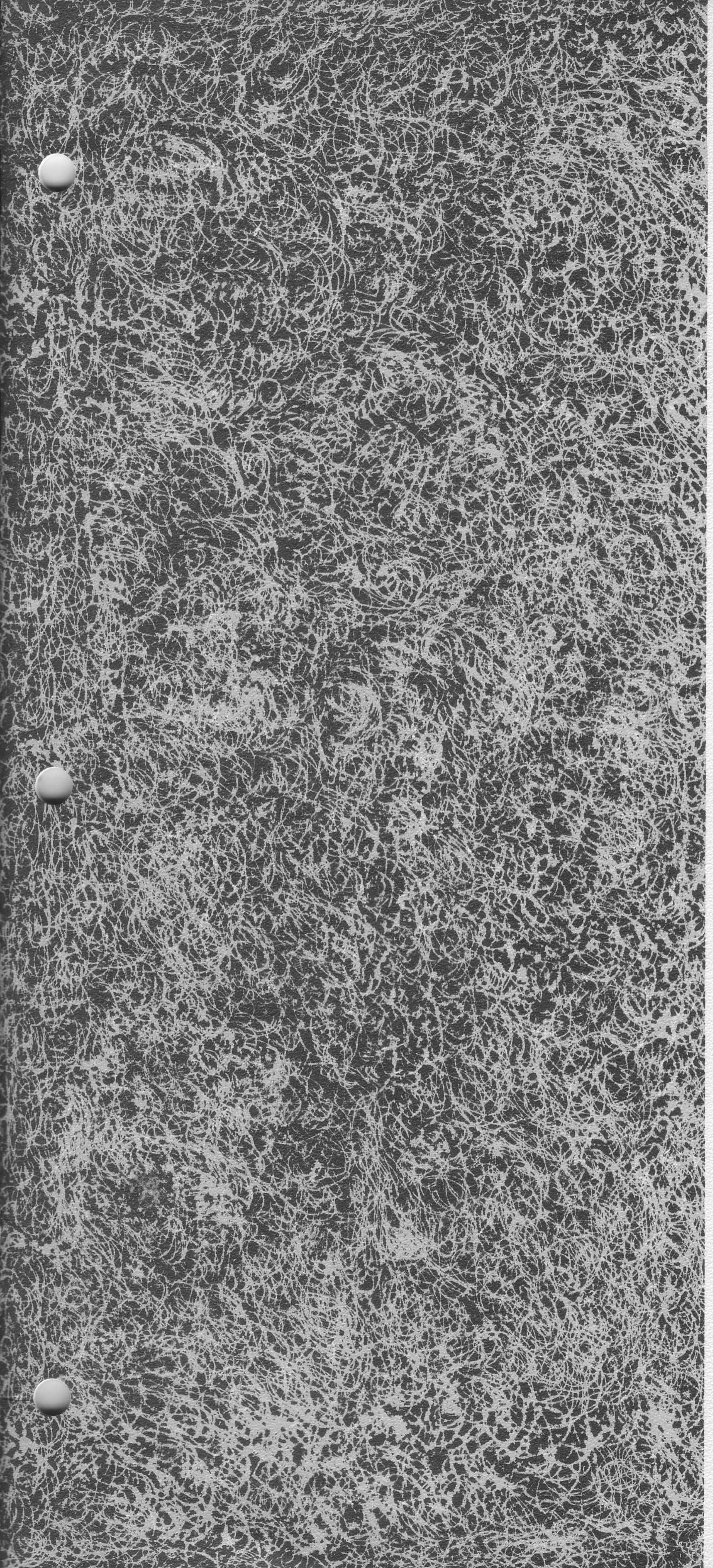


NO. 91-19A-5
& NO. 91-19A-13
APPLICATIONS
ENGINEERING
PUBLICATION

VTP

DIRECT VIEW DISPLAY
HALF-TONE STORAGE TUBES

OPERATION OF TONOTRON & MULTI-MODE TONOTRON TUBES

CREATING A NEW WORLD WITH ELECTRONICS

HUGHES

HUGHES AIRCRAFT COMPANY
VACUUM TUBE PRODUCTS DIVISION
OCEANSIDE, CALIFORNIA

TABLE OF CONTENTS

SUBJECT **PAGE**

DRAWINGS AND CURVES

FIGURE **PAGE**

PART ONE - OPERATION OF TONOTRON TUBES

PART TWO - OPERATION OF MULTI-MODE TONOTRON TUBES

PART ONE

OPERATION OF TONOTRON TUBES

GENERAL

A direct-view display storage tube is an electron tube into which information is introduced as an electrical signal, and read out at a later time as a visible output corresponding to the stored information.

The "half-tone" storage tube, represented by the Hughes Tonotron tube, accepts and stores intensity-modulated information and presents at the viewing screen a visible output whose relative brightness levels are proportional to modulation amplitude.

In the performance of its intended function, the storage tube exhibits two inherent characteristics of significant importance; these are (1) the capability of delivering a brilliant, non-flickering, uniform display, and (2) an ability to control display persistence.

Display brightness is high . . . several thousand footlamberts for some types . . . resulting from the use of a constant source of electrons to illuminate the viewing screen phosphor during the viewing operation. Thus the intermittent character of the writing gun beam has no direct effect on the finite levels of display brightness.

Persistence of the display is controllable because it is primarily dependent upon quantities of electric charge established at a storage surface, and is not perceptibly affected by the characteristic of the viewing screen phosphor. Typical display times for half-tone storage tubes range from several seconds to several minutes, depending on tube type and viewing screen diameter, but these times may be considerably extended by the use of special techniques.

Direct-view display storage tubes are available in several viewing screen diameters from three inches to twenty-one inches. They may use electrostatic or electromagnetic focus and deflection, or combinations of the two. For the purpose of this presentation, a representative 5-inch size electrostatic type is assumed, the internal construction of which is shown in Fig. 1, Basic Storage Tube Structure.

DESCRIPTION OF THE TUBE

The essential components of the tube illustrated in simplified form in Fig. 1 are: (1) the WRITING GUN, (2) DEFLECTION SYSTEM, (3) FLOODING GUN, (4) COLLIMATING SYSTEM, and (5) the STORAGE-DISPLAY ASSEMBLY.

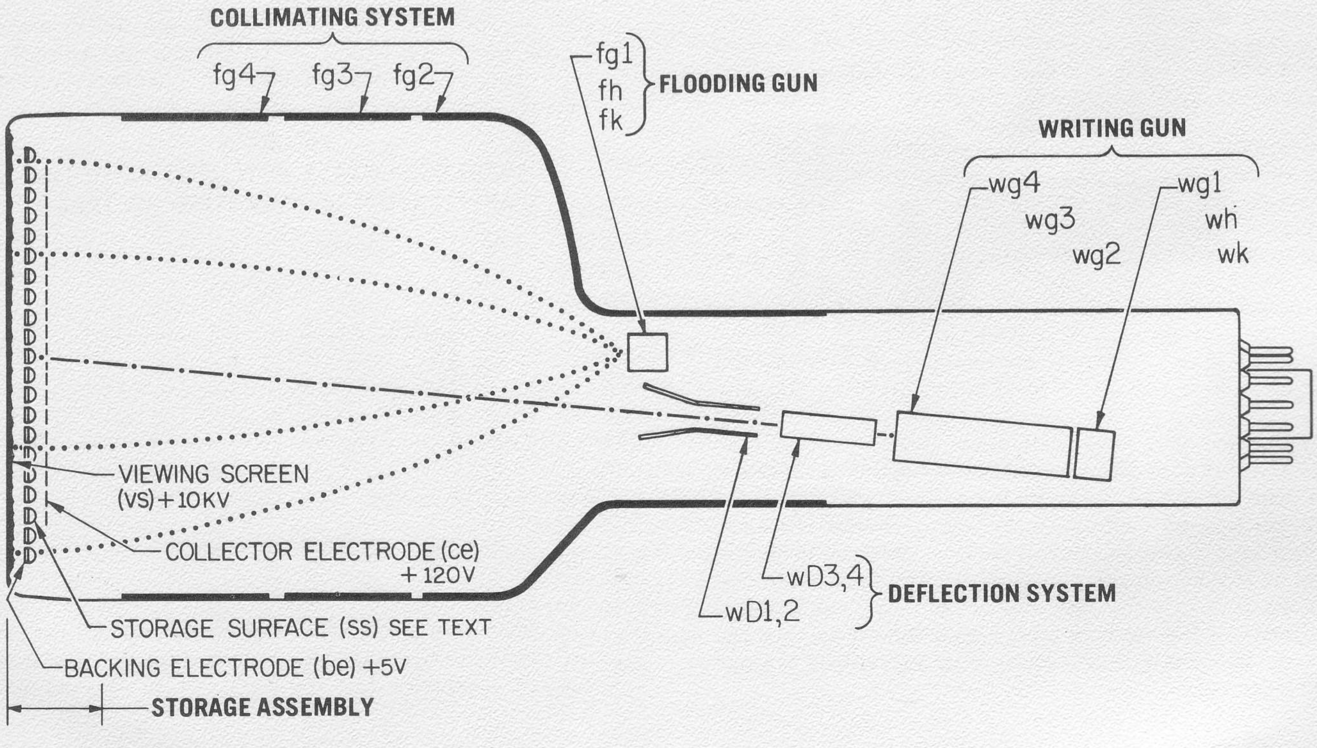
The writing gun and deflection system serve to generate a sharply focused high energy beam and position it at the proper place on the storage surface.

The flooding gun provides a constant flow of low energy electrons, which is referred to as the "flooding beam". Due to the electron lens action of the collimating system, flooding beam electrons are caused to approach the storage surface orthogonally, and uniformly over its entire area. In Fig. 1, the electrons shown penetrating to the viewing screen represent those which excite the viewing screen phosphor to produce the visible display. Flooding beam electrons are also used to erase the storage surface.

The elements comprising the storage assembly are, from right to left in Fig. 1, the collector electrode, the storage surface which is a thin film dielectric that stores written information, the fine mesh backing electrode supporting the storage surface and the aluminized viewing screen.

Tube element symbols follow the generally accepted nomenclature for storage tubes. Electron gun elements are identified by letters "w" or "f" for the writing and flooding functions respectively. Gun elements from the cathode outward toward the storage assembly (except the deflecting electrodes) are designated "grids" and numbered serially from the cathode end. The storage assembly elements are designated according to the function they perform.

FIGURE 1
BASIC STORAGE TUBE STRUCTURE

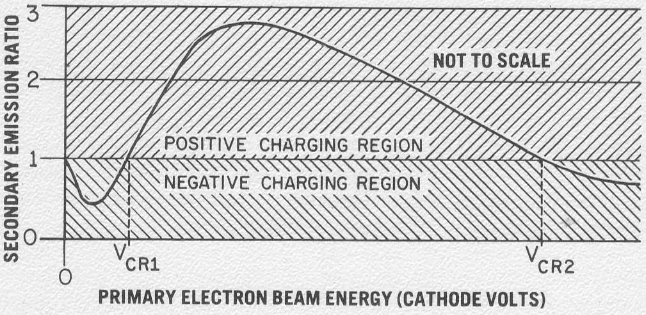


NATURE OF THE STORAGE SURFACE

A charge storage tube is an electron tube in which information is retained on a storage surface in the form of a pattern of electric charges. This definition is applicable to the direct view display half-tone storage tube.

The operation of the charge storage tube is based upon the property of the storage surface to charge in a positive or negative direction, depending wholly upon the energy of the incident electron beam. Such a property is made possible by the secondary emission characteristic of the storage dielectric. Refer to Fig. 2, Typical Secondary Emission Curve.

FIGURE 2
TYPICAL SECONDARY EMISSION CURVE FOR A STORAGE SURFACE DIELECTRIC



Between 0 volts of primary beam energy and the "first cross over voltage" V_{CR1}, approximately 40 volts, the curve indicates a secondary emission ratio less than unity. Therefore in this operating region, more primary electrons are accumulated at the storage surface dielectric than are secondary electrons emitted, and the storage surface is charged in a negative direction.

In the region between the first cross over voltage V_{CR1} and the "second cross over voltage" V_{CR2}, whose value might be as great as 20 - 25 kilovolts, the secondary emission ratio is greater than unity; the number of secondary electrons emitted at the storage surface exceeds the number of primary beam electrons arriving, and the storage surface is charged in a positive direction.

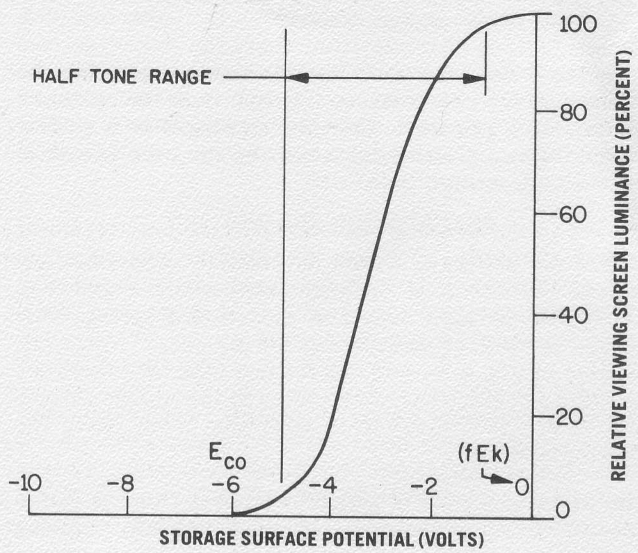
The writing of stored information occurs when the storage surface is charged in a positive direction. This is accomplished by the writing gun, whose beam energy levels lie within the range of values required to produce secondary emission ratios greater than unity.

Conversely, erasure of stored information takes place when the storage surface is made increasingly negative. The flooding gun beam, whose energy level is below the first cross over voltage, is used to perform this function.

As has previously been stated, the storage surface consists of a thin film dielectric deposited upon the electron-gun side of a fine mesh backing electrode. The area adjacent to each opening in the storage surface mesh is said to be a storage element, each of which controls the number of flooding gun electrons allowed to pass through its own area into the viewing screen field. The relative brilliance of the viewing screen as a function of storage surface potentials is shown in Fig. 3, Typical Storage Characteristics.

NATURE OF THE STORAGE SURFACE (CONT.)

FIGURE 3
TYPICAL STORAGE CHARACTERISTIC



The curve of Fig. 3 reveals one fact important to note: that storage surface potentials in the half-tone range of operation are negative with respect to the flooding gun cathode. Each storage element comprising the storage surface may be considered a virtual "control grid" for flooding gun electrons approaching its area. Thus, if a modulated writing gun beam scans all the storage elements of the storage surface, a varied charge pattern is established which causes varied levels of luminance in exactly the same pattern to appear at the viewing screen.

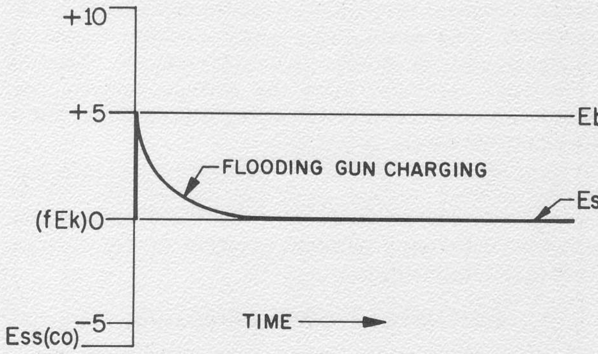
PRINCIPLES OF OPERATION

INITIAL OPERATION

When operation of the tube is initiated, the positive potential applied to the backing electrode, 5 volts, also appears at the storage surface because of the large capacitive coupling between them.

Low energy collimated flooding gun electrons, attracted by the positive gradient, accumulate on the storage surface, rapidly charging it to flooding gun cathode potential. This sequence is shown graphically in Fig. 4.

FIGURE 4
STORAGE SURFACE POTENTIAL AT INITIAL APPLICATION OF OPERATING VOLTAGES



The storage surface, once at flooding gun cathode potential, can accept no additional electrons, and all the flooding gun electrons that subsequently approach the storage surface accelerate into the high voltage viewing screen field.

PRINCIPLES OF OPERATION (CONTINUED)

INITIAL OPERATION (CONT.)

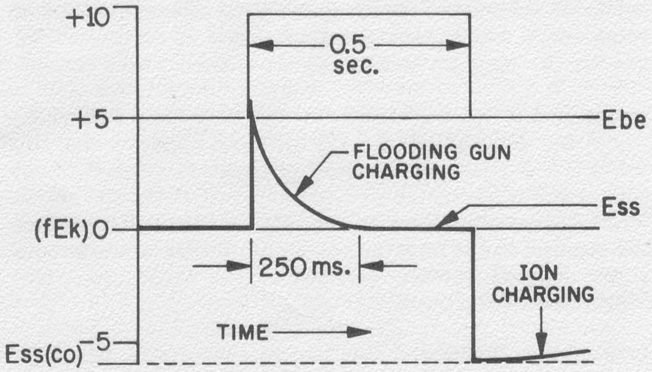
The result of this action is shown on the curve of Fig. 3, Typical Storage Characteristic; where the storage surface potential is the same as that of the flooding gun cathode, the relative viewing screen luminance is 100 percent. At this time, therefore, the viewing screen is in a state of maximum uniform brightness, and the tube is said to be in a "fully written" condition.

PREPARATION FOR WRITING

Before the writing of stored information is possible, the storage surface must be made sufficiently negative to extinguish the light output at the viewing screen. This occurs at "storage surface cut off potential" which, according to Fig. 3, is −6 volts for this tube. At this value, flooding gun electrons are repelled at the storage surface and return to the collector electrode; none reach the viewing screen.

The procedure used to arrive at this condition is called ERASING, and is accomplished most simply by applying a single manually initiated positive pulse of appropriate duration to the backing electrode. Events during the process are shown in Fig. 5, Storage Surface Potentials During Single Erase-pulse Operation.

FIGURE 5
STORAGE SURFACE POTENTIAL DURING SINGLE ERASE-PULSE OPERATION



When the positive pulse having an amplitude equal to the value of storage surface cut off potential is applied to the backing electrode, the storage surface rises a like amount due to their capacitive coupling, but electrons from the flooding gun charge it back down to flooding gun cathode potential. At the end of the pulse, the backing electrode potential drops by the same amount that it had been raised, and again the storage surface is carried capacitively with it, dropping to −6 volts. No flooding gun electrons can land upon the storage surface, now negative with respect to the flooding gun cathode, and a stable condition exists.

Thus, the storage surface is driven to cut off, erasure is complete, and the tube is ready for the writing operation. (Note: the "ion charging" notation in Fig. 5 is explained in the following section.)

WRITING STORED INFORMATION

If a modulated signal is introduced at the control grid (grid no. 1) of the writing gun, its sharply focused beam becomes energized with an intensity proportional to the signal voltage amplitude, and by means of the deflection system, is made to scan the storage surface.

WRITING STORED INFORMATION (CONT.)

By the mechanism described in the section "Nature of the Storage Surface," a charge in a positive direction is established at every storage surface element struck by the beam. In this manner, a "charge pattern" is WRITTEN on the storage surface area.

Since the number of flooding gun electrons permitted to pass into the viewing screen field is proportional to the amount of positive-going charge induced at each storage element (refer to Fig. 3.), the display pattern becomes a reproduction of the charge pattern written on the storage surface. The length of time after writing, during which an acceptable output can be read, is termed "rentention time," and is determined chiefly by "ion effects" as described below.

Flooding gun electrons do not disturb the charge pattern because, as shown in Fig. 3, the storage surface is negative with respect to the flooding gun cathode over the entire half-tone range; in addition, losses due to storage surface dielectric leakage are very small. Therefore, if storage time were governed only by these relatively stable factors, a charge pattern might prevail without appreciable deterioration for some 100 hours or more.

However, the charge pattern is adversely affected, consequently imposing a limitation on storage retention time, because of the presence of residual-gas molecules within the tube.

As these gas molecules collide with flooding gun electrons, positive ions are formed and are accelerated toward the negatively charged storage surface. Upon landing of these ions, the storage surface is gradually charged in a positive direction, as shown by the "ion charging" notation in Fig. 5. The result is a gradual brightening of the display background, accompanied by a corresponding gradual loss of display contrast.

Generally, the limit of acceptable output occurs when the background brightness rises to approximately 20 percent of equilibrium brightness, at which time the storage surface may be erased and a new cycle begun.

THE ERASING OPERATION

Erasure is the process of charging the storage surface in such a way as to eliminate previously stored information, and at the same time prepare the storage surface for subsequent writing. The operation may be carried out by a single short pulse or a train of very short pulses, depending upon operational requirements.

Where it is necessary that stored information be removed at once, erasure is accomplished by a single manually initiated or electronically timed positive pulse applied to the backing electrode. This technique, termed "static" erasure, is described in the section "Preparation for Writing" and is illustrated in Fig. 5.

If, however, it is necessary or desirable to control the degree of display persistence, pulse-train erasure is employed. In this method, referred to as "dynamic" erasure, storage surface potentials are made to become increasingly negative in discrete steps, by amounts governed by pulse amplitude and pulse-train duty cycle.

THE ERASING OPERATION (CONT.)

Of first importance in dynamic erasure is the determination of correct pulse amplitude. In Fig. 6, Effect of Erase-Pulse-Train on Unwritten Storage Surface, this is shown to be a value sufficient to overcome incremental ion charging so that storage surface potential is held at just cut off. Although the backing electrode potential wave form of Fig. 6 represents a 6 volt pulse amplitude, in actual practice a somewhat greater value may be required to compensate for capacitive and source impedance effects.

FIGURE 6 . . . EFFECT OF ERASE-PULSE-TRAIN ON UNWRITTEN STORAGE SURFACE

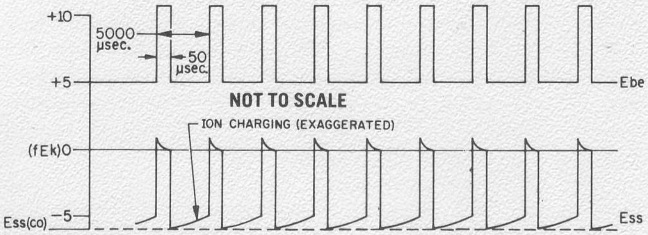
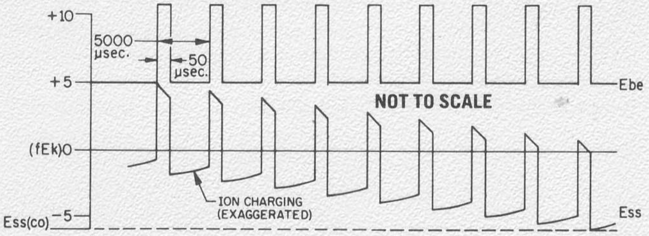
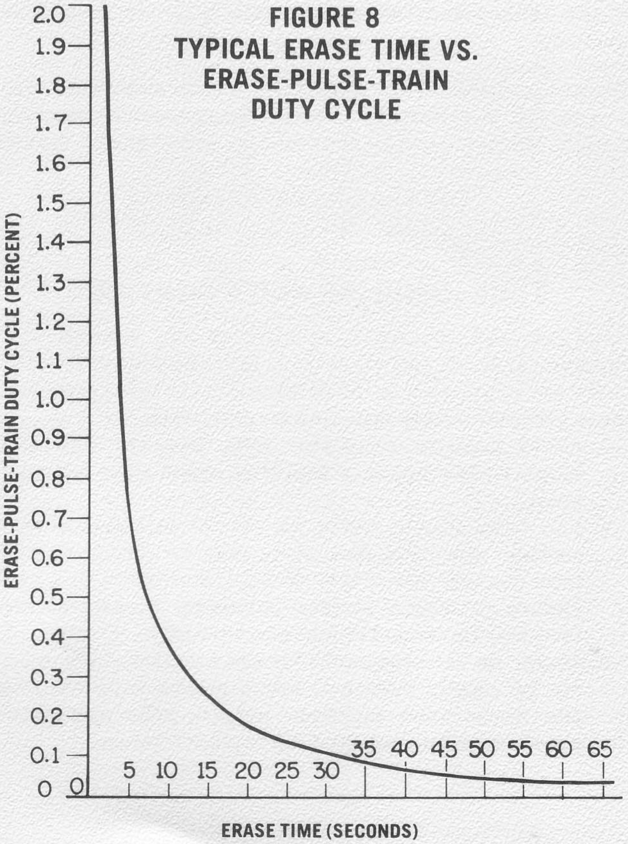


FIGURE 7 . . . GRADUAL ERASURE OF STORED WRITING BY ERASE-PULSE-TRAIN



The effect of dynamic erasure on a written storage surface is demonstrated in Fig. 7, Gradual Erasure of Stored Writing by Erase-Pulse-Train. In this example, the erase-pulse interval and duration indicate a repetition rate of 200 pulses per second, and a duty cycle of 1.0 percent. From the curve of Fig. 8, the time required for the storage surface to go progressively negative to cut off is approximately 5 seconds.

FIGURE 8
TYPICAL ERASE TIME VS. ERASE-PULSE-TRAIN DUTY CYCLE



Since erase time is a function of erase-pulse-train duty cycle, an extension of this time may be achieved either by decreasing the repetition rate . . . the practical limit being the point of discernible flicker . . . or by decreasing pulse duration.

The control of display persistence may be accomplished by adjusting the essentially independent erasing and writing operations so that they are carried out simultaneously.

It is interesting to note at this point that the background illumination is also a function of the erase-pulse-train duty cycle. Since the tube face goes to 100 percent brightness for the duration of each individual erase-pulse, and since each pulse is very brief, the eye integrates these light flashes into an overall average which increases as the pulse-train duty cycle increases.

The bright flash occuring during a single erase-pulse, or those occurring during pulse-train erasure may be eliminated by causing the viewing screen voltage to drop below 2 kilovolts for the duration of each pulse. Application circuitry is available on request.

VIEWING TIME

The principal limitation on storage retention time is the "ion charging" effect at the storage surface; this process is described in the section "Writing Stored Information." The degree of limitation imposed depends upon the pressure of residual gas for a given tube type and size, and may range from several seconds to several minutes; 60 to 90 seconds is representative for a 5-inch Tonotron type.

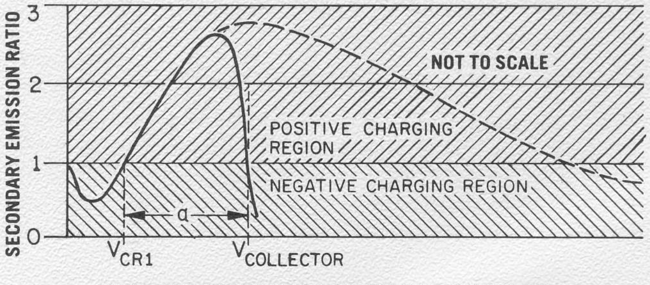
There are several methods of extending storage time, a common one of which utilizes a means to reduce the density of the flooding beam and thus reduce the ion charging effect proportionally. However, with this method, light output is reduced in like proportion, so that the amount of storage extension time that is practicable is determined by the amount of light output trade off that is acceptable.

More complete information is included in the brochure "Application Notes; Extending Storage Time," which is available on request.

OPERATING PRECAUTIONS

Should the circumstance arise whereby the storage surface potential goes beyond the first cross over, flooding beam electrons will have sufficient energy to support a secondary emission ratio greater than unity and drive the storage surface further toward collector electrode potential. This condition is referred to as RUNAWAY CHARGE, and is illustrated in Fig. 9 as the region designated "a".

FIGURE 9
TYPICAL SECONDARY EMISSION CURVE LIMITED BY COLLECTOR ELECTRODE POTENTIAL



OPERATING PRECAUTIONS (CONT.)

Runaway charge may be initiated in several ways:

1. Excessive writing beam current; this sometimes results from an attempt to achieve greater writing speed, or viewing screen brightness, than that which the tube is rated to provide.
2. Excessive writing beam dwell time; in which the writing beam scanning speed is too slow for a given value of beam current. This is also apt to occur in the event of deflection failure.
3. Writing when the flooding beam is turned off; where the limiting action of the flooding beam which prevents the storage surface potential from exceeding that of the flooding gun cathode is absent.
4. Applying erase pulses whose amplitude is too great.

If any of these irregularities is promptly observed and the writing operation stopped at once, in general, no permanent damage at the storage surface will be incurred. It is important to note, however, that these are storage surface effects, and may be present even though the viewing screen is de-energized. In this event, they would not be apparent at all.

Even if the viewing screen is energized, equilibrium brightness is reached at the time the storage surface has risen to flooding gun cathode potential, and a further positive increase produces but very slight additional light output. For this reason, abnormal conditions would still not be obvious, and it is therefore necessary that precautions be taken to forestall them.

Runaway charging at the storage surface, if allowed to develop, may manifest itself by these indications:

1. Inability to erase, caused by regenerative, rather than degenerative action of the flooding beam.
2. Brilliant flashing at random locations on the viewing screen, due to arcing between segments of the storage surface, or between the storage surface and backing electrode.
3. Constant bright or dark patterns, indicating damage to corresponding areas of the storage surface dielectric.

Runaway charge, if uncorrected, could bring about arcing between the backing electrode and viewing screen, resulting in the destruction of the aluminized phosphor coating in the arc area. Arc damage could also be caused by a high impedance in series with the backing electrode.

Provided that no permanent damage has been suffered by the storage surface, runaway charge may be overcome and normal operation of the tube resumed. With all other electrode potentials still applied, viewing screen voltage should be switched off, then the backing electrode disconnected from its supply and connected for a few seconds to the collector electrode. After reconnecting the backing electrode to its own supply and restoring proper viewing screen voltage, the tube should erase in the normal manner.

When initiating operation of the tube, the flooding beam should be energized before any writing is attempted, and at the end of operations; the writing beam should be de-energized before the flooding beam is turned off. This procedure avoids the dangers inherent in writing without the flooding beam on.

POWER SUPPLIES AND PROTECTIVE CIRCUITS

Static voltages required for the operation of the tube may be obtained from conventional power supplies. Provision should be made for convenient adjustment of the control grid voltages of both flooding and writing guns, and the potentials affecting flooding beam collimation and writing beam focus.

Since the voltages applied to the writing gun control grid, focusing electrode and accelerating electrode are referenced to the writing gun cathode, they may be readily furnished with a single negative supply and appropriate voltage divider network. This method is suitable for maintaining the ratio of focusing to accelerating voltages, required to maintain good spot size. Should separate power supplies be used, they must incorporate exceptionally good voltage regulation.

Due to the high internal voltage gradient between the backing electrode and viewing screen, it is advisable to provide protection against excessive surge currents. For the viewing screen, a limited energy type supply is preferred, with a high voltage protective resistor of 0.1 to 1.0 megohm, depending upon tube type and size, inserted in series with the viewing screen lead.

It is desirable to interlock both the writing gun control grid bias supply and the deflection voltage source with the writing gun cathode power supply in such a way that, should either the bias voltage or deflection voltage fail, the cathode supply is de-energized. This safety feature has the purpose of avoiding either excessive beam current or excessive dwell time, with their possible damaging effects.

MAGNETIC SHIELDING

Flooding beam collimation in a display storage tube may be adversely affected by magnetic fields having densities as low as 0.25 gauss. For this reason, operation of the tube within an appropriate magnetic shield is required.

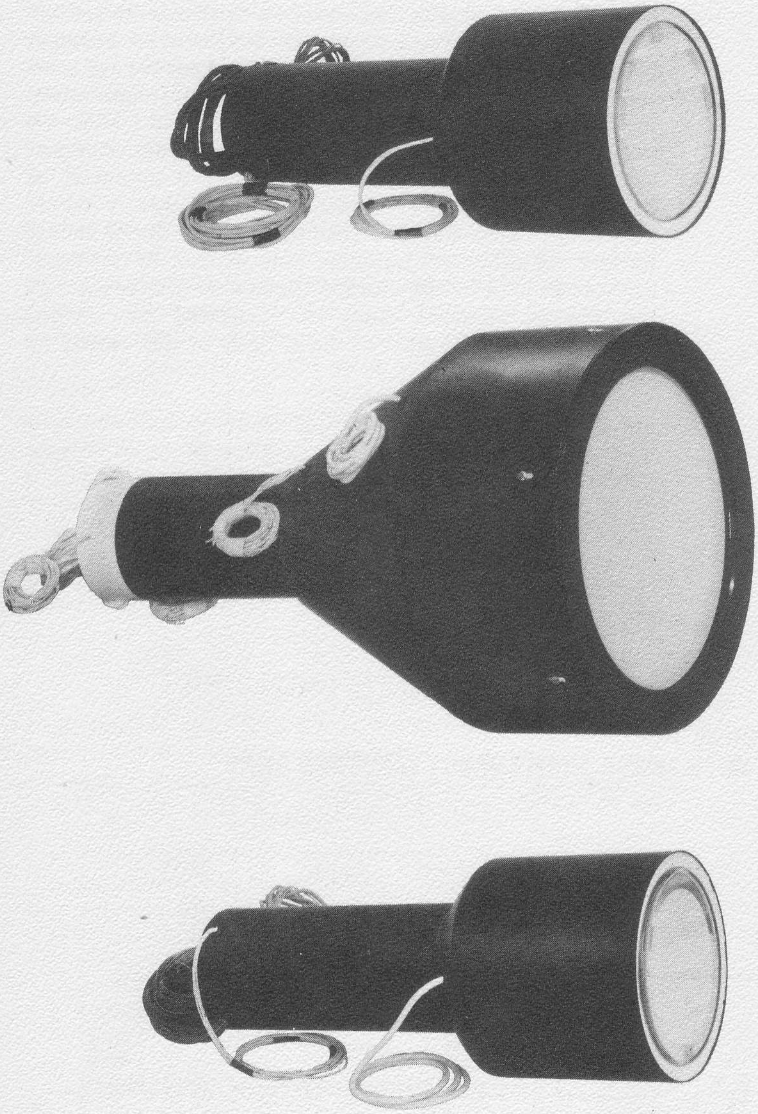
In addition, precautions should be taken to avoid exposure to random magnetic fields during transport or storage; for example, enclosing the tube in a magnetic shield container, including a face plate cover.

Specific data on shielding and demagnetization are available on request.

TUBE HANDLING AND MOUNTING

Handling and mounting procedures for conventional cathode ray tubes and other types having highly evacuated bulbs are applicable to the display storage tube; however, these precautions are repeated for emphasis:

1. Avoid bending connector pins, because this may cause undue stress or cracking in the glass to metal seals.
2. The tube should never be placed face down on a surface, since the face plate may be scratched and thus degrade the visual display. Moreover, this procedure creates a serious personnel hazard, as the tube may be caused to implode violently.
3. Under no circumstances should connector pin sockets be rigidly mounted, nor the tube supported by the neck; such methods may impose abnormal stresses on the glass, leading to glass fracture.



PART TWO

OPERATION OF MULTI-MODE TONOTRON TUBES

GENERAL

The Hughes *"multi-mode"* Tonotron tube is a new type of direct view display half-tone storage tube which is capable of selective erasure, and simultaneous presentation of stored and non stored information.

Selective erasure provides significant additional flexibility in direct view storage tube applications, since it makes possible the erasure from a display of whatever information is undesirable, without detriment to that which is necessary to retain. Moreover, by means of this feature, information can be erased into a fully written display, resulting in a dark trace presentation having higher contrast and appreciably greater resolution than that obtainable with conventional writing.

The non store mode of operation (sometimes referred to as "write through"), permits cathode ray type information such as reference markers, grid lines, or maps to be superimposed on the stored display with no serious degradation to the latter.

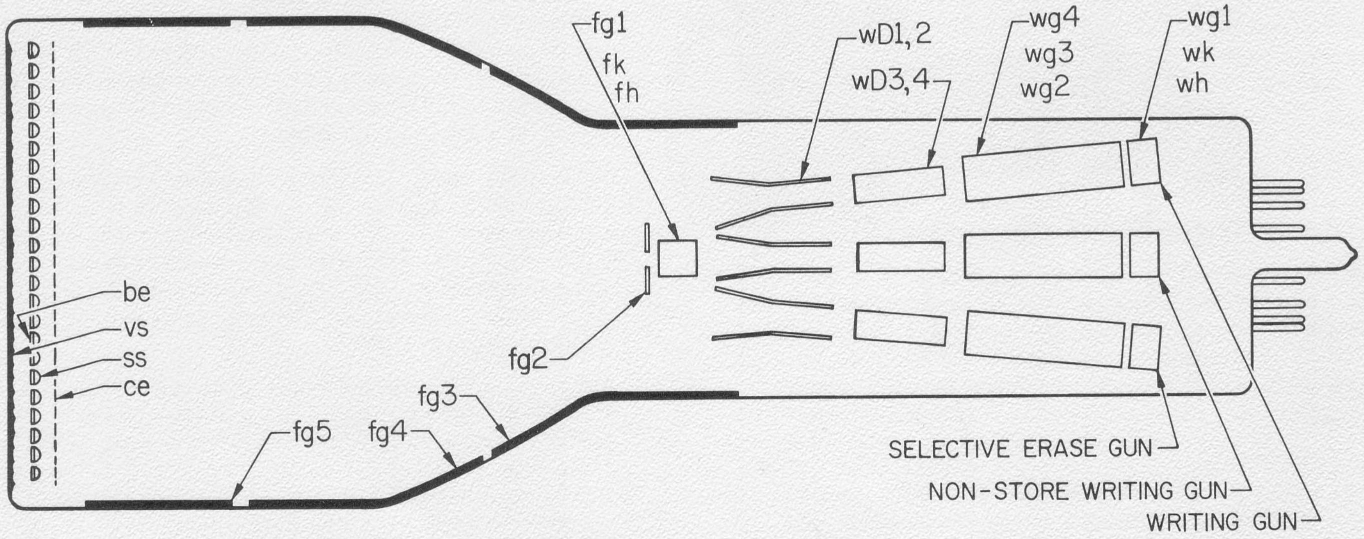
Inclusion of these features into direct view display halftone storage tubes has not previously been practical chiefly due to the nature of the secondary emission effects on which writing and erasing of stored information are based. However, in the *multi-mode* Tonotron tube, limitations imposed by secondary emission effects are surmounted by the use of a "dual effects" storage surface dielectric.

One effect, secondary emission, charges the storage surface in a positive direction, while the other, bombardment-induced-conductivity, charges it toward backing electrode potential which, under normal operating circumstances, is negative. The effect, and therefore the resulting charging direction, is selected by choice of the appropriate incident beam energy level.

At relatively low energies, about 2.5 kV, the secondary emission effect prevails and the storage surface is written with a positive charge. Conversely, at high energies, 6.5kV or greater, bombardment-induced conductivity becomes predominant and the storage surface charges toward backing electrode potential, thus erasing. At some intermediate beam energy level, near 4.5 kV, the charge deposited on the storage surface by secondary emission and that conducted toward backing electrode potential by bombardment-induced currents are very nearly equal, resulting in only a very slight effect on the stored charge pattern. In this circumstance, that portion of the beam not intercepted by the storage surface continues through the storage elements and, upon striking the viewing screen phosphor, produces the display of non stored information.

For the purpose of this presentation, a 5-inch electrostatic type multi-mode Tonotron tube incorporating three independent high energy electron guns is assumed, and is shown schematically in Fig. 10. The three guns are identified by the letters "w", "n", and "r", for the writing, nonstored writing, and selective erase guns respectively. For electrode symbol nomenclature, refer to Page 15 of this publication.

FIGURE 10
5-INCH MULTI-MODE TONOTRON TUBE WITH THREE HIGH ENERGY ELECTRON GUNS



NOTE:

ELECTRODE DESIGNATIONS FOR THE NON-STORE WRITING GUN AND SELECTIVE ERASE GUN ARE THE SAME AS THOSE SHOWN FOR THE WRITING GUN, EXCEPT THAT THE INITIAL LETTER BECOMES "n" AND "r", RESPECTIVELY, RATHER THAN "w"

BOMBARDMENT-INDUCED CONDUCTIVITY EFFECTS

Bombardment-induced conductivity may be defined as the ability of thin film insulators to conduct when subjected to bombardment by high energy electrons.

This effect is illustrated in Fig. 11A and 11B, where thin film dielectric storage surfaces are shown attached to conductive backing electrodes, and where electric fields having polarities as noted are applied. In Fig. 11A, when primary beam current I p bombards a region of the storage surface, a bombardment-induced current (an electron flow) Ic is caused to pass through that region. Under certain conditions, the induced current may be considerably greater than the primary current; a merit factor for the process is obtained by the ratio $\frac{I_c}{I_p}$, and is expressed as the conduction ratio C R. If, as shown in Fig. 11A, the polarity of the electric field is such that the direction of the induced current is the same as that of the primary current, the conduction ratio is said to be positive. In Fig. 11B the mechanism is the same, but since the electric field is reversed, the direction of the induced current (again taken to mean electron flow) is opposite to that of the primary current, and the conduction ratio is said to be negative.

FIGURE 11A **FIGURE 11B**

BOMBARDMENT INDUCED CURRENT

POSITIVE CONDUCTION RATIO **NEGATIVE CONDUCTION RATIO**

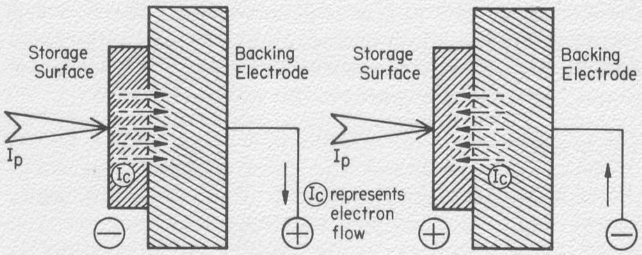
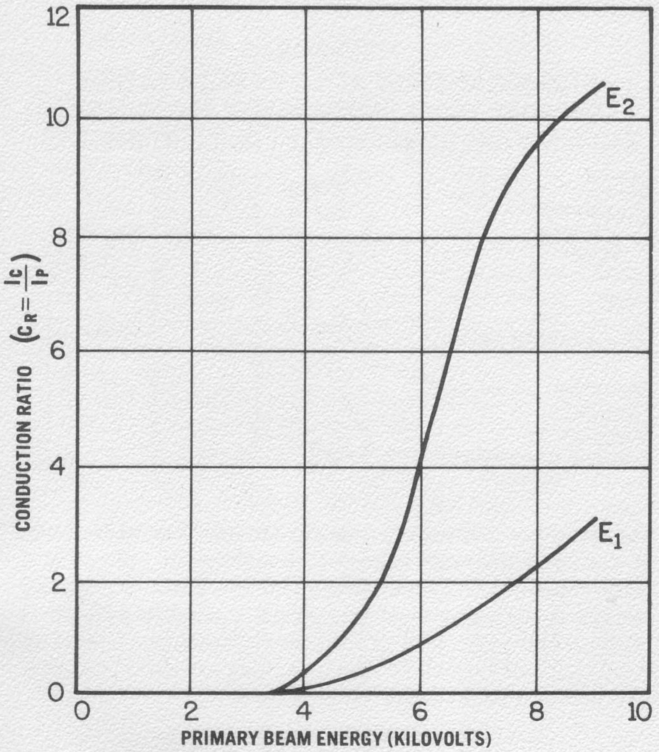


FIGURE 12
TYPICAL CURVES OF BOMBARDMENT INDUCED CONDUCTIVITY



The conduction ratio of a given dielectric material is dependent upon two factors: primary beam energy and the magnitude of the electric field. This is shown by the curves of Fig. 12, where conduction ratio is plotted against primary beam energy for two values of electric field, of which E2 is several times greater than E1 . Note that the conduction ratio remains negligible until primary beam energy reaches "critical voltage" – approximately 3.6 kV in this example, then begins to rise. In the region of critical voltage, the rate of change of conduction ratio is relatively small with either field; however, as primary beam energy is increased into the higher voltage range – 4.5 kV and greater, the conduction ratio curve for E2 , the higher value of field, is seen to be significantly more steep. When the primary beam current and the magnitude of the field are sufficiently great, the conduction ratio saturates at some maximum value. The curves of Fig. 12 represent a positive conduction ratio, but those showing negative values are essentially the same.

The bombardment-induced conductivity effect is explained by simplified semiconductor theory in this way:

When high energy electrons enter an insulator, they ionize atoms along their paths. In the process, some electrons in the insulator are raised into the conduction band, thus creating positive holes. If these electrons and holes come under the influence of an applied field, and recombination and trapping do not occur, they will acquire velocities in the appropriate direction and eventually reach the electrodes. Because an energy of only a few electron volts is necessary for the production of an ion pair, large numbers of pairs may be generated by high energy electrons.

In a 5-inch multi-mode Tonotron display storage tube, the unwritten storage surface potential is the same value as that applied to the backing electrode, typically –10 volts. When the storage surface is written, secondary emission charging effects shift this potential in a positive direction by some amount depending on writing beam intensity and scanning speed. To selectively erase the stored information, the storage surface is bombarded by a high energy beam, and by means of the negative charging effect of the bombardment-induced current, its potential is reverted toward the initial –10 volt value.

Because the conduction ratio decreases with decreasing field, the storage surface cannot discharge beyond backing electrode potential, and even though there may be small variations in the conduction ratio which affect the absolute value to which the storage surface discharges, they are of little consequence when the total voltage across the dielectric is considered.

Although the use of secondary emission effects is suitable for producing stored writing at the storage surface, use of the same effects for selective erasure is accompanied by several disadvantages. From Fig. 2, Page 5 of this publication, it may be seen that either beam energies below V_{CR1} , the first cross over, or in excess of V_{CR2} , the second cross over, would be required to achieve selective erasure by this means. The method in which beam energies below V_{CR1} are used proves unsatisfactory because selective erase speed is comparatively slow and resolution is poor. On the other hand, use of beam energies in excess of V_{CR2} , which may be as high as 20 - 25 kV, brings serious insulation and deflection

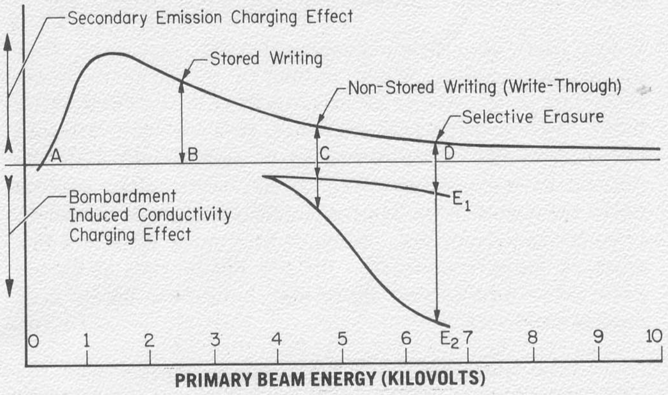
BOMBARDMENT-INDUCED CONDUCTIVITY EFFECTS (CONTINUED)

problems. Moreover, if even the most minute non-uniformities of the storage surface structure exist, then, because of the very shallow angle at which the secondary emission curve intersects unity-secondary emission ratio at V_{CR2}, non uniform erasure of the storage surface area results.

To overcome these inherent defects, the multi-mode Tonotron tube incorporates a storage surface having a "dual-effects" dielectric, in which secondary emission effects are utilized to charge the storage surface in a positive direction for stored writing, and bombardment-induced conductivity achieves a negative-going charging effect for selective erasure. Principles of operation of a dual-effects storage surface dielectric are discussed in the following section.

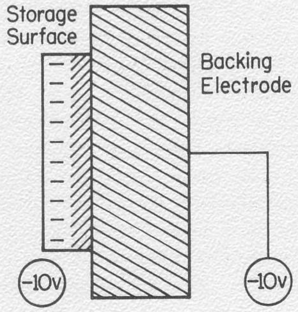
THE DUAL-EFFECTS STORAGE SURFACE

FIGURE 13
TYPICAL CHARGING CHARACTERISTICS OF A DUAL EFFECTS STORAGE SURFACE



Typical charging characteristics of a dual-effects storage surface are demonstrated by the curves of Fig. 13. Since both secondary emission effects and bombardment-induced conductivity effects are functions of primary beam energy, they are plotted on a common axis. The curve in the region above the primary beam energy axis represents positive-charging effects of secondary emission. The two below the axis show negative charging effects of bombardment-induced conductivity for two values of electric field; the lower value, E_1, corresponds to storage surface cut off, while the higher value, E_2, corresponds to storage surface full-brightness condition. Points "A", "B", "C", and "D" are keyed to the simplified functional diagrams of Figs. 14 to 17, inclusive, in which storage surface conditions are shown for the particular primary beam energy level concerned.

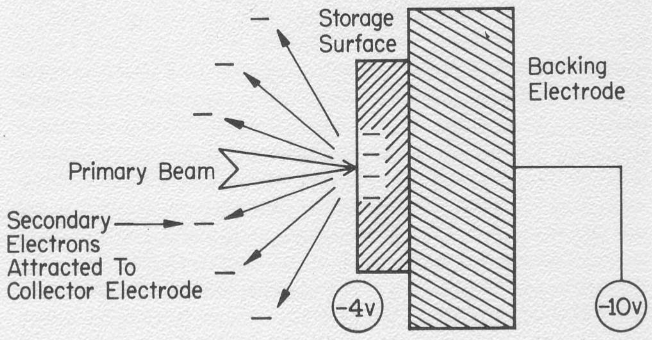
FIGURE 14
STORAGE SURFACE SHOWN CHARGED TO BACKING ELECTRODE POTENTIAL



Assume, initially, a stable condition such as that shown in Fig. 14, in which a typical value of −10 volts is applied to the backing electrode, and the potential at the storage surface is the same. As long as primary beam energy is zero, point "A" of Fig. 13, this condition will remain unchanged.

THE DUAL EFFECTS STORAGE SURFACE (CONTINUED)

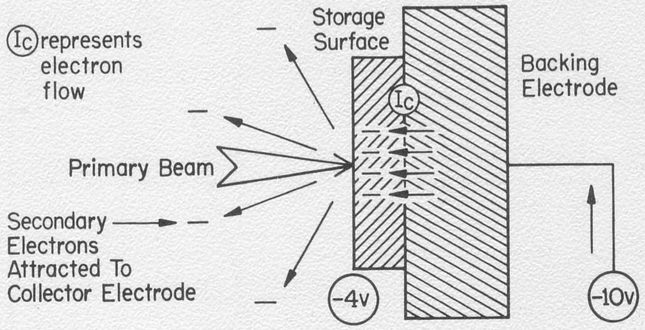
FIGURE 15
STORAGE SURFACE CHARGING IN POSITIVE DIRECTION BY 2.5 KV PRIMARY BEAM; ONLY SECONDARY EMISSION EFFECTS IN EVIDENCE



When the primary beam is energized and raised to approximately 2.5 kV, point "B" of Fig. 13, the secondary emission effect is near maximum, but bombardment-induced conduction, not yet having reached "critical voltage," is negligible; consequently, in Fig. 15, only secondary emission effects are in evidence. Since more secondary electrons are being emitted and attracted toward the collector electrode (+120 volts) than are being supplied by the primary beam, the storage surface charge is positive-going. This process, resulting in the writing of stored information, is the same as that described in the basic document for the conventional Tonotron tube (part 1 of this publication).

Fig. 13 shows that as the magnitude of primary beam energy is increased beyond the value required for writing stored information, secondary emission effects diminish, while bombardment-induced conductivity effects, beginning at about 3.6 kV, increase quite rapidly. At approximately 4.5 kV, point "C", the two opposing effects become virtually equal; that is, the positive-going charge effect at the storage surface due to secondary emission and the negative-going charge effect due to bombardment-induced conduction are very nearly the same.

FIGURE 16
STORAGE SURFACE AT 4.5 KV BEAM ENERGY SHOWING EQUAL AND OPPOSITE SECONDARY EMISSION AND BOMBARDMENT CURRENT EFFECTS



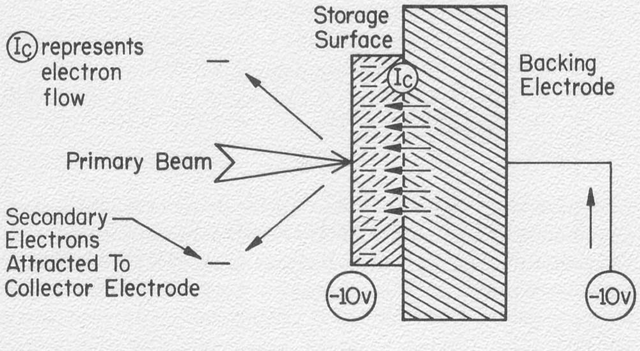
The situation is illustrated in Fig. 16, which points out that at the "equilibrium" value of electric field indicated, 6 volts, whatever the number of electrons emitted from the storage surface due to secondary emission, this number is replenished by the flow of electrons constituting bombardment-induced current I_c. Thus, in this particular instance, the resultant net charge change is zero.

THE DUAL EFFECTS STORAGE SURFACE (CONTINUED)

It is important, however, to recall from the discussion on Page 12 and from observation of the curves lying below the common base line in Fig. 13, that the conduction ratio for bombardment-induced conductivity is a function of both primary beam energy and the magnitude of electric field through the storage surface. Since the charge pattern on the storage surface may represent a relatively wide range of fields among the storage elements, perhaps from zero volts in an unwritten condition to 10 volts in a fully written condition, then the effect of the 4.5 kV beam will not be exactly the same on each. Consequently, unless the storage surface is at equilibrium value, as cited in Fig. 16, the non-stored writing beam will very slightly erase written areas and very slightly write erased areas. The degree to which stored information is degraded is not serious enough to make this mode of operation invalid; on the contrary, it is the best method presently known for accomplishing this function.

Point "D" of Fig. 13 indicates a primary beam energy of approximately 6.5kV, at which value the secondary emission effect has become relatively small since the storage surface secondary emission ratio is approaching the second cross over. At the same point, the conduction ratio for the higher value of field, E_2, is comparatively large, so that the bombardment-induced conductivity charging effect is predominant.

FIGURE 17
CONDITIONS WITH 6.5 KV PRIMARY BEAM; STORAGE SURFACE NEGATIVE-GOING DUE TO PREDOMINANCE OF CONDUCTION CURRENT



Under this condition, shown in Fig. 17, the number of secondary electrons being dislodged from the storage surface is far less than the number of electrons constituting bombardment-induced current I_c, so the storage surface is charging in a negative direction and selective erasure occurs.

As the erase process continues under sustained primary beam bombardment, the field across the storage surface, initially indicated as E_2 in Fig. 13, is progressively reduced until it approaches the value E_1, where the bombardment-induced conductivity and secondary emission effects are equal. When this condition is reached, continued primary beam bombardment results in the storage surface being held at this reduced potential.

OPERATION OF THE MULTI-MODE TONOTRON TUBE

The components of the example 5-inch multi-mode Tonotron tube shown in Fig. 10 are essentially the same as those of a corresponding conventional display storage tube, with one major exception: in the multi-mode tube, a special storage surface dielectric which exhibits the dual charging effects discussed in the preceding section is employed. Because of this single structural variance, the basic functions of the two types and, consequently, their operating conditions, are quite different.

The primary objective in a three high energy gun conventional tube is to generate a composite display of several independent input signals without need of time sharing. All three guns are therefore writing guns, operated at approximately the same cathode potential, say –2.5 kV, and, in order that maximum flooding beam current occurs at full brightness, a positive potential of about 5 volts is applied to the backing electrode.

In comparison, each of the high energy guns of the multi-mode tube performs a separate and distinct function, which requires operation of their cathodes at different potentials. Approximate voltages applied to the various cathodes are: writing gun ("w"), –2.5 kV, non store writing gun ("n"), –4.5kV, and selective erase gun ("r"), –6.5kV. Also, to make possible the utilization of bombardment-induced conductivity effects for achieving non stored writing and selective erasure, a negative 5 to 12 volt potential at the backing electrode is necessary.

The process of writing stored information is the same as that in conventional tubes, as mentioned in the preceding section. Display erasure, also, may be carried out by conventional means; that is, if an appropriate positive-going erase-pulse train is applied to the backing electrode, flooding beam erasure of the entire presentation will occur.

Methods available for erasure are not restricted to the flooding beam technique alone, however; provision is also made for selective erasure, whereby partial or complete erasure of very small, discrete areas of the display is possible. And erasure by either means may be carried out simultaneously with, or independently of, the other.

The selective erase feature of the tube is used to advantage in a variety of ways. For example, if the erase beam is made to just precede the writing beam scan, stored information may be retained at optimum brightness until immediately before the next writing sequence. Or, in a situation where information changes from sweep to sweep, the use of selective erasure prevents the smearing caused by the display of successively stored images. By appropriately programming the selective erase beam, any undesirable information may be erased without disturbance to that which is necessary to retain.

OPERATION OF THE MULTI-MODE TONOTRON TUBE (CONTINUED)

High contrast "dark trace" displays may be obtained by using the selective erase gun as a writing gun. In this mode, it is necessary that the viewing screen be initially in full brightness condition, which can be brought about readily by scanning the storage surface with the 2.5 kV writing beam. The erase gun grid is then modulated as the erase beam is scanned over the storage surface, producing a black image on a white background. If a "positive" rather than a "negative" presentation is desired, it is necessary only to invert the signals to the erase gun grid. The higher resolution gained by this method is due primarily to the greater energy of the erase gun beam.

Non stored writing makes it possible to add cathode ray type information to the display at any time, without otherwise seriously degrading it. Examples of information suitable for display in the non stored mode are reference markers, horizon lines, or even maps superimposed on the stored signals.

When the multi-mode tube is placed in service, but before regular operation is begun, it is necessary to collimate the flooding beam, and to establish the optimum operating potential at the backing electrode.

Under properly collimated conditions, electrons of the low energy flooding beam approach the storage surface orthogonally, and uniformly over the entire area. To reach such conditions, the following typical collimation adjustment procedure is suggested:

1. Apply recommended operating voltages to all electrodes.
2. Set backing electrode voltage at the positive end of its operating range, approximately –5 volts.
3. With the writing gun (2.5 kV beam), write the viewing screen to full brightness. From an initial value of zero volts, increase the flooding gun control-grid bias in a negative direction until just beyond the condition of full viewing screen coverage, then go back to the full coverage point.
4. Set flooding gun grid no's 3, 4, and 5 at the voltages specified on the label attached to the tube, then make coarse adjustments to obtain uniform full viewing screen coverage.
5. Increase backing electrode voltage in a negative direction until the display fades to a low half tone level.
6. Adjust flooding gun grid no. 5 for best possible uniformity; make fine adjustments with flooding gun grids no. 4 and no. 3.
7. Return the backing electrode to about –5 volts and repeat steps 3, 4, 5, and 6; re-write the display after each adjustment until no further improvement in uniformity can be observed.

When the backing electrode potential is at optimum value, the best balance between storage time and completeness of selective erasure occurs. Unless this balance is established, either storage time will be less than the maximum value possible, or selective erasure to cut off may not take place, depending on whether the backing electrode voltage is excessively negative, or positive, respectively. A recommended procedure for reaching optimum backing electrode potential is as follows:

1. Set backing electrode voltage at the positive end of its operating range, approximately –5 volts.
2. Using the writing gun (2.5 kV beam), write the viewing screen to full brightness.
3. With the selective erase gun (6.5kV beam), scan continuously across the display with video drive at intermediate level; increase backing electrode voltage in a negative direction until erasure to just full black occurs.
4. Check the effect of the adjustment on both writing and erasing by repeating steps 2 and 3.
5. Now with the applied video drive adequate for the scanning speed used, the display should now go to full black in a single scan. If not, make a fine adjustment at the backing electrode to a slightly more negative value.

Although the "Operating Precautions" section and subsequent sections of part 1 (pages 7 & 8) are concerned with the conventional Tonotron display tube, the provisions of these sections apply in the same measure to the multi-mode version. In addition, it should be noted that since substantially higher voltages are used with the multi-mode tube, insulation and isolation requirements are correspondingly more severe and must be taken into account.

Should tracking accuracy among the high energy guns be of major significance in a given application, an improvement in this characteristic may be obtained by using a multi-mode Tonotron tube having fewer than three guns. The various modes of operation may then be accomplished by means of appropriate pulse techniques. Application information is available on request.

GLOSSARY OF STORAGE TUBE TERMS

CATHODE RAY STORAGE TUBE

A storage tube in which the information is written by means of a cathode ray beam.

CHARGE STORAGE TUBE

A storage tube in which the information is retained on a storage surface in the form of a pattern of electric charges.

COLLIMATE

To modify the paths of electrons in a flooding beam so that they become more nearly parallel as they approach the storage assembly.

CROSS OVER VOLTAGE

The voltage of a secondary emitting surface, with respect to cathode voltage, at which the secondary emission ratio is unity.

DECAY

A change in magnitude or configuration of stored information for any reason other than writing or erasing.

DISPLAY STORAGE TUBE

A storage tube into which the information is introduced as an electrical signal, and read at a later time as a visible output corresponding to the stored information.

EQUILIBRIUM BRIGHTNESS

The viewing screen brightness occurring when the tube is in a fully written stored condition.

ERASE

To reduce by a controlled operation the amount of stored information.

HALF-TONES

Output levels, each related to a different input, that can be distinguished from one another regardless of location on the storage surface.

ION CHARGING

Spurious charging or discharging caused by ions striking the storage surface.

READ

To observe the stored information at the viewing screen.

VIEWING TIME

The time during which the storage tube is presenting a visible output corresponding to the stored information.

WRITE

To establish stored information corresponding to the input signal.

WRITING SPEED

Lineal scanning rate of the beam across the storage surface in writing.

DISPLAY STORAGE TUBE NOMENCLATURE

(From JEDEC Publication No. 33, August 1961)

The nomenclature and symbols listed below refer to a generalized tube of the display storage type.

NOMENCLATURE	SYMBOL
Writing gun (write gun)	w
Writing gun (write gun) heater	wh
Writing gun (write gun) cathode	wk
Writing gun (write gun) grids, numbered serially after cathode	wg1, wg2
Writing gun (write gun) deflecting electrodes	wD1,2-wD3, 4
Flooding gun (flood gun)	f
Flooding gun (flood gun) heater	fh
Flooding gun (flood gun) cathode	fk
Flooding gun (flood gun) grids, numbered serially after cathode	fg1, fg2
Ion repeller (if used)	ir
Collector electrode	ce
Storage surface	ss
Backing electrode	be
Screen (viewing screen)	vs

NOTES

1. *Where more than one gun serves a similar function, use w1 for the first writing gun, w2 for the second writing gun, f1 for the first flooding gun, etc.*
2. *Where a gun is designed specifically for either selective erasure or non-store writing, use "r" or "n", respectively, in place of "w" for writing or "f" for flooding.*
3. *Any mesh or mesh-like structure lying in a plane perpendicular to the axis of the tube is named by its function and is not included in the grid numbering system.*
4. *Voltages on specific electrodes are expressed in the following manner:*
    - a. *Cut-off voltage on grid no. 1 (w2g1) of writing gun no. 2: w2E(co)c1.*
    - b. *RMS voltage on grid no. 1 (w2g1) of writing gun no. 2: w2Eg1.*
    - c. *DC voltage on grid no. 4(fg4) of flooding gun: fEc4.*
    - d. *Voltage on the screen: Evs.*

You are invited to write for information on the following product lines:

DIRECT VIEW STORAGE TUBES

3-inch, 4-inch, 5-inch, 7-inch, 10-inch, 16-inch and 21-inch Tonotron* Tubes; Multi-Mode Tonotron* Tubes; Typotron® & Memotron® Storage Tubes; MTI Change Indicating Device; Projection Storage Tubes; Scan Converter Tubes, Large Screen Displays and Prototype Console Equipment.

HUGHES INSTRUMENTS

Digital Measuring Instruments; Memo-Scope® storage oscilloscopes; Memo-Corder* storage units (used with conventional, non-storage oscilloscopes); Diode Curve Tracers; Tono-Corder* (half-tone) storage units; Slow Scan TV Monitors; Digital Voltmeters; AC-DC and Ohms Converters.

ELECTRONIC WELDING EQUIPMENT

Precision weld heads; Welding Power Supplies; Weld Energy Computer; Precision Electronic Dental Welders; Laser Welders; Electronic Welding Education & Training Services.

VACUUM DEVICES

Ionization Gauge Tubes and Controls; Sorption Pumps; Ion Pumps (.2 to 1000 liters per second); Complete Compact Dry Vacuum Systems.

** Trademark of Hughes Aircraft Company*

Please call, wire or write:

HUGHES

HUGHES AIRCRAFT COMPANY

WESTERN OFFICE

HUGHES AIRCRAFT COMPANY
VACUUM TUBE PRODUCTS DIVISION
2020 OCEANSIDE BOULEVARD
OCEANSIDE, CALIFORNIA
PHONE: AREA CODE 714, 722-2101
TWX 714-278-7106

EASTERN OFFICE

HUGHES AIRCRAFT COMPANY
VACUUM TUBE PRODUCTS DIVISION
1 BALA AVENUE
BALA CYNWYD, PENNSYLVANIA
PHONE: AREA CODE 215, 664-3950
TWX 215-667-0404

INTERNATIONAL

HUGHES INTERNATIONAL
HUSINT S.A.
3, RUE AMI LULLIN
GENEVA, SWITZERLAND

CRST-35/3M/GL/4-64