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# SPACE "FRAGMENT" IN STUDIES OF THE EARTH

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16. Abstract

The "Fragment" apparatus, mounted on board the artificial earth satellite "Meteor", was created for the operational study of the natural resources of the Earth in the optical range of electromagnetic waves. The orbit of the satellite at an altitude of about 650 km makes it possible to observe one and the same sectors of the Earth's surface at the same time of day, with a periodicity of 15 days.

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# SPACE "FRAGMENT" IN STUDIES OF THE EARTH

G. A. Avanesov and Ya. L. Ziman

The "Fragment" apparatus, mounted on board the artificial earth satellite "Meteor", was created for the operational study of the natural resources of the Earth in the optical range of electromagnetic waves. The orbit of the satellite at an altitude of about 650 km makes it possible to observe one and the same sectors of the Earth's surface at the same time of day, with a periodicity of 15 days. /6*

At first, the study of the Earth from space evoked some mistrust. After all, it would seem that, being located on the ground, it would be both simpler and less expensive to study the mineral resources, water, forests and agricultural lands. But today, the advisability of the study of the natural resources of the Earth from orbital altitudes does not evoke any doubt. The reasons for this are many. We will name only the important ones of them.

The discovery of natural resources, the evaluation of their reserves and the possibilities of conservation and regeneration are becoming more and more pressing. The necessity of protection of the environment has arisen. A shortage of many valuable mineral resources, primarily oil, requires the search for new deposits. The limitedness of mineral resources in long-developed regions is forcing the surveying of hard-to-reach territories. It is necessary to "see" those deep deposits which are not easy to detect by traditional methods of geological prospecting.

The growing requirements have made evident the incompleteness of information and insufficient efficiency of existing information systems on the development of crops, the condition of forests, floods, forest fires, and volcanic and other phenomena.

*Numbers in the margin indicate pagination in the foreign text.

Thus, the combination of intensified demands and new technical resources, made available by space systems, stipulated the birth and intensive development of studies of the Earth from space.

From the beginning, the development of these studies followed the path of borrowing from aerial prospecting. But the interpretation of aerial photographs is carried out by specialists directly on the terrain. In the case of space photographs, such an approach is not applicable. The areas of the Earth's surface photgraphed from space exceed by thousands, and occasionally tens of thousands, of times those areas which may be investigaed at the present time from aircraft. Specifically, a sector of the Earth's surface measuring 240 x 175 km is photographed in a single picture from the "Salyut" orbital station, and in 10 minutes of photographing — an area of over 1 million km$^2$. From an aircraft during the same period of time, it is possible to photograph an area 1000-plus times smaller.

The greatest dissemination has been received by instruments which make it possible to "scan" the Earth from cosmic altitudes in the visible and near infrared regions of the spectrum. These are photographic, television and spectrometric systems. The majority of them passed into cosmonautics from aviation. But, as has happened more than once already, space studies, in borrowing known methods and systems, change them substantially, and introduce /7
much that is new, rising to a principally different degree of technical perfection. This is what took place in the area of remote methods of studying and monitoring the natural resources of the Earth from space.

## Photographic Equipment

A multizonal method was developed and photographic equipment created. The essence of the multizonal method consists of the fact that a sector of the Earth's surface is photographed simultaneously in several spectral zones.

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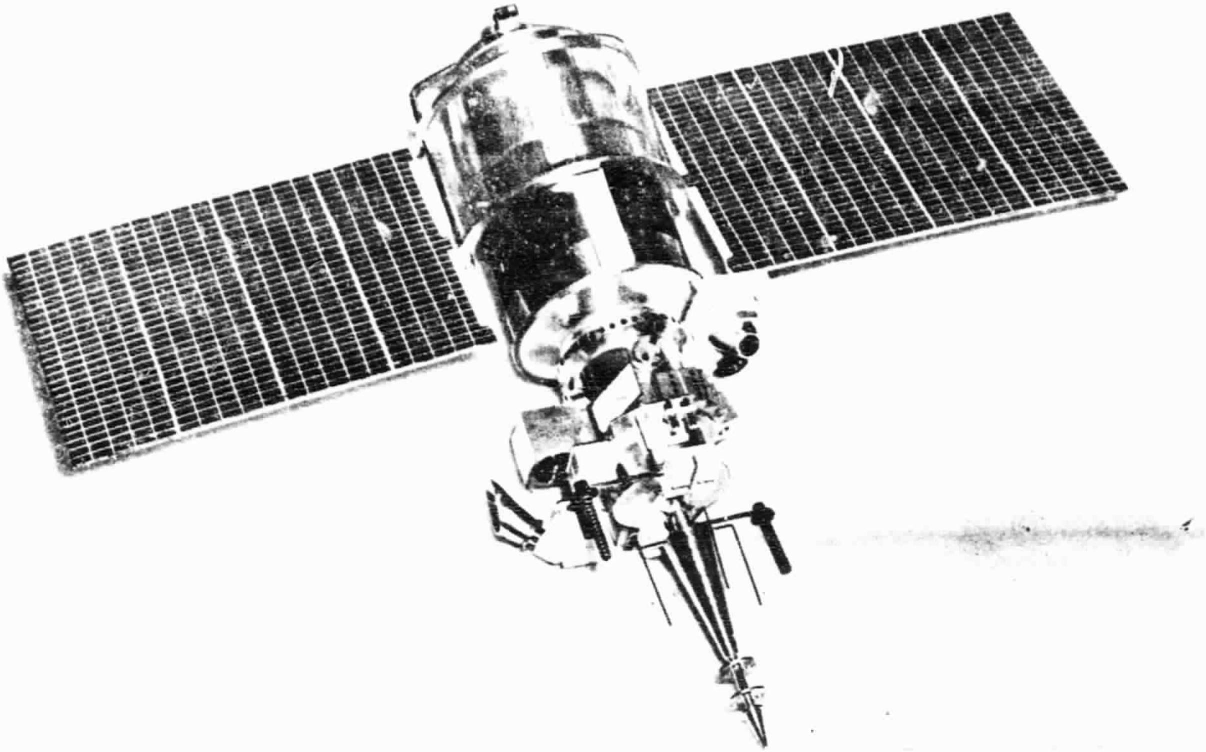

The "Meteor" artificial earth satellite, on which the "Fragment" system is mounted. The orbit of the satellite precesses at a speed equal to the angular velocity of rotation of the Earth around the sun, which ensures photographing of the Earth's surface at one and the same local times — roughly 12 o'clock.

The simplest form of equipment for multizonal photographing of the Earth's surface is multizonal photographic equipment (Zemlya i Vselennaya, 1977, No. 2, pp. 10-15.—Ed.). They are blocks of several identical, synchronously-operating photographic cameras with parallel optical axes of the lenses. The only difference is the fact that the photographic cameras are equipped with different light filters, and are loaded with films with unequal spectral sensitivity.

A more complex type of equipment is multizonal optical-mechanical scanning systems (scanning — from the English "scan" — field of vision). Information formed with scanning systems is transmitted to

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Earth through a radio channel, and may be processed, as they say, "in a real time scale", that is, practically **simultaneously** with the photographing. Utilized in scanning systems as radiation receivers are photoelectronic multipliers or solid-state detectors. These receivers ensure the possibility of photographing in a large range of electromagnetic waves, and high accuracy of measurement of radiation flows is characteristic for the obtained information.

An element-by-element sweep — scanning of the Earth's surface in a direction perpendicular to the flight — is carried out with continuous oscillation of a special mirror; scanning in the direction of the flight takes place as a result of movement of the satellite itself.

The radiation flows are divided according to the spectrum, utilizing filters (as is done in multizonal photographic equipment), or dichroic mirrors, which pass part of the electromagnetic radiation up to a certain wavelength and reflect the other part with greater wavelengths, or prisms and diffraction lattices, which deflect electromagnetic waves of unequal length into a different magnitude.

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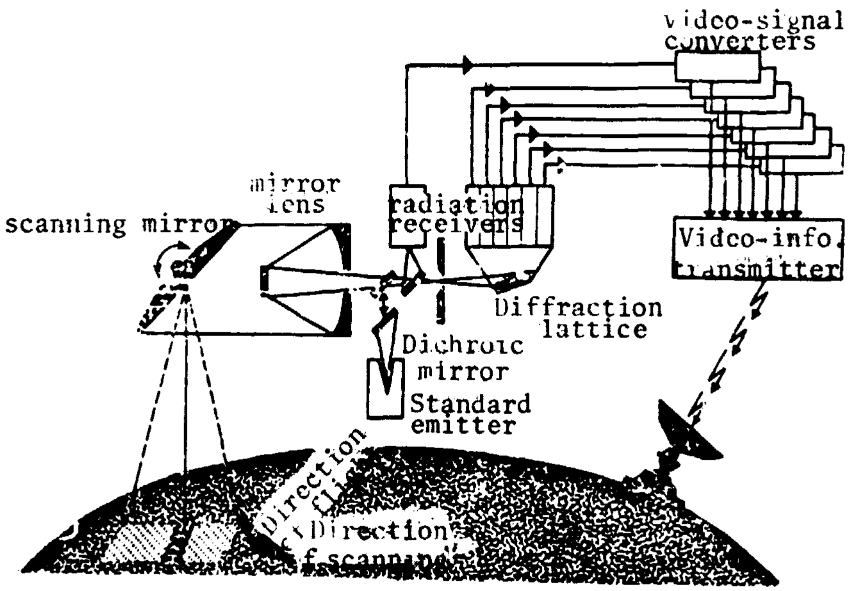

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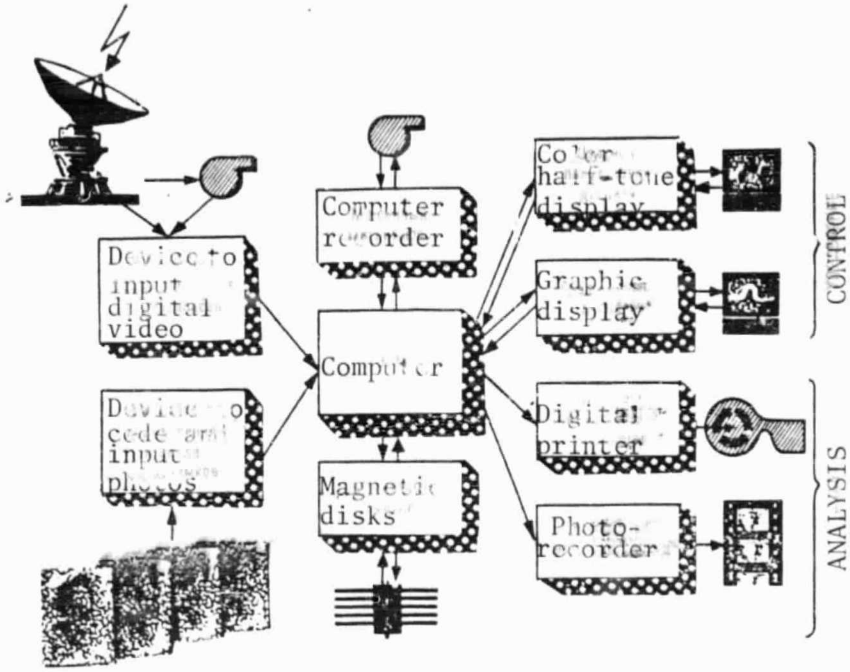


Diagram of specialized display computer complex for processing and interpretation of cosmic video-information.

Now, when we speak of the existing types of photographic equipment, we would be able to switch directly to a detailed examination of the "Fragment" system, insofar as, today, it is of the greatest interest. But, in order to retain the clarity and logic of the presentation, we are forced to primarily concentrate the attention of the readers on still another, sufficiently specific, but exceptionally important, aspect of the matter, without which the true role of "fragment" in the studies being carried out today in a near-Earth orbit would perhaps remain insufficiently disclosed. Thus, we will switch to a new theme.

## Interpretation of Space Information

Irrespective of in which region (or regions) of the spectrum and with what instruments photographing of the Earth from space takes place, and in what form the obtained video-information is recorded — on photographic films or magnetic tapes — the latter is first and foremost converted into photographic images of the photographed surface. At first, interpretation of these images was carried out exclusively by traditional visual-optical methods, which recommended themselves well during studies and mapping of the Earth's surface according to materials from aerial photography. These methods utilized mainly geometric characteristics of terrestrial formations as identifying signs — their dimensions, configuration, orientation and structure. The decisive significance here belongs to the experience of the interpreter and his knowledge of the specifics of the image on the photograph of some terrestrial formations or another, and the processes taking place in them.

Visual-optical methods are not free of shortcomings: first, in order to rapidly process the information coming from space, it is necessary to have a huge staff of specialists; second, visual-optical methods are of low effectiveness for interpretation of multizonal photographs, when the number of images of one and the same sector of the Earth's surface is greater than two, and all of the images must be analyzed together; finally, third, the accuracy of measurement of spectral brightnesses by optical-electronic and radiometric surveying systems is lost, to a considerable extent, through photographic depiction of the results of the measurements.

One may eliminate the enumerated shortcomings by resorting to /9 the help of a computer, and one may utilize the relationships of brightnesses and definite narrow zones of the spectrum — spectral "portraits" of terrestrial objects — as identifying signs. If such "portraits" were "drawn" beforehand and stored in a special "bank", then the process of identification, according to measured spectral brightnesses, would be easy to automate.

But the creation of a catalog of spectral "portraits" is more complex than it may seem at first glance. Many external and internal factors, which it is not very simple to take into consideration, affect the spectral characteristics of terrestrial formations. The external factors are primarily the effect of the atmosphere, changes in intensity of illumination conditions, and terrain relief. The internal factors are of special interest, insofar as they include changes in the most observable objects, evoked by natural processes, as well as by the effect of unforeseen natural and anthropogenic influences.

In order to ascertain and take into account all factors, photographs of vast territories from space are accompanied by synchronous photographs from aircraft and helicopters, as well as direct ground investigation. Determined according to the material of these "three-level" photographs are the spectral "portraits" of the test sectors for given concrete conditions. Formations, similar to the test formations, are sought from these "portraits". Even today, such an approach makes it possible, utilizing computer technology, to considerably simplify analysis and interpretation of space photographs of the Earth's surface.

Nevertheless, the use of a computer does not ensure <u>complete automation</u> of all processes of analysis of space video-information from the Earth, and the unequivocal solution of many problems. The capabilities of man to see and analyze images (to detect indirect signs, pick out characteristic points, lines, boundaries, distinguish structures, and so on) are not yet accessible to a computer — at least with respect to reliability.

In order to achieve maximum effectiveness in the processing and interpretation of space video-information about the Earth, it is necessary to combine the intellect of the interpreter and the capability of the computer to rapidly analyze huge masses of data. Such a combination is most effectively realized in specialized display computer complexes which make it possible to carry out digital processing of video-information in an <u>interactive</u> mode. This means that the image, at all stages of its processing, remains a means of communication between man and computer. The operator, who services the indicated complex, may, as desired, obtain an image of any stage of its processing on a color television screen. Based on visual analysis of such intermediate images, one may correct the program for their processing in the computer.

Computer processing of multizonal space video-information is more productive and graphic, and more widely represents the qualitative characteristics, than processing of images of other types. Because of this, specialized computer complexes have appeared for processing and interpreting aerospace video-information about the Earth. The spectrum of problems solved by such specialized complexes is extremely broad: included here are identification of given contours of the Earth's surface, coordinate conjunction of images to a map, transformation of images to a given scale and projection, increase of contrasts, portrayal of contours, and so on. Usually, the complexes are equipped with devices of two types of input of video-information into the computer. Some make it possible to input data, either preliminarily recorded at points of space communication onto tapes of high-speed recorders, or directly from the radio line; others provide reading, coding and input into the computer of individual and multizonal photographs. The computer, as a rule, has two types of magnetic storage — magnetic tapes and magnetic disks. Magnetic tapes are utilized for archive storage of large volumes of digital video-recordings. Recorded on the magnetic disks is information processed in the computer at a given moment, which ensures the possibility of convenient and rapid access to any portion of it.

## Operational Study of the Earth from Space

For the intensive development and introduction into science and practice of methods of study of the natural resources of the Earth by means of space technology, the requirements for space video-information have been studied. It turned out that, in order to satisfy these requirements, it is advisable to have a constantly operating space system to study of the natural resources of the Earth, which utilizes satellites equipped with technological means of remote sensing. Two ways for obtaining, processing, disseminating and utilization of space information about the Earth were noted — long-term and operational.

The former is based on the return to Earth of undeveloped film using descent vehicles. In this case, multizonal photographing of

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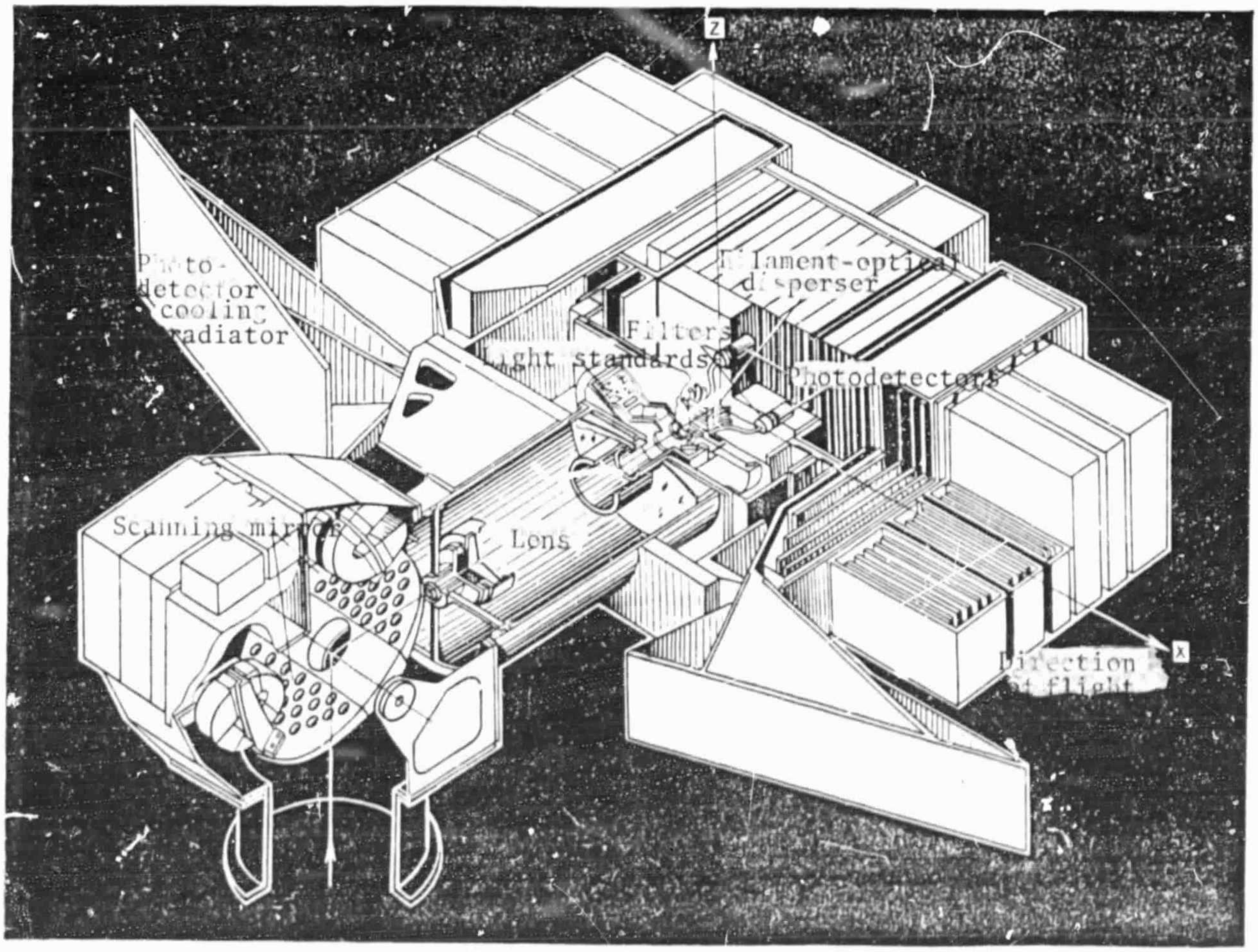
the Earth's surface with high spatial resolution is provided for, along with the utilization of the obtained data for the compilation and updating of thematic maps. This approach is important during the study of the characteristics of the Earth's surface, interior, vegetation, shelf shoals and other natural objects, which do not change substantially over a considerable time interval (months, years).

The operational problems require that the time intervals between photographing of the studied object and the delivery of the obtained information to the user be counted in days, and even hours. This is specifically information on the condition of crops in the fields. For rapid obtaining of an answer, it is necessary to transmit the information from the satellite through radio channels, and to process it promptly. Here, it is impossible to do without a complex of on-board and earth technological systems and computer technology. /10




Configurational diagram of the "Fragment"

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Besides on-board equipment for photographing the Earth's surface, this complex should have equipment for transmitting a large flow of obtained video-information to the Earth through a radio line, and for receiving, recording and express-processing of this information. Precisely such a complex, designed for the solution of operational problems, was developed in the Institute of Space Research of the Academy of Sciences of the USSR, together with a number of other organizations. At the base of the complex is an on-board multizonal scanning system, having received the name "Fragment". The name reflects its scientific research nature. In actuality, the system is not designed for global photographing. Its task is to investigate the Earth's surface within the limits of a circle roughly 2500 km in radius, with its center at Moscow. This, of course, may be called a "fragment" only on cosmic scales.

The complex has functioned successfully under test operational conditions since June of 1980. The information obtained with its help is measured in thousands of kilometers of magnetic tape and millions of square kilometers of investigated areas. Experience has been accumulated in practical work with the complex, which ensures operational collection and processing of information in the interest of the study of natural resources.

The experimental information measurement complex includes three systems: the "Fragment" photographing system proper, a system of digital transmission, receiving and recording, and a digital processing system.

The first of these systems — "Fragment" — is a very complex optical-electronic assembly weighing over 250 kg. It combines within itself photographic and spectrometric equipment. A broad band of the Earth's surface is swept (scanned) by the oscillating mirror. "Fragment" discerns the degree of detail of photographing of the Earth's surface and accuracy of measurements of its spectral brightness. The possibility and effectiveness of processing of the obtained video-information in a computer are thereby provided. The

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photographing is carried out in eight spectral zones, with resolution on the Earth's surface of up to 80 m. During the development of "Fragment", the designers had to solve many complex technical problems. So that the readers may understand, we will tell about one of them. For measurement of the solar radiation, reflected by sectors of the Earth's surface 80 x 80 $m^2$ in size from cosmic altitude, a scanning mirror over 30 cm in diameter was required. This mirror, using magnetic-electrical drive, oscillates with a frequency of 13 Hertz along an axis parallel to the direction of flight of the satellite, completing one rotation and return to the initial position in 1/13 of a second. During this period of time, the satellite manages to fly about 500 m. In order to carry out the photographing in 1/13 of a second with a resolution of 80 m, it is necessary to simultaneously scan not one, but six bands of the Earth's surface, perpendicular to the flight path. Therefore, a light filament image disperser is located in the focal plane of the photographic lens of "Fragment". The six contiguous square areas of the end portion of the disperser, aligned in the direction of flight, provide for the carrying out of photographing of the Earth's surface in a single zone of the electromagnetic wave spectrum. The light from each such area is transmitted, through its light guide, to six photodetectors, equipped with identical light filters. The described design makes it possible, during a single oscillation of the mirror, to carry out photographing, in a given zone of the spectrum, of a band of the Earth's surface 480 m in width (more precisely, six bands of 80 m each). /11

The filament-optical disperser has 35 light guides, at the output of which 35 photodetectors are mounted accordingly. Of them, 30 (6 x 5) ensure the carrying out of photographing with a resolution of 80 m in five short-wave zones of the spectrum — in the range from 0.4–1.1 μ. The remaining (five) are utilized for photographing a worse resolution in the wavelengths from 1.2–2.4 μ.

In creating "Fragment", the designers thought not only of the production and transmission of an image (like in a standard

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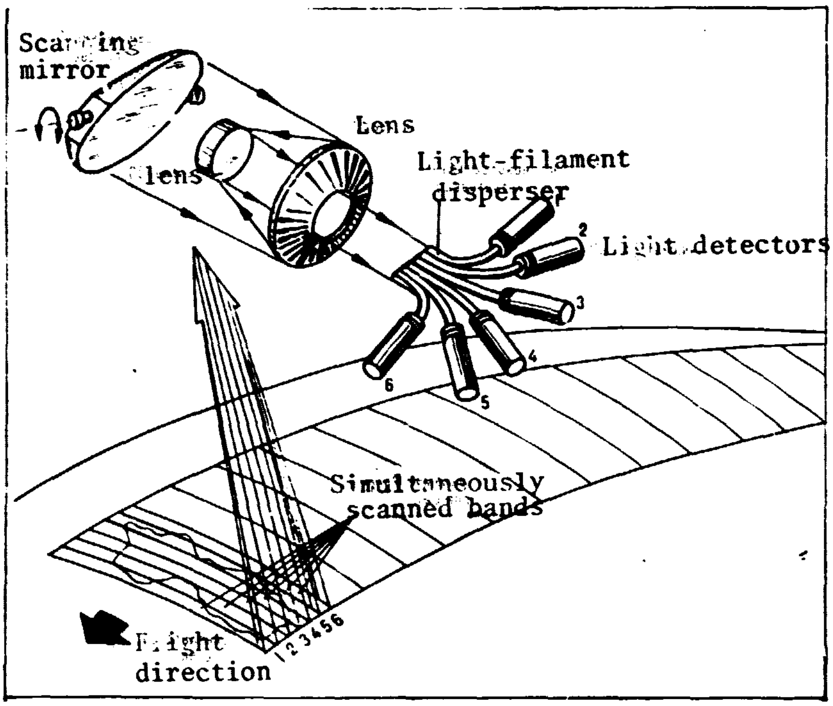
television system), but also of the accurate measurement of the spectral brightnesses of each element of the surface being photographed. Only with precise knowledge of the spectral brightnesses




Schematic of simultaneous six-band scanning of the Earth's surface in a single zone of the spectrum, realized in the "Fragment" system.

can one carry out a detailed analysis of the video-information on the computer. Only in this manner can one find out in detail about the physical, chemical and biological properties of the photographed sectors. For this purpose, the spectral brightnesses of the elements of the Earth's surface are converted, on board the satellite, into digital form (in a binary system). Then, in that form, they are transmitted to the Earth. The brightness of each element is determined according to a scale having 256 gradations, and it is expressed in the binary system with an eight-digit word ($256=2^8$). When "Fragment" carries out photographing with a resolution of 80 m, simultaneously in four zones of the spectrum, then 500 thousand such words, or 4 million bits of information, are formed and transmitted to Earth in a single second. In order to transmit, receive on Earth and register such a high flow of data on magnetic tapes, a special digital radio line was developed in the Special Design Office of the Moscow Power Institute. The basic merits of the transmission of video-information in digital form are the high reliability and protection from interference.

On Earth, the information from "Fragment" is received by a parabolic antenna of directional action, with a diameter of about 25 m. The aperture of the beam pattern of this antenna — the angle within the limits of which it "sees" the satellite — is less than 1°. Therefore, in order to receive the transmitted video-information, the antenna should track the satellite with an accuracy of up to units of minutes of arc and parts of seconds in time. Powerful mechanisms make it possible to turn the antenna with the indicated accuracy. This is done on the basis of data received as a result of trajectory measurements of the orbit of the satellite.

It is not so simple to record information arriving at a rate of 4 million bits per second. Special video-recorders would be required, in which, during the time of recording, the rate of draw through of the magnetic tape reaches 8 m/sec. In order to /12 input video-information into the computer, a rate 30 times less is necessary. It is necessary to copy the primary magnetic recording twice, with a reduction in rate. After such a procedure, carried out at the point of receiving of the information, the magnetic tapes with the recording, which may be input into the computer, enter a specialized display system for digital processing of video-information. Here, the information is subjected to complex processing.

The experiment with "Fragment" was primarily posed in order to develop the procedures and equipment for operational studies of the natural resources of the Earth from space. Besides this, the obtained information is transmitted to the numerous organizations of the Soviet Union and other socialist countries. Its utilization often has a practical nature, and proves to be economically effective.

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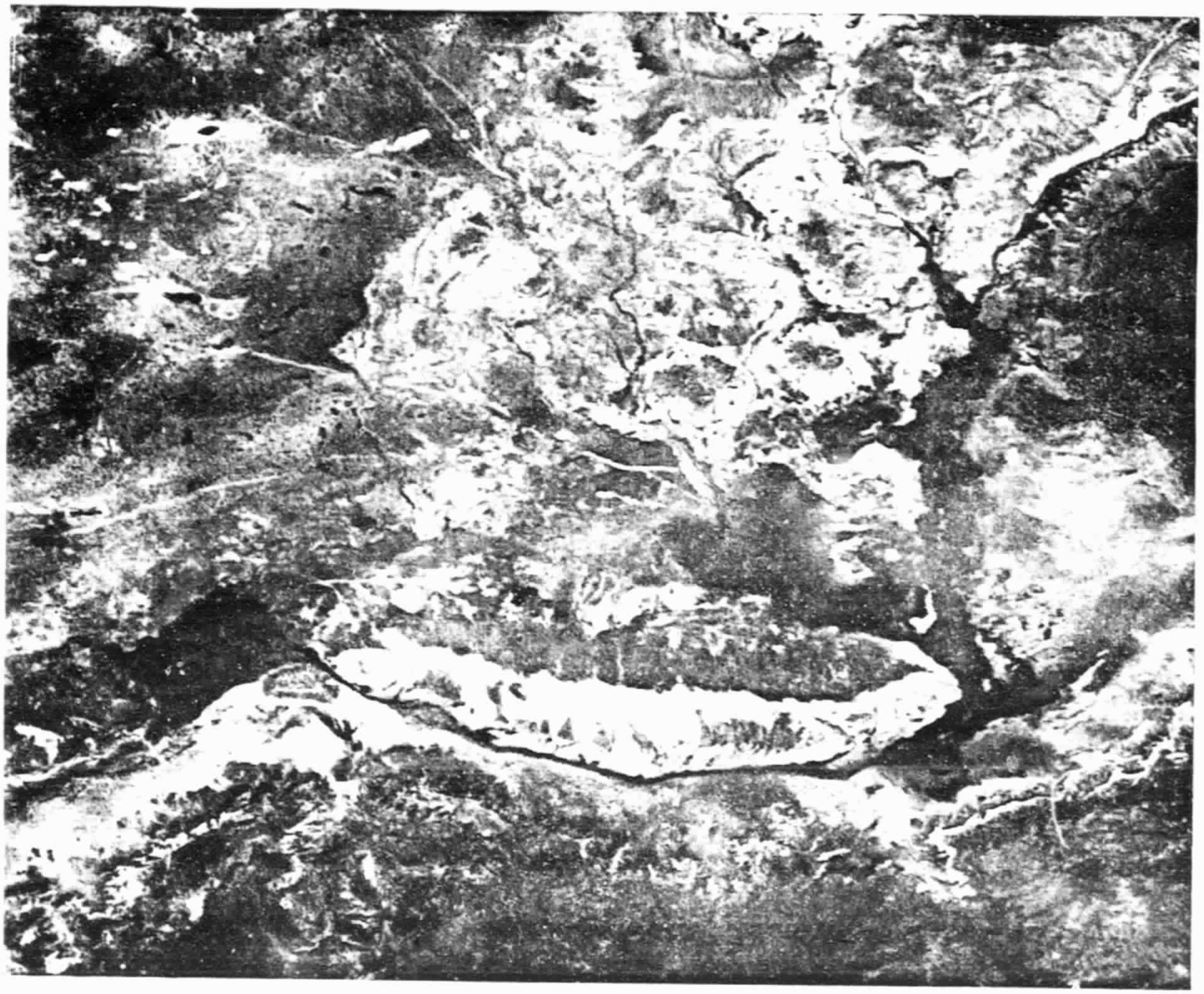

Photograph of the territory of the steppe deserts of Southern Primugodzhar' in the 0.7-0.8 μ zone of the spectrum. Against the gray background of the desert, sink holes with shrub-meadow-steppe vegetation are detected in the form of dark-gray, and almost black, small patches. The light-gray and white patches are takyrs and crustal salt springs.

For an example, we will indicate how the Institute of Cybernetics of the Ministry of Agriculture of the USSR utilized the obtained information in the Stavropol' district. Having processed this information in the form of thematic maps and summaries, the

Institute transmits it to local agricultural organs. They, in turn, effectively utilize the information for observation of seedlings and ripening of crops, for ascertaining the foci of diseases, and for crop forecasting. According to the data of the Institute of Cybernetics, the economic effectiveness of utilization of the information from "Fragment" (only in the aforementioned region) is counted in the hundreds of thousands of rubles.