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A scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences (RAS) was held on 10 – 11 May 2000 at the P L Kapitza Institute for Physical Problems, RAS. The following reports were presented in the session:

(1) **Poperechenko B A** (Moscow Power Engineering Institute, Special Research Bureau, Moscow) "Highly efficient antenna systems for space communications and radio astronomy";

(2) **Pchelyakov O P** (Semiconductor Physics Institute of the Siberian Branch of the RAS, Novosibirsk) "Molecular beam epitaxy: equipment, devices, technology";

(3) **Édel'man V S** (P L Kapitza Institute for Physical Problems, RAS, Moscow) "Low-temperature scanning tunneling microscopy";

(4) **Komyak N I** (Institute for Analytical Instrument Making (IAnP), RAS, St. Petersburg) "Devices for identifying the isotopic, elemental, phase, and structural composition of substances. Modern instrument making at IAnP, RAS";

(5) **Rakhimov A T** (M V Lomonosov Moscow State University, Scientific Research Institute of Nuclear Physics, Moscow) "Autoemission cathodes (cold emitters) on nanocrystalline carbon and nanodiamond films: physics, technology, applications";

(6) **Borodin V A** (Institute of Solid-State Physics, RAS, and the RAS Experimental Factory of Scientific Engineering, Chernogolovka, Moscow region) "Development of new-generation equipment for crystal growth from melt. The RAS Experimental Factory of Scientific Engineering in the novel economic conditions";

(7) **Shchelev M Ya** (Institute of General Physics, RAS, Moscow) "Femtosecond photoelectronics — past, present, and future";

(8) **Utkin G I** (Scientific Instrument Making Association, Moscow) "Optoelectronic methods and equipment for identifying the composition and structure of optically anisotropic objects and media by polarization technique";

(9) **Surkov Yu A** (V I Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Moscow) "Scientific instrument making in space exploration";

(10) **Tverdokhleb P E** (Institute of Automatics and Electrometry of the Siberian Branch of the RAS, Novosibirsk) "Three-dimensional micro- and nanotechnologies: new facilities, devices, elements and their applications".

An abridge version of the reports Nos 1 – 3, 5 – 7, and 9 is given below.

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Highly efficient antenna systems for space communications and radio astronomy

B A Poperechenko

1. Antennas and radio communication with rocket-driven spacecrafts

Progress in developing rocket-driven spacecrafts has imposed greater requirements on the spacecraft instrumentation systems with respect to the radio communication range and the efficiency of spaceborne equipment. Problems in meeting these requirements are closely linked to the operation of the onboard antennas through the heat-resistant coatings (HRC) and plasmas, disruption of their electrical strength in plasma, profound irregularities of the isotropic directional patterns (DP) on unoriented spacecrafts, and synchronization breakdown in ground-based receivers as a result of signal fluctuations. Solving these problems led to the development of the theory of antennas with HRC and cavity-backed slot antennas, and to the realization of new antenna circuits with incoherent composition of fields from interfering radiators. Onboard equipment for diagnozing the HRC and plasma effects was designed and built, and a theory for multimode impedance diagnostics of heterogeneous media was developed. The radiophysical parameters of the rocket-engine plume plasma were explored on test stands. And, finally, the installation of large track antennas on ground stations began (1952 – 1975).

The first combined onboard antennas for telemetry, TV, communications, and commands were set up. Also designed and built for oriented spacecrafts were antennas with specially shaped DPs and pencil-beam track antennas. A large collapsible antenna for a side-looking radar on the automatic interplanetary station (AIS) Venera 15 and 16 was constructed. The radio and mechanical parameters of this antenna were studied in extremely hostile thermoradiation environments (1980 – 1986). Finally, the possibilities of using onboard hybrid reflector antennas (HRA) in satellite communications with control of the position and shape of their beams and adaptation of the antenna DP to noise were studied (1985 – 1995).

2. Ground-based large reflector antennas (LRA) with diameters ranging from 12 to 32 meters

The high cost of LRAs and their great number and variety required optimizing the antennas' radio and cost-efficiency parameters, unifying the support equipment, limiting the set of components, and putting them into mass production.

In some LRAs two to three bands have been combined, the aperture utilization factor (AUF) has been increased, the noise temperature has been lowered, and systems have been introduced for search and automatic tracking (AT) by radio signals in conditions of insufficient pointing accuracy. A more uniform aperture distribution of the field was achieved by synthesizing optimum irradiation patterns in single-reflector antennas and by introducing minimized corrections of the reflector profiles in two-reflector LRAs. Diffraction scattering in antennas has been reduced, and methods for doing more precise calculations of the partial components of such scattering have been developed. Scanning antenna feeds for LRAs with AT have a multimode or multicomponent structure with a small deviation of the phase center and low gain losses. The problem of frequency and polarization instability of the direction-finding characteristics has been solved. The automatic tracking circuits used today are much simpler than monopulse systems and are equipped with single-channel receivers, which have an angular accuracy sufficient for information systems. Finally, multiple-beam LRAs for satellite-communication teleports have been designed using numerical simulations, and their structure and parameters have been studied.

The equipment for LRAs was designed and manufactured in the Soviet Union for operating in conditions ranging from those in the Far North to those in the tropics and was included in LRAs of broad application and in unique 32- and 64-meter radio telescopes. Among this equipment are tracking electric drives with original structure and reduced errors, inductosyn-based 17- and 20-digit angular-position pickups, and a large variety of microwave devices. The Special Research Bureau (SRB) of the Moscow Power Engineering Institute (MPEI) provided the technical specifications for the first Soviet low-noise amplifiers with a closed hydrogen-level cooling cycle, which were built by subcontractors in Kiev and Omsk in 1970 – 1976, for 12-meter reflector systems (RS) and their rotary-support mechanisms (RSM) built in Nizhniĭ Novgorod, and for other facilities. The TNA-57 antennas comprising the Orbita satellite communication system became the first large antennas of extensive applications and the basic modification for some other LRAs. These antennas proved to be cost-effective in providing satellite communications in the Soviet Union and abroad.

The economic data gathered during the construction of more than 200 LRAs of different sizes have been generalized with allowance for the degree of similarity and construction optimization and make it possible to predict the cost of the LRA to come with fairly high accuracy (10 – 20%). These predictions have been confirmed in the construction of the TNA-57 12-meter antennas and the TNA-1500 64-meter radio telescopes. Also, the technical-and-economic efficiency of multiple-beam LRAs has been substantiated.

Various methods, such as wind-tunnel testing, geodesic and radio-holographic measurements of gravity and thermal strains in 64-meter radio telescopes, and full-scale vibration-mechanical and dynamic endurance tests, have been used to study the behavior of LRAs in different conditions. The results of testing and the experience in building LRAs have made it possible to develop conceptual designs for the new 128- and 64-meter radio telescopes and, on their basis, to build new 32-meter radio telescopes as part of the Kvazar interferometric complex of the Institute of Applied Astronomy of the Russian Academy of Sciences and the new TNA-82 12-meter antennas.

The LRAs built to date are used in more than 20 different systems developed at SRB MPEI and at other organizations, including the United Satellite Communication System, the Intersputnik systems, and systems related to space monitoring, telemetry, and radio astronomy, etc.

3. Universal tracking 64-meter radio telescopes located at Bear Lakes and Kalyazin (1958 – 2000)

Radio telescopes were designed as universal instruments intended for space communications and radio astronomy. In the Soviet Union, the radio-telescope project was approved in 1968 by an interagency commission, and its technical parameters were higher than those of similar foreign first-generation radio telescopes. The first Soviet radio telescope was commissioned at Bear Lakes in 1980, and the second at Kalyazin in 1993. These radio telescopes incorporated several unique technical attainments: a system for reading the angle that determines the position of the radio-telescope axis with compensation of the strains in the rotary-support mechanism; highly precision 20-digit angular-position pickups and powerful electric tracking drives; backlash-free power trains; a homologous reflector system with corrected reflector profiles and focus compensation, and a number of unconventional engineering solutions that substantially reduced the instrument costs.

In the eighties, the first radio telescope received a large volume of unique scientific radar data from the AIS Venera 15 and 16, and from AIS Vega 1 and 2 as well as Phobos 1 and 2. In the period from 1979 to 1989, the programs issued by the Institute of Applied Geophysics (IAG) and Leningrad State University and the equipment complex of SRB MPEI were used to study bursts of solar activity. The program included (a) double-frequency mapping of the Sun, (b) polarization radiography of the solar corona, and (c) the study of the fine temporal structure of radio-frequency solar bursts and of the sources of Alfven waves. The staff of IAG has substantially improved the methods of predicting the bursts of solar activity.

Both radio telescopes are drawn in the following observation projects that promise important results: the ground – space verylong-baseline radiointerferometry (VLBR) systems Radioastron and VSOP [the Astronomy and Space Center (ASC) of the P N Lebedev Physics Institute of the Russian Academy of Sciences (ASC FIAN, Moscow)]; the Astrocomplex project which includes building an extremely stable pulsar time scale and pulsar VLBR astrometry [the Pushchino Radio Astronomy Observatory (PRAO) of ASC FIAN, Moscow region], and low-frequency VLBR investigations of the fine space – time structure of the bursts of solar activity (NIRFI and ASC FIAN). The plan is to use the radio telescopes to do VLBR studies of a basic astrogeodesic system (Moscow Institute of Geodesy, Aerial Photography, and Cartography Engineers) and VLBR ranging of planets and asteroids (Institute of Radio Engineering and Electronics of the Russian Academy of Sciences and the Russian Research and Development Space Instrument Making Institute). Equipment complexes are being prepared for launching space probes of the Spektr series, for bistatic radar of space trash, and for other purposes.

For more extensive use the radio telescopes are modernized without interfering with observations. Modernization presupposes (a) increasing the number of operating bands in each instrument up to eight in the wavelength range from 1 to 100 cm for shared and combined usage of the bands;

(b) reaching the limiting RS accuracy (~ 0.6 mm), the accuracy of the pointing system (PS) ($5-7''$), and radio-telescope sensitivity (50 – 200 Jy) in all operating bands; (c) further increasing the degree of automatization; (d) finishing off the adjustment of the metrological complex in accuracy, and (e) the full-scale fitting-out of the radio telescopes with equipment complexes.

The multiband configuration of radio telescopes is based on a single large ($6\times\varnothing 2$ m) strongly misphased horn feed. Multiband observations are done with insignificant loss of sensitivity and minimum alterations in the design of the radio telescopes. The radio-telescope frequency range can be broadened in order to incorporate millimeter waves and ensure a planned increase in RS and PS accuracy under certain restrictions on weather conditions. Experimental observations at $\lambda = 1.35$ cm with a beam width smaller than $1'$ confirmed high PS stability and clarified the top-priority measures needed to increase sensitivity. The multiband feed with a broadened frequency band was developed in cooperation with the Antenna Department of MPEI by numerically solving the exact electrodynamic problem with allowance made for the manufacturers' tolerances and the frequency bands.

The overall accuracy of measurements and adjustments achieved in the staged radio-holographic alignment of RS at Bear Lakes (in cooperation with the Radiophysics Research Institute — NIRFI, Nizhniĭ Novgorod) was 0.2 – 0.25 mm. Earlier (1980 – 1986) a laser long-range profilometer was built for performing alignments of RS at all inclinations of the reflector. The first laser station that emitted nanosecond pulses and monitored the coordinates of an aircraft with an onboard radio-frequency reference was devised and used for measurements involving large antennas in the period from 1974 to 1984. To increase the degree of homology of RS, effects associated with gravity, thermal, and wind strains in the system were studied and compensated. From 1980 – 1985, the effectiveness of photogrammetry and radio range-finder checking of strains in the reflector was investigated.

The accuracy of PS angular adjustments in the hemisphere was brought up to $2''$. The residual angular errors and the problem of their compensation are studied. The automatization of tracking and multiple rapid transfers from object to object in the around-the-clock operation was completed, while work on automatizing the test, metrological and auxiliary modes is still going on.

A precision automated metrological complex was built and is being gradually modernized. The complex is used in conjunction with radiometric, radio holographic, radio-direction-finding, and geodesic systems and the corresponding technologies.

Radio telescopes operate regularly and effectively in international VLBR networks, thus increasing the overall sensitivity of such networks and broadening the spatial frequency range. Researchers have extracted new data from observations made with radio telescopes. The Institute of Space Research (IKI) of the Russian Academy of Sciences has obtained a radio image of the jet of the radio galaxy 3C274 and that of a maser in the gas-dust complex W51. The Astrocomplex project of PRAO ASC FIAN is aimed at investigating the fine structure of fluctuations of the time and direction of arrival of r.f. pulses from millisecond pulsars in the timing and VLBR modes. ASC FIAN, in collaboration with KA HALCA (Japan), obtained a radio image of the quasar 3C147 with enhanced resolution in the ground-space interferometer mode. Radio telescopes form a unique equipment base for collective usage due to the combination of high sensitivity, accuracy, universality, reliability, and cost effectiveness.

4. Conclusion

The above findings represent the core of the solution found by SRB MPEI (with the participation of several other research and industrial organizations) for the comprehensive scientific and technological problem of building and extensively using large optimized antennas and radio telescopes with their supplying equipment for space and radio-astronomy systems.

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Molecular beam epitaxy: equipment, devices, technology

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1. Introduction

The synthesis of semiconducting thin-film compositions from molecular beams in ultrahigh vacuum became known as a new method in semiconductor materials science after the first successful experiments by Arthur and LePore [1] and Cho [2] at the end of the 1960s. This method, known as molecular beam epitaxy (MBE), gained momentum largely due to the development of unique micro-, nano-, and optoelectronic devices around structures with superlattices, quantum wells, and quantum dots, whose principle of operation is based on the wave nature of the electron (in contrast to the more common microelectronics devices). Among such devices are, primarily, semiconductor lasers and sensitive photodetectors with quantum wells, superlattices, and quantum dots in the active region; transistors with high electron mobility in the conduction channel; nanotransistors; tunnel-resonance diodes, and single-electron devices, etc. At present additional impetus to R&D in MBE is provided by the ideas and perspectives favored in building an elemental base for quantum computers. At the same time (and with the same intensity), scientific instrument making is being developed for this area of vacuum technology and analytical equipment.

Industrial realization and development of the molecular beam epitaxy method have convincingly shown that the method is indispensable in manufacturing multilayer epitaxial structures with atomically smooth boundaries and layer thicknesses, composition, and alloying profiles that are monitored with high precision. The use of highly sensitive electron-probe and optical instruments for monitoring the parameters of the new structures and controlling the process of their synthesis ensures the high reproducibility of these parameters.

The story of how this important avenue of research in scientific instrument making was founded and developed at the Semiconductor Physics Institute (SPI) of the Siberian Branch of the Russian (then Soviet) Academy of Sciences (RAS) and in the USSR as a whole was closely related to the names of two outstanding scientists: the first director of SPI Academician A V Rzhanov, and the founding father of the leading scientific school in Russia in the physics and technology of molecular beam epitaxy, Prof. S I Stenin. The