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TELEVISION TECHNIQUE IN ASTRONOMY

By Nikolai F. Koprevich

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TELEVISION TECHNIQUE IN ASTRONOMY

[Following is the complete translation of the book by Nikolai F. Koprovich entitled "Televizionnaya Tekhnika Astronomii", (English version above), Moscow, 1958, pages 3-40.]

The possibility of using television apparatus for astronomic observations is considered in this brochure. The brochure is intended for radio amateurs interested in problems concerning different applications of radio-electronics.

BRIEF SUMMARY OF THE HISTORY OF THE DEVELOPMENT OF
ASTRONOMIC INSTRUMENTS

Astronomy is the science of celestial bodies in the universe. Using the accomplishments of mathematics, physics, and engineering, it studies the unbounded universe surrounding us, which includes our own planet the earth. This science was born in the deep antiquity to satisfy practical human needs.

The history of the development of astronomic knowledge is closely related with the history of progress of astronomical observation instruments and methods of observations. At first, before the invention of the astronomical telescope, all the observations were with the unaided eye. Under these conditions, an experienced observer could distinguish and count on the sky up to 3500 sufficiently bright stars.

The invention and use of the telescope in 1610, by the Italian scientist Galileo Galilei, increased the number of stars available for observation, and has made it possible to disclose the moon's landscape, sun spots, the satellites of the planet Jupiter, etc. The Galileo

telescope consisted of a paper tube 102.5 cm long with a lens 6.2 cm in diameter.

The development of astronomic instrument building has followed the path of increasing both the diameter of the objective and its focal distance, and consequently, the dimensions of the entire instrument.

The widest application have gained reflector telescopes, in which a curved mirror is used. In 1783 Herschel constructed a reflector telescope 6.1 meters long with a mirror 45 cm in diameter. Six years later he built a telescope 12.2 meters long with a mirror 122 cm in diameter. The next large telescope was built in 1845 by the Irish amateur astronomer Ross. The telescope was 18.3 meters long and had a mirror 183 cm in diameter. This telescope took 22 years to build and was in its day the largest astronomical instrument.

The use of photography in astronomy has begun in 1876. A photographic plate has many significant advantages over the human eye. It can be made sensitive not only to visible light, but also to the ultraviolet and infrared, to which the eye does not respond. By prolonged exposure, the photographic plate can accumulate light energy and makes it possible to detect brightly growing celestial bodies, which the eye cannot see even in the

telescope.

The farther a celestial body is from us, the less light from it reaches the observer, and therefore astronomers strive to increase the diameter of the mirror, whose area determines the penetrating power of the telescope, i.e., the ability to observe remote and weakly visible celestial bodies.

At the end of 1947, construction was completed in the USA of the Palomar telescope, with a mirror 5 m in diameter. The construction took 20 years and cost 10 million dollars. This telescope is for the time being the greatest in the world in its size and technical equipment. A certain idea of its size can be gained from the following figures: the mirror weighs 14.5 tons, the tube 150 tons, and the rotary equipment approximately 500 tons. It is possible to observe with this telescope celestial bodies more than 500 million light years away from us (a light year is a distance which a beam of light covers within a year at a speed of 300,000 km/sec).

To make possible the observation of even more remote objects, a further increase in the telescope dimensions is necessary, and at the present level of technology this entails great practical difficulties.

Do there exist at present real possibilities of increasing the penetrating power of a modern telescope without increasing its dimensions? It appears that they do. For this purpose use must be made of more sensitive light receivers than a photographic plate. One of such light sensitive receivers is the photocathode of a photocell.

THE PHOTOCELL AS A LIGHT SENSITIVE RECEIVER

There exist different types of photocells, namely those with the external photoeffect, with a barrier layer, and photoresistances. All are extensively used in science and technology. The choice of any particular type depends on the task and on the requirements imposed on the light receiver when measuring the radiant energy. In astronomy, the most widely used are photocells based on the external photoeffect.

The photocell is intended to convert light energy into electricity. The illumination may be different at different points on the photocathode of the cell. In the bright places of the image, more electrons are produced than in the dark ones. All these electrons strike the anode and form a certain total photocurrent. Thus, the

photocell cannot replace the photographic plate to record a picture behind the telescope.

The photographic plate can be replaced by an electron-optical converter of light (or, as it is also called, an electron-optical image converter) or a television transmitting tube. In either case, the radiation receiver is also a photocathode. Under the influence of the light on the surface of the metal or a semiconductor, an electronic image is produced. With the aid of electric and magnetic fields it is possible to control the electron flow and to convert it again into an optical image.

An important characteristic of a photocathode is its spectral characteristic, i.e., the dependence of the photocurrent on the wavelength of the light (color) incident on the photocathode. The spectral characteristic indicates the limits of the color sensitivity of a given photocathode, and also the light wavelengths, at which it becomes no longer sensitive to light (the long-wave and the short-wave sensitivity limits).

The following types of photocathodes are used in practice: 1) antimony-cesium, with a maximum sensitivity to blue light; 2) oxygen-cesium, which has two sensitivity maxima in the blue and in the infrared regions (when operating with the second maximum, this

photocathode makes it possible to detect infrared rays which the eye does not see); and 3) oxygen-bismuth-cesium with a maximum sensitivity in the green, similar to the spectral sensitivity of the human eye. The spectral characteristics for different semi-transparent photocathodes are given in Fig. 1.

Another important characteristic of the photocathode is its quantum yield, which defines the number of electrons radiated by the photocathode under the influence of one quantum of light incident on its surface. The quantum yield will be 100% if each quantum of light causes the emission of one electron. However, all the existing photocathodes with external photoeffect have a yield which is much less than 100%. The quantum yield is different for different materials and different wavelengths of light. The greatest yield is obtained from an antimony-cesium photocathode, and amounts up to 30% at the maximum sensitivity, relative to the theoretical value. Oxygen-cesium photocathodes have a much lower yield (approximately 0.3 - 1%).

In order to compare the sensitivity of a photocathode and a photoplate as light receivers, it is necessary to have for the two common qualitative indices.

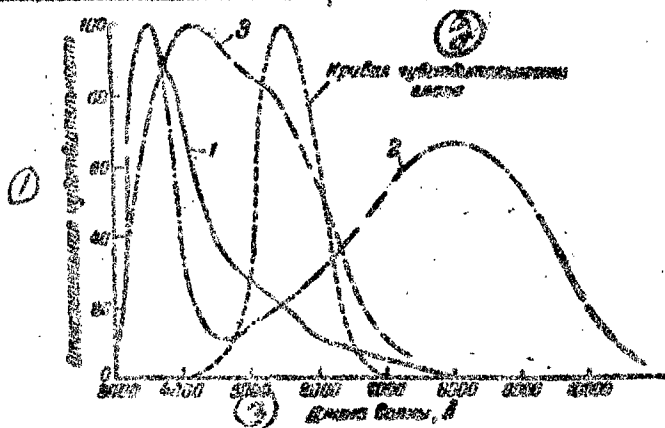


Fig. 1. Spectral characteristics of semi-transparent photocathodes.

1 -- antimony-cesium; 2 -- oxygen-cesium;
 oxygen-bismuth-cesium.

1) relative sensitivity 2) curve of sensitivity
 of the eye 3) Wavelength λ .

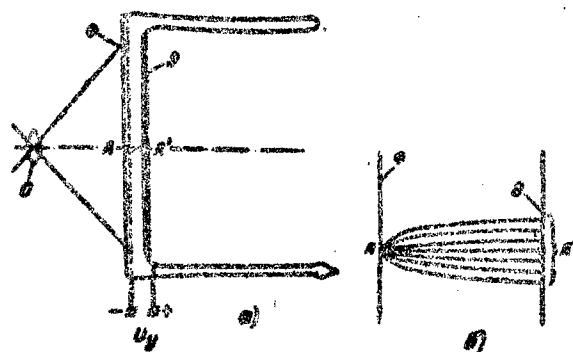


Fig. 2. Electron-optical light converter, of Holst.

A -- objective; Φ -- photocathode; Э -- screen;

U_y -- accelerating voltage.

Such a common index is the equivalent quantum yield. For a sensitive photographic emulsion it is necessary to have 1000 quanta to produce one grain of metallic silver, which appears when the photographic plate is developed. Therefore the quantum yield of a photographic plate is approximately 0.1%. If the average quantum yield of a photocathode is taken at 10%, its sensitivity is assumed to be 100 times greater than the sensitivity of a photographic plate. This means that the efficiency of a telescope with a photocathode as a light receiver becomes considerably greater. Thus, for example, a telescope with a 5 m mirror provided with a photocell, is equivalent to a telescope with a 50 m mirror using a photographic plate.

ELECTRON-OPTICAL LIGHT CONVERTERS

The electron-optical light converter consists of a semi-transparent photocathode and a fluorescent screen, which is maintained at a relatively high positive potential relative to the photocathode. If a light image is projected on the photocathode, the same image is duplicated on the screen by the photoelectrons that travel from the photocathode and bombard the screen. Electron-optical converters with high-efficiency screens-

luminophors, operating at high voltages (on the order of 10,000 volts) act as light amplifiers.

The simplest type of converter known in the literature as the Holst cup (or converter), named after the first to use such an instrument in 1934, is shown in Fig. 2a. The converter consists of a glass cylinder-tube with flat walls, from which air is pumped out. On the inner side of one of the walls is coated a semi-transparent photocathode Φ . On the opposite wall of the tube, at a distance of approximately 20 mm from the photocathode, is a fluorescent screen Ξ . Between them and the photocathode is applied an accelerating voltage $U_y = 3\text{--}4$ kv.

Under the effect of the light from the optical image, projected on the photocathode, the latter emits electrons. More electrons are emitted from the bright spots of the image than from the dark ones. This electron image is very rapidly transferred to the screen and strikes it. Part of the energy of the impact of the electrons is converted into thermal energy, and part into light energy. A visible image is produced on the screen, similar to the primary (optical) image projected on the photocathode of the converter.

Sometimes the photocathode of the converter is made sensitive to infrared. One can then see with such a converter the images of objects illuminated with infrared rays, or celestial objects which radiate these rays in larger amounts compared with visible rays. In other words, in this case one can see images which are invisible to the unaided eye.

The image on the screen of the Holst converter is not sufficiently sharp. This is due to scattering of electrons when the electron energy is transferred from the photocathode to the screen, something that is unavoidable because of absence of electron focusing. Figure 2b shows schematically how a point A of the image on the photocathode is converted, owing to lack of focusing, into a blurred spot A' on the screen of the converter. Increasing the accelerating voltage increases the sharpness and the brightness, but in this case the light produced by the screen strongly illuminates the photocathode, and a bright background appears. As the voltage is increased, the brightness of the background increases to such an extent, that the image has low contrast and soon disappears. For this reason the Holts converter operates usually at relatively low voltages,

not greater than 3 kv, and produces images with low sharpness and low brightness.

A further development in the construction of electron-optical converters has followed the path of increasing the accelerating voltage and improving the focusing of the electron image. In modern constructions of converters, the accelerating voltage usually does not exceed 17--20 kv (further increase in the voltage increases relatively little the brightness of the image, but increases the danger of breakdown of the installation inside the tube). It was found useful to cover the screen with a thin film of aluminum (0.08 mm thick). This increases the brightness of the screen by a factor of two, destroys the background completely, and increases the contrast of the image.

A diagram of a modern converter with electrostatic focusing is shown in Fig. 3. The optical image on its photocathode Φ is larger than that produced on the screen \mathcal{B} . Thus, when focused, the electron energy so to speak becomes denser, which increases additionally the brightness of the image on the screen of the converter.

Electrostatic focusing introduces certain distortion in the image. To compensate for this distortion, the surface of the photocathode is made spherical. To

focus the electric image, additional electrodes of complicated form are placed inside the converter (electronic lenses II). A focusing voltage $U_{\phi} \approx 5$ kv is applied to these electrodes. The screen of the converter is aluminized.

Such a converter can produce a brightness amplification of 30--40 times, if the accelerating voltage is $U_y = 20$ kv and an antimony-caesium photocathode is used. A smaller amplification of brightness (approximately 10 times) is obtained with an oxygen-caesium photocathode.

The converter can give a much greater brightness amplification, if the scale of magnification is made less than unity. In this case the image on the screen is less than the primary image projected on the photocathode. Thus, in a magnification scale 10 : 1, the density of the electron image is increased by a factor of 100. Upon transfer of the electron image, the gain in brightness reaches 10--20. Thus, the total magnification of the brightness is increased to 1000--2000. Such an instrument is convenient for visual observation (with the aid of an eyepiece).

The above figures concerning the amplification of brightness pertain to the case when a photographic plate

(if the image is photographed) is placed flat against the rear wall of the bulb, where the screen is deposited. However, the wall of the bulb is not less than 2--3 mm thick, and this causes a certain blurring of the image on the photograph.

To obtain a sharp photographic image, it becomes necessary to use an optical system, so that the real amplification is reduced. Thus, if an objective with a relative aperture 1 : 1 is used, then only 8% of the total light flux strikes the photographic plate, compared to what is produced by the converter screen. Depending on the material of the screen, its glow may be green, blue, or violet. Green glow is used in visual observations, since the eye is more sensitive in this region of the spectrum. In photography, on the other hand, blue or violet glow is used (the photographic plate is usually most sensitive in this region of the spectrum). In this case the real amplification of brightness past the converter reaches 7.

The efficiency of the converter can be considerably increased by replacing the screen with a photographic plate. In this case the electrons which travel with very large velocity from the photocathode will bombard the photoemulsion and produce a photographic effect in it,

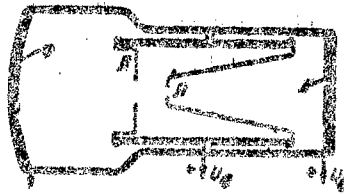


Fig. 3. Electron-optical light converter with electrostatic focusing.

Φ -- photocathode; Π -- electron lenses;
 Э -- screen; U_{Φ} -- focusing voltage; U_y -- accelerating voltage.



Fig. 4. Electron-optical converter of light with intermediate vacuum.

Φ -- photocathode; M -- metallic film; Π -- photographic plate; O -- windows; 1--3 -- converter sections.

similar to the action of light. Such a method makes it possible to decrease considerably the exposure time of the photographic plate (by a factor of 50--100, which is equivalent to an increase in brightness by the same amount). This method was proposed by the French astronomer L'Allemand in 1936 as a means of reducing the exposure when photographing celestial bodies. However, this method has a great shortcoming in that the number of photographs is limited. In such a converter the photographic plate is in a sealed glass vessel together with the photocathode. To remove the plate, it is necessary to break the vessel and destroy the converter.

A further improvement of this method has made it possible to use several photoplates, mounted on a rotating cassette. The number of plates reached 12. The cassette was rotated by an external electromagnet. This made it possible to obtain 12 photographs, after which the converter still had to be broken up (when the photoplates were removed for development).

The latest construction of this instrument, used for astronomic purposes, has been greatly improved. It makes it possible to insert and remove the photoplates without destroying the glass bulb. The diagram of such a converter is shown in Fig. 4.

The converter consists of three sections. The first is a high-vacuum chamber. In it, as usual, is placed the photocathode Φ . Instead of a photographic plate, a thin metal film M is inserted (up to several microns thick), so as to retain the vacuum in the section and at the same time transmit the electrons from the photocathode to the photoplate II, mounted behind this film. Between the film and the photocathode is applied an accelerating voltage on the order of 30 kv. This ensures a high velocity of motion of the electrons, and consequently they readily pass through the metal film and bombard the photo-emulsion.

The second and third sections have an intermediate vacuum, and communicate with each other and the outer air through tightly sealed windows O. The photoplate is first inserted in the third section, the outer window is tightly closed, and the air is pumped out from this section. When an identical vacuum is produced in the second and third sections, the window is opened, the photoplate is placed in the second section and is pressed against the metal film. After photography, the photoplate is transferred in the reverse sequence to the third section, and is then removed from the instrument. All these operations are carried out with the aid of an external electromagnet.

The process of transferring the photoplate from the converter necessitates each time the evacuation of the air from the third section. However, all these difficulties are offset by the high grade of the image obtained on the photoplate.

Another way of increasing the brightness is to use several converters connected in cascade. In this case the image from the screen of the first converter is projected by a high aperture objective on the photocathode of the second, and the image from the screen of the second converter is photographed. Such a scheme of connecting the converters will produce theoretically an amplification up to 50, but the real amplification usually does not exceed 10 or 12. In addition, owing to a large number of lenses in the objective, and also owing to the grainy structure of the screens, the scattered light is increased and the sharpness of the image is reduced.

A considerably greater amplification can be obtained by using two converters without an intermediate optical system. For this purpose a common thin glass plate is used, on one side of which is coated the material of the screen of the first converter, and on the other side the semi-transparent photocathode of the

second converter. In order not to deteriorate the sharpness of the image, the thickness of the common plate must not exceed 0.1 mm. A voltage of 30--35 kv is needed to supply such a block. The brightness amplification obtained on the photoplate is approximately 100--140.

There exist also converter constructions with magnetic focusing. In such a system, the converter is placed usually in a long cylindrical core with a large number of turns, carrying electric current. The current is experimentally chosen in accordance with the best sharpness of the image on the converter screen.

Converters with magnetic focusing produce sharper images than those with electrostatic focusing. This is particularly noticeable in multi-stage converters, where the distortion of the individual stages adds up.

To obtain very large amplifications of brightness, the number of stages could at first glance be increased without limit. This is hindered, however, by the internal noise in the converter (noise due to thermo-electronic emission of the photocathode). Thus, in a multi-stage converter with antimony-caesium photocathode, at an amplification of 100,000, this noise appears as a bright background, which is made up of a large number of bright points, moving at random over the entire area of

the screen (each bright point is the result of the striking of one or several electrons against the screen). Consequently, a gain of approximately 100,000 is the limit. At such a gain, one can hardly distinguish the image, if its brightness on the photocathode is not lower than 10^{-6} lux. A satisfactory image is obtained when the signal prevails over the noise by a factor of 10. For this case the illumination of the input image should be 10^{-5} lux, and the amplification 10,000. These figures should be considered as defining the sensitivity of the image.

The interval of illumination of the images, with which one deals in astronomy, is very large. Thus, for example, a star of first magnitude produces an illumination on the pupil of the eye of 8.3×10^{-7} lux. A difference of one stellar magnitude corresponds to a change in illumination by a factor of 2.512, while a change in five stellar magnitudes corresponds to a 100-fold change in illumination. Stars brighter of those of first magnitude are designated with negative stellar magnitudes, and weaker ones with positive magnitudes. Table 1 gives an idea of the illuminations on the surface of the earth, produced by different celestial bodies.

The illuminations of the images on the photographic plate depend on the brightnesses of the celestial objects themselves, on their angular dimensions, on the diameter of the input aperture of the telescope, and its focal distance. Table 2 lists the dimensions of images of certain celestial bodies and their illumination past the telescope (at a telescope aperture diameter of 500 mm and a focal distance of 20 m).

Table 1

1) Небесное тело	2) Звездная величина, m	3) Создаваемая освещенность на поверхности Земли, $лк$	4) Примечание
5) Солнце	-26,7	100 000	—
6) Луна (полнолуние)	-12,6	0,24	10) Соответствует освещенности, создаваемой свечой на расстоянии 2,8 м
7) Звезда	1	$8,3 \cdot 10^{-7}$	11) То же на расстоянии 1,1 км
8) Звезда (граница видимости невооруженным глазом)	6	$8,3 \cdot 10^{-9}$	12) То же на расстоянии 11 км
9) Звезда (граница обнаружения при помощи длительного фотографирования в мощные телескопы)	21	$8 \cdot 10^{-16}$	13) То же на расстоянии 1100 км

1) Celestial body 2) Stellar magnitude, m
3) Produced illumination on the surface of the earth, lux
4) Remarks 5) Sun 6) Full moon 7) Star
8) Star (threshold of visibility with the unaided eye)
9) Star (threshold of detection with the aid of prolonged photography and powerful telescopes) 10) Corresponds to an illumination produced by a candle at a distance of 2.8 m 11) The same at a distance of 1.1 km 12) The same at a distance of 11 km 13) The same at a distance of 1100 km.

Table 2

1) Небесное тело	2) Максимальные угловые размеры, секунды дуги	3) Максимальная освещенность на поверхности Земли, лк	4) Диаметр изображения после телескопа, мм	5) Освещенность изображения на фотопластинке, лк
6) Луна	1800	0,24	181	0,57
Венера	64	$8 \cdot 10^{-4}$	6,2	2,6
Юпитер	50	$1,5 \cdot 10^{-5}$	4,8	0,075
Звезда 21-й величины	—	$8 \cdot 10^{-11}$	0,06	$1,4 \cdot 10^{-8}$

1) Celestial body 2) Maximum angular dimensions, seconds of an arc 3) Maximum illumination on the earth's surface, lux 4) Diameter of image past the telescope, mm 5) Illumination of the image on the photographic plate, lux 6) Moon, Venus, Jupiter, Star of 21-st magnitude.

TELEVISION APPARATUS AS A MEANS OF INTENSIFYING
THE BRIGHTNESS AND SHARPNESS OF THE IMAGE

Television techniques can be used in astronomy for two purposes: 1) increase the brightness of the image past the telescope, and 2) compensation for shifts in the image (quiver of the image), due to atmospheric interference.

In the first case the television system can be considered in principle as an electron-optical amplifier of light, in which the photocathode and the screen are separated. The transmission of the image in a television system is carried out successively in time from point to point. The scanning of the image in a horizontal direction is by lines, and in a vertical direction by frames. In certain cases one can use circular scanning of the image, along a spiral. Such a scanning simplifies the apparatus, but the brightness of the image is uneven (it is greater at the center of the screen).

Compared with the usual electron-optical converter of light, a television system as a light amplifier has the following advantages: 1) the image from the telescope can be transmitted to a sufficiently large distance, affording in some cases convenience in observation; 2) it

is possible to obtain on the television screen a magnified image (many times greater than the dimension of the optical image on the photocathode of the transmitting tube); 3) it is possible to control continuously the scale, the contrast, and the brightness of the image for an identical exposure time during photography from the television screen; 4) in some cases it is possible to "accumulate" the image on the target of the transmitting tube.

Among the shortcomings of the television method of amplification of brightness are the following: 1) considerable complexity of the equipment (compared with electron-optical light converters); 2) lower light sensitivity when ordinary television tubes, such as are used for television broadcasting, are used; exception is television equipment in which very sensitive transmitter tubes are used, especially designed for weak illumination (such tubes are successfully used in foreign practice for astro-omic observation); 3) a lower limit on the reduction of the exposure time when the image is photographed from the television screen; in this case the minimum exposure is determined not only by the brightness of the image on the screen, but also by the duration of the transmission of the television frame; if the vertical sweep of the image is produced in $1/50$ of a second, the exposure in photo-

graphy cannot be shorter than this time; for example, at an exposure of 1/100 sec only part of the image will be recorded on the photograph (all this pertains to ordinary kinescopes, with a small afterglow of the screen -- not greater than 1/25 sec).

TELEVISION TRANSMITTING TUBES

Transmitting tubes of different types are used in television practice. Those widely used are: 1) iconoscope; 2) iconoscope with image transfer (supericonoscope); 3) vidicon (tube with photoresistor); and 4) orthicon with image transfer (superorthicon). Let us consider briefly the arrangement and the capabilities of application of these types of tubes in astronomy.

In a transmitting tube, use is made of the principle of charge storage. The electron image in them, produced by the photocathode, is transferred to the target, which can be an insulator or a semiconductor. Electric charges are accumulated on the target, and their magnitude and shape are determined by the character of the transmitted image.

The sharpness of the image, as is well known, depends on the number of elements (smallest sizes of details can be distinguished on the kinescope screen).

For the standard television scanning of 625 lines, the number of image elements reaches 521,000. On each element of the image the charges are accumulated slowly during the transmission of each frame (in our case 1/25 sec). During the time of scanning, as the electron beam moves along the target, each element is rapidly discharged during the transmission time of one element (approximately 1.3×10^{-7} sec). Thus, the electron beam removes the charges from that part of the target, over which it passes. The remaining part of the target accumulates the charges during the entire time. Therefore the process of accumulation of charges insures the production of a large signal at a relatively small brightness of optical image on the photocathode of the tube.

The first television tube, in which charge storage was used was constructed in 1932 and was called an iconoscope. Its efficiency is sufficiently low and amounts to approximately 5% compared with the theoretical ideal tube, for which the use of the principle of accumulation can be considered 100%. For normal operation of the iconoscope, illumination of approximately 50 lux is necessary for the image on the photocathode.

Iconoscopes are used at the present time in television studios for the transmission of motion picture films.

In this case the low sensitivity of the iconoscope is not decisive. As to the sharpness of the transmission, the iconoscope is still the best of all the existing transmitting tubes.

The iconoscope can be used in astronomy to transmit bright images in infrared light, for example when investigating sun spots and studying the structure of the surface of the sun on a large scale. In 1939 attempts were made in the USA to employ the iconoscope for observations of the solar corona apart from eclipses. For this purpose a non-eclipse coronagraph was used, after which the optical image of the solar corona was projected on the iconoscope and viewed on the screen of the kine-scope.

Further improvements in the iconoscope (addition of the transfer section), has led to the development of the supericonoscope.

The arrangement of the supericonoscope is shown in Fig. 5. The optical image is projected by objective O on the semi-transparent photocathode Φ . The electron image past the photocathode is accelerated and is transferred to a target M. To focus the image, a magnetic field of a short focusing coil ΦK is produced. In this case the magnetic field is not homogeneous and as a

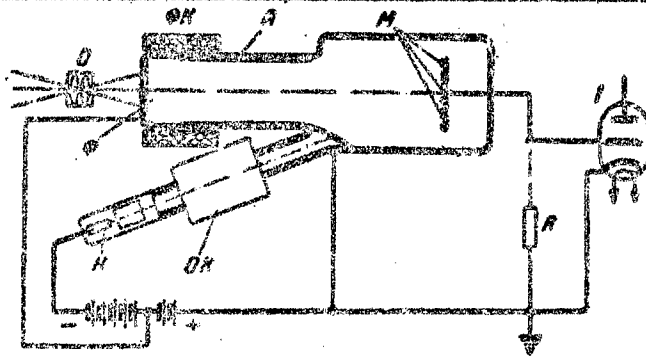


Fig. 5. Diagram of supericonoscope

O -- objective; Φ -- photocathode; OK -- focusing coil; A -- anode; M -- mosaic; K -- cathode; OK -- deflecting coils; 1 -- first stage of video amplifier.

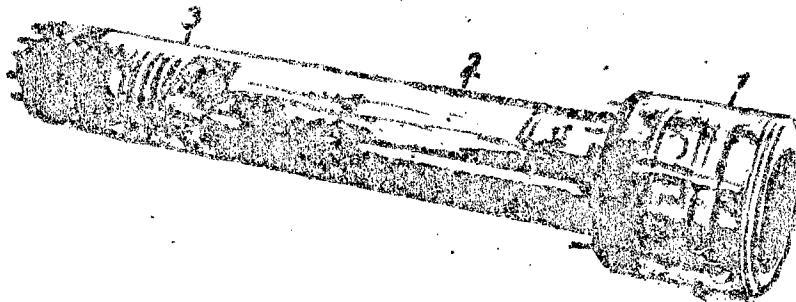


Fig. 6. External view of superorthicon

1 -- section of image transfer; 2 -- section of image sweep; 3 -- section of video-signal amplification.

result of this, as the electron image is transferred, it is increased in diameter by approximately four times (the target diameter is also four times the diameter of the photocathode).

When the image is transferred, the electrons bombard the target and knock out from its surface the secondary electrons. Positive charges are produced on the target. The bright portion of the corresponding optical image on the photocathode will lose more electrons on the target than the dark one, and the potential of the target on this portion will be found to be more positive than the potential of the dark portion of the image. Thus, a potential relief is produced on the target.

The depth of the potential relief depends on the coefficient of secondary emission of the target material. With increase in this coefficient, an increase occurs in the depth of the relief and consequently also in the size of the signal past the tube.

The target is made of a thin mica plate with a coating of creolite placed on one side, having a sufficiently large coefficient of secondary emission. The second side is covered with a metal layer, forming the signal plate. The latter has an external lead to connect it to the amplifier circuit through a load resist-

ance R.

The image is scanned with an electronic projector, located in a glass tube, sealed to the bulb at an angle of 30° . On the tube are placed a focusing coil (not designated in the figure) to contract the electrons in a narrow beam (approximately 0.1 mm in diameter) and the coils for the vertical and horizontal deflection of the electron beam.

The supericonoscope is 5--7 times more sensitive than the iconoscope. It is characterized, however, by additional distortion produced during the transfer of the electron image from the photocathode to the target. Consequently only the center part of the photocathode, 1--4 cm² in area is used in the supericonoscope.

An electronic instrument called "telescroscope" was constructed in 1940 in the USA. The instrument is designed for compensating the shifts in many stellar images, due to atmospheric interference. The telescroscope is a supericonoscope, in which there is a small hole in the center of the target. Behind the hole is placed a four-face metal prism-pyramid. Around the pyramid are placed the emitters of four electron multipliers. The entire device is contained in the ordinary glass bulb of the supericonoscope.

The image of a series of stars, which enter into the field of view of the telescope, are projected on the photocathode of such a supericonoscope. Any of the stars can be projected onto the hole in the target and serve as the "control" star. The electronic image of this star, passing through the hole, strikes the vertex of the pyramid. The electrons are reflected from the planes of the pyramid in four directions and enter into four electron multipliers, located in each plane. When the electronic image of the control star is at the center of the hole in the target (on the vertex of the pyramid), the electron fluxes at the input of the multipliers are the same, and the output currents are also the same.

The outputs of the multipliers are connected to four coils, located at the photocathode (in the image-transfer section) of the supericonoscope. The coils displace by means of their magnetic fields the electron image in two mutually-perpendicular directions. Thus, when the input electron fluxes in the multiplier are equal, the electronic image of the star remains on the center of the target.

If the optical image on the photocathode has shifted, then the electron image on the pyramid also shifts. This makes the currents in the four coils un-

equal. By choosing a suitable phase shift and size of the current in the coils, the electron image of the star can be again brought back to the center of the target.

After the working conditions for the amplification in the electron multipliers are suitably chosen, the electron image remains almost stationary on the target. The potential relief on the target is then picked off and forms in the usual manner the television image. The stable image of the stars is viewed on the screen of the kinescope.

The action of the transmitting tubes described above is based on the use of a photocathode with external photoeffect. In 1950-1951 transmitting tubes have appeared with photoresistors, frequently called "vidicons". These tubes are exceedingly simple in construction, have a large quantum yield in the photocathode-photoresistance (the quantum yield reaches 100%, something that cannot yet be obtained from a photocathode with external photoeffect), and can be manufactured to operate in any portion of the spectrum (both the visible part of the spectrum and in the infrared, much farther than can be obtained with tubes using the external effect of the photocathode).

However, photoresistor tubes still have a serious shortcoming, that at low illuminations on the photocathode they have an excessively long electric "memory" (inertia). This shortcoming manifests itself strongly in the transmission of moving images. In this case the image may become blurred or may have "tails" accompanying certain details of the image. Thus, for a Russian type LI-18 photoresistor tube, the inertia is 1 sec, and in some cases it reaches 10 sec. The inertia can be reduced in principle, but this is accompanied by a reduction in the sensitivity of the tube.

The dimension of the working part of the photoresistance in the tube, i.e., the dimension of the frame, is 9 x 12 mm. However, in spite of such a relatively small area of the output image, the tube insures sharpness in transmission of not less than 600 lines in the center of the frame. The illumination of the image on the photocathode must in this case be not less than 5 lux.

Tubes with photoresistances have found wide application in commercial television and in devices for scientific research. In astronomy these tubes are not used for the time being. However, their spectral capabilities, small size, and simplicity of construction ensure that they will be widely used in the near future

in astronomic practice. The tubes can be used in the far infrared region to study the spectra of bright stars, the sun, and its surface.

The most sensitive of all the transmitting tubes is the superorthicon. This tube is used for television broadcasting from outside the studio. The sensitivity of an ordinary superorthicon is greater than the sensitivity of an iconoscope by approximately 500 times. At a small reduction in sharpness in the transmitted image, this gain can be raised to 1000 or more.

The external view of the superorthicon is shown in Fig. 6, and its schematic arrangement is shown in Fig. 7. Structurally the tube is divided into three parts:

1) the image-transfer section; 2) the image scanning section; and 3) the video-signal amplification section.

The transfer section consists of a semi-transparent photocathode, which accelerates the electrode, and a target made of thin (5 microns) semiconducting glass film sealed to a glass ring. The specific electric resistivity of the target (3×10^{11} -- 10^{12} ohm/cm at 20°C) depends strongly on the temperature. When the target is heated its resistance decreases, and when it is cooled it increases. For normal operation of the tube, the target temperature should range from 35 to 60°C .

Located in front of the target is a fine-structure metal grid, called the grid of the target. Its purpose is to control the operating conditions of the target. For orthicons designed for an image illumination of 0.1 lux on the photocathode and upwards, the distance between the grid and the target is 0.008--0.01 mm, while for tubes designed for lower values of illumination, this distance reaches 1--1.5 mm. The target grid has up to 40 openings per millimeter. Its transparency amounts to 50 or 75%.

The optical image is projected on the photocathode. The electronic image is transferred from the photocathode to the target and is focused by a homogeneous magnetic field produced by a long cylindrical coil and an electric field in the gap between the photocathode and the target. The tube is placed in the center of the coil.

Transfer of the electron image to the target produces a potential relief, which is transmitted to its other side, where it is scanned by a beam of slow electrons, which have almost zero velocity. The electron beam is produced by an electron gun located on the other end of the tube (in the amplification section). As the beam of electrons moves along the target, the potential relief is cancelled out. And since the electron beam carries a constant amount of electrons and random returns and strikes

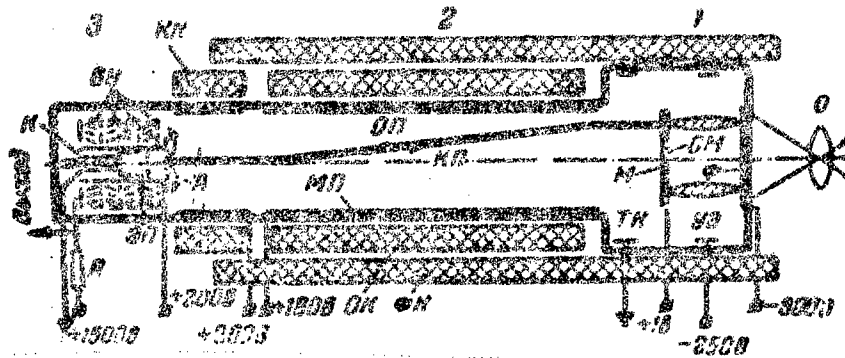


Fig. 7. Diagram of Superorthicon.

K-- cathode. Py -- secondary-electron multiplier. ЭП -- electron gun. A -- Anode. KH -- commutating beam.

OH -- Backward beam. MP -- metallic coating. M -- target. TK -- slowing-down ring. CM -- target grid.

Ф -- photocathode. O -- objective. ЯЭ -- Accelerating electrode. KK -- correcting coil. OK -- deflecting coil. ФК -- focusing coil. I -- image-transfer section. 2 -- image-sweep section. 3 -- video-signal amplification section.

1) input, 2) 300 volts

the amplification section.

The charges are distributed differently in different points of the target, and therefore the number of electrons gathered by the target from the beam during the scanning process varies. Accordingly, the current of the backward beam also changes. Thus, the electron beam becomes modulated by the signal of the image. It then enters the electron multiplier, located in the amplification section, where it is amplified by a factor of 500 or 1000.

A five-stage electron multiplier amplifies the video signals almost without adding any intrinsic noise, and the signal past the tube exceeds considerably the intrinsic noise of the following vacuum tube amplifier. The load resistance past the electron multiplier (input resistance of the amplifier) usually does not exceed 20--30 kilohms. The voltage of the signal on the resistance, upon transmission of sufficiently large details of the image, amounts to 0.1 volt on the average. For weak illumination, this voltage can drop to 0.01 volts, and in transmission of fine details with increasing video-signal frequency, its value decreases still further. Thus, when transmitting a picture element corresponding to a sharpness of 625 lines, the signal decreases by another factor of 10--15. Therefore, to obtain a sharp image on the kinescope screen it

becomes necessary to employ an additional stage, called the upper-frequency corrector. This stage gives an increased video-signal voltage gain at high frequencies, causing an increase in the definition in the transmission of fine details of the image.

Figure 8 shows a diagram of a video-signal amplifier, usually mounted near the transmitter tube, i.e., in the transmitting terminal. All the amplifier stages incorporate complicated corrections in the low and high frequency ranges. A third stage, which serves as a corrector for high frequencies, gives a reduction in gain in the low and medium frequency region by a factor up to 100.

The overall voltage gain at the high frequencies of video signals for the superorthicon to the modulator of the kinescope is usually not less than 10,000--30,000. For a scanning definition of 625 lines at 25 frames per second, the amplifier should transmit a frequency band from 50 cycles to 6.5 Mcs without distortion.

Figure 9 shows an approximate supply circuit for the individual elements of the superorthicon. All the voltages on the circuit are given relative to the zero voltage on the cathode of the electron gun.

The type II-17 superorthicon produced by our industry, under normal illumination of 0.5 lux on a photo-

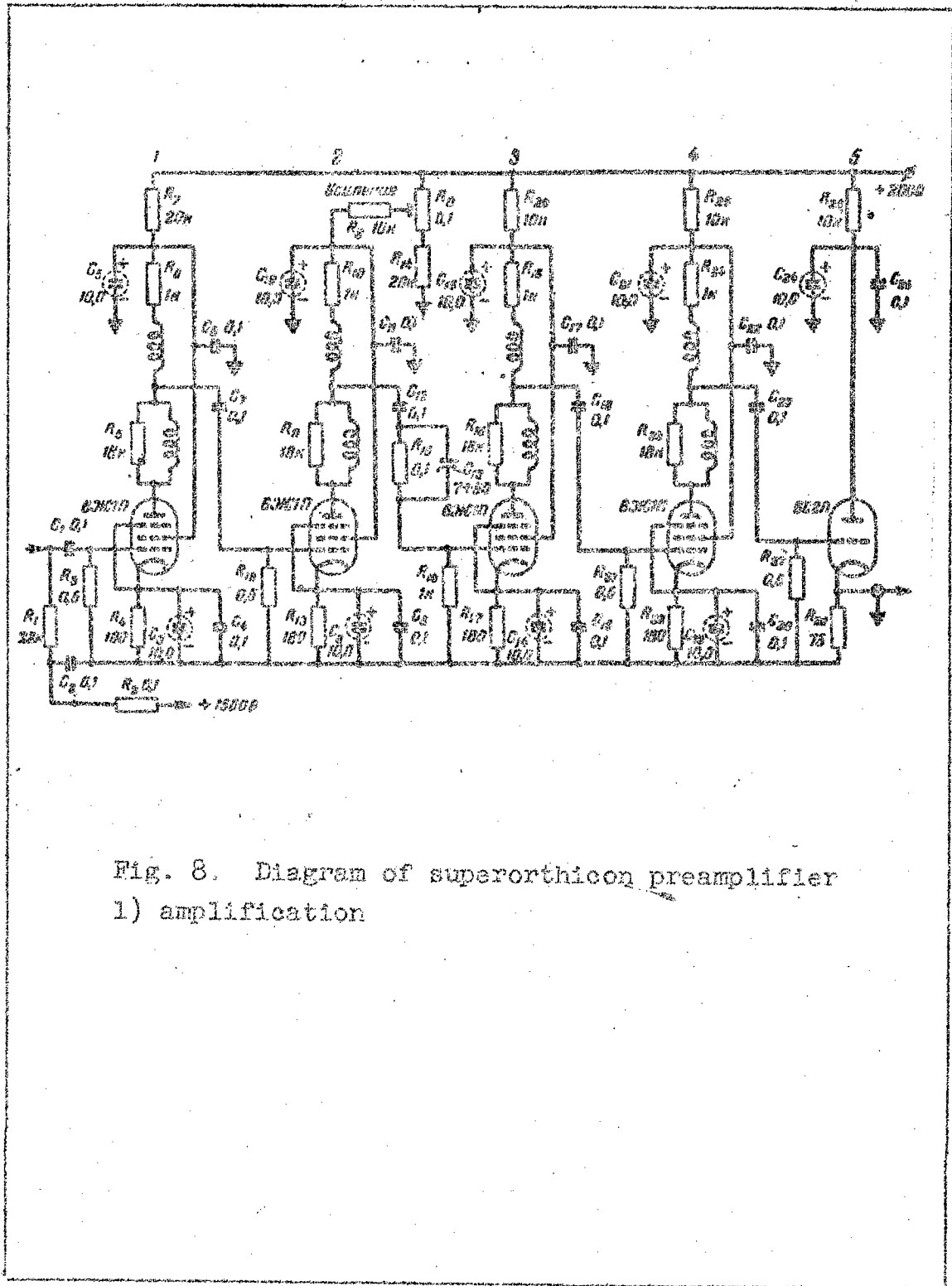


Fig. 8. Diagram of superorthicon preamplifier
 1) amplification

cathode, ensures a sharpness of image in the center of a 625 line frame. When the illumination drops to 0.1 or 0.05 lux, the definition drops to 550--500 lines.

The superorthicon has a sufficiently high overall intrinsic noise, and therefore to obtain good quality of the image it becomes necessary to increase the illumination of the transmitted object or to introduce an additional fine-structure metal grid on the side of the scanning of the electrons (the grid is located near the target). The presence of a second grid reduces the intrinsic noise of the tube and broadens the linear part of the light characteristic (i.e., the dependence of the signal on the value of illumination of the photocathode).

Owing to the large complexity of the superorthicon and the interdependence of the different sections which are linked together by a common magnetic field, the choice of the best operating conditions necessitates the consumption of a rather long time. The operation of the tube depends strongly on the temperature of the target. At a temperature less than 30°C the target resistance becomes relatively large, producing in it an excessive accumulation of negative charges. In this case, when the bright spots are displaced, "tails" appear on the moving image, so to speak left by the moving bright images.

At a temperature above 60°C , on the other hand, the conductivity of the target increases, and this leads to a reduction in the sensitivity of the tube and a loss in sharpness in the transmitted image. Thus, the interval of working temperatures of the target ranges 35--55 or 60°C .

For preliminary heating of the tube, an electric heater is used. It is located in the image-transfer section (inside the focusing coil). Temperature is controlled by changing the current through the heater.

In addition to superorthicons, designed for medium photocathode illumination (0.5--0.1 lux), there exist tubes for low illumination. Thus, a superorthicon (type 6849) is produced in the USA with a threshold sensitivity of 0.0001 lux.

The addition of several stages of electron-optical amplification of light to a superorthicon has led to the development of a supersensitive tube. Such a tube gives a satisfactory image with a photocathode illumination as 10^{-5} -- 10^{-6} lux. Its threshold sensitivity is limited only to noise due to thermoelectronic emission of the photocathode.

The superorthicon has come to be used in astronomy only recently (1954). It is used as a light receiver

in television apparatus for amplifying the brightness of images. Recently (1957) the superorthicon has come to be applied also in apparatus for compensation against atmospheric noise in astronomic observations.

ATMOSPHERIC NOISE IN ASTRONOMIC OBSERVATIONS

The stars are located at distances so large, that the light takes a century, and sometimes many thousands of years to reach us. We are therefore justified in considering that the light rays coming from the stars are parallel, and that their wave front is plane. Earth's atmosphere is not homogeneous in its optical properties, since it is never at rest over its entire extent. Volumes of air of different density, humidity, and temperature are in constant motion, are carried by the wind, and change their contours. Thus, the plane front of the incoming light wave becomes wavy in accordance with the changing operating properties of the sections of the atmosphere through which it passes. The light rays travelling from the star no longer are parallel, but become either convergent or divergent.

All this is explained in Fig. 10. Here the shaded layer is the region where the change in the optical properties of the atmosphere takes place. The plane light

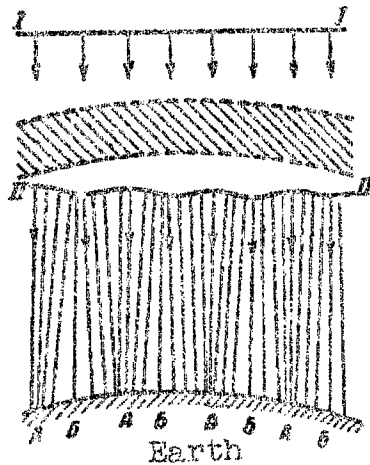


Fig. 10. Displacement of the path of straight rays of light from stars under the influence of the earth's atmosphere

wave I-I', after passing through this layer, becomes deformed into a wave II-II, the perpendiculars to which are now light rays which travel from the star. At the points A on the earth's surface the light energy becomes denser, since more light rays will strike this surface than at the point B. Since the inhomogeneities in the atmosphere are always in motion, the rays corresponding to point A and point B will alternately enter into the observer's eye, and the star will appear to flicker.

In addition to the flicker of the star image, i.e., the change in its brightness, one observes also a rapid geometrical displacement, called the quivering of the image.

All these atmospheric noises cause great deterioration in the quality of the image of the celestial objects. When observing a planet, two points on its disc, separated by an angular distance of several seconds, experience each independent oscillations. The image of the planet is subjected during the entire time to irregular and random deformations in different directions. Some parts expand and some contract. The disc of the planet will appear wavy or blurred, and the image so to speak "boils." Atmospheric noise increases if the planet is near the horizon, and decreases if it

is in the zenith, i.e., above the observer's head.

With increasing scale of the image past the telescope, i.e., when using a long-focus optical system (focal distance of 20--30 m) or a large magnification, the atmospheric noise manifests itself in an even stronger manner. The illumination of the image past the telescope decreases with increasing scale in proportion to the square of the magnification of the diameter of the image. It therefore becomes very difficult to obtain a good photographic picture of the planet on a large scale.

Thus, two opposing conditions are produced:

- 1) the reduction in the illumination of the image calls for an increase in the exposure during the photography;
- 2) an increase in the exposure, on the other hand, causes blurring of the details of the image.

When using light receivers which are more sensitive than the photographic plate, such as an electron-optical converter or a television tube, the time of exposure can be considerably reduced. This so to speak decreases the effect of the atmosphere on the quality of the astronomic picture, since on individual instantaneous photographs it is always possible to obtain a better image than on a photograph taken with a long exposure.

FIRST RESULTS OF THE USE OF ELECTRON-OPTICAL
CONVERTERS AND THE TELEVISION METHOD IN ASTRONOMY

The use of the new electronic techniques in astronomy began relatively recently. The first application of electron-optical converters for the photography of celestial objects should be dated 1949. The converters were used to photograph celestial objects in the infrared region of the spectrum.

The sensitivity of photographic plates to infrared rays is considerably less than to visible rays, and decreases considerably at weak illuminations. For objects with very low luminosity (weak nebulas, etc.), exposures of tens of hours may be useless. In this case, no image would be produced at all on the photographic plate.

On the other hand, the sensitivity of the electron-optical converters is much higher than the sensitivity of the photographic plate. It remains constant also for weak illuminations. Therefore the use of converters for photography of objects with low luminosity is very effective. In this case one can photograph celestial objects the image of which cannot be obtained by ordinary means on a photographic plate.

The use of electron-optical converters has made it

possible to obtain in infrared rays the spectra of the weak glow of the night sky, to discover new spectral lines in this region, and to detect new star clusters and nebulas.

Experiments on the application to astronomy of the television method of amplifying brightness of the image were begun at the Cambridge Observatory (England) in 1952. The results of some of the work pertain to a later period and were published in a series of journals in 1956.

Independent of these investigations, at the main astronomical observatory of the Academy of Sciences USSR (also starting with 1952), work has begun on the use of the television method in astronomy. The first publications on these works also appeared in 1956.

The diagram of the television apparatus used in Cambridge is shown in Fig. 11. The image of the celestial object is projected through the eyepiece of the telescope on the photocathode of the superorthicon. The video-signal is amplified and is made to fall on a kinescope with a screen diameter of 35 cm. The image is photographed from the screen on a motion picture film.

To focus the optical image on the photocathode, it is possible to bring the superorthicon together with its magnetic system (focusing coils and deflecting coils)

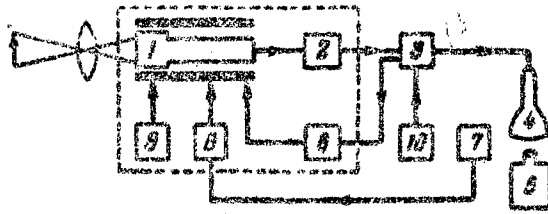


Fig. 11. Block diagram of television apparatus of the Cambridge Observatory.

1 -- superorthicon. 2 -- preamplifier. 3 -- output amplifier. 4 -- kinescope. 5 -- photographic camera. 6 -- electric motor. 7 -- control panel for optical focusing. 8 -- vertical and horizontal generators. 9 -- target blocking stage. 10 -- synchronizing generator.

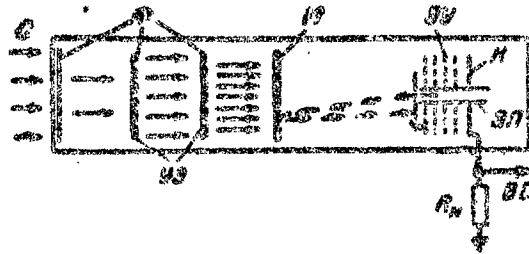


Fig. 12. Diagram of superorthicon with additional image amplifier.

C -- light. Ф -- photocathode. УЭ -- amplifier screens. М -- target. ЭУ -- electron multiplier. К -- collector. ЭП -- electron gun. BC -- output signal.

closer or farther away from the eyepiece of the telescope. The displacement is by means of an electric motor controlled from the optical focusing panel.

Interlaced scanning is used in the apparatus. The synchronizing pulses are obtained from a synchrogenerator. The number of frames per second is 25, and the number of sweep lines is 625.

The transmitting tube together with its magnetic system and the preamplifier for the video-signal are mounted on a special holder. This block is secured on the telescope. The television apparatus together with the reflector telescope (mirror diameter 250 mm) were used to photograph the moon's surface.

The television apparatus was adapted to a horizontal solar telescope (mirror diameter 250 mm). Using filters transmitting the ultraviolet or infrared rays of the sun's light to the photocathode of the transmitting tube, the sun's surface was observed in these rays. A specially constructed solar spectrograph using television apparatus was employed for spectral observations. Rare phenomena that take place on the sun's surface, which previously could not be observed by direct optical means, have now come to be examined on the screen of a kinescope and photographed.

In 1954, in the Lowell observatory (USA) experiments have been made on observing planets with the aid of a specially sensitive superorthicon (Fig. 12). In such a tube a two-stage electron-optical light converter is mounted between the photocathode and the target. The optical image, as usual, is projected on the semi-transparent photocathode. The electrons leaving the photocathode are focused at each amplifying stage. This is done by means of combined magnetic and electrostatic focusing. The magnetic field is produced by a long cylindrical coil, in the center of which is placed a tube, while the electrostatic field is produced by an interstage accelerating voltage of 10 kv.

Each stage consists of a thin glass film, covered on the photocathode side by a fluorescent material (phosphor) which produces a blue glow. Placed on the phosphor is a thin film of aluminum. On the other side of the screen is placed a semi-transparent photocathode which has a maximum spectral sensitivity in the blue light. Each stage produces a current gain of not less than 10. Thus, the gain past the second stage is 100.

The electron image is next focused on the target, where it produces a potential relief. The presence of a large gain in the transfer section greatly reduces the

internal noise of the tube when an image with low luminosity is transmitted. In this case the main noise is due to fluctuations of the fermionic emission of the first cathode. In an ordinary superorthicon, on the other hand, the intrinsic noise is determined by the low modulation of the return electron beam, which strikes the electron multiplier.

The high sensitivity of the superorthicon with additional amplification in the transfer section makes it possible to transmit images with a photocathode illumination of 10^{-5} -- 10^{-6} lux at a definition of 400 lines. It must be noted that the definition depends not only on the number of scanning lines, but also on the properties of the transmitting tube itself and on the illumination of the image on the photocathode. The threshold sensitivity of a tube with additional amplification in the transfer section is approximately the same as in a multi-stage electron-optical converter.

Television apparatus with high-sensitivity superorthicon together with a 600 mm telescope was used to photograph Mars during the time of its opposition in 1954, when its angular diameter was 20 seconds of an arc.

The optical image of Mars past the telescope, additionally amplified through a diameter of 10.5 mm,

was projected on the photocathode of the tube. The calibration apparatus was designed for 1029 interlaced scanning lines at 30 frames a second. The video-signals were amplified with a low-noise amplifier. The image was viewed and photographed from the screen of a kinescope 25 cm in diameter by means of a Leica camera. The diameter of the image of Mars on the photographs was 14 mm. The picture produced was quite sharp.

Figure 13 shows the block diagram of the television setup in the Pulkovo Observatory (USSR). The electric diagram of the apparatus of this setup somewhat simplified compared with the circuitry used in television stations. The interlaced scanning is replaced by fine scanning. In this case the image is swept during a frame time of $1/50$ sec. This makes it possible to insure relatively simply exposure of $1/50$ sec upon photographing the kinescope screen, and in addition, no synchrogenerator is necessary, which in itself is very complicated. The apparatus operates at a definition of 625 lines, which offers certain advantages, since it makes it possible to use an ordinary television set with slight modification.

The sweep generators are designed for a smooth a variation as possible of the line frequency from 15 to 22 kcs. This pertains both to the transmitting camera

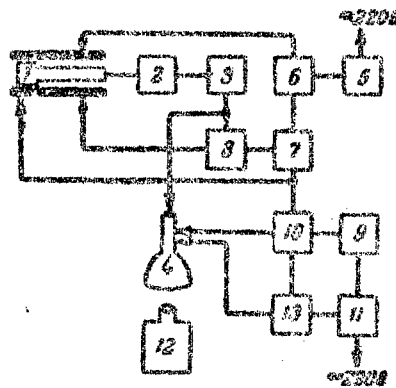


Fig. 13. Block diagram of television apparatus of the Pulkovo observatory.

1 -- superorthicon, 2 -- preamplifier, 3 -- final amplifier
 4 -- kinescope, 5 -- stabilizer, 6 -- rectifiers, 7 --
 sweep block, 8 -- shaping block, 9 -- television-set power
 supply block, 10 -- television-set synchronizing and sweep
 block, 11 -- voltage stabilizer, 12 -- photographic camera,
 13 -- electronic shutter.

and to the television set. The change in the line frequency contributes to a choice of optimum conditions for operation of the superorthicon, as necessitated by the uneven resolving ability of different specimens of transmitting tubes.

The frequency characteristic of the video channel starting with the output of the transmitting tube to the kinescope, is sufficiently uniform up to 9.5 Mcs, where a certain rise is observed, followed by a drop. At a line scanning frequency of 20 kcs and band width of 9.5 Mcs, one can insure a horizontal definition up to 950 lines. The real definition, however, is limited by the resolving ability of the superorthicon and for sufficiently bright objects (moon) it does not exceed 600--625 lines.

Images from the telescope are projected on the photocathode of the superorthicon. The electrical signals proceed from the transmitting tube to a pre-amplifier and then to the output amplifier, after which they are fed to the picture tube of the "Zenit" television set. The telescope of type 31LK2B, with a screen dimension 180 x 240 mm, gives a sufficiently uniform definition of the image over the entire area and is quite suitable for photography with a miniature camera.

As usual, the entire apparatus is fed from the ac line. The voltage is kept constant by means of stabilizers. Rectifiers produce direct current both for the transmitting tube and for all the blocks of the apparatus.

The television set has its own power supply, scanning and synchronization block, and line-voltage stabilizer. The television set circuit has been partially modified. The band width of the video channel has been increased to 9.5 Mcs, a dc restorer network is incorporated, and the linearity of the line sweep is increased. Also modified is the synchronization circuit: the pulses can be applied either directly to blocking generators through individual channels, or separated from the general television signal.

The image from the screen of the kinescope is photographed by the miniature reflex camera. An electronic synchronized shutter is used in the photography, ensuring precise exposure of 1/50 sec. This is a delay-sweep generator, operating when a triggering pulse is applied by pressing a special button. The synchronized shutter unblocks the electron beam of the kinescope during the time of passage of one frame. During the rest of the time the electron beam is blocked.

It should be noted that to obtain a good photograph with an exposure of $1/50$ sec without a synchronized shutter is a difficult matter. In practice it is impossible to open accurately the shutter of the camera at the beginning of the frame sweep and close it at the end of the frame. A small error in time will cause the appearance of white or black strips on the photograph (the white strip is produced when the exposure is less than $1/50$ sec and the dark one when it is more).

Let us consider now the optical part of the television setup. In ordinary television cameras, the optical image is projected in different scales on the photocathode of the transmitting tube with the aid of interchangeable lenses. The greater the focal distance of the lens, the greater the scale of the optical image on the photocathode, and the larger the image on the screen of the kinescope. The focal distance of an objective in a camera rarely reaches 1 m (it is usually less). To photograph a celestial object on a large scale, such a lens is not suitable. For a lens with a focal distance of 1 m, the diameter of the moon's image does not exceed 9 mm. More remote planets would be circles with even smaller diameters. Therefore in astronomical observations one uses lenses with focal distances of

18--20, and sometimes even 70 m.

The choice of a focal distance or the magnification of the image scale is determined by the quality of the astronomical image. A large image scale is used in the case of small atmospheric noise, i.e., in the case of good images. When the image quality is poor, it is useless to use large magnification.

Experiments at photographing the surface of the moon on a large scale using television techniques were carried out in Pulkovo in 1956. The apparatus was placed in the housing of the large horizontal solar pavilion, a section through which is shown in Fig. 14. There is no special tube here, and its role is assumed by the housing itself, which is approximately 50 m long.

Glass aluminized mirrors are mounted on foundations and are moved along special rails. This is necessary to focus the optical image past the telescope unto the corresponding light receivers, the choice of which depends on the particular scientific problem solved.

Light from the celestial object, in this case from the moon, strikes first the plane mirror 1, 500 mm in diameter. The mirror is provided with a clockwork mechanism, so as to follow the displacement of the celestial object. The light from it strikes an additional

stationary mirror, also plane, 650 mm in diameter. The light reflected from the additional mirror is directed up on a curved mirror 2 of the telescope, which serves as its objective (500 mm diameter, 16 m focal distance). The image of the moon at the focus 3 of this mirror measures 14.5 cm (in diameter). To increase the image, the latter is projected on an additional convex mirror 5. These two mirrors jointly yield a focal distance of 56 m. The image of the moon in the second focus 6 has a diameter of approximately 520 mm.

The television camera is installed either in the first or in the second focus. The dimension of the optical image on the photocathode of the superorthicon is 28 x 28 mm, and the image on the screen of the kine-scope is 180 x 240 mm. Consequently, the image on the screen is magnified (linearly) compared with optical by almost 6.5 times. One sees on the screen only part of the moon's surface, corresponding to a diameter of 940 mm for the first focus and 3.2 m for the second.

The quality of the image of the moon when viewed on the television screen is not always satisfactory. In some cases the optical and the electronic focusing increase but little the definition of the individual parts of the image. Owing to the large scale and to

atmospheric noise, the image always vibrates and is wavy.

It should be noted that at an optical focus of 16 m and a scale magnification of 6.5 times in the electronic apparatus, the equivalent focus of the entire system (telescope -- television apparatus) amounts to 104 m (image diameter 940 mm). For the second focus this number increases to 364 m (image 3.6 m). Instantaneous photography (1/50 sec) helps greatly under these conditions. Not all the instantaneous photographs, however, are of equal quality; in some the sharpness of the image is greater and in others it is less. It is therefore necessary to take tens of pictures and to choose the best among them.

The brightness of the image of the moon depends on its phase. During the first quarter, for a diameter of 14.5 cm (focus of 16 m), the illumination of the image is approximately 0.05 lux. In the second focus of the telescope it decreases to 0.004 lux. Direct photography of the moon at an image illumination of 0.05 lux on motion picture film with a sensitivity of 65--70 GOST units yields negatives with hardly noticeable density, if the exposure does not exceed 1/50 sec. The illumination of the image on the television screen is 30--40 lux. The gain in the brightness of the image reaches in this case

600--800. This makes it possible to obtain negatives with normal density at an exposure of 1/50 sec with a 1 : 3.5 lens.

By way of an example, Fig. 15 shows a photograph of part of the moon's surface (region near the Mare nectaris), obtained from a television-set screen. The transmitting camera was mounted in the first focus of the telescope.

In 1958 there was completed at the Pulkovo Observatory the installation of an experimental television telescope. It is based on the Cassegrain optical system, but with large magnification of this image. This scheme ensures small losses of light in the optical system, since only two reflecting mirrors are used (the principal is concave and the second is convex), large scale of image, and small dimensions of the entire telescope.

The main mirror is 285 mm in diameter. The second mirror is interchangeable. Setting the mirror to different curvatures it is possible to change the focal distance of the telescope from 20 to 54 and 120 m. With this, the dimension of the telescope tube does not exceed 2 m.

Mounted on the telescope is a light-weight television transmitting camera, using a LI-17 superorthicon. This tube can operate both in the ordinary television

sweep mode (for instantaneous photographs of images from the television screen), and in the mode of prolonged accumulation of the potential relief on the target (for several tens of seconds). In the last case the sensitivity of the tube greatly increases (in approximate proportion to the accumulation time). After the potential relief is accumulated on the target, it is swept by the electron beam. The image on the television screen is seen in this case for several tens of seconds.

The first experimental observations have shown that in the mode of storage for 6 sec (for a focus of 20 m) one can photograph stars up to 10-th magnitude. The illumination on the photocathode of the tube under these conditions is no more than 0.001 lux, and the gain in brightness reaches 30,000--40,000.

Using an optical focus of 120 m and an electron magnification in the apparatus of approximately 9, it is possible to obtain an equivalent focus of 1080 m for the entire apparatus. At so long a focus one observes clearly the definitions of images of stars, due to atmospheric noise.

In 1957 in the Dewar Observatory (USA) a compensator was installed for atmospheric noise, using television techniques. The installation was designed for

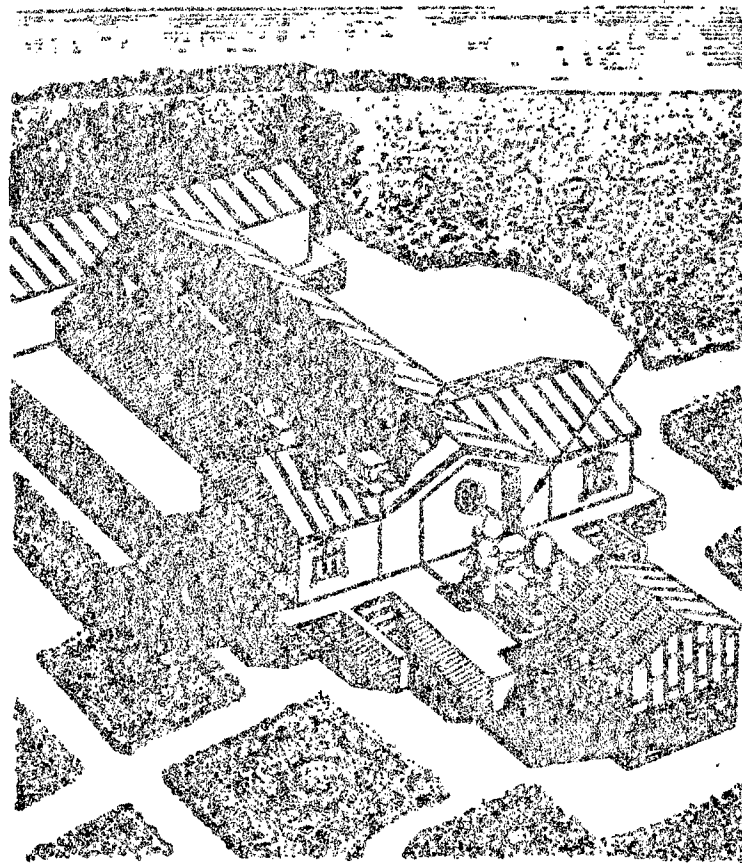


Fig. 14. Section through the solar pavilion

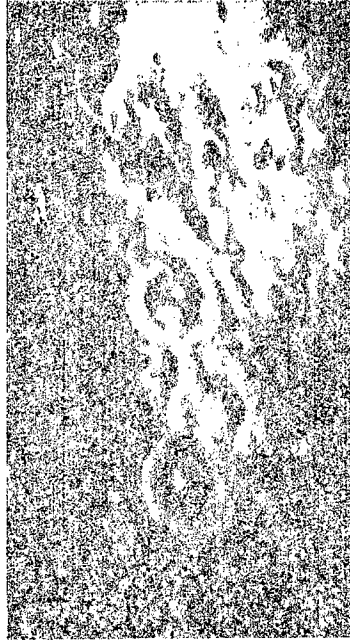


Fig. 15. Photograph from the screen of the kine-
scope, showing part of the moon's surface.

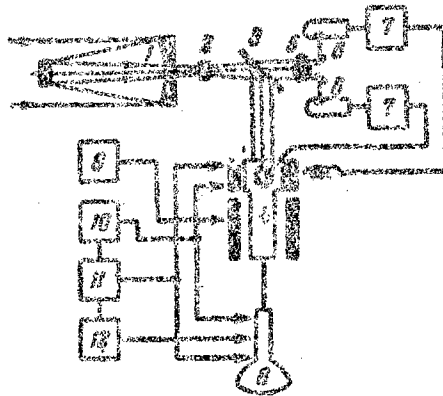


Fig. 16. Block diagram of television apparatus with
compensator for atmospheric noise.

- 1 -- telescope, 2 -- negative lens. 3 -- mirror.
4 -- superorthicon, 5 -- compensator, 6 - photomultipliers
7 -- dc amplifiers, 8 -- kinescope, 9 -- power pack for
tube, 10 -- synch generator, 11 -- sweep generators, 12--
generators for synchronizing and blocking pulses.

observation of Jupiter, Venus, and Mars.

Figure 16 shows the block diagram of this apparatus. It consists of a Cassegrain telescope with a mirror diameter of 600 mm. To increase the scale of the image past the telescope, a negative lens is used. The optical image of Jupiter reaches 12 mm (in diameter). The light passing through the lens strikes a color-selective filter (mirror). Part of the light (60%) is reflected and forms an image on the photocathode of the superorthicon. The remaining part of the light passes through a filter and forms the image of the planet on two mutually-perpendicular slits of the compensator. Behind the slits are located two photomultipliers. Their outputs are connected to dc amplifiers. The output signals of the amplifiers feed two pairs of coils, located about the transfer section of the tube. These coils are mutually-perpendicular.

A shift in the optical image on the slit changes the light flux on the photocathodes of the multipliers and increases or decreases the magnetic field in the coils. A change in this field shifts the electronic image on the target of the tube. By a suitable choice of the phase and the current in the coils it is possible to displace the electronic image in a direction opposite to the

displacement of the optical image on the slits in the photocathode of the tube. Under suitable adjustment of the gain (in the photocurrent amplifiers) the electronic image on the target, and consequently also on the screen of the kinescope remains stationary.

To increase the sensitivity of the orthicon, one can increase the time of charge accumulation on the tube target within the limits from $1/15$ -- $4/15$ sec. The time of single scanning of a frame, during which one can photograph the kinescope screen, is $1/30$ sec.

The definition of the transmission of the image in this system is greater than the usual one used in television. It ensures the fullest use of the resolving power of the telescope. The definition of the individual small details on the image of the planet is greater than in direct viewing through an eyepiece.

In addition to the aforementioned blocks, the apparatus includes a power supply for the tube, a synchronizing generator, a sweep generator, and a generator for synchronizing and blanking pulses.

CERTAIN PROSPECTS OF FURTHER DEVELOPMENT OF TELEVISION TECHNIQUES IN ASTRONOMY

Modern television tubes are unable to accumulate

the potential relief on the target for a long time, owing to a certain conductivity of the target material. In order to retain the charges on the target for a long time, it must be made of an insulator. For ordinary television transmission, a tube with such a target would be of little use (owing to the very large inertia), but for registration of images with very low illumination under prolonged accumulation of the potential relief (several hours), it would be quite useful.

Work has been carried out in England on the development of a transmitting tube for prolonged accumulation of image charges. The tube is designed for use in the photography of exceedingly weak stars, on the order of 24-th magnitude and lower. These stars are so far away from us and have such low illumination, that even in a 5 m telescope they cannot be detected on a photographic plate. An increase in the exposure time in photography is of little help. The reason for this is the scattered light from the sun sky (the sky background). Since the brightness of a 24-th magnitude star differs little from the brightness of the background of the sky (small contrast of the image), prolonged photography causes the plate to become darkened (fogged) and there is no image of the star.

The construction of the new tube is almost the same as that of a superorthicon, but its target made of a non-conducting glass can be rotated by 180° . The side of the target facing the photocathode is treated with cesium and also is an insulator. The opposite side has a conducting layer.

Under prolonged projection (several hours) of a weak optical image on the photocathode of this tube, as in an ordinary superorthicon, the potential relief is produced on the insulating target. Charges are accumulated thereby from the image of the star and from the sky background.

To cancel out the background, the photocathode of the tube is illuminated with scattered light, by applying the positive potential on the conducting layer of the target. The electrons pass through the photocathode and reach the target at low velocities, thereby cancelling out the positive charge on it and uniformly discharge its surface. This eliminates the effect of the background due to the glow of the night sky. The charge on the target due to the image of the star will also become weaker, but it will still be noticeable.

One next projects on the tube the image of the star again, and the background is again removed. After

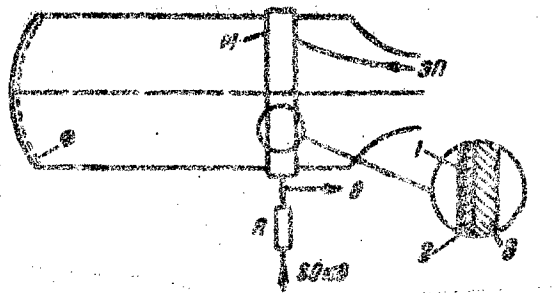


Fig. 17. Diagram of the arrangement of the Ebicon tube.

Φ -- photocathode, M -- target (1 -- grid, 2 -- aluminum foil, 3 -- semiconductor), 3 -- electron beam.

B -- output.

1) 20 kv

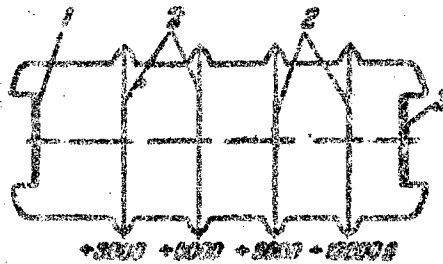


Fig. 18. Diagram showing arrangement of image multiplier.

1 -- photocathode, 2 -- thin films, 3 -- layer of lumino-phor.

such a prolonged process of accumulation, the potential relief due to the image of the star becomes sufficiently large.

The target is then rotated 180° and the potential relief is picked off the target by the sweeping beam of slow electrons, as in the ordinary superorthicon. The image on the kinescope screen can be viewed only for several frames, after which the potential relief disappears (is completely removed).

Brief information on the "Ebicon" tube and the "Image multiplier" tube have appeared in the press.

The sensitivity of the "Ebicon" is 100 times greater than the sensitivity of modern transmitting tubes. This tube is different from an ordinary superorthicon in its target construction and in the absence of an electron multiplier (Fig. 17). The target consists of a screen having a large number of cells, covered with a layer of aluminum 0.1 microns thick, and a semiconductor layer several microns thick. The electrons radiated by the photocathode are accelerated by a 20 kv voltage and are transferred to the target. Upon striking the target, the electrons produce in the semiconductor secondary electrons (i.e., an excited conductivity). A potential relief is produced on the target. When this relief is

scanned by an electron beam, a signal appears, which is picked off the load resistance R. There is still no detailed information regarding this tube.

The image multiplier has been developed especially for weak illumination. This instrument makes it possible to detect images with a brightness of 0.0005 lux. It is assumed that a combination of an "Ebicon" with a multiplier will permit detection of images with illumination of approximately 0.00001 lux.

The multiplier (Fig. 18) consists of a series of reticulated grids covered with potassium (thin films). An accelerating voltage of approximately 3 kv is applied between the grids. Owing to secondary electron emission of the screens, a gain of approximately ten per stage is obtained, and since four such stages are contained in the multiplier, the overall gain is 10,000. The electronic image is focused inside the amplifier itself by means of a magnetic field.

The image multiplier, provided with a fluorescent screen, makes it possible to view directly the image projected on it by the photocathode. In this case the instrument becomes an electron-optical converter, different from ordinary types of converters only in the construction of the amplification stages.

These instruments could successfully in astronomy, but they are still in the development stage. It is possible, naturally, that other electronic instruments will appear, combining high sensitivity with good definition of the transmitted image.

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