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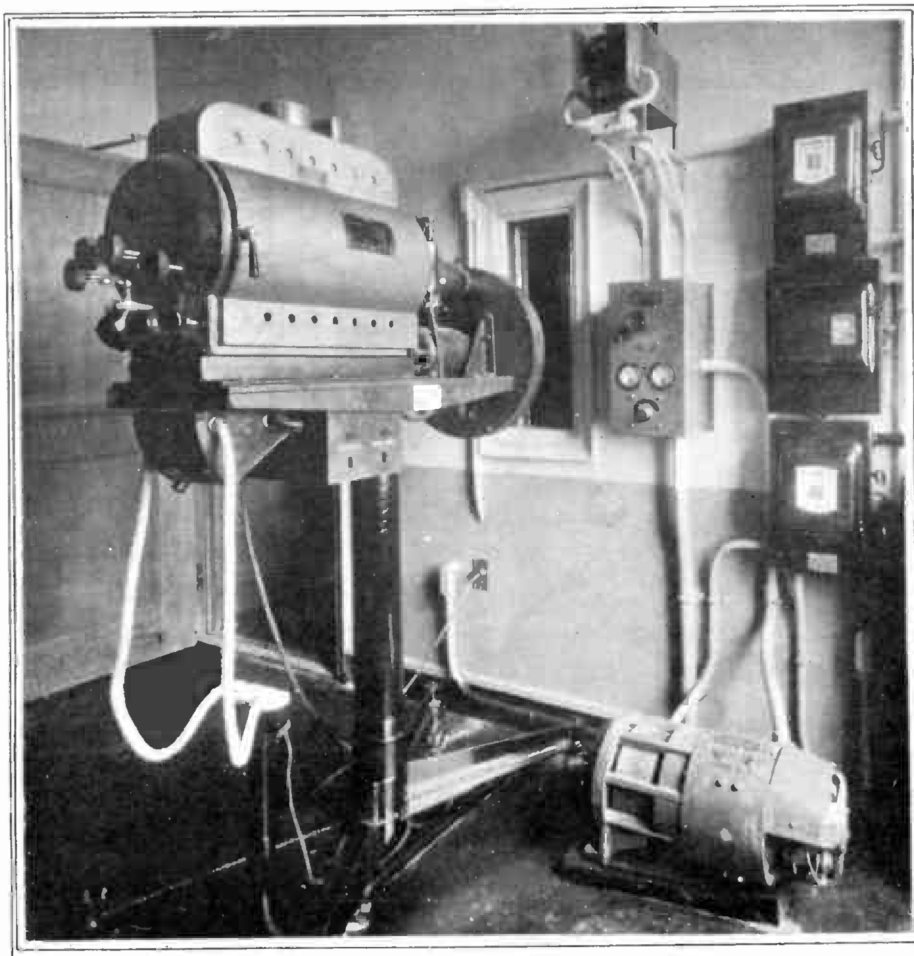

SCANNING BY THE FLYING-SPOT METHOD USES A HIGH-INTENSITY ARC LAMP.
(COURTESY COLUMBIA BROADCASTING SYSTEM)

Scanning Methods in Modern Television

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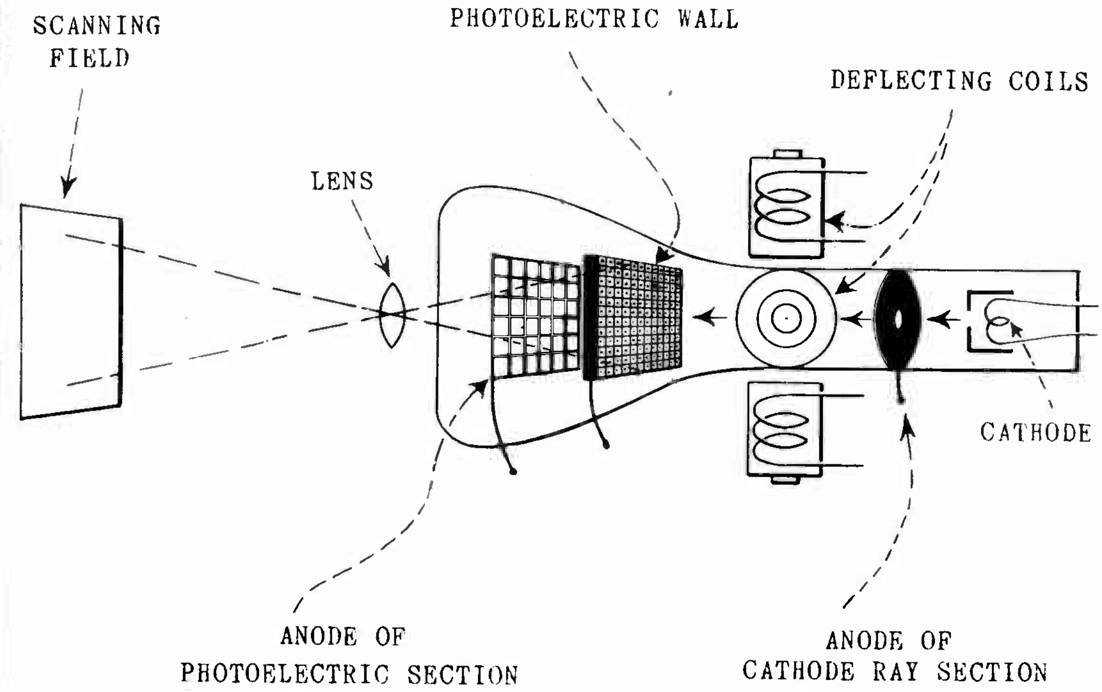

Fig. 1 - POSSIBLE CONSTRUCTION OF A CATHODE-RAY SCANNER

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SCANNING METHODS IN MODERN TELEVISION

The principle upon which any system of television must operate, in order that an image of an object or scene can be viewed at a properly designed receiver, is that the object must be exposed to light rays. The diffused reflection from each point of the object thus exposed is then picked up by one or more photoelectric cells, translated into an electric current which varies according to the change in brightness of the object thus exposed, and then passes over whatever channel is available for the communication of this current. How well this system operates will depend upon the fineness of detail required, the sensitiveness of the photoelectric cell, and the efficiency of that part of the system employed to amplify the minute currents generated by the light-sensitive cell.

CATHODE-RAY SCANNING

One method of electrical scanning of an image makes use of a device which is a combination of a multi-electrode photoelectric cell and a cathode-ray tube. These two sections have certain electric parts in common, but are separated by a gas-tight wall, in order that each section may hold gases at certain pressures which will enable them to perform their respective functions with greatest efficiency. Figure 1 illustrates this arrangement.

The photoelectric section comprises a metal gauze screen which serves as the anode, and a honeycombed wall containing a great number of metal bars, insulated from each other. On the side toward the gauze screen, these parts are tipped with a photoelectronic substance as in the ordinary phototube. A lens outside the glass wall focuses an image of the object on the photoelectric wall. The light-sensitive coating on each bar will emit a quantity of electrons proportional to the light intensity of the image-element which is focused on it. These separate bars and their common anode, the gauze, are in effect a multi-cell photoelectric pickup.

Up to this point, no selector system has been shown permitting us to switch from one photoelectric element to another to accomplish scanning. This commutating function is performed by the second section of the tube, embodying principles used in the cathode-ray oscillograph. At the right end of the figure is shown an oxide-coated filament, the cathode of this section. Around the cathode is a cylinder closed at one end except for a small opening through which electrons pass, as they are attracted by the positively-charged disc which serves as the anode of this section. Some of the electrons reach this anode surface and constitute a current flow through the battery circuit of the anode. The action so far is quite similar to that of an ordinary two-electrode vacuum tube.

However, this anode has an opening through which a quantity of electrons pass at such a high velocity that they are not turned aside toward the anode. These electrons are narrowed into a fine ray, partly because of a certain influence of a surrounding gas. Now this electronic stream constitutes an electric current just as much as if it were following a metallic conductor. Although the electron stream in a gas obeys certain fundamental electric laws of such currents, it can be made to move more easily than when confined in a metallic conductor. The electron ray can be deviated (changed in direction) by either an electrostatic or an electromagnetic field. In the illustration are shown coils for creating two magnetic fields at right angles to each other, and both at right angles to the electron ray. When alternating currents of the proper wave-shape and relative frequencies are fed to the deflecting coils, the electron ray is made to sweep in succession over the uncoated ends of the metal bars constituting the photoelectric wall. This action is similar to the movement of a stream of water from a firehose, as it is played across the face of a burning building. In this fashion we get one narrow electronic stream which is put in series, successively, with the electron streams of the first section, which depend on the image elements. The wire screen receives, therefore, electrons varying continuously with the picture elements thus scanned. This electron flow constitutes the television signal current.

MECHANICAL SCANNING

We have so far covered only the scanning process using a photoelectric unit for each element of the image, with a selector or commutator which shifts the electric path between them and the common transmission channel. We will now consider further developments which use:

1. Analysis by a single photoelectric cell, or several in parallel acting as one.
2. Synthesis by a single television lamp.
3. A single channel for the television signal.
4. A path-changer on the light side of the photoelectric cell.
5. A path-changer on the light side of the television lamp.

Since television is still a growing art, no attempt will be made to record hard and fast rules, or describe fixed combinations of apparatus. Our study will be confined to fundamental principles, the subject here being devoted to "one-eyed" scanning systems.

SCANNING PRINCIPLES

The early attempts in this field were made by flood-lighting the object by a powerful source of light, ranging into thousands of candlepower. Because of the comparatively short distance between this intense illumination and the object, human beings could not be televised successfully without extreme discomfort due to the enormous heat generated by a light so powerful, hence inanimate subjects were used. Figure 2 shows in detail the principle just mentioned. The object at the right is placed under the powerful light. Lens 1 is placed between the object and the rotating scanning disc in such a position that part of the reflected light rays from the object pass through the lens and produce an image of the object on the rotating disc.

Before continuing further it will be necessary to go into detail concerning the scanning disc so that the tracing out of parallel lines of an image will be clearly understood. Appendix "A" at the back of the lesson has been included for the purpose of illustrating this principle.

Let us return to Figure 2. About the disc in the form of a spiral are drilled a number of small holes, usually either round or square. As the disc rotates the small openings trace parallel lines of sight across the image, one after the other in rapid succession. On the opposite side of the disc is a frame, the opening of which is the same size as the formed image. This frame prevents more than a single opening being in the image at any one time. The bottom edge of the frame will usually be shorter than the top edge, because the innermost hole of the spiral which traces the bottom scanning line has a somewhat shorter useful path than the outer or top hole. As each opening moves into the image, light passes through it and is converged by means of lens 2 into the photoelectric cell, where it causes a current to pass through the cell. The amount of current that passes will be directly proportional to the brightness of that small portion of the image area which at that instant is viewed by the cell.

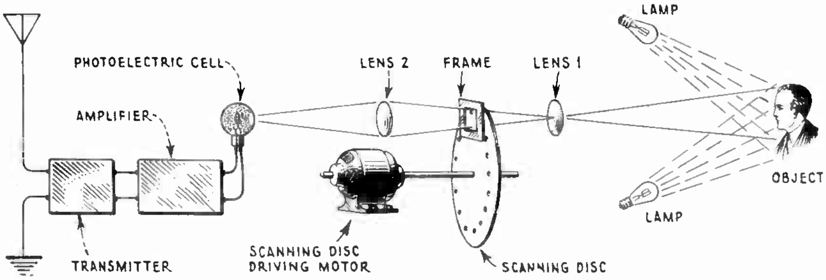


Fig.2 - PROGRESSIVE OBSERVATION AS A SCANNING METHOD

This method of scanning is described as "progressive observation", because it is the path of observation between photoelectric cell and object which is made to move progressively.

Because of the extreme inconvenience due to continuous excessive heat and light, television carried out by the formation of an image on the disc was temporarily discarded. This called for some other method of scanning; therefore, instead of exploring an image of the object, the object itself was explored by a rapidly moving pencil of light.

"Progressive illumination" is the term applied to this method, for it is the illuminating path which moves progressively across the object.

This does not change anything we have previously covered except the optical system which has been completely reversed, as you will see by referring to Figure 3. The "pencil" is actually a concentrated beam from a source of intense light such as an arc lamp. This light is passed through a lens which confines the rays to a small area. A rapidly revolving scanning disc, driven by a small motor, is placed in the path of the light beam. A small frame placed between the disc and the lamp prevents light from passing through more than one of the disc openings at a time. A demonstration of this principle can be made with the model shown in Appendix "B" at the back of the lesson.

As the small intense pencil of light passes through the openings in the disc the features of various objects are rapidly explored. Referring to the figure above, we find that some of the light, upon striking the object, is absorbed, and part is reflected. The amount of light reflected into the photoelectric cells will depend upon the subject being scanned. For example, suppose a man is seated before the scanning disc. As the spot of light passes across his hair, which we will assume is dark, considerable of the light will be absorbed and little reflected. As the light spot passes across the face more light will be reflected and the total output current of the photoelectric cells will be increased. This current will therefore follow accurately the brightness of the individual areas of the man's features as he is explored or scanned by the spot of light.

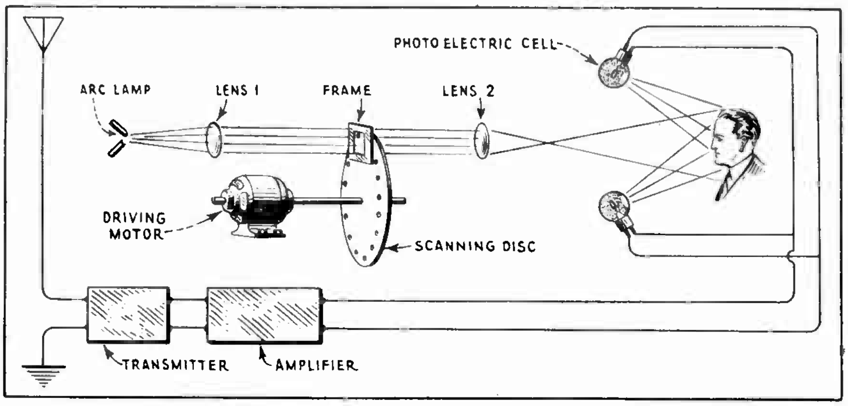


Fig. 3 - PROGRESSIVE ILLUMINATION AS A SCANNING METHOD

The current output of the photoelectric cell, or cells as the case may be, is very small. When it is passed through a resistance a voltage is developed across the terminals of the resistance; this is a signal voltage which is then fed into several stages of amplification. The increased signal voltage is used to modulate the carrier wave of a transmitter from whence it is broadcast in the usual manner. We now have a modulated signal impulse which is following the brightness of the elemental areas of the subject being televised, and it remains for us to intercept this signal and reconvert it to light.

Before entering upon a study of the problems and methods of transmitting the television signal, and interpreting it at a distant point, it is well that we cover thoroughly the physical forms and optical methods of scanning systems.

In review, it is seen that the mechanical scanning system is marked by the following features:

1. It uses a source of illumination and a photoelectric cell.

2. It requires an optical path connecting light source and cell.

3. The object or scene to be transmitted acts as an irregular reflector interposed in that optical path.

4. The two sections of this path are, in order, the illuminating path and the observing path.

5. If the illuminating path is wide (flood lighting), the observing path must be constricted and narrow.

6. If the illuminating path is constricted and narrow (spot lighting), then the observing path must be wide (phototubes spread in an open bank).

7. A path-changer (such as a scanning disc) must be in the constricted path when using either of the methods in paragraphs 5 or 6.

8. Progressive observation uses flood lighting and camera image observation by the cell, with the scanner between the object and the cell.

9. Progressive illumination uses a spread-out bank of cells and spot lighting, with the scanner between the light and the object.

As long as these principles are kept in mind, it is possible for us to investigate other path-changing systems than the disc with plain holes. The difference will be in (a) the mechanical form of the moving parts and (b) the optical principles involved.

SCANNING MOTION HAS TWO COMPONENTS

A televised scene or image appears to the electric eye as a flat picture and may be measured by a vertical height and a horizontal width, but not depth or distance. Since this is so, any analyzing system applied to that area must have a motion with two components. One component is a horizontal motion, and the other a vertical motion.

In the Nipkow scanning disc (holes placed spirally) as used in America, the horizontal component is provided by the nearly straight lines made by the scanning holes as they are rotated from one side of the image to the other. The vertical component is provided by the spiral formation of the group of holes. This is explained by saying that each hole in the spiral group is at a different distance from the center of the disc. Since the field of view is above the center of the disc, it means that each hole in succession crosses the image at a different vertical height from its bottom edge.

The same scanning disc is used differently in the chief television system of Great Britain, and also in other European countries. Instead of scanning through the top of the disc, the optical path passes through the holes when they are at one side, as shown in Fig. 4, where the holes are moving in a vertical direction.

An inspection of Figure 4 will make this clear. The scanning holes move up or down the image, providing the vertical component. Then the spiral order of the successive holes brings each one in turn closer to the center of the disc, but this displacement is now a vertical component. The model described in Appendix "B" may be used to illustrate this point.

We have accomplished the breaking up of the picture in two opposite methods, as used in American and European systems, but have used the identical disc for both. It is important to bear in mind such flexibility of mechanical design.

Whenever a system of analyzing has been decided upon for the transmitter, the same system must be used for picture-synthesis at the receiver, so far as the relation of horizontal and vertical components is concerned. If the horizontal scanning line is used, there would be no use in having the receiver disc placed as for vertical scanning lines, because then the picture received would be laid down on its side, as it were. It could be viewed satisfactorily only by a person lying down.

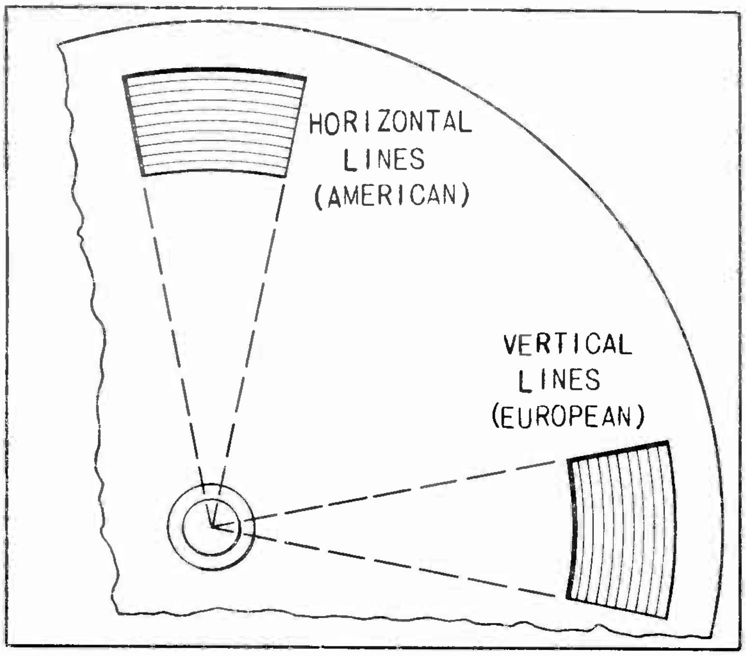


Fig.4 - A SCANNING DISC MAY BE USED FOR EITHER HORIZONTAL OR VERTICAL SCANNING

Another point may well be brought out. The scanning holes of the transmitter disc do not have to be in a single perfect spiral. For instance, instead of scanning in order with the holes representing lines 1, 2, 3, 4, 5, etc., a scanning disc may be designed so that the placement of the scanning line holes around the disc may be in some other order. This holds good as long as the holes have an equal angular displacement around the periphery. One possible arrangement would be four short spirals composed of holes which uncover the scanning lines in this order: 1-5-9-13, 2-6-10-14, 3-7-11-15 and 4-8-12-16, as applied to Figure 14. Remember that 16 is the number of holes used in our model, shown in Appendix A, only for the sake of simplicity, and actual scanning systems are not satisfactory with less than 60 lines. Whatever successive order of the lines is used at the transmitter, the same order must be used in distributing the lines of light which constitute the picture at the receiving end.

DIFFERENT FORMS OF MECHANICAL SCANNERS

With this principle clearly understood, that it is only necessary to break down the image or scene area into a group of strips, let us proceed to study other methods used to accomplish the same purpose. Holding for the present to the idea of plain holes in the scanner, we find two other devices, a cylindrical drum and a belt. The latter has not been used much because of the mechanical difficulties in making the belt run so true that any given hole in it will continue to cover exactly the same strip of the image with every repetition of its scanning function.

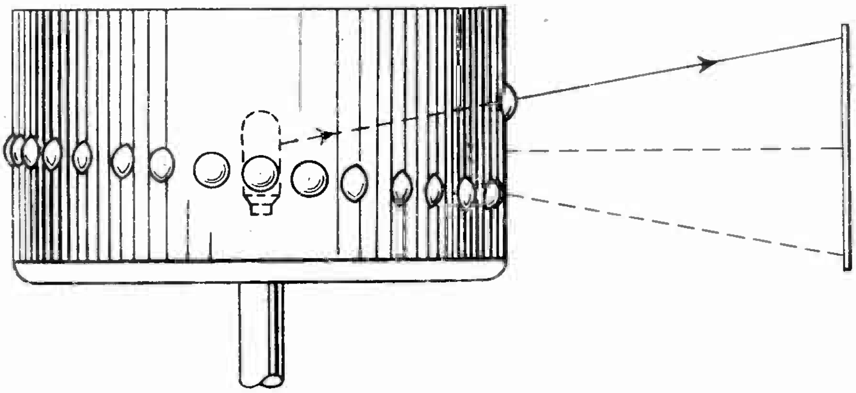


Fig. 5 - THE ADDITION OF LENSES IMPROVES THE DRUM SCANNER

On the other hand, the cylindrical drum lends itself more readily to the construction and operation of rotary mechanism which can do the accurate optical work of scanning. Figure 5 shows a perspective view of such a drum. It is seen that the horizontal scanning lines are formed by the rotation of holes in the surface of the drum, which is mounted on a vertical axis. The vertical component of the scanning motion is provided by the placement of the holes in a helical spiral, so that each hole is displaced vertically a slight distance from the adjacent ones. The drum is shown equipped with lenses.

LENSES AND PRISMS BRING IMPROVEMENT. Plain holes in scanning rotors have the same limited effectiveness which marked the pin-hole type of camera. Just as the early form of camera was improved by the use of a large opening with a lens in it, so we find that a considerable advance was made when lenses were applied to scanning discs. The plain holes of a small fraction of an inch in diameter were enlarged to an inch or more. Lenses were placed over the holes and optically centered on the spiral line. As with the camera, this allowed the passage of much more light to or from the object being scanned, and thus the optical efficiency was increased.

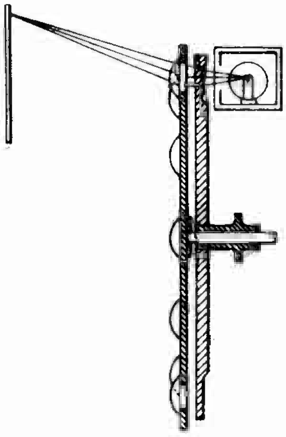


Fig.6 - LENS AND PRISM DISCS SEPARATELY PROVIDE TWO COMPONENTS OF SCANNING MOTION

A modification of the lens disc is that shown in Figure 6. The spiral is dispensed with and the lenses are placed in a circle, which satisfied our requirement for a horizontal component of scanning motion. However, it does not take care of the vertical component. For this a separate disc is used whose border consists of a peculiar glass section comprising a prism of continuously varying cross section. With every revolution of this prism disc the light-beam makes one complete vertical crossing of the image, because of the gradually changing angle of the refraction of the beam.

The same effect is secured with a single disc in another way as shown in Figure 7. This disc has a circular line of holes each equipped with a lens having the usual convex side. Each lens bears on the opposite side a small prism section which refracts the scanning beam somewhat in a vertical direction. Since each prism-section, from the nominal first one on, has an increasingly greater angle of refraction, it is seen that in one revolution of the scanning disc the

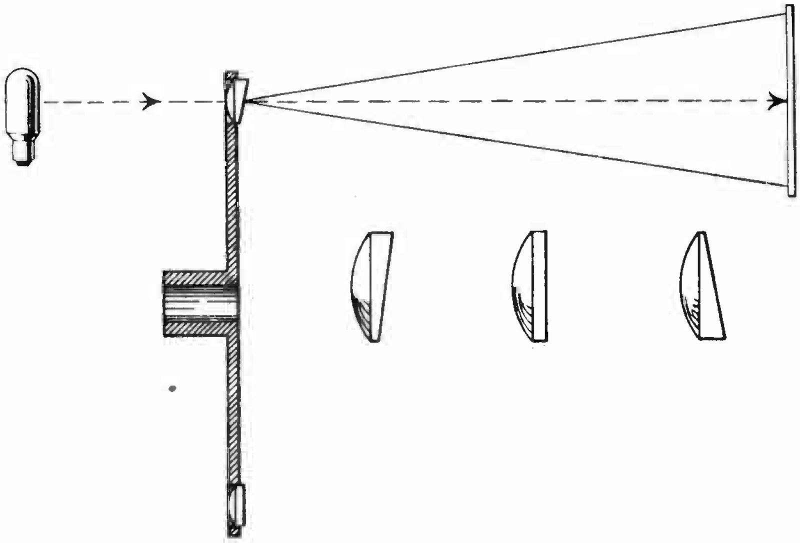


Fig.7 - A SINGLE DISC BEARING COMBINATIONS OF A LENS AND PRISM

scanning path makes one complete vertical crossing of the image. This crossing or traverse consists of a group of horizontal lines equal in number to the transparent openings in the disc.

The drum type of scanner with lenses mounted over its enlarged openings has been used more in European practice than in American.

MIRROR WHEELS. To comprehend the use of mirrors in scanning, you are reminded of the universal trick of a child in twisting a small hand-mirror to make a spot of reflected sun-light sweep across a window, or the face of some playmate or grown-up within range.

In television, one form of mirror scanner makes use of a wheel, around the rim of which are a number of flat (or curved) mirrors. These are equally spaced, tangent to the rim, and with edges touching. All are parallel to the axis of the wheel. This identical placing makes each mirror have an identical effect on a beam of light directed toward the mirror rim.

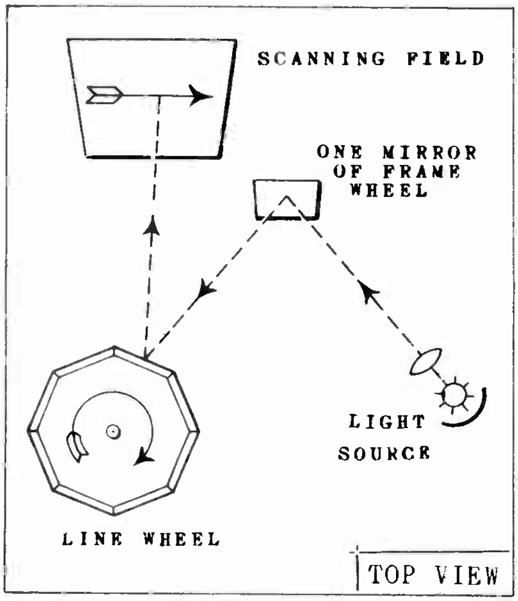


Fig.8 - SCANNING ACTION OF THE LINE WHEEL OF A MIRROR SYSTEM

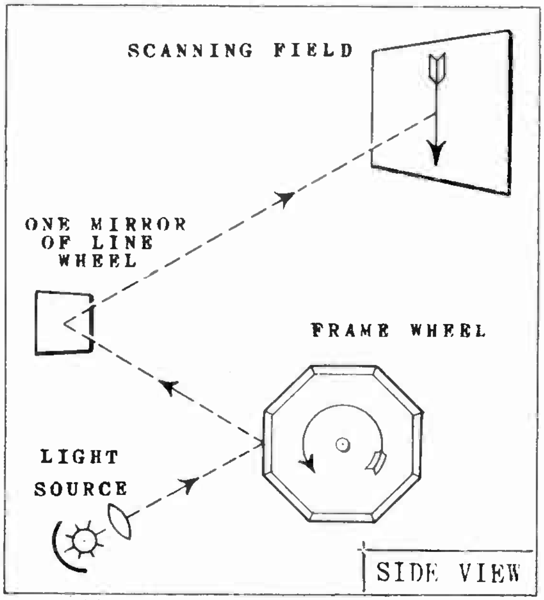


Fig.9 - SCANNING ACTION OF THE FRAME WHEEL OF A MIRROR SYSTEM

There are two such mirror wheels used in the first system to be described. We will study, one at a time, the action of each mirror wheel on the scanning path and to do this the other mirror wheel is assumed to be stationary. Figure 8 which illustrates this principle shows that a light beam impinges on a mirror (one face of the wheel which is held stationary) and is reflected to the second mirror wheel, from which it is again reflected toward the object. The object is shown here as just the lines bounding the field of vision, marked "scanning field." As the second wheel rotates in the direction shown by the arrow, the beam is given a horizontal motion that sweeps a light spot across the picture from left to right. As it continues to rotate the spot moves off the right edge of the viewing field, the light from the stationary mirror now falls on the next moving mirror face, and a light spot comes onto the left edge of the field of view. It sweeps across as did the previous light spot. It is seen then that we get one horizontal scanning line every time one of these mirrors passes in front of the incident light beam. We will call this second wheel the "line wheel."

Now let the line wheel be held stationary, as in Fig. 9, while we examine the action of the first wheel in the light path. This rotates about a horizontal axis and hence any mirror on its rim will tend to move the light spot in a vertical line. With this wheel rotating in the direction shown, the spot will make a complete traverse or crossing from the top to the bottom of the viewing or scanning field. As it moves off, another spot will appear at the top and follow the same path. This is due to the next mirror face which moved into the light beam as the first mirror left it. This wheel may be called the "frame wheel."

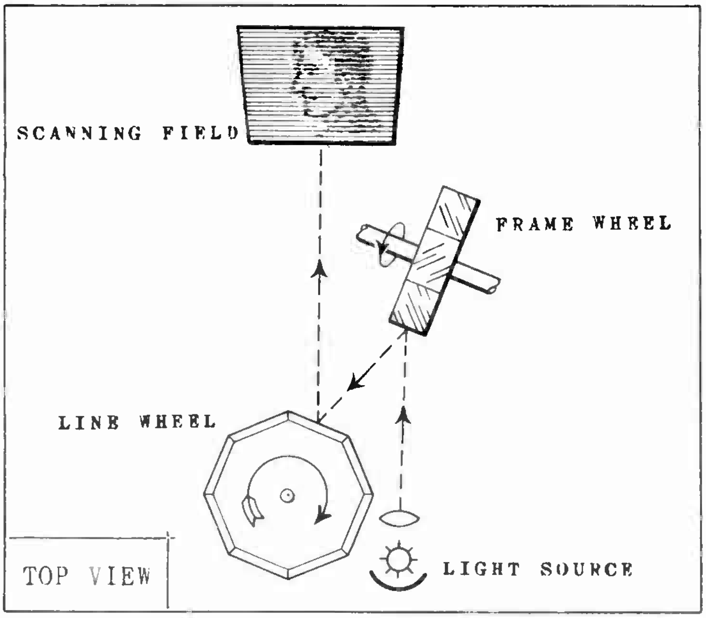


Fig. 10 - COMPLETE SCANNING ACTION OF LINE WHEEL AND FRAME WHEEL

Here we have the essentials of a true scanning motion consisting of horizontal and vertical components. When both wheels are rotated at related speeds, the scene is scanned by the light spot progressing in parallel horizontal lines down the field of view, as shown in Figure 10. The scanning rate for this method is based on: (a) one scanning line per mirror of line wheel, and (b) one frame per mirror of the frame wheel.

The same effect can be brought about by the use of one wheel, closely resembling those described above, but having the mirrors tilted slightly instead of parallel to the axis. The difference in angle between mirrors is uniform, and therefore the scanning lines will be equally displaced in a vertical direction from one another. The construction is shown in Figure 11. The scanning rate for this method is based on: (a) one scanning line per mirror, and (b) one frame per revolution of wheel. A minor variation of the mirror principle is found in the use of mirrors on a rotating wheel whose rim is cone-shaped rather than cylindrical. A mirror construction which has received more attention in Europe than in America is the "mirror screw." It uses a large number of long narrow mirror faces which are disposed along an axle and set at right angles thereto. The centers of the mirror strips are tangent to the circumference of the axle, but equally displaced from one another around the circumference. This construction makes it look like a double spiral staircase of colonial style.

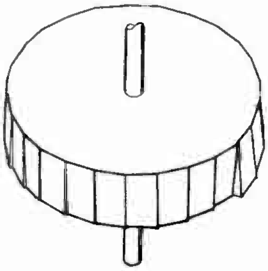


Fig. 11 - COMPLETE SCANNING PROVIDED BY ONE WHEEL HAVING TILTED MIRRORS

APPENDIX "A"

DEMONSTRATING PRINCIPLE OF SCANNING BY PROGRESSIVE OBSERVATION

Figure 12 has been drawn for explanation purposes only and not as a model to illustrate how a scanning disc is actually constructed. This point is stressed for the reason that the size of the disc, the number of openings, and the radial offset of the apertures assume different values in discs which have a practical utility in television.

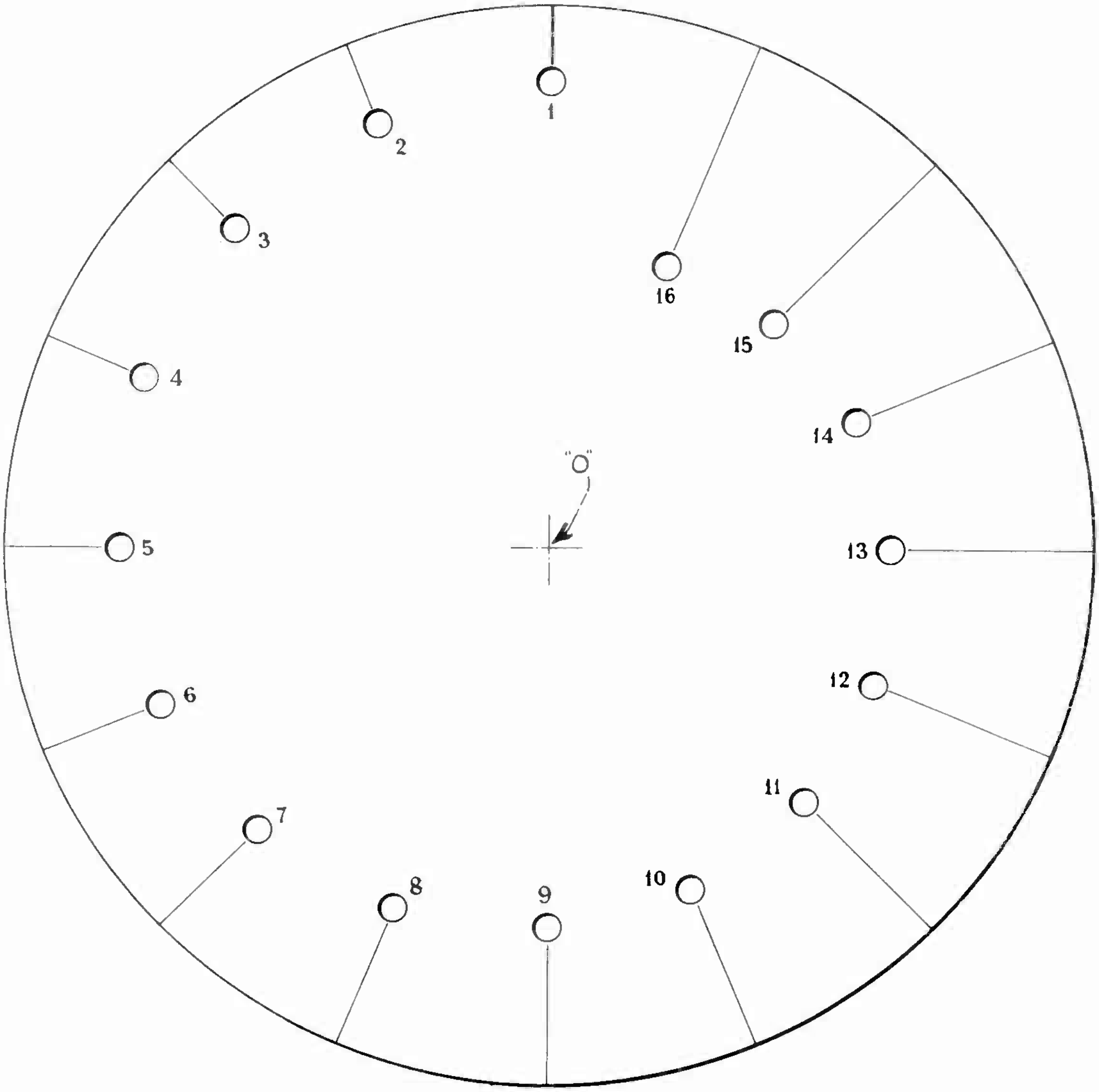
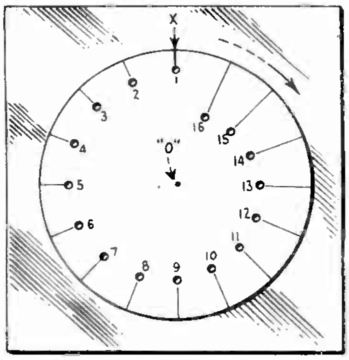


Fig.12 - EXPERIMENTAL SCANNING DISC

With this clearly in mind use Figure 12 as a guide and redraw or trace out the figure on a sheet of paper, pasting this on a piece of cardboard of sufficient weight to insure against curling or warping. Trim the material off to the edge of the circle, and cut out each opening accurately, taking care to follow all lines.

Next lay the finished disc on a white sheet of paper about 8 inches long by 7 inches wide, and place a pin through the center "O." Draw a short line "X" on the paper to coincide with line #1 on the disc. This is shown in Figure 13. With a sharp pointed pencil inscribe a small numeral "1" on the white paper at the center of opening #1. Slowly rotate the disc clockwise as shown by the arrow until opening #2 coincides with "X", and within the boundary of this opening inscribe a small numeral "2" on the paper. Repeat this for all the openings. 16 in all.

If this is carefully completed you will have drawn a row of numerals on the paper as shown in Figure 14. Enclose this row by four lines to get an area 7/8 inch wide by 1 inch long. We may let this represent the image. Further, we can let this series of numerals represent a series of slightly curved parallel lines. Again rotate the disc clockwise, at the same time peering through the openings as they come opposite point "X." When the numeral "1" is seen, hole #1 will be crossing the image area in what we will call scanning line #1. When hole #2 is crossing the area, scanning line #2 will be exposed, as marked by the small numeral "2." During one complete revolution of the disc the image area will have been completely explored from top to bottom by a series of parallel lines, as shown in Figure 15. One complete exploration of a scene or its image is called a "frame."



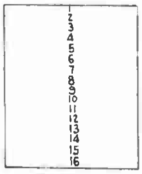


Fig. 14

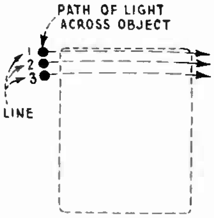


Fig. 15

Fig. 13 - EXPERIMENTAL DISC TO DEMONSTRATE PRINCIPLE OF SCANNING

APPENDIX "B"

DEMONSTRATING PRINCIPLE OF SCANNING BY PROGRESSIVE ILLUMINATION

We may again use the disc model to illustrate the second method of scanning, by the application shown in Figure 16. Procure a small block of wood and on it erect two wooden standards, V1 and V2, the upper ends of which are rounded out as shown by the small sketch A at the right. The shorter standard V1 supports a small wooden shaft "S" at point "H", the bearing for the rear end of this shaft being provided by a nail or pin through V2. A flashlight is inserted in a close-fitting tube T, or wrapped in stiff paper to simulate a tube. The standard V2 must be long enough to hold the flashlight tube at the proper elevation to cover all the scanning holes. The disc D, when mounted on the shaft "S", must revolve true, and the tube "T" must be as close to the disc as possible without touching it, thereby allowing a minimum of light to escape.

When this arrangement is complete snap the flashlight on and turn the disc so that hole #1 is in line with the light beam. A spot of light will appear on the screen, and as the disc is slowly rotated a slender pencil of light will move across the screen from left to right. As hole #2 comes around the light shining through will trace a path slightly lower on the screen. The line made by hole #3 will be lower still, and so on until #16 is reached which will be the lowest path traversed by the spot of light. These two extreme positions of the light, #1 and #16, represent the height of the scanning field. You should draw some kind of a figure on the screen between these limits and continue the experiment.

Now spin the disc by twirling the shaft between the forefinger and thumb. While doing this watch the screen and imagine your own eyes are taking the place of the several electric eyes placed in the vicinity of an object being scanned. As the various holes move by in succession, and allow the screen to be illuminated, your eyes respond to the varying intensity of the light reflected from different parts of the figure you have drawn. You will also have a sense of direction telling you from what part of the image the light is coming. On the other hand, the electric eye does not have a sense of direction. It would see those scanning lines just as though they were laid end to end on a continuous tape until the whole picture image had been passed; likewise, it sees the successive repetitions of the complete image just as though they were also laid end to end on the tape. This explains why there is a continuous signal being transmitted by a television station. Of course it must be clear that there is no signal while the scanning path is crossing an area which does not have a variation in reflection, any more than there would be a signal in between the words transmitted by a radio broadcasting station. The signal modulation actually represents work being done in the communication of intelligence, whether the effect is "sound" or "sight."

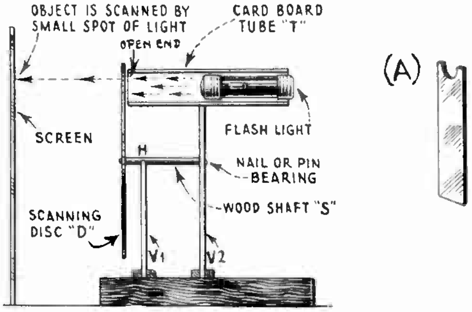


Fig. 16 - ILLUSTRATING PRINCIPLE OF SCANNING BY PROGRESSIVE ILLUMINATION

EXAMINATION QUESTIONS

1. In the cathode-ray scanner described, what are the two electric uses of the photoelectric wall?
2. Give the fundamental features of an optical-mechanical scanning system.
3. What is the chief difference between progressive observation and progressive illumination?
4. What is the advantage of lenses in the rotating part of a mechanical system?
5. Describe the scanning action of the single mirror wheel.
6. Give three ways in which the action and construction of the receiving distributor disc must resemble the transmitting scanner disc.
7. What important difference between sound broadcasting and television transmission requires the use of a scanning method?
8. What two things must be connected to the photoelectric cell to produce a television signal voltage?
9. When a scanning disc is used having the openings in a circle, what optical device can be used to provide the other component of scanning motion?
10. In the cathode-ray scanner, what two methods may be used to deflect the ray?

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THE PHOTOELECTRIC CELLS ARE SPREAD IN A WIDE BANK WHEN THE FLYING-SPOT IS USED FOR SCANNING.

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