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RADIOPHYSICS

Multivelocity Electron Beam as a Source of Microwave Oscillations in the Collector Region of a Traveling-Wave Tube

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Abstract—The generation of noise-like broadband oscillations in the collector system region of a traveling-wave tube (TWT) is investigated experimentally. Analysis of experimental results shows that noise-like broadband oscillations are generated in the collector region of the TWT due to the injection of a multivelocity electron beam into it. It is found that the maximal integrated power output from the collector region of the TWT is 12 W, and the maximal frequency and generation band are $f_{max} = 7$ GHz and $\Delta f/f \approx 0.8$, respectively. It is shown that a TWT with a collector–generator can simultaneously operate as an amplifier of an external signal and as a generator.

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INTRODUCTION

Electron-wave systems, in which a multivelocity electron beam with dense intensely oscillating space charge bunches is used as the active medium [1–3], are sources of broadband microwave radiation with a low and medium power levels and are of considerable interest for perspective applications in information–telecommunications systems [4, 5]. Such systems include vacuum microwave electronics devices in which structures of the virtual cathode (VC) type are formed [6–8].

The interest of researchers in the mechanisms and the methods for generating broadband noise-like signals in nonrelativistic electron beams in which conditions for forming dense space charge bunches are created remains undiminished [3, 6–10]. It is well known that analogous conditions are also created in the collector–recuperator of the O-type devices (e.g., traveling-wave tubes (TWTs) or klystrons), in which the spent electron beam from the interaction space gets to a multistep collector to which decelerating potentials are applied so that electrons precipitating on the steps of the collector give away their kinetic energy, thus increasing the technological efficiency of the device [11]. Some preliminary results of experiments on broadband noise-like oscillations detected in a three-stage collector–recuperator of a TWT were reported in [12], where experimental dependences of the generation efficiency and power on the potentials of the collector sections were obtained. Two regimes of TWT operation were considered, viz., the static regime in which no signal is fed to the TWT input for amplification (this regime is characterized by the absence of the spread in the electron velocities at the input of the collector–recuperator) and the dynamic regime in which a microwave signal is fed to the input of the TWT amplifier and recorded from the collector–generator output (in this case, the electron velocity spread at the input of the TWT collector–recuperator is quite large).

Since the TWT is a vacuum microelectronics device intended predominantly for amplifying various microwave signals, it would be interesting (for practical applications also) to analyze the effect of the input signal level on the characteristics of generation in the TWT collector region (i.e., to consider in greater detail the dynamic regime of TWT operation).

Thus, this study aims at a more detailed experimental investigation of the dynamic regime of TWT operation and at analysis of the effect of the input signal power on the characteristics of generation in the collector region. It would also be interesting to investigate the possibility of simultaneous operation of the TWT with a collector–generator as an amplifier of an external signal and as a generator.

1. EXPERIMENTAL

A multivelocity electron beam is fed to the collector–recuperator for the optimal deposition on the electrodes of the collector. Apart from recuperation, the collector is a generator of noise-like oscillations since the following conditions required for exciting such oscillations exist in it:

(i) the spent electron beam is a multivelocity beam;

(ii) secondary electrons are present;

(iii) reflected electrons also exist;

(iv) positive and negative ions are present.

Our experiments were carried out on the basis of a TWT with a three-stage collector whose second (mid-

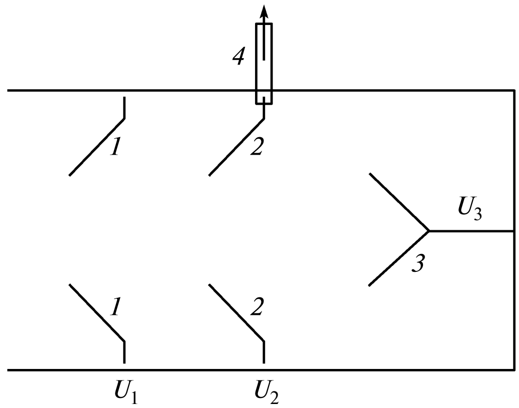

Fig. 1. Schematic diagram of the TWT collector region: *1*—first stage of the collector; *2*—second stage of the collector; *3*—third stage of the collector; *4*—broadband energy extraction; and U_1, U_2, and U_3 are the potentials applied to the first, second, and third stages of the collector, respectively.

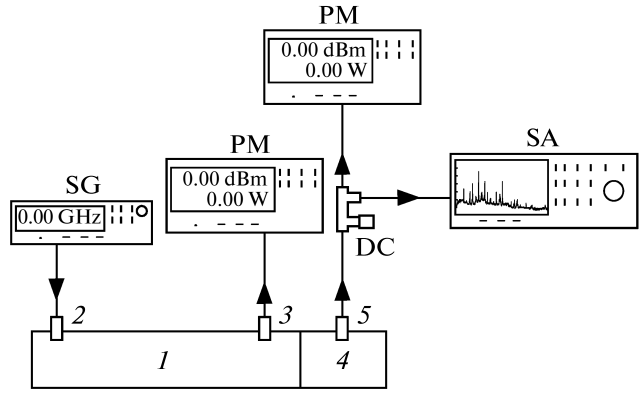

Fig. 2. Block diagram of the experimental setup: *1*—amplifying block of the TWT; *2*—microwave signal fed to the input of the amplifier block of the TWT; *3*—extraction of amplified microwave signal; *4*—TWT collector region; and *5*—extraction of microwave energy from the TWT collector region; SG stands for the signal generator; PM is the power meter; DC is the directional coupler; and SA is the spectrum analyzer.

dle) section served as a coupling loop for a broadband input of microwave energy (Fig. 1). The main parameters of the 10-cm TWT used in the experiments were as follows:

(i) accelerating voltage $U_0 = 4.2$ kV;

(ii) beam current $I_0 = 200$ mA;

(iii) output power $P_{out} = 180$ W;

(iv) electronic efficiency $\eta_e = 21\%$;

(v) technological efficiency $\eta_T = 40–45\%$;

(vi) frequency $f_0 = 1.7$ GHz.

To analyze the electron beam parameters and to measure the longitudinal and transverse electron velocities in the TWT collector region, we used a dismountable vacuum setup. The TWT collector region was connected with the chamber of the dismountable vacuum setup after which microwave test probes were introduced into the TWT collector region. The transverse electron velocities were measured using a movable split Faraday cylinder. The movable probe block included a diaphragm with a small (20 μm) aperture and halves of the Faraday cylinder. The longitudinal velocities were measured using the decelerating field. In this case, the movable probe included a diaphragm with a small (20 μm) aperture, a grid to which a negative (relative to the diaphragm) potential was applied, and a collector connected with the central conductor of the coaxial line. More detailed information on the measuring techniques is given in monograph [13].

The experimental technique for studying the dynamic regime of TWT operation was as follows. The block diagram of the experimental setup is shown in Fig. 2. Microwave signals with various power levels were fed to the input of the TWT under investigation, and the power levels of generated microwave radiation from the TWT output and from the collector region of the TWT were recorded simultaneously. The signal from the collector region was also fed to the spectrum analyzer through the directional coupler.

2. RESULTS

Let us now consider the results of the experiments. We first studied the characteristics of electron beams themselves at the input of the collector region. Main attention was paid, as noted in the Introduction, to the dynamic regime of TWT operation. Using the dismountable vacuum setup and the microwave probe, we succeeded in analyzing the dependence of the electron velocity spread on the normalized power level of the input signal. Power level P_{in} of the input signal was normalized to the power level of the input signal for which the power of the output TWT signal attains its maximal value and then saturation $(P_{in})_{max}$. Using such a normalization, we can find the relation between the optimal (for the output power) regime of TWT operation as an amplifier and as a generator. For ratio $P_{in}/(P_{in})_{max} = 1.0$, the TWT obviously operates as an amplifier in the most optimal regime as regards the output power of the amplified input signal. Let us find out how the electron beam characteristics and the parameters of generation in the TWT collector region behave for various values of $P_{in}/(P_{in})_{max}$.

Figure 3 shows the dependences of the electron velocity spectral width and of the first current harmonic I_1 at the collector input on the input power level. It can be seen that the level of grouping at the collector input attains its maximum for $P_{in}/(P_{in})_{max} = 0.8$ and sharply drops upon a further increase in the input signal power level. The electron velocity spread increases as $P_{in}/(P_{in})_{max}$ approaches 1.0 after which its value decreases.

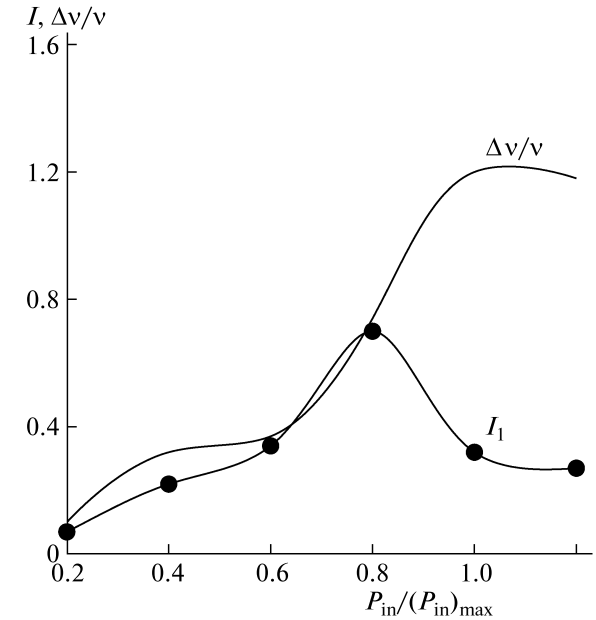

Fig. 3. Dependences of the electron velocity spectral width $\Delta v/v$ and first current harmonic I_1 at the collector input on the input signal level $P_{in}/(P_{in})_{max}$.

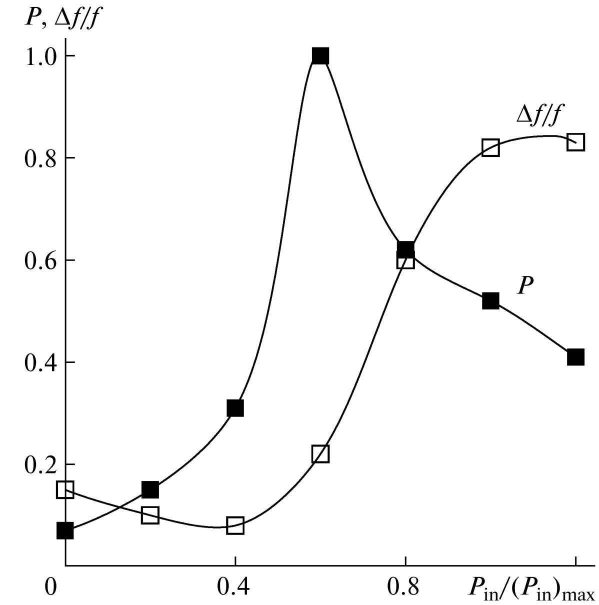

Fig. 4. Dependences of output power P_{out} and generation bandwidth $\Delta f/f$ in the TWT collector region on input signal level $P_{in}/(P_{in})_{max}$.

It was established in our experiments that the most optimal potentials of the collector stages (as regards the output power) lie in the following intervals: first-stage potential $U_1 = (0.80–0.65)U_0$ (U_0 is the accelerating voltage), second-stage potential $U_2 = (0.6–0.5)U_0$, and third-stage potential $U_3 = (0.3–0.1)U_0$. Our results are in good agreement with the data from [12].

Figure 4 shows the results of experiments on the dependence of the output power and frequency bands of generation of noise-like microwave oscillations recorded from the TWT collector region on the TWT input signal power. It can be seen that the power recorded in the TWT collector region attains its maximal value for $P_{in}/(P_{in})_{max} \approx 0.5–0.6$ and then decreases, and the bandwidth of generated frequencies increases thereby. Analyzing our results, we can conclude that the optimal (as regards the output power) regimes of TWT operation as the amplifier and as the generator are different. In other words, when the maximal output power from the TWT collector region is observed for a given value of the input signal power, the power of the TWT output signal has not yet attained its maximal value for the same input signal power. For the optimal regime of TWT operation as the amplifier (i.e., for $P_{in}/(P_{in})_{max} \approx 1.0$), the generation power that can be obtained from the TWT collector region attains up to 55–60% of its maximal possible value. On the other hand, the maximal spread in electron velocities at the input of the TWT collector part is observed just for $P_{in}/(P_{in})_{max} \approx 1.0$ (see Fig. 3). In such a multivelocity electron beam, favorable conditions for the intense formation of a large number of dense space charge bunches are created. According to the results of our experiments, the latter fact produces a positive effect in the generation band width in the TWT collector region (this dependence is also shown in Fig. 4).

Figure 5 shows the experimental results on the dependence of the maximal generation frequency on the integrated power level of the input signal. It can be

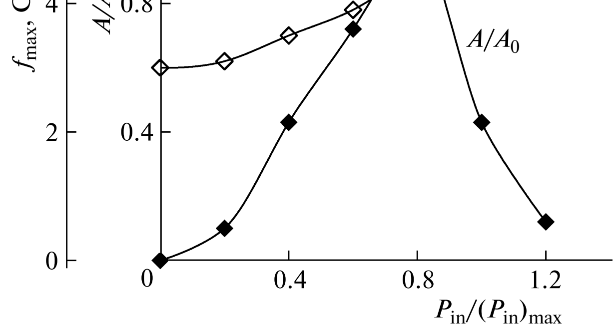

Fig. 5. Dependences of the maximal generation frequency f_{max} and signal amplitude at the TWT signal frequency (f_0 = 1.7 GHz) on the input signal level $P_{in}/(P_{in})_{max}$.

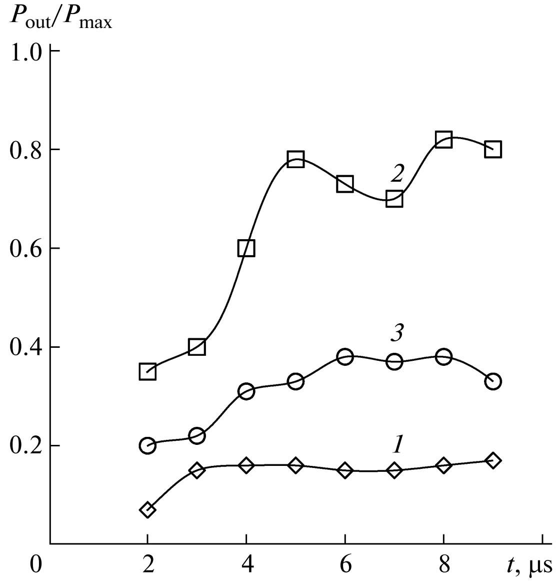

Fig. 6. Time dependences of the integrated output power P_{out} of generated noise-like oscillations in the modulating pulse of duration $\tau = 10$ μs. The curves in the figure are obtained for different levels of input signal $P_{in}/(P_{in})_{max}$: 0.3 (*1*), 0.5 (*2*), and 1.0 (*3*).

seen from the figure that maximal generation frequency f_{max} increases with the integrated power of the input signal. The same figure also contains information on the variation of the signal, obtained in our experiments at the TWT signal frequency $f_0 = 1.7$ GHz. The signal amplitude determined by residual grouping has a peak in the interval of $P_{in}/(P_{in})_{max} \approx 0.7–0.8$ and then sharply decreases due to a sharp decrease in first current harmonic I_1 in this region.

The presence of positive ions is responsible for a certain effect in the formation of space charge bunches and in keeping them from disintegration. It should be noted that the value of the residual gas pressure that was measured in our experiments did not exceed the interval (3–4) × 10^{-4} Torr. Figure 6 shows the time dependence of the integrated output power of noise-like oscillations being generated in a modulating pulse of duration $\tau = 10$ μs. Measurements were taken at the pulse plateau (i.e., the leading and trailing edges of the pulse were excluded from analysis). Experiments were performed for different power levels of the input signal. It can be seen that upon an increase in the pulse duration, the integrated output generation power increases. This result can be explained by the following two factors: vibrations of ions and their effect on the density and time of keeping of space charge bunches from breakup.

It should be noted that the maximal integrated output power from the TWT collector region amounts to 12 W, and the maximal frequency and generation bandwidth attain values of $f_{max} \approx 7$ GHz and $\Delta f/f \approx 0.8$, respectively. In the case of amplification of a noise-like signal by a TWT, the maximal integrated output power attains values of 110–130 W.

CONCLUSIONS

Thus, we have studied experimentally the generation of noise-like oscillations in the TWT collector region in the dynamic regime of the TWT operation. The optimal relations between the potentials that should be applied to the collector stages are derived. The optimal input power level for attaining the maximal bandwidth of the output radiation, maximal generation power, and the maximal frequency of generation recorded in the TWT collector region are determined. The effect of ions on the formation of space charge bunches in the collector region are considered. It is shown that a TWT with a collector–generator in the dynamic regime of operation is a hybrid electrovacuum device that makes it possible to amplify the input power by 30–40 dB and to generate simultaneously a microwave signal from the collector region. In other words, such a device can be used instead of two devices under certain conditions. The TWT with a collector–generator can be tuned either to the optimal regime of operation as an amplifier (in this case, the generation power from the collector region will not be maximal) or as a generator with the maximal possible value of the output power from the collector region; in this case, the power gain of the TWT will not attain the maximal possible value. Intermediate versions are naturally also possible. It should be noted that this device can also amplify noise-like signals fed to the amplifier input from the collector region. The integrated output power of a noise-like signal turns out to be 1.4–1.6 times lower than the mono signal amplification power. The discovered features of a TWT with a collector–generator can find practical application in radar systems and devices [5].

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REFERENCES

1. V. I. Afanas'ev, K. A. Lukin, and V. A. Rakityanskii, Radiotekh. Elektron. (Moscow) **2**, 115 (1997).
2. A. V. Pashchenko, et al., Tech. Phys. Lett. **34**, 1079 (2008).
3. Ju. A. Kalinin and A. M. Starodubov, Phys. Wave Phenom. **19**, 18 (2011).
4. A. S. Dmitriev and A. I. Panas, *Dynamical Chaos: New Information Media for Communication Systems* (Fizmatlit, Moscow, 2002).

5. N. N. Zalogin and V. V. Kislov, *Broadband Chaotic Signals in Radio Engineering and Information Systems* (Radiotekhnika, Moscow, 2006).
6. *Methods of Nonlinear Dynamics and Chaos Theory in Problems of Microwave Electronics*, Ed. by A. A. Kuraev, D. I. Trubetskov, A. A. Koronovskii, and A. E. Khramov (Fizmatlit, Moscow, 2009).
7. A. A. Rukhadze, S. D. Stolbetsov, and V. P. Tarakanov, Radiotekh. Elektron. (Moscow) **37**, 385 (1992).
8. A. E. Dubinov and V. D. Selemir, Radiotekh. Elektron. (Moscow) **47**, 645 (2002).
9. Yu. A. Kalinin and A. V. Starodubov, Tech. Phys. **55** 1788 (2010).
10. Yu. A. Kalinin, A. V. Starodubov, and A. V. Mushtakov, Tech. Phys. **56**, 838 (2011).
11. E. N. Egorov, Yu. A. Kalinin, Yu. I. Levin, D. I. Trubetskov, and A. E. Khramov, Izv. Ross. Akad. Nauk, Ser. Fiz. **69**, 1724 (2005).
12. Yu. A. Kalinin, A. V. Mushtakov, and A. E. Khramov, Tech. Phys. Lett. **33**, 655 (2007).
13. Yu. A. Kalinin and A. D. Essin, *Methods and Instruments of Physical Experiment in Vacuum Microwave Electronics* (Saratovsk. Gos. Univ., Saratov, 1991), Chap. 1.

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