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The autodyne radio spectroscope: the brilliant invention of Ye. K. Zavoisky

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Abstract: *The present paper concerns the preconditions served as the basis for the scientific discovery of the phenomenon of paramagnetic resonance, the stages of its development are discussed. The first stage is associated with the invention of the principle of autodyne reception of radiotelegraph signals with the help of the Meissner oscillator in the beats mode (Henry Round, 1913). The next stage is the autodynes usage as transceivers of radio altimeters designed to determine the height of an aircraft above the Earth's surface (Ernst Alexanderson, 20-30s). At the 3rd stage, the autodyne sensors of proximity for remote fuses have been proposed for aircraft bombs and rocket projectiles (William Alan Stewart Butement, 1939) and sensors for anti-aircraft shells that can withstand mechanical overload during an artillery shot (Merle Antony Tuve). At that, the new compounds were used to fill the nodes of electronic circuits and for the first time – the technology of PCB. In physical experiments, the autodyne becomes a tool by which the discovery of the phenomenon of the electron paramagnetic resonance (EPR) was made. The associate professor of the Department of physics of Kazan State University Ye. K. Zavoisky became the author of this discovery, and the founder of a new direction in physics. Description of the operation principle is given and the acting device of the autodyne radiospectroscopy he created, which working model is illustrated in the museum-laboratory of Ye. K. Zavoisky in Kazan State University. The contribution of the development of the VHF range (together with P. M. Vinnik), as well as in the theory and technique of autodyne and super-regenerative reception of radio signals.*

Keywords: *history of science and technology, paramagnetic resonance, the museum and laboratory at Kazan University, P. M. Vinnik, autodyne, super-regenerative reception.*

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Автодинный радиоспектроскоп — гениальное изобретение Е. К. Завойского [1]

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Аннотация: *Рассмотрены предпосылки, послужившие основой для научного открытия Е. К. Завойским явления парамагнитного резонанса. Дано описание принципа действия и устройства созданного им автодинного радиоспектроскопа, действующий макет которого демонстрируется в музее-лаборатории Е. К. Завойского в Казанском государственном университете. Отмечен вклад Е. К. Завойского совместно с П. М. Винником в освоение УКВ-диапазона, а также в теорию и технику автодинного и сверхрегенеративного приема радиосигналов.*

Ключевые слова: *история науки и техники, парамагнитный резонанс, музей-лаборатория в Казанском университете, П. М. Винник, сверхрегенеративный прием.*

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1. Introduction

In the history of Radio Engineering scientific direction related to studying and practical application of “autodynes”, we may emphasize the several stages of its origin, coming into being and development. The first stage relates to invention of the autodyne principle of radio-telegraph signals reception with the help of the Meissner oscillator in the beat mode. This principle was suggested by an engineer of the British Company *Marconi’s Wireless Telegraphy* known by name Henry

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Round in 1913 [1]. The next stage on the boundary of 1920's - 1939 relates to autodyne application as the transceivers of the radio-wave altimeters designed for determination of true flight height of the aircraft over the Earth surface [2, 3]. To our opinion, Ernst Alexanderson was successful here, who was the one star of the constellation of great invertors of Radio Engineering and the founder of the breakthrough in the beginning of 20th century in radio-telecommunication technologies [4]. He offered several engineering solutions for radio-altimeters and warning systems for aircraft collision in their flights in the airport region.

Essential contribution to autodyne development was made during the Second World War when the Britain scientist *William Alan Stewart Butement* in 1939 had suggested the autodyne "proximity" sensors for proximity fuses to the ammunitions [5, 6]. These fuses were directed in the initial period to designing of aviation bombs and the reactive shells, on the board of which the mechanical influences to the electronic elements were relatively rather small. Nevertheless, the technologic possibilities in Britain during these years did not permit the industrial model of the proximity fuse for anti-craft guns which may withstand the mechanical overloads at the artillery shot. The excellent scientific manager, the well-known American scientist-physicist *Merle Antony Tuve* had managed with this problem. At creation of new product, which sufficiently increase the artillery effectiveness, he managed to concentrate efforts of many scientists and engineers from the very different companies and universities, to implement the modern engineering and technology novelties. During undertime, the crash-proved electronic valves and the miniature components were developed, which were used earlier in the hearing-aid devices; new types of plastics and compounds for filling the units of electronic circuits; power sources providing the prolonged storage without loosing of electric capacity; for the first time, at industrial equipment manufacture, the printed-circuit technology and many other achievements.

A principally new area of autodyne application in those war years was their utilization in physics. At that, the autodyne itself was a tool, with the help of which the important discovery for the science of the phenomenon of electronic paramagnetic resonance (EPR) was made and arrives the new direction in physics — the radio-spectroscopy. The author of this discovery and a founder of new direction in physics is associate professor of Physics Department Dr. Yevgeny K. Zavoisky [3] (see Fig. 1). Materials and expositions of the Museum-Laboratory of Ye. K. Zavoisky acting in the Kazan State university from September, 1997, are dedicated to this event and the private and creative biography of the author[2]. In this paper, basing on materials of this museum and other sources, the analysis of the historical retro-perspective of creation and development of the autodyne radio-spectrometer, is carried out.

[2] http://kpfu.ru/museums/muzej-laboratoriya-ekzavojskogo (accessed: 15.11.2015)

Fig. 1. Ye. K. Zavoisky, an associate professor of physics of Kazan State University.

Рис. 1. Доцент кафедры физики Казанского университета Е. К. Завойский

2. Preconditions of autodyne radio-spectrometer creation

A phenomenon of oscillation mode dependence upon the influence of any factors' impact, including the proper reflected radiation, on its oscillating system, which was later called the autodyne effect, was discovered still at the beginning of radio engineering development. This effect was observed in the valve transmitters designed on the so-called "simple circuit", in which an antenna was directly connected to the tank of the stage with self-oscillations [3]. It was noticed that random variations of antenna parameters, for example, at its swinging by the wind, caused variations of amplitude and frequency of generated signal as well as variations of the direct current in the power supple circuit.

Unwanted oscillator property for transmitters to change the oscillations' parameters under influence of external impacts served as a prototype for development of the full class of measuring instruments, which were called in the modern metrology literature as "measuring oscillators" [3]. Their operation principle, at bottom, is based on the autodyne effect – they realize a registration of oscillator response on the external informative impact. In 1930's this area of activity formed at the turn of radio-physics, the nonlinear oscillations theory and instrumentation, was fully defined into independent scientific direction.

Scientific interests of Ye. K. Zavoisky, who was graduated from Kazan State University in 1930 and entered at the same year at the PhD course, were formed exactly in this direction. The main aim of his researches was initially the increase of frequency of generated oscillations on the basis of electronic valves developed at this time. Oscillators with the inhibitory field (circuit of Barkhausen-Kurz) had the greatest prospects in this direction, with which he actively

worked. Besides, his interests related to studying of the different factor influence on the operation mode of the UHV oscillator. The length and thickness of conductors of external circuits of valve anode and grid were among these factors, as well as the approaches of the unauthorized subjects near the parts of the oscillator and variations of the modes of anode supply and the valve filament.

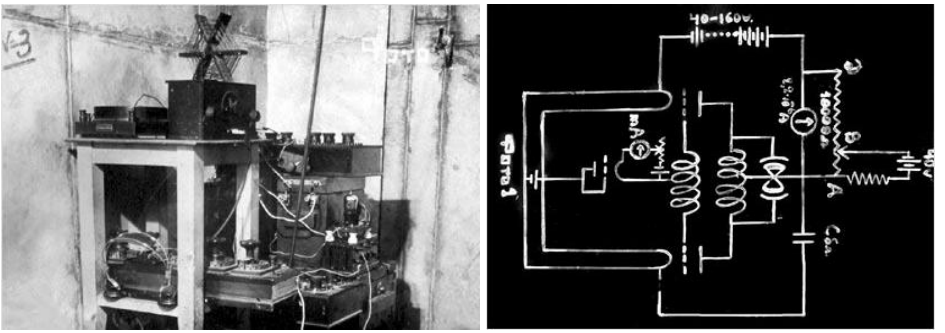
Fig. 2. Employees of the Central laboratory of radio, P. M. Winnik stands second from the right.

Рис. 2. Сотрудники Центральной радиотехнической лаборатории, стоит второй справа — П. М. Винник

The most important results of different researches and development of UHF oscillators by Ye. K. Zavoisky were obtained in the Central Laboratory of the plant named after Komintern in Leningrad, where he was directed at scientific and technology training in 1931 [7]. In this lab, together with P. M. Winnik (see Figure 2), the new circuit solutions of the valve oscillators were offered, which permitting the increase their limiting oscillation frequency, the power and efficiency (see Figure 3) [8]. The super-regenerative operation mode was comprehensively studied as well as the original circuit of the new super-regenerative receiver was proposed in which the functions of the detector device was simultaneously implemented by the oscillator and the triode that loads its oscillating circuit [9].

After brilliant defense of PhD thesis in the beginning of 1933 on theme "Research of super-regenerative effect and its theory", Ye. K. Zavoisky became the Head of Department of Physics of Kazan State University and continued the research activity actively. The deep knowledge and experience in the development of UHF oscillators obtained during PhD course, representations of operation modes of these oscillators as well as wide erudition in different areas of knowledge promoted him in successful development of new scientific direction

related to studying of physical-chemical properties of substances [9, 10]. The interest to this direction was also caused by success of foreign scientists in the field of the atom nuclear structure studying with the help of electromagnetic radiation.



(a) (b)

Fig. 3. Experimental setup (a) and Winnik–Zavoisky VHF transmitter circuit (b).

Рис. 3. Экспериментальный стенд (a) и схема УКВ-передатчика Винника — Завойского (b)

In his publication “Measuring method of excitation potential of atoms and molecules” (1936) Ye. K. Zavoisky proved a possibility of molecules excitation by electrons accelerated by high-frequency electrical fields. The phenomenon was experimentally discovered that there is an absorption of the electric component of electromagnetic field of the UHF oscillator at its definite operation mode with substances. At that, the variation of anode and grid currents in the valve oscillator was observed. In modern interpretation, this phenomenon can be understood as the auto-detection phenomenon of the autodyne response and it was called as “grid current method”.

In 1941, after acknowledgement with publications of the Dutch physicist *Cornelis Jacobus Gorter* on paramagnetic relaxation and his attempts to determine the magnetic moments of atom nucleus, Ye. K. Zavoisky decided to repeat these experiments but not to use the “calorimetric” Gorter method, rather then his own the more sensible autodyne method. Nevertheless, he did not manage to finish his own experiments since it was necessary to switch to military subjects. At the end of 1943, he returned to the work on determination of magnetic moments of atomic nuclei using the mode sensible equipment and the method of magnetic field modulation. The date of his discovery of EPR phenomenon is January 21, 1944. In this day Ye. K. Zavoisky for the first time observed in the oscilloscope screen the signal of resonance absorption, which view he transferred on the tracing-paper.

3. Structure and operation principle of the autodyne radio-spectroscope

The setup developed by Ye. K. Zavoisky consisted of the welding transformer with connection of the coil-solenoid, an ammeter, an autodyne oscillator, the Abbot profiling meter and an oscilloscope (Figure 4). In the solenoid coil with diameter of 12 centimeters, which contained of 6 turns of copper wire, there was founded the alternative magnetic field of the low frequency (50 Hz). This coil was powered from the secondary winding of the welding transformer, whose primary winding was connected the AC net through the rheostat providing adjustment of the current value. The value of the magnetic field created by the solenoid was determined on the base of AC current. At that, the factor of proportionality between the magnetic field and the current was determined experimentally.

Fig. 4. Zavoisky's experimental set to study the electron paramagnetic resonance.

Рис. 4. Экспериментальная установка Е. К. Завойского для изучения ЭПР

In the solenoid magnetic field, the radio-frequency coil *L* of the high-frequency autodyne oscillator (10 MHz) was placed, which was developed on the valve R-5 or CSCH-182 in the circuit with capacity feedback (Figure 4). The paramagnetic under consideration was placed in the coil soldered in the waterproof celluloid ampoule. If to place the paramagnetic in the AC magnetic field of the radio-frequency oscillator, which was oriented at right angle to solenoid field, then the sample may absorb the high-frequency energy feeding to the coil from the oscillator. This absorption is observed in that case only if the oscillator frequency coincides with the precession frequency of magnetic moments of electron under measurement. The sense of the phenomenon of elec-

tronic paramagnetic resonance is in this description, which consists in the resonance absorption of electromagnetic radiation by not-paired electrons.

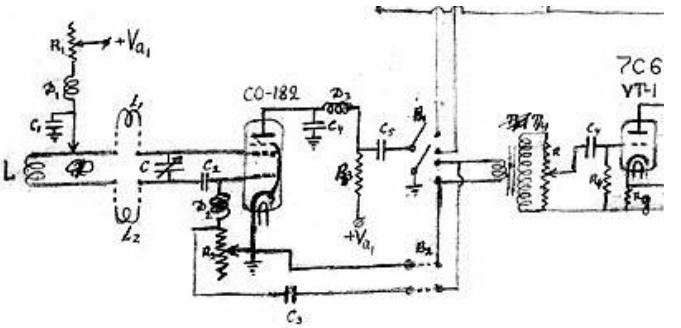


Fig. 5. Schematic diagram of Zavoisky's autodyne experimental bench.

Рис. 5. Принципиальная схема автодинной части экспериментального стенда Е. К. Завойского

To fix the EPR signal, it is possible based on variation of oscillation amplitude in the moment when the AC solenoid field passed through the resonance value or by the variation of oscillator grid current. To record these rather small variations the amplifier of low frequency was used (see on the right from the T4 transformer in Figure 5), on output of which the signal was recorded either by the help of milliammeter or on the oscilloscope screen.

4. Conclusions

From performed analysis of historical retrospective review of creation and development of the autodyne radio-spectrometer we see that the Zavoisky's phenomenon as the great scientist whose contribution was essential for not only in physics but in the theory and practice of autodyne and super-regenerative systems, was based on his deep knowledge and erudition in the various directions of science and engineering. To confirm and develop this conclusion we give the opinion of professor Ya. I. Frenkel, which was the first who attempted the first try of phenomenological theory creation of the electronic spin resonance (see footnote on p. 240): «Associate professor of Kazan State University Yevgeny K. Zavoisky with his scientific qualification is a long time ago outgrows his PhD degree and for pedagogic experience – the modest position of associate professor. He is a talented physicist with the very large erudition in different areas of experimental and engineering physics (especially in radio-physics and in oscillation theory) and the accurate experimentalist capable to solve (often at the present the very limited means) the extremely complicated experimental problems. His Doctor of Scienc-

es thesis expressively justifies of the remarkable experimental art of Ye. K. Zavoisky, in which the method of measurement of magnetic losses developed by him by means of reaction on the high-frequency oscillator – the method that is by hundreds rimes more sensible then those applied earlier, and which permitted the author to obtain the new extremely interesting experimental results concerning to magnetic properties of atoms, ions and electrons in paramagnetic bodies".

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