# Characteristics and Applications of the Iatron Storage Tube

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THE OPERATION of many types of storage tubes depends upon intensity modulation of an electron beam by an electrostatic charge on an insulator layer.[3–7] As early as 1927, Dr. Farnsworth suggested the method as a means to increase brightness in cathode-ray tubes for television.

Iatron* storage tubes have been in development at Farnsworth Electronics Company since 1949, and have been in experimental use since 1953. The properties of image storage and extremely high brightness at low voltage make the tube very attractive for radar indicators, oscilloscopes, and other uses.

This paper describes its operation with emphasis on those unusual characteristics which have no counterpart in ordinary cathode-ray tubes, and suggests modifications of an oscilloscope to use the tube. It is hoped that the applications engineer will find the answers to some of the questions which may arise when operating this storage tube for the first time.

## Description

The Iatron is a storage cathode-ray tube in which the display can be written, stored, and viewed continuously. While it is available in a variety of bulb sizes and types of writing guns, the characteristics presented here are particularly applicable to the 5-inch *Ia10P20-25* tube, shown in Fig. 1, which has an electrostatic writing gun. Continuous viewing is provided by a divergent electron beam, called the flooding beam, which expands until its spot covers the display area of the tube. Elemental areas of the large flood spot are modulated by means of a cathode-ray beam of the type used in conventional cathode-ray tubes.

The following explanation of the method of modulating the flood spot refers to Fig. 2. The flooding gun is located on the tube axis in the rear wall of the bulb. The control grid of the flooding beam is an insulator layer which covers the front surface of a fine-mesh metal screen, insulator screen, and is located in the path of the beam at the distance where the beam has expanded to its maximum size. The beam passes through the metal screen and impinges upon the aluminized phosphor on the inner face of the tube. An aquadag coating on the wall of the bulb and a metal collector screen serve to collimate the flooding beam. With proper collimation the paths of the electrons in the expanded flooding beam are made parallel to each other and perpendicular to the plane of the insulator.

The insulator screen which supports the insulator layer serves the same purpose as the screen grid of a tetrode and is operated on a fixed voltage of about +10 volts. Points on the insulator surface, however, can assume potentials which are quite different from each other and from the voltage on the insulator screen. These potentials are established on the insulator surface by charging it with the writing beam and with the flooding beam. Over the insulator control range, the number of flooding electrons which can pass through the screen at any point is roughly proportional to the insulator surface potential at that point.

### ERASING

Erasing pulses are essential to the operation of the Iatron. These are low-voltage pulses applied to the insulator screen which cause the display to fade to cutoff. Without them, the entire display area would increase eventually to maximum brightness. The increase in brightness results when positive ions, which are generated by collision between flooding electrons and residual gas molecules, are drawn to the insulator surface charging it positively. The ion density over the insulator surface is uniform and therefore the display area brightens everywhere at the same rate.

Further increase of insulator potential ceases when the insulator has become charged to about +2 volts with respect to the flooding-gun cathode. At this potential, some flooding electrons have enough energy to strike the insulator. Striking with low energy, these electrons stick and by virtue of their negative charge prevent additional voltage increase. An equilibrium insulator potential is thereby established for which the positive ions are balanced by the electrons landing on the insulator.

When the insulator suddenly becomes more positive, as by applying a voltage pulse to the support screen, flooding current strikes the insulator, quickly charging the surface down to equilibrium again. At the end of the pulse, the support screen is returned to its original potential, but the insulator is now more negative than it was before because of the charge acquired during the pulse. Positive insulator charges written by the writing beam are erased in the same way.

### INSULATOR CONTROL CHARACTERISTIC

Fig. 3 is a curve showing average phosphor flooding current over the display area as a function of insulator surface potential. The points on the curve were obtained, using +10-volts bias on the support screen, by first allowing ions to charge the entire insulator surface to equilibrium. At equilibrium, the insulator is charged to its most positive potential and phosphor current is a maximum. This current corresponds to zero insulator volts on the curve. The insulator surface was then charged negatively 0.5 volt by applying a +0.5-volt pulse to the insulator support screen. The phosphor current was measured at the end of the pulse, and the process was repeated increasing the amplitude of the pulse at each step until phosphor current reached cutoff. Thus it was determined that pulses of 3.2 volts amplitude are necessary to erase the tube to cutoff. The assumptions were made that the insulator surface is at zero volts at equilibrium, and that the insulator is charged negatively to the amplitude of the erase pulse at each step. Although, as a matter of academic interest, the insulator surface potential

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* Iatron is a trade-mark of the Farnsworth Electronics Company, a division of International Telephone and Telegraph Corporation.

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Dr. P. T. Farnsworth has made many notable contributions to the storage-tube art[1,2] and has personally directed the Iatron research and development work undertaken in 1949. Others who have contributed to the development of the Iatron include a majority of the Farnsworth Research Department. Current Iatron development has been supported primarily by the U. S. Navy, Bureau of Ships.

**Fig. 1.** 5-inch electrostatic Iatron IA10P20-25

at equilibrium was actually about 2 volts, the first assumption is valid in the sense that the insulator does not draw flooding current over the control range from equilibrium to cutoff.

### Control of Viewing Time

It is clear that the insulator cannot be charged to a potential more negative than the absolute amplitude of the erasing pulse, because it charges to an equilibrium potential which is reached when the voltage difference between the flooding-gun cathode and insulator is just sufficient for flooding electrons to strike the insulator. On the other hand, it can be prevented from charging to this equilibrium if the pulse duration is shorter than the charging time required. The erasing pulses used to obtain the curve of Fig. 3 were applied for a sufficient length of time to charge the insulator to equilibrium.

The average time required to charge the insulator from maximum brightness to cutoff is about 3 milliseconds, and a display can be made to persist for many seconds if pulses which are narrower than 3 milliseconds are applied continuously at a suitable repetition rate. On each successive pulse, the insulator will be charged negatively a small amount and will eventually reach cutoff when the product of pulse width times the number of consecutive pulses is equal to 3 milliseconds.

Pulses having a repetition frequency of $f$ pulses/sec (per second), which are $t$ sec wide and 3.2 volts in amplitude, will therefore erase signals from maximum brightness to cutoff in the approximate time $T = 0.003/f \times t$ sec, for large values of $f$. (The erasing-pulse amplitude required to erase to cutoff is increased slightly if the erasing-pulse frequency is reduced to very low values, since the insulator voltage shift by ions during the interval between pulses then becomes significant.) Hence, the viewing time of the display can be varied by controlling either the frequency or the width of the erasing pulses. The proper choice of pulse repetition is influenced by flicker and contrast as well as viewing time.

#### *Flicker*

During an erasing pulse, the entire display area is illuminated by flooding current which passes through the insulator screen (see Figs. 5 through 7). The resulting flashes of light produce flicker at low pulse frequencies, or merge to a constant background brightness at a pulse frequency of about 45 pulses/sec. However, very narrow pulses such as would be used to obtain a viewing time of the order of 1.0 minute are hardly detectable in the display even in the flicker frequency range.

#### *Contrast*

Loss of contrast is caused by background brightness. The average background contributed by erasing pulses is $B = 0.003/T(100) = (100\ f \times t)$ per cent of maximum display brightness.

Loss of contrast would be most severe using the erasing conditions required for minimum viewing time. However, this is an unrealistic condition for the Iatron as it defeats the very purpose of storage tubes. Nevertheless, it is interesting to estimate the maximum background brightness which might be encountered.

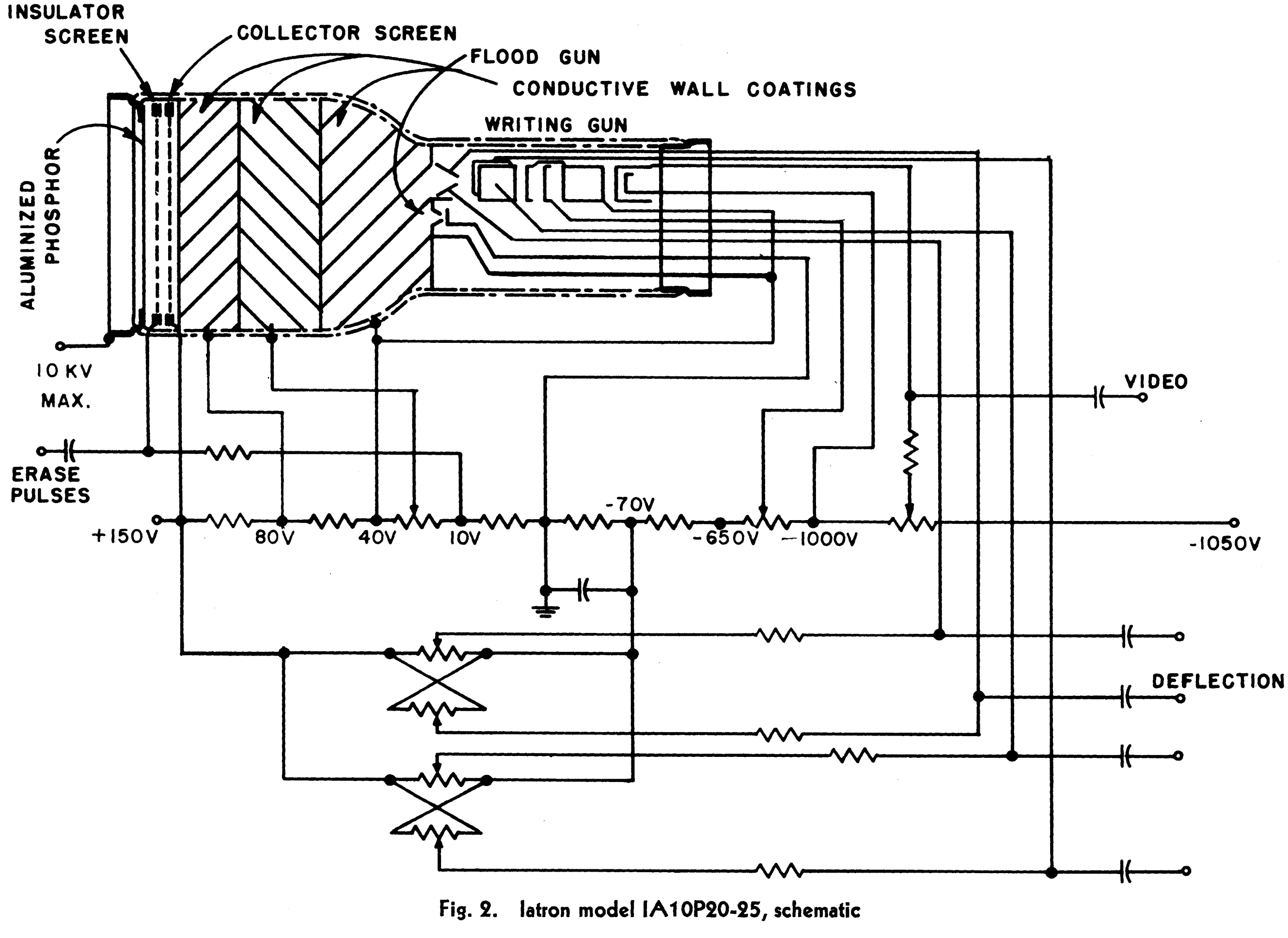

**Fig. 2.** Iatron model IA10P20-25, schematic

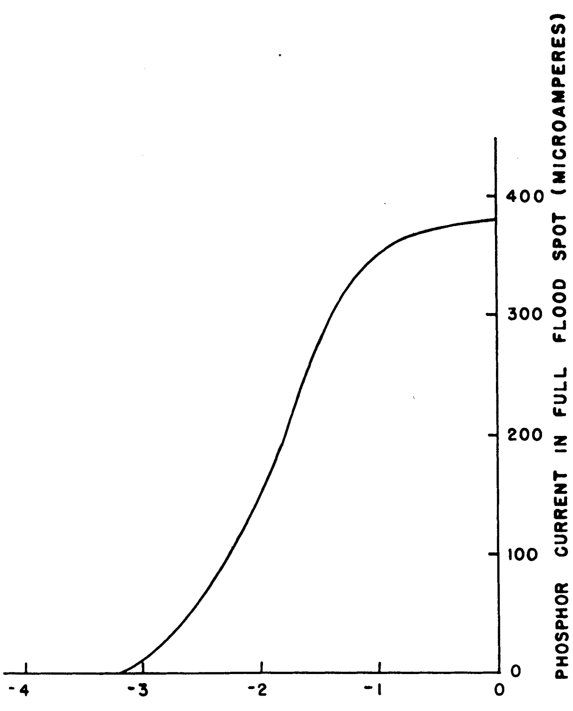

**Fig. 3. Static insulator control characteristic**

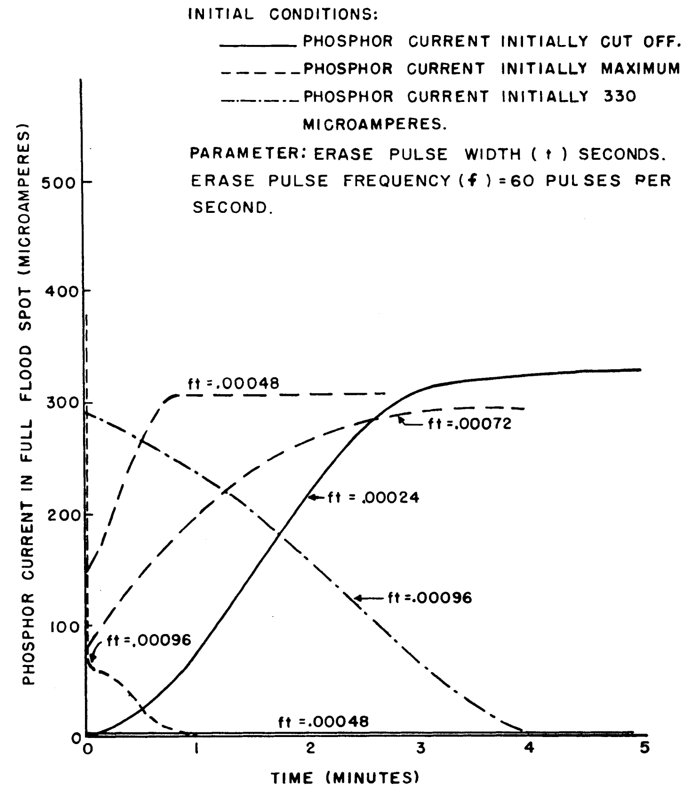

**Fig. 4. Change of phosphor current caused by positive ions and erasing pulses**

Since the minimum erasing time is 3 milliseconds and the repetition rate over which persistence is limited by the eyes of the observer is 45 pulses/sec, these values may be taken as the pulse-width and frequency which will determine minimum viewing time. Under these conditions, the display area would be viewed at maximum brightness $45 \times 0.003 = 0.135$ sec/sec of total viewing time. The average background brightness would, therefore, be about 13.5 per cent of the maximum signal brightness.

However, by the same reasoning, $B$ would be only 0.3 per cent for a viewing time of 1.0 sec. At 45 pulses/sec, the pulse width for this condition would be about 67 microseconds.

### Maximum Viewing Time

Viewing time may be limited by positive ions or by insulator leakage. Leakage is negligible at normal tube operating temperatures, and most Iatrons will store written charges for several hours if all tube voltages are removed, to avoid generation of ions, after writing.

The number of ions generated is a function of several things such as flooding current density, length of the electron paths, pressure of residual gases in the tube, etc. The time required in an average tube for ions to charge the insulator from cutoff to 50 per cent of maximum brightness is about 30 sec. The measurement is significant in that there must be a minimum product of erasing frequency and pulse width, $f \times t$, which will prevent ion charge integration on the insulator and thereby maintain nearly constant insulator potential in the interval between pulses.

Fig. 4 shows curves of phosphor current versus time for a typical tube using small values of $f \times t$. The ordinate is proportional to brightness since the flooding-spot size is constant and the power input to the phosphor is well below the level at which saturation occurs. For the condition that the insulator is initially at cutoff, an erasing product $f \times t = 0.00048$ maintains cutoff. If the insulator is initially at equilibrium however (phosphor current initially maximum), an erasing product $f \times t = 0.00048$ will not erase the tube but will allow the insulator to charge to an intermediate potential corresponding to 310 $\mu$a (microamperes) of phosphor current. Thus it is found that two stable potentials, one corresponding to cutoff and the other corresponding to 310 $\mu$a of phosphor current, are possible. They are maintained in each case because the insulator charge received from the flooding electrons during one erasing pulse is equal to the ion charge acquired during the interval between pulses.

A necessary condition for continuous operation is that signals written by the writing beam to any brightness will eventually be erased to cutoff. Lacking sufficient erasure, the display area would soon be saturated. As shown in Fig. 4, if a minimum erasing product $f \times t = 0.00096$ is used, a signal which has been written to maximum brightness will assuredly be erased.

Two curves are shown for which $f \times t = 0.00096$. In the first, the pulse was not applied until the insulator had been charged to equilibrium and allowed to remain there for a considerable length of time. By suddenly applying the pulses, phosphor current drops sharply and the tube erases to cutoff. In the second curve, erasing pulses were not applied suddenly but were operated continually while the tube was written to the initial phosphor current of 330 $\mu$a. This curve is typical of viewing-time curves obtained with continuously operating erasing pulses, the viewing time being less for larger values of $f \times t$.

The cause of the rapid decrease in brightness which is observed when an erasing pulse is suddenly applied, under the initial condition that the phosphor current is a maximum, is not fully understood. However, it is probable that the distribution of charges on the insulator on the front surface as well as on the sides of the mesh holes of the insulator screen is affected by initial conditions.

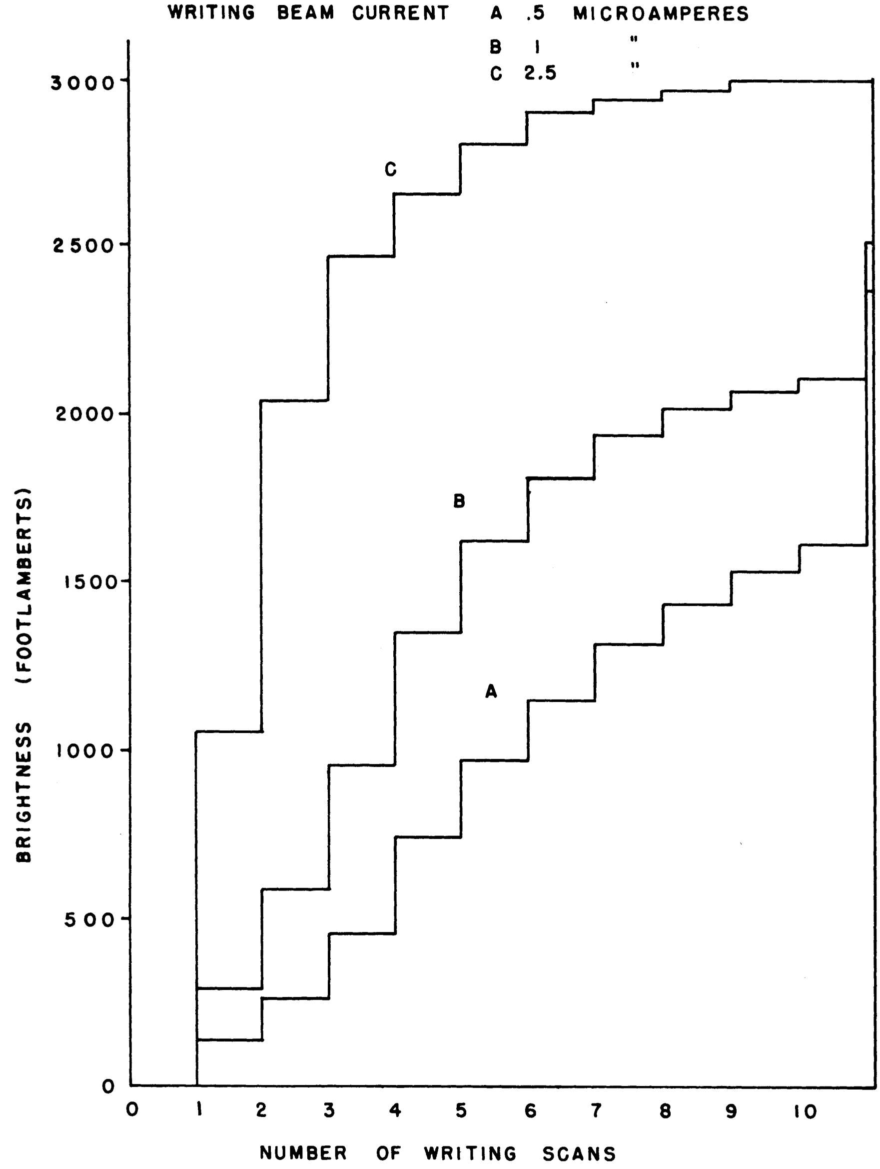

**Fig. 5. Brightness of a point written upon for ten successive writing scans and finally erased to cutoff; writing-spot scanning speed $2.75 \times 10^4$ cm/sec**

Depending upon the distribution of charges, the electric fields in the vicinity of the meshes will be modified, deflecting the flooding electrons and ions to selective minute areas of the insulator surface and, consequently, altering the erasing characteristic.

It is interesting to note that if the insulator is initially at cutoff, and a value of $f \times t$ is used so that $0.00048 < f \times t < 0.00096$, insulator areas where a large writing charge has been deposited will charge to a definite brightness level, while weak signals will be erased to cutoff. (A small area of positive charge will not persist indefinitely however, since the escape of secondary electrons from the area is inhibited by the electric field of the less-positive surrounding insulator surface, thus causing more electrons to stick, charging the area negatively. The bright area shrinks in size and disappears.) This characteristic may be used to achieve extended viewing time but with concurrent loss of half tones. Extension of viewing time by this method is even greater if still narrower erasing pulses of relatively high amplitude are used. The viewing time obtainable in this way is upwards of 30 sec after which time the written areas decay rather rapidly to cutoff.

## Writing Characteristic

With the tube operating and with proper erasing pulses being applied, the tube will be at cutoff and in readiness to be written upon. The 1,000-volt writing beam may be scanned over the insulator in any desired pattern, and video signals are applied to the control grid to modulate the beam.

The collector screen, insulator, and phosphor each intercept a part of the writing beam. The current intercepted by the insulator serves to charge it in the positive direction since the beam energy is great enough to eject a greater number of secondary electrons than the number of primary electrons intercepted.

The rate at which the insulator can be charged by the writing beam is very high. This rate is measured by measuring the brightness of the stored trace after the writing beam has been deflected across the tube at a known scanning speed. In Fig. 5 the brightness of a stored signal is plotted, as it increases in stair-step fashion, with each passage of the writing beam during successive superimposed scans across the corresponding point on the insulator. The writing spot was scanning at a speed of $2.75 \times 10^4$ cm (centimeters)/sec, and the three curves are for three values of writing-beam current. After the tenth scan an erasing pulse was applied to restore the insulator to cutoff. The bright flash which accompanies the erase pulse is shown also in Fig. 5. It can be seen that the flash is never brighter than the brightness associated with equilibrium insulator potential, and has a relationship to the brightness of the signal which is being erased.

The writing currents used to obtain the data shown in Fig. 5 were necessarily very low because of the relatively low scanning speed available for these tests. However, the writing-beam current can be as high as 150 $\mu$a at zero grid bias and will write to maximum brightness in a single-line scan at a scanning speed of about $10^5$ cm/sec.

At high brightness, the brightness increase per scan grows smaller. At the high-brightness limit saturation is reached, and further writing results only in a charge spreading on the insulator surface. Since an electron beam does not possess finite size, a few electrons will be found even at radii considerably larger than the dimensions of the spot defined by the usual methods. These fringe electrons continue to integrate on the insulator area surrounding the core of the spot after it has saturated.

The obvious implication is a serious one, that areas repeatedly written upon in a display will tend to bloom unless some form of insulator writing-charge limiting is used. In a plan position indicator radar display, for example, an equalizing signal derived from the range-deflection voltage may be added to the video signal to prevent blooming at the center. To emphasize weak targets

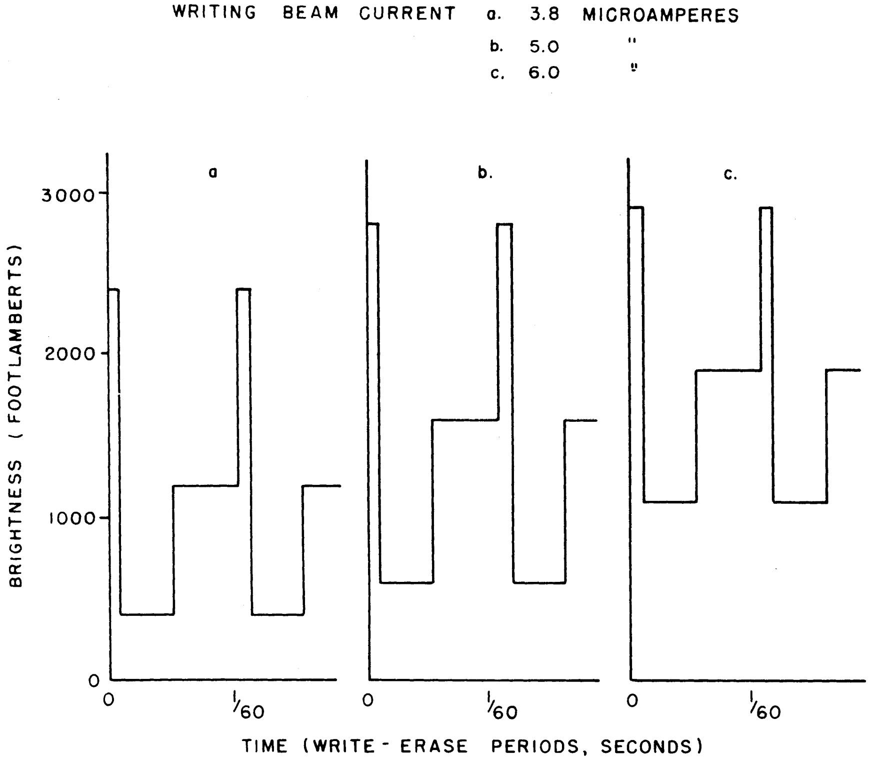

**Fig. 6.** Stable brightness levels of a point alternately written and erased upon; erase-pulse width 1,350 microseconds

in a display, video clipping will prevent blooming on strong signals. Proper choice of the erasing-pulse frequency is, of course, extremely important in this matter since writing charge can be erased before it has had the opportunity to integrate beyond a desired level. An erasing frequency equal to the deflection frequency is the best choice in many cases.

In almost any continuous display the erasing-pulse frequency and pulse width are preset, i.e., after adjustments have been made to achieve the desired viewing time no further adjustments will be required during operation. Fig. 6 illustrates typical continuous operation of an Iatron using an erasing frequency equal to the writing-beam scanning frequency, which in this case is 60 cps (cycles per second). An erasing-pulse width of 0.00135 sec was used, and the viewing time was consequently about 37 milliseconds. The way in which the average brightness varies with writing current is apparent from the three conditions shown. The two brightness levels in each graph correspond to insulator potentials immediately after writing and immediately after erasing. These are stable potentials which will be repeated until either writing current or erasing-pulse width is changed. Each erasing pulse charges the insulator downward in potential by an amount equal to the potential increase by writing during one scan. The ability of the insulator to assume stable potentials follows from its nonlinear charging characteristic wherein the charging rate decreases toward higher brightness levels; Fig. 5. If the characteristic were linear, writing charges would integrate to saturation. Since the erasing-pulse amplitude was 3.2 volts, the tube would have been erased just to cutoff if writing current were reduced to zero.

As indicated in Fig. 7, to change viewing time requires adjustment of both average writing current and the amount of erasure. In Fig. 7 the average brightness was held constant by adjusting the writing current, after the viewing time was changed, by altering the erasing-pulse width.

## RESOLUTION

To measure resolution, a raster of a known number of equally spaced lines is scanned, and the raster is shrunk until the individual lines are no longer discernible. The raster width which is normal to the lines is then measured, and resolution is specified in lines/inch.

Resolution measurements are meaningless unless brightness is specified concurrently. It is found that resolution is approximately the same at a given brightness regardless of how many scans or what writing-beam current were required to write to that brightness. While the resolution of a stored image at low brightness is nearly equal to the resolution of the writing beam itself, at high brightness it approaches a minimum of about 35 lines/inch; see Fig. 8.

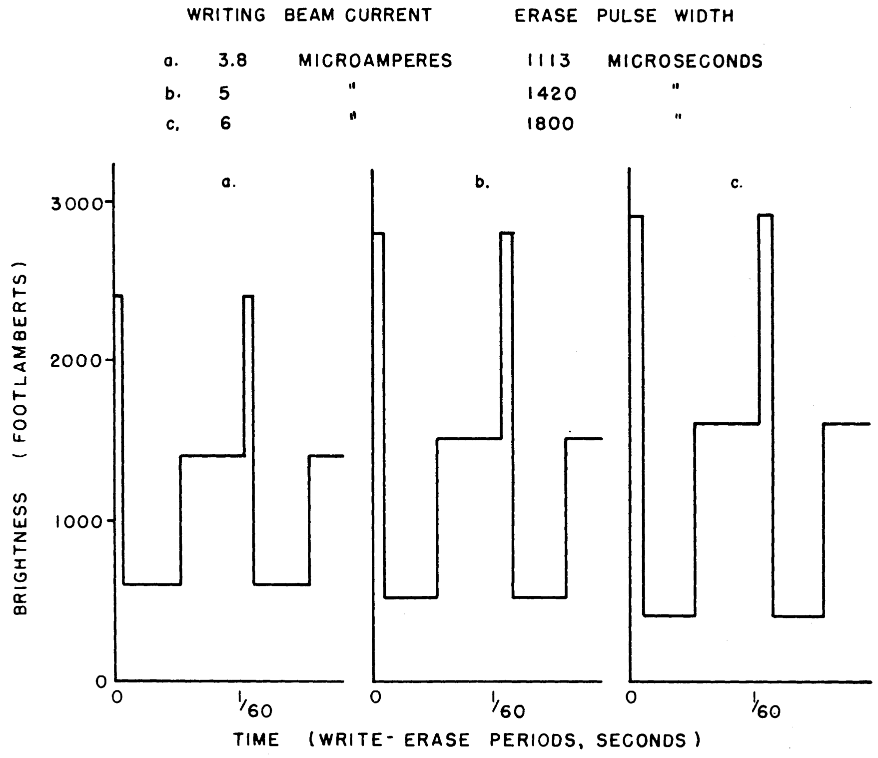

**Fig. 7.** Stable brightness levels of a point alternately written and erased upon; average brightness is constant

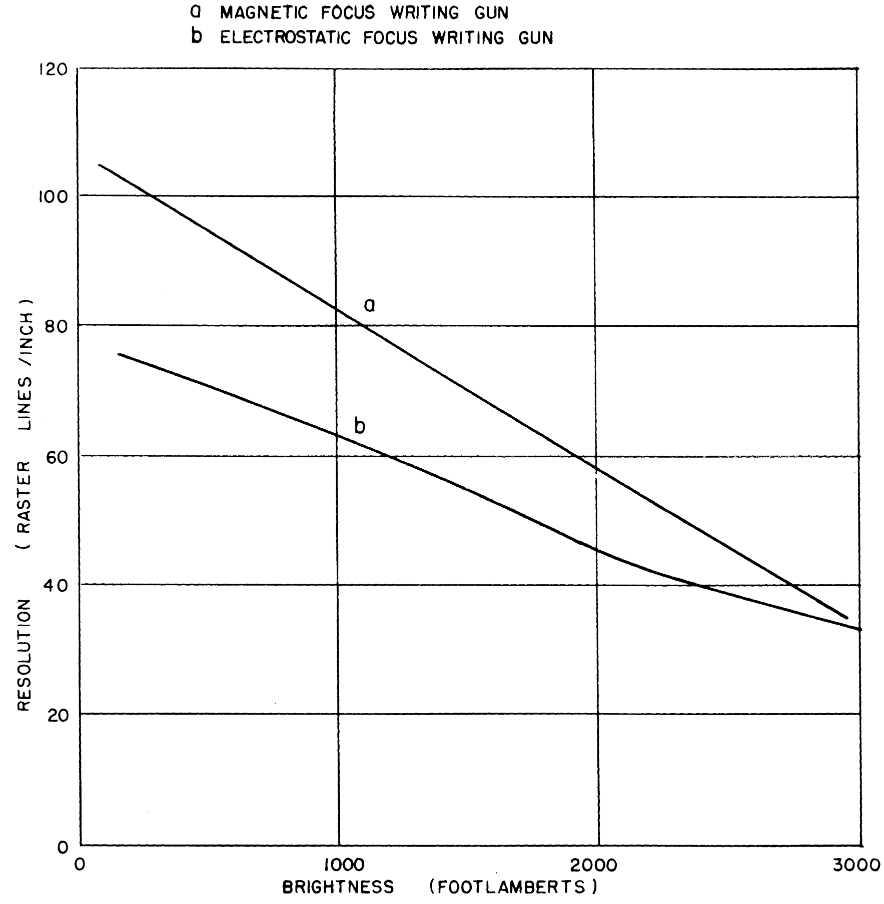

**Fig. 8. Resolution versus brightness. The curve for a magnetic focus gun having a smaller writing-spot size shows limitations attributable to the writing gun**

## Oscilloscope Application

Operation of the Iatron storage tube probably can be understood best by noting how its characteristics apply to a particular application. Since the cathode-ray oscilloscope is commonly used in all engineering laboratories, this section will be concerned with the operation of the Iatron as it might be used in an oscilloscope.

The usefulness of oscilloscopes decreases rapidly for very low sweep frequencies up to the threshold of flicker. The useful low-frequency range could be extended considerably by lengthening the persistence of the trace. Using the Iatron for this purpose, there is no flicker and the trace is bright enough to be viewed easily in a fully lighted room.

At low frequencies, storage in oscilloscope displays is ordinarily obtained by photographing the display. Another method to display low-frequency signals is to resort to mechanical means of recording. Besides the added expense and inconvenience of these methods, they also have limitations which are overcome by using the Iatron:

1. The Iatron will record transients composed of frequencies from d-c to above 1.0 megacycle/sec, whereas mechanical recorders are restricted to about 60 cps.
2. Any trace can be stored for examination or it can be erased instantaneously in the Iatron.
3. The trace can be viewed immediately in the Iatron, avoiding the delay involved in development of film.

It is also practical to store superimposed sweeps taken in sequence at several test points for directly comparing wave forms.

The advantages of an Iatron oscilloscope are expected to be greatest at low-sweep speeds, but it need not be restricted in operation to the low-frequency ranges, since a visible trace may be stored at writing-spot velocities up to nearly 1.0 million cm/sec.

At still higher speeds for which no trace will be stored, the tube can still be operated as a conventional cathode-ray tube, since the writing-beam average power input to the phosphor can be about 0.4 watt with the tube operating at 10 kv; nor does the high voltage entail a loss of deflection sensitivity. A constant sensitivity of 100 volts/inch is afforded by the electrostatic shielding property of the insulator screen which isolates the 1.0-kv deflection region of the tube completely from the 10-kv phosphor potential.

By switching the insulator screen from its normal +10 volts to about −20 volts, the flooding beam can be cut off to improve contrast when it is desired to view only the writing-beam trace and not its stored image.

In normal operation, erasing pulses will keep the insulator erased to cutoff in areas where no trace is being written, and will prevent writing charges in the trace from integrating to the extent of charge spreading. For the usual repetitive-signal mode of oscilloscope operation, an erasing-pulse amplitude control and erasing-pulse width control should be accessible on the front panel to make initial adjustments of cutoff and viewing time. An intensity control is necessary to adjust writing-beam current to compensate for changes in sweep speed and waveform of the signal.

At sweep frequencies of over 45 cps the erasing pulse can be triggered by the sweep. This is in keeping with the discussion of writing-charge limiting in which it was pointed out that maximum charge stability of areas repeatedly

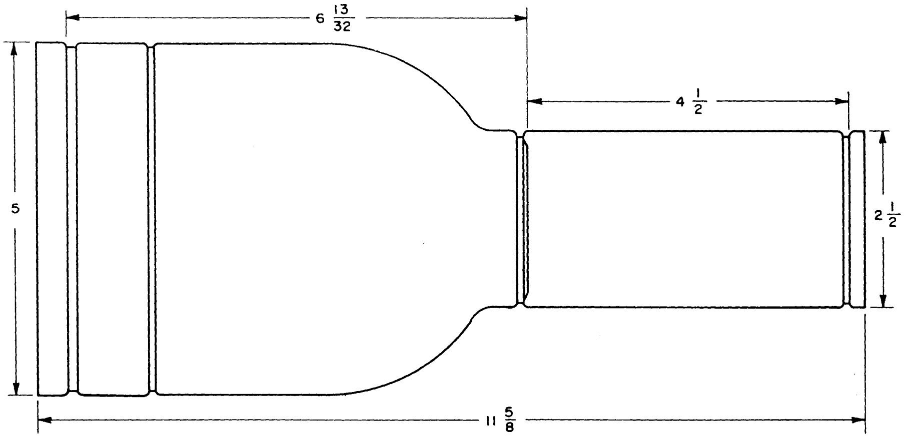

**Fig. 9. Outside dimensions of the 5-inch electrostatic Iatron IA10P20-25**

written upon exists when writing and erasing frequencies are equal. At lower sweep frequencies, flicker and blooming would be avoided if a constant erasing-pulse frequency of 45 cps or higher were used. A convenient and satisfactory frequency is 60 cps.

To display transients, maximum writing speed and storage time is desirable. A switch might be provided which, after writing, could be used to cut off the writing beam and erasing pulses simultaneously, thus avoiding overwriting of the transient trace and at the same time preventing its erasure. At extremely slow sweep speeds it is desirable to turn off the erase before the start of the writing trace to avoid any erasure before one sweep is completed. This suggests a manual on-off erase switch. Also, an instant-erase button would probably be useful to restore the insulator quickly to cutoff after operating with the erasing pulse off.

The oscilloscope should be equipped with a $z$-axis gate to assure that the undeflected writing spot is cut off, since the undeflected spot would cause insulator charge spreading from that spot over an appreciable area of the screen, and at very high current the insulator might even be damaged.

The controls described are the extent of the added complexity necessary to operate an oscilloscope adapted to the Iatron, and the additional circuitry needed to operate the flooding system is equivalent to adding one tube. An erasing-pulse generator which can perform the suggested functions could be a slave multivibrator.

Summarizing, the following controls are recommended for full utilization of the tube's capabilities:

1. Erasing-pulse gain control to adjust the amplitude of the pulses.
2. Erasing-pulse width control to adjust the duty cycle of the pulses.
3. Instant erase push-button switch to widen the erasing pulses momentarily in order to erase clutter without disturbing other erasing control settings.
4. Erase on-off switch to remove erasing pulses when it is desired to "freeze" a trace for inspection without adjusting erasing controls.
5. Write on-off switch to bias the writing-gun control grid to cutoff to prevent overwriting a "frozen" trace without adjusting the intensity control.

**Table I. Operating Voltages**

| | Volts | Current |
|---|---|---|
| **Writing gun** | | |
| heater | 6.3 | 0.6 amp, a-c or d-c |
| cathode | −1,000 | 1,080 μa, max |
| grid | −1,042 at cutoff | |
| first anode | −700 at focus | −1.0 μa, max |
| second anode | 40 | 940 μa, max |
| **Flooding system** | | |
| heater | 2.5 | 2.5 amp, a-c or d-c |
| cathode | 0 | 2.6 ma |
| anode and first wall electrode | 40 | 0.8 ma, min<br>1.0 ma, max |
| second wall electrode | 20 | 0.07 ma, min<br>0.115 ma, max |
| third wall electrode | 80 | 0.035 ma |
| collector screen | 150 | 1.25 ma |
| insulator screen | +10 | |
| phosphor | +10* | 0.38 ma, max |

Deflection-plate reference voltage for minimum astigmatism, 0 volts. Deflection sensitivity; 85 volts/inch, plate $D_3$ to $D_4$; 100 volts/inch plate, $D_1$ to $D_2$. Plates $D_1$ and $D_2$ connected to +90 volts draw 36-ma flooding current.

* Kilovolts, max.

6. Flooding-beam on-off switch to bias the insulator support screen to flooding-beam cutoff when the tube is being used as a conventional cathode-ray tube.

The type *Ia10P20-25* Iatron shown in Fig. 1 is the model recommended for oscilloscopes and other applications which require electrostatic deflection. The useful display diameter is 4 inches, and the outside dimensions are shown in Fig. 9.

Some comment on the operating circuit of Fig. 2 is necessary. The resistance in the final deflection-plate circuit should be lower than is ordinarily used with cathode-ray tubes, because when they are driven positive, the plates can draw about 36 microamperes of flooding current.

If the average voltage of the deflection plates is about 40 volts, the least astigmatism of the writing spot results since the second anode and first wall electrode are on that potential. An astigmatism control consisting of a dual potentiometer could be inserted in the bleeder at the points supplying the direct current to the plates to adjust the average deflection plate voltage. However, it is found in practice that good results are achieved with an average plate voltage near zero, as shown.

The maximum phosphor voltage is 10 kv. However, the characteristics of the tube, other than brightness, will be relatively unchanged with operation down to less than 5 kv. Therefore, to avoid any possible damage to the tube because of overvoltage accidents, particularly when extremely high brightness is not an objective, it is recommended that reduced voltage be used.

The flooding-spot size is adjusted by small changes in voltage applied to the second wall electrode after other voltages of the flooding system have been set at their specified values. Table I lists operating voltages and maximum and minimum currents of flooding-system electrodes which were measured to aid in the design of power supplies and bleeder. These measurements were made on only a few tubes, since production tubes are not available at this writing to obtain average data. It is anticipated that production tubes will have fewer electrodes, but those retained will be operated very closely to their present voltages, and tubes will operate interchangeably, requiring only the number of controls which have been indicated.

## References

1. *U. S. Patent no. 2,228,338.*
2. *U. S. Patent no. 2,754,449.*
3. STORAGE TUBES AND THEIR BASIC PRINCIPLES (book), **M. Knoll, B. Kazan.** John Wiley & Sons, Inc., New York, N. Y., 1952.
4. CHARACTERISTICS OF A TRANSMISSION CONTROL VIEWING STORAGE TUBE WITH HALFTONE DISPLAY, **M. Knoll, H. O. Hook, R. P. Stone.** *Proceedings*, Institute of Radio Engineers, New York, N. Y., vol. 42, Oct. 1954, pp. 1496–1504.
5. DIRECT VIEWING MEMORY TUBE, **S. T. Smith, H. E. Brown.** *Ibid.*, vol. 41, Sept. 1953, pp. 1167–71.
6. THE RECORDING STORAGE TUBE, **R. C. Hergenrother, B. C. Gardner.** *Ibid.*, vol. 39, 1950, pp. 740–47.
7. A MEMORY TUBE, **A. V. Haeff.** *Electronics*, New York, N. Y., vol. 20, Sept. 1947, pp. 80–83.