# THE MULTIFREQUENCY LOW-VOLTAGE PLASMA-BEAM GENERATOR

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The authors have submitted the experimental results concerning the excitation of multi-frequency oscillations in the beam-plasma generator based on the helical slow-wave structure. It is demonstrated that oscillations can be excited under the beam current up to 4 A, the accelerating voltage being up to 4 kV at several frequencies within the range 0.6-1.2 GHz in the quasi-continuous and continuous regimes.

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## 1. INTRODUCTION

The microwave devices, capable of working simultaneously in a broad frequency range [1] are of the great interest for systems of the ground-control and satellite communication. Other technical applications of such devices are possible as well. For the first time the multi-frequency excitation of the slow wave structure has been theoretically examined in [2,3]. It has been demonstrated the following. If the electron beam current increases, the generation stationary regime becomes replaced by the regime of auto modulation and stochasticity. In [4], the analytical results are proved to be true experimentally. The use has been made of a backward-wave tube (the corrugated waveguide) of the power level up to 100 kW. The accelerating voltage makes 70 kV, the beam current is up to 35 A. The pulse duration made 10 $\mu s$ and the frequency - 8 GHz. In [5], the analogous experiments were carried out also with a slow-wave structure of the interdigitally-loaded system (the accelerating voltage was up to 250 V, and the beam current was up to 100 mA).

A hybrid slow-wave structure is one of those where the excitation of intensive oscillations in a broad frequency band is possible.

The aim of the given work is the experimental attempts at finding the possibility of the multi-frequency oscillation excitation. For this purpose, it is chosen a model of a broadband and low-voltage beam-plasma generator, based on a helical slowing-down system.

## 2. DESCRIPTION OF THE INSTALLATION AND TECHNIQUES OF MEASUREMENTS

The block diagram of the installation, where the excitation of multi-frequency oscillations was carried out, is given in Fig.1. This scheme contains the following elements: an electron gun of the magnetron type (1), a slowing-down system of the helical type (6, 9), a collector (21), a solenoid (16) and a system that controls the working gas pressure.

An annular electron beam of the external diameter 28 mm and the thickness 4 mm is formed with the gun. Acceleration of electrons is realized by supplying to the cathode assembly either of the constant or the pulse negative voltage 2-4 kV (of the duration up to 0.4 ms). The beam maximum current makes 4 A.

The beam transportation is carried out in the longitudinal magnetic field. The solenoid consists of the two sections. It has permitted us to generate optimal magnitudes of the magnetic field strength (up to 0.08 T) along the generator longitudinal axis and in the area of the electron gun. In the vicinity to the electron gun, the magnetic field strength is prescribed by the accelerating voltage. Besides, it is necessary to form the annular electron beam of the dimensions stipulated. The current precipitating on the slow-wave structure must be minimal.

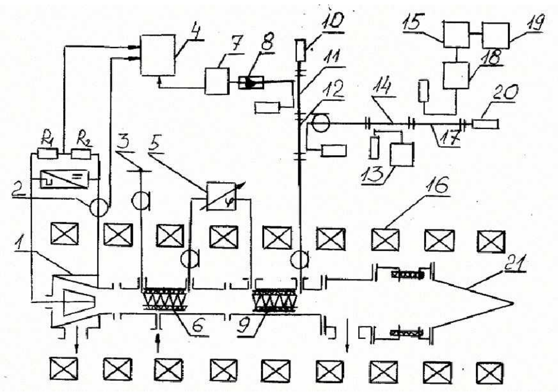

*Fig.1. The installation block diagram*

The typical pulses of voltage and current are depicted in Fig.2.

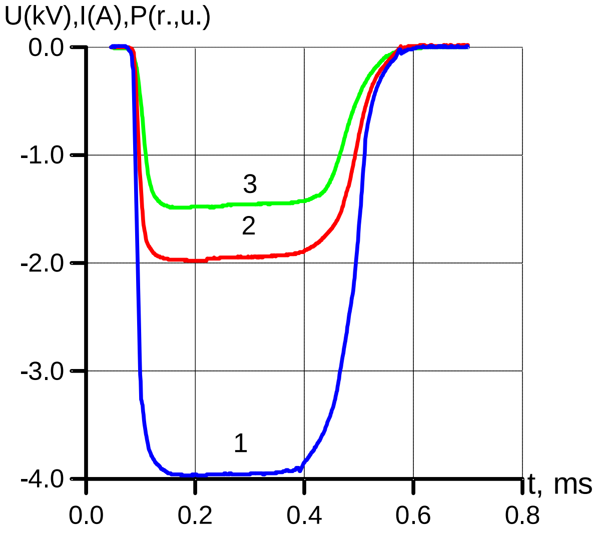

*Fig.2. The voltage pulse (1); the beam current pulse (2); the microwave oscillation envelope (3)*

The generator consists of two slow-wave sections of the helical type. They are connected with the area of the beam-plasma interaction. To the first section input, a short (3) is connected. It provides the oscillation reflection in a broad band of frequencies. The first section output is connected with the second section input via the phasor. The second section output is loaded with the matched load via a coaxial tuners (10).

The measuring equipment is connected into the track via the directed microwave couplers**.** From the coupler (11), the signal is transmitted to the detector (8). This is intended for measuring the microwave oscillation envelope with the oscillograph (7) or the analogous-digital transformer (4). Simultaneously the signal is also transmitted to the wavemeter (18) as well as to the integrator-amplifier (15) and the plotter (19). Oscillations in various sections of the microwave pulse envelope are registered with the fast-response oscillograph (13).

## 3. THE EXPERIMENT

The authors have experimentally investigated regimes of multi-frequency oscillation excitation. The oscillation spectra and their power have been measured under various conditions – i.e., the values of accelerating voltages, beam currents, the plasma densities (the working gas pressure) and the magnetic field voltage. The frequency spectrum and the fact of the simultaneous excitation of several frequencies have been indicated by Fourier analysis given to microwave oscillation realization.

If the gas pressure is low in the system, the beam-plasma discharge is not developing. The number of the wave-types excited is prescribed by the quality of the concordance between helixes, feeders and loadings. The electron beam current can exceed the starting current for each type of the waves and the beam energy when the electron velocity is close to the wave phase velocity in the decelerating structure. In this case, the oscillations are excited under the condition of the beam-wave distributed interaction.

Under the gas pressure $2{\cdot}10^{-6}$ mm Hg, the starting current values $I_n$ have been determined. Under these values arise single-frequency oscillations (see Fig. 3 a). The amplitude of these oscillations increases with the current increase.

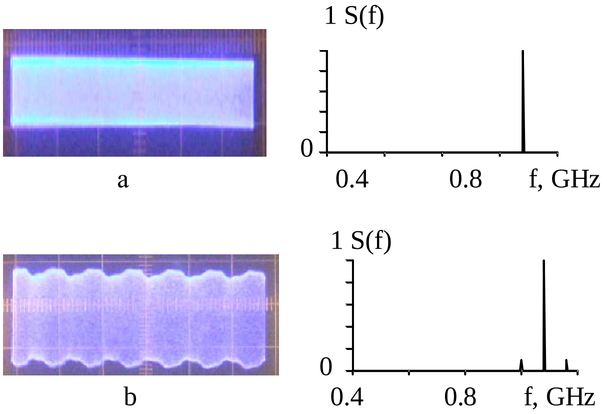

*Fig.3. Oscillograms and microwave spectra of the output signal under the low pressure without plasma:*
*a) the stationary regime; b) the auto modulation regime*

Under the accelerating voltages about 2-4 kV, the starting current is within 0.4-0.6 A. Heightening of the beam current up to 2.5-3 A results in the substitution of the automodulation regime for the single-frequency generation regime (see Fig. 3 b). Besides the basic frequency 1.08 GHz, the spectrum contains the lateral components 1.0 and 1.16 GHz. When $I/I_n \approx 5$, the level of components makes -15 dB. These results are in the rather good agreement with the data in [5]. The beam current heightening up to 4 A (it is the limiting current for the gun used) has not caused changes in the auto modulation nature. Besides, no substantial increase in the lateral components is fixed. According to [3], this regime is realizable when the beam current 10-15 times exceeds the threshold current. The oscillation power at the output makes about 300-400 Wt.

Heightening of the working gas pressure causes the generation of plasma and the formation of the helical-plasma waveguide. The device can operate in the plasmic regime if the following ratio was realized:

$$\omega_b^2 \ll \omega^2 < \omega_e^2 < \omega_{eh}^2 .$$

Here $\omega_b$ implies the beam electron frequency; $\omega$ is the working frequency; $\omega_e$ is the electron plasma frequency; $\omega_{eh}$ is the electron cyclotron frequency. Our installation operates in this regime under the gas pressure $5{\cdot}10^{-5}$- $5{\cdot}10^{-4}$ mm Hg.

Under the same accelerating voltages, the starting current diminishes 2-3 times. With the beam current like this, the oscillations are single-frequency. The higher the beam current is, for the more amount of wave types there arise conditions for the current exceeding of the starting current value for the given wave type. As the result, in the system a spectrum is excited, which consists of several frequencies. Experimentally it was observed the microwave excitation within the range of 0.4 - 1.5 GHz. The works was fulfilled with different parameters of the beam, plasma and the magnetic field strength. As the examples, in Fig.4 a, b one can see oscillograms and spectra of the two- and three frequency oscillations.

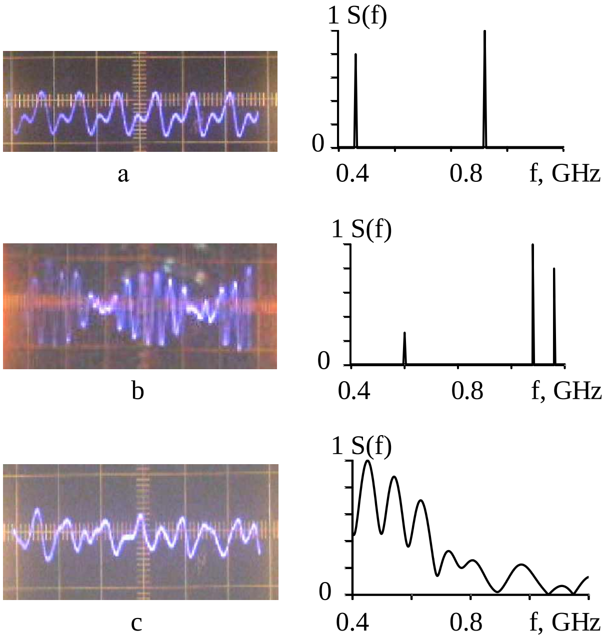

*Fig.4. Oscillograms and microwave spectra of the output signal in the beam-plasma regime*

It is necessary to mark, that in the presence of plasma the power spectral density can be made rather uniform for different frequencies. If the beam currents make 3 - 4 A, the oscillation power at the output makes 500 - 1000 W.

The further heightening of the beam current is accompanied by the transformation of the oscillations into those of the stochastic type (see Fig. 4 c). These problems are in detail investigated in [6].

In Fig.5, it is demonstrated the oscillation spectrum in the pulse regime, when the prolongation of the accelerating voltage rising edge and the trailing edge of the pulse substantially exceed the duration of the linear stage in the oscillation establishment.

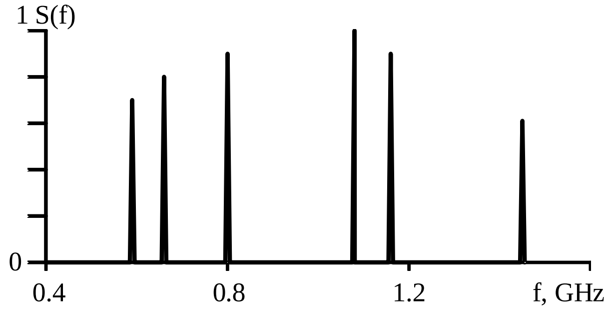

*Fig.5. The output signal microwave spectrum in the pulse mode of operation*

As this graph demonstrates, in the pulse mode of operation one can obtain the oscillation integral spectrum within the band 0.4-1.5 GHz.

## CONCLUSIONS

The experimental excitation of the multi-frequency oscillations in a vacuum helical slow-wave structure does confirms the theory. It is demonstrated that the filling of a transit channel with the plasma causes the starting current decrease. In addition, the multi-frequency oscillation spectrum is broadened and the signal amplitudes at different frequencies are leveled.

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## МНОГОЧАСТОТНЫЙ НИЗКОВОЛЬТНЫЙ ПУЧКОВО-ПЛАЗМЕННЫЙ ГЕНЕРАТОР

***В.С. Антипов, А.В. Архипов, И.А. Безъязычный, И.В. Бережная, Е.А. Корнилов***

Представлены экспериментальные результаты по возбуждению многочастотных колебаний в пучково-плазменном генераторе на основе спиральной замедляющей структуры. Продемонстрирована возможность возбуждения колебаний при токе пучка до 4 А, ускоряющем напряжении до 4 кВ на нескольких частотах в диапазоне 0,4-1,2 ГГц в квазинепрерывном и непрерывном режимах.

## БАГАТОЧАСТОТНИЙ НИЗЬКОВОЛЬТНИЙ ПУЧКОВО-ПЛАЗМОВИЙ ГЕНЕРАТОР

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Представлено експериментальні результати по збудженню багаточастотних коливань у пучково-плазмовому генераторі на основі спіральної уповільнюючої структури. Продемонстровано можливість збудження коливань при струмі пучка до 4 А, прискорюючій напрузі до 4 кВ на декількох частотах у діапазоні 0,4-1,2 ГГц у квазінеперервному та неперервному режимах.