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The Noise Generation in One-Frequency IMPATT Diode Oscillator of Millimeter Wave Range on the Effect of Low-Frequency Harmonic Oscillation

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The investigation of effect of the low-frequency harmonic oscillation on the nourishment circuit of the 7 mm wave region IMPATT diode oscillator was continued. In first time it was shown, that excitement of noise and the maximum height-frequency noise spectrum extension at a low-frequency oscillation amplitude increasing are connected with a transitory decreasing of the diode current lower the start current of height-frequency generation in the IMPATT diode oscillator.

Keywords: effect, low-frequency harmonic oscillation, IMPATT diode oscillator, 7mm wave range, spectrum, amplitude detector.

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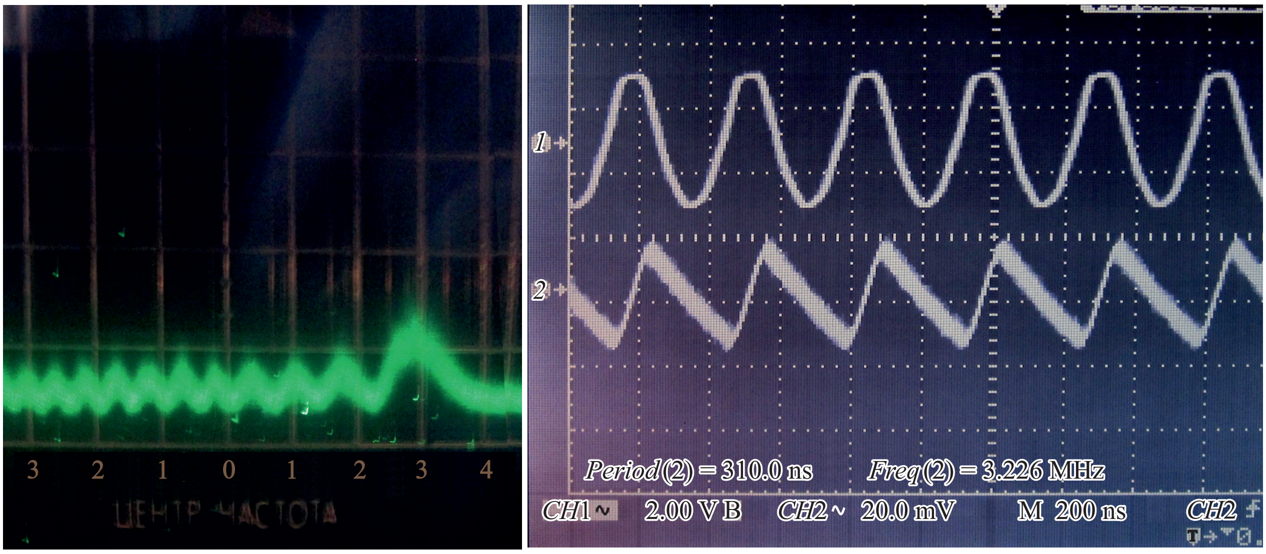
By now many different self-oscillating systems are investigated that demonstrate the chaotic dynamics. In the second half of the last century these were the self-oscillating systems based on electrovacuum tubes, such as, for example, travelling-wave tube [1–3] and backward-wave tube [4]. In the device implementing the principle of work described in [1], it was shown for the first time that in a generator composed of two 10-cm-band travelling-wave tubes closed into a ring, one of the tubes is responsible for the noise generation mode being working with a strong feedback in the non-linear mode, that has never been used before. For narrow-band systems, such as the backward-wave tube, to ensure excitation and non-linear interaction of several eigen frequencies of an electrodynamic system, this condition requires a greater exceedance of the operating current over the starting current.

Building upon this knowledge and the advancement of solid-state electronics, researchers constructed such systems based on various solid-state devices with simpler nonlinear characteristics (and, more importantly, devices that are simpler in use and do not require vacuum and high voltage). An insightful review of the evolution of a novel research trend in radiophysics (chaotic dynamics) is given in [5], where an entire section titled „Low-Frequency Periodic Influence on a Microwave Oscillator" is devoted to the issue of excitation of complex and chaotic oscillations in a self-oscillator based on a $n-p-n$ bipolar 2T982A-2 transistor under the influence of a regular signal with a frequency of 9 MHz and an amplitude of $1-5$ V from an external source. The obtained results suggest that the adjustment of amplitude and frequency of a regular low-frequency (LF) external signal provides ample opportunities for control over the microwave oscillation mode and qualitative characteristics of the oscillator signal.

However, the upper boundary of the operating frequency interval of solid-state devices (even transistors) has long remained within the centimeter range. Therefore, one was forced to construct solid-state oscillators of the millimeter range based on impact ionization avalanche transit-time (IMPATT) diodes and Gunn diodes and use multi-resonance waveguide-coaxial chambers to establish the chaotic oscillation mode (see, e.g., the description of an IMPATT oscillator in [6,7]).

The analysis of influence of a harmonic oscillation on a single-frequency transistor oscillator in [5] stimulated the author of the present study to examine the data reported in [8]. A previously unknown effect was observed in [8]: the spectrum of a single-frequency IMPATT oscillator of the 3-cm wavelength range was transformed into a continuous noise signal spectrum under the influence of a harmonic oscillation with a frequency of 150 kHz and 1 MHz on its feed circuit. However, the cause of this was not revealed in [8]. The same phenomenon has recently been examined in detail in [9], where changes in the radio-frequency (RF) signal spectrum of an IMPATT oscillator of the 7-mm range induced by a harmonic oscillation with a frequency of 3 MHz and a varying amplitude in the IMPATT feed circuit were studied. It was demonstrated in [9] that the optimum conditions for noise generation are established when the operating point is set near the start current of single-frequency oscillation in the IMPATT oscillator, and hypothesis regarding the cause of the observed transformation of the single-frequency 7-mm signal spectrum was made. However, the cause of these spectrum changes in the *a* *b*



Characteristics of the mode with a continuous microwave oscillation spectrum in the IMPATT oscillator under an LF influence at a diode current of 41 mA. *a* — Microwave signal spectrum (the scale is 20 MHz/div); *b* — waveforms: of the LF influencing signal at the diode (beam *1*, the amplitude is ~ 2 V) and the detector signal (beam *2*, the amplitude is ~ 20 mV).

temporal domain needed to be identified in order to verify this hypothesis.

No publicly available studies similar to [8,9] were found in foreign literature published in the 21st century. Studies (both theoretical [10] and experimental [11] ones published a long time ago) are focused mostly on the issue of potential suppression of the noise component in IMPATT oscillators.

The authors of [12] were the first to examine the process of chaotization of oscillations in an IMPATT oscillator under the influence of LF (3 MHz) oscillations both in spectral [9] and temporal domains. The oscilloscope record of the detector signal in microwave noise generation had the shape of a non-isosceles triangle („sawtooth"). No signals were identified at the short side of this „sawtooth,"while microwave noise was observed within the entire span of the long side. It was found in high-resolution studies that this noise is formed of very short pulses with a random amplitude and random interpulse intervals. As was demonstrated in [12], „it may be taken as a rough estimate that $\sim 10-12$ pulses of various amplitude and different interpulse intervals distributed randomly are generated within a single 20 ns division. The frequency of these RF noise oscillations is $\sim 0.5-0.6$ GHz."It was hypothesized in [12] that RF noise oscillations in a single-frequency IMPATT oscillator of the 7-mm range are excited due to a transitory reduction in IMPATT current, which drops below the start current of single-frequency oscillation excitation in this oscillator. It was also mentioned in [12] that his assumption may be verified or proven wrong only if one observes variations of the RF oscillation modulation pattern and the amplitude of influencing LF oscillations simultaneously. Note that a multi-resonance waveguide-coaxial chamber [6,7], which was designed specifically for observation of chaotic oscillations, was used in experiments with this IMPATT oscillator.

The aim of the present study is to verify or refute the conclusions made in [12] by examining the evolution of chaotization of oscillations in an IMPATT oscillator of the 7-mm range with its feed circuit subjected to the influence of harmonic low-frequency (3 MHz) oscillations through simultaneous observations of variations of the microwave signal spectrum, the modulation pattern, and the amplitude of influencing LF oscillations.

The influence of an external harmonic low-frequency (3 MHz) oscillation on an IMPATT oscillator of the 7-mm range was studied experimentally with simultaneous recording of waveforms from the detector and waveforms of the influencing low-frequency regular oscillation. In addition, it was decided to exclude the possible influence of self-excitation of microwave noise, which may occur in a waveguide-coaxial chamber [6,7] at higher diode operating currents. This is the reason why a waveguide chamber used in experiments had the following properties: chaotic oscillations were not excited in it at diode operating currents ranging from the start current (40 mA) to the maximum current in continuous operation (100 mA). At a diode current of 41 mA, an oscillation frequency of 40.22 GHz, and an increasing LF oscillation amplitude, an S4-60 spectrum analyzer measured the microwave signal spectrum, while waveforms of the input LF influencing signal at the diode and the amplitude detector signal were recorded simultaneously with an ASK-2104 dual-channel oscilloscope.

As in [9,12], the single-frequency microwave signal spectrum transformed as the amplitude of LF oscillations increased: it turned first into a multi-frequency spectrum and then into a continuous spectrum of a microwave noise signal. The detector signal transformed accordingly. It followed the sinusoidal nature of the LF oscillation at first (at a small LF oscillation amplitude), but the modulation pattern changed as the oscillation amplitude increased. The pattern became triangular (specifically, assumed the shape of a non-isosceles triangle) already when a multi-frequency microwave signal was generated [13]. As it turned out, the signal at the detector output for the studied IMPATT oscillator has a fairly small amplitude and may be observed only when the detector section is introduced into the main microwave path instead of a matched load. A D3-36A tunable attenuator, which is also mounted in the microwave path between the oscillator output and the detector, should be set to zero attenuation in this case. However, the detector signal was so weak at the first stage of generation of a noise microwave signal, which was already visualized by the S4-60 spectrum analyzer, that it could not be registered even at zero attenuation of D3-36A. The signal was picked up at the limit of oscilloscope sensitivity only when the amplitude of the input LF oscillation at the diode reached ~ 1 V. Therefore, we could not identify any features of the detector signal except for the fact that sinusoidal modulation at the diode was transformed into non-isosceles triangular modulation. A further increase in the amplitude of the input LF oscillation provides an opportunity to reveal these features, which are presented in the figure, *a*, *b*..

Panel *a* shows the microwave signal spectrum on a scale of 20 MHz/div, while panel *b* presents the waveforms of the influencing signal at the diode (beam *1*, the amplitude is ~ 2 V) and the detector signal (beam *2*, the amplitude is ~ 20 mV).

It can be seen that the width of the microwave signal spectrum is on the order of 160 MHz. This is the maximum noise spectrum width achieved at the peak of gradual spectrum broadening with an increase in the amplitude of the influencing LF oscillation. The input signal at the diode (see panel *b*, beam *1*) is almost a sinusoidal wave. The detector signal (see panel *b*, beam *2*) has the shape of a non-isosceles triangle. In addition, just as in [12], RF noise oscillations in the form of pulses with a random amplitude and a random repetition rate should be observed at the long side of this triangle. They emerge at random throughout the entire span of the long side of triangular modulation, but cannot be resolved at the set timebase (which was chosen specifically to fulfill the objective). A causal connection between two processes may be established by comparing the waveforms and timing marks in two channels of the oscilloscope.

Examining beam *2* in panel *b*, one sees that the microwave noise signal generation at the long side of triangular modulation ceases when the positive amplitude of the influencing LF harmonic oscillation reaches a value at which the decreasing diode current drops below the start current. This agrees with the assertion made in [12]. The process of noise generation stops if the positive influencing voltage increases further. Noise reappears again only when the decreasing positive amplitude of the influencing voltage drops to a level corresponding to the start current. The following conclusions may be drawn from the experimental results.

The hypothesis regarding the pulse nature of noise generation [9] has already been verified in full in [12]. The conclusions made in [12] regarding the cause of emergence of non-isosceles triangular modulation in oscilloscope records of the noise signal from the detector were also found to be correct. Crucially, the experimental data verified the conclusion [12] that the interruption of oscillation and its re-excitation under new initial conditions are the factors leading to generation of microwave noise under the influence of a low-frequency harmonic oscillation on the feed circuit of an IMPATT oscillator. This results in loss of correlation between a microwave oscillation at the „sawtooth“ minimum and the emergence of an oscillation at the maximum. This is the factor that should govern the switching between multi-frequency microwave oscillation and the microwave noise generation mode.

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Conflict of interest

The author declares that he has no conflict of interest.

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