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Problems Related to the Body Potential of Large Satellites and Their Particular Resolution with the Bulgarian Probe Experiment with Intercosmos-19 Satellite

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A certain period of time after the launching of the three satellites from the automatic unified orbital station (AUOS) series (Cosmos-900, Intercosmos-17 and Intercosmos-18) the body is charged with large negative potential with reference to the potential of the studied plasma (PP), when the solar batteries are operating (illuminated object). This is a serious defect, particularly for measurements of thermal and low-energy plasma (this does not refer to optical and high-energy experiments). The large potentials observed, exceeding $-15\,V$ on the Cosmos-900 and $-12\,V$ on the Intercosmos series appear 6-7-days after the launch of Intercosmos-17 and two month after the launch of Intercosmos-18. In certain cases this potential attains a value of -25 V. It is assumed that this is related to an error of systematic or accidental origin.

A precise analysis of the commands transmitted to the spacecraft, of the operation of the complex scientific equipment (SE) and of the service-systems is required. Two major sources of large negative body potential generation are assumed at present for the AUOS series [1]:

1. One of the possible causes is the wrong coupling of the negative output terminal (of the board power supply) -28 V with the spacecraft body through a leakage resistance of the order of tens or hundreds of kΩ. The panels of the illuminated batteries represent a system of voltage sources with surfaces under different potentials. In order to evaluate the phenomenon, we may consider this system as two electrodes with a voltage between them of the order of 30 V (i. e. double probe immersed into the studied plasma). Due to the high electron mobility, from their thermal velocity v_{T_e} and the ion collection at the expense of electrode motion with the satellite velocity, only if $v_0 \gg v_{T_i}$, a nonlinear characteristic is obtained. The equalization of the electron and ion currents of the double probe is possible only when the positive electrode is of $2 \div 5$ V more positive than PP and the negative receives potential around -25 V.

If the satellite is well insulated, from the feeding output terminal it receives a floating potential $(-4 \div +1)$ V with reference to the PP from secondary effects (rectified HF antenna voltage, photoemissions, charged particle fluxes, etc.) regardless of the solar batteries. But at reduced insulation resistance (R_{ins}) with respect to -28 V in a supply output terminal, the magnitude of the ion currents is limited and the satellite conductive surface is charged with negative potential $U_s = U_- + R_{ins} \cdot I_i$ which at low values of R_{out} and reduced N_i may attain -25 V with respect to the PP.

2. The possibility of leakage for the negative output terminal of the supply is larger than for the positive, as far as the output terminal -28 V is used as common and is permanently passed to all the instruments. The commands are transmitted to the positive output terminal $+28$ V from where the nonfunctioning instruments are switched off as well.

Series of conclusions may be drawn from the above-mentioned possible sources as to the further design of large satellites both for the constructors of the spacecraft and for the design of the different scientific experiments.

A. Recommendations to spacecraft constructors in order to avoid the effect of body charge:

a) To increase the effective spacecraft surface (2.5 m² only for AUOS); conductor and solar battery panel shielding; coating of nonconductive surface (thermal protective coat) with metal set of 5 mm step;

b) Not to switch on all the instruments to the negative output terminal -28 V and to use it for all switchings and commands. To utilize as common the positive output terminal $+28$ V;

c) At all test stages for the spacecraft (including complex ones with self-acting feeding by illuminated batteries) to control the insulation resistance of the chemical and solar batteries circuits with reference to the satellite body with additional instrument at voltage of 100 V.

B. As the Intercosmos-19 was ready for launching, the constructors of the instruments from the complex scientific equipment had to introduce some changes in the electric circuits:

a) A single command of switching on and off of a resistance 1 was introduced in the satellite-controlling block (SCB-4). Under such coupling of the spacecraft body and the supply output terminal $+28$ V, regardless of leakage from the negative output terminal -28 V, the body potential cannot exceed -12 V (excluding the case of short circuit at -28 V at the satellite body). Under resistance $R = 1\ k\Omega$ and short circuit of -28 V, an additional consumption of 0.9 W appears. Besides, the possible error at the telemetry input is 0.05 %, which is probably much less than the error generated by the satellite variations;

b) To execute thorough control over the insulation resistance at the input of the secondary sources of feeding for each instrument from the complex SE. At a voltage of 100 V the resistance of output terminals $+28$ V and -28 V to the spacecraft body should be larger than 20 MΩ at normal humidity situation;

c) This negative potential would result in significant losses of scientific information obtained by the probe experiments, therefore constructors of such instruments have to consider the possibility of expanding the operation range of the input voltages and the sweep size to the sensors (expansion of the functional capacity).

C. To resolve the problem on the body potential for Intercosmos-19 (AUOS type) in the particular case of combined probe instrument experiment.

The Intercosmos-19 satellite was launched on February 27, 1979 with the following orbital parameters: apogee — 996 km, perigee — 502 km, rotation period — 99.8 min, orbital inclination — 74°. For the first time two Bulgarian space instruments (EMO-1 and P-4) were flown and operated on board such a large spacecraft. But while the body potential did not affect the optic electrophotometer EMO-1, the combined probe instrument P-4 (designed to measure the parameters of the ion and electron plasma components) had to be largely modified in comparison to the other P-series instruments flown on small satellites (Intercosmos-8, 12 and 14) [2, 3].

a) Modification of the cyclogram of the spheric ion traps function PL-39/1 and PL-39/2 (sensors of the P-4 instrument) designed to measure the ion plasma component (M_i, T_i, N_i) in order to reduce disturbances generated by the body potential variations due to the sawtooth voltages with large amplitude at their outer grids. This affects the precision of measurement of many instruments from the ionospheric complex SE on board the spacecraft: the experiment with the high-frequency probe KM3 (Czechoslovakia); the low-frequency analyser ANCH-2ME (USSR) for measurements of the electric component; the experiment with the Langmuir cylindric probe P-4 (Bulgaria) and to a certain extent — the functioning of all antenna instruments (the thickness of the bulk charge layer varies).

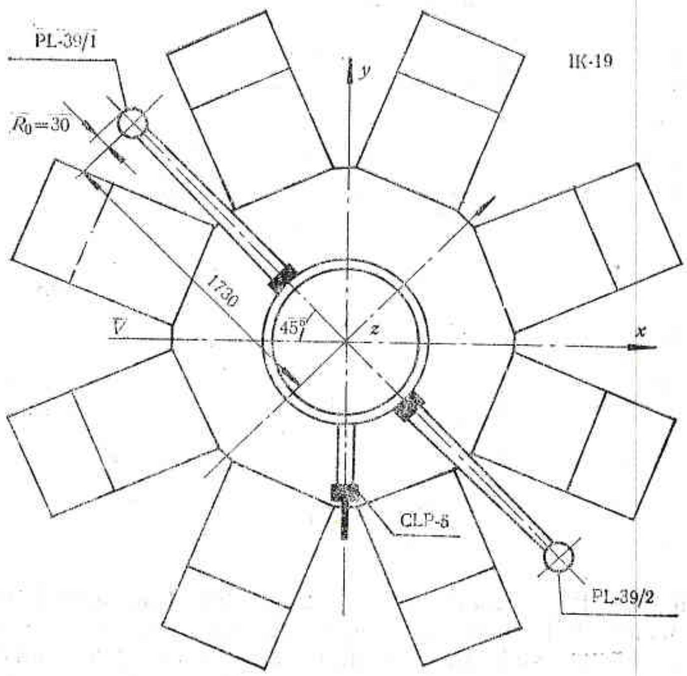

Fig. 1

The situation of the sensors to the P-4 instrument — ion traps PL-39/1,2 and the cylindric Langmuir probe CLP-5 on the body of the oriented satellite Intercosmos-19 is given in Fig. 1. The initial version of the P-4 instrument was designed for successive feeding of sawtooth voltages (points *2* and *3* of the time diagrams in Fig. 2) from the sweep generator, synchronized with the board pulses with quartz stabilized frequency board-time 1 (point *1* from Fig. 2).

Regardless of the relatively large AUOS satellite size, the net conductive surface is small (2.5 m²) and slightly differs from the surface of the small

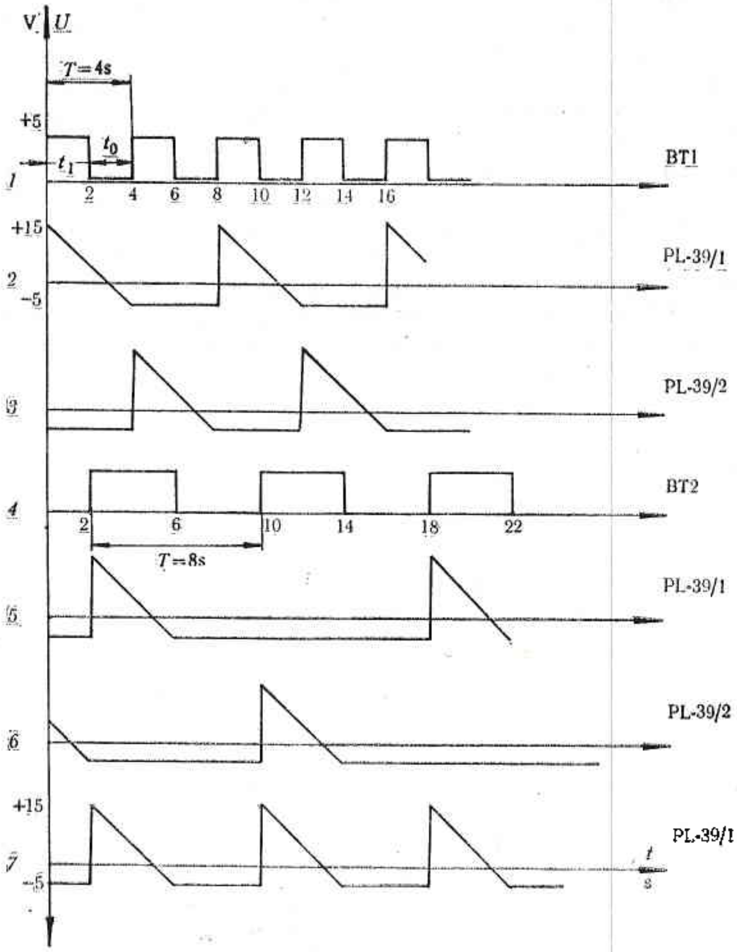

Fig. 2

satellites from the Intercosmos series. The system trap-satellite represents a double probe which collects electrons from all directions when a positive potential is fed to the IT while the satellite collects electrons only from the contrary flux. For slight potential variations of the satellite it is necessary [4]

$$\frac{S_s}{S_{IT}} > \alpha\sqrt{M_i\frac{m_i}{m_e}}, \quad \text{where} \quad \alpha = f\left[\frac{eU_0}{kT}\left(\frac{D}{R}\right)^{4/3}\right].$$

The minimum IT surface (without considering the bulk charge layer) $S_{IT} \geqslant 113\ \text{cm}^2$ at $R_0 = 3$ cm (Fig. 1).

The projection of the satellite conductive surface over a plane perpendicular to the velocity vector is $S_s = 2.5\times104/4 = 6250\ \text{cm}^2$ (under assumption

Table 1

Potential of I T, V	0	+5	+15
Coeffcient α	1.47	7.0	19.0
Required surface ratio	236	1122	3045

that the conductive surface is equally distributed). Hence the ratio between surfaces $S_s/S_{IT}=56$. But most simple calculations with the given formulas for field height $H=500$ km (perigee) at $M_i=14$, $T_e=2500$ K and $D=0.6$ cm show that this ratio is much smaller than the required even at zero potential of IT (Table 1).

Therefore, for $H=500$ km we may neglect the applied to the IT voltage effect over the satellite potential at ratio of the active surfaces more than 3,000. As far as this requirement was hardly satisfied, two modes of reducing this effect were suggested.

1. To use the Bulgarian traps supplied with a fourth outer shielding grid (flown on two rocket experiments already — Vertical — 7 and Centaur-II). But constructors did not permit a change of sensor with larger size ($R_0=3.5$ cm) and weight (85 g) due to the fact that the satellite had passed all test stages and was prepared for launching.

2. New cyclogram of the sensors IT operation (points *5* and *6* from Fig. 2) in argeement with the board-time 2 (point *4*). But the cyclogram thus suggested reduced two times the instrument resolution (measurements by 16 s). Besides, one of the IT would be in shadow and it will be difficult to determine which information has to be processed. In addition, this satellite was not provided with mass-spectrometer, thus the determination of the ion composition has to be performed with the IT measurements and this required greater frequency.

In the final version of the cyclogram for the P-4 instrument operation, a sweep voltage is supplied to the PL-39/1 sensor only at an angle of 45° of $\bar{V}$ (Fig. 1). This results from the fact that the instrument is located on the front plane of the spacecraft and the possibility to flow in an undisturbed plasma is greater, referring to disturbances provided by the solar batteries, antennas, sensor booms for the other experiments, etc. The sensor PL-39/2 is under floating potential in order to define the time interval for which a sawtooth voltage is not fed to the PL-39/1 (this is replaced by a direct voltage of -5 V). This has to overlap with the bottom level of the meander board-time 2 (point *7* from Fig. 2).

As the board meander board-time 1 is relatively accurate ($(t_1)=2.002$ s, $t_0=1.998$ s) no problems occurred from the back front of board-time 1 in the synchronization of the sweep generator to IT.

b) Introduction of additional block for the measurement of the floating potential U_{FP} on the insulated outer grid of IT. This is permanently controlled on PL-39/2 and on PL-39/1 only in M-4 mode, when a sweep voltage is fed there too. Then the U_{FP} is measured in sequence on the two IT with a period of 4 s with respect to the satellite body (and with reverse polarity on IT). It should be mentioned that we do not measure the potential plasma-spacecraft but sensor-spacecraft and the floating potential of an insulated sensor is by $0.7\div0.8$ V more negative compared with the plasma.

The emitting repeaters with high input resistance (OA with FET input) measure the U_{FP} within a range of $(+15\div-1)$ V and from the outputs the voltage is then translated to the telemetry scale range $(0\div+6)$ V and is supplied through a single channel (328-PP). The graph dependence and the formulaes for the U_{FP} determination are given in Fig. 3.

c) Range variation of the sweep generator for CLP-5 in dependence on U_{FP}.

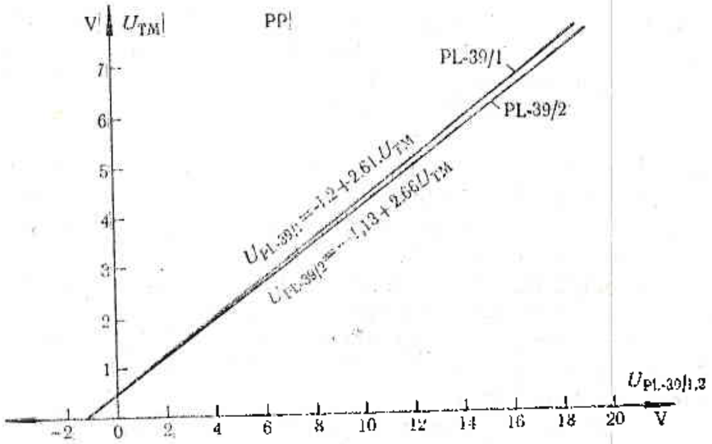

Fig. 3

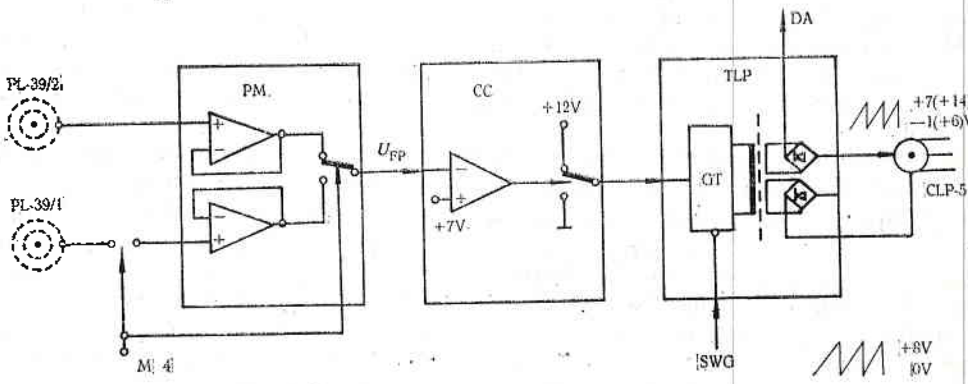

Fig. 4

The P-4 instrument measures the parameters of the electron plasma component (T_e, N_e) with the help of a cylindric Langmuir probe, mounted perpendicular to $\bar{V}$ (Fig. 1). The block diagram of the additionally designed system to this circuit is given in Fig. 4.

By the scheme of comparison which starts to operate at $U_{FP}=+7$ V (measured by the MP block) the range of sawtooth voltage variations is switched on CLP-5 from $(-1\div+7)$ V to $(+6\div+14)$ V. This is realized in the high-frequency generator of the transformer (GT) of the block TLP, which is controlled by the basic generator SWG to supply two equal linearly increasing voltages (the acceptable difference between them being 0.1 V) to the electrodes of CLP-5, as one of them is insulated from the spacecraft (between the collector of CLP-5 and the amplifier input DA).

In conclusion, we may say that problems related to large satellites are bigger than the problems attached to small spacecraft. The presence of insulated surfaces increases the possibility of variations in the spacecraft potential of the order of tens of volts (see e. g. [5]), which even under normal conditions (normal potential difference "plasma-satellite") makes difficult the operation of the probe instruments mainly and also of all low-energy measurers (electrostatic and electromagnetic scientific equipment).

The problem of the optimum potential for this type of measurements is much more complicated and this paper should be considered as a first attempt only to introduce recent Bulgarian contribution to this new and important scientific field.

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Проблемы, связанные с потенциалом корпуса спутников больших размеров, и частичное их решение при проведении болгарского зондового эксперимента на „ИК-19"

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(Резюме)

В данной работе обсуждается проблема появления относительно большого отрицательного потенциала на корпусе спутников серии „АУОС" во время их нахождения на освещенных частях орбиты. Проведено глубокое исследование возможных причин его возникновения и обсуждены методы уменьшения его влияния. Подробно рассмотрен случай „ИК-19" —(АУОС-3-Ионозонд), а также изменения, необходимые для предотвращения влияния потенциала корпуса спутника. Описываются особенности болгарского комбинированного зондового прибора „П4", выведенного на орбиту спутником „ИК-19", в двух аспектах: с одной стороны, уменьшение взаимного влияния экспериментов с точки зрения нарушения равновесного потенциала корпуса, а, с другой — увеличение его функциональных возможностей и обеспечение его работы при высоком потенциале корпуса.