The Davisson Cathode Ray Television Tube Using Deflection Modulation

By A. G. JENSEN

The paper describes a cathode ray television receiving tube incorporating several unique features. The tube was designed and constructed by Dr. C. J. Davisson and was used in some of the early demonstrations of television transmission over the coaxial cable.

THE present day coaxial cable broad-band transmission system was developed during the early 1930's, and was originally conceived as a means for multi-channel telephone transmission. During the same period the rapidly developing television art was producing video signals requiring wider and wider frequency bands. It was very soon realized, therefore, that tbis coaxial system would also lend itself admirably to the transmission of such wide band television signals. The early development culminated in the installation of a coaxial cable route from New York to Philadelphia. This system was designed to provide 240 telephone channels or a single 800 kc television channel, and both types of transmission were successfully accomplished during a series of demonstrations in 1937.[1]

The scanning equipment used for producing the television signals for these demonstrations was developed under the direction of Dr. H. E. Ives at the Bell Telephone Laboratories. It was designed to scan standard 35 mm motion picture film and consisted of a six-foot steel disk rotating at 1440 rpm and having 240 lenses mounted around the peripbery. It thus produced a television signal of 240 lines and 24 frames per second, occupying a bandwidth of about 800 kilocycles.

From this same period came the well known work of Dr. Davisson in the field of electron diffraction.[2] This work had resulted also in important advances in electron optics and in the development of tbe sharply focussed, well defined electron beam. It was natural, tberefore, tbat Dr. Ives should discuss with Dr. Davisson the possibility of designing a cathode ray tube capable of adequately displaying a picture from the television signals specified above. The outcome of these discussions was that Dr. Davisson, with the close and able collaboration of C. J. Calbick, undertook to design and construct the tube described in the following pages. In this connection it should also be mentioned that the first experimental samples of the tube were built by G. E. Reitter, while the later engineering for limited production was carried out by H. W. Weinhart.

The disk scanner was a linear transmitter, since the amplitude of the signal was directly proportional to the film brightness. The fundamental requirement for a receiving tube was therefore as stated by Dr. Davisson in an early memorandum:

"If screen brightness is proportional to beam current, as for most screens it is, then beam current in the receiving tube should be proportional to signal voltage; the modulations of beam current by signal voltage should be linear. Failure to meet this requirement results in falsification of tone values in reproduction, and when departures from linearity are marked [it leads] to unsatisfactory pictures."

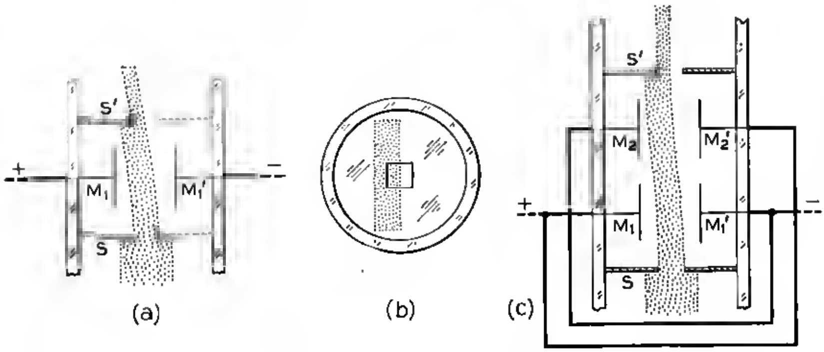

Fig. 1—Principle of deflection modulation.

It was this fundamental concept of a beam current directly proportional to input voltage, which led to the development of a tube employing deflection modulation. This is a type of modulation in which the modulating voltage causes the electron beam to be deflected across a defining aperture in such a manner that increasing modulating voltage will cause a larger area of the beam to pass through the aperture and thus increase the brightness of the screen proportionally to the modulating voltage. The principle of this type of modulation is illustrated in Fig. 1.

Figure 1(a) shows a narrow beam of electrons passing through the slit S (perpendicular to the plane of the paper) and arranged to form a sharp image of the slit in the plane of the square aperture S'. The relation of the slit image to the square aperture is shown in Fig. 1(b). A bias voltage is applied across the modulator plates M_1 and M_1' so that the slit image falls just off the square aperture for no signal voltage. As signal voltage is applied across the modulator plates the slit image will move across the aperture in such a manner that the cross-sectional area of the beam beyond the aperture is proportional to signal voltage (for small angles of deflection, such as used here).

Beyond the aperture S' the electron beam enters a projection lens system designed to project an enlarged electron image of S' onto the fluorescent screen of the tube. In order to avoid further modulation of the beam

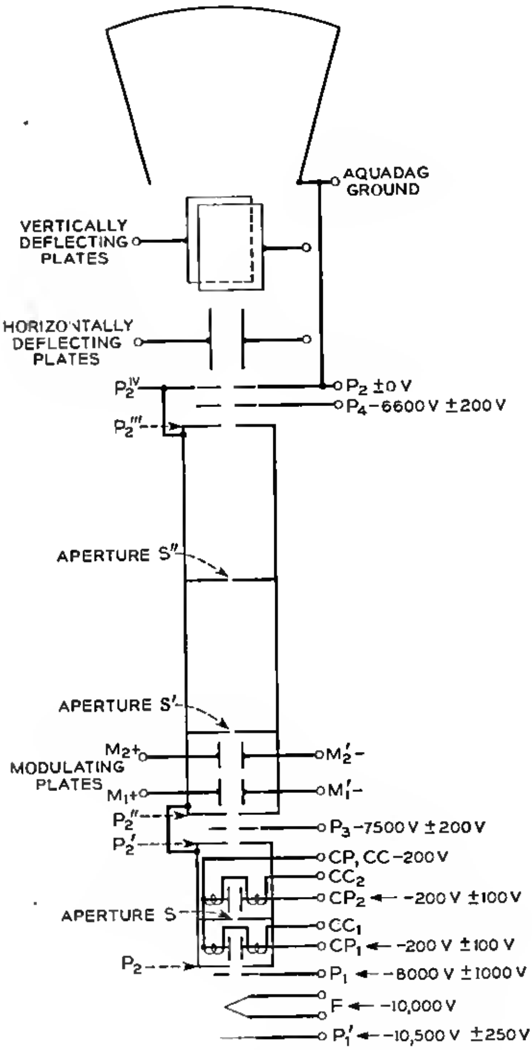

Fig. 2—Schematic diagram of electron optical system.

in the projection lens system it is essential that the beam be maintained parallel with the tube axis and not be deflected by modulation as in Fig. 1(b). To accomplish this a second pair of modulating plates M_2 and M_2'

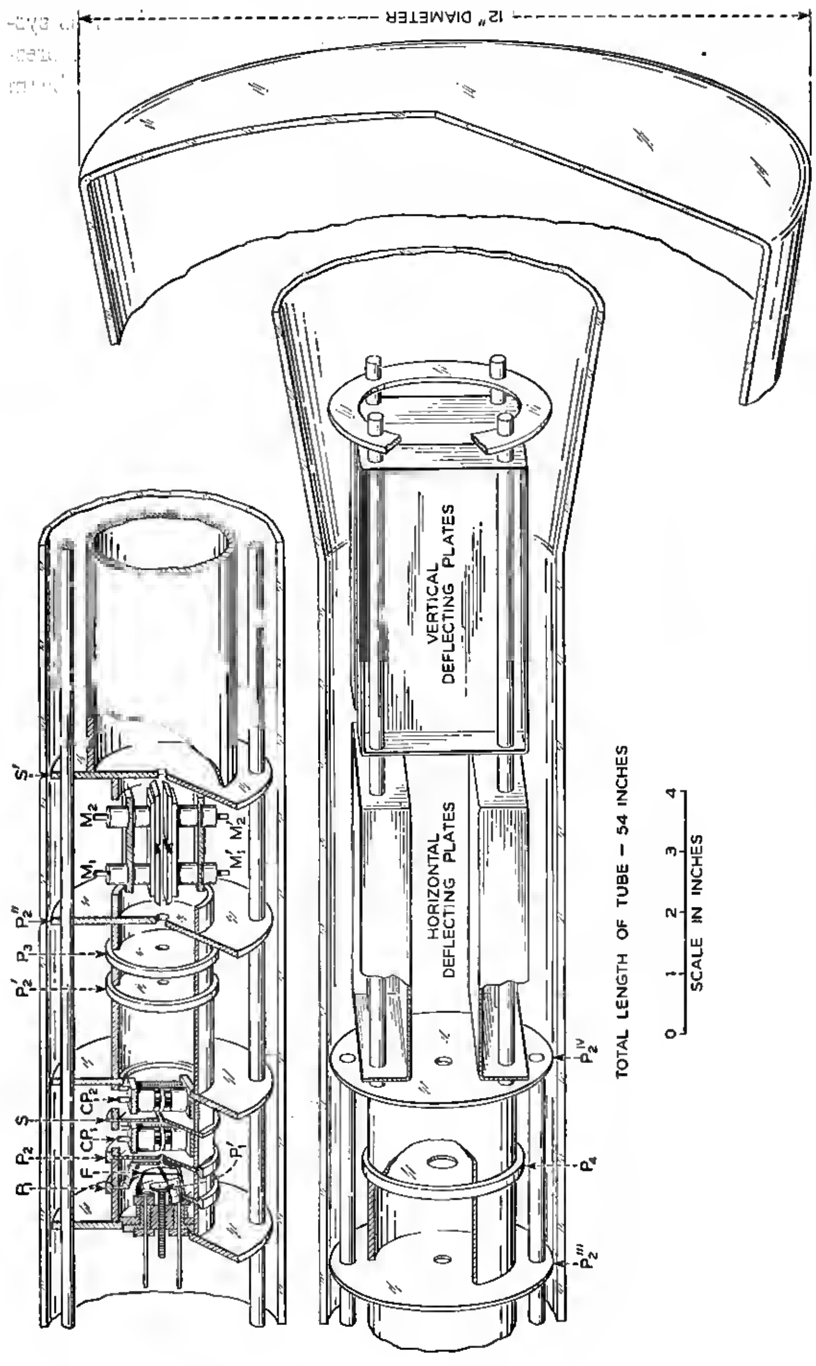

Fig. 3—Dimensional cross-section of electron optical system.

is added and cross connected to M_1 and M_1' as indicated in Fig. 1(c). Now when signal voltage is applied, the electron beam is displaced, rather than deflected, across the aperture S', and the portion of the beam entering the projection lens system is maintained in proper alignment with the tube axis.

The complete electron-optical system of the tube is indicated schematically in Fig. 2. A dimensional cross section of the tube is shown in Fig. 3,

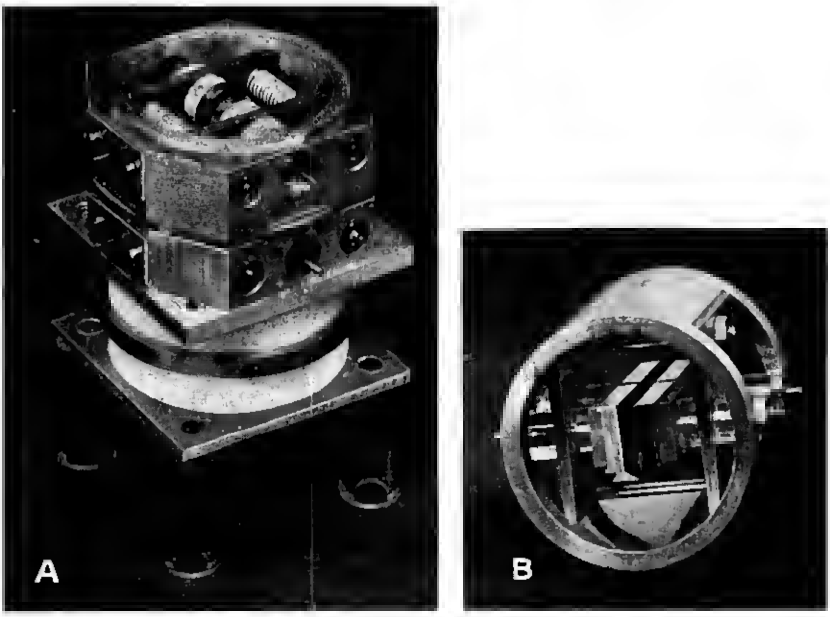

Fig. 4—Photograph of tube details.
(a). Photograph of collimating unit.
(b). Photograph of modulating unit.

while Figs. 4 and 5 show mechanical details of the assembly. Figure 6 shows the finished tube, held by Mr. Calbick.

Referring to Fig. 2*, the plates P_2, P_2', P_2'', P_2''' and P_2^{IV} are metallically connected together with separating metallic cylinders to form the structural "frame" of the entire electrode assembly. They are connected to the internal Aquadag coating and held at ground potential.

The backing plate P_1', filament F, and circular aperture plates P_1 and P_2 constitute the electron source and condensing lens system whose function

* This diagram actually shows the electrode voltages used in a later model for 441 line pictures. In the 240 line tube the anode voltage was 5000 volts.

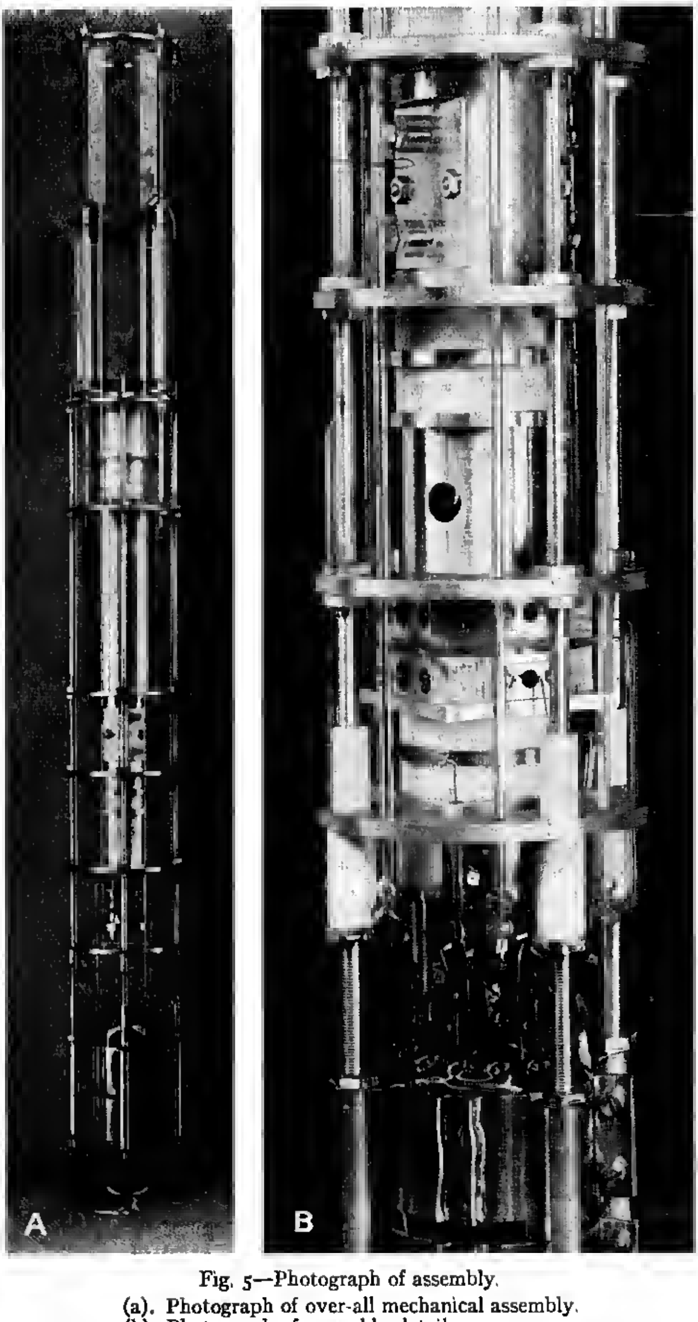

Fig. 5—Photograph of assembly.
(a). Photograph of over-all mechanical assembly.
(b). Photograph of assembly details.

is to produce an intense "focal spot" of electrons in the plane of the slit aperture S (Fig. 1).

The filament F is made of tungsten foil in the sbape of a cross (Fig. 3) and is fed by direct current with opposite ends of the cross connected together. This construction insures a nearly uniform temperature over the center area of the cross and also minimizes magnetic fields set up by the filament current, which would otherwise tend to disturb the electron optical symmetry. The filament resistance is approximately 1 ohm and the current 10 amperes. The high emission current density from a tungsten filament was expected to result in a more intense focal spot than would be obtainable with an oxide coated cathode. Also the large metallic structure inside the tube might tend to cause deactivation or poisoning of an oxide cathode.

If the mechanical alignment were perfect the "focal spot" of electrons would fall directly on the slit aperture S. Because of unavoidable small misalignments and particularly due to the fact that the filament cross is not perfectly flat, such perfect symmetry cannot be insured without some corrections. These corrections are supplied by a so-called collimating unit CP_1 ; CC_1. The unit consists of an electromagnet with insulated polepieces (Fig. 4), and by applying small correcting voltages and currents to the unit the "focal spot" is shifted until its most intense part falls on the center portion of the slit aperture S. A second identical collimating unit CP_2 ; CC_2 is mounted after the slit, in order to center the slit image on the square aperture S'.

The three circular aperture plates P_2' , P_2'' , and P_3 constitute the so-called modulator lens system and serve to form an electron image of the slit S on the square aperture S', with a magnification of 1:1. Accurate focussing is accomplished by adjusting the potential of the plate P_3 .

The function of the modulator plates M_1M_1' and M_2M_2' has already been described. The photograph in Fig. 4 shows the modulator plate assembly.

The set of three circular aperture plates P_2''', P_4 and P_2^{iv} comprise the projection lens system, which forms an electron image of the square aperture S' upon the fluorescent screen with a magnification of 5:1. Proper focussing is accomplished by adjusting the potential of plate P_4.

Two sets of coils, mounted in the lateral corners of the tube housing, were used to neutralize the earth's field. Each coil produces a field directed at an angle of 45° from the vertical and, by properly adjusting the coil current, it is possible to produce a practically uniform magnetic field, which was used to center the beam on the screen.

Because of the complicated mechanical assembly inside the tube there was originally some difficulty in properly de-gassing the tubes and maintaining vacuum. The earlier models were therefore continuously pumped,

Fig. 6—Photograph of finished tube.

and a tantalum filament manometer was used for checking pressure. Tbe tubes used during demonstrations were sealed off, but the manometer was retained as sbown in the pbotograph in Fig. 6. In this case the hot tantalum filament acted as a getter which successfully kept the pressure down to about 10^{-6} mm Hg.

The aperture S' was .006″ square. With a 5:1 magnification this resulted in a scanning line height on the screen corresponding to a 240 line picture of about 7 x 8 inches.

A stationary spot viewed on the screen showed a sharply defined rectangular cross-section of approximately uniform brightness. Adjusted for no

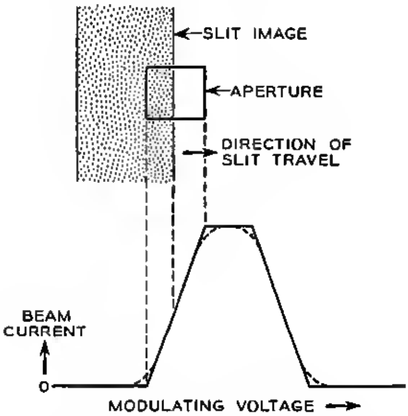

Fig. 7—Schematic diagram of modulation curve.

overlap this resulted in a flat field with only a faint indication of line structure. If the image of the slit S falling on the square aperture S' is perfectly focussed, with edges parallel to the sides of the aperture; if no stray electrons are present due to secondary emission or other causes, and if the electrons in the beam all have the same thermal emission energy, then the curve of beam current versus modulator voltage would be as shown in Fig. 7. The current is zero until the leading edge of the slit enters the aperture. The current then increases linearly until it reaches a maximum when the slit fills the aperture. If the slit is wider than the aperture the curve will have a flat top and will then decrease linearly as the trailing edge of the slit travels across the aperture.

The actual modulation curve did not show sharp corners, but was rounded both at top and bottom as indicated by the dotted lines in Fig. 7. The dispersion of thermal velocity of tbe electrons causes "chromatic" aberration of the condensing lens system (P_1 ; P_2) which therefore forms a "focal spot" of non-uniform density. Tbis in turn results in rounded corners of tbe modulation curve. Even so, the linear portion of the modulation curve corresponded to a beam current ratio of about 10:1.

As will be seen from the curve, the tube may be used equally well for either positive or negative modulation, but in the demonstrations positive modulation was employed.

An actual modulation curve for the tube later used for 441 line pictures is shown in Fig. 8. The dotted line indicates the modulation characteristic without any modification, while tbe solid curve shows the improvement

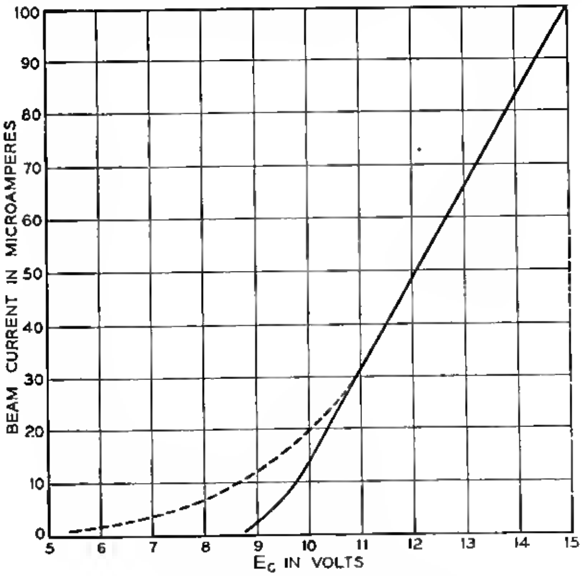

Fig. 8—Measured modulation curve.

near cut-off obtained by incorporating a non-linear circuit in the output stage of the video amplifier. With this circuit, linear modulation was obtained over a brightness range of nearly 100 to 1.

Due to the variable width of the scanning spot it is obvious that conventional aperture equalization is not applicable. The width of the rectangular spot changes from maximum at full brightness to zero or nearly zero in the deep shadows. In other words, the correct aperture equalization would be a function of brightness. Some theoretical computations indicated that the effective horizontal resolution, without any aperture equalization, might be well above the vertical resolution determined by 240 lines. That tbis was actually so was indicated by the fact that, by unbalancing the coaxial terminal equipment so as to allow a small amount of 2500 kc carrier leak to come through, the resulting vertical stripes were clearly visible, in spite of the fact that the highest frequency in the video signal was only about 800 kc.

For the reasons given above no aperture equalization was employed for the receiver; in fact, the excessive horizontal resolution was later on traded for higher brightness as mentioned below.

A slightly modified version of the Davisson tube was used later in the 1941 demonstrations of the transmission of 441 line, 30 frame television signals over the 2.7 megacycle coaxial cable from New York to Philadelphia.† In this later tube the anode voltage was raised to 10,000 volts instead of 5000 volts as used in the 1937 demonstrations. Furthermore, the square aperture S' was changed to a rectangular aperture with the horizontal side twice as long as the vertical. This alone of course doubled the highlight brightness obtainable, and in the 1941 demonstrations the received pictures had a highlight brightness of about 20 foot-lamberts, using an aperture size of .0036″ x .0072″.

Before concluding the description of the Davisson tube and its performance, one more item should be mentioned. It was found that the glass thickness of the tube's end wall gave rise to some halation due to internal reflection from the outer surface, and this in turn resulted in a somewhat degraded contrast range. A very much thicker glass wall would increase the diameter of the circle corresponding to total reflection to a point where the halation effect would be very much diluted and therefore negligible. The effect of such a thick wall was obtained in the following manner.[4] A plate glass disk was mounted between one and two inches in front of the tube fact and cemented to this by means of an airtight gasket. The intervening space was then filled with Nujol, which has approximately the same index of refraction as the glass. The resulting increase in contrast range was very noticeable.

It is interesting to note that at the time it was also proposed to add a small amount of dark dye to the Nujol in order to further decrease halation effects, and also to decrease the effect of ambient light. This is, of course, the same principle that is now widely employed in present day "dark glass" kinescopes.

Dr. Davisson designed this tube on the basis of his knowledge of electron optics. At no stage did he depart from a design which would allow him accurately to predict the performance. This accounts for the "thin" lenses used in the different focussing systems, for the small deflection angles em-

† The transmitting equipment for these demonstrations was a film scanner employing a Farnsworth image dissector and producing a 4 mc video signal. See reference[3].

ployed to insure sharp focus all over the screen, and for the extreme care with which the deflection plate system was made to avoid either "pin cushion" or "barrel" distortion. Apart from the rounded corners of the modulation curve, the entire system was indeed "calculable." It resulted in a very long tube (about 5 feet) and an unusually complex assembly of precision mechanical parts. It also resulted in an actual performance very close to the predicted performance and markedly superior to that of other television receiving tubes of the same period.

References

1. "Coaxial Cable System for Television Transmission," M. E. Strieby—*Bell Sys. Tech. Jl.*, Vol. 17, pp. 438–457, July 1938.
2. K. K. Darrow's article in this issue.
3. "Film Scanner for Use in Television Transmission Tests," A. G. Jensen—*I. R. E., Proc.*, Vol. 29, pp. 243–249, May 1941.
4. *U. S. Patent No.* 2,312,206, issued to C. J. Calbick.