Oct. 31, 1950 R. E. GRAHAM 2,527,632

STORAGE TUBE

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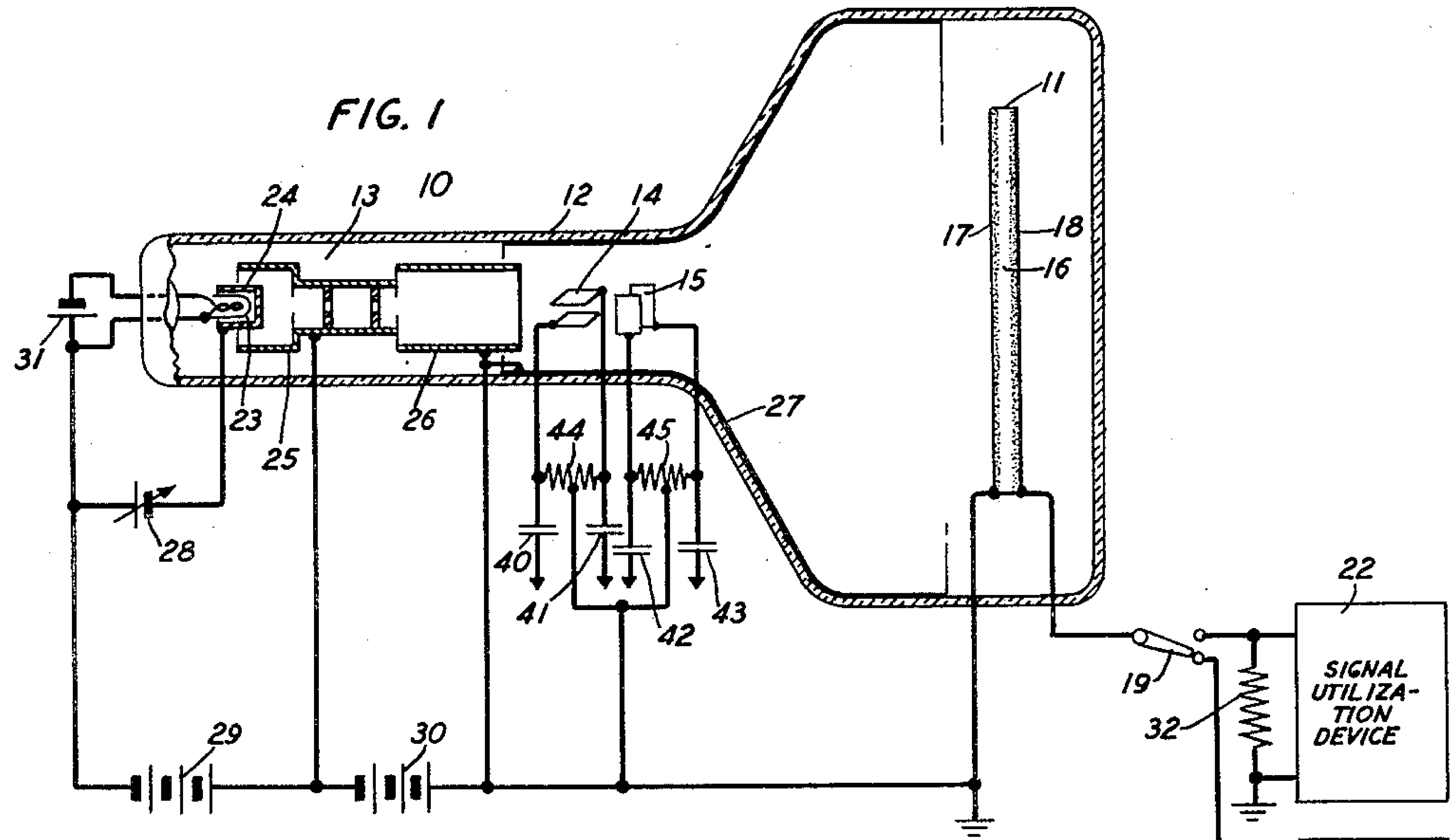
FIG. 1



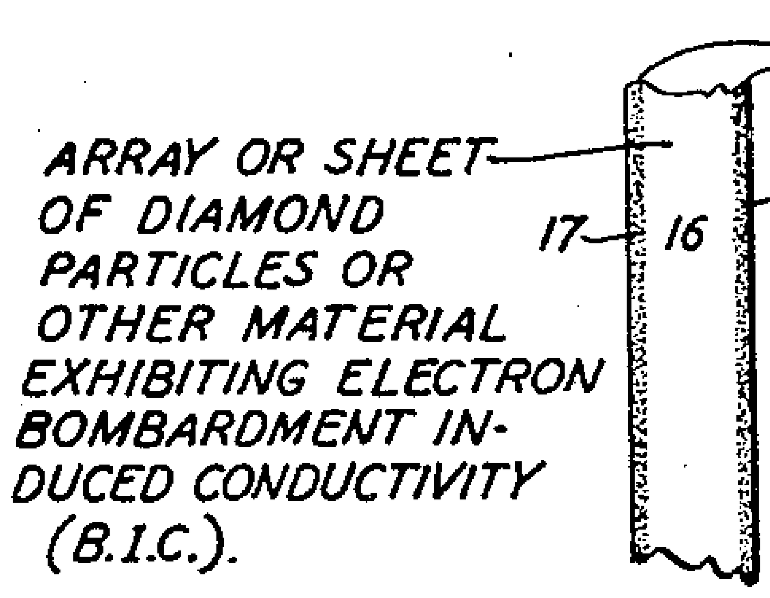


FIG. 2

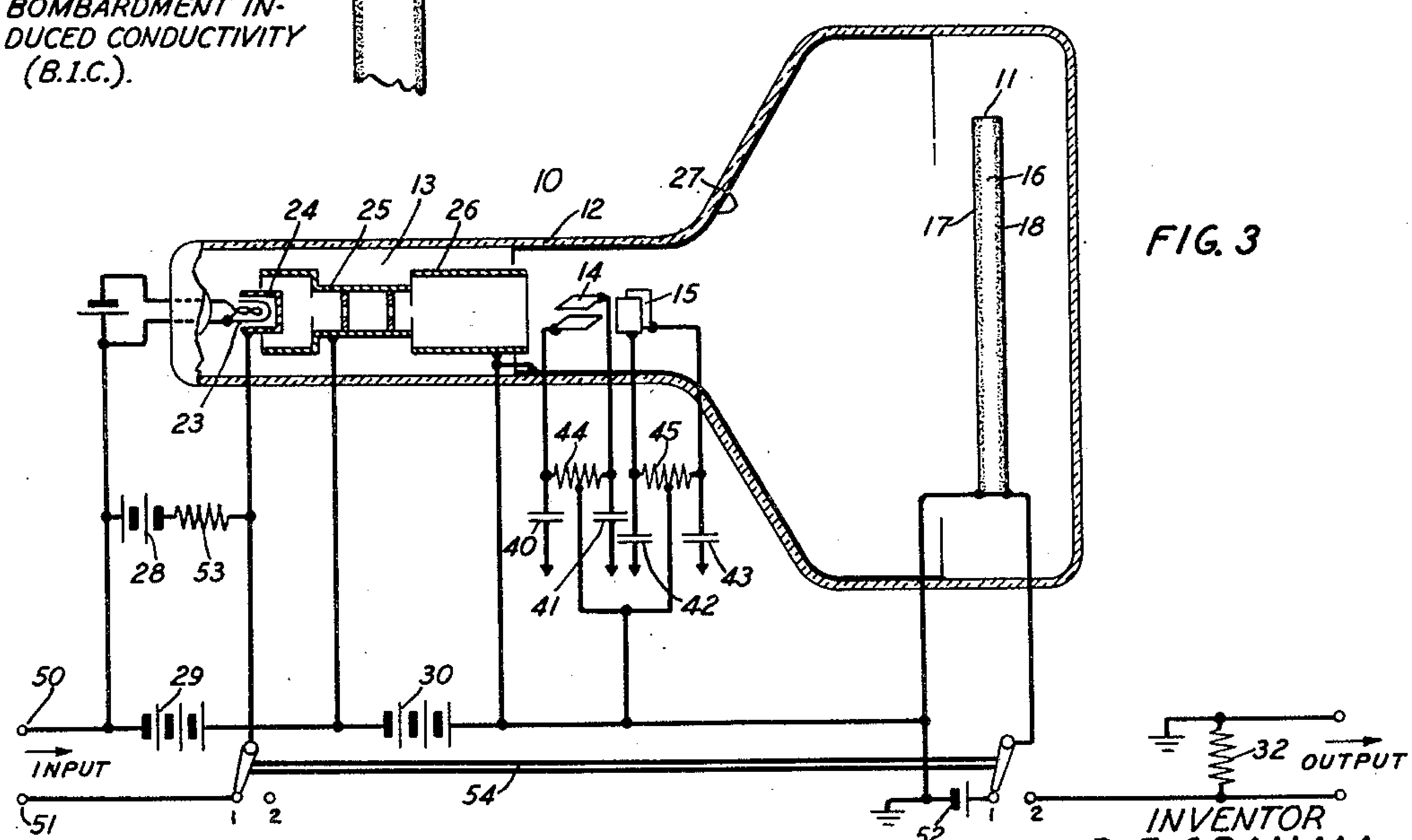


FIG. 3

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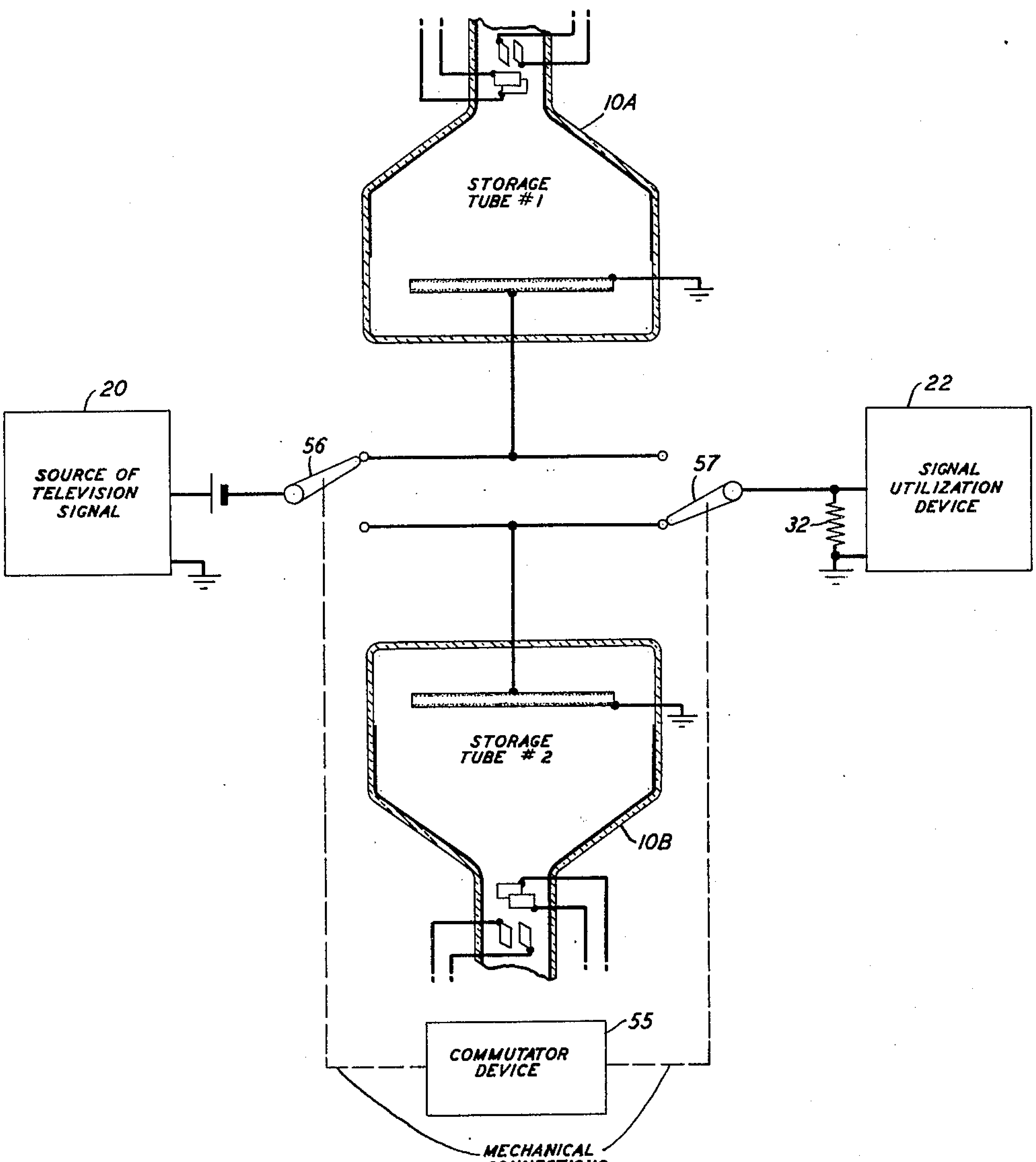
FIG. 4



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STORAGE TUBE

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9 Claims. (Cl. 250—164)

This invention relates to storage devices and more particularly to devices of this character utilizing electron beams for storing and reproducing electrical signals.

It is an object of this invention to utilize in storage tubes of the electron beam type materials exhibiting the property of electron bombardment induced conductivity.

It is another object of this invention to reduce, in storage tubes of this type, the distortions produced by stray secondary electrons.

In the copending applications of D. E. Wooldridge, Serial No. 747,888, filed May 14, 1947, and K. G. McKay, Serial No. 789,667, filed December 4, 1947, there are disclosed various materials which exhibit the property known as bombardment induced conductivity. Each of these materials (such as, for example, diamond, zinc sulphide, magnesium oxide, silicon carbide and stibnite) is normally an insulator but when it is struck by electrons (or other particles, such as alpha or beta particles, for example), it becomes conducting if at the time an electric field exists between opposite surfaces of the insulator. The bombarding particles penetrate the insulator, causing a disruptive separation of the positive and negative charges specific to the atoms which are affected by the bombarding particles. These charges are drawn toward the electrodes producing the electric field and this motion of charges constitutes a conduction current which is in many cases greatly in excess of the current of the bombarding particles.

Diamond is a favored solid insulator for this work (although other materials such as, for example, others mentioned in the Wooldridge and McKay applications can be used) because it can easily be obtained without sufficient impurities or imperfections to affect its high insulation resistance or its conducting properties under bombardment. The carbon atoms therein consist each of a nucleus exhibiting fixed units of positive charge, to which two electrons are tightly bound. This core is surrounded by four valence electrons. The carbon atoms are held together by "electron pair bonds" between adjacent atoms. The insulation resistance is high because the electron bonds are very tight. As a result of this tightness, very few electrons are displaced from their bonds by thermal agitation. This is not the case in, for example, metals, where a large number of electrons are continuously being displaced by thermal agitation and are relatively free to wander through the metal, this, under normal conditions, constituting the usual current in a metallic conducting medium.

When electron bombardment removes a valence electron from its bonds in an insulating target, producing a deficiency of one electron in the atomic structure immediately affected, this localized electron deficiency is called a "hole." Under an applied electric field the arrangement of the electrons is changed, and the location of any given hole will change. As a consequence, the hole can be conveniently regarded as a positive particle which is free to move under the influence of the field. Similarly, the electron freed from the bond in question constitutes a negative particle which is free to move under the influence of the electric field. If there is no applied field, any free electron or positive hole moves in accordance with thermal agitation and consequently has a completely random motion. Under an applied electric field, there is a directional motion superimposed on the random one. The order of mobility of the electrons in diamond is of the order of 1,000 centimeters per second for a field of one volt per centimeter. For a field of 10^4 volts per centimeter the velocity therefore is 10^7 centimeters per second. For a diamond crystal one millimeter thick, the transit time therefore is 10^{-8} seconds. The mobility of the electrons is affected by the number of "traps," that is, the presence of foreign atoms or imperfections in the crystal. If an electron gets into a trap, it takes a greater or less amount of time to get out, depending upon the thermal energy required. Further information on traps and other characteristics of diamond crystals is given in the Wooldridge and McKay applications referred to above.

In accordance with the present invention, there is provided a storage tube of the electron beam type including an electron target embodying material which exhibits the property of electron bombardment induced conductivity. Diamond is the preferred material for reasons given above. More specifically, the storage tube includes a target comprising a layer of diamond or other material exhibiting the property of electron bombardment induced conductivity sandwiched between two thin metal coatings. The signal to be stored is applied as a voltage between the two metal coatings (preferably in series with a constant polarizing voltage) while one of the metal coatings is scanned by a beam of high velocity electrons. The signal is reproduced by removing the voltage between the coatings and rescanning with the beam, the reproduced signal being formed as a voltage across an output resistor.

In a modification, the signal to be stored is utilized to modulate the scanning beam, a constant polarizing voltage being applied across the layer of material exhibiting electron bombardment induced conductivity. To recover the signal, the direct current polarizing voltage is removed and the target is scanned with a constant intensity beam.

The invention will be more readily understood by referring to the following description taken in connection with the accompanying drawing forming a part thereof in which:

Fig. 1 is a schematic representation of a cathode ray storage tube of this invention together with certain of its associated circuits and auxiliary equipment;

Fig. 2 is a schematic view showing, in greatly enlarged form, a portion of the target of the tube shown in Fig. 1;

Fig. 3 shows a modification of the device shown in Fig. 1; and

Fig. 4 is a schematic circuit diagram utilizing two of the devices of Fig. 1.

Referring more particularly to the drawings, Fig. 1 shows, by way of example to illustrate the invention, a cathode ray storage tube **10** employing a target **11** containing material exhibiting the property of electron bombardment induced conductivity. The tube **10** comprises an evacuated container **12** enclosing the target **11**, an electron gun **13** for generating, focussing and accelerating a beam of high velocity electrons toward this target, and two sets of electrostatic deflecting plates **14** and **15** for causing the beam of electrons to scan, for example, every elemental area in turn of a desired field on the target **11**. The target **11**, which will be described below in greater detail with reference to Fig. 2, comprises a layer of material **16** which exhibits the property of electron bombardment induced conductivity sandwiched between two metal layers **17** and **18**. By means of a suitable switch **19**, a source of signals **20** can be connected between the layers **17** and **18**, a polarizing source of potential **21** also being included in this circuit, for the recording operation, and the source **20** removed and a signal utilization device **22** connected across the resistor **32** during the reproducing operation.

The electron gun **13** preferably comprises a cathode **23**, a control electrode or member **24**, a first anode member **25**, and a second and final anode comprising a cylindrical member **26** and a coating **27** of conducting material on the inside walls of the envelope **12** extending from the region of the cylinder **26** to the region of the target **11**. The control electrode **24** is placed at any suitable negative potential with respect to the potential of the cathode **23** by means of an adjustable source **28**, and the first anode **25** and the final anode **26**, **27** are placed at appropriate positive potentials with respect to the cathode **23** by means of the source **29** and the source **30**. As an example, the final anode **26**, **27** can be from 1,000 to 10,000 or more volts positive with respect to the cathode and the first anode **25** can have an appropriate lower positive voltage for proper focussing. Any suitable source **31** can be utilized to heat the cathode **23**. The negative terminal of the source **29** is connected to the cathode **23** and the positive terminal thereof is connected to the first anode **25**, while the negative terminal of the source **30** is connected to the positive terminal of the source **29** and the positive terminal of source **30** is connected to the second anode **26**, **27** and to ground. Batteries have been shown only for convenience in the drawing and it is to be understood that any other means for producing direct voltages can be used instead.

Reference will now be made to Fig. 2 which shows in enlarged scale a portion of the target **11**. Fig. 2 has not been drawn to scale. As mentioned above, the target **11** comprises a thin layer **16** of insulating material which exhibits the property of electron bombardment induced conductivity and which is sandwiched between two thin metal layers **17** and **18**. By way of example, the layer **16** is a very thin cut of diamond or a simulated sheet of diamond formed by a crystalline layer (preferably one particle thick) of diamond chips or diamond dust. Alternatively, the layer **27** can be of any other suitable material exhibiting this desired property. The layer **16** can be of the order of a millimeter thick, for example. The layers **17** and **18** are of any suitable material such as gold, silver, platinum or aluminum, for example.

The layer **17** is connected directly to ground while the layer **18** is connected to the switch **19**. The upper contact of the switch member **19** is connected to the signal utilization device **22** while the lower contact thereof is connected through the biasing source of potential **21** to the source of signals **20**. When the switch **19** is in its lower position, signals are being recorded on the target **11** of the tube **10** and when the switch **19** is operated to its upper position (as by, for example, suitable commutating or controlling means) the reproduced signal is applied to the signal utilization device which may be, for example, an amplifier or an oscilloscope, or another tube like the device **10** if it is desired to produce further delay, or any other suitable device utilizing reproduced signals.

The high velocity beam produced by the gun **13** is deflected over a desired area on the target **11** by means of appropriate potentials applied to the deflecting plates **14** and **15** by electrostatic sweep circuits (not shown). As examples of satisfactory sweep circuits if the signal to be stored is a television or video signal corresponding to one complete frame, reference is made to Patent 2,178,464 issued October 31, 1939, to M. W. Baldwin, Jr., which discloses balanced electrostatic sweep circuits suitable for this purpose. Connections can be made from the balanced sweep circuits to the pairs of plates **14** and **15** by means of coupling condensers **40**, **41**, **42** and **43**, respectively, of about one microfarad capacity each. Coupling resistances **44** and **45**, of the order of many megohms each, are respectively connected across the pairs of plates **14** and **15**. The midpoints of the resistances **44** and **45** are connected to the positive terminal of the source **30** so that the average of the potentials of the deflecting plates does not deviate more than slightly from the potential of the anode **26**, **27**. This relationship is maintained to avoid changes in the sensitivity of the deflecting systems and the consequent distortion of the image which would otherwise result. For a more complete description of the advantages of balanced sweep circuits for use with cathode ray television tubes, reference is made to the above-mentioned Baldwin patent and also to Patent 2,209,199 issued July 23, 1940, to Frank Gray. The sweep circuits have the desired circuit constants and are so synchronized as to produce the type of scanning desired.

The operation of the device shown in Fig. 1 will now be described. The signal to be stored which may be, for example, a television video signal corresponding to a complete frame, is applied between the metal layers 17 and 18 positioned on opposite sides of the layer 16 which possesses the property of electron bombardment induced conductivity, the circuit starting with ground and passing through the source of signals 20, the polarizing source 21 (which may be polarized in either direction), switch 19 through its lower contact, metal layer 18, crystalline layer 16, and metal layer 17 back to ground. With the switch member 19 in its lower position, the source of signals 20 is connected in the circuit while the signal utilization device 22 is disconnected therefrom. While the signals from the source 20 are applied across the member 16, the member 16 is scanned (through the metal coating 17) by the high velocity electron beam produced by the electron gun 13. The scanning beam bombards, an elemental area at a time, the material 16 through the metal coating 17 and induces conductivity in each elemental region in turn. The freed charges in the material 16 moves under the influence of the polarizing field set up by the instantaneous intensity of the signal to be recorded. During this elemental period, a fraction of the freed charges are trapped in characteristic imperfections in the crystal structure of the material 16, setting up a local field opposing the signal from the source 20. The concentration of charges and thus the strength of the stored field varies over the area being scanned according to the instantaneous values of the signal from the source 20 during the scan.

During the recovery operation, the switch 19 is moved to its upper position, connecting the output resistor 32 between the layer 18 and ground and disconnecting the source of signals 30 and the polarizing source 21 from layer 18, and the high velocity beam is again caused to scan the crystal layer 16 and set up point-by-point conductivity between the two metal electrodes 17 and 18. The current which flows for any given beam position depends upon the polarizing field strength due to the local trapped charges. This current flow produces an instantaneous voltage drop across the resistor 32 corresponding to the signal strength at this element during the recording operation. The current flow during the recovery period is in the opposite direction to that occurring during the storage interval and acts to neutralize the trapped charges. The flow of current through the resistor 32 produces a voltage drop which is applied to the signal utilization device 22.

Another way in which the signal can be stored is to use the signal to modulate the scanning beam current using a constant polarizing voltage across layer 16. Such an arrangement is shown in Fig. 3. The signal to be stored is applied between the terminals 50 and 51 to cause the instantaneous intensity of the beam to be varied in accordance with the corresponding signal strength, a steady polarizing source 52 being applied between metal layers 17 and 18. This causes a pattern of trapped charges to be set up in the layer 16. To recover the signal, the direct current polarizing voltage source 52 is removed by moving switch 54 from its first to its second position, this switch movement also removing the input signals leaving a steady beam control voltage. Thus the crystal layer 16 is scanned with a steady beam and the reproduced (delayed) signal appears across the resistor 32 which can be connected to a signal utilization device 22, as in Fig. 1. Except for the differences above noted, the apparatus and the method of operation of Fig. 3 are the same as in the arrangement of Fig. 1.

An important advantage of the type of storage tube shown in Figs. 1 and 3 lies in its relative freedom from stray secondary emission troubles.

One application of the storage tube 10 is to delay a television or video signal by a frame time. For this purpose a pair of storage tubes 10A and 10B is used, each one being used alternately for storage and for reproduction, one being recording when the other is reproducing and vice versa. Fig. 4 illustrates this use for the storage method of Fig. 1 (an analogous circuit can be used if the method of Fig. 3 is utilized). In either case, the synchronizing signals associated with the incoming signal are used to trigger off the sweep signals supplied to the deflection input terminals (see elements 40, 41, 42, and 43 of Fig. 1 or Fig. 3). The sweep waves are of the conventional saw-tooth wave type which are used in receiving cathode-ray picture tubes. When storage tube 10A is being used for recording, as shown in Fig. 4, tube 10B is being used to pick up or reproduce the frame period of signals previously recorded thereon. At the end of each frame time, the functions of the two tubes 10A and 10B are interchanged. Any suitable commutator device 55, cooperating with switches 56 and 57, can be used to switch the tubes 10A and 10B after each frame time. Any well-known means for synchronizing the commutator device with the sweep circuits (not shown) can be used. If desired, the devices 55, 56 and 57 can be replaced by suitable electronic switching means.

Various other modifications can be made in the embodiments described above without departing from the spirit of the invention the scope of which is indicated in the claims. The specific potentials applied to the various elements are herein given merely by way of example and it is to be understood that their values may be made materially different without changing the general method of operation of the devices described herein. For example, the type of crystal used and its thickness materially affect the operating potentials required.

What is claimed is:

1. A device for the storage of electric signals comprising a target for electrons including an array of particles of an electrically insulating material which has the property of becoming electrically conducting when bombarded with electrons, conducting surfaces on respectively opposite sides of said array and in contact therewith, respective connections to said conducting surfaces, and means including a source of direct potential for applying a voltage between said respective connections.

2. A device for the storage of electrical signals comprising a target for electrons including material which is normally electrically insulating but which has the property of becoming electrically conducting when bombarded with electrons, and means including a source of direct potential for applying a signal voltage to be stored between two respectively opposite surfaces of said material.

3. A device for the storage of electrical signals comprising a target for electrons including material which is normally electrically insulating but

which has the property of becoming electrically conducting when bombarded with electrons, electric circuit means for applying a signal voltage to be stored between two respectively opposite surfaces of said material, and means separate from said signal applying means for scanning said target with a beam of electrons.

4. A device for the storage of electrical signals comprising a target for electrons including a layer of electrically insulating material which has the property of becoming electrically conducting when bombarded with electrons, means including a source of direct potential for applying a voltage across said layer, and means for scanning said layer with a modulated beam of electrons.

5. A recorder and reproducer of signals comprising a target for electrons including a layer of an electrical insulator which possesses the property of becoming an electrical conductor when bombarded with electrons, electric circuit means for applying a signal to be stored to said layer, means for forming a beam of electrons and for causing it to strike said target as said signals are being applied thereto, thereby trapping a charge in said target proportional to the intensity of the signal, and means for utilizing said trapped charge at a later time to control the production of signals.

6. A tube for the storage of electrical signals comprising a target for electrons including material which is normally electrically insulating but which has the property of becoming electrically conducting when bombarded with electrons, two metal coatings on respectively opposite surfaces of said material, means for applying a signal voltage to be stored between said two metal coatings, and means for scanning said target with a beam of electrons.

7. A tube for the storage of electrical signals comprising a target for electrons including material which is normally electrically insulating but which has the property of becoming electrically conducting when bombarded with electrons, electric circuit means for applying a voltage between two respectively opposite surfaces of said material, and means separate from said electric circuit means for scanning said target with a modulated beam of electrons.

8. A tube for the storage of electrical signals comprising a target for electrons including material which is normally electrically insulating but which has the property of becoming electrically conducting when bombarded with electrons, two metal coatings on respectively opposite surfaces of said material, means for applying a voltage between said two coatings, and means for scanning said target with a beam of electrons.

9. A tube for the storage of electrical signals comprising a target for electrons including material which is normally electrically insulating but which has the property of becoming electrically conducting when bombarded with electrons, two metal coatings on respectively opposite surfaces of said material, means for applying a voltage between said two coatings, and means for scanning said target with a modulated beam of electrons.

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