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AD 677518

FOREIGN TECHNOLOGY DIVISION

TELEVISION TRANSMISSIONS FROM OUTER SPACE

by

G. B. Bogatov

242

FTD-MT-24-229-67

EDITED MACHINE TRANSLATION

TELEVISION TRANSMISSIONS FROM OUTER SPACE

By: G. B. Bogatov

English pages: 232

TM7502295

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Akademiya Nauk SSSR

nauchno-
populyarnaya
seriya

G. B. Bogatov

TELEVIZIONNYYE
PEREDACHI
IZ KOSMOSA

Izdatel'stvo "Nauka"

Moskva - 1966

304 pages

FTD-MT-24-229-67

ITIS INDEX CONTROL FORM

01 Acc Nr	68 Translation Nr	65 X Ref Acc Nr	76 Reel/Frame Nr
TM7502295	FTD-MT-24-229-67	AM6021851	1881 2267

97 Header Clas	63 Clas	64 Control Markings	94 Expansion	40 Ctry Info
UNCL	UNCL, 0	0		UR

02 Ctry	03 Ref	04 Yr	05 Vol	06 Iss	07 B. Pg.	45 E. Pg.	10 Date
UR	0000	66	000	000	0001	0304	NONE

Transliterated Title
SEE SOURCE

09 English Title
TELEVISION TRANSMISSIONS FROM OUTER SPACE

43 Source
TELEVIZIONNYYE PEREDACHI IZ KOSMOSA (RUSSIAN)

42 Author
BOGATOV, G. B.

98 Document Location

16 Co-Author
NONE

47 Subject Codes
17, 22, 09

16 Co-Author
NONE

39 Topic Tags: space electronics, space communication, space TV, TV equipment, signal transmission

16 Co-Author
NONE

16 Co-Author
NONE

ABSTRACT : This book, intended for a wide circle of readers interested in television, discusses the use of television equipment during manned space flights and the role television will play in the establishment of extra-terrestrial observatories. Problems of transmitting radio and television signals over cosmic distances is considered as well as prospects for space television communications using electromagnetic waves in the optical range. There is a detailed discussion of present and planned use of space vehicles for relaying television programs over intercontinental distances. The principles of organizing ground radio-reception systems and a radio command network are described, along with means for detecting television signals and special methods of processing the signals received. There are 90 figures.

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English translation: 232 pages.

TABLE OF CONTENTS

This book is about television, about its applications in space research, about what role it plays in the study of earth, and about prospects of its development.

The book tells about use of television equipment during manned space flights and about what role television will play in the organization of extraterrestrial observatories on artificial and natural celestial bodies. There are discussed problems of transmission of radiotelevision signals over cosmic distances and prospects of using for targets of space television communication of electromagnetic oscillations of the optical range of waves, and corresponding equipment is described. The book goes into detail about existing and planned use of spacecraft for relaying television programs over intercontinental distances. Principles of organization of systems of ground radio reception and radio command network, methods of registering television signals and special methods of treating received signals are described.

Book is intended for a wide circle of readers, who are interested in television.

INTRODUCTION

Television long ago firmly entered our lives. In its first development television was used basicly as a means of entertainment to increase the cultural level of the population and in ideological training. But through the development of technical means and the expansion of the material, technical, and industrial capabilities of our country, it has begun to penetrate the spheres of industrial and scientific activity. Contemporary television helps us not only to get to know the world better, to increase our knowledge and to satisfy more fully our cultural demands, but also to look at the invisible and unattainable and to more efficiently use the labor of man and machines.

All know that television permitted the transmitting of the first photographs of the reverse side of moon, which was photographed by a Soviet robot space station, and undoubtedly television will help in the near future to glance on the nature of the moon, not through a telescope, but with the television eye of an extraterrestrial observatory, and perhaps, by the eyes of a vehicle traveling on the lunar surface. We wait with impatience for that day, when a picture of life on Mars and the nature of Venus and other planets will cease to be only the fruit of the imaginations of visionary writers and artists, but will appear before us in frames of television reportage directly from space. And this day is close.

After all, until recently inhabitants of our brother republics only dreamed about television transmissions from Moscow. And now they look at them. But that is not all. Is it possible to relay television programs to all the most remote corners of our boundless native land? Is it possible to bring not only the voice of Moscow, but a visible picture of its life to the most distant places on earth? Is it possible, without leaving ones own apartment, to see what is happening on the other side of the world? Yes, this dream is real. Universal television communication is taking its first, but very successful, steps. And this problem can be solved with the help of means of spacecraft launching and control.

Space television is the youngest form of applied television. However, already even here is a huge variety of technical aids, and sophisticated instruments, but methods of transmission of treatment of signals are so complicated that they are probably in no other region of application of television. But results are indubitable: the whole world, holding its breath, watched as, for the first time in history of humanity, Soviet astronaut A. Leonov opened the door of his ship and stepped into space.

Selection of technical means for creation and transmission of television signals is a complicated thing. The complexity of launching a heavy spacecraft of large dimensions limits the weight and volume of elements of airborne television systems and their power supplies. Furthermore, the problem of designing space television systems is complicated by the necessity of developing television system elements which could work during a very prolonged period — weeks and months — without observation and adjustment. These systems have to resist strong vibration during launch and work in a medium, the temperature of which is close to absolute zero or higher than the boiling point of water, where atmospheric pressure is absent and humidity is equal to zero. They can be subjected to intense irradiation by electromagnetic oscillations of different wavelengths, heavy particles and micrometeorite flows. Therefore, every system of space television requires application of special equipment and uses its own methods of creating, transmitting, receiving, and processing television signals.

We will endeavor to relate in this small book how these complicated problems are solved.

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CHAPTER I

PRINCIPLES OF TELEVISION TRANSMISSION

Obtaining of television [images, pictures]. Electronic television.

The form of communication in which the object of transmission is a moving image (transmitted from nature with help of film, magnetic, thermoplastic, electrostatic tape, or from any other information carrier), and transmission of information about representation is carried out by electrical signals on radio or wires is called television. It is based on use of such physical processes as conversion of light energy of an optical representation into energy of electrical picture signals, transmission of picture signals from transmitter to receiver and the inverse transformation of electrical energy of received signals into light energy of the reproduced representation.

This process of conversion of light energy into electrical energy and the inverse transformation of electrical energy into light energy is intimately connected with the properties of human sight, mainly with inertness and final resolving power. Thanks to structural peculiarities in the retina of the eye, continuous changes of reflectance of objects are reproduced in the form of a point structure, i.e., images visible to us constitute a unique mosaic, composed of elementary light spots. This property is used in television. Every object is examined as a combination of a large number of points with different reflectance. Different quantities of light, reflected by separate points (cells) of the examined object, are converted into electrical signals corresponding in value, which are then transmitted to the receiver for an electrical communication circuit. For production of electrical signals proportional to the luminous fluxes serve photoelectrical converters, the simplest of which is the photocell.

Transmitted electrical signals on the receiving side will be converted back to light signals in the form of luminescent points with different brightness, the relative location of which is the same as in the original. Thus is created image scanning. With decrease of the dimensions of the cells (during corresponding increase of their quantity) quality of image scanning is improved, however, only to a known limit, which is determined by the final resolving power of the eye.

Obtaining of Television Representations

The first projects of television systems copied the structure of the human eye. They anticipated simultaneous transmission of signals from all cells of the optical representation of the object, for which was to be applied in the transmitter a panel with a large number of photocells (modelling the photosensitive cells of the retina of the eye), and in receiver a panel with the same quantity of incandescent tubes (modelling the visual centers of the brain). Each photosensitive device of the transmitter should have been connected with corresponding tubes of the receiver by separate wires with electrical batteries included in their circuit (these communication circuits were to model nerve fibers of the visual apparatus). Every tube was to reproduce the brightness of the separate points of the transmitted representation. Such methods of transmission of electrical picture signals turned out to be practically unrealizable, since they needed a huge number of communication channels (hundreds of thousands of wires) for production of a clear representation.

In 1880 the Russian scientist, P. I. Bakhmet'yev, proposed, instead of simultaneous transmission of electrical signals from all cells of the representation, to carry out the successive transmission of signals corresponding to the brightnesses of separate cells of the reproduced representation of the object. This permitted transmitting signals from all cells over one pair of wires. The proposal of P. I. Bakhmet'yev was based on use of the inertness [persistence] of visual perception.

By then already it was well-known that after the beginning of light irritation of constant intensity, sensation (apparent brightness) gradually grows [increases], and, after termination of irritation, gradually drops [decreases]. During sufficiently fast changes of brightness of an examined object, the eye ceases to react to these changes and perceives only the mean value of brightness. The time of appearance of sensation and the time of preservation of visual image composes the tenth part of a second and changes with change of object brightness and color. For production of a coalescent representation, speed of transmission of its separate components should be such that, at the time of reproduction of the last cell of the representation, the eye still preserves the sensation from the influence of the luminous flux of the first cell of the representation. Such a series transmission of an image by cells is called image scanning.

Thanks to inertness of sight, an impression of continuity of travel [motion] can be created by a rapid replacement of motionless representations which fix consecutive phases of the motion of an object (as in a movie). If one were to transmit 10-25 changed representations (frames) per second, then an impression of a coalescent representation would be created, but the representation would flash. In order to create an impression of continuous motion and to avoid flashings, speed of transmission on should be 40-50 frames per second. Order of transmission and reception of separate cells in a frame can be different.

In 1884 Austrian engineer P. Nipkov proposed to use for series transmission of information a disk with little holes, which are shifted relative to each other at equal angles, where every subsequent hole in the disk is located nearer to the center of the disk by the width of the actual hole (Fig. 1). On the transmitting side is one

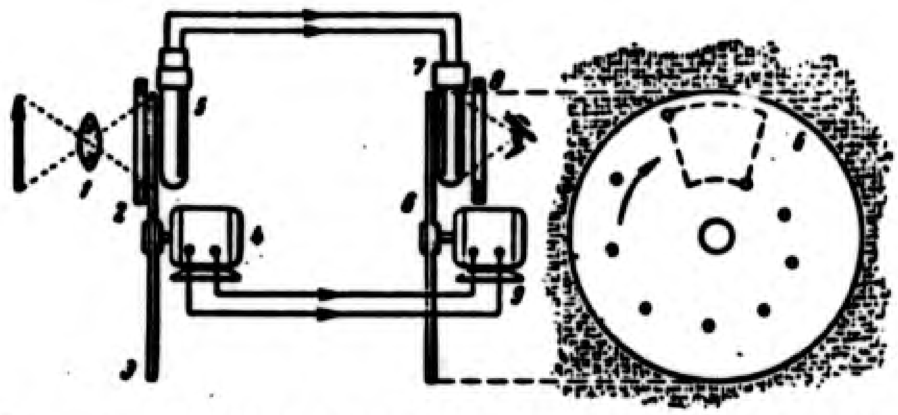

Fig. 1. Diagram of transmission of representation using a Nipkov disk. 1 – objective; 2 – limiting frame; 3 – disk of transmitter; 4, 9 – engine; 5 – photocell; 6 – disk of receiver; 7 – flat fluorescent lamp; 8 – limiting frame.

photocell, but on the receiving side is one tube. Objective projects the representation which is subject to transmission against the plane of the disk. Light gets on the photocell from the representation through the hole in the disk, since the disk itself is prepared from an opaque material. With rotation of the disk, the holes shift and there occurs scanning of the representation, limited by the frame between the first and last holes.

Transmission of representation starts from its upper left corner; at first into an electrical signal will be converted light energy from the first cell, then conversion continues from left to right, in series element by element throughout the row up to the right edge of the representation. The first line of the representation is scanned (it is, indeed, not quite a straight line but an arc of a circumference), then the second line, the third, etc., tightly adjoining line one to another. Conversion of the light energy from all cells of the last horizontal row into electrical signals completes transmission of the full television frame, after which the process is repeated with a new turn of the disk.

The luminous flux passed through the hole in the disk from the transmitted cell of the representation gets on the photocell, which converts the luminous flux falling on the photocathode into electrical current. This current is proportional to the brightness of the transmitted element of the representation.

Picture signals created in the photocell circuit are amplified many times and are then transmitted to the receiver. In the receiver is also used a Nipkov disk, only instead of a photocell, after the disk is placed a small neon tube, the brightness of glow of which is controlled by received signals of the representation. During rotation of the disk of receiver, at every moment is seen only one cell of the luminescent surface of the neon tube, and in this instant the tube correctly reproduces brightness of the corresponding point of the scanned representation. It is true, at that moment, when there is transmitted let us say, the first cell of the first line, the whole surface of the neon tube has the same brightness, but through the hole of the disk one may see only the place of representation corresponding to this cell. When the hole passes to the following cell, the neon tube reproduces the brightness of the second cell, etc.

In the first stage of development of practical television (the first successful experiments were performed in 1925-1926) was used mechanical method of decomposition, chiefly with the help of a Nipkov disk. Other optical-mechanical systems were also used. During the use of mechanical scanning the representation was scanned on several tens of lines. The maximum number of image dispersion cells in certain installations reached 20,000, then as for production of a high quality image it is necessary to reproduce hundreds of thousands of image cells. To increase considerably the number of cells of decomposition with acceptable dimensions of the disk is practically impossible, since a considerable decrease in the dimensions of the holes will cause too small a luminous flux to fall on the photocell. During transmission of movie films, luminous flux of powerful arc arriving at one cell of the representation is sufficient for production of the necessary signal. This explained the use during a certain time of optical-mechanical systems for movie film transmission. The number of lines of decomposition in these systems did not exceed 180.

Electronic Television

In 1907 Russian scientist B. L. Rozing proposed to use in television electronic scanning, which later (in the 30's) led to the fact that mechanical television systems were in general, rejected.

A example of a transmitting television system using electronic scanning is a device with a running light spot (Fig. 2). As source of light energy in this device is used projection electron beam tube possessing great brightness of glow. The screen of the tube has a line drawn through it in a definite sequence by an electron beam, as a result of which is created a screen composed of alternately flashing points. The screen is projected on the object. At every moment of time, only one cell of the object is illuminated. The light reflected (or transmitted) by the illuminated cell of the object (or slide, as on Fig. 2) then gets on the photocathode of the

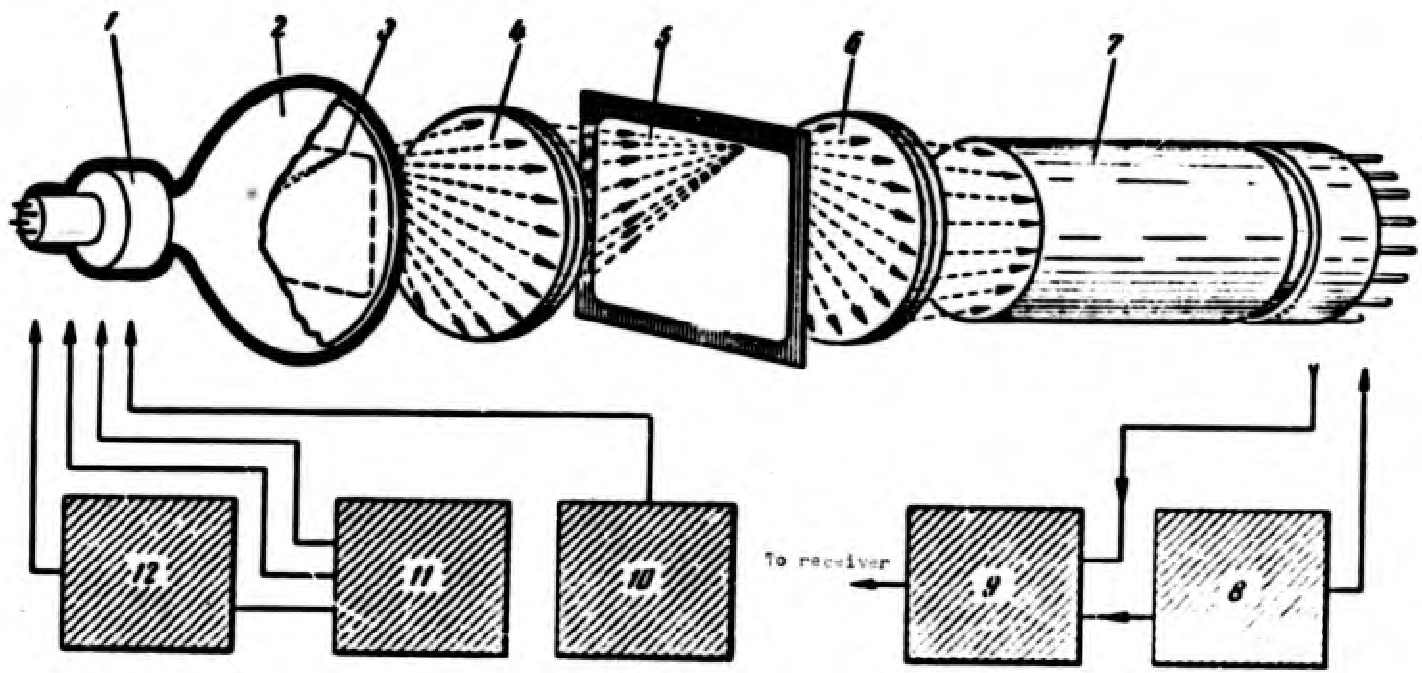

Fig. 2. Block diagram of installation using scanning by ‑unning light spot (for reproduction of slides). 1 — deflecting coil; 2 — scanning tube; 3 — luminescent spot; 4 — objective; 5 — slide; 6 — condenser; 7 — photomultiplier; 8 — power supply; 9 — amplifier of picture signals; 10 — power supply of tube; 11 — generator of scanning oscillations; 12 — generator of quenching pulses.

photocell or of the photomultiplier and creates a picture signal. During slip of the scanning light spot on the surface of the object, in accordance with change of its reflectance (or the optical density of the slide), is changed the value of luminous flux getting on the photocell and the value of the obtained picture signal. Picture signals are strengthened by amplifier and enter a communication channel, on which they are transmitted to the receiver.

Reproduction of the representation in the receiver is also produced electronically with the help of an electron beam tube. The electron beam in the receiver tube moves strictly in coordination with the beam of the scanning (translucent) tube of the transmitter. When the first line is traced in the transmitter, the electron beam of the picture tube traces the first line on the screen. The distinction consists in the fact that the electron beam of the picture tube changes its intensity with change of arriving signal, and on the screen an image is reproduced from a combination of differently luminescent points, whereas on the screen of the transmitter tube of the installation, a screen is created from equally alternating luminescent points. Electron beams in electron beam tubes move under the influence of electrical oscillations created in sweep generators. The work of sweep generators is controlled by synchronization signals which are created in a synchro generator. Electronic scanning is obtained during the passing of current along two pairs of deflecting coils. which encircle the tube throat.

In the scanning process the electron beam evenly shifts from left to right in a horizontal direction and simultaneously is displaced downwards on the width of the line (Fig. 3a). Having traced the line, the beam of electrons quickly returns to the left, after which it starts anew to shift to the right, but along the following line. This process continues until the electron beam has traced the last line. Then the beam returns to its initial position, the upper left corner of the screen.

So that beam will evenly move in one direction and shift fast to its initial position, it is necessary to use sawtooth deflecting currents, the form of which is shown on Fig. 3b and c. The frequency of oscillations carrying out frame scan (beam displacement along the vertical), should correspond to assigned frequency of replacement of frames, and the frequency of oscillations, carrying out line scanning (beam displacement along the horizontal), should be z times more than the frequency of frames (z is the number of lines on which the picture is scanned). Beam movement left to right under the influence of horizontally deflecting coils is called straight-line movement of line scanning, and its fast return to initial position is called reverse movement of line scanning. Analogously, the slow movement of the electron beam downward under the influence of the field of vertically deflecting coils is called straight-line movement of frame scan, and its fast return upwards is called reverse movement of frame scan.

The time of return of the beam to its initial position should be minimum, since during this time, desired signals will not be formed. At this time the beam is locked (the tube darkens) by special quenching pulses, so that on the screen there are no additional lines of reverse

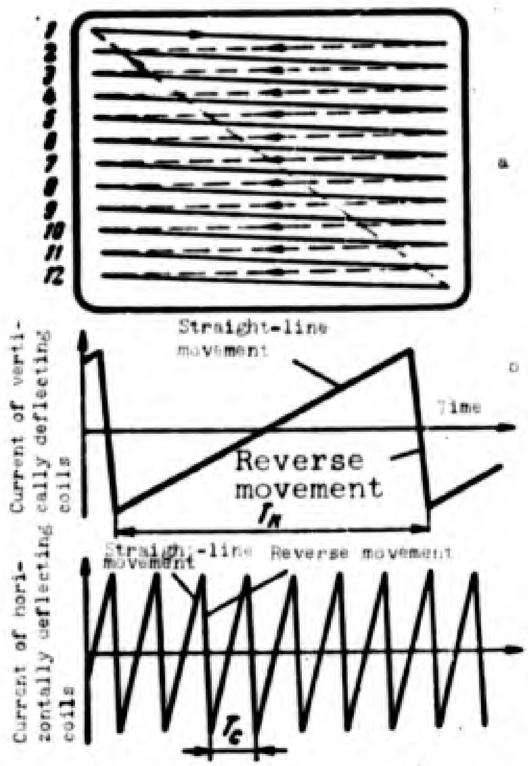

Fig. 3. Formation of right angled screen on screen of electron beam tube under the influence of magnetic fields created sawtooth currents of coils of vertical and horizontal deflection. T_c is the period of the line scanning current; T_K is the period of the screen scanning current.

movement (on Fig. 3a shown by dotted line), which interfere with observations. During reverse movement of beam, to the receiver are transmitted extinguishing and synchronizing pulses in the composition of the picture signal. Form of television signal corresponding to two lines of representation is shown on Fig. 4.

Application of electronic scanning in the given system saves us from having to use very bulky and expensive mechanical devices. By exerting influence by variable magnetic (or electrical) field on practically inertialess electron beam, it is possible to force it to be deflected in any direction and with very high speed.

For television broadcasting 4:3 is the accepted image form factor which determines the ratio of the sides of the screen. A line linear scan, as a rule, is used and in installations of applied television,

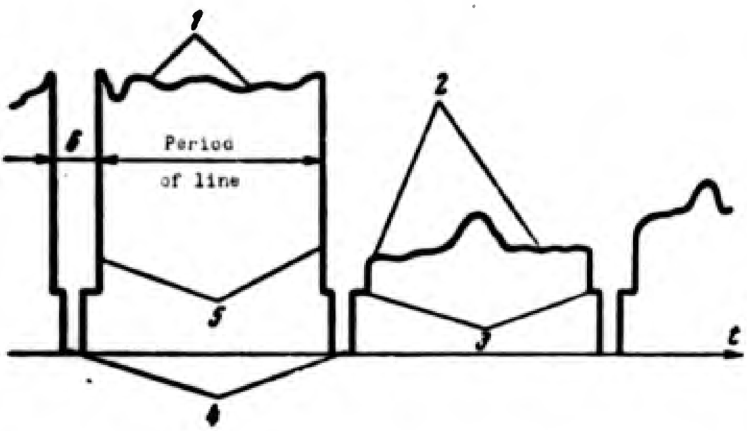

Fig. 4. Form of full television signal (frame synchronizing and quenching pulses are not shown). 1 — signals from bright picture details; 2 — signals from the dark parts of the picture; 3 — level of black representation; 4 — synchronizing pulses of line frequency; 5 — quenching pulses of line frequency; 6 — return period per line.

forming a right angled screen. However, right angled form of frame and line linear scan are not always expedient. From the point of view of best use of surface of tubes and optics, it is more profitable to use a round screen.

A round screen can be obtained during the use of spiral scanning (Fig. 5), which is created, when through the vertically and horizontally deflecting coils of the tube are passed sinusoidal currents, shifted 90° in phase; the amplitude of these oscillations is simultaneously changed from zero to a certain value (Fig. 5a and b). The screen during spiral scanning will be formed by one spiral, starting in the center of the screen and going to its outer edge (untwisted spiral) or starting from the edge and going to the center (twisted spiral). Describing one such spiral, the ray quickly accomplishes reverse movement also by a spiral, but by a steeper one, and starts to describe a second spiral. Such spirals are repeated with the frequency of replacement of frames.

What are merits of spiral scanning?

Scanning oscillations are comparatively easy to create and to transmit by cable over a distance; furthermore, a large advantage is continuity of scanning and absence of time losses connected with this on reverse movement along line. Use of optics and transmitting tubes has been improved and synchronization of generators of scanning oscillations has been simplified; synchronization signals are necessary only during replacement of frames. Accordingly, necessity decreases for devices for separation of frames and small synchronizing signals.

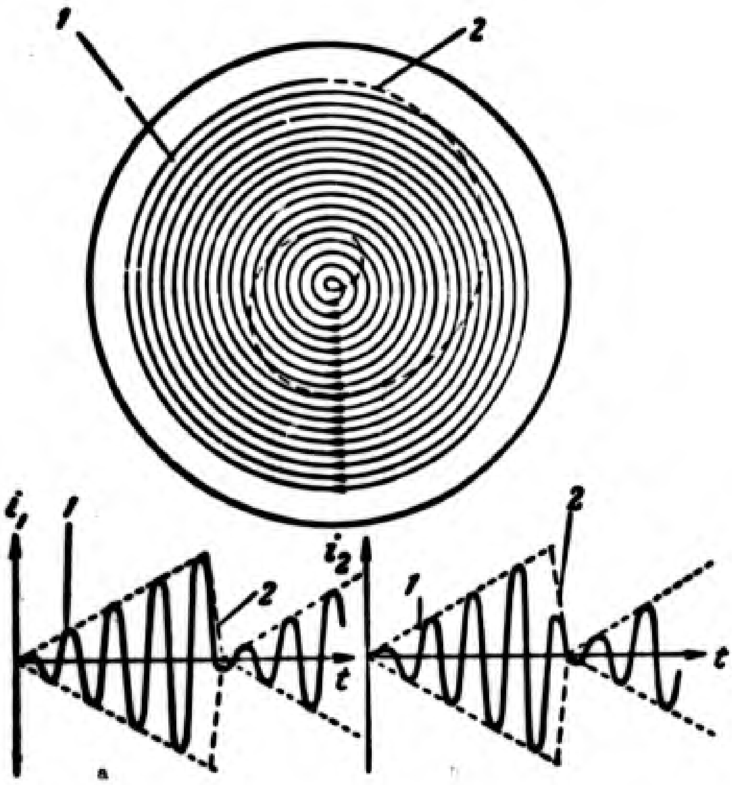

Fig. 5. Formation of spiral screen. Currents in first (a) and in second (b) deflecting coils are shifted 90° in phase.
1 – straight-line movement of scanning;
2 – reverse movement of scanning.

But spiral scanning has a number of deficiencies: image sharpness is not identical throughout the field; it is maximum at center and decreases toward the periphery of the screen, due to unequalness of speed of electron beam along the spiral (in the center speed is minimum, and on the edge of the screen it is maximum) there arises heterogeneity of brightness of glow on the field; due to more prolonged excitation of the luminophor by the electron beam, the central part of the screen turns out to be brighter. For levelling off of brightness on field, it is necessary to pass a correcting signal to the control electrode of the picture tube. Inconstancy of linear speed of electron beam on spiral also causes the signal formed by the transmitting tube to decrease as the beam approaches the center of the screen. It is true that there are methods of getting rid of or decreasing these deficiencies. With the help of television systems with spiral scanning can be solved certain special problems, which cannot be solved using an ordinary line linear scan. Thus, the origin of the spiral very accurately determines the electron optical axis of the transmitting camera. This circumstance can be used for the solution of a number of problems, when the television system is used as a measuring device. If the transmitting camera is in a quickly rotating object (for example, in a rocket), then during certain conditions, the picture transmitted by the camera will rotate, where angular velocity of this rotation characterizes speed of rotation and speed of forward motion of the object. When necessary, rotation of representation can be compensated in the receiving device.

The described practical systems of television are systems of momentary effect; in them luminous flux from every transmitted cell is used only during a short interval of time, while the scanning hole of the Nipkov disk (in the mechanical system) or the light spot (in the system with scanning by a running light spot) coincides with the given cell of the transmitted representation. Utilization factor of light in them is extraordinarily small. The cathode of the photocell is influenced at every moment by luminous flux from only one cell of representation, which consists of $\frac{1}{n}$ of all luminous flux forming optical representation (n is the number of cells of one frame).

The creating of television representations of high quality is made possible by the method of accumulation of light energy. In this method during transmission of every cell is used light energy obtained by photoelectrical converter not only during the time of transmission of the given cell, but also for the full duration of transmission of frame.

This building-up principle is used in contemporary transmitting television tubes. On Fig. 6 is shown the principle of light building-up energy with the help of a photocell, the current of which charges capacitor. The transmitted representation is projected on a panel consisting of a large number of photocells (on the figure is shown only part of the cells of one row); these cells have a general anode and photocathodes isolated from each other. Each photocathode is united through a separate capacitor with load resistance R_H. Under influence of light in circuits of separate photocells flow currents proportional to the illuminance of their photocathodes. Photocurrents charge corresponding capacitors to potentials proportional to illuminance of photocells. With the help of switch K, capacitors of every photocell by turn discharge through load resistance R_H, on which as a result of flow of currents appear voltages proportional to illuminance of connected photocells. In formation of signal participates a quantity of light n times larger than in the devices described earlier, for light acts on all photocells all the time, and obtained voltages are the result of continuous accumulation of charges in the interval between the two discharges. This permits transmission of representations with great exactitude, where transmitted objects are comparatively weakly illuminated.

However, for realization of such system, it is necessary that on one cell of representation there be at least one photocell, i.e., by the Soviet standard of broadcasting, it is necessary to have 500,000 photocells in all. It is still better if on one cell of representation, there are several photocells. In other words, we have to dispose panel with millions of photocells. Furthermore, it is necessary that during the time of transmission of one frame of representation, i.e., 1/25 s, the switch bypass contacts from at least

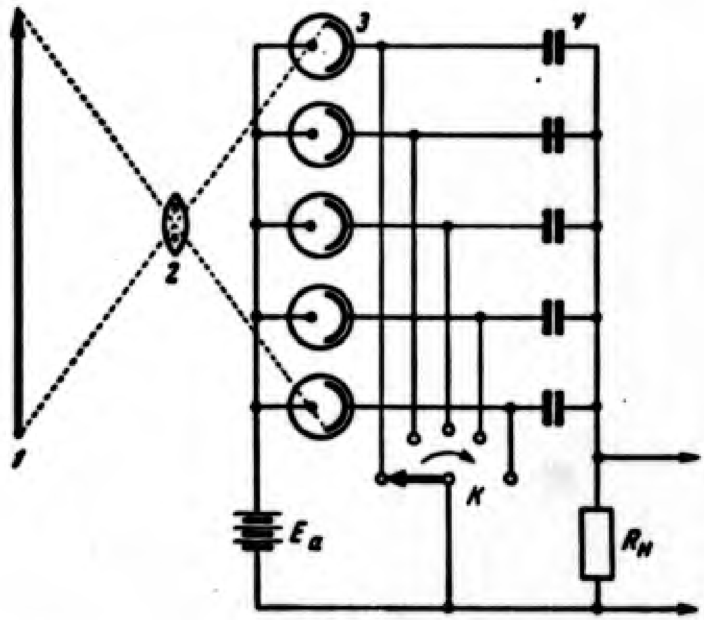

Fig. 6. Diagram of television transmitter using accumulation of charges. 1 — representation of transmitted object; 2 — objective; 3 — panel of cells; 4 — capacitors; R_H — load impedance; K — switch.

500,000 photocells. Can such a task be accomplished? Back in the early thirties, this problem was solved by creation of the iconoscope (Fig. 7), which was invented by Soviet scientist S. I. Katayev. The main node of this instrument is light sensitive mosaic or target. Mosaic is applied to the lamina of mica and is prepared in the following form. On plate is deposited thin layer of silver, it is heated, layer bursts, and silver is distributed in separate isolated drops. On these drops are created light sensitive surfaces by precipitation of cesium vapors. In this way are obtained millions of photocathodes. Metallic film covering other side of mica will form a second capacitor plate for every photocell. As switch passing through millions of contacts is used electron beam created by electron gun.

All elementary photocathodes of mosaic are continuously illuminated by corresponding image points of object formed by objective. This means that charges are stored continuously thanks to electron emission under action of light. Electrons are attracted by anode. Positive charges stored on mosaic will form electronic representation. Electron beam neutralizes charge of every cell (including whole group of photocathodes) once during scanning of every frame of representation. These discharges give rise to current pulses through resistance R. Voltage pulses created on terminals depend on illuminance of scanned picture cells and serve as a picture signal, which is strengthened by electron amplifier.

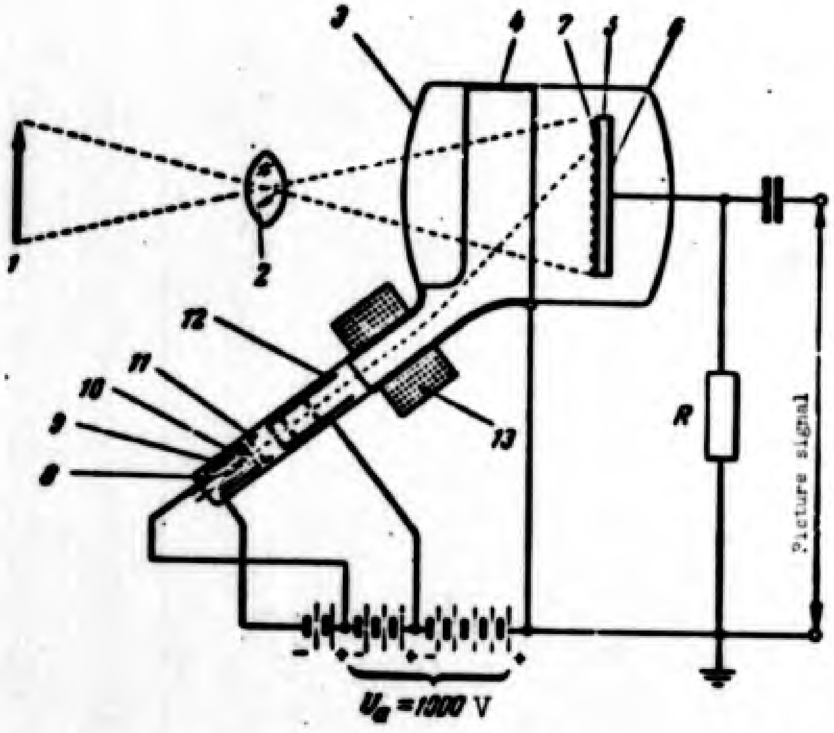

Fig. 7. Arrangement and circuit diagram of transmitting television tube of the iconoscope type. 1 — object; 2 — objective; 3 — bulb of tube; 4 — conducting covering, which plays the role of an anode collector; 5 — mica; 6 — signal plate; 7 — photomosaic; 8 — filament; 9 — cathode; 10 — control electrode; 11, 12 — anodes; 13 — focusing-deflecting system.

We have described the simplest transmitting television tube, in order to explain the principle of building-up itself. Already now are being used improved photoelectrical accumulating type converters.

CHAPTER II

TECHNOLOGY OF SPACE RADIOTELEVISION COMMUNICATION

Optical systems of television cameras. Photoelectrical converters. Receiving instruments. Television signal and its peculiarities. Amplification of television signals. Transmission of television signals over distance. Recording of television representations.

Picture signals are created in a television transmitting camera on an unpiloted or piloted spaceship. It can be delivered to the moon and the planets of the solar system and can be on earth. Problems, to be solved by a system of space radiotelevision communication are very different, and, accordingly, actual constructions, cells, and electrical circuits of transmitting television chambers must be different, not to speak of methods of treatment and transmission of picture signals. But independent of system a transmitting camera always has the following basic cells: objective, forming optical representation of transmitted object on light sensitive surface of photoelectrical converter: photoelectrical converter, converting light energy of optical representation into electrical picture signals; amplifier of picture signals; generator of electrical oscillations, carrying out electronic scanning; generator of extinguishing and synchronizing signals; device of automatic control of operating conditions of camera; sources of electrical energy.

Selection of these cells and conditions of their work determine surveyed area (capture), resolving power (number of transmitted cells of representation) and sensitivity (minimum illuminance, necessary for production of assigned quality of representation).

Optical Systems of Television Cameras

As optical system in television camera can be used lens objective (refractor), mirror objective (reflector), or mirror lens optical instrument.

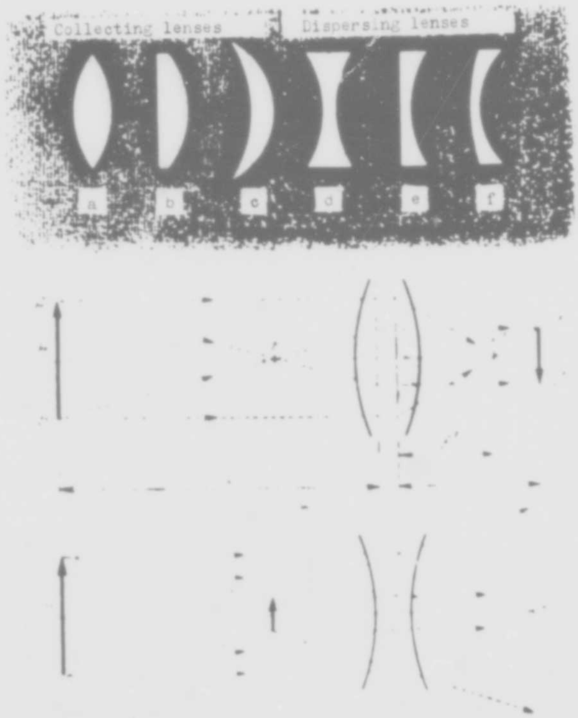

Fig. 8. Types of lenses and construction of representations given by them. a — biconvex; b — planoconvex; c — concavo-convex; d — biconcave; e — convexo-concave; f — construction of representations of collecting lenses; g — construction of representations of dispersing lenses.

Fibers (light conducting) optics are beginning to find wide application.

Objective usually consists of several optical lenses. These are pieces of optical glass (quartz, plastic or other transparent substance), limited from two sides by spheric surfaces (one of them can be flat). Surfaces of lens can be more complicated — cylindrical, parabolic and others. If middle of lens is thicker than its edge (Fig. 8a, b and c), then it brings the beam of light rays passing through it to a point and is called collecting. If middle of lens is thinner than edge (Fig. 8d, e and f), then lens transforms the beam passing through it into a divergent beam and is called dispersing. Straight line passing through centers of surfaces forming lens is called main optical axis of lens. Point on axis to which collecting lens brings rays parallel to its optical axis is called rear main

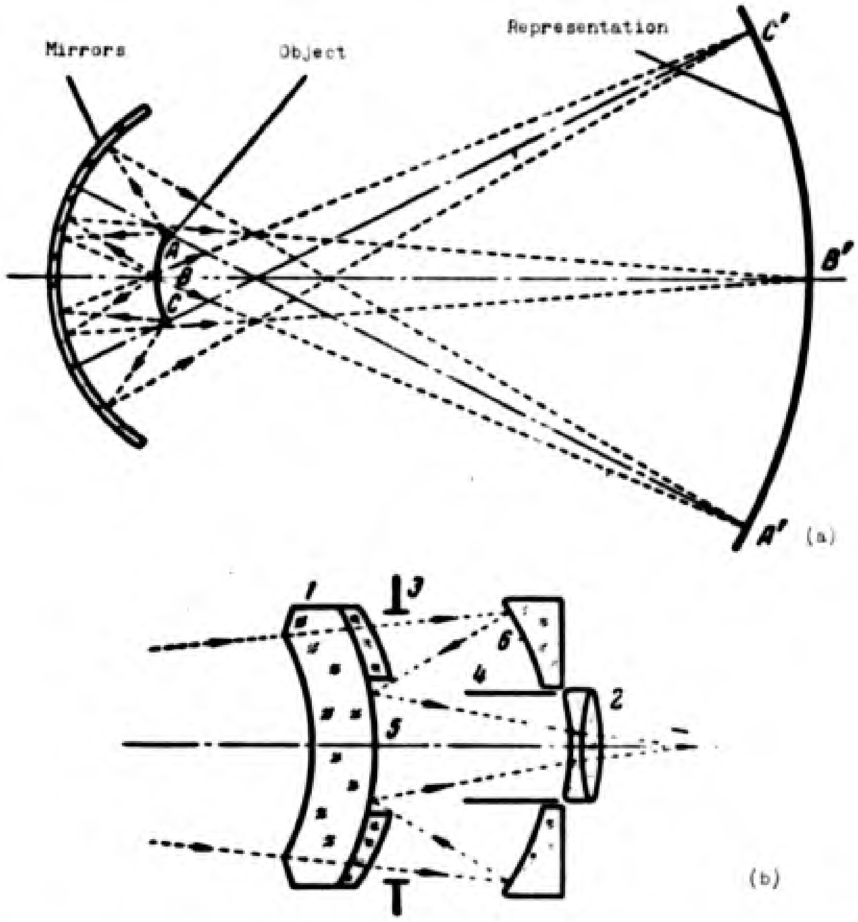

Fig. 9. Principle of action of mirror objective (a) and diagram of Maksutov mirror lens objective (b). 1 — achromatic meniscus; 2 — achromatic lens; 3 — diaphragm; 4 — blende; 5 — auxiliary dispersing mirror; 6 — main spheric mirror.

focal length of lens, but plane passing through focus perpendicularly to main optical axis is called focal plane (Fig. 8g). The dispersing lens focus is the imaginary point of crossing of the geometric continuations of the divergent rays F (Fig. 8h).

Simple lens gives representation of object (in so-called conjugate plane) distorted to a known extent: it is blurry, it has edging, its form is transmitted incorrectly, etc. Therefore, a combination of several collecting and dispersing lenses are usually applied, in order to mutually compensate distortion inserted by each lens.

In the objective the main optical axes of all lenses coincide, forming main optical axis of objective. Focal length of objective is determined by radii of curvature of surfaces of lenses, mutual distance between lenses and indices of refraction of those materials from which lenses are made.

Basic projecting cell of mirror and mirror lens optical instruments are spheric and other forms of mirror. Concave mirror collects rays of similarly collecting lens, but convex mirror disperses rays. Spheric mirrors possess a number of merits: in them distortions of projected representations are absent or occur considerably less, furthermore, they do not require application of optical glass. These properties permit the creating of a comparatively simple fast objective with sufficiently large viewing angle and high quality of representation. Principle of action of mirror objective is shown on Fig. 9a. For correction of spheric aberrations in mirror lens instruments are used additional correcting lenses, which are set before focus of objective. Spheric mirror is prepared not from optical glass, but from cheaper technical glass. Reflecting aluminum layer is deposited directly on concave surface of glass base.

Let us assume that from spacecraft is observed surface of planet from distance L (see Fig. 8g). Width of visible region H of surveyed planet is connected with focal length f' and width of frame of optical representation on photocathode of transmitting tube h by expression

$$H = \frac{h}{f'} L.$$

The greater the focal length f', the smaller the surface area which will be projected on working surface of photocathode and, consequently, the more detailed the observed object is represented on the representation. The greater the focal length, the greater the scale, but the lesser the viewing angle. Therefore, for solution of different problems various objectives are usually selected. Dimension of representation on photocathode h, focal length f' and viewing angle of camera (embracing section of representation with satisfactory quality) 2θ are connected among themselves by relationship

$$\operatorname{tg}\theta = \frac{h}{2f'}.$$

On Fig. 10 are depicted curves of dependence of width of zone of observation on viewing angle and height of flight of spacecraft.

Representation created by objective of chamber should occupy whole working surface of applied photoelectrical converter. Diameter of working part of photocathodes of contemporary transmitting television tubes is equal from 10 to 45 mm, and the diameter of special tubes with increased area of light sensitive surface is considerably greater.

In order to obtain representation of very remote objects in big scale, it is necessary to have very long focus objectives. What should be focal length of objective, if height of flight of spacecraft with television chamber on board is 250 km, required linear dimension

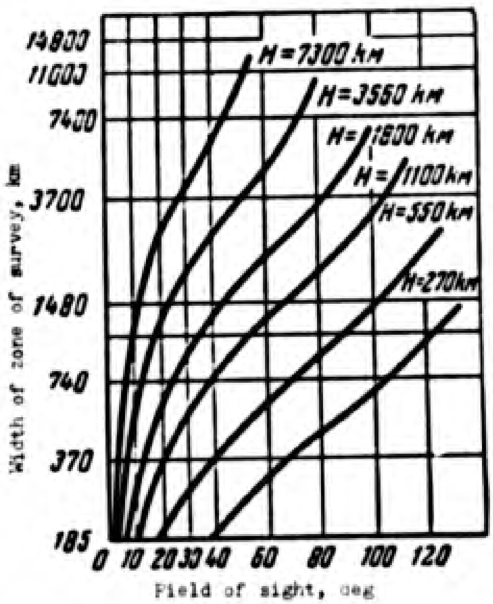

Fig. 10. Dependence of field of sight of optical device on width of zone of survey and height of satellite.

of object is 100 m, and diameter of working part of photocathode is 10 mm? We obtain

$$f = \frac{0{,}001}{100} 25000 = 2{,}5 \text{ м}.$$

With increase of focal length of objective length of the actual objective strongly increases and distance from surface of lens of objective to light sensitive surface of photoelectrical converter is increased.

For projecting of representations of remote object on light sensitive surface in big scale, telephoto lenses are created. They have distance from last surface of lens to photocathode of a few times less than focal length, where length of objective usually does not exceed 0.50-0.75 focal length. Construction of telephoto lenses is complicated enough, and in case of observations made from spacecraft, this complexity increases still the necessity to use a large diameter lens. And this is necessary because the greater the ratio of diameter of lens to focal length (which is called relative aperture), the bigger the illuminance of representation on light sensitive surface. Illuminance is proportional to the square of relative aperture. Let us assume that an objective is applied with relative aperture 1:4. From this it follows that at focal length 2.5 m, it is necessary to apply a lens of about 63 cm in diameter, if we wish to observe a region 100 m in width from a distance of 250 km. It is clear that an objective with such lenses can be used only on especially big spacecraft. Thus, diameter of objective for largest European reflector, which is in Crimean astrophysical observatory, is 2.6 m at focal length 10 mm. Diameter of mirror of the world's largest reflector is equal to 5 m, and diameter of the world's largest lens is about 1 m. Diameters of refractors of majority of lens objectives does not exceed 65 cm.

In order to decrease length of telephoto lenses and to remove their cumbersomeness, mirror lens optical systems are applied at large focal lengths. As an example optical diagram of mirror lens telephoto lens of Maksutov system is shown on Fig. 9b.

There are created objectives with variable focal length, in which it is possible to smoothly change focal length and scale of representation, respectively. Peculiarity of these optical systems, besides continuous change of scale of representation, is preservation of constant distance between object and representation. For this during change of scale of representation, it is necessary that there be ensured independent shift of at least two components of optical system, where system components, as a result of shift, should occupy different position at different scales of representation.

Objective with variable focal length is the most complicated optical system. On Fig. 11 is shown diagram of multicomponent system

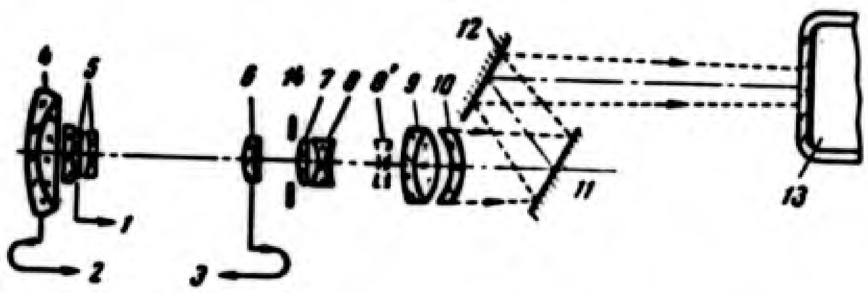

Fig. 11. Television objective with variable focal length. 1, 2, 3 – direction of shifts of sets of lenses; 4, 5, 6 – transferred sets of lenses; 7, 9, 10 – fixed sets of lenses; 8 – lens for sharp change of focal length; 11, 12 – mirror; 13 – transmitting tube.

of variable objective. Application of three mobile cells ensures best control of correction of distortions in whole range of focal lengths. For decrease of distance between objective and photocathode, refraction of rays with help of mirrors is used. Of special interest is construction of section of objective after objective of variable focal length, since this ensures change of limits of adjustment of focal length without replacement of some cells of system. It is possible to say that this unit is objective with variable focal length in objective with variable focal length. Thus, in one of types of objectives, when group of lenses (8 on Fig. 11) is advanced, range of change of focal length composes 100-500 mm, and relative aperture is 1:4; when this group of lenses is in extreme rear position (8' on Fig. 11), range composes 200-1000 mm, and relative aperture is 1:8. Thus, this system ensures two mutually covering ranges of change of focal lengths.

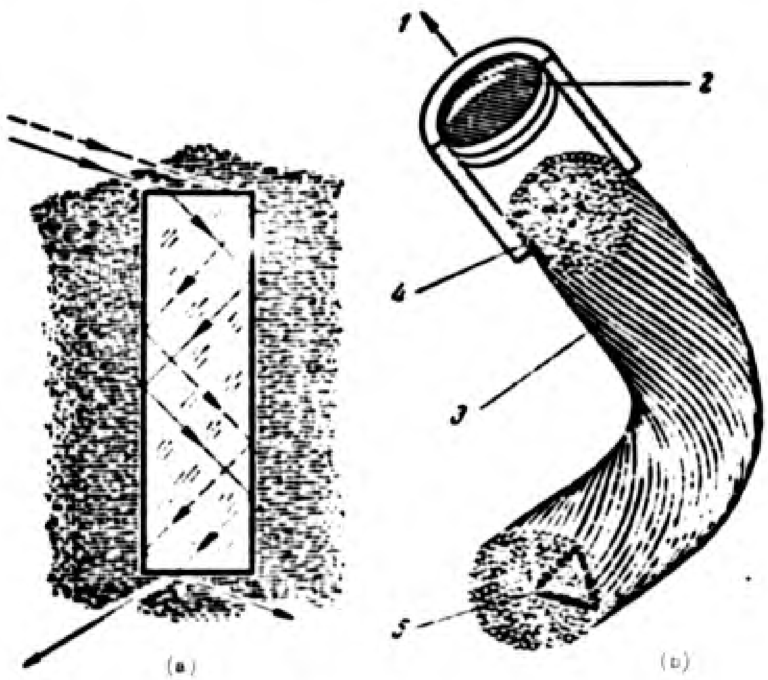

Fig. 12. Passage of light on glass rod (a) and transmission of representation by flexible braid of fibers (b). 1 – direction of sight; 2 – objective; 3 – light leading fiber; 4 – representation being transmitted; 5 – transmitted representation.

Fiber optics. In recent years much attention is allotted to use of fibers optics in television. This is the only optical system of its kind. It is in the form of a flexible beam of light leading fibers and replaces complicated systems of lenses and mirrors during transmission between two points which are not on one straight line. Furthermore, this optics permits weight of board equipment to be significantly decreased, and gives a number of special effects. For example, it is possible to produce change of dimensions and picture format, conversion or splitting of representations, and also to remove certain aberrations of optical systems, to obtain coding and decoding of representations, to decrease loss of contrast of representations, to increase light effectiveness of light collecting and light radiating systems, etc.

Principle of use of flexible optical cable for transmission of optical representation is shown on Fig. 12. Cable consists of a large number of thin transparent fibers made of glass, quartz, or plastics (Fig. 12b). Rays of light falling on one of the ends of cylindrical fiber spread to other end of rod at the expense of multiple reflection (Fig. 12a). Inasmuch as a very large number of reflections occur, it is necessary that fiber have smooth not contaminated surface. Furthermore, for lowering of light losses, material used should possess great transparency for rays of needed part of spectrum.

Photoelectrical Converters

Quality of final representation, and also region of application of installation and its possibilities are, in considerable degree, determined by photoelectrical converters — the most responsible cell of television system. Of the number of photoelectrical converters described by us in television systems of momentary effect are used photomultipliers and electronic dissectors. In systems using the building up principle of light energy are applied transmitting tubes with photoresistance, image orthicons, supericonoscopes and modification of mentioned tubes. But, before examining devices and properties of different photoelectrical converters, it is useful to tell about photocells.

Photocells. These are the simplest converters of energy of electromagnetic waves of optical spectrum into energy of electrons. In technology find application instruments using different forms of photoeffect: external, internal, and photoeffect of barrier layer.

External photoeffect consists in extraction of electrons from surface of metals under action of light falling on it. In metals there are always free electrons, but they cannot spontaneously escape beyond the limits of metallic electrode, because on its surface appear forces which hold them. For extraction of electron outside, it is necessary to accomplish certain work on surmounting of forces connecting free electrons with solid. This work (work of output) can be accomplished at the expense of communicating additional energy to electrons of metal. In photocells energy necessary for accomplishment of output work, is reported by quanta of light falling on the photocathode surface.

During heating of metal appears thermionic emission. Additional energy can be communicated to electrons of substance, by irradiating material by beam of electrons. (Emission) of electrons appearing during this emission is called secondary electronic emission.

Arrangement of vacuum photocell with photoemission is shown on Fig. 13a. Glass balloon of instrument from which air is pumped contains light sensitive cathode and metallic anode. Cathode is created on internal surface of glass bulb of instrument or is fulfilled in the form of semicylinder, corner or lattice cylinder, covered with light sensitive layer from that side whence radiation is grasped. As anode serves metallic ring, frame, grid, perforated leaf, spiral or rods. When light hits photocathode electrons are emitted from it. Number of created photoelectrons is proportional to illuminance of photocathode. In order to create ordered travel of electrons to anode and to remove space charge, which prevents emission of electrons, on positive potential is given to anode.

Different electric vacuum photocells differ from each other first of all by type of photocathode. Usually are used not photocathodes from pure metals, but complicated cathodes of semiconductor nature, since they are characterized by small work function and, accordingly, are sensitive to visible rays.

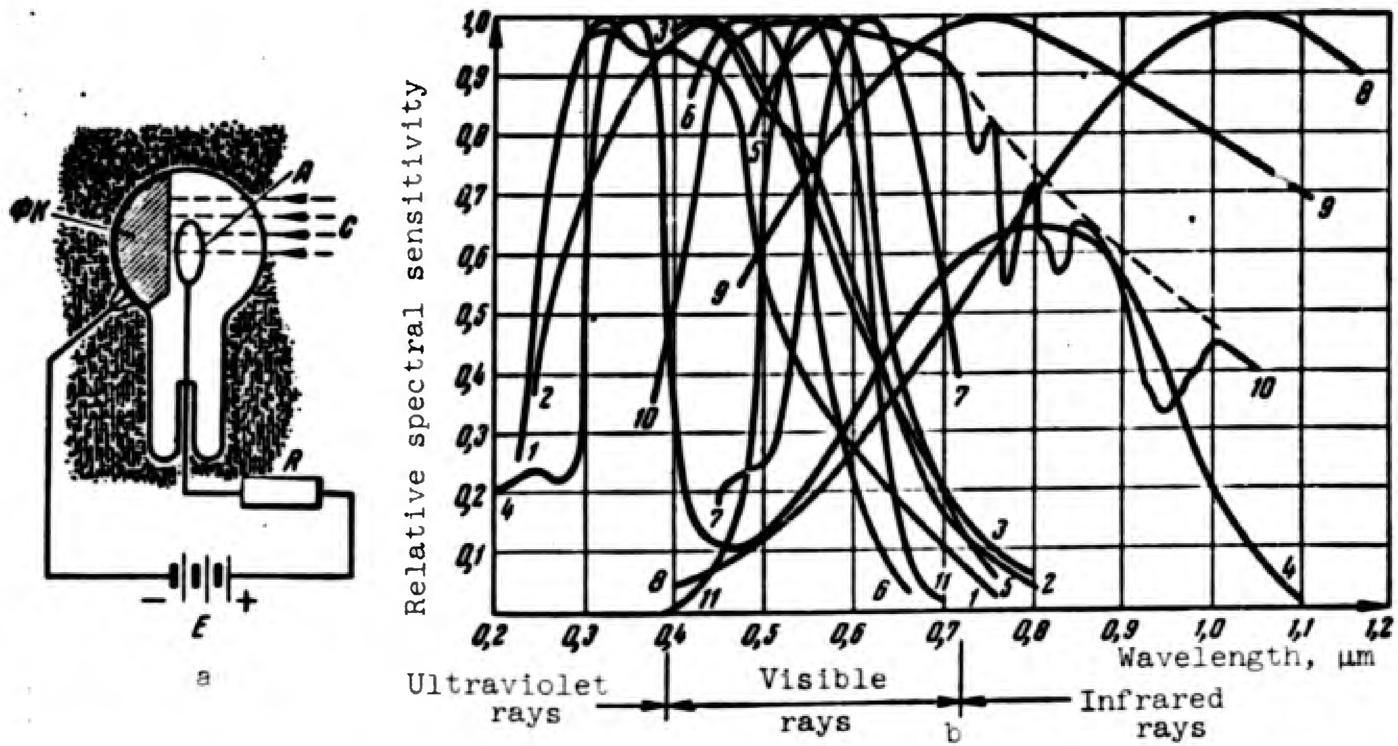

Fig. 13. Device of vacuum photocell (a) and spectral characteristics of sources and receivers of radiant energy (b). 1 — antimony-cesium photocathode; 2 — bismuth-cesium photocathode; 3 — multialkaline photocathode; 4 — silver-cesium photocathode; 5 — photosensitive layer of antimony trisulfide; 6 — selenium photosensitive layer; 7 — daylight lamp; 8 — vacuum tube with tungsten filament; 9 — moonlight; 10 — daylight; 11 — curve of luminosity of eye.

On Fig. 13b are shown spectral characteristics of sensing devices (photocathodes and photosensitive layers) of contemporary photoelectrical converters, and there are also given curve of luminosity of eye (dependence of brightness perceptible by eye on action of sources with different wavelengths and identical powers of radiation) and curves characterizing spectral composition of different sources of illumination.

Practically utilized luminous fluxes create in circuit of vacuum photocells very small currents (not more than several μA). Besides on load resistances are obtained picture signals which are insignificant in value and insufficient for useful use. What hinders us from using these signals? One would think if it is necessary to obtain on output of television camera a picture signal of definite value, then it is sufficient to use amplifier with corresponding large amplification factor and problem will be solved. However, this is not so. Difficulty is caused not by the actual smallness of signal, but by the fact that simultaneously with signal will be strengthened and parasitic signals and noise. If these interferences appear commensurable in value with picture signal, then quality of representation will be extraordinarily low, and if level of signal is considerably below level of interferences, then there can be no speech about reception of representation in general. To ensure sufficiently good quality of representation it is necessary that value of desired signal exceed value of interference by several tens of times. It is necessary to struggle with sources of interferences in all cells of device. However, their main danger is in those cells, where desired signal is engendered and where its amplification starts. On representation these interferences appear in the form of unique blinking ripple like incident snow.

Photomultipliers. Necessity to have photocells on high sensitivity, which ensure large working currents and high signal to noise ratio on output, lead to creation of electron photomultipliers, the device of which is based on the use of the phenomenon of secondary electronic emission for multiple amplification of photocurrent inside the actual vacuum device. Instrument consists of series of electrodes with surface treated with cesium (Fig. 14). The first of them serves as photocathode, but the last one serves as anode. Photocathode is applied in the form of thin layer on electrode, in form similar to intermediate electrodes — emitters. It can be carried out in the form of semitransparent covering on internal surface of multiplier bulb. The number of emitters in different instruments is different. Emitters are connected to power supply through voltage divider so that their potential grows with increase of serial number of electrodes, starting from photocathode.

From surface of photocathode under action of luminous flux falling on it are emitted electrons. They are accelerated by electrical field and bombard first emitter, punching from its surface a number of electrons exceeding the number hitting. Such an effect is attained by definite selection of material and corresponding treatment of surface of emitters. Emitters used at present can emit 5 and more electrons on one primary electron; in other words, coefficient of secondary electron emission of surfaces of emitters attains 5 and more.

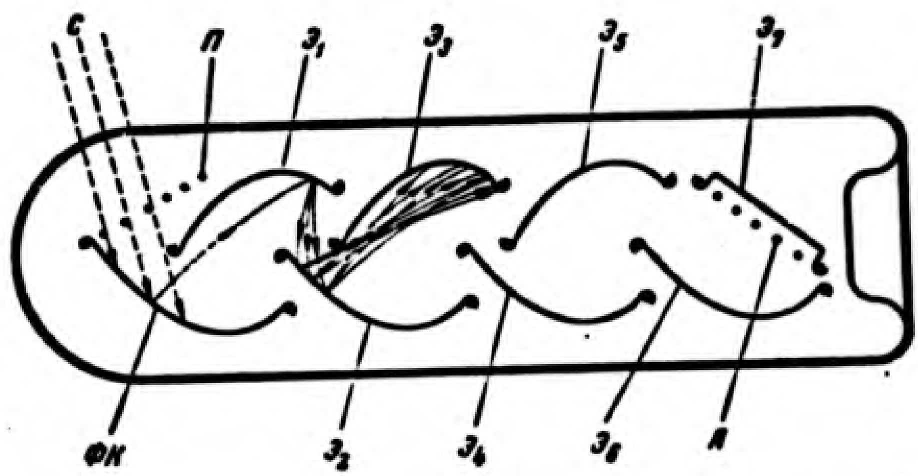

Fig. 14. Electrode system of photomultiplier: ФК — photocathode; $Э_1$, $Э_2$, $Э_3$ ... — emitters; A — anode; П — wire gauze; C — light beam.

Secondary electrons coming from first emitter get to second emitter, which is under large potential with respect to cathode, and punch from it still more secondary electrons. Thus, electron flux on the way from photocathode to anode continuously increases, and in circuit of anode will flow current considerably exceeding photocurrent obtained from cathode. Practically it is possible to attain amplification of photocurrent inside instrument of 1-100 million times, but in instruments of complicated construction, amplification attains several billion. Amplification k depends on value of coefficient of secondary emission σ and on the number of emitters n in the following way:

$$k = \sigma^n.$$

The real amplification factor should approach the theoretical amplification factor, therefore, it is necessary that all secondary electrons get from one emitter to the neighboring one, and do not fly past. For this electrodes are given a special ladle-like form, which has been found as a result of numerous experiments. According to the described diagram is built the multiplying unit of many of the photomultipliers produced by our industry. There are several types of photomultipliers built on other principles of direction of electron fluxes from one emitter to another. The inventor and creator of the first photomultiplier is the Soviet researcher, L. A. Kubetskiy.

It is impossible to strengthen comparatively powerful signals with the help of electron multiplier phototubes. Therefore combined amplification is usually applied: weak photocurrents are amplified in photomultiplier phototube, but further amplification of picture signal is produced by electron-vacuum tube or transistor (semi-conductor) amplifier.

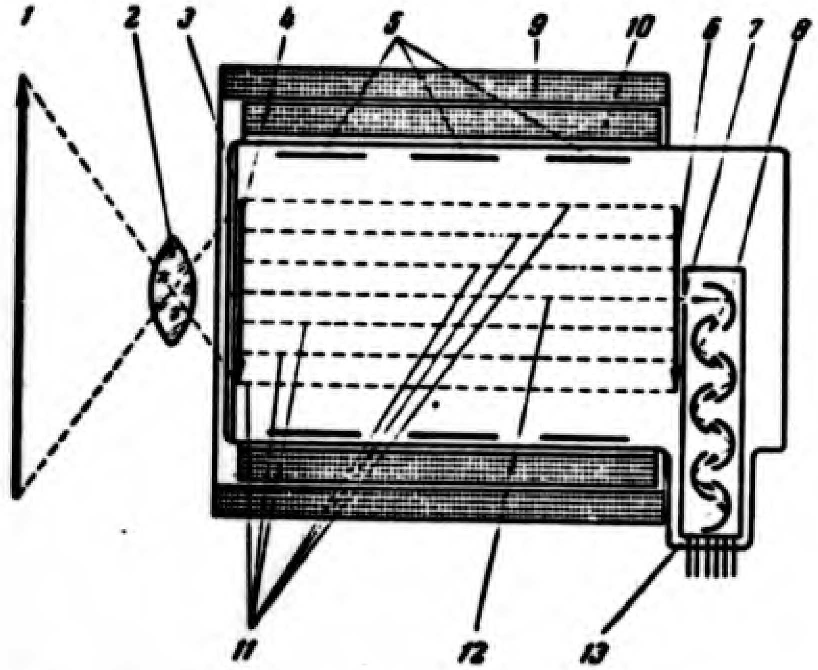

Fig. 15. Electronic dissector. 1 — object; 2 — objective; 3 — semitransparent photocathode; 4 — optical representation of object; 5 — focusing electrodes; 6 — electronic representation; 7 — inlet of electron multipliers; 8 — electron multiplier; 9 — focusing coil; 10 — deflecting coil; 11 — electron fluxes, not getting into the multiplier inlet at a given moment; 12 — electron beam getting into inlet of multiplier; 13 — intensive electron beam.

Electronic dissector. Like electron multiplier phototube, this instrument is of momentary effect. It possesses a number of essential merits and can find application in certain systems of space television. Diagram of device of electronic dissector is shown on Fig. 15. On surface of internal part of bulb of tube is created semitransparent photocathode, on which is projected transmitted representation with the help of objective. Inside tube the photocathode emits photoelectrons in quantity proportional to luminous flux falling on this section. The electronic representation formed is transferred from photocathode to electron multiplier with help of magnetic and electrical fields. Magnetic field is created by transmission of direct current on focusing coil, but electrostatic accelerating field is created by giving increasing positive potentials to rings located between photocathode and electron multiplier.

In any moment of time pass into hole of electron multipliers only electrons from one cell of representation pass. Electrons which have passed hole are introduced into first stage of electron multiplier and, after multiple amplification, get to anode. In anode circuit is switched on load impedance, on which is created voltage proportional to the number of electrons, getting on anode of electron multipliers.

For series obtaining of voltages of signals from all cells of representation is produced scanning, peculiarity of which is the fact that inlet of electron multiplier remains motionless, and the whole electronic representation shifts in space so that against hole in series, cell after cell, line after line, there pass electron fluxes from all cells of transmitted representation. The number of electrons getting into hole changes all the time in accordance with change of density of electrons. This process is carried out with help of two pairs of deflecting coils, on which are passed linearly variable currents.

Supericonoscope . Transmitting television tube of supericonoscope is instrument of storage type, which is more perfected than iconoscope. Supericonoscope was invented by Soviet scientists P. V. Shmakov and P. V. Timofeyev. Bulb of tube consists of two sections of different diameter and throat (Fig. 16). On internal side of flat front section of tube bulb is applied a semitransparent photocathode. At a certain distance from it, parallel to its plane, is

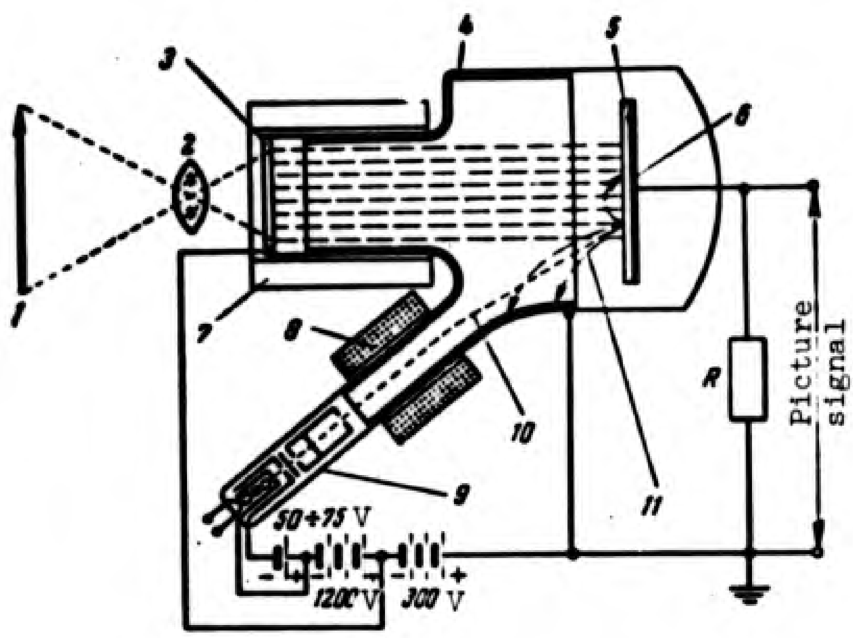

Fig. 16. Device and circuit diagram of transmitting television tube of supericonoscope. 1 — object; 2 — objective; 3 — semitransparent photocathode; 4 — conducting covering; 5 — target; 6 — signal plate; 7 — coil for focusing of electronic representation; 8 — focusingly-deflecting system of scanning beam; 9 — electron gun; 10 — scanning electron beam; 11 — secondary electrons; R — load impedance.

located target, which serves as storage unit of energy. It constitutes very thin lamina (thickness near 100 μm) of mica or glass, covered from reverse side by metallic film which is signal electrode. From the side turned to photocathode, target is covered by layer of material possessing large secondary electronic emission.

Transmitted representation is projected by objective on surface of photocathode. The electronic representation which has been formed is transferred from photocathode to target with help of magnetic and electrical fields. Magnetic field is created by transmission of direct current along the coil, set on the protruding part of bulb of tube. For production of electrostatic accelerating field, the target is given potential which exceeds potential of photocathode by several hundred volts.

Hitting against target with high speed, each of photoelectrons punches several secondary electrons, and on target there is formed distribution of potential which corresponds to distribution of illuminance on photocathode of tube. To lighter sections correspond more postitive potentials of target sections.

Distribution of charges on target will be converted into television signal with help of electron beam, which by turns runs around all target elements. Electron beam is created by electron gun, which is located in narrow cylindrical throat of bulb. Above this throat is focusing coil, which serves for reduction of divergent electrons into narrow beam, and deflection coil of electron beam by horizontal and vertical.

Between cathode of electron gun and target is applied potential difference of the order of 1000 V, thanks to which scanning beam bombards target with such high speed that the coefficient of secondary electronic emission considerably exceeds one. Electron beam brings target potential to a certain constant potential, which exceeds potential of internal conducting covering of bulb (collector) by several volts, where this potential does not depend on potential earlier existing on target. Value of current of secondary electrons depends on depth of potential relief formed earlier. Fewer secondary electrons are ejected to collector from more positive sections of target than from positive sections. The signal current formed by secondary electrons flows on closed circuit: target — collector — load impedance — capacitance of target. On load resistance at the expense of current flow there appears picture signal voltage.

For production of signal of sufficient value, illuminance on photocathode should compose several tens of lux. This is considerably less than the illuminance required by the iconoscope applied earlier. Large sensitivity of supericonoscope is explained by the fact that in it, in contrast to iconoscope, is applied not a mosaic, but a solid photocathode. This permits fuller use of light sensitive surface. Furthermore, here occurs multiplication of signal at the expense of secondary electronic emission, which appears during bombardment of target by fast photoelectrons of primary electronic representation. Here all photoelectrons get to target. Finally, supericonoscope permits the using of more short-focused optics, since photocathode is on front wall of bulb.

Below are described tubes possessing higher sensitivity than supericonoscope, although it still finds application, since pictures obtained with its help are distinguished by their high quality.

Image orthicon. Image orthicon is arranged in the following way (Fig. 17): In front section of large diameter (76 mm) tube is carried out creation and transfer of electronic representation, but in rear part of tube of smaller diameter (52 mm) is produced scanning and amplification of signal by secondary electron multiplier. Tube is placed inside long focusing coil, which creates uniform magnetic field, lines of force of which are directed parallel to its axis.

Near photocathode edges is set accelerating electrode, which serves for creation of field, to transfer electrons to target. During their travel to target, electrons emitted by photocathode preserve in planes of focusing a distribution of density on section, which is analogous to distribution of illuminance on photocathode. Accumulation of charges is carried out with help of target, a thin glass semiconducting film 3-5 μm thick, which is secured on ring together with small structure grid, which is located before target from the side of photocathode, at a distance of several tens of microns.

During travel photoelectrons collect considerable speed. Therefore, they do not settle on grid, but fly through it. Hitting against target, photoelectrons punch secondary electrons from it, and on target will be formed potential relief corresponding to distribution of illuminance on photocathode. Secondary electrons do not return to target, but are captured by grid (since they have small speeds), to which is applied positive voltage of the order of 1-2 V with respect to cathode of electron gun.

On left (on figure) side of target is created deep positive potential relief with large potential on sections corresponding to bright cells of representation. Further positive charges are transferred from left side of target to right side at the expense of displacement currents. Thus, on reverse side of target, distribution of potentials on surface will be precisely the same, as on the side turned to photocathode.

Potential relief will be converted into electrical picture signals with help of electron beam. Scanning here is produced from reverse side by beam of slow electrons, i.e., electrons, the speed of which conditions the value of coefficient of secondary electronic emission, which is less than one. Thanks to this the target under influence of electron beam obtains potential which is equal to potential of cathode of electron gun.

Electron gun consists of thermocathode, control electrode, and anode. Electrons coming from gun through narrow hole in diaphragm accumulate in very thin beam, which is deflected further by the magnetic field of the deflecting coils. Electrons approach

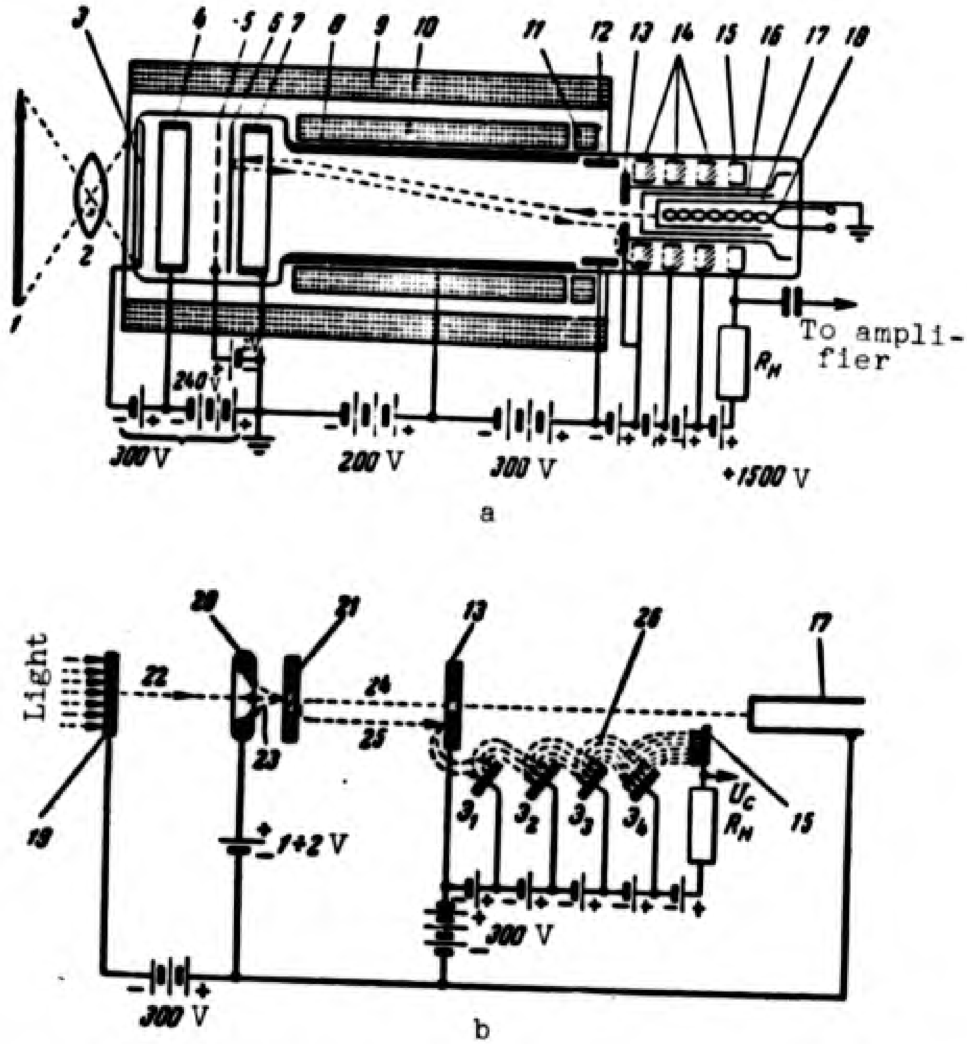

Fig. 17. Device and circuit diagram of transmitting television tube of image orthicon type (a) and diagram of travel of electrons inside image orthicon (b). 1 — object; 2 — objective; 3 — semi-transparent photocathode; 4 — accelerating electrode; 5 — grid; 6 — target; 7 — decelerating electrode; 8 — focusing electrode; 9 — focusing coil; 10 — deflecting coil; 11 — correcting coil; 12 — second anode of gun; 13 — anode of electron gun; 14 — emitters of electron multipliers; 15 — anode of electron multipliers; 16 — control electrode; 17 — cathode of electron gun; 18 — filament; 19 — cell of photocathode; 20 — cell of grid; 21 — cell of target; 22 — photoelectrons; 23 — secondary electrons; 24 — straight line flux of electron beam; 25 — return flux of electron beam; 26 — secondary electron flux.

target with low speeds, since along the way their travel is gradually delayed with help of special decelerating electrode. Its negative voltage will be selected so that velocity of electrons decreases to zero near target. If potential relief is absent on target, then all electrons of scanning beam will appear turned in the opposite direction, and, according to their reverse travel to electron gun, velocity of electrons will increase.

However if positive charge is on target, then part of electrons from scanning beam will be attracted to target, and, thus, every time after passage of scanning beam, potential relief of target will be neutralized ("erased"). The number of electrons removed from beam for neutralization is directly proportional to potential of target in a given point, but this means that the number of electrons reflected from target will also depend on potential relief of target — the more illuminance of section of photocathode and, consequently, the higher the positive potential of the corresponding section of target, the fewer electrons will be in reflected part of beam.

Reflected electrons move to anode (Fig. 17b), being accelerated during return by the very same field, which braked incident beam. Overwhelming number of electrons get on front surface of disk of electron gun anode and punches secondary electrons from its surface. Anode constitutes first stage of secondary electron multiplier. An electron beam intensified approximately a thousand times (or more) is collected by collector of multiplier, into circuit of which is switched load resistance.

Electron beam does not head for the same point of target, but accomplishes travel by defined law, and, during the time of transmission of frame succeeds in running around all points of target. In each point, the beam must receive back a different number of electrons. Since charge of every point of target depends on brightness of corresponding section of representation, density of beam changes all the time, following light and dark places of the representation. Accordingly, the value of signal voltage is changed on load resistance of electron multiplier.

Image orthicon sensitivity is so big that it permits working at photocathode illuminance, which is measured in fractions of a lux. Important tube deficiencies: are complexity of construction and corresponding complexity of its exploitation, necessity of creation of strong focusing and deflecting fields, and large weight and dimensions of the actual tube and its focusing-deflecting system.

Vidicon. In transmitting tubes described earlier of the storage type (iconoscope, supericonoscope, image orthicon), light energy into electrical energy using photoemission, but energy was accumulated using secondary electronic emission. Sensitivity of these tubes is limited by, among other things, small value of quantum output. In them on one quantum of incident light, less than one electron is necessary. In photoconductive layers (which change resistance when irradiated by light), quantum yield can appear greater than one, and sensitivity can be increased as compared to

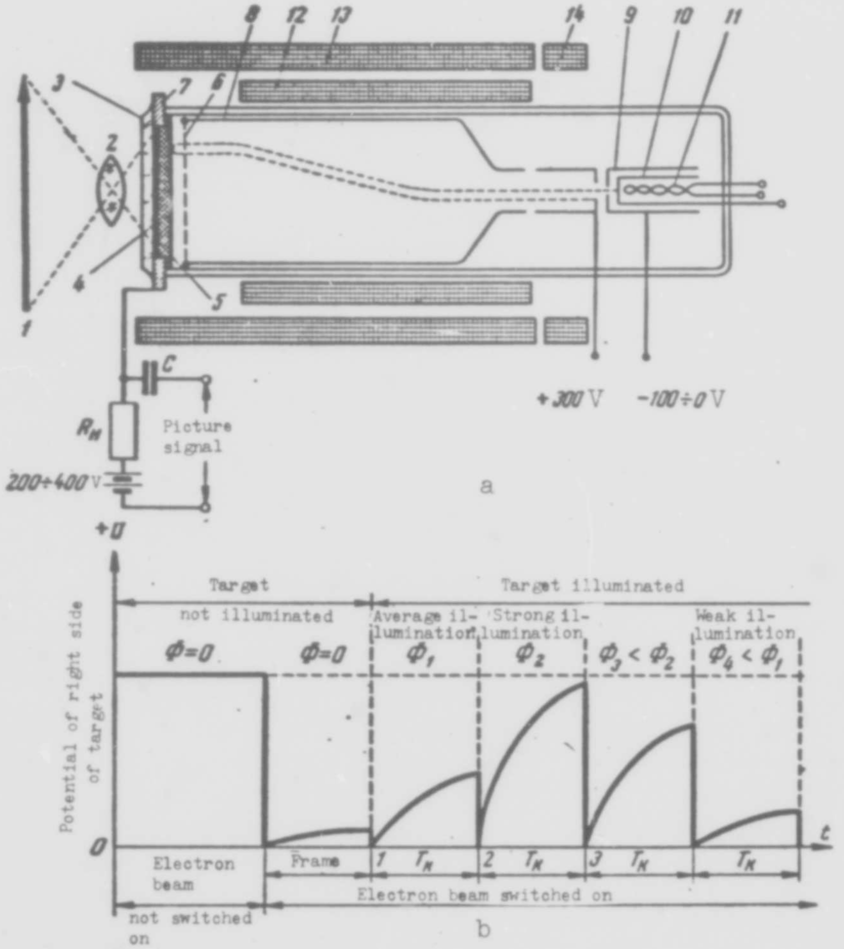

Fig. 18. Device of transmitting television tube of vidicon type (a) and processes on target during its scanning by delayed electrons (b): 1 — object; 2 — objective; 3 — glass; 4 — signal lamina; 5 — target; 6 — grid; 7 — metallic ring; 8 — focusing electrode; 9 — control electrode of electron gun; 10 — cathode; 11 — filament; 12 — deflecting coil; 13 — focusing coil; 14 — correcting coils.

photoemission layers. This permits creating a tube of simple construction, a so-called vidicon — a cylindrical glass bottle (Fig. 18) with built-in light conducting layer and signal lamina with gun to create commutating beam. Role of signal plate is played by finest metallic film, which is applied to internal and face of the bottle. The film is so thin that it is transparent for light rays. This film is united with a metallic ring, which is welded to the face wall, and with the cylindical part of the bulb. To the metallic film is applied a thin layer of photoconductor (several microns in all). As material of this layer (target) serves antimony trisulfide, selenium, and others. Spectral characteristics of these layers are shown in Fig. 13 (curves 5 and 6).

Representation of transmitted object is projected by objective through transparent signal plate to photoconductor, which from reverse side is commutated by beam of electrons. Through anode diaphragm the electrons of the beam pass with a speed correspondingly to a potential difference of 300 V. This speed is changed little before passage of electrons through grid, after which they get into a strong retarding field. During approach to target, velocity of electrons drops to a value which is determined by potential of section of target surface. This potential, in turn, is determined by potential of signal plate (20-40 V) and value of conductivity in this section of target.

In darkness the resistance of the photoconductor is very great. Electron beam, passing along photoconductor, leaves electrons on it, charging photoconductor to potential of electron gun cathode. In these conditions a potential difference of 20-40 V is created between sides of target. Current flowing under action of this potential difference through layer of photoconductor is very small in darkness. Therefore to the following income of electron beam, potential difference will be changed very little to nonilluminated part of the target and compensation of change of charge will require few electrons.

Another thing is observed on illuminated sections of target (see Fig. 18b). Resistance of these sections is small. Therefore, during the time of absence of electron beam (during the time of scanning of one frame of representation), voltage on signal plate and on commutated side of target can, in great degree, be compared with each other (at the expense of fast discharge of capacitance of target), and commutated side of target will be charged positively. At the time of commutation by electron beam, potential of this side of target is again led to potential of cathode (zero potential). This occurs at the expense of that which through illuminated section of target (point 3 on Fig. 18b) a large current flows. This booster charge current, flowing through load impedance, will create picture signals.

Tube with photoconductor is simple in construction and in operation and has good resolving power, small inherent noises, and small dimensions (diameter of bulb of usual vidicon is 25 mm, length is 150 mm, in a miniature vidicon, they are 12 mm and 75 mm respectively). These merits of tube permitted its wide application in airborne transmitting cameras of spacecraft.

However, this tube has a number of significant deficiencies — at low levels of illumination, it does not permit transmission of representations of fast-moving objects, but in the structure of its target are heteogeneities.

Improvement and creation of new transmitting tubes. In connection with growing requirements presented to applied television installations, transmitting tubes were improved in order to increase their sensitivity, to decrease noise level, to remove smearing during transmission of representations of moving objects, to increase sharpness during minimum illuminance of objects, to expand working spectrum of optical waves, to increase reliability, etc.

With improvement of image orthicons, effectiveness of processes of readout of charges is increased; highly sensitive photocathodes are used. Multistage transfer and amplification of representation before accumulation of information on target are promising. The simplest method of amplification of image brightness is optical connection of image converter with standard image orthicon, when of the object image, which has been intensified in brightness, is projected by objective on photocathode of transmitting tube.

How is this attachment, this image converter, arranged? It is a device in the form of a glass shell (Fig. 19a) with double wall and double bottom. On bottom of external glass is applied semi-transparent photocathode, but on bottom of internal glass is applied a layer of luminophor, which forms a screen. During projecting of representation from every point of photocathode will break loose photoelectrons in a quantity proportional to illuminance of this point. Being accelerated by electrical field, electrons bombard screen and make it glow. Sensitivity of image orthicon is increased when light losses are covered by light amplification in image converter which is before image orthicon. For this two-state and multistage amplifiers are needed. But in this case the instrument obtained is bulky, suffers from poor image sharpness and requires application of high voltages.

It is more profitable to combine image converter and image orthicon in one instrument (Fig. 19b). Then representation is projected on photocathode of image converter. Photoelectrons, emitted by photocathode are focused by electrical field on luminescent screen. Glow of screen (brighter than optical representation on photocathode) causes photoemission against second photocathode. Accelerated electrons bombard second luminescent screen on thin mica plate. Glow of this screen causes photoemission against third photocathode which is on other side of plate and starts the usual section of transfer of the image orthicon. Two-stage image converter permits the obtaining of 300-multiple current amplification. A limit to increase in the number of stages is imposed by decrease in image sharpness. Experimental samples of image orthicon with two amplifier stages permit the obtaining of representation with sharpness of the order of 100 lines during illuminance of photocathode 10^{-6} lux.

The aim is to increase sensitivity of vidicons. Usually vidicons require illuminance of target of the order of several lux, and this is difficult to ensure. Sensitivity of eybicon (vidicon with image transfer) is approximately 100 times higher than sensitivity of usual image orthicon, but a photocathode illuminance of $5 \cdot 10^{-4}$ lux is sufficient for its operation.

For work in infrared region of electromagnetic radiation spectrum there has been created vidicon, in which change of elementary capacitance of target under influence of infrared radiation is used.

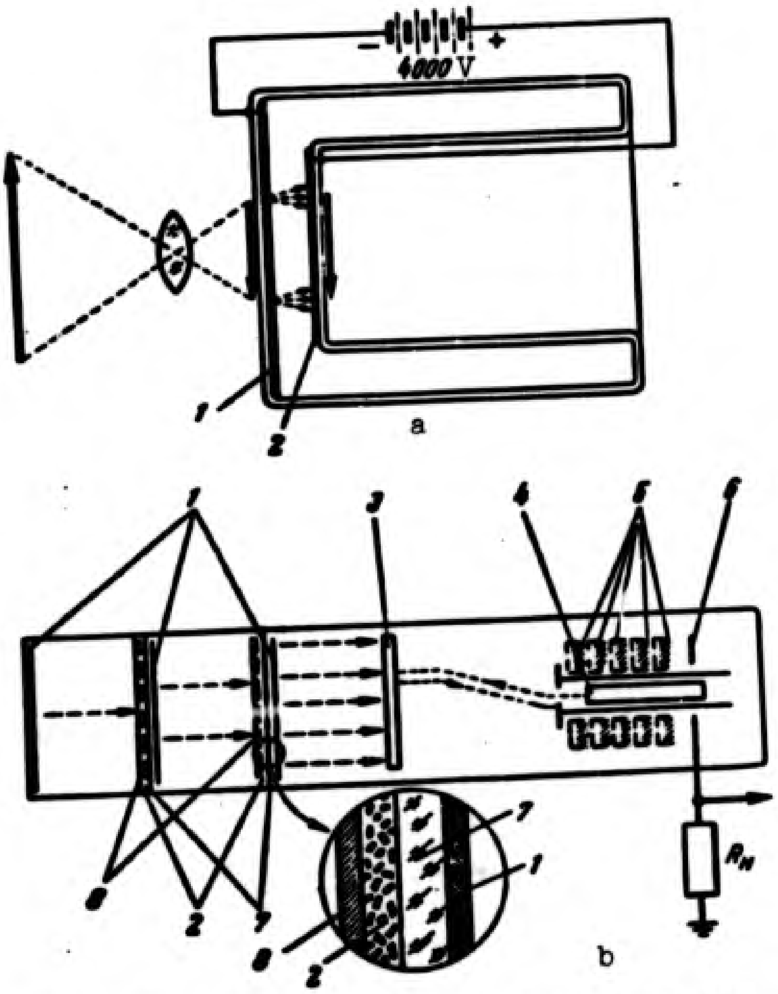

Fig. 19. Diagram of arrangement of the simplest image converter (a) and image orthicon with two stages of image converters (b). 1 — photocathodes; 2 — luminescent screens; 3 — thin glass film and small structure grid; 4 — electron gun; 5 — secondary electron multiplier; 6 — anode; 7 — glass or mica transparent plate; 8 — aluminum film.

Signal electrode of new tube is carried out from transparent conducting layer, which is turned outwards, and from a semiconductor layer deposited on the first layer. Second layer is fulfilled from ferroelectrical compositions, such as barium titanate, for example. Dielectric constant of such materials is changed with change of temperature and under influence of electrical field.

These properties of target are used in the following way. Every cell of target can be examined as an elementary capacitance, one facing of which is turned to electron gun, and the other facing of which is united through resistance with source of d-c voltage. During projecting of image against target, heat in and transferred by infrared rays, will lower the dielectric constant of every elementary capacitance, provided that temperature of tube is maintained slightly above the point of Curie for corresponding target material.[1] In this case potential difference on facings of every elementary capacitance will be changed in accordance with illuminance of every corresponding cell of representation.

When target is commutated by electron beam, it causes increase of temperature of one of electrodes of every elementary capacitance and increases potential difference on facings. This, in turn, lowers the dielectric constant still more, causing further change of potential difference. Stepwise changes of potential difference on each of capacitances lead to appearance of current pulses through load resistance of vidicon. Accordingly during travel of electron beam to surface of target, there will be formed a full video signal, which is induced by projected infrared representation.

In all transmitting television tubes, electron beam is deflected and focused by magnetic fields. At present vidicons have been created in which focusing and deflection of electron beam are carried out by electrical fields. This permitted a sharp decrease in power consumption in the focusing and deflecting circuit and a weight decrease due to rejection of the focusing-deflecting system. Circuit diagram of such tube is shown on Fig. 20.

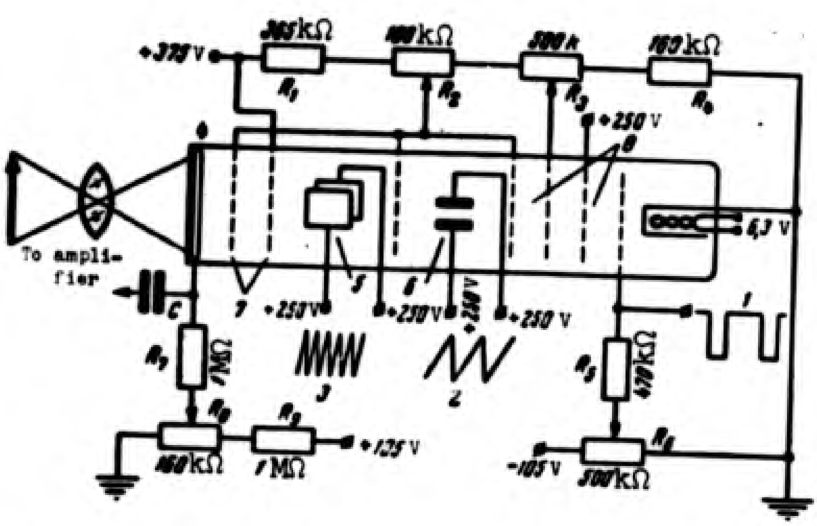

Fig. 20. Circuit diagram of vidicon with electrostatic focusing and deflection by electrical field. 1 — quenching pulses; 2 — vertically deflecting oscillations; 3 — horizontally deflecting oscillations; 4 — target; 5 — horizontally deflecting plates; 6 — vertically deflecting plates; 7, 8 — focusing electrodes.

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[1]Point of Curie is that temperature, above which the ferromagnetic state of a body disappears.

As will be shown later, it is often necessary to lower speed of scanning in transmitting television chambers. Working parameters of usual vidicons do not make it possible to introduce television systems with slow scanning. This is explained by small dark resistance of photoconductive layers of usual tubes, whereas in new tubes dark resistance (with unilluminated target) is considerably increased.

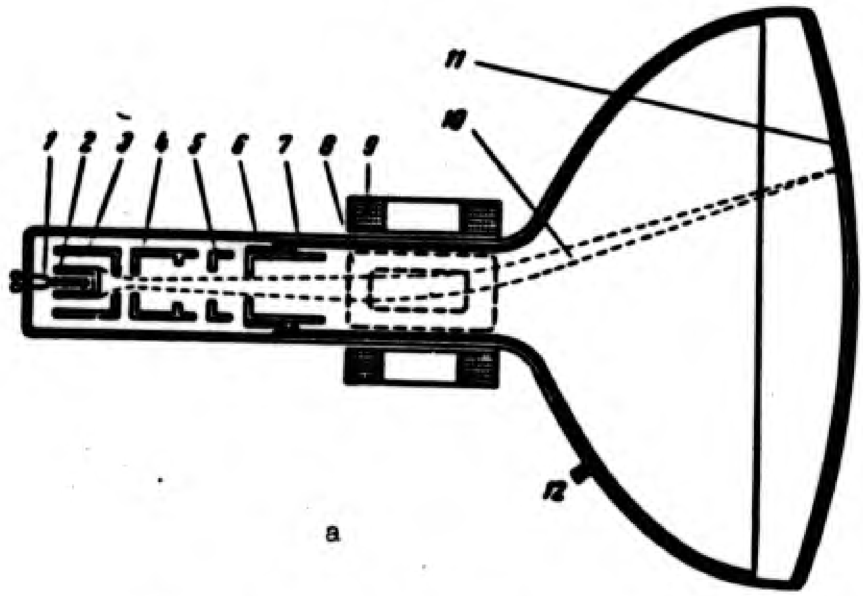
Transmitting tubes and fiber optics. Application of fiber optics to join stages permitted the perfecting of the electron-optic brightness amplifier in transmitting television tubes. In already examined image orthicon with two stages of electron-optical amplification (see Fig. 19b), optical communication between stages is ensured with help of thin glass or mica plates (cells 7 on Fig. 19b); this considerably worsens resolving power of tube. And here beams of fibers located in the appropriate way permit carrying out communication between stages with considerably smaller losses, and resolving power of electron-optical amplifier of brightness is not as worsened.

In order to simplify airborne television installations, flexible optical cable is applied jointly with special tubes of the vidicon type. Now for camera stabilization are used expansive and cumbersome Cardan suspensions, whereas flexible beam of light conducting fibers with lens objective on one end, which is connected by other end to screen of fiber optics vidicon, does not require stabilization. Screen of fiber optics vidicon is here called washer made of a large number of fibers, which replace front glass surface of bulb. On internal side of this washer is disposed target of vidicon. Fibers are distributed evenly with respect to center of screen; optical axes of fibers which form washer are parallel to axis of vidicon. To ensure great strength the thickness of the fiber screen (washer) is made 1.5 times thicker than front surface of bulb of usual vidicon. The most complicated problem encountered in the process of mastering the technology of manufacturing this tube was developing a method of obtaining a transparent conducting covering on that side of washer which is turned inside tube and plays the role of vidicon signal plate.

Receiving Instruments

Electron-beam picture tube. Basic instrument serving for reproduction of television representations, is receiving electron-beam tube. It consists of electron gun, focusing and deflecting systems, and luminescent screen. All electrodes of tube are placed in glass or metal-glass bottle, from which is pumped air, in order to decrease probability of collision of electrons with molecules of gases. Depending upon method of focusing and deflection of electron beam, several types of tubes are distinguished.

On Fig. 21a, is shown arrangement of tube with electrostatic focusing and deflection of electron beam by magnetic field. Electron gun consists of several electrodes, which serve for radiation, focusing, and change of intensity of electron beam. The gun is



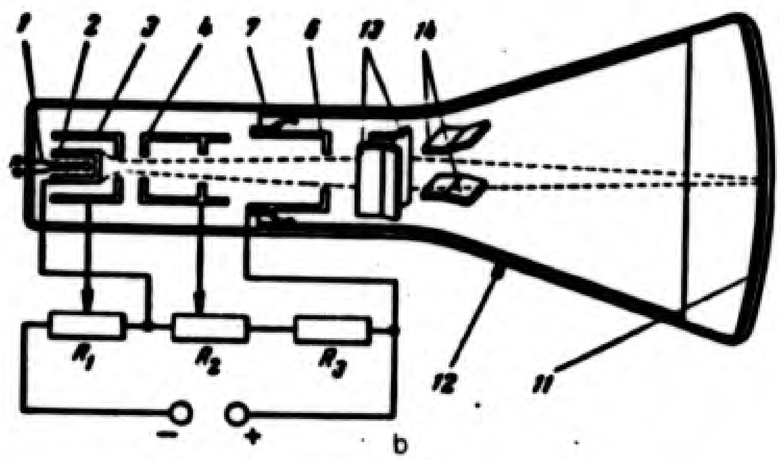


Fig. 21. Arrangement of electron-beam tubes. a) with focusing by electrostatic field and attitude control of beam by magnetic field; b) with focusing by electrostatic field and attitude control of beam by electrical field. 1 — filament; 2 — cathode; 3 — control electrode; 4 — first anode; 5 — accelerating electrode; 6 — second anode; 7 — conducting covering; 8 — coil of vertical deflection; 9 — coil of horizontal deflection; 10 — electron beam; 11 — layer of luminescent substance (screen of tube); 12 — terminal of anode; 13 — plate of horizontal deflection; 14 — plate of vertical deflection.

assembled in throat of bulb of tube and contains a heater cathode which controls and accelerates electrodes and first and second anodes.

Cathode is nickel (or tungsten) cylinder, on end of which an emitting oxide surface is created. It is heated from within by a tungsten filament, which is covered by insulating material. After cathode is disposed control electrode, full cylinder with hole, located opposite center of cathode. To control electrode moves voltage from several to tens of volts which is negative with respect to cathode. Changing potential of control electrode, quantity of electrons directed to screen of tube changes. Furthermore, the control electrode plays an important role in the common formation of the beam.

Near cathode accelerating electrode and first anode create electrical field of high intensity, which is necessary for formation of electron beam. To first anode moves a voltage of several hundred volts which is positive with respect to cathode. Somewhat more voltage moves to accelerating electrode. Second anode is connected with conducting covering of tube bottle; to it moves voltage of several thousand volts. Voltage of second anode determines velocity of electrons bombarding screen. Terminal of second anode is produced through glass in conical part of bulb. Terminals of remaining electrodes are made on base of tube which is on throat of bulb of tube.

Electrical fields created by differently charged electrodes of the gun, will form electronic lenses. They collect divergent electron beam created by cathode, into convergent (according to approximation to screen) narrow beam of electrons.

Screen of tube is created by thin layer of luminophor, powdery crystal substance capable of shining under the action of electron bombardment. Fast moving electrons bombard luminophor and return to it their energy, which is partially separated in the form of heat, but partially excites atoms of luminophor. Transition of atoms from the excited to the normal state appears in the form of radiation of electromagnetic oscillations with different frequencies, including the visible region of the spectrum.. Narrow beam of electrons creates on screen a luminescent spot of very small dimensions, which is cell of screen which determines dimensions of cell of representation. Chemical composition of luminophor and its structure determine brightness, color of glow, and ability to preserve glow during a definite interval of time after cessation of irradiation by electron beam.

Travel of electron beam on screen is ensured by deflecting system, on throat of tube. It consists of two pairs of deflecting coils, the axes of which are mutually perpendicular. On one pair of serially connected coils is passed sawtooth current of line frequency (see Fig. 3c), and on other is passed current of frame frequency (see Fib. 3b). Under action of variable magnetic field of horizontally deflecting coils, electron beam passes horizontal line from left to right with constant speed, then returns quickly to the left, renews the same motion to the right, etc. Magnetic field of vertically deflecting coils simultaneously imparts to beam much slower motion, so that after tracing one line the beam does not return to the beginning of this line, but passes to the beginning of the following line. When the beam passes the last line, sharp change of vertically deflecting magnetic field will return spot upwards, in order to start scanning the following picture frame. Let us note that lines of force of the horizontally deflecting magnetic field are located vertically, and lines of force of the vertically deflecting field are located horizontally.

Brightness of glow of luminophor is proportional to speed of bombarding electrons, current density of beam, and duration of bombardment. If electron beam runs around screen and picture signals are simultaneously fed to control electrode of tube, then beam current and, accordingly, brightness of separate cells of surface of screen are changed. Totality of light, gray, and dark points will form television representation.

In the process of exploitation, negative ions will be formed in tubes. Like electrons, they rush to screen. During deflection by magnetic field, angle of deflection of charged particles is inversely proportional to square root of their mass. Since mass of ion considerably exceeds mass of electron, ions are deflected at a smaller angle than electrons and, possessing greater mass, destroy in time the central part of the screen. Darkening of central part of screen is called ionic spot. For preventing of appearance of ionic spot, electron guns with ion traps are created.

To increase brightness and contrast of images and to prevent the appearance of an ionic spot, the surface of tube screen is metallized again, i.e., a thin layer of aluminum is applied to the luminescent layer. Film of metal, "transparent" for fast-moving electrons, delays heavy ions well and protects screen from formation of ionic spot. Furthermore, aluminum layer reflects in the direction of the spectator the part of light rays which would be irrevocably lost for him, departing inside tube.

With the help of such tubes, representation of a high quality picture can be obtained. Their screen has large dimensions for a relatively small length of the tube itself (thanks to large angle of deflection of beam), but deflecting system is heavy and consumes much energy.

For board equipment of spacecraft, electron-beam tube with electrostatic focusing and deflection of beam by electrical field (Fig. 21b) are apparently more appropriate. Here for television scanning on electron beam is exerted influence of electrical fields created by two pairs of parallel metallic plates, to which are linearly set of line and frame frequency voltages, which are variable in time.

Screens of electron-beam tubes with light conductors. As front section of bulb of tube can be used rigid fiber light conductors, washers, consisting of a large number of transparent fibers adjacent to one another. This will allow utilization factor of luminous flux to increase considerably during high speed recording on screens of tubes.

It is impossible to record representations reproduced on screen with usual tubes by way of direct contact of light sensitive film or paper with front surface of bulb of tube. This is prevented by a certain thickness of glass. Therefore objectives are usually used to transfer a clear picture from surface of luminophor to light sensitive layer of film. In many cases such a method of recording is completely acceptable in spite of certain losses of light energy. However, during recording of fast scanned representations, such a method of projection turns out to be ineffective. Application of high-transmission optics is economically unprofitable.

When washers of light-conducting fibers are used as screen, then every fiber transmits luminous flux of cell of representation from luminophor deposited from internal side of screen of tube, to external surface of screen of tube (Fig. 22). On film tightly pressed to external side of light-conducting washer, the clear image reproduced on the luminophor will be recorded. The coefficient of optical transmission of representation can be increased as compared to other optical systems. Resolving power of such fiber optics is limited by diameter and number of fibers. Experimentally it is established that true resolving power has a value of the order of 1.5 times diameter of fiber.

Instruments of large television screen. Maximum dimension of diagonal of contemporary receiving electron-beam tubes (kinescopes) does not exceed 53 cm. And what if it is necessary to have television representation of considerably large dimensions, for example, close to dimensions of movie screen? After all, during reception of television transmissions from space, it is important to obtain large pictures, so that they can be simultaneously observed and discussed by a large group of specialists.

There are many methods of obtaining television representation of large dimensions, many of which are now being developed and investigated in laboratories. For production of television representations on large screen, the most wide-spread is the method of optical increases of image from screen of projection tube on large screen with projection lens or mirror lens objective. In the first case (Fig. 23a), television representation from screen of electron-beam tube is projected on light-diffusing screen with help of objective — combination of lenses. But lens objectives permit using only very small part of luminous flux radiated by screen of tube. Now in projection television installations are chiefly used special high-transmission reflective optical systems (Fig. 23b). Concave spheric mirror of such system creates increased representation of object, if it is before mirror between focus and center of curvature of reflecting surface. For removal of image distortions due to spheric aberrations are used correcting lenses in center of curvature of mirror. Utilization factor of luminous flux for mirror-lens systems is 5-10 times higher than for usual lens objectives, and composes 20-30%.

In these installations is used projection kinescope with screen of small dimension, but high brightness of glow. Large brightness of screen is attained mainly at the expense of increase

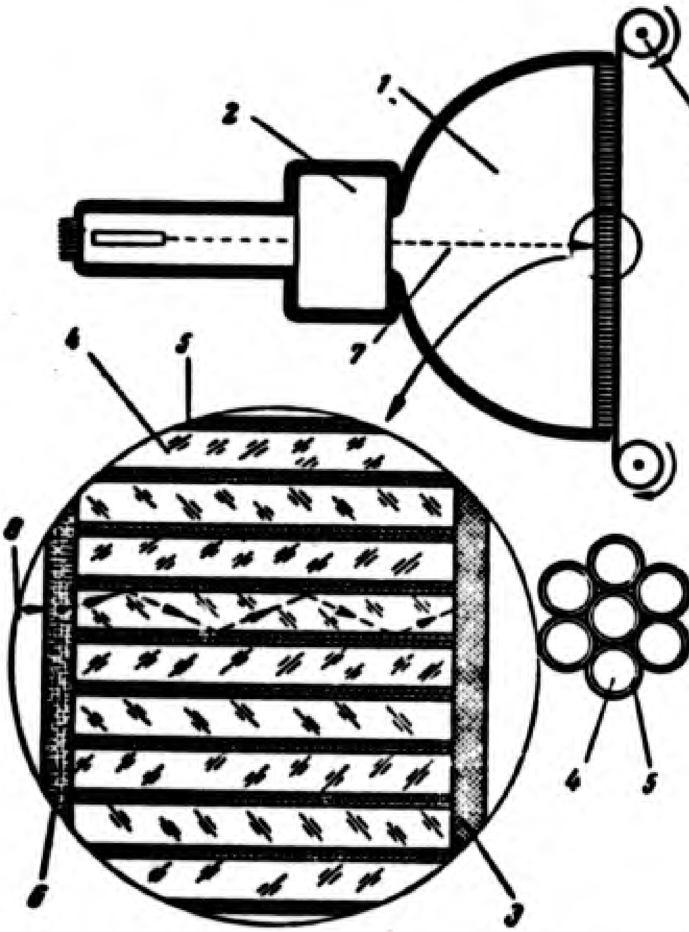


Fig. 22. Electron-beam tube with fiber screen: 1 — bulb of tube; 2 — focusing-deflecting system; 3 — photographic film; 4 — glass fiber; 5 — covering of glass fiber; 6 — luminophor; 7 — electron beam.

of beam current (to several milliamperes, instead of fractions of a milliampere in ordinary tubes) and considerable increase of anode voltage (to 20-100 kV instead of 5-16 kV in usual tubes). Bulbs of such tubes are prepared from special glass, since during prolonged bombardment by fast electrons, ordinary glass darkens quickly and luminous efficiency of screen of tube drops. Screens of projection tubes are metallized; they are prepared from thermoresistant luminophors. To prevent overheating of front glass of bulb the screen of tube is continuously cooled by air blast forced by pump.

It is necessary to note that projection tubes are used for optical scanning of representations according to method of running light spot.

Attempts were repeatedly made to create television reproducers in which television signal is controlled by light valve device modulating in intesity luminous flux of extraneous source of light.

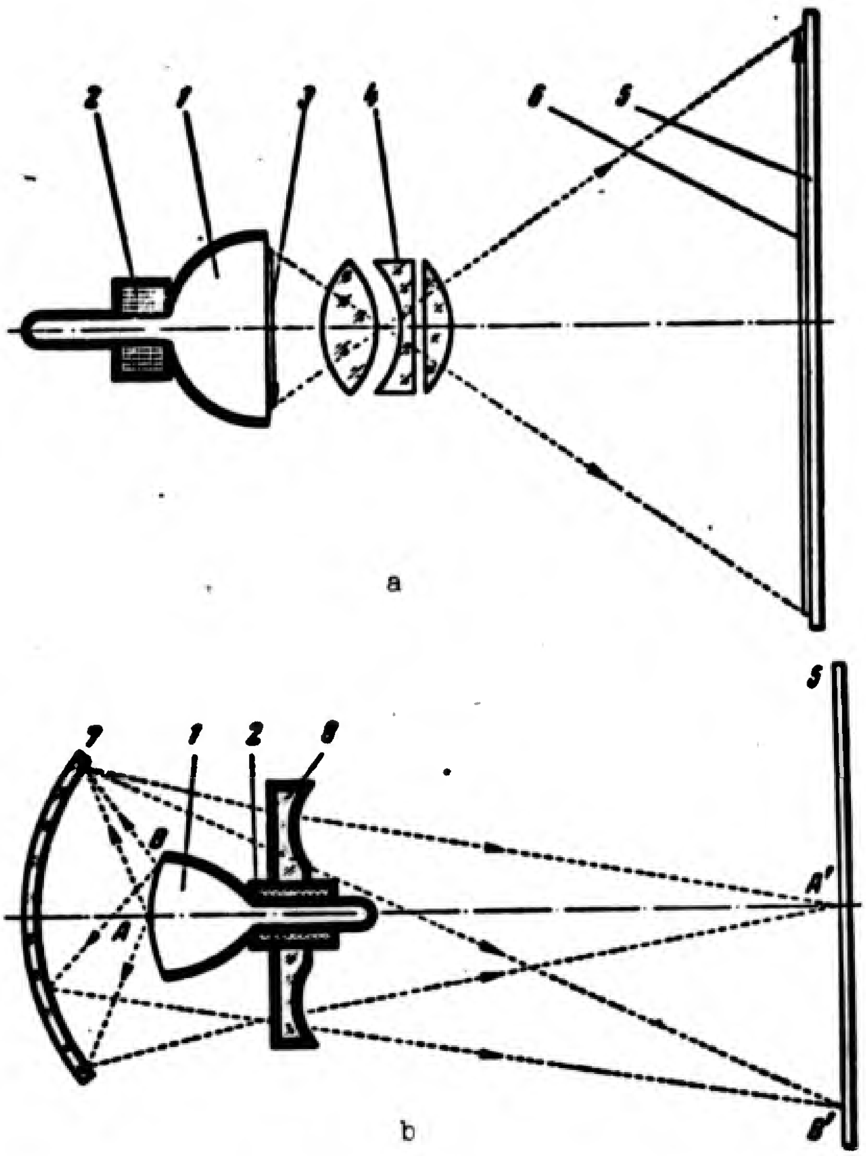


Fig. 23. Projection systems with lens (a) and mirror-lens (b) objectives. 1 — reproducing electron-beam tube; 2 — focusing-deflecting system; 3 — television representation; 4 — lens projection objective; 5 — light-diffusing screen; 6 — increased television representation; 7 — spheric mirror; 8 — correcting lens.

One of varieties of such light valve system is electron-beam tube with dark recording — skiatron, the principle of action of which is based on change of transparency of certain crystal substances during change of power of electron beam irradiating them. Screen of skiatron consists basically of thin layer of crystals of alkali halide salts (usually sodium chloride). Parts of such screen subjected to bombardment by electron beam obtain ability to absorb rays of visible light. Electron beam runs around surface of screen under influence of magnetic fields of system of deflecting coils. During change of intensity of electron beam by accepted signals, semitransparent representation is created on screen. It plays role of slide. Slide is evenly illuminated by illuminating system. Light passed by screen of skiatron is projected by special projection system on light-diffusing screen.

Deficiency of skiatron is its large persistance. Therefore, it can be applied only in such systems of space television, where transmission of low mobility representations is produced. Mobile representations on screen with area up to 75 m^2 can be created with help of diffractional modulator of light, optical circuit of which is shown in Fig. 24. Source of bright light (crater of arc tube)

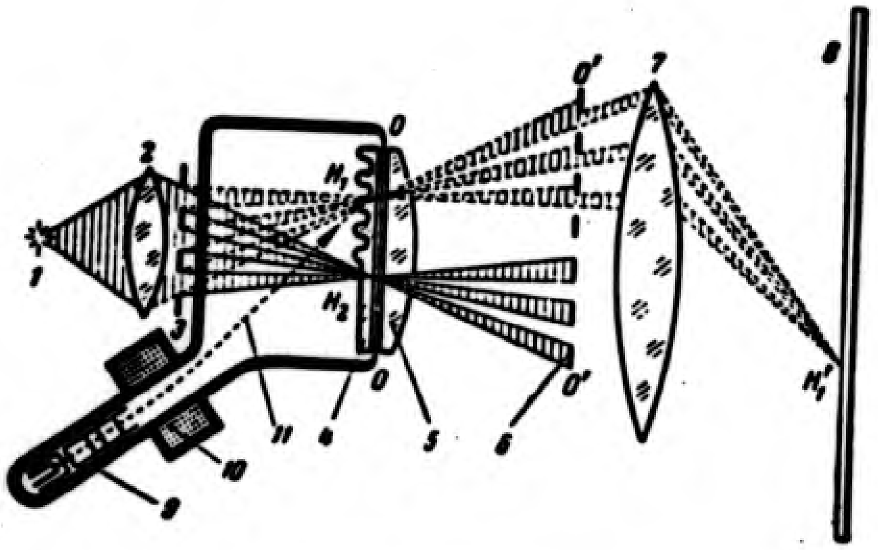


Fig. 24. Diffractional modulator of light. 1 — source of bright light; 2 — condenser; 3 — grid; 4 — modulating liquid; 5 — objective; 6 — grid; 7 — objective; 8 — light-diffusing screen; 9 — electron gun; 10 — focusing-deflecting system; 11 — electron beam.

1 with help of condenser 2 creates uniform illumination in plane OO, in which is located thin layer of modulating liquid 4. Near condenser 2 is set grid 3 of alternating parallel transparent and opaque bands. With help of objective 5, near plane OO, representation of grid 3 is focused in plane O'O', where a second grid of alternating bands is set. This second grid is oriented in space so that representation of luminescent intervals of grid 3 get on opaque bands of grid 6, if surface of modulating liquid is plane. In this case light from point H_2, which is in plane OO, does not pass further than grid 6.

If, however, surface of viscous liquid 4 is irradiated by electron beam, then it is deformed, and rays of light in this point will be deflected from initial direction (due to diffraction of light) and will partially pass through slot system 6, forming an image on light-diffusing screen 8. Thus, the points not reached by electrons of beam (for example, point H_2), on screen are not depicted, since light does not pass through grid 6. If, however, electron beam bombards a certain point, H_1, then light is refracted in this point by film, and luminescent point H_1' appears on screen. The more intense the electron beam bombarding a given point, the brighter the representation of this point gleams, since an even greater part of luminous flux from source of light 1 will pass to screen.

Mechanical and electrical data of liquid (film of special oil) will be selected here in such a manner that deformations appearing on surface of oil film faded during the time approximately equal to duration of transmission of frame. Thus, surface of oil film serves not only as modulator of light, but also storage cell of projection system. Electron beam controlled by television picture signal traces on surface 4 a television screen consisting of a definite number of lines. And on film 4 will be formed potential relief corresponding reproduced representation. Electrical charges of which this relief consists, cause surface strain of film controlling luminous flux, which, passing through slots of grid 6, creates on screen 8 a corresponding television representation.

Television Signal and Its Peculiarities

All television signals, independently of contents of transmitted representation, are characterized by the following peculiarities.

Scanning beam of transmitting television tube, accomplishing next process of decomposition (series conversion of light energy of cells of optical representation into sequence of electrical signals), returns to initial position (most frequently in upper left corner of screen) and starts following cycle. Thus is caused periodicity of television signals. If transmitted a frame of representation does not differ in content from the preceding frame, then television signals of these identical frames will be identical.

Let us assume that before objective of transmitting chamber is clean sheet of white paper. Than during transmission of separate frames of pictures, no changes of television signal will occur (Fig. 25a); maximum constant value of signal will be proportional to illuminance of photocathode of tube. If instead of white sheet of paper, we project a black sheet of paper on the photocathode, then illuminance of photocathode will greatly decrease, where only level (constant component) of television signal (Fig. 25b) will be changed. Let us assume that on photocathode is projected white sheet of paper, in the middle of which is a black point (Fig. 25c). Then once each $\frac{1}{K}$ seconds (where k is number of frames) appears

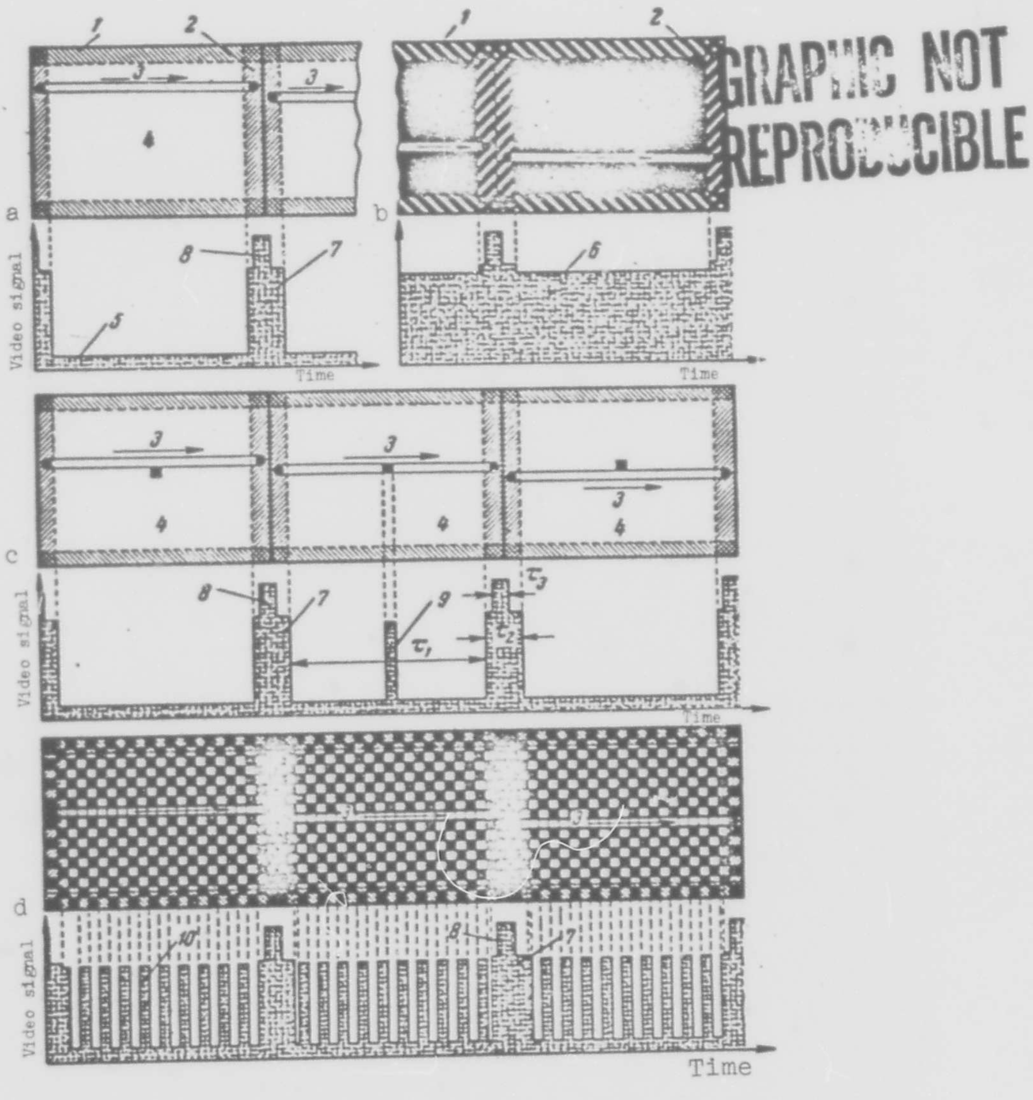


Fig. 25. Change of form of television signal during change of contents of representation. 1 — part of screen not transmitted and not reproduced because of beam suppression during the time of reverse movement on vertical; 2 — part of screen not transmitted and not reproduced because of beam suppression during the time of reverse movement on horizontal; 3 — direction of travel of scanning beam; 4 — actually transmitted and reproduced part of frame; 5 — level of white picture signal; 6 — level of black picture signal; 7 — small quenching pulse; 8 — small synchronizing pulse; 9 — video signal from dark cell of object; 10 — video signals from dark cells of object; τ_1 — duration of transmission of picture signal of one line; τ_2 — time of extinguishing of electron beam during horizontal scanning; τ_3 — time of action of synchronizing pulse of horizontal (line) scanning.

change of voltage. This variable component of television signal is a periodic function of time with the biggest period equal to time of decomposition of one frame of representation.

Now let us assume that on photocathode are projected alternated black and white square cells with side equal to height of one line (Fig. 25d). Let us assume that number of lines of decomposition equals 625 (as in Soviet television broadcasting) and ratio of width of frame to its height is equal to (4/3). In this case on one line are packed 625·(4/3) = 833 cells, but in full representation are packed more than 500,000 (625·(4/3)·625). If this representation is transmitted 25 times per second, then the total number of electrical signals sent per second on television communication channel will be equal to the number of cells in one frame multiplied by the number of frames, i.e., 12.5 millions, but corresponding frequently of electrical oscillations turns out to be equal to 6.25 MHz. One 6.25 MHz frequency variation corresponds to two cells of representation: positive half-period corresponds to one white cell, but negative half-period corresponds to second black cell of representation.

In systems of space television, the number of transmitted cells and the speed of their transmission can be other than in examined example. In general highest frequency of television signal is determined in the following way. The number of cells of representation actually transmitted for one frame is equal to $n = \alpha\beta z^2$, where z is the number of lines, and α and β are coefficients, which consider form and return period of scanning, respectively (in examining numerical example, losses at the expense of final return period were not considered for the sake of simplicity. If every representation should be transmitted k times per second, then the total number of electrical signals, S, sent per second on electrical communication channel will be equal to the number of cells multiplied by the number of frames, i.e., $S = \alpha B z^2 k$, and the highest frequency, on transmission of which this channel should be calculated, turns out to be equal to

$$F = \frac{\alpha\beta z^2 k}{2}.$$

Thus, for transmission of television signal without distortions, communication channel should be calculated on transmission of wide frequency band — from minimum, equal to frequency of replacement of frames, to maximum, highest frequency. Such a wide frequency band of spectrum of television signal, as will be shown later, causes a great number of difficulties, which must be surmounted during transmission of picture signal from transmitting tube to receiving tube. Furthermore, in television signal are contained lower frequencies than frame up to constant component. However, transmission of them is carried out indirectly.

We mentioned parameters of work of scanning devices (coefficient β in expression for passband) for the following reason. In examining the principle of formation of a linear line raster, the fact was discussed that having scanned a line, the scanning cell accomplishes fast backward motion — reverse movement about line. This return period practically composes not less than 10% period of line, i.e., total time of direct and reverse movement about line. After the whole representation has been scanned and scanning cell reaches lower right corner of frame, it quickly returns to initial point — upper left corner of frame (reverse movement on frame). Practically, return period along the frame is not less than 5% period of frame.

Inasmuch as speeds of travels on line usually exceed corresponding speeds on frame several hundreds of times, during the time of reverse movement on frame, scanning cell succeeds to accomplish over ten useless zigzaggings on lines. During reverse movements on lines and frame, scanning cell repeatedly passes the same cells, which it passed already during direct movements.

So that reverse movement is not seen on screen of transcribers, electron beams of transmitting and receiving tubes will periodically be turned off for the time of travel of scanning cell on reverse movements of lines and on the whole return period on frame. Consequently, during this time, scanning of representation is not actually produced. On borders of frame, speed of scanning cell should unevenly change in value [magnitude] and direction. Practically this cannot be done. In order not to see retarded motion of scanning cell during change of direction of travel, frame is made somewhat larger than visible frame. And electron beam is turned off as long as scanning beam is beyond the borders of visible frame. Thus, edge of frame will not be seen (see Fig. 25). To ensure such picture of scanning, the electron beam will be turned off by quenching pulses somewhat before the end of each line for the time near 16% period of line (during return period about line 10%) and somewhat before every straight movement on frame on 7.5% period of frame (during return period on frame 5%). Total loss of time (when representation is not reproduced) is about 21%. Intervals of time when electron beams are locked by quenching pulses are used for transmission of different service signals — synchronization signals ensuring synchronous travel of scanning beams on transmitting and receiving ends of system, information about average illuminance of transmitted picture (constant component) and others.

In applied systems of television, duration of transmission of service pulses can be other than in broadcasting television. Moreover, there can be no quenching pulses in general. Accordingly, required frequency band of communication channel will be changed. Inactive time of scanning during determination of frequency band is considered by introduction of coefficient β.

Amplification of Television Signals

Electrical television signals obtained on load resistances of photoelectrical converters, are too low in power to be used for direct transmission to receiver (power of obtained signals is a billionth of a watt). Therefore television signal obtained on load of photoelectrical converter is strengthened many times by video amplifier.[1]

Besides amplification of picture signals, video amplifiers of television system fulfill a number of cofunctions. The most important of them is the introduction of extinguishing and synchronizing pulses (created in special devices, given to video amplifier), the mixing of signals from various transmitting camera, automatic control of output signal, etc.

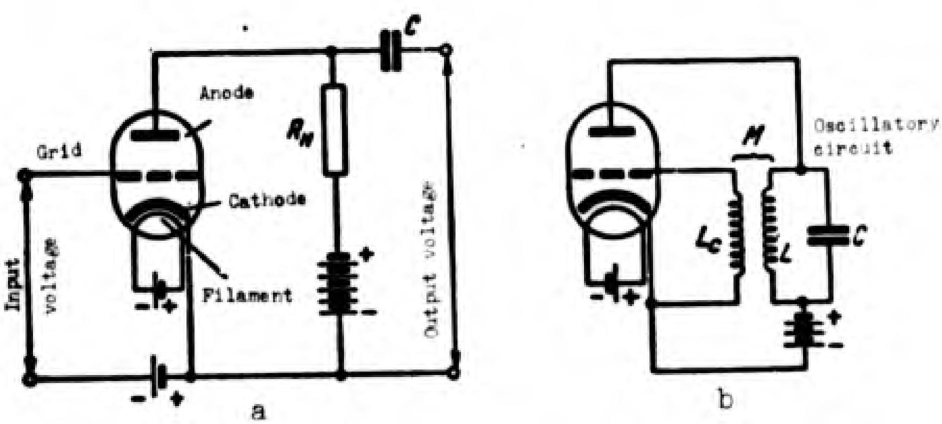


Fig. 26. Circuits amplifier (a) and high-frequency oscillator (b) with three-electrode tubes.

Wide propagation in television technology has been obtained by video amplifiers using electronic amplifier tubes. Diagram of the simplest amplifier with three-electrode electron tube is shown on Fig. 26a. Three-electrode tube constitutes glass, metallic or metal-ceramic bottle, from which air has been pumped. Inside bottle are located thermionic cathode and anode surrounding it. In space between anode and cathode is set a third electrode, called control grid. In contemporary low capacity tubes, grid has the form of metallic spiral. Heated to high temperature by filament, cathode emits electrons. Voltage on control grid, along with voltage of anode, determines quantity of electrons, which pass from small electronic cloud surrounding cathode to anode of tube. Since grid is located nearer to cathode than anode, change of anode current depends more on change of grid voltage than on change of anode voltage.

By passing high negative voltage through grid, it is possible to completely lock tube, decreasing anode current to zero, or to

[1]The prefix, "video", reflects specific properties of amplifer, caused by peculiarities of television signal.

completely open it, creating condition for flight of all free electrons to anode. This strong influence of grid voltage on value of anode current of electron tube is used for amplification of oscillations. This occurs in the following way.

Voltage subject to amplification is introduced into control grid circuit. To ensure necessary electrical conditions on control grid, besides source of strengthened signals between control grid and cathode, there is swtiched on another source of constant emf (voltage source of displacement), creating negative potential on grid. In anode circuit of tube a source is switched on which creates positive potential on anode with respect to cathode, and load impedance R_H. Positive voltage of anode creates electrical field, which accelerates travel of electrons in the direction of the anode. Source of constant emf in grid circuit creates electrical field, which repels electrons back to cathode and allows to pass to anode only part of electrons proceeding from cathode. If positive voltage of signal proceeds to input of amplifier, then this voltage is subtracted from bias voltage, and negative, repulsive action of grid field is weakened; a large number of electrons pass to anode. If negative signal voltage is set on input of amplifier, then this voltage, which is combined with bias voltage, causes large braking of electron flux proceeding from cathode, and, consequently, causes decrease of anode current. Thus, during change of grid potential under influence of arriving picture signal, quantity of electrons going past turns of grid to anode of tube changes. Variable anode current creates voltage drop on load impedance. With sufficient value of load resistance, output voltage obtained on it will be considerably more than input voltage given in grid circuit, i.e., electrical oscillations are amplified. (Ratio of increase of output voltage to increase of input voltage is called amplification factor of circuit). During amplification in anode circuit of tube, considerably higher alternating current energy is obtained than that given in the circuit of its control grid. Source of intensified energy is anode battery, rectifier, or other source of direct current. From this follows that electron tube in electronic amplifier is converter of direct current energy of anode source into alternating current energy of strengthened oscillations.

It is usually necessary to obtain more signal amplification than a single-tube circuit can provide. Therefore, multistage circuits of amplifiers are created, where output voltage from load resistance of first single-tube circuit is used as input voltage of second single-tube circuit, etc. General amplification factor of multistage amplifier is equal to product of amplification factors of separate stages. It is necessary to note that in amplifiers of picture signals more complicated tubes, pentodes, are more frequently used. Video amplifier is characteristic by the fact that it should be calculated on transmission of wide frequency band, but wide frequency band of television signals creates serious difficulties for their amplification and transmission on distance. For improvement of technical characteristics during amplification of oscillations in wide frequency band additional correcting cells are introduced into video amplifier.

With development of technology of semiconductor instruments, the fields of their application are expanding. At present possibilities have appeared not only of replacing electron tubes with semiconductor devices, but of practically creating television equipment, electrical circuits of which are collected wholly or almost wholly on semiconductors.

Semiconductors possess a number of considerable advantages as compared to electron tubes, and their application is especially promising in television equipment on board spacecraft. Considerably smaller voltages of power supplies in semiconductors and absence of filament circuits and, accordingly, of sources of preheating lower power drain tens and hundred of times. These instruments also permit considerable decrease in dimensions and weight of television equipment, since their weight and dimensions are considerably less than weight and dimensions of electronic devices with equivalent technical characteristics. Natural period of service of equipment is increased, since semiconductors last considerably longer than electronic tubes and can be compared in period of service with such parts of electronic equipment as resistances, capacitors, etc.

What then are semiconductors and how do they work?

The simplest semiconductor device is a semiconductor diode. Its principle of action is based on use of phenomena which occur in p-n junction, which will be formed during contact of two semiconductors with different types of conductivity — n-type conductivity and p-type conductivity (Fig. 27d, e).

N-type conductivity of semiconductor can be caused by introducing into crystal impurity atoms of a substance with higher valence than valence of basic substance of crystal. Let us assume that in crystal of germanium (a tetravalent element) is impurity of atoms of arsenic (a pentavalent element). Then four electrons of outer shell of arsenic atom will form valence bond with four neighboring germanium atoms, but fifth electron of impurity atom is detached and causes n-type conductivity of crystal (Fig. 27a).

Part of semiconductor having impurity of substance with smaller valence possesses p-type conductivity. Let us assume that such impurity in crystal of germanium are atoms of boron (a trivalent element). Trivalent impurity atom of boron for formation of valence filled bond with neighboring four atoms of germanium (Fig. 27b) rushes to attract to itself missing electron from other atom of germanium and leaves there breach (hole), which is easily filled by any other electron of already another atom. Formation of hole is equivalent to formation of positive ion. If electrical field is applied to crystal, then positive ion formed can be neutralized by electron detached from neighboring neutral atom under the action of thermal vibrations, i.e., one hole is filled and a new one appears somewhere else. Passing from one atom to another, hole shifts to negatively charged end of crystal, but electrons shift in opposite direction under the action of the same electrical field.

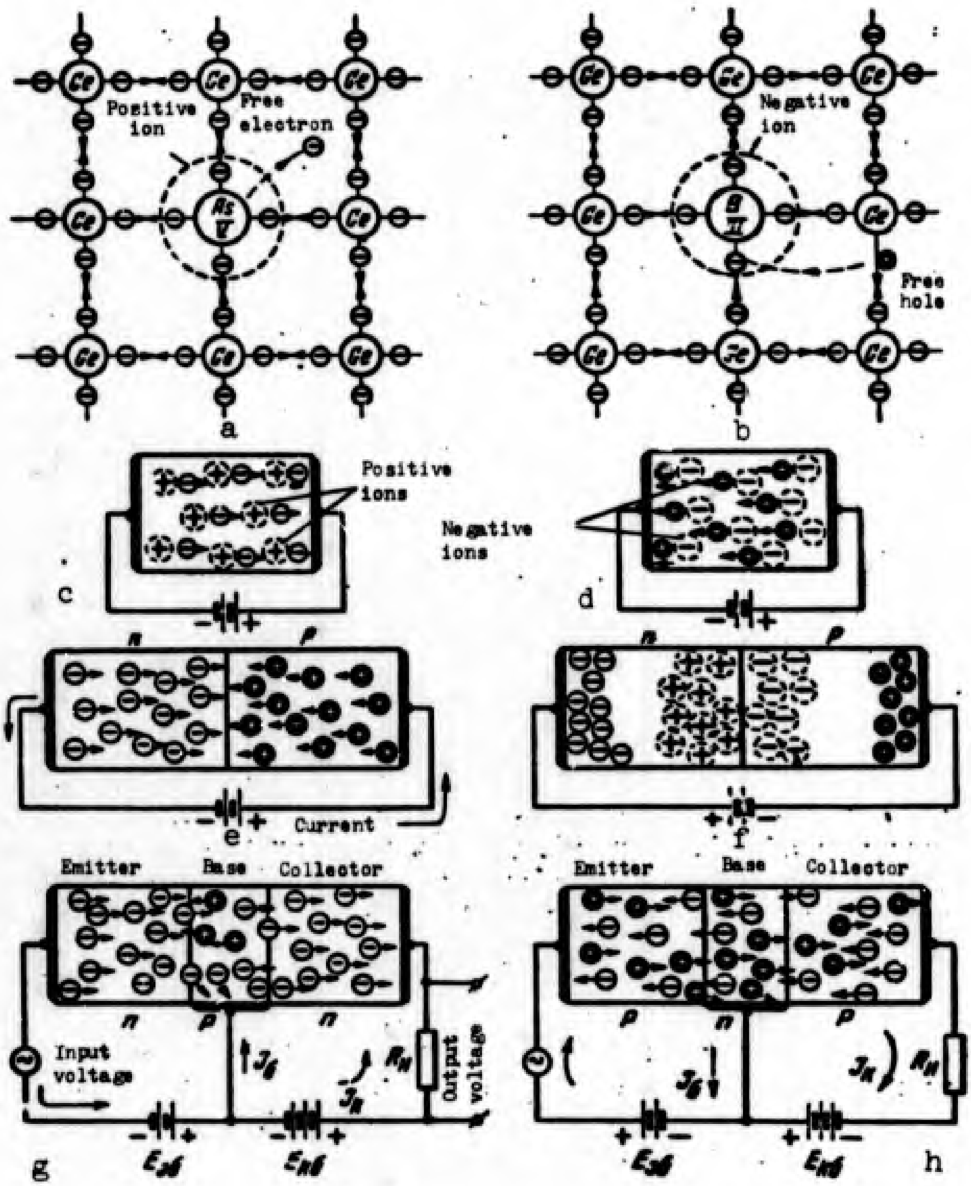


Fig. 27. Semiconductors and semiconductor devices. a) donor impurity in about grid of semiconductor, determining impurity n-type conductivity; b) acceptor impurity in crystal lattice of semiconductor, determining impurity p-type conductivity; c) n-type semiconductor; d) p-type semiconductor; e) straight inclusion of semiconductor diode; f) reverse inclusion of semiconductor diode; g) circuit diagram of semiconductor triode (transistor) type n-p-n; h) circuit diagram of transistor of type p-n-p.

Current in semiconductor diode passes in the following way. Let us assume that positive pole of emf source is united with part of crystal which possesses p-type conductivity, but negative pole is connected with end of crystal which possesses n-type conductivity (Fig. 27d). In electron field, free electrons of semiconductor will be repelled in the direction of p-n junction by electrons proceeding from source of emf. They will intersect junction and will start to fill holes which positive potential of emf source directed to this junction. Thus will be formed current composed of electrons and holes, travelling in opposite directions. This current corresponds to so-called inclusion in straight direction. If one were to apply voltage in the opposite direction (Fig. 27e), then little or no reverse current would flow. Thus, p-n junction constitutes alternating current rectifier.

Connecting two p-n junctions, directed oppositely, we obtain a semiconductor triode (transistor). One of external regions of transistor is called emitter, but other is called collector, center region is called base. Between emitter and base is applied voltage in forward direction (Fig. 27g), thanks to which current flows through junction between emitter and base. Current will introduce free electrons into base from emitter, which, in this case is n-type semiconductor. Part of these electrons will fill hole of base (part of crystal which possesses p-type conductivity in this case) and will cause small current of base. The majority of electrons penetrating base will continue their motion and will penetrate collector, whence they will be accelerated by electrical field created by emf source switched on between collector and base. Amplification in transistor occurs because collector depends basically on base current and varies directly with the latter. Usually current of collector is tens of times greater than current of base.

If voltage of signal is applied in series with emf $E_{\text{эб}}$ then, by changing base current somewhat, we can obtain considerable current collector changes. And these changes will be the greater, the smaller the input impedance of the transistor. It is indeed small thanks to the fact that here the junction is included in direct (forward) direction. Output resistance (resistance of collector junction) is great because this transition is included in reverse (backward direction). Inasmuch as output resistance of transistor is great, current of collector can be passed through high load impedance. On this load impedance, intensified signal voltage is separated.

On Fig. 27g is shown circuit diagram of transistor of type n-p-n, where region with p-type conductivity is general. If one unites two p-n junctions so that region with n-type conductivity is common, then we will obtain transistor of type p-n-p. In this case polarity of inclusion of sources of emf as compared to that shown on Fig. 27g, should be modified on reverse (Fig. 27g).

Transistor can be used not only for amplification of electrical signals, but also for generating of electrical oscillations of different form, and also for many other targets.

Transmission of Television Signals over Distance

Transmission on the radio. It is possible to transmit energy of electromagnetic field without wires if high frequency currents are used. For this television signal is fed to radio transmitter

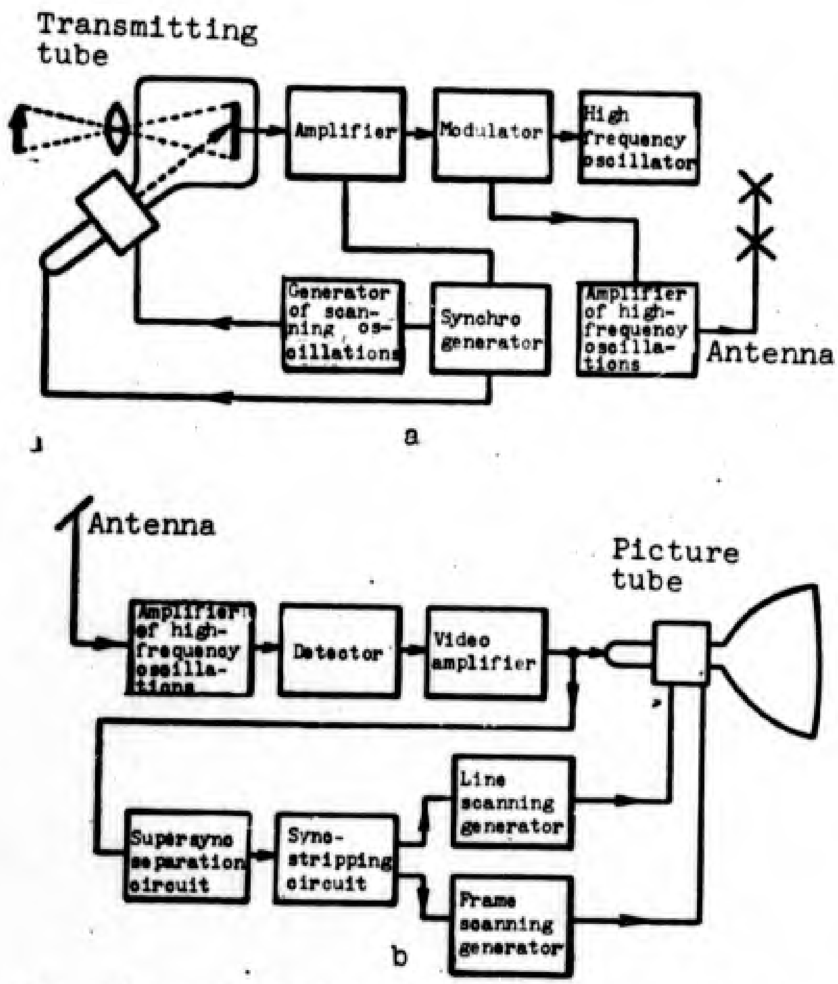


Fig. 28. Block diagram of system of radio-television communication: a) transmitter; b) receiver.

(Fig. 28a), in which two basic processes occur – creation of electrical high-frequency oscillations and change of parameters of these oscillations under influence of television signals.

In television radio transmitter, generator on electron tubes can be used for creation of high-frequency oscillations. Conversion occurs in it by output anode battery of direct current energy into alternating current energy, which is absorbed by oscillatory circuit. With the help of feedback circuit, part of energy of oscillatory circuit moves to grid of tube. In circuit shown in Fig. 26b of vacuum-tube oscillator, mutual induction M between coil in grid circuit and coil of anode circuit serves as feedback cell. In oscillatory circuit formed by capacitor C and induction coil L connected in parallel, electrical charges periodically shift, i.e., current flows in opposite directions. These are electrical oscillations of circuit. Oscillations in circuit control anode current in tube, which in turn supports oscillation in circuit. Feedback coil L_c ensures automatic opening and shutting of tube and bringing of energy of power supply into oscillatory circuit in cycle with oscillations existing in it. This permits compensating loss of energy in circuit and obtaining undamped sinusoidal oscillations.

Values of capacitance and inductance of oscillatory circuit determine frequency of created oscillations. The fewer the turns of coil, the less its inductance for a given diameter, and the faster current intensity in circuit changes. The lower capacitance of capacitor, the less time is required on process of its charging and discharge. Therefore, the lower capacitance and inductance, the shorter the period of oscillation, the shorter the wavelength and the higher the frequency of oscillations. Changing value of capacitance or inductance changes frequency of natural oscillations of circuit.

In order to transmit picture signals on the radio, it is necessary to exert influence by these signals of some high-frequency parameter oscillation, i.e., to carry out modulation of high-frequency oscillations by picture signals.

What parameters characterize harmonic oscillation? Amplitude, frequency, and phase. During modulation it is possible to control any of these parameters, in accordance with which the three possible forms of modulation are called amplitude, frequency, and phase modulation. During amplitude modulation, amplitude of high frequency current is changed in time under influence of modulating television signal, but frequency of oscillations is preserved constant. Process of modulation is carried out by modulator — component part of television radio transmitter.

Modulated high-frequency oscillations are strengthened and are fed to transmitting antenna. During flow of high frequency current around antenna electrical and magnetic fields appear. Continuously changing in value and direction, they will form a single electromagnetic field, which spreads from antenna into surrounding space. Value of energy radiated by antenna is proportional to power of feeding current and to the square of its frequency. Antenna emittance increases together with increase of its dimensions as compared to wavelength of radiated oscillations. Alternating current conductor starts to noticeably radiate radio wave, if its length is greater than (1/10) wave of radiated oscillations.

Spreading from transmitting antenna with velocity of light, electromagnetic field excites electrical oscillations in all bodies able to conduct current. On excitation and supporting of these oscillations, energy of electromagnetic field is gradually expended; with distance from radio transmitters, radio waves gradually fade.

Thousands of radio transmitters work simultaneously in different corners of the earth. Electromagnetic fields of these radio stations intersect receiving antenna and induce emf in it. In this case electromagnetic field transmits its energy to antenna; value of current excited in receiving antenna depends on field strength, dimensions, and configuration of antenna.

Received signals of many frequencies (corresponding to radiation of many radio stations) from antenna are fed to input circuit television receiver. From great number of input frequencies, oscillatory circuit separates narrow frequency band. Energy of signals separated by input circuit and, consequently, also voltage appearing on it are very small: therefore, signals are strengthened very many times. Important property of receiver is its selectivity, i.e., ability to strengthen oscillation only in defined frequency band. This property of receiver permits separating from signals of many radio stations only oscillations of defined television radio transmitter. Besides amplifications, accepted signals are subjected to certain other transformations. One such conversion is detection — process, inverse modulation. In process of detection, from accepted and intensive radio signal is separated television signal with which high (carrying) frequency oscillations were initially modulated. Picture signal separated as a result of detection is further amplified by video amplifier, but then moves to control electrode of picture tube. In the latter, electrical picture signals will be converted into sequence of bursts of different points of screen, which will be perceived by the spectator as coalescent television representation.

From video amplifier, television signals, containing also synchronization signals (see Fig. 25), branch to dividing device, which will separate synchronization signals from picture signals. Separated synchronization signals are in turn divided into line and frame synchronizing pulses. Divided synchronization signals control work of generators of line and frame deflecting oscillations.

Frequencies used for radiotelevision space communication are determined by selection of electronic devices both for transmitting and for receiving equipment. Electron tubes with control grid are unfit for work in region of decimeter and centimeter radio waves. During amplification and generation of oscillations corresponding to ranges of long, average, and short waves, electron tube can be considered inertialess instrument which instantly reacts to all current changes. However, with increase of frequency of oscillations, work of amplifying and transmitting tubes is ever increasingly influenced by interelectrode capacitances, inductance of conclusions, loss of energy, and final time of flight of electrons between electrodes.

Interelectrode capacitances of tube and inductance of its conclusions will form oscillatory circuits, which limit highest frequency with which tube can still work. Furthermore, loss of high-frequency energy on heating of conclusions and on radiation from them and also on heating of metallic and dielectric parts of tube sharply increase with increase of frequency, which leads to fall of useful oscillatory power given away by tube.

On ultrashort waves time of flight of electrons between electrodes of tube becomes commensurable with period of oscillations, in consequence of which electrons do not reach anode during the time of positive half-period on control grid. Work of tube is distributed, energy losses are increased, but generated power strongly decreases.

For creation and amplification of oscillations with frequencies in hundreds of thousands and billions of cycles per second electronic devices are used with methods new in principle of electron flux control – magnetrons, straight-flying klystrons, reflective klystrons, traveling-wave tubes, carcinotrons, and other instruments.

Traveling-wave tubes are frequently used in airborne equipment of spacecraft. How is this tube arranged and does it work?

Diagram of arrangement of traveling-wave tube is shown in Fig. 29. Action of traveling-wave tube is based on interaction of beam of electrons focused by magnetic (or electrostatic) field with electromagnetic field traveling in space (with traveling wave).

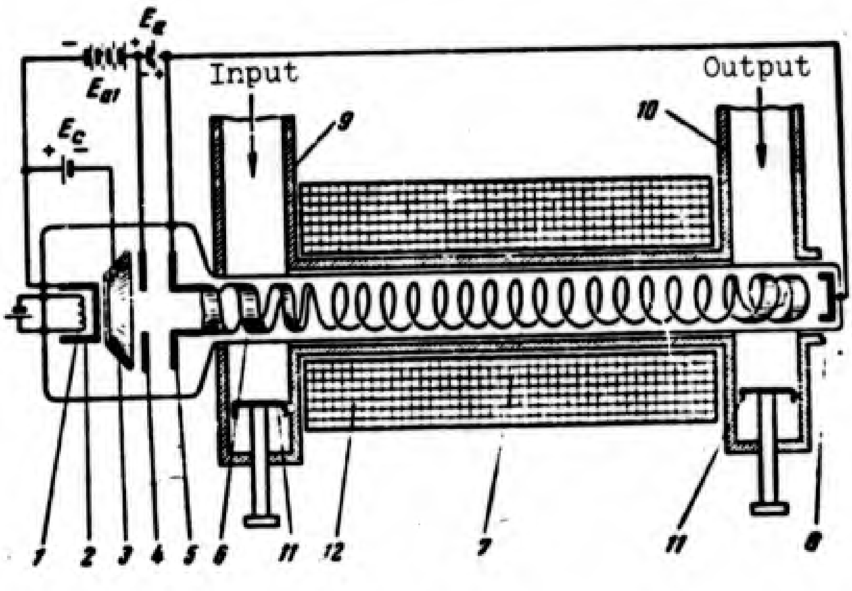


Fig. 29. Diagram of arrangement of traveling-wave tube. 1 – heater; 2 – cathode; 3 – focusing electrode; 4 – first anode; 5 – second anode; 6 – ribbon spiral; 7 – delaying spiral; 8 – collector; 9 – input waveguide; 10 – output waveguide; 11 – adjusting piston; 12 – focusing coil.

Basic cells of construction of traveling-wave tube are electron gun and delaying system (in this case carried out in the form of a spiral). Electron gun serves for creation of narrow beam of electrons, which fly through spiral, after which they are caught by the collector. For focusing electron beams, at cathode is placed control electrode and two anodes, carried out in the form of diaphragms with holes of small diameter. For focusing of electron beam on all way of travel of electrons from electron gun to collector there is applied a permanent magnet field directed along axis of spiral. This field is created by solenoid or permanent magnet, on axis of which is tube. Input electromagnetic oscillations, which are subjected to amplification in traveling-wave tube, move to the end of spiral nearest to the electron gun. Intensive high-frequency oscillations are removed from other end of spiral.

Action of traveling-wave tube consists in the fact that electrons flying through spiral return part of their kinetic energy to electromagnetic wave moving on turns of spiral. Spiral is needed in order to compare speed of shift of electrons and high-frequency field along axis of tube. On wire of spiral, high-frequency field spreads with velocity of light, but along spiral, on its axis, field shifts as many times slower as the number of times length of wire of one turn of spiral is greater than its step. Speed of electromagnetic field decreases because a speed greater than $\frac{1}{10}$ the speed of light cannot be imported to electrons even at voltages of several thousand volts between cathode and collector.

When signal, i.e., strengthened electromagnetic oscillation, goes on beginning of spiral, it exerts influence on uniform electron beam, regrouping in it electrons by their speeds. Grouped flux, advancing along spiral, in turn exerts influence on electromagnetic field and, return its energy to it, strengthens it. According to advance on spiral, field is continuously strengthened. Traveling-wave tubes can strengthen oscillation with wavelength up to 1 cm.

Distance of ground radiotelevision communication is intimately connected with range of utilized radio waves (Fig. 30). A huge range is used from less than 1 mm (300 billion cycles and above) to over 10,000 m. In contemporary radio engineering, (less than 30,000 cycles). However, transmission of television picture signals in television broadcasting is possible only on ultrashort waves, length of which is less than 10 m (frequency over 30 million Hz). Cause of this consists in that for undistorted transmission, carrier frequency of radio transmitter should be 5-10 times over highest frequency of modulating signal, but highest frequency of television signal in Soviet television broadcasting is equal to 6 MHz.

Limitation in range of utilized waves leads to limitation of distance of radiotelevision communication. Ultrashort radio waves do not possess ability to spread as far as short, average, and long radio wave. Radio waves of the latter three ranges can spread far beyond the limits of straight line of visibility due to refraction in ionized layers of atmosphere and diffractional diffraction by radio waves of earth's surface (the longer the wavelength, the smaller the role played by refraction in ionosphere and the bigger the role of diffraction of radio waves around earth). Ultrashort waves behave differently. They pierce right through ionosphere and irrevocably depart into interplanetary space. These waves almost do not round earth's surface and spread rectilinearly within limits of straight line of visibility; therefore, range of ultrashort radio stations is small.

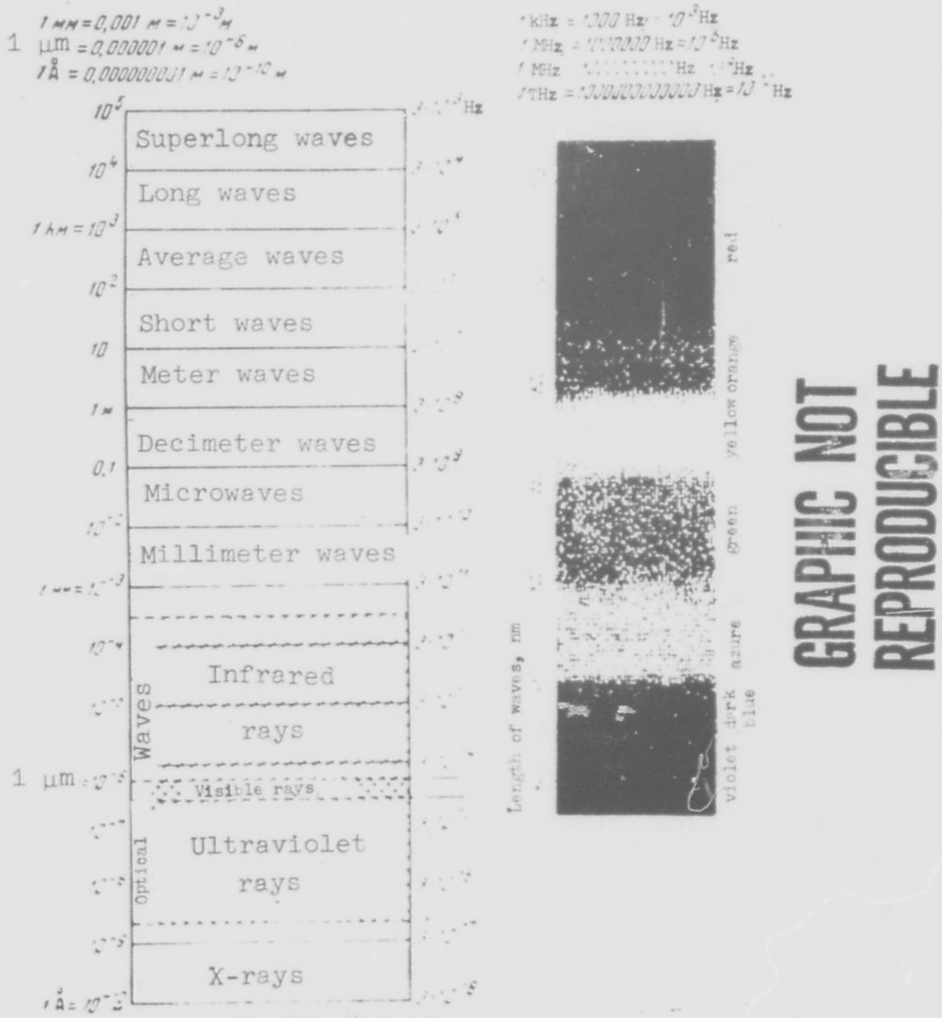


Fig. 30. Spectrum of electromagnetic oscillations observed in nature.

Distance of straight line of visibility is increases at the expense of rise of antennas. For reception of programs of television broadcasting, TV viewer usually cannot set receiving antenna on very high altitude; therefore, antennas of television centers are set on high masts. However, height of antenna is not the only method to increase distance of radiotelevision communication. Television signals are transmitted on ground cable communication circuits and on radio relay lines. The latter form circuits of ground automatically acting transceiver installations.

Huge possibilities of transmission of ultrashort waves on whole continents is opened by use of artificial earth satellites.

Recording of Television Representations

Up to recently one of main deficiencies of television consisted in possibility to reproduce only once representation transmitted by means of television. Television representation was short-lived; once born, it vanished right away, and period of its life was not more than several hundredths of a second. And it was impossible to repeat television frames.

At the same time it was necessary to preserve television representations, to record them especially during use of television in scientific investigations, in national economy, in system of national education. There have already been attained considerable successes in the technology of recording television transmissions, which allow multiple usage of especially interesting programs. This opened wide possibilities for exchange of television programs between different cities, courtries, and continents.

However, not one "terrestrial" use of television means requires such variety of arrangement of recording of television representations as space television. When systems of recording of television representations did not yet exist, we were not able to decide those most interesting problems, which already today fully are accessible thanks to television. Necessity to apply video recording in systems of space television is a result of many causes: transmission of signals on huge, space distances, periodicity of appearance of spacecraft (frequently only on short time) above point of reception of signals and use of television representations for thorough study of obtained information, impossibility of radio-television communication between spacecraft and ground receiving point when airborne television equipment creates picture signals, and others. Video recording permits deciding very many problems of space television radio communications.

In recent years many scientists and engineers have developed different methods of recording television representations, which are continuously improving and finding more and more application.

Filming of television representations. Recording of television representation from screen of reproducing instrument is produced photographically with help of filming apparatus. In contrast to usual photographing, in this case simultaneous survey is not produced of separate cells of object. On television screen in every given moment of time only small light spot, which varies its brightness during shift on screen. Other peculiarity of recording consists in that process of filming should be coordinated with replacement of television frame. These and many other peculiarities hamper filming from screen of tube and these difficulties are differently surmounted in different systems of recording.

Simplified schematic diagram of device for filming of black and white representations is shown on Fig. 31a. Television signals act on control electrode and modulate intensity of beam of electrons of projection tube. Representation formed on screen of electron-beam tube is projected by objective on film. Unexposed film is in

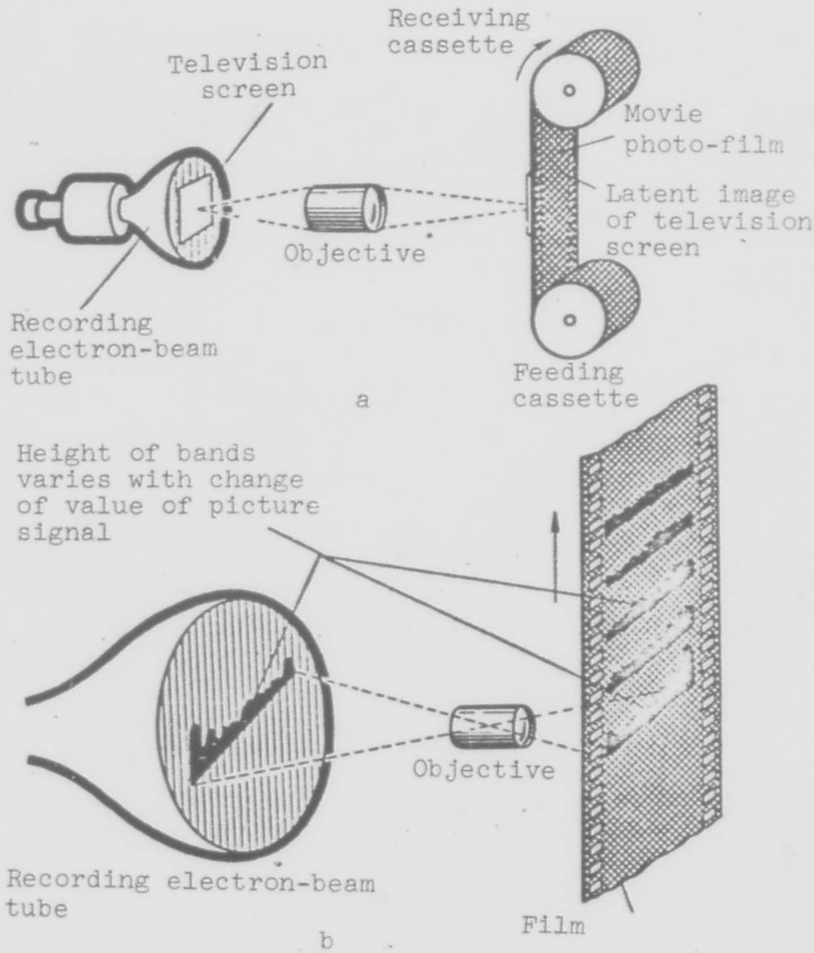


Fig. 31. Diagram of devices for filming black and white television representations (a) and recording electrical picture signals on film (b).

feeding cassette. After exposure the film enters recieving cassette. Thereafter, as and during usual filming, filmed film is processed.

Colored television representations can be recorded on one colored film or on three black and white films simultaneously. There is a method of recording colored television representations on one lens-raster movie film with black and white light sensitive emulsion.

Representation recorded on film is perhaps transmitted in required time on television by the same means by which movie films are transmitted. Recorded representation can be reproduced with help of usual movie projector directly on light-diffusing screen, without application of television installations.

Optical method of recording television signals. Not the picture itself, but picture signals, can be recorded. On Fig. 31b is shown diagram of one of systems of optical recording of picture signals. Under influence of scanning voltage, scanning of one line is produced on screen of tube. For this period luminescent spot shifts from left extreme position to right extreme position and then returns quickly to initial position. To vertically deflecting plates of tube is applied voltage on frequency near 15 MHz, which is modulated on amplitude by signals of representation. On screen appears luminescent band, height of which varies in accordance with change of value of picture signal. Representation of this band is projected on evenly moving film. After photographic treatment, parallel lines appear on film.

During reproduction the film is stretched in analogous device and transilluminated by running light spot of constant brightness, which is also formed on screen of electron-beam tube. On other side of film a photocell is set, which will convert change of luminous flux passing through film back to electrical picture signals. After amplification these signals move to television transcriber.

Video recording by ultrasonic diffractional modulator of light. Photographic recording of television representations can be produced with help of modulator of light, action of which is based on diffraction of light in high-frequency (ultrasonic) waves. It is possible to record signals with frequency band up to 20 MHz in dynamic range, which reaches 1000:1. Diagram of device is shown on Fig. 32a. Narrow slot D_1 illuminated by source of light 1 and condenser $Л_1$ with help of two lenses $Л_2$ and $Л_3$ is focused in plane OO', where its representation is covered by special opaque flap. If electrical signal on modulating ultrasonic cell 2 is lacking, light does not pass through flap. If, however, electrical picture signal is fed to cell 2, light rounds flap, as was shown by dotted line. Value of passing luminous flux depends on value of picture signal.

Ultrasonic modulator 2 constitutes vessel with liquid, in which is vibrator — piezoelectrical plate 3. Vibrator is excited from generator by oscillations with frequency between 10 and 20 MHz. Oscillations of generator are modulated in amplitude by electrical television signals. In liquid excited piezoelectrical plate creates high frequency traveling waves of different intensity. High-frequency waves create periodic changes of index of refraction of liquid.

Powerful source of light and high light effectiveness of diffractional modulator of light permit applying low-sensitivity, high-resolving films for photographic recording, which promotes increase of quality of recording. Light sensitive material is set in motion with a speed such that one line of representation is scanned by light reflected from one mirror of revolving drum. Second line is scanned by light reflected from second mirror of drum, etc.

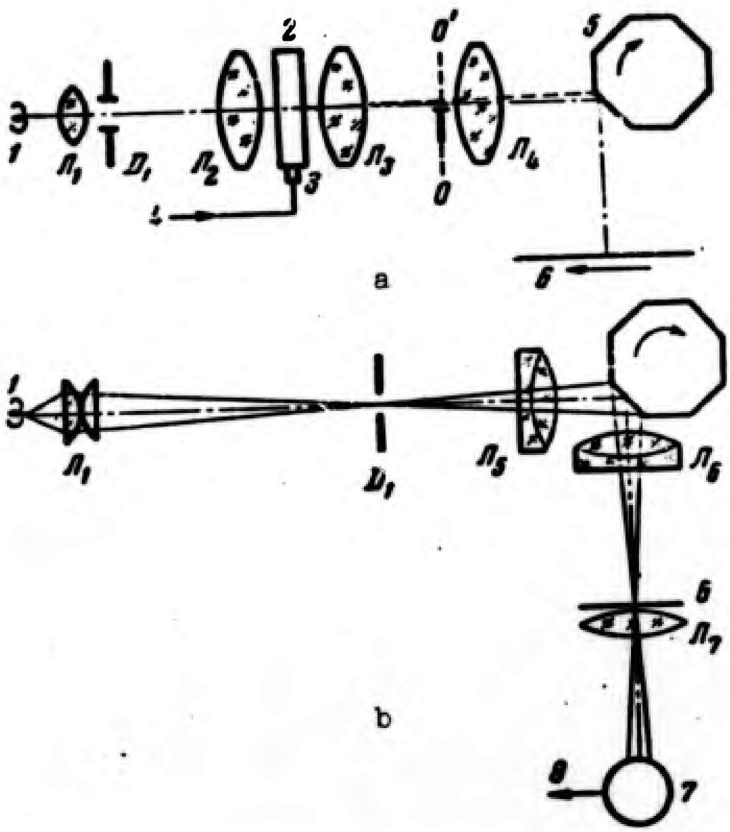


Fig. 32. Diagram of diffractional modulator of light for recording of television representations (a) and device for reproduction of television signals recorded with help of diffractional modulator of light (b). 1 — source of light; 2 — modulating ultrasonic cell; 3 — vibrator; 4 — video signal; 5 — mirror drum; 6 — film; 7 — photomultiplier; 8 — video signal; $Л_1$ — condenser; $Л_2$, $Л_3$, $Л_4$, $Л_5$, $Л_6$, $Л_7$ — projection lenses; D_1 — diaphragm.

After treatment the obtained film constitutes a series of lines of variable density. During reproduction (Fig. 32b) the film is traced by running light spot. Depending upon density of separate cells of film, there occurs corresponding change of luminous flux passing through them, which procede to photocell. On output of photocell appear electrical signals, which are fed to receiver.

Main deficiency of examined methods of preservation of television transmissions consists in necessity of photochemical treatment of film after recording. In recent years recording systems have been developed which are without this deficiency.

Recording of television signals on magnetic tape. Essence of method consists in the fact that change of value of television signal in time is fixed along length of magnetic tape in the form of change of residual magnetization. A recording once made can be preserved without limit for a long time and can later be reproduced with help of a device, analogous to a recording device. Basis of magnetic tape is any elastic material on which is deposited carrier able to preserve residual magnetization. The biggest propagation was obtained by carriers in the form of a layer of varnish containing ferromagnetic powder (oxide of iron or magnetite).

Electrical signals subject to recording are fed to winding of magnetic recording head (Fig. 33) — specially designed electromagnet. Tape is stretched past clearance of recording head. Value of magnetic field strength in clearance of core of head is proportional to value of television signal in corresponding moments of time, thanks to which picture signals are fixed on tape in the form of magnetic relief (differently magnetized sections of tape).

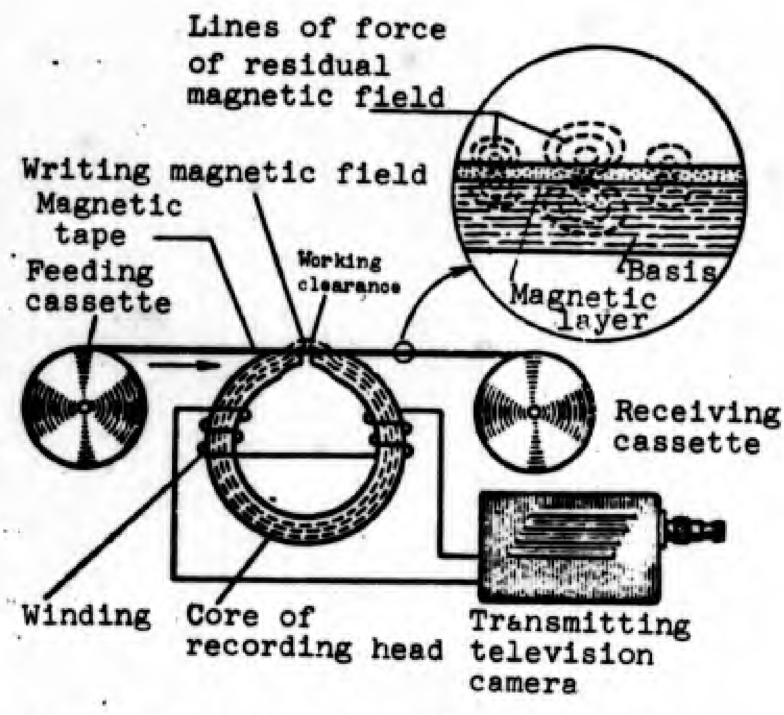


Fig. 33. Diagram of arrangement of apparatus for recording picture signals on magnetic tape.

During readout of recorded signals, magnetized tape moves past reproducing head, which is similar in construction to recording head. Lines of force of magnetic flux of elementary magnetized sections of moving tape intersect winding of head and induce in it emf proportional to intensity of residual magnetic field. Then restored television signal is fed either to television transcriber or to television transmitter (for transmission of television signals on distance). The same film, from which former recording is erased is perhaps used for recording other television reports. It is considered that recording on magnetic tape will be reproduceable after prolonged storage of film, let us say, after several thousands of years.

Basic difficulty of creating high-quality recording and reproducing equipment in television is connected with wide frequency range of picture signal, since it requires considerable increase of speed of movement of magnetic tape as compared to speed during recording and reproduction of aural signals. This in turn requires great length of magnetic tape for recording during defined time, i.e., leads to uneconomic use of magnetic tape. What then is the matter here?

In order that recording correctly depict law of change of video signal, it is necessary that during the time of shift of tape in region where magnetic field of scattering of recording head acts, video signal practically not change. Comparing dimensions of region of action of field with interval of time during which video signal remains constant, necessary speed of carrier shift can be found. Let us assume that extent of field (determined by magnetic head clearance dimensions and magnetic tape properties) is $l = 0.1$ mm. It is possible to allow that video signal remains constant during half-period of highest frequency. If one were to take the latter for 6.5 MHz, then duration of half-period would compose $0.5\ T = 0.077$ µs. This means speed of tape should attain practically unrealizable value $v = \frac{l}{0.5\ T} = 1.3$ km/s. Recording a monohour television transmission would require magnetic tape 4700 km long.

Deceleration of travel of tape is attained with help of recording heads with small clearance, magnetic tapes with improved properties, or use of magnetic tape, not only by length, but also by area. Density of recording is increased at the expense of decrease of width of magnetic tracks and their location very near one another. The latter condition is carried out by several methods. In certain systems, recording is produced on several tracks along length of tape by several recording heads.

The most useful for wide application are systems, in which recording is produced, not by length of tape, but on its width with help of revolving heads. Combination is attained of speed of drawing of the magnetic tape itself which is low and convenient for explotation, and high speed of tape relative to recording head, which is necessary for recording high frequencies. General diagram of transverse-line recording of television signals on magnetic tape is shown on Fig. 34. Recording is carried out on width of tape, with help of four heads, which are mounted at identical angular distances from each other on revolving disk — rotor. Thanks to relative shift of tape and rotor, recording on tape is similar to line scanning. When first head after recording descends from tape, the following head starts recording from opposite side of tape, etc. Recording of video signals occupies central part of tape. On edges of tape (along it) are recorded synchronizing signals and signals of sound accompaniment. Speed of shift of tape

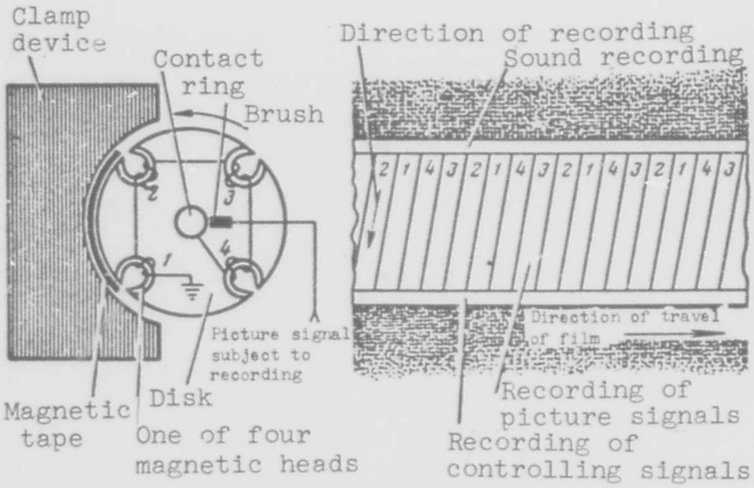


Fig. 34. Diagram of device for recording picture signals on wide magnetic tape in transverse direction.

is as low as in ordinary equipment of sound recording. Thus, in domestic system of video recording, speed of drawing of magnetic tape (70 mm wide) composes 381 mm/s. During capacitance of roll of tape of 915 m (354 mm diameter of roll) continuous recording of television programs during 40 minutes is ensured.

However, video tape recorder with four revolving heads is a rather complicated device. Therefore, much attention is allotted to development of new systems with one and two revolving heads.

Basic deficiencies of existing methods of magnetic recording and reproduction of television signals are insufficient resolving power and large relative speed of heads and tape. Therefore, new methods are created of recording television signals.

Recording of television signals on thermoplastic tape. There are several methods of recording by electron beam, based on chemical, thermal, magnetic, or electrostatic influence of electron beam on carrier.

On thermoplastic tape, change of value of television signal in time is fixed in the form of permanent deformations. For recording is taken three-ply tape (Fig. 35), the base of which is prepared from plastic with a high melting point. On base is deposited transparent conducting covering, but on it is deposited thin film (about 12 μm thick) of thermoplastic material with low melting point. In contrast to so-called thermoreactive plastics, utilized thermoplastic plastic (celluloid, polystyrene, polyethylene, polyvinyl chloride, polymethylmethacrylate, polyfluoroethylene resin and others) does not lose ability to be melted during secondary heating and cooling. Permissible operating temperatures for majority of thermoplastics oscillate within limits from 40° to 100°C.

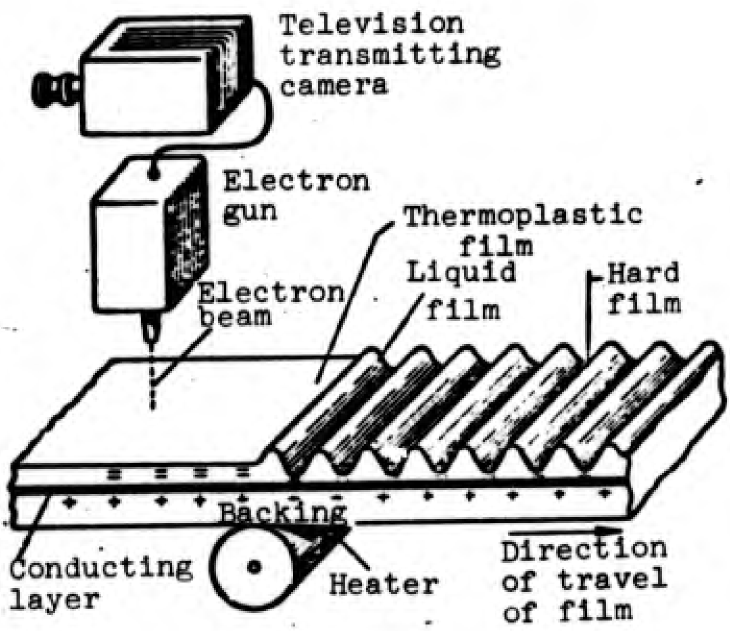


Fig. 35. Simplifi   ircuit of installation for recording celevision signals on thermoplastic tape.

Television signal is fed to apparatus of recording from usual television camera. Signal is recorded with help of electron beam, which is modulated in density by recorded picture signal. Electron beam, created by special electron gun, visits surface of film according to the law of television scanning and leaves on film negative electrical charges proportional in value to electrical picture signal from transmitting camera. Scanning of electron beam by line is carried out at the expense of deflection of beam in electron gun by horizontally deflecting plates, but scanning by frame is carried out at the expense of shift of film, rewound from one coil to another.

After irradiation by electron beam film, passes special high-frequency heater. At achievement of point of fusion of fusible thermoplastic electrostatic attractive forces between negative charges, brought on film by electron beam, and positively charged conducting layer causes lowering of the level of softened thermoplastic, until these forces are in equilibrium with forces of surface tension and hydrostatic pressure, which is rushing to restore level of surface.

During further travel of tape, deformed liquid ("manifested") section of film emerges from zone of action of high-frequency furnace, is cooled at the expense of transmission of heat to base layer, and solidifies. Deformation of film turns out to be as if "frozen". Processes of recording and manifestation continue during one hundredth of a second.

During scanning by electron beam of line, a narrow line of charges is created. After heating and cooling, on this place of film there will be formed a groove, on bottom of which are tiny protuberances and cavities. During scanning by electron beam of whole frame of representation, on surface of film there will be formed a series of parallel grooves, depth of which is determined by value of recorded signal.

Thermoplastic recording can be removed, and film is used for recording repeatedly (several thousand times). Erasing of recording is carried out by heating of film to higher temperature than during "manifestation". Levelling off occurs of surface of film at the expense of surface tension of melted film and runoff of charges from it thanks to increase of conductivity.

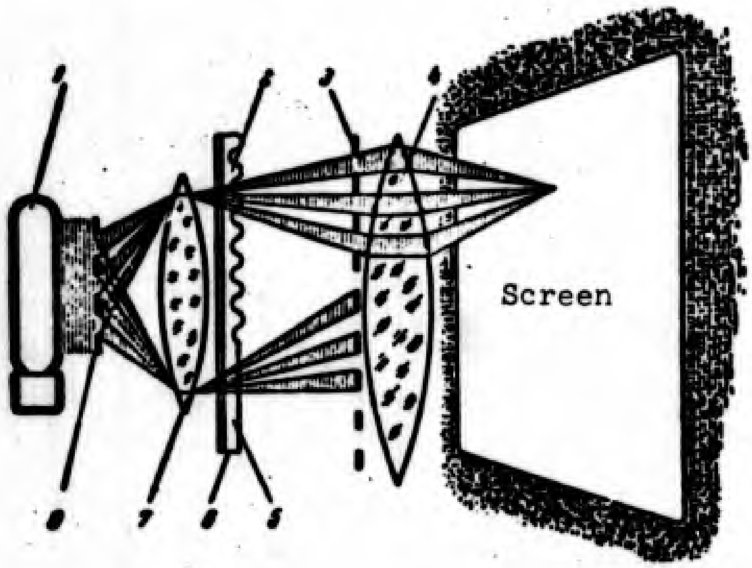


Fig. 36. Diagram of installation for optical reproduction of television signals fixed on thermoplastic tape in the form of deformations of film: 1 — projection tube; 2 — protuberance; 3 — second grid; 4 — objective; 5 — flat surface of film; 6 — thermoplastic tape; 7 — condenser; 8 — first grid.

Recording is reproduced with help of special optical system (Fig. 36). Light from outside source of constant intensity, passing through slots of grid from opaque rods, gets onto condenser, which directs light passed by grid to system of opaque rods, which forms second grid. Thermoplastic tape is located between lens and second grid. If there is undeformed film between lens and second grid, then rectilinearity of propagation of light is not disturbed, bands of light get onto opaque rods of second grid, and projection screen remains dark. In the presence of grooves and protuberances in projected section of thermoplastic tape, paths of light rays are the more distorted the deeper the groove. As a result part of light rays passes slot of second grid and collects projection objective at point of screen, corresponding to position of deformed section on projected exposure.

On thermoplastic film can also be recorded color television signals. Recording of signals of colored representations is produced by electron beam, which is split either into four or into two rays.

Bandwidth of thermoplastic recording considerably exceeds width of magnetic recording; quantity of information recorded on unit of surface of thermoplastic film is also considerably greater than on magnetic tape.

For optical reproduction of recording on thermoplastic tape, it is not obligatory to use projection system. Changes of surface strain of film can be converted anew into changes of electrical signal. After transmission on required distance, these electrical signals can be given to usual television receiver, on screen of which earlier recorded representation will be reproduced.

For production of electrical signal corresponding to recorded representation, it is possible to apply scanning device with running light spot.

Basic deficiency of system of thermoplastic recording consists in necessity to use vacuum pump for constant pumping out, since creation of thin recording electron beam is possible only under conditions of vacuum.

Electrostatic registration of picture signals. For registration of representations on artificial earth satellites, there has been developed a system of recording optical representation with the help of electrostatic converter, into composition of which enters electron gun with focusing and deflecting systems and special target, called phototape.

Phototape (carrier of recording) consists of transparent basis, thin transparent intermediate underlayer of conducting material, layer of semiconductor photoactive material and layer of insulating material (Fig. 37a). On each side of phototapes are located metallic lines 15 μm thick for electrical contact between cells of system which are connected with carrier and conducting underlayer. These lines prevent, furthermore, mutual contact of separate turns of tape during winding of it on roller.

Electric circuit of system of recording and its equivalent diagram are depicted on Fig. 37b, c. Process of recording consists of two operations; preparation of carrier and recording proper. During preparation phototape is darkened or evenly illuminated. On surface of layer of insulator, which is moving with constant speed an electron beam is focused, which carries out its scanning. Electron beam by turn locks circuits R, C_1, C_p (which are equivalents of distributed parameters of phototape) on source of direct current U.

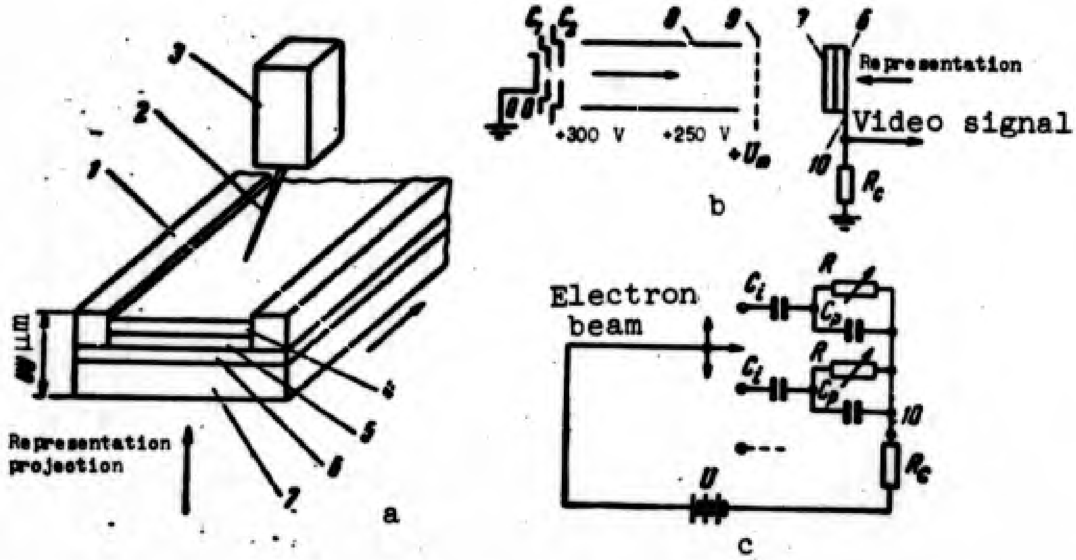


Fig. 37. Diagram of device for electrostatic registration of picture signals (a), its electric circuit (b) and equivalent diagram of electric circuit (c). 1 — metallic band; 2 — electron beam; 3 — electron gun; 4 — polystyrene insulator; 5 — antimony-cessium photoconductor; 6 — transparent conducting layer of gold; 7 — transparent basis; 8 — conducting covering of bulb of gun; 9 — collector grid of tube; 10 — signal electrode.

As a result every cell of surface, i.e., every elementary capacitance C_1, is charged to value corresponding to applied voltage U. Then electron beam is extinguished, and circuit will be opened. Thus, on phototape the remainders of potential relief from preceding recording are destroyed.

Then from the side of base layer recorded optical representation is projected on photoactive semiconductor. Electric circuit of system is again locked through conductivity of electron beam. Under action of potential difference, which is preserved on insulator after operation of preparation, on elementary circuit RC_1 will go current of discharge of capacitor C_1, value of which will be greater, the smaller R is. The least value of R corresponds to the brightest illuminated cells of phototape. After cutoff of electron beam, on insulator of phototape there remains recording of optical representation in the form of surface distribution of electrostatic charges. After turning off of electron scanning, potential relief is preserved on tape not less than two hours.

The same device is used for reproduction of recording. Phototape with constant speed is stretched past scanning electron beam, which by turn locks circuit of cells RC_1. Current of recharging, which flows on resistance R_C, will form on it voltage of video signal, which is transmitted by usual means to point of reproduction.

Characteristic for this system of recording is high resolving power, absence of need for chemical treatment and insensitivity to radiation effect.

Above we examined methods of recording television representations which can be used both in ground, and in airborne equipment of space radiotelevision communication systems. Now we will describe certain methods of recording representations, which are applied only in ground recording equipment of space radiotelevision communication systems.

Reproduction of representations on electrochemical paper. During reception of picture signals on space crafts, finds open recording of representation on electrochemical paper finds application. Open recording of representations is the form of recording, which can be produced in any conditions of illumination and is visible to operator during whole process of picture reception. This case concerns open recording carried out by electric-contact devices on special conducting paper. Paper can be used in the form of separate blanks or tapes; width of tape besides is equal to length of line of reproduced representation.

For recording of representation on electrochemical paper tape, a system is applied (Fig. 38) consisting of revolving single-turn

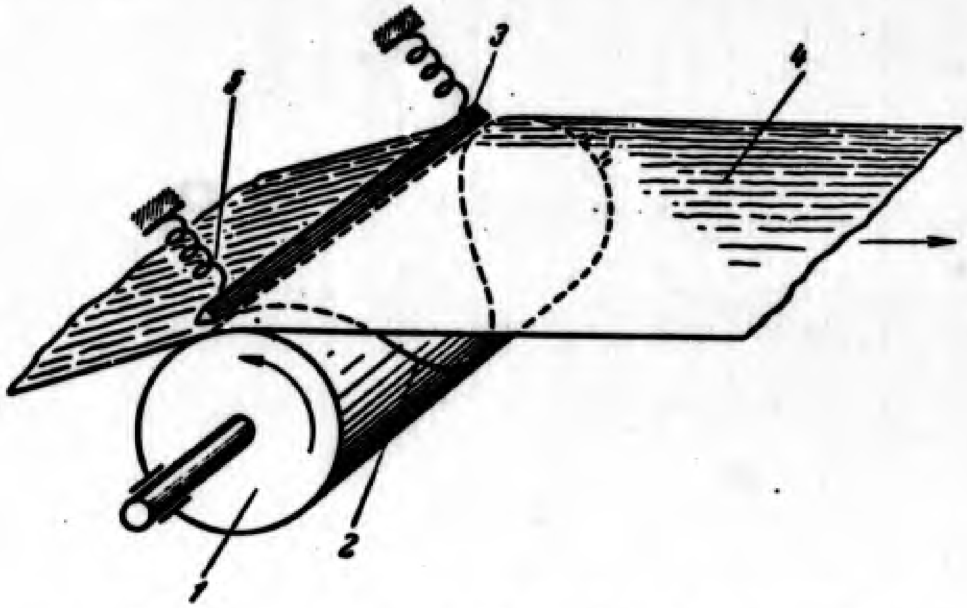


Fig. 38. Electromechanical device for recording representations on electrochemical paper: 1 — drum; 2 — spiral; 3 — writing plank; 4 — electrochemical paper; 5 — spring.

spiral, clamp or writing plank with sharp lower edge, which is parallel to generator of drum, clamp springs and system of ribbon-drive rollers intended for drawing of paper. Single-turn spiral can be carried out either in the form of spirally bent plate, strengthened by appropriate holders on axis or in the form of turn of wire, superimposed on cylindrical drum.

Writing plank is continuously pressed to paper with the help of springs; picture signal is applied between plank and spiral of cylinder. Since paper possesses electrical conductivity, electric recording circuit is always closed.

During rotation of drum, point of contact of paper with spiral shifts parallel to axis of drum and every turn of drum corresponds to one line of representation. Longitudinal shift of tape is carried out with help of tape-winding rollers.

For large sizes of reproduced representation, recording device with spiral turns out to be very bulky. Indeed, the longer the recording line, the bigger the diameter of spiral should be so that angle between plank and spiral is not less than 45-60°. At smaller angles resolving power of device, i.e., ability to reproduce small pictorial details, sharply descends.

For decrease of dimensions of recording device second spiral is used instead of writing plank; then reproduced cell is created at point of crossing of two revolving spirals. One more improvement of such two-spiral device can be application of multiturn spirals. Usually one of spirals is made multiturn, where speed of rotation of drum can be decreased many times as there are turns of spiral. Such construction permits obtaining small dimensions of reproduced cell even for long lines for comparatively small diameters of spirals.

Paper utilized for recording possesses property of electrical conductivity and is able to give so-called colored reaction on passage of electrical current. Essence of colored reaction of paper consists in that at the time of passage of current, there occur in it chemical transformations, as a result of which, substances with color of one color are turned into substances with another color. Electrochemical conducting papers possess ionic conductivity of electrolytes. Passage of electrical current may cause change of color of paper preliminarily treated chemically (at point of its contact with plank and spiral) as a result of such processes as electrolysis, discharge on electrode in contact with paper, and others.

Electrophotographic recording. During electrophotographic method, on conducting foundation is deposited thin layer of light sensitive semiconductor material (selenium, sulfur, sulfurous lead, oxide of zinc and other materials and their combinations). Semiconductor photosensitive layer is charged to a certain potential (order of several thousand volts), i.e., they stretch it past a wire having a potential of 5-8 kV. On surface of wire occurs corona discharge. Since electrical conductivity of photosensitive layer is very low in darkness, its surface holds a charge for a sufficiently long time. Then on this light sensitive layer, representation is projected or is recorded by moving light ray. It lowers resistance of semiconductor layer in corresponding places, as a result of which on surface of the last one will be formed deep potential relief — electrical representation not visible to the eye in the form of distribution of charges of different density.

Representation could be made visible, if one were to pollinate surface of this layer with small powder, the particles of which have charge opposite sign of charge of layer. The more electrical charge carried by that or another point of surface of semiconductor, the more particles attracted to these points. Those cells of representation which were not irradiated by light have small photoconductivity and preserve large charge; therefore, they are covered by dense layer of powder. Cells of surface of light sensitive layer which were illuminated earlier lose all or part of their charge due to increase of photoconductivity of layer; they are not in a state to attract particles of powder and therefore remain light.

Light sensitive layer can be applied either directly to paper or to metallic surface (and then representation formed by powder is later transferred to paper). During recording directly on electrophotographic paper, light sensitivity of paper descends, and this does not permit recording pictures with high speeds. Use of separate photoconductive layer deposited on metallic surface permits obtaining best results and attaining higher sensitivity. When representation is recorded by this method, it is convenient to deposit light sensitive layer on drum, and to dispose line of scanning along generator of cylinder (Fig. 39a). Drum slowly revolves,

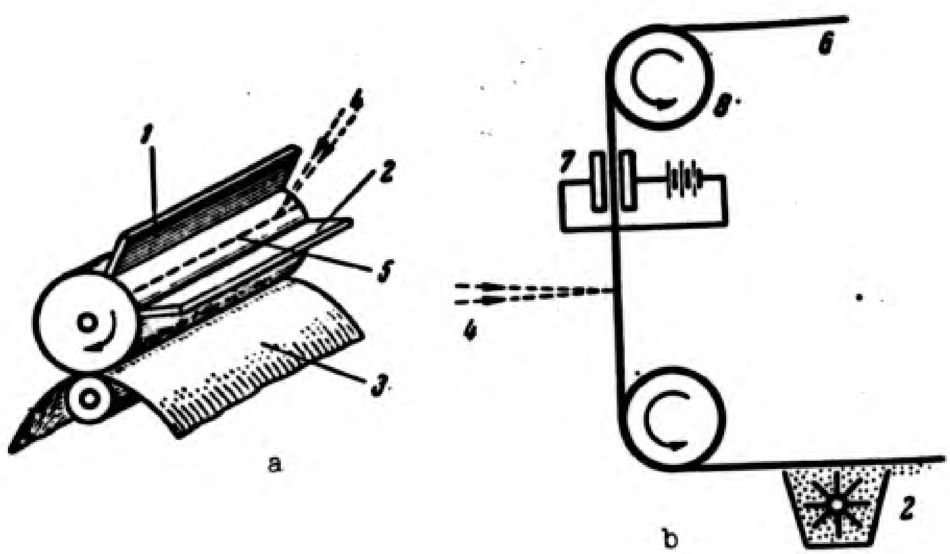


Fig. 39. Diagrams of electrophotographic recording: a) on paper; b) on tape from electrophotographic paper; 1 — charge device; 2 — duster; 3 — paper; 4 — modulating light beam; 5 — scanned line; 6 — electrophotographic paper; 7 — charge device; 8 — tape winder.

part of surface of photoconductive layer at first is charged, then is illuminated by modulated beam of light and is pollinated by coloring powder, after which dye is transferred on ordinary paper. Such construction of transcriber permits almost immediately examining representation on imprint.

It is still simpler to record on tape from electrophotographic paper. Arrangement of similar recording apparatus is shown on Fig. 39b.

Powders on paper are secured by heating of latter in such a manner that powder deposited on its surface, in composition of which enter tarry substances, is melted and thereby durably secured on paper. The whole process of treatment during use of electrophotographic method takes several seconds in all.

Existing systems of recording of moving representations still did not return all, on what are able, and in laboratories are already being checked all new systems and ideas. In one of investigated methods of recording, electron beam modulated by picture signal irradiates thin plastic plaste. Under action of electrons, plane of polarization of polarized light is changed, and this is used during optical readout of recording. In other method the electron beam irradiates film of magnetic material, evenly magnetized perpendicularly to its plane. Electron beam heats small section of film to temperature, at which strong-magnetic materials are turned into weak-magnetic materials. Thus, under influence of electron beam, initial magnetization is destroyed. When section cools, neighboring sections reverse its magnetism in the opposite direction. During readout of recording, rotation of plane of polarization of electromagnetic wave in magnetic field can be used. Possibilities are investigated of recording and readout on ferroelectric and several other methods.

Television storage transmitting tube. On Fig. 40a diagram is given of transmitting tube device, where information about transmitted representation is recorded electrostatically and is preserved in the form of electrical charges on special tape. Optical representation of object is projected by objective on photocathode of tube. Electrons emitted by photocathode are accelerated by voltage of about 10,000 V and get on storage unit tape. Before beginning of recording, tape passes through device for erasing and primary treatment and is charged negatively. Under influence of electrons potential relief is created on tape from electrical charges formed as a result of secondary electronic emission or appearance of induced conductivity on tape. After recording the tape is reeled onto a second coil, whence it can be rewound for readout. Both receiving and transmitting coils can contain up to several tens of meters of tape.

With the help of electronic lock, time of switching on of which is measured in millionths of a second, it is possible not to pass photoelectrons to tape. Periodically operational mechanical lock can also be used.

Structure of storage unit tape (of film of nickel or copper about 0.04 mm thick) is shown on Fig. 40b. On 1 cm of tape are about 2300 sharply outlined grooves. On long side of every step is

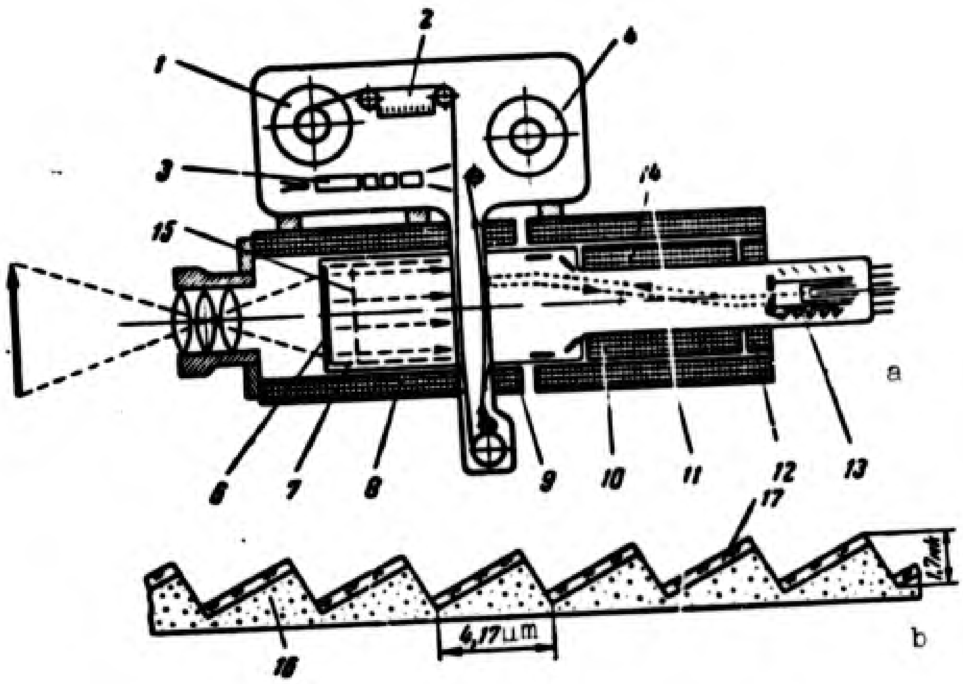


Fig. 40. Television transmitting storage unit tube with tape (a) and its storage unit tape (b). 1 – feeding cassette; 2 – device of erasing and primary treatment; 3 – additional recording gun; 4 – receiving cassette; 5 – storage unit tape; 6 – photocathode; 7 – spiral accelerator; 8 – focusing coil; 9 – focusing coil for tape; 10 – deflecting coil; 11 – focusing coil; 12 – correcting coils; 13 – electron multiplier; 14 – section of readout; 15 – electronic lock (±100 V with respect to cathode); 16 – galvanoplastic replica of copper or nickel; 17 – dielectric (magnesium fluoride or calcium fluoride).

deposited film of dielectric with high resistivity. Short side of steps is free from dielectric, which permits avoiding destruction of information and guiding of charges during readout, and also prevents closing of neighboring turns of tape while it is being wound on roller.

Reader is analogous to reading unit of usual image orthicon and is designed in such a way as to obtain possibly smaller diameter of beam. Reading beam scans surface of tape under influence of magnetic fields of deflecting system. Near sections of target, where surface of dielectric is charged by recorded signal to -5 V, all electrons of reading beam are reflected, and in those places of tape where dielectric is charged to -2 V, electrons are collected by uncovered part of base layer of tape. Thus, return electron beam falling on anode of secondary electron multipliers turns out to be signal modulated earlier.

Indices of work of this tube are very high. Main merits of tube are its high specific resolving power, which reaches 1500 lines on 1 cm (let us note that dimension of one frame is 5 × 5 cm), and possibility of multiple readout of information of recorded picture frame (up to 2000 times). Time of storage of recorded information exceeds 80 hours during negligible decrease of signal. Further improvement of construction of cells of tube, its storage unit tape in particular, will allow these parameters to improve considerablv. This tube is undoubtedly very promising for application in airborne equipment of spacecraft, since here are combined functions of conversion of light energy into electrical energy, recording of information for storage until the moment of the most favorable transmission and the functions of readout at very high resolving power. The basic deficiency of tube — necessity of vacuum installation for pumping out of gases from bulb of tube is insignificant under conditions of space application, since there is a natural vacuum there.

CHAPTER III

SELECTION OF PARAMETERS FOR SYSTEMS OF SPACE TELEVISION

Selection of number of lines of decomposition. Frequency of frames. Form factor of frame. Required frequency band of communication channel. Sensitivity of television systems. Conditions of accumulation of transmitting tubes. Required illuminance of transmitted object. Illuminance of real objects. Threshold contrast.

In television broadcasting, transmitting part is controlling link of television system. Contemporary television center in large cities constitutes complex of constructions with complicated radio-electronic, lighting engineering, cinematographic, and other equipment. For simplification and reduction of prices of television-receiving link of system, maximum of all functions is placed on television center. In order to ensure sure reception of signals by receivers on television centers, radio transmitters of high power are used.

When spacecraft are used for relaying programs of television centers long distances, then airborne equipment (or simply reflecting surface of artificial earth satellite) serves as intermediate link of radio relay communication circuit.

In a number of systems of space television intended for solution of scientific and national economic problems (meteorological, geodesic, communications, artificial satellites, outer space observatories, piloted spaceships, spacecraft for study of moon and planets of solar system), the most stringent requirements are presented to transmitting airborne equipment (small weight, compactness, simplicity of adjustment, reliability). Therefore, controlling link of such system is ground equipment — system of complicated engineering constructions.

Parameters and basic qualitative characteristics of system of television broadcasting have to anticipate possibility of television transmission of objects in different conditions. For this a number of television studios is necessary with several transmitting cameras, intended for transmission of nature scenes, and also movie projection cameras for transmission of movie films and movie inserts, mobile and reportage television installations for transmission from stadiums, from theaters, etc.

There is no necessity for similar universality in systems of applied television, therefore, technical solution is often simpler and has a definite problem in front of it. But the higher the quality of reproduction must be, the more complicated the television system. Therefore, it is obvious that system simplification depends on how far it is permissible in given conditions to impair picture quality. Sometimes it is possible to reduce number of lines of decomposition, but in a second case to reduce the number of frames, and in a third to lower requirement for accuracy of work of scanning devices. In certain cases a compromise solution permits simplifying installation and making it more compact. Let us stop on these questions in somewhat greater detail.

Selection of Number of Lines of Decomposition

Number of lines of decomposition of television system, along with its other parameters, determines resolving power, i.e., minimum dimensions of object revealed with help of television system.

In systems of television broadcasting, number of lines of decomposition is set proceeding from peculiarities of perception of representation. Usually spectator is at such distance from screen that his viewing angle is 15-20°. Therefore, spectator sees whole screen at maximum resolving power of eye; it is maximum in central (axial) zone (the latter has angle value in 2°). When pictures with small parts are examined, there occurs continuous travel of eyes, which rush to succeed to record all interesting objects within limits of small angle. Eye "feels" what is examined; in 1 minute the eyes change their point of fixation about 120 times. It is most convenient to examine representation, when ratio of distance of examination to linear dimension of representation is within limits 6-8. When television representation is examined from this distance, line (raster) structure of representation does not have to be noticeable. If one considers the resolving power of sight, then there will be obtained that number of lines of decomposition should be on the order of 600-1200.

During determination of number of lines of decomposition in applied systems, it is possible sometimes to put up with the fact that scanning structure is noticeable, since the determining value in this case is value of minimum part, which should be confidently and correctly revealed in field of sight, where value is not absolute value of part, but ratio of dimension of part to field of sight. Depending upon focal length of objective which projects representation on light sensitive surface of transmitting tube, part can be depicted both big and small. The larger the part is depicted on receiver screen, the fewer lines of decomposition can be selected. If in field of sight of objective there should be simultaneously several small parts, without background surrounding them, then it is always possible to set needed focal length of objective and relative dimensions of least part. If y scanning cells should be packed on linear dimension of least part, then number of lines can be determined by the formula

$$z = \frac{h}{d} y,$$

where h is height of picture field, and d is minimum dimension of part.

What then should value y equal? Experiments showed that object can be detected and distinguished from backgrouns only in that case, when it is covered by 3-5 lines. But object can be identified only during scanning of its surface by 10-20 lines (the discussion concerns identification of objects observed on surface of earth from aircrafts). In a number of cases, this number of lines on part is insufficient if configuration of part is complicated.

Resolving power is increased in direct proportion to focal length of optical system, under the condition that illuminance of photocathode is sufficient for production of nominal resolving power of transmitting tube. For different tubes the resolving power has following value. Maximum value of resolving power of image orthicons attains 700-800 lines; for vidicons it does not exceed 700 lines. Image orthicon resolving power attains 1000 lines. These data pertain to standard transmitting tubes. However, special transmitting tubes can be created with resolving power on the order of 2000-3000 lines and more (at the expense of increase of working surfaces of targets and photocathodes, decrease of beam current, and others). But it is not permissible to increase focal length for certain airborne installations, since this in conjugate with increase of weight and dimensions of optical system, and also with necessity of application of means for compensation of influence of temperature change of focal length.

When representation moves (and this is caused by the fact that spacecraft moves), then resolving power of representation can somewhat worsen. However, this deficiency can be removed by selecting time of exposure correctly (projecting optical representation on photocathode for only very short intervals of time) or by applying methods of compensation of travel of representation, ensuring position of moving representation relative to transmitting tube.

Frequency of Frames

In certain cases frequency of frames is selected, not on the basis of physiologic conditions of observation (critical frequency of flashing), but in consideration of speed of shift of object in field of sight, i.e., in such a manner so that object does not shift noticeably in field of sight during a frame interval of time. If frequency of frames, set proceeding from these conditions, less accepted in television broadcasting, then this decrease leads to reduction of frequency band of signal. If it is necessary to reduce considerably frequency band of signal, then, in such cases, the number of frames is sharply reduced. For reproduction of representations are used electron-beam tubes possessing property of "memory" (prolonged preservation of information, device of recording on magnetic tape, film, electrochemical paper, and others).

Form Factor of Frame

In television broadcasting, ratio of width of frame to its height is accepted as equal to 4/3 and close to ratio of sides of frame (11/8). This selection is based on the fact that viewing angle of eye in horizontal direction is greater than in vertical. In applied television, ratio of sides are selected from considerations of the most effective use of photocathode area (target), which usually has the form of a circle. The most effectively used is area of photocathode in systems with spiral scanning. In this case the whole surface of photocathode is occupied by representation, since round screen here is completely inscribed in photocathode circle.

However, preferential propagation in space television was found by systems of small scanning, where television screen constitutes rectangle with defined number of straight lines. From the point of view of effective use of photocathode, the most profitably ratio of sides of frame during linear line scanning is 1/1. In this case a square screen is inscribed in photocathode circle; as is known, of all forms of rectangles inscribed in that same circle, square has the biggest area.

However, in a number of systems another ratio of sides is used due to necessity.

Let us assume that from a spacecraft in circular equatorial orbit, transmission is conducted of representations of earth's surface from a height of 500 km. During the time of one turn around earth (1 h 34 min 32 s, or 5672 s) a band of surface 100 km wide is surveyed. If ratio of sides of frame is 1/1, then in one turn there will be obtained 401 picture frames (length of circumference of equator divided into 100 km). For production of representation of band of earth's surface in the form of mosaic of 401 nonoverlapping frames, necessary time of scanning of one frame will be approximately equal to 14 s (time of one turn divided into number of transmitted frames). From considerations of more effective conversion of optical representation into electrical signals, considerably smaller duration of transmission of frame can be required; 1 s is permissible. Then the same point of earth's surface will be examined in 14 frames of representation, which is absolutely inexpedient since system of radiotelevision communication is used with insufficient efficiency (there is great excess).

For decrease of excess is required (in similar case) very narrow frame, longer side of which is oriented perpendicularly to direction of travel of spacecraft. For example, frame of reproduced object with height 10 km and width 100 km will be covered at frequency of 1 frame per second with small excess. But during selection of such form of screen area of round photocathode of transmitting tube is used very ineffectively (Fig. 41a). In order to avoid this, methods can

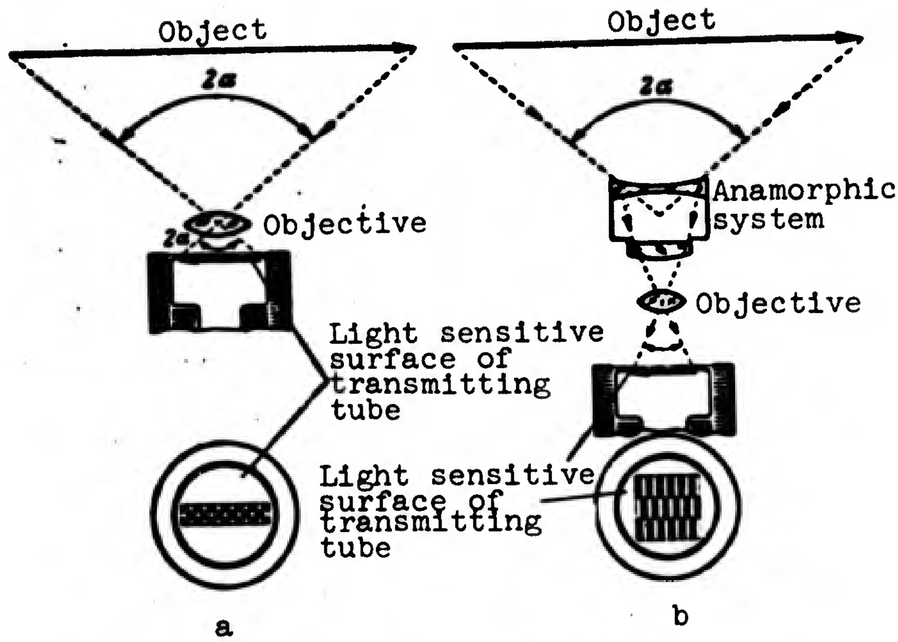


Fig. 41. Formation of wide-size screen on light sensitive surface of transmitting tube. a) with the help of usual objective; b) with the help of anamorphic objective.

be applied of optical conversion of projected representation, for example, with help of anamorphic optics (Fig. 41b). Although wide screen cameras with anamorphic optics have complicated optical system, they permit obtaining best results. In particular, more complete use of working surface of photocathode permits obtaining higher sensitivity and best signal to noise ratio. Furthermore, anamorphic optics gives smaller fall of illuminance on edges of representation during vertical angles of picture which equal wide-size camera.

Such wide screen representation cannot be reproduced on screen of usual kinescope. Values of scanning oscillations in receiver are set such that a raster of necessary size is formed on screen (Fig. 42a). However, for large ratios of picture to its height, screen area of receiver tube is used very inefficiently. But this deficiency is eliminated in a two-tube reproducing device. There, picture is reproduced on two rows of established electron-beam tubes, where only the corresponding half of the picture is formed on each kinescope screen (Fig. 42b). Electrical circuit of two-pipe transcriber is considerably more complicated, than circuit of monopipe receiver.

For production of representations of large dimensions, on screens television projection systems can be used of direct observation electron-beam tubes. Large dimensions of representation can be obtained with the help of two-pipe projection devices (Fig. 42b). Projection of wide screen representations on big screen can be carried out with help of other earlier examined devices.

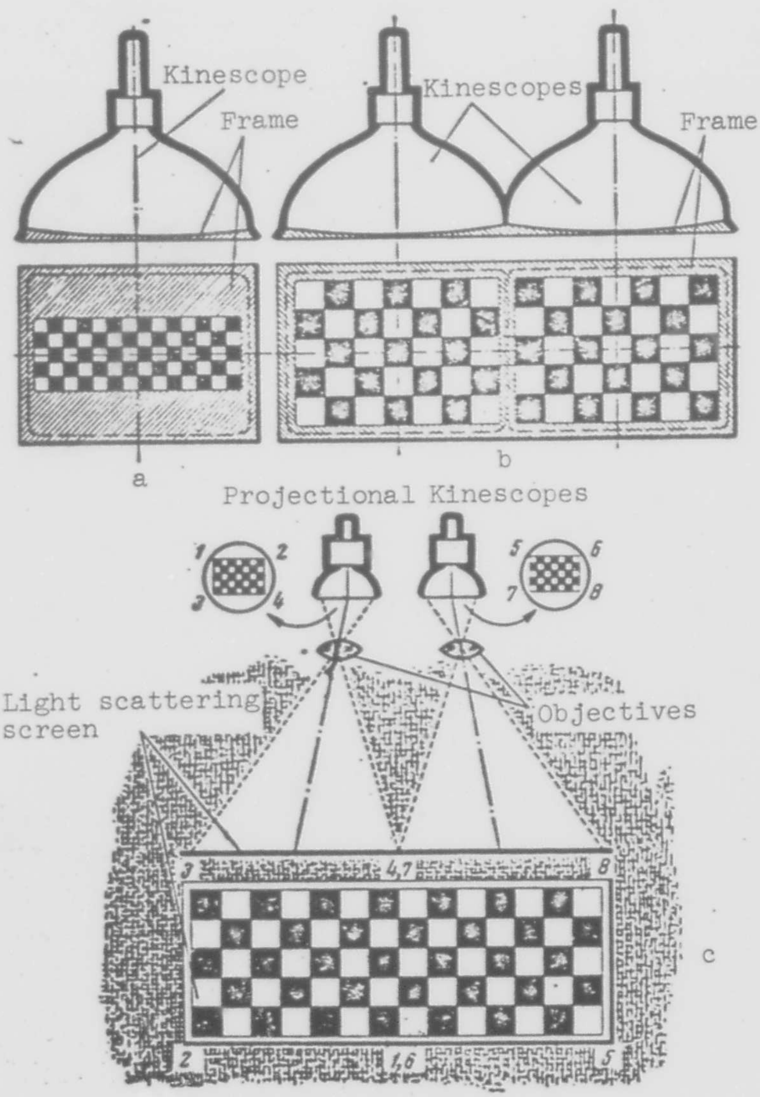


Fig. 42. Reproduction of wide-size television representation. a) on screen of one tube; b) on screens of two tubes; c) on projection screen.

Above described systems of reproduction of wide screen representations serve basically for control of movement of space television transmission. Documentary data, i.e., imprints on that or another paper, can be obtained by one of above described methods. Moreover, in a number of recording systems, no fundamental difficulties are encountered in obtaining needed dimension of imprint.

For production of representations of surface of planet with high resolving power in wide field of sight in direction perpendicular to

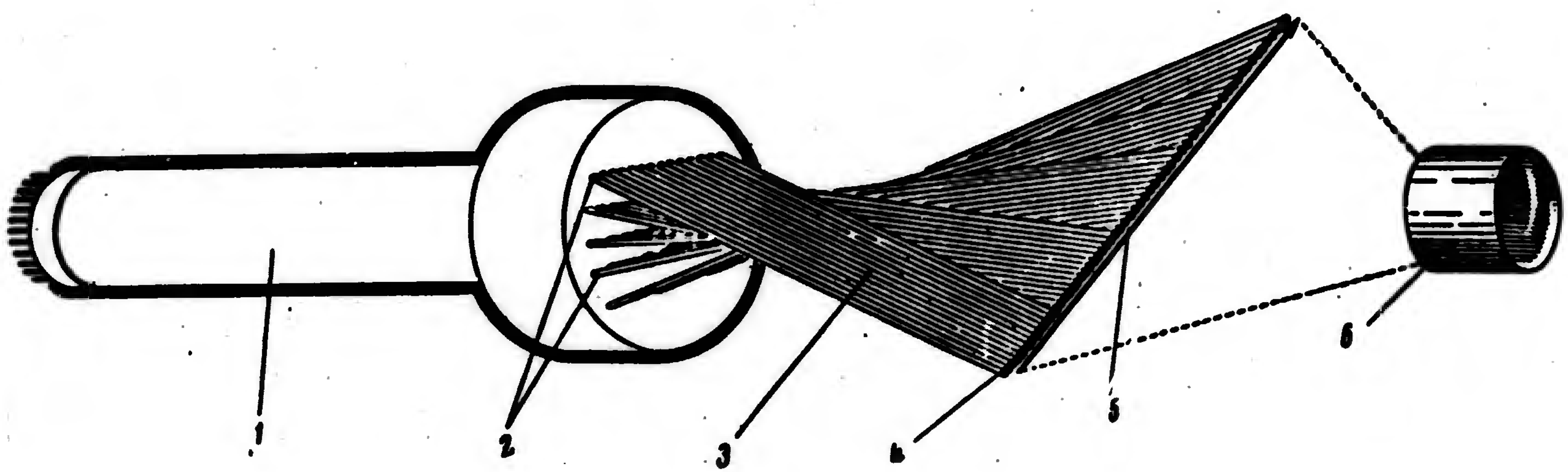


Fig. 43. Fiber optical converter of aspect ratio. 1 – transmitting television tube; 2 – line of screen; 3 – fiber converter; 4 – line from lightcarrying fibers; 5 – line of projected optical representation; 6 – optical system.

direction of flight of spacecraft fiber optics can be successfully applied. Light sensitive surface of applied transmitting tube is used rather completely. Basic cell of such television system is fiber optical converter of frame, which will convert usual television screen into one long line (or into a small number of long lines). During manufacture of such converter, fibers of screen are divided into several narrow rows, forming parallel lines of screen on external surface of screen of tube (Fig. 43). Use of such converter permits obtaining with television transmitting tube calculated on series decomposition of, let us say, fifty lines scanning of one line of fifty-multiple length.

Let us assume that each of 50 lines contains 500 cells of decomposition. Then one compound line will contain 25,000 cells. Such huge resolving power is not possessed by one television system. Scanning of field of sight in direction perpendicular to one line is attained at the expense of travel of spacecraft with camera on board.

To project observed site more sharply on light sensitive surface of tube, direct optical contact should be ensured between input lead of fiber converter and photocathode of tube. For this the photocathode is deposited not on smooth glass, but on disk consisting of a great number of glass fibers, which are parallel to axis of tube. This disk tightly touches input lead (braid of fibers) of converter of aspect ratio.

Picture signals accepted by ground station are at first reproduced in the form of multiline representation on screen of electron-beam tube. Simultaneously with help of fibers optical converter of aspect ratio (identical to converter of airborne television installation), multiline representation will be converted into single-line representation with large number of cells of decomposition. Various methods can be used to record such representation. For example, method of contact printing of single-line output representation of aspect ratio converter on another carrier. For sharper projection of representation from kinescope screen to input lead of receiving fiber aspect ratio converter, it is screen of receiving electron-beam tube must be in the form of a fiber disk. This ensures optical linkage of luminophor surface with input lead of aspect ratio converter.

Required Frequency Band of Communication Channel

Development of ground and airborne television systems and space to earth, earth to space, earth to space to earth, and space to space systems demanded use of the most various combinations of number of transmitted frames per unit of time and aspect ratio. An attempt has been made to increase resolving power of certain television systems (1000-2000 lines on frame and more). But in certain cases 100-200 lines are sufficient for production of necessary information. Television frame can be transmitted in some cases for very small fractions of a second, but in other cases, duration of transmission of one frame of representation can occupy tens of minutes and even hours. In all these cases (taking into account aspect ratio and parameters of work of scanning devices) there will be a defined frequency band required for undistorted transmission picture signal on communication channel.

Sensitivity of Television Systems

Sensitivity is a very important parameter; it establishes ability of system to work under small illuminance of transmitted objects. As was already noted above, television transmitting tube and other cells of system create and strengthen signal of interference as well as desired signal of representation. Getting in composition of video signal on control electrode of receiving electron-beam tube, interference appears in the form of a more or less big and bright ripple covering the whole representation. This ripple, which considerably lowers quality of representation, is more visible on gray and dark places of representation and less visible on light places. Quality of representation is characterized by ratio of maximum value of video signal to average quadratic value of interferences (noises); this ratio is designated by Ψ. It was determined that at $\Psi = 10:1$, quality of representation can be considered satisfactory, at $\Psi = 30:1$, it can be considered good, and at $\Psi = 50:1$, it can be considered excellent. One may assume approximately that representation starts to be visible against the background of interferences at $\Psi = 1$.

Television system sensitivity is frequently determined by that illuminance of photocathode (or target) transmitting tube, with which representation of good quality is obtained ($\Psi = 30:1$). Namely, to this case pertain all requirements for illuminance given in division dedicated to photoelectrical converters.

Conditions of Accumulation of Transmitting Tubes

When parameters of decomposition are different from parameters of broadcasting television, system sensitivity changes accordingly. Although change of frequency band connected with change of parameters of decomposition is in rather wide limits (from 10 to 1 MHz in case of image orthicon and from 10 to 4 MHz in case of vidicon and supericonoscope), luminosity of noises changes little; sensitivity of system is changed due to change of value of picture signal generated by transmitting tube.

During reduction of number of frames of decomposition, sensitivity is increased at the expense of much time, during which accumulation of charge is carried out by storage cell of tube. Still more increase of sensitivity can be attained by applying method of pulse readout of signal, when usual scannings are used in system, but they are switched once through several frames.

This method, in contrast to the preceding one, preserves constant speed of readout of accumulated charge and thereby excludes fall of signal, which is induced by deceleration of discharge of storage cell of tube. Increase of sensitivity by shown methods is attained at the expense of impairment of transmission of mobile objects and is connected with loss of resolving power during their observation and with increase of discretion of created information.

When high resolving power is not required, then sufficiently sensitive system can be built with tube of momentary effect — electronic dissector. This tube, moreover, has better operational characteristics than other tubes. In contrast to tubes using building-up principle, electronic dissector does not give decrease of value of signal on deceleration of readout of value of signal with decrease of readout speed, but absence of accumulation excludes residual signals, which hamper application of small frame during observation of moving objects. Necessary illuminance on photocathode of electronic dissector (during decomposition into 100 lines and transmission of 25 frames per second) is equal to 25 lux at a signal-to-noise ratio of $\psi = 10$.

Required Illuminance of Transmitted Object

How are sensitivity of camera tube and illuminance of transmitted object connected among themselves? Illuminance of light sensitive surface of photoelectrical converter E_{Φ} is connected with illumination of object E by the following dependence:

$$E_{\Phi} = \frac{rT_{0}EO^{2}}{4(1-v)^{2}},$$

where r is coefficient of brightness of part of object (from 0.02 for wet chernozem to 1 for freshly fallen snow), T_0 is coefficient of transmission of objective (from 0.9 for small lens to 0.6 for multilens objects), O is relative aperture of objective, which is equal to ratio of objective inlet diameter to focal length (square of relative aperture O^2 is frequently called aperture ratio of objective); v is linear increase.

The greater relative aperture of objective, the greater illuminance of photocathode of tube will be. Let us assume that light is completely reflected by part of object (r = 1) and is transmitted by objective without losses (T = 1); then limiting value of relative aperture will equal O = 2:1 (1:0.5). Illuminance of representation formed by optical system is equal to illuminance of object. However, for this the diameter of lenses should approximately twice exceed focal length of objective.

Only for small angles of sight is it possible to create optical systems with relative aperture close to limiting value O = 1:0.5. This is explained by the fact that with increase of relative aperture, picture aberrations increase and that it is necessary to make fast objectives from a large number of lenses to prevent them. At present are constructed objectives with relative apertures of 1:0.6-1:0.8.

At large distances between observed surface and airborne television chamber, it is necessary to have long focal length for production of sufficiently high resolving power. Increase of relative aperture leads to very considerable increase of diameter of lenses. As was noted above, bulky objectives can be used only on very big spacecraft. Therefore, during use of objectives with small relative aperture, illuminance of representation on photocathode sharply decreases. Thus, objective with relative aperture 1:50 (having input diameter 12.5 cm and focal length 7.5 m) ensures illuminance of representation 10,000 times smaller than illuminance of object. This value is obtained from last formula by substituting in it values $T_0 = 0.625$, $r = 0.4$, $O = 1:50$.

Illuminance of Real Objects

During natural illumination, luminous flux passing through atmosphere to earth's surface depends on latitude, angle of sun and moon with respect to horizon, and weather (which determines transparency of atmosphere). During cloudless sky, day illuminance is composed of direct illuminance created by sun's rays and scattered illuminance created by sky's light. General range of illuminance is about eight orders. Low illuminance is observed in polar regions and in winter months. When sun is at zenith, illuminance of surface of earth is about 100,000 lux; on border of terrestrial atmosphere, it is about 135,000 lux.

In the absence of sunlight, source of illumination of earth's surface is light of moon and stars. Illuminance created on earth by sunlight reflected from moon depends on phase of moon, angle of moon with respect to horizon, and time of night. Illuminated hemisphere of moon on the whole reflects 7% of light rays of sun falling on it, where quantity of reflected radiant energy monotonically increases with transition from violet to infrared rays. Illuminance created on earth's surface by full moon at zenith is equal to 0.2 lux. Illuminance created by full moon outside atmosphere of earth is 0.3 lux. With decrease of visible part of moon, illuminance decreases, not proportionally to area of light part of disk, but faster. Thus, illuminance from half of moon is 1/10 illuminance from full moon.

Total percentage of time during which illuminance is created by half of moon and more is 25-37%. Sun creates illuminance of more than 40 lux during 52-62% of total time. Sun and moon jointly ensure illuminance greater than 0.04 lux during approximately 75% of the day. In remaining 25% of the day, illuminance is created mainly at the expense of stars, zodiacal light (sunlight dispersed by dust in space) and light of galaxies. Total illuminance from all these sources is equal to 10^{-3} lux. Zori [no translation available (Trans. Ed. note)] and glow of atmosphere create illuminance of the same order or higher, but inasmuch as luminescent atmosphere is between spacecraft and surface of earth, contrast of representation worsens.

Illuminance of lunar surface depends on latitude and angle of sun and earth relative to lunar horizon. When sun is about at zenith for moon, then illuminance of lunar surface can be taken as equal to 135,000 lux. In the absence of sunlight, source of illumination of lunar surface is light of earth and stars. Light of full earth on moon is approximately 100 times more than moonlight on earth's surface, which is explained by larger area and better reflectance of surface of earth.

From given data it follows that observation of surfaces of earth and moon is possible not only during illumination of their surfaces by sun, but also at night. It is true that during creation of television systems for night observations, selection of transmitting tubes is very limited. For this it is possible to use (even with fast optics) only vidicon with transmission of representation or image orthicon with two-stage image converter.

Threshold Contrast

Illuminance characterized by sensitivity of camera tube is illuminance of light section of representation, but measured signal corresponds to maximum contrast in representation $\left(\frac{B_{макс}-B_{мин}}{B_{макс}}\cdot 100\%;\ B_{мин}=0\right)$, i.e., white section of representation borders with its black section. High contrast of black and white object are rarely encountered in practice.

If different contrasts between separate parts are on object, then television system reproduces this relationship of contrasts (half-tone) in distorted form. However, of biggest interest is minimum value of contrast with which it is still possible to obtain signal sufficient for detection of observed object. This value, usually called contrast sensitivity of television system, strictly speaking, depends on level of illuminance and contents of transmitted scene. Of great value is contrast sensitivity of the transmitting tube itself. Thresholds of contrast sensitivity defined during working illuminance are equal to 3-8% for image orthicon, to 8-10% for supericonoscope, and to 10-15% for vidicon. Electronic dissector possess high contrast sensitivity. Let us note that given values are valid during transmission of big objects, dimensions of which exceed dimension of cell of decomposition at least a few times. To the above it is necessary to add that all reasonings were conducted on the assumption that there is no medium which absorbs and disperses light between television camera and observed object. Such conditions practically take place during observation of surface of moon from spacecraft.

We will encounter the worst conditions during observations from height of surface of Mars, since it has atmosphere. And conditions will be still worse during observations of surface of earth from spacecraft since terrestrial atmosphere has considerable thickness, and contents of vapors in it vary. However, the worst conditions for observation from considerable distances are presented by Venus, which is wrapped in a dense layer of clouds.

Rays of light reflected from object of observation and local objects surrounding its (background) pass through layer of atmosphere and get into television camera. Atmosphere contains small particles which absorb and disperse light energy (molecules of air and steam gases, but also, depending upon conditions, water in liquid state and solid particles – smoke, small crystals of ice and sea salts). Terrestrial atmosphere disperses radiation of any wavelength but absorbs mainly that radiation which was apportioned to comparatively narrow sections of spectrum – "absorption band" – of molecules of gases entering composition of atmosphere. In visible region of spectrum of electromagnetic oscillations of spectrum, absorption bands are practically lacking. In infrared region there is a whole series of absorption bands which mainly pertain to molecules of steam.

Part of scattered radiation in the form of light smoke gets into objective of television camera and is put on representation of object and background, by which descends contrast of representation on photocathode of transmitting tube. The move object is observed and the more atmosphere is dimmed, the smaller contrast will be.

CHAPTER IV

PROBLEMS OF SPACE RADIOTELEVISION COMMUNICATION

Sources of noise. Doppler effect and bandwidth. The most expedient frequencies for space communication. Distance of communication and required power of signals.

It is, of course, very important to convert optical representation of object into electrical signals, but it is no less important to transmit these signals on distance, but distance between transmitter and receiver in systems of space radiotelevision communication in contemporary experiments already attains tens of millions of kilometers. Even if distance is not very great, complexity of space radiotelevision communication is caused by wide frequency band of transmitted television signals, and requirement to apply in airborne equipment comparatively simple and light receivers, not very complicated and small antennas, and low capacity radio transmitters. Moreover, spacecraft shifts in space with great speed, but this also generates a number of problems. A great deal of trouble is caused by the necessity of forced stabilization and orientation of apparatus.

In brief, problem of space radiotelevision communication consists in that signal arriving at radio receiver is so small that it becomes commensurable with values of electromagnetic oscillations of the most diverse origin, which are interferences (noises) with respect to transmitted signal. Therefore, success of transmission of radiotelevision signals on space distance depends on correctness of selection of frequency of electromagnetic oscillations carrying information about transmitted representation (carrier frequency), method of transmission of signals, method of its reception and treatment, correctness of selection of sensitivity of receiver, power of radio transmitter, correctness of selection of construction of antenna, etc. This selection in considerable degree depends on source of noises, its location, and character and intensity of noises.

Sources of Noises

For sure radio communications, it is necessary that on input of receiver, useful signal ensured by communication circuit be greater than noises created by different sources. What is source of noise? Noise is undesirable electromagnetic oscillation of the same nature, as useful radio emission. In nature there are a great number of sources of these disturbing electromagnetic oscillations. Any electrical spark is already a cause of appearance of electromagnetic waves. Radio interferences are continuously created by atmospheric electric discharges. And radio reception is hindered by all possible industrial installations (high-frequency industrial devices, electromedical equipment, electric transport, motor vehicles, electric welding equipment, and others) and instruments generating electromagnetic oscillations. To external sources of noises belong inconstancy of voltages of power supplies and mechanical vibrations and also noises caused by absorption of radio waves in the atmosphere and radiation of earth's surface. To number of external sources of noises belongs space itself.

In order to admire southern night sky on moonless night, special instruments are not necessary — myriad of stars are seen excellently even with the naked eye — but to reveal invisible electromagnetic oscillations generated by space, very sensitive instruments are necessary. Therefore humanity learned about existence of infinite space radio emissions only in the thirties of our stormy century. From space arrive radio signals in very wide frequency range, and all of them are interference to radio reception both for airborne radio reception installations and for ground radio reception systems. It turned out that different celestial bodies and objects serve as sources of radio emission: sun, planets, stars, stellar systems, interstellar gas. Up to now several thousand sources of space radio emission have already been put on map of firmament — distant fogginess (gigantic clusters of stars), rarefied interstellar gas, and space dust.

It is possible to estimate noises quantitatively by various methods — by power, voltage, current. It is convenient to estimate value of noises by so-called effective temperature of noises. The less this temperature, the less noises. At zero effective temperature, noises are absent.

Among discrete sources of radiation, one of the basic ones is the sun. Radio astronomical investigations of sun showed that its radio emission very greatly varies with time. In separate, indeed, rather short periods of time, radio emission of sun is many times greater than in usual "calm" moments of its activity. At the same time, solar radiation in range of visible rays is very constant. For all geological history of earth there were no such periods when solar radiation even doubled or halved.

For unit of flux density of radio emission is accepted value equal to 10^{-22} W on 1 m^2 of surface and on a Hz frequency band.

Density of radiation of solar noises during active solar activity and bursts of radiation increases as compared to normal value at frequency 200 MHz from 10^{-21} to 10^{-18} $W/m^2 \cdot Hz$, and at frequency 300 MHz — from 10^{-20} to 10^{-19} $W/m^2 \cdot Hz$. Density of radiation of moon is about $7.6 \cdot 10^{-22}$ $W/m^2 \cdot Hz$. Radiation of planets is small. Thus, density of noises for Mars at a frequency of 9000 MHz is $6.5 \cdot 10^{-26}$ $W/m^2 \cdot Hz$, and for Saturn and Venus is $4 \cdot 10^{-26}$ $W/m^2 \cdot Hz$.

Discrete sources of galaxy have following value of radiation density: Lutetium — 10^{-22} $W/m^2 \cdot Hz$ at a frequency of 200 MHz and 10^{-23} $W/m^2 \cdot Hz$ at a frequency of 3000 MHz, approximately the same radiation of Swan, but radiation of Bull is constant in this frequency range — it is equal to 10^{-23} $W/m^2 \cdot Hz$. Noises of comparatively high power will be accepted in the case when direction of maximum of antenna radiation pattern of receiving antenna coincides with direction to discrete source of radiation.

Distributed galactic noises have maximum lying along Milky Way and minima directed to poles of galaxy. Along with radiation of galaxy, which is observed in wide range, radiation was revealed on fully defined wave, namely — on the order of 21 cm. Source of this radio emission is interstellar hydrogen. Among extragalactic sources of radiation sources are encountered, radiated power of which is comparable with radiated power of the whole galaxy.

Applying directional antennas and correctly selecting orbit of spacecraft, it is possible to weaken considerably influence of cosmic noises on radiotelevision communication. The most unfavorable case — location of source of interference, spacecraft, and ground receiving antenna on one straight line — will certainly be encountered not frequently and will be of short duration, since angular dimensions of discrete sources are very small (only 40 discrete sources of radio-radiations have angular dimensions greater than 20'). However, hit of sun (angular dimensions of which for ground observer are 0.5°) are very undesirable in field of sight of receiving antennas even on short time. If molecular amplifier is set on input of receiver, then it is possible to put it out of commission; therefore it can appear expedient to disconnect receiver from antenna for the time of passage of sun through radiation pattern of antenna array.

In addition to noises of extraterrestrial sources noises can appear in receiving antenna array which are caused by absorption of radio waves in oxygen of air, vapors of water (fog and clouds) and by scattering caused by precipitation. These noises should not be confused with low-frequency (lower than 20-30 MHz) noises induced by static.

Electromagnetic oscillations are absorbed by ionosphere, however, at frequencies higher than 300 MHz, it is possible to disregard this.

Earth emits radio waves caused by thermal motion of charged particles in earth. With this it is necessary to consider when they are perceived by lateral lobe of radiation pattern of ground receiving antenna. During reception of signals by spacecraft, earth noises will already get into basic lobe of antenna radiation pattern of airborne antenna (on earth-space communication circuit).

Totality of these external noises determines so-called equivalent noise temperature T_a, which is connected with power of noise $P_{ша}$ and passband of receiver F by relationship

$$P_{ша} = kT_aF,$$

where k is the Boltzmann constant.

Value T_a strongly depends on section of firmament at which antenna is directed. With increase of frequency, value T_a decreases and attains minimum at frequency of 8-10 GHz. At a frequency of 1000 MHz, noise temperature can be changed from 10^o to 300^o, depending upon characteristic of antenna and conditions of work.

It is possible to decrease external noises. For this it is sufficient to fulfill antenna itself thoroughly and to select correctly frequency and method of transmission of signal.

One of basic limitations in any receiving system is internal noises. Limiting sensitivity of any receiving instrument is limited by level of internal noises. This can be illustrated on example of human sensations. Even for people with very good hearing, level of the weakest sounds which they are able to hear is limited by value noise caused by blood circulating in arteries of head. The weakest light which can be seen by the eye is limited by the presence of dim blinking spots from motion of liquid inside the eyeball. Both the ear and the eye can strengthen extremely weak signals very considerably; however, because of internal noises, we can neither see them nor hear them. Precisely the same phenomenon is observed in radio receivers.

In radio receiver noises appear due to so-called electrical fluctuations in different parts of circuit: resistances, capacitances, inductances, radio tubes. Fluctuations lead to the fact that at ends of resistances and in circuits of receiver as a result of random motion of free electrons, changing voltages continuously appear even when there are no signals on its input. Value of voltage drop is proportional to value of active component of circuit resistance. If value of this resistance does not depend on frequency, then spectrum of fluctuating voltage turns out to be practically uniform up to ultrahigh frequencies. For counting of voltage of noise, only those frequency components of fluctuating voltage which lie within limits of passband of receiver are taken into account.

Disturbing voltages are generated by radio tubes, too. Vacuum tube noises are connected with oscillations of values of anode and grid currents near mean values at constant supply voltages. Basic cause of oscillations of anode and grid currents consists in that emission current does not remain constant due to continuous change of number of electrons flying out of cathode.

Especially harmful are noises appearing on input of radio receiver (in input circuit and first tube). If value of interferences caused by different causes on input of first amplifying stage exceeds force of received signal, then reception will be difficult or in general, impossible, since in further stages of receiver, both signal and noise will be strengthened a huge number of times. Thus, noise limit limiting sensitivity of receiver; in other words, on level of interferences depends how small a signal can be accepted by a radio receiver. As was noted above, for production of television representation of good quality it is desirable that amplitude of voltage of desired signal exceed effective value of noise voltage by not less than several tens of times.

With help of different constructive measures, it is possible to decrease level of interferences caused by external causes. And with noises appearing in transmitting and receiving devices from electrical fluctuations, it is necessary to be reconciled; they are inevitable. It is true that they can be weakened, but it is impossible to remove them completely since we are not able to stop thermal motion of molecules.

Power of noises of radio receiver can also be expressed through equivalent temperature of noises:

$$P_{ш.\,приемн.} = kT_{приемн.}F.$$

For usual vacuum tube receiver, equivalent temperature of noises for a frequency of 200 MHz is 580°K; for a frequency of 1000 MHz, it is equal to 870°K, and for a frequency of 3000 MHz, it already reaches 1160°K.

Summary power of noises caused both by external and by internal sources of noise and recounted to input of receiver is proportional to sum of temperatures of noises of antenna and receiver:

$$P_{ш} = AkF(T_{а} + T_{приемн.}) = AkFT.$$

Now it is easy to determine required power of signal fed to input of radio receiver - its amplifier. For this it is necessary to multiply power of noises by required signal to noise ratio ψ:

$$P_{сигн.} = \psi P_{ш}.$$

For decrease of minimum permissible value of power of received signal, it is necessary to ensure minimum values of temperature of noises of antenna, which, at best, can be one to two orders less than natural noises of usual vacuum tube radio receiver. From this follows that decrease of level of natural noises of amplifier of receiver conceals in itself a large reserve of increase of sensitivity of radio receiver. Such amplifiers, which possess small equivalent temperatures, were created: these are quantum-mechanical and parametric amplifiers.

Equivalent temperature of noises of parametric amplifier is a few times less than temperature of noises of usual amplifier (on electronic or semiconductors devices) and can attain 100°K.

Temperature of noises of quantum-mechanical amplifier is still less; it can be 8°K. From this follows that radio signal amplifiers are now created, internal noises of which are less than noises caused by external sources.

It is necessary to note, however, that if weight of usual amplifier is measured by tens of hundreds of grams, then weight of parametric amplifier is already measured in kg, and highly sensitive quantum-mechanical amplifier weighs more than 100 kg. Thus, ground board radio receivers according to their sensitivity are close to the limit set by external noises, but board receivers should not be bulky and heavy; therefore, their sensitivity is considerably less than ground radio reception systems. Regarding, however, value of signal to noise ratio as ψ, it is determined by form of applied modulation of oscillations of carrier frequency, signals of representation, and assigned speed of transmission of information.

Doppler Effect and Bandwidth

In connection with high speed of spacecraft flight, it is necessary to consider Doppler effect to determine, bandwidth of transmission of receiver. This effect appears on receiving side during travel of radio receiver or transmitter in the form of frequency shift of received electromagnetic oscillations. If receiver and transmitter approach, then every second receiving antenna encounters a greater number of waves than in the absence of travel. This means that frequency of accepted signal increases. If, however, source of oscillations and receiver depart from each other, then number of waves perceived every second by receiver will be less than in the absence of travel. This effect will appear stronger, the higher the speed of relative shift of receiver and transmitter v and the shorter the wavelength of oscillations λ.

Bandwidth of transmission of receiver $F_{Д}$, taking into account Doppler effect, is

$$F_{д}=F+\frac{v}{\lambda}.$$

During very high speeds of flight, ratio v/λ becomes large, which requires considerable expansion of passband and leads to decrease of distance of radiotelevision communication.

The Most Expedient Frequencies for Space Communication

On Fig. 30 was shown spectrum of electromagnetic oscillations. In principle electromagnetic oscillation with any wavelength can be used for transmission of information. However no electromagnetic oscillation is used any longer for radiotelevision space communication. Here there are a number of limitations. The first of them is caused by width of required band of communication channel.

As was already noted, carrier frequency should be a few times larger than maximum frequency of spectrum of transmitted picture signal. Second limitation is put on by dependence of conditions of propagation of radio waves on their frequency. And the third is put on by the dependence of level of space noises on frequency of electromagnetic oscillations utilized for communication.

During organization of space radiotelevision communication, it is necessary to consider influence on passage of electromagnetic waves of, not only surface, atmosphere, and ionosphere of earth, but both properties of interplanetary space and influence of surfaces, atmospheres, and ionospheres of planets close to spacecraft.

Influence of earth's surface, atmosphere, and ionosphere on passage of radio waves has been studied sufficiently well. At a height of the order of 100 km above surface of earth start regions of atmosphere which are strongly ionized by ultraviolet and corpuscular solar and stellar radiation. The state of these layers (their thickness, height above surface, degree of concentrations of charged particles) depends on time of day and year. Influence of these layers on radio communications at different times of the day and year is distinguished accordingly. Depending upon degree of ionization and air density, these regions differently affect passage of radio waves of different frequencies. Separate layers of ionosphere are able to reflect and to absorb radio waves of that or another frequency range. The higher the concentration of electrons in the ionosphere and the greater the wavelength of oscillations utilized for communication, the more difficult it is for them to pierce layer of ionosphere. On Fig. 44 is shown graph of "transparency" of terrestrial atmosphere for electromagnetic oscillations of various wavelengths.

If electromagnetic oscillations with wavelengths over 50 m are sent from earth, then attaining ionosphere, they are reflected from it and return to surface of earth. Subsequent reflection of radio waves from surface of earth causes multiple repetition of this process, as a result of which radio waves can attain point diametrically opposite with respect to transmitting radio station to point of the earth. But namely this property of ionosphere, which allows establishing radio communications between remote points of earth's surface, is the one that hampers radio communications on spacecraft. Forty m radio waves can already pass, not being reflected, beyond the limits of ionosphere, but they are weakened. The nearer the direction of radio beam to vertical, the less the radio waves passing through ionosphere are weakened. Waves shorter than 20 m pass through the atmosphere almost freely. Only meter and still

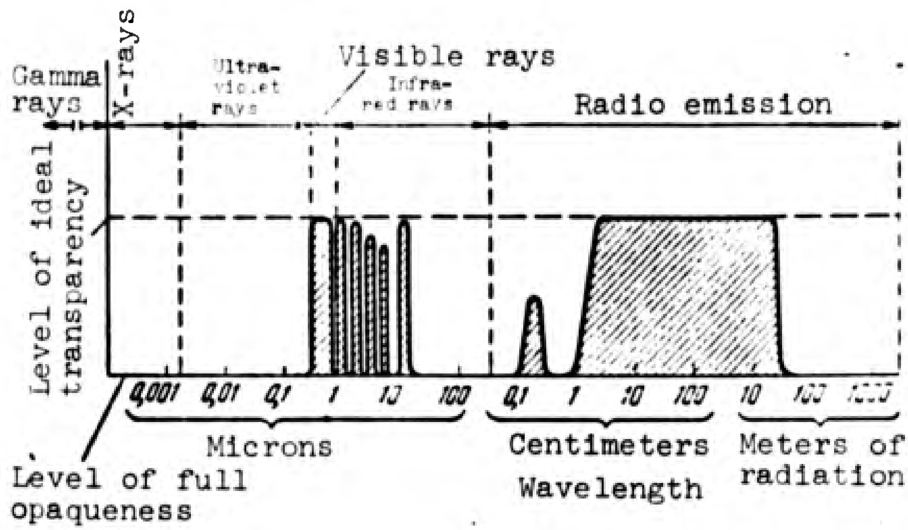


Fig. 44. Graph "of transparency" of terrestrial atmosphere for electromagnetic oscillations of different wavelength.

shorter waves are able during any state of ionosphere and any initial direction of ray to pass through it into interplanetary space or to arrive on earth from extraterrestrial radiators.

In order to decrease dimensions of board antennas, it is desirable to use ultrashort waves for radiotelevision communication. However, too short waves (less than 3 cm long) cannot be used for communication with spacecraft since they are absorbed by lower layers of atmosphere and steam are dispersed by the atmosphere. Radio waves shorter than 2 cm are especially strongly absorbed by steam and dispersed by ionosphere. However, absorption in vapors of water and oxygen of air, which is explained by appearance of resonance phenomena, is unequal within limits of range of millimeter waves. Thus, in range of waves 20-1 mm are two absorption bands of radio waves in vapors with maximum absorption on waves 1.8 and 14 mm. In the same range, oxygen of air has two absorption bands with maxima on waves 2.6 and 5 mm. Since bands of maximum absorption are rather narrow, then in range of millimeter waves wide regions can be separated in which losses due to absorption are small.

In infrared region of optical waves, atmosphere absorbs rays with wavelength over 30,000 Å, and the atmosphere does not pass rays with wavelengths shorter than 2900 Å (ultraviolet region of spectrum). Thus, optical "window" of atmosphere has width of about 27,000 Å. Use of optical waves, as will be shown later, conceals within itself huge prospects for space radiotelevision communication.

During passage of radio waves through ionosphere of earth, plane of polarization of radio waves turns. Accidental change of plane of polarization of radio wave during reception on linearly polarized antenna leads to additional weakening of signal. This effect is stronger the lower the frequency; it must be considered at frequencies lower than 100 MHz.

From the point of view of influence of cosmic noises on communication, optimum frequencies of communication lie in the 1000-10,000 MHz range.

Interplanetary gas, consisting basically of chromosphere and photosphere of sun, and space dust absorb and disperse radio waves. It is considered that these causes produce weakening of power of radio waves 10 times during passage of a distance of 100 million km.

Selection of frequency is also influenced by required power of radiotransmitters, weight and dimensions of nodes of transmitter, antennas, and their bracings. It is known, for example, that efficiency of antenna is proportional to ratio of diameter of antenna to wavelength. Weight of power supplies increases with increase of frequency since efficiency of installation decreases with increase of frequency. At present for frequencies lower than 1000 MHz is obtained efficiency of installation of 50-80%, and for frequencies higher than 1000 MHz, is obtained 10-50%. Regarding, however, radiated power, it is bigger (during use of directional antennas) the higher the frequency of electromagnetic oscillations utilized for communication.

Distance of Communication and Required Power of Signals

All examined parameters determining work of system of space radiotelevision communication are in fully defined dependence with distance of communication and required power of radio transmitter. This interconnection is determined by so-called formula of distance:

$$H = \frac{\lambda}{4\pi} \sqrt{\frac{P_{\text{перед}} G_{\text{перед}} G_{\text{приемн}}}{kTF\psi}} = \frac{\lambda}{0.467 \cdot 10^{-10}} \sqrt{\frac{P_{\text{перед}} G_{\text{перед}} G_{\text{приемн}}}{TF\psi}},$$

where H is distance of communication (in km); $P_{\text{перед}}$ is power of radio transmitter (in W); $G_{\text{приемн}}$ is amplification factor of receiving antenna; $G_{\text{перед}}$ is amplification factor of transmitting antenna; F is passband (in Hz); T is full resultant noise temperature of system (in °K); λ is wavelength (in km); ψ is signal to noise ratio on output of radio receiver.

This formula permits easy determination of parameters of space radiotelevision communication if certain of them are given. Thus, required power of radio transmitter, with remaining parameters given, can be determined from expression

$$P_{\text{перед}} = \frac{16\pi^2 H^2 kTF\psi}{G_{\text{перед}} G_{\text{приемн}} \lambda^2} = \frac{0.218 \cdot 10^{-20} H^2}{G_{\text{перед}} G_{\text{приемн}} \lambda^2}.$$

CHAPTER V

INCREASE OF DISTANCE OF RADIOTELEVISION COMMUNICATION

Increase of radio transmitter power. Increase of power of board sources of electric power. Directed transmission and reception of electromagnetic oscillations. Methods of narrowing frequency band of television signal. Realizable radiotelevision communications. Transmission of television signals on optical waves.

From the distance formula given in Chapter IV, it is clear that to ensure radiotelevision communication on assigned distance it is possible to simplify parameters of one part of radio link at the expense of complicating its other unit. Hence one may see, for example, that distant television communication can be ensured by many methods: at the expense of application of powerful radio transmitters, reduction of frequency band of transmitted signal, increase of sensitivity of radio receiver (decrease of its equivalent noise temperature), application of antennas of directional effect (increasing thereby their amplification factor), application of methods of transmission of television signals which permit lowering required signal to noise ratio.

Increase of Radio Transmitter Power

The most evident method to increase of distance of radiotelevision communication is application of radio transmitter of sufficient power.

In order to achieve maximum simplification of board equipment, one should increase power of ground transmitters to a maximum. But, after all, television representations will be transmitted more frequently, not to space, but from space. Therefore, it is necessary that board radio transmitters be sufficiently powerful. Maximum output power of ground radio transmitters can be brought to tens of millions of watts. Such transmitters are needed only during communications on very great distances — millions of kilometers. On lines of space radio communications of comparatively small extent (several hundreds and thousands of kilometers) not very high powers are required – tens, maximum of hundred thousand W. It is necessary to note that called maximum powers of ground radio transmitters are more difficult to obtain than higher frequency of electromagnetic oscillations.

Power of board transmitters is limited not only by weight and dimensions of the actual radio transmitter; designers must consider the problem of power supply of installation. The fact is that input power can exceed radiated power in several tens and even hundreds of times.

Increase of Power of Board Sources of Electric Power

Already now it is possible to set on spacecraft radio transmitters by power from 100 to 1000 W. Creation of more and more powerful rockets and improvement and creation of new sources of electrical energy permit relying on the fact that powers of radiotransmitters will be considerably increased. Basic difficulty consists in creation of power supplies of electrical energy which could ensure work of high power transmitter during prolonged time. Since efficiency of contemporary generators on electron tubes is on the order of 30%, then a 100 W transmitter will require power supplies of more than 300 W. If transmitters were wholly carried out on semiconductors, then their efficiency would increase to 60%. In equipment of many contemporary spacecraft, large part of electronic equipment is already fulfilled on semiconductor devices; however, powerful output stages of ultra high frequency radio transmitters are still constructed with application of electronic devices (main application was found by traveling-wave tube). Creation of a transmitter of more than 10 W working in range, for example, of decimeter waves completely on semiconductors will apparently, still be impossible within the next few years.

Speaking of power of board power plant, it is necessary to consider that electrical energy is consumed on board spacecraft not only by television camera, amplifiers, system of recording of picture signals, and radio transmitter. Electric power is expended to power scientific instruments and control equipment for different systems of ship, and also in instruction systems of radio communications and in devices of telemetering channels. If ship carries crew on board, then required power of power plant considerably increases.

According to different appraisals of foreign authors, from 100 to 5000 W is required to ensure conditions of normal human vital activity. Required power for different instruments of scientific equipment has following order: magnetometer – 5 W, microphone-micrometeorite counter – 2.4 W, detector of cosmic radiation – 2 W, mass spectrograph – 17 W. Powers necessary for instruments of navigational equipment in guidance systems – of approximately the same order.

What kinds of energy sources are preferrable? The source of energy can be solar, chemical, thermal, or nuclear energy. Sources known at present have the following energy contents per unit of mass of substance (kW-h/kg): nuclear fission of uranium – $2.2 \cdot 10^7$, radioactive isotopes – $4.4 \cdot 10^5$, chemical sources – 2.65, fuel cells -- 1.32, silver-zinc storage batteries – 0.22.

The most widespread converters of chemical energy directly into electrical energy – galvanic batteries – are applied during small periods of exploitation (up to 100 hours). Construction permits using them in heavy conditions (blows, vibration, etc.) and under conditions of outer space. Deficiency of such sources consists in high ratio of weight to reserve of energy. Batteries can work satisfactorily only in a narrow range of temperatures. Periods of safety of batteries are also small, although this deficiency could be excluded, if one were to apply activated batteries or ensure storage of batteries at low temperature.

In board equipment are applied different storage batteries, working jointly with converters of solar energy into electrical energy. In the beginning for this purpose were used mercury galvanic batteries possessing high capacitance at comparatively small weight. However, later they had to be rejected since it turned out that at temperatures lower than +10°C, capacitance of such batteries decreases so much that at -18°C, they, in general, cannot ensure work of equipment.

The best characteristics are possessed by silver-zinc batteries (Fig. 45a), which can be applied as galvanic cells or as storage batteries. However, silver-zinc galvanic cells have to be charged directly before use, but this, naturally, limits region of their application. Hermetic nickel-cadmium batteries with ceramic plates are applied most widely as storage batteries. Silver-cadmium batteries possess high specific capacitance.

As sources of energy of board equipment of spacecraft are long-term fuel batteries carrying out direct conversion of chemical energy into electrical energy. Efficiency of these devices can be measured by value of the order of 60-80%, whereas efficiency of best thermal machines hardly attains 35%. At present in fuel batteries with the highest density of generated energy, pure oxygen and hydrogen is used. Work of such cell is based on an effect, opposite to electrolysis of water. Arrangement of fuel cell is shown on Fig. 45b. Through vessel, filled with electrolyte (for example, solution of caustic potassium), pass electrodes – hollow rods of porous material (for example, graphite). Through internal cavities of electrodes are passed gases under pressure – hydrogen and oxygen. Diffusing through porous surface, they come in contact with electrolyte. On hydrogen electrode as a result of chemical reaction are liberated electrons, which join oxygen electrode on external electric circuit. Ions moving between electrodes lock circuit, where water being generated as a result of chemical reaction departs through hollow electrode together with stream of hydrogen. Specific energy on output of system can attain 35-90 W-h/kg.

The sun is an inexhaustible source of energy. Maximum value of power of solar radiation reaching earth is approximately equal to

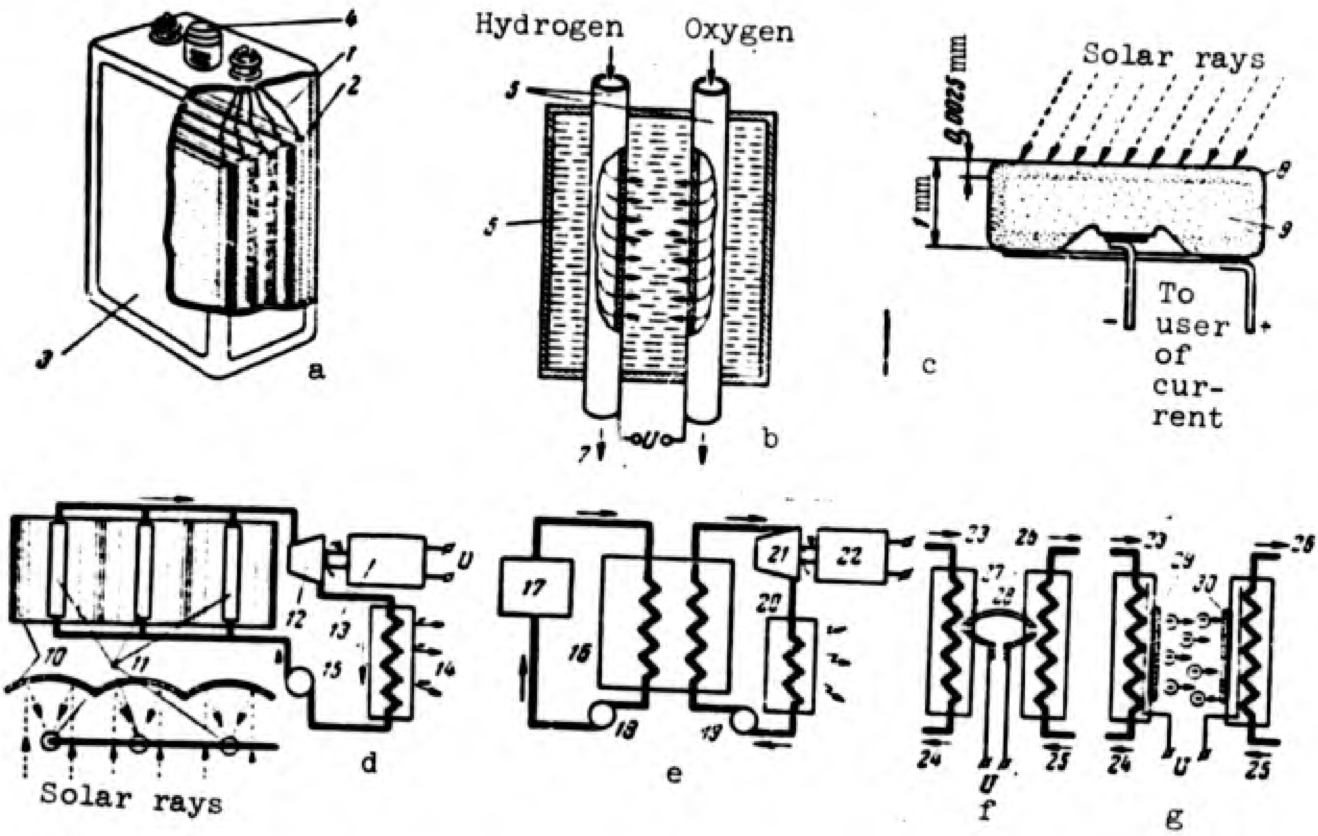


Fig. 45. Board sources of electrical energy of spacecraft. a) arrangement of silver-zinc batter; b) diagram of fuel cell, carrying out direct conversion of chemical energy into electrical energy; c) arrangement of cell of silicon photoelectrical generator; d) diagram of solar turbo-generating plant; e) diagram of nuclear turbo-generating plant; f) diagram of thermoelectric generator; g) diagram of thermionic generator. 1 – negative electrode (oxide of zinc in pack from substance not transmitting metallic particles); 2 – positive electrode (silver plates); 3 – plastic box; 4 – plug (here caustic potassium serve as electrolyte); 5 – porous graphite tubes; 6 – electrolyte; 7 – water in stream of hydrogen; 8 – layer with p-type conductivity; 9 – layer with n-type conductivity; 10 – parabolic mirror; 11 – tube of boiler; 12 – turbine; 13 – generator; 14 – radiator; 15 – pump; 16 – boiler; 17 – reactor; 18 – pump; 19 – pump; 20 – refrigerator; 21 – turbine; 22 – electric generator; 23 – from reactor; 24 – to reactor; 25 – from radiator; 26 – to radiator; 27 – hot joint; 28 – cold joint; 29 – hot cathode; 30 – cold anode.

1000 W/m^2, and beyond the borders of terrestrial atmosphere, this power attains 1400 W/m^2. Use of solar energy for production of electricity on board spacecraft has that huge advantage that it does not require reserves of fuel, – energy is scooped directly from outer space. Therefore solar batteries found very wide application on contemporary spacecraft of different assignment.

In the quality of photoelectrical generators converting energy of solar rays directly into electrical energy are widely applied silicon cells, which are considerably more effective than photoelectrical generators of other types. Theoretical efficiency of silicon solar cells does not exceed 10-20%, and for best samples, up to 14-15% of solar rays getting into photocell will be converted directly into electrical energy. On surface of earth, this gives power of about 100 W/m^2 at specific power of about 89 W/kg.

On Fig. 45b is shown cross section of silicon cell, one of variants of construction. This is a lamina of two layers of silicon with different types of conductivity. Surface layer, containing impurity of trivalent substance, possesses p-type conductivity, but internal layer possesses n-type conductivity. Contact electrodes are deposited on these layers. During hit of sunlight on surface of cell electrical current appears in external circuit. Value of valve emf on terminals of one silicon cell is from hundredth and tenth of volt to 1 V. Connecting a large quantity of such cells, a battery of barrier-layer photocells will be formed with help of which necessary voltages and currents are obtained. For increase of produced voltage, cells should usually be connected in series; in order to increase current, either the illuminated surface of every cell must be increased or a larger number of cells must be connected in parallel. Sections of batteries are disposed on external surface of spacecraft housing or on frames oriented to sun.

For production of electrical energy of sufficient power, it is necessary to use battery of large area, the more so, because incident energy decreases with decrease of angle between direction to sun and plane of panel from 90°. Power of real photoelectrical generators during large heating of panels decreases. During use in about cosmos to these factors is added erosion under influence of micrometeorites and also presence of sections of orbit, when apparatus is in shadow of earth, and deflection of orientation of panels from optimum. Correcting for these factors and considering peculiarity of construction of panels, one may assume that majority of contemporary sources of energy for spacecraft ensures power of 80 W/m^2 at specific power of 4.4 W/kg (this is without orientation of apparatus).

Increase of output power per unit of area of battery can be attained by application of special planes, which concentrate solar energy on irradiated surface. Such surfaces can be concave mirrors and focusing lenses, but simpler devices can also be used — flat reflectors, the more so, because they ensure desirable uniformity of illumination of panel of solar cells. On spacecraft can be used inflatable reflectors or reflectors composed of folded petals of various form and area.

Thermoelectric converters of solar energy into electrical energy have been created and are being used. One such thermoelectric generator is a battery composed of serially connected thermocouples. Such a battery gives electric power when one of its sides is heated by concentrated solar rays and the other side is cooled by water or air.

In other, thermionic, generator, a great number of vacuum diodes is used. With help of system, focusing sunlight, temperature of cathodes is brought to 1170-1420°K. Cathode emits electrons, which head to anode. From anode they return to cathode through external load circuit consisting of consumer of energy. There are already thermionic converters with cesium cathodes, efficiency of which attains 10-15% at operating temperature of 1550°K. Calculations show that a rigid parabolic mirror 2.75 m in diameter can ensure work of thermionic generator with output power on the order of 1 kW.

Energy of solar radiation can also be concentrated with the help of multiunit focusing mirrors. In one of thermoelectric generators, every thermocouple is collected in the form of a modulus with it's own parabolic reflector. All moduli are secured on panel. Every modulus is supplied by a device which accumulated thermal energy in order that there be no interrruptions in supplying board equipment with electric power, when spacecraft passed through shaded zones. One of such power supplies, without accumulating devices, weighs 8 kg. At intensity of solar radiation obtained earth's surface, it ensures creation of electric power of 243 W, or 30.4 W/kg. If spacecraft is constantly oriented to sun and in process of flight does not pass through shaded zones, then specific power can be brought up to 47 W/kg. During passage of apparatus through shadow regions, this value descends to 18 W/kg, since it is necessary to set system of accumulation of energy. As a result weight of storage batteries and radiator on each installation attains 57 kg.

All converters of solar into electrical energy considerably exceed steam-power units; they are simple and have no moving parts.

Thermal energy can also be converted into electrical energy. The source of this thermal energy is either solar energy or chemical or atomic energy. Thermal energy can be converted into electrical energy with the help of dynamic systems (usually turbogenerators and magnetohydrodynamic generators now being developed, based on use of properties of plasma) or static systems using thermoelectric, thermionic and ferroelectric phenomena.

In magnetohydrodynamic generator, electrical current appears at the expense of energy of moving gas plasma heated to high temperature (several thousand degrees), which intersects lines of force of magnetic field. This process is analogous to excitation of emf in conductor moving in magnetic field, but, in this case, role of conductor is fulfilled by ionized gas, but, therefore, there are no moving parts in the generator. Such generator, accordingly, is simpler and more durable than thermal electric power stations, but its efficiency by theoretical calculations attains 40-50%. Till now maximum power of operational generator has not exceeded 12 kW.

Steam-power units have developed which use energy of solar rays (Fig. 45d). In one such installation, calculated efficiency of 15 kW of power is 25%; total weight of device is 370 kg, specific power is 40 W/kg. Working fluid here is rubidium heated to necessary temperature by solar rays focused by mirror.

Thermal nuclear sources of energy are intended to power board equipment of objects in outer space, when solar converters cannot ensure fulfillment of problem on hand. These sources have to ensure obtaining high power during prolonged time during flight of spacecraft, when intensity of flux of radiant energy turns out to be insufficient for normal solar battery operation. In nuclear power supplied an isotope or a nuclear reactor can be used as a powerful source of heat.

More than 800 radioactive isotopes are known; but not all of them are useful for use in space since for this isotopes have to have relatively high specific power and long half-life, ensuring work during prolonged flights; furthermore, isotopes have to be accessible and require minimum shielding from radioactive radiation. The highest specific power of energy release as compared to other isotopes is possessed by polonium-210. However, its rather short half-life limits duration of work of installation by several months.

Plutonium-238 is good fuel for space power engineering. Thanks to long half-life, it can ensure work of power plant during 10 years without decrease of output power. Furthermore, plutonium does not require shielding.

Thermionic converters with atomic reactors can find application on spacecraft. Electronic converter can be placed inside reactor. Surface of every fuel element of reactor will simultaneously serve as surface of thermionic converter emitting electrons, but anode will be cooled by the reactor heat carrier.

Atomic energy can be converted directly into electrical energy in exactly the same way as solar energy.

Energy of radioactive isotopes can be converted by the method of direct of charging, with which electrons, flying away from radioactive isotope at high speed penetrate through insulating space and accumulate on external conducting electrode. The latter obtains negative charge. However, only small currents can be obtained in thus way if it is impossible to use large quantities of radioactive substances.

Another method consists in using contact potential difference between two heterogeneous metallic electrodes. Radioactive radiation ionizes gas contained between these electrodes. Ions and electrons formed to to oppositely charged electrodes united by external circuit. Current is also small for such batteries.

If radioactive source irradiates semiconductor p-n junction, then in junction appear carriers of charges, which are then divided by field of semiconductor junction. However, efficiency of such batteries is still small, and the p-n junction under influence of radioactive radiation is destroyed in time.

Intermediate conversion of energy of radioactive isotopes into light energy with help of photocontact devices and subsequent conversion of light into electrical energy is possible.

Curium-242 has very high power density, but short half-life limits its application by periods up to six months. Of interest is a new isotope of curium (curium-244) with half-life of 20 years and high power density.

In fission reactors the only product which can be used for prolonged work of installations is strontium-90. This isotope with a half-life of 28 years can ensure 10-year, work of power plant without necessity of levelling off power. However, for service of such installation on piloted ship and at launch site will be required corresponding shielding.

Thermoelectric generators with sources of heat in the form of a radioactive isotope at levels of power, ensured by contemporary solar cells with storage batteries, are characterized by the same or even greater value of specific power as solar batteries not supplied by concentrating devices. Application of radio isotopes in thermoelectric generators is expedient at a level of power up to several hundred W. From contemporary thermoelectric converters one should mention ["SNAP-III"] ("СНАП-III") and "SNAP-I," electrical power of which is 5 and 125 W at 2.27 and 79 kg, respectively.

It is possible that for production of high powers under conditions of space flight (and in stationary installations on other planets and satellites), sources of electrical energy with nuclear reactors will be the most useful. Both machine method as well as nonmachine method of converting nuclear reactor heat into electrical energy can be used.

On Fig. 45d, schematic diagram is shown of turbogenerating plant with nuclear reactor, heat-transfer agent and working substance in which is liquid. Heat separated in nuclear reactor is grasped by primary coolant. Liquid heated to high temperature enters heat exchange apparatus – boiler – where it returns its heat to working substance of secondary circuit. After that primary heat-transfer agent by pump of high pressure is again surpassed in reactor. Basic working cycle is carried out in secondary circuit, where working substance (also liquid) is heated at first to boiling point in boiler, but then here is completely evaporated.

Vapor exerts influence on working blade of steam turbine and rotates rotor of ordinary machine electric generator. Exhaust steam from turbine enters refrigerator, where, being condensed, it is again turned into liquid, etc. Only method of yield of heat in surrounding space is radiation. Therefore, refrigerator of space installation serves as heat radiator. An example of such power supplies for space systems is American device "Snap-II," where working substance is mercury. Thermal power of installation is 5000 W, rated electric capacity 3000 W, weight (without protective screens) 340 kg.

Electrical nuclear installations are being developed for spacecraft with output power in 30 and 60 kW; their weight will be equal (without shielding devices) to 675 and 1130 kg, respectively. Creation of nuclear sources of electrical energy with power of from 300 to 10,000 kW is considered possible.

Diagram of thermoelectric generator with nuclear reactor is shown on Fig. 45e. Its operation is based on obtaining thermal emf with the help of thermocouples. The higher the temperature of hot joint of thermocouple, the more improved the thermoelectric generator. These thermocouples have low efficiency – on the order of 2-7% – and in perspective – 15%. First working installation of similar type is Soviet reactor-converter "Romashka."

In "Romashka" heat is obtained at the expense of fission of U^{235} in active zone. Active zone, which is cylindrical, consists of fuel elements in the form of plates of uranium dicarbide and graphite constructions. Uranium is fissioned by fast neutrons. Active zone is surrounded from all sides by beryllium reflector. Returning neutrons to active zone, reflector permits reaching beginning of chain reaction with smaller quantity of uranium. Reactor is controlled with help of four rods located in side reflector. For supporting of power of reactor on assigned level is used automatic regulator – rod of beryllium in shell of heat-resistant steel.

Thermoelectric converter is on external side of reflector. Converter contains thermoelectric cells of silicon-germanium alloy. One side of thermoelements is heated by heat of reactor, the other side is cooled. Appearing current with force 88 A and power 500 W is removed to external circuit.

Best characteristics are given by another nonmachine method energy conversion – thermionic. Principle of work of nuclear power system with such converter is shown on Fig. 45g. Heated to high temperature, cathode radiates electrons, which get on cold anode, thanks to which emf appears. It is considered that an efficiency over 30% can be obtained.

To number of sources mentioned of electrical energy for board installations, it is necessary to add one more – ground. For feed of board equipment can be used electromagnetic oscillations of superhigh frequency, which are transmitted from earth to spacecraft in the form of a focused beam. Energy transfer is also possible from one spacecraft to another, but this is prevented by large weight of antennas and necessity of their exact guidance. For transmission of ultra high frequency energy to spacecraft can be used antennas of different construction – horn antennas – antennas with parabolic mirrors, systems of many flat reflectors and others. Received ultra high frequency oscillations will be converted into direct current by board rectifier.

Well-known successes have been attained in generating of ultra high frequency oscillations of high power, have been created rectifiers of ultra high frequency oscillations and so-called rectenna, or rectifying antenna. It is prepared from a great number of little dipoles, each of which is supplied by it's own diode rectifier. They are connected to busbars of direct current, which are connected among themselves in series-parallel groups.

Antennas of such type could have been prepared of any needed form and dimension in the form of a thin sheet of flexible plastic. Such an antenna could be scanned on spacecraft. Inasmuch as it possesses small directivity, there is no necessity in rigid construction or strict orientation. The fact is very essential that necessity drops subsequently of rectification of high-frequency oscillations.

Figure 46 gives curves which permit comparing value of output power of different sources of energy depending upon period of their service. These tentative data are valid, naturally, only on the nearest years.

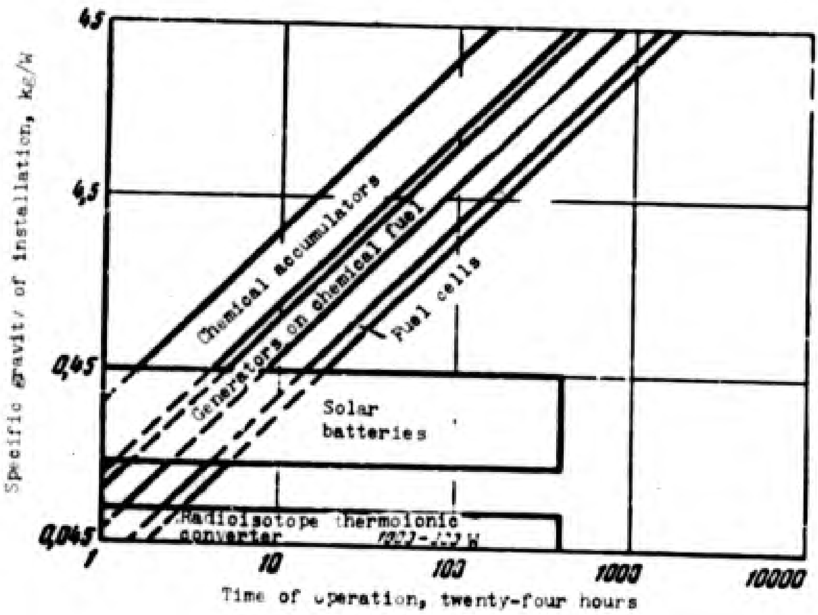


Fig. 46. Comparison weight of power plants.

Directed Transmission and Reception of Electromagnetic Oscillations

It is necessary to use directional antennas to increase of distance of space radiotelevision communication given values of power of radio transmitter and sensitivity of radio receiver. Directional effect is the name of ability of antenna to radiate electromagnetic energy in needed direction (if the discussion concerns transmitting antenna) or to extract energy from field of electromagnetic wave from needed direction (if the discussion concerns receiving antenna). The same antenna can be used both for transmission and for reception. Therefore later to be mentioned parameters of antennas are just for any of their applications.

Quantitative appraisal of directed properties of antenna is produced with help of so-called directivity of antenna. Another important parameter of antenna is its coefficient of maximum amplification, under which understand the number, which indicates how many times high power of energy joins input of receiving device during reception on antenna of given type as compared to power which can be obtained by applying a simple half-wave dipole as receiving antenna. Coefficient of maximum amplification G is equal to product of directivity D and efficiency of antenna η:

$$G = \eta D.$$

The half-wave dipole, the directed properties of which are selected for unit of measurement, constitutes conductor, length of which is equal to half of length of utilized electromagnetic oscillations. This conductor is divided by insulator into two equal parts. To near ends of this antenna are set electromagnetic oscillations (in case of transmission). Perpendicular to the dipole, radiation is maximum, and along axis of dipole, it is equal to zero. Directed properties of half-wave dipole are shown on Fig. 47a of antenna radiation pattern. Segments of straight lines coming out of point O are proportional to intensity of radiation of antenna in a given direction.

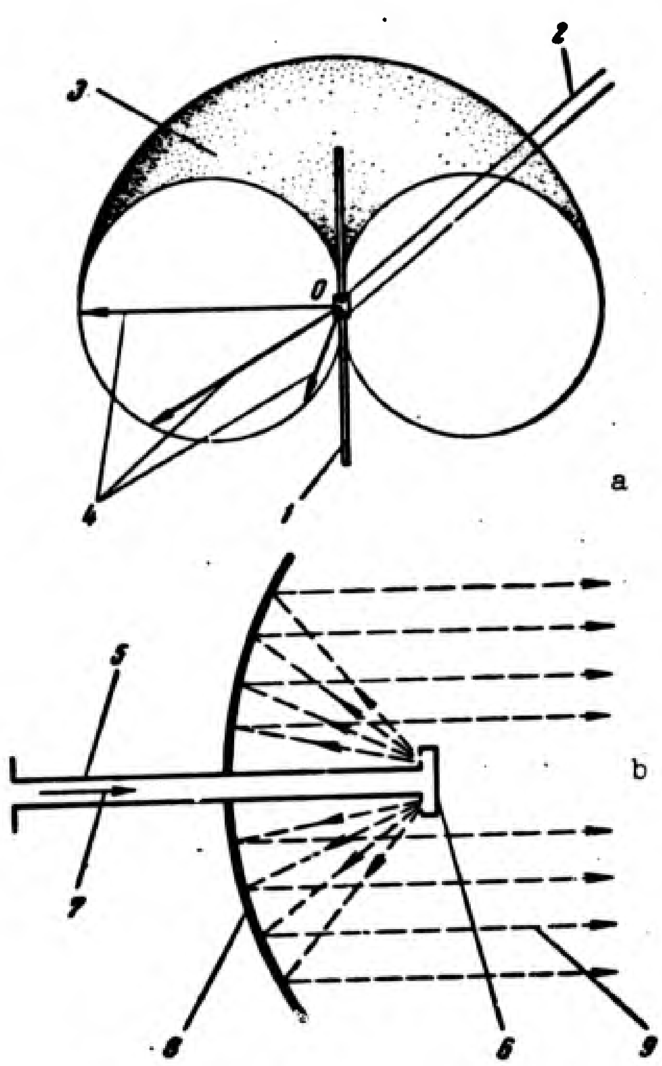


Fig. 47. Antenna radiation pattern of half-wave dipole (a) and parabolic reflector antenna (b). 1 – half-wave dipole; 2 – feeding feeder; 3 – antenna radiation pattern of half-wave dipole; 4 – segments characterizing intensity of radiation in given direction; 5 – wave guide; 6 – camera; 7 – supply of high-frequency electromagnetic energy; 8 – parabolic mirror; 9 – direction of radiation of electromagnetic energy.

Sharper antenna radiation pattern can be obtained during use of not one, but several dipoles. Increasing number of dipoles changing distance between them, placing them in several rows or changing condition of feed of dipoles can produce the most diverse antenna radiation patterns.

One method to increase antenna directivity is to apply reflecting metallic surfaces. In this case diameter of reflector should be considerably greater than wavelength of electromagnetic oscillations. Figure 47b is an antenna of such type. Energy from transmitter is set to antenna inside hollow metallic pipe called wave guide. Wave guide ends in chamber with two holes, through which occurs irradiation of antenna mirror. Form of mirror promotes concentration of radiated energy during reflection in direction of axis of mirror. Directivity of such antennas can be very great (up to 10^5-10^6) at width of ray in fractions of a degree. A general rule here is that the greater the diameter of antenna d, the narrower antenna radiation pattern (narrower ray) θ, the higher the directivity at constant wavelength:

$$\theta \cong 58\frac{\lambda}{d}; \quad D=\frac{4\pi}{\lambda^2}S_{эф},$$

where $S_{эф}$ is effective area of antenna.

The majority of controlled ground large superhigh-frequency antennas belong namely to this type of antenna with parabolic reflecting mirror. An example of such an antenna is the radiotelescope antenna in Jodrell Bank (England). The diameter of its parabolic mirror is 76 m, and the width of its antenna radiation pattern, taken on half-power points, is less than one degree. At present this is one of the greatest contemporary mobile antennas. Parabolic mirror can revolve around horizontal and vertical axes with the help of powerful electric motors. Total weight of radiotelescope is 2 thousand t; weight of foundation is 10 thousand t.

Motionless antennas of radiotelescopes have still greater significances of directivities, since their mirrors possess huge surfaces. Thus, in radiotelescope in Latvia we have being built, paraboloidal antennas will be placed on two cross-like located arms — each 2 km long.

Described antennas should be considered unique constructions. In systems of communication with objects in outer space, mobile parabolic reflectors with diameter of mirror from 18 to 26 m are the most widespread. Construction of these antennas is also a very complicated matter. Form of reflector should be carried out with precision better than 1/16 wavelength of utilized electromagnetic oscillations. From this it follows that as wavelengths decrease, mechanical tolerances decrease. Distance between focus and any point of mirror should also correspond to this allowance.

For large controlled antenna, such high degree of accuracy during manufacture and during exploitation of system is accessible with great labor. Supports of reflector and radiator have to be especially rigid in order to preserve required tolerance for all positions of reflector from vertical location of plane of outlet of antenna to horizontal. Accuracy of mutual location of different cells of antenna array are affected by difference of temperatures of cells illuminated by sunlight and cells in shadow, load in the form of ice and snow, wind, etc. Antenna array is protected from influence of environment by a protective shell of different form.

For antennas now being developed with diameter of mirror of 76-180 m, the problem is being studied of using regulated reflector surfaces. Reflector will consist of several mobile surfaces, transfered by single drive with automatic control, which is corrected by means of optical or radio meterings.

Since in given place of earth's surface, spacecraft can appear in any point of hemisphere, it is necessary to be able to control ray of antenna within limits of the whole hemisphere. Required speed of ray control is determined by maximum angular velocity with which spacecraft shifts relative to ground station. Maximum speed of ray control corresponds to communication with spacecraft in the lowest orbit.

Ray control can be carried out on given values, i.e., by means of information in the form of precomputed coordinates and time, by way of reception of signals from spacecraft or use of both forms of information. Furthermore, manual control of antenna position should also be ensured.

Reflector of large controlled antenna is usually braced on support mechanism with two mutually perpendicular axes of rotation. Rotation of reflector around these axes permits directing ray in assigned direction. These axes can be located at different angles with respect to an axis of rotation of earth.

Instrument locations are frequently organized on level of earth, sometimes inside a construction containing the whole system. Frequently these locations are united antenna and are moved together with antenna. For rotation of reflector in horizontal and vertical planes, separate mechanisms should be provided for every axis. Powers of electric motors necessary for this are great. Thus, for an antenna having a 26 m diameter reflector, a 150 kW engine is required.

Considerable difficulties appear while tracking spacecraft moving with small angular speeds, since great uniformity of reflector motion is required. Since signals taken from spacecraft are extraordinarily small in power, then antennas have to be remote from possible sources of interference. Therefore, desirably to dispose antenna in shallow natural troughs, far from industrial enterprises and from radio transmitters.

If considerable difficulties appear during creation of ground antennas of directional effect then during creation of board antennas with large directivity, these difficulties become much greater. After all it is important not only to create board directional antenna; it is not less important to direct maximum of radiation of board antenna to required point of earth's surface, i.e., to produce orientation of board antenna relative to ground points. Here, namely, because of these difficulties, board antennas of present spacecraft still do not have much directivity.

As was already noted above, increase of directional effect of antenna is attained at the expense of increase of its dimension. However, increase of dimension of antenna leads to increase of dimension and weight of bracings of antenna. According to that, as weight of payload increases, which is put into orbit by rocket carriers weight and dimensions of board antennas will increase, but their weight will not increase very much; it is assumed that an inflatable shell is used. After antenna is filled with gas (in orbit), its shell can become rigid as a result of hardening of resisn (which impregnates material of shell of type of glass cloth) under influence of solar rays, or as a result of evaporation of solvent from varnish-like material. Reflecting surface of such inflatable antenna will be metallized. During use of spaceships operational within limits of solar system, (disk-like) antenna radiation pattern of antenna arrays can be used since planet and other celestial bodies move in orbits lying in one plane.

Directed properties of antenna of defined dimensions and configuration are increased with increase of frequency of electromagnetic oscillations carrying information about transmitted representations. However, with considerable increase of frequency, it is necessary to take into account interference of ionosphere and atmosphere to passage of radio waves to earth's surface. This difficulty can be bypassed by applying intermediate relays, which can be on moon or artificial earth satellites. Such a relay will strengthen oscillations received from remote interplanetary stations and transmit signals to earth already on other frequency, the most acceptable frequency for transmission through the atmosphere.

Methods of Narrowing Frequency Band of Television Signal

Volume of transmitted information. When the problem of transmitting television signals over cosmic distance was examined, it was shown that for assigned highest possible power of radio transmitter of television signals highest sensitivity of radio reception device and assigned parameters of antenna arrays, distance of communication is determined by that frequency band, on transmission of which communication channel is calculated. From this it follows that problem of distance of television communication is intimately connected with problem of effective reduction of frequency band of transmitted signal is spoken about by information theory, which studies general regularities peculiar to both transmitted information itself and its transmission under different conditions, in particular, in the presence of interference. Under information is understood any message, any information obtained as a result of some tests. The idea, "information," is characterized by the fact that the observer does not know the result of transmission beforehand.

It is necessary to have a single measure in order to compare quantities of information of various character. This is made possible by probability theory.

Probability theory studies random events, outcome of which is not known to us beforehand. During transmission of messages selection is always carried out from the number of possible reports. The richer this selection, the more information is contained in a message. The simplest information occurs when selection is possible from only two messages, for example, in tossing a coin. In such a case there are two probabilities: either emblem ("eagle" [head]) or that side on which value of coin is designated, "tail" will lie upwards. Tossing coin once, it is impossible to anticipate on what side it will fall. But let us assume that coin is tossed many times in succession; then it is already possible to anticipate somehow, how many times one or the other side of the coin will come up.

If coin was tossed N times and "eagle" fell n times, then ratio $P_N = \frac{n}{N}$ is called frequency.

With increase of number of experiments N statistical stability occurs due to the fact that deviation of frequency P_N from a certain constant value P becomes less and less probable. When number of experiments becomes very large, value of deviation, of frequency P_N from certain average level P is practically absent, although some insignificant oscillations P_N are still observed. In this case value P_N is called probability of event "fall of eagle."

All possible values of probability can lie within limits from 0 to 1. A probability of 0 is assigned to an impossible event. Thus, zero is equal to the probability the coin will stand on edge after being tossed. An event which will certainly occur has a probability equal to 1. For example, the probability that the sun will rise tomorrow morning is equal to one. In the example examined of the tossed coin, probability of fall of eagle is equal to 0.5.

Measure of information I of a message is considered a definite function of probability of this message

$$I = \log_a \frac{1}{P_N}.$$

A unit of information is the information corresponding to the simplest case of tossing a coin, when P = 0.5. Then from the preceding equation, it follows that 1 $\log_a$ 2, whence a = 2. Such a unit of information is called binary. Selection of binary digit turned out to be very convenient.

If already known information is transmitted, then P_N = 1 and I = 0, i.e., no information proceeds.

Let us assume that a message about results of tossing Q coins at the same time proceeded. Then information will contain Q binary

digits. Number of equally possible messages in this case M = 2Q. Ascribing, for example, the figure 0 to the "eagle" and to the "tail" the figure 1, any examined message can be recorded in the form of a certain sequency of zeroes and units:
1000110110000110100010001101111001111111. . . 001101 M signs in all.

This recording can be examined as a recording of a certain number in binary calculation. For fixation of this information; any code, any signs, any cells able to take defined states can be used. The simplest binary cell can be, for example, a diode having two states: conducts current – does not conduct current. Every such cell is able to record one binary digit of information. Let us say that Q cells are able to store Q binary digits.

Source of message in television is transmitting camera, where message (totality of information about distribution of light and shadow on object and its color) will be converted into electrical signal, which is then transmitted to receiver along the line of communication. Transmission of signal occurs under conditions of inevitable presence of noises. Limiting quantity of information (binary digits) which can be transmitted without error on communication channel with noises is determined by formula

$$I_{макс} = FT \log_2 \left(\frac{P_c + P_ш}{P_ш} \right),$$

where P_c is average power of signal; $P_ш$ is average power of noises; F is passband of communication channel; T is duration of transmission of frame.

If power of signal is considerably greater than power of noises, then required passband of communication channel is determined from expression

$$F = \frac{I_{макс}}{T \log_2 \frac{P_c}{P_ш}}.$$

Hence it is clear that bandwidth of frequencies necessary for transmission of message is perhaps decreased (by way of increase of duration of transmission, increase of dynamic range, i.e., signal-to-noise ratio, or decrease of limiting quantity of information).

It was shown earlier that bandwidth of channel necessary for transmission of video signal depends on number frames, number of lines on frame and number of cells of representation on every line. From this it follows that frequency band can also be reduced at the expense of certain impairment of quality of representation. But as required frequency band is considerably decreased, will quality of transmitted representation be insignificantly worsened? What method of reduction of frequency band is the most profitable? For solution of this problem, it is necessary to quantitatively estimate contents of information in video signal.

For determination of quantity of information, continuously variable television signal represents elements with defined durations and amplitudes. This follows from the fact that for transmission of information of continuously changing signals, there is no necessity to transmit value of signals in all moments of time, but fully sufficient to be limited by transmission of these signals through defined intervals of time, duration of which is determined by frequency band of transmitted signals. These intervals of time $\Delta t = (1/F)$, where F is frequency band (Fig. 48a). Continuous function of message can be restored in point of reception on values

$$q = \frac{T}{\Delta t} = 2FT.$$

During investigations a whole range of possible values of signal split into m equal levels, dimension of interval is taken as

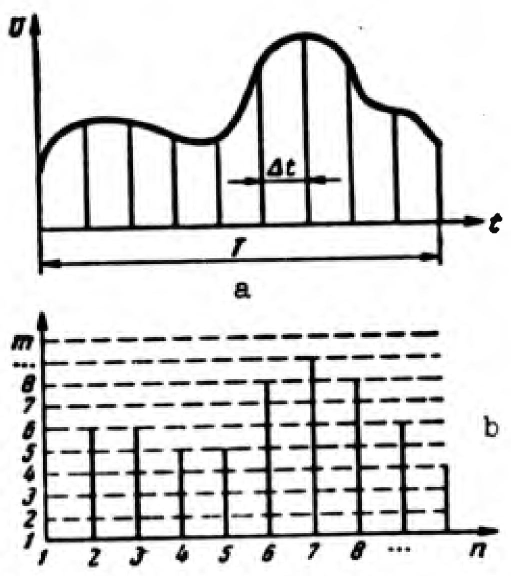


Fig. 48. Replacement of continuous signal by finite number of pulses (a) and quantization of amplitudes of pulses (b).

not less than level of voltage of interference. Each such interval is called a quantum. Replacing continuous signal by sequency of signals and rounding amplitude of every signal to the nearest border of quantum, we obtain a quantized signal consisting of discrete signals with discrete change of amplitudes (Fig. 48b). The basic advantage such conversion of continuous signal of duration T into discrete, quantized signal consists in the fact that this new signal is determined now by finite numbers q and m.

The quantity of information on one cell of representation, with equal probability to taking one of m gradations is defined as $\log_2 m$. As base of system of logarithms is taken 2, i.e., for unit of information, binary digit is accepted. Message, which can have m possible independent levels, has information of the order of $\log_2 m$ binary digits on cell of representation.

Experimentally it is established that at m = 32 pictures of acceptable quality can be obtained, but number of levels m = 64 is considered sufficient for practical purposes. Thus, one cell will contain $\log_2 64 = 6$ binary digits of information.

Maximum quantity of information (binary digits per second), determining all possible different messages on transmission of which communication channel is calculated is determined by expression

$$I_{макс} = \alpha\beta z^2 k \log_2 m.$$

For standard of Soviet television broadcasting, maximum quantity of information is determined by value

$$I_{макс} = 0{,}77 \frac{4}{3} 625^2 \cdot 25 \cdot 6 \approx 60 \text{ million binary units in 1 s.}$$

This result is valid for that case, when all signals are independent and all their amplitudes are equally probable, i.e., this huge value corresponds to representations composed of cells, brightness of which is changed chaotically within limits of discrete values.

Full independence of signal in representation is practically unreal. A large area of real television representations has identical brightness. During repetition of one representation 25 times in 1 s occurs very small change of its contents from one frame to another. Thus, in real representations there take place strong statistical communications between neighboring, for example, or corresponding cells of a series of frames. This interconnection of values is called correlation. From everything that has been said, it follows that quantity of information of real source of television signal I is less than that determined from consideration of quantitative example. Value $\frac{I_{макс} - I}{I_{макс}}$ is called excess. Excess is defined as statistical peculiarities of representations, so also limitations of visual perception. Excess of picture signals permits reducing frequency band or increasing noise immunity or decreasing necessary power of transmitted signals by way of rational coding of signals.

Statistical methods of narrowing spectrum. Statistical methods of narrowing spectrum are based on use of statistical excess of source of television message, i.e., on the fact that frequency band determined from presentation of representation in the form of chess field with number of cells $\alpha\beta z^2$ is oversized, since real representations are never so complicated.

Method of interlaced scanning. During description of principle of work of system of electronic television, a method was examined of formation of a linear line raster, where scanning element moved by lines closely adjoining one another (see Fig. 5). This is the so-called principle of per line scanning. Now in television broadcasting of all countries and in a number of applied television systems, not per line, but interlaced scanning is applied. In this case (Fig. 49), after scanning of first line of transmitted representation, third line is scanned, but second line is omitted. Then fifth and other odd lines are scanned.

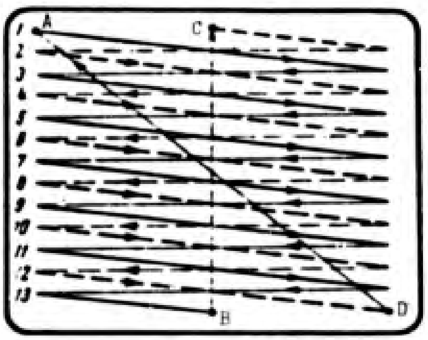


Fig. 49. Interlaced screen. A) beginning of straight movement; B) termination of straight movement in first field; C) beginning of straight movement; D) termination of straight movement in second field; 1, 3, 5 ... — lines drawn by electron beam in odd fields; 2, 4, 6 ... — lines drawn in even fields.

Upon completion of transmission of odd lines, scanning beam returns to extreme left position on second line and, moving by former method, transmits missed even lines of screen. In television braodcasting of USSR, transmission of odd lines is carried out for 1/50 s, transmission of even lines is then produced for the same time, i.e., all contents of frame are transmitted for 1/25 s. Twenty-five odd and twenty-five even fields are transmitted per second.

Fifty big fields appear before observer for 1 s, thanks to which there is no flashing of representation. The eye does not notice appearance of even and odd lines on screen only 25 times per second, since distance between lines is very small.

What gives application of interlaced scanning? During transmission of 50 full frames per second (number of lines 625, form factor of frame 4/3) required frequency band is equal to 12.5 MHz. Interlaced decomposition permitted decreasing required frequency band to 6.25 MHz, i.e., twice.

Transmitted frame can be split into four fields and, producing analogous interlacing of lines of these fields, reduce frequency of frames and frequency spectrum of signal twice more. However, quality of obtained representation turns out to be unsatisfactory from apparent effect of shift of lines on vertical and appearance of interline flickering.

Method of interpoint scanning. During interpoint scanning all odd or even cells of every line are transmitted in series, and missed cells are transmitted in the following field. Here every line is scanned in two receptions. If one were to use interlaced scanning simultaneously, then production of full frame of representation would require four fields (Fig. 50). One would think that gain obtained in frequency band as compared to interlaced scanning is

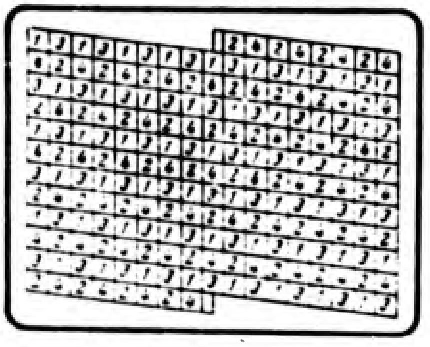


Fig. 50. Filling of point screen during combination of line interlaced and dot interlaced scanning. 1 — cells reproducible in first field; 2 — cells reproduced in second field; 3 — cells of third field; 4 — cells of fourth frame.

equal to two. However, introduced splitting of representation into cells along lines leads to decrease of subjectively perceived exactitude. As a result equivalent gain in frequency band turns out to be less that 1.5.

Scanning with variable speed. It is proposed to narrow frequency band in television at the expense of scanning with variable speed. High-frequency part of spectrum of television signal determines accuracy of transmission of sharp changes of brightness of representation and its small parts. For transmission of big parts and smooth transitions of brightness, it is necessary to transmit low-frequency spectrum of signal. Let us assume that there is carried out such system, in which speed of beams in transmitting and picture tubes is not constant, as usual, and changes depending upon state of television signal. Thus, at the time of sharp change of signal, speed of scanning drops, front of television signal is stretched in time, frequencies, necessary for its transmission descend. On sloping sections speed of scanning is increased; low-frequency components become more high frequency. On the whole the spectrum of television signal narrows.

Transmission of coordinates of new values. For restoration of initial representation on receiving end, it is sufficient to transmit only brightness and coordinates of those points of representation, in which brightness takes values different from preceding. Inasmuch as transitions to new values of brightness are more rare than transitions to preserved values, similar transmission can demand smaller frequency band than direct transmission of initial signal.

There can be transmitted either both coordinates of the new cell or one "small" coordinate, but transition from line to line is carried out with the help of a special signal, which should be transmitted after transmission of last new cell belonging to a given line. Conversion of usual television signal into pulse signal of new values is shown on Fig. 51a, b. Application of such a pulse method of transmission of picture signals permits comparatively simply increasing noise immunity.

Many methods have been proposed to reduce spectrum, which are based on the use of peculiarities of visual perception and psychology.

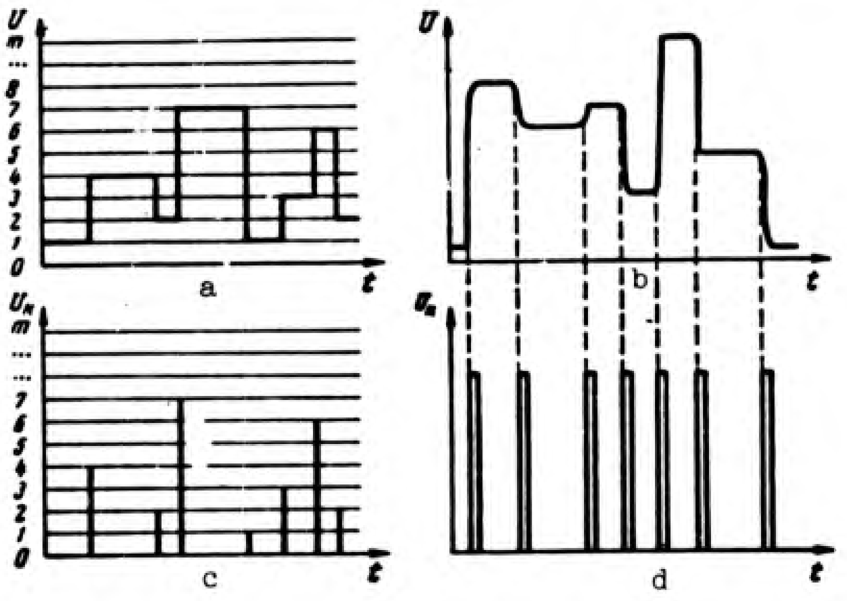


Fig. 51. Usual picture signal. a) usual signal; b) usual signal; c) replacement by signals of new values; d) replacement by signals of circuits.

When special problems are solved, then in one case it is not required to reproduce travel of object, in a second it is not required to reproduce natural colors, in a third case, it is not required to reproduce all distinctive gradations of brightness, small parts, etc. It is possible to waive certain performance figures.

Increase of sharpness of transitions. For improvement of quality of television representation during transmission with reduced frequency band, the method was offered of increase of sharpness of transitions. The basis of this method is the assumption that all smooth changes of brightness in a received television representation appear as a result of insufficient frequency band, and in transmitted representation they are sharper. For increase of sharpness of transitions, to accepted signal there are added correcting pulses obtained by special conversion (differentiation) of the same signal. Appearing increase of steepness of transitions is equivalent to expansion in receiver of frequency band of accepted signal.

Successive transmission of high-frequency components of spectrum of signal. For successive exception of one of two high-frequency components of spectrum of signal, initial spectrum of television signal is split into two parts. The lowest frequency is transmitted as usual, and average and high frequency successively through one field of representation. High-frequency part of spectrum is transferred in its central part, as a result of which, completely converted spectrum is only 2/3 of initial spectrum.

Transmission of small number of gradations. It is known that with the help of three paints — black, white and gray — an artist can depict almost any black and white object. Analogously, in television it is possible to transmit representation, quantizing signal on 6-8 levels. A representation is obtained which differs little from original with a large number of gradations. If one goes from transmission of m gradations to $m_1 < m$, gradations then information capacitance decreases

$$\frac{\log_2 m}{\log_2 m_1} \text{ times.}$$

This decrease of information permits narrowing frequency band of communication channel and increasing noise immunity of system.

Transmission of circuits. It is most important to be able to transmit sharp transitions corresponding to borders between representations of objects of different brightness. Namely they give very full presentation about object. After all an experienced artist is able to depict a person with several strokes who can be recognized by traits characteristic for him.

Principle of replacement of usual picture signal by signals of circuits is shown on Fig. 51. On Fig. 51b shows usual signal of representation. In moments of time corresponding to sharp changes of value of picture signal, with the help of a special device there are formed voltage pulses identical in duration and value (Fig. 51g). If duration of pulses is selected equal to duration of transmission of one cell of representation, then resolving power and frequency band of system remain without change.

Voltage pulses carrying information about temporary situation of borders are fed to radio transmitter. In receiver under influence of pulses there is reproduced representation of circuits of representation on control electrode of electron-beam tube. For best reproduction of borders in this case, it is desirable to apply alternated vertical and horizontal scanning.

This method of transmission has a number of merits: noise immunity and gain in power, especially considerable during transmission of representations, large part of surface of which has uniform background.

Increase of duration of transmission. Bandwidth of frequencies necessary for transmission of a message can be changed at the expense of increase of duration of transmission. For this it is necessary to accumulate initial signal, after which to transmit with delayed speed. Frequency band is reduced as many times as speed of readout less speed of recording. Intermediate recording of representation can be produced, for example, on target of transmitting tube with memory, on magnetic or thermoplastic tape, and other information carriers. During reception of such signal, it is also necessary to use accumulation; accelerated reproduction of recorded signal will lead to restoration of initial signal.

Many other methods have been proposed of reducing spectrum of frequencies of television signal, which along with those mentioned either are in the stage of theoretical and experimental investigation or find application in operational television systems of different assignment.

Realizable Radiotelevision Communications

On what distances is it possible to transmit picture signals? What powers of board radio transmitters are required for radiotelevision reportage from the moon and planets of the solar system?

For answer to these questions, it is sufficient to use formula of distance shown in p. 129 and to place in it quantitative data of this chapter on contemporary board and ground transmitters, receivers, antennas, sources of energy and methods of transmission of television signals. Let us consider several characteristic examples.

1. Let us assume that from aboard spacecraft revolving around earth at a distance of 500 km, television signals are transmitted in the 5 MHz frequency band. To board antenna of nondirectional action with amplification factor $G_{перед} = 1$, electromagnetic oscillations are fed with wavelength $\lambda = 10$ cm $= 10^{-4}$ km. What is required power of board radio transmitter, if amplification factor of receiving antenna on earth $G_{приемн} = 10{,}000$, equivalent noise temperature of ground receiver $T = 500°K$, and signal to noise ratio on output of radio receiver $\psi = 25$?

Putting shown values into formula of distance and preliminarily solving equation with respect to power of transmitter $P_{перед}$, we will obtain:

$$P_{перед} = \frac{0{,}219 \cdot 10^{-20} \cdot 500^2 \cdot 500 \cdot 5 \cdot 10^6 \cdot 25}{10000 \cdot 1 \cdot 10^{-8}} = 0{,}34 \text{ W}.$$

As we see, obtained value of power of board radio transmitter is small. Board transmitters on first earth staellites already had such power.

2. Let us present to ourselves that parameters of signal and ground devices remained the same, and on board a nondirectional antenna is also used. What is required power of radiotelevision transmitter leading transmission of picture signals from surface of moon?

For solution of this problem into formula for power of transmitter we will place a distance of $400 \cdot 10^3$ km instead of a distance of 500 km.

$$P_{перед} = \frac{0{,}218 \cdot 10^{-20} (400 \cdot 10^3)^2 \cdot 500 \cdot 5 \cdot 10^6 \cdot 25}{10000 \cdot 1 \cdot 10^{-8}} = 136\,000 \text{ W}.$$

So that radio transmitter will create oscillations of such power, it is necessary to have board power supply with power of the order of 500 kW. But we have still not learned to make very powerful board sources of electrical energy, and it will not be very simple to deliver a powerful power supply to the moon. Thus, does this mean that transmission of television signal today from moon is unrealizable? No, this is not so. We already talked about the fact that there are a number of methods to decrease frequency band of television signal. During transmission, methods of modulation are possible which permit decreasing required signal to noise ratio. It is possible to apply directional antenna on spacecraft, for example, $G_{перед} = 10$.

Let us assume that, some one or totality of methods of reduction of frequency band, it was possible to obtain not 5 MHz, but 50 kHz, i.e., one hundred times less. Let us further assume that it was possible to lower five times, i.e., $\psi = 5$. Then

$$P_{перед} = \frac{0,218 \cdot 10^{-20} (400 \cdot 10^3)^2\, 500 \cdot 50 \cdot 10^3 \cdot 5}{1000 \cdot 10 \cdot 10^{-8}} = 43,7 \text{ W}.$$

For such transmitter, a 150-200 W board source of electrical energy is necessary. And there are such sources.

3. Let us now pursue limiting power of transmitter $P_{перед} = 20$ kW and define that maximum distance on which it is possible to transmit by a 5 MHz band television signal on a carrier frequency corresponding to a wavelength also of 10 cm. It would be possible to create a transmitter of such power if one were to use, for example, a 60 kW board nuclear source of electrical energy. Let us assume that parameters of ground antenna and receiver are the same, as in the preceding examples. Then maximum range of radiotelevision communication will be equal to

$$H = \sqrt{\frac{20 \cdot 10^3 \cdot 10000 \cdot 10}{5 \cdot 10^6 \cdot 500 \cdot 25} \frac{10^{-4}}{0,467 \cdot 10^{-10}}} = 384 \cdot 10^3 \text{ km}.$$

In this example the signal to noise ratio was accepted as equal to 25.

Limiting distance of possible radiotelevision communication was obtained equal to minimum distance from earth to moon. As we see, application of a high power board transmitter and a board antenna with small amplification factor (and small directivity of action respectively) does not permit increasing distance of radiotelevision communication significantly.

It is permissible now that frequency band of transmitted television signal is reduced 1000 times, i.e., is equal to 5 kHz. Amplification factor of ground antenna $G_{приемн} = 10{,}000$, amplification factor of board antenna $G_{перед} = 1000$, signal to noise ratio $\psi = 5$, total equivalent noise temperature $T = 500^\circ$K. Then limiting distance of radiotelevision communication will be

$$H = \sqrt{\frac{20 \cdot 10^3 \cdot 10000 \cdot 1000}{500 \cdot 5 \cdot 10^3 \cdot 5} \frac{10^{-4}}{0,467 \cdot 10^{-10}}} = 281,5 \text{ million km}.$$

From this example it follows that during assigned parameters of board transmitting and ground receiving equipment, radiotelevision communication is possible on distances exceeding disatnce to Mars in periods of its opposition (these distances are equal to 101-55 million km), to Venus both at minimum distance of it from earth (39 million km, lower connection), and at maximum distance (258 million km, upper connection), to Mercury both at minimum distance (92 million km), and at maximum distance (207 million km).

Television transmissions from regions of planets more remote from earth are possible either at other parameters of communication equipment or at the expense of transmission of recorded information to earth during travel of spacecraft from surveyed planet to earth.

Transmission of Television Signals on Optical Waves

Possibility of use for communication of the highest frequency electromagnetic oscillations, up to light and gamma radiation, opens great prospects. Why is the attention of scientists attracted by electromagnetic oscillations of infrared, optical, ultraviolet ranges of waves, and also by the range of X-ray and gamma radiation?

Optical systems of communication, as compared to usual systems working in radio frequency range, will possess the following advantages: their weight and power drain will be less, and reliability due to absence of electronic devices of high power, range and signal to noise ratio will be greater. These systems will ensure secrecy of communication (thanks to very small width of ray), will be noise-immune and cost of their manufacture and exploitation will be small, which is also very significant. Large hopes are placed on optical systems of communication designed for use during space flights.

Generators and amplifiers of electromagnetic oscillations of optical range. For creation of optical systems of communication, such instruments are necessary, which permit to be generated electromagnetic oscillations of shown sections of spectrum of the same intensity and the same spectral cleanness as are accessible during generation of radio waves. Radio waves radiated by generator are limited by frequency of very narrow region of electromagnetic spectrum and are so free from noises that they can be used to use as carriers for transmission of information. Usual sources of light are essentially generators of noise, useful only for the most primitive signalling.

All usual sources of light (tube with incandescent filament, electrical arcs, etc.) constitute heated bodies. It is true that in usual neon tube, walls remain cold, but electrons and ions of gas inside it are accelerated to high speeds, which corresponds to increase of temperature. Atoms or molecule continuously pass into an excited state, and then, emitting energy in the form of light, return to their initial ground state. Where they return to their initial state independently from each other in various moments of time and thus radiate energy also independently. Therefore, radiation created by them on the whole constitutes totality of electromagnetic waves possessing arbitrary phases and differing from each other in frequency. Furthermore, this radiation is nonpolarized. Excited electrons leaving the heated tungsten filament of the illuminating tube also radiate by accidental form and independently of one from another. In other words, light waves emitted by some usual source of light are spatially incoherent. This means that light is emitted in the form of wave packages following one after another in a disorderly manner, which reinforce or cancel one another in an absolutely random manner. This wave front is changed from point to point and is inconstant in time. Thus, a wave would spread on a calm surface of water if one were to throw handful of stones there.

In this respect, light waves of usual sources essentially differ from radio waves radiated by an antenna. If sinusoidal current of defined frequency flows on wire of antenna, then in surrounding space there appear radio waves of the same frequency, polarization of which is determined by orientation of wire. Such oscillations are called coherent (being in interconnection) since these waves have defined phase and frequency of oscillations.

If one stone is thrown in water, there will appear coherent waves spreading on surface of water in the form of concentric circles. If point source of light radiates coherent waves, there front forms a spherical surface. A source of waves can be made with flat front, where electric field strength in all points of wave front will be identical. In any of these cases, during passage of wave fronts through a certain point of space, field strength will smoothly and synchronously rise and fall, being changed from positive to negative value.

If usual generator of radio waves is connected with small dipole, the latter will send spheric coherent waves into space. It is possible to join generator to several transmitting antennas, which will begin to radiate directed wave similar to plane wave.

One of basic deficiencies of usual sources of light is their small brightness, which is explained by small radiation density. Total power of solar radiation, for example, on all wavelengths is 7 kW from every square centimeter of surface. At first glance this is of very great value, however, in fact it is not so big if one were to consider width of solar spectrum. Thus, in order to obtain 1 W of energy in green part of spectrum 1 MHz wide, it would be necessary to collect and filter radiation from 8.4 m^2 of the sun's surface. And radio transmitters can generate 1000 W in a band less than 1 MHz wide.

Usual sources of light similar to sun are broad-band generators of noise, dispersing power in a wide frequency range. As single frequency sources of powerful radiation, not even gas discharge tubes radiating light only in the form of several narrow lines of spectrum can be compared with electronic generators. Therefore, attempts were undertaken to spread possibility of electronic generators to range of shorter waves. However, the shortest waves of oscillations generated by electronic devices have length near 1 mm, or 10 million Å. Obtaining of oscillations of more correct wavelengths with the help of usual electronic circuits is conjugate with huge difficulties. Especially complicated to prepare are resonator devices, which have to be commensurable with wavelength of radiated oscillations. Generator of millimeter range is difficult to create. Problem of generation of light waves which were three orders shorter had to be solved some other way. For this purpose atomic and molecular resonators are used.

There are a great number of different natural resonators which can be used in the whole range from infrared to ultraviolet regions of the spectrum. However, one separately taken atom radiates very small power, and even that in discrete portions. Consequently, it is necessary somehow to synchronize radiation of a large number of atoms in such a manner that together they can create powerful coherent wave. First molecular generator in radio-frequency band was created by Soviet scientists, N. G. Vasov and A. M. Prokhorov, in 1954. For works in the quantum electronics field, they were awarded the Lenin prize in 1959, and they were awarded the Nobel prize jointly with American scientist Townsum in 1964. In 1957-1958 quantum amplifiers were created in the radio-frequency band, using the same principle. These amplifiers, possessing low level of natural noises, sharply increased sensitivity of radio receivers of centimeter and decimeter ranges. In those same years the first ideas appeared about using methods of quantum electronics for creation and amplification of shorter waves up to optical waves.

At present there have already been created many variants of quantum-mechanical generators and amplifiers of optical range: with gaseous, liquid and solids, with different methods of energy supply (pumping) and different constructions of waveguide-resonator system. Thereby in optical range there appeared sources giving monochromatic radiation of light with high spectral density of energy.

In quantum-mechanical devices, electromagnetic radiations are used of molecules, atoms or ions of substance and their components of particles, called quantum-mechanical systems. In these devices during transition of quantum systems from one energy level to another, there occurs absorption or radiation of defined portions of energies — quanta. A quantum system, for example an atom, can absorb (or radiate) only the portion of energy, which is equal to difference of possible states of its energy. In quantum systems, particles are artificially (at the expense of energy of auxiliary generator) are shifted to a higher energy level (are excited). Under influence of external field, particle can radiate portion of energy and to to a lower energy level with energy which is smaller with respect to initial state. Such radiation of excited microsystems (called induced) is used in quantum generators and amplifiers.

Figure 52 schematically shows component parts of quantum generator of light. Resonator here will be formed by two exactly oriented mirrors. One of them is absolutely opaque, and the other passes a small part (0.5-8%) of the light falling on it. Among these mirrors oscillations are excited for which distance between mirrors is an

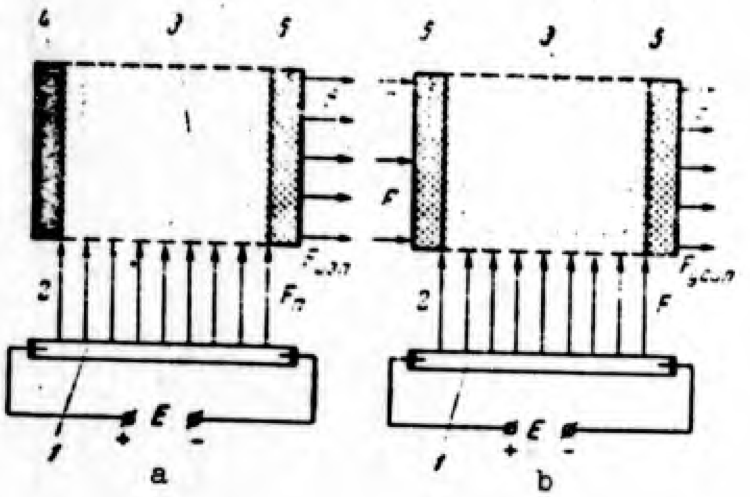


Fig. 52. Schematic representation of arrangement of quantum-mechanical instruments. a) working in conditions of generating of optical oscillations; b) working in conditions of amplifications of optical oscillations. 1 — source of light signal of pumping; 2 — light signal of pumping; 3 — active substance; 4 — mirror, completely reflecting light; 5 — partially transparent mirror; 6 — light signal on output of instrument; 7 — weak input optical signal; 8 — intensive signal.

integral number of half-waves. In interval between mirrors active substance is placed, which can be gas, liquid or crystal with impurities of atoms of certain defined element. Atoms of active substance have to possess two energy states, difference between which corresponds to radiation on desirable frequency. Surplus of atoms in excited state is necessary so that induced radiation predominates over absorption. Atoms are shifted to excited state by way "of injection" into system of electromagnetic energy on wavelength different from wavelength of induced radiation. This process is called pumping (pumping, illumination, auxiliary radiation).

Diagram of process occurring in quantum generator is shown on Fig. 53. In the absence of pumping, atoms of substance are in unexcited state (Fig. 53a). Under influence of auxiliary radiation, part of atoms of active medium is translated to excited state (white circles on Fig. 53b). Electromagnetic oscillations created as a result of transition of atoms into unexcited state spread along axis of system (Fig. 53c). Attaining one mirror, wave will be reflected (Fig. 53d), and moving to second mirror, will grow under influence of induced radiation (Fig. 53d and e). If as a result of multiple reflections, amplification becomes sufficient and loss on surface of mirror is compensated, set wave of oscillations will appear; part of oscillations emerges outside through semitransparent mirror (Fig. 53f), representing output beam of light of quantum generator. Output beam in high degree is monochromatic since induced radiation is resonance process. Output beam will be powerful and narrow-directed, since only electromagnetic osicllations which are thousandfold reflected and not experiencing any essential deflection from axis of instrument are emitted. Finally, if output signal of optical quantum generator is close in form to plane wave spreading in one direction, then it should be coherent in time. This means that phase conformity is strict between oscillations radiated on one moment of time and between oscillations radiated in a certain defined interval of time.

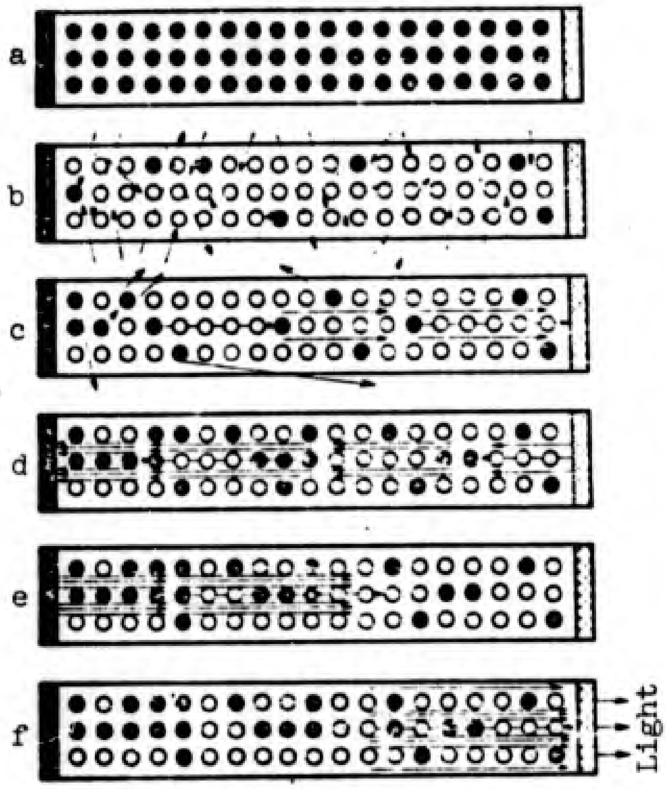


Fig. 53. Principle of action of optical quantum generator on hard working substance.

An example of a quantum optical generator is an instrument (Fig. 54a), in which source of light rays is crystal of artificial ruby (oxide of aluminum with impurity of atoms of chromium) in form

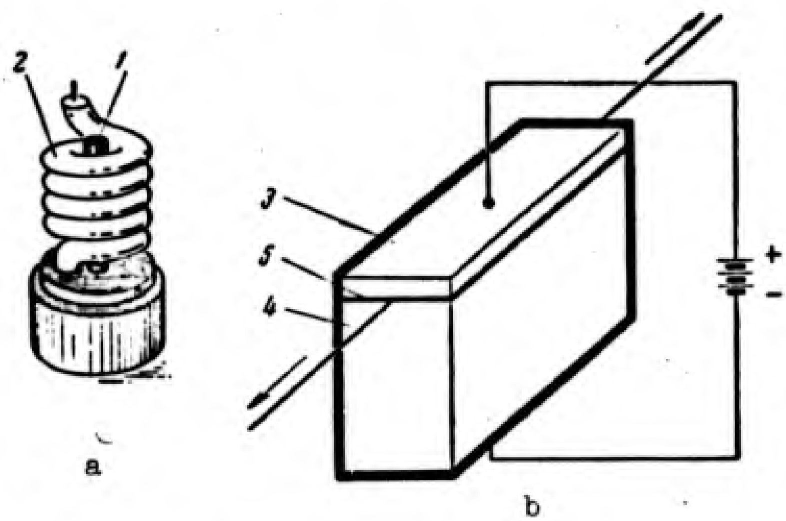


Fig. 54. Arrangement of quantum generator of light on crystal of ruby (a) and semiconductor diode quantum generator of light (b). 1 – ruby rod; 2 – gas discharge tube of illumination; 3 – arsenide-phosphide of gallium with p-type conductivity; 4 – arsenide-phosphide of gallium with n-type conductivity; 5 – radiating light transition.

of rod with strictly parallel, well buffed ends. One end is covered by silver, but second end is covered by semitransparent film. Source of induced radiation here are ions of chromium excited by powerful burst of gas-discharge pulse tube. Since emitted radiation is determined by characteristic resonance of concrete substance utilized in quantum generator, then only radiation of a limited number of waves can be generated in a given material. For example, pink ruby radiates electromagnetic oscillations with wavelength 6943 Å, dark red ruby (with smaller number of impurity atoms of chromium) – with wavelength 7009 and 7041 Å. During use of crystals of calcium fluoride with ions of samarium and uranium, oscillations are obtained with wavelengths 7080 and 25,000 Å.

Now as active medium different glasses, plastic materials, liquid, gases and even plasma are used. Optical quantum generators of different types permit obtaining oscillation with wavelength from 5900 Å, i.e., 0.59 μm, in yellow section of spectrum to 35 μm in middle of infrared region of spectrum. Induced radiation was observed even on waves as short as 0.31 μm in ultraviolet region of spectrum.

Quantum generators with gas active medium possess a number of positive properties. With their help can be obtained radiation in wide range of wavelengths, where, as a rule, they work in continuous, and not in pulse conditions and require not optical, but electrical pumping (by way of electric dishcarge in gas).

Both gas-discharge optical quantum generator and generator on solid have low efficiency. Their output energy usually does not exceed 1% from consumed. Quite recently, when a new class of quantum optical generators on semiconductors was opened, it was possible to remove this deficiency. After fundamental investigations leading to creation of such generators, in 1964 Soviet scientists B. M. Vul, O. N. Krokhin, Yu. M. Popov and A. P. Shotov were honored with the Lenin prize.

If dimensions of generators on crystal of ruby are measured in tens of centimeters, but gas generators in meters, then dimensions of semiconductor quantum generators are tenths of a millimeter. Power radiated by them counting on identical volume, is hundreds of thousands of times greater than for the best ruby generators. Such generators can work in pulse and continuous conditions and modulate their radiation very easily – for this it is necessary only to change the current feeding them. Probably, the most remarkable property of semiconductor quantum generators consists in that with their help it is possible to convert energy of electrical current directly into energy of light waves. They permit reaching conversion of energy with efficiency considerably exceeding 10%, and possibly even close to 100%.

Diagram of arrangement of semiconductor optical quantum generator is shown in Fig. 54b. Until now only miniature constructions of such generators have been built, and their output power does not exceed 1 W, however, apparently, creation of considerably more powerful devices is completely possible.

Maximum power of impulse of light of optical quantum generator, about which till now has been reported in literature, is approximately 500 MW.

During use of quantum instruments as amplifiers (see Fig. 52b) both mirrors are partially covered by a layer of silver, but source strength of pumping signal can be considerably less than in quantum generators. For amplification of light signal, distance between mirrors should allow obtaining resonance on frequency of strengthened optical signal. So that amplification factor of instrument will be high, entrance optical signal should be directed as far as possible strictly along the axis of instrument, perpendicular to surface of mirrors. On output of quantum optical amplifier there is placed some light sensing device: photographic film, photocell, or photomultiplier.

Application of oscillations of optical range of targets of communication. In order to estimate perspectivity for communication of use of optical rays, compare bandwidth of frequencies occupied by visible spectrum with passband of standard television channel F, equal to 6·MHz. Using well-known relationship between frequency of electromagnetic oscillations f and length of their wave λ

$$f=\frac{C}{\lambda}=\frac{3\cdot 10^{10}}{\lambda},$$

for boundary wavelengths of visible spectrum, we will obtain following value of frequency:

$$f_{\lambda=3000\,\text{Å}}=\frac{3\cdot 10^{10}}{3\cdot 10^{3}\cdot 10^{-8}}=1000\cdot 10^{12}\ \text{Hz};$$

$$f_{\lambda=8000\,\text{Å}}=\frac{3\cdot 10^{10}}{8\cdot 10^{3}\cdot 10^{-8}}=375\cdot 10^{12}\ \text{Hz}.$$

Thus, frequency range occupied by visible spectrum is

$$\Delta F=f_{\lambda=3000\,\text{Å}}-f_{\lambda=8000\,\text{Å}}=625\cdot 10^{12}\ \text{Hz}.$$

Ratio of this band to passband of broadcasting television channel is equal to

$$m=\frac{\Delta F}{F}=104\cdot 10^{6}.$$

From this it follows that visible region of spectrum within limits of wavelengths 3000-8000 Å accomodates more than 100 millions of television channels. Difference between lengths of optical waves in 1 Å corresponds to bandwidth near 125,000 MHz.

Radiation of quantum optical generator can be formed into very narrow, "needle-shaped," bundle with help of well-known optical systems.

Focusing radiation created by usual sources of incoherent light, it is impossible to obtain flux density of energy exceeding flux density at the surface of radiating body. Thus, at the surface of sun, radiation flux is $63 \cdot 10^6$ W/m^2. No optical focusing attachments can create radiation with large flux density of energy. And coherent monochromatic radiation of quantum optical generators can be focused within limits of area, dimensions of which are commensurable with wavelength. It is considered that value of corresponding site is $4\lambda^2$. Degree of obtainable concentration of energy can be judged from the following example. If radiated power on wavelength of 0.5 µm is 15 W, then during focusing of this power on area $4\lambda^2 = 4 \cdot 0.25$ $\mu m^2 = 10^{-12}$ m^2, flux density will be $(15/10^{-12}) = 15 \cdot 10^{12}$ W/m^2, which is 250,000 times more than density of radiation directly at the surface of sun.

From these examples it can be concluded how important optical range of waves is for radiotelevision communication. However, what are the conditions of propagation of these waves? Is it possible to produce modulation of optical waves utilized as carrying oscillations, as signals of representation? Is it possible to detect modulated optical oscillations, therby separating transmitted picture signal in point of reception?

Absorption of optical waves in lower layers of terrestrial atmosphere excludes use of waves of optical range for transmission of information under conditions of bad weather (rain, fog, snow, hail, etc.). Propagation of optical oscillations is hindered by resonance phenomena in atoms and molecules of gases forming atmosphere. However, in contrast to absorption in drop formations which made inaccessible for communication whole range of waves shorter than 2 cm; in regions of resonance absorption there remain regions of lowered absorption, where transmission of information is possible. The biggest transparency has section of range from 0.75 to 0.33 µm.

Consequently, electromagnetic oscillations of optical range can be used for transmission of information under conditions of clear weather in the absence of any kind of precipitation and smoke puffs. Connection with objects in outer space can be carried out with help of stations of optical range placed on aircraft or artificial earth satellites, flying at high altitude above layer of overcast of terrestrial atmosphere. It is possible to dispose such stations on high mountains or in regions characterized by a small quantity of precipitation and chiefly clear, cloudless weather. Ground communication is possible with the help of light conductors. For communication on optical waves between spacecraft there are practically no limitations.

A system of communication using quantum instruments would consume considerably smaller power as compared to microwave or incoherent light (or incoherent infrared) systems. By one appraisal, optical system of communication on quantum instruments requires only 10^{-16} W on binary digit per second, whereas a corresponding microwave or incoherent light system usually requires 10^{-7} or 10^{-10} W on binary digit per second, respectively.

Communication between different parts of space station can appear one more region of application of optical waves, especially in those cases, when station consists of several parts nonrigidly connected among themselves. Such a communication system will have small dimensions and consume a little energy; furthermore, it will not create interferences to systems of radio communications of space station.

Frequency of oscillations created by optical quantum generator can be changed by many methods. Thus, frequency of oscillations created by ruby generator depends on temperature of crystal. Frequency of quantum generators can be changed by external electrical or magnetic field, or changing level of pumping signal. In gas quantum generators, frequency can be regulated by change of density of composition of gas.

Methods are distinguished of external and internal modulation of optical quantum generators. Internal modulation renders action on carrier frequency in the optical generator itself, but external modulation renders action on light signal already outside the actual quantum generator. One of the methods of internal modulation of carrier frequency is based on change of pumping power. Ultrasonic oscillations, electrical fields, and magnetic fields can be used for this. External modulation is produced with the help of modulation substances which are placed on the path of ray coming out of generator. Acoustic, magnetic, and electrical effects in different materials are used.

Figure 55 shows variant of communication system, in which transmitter is optical quantum generator, and receiver is optical quantum amplifier. Television signals from transmitting camera are fed to modulator after corresponding amplification. Modulated light bundle with help of optical system of transmitter goes to optical system of receiver. Here light bundle is strengthened by optical quantum amplifier, after which it goes to light sensitive detector and demodulator, which restores useful television signal. Receiver with optical quantum amplifier has high selectivity, inasmuch as signal on output of amplifier will appear only in that case, when frequency of input signal is accurately equal to that frequency on which induced radiation appears in amplifier. There are a great number of other variants of communication system on optical waves.

In optical range it is comparatively easy to carry out sharp directivity of radiation. During equal diameters of antennas, width of antenna radiation pattern on optical frequencies is several orders of value less than in range of superhigh radio frequencies. Thus, antenna radiation pattern with radiator 10 cm in diameter on frequency of 300 THz (1 μm) is estimated by units of angular seconds. In order to obtain the same directivity in the microwave range, in particular on a 3 cm wave, it would be necessary to use an antenna about 3 km in diameter.

Such a high degree of concentration of electromagnetic energy in quantum optical generators permits using light waves not only for targets of communication, but also for energy transfer to spacecraft. Such wireless energy transfer on huge distances will be produced with

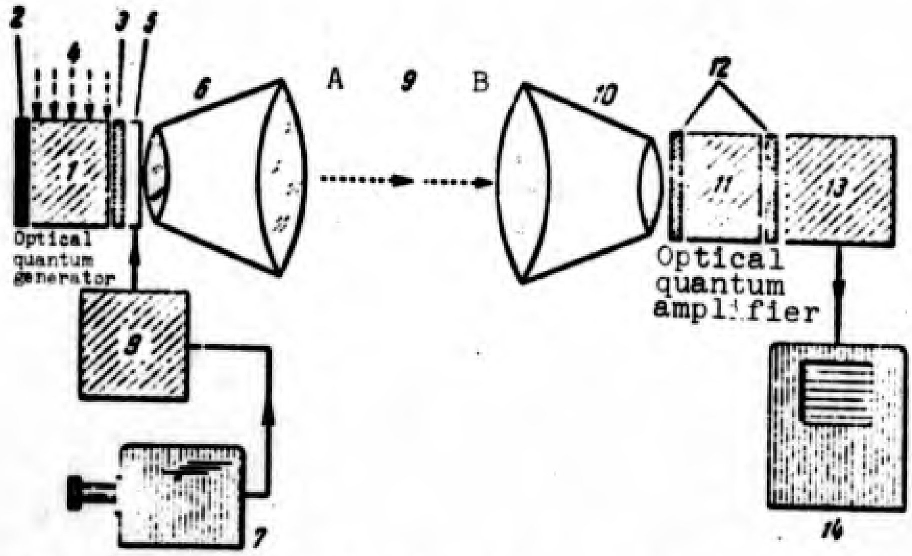


Fig. 55. System of television communication with optical quantum generator of light — transmitter and optical quantum amplifier — receiver. 1 — active medium; 2 — mirror with high reflectivity; 3 — mirror with small coefficient of transparency; 4 — optical pumping; 5 — modulator; 6 — transmitting optical system; 7 — transmitting television camera; 8 — video amplifier; 9 — medium in which light signal spreads; 10 — receiving optical system; 11 — active medium; 12 — mirror with small coefficient of transparency; 13 — photodetector-demodulator; 14 — video supervisory equipment; A) light signal on output of transmitter; B) light signal on input of receiver.

small losses which is especially characteristic for the case of application of semiconductor generators of light with high efficiency.

However, light as information carrier has its shortcomings. Absorption and light scattering in atmosphere was already discussed. Furthermore, in the signal itself, there is quantum noise caused by irregularity of emission of quanta of light in time. Noise occurs from sunlight and from other light sources, furthermore, broad-band noise of infrared radiation occurs from hot objects and others. For struggle with noises, it will be necessary to apply light filters with sharp absorbing properties for all unnecessary wavelengths of optical range. Fortunately, because of very narrow beams of light, receiver has limited field of sight and serves itself as a space filter. Use of narrow beams on transmitting and on receiving side greatly complicates problem of capture and escort of that object to which information is transmitted or whence information is received.

There are numerous experimental samples of television systems in which electromagnetic oscillations of optical range are used for transmission of picture signals. In one of such systems, television picture signals are used for amplitude modulation of light ray of optical quantum generator — laser. Power of light bundle is 500 μW; wavelength is 6328 Å. Modulated light ray passes a distance of 1.8 km, before it gets to entrance of receiver. On receiving side is used inexpensive system, diaphragm of field of sight and narrow-band optical filter (passband 50 Å). Narrow-band filter and diaphragm of field of sight are necessary here for management of transmissions in daytime. Further light rays get on photocathode of photomultiplier, from output of which signal is fed to amplifier, and then to control electrode of receiving electron-beam tube.

C H A P T E R VI

UNIVERSAL TELEVISION COMMUNICATION WITH HELP OF EARTH SATELLITES

Orbits of communication satellites. Satellites as passive radio relay stations. Satellites for active relaying of television signals. Practical systems of communication with space relays. Ground stations of systems of communication through satellites.

For transmission of television programs and other information on intercontinental distances, systems are proposed of communication with help of artificial earth satellites. The tendency to use artificial satellites for super-range communication is not accidental. Dup interest toward events of internal and international life, increasing cultural level of Soviet people, thrust to increase knowledge require not only safeguard of the most densely populated regions of country to local television broadcasting, but also omnipresent reception of television programs of central television broadcasting, exchange of television programs between big cities and with foreign television centers.

It is considered that volume of information transmitted on communication circuits grows at least in proportion to square of industrial potential. And much of this information must be transmitted considerable distances.

During the last few years, about which we have already talked there was mastered a number of new methods of transmitting broad-band signals great distances. Considerable propagation was obtained by ground radio relay and cable communication circuits. But how is communication carried out between inhabited localities on different continents and divided by ocean? Ocean extraordinarily complicates television communication. Well-known difficulties appear during organization of television broadcasting in points distant from each other and located in regions which are difficult to reach.

One of the most promising methods of transmission of considerable volumes of information (television and phototelegraph representation, of a large number of telephone conversations, telegraph communications, etc.) on distances is radio-relay communication with help of artificial earth satellites, but, subsequently, with help of its natural satellite — the moon.

What then is the essence of similar communication? With help of earth satellites, relay means rise on high altitude, and this ensures transmission of ultrashort radio waves on huge distances, since between source of radio signals and radio reception arrangement in this case already there are no mechanical barriers absorbing radio waves. Such satellites will be simultaneously seen in points of the earth located on thousands of kilometers from each other. It is true that presence of lowered layers affects propagation of oscillations of defined frequencies. From this it follows that distance of communication depends on height of flight of artificial satellite, its orbit, properties of relay utilized, and frequency of electromagnetic oscillations selected for communication.

Similar systems of communication consist of ground receiving and transmitting equipment and a certain number of satellites in constant orbit at an altitude of several hundreds or thousands of kilometers.

Artificial earth satellites intended for application in systems of communication, which are being theoretically and experimentally investigated at present are subdivided into two types: passive relays not carrying radio electronic equipment and operating as reflective antennas for relaying of signals from one point of earth to another and active relays carrying radio electronic equipment for amplification of signal before its relay to earth or another satellite. As variant of system of communication of second type is used method of transmission with delay in time, assuming accumulation of information and its transmission to ground receiving station after obtaining of corresponding instructions. Shortcoming of such system consists in the fact that satellite does not have to be simultaneously in field of sight of both ground stations.

What sort of considerations follow during selection of parameters of systems of space relays? What are the practical successes in this field of communication?

Responding to these questions, it is necessary first of all to stop on selection of orbit of communication satellite.

Orbits of Communication Satellites

Altitude at which satellite revolves around earth is determined by area of earth's surface from which it can be seen at a given time. The higher the satellite, the bigger this area and the more points from which it will be possible to see it simulteneously. Area equal to half of earth's surface constitutes theoretical maximum.

To ensure communication it is important not only to determine required height of satellite revolution, but also inclination and form of orbit. One of the basic requirements in selection of inclination of orbit (i.e., angle of inclination of plane of orbit of satellite with respect to plane of equator) is maximum stay of communication satellite above defined territory.

As is known, for a launched ship to become a satellite, it is necessary to take it to an altitude and there give it horizontal speed not less than orbital velocity. Orbital velocity for various altitudes of revolution is different. At ground level it is 7912 m/s; at 500 km, it is equal to 7619 m/s; at 2000 km, it is 6903 m/s; at 5000 km, it is 5924 m/s; at 7000 km, it is 5463 m/s. It is called circular, since body possessing such speed is able to revolve around earth in a circular orbit (Fig. 56). Series increase of speed of

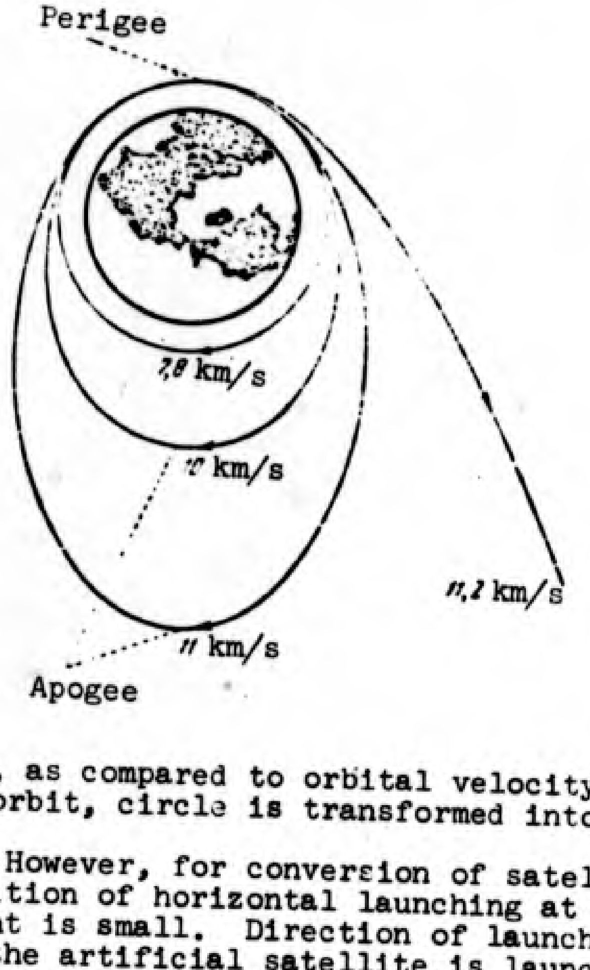


Fig. 56. Orbits of artificial earth satellites.

body, as compared to orbital velocity, leads to change of form of its orbit, circle is transformed into more and more extended ellipse.

However, for conversion of satellite around earth of one condition of horizontal launching at defined speed and on defined height is small. Direction of launch is still important. No matter how the artificial satellite is launched, the plane in which the trajectory of its flight (or plane of orbit) lies, should certainly pass through center of earth and to be, thus, in the plane of a great circle. It is impossible to force sputnik to fly above some parallel of our planet (not diposing by engine). The only exception is the zero parallel, which is the equator. Accordingly, orbit in such case is called equatorial (Fig. 57). Orbit, plane of which is perpendicular to plane of equator and passes through poles of earth, is called polar. Planes of intermediate orbits have angles of inclinations intermediate between 0 and 90° with respect to plane of equator.

Fig. 57. Possible orbits of communication satellites. 1 — equator; 2 — equatorial orbit; 3 — polar orbit; 4 — intermediate orbits; 5 — unrealizable orbit.

During determination of working surface of earth (simultaneously visible from communication satellite), it is necessary to consider that for production of small damping of radio waves, angle of elevation (angle between tangent to earth and direction to satellite) should be not less than 10° (angle δ on Fig. 60).

If with help of satellite in polar orbit, communication should be established between Moscow and Khabarovsk, then at orbit altitude of 1900 km and corresponding time of revolution of satellite of 2 h, during every turn of satellite only 10 min can be used for reception and transmission. With increase of height working time increases, and for a satellite revolving in circular polar orbit at 20,000 km, duration of simultaneous visibility of satellite from Moscow and Khabarovsk will already attain 4.5 hours (during every turn).

One satellite on polar circular orbit during its sufficient height can support radio communications between points located on close latitudes for a comparatively prolonged time.

For communication between points located approximately on identical longitude, but on different latitudes, polar orbits are absolutely unfit because of very short period of visibility of satellite from both points (for example, on Capetown-Tripoli communication circuit located on southern and northern parts of African continent). For communication between points located on various latitudes, but having close values of longitude, duration of communication will be greater if one uses equatorial orbit of satellite. Satellite revolving directly above equator will always have the same orbit (with respect to surface of earth), independently of normal rotation of earth. Turns unutilized for communication, which occur in case of polar orbit, are absent.

It is much more profitable to put satellite into orbit (having minimum inclination) from a place located as near as possible to equator. Maximum speed of rotation of earth around its axis is used, every point of earth's surface moves around center of earth with speed 465 m/s; this speed is wholly added to speed of rocket during equatorial orbit.

Before it was possible to launch satellite into equatorial orbit only from points on equator. The greater the latitude of site from which satellite is launched, the greater the angle of inclination of plane of orbit of satellite with respect to plane of equator. However, creation in the USSR of maneuvering satellites now permits selecting practically any desirable orbit of communication satellite during its launching from any point of the territory of the Soviet Union.

Super-range television communication between two points with help of only one satellite during the biggest time of continuous work during every twenty-four hours is possible only during strictly defined period of conversion. Orbit of artificial satellite constitutes ellipse almost motionless with respect to stars. And relatively to ground points (due to rotation of earth around its own axis) this travel is obtained complicated enough. If artificial satellite flies above terrestrial poles, making a complete revolution every twenty-four hours, then projection of its path on surface of the earth will have the form of a large eight, crossing at equator. Width "of eight" depends on period of satellite revolution.

So that artificial satellite through defined time periodically appears above the same site, it is necessary that it revolve an integral number of times in a stellar day. Number of revolutions per stellar day of such periodic satellites is, naturally, in definite communication with altitude of flight. Thus, during circular orbit, height of flight above equator will be equal to 265 km, if required number of revolutions attains 16; at 1670 km altitude, number of revolutions is equal to 12, and at 6420 km altitude, it is equal to 6.

Putting satellites into low orbits is considerably simpler than putting them into high orbits. However, to create communication satellites on low orbits is undesirable by many considerations. At low altitudes, magnetic field of earth has relatively large intensity and seizes protons with high energy, forming Van-Allen radiation belts. During travel of satellite in lower layers of Van-Allen belt, level of radiation is so high that solar cells and other semiconductors on board satellite very quickly break down. For increase of period of service of semiconductors in such conditions, it is necessary to use protective antiradiation coverings or to apply stabler instruments with the worst characteristics. All of this requires increase of weight of satellite equipment.

Somewhat smaller, but essential influence on satellites stabilized in rotation, is rendered by strong magnetic field. Magnetic field of earth interacts with field of current-carrying conductors and shell of satellite, which delays speed of rotation of satellite. To increase period of service of satellites stabilized in rotation it is necessary to have recourse to special measures in order to decrease magnetic field strength and length of path of eddy currents in shell of satellite.

Another deficiency of low orbits consists in that satellite does not come out from limits of terrestrial shadow a considerable part of the time. All of this time satellite instrumentation is fed from storage batteries. Therefore for normal booster charge of storage batteries during the time of flight on section of orbit illuminated by sun, it is necessary to increase number of cells of solar batteries. It is necessary to consider that equipment of satellite is subjected to frequent and sharp oscillations of temperature, but hence appears necessity of installation of a thermal control system.

During use of low orbits, simultaneous direct visibility and, accordingly, stable radiotelevision communication through satellite can be supported only with stations on relatively small section of earth's surface, and even that short term.

Escort of satellite requires considerable complication of construction of ground relay stations. Stations must have tracking antenna of large dimensions, cost of which is considerably higher than cost of antennas with stationary reflectors, and also special means of determination and precomputation of trajectory of passage of satellite.

In process of satellite tracking, ray of antenna radiation pattern of ground station should shift within limits close to 180°, and this promotes appearance of mutual interferences between this station and other radio stations. All of this considerably complicates problem of separation of frequencies for systems of radio communications with use of satellites in low orbits.

However, even during identical period of revolution, forms of satellite orbits can be different. How should we be guided in selection of form of orbit?

At first let us remember that according to second law of Kepler, segment of straight line connecting material body, which moves in an ellipse relative to one of its foci, describes equal areas in equal intervals of time. This means that at perigee, speed of body will be the biggest, and in apogee, it will be smallest. Therefore, if form of orbit is elliptical with apogee in zone of simultaneous visibility of satellite, then satellite motion will be considerably slower in it than in that case when it is put into circular orbit with that period of revolution. This means that during elliptic orbit, time of continuous television broadcasting ensured satellite relay station per day will be greater than during its travel in circular orbit with that period of revolution. Furthermore, during identical power of carrier rocket, on elliptic orbit it is possible to deliver heavier payload than on circular orbit with identical apogee. However, satellite with small altitude of perigee suffers the same deficiencies as low altitude satellites.

Travel visible from earth of equatorial artificial satellite revolving in elliptic orbit can be oscillatory: that from west to east, then from east to west and again from west to east (Fig. 58). For artificial earth satellites moving in first zone, apparent direction of travel will coincide with real direction of motion since

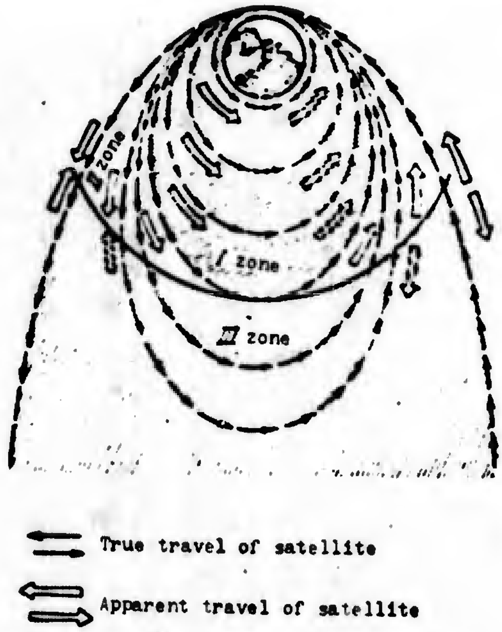


Fig. 58. Motion apparent to terrestrial observer of equatorial artificial satellite following elliptic orbit.

angular motion of satellite is faster than daily rotation of earth around its axis. For other satellites passing pratially in second and third zones, apparent and real direction will coincide only part of way; when satellite is near earth, its angular velocity is greater, and it seems to be moving eastward (second zone). According to approximation to interzonal border, it gradually delays travel, in order, attaining it, to stop instantly and start to move from east to west.

During use of periodic satellites there occur interruptions of communication. This can be avoided if there is simultaneously a large number of satellites. Where their number depends on height of flight, form of orbit and mutual location of communication satellites. Thus, in order to ensure guaranteed communication between Moscow and Khabarovsk during 99% of the day, it is necessary to evenly distribute 100 artificial communication satellites in polar orbit 3700 km high. However, if one increases height of crbit to 9000 km, then 24 satellites are sufficient.

Communication satellites can be placed accidentally or synchronized relative to each other. During accidental distribution of satellites and their orbits, a large number of satellites is required. If one were to reach synchronization of relative motion of satellites, then their number could be considerably decreased for creation of world system of communication. However, this requires complicated stabilizers. Six satellites revolving in regular sequence in equatorial circular orbit 14,000 km high, can ensure universal television communication. Period of revolution of every such satellite will be 8 hours. Any of these satellites, taking into account terrestrial rotation, will appear after each 12 hours above the same point of earth.

Minimum quantity of communication satellites necessary to ensure transmission of television programs on almost the whole territory of the earth is equal to three. Orbits of such satellites, called stationary, have to be circular equatorial orbits with altitude

35,810 km. Such satellite, shifting with respect to stars, will be motionless with respect to ground points. This is explained by the fact that period of revolution of stationary satellite is equal to 24 hours, but inasmuch as earth itself revolves in that same side and makes full turn around axis after the same time, then such satellite will seem motionless on earth's surface. From every such satellite earth will be seen at an angle of 17°, which will allow simultaneously irradiating surface of earth by radio signals in a radius of about 10,000 km. During creation in cosmos of a system of three stationary satellites, it is necessary to observe the following condition: satellites should be launched from one region located in equatorial belt of our planet, with interval of time 8 hours, in direction of daily rotation of earth. Then 3 satellites will be delivered from each other along the orbit on 120° (Fig. 59) and be on a mutual

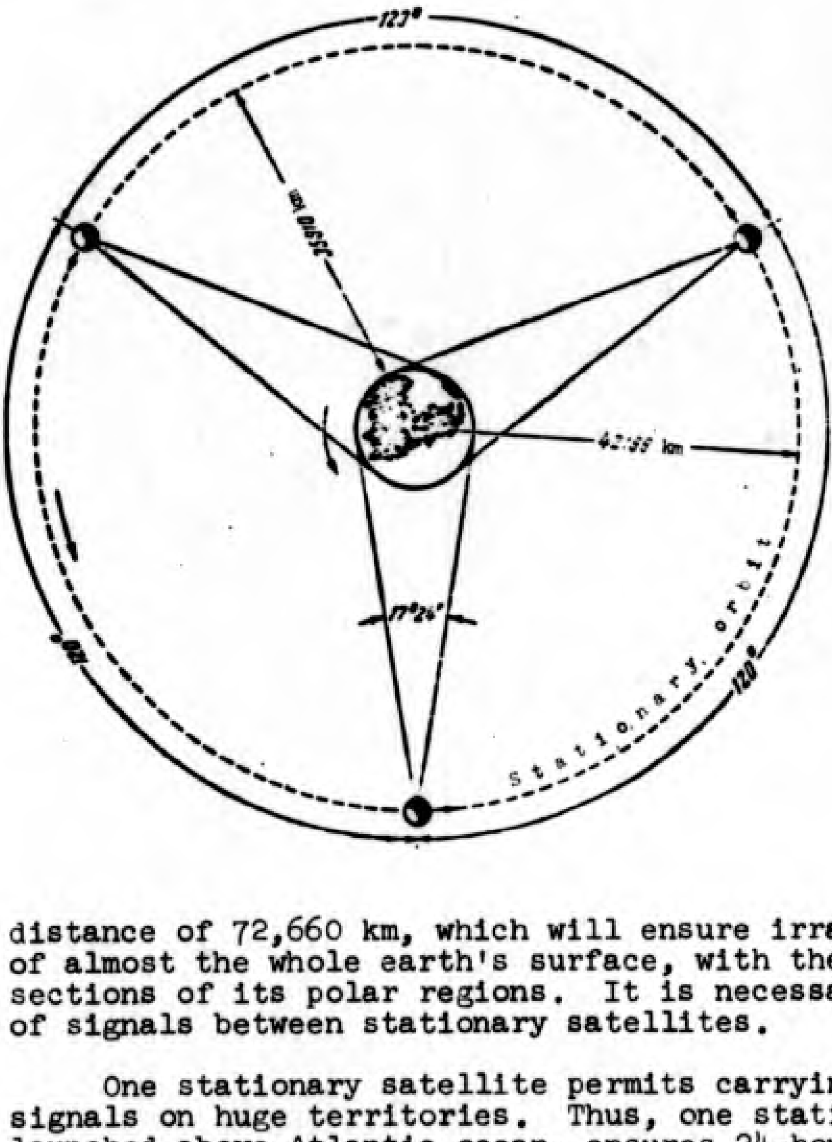


Fig. 59. Three artificial earth satellites on stationary orbits.

distance of 72,660 km, which will ensure irradiation by radio signals of almost the whole earth's surface, with the exception of small sections of its polar regions. It is necessary to ensure exchange of signals between stationary satellites.

One stationary satellite permits carrying out transmission of signals on huge territories. Thus, one stationary satellite, launched above Atlantic ocean, ensures 24-hour transmission of information to territories of all countries of South America, the United States (with the exception of Alaska), part of territory of Canada and Greenland, Western Europe, countries of Africa (with the exception Somali and part of Ethiopia), and one stationary satellite launched above the Indian ocean, ensures 24-hour transmission of information to a large part of the territory of the USSR (with the exception of islands in the Northern Arctic Ocean and Chukotski peninsula), countries of Eastern Europe, Asia Minor, India, China, Australia, and part of Africa.

For creation of system of satellites ensuring 24-hour transmission of information to territory of Polar basin, it is expedient to use satellites in elliptic orbits with apogee in the Northern hemisphere.

During use of satellites in stationary orbits, a large part of the limitations inherent to low altitude satellites is taken away. Stationary orbits pass considerably above internal Van-Allen belts with their powerful penetrating radiation and above zone of intense radiation of upper Van-Allen belt. It is natural that antiradiation shielding in this case is considerably less difficult and does not require such complicated construction as during use of low altitude satellites. Magnetic field strength of earth at altitude of synchronous orbit is one hundredth of field strength of earth at low altitudes, and time of decay of rotation of stationary satellites is increased accordingly tens of thousands of times. Stationary satellites are almost always (99% of the day) are illuminated by the sun (short-term shading occurs only at midnight for meridian above which satellite is), and this essentially simplifies problem of generating and accumulating electrical energy and decreases number cycles of change of temperature of equipment.

For a satellite revolving in a stationary orbit, the time necessary for passage of radio waves from ground station to satellite and from it to another ground station is one tenth of a second. This is not interference for television and other information-carrying systems in one direction. Such delays are essential only during telephone communication.

Creation of artificial satellites in stationary orbits encounters a number of difficulties connected with considerable complexity of methods of putting satellites into orbit, necessity of exact control of satellite orbit and adjustment of its position with respect to surface of earth on whole extent of useful period of service of artifical satellite.

It is especially difficult to put into a stationary orbit satellites which are stabilized on three axes. In this case, payload of last stage of rocket, which ensures putting satellite into orbit, should have a complicated system of guidance and orientation.

It is true that during the putting into orbit of satellites of stabilized rotation, system of guidance and orientation of carrier rocket is used only in apogee of transfer orbit. In this case difficulties consist only in installation on satellite of correcting jet engine included in apogee of transfer orbit. Besides simplification of process of putting into synchronous orbit, stabilization of satellite by rotation essentially simplifies control system of position of satellite in orbit and control of its orientation. However, during stabilization of satellite in rotation, construction of connected antenna array is considerably complicated.

Transmission of television signals can find application with certain delay in time. In this case it is not necessary that satellite be simultaneously seen from both points leading exchange of picture signals. Flying over one of them, equipment of satellite (on command from earth) will record transmitted television signals, but above second point will transmit television signals to any point of the earth. Certainly, time of recording of information and time of its transmission will depend on orbit of satellite. But, let us say, for transmission of two-hour television program to a flying satellite will require less time, if television signals are preliminarily recorded, and readout during transmission is produced with high speed. Information recorded by equipment of flying satellite can be transmitted to another point with any speed of readout. Similar transmission of television signals with delay in time can be performed only with the help of active communication satellites, carrying on board receiving, recording, and radio transmitting equipment.

Satellites as Passive Radio Relay Stations

Diagram of radio relay line with use of satellite as radiation coupled reflector of electromagnetic energy is shown in Fig. 60. In points of contact of tangents connecting satellite with surface of earth are located points A_1 and A_2. In point A_1 is placed radio transmitter, oscillations of carrier frequency of which are modulated by video signal. Electromagnetic energy radiated by transmitter antenna goes to satellite. Reception of energy reflected by satellite is possible at any point of surface of earth within angle γ. The most remote point lying on surface of earth inside angle γ is point A_2. Irradiating satellite-reflector of energy is directly proportional to power of ground radio transmitter and directivity of antenna and is inversely proportional to square of distance between satellite and radio transmitter.

Electromagnetic wave falling on satellite-reflector excites on its surface high-frequency currents, which in turn lead to appearance of secondary electromagnetic field, which spreads into space; simpler talking, occurs reflection of high-frequency energy. For effective reflection of incident energy, minimum dimensions of satellite-reflector have to be many times greater than wavelength of oscillations.

Energy reflected from satellite is weakened during propagation to receiving ground point. As a result, ratio of power of received radio signal to power of radiated signal is determined by expression

$$\frac{P_{\text{приемн}}}{P_{\text{передат}}} = A\frac{S}{d_1^2 d_2^2 \lambda^2},$$

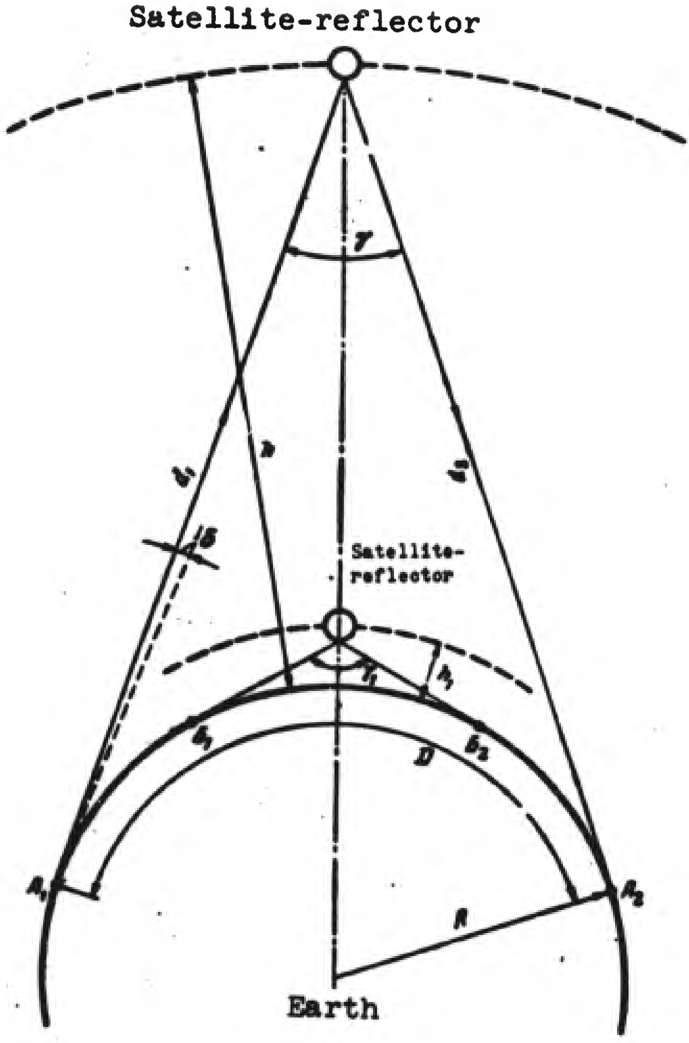


Fig. 60. Use of artificial earth satellite as reflector of electromagnetic energy in communication system.

where A is coefficient, magnitude of which depends on area of antennas and their use; S is effective reflecting surface of radiation coupled reflector; d_1 and d_2 are distances according to Fig. 60; λ — wave-length of oscillations.

<u>Form of satellites-reflectors</u>. Form of reflecting surface can be the most various. For quantitative comparison of surfaces on reflecting properties, the idea is used of effective reflecting surface. Effective reflecting surface of an object is a function of angle of incidence of electromagnetic energy.

A satellite-reflector can have the form of a sphere (1 on Fig. 61). A sphere reflects electromagnetic energy evenly in all directions; its effective reflecting surface is proportional to the square of its diameter. The shortcoming of such a relay is simplicity of arrangement and long period of service. Such a communication satellite, furthermore, does not require orientation. However, due to considerable losses of energy, it is necessary to use on earth powerful radio transmitters and receivers of very high sensitivity, and also to increase effective reflecting surface at the expense of considerable increase of dimensions of satellite.

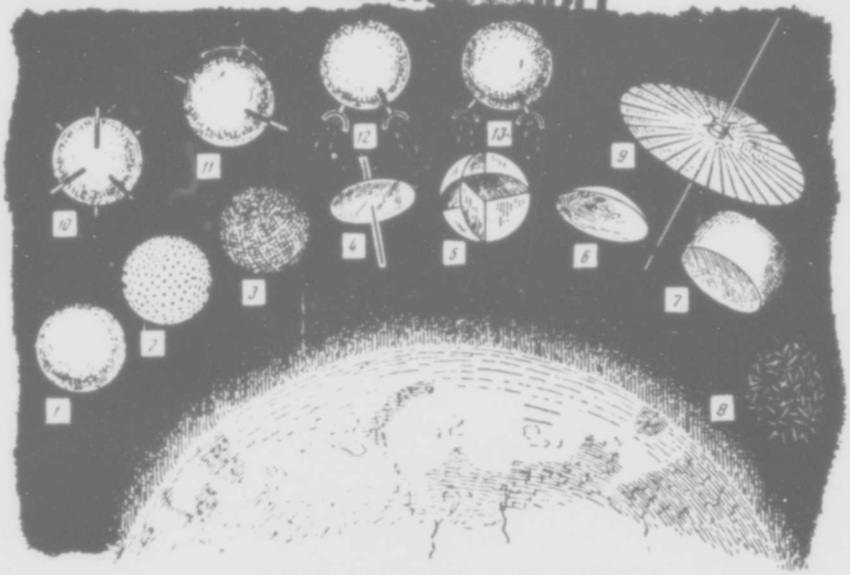


Fig. 61. Passive reflectors and active relays. 1 — inflated sphere; 2 — sphere with holes; 3 — netted sphere; 4 — flat reflector; 5 — angular reflector; 6 — reflector of double curvature in the form of a saucer; 7 — barrel-shaped reflector; 8 — cloud of artificial ionosphere of half-wave dipoles; 9 — passive satellite-reflector with biaxial gravitational system of stabilization; 10 — unoriented pseudoisotropic relay; 11 — retranslator with ring-shaped radiation stabilized at the expense of normal rotation; 12 — "balanced" active relay in which weight of antennas and power of transmitters are in optimum relationship; 13 — oriented active relay with antennas, radiation of which covers defined area of earth's surface.

Angle reflector (5) sends incident energy back in a rather narrow beam covering a relatively small section of earth's surface. It is possible to apply a complex of a large number of angular reflectors, but in this case, there appear oscillations of amplitude of reflected signals.

Plane (4), dimensions of which greatly exceed wavelength reflects energy at an angle equal to angle of incidence. Maximum of reflected energy is observed during perpendicular incidence of wave on surface. For best use of satellite, its plane must be oriented perpendicular to bissectrex of angle included between incident and reflected rays. Flat round surface possesses large effective reflecting surface. If a flat disk 23 m in diameter is required for communication on a frequency of 3000 MHz during diameters of ground antennas of 60 m, then, to obtain the same value of reflected energy by spherical satellite, its necessary diameter should be 129 m.

It is possible to use barrel-shaped, cylindrical or saucer-shaped reflectors. Barrel-shaped and cylindircal reflectors have an advantage in that for stabilization of position in space, it is sufficient to give them rotation with respect to axis perpendicular to plane of orbit during launching. For saucer-like reflector, constant orientation is necessary with the help of a special system. However, for such a satellite, utilization factor of incident energy is rather large. In curvilinear reflectors, in contrast to flat ones, width of reflected ray little depends on frequency of electromagnetic oscillations utilized. A curvilinear reflector can be more rigid than a flat one; furthermore, during its manufacture, in contrast to resonance reflectors of the plane and half-wave dipole type, there is no necessity to sustain strictly tolerances to geometric dimensions.

Carried out and projected satellites-reflectors. In spite of the fact that systems with passive relaying require use on ground stations of powerful transmitters, complicated servo systems and sensitive receivers; these systems are considered very promising because of simplicity and reliability of construction, and also thanks to reliable interference elimination.

In August 1960 there was artificial earth satellite "Echo-1" (the United States), having form of sphere 30.5 m in diameter. Surface of sphere, covered with a thin layer of aluminum, had reflectivity of 0.98 for radio waves up to 4000 MHz. Shell weighing total of 62 kg built in form of a bellows, was put into orbit with the help of a rocket. Here shell was separated from rocket and in air space was turned into a brilliant sphere at the expense of evaporation of existing water. Average height of satellite orbit was 1600 km. For this height, angle $\gamma = 106^{\circ}$, and distance of communication on earth's surface $D = 8200$ km (see Fig. 60). Purpose of experiment consisted in checking different forms of modulation during communication by reflected signals, investigation of fluctuations of reflected signals, their fadeout and polarization. The first four months the satellite served as a reflector of radio waves until solar radiation and meteorites lowered reflectance of satellite. Pressure of solar rays displaced satellite from orbit and returned it again three times. By the middle of 1963 diameter of balloon had decreased to 18 m.

Satellite-reflector "Echo-2," launched at the beginning of 1964, had a diameter of 42 m and weighed 227 kg. Inflatable spheric balloon was carried out from two layers of thin aluminum foil by 5 μm thick, among which there was a film of plastic material (mylar) 9 μm thick. Structure of shell of this satellite is 20 times harder than structure of preceding satellite-reflector, which was carried out from mylar film covered by one layer of aluminum. To ensure thermal control inside bottle, shell was covered from internal side by uniform layer of black paint, but from external side has a point covering of white paint. Performances of long-distance communication with use of this satellite were conducted by Soviet Observatory of

Scientific Research Radio Physical Institute of Gor'kiy University in Zimenkakh and the English Observatory, Jodrell Bank, of Manchester University. Signals transmitted from England and reflected by satellite were taken in the USSR, and conversely. Provision is made (for) carrying out experiments in establishing direct communication between the USSR and the United States with the help of this satellite.

Creation is outlined of satellites-reflectors in the form of light spheric balloons of still larger dimensions and lens-shaped satellites with gravitational stabilization based on the use of gravity gradient (9 on Fig. 61).

In order to decrease pressure of solar radiation and prevent destruction of satellite by meteorites, it is proposed to fulfill them from wire grid (3 on Fig. 61). Dimensions of cells of grid will be directly proportional to wavelength. If one were to use gas bottle of plastic film, then satellite will be able to be inflated in space. For this a special film will be applied (called foliating), which will be evaporated under action of solar rays, after which only wire frame will remain. Other proposal consists in putting metallic covering on grid of plastic bands by method of precipitation from vapor, i.e., making a grid capable of reflecting radio waves. Such fibers can possess effect "of memory": after going into orbit, mechanical energy stored in them under action of solar heat will force satellite to take a definite form (to emerge from compressed state).

Creation is anticipated of an experimental system of communication with help of satellites-reflectors launched in series on several pieces with the help of one rocket carrier.

In May 1963 the United States created in orbit around earth a belt of dipole reflectors. Each such dipole (250-350 million pieces were launched in all) constitutes a copper wire 1-2 cm long and 0.03 mm in diameter. Weight of one dipole is 0.0001 g. These dipoles are calculated on reflection of 8000 MHz electromagnetic oscillations. Number of deficiencies of this method of communication excludes application of belt of metallic dipoles for transmission of broad-band signals. However, this belt of dipoles can bring many troubles. These needles already in the very near future can create well-known interferences during astronomical and radio astronomical observations. Prolonged existence of this belt conceals danger for artificial earth satellites, since the latter can collide with these needles. As is known, orbital speed of needles will be about 8 km/s. If artificial satellites are directed toward revolution of belt of dipoles, then their relative speed can reach 16 km/s, and will increase probability of damage of artificial space body by needle. Such collisions are especially dangerous when the satellite is manned. Needles which are thrown out at high altitude can long remain near earth, which is also very unpleasant since they can hinder space communication.

Moon as passive relay. Possibilities have been investigated of using surface of moon as reflector of electromagnetic energy in systems of super-range ground radio communications. After first reception of radar signals reflected from moon (performed by Hungarian researchers in 1946), several analogous experiments were made on different frequencies, where possibility was proven of use of moon as passive relay on lines of ground communication of large extent. Use of moon as radiation-coupled reflector of electromagnetic energy in system of communication differs in a number of peculiarities. Signals reflected from moon have slow and fast fadeout. Because of unevenness of surface of moon, reflected signal contains components having different phase shifts, but due to rocking (libration) of moon, phase relationships among these signal components are changed. These phenomena cause fast fadeout of signal.

Slow fadings appear during reception of linearly polarized signals on linearly polarized antenna due to rotation of plane of polarization of wave during passage through ionosphere and can be excluded, if antennas with circular polarization are used at receiving point. Very unpleasant peculiarity of signal reflected from moon is limitation on frequency band, which is explained by sphericity of surface of moon. It is natural that radio communications can be maintained only between those points on surface of earth, for which moon is above horizon at a given time of day. Proceeding from this, relaying of signals is possible on distances up to 10,000 km. It is clear that duration of radio transmission is increased with decrease of distance between corresponding points.

Examining peculiarities of moon as radiation coupled reflector on the whole, it may be concluded that passive reflection of radio signals by surface of moon, apparently, will not be used for transmission of picture signals of systems of television broadcasting. For this purpose it is more profitable to use moon as carrier of active relay (Fig. 62).

Fig. 62. Use of moon as space relay. 1 – ground radio transmitter; 2 – lunar relay; 3, 4 – ground receivers.

Satellites for Active Relaying of Television Signals

Such satellites will convert and strengthen signal received from earth, and will send radio signal to earth's surface after amplification. If considerable amplification of signals is performed on satellite, then this will allow essentially decreasing power of ground transmitter and will make possible reception of relayed signals to earth with the help of receivers which are not very complicated.

Equipment of active satellite relay station. Active relay is first of all broad-band transceiver. From output of receiving board antenna (in communication circuit earth-satellite) signal joins input of receiver on one frequency and, after corresponding conversion and strengthening, is radiated by transmitting antenna on other frequency (in satellite-earth communication circuit). Use is made of various frequencies for reception and transmission so that radiation of board radio transmitter does not hinder work of its receiver. Board equipment of active satellite relay station is very similar to equipment of intermediate stations of ground radio relay communication circuits.

Type of relay on board satellite is determined by method of organization of television broadcasting. Thus, for simultaneous and independent exchange of television programs between several points, board equipment should ensure relaying of several independent broad-band picture signals. If, however, it is necessary to relay only one television program for number of points, then board relay should reemit only picture signals of one television channel.

Aerial unit of satellite can be simple antenna in the form of dipole or directed radiator. It is impossible to increase excessively directivity of board transmitting antenna. If transmitting antenna has very narrow antenna radiation pattern, then reemitted signal can be received in only comparatively small part of earth's surface, which is turned to satellite. Thus, highly directional board transmitting antenna does not create conditions for simultaneous reception of television programs at several ground points very remote one from one another. Therefore, width of antenna radiation pattern of board antenna should be not less than angle under which there is seen from satellite the part of earth's surface whither it is proposed to transmit television picture signals.

Application of directional antennas on board satellite requires space orientation of satellite (or its antennas). The higher the directivity of board antennas, the more serious the requirement for a system of space orientation and to ground guidance systems on satellite of receiving and transmitting antennas. It is true that increase of directivity of board antennas promotes decrease of required powers of ground and airborne radio transmitters and decrease of required sensitivities of ground and airborne radio receivers.

In time errors are stored in system of orientation and stabilization of satellite relay, therefore necessity appears to change its attitude (or position of board antenna). Furthermore, deflection of orbit from assigned one can demand correction of trajectory of satellite relay station. All of this can be done only after obtaining information containing necessary data about cells of orbit of satellite and about work of system of orientation. Such data can be obtained by telmetering link, on which data are also transmitted about state and operating conditions of all airborne systems.

After treatment and analysis of all information transmitted from satellite relay station, corresponding instructions are formed which are transmitted on narrow-band radio link of communication to satellite. Instructions are again formed from received signals which then go to actuating mechanisms which finish off these instructions.

It is necessary to reach high reliability of work of satellite relay stations of television signals, since during putting of satellite relay station into orbit and in space flight, board equipment is affected by vibrations, overloads, sharp changes of temperature, increased radiation; to this one should add impossibility of prophylactic departure and hand adjustment. All of this should be considered during selection of electrical circuit and designing of board device.

On satellite relay stations with directional antennas of different types, different systems of orientation and stabilization can be used. Spinning satellites (9 and 11 on Fig. 61) are stabilized at the expense of their rotation with respect to axis perpendicular to plane of orbit. This is one of the simplest methods of orientation and stabilization of object in outer space, since creation of initial rotation in needed direction does not present special difficulties.

It is much more complicated to obtain information about change of orientation of axis of rotation, and also to introduce necessary correctives during travel of satellites along orbit. Already during launching, it was revealed that direction of their axis of rotation is gradually changed due to influence on satellite of magnetic field of earth, friction against atmosphere, and interaction with gravitational field of earth, etc.

Special correcting systems are set on board satellites for elimination of appearing deflections. Regulating device can be, for example, special cavities in the form of wings, fastened to housing of satellite. One side of them is blackened for absorption of solar energy, and other should to reflect well all rays falling on it. Thanks to this, satellite has imparted to it torque of one direction, but at the expense of thermal radiation of the actual satellite, torque of the other direction is imparted to it. Both torques are balanced until balance between absorption and radiation of heat is distrubed. This can be reached by application of coverings with nonuniform spectrum of radiation of by preheating wings for distrubance of heat balance.

Satellites of such type are more profitably used at altitudes not exceeding several hundred, i.e., in such region, where magnetic field of earth possesses sufficient intensity and has well-defined polar symmetry, in consequence of which it can also be used for spin stabilization of satellite and orientation of axis of its rotation. This simplifies problem of attitude control of satellite in flight.

Interaction with magnetic field of earth can be carried out with the help of electromagnet powered from special airborne audio-frequency generators. Magnetic field of electromagnets interacts with magnetic field of earth in such a way that satellite has imparted to it torque about necessary orientation of axis rotation.

When directional antennas are applied of type of those depicted on Fig. 61 (12, 13), then it is necessary to ensure orientation of whole object in such a way that reverse ray is directed toward center of earth. On board satellite a device can be used of the automatic gyrohorizon type. Height of flight of satellite will be accurately measured by radio engineering means. Correction instructions will be transmitted from earth to satellite on narrow-band radio links. Satellite is controlled with the help of low capacity engine rotation of anchors of which creates torque during insignificant consumption energy (watts or fraction of a watt) even in reference to very large satellites.

In order to prevent probable deviation of axes of satellite from assigned attitude during falling into it of small meteorites or influence of some other forces, current-carrying wire rings can be fastened to housing of satellite. During interaction of magnetic field of rings on magnetic field of earth damping forces appear ensuring stable position of satellite in space.

If airborne antennas of very high directivity are used, it is more profitable to secure exact orientation and stabilization of not the whole satellite, but only the antennas themselves, solar batteries and other units working on solar energy. Orientation should be carried out on all axes by control signals transmitted from earth or with the help of an airborne automatic system. Possible means are very manifold.

Number of satellite relay stations required for organization of communication depends in considerable measure on height of orbit. However, one should note that although higher orbits ensure value of mutual visibility, cost of these launchings considerably increases because of the necessity of installing transmitters of increased power on board satellite relay stations. The more power required, the bigger the weight of the actual radio transmitter and weight and dimensions of its source of power supply. Furthermore, required power of radio transmitter is connected in a definite way with period of service of satellite relay station, since the smaller the radiated power, the simpler it is to ensure prolonged supply of the system with electrical energy.

It is true that height of flight of satellite can also not entail considerable growth of power of radio transmitter, if directivity of satellite antenna is increased simultaneously with height of flight. However, here limitations are already put on by properties of system of stabilization of position of satellite in space and power of rockets which put satellite into orbit.

Logical limit of increase of height of flight of satellite relay station is putting satellite into stationary orbit. If correction is carried out of position of satellite relay in stationary orbit, then it is possible to simplify ground antenna economy, since satellite tracking is considerably facilitated.

As was already noted, to relay television programs on almost the whole territory of the earth it is sufficient to place into equatorial orbit three stationary artificial earth satellites equidistant from each other. During use of three satellites on earth's surface, there will be three zones, in which two satellites will be seen simultaneously. In these zones it is possible to dispose three ground relays, each of which should have two directional antennas: one for radio reception, and the other for radio transmission. Receiving antenna is directed in the direction of one satellite, but transmitting antenna is directed in the direction of the other (Fig. 63). Ground relay will receive signals from space

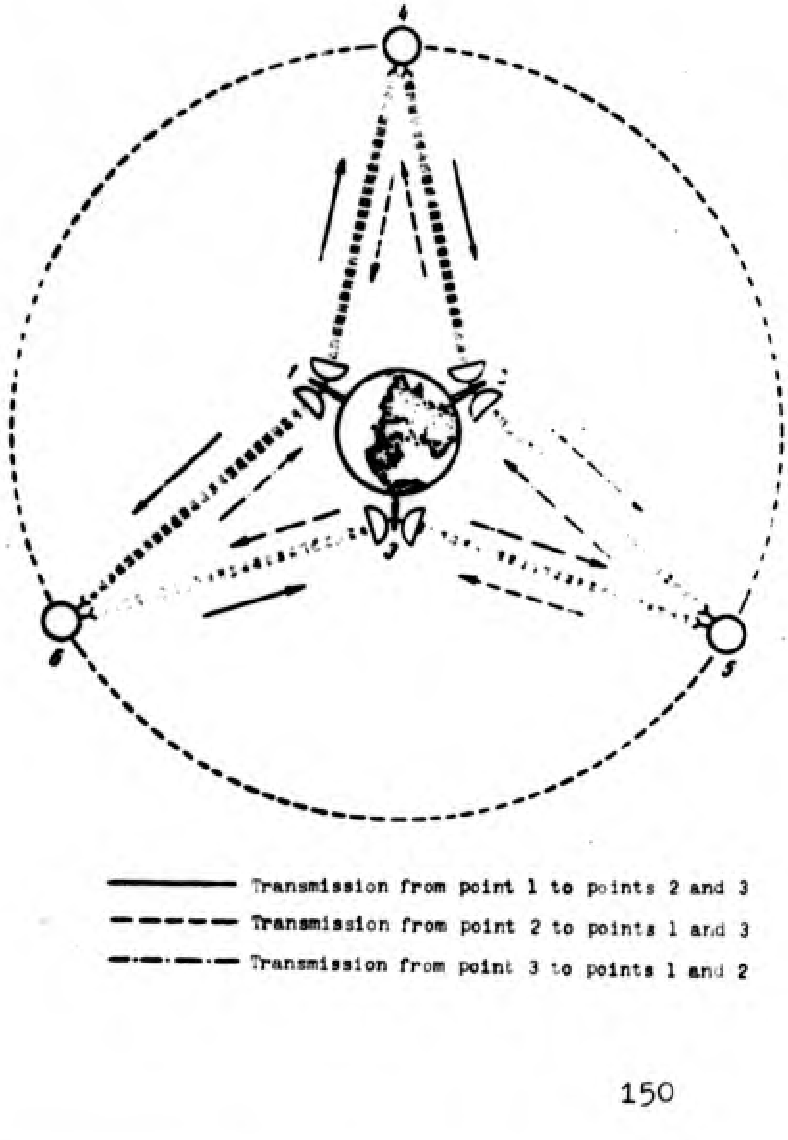


Fig. 63. Use of stationary earth satellites for relaying of television signals within limits of the earth with the help of ground relays. 1, 2, 3 – ground relays; 4, 5, 6 – active space relays in stationary orbit.

and, amplifying them, will automatically transmit them to another satellite. The satellite receiving signals will in turn strengthen electromagnetic oscillations and will direct them toward the region of the following zone, where there is also a ground relay. The third satellite will work like the first two. The whole system will be able to ensure ultrashort-wave radio communications even between points on opposite sides of the earth.

Creation of stationary satellite is a complicated problem, and creation of a system of such satellites is still more complicated. However, expediency of solution of this problem is very great.

System of universal television communication with help of three stationary satellites can be organized somewhat differently. By this diagram (Fig. 64), television radio transmitter directs its

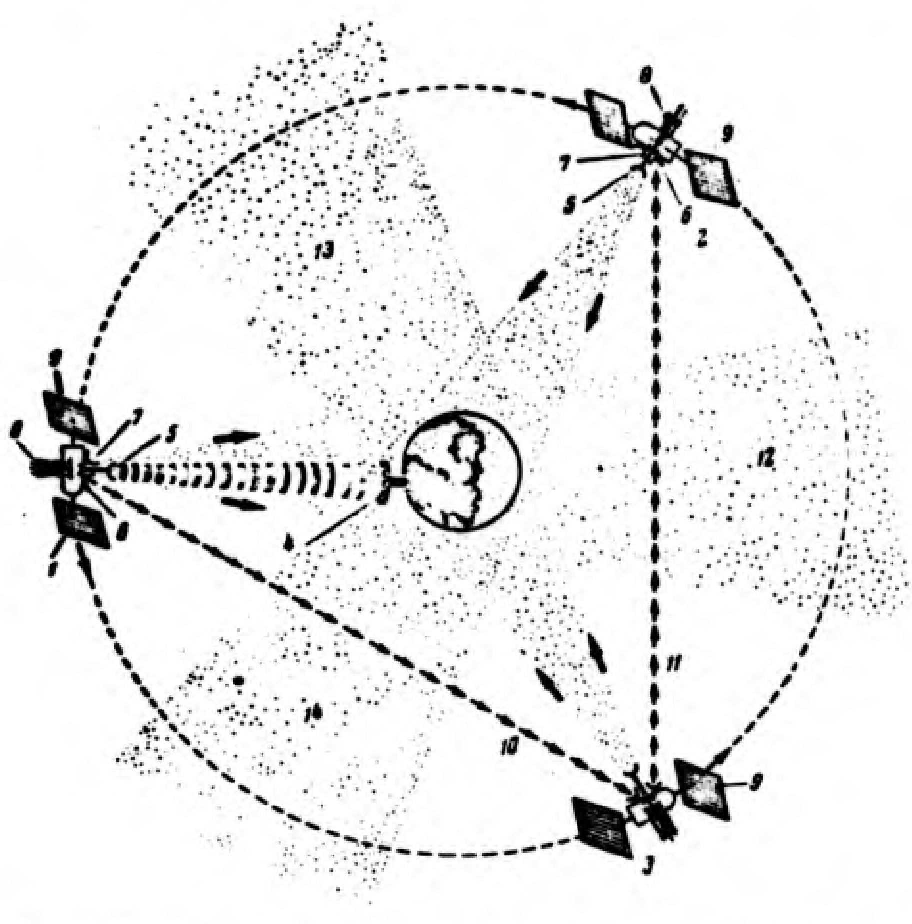


Fig. 64. Use of stationary earth satellites for direct relaying of television signals within limits of the earth. 1, 2, 3, 9 – active space relays in stationary orbits; 4 – ground transmitting station; 5, 6, 7, 8 – antennas of space relays; 10, 11 – satellite-satellite communication circuit; 12, 13, 14 – field of radiations of space relays.

signals to the nearest of three stationary earth satellites, which retransmitts television program to all territory under it. Simultaneously the same television program goes through outer space to two other satellites, which in turn irradiate with electromagnetic waves carrying picture signals remaining part of surface of the earth (excluding polar regions).

During organization of relaying of television signals both according to the first (Fig. 63), and in terms of the second (Fig. 64) diagram, the TV viewer will not manage to use oscillations radiated by satellites directly on screen of his home television set – representation will not appear. The fact is that signal is received on earth from board transmitter of small power is so small that it requires application of the most sensitive receivers. The best of them use the principle of quantum-mechanical amplification of received signals characterized by an extraordinarily small level of natural noises of amplifier. Low noise temperature of quantum-mechanical amplifiers will appear useless, if antenna array introduces foreign noises togehter with received signal. Consequently, highly directional receiving antenna should serve two purposes: the best collecting of arriving picture signals and information to minimum of outside noises. It is clear that radio reception system will constitute complicated, bulky, expensive engineering construction.

Radio reception system strengthens received signals and sends them to local television center. And here signals which go from television center can be received by antenna of ordinary television set. Thus, local television center plays role of relay, which takes program of remote television center and transmits it to its TV viewers. Antenna of television center receiving signals from satellite relay station is perhaps used and for radio transmission of program to satellite, and relaying to other television centers.

TV transmissions from satellites become accessible to TV viewers directly (passing television center) only if it is possible to create satellite relay stations with the help of radio transmitters. Power of board transmitter of stationary earth satellite required for direct transmission of program to TV viewers depends on frequency of oscillations utilized for communication, directivity of antenna, sensitivity of television receiver and applied antenna.

Let us assume that contemporary series television set, connected to usual receiving antenna dipole is used, but on satellite such an antenna is set up on the satellite. Then, if 1500 MHz electromagnetic oscillations are used for communication, it will be required to set radio 800 kW transmitter on satellite relay station. For comparison let us note that power of radio transmitters of contemporary television centers of big cities is measured in tens of kW. If, however, it is considered that such huge power (800 kW) must be obtained on space apparatus, then complexity of problem is evident.

But we have examined the worst case. Let us assume now that on satellite there will be used an antenna with large directivity, televiewer will have antenna of more complicated construction, but television receivers have great sensitivity; then required power of board radio transmitter will considerably decrease. It will no longer exceed units of kW and hundreds of W. Huge achievements in the field of rocket technology and radio electronics in our country convince one of the fact that the problem of creating space relays will be solved. In the beginning it will be impossible to manage without television center relays, but then satellite relay stations will undoubtedly be created, their signals will be received by antennas of series television sets, sensitivity of which will also increase by then.

When will this become possible? In order to answer this question, we will tell about means necessary for that case when relay transmits television signals at a frequency of 2000 MHz. If stationary satellite is used with effective radiated power of 35 W, then on earth there will be required a cup-shaped antenna about 3 m in diameter and a parametric amplifier on input of television receiver. Doubling power permits using antenna with diameter of cup less than 2 m and cheaper than amplifier on tunnel diodes. In both cases between preamplifier and series television receiver, it will be necessary to set converter which serves to ensure reception of signals on frequency exceeding limits of frequency range of given receiver. Converter consists of frequency converter, in the composition of which there is a low capacity oscillator (heterodyne), and amplifier.

It is possible to create already in the next few years stationary artificial earth satellite with effective radiated power of 35 W. For this source strength of power supply on direct current of about 210 W is required.

Inasmuch as system of three stationary satellites will not irradiate whole surface of the earth with its radio signals, it will be necessary to create a network of polar satellites for service of population of territories with latitudes of more than 80°. It is necessary to add that to ensure reliability of television communication with help of space relays it is necessary to have reserve board equipment and even reserve satellites.

Problems of conversion of television standards. However, problem of transmission of television signals on large distances is not unique. During exchange of television programs between different countries, there appear problems of language, tastes, finances, standards of television scanning, different carrier frequencies. We will examine the most essential of them.

In television broadcasting of different countries of the world, several television standards are used. Thus, in England the picture is decomposed into 405 lines and 50 fields are transmitted per second. In the United States, Canada, many countries of Latin America, and Japan, standard is used of 525 lines and 60 fields. In USSR, in socialist countries of Europe, Italy, and certain other European countries, picture is decomposed into 625 lines, and 50 fields are transmitted per second. In France, the Vatican, and in that part of Belgium where French is spoken, a standard of 819 lines and 50 fields is used.

During exchange of television programs between countries with a different standard, the problem appears of conversion of standards. Thus, if program is transmitted from France to England, then picture received at relay point corresponding to standard of 819 lines and 50 fields should be transmitted according to system of television broadcasting of England, i.e., 405 lines and 50 fields.

In 1952 exchange of television programs began between France and England; in 1953 European network of international exchange of programs was introduced, but later network of exchange of programs between USSR and majority of European countries was introduced. Converters of standards are used during exchange of programs.

The problem of accumulation is basic. Information of arriving television signal should be "recorded" and preserved as long as it is not "considered" in required standard of decomposition. According to readout recorded information should be erased well.

In converter of standards, the following processes are carried out: retransmitted television signals are sent to reproducing electron-beam tube of high quality. Picture reproduced on screen of tube is projected with help of objective on light sensitive surface of transmitting tube of television camera. Scanning in transmitting tube is carried out according to standard of decomposition of that country to which the program is sent. Different conversions of standards differ one from another basically in type of utilized transmitting tube (iconoscope, vidicon, image orthicon).

Mechanism of accumulation is conditioned by afterglow of luminophor of reproducing tube and storage unit properties of transmitting tube which remembers information of one picture field.

During development of equipment of converters of standards, measures are taken in order to exclude specific distortions which can be caused by inequality of frequencies of feeding electrical networks of different countries, geometric distortions of pictures, nonlinearity of scanning oscillations, inaccuracy of optical focusing and focusing of electron beams of reproducing and transmitting tubes, nonlinearity of amplitude and amplitude-frequency characteristics of communication channel and many other causes.

Difficulties of safeguard of high-quality representation on output of converter we made still worse by the fact that television signal should often pass long circuit of radio relay lines. Thus, program created in Holland and intended for England should pass through radio relay lines of Germany, Belgium and France, before it gets to converter of standards in Dover.

For ease of tuning different correcting cells of converter, station creating program sends in composition of full television signal whole series of testing signals. Usually there are used two converters of standards, and to television network there move signals from converter, which determine best quality of representation at a given moment.

Distinction of standards of different countries of world, different separation of carrier frequencies and signals of sound escort, distinction in carrier frequencies themselves, in forms of utilized modulation of oscillations of carrying sound escort, in languages of sound escort — all of this will appear additional obstacle for reception of television programs on space relays if power of electromagnetic oscillations arriving at antenna of television set appears fully sufficient. If, surmounting all difficulties, we obtain a picture on the television screen, then its quality should be high, because during space relaying to coupling network, there are considerably fewer intermediate sections, than during ground radio-relay communication between countries. The fewer intermediate sections, the less distortion is introduced into transmitted television signal.

Practical Systems of Communication with Space Relays

For creation of constantly operational communication circuits with use of satellite relay stations, it is necessary to produce theoretical and experimental investigation. An example of similar investigations is construction and check of experimental satellite relay station "Telstar-1" (the United States, July 1962). Period of revolution of satellite is 157.8 min, maximum removal from earth is 5645 km, minimum removal is 951 km, speed of flight of satellite at point of maximum separation is 29,000 km/h, at point of minimum removal is 18,000 km/h, and inclination is 44.8°. Since separation even at perigee is very great, influence of atmosphere on orbit of satellite is small. Period of stay of satellite in orbit is estimated at 200 years. On satellite is a 2.25 W radio transmitter. Signals of ground stations are strengthened 10 billion times on satellite. Besides connected transceiver on satellite "Telstar-1" there is radio tracking beacon, telemetric system and command receivers with decoders.

Satellite "Telstar-1," total weight of which is equal to 76 kg, has form of cut sphere (88 cm in diameter) consisting of 72 flat aluminum panels (Fig. 65). Where on 50 panels are placed sections of solar batteries of 72 cells each. On remaining panels there are strengthened transducers of testing equipment, but on one panel, there is a mirror to ensure optical observation of flight of satellite. Internal frame of satellite is carried out from fluted leaf magnesium alloy. Both halves of housing of satellite are fastened among themselves by bolts.

All electronic equipment is placed in aluminum housing 51 cm in diameter. Aluminum container is covered on the outside by film of gold and is suspended inside satellite for damping on nylon tie rods. For shielding from overloads and vibrations, every electronic unit is enclosed in an envelope of spongy polyurethane. Units are shielded by gold foil 0.075 mm thick. Collected units were assembled inside container and were again covered by a polyurethane shell. After distribution and strengthening of equipment, container was soldered, air was partially pumped from it and air was replaced by argon. Inside container an excess pressure was created of 0.7 atm,

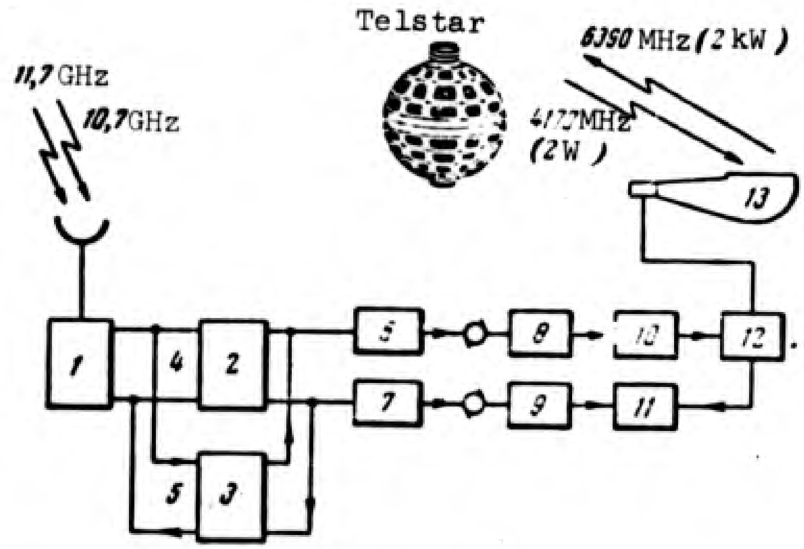


Fig. 65. "Telstar-1" and block diagram of ground system of communication circuit with use of active satellite relay station. 1 — receiving station; 2 — television center; 3 — equipment of conversion of signals; 4 — television signals; 5 — signals of telephone communications; 6, 7, 8, 9 — amplifiers; 10 — transmitter; 11 — receiver; 12 — distributor.

and temperature was maintained at approximately 50°C. In order to decrease heat radiation, whole surface of container (with the exception of its upper and lower part) is covered by heat shielding of mylar film and fibre. Upper and lower part have covering in form of umbrella, which is cell of temperature control system of container, principle of action of which is based on change of heat radiation. Height of every fluted covering can be changed with help of bellows regulators containing easily volatile liquid — methylene chloride — which is extraordinarily sensitive to oscillations of temperature. Any exceeding of given temperature causes expansion of liquid, where height of corrugated covering is somewhat increased and heat radiation is increased accordingly. During lowering of temperature, liquid is compressed, height of fluted covering decreases, and heat radiation is reduced, respectively.

Inside container there are placed communication relay, modulator, and coders of telemetric transmitter, transmitter of radio beacon, two receivers of remote control instructions, their decoding units and switching equipment.

Semiconductors are used in electronic systems of satellite. The only vacuum device is a traveling-wave tube with magnetic focusing. Output power of tube is 2.5-3 W, and its efficiency (neglecting consumption of power on preheating) attains 35%; full weight of tube with focusing magnet is about 3 kg.

It is interesting to note that out of 15,000 parts of satellite, about 7000 are used in electronic equipment (1064 transistors, 1464 semiconductor diodes, 2800 resistances, 1150 capacitors, 340 inductance coils, 70 transformers, 10 relays, 5 quartz stabilizers of frequency and 5 other parts).

In order to ensure high reliability of work of board equipment of satellite, strict sampling was carried out from a large number of parts which passed rigid tests. Thus, during the period of several months about 58,800 semiconductors were tested. For every component a special registration card was started; for board equipment parts were selected with the best indices of reliability. To increase reliability, installation of equipment of satellite was produced in industrial locations with high cleanness.

Along equator of sphere, there are mounted two main connected antennas of centimeter range in the form of two systems of waveguide radiators. A system of 72 waveguide radiators is intended for reception of signals, but system of 48 radiators is intended for transmission of intensive signals. Inside every cavity there is placed a radiator, to which energy is sent in strictly controlled phase. This ensures correct composition of radiation patterns of every cavity.

Effectiveness of radiation of these antennas is approximately identical in all directions, besides regions of poles of satellite, where effectiveness descends to zero. So that "zero" radiation of antennas is not directed towards earth, when satellite is above northern hemisphere, it is stabilized along the axis of rotation. With help of main antennas of satellite, transmission of signals of radio beacon is also carried out.

In lower part of satellite, there are two small pivoting antennas, utilized for reception of remote control instructions and transmission of telemetric data at launch and on initial stage of orbit. One more antenna in upper part of satellite is produced from its housing by pyrotechnic mechanism at the time of dropping of deflector. This antenna is used simultaneously for transmission on a frequency of 136 MHz of telemetric data and signals of radio beacon and on a frequency of 120 MHz for reception of remote control instructions.

In comparison with other cells of board equipment, the least reliability is possessed by board nickel-cadmium batteries. Storage battery consists of 19 cells and is recharged from solar battery consisting of 3600 silicon cells on external surface of satellite housing.

When solar rays fall perpendicular to equatorial plane of satellite, then solar batteries can develop power up to 15 W. Every cell of solar battery is mounted on ceramic plate, secured in plate frame, and has protective covering of artificial sapphire. Sapphire, platinum and ceramic material are selected because their coefficients of thermal expansion are close to coefficient of thermal expansion of silicon, and this ensures preservation of integrity of construction, in spite of wide limits of oscillations of temperature.

During simultaneous switching on of all systems by board electronic equipment of satellite "Telstar" about 30 W is consumed, which exceeds power developed by solar batteries more than twice. Therefore board equipment of satellite should be switched periodically by instructions from earth.

Requirements for band of transmitted frequencies, analysis of conditions propagation of radio waves and calculation of level of noises led to selection of band of frequencies 3700-4200 MHz and 5925-6425 MHz. Communication on line, satellite-earth, is carried out on frequency 4169.72 MHz, and communication on line, earth-satellite is carried out on frequency 6389.58 MHz. Frequency modulation is used in system of communication.

Block diagram of board connected satellite relay is shown in Fig. 66. Frequency modulated signals of ground station are received

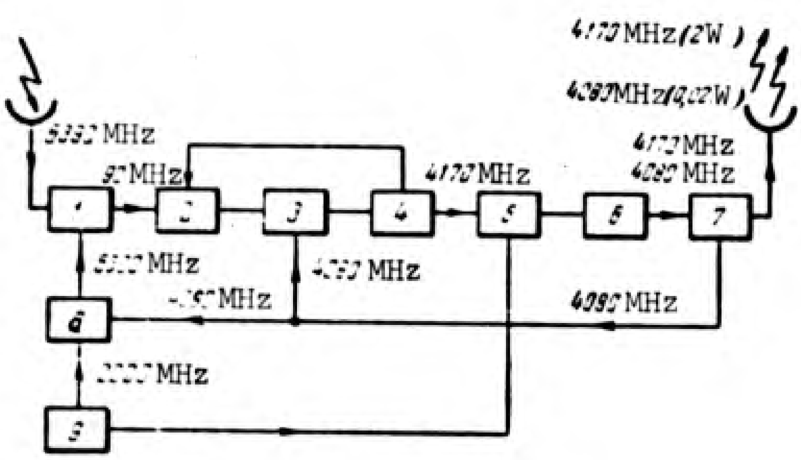


Fig. 66. Block diagram of built-in system of communication circuit using active satellite relay station. 1 – converter which decreases frequency of arriving signals; 2 – amplifier of intermediate frequency oscillations; 3 – converter which increases frequency of intensive signals; 4 – system of automatic control of amplification; 5, 7 – filter; 6 – traveling-wave tube; 8 – modulator; 9 – generator of high-frequency oscillations of centimeter range of waves.

on almost nondirectional antenna and through filter join input of first frequency converter. On output of this converter, there will be formed signal of difference frequency, 90 MHz, which moves to 14-stage intermediate frequency amplifier with passband 50 MHz. Then intensive signal joins second converter, displacing central part of signal in range 4169.72 MHz, after which through series of cells it proceeds to amplifier stage on lamp of running wave movement of which through separating device and connecting cable, already gets to transmitting antenna.

Telemetric complex of satellite "Telstar-1" jointly with necessary transducers and converters ensures transmission of separate 115 parameters, including data about volume density and energy of free protons, temperature of satellite, pressure inside housing, intensity of solar illumination of different sections of surface of satellite, value of currents and voltages in different points of equipment, influence of particles of high energies on semiconductors, etc.

Satellite will be turned on and off by radio instructions transmitted from earth on about 123 MHz. For capture and rough escort by ground antennas, satellite radiates undamped signal of radio beacon at 136 MHz through antenna serving for reception of instructions (see Fig. 65). This signal serves as carrier frequency for transmission of telemetric data to earth.

On satellite "Telstar-1" two rather coarse systems are used of stabilization along the axis of rotation. Gyroscopic stabilization is ensured by the fact that third stage of carrier rocket before separated satellite is made to rotate with speed 180 r/min. As a result there occurs stabilization of axis of rotation of satellite in space.

Second system of stabilization of attitude of satellite is calculated on suppression of magnetic moment mainly created by permanent magnet of traveling-wave tube.

Already in first days of work, "Telstar-1" ensured transatlantic transmission of television representations, telephone conversations between the United States and Europe, and also transmission of photographs. General duration of simultaneous visibility of satellite by station Andover (the United States) and by western European stations in twenty-four hours is 102 min. Maximum time during which satellite will be seen simultaneously by American and English stations is 30 min per revolution. For various causes for communication there can be practically used not whole period of simultaneous visibility of satellite by receiving-transmitting stations, but time of communication is about 20 min.

With help of satellite relay station there are conducted transmissions of colored television programs, where quality of representations obtained is excellent. Soviet TV viewers with help of satellite "Telstar-1" and system Eurovision-Intervision were witnesses of tragic events connected with murder of John Kennedy in the United States in autumn 1963.

Artificial satellite "Telstar-1" was also used for transmission of meteorological maps, which required eight times less time than during use of usual ground communication circuits of radio links. For this purpose a special phototelegraph apparatus was used with raised speed of rotation of drum.

Results obtained from experimental communication with the help of satellite relay station "Telstar-1" showed possibility of use of active satellite relay stations for establishing intercontinental communication for transmission of both television and many telephone messages simultaneously.

In May 1963 satellite "Telstar-2" was put into orbit. It differs little from its predecessor. From semiconductors of satellite air and other gases are removed. Instruments are placed in vacuum, which protects equipment from radioactive radiations. Apogee of this communication satellite is 10,720 km, and perigee is 969 km. Satellite is in zones of intense radiation less time, and, consequently will be less subjected to destructive action of radioactive radiations.

High altitude of its orbit permits transmission between the United States and Europe for an hour.

For regular transmission of Eurovision programs from Europe to America the following order is accepted. European television representation, which took, standard 625 lines and 50 fields per second, is transmitted to main switching center of Eurovision in Brussels, where conversion occurs to needed standard (if transmissions are relayed from France, then 819 lines and 50 fields obtained will be converted to standard 625 lines and 50 fields). Then picture signals are transmitted on coaxial cable to English Channel and further on centimeter radio waves through strait into England, but then by coaxial cable they enter London. Here picture signals will be converted in accordance with British (405 lines) and the American (525 lines) standards. Television signal corresponding to American standard is transmitted by cable to Goonhilly-Downs (England) and on microwaves to neighboring ground station for transmission to "Telstar." "Telstar" relays television signals in Andover. These signals are then transmitted on microwaves to Portland and further by coaxial cable to New York for distribution on broadcasting network.

Transmission from the United States to Europe is fulfilled in reverse order, with one exception: conversion of American to French standard is produced in London.

Other active satellite "Relay" in form of cylinder with eight flat facet ways was launched in December 1962 into orbit with perigee 1320 km and apogee 7440 km. Upper part of satellite has form of truncated pyramid. Its maximum diameter is about 74 cm, height 81 cm, weight 61 kg. General length of satellite with aerial unit coming forward above summit of satellite is 140 cm. On satellite there are two identical relays, each of which can work in two modes — for one-way communication of broad-band signals or for bilateral transmission of telephone signals. Power of oscillations radiated by relay transmitter during transmission of broad-band signals is equal to 10 W, and during transmission of telephone messages is 40 W. As a peculiarity of this satellite, one should note 7 reserve blocks connected in parallel to basic units of electronic equipment, which essentially increases reliability of satellite operation.

With help of satellite "Relay," transmission was conducted from the United States to Europe, Africa and Brazil, from Brazil to Europe, etc.; voice, telegraph reports, black-white and colored television representations were transmitted.

Preparation is conducted for creation of a communication system with help of stationary active artificial earth satellites. First successful launching of artificial earth satellite "Sinkom-2" (the United States) was performed in July 1963. Satellite was launched at first on strongly elongated orbit with perigee 225 km and apogee 36,210 km. Five and one-half hours after launching, speed of satellite was increased by instructions from earth, and it passed on an almost circular orbit (perigee 34,247 km and apogee 36,628 km). Due to the fact that satellite was not launched exactly into stationary orbit, it accomplished westward drift with speed 7.5° per day. Subsequently, multiple switching on of board engine of satellite produced correction of its orbit, as a result of which drift velocity was brought to 0.04° in twnety-four hours. Height of satellite was changed within limits 35,568-35,582.4 km (by other data 35,680-35,793 km); time of revolution was 23 h 55.9 min. Because of distinction of equatorial section of earth from circumference, additional displacements were noted of satellite within limits up to 0.75°. This satellite cannot be considered truly stationary, since it describes an "eight" above Brazil and the southern part of the Atlantic ocean. Upper and lower loop of "eight" touch points on 33° northern and southern latitudes. Satellite is to be maintained in assigned position at least two years with the help of jet attitude control system where nitrogen and hydrogen peroxide are used as fuel. Satellite moves along orbit with speed 10,800 km/h, whereas speed of rotation of earth at equator is equal to 1664 km/h.

"Sindom-2" consists of two concentric cylinders (Fig. 67a). On external cylinder 71 cm in diameter and 39.4 cm high are placed 3840 silicon solar cells; power provided by them is 25 W. Between external and internal cylinders there are placed engine of control of speed and orientation of satellite. Radio electronic equipment of satellite (weighing 25 kg) is placed in internal cylinder. Weight of all satellite without fuel is 41 kg.

Large part of radio electronic equipment of satellite is duplicated: on it there are two connected transmitters and two receivers, each of which can be connected to any transmitter. One receiver has two narrow-band channels on 500 kHz, second has one channel 5 MHz wide. Reception of signals is produced at frequencies of 7361 and 7363 MHz; transmission is produced at frequencies 1814 and 1816 MHz.

Block diagram of relay is shown on Fig. 67b. Signals at frequencies of 7361 and 7363 MHz, which are received by slot antenna, join one of receivers, which is triggered on command from earth. Received signals will be converted by frequency; frequency drops to 1814 or 1816 MHz. Converted signals go to adapter, output of which is united with two transmitters. Output stages of transmitters are collected on traveling-wave tubes; output power of transmitter is 2 W. Every transmitter is switched by instruction from earth. Transmitting coaxial slot antenna, which is located along axis of rotation of satellite, radiates high-frequency energy in limits of flat ray 25° wide, plane of which is perpendicular to axis of rotation of satellite.

Antenna radiation pattern of antenna has the form of an eight. Weight of board equipment of communication is about 3.5 kg, power drain is 16.3 W.

System of reception of instructions has two receivers, two pulse decoders and turnstile antenna consisting of four pins, which is also used in telemetric equipment (Fig. 67c). Each of command

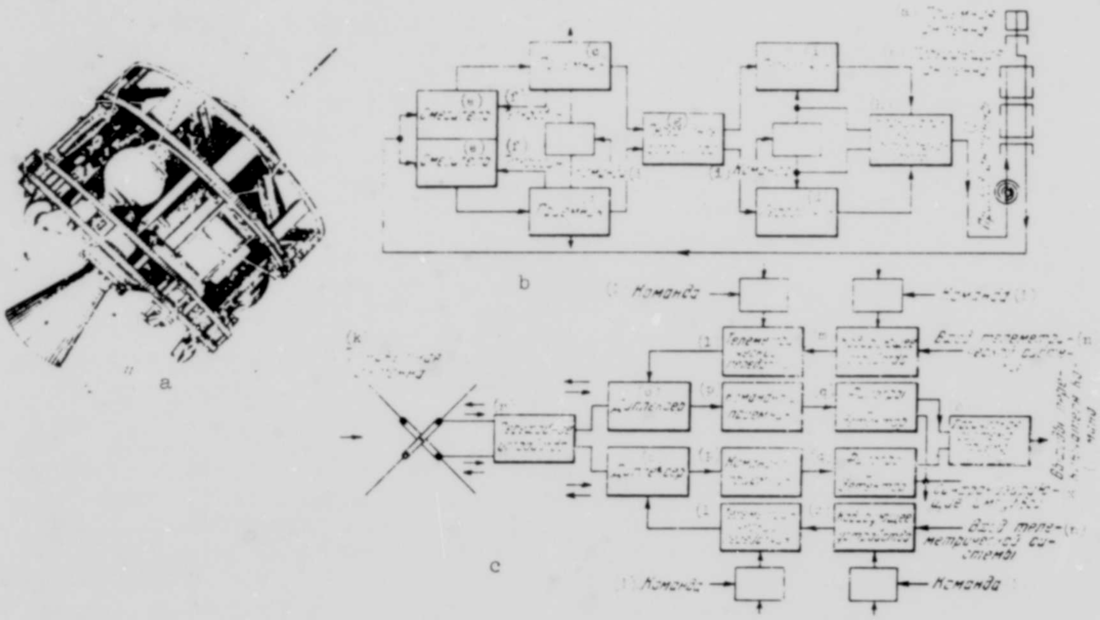


Fig. 67. Construction of satellite "Sinkom-2" (a), block diagram of its relay (b) and system of reception of instructions and telemetry (c). 1 — telemetric and command pivoting antenna; 2 — jet nozzle of system of orientation; 3 — nickel-cadmium storage batter; 4 — receiver; 5 — balloon for hydrogen peroxide; 6 — coaxial connected slot antenna; 7 — transmitter with traveling-wave tube; 8 — command receiver; 9 — bottle for nitrogen; 10 — sunseeker; 11 — timer of system of putting into stationary orbit; 12 — jet engine for putting satellite into stationary orbit; 13 — jet nozzle of adjustment of speed of flight, working on compressed nitrogen.
KEY: (a) Receiving antenna; (b) Transmitting antenna; (c) Receiver; (d) Transmitter; (e) Mixer; (f) Heterodyne; (g) Transition device (h) Coaxial switch; (i) instruction; (j) Drive of antenna; (k) Turnstile antenna; (l) Telemetric transmitter; (m) Coder; (n) Input of telemetric system; (o) Diplexer; (p) Command receiver; (q) Filters and detector; (r) Adapter; (s) Logical system of reception of instructions; (t) Output of switch of instructions; (x) Synchronizing pulses; (z) Coding device.

receivers is calculated on reception of 25 instructions — 12 for switching on of radio electronic equipment, 13 for attitude control of satellite. Receivers work on a frequency of 148 MHz with amplitude modulation.

Telemetric equipment consists of two identical 2 W transmitters operating at 136 MHz with frequency modulation. Every transmitter is intended for transmission of data about temperature inside satellite, power supplies, pressure of gas and systems of stabilization and others; 19 parameters are transmitted in all.

For determination of position of satellite in space, use is provided of two forms of information: information from sun sensors is transmitted on telemetering link to ground station, but determination of position of satellite is carried out by measurement of polarization of signal taken from satellite.

Maximum distance between points on earth's surface, communication with which was carried out with help of satellite "Sinkom-2," was 12,320 km.

In August 1964 stationary communication satellite "Sinkom-3" (the United States) was launched into a circular orbit 35,900 km high located in the plane of the equator.

In October 1964 with help of this satellite, test television transmissions from Tokyo to the United States were produced.

Above described communication satellites were created for research purposes. However, in March 1965 the United States put into stationary orbit the first commercial communication satellite "Early Bird" (which in translation signifies "early bird"). Through this stationary satellite, regular radio communications between North America and Western Europe is carried out. Satellite retransmits television programs, signals of multichannel telephony and digital information. Provision is made for transmission on 240 bilateral telephone channels with width of spectrum from 300 to 3000 Hz each. On each telephone channel, it is possible to transmit more than 22 signals of telegraph messages.

"Early Bird" is more powerful and more universal satellite than apparatuses of type "Sinkom." Satellite is equipped with two broad-band relays with bandwidth of transmission up to 25 MHz each, which permit transmitting television programs of sufficiently high quality for commercial television communication circuits.

Satellite receives signals from earth on a frequency of about 6000 MHz and carries out relaying of received signals on a frequency near 4000 MHz. Radiated power is twice radiated power of apparatuses of "Sinkom" and is 4 W. Transmitting and receiving antenna of this satellite have been considerably improved. Where function of command and telemetric subsystems are united with functions of system of communication, but secondary telemetering links are eliminated. Rated power of power supplies is increased from 29 to 45 W, for which number of solar cells is increased to 6000. For their distribution it was necessary to increase width of cylindrical surface of satellite to 60 cm.

First Soviet communication satellite "Molniya-1" was launched 23 April 1965 with help of multistage rocket. Directly after launching, elliptic orbit of satellite had following parameters: height of apogee is 39,380 km, height of perigee is 497 km, inclination of orbit is 65°, period of revolution is 11 h 48 min. Apogee of orbit is above Northern hemisphere, but perigee is above southern hemisphere. Satellite accomplishes two revolutions in twenty-four hours around earth. On one of them it flies above the territory of the Soviet Union, but on the other, it flies above territory of North America.

The biggest time of simultaneous "visibility" of satellite from Moscow and Vladivostok depends on parameters of orbit. During large deflections of period of revolution of satellite from calculated period, correction is produced with the help of board jet engine. Such correction of period of revolution was conducted, for example, 2 May 1965. Period of revolution after that became equal to 12 hours, height of perigee 548 km, and height of apogee 39,957 km.

Satellite "Molniya-1" (Fig. 68) has hermetic housing of cylindrical form with conical bottoms. On the outside of it, there

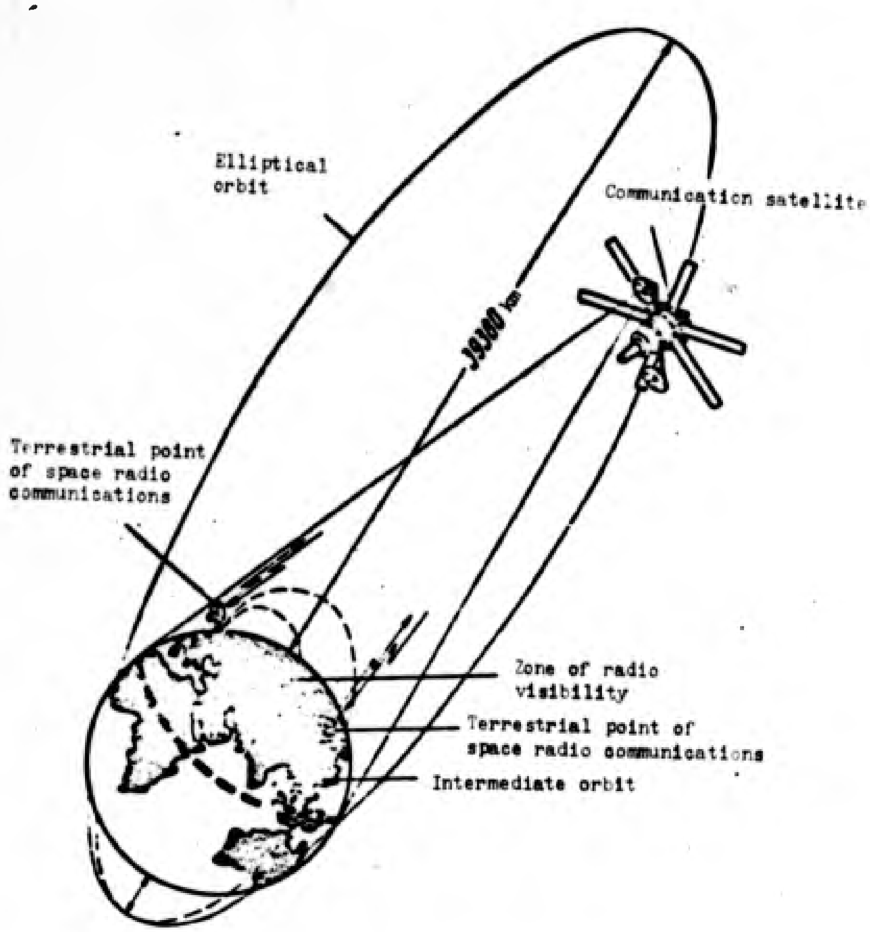


Fig. 68. Diagram of distant radio communications with use of satellite "Molniya-1."

are 6 panels with solar cells and 2 parabolic antennas. During orbital injection of panel of solar battery, antennas were in formed state and, after separation of satellite from carrier rocket, automatically opened. Correcting propulsion system and microengine are set on bottom of housing. Orientation sensors on sun and earth are located on other bottom. For thermal control are used radiator-refrigerator of cylindrical form and panel-heater in the form of a flat ring, which are braced to housing.

Radio electronic and other equipment are placed inside housing, where necessary pressure and temperature are maintained.

As sources of energy for feed of board equipment a system is used consisting of solar batteries, chemical sources of current and automatic device of adjustment of power supply.

For production of energy from whole area of solar battery, satellite is oriented during whole time of flight to sun. Simultaneously with orientation of satellite to sun during carrying out of performances of communication, one of parabolic antennas is directed to earth and with help of special drive follows earth; second antenna is reserve. Control of antenna drive is produced by signals of orientation sensor. For work with reserve antenna, satellite must turn 180° around its longitudinal axis.

Equipment on satellite "Lightning-1" permits transmitting television black and white and colored programs or carrying out a large quantity of telephone negotiations, and also transmitting phototelegraph, telegraph, and other messages.

Work of systems of satellite is controlled by telemetric equipment, control of which and also of systems of satellite is produced by airborne programmed computer for programs assigned by instructions from earth. On satellite "Lightning-1" there is also equipment for measuring radiation.

Since launch through communication satellite "Lightning-1," tests are conducted daily of bilateral line of space radio communications between Moscow and Vladivostok. Maximum duration of one performance of communication exceeds 9 hours. Tests have been successful. They showed, in particular, that satellites of "Molniya-1" type can be basis for construction of lines of relaying colored television programs.

In literature it is reported that the United States is preparing to launch stationary satellites which are to be multifunctional, i.e., will be used for communication, for navigational and reconnaissance targets, and also as space laboratories.

Ground Stations of Communication Systems Through Satellites

Peculiarity of construction of network of ground stations, applied in systems of communication through satellites will be examined by us on example of communication circuits through satellite "Telstar" and "Relay." For carrying out of experiments with communication satellites, ground stations are prepared in following points of earth: in the United States, main station is in Andover (Maine), station in Holmdel and in Nuttey (New Jersey); in England the station is located in Goonhilly-Downs near from Falmut; in France on Bretagne peninsula to the north of Lannion; in the Federal Republic of Germany in Recting near Munich; in Italy the receiving antenna and station are in the Appenine Mountains 80 km northeast of Rome; in Brazil in the vicinity of Rio de Janeiro; in Japan east of Tokyo.

Which are the main ones of these stations?

In the United States, as we have said, main station for communication is on one of the heights near Andover. This gigantic receiving-transmitting antenna with horn reflector is 52.5 m long and weighs 370 t. Antenna is placed in protective housing 55 m in diameter. Basic advantage of horn construction of antenna consists in the fact that diagram of its radiation has very small lateral lobes, as a result of which that part of noises decreases which is caused by thermal motion of charged particles in earth.

Effective surface of antenna is equal to 330 m^2; this permits obtaining antenna radiation pattern with solution 0.2° at frequencies utilized in "Telstar" system. During ensured concentration of energy on frequency 6000 MHz, amplification is attained of the order of 1 million with respect to absolutely directed radiation; amplification on frequency 4000 MHz is little more than half of this value. Another important merit of the antenna is its ability to work in a wide frequency band.

Receiver and transmitter are placed in 8.5 × 9 m metallic housing, which is for summit of horn. Power of radiated oscillations is equal to 2 kW on frequency 6390 MHz at bandwidth 25 MHz. In first stage of connected radio receiver, quantum-mechanical amplifier is used.

Two-hundred kW command radio transmitter has its own four-helical antenna. This antenna is used for reception of signal continuously radiated by satellite on frequency 136 MHz, modulation of which is carried out by board equipment of telemetry, triggered during transmission of corresponding instruction.

Satellite capture and tracking occur in three stages. Position of satellite is approximately known from data transmitted during launching and subsequent observations with the help of "Minitrack" stations at different points of the earth. First capture occurs during reception of signal of beacon on frequency 136 MHz with the help of four-helical antenna. Antenna has width of antenna radiation pattern 20°, i.e., sufficient for detection of satellite even with very indefinite information about its position. After reception of signal from satellite, its angular position is determined with a precision of ±1°. After that an instruction is transmitted of switching on connected equipment and radio beacon on 4080 MHz. And precision tracking system starts to work which determines position of satellite with an accuracy of 0.02°. By this installation of horn is attained within limits of zone of capture of vernier system of autotracking, with the help of which final centering of radio beam with respect to satellite is carried out.

Station in Goonhilly-Downs, located in southwest part of England, is equipped with a mirror-parabolic antenna 25.5 m in diameter, which can be directed toward any point of the upper hemisphere with the help of automatic control. This antenna is used both for reception and for transmission either in system of communication "Telstar," or in system "Relay." Width of ray of antenna is equal to 0.15°. Full weight of revolving platform with equipment is 870 t, power of drive motors is about 150 kW.

Power of transmitter intended for communication with "Telstar," is 5 kW, and with satellite "Relay" 10 kW. Information about position of satellite on orbit, necessary for control of antenna, joins English station on telegraph line from Goddard center of space flights, which is located in the United States. In Goonhilly-Downs this information is processed by electronic computer.

French station constitutes exact copy of station in Andover. Tracking of stationary satellite "Sinkom" is carried out by system "Minitrack."

Ground stations begin to receive signals from satellite "Sinkom" after it reaches a point located 1.5° above the horizon; at a point 0.5° above the horizon, ground stations carry out capture of satellite on signals of radio beacon.

Mobile station is placed on 10 trailers and can be transported by air or motor transport. It consists of antenna, powerful ultra-high frequency transmitter, sensitive connected receiver, equipment for connection of subscribers, receiver of system of tracking, and feed unit ensuring autonomy of station operation.

CHAPTER VII

TELEVISION AND THE SECRETS OF THE UNIVERSE

Television telescopes. Extraterrestrial observatories. Metorological and geodetic satellites of earth, which are equipped with television equipment.

Huge distances separate earth from celestial bodies; therefore, in spite of their colossal dimensions, viewing angle as seen from earth is very small. Of the number of stars, the naked eye can distinguish not more than 3500; these stars are to us in the form of light points. Representations of moon, planets, and sun have comparatively large dimensions, but are still too small, for their structure to be discernable.

In order to discern celestial bodies, it is necessary to increase viewing angle, under which they are seen. This can be achieved either by approaching celestial bodies, or by creating instruments which increase viewing angle, i.e., telescopes. But telescopes receive only an insignificant part of rays of light radiated or reflected by celestial bodies; therefore, for observation of remote celestial objects, telescopes with mirrors of large diameters are erected. The larger the area of lenses of the objective, the bigger its resolving power. Maximum diameter of mirror of largest telescope in the world is 5 m, and telescope itself together with turning device constitutes complicated, very bulky and dear construction. This telescope permits revealing celestial objects, remote from us on distance over 500 millions of light years.

In order to make possible observation of still more distant objects, it is required to increase dimensions of telescope considerably, but this is connected with very great difficulties. Thus, in reflective telescopes with increase of diameter, mirror under its own weight or due to change of temperature sags, and for lens objectives, it is difficult to prepare lens of large dimensions from transparent and uniform glass.

Not only the appearance of celestial bodies interest scientists but it is very important to know their temperature, structure, presence of atmosphere, and its composition. To obtain answers to these questions is still more complicated; therefore, astronomers try to use all possibilities, which contemporary science and technology present to them.

Television Telescopes

In contemporary scientific astronomical investigations, photographic methods are widely used. For creation of photographic representations corresponding to very weak illuminances, it is necessary to increase exposure, but this increase has limit. Properties of photographic light sensitive layers are such that during very low levels of illuminance, increase of exposure a definite, number of times is not equivalent to decrease of luminous flux that same number of times. Background of night sky and oscillations of this background relative to some average value is difficult to distinguish from very weak stars of the 22nd and 23rd magnitude. Exposure of light sensitive material should be optimum in this case. At small exposures, pictures are very low-contrast, and at more prolonged exposures is obtained superposition of one on another grains of silver of photographic emulsion, and film becomes too tight. Therefore, for best investigation of universe, it is necessary to use more sensitive receivers of light. To number of such receivers belong photocathodes of photoelectrical converters, arrangement of which is examined in Chapter II. Quantum yield of photoelectrical converters is a hundred times more than quantum output of photographic films, which permits signigicantly increasing effectiveness of registration of astronomical observations. For fixing of representation after telescope can be used image converters of light or television transmitting tubes.

It is necessary to note that external photoelectrical effect is proportional to luminous flux in a very large range. It is especially important for astronomy that this regularity is preserved to least possible levels of light, up to one quantum. Possibility of use of electromagnetic radiations of large range of wave lengths of electromagnetic oscillations is also valuable.

During use of television method of investigations from video signal, it is possible to subtract signal of uniform light background and thereby to increase contrast in needed range of signals. This contrast can be increased more at the expense of use of amplifiers with nonlinear amplitude characteristic (correctors of contrast). Use of television method of observations permits increasing brightness of representation after telescope, transmitting representation from telescope great distances, and also obtaining on screens of receiving devices increased representations, which can simultaneously observe a large group of people. Here it is possible to regulate scale smoothly, contrast and brightness of representation, memorization of representations, etc.

Serious interference for astronomical observations from surface of earth is atmosphere, which refracts rays, going to earth and partially absorbs them. Rays of light passing through layers of continuously moving air, are differently refracted and weakened. As a result decreases visible brightness of stars, they blink; their representation in telescopes shivers and spreads. Intensity of luminous flux from celestial bodies is extraordinarily small; therefore, during photographing of representations of planets, stars and nebulae, very great endurances are necessary, which are measured in minutes and even hours. Vibration of representation of luminaries leads to the fact that after manifestation of photographic film, representation turns out to be illegible and blurred.

Thanks to possibility of increase of brightness, television methods permit significantly reducing endurance and selecting for photographing the opportunity corresponding to the clearest representation in the telescope. Moreover, if great endurances during photographing are necessary, then application of television methods permits compensating vibration of representation resulting from atmospheric interferences.

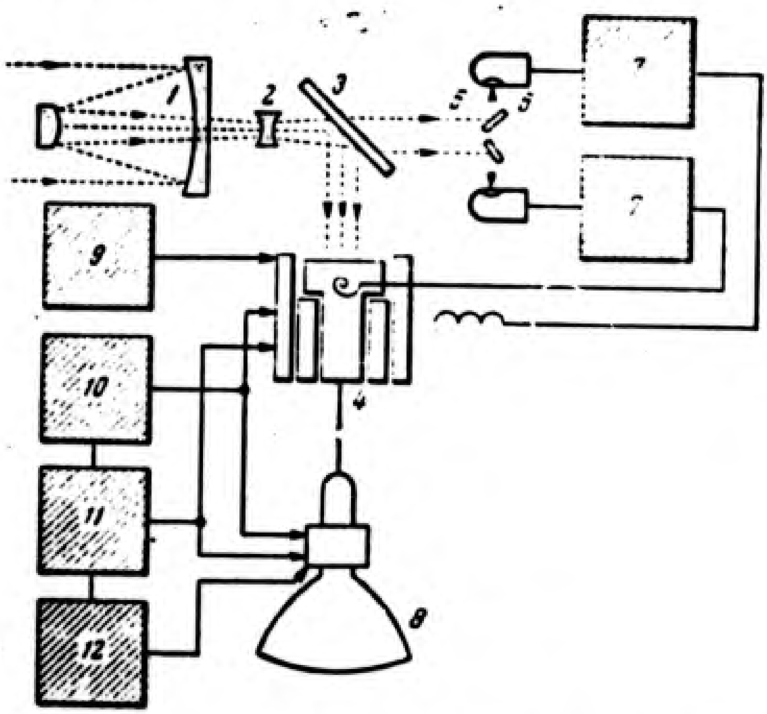


Fig. 69. Block diagram of television astronomical installation with compensator of atmospheric interferences. 1 — telescope; 2 — lens; 3 — semitransparent mirror; 4 — image orthicon; 5 — compensator; 6 — photomultipliers; 7 — d-c amplifiers; 8 — reproducing tube; 9 — feed unit; 10 — generator of synchronizing pulses; 11 — generators of scanning oscillations; 12 — generator of quenching pulses.

On Fig. 69 is shown block diagram of compensator of atmospheric interferences in which television equipment is used (built in the United States in 1957). Diameter of optical representation reaches 12 mm; part of luminous flux from lens goes to photosensitive layer of transmitting television tube of image orthicon type, but other part passes through color selective filter and will form representation on two mutually perpendicular slots of compensator. Behind slots are located two photomultipliers, signals of output of which move to amplifier but then are sent to two pairs of coils, located around section of transfer of tube. Axes of coils are mutually perpendicular. Displacement of optical representation on slots changes luminous flux getting on photocathodes of multipliers and increases (or decreases) magnetic field in coils. Change of this field leads to displacement of electronic representation on target of tube. Selection of phase and value of current in coils achieves displacement of electronic representation in direction opposite displacement of optical representation on slots and photocathode of transmitting tube. During corresponding adjustment of amplifiers of current of electron multiplier phototubes, electronic representation on target, and, accordingly, on screen of picture tube of video supervisory equipment, becomes motionless.

In one of observatories, television equipment was adjusted to horizontal solar telescope. Using filters passing ultraviolet or infrared rays of sunlight on photocathode of transmitting tube, researchers observed surface of sun in these rays. On specially built solar spectrograph with television equipment were made spectral observations. Thus it began possible to examine on screen of picture tube and to photgraph phenomena, which occur on surface of sun, and which were not accessible earlier for observation by optical methods.

Since 1952 television methods have been used in Glavnaya Astronomical Observatory of Academy of Sciences of USSR. In 1958 in Pulkovskaya Observatory was completed installation of experimental television telescope, optical circuit of which permits obtaining large increase with small losses of light in optics. Here use of image orthicon is provided for in conditions of prolonged accumulation of potential relief on target (during several tens of seconds), but, consequently, increase of sensitivity of tube. First experimental observations already showed that in conditions of accumulation during 6 s, it is possible to photograph star of the 10th magnitude. Illuminance on photocathode of tube in these conditions was not more than 0.001 lux, but gain in brightness reached 30,000-40,000.

In this observatory Soviet astrophysicist N. F. Kuprevich with help of television equipment sensitive to infrared rays in 1962 obtained unique photographs of moon. These photographs are done in infrared rays in 0.8-2.3 μm range. Series of lumar photographs obtained in infrared rays turned out to be truly remarkable. On them are recorded many, peculiarity of relief of our satellite not known till now. Usually "sea of clouds" on surface of moon is depicted in the form of plane with indefinite spots and with small quantity of craters. And on photograph obtained in infrared rays instead of plain it turned out to be annular mountans surrounding central part and filling all space "of sea." Light rays, proceeding from crater "Tinkho", are usually in the form of double luminescent lines. And new photographs, these rays are split into a series of craters stretched on one line. Other line is similarity of mountain range. Nearer to center of disk of moon, in region of crater " of Copernicus", till now were fixed dark spots. Now it has beeen clarified that these are craters with sharply expressed structure. Other appears "Sea of rains." It constitutes uneven, hilly surface, where in its upper part (near crater "of Copernicus") is clearly seen structure of annular mountains, usually not designated on maps.

Presence of annular mountains is revealed in other places of surface of moon.

In the United States, television installation was used jointly with 600 mm by telescope for photographing Mars during its opposition in 1954. Optical representation of Mars after telescope, additionally increased to a diameter of 10.5 mm, was projected on photocathode of superhighly sensitive image orthicon with two-stage electron-optical amplifier of brightness (see Fig. 19b). Television equipment was calculated on decomposition by interlaced screen into 1029 lines at 30 frames per second. Representation was examined and was photographed from screen of picture tube.

Solar bursts and their influence on earth and nearby space are no longer the subject of only scientific interest. For inhabitants of earth protected by cover of atmosphere, basic result of solar activity was disturbance of radio communications. But when space travellers emerge from under protection of atmosphere, they will meet with powerful solar radiation, and dose of irradiation, even on distances equal to distance from sun to earth can be mortal. Specific value have bursts, which constitute catastrophic disturbances of chromosphere, i.e., solar atmosphere, with appearance both of wave and of corpuscular radiation of extraordinarily high intensity. In visible part of spectrum, radiation is concentrated within limits of several narrow filaments; the most intense of them is line H_α (6563 Å). During bursts sharply is increased also X-ray and ultraviolet radiation and giganti particle fluxes of high energy are emitted. The greatest danger for journeys in cosmos is corpuscular streams. Therefore, problem of prediction of bursts becomes vitally necessary. In this connection the warning system about bursts depicted in Fig. 70 deserves attention. This system includes smasher of light ray, narrow band filter, television camera on vidicon with corresponding circuits of deflection and synchronization circuit of establishing threshold, control unit for guiding of telescope and logical position circuit.

Representation of solar disk, passing through ray smasher and narrow-band filter, passing line H_α, gets on target of vidicon. Video signals from output of camera are processed in circuit of establishing threshold and in position circuit. Support displacement in circuit of establishing threshold is set so that circuit reacts to intensity of light, somewhat exceeding expected intensity of radiation of torches. During projecting of representation of sun on target of vidicon in rays H_α it becomes easy to detect burst. For determination of position of burst are used pulses of frame and small synchronization. After detection of burst and determination of its position, system produces signal, directing telescope to region where burst was formed. Simultaneously there can be switched on a system of indication of position of burst and automatically actuated recording installation. Prediction of bursts is possible thanks to the fact that before their appearance on sun or its separate regions there are observed disturbances, study of which permits predicting approaching appearance of burst. Prediction of bursts will promote automation of observations and treatment of data.

Television technology in combination with long focus telescopes finds application for detection of spacecraft and their tracking. This is caused by the fact that observation of satellites of small dimensions during large angular shifts of them is practically impossible with help of only narrow-band optical systems. At the same time, it is possible to track satellites with still higher angular speeds with help of cameras on image orthicons.

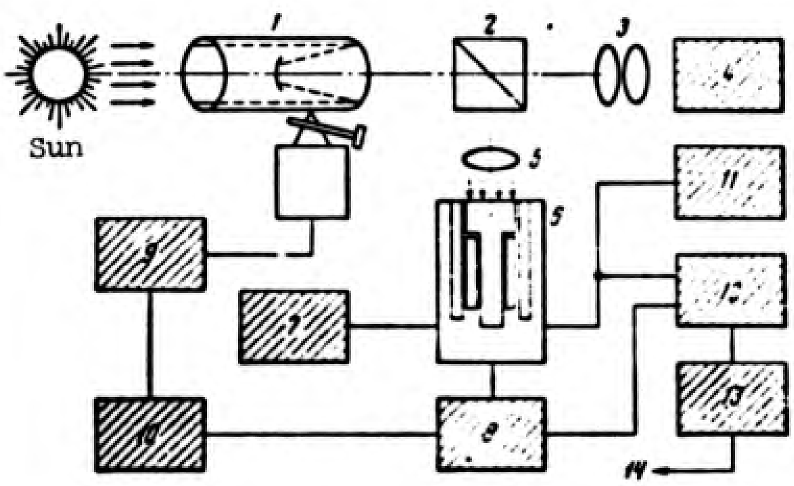


Fig. 70. Block diagram of installation for prediction of burst on sun. 1 — guiding solar telescope, 2 — smasher ray; 3 — solar filters; 4 — registration on photographic film; 5 — filter of line H_α; 6 — television camera; 7 — power supply; 8 — generator of scanning oscillations; 9 — drive of telescope; 10 — clock and synchronizer; 11 — circuit of establishing threshold; 12 — determinant of coordinates of burst; 13 — transducer of instructions for telescope with narrow field of sight; 14 — to telescope with narrow viewing angle. Burst, intensity of which exceeds threshold of operation, is revealed with the help of guiding telescope tracking sun. For detailed study of burst is used telescope with narrow field of sight.

Merits of television methods will appear all the more distinctly according to creation of transmitting television tubes, intended specially for application in astronomy. In such transmitting tubes, it is attempted to increase considerably sensitivity and resolving power. Constructions are proposed of tubes allowing storage of comparatively large charges and their preservation without change during a prolonged interval of time (up to several hours), then using them for reproduction of representation.

Application of television systems also permits producing automatic orientation of telescope in accordance with stellar motion in firmament.

Extraterrestrial Observatories

We already talked about the fact that terrestrial atmosphere is nonuniform in its optical properties. Its layers have different density, humidity, and temperature and are constantly mixed, transferred by wind, change their circuits. Light rays from stars, passing hundreds of thousands and, occasionally, millions of light years, enter layers of atmosphere in a practically parallel beam. But being refracted in atmosphere, they no longer remain parallel, and become convergent or divergent. Therefore, the observer the stars seem to be blinking. But besides change of brightness, there occur fast geometric displacements of stellar representation, which we call vibration of representation.

All these atmospheric interferences considerably distort images of celestial bodies. They are always subject to deformations of different magnitude and in different directions. Certain parts of representation are compressed, others are expanded. Disk of planet seems wavy or indented; its image seems to foam. Therefore, observatories equipped with strong and bulky tools are constructed on mountains in order to emerge beyond the limits of lower, most contaminated and restless layers of terrestrial atmosphere.

Application of compensator of statics described by us permits improving quality of representation, but distortions of representation, caused by statics, cannot be completely avoided.

The best way to get out of this hopeless position, one would think, is to create an observatory beyond the limits of the atmosphere. Carriers of these outer space observatories can be, in particular, artificial earth satellites, and our constant satellite – the moon. Such extraterrestrial space observatories will allow observing world of celestial bodies in undistorted form. During construction of observatories on artificial satellites it will be possible to create telescopes of large dimensions and to simplify considerably their construction. The fact is that in outer space thanks to weightlessness the problem of nonuniform distortion of mirror of telescope is eliminated, which so hampers work of large ground telescopes. Thus, for observations of limits of atmosphere, telescopes of larger dimension than on earth are possible in principle. It is possible to present to oneself a very large telescope with a hole more than 10 m and resolving power better than 0".01. However, in near future, apparently, one should not expect possibility of manufacturing a mirror of such diameter.

At that height, where artificial earth satellite will be, atmosphere will no longer distort astronomical observations and from such outer space observatory will be seen nonglimmering stars. This will allow producing fixation of representations of planets and their satellites with any increase, whereas in terrestrial observatories, a thousandfold increase already causes difficulty. It is necessary to say still that ground observatories cannot observe stellar sky by day

— this is hindered by atmosphere, but observation in outer space observatories will not be limited by time of day. It is obvious that astronomical observations will not depend on caprices of weather as frequently as earth.

All these advantages of outer space observatories will allow observing and fixing representation of stars and star clusters, which are inaccessible to terrestrial telescopes. Value of these observations will increase many times more because there will be increased considerably spectrum of electromagnetic oscillations, in rays of which it will be possible to observe representation of bodies of universe. It is known that spectrum of electromagnetic oscillations which use ground observatories is limited, not only by properties of instruments themselves, but also by opacity of atmosphere for many rays (see Fig. 44). Thus, for observations there remains only a small visible window, somewhat smaller than region of infrared rays and wider range of radio waves. This means that many astronomical data are hidden from us. Thus, considerable part of radiation of solar corona was apportioned to ultraviolet region and long-wave range of spectrum. Radiation of planet attains maximum in distant infrared region of spectrum, which is absorbed by terrestrial atmosphere. Very hot stars are bright in ultraviolet part of spectrum; interstellar dust has intrinsic emission in infrared region of spectrum. In distant galaxies we see only that part of their spectrum, which in spectra of close galaxies lies in inaccessible ultraviolet region. Observations of distant and close galaxies in comparable regions of spectrum permit deciding question about "aging" galaxies. Observation in regions of spectrum inaccessible at present with help of outer space observatories will allow obtaining not only expected, but also absolutely new and unexpected results.

From this follows that for best knowledge of universe, it is necessary to lift astronomical instruments higher than tight cover of atmosphere.

What sort of role is played by television and what relationship does it have to extraterrestrial observatories?

Without use of television all reasonings on expediency of creation of extraterrestrial observatories can be examined only as abstract dreams. Actually, problem of launching artificial earth satellites and creation of interplanet stations and ships is solved. But how to transmit optical representations obtained on board of spacecraft to earth? Best means of transmission of representations (essentially, only) is television.

Certainly, observation with the help of telescope removed beyond the limits of terrestrial atmosphere opens very wide possibilities for investigations, but engineering problems connected with requirements of reliability of work in unknown or insufficiently studied conditions are also very complicated.

At launch the satellite is acted up by very great forces. Besides constant acceleration, usually lying within limits from 10 to 30 g, there is also very strong vibration, which generates additional variable acceleration of the order of 20 g with a frequency from several cycles per second to several kHz. This vibration creates serious difficulties.

As soon as satellite is put into orbit, action of mechanical forces absolutely stops. This is good from the point of view of construction of telescopes of large dimensions. However, absence of large masses hampers stabilization and orientation of telescope.

High vacuum in which satellite moves, hampers supporting of thermal equilibrium, but radiation spreading in vacuum can damage equipment. Ultraviolet and X-radiation can destroy reflecting covering of mirror of telescope. From this point of view micrometeorites are dangerous.

For outer space observatories it is reasonable to select orbits which pass outside radiation belts of earth, which extend in altitude from 800 to 30,000 km. Thus, observatory should be either slightly lower than 800 km, or higher than 30,000 km. Average height of 800 km is almost the lowest level, where resistance of air is negligible even on a not quite circular orbit.

One more peculiarity of interplanetary space is field of force (field of radiation, field of gravitation and magnetic field), which can cause torques in outer space observatory.

After putting observatory into orbit, it is necessary to decrease speed of rotation of apparatus to acceptable value. During exploitation of observatory, it is necessary to direct stellar telescope against defined section of firmament and from time to time to change aiming in accordance with program of observations. In process of the actural observation, orientation of telescope should remain constant, of course, within limits of assigned accuracy.

In order to give rotation in defined direction to satellite, it is possible to use rotation of internal masses in opposite direction. For this it is possible to use reaction of outflow of gas stream. It is possible to regulate one of the torques. It is expedient to regulate two of them: to change pressure of radiation or influence of magnetic forces.

Guiding of telescope of satellite, in defined direction and stabilization of its position with the help of remote control require not only roll control, but also presence of very sensitive transducer for determination of real direction of optical axis.

And all of this is no longer fantasy. People start to store first experiment in creation and use of outer space stations. Already there are being applied different systems for production of information about object of observation. On a number of launched satellites there worked a system in which during scanning of representation was used travel and rotation of the actual satellite. As photoelectrical converters were used photocells, working in visible and infrared regions of spectrum of electromagnetic oscillations. Those systems are improved in which electronic television installations are used for production of representation.

Several years ago there appeared in foreign literature description of system intended for transmission to earth of representations of sun from stratosphere balloon. On stratosphere balloon there is a 300 mm reflector. Representation of solar surface created by it is recorded by movie camera on film and once per second with help of television board camera and radio transmitter is transmitted to earth. Presence of television installation permits producing remote control by optical focusing and direction of telescope sight. Height of rise of stratosphere balloon with equipment is 30 km.

Now there appeared second variant of such installation, "Statoscope-II." In telescope of this astronomical observatory, a 900 mm diameter mirror is already used. This installation is intended for stellar and planetary photography and infrared spectroscopy. In composition of board equipment stratofalcon are two television cameras on supersensitive image orthicons. Electrical circuit of television system is carried out basically on semiconductors. All feed is carried out from nickel-cadmium storage batteries. In installation decomposition is produced of representation on 400 lines. Sensitivity of television cameras is sufficient for observation of stars of the 8th magnitude through wide-angle television camera and stars of the 12th magnitude through narrow-angle television transmitting camera. On stratofalcon is used radio transmitter with average output power of 20 W. Already during first two launchings of stratofalcon, there were obtained data about infrared radiation of moon, Mars Jupiter and a number of stars: Betelgeuse, Aldebaran, ρPerseus, ρLeo, μGemini, Lyra, μCepheus.

For study of stars was created ultraviolet space telescope, which was lifted to a height of 240 km with the help of a rocket. In this equipment is used a specially developed transmitting television tube, a uvicon, which is sensitive to ultraviolet rays. Principle of action of uvicon is analogous to vidicon. In this case television system serves for transmission of observations. Pictures reproduced on earth are recorded on film, but video signals are recorded on magnetic tape. So that scientists can obtain at least qualitative presentation about spectral distribution of energy of radiation of stars, whole ultraviolet region of spectrum is divided into five subbands. For transmission of representation of stars only corresponding filters are used in rays of each of these subbands.

Block diagram of electronic equipment of ultraviolet stellar telescope is shown in Fig. 71. In television system is used decomposition into 600 lines. Since representation of stars has the form of small light points, then it is desirable to have possibility of observing video signal of every separate line of television screen. This process is carried out with help of so-called oscillograph of line selection.

Arrangement of uvicon is shown on Fig. 72a. On reverse side of input biconcave lens of fluoride lithium (passing ultraviolet rays) is located photocathode sensitive to ultraviolet radiation. Lens with help of grinding is adjusted exactly under dimensions of telescope. Photoelectrons emitted by photocathode are influenced by accelerating electrical field created 15 kV voltage drop. With help of electrostatic focusing system consisting of two rings, electronic representation is focused on surface of semiconductor target. Electrical conductivity excited during electron bombardment in each point of target depends on number of arriving electrons.

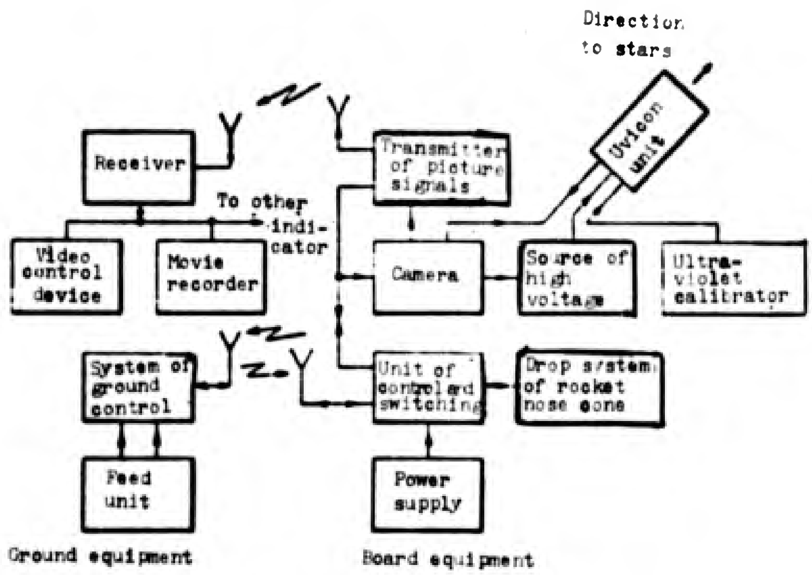


Fig. 71. Block diagram of stellar telescope beyond the atmosphere.

Further created potential relief is read by electron beam just as in vidicon.

Optical system of telescope is shown on Fig. 72b. This 76 mm diameter parabolic mirror is set in special cell, which allows regulating angle of inclination of mirror to optical axis of telescope. System with single reflecting surface is selected because those few materials which are transparent for ultraviolet rays have low passing ability, but reflecting materials have low reflectance for waves shorter than 1400 Å. Mirror is made of quartz; on reflecting surface of mirror is applied aluminum covering, but over it is applied layer of magnesium fluoride. This gives reflectivity of the order of 20% for radiation of 1000 Å. With increase of wave length of radiation to 1200 Å, reflectivity increases to 80% and then remains comparatively constant for all remaining distant part of ultraviolet region of spectrum.

Four filters (Fig. 73) are used in the form of compact system placed directly before sensitive surface of uvicon. Taking into account filtrable action of input lens of uvicon, this permits dividing whole spectrum of ultraviolet radiation into five subranges.

At present development of extraterrestrial observatories in the United States is characterized by transition from small artificial earth satellites to heavier ones carrying several tens of scientific research instruments for carrying out different experiments simultaneously. This became possible as a result of introduction of rockets-carriers able to put payload weighing several tons into orbit around earth.

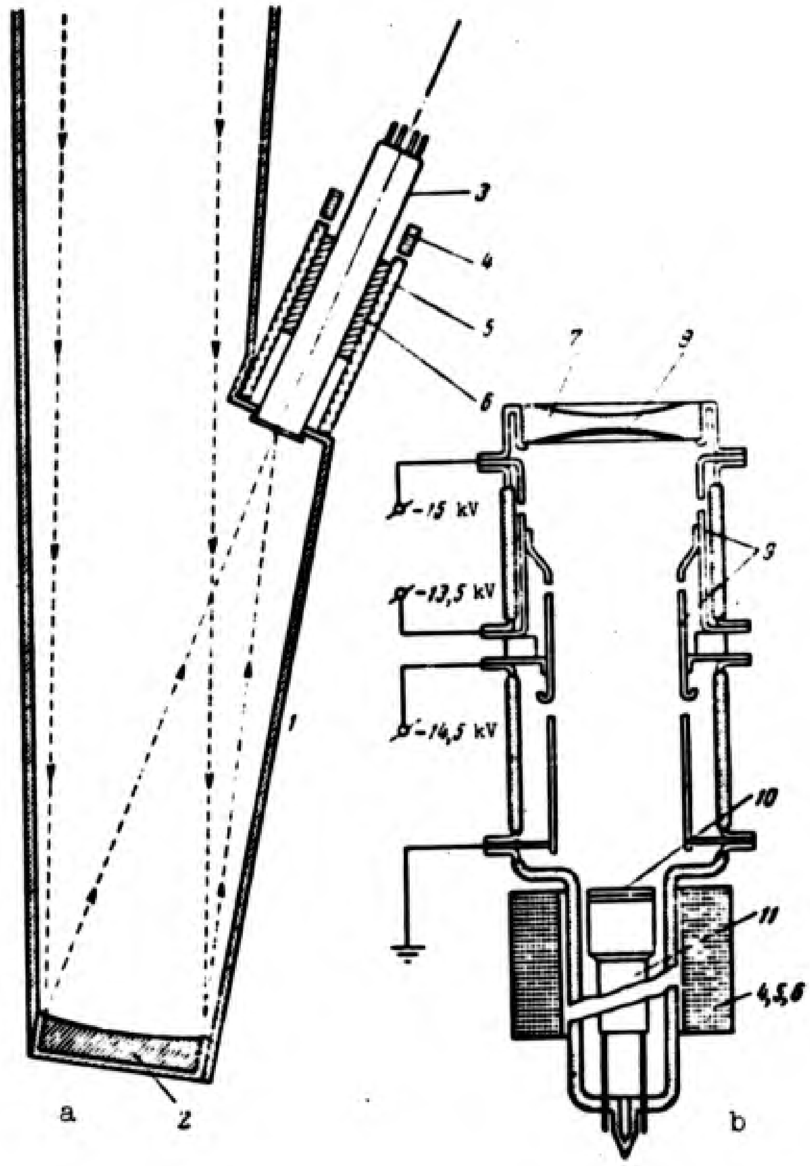


Fig. 72. Optical diagram of wide-angle telescope (a) and diagram of arrangement of uvicon (b). 1 – drawtube of telescope; 2 – extra-axial parabolic mirror; 3 – uvicon 4 – correcting coil; 5 – focusing coil; 6 – deflecting coil; 7 – lithium fluoride lens; 8 – photocathode; 9 – focusing electrodes; 10 – target; 11 – electron gun.

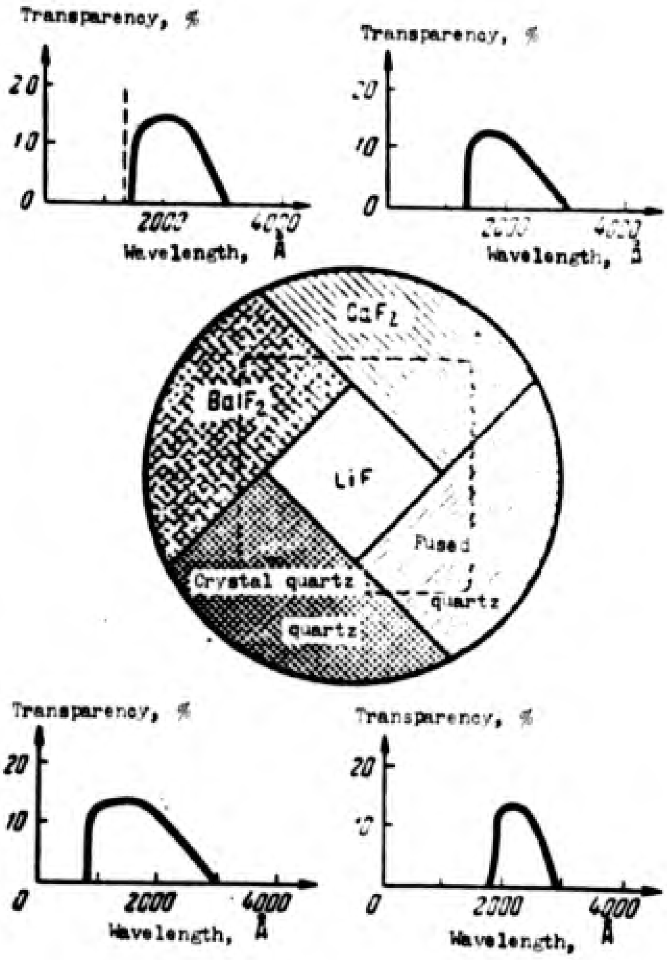


Fig. 73. Filter of transmitting television installation of stellar telescope.

Every type of extraterrestrial observatory is created as standardized spacecraft with modular sections for distribution of equipment and scientific research instruments in them. This permits carrying out individual manufacture, test, installation and, if necessary, removal or replacement of any unit of equipment of extraterrestrial observatory or scientific research instrument without damage to construction of spacecraft.

It is proposed to create observatory weighing 450-1500 kg. Such observatory will be able to investigate planets of solar system, galaxies and nebulae without interferences inserted by terrestrial atmosphere. It is assumed that orbital observatory will be stabler because of absence of seismic oscillations. Information, obtained with help of 760 mm telescope set on orbital astronomical observatory will apparently, be equivalent to that information which is obtained with the help of 5000 mm telescope in ground observatory.

In the United States, there are being developed several models of orbital observatories, on board of which will be set telescopes with different diameters of mirrors. In particular, on first orbital astronomical observatory will be set four 300 mm telescopes, but on second extraterrestrial observatory is outlined to set on 900 mm telescope with wide aperture spectrophotometer. We consider possibilities of creating orbital observatory with one 1300 mm and even with one 5000 mm telescope.

First American orbital astronomical observatory will have following dimensions: amplitude at opened panels on solar cells about 4.3 m, height at lifted solar screen of 4.2 m. Basic cells of construction of observatory are: building in the form of octahedral prism, external surface of which acts as radiator, issuing into outer space surplus of heat, separated by equipment of satellite; protective screens from solar radiation, set on upper and lower bases; panel with solar cells. Height of prism 3 m, distance between parallel edges 2 m. In central part of housing is located cylindrical pipe with internal diameter up to 1000 mm; to it are braced eight radially located right angled trusses and transverse set of frames and shelves. Sheathing of housing of observatory and wall of containers with equipment serve for protection of equipment of meteorites.

On first project is made installation including 4300 mm telescope for investigation and photographing of distant galaxies in ultraviolet region of spectrum. Three telescopes are intended for carrying out observations in three nearby sections of ultraviolet region of spectrum in range from 1100 to 3000 Å. With help of fourth telescope will be conducted observation in 400-2200 Å range. It is assumed that after 12 months of its existence in orbit, observatory will be able to transmit characteristics of not less than 100 thousand stars. Obtained data will supplement information of astronomers about composition of interstellar dust, atmospheric hot stars, planetary nebulae and, possibly, external atmospheric cold stars.

Picture signals will be transmitted to earth in the form of a continuous signal or in the form of digital signals in accordance with instructions proceeding to television scanning built-in systems from earth. Continuously operational television system will be used basically for qualitative observation and for transmission of pictures of nebulae.

Equipment of orbital astronomical observatories will be rather complicated. Main subsystems of observatories will be: four television cameras on transmitting television tubes, sensitive to ultraviolet radiation (they are intended for conversion into electrical signals of pictures obtained with help of telescopes); analog and digital equipment (which will convert these electrical picture signals into a form convenient for transmission on telemetering link); program control system; system of electromechanical and optical control, stabilization, guiding; power supply.

System of guidance, stabilization, and attitude control of observatory in orbit contains transducers of solar and stellar orientations, rate gyroscopes, controlling jet nozzles with large and small thrusts, coarse and exact revolving flywheels with single drives from electric motors, television system and special installation using magnetic cools.

In batteries of solar power supplies are used 58,000 cells, ensuring average power of 500 W. Panels are secured on housing at an angle of 33.75° to longitudinal axis of observatory. Possibilities are studied of creating devices for automatic orientation of panels with solar cells on sun.

First orbital astronomical observatory is to be put into circular orbit around earth at 800 km.

There is an American project of observatory on the moon. It will include system of communication with help of lasers, high-frequency command and telemetering link of communication, telescope, television camera about delayed scanning and device of transmission of information. Period of service of equipment is not less than one year, its weight is not more than 45 kg.

One of the assignments of system will be carrying out astronomical observations. For this purpose will be used 8-inch telescope in combination with image orthicon and photometer as light sensitive device. These instruments will allow observing stars of the 15th magnitude and will transmit pictures to earth at 85 frames per day. Lunar observatory will have one more assignment – to obtain first reliable information about work of equipment on moon.

Meteorological and Geodetic Satellites of Earth Which Are Equipped with Television Equipment

Objectives of optical tools on board spacecraft will help to study not only celestial bodies remote from us, they will be directed at our planet, too. And, undoubtedly, information obtained by such observations will appear extraordinarily valuable and will be used practically.

Up to now we do not know exact form of our planet. Television installations in combination with other devices will help to determine not only true form of earth, but also to check how far are true assumptions that its form continuously changes. Application of television means will allow us to establish whether there exists in fact assumed relative shift of mainlands.

It is known that for only 7% of surface of terrestrial land there exists exact cartography of mainlands. From artificial earth satellites it will be possible to transmit representation of hardly accessible sites and, consequently, to definitize maps, obsolete in connection with construction of hydroelectric power plants, roads, airfields, etc. Large spaces will appear covered by clouds, but also this will not serve as interference, since television camera will create picture signals at the expense of formation of representations in infrared rays of spectrum on photocathode of television transmitting tube.

On earth much depends on weather. Colossal losses and innumerable disasters bring to humanity showers and floods, hot drought and cruel frosts, strong storms and hurricanes. Therefore, it is vitally important to expect change of weather in order to take necessary measures of protection in time. There are a thousand meteorological stations, which conduct systematic observations of change of weather, and there are many aerological stations carrying out vertical soundings of atmosphere to heights of about 20-30 km. Materials of observations obtained by these stations are used for composition of synoptic maps — a basic means of weather forecast. But about 4/5 of surface of the earth is occupied by oceans and seas, but considerable part of land constitutes inaccessible regions (desert, mountains, polar regions, impassable jungles and others) and, thus, only a small part of the earth is covered by a network of meteorological stations. It is obtained that whole main part of earth's surface, where weather is properly formed, meteorologically is investigated extraordinarily weakly (episodical ship observations, meteorological station. This hampers weather forecast.

Difficulties of weather forecast can be effectively surmounted, if for observations of distribution and movement of clouds, for determination of cloud cover of earth, borders of warm and cold air masses and propagation of storms, there are used artificial earth satellites equipped with television equipment. Data obtained will allow not only predicting weather, but on the basis of performed investigations understanding weather processes and actively learning to exert influence on weather and climate. Main advantage of meteorological observations from satellites is possibility to obtain necessary information about processes in atmosphere for whole territory of the earth, and also to carry out continuous tracing of processes on large sections.

We must assume that application of television observations from aboard satellite for travel of ices in Arctic seas and oceans will be very effective. Seafarers will be warned about ice blockings, icebergs, etc. Television installations on satellites will allow watching huge massifs of woods and timely signalling about appearance of forest fires.

Huge volume of information from meteorological satellites will lead to full automation of its treatment with help of high speed electronic computers, starting from registration of signals from satellites to construction of synoptic maps or realization of numerical weather forecasts. For transmission and treatment of this information will be created ground centers of data processing and, moreover, special communication satellites.

Well, what now? Have there already been successes in the use of television in service of weather forecast on earth? Yes, and they are considerable.

Television equipment was successfully used for the first time in April 1960 on meteorological satellite "Tayros-1." Later (in 1960-1965) 9 more satellites of the same series were launched. On these satellites was television equipment intended for transmission to earth of picture of cloud cover above region located around the earth between 55° north latitude and 55° south latitude. On all satellites of this series (besides third and eighth) there were applied wide-angle and narrow-angle television cameras, satellite "Tayros-3" was equipped with two wide-angle cameras, but "Tayros-8" had one wide-angle camera.

With help of wide-angle television camera (viewing angle 104°) with low resolving power (2.5 km in center and 5 km on edges of frame) is produced observation of area having form of square with 1200 km side. Camera with narrow-angle objective (viewing angle 12.7°) possesses high resolving power (0.3 km in center and 0.8 km on edges) and is intended for transmission of pictures of areas of smaller dimensions (120 × 120 km), being in center of large square, surveyed by camera with wide-angle objective.

Satellites of the "Tayros" series differ little in construction one from another. They have form of cylindrical 18-side polygon, on external edges of which are mounted batteries of solar cells (total number 9200), completely ensuring need for electric power by way of recharging of nickel-cadmium storage batteries. Diameter of satellites is 107 cm, height is 48 cm, weight from 110 to 129 kg. Orbit of satellites "Tayros" is almost circular (so that height of apogee of first satellite of series is 740 km, and perigee is 702 km), angle of inclination of orbit is 48-58°.

"Tayros" satellites are unoriented. During appearance in orbit, third stage of rocket together with satellite revolves for stabilization with a speed of 125 r/m. After appearance in orbit, angular velocity of satellite by way of rejection in sides of light steel cables on ends of which are two loads weighing 400 g, decreases to 9-12 r/m. Ten small rockets are used for maintaining obtained angular velocity. During operation of two rockets located on opposite sides of lateral surface of satellite, speed of rotation is increased approximately 3 r/m. Oscillation of axis of rotation of satellite decreases to minimum with help of two loads, which can slip along two rods parallel to axis of rotation. Position of axis of rotation is controlled by magnetic device in the form of coil wound around lateral surface of satellite.

Optical axes of television cameras are directed parallel to axis of rotation of satellite. Thus, television chambers are turned to earth only during short part of time of orbiting. Orientation of optical axes of cameras is calculated in such a manner that they are directed towards earth under conditions of best illumination. Starting time of satellites was selected, taking into account that northern part of orbit of satellites was toward the sun. In this case satellite passes above illuminated side of earth in band from 0 to 50° north latitude. Due to depression of plane, the point of orbit nearest the sun is slowly displaced southward. As a result, three and one half after launch, the nearest point to the sun turns out to be southern part of orbit; therefore satellite passes above illuminated side of earth only in a band from 20 to 50° south latitude (in this case observation of northern hemisphere is impossible). And eight weeks after launch the nearest point to the sun again becomes the northern part of orbit, and satellite passes above illuminated side of earth only in a band from 20 to 50° south latitude.

Enlarged block diagram of equipment serving for transmission of representations from satellites is shown in Fig. 74. Both

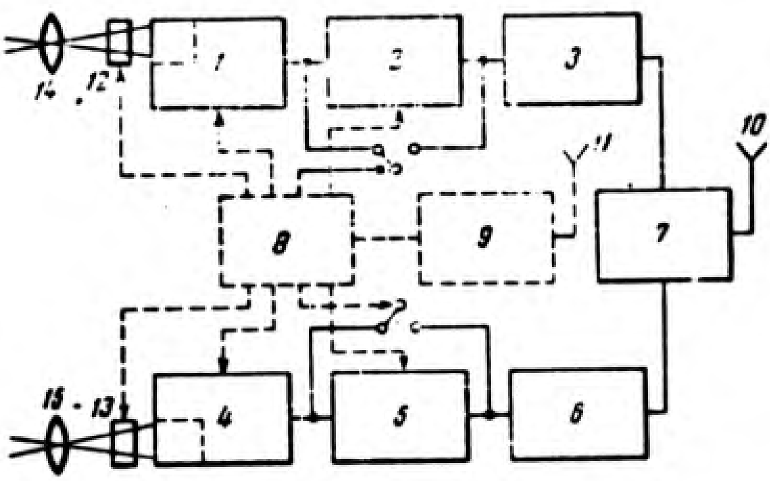


Fig. 74. Block diagram of transmitting television equipment of artificial earth satellite "Tayros-1." 1 — television camera I; 2, 5 — magnetic recording device; 3, 6 — television transmitters; 4 — television camera II; 7 — separating filter; 8 — programming device; 9 — receiver of command signals; 10 — transmitting antenna; 11 — receiving antenna; 12, 13 — locks; 14, 15 — objectives.

chambers work independently from one another. Every camera consists of miniature transmitting tube of vidicon type 12 mm in diameter and a lock located in focal plane of objective, ensuring 1.5 ms exposure. That representation, which was memorized by target of tube, is then read with help of electron beam. Scanning is produced on 500 lines; one frame is transmitted every 2 s, and frequency band of video signal is 62.5 kHz. Every television device has its own video tape recorder, transmitter, receiver of instructions and programming device. Equipment is designed in such a way that information obtained from both chambers is recorded on magnetic tape and is transmitted in series to ground station during that time, when satellite is within limits of zone of communication with receiving stations (radius of zone of reception is about 1800 km). This period is changed from 6 to 12 min. From this time on transmission of recorded signals is assigned 3.5 min. In remaining time is produced reception of directly transmitted television radio signals. On ground station signals are recorded on magnetic tape and are simultaneously examined on screen of examination device and are photographed.

Frames of distribution of overcast (their number in every series was 32) were taken through 30 s; general length of band of sections of surface taken in series is approximately 960 km. As a rule, in every twenty-four hours were taken date of observations on seven turns (450 television is cadre distribution of overcast and 7 tapes of recording of indices of transducers of radiation). Transmissions of data are ensured by two 2 W radio transmitters.

On Fig. 74 dotted line shows circuit of programming device which contains board standard of time determining sequence of instructions and carrying out synchronization of work of both cameras and recording devices. For resolution of problem of programming, there were composed beforehand maps of distribution of illuminated territory of earth, in zone of satellite.

Inasmuch as satellite revolves around its own axis, for typing to site of transmitted representations, besides position of axis, it is necessary to know angular orientation of cameras. This information was obtained with the help of 9 sun sensors, located through each 40° on perimeter of satellite. For rough determination of orientation with respect to earth is used transducer of infrared radiation, directed towards position, perpendicular to axis of rotation, and fixing line of division between earth and space.

Command-receiving point fulfills two basic functions — it gives command to transmission of television representation or its programming and receives and processes television information transmitted from satellite.

Necessary indications about program of work of satellite are reported on command-receiving point, where they are sent to equipment of programming until next performance of work with satellite. Sections of surface of earth are indicated, which have to be examined, and cameras which should be used for this, and also the order of their use; furthermore, indications about launching of board standard of time are given.

As soon as satellite enters zone of coverage of radio communications on command-receiving point, program is given automatically and with high speed. High speed of transmission of program is still necessary in order to use better that time when satellite is in region of receiving point.

Satellites are accompanied by a network of stations located mainly on the American continent. Results of observations are transmitted by telegraph to space computer center, in which parameters of orbit of satellite are determined or definitized. Computer center analyzes data and determines what sections of surface of earth can be photographed. In the same place are prepared individual programs of measurements for each of ground points and there are collected data necessary for deciphering representation in selected intervals of time.

Command-receiving points transmit operational instructions to satellite, receive and record picture signals, telemetric data, and remaining information from satellite. Representations are recorded on film, but electrical picture signals are recorded on magnetic tape. Filmed film goes to photoresearch center for treatment and further study. Magnetic tapes are reproduced immediately after recording, then they go to photoresearch center for investigation with the help of special photo-deciphering equipment.

Meteorological satellite "Tayros-8" is equipped with a new experimental system of automatic transmission of representations, which produces transmission of representations of cloud cover with slow scanning. These representations are received by 50 ground stations, in equipment of which are helical tracking antenna, radio receiver of commercial type and standard phototelegraph apparatus. Range of operation of ground stations is about 2400 km. For one satellite orbit path, every ground station can take up to three photographs. Vidicon of this system has additional polystyrene layer, which increases capacitance of target. Representations are projected on photoconductive layer, but then electrical charges are transferred to storage unit layer for their readout. Timing system ensures regular cyclic recurrence of work of system: preparation, exposure, manifestation and readout. One full cycle of transmission of frame continues 208 s, of which 200 s are expended on readout of signals of representations with speed of 4 lines per second. Picture signals are transmitted with help of 5 W transmitter, having a carrier frequency of about 136 kHz. Camera works only in solar hours; besides it there is an installation able to record on film meteorological data specially important for weather bureau.

What are the results of the work of meteorological satellites?

Toward the end of 1963, from launched satellites of series "Tayros" were obtained more than 270,200 television representations of cloud cover of earth, storms, snow, ice, etc. On their basis were conducted over 7000 analyses of cloud cover and 900 notifications about powerful storms and hurricanes were made. In 1965 number of transmitted representations already exceeded 500 thousand. Treatment of such huge quantity of information presents complicated meteorological and engineering-technical problem. The biggest difficulty during treatment of maps of distribution of overcast is connected with tying of photographies to site. In the beginning tying was carried out by superposition on photograph of coordinate grids, which, depending upon height of satellite and angle of sight were selected from corresponding set of grids manually. Later a machine was used for tying. After geographic tying the configuration of overcast was transferred on form of synoptic map together with indication of characteristics of overcast. Then these data were coded and on communication circuits were transmitted in the form of telegrams to interested organizations in a number of countries, including the Soviet Union.

The first photographs revealed already a number of interesting phenomena. They showed spiral bands of clouds connected with cyclonic storms, from 800 to 1500 km in diameter. There were revealed cellular systems of clouds with 50-80 km diameter cells. On photographs are seen strong storms, ice and snow fields, outline of sections of land, seas, big rivers.

Analysis of photographs permits revealing presence of dry or humid air, establishing system of airflows, finding position of frontal zones with divide different air masses, and also obtaining other important information.

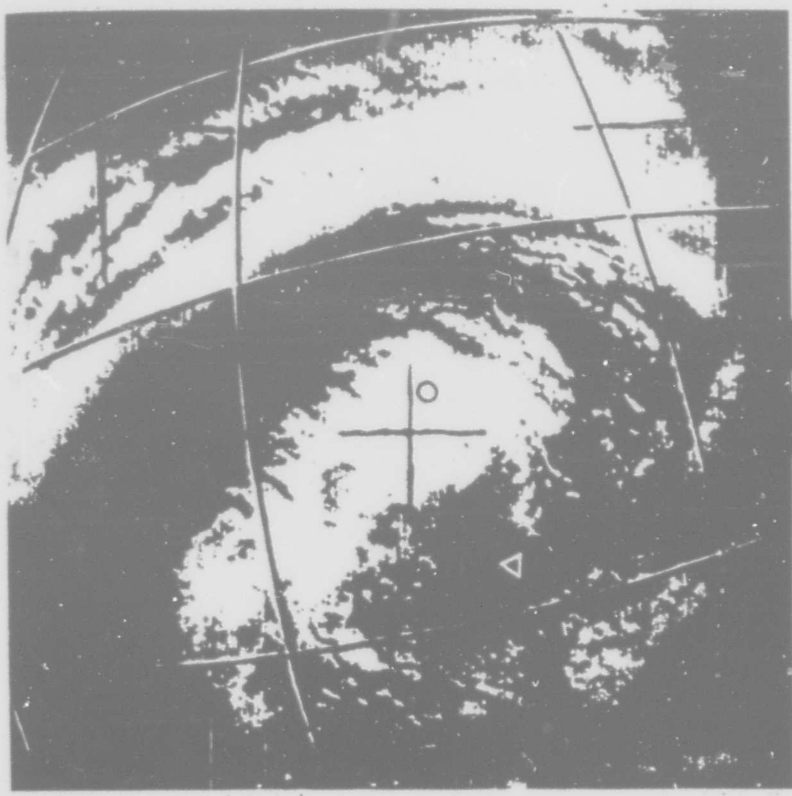


Fig. 75. Representation of spiral-like overcast of low pressure above southeast Australia, obtained with help of television equipment of satellite "Tayros-3" 9 August 1961.

Figure 75 gives photography of spiral-like overcast of low pressure above southeast Australia, obtained 9 August 1961 with help of television equipment of satellite "Tayros-3." On this photograph is a grid of geographic coordinates, applied in process of treatment of obtained representations.

Along with analysis of separate photographs of overcast great interest is presented by mosaics of separate television pictures having the form of a photograph. Use of such analysis of photographs permits obtaining presentation about synoptic situation on territories, comparable with dimensions of the earth. These photographs put into the hands of researchers the most valuable material. Investigations

Fig. 76. Mosaic of representations, characterizing distribution of overcast in region of Hawaiian islands 18 August 1961.

of distribution of overcast by photographs from satellites in tropics and southern hemisphere, on which there are very scanty meteorological data are especially interesting. Figure 76 shows mosaic of photographs of distribution of overcast in region of Hawaiian islands 18 August 1961, obtained with help of satellite "Tayros-3." On this compount photograph are seen spiral-like cloudy formations determining region of action of storms. Importance of these observations is indicated, for example, by the fact that many storms appearing on television pictures were not registered by ground meteorological stations, which were too far away from places of action of storms.

By television representations it is possible to judge not only distribution of clouds on surface, but also density and thickness of cloudy formations. These data can be obtained thanks to different reflectance of clouds having different thickness and density. The greater the density of clouds, the greater the brightness of corresponding sections of television pictures. Thus, small bright spots of clouds always correspond to well-developed cumulus or cumulo-nimbus overcast, possessing high optical thickness, whereas optically thin clouds (for example, plumose) are characteristic to small brightness. By obtained photographs embracing almost the same territory at different moments of time, it is possible to determine approximately speed of shift of clouds.

On darker background it is possible to observe snow fields. Moreover, if television observation was produced during several days, then snow fields can be easily distinguished from clouds, although they also come out white on photograph (picture of distribution of cloud cover constantly changes, and snow fields during the period of several days change little). Example of compound photography characterizing snow cover in western part of North America is shown in Fig. 77. On this map river valleys in Canada are seen well. Figure 78a shows separate frame of photograph shown in Fig. 77. On it are seen in more detail valleys of certain rivers, but on Fig. 78b is shown photograph of the same section of site, but done for 8 days up to the first photograph. Comparison of these photographs permits us to say rather exactly where there is snow lying on mountains and where there are clouds. For quantitative determination of areas covered by snow, exact geographic tying of representations is necessary. This problem is comparatively simple, when it is possible to distinguish river and lake valleys on picture.

Observation of naval ices enters program of investigations of meteorological satellites "Tayros." As example on Fig. 79 are shown two compound photographs, obtained on the basis of television transmissions from satellite "Tayros-3" in March 1962 with a 6 day interval of time. They permit estimating change of ice situation in region of Saint Laurence Bay. On the left to the right on Fig.79a, and is seen Gaspe Bay filled with ice, ice field between Gaspe Peninsula and Anticosti Island, open water to south of Anticosti Island (shore line is seen distinctly), accumulation of ice between Anticosti Islands and Newfoundland (shore line of the latter is noticeable on the actual photograph edge). Figure 79b shows well, how ice situation changed in that same region in 6 days. Region of open water was considerably expanded; as a result the northern extremity of Anticosti Island (in center) became clearly noticeable. These photographs, which permit distinguishing very fine structure of building of ice fields, were obtained from satellite in 60 s, and were ready 30 min after obtaining television signals (in this case they were obtained in zone of coverage of receiving station, i.e., transmission was conducted without delay in time without intermediate recording of signals on magnetic tape).

Fig. 77. Mosaic of representations characterizing snow cover in western part of North America, obtained by television transmissions from satellite "Tayros-4" in April 1962.

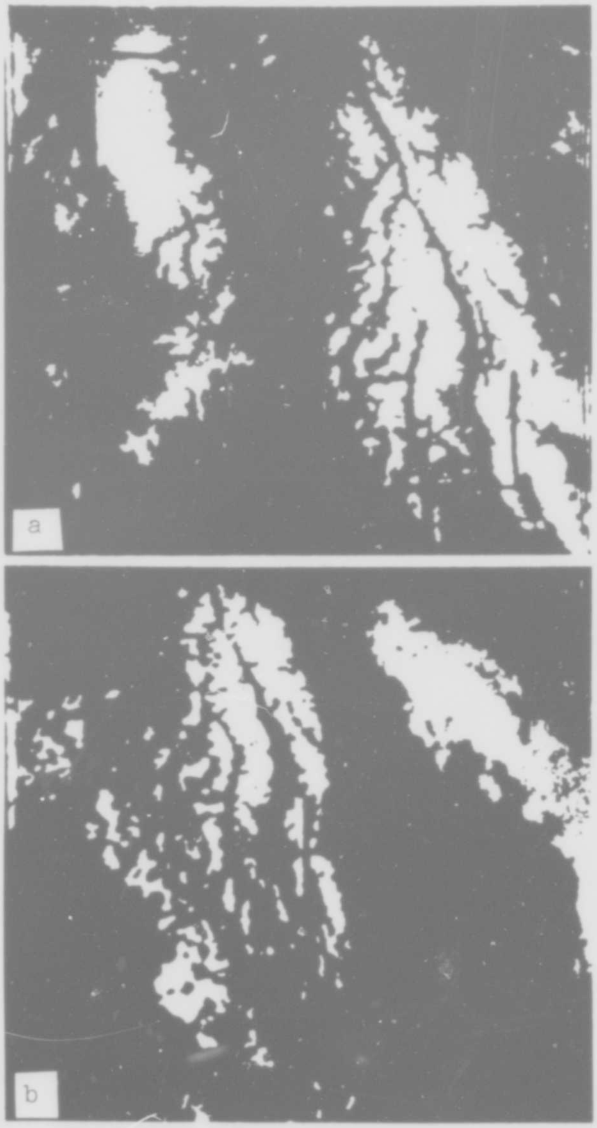


Fig. 78. Separate frame of mosaic, represented on Fig. 77 (a), and representation of the same section of site, obtained 8 days earlier (b).

Fig. 79. Mosaics of representations characterizing change of ice situation in region of Saint Laurence Bay, obtained on the basis of television transmissions from "Tayros-3" satellite in March 1962, with 6 day interval.

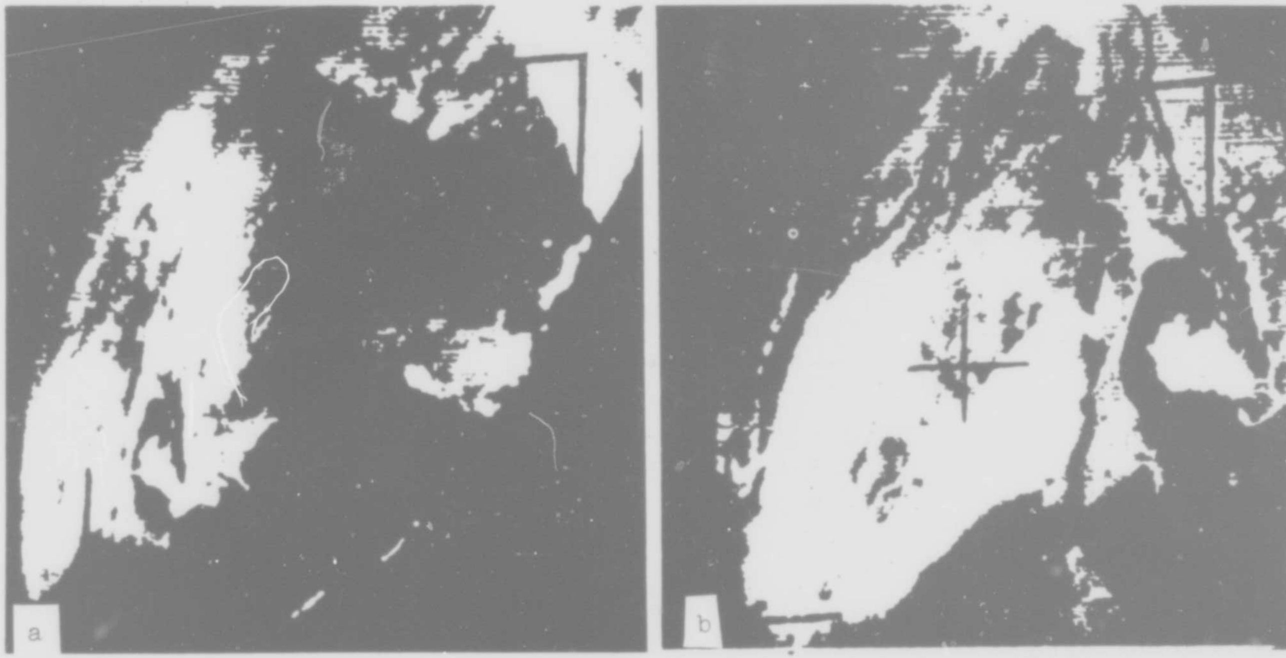


Fig. 80. Representations of ice situations of Sea of Okhotsk obtained by wide-angle (a) and narrow angle (b) cameras of "Tayros-4" satellite in April 1962.

Figure 80 gives photographs of ice situation on the Sea of Okhotsk, obtained with help of wide-angle camera of satellite "Tayros-4" 12 April 1962. Photography embraces Kamchatka (right upper angle), Sakhalin (left part of photograph), Kuril'sk islands and Sea of Okhotsk (in center). It is clear that bright areas in eastern part of sea coast of Aakhalin are covered completely by ice, and this makes it hard to distinguish islands. There are seen separate large ice fields, shore is clearly outlined. And triangular surface northwest of Kurilskiy islands cannot be reliably estimated as ice, although its limitation by islands speaks faster about the fact that it is ice and not cloud. Photography of the same region (not given here), done 12 days earlier, shows large areas, characteristic faster for ice than for clouds.

Data of television observations of overcast, ice situation and snow cover brought important results, which in a number of cases were absolutely unexpected. However on the way of use of materials obtained from meteorological satellites, only first steps are done. In forthcoming investigations, when experiment will be accumulated, will be developed new theories more deeply to be analyzed and statistically to be inovated various communications of peculiarities of cloud, snow and ice covers, and also specific character of weather-forming processes. Large flux of information requires essential development of automation of treatment of results of observations. Only automated methods of construction of combined maps of distribution of cloud cover will allow creating climatology of planetary distribution of overcast. Till now still the problem has not been solved of tracing distribution of overcast on night side of planet. Development of methods of control of vertical power and position of borders of cloud cover has important value.

But already available results of work of meteorological satellites instill confidence in the fact that the time is near, when weather will be predicted a month or even a whole season ahead. And then whole regions will be able to prepare beforehand for possible spontaneous disasters. Ahead of time weather forecasts will also be beneficial to agriculture. Increased and long-termness of weather forecasts will be reflected in other branches of the national economy (especially naval and air transport), forest fires will be extinguished in good time, etc.

In autumn 1964 in the United States, there was launched a new meteorological satellite "Nimbus-1" (Fig. 81a). Its orbit is nearly polar; inclination is about 80°. The new satellite was more improved than its predecessors of the "Tayros" series of satellites, with the exception of the "Tayros-8" satellite. On satellite "Nimbus-1" is used such equipment of automatic transmission of representations which was on "Tayros-8." Basic peculiarity of scientific program of new satellites is tendency to obtain with greatest detailization possible data about distribution of overcast on earth, which can be used in operational weather forecasts.

For solution of this problem on satellite are set three television cameras for determination of distribution of overcast in daytime. One camera is directed perpendicular to surface of earth,

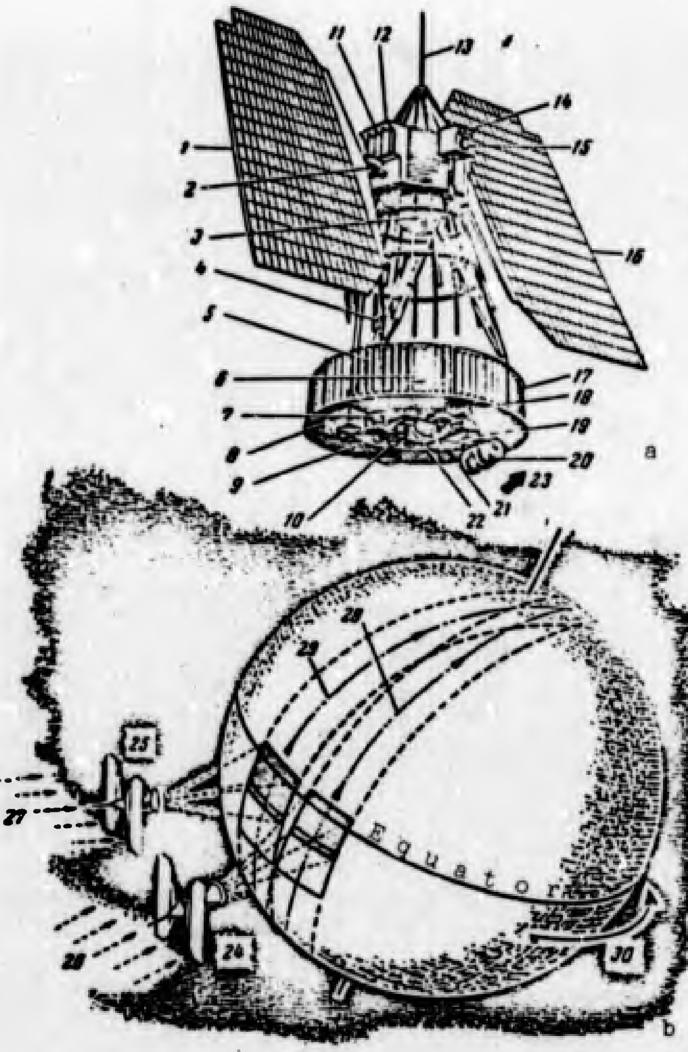


Fig. 81. Meteorological satellite "Nimbus" (a) and its zone of survey of earth's surface (b). 1 — panel with solar cells; 2 — solar aspect detector; 3 — reservoir with air; 4 — connecting rods; 5 — louvers for adjustment of temperature; 6 — antenna of beacon and telemetering link; 7 — infrared recording instrument with high resolving power; 8 — infrared radiometer with high resolving power; 9 — television cameras; 10 — antenna of system of automatic transmission of representations; 11 — louvers for adjustment of temperature; 12 — housing of system of stabilization and control; 13 — antenna for instructions; 14 — transducer of direction of sun; 15 — device of scanning of horizon; 16 — panel with solar cells; 17 — clip with transducers; 18 — antenna; 19 — instrument for recording of television signals; 20 — infrared radiometer for analysis of medium; 21 — antenna of infrared range; 22 — camera of system of automatic transmission of representations; 23 — direction of orbit; 24 — position of satellite on N-th orbit; 25 — position of satellite on N + 1st orbit; 26 — direction of rays of sun on N-th orbit; 27 — direction of rays of sun on N + 1st orbit; 28 — N-th orbit; 29 — N + 1st orbit; 30 — direction of rotation of earth.

but two others are at an angle of 35° to vertical, in plane perpendicular to direction of travel of satellite. Such diagram (Fig. 81b) installation of television chambers permits obtaining a picture of territory with dimensions of 2300 km latitude and 700 km longitude. Photographs obtained in series are covered on 10%. Full covering of band of earth's surface along given orbit is carried out with help of 32 representations from system of chambers, where recording 64 such photographs on magnetic tape is provided for.

For control of distribution of overcast on shaded side of earth is applied infrared scanning transducer with small viewing angle, ensuring obtaining of information about distribution of outgoing radiation at night. This transducer has viewing angle of $8.4 \cdot 10^{-3}$ rad and produces scanning with speed of 0.67 turns per second. Within limits of angle of 122° (from one crossing of lines of horizon to another), instrument fixes 260 indications.

During the time of its work (from 28 August to 23 September 1964) "Nimbus-1" transmitted over 27 thousand high-quality representations. Spacecraft ceased transmission of information, when its system of power supply broke.

Launching is planned of another "Nimbus," and then group of satellites of operational use "Tayros." From first five apparatuses of this group, two will be supplied with pair of systems of automatic transmission of representations, but on each of three others there will be two systems of improved cameras on vidicons. Representations will be transmitted with higher resolving power and will cover 647,500 km^2 of earth's surface. Television signals will be recorded on magnetic tape, but then will be read above central station, which will allow set of meteophotographs all over the earth. In the basic plan, to have two satellites continuously revolving around earth is provided for.

Launching is planned of other meteorological satellites, including launching into stationary orbit. Stationary meteorological satellites will be intended for production of global meteorological data and are calculated on perennial exploitation.

CHAPTER VIII

INTERPLANETARY TELEVISION TRANSMISSIONS

Television transmissions from moon. Attack of moon continues. First automatic station on moon. Television reportage from planets of the solar system. Obtaining of stereoscopic representations of planet. Attack on cosmos.

People dreamed of interplanetary flights many centuries ago. We are told this by myths and fairy tale; this is witnessed by old chronicles, books, and figures. Idea of interplanetary flights agitated many writers and scientists. Dreaming about discovering secrets of the universe, people created in their imaginations spaceships manned by their people and sent to moon and planets of solar system. However, the nearer to realization daring dreams about flight to distant worlds turn out to be, the more evident become those dangers which await courageous astronauts.

Swift penetration into secrets of cosmos, carried out in our days, proves that for successful flight to moon and planets, there are needed not only means of taking man there and returning him back to earth, but it is still necessary to very thoroughly study celestial bodies and space surrounding them preliminarily.

During preliminary inspection of moon and planets, when test of equipment and observation of behavior of animals in interplanetary space are conducted, a huge role will be played by television equipment.

Television Transmissions from Moon

First television transmission from circumlunar space. Moon is our satellite and the celestial body nearest to us; therefore, out of all objects of solar system, it is the most accessible for direct observation, and undoubtedly namely it will be first natural space platform, on which man will set foot. When secrets of moon and circumlunar space are discovered, humanity will approach discovery of the puzzle of the origin of earth, and, of course, man will subsequently be able to use moon.

Probably, moon or separate sections of its surface will be adjusted for prolonged stay there of people and for carrying out of different observations of earth, sun, and other space bodies. After all the moon has practically no atmosphere, and, therefore, observation from its surface for large and small bodies of the universe will be many times more effective than from earth. Lunar stations will enrich astronomical science by information which will answer many questions and will exceed everything which has been accumulated by science in hundreds of years.

Different contemporary methods of investigation in combination with complicated calculations already permitted studying surface of moon rather well, establishing its mass, density, dimensions, and also regularity of its motion. But many secrets of moon remain still unopened. We are ignorant of not only origin of the moon itself, but also how formations were born which are on its surface. We are ignorant of the physical state and chemical composition of surface layers of rocks of moon, not to speak of deep rocks constituting its body.

Long ago it was proven that time of full rotation of moon around its axis coincides with time its revolution around earth. This means that moon always turns same side to earth, and opposite side is practically not seen from earth. At times there are accessible to observations only narrow zones directly adjoining visible part of surface of moon. This occurs due to so-called libration of moon, i.e., for observer from earth, moon seems to be revolving around its axis nonuniformly — as if it rocks relative to its average position. Here this phenomenon permits observing about 59% of surface of moon, but remaining 41% its surface is hidden from our look. But even what terrestrial observers see must be checked. A number of formations on lunar surface which are on border of part of moon visible to earth seem long and narrow to us, and their true form is distorted.

Thus, investigation of side of moon inaccessible for observations presents huge scientific interest. This centuries-old dream of man was carried out by Soviet scientists, who, with help of designers, engineers, technicians and workers created and launched third space rocket with robot space station — "Luna-3".

This rocket, launched in Soviet Union 4 October 1959, was supplied with a compound complex of scientific and radiotechnical equipment, system of orientation, devices of control of work of board equipment according to pre-programming, system of automatic adjustment of thermal balance inside station and power supplies. On board of rocket was set up a complex of phototelevision equipment intended for photographing of part of moon invisible from earth and subsequent transmission of this representation to earth.

Interplanetary station put into orbit by third space rocket constituted thin-walled metallic container of cylindrical form with spheric bottoms (Fig. 82). Maximum diameter of container is 1200 mm, length 1300 mm (not counting antennas), weight of whole

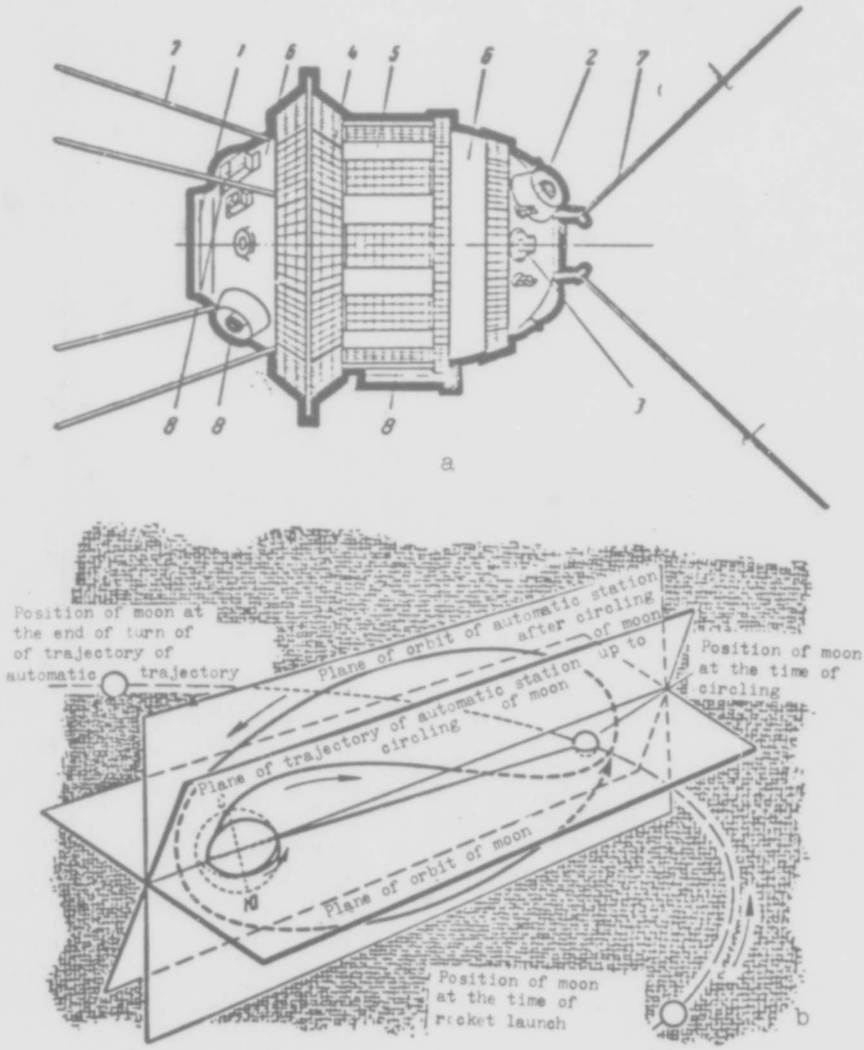


Fig. 82. Soviet automatic station "Luna-3", with help of which was obtained representation of reverse side of moon (a) and trajectory of its flight (b): 1 — illuminator for cameras; 2 — engine of system of orientation; 3 — sun sensor; 4 — section of solar batteries; 5 — louvers of system of thermal control; 6 — thermal screen; 7 — antenna; 8 — instruments for scientific investigations.

container is 435 kg. Part of equipment (board equipment, chemical power supplies and certain scientific instruments) was located on special assembly frame inside container. On the outside of interplanetary station were solar batteries, receiving and transmitting antennas, and also part of scientific equipment, not requiring hermetic sealing. Bottoms of container were used for distribution of camera and transducers of system of solar orientation. In upper bottom were small illuminators for sun sensors of system of orientation. In the same place were established controlling engines of this system.

Trajectory of motion of station was selected in such a way that at the time of survey, station was approximately on straight line connecting sun and moon. Earth had to be aside from sun-moon direction so orientation on earth instead of moon would not take place. Passing 6 October 1959, at 7000 km from moon, interplanetary station got into zone of strong lunar attraction, which forced it to change initial direction of flight; inclination of orbit was changed from 65° to 80°. Station started to round moon, "seeing" reverse side of its surface which was never visible before this from earth. Then, passing for lunar orbit at a distance of the order of 100,000 km, interplanetary station 10 October attained maximum distance from earth (470,000 km) and returned again to earth, slowly gathering lost speed. Two weeks after starting, 18 October 1959, station approached earth at a minimum distance of (47,500 km) and, rounding it, again departed on its distant journey with a greatly extended elliptical orbit.

One of the problems, which had to be solved for production of unique photographies of moon, was safeguard of corresponding orientation of robot space station in outer space. After separation of last stage of rocket, station arbitrarily revolved around its center of gravity. It is absolutely clear that to photograph moon even once, not to speak of a whole series of photographies, is impossible with such rotation. Orientation of robot space station was produced with help of system including optical and dyroscopic transducers, logical electronic devices and controlling engine. In beginning of work, system of orientation first of all ceased arbitrary rotation of interplanet station around its center of gravity, appearing at the time of separation of station from last stage of carrier rocket.

Before beginning of photographing, lower spheric bottom, on which were sun sensors, was directed towards sun with the help of system of orientation. During this time the illuminator on upper bottom, under cover of which were objectives of cameras, was turned in the direction of moon. After such preliminary orientation, optical devices of station checked it on light reflected from moon, since during process of aiming, station could not be exactly on the line from the moon to the sun. Complex of devices producing orientation was controlled by solar and lunar transducers converting direct energy and energy of solar rays reflected from surface of moon into electrical signals.

When exact aiming at moon was completed, optical devices worked a signal, permitting the beginning of automatic photographing. In period of photographing, automatic station ensured continuous guiding of station to moon; interferences caused by light reflected from earth were practically removed. Photographing started 7 October at 6:30 Moscow time; during this time the distance of interplanetary station to center of moon was equal to 65.6 thousand km.

Soviet designers created special phototelevision equipment able to work in complicated conditions of space flight, stable to changes of temperature conditions and preserving photomaterials, in spite of harmful influence of cosmic radiation. One of conditions of work of this equipment was clear interaction of all its mechanisms under conditions of weightlessness. On interplanetary station was used camera with two objectives. One objective of station with focal length 200 mm and relative aperture 1:5.6 gave representation of lunar disk, which was completely inscribed in frame. Other objective with focal length 500 mm and relative aperture 1:9.5 allowed photographing smaller area of moon, ensuring great resolving power of photographs.

Signal about beginning of surveys was given from earth on the radio, after which further process of survey and complicated process of treatment of photographic film was produced automatically by assigned program. Survey was conducted during 40 minutes. During that time were obtained great number of photographs. Last of them was made when robot space station was at a distance of 68,400 km from the moon.

In order to ensure optimum conditions of survey for differently illuminated sections of surface, automatically changing exposures were provided for. Photographing was conducted on fine-grained thermoresistant film of average sensitivity.

Unique frames were manifested and fixed by special small dimension device. Process of treatment was considered in such a way that it almost did not depend on change of temperature inside station, and thanks to almost complete weightlessness of equipment and chemical reagents, it was not disturbed. After treatment the film was dried, and evaporated moisture was absorbed, by which prolonged safety of photographic film was ensured. After treatment photographic film also automatically entered special cassette, where it was preserved up to moment of transmission of representations fixed on it to earth.

Laboratory mock-up of device, on the basis of which was developed working board device for treatment of photographic film is shown schematically on Fig. 83. Exposed film proceeds from storage unit through elastic sponges to section 3 for simultaneous manifestation and fixing. Then, passing squeezing element 5, it is subjected to short-term washing in tank 4, again passes through squeezing cell and elastic sponges 6 and joins hot drum 7, from which it emerges dry and accumulates in storage unit. Up to moment of treatment of film, device is closed; this is ensured by the fact that elastic sponges are automatically pressed to film, so that output of solutions from device is excluded even at strong vibration and high accelerations.

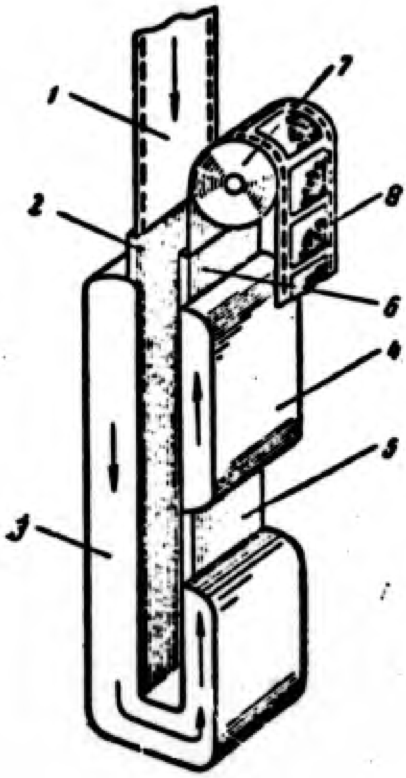


Fig. 83. Diagram of mock-up of small dimension board arrangement for treatment of 35-mm thermoresistant film. 1 — exposed film; 2 — elastic sponges; 3, 4 — tanks; 5 — squeezing cell; 6 — squeezing cell and elastic sponges; 7 — drum; 8 — picture frames.

Still on earth, before sending rocket in the direction of the moon, on photographic film were exposed testing signs, where certain signs here on earth were manifested. Remaining signs already appeared on board automatic interplanetary station during treatment of photographed frames with representation of reverse side of moon. These signs were transmitted to earth and permitted checking processes of survey, treatment, and transmission of representations.

Distribution of light and shadow on surface of moon was transmitted to photographic representation in the form of different optical density of separate sections of film. For transmission of different distribution of optical density on frame of representation to earth, it was necessary to convert these changes of density preliminarily into changes of value of electrical signal. This process was carried out by airborne television installation (Fig. 84a), in which film was transilluminated by running light spot created for electron-beam tube. Light beam passing through photographic film got on photocathode of photomultiplier. Signals obtained on load of multiplier were strengthened and were sent to radio transmitting device of a few watts.

Oscillations radiated by transmitting antenna of robot space station had to be passed huge distances in order to get to receiving antennas on earth. Radio transmission of signals of representations was produced from distances reaching 470,000 km.

Signals arriving on earth were very weak. It is impossible to carry out sure reception of such weak signals during usual method of television scanning.

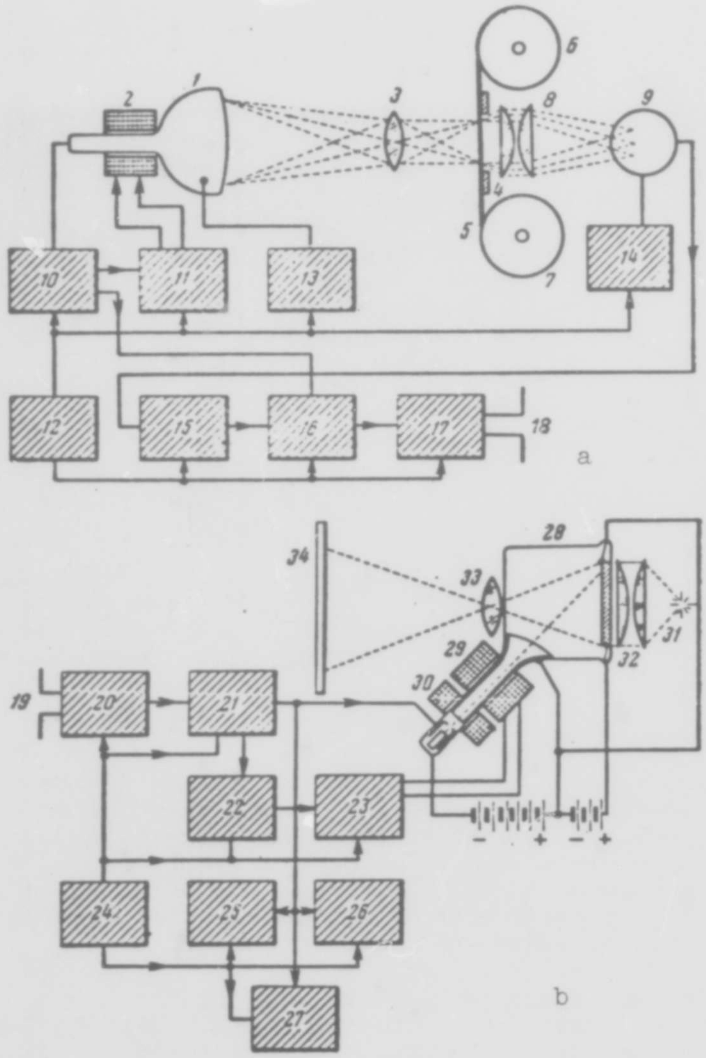


Fig. 84. Block diagram of television transmitter with running spot (a) and point of reception of picture signals (b): 1 — scanning electron-beam tube; 2 — focusing-deflecting system; 3 — objective; 4 — frame window; 5 — photographic film; 6 — passing cassette; 7 — taking cassette; 8 — condenser; 9 — photomultiplier; 10 — generator of synchronizing pulses; 11 — generator of scanning oscillations; 12 — source of electrical energies; 13 — source of high voltage; 14 — voltage source of photomultiplier; 15 — amplifier of picture signals; 16 — mixer; 17 — modulated oscillator of high frequency; 18 — transmitting antenna; 19 — receiving antenna; 20 — radio receiver; 21 — amplifier of picture signals; 22 — separator of synchronizing pulses; 23 — generator of scanning oscillations; 24 — source of electrical energy; 25,26 — device of photographic and magnetic recording of picture signals; 27 — system of recording on electrochemical paper; 28 — skiatron; 29 — deflecting system; 30 — focusing coil; 31 — powerful source of light; 32 — condenser; 33 — objective; 34 — light-diffusing screen.

To ensure sure reception of radiotelevision signals there were used on earth very sensitive radio receivers with small equivalent noise temperature and directional antennas. Reception of signals in large measure promoted considerable reduction of frequency band of transmitted television signal for light of deceleration of transmission of frame of television representation. Duration of transmission of one frame with this space reportage was a thousand times less than in television broadcasting. Frequency band of television signal was reduced a corresponding number of times.

Representation of reverse side of moon on board of station was scanned by line for light of deflection of transilluminating light beam of electron-beam tube, but vertical frame scan was ensured by slow and uniform drawing of all film with negatives.

On robot space station there were obtained a large quantity of photographs of invisible side of moon, for transmission of which much time was required. For acceleration of process of transmission of information about relief of our satellite there were used two conditions of transmission of signals. When station was distant from earth and power of signals proceeding from it very small, transmission was extraordinarily slow; during approximation to earth, power entering receiving antennas of signals was increased.

Such an important experiment required acceptance of a number of measures, removing some surprises, which could take out of commission this or that (AMC) [AMS] [Automatic interplanetary station] subassembly. In particular, all equipment of communication circuit of both on board and at ground points of observation was doubled.

Transmission of representations of moon was carried out by instructions from earth. The same method was switched feed of board television equipment and drawing of film, and television equipment was also connected to radio transmitters. Signals received by ground receiving antennas were sent to radio reception devices (Fig. 84b), where they were repeatedly strengthened and were subjected to necessary transformations. From output of radio reception device, signals were sent to different recorders and transcribers. For visual control of movement of space television transmission and study of transmitted pictures were used electron-beam tubes with dark recording (skiatrons). Open recording of representation was produced by electric-contact devices on conducting paper. In order to ensure possibility of repeated picture reproduction signals of representations were recorded on magnetic tape and photographic film. Picture signals obtained on earth recreated photographic representations on 35-mm photographic film.

During the study of obtained materials, Soviet researchers collided with whole series of difficulties, where the basic one was that obtained photographs were low-contrast.

Parts could appear on obtained photographs thanks to the large number of photographs. For this there were used different methods of deciphering photographs, for example method of superimposition of negatives. Methods were also applied of photographic camouflaging and photometric cuts which allow creating detailed maps of reverse side of moon. Rightfully first-discoverers Soviet scientists appropriated names to seas, craters and mountains discovered by them on reverse side of moon. On lunar globe appeared "Sea of Moscow", "Sea of Dream", "Crater of Tsiolkovsky", "Crater of Joliot of Curie", mountain range "Soviet", "Bay of Astronauts" and many others. It was possible to determine true form of lunar formations on border of part of moon visible to earth since on obtained photographs, approximately 70% of the surface belongs to reverse side of moon, but remaining part presents western edge of lunar hemisphere, observed from earth.

18 July 1965 Soviet Union put into orbit automatic station "Zond-3" for carrying out scientific investigations in distant outer space, and also for solution of number of problems, connected with adjustment of built-in systems of distant spacecraft. Station is equipped with large complex of scientific equipment for study of magnetic properties of circumterrestrial outer space and interplanetary medium, solar wind, low-frequency radio emission of galaxy, micrometeors, cosmic rays, and also for investigation of infrared and ultraviolet spectra of lunar surface. On board station is phototelevision equipment for photographing planets and transmission of representations from distances of hundreds of millions of kilometers.

Date of launching station "Zond-3" and its trajectory were selected in such a manner so that during passage of station past moon there were obtained photographs of its invisible part, which was still unphotographed in 1959. Trajectory and starting time of "Zond-3" were selected taking into account best illuminance of investigated region of moon.

20 July 1965 at 3:57, when station was still above visible side of moon at a distance of 11,570 km from its surface, the order was given from earth to start photographing. All further operation passed automatically. During the time of photographing, 25 photographs of lunar surface were obtained. During survey was used objective with focal length 106.4 mm with a relative aperture of 1:8. Photographing was produced on special film 25 mm wide with exposures 1/100 and 1/300 s. Television transmissions of photographs were conducted with decomposition of frame into 1100 lines with an exactitude equal to 860 cells along line. Duration of transmission of one frame was 34 minutes. Board equipment allowed changing duration of transmission of frame both in the direction of increase, and in the direction of decrease.

15 September 1965 "Zond-3" was at distance 12.5 million km from earth. By this time with station was conducted 75 radio transmissions. For radio transmission of television signals were used radio waves of the centimeter range. On board station is a highly directional parabolic antenna. Transmission began of obtained representation to earth 29 July from a distance of 2.2 million km from earth, when angle of visibility of earth from station became small enough for exact guiding of board antenna. When station was at distance of about 10 thousand km, every photograph embraced a large part of the unexplored region of the moon. During the time of photographing, position of station with respect to center of moon was changed approximately 60°, and every section of unexplored region was taken under different angles. Obtained representations have especially high quality (Fig. 85).

New photographs completely confirmed earlier conclusions concerning small quantity of extended dark cavities — "seas" — on reverse side of moon. If northern part of hemisphere of moon turned

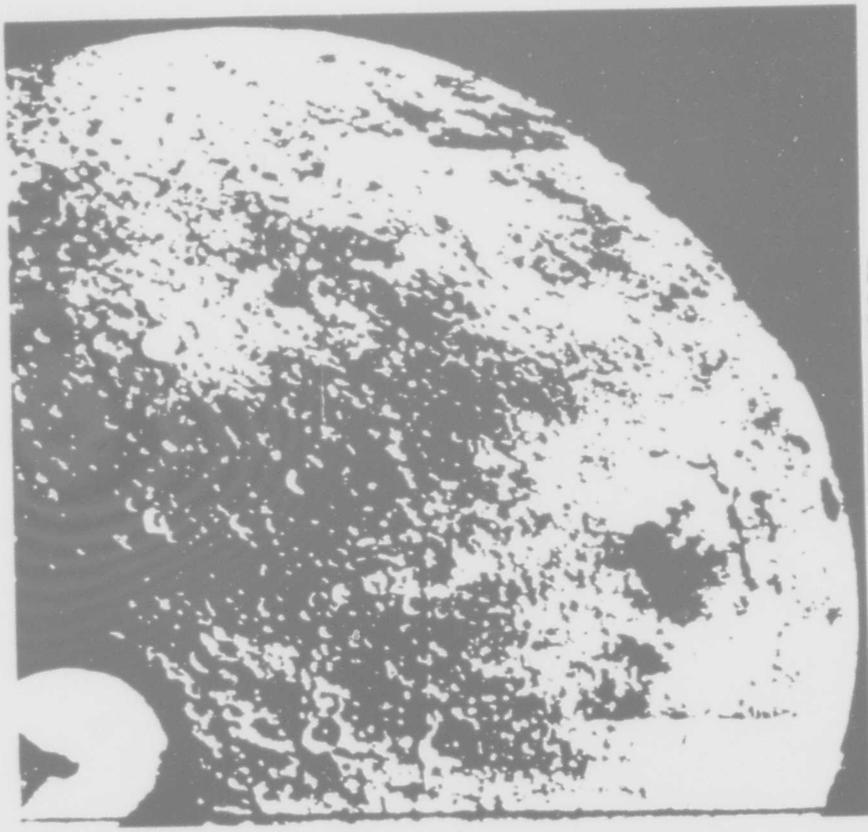


Fig. 85. Photography of side of moon invisible from earth obtained with help of robot space station "Zond-3" 20 July 1965. Big dark spot on the right is "Eastern Sea", more to the left are located objects not observed from earth. Among them are are a large quantity of craters and sea-like deepenings (tallasoids). In the lower left corner is a photometric scale.

to earth is basically covered by "seas", northern part of reverse side of moon is occupied by gigantic light height, covered with craters. The greatest interest is presented on reverse side by extensive cavities, bottom of which is studded with craters (tallasoid). On newly obtained photographs, there already appear thousands of formations.

Attack of Moon Continues

Scope of scientific investigations in cosmos is wide, and are especially manifold projects of different equipment to be used during future flights to moon and planets. There is an American project by which investigation will be performed directly on surface of moon, but then transferred to surfaces of planets of solar system. It is more convenient to talk about those problems, which have to be solved, having examined certain questions more specifically.

Series of pilotless spacecrafts developed by program "Ranger" (the United States) is designed for production of photographs of lunar surface from close distance with help of "rigid" landing on moon of capsule, in which will be placed instruments for investigation of structure of lunar surface. It is to produce measurement of gamma radiation, to determine concentration of radioactive substances on surface of moon, to obtain data about reflection of radio waves by its surface and other information about the character of its surface, and also to determine seismic activity of the moon.

Television cameras on vidicons have to ensure obtaining of representations of region of lunar impact of capsule during 30 min, after which it will fly from height from 4000 to 24 km. Representation obtained on height 24 km will embrace section of surface of moon 350 m^2 in area and will have a resolving power of 2 m.

This program creates three series of apparatuses. First series consists of two apparatuses ("Ranger" 1 and 2), which are intended for carrying out flight tests of systems, equipment and instruments; second series consists of 3 apparatuses ("Ranger" 3, 4, and 5) for delivery of capsule with instrument on lunar surface series consists of four apparatuses ("Ranger" 6, 7, 8, and 9), each of which will be equipped with several synchronously working television cameras for production of detailed information about lunar surface. All apparatuses are put into flight path to moon from intermediate orbit.

All launchings of apparatuses "Ranger" (1, 2, 3, 4, 5, 6), performed in 1961-1964, turned out to be failures. And only seventh launching could be carried out. Spaceship "Ranger-7" was launched to moon 28 July 1964 and 31 July it fell on surface of moon. Ship fell into "Sea of Clouds", near shallow "Crater Gerike". Total weight of ship attained 365.8 kg; dimensions of it during launching equaled 1.5 × 2.5 m, and in flight 4.6 × 3.1 m.

Basic equipment of ship was television equipment, intended for survey and transmissions to earth of representations of lunar surface. Equipment, total weight of which attained 173.05 kg, contained: six television cameras; two 60 W transmitters working on parabolic directional antenna; video mixer; system of remote control of cameras and two 33 V batteries, capacitance 1600 W/h. Of six cameras two were supplied with wide-angle objective. Focal length of cameras remained constant; however it permitted taking representation on distances from 1800 km to 800 m. Transmitters worked at frequencies 959.52 and 960.58 MHz with frequency modulation. Weight of television cameras is 17.21 kg, of electronic control systems of cameras — 22.08 kg, of video mixer — 1.48 kg, of regulator of sequence of operations — 6.31 kg, of transmitters — 31.86 kg, of batteries — 39.12 kg.

On ship there was also a 2 W transceiver reception of instructions and transmission of telemetric data.

Flight control was carried out by signals from earth with help of special control system and was controlled by board computer.

Television system was switched on for 16 min 40 s up to fall of ship on moon. In these latter quarter hour of flight, during which ship passed 1600 km, 4316 representations of surface of moon were transmitted. Last photograph was transmitted at that moment, when ship collided with surface of moon and was split. Fall of ship on moon was observed visually with help of telescope. Approximately 20 s after fall in place of fall was a noticed small black spot, which was then quickly turned into a small white cloud, reminiscent of a three-leaf clover. This cloud quickly dispersed and vanished.

On photographs obtained from ship, it is possible to observe parts of surface of moon, which lie far beyond the borders of resolving power of any ground telescopes. Last representations obtained from spaceship show that on surface of moon there are small craters by about 1 m in diameter and not more than 30 cm deep. These data have very great scientific value. Since up to now were observed only big formations on moon. With respect to fine structure of lunar surface there were only conjectures. According to so-called dust theory, lunar seas were considered deposits of dust a few km deep. Representations of lunar surface, obtained from close distances, show that "dust theory" is absolutely incorrect. Analysis of representations permits making the conclusion that on lunar surface there are a great number of little craters with clearly outlined edges, which could not be if surface was covered by a thick layer of dust. Furthermore, it has been established that on surface of planet are craters of large dimensions (diameter of more than 30 m), consisting of bared rocks, thrown out during process of formation still larger craters. This conclusion, in the consideration of American researchers, is the most important result of the spaceship flight.

Now already is added general presentation about structure of lunar surface. Lunar seas consist of thickened lava or substance similar to it, whereas thickness of upper layer of dust or ashes is not more than 60 cm. Thus, lunar surface is sufficiently durable to sustain weight of spaceship, although on it there can be dangerous places for landing. From this point of view, representation of lunar surface, transmitted from height of 50 km is of great interest. Representation embraces surface with 25.5 km lateral faces. On it one may see whole socket of small craters; certain of them have diameter not over 4.5 m. Such craters are edged with round ridges and in future will present danger for spaceships. Region is crossed by one of clear "rays", which originate from "Crater of Copernicus", having a 90 km diameter.

From obtained representations it follows that on surface of moon are widely spread small craters and cavity. There is not one representation, on which there would not be such formations.

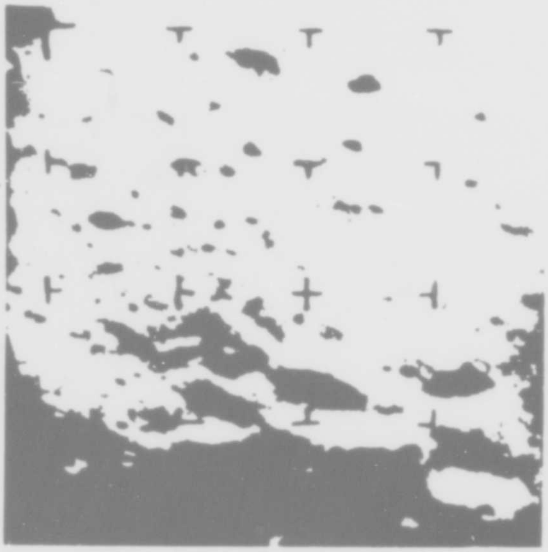


Fig. 86. Representation of lunar surface, transmitted by television system before collision of spacecraft with lunar surface (from height of 5 km above surface of moon).

GRAPHIC NOT REPRODUCIBLE

Figure 86 shows section of surface, area of which can be compared with area of volleyball site. It is absolutely evident that surface is far from even; everywhere are scattered small craters up to 90 cm in diameter. Shadows thrown off by walls of craters talk about the fact that their depth is approximately 30 cm.

It is necessary to note that "Ranger-7" transmitted representations of very limited section of surface of moon. Even first photographs, done on the biggest distance from moon, embrace an area smaller than France. Detailed study of surface of moon will demand sending to it many more television prospectors.

For this purpose, in particular, "Ranger-8" and "Ranger-9" served as apparatuses. On board of the most improved apparatus, "Ranger-9" were set 6 television cameras on 25-millimeter vidicons. Number of lines of decomposition was 1132. Interplanetary stations of this series in February-March 1965 transmitted 17,259 clear representations of lunar surface visible from earth.

First Automatic Station on Moon

Extraordinarily complicated technical problem is realization of smooth landing on moon. For this it is required to conduct numerous experiments. First such experiment was accomplished by Soviet researchers, who launched 9 May 1965 in the direction of moon a space rocket, on board of which was set automatic station "Moon-5" weighing 1476 kg. Launching was performed with help of multistage rocket, where last stage of rocket was preliminarily put into intermediate orbit of artificial earth satellite, but then by assigned program it put automatic station into trajectory of travel in the direction of moon.

Then the moon was reached by automatic stations "Moon-7" and "Moon-8", flight of which gave much for science and first of all for adjustment in natural conditions of system of radio control of trajectory, board radio equipment, system of astroorientation and instruments of autonomous control.

First soft landing of spacecraft in history on surface of moon was carried out by Soviet researchers. 31 January 1966 the USSR launched automatic station "Luna-9", which weighed 1583 kg after going into trajectory to moon. Soft landing was accomplished 3 February at 21 h, 45 min, 30 s. In region of Ocean of Storms, to the west craters Rhiner and Mariya at point of lunar surface with coordinates 7 deg 8 minutes of northern latitude and 64 deg 22 minutes western longitude.

What constitutes station "Moon-9"? It consists of three main parts: strictly automatic lunar station, which should be planted on surface of moon "softly" enough so that its equipment completely preserves its workability; propulsion system, intended for carrying out of corrections of trajectory and braking during flight to moon; sections, containing control equipment of flight. Part of control equipment, which is not used during braking, is placed in two mounted sections, which are separable right before launching of retrorocket.

Automatic lunar station constitutes hermetic container, in which is placed board radio system (receivers and transmitters), program-time device, system of thermal control scientific equipment power sources. Station has television system ensuring possibility of scanning range with transmission of representation of lunar landscape to earth. On housing of station are set: antenna, automatically opening after lunar station descended to ground, system of damping, which softens blow at the time of contact with lunar surface, and metallic lobes, which protect television device from possible landing shocks and make position of station on surface of moon stable.

Fact itself of realization of soft landing on moon is the most important stage in mastering of cosmos. However, value of first soft landing on moon is multiplied many times by the fact that station "Luna-9" is equipped with scientific and research equipment intended for carrying out investigations of our natural satellite directly on its surface.

With station "Luna-9" on 3, 4, 5, 6, and 7 February, there were conducted seven performances of reliable radio communications of total duration 8 h and 5 min.

Moreover, station "Luna-9" carried out first television reportage in history from celestial body. On command from earth on 4 February at 4 h 50 min, station "Luna-9" started scanning range of lunar landscape and transmission of its television picture to earth. Furthermore, on radio commands transmitted from ground center of space communication, detailed examination of separate sections of surface of moon was conducted by selection of scientists.

High-quality television representations transmitted from station "Luna-9", are unique, for the first time they give direct information about microstructure of lunar surface and present exceptional value for determination of structure and peculiarities of surface of moon.

Published photographs show that in region of station, surface of moon is sufficiently hard. Noticeable traces of dust were not revealed on lunar surface. On photographs near stations, there were distinguished parts about 1-2 mm in dimension. Surface of moon is rough and has many shallow deepenings and protuberances. Separate formations of type of stones are scattered around. Shadows are very contrasted, which is explained by absence of atmosphere and, accordingly, of scattered light.

Television Reportage from Planets of Solar System

Since long ago the planet Mars aroused huge interest in people. Already in 1659-1694 on the basis of his observations with help of five inch pipe, Dutch scientist Huygens made first figures of Martian surface; he described and assumed appearance of Martians.

By then it was already established that Mars is on the average two and one half times further from sun than earth, where its volume is seven times, but mass ten times less than earth's. After 300 years from moment of appearance of these first figures, thanks to labors of many scientists, our knowledge of Mars was considerably supplemented. It is known that a complete rotation around its own axis is accomplished by Mars in almost the same time as by earth, i.e., in 24 h 37 min 23 s. Atmosphere on Mars is 12 times more rarefied than terrestrial atmosphere, which corresponds to pressure of terrestrial atmosphere at height of 17,000 m. In the estimation of a number of authors, it consists mainly of nitrogen. But spectroscopic proof of presence of nitrogen from earth is impossible — atmosphere prevents it. It has been discovered, however, that in Martian atmosphere, carbon dioxide content is twice as high as in terrestrial atmosphere. And traces of water are found. Quantity of oxygen in atmosphere of Mars, apparently, is 0.001-0.0015 with respect to terrestrial atmosphere (above equal sections of surface). Atmosphere of Mars, because of smaller gravity, is more "friable", and speed of decrease of pressure on height is less here than in terrestrial atmosphere (density decreases 10 times each 40 km of height, whereas on earth it decreases 10 times each 17-18 km). On height 30 km the densities of terrestrial and Martian atmospheres are identical, and at high altitudes, pressure of Martian atmosphere is higher.

In atmosphere of Mars are observed clouds of three types: yellow, white, and blue. Yellow clouds are disposed in lower layers and consist, apparently, of small yellow-brown dust, covering the deserts of the planet. Winds and storm lift this dust into the atmospheres (once even it was possible to observe how this dust was transferred by atmospheric flows thousands of kilometers along surface of planet). White clouds appearing on different heights up to 20 km, consist, it is considered, of small ice crystals with average diameter of 1 μm. Blue clouds, apparently, are also ice crystals, but of smaller dimensions. These clouds, apparently, are connected somehow with "violet layer", which completely conceals all parts of Martian surface during photographing it in violet rays. This layer, apparently, contains still more small particles (diameter up to 0.3 μm), which for a long time remain on height of 10-15 km or more.

A great contribution about Mars to science was introduced by Soviet scientist G. A. Tikhov, who started science of astrobotany in the forties.

However, about structure of surface of Mars, about possible forms of life on it, there are the most contradictory opinions. Making simple conclusions is hindered by huge distance to Mars. From earth it is possible to distinguish only very large parts, about 200 km in dimension. Therefore, it is tempting to dispatch to Mars piloted spaceship, which will help to answer many questions. But solution of this problem will not be within man's powers very soon. After all before the creators of all forms of equipment necessary for takeoff, flight to Mars, return and safeguard of normal vital activity of astronauts there are many problems. The following figure, for example, talks about this. Depending upon interlocation of earth and Mars and selected orbits of flight of spaceship on routes, earth to Mars and Mars to earth, required time of space flight with return to earth can be different. During flight on minimum trajectory, this time is 2.66 year. The most suitable dates of start of rockets to Mars are December 1966 to January 1967, January to February 1969, February to March 1971. Initial weight of ship should provide energy to engine for flight to Mars and return of spaceship back to earth. Furthermore, one should create all conditions to ensure normal vital activity of crew during period shown.

These problems will unconditionally be solved, but they will require tense labor of army of scientists, engineers and workers of many professions.

However, it is extremely difficult to send even an unmanned spaceship to the planets. Let us show this on example of those problems which must be solved by Soviet scientists during creation of interplanetary automatic station "Mars-1", which was launched in the direction of Mars on 1 November 1962.

So that body moves along the orbit different from terrestrial, it must be taken from region in which terrestrial gravity essentially affects its flight (up to distances of about 1 million km), with speed other than speed of earth with respect to sun (30 km/s). Figure 88 shows orbit of spacecraft corresponding to different speeds of their travel. Spacecraft coming from sphere of attraction of earth with speed relative to sun not less than 33-34 km/s, i.e., faster than earth by 3-4 km/s, will be able to move along the orbit, attaining Mars. Spacecraft coming from sphere of terrestrial gravity with speed 26-27 km/s, i.e., slower than earth, will fly along the orbit to Venus. If during getting out of sphere

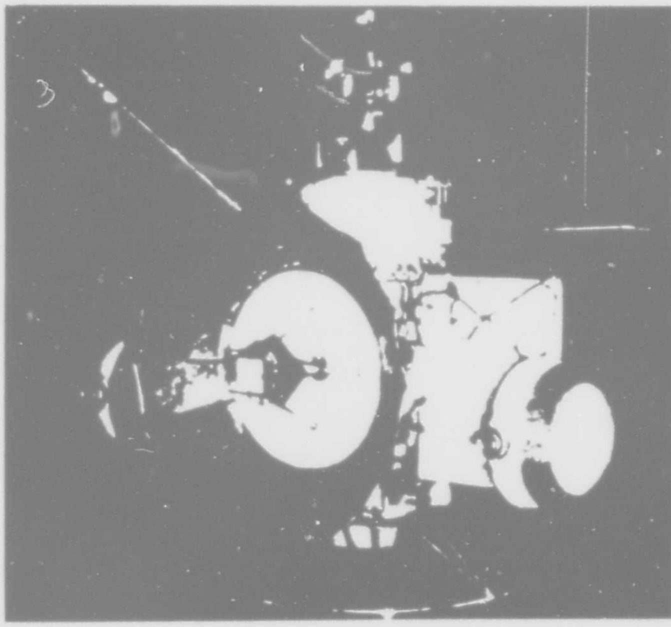


Fig. 87. Automatic interplanetary station "Mars-1".

of terrestrial gravity, spacecraft starts to outstrip earth with speed exceeding minimum necessary, it will attain orbit of Mars by an even shorter way than at minimum speed. However, for this will be required much fuel consumption, i.e., it will be necessary to decrease weight of spacecraft, but this can, in general, make flight impossible. Orbit, by which it is possible to reach to Mars with least consumption of fuel is called powerfully optimum.

Selection of orbit close to optimum is affected by inclination of plane of orbit of Mars to plane of orbit of earth, condition of radio communications with station, the most convenient passage of station near planet for carrying out of scientific investigations, etc. For flight to Mars it is necessary to select such time, when location of earth at the time of rocket launch and Mars at the time of approximation of station to it coincides in accordance with beginning and end of optimum orbit. This determines most advantageous dates of start of rocket to Mars. Launching before and after this time would demand too much fuel consumption. Optimum dates of flight to Mars follow one after the other approximately every 25 months. In 1962 this period happened on end of October to the beginning of November. This explains why on 1 November was launched powerful multistage carrier rocket, on board of which was controlled space rocket with robot space station "Mars-1".

Travel of carrier rocket passes with high accuracy on precalculated trajectory. When its flight speed attained orbital velocity, there was separated from rocket a satellite carrying space rocket

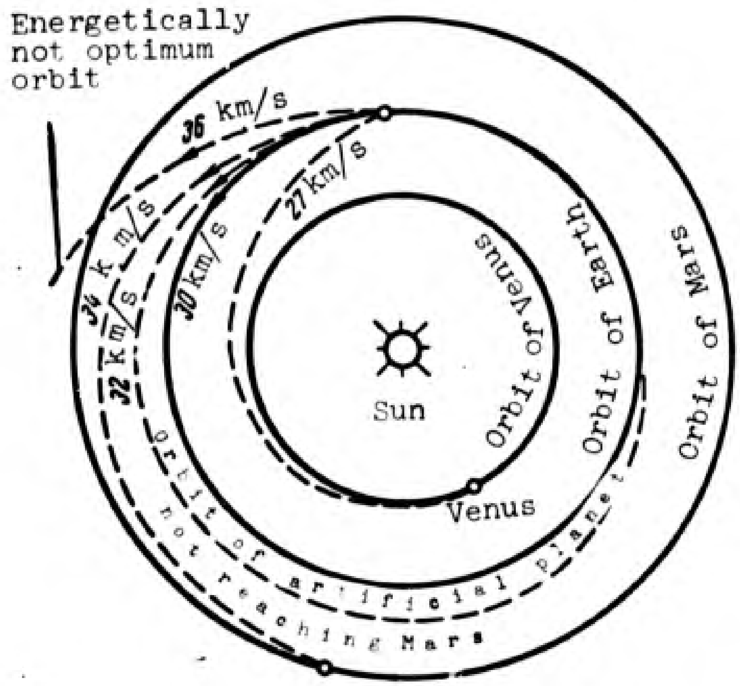


Fig. 88. Orbits of spacecraft, corresponding to different speeds of their travel.

with automatic station. Launch of space rocket from aboard satellite was performed at precalculated point of orbit. When speed of flight of this rocket exceeded speed of satellite from which it was launched, by approximately 4 km/s and rocket emerged into assigned point of outer space, its engine was turned off. At this instant station was separated from space rocket and started its free flight on trajectory to planet Mars. From this short description one may see what complicated problems had to be solved by specialists.

After separation from space rocket, travel of station in the beginning is carried out under action of forces of attraction of earth, sun and planets. Up to distances of approximately a million km, attraction of earth predominates. Subsequently, flight of station is basically influenced by gravity of sun, and it moves according to the same laws as the planets of the solar system.

Robot space station "Mars-1" (Fig. 87) has two hermetic sections: orbital and planetary. In orbital section is located equipment ensuring work of station during flight to Mars, but in planetary is located scientific instruments, working at planet. On orbital compartment are set correcting propulsion system, panel of solar cells, hemispheric radiators of control system of temperature and antenna. The biggest dimensions of station are 3300 mm in length, 1100 mm diameter of orbital compartment and 4000 mm width taking into account solar batteries and radiators, weight of station — 893.5 kg.

With help of radio systems of station were produced trajectory measurements and transmission of telemetric information to earth. Control of work of board equipment was conducted automatically, and also way of transmission of instructions on radio line from ground points. On station were established three radio systems, working on waves 1.6 m, 32 cm, 5 cm, 8 cm.

For carrying out of scientific investigations on board station were phototelevision device for photographing, specrtolexometer for detection of organic covers on surface of planet, spectrograph for study of bands of absorption of ozone in atmosphere of Mars, magnetometers for detection of magnetic field of Mars and measurement of magnetic fields in outer space, meters for exposure of radiation belts and study of spectrum of cosmic radiation, radiotelescope for registration of space radio emission, trap for registration of fluxes of small-power protons and electrons, and also concentration of positive ions and transducers for resistration of micrometeorites.

During the time of normal functioning of equipment of interplanetary station there were conducted a large number of radio transmissions from station, which were carried out both automatically, as also on instructions from earth. During these performances from aboard station there were transmitted very important scientific data of different character.

Ultimate range of communication with space rocket "Mars-1" was about 100 million km. At that time this figure was recordbreaking.

On 30 November 1964 the Soviet Union carried out another launching of automatic station "Zond-2" in the direction of the planet Mars. Launching is performed with the help of last stage of carrier rocket, which put into intermediate orbit the heavy artificial earth satellite. In calculated time from aboard satellite was launched space rocket, which imparted to automatic station "Zond-2" speed necessary for going into trajectory to the planet Mars.

This is no longer the first very complicated experiment in launching a controlled space rocket from satellite to planets of solar system. Advantages of such a method of launch as compared to launch from space rockets, directed to celestial bodies directly from surface of earth, consist in the following. During acceleration to necessary speed of rocket starting from earth, it should not only move in course of certain time, strictly sustaining assigned directions and speed, but on time drop used-up stage, switch on and off engine, change their operating conditions. Deflections from calculated data are inevitable. Errors accumulated during travel on acceleration phase of rocket inevitably lead to deflection of actual trajectory from calculated trajectory. During launching from earth satellite, it is possible to consider these errors, which are accumulated during flight of carrier rocket from earth to orbit of satellite. Second advantage of starting satellite from earth consists in the fact that interplanetary apparatus can have imparted to it considerably smaller additional speed, since, being on satellite, space carrier rocket of robot space station already has speed of the order of 8 km/s, and it is necessary to add 3-4 km/s to available speed. The smaller the value of additional speed, the less will be error during putting of station into interplanetary route. Furthermore, launching on satellite takes complications, connected with time of launch. Great value is also had by the circumstance that spacecraft, launched from earth satellite, can have on board considerably larger payload than during launching from surface of earth.

On automatic station "Zond-2" for the first time in real conditions of space flight was conducted test of electroreactance plasma engines on board station, which are utilized as controls for orientation system. In plasma electroreactive engines, working substance (plasma) is heated with help of electrical energy and is accelerated at the expense of electromagnetic forces. Substance in state of plasma has unusually high temperature for everyday presentations. Thus, temperature of the coldest plasma exceeds 8-10 thousand degrees on the Celsius scale, but speed of particles in plasma attains order of tens of kilometers per second. Plasma can be forced to move in a definite direction and to create traction.

Plasma is a substance consisting of a mixture of positively and negatively charged and neutral particles. If plasma is influenced by electromagnetic field, then it will move similarly to the way conductor through which current flows moves in electric motor. Hence, possibility of acceleration of particles of working substance to speeds of tens and hundreds of kilometers per second, i.e., is unattainable in engines working on chemical fuel or compressed gas.

Electrical energy for feed of these engines can be taken in space directly from solar batteries or from a special source of electrical energy. Value of traction of plasma engine is very easy to regulate in wide limits, changing parameters of its power supply. Such engines possess large resource of work. These characteristics of plasma engines make their application on objects in outer space with prolonged time of flight very promising.

Six plasma electrojet engines on board station "Zond-2", during prolonged time supported required position of station with respect to sun. Engine worked in accordance with signals proceeding from logical blocks of system of orientation. The latter was switched on plasma engines from ground control room when "Zond-2" was far from earth.

On 28 November 1964 Americans launched automatic station "Mariner-4" in the direction of Mars. Preceding launching of such apparatus "Mariner-3", performed 5 November of the same year, turned out to be a failure. This automatic station was to be used in interplanetary space and near Mars to produce a number of scientific investigations: measurement of radiation, magnetic fields and micrometeoritic fluxes, photographing of surface Mars and determination of characteristics of its atmosphere.

Weight of automatic station "Mariner" is about 260 kg. Housing of apparatus is carried out in the form of octahedron made of magnesium alloy. Seven sections of ship are intended for distribution of electronic equipment, and eight for sustainer engine. To lateral surfaces of octahedron are braced four solar panels 1.82 × 0.9 m in dimension. To upper base of housing are braced elliptic antenna (1.17 × 0.53 m) in the form of hundred with large amplification factor. Omnidirectional antenna with low amplification factor, 10 cm diameter and 224 cm length is assembled on end of rigid annular waveguide. Temperature in six electronic sections is regulated by light louvers with drive of spiral bimetallic tapes operating as thermocontrolled springs.

Basic source of board feed of ship is 28,244 photoelectrical solar cells assembled on four panels and duplicated recharged silver-zinc storage batteries. It is expected that power of power supplies is 640 W near earth and about 300 W for the orbit of Mars. Required power during transmission of telemetric data after passage of Mars is 140 W during fulfillment of maneuver on cruising section of flight it is 225 W. Television camera of station has reflector telescope.

First representation of surface of Mars was obtained 14 July 1965, and corresponding television signals were sent to earth on 15 July. Representation from the distance nearest to Mars of 12 thousand km was obtained on board ship 17 July. Television reportage from circum-Martian outer space was completed 24 July, when on earth received signals of the latter (twenty first) representation.

On photographs obtained are seen numerous large craters, similar to lunar craters. Representations permit making conclusion concerning the fact that at least during several billion years, there were essentially no erosional processes on Mars. This is explained by the fact that Mars does not have free water, and its atmosphere is too small.

Obtained representations do not permit revealing some signs of life on this enigmatic planet. Notorious "canals" are not revealed. This is explained, probably, by the fact that television representations embrace 1% of Martian surface and "canals" were seen by terrestrial observers in other parts of planet and in other periods of the Martian year.

On television representations there are no clouds, although they are seen from earth. It is possible that clouds are not revealed for the same reasons why "canals" are not revealed. It is also necessary to consider that these are the first and, naturally, are not very improved representations.

Venus, located nearer to earth, conceals still more puzzles than Mars. It is wrapped, as a covering, in a dense layer of clouds, which do not permit studying the structure of its surface with help of observation tools from earth. Spectroscopic methods obtained evident proofs of high contents of carbon dioxide in composition of planet, however this method was not able to obtain proofs of presence of water vapor or oxygen. In atmosphere of Venus are observed morning radiances, but actual atmosphere is in extremely excited state. In connection with character of surface of Venus are declared the most diverse hypotheses, starting from the fact that this is dried and burned desert, and finishing with assumption about the fact that whole planet is covered with water. Therefore, the tendency is understandable of many scientists to use interplanetary automatic stations with television equipment on board for study of planet-puzzles. Let us give short characteristics of certain stations already created and designed in the United States.

On one of apparatuses, there are to be instruments for determination of composition and temperature of atmosphere, temperature of surface of planet, speed of rotation of planet around its axis and slope of axis to plane of orbit, for measurement of levels of radiation and magnetic field in interplanetary space near planet, and also by instruments for exposure of possible forms of life on planet.

For investigation of planets there are to be created spacecrafts which would revolve along the orbit around investigated planet and would produce measurements with help of instruments on them. On these spacecraft will be receivers, which will collect information from capsules with instruments dropped directly on surface of investigated planet. Indications of instruments on surface of planet are relayed, thus, by equipment of spacecraft. These programs anticipate transmission to earth of representations of surface of planet, which are obtained with help of television camera aboard capsule.

On 12 November 1965 the USSR launched a space rocket, the last stage of which was put into intermediate orbit around earth. From this orbit in the direction of the planet Venus was launched automatic station "Venus-2" weighing 963 kg. Its flight to Venus will continue 3.5 months. In 4 day in that same direction was sent one more interplanetary automatic station — "Venus-3".

In literature are discussed possibilities of investigating Mercury and Jupiter. Launching of pilotless apparatuses to these distant planets is considered possible in 1968-1973. After thorough reconnaisance, which will be carried out by pilotless spaceships with different equipment, including television, to planets of solar system will be sent piloted spaceships. However, even in this case television transmissions from cosmos will elicit the greatest interest and will have huge scientific value.

Obtaining of Stereoscopic Representations of Planets

Obtaining of not only black and white, but also colored and even stereotelevision representations of planets of solar system is planned.

The simplest method of creation of volume television representation consists in use of two-channel television system.

On transmitting end simultaneously work two television chambers, set up in series in such a manner that distance between objectives equals distance between eyes (base of volume sight). After corresponding amplification, output signals of cameras are modulated by high-frequency oscillations of two radio transmitters. Reception is carried out by two receivers. On screens of two electron-beam tubes are created two representations corresponding to right and left cameras. These representations are observed with help of those or other attachments (in the simplest case with help of usual mirror or prism stereoscope).

Stereoframes can be reproduced not simultaneously, but sequentially in time. It is possible to transmit sequentially one frame after another (left frame, then right, etc.) on one communication channel, but then they will be sequentially reproduced or alternately transmitted line of left and right frames (first line of left frame, then first line of right frame, second line of left frame, second line of right frame, etc.). During series transmission it is possible to apply one transmitting tube. Two representations on light sensitive surface of one transmitting tube (Fig. 89a) are created by application of special prism (or mirror) separator. There can be applied receiving device with one usual tube (Fig. 89b), on which by turn are reproduced representations of stereopair and before which synchronously with alternation of representations revolves disk with light filters (or polaroids). Observer is supplied with eyes with light filters or polaroids.

If before observer there is set on level of eyes a revolving flap (shutter), then screen can be examined alternately now by the right, now by the left eye. Then the necessity of disks with light filters set before reproducing tube drops.

Described principle of transmission of volume television representations will be used in those spacecraft, which will produce transmission directly from surface of planets and moon. However, besides those television cameras, which will be set on self-propelled self-acting platforms, outlined to use television equipment of those satellites, which will produce topographic survey of planets and moon from circling orbits. Inasmuch as orbits of such satellites pass at large distances from planet and moon, then simultaneous observation of one and the same section of planet surface by two television cameras on satellite will not give volume representation because of too small a base. The fact is that the more base of transmission, the bigger appears the stereoeffect. To reproduce remote objects by volume, it is necessary to increase base of transmission. Therefore, volume representation of planets can be obtained only during observation of one and the same region from various points of orbit of satellite. TV transmission should be conducted from the same height, taking into account displacement of representation at the expense of rotation of planet. Problem can be solved if teletransmission is conducted simultaneously by two satellites moving on one orbit, but one displaced relative to other on defined distance (on value of base). However, to create such system of teletransmission is very complicated.

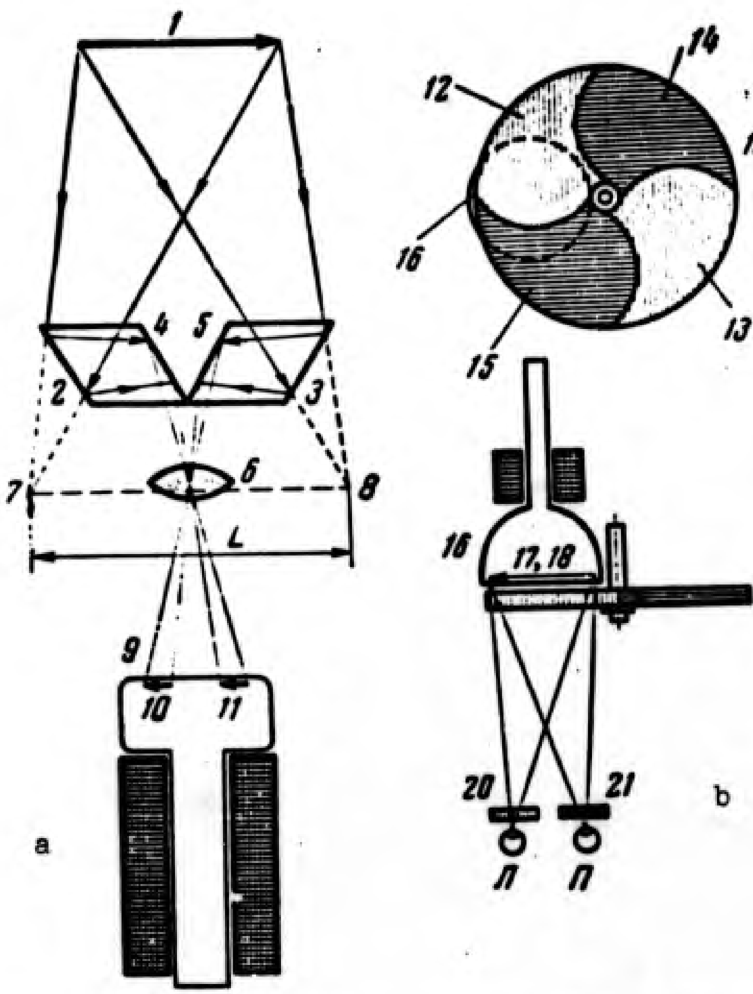


Fig. 89. Circuits of series transmission of volume television (a) and separation of left and right representations with help of revolving disk and eyes (b). 1 – object 2, 3, 4, 5 – reflecting surfaces of optical attachment; 6 – objective; 7, 8 – imaginary objects; 9 – transmitting tube; 10, 11 – left and right representation on photocathode; 12, 13, 14, 15 – filters (polaroids); 17, 18 – left and right representation on screen of tube; 19 – revolving disk; 20, 21 – eyes from light filters (or polaroids); L – base of transmission; Л and П – eyes of observer.

Another method is possible when one artificial satellite of inspected planet is used. Let us consider it on example of obtaining volume television representations of Mars. On satellite are set two cameras with viewing angle 7.5°. One of them is disposed under angle +20°, and other at an angle -20° to vertical of satellite. First camera is switched on at moment, when satellite reaches perigee on 12.5° and gives representation of region of surface of Mars with center located exactly under perigee.

Second camera gives representation of the same region through 12.5° after sputnik passes perigee (Fig. 90). In points of survey at height of satellite of 1910 km, extent of depicted area will be equal to 29 hours, then time between survey of first and second cameras is 10.4 min. For the same time, planet will turn on angle 2.5°, and this will entail partial loss of information about volume of representation.

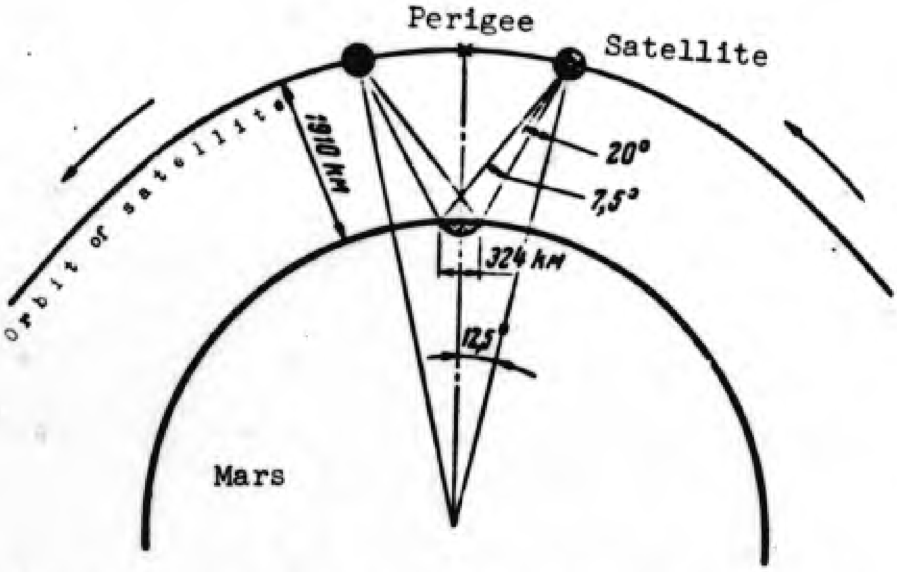


Fig. 90. Diagram of transmission of volume television representations of planet Mars.

Survey near passage of satellite through perigee is optimum both from the point of view of simplicity of safeguard of equal heights of teletransmission and from point of view of minimum losses of information at the expense of rotation of planet.

Topographic television survey of surface of planet will be possible only in the case when angles of survey are sustained very exactly. And this requires installation on satellite of system of orientation which ensures exact fixation of its own vertical with respect to planet. Moreover, into television signal there should be introduced time markings, which will allow calculating orbital position of satellite.

In principle transmission is possible of colored volume television representations. Methods of solution of this problem are many. One of the simplest methods uses effect of binocular displacement of colors by apparatus of sight of man. True, resultant colored representation is obtained only during mixing of not three, but two basic colors. In transmitting camera of such system is set transmitting tube, on photosensitive layer of which are projected by series two representations – left and right. Color separation of representation is carried out by filters of complimentary hues.

The perspective is tempting of obtaining colored volume representation of high quality in three basic colors. In order to produce mechanical connection of system of volume television with some colored system would require expanding frequency band twice as compared to instructed trichromatic system and complicating all equipment. However, use of peculiarities of television signal and properties of sight will allow, obviously, in future creating comparatively narrow-band system and with its help transmitting representation in three basic colors, where impression will be created of three-dimensional representation.

Attack on Cosmos

Soviet satellites, space system, spaceships and interplanetary stations are equipped with a large quantity of reliable and exact instruments, with help of which is conducted very complicated program of investigations without direct presence of a person on board station. Manifold sensitive instruments are able to register many times more information than is accessible to sensory organs of man. Control of spacecraft in flight is ensured with help of exact and reliable instruments. But if automatic machines can do so much, is manned flight in space ir general needed?

Very much, but not all, can be done with help of instruments on board spaceship. Complicated control system is directed towards solution of rather limited circle of problems. And what human mind is able to do, which is inaccessible to even very improved machine. How, let us say, to remove failure of any instrument, how to make decision in unexpected situation? How to select place of landing of interplanetary ship? What information one should transmit to earth in the first place, and what, in general, is not needed?

These and many other problems can be solved only by man. A new significance is taken on by the laboratory of the spaceship, which is manned.

Flights of astronauts have great value for preparation for future interplanetary journeys. After all, man is able to note the fact that instruments will not register in defined direction. Only man can give appraisal to whole complex of sensations and state on all stages of flight in cosmos, and also reliability of different devices needed for supporting best conditions of stay on interplanetary spaceship. Only man can direct his attention to newly opened possibilities of investigation of the universe, which are not provided for by any programs of investigations.

In prolonged interplanetary flights of the future, there will be needed such devices, which support constant conditions in cabin of astronaut and ensure safety of flight.

Achievements of Soviet Union in creation and launching of artificial earth satellites and space rockets of large weight and dimensions permitted proceeding already in 1960 to tests of spaceship intended for prolonged flight in outer space.

Continuous observation of state and behavior of experimental animals on satellite vehicles with help of television and telemetering systems put into the hands of scientists material on the basis of which it was possible to compose presentation on more or less distant influences of space flight on living beings, and this has great value for preparation of manned space flight. There were conducted a number of medico-biological experiments and a program of scientific space research was carried out.

Information about state of experimental animals (arterial pressure, electrocardiogram, tones of heart, respiratory rate, temperature of body, motor ability) and physical conditions in cabin and instrument section, and also data about work of board equipment were transmitted with help of telemetering systems to ground points. In pressurized cabin were measured barometric pressure, temperature, humidity, composition of air, etc. Control was also produced of functioning of systems of safeguard of vital activity of animals.

These and many other data permitted medics and biologists to decide many puzzles; however, even this was insufficient to completely compose presentation about influence of a variety of conditions of space flight on living beings. It was necessary to obtain possibility to observe visually behavior and state of animals. This is why on second satellite vehicle (as also on subsequent ships) was set television system.

Radiotelevision signals were transmitted in that period, when satellite vehicle was in zone of coverage of ground receiving points. Simultaneously occurred recording of television signals on film, where there recorded also oscillogram time marks, synchronous with oscillogram time marks, created on telemetric films. This permitted comparing direct observations of animals with objective date about changes of their physiologic functions, transmitted to earth with help of telemetering system.

In order to decrease weight of board television equipment, its dimensions and electrical energy consumed by it, number of lines of decomposition and number of frames were considerably reduced (as compared to that accepted for television broadcasting); this permitted sharply reducing frequency band of transmitted picture signals.

Representation of dog, Belka (from second spaceship-satellite in August 1960) was transmitted face through window of hatch by television camera on hatch of container. Second camera through lateral window transmitted representation of dog, Strelka, in profile. This camera was set up in cabin of ship.

This unusual television transmission started even before takeoff of spaceship. State of animals and their behavior were observed on sections of takeoff and at the time of transition from overloads to weightlessness, but then on all turns, when satellite vehicle had communication with any of ground radio reception stations. Picture signals were sent to board radio transmitter from two cameras alternately. Start-stop operation of television cameras and additional illumination were produced on commands from earth, where it was possible to switch camera at any moment.

Received signals were sent to video supervisory equipment, on screens of which were observed moving representation of Belka and Strelka. Devices of visual observation recorded picture signals by different methods. One of these methods was recording of representations on film. Obtained television films have great scientific value.

On fourth and fifth spaceships-satellites, space flight was accomplished by the dogs, Chernushka and Zvezdochka. Behavior of these four-footed passengers was also reproduced on television screens.

Huge successes in many regions of science and technology, collective mind and labor of many Soviet people prepared first manned flight into space.

On 12 April 1961 at 9 h 7 min Moscow time was launched first spaceship with a person on board. On ship "Vostok" into orbit around earth went pilot-astronaut Yuriy Gagarin. Weight of ship with astronaut was 4725 kg, neglecting weight of final stage of carrier rocket.

A huge role in this historical event was played by radio electronics. Radio electronic means entered control systems of spaceship, equipment necessary for vital activity of person; they composed basis of telemetering systems. Unique electronic equipment worked on ground stations and in computer center.

During preparation of ship for flight, orbital injection and during whole flight, Yu. Gagarin maintained bilateral radiotelephone and radiotelegraph communication with ground center of flight control.

In flight the equipment of spaceship-satellite worked on defined program, ensuring measurement of parameters of orbit, transmission to earth of telemetric information, two-way communication with earth, maintenance on ship of assigned temperature conditions, air conditioning in cockpit.

Visual control of state of pilot was produced with help of television system. One of television cameras transmitted representation of pilot face, and another of his profile.

Control of work of equipment was carried out automatically with help of board program units. However, when necessary astronaut could voluntarily or on command from earth turn to manual control of ship, determine its position and carry out descent in selected region.

Accomplishing his unprecedented trip around planet, Gagarin flew 40,000 km in space. Maximum distance of satellite vehicle "Vostok" from surface of earth was 327 km. Round-the-world journey was accomplished in 108 min.

On 14 April 1961 when Moscow solemnly met and honored first Soviet astronaut, television transmission about celebration in Moscow was watched by millions of TV viewers of England, France, Italy, Czechoslovakia, Belgium, Poland, Denmark, Sweden, German Democratic Republic, Switzerland, Hungary, FRG, Finland, Holland together with workers of many Soviet cities. Path of television signals from Moscow lay through Leningrad, Tallinn, Helsinki, Stockholm, Copenhagen, Hamburg, and Berlin to Warsaw, Prague and Budapest and branches from this line to television centers of other countries. In the evening of the same day, this transmission was seen by TV viewers of the United States of America and Canada.

On 6 August 1961 at 9 h Moscow time, the USSR launched spaceship "Vostok-2", piloted by Soviet pilot-astronaut Gherman Titov.

Weight of spaceship "Vostok-2", neglecting weight of last stage of carrier rocket, was 4731 kg. Flight of ship continued 25 h 18 min. During that time it accomplished 17 and more turns around earth, flying in outer space more than 700 thousand km.

Equipment on board "Vostok-2", included different radio electronic devices; radiotechnical system of trajectory measurements, multichannel telemetric systems ensuring objective observation of state of astronaut and control of work of all airborne devices, and also receiving-transmitting short-wave and ultrashort-wave equipment of communication, including airborne tape rocorder.

Radio transmission from ship to earth on large distances was carried out with help of two short-wave transmitters with amplitude modulation working in parallel. Transmitters worked on common antenna. During flight above territory of USSR, transmission from ship was conducted with help of third, ultrashort-wave transmitter.

Cosmonaut could conduct transmission through microphones mounted in helmet of pressure suit, or located in cabin, which he could use, by opening helmet.

Reception of signals from radio transmitters of spaceship was carried out by many receiving stations located on territory of Soviet Union. Signals of spaceship were received also by numerous radio stations abroad.

Board tape recorder was intended for recording of speech of astronaut and transmission of recorded information to earth. It was switched on automatically every time astronaut started to talk. During flight above territory of Soviet Union, recording was read (after supply of instructions from earth). In order to reduce duration of transmission, speed of readout was made 7 times larger than speed of recording.

Radio transmission from earth to ship was carried out also on two waves of short-wave range and on one ultrashort-wave.

On "Vostok-2" were set up small dimension transmitting television cameras. Representations of astronaut were transmitted from ship to receiving television centers. One television system transmitted representation with exactitude of 100 lines. Such television system was used on preceding Soviet spaceships. Television signals of this system were comparatively narrow-band. Second television system passed its first tests in this flight. Representation of astronaut on photocathode of transmitting television tube was decomposed into 400 lines. In both television systems, 10 frames per second were transmitted.

Every television system had its own radio transmitter, working in ultrashort-wave range. Reception of radiotelevision signals was produced in several points on territory of USSR. Television receiving point was located directly on spaceport, where there were main headquarters and command post of flight. One of receiving television points was placed in coordination-computer center, located many hundreds of km from spaceport.

Observation of astronaut started from that moment, when G. Titov entered cabin. On television screens it was possible to see how astronaut was organized in cabin, how he tested instruments communication, how he secured helmet of pressure suit before launch.

Launch. Ship goes into space. Representations on television screens permit judging health of astronaut under conditions of ever increasing overloads on section of putting ship into orbit.

Ship goes into orbit. Overloads are lacking. Astronaut under conditions of weightlessness. One may well see how G. Titov familiarizes himself with a situation new to him, opens helmet and goes to work. One may see, how he starts to record in flight log, how he tunes receiver, takes food, etc.

On television lines from earth was conducted systematic observation of state of astronaut and his activity in flight. During flight above territory of Soviet Union from radiotelevision system proceeded representations showing calm face of astronaut, his clearly coordinated travels during work. Frames of this historical television transmission were recorded by recorders on film. Synchronously were recorded data telemetering system about physiologic functions of organism: bioelectric and mechanical activity of heart, frequency and depth of breathing, temperature.

Data of analysis and television representations indicate that basically all physiologic functions of organism of man in flight did not have pathologic deflections.

On 9 August 1961 the Soviet people celebrated brilliant completion of second triumphal space flight. In this day Moscow encountered Gherman Titov. And again tens of millions of inhabitants of our planet participated in honoring astronaut with help of television.

In August 1962 Soviet astronauts A. Nikolayev and P. Popovich accomplished first group flight in world to outer space on spaceships "Vostok-3" and "Vostok-4".

Important place in construction of ships was occupied by radio equipment. Part of instruments of radio equipment and television cameras were placed in cabins of ships, but part, together with control equipment and systems of thermal control, were placed in instrument sections. In basis of complex of radio communications equipment was assumed equipment for ships "Vostok" and "Vostok-2".

During group flight for the first time in history, radio communication was carried out by two-way communication between two spaceships. Radio communications between ships, which was conducted on short waves, passed very stably and confidently on all distances, starting with 6.5 km (minimum distance between them) and up to maximum, which toward the end of flight was about 3000 km.

Simultaneous flight of two ships set new problems on organization and carrying out of communication. Extensive work was conducted for realization of possibility of transmission from earth to ship and reception of transmissions of astronaut from any point on territory of Soviet Union through that ultrashort-wave station, which at a given time has communication with spaceship. This permitted conducting negotiations with astronauts from one point during their flight above whole territory of USSR, so that quite often bilateral negotiations were conducted with astronauts on the radio by operator several thousand kilometers away from them.

Ground receiving-transmitting radio centers constitute complicated contemporary constructions with multikilowatt transmitters, large quantity of directed stationary antennas and tens of main receivers. Reports on board of ships were transmitted through that broadcasting center which ensured best passage of radio waves. Reception was conducted simultaneously by several broadcasting centers during use of antennas with large directive gain, reversible according to indications, continuously proceeding on broadcasting centers from coordination-computer center.

Ultimate range of communication attained 12-20 thousand km, and distance exceeding 10,000 km was usual. Prolonged program of flight permitted astronauts to abandon seat and freely to float in cabin. Besides they could not use microphones and telephones of pressure suit, are which were then disconnected. In this case radio communications was conducted with help of special system of cabin loudspeakers and microphones.

In days of group flight of ships "Vostok-3" and "Vostok-4" there was born Soviet spacevision — there was carried out direct transmission of pictures from aboard spaceships to millions of television viewers of the USSR, and also Intervision and Eurovision.

On board of each of ships were set two transmitting television cameras. One ensured large-scale representation full face, other (smaller plan) in profile. Such selection of optics and distribution of television cameras permitted obtaining the most complete information about state of astronauts.

In transmitting cameras were used transmitting television tubes of vidicon type. Chambers differed by small dimensions, insignificant weight and energy consumption, high stability, guaranteeing many days of high quality work, without some additional regulation.

From transmitting camera the television signal joined powerful board radio transmitter and was transmitted through antenna to ground receiving points. Number of lines in television screen was 400; 10 frames per second were transmitted. At these parameters of scanning, bandwidth of video signal was 800 kHz, which is 7.5 times less than band of video signals of television broadcasting.

Signals of board radio transmitters were received by ground antennas of large area and sent to highly sensitive receivers. Here received pictures were examined on video supervisory equipment and were recorded. Inasmuch as parameters of scanning of received signals differed from signals of television broadcasting, on ground points was produced conversion of standards. Converted picture signals were transmitted by radio relay and cable communication circuits to Moscow television center, but from there by usual order were relayed on Soviet Union and into tens of foreign countries.

The labor of Soviet radio specialists allowed many millions of television viewers to observe directly for the first time the "space workdays" of Andrian Hikolaev and Pavel Popovich, to see with their eyes what weightlessness is, and to "participate" directly in their flight.

And in less than a year, Soviet science triumphed again. On 14 June 1963 the unprecedented flight started of the space satellite, "Vostok-5", piloted by pilot-astronaut, Valeriy Bykovskiy. Three hours and 50 min after the flight started, television was transmitted from space all over the Soviet Union on the Intervision and Eurovision networks.

Two days after launching of "Vostok-5", the "Vostok-6" spaceship was sent into terrestrial orbit piloted by Valentina Terashkova. Tens of millions of people in many countries of earth viewed with interest on their screens the heroic flight of the female astronaut.

The quality of television pictures transmitted from the "Vostok-5" and "Vostok-6" spaceships was already much better than before. This was ensured by uniform cabin lighting which kept illumination from getting worse even when the astronaut left his seat. Automatic regulation was ensured of picture brightness on the photocathode of the tube in case of change of cabin illumination, and a special high-powered optics was developed for television transmitters.

Labor of many collectives of Soviet scientists, designers, engineers, workers created multiseater spaceship "Voskhod", on which for the first time in world on 12 October 1964 there was lifted into space a crew composed of pilot-astronaut V. Komarov, scientist K. Feoktistov, physician B. Yegorov. In 24 hours stay in cosmos, "Voskhod" flew around earth 16 times, passing distance of about 700 thousand km. And in that same minute, when world was informed about flight of first crew of astronauts, TV viewers were shown their portraits. And after three hours, tens of millions of TV viewers watched transmission from cosmos on systems, Eurovision and Intervision. Direct transmissions from aboard ship "Voskhod" and performances of Soviet spacevision were relayed several times.

Ship "Voskhod" essentially differs from ship "Vostok": new three-place cabin, new instrument equipment, a number of systems new in principle. Ship uses new television system, which ensured not only transmission to earth of reportage from cabin of ship, but also transmission to earth of picture observed from aboard ship. There were used innovations in radio direction finding and telemetering technology.

Film, taken in cosmos with help of television equipment of ship "Voskhod", was demonstrated to participants of press conference, dedicated to flight of ship "Voskhod" and taking place on 21 October 1964 in Moscow.

Several months passed after all that, and feat was accomplished in cosmos by other Soviet astronauts – colonel Pavel Belyayev and Lieutenant Colonel Aleksey Leonov. This time role of television was especially great. Millions of TV viewers of many countries of world witnessed approach of new era in mastering of cosmos – first walk of man in history from spaceship "Voskhod-2" directly into outer space.

But work of astronaut was observed not only from earth. With help of board television installation, he was observed by commander of ship, P. Belyayev. He controlled ship in such a manner that on screens of our television sets one could see as well as possible everything occurring, so that figure of astronaut soaring in space was well illuminated by solar rays.

We may expect new successes and new achievement of spacevision.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log