DYNAMIC CHAOS IN IRE: THE EMERGENCE AND DEVELOPMENT

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Abstract. **A review of the work on microwave electronics in the** Institute of Radioengineering and Electronics **over the past 60 years is presented. The discovery in 1962 of the generation in a 3-cm autogenerator (a plasma-electron beam in a pulsed magnetic field) of broadband noise oscillations is described. The work on increasing the generated noise power and efficient matching of the generator with the external path, which led to the creation of a noise generator - a solid-state oscillator of chaotic oscillations with a large number of degrees of freedom, as well as work on creating a generator of masking noise of computers. The work on noise radar, on the creation of interference stations for various types of radar stations - counteraction to air defense and anti-missile systems, was noted. The work on information aspects of the theory of dynamic chaos, on the creation of algorithms for generating pseudo-random sequences for digital communication and navigation up to pixel-by-pixel image encryption was touched upon. The characteristic feature of the works is the introduction of the results obtained into technical developments.**

Keywords: **microwave electronics, noise generators, noise location, noise stations**

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Content

1. INTRODUCTION

Having a relatively small experience in writing memoirs, the author wants in advance to apologize to the readers in some subjectivity of the presentation of this material. Events that occurred 50 years ago, it is very difficult to describe without distortions caused by age-related changes in memory. Moreover, many participants in these events are no longer alive, while others with memory are even worse than the author. Most of the work carried out in those days had this or that classification of secrecy. Reports and other documents on them either lie in some archives, or simply destroyed. Therefore, in the absence of documentary materials, the reader can only trust the author. The author still hopes that most of the facts in this material are presented more or less reliably. The author also hopes that the following work will not cause any resentment to the witnesses of those events and the relatives of the Institute's employees who have already passed out of life. Since the author is in the singular (without co-authors), the presentation of the material will go from the first person.

The possibility of generating chaotic oscillations in self-sustained oscillating systems by a small number of degrees of freedom was discovered in the Department of Microwave Electronics of the Institute of Nuclear Physics of the Academy of Sciences of the USSR in the fall of 1962, as is usually the case, by accident. Therefore, it is expedient to begin the exposition from earlier moments. Let's start with 1957, when the author, after completing the third year of the Moscow Institute of Physics and

Technology, was sent to practice at the Institute of Nuclear Physics of the USSR Academy of Sciences.

2. BEGINNING

Actually, I got to IRE in June 1957 after finishing the third course of MIPT for practice. This practice lasted several days a week until the defense of the thesis. Therefore, becoming a junior researcher, I could already imagine what the department of ultrahigh-frequency electronics is headed by (on a voluntary basis), Nikolai Dmitrievich Devyatkov.

In those years it was believed that the development of microwave electronics had to proceed along an evolutionary path. All attention was paid to mastering the millimeter range. Before the jump, the optical range remained several years. In those years, difficulties in the development of amplifiers and generators of the millimeter range with the help of traditional microwave electronics such as TWT, BWO, magnetrons, etc. became apparent. Dimensions of the slowing structures with decreasing wavelength sharply decreased. The "sagging" of the longitudinal component of the electric field with which the electron beam interacted also increased. It became obvious that traditional methods are incapable of generating and amplifying powerful electromagnetic oscillations at frequencies of the order of 100 GHz. Therefore, an intensive search for new methods of generation and amplification in the millimeter range was carried out.

In IRE these works developed in two main directions. First, a powerful experimental setup was created, based on a linear electron accelerator to energies of the order of 3 MeV. It was assumed with the help of this accelerator to form and accelerate to near-light speed compact bunches of electrons and "flare" them in the so-called Motz undulator - a periodic system of transverse magnetic fields. We also considered the possibility of emission of electron bunches due to the Cherenkov effect in waveguides partially filled with a dielectric. This work, conducted on the instructions of the legislative organs, ended with a negative result. The grouping of the electron beam at the accelerator output was clearly insufficient. In addition, the magnetron frequency of 10 cm-range, providing electromagnetic oscillations for electron acceleration, was very unstable. As a result, instead of the expected kilowatts of radiated power in the millimeter range, milliwatts of noise oscillations were measured in this range. The project was clearly ahead of its time.

Secondly, the department began work on the feasibility of an electron-ion plasma pierced by a fast electron beam to amplify and generate electromagnetic waves. At that time, plasma was in special esteem in connection with the report of Academician I.V. Kurchatov in England during the visit there NS. Khrushchev. The investigation of plasma properties was mainly concerned with controlled thermonuclear reactions. However, the more we learned about the properties of the plasma, the more it was used for other uses. In particular, the rocket launchers started talking about plasma engines and simulating the entry of bodies into the atmosphere at hypersonic speeds, and electronics engineers about amplification and generation of electromagnetic oscillations using a plasma-electron beam system. The well-known theoretical physicist from the Kharkov Institute of Physics and Technology, Yakov Borisovich Feinberg, showed the possibility of increasing the degree of electron clustering in a fast electron beam penetrating an electron-ion plasma. In Kharkov and in IRE conducted experiments that confirm the possibility of amplification of microwave oscillations in this way.

My thesis work consisted in an experimental study of the possibilities of amplifying with a plasma-beam system signals in the 8 mm-range. The initial grouping of electrons was carried out using a resonator cut from a reflective klystron. Then the beam passed through the gas discharge region and in the second resonator provided excitation of electromagnetic oscillations. From the autobiographical book of Academician ND Devyatkov "Memoirs", published in 1998 by the publishing house of the journal "Radio Engineering", I learned that the results of the work were reported at one of the conferences in the US, of course, without my name among the authors.

In IRE in the mid-fifties in the laboratory Z.S. Chernova after graduating from Moscow State University appeared a young specialist V.Ya. Kislov. His father, Yakov Vasilievich Kislov, was one of Kurchatov's assistants during the creation of the atomic bomb, and many of his friends in the university were assigned to the IAE in the plasma units. Kislov conducted a number of theoretical studies that showed that slow electromagnetic waves having a longitudinal component of the electric field can propagate in a certain frequency range from a plasma cylinder placed in a longitudinal magnetic field. In this case, unlike the spiral or other metal retardation structures, said component has a maximum on the axis of the cylinder. This means that the interaction of the plasma slowing structure with the electron beam must be much more efficient than in the case of traditional, vacuum TWT and BWT. The results obtained by V.Ya. Kislov, confirmed by the experiment, led to the fact that N.D. Devyatkov and Z.S. Chernov transferred a significant part of the department's staff to plasma topics.

In the fall of 1962, I enrolled in the correspondence IEP postgraduate course. The scientific adviser was Nikolay Dmitrievich himself, assuming complete independence in carrying out the work itself and discussing the results at the final stage. Theme of the work is the generation of electromagnetic oscillations in the millimeter range using a plasma-electron beam system.

According to theoretical conclusions V.Ya. Kislova, the generation of electromagnetic oscillations in the plasma counterpart of a backward-wave tube takes place in the range located between the plasma frequency determined by the plasma concentration or the electron cyclotron frequency determined by the magnitude of the longitudinal magnetic field and the so-called upper hybrid frequency (the square root of the sum of the squares of these frequencies). Calculations have shown that for experiments with millimeter waves, significant magnetic fields are required. Since there were no opportunities to purchase or manufacture solenoids providing the required fields, and especially power supplies of such solenoids at that time, the institute decided to create a device with pulsed magnetic fields. Such an installation was started. But in order not to lose time, work began on the installation with a solenoid that allows investigation of generation in a three-centimeter range of wavelengths.

3. BIRTH OF CHAOS

A glass vacuum system with continuous pumping was created. The device with which experiments were conducted consisted of a glass tube, on one side of which an electron injector with an oxide cathode was placed, and on the other a metal collector of electrons. The tube was placed on the axis of the solenoid. Plasma in the system was created by a fast (about one-one and a half kilovolts) electron beam in an atmosphere of mercury vapor. As it turned out in the course of the experiments, a high plasma concentration was obtained as a result of the microwave discharge that occurs when intense oscillations are generated in the plasma counterpart of a backward-wave tube.

By selecting the pressure of the residual gases, the current and voltage of the electron beam and the magnitude of the magnetic field, it was possible to quickly generate electromagnetic waves in the 3 cm band with the emission of these waves into space or into a waveguide. Measurements of the plasma concentration and the magnitude of the magnetic field confirmed the fact that a plasma BWO is operating. When the measurements of the spectrum of excited oscillations began, everything became incomprehensible. The screen of the spectrum analyzer IV-66 was clogged with intensive noises. We decided that we were aiming at an intermediate frequency amplifier and began to measure the spectrum with a tunable filter on the microwave cavity. And then the continuum. They remembered that plasma sources of noise work in microwave radiometers. But their spectral noise power density (SPMS) is defined as 65 kT. This corresponds to 2.6 10-13 W / MHz. At us SPMSH on 8 orders, i.e. in 100 million times more! Those. it's still generation.

All the surrounding staff could not say anything about this. At that time, the concept of the self-oscillator was for some reason associated with the Van der Pol generator and the corresponding second-order differential equation, which had only periodic solutions. All were in captivity of the phase plane, where the trajectories of motion could not in principle intersect. I think that the results of these experiments at that time could be appreciated and understood by a well-known expert in the theory of oscillations GS. Gorelik is the author of the famous book "Oscillations and Waves". He lectured us at MIPT and was the head of one of the laboratories at IRE. He told us that one can not fixate on the generator of Van der Pol, that self-oscillating systems can be much more complicated. But Gabriel Semyonovich a couple of years before he died under an electric train at Dolgoprudnaya station.

Detection of the generation of broadband noise oscillations and the impossibility of a clear explanation of this effect caused me the desire to tell this to all familiar people working in this field of technology.

The applied value of the detected effect was explained to me by two people. The first one is one of the employees of the Saratov Research Institute "Volna", trained at this time in the IRE. He popularly explained to me that many people in their institute are struggling to create broadband noise sources in the microwave range. The goal is to interfere with modern radar stations. These developments are mostly ineffective, because they are based on the modulation principle. He advised hastily to submit a closed application for the invention of a method for generating broadband noise oscillations and a device for its implementation.

The second person who showed great interest in the work was Captain Trofimovich (I do not remember his name and patronymic). At a seminar where I reported about a noise generator, he took me aside and advised me to stop open speeches on this topic. Trofimovich worked in the Central Research Institute of the Navy, located at that time in the Alexander Palace in Tsarskoye Selo.

The application for the invention (authors NN Zalogin and V. Ya. Kislov) was filed and registered in April 1963 [1]. It went pretty fast. Employees of the Committee for Discoveries and Inventions (then he was in the Greater Cherkassy Lane) recognized her as a pioneer and helped formulate everything according to the current standards. The authors received copyright certificates and 20 rubles of compensation. It should be noted that the material of the application was already formulated at a fairly modern level. In the application it was stated that chaotic oscillations arise due to the simultaneous excitation in the system of several frequencies that are not equidistant in frequency and the generation on the nonlinearity of the plasma of the set of combinational frequencies.

By the way, in the same 1963 (in March), a theoretical article by E. Lorenz "Deterministic non-periodic flow" was published in the American journal devoted to atmospheric physics [2]. In fact, in this paper we have presented differential equations corresponding to the simplest oscillator of chaotic oscillations. Nizhny Novgorod radiophysicists came across this work only in the second half of the 70s. The article was translated into Russian in 1981.

Thanks to the Central Research Institute of the Navy in the IRE, a research project "Sablja" was commissioned by the Legislative Bodies to increase the spectral power density of the generated noise signal and create a sealed mockup of the generator. The setting up of such work forced the management of the department to involve a fairly large team in its execution. It was also clear that the theme of my thesis should be changed.

4. NOISEOTRON

When performing the theme "Saber" there were problems associated with increasing the generated noise power and effectively matching the generator with an external path. It was decided to fill the plasma with the working space of a powerful TWT plasma in the hope that noisy oscillations would arise in the system, not on inverses, but on direct waves. To provide a positive feedback, necessary for self-excitation of the system, it was assumed that some of the power from the output of the powerful TWT would branch off and be directed to the input. Since the amplification factor of the powerful TWT was small, it was decided to turn on the feedback loop via the low-power TWT attenuator. Possible modes of generation instructed to check the young specialist - EA. Massine, a graduate of MEPhI, better known in those days as a master of sports in a handball. Yevgeny Anatolyevich took two standard 10 cm range lamps, an attenuator and started experiments. The scheme of switching on two UV-34 TWTs looked as shown in **Fig. 1**. The first TWT was a broadband amplifier and operated in a linear mode. Its output through a directional coupler was fed to a spectrum analyzer. The branched power part through the adjustable attenuator was fed to the second TWT. Its

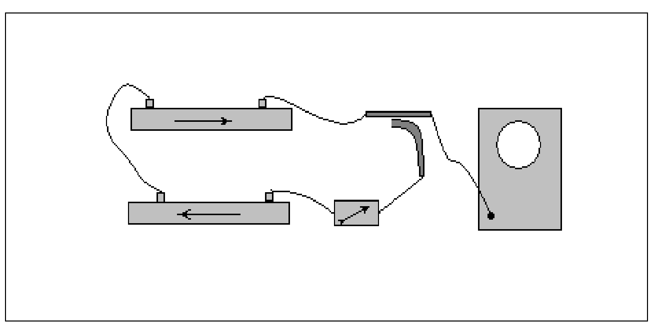

Fig. 1. *Scheme of the first noisetron.*

output came to the input of the first TWT, closing the feedback loop.

There was a new shock for everyone. It turned out that such a system in some modes perfectly noises without any plasma.

Noises in such a system arose when the second TWT was overloaded by the microwave signal at the input and operated not as an amplifier, but as an attenuator with strong nonlinear distortions of the signal.

The experiment was carried out as follows. The attenuator was output to the largest attenuation - no feedback. Further, the power supply of the TWT was switched on, and the attenuation in the feedback loop gradually began to decrease. On the spectrum analyzer it was seen that there is a regenerative enhancement of the intrinsic noise of the TWT with spectral density maxima at the natural frequencies of the system. At a certain damping value, self-excitation conditions were fulfilled, and generation occurred at one of the natural frequencies. The amplitude of the oscillations with a further decrease in the damping grew, reached a maximum, and then its value began to fall. At some point, the amplitude self-modulation of the generated oscillations began. The auto-modulation period corresponded to the double bypass time of the feedback signal. It was visible on the spectrum analyzer. The modulation spectrum was then complicated by the appearance of harmonics and subharmonics of the modulation frequency. The complication occurred according to the law of 2-4-8 (rarely 16). For a finite number of doubling of self-modulation cycles, a continual component appears in the spectrum. Unexpectedly, with a further decrease in the decoupling in the feedback loop, the generated oscillations acquired the character of broadband noise with maxima of the SPMSH at the natural frequencies of the system. Sometimes there were additional maxima in the interval between own frequencies, indicating that the noise process is also covered by auto-modulation.

The observed effects caused a storm of discussions among the laboratory staff. Various versions of the interpretation of the results obtained were suggested. The idea that plasma is the main "culprit" of chaos of oscillations was finally rejected. A variant of the amplitude-dependent additional phase advance in the TWT is proposed. But then he did not cause much enthusiasm. It was clear only that the reason for the chaos is the behavior of the TWT - the nonlinear element. And everything turned out well with reduced electron beam currents, when the nonlinearity of the electron grouping is manifested more because of the small space charge.

The registration of the results obtained went according to the same scenario. Closed application for the invention and the possibility of publication in special periodicals. The application for the broadband noise generator-noiseotron, was submitted from three authors, employees of the department E.V. Bogdanova, V.Ya. Kislova and E.A. Massine in 1966 year. When considering the application, an American patent was discovered. It describes the source of noise on one TWT with external feedback. In VINITI, however, found significant differences in the structure of the generator and, especially, in the interpretation of its functioning. The author's certificate was received. In the open press it was published only in 1979 [3].

Among the developers of electronic devices, V.Ya. Kislov about the noise generator at a closed seminar in one of the Institute of the Ministry of Economic Development of the USSR caused a healthy recovery. I was told that two employees of the Saratov Research Institute "Volna" suddenly ran off with anxiety from the seminar. It turned out that they took a taxi to Bykovo airport and thence by plane to Saratov to urgently place and apply for some modification of the noise. Indeed, the possibility of obtaining high-level broadband noises without the development of special devices that require a significant change in the traditional technology of electrovacuum devices, was very attractive for both customers and electronic equipment developers.

It should be noted that it was at this time (the end of the sixties) that broad interest in the creation of broadband noise sources in the microwave band was of great interest from organizations responsible for countering the technical means of foreign intelligence. Thanks to this interest, decent funding was provided for research into the processes occurring in the noise generator and the development of samples of broadband noise generators.

The busyness with the noise-related themes led the laboratory to curtail research and development on plasma noise generators, which, due to technological difficulties, did not promise a quick access to industrial designs. All work on plasma was transferred to the Fryazino part of the Institute, where Igor Fiodorovich Kharchenko from the Kharkov Institute of Physics and Technology appeared as the head of the laboratory №169. I managed to successfully defend my thesis on a plasma noise generator in early 1967. Nikolai Dmitrievich read the thesis before the binding and said that he had enjoyed reading the material and had no comments. After the defense, I immediately took up the noise drive theme.

Means of masking radiation, as always, were badly needed "yesterday". Since the OCD at the branch institute lasted more than three years, it came to the point that officers from the military units responsible for radio technical disguise were attached to the laboratory. Together, they created and established prototypes of noise drivers for temporary operation at facilities.

It is interesting that the creation and implementation of noise engines did not change the attitude of leading specialists of the Institute on the theory of oscillations to this topic. So, on the defense of the candidate's thesis EA. Myasin Academician Yu.B. Kobzarev said that he had many doubts about this work, but since the results are very useful for the defense industry, he will vote in favor. Professor A.E. Basharinov said that in generators with delayed feedback, on the contrary, fluctuations should have a higher degree of stability. Academician V.A. Kotelnikov wrote on one of the reports on the noise meter on the title page: "The work makes a strange impression." This remark could be translated as follows: "something is wrong here, because it can not be so." All open publications on noiseotron were banned not only because of the defensive significance of these works, but because they smell pseudoscience.

A great interest in the topic from the customers side and the associated concentration of human and instrumental resources of the laboratory made it possible to begin a systematic investigation of the processes leading to chaotization of oscillations in the noise generator. It is obvious that random processes are mathematically described only by parameters that are the result of averaging over time or a set of implementations. Simulation of direct generation is connected with a huge array of calculations. At that time, almost all academic electronic computers were located in the computer center of the USSR Academy of Sciences on Vavilov Street, access to it was carried out through a special laboratory, which was commanded by F.F. Dobryakova. At our disposal there were only electromechanical calculators "Mercedes" and "Rheinmetall", as well as a hand calculator "Felix". Therefore, it was decided to turn to experiment, since the meters of currents, voltages, power, spectrum analyzers were at hand. The construction of theoretical models was supposed to be carried out already on the basis of experimental data.

The experiments began with a detailed investigation of the characteristics of the TWT - a nonlinear element responsible for the chaotization of vibrations. The amplitude and phase characteristics of the lamp were studied for large input signals. Basically, of course, amplitude, as more accessible for measurements. In **Fig. 2** shows a typical amplitude characteristic of the UV-34 TWT in the low-current regime. The characteristic is normalized to the maximum output amplitude. In the same figure, we give variants of the approximation of the amplitude characteristic. As can be seen from the figure, the approximation using the function is very close to the real amplitude characteristic. However, it is hopeless to calculate the sequence of iterations on an arithmometer hopelessly long - you have to work with tables or resort to graphical mapping. The so-called logistic map differs from the experimental curve, but it must be calculated on an arithmometer without using tables.

It can be seen from the figure that with an increase in the amplitude of the input signal, the amplitude of the output signal first grows, then the saturation region follows, followed by a sharp drop in the output

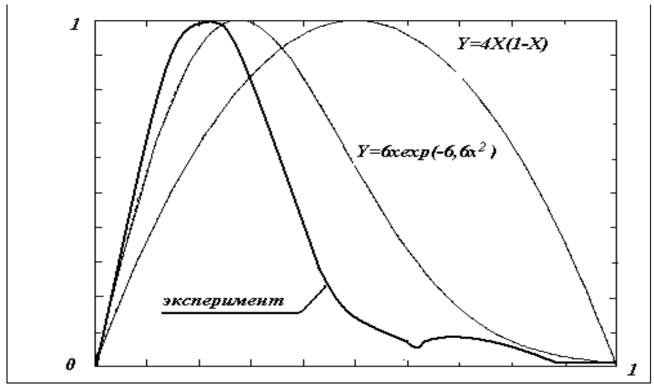

Fig. 2. *Amplitude characteristic of TWT and its approximations.*

amplitude with an increase in the input amplitude. Naturally, the assumption arose that for large values of the transmission coefficient of the feedback circuit, the generation with a constant amplitude loses its stability and the buildup of amplitude self-modulation begins. The experiment said the same thing. According to the measurements made, after the auto-modulation occurred in the two-cycle cycle, the auto-modulation period doubled. There were 3-4 acts of doubling, after which there was modulation chaos - a harmonic carrier, modulated in amplitude by noise. It required a computational confirmation that the development of automodulation could lead to chaos without any additional conditions, for example, fluctuations in the analog system. An alternative was a constant increase in the period of the cycle of amplitude changes.

The calculations were assigned to the chief theoretician of the laboratory, Vsevolod Nikolaevich Danilov. The whole room shook with the sounds produced by the electromechanical calculator. She was suffering not only from a laboratory assistant, who directly performed the calculations, but also the entire laboratory. This lasted for months. It turned out that calculations on an arithmometer inevitably led to cycles due to the finite digit capacity and the associated rounding of numbers. They began to look at the stability of cycles, introducing small perturbations. And here there were problems. It turned out that in some iterations the disturbance increases, while for others it decreases. The conversation was about an invariant measure, Lyapunov's indices, that mathematicians deal with similar questions. All this was done completely independently of Feigenbaum [4]. But the work was unexpectedly and tragically cut short. In early May 1977, Vsevolod Nikolayevich died during a hiking trip, before reaching the age of forty.

Nevertheless, it became clear both from experiments and from calculations that chaotic self-modulation occurs at a finite number of cycle doublings. In addition, it was finally clarified that the auto-modulation noise is only a precursor of the real broadband chaotization process, which develops in the noise core with even greater loads on the nonlinear element.

It was suggested that with a large steepness of the falling section of the amplitude characteristic of the TWT, the system lacks a nonlinear suppression of the small signal by a large one. There is the possibility of simultaneous excitation of oscillations at many natural frequencies of the system. Indeed, experiments on the two-frequency sounding of TWT conducted in Yu.V. Anisimova, showed that in a falling section with a large steepness, a strong signal passes through a lamp with attenuation, and an additional weak one amplifies. In this case, a combinational component appears with an amplitude that sometimes exceeds the amplitude of the weak signal. A very short moment of the appearance of oscillations was also detected at many natural frequencies of the system. A further decrease in the damping in the feedback loop already led to noise oscillations with a strong spectral rupture (maxima of the SPMS at its own frequencies).

At the end of 1972, revolutionary changes occurred in V.Ya. Kislov's laboratory. To ensure the Fryazino part of the Institute with qualified personnel, our director, Academician VA Kotelnikov, broke through the construction of a house near the metro station "Schelkovskaya". From the laboratory, subject to the transition to the Fryazino part of the apartment, Kislov himself, E.A. Measin, V.N. Danilov, Yu.V. Anisimova and E.V. Kalyanov, who moved to IRE from Saratov. As a result, the entire laboratory moved to Fryazino state at number 166. The wing of the IRE building (the former physics faculty of Moscow State University) facing the Kremlin turned out to be in an emergency condition due to a draft after a heat supply system failure. The equipment was transported to Fryazino and work on noise engine was continued there in the first building. I, who did not need to improve the housing conditions, nevertheless found myself in Fryazino, because I wanted to continue working on this topic.

Work on the oscillator of chaotic oscillations in FIDE was developed in three directions. First, the development was carried out to increase the power and efficiency of noise generators. Secondly, the physics of processes leading to noise generation continued. Finally, intensive searches for solid nonlinear elements began, which along with the TWT could provide chaos in the generators with delayed feedback.

Nikolai Dmitrievich Devyatkov is our head of department, at his time at the time was deputy director for scientific research at the Research Institute 160, the head enterprise of the first department of the Ministry of Economic Development of the USSR, located in Fryazino. Despite the fact that the noise-related topics of the MEP were related to Saratov, Devyatkov organized work on noise generators in his institute. So in the department of E.A. Helvich was tested a 3-cm-3-kilowatt noise generator on standard TWT. Yuri Pavlovich Myakinkov developed a so-called single-balloon noise generator in which an amplifier and a nonlinear element were combined by one electron beam. At FIRE began to create a very powerful one-balloon decimeter of the decimeter range.

During this period, it was possible to make significant progress in studying the effect of phase shifts of the signal in TWT on the chaos of oscillations. Young (then) specialist VI. Kalinin, who came to the laboratory after graduating from the Gorky University, carefully and thoroughly studied the so-called nonlinear resonance in TWT with delayed feedback. It turned out that the natural frequencies of the system vary very much when the amplitude of the oscillations changes. It is interesting that on the defense of the thesis VI. Kalinin already no one spoke about the doubtfulness of the results. It seems that everyone understood how the noise generator works. Opponent - Doctor of Physical and Mathematical Sciences Mark Efremovich Jabotinsky said even that the thesis is drawn to the doctoral.

Interesting results, both experimental and calculated, were obtained by G.M. Vorontsov. He worked with a noise generator containing an amplifier on the VLBM, which is an effective amplitude limiter. Applying a bandpass filter at the input of the LBVO-nonlinear element, Vorontsov achieved the randomization of oscillations by means of an inverse transformation of phase modulation into amplitude modulation. It should be noted that in the Institute, although not in our laboratory, imported computers appeared. On one of them Georgy Mikhailovich acted both as a programmer and as an operator, having managed to create a decent digital model of such a noise generator.

My main interest in this period was the search for solid elements that could provide a randomization of oscillations in the noise generator instead of the TWT. It turned out, for example, that the inclusion of an electrically tunable iron-yttrium garnet filter (YIG filter) in the feedback circuit not only leads to a rearrangement of the band of generated noise, but also to stochastization of the oscillations. When a harmonic signal exceeding a certain threshold value is applied to such a filter, a signal modulated in amplitude and phase appears at the filter output. With a further increase in the amplitude of the input signal, the modulation acquired a chaotic character. The signal spectrum expanded beyond the working band of the filter. The possibility of adjusting the average frequency by an external magnetic field was preserved.

On this device NN. Zagolin, V.I. Kalinin, E.A. Miasin and V.V. Surin received an author's certificate for an invention with a priority of March 11, 1980 [5]. It became obvious that instead of the TWT, any solid-state amplifier can be combined in a noise-jet circuit with a ferrite device. In particular, a noise generator was created using a transistor amplifier developed by the employee of the research institute "Istok" G.V. Rovensky. A model of a two-circuit transistor noise generator with one of the contours made on a ferrite device was also created.

Since the mid-seventies, we have started a series of studies on the possibilities of using avalanche-passing diodes (LFDs) in noise generators. These works were carried out jointly with AI. Melnikov from "Istok". Anatoly I. Melnikov is an associate of A.S. Tager, laureate of the Lenin Prize for the creation of the LAP. He developed diode sources of microwave noise with an equivalent temperature of 5000 kT for radiometric equipment. LPD was surprisingly successful device in terms of implementation of devices that provide chaotic oscillations in the centimeter and millimeter ranges. Incorporated through the ferrite circulator into the TWT feedback, this diode worked perfectly as a non-linear element of the noise. Intensive noise was realized in the circuit with the LAP when sinusoidal oscillations were applied. The generator, assembled on a two-circuit scheme with two LAPs, was noisy. Finally, a diode intended for operation in radiometers could serve as a guiding source of noise in amplifying chains. As a result of his work with the LAP, he defended his thesis for a candidate's degree Belyaev.

In the second half of the 70's it became clear that there was a whole class of devices creating chaotic oscillations. The delay and non-linear resistance in the feedback circuit used in the primary models of the functioning of the noise generator must be supplemented by coupled circuits with nonlinear inductances and capacitances. Those. The operation of such devices should be described in the general case by means of systems of nonlinear differential equations. The closeness to the truly chaotic behavior of the system increases with increasing degrees of freedom and the nature of nonlinearity.

The decisive work on classical noise was the doctoral thesis V.Ya. Kislov, in which he examined various methods of theoretical description of this device. At this time, one after another, work began on dynamic chaos. In the articles of Feigenbaum (1978-80), the universality of the behavior of iterative transformations was shown-the doubling of the periods and the transition to chaos for a finite number of doubling bifurcations. In the works of Ruelle and Takens on the theory of turbulence in the mid-seventies, the concept of a strange attractor was introduced, indicating the possibility of chaotic oscillatory motion in systems with finite dimensionality. In this connection, the work of Lorentz (1963) surfaced. Great contribution to the popularization and development of this direction was made by Nizhny Novgorod and Saratov radiophysics and mathematicians.

Truly "there is no prophet in his own country." Now the leadership of the Institute has become clear that the laboratory V.Ya. Kislov was not engaged in pseudoscience, but was at the level, and sometimes ahead of the new scientific direction. It was given permission to declassify the author's certificate, to publish the main scientific achievements on noiseotron, to participate in open seminars and conferences on this topic. The acquaintance with the results of the work of other scientists and the discussion of their results in a wide range of interested persons, as well as the electronic computers that appeared in the laboratory helped to complete the theoretical part of the noiseotron research and begin active work with noise generators on a solid element base.

The technical achievements of the laboratory remained mainly in the volumes of closed reports. And the work was done a lot. The possibility of obtaining intense noise in the range from hundreds of MHz to 10 GHz and above was demonstrated. The frequency band of simultaneous generation exceeded at times two octaves. So-called one-ball noise wheels were created. In them, the amplifier and the nonlinear element were in the same vacuum volume and the same electron beam was used. It was possible to provide electronic control of the band of generated noise within wide limits, both with the help of frequency-selective systems, and with tunable filters on iron-yttrium garnet and varactor diodes. On the contrary, the noise oscillations were eliminated in a given region of the spectrum. Some of the developments were implemented in special-purpose radio systems.

For a series of works on broadband, electronic noise generators in the microwave range, a group of IRE staff and industry institutes was awarded the USSR State Prize for 1980. In the laboratory laureat medals were given to V.Ya. Kislov, N.N. Zalogin and E.A. Massine. Laureate also became an employee of the Applied Problems Section (SPP) at the Presidium of the USSR Academy of Sciences Evgeny Chigin. Laureate medals were awarded in the Kremlin in a round hall under the dome, which is visible behind the mausoleum. The monetary prize went to a banquet in the restaurant "Prague".

5. TENTS

At present, there is much talk about the need to implement the latest achievements of science as quickly as possible in order to obtain a significant economic effect. I want to talk about how the so-called innovation policy was implemented 30 years ago.

In the summer of 1980, in connection with the preparation of materials for the State Prize, we were not at all until the Olympic Games. Vladimir Alexandrovich Kotelnikov, who nominated us for this award, very often brought to our laboratory various venerable scientists. Among them Academician Gury Ivanovich Marchuk was especially remembered. He was appointed Chairman of the State Committee for Science and Technology (SCST), which was then on Tverskaya between the Central Telegraph and the Moscow Soviet. The conversation turned out to be very lively. It turned out that Gurii Ivanovich worked a lot of time with nonlinear differential equations with a retarded argument. Therefore, he quickly understood everything and made an exceptionally interesting proposal for the development of the laboratory. He offered us to understand the informative radiation of modern computer technology and, if necessary, to create devices for active radio engineering masking of these emissions. According to him, there is a great danger of interception of classified information processed in closed computing centers with the help of reception and decoding of spurious emissions. Marchuk then said a very interesting phrase: "If you solve this problem, I will give you a thousand people and a plant." This statement made a great impression not only on us, but also on VA. Kotelnikov, who was then not the last person in the Presidium of the USSR Academy of Sciences. As an experiment, a temporary scientific and technical laboratory (VNTL) was organized at the Academy of Sciences with increased financing and operational supply of materials and measuring instruments, capable of conducting not only scientific research but also experimental development.

The temporary laboratory included not only employees of the laboratory of electronic generators, but also leading experts of IRE on the theory of optimal signal reception, antenna devices, propagation of electromagnetic waves, etc. Officers of the military unit attached to the State Customs Committee of the USSR, as well as employees of the 8th Directorate KGB of the USSR. The laboratory really worked with full efficiency, often in the evening and at night, when extraneous radio emissions were minimal. In a short time it was found out that the most dangerous from the point of view of information leakage are the emissions of the display on the cathode-ray tube. The pulses of the brightness modulation of the electron beam had at that time steep fronts, and the high-frequency component of these fronts was effectively emitted into space by means of random antennas. The radiation efficiency increased with frequency according to the laws of electrodynamics, and the level of high-frequency spectral components, on the contrary, decreased with frequency. As a result of direct measurements, the range of the highest emission intensity was determined. It turned out that the reception of emissions with the restoration of textual information displayed on the screen of the early eighties displays is possible in the range from 100 MHz to about 500 MHz. On the basis of the usual portable TVs "Electronics-100" and "Youth", devices for intercepting emissions were created that allow reading the text on the display screen while in the car's cabin a hundred meters from the display. Naturally, directional antennas and low-noise input amplifiers were used for this. Using the features of horizontal display generators of even one type, it was possible to adjust one by one to the displays of different computers in the same room. It turned out that they practically do not create mutual interference. The level of these emissions was so small that it was necessary to use high-efficiency directional antennas located in the shadow of the radiation of the television center, and sometimes also the rejection filters of television channels.

The demonstration of interception and restoration of information on the screen of a standard TV, however, led to the indescribable horror of the responsible security personnel of defense and government agencies. We conducted these demonstrations together with the officers of the military unit attached to the State Committee of the USSR (SCC of the USSR), near the task of the information center of the USSR Academy of Sciences in Neskuchny Garden, near the IRE on Mokhovaya Street and even in the Kremlin near the Spassky Tower. The equipment for the interception of emissions was located in the UAZ truck - a "loaf" belonging to the State Customs Committee. On the screen of the display, whose radiation was to be intercepted, simple phrases like "Glory to Soviet Science!" Were printed in large print. or "IRE - Hurray!". I did not see it myself, but the operators claimed that one of the viewers really felt bad about the heart.

Informative spurious emissions also had magnetic disk drives at the time of writing and reading information in a sequential code. However, the probability of interception of such parcels and their identification by virtue of one-time and non-repeatability is extremely low.

To mask the described radiation in the laboratory, a special transistor noise generator was developed, which generates and emits broadband noise of relatively low level, responding to the norms for industrial radio interference and medical requirements. It was powered by a 12-volt DC source, it could also run on a battery. To ensure chaotic polarization of the masking radiation, three independently operating oscillators with loop antennas in orthogonal planes were simultaneously used.

The masking noise generator, named by the authors of the "Tent", was protected by a number of author's certificates and was issued by the forces of the temporary laboratory for several years (**Fig. 3**). The "Shatras" were installed on many computer centers of government and defense institutions, each of which was contracted for research and development in relation to this facility. In this large-scale work the leading employees of the laboratory A.S. Dmitriev, V.P. Ivanov and many others. Until now, modified devices of this kind are produced by SKB IRE. As a result of the work of VNTL, the financial state of the IRE has significantly improved - there is an opportunity to update the instrument park. Employees of the laboratory, taking into account the bonus, received about twice the salary. Deductions to the trade union committee were so great that we went on a monthly basis to free excursions to Yerevan, Baku, Tbilisi, Sevastopol and other cities of the USSR.

At that time, individual computers and computer centers were not yet united by local and regional networks. The concept of "hacker" did not exist yet. In the period when market relations were created, large networks and removable storage devices on magnetic and optical disks, the problems of radio technical disguise of spurious emissions went to the background. The leakage of information went mainly through other channels. The necessary information was much easier to get on a flash drive, paying for a certain amount to some technical employee allowed to service computers, or "download" from the network using hacking techniques. One must assume that the systematic approach pursued by many organizations and firms to ensure the preservation of confidential information in computer networks will again revive a certain interest in spurious emissions, to minimize and mask them.

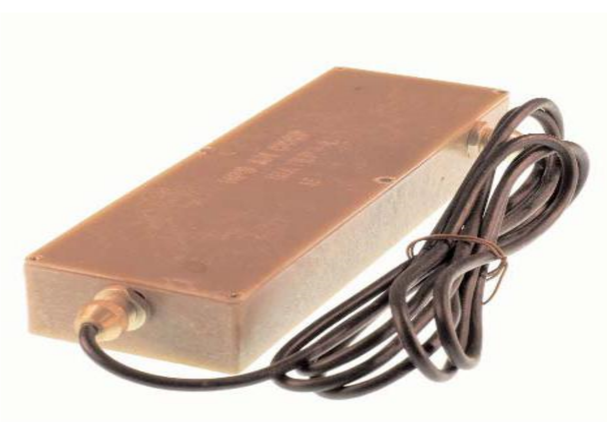

Fig. 3. *The generator of masking noises "Tent".*

Marchuk, of course, did not give a factory after the completion of works on the protection of computer information. However, the work was put forward for the Prize of the Council of Ministers of the USSR. In 1984, we received medals from the hands of Guriy Ivanovich, and his diplomas were adorned with his signature.

6. NOISE LOCATION

In the second half of the 70s, when exactly, I do not remember, the staff of the Central Research Institute-3 of the Defense Ministry came to us in Fryazino. They very emotionally told about the discovery in the US patent literature of the method of analog obtaining of the function of mutual correlation of two broadband noise signals. From the theory of radar, it is known that the optimal probing signal is a broadband chaotic signal with a normal (Gaussian) probability distribution of instantaneous values. The trouble is that the acquisition of data on target parameters in this case is possible only by calculating the mutual correlation function between the emitted and received signals. Computer methods because of very high frequencies and a wide band of a signal do not work. Digitization of such signals is impossible. The essence of the analog method of obtaining the cross-correlation function consists in a double spectral analysis of the sum of the signals emitted and reflected from the target. The first spectrum of the sum acquires periodic ruggedness. Depending on the time shift between the realizations, some spectral components are summed in phase, others in antiphase. The secondary spectrum just characterizes this time delay, i.e. double the range to the target. From the point of view of mathematical statistics, this corresponds to the well-known Wiener-Khinchin theorem.

Having understood the essence of the method, we immediately decided to test its effectiveness experimentally. One of the premises of the laboratory was turned by windows to the SKB building. We are V.I. Kalinin switched on the noise generator, sending his signal through the horn antenna P6-23 to the SKB building. Another antenna was connected to the ASH-2 spectrum analyzer. The noise signal came on the receiving antenna in two ways: as reflected from the wall of the SKB and as the transmitted on the side lobes of the directivity pattern of the transmitting and receiving antennas. On the spectrum analyzer, we saw a clear periodic ruggedness and calculated the distance to the CBS by the period of ruggedness. It turned out to be approximately 40 meters. Immediately they walked down to the courtyard with a tape measure and measured the distance manually. The data were docked with great accuracy.

With the "troika" was put a joint work, which was later transferred to an enterprise engaged in the near location in Tula. Parallel to the proposal of NA. Armanda went to work with the laboratory BP. Kutuzy. It was a question of remote measurement of the height of sea waves with reference to the so-called "Caspian monster". We are with RV. Belyaev went to the southern coast of the Crimea in the place Katsiveli, where, together with AA. Kalinkevich took measurements on the platform of the Black Sea Department of the Marine Hydrophysical Institute (CHOMGI). The possibility of measuring the height of waves from low-flying aircraft or helicopters was shown. Further work in this direction revealed the possibility of selecting moving targets, up to determining the respiration rate of a person in the ray of such a locator.

It should be noted that the double spectral processing method in radar works well only for very small ranges to targets. Everything is good only at distances of a few tens of meters. At long distances, the period of the rupture of the primary spectrum becomes so small that it requires a very narrow-band filtering and consequently an inadmissibly long time for estimating the primary spectrum in a sequential spectral analysis. The advantage of near-field radar with dual spectral processing is mainly in the extremely high resolution of the method in terms of range, but with the use of spaced reception antennas and angular coordinates. The work in this direction was interrupted due to the new responsible task of the IRE Directorate.

7. AWACS

I do not know if I can write about this now. But I'll write. This will be the last serious work done by the laboratory under the Soviet government. I think that after the collapse of the USSR, much more serious developments made in those times were declassified. In addition, there has been a long talk about the sale of systems based on the development of our laboratory to other countries.

In the spring of 1984 our director Vladimir Alexandrovich Kotelnikov came to our laboratory somehow without any accompaniment. He told us that he was at an important meeting in the Ministry of Defense yesterday about the opposition to the US AWACS system. I think that our reader knows exactly what it is (**Fig. 4**).

The meeting discussed the possibility of suppressing the flying radar along the side lobes of the radiation pattern of its receiving and transmitting antenna. Estimates of the required radiation power have shown values of the order of MW in a practically continuous regime. Given the low efficiency of the transmitter interference to power this device requires a power plant that can, in principle, provide electricity to a small city. If you suppress the main beam, then this will require power of the order of tens of watts and then at the moment of "smearing" the beam at the interference station. Since the radar operates with a beam of the order of 10, and the suppression should be carried out from the earth's surface from distances of the order of 150-250 km, several dozens of automatic, unattended stations will suffice to mask the aircraft and unmanned objects over the monitored territory.

Kotelnikov's proposal was considered by the laboratory staff in conjunction with specialists from the Voronezh Center of the Ministry of Defense, responsible for the problems of electronic warfare, and the Rostov Institute of the Ministry of Radio

Fig. 4. *AWACS aircraft.*

Industry. The idea is recognized as very promising. We made applications for the invention and started working. For this work, the lifetime of the VNTL was extended.

A computer simulation of various situations involving the use of AWACS was carried out. The detailed model of the station and the features of its use, obtained by us at the Ministry of Defense, made it possible to develop a model of a small interference station consisting of a receiving device that identifies the radar emissions and the transmitter of broadband interference in the entire range of radar operation

Together with the Rostov Institute, about 20 mockups of interference stations were developed and manufactured. Broadband noise generators and antenna systems related to IRE (for powerful transistor noise generators, NA Maksimov answered, for antennas AS Dmitriev). Receiving devices and automation were developed by Rostov. The stations were debugged at the Rostov Institute training ground near Matveyev Kurgan settlement. Each of the stations for certainty was called a female name. The whole set was called "girls" (**Fig. 6**).

The dimensions of the "girls" were determined by the size of the antennas and the battery, the electronics occupied a negligible place.

СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК

ГОСУДАРСТВЕННЫЙ КОМИТЕТ СССР
ПО ДЕЛАМ ИЗОБРЕТЕНИЙ И ОТКРЫТИЙ

АВТОРСКОЕ СВИДЕТЕЛЬСТВО

№ 290590

На основании полномочий, предоставленных Правительством СССР, Государственный комитет СССР по делам изобретений и открытий выдал настоящее авторское свидетельство на изобретение:

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Председатель Комитета

Начальник отдела

МПФ Гознака. 1979. Зак. 79-3083.

Fig. 5. *Author's certificate on the method of counteraction to DRLOU systems and the device for its implementation.*

The set of stations was transported to the test site near Orenburg for testing. An analog of AWACS, a Soviet A-50 aircraft with a "Shmel" radar station based in the Akhtubinsk area, barracks at a distance of about 200-250 km from the test site, and Tu-16 and Mig-21 flew from Orenburg to it. The tests showed that the targets on the radar station's line of interference were successfully masked, even at a distance of about 50 km from the radar. In the autumn of that year, a couple of "girls" were exported to the GDR, where they were already working on real AWACS, but in a passive mode (without turning on the transmitter of interference). The measurements showed that the interference stations "see" the real AWACS and are ready to reject interference. OCT "Tuman", conducted on the basis of this work in Rostov, led to the formulation of appropriate funds for armament. The performers mentioned in the author's certificate, as well as employees of the Voronezh Center and Rostov developers were awarded the USSR Council of Ministers Prize in 1989. There was no banquet about this - they were fighting with drunkenness.

8. SCIENTIFIC AND TECHNICAL TOURISM

The work carried out by the laboratory on the creation of radioelectronic countermeasures to long-range radar detection systems aroused keen

Fig. 6. *Employee of VNTL V.P. Ivanov with one of the "girls."*

interest among many specialists dealing with electronic warfare at that time. In particular, we talked about jamming various types of side-view radar with synthesized aperture, on countering air defense and missile defense systems of the Patriot type, on countering the radar "Cobra Yudy", etc. For the experiments, trips to Baikonur, Kamchatka, on Pacific Ocean. There was no great science in this matter, but it was so desirable to travel for public expense that it was impossible to refuse. Moreover, for a combination of two reasons - a serious form of admission to secret works and a stubborn refusal to join the ranks of the ruling party, I was absolutely out of the question. I do not regret that I neglected the end of my almost written doctoral dissertation and went on these trips. Impressions remained for the rest of my life. It should be noted that in the seventies we had already traveled to various ranges to find out the effectiveness of the noise signal on the radar and the radio reconnaissance station. Worked, in particular, in Smolino, Nizhny Novgorod region and at the air defense ground "Kapustin yar".

The first trip took place at Baikonur. At that time in the orbit was a military version of the space station "Salyut", designated as "Almaz". On it flew an experimental sample of the lateral view radar "Sword". By the way, in a slightly modified version of the "Sword" flew and on our institute aircraft IL-18, with reference to the peaceful program of remote sensing of the earth's surface.

It turned out that there is really no Baikonur. The airport where we arrived, had the name either "Far", or "Ultra". The town in which they lived was called Leninsk. North of Leninsk there was a Kazakh settlement with the railway station Tyrat. Further north, the highway and the railway along which the landfill sites were located ran parallel.

On Baikonur, every day we were taken to the Gagarin launch area (about 35 km from Leninsk). There we used our noise to attach to the radar "Kama". Kama accompanied the rockets on take-off. Therefore, its beam could be controlled within wide limits, both in azimuth and in elevation. Due to the peculiarities of the "Diamond" orbit, it took only two or three days to work. In our spare time we were taken to the "Energia-Buran" site. We looked at these cars in the hangar. Then already (much later) they found out that the roof of the hangar was covered with snow and the products were badly damaged. One night they drove to launch the Proton rocket - an impressive sight. The infrasound from the operation of the first-stage engines causes a shiver in the chest, even five kilometers from the start. Very beautifully in the night sky are separated "bokovushki".

The next work in the interests of missile men took place in the area of the Kura field in Kamchatka. We lived in a military town near the village of Klyuchi. Another group (VA Burykin, SO Starkov, BA Hadzhi) was on a ship that drifted northeast of Ust-Kamchatsk alongside the carrier of the Cobra Judy radar, Observation Island, . At that time, in accordance with the agreement with the United States, the destruction of medium-range missiles Pioneer (SS-20) was carried out. The rockets were destroyed by launching from the Chita area to the Kura test site. As far as I understand, our task was to test the effectiveness of masking the missile's head parts before entering their atmosphere, and also to look at the reaction of Americans to these actions. We worked on two launches, flying from the airfield "Klyuchi" on an AN-26 airplane. Confirmation of the effectiveness of camouflage was the calibration of the radar over the released balloon and a note with the statement that the counteraction to the radar facilities of ships in neutral waters is a violation of the accepted international norms.

We shone a hindrance to the Cobra through the airplane window, and in return received the strongest radar of the air defense radar of the ship. As a result, we suppressed the Cobra Judy, but our aircraft was

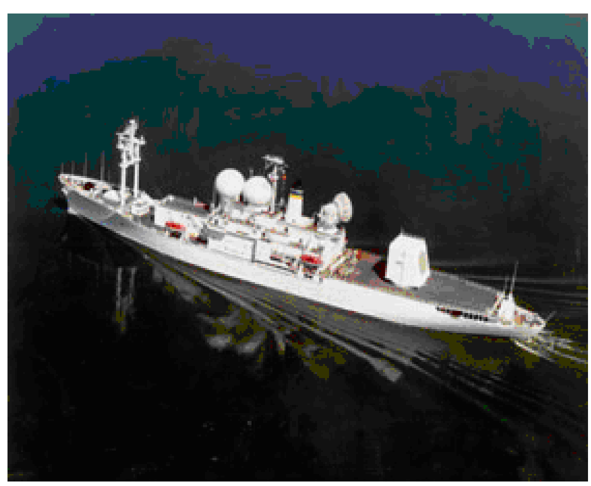

Fig. 7. *The ship "Observation Island." The radar with the Cobra Judy FAR in the stern.*

burned almost all on-board radio equipment. The pilots were very unhappy.

When we just arrived in Yelizovo (Petropavlovsk airport in Kamchatka), a nose in the nose with employees of the laboratory, BG, suddenly collided. Kutuzy, who flew to Kamchatka on their IL-18. Immediately agreed that they somehow fly past us with their "Sword", and we will light up on them a hindrance. IL-18 flew past us twice. The first time we did not work, and the second one made a noise at him. Unfortunately, the processing of the results was not made in real time, but in a special center near Moscow, where we were not allowed. The fact that we crushed the "Sword" reliably, we learned only after many years. But still nice.

In days off from work, and we spent almost a month in Klyuchi, there was a real rest. One of the first nights was watched behind the entrance to the atmosphere of the head parts of a rocket. They glowed like electric bulbs. They walked along the spurs of Klyuchevskaya hill, examined the so-called craters-parasites, collected mushrooms. We were riding a self-propelled barge along the Kamchatka River. Especially remember the flight by helicopter to the middle ridge, where the host army unit had a recreation center. There, hot springs, underdeveloped geysers with a water temperature of about 900 ° and a non-periodic outburst to a height of less than a meter, were adjacent to cold keys with a temperature of about 40 °. This allowed you to make outdoor pools, with a temperature controlled and swim in them at any time of the year.

There were so many spawning fish in the Kamchatka River that Andrey Ivanovich Panas, the future director of the Fryazino unit of the IRE, managed to kick a huge sockeye on the shore, meat and caviar which all the expedition participants ate for two days.

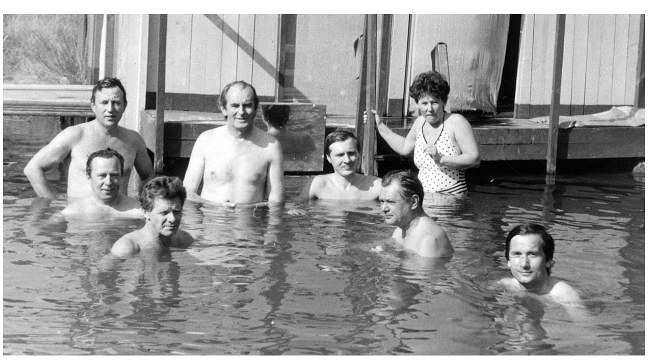

Fig. 8. *RV Belyaev, NN Zalogin and AI Panas in Kamchatka.*

9. PACIFIC OCEAN

It turned out that our visit to Kamchatka was considered a rehearsal for a more important event. The Dnepropetrovsk CBU prepared a test of a railway-based missile. It was planned to launch rocket launches from the Plesetsk landfill to the Pacific Ocean region to the southwest of the Hawaiian Islands. As the two areas for the destruction of the warheads were planned, we were divided into two groups. V.A. Burykin, A.I. Panas and S.O. Starkov left Viluchinsk on the Chukotka parachodka to a point south of the equator. I'm with NA. Maximov and A. Lyashchuk on the same parachodka, but with the name "Sakhalin", from Korsakov went to the area a little to the north of the equator. I do not mean to say the parachod, since the ship built in Poland, although it was fueled, but it heated the steam boiler, which, in turn, set in motion the steam engine. I got the cabin just above the steam boiler, and it was very noticeable in the tropics.

The path to the point of the alleged splashdown of the head parts took several days. Got into a pretty strong storm. Unpleasant, but bearable. On-board pitching during the drift is more disgusting. And in the drift we lay almost all the time waiting for the starts. Three days of drift - one night return to the point. During the day, almost all the time spent on the deck in the back of the ship, where there was a helipad. Binoculars watched the huge ships passing by, carrying cars from Japan to South America. We saw whales, sharks and a lot of flying fish. Two times they saw a green ray during the setting of the sun. The sun in these latitudes and at this time of year falls almost horizontally horizontally. At the last second you can see a bright green ray.

We did not have to work during this trip. It turned out that Observation Island is being repaired in a dock somewhere in the San Francisco area and will not be able to come to the test at a given point in principle. At that time a huge ship "Chazhma" was returning

Fig. 9. *The steamer "Sakhalin". Chukotka is the same.*

from some southern seas. We were transported with the equipment by helicopter to Chazhma, where we met with S.O. Starkov. A few days later we were already in Vilyuchinsk. V.A. Burykin and AI Panas arrived in Vilyuchinsk later on the flagship of the space flotilla "Academician Komarov."

The money received for participating in the expedition was spent on the purchase of personal computers. This turned out to be very useful, since with the collapse of the Union, the financing of all works practically ceased and the only opportunity to somehow engage in science was mathematical modeling.

10. DASHING 90's

As a result of the collapse of the USSR, the economic crisis and other factors, the financing of the Academy of Sciences almost completely ceased. In fact, the occupation of science has turned into a kind of social activity. Especially it affected the collectives dealing with mostly defense topics.

V.Ya. Kislov at this time completely reoriented to medical electronics. Employees who continued to deal with issues related to dynamic chaos, most of them united with A.S. Dmitriev. I, frankly, assumed that Alexander Sergeyevich, after reaching Kislov's critical age, would become the head of the department of microwave electronics. The fact is that unlike most of the laboratory's employees involved in applied experimental development, he actively studied the theory of dynamic chaos and soon after V.Ya. Kislov in 1988 defended on this subject a doctoral dissertation. But then something happened that resembles the events in North Korea. The head of the department was handed over to the youngest son of Vladimir Yakovlevich. Dmitrieva and her colleagues were transferred to the department, which was formerly headed by Academician Yury Borisovich Kobzarev. In the department of AS Dmitriev, active work continued on information aspects of the theory of dynamic chaos. More information about the research and development of this team can be found by referring to the Information and Communication Technologies on the basis of dynamic chaos (InformChaosLab) of the institute site http://www.cplire.ru/[6]. I will only say that three doctoral dissertations were defended in this department. A lot of work on dynamic chaos was also conducted in the Saratov branch of the IRE under the leadership of the brothers AP. and S.P. Kuznetsovs (see the section "Dynamic chaos" of the same site) [7].

In the Fryazino part of the IRE, in a laboratory headed by V.I. Kalinin also continued work on oscillators of chaotic oscillations and their applications in various fields of radio electronics.

I, and a few other employees who were out of work, at first engaged in issues related to algorithms for generating pseudo-random digital sequences. The fact is that the development of electronic computers, digital communications, navigation, etc. required the development of such algorithms, since there was practically no data on this direction in the open technical literature. It was desirable to create algorithms that ensure the generation of pseudo-random sequences of numbers of a possibly longer period with good statistical characteristics. It was desirable to provide a combination of relative simplicity of algorithms with the difficulties of its identification in the analysis of the sequence. In order to better understand the essence of the matter, it was decided to work with sequences of a finite set of positive integers. The question of the possible magnitude of the period stands in this case most acutely.

In this paper, it was natural to assume the use of the methods used to create models of analog oscillators of chaotic oscillations, in combination with some logical operations that are impossible when simulating such generators. The basic idea of obtaining large periods is to increase the geometric dimension of the system in which the generation occurs. Two main groups of algorithms were considered. This is a system that transforms at each step a certain vector, with dimension n, an analog of a system of n differential equations. Another option is analogous to a system with delayed feedback, where each successive sequence value is a function of several previous values. To ensure work with a limited number of positive integers, the algorithms used a logical operation - taking the remainder of the result of division, resulting from the next step of the number to the maximum of the numbers used.

As a result of the research, dependencies of the guaranteed period of generated sequences on the system dimension were obtained. It turned out that working with vector equations provides a longer period than working with systems with a lagging argument.

On the basis of our research, V.V. Kolesov offered a method of pixel-by-pixel image encryption. This to some extent resembles the widely known method of double-permutation in cryptography. However, unlike signs and spaces, work occurs with individual pixels of the image. The resulting chaotic numerical sequences allow this to be done. It turned out that with this method it is possible to restore the whole image even with the loss of fragments of the coded matrix. More on this and much more can be found in the book "Broadband chaotic signals in radio engineering and information systems", published by the publishing house "Radiotekhnika" in 2006 [8].

In recent years, we have been able to resume work on the use of broadband chaotic signals in the active location. This time in sonar. The fact is that the velocity of propagation of longitudinal acoustic waves in an aqueous medium is about 20 thousand times less than the speed of propagation of electromagnetic waves in the atmosphere. This means that the wavelengths of the sounding signal characteristic of the radar are realized in sonar at frequencies of tens to hundreds of kHz. Modern computer technology easily copes with generation, digital-analog and analog-digital signal conversions, as well as with the correlation processing of such signals. The specific feature of sonar is also that longitudinal waves in water experience strong damping, the greater, the smaller the wavelength. As a result, there are serious problems in the development of sonar with increased range. The series of short pulses with high-frequency filling that are habitual for sonarization with increasing distance to the target require an increase in the time interval between pulses. This is necessary to ensure unambiguity in measuring the range to the target. As a result, the power of such signals is sharply reduced. An increase in the duration of pulses reduces the resolution of the location. The way out of the crisis is associated with the use of complex signals, combining a significant duration and thus power with a short autocorrelation function - a good resolution in range. The use of complex signals in sonar began according to traditional paths for radar detection. In particular, in the Fryazino part of the IRE, a sonar was developed using a signal with linear frequency modulation. However, the broadband chaotic signal is considered optimal for the active location of the signal. The duration of such a signal can be increased almost indefinitely, providing good power engineering while maintaining high resolution in range.

In recent years, we have started active work on mathematical modeling of various versions of sonars using broadband chaotic signals, and together with NIIP im. V. Tikhomirov, that in Zhukovsky, and the development of such sonar.

11. CONCLUSION

In the mid-fifties, it seems soon after the twentieth congress, Pyotr Leonidovich Kapitsa suddenly appeared at MFTI. He was one of the founders of the Institute, and after the so-called Nikologorsky exile and the return to the chair of the Director of the Institute of Theoretical Physics of the Academy of Sciences of the USSR, I decided to visit Dolgoprudny and talk with students. In the assembly hall of the Institute he spent about an hour talking with us. I especially remember the call of Petr Leonidovich never to study in science what you are not interested in doing. This was so contrary to the official instructions on the production discipline - "do what the boss orders", which I remember for a lifetime. It should be noted that for the last fifty-five years of my life I have tried to follow Pyotr Leonidovich's advice. I will also add that many of the employees with whom he worked or communicated all these years completely spontaneously followed Kapitza's precepts.

The second commandment, which we tried to follow, belonged to Nikolai Dmitrievich Devyatkov. He claimed that radio electronics is a technical science, and even in the Academy of Sciences, when dealing with radio electronics, it is necessary to strive for the introduction of the results obtained into technical developments. It should be noted that the point of view of Devyatkov was actively supported by Vladimir Yakovlevich Kislov. Being the head of the laboratory, the temporary scientific and technical laboratory, and then the department, he skilfully combined scientific research in the field of dynamic chaos with the implementation of developments aimed at creating unique means of electronic warfare and radar. The receipt of the USSR State Prize and two CM prizes of the USSR was due precisely to the combination of scientific research in a new direction in radiophysics with technical developments that enabled the results of these studies to be implemented.

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