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BISTABLE ELECTRO-OPTICAL NETWORK

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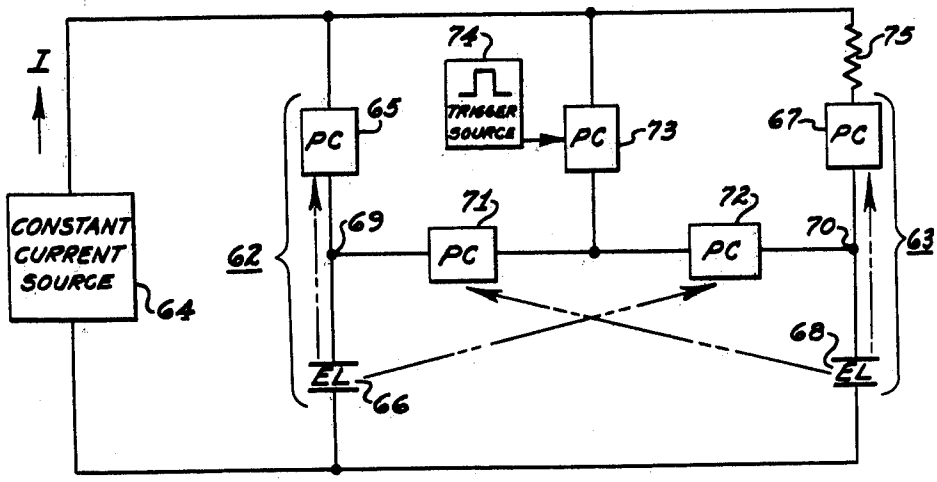


Fig. 1

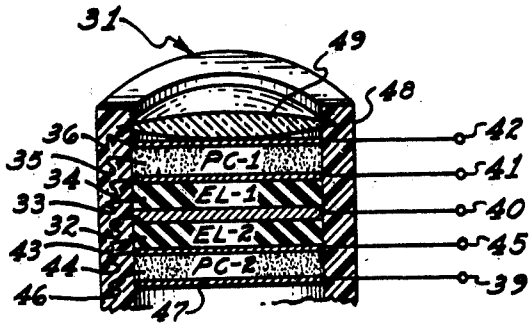


Fig. 2

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BISTABLE ELECTRO-OPTICAL NETWORK

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Original application Dec. 27, 1957, Ser. No. 705,680, now Patent No. 2,997,596, dated Aug. 22, 1961. Divided and this application Jan. 19, 1961, Ser. No. 83,730

6 Claims. (Cl. 250—208)

This invention relates to bistable electro-optical networks, and more particularly to electrical networks including electroluminescent phosphors and photoconductors as elements thereof and adapted to operate in either one of two stable states.

The phenomenon of electroluminescence upon which the operation of the networks of the present invention in part depends is the process by which certain semiconducting materials, known as phosphors, emit radiation under the primary stimulus of an applied electrical field or potential. For a survey and bibliography on the subject of electroluminescence, reference is made to an article by G. Destriau and H. F. Ivey, "Electroluminescence and Related Topics," Proceedings of the Institute of Radio Engineers, vol. 43 (1955), pp. 1911–1940.

As noted in the above article electroluminescent phosphors have in the past been used as light sources in devices frequently called electroluminescent capacitors or electroluminescent cells. Such devices often resemble a flat plate capacitor and may comprise two parallel planar electrodes which have sandwiched between them, in one form or another, an electroluminescent phosphor. The phosphor may be in the form of microcrystals suspended in a transparent plastic or dielectric binder. Alternatively, the phosphor may be in the form of a continuous, transparent crystalline layer such as that disclosed in U.S. Patent No. 2,709,765 to L. R. Koller, or in the form of single crystals as disclosed in U.S. Patent No. 2,721,950 to Piper and Johnson. In general the microcrystal-in-plastic type of phosphor dielectric exhibits electroluminescence only under excitation by alternating electric fields, whereas in the two patents referred to above, the phosphors exhibit electroluminescence when excited by either alternating or unidirectional electric fields. The carrier-injection electroluminescence described in the aforementioned article is a type of electroluminescence excited by unidirectional electric fields.

Prior known electro-optical networks employing both electroluminescent phosphors and photoconductors disposed and interconnected for mutual cooperation have been used as amplifiers or oscillators, etc. Networks of this type are shown in U.S. patent application Serial No. 585,027 now Patent No. 2,904,696 by R. E. Halsted and J. F. Elliott and U.S. patent application Serial No. 585,052 by C. F. Spitzer now Patent No. 2,975,290, both applications being assigned to the assignee of the instant application.

The term "photoconductor" as used herein is intended to apply to any material the impedance or conductivity of which varies as a function of the radiation emitted by a particular associated electroluminescent phosphor. A photoconductor is said to be in "radiation-coupled relationship" with an electroluminescent phosphor when they are so related that the impedance or conductivity of the photoconductor varies as a function of the radiation emission of the electroluminescent phosphor. Further, the network in which the photoconductor and the electroluminescent phosphor are included will be said to be an "electro-optical network" when there is an interaction in the network between electrical energy and radiant or light energy.

An electroluminescent cell and a photoconductor connected in electrical series relation and positioned in radiation-coupled relationship may be termed an "electro-optical pair," for purposes of this specification. Such an electro-optical pair, when connected across a predetermined value of voltage is adapted to be bistable; that is, the pair will draw only one of two possible values of current, one high and one low. Correspondingly, the intensity of radiation emitted from the electroluminescent cell will be high or low, depending on whether the value of current is high or low. When the electro-optical pair is in its "dark" state (emission from the electroluminescent cell is low), application of an external radiation signal to the photoconductor will switch the pair to its other state. If two such independently stable electro-optical pairs are so mutually interrelated that proper signal feedback is transmitted from one pair to the other, a novel apparatus is obtained that has two stable states and is adapted to be shifted from either one of its stable states to the other by application of a radiation trigger signal to the respective photoconductor coupled to the "dark" electroluminescent cell. Such a bistable apparatus is extremely useful, especially in digital computers for register and counter elements. When used as a register element, the two stable states would be designated respectively as the binary digits 1 and 0. Input radiation triggering means is provided to independently switch the device to either of its stable states. When used as a counter element, the device is switched from the stable state in which it is operating to its other stable state upon application of a common input trigger signal; that is, the device would return to a particular stable state after each two input trigger signals.

A bistable device employing these electroluminescent phosphors has the additional desirable feature of providing a visible indication of the state of the device. Thus, one electroluminescent phosphor glows only when the network is in one of its two stable states and the other electroluminescent phosphor glows only when the network is in the other stable state.

It is therefore a principal object of this invention to provide a bistable device comprising two mutually interrelated electro-optical pairs.

Another object of this invention is to provide a novel bistable electro-optical network.

Another object of this invention is to provide an electrical network including electroluminescent phosphors and photoconductors as elements thereof and adapted to operate in either one of two stable states.

Another object of this invention is to produce an output signal from an electro-optical network in response to every two input signals.

Another object of this invention is to provide an electrical network including electroluminescent phosphors and photoconductors as elements thereof and adapted to operate in either one of two stable states, wherein the particular phosphors luminescing are indicative of the stable state in which the network is operating.

The foregoing objects are achieved by providing networks having first and second electro-optical pairs connected in parallel. A source of electrical energy is coupled across the parallel-connected electro-optical pairs. A point of the first electro-optical pair between the electroluminescent cell and the photoconductor thereof is coupled to a point of the second electro-optical pair between the electroluminescent cell and the photoconductor thereof. This coupling between the first and second electro-optical pairs is one means whereby feedback is provided so that the network can operate in only one of two stable states; that is, wherein the "on" electro-optical pair draws relatively large current and its electroluminescent phosphor emits a relatively intense radiant energy signal, and the "off" electro-optical pair draws

relatively little current and its electroluminescent phosphor emits relatively little, if any, radiant energy. Upon application of a radiant energy trigger signal to the photoconductor of the "off" electro-optical pair the network shifts to its other stable state. In this other stable state the formerly "off" electro-optical pair is "on" and vice versa.

The invention will be described with reference to the accompanying drawings, wherein:

FIGURE 1 is a circuit diagram of the bistable network of this invention, including one form of triggering means;

FIGURE 2 is a perspective view, partly in section, of an electro-optical pair useful in the circuit of FIG. 1.

In the bistable network of FIG. 1 an electro-optical pair **62** is connected in parallel with an electro-optical pair **63**. Pair **62** comprises a series-connected electroluminescent cell **66** and photoconductor **65** positioned in radiation-coupled relationship indicated by the arrow and broken line between them. The arrows and broken lines elsewhere in FIG. 1 indicate the same radiation-coupled relationship and this convention will be employed throughout this application. Electro-optical pair **63** comprises a series-connected electroluminescent cell **68** and photoconductor **67** positioned in radiation-coupled relationship. Appropriate feedback, to be described hereinafter, causes this network to operate in only one of of two stable states.

Examples of electro-optical pairs useful in the circuit of FIG. 1 are shown and described in the aforementioned U.S. patent application Serial No. 585,052 by C. P. Spitzer. A device **31** including such an electro-optical pair is shown in FIG. 2. Device **31** is adapted to receive either or both electrical and light input signals and to produce either or both electrical and light output signals. In device **31** an electrode **32** consists of a rigid opaque metallic member serving as both an electrode and a supporting member and which is preferably polished for maximum light reflection. Deposited on one side of electrode **32** are an electroluminescent layer **33**, a light-transmitting electrode **34**, a photoconductive layer **35**, and a light-transmitting electrode **36**. Deposited on the other side of electrode **32** is an electroluminescent layer **43**, a light-transmitting electrode **44**, a photoconductive layer **46** and a light-transmitting electrode **47**. Lead wires are soldered or otherwise electrically connected to each electrode.

Electroluminescent layer **33** and adjacent electrodes **32** and **34** comprise an electroluminescent cell EL–**1**, and electroluminescent layer **43** and adjacent electrodes **32** and **44** comprise another electroluminescent cell EL–**2**. The above two electroluminescent cells are connected in series by the common electrode **32** so as to make the cells EL–**1** and EL–**2** effectively one electroluminescent cell which is in radiation-coupled relation with two photoconductors for reasons that will appear later. Similarly, photoconductive layer **35** and its electrodes **34** and **36** comprise one photoconductor PC–**1** and the photoconductive layer **46** and its electrodes **44** and **47** comprise a second photoconductor PC–**2**. A casing **48** which consists of the light-opaque, electrically-insulating material is used to support the cells, photoconductors and a lens **49** adjacent electrode **36**.

It should be understood that the word "light," as used in this application, includes any radiation emitted by an electroluminescent phosphor to which a photoconductor is responsive and may for example, include ultraviolet or infrared radiation.

Light-transmitting, electrical conducting electrodes **34** and **36** may be layers of titanium dioxide or tin oxide, commonly referred to as conducting glass. Alternatively, a very thin light-transmitting layer of evaported metal, such as aluminum or silver, may be used. If the light-transmitting, electrical conducting electrodes are titanium dioxide they may be prepared and rendered conductive in accordance with the teachings of U.S. Patent No. 2,717,844 to L. R. Koller.

Electroluminescent layers **33** and **43** may be phosphors such as zinc sulfide activated by three-tenths percent by weight of copper and written as ZnS:Cu, prepared as a continuous crystalline layer, as disclosed in the above-mentioned patent 2,709,765 to L. R. Koller, or single crystalline phosphors of the type disclosed in the above-mentioned Patent 2,721,950 to Piper and Johnson. These types of electroluminescent layers are responsive to both direct or alternating electric fields. The average brightness B of the light output of an electroluminescent phosphor as a function of the voltage V_c applied to it may be closely approximated by the expression,

$$B=kV_c^n \tag{1}$$

where n is a constant characteristic of the particular electroluminescent phosphor used and k is a constant of proportionality. Values of n, in Equation 1, range approximately from 1 to 7 for known phosphors.

Photoconductive layers **35** and **46** are thin light-permeable layers of photoconductive material. The material may, for example, comprise cadmium sulfide or lead sulfide, which may be sprayed, sputtered, or evaporated on one of the light-transmitting electrodes **34** or **36** and **44** or **47**. More generally, photoconductive layers **35** and **46** may, for example, consist of any of the sulfides, selenides, or tellurides of cadmium, lead, or zinc, or may be any other known photoconductor.

The physical arrangement of the device **31** is such that light emitted by electroluminescent cell EL–**1** falls on photoconductor PC–**1**. This cell and photoconductor are connected in electrical series relation between terminals **40** and **42**, and therefore constitute an electro-optical pair such as pair **62** or **63** (FIG. 1). The current drawn by this pair depends on the voltage applied to the terminals **40** and **42** and the amount of external radiation applied to photoconductor PC–**1** through lens **49**.

It will be noted with reference to FIG. 1 that electroluminescent cell **66**, for example, is indicated as being in radiation-coupled relationship with two different photoconductors **65** and **72**. Therefore, the device **31** of FIG. 2 includes two series connected electroluminescent cells composed of electroluminescent layers **33** and **43** with their common opaque electrode **32** and their respective light transmitting electrodes **34** and **44**. Each of electroluminescent cells EL–**1** and EL–**2**, is radiation-coupled to its respective photoconductor indicated generally by PC–**1** and PC–**2**. The relationship between the diagrammatic illustration of FIG. 1, for example, and the physical embodiment of FIG. 2 may be understood, by noting that there is one device **31** for each of the electro-optical pairs **62** and **63** (FIG. 1) and their radiation-coupled photoconductors **72** and **71**, respectively.

Referring once more to FIG. 1, electro-optical pairs **62** and **63** are connected in parallel across a source of electrical energy, such as constant current source **64**. Electro-optical pair **62** comprises a photoconductor **65** and an electroluminescent cell **66** connected in series. Electro-optical pair **63** comprises a photoconductor **67** and an electroluminescent cell **68** connected in series. A connection point **69** is provided between photoconductor **65** and electroluminescent cell **66** and a connection point **70** between photoconductor **67** and electroluminescent cell **68**. A pair of series-connected photoconductors **71** and **72** is connected between points **69** and **70**. Photoconductors **71** and **72** are positioned in radiation-coupled relationship with respective electroluminescent cells **68** and **66**. The network is switched from one stable state to another upon application of a radiation input trigger signal from a trigger source **74** to a photoconductor **73** connected between the photoconductor ends of electro-optical pairs **62** and **63** and the common connection point of the series-connected photoconductors **71** and **72**.

In the operation of the circuit of FIG. 1, current I from source **64** substantially divides between electro-optical pairs **62** and **63**. The network is in its designated first

stable state when electro-optical pair 62 is "on" and in its designated second stable state when electro-optical pair 63 is "on."

Assume now that the circuit is in its first stable state. Electroluminescent cell 66 is lighted and illuminates photoconductors 65 and 72. Electroluminescent cell 68 is dark and consequently photoconductors 67 and 71 are not illuminated and have a high resistance. The greater portion of current I therefore flows through electro-optical pair 62. Upon application of a rediation input trigger signal from trigger source 74 to photoconductor 73, a relatively low resistance is provided for current flow through photoconductors 73 and 72 to electroluminescent cell 68. The impedance of photoconductors 72 and 73 in parallel with the decreasing impedance of photoconductor 67 provide an impedance which is low as compared with that of photoconductor 65. The light output of electroluminescent cell 68 thereupon tends to increase and the resistance of radiation-coupled photoconductor 67 tends to decrease so that a greater portion of current I is drawn through electro-optical pair 63. The increase of current through electro-optical pair 63 is accompanied by a decrease in current through electro-optical pair 62, a consequent decrease in the light output of electroluminescent cell 66, and a consequent increase in the resistance of photoconductor 65. The current in electro-optical pair 63 continues to increase and that in electro-optical pair 62 continues to decrease while the radiation input trigger signal is applied to photoconductor 73, until electro-optical pair 63 has reached its stable "on" condition and electro-optical pair 62 has reached its stable "off" condition. At this time the circuit is in its second stable state. Upon application of the next radiation input trigger signal to photoconductor 73, passage of current through photoconductor 71, which has been illuminated by electroluminescent cell 68, serves to change the state of the network once again. Thus, the network of FIG. 1 is changed from one stable state to the other by application of an electrical signal to the "off" electro-optical pair.

Photoconductors 71 and 72 must have response times relatively slow compared to the time necessary for the network to switch from one stable state to the other in order that their resistances remain either high or low sufficiently long for the switching operation to reach completion.

A resistor 75 is included in series relationship with electro-optical pair 63 and serves to effectuate resetting or initial setting of the bistable circuit upon the respective removal and reapplication or initial application of the source of current. With the source of current 64 removed, both electro-optical pairs 62 and 63 are "off." When current source 64 is applied to the network, current increases more rapidly in electro-optical pair 62 than in electro-optical pair 62. Thus the network will assume its first stable state.

In the above description of the operation of the circuit of FIG. 1 it may be seen that electro-optical pairs 62 and 63 connected in parallel to constant current source 64 constituted a bistable network. Feedback is provided by the high internal impedance of constant current source 64. It is within the scope of this invention to provide other means for electrically triggering this bistable network than that shown in FIG. 1. Furthermore, this triggering means may be applied so that the network operates as either a register element or as a counter element.

A theory of the operation of the bistable apparatus of this invention, as presently understood, and a method of determining certain circuit parameters are described in a copending application Serial No. 705,680, filed December 27, 1957 now Patent No. 2,997,596, August 22, 1961, from which the present application has been divided.

While the principles of the invention have now been made clear in illustrative embodiments, there will be immediately obvious to those skilled in the art many modifications in structure, arrangement, proportions, the elements, materials, and components, used in the practice of the invention, and otherwise, which are particularly adapted for specific environments and operating requirements, without departing from those principles. The appended claims are therefore intended to cover and embrace any such modifications, within the limits only of the true spirit and scope of the invention.

What is claimed is:

1. A signal responsive network comprising a pair of electrical circuit branches, each of said branches comprising an electroluminescent cell and a photoconductor connected in series, one end of each of said branches being connected to a first common point, the other end of each of said branches being connected to a second common point, the electroluminescent cell and the photoconductor of one of said branches being positioned in radiation-coupled relationship, and the electroluminescent cell and the photoconductor of the other of said branches being positioned in radiation-coupled relationship, a resistor connected in series in one of said pair of branches, a feedback means coupled between the first and second electro-optical pairs for providing feedback which causes the network to operate in only one of two stable states when a constant current source is connected in parallel with said pair of electrical circuit branches, and means for connecting a constant current source in parallel with said pair of electrical circuit branches.

2. A counter network element comprising at least five electrically distinct connection points, a first photoconductor connected between the first and second of said points, a first electroluminescent cell connected between the second and third of said points, a second photoconductor connected between the first and fourth of said points, a second electroluminescent cell connected between the third and fourth of said points, the first electroluminescent cell and the first photoconductor being further positioned in radiation-coupled relationship, the second electroluminescent cell and the second photoconductor being further positioned in radiation-coupled relationship, a third photoconductor connected between the second and fifth of said points, a fourth photoconductor connected between the fourth and fifth of said points, the first electroluminescent cell being further positioned in radiation-coupled relationship with the fourth photoconductor, the second electroluminescent cell being further positioned in radiation-coupled relationship with the third photoconductor, and a fifth photoconductor connected between the first and fifth of said points.

3. A network element as defined in claim 2 further including a constant current source, and means for connecting said source to said first and third points.

4. A network element as defined in claim 3 further including triggering means positioned in radiation-coupled relationship with said fifth photoconductor and adapted to apply a radiation input trigger signal thereto.

5. A binary counter network comprising a first electroluminescent cell and a first photoconductor electrically connected in series, said first electroluminescent cell being positioned in radiation-coupled relationship with said first photoconductor, a second electroluminescent cell and a second photoconductor electrically connected in series, said second electroluminescent cell being positioned in radiation-coupled relationship with said second photoconductor, a third photoconductor positioned in radiation-coupled relationship with said second electroluminescent cell and having one terminal connected to a junction between said first electroluminescent cell and said first photoconductor, a fourth photoconductor positioned in radiation-coupled relationship with said first electroluminescent cell and having one terminal connected to a junction between said second electroluminescent cell and said second photoconductor, means for connecting a constant current source in parallel with the two series circuits consisting of said first electroluminescent cell in series with

said first photoconductor and said second electroluminescent cell in series with said second photoconductor, and switching means connected to a second terminal of said third photoconductor and to a second terminal of said fourth photoconductor for momentarily coupling said third and fourth photoconductors in parallel with said first and second photoconductors, respectively.

6. A binary counter network as defined in claim 5 wherein said switching means consists of a fifth photoconductor and triggering means positioned in radiation-coupled relationship with said fifth photoconductor for applying a radiation input trigger signal thereto.

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