Space Experiment on the International Space Station with P-band SAR

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The problem of building the side-looking P-band SAR on board the International Space Station (ISS) is consi-dered. Proposed space experiment "ISS-SAR(P)" is aimed at the development of SAR research of the Earth from space.

1. Introduction

Proposed experiment is aimed at the development of SAR research of the Earth from space. Satellite experiments conducted in USSR, USA and European countries have demonstrated high efficiency of SAR for remote sensing of the Earth's resources. One of the promising ways to develop radar technique is to extend the waveband used for the remote sensing, especially in low frequency band. The lowest frequency used up to date in spaceborne SAR is 1.3 GHz (wavelength 23 cm), which is L-band. At the same time airborne experiments conducted in Russia (IMARK system), Sweden, France, Germany and other countries have shown the potential of lower frequency band (less than 1GHz) for surface and subsurface remote sensing. It is specified mainly by higher penetration ability of P-band electromagnetic waves in soil, vegetation, snow, ice covers, which makes possible to discover characteristics of the objects located above the ground and at certain depth within it.

2. Motivation

In last decade the next noticable trend toward the change of habitual living Environment on the Earth was observed:

- a severe reduction of forests (forest biomass), af-fecting the carbon balance;
- a considerable reduction of water storage in Earth glaciers, reduction of ice covering in polar water areas;
- a change of sea waters movement direction, e.g. in largest sea currents (Gulf stream, Kuroshio);
- acute pollution of particular inland water reservoirs (Black Sea, Caspian Sea, Azov Sea, Baikal).

The utilization of spaceborne P-band SAR is rather promising for the research of the environment and of its ecological state. It was proved by the results of multiple airborne experiments (see next section). In recent years the problem of building the spaceborne P-band SAR was discussed at many international conferences on radar and Earth remote sensing (BioGeoSAR'2007, EUSAR'2006, '2008, '2010, IGARSS'2010). One of the known prospective projects in this area currently being developed is ESA project "Biomass". Major problems in the development of spaceborne P-band SAR are concerned with difficulties in antenna design and in taking account of the effect of ionosphere.

Conditions of measurements by means of airborne SAR and spaceborne SAR at P-band are considerably different. Sensing from space has number of methodological and technical difficulties. One of the difficulties arises from the need to take into consideration propagation of waves in the ionosphere. When propagating through ionosphere, P-band waves change their phase and polarization plane. Random nature of spatial and time inho-mogeneities makes it difficult to take into account the effect of ionosphere. In our case the performance of "GLONASS" experiment on the International Space Station (ISS) aimed at the study of the ionosphere by means of tomography gives a unique opportunity of taking account of the effect of ionosphere. In-formation on the ionospheric characteristics obtained in this experiment may be used for the interpretation of P-band SAR data.

3. Airborne experiments

Consider an example of airborne studies carried out by means of P-band SAR. Forest biomass is the main storage of vegetation carbon and one of the most important elements of carbon cycle, which is directly connected with the climate of the Earth. Therefore the problem of studying the dynamics of spatial distribution of forest cover over the Earth's surface is very urgent. There are many ways of remote sensing of forest cover spatial distribution variations. The utilization of optical sensors has shown good results in classifying the forest formations (deciduous, coniferous and mixed forests) and in monitoring the changes in deforestation and forest regeneration. However these methods are of little value for measuring with high accuracy the forest biomass, which is mainly contained in trunks and large branches of the trees. The main reason of that is insufficient sensitivity of optical band signals to forest structure. Natural objects effectively interact with electromagnetic radiation if the wavelength within the object is comparable to the object's dimensions. From this perspective most suitable frequency band for measuring the forest biomass remotely is microwave one, and preference should be given to longer wavelength bands (P or VHF), since the wave length here is comparable to size of tree trunks and branches. As an example, Figure 1 demonstrates SAR images of an area in national park Meshchera in Ryazan Region with various natural objects (forests, open and vegetated water bodies, soil covers, peat lands etc.). One can see that P- and VHF-band signal has considerably higher penetration ability in comparison with L-band.

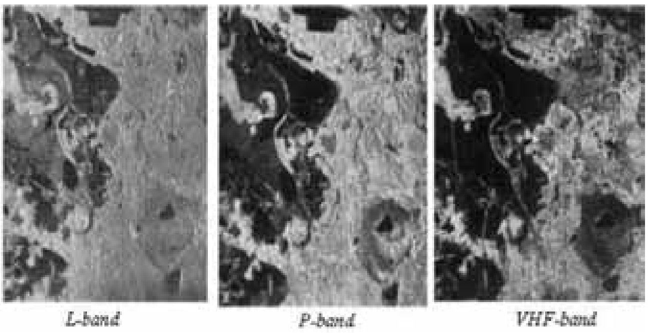
L-band P-band VHF-band

Figure 1: Spas-Klepiki, Ryazan Region. L-, P- and VHF-band SAR images.

As applied to the forest this allows to measure its bio-mass directly. Besides, the use of spaceborne SAR makes it possible to investigate forestlands over the large areas with high resolution.

However the use of P-band SAR is not limited to the studying of forestland. Airborne experiments have demonstrated that this band is unique for marine survey. Analysis of SAR images of sea surface obtained at various wavelengths shows that stratification of sea water movement becomes apparent most clearly at P- and VHF-band images. In Figure 2 SAR images of Barents Sea are given at three frequency bands. One can see that P and VHF bands have high information content. These images reveal:

1 – sea regions with different salinity;
2 – disturbance areas;
3 – whirlpool behind the cliff;
4 – river delta with pollution carry-over.

Thus, the utilization of P-band SAR can be of significant help in the research of sea disturbance, sea currents, river delta processes etc.

From stated above one can conclude that development of spaceborne P-band SAR gives opportunity to obtain an effective tool for solving the actual problems of forestry, geology, oceanology, subsurface sensing at the global scale and at the significantly higher level due to higher penetration ability of the signal.

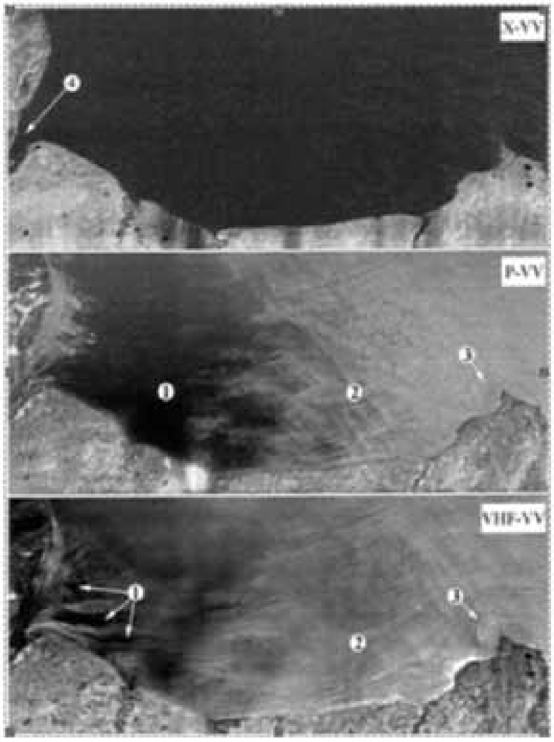

Figure 2: SAR images of Barents Sea area obtained at L-band (wavelength 4cm, VV polarization), P-band (wavelength 68 cm, VV polarization) and VHF-band (wavelength 254 cm, VV polarization).

4. Principles of building the P-band SAR on ISS

The key problems of building the spaceborne P-band SAR are related to the difficulties in antenna system design and in taking account of the effect of ionosphere. An important problem is SAR external calibration also. The conditions of space experiment on ISS have a number of essential limitations. In accordance with the operating procedure of the onboard equipment average power of transmitter should not exceed 50 W. Radar antenna area is restricted by a value of 32 m^2. Inclination of the orbit towards the equator is 51.7°. According to international agreement allowed frequency band for Earth radar is 432-438 MHz. It restricts the slant range resolution by a value of 25 m.

Antenna system is a key element which specifies the relationship between SAR equipment parameters, geometry and characteristics of radar survey areas. On the preliminary stage of this project various acceptable options of antenna design were considered such as mirror antennas and active phased array antennas (APAA) of various dimensions. Up to date it was decided to use the mirror antenna with 32m^2 square. Antenna has double set of elements which enables working at both horizontal and vertical polarizations. Figure 3 represents a scheme of location of antenna on ISS.

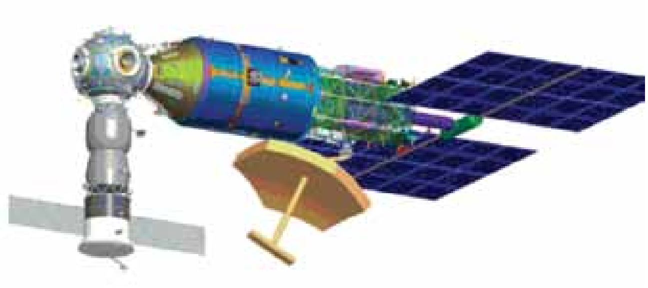

Figure 3: A scheme of location of P-band SAR antenna on the ISS.

The antenna, its feed and the rod for installing the antenna system will be delivered onboard with cargo spacecraft “Progress”. Antenna system will be installed on its place by operator during extravehicular activity.

Figure 4 demonstrates the direction of antenna beam relative to the flight direction of the ISS.

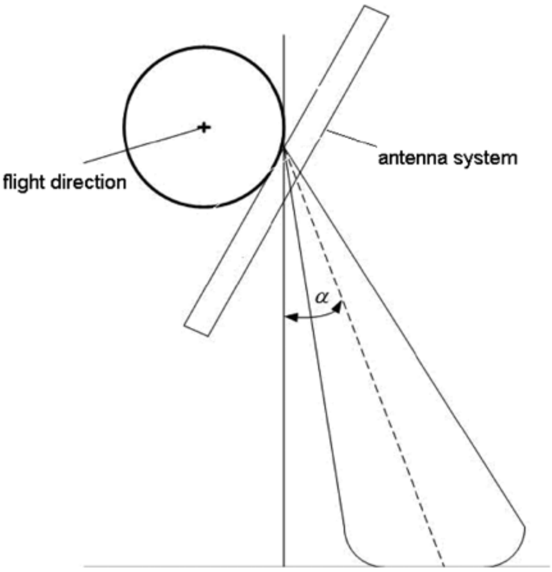

Figure 4: Direction of antenna beam relative to the flight direction of the ISS.

An irradiator in a focal area made as a set of linear phased array of emitters will provide beam scanning in elevation plane. Observation angle α may be selected in the range 100 - 35° . It is expected that width of the radar swath on the ground will be 40-60 km. Five beams of radar antenna will form an observation swath 250 km wide on the ground. Location the antenna system on the left side with respect to the flight direction is favorable for increasing the study area of coniferous forests in Northern hemisphere.

5. Power characteristics

Energy characteristics of the proposed SAR system may be estimated on the basis of survey geometry and antenna parameters. Radar cross section σ_N of noise equivalent may be estimated by formula:

$$(1) \quad \sigma_N = \frac{4^4 \pi^3 r^3 V \Delta F_m K_b T_P \sin\theta}{W_0 G^2(\alpha) \lambda^3 c Y_S T_i f_r}$$

Here r is surface element range, V is vehicle speed, ΔF_m is frequency deviation of chirp signal, K_b is Boltzmann constant, T_P is noise temperature, T_i is duration of sensing impulse, Θ is incidence angle, λ is wavelength, W_0 is emitted power, G *(α)* is antenna pat-tern, c is speed of light, Y_S are losses along the propagation path and in the receiving and processing system, fr is pulse repetition rate. Given formula contains only information on radar system parameters and does not depend on the image parameters or on the processing technique, which makes it preferable for the obtaining of objective characteristics.

Let us estimate maximum antenna gain by its geometric size:

$$G = \frac{4\pi S\eta}{\lambda^2} \quad (2)$$

Here S is antenna area, η is antenna efficiency, which is assumed to be 0.5. For given antenna dimensions $G = 25$ dB.

Losses along the propagation path and in the receiving and processing system are taken to be $Y_S = 2$, transmitted radar impulse power $W_0 = 50$ W, chirp impulse duration $T_i = 25$ ms, receiver noise temperature $T_P = 500$°K. Assuming that Doppler frequency band for antenna of given size is equal to 2.4 kHz, pulse repetition rate for polarimetric mode is chosen to be $f_r = 4.8$- 5.0 kHz.

Under given initial conditions radar sensitivity as noise equivalent radar cross-section $\sigma_N =$ 30 dB. Working in one polarization mode with the same pulse repetition frequency gives value of σ_N will be 3 dB better.

Swath width for radar looking angle of 30° is 58 km in ground range. Considering that pulse repetition rate is chosen on account of polarimetric mode, ground range ambiguity in polarimetric mode is 64 km, which is enough for range disturbance suppression. Then ground range resolution will be 50 m.

Single polarization mode allows the operation at doubled pulse repetition frequency, what allows increasing the radar sensitivity while working without range ambiguities at larger observation angles, up to 40°. In this case swath width will be 75 km and ground range resolution would be 38 m.

6. Expected results

Taking into account the ISS orbit the following objects can be investigated:

- forests and open soil regions of Buryatia, Mari El Republic, forest regions of southern part of Krasnoyarsk Krai and forestlands at Meshchera test sites;
- forests of equatorial Africa and South America;
- Sea of Okhotsk at various times of a year;
- sea ice properties in winter and sea ice cover dynamics;
- mountain glaciers (crevasses, top layers stratification) of Caucasus, Altai, Alps, Himalayas, including those under snow cover;
- water stratification in the areas of large sea currents, first of all Kuroshio and Gulfstream.

In the course of the space experiment the following issues should be worked out:

- methodical questions of measuring, digital processing and interpreting of backscatter data obtained from space by means of P-band SAR;
- methodical questions of measuring, digital processing and interpreting of data on magnitude and polarization characteristics of P-band signal scattered by point and distributed targets on the ground surface;
- estimation of actual parameters of geometric and polarization distortions arising due to the effect of ionosphere;
- methodical questions related to the account of the effect of ionosphere on the microwaves propagation and to the appropriate correction of obtained data;
- methodical questions concerning external calibration of P-band SAR;
- studying the possibility of estimating the sea disturbance parameters, stratification (including sea currents) and sea surface salinity;
- obtaining data on backscatter from coniferous, deciduous and mixed forests and estimating the possibility of classifying them;
- investigating the possibility of determination of forest biomass using space measurements and correlating them with test site data;
- studying the possibility of obtaining data on hydrological regime of soils;
- studying the possibility of estimating the characteristics of the surface under snow and ice cover;
- investigating the possibility of detecting and studying the large- and medium-scale surface water pollutions.