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VOLUME XXVI

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PREFACE

In January 1947 the Bureau of Ordnance of the United States Navy and Harvard University together sponsored a Symposium on Large-Scale Digital Calculating Machinery as a means of furthering interest in the design, construction, application, and operation of computing machinery. This meeting was attended by over three hundred people, nearly four times the originally expected attendance, and by popular demand the proceedings were published as Volume XVI of the Annals of the Computation Laboratory.

At the Oak Ridge meeting on computing machinery in April 1949, Mina Rees and John Mauchly, representing the Association for Computing Machinery, suggested that another symposium should be held at Harvard summarizing recent and current developments. The staff of the Computation Laboratory had already considered this possibility in connection with the announcement of the completion of Mark III Calculator, and were delighted with the suggestions of Dr. Rees and Dr. Mauchly. Accordingly, the Bureau of Ordnance was again invited to join Harvard University in sponsoring a second symposium with emphasis on the application of digital calculating machinery.

From experience with the first symposium, it was expected that perhaps three hundred people might attend. The response of more than seven hundred participants clearly indicated the rapidity with which the field of automatic computation is growing.

This volume, the twenty-sixth of the Annals of the Computation Laboratory, contains all the papers presented at the second symposium except one. Two of the speakers, Manuel S. Vallarta and Frederick V. Waugh, found at the last minute that they were unable to attend. However, their papers were received and were read by J. Curry Street and Leon Moses, respectively, both of Harvard University. Because of the tremendous editorial difficulties experienced with the proceedings of the first symposium, each speaker at the second was requested to supply his manuscript in advance, in order to avoid dependence upon transcription from sound recording. Thirty-nine papers are herein published essentially as submitted. Thus the work required to prepare this volume for publication was greatly reduced. However, it was necessary to redraw many of the illustrations for offset reproduction; this was done by Carmela M. Ciampa, assisted by Paul Donaldson, photographer of Cruft Laboratory, Harvard University.

Since the symposium was held in September, prior to the opening of the fall term, it was possible to make use of the dormitories in the Harvard Yard and the dining facilities of the Harvard Union. Arthur Trottenberg of Harvard University supervised arrangements for the use of these facilities and other accommodations. Preparation of the program and registration lists and the registration of the members of the symposium after their arrival were carried out by Betty Jennings, Jacquelin Sanborn, Jean Crawford, and Holly Wilkins. It is a pleasure to acknowledge the coöperation of Edmund C. Berkeley, secretary of the Association for Computing Machinery, in this connection.

The staff of the Computation Laboratory wishes to express its appreciation to the members of the symposium for their attendance and for their participation in the discussions, to the chairmen of the several sessions for their assistance, and to the speakers not only for their addresses during the symposium but also for their coöperation in preparing the manuscripts of their papers.

The staff also wishes to express its gratitude to the Bureau of Ordnance and to its representatives, Captain G. T. Atkins and Mr. Albert Wertheimer, for many years of pleasant association throughout the building of Mark II and Mark III Calculators, for their continued interest and help, and for making possible both the Second Symposium on Large-Scale Digital Calculating Machinery and the publication of its proceedings.

HOWARD H. AIKEN

Cambridge, Massachusetts
May 1950

THE SELECTRON

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The initial work on a special type of electrostatic memory tube, called the Selectron, was reported on January 8, 1947, at the first Symposium on Large-Scale Computing Machinery.[1] The present paper is a report of the tube developed as a result of work in progress since that date. Important changes in the initial tube were found necessary to obtain a practical and reliable device for use in electronic computers.

The memory of an electronic computer can be idealized as a large set of cells, each identified by a coded address and each capable of retaining a single on-off signal. A combination of such signals occurring simultaneously on several channels or sequentially on a single channel constitutes a number. The memory will be particularly useful if the occurrence of the set of pulses specifying the address will give access to the signal stored, or to be stored, in the shortest possible time without consideration of any previous selection. A device with such a digitalized address system and such direct access to any stored signal can be used singly or in groups in a most flexible manner, since no amplitude-sensitive qualities have to be dealt with and no specific sequences are intrinsic to the memory.

The Selectron (Fig. 1) is a vacuum tube designed in an attempt to realize such an ideal memory device. The principle of the tube depends on quantizing both the address of the stored information and the information itself. The selection of the address is obtained by means of two orthogonal sets of parallel spaced metallic bars forming a checkerboard of windows. A shower of electrons impinges on this checkerboard. Electrons are stopped in all windows except in a selected one by applying address-selecting voltages to certain groups of bars connected into appropriate combinations. The storage is in terms of the two stable potentials that tiny floating metallic elements, located in register with the windows, assume under continuous electron bombardment. The reading signals are sizable electron currents passing through a hole in the storing elements. The signals produce also a visual monitoring display.

The basic principle of the Selectron has not been changed. The main improvement is the use of discrete metallic eyelets as the storing elements. In addition to very reliable storage, these eyelets have a "grid-action" effect yielding strong electronic reading signals.

The Selectron tube, called SE256, has 256 storing elements, is 3 in. in diameter and 7 in. long, and utilizes a 40-lead stem. The diametral and axial cross sections of the tube are shown in Figs. 2 and 3. Eight elongated cathodes of rectangular cross section are located in a diametral plane of the tube. Between and parallel to the cathodes are a set of nine selecting bars of square cross section. These vertical selecting bars are connected into six groups: V_1, V_2, V_3, V_4, and V_1', V_2', as shown in Fig. 4. On either side of the plane of the cathodes and V bars there is a set of 18 parallel bars of square cross section at right angles to the V set. These two sets of horizontal selecting bars sandwich the cathodes and V bars as do all subsequent electrodes of the tube, the tube being symmetrical with respect to the cathode plane. The 36 horizontal selecting bars are connected in 12 groups: H_1 to H_4 and H_1' to H_8', as shown in Fig. 4. There are nine vertical bars for eight gates and 36 horizontal bars for 32 gates, the excess bars taking care of the end effects.

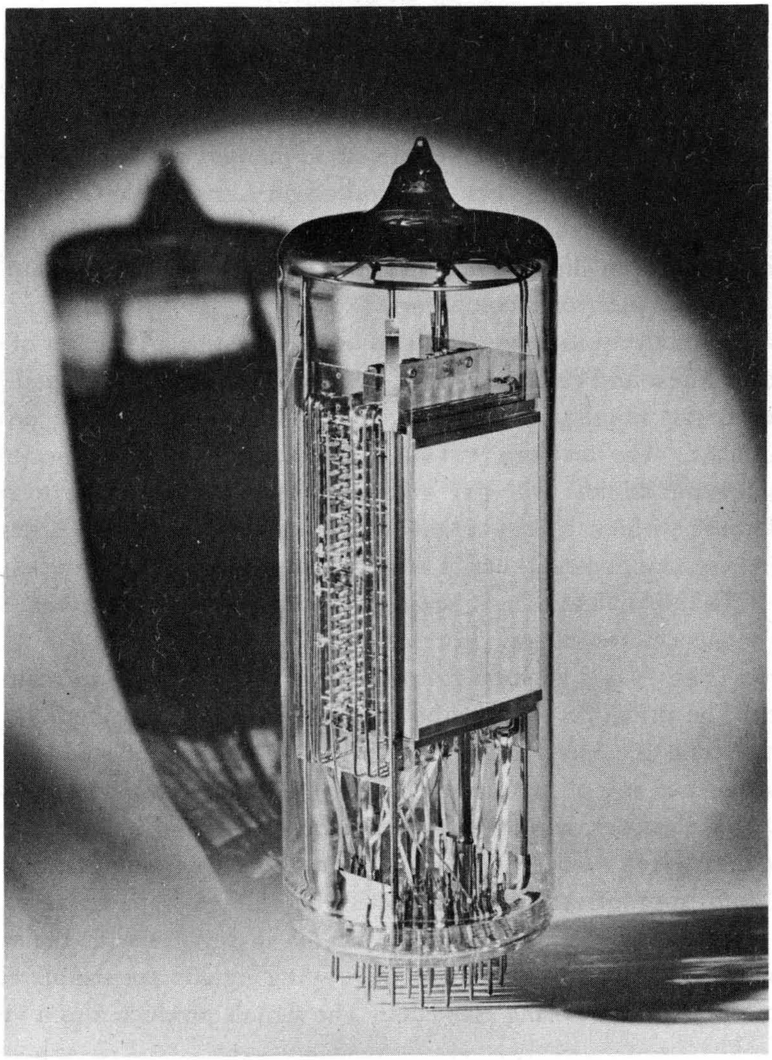

FIG. 1. The Selectron.

On either side beyond the horizontal bars there is a collector made of two flat plates perforated with round holes whose centers match the centers of the windows formed by the

V and *H*-bars. Adjacent to the collector plates there are two perforated mica sheets holding between them 128 metallic eyelets. These eyelets, made on automatic screw machines, have a conical head, a center hole, a holding collar and a shielding tail. They are nickel-plated steel. On the other side of the two mica plates is another perforated metal plate—the writing plate. The two collector plates, the two eyelet mica plates, and the writing plate form a tight assembly riveted together at the ends and in the center.

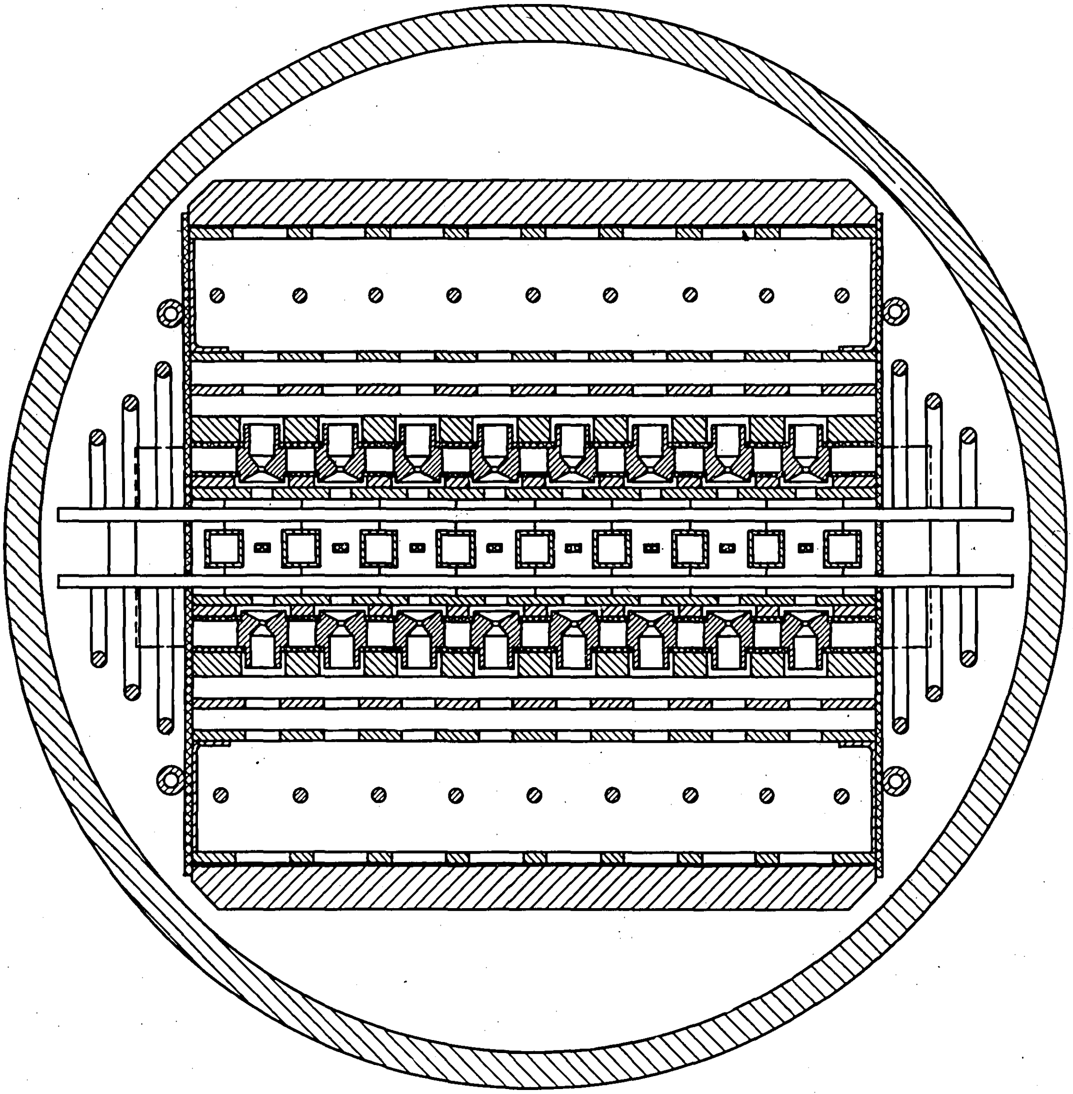

FIG. 2. Diametral view of Selectron.

Beyond the writing plate is another metal plate—the reading plate—perforated with holes in register with the holes of the other plates. Beyond it is a Faraday cage formed by two perforated plates spaced some distance apart and closed on all four sides by a metallic wall.

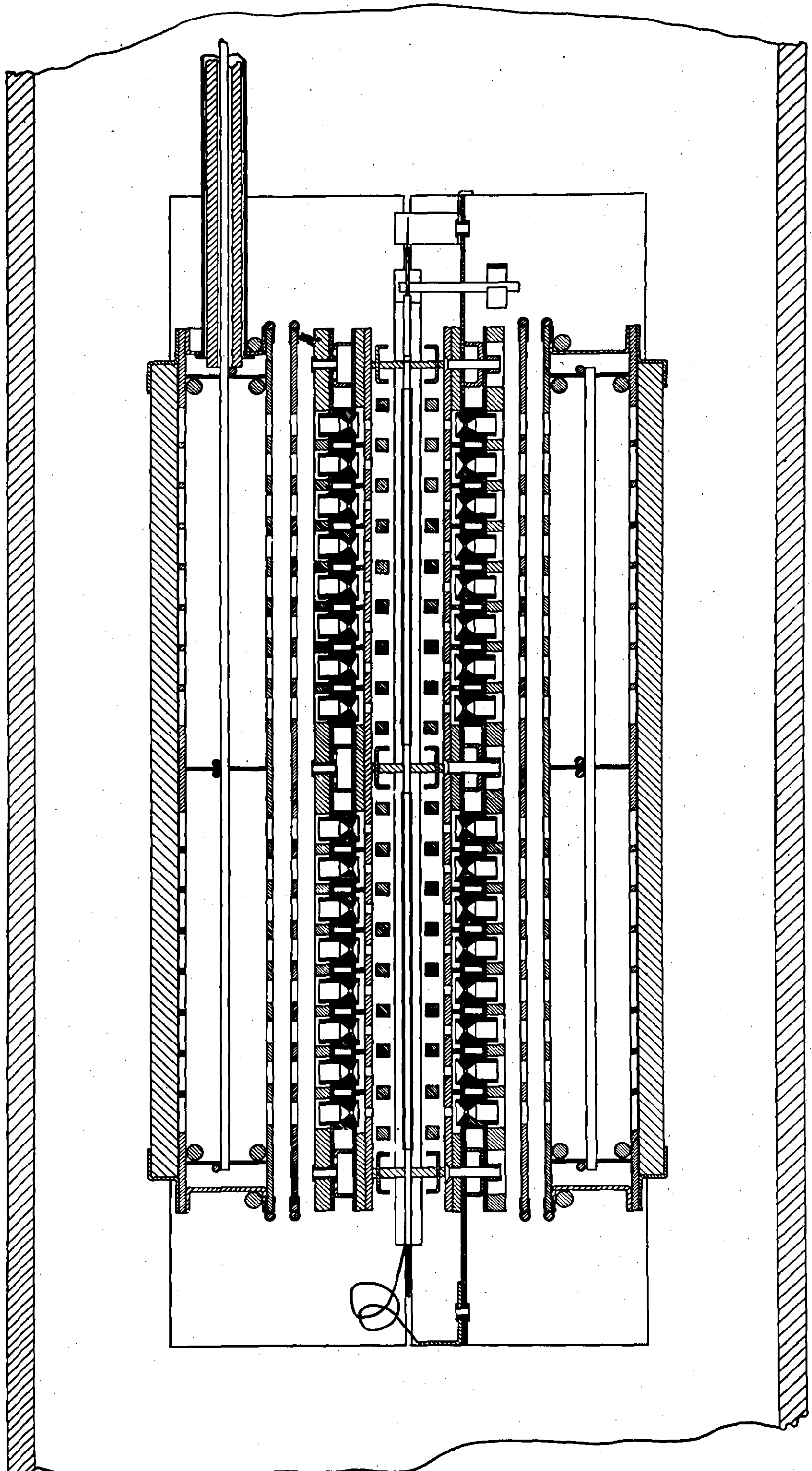

FIG. 3. Axial cross section of Selectron.

A glass plate coated with a fluorescent material is placed against the outer plate of the cage. In the central plane of the cage there are nine wires which are spaced so as to be between the holes of the perforated plates. These reading wires are connected together and the corresponding lead to the stem is shielded.

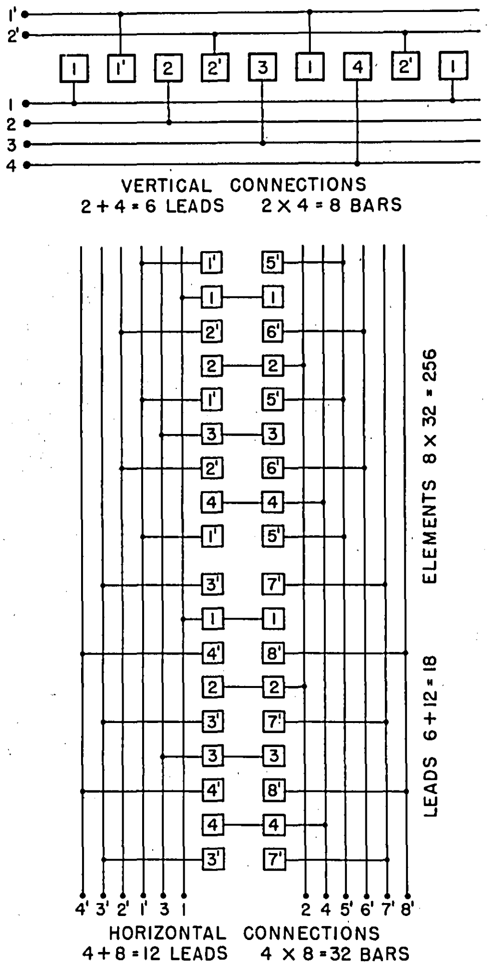

Fig. 4. Connections of selecting bars.

In the quiescent state of the tube storing information previously written-in, all the selecting bars are at the potential of the cathodes (0 v) and all other electrodes at potentials indicated in Fig. 5. In this condition electrons emitted from the cathodes are focused into 256 beams by the combined action of the *V* and *H* bars at zero potential and the collector plate at some positive potential, such as 180 v. These beams are focused through the centers of the collector holes and are directed on the eyelets. Since the eyelets are not connected anywhere—are electrically floating—their potentials will adjust themselves so that the net electron current to them is exactly zero. It turns out that there are two naturally stable potentials for which this is the case. This can be understood by examining the current to the eyelet as a function of its potential as shown in Fig. 6. When the eyelet is more negative than the cathode, no current reaches it because it repels any incurring electrons. As the eyelet is made more positive, some electrons strike it, producing a negative current. At a still more positive potential, secondary emission from the surface of the eyelet starts as a result of the primary bombardment and tends to cancel the negative current, being a loss of negative charge. Eventually, the two are equal at the so-called first crossover. For still more positive potentials, the secondary emission is greater than the primary emission and a positive current is obtained. Finally, when the eyelet reaches the collector potential and becomes more positive, the secondary electrons are suppressed owing to a retarding field at the surface of the eyelet. The current therefore passes through zero again to become negative. It will be recognized that the cathode and the collector potentials are stable, because a deviation from the zero-current potentials tends to produce a current in a direction tending to restore the equilibrium potential. The first crossover point, on the other hand, is unstable. The restoring current at the two stable potentials makes up for any possible detrimental ohmic or ionic currents. Therefore, any eyelet left in one or the other of the two potentials will keep it indefinitely (as long as power is on the tube) without any deterioration of information whatsoever.

To write or read into or from the memory, the quiescent state of the selecting *V* and *H* bars is momentarily disturbed so that the current reaches only the one selected eyelet into which writing or from which reading is desired. This is accomplished by applying a negative pulse to all the selecting *V* and *H* bars except one in each of the four groups *V*, *V'*, *H*, and *H'*. The bars are connected in such a way that one and only one gate in each of the *V* and *H* directions will have its two limiting bars at cathode potential, while all others will have one or both limiting bars at the pulsed negative potential, as can be seen by examining Fig. 4. When a *V* or *H* bar is sufficiently negative it cuts off almost entirely the current from the adjacent cathode or cathode location and the small remaining part is deflected and does not reach the hole of the collector. When both sides of a gate are negative, a potential barrier is formed through which no electrons can pass. It follows, therefore, that only the particular selected window with its four bars at zero potential will still have its original current, while all others will be completely cut off.

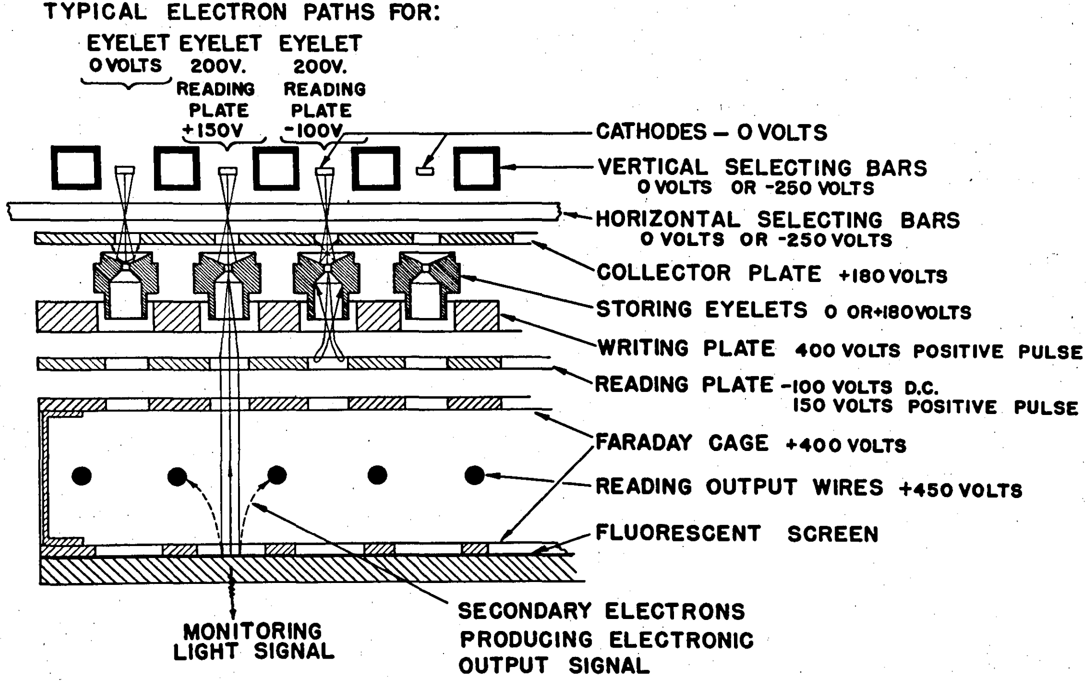

FIG. 5. Operating potentials of Selectron elements.

This principle of selection operates on the basic idea that both sides of a gate have control of the passage of electrons through it and that therefore combinatorial systems of connections are possible by connecting each side of the gate to appropriate sides of other gates. In fact, since this is done in both directions, a fourth-power relation exists, in general, between the number of necessary connection groups and the number of controlled windows. Since each connection group is connected through the vacuum envelope of the tube and is controlled by an external circuit, the economy in the number of connections is of particular interest when tubes with larger capacity are contemplated. The fourth-power relation has of course a spectacular effect in this case; for example, 128 leads can be made to control 1,049,576 windows.

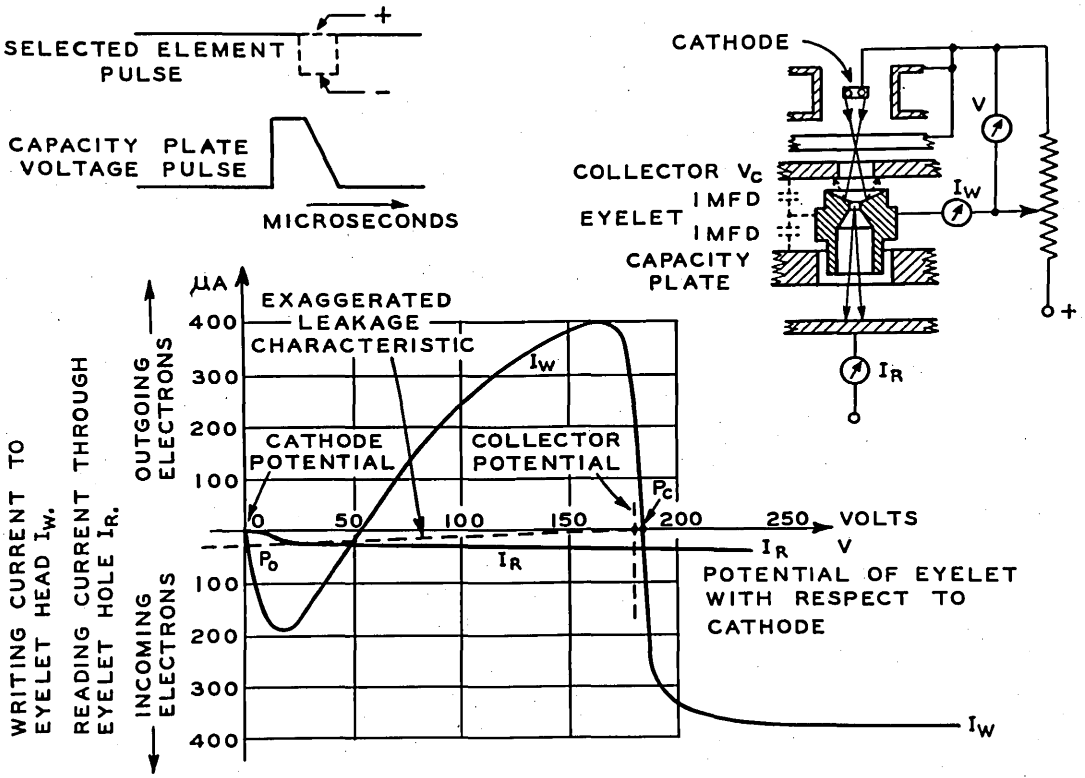

FIG. 6. Current to eyelet as a function of its potential.

Writing and reading are done one element at a time (or two if the tube is used as a two-channel device) and require selection.

To write into a particular element, current is interrupted everywhere except to that element. Then a voltage pulse of the shape shown in Fig. 6 is applied to the writing plate. Because of the capacitive coupling between the eyelet and the writing plate, the rapid rise of this pulse will cause the eyelet to jump up in potential by an amount adjusted to be a substantial proportion of the collector potential or more. If the eyelet was initially at cathode potential, it will now have been brought near collector potential and will settle at that potential during the plateau of the pulse. If it had initially the collector potential, it will acquire momentarily twice the collector potential and will receive substantial negative current (see Fig. 6) which will also bring it to the collector potential during the plateau time. Whatever the initial condition, at the end of the plateau time the eyelet will be at collector potential. At this instant the choice is made between positive and negative writing. For positive writing, no additional pulses are applied to the selecting bars, and the current remains on the eyelet during the relatively slow decay of the writing pulse. The decay is slow enough to allow the electronic locking current to keep the eyelet at the collector potential in spite of the displacement capacitive current tending to drag it to cathode potential. This "slow" decay is in fact only one to several microseconds. For negative writing, an additional pulse is applied to one or more of the four selecting bars in the groups *V*, *V′*, *H*, and *H′*, which cuts off the current to the selected eyelet during the decay time of the writing pulse. The capacitive down drag is therefore not counteracted and the eyelet is brought to cathode potential.

Immediately after the end of the writing pulse the selection pulses end, and current is reëstablished to all eyelets. Only residual ohmic (on other second-order electron or ionic currents) affect the unselected eyelets during the short selection time, and therefore at the end of the writing pulse they have almost their original potential. This potential is reached almost immediately thereafter by virtue of the stabilizing currents.

The reading signal is derived from the current passing through the central hole in the eyelets. Part of the current directed at the eyelet is directed at that tiny hole. When the eyelet is positive, at collector potential, the electrons directed at the hole go through it by virtue of their inertia. When the eyelet is negative, at cathode potential, it exercises "grid action" and electrons are repelled and do not go through the hole. The electrons' paths are shown in Fig. 5 for the three cases, while the current characteristics are shown in Fig. 6. The presence or absence of the current through the eyelet is therefore an indication of the state of the eyelet.

In the quiescent state of the tube the reading plate is biased off negatively and the reading current going through all the positive eyelets (any number from 0 to 256) does not reach the reading circuits. To read, an element is selected by applying negative pulses to all but four bars, as explained above. Immediately thereafter a positive pulse is applied to the reading plate which allows the current through the selected element, if current there is, to proceed to the output electrodes. The electrons penetrate into the Faraday cage, strike the fluorescent screen, producing a light signal, and also cause the emission of secondary electrons. These secondary electrons are collected by the reading wires which are connected in parallel and constitute the reading output signal. The reading wires have a low electrostatic capacity and are well shielded from capacity pick-up by the Faraday cage.

For monitoring purposes it is convenient to bias positively the reading plate. A display of the stored pattern appears then on the fluorescent screen.

The main characteristics of the Selectron SE256 may be summarized as follows. The tube has a capacity of 256 on-off signals. The storage time is indefinite. The access time to any element is approximately 10 μsec and is independent of all previous accesses to other elements. The address selection is by means of combinations of non-amplitude-critical pulses of about 200 v applied to circuits with pure capacitive loading of 10 to 20 $\mu\mu$f. The writing and reading require also pulses whose amplitude and duration have considerable tolerances and are applied to pure capacitive loading, 200 $\mu\mu$f for writing and 50 $\mu\mu$f for reading. The output is a direct electronic current of 20 to 40 μamp per element. The tube is its own monitor. The supply voltages have wide tolerances. The total power dissipation is 40 w.

About a score of tubes have been made to date. These tubes were tested first by d.c. or simple pulse tests. Uniform characteristics of selection and control have been observed in all tubes, as these depend on geometric factors that are easily reproducible. The cathode emissions and secondary emissions of the eyelets were also found essentially uniform. The period of quiescent-state storage has, of course, been found to be as long as desired or as there was patience to observe it.

A program has been initiated to test the tubes in conditions as similar as possible to those of an actual computer straining its memory severely. The system consists of taking two Selectrons, setting an arbitrary pattern of stored information in one of them, interrogating the elements of that tube one by one in succession, and registering the answers in the corresponding windows of the other tube. The stored pattern will thus be transferred from tube No. 1 to tube No. 2. The pattern is then transferred in a similar manner from tube No. 2 back into tube No. 1, but this time the polarity is reversed so that positive elements in one tube correspond to negative ones in the other. The life test consists of letting this back-and-forth transfer proceed automatically at a reasonably high repetition rate and observing whether the initially set pattern remains unspoiled in the system.

To date, runs of 20 hr without any failures have been observed. The over-all characteristics of the pair of tubes in the life-test circuit did not change measurably in 700 hr. We are engaged at present in improving the testing circuits to be certain that they are not the cause of the occasional failures that still occur in long runs. We are also attempting to gain greater safety factors in the tubes themselves.

The research has reached the stage at which a Selectron of a capacity of 256 elements has been designed. It is practical and reliable in its operation and reasonably easy to build. While the life tests are still in progress and data from them are incomplete, there is every reason to believe that tubes with fairly long life can be made. The fast access time, the digitalized operation for address reading and information registering, the relatively intense output signals and self-monitoring by luminous display make the tube particularly useful for electronic computing machines and other information-handling machines.

REFERENCE

1. J. Rajchman, "The selectron—a tube for selective electrostatic storage," *Proceedings of a Symposium on Large-Scale Digital Calculating Machinery* (Harvard University Press, Cambridge, 1948), p. 133.