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OPTIMISATION OF SATELLIE TELECOMMUNICATION SYSTEMS DUE TO THE SPACE CRAFT ORBIT INJECTION

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Abstract**—***In this article the method of satellite telecommunication optimization during the SC's spacewalk via radio impenetrable ionospheric environment density production is considered. Power-effectual method of high-intensive artificial plasma for positive ions and negative particles in ionospheric plasma is operated; modeling and analysis of all the results are accomplished.*

Index Terms—Space craft; satellite telecommunications; ionospheric environment; radio communication; plasma clearing; low-temperature plasma.

I. INTRODUCTION

The problem of reliable connection with the space craft (SC) during its orbit injection is connected with powerful blast wave creation around the SC's corps. As a consequence, plasma's film is created around SC during its moving in the ionospheric environment. Since SC's motion velocity is a variable quantity and electrons' concentration in ionosphere is also changes depending on different factors, then the thickness and density of high-temperature plasma has stochastic alteration [1]. So, it is extremely complicated to take into consideration the influence of plasma's parameters alteration on radio waves expansion.

II. PROBLEM STATEMENT

Plasma warms up to the high temperatures and tries to enter to the chemical interaction with SC's surface. Furthermore, plasma changes antennas' characteristics and negatively influences on characteristics of radio waves expansion. This influence is defined by the act when electromagnetic wave sets in motion free electrons; in space their concentration changes and it engenders the difference of radio waves trajectories forms [2]. Their interference leads to radio signal's disfiguration and weakening and as a consequence, radio wave reverberates from the plasma. Plasma's film assists radio waves deceleration, so far as radio waves velocity in plasma depends on dispersion, then signals are disfigured.

As a consequence, the telemetry with SC is absent during some minutes and it fully depends on motion velocity and the angle of SC's injection in the time of start. This period is the most dangerous from the standpoint of controllability, reliability and safety of SC's flight.

III. REVIEW

There are 3 methods to optimize noise immunity of communication signals with SC: organizational, energetical and signal [3].

Organizational methods are connected with telecommunication satellite injection into different orbital altitudes. But this method considerably raises the value of SC's flying management and really worsens electromagnetic compatibility of satellite telecommunications.

Energetical and signal methods are connected with strengthening the radio signals' power and frequency diapason changing.

Indicated methods except for not high reliability, complicated hardware realization and high value, considerably worsen electromagnetic compatibility of radio navigational systems.

There are some new methods of increasing the communication reliability with SC that are connected with immediate influence on radio impenetrable environment.

Indicated problem received a name "plasma clearing".

The author [4] proposes the method of information transmission via plasma, founded on simultaneous influence on plasma by electronic flow, acoustic wave and information signal.

The analysis of all modern available methods of "plasma clearing" showed that nowadays there are no methods which can give some acceptable results while using them in board systems.

It is connected either with reduced mass-clearance indices, or with considerable energy consumption, or with SC's aerodynamic deterioration [5].

In [6] progressive energy-efficient method of influence on plasma radio impenetrable membrane is proposed, in order to locally weaken its density. Indicated method is based on noise immune communication channel creation by the influence on plasma membrane from SC's side. It is possible by the interaction of high-temperature plasma's elementary particles with artificially created source of low-temperature plasma [7], [8].

It is suggested to generate low-temperature plasma with negative radiation around SC's antenna compartment that locally "clears" ionized external plasma's flow and at the same time to create noise immune communication channel. The process is happening without any intrusions into external SC construction and depends on geometry, plasma's electrodes type, pressure and gas-filling origin.

For efficient making of "window" in external ionized environment, it is necessary to develop the method of quasi-neutral, equipotential artificial plasma with negative radiation creation.

IV. THE DETERMINATION OF EXISTING PLASMA'S WITH GENERAL NEGATIVE RADIATION BORDERS

The existence of discharge with general radiation plasma is limited by gas pressure (by which the discharge volume is filled) and burning tension.

These restrictions by the pressure are manifested in those that with gas pressure increasing, the complicated conditions are not accomplished.

With reduction of gas pressure, plasma can grow up till 0.133 Pa and less. But following this condition, it is necessary to increase the burning tension.

Provided certain small p the burning tension is highly manifested, so tension source is not provided discharge's burning.

Depending on gas origin restrictions on plasma creation have different limiting meaning of pressure, tension, diameter and number of electrodes in device.

For instance, in argon's inert gas, plasma with general radiation was constructed in device that has a diameter 46 mm and by 20 electrodes; the most limiting meaning of pressure during the research of this discharge constituted 535.95 Pa, for the anode tension $U = 188$ V and discharge current $8.1 \cdot 10^{-2}$ A. With the minimal pressure $p = 3.47$ Pa, the maximal burning tension was 690 V, and discharge current – $1.3 \cdot 10^{-3}$ A.

The measured discharges' parameters with plasma with general radiation is directed in Table I for neon, air, hydrogen, gas that burns (propane) C_3H_8, carbonic acid gas and nitrogen in device with 20 electrodes and gap's diameter $D = 46$ mm.

It is obviously, that discharge with plasma with general radiation in inert gases have existed under less tensions, than in the molecular gases atmosphere, and the difference in limiting pressures' meanings is observed.

The borders of plasma with general radiation existence depending on discharge's gap diameter are introduced in Table II.

TABLE I

PARAMETERS OF DISCHARGES DEPENDING ON THE GAS KIND, TENSION AND DISCHARGE

# f/p	Gas	p, torus	U, V	$I \cdot 10^{-3}$, A
1	Argon	4.02–0.026	190–690	81–1.3
2	Helium	5.14–0.04	185–760	58–1.7
3	Neon	1.7–0.08	210–730	36–1.5
4	Air	3.26–0.09	560–980	71–2.4
5	Hydrogen	3.8–0.12	540–1020	25–3.1
6	Propane C_3H_8	3.4–0.16	550–960	110–1.4
7	Carbonic acid gas CO_2	4.9–0.06	610–1220	94–1.7
8	Nitrogen	6.21–0.11	510–870	133–2.1

TABLE II

THE BORDERS OF PLASMA WITH GENERAL RADIATION EXISTENCE DEPENDING ON DISCHARGE GAP DIAMETER

# f/p	p, torus	N – a number of electrodes	$2R \cdot 10^{-3}$, m
1	1.0	16	27.0
2	1.5	16	18.0
3	2.0	16	13.5
4	2.5	16	10.6
5	4.0	16	6.7

These meanings are a little bit high for the molecular gases.

Following the condition of constant discharge's gap diameter, increasing the number of rod electrodes N displays the restrictions by creation the plasma with high pressures.

V. THE DETERMINATION OF LOCALIZED DISCHARGE CHARACTERISTICS

Discharge gap consists of rod anodes and cathodes that are disposed evenly on cylindrical generant across the inner discharge's camera surface. According to such disposition, anode and cathode are alternated between themselves in that way, like any couple of neighbour rod electrodes represents anode and cathode, and creates separate elementary discharge gap. Herewith, every anode (and cathode) is located between two cathodes (anodes). Such geometry of electrodes' disposition connects separate discharge gaps into one general, Fig. 1.

The most optimal electrodes' diameter is disposed within 0.8 – 3 mm.

Electrodes' length l was chosen so as to discharge gap D was considerably lesser $l \left(D << l \right)$.

It is necessary for the reduction of flat ends non-homogeneity influence in discharge's process. In general, discharge gap represents cylinder with accurate borders, Fig 1, so in henceforth, the discharge will be called localized.

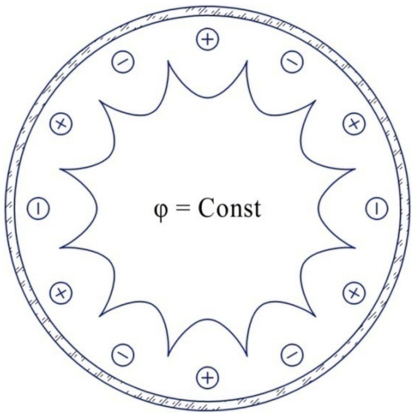

Fig. 1. Electrostatic field of a localized discharge interval: + anodes; – cathodes

Localized discharge represents typical occurrence of electric current passage in gas. In contrast to discharge with flatly-parallel intervals, the discharge in this device doesn't have the variety of discharge zones. In longitudinal and transversal directions, only one sphere is observed in discharge – negative radiation and one dark space that are located between electrodes and radiation. According to all mentioned pressures and researched gases, this discharge doesn't have any other zones. Changing the role between cathodes and anodes can't lead to the discharge's shape alteration.

The measured volt-ampere discharge's characteristics, for instance, in argon, are located in comparatively small pressures' interval 2.67–79.8 Pa (Fig. 2).

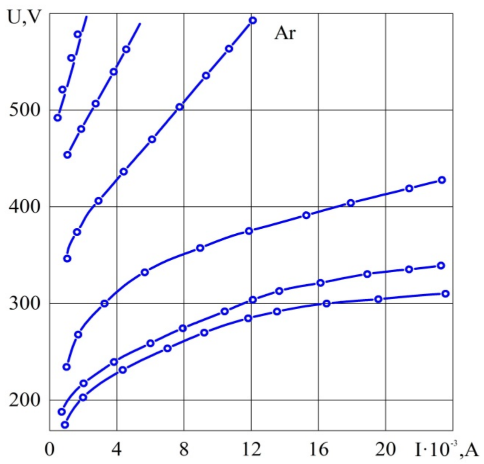

Fig. 2. Volt-ampere characteristics of a localized discharge, on condition of argon pressure changing: 1 – $p = 2.66$ Pà ; 2 – $p = 5.32$ Pà ; 3 – $p = 7.98$ Pà ; 4 – $p = 13.3$ Pà ; 5 – $p = 53.2$ Pà ; 6 – $p = 79.8$ Pà

But, in spite of a little pressure interval, the measured dependences $I = f(U)$ are considerably scattered for the tension and discharge current.

In the interval 2.67–79.99 Pa, they are located in the region of 700–1000 V and discharge current to $8 \cdot 10^{-3}$ A. When the pressure has changed within 79.99–186.65 Pa, the characteristics are changing heir position to the region of relatively small tensions 180–660 V and discharge current is reached 0.005–0.018 A.

In inertial gases, following the condition of small pressure, the dependences $I = f(U)$ are lying in the region of high tensions and on the whole, rectilinear. It affirms the fact that in dark space, the small spatial discharge is created.

With increasing the pressure, in these inertial gases, the volt-ampere characteristics acquire more increasing characters that is conditioned with spatial discharge increasing in the dark space. It is typical, that in spite of creation the complicated conditions in localized device, the discharge with small currents burns on considerably slight tensions 250–300 V. Such tension in the discharge is near to the tabular tension of short normal discharge that glows with flatly-parallel intervals.

Plasma with general radiation is created by the same way and in discharges with molecular gases.

In case of discharge in the simple air's atmosphere, hydrogen, burning gas C_3H_8, carbonic acid gas, in nitrogen, every time the column of plasma's radiation with the typical colourfulness that is conditioned by the gas kind was created.

In spite of inertial gases, volt-ampere characteristics in molecular gases are lying in the region of higher tensions (Fig. 3) and in somewhat bigger pressure's interval.

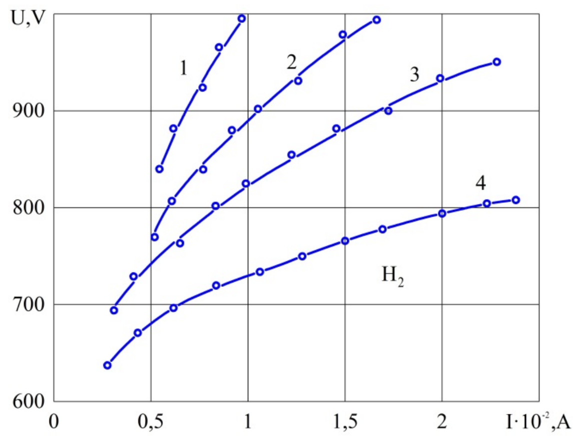

Fig. 3. Volt-ampere characteristics of a localized discharge, on condition of hydrogen pressure changing: 1

$- p = 18.62$ Pà ; $2 - p = 25.27$ Pà ;
$3 - p = 39.91$ Pà ; $4 - p = 53.27$ Pà

The upper borders of pressure for the molecular gases that were researched, have insignificant differences. For the molecular gases, small changing of slope characteristics with the pressure increasing is typical. Herewith, the convexity of these characteristics slightly expressed.

It affirms the slow discharge's volume increasing in dark space, when the anode tension increases.

We should notice that the diameter of plasma's with general radiation column diameter has bigger sizes than during the discharge in inertial gases.

All the characteristics, that is mentioned in Figs 2 and 3, have monotonous dependence and show that in all gases and by indicated pressures, the discharge with plasma with general radiation is located in anomalous regime.

Following the mentioned comparison, Fig. 4, it is clear that dependence $I = f(U)$ of discharge with flatly-parallel interval is located in the region of much higher tensions, by small discharge currents. Similar dependence of a localized discharge, conversely, located in the region on considerably lesser tensions and relatively high discharge currents.

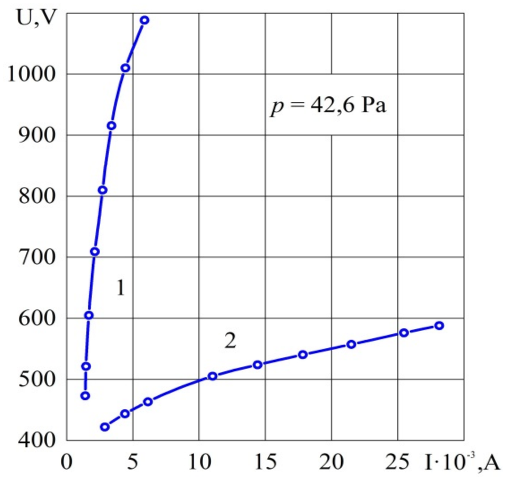

Fig. 4. Comparison of volt-ampere characteristics of a localized discharge – 2 and discharge that glows with flatly-parallel interval – 1, on condition of identical cathode area, energy contribution and pressure

From the comparison of volt- ampere characteristics received that $\frac{dI_{\text{lok}}}{dU}$ of a localized discharge is more than in 30 times higher in comparison to $\frac{dI_{\text{pl}}}{dU}$ of a discharge with flat interval.

Such big difference in $\frac{dI_{\text{lok}}}{dU}$ is conditioned by the fact that localized discharge doesn't have ambipolar diffusion of charge-carrier on discharge's camera inner walls and by high-intensive charge-carriers' imitation processes that are created on the whole cylindrical surface of a localized plasma.

VI. The Determination of Gas's Pressure Influence on Discharge's Regime

In spite of the fact that researches of discharge with plasma with general radiation was carried out in a small gas pressure interval, the changes of pressure were considerable and noticeable.

The alteration of pressure influences on plasma's with general radiation diameter and on radiation intensity. Burning tension U and discharge current also had considerable changes with gas pressure changing.

In accordance with Fig. 5, one can see that with pressure increasing, the tension sharply falls. Especially considerable reduction of U is happening in diapason to 26.66 Pa, whereupon he tension on discharge slightly subsides.

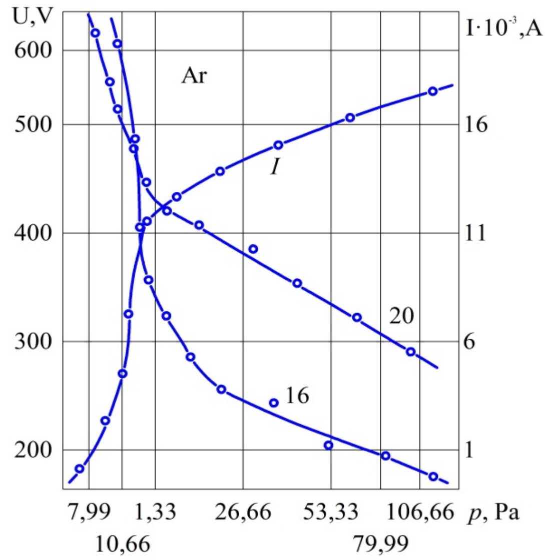

Fig. 5. Dependence of arcing tension U and current I in the localized discharge, from argon pressure, when $U = \varphi(p)$, if $I = \text{const}$; $I = f(p)$, if $U = \text{const}$, likewise $16 - U = \varphi(p)$ in case of 16 electrodes and $20 - U = \varphi(p)$ in case of 20 electrodes

It allows the establishment that with increasing the number of electrodes N, dependence $U = \varphi(p)$ travels to the region of higher tensions. Such passage is conditioned with complicated conditions expansion in the discharge gap.

From the dependence $I = f(p)$, when tension is not variable $(U = 600\ \text{V})$, it is clear that with increasing the argon pressure, tension sharply growth in the regions, where tension is sharply falls, Fig. 5. During the further pressure increasing, tension rise happens with minor speeds.

It is established that, when $p = 7.99\ \text{Pà}$, the column of plasma with negative radiation has a diameter no more than 10 mm. With the pressure increasing, the radiation intensity rises and the diameter of column augments to 60 % of discharge gap diameter.

In molecular gases this dependence eventuates analogously. The difference is only in the fact that dependence $U = \varphi(p)$ is observed over much higher temperatures and much higher pressure interval.

It is typical that in argon with pressure increasing to 13.33 Pa, sudden tension falling is observed nearly from 600 to 400 V, whereupon the tension falling happens considerably slowly. The same figure is observed in neon, but he most critical point here is the pressure 18.66 Pa.

Thus, the pressure of working gas and number of discharge gap electrodes are fully influence on localized discharge regime. The same influence can be reached, when the diameter of discharge gap but not the number of electrodes will be changed. With the diminution of discharge gap diameter, the similar effect is reached, like with increased number of rod electrodes.

During the increasing of complicated conditions in localized discharge degree, plasma's diameter, like this research affirms, lessens.

It is conditioned be the fact that conditions of ionization and excitation of gases' neutral particles worsen in case when anode is approaching to the cathode.

Limiting pressure can be determined like this:

$$p = \frac{Nl_0 p_0}{1.1\pi D}, \tag{1}$$

when $l_0 p_0 = d_0 p_0 + L p_0$; L is the negative radiation's expansion.

Depending on the diameter of discharged device D, a number of rod electrodes N and gas's origin combination and also cathode material $l_0 p_0$, it can be determined by what biggest pressure of working gas p plasma with general radiation can exist in a localized discharge. Following the purpose of making more precise the equation (1) a set of localized discharges with the same diameter D but with different number of electrodes N was experimentally investigated; another set with the identical number of electrodes N but with different diameters. In discharged devices with identical diameter $D = 4.6 - 10^{-2}$ m that are filled with neon, depending on a number of rod electrodes out of iron, a localized plasma with limiting neon's pressures p_{lim}, that is represented in Table III was received.

TABLE III

LOCALIZED PLASMA DEPENDING ON A NUMBER OF ELECTRODES AND LIMITING

Device diameter $D\cdot10^{-2}$, m	A number of electrodes N	Limiting pressure p_{lim}, Pa	
		for (1)	Experimental
4.6	12	177.32	187.98
4.6	16	245.31	257.31
4.6	20	306.64	325.31
4.6	24	369.3	379.97

Dependence of limiting neon's pressure meaning p_{lim}, when plasma with general radiation is forming in a localized discharge on discharge gap pressure D following the condition of constant number of electrodes $N = 16$ is represented in a Table IV.

Following the information that is represented in a Tables III and IV, it is clear that experimental limiting pressure of a working gas p_{lim}, in device differs from estimated no more than by 11%.

TABLE IV

DEPENDENCE OF LIMITING PRESSURE ON DISCHARGE GAP PRESSURE, FOLLOWING THE CONDITION OF CONSTANT NUMBER OF ELECTRODES

Device diameter $D\cdot10^{-2}$, m	A number of electrodes N	Limiting pressure p_{lim}, Pa	
		for (1)	Experimental
7.6	16	154.65	161.32
4.6	16	245.31	258.64
3.2	16	353.3	375.97
2.6	16	434.63	473.29

Owing to the biggest number of electrodes $N = 24$ and the least diameter $D = 2.6\cdot10^{-2}$ m from all devices that were discovered, the highest limiting pressure following the expression (1) is $p_{\text{lim}} = 652\ \text{Pa}$.

During the transition into an anomalous regime of a localized discharge p_{lim}, has still more significance, since plasma's with negative radiation extension L is growing with the increase of discharge's anomaly.

When working gas's pressure $p \le p_{\lim}$ all the area of plasma's column has homogeneous structure (Fig. 6)

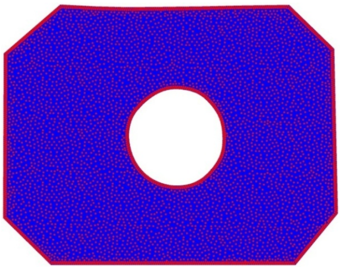

Fig. 6. Cross-cut of plasma with a localized discharge, when $p \le 650.37$ Pa

When working gas's pressure is $p \le p_{\lim} \le 1093.2$ in the device with $D = 4.6 - 10^{-2}$ m and $N = 16$, the diameter of plasma's column considerably increases, and radiation intensity growth to the discharge's with hollow cathode intensity (Fig. 7)

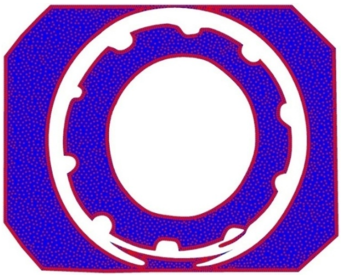

Fig. 7. Cut of plasma with a localized discharge on condition, that $650.37 \le p \le 1090.6$ Pà

Volt- ampere characteristic of a discharge with localized plasma, when $p \le p_{\lim}$ is fulfilled to the curve *1* like it is represented in a Fig. 8.

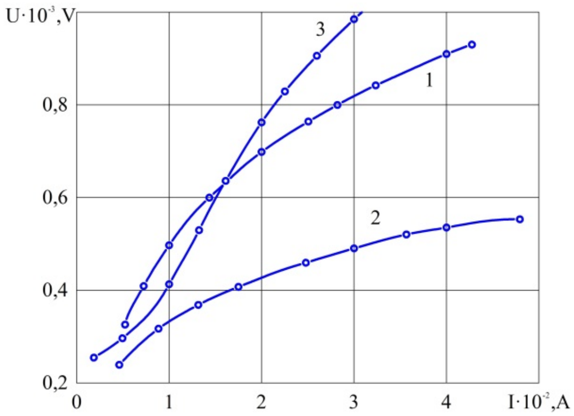

Fig. 8. Volt-ampere characteristics of a localized discharge according to the different pressures in neon: *1* – $p_1 = 650.37$ Pà ; *2* – $p_2 = 824.6$ Pà ; *3* – $p_3 = 1103.9$ Pà

The characteristic is not significantly changes the slope in a region of big discharge currents, following the condition of a small increasing of burning tension (Fig. 8 curve *2*).

Plasma comes up to an electrode system, faraday space is nearly to absent and the absorption of neighbour negative radiations is happening similarly to the effect of hollow cathode. As a consequence of such actions, discharge current and the intensity of localized discharge plasma intensity is significantly increase.

On condition, that $p > 1093.2$ Pà , plasma with general lightning is breaking down into some separate radiations that are localizing near every rod cathode (Fig. 9).

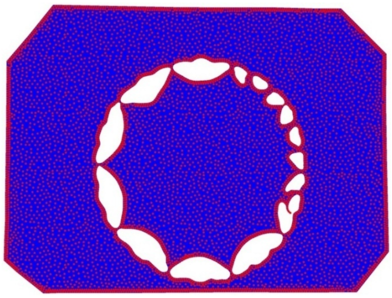

Fig. 9. Radiation of plasma's column, when $p > 1090.6$ Pà

Volt-ampere characteristic is coming back to the initial position, that is to say, it once again having a steep ascent in the region of big tensions (curve *3* that is shown in Fig. 8)

Thus, the discharge in a localized device, depending on pressure, is having three forms.

1. Discharge with localized plasma.
2. Discharge with localized plasma and hollow cathode's effect.
3. Discharge with localized negative radiation.

VII. Establishment of Plasma's Characteristics Dependences on Discharged Gap Parameters

Dependence of burning tension U and discharged current I on discharged gap length or rod electrode's length l_c has the significant substance.

With the slight l_c meanings, localized discharge is working with the high tensions U and with big current density j_0. With increasing the l_c, burning tension U_g, current density j_0 is reducing almost linearly, and general discharge current I, increases.

With the small lengths l_c, discharge is located in an anomalous regime. When $0.88 \le l_c \le 0.152$ m, curves *1* and *2* behaviour is indicated on an anomalous discharge.

In certain way, opened butt ends of discharged gap are having influence, and are manifested in going out a certain part of charge-carriers through them. When $l_c = 0.138$ m, $\frac{l_c}{D} = 3$ the influence of butt ends is not huge. In a point, when $l_c = 0.152$ m, normal discharge's regime starts almost to $l_c = 0.21$ m. However, detailed researches of processes with rod cathodes shows that they are fully enveloped with discharge in all burning regimes, when $0.152 \le l_c \le 0.21$ m.

Free plots from discharge on rod electrodes are not observed. It can be supposed that on this interval $0.152 \le l_c \le 0.21$ m, the further falling of burning tension is occurred in interval 1 V, but this dimension ΔU is situated within the measuring errors.

During the measuring of volt-ampere discharge's characteristics with different rod electrode's lengths, a curve's family id received $U = \varphi(I)$ after every 0.01 m, in which the following typical peculiarity is revealed (Fig. 10).

With increased l_c around discharge current $9 \cdot 10^{-3}$ À extremity is observed. When $l_{\tilde{n}} = 0.16$ m, clearly defined maximum (with $I = 6 \cdot 10^{-3}$ A) and minimum (when $9 \cdot 10^{-3}$ A) are observed.

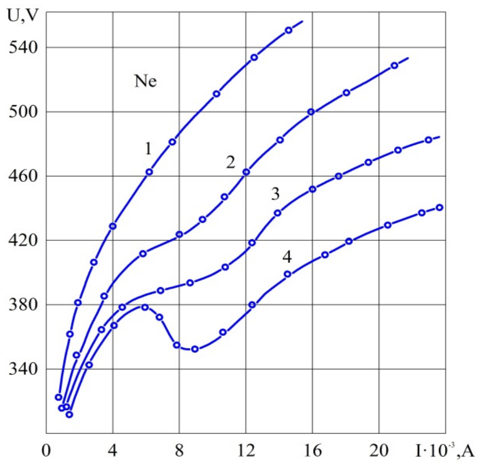

Fig. 10. Discharge volt-ampere characteristics, on condition of rod electrodes different lengthes, when neon pressure $p = 17.29$ Pà : $1 - l_1 = 0.13$ m;

$2 - l_2 = 0.14$ m; $3 - l_3 = 0.15$ m; $4 - l_4 = 0.16$ m

After mentioned extremity, the slope of volt-ampere characteristic changes, so, as a result, dependence $U = \varphi(I)$ comes to the region of big discharge currents with weak increasing of burning tension.

In a moment, when discharge comes through the extremity, the broadening of cylindrical plasma's with general radiation column and the growth of radiation intensity are observed.

This effect is conditioned by discharge's passage to the regime of hollow cathode, since with increasing the length of discharge gap, the increasing of rod cathodes' area and diminution of flat ends' aperture effect is occurred.

As a consequence, ionization and excitation of neutral atoms by electrons is considerably strengthened. Following this reason, the slope of volt-ampere characteristic changes too.

As a result of ionosphere environment's elementary particles and artificially created energy-efficient plasma with negative radiation interaction, the process of positive ions and negative particles neutralization, or ion-ionic recombination, with stabilized neutral particle participation is having its place.

The results of mentioned neutralization process modeling, according to [9] and a "window" with reduced density creation in external ionized environment that is showed in a Fig. 11.

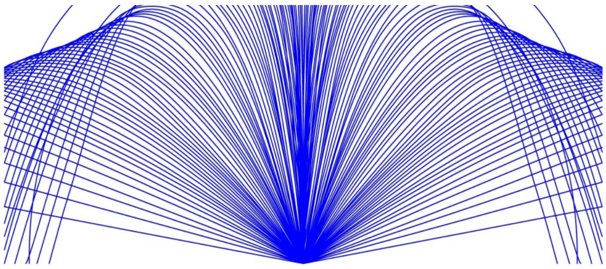

Fig. 11. Creation of "window" with reduced density for the passage of radio communication signals

VIII. CONCLUSION

On basic of these researches, for posed purpose gaining, it is received.

1) As a result of the investigation of coplanar discharge properties, υ-processes and effect of summation a huge amount of short discharges that glow, a method of increasing plasma's with negative radiation volume in a short discharge is developed.

2) The extension of received plasma is so considerable that it can be collated with plasma with negative column.

3) The difference of developed method is laid in the fact that for the enhancement of transversal plasma sizes, a coplanar effect is used; and for the augmentation of longitudinal sizes, local effect is utilized.

4) On the ground of measured characteristics it is established that energy contribution for the localized plasma's volume unit creation is lesser in 3.2 times than for the plasma with common negative radiation creation, and considerably lesser than for the plasma with positive column forming.

5) The results of modeling are persuasively assure that a channel with plasma's reduced density is formed around the SC's antennas compartment, but it is enough to pass the satellite telecommunications system signals.

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О. В. Шефер. Оптимізація супутникових телекомунікаційних систем зв’язку під час виведення космічного апарату на орбіту

Розглянуто спосіб оптимізації супутникових телекомунікацій під час виведення космічного апарату на орбіту, шляхом зменшення щільності радіонепроникного іоносферного середовища. Розроблено енергоефективний спосіб генерації високоінтенсивної штучної плазми для нейтралізації позитивних іонів та негативних частинок іоносферної плазми, виконано моделювання та аналіз результатів.

Ключові слова: космічний апарат; супутникові телекомунікації; іоносферне середовище; радіозв’язок; просвітлення плазми; низькотемпературна плазма.

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Напрямок наукової діяльності: підвищення завадостійкості сигналів, супутникові радіонавігаційні системи, радіотехнічні пристрої та засоби телекомунікації.
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А. В. Шефер. Оптимизация спутниковых телекоммуникационных систем связи во время вывода космического аппарата на орбиту

Рассмотрен способ оптимизации спутниковых телекоммуникаций при выводе космического аппарата на орбиту, путем уменьшения плотности радионепроницаемой ионосферной среды. Разработан энергоэффективный способ генерации высокоинтенсивной искусственной плазмы для нейтрализации положительных ионов и отрицательных частиц ионосферной плазмы, выполнено моделирование и анализ результатов.

Ключевые слова: космический аппарат; спутниковые телекоммуникации; ионосферная среда; радиосвязь; просветление плазмы; низкотемпературная плазма.

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