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General View of Picnic on the Lawn.

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ED. DICKEY - EDITOR

THE SELECTRON - A TUBE FOR SELECTIVE ELECTROSTATIC STORAGE*

By

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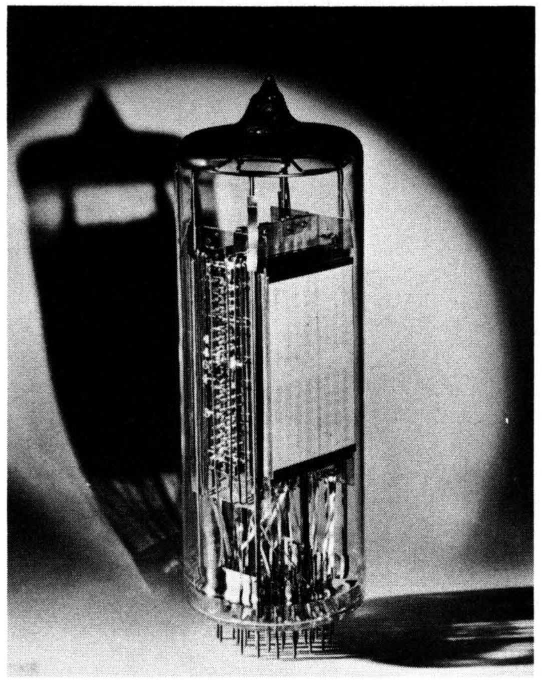
Introduction

Electronic circuits have been developed in recent years, particularly during the war, by means of which it is possible to perform the elementary operations of arithmetic with great accuracy and at a very high speed. This fact opened the possibility of building computing machines capable of solving very many important problems in science and technology which hitherto were unsolved because their solution could be obtained only by almost interminably lengthy numerical computations. This possibility has been partly realized already in some large scale digital machines.

An essential part of such a machine is its "inner memory" or "number storage device" into which numbers can be registered and subsequently extracted so that a long sequence of numerical operations can be made automatically by storing momentarily intermediary results. The usefulness of the machine, is in fact, almost entirely dependent on the capacity of the memory and the shortness of the access time necessary to "write" into and "read" from it.

The digital computation is in terms of ordinary decimal digits or more conveniently in terms of binary digits. In any case all signals handled electronically are merely on-off signals, that is to say merely the two cases of a single alternative, yes or no. The combination of such signals occurring simultaneously on several channels or sequentially on a single channel constitute numbers. The various methods of combining the pulses lead to machines with different systems. The function of the memory is therefore merely to store on-off signals. It will be particularly adaptable to any desired digital system or mode of operation if it permits the storing of a single on-off signal under a given address and if the address itself is specified by a combination of on-off signals so that the occurrence of these pulses will give access to the stored, or to be stored, signal in the shortest possible time without consideration to 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 is a vacuum tube designed primarily in an attempt to reach these ideal requirements of the inner memory of such a computing machine. It is also suitable for other information handling devices. The emphasis is on reliability and short access time. Extreme reliability is



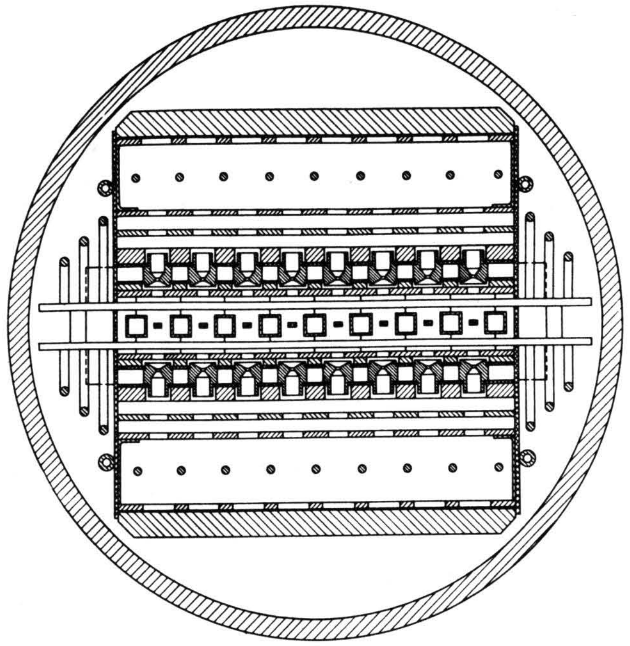
The Selectron

necessary in digital computation because a single error in a long sequence of registrations may well render the whole computation meaningless.

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 which tiny floating metallic elements, located in register with the windows, assume under continuous electron bombardment. The reading signals are sizeable electron currents passing through a hole in the storing elements. These signals produce also a visual monitoring display.

The main principle of the Selectron was reported in our June, 1947 issue. The present paper deals mostly with the novel features which make the tube more reliable and practical. It is confined to the description of the latest laboratory tube,

*This paper was presented at the I.R.E. Tube Conference at Princeton University in June, 1949.



type SE256. The main improvement is the use of eyelets which in addition to positive storage, provide a grid action yielding a strong electronic reading signal. The selecting grid network has also been made more efficient.

Description of the Tube

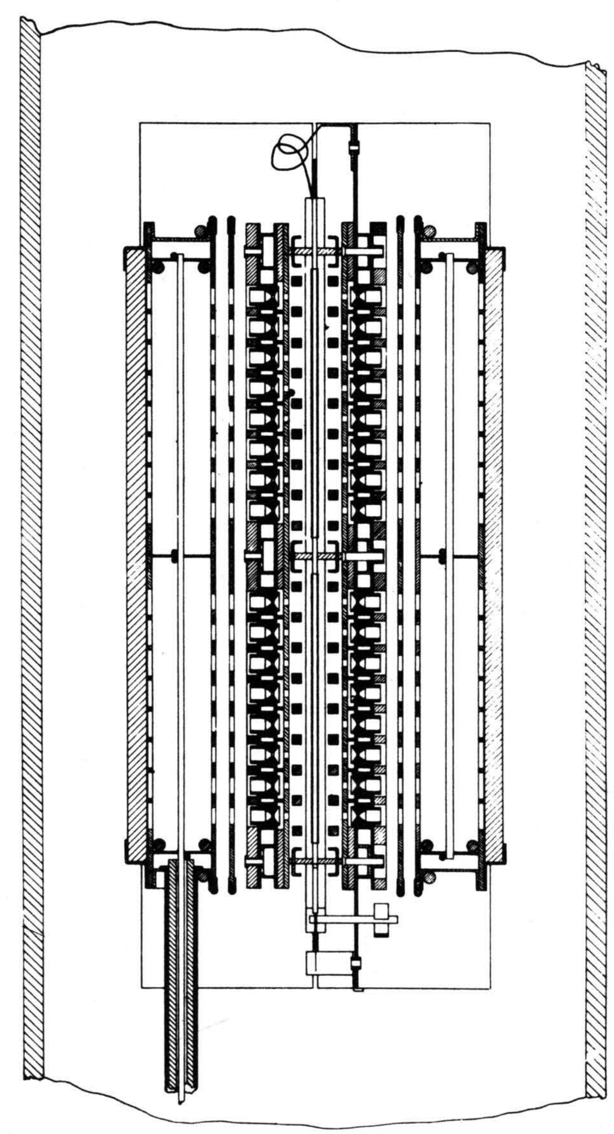
The Selectron tube, called SE256, has 256 storing elements, is 3" in diameter and 7" long and utilizes a 40 lead stem. The diametral and axial cross sections of the tube are shown on Figure 1 and Figure 2. Eight elongated cathodes of rectangular cross section are located in a diametral plane of the tube. Between and parallel to the cathodes are a set of nine selecting bars of square cross section. These vertical selecting bars are connected into 6 groups: V1, V2, V3, V4 and V'1,V'2, as shown on Figure 3. 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: H1 to H4 and H1' to H8' as shown on Figure 3. There are 9 vertical bars for 8 gates and 36 horizontal bars for 32 gates, the excess bars taking care of the end effects.

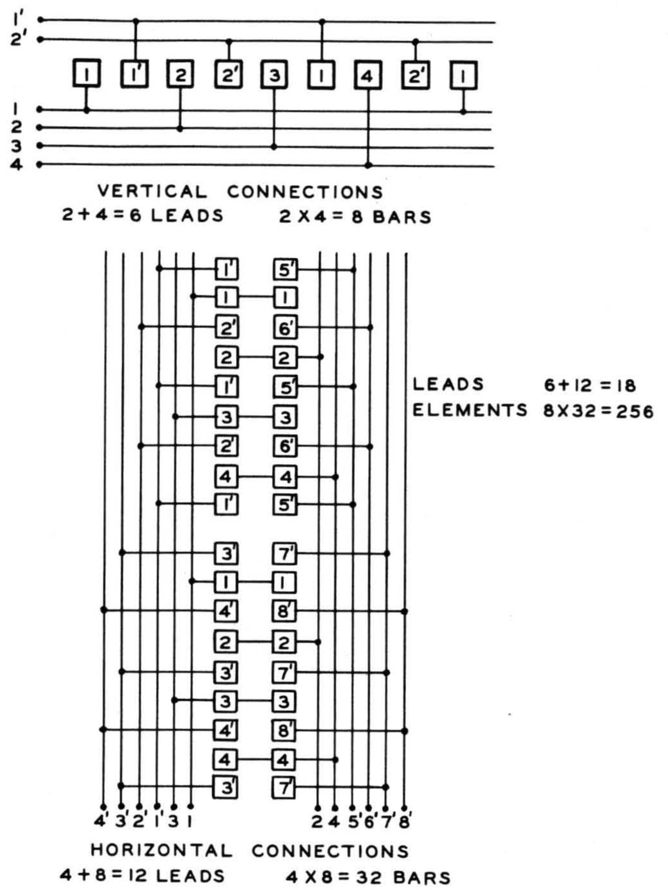
On either side beyond the horizontal bars there is a collector made of two flat plates perforated with round holes whose centers match the centers of the windows formed by the V and H bars. Adjacent to the collector plates there are two perforated mica sheets holding between them 128 metallic eyelets. 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.

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. 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.

Operation of the Tube

In the quiescent state of the tube storing information previously written-in, all the selecting bars are at the potential of the cathodes (zero volts) and all other electrodes at potentials indicated on Figure 4. In this condition electrons emitted from the cathodes are focussed 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 volts. These beams are focussed through the centers of the collector holes and are directed on the eyelets. Since the eyelets are not connected anywhere, are electrically floating, their potential will adjust itself 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 on Figure 5. When the eyelet is more negative than the cathode no current reaches it because it repells any incurring electrons. As the eyelet is made more positive some electron current strikes it, producing a negative





CONNECTIONS IN SELECTRON TYPE SE256

current. At more positive potential secondary emission from the surface of the eyelet starts as a result of the peimary bombardment and tends to cancel the negative current being a loss of negative charges. Eventually, the two are equal at the so-called first cross-over. 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 due to a retarding field on 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 cross over 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.

The Selection

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 to remain at cathode potential, while all others will have one or both limiting bars at the pulsed negative potential, as can be seen by examining Figure 3. 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.

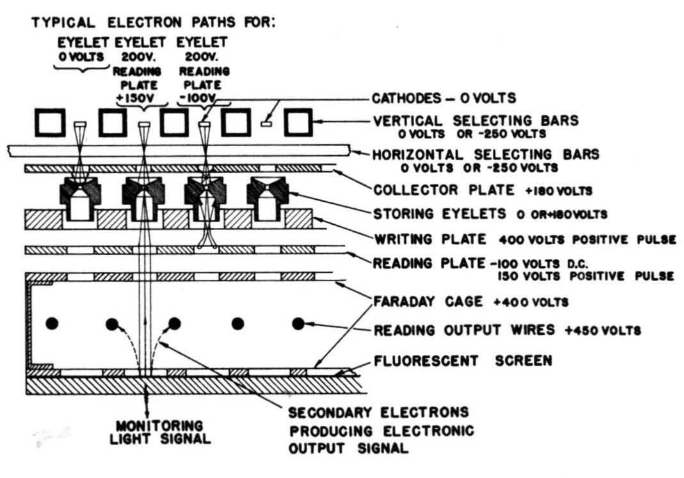
This principle of selection operates on the basic idea that both sides of a gate have control on the passage of electrons through it and that therefore combinatorial system of connections are possible by connecting each side of the gate to appropriate sides of other gates. In fact, since this is done in both directions, a fourth power relation exists, in general, between the number of necessary connections 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.

Writing

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 it. Then a voltage pulse of the shape shown on Figure 5 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 an amount adjusted to be a substantial proportion of the collector voltage 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 become momentarily twice the collector voltage and will receive substantial negative current (see Figure 5) which will also bring it to the collector voltage 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 voltage 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.

PRINCIPLE OF SELECTRON



Immediately after the end of the writing pulse the selection pulses end and current is reestablished to all eyelets. Only residual ohmic (or other second order electron or ionic currents) flowed to 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.

Reading

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 Figure 4 for the three cases, while the current characteristics are shown in Figure 5. The presence or absence of the current through the eyelet is therefore an indication of the state of the eyelet.

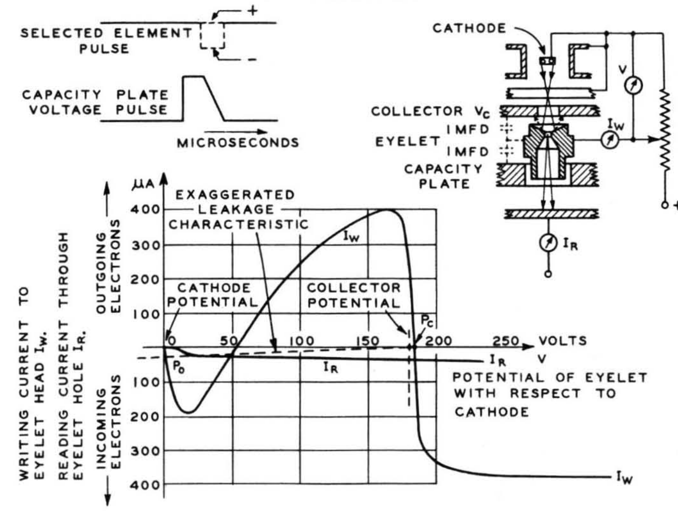
In the quiescent state of the tube the reading plate is biased off negatively and the reading current going through all the positive eyelets (any number from 0 to 256), does not reach the reading circuits. To read, an element is selected by applying negative pulses to all but four bars as explained above. 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 current penetrates into the Faraday cage, strikes the fluorescent screen, producing a light signal and causes also 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.

Experimental Results

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 20 microseconds 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 volts applied to circuits with pure capacitive loading of 10 to 20 μμf. The writing and reading require also pulses whose amplitude and duration have considerable tolerances and are applied to pure capacitive loading, 200 μμf for writing and 50 μμf for reading. The output is a direct electronic current of 20 to 40 microamperes per element. The tube is its self monitor. The supply voltages have wide tolerances. The total power dissipation is 40 watts. The tube is 3" in diameter, 7" long and has a 40 lead stem.

CHARACTERISTICS OF STORING EYELET IN SELECTRON



About a score of tubes were made to date. These tubes have been 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 geometrical factors which 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 #1 to tube #2. The pattern is then transferred in a similar manner from tube #2 back into tube #1, but this time the polarity is reversed so that positive elements in one tube correspond to negatives ones in the other. The life test consists of letting this back and forth transfer proceed automatically at a reasonably high repetition rate and observe whether the initially set pattern remains unspoiled in the system.

To date, runs of fourteen hours without any failures have been observed. The overall characteristics of the pair of tubes in the life test circuit did not change measurably in 400 hours. We are engaged at present in improving the testing circuits to be certain that they are not the cause of the occasional failures which still occur in long runs. We are also attempting to gain greater safety factors in the tubes themselves.

Conclusions

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 is 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, its relatively intense output signals and self monitoring by luminous display make it particularly useful for electronic computing machines. It is probably also that the tube may find applications in other information handling machines.