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[72] Inventor **Stephen A. Dalyai**
Old Bridge, N.J.

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[73] Assignee **Bell Telephone Laboratories, Incorporated**
Murray Hill, Berkeley Heights, N.J.

[54] **SOLENOID DRIVER CIRCUIT**
5 Claims, 1 Drawing Fig.

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[50] **Field of Search** ..... 317/123 CD, 151, 148.5, 154

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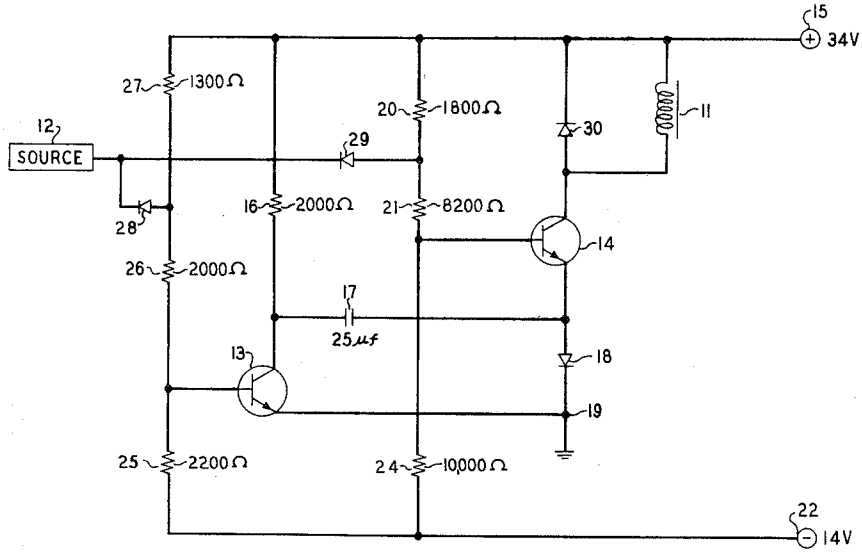
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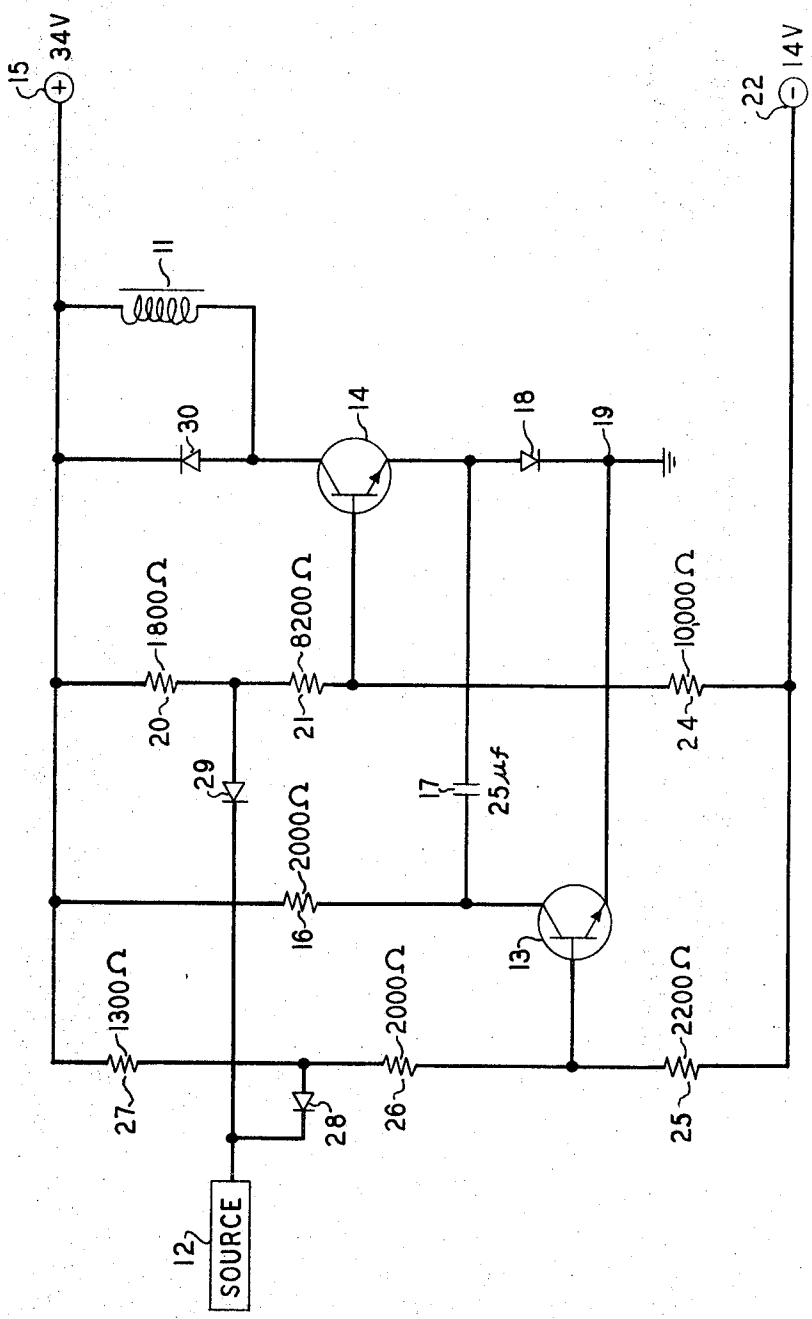
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Primary Examiner—Lee T. Hix
Assistant Examiner—C. L. Yates
Attorneys—R. J. Guenther and Kenneth B. Hamlin

ABSTRACT: A circuit for operating and holding a solenoid in response to an applied signal includes two transistor switches. The first switch closes a path between a capacitor and the solenoid coil to attain a voltage level necessary to operate the solenoid. The second switch closes a path between the capacitor and ground discharging the capacitor thereby decreasing the voltage applied to the coil after a predetermined time to a lower level required during the hold condition.





INVENTOR
S.A. DALYAI
BY
Lucian C. Canepa
ATTORNEY

SOLENOID DRIVER CIRCUIT

This invention relates to circuits for controlling solenoids, and more particularly to circuits for producing both operating and holding currents in solenoids.

The term solenoid or electromagnet is used herein in its broadest sense and includes generally a coil for producing a magnetic flux and an element in the form of an armature or plunger movable in response to such flux in, for example, relays, actuators, valves and the like to produce either a direct result or a control operation.

It is well recognized that a relatively large current is required to flow in the coil of a solenoid in order to cause the armature or plunger to move from a normal unattracted position to its magnetically attracted position at which time only a relatively small current is required to flow to maintain the armature or plunger in such attracted position. A distinction is thus made between these two currents of different magnitude, the former being referred to as the operating current and the latter current of smaller magnitude being referred to as the holding current.

It is desirable that the magnitudes of these two required currents be as small as possible to minimize the generation of heat in prolonged energization of the solenoid or electromagnet. Efforts in the past have been devoted to reduction of these currents and such efforts have usually resulted in an expensive or complicated structure. One such approach involved the use of auxiliary relay contacts which, in effect, are used to insert a current limiting resistance in series with the solenoid coil once the armature or plunger is in its attracted position. Use of auxiliary contacts, however, to connect a current limiting resistor in series with a solenoid winding following energization of the latter has the disadvantages of wear and unreliability inherent in movable mechanical parts, and the further disadvantage of increased physical size of the device. Use of an auxiliary contact to shunt a portion of a solenoid coil and to reinsert such portion effectively in the circuit upon energization of the solenoid has the aforementioned disadvantages as well as that of delayed operation of the solenoid.

Still other prior art techniques have incorporated the use of transistors as controllable impedance elements in multipath arrangements, providing a first impedance path to cause the device to operate and a second impedance path to effect holding the device operative. These techniques suffer from the disadvantages that they require large numbers of elements and increased cost.

Accordingly, it is an object of the present invention to decrease the time required to operate a solenoid.

Another object of the present invention is to reduce device heating.

Still another object of this invention is to reduce power supply current drain.

A still further object of the present invention is to reduce voltage source requirements in solenoid control applications.

These and other objects of the present invention are realized in a specific illustrative embodiment that includes first and second transistors normally biased to cutoff. The transistors are arranged such that an input signal will cause both transistors to saturate. A capacitor charged to the circuit bias supply voltage is connected to the emitter of the first transistor and the collector of the second transistor. At the incidence of an input signal, the transistors saturate and the solenoid coil connected to the collector of the first transistor experiences a voltage twice that of the circuit bias supply. The second transistor provides a path to ground for discharging the capacitor leaving the voltage across the solenoid at a level equal to the supply voltage for the remainder of the input signal.

It is accordingly a feature of the present invention that a transistor voltage doubler be provided for increasing the speed of operation of a relay.

A further feature of this invention is the provision of a switching transistor for disabling the voltage doubler.

A complete understanding of the present invention and of the above and other features and advantages thereof may be gained from a consideration of the following detailed description of an illustrative embodiment of that invention presented in connection with the accompanying single FIGURE drawing.

It is to be noted that the values assigned the various elements shown on the drawing are illustrative only and may be replaced by more appropriate values if usage so dictates.

Initially, when there is no input signal to the circuit from source **12**, source **12** provides a potential near ground resulting in both transistor **13** and transistor **14** being biased to cutoff. Since transistor **13** and transistor **14** are in cutoff, no substantial current flows through either of them. In this state or initial phase, capacitor **17** is charged to the voltage of the voltage source **15** by means of the series circuit comprising voltage source **15**, resistor **16**, capacitor **17** and diode **18** to ground terminal **19**.

At the incidence of a positive-going input signal from source **12**, transistor **13** and transistor **14** saturate. At the beginning of this second phase, the voltage of the emitter of transistor **14** is the voltage at the lower-voltage (right-hand) terminal of capacitor **17**, or the negative of the voltage of source **15**. As transistor **14** saturates, the collector voltage decreases to the voltage at the emitter of transistor **14**. At this time, the circuit enters a third phase wherein the terminal of coil **11** connected to the collector of transistor **14** also decreases to the voltage at the emitter of transistor **14**. Since the voltage at the other terminal of coil **11** is connected to the positive terminal of voltage source **15**, the resultant voltage across coil **11** is twice the voltage level of voltage source **15**. This high-level voltage supplies the initial current surge required to operate the solenoid.

Since transistor **13** has also been caused to saturate at the incidence of an input signal from source **12**, a path is provided between the higher-voltage (left-hand) terminal of capacitor **17** and ground terminal **19**. When capacitor **17** has completely discharged through this path, the emitter and consequently the collector of transistor **14** approach ground potential. As a result, the terminal of coil **11** connected to the collector of transistor **14** also approaches ground potential and the total voltage across the coil approaches the voltage of the voltage source **15**. This corresponds to the holding condition of the solenoid. Again, as source **12** ceases to supply an input signal, the circuit enters the first phase wherein transistor **13** an transistor **14** again assume the cutoff condition, and capacitor **17** charges to the level of voltage source **15**.

Additionally, biasing resistors **24**, **25**, **26** and **27** provide the requisite bias voltages to effect proper operation of the circuit of the illustrative embodiment shown in the figure. Diodes **28**, **29** and **30** are unidirectional current devices used in a conventional way to prevent current flow in portions of the circuit as required for proper operation.

In the illustrative embodiment shown on the drawing, a relationship can be derived to determine the minimum value of capacitor **17** required to supply an operating current to the solenoid for a prescribed time. (The symbols used represent the elements shown on the drawing and the subscripts of those symbols correspond to the numerical designations of those elements as they appear in the FIGURE.)

Coil **11**, capacitor **17** and the forward resistances of transistor **14** and diode **18** form a series RLC circuit. Using straightforward circuit analysis techniques, the values of capacitor **17** and collector supply voltage V_{15} can be determined for the underdamped, critically damped and overdamped conditions. In the critically damped condition, for example, the current in coil **11**, i_{w1}, is given by the following relation

$$i_{w_1}=\frac{2V_{15}}{L_w}te^{-\frac{R_c t}{2L_w}} \qquad (1)$$

assuming that

$V_{CE}<<V_{15}$

$V_{BE}<<V_{15}$

$V_{18} << V_{15}$
$I_B << I_c$ and
$C_{17}=A4L_w/R_r$ and where
L_w is the inductance of coil **11**,
R_r is the resultant resistance formed when the forward resistances of transistor **14** and diode **18** are combined in series,
V_{15} is the collector supply voltage,
I_B is the steady state base current of transistor **14**,
I_c is the steady state collector current of transistor **14**,
V_{CE} is the collector to emitter voltage drop of transistor **14**,
V_{BE} is the base to emitter voltage drop of transistor **14**, and
V_{18} is the voltage drop across diode **18**. In many applications, L_w will be small and can be ignored. Where L_w is small enough to be ignored, the current in coil **11**, i_{w2}, is given by

$$i_{w_2}=\frac{2V_{15}}{R_w}e^{-\frac{t}{R_wC_{17}}} \qquad (2)$$

assuming that
$V_{CE} << V_{15}$,
$V_{BE} << V_{15}$,
$V_{18} << V_{15}$, and
$I_B << I_c$, and where
R_w is the resistance of coil **11**. The value of capacitor **17** is then given by the following relation based on Equation (2) above

$$C_{17}=\frac{To}{R_w ln\frac{2V_{15}}{I_0R_w}} \qquad (3)$$

where
I_o is the operate current of the solenoid and
T_o is the operate time of the solenoid.

Further, according to well-known techniques, the value of resistor **16** should be chosen such that the desired recovery time T_R (that is, the time required to fully recharge capacitor C_{17}) is equal to five times the time constant of the $R_{16}C_{17}$ combination. Thus,

$R_{16}=AT_R/5C_{17}$ (4)

While a particular illustrative embodiment of the present invention has been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from this invention in its broader aspects. In particular, switching devices other than transistors may be used as may other energy storage devices. Similarly, diodes may be eliminated in favor of other current steering devices.

I claim:

1. Apparatus for operating a solenoid in response to an externally applied signal comprising:
a solenoid coil having first and second terminals,
a voltage source having first and second terminals, said voltage source first terminal being connected to said solenoid coil first terminal,
a capacitor having first and second terminals,
means for charging said capacitor by establishing a charging path from said voltage source first terminal through said capacitor to said voltage source second terminal,
first and second transistor switches responsive to said externally applied signal for simultaneously connecting said capacitor second terminal to said solenoid coil second terminal and said capacitor first terminal to said voltage source second terminal, and
means responsive to said second transistor switch for interrupting said charging path.

2. In combination in a solenoid driver circuit:
an inductive coil having two terminals,
a source of direct current voltage having a reference terminal and a voltage level terminal, said voltage level terminal being connected to a first of said two coil terminals,
a storage capacitor having first and second output terminals,
means connecting said storage capacitor first terminal to said voltage source voltage level terminal and means connecting said storage capacitor second terminal to said voltage source reference terminal for charging said capacitor,
switching means responsive to external stimuli for simultaneously connecting said capacitor second output terminal to the second of said two coil terminals and said capacitor first output terminal to said voltage source reference terminal, and
means responsive to said external stimuli for disconnecting said storage capacitor second output terminal from said voltage source reference terminal.

3. A combination in accordance with claim **2** wherein said means connecting said storage capacitor first terminal to said voltage source reference terminal includes a diode poled to conduct current from said storage capacitor second terminal to said voltage source reference terminal.

4. A combination in accordance with claim **2** wherein said switching means includes a first transistor having base, collector and emitter electrodes, said first transistor collector electrode being connected to said storage capacitor first terminal and said first transistor emitter electrode being connected to said voltage source reference terminal.

5. A combination in accordance with claim **4** wherein said switching means further includes a second transistor having base, emitter and collector electrodes, said second transistor collector electrode being connected to the second of said two coil terminals and said second transistor emitter terminal being connected to said storage capacitor second terminal.