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TELEVISION PICKUP SYSTEMS
(TELEVISION PRINCIPLES - CHAPTER 7)

C. E. Dean
Editor

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TELEVISION PICKUP SYSTEMS
(TELEVISION PRINCIPLES - CHAPTER 7)

INTRODUCTION

In Chapter 2 and other preceding chapters one method of television signal pickup has been described, namely the use of a mosaic of insulated particles on which the scene is optically focused. The present chapter discusses the television signal pickup problem in general, and describes some alternative pickup systems.

The phenomenon of secondary emission plays an important part in this field; for example, one of the camera tubes to be described has a secondary-emission multiplier as a discrete component. Secondary emission and multipliers are also of general interest in television. For these reasons the first two sections of this chapter are devoted to these subjects.

In addition to the electrical features, any pickup system must have optical apparatus in the form of lenses to focus the scene for transmission. One section of the present chapter is devoted to this.

SECONDARY EMISSION

A physical effect of great and increasing importance at the moment in the field of vacuum-tube design for amplification and other purposes is that by which an electron incident with sufficient velocity upon a suitable surface is able to knock out, or cause the material of the surface to emit, other electrons, the number of electrons so emitted being often much greater than that of the incident electrons. This effect is called "secondary emission", and it has been widely known for a long time, for example in connection with the action of the dynatron oscillator. An introductory account of secondary emission is given in Chapter 2 (Report 1789), pages 33-36.

Secondary electrons can be knocked out of most substances under the influence of electronic or ionic bombardment, but certain substances, notably metals, are considerably better secondary emitters than others. The fact that more electrons may be emitted by the target than are incident upon it does not imply that something is obtained for nothing, or that there is any apparent violation of the physical laws regarding conservation and transfer of energy, for the secondary electrons thrown out from a bombarded surface are always of low velocity, usually corresponding with a fall thru a potential of only two or three volts.

A substance capable of emitting a large number of secondaries per primary electron striking it is usually a substance of low "work-function". That is, the energy which must be given to an electron residing within the substance in order to dislodge it is usually lower for a substance which emits secondary electrons copiously under electronic bombardment than for one which emits but few secondaries. This rule is by no means universal, however, and a major influence is exerted by the chemical and physical condition of the surface.

In order to provide a convenient measure for the ability of a substance to emit secondary electrons, the ratio of number of electrons emitted to the number striking in a given time is taken. This may be designated by

$$\frac{i_s}{i_p} = \frac{\text{secondary-emission current}}{\text{primary incident current}},$$

or by the more common notation,

$$s/p = \frac{\text{number of secondary electrons}}{\text{number of primary electrons.}}$$

This ratio s/p is usually fairly small for pure metals such as tungsten and molybdenum, is slightly greater than unity for nickel, and is about two for potassium and cesium. However, a marked increase in the ratio s/p can be obtained by using a surface contaminated with very thin films of certain impurities such as oxides and nitrides. These impurities seem to have the effect of materially lowering the work-function of the surface.

Moreover, it has been discovered that the effect of secondary emission is not absolutely confined to the surface of the target, but rather is a function of at least two things, namely the chemical composition of a film of low work-function on the surface of the target, and the atomic number of the metal forming a base for the film. It is probable that the greatest secondary ratios are obtainable with a film of material of low work-function (for example cesium oxide or lithium borate) of controlled thickness deposited upon a base of a heavy metal of good conductivity (for example silver or gold).

The following table shows the value of the ratio s/p for a variety of pure metals, and for a few complex surfaces (usually the oxide), together with some other data:

Target Material	Max. Value of s/p	Work-Function in Volts	Velocity of Primaries in Volts for Max. s/p
Pure Metals:			
Beryllium	5.4	-	600
Aluminum	2.4	1.8 to 3.9	400
Calcium	5	1.7 to 3.3	520
Copper	1.3	4.0 to 4.8	600
Silver	1.5	3.0 to 4.7	800
Complex Surfaces (All values approximate):			
Potassium	2.5	1.0 to 2.0	600
Rubidium	5.8	1.2 to 1.5	700
Cesium	8.5	0.7 to 1.8	400 to 600

The secondary-emission ratio also depends upon the velocity of the electrons striking the target, but contrary perhaps to first expectations, does not continue to increase indefinitely. Figure 1 shows the kind of curve obtained on plotting the value of s/p against the accelerating voltage of the electrons falling upon the target. The value of accelerating voltage giving a maximum value of s/p is tabulated in the last column of the above table.

ELECTRON MULTIPLIERS

One of the most important applications of the phenomena of secondary emission is in vacuum tubes for the amplification of small electronic currents without the use of thermionic cathodes. Such tubes are called multiplying tubes, or electron multipliers, and there now exist several different types of these, the more important of which are described in the present section.

Reciprocal and Cascade Types

Broadly electron multipliers are of two types, reciprocal and cascade, the latter being by far the more important in practice. In the reciprocal multiplier, a pair of secondary-emissive surfaces is placed so that electrons emitted from one strike the other, there to cause emission of secondaries which in turn strike the first surface, and so on in repetition. In the cascade type of multiplier, on the other hand, electrons emitted from the first surface (or from some auxiliary source such as a thermionic or photoelectric cathode), become incident upon a secondary-emissive surface, and secondaries from this fall upon another similar surface, from which secondaries in turn fall upon still another surface, and so on until the electrons

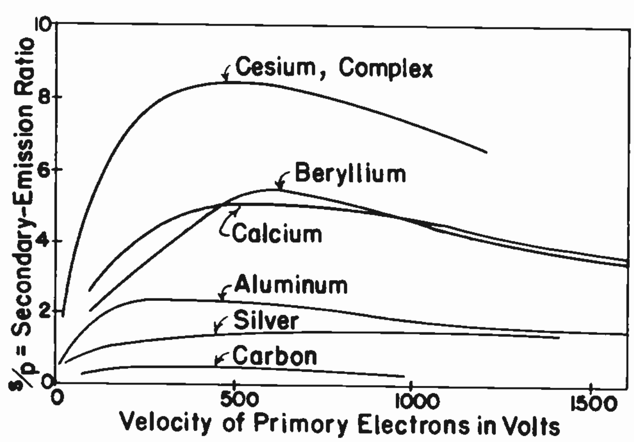


Fig. 1. Secondary Emission of Certain Surfaces for Various Primary Velocities.

emitted at the final surface are caught by a suitable collector electrode.

In Figure 2 is shown an example (in diagrammatic form) of a cascade multiplier embodying four stages of multiplication. In this particular form the primary-electron emission is photoelectric, produced by light incident upon the first surface P_1 at the left-hand side. Electrons from this surface, accelerated by a potential difference between it and a gauze thru which the light can pass, traverse a semi-circular path under the influence of a transverse magnetic field, which is also provided. With correct adjustment of the electrode potentials and the magnetic field strength, such electron paths terminate upon the surface of secondary-emissive plate P_2, from which more than one electron is knocked out for each primary electron striking it. These secondaries from P_2 are in turn accelerated by a potential difference existing between the surface from which they are emitted, P_2, and an electrode D which lies opposite and has a positive relative potential. Again therefore the secondaries traverse roughly semi-circular paths from P_2 to P_3. At P_3 further secondaries are emitted, and so on, until the secondaries emitted from the final plate P_5 are accelerated thru a positive grid and are collected by an electrode P_6 which is maintained at a sufficiently high positive potential to attract and capture all electrons passing thru the grid. The current collected by the last electrode may be many times — in fact, many hundred thousand times — that emitted initially from the photoelectric surface, and may be used to develop a potential difference for application to a conventional amplifier, or for any other purpose, by inserting a load resistor R in series as shown. The current collected is substantially independent of the potential of the collector P_6, provided that this potential is high enough to capture all available electrons. This means that the multiplier presents an indefinitely high output impedance, a feature which has useful applications.

The second example of a multiplier, shown in Figure 3, is of the reciprocal type, and, though not as practically useful at present, merits explanation here. The electrodes A and B are coated with secondary-emissive material. In order to facilitate explanation, let us suppose that upon one of the surfaces, say A, falls some light. Let it be assumed that at a certain instant an electron is photoelectrically emitted from this surface, and is accelerated under the influence of a central annular positively poled electrode. The electron is guided down the tube by a longitudinal magnetic field (produced for example by a solenoid surrounding the tube). The electron attains its maximum velocity when passing thru the anode, but does not strike it; instead, the electron due to the opposing field decelerates until it reaches the vicinity of the other electrode B. Now, on emission, the electron altered the potential of the electrode A due to the removal of a quantity of negative electricity equal to the electronic charge; in consequence of this a

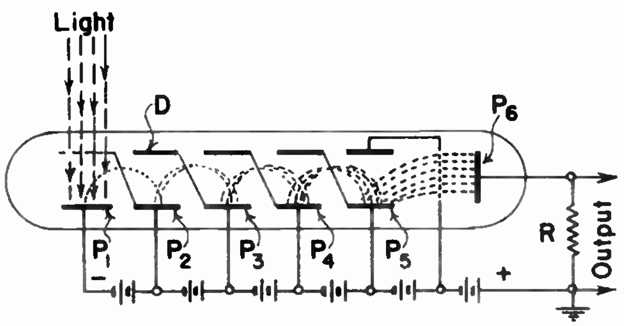


Fig. 2. Cascade Electron Multiplier.

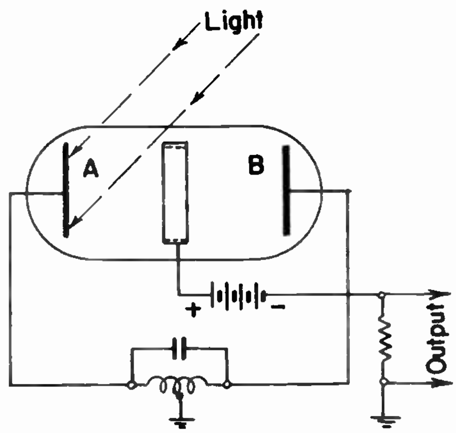


Fig. 3. Reciprocal Electron Multiplier.

small positive impulse was given to the A end of the tuned circuit which is connected between A and B. This action also gave a corresponding slight negative impulse to B. However, if the time of transit of the electron from A to B is equal to a half period of free oscillation of the tuned circuit, then by the time the electron arrives near B this plate will have reversed its polarity and will have assumed a slightly positive potential. It is possible in this way for the electron to fall against the surface B with sufficient velocity to evoke the emission of secondaries. These, being emitted with low velocity, will immediately begin to accelerate towards the other end of the tube under the influence of the anode field; their emission, also, has the effect of an added kick to the oscillating potential being built up across the tuned circuit, so that the process is regenerative.

An oscillatory electron flow is therefore rapidly built up within the tube. As the electron density in the space current rises, the mutual repulsion of the electrons drives the marginal ones outwards, in spite of the magnetic field, until they are collected at the anode.

The above description has assumed that the constants of the system. (for example the s/p ratio of the surfaces for low-velocity impacts) are compatible with the spontaneous generation and building up of oscillations; such conditions make the device a high-frequency oscillator. When it is desired to use the tube as a multiplier, a local oscillator is used to produce a steady driving high-frequency potential across the plates A and B, and the current collected at the anode is then proportional to the light falling upon one plate, or to a primary electron current introduced in some way into the tube, as, for example, thru an orifice in one of the plates.

The above explanation of the operation of the reciprocal multiplier has been considerably simplified; a full description, taking into consideration the phase relation between the oscillatory potential difference and the electron space flow, is available in the references given at the end of this chapter.

The potential of the anode determines the time of transit of an electron from one plate to the other, and must therefore be adjusted in conjunction with the frequency of the driving oscillator so that a double transit corresponds approximately with a complete cycle. The magnetic field strength and the anode potential determine the rate of collection of electrons at the anode, and therefore the output current.

When used for television, a video output can be obtained across a suitable load in the anode circuit. The high-frequency components which have values near the frequency of the input driving oscillation are normally eliminated due to being outside the range of the video amplifier.

Cascade Multipliers Not Requiring Magnetic Field

An electron-guiding magnetic field is required in both of the multipliers described above. However, this is unnecessary in certain forms of cascade multipliers which are now in common use. Figure 4, for instance, shows one such tube, in which primary electrons, photoelectrically emitted, fall upon a grid or mesh coated with secondary-emissive

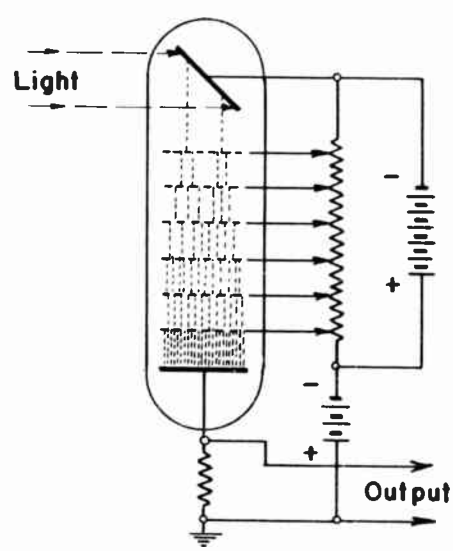


Fig. 4. Cascade Multiplier Using Sensitized Grids and Not Requiring a Magnetic Field.

material, and low-velocity electrons thus produced pass thru the mesh to fall in turn upon a further mesh, thereby evoking fresh secondaries. A load connected in series with the final collector electrode serves to develop a potential difference proportional to the original photo-current.

A similar arrangement but depending upon a rather different principle is illustrated in Figure 5. Here, a succession of secondary-emissive surfaces, P_2, P_3, etc., are disposed in a formation which permits the acceleration of the primaries, while secondaries are drawn off in a different direction. The electrodes of the multiplier are so shaped and placed in relation to each other, as indicated in the drawing, that each one more or less shields the electrons leaving it from the influence of the field due to the next collateral plate until they are well on their way to the plate they are intended to strike. For example, secondaries leaving P_3 are thus sufficiently shielded from the influence of P_5, and strike P_4 as desired.

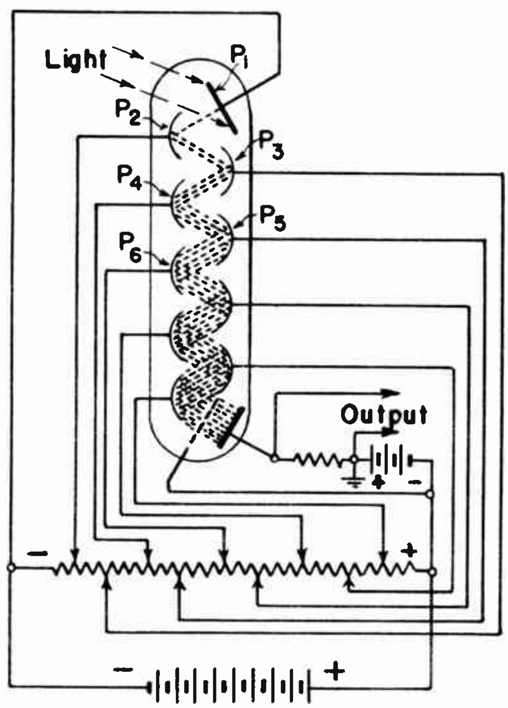


Fig. 5. Cascade Multiplier With Plates so Arranged as Not to Require a Magnetic Field.

General Characteristics of Cascade Multipliers

Since it is principally with the cascade multiplier that the practical television art is concerned, it is well at this point to examine its characteristics a little more closely.

First of all, it should be noted that a fairly high total biasing voltage is required, because the potential difference between each plate and the next must be sufficient to enable an electron to acquire enough velocity to produce more than one secondary, on the average, since otherwise no magnification will occur. Reference to Figure 1 shows that even with an efficient cesium surface, the stage potential should be at least fifty volts. For ten stages this results in a total potential of 500 volts; however, in practice it is often necessary to provide a stage potential of 150 volts, or a total of 1500, to obtain a gain of two per stage.

The results of computations for multipliers with one, two, five, and ten stages, giving the gain for various total applied voltages, are shown by Figure 6. This reveals the interesting information that for the lower total voltages, there is no gain in increasing the number of

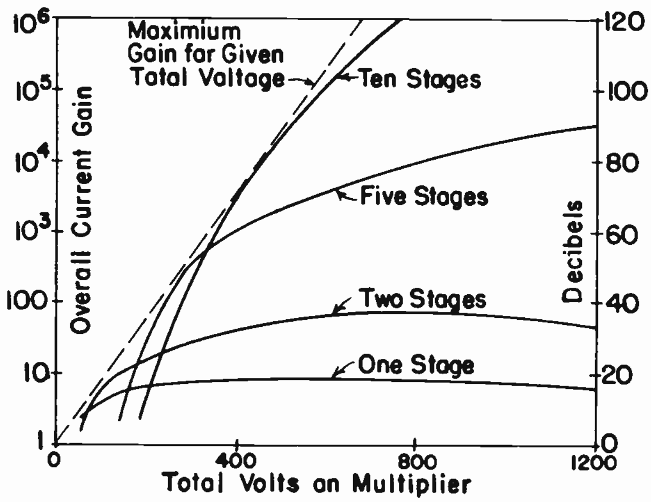


Fig. 6. Theoretical Overall Gains of Cesium-Silver Cascade Multipliers.

stages beyond a certain point. For example, with a 340-volt total supply, it is immaterial whether five or ten stages are used; the gain will be rather less than a thousand times in either case. A five-stage multiplier is, however, actually better in this case than the ten-stage multiplier, since the slope of the voltage-sensitivity curve is less; therefore it is less susceptible to variations of gain with supply-voltage variations.

For higher overall voltages, Figure 6 shows that the ten-stage multiplier has a definite advantage, and a total gain of over a million can be obtained with an 800-volt supply.

The data of Figure 6 do not allow for leakage of electrons due to some not striking a target, or striking a target in a comparatively insensitive spot. In practice, therefore, the gain is likely to be appreciably less than that theoretically possible.

The gain of a multiplier under given conditions of stage voltage can be readily computed from the equation,

$$i = i_o R^n,$$

where i = the final output current,

i_o = the initial photoelectric or other current,

R = the secondary-emission ratio, s/p, for the particular surface and the particular stage voltage used, and

n = the number of stages.

This assumes that R is the same for every stage. For a practical multiplier in which a potential of approximately 100 volts per stage is used, the value of R can be taken to be a little greater than 3.

Electron Multiplication in a Television Receiving Tube

So far we have not considered any case of a multiplier made up in a tube with a thermionic cathode and a control grid. Since this type of multiplier is important, in that it has applications in television receiver design, it is of interest to notice what is available. Figure 7 illustrates the construction of a tube now commercially available in Britain (Mullard Type TSE4), in which a stage of secondary-emission multiplication is included. As an output video tube, 30 volts maximum peak-to-peak plate swing may be obtained with an anode load of 5000 ohms.

The stage gain under these conditions is approximately 80. The tube can be used as a radio-frequency amplifier at 45 megacycles, and as an intermediate-frequency amplifier, as well as for normal video work. Under certain conditions of adjustment the transconductance may be as high as 20,000 micromhos.

By inserting a suitable load in the target circuit, it is possible to draw off currents of different phase from that

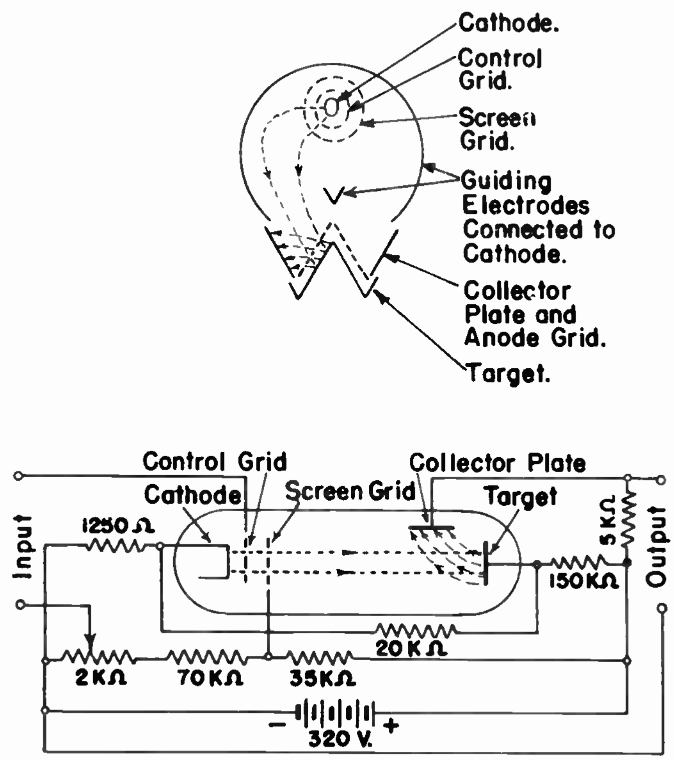


Fig. 7. Mullard Type TSE4 Secondary-Emission Amplifier and Connections in Video Stage.

at the anode. The transconductance on the target is approximately -12,000 micromhos, the negative sign indicating the opposite polarity from the usual g_m of a tube.

The operation of this tube will be clear from the structural diagram of Figure 7. The two guiding electrodes serve to direct the electronic flow proceeding from the cathode towards the target; the latter is the electrode adapted to emit secondaries under bombardment. The secondaries thus emitted are caught either by the collector plate or by the anode grid connected thereto.

Owing to the high slope, accurate control of bias potential is demanded. A rather unconventional bleeder circuit is recommended by the manufacturers and shown in Figure 7. This insures correct operating potentials when first switching on; without precautions, there is some danger of incorrect potentials being initially assumed because of the secondary-emission effect.

The tube noise is equivalent to that of some of the best pentodes obtainable.

The rated input capacitance is approximately 12 micro-microfarads, and the rated output capacitance approximately 10 micro-microfarads.

IMAGE PRODUCERS AND INTENSIFIERS

Before proceeding to examine forms of electronic scanning devices which are now in use as alternatives to the mosaic camera tube, which has been described in Chapter 2, it is well to become familiar with some electron-optical image-forming devices of a simple kind.

Magnetically Focused Image Producer

Figure 8 represents an image producer which has an evacuated cylindrical envelope with a thin photoelectric coating as the cathode on the interior surface of one end, and a coating of material capable of luminescing under electronic bombardment as the anode at the other end. In order to obtain electrical contact to all parts of the cathode it is usual to deposit the photo-sensitive material (cesium oxide) upon a semi-transparent layer of silver; the luminescent screen is like the phosphor of a picture tube and can consist of a fluorescent or phosphorescent powder deposited upon sputtered aluminum. A potential difference of a few thousand volts is set up between the cathode and screen. An optical image is formed by means of a lens upon the photoelectric material, as shown. Electrons springing from the surface of the cathode are accelerated toward the opposite end of the tube and impinge eventually upon the fluorescent screen where they produce luminescence.

Without any accessory devices, the image formed upon the fluorescent screen will bear only a rough resemblance to the original projected upon the cathode. This is because wherever the cathode is brightly illuminated the photoelectric emission will be most copious, and electrons from these portions after traveling down the tube will excite an approximately corresponding area of the screen to bright luminescence. But the image will not be exact, or sharp, because the electrons emitted from a surface under the influence of the incident light have velocities which are random in direction and amount, the latter being of the order of a few tenths of a volt. This is illustrated diagrammatically in Figure 9, which shows an enlarged view of a small portion of

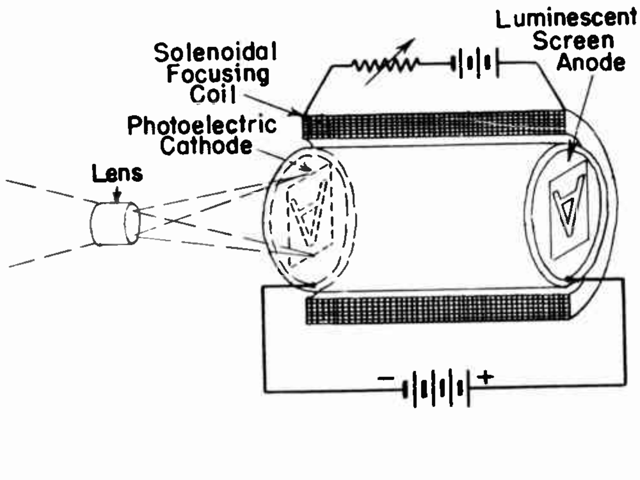


Fig. 8. Magnetically Focused Image Producer.

the cathode surface and an arrow indicating by its magnitude and direction the velocity of an emitted electron. This velocity possesses a lateral component, so that the electron, while being accelerated down the tube, will move sidewise, and will therefore strike the screen at a point some distance from its proper image-forming position.

Only in the case of photoelectric emission with zero velocity (for instance, emission excited by light of a color at the photoelectric threshold, such as infra-red radiation), and only with a perfectly smooth cathode surface, could the electrons from the cathode be kept in straight parallel paths as they pass down the tube to strike the screen. Since this is not a practicable method of sharpening the image, another device is resorted to, termed "solenoid magnetic focusing". This type of focusing has no lens analog, but is a special or limiting case of the magnetic lens referred to below on pages 151 and 152.

In Figure 8 is shown a sectional view of a coil of wire surrounding the tube, with arrangements to pass a controllable amount of current thru it. This produces a longitudinal magnetic field in the tube. So long as electrons are moving parallel to this field, that is parallel to the axis of the tube, the magnetic field has no effect upon them, but if they are moving across the tube, or have a lateral velocity component, the field urges them always in a direction at right angles to this transverse velocity component. Now a constant force which is always at right angles to the direction of motion of a mass, causes the mass to move in a circular path. Therefore, on looking down the length of the tube, the electron paths (if they could be seen) would appear as in Figure 10 which shows a pair of electrons springing from the point P with different lateral components of velocity. One of them, with the higher lateral velocity, traverses a path which would appear as a circle of larger radius than that described by the other having the lower sidewise velocity. But both electrons traverse their own circular paths completely in equal times and (if they were moving in a plane) would arrive back at P together. Owing to the steady acceleration down the tube, however, they do not arrive back at P but, as shown in Figure 11, converge upon a point P' in the screen which lies on a paraxial line thru P.

To show that the time for completion of the circular paths of Figure 10 is the same for electrons of unequal initial lateral velocities, let us write

$$t = 2\pi r/v,$$

where t = the length of time to complete the circle,

r = the helical radius, and

v = the initial lateral velocity.

But the radius of the circular path described by any electron moving at right angles to a magnetic field is

$$r = \frac{mv}{He},$$

where m = the electronic mass,

e = the electronic charge, and

H = the magnetic field strength.

Upon substituting this value of $\underline{r}$ in the first equation, we obtain

$$t = \frac{2\pi m}{He},$$

which is independent of initial velocity, and depends only on H.

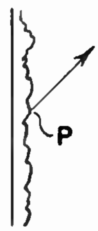


Fig. 9. Typical Direction and Velocity of Emitted Electron.

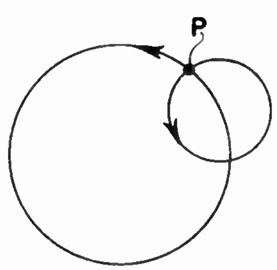


Fig. 10. End-On View of Tube of Figure 8 Showing Paths of Two Electrons.

The time that it takes an electron to swing around in exactly one full circle depends therefore upon the strength of the magnetic field within the tube and since, for focus, this time must coincide with that which it takes an electron to be accelerated from the cathode to the screen (which depends upon the potential difference between them and their separation), the ampere-turns of the coil must be regulated in conjunction with the accelerating field until the image comes into focus on the screen. For any one value of the electrostatic field there are in general a number of values of magnetic field strength which will yield a focus, corresponding with electronic paths which are helixes of one, two, or more revolutions. The first focus, where the number of revolutions is unity, is the most exact.

Note in Figure 8 that the image formed on the screen is inverted if the image on the cathode is inverted; there is no change such as would be obtained on forming an image with a lens. Moreover, there is a one-to-one correspondence between the size of the original and the reproduced images, provided the coil covers the entire length of the tube between cathode and screen.

This kind of device is not really useful as a piece of apparatus on its own account, except possibly for forming a visible image of an object irradiated with invisible rays, or of an object thru fog which is, to a certain degree, permeable to infra-red radiation.

However, it illustrates the principles of electronic image formation in one of the simplest cases.

Electrostatically Focused Image Producer

Another device of a similar nature is shown in Figure 12. Here the function of the focusing coil is performed by a system of positively poled electrodes within the tube, in the form of annular rings between which exists a potential gradient. These may also serve to accelerate the electrons from the cathode.

Owing to the curvature of the equipotential planes between the focusing electrodes, they act as a lens or rather as a system of lens surfaces, and an electronic image is formed upon a suitable luminescent screen at the far end of the tube. This image, unlike the previous case, is inverted (or, as shown in the drawing, reinverted), and its size bears a relation to that of the optical image on the cathode dependent upon the relative distances of screen and cathode from the electronic lens.

Image Intensifier

Having examined two simple cases of electronic image production, the next step is to inquire what happens when, instead of falling upon a luminescent screen, the focused electronic phalanx strikes a secondary-emissive surface.

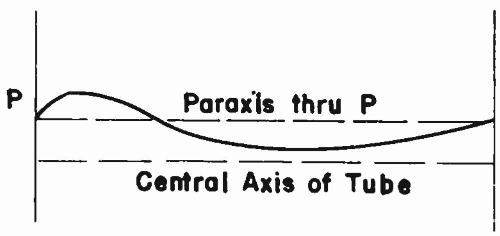


Fig. 11. Side View of Tube of Figure 8 Showing Path of an Electron.

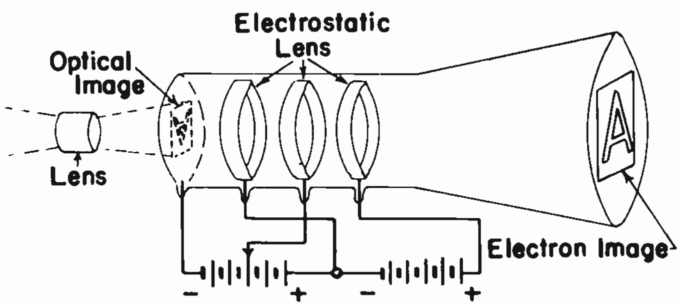


Fig. 12. Electrostatically Focused Image Producer.

For example let us suppose that in the tube of Figure 8, the magnetic field is so adjusted that the first plane of electronic convergence coincides not with the screen but with a fine-mesh grid coated with secondary-emissive material, this grid being located in the middle region of the tube and maintained at a suitable positive potential with respect to the cathode. The low-velocity secondaries emitted in this case can be drawn thru the mesh towards the fluorescent screen, if the latter is at a higher potential, and by properly proportioning the various distances and potentials an image, this time formed by secondary electrons, can be produced upon the screen.

If the secondaries are more numerous than the primaries and are caused to fall thru sufficient potential difference, an intensified effect will be produced upon the screen. This arrangement is therefore known as a "secondary-emission image intensifier".

THE DISSECTOR TUBE

With the foregoing explanations in mind, it is now possible to investigate the manner in which the dissector tube functions in the camera of a television transmission system. Figure 13 shows a very much simplified oblique view of a dissector tube arranged for television scanning; a lens at the left forms

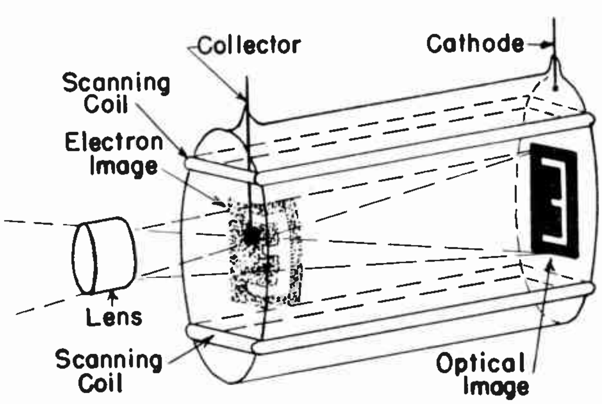


Fig. 13. Principle of Dissector Tube.

an optical image upon the surface of the cathode at the right, but since there is no luminescent screen in the way, the image can be formed directly upon the front of the cathode without making the coating semi-transparent. As in an image-producing tube, an electron image of the illuminated part of the cathode is formed by means of a focusing winding, which is not shown; instead of falling upon a screen, the electrons strike the end of the tube with the exception of a small number which are intercepted by a collector electrode. This electrode by its size (or, more usually, by the size of an aperture in a masking electrode in front of it) defines a scanning element of the picture. If it were possible in some manner to move the electron image as a whole from side to side and up and down so that every part of it fell in turn upon the collector, then the collector-current would serve to provide a video signal for use in television transmission.

In the illustration of Figure 13 a pair of scanning coils are shown surrounding the tube in such a way that a vertical magnetic field can be produced between them; this vertical field has the power of deflecting sideways the whole of the electron stream proceeding from the cathode. The result of such a deflection has been indicated in the drawing by the dotted area at the end of the tube; the electron image falls partly on the end face and partly on the cylindrical wall in the position shown. Clearly, by varying the strength of the field a lateral scanning motion can be given to the electron image and strips will be traced across it, due to its motion, by the collector electrode.

A saw-tooth current waveform is passed thru the coils, and an additional pair of coils (not shown in the diagram) are applied at right angles to the first for the purpose of deflecting the image vertically so as to obtain a complete scan.

Owing to the fact that the collector electrode (or "finger" as it is sometimes called) is small and is relatively close to the lens, it blocks only a small part of the light forming the optical image on the cathode. What it does block is distributed evenly over the image so that no shadow is cast.

The foregoing explanation, particularly of the scanning process, is very much simplified for the purpose of clarity. For example, in practice there is an interaction effect between the scanning and focusing fields, the result of which is to introduce a twist into the scanning action; to correct this, the positions of the coils have to be turned, or skewed, around the axis of the tube thru a certain angle, which in some cases may be as much as a right angle.

The sensitivity of the straight dissector tube of Figure 13 is very low indeed. To obtain a rough idea of its magnitude let us suppose that the cathode surface is sensitized to give a photo current of 40 micro-amperes per lumen, and that a full-white image of one lumen total flux is focused upon it. The total photo current will be 40×10^{-6} ampere, and the average current caught by the collector at any time will be this amount divided by the number of picture elements. With 200,000 picture elements, the result is only 200×10^{-12} ampere. With this current and a load of one megohm, there results only 200 microvolts video output; this is too small from two points of view, namely: (I) A megohm load is impracticable where a band of frequencies extending up to 4 megacycles is required and the electrode capacitance to ground cannot be reduced below about 8 or 10 micro-microfarads; and (II) The thermal noise for a megohm load and a 4-megacycle band would swamp the signal, the root-mean-square value of this noise being about 250 microvolts.

For these and other reasons it is essential to augment the effective collected current. In the mosaic tube or Iconoscope, described in Chapter 2, the result of primary photoelectric emission from each element of the screen is allowed to accumulate for a time equal to the whole of the scanning cycle in order to produce a large enough output to rise above the noise level. In the dissector there is no such effect, and other measures have to be employed. The development of the electron multiplier has solved the difficulty in a practical fashion as far as tubes for film-scanning purposes are concerned. Figure 14 shows a sectional view of a dissector including nine stages of electron multiplication.

Referring to Figure 14, the cathode is in the form of a metal electrode coated on its inner surface with cesium oxide on a base of silver, giving a photoelectric emission of 35 microamperes per lumen. The accelerating electrode or anode consists of a coating of nickel over about three-quarters of the cylindrical wall space of the tube, leaving a clear plane window at the far end for the image-forming rays to enter. The finger contains a nine-stage electron multiplier of the cascade type with the electrode leads brought out thru a pinch; near the top of the sheath of the multiplier there is a small cavity terminated at the inner end with an orifice defining the size of the scanning element. It is in the plane of this orifice that the electron image is formed, and electrons from a small portion of this image pass thru the aperture with sufficient velocity to produce secondary emission from a small curved plate situated immediately behind it. Secondaries from this plate are drawn off in a direction at right angles, similar to the action of the multiplier of Figure 5. To make the arrangement more efficient, small grids cover the entrance to each plate of the multiplier. This gives the primary electrons their full velocity before they become subject to the field produced by the higher voltage of the next stage, which might otherwise cause them to miss the stage.

By means of the electron multiplier in the dissector, a current magnification of a hundred thousand or a million times can easily be obtained, and this is sufficient to insure an adequate video output in motion-picture transmission.

It is true that what is required is an improved signal-to-noise ratio in comparison with the use of ordinary thermionic amplification, and secondary emission is not free from noise on its own account. Nevertheless, the use of a multiplier gives a great improvement over what would otherwise be obtained. This enables the dissector tube to be used successfully in film-scanning equipment, where plenty of light is available to form a strongly illuminated image on the cathode.

The signal-to-noise ratio for the first stage of a multiplier can be obtained from the shot-effect equation,

$$i_s = \sqrt{2 i_o e F} ,$$

where i_s = the current responsible for the noise,

i_o = the current collected initially from a picture-element,

e = the electronic charge, and

F = the frequency band passed by the amplifiers used for the video signal.

For a high-light illumination of 200 foot-candles in the image focused on the cathode of the dissector, such as might be obtained from a film projector, a signal-to-noise ratio of about 50 to 1 is obtainable.

The following figures indicate the magnitudes of the various quantities involved in the practical operation of a dissector:

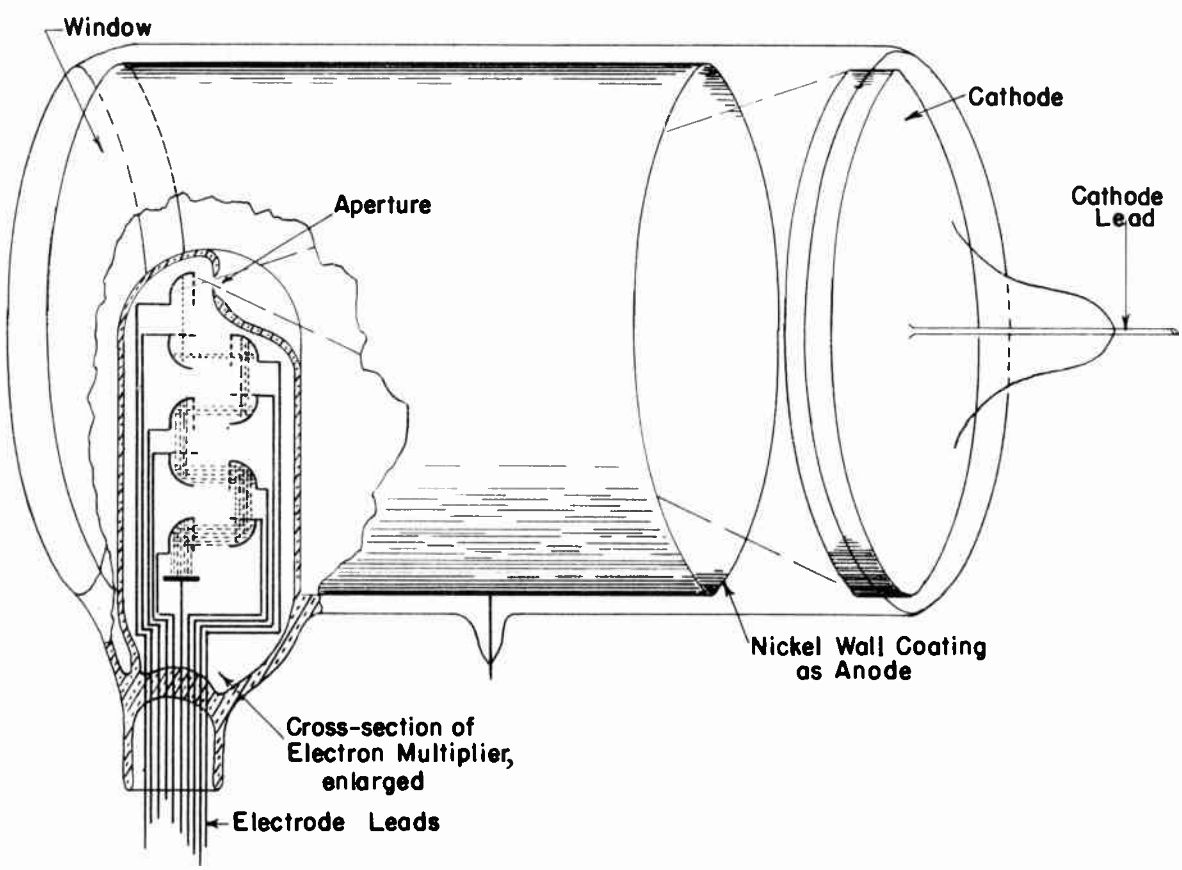


Fig. 14. Details of Practical Form of Dissector.

Potential between cathode and wall anode	600 volts
Cathode sensitivity	35 microamperes/lumen
Number of stages in multiplier	11
Total multiplier potential difference	1100 volts
Output from multiplier at the high lights	33 microamperes
Output capacitance	8 micro-microfarads
Load resistor	4000 ohms
Focusing-coil details	12 inches long 5-1/4 inches diameter 17,500 turns
Focusing current	20 milliamperes direct current
Horizontal deflecting coil	8-1/2 inches long 5 inches wide 65 turns in each of the two windings
Horizontal deflecting current	400 milliamperes peak-to-peak swing
Vertical deflecting coil	9 inches long 6-3/4 inches wide 2000 turns in each of the two windings
Vertical deflecting current	16 milliamperes peak-to-peak swing
Overall resolution	400 lines

Shading effects are absent from the dissector. The background or direct-current component is present in the output signal. Blanking may be inserted directly, either on the cathode or on one of the electrodes of the multiplier.

IMPROVED CAMERA TUBES

Following the line of development which led to the mosaic camera tube, there has been produced an improved type of storage tube in which the principle of secondary emission is employed to augment the primary current from the image plate. This tube is called an "image-multiplier Iconoscope" in this country and a "Super-Emitron" in England. The principle of this new type of tube is illustrated diagrammatically in Figure 15.

Instead of forming the optical image upon the same side of the plate as that from which the electrons are emitted, the semi-transparent photoelectric cathode already described in connection with Figure 8 is used. Electrons of the image area are drawn off under an electric field towards the mosaic, as in the dissector tube, but are focused somewhat differently by means of a magnetic lens. This consists of a relatively short coil surrounding the tube to form an electronic image in the plane of the mosaic plate. As opposed to solenoid focusing with a long coil, such as with the image producer of Figure 8, the image formed by a magnetic lens is inverted and may be larger or smaller than the original from which it is formed.

The effect of electron impacts upon the globules of the mosaic is to give rise to secondary emission which raises their individual potentials in the same way as a luminous image falling upon it — by loss of electronic charges. The scanning beam then operates, as has been previously described in Chapter 2, to return

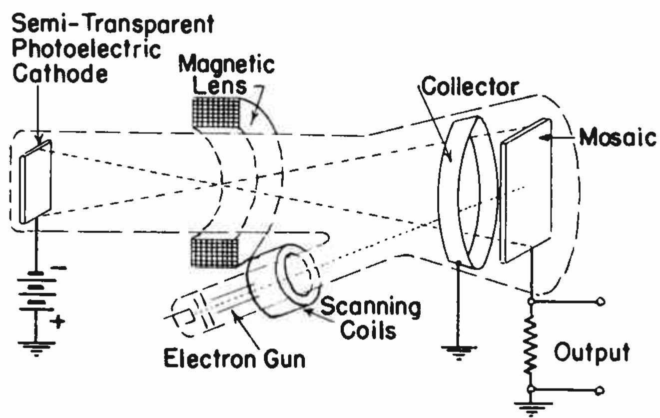


Fig. 15. Principle of Image-Multiplying Iconoscope of Magnetically Focused Type.

their potentials to a datum value, and at the same time to give rise to a dielectric displacement current in the insulator of the plate from which a video signal is derived in turn.

The process is therefore the same as in the ordinary Iconoscope, except that superior performance is obtained from the use of secondary emission to charge the globules, as by this means less light is required in the primary optical image for adequate signal strength. Shading troubles are also less pronounced.

In another form no silver globules are used; the secondary emitting properties and storage properties of an insulating film (which may be of mica) replace the action of the globules. This film can be made of practically zero photoelectric sensitivity.

A tube of this kind is shown in Figure 16, including the lens by which the optical image is formed upon the photoelectric cathode thru the end wall of the tube and the semi-silvered cathode backing. From the layout of the tube, it appears highly desirable to maintain efficient magnetic shielding between the two legs of the tube — that devoted to the production and deflection of the scanning beam, and that devoted to the electronic image formation — as otherwise

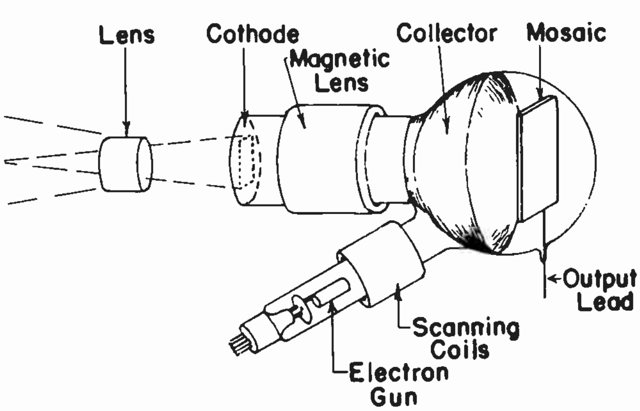


Fig. 16. Details of Image-Multiplying Iconoscope of Figure 15.

serious distortion of the electronic image on the plate will result.

In Figure 16, the electron gun and mosaic plate are shown as though they are in line with the orientation of the image on the photoelectric cathode. In practice, however, the gun and plate are rotated with reference to the image on the cathode by an amount to compensate for the image twist introduced by the magnetic electron lens. This twist, if the magnetic coil were indefinitely short, would amount to exact inversion, but owing to the finite length of the coil the twist is less than 180 degrees by an angle which is proportional to the square root of the coil length.

This completes the present review of contemporary electronic pickup devices; in a following section their use for motion-picture scanning is described.

SOME OPTICAL DEVICES USED IN TELEVISION

In television cameras and in equipment for the televising of films it is always necessary by some means to form one or more optical images — for example, to form an optical image of the subject to be transmitted upon the mosaic plate in a mosaic type of television camera.

Lenses used for optical image formation possess certain properties, described in optical treatises, with which a radio engineer or a television circuit technician may not be familiar. This section presents some of these properties in a simple manner.

Referring to Figure 17, (a) to (d) represent various types of simple lenses. The first is a biconvex lens, which on account of the greater thickness of glass in the center, has the property of retarding the central portions of a wave-surface with respect to marginal portions. A plane or but slightly convex wave-front can therefore be rendered concave, so that a real optical image is produced. The second lens, shown at (b), is termed a meniscus lens, and possesses roughly the same properties as a biconvex lens, except that it is better adapted to add to the convergence of already convergent light.

Diagram (c) represents a different type of lens, one which is incapable of producing a real image but which adds to the convexity of an already convex wave front, or reduces the convergence of convergent light.

The three lens-forms (a), (b), and (c), suffer from the disadvantage that light of different colors is not converged or diverged to the same extent. A prism-like action arises by which a dispersion is produced between the various colors of the spectrum. To overcome this defect, the fourth simple lens, shown at (d), has been devised. This consists of a doublet formed by combining a convergent lens of type (a) or (b), made of glass of one dispersive power, with a divergent lens of material having a different dispersive power. By this means the spectral dispersion or "chromatism" of a lens may be destroyed without at the same time destroying its lenticular properties, that is its normal lens properties. Such a lens is termed an "achromatic doublet" or "achromat".

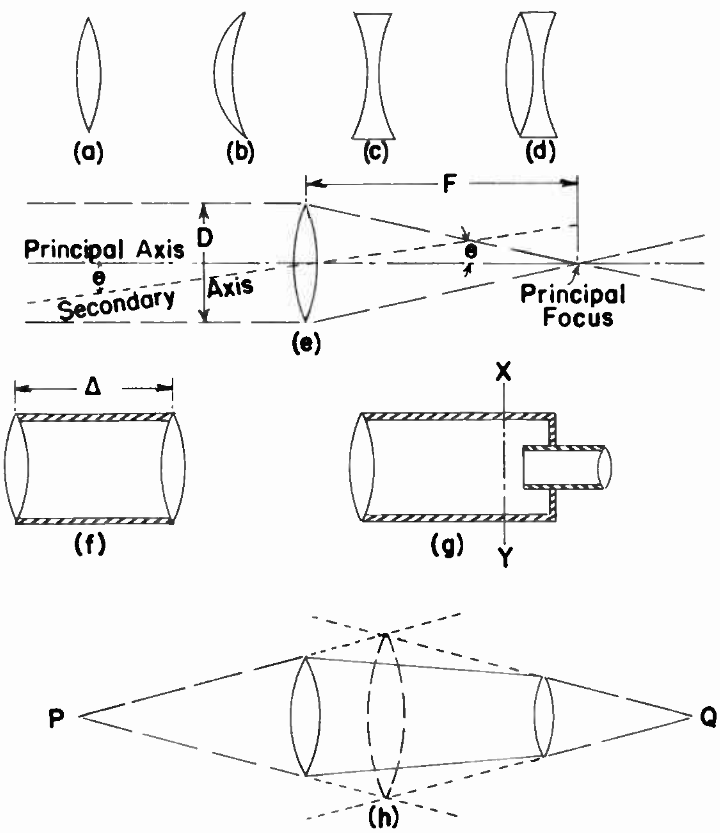


Fig. 17. Simple and Compound Lenses.

Lenses are not usually employed singly, in the form of simple lenses, because of certain blurrings and distortions which they produce in the images they form. For a description of the magnitudes of these distortions, a notation is required which may be simply derived from diagram (e). This shows a simple biconvex lens of diameter D, receiving parallel rays of light upon the left surface; such rays are converged to a point on the principal axis called the "principal focus" at a distance F from the center of the lens, as indicated. Any skew ray passing thru the center of the lens determines a secondary axis.

The quantity F/D is called the "photographic aperture", or "F-number" of the lens, and is hereafter designated by the symbol P.

The lens-blurrings, or "aberrations" as they are called, are given in kind and relative magnitude by the table on the following page. In the case of the non-axial aberrations, θ is the angle between the secondary axis for any particular point and the principal axis of the system.

From this list it will be seen that in most cases an increase in P (that is, a decrease in diameter or an increase in focal length of the lens) results in a diminution of the aberration or blurring of the image.

Aberrations may also be reduced by making use of compound lenses, formed by the juxtaposition of two or more simple lenses in the manner shown by diagram (f) of Figure 17. This shows an elementary form of compound lens using two simple biconvex lenses spaced apart a distance Δ. The focal length of such a combination is given by

$$F = \frac{F_1 F_2}{F_1 + F_2 - \Delta},$$

where F_1 and F_2 are the individual focal lengths.

TABLE OF CHIEF CHARACTERISTICS OF THE VARIOUS TYPES OF LENS ABERRATIONS

Aberration	Type	Effect in the Image	Order
Chromatic (longitudinal)	Axial	Differently colored rays are brought to a focus at different distances from the lens.	$1/F$
Chromatic (lateral)	Non-axial	Differently colored rays from an object point off the axis are focused at different distances from the axis.	$(\tan\theta)/F$
Spherical	Axial	Rays passing thru lens annuli of different diameters come to a focus at different distances from the lens.	$1/F^3$
Coma	Non-axial	An image element off the axis is focused as a series of gradually enlarging overlapping discs from the center outwards (fish-tail flare effect).	$(\tan\theta)/F^2$
Curvature	Non-axial	The surface upon which the image is most sharply defined is not plane but curved, usually concave towards the lens.	$(\tan^2\theta)/F$
Astigmatism	Non-axial	Radial lines are not focused with the same sharpness as others (for example marginal vertical or horizontal lines) in the image.	$(\tan^2\theta)/F$
Distortion	Non-axial	All parts of the image are sharply focused but marginal rectilinear markings in the object are imaged as curved lines (that is magnification changes from place to place in the image).	$\tan^3\theta$

One simple case of reduction of aberration exists when two equal lenses of double the focal length required are put close together. Spherical and chromatic aberrations with such a combination are considerably less than they would be for a single lens of the same diameter and equivalent focal length.

The arrangement of diagram (f) (which with doublet components of type (d) is used in the ordinary film projection lens) should not be confused with the arrangement (g), in which one lens forms an image in the plane X-Y and the other serves for examination or projection of this image. This lens combination (g) is typical of many optical instruments, such as the microscope, the telescope, etc.

An economy of lens diameter for a given light-collecting power is often effected by using a lens combination instead of a simple lens. A rough indication of this is given in diagram (h). This shows a pair of separated simple lenses forming an image of a point source P at point Q. By projecting forward the lines representing the marginal rays collected by the first lens and by projecting backward those representing the marginal rays reaching Q, the position and size of the simple lens of equivalent light-collecting power are obtained, as shown dotted. It is to be noted that the simple lens so obtained is not uniquely equivalent to the actual lenses; in general, for different values of the object and image distances, or for more extensive areas to be imaged, the position and size of the equivalent lens change.

A problem of fundamental importance in television optical systems is that of obtaining complete "luminous transfer" throughout the system. This means that, in the absence of lens losses and optical distortions, the image as formed on, say, the mosaic plate of a camera must contain all the light flux originally caught and have the same intensity all over when the object is evenly bright and evenly illuminated. The most frequent case of incomplete luminous transfer is when the projector lens of a system does not catch all the light (for example the marginal rays) passed from the condenser. Optical systems of the kind shown at (g) generally exhibit this defect.

A way of tackling the problem, which is widely used in optics, is indicated in the diagram of Figure 18(a). This shows a condensing lens forming an image of a light source A upon a film gate B. In the absence of precautions, the light passing thru the film would be contained more or less within the conical limits represented by the exterior dotted lines, and some of it would inevitably be lost by the projector lens which is located to the right. This type of operation results in an image which is bright in the center and dark at the edges. However, by placing a lens at C, called a "field lens", chosen so as to form an image of the condenser lens upon some suitable part of the projector lens (such as the entrance pupil), the light-flux passing thru the film is conserved and complete luminous transfer is obtained.

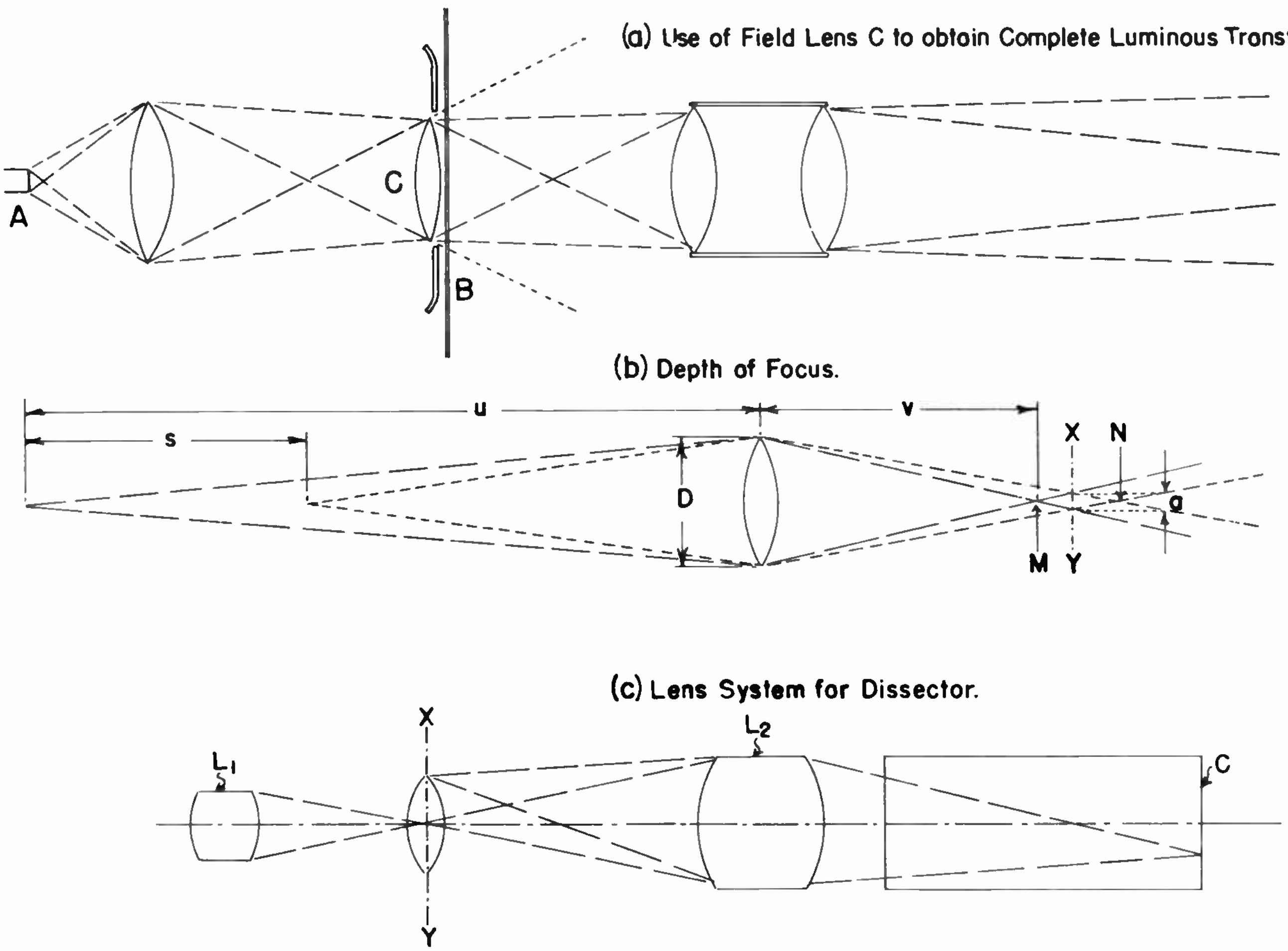


Fig. 18. Diagrams Showing Lens Systems and Depth of Focus.

Another problem of importance is that of depth of focus, or of obtaining a sharp image including portions of a scene lying at different distances from the lens. This is represented in Figure 18(b), in which light from a remote point falls on the lens and is focused at M, while light from a nearer point converges to N. Somewhere between M and N is a plane X-Y in which the best compromise focus is obtained (that is in which the blurring of near points and distant points is about equal). The image of an object point at either the far or near distance is then a circular patch having a diameter indicated as a in the drawing.

Suppose that the spread of object points along the axis is s, the most distant object point being at distance u from the lens, and the corresponding image point being at distance v from the lens. Then if the focal length of the lens is F and its diameter is D, and the maximum allowable "disk of confusion" is of diameter a, we can obtain a relation of the form,

$$\frac{s}{u} = 1\Big/\left(\frac{Dm}{2a} + 1\right) ,$$

where $m \equiv v/u$ (that is, m is defined as equal v/u). The quantity m is termed the "magnification". However, in practice Dm/2a is much larger than the unity term in the parenthesis. Neglecting the unity term, we get

$$\frac{s}{u} \doteq \frac{2a}{Dm} .$$

Introducing also the approximation that v equals the focal length F, we obtain

$$s \doteq \frac{2au^2}{FD} .$$

This shows that a short-focus lens (small F) is better than a long-focus one for focal depth; the equation also shows that a small diameter D is desirable, and a good long front conjugate distance u. All of these conclusions are borne out by experience. On the other hand, it must not be overlooked that if the magnification m and the photographic aperture F/D of the lens are both fixed, it follows that, to a practical degree of approximation, the depth of focus is independent of the lens size and focal length. This observation applies more particularly to cases in which it is required to form a close-up image, say of a head and shoulders, entirely filling some predetermined area such as a mosaic plate.

It is not always possible, for example with a dissector tube, to use a short-focus lens of small diameter. An alternative sometimes used is shown in Figure 18(c). Here, a first lens L_1 forms an image in the plane X-Y, and a second lens L_2 of suitably large diameter and focal length forms an image of this image on the cathode C of the dissector tube. A field lens is placed in the plane X-Y to obtain good luminous transfer. The lens L_1 can then be of short enough focus to obtain good focal depth, and the system also simplifies image-masking, which can be carried out in the plane X-Y.

Before concluding this section, a point which is sometimes overlooked or misunderstood in optical design should be mentioned. It has already been pointed out that a cause of blurring of the image with simple lenses resides in the spherical aberration produced. This may be completely overcome in compound lenses by the design of the components, and a measure of the accuracy with which correction for this (and other aberrations) is carried out is usually the price of the lens. But spherical aberration is also produced by passage of light thru a small thickness of absolutely plane-parallel glass sheet. The introduction of such a sheet (for example the end wall of a camera tube) may well destroy a large part of the benefit derived from the use of an expensive lens. It may thus be better to employ a thin spherical wall for the optical window of a tube than a thick optically flat and parallel window.

FILM-SCANNING SYSTEMS

The problem of deriving a television signal from the images on motion-picture film, while much simpler than that of picking up a real scene in the studio or out of doors by reason of the strong and steady light available for formation of the primary optical image, presents some difficulties of its own.

Of these difficulties, undoubtedly the outstanding one is that, while ordinary motion-picture film is standardized for passage thru the projector at the rate of twenty-four images per second, the sound track being recorded for reproduction at a corresponding rate, the television scanning process, which is locked in step with the 60-cycle line, requires the completion of scanning of one picture in a thirtieth of a second, or development of the signal at the rate of thirty images per second.

At first sight this might seem to imply that the film would have to stretch, or breed new pictures, or else that the scanning apparatus would, as it were, eat its way backwards along the film until it became entangled in the reel from which it is unwinding. This, however, is not the case.

There are two kinds of motion-picture scanning systems, which may be distinguished from each other by the fact that in one kind the motion of the film thru the gate is continuous even during the time occupied by the process of scanning, while in the other kind the film or an image of the film is effectively stationary during the scanning process. These may be called respectively the "continuous" and "intermittent" types from the character of the film motion.

<u>Intermittent Method for American Standard Signal</u>

The intermittent method is more frequently used and is chosen here for purposes of a first explanation of principles. The mode of scanning in such a system is illustrated in simplified form in Figure 19. The ten segments of film shown represent ten different stages in the scanning process. Commencing with the top left-hand segment, this illustrates three pictures of the film, A, B, and C, of which A is situated in the scanning gate and is being traversed in such a manner as to scan interlace #1. The interlace number of each picture being scanned is shown by a small digit. Before the first picture moves on, interlace #2 is scanned, as shown in the next segment. Then, by means of an intermittent-motion mechanism, the film is moved downward past the gate to the extent of one picture height, and, with picture B located in the gate, interlace #1 is again scanned as indicated by the third segment, followed by interlace #2 again in the fourth segment.

At this point, instead of moving the film downward to bring a new picture into the gate, interlace #1 is rescanned, making a total of five interlaces scanned on two pictures of the film.

The cycle of the film-moving mechanism is then virtually complete; but in order to coordinate the electrical scanning cycle with it, so as to reach a point where both mechanical and electrical cycles repeat together, the remaining five segments must be considered. The film

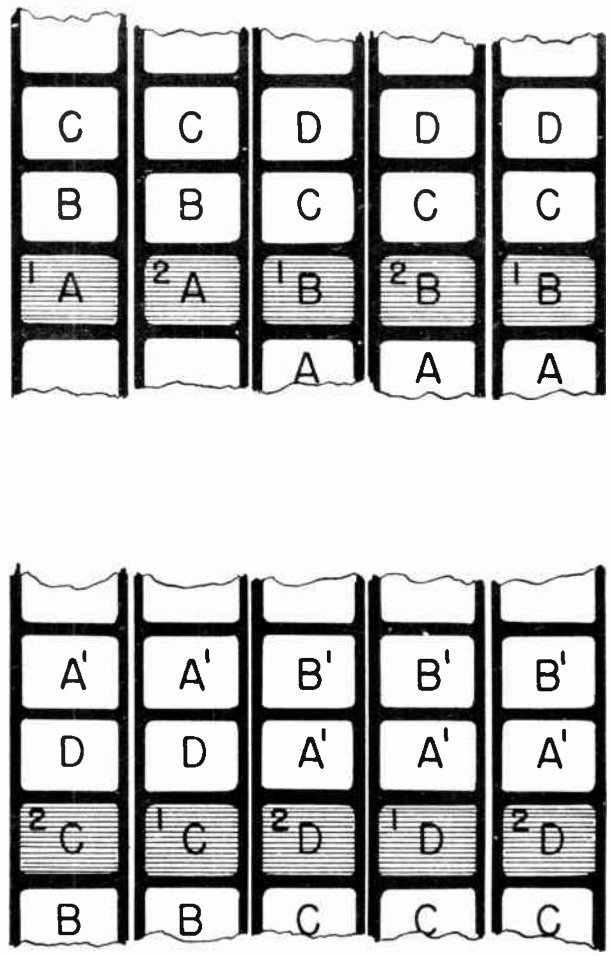


Fig. 19. Scanning of Two and Three Television Fields Thru Successive Movie Frames to Accommodate 24:30 Ratio.

moves downward to bring picture C into the gate, and interlace #2 is scanned (bottom left-hand segment in Figure 19), followed immediately by interlace #1 in the next segment. The film moves again to bring picture D into position, and interlaces #2, #1, and again #2, are scanned, as shown in the last three segments.

It will now be evident that the next picture, designated by A', is scanned with a #1 interlace, and since this is similar in all respects to the state of affairs at the commencement of the explanation, the whole cycle has been completed. During this cycle, four film pictures have been dealt with, and ten interlaces have been scanned (of which two are repetitions). Thus from four film pictures five complete television frames have been obtained; this allows the film to pass thru the gate at the correct sound-track speed of twenty-four frames per second while thirty television frames are scanned per second, since 24:30 = 4:5.

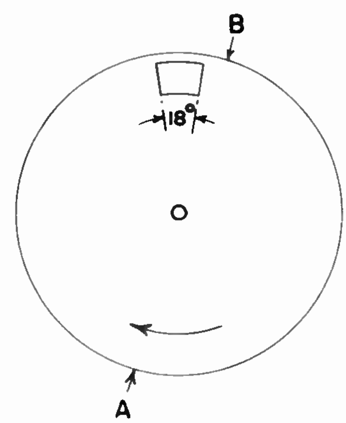
In Europe this type of difficulty does not arise, because the motion-picture film is passed thru the scanner at 25 pictures per second, which ties in very well with the 50-cycle frequency of the power system, and the European television standard of 50 fields per second.

Description of Intermittent Type of Equipment to Give American Signal

As an example of the kind of system illustrated in Figure 19, Figures 20 and 21 show an arrangement employing a photo-matrix camera tube for film scanning. This arrangement is one which has been used in our laboratories for scanning 16-millimeter film.

The tube is arranged in such a manner that an optical image of the film gate can be projected upon the mosaic, as shown in Figure 21, and the mosaic is scanned in the usual way by a magnetically deflected electron beam. The optical projection is not continuous, but is limited by means of a shutter disk rotating between the projector and the mosaic; this disk allows the image to fall briefly upon the mosaic once per revolution, the duration of projection being one-twentieth of the interval between the beginning of one projection and that of

Fig. 20. Shutter for Illuminating Mosaic Only During Field Retraces.



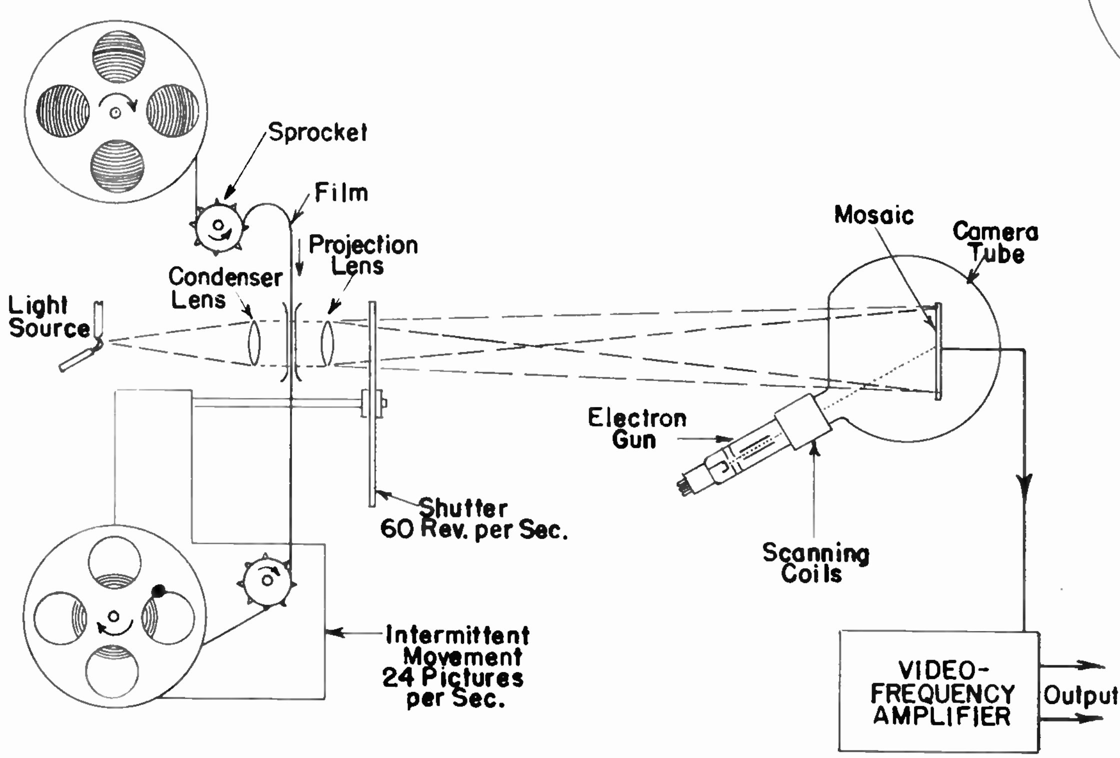


Fig. 21. Film Scanner of Intermittent Type.

the next. The layout of the shutter disk is shown in the diagram of Figure 20; here the effective width of the slot is shown as 18 degrees, which is 1/20 of 360 degrees.

The purpose of this short period of illumination of the mosaic is to enable an electric image to be formed, by the acquirement of various charges on the mosaic globules, during the limited length of the field-retrace period. Scanning by the electron beam is then carried out in the absence of light on the plate, relying on the memory or storage feature of the mosaic. This process is therefore called "dark scanning". The film may be either stationary or moving during the scanning process without in any way affecting the derivation of the video signal, since the shutter prevents any light from passing thru to the mosaic.

The shutter disk is rotated at 60 revolutions per second by means of the shaft driven synchronously with the power line. Since the picture-scanning circuits are also synchronized with the power line, the scanning process on the mosaic of the camera tube is kept in step with the rate of rotation of the shutter disk, which flashes a film image on the mosaic for a short period during each retrace interval.

The portion of the mechanism of the film projector designated in Figure 21 as the "Intermittent Movement" possesses the property of allowing the film to remain stationary in the gate for a period of about 85 percent of the time allowed for the normal projection of a frame in a cinema, which is 1/24 second. Then, in the remaining 15 percent of the time, the mechanism functions to drag the film rapidly downwards thru the gate to the extent of one picture-height. By reason of the shape of a wheel of this mechanism which is adapted to engage a projecting knob on a steadily revolving flange, this portion of the machine is sometimes called the "Maltese cross". The action is analogous to the passage of persons thru a subway turnstile gate, the projecting knob playing the part of a recurrent "person".

The speed of the intermittent movement is set by the gearing at such value that one frame of the film is moved for each 2-1/2 revolutions of the shutter disk. The phase is set so that the film is never in motion when the shutter-disk aperture is exposing the mosaic to light from the film.

The operation of the system may well be considered in more detail. During each gap in the scanning process necessary for field retrace, a film picture is flashed upon the mosaic, the film being stationary in the gate. Owing to the brightness of the projector source, the globules of the mosaic are charged rapidly by photoelectric emission and when the shutter obscures the optical image and the scanning process begins, a video signal is developed in the usual way. At the end of the first interlace, the scanning beam is cut off by the camera blanking signal, and the optical image again falls on the mosaic thru the aperture in the shutter.

At an interval after the end of the second exposure, while the second interlace is being scanned on the plate (the center of the aperture having passed the point marked A in Figure 20), the film is moved onward thru the gate by one picture height. The intermittent movement driven thru step-down gearing from the disk shaft accomplishes this, as already noted.

Let us consider that the motion of the film is completed in 150 degrees of rotation of the disk. Then by the time the aperture has come into the operative position the film is stationary again. The image flashes on to the mosaic, and interlace #1 is scanned; the image flashes again and interlace #2 is scanned; a third time the image flashes and immediately afterwards, when the center of the aperture reaches B, the film starts to move. The film motion lasts for 150 degrees of revolution as before, and in the meantime interlace #1 is being rescanned on the electric image of the picture last illuminated.

It will be clear that by moving the film again when the center of the aperture reaches A two and a half revolutions later, only two interlaces are scanned on the next picture, namely interlaces #2 and #1 in that order. It will be seen that two and a half revolutions starting at B and ending at A cause the aperture to pass the gate twice, but the same number of revolutions starting at A and ending at B cause the aperture to pass the gate three times.

In this way, three exposures are made during the next two and a half revolutions of the disk (giving rise to the electric images scanned by interlaces #2, #1, and #2), and this completes the electrical cycle as described in connection with Figure 19. Thus the film is stationary alternately for two and for three exposures of light to the mosaic, in spite of the fact that the periodicity of film motion is perfectly regular at 24 frames per second while scanning takes place regularly at 60 interlaces or fields per second. A group of five interlaces completes the mechanical cycle, but as previously explained, another five interlaces and two film motions are required to complete the electrical cycle. The whole process then repeats.

It has already been remarked that in Europe the television and film picture rates are so closely the same that no provision for slip need be made. Because of this, an excellent mechanical film-scanning technique has been developed in which a disk scanner is used, having two spirals of holes opened alternately by an auxiliary shutter to form the two interlaces. By means of a two-position optical system, the effective size of the scanning area of the disc is kept constant.

Continuous Method of Film Scanning

As mentioned previously, the more usual of the two film-scanning systems was chosen for the initial explanation; we now turn to a consideration of the other method, that in which the film has a continuous, or uniform, motion.

This method of film scanning eliminates all of the complexities connected with the 24-to-30 frame relation. A picture is projected upon the image surface of the scanning device by means of a continuous-motion film projector. This projector is capable of forming a stationary and evenly luminous picture upon a screen (or upon any other required surface) from a film which is passing at constant velocity thru the gate. In this method, which can obviously be used with either a dissector or a photo-matrix pickup device, all the technical difficulties are concentrated in the mechanism for producing the stationary image of constant brightness from the moving film.

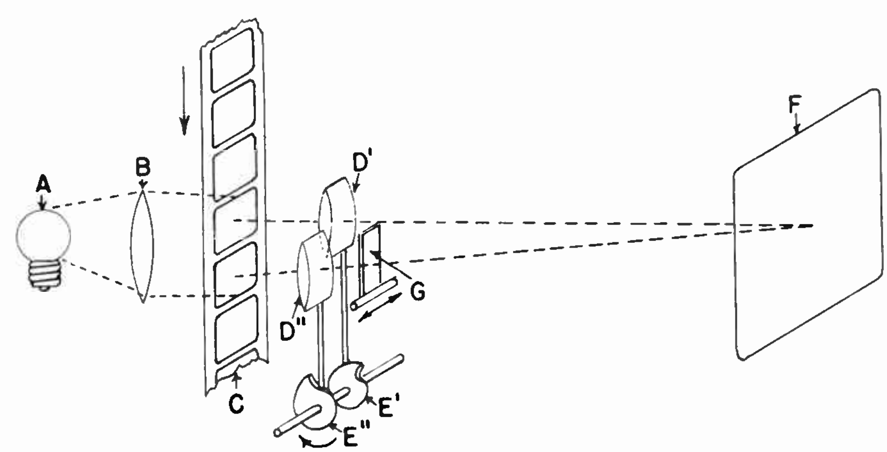


Fig. 22. Film Scanner of Continuous Type.

There are several such arrangements known in the motion-picture field, and one, expressly adapted for television, has recently been described in the JOURNAL OF THE SOCIETY OF MOTION PICTURE ENGINEERS.

An example of a continuous-motion projector which has been successfully used for television film scanning in England is illustrated diagrammatically in Figures 22 and 23. The principle is shown in Figure 22. Light from a source A is condensed by a lens B upon two frames of a continuously moving film C. Another lens, consisting of D' and D", is split vertically into two portions so that the optical center lies in the cleavage plane, and the cams E' and E" operate upon these two halves in such a manner that, while D' forms an image of one frame of the film upon the screen F, the other half D" is moving upward to take the next successive frame. On its return stroke, D" holds its image stationary in the same place. Figure 22 shows D' and D" at a point of transition where both are operative together and a shutter G, moving in a lateral groove, is just obscuring the portion D" before the cam E" pushes it upwards.

By making the lens D'-D" of rectangular shape and choosing a size for the shutter G such that it obscures just as much of one half of the lens as it opens of the other half, the illumination on the screen F is maintained constant throughout the cycle. This is an important point.

The arrangement shown in Figure 22 suffers from the disadvantage that unless the screen F is kept at a fixed distance from the film, the throw of the cams, E' and E", would have to be changed for every new distance. This defect is easily obviated by the optical system shown in Figure 23 in which the lenses D'-D" act to collimate the light from the image, after which it is brought to a focus on the screen F by an auxiliary lens H.

The method of continuous projection possesses a great advantage in that no special relationship is required between the film picture rate and the television scanning rate. The screen F is merely replaced by a scanning device such as a dissector or Iconoscope; the system will function perfectly at any odd ratio of speeds.

Devices other than cam-driven lens segments have been used in the construction of continuous-motion projectors;

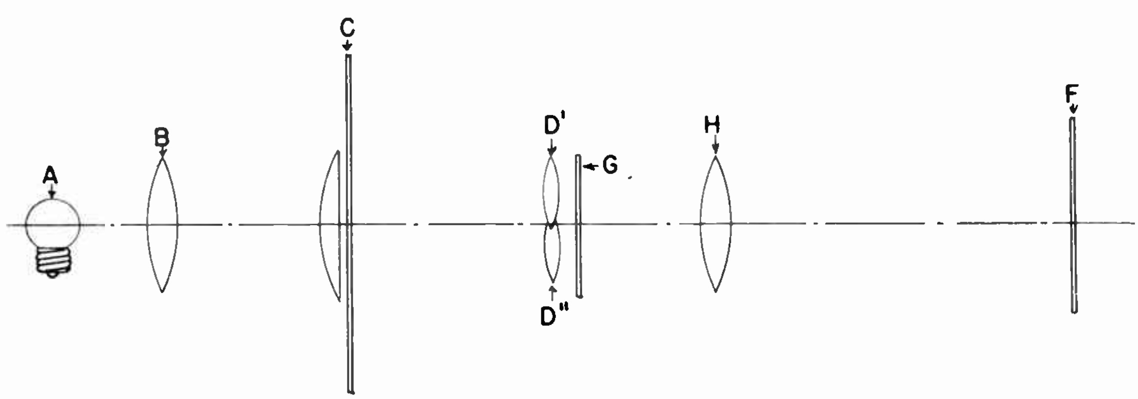


Fig. 23. Improved Lens System for Continuous Film Scanner of Figure 22.

some use tilting mirrors, and one of these (a projector of German design), which would otherwise be suitable for television use, is spoiled by having discontiguous mirrors with lines sand-blasted on the mirrors themselves to cover up the defect by tripling the "shadow-passage" rate. Among the devices successfully used in continuous-motion projectors suitable for television are mirror polyhedra, lensed disks, and rotary polyhedral glass blocks.

INTERMEDIATE-FILM METHODS

There is one more system of television pickup which must be noticed in concluding the present chapter. This is the intermediate-film system in which the scene is photographed with a motion-picture camera, the film quickly processed, and the film then scanned. This method has found favor, especially in Germany, for picking up outdoor scenes. It provides a photographic record capable of being cut and edited for later inclusion in news bulletins.

The intermediate-film method is also applicable for reception. A complete system with the intermediate-film method at both transmitter and receiver is shown in Figure 24. The upper portion of this diagram shows a transmitter in which film from the magazine of an ordinary movie camera, after exposure to the scene in the normal way, is passed out of the camera thru a light-proof flexible tube and into a tank of developing solution of a type capable of fully developing the emulsion in about 10 seconds. The developed film then passes into a fixing tank in which the emulsion unaffected by light is dissolved away, and the surface is then hardened in order to avoid scratching in the process of transfer to the scanning apparatus. The film images are then scanned by some suitable device such as a photo-matrix tube or a dissector tube, and the film is wound, after drying, upon a spool.

The video signal obtained from the scanning process is transmitted by radio in the usual way.

Fast acting developers of the pyrocatechin-alkali type are used, in conjunction with acid-hypo fixing solutions and a chrome-alum hardening bath. The total delay time between the photographing of an image and its subjection to the scanning process is of the order of 30 seconds, the particular value depending upon the solutions used and their temperature. All tanks are thermostatically controlled. The concomitant sound is delayed for a corresponding time, usually by being recorded magnetically on an endless steel tape.

The lower diagram of Figure 24 shows an intermediate-film receiving system; this may of course be used for any television reception. It is specially suitable for use in a motion-picture theatre for viewing by a large audience.

In the intermediate-film receiver the video signal after demodulation re-creates an image which is then photographed by means of a moving-picture camera in fixed mechanical relation to it. In some systems, however, a complete image is not built up, but the signals are recorded line by line, as they are received, directly upon the film. The process utilizes an endless belt of film stock, which is identical with the ordinary type except that its surfaces are specially hardened to resist scratching. This is coated with photographic emulsion in the unit marked "Re-Emulsifying", after which the emulsion is dried and set in a hot-air chamber. The film then passes thru the camera where a succession of images in the usual movie form becomes latent upon it. The film then passes thru developing, fixing, and washing, tanks. After this it is dried and passed thru a normal movie projector which throws a moving picture upon the theatre screen.

After passing thru the projector, the emulsion is scrubbed off the belt by stiff brushes under the influence of hot-water jets, and the belt then moves onward into the re-emulsifying unit where the cycle of operations starts over again.

The sound, which is also received by radio, is delayed the requisite time to insure synchronization of sound and vision on the screen.

This receiving system illustrates the elaborate developments

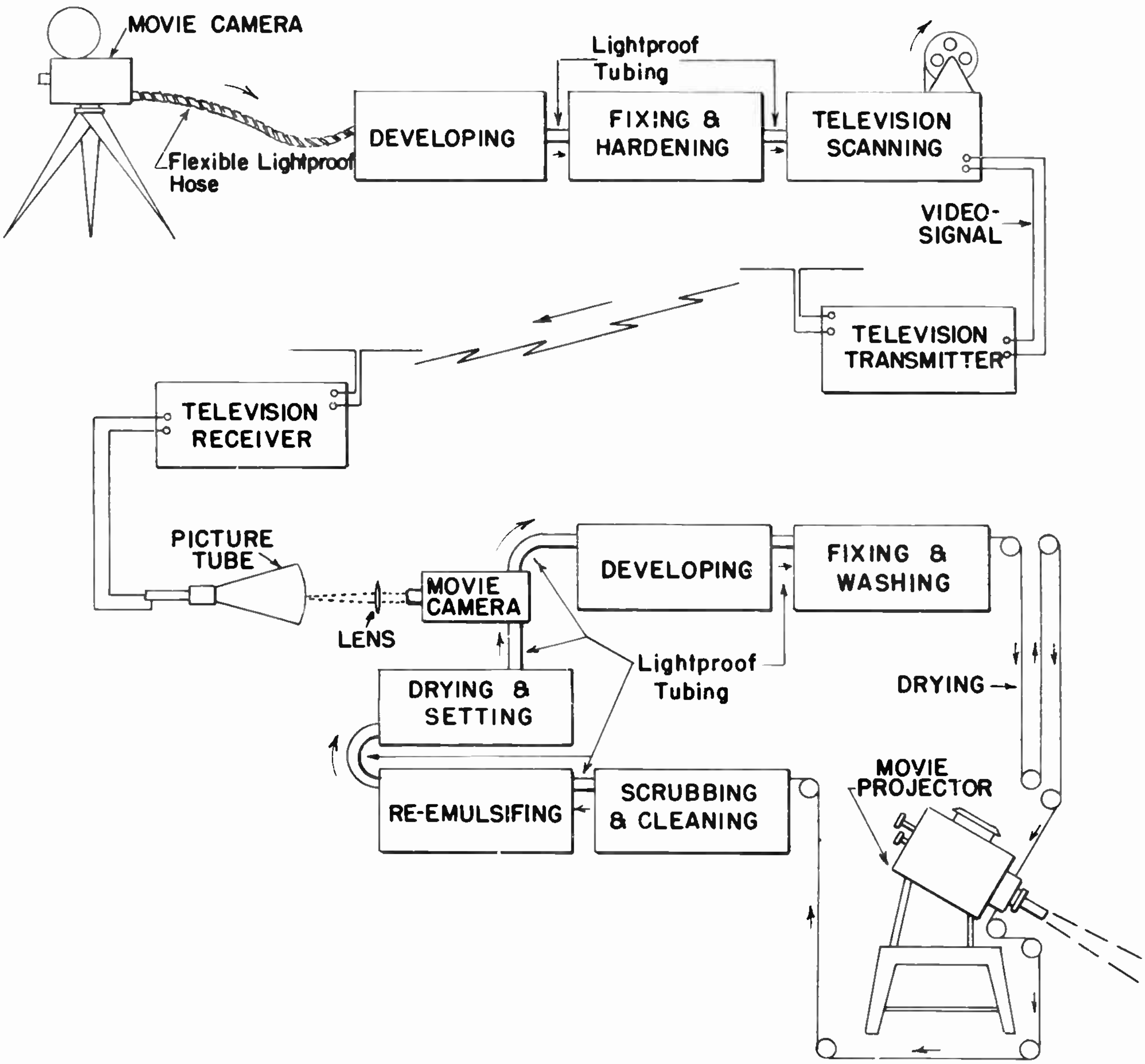


Fig. 24. Intermediate-Film Method in Transmitter and Receiver.

which have been made and actually used to increase the quantity of light available for the formation of the image. Fortunately the quantity of light obtainable from a picture tube at a reasonable cost is sufficient for ordinary home reception, so that these expensive and complex systems are required only for large audiences.

REFERENCES

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General

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