

Dec. 16, 1958

E. E. SUMNER

2,864,975

TRANSISTOR CIRCUIT FOR OPERATING A RELAY

Filed July 12, 1957

2 Sheets-Sheet 1

FIG. 1

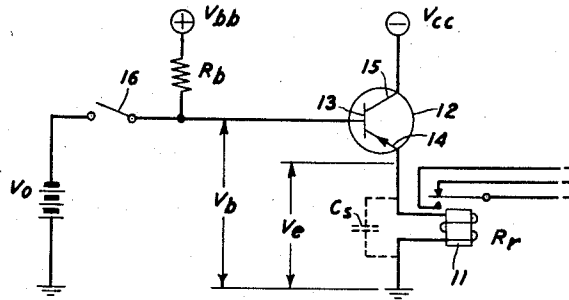
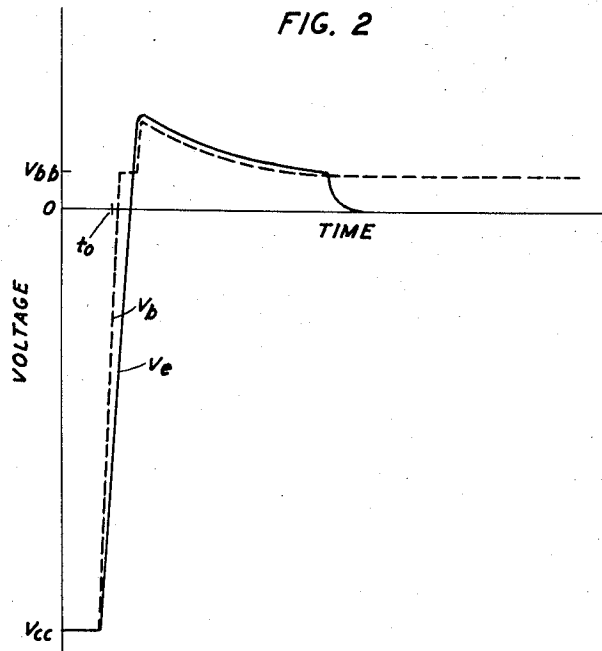


FIG. 2



INVENTOR
E. E. SUMNER
BY *W. E. Sumner*
ATTORNEY

Dec. 16, 1958

E. E. SUMNER

2,864,975

TRANSISTOR CIRCUIT FOR OPERATING A RELAY

Filed July 12, 1957

2 Sheets-Sheet 2

FIG. 3

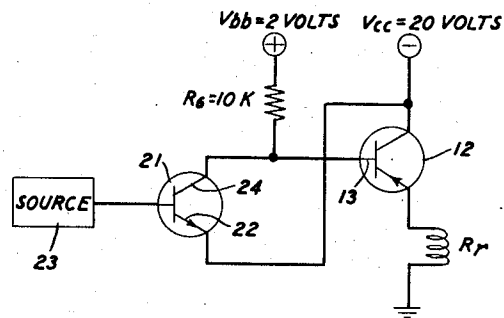


FIG. 4

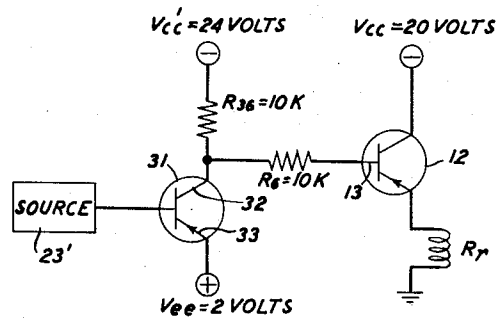
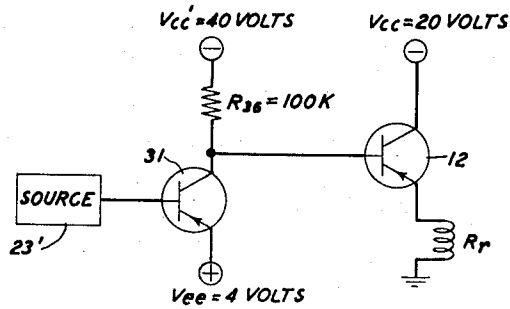


FIG. 5



INVENTOR
E. E. SUMNER
BY *W. E. Keefe*
ATTORNEY

1

2,864,975

TRANSISTOR CIRCUIT FOR OPERATING A RELAY

Eric E. Sumner, North Caldwell, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application July 12, 1957, Serial No. 671,596

7 Claims. (Cl. 317—9)

This invention relates to relay circuits employing transistors.

When a transistor is employed to control the operation of a relay, one problem of concern is the transient which occurs when the relay is released. If no protective means are employed, this transient may result in sufficient overshoot of the collector voltage to damage and perhaps destroy the transistor. This problem has previously been given consideration with the resultant suggestion of circuits employing diodes or resistor-capacitor combinations to provide a dissipative path for the inductive transient.

A principal object of the invention is to simplify the circuitry necessary to protect a transistor, which is controlling the operation of a relay, from destruction which may occur if the transients, which result from the release of the relay, are sufficiently large.

Another object of the invention is to reduce the cost and bulk of such protective circuits and to avoid, for example, the use of such relatively costly or bulky items as diodes and capacitors.

Another object is to increase the efficiency of transistor protection circuits.

In accordance with one illustrative embodiment of the invention described in more detail below, collector voltage overshoot is limited to a predetermined value by employing emitter-follower configuration for the transistor which is to control the operation of the relay. The relay winding is therefore connected in series with the emitter electrode. Further, a voltage is applied to the base electrode through a series resistor, the values of the voltage and resistor being chosen in accordance with a prescribed equation to limit collector voltage overshoot. A feature of the invention is that efficient protection is achieved without the addition of costly or bulky circuit components.

The objects and features of the invention may be more fully appreciated from a consideration of the following detailed description when read in accordance with the attached drawing in which—

Fig. 1 is a schematic diagram of a transistor circuit for operating a relay in accordance with the principles of the invention;

Fig. 2 is a voltage-time diagram illustrative of certain operating principles of the circuit shown in Fig. 1; and Figs. 3, 4, and 5 are further circuits illustrating principles of the invention.

Operation of the relay 11 in Fig. 1 is controlled by a transistor 12 having base 13, emitter 14, and collector 15 electrodes. Emitter-follower (alternatively referred to as common-collector) configuration is employed which means that input signals are applied to base 13; and the load, i. e., the winding of relay 11, is connected in series with the emitter 14.

The input signal in this case is illustrated merely as a source of negative voltage V_o applied to the base through a switch 16. The switch may, for example, comprise another transistor but, for the present, may be considered merely as a manually operated switch. A source of posi-

2

tive voltage V_{bb} is also connected to the base through a resistor R_b .

When the switch 16 is closed, the voltage of source V_o is sufficient to drive the transistor into its saturation operating region which results in operation of the relay. When operated, a steady-state current I_r flows through the relay winding, this current being closely

$$I_r = \frac{V_{cc}}{R_r} \quad (1)$$

where R_r is the direct-current resistance of the relay winding.

When switch 16 is opened, the transistor is at first cut off by the voltage V_{bb} applied to the base. This disrupts the flow of current from the source of collector potential V_{cc} and thereby tends to cause the relay to release. However, the energy stored in the inductance of the relay winding must be dissipated and its transient, which arises from this dissipation, may cause the collector-to-base potential V_{cb} to rise above the safe operating value for the transistor and thereby cause the collector to break down and perhaps be permanently damaged.

In accordance with the principles of the invention, however, the overshoot and potential at the collector are limited to a predetermined safe value by the voltage source V_{bb} and resistor R_b whose values are as prescribed below.

Fig. 2 illustrates certain voltages of the Fig. 1 circuit. Prior to the opening of switch 16, the base and emitter electrodes are both substantially at the potential of the collector supply V_{cc} . At time t_0 , when the switch is opened, the base potential, V_b , rises substantially instantaneously, neglecting capacity effects, to a value V_{bb} , thus cutting off the transistor. Also at time t_0 , the potential of the emitter electrode, V_e , rises with the in-cipience of the inductive transient as the energy stored in the coil starts to charge the stray capacity C_s associated with the coil.

The emitter potential V_e will eventually reach a value which exceeds the base potential, at which time the transistor again conducts. At this time, the base potential V_b will also start to rise, differing from the emitter potential only by the small drop across the emitter-base junction. The transient will quickly pass a crest and begin to decay, the emitter potential decaying toward ground potential. When the transistor is again cut off by the decay of the emitter potential, the base potential will assume a steady-state value of V_{bb} .

When the transistor is conducting, with switch 16 open, the base voltage is

$$V_b = V_{bb} + \frac{I_r R_b}{\beta} \quad (2)$$

where β is the current gain from base to emitter and is equal to $1/1-\alpha$, α being the current gain from emitter to collector.

Since the relay operate current, I_r , is approximately V_{cc}/R_r , then

$$V_b = V_{cc} \left[\frac{V_{bb}}{V_{cc}} + \frac{R_b}{\beta R_r} \right] \quad (3)$$

The collector-to-base voltage, V_{cb} , the critical voltage to be limited insofar as collector burnout is concerned, is obviously the difference between the collector voltage ($-V_{cc}$ in the circuit shown) and the base voltage V_b ; or,

$$V_{cb} = V_{cc} - V_b = -V_{cc} - V_{cc} \left[\frac{V_{bb}}{V_{cc}} + \frac{R_b}{\beta R_r} \right] \quad (4)$$

Since V_{cc} is usually fixed by other considerations, protection is achieved by limiting the overshoot factor

$$\left(\text{i. e., } \frac{V_{bb}}{V_{cc}} + \frac{R_b}{\beta R_r} \right)$$

3

to a safe percentage N . Further, since β and R_r are also more or less fixed, values are chosen for V_{bb} and R_b in accordance with the invention, so that the overshoot is limited to a safe value for the particular transistor employed. That is, V_{bb} and R_b are proportioned so that:

$$\frac{V_{bb}}{V_{cc}} + \frac{R_b}{\beta R_r} \approx \frac{N}{100} \quad (5)$$

For example, assume that transistor 12 can safely withstand an overshoot of 20 percent, beyond V_{cc} , and that

$$\begin{aligned} V_{cc} &= -20 \text{ volts} \\ \beta &= 100, \text{ and} \\ R_r &= 1k \end{aligned}$$

Then, assuming a base voltage V_{bb} of +2 volts, it may be seen that a resistor R_b of 10k will achieve the desired protection. Resistor R_b is preferably substantially equal to this value; if too large, the overshoot will be excessive, and if too small, it will unduly increase the operate current through switch 16.

Certain other considerations must be taken into account, of course, in selecting V_{bb} and R_b . For example, the forward drop of the emitter-to-base junction, and the leakage characteristics of the transistor may be somewhat modifying. Also, the reverse base drive current supplied by V_{bb} and R_b must be sufficient to provide I_{co} for the transistor when the switch 16 is open.

In those cases where V_{bb} is fixed by other considerations, the value of R_b is readily determined; R_b in such cases should be substantially equal to, or slightly less than

$$\beta R_r \left(\frac{N}{100} - \frac{V_{bb}}{V_{cc}} \right)$$

Figs. 3, 4, and 5 illustrate principles of the invention in several practical circuits. (Numbers like those in Fig. 1 identify similar elements.) In these circuits, the switch 16 of Fig. 1 is replaced by a transistor switch.

The switch in Fig. 3 comprises a second transistor 21 of conductivity type opposite to that of transistor 12. The emitter 22 of transistor 21 is tied to the collector supply V_{cc} of transistor 12 so that, in the absence of input signals from source 23, transistor 21 is biased to saturation. Collector 24 of transistor 21 in the saturation condition will also be at approximately -20 volts due to the very small collector-to-emitter resistance in the saturation condition. Since the base of transistor 12 is direct-coupled to collector 24, base 13 is also at -20 volts and transistor 12 is also in the saturation condition.

When signals from source 23, which may, for example, comprise negative pulses, are applied to cut off transistor 21, transistor 12 is also cut off and the relay (indicated merely by its winding designation R_r) releases. In accordance with principles of the invention and as discussed in connection with Fig. 1, the overshoot in the collector-to-base voltage of transistor 12 is limited to an assumed safe value of 20 percent by the source V_{bb} of two volts which is applied to the base of transistor 12 through resistor R_b of a value substantially equal to 10,000 ohms. With these parameters, the collector-to-base voltage of transistor 12 during the inductive transient when the relay releases, will be limited to 24 volts.

Fig. 4 illustrates another embodiment in which transistors of like conductivity types are employed. In this embodiment, the transistor switch comprises transistor 31 while transistor 12 is again employed to drive the relay. In the absence of signals from source 23', transistor 31 is in saturation due to the two-volt forward emitter bias V_{ee} . When saturated, the collector 32-to-emitter 33 resistance is very small so that the collector 33 is also substantially at +2 volts. Since the emitter of transistor 12 is returned through the relay winding to ground potential, transistor 12 is cut off by this two-volt base bias and the relay is released.

When signals from source 23, which may, for example,

4

comprise positive pulses, drive transistor 31 to cut off, the collector of transistor 31 rises towards V_{cc}' or -24 volts, thereby driving transistor 12 to saturation and operating the relay. When the positive input pulses cease, the relay releases.

In this configuration, the V_{bb} of the overshoot factor is the +2 volts of V_{ee} since it is this voltage which is applied to the base of transistor 12 when the latter is cut off and the potentially harmful transient occurs. Resistor R_b is thus connected between the collector 32 of transistor 31 and the base 13 of transistor 12. The R_b of Equation 5 should technically include the total resistance of the circuit connecting V_{ee} to the base of transistor 12. However, the saturation collector-to-emitter resistance of transistor 31 is so small that it can be neglected. Therefore, assuming again a safe maximum collector overshoot of 20 percent, it can be seen from the above that R_b should have a value approximately equal to:

$$\beta R_r \left(\frac{N}{100} - \frac{V_{bb}}{V_{cc}} \right)$$

of 10,000 ohms.

To assure saturation of transistor 12 when the relay is to be operated, the value for resistor 36 can be determined from the following relationship:

$$\frac{V_{cc}' - V_{cc}}{R_b + R_{33}} = \frac{I_R}{\beta} \quad (6)$$

Assuming a value for V_{cc}' of -24 volts, it can be seen that resistor 36 should also be 10,000 ohms. (I_R is 2 milliamperes with V_{cc} equal to 20 volts and R_r equal to 1,000 ohms; β , as noted above, is assumed to be 100.)

At some sacrifice in speed of relay release, R_b can be omitted with the resulting configuration as shown in Fig. 5. With R_b equal to zero (neglecting the base resistance of transistor 12 and the small collector-emitter resistance of transistor 31 in the saturation condition), V_{bb} (actually V_{ee} in this configuration) may be 20 percent (the desired maximum overshoot) of V_{cc} or four volts. Assuming in this case a collector voltage V_{cc}' of the transistor switch 31 of -40 volts, resistor 36 should, from Equation 5, have a value of 100,000 ohms.

Although the invention has been described in relation to specific embodiments, the embodiments shown and described are intended to be illustrative only. Numerous other embodiments and modifications will readily occur to one skilled in the art without departing from either the spirit or the scope of the invention.

What is claimed is:

1. A transistor circuit for operating a relay having at least a winding comprising a transistor having base, emitter, and collector electrodes, a circuit including said winding connected between said emitter and a point of fixed potential, a source of voltage V_{cc} connected to said collector, means for applying signals to operate said relay to an input circuit connected between said base and said point of fixed potential, and means for limiting the collector-to-base voltage to a predetermined safe value regardless of inductive transients which may occur when said relay releases, said safe value being N per cent greater than said voltage V_{cc} , said last-named means comprising a source of voltage V and a circuit for applying said voltage V to said base electrode, said voltages V and V_{cc} being related as follows:

$$\frac{V}{V_{cc}} \approx \frac{N}{100} - \frac{R_b}{\beta R_r}$$

where R_b is the resistance of said circuit means, β is the base-to-emitter current gain of said transistor and R_r is the effective series resistance of said winding.

2. In combination a source of signals, an inductive load, a transistor having base, collector, and emitter electrodes and being subject to damage by excessive collector voltage, means for applying said signals between said base and a point of reference potential, a source of col-

5

lector voltage V_{cc} connected to said collector, means connecting said load between said emitter and said point of reference potential, whereby said collector-to-base voltage tends to increase beyond said value V_{cc} as a result of inductive transients which occur when the voltage across said load is reduced in response to said signals, and means for limiting the overshoot in said collector-to-base voltage to a safe percentage, N , of said collector voltage comprising a resistor R_b and a source of voltage V_{bb} , means for applying voltages from said source to said base through said resistor, said base voltage V_{bb} and said resistor R_b having values to satisfy the following relation:

$$\frac{N}{100} \approx \frac{V_{bb}}{V_{cc}} + \frac{R_b}{\beta R_r}$$

where R_r is the effective series resistance of said inductive load and β is the base-to-emitter current gain of said transistor.

3. In combination, a source of electrical signals, a relay having a winding and means for operating said relay in response to said signals comprising a pair of transistors of opposite conductivity type, each having a base, emitter, and collector electrode, means for applying said signals to the base of a first of said transistors, means connecting the collector of said first transistor to the base of said second transistor, a circuit including said winding, the emitter of the second of said transistors and a point of fixed potential, a source of voltage V_{cc} connected to the collector of said second transistor, means for biasing said first transistor in the absence of said signals in the saturation condition and means for limiting the collector-to-base voltage overshoot of said second transistor to a safe percentage, N , of said voltage V_{cc} comprising a source of voltage V_{bb} and a resistor R_b connected in series and to the base electrode of said second transistor, said voltage V_{bb} and said resistor R_b having values to satisfy the following relation:

$$\frac{N}{100} \approx \frac{V_{bb}}{V_{cc}} + \frac{R_b}{\beta R_r}$$

where R_r is the effective series resistance of said inductive load and β is the base-to-emitter current gain of said transistor.

4. In combination, a source of signals, a relay having a winding and a pair of like conductivity type transistors each having a base, collector, and emitter electrode, means for applying said signals between the base electrode of a first of said transistors and a point of reference potential, means connecting the winding of said relay between the emitter of the second of said transistors and said point of reference potential, means for applying a voltage V_{cc} to the collector of said second transistor, means for applying a voltage V_{ee} to the emitter of said first transistor,

6

said voltage V_{ee} having a value and polarity sufficient to drive said first transistor to saturation in the absence of said signals, and means for limiting the overshoot in potential at the collector of said second transistor when said relay releases to a predetermined safe percentage N of said voltage V_{cc} comprising a resistor R_b connected between the collector of said first transistor and the base of said second transistor and having a value substantially equal to:

$$\beta R_r \left(\frac{N}{100} - \frac{V_{ee}}{V_{cc}} \right)$$

where R_r is the effective series resistance of said inductive load and β is the base-to-emitter current gain of said transistor.

5. The combination in accordance with claim 4 and a second resistor connected between a source of voltage V_{cc}' and the collector of said first transistor, said second resistor having a value substantially equal to:

$$\frac{\beta R_r}{V_{cc}} (V_{cc}' - V_{cc}) - R_b$$

6. In combination, a relay having at least a winding, a source of signals and means for operating said relay in response to said signals comprising a pair of transistors of like conductivity type and each having a base, collector, and emitter electrode, means for applying said signals to the base electrode of a first of said pair of transistors, a substantially direct connection between the collector of said first transistor and the base electrode of the second of said transistors, means including said winding in a circuit connected between the emitter of said second transistor and a point of fixed potential, a source of voltage V_{cc} connected to the collector of said second transistor and means for limiting the overshoot in the collector voltage due to inductive transients which occur when said relay releases to a predetermined safe percentage N of said collector voltage V_{cc} comprising a source of voltage V_{ee} connected to the emitter electrode of said first transistor, said voltage V_{ee} being N percent of said voltage V_{cc} , and sufficient in magnitude to drive said first transistor to saturation and said source of signals being sufficient in voltage to drive said first transistor to cut off.

7. The combination in accordance with claim 6 and a source of voltage V_{cc}' and means including a resistor R for applying said voltage V_{cc}' to the collector electrode of said first transistor, said resistor R being substantially equal to:

$$\frac{\beta R_r}{V_{cc}} (V_{cc}' - V_{cc}) - R_b$$

No references cited.