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Vladimir Aleksandrovich Kotel'nikov: the life's journey of a scientist

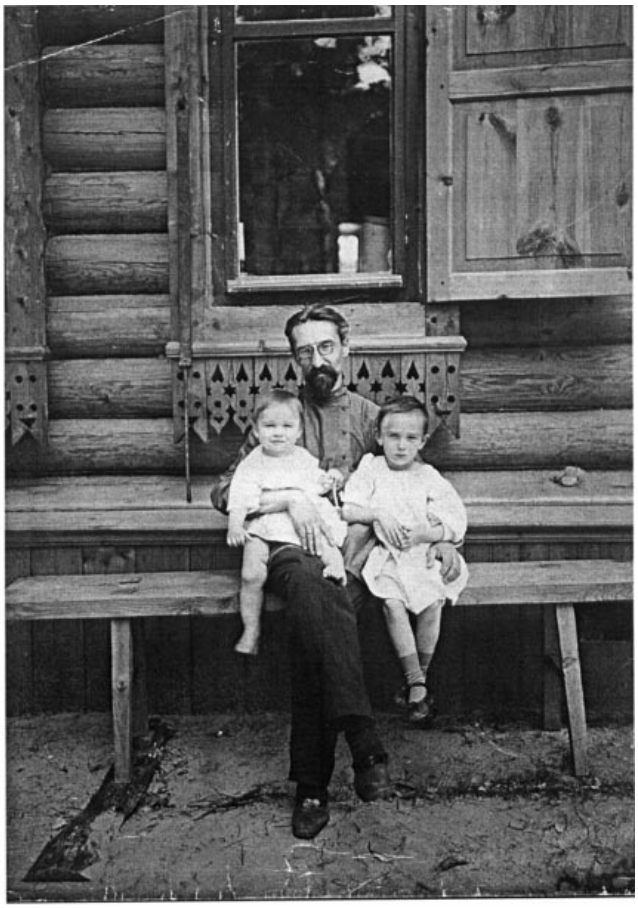
N V Kotel'nikova

In this talk we will outline some of the least known pages of V A Kotel'nikov's biography, covering his 'pre-academic' life. We describe his childhood and the path that led him to science, and also characterize the main stages of his creative life. Our guiding principle in this endeavor is to ''tell it like it was''. The text is based on Vladimir Aleksandrovich's reminiscences noted down by relatives and friends, on documents in the family archive, and on certain publications.

Childhood. Vladimir Aleksandrovich Kotel'nikov was born on September 6, 1908 in the city of Kazan' into the family of Kazan' University Professor Aleksandr Petrovich Kotel'nikov (1865–1944) and Varvara Petrovna Kotel'nikova (Litvinenko) (1878–1921), who was born and grew up in Kiev and graduated from a Kiev girl's school (gymnasium). The family had three children — Tatiyana, Vladimir, and Vsevolod, with three-year gaps between them.

The Kotel'nikovs, a minor nobility family, never rich, can be traced back to 1622. The line produced military officers, an office employee, lower-rung salaried persons, engineers, and scientists. Vladimir Aleksandrovich's great-great-great-grandfather — Semen Kirillovich Kotel'nikov (1723–1806), a mathematician, was only the seventh Russian scientist elected to full membership in the Russian Empire Academy of Sciences (1751).

His grandfather — Petr Ivanovich Kotel'nikov (1809–1879), mathematics Professor at Kazan' University, Dean of the Department of Physics and Mathematics — was the closest assistant to Nikolai I Lobachevsky. He was the only mathematician in the world who, during Lobachevsky's lifetime, not only understood his geometry but was openly his staunch supporter, posing a challenge to the entire scientific community at the time when Lobachevsky was vehemently vilified. Petr Ivanovich was the only person from whom Lobachevsky received public recognition of his merits as the creator of a new science.



Aleksandr Petrovich Kotel'nikov with son Vladimir (left) and daughter Tatiyana at the dacha in the village of Arakchino near Kazan' (1909).

Vladimir Aleksandrovich's father was Aleksandr Petrovich Kotel'nikov, also a professor at Kazan' University. He was an outstanding mathematician and mechanic, the creator of screw calculus, and one of the founders of the mechanics of a non-Euclidean space and spacetime geometry.

The happy and cloudless childhood of the boy Vladimir was spent mostly in Kazan' and lasted until the age of six (until the World War I). The Kotel'nikovs' home was frequented by friends and colleagues from the university and had lots of books and music. The adults were engrossed in work. As the children grew up, they were taught to play the piano and speak German. At the age of six, Vladimir learned to read and write and knew basic arithmetic, elementary algebra, and geometry, but for some reason he 'got stuck' on trigonometry. He was a great reader, set up interesting physical experiments under his father's guidance, and designed various mechanisms. Aleksandr Petrovich was a keen photographer and Vladimir observed the entire process, from preparing the photographic emulsion for photographic plates to printing the photographs. They attended exhibitions and even saw a genuine airplane. The father used to bring his son to the university where he showed him the mathematics study he himself created, with mathematical models of his own making. Much later this room and its rich library became the launching pad for the Mathematics and Mechanics Research Institute of Kazan' University [1].

In the summer of 1914 the parents made plans to move to Kiev, the city where the mother was born. She just could not get used to living in Kazan's climate and was frequently ill. At last she was able to persuade her husband to agree to an offer of professorship at the chair of mathematics at Kiev University. Aleksandr Petrovich was to start work at his new post in September. But suddenly their entire life was turned upside down — the World War I began. The family arrived in Kiev in August 1914 on the day when the frontline collapsed and the German army broke through; there was terrible panic, triggering an exodus of the population from the city. That was the beginning of the Kotel'nikovs' ordeal. It was with enormous difficulty that they were able to leave Kiev the next day and ultimately reach Kazan'. It then happened that the family found itself at the center of horrendous events near Kazan', then in Kazan' itself, and since the autumn of 1918 again in Kiev. Aleksandr Petrovich had to return to work in Kiev, which was terribly difficult. There was some hope that life in the new hetman republic would return to normal and the university would reopen. The matter is that the lectures in Kazan' University stopped when the university was evacuated to Saratov. In 1917, the university was closed, Aleksandr Petrovich lost his job and at the end of 1918 the Kotel'nikovs relocated to Kiev again. Vladimir Aleksandrovich recalled that their life in Kiev resembled very closely Mikhail Bulgakov's description in the novel *The White Guard* — the same period, the same place and the same circumstances. "It was a great year and a terrible year, the 1918th after Christ was born, but the year 1919 came to be even more terrible...." The city was a constant battleground, continually changing hands, and anarchy and destruction reigned. The times were terrible and hunger loomed. No money, nothing to

Petr Ivanovich Kotel'nikov (1809 – 1879), Vladimir Aleksandrovich Kotel'nikov's grandfather.

Aleksandr Petrovich Kotel'nikov (1865 – 1944), Vladimir Kotel'nikov's father.

sell — how could one feed a family? The professor boiled soap using recipes and ingredients that his friends and former colleagues would procure for him. The children would unravel covers and curtains and roll the thread into balls. The mother would bake buns from produce and additives that friends would provide... And the father would sell all this at the market. However, each evening Aleksandr Petrovich would sit at his desk and work late into the night. It is probable that the father's example, the passion of the scientist, his habit of permanent immersion in his work instilled in Vladimir the desire and ability to work on his own. Books and textbooks, which in this family were treated as living essentials, travelled with the owners from town to town. Reading them was exciting, and he digested 'science' on his own. Of course, he could ask his father for explanations of difficult points but this was not necessary.

In 1920, Aleksandr Petrovich was invited to work at the Kiev Polytechnic Institute, the very first higher education establishment to restart after all the 'perturbations'. Life seemed to slowly start improving. But misfortune struck: the entire family, with the single exception of Vladimir, who was miraculously spared, fell ill with typhus in 1921. Thereupon the great distress overtook their family — the mother and aunt Liza, the father's sister, died of typhus. All domestic chores and children's upbringing fell on Aleksandr Petrovich's shoulders. The older siblings — Tatiyana and Vladimir — greatly helped. Their tasks were to keep the house in order, cook dinner, help father with the vegetable garden, which was the main source of food, and take care of the younger brother Seva — he was to play the role of 'emergency helper'.

School. Institute. University. Vladimir entered school in 1922, directly into the 5th grade. Learning was easy, since he already knew so much. Physics was taught by an instructor of the Polytechnic Institute. His lectures were invariably very interesting and often took place in the institute's building where excellent experiments were demonstrated in a large lecture-hall. The mathematics teacher was a student of the same institute. As far as problem solving was concerned, Vladimir was his equal. Pupils published a hand-written newspaper ('wall paper') and children wrote articles about exciting achievements in science and engineering. Boys would only write about airplanes: this was the time of explosive progress in aviation. But Vladimir decided to write about radio. He believed he more or less knew the essentials of aviation but radio remained a total mystery.

He saw, or rather heard, a signal of a radio station for the first time in Kazan' in 1918 from either 'the reds' or 'the whites' during the battle for the city. His father explained that messages are sent via radio waves that we cannot hear or see. His son's question: "How does it work?" met with the answer: "This is something you cannot understand yet." After an answer like that, Volodya would typically try to think up his own explanation for the incomprehensible phenomenon or device and he usually succeeded. In this case, however, he failed miserably. Radio was awe-inspiring!

He did write that article. In fact, it required rapidly learning trigonometry which was not yet taught at school. However, this was insufficient for being truly able to read and understand papers in the radio engineering journal *Wireless telegraphy and telephony* that his father brought home on his request. (No popular magazines yet existed for the science concerned with radio engineering, which was only making its first steps.) That was when he decided that radio would be his field of serious work.

Volodya Kotel'nikov: "How in the world does radio function?"

In 1924, the family moved to Moscow. Kiev was the scene of intense 'Ukrainization'. Administrators demanded that professors deliver lectures in Ukrainian. Aleksandr Petrovich decided to take the children to Moscow. For some time already he had been invited to take up professorship at the Moscow Higher Technical School (MVTU in Russ. abbr.). Vladimir graduated from a secondary school in Moscow in 1925. All in all, he had spent three years in school but, as he always studied much himself, his level was sufficiently high for trying to enroll in a higher educational institution or university. Radio engineering as a major subject — Vladimir dreamed about it — was also taught at the MVTU but it accepted only people with worker or peasant roots, and only after they graduated from the so-called *rabfak* (workers' faculty pre-training schools). He had to enroll in a communications technical school. A year later, in 1926, he did get into MVTU — bars to enrolling were removed that year. Learning was a pleasure, and it was interesting. He attended only the lectures that he considered cognitive and useful and dealt with the rest by gaining an understanding from relevant textbooks. In parallel, he attended lectures at Moscow State University and covered the entire curriculum of the Physics and Mathematics Department of the University (it was at the time housed right in the center, on Mokhovaya street, where the Institute of Radioengineering and Electronics (IRE RAS) now resides).

Postgraduate courses. The Kotel'nikov theorem. In 1930, Vladimir graduated from the Moscow Power Engineering Institute (MEI), which by that time had separated from MVTU, and was, against his wishes, sent to the postgrad-

uate course. His dream was to join the Central Radio Laboratory (TsRL), the name of the former Nizhnii Novgorod Radio Laboratory after it was transferred to Leningrad. As a student, Kotel'nikov had practice terms there twice, after the first and third years, under B A Ostroumov's supervision. The results obtained during the first practice term allowed Vladimir to publish his first research paper "A triple characterograph (automatic recorder for volt – ampere characteristics)" in the proceedings of the Nizhnii Novgorod Radio Laboratory *Wireless telegraphy and telephony* (No. 46, 1928). However, at the dean's office he was told that, being the best graduate of the year, he should stay at the MEI. Kotel'nikov refused — he wished to do science. Teaching was not attractive for him at the time. While negotiations dragged on — MEI tried to persuade him and he refused — all vacancies at TsRL were filled. Only the dullest positions were still open — sheer supervision and maintenance work in other establishments. Kotel'nikov feverishly tried to figure out what to do with his life. He was not ready yet to give up on his dream. A way out was suddenly suggested by Professor I G Klyatskin, who ran into Vladimir in the corridor of the institute and offered him a position in his laboratory at the Communications Research Institute of the Red Army (NIIS RKKA). The decision was made. Alas, three months later the MEI administration learned about his place of work. A terrible scandal ensued, Klyatskin was accused of unprincipled behavior ... it couldn't be helped, Vladimir had to bow to fate and return to MEI. There he was immediately made postgraduate as of January 1931 (without any exams) and at the same time given the job of senior laboratory assistant. As a senior laboratory assistant, Vladimir was responsible for setting students' laboratory practice going. He was later promoted to assistant professor.

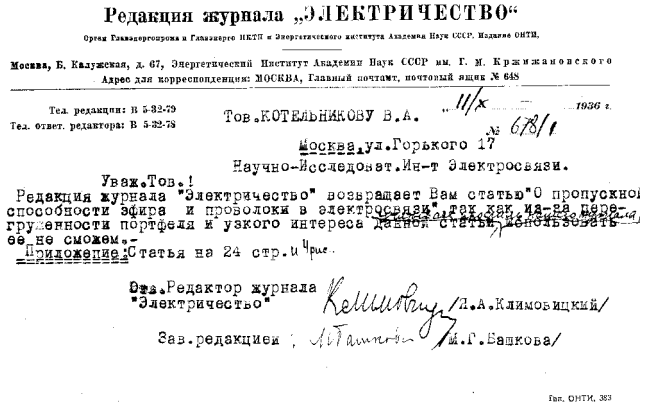
Author of the Kotel'nikov theorem.

It was within the precincts of the laboratories that he first met his future love and wife, Anna Ivanovna Bogatskaya (1916 – 1990). They got married in 1938, brought up three children, and led a life of love and devotion until the end of their days.

The postgraduate course at MEI in those years was cardinally different from what we know now. Postgraduates were their own bosses: no science advisors, no tutoring, no research tasks assigned. The only obligatory learning courses were philosophy and a foreign language; other subjects were selected by the postgraduate student himself. Vladimir decided that since he could not change the framework, he would do his research on his own. He carefully scrutinized pressing problems of radio communication and wire communication. As a result, he prepared in 1932 three papers, one of which — "On the transmission capacity of 'ether' and wire in electric communications" — was submitted as a report to the anticipated 1st All-Union Congress on the Technical Reconstruction of Communication Facilities and Progress in the Low-Currents Industry. The congress was cancelled but contributions to it were published in 1933 (Kotel'nikov's report was accepted for publication in November 1932) [2]. Completing his postgraduate term, Vladimir presented his results to the Learned Council of the department. The presentation was approved but the paper "On the transmission capacity of 'ether'..." and the significance of the sampling theorem proved in it were not understood by the council members — "sure, appears correct, but sounds more like science fiction". More is the pity! The work was outstanding in two aspects. First, it was a well-reasoned program document that cut off blind paths and pointed to promising and feasible approaches to the expansion of radio communication in the aspects of overcoming "overcrowding in the ether and wires". Among other things, the paper outlined a promising technique of transmitting radio waves "on one sideband". Time proved that the predictions by the young Kotel'nikov were right. He himself was advancing unflinchingly along a chosen path together with his laboratory at the Research Institute of Communications of the People's Commissariat of Communications (NIIS NKS) and then with his much later creation — the Institute of Radioengineering and Electronics of the USSR Academy of Sciences (IRE AN SSSR). Second, this work was future-oriented. For the first time there, it was a substantive discussion of the information aspect of communications problems. Vladimir built a mathematical foundation for the prediction of digital data transmission (he proved what in the future became the famous Kotel'nikov theorem). His idea formed the basis for today's information theory. In this aspect, the work was ahead of its time by at least 15 years. It was fully appreciated only at the end of the 1970s when it became possible to replace the analog system of data transmission with that of a digital one [3].

No science degrees were given to people in the early 1930s. On the initiative of the Leningrad Electrotechnical Institute (LETI), the candidate's degree in technical sciences (an equivalent to a PhD) was formally conferred on Kotel'nikov in 1938 without a viva voce procedure.

The subsequent history of the Kotel'nikov theorem, also known as the sampling theorem, formulated and proved by a 24-year-old 'unsupervised' postgraduate, reads very much like a detective story. Vladimir fully understood its signifi-



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Увaж. Тов.!
Редакция журнала "Электричество" возвращает Вам статью "О пропускной способности эфира и проволоки в электросвязи", так как из-за перегруженности портфеля и узкого интереса данной статьи, использовать ее не сможем.
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Letter from the editorial board of the journal *Electricity* rejecting the paper with the Kotel'nikov theorem (handwritten insert into the typed letter: "...in view of the specific profile of our journal, ...").

cance and tried to publish an article in 1936 in a journal *Elektrichestvo* (Electricity) (the official publication of the Energy Institute of the USSR Academy of Sciences) more widely read by professionals but the manuscript was rejected! "OK, rejected, so be it! People who need to know will read it in 'Conference proceedings' ", — was his decision and he continued to work, completely forgetting this episode. He only recalled it almost seventy years later, when he was shown the rejection letter that survived in his archive (see the figure above).

Fifteen years later (1948) Claude Shannon formulated his sampling theorem [4]. Ideas do hang in the air, and similar theorems did appear at different points on the globe, spread over time and differing in the rigor of proof of the theorem. Because this theorem is of supreme importance in information theory, experts in the field focused their attention on it, especially in the 1970s when progress in electronics made it technically possible to implement the digital transmission and recording of data. In 1977, when the discoverer's priorities were realigned, it was proposed to refer to it as the WKS-theorem, namely, the Whittaker–Kotelnikov–Shannon theorem [5, 6]. Ultimately, in 1999, the Eduard Rhein Foundation, summarizing the results of the most outstanding scientific discoveries of the 20th century, awarded its Prize in the nomination 'for fundamental work' to Russian scientist Vladimir Aleksandrovich Kotel'nikov "for the sampling theorem first rigorously formulated and published", the theorem which is the cornerstone of all modern (now digital) radio engineering and computation engineering.

In an article preceding Kotel'nikov's nomination for this prize, Hans Dieter Lüke wrote about the article "On the transmission capacity of 'ether' and wire in electric communications" that as this brilliant paper was never published in internationally accessible journals, publications of the sampling theory in theoretically exact formulation appeared in the literature on communications systems independently of each other [6]. In view of the fact that this work continues to be of great interest even today, albeit from a historical point of view, *Physics Uspekhi* publishes it for the first time in an 'internationally accessible journal' in the present issue of our journal in the Supplement to this presentation.

Research Institute of Communications of the People's Commissariat of Communications. (Later renamed TsNIIS NKS by adding 'The Central'.) Having graduated from the postgraduate course in 1933, Vladimir Kotel'nikov, continuing to teach at MEI (first as lecturer, then as assistant professor), began working at the NIIS NKS (engineer, chief radio engineer of the institute, head of a new laboratory). In 1936, Kotel'nikov published two pioneering papers in nonclassified publications [7, 8] in which he, as one of the first to achieve it, made use of probability theory to analyze the efficiency of multichannel systems for signal diversity reception and proposed a general analytical method for studying a nonlinear distortion of signals in various devices. Progress in such methods was achieved in the late 1940s in the work of outstanding Soviet and Western scientists [9]. In 1935–1936, the government finalized the strategy of building trunk lines of short-, mid-, and long-range radio communications. In the framework of this directive, NIIS began to develop new equipment for such communication lines. From his days at MEI, Kotel'nikov 'carried' the firm conviction that the wonderful idea of "analog transmission on one sideband" [2] can and must be implemented. Having overcome the resistance of his superiors, he and his team succeeded in implementing this idea and created unique equipment. The industry refused to accept the order for manufacturing the devices designed: "Impossible to produce as no one has ever built it anywhere". "We'll do it ourselves" was Kotel'nikov's decision, and the team succeeded. The equipment was installed on the Moscow–Khabarovsk trunk line (1939). This was an outstanding project for the time. However, the unique radiotelephone circuit, though ready and tested, was not certified for service; the reason was: "too easy to intercept". It was necessary to find a way out, and in a very short time. Kotel'nikov had never worked in cryptography before and had no access to the relevant literature and experts. After a careful analysis, he came to the conclusion that the problem could be handled. The team urgently accepted a challenge. They started from scratch. They had to solve numerous scientific and technical problems as the new equipment would be of an absolutely unknown type. Having read a paper by H Dudley [10] that appeared in October 1939, Kotel'nikov immediately understood the excellent potential advantages of the vocoder (artificial voice generator), described there as a promising device for basing the necessary voice encoding equipment. The first vocoder in the USSR was already working in the laboratory at the beginning of 1941. Kotel'nikov worked under the enormous pressure of deadlines, and had to figure out the main problems of cryptography. He presented his arguments in the report "Fundamentals of automatic encoding", which was submitted just three days before the Great Patriotic war broke out, on June 19, 1941. The report had for the first time "given clear formulation of requirements that a mathematically non-decipherable system must meet, and proof was given of the impossibility of its deciphering" [11]. This work laid the basis for the development of cryptography in the USSR. Unfortunately, not many people know about this work — it was never published in the open media. Four years later, C Shannon described approaches to building deciphering-resistant systems in a classified report dated September 1, 1945. This report was declassified and published in 1949 [4].

The war years. The arrival of the war forced Kotel'nikov and his group to interrupt their research projects and urgently begin designing pilot samples of new equipment. They worked almost around the clock. Soon, with the war front approaching Moscow, NIIS was disbanded and all staff dismissed. Only Kotel'nikov's laboratory was left working

Staff of Kotel'nikov's laboratory (Ufa, April 1943). Standing (left to right): E Kunina, E L Gavrilov, V N Melkov, N N Naidenov. Sitting (left to right): A M Trakhtman, D P Gorelov, Kotel'nikov, I S Neiman, V B Shteinshleger.

as it conducted classified work on radio telephony that was urgently needed at the front. The instruction was: receive the money and pay off all discharged employees of the institute; burn the documentation except the most important; prepare the equipment of the laboratory for evacuation, and if the German army broke through to Moscow, blow up the building of the institute. The first three instructions in the order were implemented. Luckily, there was no need to blast the building. On October 17, 1941, the following entry appeared in Kotel'nikov's personal work-book: "Dismissed from work in view of going on vacation". And the 'vacations' did begin: step by step, the laboratory was evacuated to the town of Ufa in the Bashkiriya in October and November. There was a complication in resuming the work on the equipment: most of the design documents had been destroyed. Despite this, several units of secret radiotelephonic apparatuses were produced by autumn 1942 and were immediately sent to the Transcaucasian front, which had no communication with the center during the battle of Stalingrad (the armies were then using wire communication lines). As a result, it became possible to restore communications via the radio channel. By the beginning of 1943, production lines for this equipment were functioning and the Armies in the Field started using it. This saved the lives of many Soviet soldiers and constituted a huge contribution to the ultimate victory. At the time, this was the most advanced system of secret radiotelephone communications, virtually 'crack-proof'. This same equipment was used to connect Moscow to the Soviet delegation at the signing of Germany's capitulation in May 1945. The staff of the laboratory received awards for this work — First Class Stalin Prizes (1943). The money was donated to meet the needs of the war effort. Kotel'nikov's prize money went into building a tank.

Experts believe that no efficient algorithms for deciphering messages encoded with modernized systems of this type were available until the early 1970s [12].

Return to Moscow. The Moscow Power Engineering Institute. In the spring of 1943, Kotel'nikov's laboratory was relocated from Ufa back to Moscow and transferred to the disposal of the People's Commissariat of Internal Affairs (NKVD) of the USSR. There it was bandied from department to department... At that very moment Kotel'nikov was found by V A Golubtsova — the new Rector of MEI. The war was

Kotel'nikov (center) in the laboratory room of RTF MEI (1946).

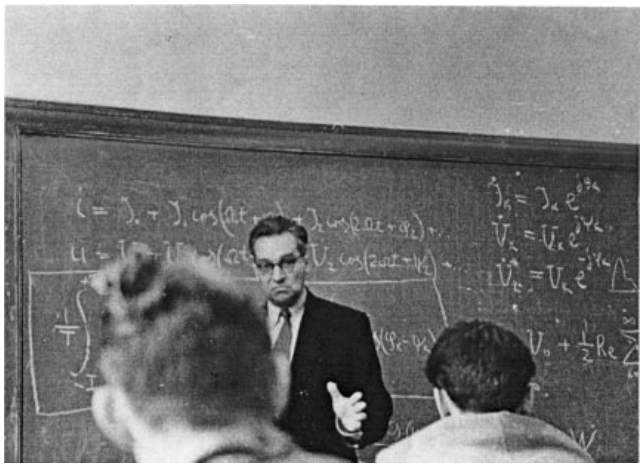
still on but the country was beginning to reconstruct the national economy ruined by the enemy. MEI required rebuilding too — the country needed engineers. Having outlined MEI's problems and prospects for expansion, Golubtsova suggested that Kotel'nikov return to MEI. Kotel'nikov was only too glad to oblige. He preferred to do science in a nonmilitary establishment, and even more so in his alma mater. Incidentally, Golubtsova's husband was G M Malenkov, First Secretary of the Central Committee of the Communist Party of the Soviet Union. It is probable that this was the decisive factor that made it possible for Kotel'nikov, in his position as head of a top-secret project, to escape from the NKVD system to MEI. The order finalizing the transfer to MEI to a position of Head of the Chair of Fundamentals of Radio Engineering (ORT) that he was yet to create at the Radio Engineering Department (RTF) was signed on November 1, 1944. Some time later Kotel'nikov was also elected Dean of the RTF. He is regarded as one of the founders of RTF. His multifaceted efforts at MEI built the 'V A Kotel'nikov scientific and pedagogical school' that advanced along three main directions: further expansion of the ideas of the theory of potential noise immunity that he had created; research related to the theory of the electromagnetic field and expansion into yet unconquered ranges of the electromagnetic spectrum (millimeter, submillimeter, infrared, and optical wave bands), and engineering applications of the theory [12].

Kotel'nikov was firmly convinced that the main task of a training program was to impart a good knowledge of physics and mathematics and to teach the future specialists to think independently. He was the first to introduce theoretical physics into the MEI curriculum. Kotel'nikov's courses on 'Fundamentals of radio engineering' and 'Electrodynamics' (he always conducted them himself) were tremendously popular. They were attended by students and lecturers not only from the Radio Engineering Department but from other

departments as well. Kotel'nikov was known as Reformation Dean. While he held this post, a number of important transformations took place in the department; for instance, he introduced a new speciality for study — radiophysics [13].

At the same time he continued to supervise and consult his former laboratory on the main problems of secret telephony.

Theory of potential noise immunity. One day in the spring of 1946 Golubtsova called Kotel'nikov to her office and stated quite decisively: "Vladimir Aleksandrovich, you absolutely must maintain a thesis for doctorate of sciences". OK, so be it. This had not been a point he had been thinking about earlier. He had no concrete ideas about the subject of his thesis. A legend exists that a draft of a future DSc thesis on potential noise immunity was scribbled on scraps of paper in the difficult years of evacuation but was unfortunately lost on the way back to Moscow. Not true. One suitcase was indeed stolen but no rough copy of the thesis was in it. No thesis existed at the time. The most valuable object in the suitcase was a loaf of bread. In the summer Kotel'nikov took his usual holiday, packed the family off to the summer cottage and started creating the "Theory of potential noise immunity" — that was the title he gave to his thesis. Completing the writing during the holiday weeks proved impossible and he had to finalize the text in the evenings after work. The thesis was ready by autumn. However, the dissertation presentation and its defense ran into a snag. It was not easy to find official opponents because nobody understand the essence of the work presented. "For the science community, the theory emerged virtually 'from thin air'" [14]. The author could not even cite anyone. This work was ahead of its time by about ten years. Academician Nikolai D Papaleksi was invited to write a review of the doctoral dissertation. Papaleksi took a look at the thesis and concluded that he failed to understand anything. To make matters worse, there were no references to other publications and the competitor had no supervisor — he stood all by himself. Papaleksi refused to act as opponent. Ultimately, the official opponents were found and the thesis was defended in January 1947. Witnesses recalled that the impression was that hardly anyone was able to understand much, even the opponents. But everyone had the feeling that right then and there "something very important was being born". It became clear later that what was born on that day was one of the two mutually complementing branches of the information theory. The other branch, C Shannon's work,



"That's how it is...very simple...." (Giving a lecture at MEI (1947).

At a demonstration in a red-letter day, with wife and daughter Nataliya (1948).

appeared in 1948 [4]. In his work Kotel'nikov analyzed for the first time the main problems of communications from the standpoint of probability theory. It provided a powerful impetus for the advance of the statistical theory of message transmission, statistical synthesis of optimal methods of signal processing, and development of efficient algorithms for signal receivers [15]. The author only published a single short paper "Problems of noise immunity in radio communications" (1947) [16] on the topic of his thesis. The second copy of the thesis was duly submitted to the V I Lenin State Library in Moscow for archiving. The work was never published in full at the time. Kotel'nikov probably understood that the situation was no different from what he faced in the case of the previous paper "On the transmission capacity of 'ether' and wire in electric communications". Given that even Academician Papaleksi failed to understand the work, what hope was there of publishing it? "Whoever needs to will find and read it at the Lenin Library", was his decision. Kotel'nikov's monograph *The Theory of Potential Noise Immunity* [17] was published only in 1956, after the first papers devoted to this topical problem began to appear in Western journals. The publication created a huge stir in the entire 'radio engineering world'. Kotel'nikov became world famous!

In 2005, a list of "Printed works of V A Kotel'nikov. 1950" was discovered in Kotel'nikov's archive. The relevant line reads: "*The Theory of Potential Noise Immunity* — a monograph of 12 printer's sheets [1], manuscript, prepared for publication by Svyaz'izdat". It is hardly possible for those who knew Kotel'nikov to imagine that he 'delayed' the realization of a pre-planned job by six years. It is likely that this work was also declined by the publisher.

The Marfino Laboratory or "Third Circle". Alexander Solzhenitsyn's *The First Circle* and K F Kalachev's memoirs *The Third circle* [18] describe events that took place at the

[1] *Translator's note*: 1 printer's sheet comprised 40,000 typographical units, roughly 4000 words.

Two times First Class Stalin Prize (State Prize) laureate (1946).

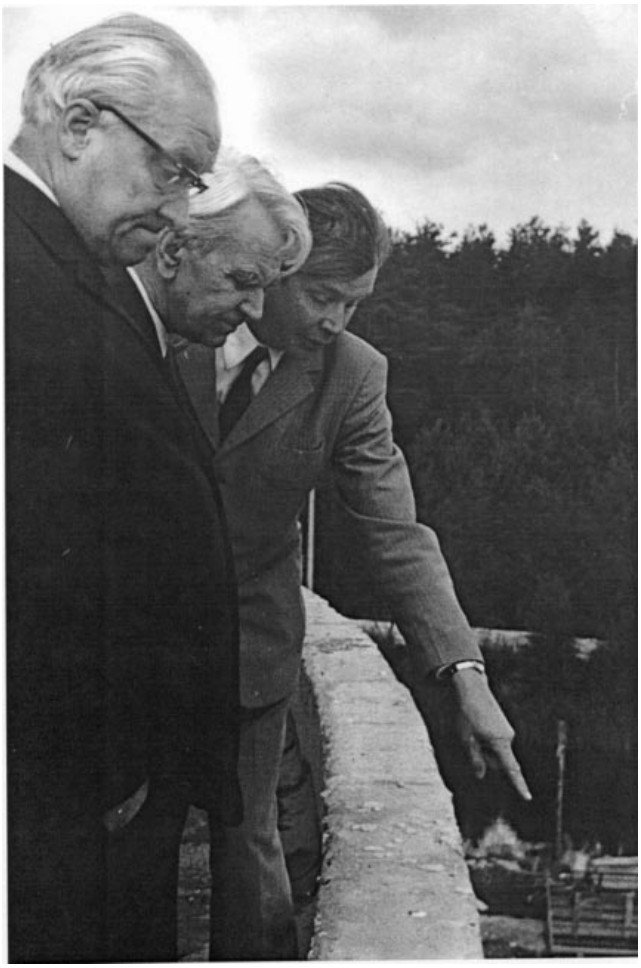
same time and in the same place — the Marfino Laboratory. Both authors worked there but their stations in life, feelings, visions, and reactions were inevitably different. Solzhenitsyn's 'First circle' is a circle of hell for an imprisoned engineer. For Kalachev, a 'free' expert, the 'third circle' is the third stage in the work on secret telephony. The principal scientists and designers of the Marfino Laboratory came from Kotel'nikov's former laboratory which became subordinated to the NKVD technical department after their return from evacuation. Kalachev also worked on Kotel'nikov's team but that was before the war. At the time the Marfino Laboratory was created, Kotel'nikov had already returned to work at MEI.

In 1947, the Ministry of Internal Affairs (MVD) and the Ministry of State Security (MGB) of the USSR decided to establish a Specialized Laboratory for developing the equipment for 'absolutely security-restricted' telephone conversations over governmental radio-frequency communication lines. In view of the top importance of the tasks assigned to the laboratory, it was decided that it must be headed by a brilliant scientist, a well-known expert in the field. There was every reason to consider Kotel'nikov the founding father of secret telephony [11, 18].

One day (in 1947) Kotel'nikov was called to the office of the Minister for the USSR State Security V S Abakumov. The conversation proceeded in a polite and respectful manner. Having outlined what sort of Specialized Laboratory he needed, Abakumov suggested that Kotel'nikov be its head. Kotel'nikov declined the offer. The Minister was surprised to the extreme — he was not in the habit of being turned down. His 'proposal' normally meant 'order'. Abakumov asked what the reason for the refusal was. Kotel'nikov calmly explained that he wished to be engaged in scientific research. Abakumov tried to win the stubborn scientist over by promising numerous perks and privileges. Kotel'nikov stood his ground. "Well, that's a pity ..." concluded the Minister, and the meeting ended.

On his way back to MEI, Kotel'nikov mulled over the resulting situation and what kind of aftermath this "that's a pity..." may bring. Back at MEI, he went straight to the Rector Golubtsova and described for her the visit to MGB. Having heard him out, she asked what he himself wanted. The answer was: "To work at MEI". To which she replied: "Then continue to work calmly as before".

From Special Sector to Special Design Bureau (OKB) of MEI. Having created the ORT Chair at the MEI RTF Department, Kotel'nikov surrounded himself with a team of highly talented scientists and engineers. In 1944 – 1947, they developed telemetric equipment for airplanes, which was found to be excellent. In 1947, exciting new projects were launched in the USSR in the framework of the Missile and Space Program, which MEI actively joined. A Sector of Special Tasks was set up by direction of the USSR Government to carry out research and development studies for the needs of rocket weapon (Special Sector). The Special Sector was mostly based on the (substantially expanded) staff of the

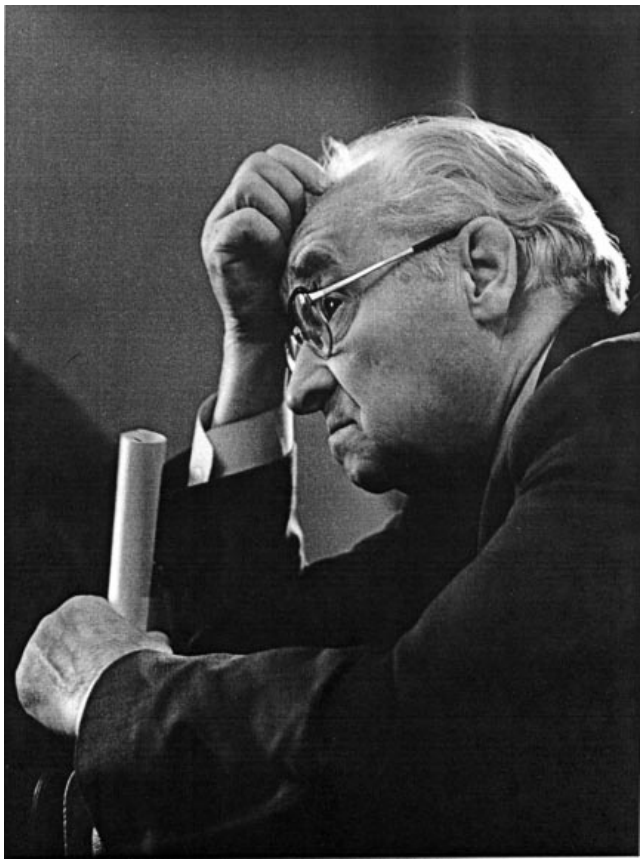


It is clearer if seen from the height of the antenna (Medvezh'i lakes). Left to right: Kotel'nikov, M V Keldysh, A F Bogomolov.

ORT Chair. It did not take long time for the sector to become one of the leading organizations of the missile and space industry and was later renamed OKB MEI. It was headed by Kotel'nikov. Under his guidance a large-scale research, design, and development program was implemented to develop integrated radio engineering systems on different scales and to vigorously expand the missile and space industry. In a number of cases the Special Sector took on itself the problems that an industry rejected as too difficult or problematic. Kotel'nikov in his capacity of Chief Designer of the Special Sector was a member of the interdepartmental Council of Chief Designers, headed by Sergei P Korolev. The presence of every chief at every systems test, not to mention a missile launch, was a *conditio sine qua non* — "to have someone responsible in case something went wrong". At the time when the Missile and Space Program was in its infancy, life at the 'raketodromes' (proving grounds) was quite rough. Like many other expert technicians, those of the Special Sector lived in mud-huts excavated right in the steppe, not far from the missile testing grounds. Bosses were allotted 'more comfortable' quarters — in some sort of a small house close to the Kapustin Yar railway station, or in railway carriages of a train parked in a dead end. They would be taken to the testing area by cars. Kotel'nikov preferred to live in a mud-hut with the 'crowd', and would use a joke to deflect suggestions to move to 'bosses apartments': "Too far to drive to the workplace". Missiles were launched around the year, regardless of the weather — in terrible heat, in the rain, in freezing weather, during a snowfall... Everybody worked with great enthusiasm, notwithstanding the difficulties. Note that Kotel'nikov continued to be the Dean of RTF, and continued to carry out his duties at the ORT Chair, as its Head and lecturer.

Kotel'nikov headed the Special Sector until 1955 when he handed the 'reins of government' to his highly talented pupil A F Bogomolov (a future academician). However, his connection to the Special Sector (under a new name OKB MEI) was not broken. In 1983 – 1984, the two bodies built by him, IRE AN SSSR and OKB MEI, worked successfully 'hand in hand' throughout the entire stage of preparation and implementation of the brilliant project that he thought up and headed — the radio-cartographic scanning of the surface of Venus. The experiment proved a success and produced unique and spectacular results!

The USSR Academy of Sciences. The Institute of Radioengineering and Electronics. In 1953, in late summer or early autumn (Kotel'nikov was not sure about the date), Academician Aksel' Ivanovich Berg invited Kotel'nikov to the Central Research Institute of Radio Engineering (TsNIRTI), which he was Director of at the time. Berg told him that an idea was being discussed of establishing within the Academy an institute that would have for its main task theoretical studies and engineering in the field of radio engineering and electronics, and asked for help in composing consitutative documents. Kotel'nikov was only too happy to help. He felt great respect toward Berg. They had known each other since way back. In pre-World-War years (1933 – 1937) Berg, then Head of the Research Institute of Naval Communications, visited NIIS NKS and read a report to the staff. He remembered a young engineer Kotel'nikov who was very active and asked well-informed questions, of the sort we say hit the bull's-eye. After the report, the two continued to discuss for a long time various problems in radio engineering. The paths of the two 'radio men' kept crossing.



Auditioning interesting report.

Immediately after the war they were organizing the A S Popov Society, followed each other as Chairman of the Organizing Bureau of the Society, worked together on the State Commission on assessing the work of the Marfino Laboratory and the equipment it developed (1950 and 1952).

Kotel'nikov arrived at TsNIRTI in the evenings and 'composed' documents in Berg's study. The academician himself was too busy. The relevant directions and other constituent documents for the institute, which was to have the title 'The Institute of Radioengineering and Electronics', were soon prepared, debated and approved. All the resolutions involved were passed in September 1953 and the IRE AN SSSR had 'arrived'. Academician Berg was given an assignment as its Director. The same autumn Kotel'nikov was invited by the Academician-Secretary of the Division of Technical Sciences B A Vvedensky and was informed: "We wish to propose your candidature for Full Member of the Academy, any objections?" Much surprised, Kotel'nikov gave his agreement and Vvedensky added that if Kotel'nikov was elected, the Division planned to offer him the directorship of the Institute of Automation and Telemechanics, where the Academy faced problems with its director. Kotel'nikov was indeed elected Full Member of the USSR Academy of Sciences in October 1953 (bypassing the first stage of Corresponding Membership). It appears that his candidature was seconded by Academicians Berg and Vvedensky. (Kotel'nikov took no part in the election campaign.) Immediately after the election Berg suggested that the new academician start the process of creating the just enacted IRE, in the position of the First Deputy to its Director. Kotel'nikov agreed. To create such an Institute! Marvelous!

In November 1953, Kotel'nikov was transferred to his new position of Vice Director of IRE, which still existed on paper only, and became its Director in 1954. (Berg had already been promoted to Deputy Minister of the USSR Ministry of Defense in 1953.) Berg was known as an incomparable strategist and kept his plans well hidden until the right time. He jokingly remarked some time later that he could already discern in Kotel'nikov the directorship of the Institute. Enormous work has begun on the establishment of the institute: the selection of personnel, definition of the subjects of research, searching of premises for the institute, their putting in order, setting up the design bureau, etc. In a very brief space of time, IRE AN SSSR turned into the leading institute in the field of radiophysics, radio engineering and electronics not only in this country but also the world over.

Kotel'nikov was not only Director of the Institute but at the same time the initiator, scientific leader and immediate executor of numerous scientific and technical projects whose realization yielded unique scientific results. All those who collaborated with Kotel'nikov noted his exceptional erudition, scientific intuition, ability of inquiring into the heart of the matter, and the possession of enormous capacity for work.

Vladimir Aleksandrovich Kotel'nikov was forty five years of age at the instant of his election as Full Member of the USSR Academy of Sciences and the onset of establishing IRE. Next fifty one years of his active and successful creative life were ahead of him.

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