Feb. 25, 1969 JAMES E. WEBB 3,430,063
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SOLID STATE SWITCH

Filed Sept. 30, 1966

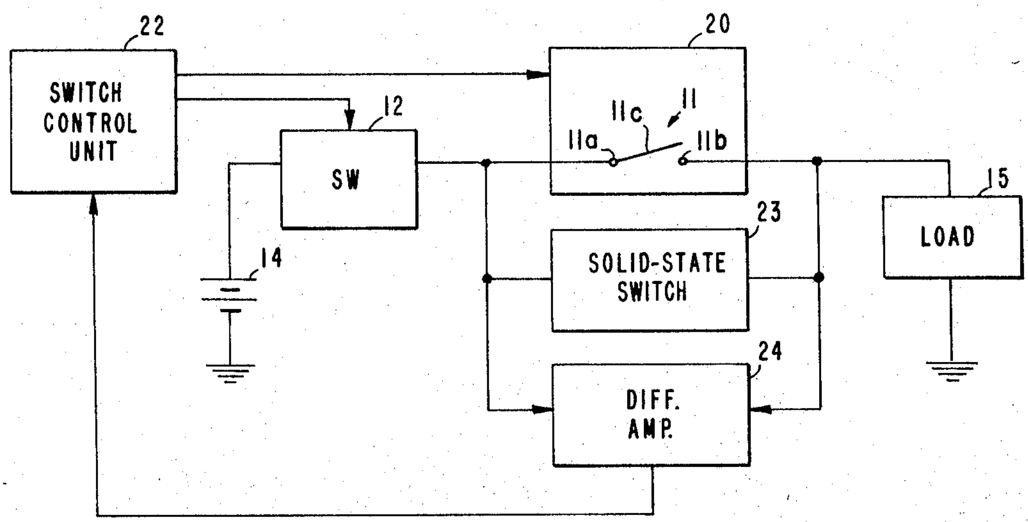

FIG. 1

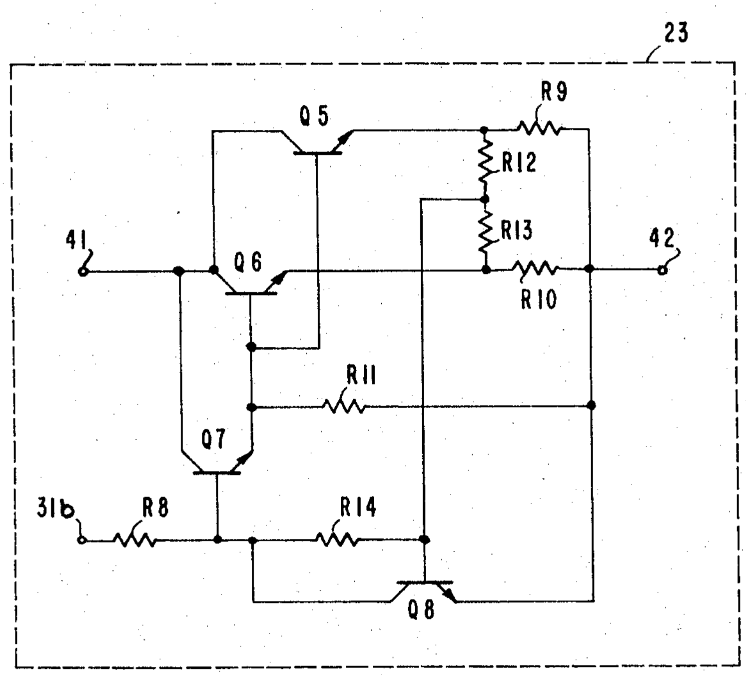

FIG. 4

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Filed Sept. 30, 1966 Sheet 2 of 3

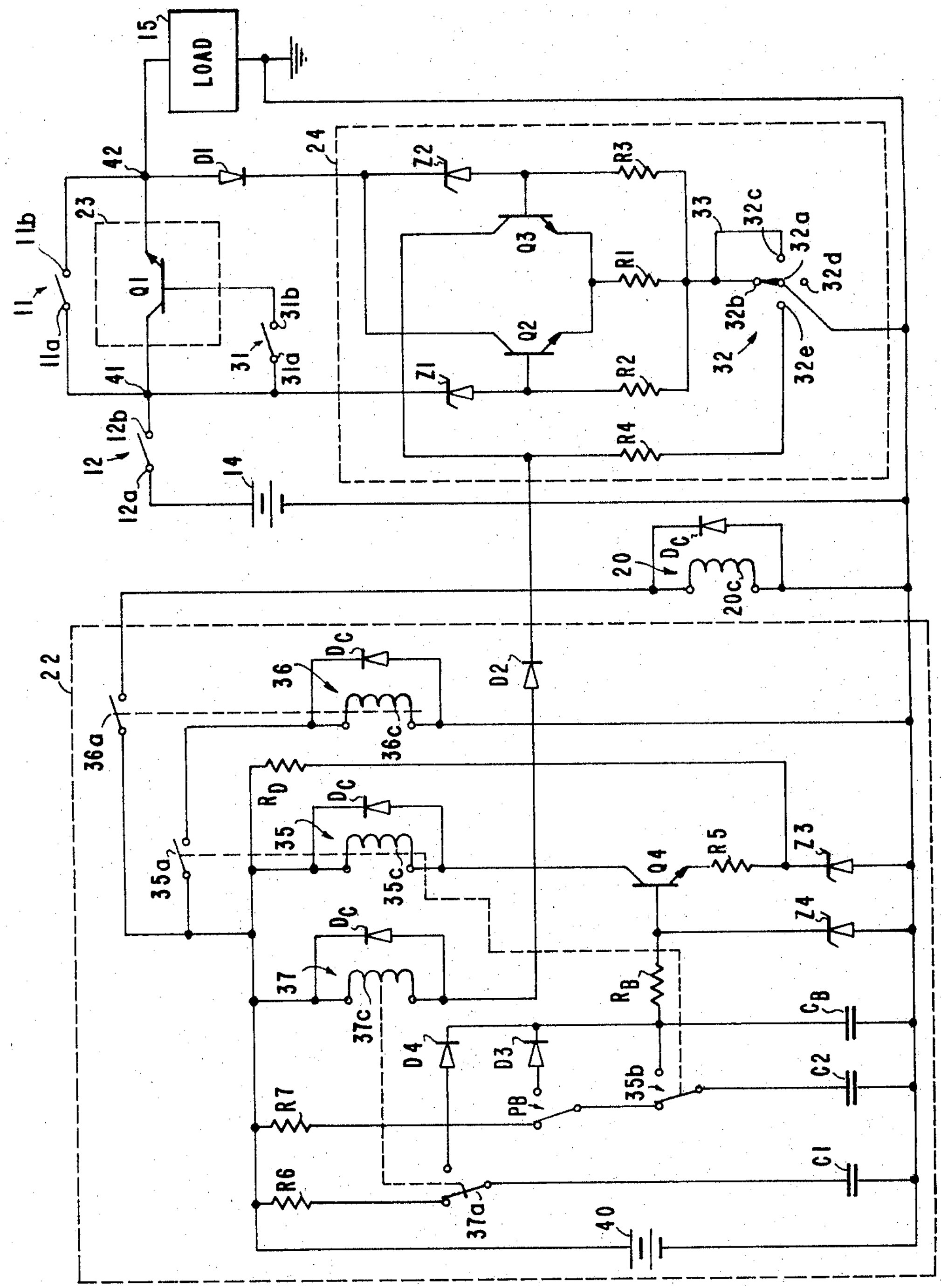

FIG. 2

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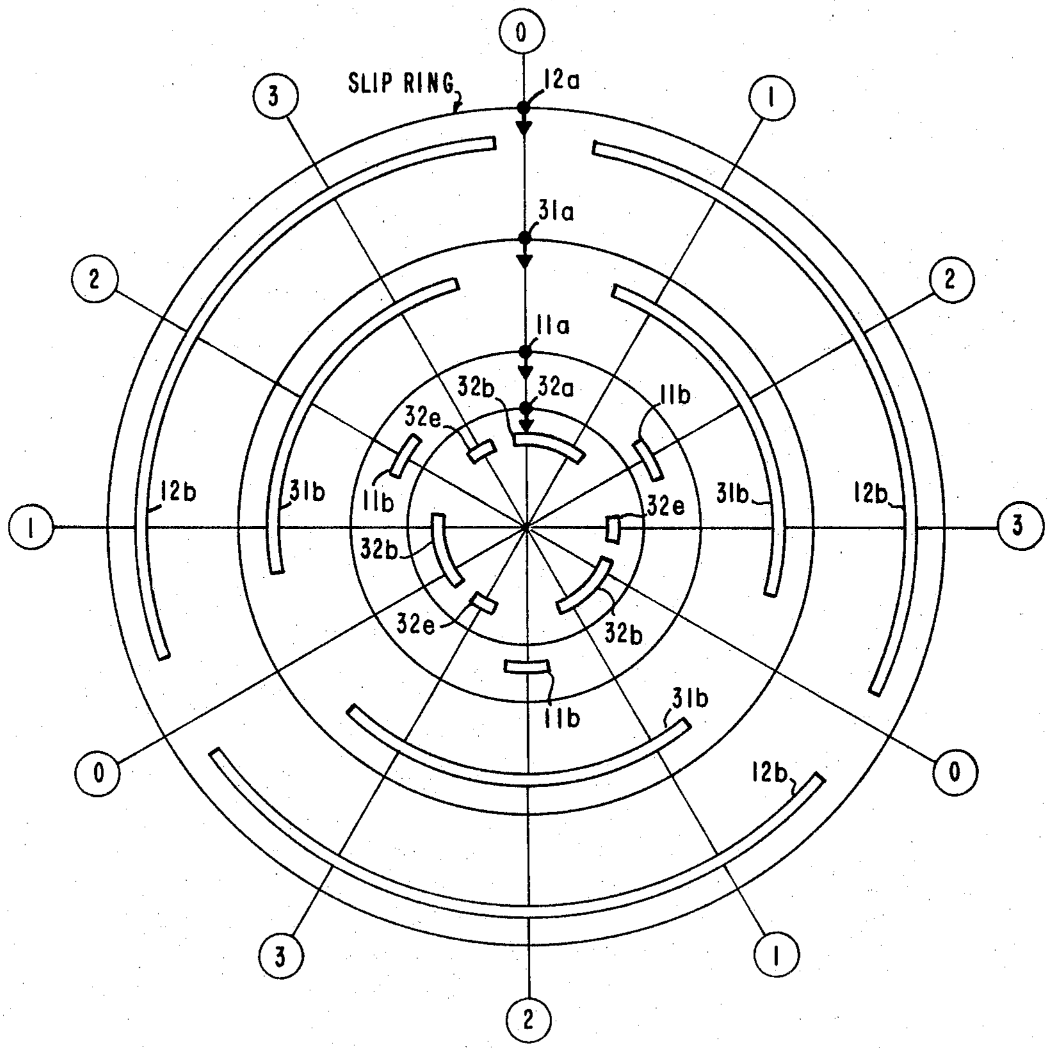

FIG. 3

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United States Patent Office

3,430,063

Patented Feb. 25, 1969

3,430,063

SOLID STATE SWITCH

James E. Webb, Administrator of the National Aeronautics and Space Administration with respect to an invention of Alden L. Schloss, North Hollywood, and Robert A. Booth, Sunland, Calif.

Filed Sept. 30, 1966, Ser. No. 584,070

U.S. Cl. 307—136 8 Claims

Int. Cl. H01h 9/30, 33/00; H02h 3/00

ABSTRACT OF THE DISCLOSURE

A solid state switching circuit is disclosed in which the switching of a normally open contact to a closed position is controlled, by sensing the potential thereacross with a difference amplifier, to permit the closing of the contact only when the potential difference across the contact does not exceed a preselected value.

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

This invention generally relates to switching circuitry and, more particularly, to a switch in which solid state circuitry is incorporated to increase the switching capacity or rating of low rated relay contacts.

Generally, the switching capacity or rating of contacts of switching devices, such as relays, are defined in terms of the maximum current which can safely flow through the contacts and, more particularly, the maximum safe open circuit voltage across the contacts. The open circuit voltage determines the electric field strength across the contacts and this may be exceedingly high, especially just before normally open contacts come into contact or are closed, as well as, just after normally closed contacts break away from one another. Generally, with high open circuit voltage and reasonably high current, arcing occurs, which tends to reduce the cycle life of the contacts. In such situations, low rated contacts, characteristic of low priced conventional relays, cannot be used with any degree of reliability. Rather, only heavy duty relays, having contacts with high voltage and high current ratings must be employed.

It is appreciated by those familiar with the art that by reducing the maximum current which is to flow through the contacts, higher open circuit voltages may be impressed across the low rated contacts, without detrimental effect. However, the reduction of current is not always possible. Thus, herebefore, whenever high current high voltage had to be switched to a load or any electrically operated equipment, only high rated contacts of heavy duty relays could be used with any degree of reliability.

Heavy duty relays are generally quite larger, heavier and considerably more expensive than comparable relays with contacts of lower ratings. The weight, size and cost of heavy duty relays often limits their use in various applications, both for commercial and military purposes. For example, heavy duty relays, because of their size and weight, are often excluded from equipment constructed for space exploration, where the primary design criteria are lightweight and compactness. Also, the cost of heavy duty relays often accounts for their limited use in commercial items.

It is a primary object of the present invention to provide a new, relatively inexpensive switching circuit.

Another object of the present invention is to provide a new switching circuit which is smaller and lighter than

comparable switching circuits with the same current and voltage ratings.

A further object of the present invention is to provide a relatively inexpensive, highly reliable switching circuit, in which relatively low rated contacts are reliably employed to switch high current high voltage signals thereacross.

Still another object of the present invention is to provide a switching circuit wherein low rated contacts are controlled so as to reliably switch signals of higher currents and higher voltages than the conventional voltage and current ratings of the contacts.

Still a further object of the present invention is to provide a highly reliable, relatively inexpensive switching circuit in which the switching capacity of a relatively low rated relay contact is greatly increased.

These and other objects of the present invention are achieved by providing a switching circuit or switch which incorporates a solid state control circuit, used to control the maximum open circuit voltage across a low rated relay contact so that the closing or opening of the contact is performed only when the open circuit voltage thereacross is not greater than a predetermined value. After the contact is closed, the open circuit voltage may be greatly increased, it being limited only by the contact's insulation. As a result, relatively small low rated contacts may be used to switch relatively large currents at relatively high voltage, herebefore only possible with heavy duty contacts of a heavy duty relay.

Briefly, in one embodiment of the present invention, the switching circuit includes a normally open low rated contact, shunted by a solid state switch and a differential amplifier. When the contact is to be switched to the closed position, the solid state switch is enabled by being switched to a conductive state so that current may flow therethrough. The differential amplifier senses the potential difference across the normally open contact, providing an enabling signal whenever the potential or voltage difference, i.e., the open circuit voltage across the contact, is equal to or less than a predetermined value. In response to the enabling signal, the normally open contact is closed at the low voltage difference sensed by the differential amplifier. Thereafter, the open circuit voltage may be increased to a value substantially higher than the maximum open circuit voltage rating of the contact, in the absence of the solid state switch connected thereacross. To break the closed contact, a first enabling signal is provided which opens the contact, while the solid state switch connected thereacross is in a conductive state, so that the voltage hereacross is relatively low. Thus, the opening of the contact is accomplished at a low open circuit voltage. Thereafter, another signal is supplied which disables the solid state switch so that the voltage across the now open contact may be increased to the circuit's normal open circuit voltage. Consequently, both closing, hereafter also referred to as making, as well as opening, hereafter also referred to as breaking, the contact are accomplished with open circuit voltages, considerably lower than the maximum circuit's open circuit voltage. This property enables the low rated contact to switch signals of current and voltage characteristics, considerably larger than the contact's current and voltage ratings in the absence of the solid state switch connected thereacross.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIGURE 1 is a simplified block diagram of a switching circuit in accordance with this invention;

FIGURE 2 is a circuit diagram of a switching circuit in accordance with this invention;

FIGURE 3 schematically represents decks of a stepping relay which is employed in the invention; and

FIGURE 4 is a schematic diagram of another embodiment of the solid state switch of the type represented in FIGURES 1 and 2.

Reference is now made to FIGURE 1 which is a simplified block diagram of the switching circuit of the present invention. Briefly, the circuit includes a normally open contact **11** which, together with a switch **12**, is connected between a source of electrical power, such as battery **14** and a load **15**. The contact is shown including a pair of terminals **11***a* and **11***b* with a movable arm **11***c* connected at one end to terminal **11***a*. When arm **11***c* is in contact with terminal **11***b*, the contact **11** may be thought of as being closed, while in the arrangement as shown in FIGURE 1, the contact is in an open position. Contact **11** is assumed to have a lower open circuit voltage rating than the voltage across battery **14**. Contact **11** is assumed to form part of a switching device, such as a relay **20** which is controlled by a switch control unit **22**, which also controls the switch **12** in a manner to be described hereafter in detail. Contact **11** is shown shunted by a solid state switch **23** and a difference amplifier **24**, the output of which is connected to unit **22**.

In operation, when current or voltage is to be supplied from battery **14** to load **15**, unit **22** provides an enabling signal to switch **12**, closing the switch. This in turn enables the solid state switch **23**, switching it to a conductive state. As a result, the voltage thereacross decreases. The voltage across switch **23**, as well as across open contact **11**, is sensed by the difference amplifier **24**, connected thereacross. When the voltage across contact **11** is equal to or less than a predetermined voltage difference, difference amplifier **24** supplies a signal to unit **22** which in turn energizes relay **20** to close contact **11**. Thus, the closing of contact **11** occurs not when the open circuit voltage thereacross is equal to the voltage of battery **14**, but rather at an open circuit voltage represented by the voltage difference necessary for the difference amplifier **24** to provide the signal to unit **22**. In practice, difference amplifier **24** provides the signal to unit **22** when the open circuit voltage of contact **11** represents a small fraction of the voltage of battery **14**. Thus, contact **11** is switched to a closed position at a much lower open circuit voltage than the maximum open circuit voltage impressed thereacross. As a result, higher currents may be supplied through contact **11**, since the making or closing of the contact is accomplished at a relatively low open circuit voltage.

To open contact **11**, unit **22** provides a signal to relay **20** which in turn opens contact **11**, while solid state switch **23** is still conducting so that the voltage across contact **11** is relatively low. Consequently, the opening of contact **11** is performed during a low open circuit voltage thereacross. After contact **11** is opened, unit **22** provides a disabling signal to switch **12** which opens and thereby separates switch **23** and amplifier **24** from the battery **14**, causing switch **23** to be switched to a nonconductive state. As a result, the open circuit voltage across contact **11** increases to the voltage represented by battery **14**. However, contact **11** is not affected because the contact opened when the open circuit voltage thereacross was still relatively low, since the opening occurred when solid state switch **23** was in a conductive state.

For a more complete explanation of the present invention, reference is made to FIGURE 2 which is a circuit diagram of one embodiment of the switching circuit of the present invention which has been reduced to practice. Relay **20** comprised of a stepping relay consisting of four decks. The relay could be sequentially positioned in any one of four positions, hereafter referred to as position "0" through position "3," respectively. One deck formed contact **11** while another deck was utilized to

define switch **12**, shown in FIGURE 2 as consisting of terminals **12***a* and **12***b*. A third deck was utilized to define a contact **31** with terminals **31***a* and **31***b*.

As will be explained hereafter in detail, contacts **12** and **31** are utilized to control the sequence in which solid state switch **23**, shown in FIGURE 2 as comprising of an NPN transistor Q1 is switched into conduction. As seen from FIGURE 2, the collector of Q1 is connected to terminals **11***a*, **12***b*, and **31***a* of contacts **11**, **12**, and **31** respectively, at a junction point **41**, while the base of the transistor is connected to terminal **31***b* of contact **31**. The emitter of the transistor Q1 is connected to terminal **11***b* of contact **11** as well as to the load **15**, one side of which is shown as grounded at a junction point **42**. The fourth deck of stepping relay **20** defines a fourth contact designated in FIGURE 2 by numeral **32**. It consists of terminal **32***a*, permanently connected to ground as well as terminals **32***b*, **32***c*, **32***d*, and **32***e*. Terminals **32***b* and **32***c* are interconnected by line **33**. In operation, terminal **32***a* is in contact with terminal **32***b* when relay **20** is in the "0" position, while being in contact with each of terminals **32***c*, **32***d*, and **32***e* respectively, when the relay is in the positions "1," "2," and "3" respectively.

The difference amplifier **24** comprises a pair of NPN transistors Q2 and Q3 having their emitters connected through a resistor R1 to terminal **32***b*, while the bases of Q2 and Q3 are connected to the same terminal through resistors R2 and R3, respectively. The base of Q2 is connected to contact **12** through a Zener diode Z1, while the base of Q3 is connected through a Zener diode Z2 and a conventional diode D1 to the junction point **42**. The switch control unit **22** includes three relays, generally designated by numerals **35**, **36**, and **37** and an NPN transistor Q4. Relay **35** has one normally open contact **35***a* and a normally closed contact **35***b*, while relay **36** has a single normally open contact **36***a* which is connected in series with the coil **20***c* of relay **20** across a voltage source, such as battery **40**. Similarly, coil **36***c* of relay **36** is shown connected in series with normally open contact **35***a* across battery **40**.

On the other hand, relay coil **37***c* of relay **37** is connected in series with a diode D2 and a resistor R4 between the positive terminal of battery **40** and terminal **32***e* of contact **32** of relay **20**, with the junction point of diode D2 and resistor R4 being connected to the collector of Q3. The collector of Q4 in unit **22** is connected to the positive terminal of battery **40** through coil **35***c* of relay **35**, while the emitter is connected to the other or ground terminal of battery **40**, through a resistor R5, connected in series with Zener diode Z3, with the base being connected to the same terminal through another Zener diode Z4. The base is connected through a resistor RB to contact **35***b* and to ground through a capacitor CB. Also the junction point of R5 and Z3 is connected to the positive terminal of battery **40** through a resistor RD. A charging resistor R6 is utilized to charge a capacitor C1 through normally closed contact **37***a* of relay **37**, while another charging resistor R7 is utilized to charge another capacitor C2 through a normally closed contact designated PB and normally closed contact **35***b* of relay **35**. The coils of the various relays may be shunted by diodes generally designated DC.

The operation of the switch diagrammed in FIGURE 2, with relay **20** assumed to be in position "0" and all the other relays in their deenergized or OFF state, may best be explained in conjunction with FIGURE 3 to which reference is made herein. FIGURE 3 is a diagram of the four decks of stepping relay **20**, superimposed for explanatory purposes only. Therein, the contacts on the various relay decks are designated by the numerals of the terminals to which they are connected. In FIGURE 3, the encircled numerals represent the relay's positions. Thus, as seen from FIGURES 2 and 3, when relay **20** is in position "0," contacts **11**, **12**, and **31** are open, with terminal **32***a* of contact **32** being connected to terminal

32*b*, forming part of the difference amplifier **24**. Also, when all the relays of unit **22** are in the deenergized or OFF state, capacitors C1 and C2 are assumed to be charged up to the potential represented by the voltage of battery **40**. To turn the switch to an ON state, normally closed contact, designated PB in unit **22**, is momentarily switched to a normally open position. This may be accomplished either manually or by automatic means. As a result, capacitor C2 discharges through a diode D3 connected in series with a resistor RB which is in turn connected to the base of transistor Q4. As a result of the discharging of capacitor C2, transistor Q4 is switched to conduction and is caused to saturate. The Zener actions of Zener diodes Z3 and Z4 are utilized to control transistor Q4 to switch to a nonconductive or OFF state when the charge across capacitor C2 falls below the sustaining Zener voltage of diode Z4. This enables transistor Q4 to operate as a switch inasmuch as the decay turnoff time is reduced. In the embodiment actually reduced to practice, the switching time was set to be equal to 100 milliseconds, sufficient to energize the coil **35***c* of relay **35**. As a result, normally open contact **35***a* closes, while normally closed contact **35***b* opens. The opening of normally closed contact **35***b* provides a parallel discharge path for capacitor C2, and thereby bypasses the manually depressed contact PB. On the other hand, the closing of contact **35***a* energizes relay **36**, which in turn results in the closing of contact **36***a* thereof. As a result, coil **20***c* of stepping relay **20** is provided with an energizing pulse which in turn causes the stepping relay to step from position "0" to position "1."

Referring again to FIGURE 3, it is seen that as the relay **20** steps from position "0" to position "1," the first thing to occur is the closing of contact **12** when terminals **12***a* and **12***b* thereof come into contact with one another. Thus, the first thing to occur is the closing of contact **12** (FIGURE 2). The second thing to occur during the stepping from position "0" to position "1" is the contact made between terminals **31***a* and **31***b*, representing the closing of contact **31**. Terminal **32***a* remains in contact with terminal **32***b* as well as **32***c*, which as seen from FIGURE 2, are directly connected to one another as long as the relay **20** is in either position "0" or position "1." However, as clearly seen from FIGURE 3, when relay **20** is in position "1," contact **11** still remains open since no direct path is provided between terminals **11***a* and **11***b* thereof.

When relay **20** is in position "1," and contacts **12** and **31** are closed, it is appreciated that transistor Q1 is switched to conduction or saturation, thereby providing a current path for current from battery **14** to the load **15**. Also, when the transistor Q1 is switched into conduction, the voltage thereacross starts to decrease. The values of the Zener diodes Z1 and Z2, which form part of difference amplifier **24**, are selected so that when the voltage difference across contact **11**, which also represents the voltage difference across the solid state switch **23**, is of a predetermined low value, transistor Q3 is switched to a conductive state. When Q3 conducts, the collector thereof and therefore the junction point of diodes D2 and resistor R4, may be assumed to be slightly above ground. As a consequence, coil **37***c* is energized, causing the normally closed contact **37***a* through which capacitor C1 has been charged, to open.

When normally closed contact **37***a* is in an open position, capacitor C1 discharges through a diode D4 which is connected in series with resistor RB, again switching transistor Q4 to a conductive state. This, as herebefore explained, results in a second energizing signal or pulse being supplied to coil **20***c* of relay **20** which causes the relay to step from position "1" to position "2." As seen from FIGURE 3, as the relay **20** steps from position "1" to position "2," the first thing to occur is the disengagement of terminal **32***a* from terminal **32***b*, which results in the disruption of the supply of bias current to difference amplifier **24**. Briefly thereafter as the relay **20** continues to rotate, terminals **11***a* and **11***b* of normally open contact **11** are engaged, thereby closing contact **11**. Thus, when relay **20** reaches position "2," the difference amplifier **24** is no longer supplied with biasing current. On the other hand, normally open contact **11** is closed and at the same, solid state switch **23** is in a conductive state. It should be pointed out that the closing of normally open contact **11** occurs when the open circuit voltage thereacross was equal to or less than the voltage difference necessary for difference amplifier to provide unit **22** with an enabling signal, provided when transistor Q3 is in a conductive state.

When relay **20** is in position "2," the switch of the present invention is assumed to be in an ON state, since most of the current from battery **14** is supplied to the load **15** through the closed contact **11**.

To return the switch to the OFF state, the normally closed contact PB is again, either manually or automatically, switched to the open state to enable capacitor C2 to discharge into transistor Q4, which in turn energizes relay **35**, leading to the closing of contact **35***a* which energizes relay **36**. The energization of relay **36** causes the closing of contact **36***a* which in turn results in the supply of an energizing signal to coil **20***c* of relay **20**. When this occurs, relay **20** steps from position "2" to position "3." The first thing to occur during such position change is the disengagement of terminals **11***a* and **11***b* from one another, i.e., contact **11** is opened while the solid state switch **23** is still in a conductve state. This permits the opening of contact **11** without any appreciable arching, since a current path for current from battery **14** to load **15** is provided through the solid state switch **23** which is in a conductive state. After the opening of contact **11**, as the relay continues to rotate towards position "3," terminal **32***a* of contact **32** engages terminal **32***e*. As seen from FIGURE 2, when terminals **32***a* and **32***e* are in contact, one side of resistor R4 is connected to ground so that the coil **37***c* of relay **37** is energized. As herebefore explained, when relay **37** is energized, its normally closed contact **37***a* is opened, thereby enabling capacitor C1 to discharge into transistor Q4 which in turn results in the supply of another energizing signal to coil **20***c* of relay **20**, causing it to move from position "3" to position "0."

During the change in the position of relay **20** from position "3" to position "0," the first thing to occur is the contact made between terminal **32***a* of contact **32** with terminal **32***b*, thereby reenabling the difference amplifier **24**. Also, contact **31** is opened and briefly thereafter, contact **12** is reopened. The opening of contact **31** and contact **12** removes the supply of potential to the solid state switch **23**, thereby causing the switch to return to a nonconductive state. All the contacts of the various relays are returned to the state diagrammed in FIGURE 2.

Summarizing the foregoing description, in accordance with the teachings of the present invention, the closing and opening of a low rated contact, such as contact **11**, is controlled by the switch of the present invention by means of a solid state switch, connected across the contact, as well as a difference amplifier, which provides a control signal whenever the open circuit voltage across the contact is equal to or less than a predetermined value. When the control signal is provided by the difference amplifier, the low rated contact is closed, while the open circuit voltage thereacross is relatively low. Consequently, relatively high currents may be switched by the low rated contact without adverse effects. For example, in the arrangements diagrammed in FIGURE 2, battery **14** may comprise a battery of a voltage of 25 to 75 volts DC, while the closing of contact **11** may occur only when the voltage thereacross is equal to three volts or less. Thus high currents high voltage signals may be switched between battery **14** to load **15** through contact **11** which is assumed to have a low open circuit voltage rating since the closing and opening thereof occurs when the voltage across it is not equal to the battery voltage 14 but rather to three volts or less.

Once contact 11 is closed, current is supplied therethrough to load 15, even though solid state switch 23 is in a conductive state. The opening of contact 11 is accomplished while the solid state switch is in a conductive state, i.e., the voltage across the contact 11 is relatively low, minimizing the occurrence of any arcing thereacross. Only when contact 11 is in a complete open state as diagrammed in FIGURE 2, is solid state switch 23 disabled or returned to a nonconductive state, such as by the sequential opening of contacts 31 and 12, which occur during the switching of relay 20 from position "3" to position "0" as hereinbefore described in conjunction with FIGURES 2 and 3.

Although in FIGURE 2 the solid state switch 23 is represented only by a single transistor Q1, it is appreciated that various solid state switching arrangements may be employed. FIGURE 4, to which reference is made herein, is a schematic diagram of an actual solid state switch employed in controlling the opening and closing of contact 11. In FIGURE 4, solid state switch 23 is shown comprising of four NPN transistors designated Q5 through Q8 respectively. The collectors of Q5, Q6, and Q7 are all tied together at junction point 41, which represents the junction point of terminals 11*a*, 12*b*, and 31*a*, diagrammed in FIGURE 2, while the base of Q7 and the collector of Q8 are connected to terminal 31*b* through a resistor R8. The emitter of Q8, as well as the emitter of Q5 through a resistor R9 and the emitter of Q6 through an equal resistor designated R10, are connected to junction point 42 representing the junction point of diode D1, load 15, and terminal 11*b*, diagrammed in FIGURE 2. The emitter of Q7 and base of Q6 are also connected to junction point 42 through a resistor R11, while the base of Q8 is connected to the junction point of two equal resistors R12 and R13 connected in series between the emitter of Q5 and the emitter of Q6. The collector of Q8 is connected to the base thereof through a resistor R14. Briefly, transistors Q5 and Q6 are connected in parallel to provide current paths when the solid state switch 23 is switched in a conductive state, while transistor Q7 acts as a current amplifier. Q8, on the other hand, serves as a current limiter to limit the flow of current from battery 14 to load 15.

Although specific embodiments of the various circuits, hereinbefore referred to, have been described, it should be appreciated that the specific enbodiments are presented for explanatory purposes only and that other arrangemetns may be employed in the switching circuit, the main function of which is to increase the current and voltage ratings of a relatively low rated contact, such as contact 11. This is accomplished by controlling the open circuit voltage across the contact just before the contact is closed, as well as when the contact is opened.

There has accordingly been shown and described herein, a novel switching circuit in which a solid state switch and a difference amplifier are utilized to sense the open circuit voltage across a low rated contact and provide control signals to control the closing of the contact only when the open circuit voltage thereacross is equal to or less than a predetermined low value. The opening of the contact is accomplished while the solid state switch connected thereacross is in a conductive state, and thereby returns the entire switching circuit to an OFF state. It is appreciated that those familiar with the art may make modifications and/or introduce equivalents in the arrangements as shown without departing from the true spirit of the invention. Therefore, all such modifications and/or equivalents are deemed to fall within the scope of the invention as claimed in the appended claims.

What is claimed is:

1. A switching circuit comprising:

contact means being switchable between an open position and a closed position;

difference sensing means connected across said contact means for sensing the voltage thereacross when said contact means are in said open position and for providing a control signal when the sensed voltage is not greater than a predetermined value; and

control means coupled to said difference sensing means and responsive to the control signal therefrom for switching said contact means to the closed position thereof, whereby said contact means switch from the open position to the closed position only when the voltage thereacross is not greater than said predetermined value.

2. A switching circuit comprising:

contact means being switchable between an open position and a closed position;

difference sensing means connected across said contact means for sensing the voltage thereacross when said contact means are in said open position and for providing a control signal when the sensed voltage is not greater than a predetermined value;

control means coupled to said difference sensing means and responsive to the control signal therefrom for switching said contact means to the closed position thereof, whereby said contact means switch from the open position to the closed position only when the voltage thereacross is not greater than said predetermined value; and

a transistorized circuit coupled across said contact means, said circuit being switchable to a conductive state to reduce the voltage across said contact means to a value not greater than said predetermined value.

3. The switch circuit as recited in claim 2 wherein said difference sensing means comprises a difference amplifier and said contact means comprises a first normally open contact of a multiposition relay, said relay being switchable to a position wherein said normally open contact is closed when the voltage across said normally open contact is equal to or less than the open circuit voltage rating thereof.

4. The switch circuit as recited in claim 3 wherein said relay includes at least a second normally open contact connected between a voltage source and said transistorized circuit, said second normally open contact being switchable by said relay to a closed position to switch the transistorized circuit to said conductive state.

5. A switching circuit, in combination comprising:

a multiposition multicontact stepping relay switchable from one position to another, said positions defining a sequence of positions, said relay including a first normally open contact;

a solid state stage connected across said first normally open contact, said stage being switchable to a conductive state to provide a current path across said first normally open contact;

a difference amplifier connected across said first normally open contact for providing a voltage indicating signal when the voltage across said normally open contact is not greater than a predetermined value; and

a switch control stage coupled to said relay and responsive to the voltage indicating signal from said difference amplifier for switching said relay to a position wherein said first normally open contact is closed.

6. The switching circuit as recited in claim 5 wherein said relay includes a second normally open contact connected in series with said first normally open contact across a potential source and a load, said solid state stage being in a nonconductive state when said second contact is in its normally open state, said relay being in a "0" position when both said first normally open contact and said second normally open contact are in their open state, said switch control stage being responsive to a first control signal for switching said relay from the "0" posi-

tion to a subsequent "1" position in said sequence, said second normally open contact being in a closed position when said relay is in said "1" position, so that the solid state stage is switched to a conductive state, said difference amplifier providing to said switch control stage said voltage indicating signal when the voltage across said first normally open contact is not greater than said predetermined value, whereby said control stage steps said relay to a "2" position, wherein both said first and said second normally open contacts are closed.

7. The switch circuit as recited in claim **6** wherein said solid state stage includes first, second, and third terminals, said first and second terminals being connected across said first normally open contact, said relay including a third normally open contact, connected between said third terminal and said second normally open contact, said relay including means whereby said second contact is closed before said third contact when the relay is switched from said "0" position to said "1" position.

8. The switching circuit as recited in claim **7** wherein said relay includes a fourth contact which is normally open when said relay is in said "2" position, said relay

including means whereby said first contact is opened when said relay is stepped from the "2" position to a subsequent "3" position at which said fourth contact is closed, said switch control stage including means energizable when said fourth contact is in a closed position for stepping said relay to said "0" position, said relay including means whereby said third and second contacts open sequentially as said relay steps from said "3" position to said "0" position.

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ROBERT K. SCHAEFER, *Primary Examiner.*

T. B. JOIKE, *Assistant Examiner.*

U.S. Cl. X.R.

317—11

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,430,063 February 25, 1969

James E. Webb, Administrator of the National Aeronautics and Space Administration with respect to an invention of Alden I. Schloss and Robert A. Booth

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

In the drawings, Sheets 1 to 3, the lower right corner, and in the heading to the printed specification, line 5, "Alden L. Schloss", each occurrence, should read -- Alden I. Schloss --.

Signed and sealed this 20th day of October 1970.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR
Commissioner of Patents