# DIRECT-VIEW STORAGE TUBES

George F. Smith

Technical Memorandum No. 511
May 1958

RESEARCH LABORATORIES

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ABSTRACT

Direct-view storage tubes offer a new means for bright display of electronic information. The principles of operation of these devices are discussed and recent progress in the field is reported. Tubes of the infinite-persistence bistable type, such as the Memotron and Typotron tubes, are well suited for storing and displaying transient waveforms and high-speed alpha-numeric information. Direct-view tubes of the halftone variety, such as the Tonotron tube, are particularly well adapted for simultaneous storage and presentation of radar or sonar displays. Performance parameters are discussed; these include brightness, writing speed, stored resolution, halftone range, persistence, and erasure. The status of current developmental work on large-screen tubes and on multicolor storage tubes is outlined.

# I. INTRODUCTION

As the name implies, a direct-view storage tube is a storage tube in which the output is visual. The primary function of such a device is to provide a bright and persistent display of nonrecurrent pictorial information. Storage tubes are well suited for the persistent display of such types of information as radar or sonar data, processed alphanumeric information, transient waveforms, and narrow-band television pictures. On the exterior, storage tubes closely resemble ordinary cathode-ray tubes. A few tubes typical of those now in production at Hughes Aircraft Company are shown in Figure 1. Several companies are currently manufacturing 5-inch tubes similar to those shown in the figure. Larger storage tubes having diameters up to 21 inches and specialized tubes, such as a multicolor storage tube, are currently being developed in order to increase the capacity for the storage and display of information, or to afford more convenient viewing.

There are two kinds of direct-view storage tubes: bistable and halftone. The bistable or two-tone tube presents two shades of grey, namely, black and white, and incorporates regeneration to provide an indefinitely long retention time. The halftone tube provides a continuous range of grey shades but has a limited retention time. The external and internal appearance of both tubes is similar; the schematic drawing in Figure 2 will serve to illustrate both types, each of which consists of four essential elements: a storage mesh, an adjacent phosphor viewing screen, a flood gun, and a writing gun. The storage mesh is a fine metal screen with several hundred holes per linear inch. A thin layer of insulating dielectric is deposited on the side of the mesh facing the flood gun. The flood gun covers the storage surface with a uniform broad beam of slow electrons. A charge pattern corresponding to the picture to be viewed may be deposited on the surface of the dielectric. Each elemental area of the charge pattern controls the transmission of electrons from the flood gun in the same way as the control grid of an ordinary receiving tube controls the plate current. In areas where the charge pattern is relatively more positive, flood electrons can penetrate the storage mesh; in areas where the pattern is negative, the flood electrons are repelled and cannot penetrate the mesh. Those electrons which succeed in passing through the storage mesh are then accelerated so that they may strike the phosphor viewing screen at a high energy and produce a light pattern corresponding to the charge pattern on the insulating storage surface. As long as the charge pattern remains undisturbed, the picture to be viewed persists. The writing gun, which may be a conventional cathode-ray gun, serves to deposit the charge pattern. If a uniform negative "black" pattern is assumed, the writing gun can deposit a positive "white" pattern on the dielectric surface. The dielectric material is chosen to have a high secondary-electron-emission ratio at the bombarding energy of the

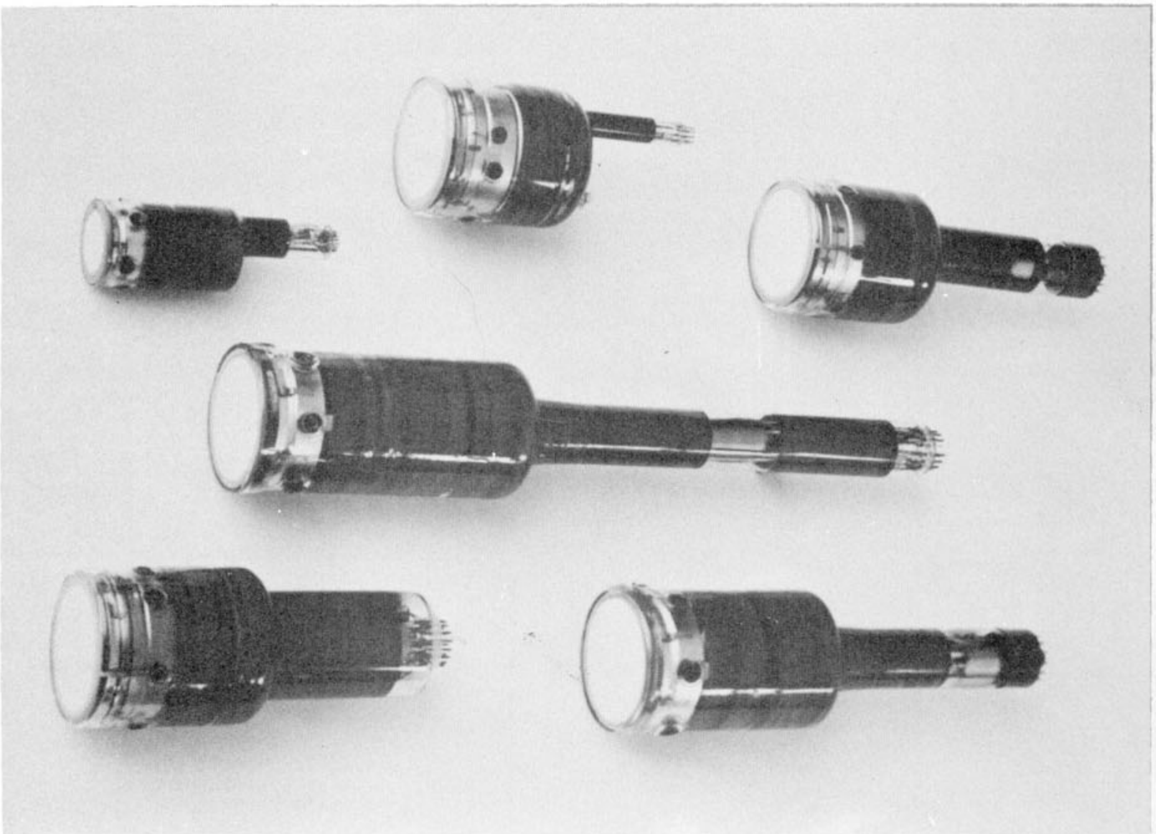

Figure 1. Typical production direct-view storage tubes, 5-inch and 3-inch models

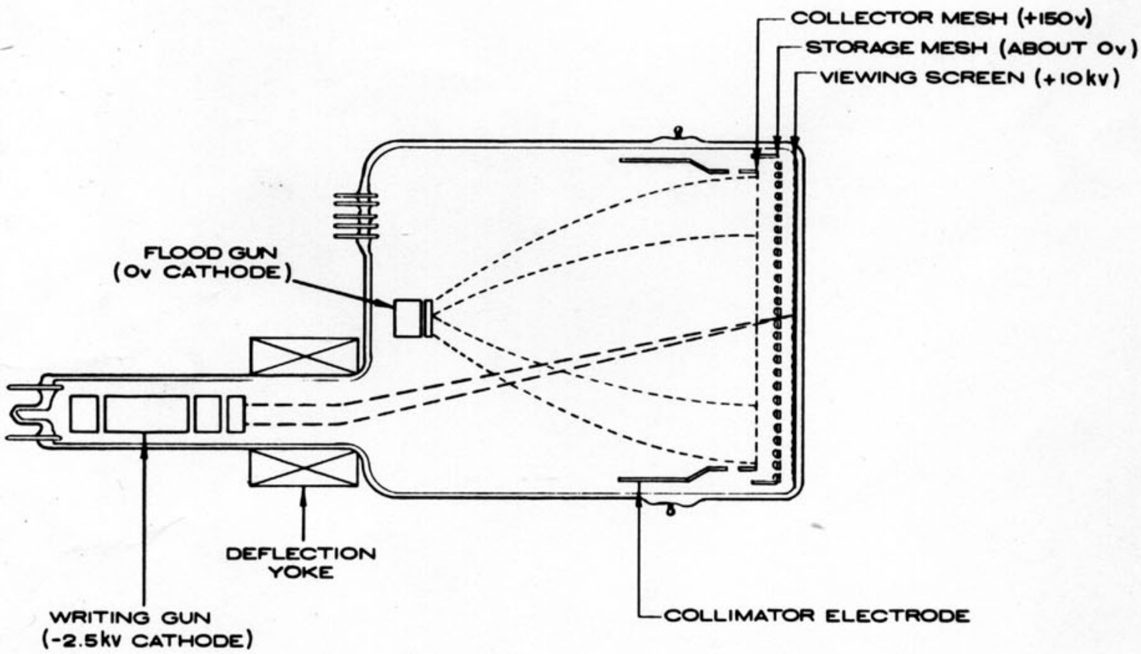


Figure 2. Schematic of a direct-view storage tube

writing electrons. Several secondary electrons are emitted from the insulating surface for every incident primary electron, so that the surface is rapidly charged in the positive direction by the writing gun. Erasure is usually accomplished by bombarding the entire target with low-energy electrons from the flood gun. The modes of erasure are different for the bistable and halftone tubes and will be discussed later.

## II. BISTABLE TUBES

The bistable mode of storage is well suited for the display of processed data or transient waveforms, such as alpha-numeric information from a computer or an A-scan radar presentation. This type of storage tube was first proposed by A. V. Haeff[1] in 1947. The Memotron[2] and Typotron[2,3] tubes incorporate bistable storage; production models of these two tubes have been available for the past three years.

A typical bistable-storage-characteristic curve is shown in Figure 3, where display brightness is plotted against storage-surface potential. Some of the electrons from the flood gun provide the display and others are responsible for the regenerative action. There are two equilibrium dielectric potentials: (a) flood-gun cathode potential, or black, and (b) collector-mesh potential, or white. In the absence of a writing beam, the black and the white areas of the dielectric are maintained at their respective equilibrium potentials by the low-energy flood electrons. In the white areas, where the dielectric is charged to the collector potential, the flood electrons strike at a velocity sufficient to produce a secondary-emission ratio greater than unity; i. e., more than one secondary electron is released for every incident flood electron. As long as the collector remains more positive than the dielectric surface, it will attract and collect the secondary electrons so that

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[1] A. V. Haeff, "A Memory Tube," Electronics 20, 80-83 (September 1947); S. T. Smith and H. E. Brown, "Direct Viewing Memory Tube," Proc. IRE 41, 1167-1171 (September 1953).

[2] Memotron and Typotron are trade-marks of the Hughes Aircraft Company.

[3] H. M. Smith, "The Typotron, A Novel Character Display Storage Tube," IRE Convention Record 3, Part 4, 129-134 (1955).

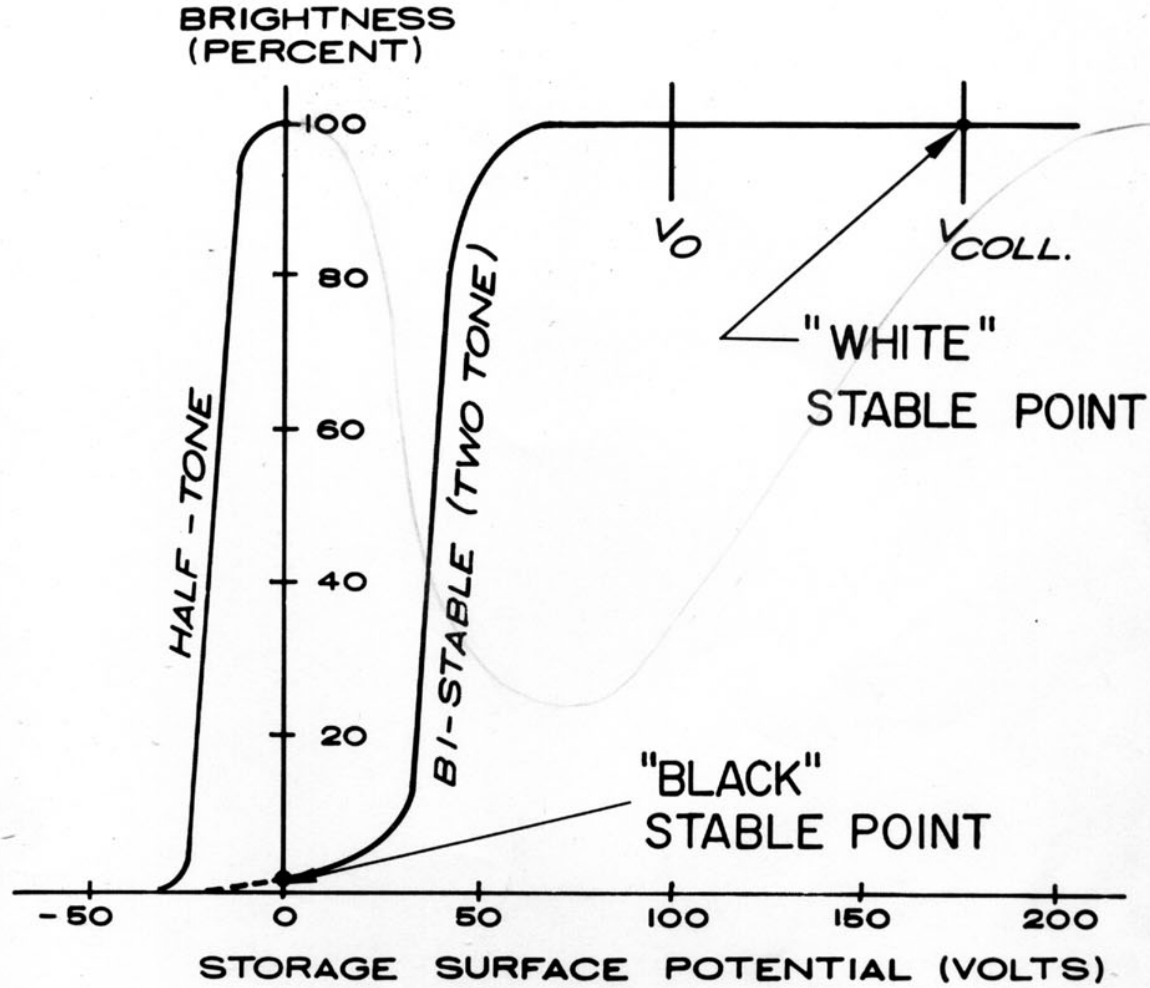


Figure 3. Typical storage characteristics, showing brightness as a function of storage dielectric potential. Curves are shown for both the bistable mode and the halftone mode

a net positive charging current will exist. Any tendency of the surface potential to fall below the collector potential is thus compensated for by the positive charging action of the secondary emission. In the black areas, near zero-volt potential, the flood electrons strike the surface with almost zero velocity and produce virtually no secondary electrons. Hence any tendency of the surface potential to rise above zero volts is compensated for by the negative charging action of the extremely low-energy flood electrons. Surface areas with a potential having any value between zero and that of the collector potential will be driven in either the negative or the positive direction until they reach one or the other of the stable points.

A critical potential, labeled $V_o$ in Figure 3, divides the two regions of negative and positive regeneration. In order to write a black surface to white, the writing beam must raise the storage-surface potential to a value just beyond this critical potential, so that positive regeneration will carry the surface the rest of the way to the collector potential. As discussed in Section I, the writing beam deposits a positive charge pattern, by using the high secondary-electron-emission ratio of the dielectric at the writing-beam energy. A stored pattern can be erased by momentarily decreasing the collector potential in order to eliminate the bistable regeneration. If the collector potential is decreased to a value slightly below the critical potential, $V_o$, positive regeneration is eliminated and the potential of the written area will be reduced to zero volts, that is, to black.

The 5-inch Memotron tube, which incorporates a cathode-ray-type spot-writing gun, has a linear writing speed of 100,000 inches per second, with a resolution of 60 white lines per inch. The Typotron tube utilizes the same storage assembly but is equipped with a character-writing gun for writing alpha-numeric information directly. A schematic diagram of the Typotron tube is shown in Figure 4. The beam of electrons from the writing gun is formed into the shape of a character by passing it through the character matrix, a stencil containing 64 letters, each approximately 0.016 inch high. The beam is returned to the axis by a magnetic lens and is then directed to any chosen spot on the storage target by means of deflection plates. The 5-inch Typotron tube can write 25,000 letters per second; thus it can operate as a direct-output device for a high-speed digital computer. Figure 5 shows the face of a Typotron tube on which all the characters of the stencil have been stored. Both the Memotron tube and the Typotron tube can present only two shades, black and white, but both provide indefinitely long retention times.

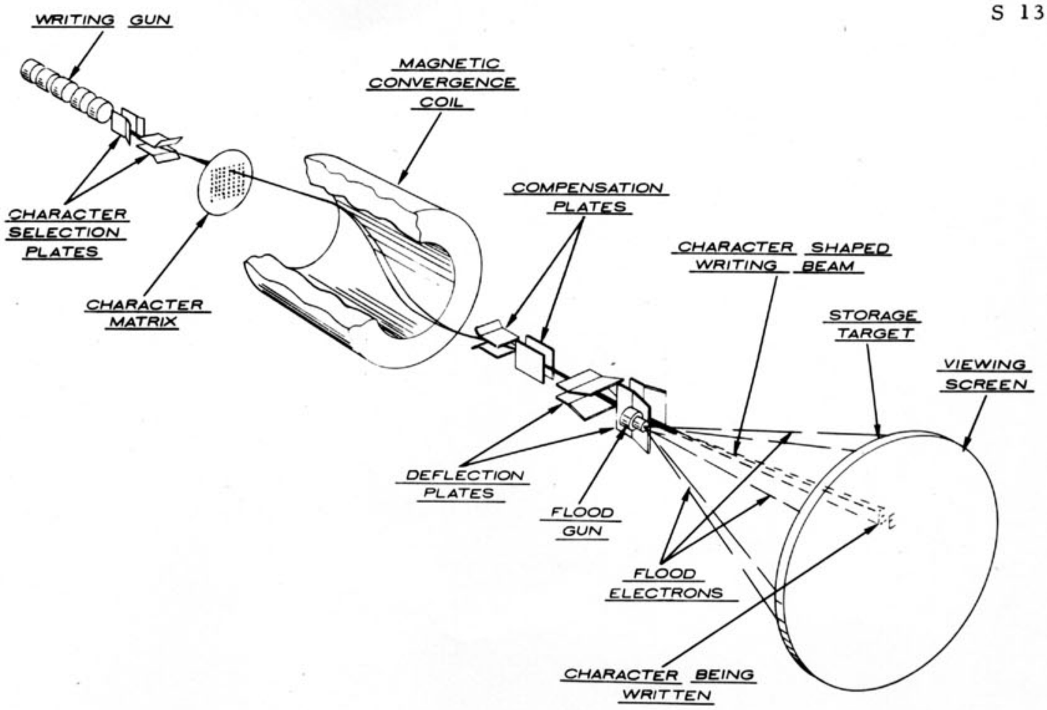


Figure 4. Schematic of the character-writing Typotron storage tube

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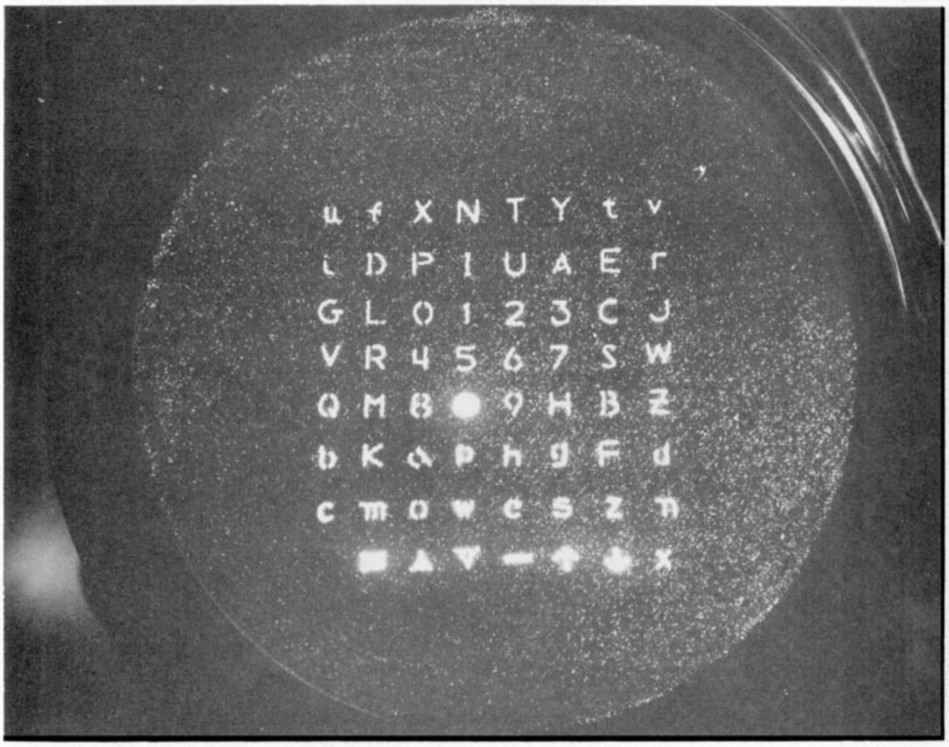

Figure 5. Stored characters on a 5-inch Typotron tube

## III. HALFTONE TUBES

The first work on a direct-view halftone storage tube[4,5] was begun by Max Knoll and others about 1949. Tubes of this type, such as the Hughes Tonotron[6] tube, have been in production for nearly two years. The principal advantage of the halftone storage tube is that, unlike the bistable tube, it can store and display a continuous range of grey between black and white. For this reason it is much better suited for raw radar displays, where discrimination of targets in noise is desired. Halftone pictures can be stored at constant brightness (up to several thousand foot-lamberts) for periods as long as one minute, or the display can be made to fade toward black with an arbitrary time constant, just as in a long-persistence cathode-ray tube. The continuous grey scale is obtained only with a finite retention time, but the retention times available are adequate for most applications.

Figure 3 shows both a typical halftone storage characteristic and a bistable characteristic. The interesting features of the halftone characteristic are shown in more detail in Figure 6. The entire halftone potential range is negative with respect to the flood-gun cathode. This means that none of the electrons from the flood gun can strike the storage surface and hence that the charge pattern should be undisturbed during viewing, even without regeneration. Unfortunately, this is not strictly true since positive ions are formed by the flood beam from the residual gas in the tube. Some of these ions are attracted toward the negative storage surface and slowly charge it positive toward white. The retention time is determined by the gas pressure in the envelope. Values of the order of a minute can be achieved.

As in the case of the bistable tube, writing is accomplished by means of a well-focused beam of high-energy electrons from the writing gun. By virtue of its high secondary-emission ratio, the dielectric surface is charged positively when bombarded by these electrons.

The flood gun is commonly used for erasure. It is clear from Figure 6 that in order to erase, the storage-surface potential must be

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[4]M. Knoll, H. O. Hook, and R. P. Stone, "Characteristics of a Transmission Control Viewing Storage Tube with Halftone Display," Proc. IRE 42, 1496-1504 (October 1954); M. Knoll and B. Kazan, "Viewing Storage Tubes," Advances in Electronics, Vol. VIII, Academic Press, New York, 1956.

[5]R. C. Hergenrother and B. C. Gardner, "The Recording Storage Tube," Proc. IRE 38, 740-747 (July 1950).

[6]Tonotron is a trade-mark of the Hughes Aircraft Company.

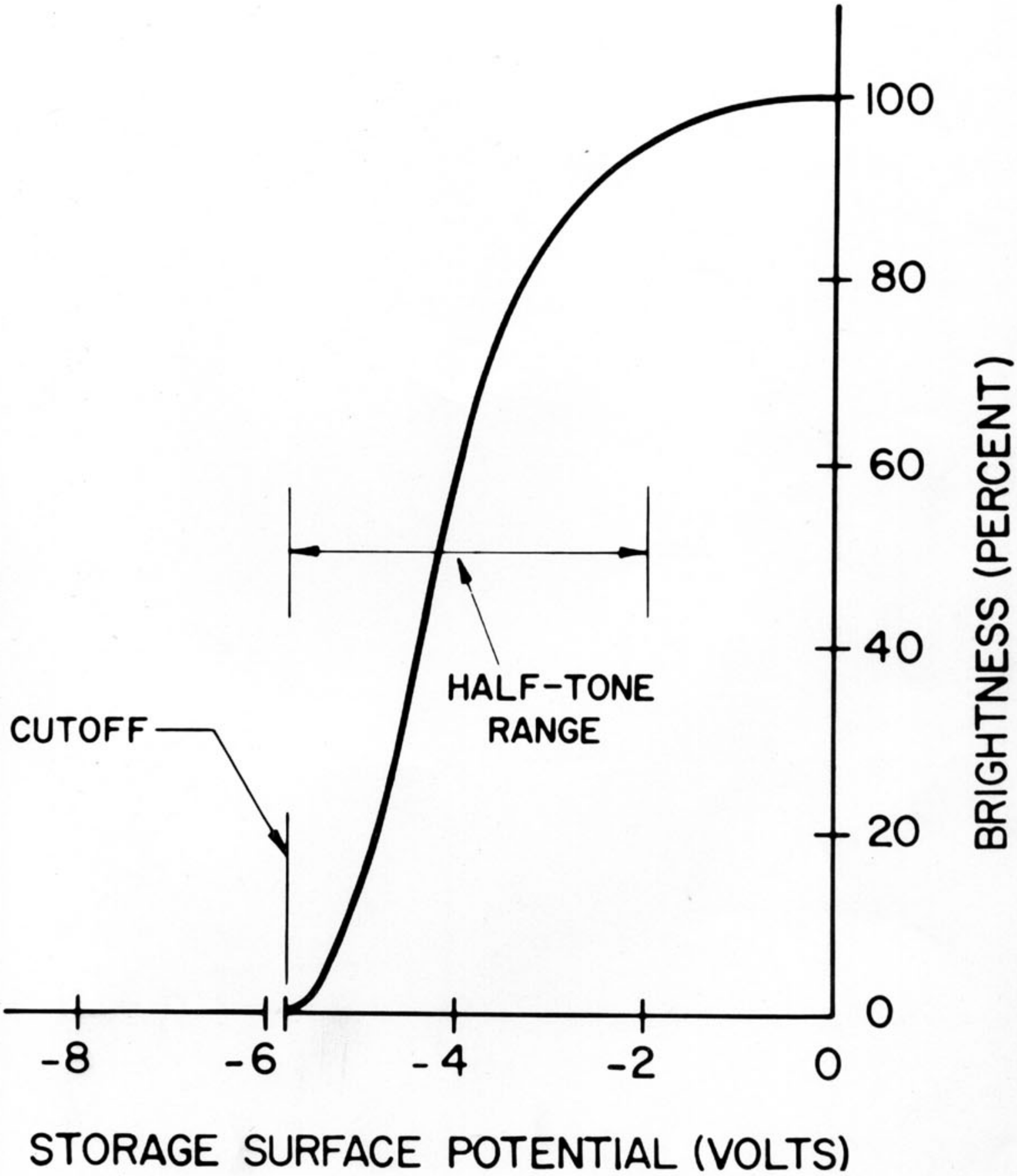


Figure 6. Halftone storage characteristic of a 5-inch Tonotron tube

lowered to its cutoff value, in this case about minus 5.5 volts. This is done by momentarily raising the metal-mesh potential by plus 5.5 volts. The storage surface potential is then capacitively increased by an equal increment. Thus any part of the storage surface having a potential on the useful part of the storage characteristic is elevated slightly above the cathode potential. Flood electrons then strike the storage surface, and since they have only a few volts of energy, for which the secondary-emission ratio is less than one, they charge the surface negatively down to the flood-cathode potential. After this happens, the storage mesh is lowered by the same 5.5-volt increment, capacitively lowering the entire dielectric surface to its cutoff potential. This process can be carried out all at once with a single pulse, or a pulse train consisting of widely spaced short pulses can be used; in this case the erasure is spread out over a period of time. If the latter mode of operation is used, the stored pattern will fade out with a time constant that depends only on the duty cycle of the erase pulse train. Halftone tubes also have been made with a separate low-energy erase gun to be used for spot-by-spot or line erasure, although the performance of such a low-energy gun cannot provide high erasing speed or resolution.

When operated properly, a 5-inch halftone storage tube provides a display quite adequate for the tonal range and resolution of a typical standard television picture. However, particular care must be taken to ensure that the video input is matched to the dynamic range of the storage tube. An ordinary cathode-ray tube has a very large dynamic range since the phosphor brightness is directly proportional to the writing-beam current for any current that the gun will provide. It can be seen in Figure 6 that the dynamic range of the halftone storage tube is definitely limited. In order to make full use of the range, the erase-pulse amplitude and the video signal must be carefully matched to the storage characteristic. If the erase pulse is too large, the storage-surface potential will be reduced beyond the cutoff point and thus a threshold for writing (eliminating low-level signals) is introduced. On the other hand, if the amplitudes of the video peaks are excessive, the tube may be driven to saturation and the large-signal detail will thereby be clipped. The problem of matching the video to the storage characteristic can become particularly severe if a fast storage tube is used for a long-range radar display or for certain types of slow-scan television. In such applications the writing beam may scan the storage target so slowly that it is difficult to keep the beam current low enough to prevent saturation in the highlights.

Five-inch halftone tubes have full-brightness writing speeds of a few hundred thousand inches per second, with written resolutions of from 60 to 80 lines per inch. The written resolution is generally somewhat better for shades of grey than for full-brightness writing. Five or six halftone shades are available, with full-tone brightnesses up to several thousand foot-lamberts. Controlled-fade times of from two to

Figure 7. One field of a television picture stored on a 5-inch Tonotron tube

thirty seconds are feasible, with maximum retention times of the order of one minute. Figure 7 is a photograph of a picture stored on a 5-inch Tonotron tube. One field of a commercial TV picture was used as the input signal. The individual scan lines in the picture are clearly visible in the original photograph.

## IV. LARGE-SCREEN AND MULTICOLOR STORAGE TUBES

More over-all resolution and the convenience of a larger display are desirable in indicator tubes for air-traffic control, ground radar, and processed data systems. A 21-inch halftone tube,[7] shown in Figure 8, is under development for such applications. This tube makes use of curved, self-supporting screens and an envelope with a curved faceplate. Because of mechanical considerations, neither the meshes nor the faceplate can be flat when the tube diameter becomes this large. A 21-inch storage assembly is shown in Figure 9. The thick, self-supporting target material, which cannot be fabricated with as many holes per inch as the thin, flat material, still provides several times as many holes in the entire target and a substantially increased total resolution. Current developmental tubes provide resolutions in excess of 750 distinguishable white lines. The spot-writing version of the 21-inch tube can write at least 40,000 inches per second, and the light output is in excess of 50 foot-lamberts, an output quite adequate for use in normally lighted areas. A letter-writing version of the 21-inch tube can write 40,000 letters per second with a displayed letter size of 0.15 inch. Halftone uniformity comparable to that of the 5-inch storage tube has been achieved. Figure 10 shows a stored pattern of alpha-numeric information on the 21-inch storage tube.

Also in the advanced development stage is a multicolor storage tube[8] which incorporates shadow-mask color selection together with halftone storage in a 10-inch envelope, as shown in Figure 11. A storage screen is inserted between the shadow mask and the color-dot plate of a conventional three-gun color tube. A ring-type flood gun has

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[7] N. J. Koda, N. H. Lehrer, and R. D. Ketchpel, "Twenty-One-Inch Direct-View Storage Tube," IRE WESCON Convention Record 1, Part 7, 78 (1957).

[8] C. D. Beintema, S. T Smith, and L. L. Vant-Hull, "Multicolor Storage Tube," IRE Transactions PGED ED-4, 303-309 (October 1957); L. L. Vant-Hull and C. D. Beintema, "Multicolor Storage Tube," WADC Technical Report 57-400, Final Report under Contract AF 33(616)-2177, August 1957.

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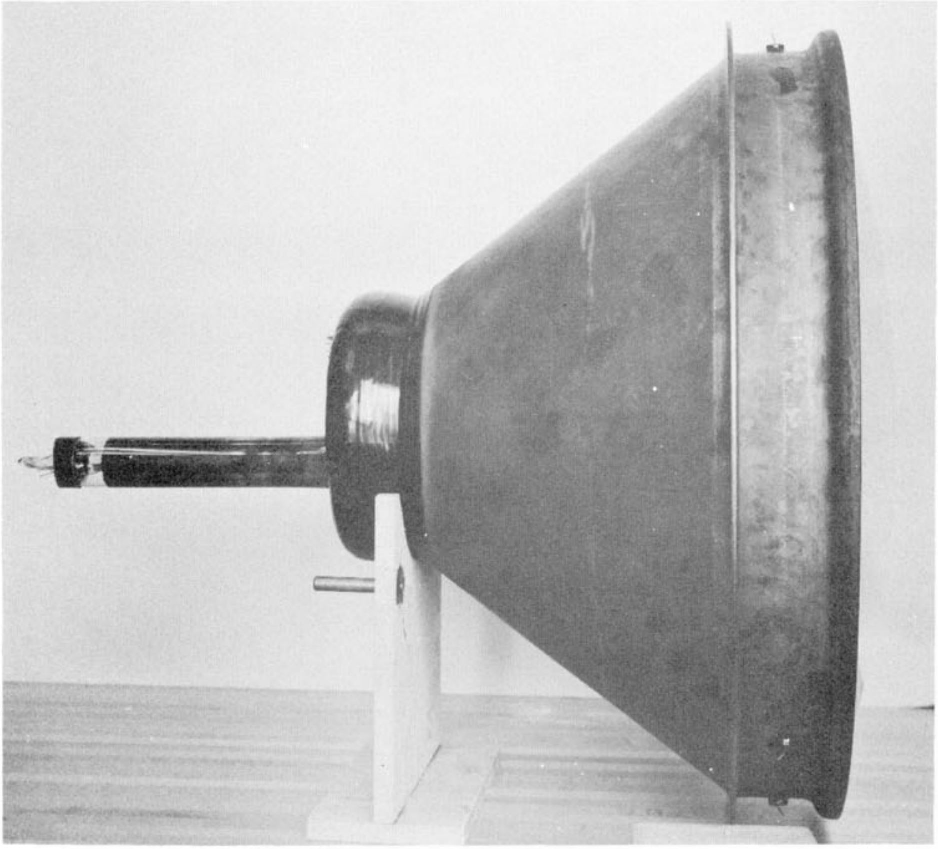

Figure 8. Developmental 21-inch Tonotron tube

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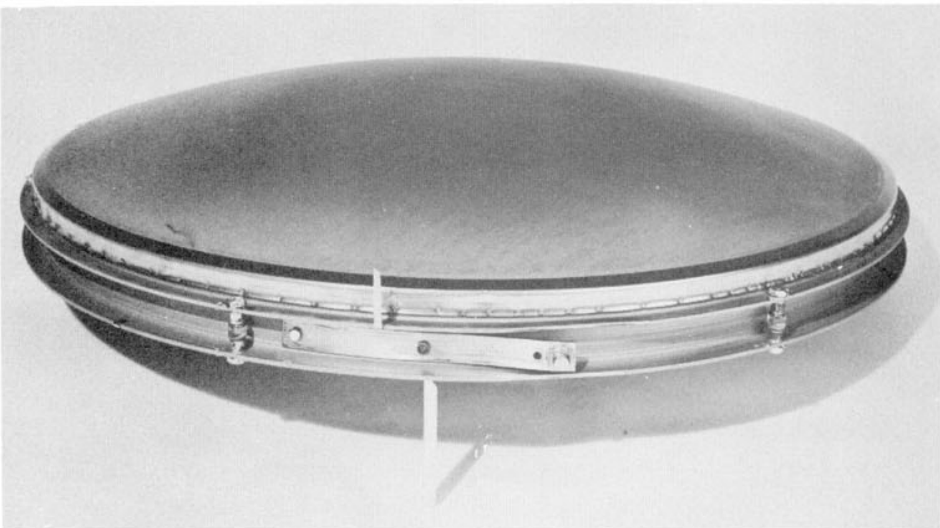

Figure 9. Storage-mesh assembly for 21-inch tube

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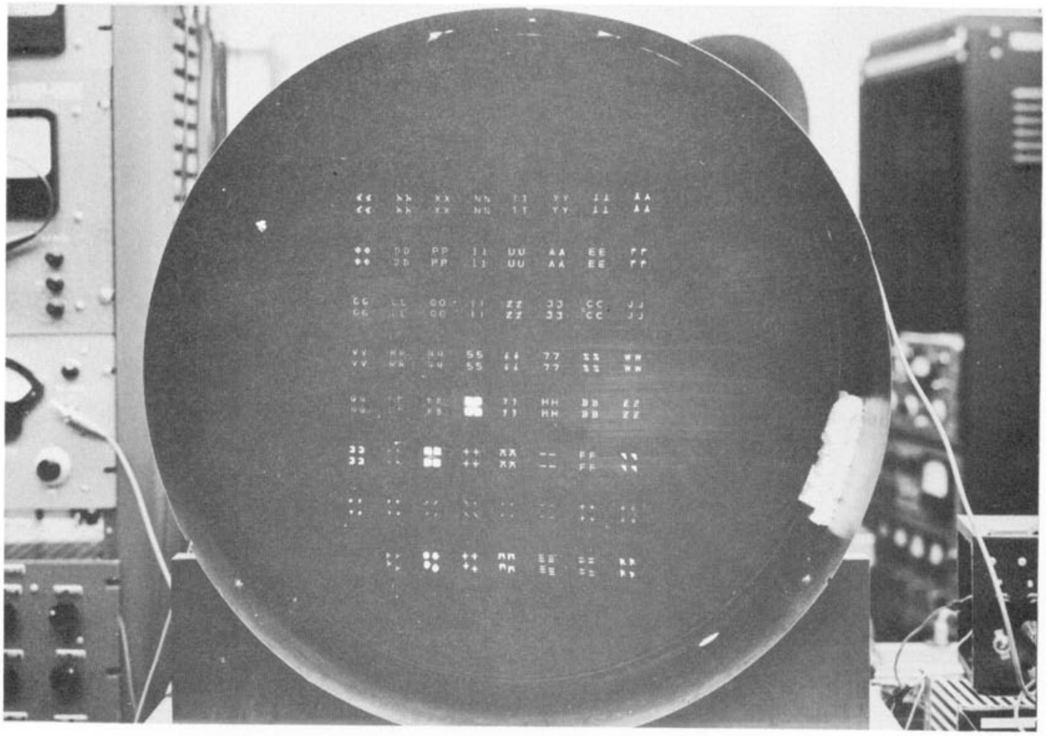

Figure 10. Stored characters on 21-inch tube

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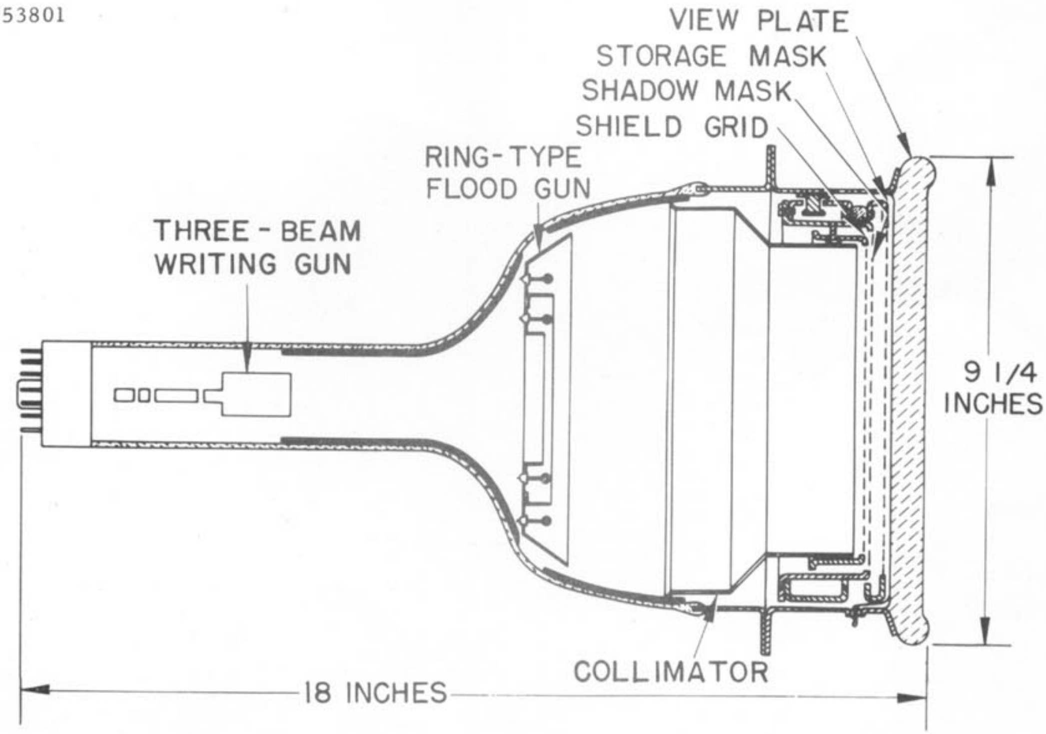


Figure 11. Schematic of the multicolor storage tube

been added to provide the low-energy viewing beam. As shown in Figure 12, the storage target has one hole for every phosphor color dot. The writing beam from one gun, say the red gun, can strike the dielectric around only those storage-surface holes that are aligned with red phosphor dots. The flood beam coming through the shadow mask from the extended-source flood gun illuminates the entire storage surface but penetrates it only where the charge pattern is positive. Excellent color purity has been achieved over the entire 6-inch useful screen diameter of the tube and at least seven distinct colors can be distinguished. A color storage tube could be used for any application in which another display dimension is required, e.g., for the display of identification, speed, or altitude, in addition to the usual radar parameters of range and azimuth.

## V. SUMMARY

Five-inch direct-view storage tubes are currently available in a variety of models. The bistable tube is well suited for transient oscillograph applications. Because of their ability to store shades of grey, the halftone tubes are better suited for many radar and picture applications. Developmental samples of 21-inch storage tubes have been constructed, with spot-writing and character-writing guns. The large tubes provide substantially greater resolution and ease of viewing. Experimental models of a multicolor storage tube have been made.

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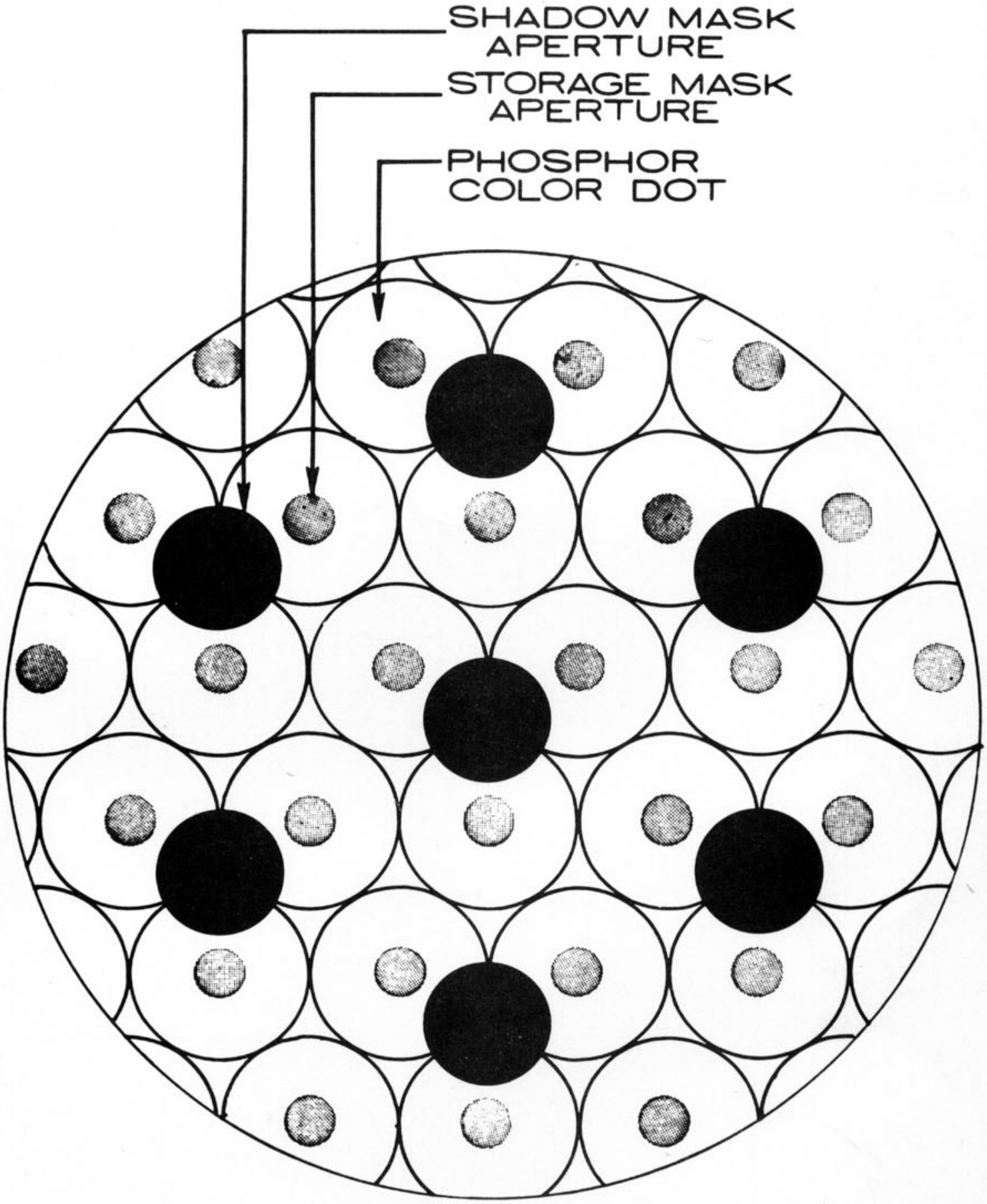


Figure 12. Alignment of shadow mask, storage mask, and phosphor dots in the multicolor storage tube