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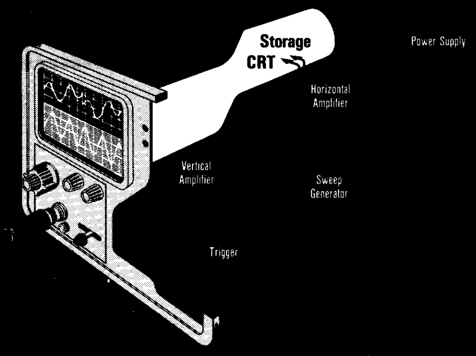
Circuit Concepts



SPLIT-SCREEN

Storage Cathode-Ray Tubes and Circuits

STORAGE CATHODE-RAY TUBES AND CIRCUITS

BY

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TEKTRONIX®

CIRCUIT CONCEPTS

SECOND EDITION, THIRD PRINTING JUNE 1969
062-0861-01
PRICE $1.00

BEAVERTON, OREGON 97005

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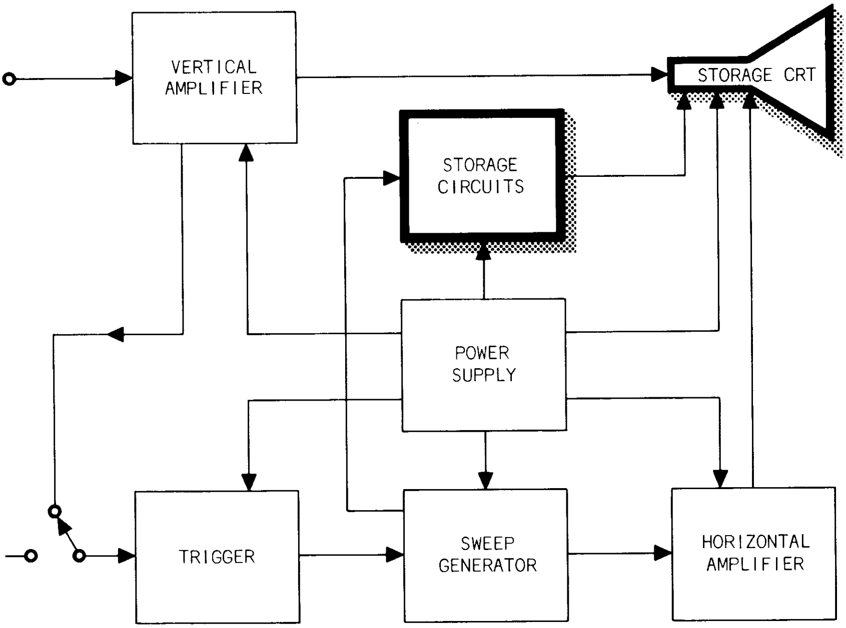

VERTICAL AMPLIFIER
STORAGE CRT
STORAGE CIRCUITS
POWER SUPPLY
TRIGGER
SWEEP GENERATOR
HORIZONTAL AMPLIFIER

1

INTRODUCTION

An electrical event that occurs only once can be displayed on a conventional cathode-ray tube but the display is present only for a short period of time. This time may range from a few microseconds to several seconds. A storage cathode-ray tube allows a display to be retained for much longer periods of time (up to an hour or more).

The retention feature of a storage CRT is useful when displaying signals which occur only once or have low repetition rates. In the past many single-shot events required that the display be photographed. Storage offers a convenient alternative. Signals having low repetition rates often cause a flickering of the display which is distracting. Storage allows these signals to be displayed at a constant light level.

Storage cathode-ray tubes may be classified as either bistable or halftone tubes. The stored display on a bistable tube has one level of brightness. A halftone tube has the capacity of displaying a stored signal at different levels of brightness. The brightness of a halftone tube is dependent on beam current and the time the beam remains on a particular storage element. A bistable tube, as the name implies, will either store or not store an event. All stored events have the same brightness.

Storage cathode-ray tubes may also be classified as either direct-viewing or electrical-readout type tubes. An electrical-readout type tube has an electrical input and output. A direct-viewing type tube has an electrical input but a visual output.

This book deals primarily with direct-viewing bistable storage tubes and associated circuit concepts. Basic direct-viewing storage tube principles develop in a step-by-step manner from a simple model to a functioning tube. Also covered: the characteristics of bistable tubes and associated typical circuitry.

2

BASIC PRINCIPLES OF DIRECT-VIEWING STORAGE TUBES

storage target

bombarding energy

A *storage target* is a surface having the ability to store information when bombarded by an electron beam. One of the key questions in analyzing storage target behavior is how much bombarding energy a beam of electrons has as it arrives at the storage target surface. The bombarding energy of an electron on a target is directly related to the potential difference between the voltage of the target and the voltage of the electron's source (usually a thermionic cathode). Consider Fig. 2-1 which shows a cathode, two accelerators, a decelerator and a target. Electrons are emitted from the heated cathode at zero volts, accelerated to +1000 V, decelerated to +500 V, accelerated to +3000 V and then bombard a target whose voltage is +200 V. The electron potential at the target is *+200 V*, because the high-speed electrons in the +3000 V field must pass through a decelerating field immediately surrounding the target.

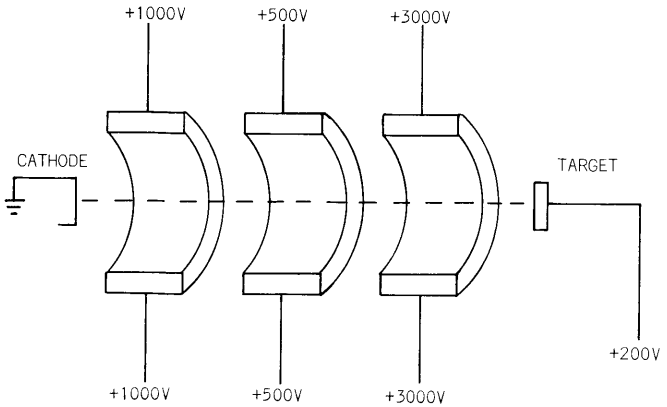


Fig. 2-1. Electron potential at target is equal to target voltage - cathode voltage.

This idea is emphasized at the outset, because more complex situations involving this principle will be discussed later. Remember, it is not necessary to know the whole history of an electron along its entire path in order to know its bombarding energy. If the voltage of the emitting source and the target is known, the electron potential can only be equal to the voltage difference.

electron potential

ELECTRON POTENTIAL = TARGET VOLTAGE - CATHODE VOLTAGE

The above formula implies that an electron emitted from a cathode at zero volts would have zero potential on arriving at a target held at zero volts. The assumption has been made that electrons emitted from a hot cathode have no initial velocity. It has been found that electrons emitted from *any* source (thermionic cathode, photoemission, field emission, and secondary emission) have an energy of emission associated with them. Electrons emitted from a thermionic cathode will have a range of energies which can be measured by the retarding potential required to repel the electrons. A target with a voltage of -0.01 volts will repel only about 10% of the electrons emitted from a hot cathode at 850°C at zero volts. When the target voltage is -0.1 volts, about 66% of the electrons are repelled and when the target is at -1 volts, about 99% of the electrons are repelled.

stopping potential

The potential required to repel substantially all of the electrons from a particular cathode in a particular tube is often referred to as the *stopping potential* for that tube. The idea of stopping potential is useful later to explain why the region between complete collection and substantial repulsion of emitted electrons by a target is a rounded curve rather than a sharp cutoff.

secondary emission

Most storage tubes use the phenomenon of secondary electron emission to build up and store electrostatic charges on the surface of an insulated target. An understanding of this concept is imperative to the understanding of storage tubes.

When a target surface is bombarded by electrons, some of the energy of the bombarding or *primary* electrons separate other electrons known as secondary electrons from the surface of the target. The number of secondary electrons emitted depends on the number and velocity of the bombarding or primary electrons, the target composition, surface condition, and the angle of bombardment. The amount of secondary emission is usually expressed as the ratio of secondary-emission current (number of electrons per unit time) to the primary beam current and is termed the secondary-emission ratio or δ (delta).

secondary-emission ratio

$$\text{Secondary-Emission Ratio, } \delta = \frac{\text{Secondary-Emission Current, } I_s}{\text{Primary Beam Current, } I_p}$$

An elementary but fundamental experiment with this effect is the determination of how the secondary-emission ratio changes when the bombarding primary electron beam energy is changed.

secondary-emission measurement

A typical experimental device for the measurement of the secondary-emission ratios of a variety of materials is shown in Fig. 2-2.

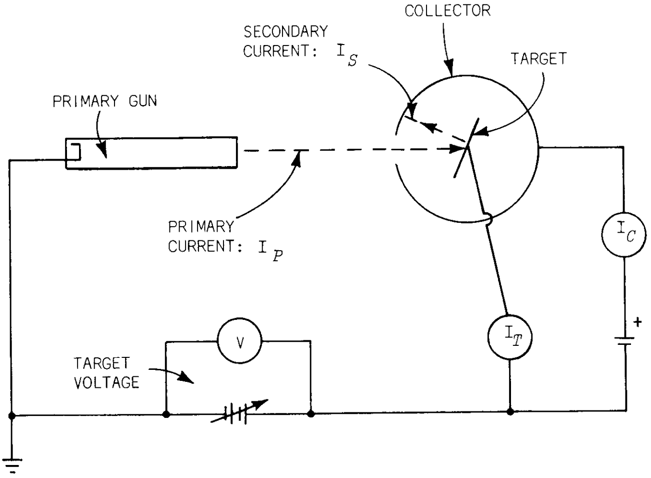


Fig. 2-2. Secondary-emission circuit for a conductive target.

The target voltage relative to the cathode determines the primary electron potential. The plot (Fig. 2-3) shows secondary-emission ratio (δ) vs target voltage.

In this experiment, a primary electron gun forms an electron beam which bombards a metal target plate in a vacuum. The target voltage is the independent variable for the curve to be plotted. A collector electrode surrounds the target, and it is held a few volts more positive than the target electrode by a voltage supply which is between the target and the collector. There will always be a strong enough field around the target electrode to insure collection of all the secondary electrons in this device.

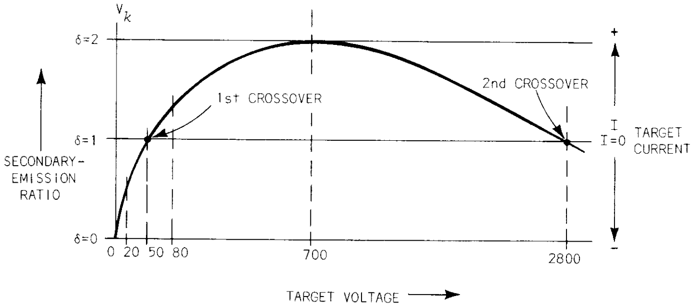


Fig. 2-3. Typical secondary-emission yield curve.

At some low positive target voltage, such as +20 volts, a primary beam current of 10 µA may cause a secondary current of perhaps 5 µA to flow from the target to the collector. The secondary-emission ratio would be 5 µA/10 µA, or 0.5. Notice that since the target is receiving 10 µA but is losing 5 µA of current by secondary emission, the net electron current collected by the target, and leaving the envelope through the target-lead wire, is only 5 µA.

At some higher target voltage, such as +50 volts, the bombarding energy is higher and the secondary current may rise to become equal to the primary-beam current. A 10 µA beam producing 10 µA of secondary-emission current from the target to the collector then results in a secondary-emission ratio of 1. Since the target is collecting 10 µA and losing 10 µA, the net flow of current in the target lead-wire is zero. Conditions where the secondary-emission ratio is unity will later be seen to have a special importance. Since the secondary-emission curve crosses the ordinate lines of $\delta = 1$ at such points, these points are often called *crossover* points, and the point just described, which is *the lowest target voltage at which this crossover occurs,* is usually referred to as the *first crossover* point.

first crossover

Fig. 2-3 shows that the direction and amount of flow of current in or out of the secondary-emission target surface, and in the lead-wire to the target, depends on the secondary-emission ratio. An additional scale of ordinates has been added on the right side of the figure to show net current through the target surface. The current scale is in units such that one unit equals the total primary-beam current.

When the secondary-emission ratio is one, there is no net flow of current to or from the target, and the current in the target lead-wire is labeled $I = 0$ in the figure. The current ordinate in Fig. 2-3 is given a positive direction for current flow into the collector, since the target surface is losing negative charge or gaining positive charge.

At some higher target voltage, such as +80 volts, the 10 μA of primary current may cause 13 μA of secondary current, resulting in a secondary-emission ratio of 1.3. The net flow of current at the target surface is now away from the target, since more current is emitted than is collected. An electron current of 3 μA now flows into the collector from the target lead-wire. At a higher target voltage, such as +700 volts, the secondary-emission ratio may reach a maximum, for example at $\delta = 2$. Above this voltage, the secondary-emission ratio decreases until, at perhaps +2800 volts, the secondary-emission ratio may again equal 1. This is another crossover point of special interest, and is commonly called the *second crossover* point. The drop in secondary emission which occurs above the maximum point is believed to be the result of deeper penetration of the more energetic primary electrons into the target material, before collision with the target atoms occurs. Large numbers of secondary electrons may be produced below the surface, but many are captured within the target before they reach the surface, and do not contribute to the current leaving the target.

second crossover

constant collector voltage effects

The preceding explanations have discussed the phenomena of secondary emission with the collector electrode always more positive than the target. Other electron-optical effects take place when the collector electrode voltage is held constant. These effects provide the basis for the study and understanding of bistable storage devices.

Fig. 2-4 differs from Fig. 2-2 in that the collector electrode is held at a fixed +200 V. This is the first of a series of changes to be considered in the step by step evolution of the understanding of a direct-viewing bistable storage tube.

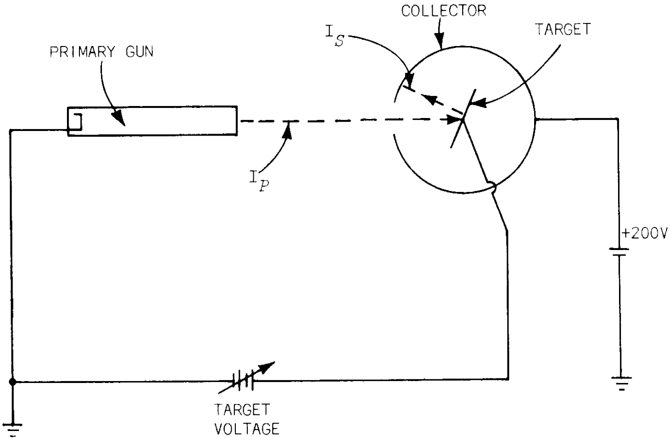


Fig. 2-4. Secondary-emission circuit modified to show effects of fixed collector voltage.

With the arrangement in Fig. 2-4, the secondary emission which occurs when the target is below +200 volts is collected as before, because the collector is more positive than the target. This emission and collection is shown on the curve of Fig. 2-5, just below the fixed collector voltage point.

When the target is well above the collector voltage, at +500 volts for example, secondary-emission electrons leave the target surface due to their energy of emission. The electrons are emitted into a retarding field caused by the lower collector voltage, which reflects most of them back to the target. Under these conditions, the net secondary-emission current is near zero, since essentially no secondary current reaches the collector. The target is receiving the primary beam current, and is acting simply as a collector of current. Current measurements from outside the envelope would show that the target current equals the primary beam current, $\delta = 0$, and the collector current is zero.

These are also the current conditions for a target material which is such a poor emitter of secondary electrons that no substantial emission current is collected. It can be seen that current measurements in this device cannot distinguish between the total return to the target of secondary electrons by the collector, and a true secondary-emission ratio of zero.

effective secondary emission

Another important effect occurs in the vicinity of zero volts, on the curve of Fig. 2-5. This effect results in a modified "effective" secondary-emission curve.

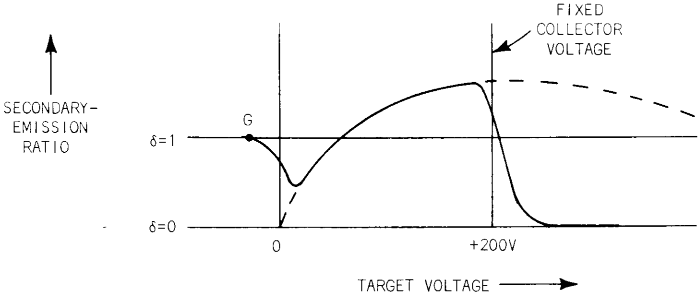


Fig. 2-5. Secondary-emission curve modified by fixed collector voltage.

At some point G which is substantially below zero volts (e.g., -5 V), the target is surrounded by a negative (repelling) field, which reflects all primary electrons to the collector. External current measurement shows that the collector current equals the primary current, and the target current is zero. These are the same current measurements which occur at the crossover points, where the secondary-emission ratio is one. At this voltage the target has an apparent or net effective secondary-emission ratio of one. The current measurements cannot distinguish between the total reflection of primary electrons, and the physical effect of a true secondary-emission ratio of unity.

As target voltage is increased, approaching zero volts from the negative side, it leaves the region of reflection of primary electrons and enters the region of actual target bombardment and true secondary emission.

The region around zero target volts is of particular interest since both halftone and bistable storage targets operate partially in this region.

apparatus effects

The results of these two "apparatus effects" is the *net* secondary-emission curve of Fig. 2-5. This is *the* important curve for bistable devices, and will be used often.

To summarize: The curve differs from the physical effect of secondary emission at both ends of the curve; near zero volts and near collector voltage. It differs for the same reason in each case; reflection of electrons by a more negative electrode. Reflection of primary electrons by the target occurs below zero volts; reflection of secondary electrons by the collector occurs above the collector voltage.

3

CHARGING AND BISTABILITY

At this point, another important change in the experimental tube will be discussed which will result in a device which is capable of simple storage effects. This effect will be accomplished by the use of a floating target instead of a target whose voltage is externally controlled.

floating target

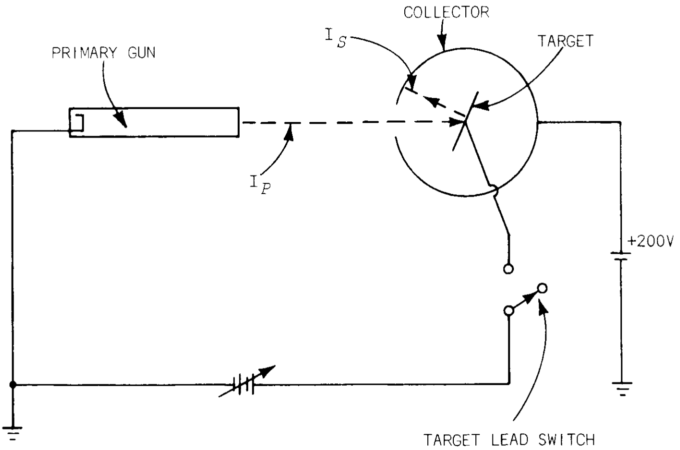


Fig. 3-1. Secondary-emission circuit modified to allow floating target.

The device shown in Fig. 3-1 can be used to determine experimentally in which direction the potential on the floating target changes due to target charging, for any particular initial target voltage. With the switch closed, the target supply may be adjusted to any starting condition, and then the switch opened and the changing target voltage measured.

floating target potential change

When the target is set at some low voltage such as +20 volts, a secondary-emission ratio of about 0.5 may typically result, as shown at point D in the curve of Fig. 3-2. For every unit of primary current collected by the target, 0.5 unit of secondary current flows back into the vacuum, so the net collection effect is 0.5 unit of electron current, which flows out of the envelope on the larget lead-in wire.

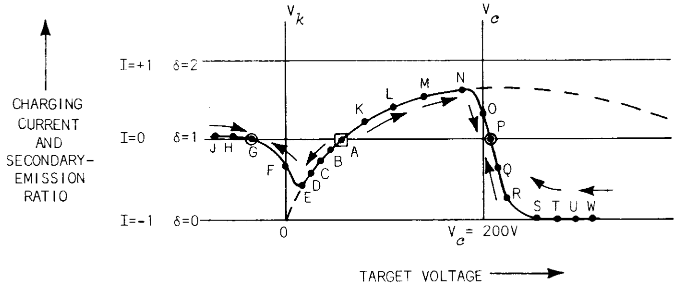


Fig. 3-2. Secondary-emission curve - fixed collector voltage.

If the switch in the target lead is now opened, the current in the target lead-in wire is interrupted, and the target starts to charge in a negative direction, due to the net collection of electrons. The target voltage then shifts downward from point D.

The curve of Fig. 3-2 is the result of opening the switch in the target circuit at many different target voltages, to determine its charge direction as a function of target voltage, as shown by the direction of the arrows. As the target charges more negative from point D, its voltage decreases sequentially to the voltage at points E, F, and G on the curve. The secondary-emission ratio changes as the target voltage changes, but it remains below one, between points A and G, so the direction of target charging remains negative, although the charging rate varies.

The rate of charging decreases as the target voltage closely approaches voltage G, since the secondary-emission ratio approaches 1. When the target reaches point G, the net charging rate becomes zero and there is no further drop in target voltage.

If the target circuit is opened when the target is between point G and J there is no net charging by secondary emission. Positive ion bombardment and conductivity across the insulating target support structure will cause the target to charge slowly in a positive direction, until point G is reached. The curve above point J shows that this effect results in a positive direction of charge, just as if the secondary-emission ratio were greater than one.

A target's voltage becomes *stable* when it arrives at point G. The charging effects balance to zero at this point, whether the target has been dropping in voltage from a higher voltage or charging positive from a lower voltage.

erase

lower
stable
point

If a target at point G is temporarily disturbed from its rest position by a small voltage shift, in either direction, the net charging effect is no longer zero. A charge arises having a direction which restores the target to the voltage of point G. Since there is a restoring force on a target in the vicinity of point G, this point is a stable point as long as the primary electron beam is present to preserve this stability. A target at this point on the curve is referred to as being erased or unwritten. To "erase" a target in this device means to change the voltage to the lower stable point of the curve.

write

upper
stable
point

The curve segment P-W has a net charging direction which is negative over the whole segment. When the target circuit is opened at the voltage of point W, for example, the target charges in a negative direction toward point P because $\delta<1$. As point P is approached, the charging ratio decreases because the secondary-emission ratio is approaching one, and the net target current is approaching zero. At point P, the target voltage stops dropping and becomes stable, the net charging rate is zero because $\delta = 1$. A target at this point on the curve is referred to as being "written." To "write" a target in this device means to change its voltage to the upper stable point on the curve.

The segment A-P of the curve lies entirely above a secondary-emission ratio of unity, so at every point on the segment, the net current is away from the target. This loss of negative charge drives the target more positive. When the switch is open, a target at point K increases in voltage until it reaches the voltage of point P, the rate of charge dropping to zero as it approaches.

When a target has charged to the voltage of point P, either from a higher or lower voltage, it has reached a voltage which is stable. A small disturbance of the target voltage will be corrected by restoring forces that return the voltage to point P, *as long as the primary beam is present to preserve stability.*

stable points

Notice that at the two stable points G and P, the curve of Fig. 3-2 crosses the line I = 0 with a negative slope. A stable point in a floating target voltage occurs wherever the curve of net charging current crosses I = 0 with a negative slope.

unstable point

At point A, the net charging current is also zero, but a small change in target charge from any "noise" source will send the target charging up or down to point P or G, depending on which way the voltage is first shifted by noise. Point A is a uniquely unstable point, and it should be noted that an unstable point in the voltage of a floating target occurs wherever the curve of net target charging current crosses I = 0 with a positive slope.

Since the target now has two stable points, G and P, at which its voltage will be held by restoring forces, (which point depends on its history before the switch in the target circuit was opened) we see that this device is an elementary bistable storage tube. This tube may be interrogated by measuring the target voltage. The measurement will tell whether the voltage supply was above or below the voltage of point A at the time that the switch was opened. The information is present in the form of a voltage at the target lead-wire, but there is no image displayed. This tube is an electrical readout tube (of one-bit capacity) as opposed to a direct-viewing storage tube. Bistable storage is frequently referred to as having "infinite" persistence, since the tube will retain its stored information indefinitely.

mechanical stability model

Stability is dependent on the presence of a restoring force. This fundamental idea can be made more familiar by comparison to a mechanical model. Fig. 3-3 shows a shaped surface with a small ball resting on it, under the influence of gravity. The ball will remain indefinitely in either of the stable positions G or P, if once placed in either of these positions. These sections of the model are comparable to the stability of the storage target just described, which will remain at either of its two stable voltages indefinitely.

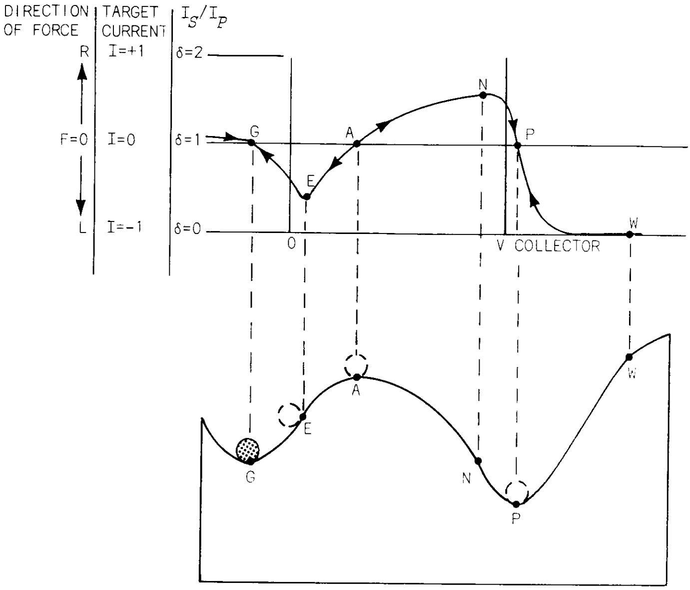


Fig. 3-3. Mechanical stability model and secondary-emission curve.

If the ball at point G is displaced to the right, to point E, it experiences a strong restoring force which returns it to point G; in fact, the surface at point E is the steepest slope on this portion of the model. This section of the model is comparable to a target at point E which is restored to stable point G, and has the highest negative charging rate on this part of the curve, at point E, where the effective secondary-emission ratio is low.

If the ball is placed at point A on the mechanical model it is unstable, and will drop to point G or P at the slightest disturbance, just as a target at point A on its curve is unstable and will shift to G or P at the slightest disturbance.

Notice that points E, N, and W on the target charging curve are points of highest charging rate, and correspond to points of maximum slope on the mechanical model. Points G, A, and P have zero charging rate on the charging curve and zero slope on the model.

The slope of the surface of the mechanical model is such that a graph of the forces on the ball at any point on the model's surface has the shape of the δ curve. The graph and the arrows on it show the amount of force on the ball, and the direction of force, which is to the left where the curve is below the line F = 0. An ordinate scale may be added on the left side of the graph showing this force. This one graph now shows effective secondary-emission ratio of a target, the amount and direction of target charging, the amount and direction of force on the ball, and the stable points for both the ball and the target.

Important Note--

-- The text to this point is applicable to storage cathode-ray tubes in general. The material on the next few pages should not be interpreted as necessarily applying to Tektronix storage tubes but as part of the historical evolution of storage CRT's. After the evolution of storage in general is completed, the construction characteristics and operation of Tektronix storage tubes is covered starting with Chapter 5.

target
control
with two
guns

It is possible to change the voltage of a target in either direction by shifting the cathode voltage of a single bombarding electron gun, to obtain a high-energy or low-energy beam at the target. Either a high or low secondary-emission ratio can be obtained, making the target charge up or down to the opposite stable point. In practical storage tubes, however, the cathode of a primary beam is generally not shifted in voltage, because the bias, focus, anode, and deflection voltages would all have to be shifted with it to maintain the beam size, location and current. It has been found much more practical to use two guns having their cathodes fixed at different voltages, and to keep most of the gun electrodes at fixed voltages.

Accordingly, a step in the series of modifications of the previous simple devices, evolving toward the complete storage tube, can now be made. The next change will be to add a second electron gun, providing a second beam of primary electrons.

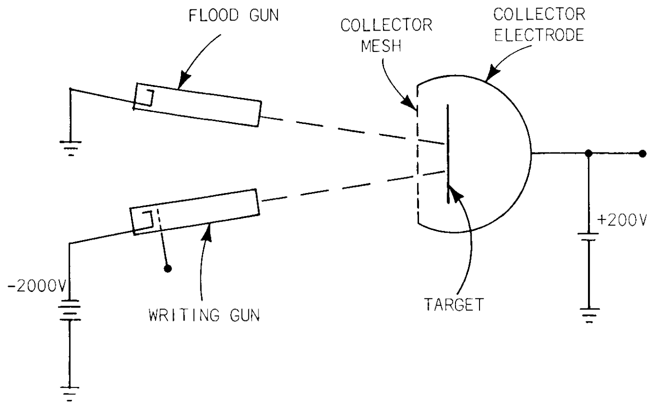


Fig. 3-4. Floating target control with two guns.

mesh

In the tube of Fig. 3-4, the entrance aperture in the collector has been enlarged to admit two electron beams. The resulting reduction of the strong collecting field in front of the target has been corrected by placing a mesh across the entrance aperture. The mesh maintains substantially the same field that would be there if a solid part of the collector occupied that position. A transparent high-transmission mesh is used for this purpose, to pass most of the primary electrons.

flood gun

writing gun

The upper gun will be called the *flood gun* and the lower gun the *writing gun*, in anticipation of later usage. For the present, the distinguishing feature of the flood gun is that it will flood the target at all times, not just intermittently as the writing gun does. Assume for the moment that the lower gun, the writing gun, has been biased to cut off, and is not bombarding the target. The tube cannot be written or erased by an external target voltage supply, because there is no connection to the floating target. This tube also cannot be written or erased with the single-gun effects of shifting cathode voltage, because we have fixed the cathode voltage instead of providing a variable voltage supply.

Since the flood-gun cathode is at zero volts, the target voltage in the charging-current curves may be read directly as the voltage difference from cathode to target. This is not the case for the writing gun, as the writing-gun cathode is fixed at -2000 volts relative to the flood-gun cathode.

writing

Writing is accomplished by gating on the writing beam with the writing-gun grid.

The combined effect of two beams hitting the same target surface is simply the sum of the individual effects that each beam would have alone. The secondary-emission ratio due to one beam is not known to be affected by the presence of a second beam having a different bombarding energy. (See Fig. 3-5.)

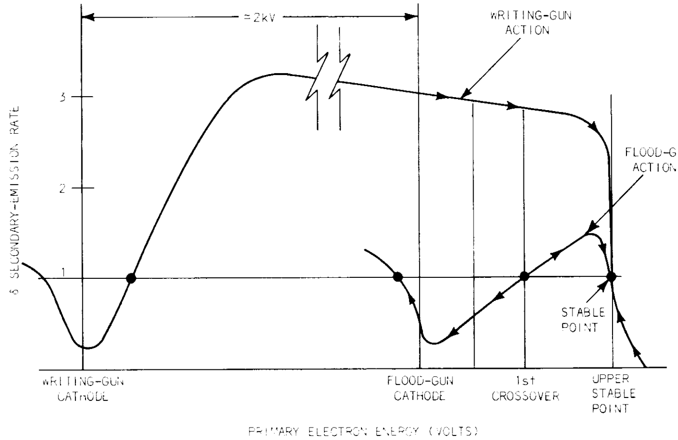


Fig. 3-5. Secondary emission.

When the target is at its lower stable point and the writing gun is gated on, electrons arrive at the target with a potential of about +2000 volts. The high secondary-emission ratio of the target for +2000 volts causes a high positive charging rate and the target voltage immediately starts to increase. As the target voltage leaves the lower stable point, restoring forces begin to oppose the writing effect of the writing gun, due to the stabilizing effect of the flood gun.

If the effect of the writing-gun current is greater than the effect of the flood-gun current, the target will charge up to the first crossover point and higher. After the target voltage exceeds the first crossover point for flood-gun emission, the flood gun is no longer opposing the writing effect, but is aiding it. It is only necessary for the writing gun to be gated on long enough to carry the target just past the first crossover. Flood currents alone will carry the target the rest of the way to the upper stable point. When the writing-gun beam is gated on for too short a period to carry the target past first crossover, the flood beam will return the target to the lower stable point after the writing beam is biased off, and storage will not occur.

target charging

During writing, the target shifts over the range from the lower stable point, slightly below zero volts, to the upper stable point, at about +200 volts. The writing-beam potential shifts from +2000 volts to +2200 volts because of the target voltage change.

This represents a little change in secondary-emission ratio for the writing beam, and, for any particular beam current, we may regard the writing beam as a nearly constant source of positive charge (via loss of secondaries) being delivered to the target, which overcomes the stabilizing current due to the flood gun.

erasing

The above explains how writing and storing are accomplished without shifting cathode voltages, by using two guns. Restoring the target to the lower stable point is carried out by pulsing the collector negative.

negative target charging

If it is assumed that the capacitance from the collector to the target is at least equal to the capacitance from the target to all other electrodes (which is a very conservative assumption in this tube), then half of the collector voltage change appears on the target. If the collector voltage is suddenly dropped by 150 volts, from +200 volts to the first crossover point at about +50 volts, two effects occur which tend to charge the target negative. One of these is the capacitive coupling of the collector signal to the target, which immediately drops the target voltage by 75 volts (in this example) to a new target voltage of +125 volts. The other effect is the negative charging of the target by primary collection. The collector cannot collect secondaries from the target when the collector is far more negative than the target, so, the secondaries are reflected back to the target, the effective secondary-emission ratio is below one, and the target collects flood-gun primaries and charges negative. This continues until the target reaches the lower stable point just below 0 volts.

The collector cannot now be suddenly returned to +200 volts without changing the target voltage, because the target would be pulled above the first crossover by capacitive coupling, and be written again by the flood beam. Instead, the collector may be returned to its voltage of +200, if desired, by a series of steps of voltage, each step small enough so that the target is not driven above first crossover, and each step followed by a delay long enough for the target to charge back down to the lower stable point from which it was displaced by capacitive coupling. A more practical method is to raise the collector voltage continuously, but at a rate slow enough that the negative-charging restoring forces on the target, near the lower stable point, are able to overcome the capacitively coupled positive charging effect enough to keep the target below first crossover and that the target doesn't charge positive to the upper stable point. A typical erase waveform that could be applied to the collector is shown in Fig. 3-6.

erase waveform

The recovery time needed for the collector voltage depends on the particular tube design and the flood current.

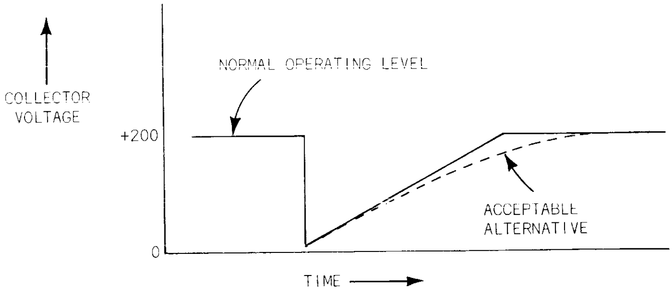


Fig. 3-6. Erase waveform for secondary-emission circuit.

It has been seen, in this section, that a floating target with no access to external supply voltages can be put in either stable position by control of the primary beam energy, or by control of the collector voltage. This is the first tube in the sequence which writes, stores, and erases a floating target with guns at fixed voltages.

4

BISTABILITY IN MULTIPLE TARGETS AND DIELECTRIC TARGETS

multiple targets

The next step in the structural evolution of a bistable storage tube (shown in Fig. 4-1) is to increase the number of targets within the tube.

In this tube, the flood-gun spot size has been very greatly enlarged to extend over all of the targets. This can be done with a relatively simple short gun, having no need for deflection plates. The writing gun still emits a focused, directed beam, and all of the writing beam current is directed toward one target at a time, such as target 3 in Fig. 4-1.

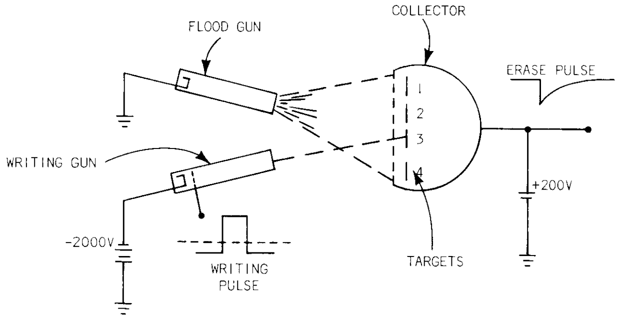


Fig. 4-1. Control of multiple targets with two guns.

Initially, the writing gun is biased off, the flood-gun cathode is grounded, the collector is fixed at +200 volts, and all targets are at their lower stable point. The restoring forces of bistability are present for all of the targets, and the flood gun is able to hold each target independently at either of its two stable points, once they are written or erased to those points.

When the writing beam is gated on and bombards target 3, for instance, this target charges positive and is written to its upper stable point. Target 3 is then held at its upper stable point, while the other targets remain held at their lower stable point by the flood gun.

When the erase pulse in Fig. 4-1 is applied to the collector, the written target is made to act as a net collector of current, and is driven to its lower stable point, as previously described. The unwritten targets 1, 2, and 4, are driven negative and then positive again back to the lower stable point, by capacitive coupling to the collector, as the erase pulse goes negative and positive.

When the erase pulse is applied to the collector, the written target's voltage drops (due to capacitive coupling) below first crossover and the target charges negative to its lower stable point (due to flood-gun bombardment). The erase pulse couples to the unwritten targets causing unwritten targets to descend with the erase pulse, to a voltage BELOW the lower stable point. At this time a strong negative field surrounds each unwritten target repelling flood-gun electrons. Unwritten targets then follow the erase pulse positive to the lower stable point. All targets at this time are at the lower stable point (erased).

dielectric sheet target

The next step in the structural evolution of a direct viewing storage tube is to substitute a single large dielectric target for the individual metal targets. Imagine increasing the number of rows and columns of metal targets indefinitely and at the same time decreasing the size of the targets and the space between them. When the targets become much smaller than the beam, we substitute a dielectric material for each target, as well as for the vacuum which insulates each target from its neighbors. The result is that the target array is replaced by a single dielectric sheet which is capable of having any area element of its surface written and held positive, or erased and held negative without effecting the adjacent area.

independent targets

In preceding tubes, each target was charged to the same potential over its whole surface, since the targets were conductors. With a dielectric target, each small area of the target may be charged to either stable point independently of its surrounding areas, as if the target surface consisted of very many small metal targets, which are incapable of current flow between targets.

The dielectric material may be a sheet of glass or mica, or other dielectric materials known to have a high secondary-emission ratio. These materials often have secondary-emission ratios which reach a maximum in the range of 2 to 5, and sometimes higher. With this change, the tube has evolved to the capability of writing, storing, and erasing a high resolution bistable two-dimensional charge-image. The next step will be to provide a visible image.

visible light image

When the preceding tube has a charge-image stored on its dielectric target, the written portions are being bombarded by flood electrons having much more energy than the few low-velocity electrons reaching the unwritten portions. This energy may be used to produce a visible light image by using a fluorescent material for the target dielectric.

phosphor dielectric

The target may consist of a phosphor layer coating a glass supporting plate, and the phosphor may be viewed through the glass plate from the side opposite the electron gun. Fig. 4-2 shows this tube.

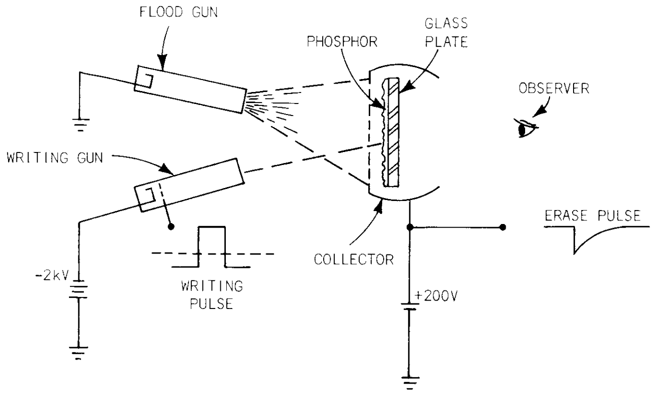


Fig. 4-2. Elementary direct-viewing bistable storage tube.

A large aperture has been placed in the rear of the collector so that the image may be viewed from that side.

The phosphor coating serves as a dielectric target, and has the same bistable storage properties exhibited in the previously described tube. Both the written and unwritten target areas are held at stable points which insure no net current flow to or from the target surface. Even though the arriving and secondary currents are equal, cancelling the transfer of charge to zero, there is a considerable net transfer of energy to the target. The flood electrons bombard the written areas of the target at the potential of the upper stable point. The secondary electrons leave the target with much lower energy. Some of the energy, which was largely dissipated as heat in preceding tubes, is now converted to visible light by the fluorescent phosphor target. In unwritten areas, the few flood electrons which reach the target (to maintain equilibrium with ion collection and leakage) arrive with too little energy to cause much target fluorescence or secondary emission.

target fluorescence

Since all the target areas are charged to either one of two possible stable potentials, the resulting light output in any element of target area is either of two intensities; full brightness or minimum brightness. There is no gray scale or halftones of brightness. This is characteristic of bistable storage tubes, and limits their usefulness to applications for which halftones are not essential, but 'infinite' persistence is desirable, such as in oscilloscopes.

no gray scale or halftones

A tube of the type described was built and reported by A. Haeff in 1947. The tube is extremely interesting in comparison to the development of succeeding years. This early tube had the advantage of simple target construction, but suffered from low brightness due to the relatively low energy of phosphor bombardment. It also had a very limited stable range of collector voltage, as evidenced by the tendency of the written image to spread over unwritten areas or erase into written areas.

early tube limitations

The brightness of the image formed by this tube may be increased, to a small extent, by raising the operating voltage of the collector. This increases the voltage of the target surface at the upper stable point, so that the more energetic primaries cause higher brightness of the written areas.

collector voltage critical

It has been found, however, that the collector voltage cannot be increased much before the image becomes badly degraded. The written areas expand into the unwritten areas as a result of motion of the boundary which separates the written and unwritten areas.

The opposite effect occurs when the collector voltage is low. Conductivity and other effects can lower the voltage in written areas near the boundary, and the boundary moves into the written areas.

When operating conditions permit the boundary to move in either direction, the image is ultimately erased, either by the entire viewing screen fading to a dark condition or by "fading positive" to a fully written bright viewing screen.

Since the collector voltage could not be raised enough to achieve high brightness in bistable tubes, other means were used, as described in the next section.

NOTE --- The text to this point applies to storage cathode-ray tubes in general.

5

SIMPLIFIED BISTABLE STORAGE TUBES

The suspended coated mesh type, or "current-transmission" type of storage tube has been, and probably still is, the mainstay of the direct-viewing storage tube art. However, the recently developed Tektronix storage tubes achieve a simplicity of structure which justifies describing them as the beginnings of a "third generation" in storage tubes.

image boundary migration

The development of these tubes depends upon controlling the boundary migration of stored traces, without resorting to complex tube electrode and target structures. Image boundary migration occurs in several types of bistable tubes particularly under unfavorable operating conditions. The exact cause of image boundary migration is subject to conjecture.

A part of the target surface is held positive by the flood gun where it was written by a writing gun. This area charges to the collector potential. The adjacent area is unwritten and charges down to the vicinity of the flood-gun cathode potential. This results in a high voltage gradient across the boundary of the stored area. Since the target is not a perfect insulator, the potential across the boundary must shade gradually from one stable potential to the other, over a finite distance. This leads to the result that, in a smooth uninterrupted target, there must be transition areas, which are at the first crossover potential, where there are no forces of bistability. If a charge is then delivered to this unstabilized area from some other source, it will shift in potential so that it is no longer at first crossover. This results in a shift in location of the boundary of the stored image.

When considering the sources of charge into or out of this area, many possibilities come to mind. Leakage currents are possible from the adjacent target areas. Where a contacting backing plate or collector mesh is used, leakage currents from these electrodes can occur. Ion bombardment may also be present.

leakage current sources

With this conceptual background, the approach was to attempt to simplify target structure by combining the functions of the storage dielectric and the phosphor in a single layer, and to explore several types of interrupted target surfaces to prevent image spreading.

(Throughout this discussion, voltages will continue to be referenced to a grounded flood-gun cathode. Also, a flood gun and writing gun are, of course, assumed to be present, although they are not always shown in the figure.)

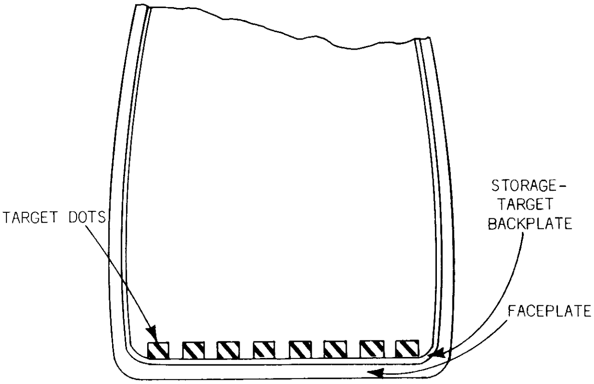


Fig. 5-1. Dot-pattern bistable direct-viewing storage tube.

Tubes of the type shown in Fig. 5-1 were then constructed. In this tube, the storage dielectric consists of dots of phosphor deposited on a conductive-coated faceplate. This conductive coating will be called the storage-target backplate, and is the collector of secondary electrons. The phosphor was deposited in thicknesses typical of a conventional cathode-ray tube. It was found that isolation of areas of phosphor in dots would serve the purpose of preventing spreading of the stored trace.

storage-target backplate

dot-pattern target

The simplicity of the dot target was attractive, and the good performance of the tube made it seem likely that this would become the first product of this type. Then, a still simpler target was developed.

phosphor particle targets

A series of tubes of the type shown in Fig. 5-2 were made, having no phosphor dots, but having increasing weights of phosphor deposited as scattered particles. It was anticipated that when enough phosphor was used so that the particles touched each other, forming a continuous layer, no storage would be obtained because of the apparently instantaneous migration of the stored image boundary across the target face. Fortunately, this was not the case. It was found possible to increase the weight of settled phosphor to amounts which result in targets having a thickness of more than one particle layer. This is the principal finding which makes this new tube possible. The increase in thickness resulted in a higher operating voltage which made an essential contribution to the brightness.

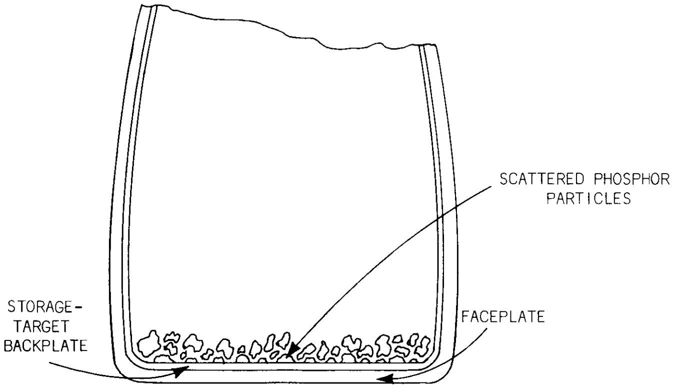


Fig. 5-2. Scattered-particle tube.

When still larger weights of phosphor were deposited, resulting in even thicker targets, a threshold was discovered above which storage could not be obtained. Since the predicted failure to store did occur, although at a greater thickness than was anticipated, it was felt that the conjecture concerning the need to prevent image spreading was again confirmed. It is now believed that targets thicker than a single particle layer, but thin enough to store, are very porous in structure and also have very little semi-continuous-layer targets

conductivity in a direction transverse to the tube axis across the face of the target. These targets may be thought of as *semicontinuous layers* or loosely packed particles. The low transverse conductivity of these loosely packed particles may be attributed not only to the low packing density of the phosphor particles but also to the irregular particle shape, which may reduce the area of contact between adjacent particles.

The effect of varying thickness on the storage characteristics is shown, for the semicontinuous target, in Fig. 5-3. These curves also apply in general to the dot target previously described.

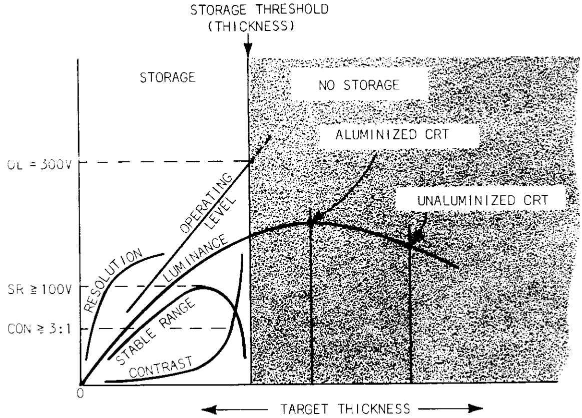


Fig. 5-3. Performance versus target thickness.

luminance

Referring to the curve showing luminance as a function of thickness, a general dome-shaped curve having a peak which corresponds to the thickness of a conventional aluminized cathode-ray tube can be seen. Above this point in thickness, the brightness drops off because of absorption of light passing from the rear surface of the phosphor through the viewing screen to the faceplate. Above a thickness which is a storage threshold, storage has not been obtained using the semicontinuous type of target.

contrast

Within the range of thicknesses in which the semicontinuous targets will store, contrast varies as a function of thickness as shown by the contrast curve. It is apparent from the curves that the highest brightness and contrast will be obtained by approaching the storage threshold of thickness as closely as possible.

resolution

An approximate resolution curve is also shown in this figure. This curve is an estimate intended to depict the fact that in very thin storage layers, where phosphor particles are separated from each other by an expanse of empty faceplate, the resolution is degraded since it is limited by the number of particles present on the faceplate. When enough phosphor is present to form a semicontinuous layer, there is no further improvement in resolution obtainable by increasing the thickness.

stable range

The stable range curve requires a little more extensive explanation. Bistable targets have the ability to store over a range of voltage on the collector electrode, which is the storage-target backplate (STB) in this tube. A uniform target may store with the storage-target backplate at any voltage in the range from 100 to 200 volts, for example. This range is called the *stable range*.

retention threshold

fade positive

If the STB voltage is lowered below this stable range a stored trace fades out. The voltage at which the trace fades out is called the *retention threshold*. If the back plate is raised above the stable range, the whole target takes on the fully written brightness level. This voltage is called the *fade-positive* voltage. The range between the fade-positive level and the retention threshold is called the stable range (see Fig. 5-4).

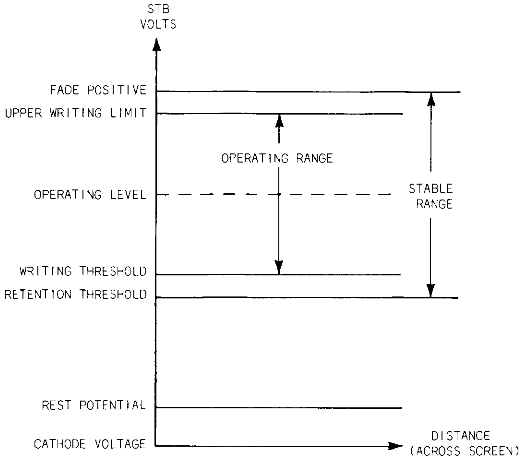


Fig. 5-4. Storage-target-backplate voltage versus distance across screen.

The existence of an adequate stable range of backplate voltage is of the greatest commercial importance. This range must accommodate power supply drift in the instrument using the tube, drift due to the aging of the targets, errors in measuring the stable range, which is difficult to measure, and especially nonuniformities in the stable range across the face of the target. The stable range versus thickness curve appears to peak at well over 100 volts, at a thickness close to the storage-threshold thickness.

When the STB voltage is at retention threshold (RT) the tube will NOT store new information. If information has been stored (when STB was above RT) it will still be present but new information cannot be stored. For a given set of operating conditions the lowest STB voltage at which a signal can be written and completely stored is called *writing threshold* (WT). This is a few volts more positive than retention-threshold voltage.

writing threshold

When the STB is operated very close to the fade-positive voltage, resolution of a stored trace suffers. The highest STB voltage at which a signal can be written and still maintain a given resolution under given conditions of operation is called the *upper writing limit* (UWL). The voltage range between the writing threshold and the upper writing limit is the *operating range* of the tube.

upper writing limit

operating range

An optimum adjustment of the STB voltage is typically in the middle of the operating range.

The collector, called STB, contacts the viewing side of the storage layer. The collector and adjacent porous-target elements operate together, permitting penetration of a high-gradient collection field from the faceplate side of the storage layer. Structural features combine as the source of high-storage stability, yielding a wide stable range.

collector placement

6

CHARACTERISTICS

collimation system

Equal operating characteristics across the screen occur only with even flood-gun electron distribution and when flood-gun electron paths parallel the CRT axis. A collimation system, as shown in Fig. 6-1, forms an electron lens which uniformly distributes flood-gun electrons over the storage target area.

ceramic-tube envelope

Timely development of a practical ceramic cathode-ray tube envelope greatly facilitated design of the flood-current collimation system. The ceramic envelope uses a flat glass faceplate which carries the conductive coating through the seal, out of the vacuum region, for external contact. This configuration permits a minimum gap between wall coating and storage target. And it extends the viewing area to the full tube envelope diameter.

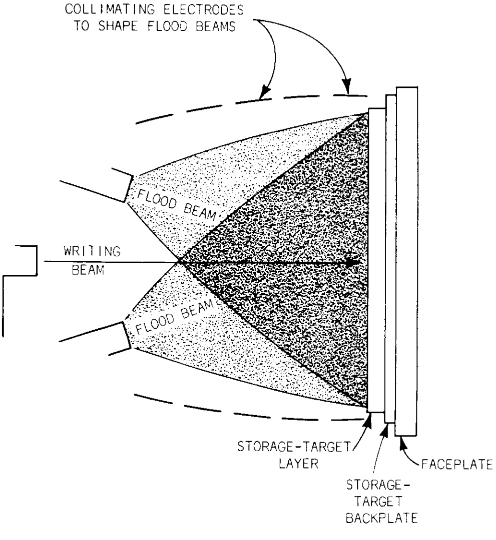


Fig. 6-1. Collimation system.

The lenses formed by the rear collimation electrodes and the flood-gun anode plate converge the flood electrons. The collimation electrodes closest to the faceplate provide fine adjustment of the flood-current trajectories to cover the extreme rim of the target and optimize uniformity of target coverage. The collimation electrodes in the center have a small effect on both of these characteristics.

background illumination

The amount of background illumination present on a storage tube may vary from zero (backplate voltage below retention threshold) to maximum with the entire screen written (backplate above fade-positive). When the backplate is set midway between fade-positive and retention threshold there is some background illumination and the *average* potential of the rear target surface is found to be *above* flood-gun cathode potential.

An examination of the screen with a magnifying glass will show that some target elements are written even when the backplate voltage is low and more become written as it is raised to its operating level. For these written target elements, the backplate is above their fade-positive potential and they are written and cannot be erased without lowering the backplate potential below the retention threshold potential for the majority of the screen. Because of this characteristic, when the backplate potential is at the operating point for most of the targets, it is above fade-positive for some target elements and a background illumination is present.

background luminance

contrast ratio

Background luminance is the luminance of the storage target when completely erased at a specified backplate operating voltage. *Contrast ratio* is the ratio of stored luminance to background luminance at a given operating voltage. The contrast ratio improves with a lower backplate potential but the writing speed and written luminance also decrease.

beam current density

The dotted circle in Fig. 6-2 represents the outline of a spot where the writing beam is bombarding the target. The writing beam is not deflected in this figure, but remains fixed in this spot while it is gated on and off. The current density is not uniform in an actual writing beam, but is concentrated in the center and tapers off toward the edge of the spot. When the writing beam is gated on, the high

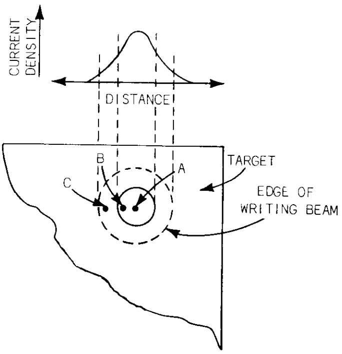


Fig. 6-2. Beam-current distribution.

current density at the center of the beam (point A) easily carries the target potential past the first crossover voltage and the target at point A becomes written quite early in the duration of the writing pulse (for some given beam current). Point B receives less beam-current density, since it is further away from the center of the spot, and it charges positive more slowly, crossing the first crossover point later in the duration of the writing pulse. It is not necessary that the writing beam charge the target all the way to the upper stable point by the time the writing beam is gated off. If the writing beam has carried the target over the first crossover and is then gated off, the flood-gun current will carry the charging to the upper stable point.

The beam-current density at point C is lower than at either point A or B and therefore the charging rate is much lower. If the writing gun is gated off before the target voltage at point C has passed first crossover, the flood-gun current will carry it down to the lower stable point. The solid circle represents the outer boundary of the region in which all points have been charged at least to the first crossover before the writing gun is gated off.

writing time

dwell time

written spot

The "writing time" or "dwell time" may be defined as the minimum time required for some target area to be written positive by a writing beam having a specific maximum-current density. If any area of the target is written by the spot, it may be convenient to define this as a written spot.

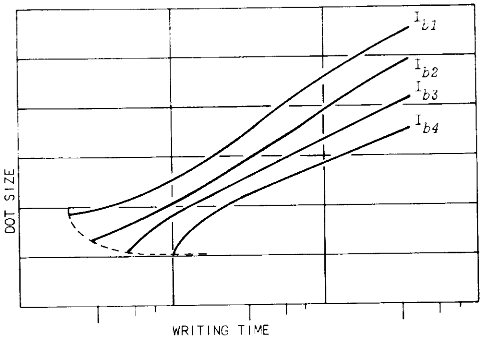


Fig. 6-3. Dot size versus dwell time.

dot size

Displayed dot size increases with dwell or writing time as graphically shown in Fig. 6-3. Minimum dot size then occurs when the time spent writing is no more than required to achieve a stored image.

A situation similar to that of Fig. 6-2 is shown in Fig. 6-4 which shows the path of a writing beam. Point A has been more than adequately written, point B has been written somewhat above the first crossover and point C has been carried only part way toward first crossover and will fall back to the lower stable point. Each of these points begins to receive writing current as the leading edge of the writing spot passes over the point, and continues to receive writing current until the trailing edge of the spot passes over this point. At the moment the trailing edge of the writing spot passes over any point, the point has been written or not according to whether or not it has reached the first crossover.

writing speed

Writing speed may be defined for a target as the highest spot velocity which will leave an unbroken stored trace of specified length, for a specified spot diameter and current.

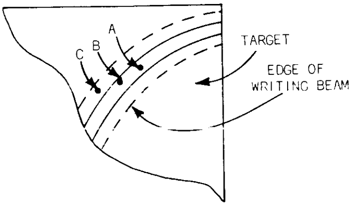


Fig. 6-4. Beam-current distribution with writing beam.

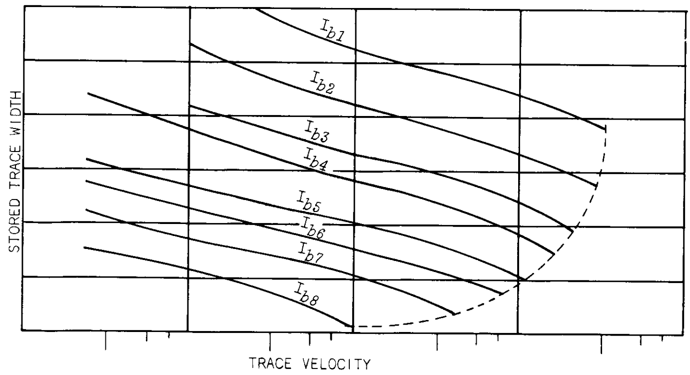


Fig. 6-5. Trace width versus velocity.

Decreasing trace velocity below maximum writing speed yields an increase in stored trace width (Fig. 6-5). Additionally, decreasing beam current or increasing sweep speed reduces stored trace width. Minimum trace width then occurs just prior to a nonstored trace condition.

Consider Fig. 6-4 with a new set of criteria. The writing beam is moving so fast that point A is not charged to first crossover before the trailing edge of the spot has passed. A single sweep of the writing beam will not write the target. After the passing of the writing beam, the flood-gun current returns the charged target areas to their lower stable voltage. A second sweep of the writing beam would again charge some of the targets to a voltage below first crossover, and with its passage the flood-gun current would return these targets to their lower stable point.

integrate mode

A stored image of a number of repetitive traces, each of which would be too fast to store alone as a single-sweep event, may be obtained by use of the integrate mode of operation. An increase of several orders of magnitude in writing speed of *repetitive* signals is obtained, compared to the writing speed of a single-shot transient, by turning off the flood-gun current between sweeps.

The sequence of events is as follows. The flood-gun current is turned off (by opening the flood-gun cathodes). The writing beam sweeps across the screen charging the targets to some voltage below first crossover. The storage target elements are good insulators and, in the absence of the restoring flood-gun current, the target potential for each element will remain where it has been set by the passage of the writing beam. The next passage of the writing beam will charge the targets further toward first crossover and subsequent sweeps will charge the target elements past first crossover. The flood-gun current is now turned on, returning all unwritten target elements below first crossover to the lower stable point, and charging all written targets above first crossover to the upper stable point.

An increase in writing speed for a *repetitive* trace has been achieved. The brightness of the stored trace may exceed the brightness of the high-speed repetitive *unstored* trace, particularly where the repetitive duty cycle is low. Using Integrate may then serve as a brightness intensifier for direct viewing or photography.

single-sweep writing-speed enhancement

It has been seen that the writing speed of a storage tube may be improved for repetitive sweeps (Integrate) and now single-sweep writing-speed improvement will be explored. Single-sweep writing-speed enhancement may be achieved in two ways. In some oscilloscopes the flood-gun cathodes are pulsed negative, while in others the backplate or collector is pulsed positive. The latter method will be discussed first.

rest potential

Consider a group of targets in a ready-to-write state. Their *average* potential is somewhat above the flood-gun-cathode potential and this average potential is called the rest potential of the target. The targets are held at rest potential due to flood-gun action. Fig. 6-6A shows the target element potential at the end of a single sweep of the writing gun versus distance across the target. The writing beam has charged some of the targets to a higher voltage than rest potential. *If* nothing else happens, the flood-gun current will restore these targets to rest potential and the sweep will not have written. Before this restoring can take place, a positive pulse is applied to the backplate, lifting the potential of all the targets by some amount (See Fig. 6-6B). The "amount" needed is such that the targets that have been charged by the writing gun are now above first crossover *and* the targets not charged by the writing gun are below first crossover. The targets above first crossover charge positive due to flood-gun enhancement pulse

action and those below first crossover charge negative (see Fig. 6-6C). The enhancement pulse applied to the backplate now steps negative to its original value and the target elements step negative as shown in Fig. 6-6D. The targets that were charged positive by the writing gun are still above first crossover and will continue to be charged to the stored state by the action of the flood gun. The targets that were charged negative by the writing gun are below first crossover and will be charged back to rest potential.

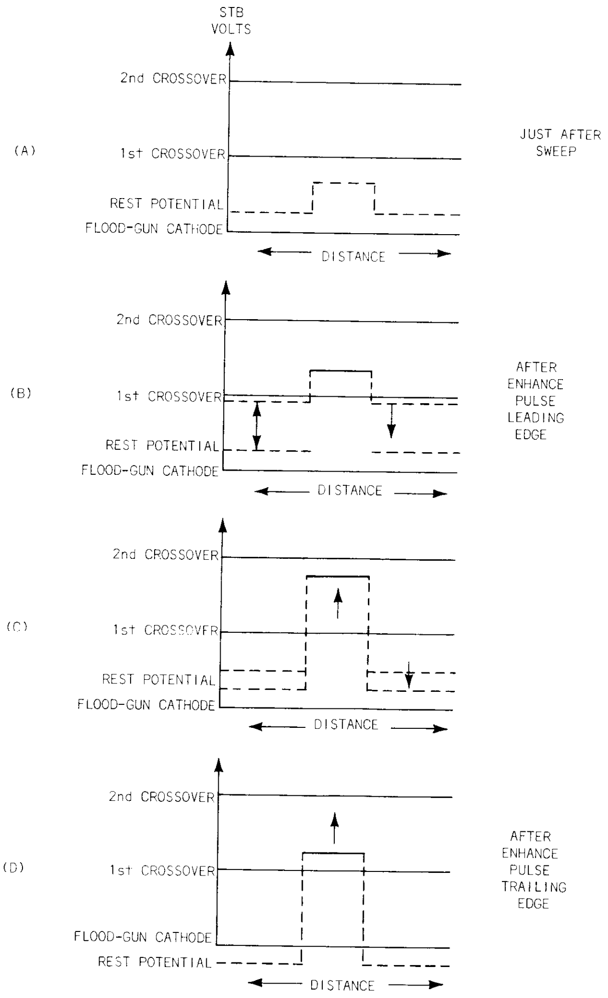


Fig. 6-6. Target voltages during enhancement.

The return of the enhancement pulse to its original level is needed because when it was pulsed positive it was *above* fade-positive potential. Fade-positive does not occur instantaneously but leaving the backplate at this voltage for too long a time would result in the entire screen becoming written.

Both the amplitude and duration of the enhancement pulse are important. In some oscilloscopes the duration is set internally and the amplitude is a front panel control. In others the amplitude is set internally and the duration is a front panel control.

In some oscilloscopes, the enhancement pulse is a negative pulse applied to the flood-gun cathodes. The *effect* is the same as pulsing the backplate positive; namely the *difference* between the target voltage and the flood-gun cathode voltage is such that those targets that were charged by the writing gun have a δ of more than 1 (above first crossover) and those not charged by the writing gun have a δ of less than 1 (below first crossover).

split-screen backplate pulsed

Pulsing the flood-gun cathode enhances the *entire* screen. The enhancement can be limited to either half of a split screen when the backplate is pulsed. However, more circuitry is required.

enhanced writing speed

Consider a storage tube where writing speed enhancement, as just presented, is being used. After the backplate has stepped positive, some of the targets are charging positive and some are charging negative. Consider the targets that are charging negative. When the backplate steps down to its operating level these targets also step negative and may be below flood-gun cathode potential (see Fig. 6-6D). They repel flood electrons because they are below flood-gun potential. The background is completely dark and the contrast ratio is excellent. The targets slowly restore their normal rest potential by the collection of positive ions or target leakage, which may take several seconds. During this time, contrast improves or enhances since the written targets remain at normal operating voltage and brightness.

Consider again that the collimation system distributes flood-gun electrons uniformly over the target area. Keeping this in mind, recall what occurs across the target area. Low-energy flood electrons develop a negative target charge until target voltage equals flood-gun cathode potential. At this point, the low-energy flood electrons fail to reach the target and turn back. Flood electrons land only if the negative charge leaks out or suffers positive-charge neutralization. On the other hand, when flood electrons reach the target with enough energy to cause secondary emission greater than unity, targets become electron-depleted, and acquire a positive charge. Target potential increases until reaching a positive value equal to storage-target-backplate voltage.

near-
target
potential

Written target elements, those charged to collector potential, cause collimation distortion. Collimating electrodes establish an electrostatic field across the CRT, perpendicular to the CRT axis. This forces flood electrons into a path paralleling the CRT axis. Collimating force lines gradate toward the unwritten target surface reaching target potential quite close to the rear target surface. Call this line nearest the target surface "near-target potential."

Refer to Fig. 6-7. Assume the target charge represents flood-gun voltage. The near-target potential then occurs a fraction of a millimeter to the rear of the target surface. This figure also shows equipotential surfaces in ten-volt increments extending back into the tube. Assume the +40-volt line develops two centimeters from the target surface. As long as these lines remain as shown, a uniform distribution of flood electrons strike the rear target surface.

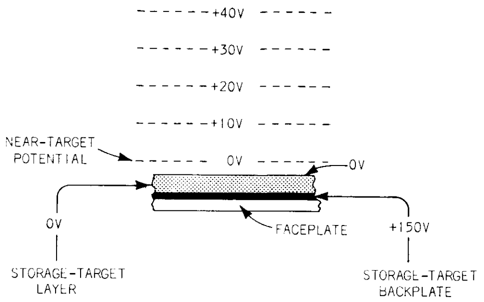


Fig. 6-7. Near target potential line.

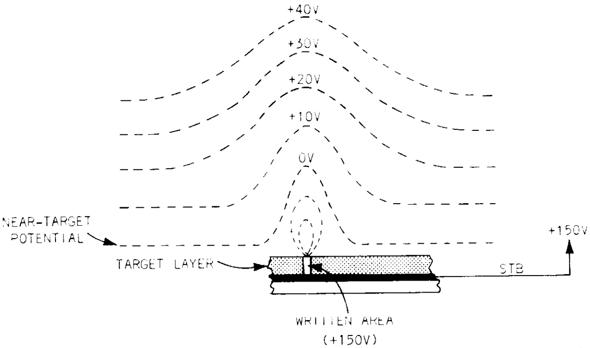


Fig. 6-8. Near-target potential distorted by written charge.

The near-target potential parallels the entire target surface during the period in which all target particles are equally charged. What happens when some particles are written and the rest remain unwritten? Written storage particles assume a charge equal to the storage-target-backplate voltage. Fig. 6-8 shows the resultant potential-surface distortion: The small written area presents a +150 volts to the near-target-potential surface, forcing it far back, forming a convergent lens to flood-gun electrons.

stored-trace shadowing

To a viewer the lens creates a dark area surrounding the displayed waveform. (Fig. 6-9) Most of the *unwritten target* area receives uniform flood-electron distribution, emitting therefore, normal background light. Flood electrons, at higher velocity, strike the *written area* center. Written area centers then emit light for maximum storage viewing brightness. Flood electrons traveling toward the *outer edges* of the written area converge, missing the outer edges. This failure to strike target elements causes the written area perimeter to appear darker than the nonwritten target area.

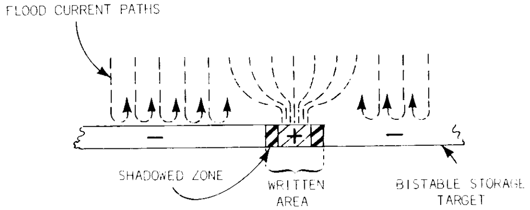


Fig. 6-9. Trace shadowing.

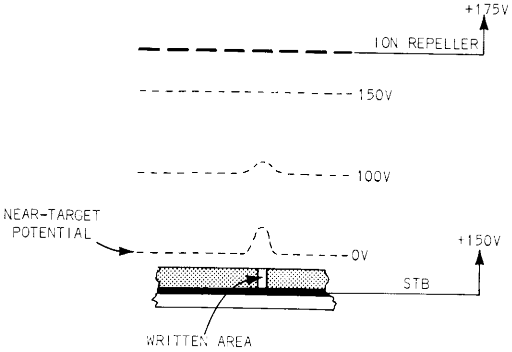


Fig. 6-10. Ion-repeller fields.

eliminating trace shadowing

Two construction methods eliminate the problem of trace shadowing: (1) an *ion-repeller mesh* and, (2) *exposed collector* techniques. Both methods minimize the lens effect in the area of the near-target-potential surface to improve collimation.

ion-repeller mesh

Including an ion-repeller mesh in the storage tube eliminates trace shadowing. One normally considers an ion mesh as a protective device which repels positive ions damaging to the central target area. Tektronix includes an ion-repeller mesh, in direct-viewing bistable storage tubes, to eliminate trace shadowing as well as preventing target bombardment by positive ions.

Assume for Fig. 6-10 the following:

(1) Flood guns return to ground, thus nonwritten target elements sit at 0 volts.

(2) The ion-repeller mesh operates as the most positive tube element, with a mesh fine enough to create a uniform field but coarse enough to intercept negligible quantities of writing-beam current.

(3) The mesh is positioned about 5 millimeters back of the target surface.

(4) The near-target-potential surface occurs some fraction of a millimeter from the target surface.

Under these conditions the ion-repeller field compresses the lens formed by the near-target-potential surface. As shown, written targets present STB voltage to the near-target potential, warping the surface. However, this surface extends only a short distance before coming under the influence of an ion-repeller electrostatic field equal to the STB voltage. Flood electrons now converge much less than in meshless construction. An observer sees no trace shadowing.

Creating a field, equal to storage-target-backplate voltage, less distant from the near-target-potential surface, flattens the lens caused by written target elements. The ion mesh as described lays about 1/4 inch from the target surface. Moving mesh suspension much closer creates assembly problems. Therefore, construction methods were developed where the collector is exposed. This sets up a field close to the rear target surface equal to STB voltage.

exposed collector

Exposed collector tubes are made in two basic configurations: dot target and raised-collector target.

dot target

Fig. 6-11 shows dot-target construction. Laid on the faceplate, the collector forms a fence-fabric or beehive pattern. Phosphor dots fill the hexagonal area in the backplate mesh.

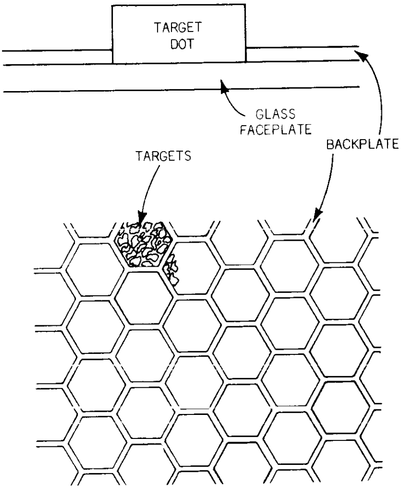


Fig. 6-11. Dot target.

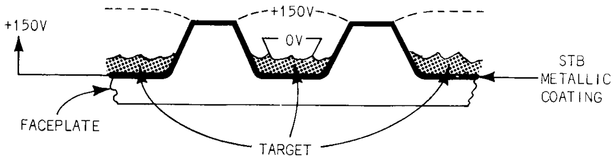


Fig. 6-12. Raised-collector cross section.

Dot-target tubes suffer less trace shadowing than the semicontinuous layer type. When trace shadowing exists, suspending a field-forming mesh behind the target surface eliminates trace shadowing.

raised collector

Fig. 6-12 represents a cutaway of the raised-collector CRT. The raised collector appears to punch through the target surface in a regular pattern. The equipotential surface across collector tips results from STB voltage, shown at +150 V. This surface occurs a very short distance from the rear of the target surface, creating a comparatively flat near-target-potential surface.

The lens formed between the written areas and unwritten areas terminates on the exposed collectors. Since the lens aperture is restricted to the dimension between collector tips, flood-electron distribution remains uniform. Consider that electrons strike perpendicularly--no trace shadowing occurs.

A storage system must include a provision for an operator to erase a stored presentation. Actuating the erase circuits drives all target elements below first crossover to be held at rest potential by flood-gun action. Erase circuits apply pulses to the backplate, flood gun or both.

backplate-erase pulse

Fig. 6-13 shows an erase-pulse shape for backplate application. The pulse capacitively couples to the entire screen area, to each individual target particle.

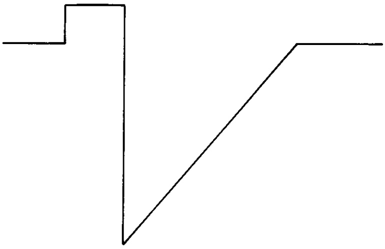


Fig. 6-13. Backplate erase pulse.

Erase-pulse geometry must write *all* targets, then drop *all* targets below first crossover and terminate by ascending to the quiescent level.

Screen make-up, of many small targets charged to different voltages, creates the necessity for a positive write step preceding negative erase excursion. [Single targets surrounded by a collector (backplate), such as the models shown in Chapter 3, erase without a write step.]

A storage-tube screen consists of myriad target elements charged to one of two voltage levels. This electrostatic environment prevents a simple pulse erasure. Applying a simple negative-pulse shape to the backplate results in one of two conditions: (1) No erasure or (2) partial erasure, sometimes called "railroad tracks."

Fig. 6-14 represents a CRT presentation illustrating the first, or no-erasure condition. A single dot appears in the CRT center. This dot, greatly enlarged, represents a single illuminated stored target element. The stored target element, charged to a second-crossover voltage, is surrounded by hundreds of target elements held below first-crossover voltage. A simple negative pulse applied to the backplate fails to erase. The pulse couples across to all targets equally. During the negative excursion, the nonstored areas set up a strong electrostatic field completely shielding the small stored area from flood-gun electrons. Each target element follows the erase pulse with fidelity, returning to its original voltage level. The pulse interrupts the display for a short time but fails to erase.

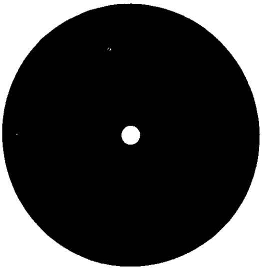


Fig. 6-14. Single-stored target (not drawn to scale).

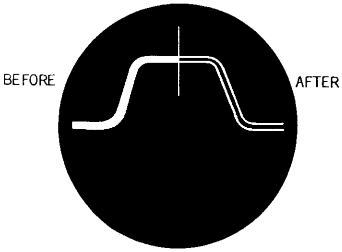


Fig. 6-15. Partial erasure.

Enlarging target area stored changes electrostatic environment to create the second or partial-erasure condition. Fig. 6-15 (before) shows one trace-width stored--a relatively large target area. The electrostatic field created in nonstored-target elements influences only adjacent stored-target elements. A simple erase pulse erases the trace center, but not the edges. Nonstored electrostatic fields shield edge-target elements forcing them to remain stored. With the passing of a simple erase pulse an illuminated trace outline remains. Fig. 6-15 (after) illustrates this "railroad track" presentation.

The more target areas stored, the higher the percentage of erasure. If *all* target elements are above second crossover, 100% erasure results from application of the simple erase pulse.

The complex erase waveform, shown in Fig. 6-16, causes *all* target elements to fade positive, or store, then erases the entire screen. Complex erase-waveform geometry must meet certain criteria:

1. Positive step amplitude must drive nonstored targets above first crossover.

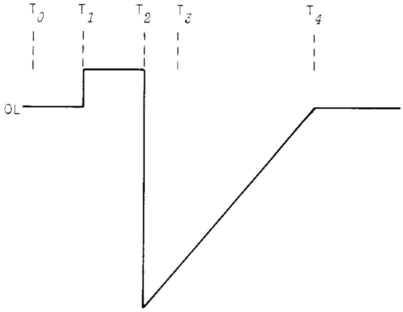


Fig. 6-16. Backplate erase waveform.

2. Positive step duration allows completion of the fade-positive action of previously nonstored targets.
3. The negative excursion should drive all targets below first crossover, but not below flood-gun cathode potential.
4. Ascending ramp slope must remain shallow enough for flood-gun action to hold all targets below first crossover.

Fig. 6-16 shows backplate voltage stepping positive at T_1, from a preset operating level (OL). Backplate voltage remains at the more positive level between T_1 and T_2, at which time the waveform assumes the shape of a simple erase waveform.

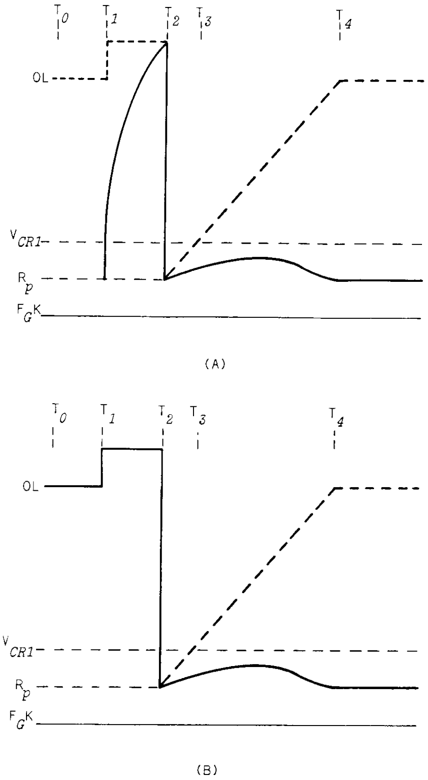
The complex backplate waveform superimposed on the nonstored- and stored-target waveforms appears in Fig. 6-17. Consider the nonstored-target waveform in Fig. 6-17A:

T_0 - Target elements rest at a stable point below first crossover.

T_1 - Target voltage steps *above* first crossover as a result of the backplate stepping positive.

Since these target elements are now in an unstable portion of the charge curve *above* first crossover, they charge toward second crossover. Transition from one stable point to another takes time. The positive excursion must then last long enough for unstored-target elements to reach storage-target-backplate voltage, completing fade-positive at or before . . . .

T_2 - All targets are now stored. Refer to Fig. 6-17B. *All* target elements descend to an equal voltage below first crossover.



(A)

(B)

Fig. 6-17. Composite target element erasure.

T_3 - Flood-gun current contains target potential below first crossover during backplate-voltage ascension. The ramp slope remains within the device charging capability, holding target elements below first crossover.

T_4 - Erase waveform returns backplate to operating voltage level and target elements charge to a stable rest potential below first crossover.

The positive ramp need not be linear as illustrated. Ramps can, and usually do, follow an RC charge rate.

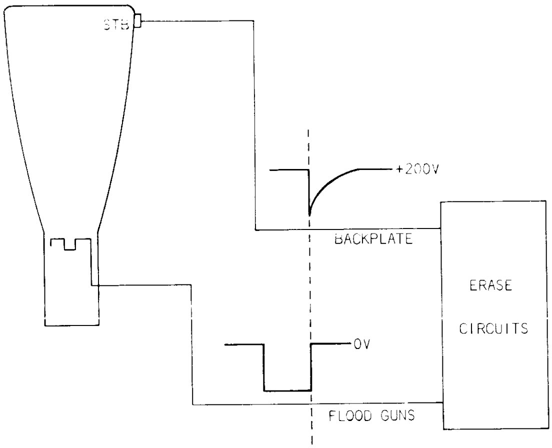


Fig. 6-18. Both flood gun and backplate erase pulsed.

Erase waveforms may be applied to either flood gun, backplate or both. Fig. 6-18 illustrates portions of the erase waveform applied to both flood gun and backplate. The negative pulse applied to the flood guns causes all target elements to fade positive, or write. Following the write pulse, the negative erase pulse appears at the backplate driving all targets below first crossover.

NOTE: This technique negates split-screen operation. Flood-gun cathodes are common to the entire screen: Applying "write" pulses to the flood-gun cathodes writes the entire screen area. Split-screen displays require separate backplates, individually pulsed, for erasure.

image retention
buried charge

Occasionally an image remains or appears to return after an erase cycle. The retained image usually results from allowing a bright display to remain written for a long period. Written charges then penetrate deep into the target dielectric. Low-energy flood electrons fail to either fully write or fully erase the *buried charge*.

bright residual images

Target areas experiencing positive buried charges fade positive after an erase cycle, displaying the previously stored image. These are called *bright residual images*.

dark residual images

Target areas accumulating negative buried charges repel flood electrons, displaying dark images similar to trace shadowing.

An operator suspecting image retention initiates repetitive erasure. He accomplishes this by actuating the erase circuits in a fairly rapid series of five or more erasures. The buried charge, thus the residual image, appears to become more neutralized with each erasure.

When repetitive erasure fails to deplete the residual charge, write the entire viewing area, let the screen remain fully written for a few minutes, then erase. This should neutralize any residual image.

phosphor burns

Users sometimes confuse phosphor damage with retained images. Multiple erasure corrects for retained images but has no effect upon phosphor burns. Hence, keying the erase switch might aid determination of the type of display discrepancy.

200 versus 201 characteristics

Different characteristics can be obtained in a storage tube by varying the composition of the target. The tubes will have different writing speeds, brightness, contrast ratios and life characteristics. The charts in Fig. 6-19 show the characteristics of two types of targets. The 200 has a better contrast ratio and is brighter, but changes with use. The 201 has better writing speed, less brightness and less contrast ratio than the 200, but doesn't change as much with use. The 201 is usually selected where maximum writing speed is desired, while the 200 is used for general purpose.

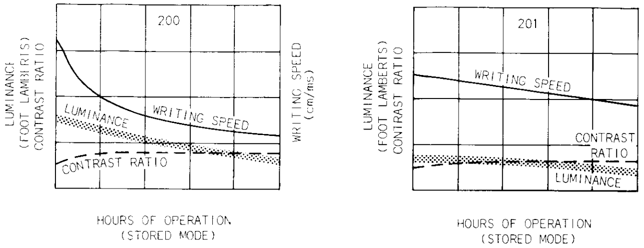


Fig. 6-19. Typical target-life characteristics.

7

TRANSMISSION STORAGE TUBES

"Current transmission" type storage devices store nonvisible images in a mesh dielectric, suspended to the rear of the phosphor viewing screen. The storage mesh then gates current to luminesce the viewing phosphor. Transmission tubes divide into two basic categories: bistable and halftone. Storage principles presented in Chapters 1 through 4 apply to both types.

perforated dielectric target

Fig. 7-1 shows a target consisting of a dielectric sheet on which a charge image writes and stores. No visible target image results. In this figure the upper half of the target has been written positive and the lower half held negative. The target has been modified, however, by using a dielectric sheet which contains a great many small holes.

Flood-gun emission approaching the holes in the *written* upper half of the target pass through a field having a potential not too different from the potential of the written surface of the target. Since this voltage may be two hundred volts positive, electrons pass through the holes at high velocity.

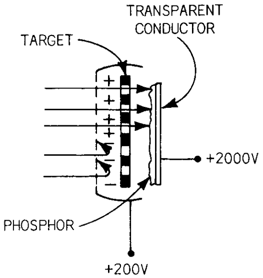


Fig. 7-1. "Grid control" of current through a perforated dielectric target.

Flood emission approaching the *unwritten* half of the target meets with a negative potential near the *unwritten* target surface. Most of this emission is reflected in front of the holes, since most of these electrons do not have sufficient energy to penetrate the retarding field.

phosphor viewing screen

The flood-gun current which passes through the target may be used to form a visible image by placing a phosphor layer in its path. A phosphor viewing screen has been deposited on a separate conductive electrode behind the perforated target. Electrons bombard this layer with a high velocity resulting from this electrode's potential. We may increase the phosphor voltage substantially, independent of the collector voltage, to obtain much higher brightness.

For example, the collector could be operated at +200 volts while the phosphor viewing screen is run at +2000 volts. After electrons pass the written area of the target, around +200 volts, they are accelerated to the much higher velocity of +2000 volts by the field between the target and the viewing screen and a visible image is formed on the viewing screen. This tube has the disadvantage of requiring a self-supporting dielectric target sheet, pierced with a great many apertures.

dielectric-coated mesh

This difficulty is overcome by supporting a dielectric coating on a metal mesh, as shown in Fig. 7-2. The dielectric-surface bistable charge mechanism is the same as described before, since the surface may charge independent of the mesh potential, because the surface of the dielectric is insulated from the mesh by the body of the dielectric.

mesh voltage

In this structure, the field in the apertures is influenced by both the dielectric surface potential and the potential of the supporting mesh, which act together as a composite grid to control the passage of current through the target. The mesh is usually operated at zero volts, so that the field in the apertures of unwritten regions will remain cut off to flood current. Flood-gun emission easily passes through the field in the apertures at written areas, and is then accelerated to form the bright image on the viewing screen by a high potential on the aluminizing.

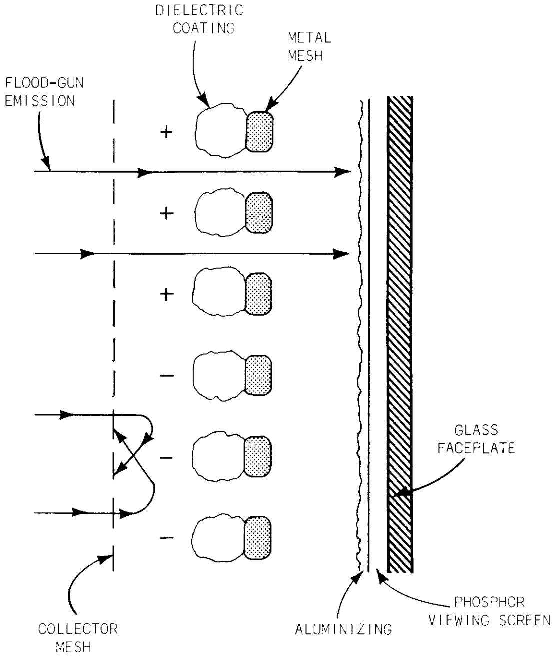


Fig. 7-2. Target with coated mesh.

This tube is the *first* tube in an evolutionary sequence which writes, stores, displays, and erases a bistable image *and* which uses a practically realizable storage target structure.

contacting collector mesh

During the development of the transmission-type bistable tube, it was discovered that improved operation resulted when the collector mesh contacts the surface of the dielectric (Fig. 7-3). In areas where the collector is touching the dielectric, conductivity to the collector and the shadowing of flood-gun bombardment by the collector, appear to act to some extent as barriers to migration of the boundary between written and unwritten areas. This extends the stable range of collector voltages over which the image does not become seriously degraded. The increase in stable range was quite an important development, since it had been marginal. The pitch and orientation of the collector mesh and the mesh which supports the dielectric are made dissimilar. Observation of a magnified portion of the image shows

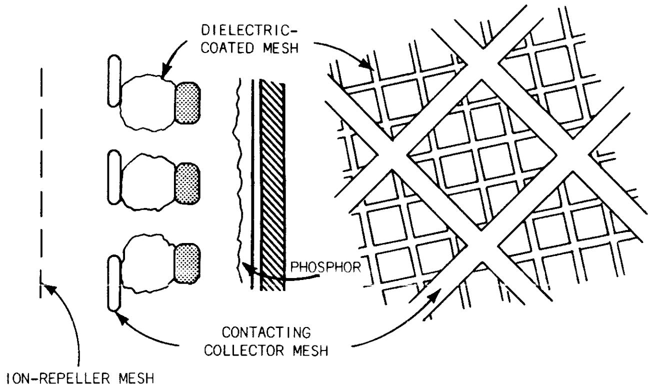


Fig. 7-3. Contacting collector mesh.

that all of the dielectric which is exposed to the flood gun through one square opening of the collector mesh, acts together in charging to either stable point. The tube of Fig. 7-3, the Haeff "transmission"-type bistable tube described here, typifies "second generation" storage tubes.

halftone

Halftone storage CRT's develop from the bistable transmission storage tube. Bistable tubes have two brightness levels, maximum and minimum. Halftone tubes on the other hand display images in several discernable brightness levels (gray scale halftones) from dark to maximum brightness.

Halftone and bistable transmission tubes exhibit similarities and differences. Consider first the similarities:

(1) A high-energy writing beam writes the targets positive by secondary emission.

(2) Structurally each uses a writing gun, flood guns, dielectric targets, ion repeller and viewing screen.

(3) Collection of flood electrons erases the image.

(4) Flood-gun current produces the visible display.

Now the differences:

(1) The halftone tube's sensitivity to flood-beam collimation creates design problems.

(2) The long-persistance bistable tube has no halftones; while the halftone tube with its gray scale has limited viewing time.

(3) *Theoretically* the halftone tube has higher writing-rate possibilities.

(4) Halftone tubes have highest brightness, due to high-transmission target structure.

The secondary-emission curve, Fig. 7-4, shows bistable storage characteristics. Targets rest at one of two stable points. Flood-gun current drives targets below first crossover voltage to the lower stable point (L). Targets at this point repel flood electrons causing the effect of a unity secondary-emission ratio. Positive ions do charge target elements more positive but low-energy flood electrons then return these target elements to the lower stable point.

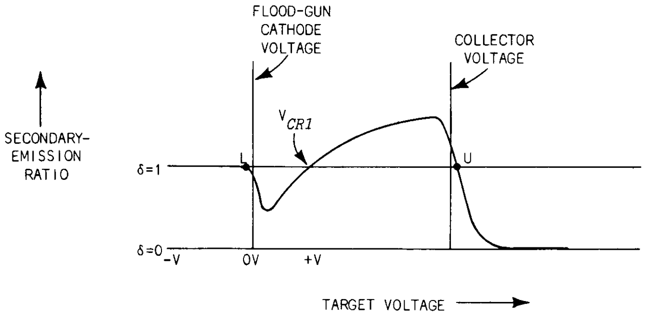


Fig. 7-4. Secondary-emission curve.

A voltage pulse or high-energy writing beam which raises a target above first crossover creates a *write* condition. Flood electrons strike target elements above first-crossover voltage with enough energy to cause secondary emission greater than 1. This charging action continues until target and collector potential are equal. Secondary-emission ratio now returns to unity at this, the second (upper), stable point.

bistable brightness

Fig. 7-5 shows that brightness varies little between first crossover and the upper stable point. One might expect halftones to exist in the region between first crossover and the lower stable point; however, flood-gun current drives target elements in this region toward the lower stable point.

Notice that 0% brightness occurs at target voltage more negative than the lower stable point. The background light at the lower stable point indicates that a minute quantity of flood electrons reach the phosphor viewing screen. Quantity *and* energy of flood electrons striking the phosphor determine brightness.

halftone transmission tubes

Halftone tubes are bistable devices operated with target voltages more negative than flood-gun potentials. The lower stable point represents maximum brightness. Cutoff, a few volts more negative, represents a dark screen or unwritten target.

The brightness curve, Fig. 7-5, indicates 0% brightness occurs at target voltages more negative than the lower stable point. Consider the 0% brightness point cutoff, the point of absolute secondary-emission ratio of 1.

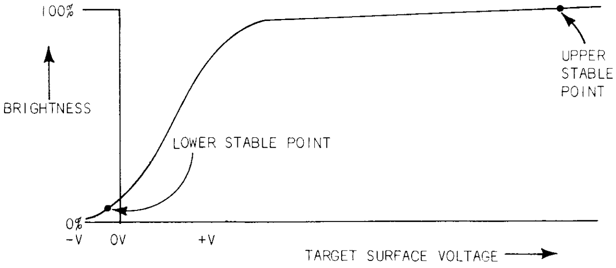


Fig. 7-5. Bistable brightness curve.

In Fig. 7-6 the secondary-emission curve extends to cutoff (point C). Flood electrons drive target elements to the lower stable point L. Target mesh elements, acting as a grid, setting at the lower stable point, allow a small quantity of flood electrons to reach the screen. Applying more negative voltages to the target grid reduces this current until, at point C, 100% repulsion or cutoff occurs.

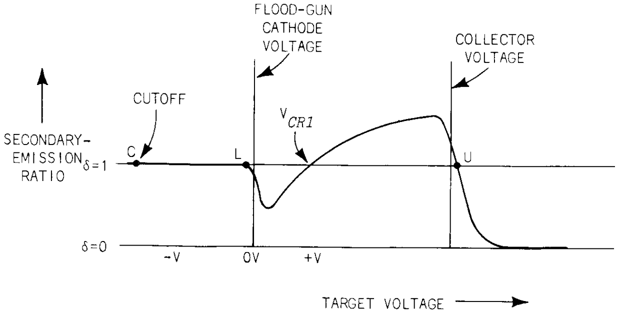


Fig. 7-6. Secondary-emission curve.

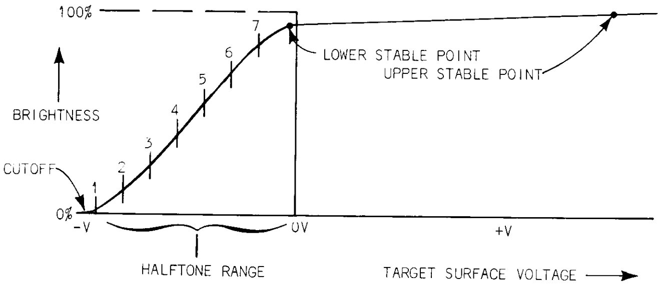


Fig. 7-7. Halftone storage brightness curve.

Operating between target voltages C and L, and returning the phosphor to a high positive voltage, allows halftone storage displays. One realizes several discernible brightness levels -- seven in Fig. 7-7. These tubes display a written image at any one of the brightness levels and brightness extends from 0% to just under 100%. (Assume, for now, that halftone tubes operate only between cutoff and the first-crossover target voltage.)

halftone construction

Halftone target construction lowers target grid cutoff. The basic secondary-emission curve serves to explain both bistable and halftone storage. This leads one to think both transmission tube types are alike -- not so! Haeff tubes *store* in bistable *and* halftone modes. These tubes produce a *visible image* in the bistable mode only. This is because halftone writing takes place below target grid cutoff. Therefore too few flood electrons reach the phosphor.

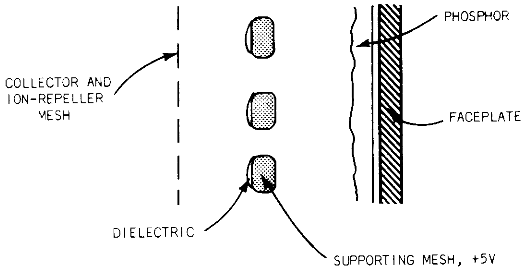


Fig. 7-8. Halftone construction.

Fig. 7-8 shows one type of halftone construction. The target dielectric is evaporated on the supporting mesh in a very thin dense layer. A thinner dielectric reduces mesh aperture shielding, resulting in more positive mesh aperture fields. Aperture fields increase even more, lowering transmission cutoff, by operating the supporting mesh at a positive voltage (shown at +5 V). Enough flood electrons now reach the phosphor to produce an image at maximum brightness, when the target grid elements rest at the lower stable point.

The collector need not contact the target surface and operating positive serves as an ion repeller. This simplifies *halftone* structure. Adjacent target elements charge to small voltage differences compared to bistable tubes. Flood emission creates no boundry migration, therefore a contacting collector becomes unnecessary.

Applying a positive pulse causes the target to collect flood electrons, driving the target more negative. Assume the target rests at point L of Fig. 7-9. Further, point L is -3 V, C is -10 V, and V_{CR1} is +40 V. Now apply a +10-V pulse. The positive excursion elevates the target into an unstable region above flood-gun potential. Flood electrons charge the target negative, attempting to return it to the lower stable point. This charging action continues during the positive erase pulse interval. Terminating the pulse drops the target to point C. Since point C represents cutoff, the target rests at the nonstored or unwritten state and no electrons reach the phosphor.

halftone erasure

Erase pulses must be large enough in amplitude to cause target collection of electrons, yet not so great that any target element exceeds first-crossover

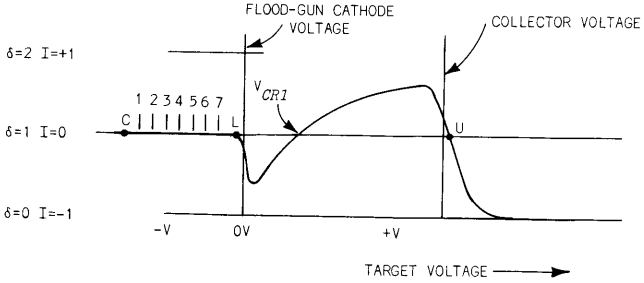


Fig. 7-9. Secondary-emission curve.

voltage. Positive pulse duration fixes the quantity of target charge which must equal L-to-C voltage (7 volts for conditions assumed above).

Halftone transmission tubes in use develop problems detrimental to a "clean" storage presentation. These effects are residual images, target elements charged to the upper stable point, and accumulation of positive ions in grid apertures. The complex erase pulse of Fig. 7-10 serves to eliminate these problem effects with each erasure.

One might consider Fig. 7-10 a combination of bistable and halftone erasure. The portion of the waveform occupying T_0 through T_3 is the bistable erasure; and that occurring from T_3 through T_4, the halftone portion.

T_0 -- The mesh rests at quiescence, a few volts more positive than the lower stable point.

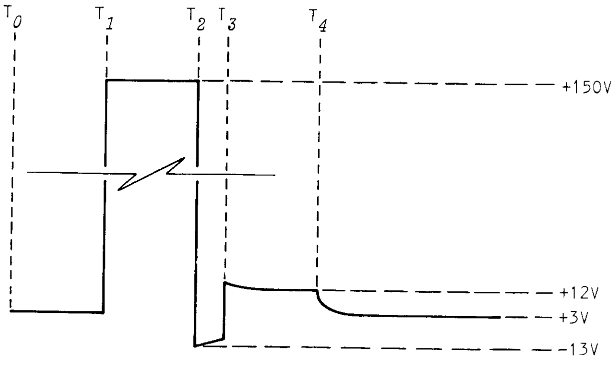


Fig. 7-10. Halftone erase cycle.

T_1 -- Actuating erase circuits applies a large positive excursion, driving target elements above first crossover. Target elements then charge toward the *upper stable point.* Writing-target elements bistably deplete buried target charge (residual image) and allow erasure of target elements inadvertently written to the upper stable point.

T_2 -- The negative pulse, lasting from T_2 to T_3, drives target elements below first crossover. Descending to a level below the lower crossover point, the pulse repels any positive ions occupying the aperture area.

T_3 -- This positive excursion elevates target elements into an unstable region below first crossover. Flood electrons accumlate on target elements so that at:

T_4 -- When the erase pulse returns the collector to quiescence, target elements drop below the lower stable point to cutoff. All target elements are erased.

Complex erasure waveforms such as the one explained, require as much as one-half second cycle time.

halftone writing

When the target is at cutoff the screen is dark. Arrival of a high-energy writing beam then charges target elements positive which in turn allows flood electrons to strike and luminesce the viewing screen. Electron quantity passing through the target mesh depends upon how far positive (toward the lower stable point) the target charges. Depending upon writing-beam density and dwell time, target elements charge to some increment between points C and L. Target areas charged to point 1 gate a small quantity of flood electrons for minimum image brightness. Point 7 represents maximum brightness.

Target areas charge toward the lower stable point becoming fully written after several minutes. Consider an area charged to increment 1 and another to 7: One dim and one very bright image appears on the screen. Positive ions charge target elements toward point L. Area 7 becomes fully written followed a few minutes later by area 1. Both images are now fully written. Unfortunately, the entire target area fades positive. Therefore, shortly after an area charged to increment 1 becomes fully written, the entire target area charges to point L. The overall screen area is now at maximum brightness displaying no intelligence. The target must be erased for waveform monitoring.

store

A technique called *store* increases viewing time. Positive ions, the cause of fade positive, result from the ionizing action of flood electrons. Reducing flood current then increases viewing time, accompanied by reduced brightness.

Actuating the *store* circuits applies (actually or effectively) a train of pulses to the flood-gun anode or cathode. These pulses turn the flood guns on and off. Pulse train duty cycle establishes average flood-gun cathode current, thereby setting viewing time and brightness: If viewing time *increases* by 10, brightness *decreases* by 10 since average flood current *decreases* by 10.

variable persistance

Another application of a pulse train develops the concept known as *variable persistance.* The technique partially erases the target area with a series of short-duration erase pulses. This maintains a good contrast ratio between written areas and background illumination, eventually erasing the entire target surface.

Applying short-duration fixed-amplitude erase pulses (usually to the flood guns) cause target elements to charge toward cutoff at the pulse rate. The viewer sees little if any flicker.

To him the image merely fades into the background. Varying the "fast" erase-pulse duty cycle changes the rate of erasure. A front panel control allows operator control of erasure, or call it duty cycle or variable persistence.

Variable persistence applies well to observations of repetitive signals superimposed on random signals (noise). Random signals write at lower halftones than repetitive. The random signals experience early erasure allowing one to view a "clean" repetitive signal.

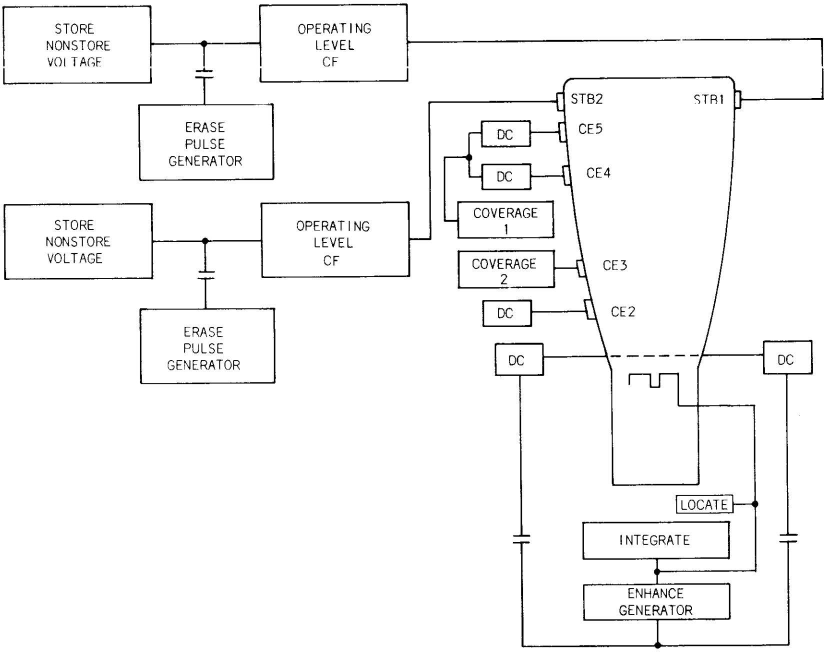


Fig. 8-1. Basic storage block diagram.

8

BASIC STORAGE CIRCUITS

basic bistable storage circuits

Some circuits that follow include waveforms, voltages and component values. These are not precise or absolute entries. They are approximate design-center calculations to aid conceptual descriptions. Further, the table at chapters end, Fig. 8-36 lists semiconductor considerations.

block diagram

Fig. 8-1 shows the block diagram of the storage circuitry needed by a typical storage tube. The storage-target-backplate connection for the upper half of the screen is labeled STB1 and for the lower half, STB2. The STB voltage is set in the store, nonstore voltage circuit and coupled to the backplate through the operating level cathode followers. The erase pulse generator provides the necessary waveform to erase the display, which is coupled through the operating level CF. The lower half of the screen has the same independent circuitry. DC voltages are provided for the wall bands or collimation electrodes. CE3 is an adjustable DC voltage for flood-gun electron coverage of the entire screen. The integrate circuitry affects just the flood-gun cathodes while the enhance circuitry provides a pulse to both the flood-gun cathode and flood-gun grid.

store, nonstore voltage

Fig. 8-2 shows the circuitry that might be used to set the store and nonstore voltages on the backplate. SW1 selects the voltage set by R2 when the backplate is to be operated in the storage mode. R2 is set at a voltage that will allow the backplate to be in the middle of the operating range when half of the tube is to be operated in the storage mode. This voltage is about +225 volts at the upper arm of R2 but will vary from tube to tube. C2 is a noise bypass cap for the pot.

R4 sets the voltage for nonstore operation and is typically +120 at the upper end of the pot.

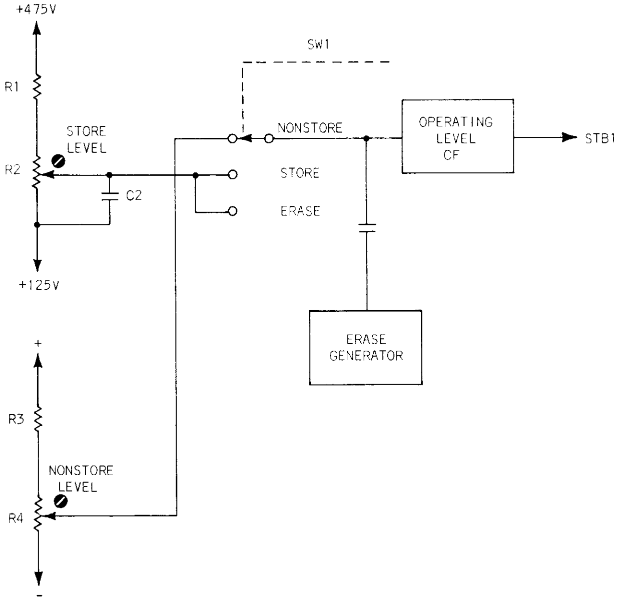


Fig. 8-2. Store, nonstore voltages circuit.

erase pulse generator

When the switch (Fig. 8-3) is pressed to ERASE, a positive pulse is applied through C2 to the operating level CF. The input to the operating level CF steps positive and decays back to its quiescent voltage on a time constant determined by R2, and the parallel combination of R5, R1. D1 conducts when the input to the CF steps positive and is off when input is at quiescent level.

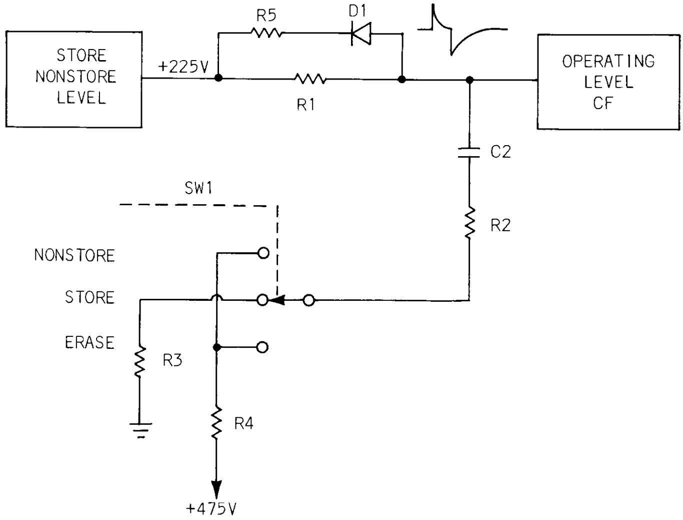


Fig. 8-3. Erase pulse generator.

When the switch is released it returns to the STORE position and a negative pulse is applied to the input of the CF. The pulse discharges to its quiescent level determined by the longer time constant R2 and R1 (D1 is biased off during negative step).

The erase pulse is shown in Fig. 8-4. Section A is the time required to depress the DISPLAY switch to ERASE and release it for return to STORE position.

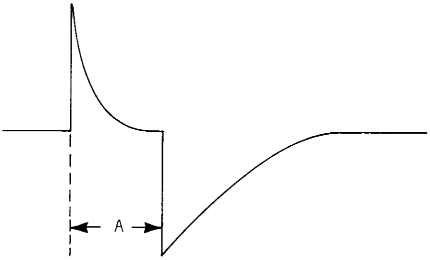


Fig. 8-4. Erase pulse.

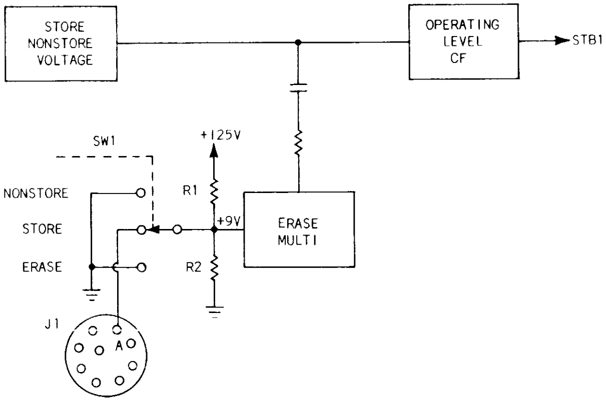


Fig. 8-5. Erase multivibrator.

Fig. 8-5 shows a circuit that will allow the screen to be erased with a switch or by grounding the appropriate pin of a remote erase jack. The input to the erase multi is held at about +9 volts by R1 and R2. When the switch (SW1) is depressed to ERASE or a ground is applied to Pin A of J1, the monostable erase multivibrator will switch and generate the required input for the operating level CF.

erase multivibrator

An erase multivibrator circuit is shown in Fig. 8-6.

Quiescently V1 is on and V2 is conducting slightly. When the junction of R1-R2 is grounded, a negative edge is applied to the grid of V1. V1 cuts off, its plate goes positive, turns V2 on hard, producing a

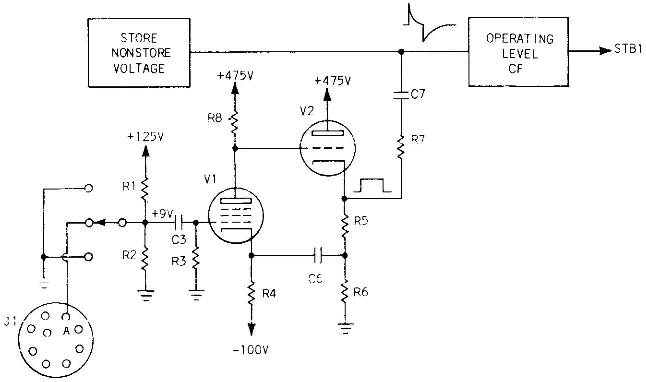


Fig. 8-6. Erase multi circuitry.

positive step at the cathode of V2. This step is coupled through R7 and C7 to the operating level CF and through R5 and C6 to the cathode of V1 holding it positive momentarily. As soon as C6 has time to discharge, V1 will again conduct and the multivibrator will return to its quiescent state, which then produces the trailing edge of the erase pulse at the cathode of V2.

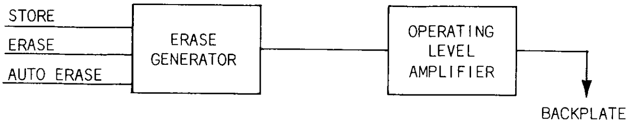


Fig. 8-7. Erase generator.

erase generator

Fig. 8-7 shows a different erase generator which may be driven by various inputs. The inputs will be negative-going pulses which will cause an erase pulse to be applied to the operating level amplifier and therefore to the backplate.

Q1 and Q2 (Fig. 8-8) form a monostable multivibrator. Quiescently Q1 is saturated and Q2 is off. Q1's base is held positive through R2, D1, and R3 while its emitter is tied to -12.4 V. Q1's collector is negative and biases Q2 off.

A negative-going pulse applied to R1 will reverse-bias D1. Q1's base will be tied to -12.4 volts through R2 and turns off, turning Q2 on. As Q2 saturates, its collector drops and this negative

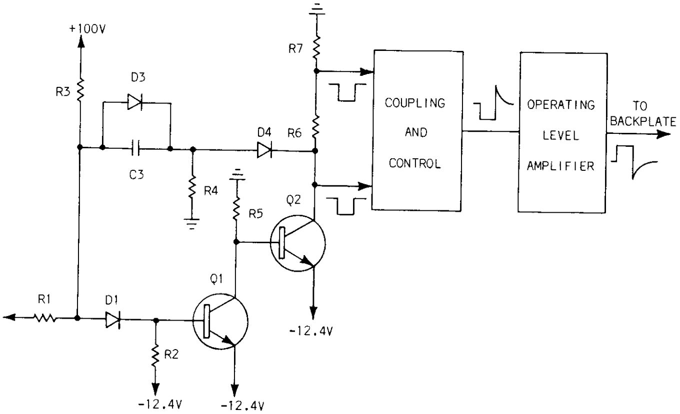


Fig. 8-8. Erase generator circuitry.

step is coupled through D4 and C3 back to the input holding D1 off and the multi in its unstable state until C3 discharges. When D1 becomes forward-biased Q1 turns on, Q2 turns off and the cycle is completed.

The pulse output of Q2 must have a differentiated trailing edge before being applied to the storage target backplate. The coupling and control circuit limits the maximum swing of the waveform applied to the operating-level amplifier and differentiates the trailing edge.

erase positive

The negative edge of the erase generator is DC coupled through R8 and R9 to the operating-level amplifier (see Fig. 8-9). The maximum negative amplitude of the output is controlled by R21 through

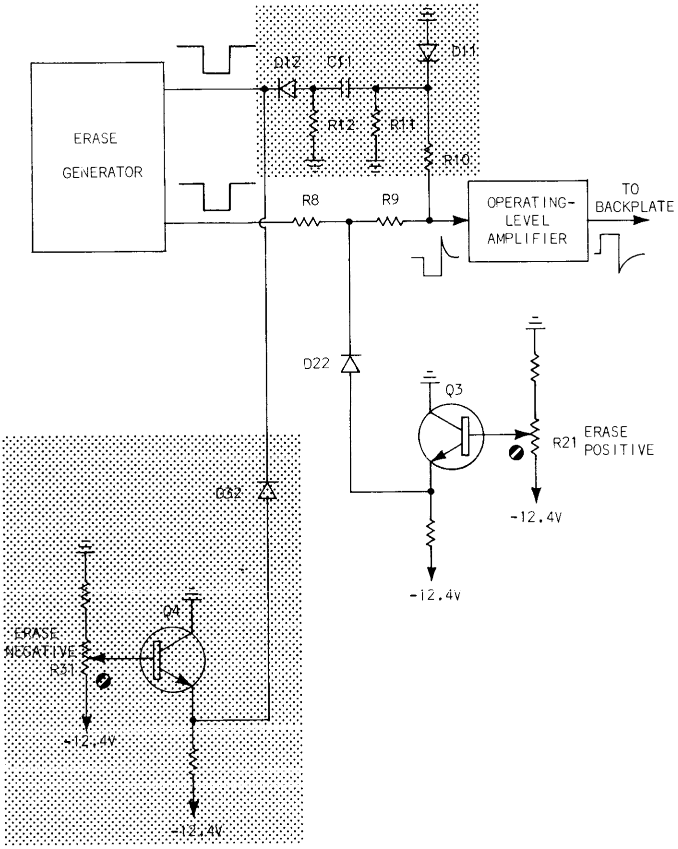


Fig. 8-9. Erase-positive circuitry.

Q3 and D22. (The label of this control is referenced to the output of the operating-level amplifier which inverts the output of the coupling and control circuit.)

When the output of the erase generator is negative, D12 is forward-biased and C11 charges. D11 prevents the right side of C11 from going below ground. When the erase-generator output steps positive, D11 is reverse biased and C11 discharges. The top of R10 steps positive and decays back to its quiescent level.

erase negative

The erase-negative control, R31, (referenced to output of operating level amplifier) limits the maximum positive level at the cathode of D12 through Q4 and D32. (Fig. 8-10)

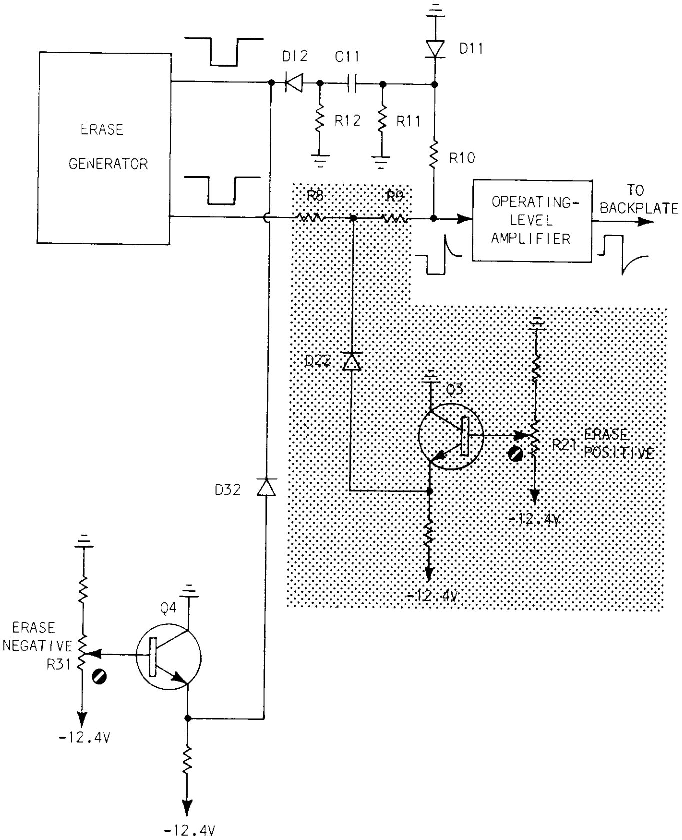


Fig. 8-10. Erase-negative circuitry.

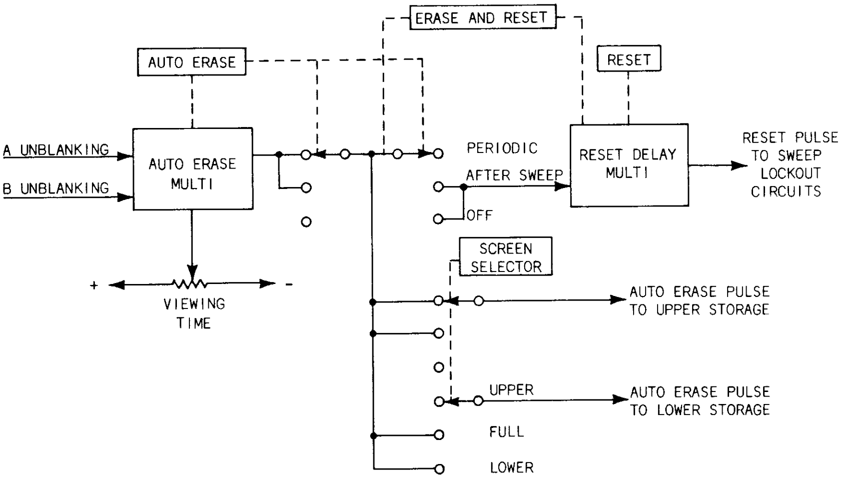


Fig. 8-11. Auto erase.

auto erase

It may be desirable to erase the display on a storage tube manually, after the sweep, or after some controllable fixed period of time. Fig. 8-11 shows an auto erase circuit block diagram of such a system.

viewing time control

In the AFTER SWEEP position of the AUTO ERASE switch, the auto erase circuit uses the sweep unblanking pulse from either A sweep or B sweep depending on which time base is feeding the horizontal amplifier of the oscilloscope. The scope is operated in single sweep mode. The trailing edge of the unblanking pulse switches the auto erase multi to its unstable state. The duration of the unstable state is controlled by a VIEWING TIME control on the front panel of the oscilloscope. When the multi returns to its stable state, the negative step at the multi output constitutes the auto erase pulse. This pulse is fed to either the upper or lower erase generator. The auto erase multi also drives the lockout reset multi in the sweep generator with its negative output. The *reset delay multi* is switched to its unstable state by the negative step of the output of the auto erase multi. When the reset delay multi returns to its stable state a positive step is fed to the sweep generators as the reset pulse.

reset delay multi

In the periodic position of the AUTO ERASE switch, the auto erase multi free runs at a rate controlled by the VIEWING TIME control.

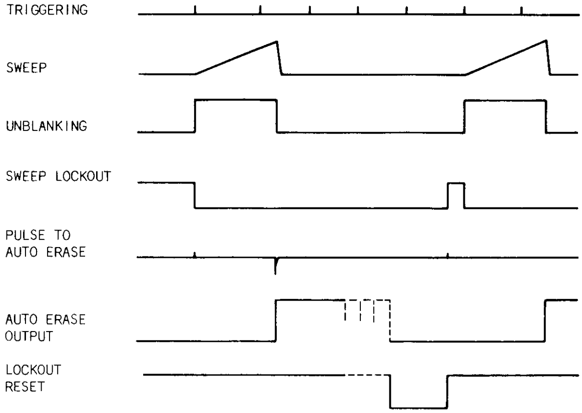


Fig. 8-12. Oscilloscope waveforms when using auto erase.

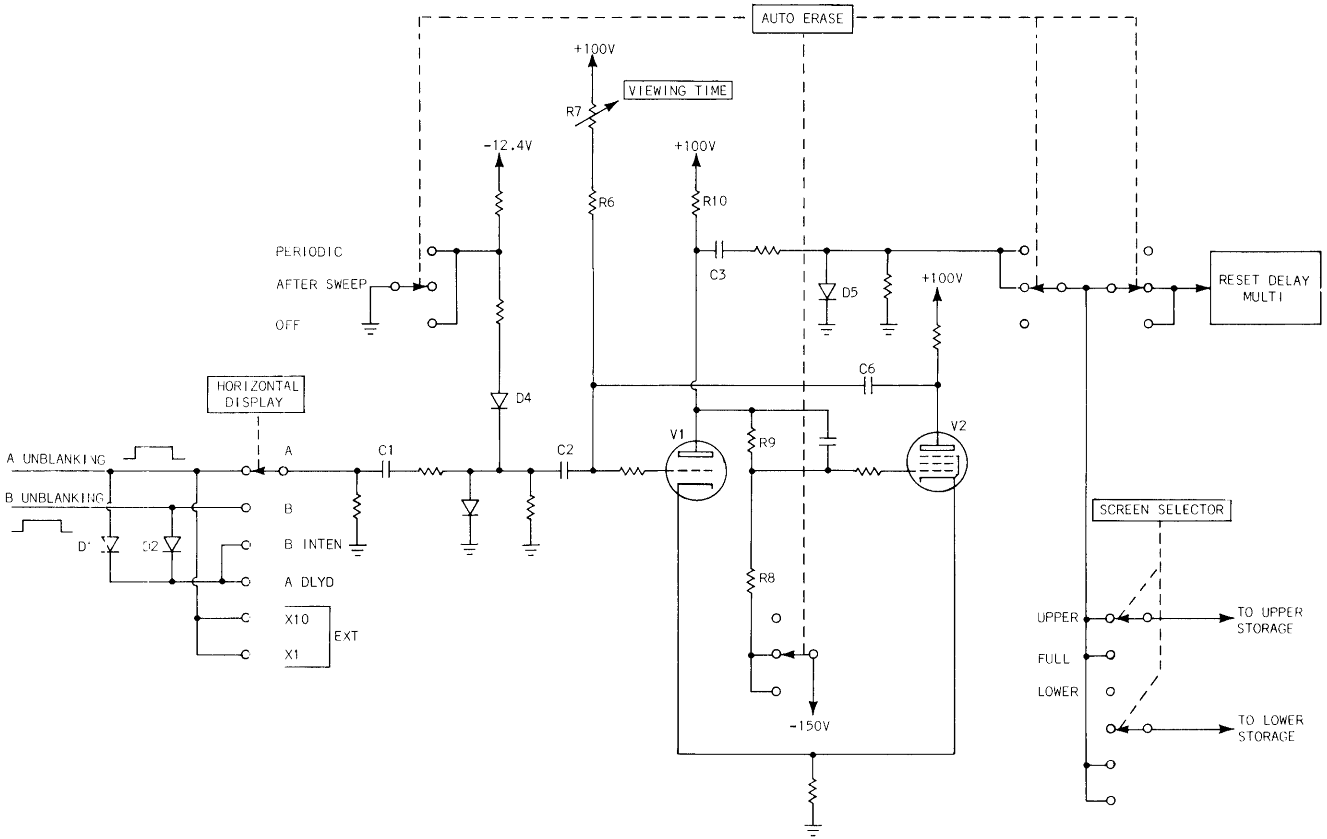


Fig. 8-13. Auto erase multi circuitry.

auto erase multi

Fig. 8-13 shows an auto erase multi. When the AUTO ERASE switch is in the AFTER SWEEP position, V1 and V2 form a monostable multi. Quiescently V1 is conducting and V2 is cut off because V1's grid is returned to +100 V through R6 and R7 while V2's grid voltage is set by a divider composed of R8, R9, and R10 between +100 and -150 volts.

The leading edge of either unblanking pulse will be shorted to ground by either D1 or D2. The trailing edge of the unblanking pulse is coupled through C1 and C2 to the grid of V1. The multi switches to its unstable state (V1 off, V2 on). The positive step of the output (V1 plate) is coupled through C3 and shorted to ground by D5. The time duration of the unstable state is determined by C6, R6 and R7 and controllable by the VIEWING TIME control R7. There is no output from this circuit until C6 discharges and V1 starts conducting and the multi returns to its stable state. When V1 turns on, the negative signal on its plate is coupled through C3 to the output.

When the AUTO ERASE switch is in the PERIODIC position the multi *free-runs* at a rate determined by C6, R6 and R7 (VIEWING TIME control). V2's grid return, to -150 volts, is opened and the top of D4 is grounded preventing the unblanking-pulse trailing edge from reaching the multi.

When the AUTO ERASE switch is in the OFF position, the multi is in its monostable state, *but* D4 is shorting all inputs to ground and there is no output from the multi.

auto erase

reset delay multi

When the AUTO ERASE is in the AFTER SWEEP position, the scope is operated in the single sweep mode. After the sweep, a reset pulse is needed to reset the lockout multi so the sweep may be triggered. The reset delay multi provides this pulse.

There are four methods of originating a reset pulse using this multi: namely, the ERASE button on the front panel of the scope may be depressed, a ground may be applied to the remote-control input jack on the rear panel, switching the AUTO ERASE switch from the OFF position, or by an auto erase pulse from the auto erase multi.

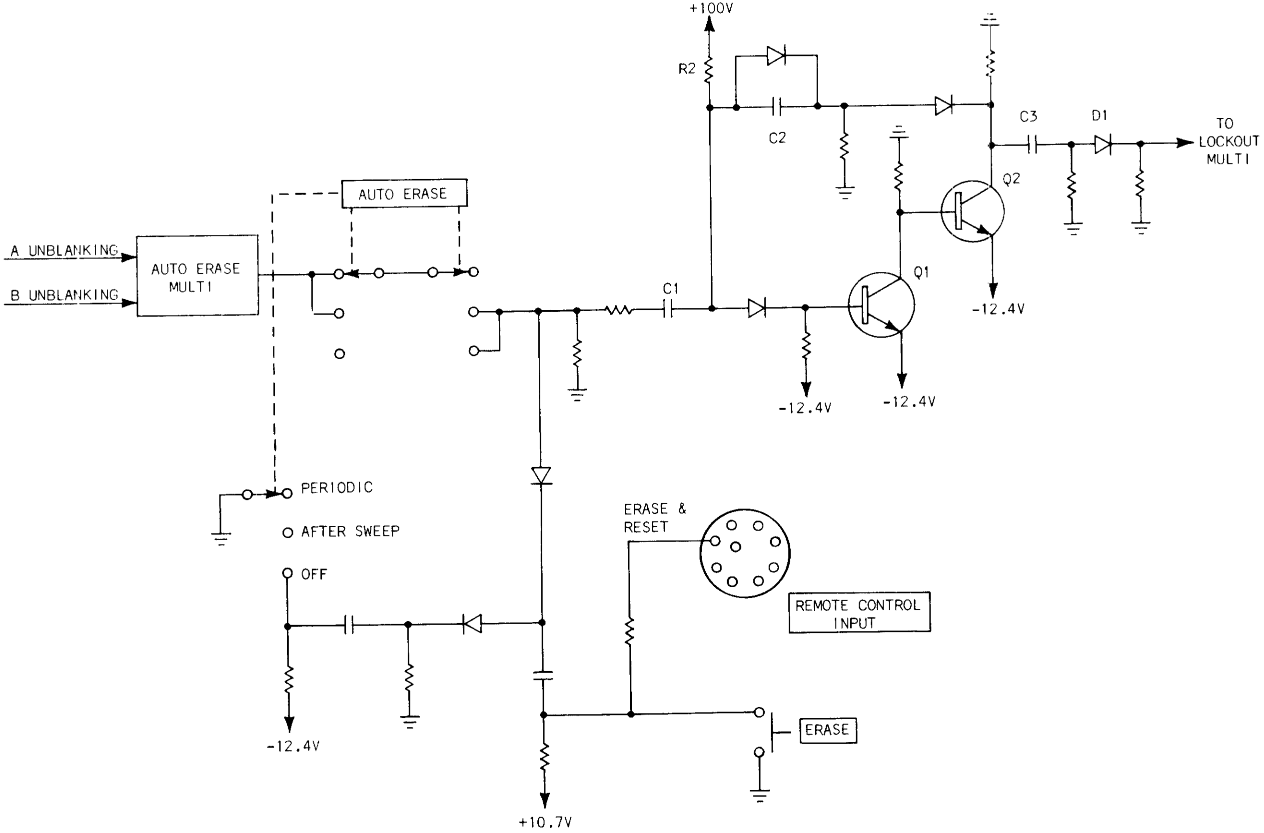


Fig. 8-14. Auto erase reset delay multi.

Q1 and Q2 (Fig. 8-14) form a monostable multi with Q1 on and Q2 off in its stable state. Any *negative*-going signal applied through C1 will cause the multi to switch to its unstable state. C2 and R2 determine the duration of the unstable state. When the multi switches from stable to unstable the collector of Q2 drops but D1 is off and there is no output. When the multi switches from its unstable to stable state the positive pulse output is coupled through C3 and D1 and on to the lockout multi as a reset pulse.

operating-level cathode follower

Fig. 8-15 shows an operating level cathode follower circuit. This circuit provides a constant voltage source for the storage target backplate. As the screen becomes increasingly written, the STB current increases slightly, but the STB voltage is held constant by the operating level CF. The voltage on the grid of V1 will depend on the store, nonstore circuit (about +120 V in nonstore, about +225 V in store). D1 prevents the grid of V1 from going negative during the trailing edge of the erase pulse.

D2 is protection for V1 during warm-up. If V1 were slow to warm up, the grid could be at +225 volts and the cathode at ground, thereby exceeding the grid-cathode voltage specifications.

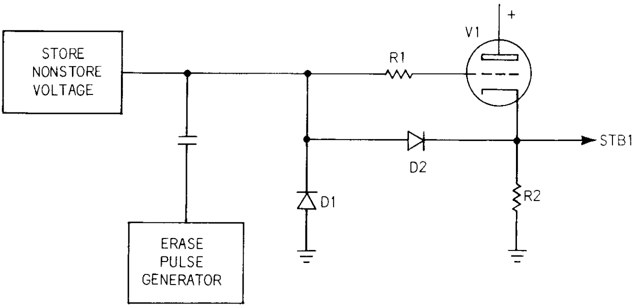


Fig. 8-15. Operating-level cathode follower.

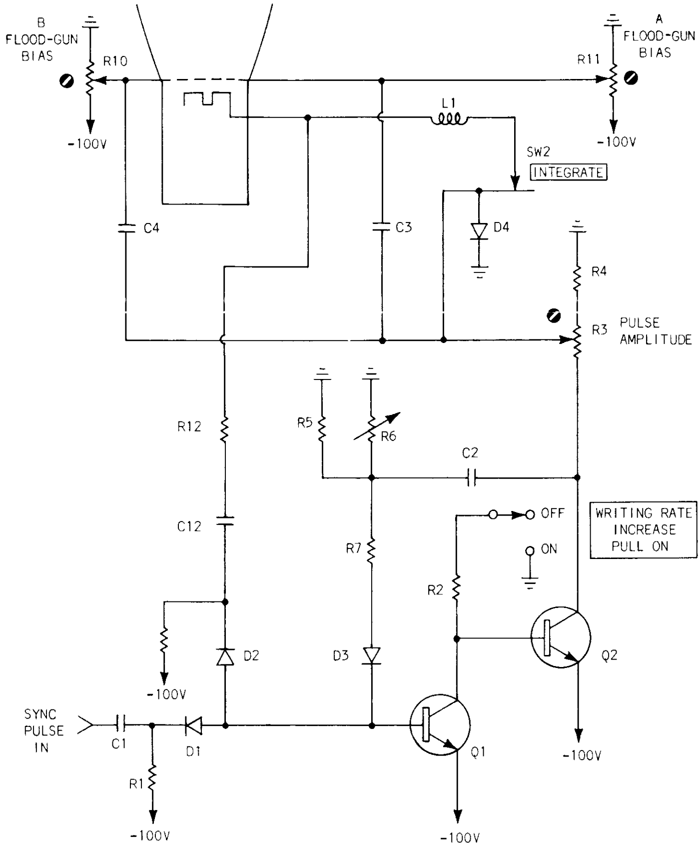


Fig. 8-16. Enhance generator.

trace-enhancement generator

A trace-enhancement circuit is shown in Fig. 8-16. This circuit furnishes a negative pulse to the flood-gun cathodes and grids for writing-speed enhancement. The pulse occurs at the end of the sweep. Its amplitude is an internal adjustment and its duration a front panel control.

integrate

At the end of the sweep, a negative-going pulse from the sweep circuit is applied through C1 and D1 to the base of Q1. A pulse may also be applied to this base when the INTEGRATE button is depressed through L1, R12, C12, and D2. D1 and D2 are both quiescently reverse biased due to current from the -100-volt supply to ground through the base-emitter junction Q1, D3, R5, R6, and R7. SW4 is the WRITING RATE INCREASE switch. If this switch is ON, a ground is applied to Q1 collector and it is operative. If the switch is OFF the collector is open and incoming pulses have no effect on the circuit.

writing rate increase

When the switch is ON, Q1 is on and the drop across R2 holds Q2 off with its collector near ground. A negative pulse applied to the base of Q1 causes it to turn off, causing Q2 to turn on. The large negative pulse from the collector of Q2 is applied to the pulse amplitude network (R3, R4), and to the base of Q1 through C2. The regenerative feedback to the base of Q1 holds it off till the pulse decays. The decay time is determined by the time constant of C2, R5, R6, and R7 with R6 being adjusted from the front panel of the oscilloscope. As soon as the pulse has decayed, Q1 will turn on, turning Q2 off, ending the cycle. During the time Q2 is on, the flood-gun cathodes and grids have been held negative thus enhancing the writing rate. When the INTEGRATE button is depressed the flood-gun cathodes are opened and the grids are pulsed negative by the enhance generator to insure that no flood-gun electrons reach the screen to discharge the targets.

The following circuits are from scopes which apply *write* pulses to flood-gun cathodes followed by *erase* pulses to the storage target backplate. This technique eliminates split-screen capability but reduces power supply requirements.

storage display units

Storage display units are circuit vehicles. These specialized instruments store displays of combined alphanumeric and graphic information from data transmission systems such as digital computers. Storage display units must include front panel and remote control of ERASE, NONSTORE and VIEW modes. Circuits initiating these modes are described.

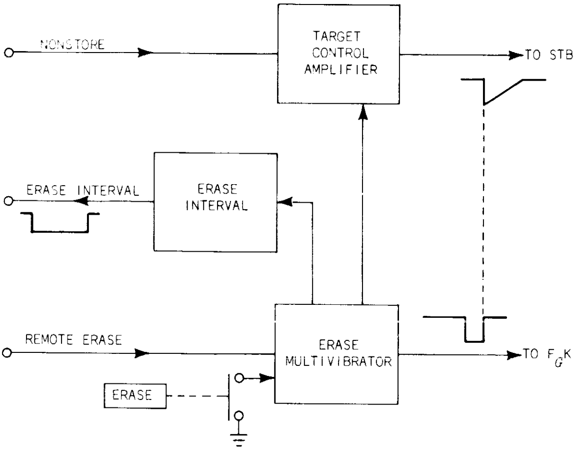


Fig. 8-17. Cathode pulsed to write, STB pulsed to erase.

Circuits blocked in Fig. 8-17 generate flood-gun cathode (F_GK) and STB waveforms and also provide for remote programming.

erase interval

Actuating the normally open ERASE switch flips the astable erase multivibrator, generating a 25-millisecond negative pulse. Pulsed negative, flood guns "write" the target during negative-pulse time. This pulse serves as the input to erase interval and target-control blocks. Target-control amplifier circuits react to the positive-pulse excursion, developing STB "erase" waveforms upon termination of flood-gun "write" pulses. Negative-write-pulse edges cause erase interval circuits to initiate a negative output pulse, which terminates as the STB erase ramp approaches STB operating level.

remote programming

Erase-interval pulses, although slightly less in duration, represent erase cycle time. Routed to remote programming inputs, these pulses are *busy* signals, preventing input intelligence during erasure.

REMOTE ERASE and NONSTORE are inputs from remote program sources. Consider these lines either open or ground. Grounding remote erase flips the erase just as the local ERASE switch. Grounding nonstore lowers STB voltage to an operating level below ground, preventing flood electrons from reaching the target.

erase

Erase and remote erase functions depend upon proper coupling. Consider first the erase action (Fig. 8-18). Closing the ERASE switch grounds the junction of C1-R1; in effect, generating a negative pulse from +12.5 volts to 0 volts. This pulse couples across C1 to flip the multi.

R2 presents a resistance to the charge (or discharge) current for C3. Assume a user holds the ERASE switch closed for a second or so. The input side of C1 is grounded during feedback time. If not for R2, C1 then shunts C3 current to ground. Impulses do develop across R2 at a constant amplitude, insuring multi-switch time dependence on R3-C3 time constant.

remote erase

REMOTE ERASE merely parallels local manual ERASE: D1 may be on or off at quiescence but turns on hard during remote erase. Either active devices or a manual switch activates the remote erase line. Fig. 8-18 suggests a collector-loaded amplifier pulsed to saturation. This grounds C2-R5 connection, developing a negative 10-volt pulse. The pulse turns coupling diode D1 on hard, presenting a switching pulse to the erase multi. R2, R3, and C3 function as described above.

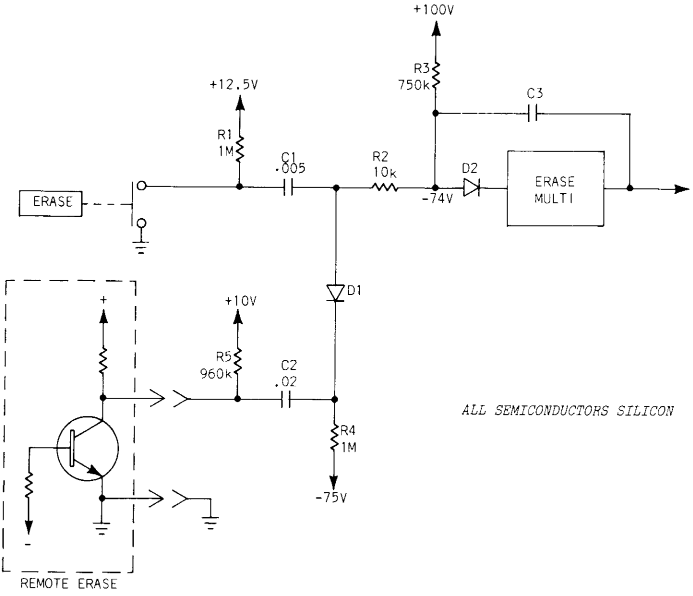


Fig. 8-18. Erase coupling circuits.

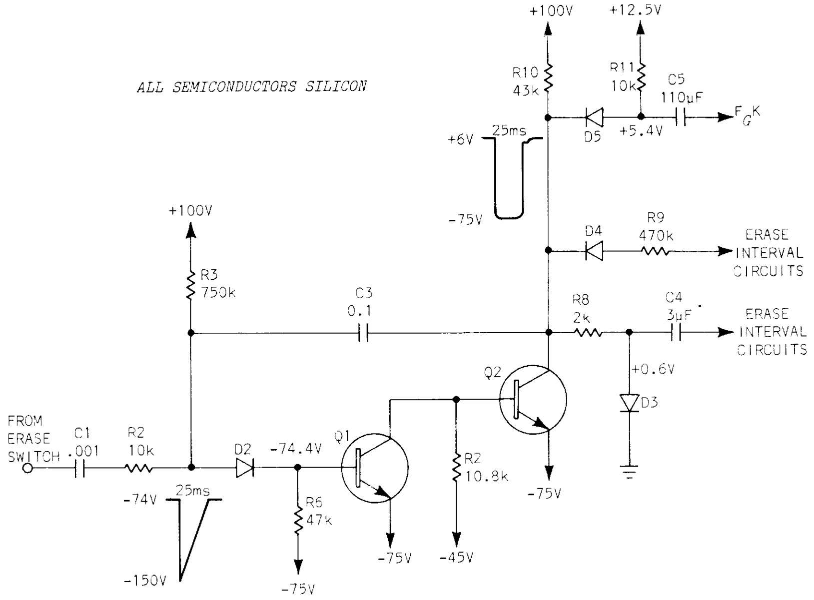


Fig. 8-19. Erase multi.

erase multi

Fig. 8-19 shows the erase multi circuit. At quiescence Q1 is on, Q2 is off. D2 conducts creating drops across R3 and R6. The drops across R6 forward-biases Q1, driving it to saturation. Saturated, Q1 holds Q2 cut off.

Q2 collector voltage sets about 6-volts positive. D3 is on, conducting through R8, D4, R9, R10, D5, and R11. C4 and C5 are electrolytics protected by D3 and D5. These diodes limit maximum positive levels applied to C4 and C5. Positive excursions to C4 cannot exceed the junction drop across D3, while D5 cuts off when positive collector excursions approach +12 volts. D4 also disconnects during positive excursions to prevent positive pulses across R9.

Actuating the ERASE switch applies a negative pulse to D2. D2 cuts off, reverse-biasing Q1. Q1 collector voltage now ascends toward -45 volts, turning Q2 on. Q2 saturates. Collector voltage drops to about -75 volts, appearing as a fast negative pulse to associated coupling circuits. C3 couples this 80-volt pulse to the anode of D2, driving this point to -155 volts. C3 must now discharge through R3 toward +100 volts. Time constant R3-C3 and applied voltage determine ramp slope at D2 (anode).

When ramp voltage represents forward-bias for D2: D2 turns on, switching Q1 on which reverse-biases Q2--the pulse terminates.

D5 acts as a short circuit allowing the 80-volt pulse to couple, via C5, to the flood-gun cathode. D4 couples the full pulse to R9. D3 disconnects, functioning as a high impedance during negative pulse time. R8 limits the quantity of charge current to C4.

output coupling

The erase multi provides a negative pulse of 80 volts for 25 milliseconds to output coupling circuits. Coupling circuits route this pulse to three circuit areas: Flood guns, erase interval, and target control amplifier. Fig. 8-20 shows these circuits.

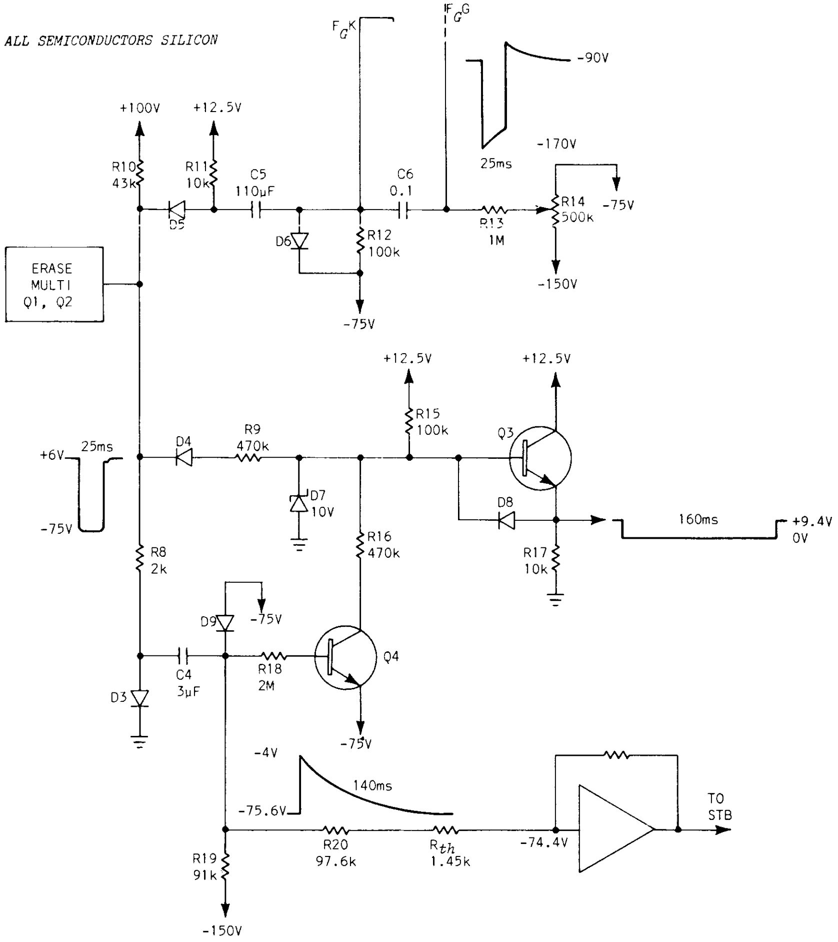


Fig. 8-20. Flood erase, erase interval circuits and input to target control amplifier.

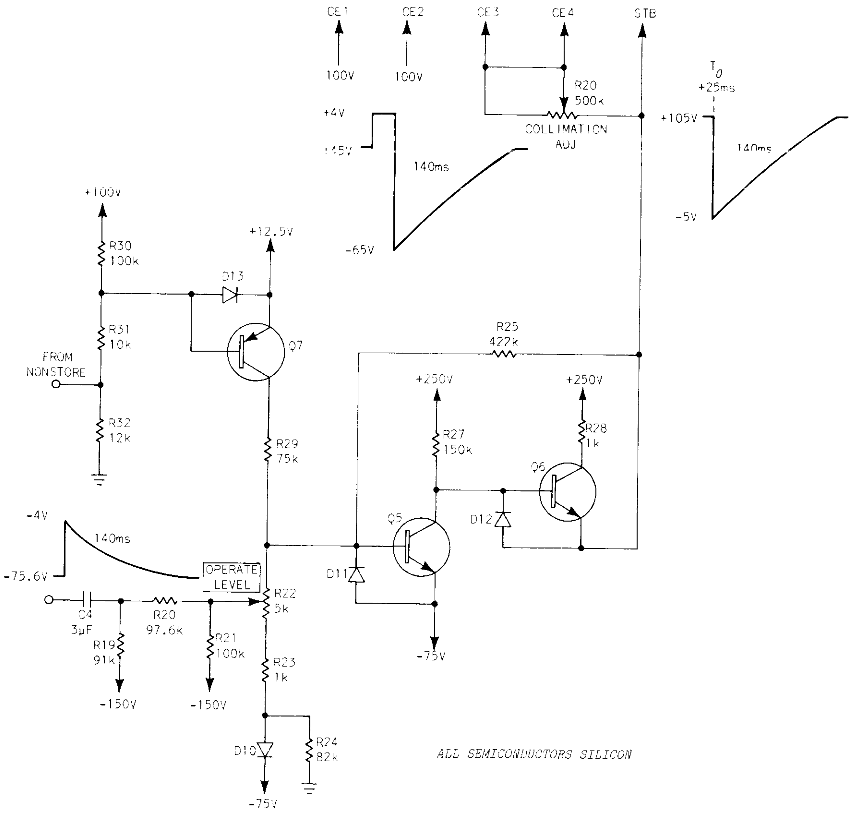
Consider flood-gun circuits first. The negative pulse disconnects D6 driving flood-gun cathodes below -150 volts, creating sufficient energy to write target elements. Cathode pulses remain fairly rectangular. Write pulses also couple to the flood-gun grids, via C6, maintaining electron quantity constant. One initially adjusts R14 for proper operating bias. Applying write pulses to both cathode and grid maintains static bias during negative pulse time.

erase interval

Negative excursions at D4 initiate erase-interval pulses. Quiescently zener diode D7 regulates Q3 base voltage at +10 volts. Emitter follower Q3 then develops +9.4-volt output level. R15 serves as a load for D7, although a small current from D4 also flows through R15. Q4 turned off, contributes no drop across R15 at quiescence. Write pulses Turn D7 off, Q3 off, and D8 on. Current through D4 increases with the negative-pulse excursion, increasing the drop across R15. Q3 base voltage descends to about one-half volt below ground. D7 and Q3 cut off. D8, forward-biased, maintains output voltage at about 0 volts. This condition lasts for the negative-multi pulse duration. Terminating the multi pulse would also terminate the erase-interval pulse--but, Q4 turns on with the positive-write pulse excursion. Q4 collector current holds Q3 reverse-biased. Output therefore remains at 0 volts until interruption of Q4 collection current.

Active devices D9 and Q4 with associated passive components terminate erase-interval pulses and generate erase waveforms following write pulses. D9 clamps the input prior to and during negative-multi pulse time. The positive excursion however, turns D9 off.

A positive voltage, about 72 volts, develops at the junction of C4, R19, R20, R18, and D9. Q4 saturates, holding Q3 in reverse-bias. C4 must discharge through resistive components forming the erase waveform. R18 limits the amount of Q4 base current contributing to capacitive discharge. Discharge current then flows only through R19, R20, and the equivalent input resistance of the target-control amplifier. C4 discharges toward D9's turn-on bias. 140 milliseconds represents circuit recovery time and the STB erase waveform interval. This waveform is applied to the inverting, fedback, target-control amplifier.



ALL SEMICONDUCTORS SILICON

Fig. 8-21. Target control amplifier.

target-control amplifier

Q5 and Q6, of Fig. 8-21, develop open-loop gain for the fedback target-control amplifier. This inverting amplifier establishes the STB operating level and erase waveform amplitude. Q7, normally off, presents an additional input to the target-control amplifier during (remotely programmed) nonstore. Activating Q7 drops STB operating level below ground.

To simplify the circuit for amplifier analysis, determine the components to eliminate. D10 clamps R23 return voltage equal to Q5 base voltage. This prevents quiescent bias current flow through R22 and R23. D10 cathode sets at -75 volts and the anode returns to ground through R24. -75 volts less the drop across D10 develops across R24 as the negative return for R23: -74.4 volts. R22 also returns to -74.4 volts since the emitter-base junction of Q5 also drops 0.6 volts.

D11 protects Q5 by preventing reverse breakdown. Negative base voltages approaching -76 volts turn D11 on, clamping at this level.

R27 is a large collector load to develop high-open loop gain. Emitter-follower Q6 preserves open-loop gain by isolating R27 from output loading. D12 speeds follower action. NPN emitter followers follow negative excursions more slowly than positive. D12 turns on fast during negative excursions, acting as an additional current source, then turns off during positive excursions allowing normal follower action. R25 closes the feedback loop from amplifier output to null point, at the base of Q5.

Assume the formula $A_v = \frac{-R_f}{R_a}$ expresses amplifier voltage gain. $V_o = V_{in}\left(\frac{-R_f}{R_a}\right)$ then expresses output voltage, rereferenced to Q5 base voltage: -74.4 volts.

R25 is R_f. R_a and V_{in} are not quite as simple. Current which establishes STB operating level flows through R19, R20, R23, and R22. This complex network resolves to an equivalent resistance value dependent upon the setting of R22. Moving the wiper to the R23 connection of R22 sets maximum resistance at approximately 6 kΩ. Adjusting R22 to the other extreme reduces equivalent resistance by about 600 ohms.

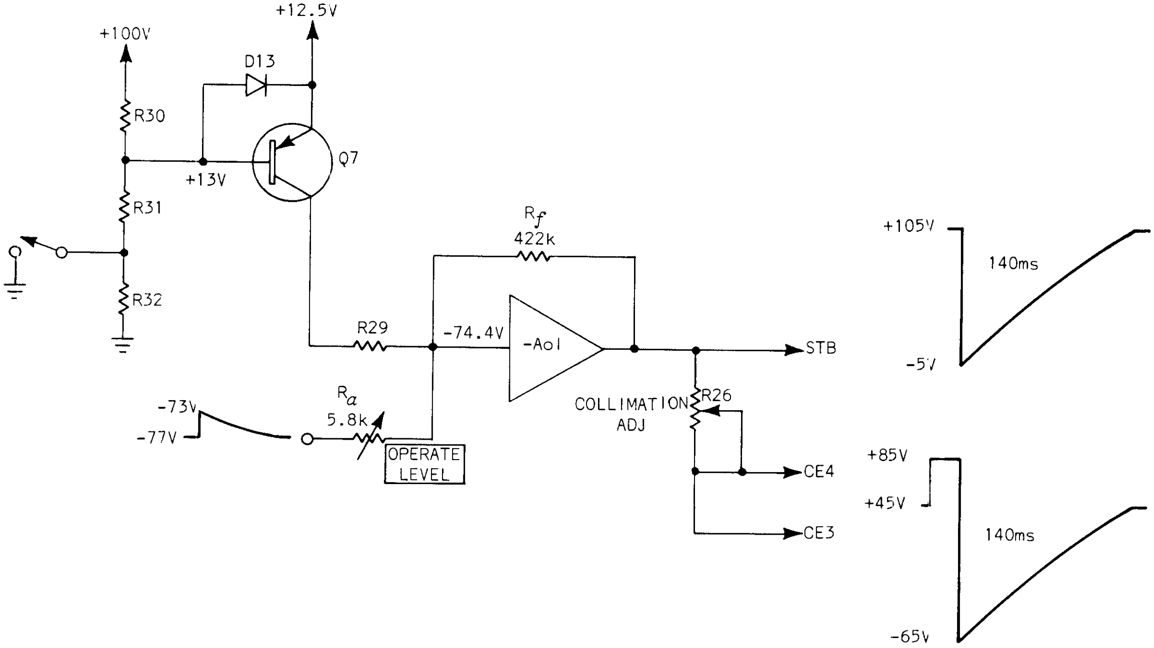


Fig. 8-22. Target control amplifier.

Adjusting R22 sets R_a, therefore setting amplifier gain. Changing R22 also changes the equivalent voltage to which R_a returns. V_{in} is maximum when R_a is minimum and minimum with R_a set to maximum.

Setting STB operating level hardly requires such a complex network. This arrangement allows proportioning of erase-pulse amplitude to operating level, and utilizes the low output impedance of the fedback amplifier as the STB voltage source.

Fig. 8-22, the simplified target-control amplifier illustration, shows R_a and V_{in} values with R22 set to midrange. Input voltage across R_a creates a current demand which flows through R_f. The voltage drop across R_f establishes STB operating level and collimation-electrode 3 and 4 voltage. Arrival of a differentiated waveform changes the voltage across R_a, thus current demand through R_f. The STB waveform results.

One empirically sets R26 for optimum collimation. Collimation electrodes collect some flood current. This circuit makes use of the current to maintain optimum potential between target elements and the nearest two collimation electrodes. Collimation electrodes more removed from the rear target surface affect collimation (during erasure) very little. These electrodes return to a low-impedance voltage source.

Although called secondary-emission current, some of the current consists of flood electrons repelled by unwritten target elements. Flood electrons turned back from the rear target surface travel toward positive tube elements. CE3 and CE4, nearest the rear target surface, collect many of these electrons.

Secondary emission accounts for most of the current when target elements charge toward the upper stable point. This causes the positive pulse preceding CE3 and CE4 erase waveform. During the "write" interval, target elements repel fewer flood electrons. Collimation electrodes thus receive fewer electrons, decreasing the current through R26.

Negative erasure excursions drive target elements below first crossover, where secondary emission is less than unity. Flood electrons flowing in R26 maintain collimation potential.

Switching Q7 into conduction removes CRT storage capability. With the remote NONSTORE switch open, Q7 is cut off. Voltage divider R30-R31-R32 reverse-biases Q7. D13 clamps this potential at one junction above emitter return voltage. Closing the NONSTORE switch drops Q7 voltage, driving it into saturation. +12.5 volts now appear at the collector of Q7. This additional amplifier current demand drops the STB voltage enough negative that only writing beam electrons strike with sufficient force to energize the phosphor. The display is that of a "normal" CRT.

Besides remote-programming capabilities and applying erase waveform to both flood-gun cathode and storage target backplate, the next circuit reduces average flood current, increasing apparent CRT storage life. The circuit gates flood electrons at 10% duty cycle after about 1.5 minutes viewing time. Sufficient flood electrons strike the target elements to retain a nonvisible stored image. Stored images again become visible images upon recall. Recall occurs by activation of "view" circuits, either local or remote, or by the arrival of new information.

A block diagram of the circuits appear in Fig. 8-23. Four amplifiers drive the CRT storage elements. Four circuits function as amplifier inputs: nonstore, operating level adjust, hold multi and erase multi.

operating level adjustment

Varying the operating level input to the fixed-gain STB driver amplifier varies the STB operating level (OL). User access to the Operating Level Adjustment allows him to reset OL during tube aging.

Routing a portion of the operating level input to the CE driver amplifier, via the STB driver amplifier, causes collimation electrode voltage to change with the operating level. Maintaining OL and CE voltages proportionally insures even flood-electron distribution across the target area.

Grounding the remote nonstore line actuates the nonstore circuit. An input from nonstore drives the STB voltage to the flood-gun cathode potential. Only the writing beam strikes the phosphor and no stored image results.

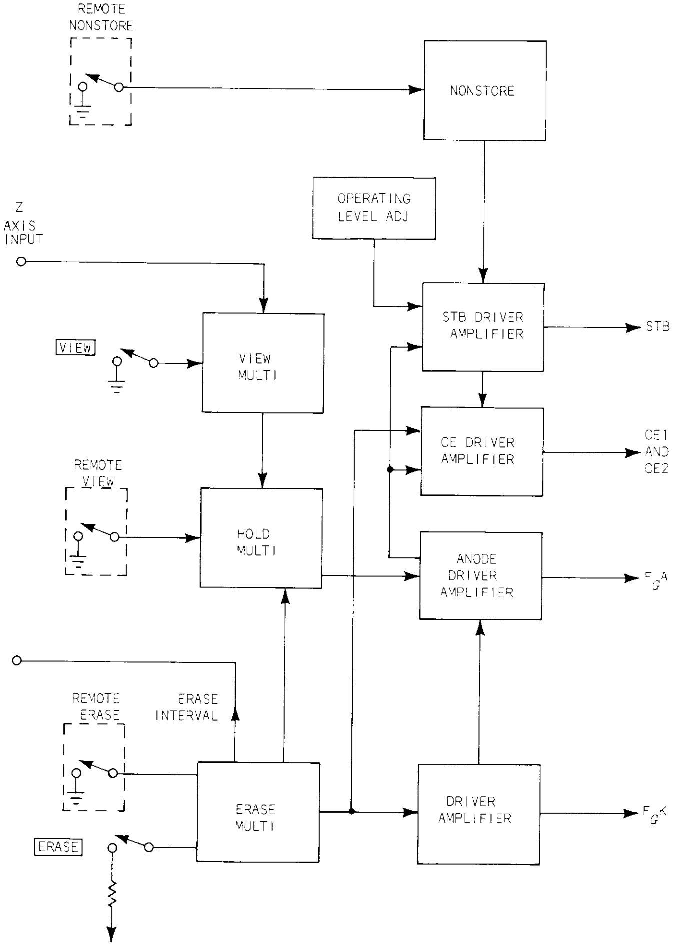


Fig. 8-23. Data-display storage block diagram.

Multivibrators initiate the remaining two inputs. Two multivibrators, view and erase, are single shot flip-flops.

The hold multi free-runs at 1 kHz with 10% duty cycle. The hold-multi output, via the anode driver amplifier, drives the flood-gun anode from operating bias to cutoff at a 1-kHz rate. Either the erase or view multi, or the REMOTE VIEW switch "locks out" the hold multi, allowing a *visible* storage display.

view multi

The view multi prevents hold-multi switching. Closing the view switch or the arrival of Z-axis (writing gun) modulation triggers the view multi. A negative pulse of about 1.5-minutes duration results.

remote view programming

Remote-view programming, represented by a switch, curtails hold--multi cycling for the duration of a grounded line condition.

Both methods of locking out hold-multi switching allow full flood-current flow for visual display of any stored images. Erasure also requires full flood current, therefore, one erase multi output prevents hold-multi switching. Closing either ERASE or REMOTE ERASE triggers the erase multi which then generates pulses lasting about 450 milliseconds. Besides preventing hold-multi switching, these pulses function as an erase-interval driver-amplifier input, and one of two collimation-electrode-amplifier inputs.

erase interval

Erase interval pulses act as busy signals, signaling remote sources to hold new data during erasure.

anode-driver interval

During the first 50 milliseconds of an erase cycle, the driver amplifier output develops as a negative output pulse. This pulse is routed to flood-gun cathodes and the *anode-driver amplifier.* The flood-gun pulses increase cathode-to-backplate voltage, writing all target elements to crossover.

The anode-driver amplifier receives a replica of the flood-gun cathode pulse. It routes this pulse to flood-gun anodes, collimation-electrode amplifier, and storage-target-backplate amplifier.

Pulsing flood-gun anodes causes these elements to follow flood-gun cathodes, thereby maintaining correct bias during erasure.

collimation-electrode driver amplifier

Accepting a negative anode-driver pulse and a positive erase-interval pulse, the collimation-electrode driver amplifier sums these inputs, developing a complex output waveform. This waveform, applied to the collimation electrodes, optimizes collimation during the write and erase portions of an erase cycle.

STB driver amplifier

Storage-target-backplate driver-amplifier input circuits differentiate the trailing edge of the anode pulse. This signal, amplified and inverted, develops at the STB as an erase waveform.

A brief summary: Allowing the *hold* multi to free-run maintains target elements in their previously established stable state. Stored images are not visible. Triggering the *view* multi shuts off the *hold* multi. Stored images now become visible and new data may be written.

Erase-multi switching also interrupts the hold multi. Erase-multi pulses, via appropriate amplifier circuits, initiate flood-gun cathode, flood-gun anode, collimation electrode, and storage-target-backplate erase waveforms

Flood-gun cathode waveforms *write* all target elements to the upper stable point followed by STB erase waveforms, which drive all target elements to the lower stable point. During erasure the flood-gun anode follows the flood-gun cathode for proper erase bias. Flood-gun cathode pulses summed with erase-interval pulses cause CE1 and CE2 waveforms. These complex waveforms maintain optimum erase collimation.

Nonstore merely drops STB operating level to flood-gun cathode potential, eliminating bistable storage.

The hold multivibrator free-runs except during switching time of the erase multi or view multi or both, or during closure of the REMOTE VIEW switch. This multi is called a TTL gate or a tee-squared logic gate.

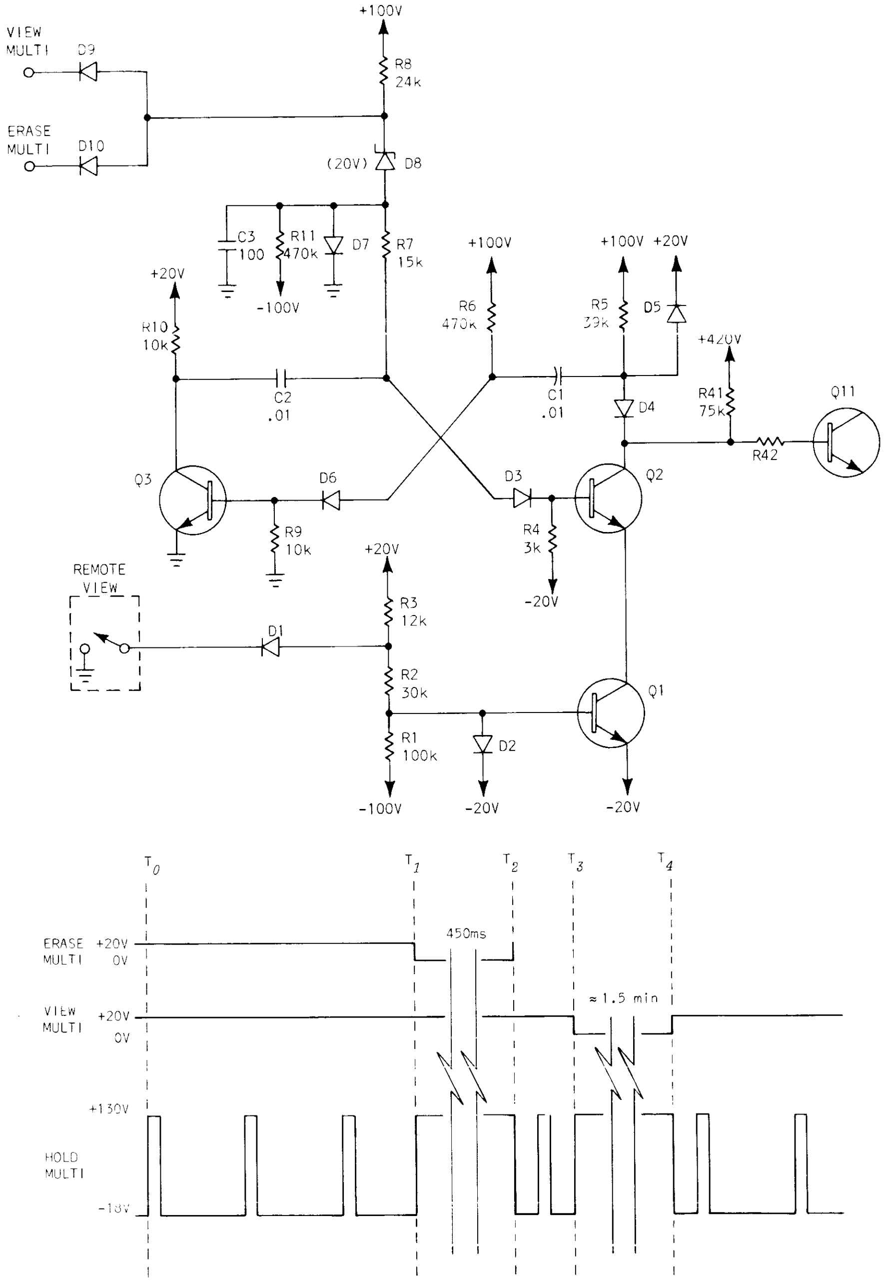


Fig. 8-24. Hold multivibrator.

Fig. 8-24 includes hold-multi circuitry and associated input and output waveforms. Erase-multi and view-multi inputs assume one of two levels: 20 volts or 0 volts. Hold-multi output also reaches two voltage levels: +130 volts and -18 volts.

Between T_0 and T_1 the hold multi free-runs, generating flood-gun anode pulses. These pulses gate flood current at a 10% duty cycle. At T_0, erase and view inputs set at +20 volts. Hold output pulses result. These 100-microsecond pulses occur every millisecond. Arrival, at T_1, of an erase-multi pulse stops hold-multi switching. Hold-multi output now remains at "normal" flood-gun anode bias, +130 volts. Upon erase-pulse termination, T_2, the hold multi again free-runs. The view-multi switching pulse arrives at T_3 preventing *hold*-multi free-run during view-multi switch duration. Closing the REMOTE VIEW switch creates a zero-volt input, again preventing hold-multi oscillation. Free-run resumes only when the REMOTE VIEW switch opens and multi inputs set at +20 volts.

Hold-multi free-run characteristics are conventional. Time constants C1-R6, C2-R7 and applied voltage determine switching rate.

TTL TTL circuit configuration to allow lock-out may be unfamiliar. Cascoding Q1 and Q2 provides an additional input terminal. Both Q1 and Q2 must turn on to maintain oscillation. Interrupting conduction of either develops a "high" multi output.

Closing the REMOTE VIEW switch reverse-biases Q1. Prior to closing the REMOTE VIEW switch, voltage-divider R1-R2-R3 develops forward bias for Q1 and D2. D2 clamps at Q1 forward bias reducing Q1 base-current demand. Voltage division and clamping also apply about 17 volts to the anode of D1. Closing the REMOTE VIEW switch applies zero volts, plus the drop across D1, at connection R2-R3. Q1 base voltage then drops 2 volts below emitter return voltage. Both Q1 and D2 turn off. Interrupting Q1 collector current removes Q2 emitter current, allowing Q2 collector voltage to reach maximum positive level. Q2 collector voltage remains at this level during REMOTE VIEW switch closure.

Q2 direct-couples to the anode-driver amplifier whose circuits establish maximum positive (Q2) collector voltage. Partial circuit R41, R42, and Q11 represents the anode-driver input. Assume this circuit provides +130-volt collector return.

D4 cathode voltage is common to Q2 collector voltage. D5 clamps D4 anode to +20 volts. D4 then disconnects during Q2 off time, removing the output-shunting effects of C1 during this interval.

D4 turns on when Q2 conducts, connecting multi coupling circuits to the collector of Q2. Turned on, Q1 and Q2 drop about 2 volts. D4 turns on, allowing negative collector pulses to develop across R5, C1 and R6.

Consider the REMOTE VIEW switch normally open. Q1 then remains forward-biased, functioning as an emitter-current source for Q2. Base circuit components satisfy DC turn-on requirements for Q2. Conduction through R4, D3, and R7 turn Q2 on. D7 clamps connection D8-R7 one diode junction above ground. Zener diode D8 then elevates this voltage by 20 volts. Diodes D9 and D10 may or may not quiescently conduct. Both the anodes and cathodes return to *approximately* +20 volts. R11 and C3, shunting D7, filter hold-multi pulses. This filter prevents hold pulses from feeding through to the *erase* multi. These pulses could trigger the erase multi causing random erasure.

Zero-volts input from view or erasure turns Q2 off. D9 or D10 couple the negative signal to D8. D8 drives the anode of D7 20-volts negative. R7 then returns to -20 volts. D3 and Q2 turn off. When D9 and D10 cathode inputs return to +20 volts, D7, D3 and Q2 turn on. The hold multi again free-runs.

D3 causes Q2 to switch more quickly and isolates the base of Q2 from input components. D6 functions in the same manner for Q3 base circuitry.

view
multi

Diode D9 connects to the view-multi output. Fig. 8-25 shows the monostable view-multi circuits. Q5 conducts and Q4 remains cut off under stable conditions. Closing the VIEW switch develops a 20-volt negative pulse which couples via C5

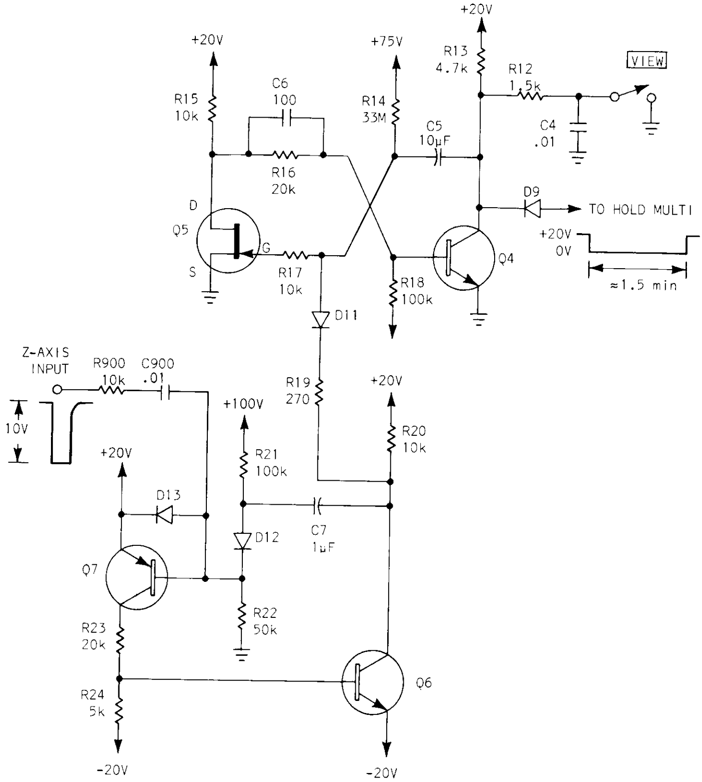


Fig. 8-25. View multivibrator.

triggering multi switching. The discharge of C5 through R14 establishes about 1.5-minute recovery time.

D11 couples a trigger, switching the view multi, during Z-axis modulation. Connected as a single-shot flip-flop, Q6 and Q7 function as a low-impedance trigger source. C900 and R900 represent Z-axis output impedance. Connected directly, this circuit provides too little current to trigger the view multi. However, Z-axis voltage applied to Q7 turns Q6 and Q7 on, driving the view multi as a trigger current source.

Quiescently, Q6 and Q7 are off. Voltage-divider R22-D12-R21 develops reverse bias for Q7. D13 clamps base voltage one diode junction above emitter potential. Failure of Q7-collector current flow through R23 and R24 reverse-biases Q6.

Arrival of Z-axis modulation turns Q7 on, which in turn forward-biases Q6. Q6 saturates. D11 connects, allowing Q6-collector current to charge C5. The resultant negative trigger turns Q5 *and* Q7 off, initiating view-multi (and terminating Q6-Q7) switching. The negative pulse appears at the gate of Q5 and couples across C7, disconnecting D12. D13 conducts, reverse-biasing Q7, which removes Q6 forward bias. D11 disconnects, isolating view-multi time constants C5-R14.

View-multi switching consumes about 1.5 minutes while the erase monostable multi switches in about 450 milliseconds.

Closing local or remote switches generates negative triggers, toggling the erase multi.

ERASE switch circuits appear in Fig. 8-26. R25 and R26 apply +10 volts to the anode of D14. An equal voltage develops across R28. Closing either the REMOTE ERASE or ERASE switch creates a negative pulse. This trigger develops, via capacitive coupling, across R31 to initiate erase-multi switching. C9, R31, and Q8 represent input circuits of the erase multi.

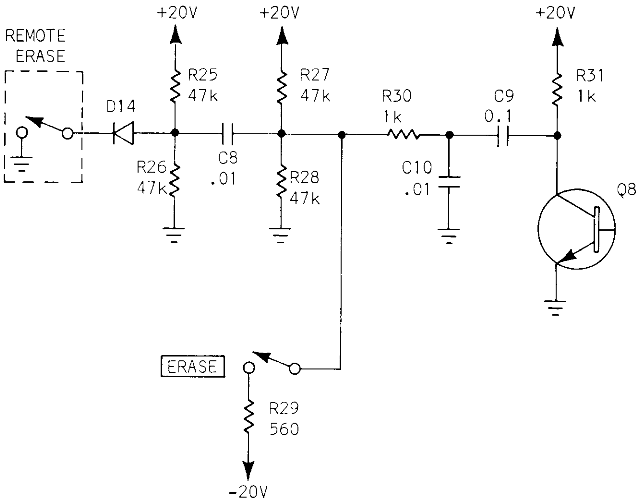


Fig. 8-26. Erase switch circuits.

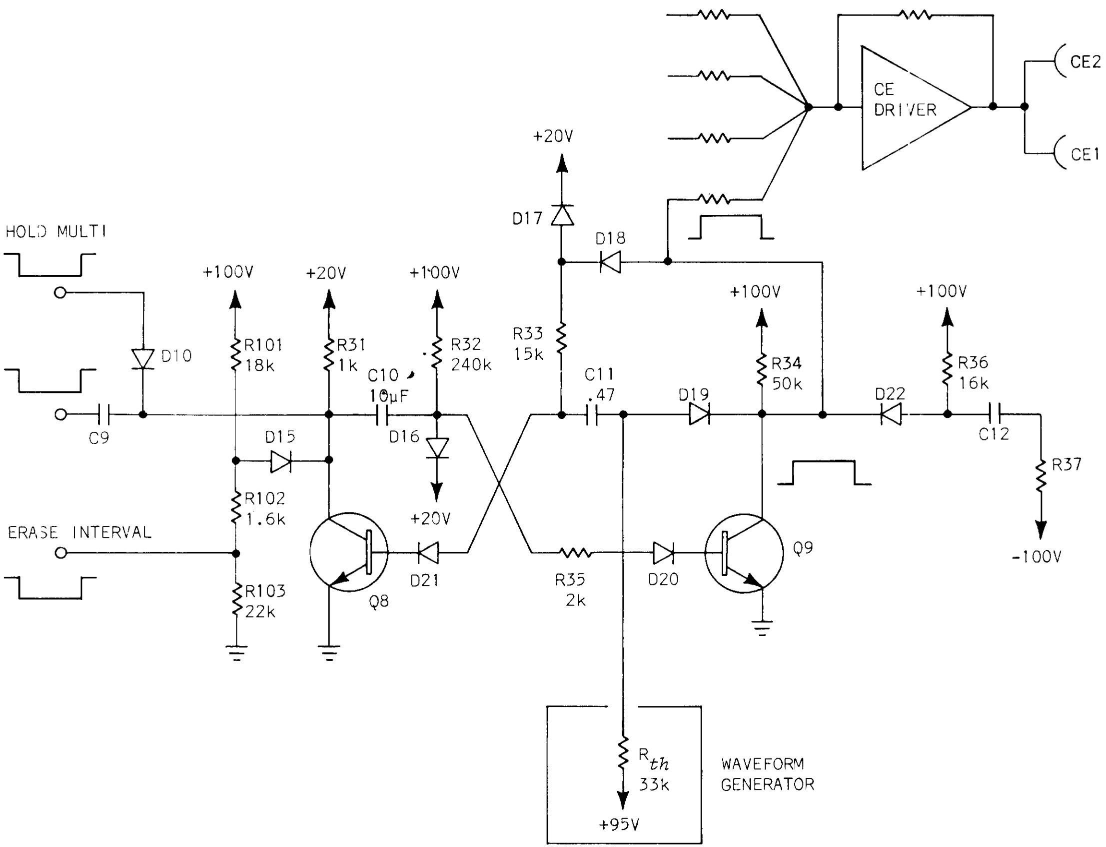


Fig. 8-27. Erase multivibrator.

erase multi

Fig. 8-27, the erase-multi schematic, includes C9, R31, and Q8 but not the preceding switch circuits. Diode D10 appeared earlier in Fig. 7-24 as the erase-multi coupling diode.

During the stable mode Q9 saturates holding Q8 off. Some diodes are on and some off. "On" diodes are D19, D20, and D22. "Off" diodes include D10, D15, D16, D17, D18, and D21.

Q9 remains on due to base current flow through D20, R35, and R32. The D20-Q9 configuration speeds switching and isolates the base of Q9 during "off" time. D21 performs the same function for Q8.

D16 protects C10. C10 breaks down at about 25 volts. Interruption of Q9 conduction, such as removal from the circuit, allows C10 to charge, through R32, toward +100 volts. D16, however, clamps at +20 volts holding C10 to a moderate charge. Q9 base current normally develops +2 volts at the anode of D16.

D19 couples Q9 collector voltage to the waveform generator, shown as an equivalent input circuit. Diode D22 couples to the *driver amplifier*. D22. R36, C12, and R37 are portions of this amplifier's input circuitry. One collimation-electrode driver amplifier input connects directly.

Two outputs are also taken from the collector of Q8. D15 couples Q8 collector voltage to external programming. This diode disconnects during Q8 off time for collector isolation. Q8 collector waveforms also couple through D10, providing *hold-multi* lock-out.

Negative triggers couple, via C9 and C10, to the anode of D20. D20 turns off. Q9 turns off. D19 disconnects as Q9 collector voltage rises. This removes the shunting effects of C11 and the waveform-generator R_{th}. D17 and D18 turn on, clamping Q9 collector voltage at about +20 volts. These diodes now provide a positive return for D21. D21 turns on. Q8 saturates. D10 and D15 connect to couple negative erase-interval pulses.

The *erase multi* recovers in about 450 milliseconds, determined by R32-C10 and the applied voltage.

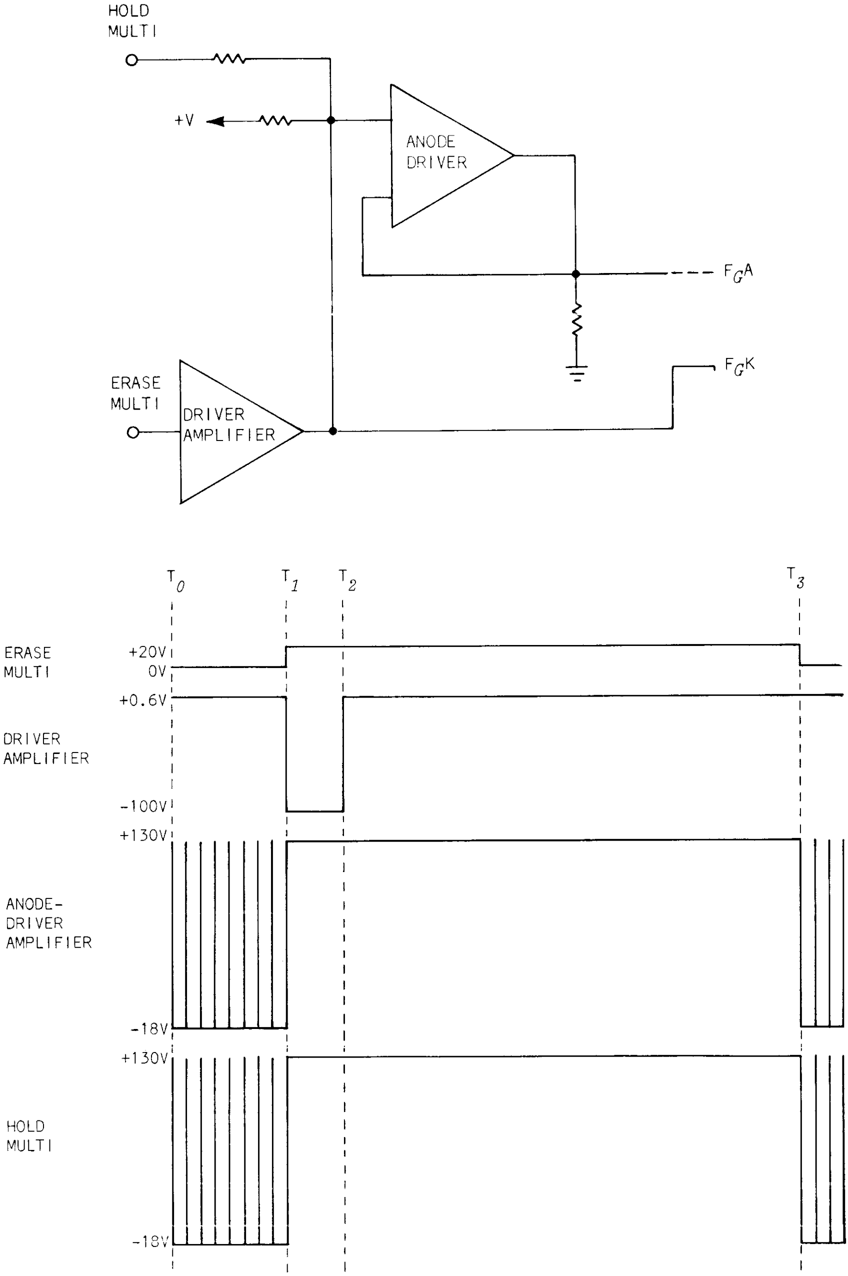


Fig. 8-28. Driver and anode driver amplifiers.

driver amplifier

anode-driver amplifier

Driver and anode-driver amplifiers function together, so are on the same block illustration, Fig. 8-28. This figure also includes pertinent waveforms. Assume here the view multi is stable, allowing the hold multi to free-run.

Waveforms of Fig. 8-28 indicate that at:

T_0 - The erase multi in its stable mode allows the driver amplifier to maintain a slightly positive output voltage. It also allows the hold multi to free-run, which waveform the anode driver reproduces. Note: +130 volts is a nominal level set at the anode-driver input.

T_1 - The erase multi switches. The driver-amplifier output drops to -100 volts and anode-driver output rises to +130 volts. Anode voltage remains high because of erase-multi lock-out of the hold multi.

T_2 - All outputs, except the driver amplifier, remain unchanged. The driver amplifier returns flood-gun cathode voltage to quiescence.

T_3 - Erase pulse terminates. The hold multi again free-runs creating waveforms reproduced by the anode-driver amplifier.

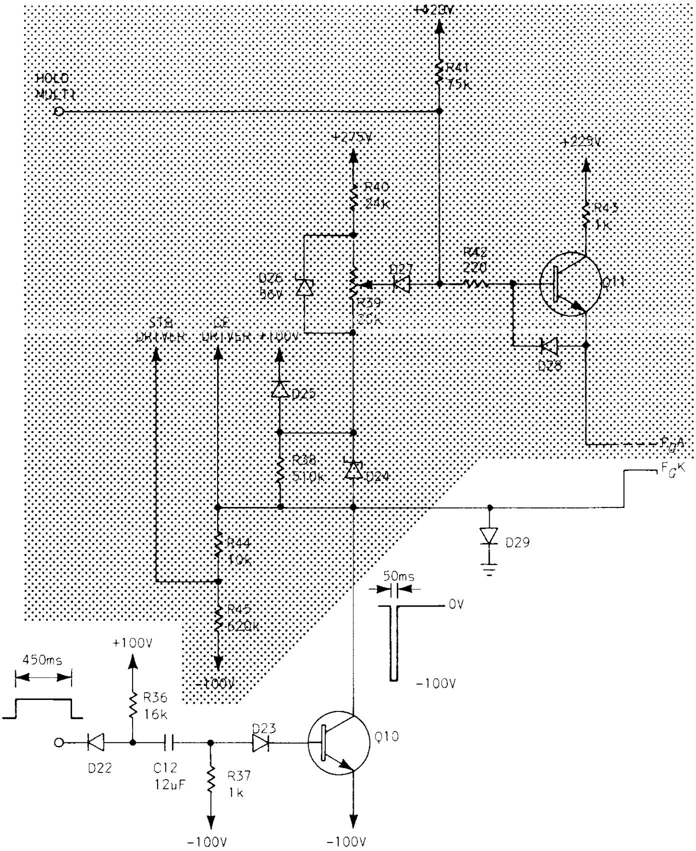


Fig. 8-29. Driver amplifier.

The circuits for these amplifiers appear in Fig. 8-29.

Q10-base circuit components cause Q10 saturation during the first 50 milliseconds of the erase pulse. Driving flood-gun cathodes negative creates sufficient cathode-to-STB potential to *write* all target elements. The negative cathode pulse also couples to the anode driver amplifier, collimation-electrode driver amplifier, and storage-target-backplate driver amplifier. Prior to an erase pulse: D22 is on; D23 and Q10 are off; and D29 is on. D22 conduction charges the R36 side of C12 to about zero volts. Current through R37 charges the other side of C12 to -100 volts. D23 and Q10 lack forward bias. Flood-gun cathode current turns D29 on, which provides most of the flood current.

Positive erase excursions turn D22 off and C12 charges toward +100 volts. Charging current develops on bias, across R37, for D23 and Q10. Q10 saturates, turning D29 off. Q10 via D23 now provides C12 charging current. C12 reaches a charge equal to turn-on for D22 at an interval determined by time constant: C12-R36.

Write pulses terminate with D22 turn-on. Turning D22 on stops C12 charging. Eliminating charge current turns D23, thus Q10, off. Q10 collector ascends, clamped to zero volts by D29.

D23 improves Q10 switching time and protects the base. The negative portion of an erase pulse develops a 20-volt pulse across R37. D23 prevents the appearance of this pulse at the base of Q10.

Refer to Fig. 8-30. Anode-driver-amplifier coupling circuits allow one to adjust R39 without changing anode *write*-pulse amplitude. Adjusting R39 sets flood-gun operating bias and V_{cc} for the output half of the *hold* multi.

D25, quiescently on, establishes 100 volts across Zener diode D24 and at one end of R39. D26 regulates the drop across R39. One therefore sets Q11 base voltage between +100 and +156 volts. Q11 base voltage also functions as V_{cc} for Q2 in the hold multi.

An 80-volt write pulse appears at the flood-gun anode. When Q10 collector voltage descends 20 volts, D24 turns on, disconnecting D25. D24 remains on until Q10 collector voltage rises to -20 volts. D25 then realizes forward-bias clamping at the +100 volts.

An 80-volt pulse develops at the anode of D25. D26 regulates the drop across R39. Equal-amplitude pulses then develop at the wiper of R39. One changes anode write-pulse DC level but not amplitude with adjustment of R39.

D27 isolates R39 and associated components during hold-multi free-run. Negative hold pulses disconnect D27 preventing hold-current flow through R39.

R42 and R43 combat negative-resistance input characteristics of emitter-follower Q11. Suppressor R42 loads the input to damp oscillations. Additionally, degenerative signals developed across collector load R43, couple via "Miller" capacitance to the base.

D28 speeds Q11 follower action. NPN emitter followers charge output capacitance more rapidly during positive excursions than negative. Large-amplitude negative excursions may even reverse-bias an NPN emitter follower. In this event D28 turns on reproducing negative waveforms.

Flood-gun cathode *write* pulses develop across voltage-divider R44-R45 as input signals to the collimation-electrode driver amplifier, and the storage-target backplate driver amplifier.

Because of STB driver-input shunting, 40 volts of the 100-volt write pulses develop across R45. Of course the 100-volt write-pulse amplitude develops as an input to the CE driver amplifier.

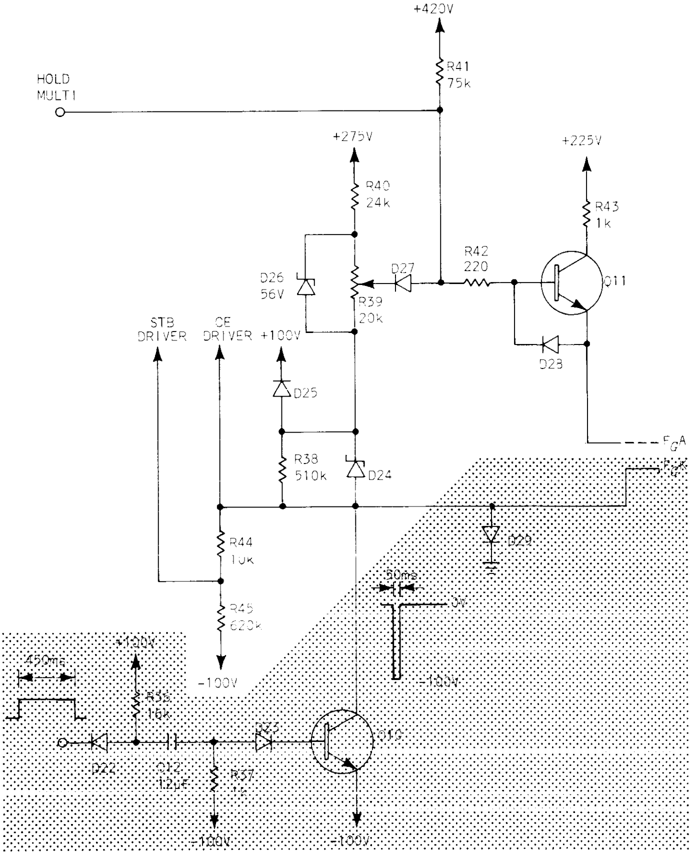


Fig. 8-30. Anode driver amplifier.

collimation-electrode amplifier

Fig. 8-31, a simplified block of the collimation-electrode amplifier includes time-related inputs. This inverting fedback amplifier accepts four input voltages, amplifying and summing to develop collimation-electrode voltage.

inverting fedback amplifier

Since the collimation-electrode driver amplifier functions as a fedback amplifier, all signal current appears to flow in the passive feedback devices. A null point exists at the amplifier input terminal. Input voltages across associated input resistances create current demand of individual quantity and polarity. Summing individual input currents establishes total input current. The amplifier output serves as a source for total input current which then flows through feedback resistance. Resulting voltage drops across R_f represent output voltage. Accept this statement as long as amplifier open-loop gain (AOL) remains high.

The summary above sets conditions for a fairly simple method of determining output voltage. Assign R_f to the feedback resistance and R_a to input resistance. Numerical suffixes identify individual resistance legs. Label input voltage V_{in}, adding numbers agreeing with associated input resistance. Observe polarities and since the amplifier inverts, assign R_f a negative value. For Fig. 8-31:

$$V_{out} = V_{in1}\left(\frac{-R_f}{R_{a1}}\right) + V_{in2}\left(\frac{-R_f}{R_{a2}}\right) + V_{in3}\left(\frac{-R_f}{R_{a3}}\right) + V_{in4}\left(\frac{-R_f}{R_{a4}}\right)$$

Four input voltages of differing amplitudes and polarities cause a complex output waveform (Fig. 8-31). Operating level (OL) and collimation (CE) voltages remain constant once set. Erase multi and driver voltages change with each erasure. One can change R_{a3} gain contribution but not the input voltage of this leg.

Inserting OL prevents in-use collimation adjustments with STB changes. OL adjustment is basically an STB setting. However, a portion of the OL drives collimation electrodes with STB adjustments (required as the tube ages). Original calibration sets the CE adjust for optimum flood-electron collimation. Adding the OL input to the CE driver maintains STB-to-CE voltage relationship, removing the requirement for CE adjustment with each OL change.

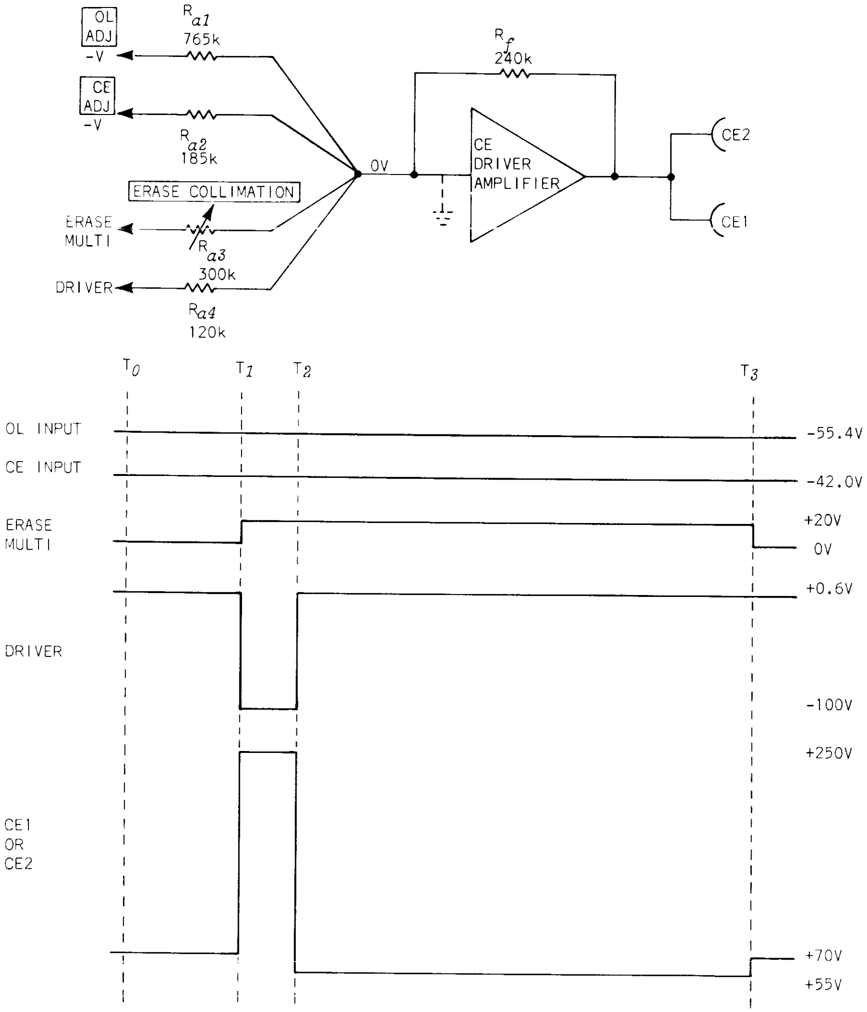


Fig. 8-31. Collimation-electrode amplifier.

Waveforms of Fig. 8-31 show time-related input and output waveforms:

T_0 - OL and CE inputs create additive outputs of positive polarity. Erase-multi voltage contributes nothing. However, driver voltage forces the output voltage negative, in opposition to OL and CE effects. The resultant output voltage rests at +70 volts.

T_1 - The write pulse. OL and CE inputs remain unchanged. Erase-multi voltage steps positive 20 volts, attempting to force the output negative by gain-times-input voltage. Driver voltage opposes this change by stepping negative 100 volts. As a result, collimation electrodes ascend to +250 volts.

T_1-T_2 represents the write interval --when all target elements charge to second crossover. The entire rear screen surface charges to STB potential. Collimation electrodes must present a proportional voltage increase to maintain straight-line electron-paths into the target area.

T_2 - Terminating the driver pulse returns all inputs except erase to quiescence. The positive erase-multi level causes output voltage to descend below quiescence, shown as +55 volts. This condition lasts until the erase-multi pulse ends, at T_3.

Between T_2 and T_3 target elements drop below first crossover, charging toward the lower stable point. Again collimation electrodes assume a voltage, in relation to target elements, for optimum collimation. The negative CE waveform-drop below quiescence equals target-element descent below first crossover. This voltage varies from one CRT to another--thus, the *Erase Collimation adjustment*.

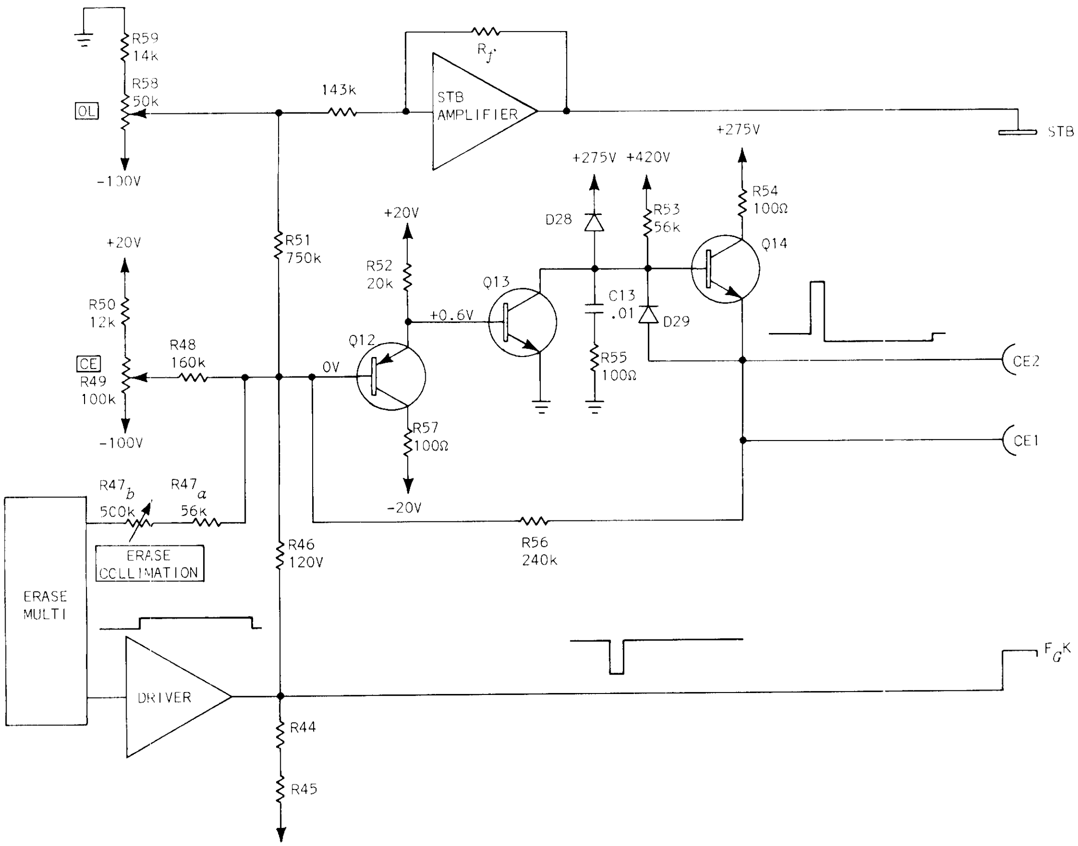


Fig. 8-32. Collimation-electrode amplifier schematic.

Collimation driver amplifier schematic, Fig. 8-32 contains circuit details.

input summing

R51, in series with network R58, R59, and STB amplifier input resistance, constitutes OL input circuitry. CE input results from the equivalent values of R48, R49, and R50. OL and CE adjustments, R49 and R58, change both input resistance and voltage. Erase-multi pulses appear across R47A and R47B. Adjusting erase collimation changes only the resistance of this input leg. The last input circuit has neither resistance nor voltage adjustments. Driver-amplifier output voltage develops across R44 and R45 as an input signal. Fixed resistor R46 then functions as the fedback-amplifier input resistance.

A null point occurs at the base of Q12. All input circuits connect at the amplifier input terminal -- the base of Q12. Q12, Q13, and Q14 develop and preserve open-loop gain (AOL), and R56 closes the feedback loop. Feedback current through R56 maintains a voltage null at the base of Q12.

AOL

Emitter-follower Q12 couples input signals to Q13. This arrangement allows zero-volt input terminal *and* Q13 emitter return voltage. Collector-loaded amplifier Q13 develops open-loop gain and phase inversion. Q14 preserves open-loop gain by isolating the collector circuit of Q13 from output circuit loading. Q14 also causes very low amplifier output impedance.

D28 protects Q14 against base-collector breakdown. D28 prevents Q13 collector voltage rise above +275 volts, the collector return for Q14. Removing D28 and opening Q13 applies +420 volts, through R55, to the base of Q14--catastrophic!

D29 acts as an additional current path should Q14 be unable to follow the high-amplitude negative waveform portions. It also protects Q14 by limiting reverse-bias amplitude.

Placing R54, R55, and C13 in this circuit damps Q14 oscillation. All followers have *negative input resistance* characteristics. Followers driven by high-amplitude pulses therefore ring. Degenerative feedback and selective input loading combat emitter-follower oscillatory tendencies.

Collector signals develop Miller-effect degeneration. Out-of-phase signals across R54 couple, via collector-to-base capacitance, to the base of Q14, supplementing C13-R55 loading effects.

Network C13-R55, with proper time constants, appears a regenerative current source. Negative input resistance characteristics create a regenerative current. The regenerative current adds to Q13 collector signal current flowing in the collector load. Oscillation would result but C13-R55 shunting equals the negative input characteristic of Q14.

Fig. 8-32 omits the anode driver amplifier in the interest of clarity. It does include the storage-target-backplate driver amplifier, indicating symbolically another inverting fedback amplifier.

Fig. 8-33 shows the *STB driver amplifier* with appropriate time-related waveforms. Notice first the waveforms. There are two inputs and a single output. The flood-gun cathode pulse initiates input D32 and is therefore included. Input OL, once set, remains fixed. The voltage at D32 quiescently sits 0.6 volts below ground. Coincident with flood-gun cathode pulse termination, D32 steps 40 volts positive, decaying toward quiescence at an RC rate. STB voltage resulting rests at OL, descends to zero volts, remains here for an interval, finally ascending to OL at a rate determined by D32 voltage. The STB "erase" waveform properly begins following the flood-gun cathode "write" pulse.

STB waveform shape indicates nonlinear amplification. D32 voltage drive purposely exceeds AOL capabilities. of the STB driver amplifier. This technique eliminates waveshape adjustment with each OL change. Decreasing the OL increases waveform dwell-time at zero volts. Increasing the OL decreases zero-volt dwell-time, perhaps faithfully reproducing the input waveform. In any case this waveform drives all target elements below first crossover then recovers slowly enough to avoid fade-positive.

The amplifier block shows three adjustments: Operating Level, Amplitude and Recover. Backplate OL results from the product of OL adjustment voltage and $\frac{R_f}{R_{a1}}$. Changing either R_{a1}, input voltage or both varies backplate OL. The two remaining adjustments are more complex.

D32 clamps one diode junction below ground at quiescence. Here, input voltage times ratio $\frac{R_f}{R_{a2}}$ adds a few volts to the operating level. D32 functions mainly as a timing switch initiating the erase waveform portion *after* the write pulse. The anode driver side of the 9-µF capacitor charges to about 40% of the flood-gun cathode voltage during negative pulse time. D32 remains on during quiescent and negative pulse time. However, termination of the flood-gun cathode pulse couples across the RC network turning D32 off. Recovery now depends upon capacitive and resistive components.

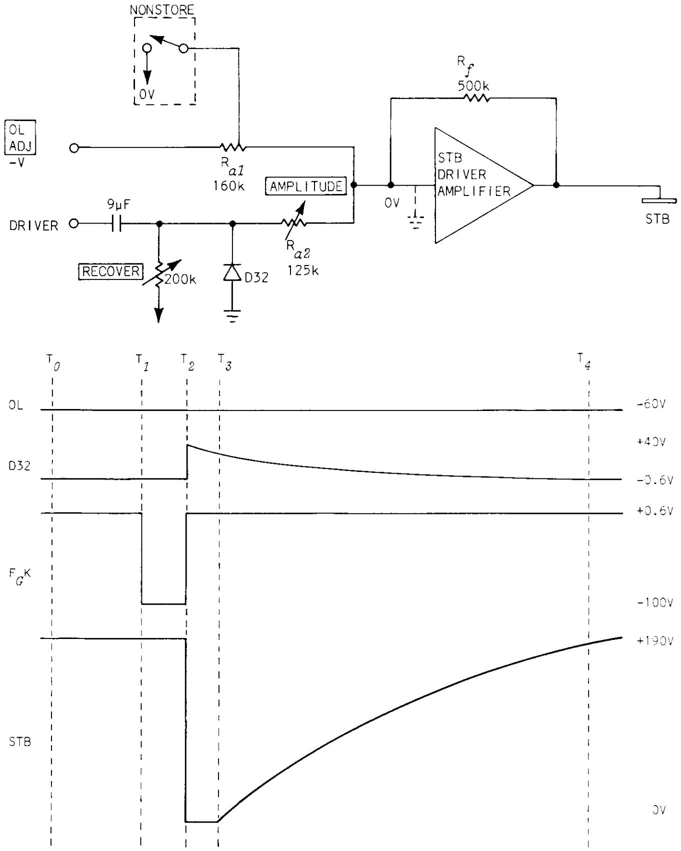


Fig. 8-33. STB driver amplifier.

Name tags *Amplitude* and *Recover* identify exclusive functions. Both adjustments affect rate of charge. The Amplitude adjustment controls amplifier gain while Recover affects only rate of charge. Recover also returns to a negative voltage giving it greatest control of recovery.

Keeping in mind adjustment interaction, one sets Amplitude for nominal erase waveform negative dwell-time. He then adjusts Recover for proper erase ramp slope. Recovery time is a compromise: Long enough to prevent fade-positive, yet short enough for reasonable erase cycle time.

Remotely programmed, the nonstore input grounds the amplifier input. This drives STB voltage below the operating level required for bistable storage.

Fig. 8-34 details the *storage-target-backplate amplifier*.

storage-target-backplate amplifier

Adjusting R58 sets input voltage and to a degree, input resistance. The equivalent resistance of R58-R59 added to R60 and R61 establishes input resistance of the OL circuit. R51, a part of the collimation driver amplifier, connects to R58 wiper but presents negligible shunting. Consider Q19 for now an open circuit and therefore no load on OL input resistance.

R64 and R65 make up input resistance for erase-waveform inputs. R66 is R_f. Feedback current through this device maintains a signal null at the base of Q15 as long as AOL remains high. Keep in mind that AOL deteriorates during maximum erase excursions.

Q15-Q16 configuration allows both the base of Q15 and the emitter of Q16 to operate at zero volts. Q16 develops open-loop gain preserved by emitter-follower Q17. D33 aids negative waveform emitter-follower action and protects D17 emitter base junction. C14-R71 damp oscillations due to Q17 negative-resistance input characteristics.

Q17-Q18 function as an emitter follower. Cost and space savings determined Q17-Q18 cascoding. Dissipated power divides equally across Q17 and Q18. A single transistor capable of dissipating this power costs several times more than Q17 and Q18

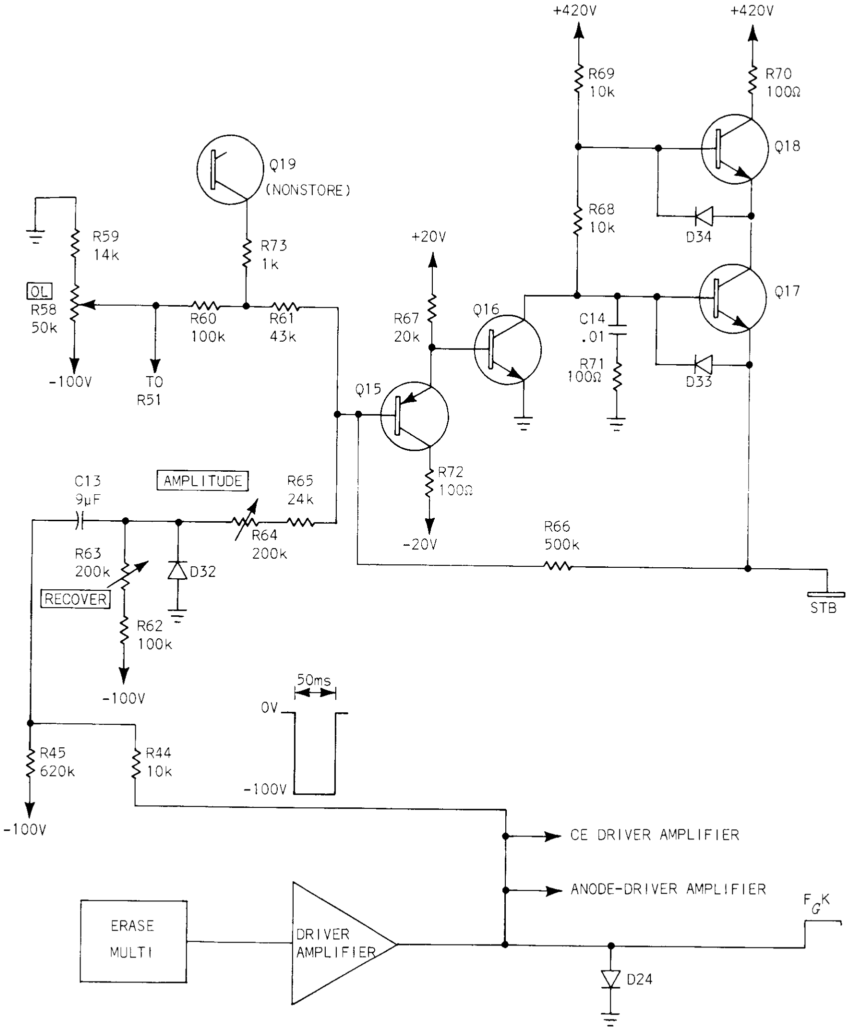


Fig. 8-34. STB driver amplifier schematic.

combined. Further, heat sinks and high-voltage resistors required for the single-transistor configuration consume space.

D34 protects Q18 against excessive emitter-base reverse-bias.

R44, R45, R62, R63, R64, R65, D32 and C13 all function to generate the STB erase waveform. At quiescence and during the negative portion of a flood-gun cathode *write*-pulse D32 conducts. C13 then bypasses R45. C13 charges to about 40 volts during the 50-millisecond write-pulse interval. The positive write-pulse excursion turns D32 off, so a positive 40-volt pulse develops here. C13 then discharges establishing the STB erase waveform shape.

C13 discharge current flows through R64 and R65 paralleled by R62 and R63. It also flows through the equivalent resistance of R44 and R45.

Under new tube conditions, initial positive pulses overdrive the STB amplifier for several milliseconds. Q15 turns off, Q16 saturates and STB voltage approximates zero volts. After perhaps 10 to 20 milliseconds, C13 discharges sufficiently for the STB amplifier to amplify the differentiated input waveform.

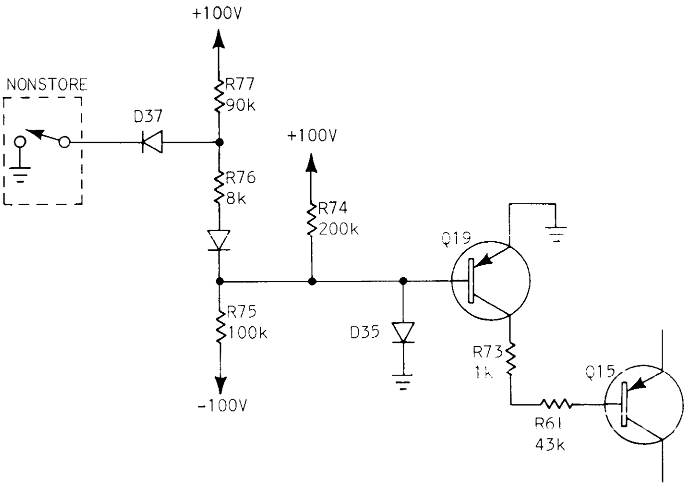


Fig. 8-35. Remote nonstore provision.

Remotely programming NONSTORE turns Q19 on. This added current demand through R66 drops STB voltage to about zero volts. Fig. 8-35 details Q19 switching circuits. The NONSTORE switch represents a remote program circuit which grounds the line of D37. Consider this switch open. D35 clamps at one diode junction above ground, reverse-biasing Q19. Turned off, Q19 appears an open circuit to the fedback STB amplifier.

Closing the NONSTORE switch saturates Q19. Actuating NONSTORE turns D37 on. R76 now returns to +0.6 volts. From Q19 base, R76, D36, R75 and R74 appears as an equivalent resistance of 7 kΩ returned to -30 volts. D35 turns off and Q19 saturates, creating a current demand which then drops STB voltage below storage requirements. Flood electrons cannot generate sufficient velocity to luminesce the phosphor. This does not prevent the writing beam from energizing the phosphor for a "normal" CRT presentation.

	FORWARD-BIASED JUNCTION			V_{CE} (SAT)
	ACTIVE	CUT-IN/CUT-OFF	SAT	
Si	0.6	0.5	0.6	0.2
Ge	0.2	0.1	0.2	0.1

Fig. 8-36. Semiconductor operating voltages.

INDEX

CIRCUIT CONCEPTS BY INSTRUMENT

Most concepts discussed in this book are applicable to all Tektronix products containing a storage CRT. However, the concepts listed on the following pages are used in only certain products. Applicability is indicated by a ●.

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	549	564	601	611						
Dot Pattern Target (p 30)	●									
Semicontinuous Layer Targets (p 32)		●								
Integrate Mode (p 39)		●								
Writing-Speed Enhancement (p 40-42)	●	●								
Split Screen (p 42)		●								
Ion-Repeller Mesh (p 45)	●									
Exposed Collector (p 46)	●		●	●						
Both Flood Gun and Backplate Erase Pulsed (p 52)			●	●						
BASIC CIRCUITRY (p 66-81)	●	●								
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