A Brief History of Radar

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A Brief History of Radar in the Soviet Union and Russia

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Discourse

"From letters one makes syllables,
From syllables, words, and
From words discourse.
Do your duty by them." **

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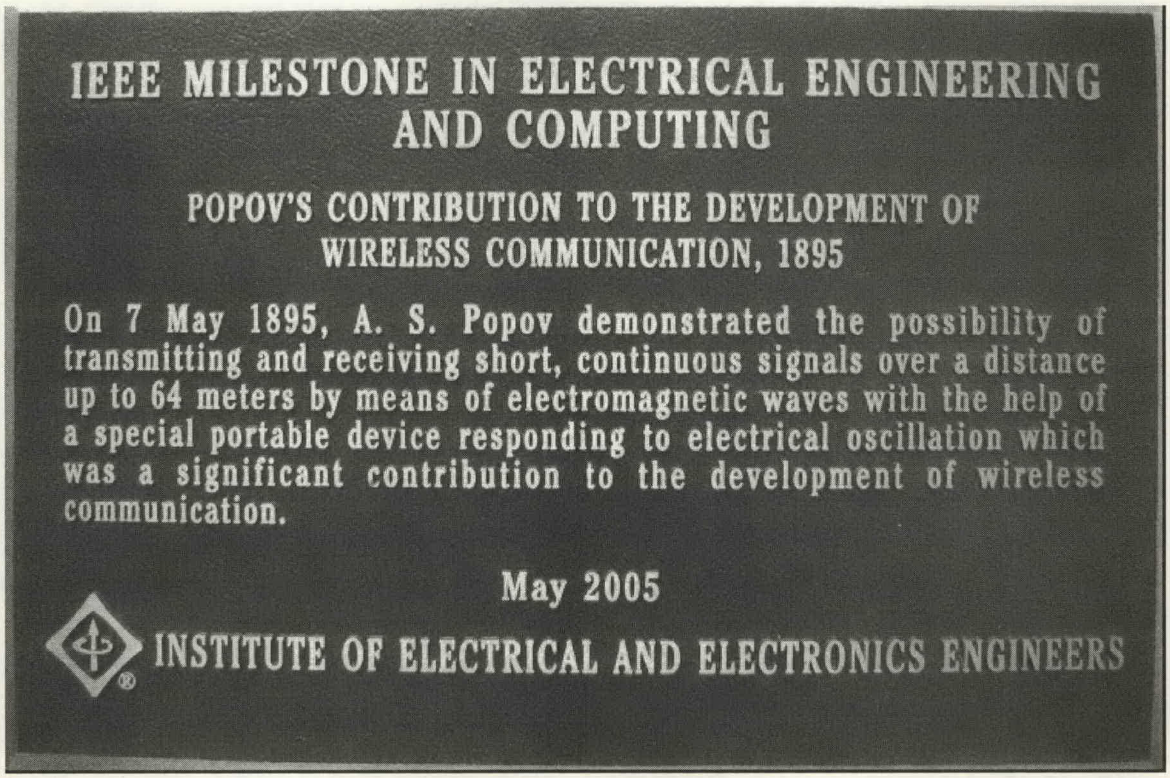
** *From* ***Champ Fleury*** *(1529) by Geofroy Tory*
Translation by George B. Ives



W. Cleon Anderson, President of the Institute of Electrical and Electronics Engineers (IEEE), dedicated this Memorial Plaque at Saint-Petersburg State Technical University "LETI," in May 2008, devoted to A. Popov's experiment on wireless communication by means of electromagnetic waves on May 7, 1895.

This day is celebrated in Russia as Radio Day.

[The address where the above plaque may be seen is J Popov St., No. 5. St. Petersburg, Russia.]

*This work is dedicated
to the celebration
of the 150th anniversary
of the birth of
Alexander Popov,
the pioneer of
wireless communications
by means of
electromagnetic waves.*

A Brief History of Radar in the Soviet Union and Russia

Victor S. Chernyaк & Igor Ya. Immoreev

ABSTRACT

In his report about experiments with radio communication in the Baltic Sea in 1897, Russian scientist Alexander Popov reported the detection of a warship "Lieutenant Il'in" when it crossed the radio communication link between two other ships "Europe" and "Africa" [1]. This observation was the first mention about the possibility of object detection by means of radio waves. The first patent on the phenomena was obtained in 1904 by German engineer Christian Hülsmeyer who called this device the "Telemobiloskop" [2]. However, neither A. Popov's observation nor C. Hülsmeyer's invention was the subject of any development up to the 1930s of the 20th century.

This is a partial summary of the work done by the Soviet Union and Russia in the field of radar.

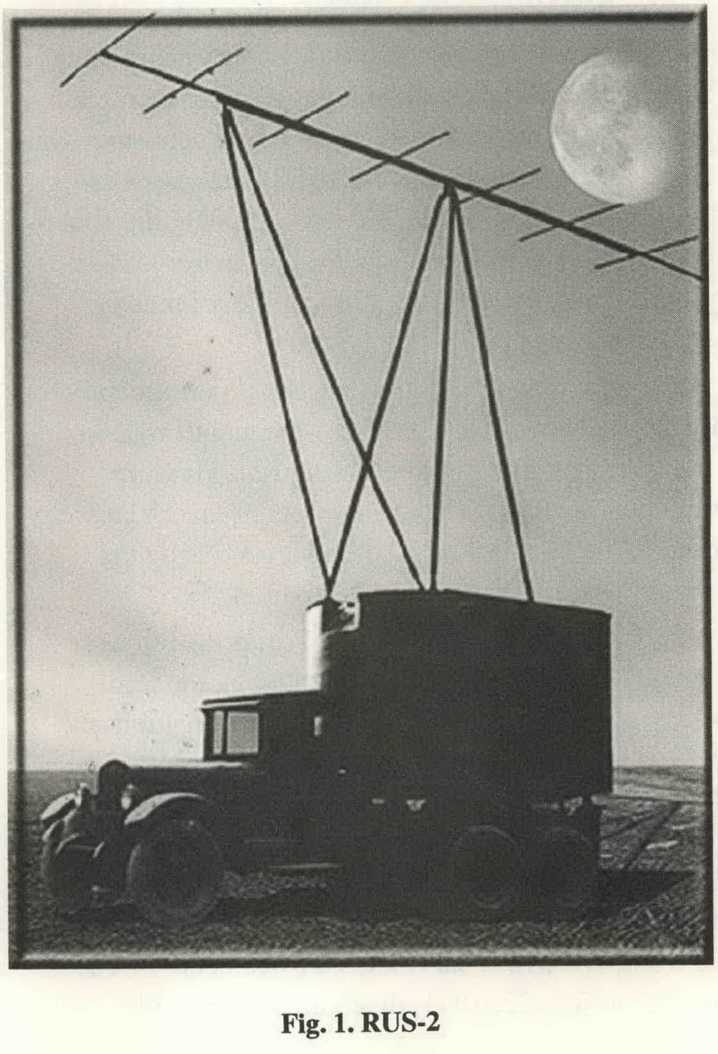


Fig. 1. RUS-2

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THE FIRST SOVIET RADARS BEFORE AND DURING WORLD WAR II

The growing role of military aviation together with the increase of aircraft velocity were the reasons for going from sound detection to radio detection methods.

In the Soviet Union, this problem was solved independently of other countries. Radar as a technical means was proposed by a military engineer Piotr Oshchepkov in 1932. This proposal was supported actively by military authorities of the Soviet Union. Successful field tests of the first radar were carried out in July and August, 1934. This was a CW VHF-band radar with separated transmitting and receiving stations. The radar detected airplanes at altitudes of 5-6 km and ranges of more than 3 km by observing the measuring beat frequencies between direct and reflected signals [3-5]. In October 1934, the results of that testing led to concluding the first in the world industrial contract for production of five radars. Thus, in 2009, the Russian radar industry commemorates its 75th anniversary.

The first industrial radar "RUS-1"[1] was accepted by the Red Army[2] in 1939. Its wavelength was 4m, and its transmitting and receiving stations were separated by 35 km. Forty-five sets of this radar were used in the Far East and the Caucasus during the Great Patriotic War against Nazism [4, 5].

The first pulsed radar "Redut" (in production "RUS-2," see Figure 1) was adopted by the Red Army in 1940. An important role in its creation was played by the outstanding Russian scientist Yu. Kobzarev. This radar also had a shorter baseline (up to 1000 m). It not only detected airplanes but also measured distances and angle coordinates of detected targets. By the beginning of the Great Patriotic War, 12 radars "RUS-2" had been produced [6, 7]. On July 22, 1941, this radar successfully detected the raid of more than 200 German bombers at about 100 km to the west of Moscow. Thanks to the timely detection, this attack was repulsed with the antiaircraft artillery and fighters. Just a few German bombers managed to reach Moscow [8].

A shipborne modification of the radar "RUS-2" (called "Redut-K") was developed in 1940. In April, 1941 it was installed on the cruiser *"Molotov"* and used in battles on the Black Sea [7].

In February, 1941, the antenna duplexer was independently invented in the Soviet Union. This invention permitted the creation in 1941, the first true monostatic pulse radars with the common transmitting and receiving antenna: the mobile radar "Redut-41" (produced under the same name "RUS-2") and the stationary radar "RUS-2s," P-2, "Pegmatite" (see Figure 2) [4, 6, 7].

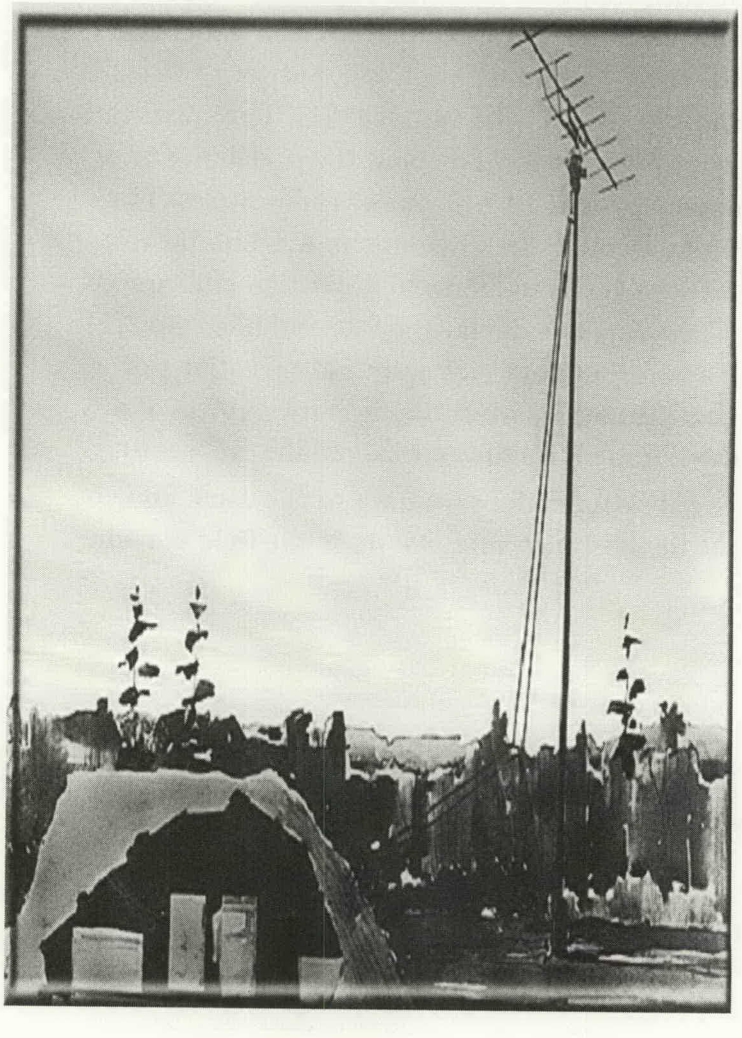

Fig. 2.

[1] Hereinafter we present radar names in Russian notation. To identify them with US terminology refer to [39].

[2] The Soviet Army was called the Red Army up to 1943.

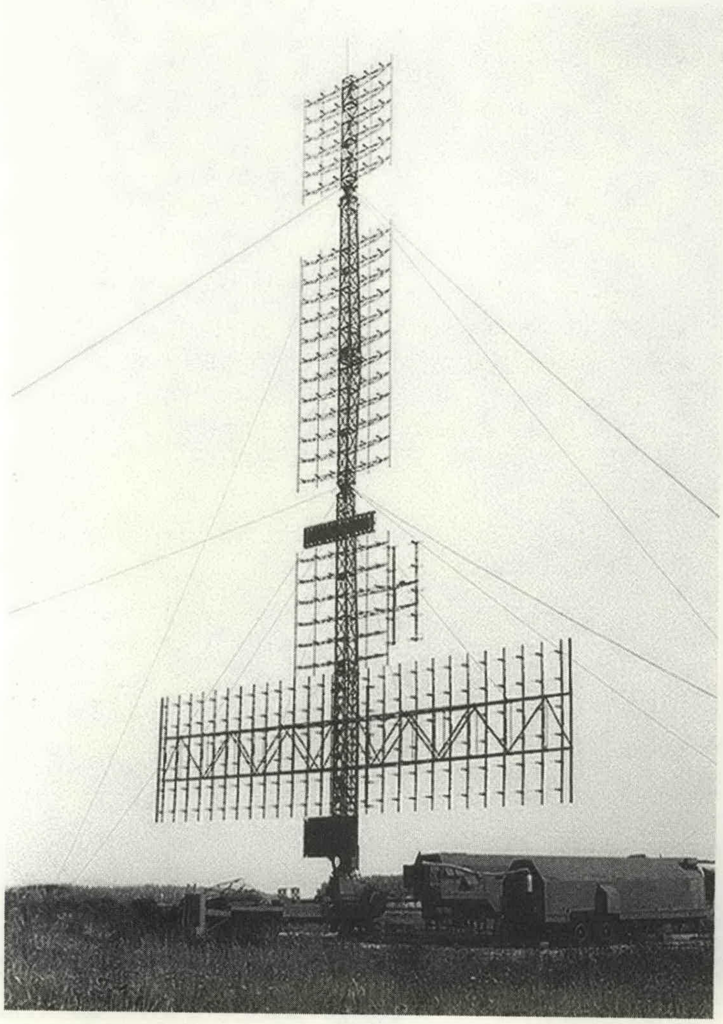

Fig. 3.

Fig. 4.

The first airborne radar "Gneis-2" was adopted by the Red Army in 1943. Its wavelength was about 1.5 m. In the same year, more than 227 sets of this radar were produced. These radars were used successfully in the Air Force and Navy aviation during the War [7].

A more effective surveillance and pointing radar "P-3" was created for the air defense (AD) system in 1944. This radar detected aircrafts at ranges of 35 km for flight altitudes of 1000 m and at ranges up to 100-130 km for flight altitudes of 8000 m [6]. In 1944, instead of the shipborne radar "Redut-K," the novel radar "Guis-1" was developed. This radar was used in convoying the Allied powers' ships [7].

Thus, on the basis of research and inventions in the 1930s, several types of ground based, shipborne, and airborne radars were created, adopted by the Red Army, and used during the Great Patriotic War.

INTENSIVE DEVELOPMENT OF RADARS AFTER WORLD WAR II

Immediately after the end of WWII, in 1946, the USSR Council of Ministers adopted the state program of radar engineering and industry development in the Soviet Union. According to that program, scientific research institutes, design bureaus, and plants appeared for developing and producing new radars in various frequency bands. That program marked the beginning of the intensive development of military radars in the USSR [7, 59].

Fig. 5.

Fig. 6.

The special geopolitical state of the Soviet Union caused the development of a unique wide range of designed and deployed radars. In the structure of the Soviet Army's Aircraft Defense (AD), priority was given to the radar [9].

Some measures were adopted for radar science development and training radar engineers in leading the higher education institutes of the country. Translations of monographs of American specialists from the so-called Massachusetts book series were published with large numbers of copies. In the 1950s and the beginning of the 1960s, the first fundamental works of domestic scientists were published [10–14].

All of this resulted in the rapid development of radar science and technology.

In this brief survey it is not possible to consider all of the variety of radars created in the USSR during the period after WWII. That is why we shall consider below some typical radars of three main classes intended for solving different strategic and tactic tasks in the defense system:

- Air Defense (AD) Surveillance radars creating the base of the radar field for defense of borders and objects;
- Radars for mobile Surface-to-Air Missile (SAM) systems used for defense of troops and objects;
- Radars for Anti-Ballistic Missile (ABM) systems, whose goal is the detection of warheads of strategic missiles and the guidance of interceptors.

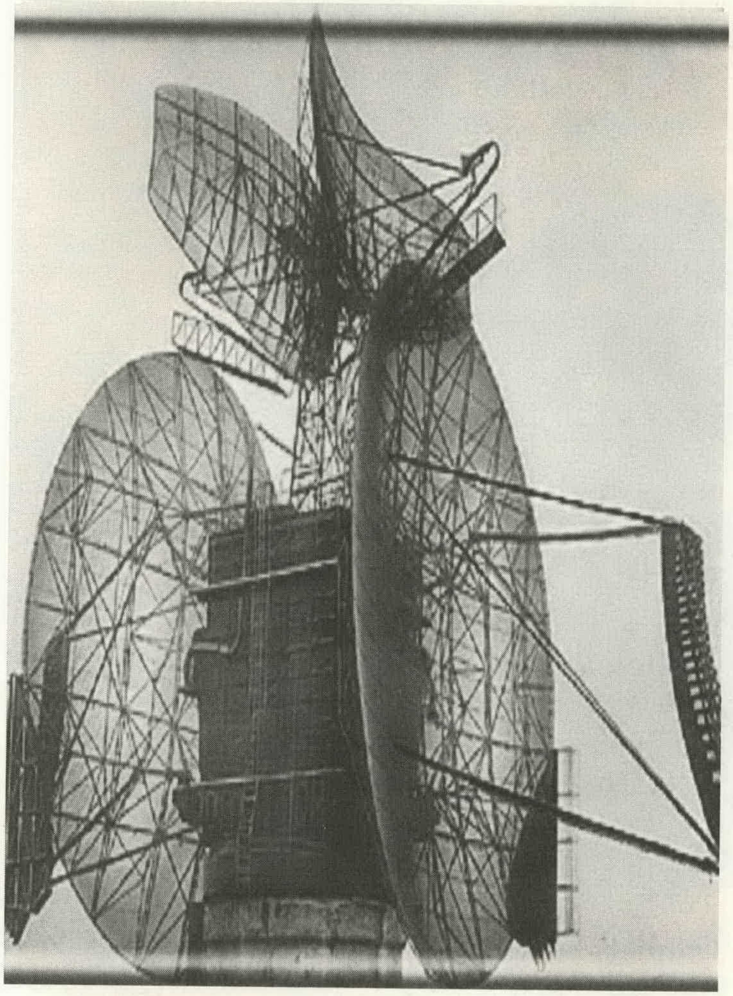

Fig. 7.

SURVEILLANCE RADARS OF THE AD SYSTEM

Surveillance radars of the Air Defense (AD) system in the USSR traditionally operated in the following three main frequency bands:

- VHF band
  (wavelengths from 10 m to 1 m);
- UHF-band and L-band
  (wavelengths from 1 m to 0.15 m);
- S-band
  (wavelengths from 0.15 m to 0.075 m).

VHF-Band Radars

The first after-war radars of this band were adopted by the Soviet Army in 1945. After the first, relatively simple radars, P-3, P-8, and P-10, the more perfect surveillance radars P-12 ("Yenisei") and P-18 ("Terek") were created [9, 15, 44]. Target detection range for these radars were from 18 km to 160 . . . 170 km, depending on target flight altitudes between 50 m and 10 km. Elevation angle coverage was between 0.6° and 30°. In the radar P-18 developed in 1970, an effective protection system against clutter was applied. In the modernized radars P-18M and P-18-2, outdated electronic components were renewed and radar performance was improved essentially according to more rigid requirements imposed on the Air Defense system [48]. These radars were among the most popular radars in the Air Defense system of the USSR.

Later, VHF band became basic for early warning radars. In 1959, the first high-potential radar P-14 ("Lena") was created, whose energy potential (the product of a transmitter mean power and antenna effective area) was about 500 kW × μ^2. In 1968, the radar P-70 ("Lena-M") was developed. It was the first domestic radar with linear-frequency modulated signal and significantly higher energy potential (17000 kW × m^2). The detection range for targets with RCS of a fighter was 700 km for the radar P-14 and 2300 km for the radar P-70 at the mainbeam maximum [9, 44, 49].

The latest radars of this series were the 3-D radar 55Zh6 ("Nebo") with its modernized version 55Zh6-U ("Nebo-U,") (see Figure 3), and the mobile 2D radar 1L119 ("Nebo-SVU") (see Figure 4) which was able to detect aeroballistic targets [16, 44, 60].

An effective interference protection system enabled these radars to give coordinate and trajectory information under conditions of intensive electronic counter-measures. Due to the chosen frequency band, the radars could detect Stealth targets. In radars "Nebo" and "Nebo-U," three coordinates of targets were measured by means of combining measurements of the range-azimuth channel and the range-altitude channel. The radar "Nebo-U" detected fighters at the range of up to 320 km for flight altitudes up to 65 km [9, 15].

Fig. 8.

UHF-Band Radars and L-Band Radars

One of the first Soviet radars working in the lower part of this band was the radar P-15 (“Tropa”) adopted by the Soviet Army in 1955 (see Figure 5). It was capable of aircraft detection at flight altitudes between 100 m and 6 km. In this radar, for the first time, the Moving Target Detection (MTD) system was used. Later, after the change to new circuit components, a modified version of the radar P-15 with the magnetron transmitter, called P-19, became the most widely used radar in the Soviet Army. With that radar, the frequency agility method against jamming was tested for the first time. The pulse accumulation technique was introduced for better target displaying. The transmitter pulse power was upgraded up to 900 kW for pulse duration near 2.5 μs, that made possible an increase in the radar detection range from 100 km to 240 km [7].

Later, the decision was made to use the lower part of the UHF band for detecting low-altitude targets, because in this band, it is easier to ensure efficient suppression of ground clutter and clutter from close objects. A problem of creating a radar field at low altitudes became especially urgent to the middle of the 1980s after the incident with the German light aircraft piloted by Rust, which managed to cross USSR territory from its western border to Moscow, with a landing on Red Square. Work on modernization of the radar P-19 was very intensive. As a result of this work, the first Soviet full solid-state radar “Kasta-2E1” (51U6) [17] and its modernized version “Kasta-2E2” (39N6) [18] were developed. The designers succeeded in developing a highly effective MTD system with ground clutter suppression factor up to 54 dB.

The testing of the radar “Kasta-2E2” (see Figure 6) demonstrated its possibility of detecting and tracking various air targets at low and extremely low flight altitudes with a range up to 41 km, including Stealth aircrafts, hovering helicopters,

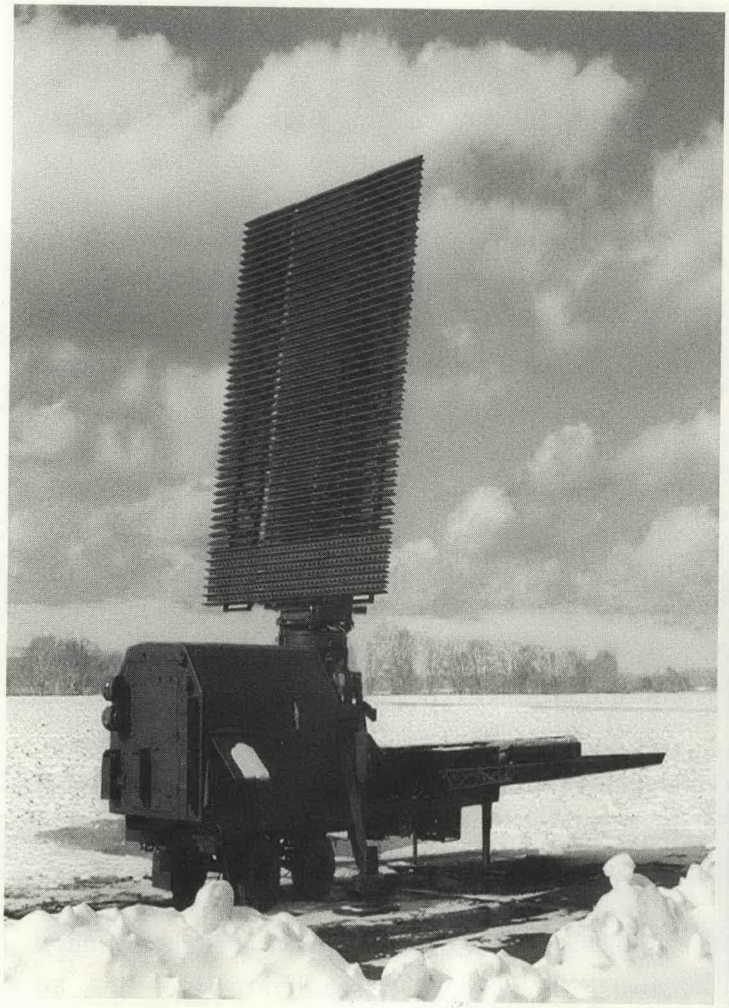

Fig. 9.

Fig. 10.

remotely-piloted vehicles, cruise missiles, as well as moving targets on the sea surface.

One of the first Soviet complex radar systems, "Altai" (P-80), was created in the L-band. This trailerable complex had two 2-D radars and from two to four altitude finders PRV-11 "Vershina" [7-9]. This complex was repeatedly modernized and widely used in the Soviet Army.

In 1961, the powerful 3-D radar "Pamir" (P-90) was designed to operate in this band. It possessed the best performance characteristics in comparison with other analogous radars at that time. Each of two antennas (arranged at angle 180°; with respect to each other) had a system of partial patterns for measuring target elevation angle by the amplitude monopulse method (see Figure 7). However, this radar was stationary, and necessary construction work restricted possibilities of its wide application. As a result, only six radars "Pamir" were produced [7-9].

At the end of the 1970s, the rapid development of technology and techniques of Phased Array Antennas (PAAs) began. The upper part of the UHF band turned out to be the most appropriate for PAA creation due to the fact that solid-state amplifiers of sufficient power for transmitters, amplifiers with low noise temperature for receivers, and other necessary components with small power losses for this frequency band had been created by that time. This band turned out to be suitable for printing technologies introduced in antenna manufacturing. That is why, one of the first Air Defense surveillance radars with PAAs, "Gamma-DE," (see Figure 8) was developed just in the L-band. An antenna

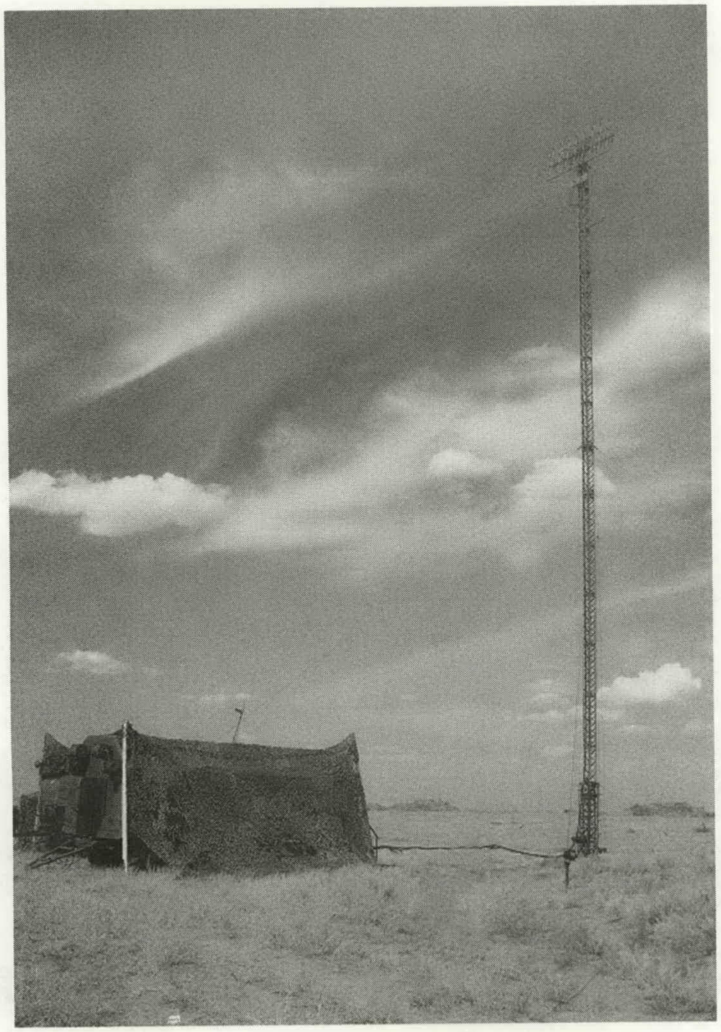

Fig. 11.

system of this 3-D solid-state radar consists of the common active transmitting PAA and the semi-active receiving PAA. The radar provides detecting and tracking targets in severe clutter and jamming environments at ranges up to 360 km for flight altitudes up to 45 km [19].

Other modern L-band radars are 59N6 "Protivnik-GE" and its modernized version "Protivnik-G1E" (see Figure 9). They are mobile radars with digital PAAs in the vertical plane. These radars are notable for high level of automation, including processes of target detection and coordinate measurement. The radars have an effective protection system against natural and deliberate interferences and ensure detecting and tracking targets with RCS of the fighter type at ranges up to 400 km for flight altitudes up to 120 km [40].

A world trend of creating en route radars for air traffic control (ATC), working at the wavelength of 23 cm (according to recommendations of International Civil Aviation Organization, ICAO) had a positive influence on the development of L-band radars.

The first ATC radars were designed on the basis of military radars. In particular, the 3D radar "Pamir" (P-90) was used as a prototype of the radar "Utes." The latest achievements of the radar technology, including solid-state transmitters and equipment for digital signal and data processing, were applied to such recently developed 2-D radars as the en-route radar "Utes-T" and the radar "Utes-A" intended for aerodrome zones (see Figure 10).

A multi-section radar complex 52E6 MU was also designed for operating in the L-band. It is intended for creating lengthy zones (up to 400 . . . 500 km) of radar detection and warning of air objects. The complex employs the principle of "forward scattering" and can detect targets at flight altitudes between 30 and 7000 m (see Figure 11) [60].

S-Band Radars

During the entire period of the radar development in the USSR and Russia, the majority of radars was created just in this frequency band. The first S-band radars, P-20 ("Periskop") and P-50 ("Observatoriya"), were developed and tested in 1950. They were 3-D radars; the V-beam method was applied for measuring the target elevation angle (altitude).

The mobile radar P-20 could detect aircrafts at ranges up to 200 km for flight altitudes up to 13 km (see Figure 12). The more powerful stationary radar P-50 was designed for protection of important state objects. It could detect aircrafts at ranges up to 400 km for flight altitudes up to 400 km for flight altitudes up to 16 km [7].

Between the 1950s and 1970s, a series of mobile and relatively inexpensive 3-D S-band detection

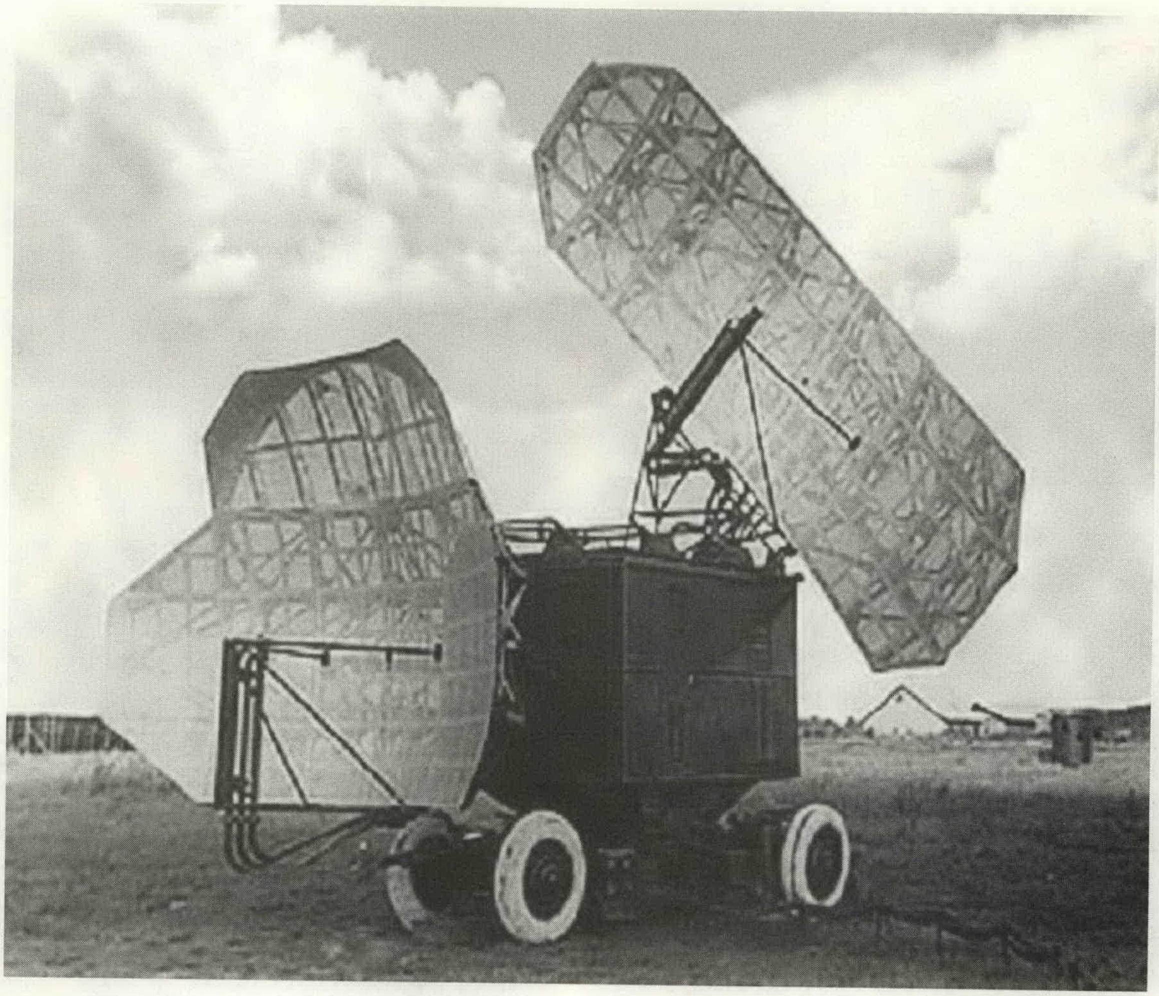

Fig. 12.

radars P-30, P-35, P-37 were developed, put in quantity production and passed through some modernizations.

The 3-D radar P-35 (see Figure 13) was developed in the end of the 1950s. This radar and the radar P-37 were modernized several times. In these radars, surveillance in the elevation plane is realized by means of several narrow beams. The pulse power for each beam is up to 650 . . . 800 kW. Because of the large horizontal dimension of the antenna reflector (about 11 m), the large power of the transmitter, and the high sensitivity of the receiver, the radars are capable of detecting targets with RCS of 10 m^2 at ranges 270 and 350 km, with pulse duration 1.2 μs and 3.1 μs, respectively [21].

The radars P-35 and P-37 were practically the first Russian radars of dual application. They were prototypes for constructing the radars 1L117 and 1L118 for the ATC system. The radar 1RL139-2 (the modified radar P-37) is the most widespread en-route radar of the Russian ATC system [21, 53]. As a result of significant modernization of the radar P-37, the radar 1L118 ("Lira-1") was created, which had improved performance characteristics (see Figure 14) [53].

One of the modern surveillance radars of the S-band is the 3-D mobile radar "Gamma-S1E" (see Figure 15). It has a plane printed PAA scanning in elevation plane, with mechanical rotation in azimuth. A powerful klystron transmitter of high efficiency, with an effective MTD system, and other modern technical solutions allow this radar to detect targets at ranges up to 400 km for flight altitudes up to 30 km [22].

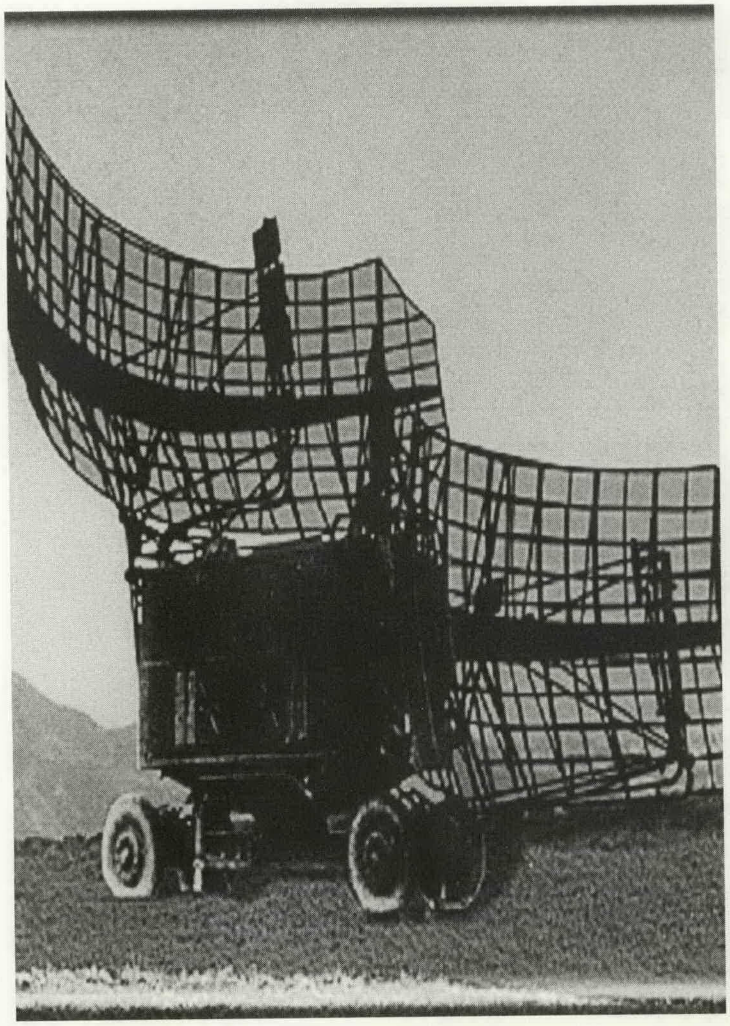

Fig. 13.

Fig. 14.

RADARS FOR SURFACE-TO-AIR MISSILE (SAM) SYSTEMS

First SAM systems

Surface-to-Air Missile (SAM) Systems were adopted in many countries (USSR, USA, Great Britain, France) at the end of the 1950s – beginning of the 1960s for protection of military and industrial objects, troops, and ships against air attacks.

In this period, some SAM systems were created in the USSR [15]:

- The stationary multi-channel SAM system S-25 deployed near Moscow;
- The mobile medium-range SAM system S-75 (see Figure 16);
- Some modifications of the short-range low-altitude SAM system S-125;
- The long-range SAM system S-200 (see Figure 17).

The Air Defense system of the Ground Forces in the USSR employed the mobile SAM "Krug" with performances close to that of S-75.

These SAM systems were composed of both surveillance radars and radars for target tracking and missile guidance.

The incident is well-known when on May 1, 1961, a SAM S-75 had mortally destroyed a US U-2 reconnaissance aircraft flying over Soviet territory at an altitude of 22 km that, earlier, was considered as inaccessible for SAM complexes.

Fig. 15.

SAM Systems of the Next Generation

In the 1970-1980s, technical characteristics of military aircrafts changed significantly: maximum aircraft speed increased up to 3 - 3.5 M; tactical aircraft began to fly at extremely low altitudes; unmanned aircraft were adopted; self-guided missiles homing on radars by their radiation appeared, and systems for electronic suppression of radars were improved.

These changes required a significant increase in the operating speed of radars and comprised a complex pass to the electronic scanning of antenna beams, and to use a powerful controlling computational complex.

Besides, it became clear that it is not possible to create one multi-functional SAM system capable of defending all types of objects against various types of targets. That is why, in the USSR, the following three types of SAM systems were developed:

- S-300P for Air Defense Forces;
- S-300V for Air Defense of Ground Forces;
- S-300F for Naval Air Defense.

An interesting comparison of radars used in the Russian SAM with those used in Western (first, American) SAM systems was published by the well-known American scientist and radar specialist Dr. David Barton [23]. in his opinion, a significant advantage of the Russian SAM systems is in the use of several (two or more) specialized radars for air surveillance and fire control. Dr. Barton noted that this property permits each radar to be optimized for performing its functions, to increase effectiveness, and to lower costs of the SAM system as a whole.

SAM System S-300P

The system S-300P was designed in 1978-1982 and was intended previously for defending administrative and industrial objects, military headquarters and bases, and stationary command posts against strategic and tactical aviation, and strategic cruise missiles. Two SAM modifications exist: the trailable system S-300PT with deploying time of 90 minutes on a previously prepared site and the mobile S-300PS system with a deployment time of 5 minutes [54]. The main unit of both SAM systems is a command post. It is associated with the S-band radar 64N6E intended for surveillance and target designation (see Figure 18). Its antenna is a plane space-fed PAA with a wide-angle two-coordinate electronic scan. The radar 64N6E ensures target detection at ranges up to 200 km for flight altitudes up to 10 km and can track up to 100 targets [24, 25].

The fire-control radar 30N6E (see Figure 19) works in the upper part of the L-band and ensures killing aerodynamic targets at distances of 150 km,

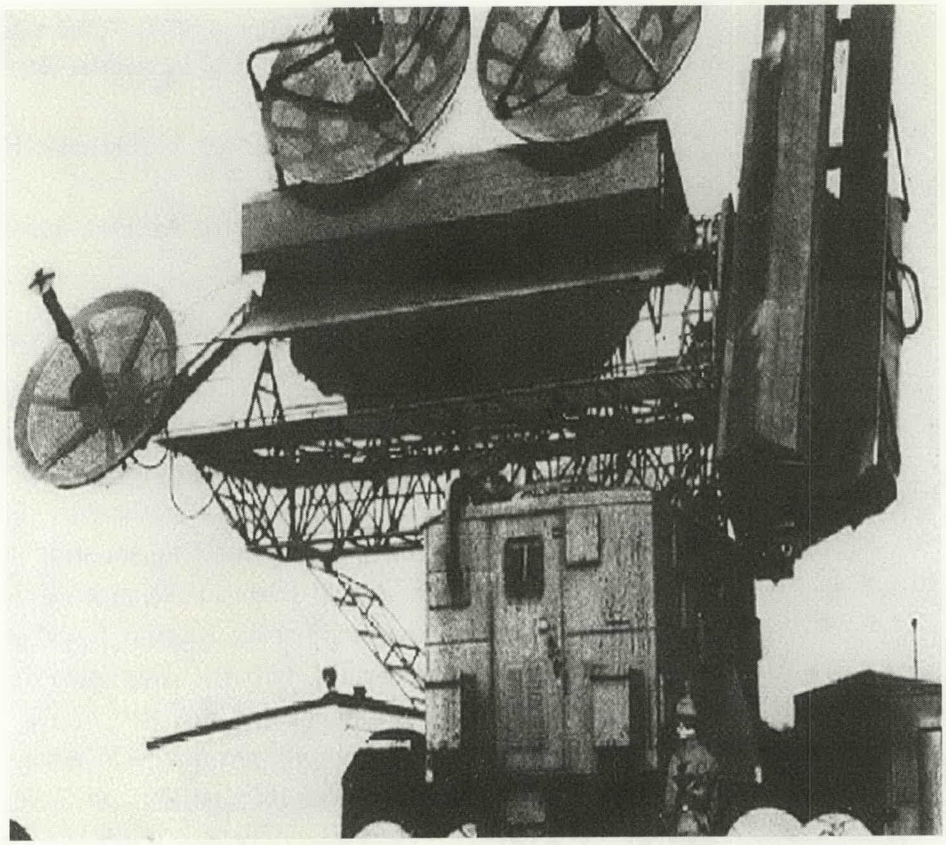

Fig. 16.

strategic cruise missiles at flight altitudes between 6 and 100 m at distances between 30 and 38 km, and aeroballistic targets at distances of 40 km [24, 25]. The radar 30N6E can flexibly change its surveillance sectors, depending on target type.

The high effectiveness of radar and firing means of the export variant of the SAM S-300PMU1 was demonstrated on several international exhibitions. For instance, the Abu-Dhabi exhibition, shootings were performed at missiles of the "Lance" type. Apart from the targets themselves, their fragments greater than 50 cm in size were shot down by the SAM system.

Further improvements of the SAM system S-300P were stimulated by their high competition capability on the world market. Export requirements have led to the creation of a new modification of the SAM system S-300PMU2 ("Favorit," 1997) [26]. According to the opinion of some specialists, S-300PMU2 is the most universal SAM system in the world.

SAM System S-300V

The mobile all-weather SAM system S-300V [27-30] is intended for defending tactical army forces (troop concentrations) and their support facilities, as well as administrative and industrial centers, against tactical, operational-tactical ballistic missiles, aeroballistic, and cruise missiles, tactical and strategic aircraft and helicopters. The SAM system can work independently of other sources of information or command posts and can defend different army formations including those on-the-move.

All units of the SAM system S-300V are mounted on the unified tracked vehicles, GN-830, designed for off-road mobility. Each unit has autonomous power supply, radio communication links, and navigation equipment.

The SAM system S-300V consists of three specialized radars with PAAs.

- The 3-D S-band radar 9S15MT (see Figure 20) is responsible for target

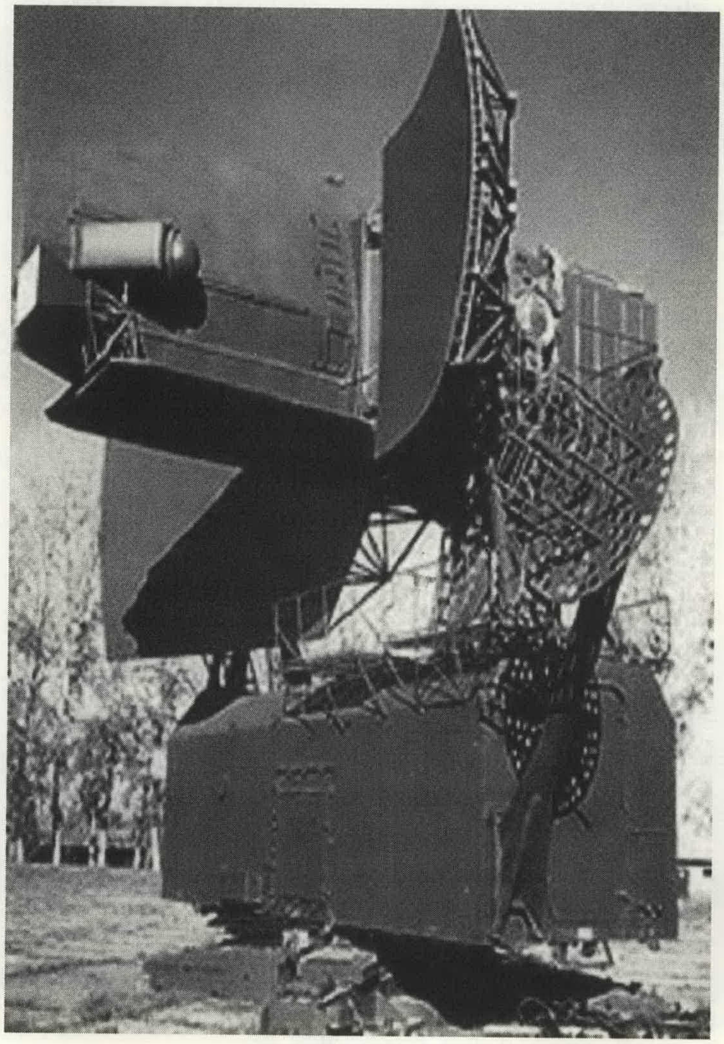

Fig. 17.

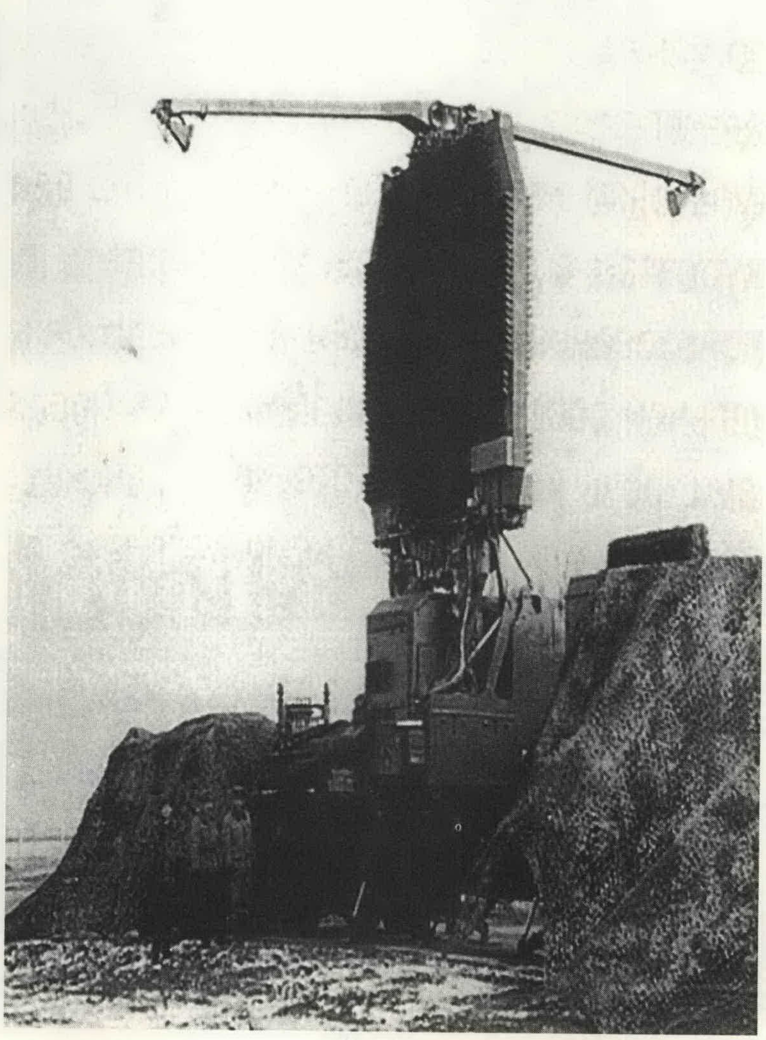

Fig. 18.

detection and acquisition at ranges between 10 and 250 km for flight altitudes up to 30 km; it can track simultaneously up to 200 targets.

- The 3-D sector X-band radar 9S19M2 (see Figure 21) is used for additional search of ballistic missiles within assigned sectors of ± 30° at ranges between 20 and 175 km and can simultaneously track up to 16 targets.
- The 3-D multichannel radar for tracking and guidance 9S32-1 (see Figure. 22) provides surveillance within the assigned sector between 0° and 42° in elevation angle at distances up to 150 km, tracks up to 12 targets designated by the command post, and controls the firing units of interceptor missiles by providing target data for pre-launch loading into the missile, controlling the launch process, and mid-course corrections. The same radar automatically makes a near-horizon surveillance for detecting low-flying targets.

Since terminal guidance of the interceptor missile is provided by a semi-active seeker, homing on reflected target illumination, the SAM system contains a special CW target illuminating radar. This radar is mounted directly on a launcher unit (see Figure 23).

SAM System S-300F

This system [31] is intended for defending groups of battleships against attacks of modern aircraft,

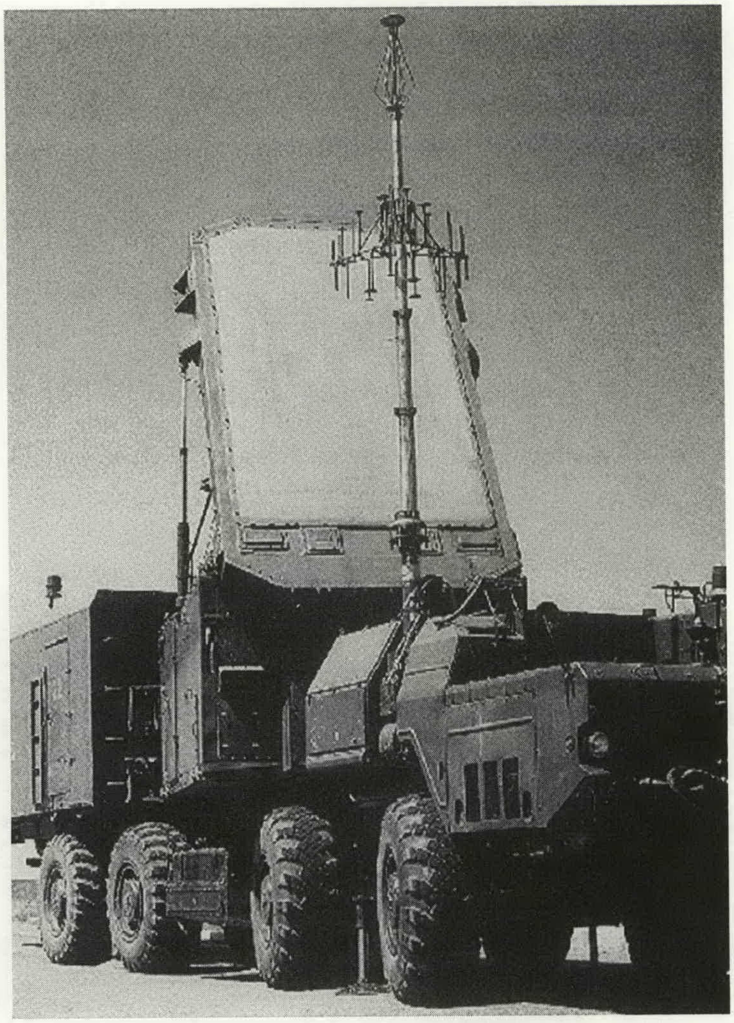

Fig. 19.

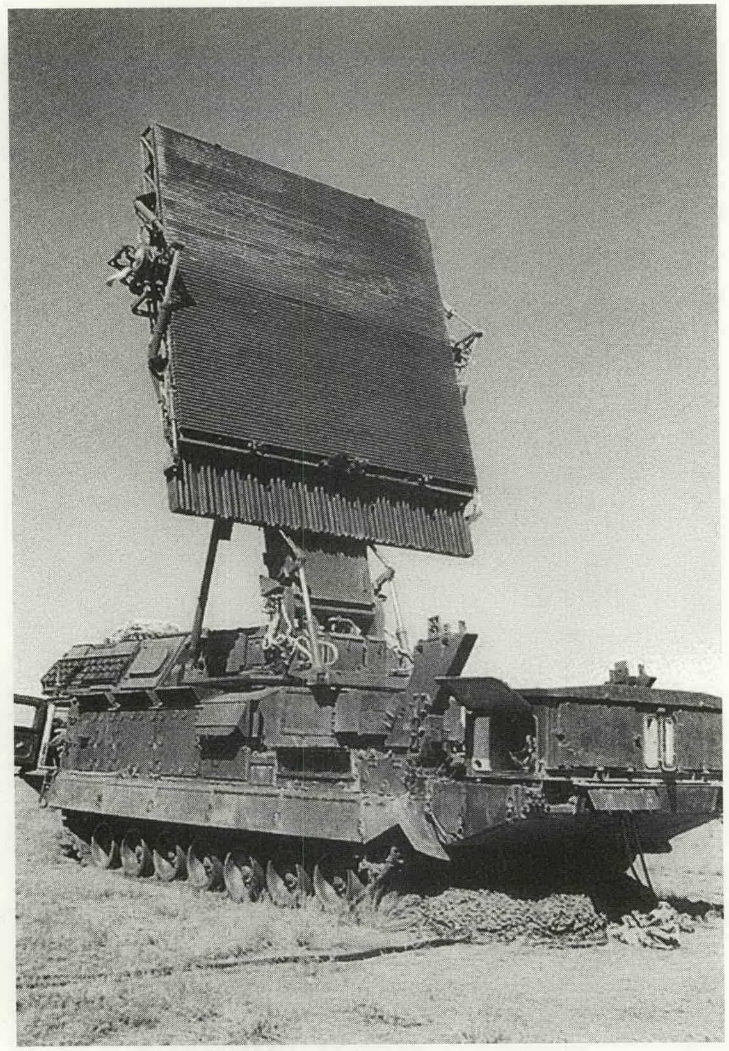

Fig. 20.

cruise missiles, and other air attack means including maneuvering targets and targets flying at extremely low altitudes above the sea surface. The SAM system S-300F (and its modification "Rif") is a part of the ship armament. It obtains information about the target designation from the shipborne surveillance radars.

The multi-functional radar "Fort" of the system S-300F provides target tracking and interceptor missile guidance with high accuracy at ranges between 5 and 75 km for flight altitudes between 0.025 and 25 km. It can track simultaneously up to 6 targets and guide up to 12 missiles. The PAA of this radar has an electronic antenna beam stabilization system ensuring operation under pitching or rolling conditions without loss of interceptor guidance accuracy.

SAM Systems of the New Generation

The new SAM S-400 "Triumf" is a SAM system of the fourth generation. It is intended to engage current and future air threats. The structure of this system and its unique performance characteristics ensure more than a two-fold increase of application effectiveness in comparison with SAM systems of the previous generation. In particular, the system can detect aircraft constructed on the base of Stealth technology and other targets at maximum ranges and all altitudes of their combat employment (see Figure 24). The SAM system S-400 "Triumf" consists of the all-around surveillance radar 64N6, the sector-scan radar 76N6 [56], the new radar 92N6 with target detection range of about 600 km, and the multi-functional guidance radar 30N6 [42, 43, 55].

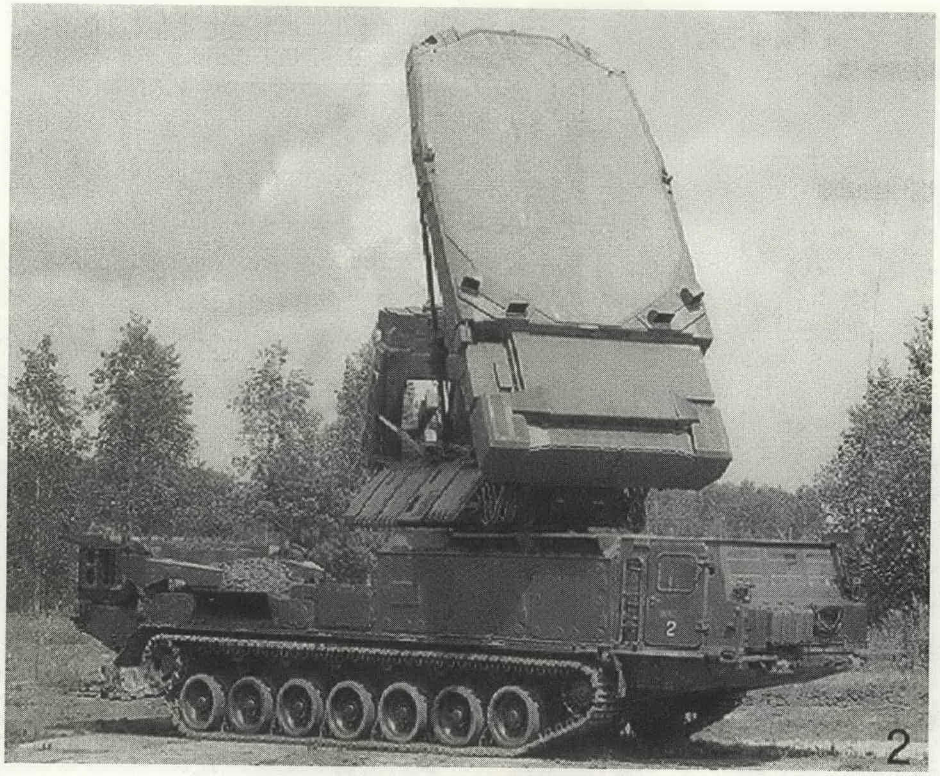

Fig. 21.

Short-Range and Medium-Range SAM Systems

Such SAM systems are very popular on the world market. The best known of them is the Russian SAM system "Kub."

The radar equipment of this SAM system consists of one L-band radar intended for tracking and illuminating targets, and one S-band radar for guidance of interceptor missiles. The radars ensure target detection at ranges up to 50 km at elevation angles from –8° to +9°.

More than 500 sets of this SAM system were produced. It was exported to 22 countries. This SAM system was used in the conflict between Egypt and Israel in 1973.

On the base of the SAM system "Kub," the modernized SAM system "Buk-M1" was created [32]. Unlike its prototype (having the operation range up to 22 and 24 km), the SAM system "Buk-M1" (see Figure 25) can kill targets at ranges up to 35 km, flying with speeds up to 830 m/s in a background of barrage jamming. In the modernized SAM system "Buk-M2" (using the modern component base), the target kill range is increased up to 45 km for target speed up to 1100 m/s.

Apart from SAM systems intended for battlefield applications, the Russian Army has mobile short-range SAM systems for defending such objects as nuclear power plants, defense industry plants, and other objects which must be defended against terrorist attacks in peace-time and against precision-guided weapons in war-time [33].

The best known SAM systems of this class are Surface-to-Air Missile-Gun (SAMG) complex "Tunguska" (see Figure 26) and the SAM system "Tor-M1" (see Figure 27).

The SAMG complex "Tunguska" has two coherent-impulse radars. The first L-band radar detects fighters at flight altitudes between 25 and 3500 m for ranges up to 20 km. The second S-band radar ensures sufficiently accurate tracking of detected targets in three coordinates [57].

The system "Tor-M1" detects targets at range up to 25 km and can track simultaneously up to 12

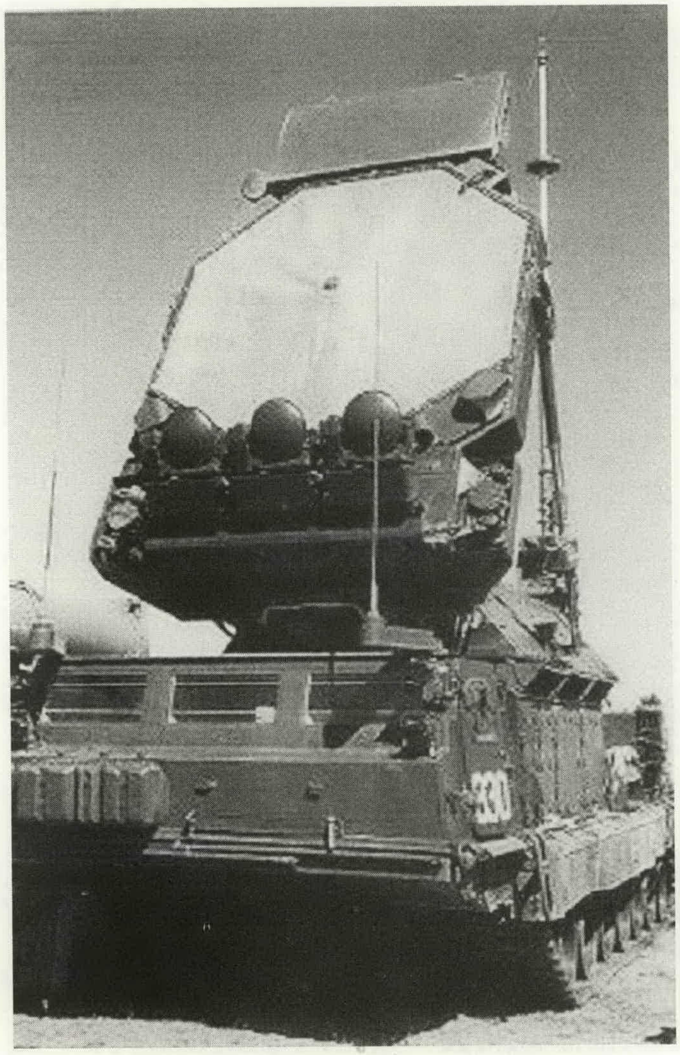

Fig. 22.

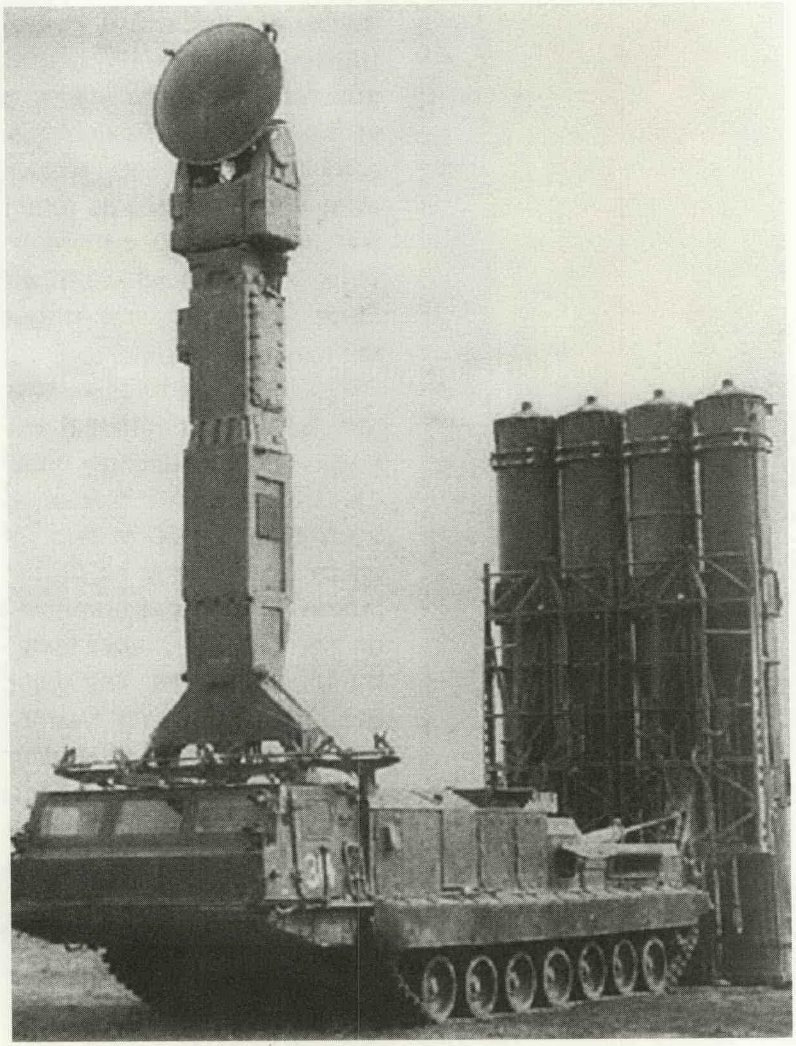

Fig. 23.

targets. It takes only 5 to 8 seconds from the moment of target detection to the moment of interceptor missile launch.

The modernized SAM system “Tor-M2” was shown in the military parade in Moscow on May 1, 2008 and will be adopted by the Russian Army in 2009. The main advantage of the SAM system “Tor-M2” is its possibility to fight against precision-guided weapons including cruise and anti-radar missiles [47].

The newer Russian short-range SAMG system is “Panzir-S1” (see Figure 28). The radar with a PAA can measure all three spatial coordinates and the radial velocity of detected targets. This radar is considered as basic for the series of modern radars with detection range between 26 and 160 km [34].

RADARS FOR ANTI-BALLISTIC MISSILE (ABM) SYSTEMS

On March 4, 1961, for the first time in the world, the first Soviet experimental ABM system “System-A” deployed on the Sary-Shagan polygon near Lake Balkhash intercepted and destroyed a ballistic missile warhead. The warhead velocity was more than 3 km/seconds, and the interceptor had a high-explosive fragmentation (non-nuclear) charge. The difficult problems of precise tracking of the warhead and interceptor were solved with the help of a multi-site radar system containing three monostatic pulse radars with a short decimeter wavelength, located at the vertices of a regular triangle with sides

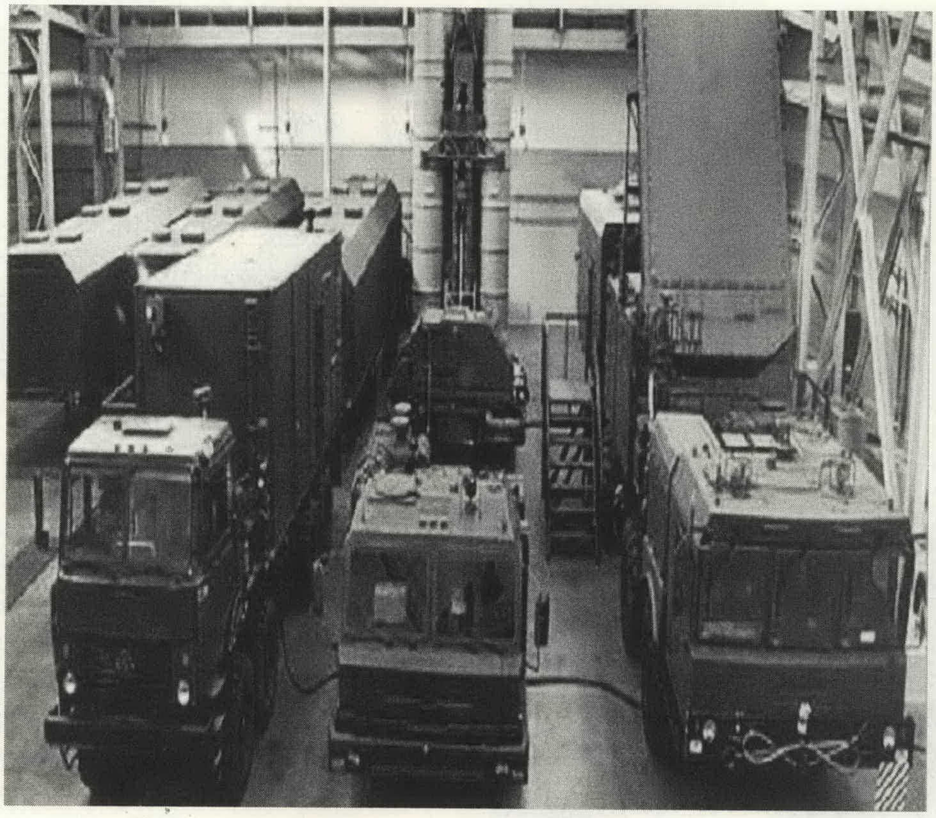

Fig. 24.

of about 150 km. The trilateration method was used for target and interceptor coordinate determination and tracking. Accuracy of range measurements of each radar was better than 5 m (rms value). The system detected missile warheads and began their tracking at a range up to 700 km [35].

Later, in conformity with the USSR-USA ABM Treaty (permitted to have one local ABM system for each side), the ABM system "A-35" was deployed around Moscow. Its testing was finished in 1978. Before that system deployment, the experimental system "Aldan" was created on the Sary-Shagan polygon [38].

The modern ABM system of the new generation was created around Moscow by the end of the 1980s. It incorporates the long-range surveillance and target designation radar "Dunai-3U" and the multi-functional engagement radar "Don-2n" for tracking targets and guiding interceptor missiles [36, 37, 38]. The radar "Dunai-3U" (its receiving station is shown on Figure 29) is intended for detecting and tracking ballistic missiles and artificial earth satellites, determination of their coordinates and trajectory parameters. The radar employs transmitting and receiving slotted waveguide antenna arrays diversified on terrain. The main mode of its operation is the programmed line-by-line scanning within an assigned sector.

The multi-functional engagement radar 5N20 "Don-2n" (see Figure 30) is a unique powerful pulsed radar in centimetric wave band, with hemispheric electronic scanning. The search capability, measuring accuracy, target handling capacity, and adaptation for environmental conditions enable such radar to be used for both exo-atmospheric and endo-atmospheric target tracking and guidance of interceptor missiles in clutter and jamming environments.

CONCLUDING REMARKS

1. In this brief review, some typical Russian radars of three main classes have been considered: surveillance radars for Air-Defense (AD) systems, radars for Surface-to-Air Missile (SAM)

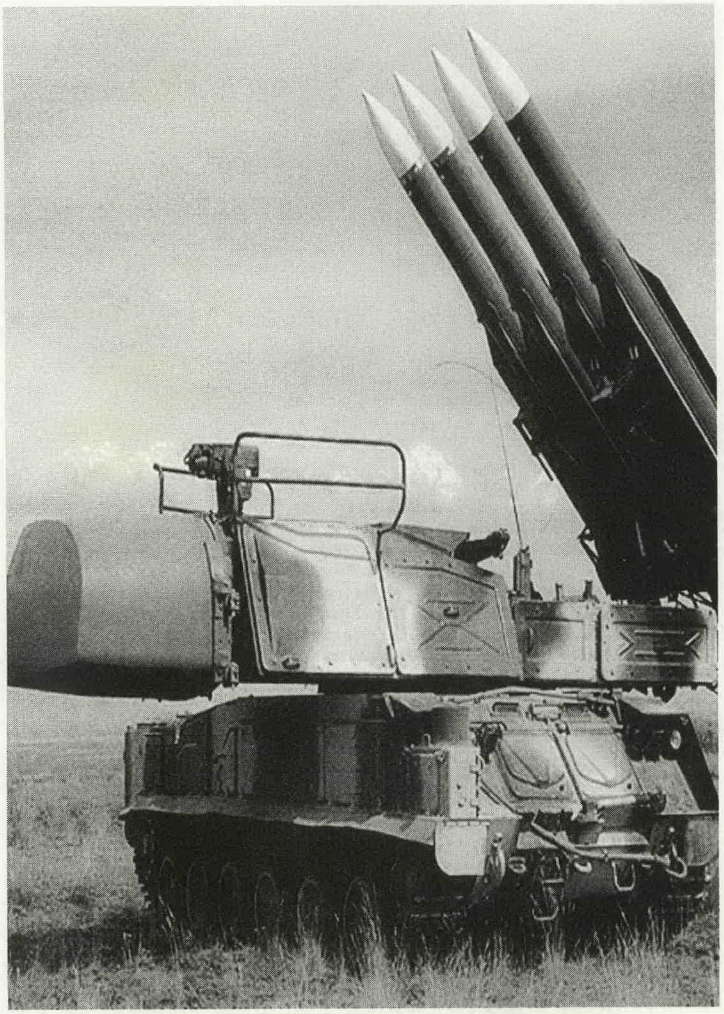

Fig. 25.

systems and radars for Anti-Ballistic Missile (ABM) systems. Of course, there are many other types of radars in Russia: different airborne, shipborne, and spaceborne radars, radars for Ballistic Missile Early Warning System (BMEWS), radars for the system of space inspection, Over-The-Horizon (OTH) surface wave and sky wave radars, synthetic aperture radars (SAR), ultra-wideband (UWB) radars, multisite radar systems, etc. (see, for example, the incomplete list of radars in [39]).

2. A wide spectrum of Soviet and Russian radars is a result of the efforts of scientists and engineers of multiple research institutes and design bureaus, as well as engineers and workers of manufacturing enterprises. It is necessary to note especially a role played by leaders of the works on creating radars (in Russia they are called General Constructors), whose talent and management abilities allowed the creation of Russian radar engineering of high level. ***The Radar Encyclopedia*** [58] recently published in Russia is devoted to activity of such leaders and their teams [58].

3. Although the development of radars in the USSR (as well as in other countries) was stimulated during many years by military needs, in the last years many novel radars were developed in Russia for civilian and scientific purposes. They are not only the conventional ATC radars but also weather radars, radars for mapping Earth (and other planets), radars for mineral resources and soils exploration, radars for pipeline inspection, ground penetrating radars for seeking underground objects, automotive radars, medicine radars, etc.

4. Under today's conditions of limited economy resources, radars of dual (military and civilian) applications play an important role. This concerns, first, radars in the L- and S-frequency bands. Such radars may have unified components and technical decisions (digital signal processing, etc.)

5. Unfortunately, the second half of the 1990s was a very difficult period for radar science and industry, as for the whole of industry in Russia. However, now the situation is becoming better. The Russian radar industry comes to the world market. Scientific organizations and industrial enterprises carry out new projects and realize quantity production of radars based on modern technologies.

Fig. 26.

Taking into account a high level of the radar science in Russia, important achievements and great experience of our radar industry during 75 years, we are sure that Russian radar engineering will hold its position in the world in this important sphere of high technologies.

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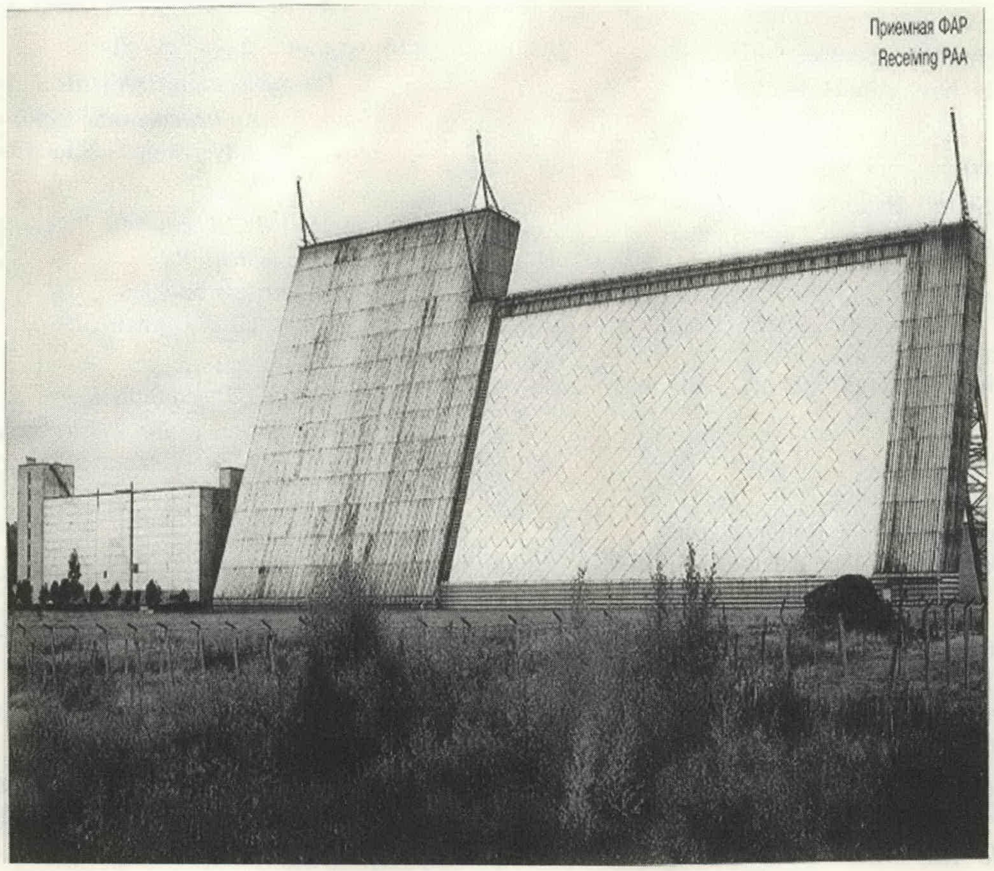
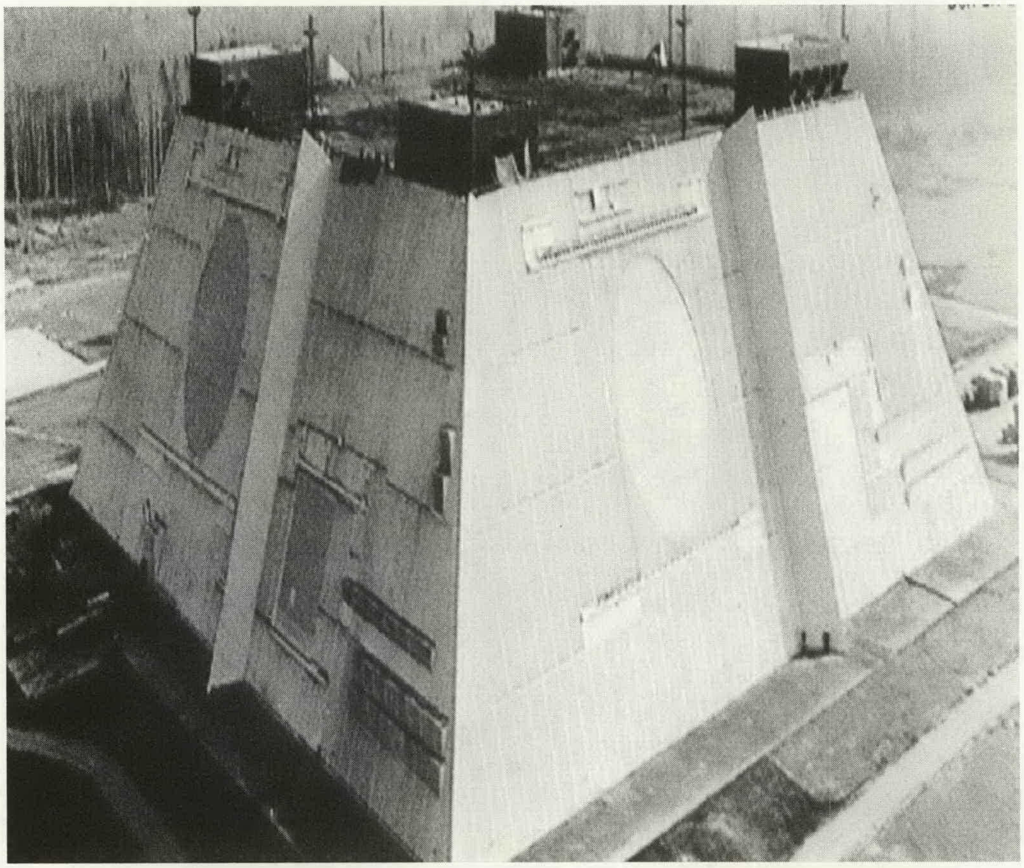


Fig. 29.



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