RUSSIAN SPACEBORNE IMAGING RADARS: SCIENTIFIC AND TECHNICAL ACHIEVEMENTS AND PRIORITY PERSPECTIVES OF DEVELOPMENT

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INTRODUCTION

The paper deals with a short retrospective overview of Russian (USSR) contribution in creation and development of spaceborne radars for Earth remote sensing. We discuss the technical experience accumulated during the process of manufacturing and exploitation of Russian spaceborne imaging radars and the main results of recent scientific investigations carried out in the Joint-Stock Company "Radio Engineering Corporation "Vega" ("Vega" Corp.) and in other Russian enterprises. The perspectives for radar remote sensing are considered as well.
Comparing the approaches to radar design and technical solutions chosen by Russian and foreign specialists we find much of sameness, but there is some difference. Some of these Russian solutions are more progressive and worth discussing for the benefit of remote sensing technology.
The limited size of the paper does not permit the authors to present a detailed material on the subject but only a brief analysis of references, in which both detailed printing publications and many of on-line resources are included.

SPACEBORNE SIDE-LOOKING RADARS

The launch of "Kosmos-402" Soviet Union satellite in April 1, 1971 marked a new era in the Earth radar remote sensing from space [2-3]. The satellite known in foreign publications as RORSAT (Radar Ocean Reconnaissance Satellite) was the active element of the Naval Space Reconnaissance and Targeting System (MKRT), which was created for USSR Navy Department. Constructed by MNIIP (old name of "Vega" Corp.) spaceborne radar complex included the X-band side-looking radar, special purpose computer and a data link, which provided observation of Ocean water areas, automatically ship detection, its coordinates measurement and transmission to ground and ship-based command posts. Serial manufacturing of 28 satellites with the radar complex was organized and they were successfully exploited up to 1985.
The side-looking radar was equipped with one (later – two) double section wave guide slotted travelling wave type antenna array with dimensions of 10×0.7 m^2 (see fig. 1). In the first series of the spacecraft the antenna wave-guides were fed alternately from opposite sides with two different phase distributions. It allows forming two beams (near and far), which were a prototype of ScanSAR mode that is now used in SARs. Such a saving solution can be well applied in ice patrol SAR for mini satellites, where signals with narrow frequency band are used.
Analysing the RORSAT complex exploitation experience, some comments should be made:

1. A strong reflection from hydrometeors occurred in X-band resulting in the reduced probability of ship detection especially in equatorial latitudes. It is desirable to use longer wavelength of the radar or some additional measures (e.g. dual or circular signal polarization) in order to diminish hydrometeors effects.
2. A nuclear power supply was used in the spacecraft that provided a high-energy potential of the radar. The nuclear spacecraft component had double means of safety: an automatic system which moves the reactor into a higher safe orbit at the end of operating period and a special device that disperses the active elements in case of spacecraft crash. Even full crash of "Kosmos-954" and drop of satellite remnants on territory of Canada in 1977 did not constitute a serious threat to human life [2-3]. Now the principles of nuclear power supply usage in space and safety requirements are approved by the United Nations. The interest to create nuclear power supply radars now exists [4].

Next spacecrafts generation of "Kosmos-1500" and "Resource" with side-looking radar provided the Earth surface observations with resolution of 1÷2 km [8]. Long-term operating experience of these radars has confirmed the importance of obtaining regular information about sea surface and ice conditions. But it is necessary to attain a better spatial resolution that requires SAR application.

Fig. 1. View of RORSAT prototype with unfolded radar antenna [2]

SPACEBORNE SAR

Principles of spaceborne SAR design were formulated in 1963-65 in the USSR (MNIIP) and abroad (see published in 1967 [9]). Manned Orbit Station Almaz-A" with SAR called "Mech-A" ("Sword") was ready to start in March 1978. American SEASAT-A SAR was launched in June 1978 effectively operating up to October 1978. For some reasons beyond the technical aspects, the launch of Manned Orbit Station was cancelled [6, 10][1]. An automatic alternative "Mech-K" SAR (also known as Ekor-1) was made, in which photo register device served by cosmonauts was substituted by analogue video tape recorders and a data link. "Mech-K" SAR was exploited onboard "Kosmos-1870" spacecraft 1987-89 delivering images with resolution of 20 m after optical aperture synthesis [13]. The upgraded "Mech-KU" (Ekor-A1) SAR onboard "Almaz-1" spacecraft had digital magnetic storage and data link through the satellite-retransmitter. Digital image synthesis was realized in the ground station with resolution of 10-12 m.

The accepted "Mech" SARs designs principles differed from foreign SARs and in some cases were more progressive [13]. So, data storage on space board was provided in addition to direct data transmission to ground station. Two antennas were used to provide starboard or port surveillance. Shooting incident angle could be changed of 15° up to 60° by spacecraft roll. It considerably decreased the revisit time.

The spacecraft lengthwise axis was oriented along the ground speed vector using Doppler navigator. So, there is no need to eliminate linear range migration of the signal that considerably facilitates aperture synthesis. Now spacecraft steering along to ground speed vector is applied in the majority of SARs [14]. The S-waveband was chosen for SAR. S-band advantages are: imagery features close to L-band images, possibility of higher resolution of 1-2 m, since 200 MHz frequency band is allocated by the Radio Regulations comparing with 85 MHz in L-band. High imaging efficiency of S-band sensing was evidenced by "Kosmos-1870" and "Almas-1" spacecrafts operation, including joint experiments with AIRSAR, SIR-C/X-SAR, ERS-1/2 SARs [15-17].

SCIENTIFIC AND TECHNICAL BASE CREATED FOR FUTURE SAR DEVELOPMENT

The theoretical researches, design works of following generation of spaceborne SAR have been under way in Russia within two decades. Russian specialists have taken an active part in the international projects. A large number of the Russian specialists take part at the international forums, especially at EUSAR Conferences, where theory and experiments of remote sensing, instruments design also as image processing software are widely discussed.

The results of "Vega" Corp. scientific activity include:

1. The approach to spaceborne SAR design was formulated [1, 5]. The approach implies that the specified requirements to SAR performance are used only for choosing the basic constructive solutions concerning SAR wavelength, antenna type, polarisation and dimensions, modes of operation etc. Within this basic solutions the alternatives are realised such as experimental, forced and extended operational modes without guaranteed performance, but allows to check some new ideas for SAR upgrading or to receive any rough timely information from disaster regions etc.

So, a far distant sea experimental survey mode with high signal ambiguity was implemented in "Mech-KU" SAR. Besides sampling rate of 20 MHz (of Nyquist criterion) for signal with 14 MHz spectrum width, the sampling rate of 28.8 MHz was introduced, that allows to correct hardware distortions and obtain 10-12 m resolution images suitable for calibration [18]. Elements of such design approach we find it as RADARSAT-1 where far and near range modes were introduced as experimental modes and later were presented as regular survey modes.

2. Computer technologies are widely used in SAR designing and SAR data handling. Specific software has been elaborated for SAR equipment testing and correction [18, 19]. High efficient algorithms for image focusing based on coherent accumulation of signal frames were studied [20]. The relative platform-target motion model, which has been recently offered [21], is especially convenient for high orbit SAR.

3. SAR signal processing simulation method based on “inverse synthesis” of in-flight radar complex images was proposed [22]. It allows generating simulated images very close to the images, which are anticipated in practice. Quantitive comparison of simulated images with prototype images is possible. Block-diagram of simulating algorithm is given in Fig. 2. “SLCI” is a single-look complex image, b_1, b_2 – are replicas of data collecting algorithms (e.g. terrain and moving targets or a pair of interferometer images etc), b_s – is the image focusing replica. Pre-processing procedure includes side lobes suppression amplitude weighting and retouch for erasing receiver’s noise along flat surfaces.

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[1] The first application of space-based SAR in USSR was in "Venera-15/16" space missions in 1983. The spaceborne SARs called "Poljus-V" were constructed by OKB MEI (Design Bureau of Moscow Energy Institute). The unique images and a map of the North hemisphere of Venus with resolution of 1.3×1.3 km obtained in cooperation with IRE RAS (Institute of Radio-engineering and Electronics of Russian Academy of Science) and IPPI RAS (Institute for Information Transmission Problems RAS) have been of great scientific importance [11-12].

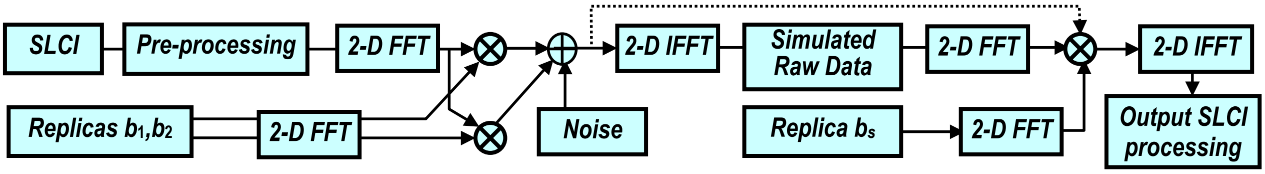

Fig. 2 Block-diagram of SAR signals processing simulation. Dotted line allows excluding extra calculations

The simulated complex image may be considered as the result of the sequential implementation of inverse 2-D deconvolution procedure for generation of simulated radar hologram (raw data) and direct 2-D convolution being applied to image focusing. Proposed simulation technique can be applied for physical interpretation of radar remote sensing data, e.g. for evaluation of ice fields compression during interferometer processing of SAR images [22].

4. Multi polarization, multi band (X, L, P, VHF) radar data obtained by "Vega"'s airborne SAR IMARK during joint experiments with IRE RAS and other organizations [23] are applied for future spaceborne SARs modelling. Works are under way for SAR end-to-end testing with fibre-optical delay lines. Valuable results of OKB MEI, IRE RAS and ESA joint experiments on spaceborne SAR external calibration using large mirror antennas should be appreciated [24].

5. Actual problem of regular in-flight exploitation of spaceborne SARs, their calibration as well as new SARs designing and SAR data interpretation require generation of radar database. It should include renewable sets of multi wavebands, multi polarization complex images obtained by airborne and spaceborne SARs including terrain atlases like [25] and radar portraits of man-maid objects like that as shown in Fig. 3. It is expedient to represent the portraits of man-maid objects for SAR modelling in the form of point reflectors (complex δ-functions in 3-D coordinates) using "skeleton" procedure. Thus data volume is considerably less in comparison with the original image.

PERSPECTIVES OF SAR DEVELOPMENT

The priority for spaceborne SAR design is to create modern SARs, with high performance, lightweight and low energy consumption. It includes:

1. Putting into operation a multi mode S-band SAR, designed by "Vega" Corp., for "Condor-E" small spacecraft constructed by NPO Machinostroenia [6, 19]. The high resolution (from 1-2 m) of images taken in S waveband will enlarge the possibilities of terrain and objects identification via synergetic processing of X, C, S and L wavebands data.

2. Developing a multiband (X, L, P) polarimetry spaceborne radar complex [1, 7, 26]. The decimetre SAR channels, designed by "Vega" Corp. provide image resolution from 3 m in L-band and 30 m in P-band [1, 26]. A combined L+P bands active phase array antenna is used [27]. The carrier frequencies (1305 and 435 MHz) of SAR signals are multiple - 3:1. It allows using the L-band received signal as a reference function for P-band images autofocusing in order to diminish the destructive effects of ionosphere in P-band. The complete set of polarisations is provided in P and L bands.

3. Working-out the draft principles of SAR construction for high orbital or geosynchronous orbital spacecrafts [4]. The advantages of geosynchronous SARs comprise the capability of regular observation of specific areas with low revisiting time. The high stability of orbit movement increases the accuracy of coherent change detection processing of complex images.

4. Researches, modelling and design of UWB short pulse radar elements and UWB airborne and spaceborne SARs [28-29], which can enlarge the capabilities of radar remote sensing.

5. Increasing SAR information products accuracy via usage of modern methods and instruments of in-flight internal and external SAR calibration [1, 19, 24] and integrating of the developed SARs in the global geoinformation system.

SUMMARY

The total experience of development and application of spaceborne imaging radars in "Vega" Corp., the recent scientific researches formed the basis for successful integration of the Russian sector in global geoinformation technology.

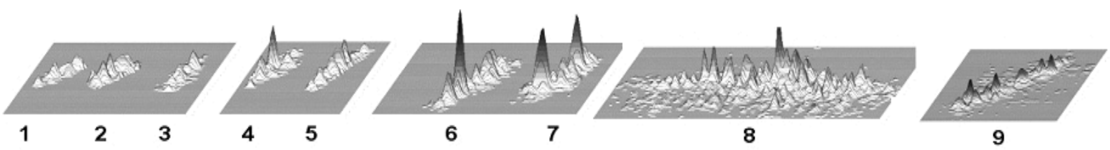

Fig. 3. The radar relief portraits of the vessels with their RCS estimation [1]: 1 – σ=3500 m^2, 2 – σ=6060 m^2, 3 – σ=3900 m^2, 4 – σ=6500 m^2, 5 – σ=7360 m^2, 6 – σ=16920 m^2, 7 – σ=16050 m^2, 8 – σ=41600 m^2, 9 – σ=3600 m^2

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