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THE TELEVISION PICTURE TUBE

By R. C. Hergenrother*

(Delivered before the Club on November 10, 1939)

History of the Cathode-Ray Tube

The principle of the cathode-ray tube, that of directing a narrow beam of electrons on a fluorescent screen where it produces a luminous spot, is old in the history of electronic devices. The deflecting effect of electric and magnetic fields on such electron beams was one of the first tools used by physicists to study the nature of electrons and other charged particles.

One of the earliest tubes which may be called a bona fide cathode-ray oscilloscope tube was described over forty years ago, and is shown in Fig. 1. The development of such tubes, which were rarely seen outside a physics laboratory, progressed slowly. The discovery of thermionic emission and its application to the cathode-ray tube marked a great advance. It is of interest to note that the early oxide-coated cathodes made by Wehnelt were for the purpose of getting greater thermionic emission in the cathode-ray tubes with which he was working.

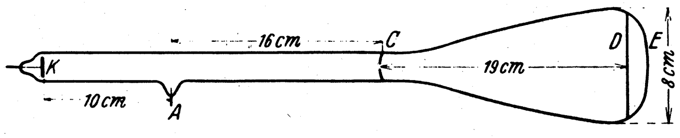


Fig. 1 - Drawing of an early Braun Tube
(Reprinted from *Wied. Ann. Bd.* 60 (1897)

The classic work of Busch in 1926[1], who showed theorectically and experimentally the image-forming properties of magnetic and electric fields, marks the early development of electron optics and the introduction of a theorectical basis for the design of cathode-ray tubes. The science of electron optics has been enlarged since that date at an accelerating pace by many workers, which has resulted in a clearer insight in the theory and design of electron-beam devices in general.

With the advent of television, the cathode-ray principle, which offered a virtually inertialess scanning means, assumed an increasing importance until today it is the basis of most of the high-definition television transmitting and receiving devices. It is of interest to note that the use of a cathode-ray tube for the reception of television images was proposed as early as 1907. This proposal was made independently in Russia by Boris Rosing[2] and in England by A. A. Campbell-Swinton[3].

The particular type of cathode-ray tube employed for the reception of television images is variously known as a television-cathode-ray tube, or a Kinescope, or a picture tube.

General Operation of the Picture Tube

Let us consider briefly the operation of the picture tube in receiving a television image. The tube has an electron gun which projects a narrow diverging beam of electrons towards a fluorescent screen; this electron beam passes through an electron-optical lens which converges the beam to a very small area on the screen where it produces an intense spot of light. The electron beam, and consequently the fluorescent light spot, is deflected over the fluorescent screen in successive lines by means of periodically varying electric or magnetic deflecting fields which act on the electron beam. These deflecting, or scanning, fields are produced by circuits which are controlled by the scanning action at the transmitter in such a way that the beam in the receiving tube acts synchronously and in phase with the scanning action at the transmitter. The television picture signal, amplified to the proper voltage, is applied to a grid, or modulating electrode, of the electron gun where it controls the amount of current in the electron beam. The brightness of the fluorescent spot appearing on the screen of the tube is thus changed from point to point along its scanning path, in accordance with the corresponding point-to-point change in the light intensity of the image at the transmitter.

*Hazeltine Service Corp. Laboratory, Little Neck, L. I., N. Y.

The subject of electron optics may be approached most readily by comparing it with the optics of visible light, since everyone is familiar with this subject to some degree. We shall therefore develop briefly some useful electron-optical concepts by showing the analogy between the action of an optical system on light rays and of an electric field on a beam of electrons.

General Characteristics of Electron-Optical Lenses

The shape of the path which an electron or other charged particle will take in an electric field depends on the electric-field configuration. Such an electric field can be represented by equipotential surfaces. The electrode surfaces, being conductors, are equipotential surfaces whose shape is fixed but whose potential can be controlled.

It is possible to produce electric fields of such a nature that electrons (or other charged particles) starting from a common point with equal velocities, but leaving in various directions, will converge at some other point in the electric field. It is thus possible to produce an "electron image" of an "electron object" in a way analogous to that by which a glass lens produces a luminous image of a luminous object. The electrodes and the associated electric field having this property are spoken of as an "electrostatic lens".

Fig. 2 shows an "electric double-layer" which can be visualized as two plane parallel conductors 1 and 2 which are permeable to electrons. This would be approximated by two sheets of very fine-mesh metallic screen. Let the potential of the conductor 1 be E_1, and the region to the left of this near the conductor be field-free. Similarly let the conductor 2 have a potential E_2, and let the space to the right be field-free. If an electron passes thru this electric double layer, entering with a velocity v_1, it will leave with a different velocity v_2, which will be greater than v_1 if E_2 is more positive than E_1. The increase in velocity of the electron will be due to the electric field between 1 and 2, this field being normal to these two surfaces. Therefore v_2 will have a greater component normal to the surfaces than v_1, whereas the tangential component of v_2, which is v, is the same as the tangential component of v_1. If the angles which v_1 and v_2 make with the surface normal are respectively θ and ϕ, it is clear from the vector diagrams shown in Fig. 2 that

$$\sin\theta = \frac{v}{v_1},$$

and

$$\sin\phi = \frac{v}{v_2},$$

from which it follows that

$$\frac{\sin\theta}{\sin\phi} = \frac{v_2}{v_1}$$

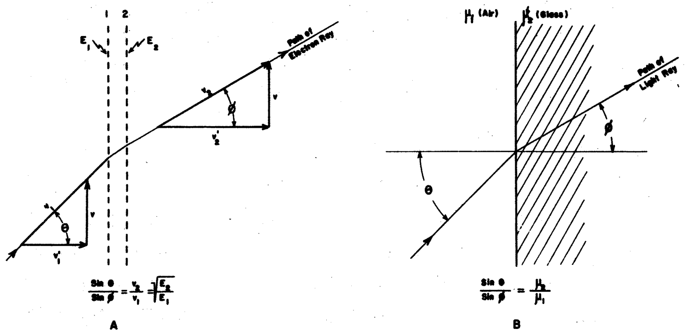


Fig. 2 - Electron refraction at a flat electric double layer and the optical analogy

An electron of mass m starting from rest at a point of zero potential and moving through an electric field will acquire a velocity v. At each point in the field the kinetic energy $1/2\ mv^2$ of the electron will equal the potential energy eE of the field where e is the electron charge and E is the electric potential at the point. Thus the square of the electron velocity at any point of the path is proportional to the electric potential at that point. Therefore the above equation can be written

$$\frac{\sin\theta}{\sin\phi} = \frac{v_2}{v_1} = \frac{E_2}{E_1}$$

The light-optical analogy of the electron-optical example of Fig. 2-A is illustrated in Fig. 2-B. A ray of light passing from the optical medium of refractive index μ_1 into an optical medium of refractive index μ_2 thru a flat interface at an angle of incidence θ is refracted and leaves the interface at an angle ϕ. The well-known optical law of refraction describing these relations is

$$\frac{\sin\theta}{\sin\phi} = \frac{\mu_2}{\mu_1}.$$

From this we may observe certain electron-optical principles (which can be theoretically deduced by other methods with complete rigor and generality), as follows:

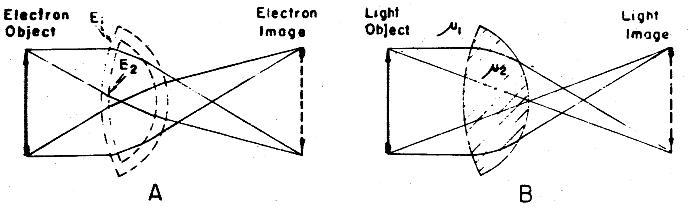
(1) The path of an electrically charged particle starting from rest in an electric field is independent of the magnitude of its charge or its mass. (The sign of the charge on the particle determines in which of two directions it is urged by the electric field. Also the speed of the charged particle depends on its charge-to-mass ratio.)

(2) The path of an electrically charged particle in an electric field is independent of the magnitude of the electrode potentials (of which there may be two or more), but depends only on the ratios of these potentials.

(3) The square root of the potential plays the same role in electron optics which the refractive index does in light optics.

(4) If two systems having the same electrode voltages are geometrically similar, the paths of charged particles through them will also be similar. (For example, if all dimensions of one system are double those of another, the two systems are similar.)

Let us now consider two electric double layers of the type described above, which are not plane-parallel, but are curved into intersecting spherical shells, so that the space between the two layers has a lens shape. This is illustrated in cross-section in Fig. 3, along with the light-optical analogy, which is a double convex lens. This lens-shaped electric double layer will have the property of being able to focus electrons proceeding from an electron object into an electron image in the same way that the light-optical lens has the property of focusing the rays proceeding from a light object into a light image. In fact, the formula which states the focal length of the light-optical lens in terms of the radii of curvature of the surfaces and the refractive indices of the lens and the surrounding medium can be converted to the corresponding formula for the electron-optical lens by substituting $\sqrt{E_1}$ for μ_1 and $\sqrt{E_2}$ for $\sqrt{\mu_2}$.



A

B

Fig. 3 - Electron lens constructed of electric double layers, and the optical analogy

The light-optical lens is subject to two limitations, namely (1) the refractive indices available for the material (glass) of the lens are limited to about one and one-half times that of the surrounding medium if it is air, and (2) the refractive index of a given material is constant and therefore the focal length of a given lens is constant. The electron lens, on the other hand, may have any desired ratio of the voltages E_1 and E_2, and this ratio may be changed at will, thus changing the focal length. The electron lens shown in Fig. 3 may be made converging or diverging, or it may even act as an electron mirror, according to the ratio and sign of E_1 and E_2.

However, electron lenses of this type have no practical utility because no conductors which are freely permeable to electrons are known. If a metallic mesh is used, then no matter how fine the metallic mesh is made, those electrons passing very close to the mesh would be deviated more than those passing through the aperture centers, thus producing a sort of diffraction effect which would blur the image. This has been tested experimentally by Knoll and Ruska[4].

To construct a useful electrostatic lens, it is necessary to produce suitably shaped equipotential surfaces in free space. This can be done in a large variety of ways. In fact, if any system of arbitrarily shaped apertured conductors, which are surfaces of revolution about a common axis, is connected to an arbitrary set of potentials, an electrostatic lens will be produced. The equipotential surfaces of the resultant electric field will in general be curved and they will be surfaces of revolution about the common axis, which is called the electron-optical axis of the system. Of course the usefulness and efficiency of the resultant electric field as a lens will depend on the specific shape and potentials of the conductors. We shall now examine a few of the useful and efficient structures which are used for electron lenses in picture tubes.

The First Lens of the Picture Tube

Figure 4 shows an example of one type of television picture tube having electrostatic focus and magnetic scanning.

The electrons emitted from the spot of electron emitting material on the end of the cathode are gathered into a diverging beam by the electric fields of the adjacent electrodes which constitute the "first lens" of the tube. Another electric field between the ends of the coaxial cylinders, constituting the so-called first anode and second anode, forms a "second lens" which converges the beam to a small spot on the fluorescent screen.

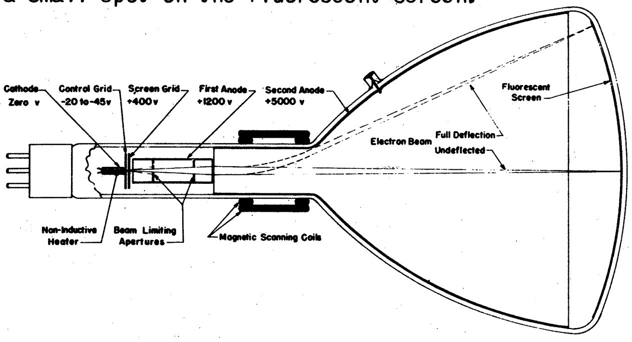


Fig. 4 - Cross-section view of one particular design of a television picture tube

We shall now examine the first lens in more detail. Figure 5 shows a cross-section of the electric equipotential surfaces, representing the field at the first lens of such an electron gun. The control grid and screen grid are metal disks having circular apertures which are accurately aligned on the electron-optical axis.

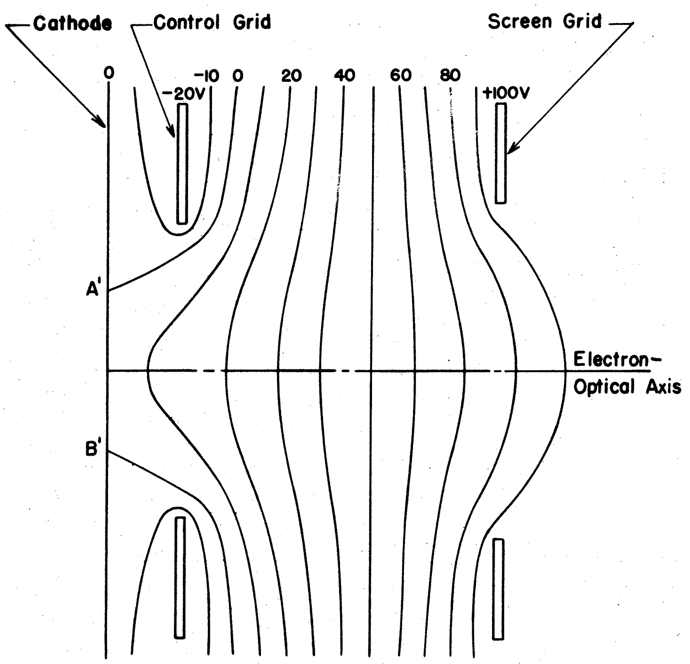


Fig. 5 - Equipotential surfaces at the "first lens" of an "electron gun"

On the cathode surface there is a disk-shaped region whose diameter is indicated by the line $A'B'$. In front of this disk the potential is positive, because the effect of the positive screen grid exceeds that of the negative control grid. Thermionic emission can therefore take place over this disk. Outside of the region of this disk, the potential gradient is such as to retard electron emission. The boundary of this disk is not sharply defined since some of the thermionic electrons have sufficient initial velocity to overcome a slight retarding field. The velocity distribution of the thermionic electrons is Maxwellian, with a most probable velocity of about 0.4 equivalent volts for an oxide-coated cathode. As the potential of the control grid is made more negative, keeping the screen-grid voltage constant, the diameter $A'B'$ of the emitting disk decreases until a value of grid voltage is reached for which $A'B'$ becomes zero and all thermionic emission from the cathode is prevented. This voltage is the grid-cutoff voltage. The relation of beam current to grid voltage is approximately the same as that obtaining in a vacuum-tube amplifier, that is, a three-halves power relation.

The curved equipotential surfaces produce an electron-optical lens effect, but the computation of this effect is no longer as simple as that of the mesh lens. Indeed, the light-optical lens which would be the analog of this electron-optical lens would consist of a nest of infinitely thin lenses having the shape of the equipotentials, with each successive lens having an infinitesimally different refractive index corresponding to the electrical potential.

An analysis of the behavior of the electron beam in a field similar to that of Fig. 5 has been made by Maloff and Epstein[5]. The paths of electrons leaving the cathode are shown in Fig. 6. Consider a point on the cathode above the electron-optical axis but within the disk from which electrons are being emitted. From this point electrons will be emitted in all directions, with a Maxwellian distribution of velocities. The path of an electron starting from this point in an upward direction, tangent to the surface, with a velocity of 0.35 equivalent volts, is shown by curve (1). Curve (2) shows the path taken by an electron starting in a downward direction, tangent to the surface, with a velocity of the same amount, that is 0.35 equivalent volts. Any electrons leaving this point with velocities of 0.35 equivalent volts or less, will have paths lying between these extreme paths, regardless of the direction in which they leave the cathode. If the corresponding paths are determined for corresponding electrons starting from a point equally distant, but on the opposite side of the electron-optical axis from the first point, they will be symmetrical to these first two, as shown by curves (3) and (4).

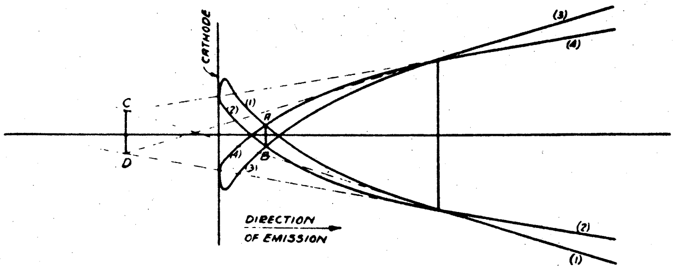


Fig. 6 - Electron paths in the first lens of an electron gun showing the electron "crosss-over" AB. (Reprinted from I.R.E. *Proc.*, *Dec.* 1934, pp. 1399. See Ref. 5)

Curves (1) and (4) intersect in the point *A*, whereas curves (2) and (3) intersect in *B*. The line *AB* thus represents the diameter of a disk through which any electron having a velocity less than 0.35 volts and leaving any point on the cathode must pass. The disk *AB*, which is called the "electron cross-over", is not an image of the emitting cathode but is a region in which the electron beam has a minimum diameter. For this reason it is used as the electron object for the second lens. Since the electron paths are still curved after passing the cross-over, the second lens uses the virtual image *CD* of the cross-over

AB as a virtual electron object. The distribution of electron density over the cross-over varies exponentially along the radius as measured from the electron-optical axis. The electron spot which the second lens focuses on the screen therefore also shows such a radial intensity distribution.

The first lens, which is sometimes called an electron-immersion lens, thus serves to collect the electrons from a small area of the cathode and direct them into a beam. The angle at which the beam diverges is dependent on the size of this emitting area, which is in turn dependent on the grid potential. When the potential of the grid is almost at cutoff, the emitting area is very small, and the angle of divergence of the beam is very small. As the grid is made less negative, the emitting area and the beam angle increases. However, if the voltage of the positive electrodes which are normally kept at a constant potential, is increased, the cross-over diameter and the beam angle both decrease. In some electron guns one or more limiting apertures are placed beyond this lens, in order to avoid excessive beam angles at large beam currents. Such apertures are placed in a region of the gun which is field-free, in order to avoid drawing into the electron lens, and thus to the fluorescent screen, the secondary electrons produced in the vicinity of these apertures.

A number of type of "first lenses" in addition to the one just described are shown in Fig. 7. These lenses make use of an electron cross-over, but differ in details from the lens already described. It is interesting to note that such lenses can have three or four or more elements, corresponding to triode, tetrode, and higher structures of conventional amplifying vacuum tubes. There is a similarity in the electrical characteristics of these lens structures and the corresponding vacuum-tube structures. For example, the relation of beam current to grid voltage of a triode first-lens structure varies greatly with the voltage of the final anode, whereas this characteristic for a tetrode structure is only slightly affected by the final-anode voltage.

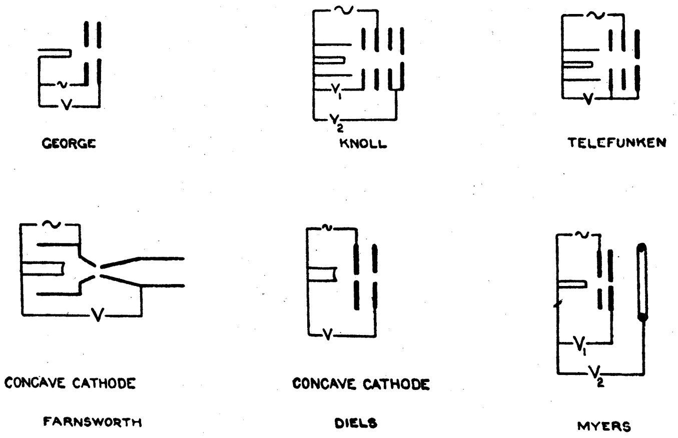


Fig. 7 - Various types of first lenses or electron immersion objectives (Reprinted from *"Electron Optics"* by L. M. Myers page 470)

The Electrostatic Second Lens

The electrostatic second lens, whose function is to focus the electron cross-over on the fluorescent screen, may have a variety of forms, but usually consists of coaxial cylinders which are at different potentials. Figure 8 shows the potential plots and electron paths for a number of such cylindrical combinations.

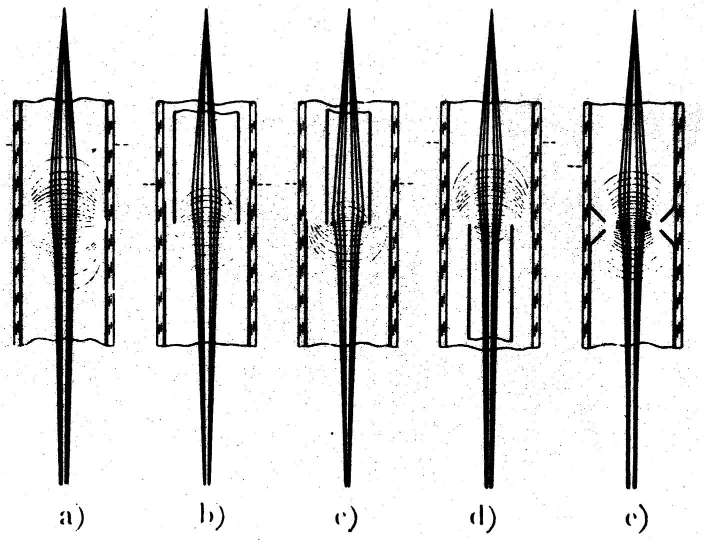


Fig. 8 - Electron lenses constructed of coaxial cylinders, showing electron paths (Reprinted from *Zeitschr. f. Techn. Physik,* Vol. 12, 1936, p. 608 - "Electron Optics in Television" by Max Knoll)

The characteristics of one such type of lens having a smaller cylinder for the first anode, than for the second or final anode, have been investigated by D. W. Epstein[6]. The image-forming properties of this type of lens were studied for a series of different values of the ratio of the diameters of the first and second anode cylinders. Such lenses are described optically as thick lenses, and their focal length and magnification must be expressed in terms of more general optical parameters than those applying to a single thin lens. However, for a given configuration of object and image distances with a thick lens, an equivalent thin lens exists which will have the same image properties. It is convenient to consider such an equivalent thin lens to which we can apply the thin lens equation,

$$\frac{1}{f} = \frac{1}{a} - \frac{1}{b} \ ,$$

where f is the focal length, a the object distance, and b the image distance. The equation for the magnification of the electron lens in these terms is

$$M = \frac{b}{a}\sqrt{\frac{v_1}{v_2}},$$

where V_1 is the first-anode potential and V_2 is the second-anode potential. The potential is different on the two sides of the lens, and if we pursue the optical analogy of a lens forming a light image, we must have on the image side of the lens a different refractive index from that on the object side. This factor is taken care of by the square root of the ratio of potentials in the preceding equation.

It is interesting to note that electron lenses are subject to the same type of defects as optical lenses. One of the defects, which is important in the electron-optical systems of the type which we have been describing, is spherical aberration. This defect increases the size of the electron spot on the fluorescent screen, which we are trying to keep as small as possible. The amount of the spherical aberration which the electron lens exhibits increases with the divergence angle of the beam which is entering the lens. Accordingly, it is desirable to keep the angle of divergence of the entering beam as small as possible. Unfortunately this conflicts with increasing the current in the beam, as we have seen in the discussion of the first lens. The electron-lens design must strike a balance between these two factors to get the maximum beam current in the electron spot on the screen without exceeding the spot-diameter limit which is imposed by the picture-detail requirements of the television image.

The Magnetostatic Second Lens

An electron which is moving in space, as in an electron-beam, is equivalent to an electric current. This equivalent current for one electron, expressed in amperes, is equal to the product of the electron charge in coulombs and the electron velocity in centimeters per second. Just as a magnetic field will exert a force on a wire carrying a current, so will it act on a moving electron or other charged particle. The force which the magnetic field exerts on a wire or on a moving electron acts at right angles to the direction of motion of the electron and at right angles to the magnetic field. The amount of this force is proportional to the sine of the angle between the direction of electron motion and the magnetic field ($F - B\ e\ v \sin\theta$). This interaction of the moving electron and the magnetic field is the basis of the electron optics of magnetic fields, or so-called magnetostatic lenses.

It is of interest to note the differences between the action of the electric field and the action of the magnetic field on the electron. In an electric field the force acting on the electron does not depend on the velocity of the electron. Also the direction of the force is in the direction of the field and this force will in general change the speed of the electron. In particular, the speed at any point in the electric field is expressed by the relation $1/2\, m v^2 - V_e$, where V is the potential difference between the starting point (usually the cathode) and the point in the field at which the electron happens to be.

In a magnetic field, on the other hand, the force always acts at right angles to the direction of motion of the electron. This means that a magnetic field cannot speed up or slow down the electron, but can only deflect its path. Also, the strength of this deflecting force is directly proportional to the velocity of the electron. The deflection of an electron or other charged particle or ion depends on the ratio of the charge ot the mass. This charge-to-mass ratio appears in all equations describing the effects of magnetic fields on moving charged particles, but does not appear in the equations describing the effects of electric fields.

A magnetic field of axial symmetry is a magnetostatic electron lens and may be used for the second lens of the picture tube, instead of the electrostatic lens which was described. The electron-optical properties of such a magnetic field do not have a simple light-optical analogy as in the case of the electric field. The analysis of the lens action of such magnetic fields was carried out in 1926 by Busch, as we have already mentioned. This analysis was made for the so-called "paraxial" case, which means that the divergence angle of the electron beam entering the lens was kept small. This analysis leads to very useful concepts and formulas for the magnetostatic lens.

A diagramatic representation of the action of a "short" magnetic lens is shown in Fig. 9. This lens, which is shown in cross-section, consists of a short solenoid carrying an electric current. The magnetic field produced by the solenoid is symmetrical about the axis of the coil, making this axis the electron-optical axis of the lens. The electrons are given a velocity by means of an electron gun which may be of the type of the cathode-ray tube "first lens" which has already been described, but this is omitted in the drawing for simplicity. The electrons leave this gun and enter an electric field-free space, in which their velocity remains constant. The electron object at the left can be considered to be the virtual image of an electron cross-over, such as has already been described. An electron which is directed along the solenoid axis is always parallel to the magnetic field and therefore passes through the lens without deflection. An electron entering the lens at an angle is acted on by the magnetic field and moves in a spiral path, receiving both a deflection towards the axis and a twisting motion about the axis through

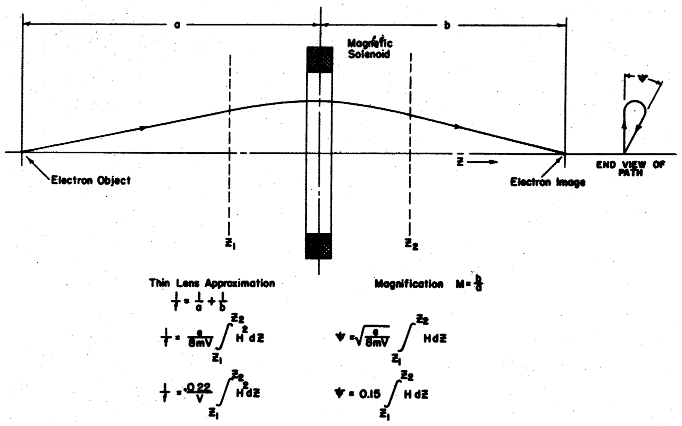


Fig. 9 - Magnetic electron lens action of a solenoid

an angle intersecting the axis again at the point shown. Electrons leaving the electron object at a point which is at a small distance *k* above the electron-optical axis will be given a deflection and a twist about the axis which will bring them to a focus at a point distant *Mk* from the axis, where *M* is the magnification of the lens. A line drawn between the image point and the optical axis is not directed opposite to a line drawn from the corresponding object point to the axis as is the case with an optical lens, but is rotated through the angle, which is a constant of the lens. This means that the magnetostatic lens will produce an electron image of a more or less extended electron object, and this image will be rotated through a certain angle relative to the inverted position. Strictly speaking, this is again an optically "thick" lens, but most lenses of this type can be described to a good degree of approximation by the thin-lens formula which is shown in the drawing.

The focal length of the lens is expressed in terms of the magnetic field intensity along the electron-optical axis. It is to be noted that the focal length is independent of the polarity of the magnetic field since this enters as a square. Therefore the current in the solenoid may be reversed without changing the focal length. Also, the focal length is proportional to the mass of the particle divided by its charge. Thus a negative ion (which has a mass thousands of times greater than an electron) is hardly affected by a field which would be suitable for focusing an electron beam. It should also be noted that the focal length is directly proportional to the voltage of the cathode-ray beam and inversely proportional to the square of the current through the solenoid, assuming that the field is proportional to the current. The angle through which the image is rotated is also expressed in terms of the magnetic field intensity along the electron-optical axis. The magnetic field enters as the first power here, so if the current through the solenoid (and therefore the magnetic field) is reversed, the image is rotated by an equal angle in the opposite direction from the inverted position.

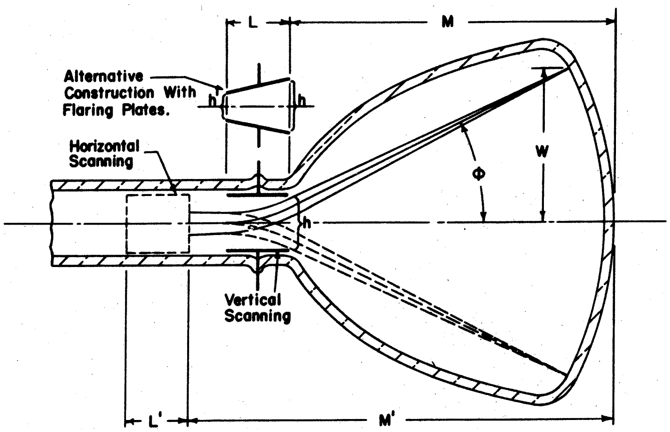
Since the glass wall of a tube is no obstacle to the magnetic field, magnetostatic lenses are usually placed outside of the tube, surrounding the tube neck between the first lens (which of necessity is electrostatic) and the scanning system. Electrostatic lenses, on the other hand, must be built inside the tube. The external location of the magnetostatic lens allows a simplification of the tube structure and permits control of the positioning and centering of the lens. However, it is necessary to supply electrical power to the lens. Focusing can be affected by changing the current through the solenoid. It is possible to use a permanent magnet for the magnetic field, but this eliminates the convenient adjustment of the focus by means of a current control. The focus must then be adjusted by controlling the beam voltage. A small range of focus adjustment is also possible by changing the position of the lens between object and image. A hybrid magnetostatic lens having part of the field supplied by a current and part supplied by a permanent magnet can also be used.

Deflection of the Beam for Scanning

Deflection by an Electric Field. Up to this point we have discussed the formation of the electron beam and the focus of this beam to a small spot on the fluorescent screen. We shall now consider how this beam is to be deflected, to produce the scanning action by which the television image is built up on the screen. This deflection is generally applied to the beam after it has left the second lens. If the deflection occurs within the second lens, the effects of aberrations on the electron beam within this lens are increased.

If the electron beam is made to pass at right angles through a uniform electric field, such as exists between parallel condenser plates, the electrons are acted on by a deflecting force whose effect is shown in Fig. 10. If we assume that the field is uniform between the plates, and ends abruptly at the edges, that is, if we ignore the effects of the fringing field which actually exists, we find that the deflection can be expressed by the simple equation shown. The electrons are acted on by a uniform force in the direction of the electric field and travel in a parabola, just as does a projectile traveling without friction in the earth's graviational field. After leaving the edge of the electric field, the electron beam continues in a straight line to the fluorescent screen. It is seen that the tangent of the angle of deflection is proportional to E', which is the voltage applied to the deflecting plates, proportional to the length L of these plates, inversely proportional to E the voltage (speed) of the entering cathode-ray beam, and inversely proportional to h the separation of the plates.

The maximum angle to which the beam may be deflected is limited by the separation of the plates. If a line is drawn through the straight portion of the deflected beam it will intersect the undeflected beam at a point which is midway between the ends of the plate. Thus as the angle of maximum deflection is increased, the plate length must be disinished, making the deflection system less sensitive.



E = Voltage of Electron Beam

E' = Voltage Difference Between Deflecting Plates

With Parallel Plates:

$$\tan\Phi = \frac{L}{2h}\frac{E'}{E} \quad \text{Also} \quad W \approx \frac{1}{2h}\left(LM+\frac{L^2}{2}\right)\frac{E'}{E}$$

With Flaring Plates:

$$W \approx \frac{1}{2}\left[\frac{h'L^2}{(h-h')^2}\left(\frac{h}{h'}\log\frac{h}{h'}-\frac{h}{h'}+1\right)+\frac{LM}{(h-h')}\log\frac{h}{h'}\right]\left[\frac{E'}{E}\right]$$

Fig. 10 - Deflection of the electron beam by means of an electric field

If the approximation is made that the tangent of the angle of deflection is equal to the angle itself in radians, the deflection of the spot on the screen can be expressed in terms of the distance between the fluorescent screen and the deflection plates as shown.

An increase in the total deflection obtainable with a given potential difference on the deflection plates can be obtained by flaring the deflecting plates as shown. When the plates are brought closer together at the edges where the beam enters the field, the field intensity and therefore the deflection effect is increased. This separation h' is limited by the beam diameter. The lower equation in Fig. 10 shows the expression for the deflection of the beam in terms of the separation of the entrance and exit edges of the plates. This equation reduces to the simpler form when h' equals h. The flared-plate construction is almost universally used because of the increase in efficiency which is obtained.

The electric field between the deflecting plates is distorted if other conductors are brought near it. For this reason it is necessary to separate the vertical and horizontal deflecting systems longitudinally as shown.

Deflection by a Magnetic Field

An alternative method of deflecting the electron beam in the picture tube makes use of a magnetic field.

If a uniform magnetic field acts in a direction normal to that of the electron beam, the electrons will be constrained to move in a curved path by the force which this field exerts on them. If there is no electric field present, the speed of the electrons remains constant, and the uniform magnetic field will exert a uniform force on each electron, this force acting always at right angles to the direction of motion. The path of the electron will thus be a circle which lies in a plane normal to the magnetic field. The radius of this circle will be such that the centrifugal force of its motion will balance the constant magnetic deflecting force. Thus

$$\frac{mv^2}{r} = B\,e\,v$$

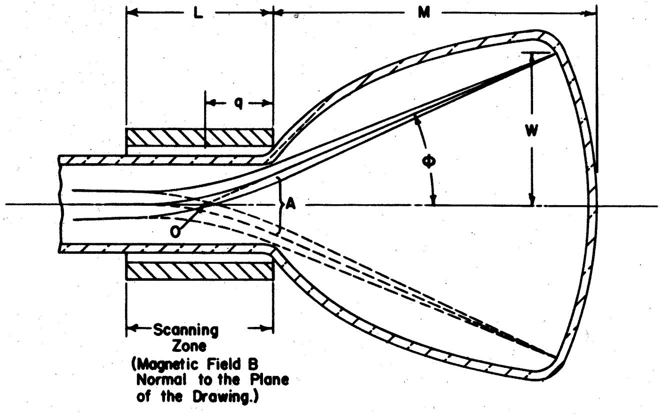
which gives

$$r = \frac{m}{e}\,\frac{v}{B}\ .$$

Figure 11 illustrates this deflecting action of the magnetic field. A uniform magnetic field extending over a length L acts in a direction normal to the plane of the drawing. This field is assumed to drop abruptly at the end boundaries. The bowing out or fringing of the field which occurs at the ends of a real field is here ignored, as it was in the discussion of the electric deflection field. Under these conditions, the electrons begin to move in a circular path as soon as they enter the magnetic field. When the electrons leave the field they continue in a straight line. The sine of the angle of deflection of the beam is proportional to the magnetic field strength and to the length of the field, but inversely proportional to the square root of the beam voltage (velocity). The sine of the angle of deflection is also proportional to the square root of $\frac{e}{m}$ so that an ion would be deflected only a fraction of a percent as much as an electron by such a field.

The maximum angle to which the beam may be deflected by a given length of scanning field is limited by the effective size of the tube neck diameter. The center of scanning O is near the center of the scanning coil for small

angles of deflection, but moves farther to the right of the center as the scanning angle increases. The ratio of the scanning-zone length to the diameter of the



With Uniform Field Over Scanning Zone:

$$\sin\Phi = \frac{BL}{\sqrt{2E}}\sqrt{\frac{e}{m}} \qquad \sin\Phi = 0.30\frac{BL}{\sqrt{E}} \qquad W \approx 0.30\frac{B}{\sqrt{E}}\left(\frac{L^2}{2} + LM\right)$$

Fig. 11 - Deflection of the electron beam by means of a magnetic field

angles of deflection, but moves farther to the right of the center as the scanning angle increases. The ratio of the scanning-zone length to the diameter of the neck must be decreased as the maximum deflection angle is made larger. In the extreme, as the deflection angle approaches 90°, the length *L* approaches half the effective internal neck diameter *A*. Thus as the maximum angle of deflection is increased, not only must the maximum field strength in the deflecting field be increased, but a shorter deflecting coil must also be used.

Apparatus for Producing Magnetic Deflecting Fields

The production of a uniform magnetic field over a well-defined zone is not as simple as is the production of a uniform electric field. The magnetic deflecting field is produced by electric solenoids, which are referred to as scanning coils. These are placed with windings on opposite sides of the neck of the tube, producing a magnetic field at right angles to the tube axis. The magnetic field distribution depends upon the arrangement of windings in the scanning coils. Some of the deflecting coil shapes which have been used are shown in Fig. 12. The computation of the magnetic-field distribution produced by various scanning coils would be quite simple, if the coils were extremely long in comparison to their width so that the magnetic field produced by the end turns could be ignored. Actually the effect of the end turns is appreciable and becomes more important when the coil is made shorter.

If we ignore the end turns, or in other words if we consider the field in the center of a very long scanning coil, it is possible to get a perfectly uniform field within the cylindrical volume between the coil pair. It can be shown that this will be the case when the turns distribution in the coil is such that the ampere-turns per unit length measured in the direction of the magnetic field, is constant. The distributed type of scanning coil, as shown in the cross-sectional view in Fig. 12 follows this principle. The view of the complete scanning coil of this type shows the end turns bent-up at right angles to the longitudinal conductors. This is done to minimize the effect of the magnetic field from these end turns in the scanning region.

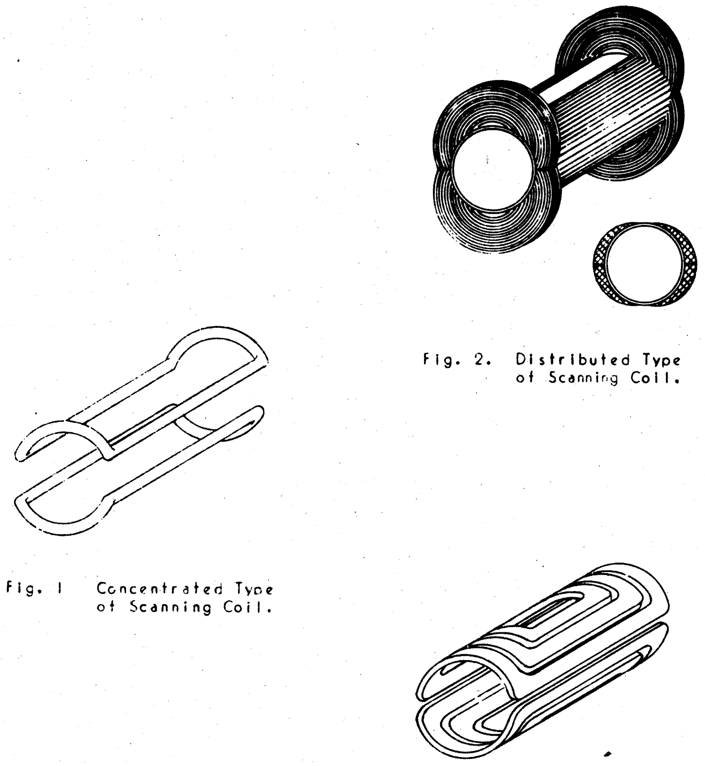


Fig. 2. Distributed Type of Scanning Coil.

Fig. 1 Concentrated Type of Scanning Coil.

Fig. 12 - Various shapes which are used for magnetic deflection or scanning coils

Since two separate scanning actions are needed, it is necessary to have two sets of scanning coils, and these are of course turned at right angles to each other. These coils are commonly arranged to have the same center of scanning, one pair of coils enclosing the other pair. This superposition is possible, since the magnetic field produced by one coil pair is not affected by the presence of the material of the other coil. The flux return path of a coil pair is of course in the surrounding space. By covering the outside of the set of coils with an iron sheath, a greater portion of the total energy of the whole magnetic field is confined to the scanning zone. This increases the efficiency of the scanning coil and also shields other equipment from the stray fields. The set of two pairs of scanning coils enclosed in the iron sheath is known as a "scanning yoke". It is of course possible to use separate scanning centers in magnetic deflection systems. When this is done, one scanning coil is usually of the type already described, placed on the neck of the tube as far forward as the bulb permits. The other scanning coil, usually the lower- or field-frequency coil, is wound on a U-shaped core of iron. The ends of this U form pole pieces for the deflecting field, and are placed still farther forward against the flaring part of the bulb. The field shape is controlled by the shape of these pole pieces.

The Four Principal Types of Picture Tubes

We have seen that the electron beam may be focused by means of either an electrostatic or a magnetostatic electron lens, and that this beam may be deflected for scanning by means of either an electric or magnetic field. The four possible combinations which may be made of these focusing and scanning means lead to four principal types of picture tubes which are shown schematically in Fig. 13. Each of these types has been used successfully for the reception of television images, although the type which uses magnetostatic focus and electric scanning has not found general favor with television set makers. Each principal type of picture tube has its own circuit requirements and the choice of any particular type is closely connected with the circuit design. The use of magnetic focusing and scanning fields allows the necessary parts to be placed outside of the tube, thus simplifying the tube structure. The completely magnetic type has been widely used in Europe. The type with electrostatic focus and magnetic scanning and the completely electrostatic type seem to be favored in the United States.

There are, of course, still further possible variations of these four principal types, which may be regarded as hybrids. Thus a combination of electrostatic and magnetostatic lenses can be used for focusing and it is quite possible to use electric deflection for one scanning direction and magnetic deflection for the other. Such hybrids however, have not found favor for television tube use.

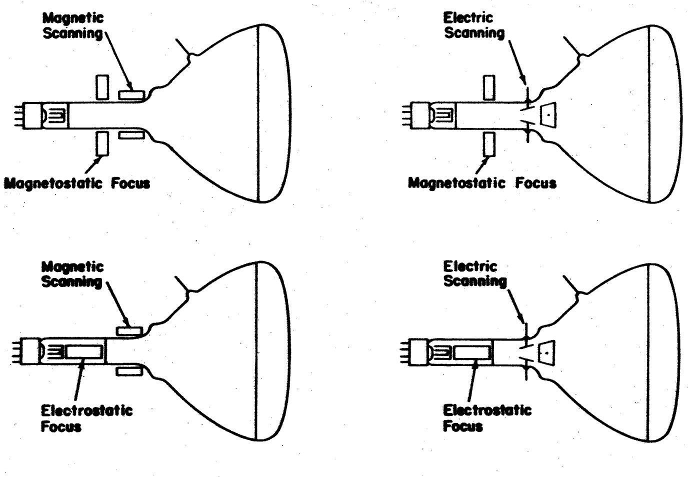
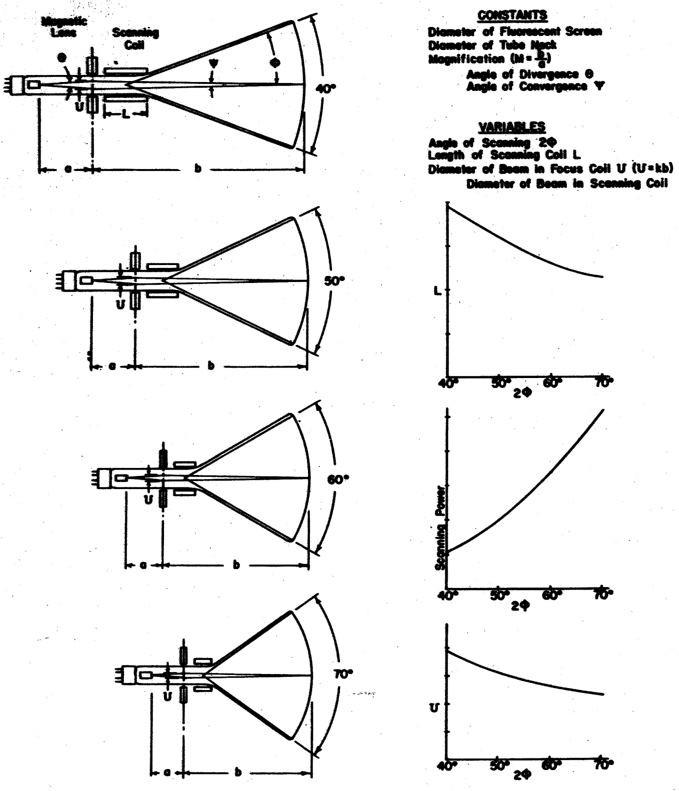


Fig. 13 - The four principal types of picture tubes

Wide-Angle Tubes

The angle through which the electron beam is deflected by a magnetic deflecting field depends on the length of the field and the magnetic field strength, as we have already noted. The nagle through which the beam must be deflected by the field in order to scan the full extent of the fluorescent screen, determines the maximum length of magnetic deflecting field which can be used with a given neck diameter of the picture tube. For this reason, tubes of wider angles require more than a proportional increase in the scanning field strength. A similar condition is true in the case of electric deflection. It was common practice a number of years ago to use maximum deflection angles of the order of 15 or 20°. Within the last few years there has been a tendency among television set makers to use tubes of greater deflection angles.

Fig. 14 shows how various parameters of the tube are influenced by this increase of angle. The examples shown here have magnetic focus and magnetic deflection, but similar relations would hold true for the other types. The parameters which are held constant are the diameter of the fluorescent screen, and the diameter of the tube neck. The beam voltage and the beam current are both kept constant,



MAGNETIC FOCUS-MAGNETIC DEFLECTION PICTURE TUBE SHOWING THE EFFECTS OF CHANGING THE TOTAL SCANNING ANGLE.

Fig. 14 - The effect of changing the maximum angle of deflection in a magnetically focused and scanned picture tube

thus the brightness of the fluorescent screen is the same in each case. Constant beam current means constant angle of divergence θ of the electron beam, since the first lens of the electron gun is kept constant. In order that the spot size should remain the same for each case, the magnetostatic lens is so positioned that the ratio of the electron-image distance b to the electron-object distance a remains constant.

The appearance of the tube is shown as the maximum deflection angle is made respectively 20, 25, 30 and 35°, that is, total angles of 40, 50, 60 and 70°.

The most obvious result of increasing the scanning angle is to shorten the overall length of the tube. This is very desirable for tubes which are mounted with the axis horizontal for direct viewing, since it allows the use of a cabinet of reasonable depth. Another result is that at the scanning angle of the tube is increased, the diameter U of the beam entering the magnetostatic lens is diminished. (This happens since a diminished when the scanning angle is increased, whereas the angle of divergence θ of the beam remains constant.) This relation is shown in the lower curve on the right. Because of this decrease in the size of the beam entering the lens, the lens will exhibit less spherical aberration. Also, the smaller diameter of the beam passing through the deflecting field region renders the beam less susceptible to distortion by the fringing field. The total path length of the beam is diminished as the maximum scanning angle is increased, so that space charge effects, or the effects of the mutual repulsion of the electrons in the beam, becomes smaller.

As we have already noted, the length of the scanning coil must be diminished as the scanning angle is increased; this relation is shown in the top curve at the right. The power which must be supplied to the deflection coil by the circuit to which it is connected increases as shown in the center curve at the right. It is of interest to note that the power in the magnetic deflecting field is wattless since it does not change the speed of the cathode-ray beam.

The development of more efficient scanning circuits has made it permissible to secure the advantages of increased scanning angles, since the necessary power in the magnetic deflecting circuits is available. Current values of scanning angles as measured by extreme deflections, that is across the diagonal of the picture, or the fluorescent screen diameter, are in the neighborhood of the 60° value shown.

If the deflected electron beam is to remain in focus on the fluorescent screen, the screen surface must be approximately spherical in shape with the center of curvature at the center of scanning. The tolerance within which the screen may deviate from such a surface depends on the angle of convergence of the beam, or the "depth of focus". It will be noticed that the curvature of the bulb increases with the increase in scanning angle if the center of curvature is kept at the center of scanning, as is done in the series of tubes illustrated. A compromise is usually made with this requirement by using a screen of less curvature in order to minimize the geometrical distortion of the picture on the curved surface. In the extreme case, the fluorescent screen is made flat.

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The Radio Club of America

The Radio Club of America was founded in 1909 by a group of amateurs who found themselves intensely interested in the science of the then infant "wireless" communication but able to develop themselves in this field of science only by the interchange of their personal experiences. To these amateurs the Club was a natural development. In the thirty years of its existence the Club has grown to a membership counted in the hundreds. Throughout its history the basic thesis has been the desire to offer personal experience and knowledge for the general good.

In a world so highly competitive as ours, too frequently sight is lost of the fact that it is as important to give as to receive. To the perpetuation of this philosophy, especially in the field of the technical details of radio communications, the Club has been dedicated.

It is not surprising, therefore, that during the past thirty years the membership of the Club has been made up of the outstanding figures in the field of radio invention and engineering. Nor is it surprising that now after thirty years, the founding members, having long since grown to man's estate, have taken important places in the field of radio communication in this country and abroad.

As in the beginning, the Club still distinguishes itself from other purely scientific and technical organizations by the freedom of interchange of ideas on the subject of its major technical interest, radio, and by the continuing effort to provide the social rallying point of those with this common interest.

Activities

Based on this general philosophy, the activities of the Club combine scientific education through the presentation and discussion of technical papers at its regular monthly meetings with the development of lasting friendships through the conduct and direction both of its technical discussions and purely social gatherings.

The monthly meetings are held at Columbia University usually on the second Thursday of the month. Guided inspection tours of the many important radio projects in and about the New York area supplement the regular meetings as these projects are developed. Joint meetings with other technical societies are included both in the New York area and in other cities as important opportunity for such meetings arise.

Of equal importance to the educational phases of the activities of the Club are the published Proceedings of The Radio Club of America.

For almost thirty years the Proceedings have served for the publication of all suitable papers and discussions presented at the meetings of the Club. Thus, they comprise a historical record of much that is basic and important to all radio communication. They provide, also, a current history of so wide a range of activities in the field of radio communications as to be a requisite portion of any complete radio library.

In addition to the social contacts provided by the gatherings at dinner preceding each monthly meeting and the opportunity for developing and cementing friendships which follow these meetings, an annual banquet, traditionally held late in October of each year, serves to bring together the large and varied membership of the Club.

The Armstrong Medal

From time to time members whose achievements entitle them to the distinction are awarded the Armstrong Medal. This is given in accordance with the conditions and requirements formulated in the establishment of this honor by the Board of Directors of the Club in 1935. These are: "The Radio Club this day hereby establishes an award to be known as the 'Armstrong Medal,' to be bestowed by the Board of Directors of The Radio Club of America upon any person within its membership who shall have made, in the opinion of the Board of Directors, and within the spirit of the Club, an important contribution to Radio Art and Science."

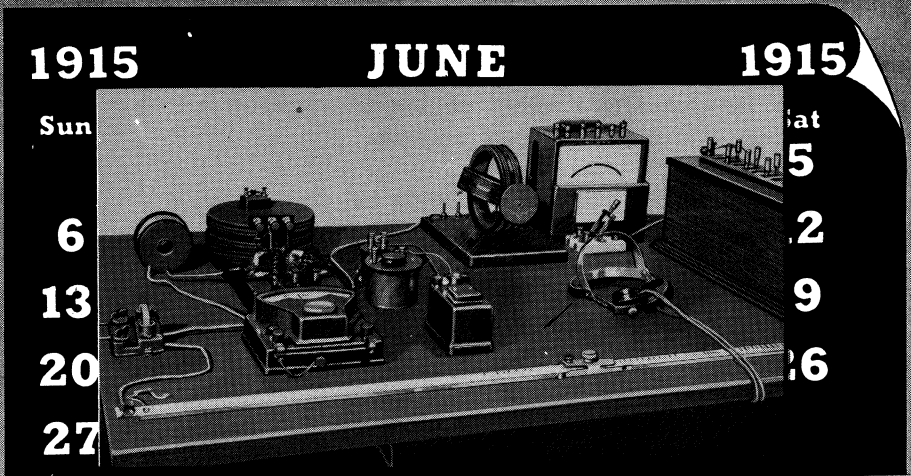
Membership

For all who share its aims, the Club can be of immense value. An application for membership can be obtained from the Club offices at 11 West 42nd Street, New York City, or from any of the Officers or Directors of the Club.

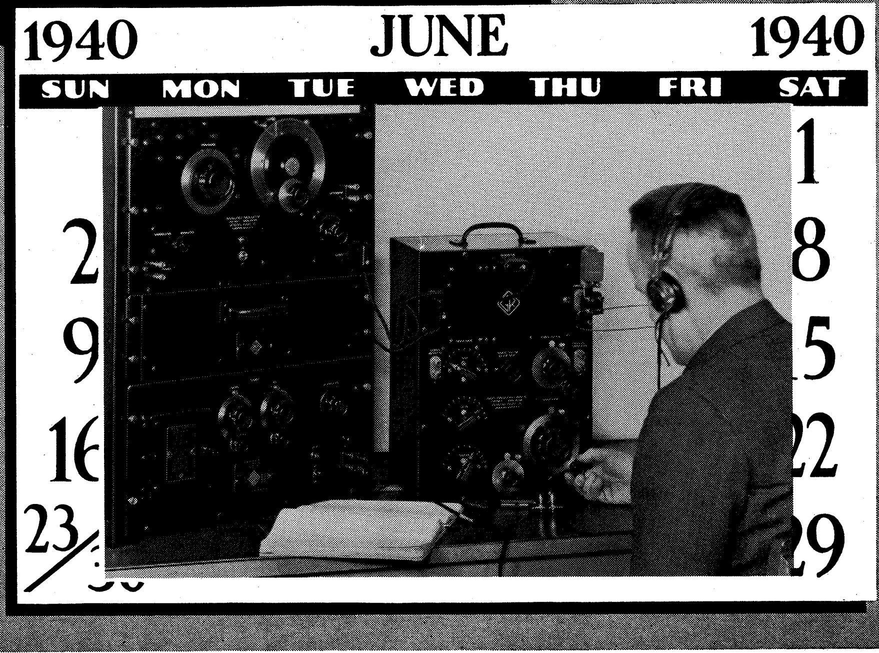
As defined by the Constitution of the Club, "A Member shall be a male or female person, not less than seventeen years of age, who has been interested in the investigation of the principles of radio communication and in radio operation, either in its commercial or amateur aspects, for a period of at least one year."

The entrace fee is $1.00; the annual Membership dues are $3.00 per year, except that for members elected after July first of any year the dues are $1.50 for that year. Additionally, it is required that the application for membership shall include the names of three Fellows or Members to whom the applicant is personally known.

25 YEARS AGO



1915 — *SKIN-EFFECT RESISTANCE MEASUREMENTS OF CONDUCTORS at radio frequencies up to 100,000 cycles per second. During 1915-1916 important research on this problem was undertaken at one of the leading educational institutions with the equipment shown — the latest then available. Included in the set-up are an Alexanderson r-f alternator delivering 2 kw at 100,000 cycles, a hot-wire ammeter, adjustable paper condenser, variable air condenser, fixed telephone condenser, single slide-wire, fixed and adjustable inductances, a portable galvanometer, a headset and 1,000-cycle commutator interrupter. These instruments represented the latest developments in the instrumentation field in 1915.*



1940 — *TWENTY-FIVE YEARS LATER the same measurements can be duplicated with this equipment at frequencies up to 1,000,000 cycles per second and with accuracies far in excess of those possible in 1915. Included are General Radio Type 516-C Radio Frequency Bridge, Type 684-A Modulated Oscillator, Type 619-E Heterodyne Detector, Type 663 Resistors and a headset. Before 1940 has gone by G-R instruments will probably be available to extend the frequency range of these measurements to 10,000,000 cycles!*

● GENERAL RADIO COMPANY celebrates its 25th Anniversary this month. The twenty-fifth year in the life of most companies or persons is not particularly significant; but in the radio and electronic measuring-apparatus field twenty-five years takes one practically back to the beginning. General Radio is probably the oldest company of its kind in the world. It has been continuously engaged (under the same name, with the same directing head and with the same managerial policy) in the design, manufacture and sale of precision electrical laboratory apparatus for use at communication frequencies. General Radio instruments have always kept abreast of the developments in the electronic art and its apparatus has in no small measure contributed to the ease with which further developments have been and are possible.

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