A DEVICE FOR DETERMINATION OF THE ELECTRICAL POTENTIAL OF A ROCKET CARRYING AN ELECTRON GUN

K. I. GRINGAUZ, L. S. MUSATOV, N. M. SHUTTE,
A. P. BELIASHIN. L. I. DENSTCHIKOVA and V. F. KOPILOV
Space Research Institute of the U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.

Abstract. Data on the principle of operation, sensors and electronics of a device for determination of the electrical potential relative to the surrounding medium of a rocket carrying an electric gun are presented. The device operated successfully on board an Eridan rocket during the ARAKS experiment.

1. Introduction

In carrying out experiments with electron accelerators (electron guns) installed on board a rocket, it is necessary to know the rocket's electric potential ϕ relative to the environment, since the real energy of injected electrons is $E = E_{\text{accel}} - e\phi$, where E_{accel} is the energy defined by the accelerator design.

The value of ϕ is mainly defined by the intensity of the injected electron beam, i.e. the gun current, and by the electron flow to the rocket surface from the environment which, in turn, depends on ϕ, and which cannot be accurately calculated.

In the first rocket experiment (1969) with the electron accelerator [1], current pulses of about 0.5 A, with a duration of about 1 s, were injected into the ionosphere. To ensure neutralization of the rocket body a deploying metallized 'umbrella' of large area was used resulting in a considerable increase in the rocket cross-section gathering the neutralizing charges from the environment. In [1] it is shown that the ϕ-value in this experiment was low; which can be explained by the efficiency of the 'umbrella'.

In the second experiment (Echo, 1970), the injection current pulses were only about 70 mA during 0.16 s. The value of ϕ in this case did not exceed 200 V [2].

In the joint Soviet-French experiment, ARAKS, we used injected electron pulses of two different widths: 2.56 s and 20 ms. In this experiment no metallized 'umbrella' was employed for neutralization. A powerful caesium plasma generator was installed on board the Eridan rocket which, however, was switched on during part of the flight only [3]. Therefore, high values of ϕ could be expected at least when the plasma generator was switched off.

Previous rocket experiments used a retarding potential analyzer [1–4] for determining ϕ, while in the 'Echo-2' experiment it was a Langmuir probe method [5]. In experiment [1], the retarding potential value was varied from 0 to 2000 V in 70 ms and, in the 'Echo-1' experiment [2, 4], from 0 to 8750 V. During a 1-s cycle of the retarding potential there were 10 injection current pulses of 16 ms duration. An alternative 0.5-s cycle could be used during which a single pulse was generated.

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In the 'Echo-1' experiment, under operating conditions of analyzer and gun similar to these, only a comparatively rough estimate of the ϕ value could be made and, in any case, no conclusions on time variations of ϕ during one pulse of the injection current could be drawn.

The use of very long current pulses (with $\tau = 2.56$ s duration) in the ARAKS experiment enabled us to choose the duration of the analyzing voltage cycle in such a way that we could determine ϕ several times during the pulse and, to a certain degree, follow the dynamics of the ϕ-variation for this period.

A device designed for the control of the rocket's electrical potential relative to the environment, consists of two flat retarding potential electron analyzers ('traps') and an electronic unit supplying the necessary voltages to the analyzers and transmitting data to the telemetry system input.

2. Principle of Operation

For the retarding potentials, sawtooth voltages were applied to the analyzer grids, relative to the rocket body. At one analyzer, the maximum value of this voltage was about 300 V, and, at the other, about 3000 V.

When the experiment was in the planning stage the following simple phenomenological model was used, which later proved to be oversimplified. During the flight, the rocket is surrounded by cold ionospheric plasma with an electron temperature of 0.1–0.2 eV. Electron fluxes around the rocket with energies $E > e\phi$ are negligible since they are lower than the amplifier sensitivity threshold 10^{-10} A. When the accelerator is operating, the rocket body should be charged to some positive potential ϕ and under the effect of the rocket electric field the ionospheric electrons will assume an energy $E - e\phi$ at the analyzer input. As long as there is a sufficiently negative voltage on the grid these electrons cannot reach the collector. With $|V_R| \leq \phi$, the instrument is 'opened', the collector current increases stepwise to the maximum value I_m depending on the ionospheric electron density $n_e(h)$ and the ϕ-value. The current is registered until the condition $|V_R| > \phi$ is brought on again. Note that, if $n_e \sim 10^5$ cm^{-3}, $T_e \sim 0.2$ eV and $\phi = 0$, the I_m value for the traps

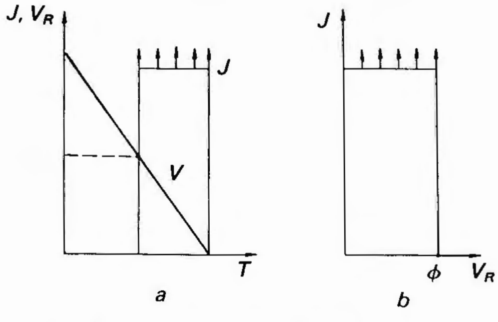

Fig. 1. Diagram of variation of analyzing voltage V_R and collector current J expected for one cycle of V_R.

should be about 4×10^{-7} A, whereas with $\phi = 100$ V and the same parameters of the ionospheric plasma surrounding the rocket, the I_m value is about 10^{-5} A.

Figure 1 gives the diagram of the retarding voltage V_R versus time (Figure 1(a)) and the expected dependence of the collector current J on the retarding voltage V_R and on the rocket potential value ϕ, for one cycle of V_R variation (Figure 1(b)).

The above described method of ϕ-determination is valid if losses of electron energies due to collisions in the space charge surrounding the rocket are negligible. This limitation is also applicable to [1-4].

3. Instrumentation

Two identical analyzers were installed at a distance of about one meter from the injector with their optical axes normal to each other and to the rocket and injector axes. The instrument block-diagram is presented in Figure 2.

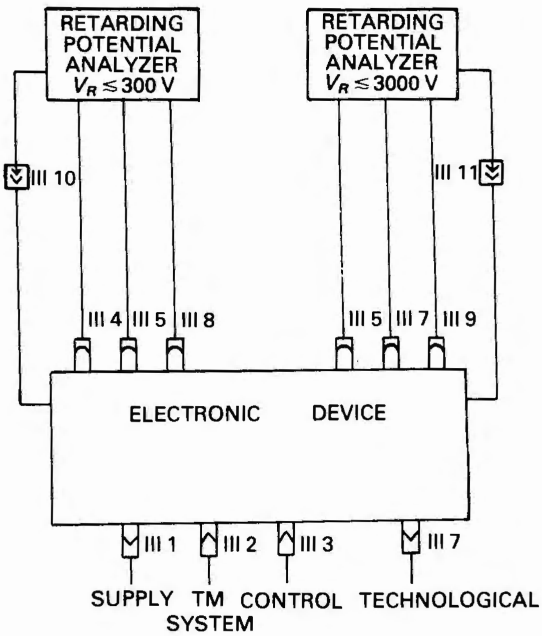

Fig. 2. Block diagram of the experiment.

3.1. The retarding potential analyzer

A photograph, and a schematical, cross-sectional view, of the analyzer is given in Figure 3. It is a flat parallel six-electrode device having a cylindrical body of stainless steel. A grid (3) which prevents ionospheric ions from reaching the analyzer and an analyzing grid (1) below the aperture, are covered by the external grids (4). Below, there is a group of six screen grids (5) placed in a cylindrical vessel and connected to the analyzer body. The vessel outlet and the analyzer aperture

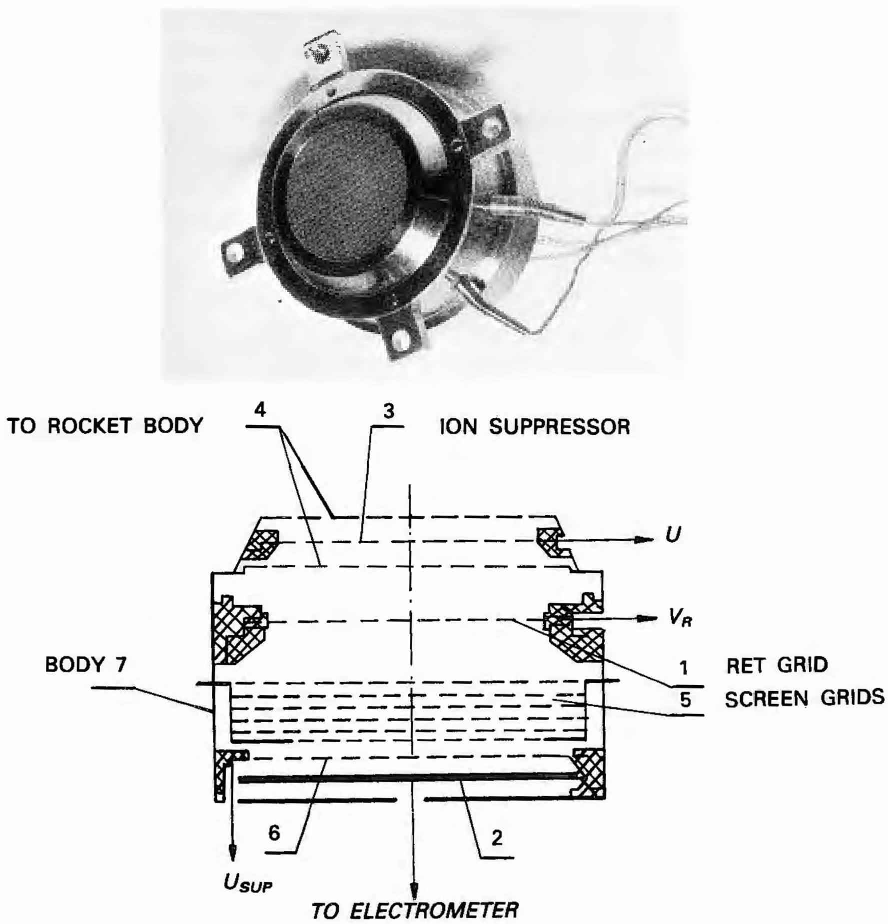

Fig. 3. Photograph and cross-section of analyzer.

have a diameter of 40 mm defining the field of view of the analyzer as ±45° from its axis. The suppression grid (6) and the collector (2) are placed behind the screen grids (5) on insulating rings. All grids of the electrode system are made of nickel covered by gold. The total optical transparency of the grids is 40%. The collector consists of a thin nickel disk. Insulation of the electrodes is accomplished by fluoroplastic rings. The electrode terminals are brought out via shielded wires with fluoroplastic insulation. The analyzer has a diameter of 70 mm (excluding the supporting flange) and a height of 50 mm, and its mass is about 170 g. Normal operation of the analyzer is possible at temperatures from −60 °C to +100 °C.

The sawtooth voltage relative to the body is applied to the analyzing grid (1). Grid (3) is under a small positive voltage of +40 V to prevent penetration of ambient ions to the analyzer while $\phi \leq 0$ (in the intervals between gun pulses). The suppression grid (6) is intended for suppression of secondary and photoelectrons. A group of grids (5) shields the collector from the varying electric field generated by the analyzing grid (1).

3.2. Electronics

The electronics system shown in Figure 4 consists of the following functional units (see Figure 5): trigger pulse former; driving generator; output stage; compensation scheme; two d.c. current amplifiers; and a stabilized power source.

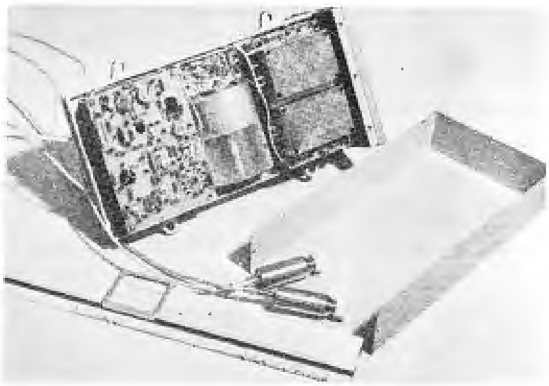

Fig. 4. Photograph of the electronics unit.

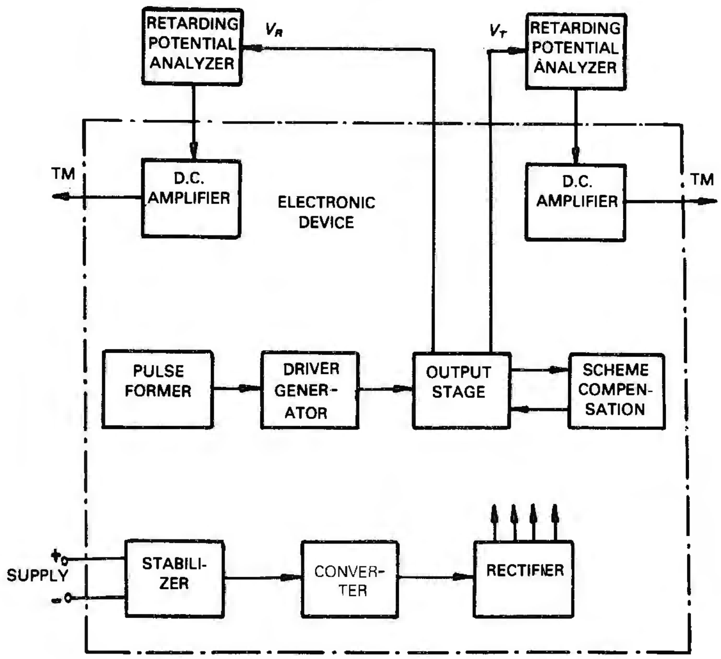

Fig. 5. Functional block diagram of the electronics.

Instrument operation is synchronized with the onboard programming-timing device. The pulse coming from this device is normalized in amplitude and duration in the trigger pulse former. The normalized pulse provides for synchronization of the driving generator which forms a sawtooth voltage with a 0.56-s period. This voltage energizes the output stage which operates in a push-pull mode. The retarding voltage thus generated varies in a sawtooth fashion from approximately −3000 to 0 V. This voltage is applied to the analyzing grid of one of the analyzers. The voltage from a divider which provides a division factor of 10 enters the other analyzer. Data on the voltage values are continuously recorded by the telemetry system of the rocket which also records data on the analyzer collector currents from the outputs of two identical d.c. amplifiers. These amplifiers use a balanced FET input stage and are operated with unity negative feedback and a closed loop gain of about 1500. Its dynamic range is from 10^{-10} A to 10^{-6} A.

Input signals to the telemetry system are voltages from 0 to 5 V. A direct current of 10^{-10} A at the input of the a.c. amplifier causes a 0.02 V voltage at its output. Output resistance of the amplifiers is not more than 500 ohm. The readout time does not exceed 2×10^{-4} s. The device is supplied with 28 V from the onboard power source. This voltage enters the stabilizer providing a stable output voltage with a possible source voltage variation of $\pm15\%$.

To prevent interference from the sawtooth voltage generator with the signal amplifiers their voltage supply circuits are decoupled. For this purpose, two identical push-pull voltage transformers are used which provide the necessary voltages to the sensors and all instrument units.

Registration of collector currents and analyzing voltages was done every 30 ms whereas the operating cycle of the analyzing voltage was ~0.64 s. Thus, during every long pulse, four retardation curves in each analyzer were obtained. The minimum retarding voltage with which the analyzer collector current was measured was 9 V; consequently, electrons with energy $E<9$ eV were not recorded in the experiment. The total weight of the electronics with sensors is about 1.6 kg.

4. Instrument Operation during Flight

In Figure 6, samples of recordings of telemetry information for different periods of injector operation are given.

Throughout the entire flight the currents in the analyzers were recorded only during injector operation. The general appearance of the retardation curves did not change with injection energy between 27 keV and 15 keV. In all cases, a sharp increase of current between 10^{-7} and 10^{-6} A was observed with decreasing retarding potential. It always took place with V_R-values $\ll 300$ V.

At altitudes $h \geqslant 150$ km, the rocket potential was ~150 V, decreasing to several tens of volts at altitudes $h \sim 100$ km.

Figure 7 shows samples of the retardation curves recorded at different altitudes during the flight. One can see from the figure that the steepness of the current

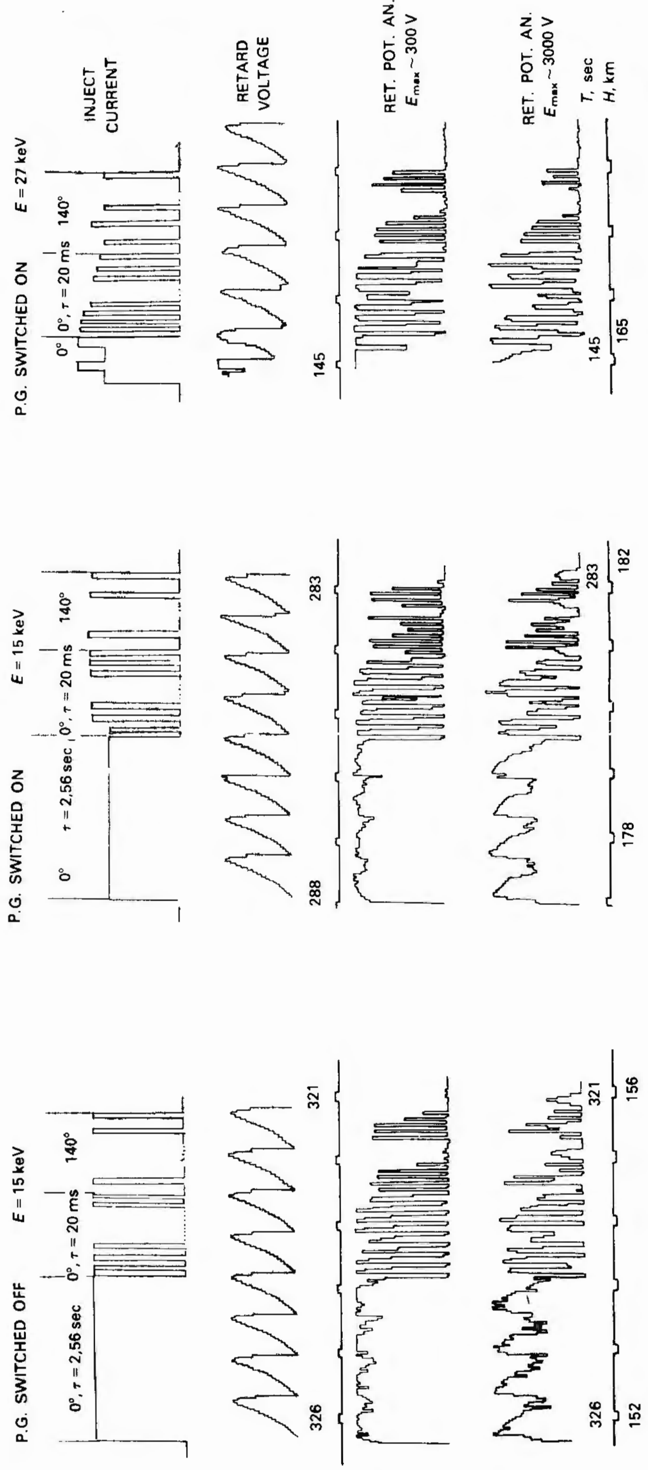

Fig. 6. Example of recorded telemetry information.

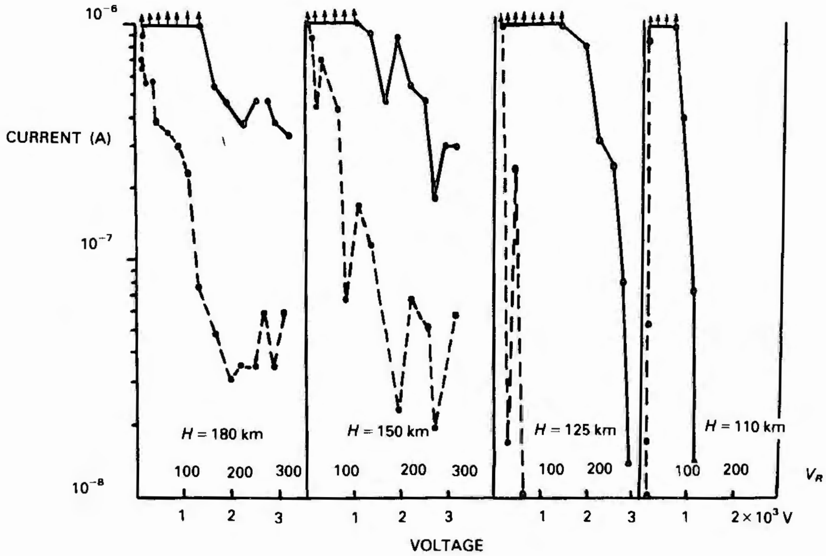

Fig. 7. Current-voltage characteristics for different altitudes during rocket flight. Solid lines correspond to RPA with $V_R \leqslant 300$ V; dotted lines correspond to RPA with $V_R \leqslant 3000$ V.

increases is not as high as might be expected based on the idealized model described above. This indicates that electron heating took place. In addition, most retardation curves show the presence of electron currents when $|V_R| > \phi$. In most cases, considerable variations in intensity of these currents were observed during the retarding potential cycle. With decreasing altitude, fluxes of the more energetic electrons fell until they fully disappeared at altitudes $h \leqslant 120$ km.

5. Conclusion

The instrument operated successfully during the Eridan rocket flight in the ARAKS experiment and allowed the electrical rocket potential to be determined during electron injection by the onboard accelerator. The rocket potential at an altitude of about 100 km was several tens of volts; up to an altitude of about 150 km it increased to about 200 V changing little with further increase in altitude.

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