The First Orbital X-band Side-Looking Radar of Cosmos-1500, an IEEE Milestone Candidate

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***Abstract*— We revisit the history of development and operation of the first-ever orbital X-band real aperture side-looking radar (RA-SLR) onboard the USSR satellite “Cosmos-1500.” This radar was conceived, designed and tested in the early 1980s, and then supervised in orbit, by the team of Ukrainian scientists and engineers led by Professor Anatoly Kalmykov at the O. Y. Usikov Institute of Radiophysics and Electronics of the National Academy of Sciences of Ukraine (IRE NASU). It had original 12-m deployable slotted-waveguide antenna and onboard signal processing unit. Instead of planned experiments, only five days after placement into the polar Earth orbit in the autumn of 1983, SLR of Cosmos-1500 rendered truly outstanding service. It provided a stream of microwave images of the polar sea ice conditions that enabled the rescue of the freighters in the Arctic Ocean. However, the way to success was far from smooth. Besides of the technical problems, A. Kalmykov had to overcome the jealousy and hostility of both his home institute administration and the USSR bureaucracy. Later, SLR of “Cosmos-1500” was released to the industry and became the main instrument of the USSR and Russian series of remote sensing satellites “Okean” and Ukrainian satellites “Sich-1” and “Sich-2.” We believe that SLR of “Cosmos-1500” is a perfect candidate to the status of IEEE Milestone in Ukraine.**

Keywords—history of microwaves, orbital side-looking radar, remote sensing

I. Prehistory, Names and Dates

Since 1976, the Institute of Marine Hydro-Physics (IMH) of the Academy of Sciences of Ukrainian SSR (now, National Academy of Sciences of Ukraine, NASU) in Sebastopol and the Design Bureau “Yuznoye” (now, DB Pivdenne, DBP) in Dnepropetrovsk (now, Dnipro) were involved into the design of experimental USSR satellites “Cosmos-1076” and “Cosmos-1151,” equipped with sensors called “scatterometers” [1-3]. Their task was determining the parameters of the sea waves, in line with secret decree of the Central Committee of the Communist Party of the Soviet Union (CC CPSU) on the development of the orbital remote sensing system “Resurs.” By that time, IMH had already enjoyed collaboration, around the sea waiving research using the airborne sensors, with the radar group of Anatoly I. Kalmykov (1936-1996) from IRE NASU in Kharkiv [4-9]. However, the scatterometers of the late 1970s (designed in Moscow) had failed to satisfy the customers that proved the necessity of more dedicated efforts aimed at development of active microwave sensors, i.e. radar. This could place Kalmykov in the center of design and testing, however, he lacked both equipment and research manpower. Part of the problem was in the hostility of the then IRE administration.

Fig. 1. Anatoly Kalmykov in his office at IRE NASU around 1990.

According to insiders [10], by the summer of 1979 Kalmykov had given up and was close to moving to IMH in Sebastopol. As stated by the same source, it was IMH director, who persuaded the top bosses of the extremely powerful USSR “Ministry of General Machine-Building,” an Orwell-style cover for the Ministry of Space Industry, to intervene and rescue Kalmykov’s team at IRE. V. P. Shestopalov, then IRE director, received a phone call from Moscow, suggesting him to urgently organize, at IRE, a research unit dealing with space radio oceanography and sea ice sensing. The ministry also promised to allocate to IRE significant funds dedicated to such research. As a result, the 20-strong Department of Earth Remote Sensing Techniques was created at IRE on Sept. 1, 1979, headed by Kalmykov.

Already in 1980, the department initiated research and development of novel all-weather active orbital sensor, specifically designed to study the sea surface and ice covers. This was an X-band RA-SLR. A prototype airborne system allowing in-flight testing was also designed and the flights onboard dedicated turboprop aircraft IL-14 were organized. Here, it was decided to add to SLR another, passive sensor, working in the millimeter-wave band – Ka-band radiometer, developed also at IRE. Moreover, on-board electronic data processing block was developed at DBP and IMH, which was added both to the airborne prototype and orbital system.

The very first experiments had already confirmed high efficiency of the designed instruments for studying the water and ice surfaces [11,12]. The joint use of microwave images obtained from X-band SLR and Ka-band radiometer offered, in principle, more efficient study of the state of the sea and ice, deeper than using the data from each individual sensor. However, initial tests had also shown that obtaining reliable

Fig. 2. The spacecraft "Cosmos-1500" with microwave equipment for remote sensing of the Earth at the permanent USSR Exhibition of Achievements of National Economy in 1985 [2].

information on the water-surface waving needed much deeper level of the data processing than available at that time. In contrast, more reliable data were obtained on the possibilities of airborne observations of ice. The results of these studies convinced Kalmykov of the prospects for radar observations of sea ice from space.

However, attempts to interpret the ice sounding data beyond simple discrimination between thin and thick ice did not lead, unfortunately, to the creation of an adequate model. The phenomenon of the scattering from the ice turned out to be much more complicated than the scattering from the water surface. Still, other possible applications emerged [13].

"Cosmos-1500" satellite (Fig. 2) was launched on Sept. 28, 1983 from Plesetsk on Tsyklon-3 rocket vehicle and placed into low-altitude near-circular polar orbit. It remained operational until July 16, 1986. This was the first ever satellite to carry X-band RA-SLR working at the wavelength of 3.16 cm with vertical polarization; the swath width was about 460 km, and the spatial resolution was 2.1–2.8 km (in the flight direction) by 0.8–3.0 km (normal to the flight) [14-18] (note that the reproduced from [2] Table I gives slightly different values). Antenna system was based on the 12-m long slotted waveguide, which was kept folded at the launch and then automatically unfolded in orbit. This radar was supplemented with 37-GHz horizontally polarized side-looking radiometer, designed at IRE NASU, and 4-channel visible range imaging system of IRE RAS. The polar orbit was selected to provide data on the ice conditions in the Arctic and thus to support the navigation for ships in the northern latitudes, which were not visible from geostationary satellites. The chosen RA-SLR parameters were considered as optimal for all-weather study of the polar sea ice, the main processes of ice formation, and the dynamics of ice covers.

Besides of carefully selected radar parameters, high efficiency of SLR "Cosmos-1500" system was achieved due to onboard preliminary processing of the information and transmitting it using the 137.4 MHz Automatic Picture Transmission (APT) channel to users including central site in Moscow and autonomous point in Kharkiv.

TABLE I. THE PARAMETERS OF THE SLR "COSMOS-1500"*

Parameters of RA-SLR of "Cosmos-1500"	
Wavelength, cm	3.1
Polarization	VV
Viewing angle range	20°-46°
Antenna pattern width: in the azimuthal plane in the elevation plane	 0.2° 42°
Spatial resolution, km: along the flight direction transverse to the flight direction	 2 ×2.5 0.8 × 2.5
Receiver sensitivity, dB/W	-140
Transmitter power	100 kW
Pulse duration, μs	3
Pulse repetition frequency, Hz	100
Orbit altitude, km	650
Orbital inclination	82.6°
Swath, km	450

*Reproduced from [2] after correction of typos and translation mistakes.

Here, Kalmykov had to fight with Moscow colleagues from IRE RAS, who wanted to have a full monopoly on the satellite imagery. Many details of the SLR of "Cosmos-1500" design and operation can be found in the reviews [1-3,14,16-18]. Being a completely civil-purpose instrument, it outperformed greatly the preceding USSR military orbital SLR "Chaika" [3]. Unique capabilities of Kalmykov's SLR were enhanced by the simultaneous acquisition of overlapping images from two other sensors so that three different wavelength bands were involved. This enabled improved interpretation of images and reduction in errors of retrieved parameters.

II. RESCUE MISSIONS OF COSMOS-1500 SLR

By the time of the launch of the "Cosmos-1500" spacecraft, a true drama had developed on the Northern Maritime Route. That season, the winter came earlier than usual and a caravan of 22 freighters with cargo worth some 8B USD [1-3], carrying the goods to the Arctic regions of the USSR, got blocked in the ice in the Long's Strait near the Wrangel Island. The MV "Nina Sagaydak" was soon crushed by the ice and sank, and there was a real threat of complete loss of the caravan. In the polar night season, the air surveillance was pointless, and the SLR of "Cosmos-1500" became the only available source of trusted information, able to survey both the Long's Strait and the adjacent regions of the ocean.

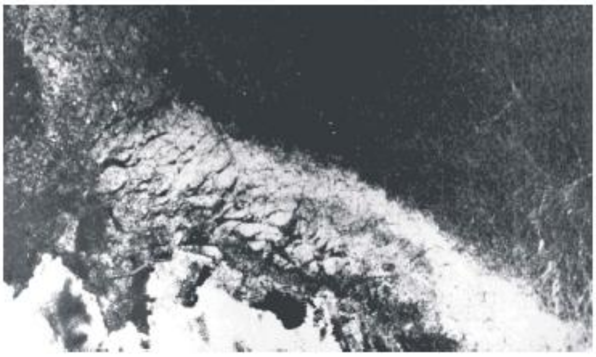
Already the first radar images of the disaster area (Fig. 3) showed that the situation was not hopeless. Indeed, 100 km North of the caravan, near the Wrangel Island, an extensive polynya (sea area, where the ice is either absent or very thin) could be seen, together with a strip of wide cracks and crevasses in heavy multi-year ice along which it was possible to direct the caravan to the polynya. Although the ad-hock staff of the rescue operation was reluctant to trust the microwave imagery, in the total absence of alternatives it took up the risks and ordered the icebreaker to go North. On reaching the polynya, the icebreaker and the freighters turned South-West and, in a few days, reached safe waters.

Amazingly, within its short (33 months) lifetime, SLR of "Cosmos-1500" was destined to repeat its rescue mission, however, in the Southern hemisphere [1-3,17]. The research MV "Mikhail Somov," sent to Antarctica to bring a rotation crew to a USSR polar station, was blocked in the 5-m thick ice. To rescue her, a USSR icebreaker was sent, on board of which the satellite information reception point was deployed.

(a)

(b)

Fig. 3. Rescue mission of the USSR freighter caravan in the Long's Strait, November 1983. Radar image (a) and topical map (b) demonstrating the ships location and the route of their escape from the heavy ice area (■ thin young ice, ■ one-year ice, ■ thick perennial ice; rescue route is the yellow line (reproduced from [2]).



(a)

(b)

Fig. 4. Rescue mission of the USSR MV "Mikhail Somov" in the Antarctic, July 1985. Radar image (a) and topical map (b) demonstrating the ship location and the escape route of the ice-breaker "Vladivostok" (reproduced from [2]; color legends are the same as in Fig. 3; note a misprint: the continent edge is Antarctica).

This ensured prompt reception of all-weather microwave radar images. The high polar orbit of "Cosmos-1500" was well suited for such a mission. Its images enabled every day correction of the icebreaker route in the ice fields both on the way to the blocked ship and back to the clean waters. At the crucial phase of the operation, radar images revealed a wide polynya in heavy ice, stretching towards the drifting ship. Thanks to this, instead of using a helicopter to evacuate the crew of the drifting ship, which had to be abandoned, the icebreaker rushed towards "Mikhail Somov," freed her from the ice trap and led her out of the ice [17].

The last mission of SRL of "Cosmos-1500" was the monitoring of the snow melting in Ukraine in the spring of 1986, after unusually snowy winter. This time microwave images helped estimate correctly the degree of excessive filling of the reservoirs on the Dnieper River.

III. Obstacles to Overcome: Not Only Technical

When creating the SLR of "Cosmos-1500," Kalmykov had to overcome many problems of organizational, technical and human nature.

Until 1972, Kalmykov who collaborated with IRE's theoreticians enjoyed support and encouragement from the first IRE director, O. Y. Usikov. All changed when the latter was replaced by V. P. Shestopalov by the decision of the CPSU Committee of the Kharkiv Region. As mentioned, by 1979 Kalmykov got so desperate that prepared moving to IMH. In Sebastopol, his friend and the head of collaborating group was V.V. Pustovoytenko who had his own troubles with his administration, however, was supported from Moscow. Still, even after creation of his own department at IRE with rich funding from the Ministry of Space Industry, Kalmykov's working conditions remained far from perfect.

As admitted in [3], resistance of V. P. Shestopalov was overcome only due to extraordinary personal efforts of V. M. Konyukhov, Chief Designer of a division of DBP in Dnipro, responsible for the whole remote sensing payload. Here, it should be explained that, in the USSR, R&D centers of the civilian Academy of Sciences were never awarded the role of the state program coordinators. Instead, this was entrusted to the industry bosses or the directors of ministerial R&D centers in Moscow or Leningrad. Konyukhov was a rare exception. Perhaps, this was because it was he who initiated, in 1974, the development at DBP of equipment for the study of oceans from orbit [1,3] that led to the mentioned above secret decree of CC CPSU and the government (1977) about the creation of system "Resurs."

Thus, Konyukhov coordinated the work of all three Ukrainian R&D centers, one ministerial (DBP) and two academic (IRE NASU and IMH NASU). Still, he was supervised from Moscow, where the other powerful organizations, such as IRE RAS and ministerial R&D Institute of Device Building were responsible for the development of information storage, processing and transmission to customers' equipment for "Cosmos-1500."

As recalled in [3], a mutually beneficial collaboration between the Ukrainians was established rather quickly, however, similar level of synergy was nearly impossible with the central organizations. In 1982, the conflict led to a sharp discussion where the directors and leading experts of several powerful Moscow R&D centers opposed Kalmykov, Pustovoytenko and B. Y. Khmyrov (Konyukhov's successor at DBP) and demanded to transfer the radar development to their laboratories. To rationalize their demands, which were fed by professional jealousy, they used a vague accusation of allegedly insufficient “information potential” of Kalmykov’s SLR data. Still, as Khmyrov remained a staunch supporter of Kalmykov, these attacks were rebuked, IRE team released the radar in 1983, “Cosmos-1500” was assembled at DBP, and launched according to the schedule.

When SLR got successfully to its orbit, the feud between the developers became quickly forgotten. However, suddenly new opponents had emerged. As mentioned, on the fifth day of work, all planned experiments were cancelled in favor of the rescue mission of the USSR freighters, blocked by heavy ice in the Arctic. Unexpectedly, powerful administration of the USSR Chief Directorate of the Northern Maritime Route displayed a huge distrust to the satellite data, which showed non-trivial escape route - to the North of the disaster site. At the crucial meeting, Kalmykov had to voice a threat to file a complaint to the almighty CC CPSU. This worked out and caravan’s icebreaker was ordered to move North.

IV. Cosmos-1500 SLR Versus Similar Achievements

Development of methods for remote sensing of the sea surface from aerospace carriers started in the mid-1970s. The first space-based Earth imaging experiment using the L-band synthetic aperture radar (SAR) of "Seasat-A" was conducted in 1978. The results of this experiment exceeded all expectations and showed the high information capabilities of such systems. The USSR program of ocean radar sensing, which began with the launch of “Cosmos-1500,” followed a different path - the use of SLR. It should be noted that SLR was not the only USSR satellite radar at that time: in parallel, SARs were also designed. The SAR "Travers" was installed on board the spacecraft "Resurs-O-1" launched as "Cosmos-1689" in 1985 [2,3]. Later, it became a part of the "Priroda" module of the orbital station (OS) "Mir". The other SAR required the OS power; it was launched in 1987 on board of "Cosmos-1870" and in 1991 on “Almaz-1” [2,3,19-21].

SLRs have an order of magnitude lower resolution than SAR, but are attractive due to higher radiometric accuracy and an order wider swath. By its characteristics, the orbital SLR of “Cosmos-1500” had no contemporary analogues in the practical study of the ocean and ice. Although “Seasat,” “Shuttle,” later ERS-1, “Radarsat,” etc. systems had high potential characteristics, the practical use of their information turned out to be efficient only for the land sensing.

V. Impact

In 1987, Kalmykov and 9 members of his team were awarded the National Prize of Ukraine in Science and Technology with citation, “For the development and implementation of radar methods of Earth remote sensing from aerospace carriers.”

Their work, nearly 40 years ago, initiated new research area and discipline in Ukraine: remote sensing of Earth from space. At the global level, it was one of cornerstones of what was christened Oceanography from Space [19] and had initiated the use of radar images for safe polar navigation.

In the process of design and development of the first X-band orbital SLR of "Cosmos-1500," wide range of scientific and technical problems had been solved. This enabled the derivatives of this SLR to be exploited on all remote sensing satellites of the USSR/Russia State Space Operative System "Okean" and Ukrainian satellites “Sich.” It was successfully used to detect and monitor many critical situations and natural disasters on global scale [1-3,22-25].

All the above presented tells that the SLR of “Cosmos-1500” satisfies the requirements of the IEEE History Committee to be nominated an IEEE Milestone in Ukraine.

References

[1] G. K. Korotayev et al., “Thirty years of domestic space oceanology,” Space Sci. Technol., vol. 13, no 4, pp. 28-43, 2007.

[2] V. K. Ivanov and S. Y. Yatsevich, “Development of the Earth remote sensing methods at IRE NAS of Ukraine,” Telecommunicat. Radio Eng., vol. 68, no 16, pp. 1439-1459, 2009.

[3] V. V Pustovoytenko, et al., “Space pilot of the nuclear-powered vessels,” Proc. Int. Crimean Conf. Microwave Telecom. Technol. (CriMiCo 2013), 2013, pp. 19–22.

[4] A. I. Kalmykov, I. E. Ostrovskii, A. D. Rozenberg, and I. M. Fuchs, “Influence of the state of the sea surface upon the spatial characteristics of scattered radio signals,” Sov. Radiophysics, vol. 8, no 6, pp. 804–810, 1965.

[5] A. D. Rosenberg, I. E. Ostrovskii, and A. I. Kalmykov, “Frequency shift of radiation scattered from a rough sea surface,” Sov. Radiophysics, vol. 9, no 2, pp. 161–164, 1966.

[6] F.G., Bass, I.M Fuks,., A.I., Kalmykov, Ostrovsky, I.E., Rosenberg, A.D. “Very high frequency radiowave scattering by a disturbed sea surface part I: scattering from a slightly disturbed boundary,” IEEE Trans. Antennas Propag., vol. 16, no 5, pp. 554–559, 1968.

[7] F. G. Bass, S. Y. Braude, A. I. Kalmykov, et al., “Radar methods for the study of ocean waves,” Sov. Phys. Uspekhi, vol. 18, no 8, pp. 641–642, 1975.

[8] F. G. Bass, S. Y. Braude, I. M. Fuks A. I. Kalmykov, et al., “Radio-physical investigations of sea roughness at the Ukrainian Academy of Sciences,” IEEE Trans. Ant. Propag., vol. 25, no 1, pp. 43–52, 1977.

[9] A. I. Kalmykov, et al., “Radar detection of oil slicks on a sea surface,” Izvestia AN SSSR Fizika Atmos. Okeana, vol. 13, no 4, pp. 406–414, 1977.

[10] Private communication of Viktor D. Yeryomka, 2018.

[11] A. I. Kalmykov and A. P. Pichugin, “Special features of the detection of sea surface inhomogeneities by the radar methods,” Izvestia AN SSSR. Fizika Atmosfery i Okeana, vol. 17, no 7, pp. 754–761, 1981.

[12] A.I. Kalmykov, A.P. Pichugin, Y.A. Sinitsyn, and V. P. Shestopalov, “Some features of radar monitoring of oceanic surface from aerospace platforms,” Int. J. Remote Sens., vol. 3, no 3, pp. 311–325, 1982.

[13] S. A. Velichko, A. I. Kalmykov, Y.A. Sinitsyn, and V. N. Tsymbal, “Influence of wind waves on radar reflection by the sea surface,” Radiophysics Quantum Electron., vol. 30, no 7, pp. 620–631, 1987.

[14] A. I. Kalmykov, V. B. Efymov, and S. S. Kavelin, “Radar system of satellite Cosmos-1500,” Earth Explor. Space, vol. 5, pp. 84–93, 1984.

[15] V. B. Efimov, A. I. Kalmykov, et al., “Study of ice covers by radiophysical means from aerospace platforms,” Izvestia AN SSSR. Fizika Atmosfery i Okeana, vol. 21, no 5, pp. 512–520, 1985.

[16] A. I. Kalmykov, et al., “Kosmos-1500 satellite side-looking radar,” Soviet J. Remote Sens., vol. 5, no 3, pp. 471–485, 1989.

[17] A. I. Kalmykov, et al., “Observations of the marine environment from spaceborne side-looking real aperture radars,” Remote Sens. Environment, vol. 45, no 2, pp. 193–208, 1993.

[18] A. I. Kalmykov, A. S. Kurekin, and V. N. Tsymbal, “Radiophysical researh of the Earth’s natural environment from aerospace platforms,” Telecommunic. Radio Eng., vol. 52, no 3, pp. 41-52, 1998.

[19] W. S. Wilson., et al., “A history of oceanography from space, Remote Sens. Environ. vol. 6, Manual of Remote Sens. Amer. Soc. for Photogrammetry and Remote Sens., pp. 1–31, 2005.

[20] E. M. Agee, “Observations from space and thermal convection: a historical perspective,” Bull. Am. Meteorol. Soc., vol. 65, pp. 938–949, 1984.

[21] A. Freeman, D. Evans, and J. J. van Zyl, “SAR applications in the 21st century,” Proc. Europ. Conf. Synth. Apert. Rad., 1996, pp. 25-30

[22] L. M. Mitnik and A. I. Kalmykov, “Structure and dynamics of the Sea of Okhotsk marginal ice zone from Okean satellite radar sensing data,” J. Geophys. Res., vol. 97, no C5, pp. 7429–7445, 1992.

[23] A. Kalmykov, et al., “Radar observations of strong subsurface scatterers. a model of backscattering,” Int. Geosci. Remote Sens. Symp. (IGARSS-1995), vol. 3, pp. 1702–1704, 1995.

[24] A. I. Kalmykov, et al., “The two-frequency multipolarisation L/VHF airborne SAR for subsurface sensing,” AEU-Archiv fur Elektronik und Ubertragungstechnik, vol. 50, no 2, pp. 145–149, 1996.

[25] S. A. Velicko, A. I. Kalmykov, and V. N. Tsymbal, “Possibilities of hurricanes investigations by real aperture radars Cosmos-1500/Okean type,” Turkish J. Phys., vol. 20, no 4, pp. 305–307, 1996.