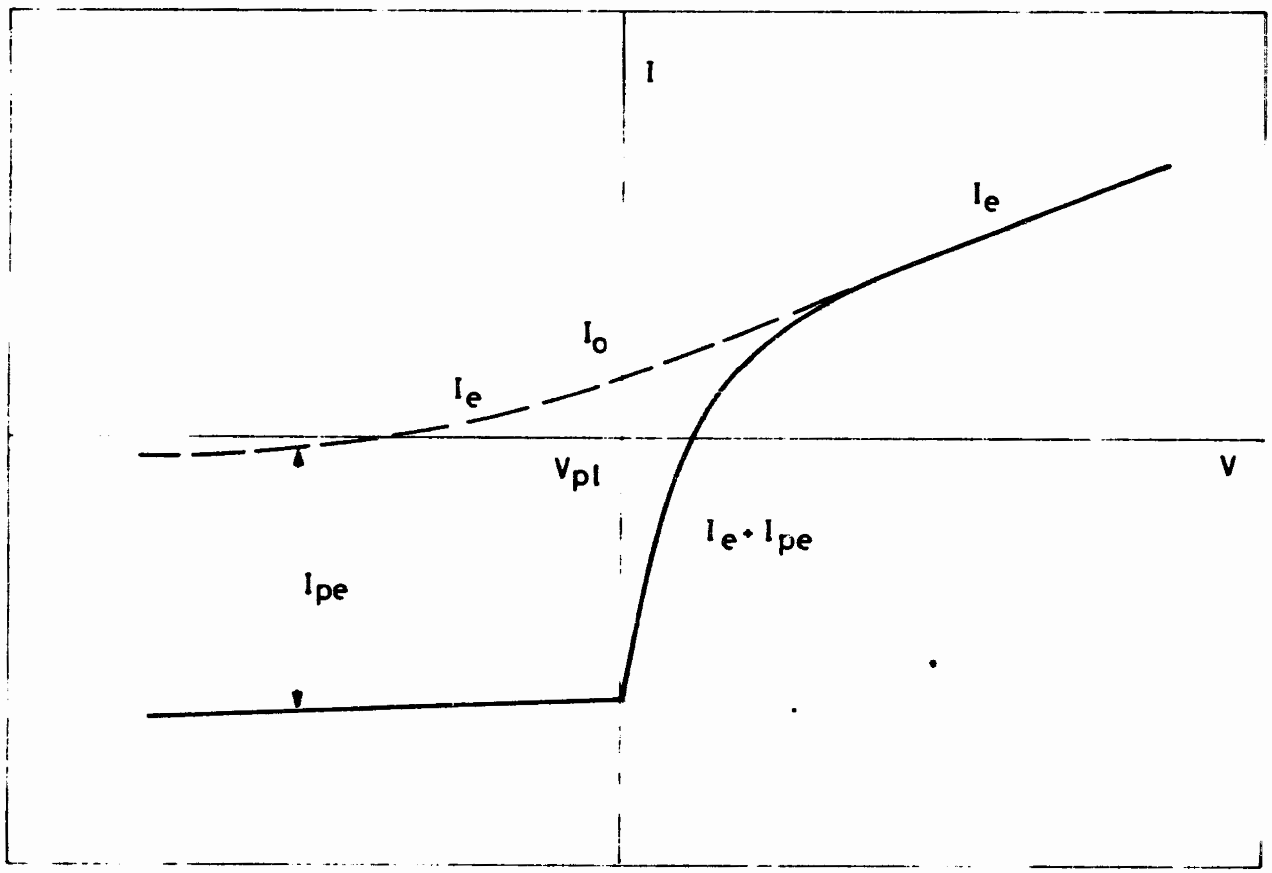

FIG.4 CURRENT-VOLTAGE CHARACTERISTIC OF A CONDUCTIVE BODY IN A SPACE PLASMA

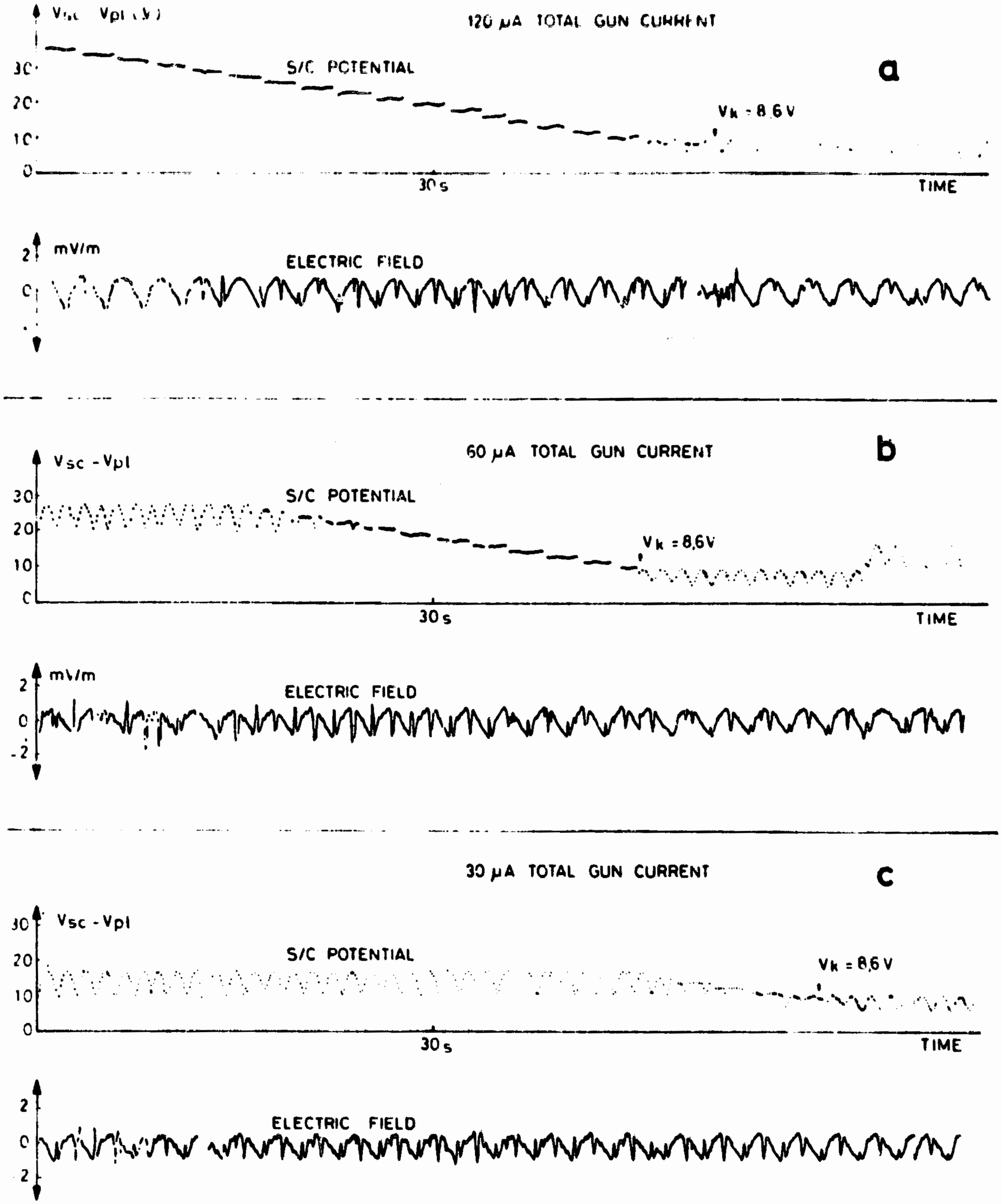

FIG.5 SPACECRAFT POTENTIAL AND ELECTRIC FIELD

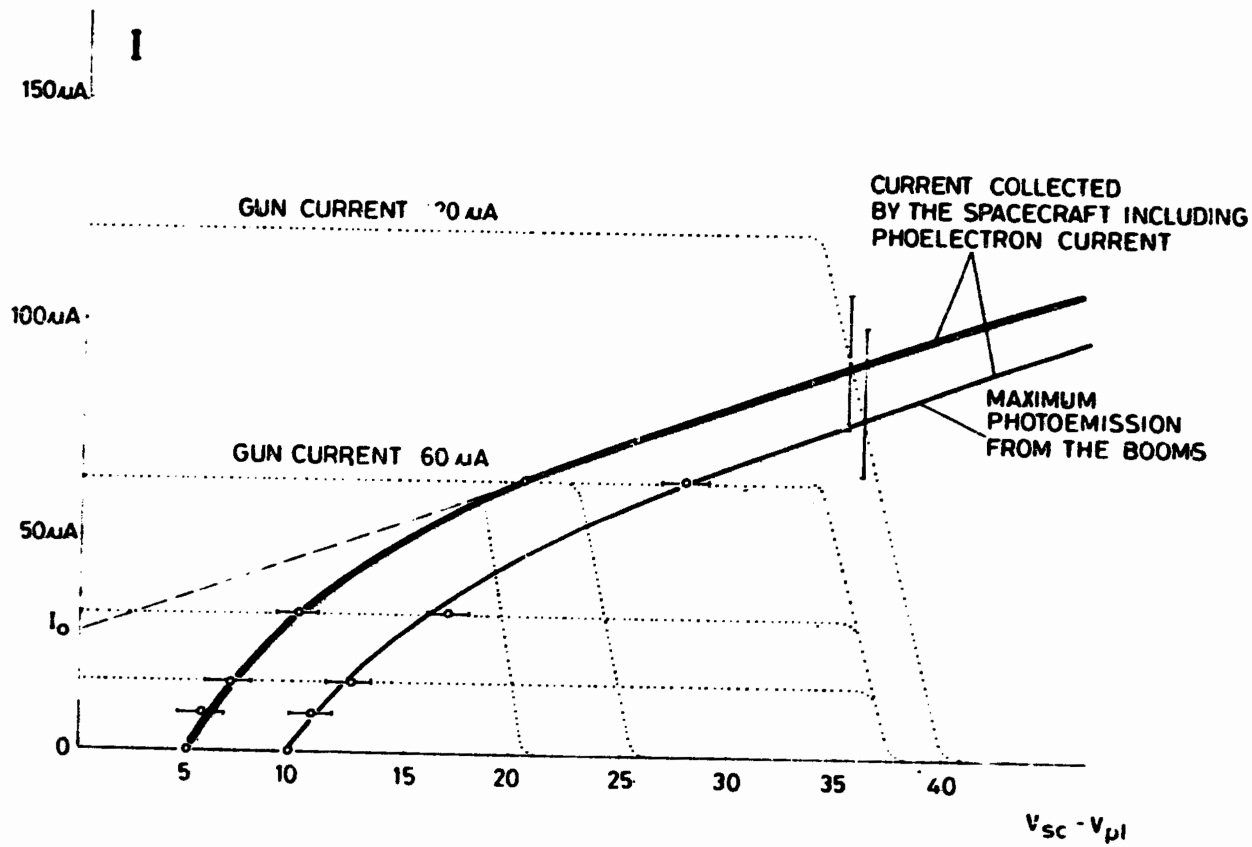

FIG. 6 CURRENT - VOLTAGE CURVES