Scientific investigation, technological development and economical governmental support: the historical development of RADAR science and technology II[1]

Gorokhov V. G. (vitaly.gorokhov@mail.ru)

Institute for Philosophy of the Russian Academy of Sciences
Institute for Technology Assessment and System Analysis of the Forschungszentrum Karlsruhe

5. RADAR systems engineering

The second phase in radar development was characterized by "revolutionary" changes in the paradigm of scientific and engineering thought. Instead of radio engineering, systems engineering was now the model for furthering this scientific discipline. A systems and cybernetics theoretical representations was substituted for the electrodynamics representations which entails radical changes in the very structure of radar theory, its conceptual and mathematical apparatus. A "neoclassical" period of its development as systems engineering began.[2]

During the phase discussed here, systems engineering methods began to be used in radio location along with the methods of other disciplines.[3] "Modern radiolocation uses the latest achievements of information theory and cybernetics, computer electronics, antenna-feeder, receiver, transmitter and indicator engineering, automatic control and regulation".[4] And more important: It becomes part of a new *family* of scientific and engineering disciplines with a systems orientation, becomes one of the disciplines serving system engineering and, as a result, it acquires a new quality, is transformed into a new discipline.[5] "The practical application ... scientific prospects ... and technical level of radar systems, — wrote Academician A.L. Mints in the foreword to the book "Introduction to radar systems engineering", — make radar systems engineering an independent, quickly developing discipline ... Radar systems engineering has long since turned into a specialty serviced by a large variety of' engineers and other scientists". [6] Though at first glance the main task here is

---

[1] This article has been prepared in the scope of RFFI-Project "The change of the paradigm of scientific and technological development in the context of the establishment of the global information society" 09-06-00042.
[2] See: L.N. Ridenour (Ed.). Radar System Engineering. N.-Y., L.: McGraw-Hill Book Company, 1947; S.A. Hovanessian. Radar System Design and Analysis.Washington: Artech House, 1984; G. Galati (Ed.). Advanced radar techniquies ans systems. London: Peter Pergrinus Ltd., 1993;
[3] "Systems Engineering is the *professional, intellectual and academic discipline* the primary concerns of which are the analysis and design of large-scale, complex, man / machine systems. … The Systems Engineering methodology employed by the *interdisciplinary team* must allow for the maximum effective contribution of each scientific discipline. … The interdisciplinary team needs a way to organizing itself and working cooperatively. The methodology that the interdisciplinary team adopts solve the jargon problem, not by changing the jargon of every individual discipline because that is impossible and perhaps even undesirable, but by introducing a methodology that includes a common language for communicating ideas about systems and systems phenomena" (Wymore, A. Systems Engineering Methodology for Interdisciplinary Teams. N.Y.: John Wiley & sons, 1976, pp. 1, 14).
[4] M. Skolnik. Introduction to radar systems. N.Y.: McGrow-Hill, 1962, p. 5
[5] System engineering handbook / Ed. by Robert E. Machol, in coll. with Wilson P. Tanner, Jr., Samuel N. Alexander. - 1965
[6] Kontorov, D. S., Golubev-Novozhilov, V. S. Vvedenie v radiolokatsionnuyu sistemo-teckniku (*Introduction to Radar System Engineering*). Moscow: Sovietskoye Radio, 1971, p. 6-7 (in Russian)

a synthesis of heterogeneous knowledge, theoretical notions and methods, it implies co-ordination, alignment, management, and organization of different activities aimed at solution of a certain integrated scientific and engineering problem.

5.1. Organisational aspects

Picturing a new type of engineer and organizer, these words cast a light on the ongoing process of integration of modern differentiated engineering activities, which opens a radically new phase in their evolution.[7] "A fact that has been too little recognized when radar systems are discussed is that the organization which is to make use of the positional information afforded by radar is usually at least as important as is the radar itself. A good organization can make excellent use even of inferior radar information, as was proved by the success of the British Home Chain of radar stations, the first large-scale radar installation to be made. An inadequate organizational set-up can do a poor job, even though provided with splendid radar from the technical standpoint. The many problems that enter into the creation of an adequate organization for the use of radar data have not received the study that they should".[8]

The Development of Radar during the First Post-war Years in Russia

"The Council for Radiolocation worked out the strategy of the development of radars and radio electronics and began setting up new research institutes, design bureaus, and factories. The principal objective was the mass production of new electronic hardware. The few factories of the People's Commissariat of Electric Industry could not manage it. The chief directorates of a number of defence commissariats set up in 1944 and 1945 were busy sorting out local problems. The new atomic, rocket, and radar industries required large infrastructures covering the whole country. … In 1946, after a long struggle, the Council for Radiolocation was transformed into the Committee for Radiolocation of the Council of Ministers of the USSR, codenamed No. 3 Special Committee.[9] … According to the plans

---

[7] "After the war, State Defense Committee functions were transferred to the Council of Ministers. … The industrial ministries, formed from the people's commissariats, received a great deal of independence. However, solving the new and very complex scientific and technical problems called for the formation of the special committees described previously. These committees allowed the higher political leadership and Stalin personally to manage the solution of complex problems that required enormous material expenditures, scientific leadership, and participation of various branches of industry. In the mid-1950s, the interests of the three Special Committees became intertwined. They began to move atomic explosives from airborne bombs into missile warheads. A massive campaign was underway to "missilize" the infantry forces, navy, and air force. Radio electronic systems from auxiliary facilities were converted into the primary means of determining the effectiveness of anti-aircraft defense and, later, anti-missile defense. … the organizers of industry, having cast aside their departmental differences, decided to consolidate the management of the country's entire military-industrial complex. … And so the special committees were dissolved and the managerial coordination of all the defense ministries was transferred to a new agency — the Commission on Military-Industrial Issues under the USSR Council of Ministers, or the VPK. … The full name of this body was the Commission on Military-Industrial Issues, but it was more commonly known as VPK—*Komissiya po voyenno-promyshlennym voprosam* (Military-Industrial Commission). Officially formed in December 1957, the VPK was the top management body for the entire Soviet defense industry. Commission members typically included the ministers of various branches of the defense industry (including the rocket industry)" (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 23).

[8] L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 13

[9] "Of the three new technologies—radar, atomic, and missiles—atomic technology was the most science-intensive. Perhaps because of this, Special Committee No. 1 included two academicians: Igor Kurchatov and Petr Kapitsa. Malenkov headed two of the three Special Committees (radar and missiles), created in 1945–46; Beriya headed the third (atomic). Both Malenkov and Beriya reported directly to Stalin, who attentively, strictly, and in a very demanding manner monitored the execution of the scientific, technical, and production tasks assigned to the committees. Stalin's supervision was anything but detached. Stalin inserted his corrections and additions into drafts of decrees that had already been accepted. One such Stalin initiative was the top secret decree dated 21 March 1946, "On Awards for Scientific Discovery and Technical Achievement in the Use of Atomic Energy and for Cosmic Radiation Research Projects Contributing to the Solution of This Problem." This

of the Council for Radiolocation, new-generation technologies had to be created. The Council of Ministers approved these plans and issued a directive dated July 10, 1946, where the principal tasks for the period through 1950 were outlined. … After the reorganisation of the Ministry of Electric Industry, the Ministries of Armaments, Agricultural Machinery, Aviation Industry, and Shipbuilding became the leading agencies as concerned the organisation of radar production. The Ministry of Communications Industry … was established on June 28, 1946. It was charged with the development and production of radar and radio navigational installations and other systems. The Ministry of Armaments … was established on the basis of the People's Commissariat of Armaments on March 15, 1946. It was responsible, among other things, for the development and production of radar and radio navigational installations and creating fire control stations for field and anti-aircraft artillery. The Ministry of Agricultural Machinery was established on the basis of the People's Commissariat of Munitions on January 7, 1946, and absorbed a number of facilities that had belonged to the Ministries of Medium Machinery, Transportation Machinery, and Mortar Artillery. It was … charged with the development and production of remote control detonators for various missiles and bombs. The Ministry of Aviation Industry established on January 5, 1946 … was charged with the development and production of onboard radars. The Ministry of Shipbuilding established on March 15, 1946 … was charged with the development and production of naval radars.

Finally *Axel Berg*'s[10] efforts led to the creation, on June 28, 1946, of the *Ministry of Communications Industry*, which now was in charge of the majority of the USSR's plants making radar components. In a centralized economy, the centralization of radar industry was the single correct decision …

Three research institutes and six special design bureaus of the Ministry of Communications Industry, three design bureaus of the Ministry of Armaments, seven design bureaus of the Ministry of Aviation Industry, two research institutes and three design bureaus of the Ministry of Agricultural Machinery, and the Research Institute of Artillery Instrumentation and the State Red Banner Research Institute of the Air Force that belonged to the Ministry of Defence were engaged in radar research. … Late in 1949, the Committee for Radiolocation was suddenly disbanded. In 1950, the government decided that guided surface-to-air missiles were the only weapons effective against high-flying enemy aeroplanes, which were the most dangerous. As soon became clear, rockets and rocket systems could only be created jointly by a large number of facilities and organisations of practically every industry. In February 1951, the Third Chief Directorate of the Council of Ministers of the USSR was created to coordinate the development and production of guided anti-aircraft rockets.[11]

---

decree called for large monetary awards to be granted to individuals who solved specific scientific and technical problems. It stipulated prizes of one million rubles for the directors of the work and would confer on them the titles of Hero of Socialist Labor and Stalin Prize laureate. At government expense they would be granted, in any region of the Soviet Union, ownership of a villa, a furnished dacha, a car, double pay or salary for the entire period of time they worked in that field, and the right to free transportation (for life for the individual and wife or husband and for the children until they came of age) within the USSR by rail, water, or air transport. Large monetary awards were stipulated not only for the directors but also for the primary scientific, engineering, and technical employees who were involved in the work" (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 21)

[10] "Berg organized and became the director of the head Central Scientific-Research Institute No. 108 (TsNII-108) under the Radar Committee. From 1953 through 1957, he occupied the high-ranking post of USSR deputy minister of defense. Berg infused the working environment with new and creative plans. He immediately proposed radical designs and unwaveringly rejected slipshod work". Later he was Director of NII-20 of the Ministry of the Communications Systems Industry (MPSS) directed development of the telemetry systems. (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II) / by Boris E. (NASA History Series). Washington, DC: NASA History Division, Office of External Relations, 2006, p. 4).

[11] "In June 1947, the Radar Council was converted into Special Committee No.3, or the Radar Council under the USSR Council of Ministers. M.Z. Saburov, Chairman of the USSR *Gosplan,* was appointed council chairman. A.I. Shokin, who would later become deputy minister of the radio electronic industry and then minister of electronics industry, managed the committee's day-to-day activity. … The Radar Committee was abolished in August 1949, and its responsibilities were divided among the Ministry of Armed Forces and the ministries of the various branches of the defense industry. In 1951, drawing on the personnel from the abolished committee, under the aegis of Lavrentiy Beriya, the Third Main Directorate (TGU) was created under the USSR Council of Ministers. … The Third Main Directorate was entrusted with the task of missile defense. Ryabikov was

On August 12, 1950, Minister Ustinov appointed Konstantin Gerasimov, his deputy, Director of the KB-1, Pavel Kuksenko and Sergei Beria Head Designers to work on the Berkut system[12], and *Alexander Raspletin* Deputy Head Designer and the head of the department developing radars.[13] … On September 6, 1950, the Council of Ministers of the USSR also transferred 60 Soviet and German professionals … to the KB-1. The KB-1 kept appropriating equipment and completed or partially completed the construction of residential buildings and what was being built in its sites in downtown Moscow and at the outskirts. The best professionals continued to arrive from all over the country. …All work on the Berkut system continued under a lot of secrecy. No one was the wiser, not even the directorate heads of the Ministry of Defence, which was unheard of in the history of weapons design. All ready items were commissioned and accepted directly by the Third Chief Directorate. This continued until 1953".[14]

ANTIAIRCRAFT ROCKET SYSTEMS AND COMPLEXES OF THE AIR DEFENCE

http://www.vko.ru/books/006-020.pdf

Prof. A.I. Berg

Director of the Scientific Institute for Radar Research

[NII-20]

A.A. Raspletin

Chief Designer (from 1953) of the Design Bureau = KB-1. later – member of the Russian Academy of Sciences

---

appointed the direct chief, and Kalmykov, Vetoshkin, and Shchukin were appointed his deputies" (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II) / by Boris E. (NASA History Series). Washington, DC: NASA History Division, Office of External Relations, 2006, p. 4, 5)

[12] «The duo of Kuksenko and Sergey Beriya, who remained at NII-20, cooperated with the Mikoyan KB to develop the Kometa, a cruise missile that was supposed to strike a sea target after it separated from the carrier aircraft. The Kometa was launched from the Tu-4 carrier aircraft approximately 150 kilometers from the target and was supposed to enter the beam of the radar mounted on the carrier aircraft. The radar guided the Kometa to the sea target. When the Kometa was approximately thirty kilometers from the target, it was supposed to switch to homing mode and strike the target. This was the projected mission that Sergey Beriya and his academic advisor Pavel Kuksenko presented at the meeting in Ustinov's office in 1947. The radar portion of the system was to be developed at the small SB-1, which had been located at NII-20. … In August 1950, SB-1 was reorganized into the much bigger KB-1» (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 203).

[13] "Right away, without taking their views into consideration, the primary radio engineering scholars were taken from another organization, TsNII-108, the main radar scientific-research institute, headed at that time by Aksel Ivanovich Berg. The first leading specialist taken from Berg was Aleksandr Andreyevich Raspletin. At TsNII-108 he had directed the main developmental laboratory for radar systems. Kuksenko and Beriya agreed to the appointment of Raspletin as deputy chief designer on the Berkut system and as chief of the KB-1 radar department. This appointment had decisive importance for the fate of the Berkut system. It was Raspletin in particular who had the fundamental ideas that gave Berkut its unique technical characteristics, unparalleled in the world" (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 208).

[14] M. Pervov. From "Berkut" to "Triumf" (http://www.aviarus-21.com/index-eng.htm)

Fig. 19[15]

Today, no industrial field — be it the heavy, electrical, electronic, chemical, or any other type of industry — can do without engineers. If we add in the people who perform engineering functions at the various stages of engineering (research engineers, design engineers, production engineers, maintenance engineers) in all these sectors of industry, we shall have a very impressive spectrum of engineering professions. The work of an engineer strictly within the bounds of his speciality is not difficult to direct. But if a large number of specialists in the various fields of engineering are engaged in developing a very complex technical system, such as a space project or a power generation system, which consists of diverse units, the coordination of engineering becomes a very difficult engineering and scientific task. It takes special, interdisciplinary experts to carry it through. Such are, for instance, a chief designer, or research coordinator, and the like. There are generalist *systems engineers*, whose function is to organize and manage the various engineering activities; the range of disciplines required to train this type of organizer to manage the various engineering activities must be very wide indeed. Such an expert must have both a general idea of the whole system under development as well as an in-depth specialized knowledge. His primary function is to coordinate and direct the execution of all the tasks involved in the project (see Fig. 16).

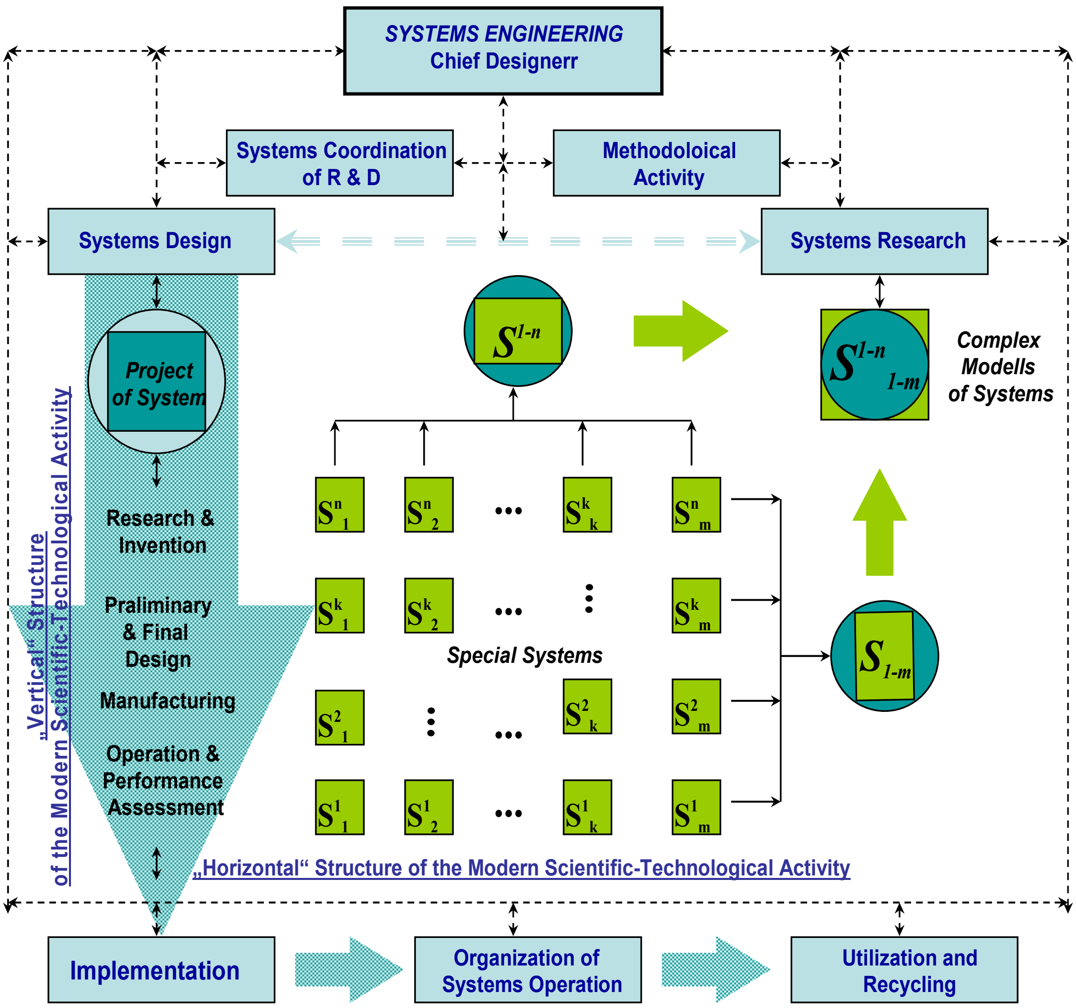


Fig. 16

[15] Alperovich K.S. Gody raboty nad sistemoy PVO Moskvy — 1950-1955 [The years of working with Moscow defensive intercept system — 1950-1955]. Moskva: NPO "Almaz", 2003, p. 4. - http://www.vko.ru/books/006-020.pdf (Russian).

It is necessary to distinguish between the “horizontal” and “vertical” structures of systems engineering activities, such as modern scientific-technological activity and the respective methods of synthesizing systems engineering knowledge (see Fig. 16). The “horizontal” structure of systems engineering activities is concerned with the distribution of specialists’ work among the types of components and various aspects of the system: development of machine units, design of man-machine interaction patterns, elaboration of economic, organizational, and other aspects of systems, etc. The organization of these activities is the function of a generalist who is supposed to have knowledge of all of the units and aspects of the system and of the different types of system from their concrete form. The generalists’ activities represent a “horizontal” synthesis of systems engineering knowledge. The “vertical” structure of systems engineering activities constists of the co-operation of specialists in research, invention, design, development and operation. Systems engineering is a framework for the coordination of all of these activities. The co-ordinator’s job is to unite different experts, from the researcher to the maintenance engineer. Yet another of the co-ordinator's responsibilities is the duplication and scheduling of operations. By making use of systems concepts, the coordinator ensures the integrity of the systems engineering activities, and for the synthesis of systems engineering knowledge along the vertical lines of these activities.

A complex systems model of an intricate engineering project may be constructed by two methods (Fig. 16). First, it may be “assembled” out of special systems on one and the same level in the “vertical” structure, i.e., it constitutes only a “horizontal” synthesis of systems engineering knowledge with respect to some individual activity: either research, design, or manufacture, etc. As far as the “horizontal” synthesis is concerned (with respect to the project), a complex systems model incorporates the knowledge of different specialists in the “horizontal” structure of the given activity. Such models should be synthesized in comprehensive theoretical research at all levels of the “vertical” structure of systems engineering (Fig. 16). Second, models of complex systems are based on a “vertical” synthesis of all ideas about one and the same subsystem held by the researcher, inventor, designer, etc. The thus obtained systems models are then synthesized in an integrated systems model of a complicated engineering project with regard to all of the subsystems in the “horizontal” structure of systems engineering. Finally, at the third stage in Fig. 16, all of the complex systems models are put together in an integrated systems model (second-level synthesis).

Systems engineers act as *generalists.* Together with specialists, they ensure that the objectives agreed upon are realized as quickly and efficiently as possible, and at minimum cost. In complex engineering systems, the decisions taken by the project manager must have a solid scientific and engineering foundation.

With such complex engineering systems, the decisions taken by the project manager must have a solid scientific and engineering justification. A single person is unable to provide it since lie cannot be equally well versed in electronics, economics, ergonomics, and so on. Thus, the development of large engineering systems and integration of diverse engineering activities are pressing problems currently in the various fields of science and technology. But if a large number of specialists in the various fields of engineering are engaged in developing a very complex technical system, such as a space project or a power generation system, which consists of diverse units, the coordination of engineering becomes a very difficult engineering and scientific task. It takes special, interdisciplinary experts to carry it through. Such are, for instance, a chief designer, or research coordinator, and the like. Such an expert must have both a general idea of the whole system under development as well as an in-depth specialized knowledge. His primary function is to coordinate and direct the execution of all the tasks involved in the project. *Alexander Raspletin* (Chief Designer[16] of KB-1 and Developer of the Air defence system near Moscow and anti-aircraft missiles, later a member of the USSR Academy of Sciences)[17] provided a striking example of organizational engineering activity. I believe that about him we can say the words what said academician O.M. Belotserkovsky (Soviet mathematician, expert in theoretical and applied aerodynamics and computational mathematics) about another Chief Designer of the large-scale missile and spacecraft systems Sergei Korolev[18] provided a striking example of organizational engineering activity: "Hundreds of thousands of people took part directly in the development of Soviet cosmonautics, and among them were many deep thinkers, penetrating theoreticians, excellent designers, bold experimenters, strong-willed organizers, and diligent workers. All of them made their contribution, and all these efforts were directed to their common goal by Korolev, the chief designer of missile and spacecraft systems, who worked in close cooperation with leading scientists from the USSR Academy of Sciences... with members of the council of chief designers heading tie 'various space and missile systems' development projects, and with major production managers... His organizational talent enabled him to unite and channel the activities of numerous research and development institutions regardless of their departmental subordination. Owing to his purposefulness, lie was able to inspire the participants in the project and win them over to his ideas. He in person could secure a quick decision at all levels, convince his colleagues, and find jointly acceptable solutions".[19]

The transition from classical radiolocation to radar systems engineering is, first, a transition from the development of individual radar stations of varying types to the development of multifunctional systems. Several radars interlocked into the centre of the collecting and processing radiolocation information comprise a radiolocation unit; several such units exchanging information *form* a radar system, "in fact, a new quality".[20] A radar system makes it possible to solve problems which cannot be solved by individual radar facilities. A series of specific system problems arise in designing radar systems. Any radar system, in turn, is a subsystem of a larger system — the control system which is part of a still larger system, for example, a navigation system.

Frequently, a complex system proves inoperative as a whole even though its components meet all the specifications. Suppose, an aeroplane is being developed by various types of engineer.

[16] "… new scientific and technical problems required technical management that would play a much stronger role. The central figure became the chief designer, rather than the director-administrator bestowed with many government awards". (Chertok, B. E. Rockets and People: Creating a Rocket Industry (Volume II). The NASA History Series. Washington, DC: NASA History Division, 2006, p. 155).

[17] Born 25.08.1908, Dead 08.03.1967, Moscow, Corresponding member since 20.06.1958 - Division of Technical Sciences, Academician since 26.06.1964 - Division of General and Applied Physics. Chief Designer - 1953-1967 - of KB-1 – today Corp. "Almaz".

[18] Sergei Korolev (1906-1960), Soviet researcher and designer in rocket and space technology, member of the USSR Academy of Sciences, chief designer of the first satellites and spacecraft. He was not merely an engineer (he graduated from the aeromechanics department of the Bauman Higher Technical School in 1930), but he was also a great engineer and scientist (over 150 aviation, missile and space projects were carried out by him personally or under his direction). He founded a large school of disciples. A large number of his close associates (his deputies and leading engineers at his design office) have become academicians and corresponding members of the USSR Academy of Sciences, heads of research, development, and educational institutions and make up the core of Soviet space science and technology).

[19] O.M. Belotserkovsky. Sergei Korolev. In: Voprosy istorii estesvoynanija i tekhniki [Problems of the History of Natural Sciences and Technology], 1981, No. 4, pp. 55, 62 (in Russian).

[20] Kontorov, D. S., Golubev-Novozhilov, V. S. Vvedenie v radiolokatsionnuyu sistemo-teckniku (*Introduction to Radar System Engineering*). Moscow: Sovietskoye Radio, 1971, p. 6 (in Russian). See also: Werner Wiesbeck. Radar Systems Engineering. - http://www.ihe.uni-karlsruhe.de/lehre/grt/RSE_LectureScript_WS0607.pdf, Ridenour, Louis N., Hershberger, W. D. Radar System Engineering. Science, Volume 107, Issue 2768, 1948, pp. 74-75

If an engine expert is doing the design, then, say, he will not pay the electronics due attention. A fuselage designer will only be concerned with an optimum plane configuration, neglecting for instance, the arrangement of the radar aerial. An electronics engineer will cram the plane with a variety of equipment, ignoring the plane's mass and configuration. An ergonomics expert will request a maximum of comfort for the crew, a cost estimator will try to hold costs down to a minimum... and the plane will never take off. It is a tradeoff between the optimum solutions, objectives and criteria proposed by the various experts taking part in the development of a complex system that coordinators and all-rounders are expected to achieve. With such complex engineering systems, the decisions taken by the project manager must have a solid scientific and engineering justification. A single person is unable to provide it since he cannot be equally well versed in electronics, economics, ergonomics, and so on. Repeated diagnostic analysis of such a system aimed to reveal its potentials and "bottlenecks” and to eliminate the identified drawbacks is needed in order to control its development. For this reason, every manager of a large project should set up a scientific coordination centre consisting of interdisciplinary experts.

Russian Example: Air defence system near Moscow

1. Brief history

«The history of the project (the first Moscow-based air defense system – V.G.) has several versions. I am not about to judge which of them is the more authentic one, but it all boils down to the fact that the initiative for the creation of the organization that we know today as Almaz came personally from Stalin.[21] Under great secrecy, in 1950, we passed on scraps of information to each other about the government decree promoting Pavel Kuksenko and Sergey Beriya to a higher level in the hierarchy of defense technology developers. The rumors were quickly confirmed. And how all of this took place actually managed to be bound into a single historic sequence many years later. In 1950, the U.S. proclaimed “absolute supremacy” as its strategy in the Cold War. When the USSR obtained the atomic bomb in 1949, U.S. territory was still secure. For that reason, the military and political aspect of U.S. strategy revolved around using atomic weaponry against the USSR to inflict “preventive” strikes from the air. After the R-1, we had already developed new medium-range missiles, and work had begun on super long-range bombers and fighter jets. But there was no system capable of reliably protecting Moscow and other important strategic centers against American [Boeing B-17] Flying Fortresses”.[22]

---

[21] The Almaz Scientific-Production Association (NPO Almaz) is the direct descendent of the original SB-1 formed in 1947. During the Soviet era, it was one of the largest, most influential, and most secret defense industry organizations and produced various tactical and strategic weapons systems, including antiaircraft missile systems, antiballistic missile systems, and antisatellite systems. During its existence, it has been known variously as SB-1 (1947–50), KB-1 (1950–66), MKB Strela (1966–71), TsKB Almaz (1971–88), NPO Almaz (1988–95), AOOT Almaz (1995–96), TsKB Almaz (1996–2001), and NPO Almaz Named After Academician A. A. Raspletin (2001–present).

[22] Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 206.

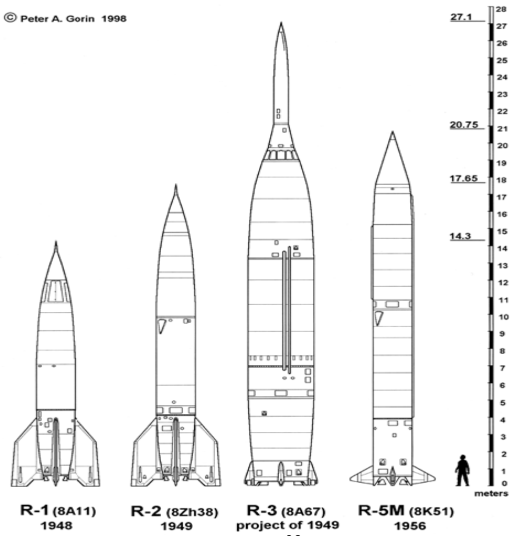


Fig. 17[23]

2) Formative influences of the German scientists and engineers:

“The Germans’ technical experience, of course, saved us many years of creative work. … In Germany we learned that a single organization or even a single ministry was incapable of dealing with rocket technology. The development of missiles required strong, nationwide cooperation. And the main thing was that we needed high-quality instrument building, radio engineering, and engine building infrastructure.”

a) After II Word War many Russian scientists and engineers were working in Germany.

“The majority of the Soviet specialists who worked at Institutes RABE and Nordhausen spent considerably less time there, 6 to 12 months. … While working in Germany, we had understood that after the war, international scientific cooperation would be of utmost importance for the development of domestic science and technical progress. We dreamed that instead of the confrontation that had begun to emerge, the interaction of the scientists from the victorious countries would be a natural continuation of the military alliance”. It was organized lectures from this scientists for the higher engineering programs at the N.E. Bauman Higher Technical Institution (TU). They were supposed to pass on the experience and knowledge we had acquired in Germany. “There, the entire “elite” of the still quite young rocket industry had been assembled to retrain military and civilian engineers”.[24]

b) After II Word War many German scientists and engineers must be working in USSR also in radar sphere.

“In October 1946, the best German engineers who worked for the Soviet missile program were ordered on the trains and sent to the various locations in the USSR to assist in the organization of missile production and design. By the beginning of the 1947, Soviets completed the transfer of all works on rocket technology from Germany into secret locations in the USSR. In the fall of 1947, Soviet-German team launched eleven A-4 rockets near the village of Kapustin Yar in the steppes north of the Caspian Sea. … On September 13, 1946, Soviet of Ministers USSR issued decree No. 2163-880s entitled "On removal of hardware from the German military enterprises”. The document

[23] “The drawing shows the gradual progression of Soviet ballistic missiles from the R-1, a copy of the German V-2, to the R-2, to the R-5M, the first Soviet ballistic missile capable of carrying a nuclear warhead. The R-3 missile was an ambitious long-range project that was abandoned in 1951 although it allowed Soviet engineers to adopt and abandon certain key technological paths” (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 241).
[24] Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 27, 28

officially launched the process of transfer of German rocket production potential to the USSR. … It included 2,200 specialists in the fields of aviation, nuclear technology, rocketry, electronics, radar technology and chemistry. They would be assigned to various industrial enterprises of the USSR: number of people to be deported – 350 radar and radio experts for the Ministry of Communications. … According to newly researched Russian data, the actual number of deported German rocket specialists reached 177 people, including 24 people with doctorate degrees, 17 people with master degrees, 71 people with engineering degrees and 27 workers. … Total 136 people were employed by a newly created NII-88 research institute … Along with working on prospective designs during summer of 1947, NII-88 completed assembly of several A-4 rockets of the "T" series, in addition to "N" series assembled back in Germany. Both batches, along with auxiliary hardware from Germany were shipped to a newly founded test range in Kapustin Yar. On July 26, 1947, the Soviet of Ministers officially scheduled test launches of the A-4 missiles in Kapustin Yar during September-October 1947. By the end of 1950, Germans who worked for OKB-456 were sent back to Germany".[25]

"The German specialists received fairly high salaries, depending on their qualifications, academic titles, and degrees".

Salary range comparison of German and Soviet engineers at NII-88 in 1947-1948:

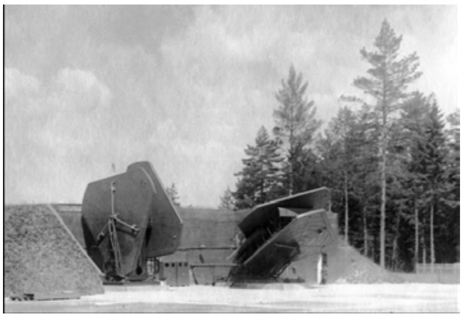
"Thus, for example, Drs. Magnus, Umpfenbach, and Schmidt each received 6,000 rubles per month, Gröttrup and Willi Schwarz received 4,500 rubles each, and graduate engineers received, on average, 4,000 rubles each. For the sake of comparison I can cite the monthly wages of the primary leading specialists of NII-88 (in 1947): Korolev (chief designer and department chief)—6,000 rubles; Pobedonostsev (the institute's chief engineer)—5,000 rubles; and Mishin (Korolev's deputy)—2,500 rubles. My monthly salary was 3,000 rubles. The average salary of the German specialists in the Ministry of Aviation Industry, to which OKB-456 was subordinate, also exceeded that of Soviet specialists. OKB-456 chief designer V. P. Glushko received a salary of 6,000 rubles per month in chief of engine production, received 5,000 rubles per month. Glushko's deputy V.A. Vitka had a salary of 3,500 rubles". The Germans were permitted to transfer money to their relatives in Germany". At the time average Russian engineer would earn around 1,000 rubles a month.[26]

3) Air defence system near Moscow (continue)

"There were a total of 56 elements of the inner and outer air defence circles. Built over three years were more than 500 km of concrete roads, 56 underground bunkers housing the equipment of the B-200 radars, as many launch stations, and electrical substations at and power lines leading to each of them. Over 1,000 km of various cables were laid. Various plants began making equipment and instrumentation for the system. … In mid-1954, the head facility located near Moscow was ready for commissioning tests."[27]

[25] Anatoly Zak. Home rockets spacecraft centers people chronology. - http://www.russianspaceweb.com/a4_team_moscow.html
[26] Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 43-45.
[27] M. Pervov. From "Berkut" to "Triumf" (http://www.aviarus-21.com/index-eng.htm)

Air-Defense Rocket Center near Moscow
(1953) http://www.vko.ru/books/006-020.pdf



Guided-Missile Control Center in the State Central Testing Grounds at Kapustin Yar
(1954)

Fig. 18[28]

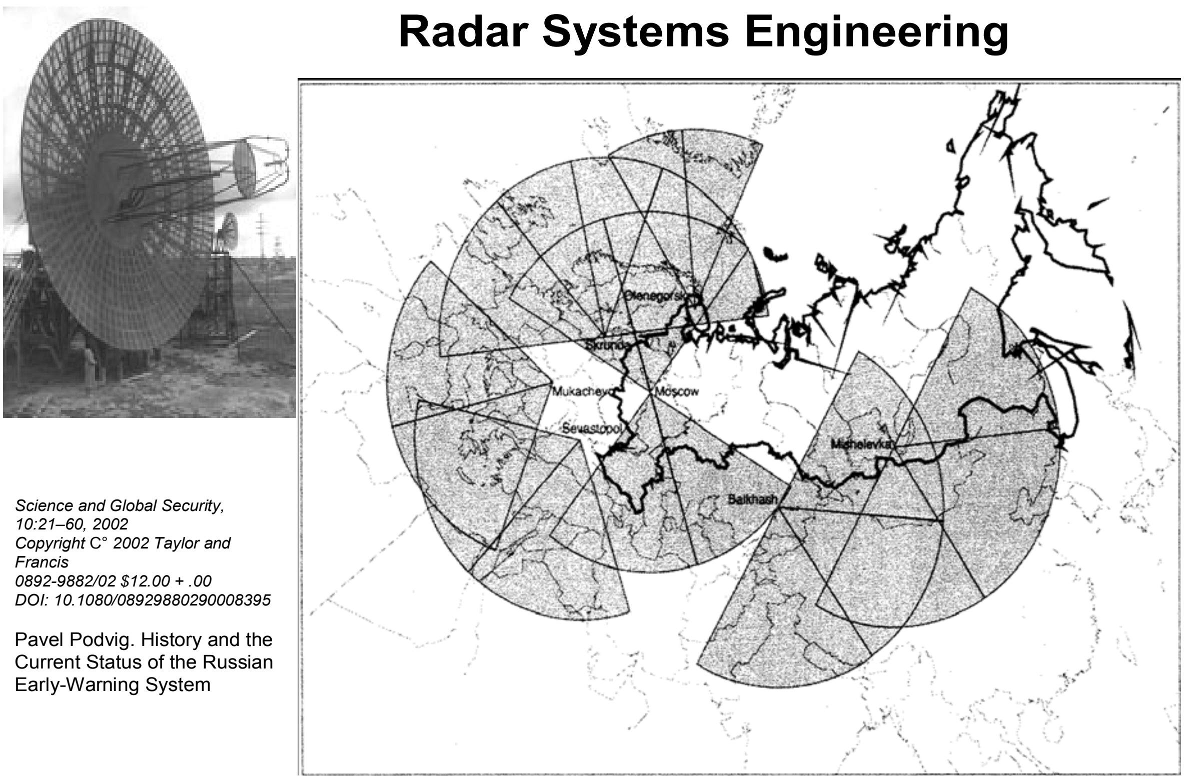
“On May 7, 1955, the Central Committee of the Communist Party of the USSR ordered the S-25 system adopted by the Air Defense. On the insistence of the military, the system would be experimentally used for a year before it became the principal means of air defense, initially also for a year. The manufacturers were charged with maintaining the system and warranting it for these two years”.[29]

It was only a first step in the development of the radar systems engineering in the USSR. The next step was the design of an integrated early warning system. The new system was intended to be fully integrated with the existing and future Moscow missile defense system.

“The Soviet Union began construction of its first early warning radars in 1963–1964. The first early warning system consisted of two Dnestr-M (Hen House) radars, built at sites in Olenegorsk, Kola Peninsula, and Skrunda, Latvia, and a command center near Moscow. The construction was completed in 1968–1969, and in August 1970 the system was accepted for service”. Then was the development of the early warning and missile defense radars in 1972. “The project also called for deployment of a network of early-warning abovethe-horizon radars that were supposed to detect incoming missiles and warheads as they approach their targets on the Soviet territory. The radars were intended to provide an important second layer of early warning sensors, which were based on physical principles different from those deployed on satellites. Besides, radars could provide more accurate information about trajectory of incoming missiles than satellites, which allows estimates of scale of an attack.” The new

[28] “In September 1947, on our special train, we set out for Kapustin Yar, where the Ministry of Defense had created the State Central Test Range for the testing of rocket technology. … Kapustin Yar was an old village in the lower reaches of the Volga River, on a flood plain that was usually not covered with water. This was the area between the Volga and Akhtuba Rivers. Further along the firing line were the uninhabited Volga steppes” (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II). Washington, DC: NASA History Division, 2006, p. 30, 31).
[29] M. Pervov. From "Berkut" to "Triumf" (http://www.aviarus-21.com/index-eng.htm)

radars were intended to increase the coverage provided by the network of early warning radars to include the North Atlantic, areas in the Pacific and Indian oceans, and the eastern Mediterranean Sea (see Fig. 19). This work began in 1973 and continued until 1978.[30]



Early warning and missile defense radars deployed by 1979

Fig. 19

“According to a plan which was drafted in the beginning of the 1970s, the early warning system was to include a space-based component in addition to the network of above-the-horizon and over-the-horizon radars. Satellites were necessary to extend the capabilities of the early warning system, for they were capable of detecting ballistic missiles almost immediately after launch. Initially, work on the space-based component of the early warning system was assigned to the design bureau headed by A. I. Savin. In 1973, this design bureau was reorganized into the TsNII Kometa (Central Scientific Research Institute Kometa), which became the primary developer of the space-based component of the early warning system. Development of spacecraft platform was assigned to the S. A. Lavochkin Design Bureau”.

---

[30] P. Podvig. History and the Current Status of the Russian Early-Warning System. *Science and Global Security, Taylor and Francis 10:21–60, 2002*

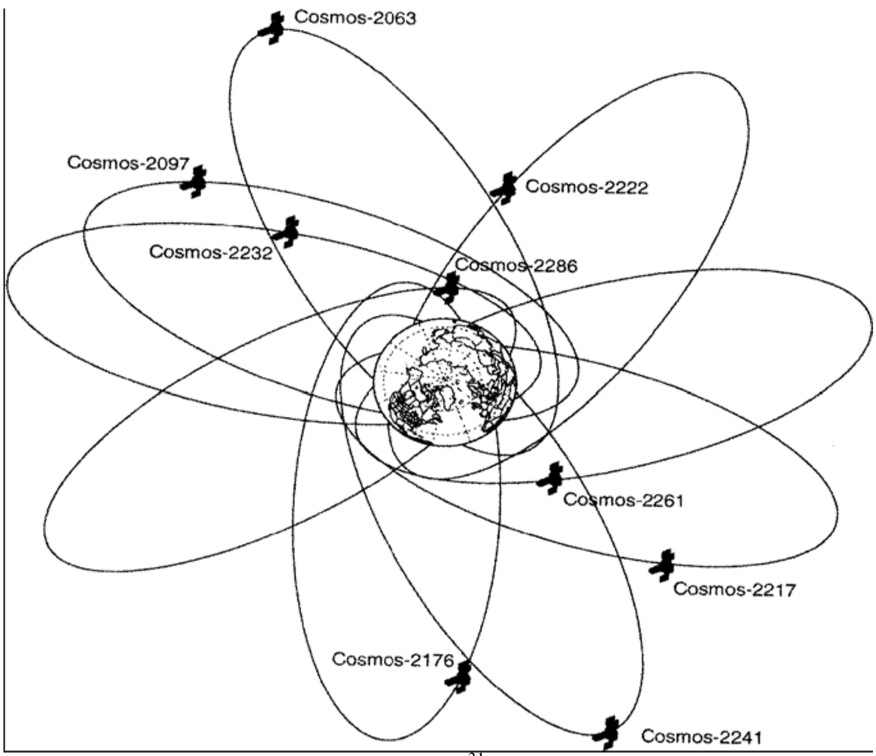


Fig. 20[31]

C.P. Snow was writing in his book "Science and Government" in 1960: "In military technology in particular, where the level of the United States and the U.S.S.R. is very much the same and where the investment of scientists and money is also similar … So I believe we are in the same boat and that all countries can learn from each other's concrete experience".[32]

This period is characterized also as *civil* use of radar for air and sea traffic control, navigation and fire control radar, highly miniaturised automotive radars for observing the road ahead, spaceborne radar.[33] But this is another history.

[31] "The system, however, was designed to include up to nine satellites simultaneously. Satellites in the constellation were placed into one of nine orbital planes, which were separated by about 40 degrees from each other". The Figure shows the configuration of orbital planes that existed in January 1995" (P. Podvig. History and the Current Status of the Russian Early-Warning System. *Science and Global Security, Taylor and Francis 10:21–60, 2002*).

[32] C.P. Snow. Science and Government. Cambridge, Masschusetts: Harvard University Press, 1961, p. 70, 55.

[33] "Most of us associate radar with combat scenes in movies or an occasional speeding ticket. Conventional radar uses beamed and reflected microwave energy to detect, locate, and track objects over distances of many miles. Almost all types of radar were developed for defense applications, and they continue to be used by the military and a few civilian organizations. Commercial use has been limited primarily because most radar systems are large, and they can be complex and cost $40,000 or more. A dramatic change in radar use is imminent, resulting from work done at LLNL". LLNL – Lawrence Livermore National Laboratory, a United States Department of Energy national laboratory (managed and operated by the University of California, in Livermore, California until September 30, 2007) is a premier research and development institution for science and technology applied to national security. MIR - compact, low-power radar system called micropower impulse radar, "which is orders of magnitude less expensive to produce than other conventional radars. Unlike conventional radar, which sends out continuous waves in bursts, MIR uses very short electromagnetic pulses and can detect objects at much shorter range." Among the scores of uses for MIR are new security and border-surveillance systems; underground, through-wall, and ocean imaging; fluid-level sensing; automotive safety, including collision-avoidance and intelligent cruise-control systems; and medical diagnostics etc. (S. G. Azevedo, T. E. McEwan. Micropower impulse radar. In: Science & Technology Review January/February 1996). - http://wwwlasers.llnl.gov/ lasers/idp/mir/mir.html

5.2. Theoretical aspects

Systems engineering sets itself the goal of developing a new system, and consists of a combination of various scientific and engineering concepts without reducing them to a unified theoretical conception. This enables a researcher or developer, while solving a special systems engineering problem, to draft varying schemes of complex engineering artifacts. Such schemes actually constitute a "syncretistic" combination of various concretizations of theory (elements of electric circuits and mechanical diagrams, algorithmic, skeleton-, and block diagrams of automatic control theory and other disciplines) and the representations of the object under development: elements of different plans of production, development, functioning, etc. A common theoretical-structural scheme includes the components of intermeshing diagrams, electronic circuits, and block and wiring diagrams that underlie the design and assembly of mechanical, electric and other units.

Because of their complexity, radar systems are difficult to describe mathematical1y. This is why a simplified approximation is required as in any other scientific and engineering discipline. This approximation can then be further differentiated by a series of subsequent operations. Mathematical formalization permits the development of a single methodology for analysis and design of any radar systems.[34] A system is represented in the form of a structural diagram, which makes it possible to optimize its structure mathematically. Another important distinguishing feature of systems engineering is the use of abstract algorithmic theoretical schemes (see Fig. 21).

[34] Radar systems engineering theory are derived some general rules "which will disclose what level of performance can be expected of a given system. By using these rules to eliminate the least profitable lines of investigation, the radar systems engineer may concentrate his attention on those areas where greatest advantage can be taken of new components and design techniques … The objective is to permit the working engineer to prepare realistic specifications for a radar system and its major components, to synthesize a radar system meeting given requirements, to predict the performance of a given radar under stated conditions of use, and to set up reasonable procedures for evaluation of major radar characteristics. The use of mathematics has been held to a minimum, consistent with the need to arrive at quantitative results. … By reducing some of the complex theory behind radar processes to a set of simple definitions and equations which are within the understanding of any practicing engineer, the real problems in radar system development should be made more apparent to those whose component and circuit designs will lead to new and improved systems" (D. Barton. Radar System Analysis. Prentice-Hall, 1964, p. viii).

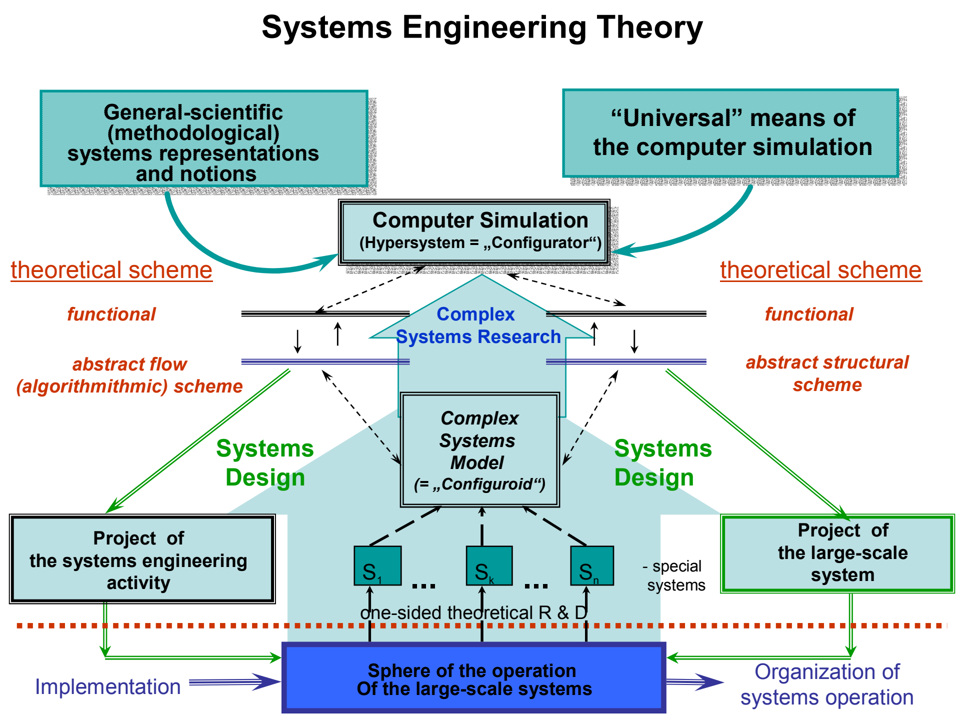


Fig. 21

The non-classical, specific evolution of systems engineering is stipulated by the necessity of solving complex engineering problems. Though integrating a complex collection of different types of knowledge and methods, and bearing up against a variety of disciplines, it uses them for handling specific problems that cannot be solved by any of these disciplines separately. Hence, the formulation of the systems engineering theory starts directly with the development of a generalized theoretical (ontological) scheme. It is worth noting that such a scheme cannot be borrowed from any of the existing scientific disciplines. This requires a certain methodology. The most adequate concrete methodological basis for the comprehensive theoretical research in systems engineering is provided by systems approach. The use and development of the latter determines its status as a comprehensive scientific-engineering discipline. It is worth noting that methodological knowledge makes an integral part of the systems engineering theory. A specific feature of modern scientific and engineering disciplines, in particular systems engineering, is that they are systems oriented. In other words, all of them (systems engineering, ergonomics, engineering cybernetics, systems analysis, etc.) operate according to a certain "universal" ontological scheme represented by different versions of the general systems theory and methods and tools of systems approach. This "universal" scheme provides a basis for an ideal model, for specific viewing of the object under study and design, the reality which the systems engineer faces and operates in, the only reality permitting a synthesis of "particular" theoretical concepts (see Fig. 21)..

The main problem facing **theoretical systems engineering** is the transition from the syncretistic description of a complex engineering problem by the theoretical means and concepts of various scientific disciplines to a homogeneous abstract theoretical scheme. It is necessary, first of all, to be able to make use of the appropriate mathematical apparatus in systems engineering. To this end, a uniform description of qualitatively heterogeneous elements must be given. This is the reason why, in theoretical systems engineering, the theoretical schemes are principally formulated as abstractly as possible.

Generalized structural schemes came into being by way of generalizing different structural schemes: automatic control theory, network theory, switching circuit network theory, computer logics, and those used in socio-economic case studies — are combined in the so-called structural analysis of complex systems. A major problem of systems engineering is determination and choice of the system's structure.[35] For this purpose special abstract circuit diagrams are drawn up which help determine the composition of subsystems and elements; functions are distributed and interactions between the system and the environment are discovered. When the structure is addressed abstractly, the internal properties of each individual element are of no interest. See for example block diagram of a monopulse radar device in **Fig. 21. "**The summation channel is evaluated as in normal pulse radar for the measurement of the range and the velocity. Both difference channels determine the angles in azimuth and elevation. For the transmitting case (arrows in opposite directions), the power is fed into the summation channel and the difference channels are decoupled and remain without power. Three parallel receiving channels are required for monopulse radar, which must be synchronized with one another".[36]

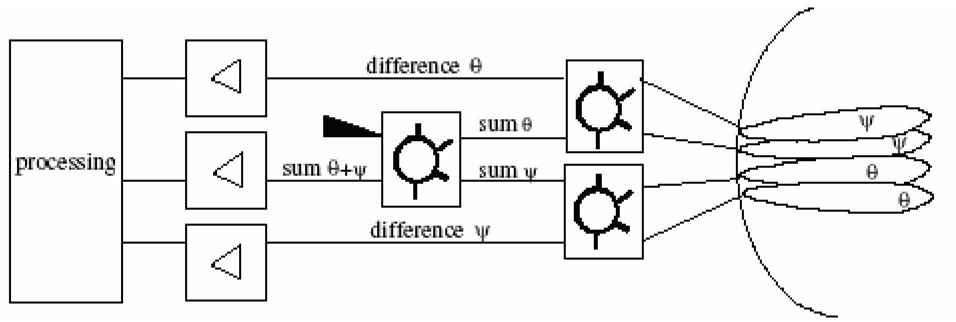


Fig. 21. Block diagram of a monopulse radar device

The structure may be characterized by topological properties, the time it takes information to pass through the communication network and the reliability in case its integrity is violated. Particularly important for radar systems are the topological properties, i.e., special and directional distribution of communication networks. Actually, in an abstract analysis of structures, the configuration of internal relationships in the system is studied and the basic typical networks — linear, circular, multiple, star and their combinations — are distinguished. For example, in the course of structural studies of automatic control systems, nothing remains but relations, their number, differential order, sign, and configuration[37] (see Fig. 22).

[35] "Studies in the radar-electronic field have been carried out on three levels: the level of circuit and component design, that of mathematical analysis and statistics, and the level of systems engineering. … It is the purpose of this book to gather into one volume the theory and practical procedures used by radar system engineers who design, specify, or evaluate entire radars as components of larger systems. The components, circuits, and mechanisms which are combined to build the radar will be described only to the extent that their properties will influence the over-all performance of the radar in its role as a source of information in the larger system" (D. Barton. Radar System Analysis. Prentice-Hall, 1964, p. i).

[36] W. Wiesbeck. Lecture Script "Radar System Engineering". 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe, p. 134: www.ihe.uni-karlsruhe.de

[37] V.I. Nechiporenko, Structural Analysis and Methods of Building Reliable Systems. Moscow: Soviet Radio Publishers, 1968, p. 11-12; V.I. Nechiporenko, Structural Analysis of Systems (Efficiency and Reliability). Moscow: Soviet Radio Publishers, 1977; Tzvirkun. A.D. Structure of the Complex Systems. Moscow: Soviet Radio Publishers, 1975 (All in Russian)

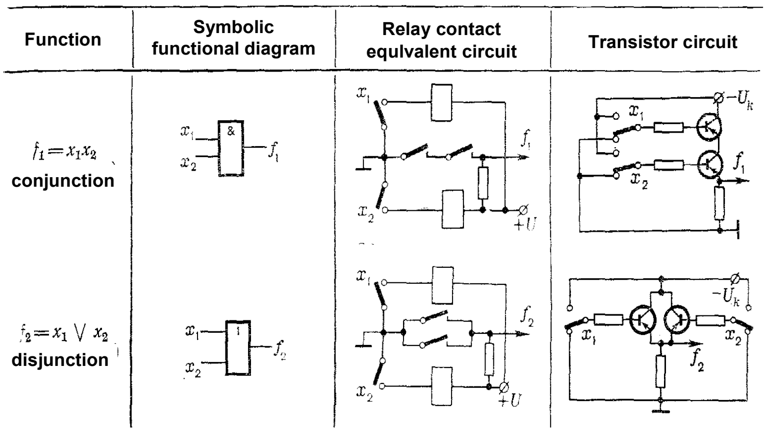


Fig. 7[38]

Mathematical studies of circuit diagrams in radar systems engineering are based on graph theory. A radar system is represented in the form of a structural graph which makes it possible to optimize its structure mathematically.

Generalized algorithmic schemes were applied in cybernetics and in the transformation of matter, energy and information. Actually, they are idealized representations of any system's functioning, and are the starting point for computer programming (they are related to the respective functional schemes in the theory of programming). See for example in the **Fig. 21** an algorithm of medical ultra-wideband (UWB) radar's signal processing.[39]

38

39 Pavlov S.N., Samkov S.V. Algorithm of signal processing in ultra-wideband radar designed for remote measuring parameters of patent's cardiac activity. In: Ultra Wideband and Ultra Short Impulse Signals, 19-22 September, 2004, Sevastopol, Ukraine pp. 1-3 - http://www.radar 04_uwbusis_id01.pdf

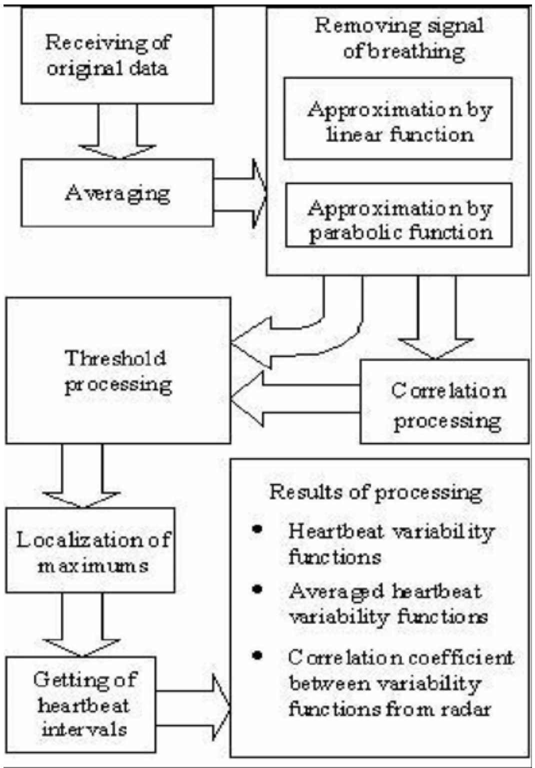


Fig. 21. Algorithm of UWB radar's signal processing

The application of the conceptual and mathematical apparatus of information theory and cybernetics in radiolocation made analysis of the so-called fine structure of a complex signal, irrespective of its specific type, possible. The concept of radar information is associated with the description of the information carrier (signal). Radio waves are regarded in such a case only as a type of waves of arbitrary nature. “Electromagnetic waves only of the radio-wave band were used initially in radio location; hence, it was named radiolocation. Today, radiolocation uses a wide range of electromagnetic waves, including infrared and light oscillations (thermo-location and light-location), and also X-ray and gamma radiation. Radiolocation methods based on the use of mechanical ultrasound oscillations of elastic media instead of electromagnetic waves are also used”.[40]

The functioning of a radar system is regarded in systems engineering as an algorithm for processing radar information. Transition to theoretical synthesis of the algorithms or radar signals’ processing was stimulated by developing analogue processing of data by means of selsyns, resolution devices and potentiometers that performed certain mathematical operations. In the early 1950’s, more active use was made of digital computation in radiolocation. As a result, it is today difficult to draw a distinction between the functions of radar systems and those of computer systems.

A general theoretical basis for the synthesis of algorithm processing in radar systems engineering is the statistical decision theory. First, a mathematical representation is assumed or set followed by a logical representation of the algorithm which represents a sequence of operations with the signal. The latter is then correlated with the chosen structure of the radar system. The methods of information processing in radar systems are described in a special theory of radar signal analysis and synthesis.[41]

---

[40] Teoreticheskije osnovy radiolokatzii [Theoretical foundations of the radiolocation]. Moscow, 1970, p. 5 (in Russian)

[41] D. Barton. Radar System Analysis. Prentice-Hall, 1964

x x x

The development of large-scale systems and integration of diverse engineering activities are pressing problems currently in the various fields of science and technology. The significance of these problems for spacecraft, power-generation and distribution, or town planning is evident. But the systems approach also comes into its own in the traditional branches of technology, such as, say, automotive engineering. It is not sufficient today to design a good automobile; it is also necessary to plan for its service and maintenance, including the location of either filling or battery-charging stations (for electric automobiles), service stations, spare-part production, the development of a highway network, including roadways with special covering, and so on. This is a socio-economic, not just an engineering, task. It is not enough to bring forth a new invention — it is necessary to provide for its manufacture and use in a particular social and natural environment and to ensure its optimum interaction with man and his surroundings. The modern design engineer must now consider not only the design and producibility of a product, but also psychological, social, aesthetical, and many other factors. But this means that physics, mathematics, and the engineering disciplines do not exhaust the knowledge indispensable for the present-day engineer. This is particularly clear when developing complex man-machine interfaces such as that for a computer system. What is needed here is not just the design of separate hardware components and their adaptation for convenience of handling, but planning (or, rather, reorganizing) the human activity to integrate machine components into it. In order that the computer (and modern technology in general) might become a means of development and magnification of man's intellectual capabilities, the design should be directed from man to machine, not the other way round.