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V A Kotel'nikov and his role in the development of space radio electronics in our country

B E Chertok

Vladimir Aleksandrovich Kotel'nikov's contribution to astronautics, to space technology in general, and to space radio engineering in particular is so huge that one can elaborate on this subject for a long time and in great detail. Here, I briefly list the main investigations in this area, performed under his supervision and more recently by the school he created. Furthermore, I will enlarge on some of his personal traits as a great scientist, who I met during my work of very many years in this field.

Kotel'nikov and Chertok at a session of the A S Popov Russian Scientific-Technical Society of Radio Engineering, Electronics, and Communications (Moscow, House of Scientists, May 2003).

The matter is that Kotel'nikov quite often reproached me for drawing him into work in the area of astronautics. He would do this very politely and subtly, so that I could not understand whether he was really displeased with this or was paying me a compliment in this way.

Everything commenced when Stalin approved on 13 May 1946 the historic resolution on the creation of the rocket branch of industry, engineering, and science in the Soviet Union.

In line with this resolution, despite the hard postwar time the country was enduring, base institutions were established and were growing quickly. In particular, they established a leading research institute for rocket technology, the Scientific Research Institute of the Ministry of Armaments in Podlipki, which went down in history as NII-88, the now universally known Central Scientific Research Institute of Machine Building (TsNIIMash in Russ. abbr.), and the S P Korolev Rocket and Space Corporation (RKK) 'Energiya'. I was Deputy Chief Engineer responsible for control systems.

One fine day, early in April 1947, the President of the USSR Academy of Sciences Sergei Ivanovich Vavilov came to the Institute to familiarize himself with its work. He was that kind of scientist who realized that a breakthrough in this new area called for combining the efforts of industry and academic science with the potentialities of personnel of higher education establishments.

Vavilov arrived at NII-88 with Rector of the Moscow Power Engineering Institute (MEI in Russ. abbr.) Valeriya Alekseevna Golubtsova rather than with a retinue of academic scientists.

The meeting of Vavilov and Golubtsova with the governing body of NII-88, in which I participated, marked the beginning of the process of drawing academic scientists and the scientists from institutes of higher education in a new area of human activity — rocket and space exploration.

One of the outcomes of the utmost significance of this meeting was drawing Vladimir Aleksandrovich Kotel'nikov into creative activity in the area of rocket technology.

On familiarizing himself with the problems which then called for the active participation of scientists of different expertise, Vavilov came up with the idea of establishing

V A Kotel'nikov and B E Chertok with a group of staff members and guests of the Special Design Bureau (OKB) of MEI. Sitting in the first row (from left to right) are M E Novikov, M N Meshkov, A L Zinov'ev, A F Bogomolov, K A Pobedonostsev, Kotel'nikov, and Chertok (Moscow, OKB MEI, 1997).

within the Academy a specialized institute — which was to become the Institute of Space Research (IKI) — and promised to oblige academic institutes to directly participate in this NII-88 activity.

Golubtsova in turn suggested that I — Deputy Chief Engineer of NII-88, a former student and postgraduate student of MEI — should come to my native institute and tell the scientists there about our problems.

Already the next day (one could not afford to linger in those days) I went to MEI. There assembled a group of scientists, maybe the Scientific Council, with Golubtsova herself presiding over the meeting. I outlined the main problems we were facing, although we lacked the understanding of what these problems consisted in, because the business was still early in the making. The next day Golubtsova called me once again and I found myself in a group, among which was Kotel'nikov as the supervisor and Head of the Chair of Fundamentals of Radio Engineering. And then I told them what was most important to us at that time — to be able to continuously monitor rocket parameters in real time by radio engineering aids. Attempts to do this with the help of conventional air-defense radar had not met with success. It was either that the radar measurements were insufficiently precise or that they were basically unsuitable for the parameters of motion of the rockets launched.

Only 10 days after our meeting in Golubtsova's study, on 27 April 1947 the Government passed a resolution, which was approved by Stalin, about setting up at MEI a top-secret Special Sector for carrying out specialized research in the interests of jet armament. So prompt and efficient a reaction was impressive even to us, who were accustomed to timely decisions by the Government.

Kotel'nikov was appointed scientific leader of the works of the Special Sector.

At that time Kotel'nikov was the Dean of the Radio Engineering Department at MEI and the Head of the Chair of Fundamentals of Radio Engineering. It was not until January of 1947 that he defended his doctoral dissertation. However, during the war with Hitlerite Germany in 1943 he was awarded a First Class Stalin Prize, and in 1946 a second First Class Stalin Prize, for the development of special communication systems. At that time, Kotel'nikov was regarded as belonging to the generation of young scientists in the field of radio engineering. He had gained the recognition of the scientific community not only for his secret inventions; he had developed the theoretical foundations of information conveying and showed practical ways of using them. Back in 1933 he published the so-called sampling theorem which proved to be the key element of digital communication technologies. The gist of Kotel'nikov's theorem is that it predicts the conditions when the initial signal of an information transmitter may be recovered error-free from the values of discrete samples. He was the first to show that analogue information may be transmitted by pulses, to state it in modern terms, in a digital code and may be recovered upon transmission. Kotel'nikov became well known to the radio engineering and communication community after the construction of the theory of potential noise immunity. This was the subject of his thesis for Doctorate of Sciences defended in 1947.

Kotel'nikov's 'involvement' in space radio engineering commenced with issuing the Government's Resolution on establishing the Special Sector at MEI. This was precisely the reason we met; later on, we would meet dozens of times, and he would say in jest that I had involved him in this affair. His activity in this area during subsequent years was really exceptionally fruitful, both in the volume and the content of what he contributed as a personality and a scientist. Sometimes his mere presence and participation in the work, even without inventing anything new, seemed to be a breath of fresh air in situations where the problem had to be completely revised.

The young team of the MEI Special Sector rallied round Kotel'nikov and worked with great enthusiasm. To his historical credit, the Sector turned into a scientific school. In essence, it was precisely he, Kotel'nikov, who laid the groundwork for and set up the now widely known Special Design Bureau (OKB in Russ. abbr.) at MEI — a powerful and highly qualified organization which designs and makes radio-engineering systems intended for missiles and spacecraft.

Kotel'nikov entered the closed community of rocketeers, which was led by S P Korolev, as a scientist and engineer. He shared with us, rocketeers, the difficulties of the first years of life in the proving ground, and the conditions were such that we literally 'slept under a common overcoat'. Kotel'nikov quickly gained authority over worldly-wise combatant generals and chief designers. His sense of humor and inexhaustible optimism would smooth over tensions between chief designers in situations where missile launches failed. The participation of Kotel'nikov and his collaborators was so substantial that both the work and flight tests could no longer be thought of without the systems developed by the MEI Special Sector and, more recently, without the equipment which was designed by the OKB MEI and then went into major serial production. All the first flights, which went down in the annals of space rocket technology and underlay the priority of our country, were made with the inevitable use of radioengineering devices created by Kotel'nikov's school. The case in point is rocket-borne and ground-based radioengineering equipment which monitors the flight of a rocket and its trajectory, as well as providing an impression of the spacecraft orbit in real time, not to mention, which is very important, remote measuring equipment which continuously transmits to the Earth the values of all the parameters of interest to both the developers and those who operate the spacecraft.

Kotel'nikov achieved independence from the industrial ministries in the production of the systems under development; at MEI he set up an experimental workshop — subsequently a plant with a closed cycle. They had to make their equipment and systems in cut-throat competition with powerful industrial organizations for the right to equip the first intercontinental rockets and spacecrafts. Nowadays it is quite often said that there was no competition in our previous system, our former economy. Nothing of the kind: there was competition, maybe even more severe than in the so-called free-market economy. Because industrial ministries believed that it was their exclusive right to develop systems of this kind. In particular, the Ministry of Industry of Communication Facilities and the Ministries of Radio Engineering and Electronics insisted on that. And now, some special-purpose department, an OKB at a higher education establishment! Everybody knew and respected Kotel'nikov, but he was subordinate to the Minister of Higher Education, and this aroused intense jealousy. And there were many committees, in which I had to participate, to decide whose design was to be put into operation and added to the armory. Kotel'nikov's school won all these contests despite the departmental pressure.

The first systems developed by Kotel'nikov and his colleagues for rocket technology were 'Indikator-D' and 'Indikator-T'. The first R-2 rockets of Chief Designer Korolev were equipped with these systems in flight tests beginning in 1950.

The Indikator-D system enabled precise recovery for the first time of the rocket trajectory from the observations of ground-based radio posts.

Indikator-T was the first radio-telemetric system made at MEI. In 1953, a start was made on batch production of rocket-borne equipment for the radio monitoring of the trajectories of rocket flights. In 1955, a phase-metric Irtysh system was made for monitoring orbits.

The subsequent Rubin and Almaz modifications of external trajectory measuring systems were made in large batches and were an obligatory constituent in the flight tests of all types of rockets and the majority of spacecraft.

In the early 1950s, Kotel'nikov's team developed the famous radio-telemetric Tral system. This system outstripped the level of the corresponding foreign and domestic systems by no less than 10 years. In the conditions of extremely limited component types, which lagged behind the American one, they made an efficient system using a time-pulse code and ingenious circuit-technical solutions which ensured high reliability. On-board Trals were produced in large quantities. The Tral system was the main tool in the elaboration of the first intercontinental missile R-7 and crewed space vehicles, as well as the flight tests of the basic missiles of our nuclear-missile shield. Dozens of ground-based radio posts were constructed on the territory of the Soviet Union, which were united in a single control-measuring complex. The telemetric Tral stations and orbit control Kama stations, which were developed by the MEI Special Sector and quantity-produced by industry, were obligatory equipment in these posts.

In 1957, the telemetric system developed by MEI was first launched in space in the second artificial Earth satellite; for the third artificial satellite, Kotel'nikov's team developed a complex of trajectory and telemetric measurements.

In 1953, the academic community elected Vladimir Aleksandrovich Kotel'nikov a Full Member — an Academician — of the USSR Academy of Sciences, foregoing the traditional stage of Corresponding Member. He was appointed Deputy Director of the newly established academic Institute of Radioengineering and Electronics (IRE). In 1954, Academician Kotel'nikov superseded Academician Aksel' Ivanovich Berg as Director of this Institute. In 1955, he had to leave the post of Chief Designer at MEI Special Sector. The engineering scientific and technical school of MEI was subsequently headed by Academician-to-be Aleksei Fedorovich Bogomolov. The magnificent creative team formed by Kotel'nikov continued its work in the Special Design Bureau at MEI, established by the governmental resolution on the basis of the Sector. In 1961, OKB MEI was decorated with the Order of the Red Banner of Labor for participation in the creation and launch of the first crewed space vehicle 'Vostok' with the cosmonaut Yurii Gagarin. OKB MEI Chief Designer Bogomolov became a full member of Korolev's

Council of Chief Designers, and later of Yangel's and Chelomei's ones. The team of OKB MEI also became famous for the development of high-efficiency ground-based antennas and relaying stations for space communication systems and television. In all, 160 antenna systems were constructed on the territory of the USSR and abroad, which enabled millions of people to make use of space communications and television. In 1950 – 1954, Kotel'nikov, in collaboration with MEI Assistant Professor A M Nikolaev, wrote a brilliant two-volume work *Osnovy Radiotekhniki* (*Basics of Radio Engineering*). Prior to his election to the Academy of Sciences, Kotel'nikov, who as scientific leader of the Special Sector was always overloaded with rocket – space problems, retained the post of Dean of the Radio Engineering Department and continued his pedagogical activity as the Head of the Chair of Fundamentals of Radio Engineering.

The Institute of Radioengineering and Electronics of the USSR Academy of Sciences, which Kotel'nikov supervised until 1987, gathered the cream of the crop of the radioelectronic scientific community of the Soviet Union. There, basic research was conducted in the most important areas of radio engineering and electronics.

At IRE, Kotel'nikov pioneered a new avenue of space research: planetary radiolocation and investigations of planetary radio emission. The radar of Venus, Mercury, Mars, and Jupiter was carried out under his supervision. In 1964, he was awarded a Lenin Prize for this work.

On Kotel'nikov's initiative and under his scientific supervision, an extremely intricate radio engineering complex was brought into existence, which comprised high-power transmitters, large narrow-beam antennas, high-sensitivity receivers, and a sophisticated system of automated processing of planetary measurements.

During his time of supervising IRE, Kotel'nikov laid the foundations of radio-engineering planetology.

Kotel'nikov came up with the idea of using the scientific, technical, and industrial potential of domestic radio engineering and cosmonautics for the cartography of Venus. The basic ideas and techniques of this unique experiment were elaborated at IRE, the Institute of Applied Mathematics of the USSR Academy of Sciences, and OKB MEI under Kotel'nikov's scientific supervision.

OKB MEI developed the radar equipment for the Venera-15 and Venera-16 interplanetary stations which were made by the G N Babakin Research Center.

Two of the Soviet Union's largest antennas were equipped to receive and record information on Earth. One of them, with a mirror 70 m in diameter, is now abroad; the other, 64 m in diameter, is located near the Medvezh'i Ozera near Moscow and is the property of OKB MEI and is a source of pride. In 1983 – 1984, with the aid of the radar equipment mounted aboard the Venera-15 and Venera-16 interplanetary stations, for the first time in history it was possible to accomplish the cartography of the planetary surface of Venus shielded by its opaque atmosphere. The experience gained in that experiment permitted developing a side survey radar and an ultrabroad-range radiometric complex for the Priroda module of the orbital Mir station.

In a brief report it is impossible to show the wealth of radio-space problems which were solved with the creative contribution by Kotel'nikov. An atlas of the Venus surface, edited by Kotel'nikov, was made in 1989. Hundreds of scientists and engineers from several dozen organizations participated in this interplanetary experiment. Academician Kotel'nikov proved in practice how efficient the concerted effort of the institutions of higher education and of the Academy of Sciences can be. An excellent example is provided by the activities of OKB MEI and the IRE of the USSR Academy of Sciences, which gained worldwide recognition. From 1969 to 1988, Kotel'nikov was Vice-President of the USSR Academy of Sciences, and First Vice-President from 1975. While filling this post, he made a huge contribution to the formation of governmental policy in the development of the most important areas of science.

Although Kotel'nikov was no longer a member of the Council of Chief Designers as earlier when he was the Chief Designer of the MEI Special Sector, he would often render assistance when serious problems arose. A lot of purely radar problems had to be solved in the course of spacecraft operation. The corresponding equipment is extremely sophisticated, so that high reliability is hard to achieve. Sometimes there occur irregular situations, breakdowns, etc. This is especially dangerous in the case of crewed systems, say, when a failure occurs in the transport – orbital station approach-and-docking system. In these cases, the Military Industrial Committee under the Council of Ministers immediately set up an emergency commission. They addressed the Academy of Sciences President M V Keldysh: "Cooperation of the Academy of Sciences is required; whom do you include on this commission?" And, of course, Kotel'nikov was included. I quite often had to meet him during the work of these commissions. He was characterized by and helpful in the following: he tried to quench the debate on the 'who is to blame' subject and, above all, to thoroughly examine the physical essence of the system and grasp the physics of the failure. He suggested that this should be elucidated. And, as a rule, this was possible to do. It is worth noting that Kotel'nikov had an exceptional intuition. Sometimes I was astonished at how promptly he, not knowing the full story of the design, found, if not the very cause in detail, at least the guiding idea which had to be followed to understand the cause of the failure that had occurred. Together we would quickly hit upon the way to remedy the problems occurring.

A substantial part of his scientific and organizational activity was devoted to cosmonautics. For many years he presided over the 'Radioastronomy' Scientific Council of the USSR Academy of Sciences and the Council for International Cooperation in the Area of Investigation and Use of Space. The supervisor of the Interkosmos Council was entrusted not only with the scientific and technical tasks, but also with the social and political tasks of international cooperation in the area of cosmonautics. At the present time it would be hard to recollect the list of different committees and expert commissions which Kotel'nikov was president of or a member of. In one such commission in 1989 I was entrusted, together with Kotel'nikov, with the task of drawing the French science and industry into the deployment of a global satellite communication system and, directly, television on the basis of employing our Energiya giant rocket-carrier. During negotiations in Paris, the French side did not exhibit much enthusiasm and, to unburden ourselves, Kotel'nikov and I went to the Louvre. In the Louvre, I not only enjoyed contemplating the great works of art, but was also surprised by Kotel'nikov's erudition, with his advice on what to see and where. He explained that attempts to make the rounds of the whole Louvre would result in having nothing to recollect at a later time. Even in this field, seemingly distant from his activities, he could spot and contemplate the masterpieces of human

genius and in doing this gain, as I witnessed, emotional satisfaction.

For his scientific activity Kotel'nikov was honored with many awards — governmental, domestic academic, and international. In 2000, Professor Bruce Eisenstein (USA) thus praised the scientific merits of Kotel'nikov: ''Academician Kotel'nikov is an outstanding hero of the present. His merit is world-wide recognized. We are in the presence of a giant of radio-engineering thought, one who made some of the most significant contributions to the development of radio communications.'' From 1973 to 1980, Kotel'nikov was Chairman of the Supreme Soviet of the Russian Soviet Federative Socialist Republic (RSFSR). Today this should be remembered also for the reason that in those days the state estimated at its true worth science as a productive force, which ensured the economic and defense might of the country.

In connection with the 95th birthday of Academician Vladimir Aleksandrovich Kotel'nikov, on 21 September 2003 the President of the Russian Federation Vladimir V Putin signed a decree on decorating him with the First Class Order 'For Service to the Homeland'. He came to be Russia's fourth holder of this order.

At present, the scientific and technical school created by Academician Kotel'nikov is actively introducing the newest radio-engineering products into the cosmonautics world.

We have the right to pride ourselves in being members, together with this outstanding Russian scientist, of the Russian Association of Members of the International Academy of Astronautics.