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DESIGN AND STUDY OF THE LOW-VOLTAGE VIRCATOR UTILIZING SPENT ELECTRON BEAMS

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Introduction

Currently, devices based on the electron beams with a virtual cathode (vircators, VCs) are the subject of active research in the field of vacuum microwave electronics .

Vircators

- **simplicity of design,**
- **the possibility of easy control of generation regimes due to changes in control parameters,**
- **low requirements for the quality of the electron beam,**
- **the ability to work in the absence of an external magnetic field**

Spent electron beams at the exit from the interaction space of vacuum electron devices have a significant electron velocity spread and a electron beam residual grouping [1-3].

For the design and development of sources of broadband noise-like microwave oscillations with middle-power level (10-100 W) such spent electron beams could be useful.

[1] K. MASUDA, et al., Fusion Technology 30 (1996), P. 805.
[2] M. FUKS, E. SCHAMILOGLU, E. ABUBAKIROV, in Proceedings of the PPPS-2001 Pulsed Power Plasma Science, Las Vegas, NV, USA, 2001, P. 1622
[3] I.G. GACHEV, et al, J Infrared Milli Terahz Waves 31 (2010), P. 1109

Purpose of this work

In this work we have carried out the study the low-voltage vircator utilizing the spent electron beam at the exit from the interaction space of travelling-wave tube

Description of the studied system

The studied hybrid microwave device (Figure 1) consists of a travelling-wave tube (TWT) type amplifier (monosignal amplifier), an additional drift tube located after the TWT energy output, a measuring probe and a collector, the potential of which can vary widely. The measuring probe consists of a diaphragm, a retarding grid, a coaxial line and has the ability to move in three mutually perpendicular directions in the drift tube. The measuring probe makes it possible to measure the distribution of longitudinal electrons velocities and to record the power of microwave oscillations by exciting a coaxial line.

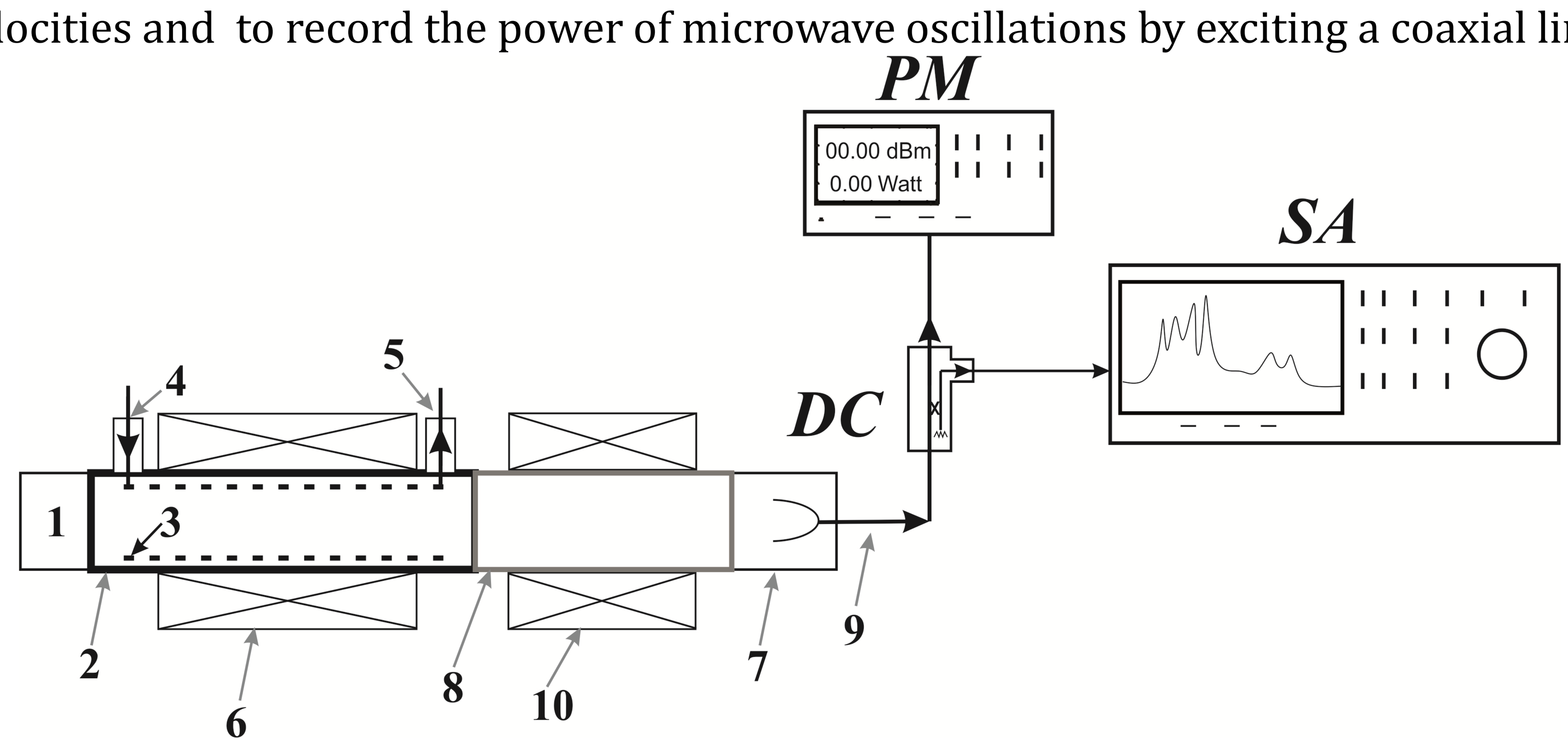

Figure 1: Sketch of the research model of the TWT with a generator (low-voltage vircator) based on the spent electron beam. The numbers in the figure indicate:
1 - the electron gun of the of the TWT monosignal amplifier;
2 - metal vacuum shell of the amplification section of the TWT monosignal amplifier;
3 – slow-wave system of the helix-type ;
4 - input energy;
5 - energy output;
6 - magnetic focusing system;
7 - collector;
8 - an additional section of the drift tube;
9 - output energy from the additional section of the drift pipe;
10 - magnetic focusing system of an additional section of the drift pipe.
The symbols in the figure indicate: DC - directional coupler, SA - spectrum analyzer, PM - power meter.

Experimental studies were carried out on a demountable vacuum setup in a pulsed mode (pulse duration was τ = 50 µs, duty cycle was Q = 1000). All elements of the hybrid device under study were placed in one evacuation research chamber of a demountable vacuum setup. All experimental measurements were carried out with continuous pumping (at a minimum residual gas pressure of $10^{-6} \div 10^{-7}$ Torr).

The parameters of the used TWT monosignal amplifier were the following: accelerating voltage U_0 = 4.2 kV, beam current – I = 200 mA, output power 180 W (in saturation mode), electronic efficiency ~ 21%, gain ~ 45 dB, operating frequency band 1-3 GHz. The electron beam was focused by a periodic magnetic field as in TWT so and in the drift tube. The amplitude of the focusing field is B = 0.05 T, the period is 25 mm.

Results

The dependence of the electrons distribution along the longitudinal velocities ΔV / V (where ΔV is the scatter width, V is the average speed) on the operating modes of the used TWT was studied. The spread of electrons along the longitudinal velocities was measured at the entrance to the drift tube. The following operating modes of the used TWT were considered: linear mode, saturation mode, and supersaturation mode. An analysis of the obtained experimental results showed that the electron scatter in the linear mode was about 20%, in the saturation mode about 80%, and in the supersaturation mode it reached 90%.

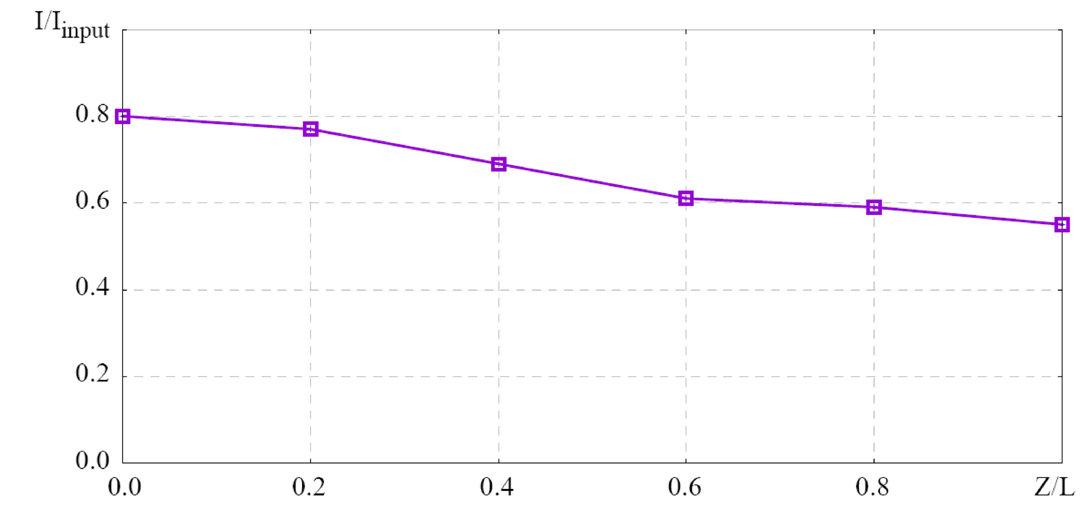

Figure 2: The dependence of the electron beam current on the length of the additional drift tube Z/*l*, where *l* is the total length of the additional drift tube

The dependence of the electron beam current on the length of the additional drift tube was studied. The obtained results are shown on the Figure 2. The observed decrease in electron beam current is due to the sedimentation of "slow" electrons to the TWT slow-wave system and the drift tube at points of the zero magnetic field of the magnetic periodic focusing system. Experimental studies have shown that the current in the drift tube was in the range of 120-130 mA.

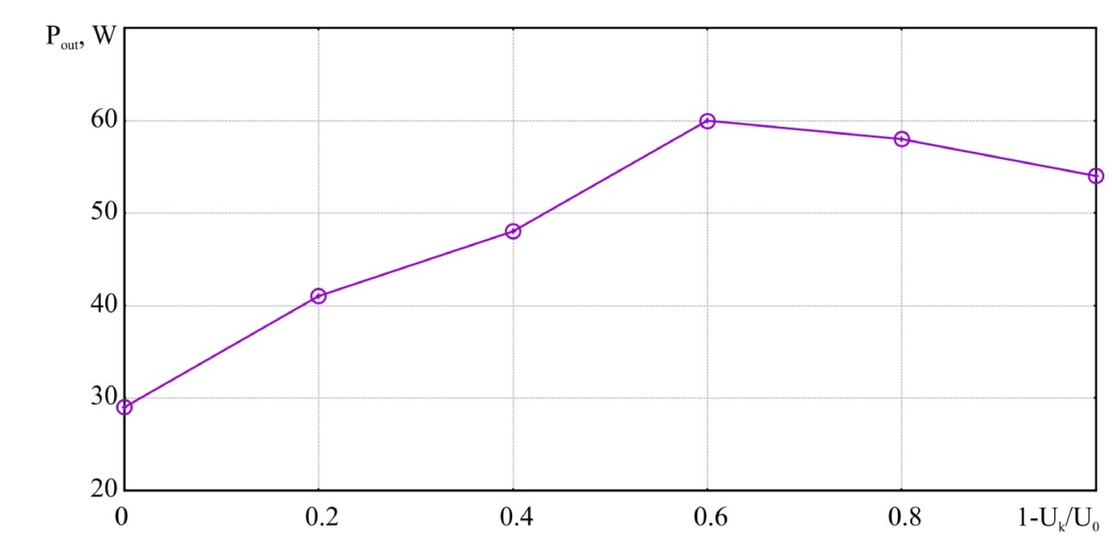

Figure 3: The dependence of the output power with an additional drift section on the ratio of the accelerating voltage to the collector voltage k = (1 - U_k/ U_0)

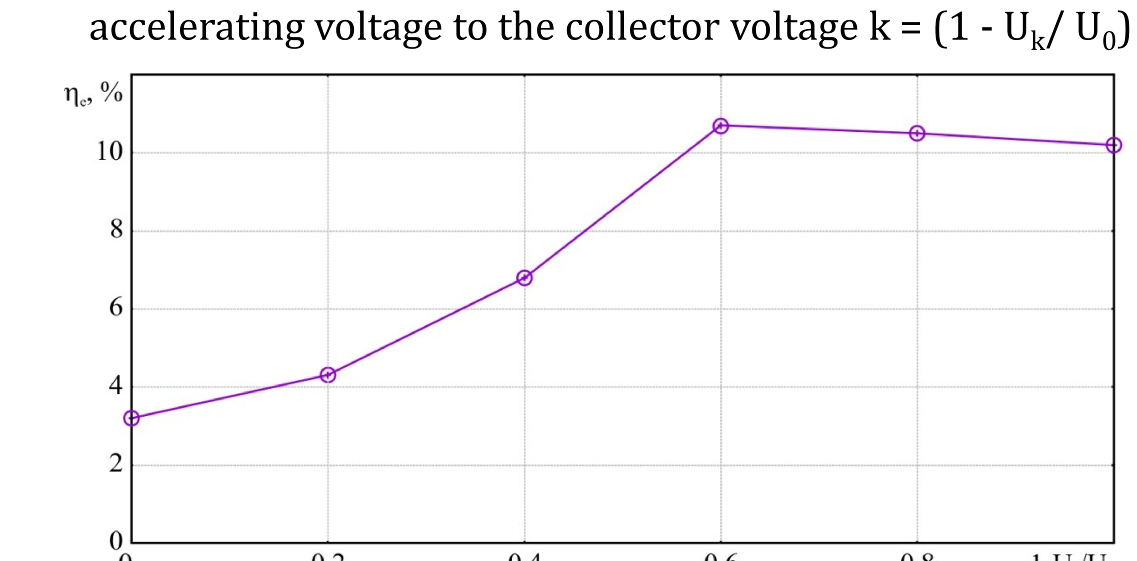

Figure 4: The dependence of the electronic efficiency of the generator on the ratio of the accelerating voltage to the collector voltage k = (1 - U_k/ U_0)

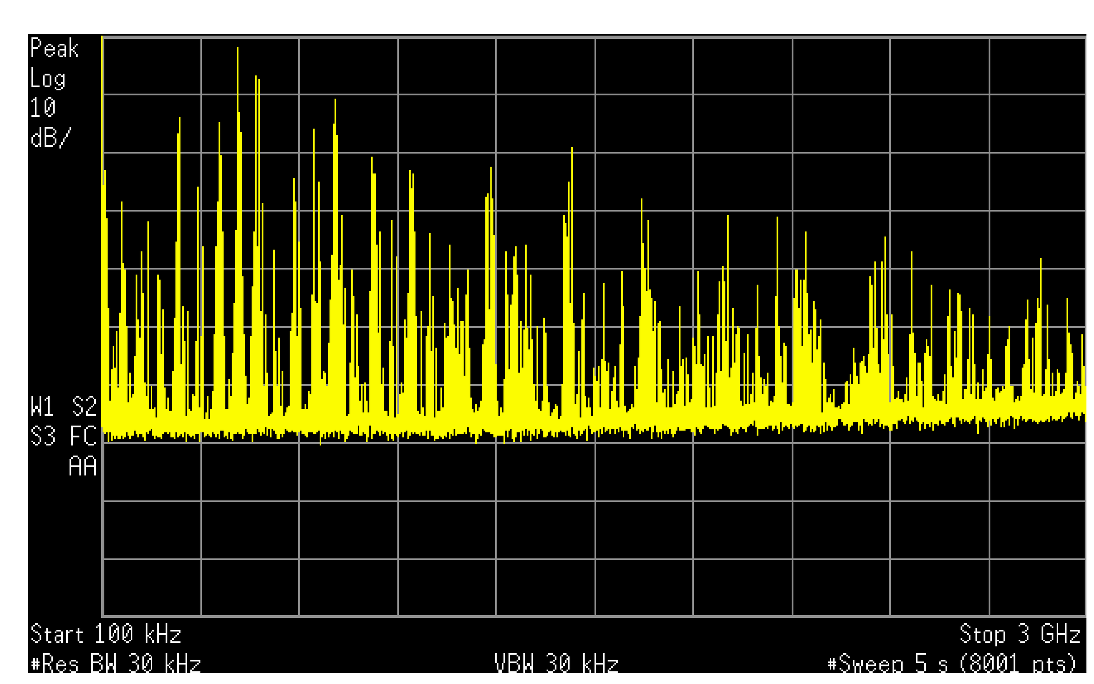

Figure 5: Typical power spectrum of the output signal of a low-voltage vircator using a spent electron beam at the exit from the interaction space of a traveling-wave tube

Conclusion

We performed the calculation of the efficiency of the investigated device. The calculation of the electronic efficiency value showed that it is 3% in the linear operation mode of the used TWT amplifier, 11% in the saturation mode, and 11.5% in the supersaturation mode. Thus, it is possible to determine the main parameters of the oscillator based on the spent electron beam from the TWT amplifier: accelerating voltage 4.2 kV, beam current 130 mA, output integrated power 60 W, electronic efficiency 11%, operating frequency band 1-3 GHz.

It should be noted that when applying a signal from an additional drift tube to the TWT input, an amplifier of noise-like oscillations can be implemented. The following results were obtained in a preliminary experiment: the integrated microwave output power was 130 W, the electronic efficiency was 23.8%, and the gain was 48 dB in the frequency band 1-3 GHz.

Thus, the studies showed that the use of a spent electron beam leads to the generation of broadband noise-like oscillations. Also, the above studies have shown that it is possible to implement various multifunctional (hybrid) systems in one device: a TWT monosignal amplifier and a broadband noise-like oscillator (low-voltage vircator).

Acknowledgment

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