Practical Tubes for Bright Radar Displays

[9] *Boot, H. A. H., S. A. Self* and *R. B. R. Shersby-Harvie:* Containment of a Fully-Ionized Plasma by Radio-Frequency Fields. J. Electronics & Control Vol. 4 (1958),No. 5, p. 434...453.

[10] *Tuck, J. A.:* Review of Controlled Thermonuclear Research at Los Alamos. 2nd UN Conf. on the Peaceful Uses of Atomic Energy, Geneva 1958. Vol. 32, Pap. P/1860, p 3.

[11] *Ellis, R. A., L. P. Goldberg* and *J. F. Gorman:* Loss of Charged Particles in a Stellarator During Ohmic Heating. Phys. of Fluids Vol. 3(1960), No. 3, p. 468...473.

[12] *Weibel, E. S.:* Confinement of a Plasma Column by Radiation Pressure. The Plasma in a Magnetic Field. Standford, Calif.: 1958. p. 60...76.

[13] *Knechtli, R. C.* and *D. G. Dow:* Contribution of R-F Fields to the Containment of Dense Plasmas. Hughes Res. Lab. Rep. No. 137, 1960. (Available from Author on request).

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Practical Tubes for Bright Radar Displays

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1. Introduction

Radar has become an integral part of present-day activities. In particular, modern travel requires means for control, navigation, and surveillance of transportation facilities under all weather conditions and at various speeds. From fishing boats to jet aircraft, the need for safe, dependable manoeuvers is of prime interest.

Radar displays, as developed during the last two decades, were mostly dim and required either viewing in darkened areas or elaborate shielding of the screens. Furthermore, dark-adaption of the human eye was necessary in many instances.

New methods for bright radar displays have been developed during the last several years, and commercial devices are now available which allow viewing under conditions of high ambient light levels. Two distinctly different systems approaches are available. The first approach is useful when radar information is to be displayed directly on a relatively small screen and without addition of other signals. In this case, display storage tubes are most useful. The second approach incorporates the use of scan-conversion storage tubes in connection with direct-view or projection-television display devices. Such a system provides maximum flexibility in allowing the processing and mixing of signals and the arrangement of multiple displays at desired locations and in a large variety of sizes.

This paper describes the two devices used in these systems, display storage tubes and scan-conversion storage tubes, and their characteristics.

2. Display Storage Tubes

Display storage tubes have three main features which give them an advantage over conventional cathode-ray tubes as display devices. First, they have a high display brightness, 2,500 foot-lamberts (0.9 sb)[1]) for some types, which makes possible displays of high contrast under conditions of high ambient lighting. Second, they are able to present a continuous display of information for many seconds after the electrical signal containing the input information has ceased. This storage feature, combined with controlled erasure, makes possible displays in which the brightness decay of displayed information may be varied to fit individual situations. Third, they are able to integrate repetitive signals in a modulated writing beam so that repetitive information may be distinguished from random noise.

These characteristics make display storage tubes useful for the presentation of radar information. Displays of radars with slow antenna rotation rates, and displays which must be viewed under conditions of high ambient illumination, such as in many aircraft cockpits or in airport control towers, may well take advantage of these features. Display storage tubes are also suited to a variety of other applications including transient studies, data transmission including halftones, and visual communications requiring steady, non-flickering, narrow-bandwidth transmission over telephone lines.

2.1. *Principles of operation*

The writing and viewing sections of the RCA-7448, which will be used as a model for a description of the operating principles of display storage tubes, are shown in Fig. 1. The writing section contains an electrostatically focused gun that produces an electron beam which is electrostatically deflected by two sets of deflecting electrodes. The viewing section contains an aluminized screen having high visual efficiency on the inside surface of a flat faceplate, a backplate capacitively coupled to a storage grid, and a viewing gun having five grids.

Viewing operation

The viewing gun provides a low-velocity electron stream which continuously floods the electrodes (grid 5, storage grid, and backplate) controlling the storage function and the brightness of the display. A display having high brightness is possible because the very efficient phosphor is excited continuously rather than intermittently, as in conventional cathode-ray tubes, by the high-current viewing beam.

Grid 3 consists of a band of conductive coating positioned on the bulb-wall interior, as shown in Fig. 1. This figure also shows the location of grid 4, which consists of a metal cylinder. Grids 3 and 4 collimate the paths of the electrons in the stream before they reach grid 5. Collimation is required so that the lowvelocity electrons will approach the storage grid in paths perpendicular to the plane of the storage grid. This normal approach of the electrons to every point on the storage grid together with their uniform velocity, makes possible uniform control of the electrons by the storage grid.

[1]) 1 foot-lambert is the brightness of a surface emitting (or reflecting) 1 lumen(lm)/ft^2. 1 lambert = 1 lumen(lm)/cm^2 = $1/\pi$ stilb (sb).

Grid 5 consists of a fine metal mesh which serves to accelerate electrons in the beam and to collect viewing-beam electrons turned back near the storage grid when its potential is negative. The storage grid consists of a very thin deposit of material having excellent insulating properties and covering the gun side of the backplate, which is a fine metallic mesh. The deposit leaves the size of the openings in the mesh essentially unchanged.

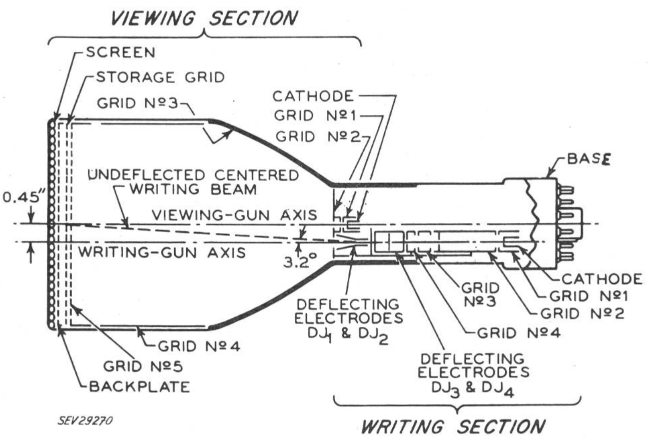

Fig. 1
Schematic Diagram of 7448 Display Storage Tube

The storage grid serves to control the viewing beam so that the stored information can be displayed on the phosphor screen. If the storage-grid potential is made sufficiently negative with respect to the viewing-gun cathode, electrons in the viewing beam are turned back as they approach the storage grid and are collected by grid 5. Under this condition, the viewing beam is cut off.

When the storage grid is at the same potential as the viewing-gun cathode, electrons in the viewing beam approach sufficiently near the plane of the storage grid to be attracted by the viewing-screen field, which penetrates the openings in the storage grid. Under the influence of this field, most of the viewing-beam electrons which have passed through grid 5 are accelerated through the storage-grid and backplate openings to the phosphor screen and cause it to fluoresce brightly over its entire area.

At values of storage-grid potential between those which produce viewing-beam cutoff and those which produce saturation brightness, the number of electrons which penetrate the storage-grid openings, and hence the amount of light emitted by the screen, is a function of the storage-grid potential, as shown in Fig. 2 for the 7448 display storage tube.

Within the range of storage-grid potentials considered thus far, no viewing-beam electrons are attracted to the surface of the storage grid. Hence, in the absence of deliberate writing, leakage through the insulating material, or spurious charging such as might be caused by positive-ion bombardment, a charge pattern once established on the storage grid should remain indefinitely. If, however, the storage grid is made positive with respect to the viewing-gun cathode, viewing-beam electrons are attracted to the surface of the storage grid and land on it. If the electrons which land do not have sufficient energy to produce a secondary-electron emission ratio in excess of unity, a net flow of current into the storage grid will result. Because the storage grid is conductively isolated from the metallic backplate, the storage grid is free to charge negatively under the influence of this current.

This negative-charging phenomenon provides a mechanism by which an undesired charge pattern on the storage grid can be removed, i. e., erased. For example, let it be assumed that the entire storage grid has been charged to zero potential with respect to the cathode of the viewing gun by the writing beam (the cathode of the viewing gun is usually taken as a ground reference), and that the backplate is suddenly shifted from its «dc» potential level of 2 V to a positive potential of 10 V. Because of the very close capacitive coupling between the backplate and the storage grid, the storage grid rises from its initial potential of 0 V to a potential of 8 V. Viewing-beam electrons are now able to land on the storage grid and negative charging of the storage grid takes place, as explained above. Charging continues until the storage-grid potential is re-established at 0 V. When this condition occurs, viewing-beam electrons can no longer land on the storage grid. Now, if the backplate potential is returned to its initial value of 2 V, the storage-grid potential drops correspondingly to − 8 V. This negative voltage, as may be seen by referring to Fig. 2, essentially cuts off the viewing beam of a typical 7448 display storage tube and thus erases any charge pattern on the storage grid.

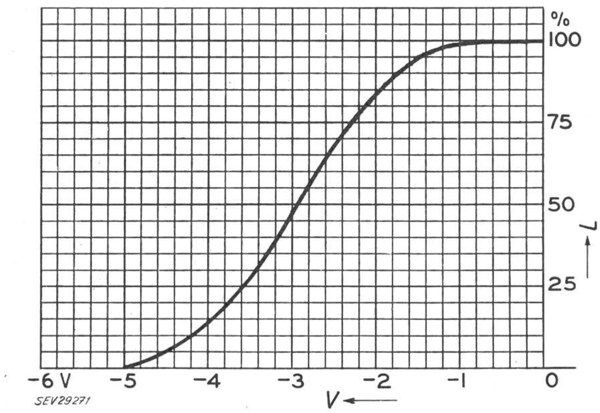

Fig. 2
Light Emitted by Screen as a Function of Storage-Grid Potential
Writing section: normal operation
L Relative brightness in % of satured brightness;
V Storage-grid voltage¹)
Viewing section

Heater voltage: 6.3 V	Grid No. 4 voltage } Adjusted for best collimation
Screen voltage¹) = 10k V	Grid No. 3 voltage } Adjusted for best collimation
Backplate voltage¹) = 2 V	Grid No. 1 voltage } Adjusted for best collimation
Grid No. 5 voltage¹) = 150 V	Grid No. 2 voltage¹) = 125 V

¹) Referred to cathode of viewing gun

Writing operation

The writing gun is similar to that used in electrostatically focused and electrostatically deflected oscillograph tubes, and produces a well-defined focused beam. This beam may be deflected and modulated in the same manner as for oscillograph tubes.

The writing-beam electrons landing on the storage grid have sufficient velocity to produce a secondary-electron emission ratio greater than unity. Thus, those elements on the storage grid scanned by the beam assume a less-negative charge wherever the writing beam strikes. By controlling the amplitude and duration of the writing-beam current, it is possible to establish on any storage element a positive charge. Consequently, a storage element can be charged to any potential intermediate between the storage-grid-cutoff voltage and zero voltage.

As mentioned previously, the potential of any storage element determines the number of viewing-beam electrons passing through the storage grid in the immediate vicinity of that element. When the potential is such as to allow passage of electrons, these electrons are accelerated and strike the screen directly opposite the storage element. As a result, they produce a luminescent spot.

Prasing operation

Because the potential of a storage element is not changed by the viewing operation, a charge pattern established on the storage grid by the writing gun produces a corresponding visible pattern on the screen which may be viewed for a period determined by a predetermined erasure rate when dynamic erasure is employed.

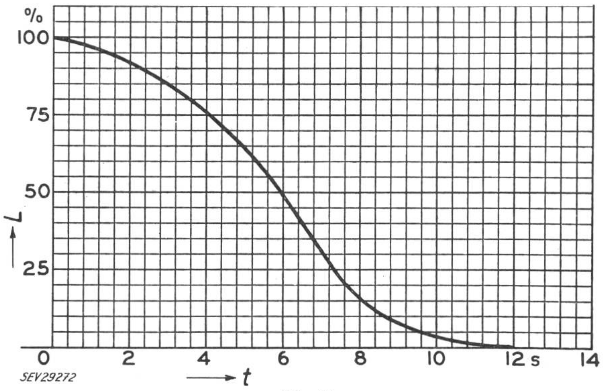

Fig. 3
Brightness-Decay Characteristic of 7448 Display Storage Tube
Erasing conditions
Pulse shape: rectangular
Pulse duration: 10 µs approx.
Pulse-repetition frequency: 200 pps
Pulse amplitude: 6...10 V
L Relative brightness in % of saturated brightness; *t* Time in seconds after writing to saturated brightness
For data on viewing section: refer to caption to Fig. 2

In most applications of the 7448 display storage tube, it is desirable for the writing to be followed by a gradual decay of stored information. This kind of performance is obtained by applying a continuous series of pulses to the backplate at a rate no lower than the phosphor flicker frequency. The technique of erasing by applying a series of pulses to the backplate is known as dynamic erasure. The amount of charge erased during each erasing pulse is dependent on the duration, amplitude, and shape of the pulse. These factors, together with the erasing-pulse repetition frequency, determine the observed rate of decay of stored information. The brightness-decay characteristic for a typical 7448 display storage tube erased dynamically is shown in Fig. 3. A photograph of the tube is shown in Fig. 4.

2.3. Developmental variations

The design concepts of the 7448 tube can also be used in the development of display storage tubes which are basically similar to the 7448 but are different in one or more particulars to suit specific applications.

7-Inch Tubes. One variation, size, is represented by the 7-inch display storage tubes. Although this tube retains the rugged envelope, standard base, and bulb connections of

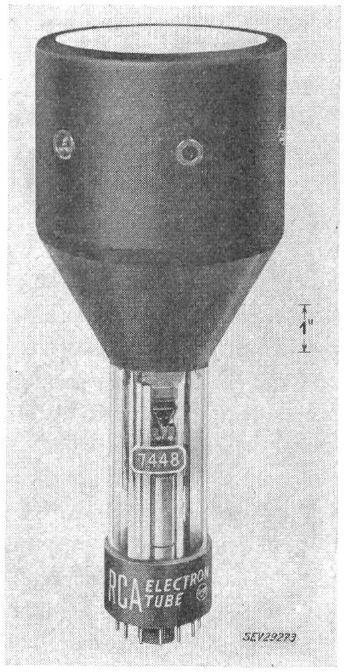

Fig. 4
7448 Display Storage Tube

the 7448, the size is increased to make possible a display area 5.2 inches in diameter, instead of the 3.8 inch-diameter display of the 7448 tube.

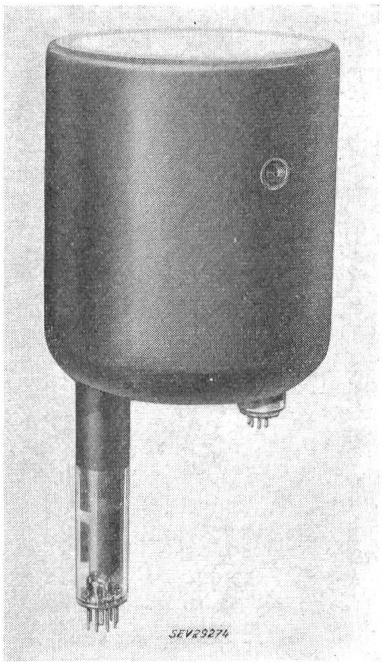

Fig. 5
C 73958 Display Storage Tube

Magnetic-Deflection Tubes. The 7448 tube employs electrostatic deflection of the writing gun. Occasionally, however, display storage tubes employing magnetic-deflection of the writing gun are required, so that low-voltage, high-current deflection supplies, possible with transistors, can be used. Accordingly, display storage tubes employing magnetic deflection have been designed, such as the developmental type RCA Dev. No. C73958 shown in Fig. 5. In this tube, the writing gun is mounted off the tube axis, which is convenient for offset PPI[2]) displays. If centered displays are required, they can be obtained by the use of permanent magnets.

Additional-Writing-Gun Tubes. Another variant of the basic 7448 design consists of the inclusion of an additional writing gun. With two writing guns, it is possible to write information from two separate sources simultaneously.

Selective-Erasing-Gun Tubes. Similarly, it is possible to include an electron gun whose function is the selective erasure of written information. Dynamic erasure, which has been discussed previously, effects the simultaneous and gradual erasure of the entire storage surface. Through the use of a selective erasing gun, it is possible to restrict erasure to discrete selected portions of the display area. The portions of the display area to be erased are selected by electrostatic deflection of the selective erase beam. In present tubes, erasing rates of about 2 in²/s (or 12 cm²/s) can be realized with an erasing line ¼ in (6 mm) wide. With some types of scanning, such as «B scan»[3]), it is feasible to deflect the selective-erasing gun in such a manner that old information is erased just prior to the writing of new information.

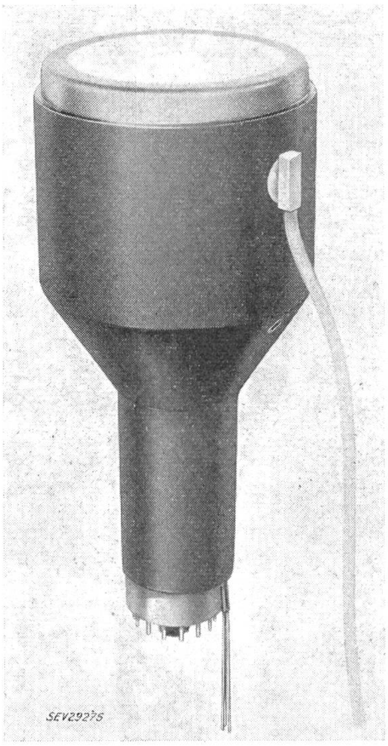

Fig. 6
C73999 Display Storage Tube

Shielded Display Storage Tubes. Display storage tubes are highly susceptible to display distortion caused by extraneous magnetic fields. DC magnetic fields in the vicinity of an operating display storage tube can cause display distortion by deflecting the viewing (flood) beam. A perceptible effect is noticeable with fields as low as 1 mGs (milligauss). DC magnetic fields in the vicinity of a non-operating display storage tube (such as during shipment) can cause certain parts of the tube to become permanently magnetized. Slightly noticeable permanent magnetization is caused by field strengths as low as 0.5 Gs. In this case, viewing-beam distortion may be apparent during operation at a later time, even though the offending magnetic field may have since been removed. This distortion will be manifested as degraded display uniformity.

A method of providing protection against magnetic fields consists of «potting» the display storage tube permanently inside a magnetic shield during manufacture. New shock-resistant anti-magnetic materials are being used for these shields. The permanently shielded display storage tube would be protected against permanent magnetization during shipment and also against extraneous magnetic fields during operation. Such a tube is the developmental type RCA Dev. No. C73999, shown in Fig. 6.

2.4. Display uniformity

In many applications it is useful to attach significance to the relative brightness of individual elements of the display. The brightness of these elements is a function of the amplitude of the video drive voltage applied to the control grid of the writing gun. It is desirable in these applications that display elements positioned at different locations on the tube face be of equal brightness when these elements are written with video drive voltages of equal amplitude. The ability of display storage tubes to generate display elements whose brightness depends only upon the video drive voltage and is independent of the position of the element in the display is limited by the characteristics of the writing, viewing, and erasing operations.

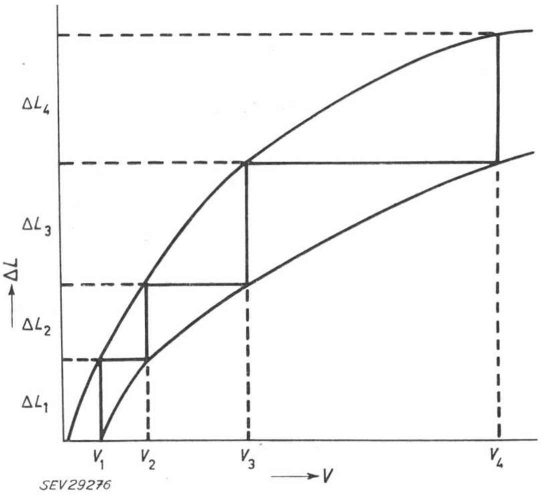

Fig. 7
Display Uniformity in Terms of Brightness Levels
ΔL Brightness range; V Writing-gun video drive voltage
$\Delta L_{1,2,3,4}$ Brightness ranges corresponding to voltages $V_{1,2,3,4}$

A fixed video drive voltage, V, will actually produce a range of brightness values, ΔL over the display. The magnitude of the brightness spread will be different at different video drive voltages. In Fig. 7, dynamic control characteristics, expressed as curves of brightness versus video drive voltage, are shown for the two different display areas which determine the value ΔL. All other areas of the display will

[2]) PPI = Plan Position Indicator.

[3]) «B scan» is a modification of the circulas scan in which the beam scans only a sectors of the total circle.

have brightness-versus-video-drive curves which fall between the two extremes shown. Ranges of brightness, ΔL_n, have been chosen on these curves, each of which can be definitely ascribed to one corresponding video drive voltage V_n. These ranges are picked so that the brightness value within a given range can only be produced by one of the control voltages, V_n. It can then be said that the number of unambiguous brightness levels in the display is equal to the maximum number of separate ranges ΔL_n which can be chosen without making uncertain the corresponding video drive voltage V_n. Specification of display uniformity in terms of the number of unambiguous brightness levels makes possible a determination of the accuracy to which different areas of the display may be compared in brightness. The accuracy to which video drive voltages may be determined from brightness observations may also be specified.

In addition to the uniformity of the tube used, display uniformity is limited by variations in the scanning speed of the writing gun (such as would result from nonlinear deflection in B-scan systems), by variations in integration (such as overlapping B-scan lines caused by hum in deflection circuits), and by hum in video-drive circuits. These considerations make it difficult to obtain measurements of display uniformity which are not influenced by the choice of video and deflection circuits.

The use of gray scales generated by step-function video signals is not sufficient for judging display uniformity as defined here because with this method no comparison is made of the different brightnesses produced by one fixed video drive voltage at different positions on the display.

2.5 Writing speed

The useful writing-gun control-grid range of a display storage tube is the change required in the writing-gun control-grid voltage to change an element of the display from zero to maximum brightness. The useful control range is a function of the maximum writing speed of which the display storage tube is capable, the writing-beam scanning speed, and the amount of integration. A fairly large useful control range, say from 20...60 V, is desirable. With smaller useful control ranges, any hum in the video circuits causes increasingly greater variation in display brightness. Because of the different scanning speed and integration requirements of different systems, display storage tubes are now available with various writing-speed capabilities.

The relation between writing speed and scanning speed may be demonstrated by subdividing the dynamic control characteristic, which relates video drive voltage on the writing-gun control grid to display brightness, into a writing-gun, an insulator-charging, and a storage-grid characteristic, as shown in Fig. 8.

The writing-gun characteristic is described in terms of the density of the writing-beam current as a function of writing-gun control-grid voltage at a fixed accelerating voltage. The writing-beam current, through the mechanism of secondary emission, removes electrons from the insulator surface of the storage grid. The number of electrons removed depends upon the secondary-emission ratio at the fixed accelerating voltage, the voltage change induced on a unit area of the insulator surface is directly proportional to the number of electrons removed and inversely proportional to the capacitance from the front to the back surface of the insulator.

The insulator-charging characteristic is shown as the change in insulator voltage versus writing-beam current, with the writing-beam scanning speed as a parameter. From the writing-gun characteristic and insulator-charging characteristic, the insulator voltage change resulting from a particular control-grid video drive voltage at a given scanning rate may be determined. A storage-grid control characteristic then relates the change in the insulator-surface voltage to the corresponding change in brightness.

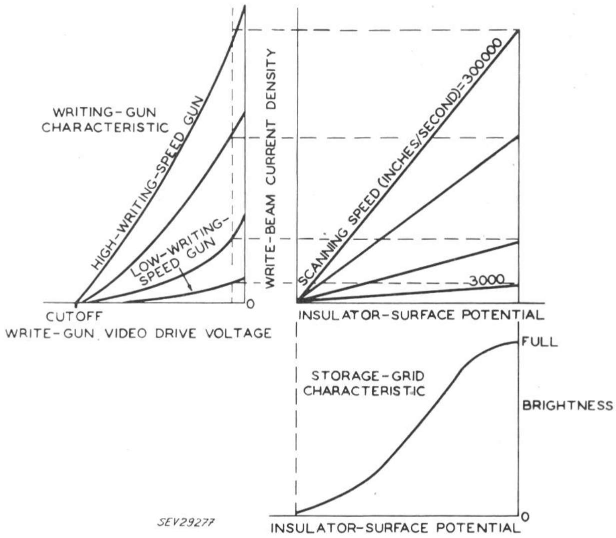

Fig. 8
Analysis of Transfer Characteristic Components

In the interest of obtaining a wide useful control-grid range, the tube selected for a given application should not have a higher writing speed capability than is required. In Fig. 8, insulator-charging characteristics for different scanning speeds are shown matched to writing-gun characteristics for a tube which has a writing-speed capability high enough to write a full brightness display but low enough to provide a full useful control range.

In addition to scanning speed, the amount of integration will also affect the required writing speed. Linear writing speed is usually defined as the maximum sweep speed at which it is possible to write a line from the black level to a specified brightness with the writing grid at a value near zero bias for some writing-gun accelerating voltage.

If a given line is written several times before erasure, the sum of the voltage changes must be considered in determining the brightness. In this manner, a repetitive signal may be integrated from the noise. The writing speed needed for an application in which each successive line overlaps the previous one somewhat, and thereby is integrated, is less than that determined from the linear-scanning rate. In the limit, where successive scanning lines overlap completely, an area writing speed is most useful. Area writing speed is dependent on total beam current and independent of beam-current density. The minimum time required to write a stationary focused spot to maximum brightness is dependent on the current density of the writing beam. A review of system requirements is recommended in order to ensure optimization of this and other parameters.

The 7448 tube has a writing speed of 3×10^5 in/s (7.5×10^5 cm/s), and the RCA-7315 display storage tube a writing speed of 3×10^3 in/s (7.5×10^3 cm/s). Intermediate speeds are available in developmental tubes similar to the 7448.

2.6 Tube parameters

In many applications the high brightness feature common to display storage tubes is not necessary. Resolution, uniformity, or viewing duration, which are often of greater importance, may be improved at the cost of a reduction in brightness by methods involving proper choice of operating voltages, auxiliary circuitry, or modifications in the tube design. An illustration of the first method is the increased viewing duration, slight improvement in uniformity, and resulting loss in brightness sometimes observed when the collector grid is operated at about one-half of the maximum rating. An illustration of the second method is a technique in which the viewing beam is pulsed on and off in order to achieve viewing durations of up to about 30 min at a brightness of about 30 foot-lamberts (0.01 sb).

The third and most effective method for improving tube parameters is that available to the manufacturer during the initial tube design. By means of new internal structures and spacings, brightness may be traded for resolution. A developmental model of a 5-inch display storage tube, RCA Dev. No. C73959, having a stored limiting resolution about twice that of currently available tubes was recently demonstrated. The saturated brightness of this tube when operated with a view-screen potential of 5 kV was in the order of 200 foot-lamberts (0.06 sb). Typical writing-speed capability of this tube is 3×10^3 in/s. When the display is written to one-half the saturated brightness at this writing speed, the resolution as measured by the shrinking-raster method, is about 110 lines per inch. The limiting TV resolution at this brightness and at a lower writing speed is about 1000 lines per target diameter. This resolution represents a marked improvement which will open up many new applications for display storage tubes.

3. Scan-Conversion Storage Tubes

3.1 General

Scan-conversion storage tubes are designed for use in data-processing applications in which signal information must be continuously transformed, with minimum loss in detail, from one time base or scanning presentation to another. In addition, some tubes provide a means of obtaining bright displays having a continuous range of halftone information under conditions of high ambient illumination.

In a typical systems application, PPI (Plan Position Indicator) information generated by radar installations is transformed by the scan-conversion tube into TV-type signals so that the information can be viewed on direct-view and projection television monitors. If desired, a large number of such monitors may be used to repeat the display at locations remote from the master-display unit. For example, the tube may be used in airport-surveillance applications in which aircraft-traffic-condition information may be sent over ordinary TV-type distribution systems to distant cities. Also, information from several radar installations as well as ground map or special command information picked up by TV cameras may be readily mixed and presented as a composite display.

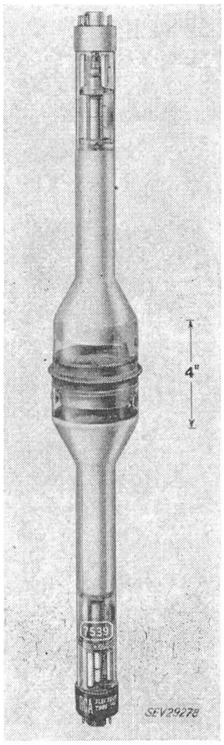

Fig. 9
7539 Scan-Conversion Storage Tube

The characteristics of the RCA 7539, which will be used as an example of a scan-conversion storage tube, are such that the stored information may be extracted and displayed at high-brightness levels for a period corresponding to many TV scanning frames. Depending on the signal-to-noise ratio required, this period may be adjusted from several seconds to more than a minute by suitable choice of tube operating voltages. Fig. 9 is a photograph of the 7539 tube.

The resolution capability of the 7539 tube, as shown in Fig. 10, is 150 range rings per display radius with a response of 50% or better. To utilize fully the resolution capability of the 7539, the TV monitor system must be designed for a resolution in excess of 1000 TV lines.

The 7539 has three sections—a writing section, a reading section, and a target section—as shown in Fig. 11.

Writing Section. The writing section contains an electron gun consisting of an indirectly heated cathode, a control grid 1, an accelerating grid 2, a focusing grid 3, and a final accelerating electrode 4 connected to the external conductive coating. The writing gun produces a high-velocity electron beam which is focused electrostatically and deflected by the magnetic fields of external deflecting coils.

Reading Section. The reading section contains an electron gun consisting of an indirectly heated cathode, control grid 1, and an accelerating grid 2. The reading gun produces a medium-velocity electron beam which is focused and deflected by the magnetic fields of external focusing and deflecting coils.

Target Section. The target section contains a target, shading-electrode, and an output-signal electrode. The target consists of a very thin layer of a high-resistivity material deposited on the front (the reading-gun side) of the backplate. The backplate is composed of an extremely thin layer of metal deposited on the reading-gun side of a very fine metal mesh. The backplate allows high transmission of incident writing-beam electrons. The thin layer of high resistivity material is called the storage layer. The storage layer, under normal operating conditions, has a secondary emission ratio greater than unity. The storage layer also serves as a dielectric for the capacitor formed between the backplate and the front surface of the storage layer.

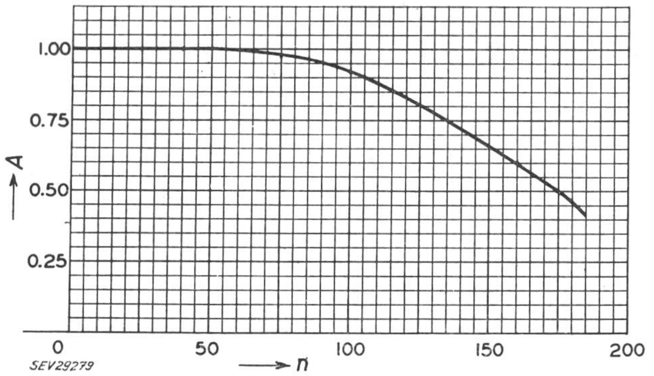

Fig. 10
Resolution Characteristic of 7539 Scan-Conversion Storage Tube
A Relative response; *n* Range rings per display radius

Heater voltage = 6.3 V each gun; Backplate voltage[1]) = – 5 V; Output-signal-electrode voltage [1]) = 0 V; Shading-electrode voltage[1]) = + 10 V

	Writing Gun	*Reading Gun*
Grid No. 4 voltage [V][1])	0	—
Grid No. 3 voltage [V][1])	Adjusted for best focus	—
Grid No. 2 voltage [V][1])	– 9800	Adjusted for most uniform display
Grid No. 1 voltage [V][1])	Adjusted for threshold of writing in absence of video-input signal	Adjusted for reading duration of 10 s
Cathode voltage [V][1])	– 10,000	– 2,000
Focussing-coil current	—	Adjusted for best focus
Scanning:	PPI	TV
Radial repetition rate [c/s]	1,000	—
Radial range period [μs]	610	—
Rotational rate [r.p.m.]	6	—
Vertical rate [c/s]	—	60
Horizontal rate [c/s]	—	28,350
Video-input signal:		
Pulse length [μs]	0.75	—
Peak-to-peak voltage above cutoff [V]	5	—

[1]) Referred to ground

3.2 Principles of operation

When the front surface of the storage layer is bombarded by the medium-velocity electron beam of the reading gun, secondary electrons are emitted. Because the secondary-electron emission ratio of the front surface is greater than unity, the surface begins to charge in the positive direction. Under continued bombardment, the surface becomes increasingly positive with respect to the output signal electrode until a retarding potential of a few volts is built up and equilibrium is established.

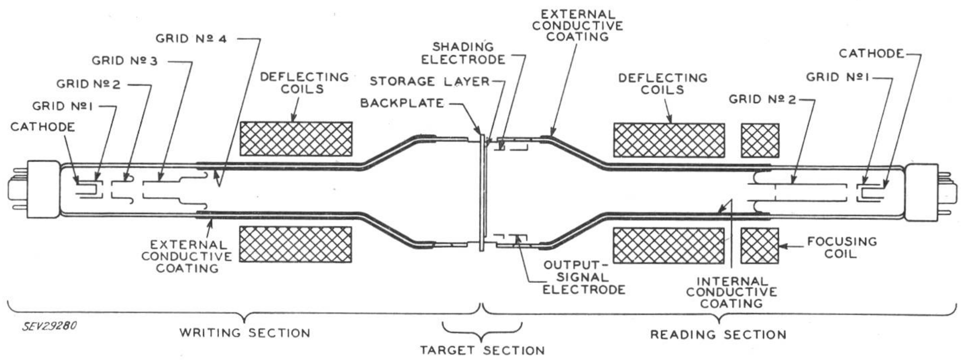

Fig. 11
Schematic Diagram of 7539 Scan-Conversion Storage Tube

The opposite side of the storage layer, the back side, is in mechanical and electrical contact with the backplate. Because the backplate is at a negative potential with respect to the output signal electrode, a difference of potential exists between the two surfaces of the storage layer during conditions of equilibrium. During the writing process, the high-velocity electron beam bombards the target, passes through the backplate, and penetrates the storage layer. The resulting bombardment-induced conductivity produced in the storage layer lowers the potentials of the front surface elements by varying degrees toward the negative potential of the backplate. The front surface of the storage layer thus acquires a pattern of potential variations which corresponds to the input video signal. When the writing beam is removed, the storage layer gradually regains normal resistivity.

Because the output signal from any given area of the storage layer is a continuous function of the input signal, provided that area is not written beyond saturation, storage of a continuous range of halftone information is possible.

The writing or discharging characteristics of the 7539 tube is a function of writing-beam current, writing-beam velocity, scanning speed, and width and repetition rate of the input-pulse signal.

The change in potential of the storage-surface elements caused by writing-beam bombardment upsets the equilibrium conditions established by the reading beam. Secondary electrons, produced by reading-gun bombardment of the storage-surface elements that have been driven toward the negative backplate voltage by writing, are now accelerated to the output signal electrode and constitute the output signal current. The reading process, therefore, serves as an erasing process by removing the stored potential pattern and driving the storage surface back toward the equilibrium value.

Because the storage layer does not immediately regain its normal resistivity after the writing beam is removed, and because there is relatively large capacitance between the front surface and the back surface of the storage layer, a large number of scans are required before equilibrium is re-established. The stored signal accordingly «persists» for some time. Fig. 12 shows a typical storage characteristic of the 7539 tube.

The reading or charging characteristic of the 7539 is a function of backplate potential and reading-gun current. Increasing backplate potential and decreasing reading-beam current result in increased charging time. By suitable adjustment of these operating values, the reading time can be varied from a few seconds to over a minute.

Because the reading process removes the stored-charge pattern and brings the storage-surface elements to the equilibrium potential essential for writing, an erasing process is not ordinarily required.

The maximum number of scanning frames (copies) obtainable during the reading process depends on the magnitude of the potential variations produced on the

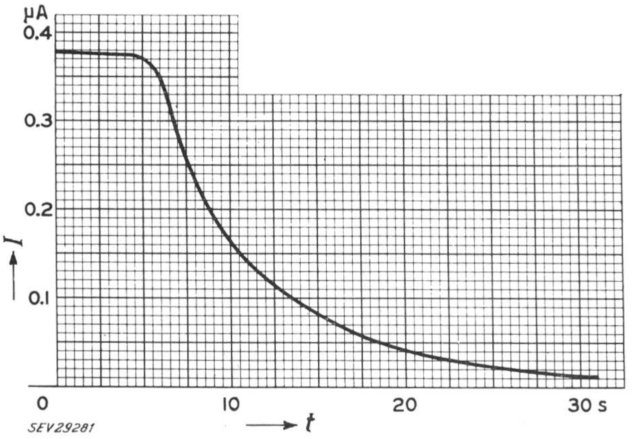

Fig. 12
Storage Characteristic of 7539 Scan-Conversion Storage Tube
I Peak-to-peak output-signal; *t* Time after writing
For data on writing and reading guns refer to Fig. 10

storage-surface elements during the writing process, and the minimum value of reading-beam current that can be used in relation to the noise level of the associated amplifier.

The shading electrode is used to reduce variation in the equilibrium potential of the storage surface elements as a function of their location on the surface. As a result of its action, the output signal is relatively free from the effect commonly called «shading». The shading electrode is operated at a potential somewhat positive with respect to that of the backplate.

Bibliography

[1] *MIT Radar School Staff:* Principles of Radar. New York: McGraw-Hill 1946.

[2] *Knoll, M.* and *B. Kazan:* Storage Tubes and Their Basic Principles. New York: Wiley 1952.

[3] *Knoll, M., P. Rudnick* and *H. O. Hook:* Viewing Storage Tube with Halftone Display. RCA Rev. Vol. 14 (1953), No. 4, p. 492...501.

[4] *Knoll, M., H. O. Hook* and *R. P. Stone:* Characteristics of a Transmission Control Viewing Storage Tube with Halftone Display. Proc. IRE, Vol. 42 (1954), No. 10, p. 1496...1504.

[5] *Smith, E. M.:* Operation and Performance of the 6866 Display Storage Tube. RCA Rev., Vol. 18 (1957), No. 3, p. 351...360.

[6] *Pensak, L.:* Picture Storage Tube. Electronics, Vol. 22 (1949), No. 7, pp. 84...88.

[7] *Pensak, L.:* The Graphechon—A Picture Storage Tube. RCA Rev., Vol. 10 (1949), No. 1, p. 59...73.

[8] *Benner, A. H.* and *L. M. Seeberger:* Graphechon Writing Characteristics. RCA Rev., Vol. 12 (1951), No. 2, p. 230...250.

[9] *Patrick, N. W.* and *P. P. Damon:* Recent Developments in Display Storage Tubes. Proc. Nat. Aeronautical Electronics Conf. 1959.

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Rückwärtswellen im Hohlleiter mit anisotropem Dielektrikum

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1. Einleitung

Elektromagnetische Wellen im freien Raum oder längs einfacher zylindrischer Leitungen transportieren Energie in Richtung ihrer Phasengeschwindigkeit. In Wellenleitern, deren metallische Berandung sich in Achsenrichtung periodisch in ihrer Geometrie verändert, treten Wellen auf, bei denen die Richtung der Phasengeschwindigkeit derjenigen des Energietransports entgegengesetzt ist. Solche Wellen werden als Rückwärtswellen bezeichnet (RW). Da die Energieströmung von der Energiequelle ausgeht, bewegt sich die Wellenphase bei RW — im Gegensatz zum gewohnten Bild — auf die Energiequelle zu. Diese RW gaben Anlass zur Entwicklung einer eigenen Gruppe von Mikrowellenröhren (backward travelling wave tubes). In den periodisch veränderlichen Leitungsstrukturen, die bei diesen Anordnungen verwendet werden, hat man es stets mit einer unendlichen Gesamtheit von rechts- und linkslaufenden Teilwellen zu tun, die nur als Ganzes den periodischen Randbedingungen genügen. Die darin enthaltenen RW können nur gemeinsam mit allen übrigen Teilwellen auftreten und sind nicht separat erregbar.

Im folgenden soll untersucht werden, unter welchen Umständen in gewöhnlichen Wellenleitern mit glatter Berandung separate RW auftreten können. Umschliesst der Wellenleiter ein normales Dielektrikum, so ist ein solcher Fall nicht denkbar. Wir betrachten daher ein Medium mit Tensorcharakter bezüglich seiner Dielektrizitätskonstante (DK), wobei wir zwecks Vermeidung unnötiger Komplizierungen uns den einfachsten Fall vornehmen, nämlich, dass das Medium in longitudinaler Richtung eine DK ε_z und in transversaler Richtung eine von ε_z verschiedene DK ε_t besitzt. Man findet, dass für negative Werte von ε_t separate RW des elektrischen Typs existieren. Ein solches Medium ist physikalisch tatsächlich realisierbar, wenn nämlich der Hohlleiter mit einem Plasma erfüllt ist, das in longitudinaler Richtung durch ein äusseres Feld B_{0z} magnetisiert ist. Die theoretische Behandlung eines solchen Plasmas zeigt, dass seine DK durch einen Tensor beschrieben wird, der sich unter geeigneten experimentellen Bedingungen genügend genau auf einen Tensor mit rein diagonalen Elementen reduzieren lässt[1]).

2. Problemstellung und Lösung der Feldgleichungen

Wir betrachten also einen zylindrischen metallischen Hohlleiter beliebiger Querschnittsformen (Fig. 1), dessen Dielektrikum durch den $(\vec{\varepsilon})$-Tensor

[1]) *Schumann, W. O.:* Über die «Backward Wave» im metallischen Hohlleiter, der mit längsmagnetisiertem Plasma gefüllt ist. Z. angew. Phys. Bd. 11 (1959), Nr. 9, S. 333...335. Prof. *Schumann* verdankt der Autor die Mitteilung, dass die Existenz von Rückwärtswellen im längsmagnetisierten Plasma experimentell nachgewiesen werden konnte.