JPRS L/10266

20 January 1982

USSR Report

SPACE

(FOUO 1/82)

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SPACE APPLICATIONS

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UDC 502.3:629.78

INTEGRATED EXPERIMENT WITH 'METEOR' ARTIFICIAL EARTH SATELLITE: IMPORTANT STEP IN DEVELOPMENT OF OPERATIONAL INVESTIGATIONS OF THE EARTH FROM SPACE

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 1 Jul 81) pp 5-7

[Article by N.P. Kozlov, R.Z. Sagdeyev and N.N. Sheremet'yevskiy]

[Text] In our country, the development of facilities for remote sounding of the Earth from space is moving in two basic, mutually supplementary directions. The first of them is based on photographic surveys of the Earth's surface, delivery of the exposed photographic film to Earth, and utilization of the materials obtained for comprehensive thematic mapping. The basic space experiments in this field were performed by USSR Pilot-Cosmonauts Comrades G.T. Dobrovol'skiy, V.N. Volkov, V.I. Patsayev, V.G. Lazarev, O.G. Makarov, P.I. Klimuk, V.V. Lebedev, V.I. Sevast'yanov, V.F. Bykovskiy and V.V. Aksenov, in the "Salyut" manned orbital stations and "Soyuz" spacecraft.

As a result of these experiments and the scientific research and planning and design work based on them, the multizonal space photography method was developed; within the framework of the "Intercosmos" program, specialists from the USSR and the GDR created the MKF-6 multizonal space camera, which realizes this method and is intended for extensive productive use. After being developed on the basis of the results of flight testing carried out with the "Soyuz-22" spacecraft, the MKF-6M was made available for practical use by interested organizations in 1977. Since that time these cameras have been used successfully on the "Salyut-6" manned orbital station, as well as in laboratory aircraft operating under the Investigation of the Earth's Natural Resources (IPRZ) program in many areas of our country and other socialist countries.

The creation of the MKF-6M camera and the equipment for processing photographs that accompanies it was an important step in the development of photographic aerospace investigations of the Earth. The photographs of the Earth's surface obtained with these cameras are now being used effectively by many scientists and production organizations from different ministries and departments in order to solve many diversified problems involving the Earth sciences and different economic branches.

The second direction for investigation of the Earth from space involves surveying in the most variegated bands of the visible, infrared and superhigh-frequency zones of the spectrum of electromagnetic waves passing through the Earth's atmosphere, the transmission (by radio) of the information obtained from satellites to reception points, and the operational processing and delivery of this information to consumers who are engaged in observing, investigating and monitoring transient processes taking place on the Earth's surface and in its seas and oceans.

An analysis of Soviet and foreign experience in using information obtained in space for IPRZ purposes shows that it is operationally delivered data that is of the greatest value, since it provides a highly efficient means for solving extremely important national economic problems, such as--in particular--monitoring the status of agricultural lands and the work being done on them, searching for regions of increased biological productivity in the sea and many others. The development of this direction requires the solution of technically more complicated problems, both on board the spacecraft involved and on Earth itself at the information reception and processing points. The complexity of the solution of the problem increases acutely when the Earth's surface is to be surveyed with high spatial, spectral and radiometric resolution and the video information obtained is to be transmitted to Earth over a digital radio line. Operational processing and interpretation of the obtained video information is possible only on the basis of specialized computer technology. The inclusion of specialized computer facilities in the cycle of obtaining, transmitting and processing this video information, as well as the development of the necessary software for these facilities, is an extremely complex problem in and of itself.

A second-generation "Meteor" artificial Earth satellite containing a complex of experimental equipment that made it possible to begin an extensive experiment that models the regular, operational utilization of space facilities for IPRZ purposes was launched on 18 June 1980.

The "Meteor" was injected into a solar-synchronous orbit (with an inclination of about 97°) that provides the possibility of surveying any area in the Soviet Union under approximately identical solar illumination conditions. The high accuracy of the satellite's orbital orientation and its altitude of about 630 km above the Earth's surface made it possible to conduct surveying with a spatial resolution of tens of meters.

In addition to the regular radio and television complex that has already been used repeatedly for IPRZ purposes, three new experimental opticoelectronic instruments were installed in the satellite. They make it possible to survey the Earth's surface in different bands of the visible and near-infrared zone of the spectrum, with medium and high spatial resolution.

The video information that is obtained is transmitted to Earth, at the surveying rate, over specially developed high-information-content communication links, including digital ones that insure the preservation of the high radiometric accuracy of the video information obtained by the surveying instruments. Along with the industrial organizations, the USSR Academy of Sciences' Institute of Space Research (IKI) and the OKB [Experimental Design Office] of the USSR Ministry of Higher and Secondary Specialized Education's Moscow Power Engineering Institute participated in the development of the on-board and ground equipment used in this experiment.

The video information arriving from the satellite is processed at IKI and the USSR State Committee for Hydrometeorology's State Scientific Research Center for the Study of Natural Resources in specialized display-type computer complexes. Specialists from the USSR Academy of Sciences' IKI have developed a problem-oriented software system for these complexes. This system makes it possible to solve, in an interactive mode (a specialist-computer dialog), an extensive circle of problems concerning the service processing and correction of the video information, its geographic coordinate correlation and conversion into given cartographic projections and scales, the obtaining of various statistical characteristics, and the implementation of thematically oriented brightness and color transformations that insure the production of high-quality images and a thorough interpretation of them.

As research conducted at Moscow State University and other organizations has shown, the use of the experimental video information obtained with the "Meteor" satellite for the purpose of solving various problems in the national economy and the Earth sciences has confirmed the effectiveness of this experiment and the prospects of many of its technical and methodological solutions.

At the same time, during the course of the experiment we discovered quite a few incompletely solved scientific and technical, methodological and organizational problems. Here we are speaking of the reliability of individual on-board instruments, the equipment for the high-speed registration of video information that is being received, the display equipment for the digital processing of images and the equipping of interested scientific and production organizations with it, the provision of the processing of space video information with a priori data on the spectral and structural characteristics of objects being investigated, the functioning of the operational processing service and the dissemination of information obtained from space and, of course, the readiness of most consumers to change over to digital video information and use it effectively. The detection of these shortcomings, their analysis and the search for ways to eliminate them is also an important goal of the experiment that is being conducted.

The "Meteor" is continuing to function successfully in orbit. The experiment is not yet completed, but we can already say with confidence that it was an important step in formulating operational investigations of the Earth's natural resources in our country. The "Meteor" and its fittings undoubtedly reflect, in the highest degree, our contemporary ideas about the use of spacecraft for operational IPRZ. The information obtained from it and the software that has been developed for processing and intepreting this information answer fully the present requirements of the most diversified consumers. Most of the theses advanced above are convincingly confirmed and discussed in detail in the rest of the articles in this issue of ISSLEDOVANIYA ZEMLI IZ KOSMOSA.

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CSO: 1866/18

UDC 551.507.362

'METEOR'-SERIES SATELLITES INTENDED FOR STUDYING THE EARTH FROM SPACE

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 29 May 81) pp 8-20

[Article by Yu.V. Trifonov]

[Text] The Soviet experimental program for studying the Earth's natural resources from space with the help of automatic satellites, which later received the name "Meteor-Nature" in the periodical press, began in 1974 with the launching of an experimental spacecraft of the "Meteor" type that was equipped with a multispectral television camera. Between that time and 1979, three similar spacecraft (KA) were launched into orbit. The first two KA's were injected into orbits at an altitude of 900 km, with an inclination of 82°, while the subsequent KA's in the "Meteor-Nature" program (beginning in 1977) were placed in synchronous solar orbits with an average altitude of 650 km and an inclination of 98°. All of the "Meteor" satellites functioned successfully in orbit and transmitted multispectral television information to Earth on a regular basis (see table.)

"Meteor-Nature" Program KA Launches

№ п.п. (1)	Дата запуска (2)	Характеристики орбиты (3)		
		наклонение, град (4)	средняя (5) высота, км	период, мин (6)
1	09.VII. 1974 г.	81,2	891	102,6
2	15.V. 1976 г.	81,2	887	102,4
3	29.VI. 1977 г.	97,9	643	97,5
4	25.I. 1979 г.	98,0	643	97,4

Key:

1. Spacecraft number
2. Date of launch
3. Characteristics of orbit
4. Inclination (degrees)
5. Average altitude (kilometers)
6. Period (minutes)

The main goals of the "Meteor-Nature" program were:
the creation and development of equipment and methods for obtaining, transmitting and processing multispectral television information of low and average resolution for the purpose of studying natural resources;
the creation and development of techniques for decoding and interpreting multispectral television information on the Earth's underlying surface for the benefit of different branches of the national economy;
the development of equipment and methods for correcting KA trajectories for the purpose of obtaining special orbits and guiding KA courses over test ranges;

obtaining experience in the experimental operation of KA's for IPRZ [investigation of the Earth's natural resources] purposes and the creation of a scientific and technical reserve for the development and improvement of natural resource KA's and the equipment associated with them.

The pivotal element in the realization of this program was the informational radio and television complex (RTVK) that was installed in all the "Meteor" KA's. It consists of two low- (MSU-M) and medium-resolution (MSU-S) multichannel scanning units, memory units, automatic equipment, synchronizers and two transmitters (one each for the decimeter and meter bands). All of the RTVK units are duplicated. The specifications for this equipment and a description of it is given in [1]. All of the multispectral information was received at Goskomgidromet's basic information reception points in Moscow, Novosibirsk and Khabarovsk, while the low-resolution information on one of the subbands was also received at independent (simplified) reception points located in different parts of the USSR. The information from the RTVK's multispectral scanners was not of a metrological nature and was transmitted over an analog radio link, so the decoding and interpretation of the information was done by visual methods, without the use of digital methods.

The integrated nature of the study of the Earth and its atmosphere was characteristic of all the experiments done with KA's in the "Meteor-Nature" program. For instance, along with the multispectral television instruments, in the KA's we tested (in various combinations) seven more instruments operating in the visible, infrared and microwave bands of the spectrum, as well as eight instruments for measuring corpuscular radiation and other parameters of space itself. Most of them were built and tested on a spaceflight for the first time. The makeup, purpose and brief descriptions of the instrument packages in the information complexes of KA's in the "Meteor-Nature" program from 1974 to 1979 are given in [2]. The results of the work performed by most of these instruments have been published in journals and the proceedings of conferences. Not all of the instruments fulfilled the hopes placed in them and the results of several developments and tests were negative, but on the whole we laid the foundation for and obtained valuable experience in building prospective instruments for remote sounding, some of which have been used in second-generation natural-resource KA's.

The main result of the development of the basic information system for KA's in the "Meteor-Nature" program--the multispectral radio and television complex--and the spacecraft as a whole was a transition from individual experiments to the experimental operation of this space system on the basis of one or two KA's and three ground information reception and processing points.

During the actual operation of this system since June 1976, the multispectral low- and medium-resolution equipment has been used to photograph the Soviet Union's territory more than 400 times; that is, for all practical purposes an overall survey of that territory was made on the average of every 4-5 days. Despite the fact that in a significant percentage of the photographs the underlying surface was covered with clouds, more than 100,000 duplicate negatives and 70,000 photographs and ortoplany [translation unknown] of multispectral television information have been sent to hundreds of scientific research organizations belonging to 20 national economic ministries and departments during this time. This information was used most effectively in the interests of hydrology, the maritime fleet, geology and forest management. Numerous examples of the interpretation of the information for the benefit of these branches are presented in [2-5].

The information provided by the RTVK is used to evaluate the ice situation in the seas and oceans, including mapping the distribution and dynamics of the movements of ice fields, evaluating the age and solidity of ice, detecting free-floating icebergs and so on. On the basis of these evaluations a number of important national economic measures have been instituted, including the superearly sailing of ships along the Northern Sea Route in the Arctic and the operation of ships belonging to seasonal Antarctic expeditions, as well as experimental voyages of atomic-powered icebreakers in the high northern latitudes. The directions for "Investigation of the Distribution and Dynamics of Sea Ice on the Basis of Television Pictures From the 'Meteor' Artificial Earth Satellite," which were developed by Goskomgidromet's Arctic and Antarctic Institute, have been introduced into operational practice. In addition to this, RTVK photographs were used to make regular and operational evaluations of the boundaries and dynamics of the snow cover in mountainous and semi-mountainous regions and the hydrological regime of rivers and other bodies of water, particularly during high-water periods. This type of work is being done constantly along the trace of the Baykal-Amur Main Railway Line.

The USSR Ministry of Geology is one of the main consumers of the broadly disseminated multispectral information produced by the KA's in the "Meteor-Nature" program. Under the leadership of the VNPO [probably All-Union Scientific Production Association] "Aerogeologiya," many of its organizations are developing the principles of the techniques and technological processes for the integrated utilization of space surveying materials in regional prospecting work. Important practical results have already been obtained. RTVK information is used widely to detect and define more precisely tectonic structures and the lineaments of the Earth's crust. According to the estimates of geologists, the annual economic effect from the use of multispectral information in this matter alone is about 10 million rubles. Data from RTVK photographs have been used to compile space-tectonic maps of the USSR on scales of 1:5,000,000 and 1:2,500,000 that are used as the basis for predicting the presence of useful minerals and determining the overall strategy of prospecting work. Data have also been obtained for predicting potential oil- and gas-bearing structures in several regions of the USSR and the confinement of gold ore manifestations to areas where annular structures and linear faults intersect has been established in one of the eastern regions of this country. According to some estimates, the monetary savings when territorial geological structures covering 1 million km^2 are studied by space methods are about 3 million rubles.

Forest management specialists have achieved significant results through the use of spectrozonal satellite information to detect forest fire nuclei and monitor their propagation. Special techniques for using satellite information for this purpose, as well as for the operational evaluation of the weather situation in hazardous fire periods in areas that are being protected and the organization of the utilization of airborne firefighting facilities, have been developed and introduced into operational practice at forest conservation establishments.

Simultaneously with the obtaining of operational results related to the interpretation of information for the benefit of the national economy, during the development and flight testing of the KA's in the "Meteor-Nature" program a number of problems that are important for the development of space technology for remote sounding were solved for the first time in Soviet practice.

Requirements for KA's for Remote Sounding. In order to solve the complex of problems involved in investigating the Earth from space by remote sounding methods, in

addition to the presence on board a satellite of the special information-measuring instruments and radio links for the transmission of the information it is necessary that the spacecraft--the carrier of these instruments--satisfy a broad spectrum of requirements that are determined by its purpose. The use of methods and equipment for the remote sounding of the Earth and atmosphere are realizable in practice and are useful if the following are provided for in the KA and the space system:
the obtaining of spectrozonal measuring information of the necessary spatial and spectral resolution, with minimal geometric distortions and geographic correlation of the images and the geographic area with the required degree of accuracy;
the possibility of simultaneously (synchronously) obtaining integrated measurements and images of the Earth's underlying surface in several different bands and subbands of the electromagnetic wave spectrum;
permanent or regulatable periodicity in obtaining information various regions of the Earth under identical illumination conditions, in order to study the dynamics of processes taking place in natural formations;
the possibility of operational and accurate guidance of KA surveying routes over certain regions for frequent observations during natural calamities or over terrestrial measurement ranges when integrated experiments are being conducted beneath the satellite;
the optimum combination of a sufficiently operational global survey of the Earth's surface and the possibility of obtaining local information via a detailed survey.

An analysis of the systems requirements and principles of construction of remote-sounding information equipment for KA's shows that the KA's themselves must have a number of special structural and design features.

In order to insure constant observation of the Earth with the required geographical correlation of the measurement data and minimal geometric distortion of the images obtained, a KA used in remote sounding must first have a high degree of accuracy in its orientation in the orbital system of coordinates (both on the Earth and along the satellite's velocity vector) and stabilization of the craft's intrinsic angular motion velocities around its center of mass. The higher the spatial resolving power of the remote sounding equipment and the more accurate the geographical correlation requirement, the greater the orientation and stabilization accuracy must be. Special attention must be paid to the KA's dynamic characteristics so as not to allow uncompensated disturbing moments in the satellite equipment, such as when the solar batteries are being rotated as they are being oriented on the Sun or when the scanners or other moving masses are swinging.

Since the program for the investigation of natural resources by remote sounding methods is largely an experimental one, the stipulated possibility of installing a complex of information-gathering instruments and several radio circuits in the KA and insuring the simultaneous activation of these instruments in different modes, such a KA requires a rather powerful electricity supply system with a large dynamic load range and complex control logics. The multimode nature of the output of the remote sounding information, in combination with the choice of certain regions for obtaining and releasing the data, makes it necessary to have a special time-programmed device with a long-term memory or a control computer on board the KA. In combination with the desire to economize on on-board energy resources and the limited nature of the ground reception points' radio visibility zones, the large masses of data that are accumulated and transmitted make it necessary to use highly directional, oriented on-board antenna that sometimes require special electric guidance drives. Since the remote sounding equipment is used to make measurements, it is necessary to provide constant temperature conditions and sometimes even "deep" cooling of the sensors. In addition to this, it is necessary to shield the sensitive equipment from noise and interference from the comparatively powerful electrical and radio systems over a broad band of the electromagnetic wave spectrum.

It is only natural that a spacecraft and its systems must have a service life of several years. To this we can add that for remote sounding KA's it is possible to require a high degree of independence; that is, the capability of functioning for quite a long time (particularly in the operational mode) without requiring information communication sessions with the ground control complexes, which for Soviet KA's form a unified command and measurement complex for the purpose of reducing the amount of work that must be done. This requirement is also related to both insuring the on-board equipment's high reliability and using effective and automatic on-board monitoring and satellite control systems.

The spacecraft's design must provide high dynamic accuracy and temperature stability for the placement of the measuring instruments relative to the optical axes and must be a general-purpose one that makes it possible to install various sets of experimental information equipment quite easily. In addition to everything else, the design must be suitable for the installation of correcting engines for the initial setting of the required orbit and subsequent control of it.

The "Meteor"-series spacecraft possess all of these variegated qualities to a considerable degree, both in the first- and (particularly) second-generation units. Created originally for meteorological purposes, they satisfy most of the requirements for remote sounding of the Earth.

Structure of the "Meteor-Nature" Program KA's. From the beginning of its implementation in 1974, the "Meteor-Nature" program was developed as an integrated program providing for the conduct of experimental projects in obtaining, transmitting and processing information from investigations of the Earth and its atmosphere and near-Earth space, as well as design experiments aimed at the further improvement of KA's for remote sounding. As has already been mentioned, the program was based on the use of the design and the electrical and radio complex of the first-generation "Meteor" meteorological spacecraft.

Let us dwell briefly on several special features of the instrument complexes for KA's in the "Meteor-Nature" program, one of which is shown in the generalized block diagram shown in Figure 1. A variety of simultaneously operating instruments that can be categorized by several specific features is typical of these complexes. These features are:
the bands of the electromagnetic radiation spectrum used for obtaining information: the visible, infrared (1-25 μm), superhigh-frequency (0.8-8.5 cm) and X-ray bands;
the observation principle: electromechanical and electronic scanning for both area and spectrum, tracking, direct measurement of corpuscular flows, optical observation of stars and so on;
the orientation and geometric shapes of the fields of view of instruments directed toward the Earth for vertical, slant and circular sounding, into space and toward the Sun for calibration purposes, and instruments aimed in different directions for corpuscular and geophysical measurements;
the information transmission methods: digital and analog, with the help of telemetric and special information radio links in the meter and decimeter bands.

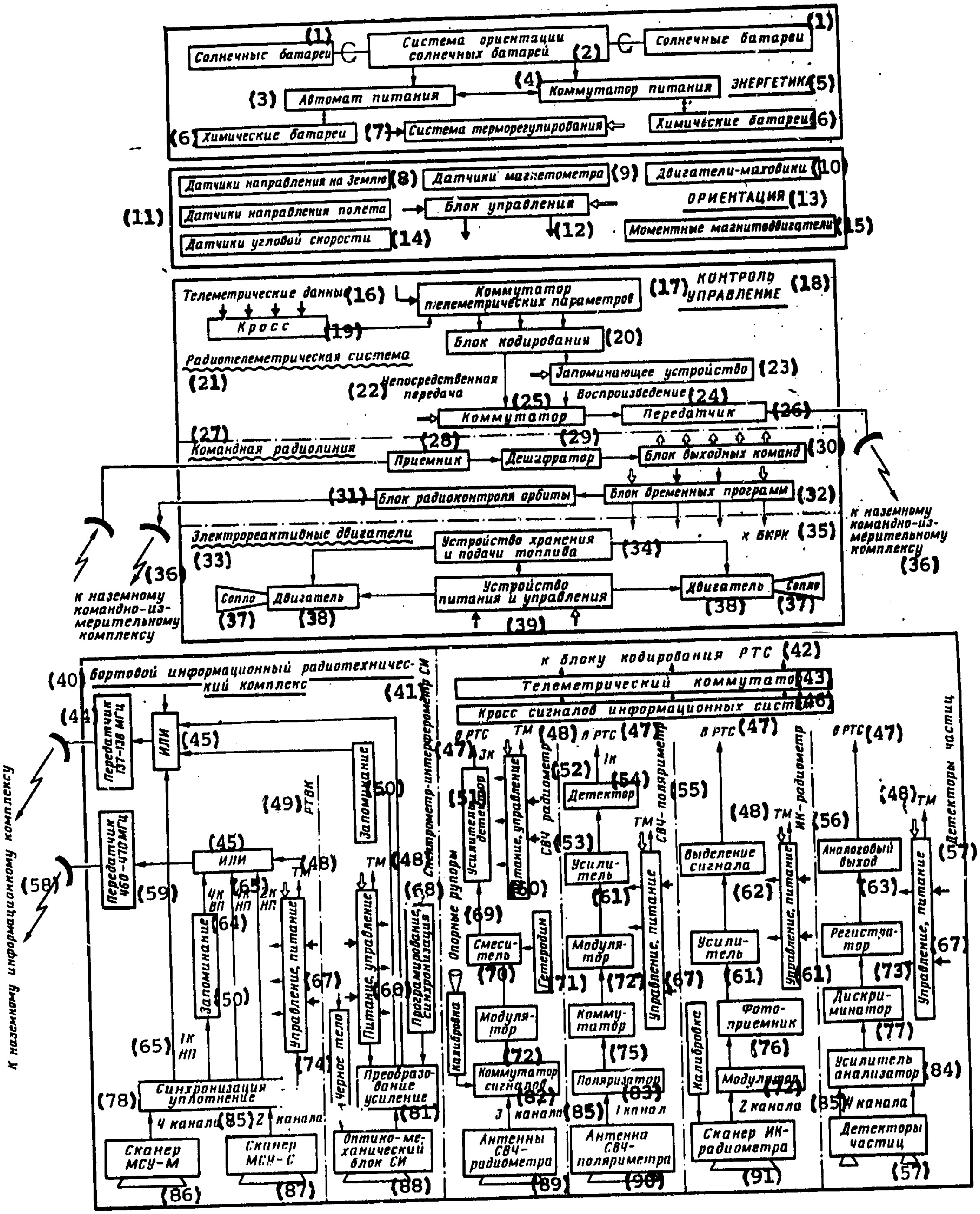

Figure 1. Block diagram of "Meteor-Nature" program spacecraft. [Key on next page]

Key to Figure 1:

1. Solar batteries
2. Solar battery orientation system
3. Automatic power feed unit
4. Power feed commutator
5. Power engineering
6. Chemical batteries
7. Temperature regulation system
8. Direction-to-Earth sensors
9. Magnetometer sensors
10. Flywheel engines
11. Flight direction sensors
12. Control unit
13. Orientation
14. Angular velocity sensors
15. Moment magnetic engines
16. Telemetric data
17. Telemetric parameter commutator
18. Monitoring, control
19. Distribution frame
20. Encoding unit
21. Radiotelemetric system
22. Direct transmission
23. Memory unit
24. Reproduction
25. Commutator
26. Transmitter
27. Command radio link
28. Receiver
29. Decoder
30. Output command unit
31. Orbit radio monitoring unit
32. Temporary program unit
33. Electric reaction engines
34. Fuel storage and supply unit
35. To on-board radio information complex
36. To ground command and measurement complex
37. Nozzle
38. Engine
39. Fuel feed and control unit
40. On-board radio information complex
41. Solar radiation spectrometer-interferometer
42. To radiotelemetric system encoding unit
43. Telemetric commutator
44. 137-138 MHz transmitter
45. OR
46. Information system signal-distribution frame
47. To radiotelemetric system
48. Telemechanics
49. RTVK
50. Memory
51. Amplifier, detector
52. Radiometer
53. Superhigh frequency
54. Detector
55. Superhigh-frequency polarimeter
56. Infrared radiometer
57. Frequency detectors
58. To ground information complex
59. 460-470 MHz transmitter
60. Power feed, control
61. Amplifier
62. Signal discrimination
63. Analog output
64. Auxiliary instruments (4 channels)
65. Observation instruments (. channels)
66. Calibration
67. Control, power feed
68. Programming, synchronization
69. Reference speakers
70. Mixer
71. Heterodyne
72. Modulator
73. Recorder
74. Black body
75. Commutator
76. Photographic receiver
77. Discriminator
78. Synchronization, consolidation

79-80. Not used

81. Conversion, amplification
82. Signal commutator
83. Polarizer
84. Amplifier, analyzer
85. . channels
86. MSU-M scanner
87. MSU-S scanner
88. Solar radiation opticomechanical unit
89. Superhigh-frequency radiometer antennas
90. Superhigh-frequency polarimeter antenna
91. Infrared radiometer scanner

The aspirations for the realization of such diversified experiments with a single spacecraft made it necessary to solve both electrical engineering and design problems. In addition to the already mentioned problems of providing a power supply time-programmed control of the instrument complexes' information collection and transmission processes, the electrical engineering problems involved in creating and developing the KA's included the important matter of insuring the electromagnetic compatibility of all the variegated instruments; that is, eliminating interference with each other both by minimizing low-frequency interference in the power circuits and relative to radio (high-frequency) interference in the ether. This was the most acute problem, since the use of highly sensitive instruments to measure signals counted in microvolts and microamperes over quite broad bands of the spectrum was essentially on the borderline of achievability for delicate physical experiments. Engineering solutions were found that made it possible to minimize the interference so much that it had no serious effect on the final outcome of the experiments and, in addition, experience for the future solution of more complicated problems was gained.

An important place in the development of instrument complexes for the "Meteor-Nature" program KA's was given to problems of reliability. It is a well-known fact that the "Meteor" series KA's have on-board electrical and radio systems--power supply, orientation, thermal regulation, monitoring and programmed-command control--and designs that are highly reliable. The principles of reliability used in the creation of the information instruments were basically those used in the "Meteor" program: a unified program for insuring reliability in all stages of the development, manufacturing and ground and flight tests; special, moderated operating modes for the electrical and radio elements; the provision of standby equipment and functional redundancy; the use of thermally stabilized tests and other methods. In most cases this produced good results or laid the foundation for the creation of highly reliable second-generation information instruments.

Design. Significant complexities in the creation of the "Meteor-Nature" program KA's were caused by the problems involved in placing and insuring the normal capability to function of the instrument complexes within the framework of the available structural means. An idea of the principles behind the layout of the instruments in these KA's can be gotten from Figure 2, which shows the structural configuration of the instruments, as well as from the photograph (Figure 3 [not included]) of a model of one of them. The following principles were realized in the solution of the structural layout problems:

for the purpose of insuring the maximum coincidence of the KA's optical axes as a whole, as determined by its orientation sensors (the local vertical plotting device), with the optical axes of the instruments, which require precise orientation on the Earth, the latter were placed on a single instrument platform, in connection with which the accuracy and dynamic rigidity of the platform is insured by structural and technological decisions; the platform is standardized to a considerable degree, which makes it possible to place different instruments on it;

most of the instruments' sensitive elements were placed outside the KA's sealed body, which made it possible to avoid the use of windows, which lower the overall useful signal level and distort its spectral composition; the instruments have their own microatmosphere (microclimate); the electronic and electrical units and assemblies, which were not designed for use in open space, were put together in the form of sealed, monolithic units;

instruments that were particularly sensitive to vibrations and linear overloads arising during the active part of injection into orbit or to structural noises (vibroaccelerations) arising during the rotation of inadequately balanced dynamic masses inside the KA, were mounted on special shock absorbers; when it was necessary to preserve high geometric accuracy, the entire instrument platform holding the sensors was mounted on shock absorbers.

Particular difficulties were encountered when the attempt was made to combine the rigid dimensional limitations in the placement of a multi-instrument complex with the need for providing variegated, nonintersecting (in three-dimensional space) fields of view for the information instruments and the rather broad radiation patterns of the several antennas of the radio transmitting systems. At the same time, for the purpose of increasing reliability, the problem of getting rid of any overlapping mechanisms and the use of stationary antennas was solved.

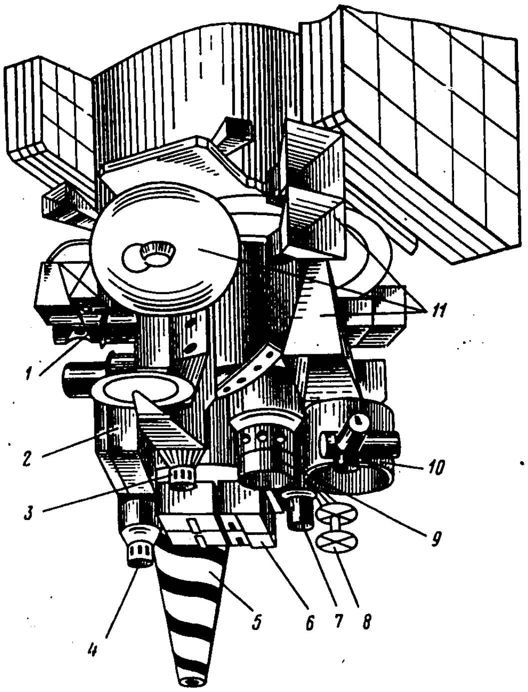

Figure 2. Structural diagram of instrument placement: 1. infrared equipment; 2. A-019 unit; 3. local vertical plotting device; 4. experimental model of local vertical plotting device; 5. combined conical antenna; 6. RTVK complex; 7. radiation measuring complex; 8. decimeter band antenna; 9. radiation measuring complex unit; 10. solar radiation equipment; 11. superhigh-frequency equipment.

The information instruments' ability to function and the quantitative and qualitative characteristics of the remote sounding information received from a KA are largely determined by the degree of adherence to the assigned thermal mode stability for each separate instrument. On the basis of constancy of the object's orientation on the Earth and the stable, cyclic nature of its orientation on the Sun, as determined by the synchronous solar orbit, in order to solve the problems of heat exchange among geometrically complex systems of instruments located outside the sealed compartment, with due consideration for their mutual and variable shading effect on each other, standard calculation methods were developed that also allowed for the actual planned programs for turning on one piece of equipment or another during an orbit, as well as that equipment's own internal heat generation. Calculations made on the basis of averaged heat flows made it possible to evaluate the average-mass quasistationary temperature, which was then used to select the thermal stabilization methods. In addition to this, the developers were given design recommendations that had as their purpose insuring the stability of the instruments' (photoreceiver, bolometer and so on) sensitive elements within several degrees. In order to allow for degradation of the thermal-regulation coatings' (TRP) optical qualities, which is an important element in insuring the thermal regime's stability, for the first time in the USSR a special scientific research project to study the effect of space factors on TRP properties was carried out with several "Meteor" KA's [6]. The quantitative and qualitative properties of almost all the coatings in use were studied during an extended spaceflight (up to 3-4 years). The results of the research were taken into consideration when designing the thermal regulation systems for "Meteor-Nature" program KA's and were the basis for the creation of coatings with better radiation stability.

As a result of the work that was done, it became possible to create thermal regime support systems for KA instrument complexes that are notable for their structural simplicity and reliability during extended operating periods. They include: radiators with TRP's of the solar reflector type; electric heaters with automatic or command-regulated power levels for equalizing the temperature fields for a piece of equipment; vacuum-screen thermal insulation that reduces the unevenness of the effect of heat exchange with the external medium.

These systems, which have been tested in many flight experiments, provide the instruments with the required temperature conditions.

Ballistic Plotting for the "Meteor-Nature" Space System. One essential problem was insuring the proper ballistic plotting of the space system for studying the Earth's natural resources and maintaining the stability of the orbits selected and realized for remote sounding KA's. As is known, the most suitable orbits for such KA's are solar-synchronous or geosynchronous ones, in which a KA passes over the same latitudes at the same local solar time, so that there is an almost constant degree of illumination, which makes it possible to compare changes in the reflective characteristics of natural formations.

For IPRZ [study of the Earth's natural resources] KA's it is advantageous to use 0900-1100 hours local time for observations, since in connection with this--in the first place--there is good illumination in the images obtained, as well as sufficient contrast because of shadows and--in the second place--as a rule the cloud cover over the regions being observed is minimal at that time and observation efficiency is increased. In such orbits there is also no loss of television information related to low angles of Sun altitude above the horizon, which does occur when orbits of other types are used.

The realization of a solar-synchronous orbit for Soviet spacecraft was achieved for the first time during the launch of a "Meteor-Nature" program KA in July 1977.

In paying tribute to the specialists in rocket technology who successfully solved this problem, which was a new one for the USSR, it is necessary to mention that the universal principles used in the "Meteor" KA's design and structure made it possible to inject it into orbit and provide it with a normal, long-term ability to function with practically no design changes. Only elements in the orientation system and the KA's control-program unit had to be reworked, the reason for this being the change in the altitude of the orbit.

In addition to the solar-synchronous nature of the orbit, for a remote-sounding KA it is necessary that the orbit's parameters correspond to several other requirements. It is desirable that the orbit be close to circular, so that the images obtained have identical scales and minimal geometric distortions, which makes it easier to interpret them and compile measurement results. Since remote-sounding KA's (particularly those used to make operational observations) are also used to track the dynamics of natural formations, it is necessary that the KA orbits be repeated;

that is, the satellite's route over the Earth must be repeated after a whole number of days. If there are several satellites instead of just one in the space system, in order to insure effective viewing of the Earth and operational communications between the KA's and the ground information reception points, the parameters of the spacecraft' orbits must be correlated with each other in a certain manner. In order to satisfy this entire complex of requirements, it is necessary to observe (with quite high accuracy) the calculated values of the orbital inclinations, eccentricities and period, not only after injection of the KA's into orbit, but throughout the entire period of their active existence.

Almost all modern launch vehicles used to inject KA's into orbit have limited accuracy; that is, the parameters of the initial orbits have significant limits of the possible deviations from the calculated values. For example, the American "Atlas-E" launch vehicle injects a "Tiros-N" KA into an orbit with an average altitude dispersion of 37 km (for a nominal altitude of 830 km), a difference between perigee and apogee altitudes of 56 km, and period deviations of up to 1 minute. Because of the effect of various factors, after a KA is injected into orbit, the latter's parameters are subjected to significant period and constant changes, the effect of which quickly disrupts the necessary relationships between the orbital parameters of different KA's.

The stability of remote-sounding space systems is maintained by the use of correcting propulsion systems (KDU) that carry out the initial orbital correction (that is, correct the errors made when the launch vehicle injects a KA into its initial orbit) and make periodic corrections to compensate for perturbations that accumulate during the KA flight process.

At the present time, so-called electric reaction engines (ERD) are the ones most widely used. ERD's of different types use the principle of acceleration and discharge of a gas that is ionized and heated to a high temperature (is in a plasma state), through the use of an electromagnetic or electrostatic field. In ERD's the gas ions pass through accelerators and acquire velocities on the order of tens of kilometers per second, whereas in the most modern oxygen-hydrogen rocket engines the maximum discharge velocity is 4-5 km/s. Because of the high discharge velocity an ERD consumes 5-10 times less fuel to generate the same amount of thrust, thanks to which there is a sharp reduction in the required fuel reserve for the KA and, consequently, the overall weight of the entire installation. Thus, for protracted service periods, the use of an ERD is more profitable than the use of a micro-ZhRD [liquid propellant rocket engine].

One of the important results of the "Meteor-Nature" program was the successful experiments for the flight testing of electric reaction engines and the development of orbit correction techniques [7,8]. The experiments were initially conducted with several types of ERD's built in the USSR under the scientific leadership of Academician L.A. Artsimovich, after which a stationary plasma engine (SPD) was selected for further development because of a number of its indicators. The engines had an average thrust of 2-2.5 g. In the flight testing stage (1973-1975) the fundamental questions of the ability of such engines to function in space and their reliability and stability of thrust were answered, their electromagnetic compatibility with a satellite's electrical and radio systems was investigated, and test corrections of KA orbits were made, during which the possibilities of a significant reduction in orbital eccentricity and the maintenance of orbital stability were confirmed. During the next stage, a technique was created and worked out for making optimal (with respect to time and energy consumption) corrections for the purpose of establishing repeated orbits (a repeated solar-synchronous orbit with a 5-day repetition period was established in one of the experiments), in connection with which the developers determined the optimum strategy for alternating active periods when the KDU's were turned on and passive ones when orbital measurements were being made.

A matter of considerable interest for the solution of remote sounding problems is the establishment of not simply a repeated orbit, but one for which the KA passes over a certain region with a given periodicity. An example of this would be a test (measuring) range where simultaneous subsatellite (airborne and ground) observations are made for the purpose of developing unified techniques for interpreting space information. The technique for the solution of this problem was worked out during an experiment with one of the "Meteor-Nature" KA's, with the accuracy of track guidance over the required region being 5-10 km for a daily repetition period.

Basic Results of the Realization of the "Meteor-Nature" Program. The following scientific and technical problems were solved for the first time in Soviet practice during the implementation of this program.

1. A first-generation experimental-operational space system for studying the Earth's natural resources was created on the basis of obtaining, processing and using medium- and low-resolution multispectral television information for the benefit of geology, hydrology, the maritime fleet, forest management, hydrometeorology and other branches of the national economy. The system produces a significant annual economic effect.

2. The obtaining of a solar-synchronous orbit for remote-sounding spacecraft was mastered.

3. The design and on-board control complex of a "Meteor"-series KA was used as the basis for the creation of a specialized first-generation "Meteor-Nature" spacecraft for studying the Earth's natural resources; structural-component principles of instrument platforms for a complex of remote sounding instruments were developed and realized in monolithic block and unsealed versions; problems connected with electromagnetic compatibility and providing the proper thermal modes for multi-instrument complexes were solved; experience was accumulated for the further improvement of KA's for studying the Earth's natural resources.

4. Methods for the visual interpretation of medium- and low-resolution, multispectral, wide-angle, television images for the benefit of the branches of the national economy mentioned above were developed and introduced into operational practice and methodical work on expanding the sphere of utilization of the incoming information is being done.

5. Integrated scientific research and experimental design work has been done on the creation and development, under spaceflight conditions, of various experimental instruments for the remote sounding of the Earth and its atmosphere in the visible, infrared and superhigh-frequency bands and the experimental interpretation of the information obtained; scientific, technical and design experience for the creation of improved remote sounding instruments of an operational nature has been gained.

6. An optimum technique has been created and developed for correcting a spacecraft's trajectory with the help of low-thrust electric reaction engines for the purpose of obtaining repeated orbits and guiding KA tracks over experimental natural-resource-study ranges during subsatellite experiments.

BIBLIOGRAPHY

1. Selivanov, A.S., Tuchin, Yu.M., et al., "A Radio and Television Complex for Experimental Satellites for Observations of the Cloud Cover and the Earth's Surface," in "Kosmicheskaya geofizika" [Space Geophysics], Leningrad, Izdatel'stvo Gidrometeoizdat, 1978, pp 3-10.

2. Vetlov, I.P., "The 'Meteor' Space System at the Service of Hydrometeorology," ISSLEDOVANIYA ZEMLI IZ KOSMOSA, No 2, 1980, pp 11-28.

3. Gurvich, A.S., Yegorov, S.T., and Kutuza, B.G., "Radiophysical Methods of Sounding the Atmosphere and the Ocean's Surface From Space," ISSLEDOVANIYE ZEMLI IZ KOSMOSA, No 1, 1981, pp 63-69.

4. Vlasov, A.A., Yegorov, S.T., and Plyushchev, V.A., "Comparative Analysis of Radiothermal and Infrared Images Obtained With Artificial Earth Satellites," ISSLEDOVANIYE ZEMLI IZ KOSMOSA, No 1, 1981, pp 43-47.

5. Kirillov, A.B., and Borisov, O.M., "An Experiment in Space Geological Map Comparison on the Basis of the Interpretation of Television Photographs Taken by a 'Meteor' Artificial Earth Satellite," ISSLEDOVANIYA ZEMLI IZ KOSMOSA, No 4, 1980, pp 25-30.

6. "Distantsionnoye zondirovaniya atmosfery so sputnika 'Meteor'" [Remote Sounding of the Atmosphere From a "Meteor" Satellite, collection of works], Leningrad, Izdatel'stvo Gidrometeoizdat, 1979.

7. Artsimovich, L.A., Andronov, I.M., Trifonov, Yu.V., et al., "Development of the Stationary Plasma Engine (SPD) and Its Tests in a 'Meteor' Artificial Earth Satellite," KOSMICHESKIYE ISSLEDOVANIYA, Vol 12, No 3, 1974, pp 451-468.

8. Andronov, I.M., Trifonov, Yu.V., Taynov, Yu.F., et al., "Electric Reaction Propulsion Systems in Space," KOSMICHESKIYE ISSLEDOVANIYA, Vol 12, No 3, 1974, pp 447-450.

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UDC 502.3:629.78

TECHNICAL EQUIPMENT COMPLEX FOR EXPERIMENT IN REMOTE SENSING OF EARTH FROM SPACE

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 29 May 81) pp 21-27

[Article by Yu.V. Trifonov]

[Text] Intensive work is being done in the Soviet Union on the development and improvement of space facilities for obtaining operational information for the investigation of the Earth's natural resources. In [1] there is a brief description of the content and basic results of the work that has been done to create an experimental-operational space system for IPRZ [investigation of the Earth's natural resources] that has received the title "Meteor-Nature." With respect to both the information instruments and the basic "Meteor" spacecraft used to carry them in space, this system belongs in the category of first-generation space facilities. The information equipment used in the system to obtain multispectral television information does not have measuring capabilities, the interpretation of the information is by visual methods and, in addition, the resolving power of the equipment is inadequate for extensive utilization in agriculture, the fishing industry and several other branches, although it does insure the solution of a number of important national economic problems.

As is known, in the USSR we are planning the creation of a permanently operating space system for the investigation of natural resources, part of which will be an operational subsystem for studying the Earth in order to obtain information on the characteristics of rapidly changing components of the environment. As the basic instruments (the information from which will be transmitted to Earth over radio channels) for studying the Earth's surface, it has been proposed that we use two multizonal, opticomechanical scanning devices: a high-resolution one, with local scanning resolution of 50 m in the visible band and 200 m in the infrared band and a field of view of 180-200 km for 8 spectral zones in the 0.4-12.5 μm spectral band, and a medium-resolution one, with local scanning resolution of 150-200 m in the visible band and 500-600 m in the infrared band and a field of view of 500-700 km for 4 spectral zones in the 0.4-12.5 μm band. The viewing periodicity along the equator for a single spacecraft with this operational subsystem will be 14-17 days when the high-resolution multizonal scanning unit is used and 4-5 days with the medium-resolution one.

Starting in 1980 and continuing this year, an integrated experiment is being conducted for the purposes of testing and developing, under real conditions, new information-measuring equipment for obtaining high- and medium-resolution multizonal space information and working out the methodological problems involved in deciphering and interpreting measured space information for studying the Earth. In this experiment there is a capability for realizing simultaneous surveying of the Earth's surface, with different types of scanning devices, in 10 subbands of the spectrum from 0.4 to 2.4 μm, with 30-800 m resolution and fields of view ranging from 30 to 2,000 km. Detailed descriptions of the information equipment and the goals of the experiment were published in [2].

The most important goal of the experiment is the further development of the structural configuration, design and reliability of the improved spacecraft that is the carrier of a unique complex of remote sounding instruments.

Composition of the Information Equipment for the Integrated Experiment. The experiment is being conducted with three complexes of on-board and ground information equipment that is used to observe the Earth's surface in the interests of investigating the Earth's natural resources. On the spacecraft that was launched into a solar-synchronous orbit with an average altitude of 634 km on 18 June 1980, there is the following equipment:

1. A BIK-E experimental on-board information complex that consists of:
an MSU-SK medium-resolution multizonal scanning unit with a tapered opticomechanical scanner;
an MSU-E high-resolution multizonal scanning unit with electronic scanning, which unit was realized on the basis of charge-coupled (PZS) receivers;
an information conversion and multiplexing unit;
a digital radio transmission unit operating in the 460-470 MHz band.

2. A "Fragment" experimental multizonal system, consisting of:
an opticomechanical scanning unit with calibration devices;
a system of photoreceivers with a fiber-optics collector;
an analog-to-digital converter;
synchronization, commutation and multiplexing devices;
a digital radio transmission unit operating in the 1,000 MHz band.

The "Fragment" system measures the spectral energy brightnesses of natural formations in eight spectral bands with differing degrees of accuracy, using on-board calibrating and standard light sources during the measurements.

3. An operational radio and television complex (RTVK) with characteristics described in [3].

Figure 1 is a block diagram of the on-board and ground information complexes used in the experiment.

It should be mentioned here that there are some limitations, related to the utilization of a single radio band (460-470 MHz) and a single "Fobos" ground antenna as well as the amount of information produced by the separate scanning devices, on the simultaneous transmission of information from the RTVK and BIK-E complexes. Since the maximum amount of information that can be carried by a radio link on this band is 8 Mbit/s, at any moment it is possible to transmit information from only one of the four (MSU-M, MSU-S, MSU-SK, MSU-E) scanning units, which is reflected in the

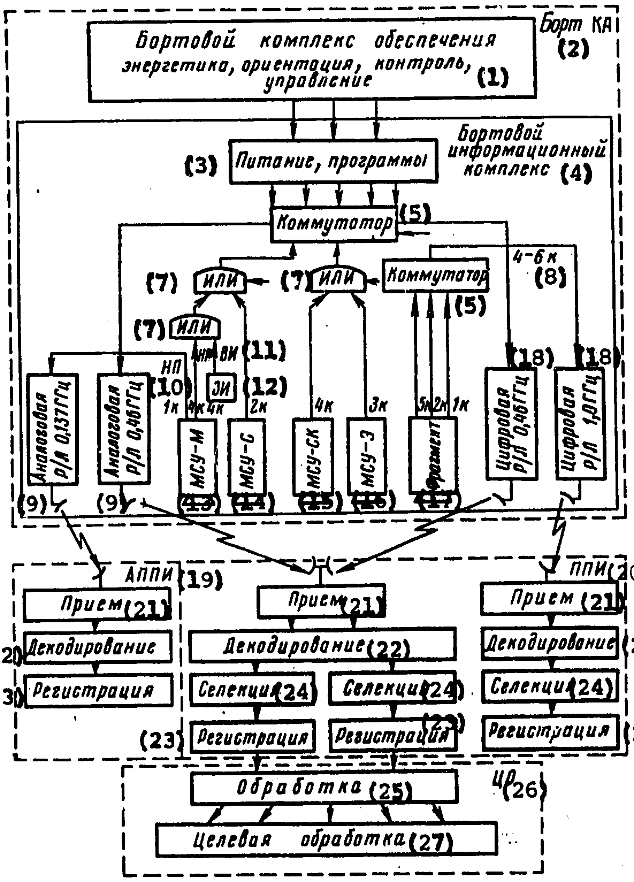

Figure 1. Block diagram of the experiment.

Key:
1. On-board power engineering, orientation, monitoring and control complex
2. On board the spacecraft
3. Power, programs
4. On-board information complex
5. Commutator
6. Not used
7. "OR"
8. ... channels
9. Analog radio link, ... GHz
10. Observation instruments
11. Auxiliary instruments
12. ZI [expansion unknown]
13. MSU-M
14. MSU-S
15. MSU-SK
16. MSU-E
17. "Fragment"
18. Digital radio link, ... GHz
19. Analog information reception point
20. Information reception point
21. Reception
22. Decoding
23. Recording
24. Selection
25. Processing
26. Central section
27. Purposeful processing

diagram in Figure 1 by the "OR" logic elements. The transmission of information from the "Fragment" system takes place independently of the BIK-E and RTVK systems

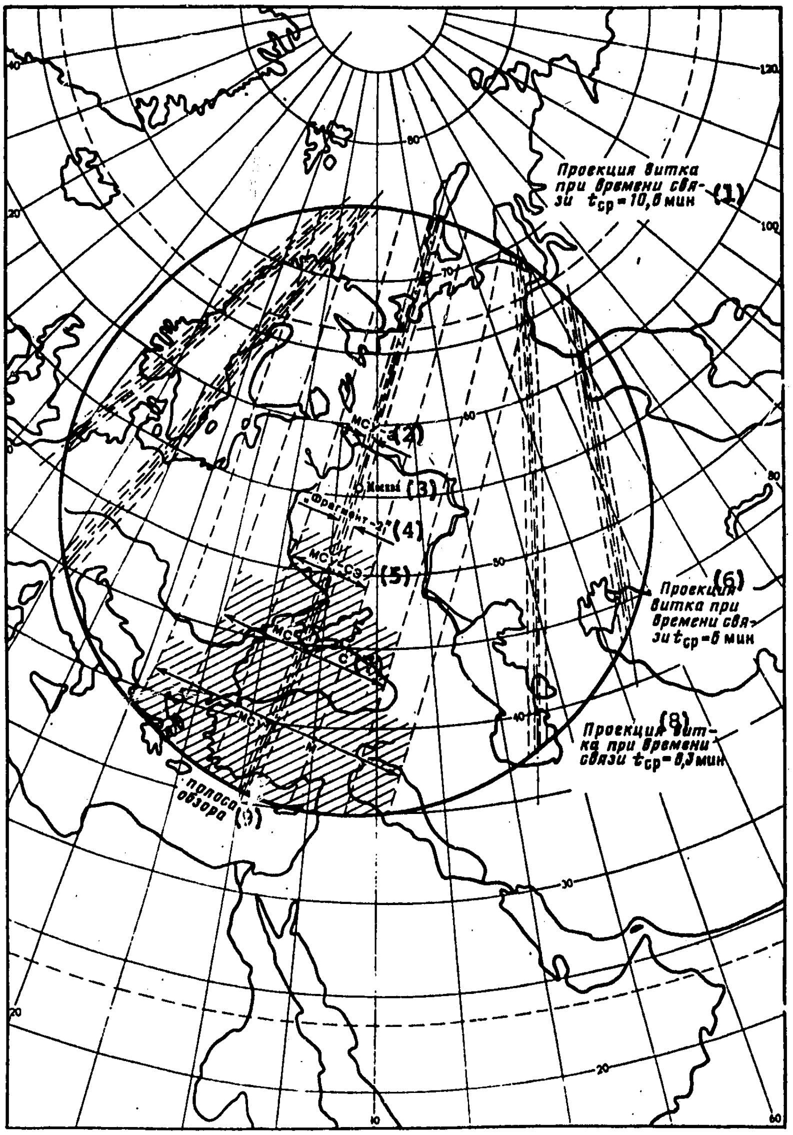

Figure 2. Field of view of information equipment in the experiment.

Key:

1. Projection of orbit during communition time, t_{ave} = 10.6 min
2. MSU-E
3. Moscow
4. "Fragment-2"
5. MSU-SE
6. Projection of orbit during communication time, t_{ave} = 6 min
7. MSU-S
8. Projection of orbit during communication time, t_{ave} = 8.3 min
9. Field of view

and is carried out over from four to six of the eight available channels. Selection of the simultaneously operating scanners and a comparative analysis of the images and measurements obtained for the same region of the Earth were two of the basic goals of the experiment.

Information is sent from the BIK-E complex over a digital radio link to the Goskomgidromet [USSR State Committee for Hydrometeorological Services] reception point in Obninsk, where the RTVK information is also received. It is then sent to GosNITsIPR [State Scientific-Research Center for Study of Natural Resources] for primary processing. Information from the "Fragment" system is transmitted over a digital radio link to an MEI [Moscow Power Engineering Institute] OKB [Experimental or Special Design Office] reception point and is processed at the USSR Academy of Sciences' IKI [Institute of Space Research] and GosNITsIPR.

Figure 2 shows the disposition of the fields of view on the Earth for all the instruments used in the on-board information complex during the experiment, together with the radio visibility zones for the points receiving information from the BIK-E, "Fragment" and the RTVK.

Features of the Design and Structural Formulation of the Spacecraft. The basic spacecraft used in the experiment was a second-generation "Meteor-2" KA [spacecraft], which is distinguished from a "Meteor" KA by the following basic qualities:
increased accuracy of triaxial orientation and stabilization of the angular velocities, which makes it possible to use information instruments with opticomechanical scanning and local resolution of up to 80 m, as well as an enlarged energy supply system capacity;
expanded capabilities for automatic time-programmed control of the processes of obtaining and transmitting information, including control over the light conditions and sensitivity levels of the measuring equipment;
additional structural configuration and weight-and-size capabilities, which made it possible to install a multiband instrument complex and several information radio links;
a general-purpose automatic-testing system and technique, utilizing the control computer's hardware and software, which made it possible to carry out ground checks of the KA's additional instrument information complexes with a high degree of reliability and to insure (along with other methods) their reliable operation in orbit.

Along with the solution of a considerable number of experimental problems, the use of the improved spacecraft made it possible to continue operating the RTVK, which is the basic source of low- and medium-resolution multizonal information in the "Meteor-Nature" program [1].

Figure 3 is a structural diagram of the placement of the information complexes on the spacecraft. The complex of remote-sounding instruments was laid out in accordance with the basic principles formulated in [1], although there are also a number of interesting features.

The specially developed load-bearing housing of the "Fragment" equipment was used as the structural foundation for the placement of the information measuring instruments and orientation system sensors, as well as the antenna complex. This made it possible, on the one hand, to achieve the required geometric accuracy of coincidence of the instruments' optical axes and, on the other hand, to make do without a special instrument platform; this, in turn, improved the KA's weight and size characteristics. The ratio of the information instruments' mass to that of the entire satellite

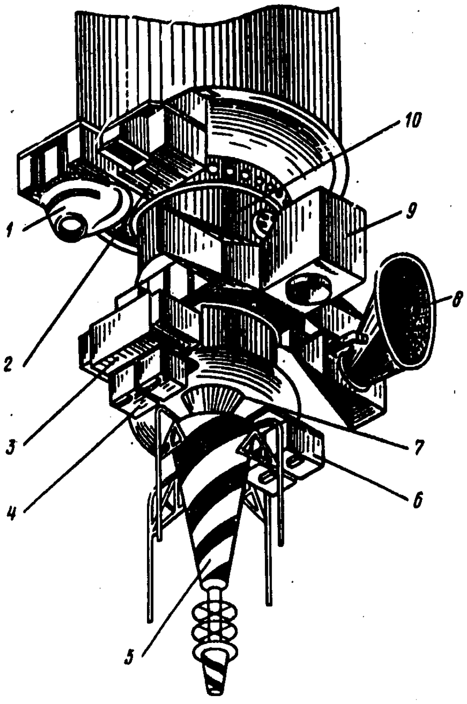

Figure 3. Structural diagram of spacecraft's instrument complex: 1. experimental medium-resolution scanning unit; 2. experimental scanner based on PZS structures; 3. monoblock containing automatic equipment for information complex; 4. low-resolution RTVK scanner; 5. antenna-feed complex; 6. medium-resolution RTVK scanner; 7. local vertical plotting device; 8. radiant refrigerating unit; 9. "Fragment" television complex; 10. gas-reaction damping system compartment.

is more than 0.30, which is a very good indicator for such KA's. It is necessary to mention here that all the information complex instruments are not airtight.

Among the nontrivial design solutions that were found during the creation of this satellite is the combination into a single structural module of a large number (up to six) antenna systems operating on different wavelengths. This module (see Figure 3) is mounted along the spacecraft's longitudinal axis under the infrared local vertical plotting device (PMV). Since the working field of view of the PMV is a wide-angled cone with a narrow field of vision bearing on the edge of the Earth's visible disk (the infrared horizon), the inner space of this cone (its "dead" zone with the axis pointing at the center of the Earth) was used for the placement of the unified antenna module and its radiation patterns. The stiffening ribs that encompass the PMV's protective germanium fairing were used to attach the antenna module to the satellite's instrument compartment and for the passage of the feeder devices. Special measures were implemented concerning the thermal regulation of the antenna module's supporting structure in order to prevent uneven heating of it and the addition of interference to the PMV's input signals, along with measures to protect the PMV from the antenna module's radio emissions. The KA's successful operation in orbit with the antenna module in this location demonstrated this design's viability and the possibility of its further use.

Projects for the thermal regulation of the information instruments received further development. As is known, when instruments are mounted outside the sealed compartment, there arise difficulties in providing the required thermal conditions for the measuring information instruments. This is related to the fact that in the absence of a gaseous medium in and between the instruments, the possibility of utilizing forced convection and the gas's thermal conductivity to equalize the temperatures of the instruments' elements and the satellite's structural parts is eliminated. The thermal conductivity of the elements of the instruments' and satellite's parts, as well as radiation, play the main role in these processes. The integrated utilization of special thermal regulation coatings and flat electric heaters and radiators, the creation of special structural bridges for overflowing heat along the structural elements, and the use of a technique for making thermal calculations for each instrument separately and as a part of the whole that was worked out and tested experimentally made it possible to solve successfully the complicated problem of providing the given, quite variegated and narrow ranges of required information instrument temperatures.

In order to create the optimum sensitivity and detection capability regimes for the straightedges of the PZS-structures used in the MSU-E instrument, it was necessary to cool them to a temperature of -40°C. This was achieved with the help of a cooling screen mounted on the shaded side of the spacecraft's body and a specially designed heat pipe, the other end of which was installed directly in the photoreceiver assembly of the MSU-E instrument. The temperature gradient in the heat pipe, which is about 1.5 m long, did not exceed 4-5°, and the required cooling of the photoreceiver was insured. The "Fragment" complex's photoreceivers were also cooled to the required temperatures with the help of radiators.

Considerable difficulties were overcome in minimizing interference and other kinds of noise in the KA's on-board network and insuring the equipment's electromagnetic compatibility, particularly in the area of eliminating pulsations in the satellite's on-board network caused by variable-sign dynamic loads occurring during swinging of the "Fragment" equipment's receiving mirror, which has considerable mass. In addition to this, the introduction of additional radio links and the use of collocated antennas also required the introduction of filters, screens and other shielding measures. As a result, interference of the large complex of variegated radio instruments with each other was practically eliminated and did not affect the quality of the video information that was obtained.

Preliminary Results of the Experiment. The new integrated space experiment in remote sounding has been functioning for more than a year. The spacecraft as a whole and most of the information complex instruments have retained their ability to function and are gathering and transmitting to Earth multizonal information about our planet's underlying surface. Elsewhere in this issue there are detailed explanations of the results of the operation of the information complexes and the processing and interpretation of the information both for the benefit of the planning and design organizations that created the satellite and the scientific equipment and for the direct benefit of consumers in different branches of the national economy. The experiment is going well and is making it possible to obtain valuable scientific and practical data for improving information gathering and processing equipment for the purpose of the further development of remote sounding methods.

BIBLIOGRAPHY

1. Trifonov, Yu.V., "'Meteor'-Series Satellites Used to Study the Earth From Space," this issue, pp 8-20.

2. "A New Experiment in Investigating the Earth From Space," ISSLEDOVANIYA ZEMLI IZ KOSMOSA, No 1, 1981, pp 5-6.

3. Selivanov, A.S., Tuchin, Yu.M., et al., "A Radio and Television Complex for Experimental Satellites for Observations of the Cloud Cover and the Earth's Surface," in "Kosmicheskaya geofizika" [Space Geophysics], Leningrad, Izdatel'stvo Gidrometeoizdat, 1978, pp 3-10.

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CSO: 1866/18

UDC 551.507.362

RADIO AND TELEVISION COMPLEX FOR 'METEOR' SATELLITES USED TO INVESTIGATE EARTH'S NATURAL RESOURCES

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 22 May 81) pp 28-34

[Article by A.S. Selivanov and Yu.M. Tuchin]

[Text] The diversity of the problems and methods involved in studying the Earth from space requires the creation and optimum utilization durings surveys of the Earth's surface from a satellite of several types of television equipment that are differentiated by such parameters as the scale of the image that is produced, local resolution, the number of spectral channels, and the operational nature of the obtaining of the information [1].

The basic advantage of space surveying methods consists of their global nature, which makes it possible to obtain images of large sections of the Earth's surface at the same time and under the same transmission and recording conditions. Therefore, along with television systems analogous to those used in the "Landsat" artificial Earth satellite [2], which have resolution of about 80 m and a viewing field of 185 km and have proven their effectiveness, it is also feasible to use systems with lower resolution but a considerably larger viewing field.

A prototype of such systems is the complex of equipment for meteorological satellites, which--as was already mentioned long ago--can produce information that is useful for more than meteorological purposes [3]. Nevertheless, however, the quality of meteorological television systems is still inadequate for their extensive use in the investigation of natural resources (IPR). It is necessary to improve their sensitivity and resolution and enlarge the number of spectral channels available, thereby expanding the circle of problems that can be solved with their help not only in meteorological, but also in other scientific and national economic branches.

A complex of instruments that was developed in order to investigate the possibilities of this type of equipment has been installed in experimental satellites created on the basis of "Meteor"-type satellites [4]. The first satellite carrying this equipment was launched on 9 July 1974, and the effectiveness of its utilization was confirmed. Four more satellites in this series were then built. They have enabled us to provide the conditions for the experimental operation of an operational system for IPR and schedule regular dissemination of the obtained information among many consumers [5]. At the present time two of these satellites, which were injected into orbit on 25 January 1979 and 18 June 1980, are functioning. The latter one is essentially a satellite of a new generation, because an experimental system with better characteristics has been installed in it along with the regular equipment that is described in this article.

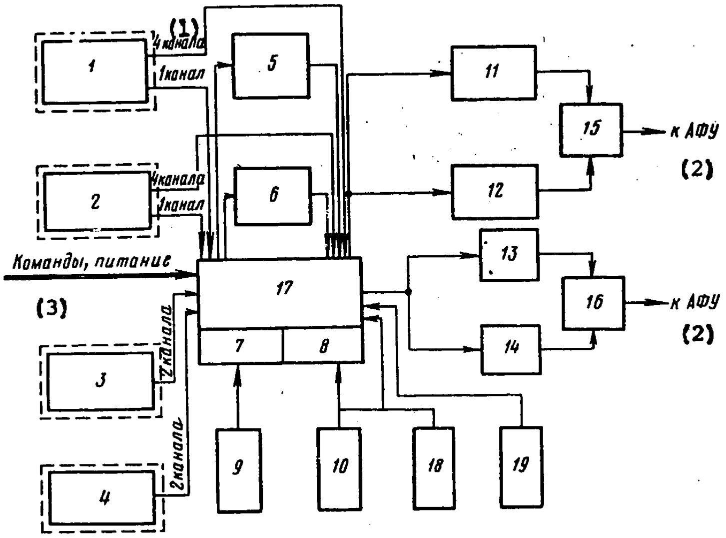

Figure 1. Functional block diagram of radio and television complex.

Key:
1. . channels
2. To antenna feed
3. Commands, power

On-Board Radio Equipment. Part of the satellite's regular equipment consists of a duplicated complex of instruments (Figure 1): an MSU-M low-resolution, quadrizonal, opticomechanical scanner (1, 2); an MSU-S medium-resolution, bizonal, opticomechanical scanner (3, 4); magnetic recording units (5, 6); timers (7, 8); driving oscillators (9, 10); decimeter band transmitters (11, 12); meter band transmitters (13, 14); antenna switches (15, 16); links with the satellite's antenna feed (AFU). The control system is a block of automatic equipment (17) and, in addition, there is a unit for displaying on-board time (18, 19).

Synchronous driving of the scanners in both types of instruments is achieved with signals formulated in a timer (7, 8), where the fundamental frequencies for the other instruments in the complex are also formed. The master frequency of a highly stable quartz oscillator (9, 10) operates the timer.

The communication channel consolidation operations are carried out in the timer at the same time. Information is transferred from several spectral channels into a single communication channel according to the principle of temporal consolidation, which is realized here by the switching of channels and the formation of a pulse-amplitude modulated sequence of signals.

All four channels of the MSU-M instrument can be transmitted directly into the basic decimeter communication channel. In connection with this, the switching frequency is several times greater than the maximum video signal frequency, so signal conversion does not affect the clarity of the image.

From the MSU-S instrument it is possible to transmit only one channel, or two with interlaced switching. In the latter case the clarity of the image in the direction of the flight is halved, but at the same time is equalized with the clarity along the line. For ground system synchronization, a pilot signal that is added to the basic signal is transmitted over the single channel.

The memory units (5, 6) in the later satellites provide for the recording and reproduction of four spectral channels for each instrument. The recording and reproduction times are identical and are 6 minutes in the 5 kHz band for each channel.

The display device (18, 19) makes it possible to produce a number of operational telemetric parameters on a photograph from the MSU-M, as well as on-board time (in minutes) and a gradation key, which is used to monitor the channel's linearity and the photograph processing operation.

Thus, a pulse-amplitude modulated signal in the direct transmission mode or in the reading mode with the memory unit (ZU) arrives at the input of one of the transmitters (11, 12), which is operating in the international 460-470 MHz band in the frequency modulation mode. The magnitude of the deviation is ±160 kHz. The transmitter's power is about 5 W.

In addition to the decimeter-band radio link, the system has meter-band radio link (13, 14) that also operates on an international band (about 137 MHz) and is used to transmit one of the spectral channels (selectable) with reduced clarity (3 km) to simplified, autonomous Goskomgidromet [USSR State Committee for Hydrometeorological Services] reception points and many analogous foreign points. Video information is transmitted over the meter-band radio link according to the generally accepted phototelegraphy standard. The rated value of the subcarrier is 2.4 kHz with a frequency deviation of 9.6 kHz [sic]. The maximum scope of the amplitude-modulated (AM) signal corresponds to the level of white in the image. The weight of the complex is 60 kg.

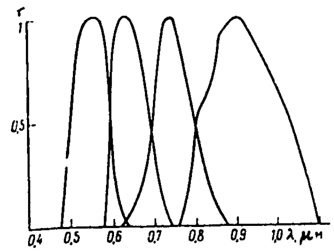

Figure 2. Spectral characteristics of MSU-M.

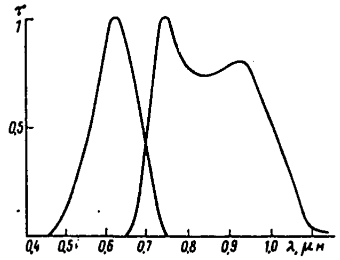

Figure 3. Spectral characteristics of MSU-S.

Opticomechanical Scanners. According to their operating principle, the scanning units (scanners) are opticomechanical systems with single-line scanning and single-element receivers for which frame scanning is accomplished because of the satellite's motion. The MSU-M operates in four spectral bands and the MSU-S in two (Figures 2, 3). The scanners' parameters are given in more detail in Table 1.

In single-line scanners, frame resolution is determined by the ratio of the flight speed to the scanning rate. One special feature of wide-angle scanners with a fixed

Table 1. Scanner Parameters

Parameters	MSU-M	MSU-S
Nominal orbital altitude, km	650	650
Local resolution at the nadir, km:		
along the flight direction	1.7	0.142
along a line	1	0.24
Scanning angle, deg	106	90
Viewing field, km	1,930	1,380
Number of elements in active part of line	1,880	5,700
Service part of line	0.25	0.25
Scanning rate, lines/s	4	48
Number of spectral channels	4	2
Weight with drive, kg	4.5	5.5

instantaneous viewing field is inconstancy of the local resolution along a line, which is caused by prospective distortions and the curvature of the Earth's surface. In the MSU-M, for instance, resolution at the end of a line is almost four times worse than in the center; in the MSU-S, it is 2.5 times worse. In order to equalize frame and line resolution it is advisable to have some excess resolution along a line at the nadir, which has been done in the MSU-M. In the MSU-S, optimum relationships are achieved only for the mode of simultaneous transmission of both channels with switching every other line.

The substantial difference in scanning rates resulted in the necessity of selecting different scanning principles. Scanning is carried out in the MSU-M with the help of a swinging mirror that is driven by a cam mechanism, while in the MSU-S it is done with the help of a rotating mirrored pyramid. In view of the similarity of many elements in the instruments' designs, however, only a single description of them is given below.

The basic element of the image-forming system is an OKS-4-75SA lens with focal length F = 75 mm and an intake aperture diameter of 18.75 mm. In the focal plane of the lens there are diaphragms that form the scanner's instantaneous viewing field in accordance with the required local resolution. The scanners' optical layout is shown in Figure 4.

The flow of radiation, after being reflected from mirror 1 (Figure 4a) or one of the faces of pyramid 1' and mirror 1" (Figure 4b), passes through lens 2 and is directed by mirror 3 into spectrum-splitting mirror 4. The latter reflects the radiation flow in the visible band into diaphragm 5, while infrared radiation passes into diaphragm 6. Having passed through the diaphragm, the flow is collected by lens 7 and, with the help of mirror 8, is directed into a photoelectronic multiplier (FEU). After passing through diaphragm 5 and collecting lens 10, the visible radiation is divided into three zones by interference mirrors 11, 12, 14, 15 and 16 and is directed into FEU's 13, 17 and 18. The MSU-S instrument contains only optical elements for two channels (9, 13) and avalanche photodiodes are used instead of FEU's.

Other parameters of the instruments are presented in Table 2. The width of the spectral channels is given at the 0.5 level with an accuracy of ±0.01 μm. Measured values of the signal-to-noise ratio corresponding to an object of maximum brightness (a reflection factor of unity, with the Sun at the zenith) are given in the table.

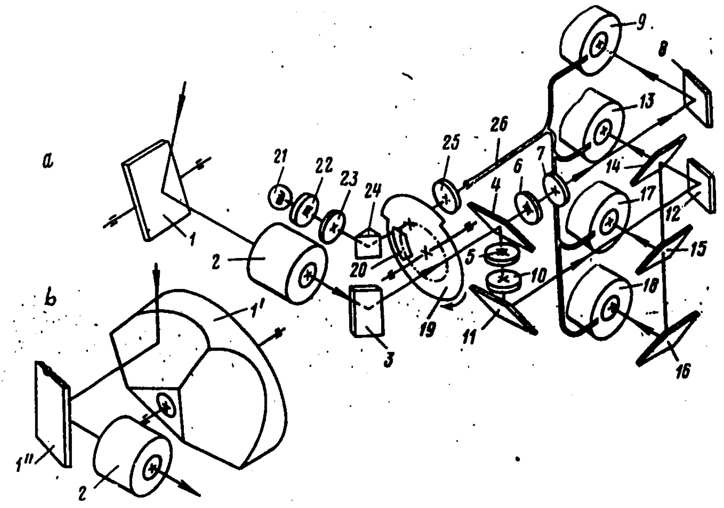

Figure 4. Optical Diagrams of MSU-M (a) and MSU-S (b).

Table 2. Spectral Bands of Scanners

Instrument	Spectral Range, μm	Type of Photoreceiver	Signal-to-Noise Ratio (Average)
MSU-M	0.5 -0.6	FEU114	115
	0.6 -0.7	FEU114	77
	0.7 -0.8	FEU114	53
	0.8 -1.0	FEU112	35
MSU-S	0.58-0.7	Avalanche diode	24
	0.7 -1.0		41

Photometric calibration of the instruments is accomplished by cutting off the basic light flow with the help of a "comb" at obturator 19, in connection with which a light beam reaches the FEU from the calibration channel through port 20, which is closed with an optical wedge. The obturator revolves cophasally with the line scanning. The calibration channel consists of an SMN-10-50 incandescent bulb (21), diaphragm 22, lens 23, rotating prism 24, collecting lens 25 and lightguides 26, which direct the calibration flow to the photoreceivers. A more detailed description of the scanners has already been published [6].

Reception and Utilization of the Information. Above it was mentioned that the "Meteor" satellites' radio and television complex for investigating natural resources, which was initially built as a purely experimental system for working out methods for studying the Earth from space and gaining experience in working in this field in different national economic branches, was put into experimental operation in 1978, after many positive practical results were obtained. At the present time the system is supplying information, on a regular basis, to more than 70 large consumers in different national economic and scientific branches.

The system is operated by Goskomgidromet's services and works on the basis of requests from consumers. The basic flow of information is received by stations located in Moscow, Novosibirsk and Khabarovsk. The highest quality information from the low- and medium-resolution scanners is obtained via the direct transmission mode in the decimeter band. The locations of the receiving points makes it possible to cover the greater part of the Soviet Union's territory by direct transmission, since the assured transmission zone of each point has a radius of about 2,500 km. Observation of the remaining part of the Earth is possible when the low-resolution scanner is used and the signal is recorded in the on-board memory unit. One recording session (6 min) covers a region of about 1,930 x 2,500 km.

Direct transmission of information to simplified reception points, using the meter band, proved to be useful, even as a supplement to the operation of the standard "Meteor" meteorological system. The capability of transmitting an image in one of four narrow spectral zones (by choice) over this line makes it possible to improve the decodability of the photographs in many cases. At the same time, this information can be received anywhere, including remote regions, large ships and so forth. The meter and decimeter radio lines can operate either separately or jointly.

"Meteor" satellites for investigating natural resources are injected into a solar-synchronous orbit with a nominal altitude of 650 km and an inclination of about 98°. In connection with this, constancy of the surface observation conditions is achieved; that is, the satellite always passes over a point at the same local time. At Moscow's latitude the periodicity of observation is 4-5 days, with suitable overlapping of the photographs. At the reception points the information is recorded on magnetic and photographic film. Magnetic recording is used for primary conservation of the images for a short period of time. It is done on "Kadr-3" series-produced videotape recorders operating in the predetector mode (the frequency-modulated signal is entered and read on a subcarrier of 4 MHz).

Photographic recording is done on the standard phototelegraphic equipment that is used for postal exchanges and decentralized newspaper printing. Images produced by the low-resolution scanner are registered, separately for each spectral channel, on photographic film with a 240 x 300 mm format. The photograph format for the medium-resolution scanner is 600 x 480 mm. After duplication, the negatives obtained are sent to the consumers. The originals are placed in archive storage. The system's average productivity is up to 32 low-resolution scanner and 12 medium-resolution scanner negatives per day.

As is obvious, the system is oriented mainly on visual or visual-instrumental deciphering of the photographs, which corresponded to the actual capabilities of the information users in previous years and still, in many cases, corresponds to the present situation, since the methods and technology for utilizing aerial photographic surveying have been well developed in many branches.

The circle of problems involving investigation of the Earth from space that can be solved effectively with the help of the "Meteor" system is predetermined by the characteristics of the instruments used to make the observations, primarily their broad scope (and the low periodicity of observation that emanates from this) in combination with their multizonality and the degree of local resolution selected (up to 240 m). These problems include the following: in hydrology--evaluating the ice situation with the publication of data for the transport and fishing fleets and evaluting the state of the hydrographic network and snow reserves; in oceanography--observing vortex phenomena, internal waves and river discharges; in geology--defining regional geological structures; in forest management--detecting and following the course of forest fires in regions that are hard to reach.

A number of new techniques that will expand the possibilities for the use of this type of information are under development.

BIBLIOGRAPHY

1. Vinogradov, B.V., and Kondrat'yev, K.Ya., "Kosmicheskiye metody zemlevedeniya" [Space Methods for Studying the Earth], Leningrad, Izdatel'stvo Gidrometeoizdat, 1971, pp 8-27.
2. "Data User's Handbook," ERTS, Goddard Space Flight Center, Greenbelt, Maryland, 1972, pp 23-26.
3. Barrer, E.K., "Pogoda iz kosmosa" [Weather From Space], Leningrad, Izdatel'stvo Gidrometeoizdat, 1970, pp 108-121.
4. Aleksandrov, L.A., "Planetary Weather Patrol," IZVESTIYA, 28 September 1977.
5. Vetlov, I.P., "The 'Meteor" Space System at Hydrometeorology's Service," ISSLEDOVANIYA ZEMLI IZ KOSMOSA, No 2, 1980, pp 11-27.
6. Selivanov, A.S., Chemodanov, V.P., Suvorov, B.A., et al., "Opticomechanical Scanners for Observing the Earth," TEKHNIKA KINO I TELEVIDENIYA, No 6, 1978, pp 16-21.

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CSO: 1866/18

UDC 551.507.362

EXPERIMENTAL ON-BOARD INFORMATION COMPLEX FOR OBSERVATION OF THE EARTH

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 22 May 81) pp 35-39

[Article by A.S. Selivanov, Yu.M. Tuchin, M.K. Narayeva and B.I. Nosov]

[Text] The improvement of multizonal equipment for observing the Earth that is used for the investigation of natural resources (IPR) is following the path of improving the measuring capabilities and resolving power of the equipment, as well as the introduction of new information transmission and processing methods.

On the basis of the experience gained in the process of operating the "Meteor"-series satellites' radio and television complex (RTVK) [1] for investigating the Earth's natural resources, the next step in the development of remote sounding facilities was taken, in the form of an experimental on-board information complex (BIK-E) that has qualitatively new parameters and correspondingly broader possibilities for practical use. The purpose of this development project was to test equipment decisions and observation methods for prospective IPR systems.

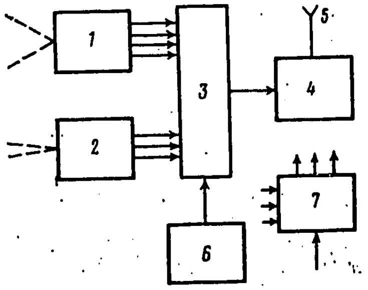

Figure 1. Functional block diagram of on-board information complex.

Practical experience confirmed the advisability of using wide-angle observation equipment in an IPR system. The BIK-E also features a wide-angle, medium-resolution scanning unit having a field of view that is narrower (up to 600 km) than that of earlier designs and, at the same time, has 50 percent better spatial resolution; the number of spectral channels has been increased to four and high light flow measurement accuracy has been achieved.

A three-channel scanning device has been developed for the solution of problems requiring resolution in comparatively small observed sections.

The BIK-E equipment was installed, in addition to the regular RTVK apparatus, in the "Meteor" satellite that was launched on 18 June 1980 [2].

On-Board Equipment. The BIK-E (Figure 1) contains two units for the transmission of spectrozonal images: an MSU-SK medium-resolution opticomechanical scanner with a

Parameters of the Scanning Devices

Parameters	MSU-SK	MSU-E
Scanning belt (km) for flight altitude of 650 km	600	28
Dimensions of projection of field diaphragm (element) of the structure) on the Earth's surface at the nadir, m:		
per line	175	28
per frame	243	28
Scanning angle, deg	66.5	2.5
Angle of inclination of the sighting line, deg	38.9	0
Scanning rate, lines/s	48	218
Scanning efficiency	0.74	0.91
Number of elements in active part of line	3,614	1,000
Number of spectral channels	4	3
Diameter of lens's intake aperture, mm	200	87.5
Weight, kg	47	17

tapered reamer (1) and an MSU-E high-resolution opticoelectronic scanner with a plane reamer (2), the parameters of which are presented in the table above. Signals from these units pass, in successive order, into the block of 8-bit analog-to-digital converters and digital-flow formers (3), the radio transmitter (4) and the satellite's antenna (5). The units in the complex are synchronized by a highly stable reference generator (6). Control of the complex and collection of telemetric parameters from the instruments is carried out by an automatic equipment unit (7). Units 3, 4 and 6 have a cold reserve. All the instruments in the complex operate outside the satellite's sealed compartment.

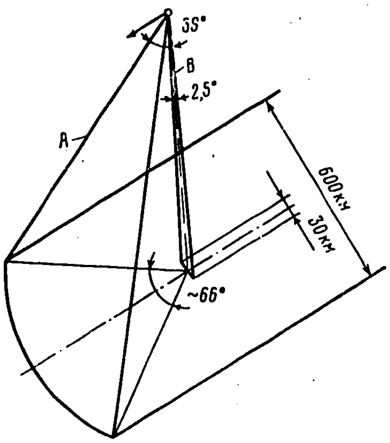

Figure 2. Diagram of coverage of the Earth's surface by the scanning devices: A. MSU-SK instrument; B. MSU-E instrument.

The scanners do not operate simultaneously, but are turned on by commands from Earth. The system's parameters have been selected so that when each of these devices is in operation, the digital flow's information content is 7.68 Mbit/s. Transmission is realized on a carrier frequency of 466.5 MHz by the double relative phase manipulation (DOFM) method. The indicated frequency was chosen on the basis of considerations of maximum utilization of the receiving equipment already existing in Goskomgidromet's [USSR State Committee for Hydrometeorology] system of ground points for the "Meteor" space meteorology system, and makes it possible to observe almost all the USSR's territory in a direct transmission mode. The coverage of the Earth's surface by these scanning devices is illustrated by the diagram in Figure 2.

An increase in the accuracy of light flow measurement requires an increase in the signal-to-noise ratio at a scanner's output, which is achieved by using improved photoreceivers and a necessary increase in the effective diameter of the optical system's outlet opening, which is 200 mm in the case of the MSU-SK. With such a diameter, wide-angle scanning can no longer be realized by traditional methods [3]. A comparative evaluation of the entire set of factors during the creation of the MSU-SK medium-resolution scanner resulted in the use in it of the principle of conical scanning, despite the known difficulties of receiving images transmitted by such devices. An argument of no little importance in favor of conical scanning is the constancy of the geometric and photometric observation conditions and the constancy of line resolution that are intrinsic in it.

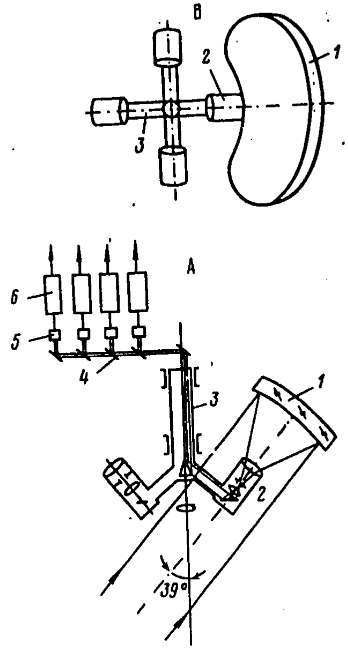

Figure 3. Structural diagram of the MSU-SK.

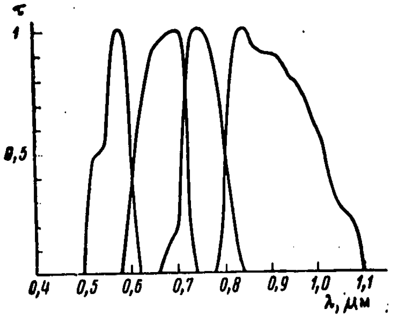

Figure 4. Spectral characteristics of the MSU-SK.

According to a simplified diagram of the MSU-SK (Figure 3), it functions in the following manner: at an angle of 39° to the vertical, radiation from the underlying surface is gathered by spherical mirror 1 and directed to one of the four optical arms 2 that are located on scanning wheel 3, which rotates around a vertical axis. In the optical arm the radiation flow is focused with the help of a number of optical assemblies and a flow corresponding to a single television element is separated from it, directed toward the scanning wheel's axis of rotation, refracted, and then split in spectrum-separation system 4. Photoreceivers 5 convert it into a video signal that, after shaping in amplifiers 6, is sent to the instrument's output.

Four lines of the image are "drawn" during one revolution of the scanning wheel, it being the case that the sighting axis describes a conical surface in space, while its trace on the Earth's surface (a line) is a circular arc with a central angle of about 66°.

Channel calibration is carried out both according to an internal standard and with respect to the Sun. The MSU-SK's spectral characteristics are presented in Figure 4.

The high-resolution multichannel scanning unit (the MSU-E) is constructed on the basis of the principle of using linear radiation receivers based on devices with charge coupline (PZS) with 1,024 elements per line, which is the most promising principle for such devices. Figure 5 depicts the basic principle of the MSU-E's design. With the help of lens 1, the image of the Earth's surface is projected through spectrum separation system 2 onto three PZS straightedges 3, each of which operates in its own spectral band (Figure 6). After leaving the linear photoreceivers, the video

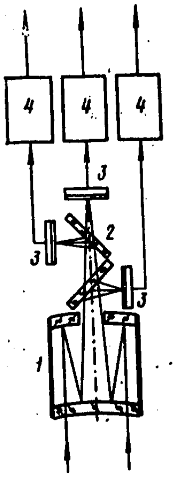

Figure 5. Structural diagram of the MSU-E.

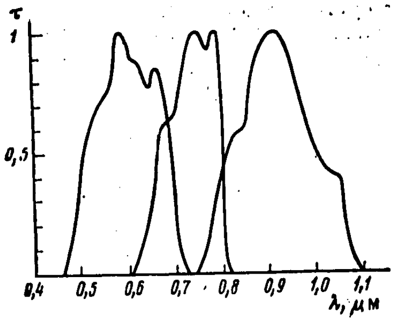

Figure 6. Spectral characteristics of the MSU-E.

signal enters channel signal amplification and shaping units 4. All of the straightedges are placed perpendicularly to the direction of the flight. Line scanning is carried out electronically, while frame scanning is realized because of the motion of the satellite. A necessary element of the device is a radiation-type refrigerating unit, which provides a temperature in the area of the PZS's of from -30 to -50°C and makes it possible to reduce the structural noise of the receivers in the PZS's significantly. In this model of the MSU-E, no provisions were made for in-flight calibration.

Information is received from the BIK-E by an experimental information discrimination system (SVPI-E) that uses a standard "Meteor" system antenna fitted with a low-noise receiver. The received signal, which is in digital form (in the form of a four-bit, four-level code) is retransmitted over a radio relay link to the reception point at the Main Data Reception and Processing Center (GTsPOD).

The information that is received is recorded on two types of equipment. Information from the MSU-SK is recorded on equipment for receiving newspaper pictures that has a negative format of 600 x 480 mm. Images from the MSU-E are reproduced on "Volga" phototelegraphy units, which have a negative format of 240 x 300 mm. Since the "Volga" recorder operates with a scanning rate of no more than 8 lines/s, the scanning rates are linked by a magnetic memory unit that reduces the scanning rate by a factor of eight.

Flight tests of the MSU-E resulted in stable operation of the radio part of the complex and demonstrated the prospectiveness of the selected transmission channel for territorial information reception points.

The quality of an MSU-SK image was high, and special measurements confirmed that the theoretical measurement accuracy was realized for all practical purposes. Slanted sounding of the surface, which is inherent in the conical scanning method, also contributed to the obtaining of interesting information about water surfaces. The operation of the PZS-based MSU-E instrument confirmed the effectiveness of this means of observation for natural and national economic objects requiring improved resolution, such as agricultural lands. The limited capabilities of this device, which are the result of its small local coverage band (about 30 km), can be overcome in the future by increasing the number of elements in the PZS straightedge, introducing remote control of the sighting line's position, and developing techniques that make it possible to extend the results of the decoding and interpretation of sections covered by the MSU-E to the larger areas observed by the MSU-SK

BIBLIOGRAPHY

1. Selivanov, A.S., and Tuchin, Yu.M., "Radio and Television Complex for 'Meteor' Satellites Used to Investigate the Earth's Natural Resources," this issue, pp 28-34.

2. "A New Experiment in Investigating the Earth From Space," ISSLEDOVANIYE ZEMLI IZ KOSMOSA, No 1, 1981, pp 5-6.

3. Selivanov, A.S., Chemodanov, V.P., Suvorov, B.A., et al., "Opticomechanical Scanners for Observing the Earth," TEKHNIKA KINO I TELEVIDENIYA, No 6, 1978, pp 18-22.

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CSO: 1866/18

UDC 629.78:528.7

EXPERIMENTAL INFORMATION AND MEASUREMENT COMPLEX BASED ON 'FRAGMENT' MULTIZONAL SCANNING SYSTEM

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 12 Jun 81) pp 40-44

[Article by G.A. Avanesov, Institute of Space Research, Moscow]

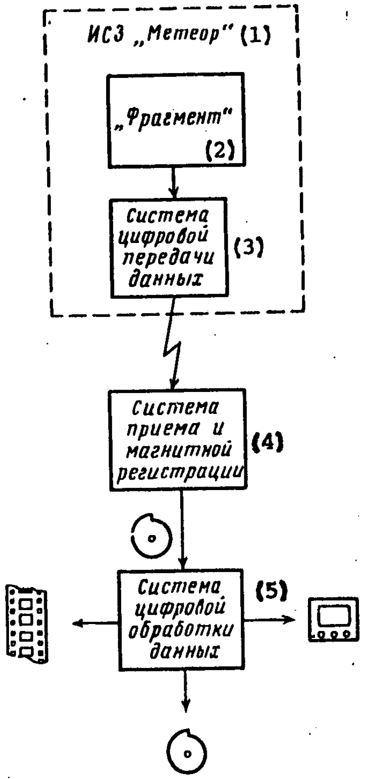
[Text] During the Ninth and Tenth Five-Year Plans, the USSR Academy of Sciences' Institute of Space Research carried out research and performed experiments for the purpose of creating and developing methods and specialized space facilities for IPRZ [investigation of the Earth's natural resources] in the optical band of electromagnetic emissions (EMI) so that they could subsequently be introduced into the practice of regular observations of the Earth from space.

The most important and complicated problem in this research was the development of a method and a complex of equipment that would insure the operational acquisition and processing of multizonal video information that is distinguished by high radiometric accuracy and depicts, with good spatial resolution, rapidly occurring changes in objects on the Earth's surface.

The importance of the solution of this problem is a consequence of the fact that only operationally acquired video information insures the realization of those basic advantages that space facilities provide in the process of searching for, evaluating the state of, and monitoring the utilization of the Earth's natural resources. In connection with this, the greatest economic effectiveness is achieved in the solution of such problems as evaluating the status and predicting the yields of agricultural crops and the biological productivity of water masses.

The complexity of the solution of this problem is the result of a number of factors, primarily of a scientific and technical nature, that emanate from the necessity of creating and tuning a complicated on-board and ground complex of interrelated equipment.

In addition to the actual on-board equipment for surveying the Earth's surface, this complex must also contain equipment for the transmission for a large flow of acquired video information to Earth over a radio link, facilities for receiving and recording this information, and equipment for processing it rapidly. It was necessary to develop all these elements and combine them into a unified system. The initial and basic component of this complex was the "Fragment" multizonal scanning system developed by the USSR Academy of Sciences' IKI [Institute of Space Research].



Generalized diagram of the information and measurement complex based on the "Fragment" multizonal scanning system.

Key:

1. "Meteor" artificial Earth satellite
2. "Fragment"
3. System for digital transmission of data
4. Receiving and magnetic recording system
5. Digital data processing system

This experimental information and measurement complex (EIIK) has been functioning successfully in an experimental operation mode for more than a year. The amount of information obtained with its help is measured in thousands of kilometers of magnetic tape and millions of square kilometers of the Earth's surface that have been investigated. A considerable amount of practical experience in working with this complex, which insures the operational collection and processing of information in the interests of investigating natural resources, has been accumulated.

A generalized diagram of the EIIK is shown in the figure on this page. It contains the following systems: 1) the "Fragment" multizonal optical scanning system; 2) a system for the digital transmission of the multizonal video information; 3) a system for the reception and magnetic recording of the multizonal video information; 4) a system for the digital processing of the multizonal video information.

The "Fragment" and the system for the digital transmission of information were installed on a "Meteor" artificial Earth satellite that was launched into a near, circular, solar-synchronous orbit at an altitude of 650 km on 18 June 1980. The orbit makes it possible to observe the same section of the Earth's surface with a periodicity of 15 days [1].

The system for the reception and magnetic recording of the multizonal video information has been set up at an MEI (Moscow Power Engineering Institute) OKB (Experimental or Special Design Office) reception point in Moscow Oblast. The system for the digital processing of the multizonal video information was developed at the USSR Academy of Sciences' IKI and GosNITsIPR [State Scientific-Research Center for Study of Natural Resources].

The "Fragment" system provides for the simultaneous scanning of the Earth's surface in 8 bands of the visible and near-infrared spectrum, in a belt about 85 km wide, for a belt that lies across the satellite's flight path [1,2], in addition to the conversion of the received radiation into an electrical signal, the comparison of the electrical signal to a master standard and its conversion to digital form, the accompaniment of the basic signal with service information about the state of the subsystems and their operating modes, and the introduction of synchronization and telemetric frame formation signals. The surveying modes are controlled over a command radio link.

The system for the digital transmission of the video information forms the synchronous messages and transmits the data, by the phase manipulation method, in the decimeter band of electromagnetic waves. The radio line's transmission capacity is about 4 Mbit/s [3].

Synchronous message discrimination, primary decoding of the signals (consisting of separating them according to channel), and recording of the information on a high-speed magnetic recorder takes place in the receiving and magnetic recording system. After each communication session the information is rerecorded, in a parallel-serial code, on digital telemetric magnetic recorders of the 17S06-07 type. The magnetic recordings obtained in this manner are sent to the USSR Academy of Sciences' IKI and GosNITsIPR for processing.

The system for the digital processing of video information that is in operation at the IKI provides the following: rapid review of the digital video recordings on a color half-tone display; rerecording of the information on magnetic tape usable in the YeS EVM [Unified System of Computers]; radiometric correction of the digital video information; reproduction of the digital video recordings on a black-and-white photographic medium on a scale of 1:1,600,000; processing of the data with statistical analysis and interpretation programs; processing of the data with geometric transformation programs.

After this, photographic processing is used to produce black-and-white negatives on a scale of 1:500,000 and, with the help of an MSP-4 multicamera synthesizing projector, color images on a scale of 1:320,000 are produced. The black-and-white 1:500,000 negatives and control prints made from them are sent to GosNITsIPR for publication and dissemination.

In order to create these systems, the complex's developers had to solve a number of complicated scientific and technical problems. In the development of the multizonal optical scanning system, the problems centered around creating a precision scanning assembly, a high-quality input optical system, devices for the on-board verification calibration of the opticoelectronic channel, photoreceiving units, high-speed analog-to-digital converters, an electric power supply, and the design of the system as a whole, with due consideration for the requirements imposed by the operating conditions relative to reliable functioning in space [2,4,5].

The problems related to data transmission, reception and recording were concentrated around the high-volume radio line and the magnetic recording facilities, it being the case that the latter had to insure the transformation of the information flow rate to the limits imposed by the rate of information input into the computer [3].

In the area of digital processing of the information, the problems involved the creation of specialized processing facilities and problem-oriented software [4].

Finally, the problems encountered in providing metrological support for the experiment required the creation of techniques for making energy calculations for the optical scanning systems and the specialized measuring devices, as well as a reliable technique for the relative and absolute calibration of the on-board system's measuring channels [7,8].

The goals of the experiment with the EIIK based on the "Fragment" multizonal optical scanning system, as formulated and refined during the different stages of the development process, assumed the possibility of overcoming the enumerated difficulties and can be reduced to the following: 1) the development of new facilities for acquiring multizonal video information in the visible and near-infrared bands of the spectrum; 2) the development and optimization of a method for the operational study of the Earth's surface on the basis of multizonal video information; 3) the development of systems and methods for the digital transmission of video information; 4) the investigation and optimization of methods for the computer and visual-instrumental processing of multizonal video information; 5) the experimental production utilization of aerospace video information to solve practical problems encountered in studying the Earth from space; 6) the development of recommendations for the construction of on-board and ground equipment, the organization of surveying work, and the technology for collecting and processing data in the prospective system for the operational study of Earth from space.

At this time the processing of the data obtained during the experiment is far from perfect. Accordingly, the results supplied from the experiment can be only of a preliminary type, although some of them are already useful.

The protracted and flawless functioning of the on-board systems under the conditions encountered in space indicates that the design and engineering decisions made during their development were correct. From the photographs that have been obtained, it is possible to say that the surveying system's actual resolving power is close to what had been calculated for it. Confirmation of the power calculations for the system has been obtained and maintenance of the radiometric calibration's reliability has been insured, which facts follow from an analysis of the video information and information about the built-in reference radiation emitter. In a correspondingly indirect manner, the correctness of the methodological and technical decisions made during the creation of the reliable monitoring and measuring equipment and all the ground development and testing procedures has been confirmed. All of this enables us to say that during the course of the experiment, the first and third problems involved in the development of the on-board equipment have been solved successfully.

During the course of the experiment we were able to refine our techniques for planning the surveying work and organizing the reception, registration and primary processing of the information on the basis of operational forecasting of the cloud cover, using data obtained during meteorological observations made with "Meteor"-series satellites. Procedures for selecting data for secondary types of processing, which is of great practical value for the solution of production problems, were also worked out. The work in this field was done for the purpose of minimizing the technological information processing cycle. The results obtained in connection with this correspond to a considerable degree to the problems encountered in working out the method for the operational study of the Earth's surface on the basis of multizonal video information.

One important goal of the experiment is the development and investigation of methods for the computer and visual-instrumental processing of multizonal information. Here we can mention that all the service forms of processing that had been prepared by the time the experiment began proved to be quite effective and required minimal reworking. The visual-instrumental types of processing that were applied to the survey materials demonstrated their suitability for practical use in many branches of the national economy. As far as the computer processing algorithms and programs (including automatic classification according to given and developed indicators) are concerned, it would be premature to draw any conclusions about their practical use at this stage because of the small volume of material that has been processed.

The USSR Academy of Sciences' IKI and GosNITsIPR offer rather easy access to the survey materials acquired by the EIIK on the basis of the "Fragment" multizonal scanning system, which should facilitate the use of this new type of space information for the practical solution of problems encountered in the Earth sciences.

The extended functioning of the EIIK and the large volume of material that has been acquired enables us to hope that this large and complex experiment will have a positive effect on the development in this country of operational methods for studying the Earth from space in the interests of the national economy and science.

BIBLIOGRAPHY

1. "A New Experiment in Space," ISSLEDOVANIYE ZEMLI IZ KOSMOSA, No 1, 1981, pp 5-6.

2. Avanesov, G.A., Glazkov, V.D., Ignatenko, S.A., et al., "The 'Fragment' Multizonal Scanning-Surveying System," this issue, pp 45-56.

3. Bogomolov, A.F., Popov, S.M., Smolyannikov, Yu.D., and Stepin, A.V., "Problems in the Digital Transmission and Recording of Multizonal Video Information and Their Solution in the 'Fragment' Experiment," this issue, pp 57-64.

4. Avanesov, G.A., Glazkov, V.D., and Tarnopol'skiy, V.I., "Development of a Specialized Opticoelectronic System for the Operational Collection of Multispectral Video Information about the Earth's Surface From an Artificial Earth Satellite," in "Mnogozonal'nyye aerokosmicheskiye s"yemki Zemli" [Multizonal Aerospace Surveys of the Earth], Moscow, Izdatel'stvo "Nauka", 1981, pp 57-76.

5. Tarnopol'skiy, V.I., "Some Questions on the Planning of Satellite Multispectral Optical Scanning Systems," ibid., pp 76-87.

6. Krasikov, V.A., and Shamis, V.A., "Processing Multizonal Video Information With Specialized Computer Complexes," ibid., pp 244-248.

7. Sychev, A.G., and Tarnopol'skiy, V.I., "On the Spectrometric Characteristics of Spectral Surveying Systems," ibid., pp 87-93.

8. Avanesov, G.A., Ziman, Ya.L., Sychev, A.G., and Tarnopol'skiy, V.I., "Metrological Support for Measurements of the Brightness of the Earth's Surface by the 'Fragment' Multizonal Scanning System," this issue, pp 65-77.

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CSO: 1866/18

UDC 528.7:621.397.331.2:629.78

'FRAGMENT' MULTIZONAL SCANNING SYSTEM

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 12 Jun 81) pp 45-56

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[Text] One of the basic contemporary operational means of obtaining space video information on the two-dimensional distribution of the intensities of the reflected and intrinsic radiation of objects on the Earth's surface and the underlying layer are multizonal scanning systems (MSS) that use as their radiation receivers point (nonscanning) detectors in combination with opticomechanical scanning devices [1]. Theoretically, systems of this type can be realized for any spectral band of electromagnetic waves that corresponds to transparency "windows" in the Earth's atmosphere. By using different types of detectors in MSS's, it is possible to cover a broad spectral range of measured emissions, which capability distinguishes them quite radically from other video information systems. The simplicity of an information-measuring channel using a point receiver with a minimum number of transformation steps for the measured radiation, the possibility of its periodic calibration with a standard source, and the use of a single optical system and a single image-scanning system make it possible to achieve high indicators as far as the accuracy of radiation flow measurements are concerned. Besides this, when processing the results of an analysis of multizonal information from an MSS, it is relatively simple to solve the problems involved in the point-by-point spatial matching of images obtained on different channels.

Starting with these premises, as well as theoretical and experimental research (the individual results of which are explained in [1-7]), the "Fragment" MSS was developed and a full-scale experiment was carried out with the help of a "Meteor" artificial Earth satellite.

Below we present a brief substantiation of the technical decisions realized in the "Fragment" MSS. Figures 1 and 2 are a functional diagram and general view, respectively, of this system.

Surveying Parameters of the "Fragment" System. The basic surveying parameters of this system include (for a given orbital altitude H = 650 km and a velocity $V_x \approx 7$ km/s relative to the underlying point on the Earth's surface): number of spectral intervals of sensitivity n and their position in the spectrum; effective spectral

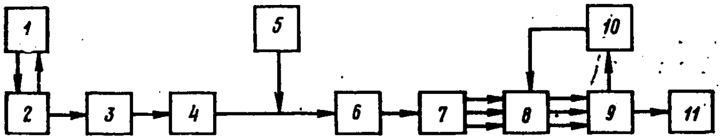

Figure 1. Functional diagram of experimental opticoelectronic system for the operational collection of multispectral video information about the Earth's surface from an artificial Earth satellite: 1. drive; 2. scanning mirror; 3. lens of receiving optical system; 4. opticomechanical commutator; 5. reference radiation emitter with operating and standard groups of light sources; 6. fiber-optic splitter; 7. spectral band-pass filters; 8. photoconverter elements; 9. encoding unit; 10. autocorrection circuit; 11. data transmission system.

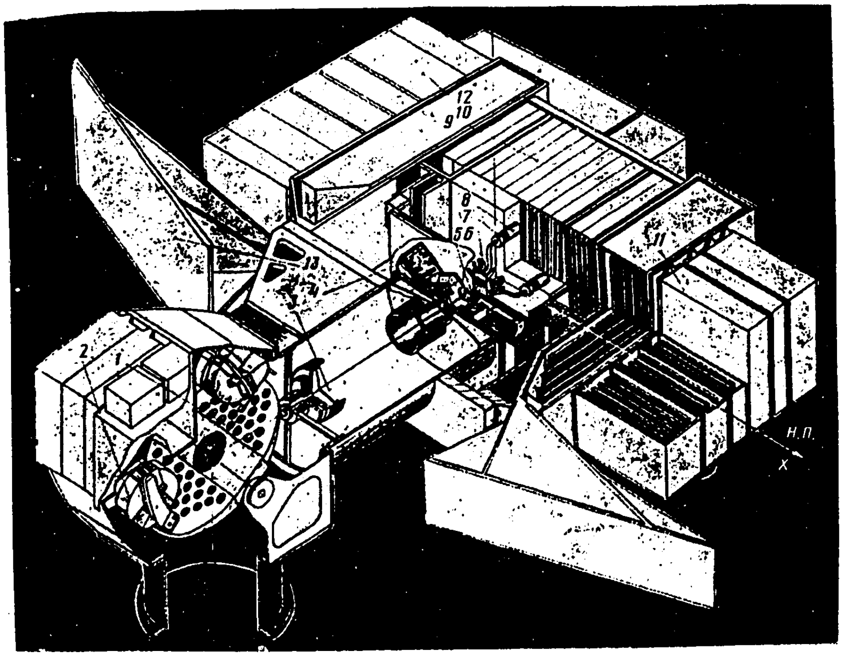

Figure 2. General view of "Fragment" multispectral scanning system: 1. scanning mirror; 2. mirror drive; 3. lens; 4. reference light sources; 5. opticomechanical commutator; 6. fiber-optic splitter; 7. spectral band-pass filters; 8. photoreceivers; 9. blocks of amplifiers for direct current and high-voltage power sources for photoreceivers; 10. analog-to-digital conversion unit; 11. control and information collection and processing system units; 12. electric power system units; 13. cooling radiators for photoreceivers.

width $\Delta\lambda_j$ of the sensitivity intervals; maximum values of the energy brightness's spectral density $B_{j\ max}$ measured by the system in each spectral interval of sensitivity; relative mean-square measurement error σ_{B_j}; viewing band width L_y; surveying rate $M = L_yV_x$; dimensions of instantaneous fields of view $\delta_x \cdot \delta_y = \Delta S$ in each spectral interval of sensitivity.

In accordance with the content of the research problems for the solution of which the "Fragment" system was developed, eight spectral measurement intervals were realized in it: 0.4-0.7, 0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1, 1.2-1.3, 1.5-1.8 and 2.1-2.4 µm. The effective spectral widths of the sensitivity intervals are: $\Delta\lambda_1$, $\Delta\lambda_5$, $\Delta\lambda_7$, $\Delta\lambda_8 \leqslant 3\cdot10^{-1}$ µm, $\Delta\lambda_2$, $\Delta\lambda_3$, $\Delta\lambda_4$, $\Delta\lambda_6 \leqslant 10^{-1}$ µm.

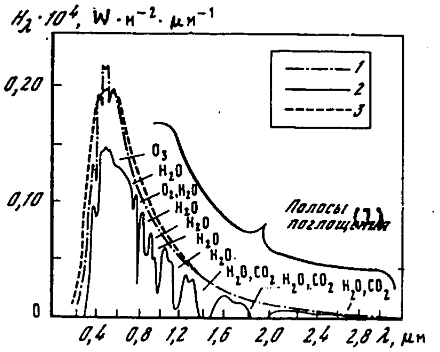

Figure 3. Spectral distribution of density of flow H_λ of direct solar radiation beyond the upper limit of the Earth's atmosphere (1) and at sea level (2) in comparison with the radiation of an absolutely black body (AChT) with a temperature of 8,000 K (3).
Key: 1. Absorption bands

The basis of the selection of these measurement intervals was the available material on the optics of terrestrial landscapes and the atmosphere for the band of reflected solar radiation ($\lambda < 3.5$ µm) that is practically free from superimposition of thermal radiation from the Earth's surface, in which--in turn--the selective nature of radiation transfer in the Earth's atmosphere unambiguously narrows the zones of the possible location of the working spectral intervals to "transparency windows" (Figure 3).

During the determination of the values of $B_{j\ max}$ needed to tie in the energy scales of the "Fragment" system's measuring channels in both the planning stage and during calibration, as well as for formulating the surveying program and controlling the system's operation while in flight, a tentative radiation prediction defining the seasonal variation in the upper limit of the band of measured brightnesses was made [7]. In view of the essential importance of their correct determination for the successful realization of the experimental program, the values obtained for $B_{j\ max}$ were confirmed by the results of corresponding measurements made on board a laboratory aircraft [3,7], including measurements made with a specially developed model of the "Fragment" system that measured the values of the energy brightness's spectral density in spectral intervals, space angles of the instantaneous fields of view, range of viewing angles that all corresponded to the projected system's same parameters.

The system's other surveying parameters were determined for one basic condition: the necessity of insuring sufficient accuracy and representativeness of the measurements without simultaneously infringing on the limitations on the magnitude I of the information flow sent into the communication link by the system:

$$I = L_y V_x \sum_{j=1}^{n} \frac{q_j}{\delta_x \delta_y} + l \leqslant 4\cdot10^6 \text{ bits/s}, \qquad (1)$$

where q_j = number of radiation flow quantization levels b_j during its conversion into the output code, while variable ℓ characterizes the volume of additional and auxiliary data.

Since the variable σ_{B_j} can be represented in the form

$$\sigma_{B_j} = (\sigma_{p_j}^2 + \sigma_{k_j}^2)^{1/2}, \qquad (2)$$

where the components having normal distributions of the values' probability densities are caused by fluctuations in the measured flow, channel noises σ_{p_j} and quantization noises σ_{k_j}, from the condition

$$\sigma_{k_j} = \left(\frac{q^2}{12}\right)^{1/2} \ll \sigma_{p_j}\ , \qquad (3)$$

when the degree of accuracy of the measurements in the intervals $j = 1,\ldots,5 \sigma_{B_j}$ = 2-3 percent was acceptable for the realization of the experiment's goals, the value of q_j was defined as 7 for all the measurement channels.

In accordance with the purpose of the experiment, no requirements for a global survey of the Earth were set when determining the value of L_y and, at the same time, the limitation on the relationship of the orbital altitude and the width of the field of view that determines the viewing angle β was taken into consideration; this requirement is related to the fact that the indicatrices of the measured brightness in the band of reflected radiation can be regarded as orthotropic only within the limits of extremely small sighting angle intervals, the expansion of which during surveying threatens to cause a substantial distortion of the brightness distribution pattern for the section of the Earth's surface being investigated. On the other hand, an extraordinarily small value of L_y makes the correct geographical correlation of the acquired data more difficult, so the value L_y = 85 km, which satisfies both conditions, was adopted.

The selection of the linear dimensions (δ_x and δ_y) of the instantaneous viewing fields was one of the most complex questions during the determination of the system's surveying parameters, since any rigorous physical-geographical substantiation of the choice was lacking. Taking experimental estimates into consideration and comparing them with previously conducted experiments, the following initial condition was adopted during the development of the "Fragment" MSS:

$$\delta_{x_j} = \delta_{y_j} = \delta_j < 10^{-1}\ \text{км} \qquad (4)$$

for measurements in the basic spectral intervals ($j = 1,\ldots,5$).

For the limitations on I and L_y stipulated above, in order to fulfill condition (4) it proved to be necessary to insure that relationship of the terms of the sum in expression (1) such that the relationship I - l/I and, consequently, the relationship of the viewing time η_{ck} of a band of width L_y during a single scan and the total time of the scan was at least 0.65; that is,

$$\frac{I - l}{I} \simeq \eta_{\text{ск}} > 0{,}65 \qquad (5)$$

In addition to this, the condition

$$\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6/3 = \delta_7/3 = \delta_8/6 \qquad (6)$$

was adopted, which made it possible to reduce the number of components of flow I for j = 6, 7, 8 and, at the same time, produce some equalization of the values of the signals in the system's measurement channels. As a result of the adoption of conditions (5) and (6), it proved to be possible to provide the base value $\delta_{j=1,\ldots,5} = 8 \cdot 10^{-2}$ km.

Scanning Setup and the Scanning Device. In an MSS, the choice of the scanning setup is determined by the accepted scanning trajectory of the brightness field being investigated, which is composed of the satellite's motion and the spatial displacement of the sighting angle of the system's scanning device.

On the basis of the initial condition--the line-by-line variant of the analysis of the brightness field--of the two possible scanning trajectories (straight line and conical), which, as analysis showed [2], are approximately equivalent, in the "Fragment" system the final choice was made in favor of a straight-line trajectory. The adoption of the final decision was affected by several features of the "Fragment" system's arrangement on the "Meteor" satellite and the type of recorders used in ground operations with the acquired data.

In the general case, a straight-line scanning trajectory is characterized by the condition of constancy of the instantaneous viewing field's linear rate of displacement, as well as a constant scanning plane azimuthal angle. Prospective distortions of the linear instantaneous viewing field are variable along a line, but the range of their changes for $\theta \leqslant 15°$ (θ is the current value of the viewing angle) is not large: $\leqslant$ 3.5 percent for δ_y and $\leqslant$ 6.5 percent for δ_x. The change in the optical path in the atmosphere during sighting of the center and edges of the surveyed strip is proportional to $\cos^{-1} \theta$ and is less than 3.5 percent for $\beta = 30°$.

Generally speaking, the realization of the chosen trajectory is possible in a set of the most variegated opticomechanical scanning arrangements using either rotation or oscillation of the individual optical elements or by providing for the necessary displacements of the receiving optical system. For design reasons, however, we took into consideration only scanning setups based on the use of mirror optics without the enlistment of the entire system in the scanning process.

From the viewpoint of location of the scanning element (SE), two variants were taken into consideration in the setup: placement of an afocal SE in the converging beams behind the receiving optical system or the utilization as an SE of one of its components, including one having optical power; placement of an afocal SE in the parallel beams in front of the receiving optical system.

At first, the first version appears to be quite compact, but when it is realized the scattering disk is enlarged substantially. This enlargement is caused primarily by the effect of field aberrations, because in this case the receiving optical system's viewing field must completely overlap the surveyed band of width L_y, although defocusing during movement of the SE also contributes to it.

In the second version of the scanning setup, an increase in the size of the scattering disk is possible only because of distortions in the SE's shape, and can be minimized if there are sufficiently rigorous requirements for the quality of the SE's reflecting surface. In this variant it is possible, in principle, to use several basic types of afocal SE's. A comparison of layouts of this type, using the value of η_{ck} and the SE's dimensions as the basic criterion, was made in [2] and was resolved in favor of a one-sided oscillating mirror, the drive of which realizes a sawtooth ($\eta_{ck} > 0.5$), periodic law of motion.

For the system being described, this scanning device was realized in the form of a metal and glass mirror and a magnetoelectric oscillating system consisting of a framework coupled with the scanning mirror that is in the permanent magnetic field of a stator, as well as a regulator of the magnitude of the electric current in the

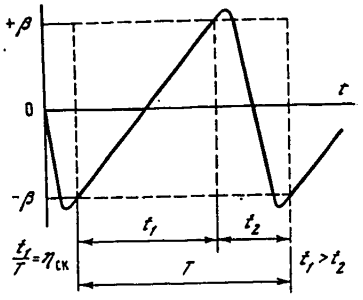

Figure 4. Diagram of angular displacement of the system's sighting angle.

framework; when the mirror moves along the given trajectory, this system provides a value $\eta_{CK} \overset{\sim}{\sim} 0.65$ (Figure 4).

The Measuring Video Channel. In the process of acquiring space video information with the help of the MSS, the information undergoes several transformations (from radiation to current to voltage and so forth) that gradually reduce the accuracy of the description because of the presence and accumulation of errors in the individual converting units in the measurement system. This usually happens until the actual measurement process is completed; that is, the comparison of the intermediate signal with the standard and the acquisition of a concrete number (the coded signal). The coded signal, which is more noiseproof than the analog representation of the video information, makes it possible to regenerate the original form of the signal under certain conditions, thereby eliminating the effect of errors in subsequent units on the measurement results. Consequently, by organizing the measurement process on board the satellite, it is possible to reduce to a minimum the number of converting units in the measuring video channel, thereby increasing the accuracy of the measurement of the original information and improving the conditions for its transmission to Earth.

Thus, the MSS's video channel's basic task is to convert measured brightness values into equivalent numerical values. In the "Fragment" system this process is realized with the help of successive operations in the following converters: an optical linear scale converter (the receiving optical system, or POS); a spatiotemporal optical converter (the scanning element and the analyzing diaphragm); an optical selector (the fiber-optic splitter and the spectral band-pass filters); a photoelectric linear scale converter (the radiation receiver and the direct-current amplifier, or FPU); an analog-to-digital converter (ATsP).

The Optical Linear Scale Converter. The receiving optical system of the "Fragment" conjugates the spaces of objects (x,y) and images (x',y') and transforms the original brightness distributions $B(\lambda,x,y)$ into an illumination distribution $E'(\lambda,x',y')$. It introduces distortions that are caused primarily by diffraction in the intake aperture and the imperfection of the system itself (aberrations, defocusing) and result in suppression of the higher harmonics of the brightness field's spatial spectrum. The limitation on reducing the energy of the spatial spectrum of a single band of width $Q = \delta$ by about 5 percent gives a condition for the relationship between the size of the scattering disk and the corresponding size of the instantaneous viewing field δ and the size δ' of the field diaphragm:

$$r_e/\delta' \leqslant 0{,}125, \qquad (7)$$

where r_e = conditional radius of the scattering disk for which the energy density, as approximated by a gaussoid, decreases by a factor of e relative to the value corresponding to the center of the disk.

Since the diffraction component of the scattering disk is determined by the angle and dimensions of the POS's intake aperture, as well as the length of the radiation wave, minimization of the disk's size for a given intake aperture must be accomplished primarily by eliminating aberrations and having high quality manufacturing and assembly of the elements. However, eliminating both spherical aberration and the coma is impossible for a single mirror. Therefore, it is necessary to use two-mirror systems that are, as a rule, constructed either according to Cassegrain's classical method, in which a primary parabolic mirror eliminates spherical aberration and a secondary convex hyperboloid is used to reduce the coma, or by the (Doll-Kirkkhem) and (Richi-Kret'yen) methods, which are modifications of it.

In accordance with what has been said, the "Fragment" system's POS was produced by the "Karl Zeiss-Jena" People's Enterprise in the GDR in the form of a Cassegrain lens with a circular intake aperture having a diameter $D_{in} = 0.24$ m and a focal length $f' = 1$ m, and that has a scattering disk measuring $4r_e \approx 30 \cdot 10^{-6}$ µm $< \delta'_{j=1,2,3,4} = 130 \cdot 10^{-6}$ µm at $\lambda = 0.5$ µm; that is, one that satisfies condition (7). Condition (7) is also fulfilled for the other spectral intervals, since the increase in the disk's size as the wavelength gets longer is outstripped by the enlargement of the system's instantaneous viewing fields stipulated above. The POS's reflecting surfaces are aluminum-plated. In the POS there is also a thermal compensation unit that eliminates defocusing of the POS in the temperature interval from -40 to +20°C.

The Spatiotemporal Optical Converter transforms brightness distribution $B(\lambda,x,y)$ in the coordinate space of objects (x,y) into a temporal radiation flow distribution $\Phi'(\lambda,t)$. The functions of this link in the system are carried out by the scanning device and the analyzing (field) diaphragms, in connection with which the scanning device moves the system's field of view, which is an image of the analyzing diaphragm relative to the space of objects (or, which is the same thing, an image of the space of objects relative to the analyzing diaphragm), in accordance with the previously determined scanning trajectory that describes the motion of its center within the limits of the scan's working section.

In the general case, the MSS's instantaneous field of view can be formed by analyzing diaphragms placed in the x direction (the carrier's direction of flight is m). This measure enables the linear rate of transverse displacement V_y of the field of view during scanning to be reduced by a factor of m and, consequently, the scanning frequency F_{ck} is also lowered, although the number of radiation receivers must be increased by a factor of m.

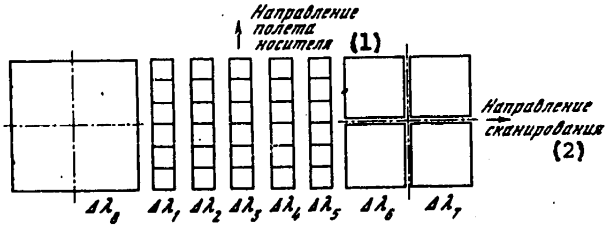

Figure 5. Shape of instantaneous field of view of the system.

Key:
1. Direction of flight of the carrier
2. Scanning direction

In the system being described, the instantaneous field of view is represented by a matrix of square analyzing diaphragms (Figure 5) consisting of n columns (conforming to the MSS's number of spectral intervals of sensitivity), each of which contains m_j analyzing diaphragms. In connection with this, the number m_j and size δ_j' of the analyzing diaphragms in the different spectral channels is not the same, but is governed by the rule

$$\delta_1' m_1 = \ldots = \delta_j' m_j = \ldots = \delta_n' m_n, \tag{8}$$

or, precisely, $m_1 = m_2 = m_3 = m_4 = m_5 = 6$; $m_6 = m_7 = 2$; $m_8 = 1$. The original value of $m = 6$ for $j = 1,\ldots,5$, which was chosen to fulfill condition (8), was selected by a technique described in [6].

For this matrix-type instantaneous field of view, the video signal for each spectral interval that corresponds to the same point on the surface being investigated is shifted temporally relative to the video signal in the first spectral interval by the amount

$$\Delta t_j = \Delta\delta_j / V_v, \tag{9}$$

where $\Delta\delta_j$ = distance along the y-axis between the centers of the analyzing diaphragms of the first and j-th spectral intervals of sensitivity.

The Optical Selector. The basic function of this unit is to separate the required spectral intervals from the radiation flow $\Phi_j'(\lambda,t)$ formed by the receiving optical channel and transfer them to the radiation receivers in the appropriate measuring channels. In the "Fragment" system the optical selector is realized with separate spectral and spatial selection, for which a fiber-optic splitter is used, the input faces of the light guides of which form the matrix of analyzing diaphragms, along with spectral band-pass filters of the required quality. The splitter is a rigid, three-dimensional designed organized in such a manner that when there is overall minimization of the lengths of the light guides for the purpose of reducing light losses, the lengths of the light guides abutting certain spectral band-pass filters and radiation receivers are distributed in an order corresponding to the order of distribution of the solar disk's brightness values ($T_{ts} \approx$ 6,000 K) in the system's spectral intervals of sensitivity.

The Photoelectric Linear Scale Converter (FPU) transforms the flow $\Phi_j''(\lambda,t)$ coming from the selector's input [sic] into an electrical signal, limits the frequency bands and carries out electrical scale conversion for matching with the coding unit (the ATsP). The nature of the transformations is described by the absolute spectral sensitivity $g_{PLE}(\lambda)$ of the radiant energy receiver (PLE), which is defined as the ratio of the receiver's reaction $u_{PLE}(\lambda)$ to the monochromatic flow received by it to the value $\Phi(\lambda)$ of this flow:

$$g_{PLE}(\lambda) = u_{PLE}(\lambda)/\Phi(\lambda)$$

and the combined temporal transfer function $k(\omega)$.

Thus, the general principles for selecting the radiation receivers for the system we are describing did not differ from the generally accepted ones. FEU-114 photoelectronic multipliers were used for operation in intervals $j = 1,\ldots,4$, an FEU-112 was used for $j = 5$, FD-8 photodiodes for $j = 6, 7$, and an FS-2AN photoresistor for $j = 8$.

The Measuring Device. The process of converting the FPU's electrical signal into the corresponding provisional numerical value is performed in the "Fragment" system by the ATsP. The provisional nature of the result is eliminated by calibrating the instrument.

It is a well-known fact that the relationship between measured brightness B and its representation at the output of an ideal measuring device can be reflected by the following relationship:

$$N \simeq kB, \tag{10}$$

where N = output code; k = conversion ratio.

In practice, the numerical values obtained as the result of the transformations we have been discussing differ from the true value by the magnitude of the system's error. The error includes two components: a random one, depending on noise, interference and so on, a systematic one, which depends on changes in the scale and nonlinearity of the video channel's conversion, as well as drifting of its zero level [4].

Achievement of the permissible value of the random measurement error, which is one of the given surveying parameters of the "Fragment" system, is accomplished by realization of the metrological characteristics of its elements that provide the necessary relationship of signal and noise in the measuring video channel.

One real method for reducing systematic errors in the measuring video channel is the use of the information that can be obtained during the conversion of a standard, previously known input signal. Actually, in the general case, if two reference emitters with known brightnesses $B_1^{re}(\lambda)$ and $B_2^{re}(\lambda)$ are introduced, and assuming linearity of the conversion characteristic, according to the reactions N_1^{re} and N_2^{re} that correspond to them it is possible to determine parameters k_j and N_{0j} of the conversion characteristic by solving an extremely simple system of equations of the type

$$N_{1j}^{re}=\bar{B}_{1j}^{re}k_j'+N_{0j}; \quad N_{2j}^{re}=\bar{B}_{2j}^{re}k_j'+N_{0j}, \tag{11}$$

where $\overline{B}_{1j}^{re} = \int_{\Delta\lambda_j} B^{re}(\lambda)d$; N_{0j} = the code of the actual zero level. In connection with this, by simple overlapping of the flows entering the FPU by the commutator, it is easy to realize $\overline{B}_2^{re} = 0$ for the area $\lambda < 3.5$ µm, given this $\Delta\lambda_j$.

As a result, there are two possible ways of solving the problem [4]: 1) the introduction of correction factors according to the results of the transformation of a standard signal (realization of the correction of systematic errors); 2) the introduction of a self-tuning (automatic correction) system in the video channel, in connection with which the systematic errors are minimized because of feedback that encompasses either separate units or the entire measuring channel.

The process of the correction of systematic errors is usually reduced to three operations: acquiring information on the video channel's characteristics according to the results of the transformation of a standard input signal; finding the video channel's error; introducing correction factors into the results of measurements of the emissions being investigated.

It is possible to acquire information about the state of the video channel in the MSS only periodically, during passive scan periods. During this time, the radiation being investigated is replaced by radiation from a standard source with the help of the commutator. The basic shortcoming of this method is the loss of information on the video channel's characteristics during the active part of the scan, which can sometimes lead to the appearance of an error during this interval. However, when the scanning frequencies are relatively high and the measuring video channel's parameters have a certain amount of temporal stability, these errors can be ignored.

The general shortcomings of methods for correcting systematic errors are either the large amounts of time needed or the extreme complexity of the equipment used. Therefore, these methods are usually realized on Earth and are feasible when there is a computer in the aerospace video information collection and processing system.

The use of self-tuning methods with the measuring video channel requires the addition to it of supplementary regulatable elements that produce such an effect on the transfer functions of the individual assemblies in the channel that systematic error is reduced for any kind of disturbing effect and any value of the radiation being measured. In contrast to methods for correcting systematic errors that are based on information redundancy in the measuring channel, automatic correction methods are free from this flaw. While making it possible to increase measurement accuracy, at the same time automatic correction methods allow considerably lower requirements for the basic elements that make up the video channel and for the accuracy of their regulation and tuning. The gain is achieved because of the increase in the amount of equipment used; that is, equipment redundancy in the video channel. In the final account, however, the use of automatic correction methods frequently leads to an improvement in the weight and size indicators and operational reliability of the measuring channel in connection with the elimination of nonstandard precision elements from the system. These methods are of particular value when measuring systems are being built in a microminiature version with the extensive use of integrated circuits, as well as when constructing converting systems based on elements that do not provide high accuracy but are reliable.

The practical realization of automatic correction is possible with the help of both analog and digital-to-analog devices. It is also completely obvious that for the realization of periodic automatic correction it is necessary to have memory units to store the error signal for the period of time that passes between automatic correction cycles.

Figure 6 is a structural diagram of a system for digital-to-analog automatic correction of systematic errors caused by zero level drift and a change in the video channel's scale conversion ratios. The basic special feature of this system is that it encompasses the video channel as a whole, which creates definite advantages. In addition to this, digital-to-analog automatic correction devices make it possible to realize higher accuracy characteristics when standard elements are used.

In accordance with the views that have been expressed here, the following elements were introduced into the "Fragment" system's measuring video channel (Figure 1): an opticomechanical commutator; a reference emitter with working and standard groups of light sources, the relative spectral characteristic of the emissions of which has a color temperature of approximately T_{ts} = 6,000 K; a compensation circuit that encompasses the encoding unit and the photoconversion elements and that performs, by compensating for zero level drift and a change in conversion conductance, automatic correction of the multiplicative and additive errors contributed by the equipment, it being the case that the correcting control signals are a function of the value of

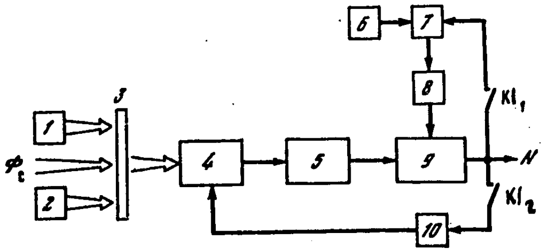

Figure 6. Structural diagram of measuring video channel with automatic digital-to-analog correction of systematic errors: 1, 2. standard radiation sources; 3. optical commutator; 4. photoreceiving devices; 5. signal processing unit; 6. digital equivalent of standard radiation; 7. conversion scale corrector; 8. reference voltage source; 9. analog-to-digital converter; 10. digital-to-analog zero level corrector; Kl_1, Kl_2 = electronic keys.

the deviation of the dark signal and the reference emitter's signal from the zero and reference levels, respectively. Since the rate of drift of parameters k_j and N_{0j} because of the FPU is considerably higher than because of the change in the optical properties of the scanning element in the POS, it proved to be possible to place the reference emitter and the commutator behind these optical elements.

Thus, the "Fragment" system's measuring video channel operates in the following manner. Radiation rising from the Earth's surface strikes the scanning mirror (Figure 1), is gathered by the lens and focused on the analyzing (field) diaphragms of the input faces of the fiber-optic splitter's light guides. The light guides transmit the radiation to the spectral band-pass filters. The filtered radiation is transformed by the photoconversion units into electrical signals that are proportional to the brightness of the scanned section of the Earth's surface in the segregated spectral interval, after which the signals are transformed in the encoding unit and sent to the data transmission system. By changing the position of the scanning mirror, which is moved by a drive, the device's instantaneous fields of view, as determined by the configuration and sizes of the analyzing diaphragms (Figure 5) are moved across the direction of the carrier's flight in such a manner that the collection of data on the brightness of the Earth's surface takes place only during movement in one (the working) direction during time t_1 (see Figure 4). Reversing of the mirror's movement and the return of it to its original position takes place during time segment t_2, which is a minor part of the total scanning time T. During time segment t_2, opticomechanical commutator 4 first cuts off the flow of radiation entering the input faces of the fiber-optic splitter's light guides and replaces it with radiation from the reference radiator, the spectral density of the energy brightness of which is similar to the spectral density of the Sun's energy brightness. The electrical signals produced by the photoconversion elements, which correspond to periods of shading and measurement of the reference radiation's intensity, are transformed in the encoding unit and compared, respectively, with the signals' zero and fixed reference levels. The magnitudes of the mismatching of the compared signals with these levels are used to generate control signals in the feedback circuit that affect the position of the zero and the conversion conductance of the photoconversion units in such a manner that the mismatch is eliminated, thereby accomplishing automatic correction of the video channel's multiplicative and additive equipment errors.

On the whole, the technical decisions that were discussed above that were embodied in the "Fragment" MSS made it possible to realize the combination of its basic parameters, which are:

Scanning band width, km	85
Surveying rate, km^2/s	590
Total information content, bits/s	$5.6 \cdot 10^6$
Total number of channels	35
Intake aperture area, cm^2	358
Weight, kg	280
Power consumption, W	220
Dimensions, mm	1,660 x 1,440 x 730

The surveying characteristics of the "Fragment" system for the selected spectral intervals are presented in the table below.

Characteristics of "Fragment" Multispectral Scanning System

	Working Spectral Intervals, μm							
Characteristics	0.4-0.7	0.5-0.6	0.6-0.7	0.7-0.8	0.8-1.1	1.2-1.3	1.5-1.8	2.1-2.4
Upper limit of measurable brightness, $W \cdot cm^{-2} sr^{-1} \mu m^{-1}$	320	320	270	210	133	70	33	13.3
Relative mean-square error of measurements, %	1.5	1.5	1.8	2.5	3.3	5	7	
Instantaneous fields of view, rad$\cdot 10^{-3}$	0.13	0.13	0.13	0.13	0.13	0.39	0.39	0.78
Linear dimension of instantaneous field of view at the nadir, m (H = 630 km)	80	80	80	80	80	240	240	480
Total information content, bits/s$\cdot 10^6$	0.96	0.96	0.96	0.96	0.96	0.32	0.32	0.16
Video information content, bits/s$\cdot 10^6$	0.65	0.65	0.65	0.65	0.65	0.21	0.21	0.10

On the whole, the results of the full-scale experiment using the "Meteor" satellite confirmed the rationality of the technical decisions that were made and realized in the "Fragment" MSS. The scientific and technical goal that was formulated--the development of a measuring MSS to be used for the solution of various long-term and operational, prospecting and precautionary, economic and scientific problems--was achieved. At the ground reception points that were not equipped with special computer equipment for the correction of the video information, operational visual and instrumental analysis of the incoming data was accomplished successfully. The accuracy that was realized makes it possible to automate space video information processing operations, using computer facilities that are produced industrially [5].

BIBLIOGRAPHY

1. Avanesov, G.A., "Operational Facilities for Acquiring Space Video Information in the Optical Band," in "Kosmicheskiye issledovaniya zemnykh resursov" [Space

Investigations of Terrestrial Resources], Moscow, Izdatel'stvo "Nauka", 1975, pp 24-34.

2. Avanesov, G.A., Glazkov, V.D., and Tarnopol'skiy, V.I., "Development of a Specialized Opticoelectronic System for the Operational Collection of Multispectral Video Information About the Earth's Surface," in "Mnogozonal'nyye aerokosmicheskiye s"yemki Zemli" [Multizonal Aerospace Surveys of the Earth], Moscow, Izdatel'stvo "Nauka", 1981, pp 58-76.

3. Avanesov, G.A., Barinov, I.V., Glazkov, V.D., et al., "Modeling a Space Experiment With the Help of an Airborne Laboratory," in "Kosmicheskiye issledovaniya zemnykh resursov", Moscow, Izdatel'stvo "Nauka", 1975, pp 280-290.

4. Avanesov, G.A., Glazkov, V.D., and Khodarev, Yu.K., "Principles of the Construction of a Measuring Video Channel," ibid., pp 56-80.

5. Avanesov, G.A., Ziman, Ya.L., and Khodarev, Yu.K., "Technology for the Thematic Automated Processing of Video Information," ibid., pp 179-188.

6. Tarnopol'skiy, V.I., "Some Questions on the Planning of Satellite Multispectral Optical Scanning Systems," in "Mnogozonal'nyye aerokosmicheskiye s"yemki Zemli", Moscow, Izdatel'stvo "Nauka", 1981, pp 76-87.

7. Avanesov, G.A., Ziman, Ya.L., Sychev, A.G., and Tarnopol'skiy, V.I., "Metrological Support for Measurements of the Brightness of the Earth's Surface by the 'Fragment' Multizonal Scanning System" this issue, pp 65-77.

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CSO: 1866/18

UDC 528.727

PROBLEMS IN DIGITAL TRANSMISSION AND RECORDING OF MULTIZONAL VIDEO INFORMATION AND THEIR SOLUTION IN THE 'FRAGMENT' EXPERIMENT

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 20 May 81) pp 57-64

[Article by A.F. Bogomolov, S.M. Popov, Yu.D. Smolyannikov and A.V. Stepin]

[Text] There is a continual and significant growth in the flows of information coming from aerospace systems for investigating the Earth's natural resources. This is taking place in connection with an improvement in the resolving power of optical, radar and radiometric systems, an improvement in picture detail and enlargement of the area surveyed, and the use of several spectral or polarized channels and equipment integration for the acquisition of the greatest possible amount of information about the Earth.

In the near future we are planning to create research complexes with summary information bands (conforming to the video frequency) to 10-40 MHz. The transmission of remote sounding data from a satellite to ground reception points can be carried out over a radio channel by either the digital or analog method. In comparison with analog systems, digital systems require expansion of the band of frequencies used in the ether and an increase in the operating speed of the transmitting, receiving and recording equipment.

However, digital transmission has a number of important advantages for both the overall plan (high technological qualities and reliability of the equipment, simplicity of coupling with digital computers) and its specific (information) elements. They include: low sensitivity to the effect of noise and distortion accumulations in the signal amplification, transmission, reception, memory and relay channels; information flexibility, which means simplicity in combining different and independent data sources (including nonsynchronous ones), the possibility of sacrificing accuracy for transmission speed, and so on.

The basic indicator of a radio link's effectiveness is its degree of economy in both power and the band of frequencies occupied in the ether and used per unit of information for a given degree of transmission reliability. A comparison of analog and digital methods according to these criteria has been done more than once and can be represented most graphically by a so-called Sanders diagram (Figure 1) [1]. As is obvious, a digital channel with phase manipulation of the carrier frequency provides a high degree of on-board transmitter economy, while with respect to the band of frequencies used it is only insignificantly behind the optimum (according to this criterion) analog channel with frequency modulation.

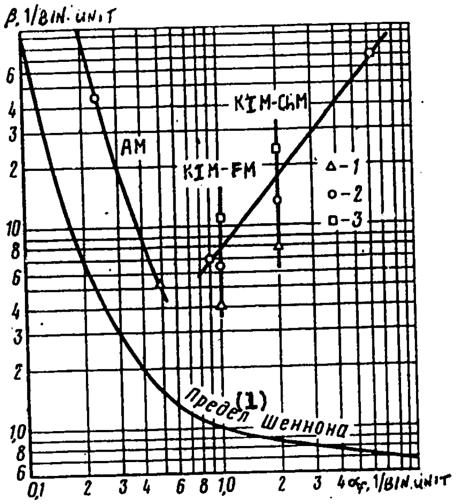

Figure 1. Dependence of specific signal energy consumption β on specific frequency band α (per binary unit of information) for a given transmission quality: AM = amplitude modulation; ChM = frequency modulation; KIM-FM, KIM-ChM = digital (pulse-code) modulation with phase and frequency manipulation of the carrier frequency: 1. mean quadratic error 10^{-1}; 2. mean quadratic error 10^{-2}; 3. mean quadratic error 10^{-3}.

Key: 1. (Shennon's) limit

Calculations show that a communication channel with a traffic capacity on the order of 100 Mbits/s that is to be used with an object of the "Meteor" type must have a transmitter on board the object with a capacity of several tens of watts when ground antennas with an effective area on the order of 25-100 m^2 are used. The existence of cheap and reliable antennas of the "Orbit" type, with an effective area on the order of 50 m^2, as well as on-board and ground digital transmission equipment that was developed by the OKB [Special or Experimental Design Office] of the USSR Ministry of Higher and Secondary Specialized Education's Moscow Power Engineering Institute is already making it possible to realize radio links with the operating speed that is required for remote sounding problems.

Model testing of the basic equipment decisions envisaged for prospective scientific information transmission complexes was carried out with the "Fragment-RL" equipment during the "Fragment" experiment. Temporal packing of the information, which provided for the transmission of 4-6 spectral bands into a single digital flow, was used in it. The data transmission rate was about 4 Mbits/s. The use of the most noise-resistant type of modulation (phase manipulation of the carrier frequency at ±90°) and directional on-board and high-efficiency ground antennas provided the communication channel with a high energy potential. Figure 2 is a structural diagram of the equipment at the information reception point. The radio signal is received by an antenna with an effective area on the order of 50 m^2 in the decimeter wave band. The antenna is guided onto the object with the help of a programmed unit and according to target acquisition instructions from GosNITsIPR.

After passing through the antenna amplifier, which has a noise temperature on the order of 300 K, the signal is transferred to an intermediate frequency on which the basic amplification, selection and synchronous rectification of the signal takes place. Reestablishment of the reference voltage for synchronous rectification is accomplished by an arrangement with twinning of the carrier and the use of a phase autoadjustment system to improve filtration of the input signal under noisy conditions. The parameters of the reference voltage reestablishment setup were selected in such a manner as to insure netting without tuning for all possible instabilities of the transmitter's carrier frequency and the receivers' heterodynes, while not allowing deterioration of the interference-free reception of the phase-manipulated signal in the presence of fluctuating interference.

From the output of the synchronous rectifier, the video signal enters the input of the signal synchronization and processing unit, where the symbol recurrence

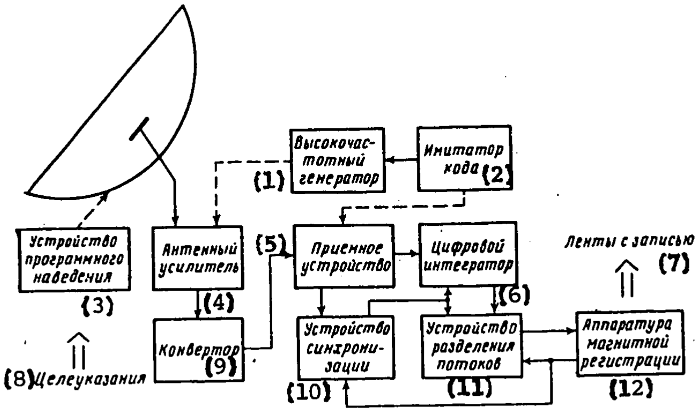

Figure 2. Structural diagram of "Fragment-RL" equipment.

Key:

1. High-frequency generator
2. Code simulator
3. Programmed guidance unit
4. Antenna amplifier
5. Receiver
6. Digital integrator
7. Tapes with recording
8. Target acquisition
9. Converter
10. Synchronization unit
11. Flow separation unit
12. Magnetic recording equipment

frequency is separated and optimum postrectification processing of the code's video pulses is carried out by digital integration of the signal in a period of time equal to the duration of the symbol. The synchronization unit also distinguishes the special "Fragment" system marker messages and uses them to distribute the information into four separate flows of 960 kbits/s each for the purpose of organizing their registration by magnetic recording equipment. The marker message signals also serve to eliminate the "ambiguity" that is inherent in communication channels with phase-manipulated signals.

The reception and conversion complex includes monitoring and testing equipment that makes it possible to check the fitness for operation of the entire ground complex (including the antenna) before a communication session, while during the session it evaluates the quality of the signal being received.

The basic specifications of the "Fragment-RL" radio line are as follows:

Information transmission rate	3,840 kbits/s
Type of modulation in the radio line	phase manipulation
On-board transmitter power	5 W
Effective area of receiving antenna	at least 50 m^2
Directivity factor of transmitting antenna	about 2
Realized reception range	3,000 km
Power reserve over threshold level at a distance of 2,000 km	at least 10 dB

A further improvement in the radio link's traffic capacity can be achieved by changing over to double phase packing of the channel. On the basis of the facilities that have been created, with a partial replacement of the units it is possible to build a digital communication channel with an operating speed of up to 80-100 Mbits/s.

During the conduct of the "Fragment" experiment, problems related to methods of recording digital multizonal video information were worked out and recommendations for the construction of ground magnetic recording facilities in the prospective system for the operational study of Earth from space were worked up [2]. Some of the advantages of the digital transmission of video information from objects in space were mentioned above. As in the case of a radio channel, the use of digital methods in magnetic recording equipment makes it possible to achieve high quality indicators and stability of the channel's characteristics and the absence of an increase in noise after multiple rerecordings and storage, as well as the capability of compensating for temporal distortions arising as the result of unevenness of the tape's rate of movement.

However, the use of digital methods requires a recording-reproduction channel band that is 10-30 times wider than when recording in analog form is used. This leads to a situation where (for example) in order to record a single communication session with the "Fragment" system utilizing the digital recording methods used in digital computers, 14 km of tape moving at a rate of 15 m/s would be required. If we take into consideration the fact that a further increase in digital information flows can be expected in the near future, it becomes clear that the methods for recording digital information that are widely used today cannot solve the problem of recording at the reception speed.

The creation of magnetic recording devices using digital recording methods with high tape-use efficiency and having an information band of up to 100 Mbits/s and more is a complicated scientific and technical problem. In the initial stage of the "Fragment" experiment, the entire complex of instruments used was examined systematically with due consideration for actual achievements and prospects for the development of theory, technology, techniques and materials. The requirements for the magnetic recording system as a whole and for its component parts were formulated and crossmatched.

Another special feature of the development of a magnetic recording system within the framework of the "Fragment" experiment was the need for information coupling of the newly developed devices with those possessed by the consumers of the information that had a different operating speed, input signal structure and placement of the information on the magnetic tape.

Figure 4 is a functional diagram of the "Fragment-RL" magnetic recording system. It includes: 1) an MZU-V (N2S3-F) high-speed magnetic memory with an information band of from 16 to 1.6 Mbits/s; 2) an MZU-S (N2S1) medium-speed magnetic memory with an information band during recording of from 5.1 Mbits/s to 176 kbits/s; 3) an MZU-M low-speed magnetic memory with an information band of from 900 to 56 kbits/s; 4) a signal formation and commutation unit (UFK).

After reception and separation of the synchrosignals, the information in digital form enters the UFK. In the reception-from-satellite mode, from the UFK the information is relayed simultaneously to two MZU-V magnetic recorders that provide continuous recording in a sequential engagement mode. After reception and recording of the data flow, it is rerecorded from the MZU-V's on an MZU-S magnetic recorder. The rerecording is necessary in order to match the "Fragment-RL" system's information channels and the computer input units, which have a different traffic capacity. Signalgrams from the MZU-S are sent to the consumers' computer centers for processing of the information.

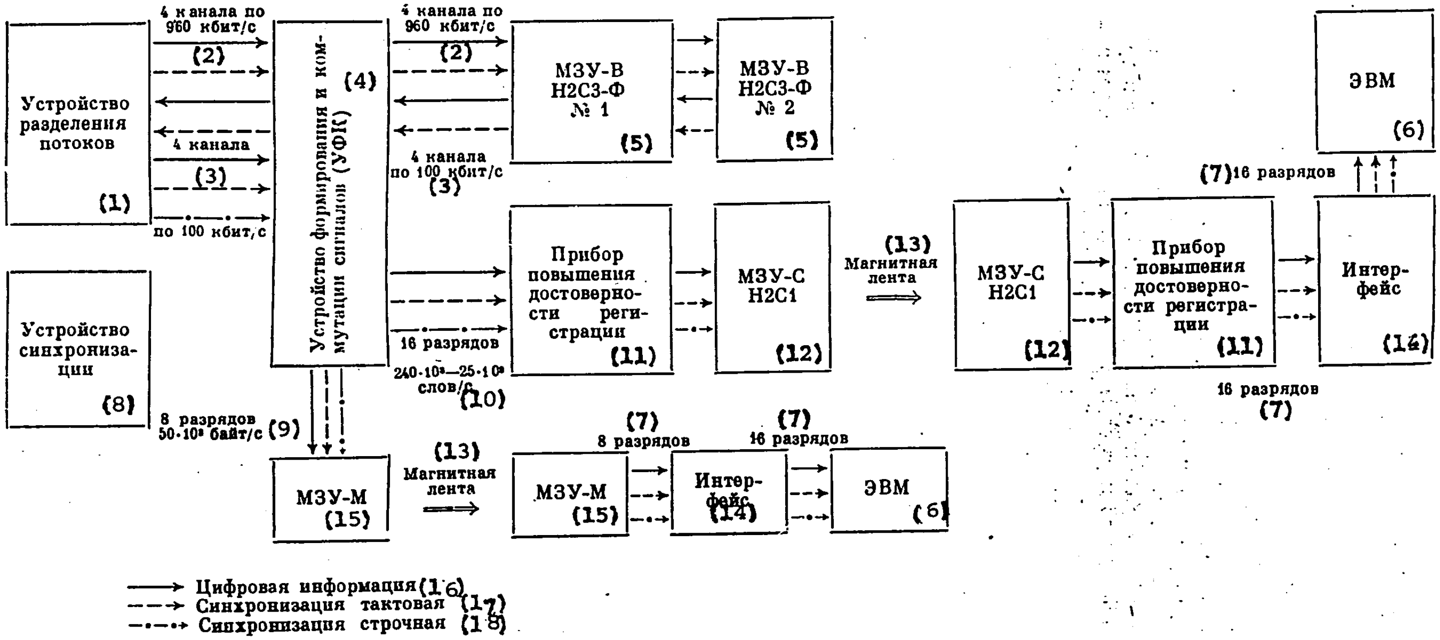

Figure 4. Functional diagram of "Fragment-RL" magnetic recording system.

Key:
1. Flow-splitting unit
2. 4 channels, 960 kbits/s each
3. 4 channels, 100 kbits/s each
4. Signal formation and commutation unit (UFK)
5. MZU-V, N2S3-F, No .
6. Computer
7. .. bit positions
8. Synchronization unit
9. 8 bit positions, $50\cdot10^3$ bytes/s
10. 16 bit positions, $250\cdot10^3$-$25\cdot10^3$ words
11. Instrument for increasing reliability of recording
12. MZU-S, N2S1
13. Magnetic tape
14. Interface
15. MZU-M
16. Digital information
17. Time synchronization
18. Line synchronization

If a photorecorder with low-speed mechanical scanning is used for operational monitoring, there is yet another rerecording of the information in the MZU-M, from which information can be entered in the computer through interface units just as it is from the MZU-S. The basic information profiles are presented in the functional diagram (Figure 4).

In order to guarantee the information characteristics of the type N2S3-F MZU-V and the type N2S1 MZU-S, a standardized tape-moving mechanism with automatic control systems and a bestonval'nyy [translation unknown] drive in the 0.25-8 m/s speed range was developed. When used together with an instrument for the digital correction of temporal distortions, this tape-moving method insures the elimination of the effect of instability in the magnetic tape's movement on the output signal's parameters. It can operate, without any intermediate buffer units, with photorecorders having high-speed electronic or mechanical line scanning.

For the medium-speed N2S1 magnetic memory unit, the widely used method of recording without returning to zero (BVN-M) was utilized, thus making it possible to obtain good information flexibility.

The basic specifications and a list of the functional systems and service equipment for the N2S1 medium-speed magnetic memory are given below:

Magnetic tape movement speeds, m/s	0.25, 0.38, 0.5, 0.76, 1, 1.5, 2, 3, 4, 6, 8
Number of recording channels	24
Recording density, bits/mm	32
Width of magnetic tape, mm	25.4
Type of magnetic tape used	I4406-25
Capacity of magnetic tape reels, m	2,200
Maximum recording speed, Mbits/s	5.1
Dimensions, mm	1,672 x 565 x 648

There are built-in automatic and oscillograph monitoring systems, a programmable command unit, a measured information error compensator, a time synchronization error compensator, and a channel for recording a voice accompaniment. Capabilities for remote control of the entire rack's working modes and remote acquisition of command execution signals are also provided.

The following service equipment has been developed: a stationary control panel that insures the interaction of two or three N2S1 racks in the continuous, sequential recording and rerecording mode; a portable remote control panel; an instrument for rack tuning and monitoring; an instrument for the demagnetization of magnetic tape on reels; an instrument for cleaning magnetic tape and preparing it for operation or storage; an instrument that compensates for temporal distortions arising because of unevenness of the tape's movement during information reproduction.

In order to solve various problems, N2S1 racks can be used as the basis for the organization of an independent magnetic recording system that has quite good information and operating characteristics.

During the development of the type N2S3-F MZU-V high-speed magnetic memory unit, the basic scientific and technical problem was the creation of the recording (digital information reproduction) channel, which had to record 1,000-2,000 bits/mm^2 with a reliability level of no worse than 10^{-7} and an operating speed of up to 5-10 Mbits/s. Different versions of the utilization of analog recording systems were discussed. In [3] there is an analysis of the accuracy characteristics of analog recording methods and it is shown that the frequency modulation recording method has quite good characteristics. For the realization of this method within the framework of the "Fragment" experiment, with recording of the information from each spectral band on a separate track, the tape movement rate would be 1.5 m/s. However, intrinsic flaws in the frequency modulation method forced it to be rejected. Basically, they are as follows:

the appearance of temporal deviations in the signal as the result of fluctuations in the tape movement speed during recording and reproduction results in geometric distortions of the image;

the appearance of temporal mismatches between spectral band information recorded on different tracks because of dynamic misalignments of the tape that occur when it is moving leads to a lowering of the resolution of the detailed spectral analysis;

the small dynamic range of the reproduced signal.

Another recording method, which makes it possible to reduce the magnetic recording system's operating speed, is proposed in [4] and is based on one of the methods for reducing redundance in the original information. The recording speed is approximately halved by the use of differential pulse-code modulation (DIKM) with prediction on the basis of the preceding element, where only the difference between the current and preceding image brightness values is transmitted. However, the use of DIKM results in a situation where a single error leads to distortion of the following group of elements; that is, the errors are reproduced until the end of the line is reached. This effect results in undesirable distortions in the video information. In order to eliminate the effect of errors when DIKM is used, it is necessary to increase the reliability in the data transmission channel by two or three orders of magnitude, by further increasing the on-board transmitter's power or introducing redundant encoding.

Taking these things into consideration, at the stage of the actual conduct of the "Fragment" experiment, a multichannel digital recording method was selected for the N2S3-F high-speed magnetic memory and the following technical characteristics were realized:

Number of recording and reproduction channels	16
Recording density	120-160 bits/mm
Recording frequency on a track	up to 1 MHz
Ratio of frequency band transformation during reproduction	1/8-1/10
Type of tape	I4406-25

Continuous recording of the information is insured by the sequential operation of N2S3-F racks and commutation of the recording channels. The completion of the following developments for the MZU-V will result in an increase in the number of recording channels: reproduction of up to 40 channels and the development of new magnetic heads, as well as the use of new and promising magnetic tapes that will provide a signal-to-noise ratio of 25-30 dB in the frequency range up to 5-10 MHz.

For the MZU-M, a Soviet-produced digital magnetic recorder was used; it has the following characteristics:

Tape movement speed, m/s	0.125, 0.25, 0.5, 1, 2
Number of recording channels	20
Recording density, bits/mm	25
Width of magnetic tape, mm	25.4
Reel capacity, m	1,000

The experience gained during the conduct of the "Fragment" experiment enables us to draw the following conclusions about the operation of the radio link and the recording equipment.

1. The principles chosen for the construction of the digital transmission and magnetic recording system insured the solution of the scientific and technical problem formulated for the "Fragment" experiment.

2. On the whole, the rationality of the technical decisions that were made was confirmed and actual ways were noted for the further improvement of digital data transmission, reception and recording equipment for prospective systems for studying the Earth from space at operating speeds of up to 100 Mbits/s.

BIBLIOGRAPHY

1. Sanders, P., "Comparison of the Efficiency of Several Communication Systems," ZARUBEZHNAYA RADIOELEKTRONIKA, No 12, 1960, pp 52-76.

2. "A New Experiment in Investigating the Earth From Space," ISSLEDOVANIYA ZEMLI IZ KOSMOSA, No 1, 1981, pp 5-6.

3. Gitlits, M.V., "Magnitnaya zapis' v sistemakh peredachi informatsii" [Magnetic Recording in Information Transmission Systems], Moscow, Izdatel'stvo "Svyaz'", 1978, pp 212-215.

4. Asmus, V.V., Mishkina, A.A., Rivkin, L.Yu., Tishchenko, A.P., and Shapovalov, S.V., "Multizonal Video Information Input-Output With the Elimination of Information Redundancy," ISSLEDOVANIYE ZEMLI IZ KOSMOSA, No 2, 1981, pp 82-86.

11746
CSO: 1866/18

UDC 528.7:629.78

METROLOGICAL SUPPORT FOR MEASUREMENTS OF BRIGHTNESS OF EARTH'S SURFACE BY 'FRAGMENT' MULTIZONAL SCANNING SYSTEM

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 12 Jun 81) pp 65-77

[Article by G.A. Avanesov, Ya.L. Ziman, A.G. Sychev and V.I. Tarnopol'skiy, Institute of Space Research, Moscow]

[Text] Modern remote methods for investigating the Earth rely to a considerable degree on the use of quantitative methods for processing data acquired with the help of various surveying systems (SS). Thus, the reliability of the results of such investigations is directly dependent on the SS's measuring properties [1], which determine the possibility of making an objective comparison of the results of measurements made in different situations by different SS's. It is obvious that a necessary condition for such a comparison is the appropriate metrological support.

In the concept of the metrological support of measurements we include the choice of the physical unit for representing the results of the measurements, the transfer of the selected unit from the standard that reproduces it to the SS's measuring scale, and provision of the necessary minimization of the measurements' total error with respect to the unit of the selected physical value.

Let us discuss the realization of such metrological support for an optical-band SS, using as our example the planning and radiometric calibration of the "Fragment" multizonal scanning system (MSS) [2].

According to its operating principle, the "Fragment" system is a radiometer-brightnessmeter, since its instantaneous fields of view cover the investigated surface completely when measurements are being made. If we take into consideration the negligible size of the solid angle at which the intake apertures of radiometer-brightnessmeter SS's used in remote investigations of the Earth are visible from the planet's surface, it is obvious that as the radiometric value that quantitatively defines the radiation being investigated with the help of such SS's, we should take the density of the radiant flow on the surface, as related to the magnitude of the spectral interval and the solid angle; that is, the spectral density of the energy brightness (SPEYa). And although in practice the resolution values with respect to the surface, the solid angle and the spectrum are finite, the essence of the problem of resolution does not change: an SS measures the average SPEYa value, in conneection with which the higher the resolution, the smaller the error related to the finiteness of the enumerated values[1].

Considering the essential importance of the question of selecting the physical unit in which the measurement results are presented, let us discuss it in detail.

Actually, the relationship between a measured value and the output signal of any (j-th) SS measuring channel is defined by the relationship

$$S_j=\frac{g_j}{B}=\frac{\int\limits_0^{\infty} B(\lambda)\,S_j(\lambda)\,d\lambda}{B}, \tag{1}$$

where S_j = a value characterizing the j-th measuring channel's sensitivity; $S_j(\lambda)$ = = absolute spectral sensitivity of the j-th channel; g_j = output reaction of the j-th channel; $B(\lambda)$ = spectral brightness of the surface being investigated; B = = measured value of the brightness.

In principle, value B can be characterized by different methods. When calibrating radiometer-brightnessmeters, the value that is normally used for B is the total integral brightness of some standard radiation source, the integral brightness of this source within the limits of the spectral sensitivity interval ($\Delta\lambda$) of the SS channel that is being calibrated, or the effective brightness for the given channel [3]. Expression (1) can then be rewritten as

$$S_{\text{и}}=\frac{\int\limits_0^{\infty} b_{st}(\lambda)\,S(\lambda)\,d\lambda}{\int\limits_0^{\infty} b_{st}(\lambda)\,d\lambda}, \tag{2}$$

$$S_{\Delta\lambda}=\frac{\int\limits_0^{\infty} b_{st}(\lambda)\,S(\lambda)\,d\lambda}{\int\limits_{\Delta\lambda} b_{st}(\lambda)\,d\lambda}, \tag{3}$$

$$S_m=\frac{\int\limits_0^{\infty} B_{st}(\lambda)\,S(\lambda)\,d\lambda}{\int\limits_0^{\infty} B_{st}(\lambda)\,s(\lambda)\,d\lambda}, \tag{4}$$

where S_i, $S_{\Lambda\lambda}$, S_m = integral, absolute and effective sensitivity, respectively, of the radiometer's j-th channel; $B_{st}(\lambda)$, $b_{st}(\lambda)$ = absolute and relative spectral characteristic, respectively, of the emitter being used to calibrate the radiometer; $S(\lambda)$, $s(\lambda)$ = absolute and relative spectral sensitivity, respectively, of the radiometer.

Let us evaluate the effectiveness of the utilization of expressions (2)-(4) when calibrating an SS. We will mention here that during a remote investigation of the Earth's surface, for the purpose of detecting features of the objects being investigated it is, as a rule, necessary to have the capability of judging the spectral composition of the radiation rising above them. However, since the output signal of the radiometer's j-th channel is proportional to the integral of the product of two functions; that is,

$$g_j \sim \int_0^\infty B(\lambda)s(\lambda)\,d\lambda,$$

by its value alone it is impossible to make an unambiguous judgment about the spectral composition of the radiation being registered. From this it follows that the use of integral sensitivity when determining the brightness of an investigated object is possible only if the object and the emitter used during the calibration have the same spectral distribution of energy.

In the case of investigations of the Earth's surface, as a rule the spectral composition of the registered radiation is unknown, so integral sensitivity S_i cannot be used to calibrate the equipment, since it is determined to a considerable degree by the spectrum of the emitter used for the calibration.

Since SS's for investigating the Earth's surface have comparatively narrow spectral channels, we should assume it to be more nearly correct to calibrate the equipment according to its absolute sensitivity, which makes it possible to standardize the measurement results to some degree. In this case, however, there remains the standardization error, which is related to the impossibility of the precise determination of the effective width of the spectral channels, as well as the error caused by noncoincidence of the spectral characteristics of the emitter used during calibration and those of the source being measured within the limits of the spectral sensitivity zone of the channel being calibrated.

Equipment calibration according to effective sensitivity would be feasible providing that the form of the characteristics of the relative spectral sensitivity, which is identical for all the spectral channels of the SS being calibrated, is maintained. Since this condition is usually not fulfilled, when effective sensitivity is used it is necessary to introduce some normalizing factor for each spectral channel.

In connection with the special features of the different definitions of sensitivity that have been mentioned, it has been proposed that, during the calibration of an SS, its sensitivity to the spectral density of the energy brightness (or SPEYa) be determined in accordance with the expression

$$S_{SPEYa} = \frac{g}{B_{st}(\lambda_x)} = \frac{\omega \int_0^\infty B_{st}(\lambda)\,S(\lambda)\,d\lambda}{B_{st}(\lambda_x)}, \qquad (5)$$

where S_{SPEYa} = the sensitivity being determined; $B_{st}(\lambda_x)$ = SPEYa on the wavelength λ_x of the source used for calibration; λ_x = some wavelength within the limits of the spectral sensitivity of the instrument being calibrated. With such an approach, standardization of the measurement results takes place automatically during the calibration process. Calibration of instruments according to their sensitivity to SPEYa makes it possible, by using the results obtained with their help, to determine directly the SPEYa of an investigated object with the expression

$$B(\lambda_x) = \frac{g}{S_{SPEYa}},$$

where $B(\lambda_x)$ = SPEYa of the investigated object's radiation on wavelength λ_x.

Let us mention here that the magnitude of this error depends substantially on the choice of the wavelength λ_x on which the calibration is carried out. It is obvious that as λ_x we should choose that wavelength on which the ratio of the standard and measured sources' SPEYa equals the ratio of these same sources' effective brightnesses. In the case where this equality is fulfilled, the standardization error will be reduced to zero. The wavelength that corresponds to this condition is usually called the effective wavelength [4] and is given by the relationship

$$\frac{B_{st}(\lambda_e)}{B(\lambda_e)}=\frac{\int_0^\infty B_{st}(\lambda)s(\lambda)\,d\lambda}{\int_0^\infty B(\lambda)s(\lambda)\,d\lambda}. \qquad (6)$$

Let us mention here that in the general case, when there is no prior information on the spectral composition of the radiation being registered, it is not possible to determine λ_x from relationship (6). Moreover, λ_x will be different for each specific spectral characteristic B .

Let us assume, however, that spectral characteristics $B_{st}(\lambda)$ and $B(\lambda)$ are approximated by straight lines within the limits of the spectral sensitivity zone of the measuring channel being calibrated. This assumption is correct in most cases, since radiation from objects on the Earth's surface usually has quite smooth spectral characteristics, while the spectral channels of the measuring equipment are comparatively narrow. In this case it can be assumed that

$$\begin{aligned} B_{st}(\lambda)&=B_{st}^0+B_{st}^1\lambda,\\ B(\lambda)&=B^0+B^1\lambda, \end{aligned} \qquad (7)$$

where B^0_{st}, B^1_{st}, B^0, B^1 = some constant factors.

In this case, relationship (6) is rewritten in the form

$$\frac{B^0_{st}+B^1_{st}\lambda_e}{B^0+B^1\lambda_e}=\frac{\int_0^\infty (B^0_{st}+B^1\lambda)s(\lambda)\,d\lambda}{\int_0^\infty (B^0+B^1\lambda)s(\lambda)\,d\lambda}.$$

It is easy to show that from this relationship it follows that

$$\lambda_e=\frac{\int_0^\infty \lambda s(\lambda)\,d\lambda}{\int_0^\infty s(\lambda)\,d\lambda}, \qquad (8)$$

which coincides with the expression for the effective value of the wavelength that was introduced in [5,6] for the case of constant brightness. Let it be noted that factors B^0_{st}, B^1_{st}, B^0 and B^1 are not part of expression (8); that is, λ_e does not depend on the slope of straight lines (7) and, consequently, does not depend on the spectral composition of the standard and measured radiation. Thus, when determining equipment's sensitivity to SPEYa on wavelength λ_e, the standardization error will equal zero for measured radiation with any spectral composition. Let us emphasize again that this is correct only if the spectral characteristics of the standard and measured radiation can be approximated by straight lines within the limits of the area of sensitivity of the spectral channel being calibrated.

Thus, we should recognize the fact that it is actually feasible to calibrate the energy scales of on-board radiometric equipment in SPEYa units, relating the results of measurements to the wavelength λ_e, as determined from relationship (8), that is the effective wavelength for each spectral channel.

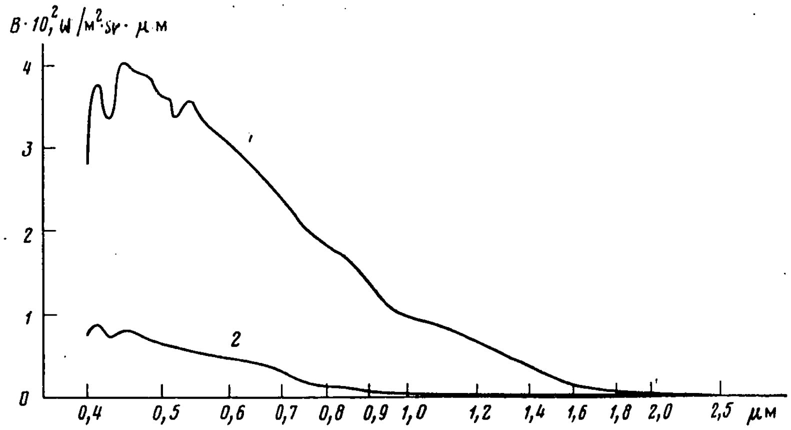

Figure 1. Evaluation of the range of brightnesses measured during an investigation of the Earth's surface from aerospace carriers at altitudes above 30 km, a solar zenith angle of 20°, and sighting along the nadir: 1. snow-covered surfaces; 2. water surfaces.

The selection for the "Fragment" system of the SPEYa unit as the physical unit for presenting measurement results predetermined the calibration method, which consisted of determining the relative spectral and absolute sensitivities of the channels as a condition for transmitting the chosen physical unit of the system's energy scale. The initial requirement for the formulation of this calibration method was the realization of an emitter having a known SPEYa within the limits of the spectral and dynamic operating bands of the "Fragment" system (Figure 1) and satisfying the condition

$$A_{rad} \geqslant D_{in} + l\Delta\beta_{max},$$

where A_{rad} = size of the emitter; D_{in} and $\Delta\beta_{max}$ = diameter of the intake aperture and maximum size of the "Fragment" system's field of view, respectively; ℓ = distance between the emitter and the SS being calibrated, which makes it possible to realize SS calibration using an elongated source [7].

In order to determine the dynamic range of the SPEYa values that must be measured by the "Fragment" MSS and reproduced by the emitter during calibration, an approximative prediction of the seasonal variations in the upper limit of the measured brightnesses was made. The prediction (Table 1) allowed for the seasonal change in the Sun's altitude for the area extending from 35° to 70° North Latitude at 1000 hours local time (LT).

Table 1. Seasonal Variations in Upper Limit of Theoretical Band of Measured Brightnesses (Relative Units)

Северная широта, град (1)	Январь (2)	Февраль (3)	Март (4)	Апрель (5)	Май (6)	Июнь (7)
70	0	0	$7,9\cdot 10^{-2}$	$3,2\cdot 10^{-1}$	$5,0\cdot 10^{-1}$	$6,6\cdot 10^{-1}$
65	0	$5\cdot 10^{-3}$	$1,3\cdot 10^{-1}$	$4,0\cdot 10^{-1}$	$6,0\cdot 10^{-1}$	$7,3\cdot 10^{-1}$
60	$1,7\cdot 10^{-3}$	$4,7\cdot 10^{-2}$	$2,3\cdot 10^{-1}$	$4,8\cdot 10^{-1}$	$6,8\cdot 10^{-1}$	$7,8\cdot 10^{-1}$
55	$4,7\cdot 10^{-2}$	$1,1\cdot 10^{-1}$	$2,9\cdot 10^{-1}$	$5,6\cdot 10^{-1}$	$7,5\cdot 10^{-1}$	$8,5\cdot 10^{-1}$
50	$1,1\cdot 10^{-1}$	$1,9\cdot 10^{-1}$	$4,0\cdot 10^{-1}$	$6,4\cdot 10^{-1}$	$8,1\cdot 10^{-1}$	$9,1\cdot 10^{-1}$
45	$1,9\cdot 10^{-1}$	$2,7\cdot 10^{-1}$	$4,8\cdot 10^{-1}$	$7,0\cdot 10^{-1}$	$8,6\cdot 10^{-1}$	$9,4\cdot 10^{-1}$
40	$2,7\cdot 10^{-1}$	$3,7\cdot 10^{-1}$	$5,6\cdot 10^{-1}$	$7,7\cdot 10^{-1}$	$9,1\cdot 10^{-1}$	$9,8\cdot 10^{-1}$
35	$3,8\cdot 10^{-1}$	$4,4\cdot 10^{-1}$	$6,2\cdot 10^{-1}$	$8,4\cdot 10^{-1}$	$9,4\cdot 10^{-1}$	1,0

Северная широта, град. (1)	Июль (8)	Август (9)	Сентябрь (10)	Октябрь (11)	Ноябрь (12)	Декабрь (13)
70	$6,8\cdot 10^{-1}$	$5,8\cdot 10^{-1}$	$4,0\cdot 10^{-1}$	$1,9\cdot 10^{-1}$	$5\cdot 10^{-3}$	0
65	$7,5\cdot 10^{-1}$	$6,6\cdot 10^{-1}$	$4,8\cdot 10^{-1}$	$2,7\cdot 10^{-1}$	$6,3\cdot 10^{-2}$	0
60	$8,0\cdot 10^{-1}$	$7,3\cdot 10^{-1}$	$5,6\cdot 10^{-1}$	$3,6\cdot 10^{-1}$	$1,5\cdot 10^{-1}$	$1,2\cdot 10^{-2}$
55	$8,6\cdot 10^{-1}$	$8,5\cdot 10^{-1}$	$6,4\cdot 10^{-1}$	$4,4\cdot 10^{-1}$	$2,3\cdot 10^{-1}$	$9,4\cdot 10^{-2}$
50	$9,1\cdot 10^{-1}$	$8,6\cdot 10^{-1}$	$7,1\cdot 10^{-1}$	$5,4\cdot 10^{-1}$	$3,4\cdot 10^{-1}$	$1,7\cdot 10^{-1}$
45	$9,5\cdot 10^{-1}$	$8,8\cdot 10^{-1}$	$7,8\cdot 10^{-1}$	$6,2\cdot 10^{-1}$	$4,2\cdot 10^{-1}$	$2,7\cdot 10^{-1}$
40	$9,8\cdot 10^{-1}$	$9,3\cdot 10^{-1}$	$8,4\cdot 10^{-1}$	$7,0\cdot 10^{-1}$	$5,0\cdot 10^{-1}$	$3,6\cdot 10^{-1}$
35	$9,9\cdot 10^{-1}$	$9,5\cdot 10^{-1}$	$8,8\cdot 10^{-1}$	$7,7\cdot 10^{-1}$	$5,5\cdot 10^{-1}$	$4,4\cdot 10^{-1}$

Key:
1. North Latitude, deg
2. January
3. February
4. March
5. April
6. May
7. June
8. July
9. August
10. September
11. October
12. November
13. December

The calculations were made with the expression

$$B_{j\,\max} = H_j \frac{\cos z_{\odot}}{\pi} r_j \exp\left[-(\tau_a + \tau_a \sec z_{\odot})\right],$$

where H_j = averaged value of the spectral solar constant in the j-th spectral interval, W/m^2; z_o = zenith angle of the Sun, deg; τ_a = optical thickness of the atmosphere in the vertical direction; r_j = coefficient of spectral brightness of a provisional bright object, as averaged for the j-th interval.

The theoretical values that were obtained for $B_{j\,\max}$ (Table 2) were compared with the results of corresponding measurements made on board a laboratory airplane (Table 3). These measurements were made with a special photometric instrument that measured the value of the energy brightness's spectral density in the spectral intervals, solid angles of the instantaneous fields of view, and range of sighting angles corresponding to the parameters of the project "Fragment" system.

The results of subsequent determinations of the value of the SPEYa of the Earth's surface, on the basis of materials gathered with the "Fragment" MSS on board a "Meteor" satellite during an interval that encompassed a sufficiently representative period of time from June 1980 to May 1981, confirmed (Figure 2) the adequate reliability of the prediction.

Table 2. Maximum Calculated Values of Spectral Density of the Energy Brightness in each "Fragment" MSS Spectral Interval of Sensitivity (35° N.Lat., June, 1000 Hours LT)

Спектральная плотность энергетической яркости, Вт·м⁻²ср⁻¹мкм⁻¹ (1)	Спектральный интервал, мкм (2)							
	0,4–0,7	0,5–0,6	0,6–0,7	0,7–0,8	0,8–1,1	1,2–1,3	1,5–1,8	2,1–2,4
$B_{j\,\max}$	320	320	270	210	133	70	33	13,3

Key:
1. Spectral density of energy brightness, $W{\cdot}m^{-2}sr^{-1}\mu m^{-1}$
2. Spectral interval, μm

Table 3. Results of Full-Scale Measurements of Spectral Density of the Brightness of the Earth's Surface (December 1976)

Сюжет и условия съемки (1)	Спектральный интервал, мкм (2)	Экспериментальные данные (3)			Экстраполяция к условиям табл. 2 $B_{j\,\max}$, Вт·м⁻²ср⁻¹мкм⁻¹ (6)
		$B_{j\,\max}$, (4) Вт·м⁻²ср⁻¹мкм⁻¹	δ_{B_j}, (5) Вт·м⁻²ср⁻¹мкм⁻¹	δ_{B_j}	
Дельта Волги (ледовые и снежные участки на воде и суше; заросшие камышом протоки; $z_\odot \approx 70°$, видимость более 30 км) (7)	0,4–0,7	80	3,3	4,1	315
	0,5–0,6	85	2,0	2,4	325
	0,6–0,7	13	0,9	7,1	—
	0,7–0,8	60	3,5	5,9	225
	0,8–1,1	—	—	—	—
Побережье Черного моря в районе Сухуми (кромка берега, участки водной поверхности и зеленой растительности; $z_\odot \approx 70°$, ясно) (8)	0,4–0,5	26	2,1	7,9	110
	0,5–0,6	—	—	—	—
	0,6–0,7	13	0,9	7,1	—
	0,7–0,8	40	2,8	7,1	170
	0,8–1,1	53	3,5	6,5	73

Key:
1. Subject and surveying conditions
2. Spectral interval, μm
3. Experimental data
4. $B_{j\,\max}$, $W{\cdot}m^{-2}sr^{-1}\mu m^{-1}$
5. δ_{B_j}, $W{\cdot}m^{-2}sr^{-1}\mu m^{-1}$
6. Extrapolation to conditions in Table 2 of $B_{j\,\max}$, $W{\cdot}m^{-2}sr^{-1}\mu m^{-1}$
7. Volga River delta (ice and snow sections on land and water; channels overgrown with reeds; $z_\odot \approx 70°$, visibility more than 30 km)
8. Black Sea coast near Sukhumi (edge of shore, sections of water surface and green vegetation; $z_\odot \approx 70°$; clear)

In accordance with the considerations explained above, the emitter that is used directly for calibration and, in connection with this, reproduces some SPEYa value inside the chosen dynamic range, should be metrologically tied in with the standard that reproduces the selected physical value. Since the final reliability of the measurement results turned out to be directly dependent on the standards used, the accuracy of the transmission of the SPEYa value from the standard to the working emitter, and the structure of the specific SS calibration method, special attention was given to the problems involved in selecting the standardization and calibration facilities.

Until recently, photometric equipment and methods based on light and temperature standards were primarily used to calibrate opticoelectronic systems. The changeover to energy values required complicated recalculations. In particular, the known color temperature of the luminous body of light-measuring bulbs was used to find its true temperature, after which the bulb's spectral brightness was calculated with the

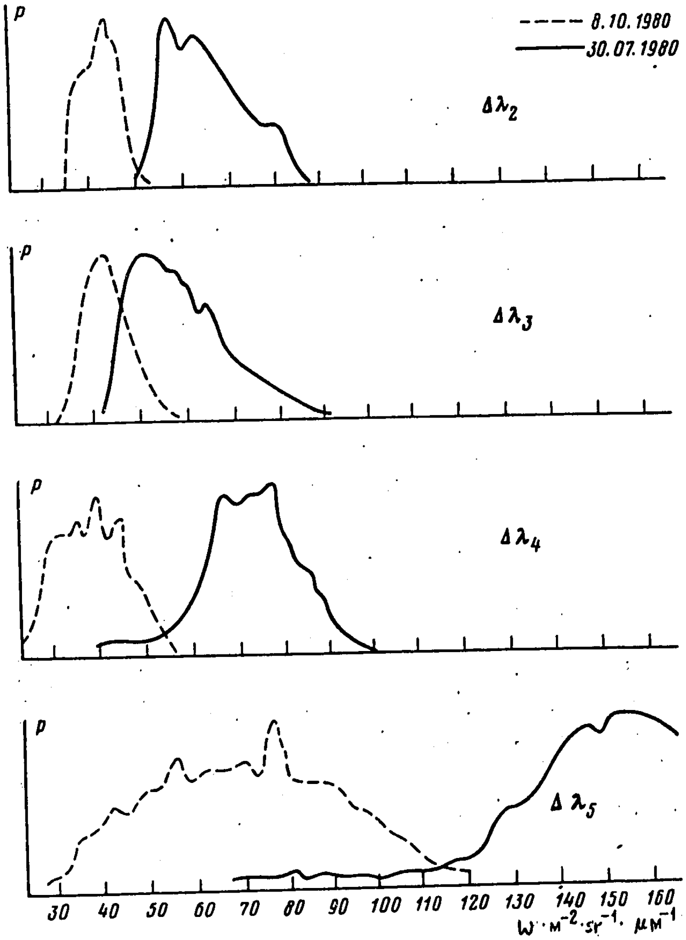

Figure 2. Histograms of SPEYa values of agricultural lands in the Don-Khoper interfluve, as derived from "Fragment" MSS survey materials gathered on 30 July 1980 and 8 October 1980: P = relative frequency of registration of SPEYa value.

help of data on the radiating capacity of tungsten. The need for such a recalculation, as well as the indeterminacy of the data used in it, resulted in substantial errors during calibration. Some investigators used different models of an absolutely black body during calibration. However, the low quality of these models, the inadequate analysis of their metrological characteristics, and the lack of standard, practical measurement techniques also resulted in significant errors.

The situation improved substantially with the creation and approval of a system of State Special Standards (GSE) for energy photometry that differ in both operating principle and the spectral band used [8].

One of these standards--the State Special Standard for the Spectral Density of Energy Brightness in the 0.25-2.5 μm Band [9]--was also used as the basis for the

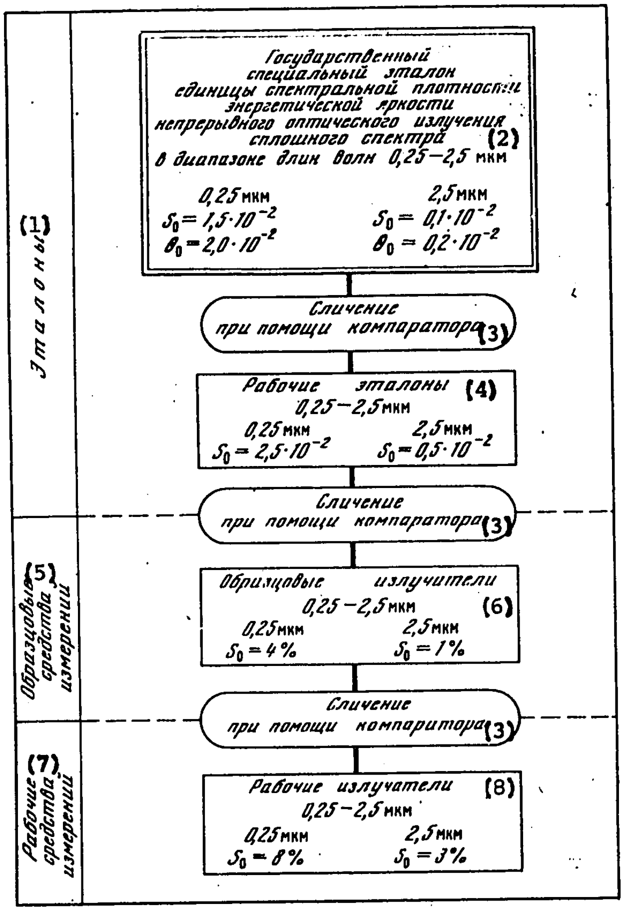

Figure 3. Union-wide testing method for equipment for measuring the spectral density of the energy brightness of continuous optical radiation in a continuous spectrum in the 0.25-2.5 μm band: Θ = uneliminated systematic error; S = root-mean-square deviation.

Key:

1. Standards
2. State Special Standard for Unit of Spectral Density of Energy Brightness of Continuous Optical Emissions in a Continuous Spectrum in the 0.25-2.5 μm band
3. Comparison, using a comparator
4. Working standards
5. Prototype measurement equipment
6. Prototype emitters
7. Working measurement equipment
8. Working emitters

formulation of the calibration methods for the "Fragment" MSS, which operates within the limits of this spectral band. The use of this standard was based on the approved testing method for equipment for measuring the spectral density of energy brightness (Figure 3). In this setup the SPEYa unit is passed from the GSE to the working standard, which is based on a series-produced SI10-300U ribbon-filament lamp or a special lamp of the "black body" type. From the SPEYa working standard, the SPEYa unit is passed to prototype measuring equipment based on SI10-300U or SI8-200U

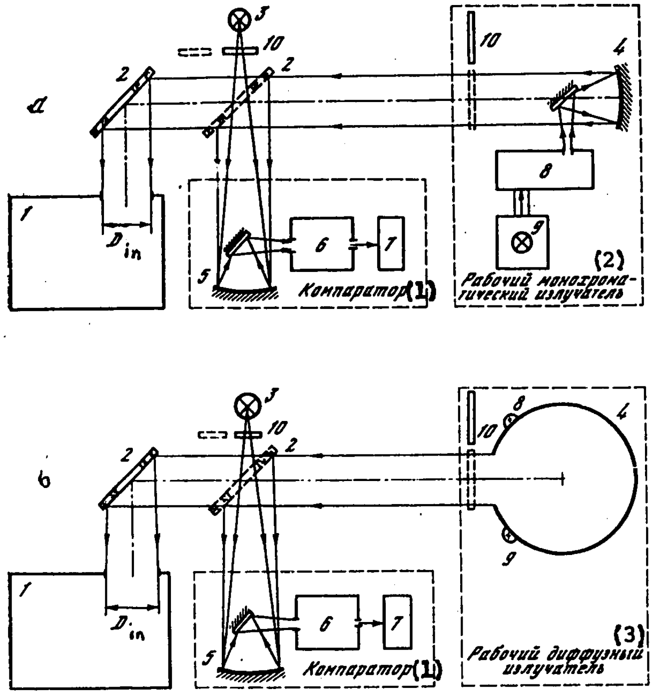

Figure 4. Setup for measurement of relative spectral characteristic (a) and absolute sensitivity (b) of surveying systems: a: 1. surveying system; 2. deflecting flat mirror; 3. prototype measurement means (SI10-300U lamp); 4. collimator mirror; 5. optical system of comparator; 6, 8. twin monochromators; 7. block of comparator photoreceivers; 9. halogen lamp; 10. shutters; b: 1. surveying system; 2. deflecting flat mirror; 3. prototype measurement means (SI10-300U lamp); 4. diffuse illuminator; 5. optical system of comparator; 6. twin monochromator; 7. block of receivers; 8, 9. halogen lamps of illuminator; 10. shutters.

Key:
1. Comparator
2. Working monochromatic emitter
3. Working diffuse emitter

lamps. At the surveying system calibration stage, prototype measurement equipment must be used. Figure 4 depicts simplified setups for the two calibration stages.

Let us concentrate on a discussion of the possible sources and comparative magnitudes of the errors that affect the final result of a measurement. Let us mention here that, first of all, the final result must contain errors related to the transmission of the SPEYa unit from the standards to the prototype means that are defined in GOST [All-Union State Standard] 8.196-76 [9]; depending on the wavelength, they can be as large as several percent.

Among the calibration error sources we can include instability of the radiation sources' brightness, nonlinearity and instability of the calibration setup's comparator, nonreproducibility of the monochromators' wavelengths, noncoordination of the emitter's and comparator's monochromators' wavelengths. However, careful construction of the installation used for calibration, preliminary selection of the photoreceivers used in the comparator and the introduction of different systems for monitoring the stability of the emitters' operating modes make it possible to reduce these errors to values on the order of 1 percent.

Thus, in our case the accuracy of the SS's energy calibration was basically determined by the error in the transmission of the SPEYa unit from the standard to the prototype and working measurement equipment, and was standardized at a level of several percent. This means that, inasmuch as the joint processing of data from a minimum of several SS's is necessary for remote investigations of the Earth, when constructing the SS's it is not advisable to require an equipment accuracy level of better than 1-3 percent for each separate SS operating in the 0.25-2.5 μm band, which figure was realized during the creation of the "Fragment" MSS (Table 4).

Table 4. Averaged Certified Characteristics of "Fragment" MSS

(1) Спектральные интервалы		Случайная среднеквадратическая аппаратурная погрешность в полном динамическом диапазоне, % (4)	Коэффициент перехода от значений выходного кода к измеренной величине СПЭЯ, Вт·ср$^{-1}$·м$^{-2}$·мкм$^{-1}$ (5)			Эффективная длина волны λ_e, мкм (7)
обозначение (2)	полуширина, мкм (3)		Режимы усиления (6)			
			I	II	III	
$\Delta\lambda_1$	0,397—0,627	0,8	$1,33\cdot10^{-1}$	$5,04\cdot10^{-1}$	1,63	0,545
$\Delta\lambda_2$	0,508—0,586	1,0	$2,49\cdot10^{-1}$	$8,59\cdot10^{-1}$	2,36	0,543
$\Delta\lambda_3$	0,601—0,679	1,5	$2,01\cdot10^{-1}$	$6,71\cdot10^{-1}$	2,30	0,638
$\Delta\lambda_4$	0,688—0,743	1,8	$1,67\cdot10^{-1}$	$5,52\cdot10^{-1}$	1,65	0,715
$\Delta\lambda_5$	0,824—0,935	2,8	$1,36\cdot10^{-1}$	$3,98\cdot10^{-1}$	1,19	0,890
$\Delta\lambda_6$	1,166—1,305	2,1	—	$4,90\cdot10^{-1}$	—	1,240
$\Delta\lambda_7$	1,516—1,698	1,9	—	$3,16\cdot10^{-1}$	—	1,620
$\Delta\lambda_8$	2,080—2,304	2,4	—	$1,27\cdot10^{-1}$	—	2,200

Key:
1. Spectral intervals
2. Designation
3. Half-width, μm
4. Random root-mean-square equipment error in full dynamic range, %
5. Coefficient of conversion from output code to measured SPEYa value, W·sr^{-1}·m^{-2}·μm^{-1}
6. Amplification modes
7. Effective wavelength λ_e, μm

Let us emphasize that insuring a root-mean-square random measurement error at a level of several percent requires special construction of the entire information-carrying channel. Actually, repeated conversion of the information in the channel will lead to losses of it until the entire measurement process is completed; that is, until the comparison of some intermediate signal with a standard (the unit of measurement) and the acquisition of a real number (the encoded signal). The encoded signal, which is more resistant to noise and interference than the analog representation of the information, makes it possible to eliminate almost entirely the effect of subsequent parts of the information and measuring complex on the measurement results. Consequently, by carrying out the measurement process as close as possible to the SS's input element, information losses can be reduced; from this there naturally follows the necessity of including an encoding unit in the SS (the on-board part of the information and measurement complex) and using a digital radio link [2,10].

However, the encoding units (analog-to-digital converters (ATsP)) used in on-board optical-band SS's only convert an electrical signal into a concrete number. As a result of instability in the preceding opticoelectronic conversion units, measurement errors are generated that, as a rule, exceed the allowable level by several percent. Because of this it is necessary to introduce special monitoring of the stability of the analog opticoelectronic conversion units in the SS and some kind of procedure for correcting the measurement results according to the data provided by this monitoring.

Let us discuss the principles of the realization of this monitoring in the "Fragment" MSS. In this system, the analog opticoelectronic conversion members include the receiving optical system, which consists of the scanning mirror and mirror lens, the fiber-optic selector with spectral band-pass filters, and the photoreceiving devices (FPU) [2].

The stability of the receiving optical system's parameters is determined by the deterioration caused by the effect of the conditions encountered in space; this primarily means hard radiation and micrometeorite bombardment. The use of mirror optics made it possible to assume negligibly little deterioration because of hard radiation, while the effect of micrometeorite bombardment during the calculated operating period (1 year) also turned out to be almost unfelt [11], so this unit's conversion function was assumed to be practically constant.

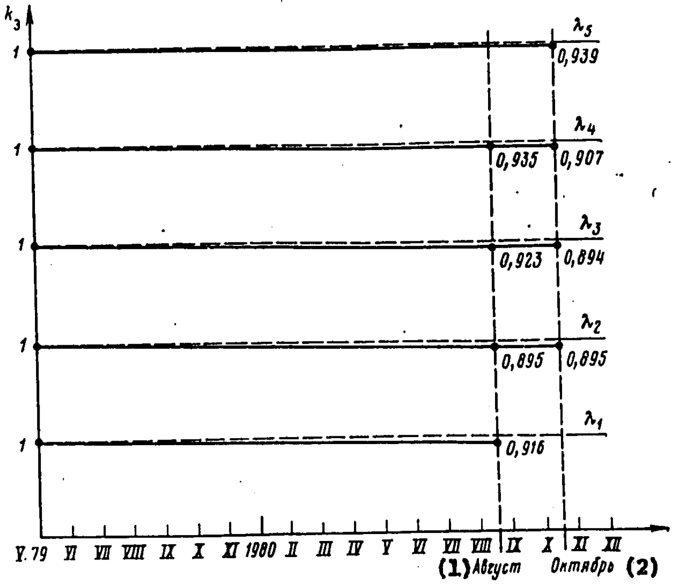

Figure 5. Change in coefficient k_e of decrease in working reference emitter's intensity relative to the standard reference emitter for the "Fragment" MSS during preflight tests and the first months of the flight.
Key: 1. August 2. October

The stability of the conversion performed by all the subsequent analog members is monitored and corrected automatically by a special reference emitter that was added to the conversion channel with the help of an opticomechanical commutator with a periodicity on the order of the scan tracking; that is, about every 70 ms [2]. The comparatively slow deterioration of the reference emitter, which was about 10 percent during the year-long preflight adjustment period and during the first months of the flight (Figure 5), has been evaluated by the episodic introduction into the channel of a monitoring emitter and can be allowed for quite easily during ground processing of the measurement results.

Thus, one of the basic goals formulated during the creation of the "Fragment" MSS--the acquisition of video information about the spatiotemporal structure of the brightness field of the Earth's surface that is suitable for automated processing and has objective measurement properties--has been achieved because of the realization of the appropriate metrological support.

The "Fragment" MSS has been certified, in accordance with the proposed principles and techniques, as an instrument for measuring the spectral density of the energy brightness of the Earth's surface in the 0.4-2.5 μm band, with the basic characteristics presented in Table 4 and Figure 6.

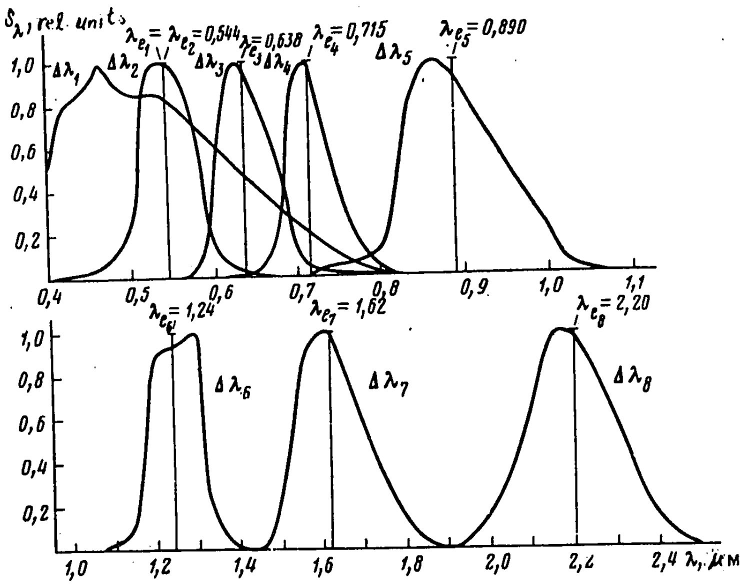

Figure 6. Relative spectral sensitivity characteristics of "Fragment" MSS, as averaged for six measuring channels for $\Delta\lambda_1$-$\Delta\lambda_5$ and three for $\Delta\lambda_6$ and $\Delta\lambda_7$.

The digital codes that are the result of the measurements made by the "Fragment" MSS can be used to determine, with up to 5 percent accuracy, the values of the absolute SPEYa of corresponding sections of the Earth's surface, as observed from a satellite, on effective wavelengths lying within the SS's eight spectral sensitivity intervals [2], it being the case that the effect of the spectral distribution of the brightness of an investigated section on the measurement result, which has been minimized because of the calibration method that was selected, can be eliminated by the use in the data processing operations of a specially developed computation procedure [12] that makes it possible to reproduce the true nature of the spectral distribution of the brightness of an unknown object that is being investigated.

FOOTNOTE

1. Such an approach is correct not only for radiometers with a narrow instantaneous viewing field angle, but also for frame surveying systems (television and photographic systems, for example), which in this case can be regarded as a set of a large number of radiometric channels with a small field of view, the size of which is determined by the element of spatial quantification realized during the processing of the information.

BIBLIOGRAPHY

1. Sychev, A.G., and Tarnopol'skiy, V.I., "On the Spectroradiometric Characteristics of Multispectral Surveying Systems," in "Mnogozonal'nyye aerokosmicheskiye s"yemki Zemli" [Multizonal Aerospace Surveys of the Earth], Moscow, Izdatel'stvo "Nauka", 1981, pp 87-93.

2. Avanesov, G.A., Glazkov, V.D., Ignatenko, S.A., et al., "The 'Fragment' Multizonal Scanning System," this issue, pp 45-56.

3. Kholopov, G.K., and Shuba, Yu.A., "On Standardizing the Sensitivity of Radiometers," OMP [expansion unknown], No 10, 1977, p 6.

4. Kholopov, G.K., "On Calculating the Effective Wavelength of a Measuring System," ZhPS [possible Journal of Applied Science], Vol 23, No 2, 1975, p 354.

5. Strömgren, B., "Handbuch der Experimental Physik", Leipzig, Akademische Verlags Gesellschaft mbH, Vol 26, 1937, 321 pp.

6. Kod, A.D., "Energy Distribution in Stellar Spectra," in "Zvezdnyye atmosfery" [Stellar Atmospheres], Moscow, 1963, pp 73-74.

7. Kelton, G., et al., "Infrared Target and Background Radiometric Measurements: Concepts, Units and Techniques," INFRARED PHYSICS, Vol 3, 1963, pp 139-169.

8. Katyuk, A.F., Panasyuk, V.S., Samoylov, L.N., et al., "Unified System of State Standards for the Energy Photometry of Coherent and Noncoherent Optical Radiation," IZMERITEL'NAYA TEKHNIKA, No 3, 1976, pp 17-24.

9. "Gosudarstvennyy spetsial'nyy etalon i obshchesoyuznaya poverochnaya skhema dlya sredstv izmereniy spektral'noy plotnosti energeticheskoy yarkosti nepreryvnogo opticheskogo izlucheniya sploshnogo spektra v diapazone dlin voln 0.25-2.5 μm" [State Special Standard and All-Union Testing Method for Equipment for Measuring the Spectral Density of the Energy Brightness of Continuous Optical Radiation in a Continuous Spectrum in the 0.25-2.5 μm Band], GOST 8.196-76.

10. Avanesov, G.A., "Experimental Information and Measurement Complex Based on the 'Fragment' Multizonal Scanning System," this issue, pp 40-44.

11. Karachentsev, I.D., "Effect of Micrometeorite Particles on the Optical Surfaces of Telescopes Beyond the Earth's Atmosphere," ISKUSSTVENNYYE SPUTNIKI ZEMLI, No 15, 1963, pp 57-65.

12. Bogdanov, A.A., Nalimov, V.N., Sychev, A.G., et al., "On the Possible Improvement of Radiometric Accuracy During Remote Investigations of the Earth With Multizonal Surveying Systems," ISSLEDOVANIYE ZEMLI IZ KOSMOSA, No 3, 1981, pp 77-94.

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CSO: 1866/18

UDC 528.711.4:53.089.6

PREFLIGHT PHOTOGRAMMETRIC CALIBRATION OF 'FRAGMENT' MULTIZONAL SURVEYING SYSTEM

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 12 Jun 81) pp 78-81

[Article by Ya.L. Ziman and V.I. Yurov, Institute of Space Research, Moscow]

[Text] The multipurpose utilization of space video information about the Earth that is obtained with scanning opticoelectronic surveying devices--the "Fragment" multizonal scanning system (MSS) in particular--predetermines the necessity of carrying out photogrammetric processing of this information for the purpose of determining the geometric characteristics of terrestrial formations and their geographic coordinate correlation. In recent years there have been quite a few publications devoted to the discussion of the geometry of images obtained with scanning surveying systems and the photogrammetric calibration of these systems. However, this problem cannot yet be regarded as solved. In view of this, during the preparations for the structural flight testing (LKI) of the "Fragment" MSS, a special technique was developed for its photogrammetric calibration and the instrument package enabling this technique to be realized was created.

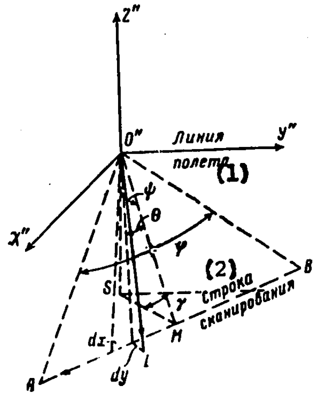

Figure 1. Parameters determining the scanning geometry.
Key: 1. Line of flight
2. Scanning line

In connection with the photogrammetric calibration of the "Fragment" MSS, the problem of determining its following elements was formulated (a large part of these elements is shown in Figure 1):
focal length of the lens;
geometric characteristics of the matrix of the fiber-optic splitter (VOR) (dimensions of the matrix's elements and their relative positions) [1];
orientation angles of the VOR's matrix in the instrument's system of coordinates--O"X"Y"Z"--as determined by its mounting brackets;
the viewing angle ϕ between the scanning rays corresponding to the first and last elements of the lines of acquired video information. The projecting rays corresponding to the first and last elements of a line determine the scanning plane O"AB;
angles ψ, γ and θ, which determine the orientation of scanning plane O"AB in the

system O"X"Y"Z" (angle ψ characterizes the inclination of scanning plane O"AB to the O"Z" axis of the system of coordinates of the instrument being tested; γ is the angle between the plane O"MS, which is perpendicular to O"AB and passes through O"Z", and the O"Y" axis; θ is the angle in the scanning plane between O"M and the bisector of angle O"AB);
the longitudinal and transverse distortion of the images obtained (transverse distortion dy is the image element displacement caused by divergence of the scanning beam O"L from scanning plane O"AB; longitudinal distortion is the image element displacement along a line caused by divergence of the beam's actual scanning setup from the projected scanning law);
the total scanning period T (the time interval between registration of two elements of the same order on adjacent lines);
the active scanning period T_a (the time interval between registration of the first and last element on a single line).

The lens's focal length and the dimensions and relative position of the VOR matrix's elements were measured by known methods before their installation in the instrument. All the other elements were determined for a functioning instrument with the help of a specially developed technique [2].

This technique is based on the possibility of forming a narrow light beam that moves in space, the registration of this beam by the MSS, and the determination in an external coordinate system of its position and the position of the investigated instrument's coordinate system O"X"Y"Z".

Angles ϕ, ψ, γ and θ are calculated on the basis of data from measurements of the directions of projecting beams O"A and O"B in the O"X"Y"Z" coordinate system. In order to determine longitudinal and transverse distortion, in addition to the measurement of the directions of O"A and O"B there were measurements of the directions of beams corresponding to certain points on a line, and these data--with due consideration for the scanning law--were used as the basis for calculating the values of dx and dy corresponding to those points.

An image line is formed in each zone of the spectrum, and these lines are arranged parallel to each other. In order to establish the relationship of the coordinates of line points obtained in different spectral zones, it is necessary to know the matrix of radiation receivers is oriented with respect to the line. If the matrix's characteristics are known, in order to determine its orientation elements it is sufficient to know the coordinates of the elements that are the matrix's "coordinate marks" and the simultaneous angular position of the zonal scanning beams that correspond to them.

Since the VOR matrix is set immovably in the lens's focal plane, its position can be determined by a single parameter β, which is the angle between a scanning line and the symmetry of the matrix corresponding to that line.

Period T is measured for an unmoving light beam that is registered periodically by the MSS. In order to measure active scanning time T_a, the light beam is oriented in such a manner that it is received by the surveying equipment while surveying the last element of a line. In this case the time interval is measured between signal pulses, one of which corresponds to the initial element of a line, while the second corresponds to the position of the last element of that line.

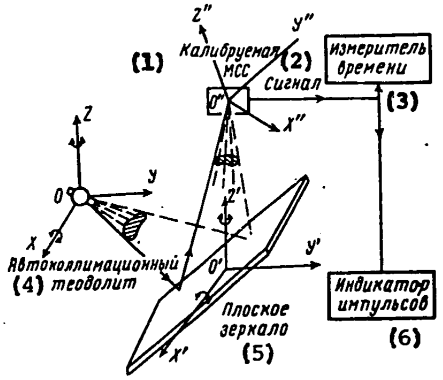

Figure 2. Layout of installation for photogrammetric calibration of opticoelectronic scanning systems.

Key:
1. MSS being calibrated
2. Signal
3. Timer
4. Autocollimating theodolite
5. Flat mirror
6. Pulse detector

Figure 2 depicts the layout of the installation that makes it possible to register the beam's position at certain moments of time. The setup consists of an autocollimating theodolite, a flat mirror with two degrees of freedom and the appropriate goniometric attachments, a detector of the pulses arriving from the photoreceivers of the instrument being calibrated, and a timer for recording the arrival of signals.

Turning of the autocollimating theodolite and the flat mirror makes it possible to change the direction of the light beam that is formed by the theodolite and enters the MSS's input, in connection with which the dimensions of the mirror and the relative positions of the instrument being calibrated, the theodolite and the mirror insure the formation of a bundle of beams that are directed into the scanner's optical system and cover its entire viewing field. The discrete positions of the theodolite and the mirror that insure the entry of the light beam into the MSS are found, for different fixed positions of the scanning mirror, by visual observation in the theodolite of the illuminated elements of the VOR's matrix (in the so-called static mode). In the operating instrument (in the dynamic mode), the moments the light beam is registered by the photoreceivers are reflected by the arrival of pulsed signals from them. The acquisition of a signal corresponding to a given line element is insured by the theodolite's and mirror's orientation search mode. The approximate orientation of the theodolite and mirror that insures the rapid finding of the given orientation in the dynamic mode, when the system calibration is carried out, is determined in the static mode.

In the dynamic mode, when a light beam strikes the scanner's field of view, two impulses are visible on the pulse detector, which visualizes the scanning of a line: the first is from the marker of the beginning of a line, while the second is from the measuring device. When a pulse appears on the detector, the orientation of the theodolite's beam, the mirror's plane and the time interval between the moments of registration of the initial pulse and the signal from the light beam are measured. In addition to these measurements, there is also coordinate correlation of the mounting planes of the instrument being calibrated relative to the measuring device's coordinate system (OXYZ for the autocollimating theodolite or O'X'Y'Z' for the mirror).

Repeated measurements of each of the unknown parameters make it possible to evaluate the accuracy of the determinations that are made. Formulas for calculating these elements and their errors are presented in [3].

Experimental investigations of the photogrammetric characteristics of the "Fragment" multizonal scanning system were conducted on the basis of the technique explained above. The results of these investigations are presented in Table 1. Primary

Table 1. Parameters of the "Fragment" Multispectral Scanning System

Item	Value of Parameter	Accuracy
Viewing angle	7°35'34"	±00'22"
Orientation angles γ, ψ and θ of scanning plane relative to MSS's system of coordinates	-0°48'36" 0°14'54" -0°22'42"	±00'11" ±00'10" ±00'17"
Angle β between a line and the line of symmetry of the VOR matrix's position	-9°12'00"	±00'05"
Scanning period	76.78 ms	±0.055 ms
Active scanning time	51.43 ms	±0.059 ms

Table 2. Scanning Line Distortion

Line Element Number	Transverse Component	Longitudinal Component
1	0.0	0.0
205	3.6	9.2
409	-0.7	10.8
614	0.5	9.5
819	-0.4	14.1
1,024	0.0	0.0

processing of the video information acquired during the LKI of the "Fragment" MSS, which makes it possible to monitor the measurement of the last two parameters on board, indicates that the effect of space surveying conditions on the instrument's characteristics are insignificant. For instance, according to the LKI data the scanning period is 76.78±0.039 ms and the active scanning time is 51.24±0.064 ms.

Distortion values for six points on a line are presented in Table 2.

The distortion values are given in fractions of an element of resolution. The error in determining the transverse and longitudinal components of distortion was ±0.3 and ±0.7 of an element of resolution. Judging from the data in Table 2, the transverse component of distortion can be ignored, since in most cases it does no exceed a single element of resolution. It is necessary to allow for the longitudinal component of distortion when the goal of precise photogrammetric processing of the acquired photographs is set.

In conclusion, let us mention that the results of the geometric calibration confirmed the good quality of the production and assembly of the parts of the "Fragment" multizonal scanning system that affect the geometric characteristics of the image that is formed. The data presented in Tables 1 and 2 can be used to correct acquired video information at the stage of its geometric transformation.

BIBLIOGRAPHY

1. Avanesov, G.A., Glazkov, V.D., and Tarnopol'svkiy, V.I., "Development of a Specialized Opticoelectronic System for the Operational Collection of Multispectral Video Information About the Earth's Surface From an Artificial Earth Satellite," in "Mnogozonal'nyye aerokosmicheskiye s"yemki Zemli" [Multizonal Aerospace Surveys of the Earth], Moscow, Izdatel'stvo "Nauka", 1981, pp 57-76.

2. Yurov, V.I., "Method for the Photogrammetric Calibration of Optical Scanning Systems," Patent No 717534, 25 February 1980, OTKRYTIYA, IZOBRETENIYA, PROMYSHLENNYYE OBRAZTSY, TOVARNYYE ZNAKI, No 7, 1980.

3. Yurov, V.I., "Geometric Calibration of Surveying-Searching Scanning Systems," GEODEZIYA I KARTOGRAFIYA, No 2, 1979, pp 26-31.

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CSO: 1866/18

UDC 551.46.0:629.78

INVESTIGATION OF CONDITIONS FOR SURVEYING OCEAN'S SURFACE IN 0.4-1.1 μm BAND OF THE SPECTRUM

Moscow ISSLEDOVANIYE ZEMLI IZ KOSMOSA in Russian No 5, Sep-Oct 81 (manuscript received 22 May 81) pp 82-89

[Article by A.S. Selivanov, Yu.M. Gektin, A.S. Panfilov and A.B. Fokin]

[Text] At the present time a great deal of attention is being devoted to the study of such objects and phenomena in the ocean as frontal zones, meanders, vortices and internal waves, which exist over almost the entire range of spatial and temporal scales [1].

Systematic investigations of frontal zones by remote methods, using equipment installed in aircraft and satellites, is being done primarily in the far-infrared band of the spectrum; that is, by obtaining images of thermal contrasts on the ocean's surface [2,3]. Analysis of these images makes it possible to observe the formation development processes of frontal zones, meanders and vortices in different areas of the ocean [4,5].

Analogous information can be obtained in the visible and near-infrared bands of the spectrum (from 0.45 to 1.1 μm). Such observations can be an essential supplement to the thermal images as far as eliminating the effect of the atmosphere is concerned [6], as well as discovering front genesis processes that do not have surface thermal contrasts. Besides this, radiometers functioning in the visible band of the spectrum have (as a rule) higher spatial resolution, which makes it possible to study the fine structure of such phenomena.

Until recently, observations of frontal zones in the visible and near-infrared bands were of an episodic nature. The basic reason for this is that observations of such phenomena with equipment intended primarily for investigating land areas are possible only when certain observation conditions that are realized extremely rarely are fulfilled. For a purposeful study of them, it is necessary to have equipment that is specially oriented for this purpose. At the present time, however, there are no clearly formulated requirements for conditions for observing frontal zones and requirements for observation equipment that emanate from these conditions.

Some of the first experimental surveying data in the visible and near-infrared bands of the spectrum were obtained with a hand-held camera on board the "Salyut-6" orbital station [7]. Only approximate information relative to the conditions for obtaining these photographs was available, since the conditions were not set specially and were not studed with the necessary degree of reliability. Therefore, a series of projects for the making of analogous observations with automatic satellites, airplanes and ships were carried out. "Meteor"-series satellites were used for surveying with low- and medium-resolution multizonal scanning equipment operating in the 0.5-1.1 μm band that had spatial resolution of 1 km and 240 m for viewing belts of 2,000 and 1,400 km, respectively [8,9]. Figures 1-3 [not reproduced] are quite typical images of the ocean surface, showing meanders, vortices and internal waves.

Analysis of the information that was acquired made it possible to determine the optimum conditions for observing frontal zones, as well as to advance a number of hypotheses concerning the nature of the observed optical phenomena.

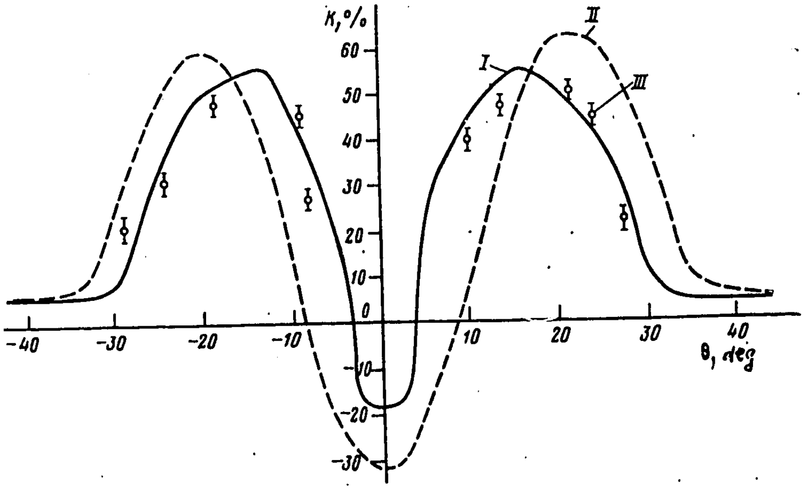

Figure 4. Dependence of magnitude of contrast on the angular distance to the center of a light spot for $Z_{\odot} = 50°$: I. experimental curve plotted from aerial surveying data; II. theoretical curve; III. satellite data.

First of all, it was established that the maximum contrasts ($K = L_{max} - L_{min}/L_{max}$, where L is the object's brightness) on a water surface are observed in the area of a patch of direct sunlight. All the images of contrasting formations on the water's surface that are seen in the photographs are clearly visible at no more than 30-40° along the azimuth from the center of a light spot. Analogous results are obtained in surveys of sliki [probably oil slicks] in the area of a patch of sunlight made from airplanes (regardless of the nature of the slicks' formation). However, it should be mentioned that for large observation angles from the center of a light spot (more than 30°) the contrasts on the surface do not disappear, but remain constant for all azimuthal angles at a level of 5-7 percent. Figure 4 shows the experimental dependence of the magnitude of contrast K on the azimuthal deviation Δθ of the sighting direction from a spot of light's geometric center, as derived from the results of surveying done from an airplane and a "Meteor" satellite.

The dependence of the amount of contrast on the sighting angle β, as measured from the vertical, was determined experimentally with the help of photographs made from an airplane at different Sun heights. Figure 5 shows the results obtained for observations of the central part of a patch of light and for an area located in an

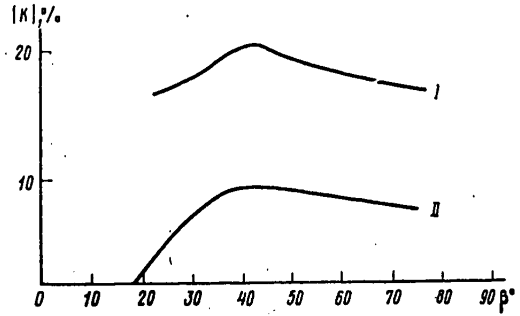

Figure 5. Dependences of absolute magnitude of contrast |K| on sighting angle β: I. for observations of the central part of a patch of light; II. for an azimuthal angle of about 120° from the direction to the center of the patch.

azimuthal direction of 120° relative to the direction to the patch. From Figure 5 it is obvious that the maximum values of K are seen for angles β $\approx$ 40°.

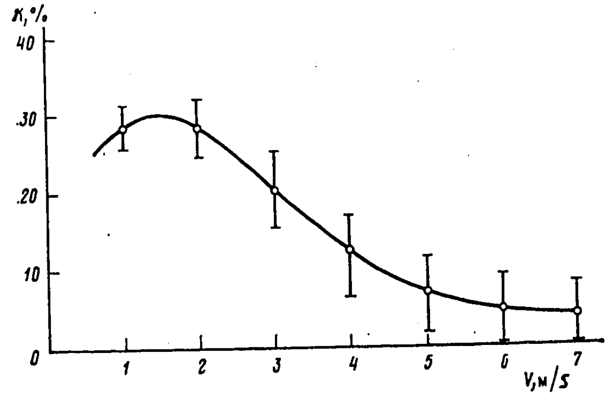

Figure 6. Dependence of magnitude of contrast for the area of a light spot on the velocity of the low-level wind.

The velocity of the wind near the surface and the choice of the plane of polarization of the radiation during observations have a considerable effect on contrast in an image. As the wind speed increase, contrasts decrease gradually and begin to disappear at speeds of 5-7 m/s (Figure 6). Rotating the polarization plane during observations through an angle of 90° relative to the plane with K_{max} also leads to a considerable decrease in contrast.

As the result of an analysis of the images that have been obtained, a weakly expressed spectral selectivity of the observed phenomena in the investigated band of wavelengths has been established. Figure 7 depicts the dependences of the amount of contrast of surface formations on the wavelength, as plotted from satellite and aircraft observation data. Although an insignificant drop in the magnitude of the contrasts in the infrared band is visible in Figure 7, it does not go beyond the limits of measurement accuracy.

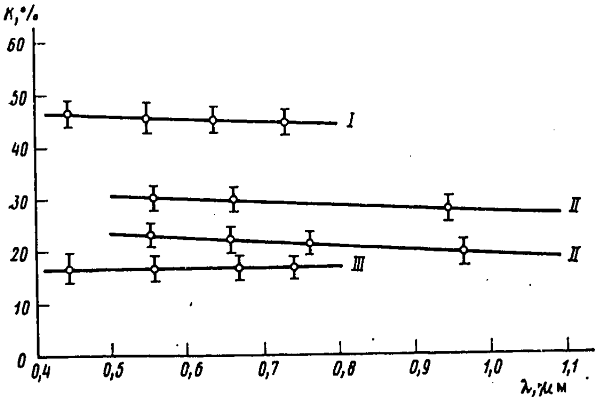

Figure 7. Dependence of magnitude of contrast on the spectral area of observation: I. aerial surveying from altitude H = 6 km; II. satellite observations from H = 650 km; III. ship surveying from H = 12 m.

Observations made in the area of a patch of light--particularly the nonselectivity of the contrasts right up to the near-infrared band (for water this is an area of total absorption) and the polarization effects--make it possible to suggest that frontal zone observations are possible because of the surface manifestation of various dynamic processes. The contribution of radiation coming from under the water's surface is so small that in the area of a patch of light it can be ignored completely[1].

Let us discuss the following model of observed phenomena: the contrasts on an image of a water surface are formed because of differences in the spectrum of the wave action, which modulate the observed brightness field; differences in the wave action spectrum are caused by the interaction of wind-caused surface wave action with subsurface dynamic processes.

Such interaction is quite well known for internal waves and nonuniform currents [10-12], it being the case that waves measuring from 1-2 to 20-30 cm long play the basic role in these processes.

As an example, let us compute the magnitudes of the contrasts formed during the interaction of wind-caused wave action with internal waves. In order to do this we will use the functions of the distribution of surface slopes because of wind velocity [13,14]. The brightness of the surface in the area of a patch of sunlight can then be represented as follows [15]:

$$L = \mathrm{const}\left[\exp\left(\frac{\Delta\theta^2}{2\sigma_0^2}\right) L_{п}\rho_{п}(\sigma) + L_{р}\rho_{р}(\sigma)\right], \qquad (1)$$

where L_{π}, L_p, ρ_{π}, ρ_p = brightness and reflection factor for direct solar radiation

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[1] It is necessary to mention that outside the area of a light spot, where the contrasts do not exceed 5-7 percent, observed phenomena do not have to be entirely of a surface nature: manifestations of such factors as the color of the water, turbidity, bottom relief and so on are possible there.

and solar radiation scattered by the sky; σ_0^2 = dispersion of the surface slopes; $\Delta\theta$ = angular deviation of the sighting direction from the patch's geometric center; const = a constant allowing for the geometric observation conditions. The relationship of the dispersion of the marine surface's slopes during interaction with internal waves σ^2 and without them σ_0^2 is determined with the formula [15]

$$\sigma^2 = \sigma_0^2 \exp\left[R \frac{U}{C}\right], \tag{2}$$

where

$$R = -5{,}1\lg\left(\frac{V}{C}\right) + 6{,}47;$$

V = wind velocity; C = phase velocity of the internal wave; U = orbital velocity of the particles.

Image contrast $K = (L - L_0)/L_0$, where L_0 and L are the brightness of a surface "undisturbed" and "disturbed" by an internal wave, can then be calculated with the formula

$$K = \frac{\exp\left(-\frac{\Delta\theta^2}{2\sigma_0^2}\right) - \frac{\sigma_0}{\sigma}\exp\left(\frac{\Delta\theta^2}{2\sigma^2}\right) + \frac{L_{\text{p}}}{L_{\text{п}}\rho_{\text{п}}}(\rho_{\text{п}} - \rho_{\text{p}})}{\frac{L_{\text{p}}\rho_{\text{p}}}{L_{\text{п}}\rho_{\text{п}}} + \exp\left(-\frac{\Delta\theta^2}{2\sigma_0^2}\right)}. \tag{3}$$

When evaluating the value of $L_p\rho_p/L_\pi\rho_\pi$ we will take into consideration only the scattered sky radiation (index p) near the Sun. This is correct for an analysis of the reflected radiation in the area of a patch of light, since scattered radiation in this area is considerably brighter than in other parts of the sky and is reflected from the water's surface in the same directions as the direct radiation (index π).

The experimental value is $L_p/L_\pi \approx 3_{10^{-3}}$ [16], while according to the results published in [17], $\rho_p/\rho_\pi \approx 6$ (for a Sun zenith distance $Z_\odot \approx 50°$), so that $L_p\rho_p/L_\pi\rho_\pi \approx$ $\approx 1.8_{10^{-2}}$. Substituting the average internal wave parameters [10,11,15] $\sigma = 7.5°$ and $R(U/C) = -0.53$ when $V = 3$ m/s into (3), we can calculate the magnitudes of the contrasts. Figure 4 shows the theoretical dependence of K on $\Delta\theta$, as well as the experimental data.

The insignificant differences between the experimental data and the theoretical calculations can be explained by the incomplete allowance for sky-scattered radiation, as well as the averaging of the parameters used for the internal waves. From the experimental data (Figure 4) it follows that the phenomenon of contrast inversion (the value of the contrast changes its sign) is observed near the center of a light spot. In the images that have been obtained it is seen as a change in the brightness of different areas: dark areas in the center of the spot ("undisturbed" by internal waves) become light at the edge and the reverse pattern is seen for "disturbed" areas. This phenomenon is explained by the different distribution of brightness for "disturbed" and "undisturbed" zone. Figure 8 shows these distributions, as calculated with formula (1), in relative units.

Contrast inversion point $\Delta\theta_0$ can be found by equating the numerator of expression (3) to zero and ignoring the effect of scattered radiation. We then obtain

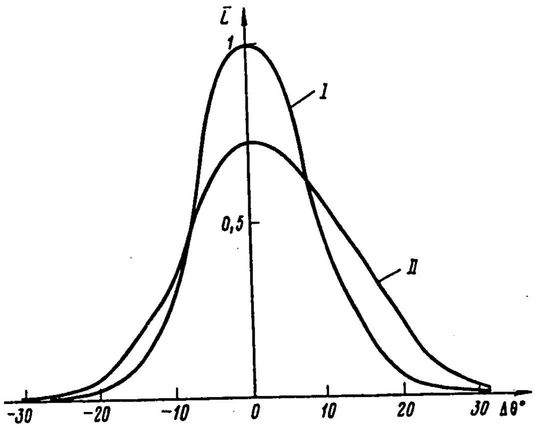

Figure 8. Relative distribution of brightness L in a patch of light as a function of the angular distance Δθ to its center for two areas of a surface: I. "disturbed" by an internal wave; II. "undisturbed" by an internal wave.

$$\Delta\theta_0^2 = \frac{2\ln(\sigma_0/\sigma)}{\sigma_0^2 - \sigma^2}\sigma_0^2\sigma^2. \quad (4)$$

For the parameters determined previously, $\Delta\theta_0 = 8.7°$, which is extremely close to the experimental value.

Thus, the good coincidence of the experimental and model relationships confirms the correctness of the chosen model and the correctness of the statement that frontal zones, meanders, vortices and internal waves are seen in the visible and near-infrared bands because of their surface effects.

The material presented in this article makes it possible to state that the effective observation of dynamic processes in the ocean is possible in the visible and near-infrared bands of the spectrum, in connection with which:
it is necessary to conduct the survey in the area of a patch of sunlight, where the contrasts reach their maximum values;
maximum contrast values are seen for zenith distances of the Sun and sighting angles of $\approx$ 40°;
the width of the survey's spectral band is of no substantial importance, since the observed phenomena do not have clearly expressed spectral selectivity;
contrasts on the surface disappear when the surface wind velocity exceeds 5-7 m/s.

BIBLIOGRAPHY

1. Fedorov, K.N., and Kuz'mina, N.P., "Oceanic Fronts," in "Itogi nauki i tekhniki. Ser. Okeanologiya" [Results of Science and Technology: Oceanography Series], Moscow, VINITI [All-Union Institute of Scientific and Technical Information], Vol 5, 1979, pp 4-44.

2. Novogrudskiy, B.V., Sklyarov, V.Ye., Fedorov, K.N., and Shifrin, K.S., "Izucheniye okeana iz kosmosa" [Studying the Ocean From Space], Leningrad, Izdatel'stvo Gidrometeoizdat, 1978, 56 pp.

3. Stevenson, R.E., and Scally-Power, P., "World-Wide Oceanic Fronts From Satellites," EOS--TRANS. AMER. GEOPHYS. UNION, Vol 58, No 9, 1977, 6 pp.
4. Doblar, R.A., and Cheney, R.E., "Observed Formation of a Gulf Stream Cold Core Ring," J. PHYS. OCEANOGR., Vol 7, No 6, 1977, pp 944-946.
5. Harris, T.F., and Legeckis, R., "Satellite Infrared Images in the Agulhas Current System," DEEP SEA RES., Vol 25, 1978, pp 543-548.
6. "Atmospheric Correction of Satellite Observation of Sea Water Color," Ispa, Italy, Commission of the European Communities, 1976, 61 pp.
7. Grechko, G.M., Grishin, G.A., and Tolkachenko, G.A., "Observations of Visible Manifestations of Ocean Dynamics From the 'Salyut-6' Orbital Station," ISSLEDOVANIYE ZEMLI IZ KOSMOSA, No 4, 1981, pp 5-10.
8. Selivanov, A.S., Chemodanov, V.P., Suvorov, B.A., and Narayeva, M.K., "Opticomechanical Scanners for Observing the Earth," TEKHNIKA KINO I TELEVIDENIYA, No 6, 1978, pp 18-22.
9. Selivanov, A.S., Tuchin, Yu.M., Ovodkova, S.G., and Seregin, V.A., "Television Complex for Experimental Satellites," TEKHNIKA KINO I TELEVIDENIYA, No 3, 1977, pp 43-45.
10. Hughes, B.A., "The Effect of Internal Waves on Surface Wind Waves," J. GEOPHYS. RES., Vol 83, No C1, 1978, pp 455-469.
11. Hughes, B.A., and Grant, H.L., "The Effect of Internal Waves on Surface Wind Waves," J. GEOPHYS. RES., Vol 83, No C1, 1978, pp 443-454.
12. Basovich, A.Ya., and Talanov, V.I., "On the Transformation of Short Surface Waves in Heterogeneous Currents," IZVESTIYA AN SSSR. FAO, Vol 13, No 7, 1977, pp 766-773.
13. Cox, C., and Munk, W.H., "The Measurement of the Roughness of Sea Surface From Photographs of the Sun's Glitter," J. OPT. SOC. AMERICA, Vol 44, No 11, 1954, pp 838-850.
14. Cox, C., and Munk, W.H., "Statistics of the Sea Surface Derived From Sun Glitter," J. MARINE RES., Vol 13, No 2, 1954, pp 198-227.
15. Luchinin, A.G., and Titov, V.I., "On the Possibility of the Remote Optical Registration of the Parameters of Internal Waves According to Their Manifestations on the Ocean's Surface," IZVESTIYA AN SSSR. FAO, Vol 16, No 12, 1980, pp 1284-1290.
16. Makarova, Ye.A., and Kharitonov, A.V., "Raspredeleniye energii v spektre Solntsa i solnechnaya postoyannaya" [Distribution of Energy in the Sun's Spectrum and the Solar Constant], Moscow, Izdatel'stvo "Nauka", 1972, 350 pp.
17. Mullamaa, Yu.-A. R., "Atlas opticheskikh kharakteristik vzvolnovannoy poverkhnosti morya" [Atlas of Optical Characteristics of an Agitated Sea Surface], Tartu, Estonian SSR Academy of Sciences, 1964.

18. "A New Experiment in Investigating the Earth From Space," ISSLEDOVANIYE ZEMLI IZ KOSMOSA, No 1, 1981, pp 5-6.

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