Characteristics and Applications of the Iatron Storage Tube*

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

Iatron® storage tubes have been under development 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 Iatron operation with emphasis on those unusual characteristics that 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 that may arise when operating this storage tube for the first time.

1. 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 (127-millimeter) *Ia10P20-25* tube, shown in Figure 1, which has an electrostatic writing gun. Continuous viewing

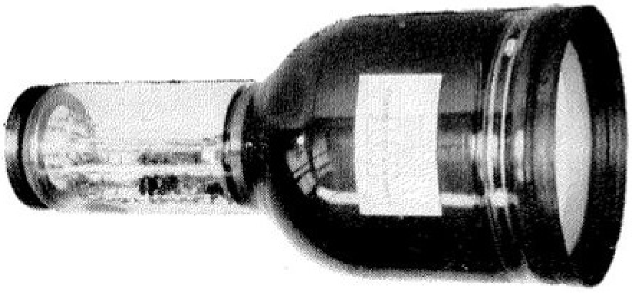

Figure 1—The 5-inch (127-millimeter) electrostatic-deflection Iatron *Ia10P20-25*.

is provided by a divergent electron beam, called the flooding beam, which expands until it covers the entire display area of the tube. Elemental areas of the large flooding beam are modulated by a conventional cathode-ray beam.

The following explanation of the method of modulating the flooding beam refers to Figure 2. The flooding gun is located on the tube axis at the juncture of the neck and bulb. The control grid of the flooding beam is an insulating layer that covers the gun-facing side of a fine-mesh metallic screen. This insulator-screen 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 metallic screen and impinges on the aluminized phosphor on the inner face of the tube. An aquadag coating on the wall of the bulb and a metallic 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-screen.

The metallic screen that supports the insulator layer serves the same purpose as the screen grid of a tetrode and is operated on a fixed voltage

* Reprinted from *Communication and Electronics*, number 29, pages 47–53; March, 1957. Iatron is a registered trademark of Farnsworth Electronics Company. 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 United States Navy Bureau of Ships.

[1] M. Knoll and B. Kazan, "Storage Tubes and Their Basic Principles," John Wiley & Sons, Incorporated, New York, New York, 1952.

[2] M. Knoll, H. O. Hook, and R. P. Stone, "Characteristics of a Transmission Control Viewing Storage Tube with Halftone Display," *Proceedings of the IRE*, volume 42, pages 1496–1504; October, 1954.

[3] S. T. Smith and H. E. Brown, "Direct Viewing Memory Tube," *Proceedings of the IRE*, volume 41, pages 1167–1171; September, 1953.

[4] R. C. Hergenrother and B. C. Gardner, "The Recording Storage Tube," *Proceedings of the IRE*, volume 39, pages 740–747; July, 1950.

[5] A. V. Haeff, "Memory Tube," *Electronics*, volume 20, pages 80–83; September, 1957.

[6] United States Patent 2 228 338.

[7] United States Patent 2 754 449.

of about +10 volts. Points on the insulating surface, however, can assume potentials that are quite different from each other and from the voltage on the metallic screen. These potentials are established on the insulating surface by charging it with the writing beam and the flooding beam. Over the insulator control range, the number of flooding electrons that can pass through the screen at any point is roughly proportional to the potential at that point of the insulating surface.

1.1 Erasing

Erasing pulses are essential to the operation of the Iatron. These are low-voltage pulses applied to the insulator-screen that cause the display to fade to cutoff. Without them, the entire display area would eventually increase 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.

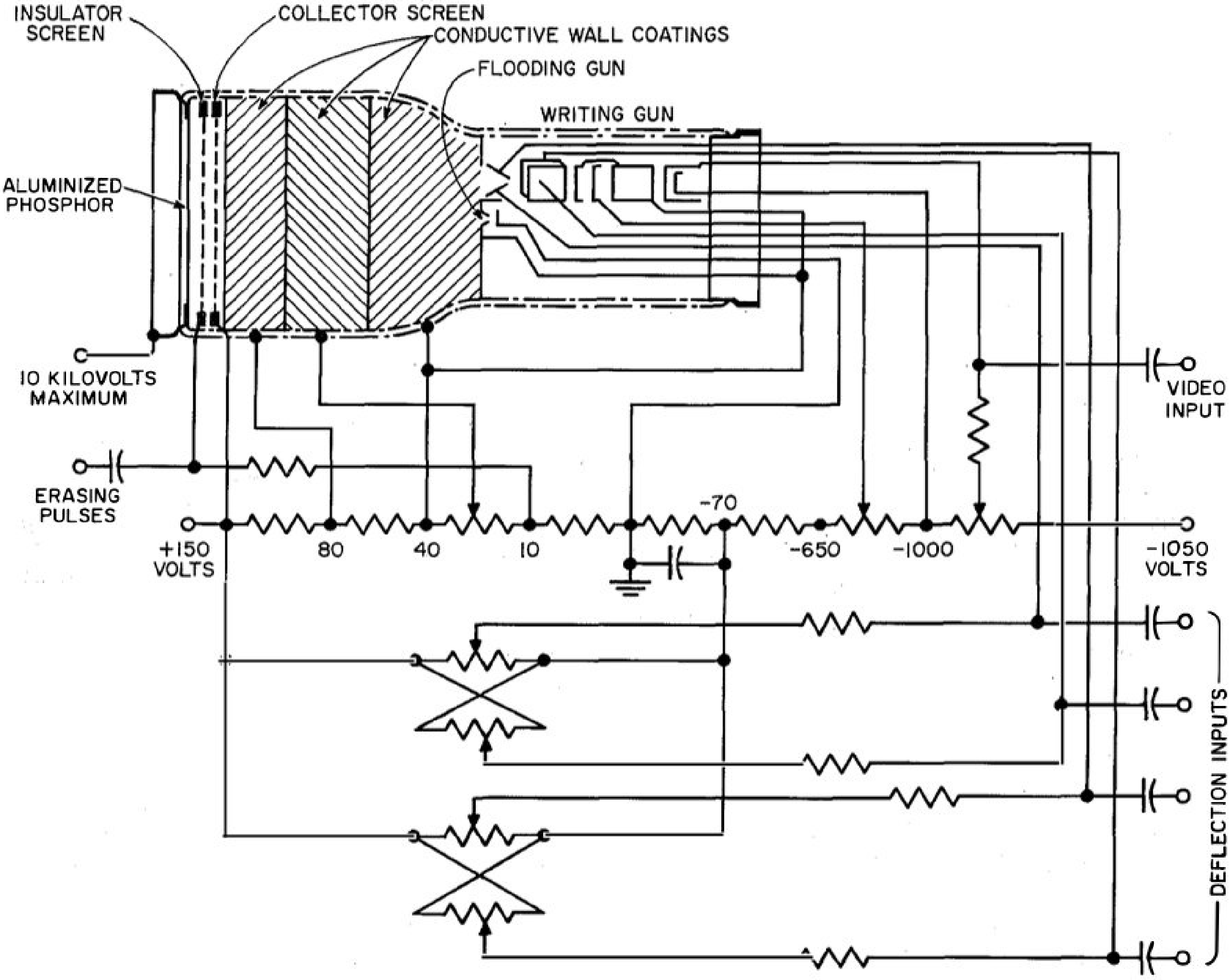

Figure 2—Diagram of Iatron model *Ia10P20-25* and associated circuits.

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 adhere and, by virtue of their negative charge, prevent additional voltage increase. An equilibrium insulator potential is thereby established at 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.

1.2 Insulator Control Characteristic

Figure 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 a +10-volt 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 0.5-volt negatively 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-volt 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 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.

1.3 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 that is reached when the voltage difference between the flooding-gun cathode and insulator is just sufficient for flooding electrons to strike the insulator. But it can be prevented from charging to this equilibrium if the pulse duration is shorter than the charging

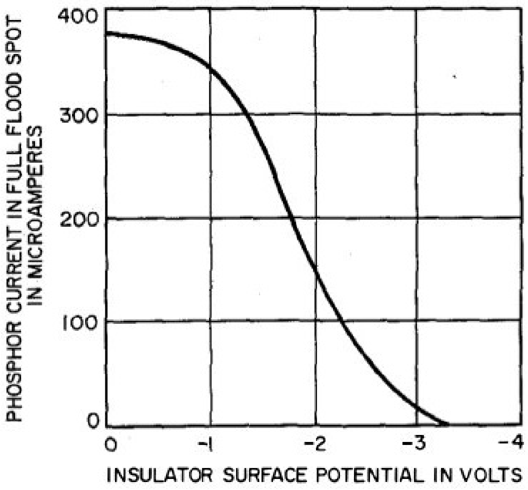

Figure 3—Static insulator control characteristic.

time required. The erasing pulses used to obtain the curve of Figure 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 that 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 per second, which are t seconds wide and 3.2 volts in amplitude, will therefore erase signals from maximum brightness to cutoff in the approximate time $T=0.003/ft$ second, 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 frequency is influenced by flicker and contrast as well as by viewing time.

1.3.1 *Flicker*

During an erasing pulse, the entire display area is illuminated by flooding current which passes through the insulator screen (see Figures 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 per second. 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.

1.3.2 *Contrast*

Loss of contrast is caused by background brightness. The average background contributed by erasing pulses is $B = 0.003/100T = 100\,ft$ percent 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 that might be encountered.

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 per second, these values may be taken as the pulse width and frequency that will determine minimum viewing time. Under these conditions, the display area would be viewed at maximum brightness $45 \times 0.003 = 0.135$ second per second of total viewing time. The average background brightness would, therefore, be about 13.5 percent of the maximum signal brightness.

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

1.4 Maximum Viewing Time

Viewing time can 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 after writing, to avoid generation of ions.

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, et cetera. The time required in an average tube for ions to charge the insulator from cutoff to 50 percent of maximum brightness is about 30 seconds. The measurement is significant in that there must be a minimum product of erasing frequency and pulse width, ft, which will prevent ion charge integration on the insulator and thereby maintain nearly constant insulator potential in the interval between pulses.

Figure 4 shows curves of phosphor current versus time for a typical tube using small values

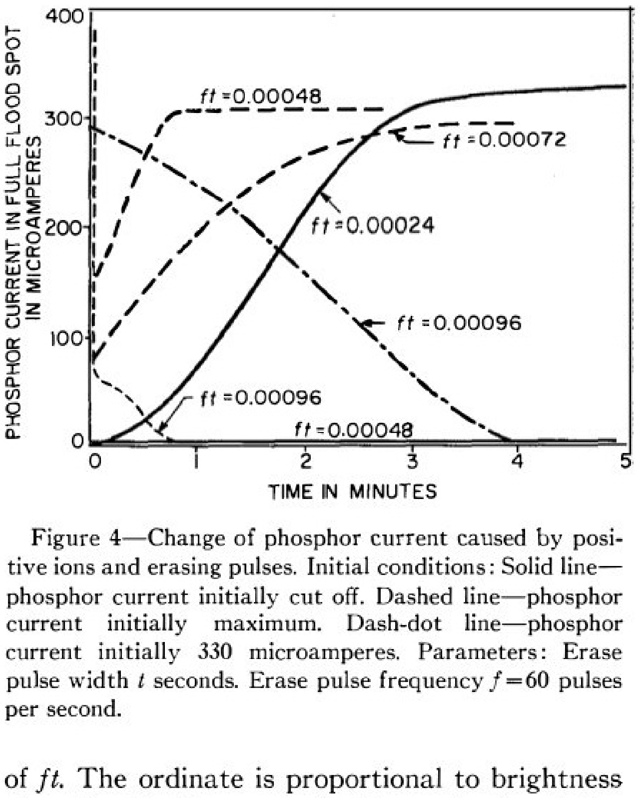

Figure 4—Change of phosphor current caused by positive ions and erasing pulses. Initial conditions: Solid line—phosphor current initially cut off. Dashed line—phosphor current initially maximum. Dash-dot line—phosphor current initially 330 microamperes. Parameters: Erase pulse width t seconds. Erase pulse frequency $f = 60$ pulses per second.

of ft. 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 $ft = 0.000\,48$ maintains cutoff. If the insulator is initially at equilibrium (phosphor current initially maximum), however, an erasing product $ft = 0.000\,48$ will not erase the tube but will allow the insulator to charge to an intermediate potential corresponding to 310 microamperes of phosphor current. Thus it is found that two stable potentials, one corresponding to cutoff and the other corresponding to 310 microamperes 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 Figure 4, if a minimum erasing product $ft = 0.000\,96$ is used, a signal that has been written to maximum brightness will assuredly be erased.

Two curves are shown for which $ft = 0.000\,96$. 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 present continually while the tube was written to the initial phosphor current of 330 microamperes. This curve is typical of viewing-time curves obtained with continuously operating erasing pulses, the viewing time being less for larger values of ft.

The cause of the rapid decrease in brightness that 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. Depending on 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 $0.000\,48 < ft < 0.000\,96$, 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 can 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 upward of 30 seconds, after which time the written areas decay rather rapidly to cutoff.

1.5 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 on. The 1000-volt writing beam can 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 determined by measuring the brightness of the stored trace after the writing beam has been deflected across the tube at a known scanning speed. In Figure 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 2.75×10^4 centimeters per second 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 Figure 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 that is being erased.

The writing currents used to obtain the data in Figure 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 microamperes at zero grid bias and will write to maximum bright-

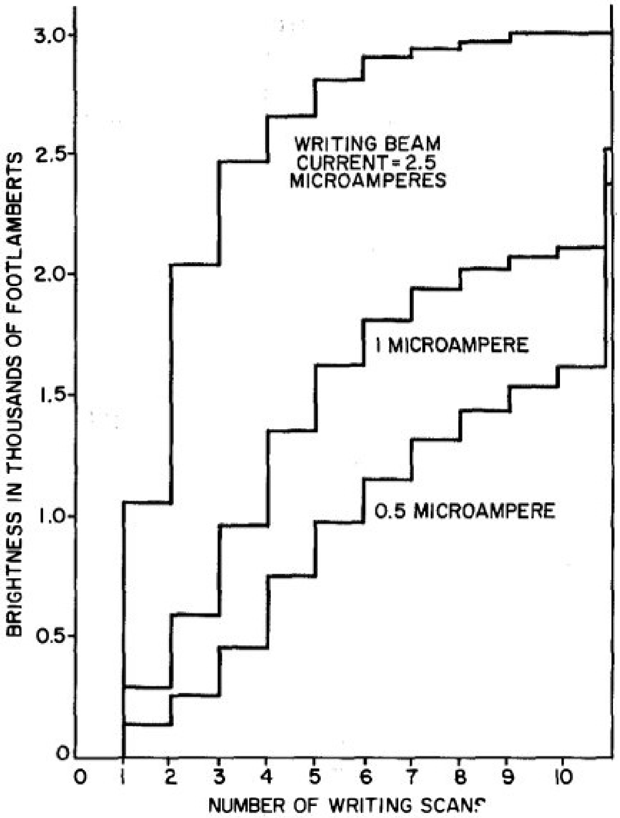

Figure 5—Brightness of a point written on for 10 successive writing scans and finally erased to cutoff; writing-spot scanning speed 2.75×10^4 centimeters per second.

ness in a single-line scan at a speed of about 10^5 centimeters per second.

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 can be added to the video signal to prevent blooming at the center. To emphasize weak targets 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; after adjustments have been made to achieve the desired viewing time no further adjustments will be required during operation. Figure 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 cycles per second. An erasing-pulse width of 0.001 35 second 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

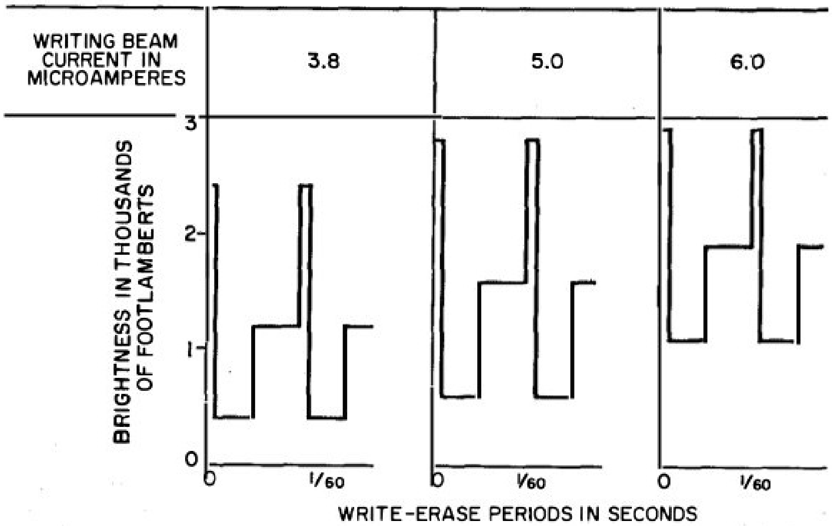

Figure 6—Stable brightness levels of a point alternately written and erased; erasing-pulse width = 1350 microseconds.

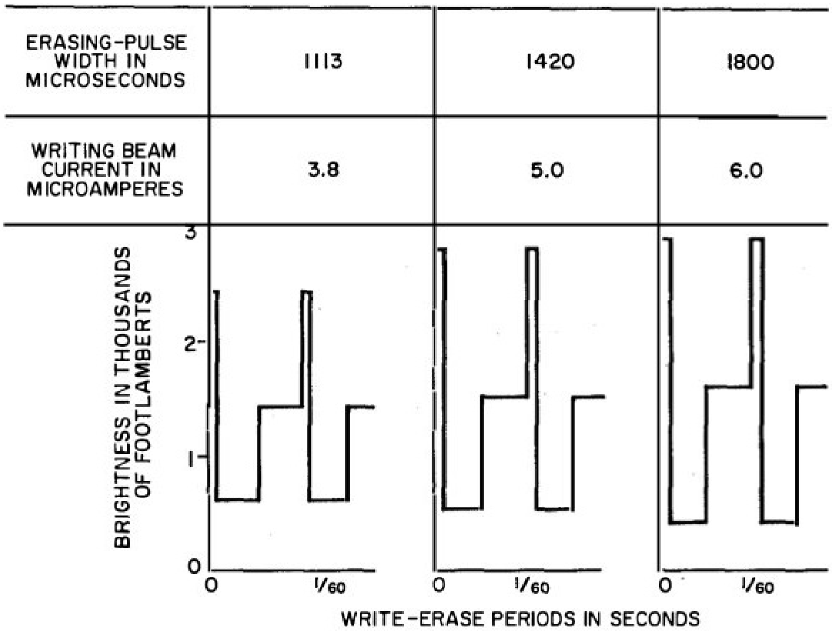

Figure 7—Stable brightness levels of a point alternately written and erased; average brightness is constant.

correspond to insulator potentials immediately after writing and immediately after erasing. These are stable potentials that 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; Figure 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 Figure 7, a change of viewing time requires adjustment of both average writing current and the amount of erasure. In Figure 7, the average brightness was held constant by adjusting the writing current, after the viewing time was changed, by altering the erasing-pulse width.

1.6 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 that is normal to the lines is then measured and resolution is specified in lines per 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 per inch (14 lines per centimeter); see Figure 8.

2. 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

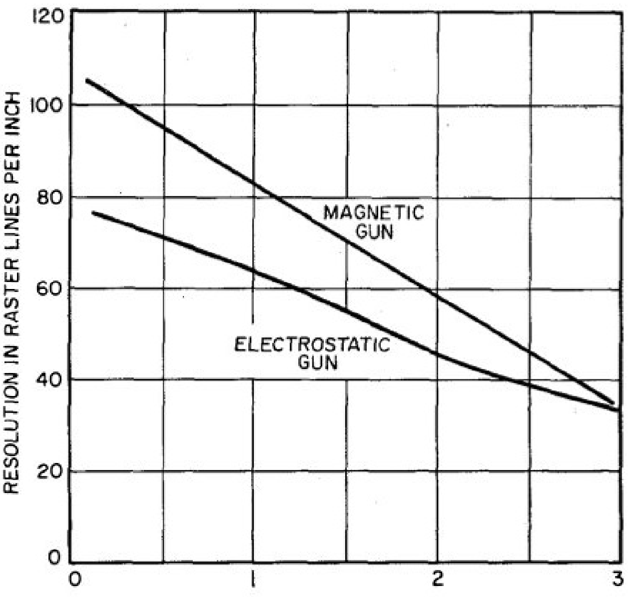

Figure 8—Resolution versus brightness. The curve for a magnetic-focus gun having a smaller writing-spot size shows limitations attributable to the writing gun.

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 that are overcome by using the Iatron:

A. The Iatron will record transients composed of frequencies from direct current to above 1 megacycle, whereas mechanical recorders are limited to about 60 cycles.

B. Any trace can be stored for examination or it can be erased instantaneously in the Iatron.

C. 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 waveforms.

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 can be stored at writing-spot velocities up to nearly 10^6 centimeters per second.

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 1 kilovolts; nor does the high voltage entail a loss of deflection sensitivity. A constant sensitivity of 100 volts per inch (39 volts per centimeter) is afforded by the electrostatic shielding property of the insulator screen, which isolates the 1-kilovolt deflection region of the tube completely from the 10-kilovolt 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 cycles, 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 written on 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 cycles or higher were used. A convenient and satisfactory frequency is 60 cycles.

To display transients, maximum writing speed and storage time is desirable. A switch might be provided that, after writing, could be used to cut off the writing beam and erasing pulses simultaneously, thus avoiding over-writing of the transient trace and at the same time preventing its erasure. At extremely slow sweep speeds, it is desirable to turn off the erasing pulses before the start of the writing trace to avoid any erasure before one sweep is completed. This suggests a manual on–off erasing switch. Also, an instant-erasing 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 circuit needed to operate the flooding system is equivalent to adding one tube. An erasing-pulse generator that can perform the suggested functions could be a slave multivibrator.

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

A. Erasing-pulse gain control to adjust the amplitude of the pulses.

B. Erasing-pulse width control to adjust the duty cycle of the pulses.

C. Instant-erasing push-button switch that widens the erasing pulses momentarily to erase clutter without disturbing other erasing-control settings.

D. Erasing on–off switch to remove erasing pulses when it is desired to freeze a trace for inspection without adjusting erasing controls.

E. Writing on–off switch to bias the writing-gun control grid to cutoff to prevent over-writing a frozen trace without adjusting the intensity control.

F. 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.

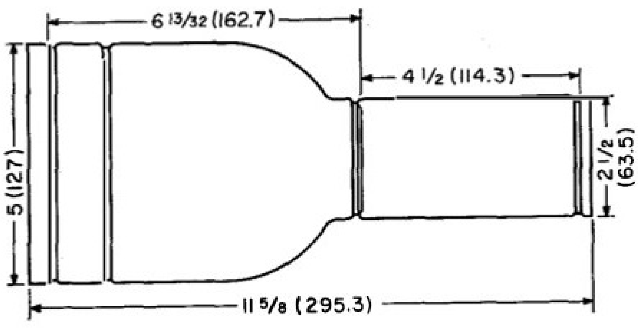

Figure 9—Outside dimensions of the 5-inch (127-millimeter) electric-field-deflection Iatron *Ia10P20-25*.

The type-*Ia10P20-25* Iatron shown in Figure 1 is the model recommended for oscilloscopes and other applications that require electric-field deflection. The useful display diameter is 4 inches (102 millimeters) and the outside dimensions are shown in Figure 9.

TABLE 1

OPERATING VOLTAGES FOR IATRON*

Electrode	Voltage	Current
Writing Gun		
Heater	6.3	0.6 ampere, alternating or direct current
Cathode	−1000	1080 microamperes, maximum
Grid	−1042 at cutoff	
First Anode	−700 at focus	−1.0 microampere, maximum
Second Anode	40	940 microamperes, maximum
Flooding system		
Heater	2.5	2.5 amperes, alternating or direct current
Cathode	0	2.6 milliamperes
Anode and First Wall Electrode	40	{0.8 milliampere, minimum 1.0 milliampere, maximum
Second Wall Electrode	20	{0.07 milliampere minimum 0.115 milliampere, maximum
Third Wall Electrode	80	0.035 milliampere
Collector Screen	150	1.25 milliampere
Insulator Screen	+10	
Phosphor	+10 kilovolts, maximum	0.38 milliampere, maximum

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

Some comment on the operating circuit of Figure 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 at that potential. An astigmatism control consisting of a dual adjustable voltage divider 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 kilovolts. However, the characteristics of the tube, other than brightness, will be relatively unchanged with operation down to less than 5 kilovolts. 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 1 lists operating voltages and maximum and minimum currents of flooding-system electrodes that were measured to aid in the design of power supplies and bleeders. These measurements were made on only a few tubes, since production tubes were 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 that have been indicated.