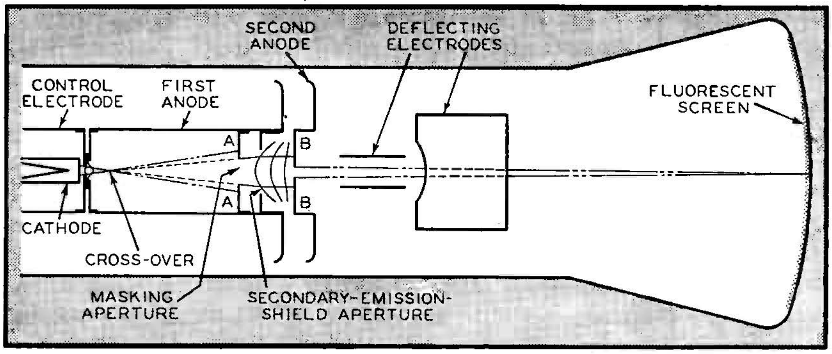

FIG. 1—A conventional cathode-ray tube electron gun, in which the first anode operates at a positive potential and contains a masking aperture which is shown at AA

Improved ELECTRON

Gun design involving zero current for first anode simplifies power-supply problem and gives sharper focus. The beam is also less subject to stray fields capable of causing variation in spot brightness. Several constructional advantages are inherent in the design

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CATHODE-RAY oscilloscope tubes that provide improved operating characteristics have recently been designed. The improvement is achieved by the use of a modified electron gun which requires no first-anode current and gives sharper focus.

Figure 1 is a conventional gun. The oxide-coated cathode provides a supply of electrons that pass through the control-electrode aperture. The first anode, which operates at positive potential, accelerates the electrons toward the gun axis and causes them to cross over at the point indicated. It is this cross-over, rather than the cathode surface, which is imaged on the fluorescent screen.

The cross-over size and intensity depend on the control-electrode bias voltage. The electrons travel through the first-anode cylinder in straight lines and at a uniform velocity until they reach the end of the cylinder. Near the end of the cylinder the electron-beam diameter is limited by a masking aperture shown at AA. The central section of the beam passes into the accelerating and focusing field between the end of the first anode and the second anode. This field constitutes another electron lens, often called the final focusing lens. Its strength, or focal length, is varied by varying the first-anode voltage.

The beam is usually limited in diameter again at the second-anode aperture, as indicated at BB. This procedure insures that the beam is small and well centered as it passes the deflecting electrodes. The deflecting electrodes are used to apply an electric field at right angles to the beam. This field bends the beam proportionately to the potential applied. The set of deflecting electrodes nearer the gun provides deflection at right angles to that of the other set. The beam converges to a focus, or second cross-over, at the fluorescent screen.

Desirable Characteristics

A gun approaching ideal performance for an electrostatic-deflection type of cathode-ray tube should have the following characteristics:

(1) A small, focused electron spot of high brilliance which exhibits only a small increase in size as it is deflected across the screen.
(2) The ability to operate at low final-anode voltage.
(3) High deflection sensitivity.
(4) Short overall length.
(5) Sensitive control of spot brightness.

A small brilliant spot can be achieved by operating the final anode at as high a voltage as possible, by making the gun long and the gun-to-screen distance short, by using a high-emission cathode, by forming the first cross-over at as high a voltage as possible, and by permitting a wide beam divergence angle.[1] On the other hand, to produce a small change of spot size with deflection, the beam should have a small diameter in the deflecting field; that is, the beam divergence angle should be small, and it should be deflected through only a small angle, thus requiring a long gun-to-screen distance.[2]

Deflection distortion occurs in electrostatic deflection cathode-ray tubes because the electric field which deflects the beam also accelerates one side of it more than the other. The side nearest the posi-

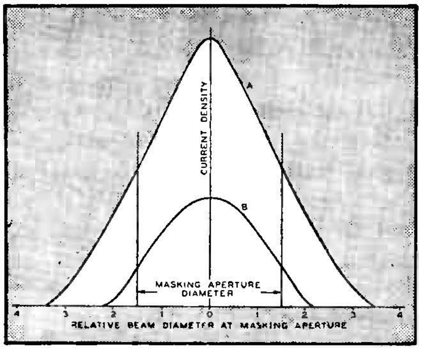

FIG. 2—Current density across beam before it enters masking aperture, for two different operating conditions

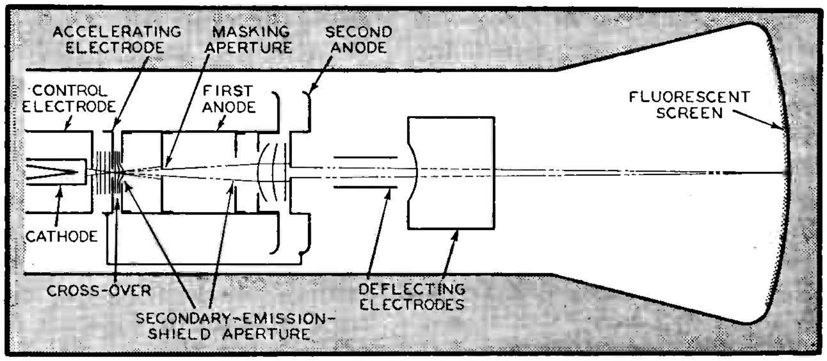

FIG. 3—Gun design introduced in 1937, in which the gun shown in Fig. 1 was modified by placing adjacent to the control electrode an accelerating electrode connected to the second anode

GUN for C-R TUBES

tive deflecting electrode is deflected less than the side nearest the negative deflecting electrode. The result is that the focused spot is elongated in the direction of deflection in proportion to the square of the deflection. This spot distortion is inversely proportional to the diameter of the beam in the deflecting region.

Operation at low final-anode voltage is desired because it results in a compact, low-cost, anode power supply and high deflection sensitivity. However, as the anode voltage is increased, the beam current rises as the 3/2 power of the voltage, the spot size decreases due to less space-charge effect, and the fluorescent screen becomes more efficient, giving the overall result that the spot brightness for a given spot size goes up somewhat faster than the square of the anode voltage. Thus, the anode voltage must be high enough to provide sufficient sharpness of focus and brilliance for the maximum required spot-displacement velocity. It generally cannot be less than 500 volts and may be as high as 15,000 volts.

It is to be noted that space charge increases spot size because of the mutual repulsion of the electrons in the beam.

High deflection sensitivity requires long, closely spaced deflecting electrodes and long gun-to-screen distance. These requirements tend to produce a spot of low brilliance.

Short overall length permits a design for small spot size but at the expense of deflection sensitivity and increased distortion with deflection angle.

Sensitive control of spot brightness, sometimes called small grid drive, requires that as large a portion of the current from the cathode as possible go to the screen. In the past, brightness control has usually been a semi-permanent manual adjustment. Sharper focus was secured at the expense of small grid drive. Now the brightness is often modulated at high frequency by an amplifier so that sensitivity is important.

Beam Considerations

The maximum deflection angle, the length of the deflecting electrodes, and the amount of distortion with deflection that can be tolerated determine the maximum permissible diameter of the beam at the end of the gun. Since even with this limitation the current in the beam should be as high as possible, it is an important gun-design consideration to make the current high without at the same time producing a large focused spot.

It is possible to generate a narrow enough beam to pass through the masking aperture without limiting, but usually a large beam is masked down to the desired size. Generation of a narrow beam without masking provides better utilization of the high-voltage current and sensitive control of the beam current but has the disadvantage of providing lower maximum current to the screen. The reason for this is that the beam is more intense at the core than at the edge and this core density rises rapidly with beam size.

The current density across the beam before it enters the masking aperture is shown graphically in curve A of Fig. 2. If the aperture diameter of the control electrode is reduced or the bias voltage of the control electrode is increased, or the accelerating-electrode aperture is moved farther away, the distribution becomes similar to curve B. The beam diameter is reduced but the total current is reduced much more.

By placing a masking aperture in the beam, usually in a region which is field-free, as shown at AA (Fig. 1), only the intense central core of the beam is passed through the gun to the deflecting electrodes. The beam is also usually masked in the second-anode aperture as shown at BB. The latter arrangement prevents the beam from striking the deflecting electrodes in case of misalignment. In addition, current masked at this electrode reduces the amount which has to be handled in the first-anode circuit.

By enlarging the control-electrode aperture diameter, it is possible to increase the current density at the center of the beam. This enlargement must not be carried very far because it increases the amount of masked current and the size of the cross-over. The latter, since it is imaged at the screen, produces a larger focused-spot size. However, as the control-electrode bias is increased, the control-electrode-aperture diameter is in effect decreased and, therefore, at lower currents a smaller spot size is obtained.

By proper design it is thus possible to have a small spot for fine detail as well as a brighter large spot for high-speed traces.

Modified Gun Design

Figure 3 shows a sectional view of a gun design introduced when the RCA-902 was announced in the autumn of 1937. The gun structure of Fig. 1 was modified by placing adjacent to the control electrode an accelerating electrode connected to the second anode. This arrangement overcame the interaction between focus and brightness control. It also permitted the electron cross-over to be formed at a higher voltage with the result, as developed in Langmuir's paper,[1] that a smaller focused spot was obtained at the screen.

Because high voltage was used on the accelerating electrode, its spacing to the control electrode could be made greater. The increased spacing offered two important advantages: first, a narrower beam was generated, and second, mechanical alignment of the apertures was not as critical. The latter resulted because the electrostatic fields acted to pull the beam through the centers of the apertures. Thus, the closer the spacing the farther the beam was bent away from the axis for a given amount of misalignment.

In Fig. 4 a gun construction is shown in which the accelerating electrode has been lengthened to carry a masking aperture and the first anode shortened to a disc which is used only for focusing. This structure is known as a zero-first-anode-current gun. It offers design possibilities of better focus and has the important circuit advantage of requiring no current from the focusing connection on the power-supply bleeder.

Since cathode-ray oscilloscope tubes require relatively small currents, it is cheaper and simpler to supply the first-anode circuit from a bleeder across the second anode supply than to provide a separate first-anode supply. However, if the first anode requires a current greater than that required by the second anode, which is now often the case, a large percent of the current from the supply must flow through the bleeder to furnish reasonably good voltage regulation in the first-anode circuit.

It so happens that poorer first-anode voltage regulation than second-anode voltage regulation can be tolerated because the first-anode voltage for optimum focus decreases slightly with increased values of beam current. Generally, however, enough current can not be used in the bleeder to provide the desired regulation. Moreover, the first-anode current varies too much from tube to tube to make such compensation entirely satisfactory. The result is that the focus has to be corrected even for fairly small changes in current.

On the other hand, with the zero-first-anode-current gun, the focus ratio of first-anode voltage to second-anode voltage is determined only by the bleeder tap instead of being influenced by first-anode current, and thus larger changes in beam current can be made without refocusing. In new equipment designs, it may be possible to decrease the bleeder current enough to use less filter capacitance than now required, but even without any decrease in bleeder current, there is still the advantage of less change in focus with beam-current change.

Constructional Advantages

From the viewpoint of tube construction, this gun offers several advantages. The longer accelerating-electrode cylinder is easier to support accurately. The beam is reduced to a small size before reaching the final focusing field. Because of this feature, badly aberrated rays from the edge of the focusing field are prevented from entering the second-anode aperture and thus causing stray current to the deflecting electrodes and the screen. The first anode can be made either as a cylinder or an apertured disc. By changing the length and diameter of the cylinder or the diameter of the aperture, it is possible to vary the focus voltage over a wide range. Therefore, it is easy to match focus-voltage specifications set by previous designs. There is also freedom from reverse currents due to secondary emission from low-voltage electrodes since they are not required to mask the beam. Consequently, aperture discs previously used in the first anode as electrostatic shields against secondary emission can be removed.

Other designs which are practical have been proposed.[3]

An application of a zero-voltage, zero-current focusing electrode to an electrostatic-focus electron microscope is also of interest.[4] In this case, fine adjustments of focus are made by moving the image surface.

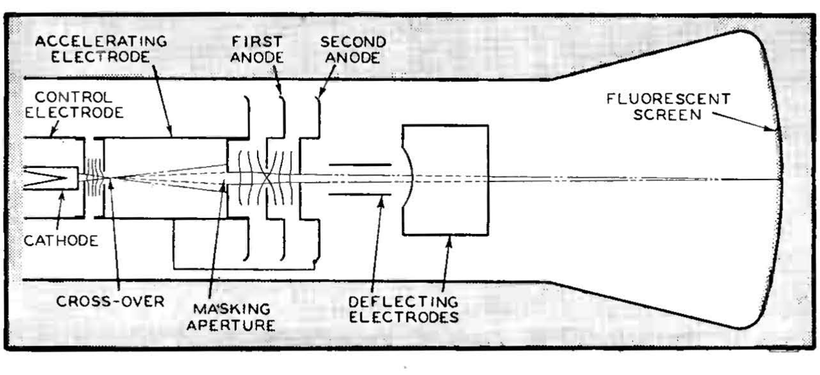

FIG. 4—Gun design based on zero first-anode current, in which the accelerating electrode has been lengthened to carry a masking aperture and the first anode shortened to a disc which is used for focusing

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