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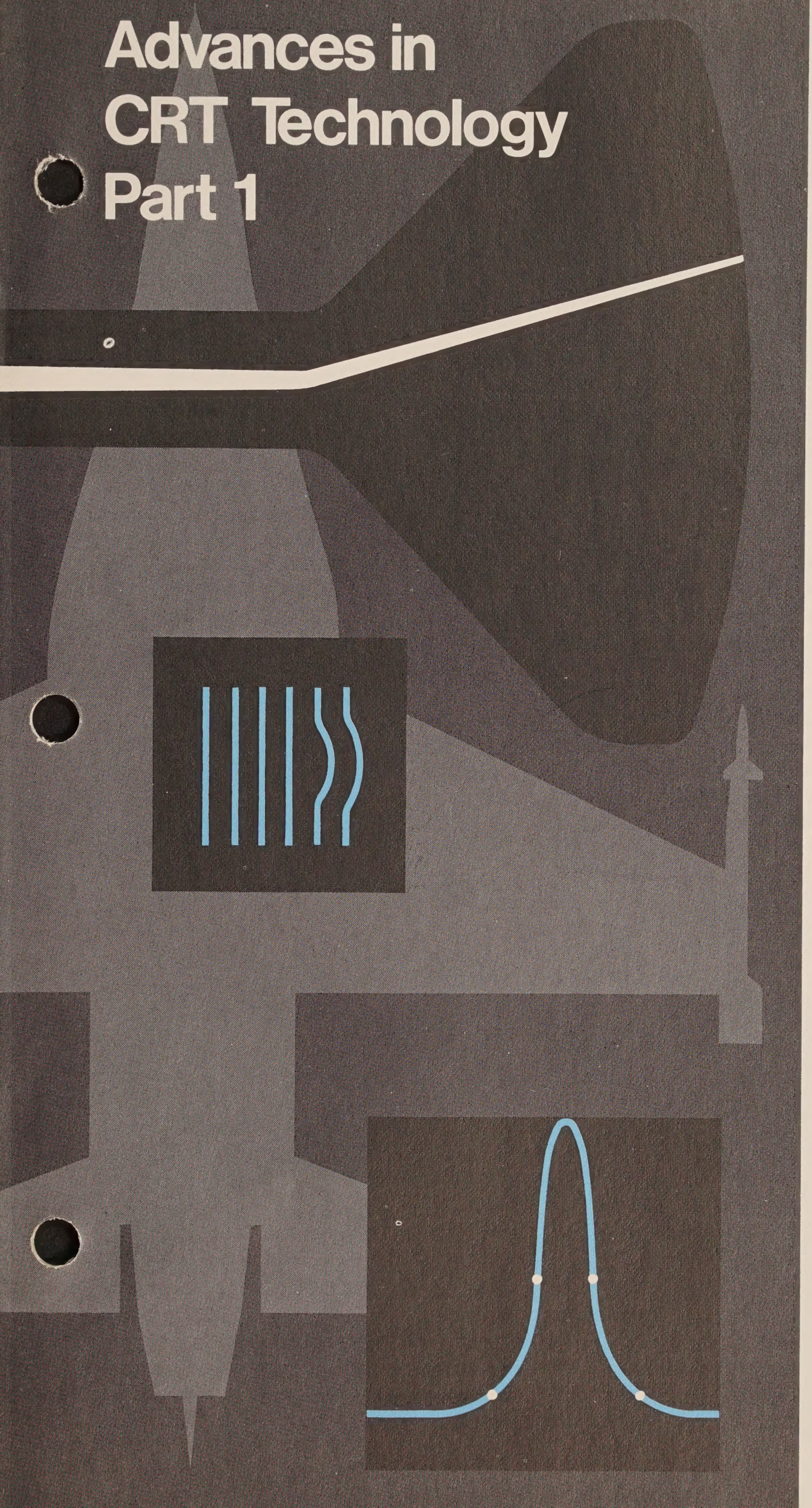
Advances in CRT Technology Part 1



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Tech-notes

This issue of *Tech-notes* is Part 1 of a two-part discussion that will cover the basic functions and structure of cathode-ray tubes as well as advances made in CRT technology in recent years.

The cathode-ray tube (CRT) is still the dominant electronic display device for higher-resolution applications, in spite of the fact that over the past 30 years many experts have predicted that it would be replaced with a flat panel display. The enduring dominance of the CRT is due to its continuing technical and economic superiority. Its technical superiority is based on many factors, some of which include high-phosphor luminous efficiency, simplicity of operation, ease of scanning and wide bandwidth. Furthermore, the CRT is versatile in that it can be used for stroke or raster address and is capable of presenting shades of gray or bi-stable displays. From an economic standpoint, the CRT offers the lowest cost per resolution element. There are, however, some disadvantages to the CRT: the CRT bulb is quite deep compared to the display area, the phosphor persistence is uncontrollable, and the spot has a gaussian-like intensity distribution which degrades the MTF (modulation transfer function) of the device. The device is not only non-linear, but may have limited life compared to other components.

Non-CRT approaches to display devices suffer from several shortcomings, especially low luminous efficiency. For example, Figure 1 indicates the screen current and phosphor luminance for a single CRT resolution element of a 500-line TV raster. Note that the screen current is represented by an idealized current pulse which is repeated every 33 ms and has a duration of .013 μs. The average brightness of the spot is about 100 fL, but the instantaneous peak brightness can be 800,000 fL or more. A comparison of the average luminous efficiencies of various display media is shown in Figure 2. Notice that other approaches possess only 10% or less of the luminous efficiency of the phosphor. Thus, these other approaches may require anywhere from 10 to 100 times the power to produce a display brightness comparable to that available in a CRT.

In summarizing the performance characteristics of the CRT, it may be noted that the CRT is clearly unchallenged as a high-resolution display device. The main reasons are its simplicity, high luminous efficiency and low cost.

This article reviews basic CRT operation and describes some new advancements in technology, with emphasis on their impact on monochrome CRT design and applications. The new areas of technology are:

(1) The direct-replacement laminar-flow gun, which provides increased resolution.

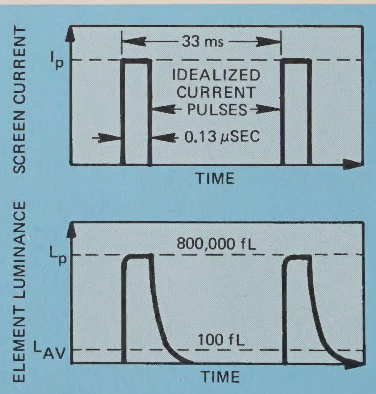


Figure 1. Current and luminance for a single CRT resolution element of a 500-line TV raster.

DISPLAY	PEAK LUMINANCE (fL)	MAXIMUM AVERAGE LUMINANCE @ 1/500 DUTY CYCLE (fL)	EFFICIENCY (LUMENS/WATT)
PLASMA	7500	10–15	0.5–1.0
AC EL	500	1– 5	5–10
DC EL	3000–5000	25–50	0.5–1.0
LED	5000	5–10	0.5
CATHODO-LUMINESCENT PHOSPHORS	≳100,000	≳500	100

Figure 2. Average luminance and luminous efficiency of display media.

(2) Improved phosphor, which exhibits higher brightness and longer life.

(3) The dispenser cathode, which makes possible a substantial increase in cathode life.

CRT Design and Operation

The cathode-ray tube design consists of four basic parts (References 2-4):

(1) The bulb, which provides the vacuum enclosure needed for utilization of the electron beam. The display area is also defined by the bulb.

(2) The electron gun, which supplies a modulatable, high-density, deflectable beam for excitation of the phosphor.

(3) The phosphor, which converts the kinetic energy of the electron beam into the luminous display.

(4) A means of deflection for locating the beam at the desired point on the screen.

The crossover electron gun has been the standard gun since the development of the CRT. The gun is illustrated in Figure 3. The laminar-flow gun (see Figure 4), References 5, 19, is physically and electrically interchangeable with its crossover counterpart. In the crossover gun, the electrons are converged to a crossover which is imaged on the viewing screen. In the case of the laminar-flow gun, the electrons emitted from the cathode tend to flow in streamline paths until they

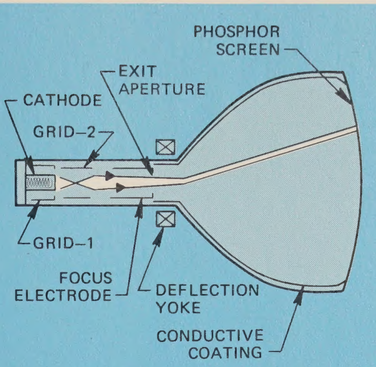


Figure 3. Schematic of crossover-gun CRT, electrostatic-focus, magnetic-deflection type.

are converged to a focus at the viewing screen. The operation of both types of tubes can be understood by dividing the CRT into various electron-optic regions (see Figure 5). These regions are described as follows:

(1) The Beam-Forming Region. In this region, the cathode is subjected to an intense electric field, which causes the emission of electrons. In addition, an electrode is provided that can modulate the emission of the electron beam.

(2) The Focusing Region. Either magnetic or electrostatic fields

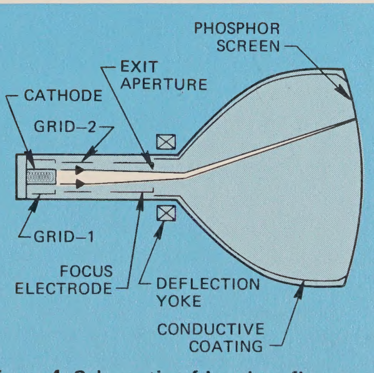


Figure 4. Schematic of Laminar-flow gun CRT, electrostatic-focus, magnetic-deflection type.

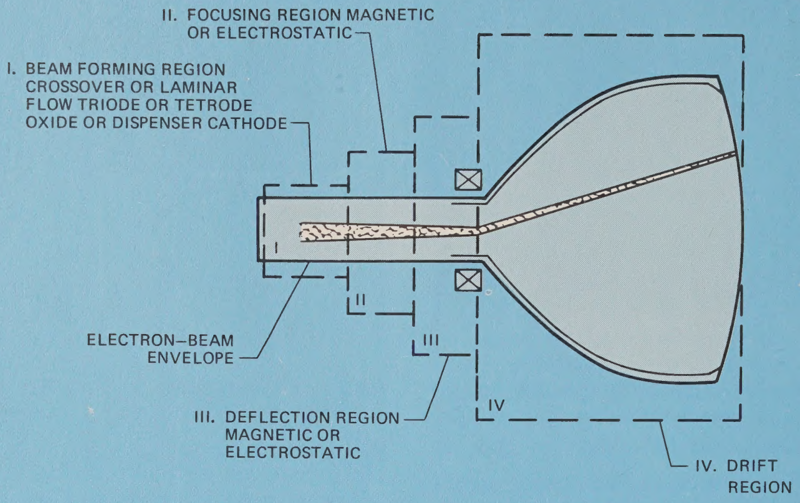


Figure 5. Electron-optic regions of the CRT.

are used to cause the electron beam to converge to the focus at the viewing screen.

(3) The Deflection Region. Either magnetic or electrostatic fields can be used to aim the beam to the desired position on the viewing screen.

(4) The Drift Region. This is a field-free region in which the neck region of the bulb expands funnel-like into the broad display portion of the tube.

Beam-Forming Region

The beam-forming region can utilize such design alternatives as oxide versus dispenser cathode, triode versus tetrode structure, and crossover versus laminar flow. The oxide cathode (see Figure 6), References 10, 20, consists of a thin coating (usually a few thousandths of an inch thick) of a barium-strontium oxide compound sprayed on the capped end of a small nickel cylinder. The function of the barium-strontium compound is to reduce the work function of the surface so that electron emission may be increased. The dispenser cathode has the barium compound dispersed throughout a porous tungsten structure. The cathode temperature is hotter than that of the oxide cathode, which causes the barium compound within the pores to diffuse to the surface, constantly renewing the emitting region.

In the triode structure shown in Figure 7, (Reference 7), the accelerating electrode is maintained at several kilovolts or more; it is frequently tied to the focus or screen potential, thereby eliminating the need for one power supply. The use of such a high potential on the accelerating electrode requires a large spacing to the G1 (grid 1) to avoid excessive values of voltage cut-off. With such large spacing, the resolution of the tube may be degraded at high currents due to space-charge induced blow-up in the beam between the G1 and the accelerating electrode.

The tetrode structure utilizes an additional electrode (the G2 electrode), which is operated at a fixed low voltage, usually ranging from 100 to 1000 volts. This low voltage makes the G1 cut-off value independent of changes in the focus or screen potentials. Furthermore, the G2-to-G1

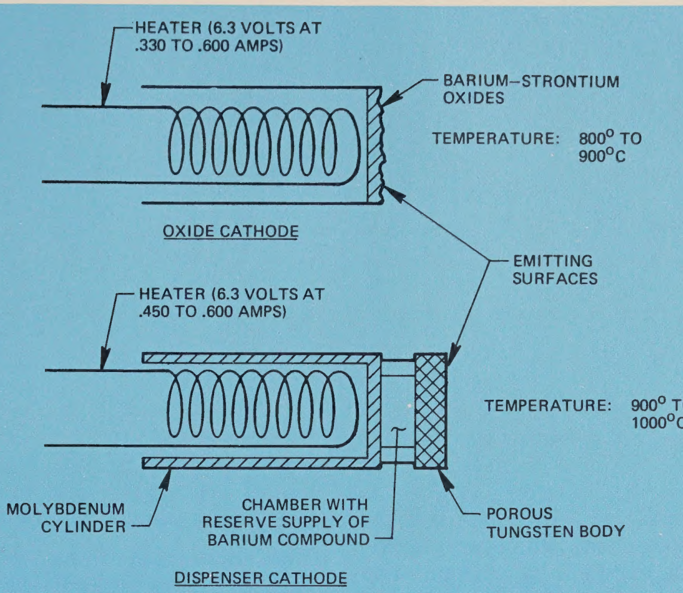


Figure 6. Comparison of oxide and dispenser cathode structures.

spacing can be small, reducing space charge effects in that region.

The crossover gun (see Figure 8), References 5, 19, is designed to achieve an intense source of electron emission by sharply curving the equipotential lines in front of the cathode. This causes the electrons to abruptly converge to a crossover immediately after leaving the cathode. The electric field is very high at the center of the cathode and falls off rapidly as radial distance increases. Consequently, the emission density is somewhat conical in shape, as shown in Figure 8. The space-charge repulsion forces rise sharply as the electron beam converges to a crossover.

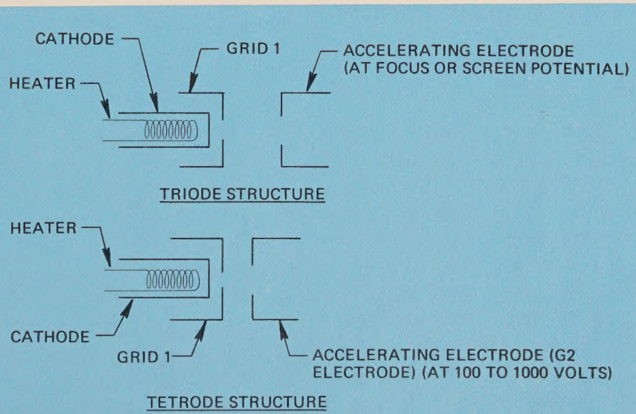


Figure 7. Comparison of triode and tetrode structures.

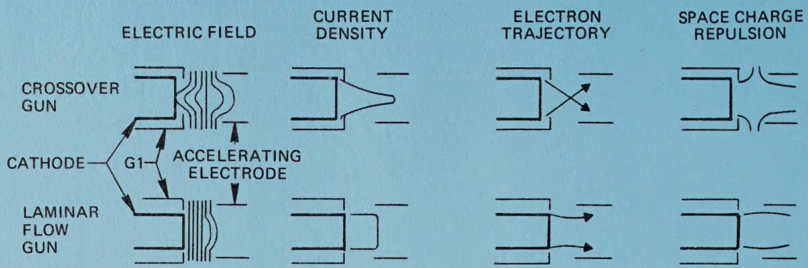


Figure 8. Comparison of crossover and Laminar-flow beam formation.

The laminar-flow gun is designed to achieve a uniform intense source of electron emission. Furthermore, it must do so at the same potentials as the crossover gun, for which it is the direct replacement. Both these requirements are satisfied by appropriately shaping the electrodes. In the ideal case, this uniform emission density has the form of a cylinder of emission from a circular cathode. Thus, ideally, the laminar-flow gun can provide three times the current from the same cathode area, since the volume of a cylinder is three times that of a cone. In practice, a factor of two is realistic. The uniform electric field causes the electrons to move in streamline-like paths, although there may be some beam compression immediately after leaving the cathode. Avoidance of the crossover minimizes space-charge repulsion forces in the beam in the vicinity of the cathode.

Focusing Region

The focusing region can utilize magnetic and electrostatic focusing design alternatives (see Figure 9), Reference 6. A magnetic field, essentially parallel to the longitudinal axis of the tube, is created by means of a coil around the neck of the tube. The divergent electron beam enters the field and the resulting forces impart a focusing action on the beam. Magnetic focusing provides the highest resolution.

An electrostatic lens, appropriately shaped by electrode design and applied voltages, converges the divergent electron beam to a focus at the screen. There are two types of electrostatic lenses: the bipotential focusing lens and the unipotential focusing lens.

The bipotential focus design (see Figure 10), Reference 6, is also known as the high-voltage focus gun because the focus potential is 15% to 25% of the viewing-screen potential. The lens is called bipotential because one element of the lens is formed between the focus electrode and the G2 electrode, which is at a lower potential, and the second element between the focus and an electrode at viewing-screen potential. The resolution attained with this type of gun cannot match that provided with magnetic focus, but it is 30% to 50% better than that which can be achieved with a unipotential focus gun. The focus electrode may draw current, depending on the size of the aperture used to trim the beam. The smaller the aperture, the larger the focus electrode current and, over a wide range, the smaller the spot size. The resolution is quite sensitive to changes in focus voltage.

The unipotential-focus gun design (see Figure 11), Reference 8, is also known as the low-voltage-focus gun or the Einzel gun. This is called the unipotential gun because the electrodes on both sides of the focus electrode are at the same potential, which is higher than that on the focus electrode. The focus voltage is usually 0

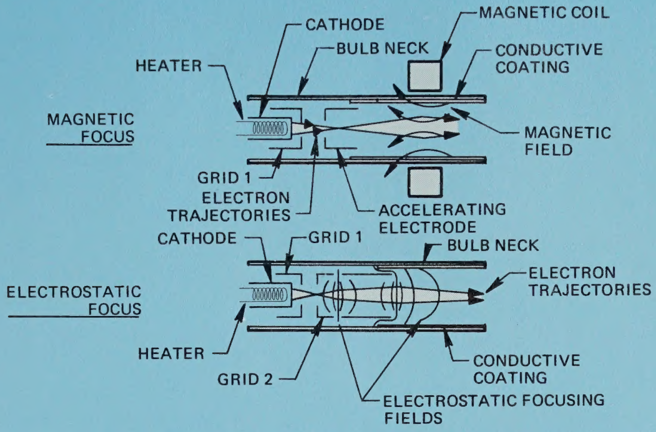


Figure 9. Comparison of electrostatic and magnetic focusing.

to 500 volts and frequently uses the same supply as the G2 electrode. Note that the electron lens here is different from that of the bipotential gun in that it is a saddle-type lens formed by injecting the potential lines from the focus electrode between those provided by the unipotential electrodes. Consequently, this lens has severe abberations which degrade the resolution. Aperturing the beam improves the resolution, but at the expense of grid drive. The advantages of the unipotential gun are that the focus electrode draws negligible current and the resolution is insensitive to moderate changes in the focus voltage. Electron guns of comparable length and diameter, operating at the same screen potential, are assumed in comparing their performance.

Deflection Methods

In magnetic deflection (see Figure 12), Reference 17, two pairs of coils are used, one coil from each pair being located on the opposite side of the neck. The magnetic fields are at right angles to each other to provide horizontal and vertical deflection of the

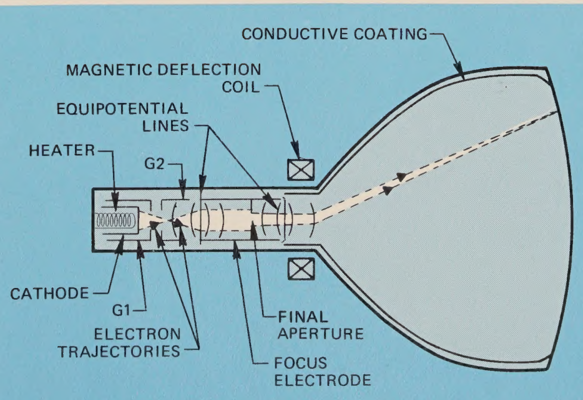


Figure 10. Bipotential electrostatic-focus gun.

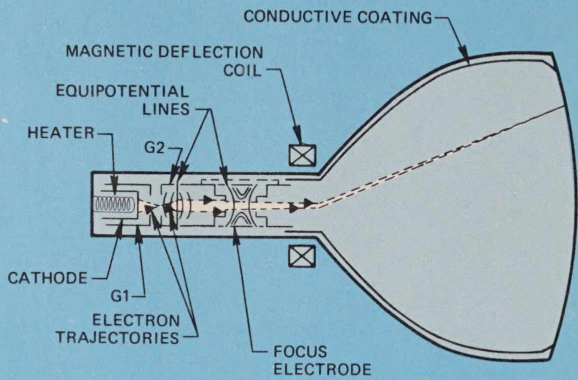
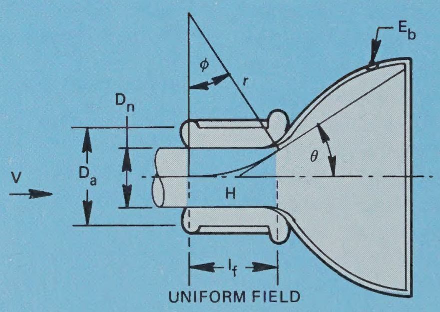


Figure 11. Unipotential electrostatic-focus gun.

electron beam. By adjustment of the current in the coils, the force acting on the electron beam can be controlled to deflect the beam to any desired point on the screen. The deflection amplitude is directly proportional



TERMS:

H = UNIFORM MAGNETIC FIELD = ni/D_a
n = NUMBER OF TURNS OF ONE PAIR OF COILS
i = DEFLECTION CURRENT
D_a = INSIDE DIAMETER OF THE YOKE CORE
V = VELOCITY OF THE ELECTRON = $\sqrt{2E_b e/m}$
E_b = BEAM ACCELERATION IN KILOVOLTS (ANODE VOLTAGE)
e = UNIT CHARGE OF AN ELECTRON
e/m = CHARGE-TO-MASS RATIO OF ELECTRON OR ION TO BE DEFLECTED
l_f = LENGTH OF FIELD H
θ = DEFLECTION ANGLE
r = RADIUS OF CURVED ELECTRON PATH WITHIN FIELD H
D_n = INSIDE DIAMETER OF YOKE COILS
L = YOKE INDUCTANCE

$$\text{SIN}\,\theta = i(\sqrt{L})\left(\frac{1}{\sqrt{E_b}}\right)\left(\sqrt{l_f\left(\frac{1}{D_a D_n}\right)\left(\frac{e}{2m}\right)}\right) \times \text{CONSTANT}$$

*CONSTANT = 1.26×10^{-8} HENRY WITH DIMENSIONS IN CENTIMETERS

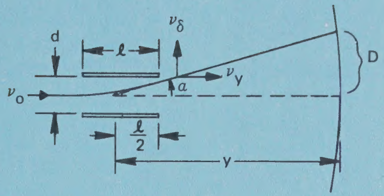
Figure 12. Magnetic deflection.

to the coil current and inversely proportional to the square root of the screen potential.

Electrostatic deflection (see Figure 13), Reference 12, utilizes two sets of metal plates set at right angles to each other to provide horizontal and vertical deflection when a difference in potential is applied between the two plates in each pair. The deflection amplitude is inversely proportional to the screen potential.

A summary of focus-deflection combinations is shown in Figure 14. Electrostatic deflection provides the highest deflection speeds available, but only moderate resolution. It is normally used in combination with electrostatic focus. Magnetic deflection provides slower deflection speeds and exhibits moderate resolution when used with electrostatic focus; this combination is the most widely used. Magnetically-deflected, magnetically-focused tubes provide the highest resolution.

The May/June 1979 issue of *Tech-notes* will continue the discussion of CRT technology. CRT limitations, and CRT performance using advanced technology will be covered.



$$D = \frac{Ly\,V}{2d\,E_b}$$

WHERE,

V = DEFLECTION VOLTAGE

E_b = SCREEN VOLTAGE

Figure 13. Electrostatic deflection.

References

1. van Raalte, J. A. "Matrix TV Displays: Systems and Circuit Problems," *Proceedings of SID*, 17, No. 1, p. 9, (1976).
2. Moss, Hillary. "The Electron Gun of the Cathode Ray Tube — Part I," *Journal of the British Institution of Radio Engineers*, 5, pp. 10-22, (Jan.-Feb. 1945).
3. Moss, Hillary. "The Electron Gun of the Cathode Ray Tube — Part II," *Journal of the British Institution of Radio Engineers*, 6, pp. 99-128, (June, 1946).
4. Moss, Hillary. "Engineering Methods in the Design of the Cathode Ray Tube," *Journal of the British Institution of Radio Engineers*, 5, pp. 204-223, (Oct.-Dec. 1945).
5. Lehrer, Norman H. "Application of the Laminarflo Gun to Cathode

DEFLECTION	FOCUS	CHARCTERISTICS	APPLICATION	VERTICAL RESOLUTION TV LINES @ 0.5 MTF
ELECTROSTATIC	ELECTROSTATIC	HIGH SPEED MODERATE RESOLUTION	SCOPE TUBES	450 TO 500
MAGNETIC	ELECTROSTATIC	MODERATE TO HIGH RESOLUTION	TV, COMPUTER TERMINAL TUBES WIDELY USED	700 TO 900
MAGNETIC	MAGNETIC	HIGHEST RESOLUTION	PROJECTION RECORDING TUBES	1600 TO 2000
ELECTROSTATIC	MAGNETIC	———————	NOT GENERALLY EMPLOYED	

Figure 14. Focus-deflection combinations.

Ray Tubes," *SID Journal*, pp. 7-11, (March/April, 1974).

6. Maloff, I. G. and D. W. Epstein. *Electron Optics in Television*, pp. 100-123, 163-165, McGraw-Hill Book Company, New York and London, (1938).
7. Parr, G. and O. H. Davie. *The Cathode Ray Tube and Its Applications*, pp. 23-26, Chapman and Hall Ltd., London, (1959).
8. Cosslett, V. E. *Introduction to Electron Optics*, pp. 68-71, 128-129, 142-162, Clarendon Press, Oxford, (1946).
9. Moss, Hillary. "On the Limit Theory of Circular Electron Beams," *Proceedings of the Fourth Symposium on Electron Beam Technology*, March, (1962), Sponsored by Alloyd Electronics Corp., 35 Cambridge Parkway, Cambridge 42, Massachusetts.
10. Zalm, P. and A. J. A. van Stratum. "Osmium Dispenser Cathodes," *Philips Technical Review*, 27, No. 3/4, pp. 69-75, (1966).
11. Sears, F. W. *Principles of Physics III — Optics*, pp. 68-70, Addison-Wesley Press, Inc., Cambridge 42, Massachusetts, (1948).
12. Millman, J. and S. Seely. *Electronics*, pp. 63-86, McGraw-Hill Book Company, Inc., New York and London, (1941).
13. Pfahnl, A. "Aging of Electronic Phosphors in Cathode Ray Tubes," pp. 204-208. *Advances in Electron Tube Techniques*, (Sept. 1960).
14. Spangenberg, K. R. *Vacuum Tubes*, p. 392, McGraw-Hill Book Company, Inc., New York and London, (1948).
15. RCA Phosphor Publication TPM-1508B.
16. Larach, S. and A. E. Hardy. "Some Aspects of Cathodoluminescent Phosphors and Screens," *Proceedings of SID*, 16, No. 1, pp. 20-29, (1975).
17. "Cathode Ray Tube Displays," *Vol. 12 Radiation Lab Series*, McGraw-Hill Book Company, Inc., New York, (1948).
18. Seats, P. "Fundamentals of Cathode Ray Tubes," *Digest of Technical Papers of the 1976 International Symposium of the SID*, pp. 172-173.
19. Silzars, A. and D. J. Bates. U. S. Patent No. 3,740,607 — Laminar Flow Electron Gun and Method.
20. Wagener, P. S. *The Oxide Coated Cathode*, Vol. I and II, Chapman and Hall Ltd., London, (1951).
21. Langmuir, D. B. "Theoretical Limitations of Cathode Ray Tubes," *Proceedings I. R. E.*, 25, p. 977, (August, 1937).

Author:

Norman H. Lehrer

Norman H. Lehrer is presently employed as Staff Scientist, Stewart Division, by the Watkins-Johnson Company. He joined Watkins-Johnson Company almost nine years ago and shortly thereafter founded the Cathode-Ray Tube product line. He has been primarily responsible for the development and application of the laminar-flow gun to cathode-ray tubes. Prior to joining Watkins-Johnson Company he was president of Electro-Vision Industries, Inc. and manager of the Image Sensing and Display Department of the Hughes Research Laboratories.

While at Hughes, Mr. Lehrer was awarded the L. A. Hyland Patent Award in 1968 for recognition as one of the 12 initial outstanding inventors at the Hughes Aircraft Company. This award was based on his invention, promotion and development of the multimode storage tube, which is widely used in the western world's military aircraft. The Society for Information Display awarded him in 1974 its most prestigious award, the Frances Rice Darne Memorial Award, for "pioneering advancement of the display storage tube and continuing contributions to display technology."

Mr. Lehrer received his Master of Science Degree in Physics from New York University, and his Bachelor of Science Degree in Physics from the College of the City of New York. He holds several patents and has given many presentations on display devices.

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