Nov. 11, 1958 S. HANSEN 2,860,282

ELECTRON DISCHARGE STORAGE TUBES

Filed April 25, 1955 4 Sheets-Sheet 1

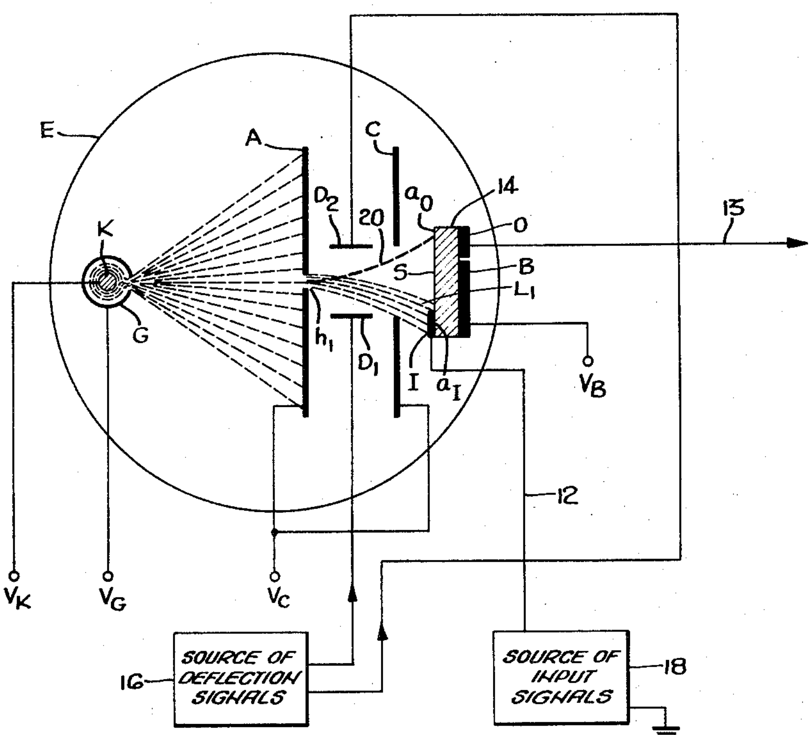

FIG. 1.

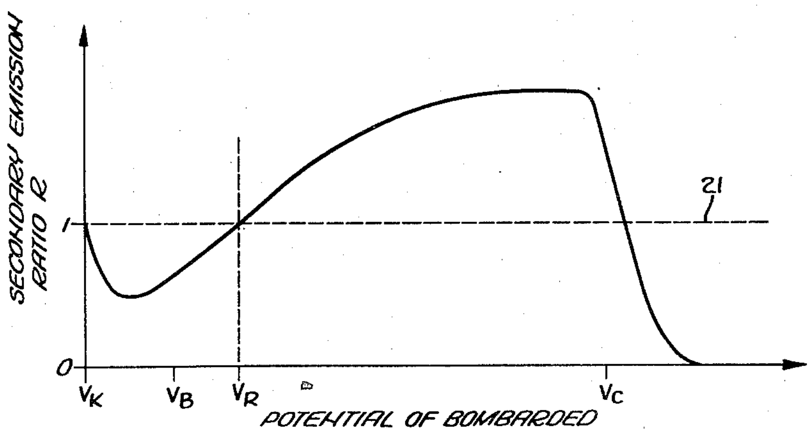

FIG. 2.

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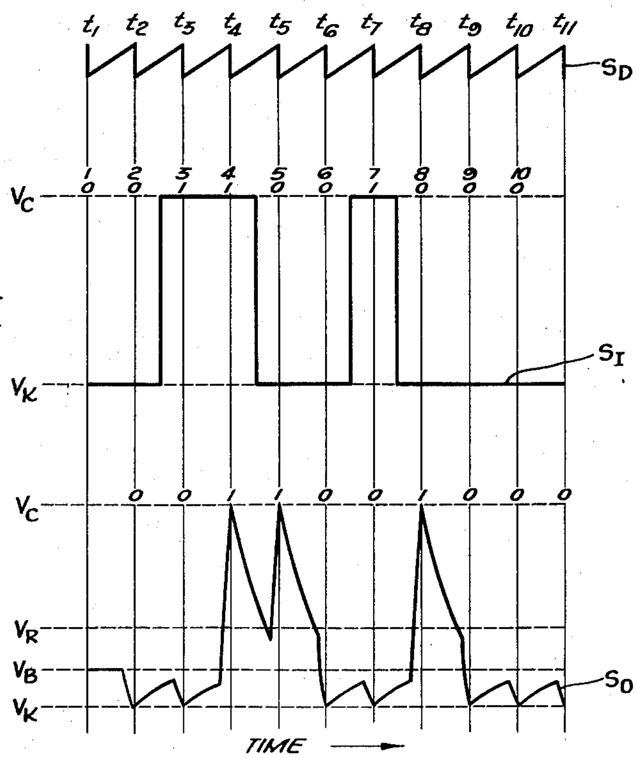

FIG. 3.

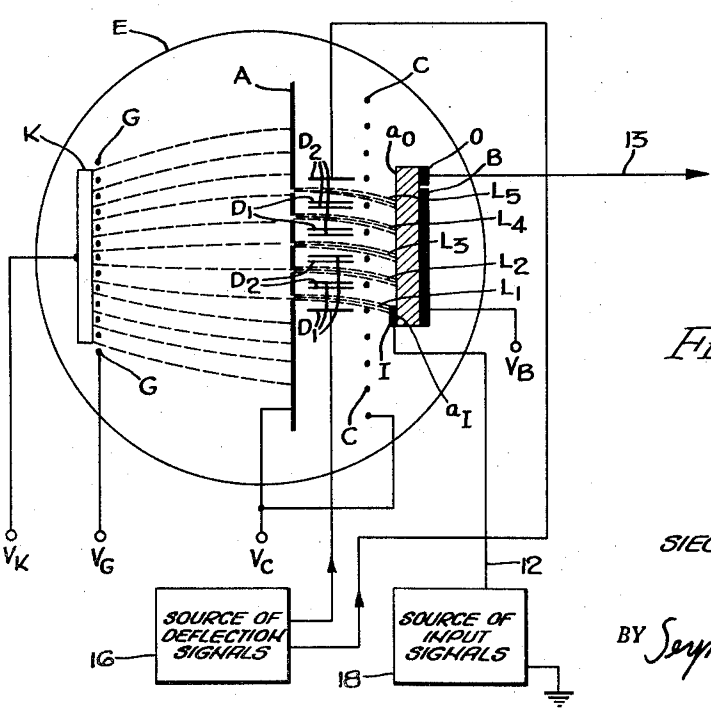

FIG. 4.

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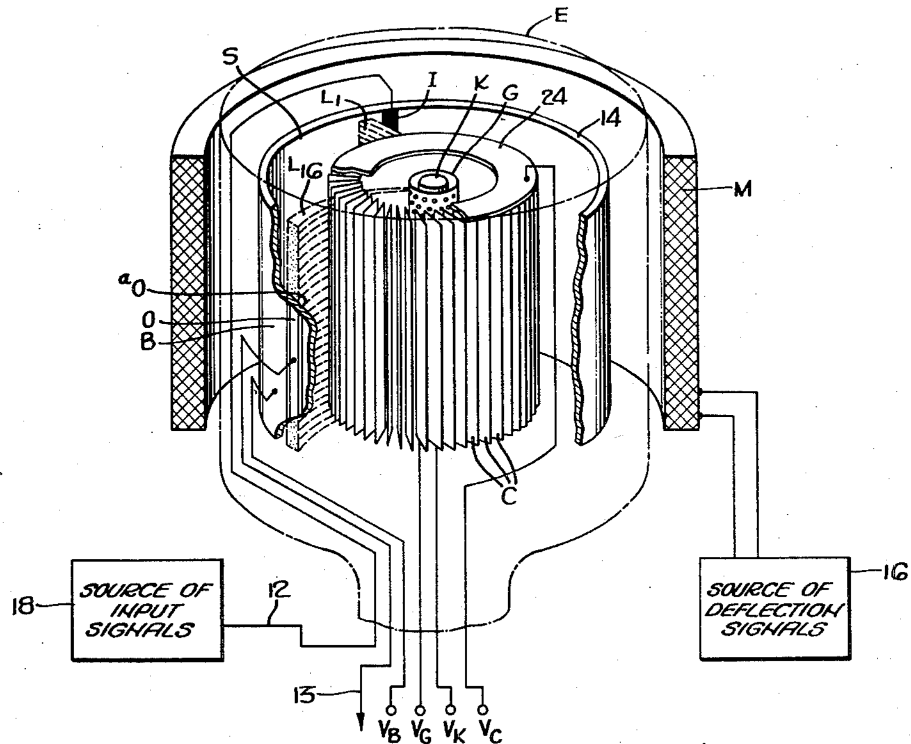

FIG. 5.

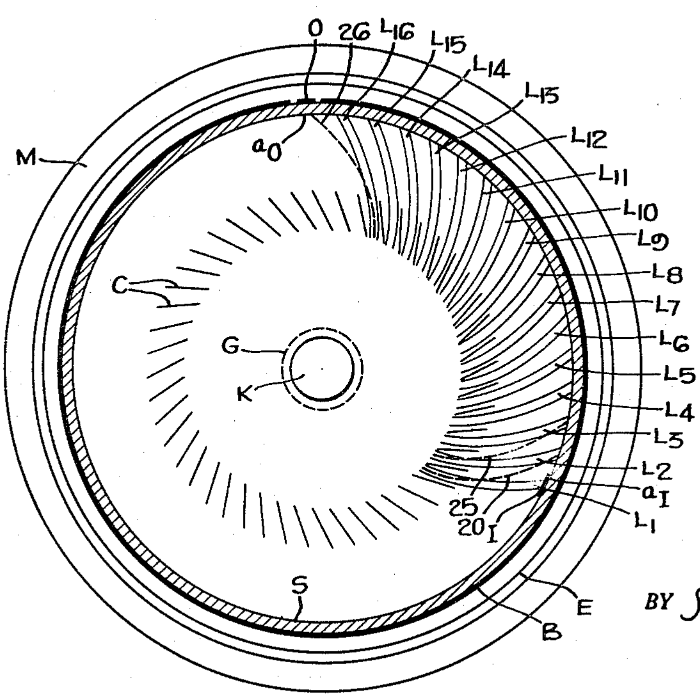

FIG. 6.

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ELECTRON DISCHARGE STORAGE TUBES

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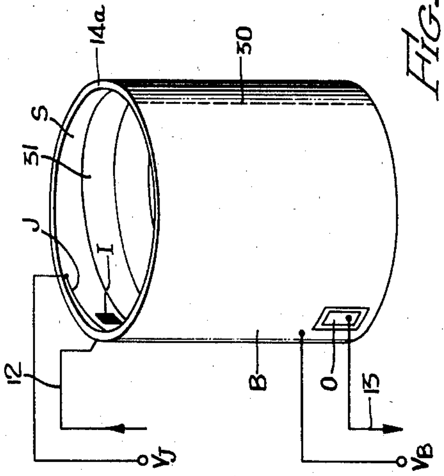

FIG. 7a.

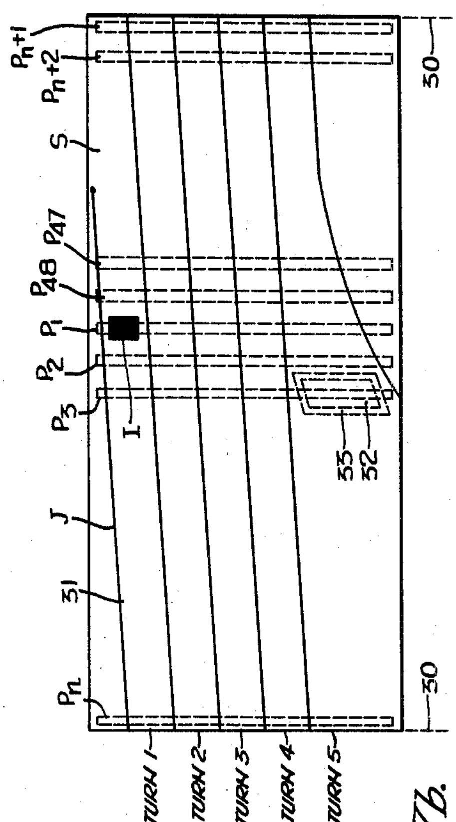

FIG. 7b.

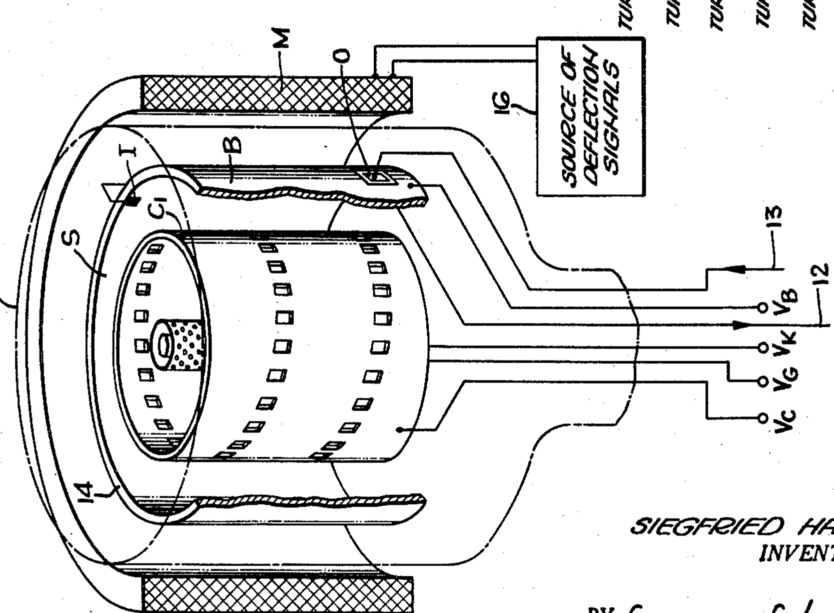

FIG. 8.

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ELECTRON DISCHARGE STORAGE TUBES

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Application April 25, 1955, Serial No. 503,614

22 Claims. (Cl. 315—8.5)

The present invention relates to electron discharge storage tubes and more particularly to an electronic signal shifting apparatus in which binary electrical intelligence signals stored on areas of a secondary electron emissive storage surface are transported to remote areas of the storage surface by being shifted across the storage surface to the remote areas.

In the electronic computing and switching art, electron discharge storage apparatus utilizing the signal retaining properties of a secondary emissive storage surface are widely used for the storage of binary information. In the typical operation of a prior art storage tube, storage of an applied binary electrical intelligence signal is accomplished by directing an electron beam at an area of a secondary emissive target surface and modulating the beam in accordance with the applied intelligence signal in such a manner as to produce on the area either a charge pattern or a potential level representative of the intelligence signal. Interrogation or read-out at a later time of an intelligence signal stored in this manner is accomplished by again directing the electron beam at the area in which the intelligence signal has been stored and noting as the beam impinges upon the storage area the resultant modulation of the beam current or of some related quantity.

Various methods of modulating the electron beam in accordance with an applied binary intelligence signal have been utilized in the prior art for effecting storage of the intelligence signal on a secondary emissive surface with the modulated beam. It is advantageous to consider these methods in some detail since a general familiarity with the basic principles of operation of prior art storage tubes will greatly facilitate understanding of the novel mode of operation of the signal shifting apparatus of the present invention.

In one species of prior art storage tube, for example, a cathode which is the source of the electron beam is normally maintained at a markedly negative potential with respect to a target electrode, so that electrons striking an area of the target surface have sufficient velocity to eject more electrons from the area by secondary emission than arrive in the beam, thereby causing the area to charge positively with respect to the cathode because of the net loss of electrons from the area through the described secondary emission phenomena. In this species of storage tube, therefore, the electron beam will "write" positive charge on the storage surface whenever it impinges on the surface. Modulation of the "writing" beam by a binary intelligence signal is accomplished by applying the intelligence signal to a grid structure to either interrupt or pass the electron beam in accordance with the binary signal as the beam is directed at a selected storage area, thereby effectively storing the binary signal on the storage area as a region selectively charged to an upper or lower range of potential. A signal storage apparatus of the described type is exemplified by the arrangement shown in U. S. Patent No. 2,689,301, entitled "Arrangement for Storing Intelligence Signals Electronically," by A. M. Skellett, issued September 14, 1954.

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In the equipment shown by Skellett an additional cathode and beam forming apparatus is provided for forming a so-called "holding" beam which floods electrons over the entire storage surface to maintain or hold all storage areas at their upper or lower range of potentials so that stored or written charge does not leak off the storage surface but is instead continuously regenerated by the action of the holding beam. The cathode which is utilized in the formation of the holding beam is maintained at a potential fairly close to the normal potential of the storage surface. Electrons in the holding beam therefore have relatively low velocities, their final velocity upon impingement being selectively determined at each storage area by the potential range to which the storage area has been charged by the writing beam. The secondary electron emission ratio of a storage area bombarded by the holding beam is thereby selectively determined by the potential range of the bombarded area. If, for example, a storage area has been charged or left at a predetermined lower range of potential, the secondary emission ratio of the area will be less than one when the area is bombarded by the relatively low velocity electrons of the holding beam, causing electrons to deposit on the storage area, thereby charging the storage area towards the potential of the holding beam cathode.

On the other hand if the storage area is already at a predetermined upper range of potential (because of action of the writing beam), then the secondary emission ratio of the area will be greater than one when the area is bombarded by the relatively low velocity electrons of the holding beam, thereby causing the area to charge positively with respect to the potential of the holding beam cathode because of the net loss of electrons through secondary emission. Thus in operation, storage areas at either the upper or lower range of potential are maintained at their respective ranges of potential by the action of the holding beam.

Another species of prior art signal storage apparatus which also uses a "writing" beam (a beam in which the electrons have sufficient velocity so that they uniformly cause a secondary emission ratio greater than one in a bombarded storage area) is based upon certain principles of operation first suggested by Prof. F. C. Williams of the University of Manchester, England. In this type of storage tube apparatus binary intelligence signals are not applied to a grid structure to pass and interrupt the writing beam, but are instead utilized to deflect the writing beam after it has been directed at a selected storage area so as to draw at the storage area a charge pattern or image which is representative of the binary intelligence signal. For example, signals representing the binary digits 0 and 1 have been variously represented as dot and dash, dot and double dot, and dot and circle patterns of charge drawn at the associated storage area by the writing beam. Readout of a charge pattern of this type is accomplished by again interrogating the area with the writing beam. Auxiliary flood type holding beams are sometimes provided with Williams tube apparatus. An excellent summary and bibliography to Williams tube apparatus may be found in an article entitled "An Improved Cathode Ray Tube Storage System," by R. Thorensen, at page 167 of the Proceedings of the Western Computer Conference, published by the Institute of Radio Engineers, June 1953.

In a third species of prior art signal storage tube apparatus, applied binary intelligence signals are utilized to vary the potential of the electron beam cathode to effectively modulate the velocities of the electrons in the beam in accordance with the applied binary intelligence signal, so that a storage area at which the beam is directed will have a secondary emission ratio less than or greater than one in accordance with the applied intelligence signal. In an apparatus of this type the intelligence signal is effectively being utilized for switching the electron beam between writing beam operation and holding beam operation. Read out of a storage area in which an intelligence signal has been recorded in the described manner may be accomplished by re-interrogating the area with the electron beam in either its holding beam or writing beam phase of operation.

Because of the extremely high speed with which an electron beam may be deflected to a selected storage area, prior art storage tubes of the described type are very well adapted for providing high speed "random access" memory systems for use in connection with electronic computers and switching systems. In the computer art the term "random access" as applied to an electronic memory means that all storage locations in the memory are equally accessible, essentially the same amount of time being required for read out of binary information from any selected storage location in the memory.

In many types of computation a "serial" electronic memory in which the storage locations in the memory are consecutively available at a reading station is preferable to a "random access" memory. In a purely serial electronic memory one gains access to a selected storage location merely by waiting for the selected storage location to appear at the reading station. It is generally recognized by those skilled in the art that many fewer components are utilized for storage and read out from a serial memory than from a random access memory and therefore serial memory systems of various types are widely used in the electronic computing and switching arts. Serial memory systems presently utilized are essentially mechanisms for transporting binary intelligence signals from a recording or writing station to a remote reading station so that intelligence signals serially applied at the writing station are conveyed as a serial signal train to the reading station by some simple and completely automatic mechanism.

For example, in a magnetic drum or magnetic tape type of serial memory, binary intelligence signals are written or stored on a magnetizable surface of a tape or drum as bidirectionally magnetized areas of the surface, these stored signals being transported to a remote reading transducer by moving the tape or drum so as to pass the magnetized areas beneath the reading transducer. As another example, in a mercury delay line type of serial memory, binary intelligence signals are introduced as compressional waves at one end of a tube of mercury or other dense material, these compressional wave propagating down the tube to a reading transducer at the remote end of the tube. In a magnetic core shift register, binary signals are stored by being applied to selectively magnetize an input magnetic core of a serially connected chain of cores, the magnetic state of each core in the chain being transferred or shifted to the successive core at each application of a separately supplied advancing signal, thereby causing the binary signals to be shifted from core to core from the input core to a remote output core.

It is clear that each of the above described types of prior art serial memory is based upon a different fundamental method or mechanism for transporting stored binary intelligence signals. In a magnetic tape or magnetic drum memory, transport of intelligence signals is accomplished by a physical translation of the surface on which the signals are stored. In acoustic memories, the fundamental signal transport mechanism is the acoustic propagation of high frequency waves in a dense medium. In a magnetic core shift register, each core acts as a binary switch which passes or blocks an applied advancing signal so as to selectively magnetize or not magnetize each successive core, in accordance with the state of magnetization of the preceding core, binary intelligence signals being transferred or transported from core to core in this manner.

According to the basic concept of the present invention there is provided a new, fundamental method and apparatus for transporting binary intelligence signals. In the practice of the method of the present invention, binary electrical intelligence signals stored on areas of a secondary electron emissive storage surface of a semiconductive target electrode are transported to remote areas of the storage surface by being shifted across the storage surface to the remote areas.

Binary electrical intelligence signals are stored on the secondary electron emissive storage surface as areas which are selectively charged to either an upper or lower range of potential. Following a convention commonly used in the storage tube art signals stored as regions charged to the upper range of potential are called positive signals while signals stored as regions charged to the lower range of potential are called negative signals.

The method of transporting a binary intelligence signal of either polarity across a storage surface comprises the steps of first directing a narrow beam of electrons at an initial area of the surface in which the signal has been stored to maintain the area at its potential range, through a "holding beam" type of action, so long as the electron beam impinges upon the area; and then deflecting the electron beam across the storage surface at a predetermined velocity such that as the electron beam moves across the storage surface, the region of the storage surface beneath the beam is maintained at the range of potential which formerly existed at the initial area. In this manner the binary signal originally stored on the initial area is shifted by the electron beam across the storage surface to remote areas of the storage surface.

In one simple embodiment of the invention unidirectional transport of binary signals from an initial input storage area to a remote output area is accomplished by cyclically deflecting an electron beam back and forth between the initial area and the remote area. The beam is advanced from the initial area to the remote area at the predetermined velocity so as to transport applied signals to the remote area at each advancing sweep of the beam while on its return sweeps the beam is swept back to the initial area at a sufficiently higher velocity so that transported signals are not returned to the initial area on these return sweeps but are instead left at the remote area to which they have been advanced. In this manner successively applied signals are unidirectionally transported across the storage surface from the initial area to the remote area by the corresponding advancing sweep of the electron beam.

Areas which are left behind the beam as it advances across the storage surface decay rapidly to the lower range of potential by reason of leakage through the semiconductive target electrode to a conductive backing plate which is maintained at the lower range of potential. Essentially the use of semiconductive material in the target electrode and the provision of a conductive backing plate at the lower range of potential establishes a mechanism for removing charge from the storage surface so that areas of the surface when charged to the upper range of potential will be rapidly discharged to the lower range of potential, thereby tending to maintain the storage surface at the lower range of potential. On the other hand, the electron beam, through its "holding beam" action, is able to maintain regions upon which it impinges at either the lower or higher ranges of potential, thereby overcoming at the electron bombarded regions the normal tendency of the charge removing mechanism to return all surface areas to the lower range of potential.

In the absence of this charge removing mechanism, transport of a primary signal across the storage surface would result in a line of signal being drawn across the surface, the elements of the line of signal being remanent signals left trailing behind by the primary signal as it is transported across the storage surface. However, with the provision of a charge removing mechanism, trails of remanent signal are effectively erased by being uniformly returned to the lower range of potential, thereby confining a transported signal to the surface region beneath the associated electron beam. Such confinement of signals to the regions beneath their associated electron beams is a preferred mode of operation for the signal shifting apparatus of the present invention. With this mode of operation, successive signals being shifted in a particular path across a storage surface always find the surface in a uniform condition, thereby allowing more reliable shifting of signals at higher speeds than are obtainable with other modes of operation wherein remanent signals may be encountered by an advancing primary signal.

In more complex embodiments of the present invention multiple electron beams are utilized and arrangements are made in which signals advanced by one beam are engaged by a successive beam and advanced still further, the binary signals thereby serially progressing in this manner from each beam to the successive beam at each cycle of deflection of the multiple electron beams. Very large numbers of signals may simultaneously progress in serial fashion across a storage surface in a multiple beam apparatus of this type and therefore such apparatus is well adapted for use as a serial electronic memory having relatively large signal storage capacity.

In one form of multiple beam signal shifting apparatus electrostatic deflection is utilized for simultaneously sweeping a plurality of electron beams back and forth in their advancing and return sweeps. The electron beams pass through an array of alternately connected electrostatic deflection plates and are thereby swept back and forth in synchronism by a sawtooth deflection voltage applied to the plates by a source of deflection signals. The amplitude of motion of each beam across the storage surface is equal to the spacing of the beams at the storage surface, so that every signal progressing across the storage surface is shifted a distance equal to a beam spacing at each advancing sweep of the beams, the signals progressing in this manner from beam to beam as they are shifted across the storage surface from an input storage area to a remote output storage area.

In a preferred embodiment of the present invention which utilizes magnetic deflection, symmetrical deflection of multiple electron beams in the described manner is more readily obtained by utilizing a signal shifting tube in which arcuate electron beams are formed which issue from a central cylindrical cathode and are directed at associated serially adjacent areas on the surface of a coaxial cylindrical target electrode which encloses the central cathode. Initial curvature and symmetrical deflection of the beam is obtained by applying an axial magnetic field which permeates the entire structure and is cyclically varied between upper and lower values so as to correspondingly increase and decrease the curvature of the electron beams, thereby sweeping each beam forward and back between its associated area and the serially successive area at each cycle of variation of the axial magnetic field. A binary signal introduced at a selected input area will therefore be shifted around the storage surface from area to area as the electron beams are swept back and forth in synchronism by the cyclically varying magnetic field.

In a modified embodiment of the invention, the signal storing capacity of the preferred embodiment of the invention is increased by many orders of magnitude by substituting a modified target electrode on which a helical conductive stripe is imprinted on the cylindrical target surface and is maintained at a relatively low potential, the successive turns of the helical stripe defining boundaries for a long helical track of unobstructed storage surface along which progressing binary signals are shifted as they are transported from an input area at the beginning of the track, to an output area at the end of the track. In operation, signals being shifted along the track cannot propagate across the bounding turns of the helical stripe. Thus the influence of a signal on one turn of the track is entirely isolated from adjacent turns. Because of this effect, a vertically extended electron beam can simultaneously advance independent signals on each turn of the helical track. The number of signals which may be stored in a serial memory of this type can therefore be approximately equal to the product of the number of turns and the number of extended electron beams formed. Since intelligence signals will propagate along a quite narrow helical track, the track may have avery large number of turns packed into a target surface of relatively small total area, thereby allowing storage of a very large number of signals on the helical track. Storage capacities of thousands of signals may be obtained in this manner on a storage surface of relatively small area.

Although conductive striping of the storage surface is a preferred modification for increasing the storage capacity of the signal shifting apparatus of the present invention similar results may be obtained with an unstriped target surface, by using a modified cylindrical collector in which beam forming apertures are helically arranged so that a helical array of electron beams is formed by electrons passing through these apertures. In a modified signal shifting apparatus of this type, an input terminal may be positioned at an area of the surface upon which a first beam in the helical array of beams may impinge, while an output terminal may be positioned at an area of the storage surface upon which the last beam in the helical array of beams may impinge. In operation intelligence signals applied to the input terminal will be serially shifted in a helical path on the storage surface from the input terminal to the output terminal, the progressing intelligence signals being shifted from beam to beam of the helical array during the course of its passage.

It is therefore an object of the present invention to provide a method and apparatus for shifting electrical binary intelligence signals across a secondary electron emissive storage surface of a semiconductive target electrode.

It is another object of the present invention to provide an electron discharge signal shifting apparatus in which binary electrical intelligence signals stored on areas of a secondary electron emissive storage surface of a semiconductive target electrode are transported to remote areas by being shifted across the storage surface to the remote areas.

Another object of the invention is to provide a method and apparatus for transporting a stored binary electrical intelligence signal across a secondary emissive storage surface by engaging the area of the storage surface in which the signal has been stored with an electron beam and deflecting the electron beam across the surface so as to effectively shift the intelligence signal across the surface under the moving electron beam.

It is yet another object of the present invention to provide apparatus for storing electrical intelligence signals on a secondary emissive storage surface of a semiconductive target as areas selectively charged to either a lower or upper range of potential and for shifting the stored signals across the storage surface by engaging the charged areas with electron beams and deflecting the electron beams across the surface so as to shift the signals across the surface as charged surface regions maintained beneath the moving electron beams.

It is still another object of the present invention to provide apparatus for storing primary electrical binary signals on a secondary emissive storage surface of a semiconductive target as areas selectively charged to either a lower or upper range of potential and for shifting the stored signals across the storage surface by engaging the charged areas with electron beams and deflecting the electron beams across the surface so as to shift the primary signals across the surface as charged surface regions maintained beneath the moving electron beams, said apparatus including mechanism for removing charge from the surface so that regions of the surface charged to the upper range of potential tend to be rapidly discharged to the lower range of potential unless maintained at the upper range of potential by engagement with electron beams, whereby primary signals being shifted across the surface are confined to the surface regions beneath the moving electron beams while remanent signals left trailing behind the shifted primary signals is rapidly erased by the charge removing mechanism.

It is still another object of the invention to provide a method and apparatus for shifting, across a secondary emissive storage surface, binary electrical intelligence signals which have been stored on the surface as areas of the surface selectively charged to either a lower or upper range of potential, wherein associated electron beams are directed at the charged areas to maintain each area at its range of potential, and these electron beams are deflected across the storage surface at a predetermined velocity so that as the electron beams move across the storage surface the regions of the storage surface beneath the beams are maintained at the ranges of potential which formerly existed at the associated charged areas.

It is yet another object of the invention to provide a method and apparatus for unidirectionally shifting applied binary electrical signals across a secondary emissive storage surface from an initial storage area of the surface to an adjacent area by cyclically deflecting an electron beam back and forth between the initial area and the adjacent area.

It is a further object of the invention to provide a method and apparatus for unidirectionally shifting applied binary electrical signals across a secondary emissive storage surface from an initial storage area of the surface to an adjacent area by cyclically deflecting an electron beam back and forth across the storage surface between the initial area and the adjacent area, the beam being advanced from the initial area to the adjacent area at a predetermined velocity so as to shift applied signals across the surface to the adjacent area at each advancing sweep of the beam, and being swept back to the initial area at sufficiently higher velocity so that transported signals are not returned by the beam but are instead left at the adjacent area to which they have been advanced.

It is still a further object of the invention to provide a signal shifting apparatus in which a plurality of serially arranged electron beams are cyclically deflected back and forth across a secondary emissive storage surface, the amplitude of motion of each beam across the storage surface being equal to the spacing of the beams at the storage surface so that binary electrical signals advanced across the surface by one beam are engaged by the successive beam and advanced still further, the signals being shifted a distance equal to a beam spacing at each cycle of deflection of the beams and thereby progressing serially in this manner from beam to beam as they are shifted across the storage surface.

It is still another object of the present invention to provide an electron discharge signal shifting apparatus in which a plurality of arcuate electron beams are formed, issuing from a central cathode and directed at associated serially adjacent areas on a secondary emissive storage surface of a generally cylindrical target electrode which encloses the central cathode, initial curvature of the beams being caused by an applied magnetic field which is cyclically varied between upper and lower values so as to correspondingly increase and decrease the curvature of the electron beams to thereby sweep each beam back and forth between its associated area and the serially successive area at each cycle of variation of the magnetic field, whereby binary signals introduced at an input area are shifted by the electron beams from area to area as the electron beams are swept back and forth by the cyclically varying magnetic field.

It is an additional object of the present invention to provide a signal shifting apparatus in which a single extended electron beam may simultaneously shift a plurality of independent binary electrical signals across a secondary emissive storage surface at each advancing sweep of the electron beam, said apparatus including conductive striping traversing the storage surface at levels corresponding to predetermined levels of the extended electron beam and maintained at a predetermined potential to electrically isolate the levels of the storage surface from each other, so that electrical signals being shifted across the storage surface at one level by the electron beam cannot propagate across the striping to adjacent levels thereby permitting other independent signals to be shifted by the electron beam on the adjacent levels.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the invention.

Fig. 1 is a schematic diagram illustrating a simple embodiment of an electron discharge signal shifting apparatus according to the present invention;

Fig. 2 is a graph which illustrates the relationship between the secondary emission ratio of an electron bombarded area of a secondary emissive storage surface and the voltage potential of the area with respect to the electron source;

Fig. 3 is a waveform chart illustrating on a common time scale voltage waveforms of electrical signals produced in the operation of a signal shifting apparatus according to the present invention;

Fig. 4 is a schematic diagram illustrating an embodiment of the electron discharge signal shifting apparatus of the present invention in which a plurality of electron beams are utilized for serially shifting binary electrical signals across a secondary emissive storage surface of a semiconductive target electrode;

Fig. 5 is an isometric view illustrating a preferred embodiment of a signal shifting apparatus according to the present invention;

Fig. 6 is a plan view of the signal shifting apparatus shown in Fig. 5;

Fig. 7*a* is an isometric view of a modified target electrode which may be substituted in the preferred embodiment of the signal shifting apparatus of the present invention shown in Fig. 5 to greatly increase the signal storing capacity of the apparatus;

Fig. 7*b* is a diagram showing a plane development of a signal storing surface of the modified target electrode shown in Fig. 7*a*; and

Fig. 8 is an isometric view of another modified form of the preferred signal shifting apparatus shown in Fig. 5.

Referring now to Fig. 1 there is shown an electron discharge signal shifting apparatus, according to the invention, which is adapted for receiving electrical binary intelligence signals applied to an input conductor **12** and for shifting the intelligence signals to an output conductor **13**. In the internal operations of the signal shifting apparatus shown in Fig. 1 each applied binary intelligence signal is utilized to selectively charge an input storage area a_I of a secondary emissive storage surface S to either a predetermined upper range of potential or a predetermined lower range of potential thereby storing the binary intelligence signal on the storage area a_I of surface S, the stored signal then being shifted or transported across storage surface S to an output storage area a_O which is electrically coupled to output conductor **13**. The following nomenclature will be adopted in referring to these signals, that signals stored or represented as regions at the upper range of potential will be called positive signals, while signals stored or represented as regions at the lower range of potential will be called negative signals.

As will be shown hereinafter embodiments of the present invention may be constructed in which additional intelligence signals may be applied to the signal shifting apparatus while precedingly applied signals are still being transported across the storage surface, to thereby form a serial train of intelligence signals progressing in serial order across the storage surface between the input storage area and the output storage area. In this manner large numbers of intelligence signals may be simultaneously stored on the storage surface. However, it is believed that a clear understanding of the basic principles of the invention may best be gained by considering first the very simple embodiment of the invention, shown in Fig. 1, which is adapted for the storage of a single intelligence signal rather than a plurality of intelligence signals.

As shown in Fig. 1, this simple embodiment of the invention includes an evacuated tube or chamber E in which is provided apparatus for producing an electron beam L_1 and for directing the beam at the surface S of a semiconductive target **14**. Apparatus is also provided for deflecting the electron beam L_1 so as to cyclically move the beam back and forth between the storage areas a_I and a_O of storage surface S.

To assist in forming electron beam L_1, an electron emissive cathode K connected to a source of relatively low potential V_K is provided to act as a source of electrons, electrons emitted by cathode K being attracted by an accelerating anode A which is maintained at a relatively high potential with respect to the potential V_K of cathode K. Accelerating anode A has a hole or aperture h_1 and is positioned with respect to cathode K so that a portion of the attracted electrons pass through aperture h_1 to form electron beam L_1. A pair of electrostatic deflection plates D_1 and D_2, connected to a source of deflection signals **16**, are positioned on either side of the path of electron beam L_1 for operation in deflecting the beam so as to play back and forth between storage areas a_I and a_O of storage surface S. In Fig. 1, beam L_1 is shown as impinging upon storage area a_I while a dotted line **20** indicates the path beam L_1 will have when it is deflected to impinge upon storage area a_O. A collector anode C, which is maintained at a relatively high potential V_C, is positioned adjacent storage surface S for collecting secondary electrons which may be emitted by storage surface S when under bombardment by electron beam L_1. Accelerating anode A may also be conveniently connected to the source of potential V_C, as shown in Fig. 1.

A grid G is provided for use in regulating the flow of electrons from cathode K to thereby control the intensity of electron current in electron beam L_1. As shown in Fig. 1 grid G partly surrounds cathode K, grid G being connected to a source of potential V_G which may be at a potential level slightly below potential V_K. The rear surface of semiconductive target **14** is electrically connected to a conductive back plate B which may conveniently be a metallic film deposited on the rear surface of target **14**.

As shown in Fig. 1 back plate B may be connected to a source of potential V_B which is in the lower range of potential and may be at or near the cathode potential V_K. Referring again to Fig. 1 an output terminal O is provided electrically coupled to the output storage area a_O. Output terminal O may be an isolated conductive backing or metal film on the rear surface of target **14**, positioned opposite storage area a_O, as shown in Fig. 1, so that intelligence signals shifted to storage area a_O are capacitatively applied to output terminal O. As explained hereinbefore, input signals for the shifting apparatus are applied over input conductor **12**, the signals being shown in Fig. 1 as originating from a source of input signals **18**.

Input conductor **12** is connected to an input terminal I which is electrically coupled to input storage area a_I, each applied intelligence signal thereby charging storage area a_I to a high or low range of potential in accordance with the voltage level of the applied intelligence signal. As shown in Fig. 1, input terminal I is a thin conductive film coated over a portion of storage area a_I. It will be understood that storage area a_I includes that portion of surface S which is underneath terminal I and also includes those peripheral regions of surface S surrounding terminal I which are directly charged to a high or low potential range by intelligence signals applied to input terminal I.

Storage surface S ordinarily tends to be maintained at the back plate potential V_B by reason of volume conduction through the semiconductive target **14** to the back plate. However, if an area of storage surface S is first charged to either the lower or upper range of potential and is then bombarded by electron beam L_1 the bombarded area will not return to the back plate potential V_B but will be charged by beam L_1 toward one of two stable potentials corresponding respectively to the collector potential V_C or the cathode potential V_K in accordance with the initial potential range of the area before bombardment. Those skilled in the art will readily understand the mechanism by which an area of storage surface S may be charged to these alternate potential levels.

If, when an electron beam impinges on a storage area, the storage area is already at the predetermined upper range of potential then the electrons arriving at the area acquire sufficient velocity so that more electrons are ejected from the area by secondary emission than arrive at the area in the electron beam. The ejected or secondarily emitted electrons are attracted to collector anode C and are thereby removed from the bombarded area. As a result the area of storage surface S under bombardment becomes more positive by reason of the loss of the secondarily emitted electrons. Additional electrons arriving at the bombarded area will therefore have even higher velocities of impingement. The area under bombardment thus becomes increasingly positive until it is charged to a limiting potential corresponding to the collector potential V_C.

On the other hand if the area of storage surface S is at the predetermined lower range of potential before bombardment, then electrons directed at the area in the bombarding electron beam L, will have considerably lower velocities as they arrive at the storage area so that fewer electrons are ejected by secondary emission than arrive at the storage area in the electron beam, causing a net increase or deposition of electrons on the storage area. Under these conditions the storage area rapidly charges to a potential corresponding to the potential V_K of cathode K which is the source of electrons.

Thus it is clear that when under bombardment by electron beam L_1 an area of storage surface S will be charged either towards potential V_C or potential V_K depending upon whether the area was at the predetermined upper range of potential or at the lower range of potential immediately before being bombarded by electron beam L_1. Electron beam L_1 therefore functions as a "holding" beam which maintains any area upon which it impinges at the potential range the area had before bombardment. It is also clear that if electron beam L_1 is removed from such an area the area will be uniformly returned or discharged to the lower range of potential by conduction through semiconductive target **14** to back plate B.

Moreover it is a feature of the present invention that if beam L_1 is deflected away from such an area at a sufficiently low predetermined velocity, then as the beam moves across the surface away from the area, the region of the surface immediately beneath the moving beam will be maintained at the same range of potential that originally existed at the initial area from which the beam started its advance. In this manner a positive or negative signal stored on storage surface S as an initial area selectively charged to either the upper or lower potential range, may be shifted across surface S by electron beam L_1 as a correspondingly charged region maintained beneath the moving electron beam.

Consider for example, referring again to Fig. 1, the operation which occurs when electron beam L_1 is deflected across storage surface S from storage area a_I to storage area a_O. Let it be assumed in the following description of operation that a positive intelligence signal has been applied to input terminal I and that therefore storage area a_I has been charged to the upper range of potential. In operation electron beam L_1 is directed at storage area a_I while the area is at this upper range of potential and is then advanced or deflected from storage area a_I to storage area a_O.

As the beam in its advance begins to move off input terminal I the beam encounters and bombards a peripheral region of storage area a_I which has become charged by direct conduction and other effects to the upper range of potential. Under bombardment by the electron stream this peripheral region rapidly becomes more positive as it charges because of the bombardment towards collector potential V_C. Meanwhile as this peripheral region becomes highly charged electron beam L_1 continues to advance so that this formerly peripheral region becomes the central region under bombardment by the beam while further peripheral regions in the direction of the advancing beam now become charged by direction conduction and other effects to the upper range of potential.

Thus when beam L_1 is advanced across storage surface S from area a_I to area a_O it always encounters in the direction of its advance peripheral regions which have already become charged to the upper range of potential so long as the beam is advanced across the surface at a sufficiently low velocity which does not exceed the rate or velocity of creation of such peripherally charged region. Under these conditions, the beam through its "holding" action is able to continuously maintain a charged region beneath it as it sweeps across the surface, the potential range of the region beneath the beam corresponding to the potential range of initial area a_I from which the beam started its sweep. In this manner positive signals introduced at storage area a_I are shifted across the storage surface by electron beam L_1 as positive signal regions which are maintained beneath beam L_1 as it moves across storage surface S. When such a positive signal region reaches output area a_O a large positive pulse is capacitively coupled to output terminal O and in this fashion the shifted positive signal is applied to output terminal **13**.

It is clear that negative signals applied to input terminal I will be similarly shifted by electron beam L_1 across storage surface S to output storage area a_O. When a negative signal is applied to input terminal I, storage area a_I is charged to the lower range of potential and therefore when electron beam L_1 is deflected from storage area a_I to area a_O the regions beneath the moving beam are maintained at the lower range of potential corresponding to the potential range of storage area a_I from which the beam started its sweep. Electron beam L_1 is therefore effective in transporting negative signals as well as positive signals across storage surface S from input storage area a_I to output storage area a_O.

It will be noted that when a positive signal is shifted across the storage area it tends in its traverse to leave remanently charged regions trailing behind it which are at the upper range of potential. It is a feature of the present invention that signal trails of this sort are rapidly erased or discharged to the lower range of potential by reason of conduction through semiconductive target **14** to the potential V_B of back plate B. Because of this effect transported or shifted signals are confined to the surface region beneath beam L_1. Such confinement of shifted signals to the region lying beneath electron beam L_1 is a preferred mode of operation for the signal shifting apparatus of the present invention. With this mode of operation successive signals being shifted across the storage surface always find the surface in a uniform condition thereby allowing more reliable shifting of signals at higher speeds than are obtainable with other modes of operation wherein remanent signal may be encountered by an advancing binary intelligence signal.

It will be remembered that in operation beam L_1 is cyclically swept back and forth between storage areas a_I and a_O so as to serially shift to area a_O binary intelligence signals which are successively introduced at storage area a_I. Unidirectional shifting or transport of binary signals in this manner is accomplished by utilizing a high velocity return sweep or flyback of beam L_1 from area a_O to a_I so that binary intelligence signals shifted along by the beam on its forward sweep will be left at area a_O and will not be swept back again on the return sweep or flyback. Thus in operation the described apparatus functions as a single digit binary shift register in which binary intelligence signals are advanced in one direction by the forward sweeps of electron beam L_1 and are left undisturbed during return sweeps of beam L_1.

The described method and apparatus for shifting intelligence signals across a semiconductive secondarily emissive storage surface may be further clarified by consideration of Fig. 2 which is a conventional and remarkably illustrative diagram which is descriptive of the relationship between the potential of a storage area of surface S when under bombardment by electron beam L_1 and the secondary emission ratio R of electrons leaving the bombarded storage area to the electrons arriving at the storage area in the electron beam L_1. As shown in Fig. 2 the ratio R is plotted on a vertical scale while the potenial of the storage area under bombardment is plotted on a horizontal scale. A dotted line **21** has been drawn to indicate the transition between operating regions above dotted line **21** where ratio R is greater than one and operating regions below the dotted line where ratio R is less than one.

As shown in Fig. 2 the storage area under bombardment may be at an operating point at which ratio R is exactly one and the region is at a predetermined potential V_R. This operating point, however, is quite unstable since the slightest increase in potential will cause the storage area to have a ratio greater than one thereby causing the storage area to rapidly charge towards the collector potential V_C. On the other hand a slight decrease in potential would cause the ratio R to drop below one, thereby causing the storage area under bombardment to charge rapidly towards the cathode potential V_K. Thus it may be understood that the possible potentials of a storage area under bombardment may be divided into a predetermined upper range of potential above potential V_R and a predetermined lower range of potential below potential V_R.

It is clear in view of the foregoing that a storage area under bombardment will charge towards collector potential V_C or cathode potential V_K in accordance with the range the range of potential at which the storage area is maintained before bombardment. In this manner an area in which a positive or negative signal has been stored is maintained at its corresponding potential range when bombarded by an electron beam of the described type.

An area under direct bombardment by electron beam L_1 will, it is clear, tend to be either at a potential close to V_C or at a potential close to V_K. A positive signal stored as a region of a storage area which is at a potential close to V_C will be surrounded because of surface conduction and other effects by a peripheral region which is also at the upper range of potential albeit at a somewhat lower potential level. Therefore as electron beam L_1 is moved into this peripheral or boundary region it is able to positively charge the boundary region towards collector potential V_C and is therefore able to sweep or transport a charged region beneath itself, as the beam sweeps across the storage surface. In this manner positive signals are transported across a storage surface by the electron beam. Meanwhile areas which are left behind beam L_1 rapidly discharge towards the back plate potential V_B thereby erasing any remanent signal which may be left trailing behind the transported signal.

Negative signals, which it will be remembered are represented as regions at the lower range of potential, are transported across the storage surface by a somewhat similar mechanism. When a negative signal region is engaged by electron beam L_1 the region charges rapidly towards the cathode potential V_K which is in the lower range of potential. As the beam is swept forward it falls upon peripheral regions which are also at the lower range of potential both because of surface conduction in the manner described before and also because of the natural decay of any obstructing remanently charged areas by reason of leakage through the semiconductive target to the back plate. Thus as the beam is swept across the storage surface, regions beneath the beam are readily charged towards potential V_K, and in this manner the negative signal is advanced across the storage surface.

When beam L_1 after it has advanced a signal on its forward sweep is swept back on its return sweep with sufficient rapidity, the beam is unable to supply enough current to charge the sizable capacitances made by storage surface S and back plate B at a rate consonant with the speed of return of the beam. Therefore if the return sweep is made sufficiently rapid, the advanced signal will not be swept back again but will be left at the storage area to which it has been shifted.

It will be shown at a later point in this specification that a signal advanced in this manner may be engaged by another electron beam and be advanced still further.

However, confining ourselves for the moment to the consideration of the single beam shifting apparatus shown in Fig. 1, reference is made to Fig. 3 in which are illustrated on a common time scale certain signal waveforms illustrative of the operation of the signal shifting apparatus shown in Fig. 1. Referring now to Fig. 3 there is shown a sawtooth voltage waveform S_d which may be applied to deflection plate D_2 by source of deflection signals **16** to control the deflecting of electron beam L_1 in the manner described hereinbefore, each extended ramp-like rise of signal S_d corresponding to the forward sweep of electron beam L_1 from area a_I to area a_O and each sharp fall of waveform S_d corresponding to the flyback or return sweep of beam L_1 to area a_I. The return sweeps of beam L_1 will therefore correspond to equi-spaced time positions $t_1, t_2, t_3, \ldots$ as shown in Fig. 3.

For the purpose of clarifying the operation of the signal shifting apparatus shown in Fig. 1 there is also shown in Fig. 3 an input signal S_I which may be applied to input terminal I by source of input signals **18**, signals S_I being composed of intelligence signals which are successively representative of ten binary digits 0011001000, these intelligence signals of signals S_I being numbered 1 through 10 as shown in Fig. 3. As shown in Fig. 3 the first binary digit (0) is represented by signals S_I being at a relatively low level at time t_1. All other 0 binary digits are similarly represented by signal S_I being at its low level while binary 1 digits are represented by signal S_I being at its high level. For example, the third binary digit, a binary 1 is represented by signal S_I being at its high level at time t_3. Thus signal S_I at each of the times $t_1, t_2, t_3, \ldots t_{10}$ may be used to charge storage area a_I to a range of potential corresponding to the respectively associated binary digits 0011001000.

For example, at time t_1, as beam L_1 sweeps back to storage area a_I it finds storage area a_I maintained by signal S_I at the lower range of potential representative of the first binary digit (0). Beam L_1 thereupon begins to charge area a_I towards the cathode potential V_K and during the interval between times t_1 and t_2, as the beam moves towards storage area a_I, the beam continues to charge the surface regions beneath it towards potential V_K.

In this connection it is instructive to examine the waveform of an output signal S_O which is produced at storage area a_O by the successive arrivals of beam L_1 at storage area a_O in response to successive cycles of deflection signal S_d. By considering signal S_O as shown in Fig. 3, it becomes clear that as beam L_1 approaches storage area a_O, shortly before time t_2, storage area a_O which has been at back plate potential V_B is more or less abruptly charged towards the cathode potential V_K thus producing a negative voltage excursion of signal S_O which reaches its peak at time t_2 as beam L_1 is centered directly upon area a_O. Then as beam L_1 is abruptly swept back to storage area a_I the voltage level of signal S_O decays again on an extended decay curve and towards back plate potential V_B making another excursion towards potential V_K and reaching its peak only when beam L_1 again arrives at area a_O at time t_3. During the time interval between t_3 and t_4 the voltage level of signal S_O again decays towards potential level V_B until shortly before time t_4 when beam L_1 again reaches area a_O.

However, at this time t_4 the arriving electron beam L_1 is shifting a positive signal region across the storage area, this positive signal region having been picked up by the beam at storage area a_I at the preceding time t_3. Thus as the advancing beam reaches storage area a_O the positive signal region is swept or shifted into storage area a_O in the manner hereinbefore described charging area a_O abruptly towards potential V_C, as illustrated by the peak attained by signal S_O at time t_4.

Once again during the interval between t_4 and t_5 the voltage level of signal S_O decays towards V_B on an extended decay curve which is characteristic of the semiconductive material of target **14**. The next arrival of the beam at time t_5 again charges area a_O to potential V_C in accordance with the high level potential applied to area a_I at time t_4. When the beam arrives again at area a_O shortly before time t_6, the voltage level of signal S_O has again decayed towards potential V_B.

It should be noted that in so decaying, the voltage level at area a_O has dropped below potential V_R before the beam L_1 again arrives at storage area a_O. Thus, at this time since area a_O is already at the lower range of potential below V_R the arriving electron beam is able by bombardment of the storage area to charge the storage area towards potential V_K at time t_6 in accordance with the low level of signal S_I at time t_5.

It is not necessary to consider signal S_O in further detail since in explaining what occurs at time t_2 through t_6 all separate cases of operation of the signal shifting apparatus of Fig. 1 have been clarified. For example, at time t_3 a negative signal region was shifted into an area which had previously been charged to the lower potential range by a negative signal. At time t_4 a positive signal region was shifted into an area which had previously been charged to the lower potential range. At time t_5 a positive signal region was shifted into an area which had previously been charged to the upper range of potential and at time t_6 a negative signal region was shifted into an area which had previously been maintained at the upper range of potential. Thus all separate cases of operation of the signal shifting apparatus of Fig. 1 have been explained in detail.

Summarizing now the operation of the embodiment of the invention shown in Fig. 1 it should be clear that in operation the signal shifting apparatus receives binary intelligence signals applied to input terminal I and effectively shifts those binary signals over storage surface S to storage area a_O where the shifted or transported intelligence signals are coupled to output terminal O and thence to output conductor **13**. Each signal so shifted is delayed by the time required for the signal to progress from input storage area a_I to output storage area a_O. The simple embodiment of the invention shown in Fig. 1 has a single electron beam which by being cyclically deflected across storage surface S between areas a_I and a_O picks up signals deposited at area a_I and advances them to area a_O for coupling to output conductor **13**. Either positive or negative signals may be shifted across the storage surface and therefore in operation the simple embodiment of the invention shown in Fig. 1 may function as a 1-binary digit shift register.

Summarizing also the various characteristics which are exhibited by the target electrode, it is clear from the preceding description that the target electrode should be capable of exhibiting a secondary emission ratio greater than unity in order to provide either a positive or negative net current flow to the area upon which the electron beam is impinging. Secondly, it is also clear from the discussion set forth hereinabove that the material from which the target electrode is formed should have a bulk resistivity which is sufficiently low to allow charge remanents left by the moving electron beam to discharge to the conductive backing of the target electrode so that the regions where the remanents were left is discharged to a point below the crossover potential Vr before the succeeding sweep of the electron beam. Conversely, a third requirement of the target electrode is that it have a bulk resistivity which is sufficiently high to permit partial charge retention by the surface of the target during the flyback period of the electron beam, and in addition, to permit the use of an electron beam of reasonable current density. In general any semiconductor will satisfy the foregoing criteria, since all known semiconductors will readily emit secondary electrons, and have a bulk resistivity which is sufficiently high to permit a charge to be placed on the surface thereof while still being of sufficiently low resistivity to permit the charge to leak off if left unsupported by a holding beam of electrons. It should be noted however, that the selection of a particular semiconductor material for the target electrode will influence the maximum iteration rate at which binary information in the form of charged areas can be stepped across the surface of the target electrode, since the bulk resistivity and dielectric constant of the material will determine the time constant of the discharge path for surface areas which have been left with a high level charge as the electron beam sweeps past. In other words, the time constant of the selected material will influence the time to be allotted for a sweep of the electron beam, since the time constant should be sufficiently small relative to the period of the beam sweep to enable target areas having charge remanents left by the beam sweep to discharge to a voltage below the cross-over voltage Vr before the electron beam again impinges on the area during the successive sweep. On the other hand, as will be understood in more detail from the description set forth hereinbelow, the time constant of the particular semiconductive material selected will also influence the flyback time of the electron beam since the time constant should be sufficiently large relative to the flyback time to prevent a charged area from discharging below the crossover voltage Vr during the flyback period in which the holding beam is returned to its initial position to initiate another scan.

Typical materials which may be employed in the target electrode in practicing the present invention, are monatomic semiconductors such as silicon and germanium, semiconducting ceramics such as zirconium oxide, metallic oxide semiconductors such as copper oxide, or intermetallic compound semiconductors embodying elements of the third and fifth columns, for example, of the periodic table. Still other materials which may be employed in the target electrode are those materials, such as certain glasses, which become semiconducting when heated to an elevated temperature. For example, Corning 0080 Lime glass exhibits a bulk resistivity of .13 megohm centimeter at 350° centigrade and a dielectric constant of 6.75, while Corning 774 borosilicate glass has a bulk resistivity of 4 megohm centimeters at 350° centigrade and has a dielectric constant of 5.0; accordingly, either of these materials could be employed in practicing the invention. To illustrate this latter point further, the foregoing figures for borosilicate glass indicate that the glass has a time constant of approximately 1.75×10^{-6} seconds at 350° centigrade. Thus if one assumes a ratio of beam sweep interval to flyback interval of five to one, it will be seen that this particular material will operate very effectively at iteration rates of the order of 200 kilocycles since the time constant of the target electrode will then be approximately twice as long as the flyback interval and will be less than half as long as the beam sweep interval. Accordingly, if the tube operating voltages are selected to provide a crossover voltage Vr which is substantially less than the voltage to which a charged area of the target discharges during the flyback interval, and more than the voltage to which a charged area discharges during a sweep interval, the target of borosilicate glass will function in accordance with the teachings of the invention.

If the general configuration shown in Fig. 1 is provided as a multiple array wherein a plurality of electron beams are produced, arrangements may be made in which a signal advanced by one beam is picked up by a successive beam and advanced still further, the binary signals therefore serially progressing from each beam to the successive beam at each cycle of the deflection voltage. In a multiple array of this type the number of signals which can be shifting through the apparatus may be made very large if desired. Such a multiple beam shifting apparatus is shown in Fig. 4.

In the multiple beam embodiment of the present invention shown in Fig. 4, a common cathode K supplies electrons to produce five electron beams (L_1, L_2, L_3, L_4 and L_5) through a perforated accelerating anode A. These beams pass through an array of alternately connected deflecting plates D_1 and D_2 and are thereby swept back and forth in synchronism by a sawtooth deflection voltage supplied to the deflecting plates by the source of deflection signals **16**. It will be understood that all the deflection plates D_1 are connected to the source of deflection signals **16** and that all the deflection plates D_2 are connected together and separately connected to the source of deflection signals **16**.

In Fig. 4 the electron beams L_1 through L_5 are shown as they would appear at the completion of their return sweep or flyback, electron beam L_1 then being directed at storage area a_I and electron beam L_5 being directed at a storage area of surface S just preceding the storage area a_O. The amplitude of motion of each beam across the storage surface S is equal to the spacing of the beams at the storage surface and therefore when storage area a_I is charged to its upper range of potential by a positive signal the next forward sweep of beam L_1 will advance or shift the positive signal to a point where it can be in effect picked up by beam L_2, the positive signal progressing in this manner from beam to beam at each cycle of the deflection voltage until at the end of the 5th cycle the charged area is shifted by beam L_5 to the output storage area a_O. While this first binary intelligence signal is being shifted to output storage area a_O other intelligence signals may be serially applied to input terminal I so that a serial train of intelligence signals is produced which are being synchronously shifted or transported across storage surface S. It will be understood therefore that the particular embodiment of the invention shown in Fig. 4 is adapted for the shifting and storage of five binary intelligence signals.

The particular embodiment of the invention shown in Fig. 4 has a limitation which may limit the useful lifetime of the apparatus in that the storage surface S is exposed to or has a "line of sight" view of cathode K so that negative ions and particles of cathode material emitted by cathode K may be accelerated against storage surface S where they may have a deleterious effect on the secondary emissive properties of the storage surface. Furthermore a somewhat complicated mechanical structure is required for positioning the deflection plates D_1 and D_2 so that symmetrical electrostatic deflecting forces are applied to all of the electron beams L_1 through L_5.

The described disadvantages of the particular embodiment of the invention shown in Fig. 4 are eliminated in a preferred embodiment of the invention shown in Fig. 5, in which magnetic deflection is utilized for the deflection of the multiple electron beams which are formed in the signal shifting apparatus. As shown in Fig. 5 cathode K has an extended cylindrical shape and is enclosed by coaxial cylindrical grid G. Collector anode C is composed of a large number of conducting vanes which are coaxially arranged around cathode K to form a generally cylindrical structure in which the vanes are arranged slantwise as in a Venetian blind to form a large number of angled openings through which electrons emitted by cathode K pass to form multiple electron beams. All the vanes of collector C are positioned and conductively connected to one another by an annular aligning ring **24**.

Semiconductive target **14** is cylindrical in shape and coaxially encloses the cylindrical structure of anode C. As shown in Fig. 5 portions of target **14** are cut away to allow an unobstructed view of the interior structure of the signal shifting apparatus. The vanes of collector C are so angled that no area of storage surface S of target **14** has a straight "line of sight" view of cathode K. An axial magnetic field is provided by a magnet winding M which encloses the evacuated tube E.

The applied axial magnetic field causes electrons emitted by cathode K to travel in arcuate paths thereby causing the electrons to avoid the barrier presented by the vanes of collector C. Because of their path curvatures, emitted electrons can pass between the angled vanes of collector C to thereby form arcuate electron beams of rectangular cross section which may impinge upon storage surface S. To such electron beams L_1 and L_{16} are shown in Fig. 5. It will be understood however that every aperture of collector C is capable of producing an electron beam.

As shown in Fig. 6 the outer surface of target **14** is conductively coated to form backing plate B. Output terminal O is an isolated vertical strip of conductive material also plated on the outer surface of target **14** opposite storage area a_O to which beam L_{16} may be deflected in the operation of the signal shifting apparatus. Input terminal I as shown in Fig. 5 is a vertical conductive strip which is coated on storage surface S of target **14** at a point where it may be bombarded by electron beam L_1 during the operation of the signal shifting apparatus.

It is clear from a consideration of the structure shown in Fig. 5 that ions and uncharged material emitted by cathode K will be unable to reach storage surface S. The uncharged particles will of course travel in straight lines and will therefore inevitably be intercepted by the vanes of collector C while charged particles since their mass is far greater than the mass of electrons will not have sufficient path curvature to pass through the angled vanes of collector C and will therefore also be intercepted by collector C.

The operation of the signal shifting apparatus shown in Fig. 5 may be more readily understood by referring to Fig. 6 in which the signal shifting apparatus is shown as it would appear when viewed from a point directly above cathode K. Annular ring **24** is not shown in this view for the purpose of facilitating examination of the angled vane structure of collector C and of the electron beams which are formed by passage of electrons through the apertures of collector C. In Fig. 6, 16 electron beams L_1 through L_{16} are shown of a total of 48 electron beams which may be formed by collector C.

It is clear that if the applied axial magnetic field is varied between upper and lower values each of these beams will correspondingly be varied in curvature. At the lower value of field strength, the curvature of each beam will be relatively slight although sufficient to allow the beam to pass through the angled vanes of collector C. As the applied field is increased to its upper value the curvature of each beam will be increased so that the point of impingement of each beam is advanced from the storage area at which it is normally directed (at the lower value of the applied magnetic field) to an adjacent storage area.

In Fig. 6 all of the beams L_1 through L_{16} are shown as they would appear when the applied magnetic field is at its lower value, beam L_1, for example, being directed at storage area a_I and beam L_{16} being directed at a storage area immediately preceding storage area a_O. When the axial magnetic field is raised to its upper value beam L_1 will change its curvature until it assumes the path indicated by dotted line **20**. Similarly beam L_2 will change its curvature until it assumes the path indicated by a dotted line **25** and beam L_{16} will assume the curvature indicated by a dotted line **26** so as to impinge upon storage area a_O.

In operation source of deflection signal **16** cyclically varies the current applied to winding M so as to cyclically vary the magnetic field between its lower and upper values. In response to the varying magnetic field, the electron beams L_1 through L_{16} are swept back and forth in synchronism, each increase of the magnetic field to its upper value causing an advancing sweep of the beams and each decrease in the magnetic field to its lower value causing a return sweep of the beams. Since the amplitude of motion of each beam is equal to the spacing of beams it is clear that an intelligence signal introduced at terminal I may be shifted from beam to beam in the same manner as has been described in connection with the multiple beam shifting apparatus shown in Fig. 4.

In the preferred embodiment of the invention shown in Fig. 6 output terminal O has been separated from input terminal I by a distance which allows the signal shifting apparatus to be used as a 16 digit shift register in which 16 binary intelligence signals may be stored on storage surface S as the intelligence signals are shifted from storage area a_I to storage area a_O. It is clear, however, that by increasing the spacing between output terminal O and input terminal I the capacity of the shift register may be greatly increased. For example, by placing output terminal O opposite the storage area which immediately precedes storage area a_I a shift register having a capacity of 47 binary digits may be obtained.

Moreover the digit storing capacity of the preferred embodiment of the invention shown in Fig. 6 may be additionally increased by many orders of magnitude by substituting for target **14** a modified target **14***a* of the general type shown in Fig. 7*a*. As shown in Fig. 7*a*, a helical conductive stripe J is established on storage surface S, helical stripe J starting shortly above terminal I and winding round and round storage surface S and ending below output terminal O. The successive turns of the helical stripe J define or demark boundaries for a long helical track **31** on storage surface S, track **31** being always bounded above and below by upper and lower turns of conductive stripe J, so that track **31** winds round and round storage surface S from input terminal I to output terminal O.

As shown in Fig. 7*a*, input terminal I may be a square or area of metal film deposited on storage surface S at the beginning of track **31** and electrically connected to input conductor **12** which may extend to terminal I through a small hole in target **14***a*. Output terminal **13** as shown in Fig. 7*a*, may be an isolated conductively coated area on the rear surface of target **14a** and positioned at the end of spiral track **31**.

The helical conductive stripe J is provided to cause successive turns of track **31** to be electrically isolated from one another so that intelligence signals which may be shifted along on one turn of track **31** cannot propogate across stripe J into adjacent turns. To insure such isolation, conductive stripe J may be connected to a source of relatively low potential V_J. It will be understood that potential V_J is in the lower range of potential, that is, that potential V_J is lower than potential V_R mentioned hereinbefore in connection with the description of Fig. 2.

Consider, for purposes of example, how the operation of the signal shifting apparatus shown in Fig. 6 would be modified if the target **14a** shown in Fig. 7*a* were substituted for target **14**. Let it be assumed that target **14a** would be so oriented that electron beam L_1 impinged upon terminal I of target **14a** while electron beam L_3 impinged upon an area of storage surface S immediately above output terminal O.

In order to facilitate description of the operation of the signal shifting apparatus under these stated conditions there is shown in Fig. 7*b* a development of target **14a** showing storage surface S as it would appear if target **14a** were cut away along a dotted line **30** (shown in Fig. 7*a*) and then unrolled to expose storage surface S as a flat area.

As shown in Fig. 7*b* spiral track **31** has five turns about storage surface S, these turns being designated turn **1**, turn **2**, turn **3**, turn **4** and turn **5**. In addition for the purpose of indicating the normal areas of impingement of electron beams L_1, L_2, L_3, to L_{48} (where L_{48} is the forty-eighth beam formed by collector C), these areas of impingement of the beams are designed P_1, P_2, P_3, etc. to P_{48} and are demarked by dotted lines as shown in Fig. 7*b*.

It will be understood that the areas P_1 to P_{48} correspond to the areas of impingement of the electron beams L_1 to L_{48} when the applied magnetic field is at its lower value. In operation when the applied magnetic field is being varied between its upper and lower values, beam L_1, for example, will move back and forth between areas P_1 and P_2, each of the other beams similarly moving between its associated area and the next successive area.

For purposes of clarification many of the areas of projection have not been shown. It will be understood, however, that they are uniformly distributed across storage surface S. The reference character P_n is used to designate the impingement area immediately preceding the sectioning line or cut away line **30** while reference characters P_{n+1}, P_{n+2} have been utilized for designating the two impingement areas immediately succeeding sectioning line **30**. In addition a dotted line **32** designates the projected boundary of output terminal O on storage surface S and a dotted line **33** designates the projected boundary of backing plate B on storage surface S.

Consider now with reference to Fig. 7*b* the operation of the modified signal shifting apparatus. If an intelligence signal is applied to input terminal I, the next forward sweep of the electron beams will advance the applied intelligence signal from input terminal I to that portion of area P_2 which lies within turn **1**, this area being designated for purposes of convenience P_{2-1}. Other areas of track **31** will be similarly designated. It will be understood, of course, that the intelligence signal is so advanced by beam L_1 sweeping across surface S from area P_1 to area P_2. Because of the isolating action of conductive stripe J when it is maintained at potential V_J, the intelligence signal can only propagate in the described manner (from area P_{1-1} to area P_{2-1}) and cannot propagate across conductive stripe J to areas P_{1-2} or P_{2-2}. Thus, in this manner the influence of a charged area on one turn of track **31** is entirely isolated from adjacent turns.

It is clear therefore that while beam L_1 is shifting an intelligence signal from P_{1-1} to P_{2-1} it may also be shifting a second intelligence signal from P_{1-2} to P_{2-2}, a third intelligence signal from P_{1-3} to P_{2-3}, a fourth intelligence signal from P_{1-4} to P_{2-4}, and a fifth intelligence signal from P_{1-5} to P_{2-5}. Thus, by reason of the isolating action of conductive stripe J, beam L_1 may simultaneously advance five independent intelligence signals on the five turns of spiral track J. Each of the other beams is similarly operable for shifting intelligence signals on each of the five turns of track **31**.

In the light of the foregoing explanation consider therefore the path followed by an intelligence signal introduced at input terminal I. As stated hereinbefore at the first advancing sweep of electron beams L_1 through L_{48}, the signal is advanced by beam L_1 from P_{1-1} to P_{2-1}. At the second advancing sweep of the electron beams the signal would again be advanced along turn **1** to area P_{3-1}. In this manner the signal progresses from beam to beam along turn **1**, proceeding from turn **1** to turn **2** by being shifted from $P_{(n)-1}$ to $P_{(n+1)-2}$ and progressing in like manner along turn **2** until it progresses from turn **2** to turn **3** by being shifted from area $P_{(n)-2}$ to area $P_{(n+1)-3}$. The intelligence signal progresses serially in this manner from beam to beam along the successive turns of track **31** until it arrives at the particular area which is stationed opposite output terminal O, this area as shown in Fig. 7*b* being designated as area P_{3-5}. The intelligence signal then capacitatively produces an output signal at terminal O which is applied to output conductor **13**.

It will be understood that as the first applied intelligence signal is progressing along spiral track **31** another intelligence signal may be applied to input terminal I to produce a serial train of intelligence signals which are simultaneously being shifted from input terminal I to output terminal O. The digit storage and shifting capacity of the preferred embodiment of the invention is thereby increased, from a 47 digit capacity (with target **14**) to a 194 digit capacity with the modified target **14a** shown in Figs. 7*a* and 7*b*. Storage capacities of thousands of binary digits may be readily attained in this manner on a storage surface of relatively small area.

The storage capacity of surface S is much enhanced by the fact that individual storage areas need not be any larger than is required for propagation of an intelligence signal from the storage area to an adjacent area. Thus, track **31** may be made as narrow as will permit propagation of signals along the track. The energy content of the shifted intelligence signal may be increased and in effect amplified by widening the last turn, turn **5**, of track **31** as it approaches output terminal O so that the area used for the propagation of intelligence signals increases as the output terminal is approached. In this manner the intelligence signals arriving at the output area P_{3-5} have sufficient energy content to produce a usable output signal while intelligence signals propagating in preceding turns in track **31** may have very low energy contents.

Although the use of helical striping of storage surface S in the manner generally described in connection with Figs. 7*a* and 7*b* is a preferred method for increasing the storage capacity of the signal shifting apparatus of the present invention, similar results may be obtained with an unstriped target structure by using a modified collector C_1 of a type shown in Fig. 8. As shown in Fig. 8 collector C_1 has a large number of apertures which are helically arranged about collector C_1 so that a helical array of electron beams may be formed by electrons passing through these apertures. In operation intelligence signals applied to input terminal I will be serially shifted in a helical path or track on surface S from input terminal I to output terminal O, a progressing intelligence signal being shifted from beam to beam of the helical array of beams during the course of its passage.

It should be understood, of course, that the foregoing disclosure relates only to preferred embodiments of the invention and that numerous modifications or alterations may be made therein without departing from the spirit and scope of the invention. For example, in the several embodiments of the invention which have been described hereinbefore binary intelligence signals have been stored on a storage surface by being applied to an input terminal which is in direct electrical contact with an input area of the storage surface. However, it is clear that direct electrical connection between the input terminal and the input storage area is not required and that other forms of coupling of the intelligence signals to the input storage area may be utilized. Thus in some embodiments of the invention the input terminal may be a conductive strip established on the back surface of the target electrode opposite the input storage area so that binary intelligence signals which are applied to the input terminal are capacitatively presented at the input storage area. In other embodiments of the invention, the electrical input intelligence signals may be utilized to control the passage or interruption of a separate "writing" beam which is permanently directed at the input storage area, the "writing" beam then successively charging the input area to its upper potential range or leaving the input area at its lower potential range in accordance with the successive voltage levels of the input signal.

It will also be clear to those skilled in the art, that the application of the basic principles of the present invention permit bidirectional transport or shifting of bilevel electrical signals across a storage surface as well as unidirectional transport of signals in the manner hereinbefore described. In the several embodiments of the invention hereinbefore described, reversal of the signal shifting direction may be readily accomplished by reversing the velocities of sweep of the electron beams so that the beams have a sufficiently low velocity in the desired shifting direction and a higher velocity in the undesired shift direction. In this manner reversal of shift direction may be obtained whenever such reversal is desired. Moreover the signals may be shifted forward and backward at varying speeds through corresponding variation of the beam sweep velocities and may even be held stationary for indefinite periods by halting the cyclical deflections of the electron beams. With such modes of operation, the signal shifting apparatus of the present invention is ideally adapted for use as a variable speed buffer or intermediate storage device.

Still other substitutions, additions and alterations to the present invention may be practiced by those skilled in the art without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed as new is:

1. In the process of shifting stored bilevel electrical signals across a secondary electron emissive surface of a semiconductive target electrode on which the bilevel signals are stored as the voltage levels of surface regions each charged to an upper or lower range of potential, the method of shifting a first bilevel signal from a first region to an adjacent second region which comprises the steps of: directing a first electron beam at the first region to maintain the first region at its potential range so long as the beam impinges upon the first region, and deflecting the first electron beam across the surface from the first region to the second region at a sufficiently low velocity to maintain the surface region beneath the moving beam at the potential range of the first region thereby to shift the first signal from the first region to the second region with the first electron beam.

2. The method defined by claim 1 which includes the additional step of removing charge from the surface to tend to discharge each surface region to the lower range of potential whereby the first signal as it is shifted by the first electron beam is confined to the surface region beneath the beam and does not leave remanent signal trailing behind.

3. The method defined by claim 2 which includes the further step of redeflecting the first electron beam from the second region to the first region at a velocity sufficiently high to prevent shifting of signals from said second region to said first region by said beam, whereby the beam may be utilized for unidirectionally shifting an additional signal from the first region to the second region.

4. The method defined by claim 2 which includes the additional step of shifting the first signal from the second region to a third region by directing a second electron beam at the second region and deflecting the second electron beam across the surface from the second region to the third region at a sufficiently low velocity to maintain the surface region beneath said second beam at the potential range of said second region.

5. In the process of shifting stored bilevel electrical signals across a secondary electron emissive surface of a semiconductive target electrode on which the bilevel signals are stored as the voltage levels of surface regions each charged to an upper or lower range of potential, the method of unidirectionally shifting bilevel signals across the surface from a first area to an adjacent second area which comprises cyclically performing the steps of: deflecting an electron beam across the surface from the first area to the second area at a predetermined velocity such that as the beam is moved across the surface the surface region beneath the moving beam is maintained at the potential range of the first area to thereby shift a signal from the first area to the second area, and redeflecting the electron beam across the surface from the second area to the first area at a higher velocity such that the shifted signal is not shifted back to the first area but is left at the second area to which it has been advanced.

6. In the process of shifting binary electrical intelligence signals across a secondary electron emissive storage surface of a semiconductive target electrode from which charge is being removed so that areas of the storage surface when charged to an upper range of potential will be rapidly discharged to a lower range of potential thereby tending to maintain the storage surface at the lower range of potential, the method of charging a predetermined area of the storage surface to the upper range of potential whenever an adjacent area of the storage surface is at the upper range of potential, said method comprising the steps of directing a beam of electrons at the adjacent area to maintain the adjacent area at the upper range of potential so long as the electron beam impinges upon the adjacent area, and deflecting the electron beam across the storage surface from the adjacent area to the predetermined area at a sufficiently low velocity to maintain the region of the storage surface beneath the beam at the upper range of potential.

7. In the process of shifting binary electrical intelligence signals across a secondarily emissive storage surface of a semiconductive target electrode from which charge is being removed so that areas of the storage surface when charged to an upper range of potential will be rapidly discharged to a lower range of potential thereby tending to maintain the storage surface at the lower range of potential, the method of charging a predetermined area of the storage surface to the upper range of potential whenever an adjacent area of the storage surface is at the upper range of potential, said method comprising the steps of directing the beam of electrons at the adjacent area to eject secondary electrons from the adjacent area and increase the potential of the adjacent area for expanding at a predetermined initial velocity the boundaries of the surface region at the upper range of potential, and deflecting the electron beam across the storage surface from the adjacent area to the predetermined area at a velocity less than or equal to the predetermined initial velocity to maintain the region of the storage surface beneath the beam at the upper range of potential.

8. A signal shifting apparatus comprising a semiconductive target electrode having a secondary electron emissive surface, means for successively storing applied bilevel electrical intelligence signals on a predetermined initial area of said surface, means for shifting stored signals across said surface from the initial area to a remote area of said surface, and an output electrode electrically coupled to the remote area whereby bilevel electrical signals shifted across said surface to the remote area are presented as corresponding bilevel potential variations at said output electrode.

9. The signal shifting apparatus defined by claim 8, wherein said means for shifting stored signals across said surface includes beam forming apparatus for forming a first electron "holding" beam and directing said "holding beam" at said initial area to regenerate binary electrical intelligence signals stored on the initial area, and beam deflection apparatus for successively deflecting said first "holding" beam back and forth across said surface between the initial area and an adjacent area of said surface, the beam being deflected forward across said surface from the initial area to the adjacent area at a velocity such that during successive forward deflections of the first beam, signals regenerated by said beam at said initial area are successively shifted across said surface beneath the moving beam to the adjacent area.

10. The signal shifting apparatus defined by claim 9 wherein said beam forming apparatus includes means for forming a second electron "holding" beam and for directing said second electron beam at the adjacent area to regenerate signals shifted to the adjacent area by the first electron beam, and said beam deflecting apparatus is operable for successively deflecting said second electron beam back and forth across said surface between the adjacent area and a further adjacent area, the second beam being deflected forward across said surface from the adjacent area to the further adjacent area at a velocity such that during successive forward deflections of the second beam, signals successively regenerated by said second beam at the adjajcent area are successively shifted across said surface beneath the moving beam to the further adjacent area.

11. The signal shifting apparatus defined by claim 8 wherein said surface has a plurality of sequentially adjacent storage means established thereon, said plurality of areas including the initial area and an area adjacent to and sequentially preceding the remote area, and said means for shifting stored signals from the initial area to the remote area includes apparatus for forming a corresponding plurality of electron "holding" beams and for directing said beams at correspondingly associated storage areas respectively of said plurality of areas, and beam deflection apparatus for cyclically deflecting said beams back and forth across said surface in synchronism each beam being deflected back and forth between its respectively associated storage area and a corresponding sequentially adjacent area, each beam being deflected forward across said surface at a sufficiently low velocity to shift signals stored at the associated area across the surface to a sequentially adjacent area, whereby signals originally stored at the initial area are shifted across the surface to a sequentially adjacent area at each cycle of deflection of the beams, stored signals progressing in this manner from area to area until they are shifted to the remote area.

12. A signal shifting apparatus comprising an evacuated container, a semiconductive target electrode positioned within said container and having a secondary electron emissive surface, first means responsive to an applied binary electrical signal for selectively charging an initial area of said surface to an upper or lower range of potential in accordance with the binary signal, second means for forming an electron "holding" beam and for directing said beam at the initial area to bombard the initial area with electrons to maintain the initial area at the potential range which it had immediately before bombardment by said beam, and third means for deflecting said electron beam across said surface away from the initial area at a velocity such as to maintain the region of said surface beneath the beam at the same potential range as the potential range of the initial area from which the beam started its sweep.

13. The signal shifting apparatus defined by claim 12 wherein said apparatus includes fourth means for removing charge from said storage surface to tend to maintain said surface at one of said upper and lower ranges of potential, whereby areas of said surface can only remain charged to the other of said ranges of potential if they are being bombarded by electrons of the "holding" beam so that areas left behind the moving electron beam rapidly discharge to said one range of potential.

14. The signal shifting apparatus defined by claim 13 wherein said third means includes apparatus for redeflecting said electron beam back across said surface in a return sweep to the initial area at a velocity, greater than the first-named velocity, such that as the electron beam sweeps across said surface the beam supplies insufficient electrons to appreciably charge or discharge said surface, whereby areas of said surface traversed by said beam on its return sweep remain at said one range of potential.

15. The signal shifting apparatus defined by claim 12 wherein said apparatus includes fourth means for removing charge from said storage surface to tend to maintain said surface at the lower range of potential whereby areas of said surface can only remain charged to the upper range of potential if they are being bombarded by electrons of the holding beam, so that areas left behind the moving electron beam rapidly discharge to the lower range of potential.

16. The signal shifting apparatus defined by claim 15 wherein said fourth means includes apparatus for redeflecting said electron beam back across said surface in a return sweep to the initial area at a second velocity greater than the first-named velocity such that as the electron beam sweeps across said surface, the beam supplies insufficient electrons to appreciably charge or discharge said surface whereby areas of said surface traversed by said beam on its return sweep remain at the lower range of potential.

17. An evacuated electron discharge device including a charge storage surface having first and second adjacent storage areas, charging means operable for charging said first storage area to a predetermined first range of potential, means for removing charge from said storage surface to tend to maintain said storage surface at a predetermined second range of potential, beam forming means for forming an electron beam and for normally directing said beam at said first storage area to engage said first area when it is at the first range of potential to maintain the first area at the first range of potential, and deflection apparatus actuable for deflecting said beam to said second storage area to charge said second storage area to the range of potential previously maintained at said first storage area.

18. An evacuated electron discharge device including a charge storage surface having first, second and third sequentially adjacent storage areas, charging means operable for charging said first storage area to a predetermined first range of potential, means for removing charge from said storage surface to tend to maintain said storage surface at a predetermined second range of potential, beam forming means for forming first and second electron beams associated with said first and second storage areas respectively and for normally directing each beam at its associated storage area to engage the associated area when it is the first range of potential to maintain the associated area at the first range of potential, and deflection apparatus actuable for deflecting said first and second beams to said second and third storage areas respectively, to charge said second and third storage areas

to the potential ranges previously maintained at said first and second storage areas, respectively.

19. An evacuated electron discharge device including a charge storage surface having a series of first, second, . . . *n*th, *n*+1st storage areas, means operable for charging said first storage area to a predetermined first range of potential, means for removing charge from said storage surface to tend to maintain said storage surface at a predetermined second range of potential, beam forming means for forming first, second, . . . *n*th electron beams associated respectively with correspondingly numbered storage areas and for normally directing each beam at its associated storage area to engage those areas which are at the first range of potential, and deflection apparatus actuable for deflecting said first, second, . . . *n*th electron beams to said second, third, . . . *n*+1st storage areas respectively to charge each of the storage areas to the potential range previously maintained at the immediately preceding storage area in said series of storage areas.

20. In a signal shifting apparatus in which an extended electron "holding" beam is deflected across a secondary emissive storage surface to shift bilevel electrical signals across the surface beneath the moving beam, apparatus for electrically isolating predetermined levels of the storage surface corresponding to associated levels of the extended electron beam so that independent bilevel electrical signals can be shifted across the surface at each of the predetermined levels by the electron beam, said apparatus comprising: conductive striping established on the storage surface and demarking the predetermined levels of the storage surface, and means for maintaining said conductive striping at a predetermined potential such that bilevel electrical signals being shifted across the surface at the predetermined levels cannot propagate across said striping to adjacent levels.

21. In a signal shifting apparatus in which a plurality of extended electron beams are deflected across an inner secondary emissive storage surface of a generally cylindrical target electrode to shift bilevel electrical signals across the surface beneath the moving beams, apparatus for electrically isolating levels of the storage surface to form a long helical track of unobstructed storage surface along which bilevel signals can be shifted by the beams, said apparatus comprising: a helical conductive stripe established on the storage surface, said helical stripe having a plurality of successive turns winding around the storage surface, the successive turns of said conductive stripe defining boundaries for the helical track, and means for maintaining said stripe at a predetermined potential such that bilevel electrical signals being shifted across the surface on the helical track cannot propagate across the bounding turns of said helical stripe.

22. A signal shifting apparatus comprising an evacuated envelope, an electron emissive cathode centrally positioned within said evacuated envelope, a generally cylindrical semiconductive target electrode surrounding said cathode, said target electrode having an inner secondary electron emissive storage surface, a generally cylindrical collector electrode surrounding said cathode and positioned intermediate said cathode and said target electrode, said collector electrode having a plurality of axially extended apertures for forming a corresponding plurality of spaced axially extended electron beams directed at said storage surface of said target electrode, deflection apparatus for generating an axial magnetic field and for cyclically varying said field between upper and lower values so as to correspondingly increase and decrease curvature of the electron beams to sweep the beams back and forth across said storage surface, the plurality of beams being directed at a corresponding plurality respectively of spaced sequentially adjacent axially extended areas of said storage surface when the field is at its lower value, the amplitude of motion of each beam across said surface being equal to the spacing between said areas, first means for normally maintaining said target electrode at a predetermined first potential with respect to said cathode such that the secondary emission ratio of said surface is normally less than 1 when it is bombarded by electrons in said electron beams, second means for storing applied bilevel electrical signals on a region of said storage surface in a predetermined one of said plurality of areas, said second means including apparatus for charging the region whenever the applied bilevel signal is at a predetermined level, to a predetermined second potential such that the region has a secondary emission ratio greater than 1 when it is bombarded by electrons in said electron beams; whereby after storage of a bilevel signal on said region, each cycle of deflection of said beams causes the stored signal to be shifted to a sequentially successive area of said plurality of areas.

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