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An Ultrabroadband Microwave Chaos Generator with Electron Feedback: On the Band of Generation, Statistical Properties of Signals, and Field of Application

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Abstract—An experimental investigation of the chaotic signals of a microwave generator with electron feedback (based on a virtual cathode) was carried out. It was found that microwave chaos generators with electron feedback are of ultraband generation. The statistical properties of the generated chaotic signals were shown. The perspective fields of application for the considered ultrabroadband chaos generators were given.

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INTRODUCTION

The use of chaotic signals as information media [1, 2] in radiolocation and communication systems is one of the thriving trends in the development of information and telecommunication systems. Chaotic signals, especially broadband and ultrabroadband ones, are no less required in solving electronic countermeasure problems [2]. A number of manufacturing processes [3] (such as dehydration, refining and improving petroleum and its products, organic synthesis using SHF energy absorption, medical problems, etc.) are also promising fields for using such signals. To generate such signals, the design and implementation of broadband chaotic sources operating within the range of high frequencies (HF) and superhigh frequencies (SHF) is necessary. Currently, the use of sources of broadband and ultrabroadband low- and mean-power chaotic signals based on new methods of chaotic signal generation is the most promising. For example, there are chaotic oscillation generators [1] that use a decelerating electric field to form bundles (current density compressions) within turbulized electron beam. Such devices are called low-voltage vircators with electron feedback [1].

DESCRIPTION OF THE EXPERIMENTAL INSTALLATION, I.E., GENERATOR MODEL

In this paper, the results of an experimental investigation of the oscillations in a broadband chaos generator that is based on the use of an intense electron beam with electron feedback are presented. To establish the mentioned electron feedback in such devices, the additional deceleration of electron flow due to the application of the negative potential to the collector is used. In Fig. 1, a scheme model of low-voltage vircator with electron feedback is presented. To record signal power spectra, a digital spectrum analyzer (Agilent Technologies ESA-E Series Spectrum Analyzer E4402B (9.1 kHz - 3.0 GHz)) was used. The registration of temporary the generated signals was carried out using real-time digital storage oscilloscopes (Agilent Technologies Infiniium DSO 81004B Series oscilloscopes and Tektronix DPO 72004 Digital Phosphor Oscilloscope Series). The power supply for the experimental sample of chaos generator with a virtual cathode and electron feedback was provided under pulse conditions. The pulse duration was $\tau = 10$ μs. The main control parameters were set as follows: accelerating voltage $U_0 = 2450$ V, collector voltage U_k changed in the interval from –250 to 2300 V, and beam current $I = 190$ mA. The technique used in conducting the experiment was as follows. For each change in electron beam deceleration coefficient, the power and temporary realization spectra were registered. The electron-beam deceleration coefficient was modified by varying the collector voltage U_k and accelerating voltage U_0.

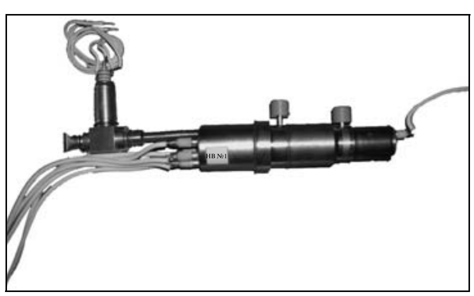

Fig. 1. Photograph of low-voltage vircator breadboard with electron feedback.

RESULTS OF THE EXPERIMENTAL RESEARCH

We consider the results of investigating the generated frequencies band depending on the control parameter, which is the electron beam deceleration coefficient K:

$$K = 1 - \frac{U_k}{U_0},$$

where U_k is the collector voltage and U_0 represents the accelerating voltage.

In Fig. 2, oscillation power spectra obtained from the screen of the E4402B Agilent Technologies digital spectrum analyzer are presented for the electron beam deceleration coefficient value $K = 0.2$ (Fig. 2a) and $K = 0.6$ (Fig. 2b). It can be seen that small values of the electron beam deceleration coefficient result in the generation of a mostly narrow spectrum (350 MHz) in the long-wave segment. As far as parameter K grows to 0.6, the oscillation frequency increases and the oscillation spectrum expands considerably. Moreover, the band of generated frequencies is more than two octaves in the case of a maximum integral power up to 3 W. The presence of generation in the long-wave segment of spectrum, represented by oscillations with frequencies less than 300 MHz, is of great interest. The precise boundaries of the superhigh frequency interval are hard to identify [4, 5], but this interval usually includes frequencies from 0.3 (or 0.03 [5]) to 30 GHz (or 3000 GHz [5]).

Thus, the considered source of ultrabroadband oscillations not only generates superhigh frequencies, but also provides oscillations in the superhigh frequency range, i.e., the long-wave segment of the superhigh frequency range (oscillations with frequencies less than 300 MHz). The presence of superhigh frequency oscillations may be explained as follows. The interaction space of the low-voltage vircator has a small volume where slow positive ions may be formed and accumulated. Residual gasses ionized by the electron beam in the process of the generator's operation may act as the source of positive ions. Moreover, positive ions may be also formed as a result of electrons getting to the surfaces of electrodes. Positive ions provide relaxation, transverse, and plasma oscillations [6].

Changes in the statistical properties of generated signals caused by changes in the electron beam deceleration coefficient seem to be interesting for research. To solve the above-mentioned problem, the distribution densities of the probability of the output signal's instantaneous amplitude value entry in the given interval under different values of K were plotted. Distribution plotting was carried out as follows: the maximum possible peak-to-peak amplitude of the caught signal A was determined in the digitized temporary realization. Using the results of the conducted experiments, the value $A = 0.04$ V was selected. Then the value A was divided into 200 similar intervals $\Delta A = 0.0002$ V. The

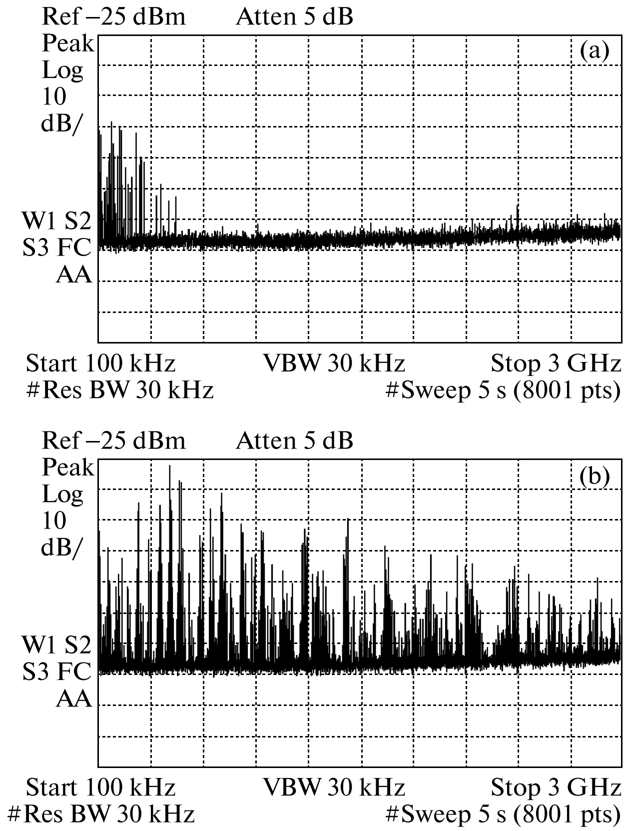

Fig. 2. Output signal power spectra from the designed generator model obtained under different values of the electron beam deceleration coefficient: $K = 0.2$ (a) and $K = 0.6$ (b).

number of entries of the value of the instantaneous signal amplitude was calculated for each interval ΔA, and these values were normalized with respect to total number of points of the temporary realization of the caught signal. As a result of the experimental research, it was found that the density distribution of the probability for values of the instantaneous signal amplitude is close to Gauss or normal distribution in case of small values of K. This result is presented in Fig. 3a. If the electron beam deceleration coefficient increases as shown in Figs. 3b–3d, the probability distribution becomes a double-peak. Thus, the change in electron beam deceleration coefficient leads to significant changes in the statistical parameters of the generated signals, in addition to changes in their spectral structure.

APPLICATION AREAS FOR THE OBTAINED RESULTS

The discovered peculiarities of the designed sources of ultrabroadband signals, namely the ultrabroad band of the generated frequencies (more than two octaves), and the possibility of controlling the statistical parameters of the generated signals may be applied first and foremost in the field of information

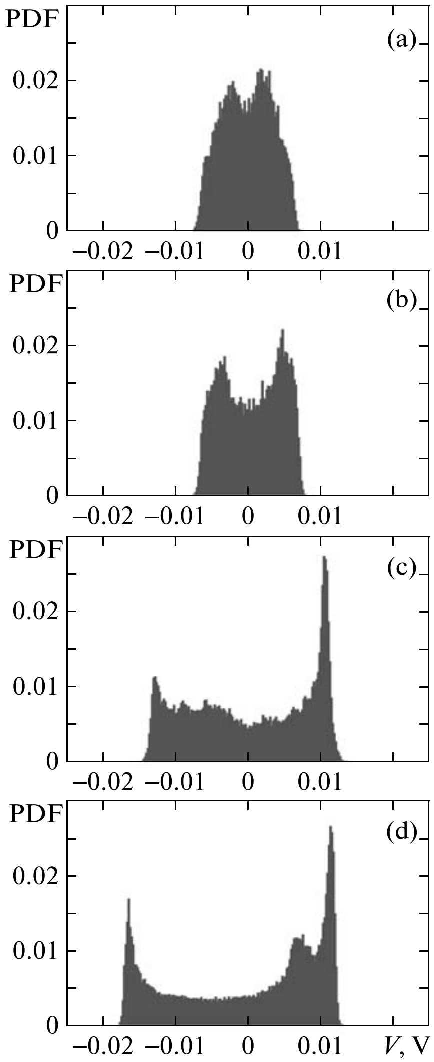

Fig. 3. The density distribution of the PDF probability of entry of the instantaneous signal amplitude value of the investigated experimental sample in the given value interval under different values of the electron-beam deceleration coefficient: $K = 0.49$ (a), $K = 0.63$ (b), $K = 0.94$ (c), and $K = 1.1$ (d).

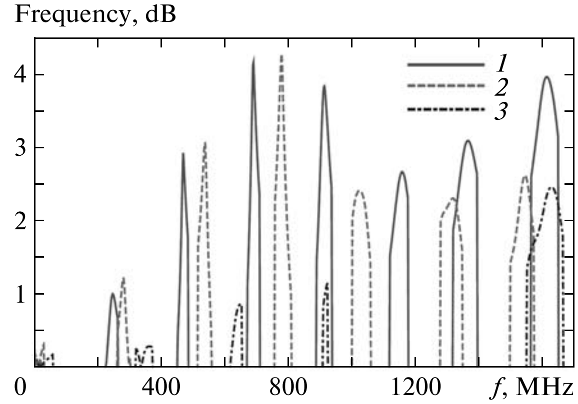

Fig. 4. Frequency bands of electromagnetic radiation absorption by water-in-oil emulsions with different weight contents of water. (*1*) water-in-oil emulsion with 50% water content, (*2*) emulsion with 40% water content, and (*3*) emulsion with 30% water content.

and telecommunication systems, such as data transmission systems based on broadband chaotic signals and systems of electronic countermeasures. Technologies of oil and water-in-oil emulsion treatment using microwave radiation may become another promising field for the developed ultrabroadband sources. Currently, several methods of oil treatment aimed at improving the physical and chemical parameters are known: the reduction of viscosity and volume content of water, salts, and other inclusions [7–10]. Methods of HF and SHF field action on water-in-oil emulsions form a separate group. Despite the fact that investigations in this field started in the 1980s [10–12], there is no explanation for the mechanism of field interaction with emulsion components now. The conducted experimental research showed that the most efficient ranges of absorption frequency of microwave radiation by water-in-oil emulsions belong to an area of from dozens of megahertz to a gigahertz, which correlates well with the data from scientific literature [7]. Investigations of the decrease in the microwave signal passing through the coaxial tank filled with water-in-oil emulsions with a different volume content of water were carried out using the E5062A SHF chain analyzer, Agilent Technologies. It was found that higher frequency ranges of the most efficient microwave radiation absorption correspond to water-in-oil emulsions with a lower volume of water. This result is presented in Fig. 4. The designed model of a vacuum generator with electron feedback provides coverage for all the efficient frequency absorption ranges found.

CONCLUSIONS

Thus, the designed model of a vacuum generator with electron feedback provides control over the statistical properties of generated signals in addition to control over the generation frequency band by the changing oscillation mode from narrowband (almost single-frequency) to ultrabroadband. Information and telecommunication systems, along with oil and water-in-oil emulsion industrial treatment technologies aimed at improving of the quality of produced oil through its dehydration and reduction of viscosity, may act as application areas for the designed model.

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