CHAPTER 6

# 20 RELAY-DRIVING SWITCHING PROJECTS

Operational amplifiers can be used in a variety of high-precision relay-driving switching applications, in which the relay is used to activate external circuitry via its contacts. In these applications the op-amps can readily be made to function as high-precision over-temperature or under-temperature switches, as sensitive light-activated switches, as water or steam-activated switches, as precision a.c. or d.c. voltage-sensitive switches, as time switches, or as switches that are activated by touch, sound, or tone.

Twenty useful and versatile op-amp relay-driving switching projects of various types are described in this final chapter of this volume. All of these projects are designed around the popular type 741 integrated-circuit op-amp, and the pin connections shown in the following diagrams apply to the 8-pin dual-in-line version of the device only.

## Precision temperature-activated switches

*Figure 6.1* shows how an op-amp can be connected as a relay-driving precision frost or under-temperature switch. In essence, the circuit consists of a fixed potential divider ($R_2$ and $R_3$), which generates a stable reference voltage, and a variable potential divider ($R_1$ and $TH_1$), which generates a temperature-dependent voltage. These two potential dividers are effectively connected as a Wheatstone bridge, with the bridge output feeding to the input terminals of the operational amplifier. The op-amp is connected as an open-loop differential amplifier or voltage comparator, and its action is such that its output is driven to positive saturation if its negative terminal is more than a few hundred microvolts negative to the positive terminal, and is driven to negative saturation if its negative terminal is more than a few hundred microvolts positive to the positive terminal. The output of the op-amp is coupled to relay-driving common-emitter amplifier $Q_1$ in such a way that the relay and transistor are cut off when the op-amp is positively saturated, and are driven fully on when the op-amp is negatively saturated.

$TH_1$ in this circuit is a negative-temperature-coefficient thermistor, so its resistance falls as temperature rises, and vice versa. In practice, variable resistor $R_1$ is adjusted so that the $R_1 - R_2 - R_3 - TH_1$ bridge is balanced at a temperature very close to the required trip or switching value, and under this condition zero voltage difference exists between the negative and positive terminals of the op-amp. Consequently, when the

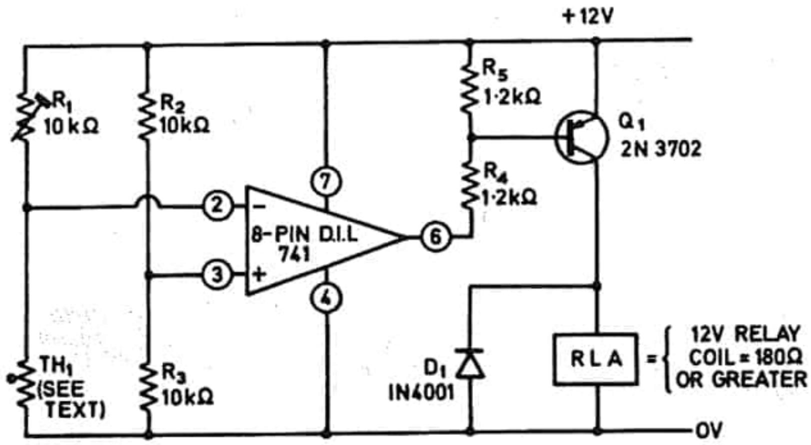



*Figure 6.1.* Precision frost or under-temperature switch.

temperature rises above the trip level the bridge goes out of balance in such a way that the negative terminal of the op-amp goes negative to the positive terminal, and the op-amp is driven to positive saturation, and $Q_1$ and the relay are cut off. When the temperature falls below the trip level, on the other hand, the bridge goes out of balance in such a way that the negative terminal of the op-amp goes positive to the positive terminal, and the op-amp is driven to negative saturation and drives $Q_1$ and the

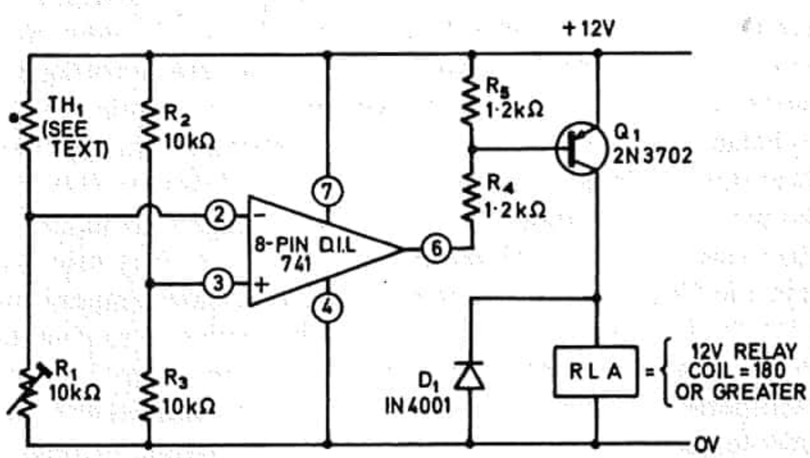



*Figure 6.2a.* Precision fire or over-temperature switch.

relay on. Thus, the relay turns on whenever the temperature falls below the pre-set trip level.

The action of the above circuit can be reversed, so that the relay turns on whenever the temperature exceeds a pre-set trip level, by simply transposing the $R_1$ and $TH_1$ positions, as shown in *Figure 6.2a*. Alternatively, the action can be reversed by leaving $R_1$ and $TH_1$ as they are but transposing the negative and positive input terminal connections of the op-amp, as shown in *Figure 6.2b*.

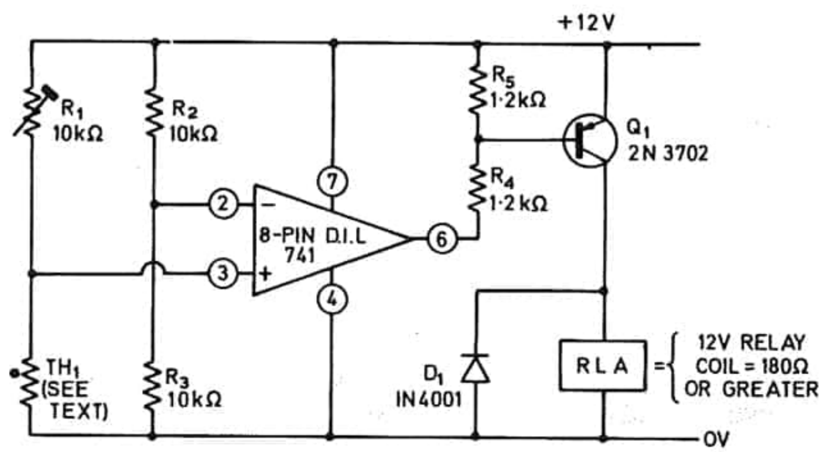



*Figure 6.2b.* Alternative precision fire or over-temperature switch.

Two points of particular importance should be noted concerning the *Figure 6.1* and *6.2* circuits. The first point is that each circuit goes through its switching phase when the bridge is approximately balanced, and the balancing point of a bridge is independent of the actual supply line voltage. Consequently, the thermal switching accuracy of the circuit is unaffected by variations in the circuits supply rail voltages.

The second point to note is that the op-amp can be driven from positive saturation to negative saturation by differential input voltage changes of only a few hundred microvolts. Since steady voltages of approximately 6 V are applied to the op-amp input terminals when the bridge is balanced, these changes of a few hundred microvolts represent percentage input voltage changes of the order of less than 0.01 % and these changes can be caused by a similar percentage shift in any one of the bridge resistances. Consequently, the circuits are very sensitive to changes in the $TH_1$ resistance, and give true precision temperature-sensing action. In practice, the circuits can be expected to give thermal switching accuracies of better than 0.05 °C at room temperatures.

The temperature-sensitive circuits that we have looked at so far give either over-temperature or under-temperature switching. If required, both types of action can be combined in a single two-relay circuit by using the connections shown in *Figure 6.3*. In this case the left (under-temperature) half of the circuit is based on that of *Figure 6.1*, and the right (over-temperature) half is based on *Figure 6.2b*. Both halves of the circuit share a common $R_1 - TH_1$ temperature-sensing section, but the under-temperature and over-temperature switching levels of the circuit are independently adjustable; the setting up procedure is as follows.

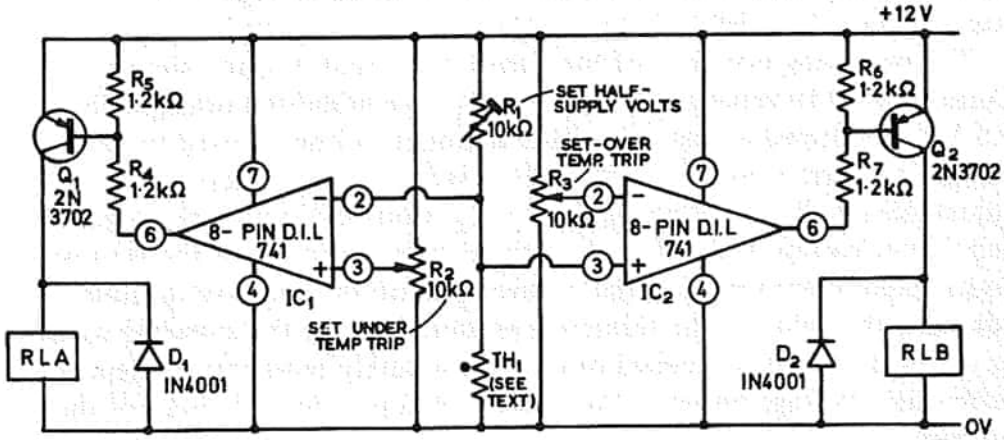



*Figure 6.3.* Combined under/over-temperature switch, with independent outputs.

First, set $R_2$ and $R_3$ to approximately mid travel, and then, with thermistor $TH_1$ at its 'normal' temperature, adjust $R_1$ so that approximately half-supply volts are developed across $TH_1$. Now reduce $TH_1$ to the required under-temperature trip level, and adjust $R_2$ so that relay *RLA* just turns on. Finally, raise $TH_1$ to the required over-temperature trip level, checking that *RLA* turns off, and adjust $R_3$ so that relay *RLB* just turns on. All adjustments are then complete, and the circuit is ready for use.

The thermistors used in the *Figure 6.1* to *6.3* circuits can be any negative-temperature-coefficient type that presents a resistance in the approximate range 900 Ω to 9 000 Ω at the required trip temperatures. Many suitable thermistor types are available from different manufacturers.

In some temperature-sensing applications a suitable thermistor may not be readily available, or alternatively, conventional thermistors may not be suitable. In low-temperature applications, for example, a finite amount of power is dissipated in the thermister by the measuring circuitry, and this power dissipation may cause sufficient self-heating of the thermistor to upset its accuracy. In such cases a circuit of the type shown in *Figure 6.4*, in which a conventional silicon diode is used as a temperature-sensing element, may prove useful.

If a fixed current of a milliamp or so is passed through a conventional silicon diode a forward voltage of approximately 600 mV is developed across the junction of the device. The precise value of the forward voltage is subject to variation with temperature, and the junction in fact exhibits a negative-temperature-coefficient of approximately $-2$ mV/°C. All silicon diodes exhibit a similar temperature coefficient, and can thus be used as temperature-sensing devices. Since only 600 $\mu$W or so of power are dissipated in the diode at currents of 1 mA, self-heating effects are negligible, and the diode thus offers certain advantages over conventional thermistors in low-temperature sensing applications.

The operating principle of the *Figure 6.4* circuit is quite simple. Current is fed to zener diode $ZD_1$ via $R_1$, so a stabilised potential of 5.6 V is developed across $ZD_1$. This stabilised voltage is used to generate a constant current in silicon diode $D_1$ via $R_4$, and to generate an adjustable stabilised voltage in $R_3$ via $R_2$. Consequently, a temperature-dependent voltage is developed on the positive terminal of the op-amp, and a fixed reference potential is developed on the negative terminal. By adjusting the value of the reference potential via $R_3$ the *standing* voltage of the diode can be cancelled out to give a purely temperature-dependent differential voltage between the negative and positive terminals of the op-amp.

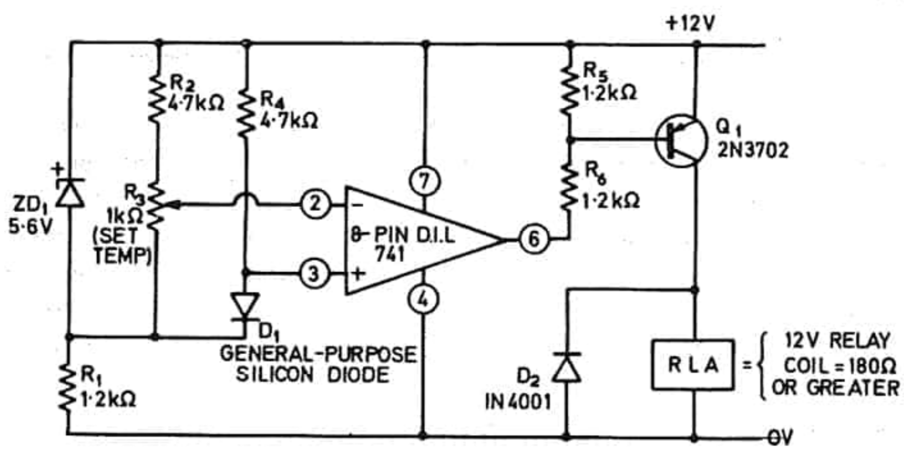



*Figure 6.4.* Over-temperature switch, using silicon diode temperature sensor.

Suppose then that $R_3$ is adjusted to give zero differential voltage at the required trip temperature. If the temperature now rises above the trip level the forward voltage of $D_1$ will fall, so the positive terminal of the op-amp will become negative relative to the negative terminal, and the op-amp will go into negative saturation. Under this condition, therefore, $Q_1$ and the relay are driven on. If, on the other hand, the temperature falls below the trip level, the $D_1$ voltage will rise, so the positive terminal of the op-amp will become positive relative to the negative terminal, and the op-amp will go into positive saturation. Under this condition $Q_1$ and the relay will be cut off.

Thus, the relay in the *Figure 6.4* circuit turns on only when the temperature exceeds the pre-set trip level. In practice, this circuit can be expected to give a thermal switching accuracy of better than 0.5 °C throughout the temperature range −50 °C to +120 °C. Temperature-sensing element $D_1$ can be any general-purpose silicon diode. The action of the circuit can be reversed, so that it acts as an under-temperature switch, by simply transposing the input terminal connections of the op-amp.

*Figure 6.5* shows how a pair of silicon diodes can be used as temperature-sensing elements in a differential temperature switch, which turns on only when the temperature of $D_2$ is greater than that of $D_1$, and is not influenced by the absolute temperature of the two diodes. Circuit operation is as follows.

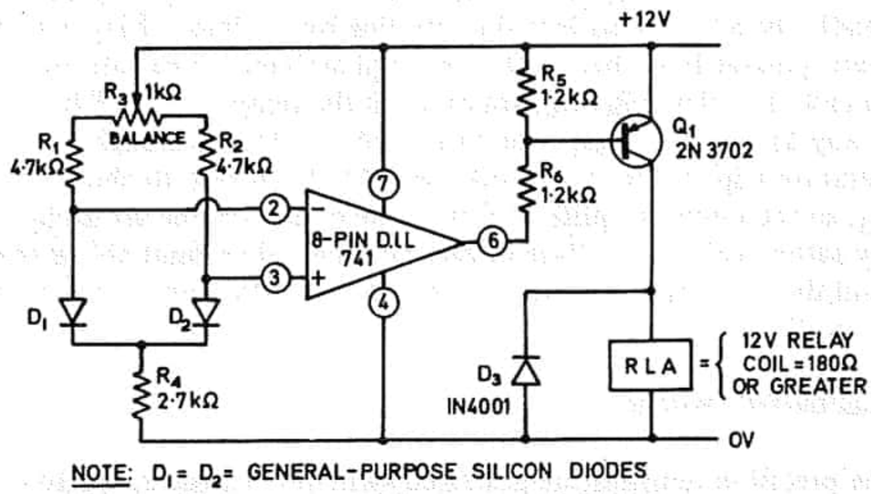



*Figure 6.5.* Differential temperature switch.

$D_1$ and $D_2$ are general-purpose silicon diodes, and are used as temperature-sensing elements. A standing current can be passed through $D_1$ from the positive supply line via $R_3$, $R_1$, and $R_4$, and a similar current can be passed through $D_2$ via $R_3$, $R_2$, and $R_4$. The relative values of these currents can be adjusted over a limited range via $R_3$, thus enabling the forward volt drops of the diodes to be equalised, so that they give zero differential output when they are both at the same temperature.

Suppose then that the diode voltages have been equalised in this way, so that zero voltage differential exists between them. If now the temperatures of both diodes are raised by 10 °C, the forward voltages of both diodes will fall by 20 mV, and zero voltage differential will still exist between them. The circuit is thus not influenced by identical changes in the ambient temperatures of $D_1$ and $D_2$. Suppose, on the other hand, that the temperature of $D_2$ falls 1 °C below that of $D_1$. In this case the $D_2$ voltage will rise 2 mV above that of $D_1$, so the positive terminal of the op-amp will go positive to the negative terminal, and the op-amp will go into positive saturation and hold $Q_1$ and the relay off. Finally, suppose that the temperature of $D_2$ rises 1 °C above that of $D_1$. In this case the $D_2$ voltage will fall 2 mV below that of $D_1$, so the positive terminal of the op-amp will go negative relative to the negative terminal, and the op-amp will go into negative saturation and drive $Q_1$ and the relay on. Thus, the relay turns on only when the temperature of $D_2$ is above that of $D_1$ (or when the temperature of $D_1$ is below that of $D_2$).

In the explanation above it has been assumed that $R_3$ is adjusted so that the $D_1$ and $D_2$ voltages are exactly equalised when the two diodes are at the same temperature, so that the relay goes on when the $D_2$ temperature rises a fraction of a degree above that of $D_1$. In practice, $R_3$ can readily be adjusted so that the standing bias voltage of $D_2$ is some millivolts greater than that of $D_1$ at normal ambient temperatures, in which case the relay will not turn on until the temperature of $D_2$ rises some way above that of $D_1$. The magnitude of this differential temperature trip level is in fact fully variable from zero to about 10 °C via $R_3$, so the circuit is quite versatile. The circuit can be set up by simply raising the temperature of $D_2$ the required amount above that of $D_1$, and then carefully adjusting $R_3$ so that the relay just turns on under this condition.

**Light-activated switches**

The precision temperature-activated switches of *Figures 6.1* to *6.3* can readily be made to function as light-activated switches by using light-dependent resistors (LDR) in place of the thermistors in their bridge networks. *Figure 6.6* shows the basic circuit of a light-activated switch, which turns on when the light intensity exceeds a pre-set level.

The LDR in this (and the *Figure 6.7* to *6.9* circuits) presents a low resistance under bright conditions, and a high resistance under dark conditions. Thus, under dark conditions the LDR resistance is high, so the voltage on the negative terminal of the op-amp is below that of the positive terminal, so that the op-amp is positively saturated and $Q_1$ and the relay are cut off. Under bright conditions, on the other hand, the LDR resistance is low, so the op-amp is negatively saturated, and $Q_1$ and the relay are driven on. The actual trip level of the circuit can be adjusted via $R_1$.

The action of the above circuit can be reversed, so that it functions as a dark-activated switch that turns on when the light intensity falls below a pre-set level, by merely transposing the $R_1$ and LDR positions, as shown in *Figure 6.7*. This circuit also shows how the design can be provided with electro-mechanical self-latching by wiring a pair of

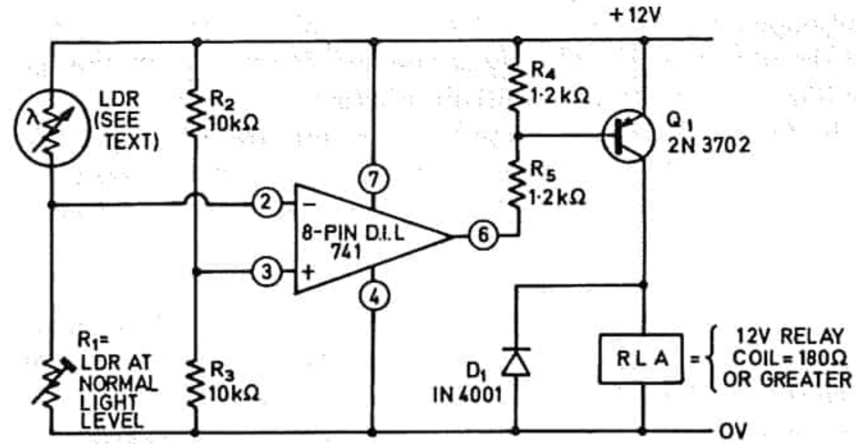



*Figure 6.6.* Precision light-activated switch.

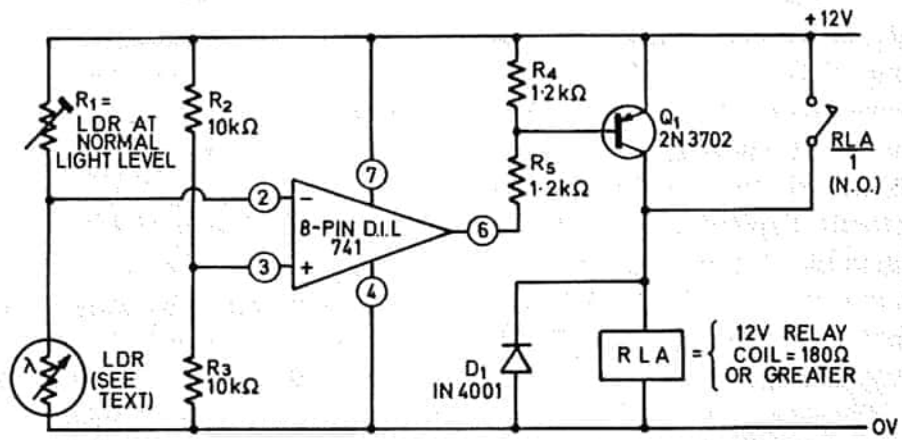



*Figure 6.7.* Self-latching dark-activated switch.

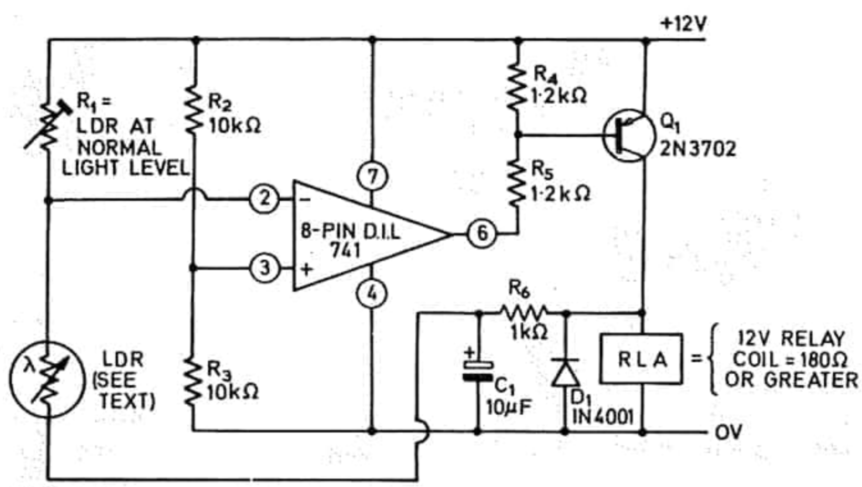



*Figure 6.8.* Dark-activated switch with electronic self-latching.

normally-open relay contacts between the emitter and collector of $Q_1$, so that the relay is automatically connected directly across the power supply lines once it has been initially activated by the sensing circuitry. Once the *Figure 6.7* circuit has self-latched into the ON mode, it can only be reset into the off state again by raising the light intensity above the trip level and momentarily breaking the supply connections to the relay.

The dark-operated switching circuit can be provided with a purely electronic self-latching facility, if required, by using the connections shown in *Figure 6.8*. Note in this case that the low end of the LDR is taken to the 0 V line via $R_6$ and the relay coil. Normally, when the light intensity is above the trip level, the relay is off, so the voltage on the negative terminal of the op-amp is dictated by the resistive values of the potential divider chain formed by $R_1$ – *LDR* – $R_6$ and the relay coil. Once the relay has turned on, however, 12 V is developed across its coil via $Q_1$, and this potential is imposed on the negative terminal of the op-amp via $R_1$ and the *LDR*, and thus locks the op-amp into the negatively saturated mode and holds the relay on. Once the relay has locked on, it can only be turned off again by raising the light intensity above the trip level, and momentarily breaking the supply connections to the circuit. Capacitor $C_1$ is used in this circuit to enhance stability and suppress the effects of sudden transient changes in light level.

A two-relay combined light/dark switch can be made by using an LDR in place of the thermistor in the *Figure 6.3* circuit. If required, the circuit can be modified so that it drives a single relay, which turns on when the light intensity goes above or below pre-set levels, by using the connections shown in *Figure 6.9*. In this case $IC_1$ acts as a dark-sensitive switch, and

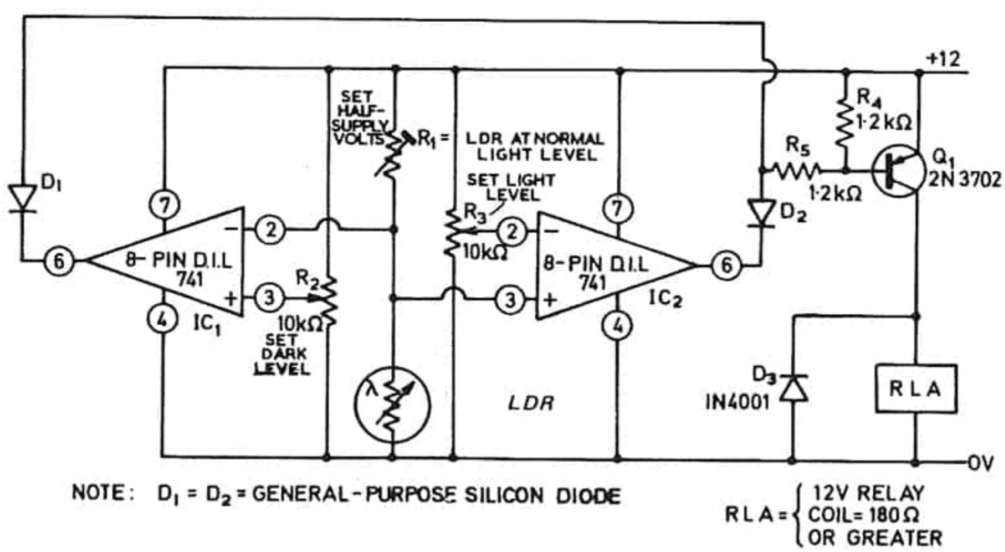



*Figure 6.9.* Combined light/dark switch with single input.

$IC_2$ as a light-sensitive switch, and the outputs of these two switches are fed to the relay via $Q_1$ and gating diodes $D_1$ and $D_2$ in such a way that the relay turns on whenever either op-amp goes into negative saturation. The procedure for setting up the *Figure 6.9* circuit is as follows.

First, set $R_2$ and $R_3$ to approximately mid travel, and then, with the LDR at its *normal* illumination level, adjust $R_1$ so that approximately half-supply volts are developed across the LDR. Now fully rotate the $R_2$ slider towards the positive supply line, and rotate the $R_3$ slider towards the 0 V line, and check that the relay is off. Next, reduce the LDR illumination intensity to the required *dark* trip level, and adjust $R_2$ so that the relay just turns on. Now increase the illumination level slightly, and check that the relay goes off. Finally, increase the illumination to the required *light* trip level, and adjust $R_3$ so that the relay again just turns on. All adjustments are then complete, and the unit is ready for use.

The LDRs used in the *Figures 6.6* to *6.9* circuits can be any cadmium sulphide photocells that present a resistance in the range 900 Ω to 900 kΩ at the required trip levels of light intensity.

## A water or steam-activated switch

*Figure 6.10* shows how the operational amplifier can be made to function as a sensitive water or steam-activated relay-driving switch. The op-amp is again wired as a voltage comparator, and has a fixed voltage

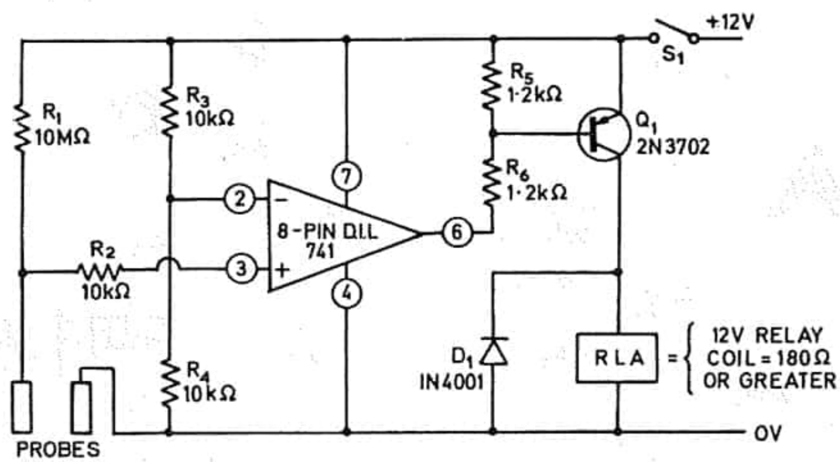



*Figure 6.10.* Water or steam-activated switch.

applied to its negative terminal via $R_3$ and $R_4$, and a variable voltage applied to the positive terminal via the potential divider formed by $R_1$ and the resistance of the two probes. If the probes are open circuit, negligible voltage divider action takes place, and almost the full supply line voltage is applied to the positive terminal of the op-amp: under this condition the relay is off. When, on the other hand, a resistance of less than 10 MΩ is connected across the probes, the voltage divider action is such that the voltage on the positive terminal of the op-amp is less than that of the negative terminal, and under this condition $Q_1$ and the relay turn on. Thus, the relay turns on whenever a resistance of less than 10 MΩ appears between the two probes.

Water and steam exhibit the characteristics of relatively low-value resistances. Consequently, when water or steam come into contact with both metal probes simultaneously, the relay turns on, and the circuit thus acts a water or steam-activated switch. The circuit has a variety of applications in the home and in industry. It can be used to sound an alarm when rain water falls on the probes, when flooding occurs in basements, when water rises to a pre-set level in tanks or baths, or when steam is ejected from a kettle spout as the liquid in the kettle starts to boil. If required, the sensitivity of the circuit can be reduced by increasing the value of $R_1$, since $R_1$ determines the maximum value of probe resistance that is needed to activate the circuit.

## Voltage-activated switches

Operational amplifiers can readily be made to function as precision over-voltage or under-voltage switches in both d.c. and a.c. applications. *Figure 6.11*, for example, shows the connections for making a precision d.c. over-voltage switch for use with test voltages of 5 V or greater.

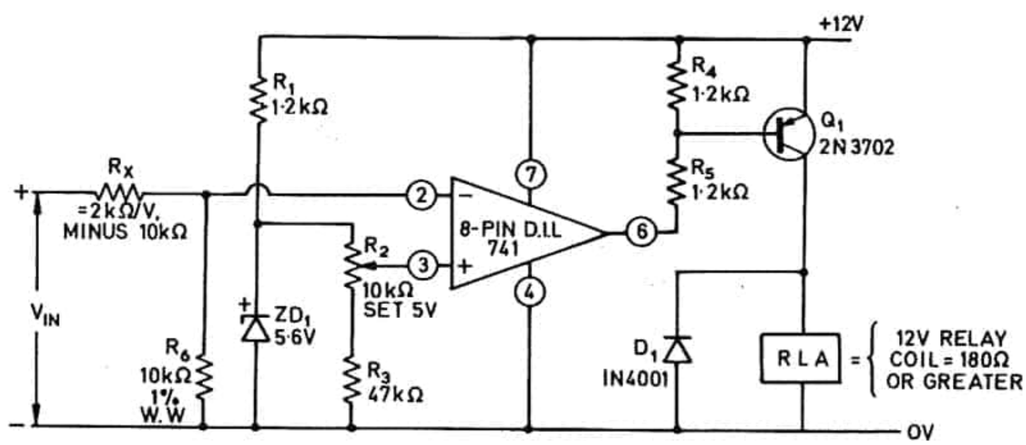



*Figure 6.11.* Precision d.c. over-volt switch, covering 5 V upwards.

The operation of the *Figure 6.11* circuit is quite simple. A zener-derived reference potential of 5 V is applied to the non-inverting pin of the op-amp via $R_2$, and the test voltage is applied between the inverting pin and ground via $R_x$. $R_6$ is a precision 10 kΩ resistor wired between the inverting pin and ground. The basic action of the circuit is such that the relay is off when the inverting pin voltage of the op-amp is less than the 5 V of the reference potential, and the relay is on when the inverting pin voltage is greater than 5 V.

Since $R_x$ is wired in series between the actual test voltage and the 10 kΩ impedance of the inverting pin of the op-amp, $R_x$ enables the circuit to be ranged so that it triggers at any required voltage in excess of the 5 V reference value. The value of $R_x$ for any required trigger voltage value is in fact selected on a basis of 2 kΩ/V – 10 kΩ. Thus, for 50 V triggering, $R_x$ = 50 x 2 kΩ – 10 kΩ = 90 kΩ. For 5 V triggering, $R_x$ should be given a value of zero.

The *Figure 6.11* circuit is very sensitive, and exhibits negligible backlash; triggering accuracies of 0.5 % can easily be achieved. For maximum accuracy, the zener reference supply of the circuit should itself be stabilised, or the zener should be fed from a constant-current source.

The *Figure 6.11* circuit can be made to function as a precision under-voltage switch, which turns on whenever the input voltage falls below a pre-set level, by simply transposing the inverting and non-inverting pin connections of the op-amp, as shown in *Figure 6.12*. This circuit also

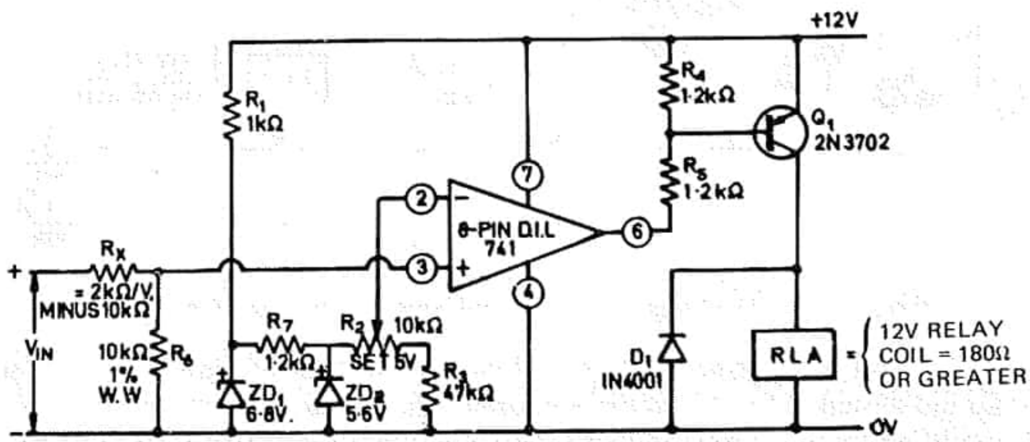



*Figure 6.12.* Precision d.c. under-volt switch, covering 5 V upwards.

shows how the zener reference supply can be stabilised for high-precision operation. Note in both of these circuits that, once 5 V has been accurately set via $R_2$, the final triggering accuracy of each design is determined solely by the accuracies of $R_x$ and $R_6$. In high-precision applications, therefore, both $R_x$ and $R_6$ should be precision wire-wound types.

*Figure 6.13* shows how the *Figure 6.11* circuit can be modified for use as an over-voltage switch covering the input voltage range 10 mV to 5 V. In this case the input voltage is connected directly to the inverting terminal of the op-amp, and a variable reference potential is applied to the non-inverting terminal. This reference potential is adjusted to give the same value as that of the required trigger voltage. Note that this circuit makes use of two sets of supply lines, to ensure proper biasing of the op-amp.

*Figure 6.14* shows how the above circuit can be modified for operation from a single set of supply lines. In this case the zener diode is given a value of 6.8 V, and $R_1$ is connected in series with $ZD_1$ via the negative supply line. Note that the $R_1 - ZD_1$ junction forms the common input signal connection of the op-amp. Consequently, the positive supply terminal of the op-amp is biased 6.8 V positive to the common line, and the negative supply terminal is biased 5.2 V to 11.2 V negative to the common line. The op-amp is thus correctly biased even though only a single set of supply lines is used.

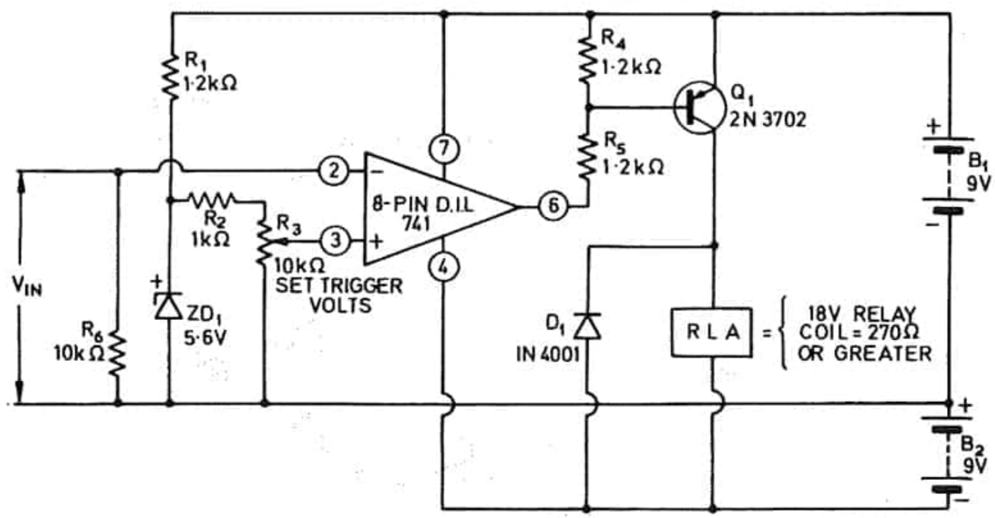



*Figure 6.13.* Dual supply d.c. over-volt switch, covering 10 mV to 5 V.

The four voltage-activated switching circuits that we have looked at so far are designed for d.c. activation only. These basic circuits can be modified for a.c. activation by interposing suitable rectifier/smoothing networks between their input terminals and the actual a.c. input signals,

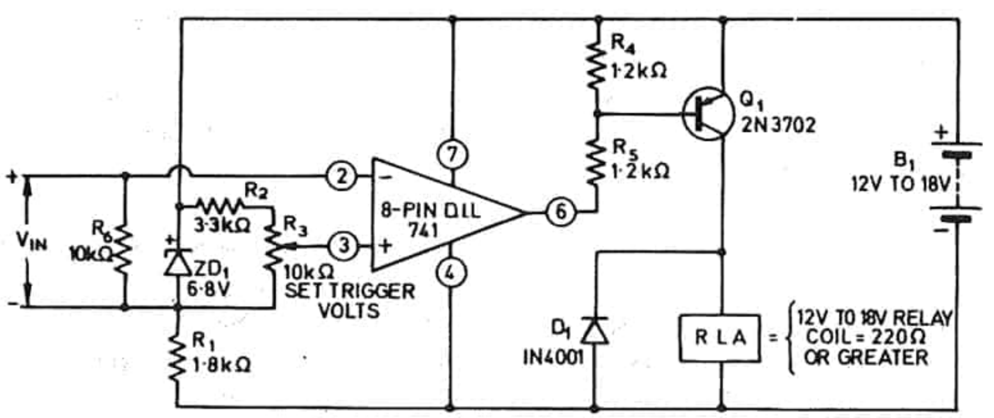



*Figure 6.14.* Single supply over-volt switch, covering 10 mV to 5 V.

so that the a.c. signals are converted to d.c. before being applied to the basic circuits.

*Figure 6.15a* shows the practical circuit of a precision a.c. over-voltage switch that is designed to work with sine wave signals in excess of 2.5 V r.m.s. Here, the a.c. signal is converted to d.c. via voltage doubling and smoothing network $R_x - C_1 - D_1 - D_2 - C_2 - R_1$, and the resulting d.c. voltage is applied to the inverting input of the op-amp via $R_2$; a zener-derived 5.6 V reference potential is applied to the non-inverting terminal. The circuit action is such that the relay turns on only when the d.c. voltage on the inverting terminal exceeds 5.6 V.

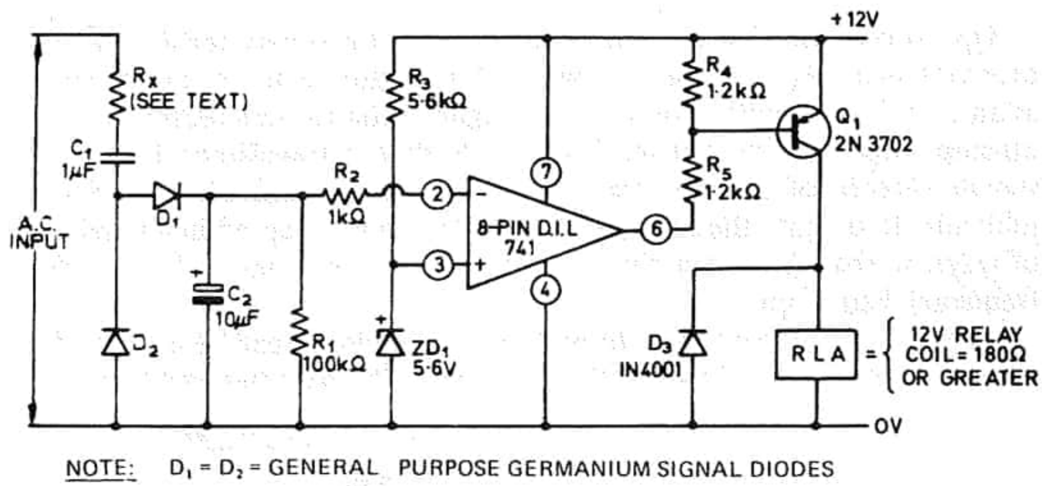



*Figure 6.15a.* Precision a.c. over-volt switch.

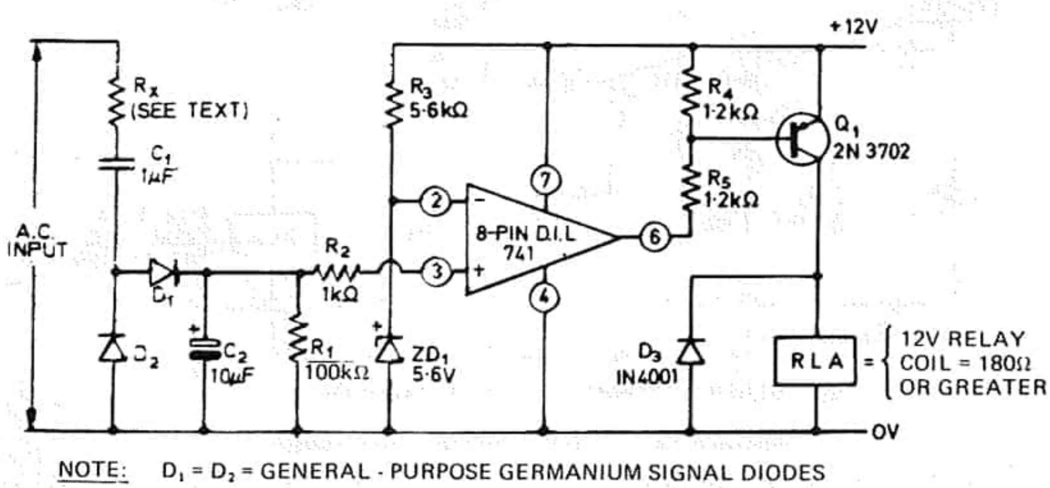



*Figure 6.15b.* Precision a.c. under-volt switch.

The action of the above circuit can be reversed, so that it works as an under-voltage switch, by transposing the input terminal connections of the op-amp, as shown in *Figure 6.15b*.

It should be noted that both of the *Figure 6.15* circuits exhibit a basic input impedance, with $R_x$ reduced to zero ohms, of approximately 15 kΩ, and that under this condition a sine wave input of roughly 2.5 V r.m.s. is needed to operate the relay. Consequently, when $R_x$ is given a finite value it acts as a potential divider with this 15 kΩ input impedance, and enables the circuit to be ranged to trigger at any required a.c. voltage level in excess of 2.5 V. The $R_x$ value should be chosen on the basis of approximately 6 kΩ/V – 15 kΩ.

## Miscellaneous switching projects

Operational amplifiers can be made to function as very sensitive a.c. over-volt switches in a variety of ways. One method is to use the op-amp as an open-loop amplifier of a.c. input signals, and to then rectify the op-amp output and use the resulting d.c. to drive a transistor-relay switch. Circuits of this type may require a.c. input signals of only a few millivolts to operate the relay. Such circuits can be adapted in a number of ways, so that they are activated by specific frequencies, or by specific frequency bands, etc.

*Figure 6.16*, for example, shows how such a circuit can be adapted for use as a touch-operated switch that is activated by a bodies capacitive

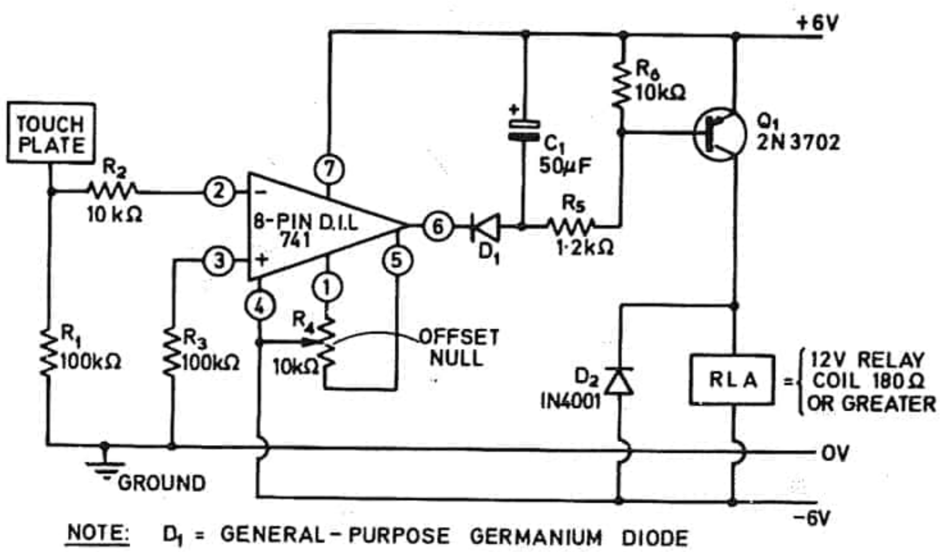



*Figure 6.16.* Touch-activated relay switch.

pick-up of the 50 Hz or 60 Hz stray signals from the a.c. power lines. The capacitive pick-up signal is applied to a touch plate, and is thence fed to the inverting input terminal of the op-amp via $R_2$. The output signal of the op-amp is then rectified and smoothed by $D_1$ and $C_1$, and the resulting d.c. is used to operate the relay via $Q_1$.

Note in this circuit that the rectifier and relay-driving network are d.c.

coupled to the output of the op-amp, and that the op-amp is provided with an offset-null control. In practice, the offset-null control is adjusted so that the op-amp output is just short of positive saturation under quiescent conditions. Under these circumstances a small d.c. bias is applied to the base of $Q_1$ via $D_1$ and $R_5$, but is not sufficient to drive $Q_1$ or the relay on. Consequently, when a.c. signals are applied to the op-amp, the negative-going parts of the output signals apply sufficient extra biasing to drive $Q_1$ and the relay on, and the circuit exhibits very high sensitivity. When the offest-null control is correctly adjusted, the relay can be activated by input signals as low as 1 mV r.m.s.

The touch plate in the *Figure 6.16* circuit can be a simple metal disc a few centimetres in diameter. Note that the common rail of the circuit must be grounded for correct operation, and that the circuit will only work if it is within reasonable proximity of the a.c. power lines. To set up the circuit, first adjust $R_4$ (the offset-null control) so that the relay goes on, and then turn $R_4$ back just past the point at which the relay goes off again. Now touch the touch plate, and check that the relay turns on. All adjustments are then complete, and the circuit is ready for use.

*Figure 6.17* shows how the above circuit can be modified so that it acts as a voice-frequency relay switch. The two circuits are similar, except that in the case of the *Figure 6.17* circuit the op-amp is wired as a

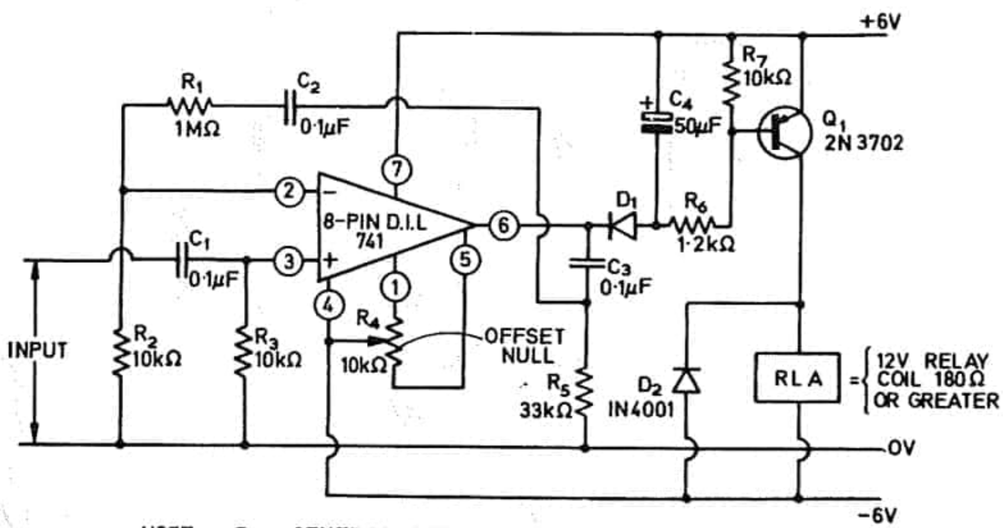
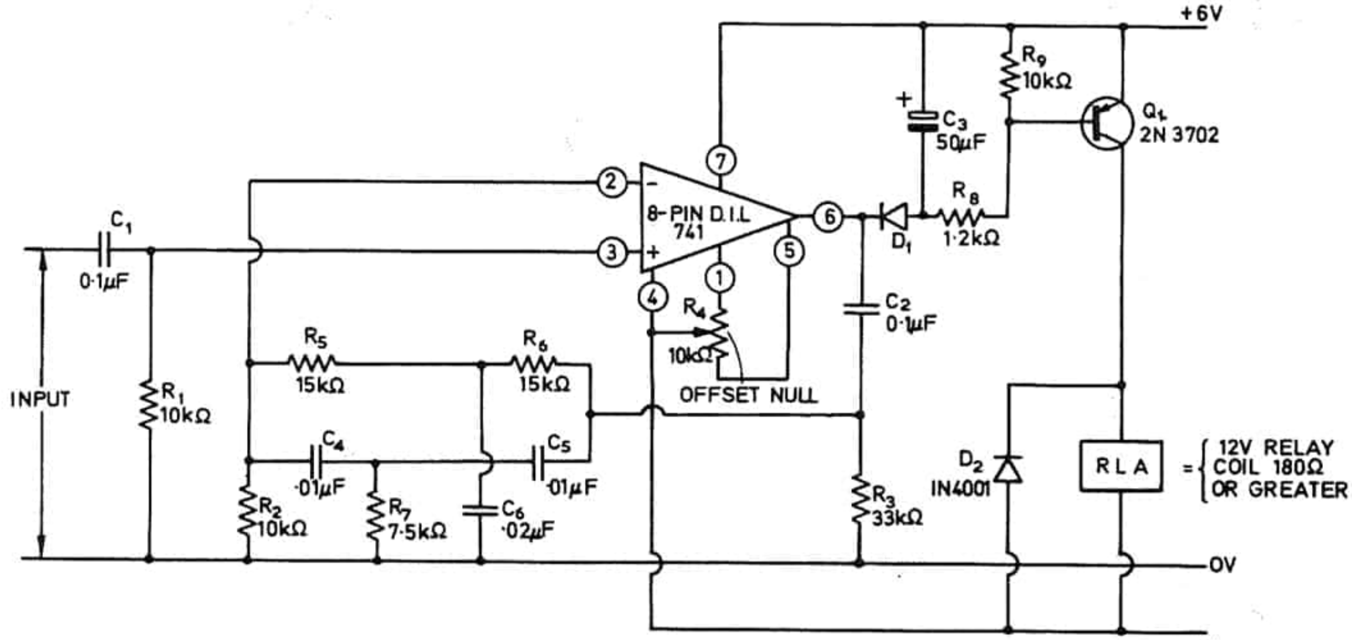



*Figure 6.17.* Voice-frequency relay switch.

non-inverting a.c. amplifier with a maximum gain of x 100, and with its bandwidth restricted to the lower audio frequency range. The circuit has a typical sensitivity of 5 mV r.m.s. to signal frequencies in the range 50 Hz to 2 kHz, and a sensitivity of 10 mV over the range 50 Hz to 4.5 kHz.




NOTE: $D_1$ = GENERAL-PURPOSE GERMANIUM DIODE

*Figure 6.18.* 1 kHz tone-activated relay switch.

The *Figure 6.17* circuit is set up by first adjusting $R_4$ so that the relay goes on, and then turning $R_4$ back so that the relay just goes off again. The relay should then operate if a 1 kHz signal of a 5 mV or so is applied to the circuits input. The circuit can be used as a sound-operated switch, if required, by simply feeding the output of a pick-up microphone to the unit via a simple pre-amplifier, to give the required 5 mV drive voltage.

Finally, *Figure 6.18* shows how the above circuit can be modified for use as a 1 kHz tone-operated relay switch by incorporating a twin-T filter network in the negative feedback path of the non-inverting amplifier. The circuit is set up in the same way as the *Figure 6.17* circuit, and needs an input of 5 mV r.m.s. to operate the relay at 1 kHz: under this condition the circuit bandwidth is roughly ±2.5 % of the centre frequency. To maintain this narrow bandwidth, the input signal must be limited to less than 10 mV r.m.s., since the bandwidth is proportional to the amplitude of the input signal of the circuit.

## Time-activated switches

Finally, to conclude this last chapter of this volume, *Figures 6.19* and *6.20* show how op-amps can be used as time-activated switches with relay outputs. The *Figure 6.19* circuit acts as a 100 s delayed-turn-on relay driver, in which the relay does not turn on until 100 s after $S_1$ is closed. The *Figure 6.20* circuit acts as an auto-turn-off relay driver, in which the relay turns on as soon as $S_1$ is operated, but turns off again automatically after a delay of 100 s.

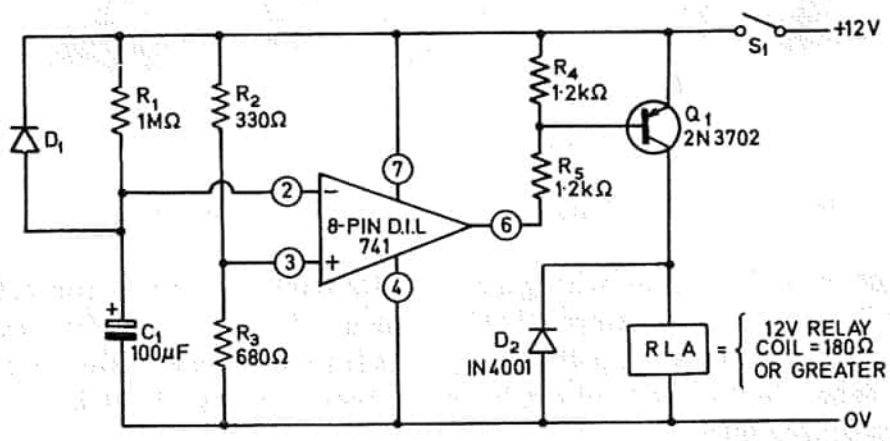



*Figure 6.19.* 100 s delayed-turn-on relay driver.

The operation of the *Figure 6.19* circuit is as follows. When $S_1$ is first closed $C_1$ is fully discharged, so the inverting terminal of the op-amp is effectively shorted to ground at this moment and the non-inverting terminal is held positive via $R_2$ and $R_3$. Under this condition the op-amp output is driven to saturation, so $Q_1$ and the relay are both cut off. $C_1$ starts to charge exponentially via $R_1$ as soon as $S_1$ is closed, and after a pre-set delay of about 100 s the inverting terminal voltage rises above that of the non-inverting terminal, at which point the op-amp comes out of positive saturation and $Q_1$ and the relay turn on. The operating sequence is then complete.

The *Figure 6.19* circuit gives time delays of approximately 1 s per $\mu$F of $C_1$ value, and thus gives a delay of 100 s with the component values shown. If required, the delay can be made variable by replacing $R_1$ with a 1 M$\Omega$ variable resistor. $D_1$ is used in the circuit to rapidly discharge $C_1$ via the low value resistance of $R_2$ and $R_3$ when $S_1$ is opened, thus giving a rapid reset action.

The action of the *Figure 6.19* circuit can be reversed, so that it gives automatic-turn-off operation, by simply transposing the inverting and non-inverting terminal connections of the op-amp, as shown in *Figure 6.20*. This diagram also shows how the circuit can be adapted for

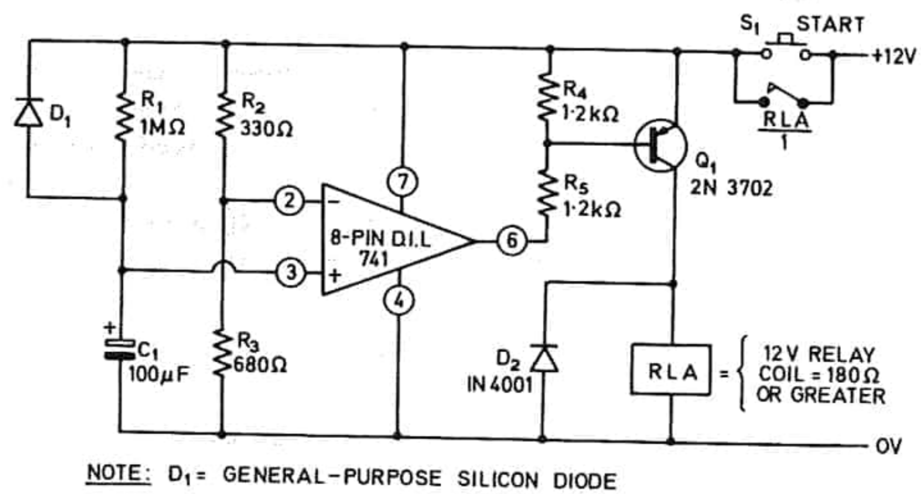



*Figure 6.20.* Pushbutton activated auto-turn-off relay driver.

pushbutton activation by wiring a pair of normally-open relay contacts in parallel with $S_1$. An external load can be activated via an additional pair of relay contacts, or, if the load works from the same power supply as the delay circuit, the load can be wired directly across the delay circuits supply lines.

The relays used in the *Figure 6.19* and *6.20* circuits can be any 12 V types having coil resistances of 180 $\Omega$ or greater.

# APPENDIX

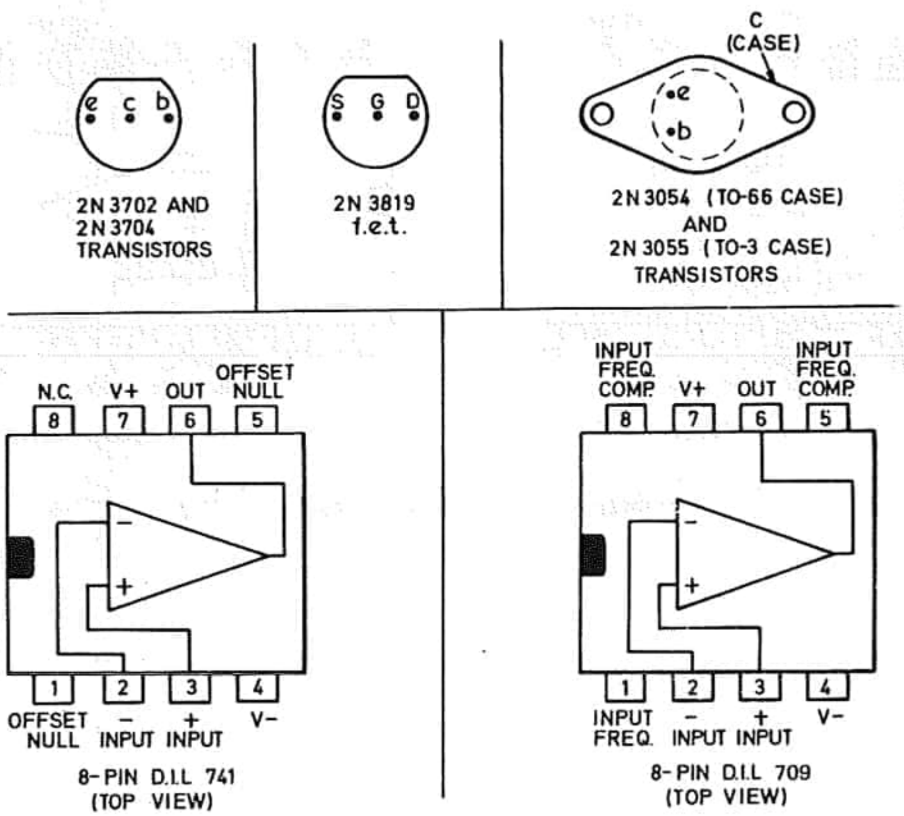



*Figure 7.1.* Outlines and connections of semiconductor devices used in the volume.

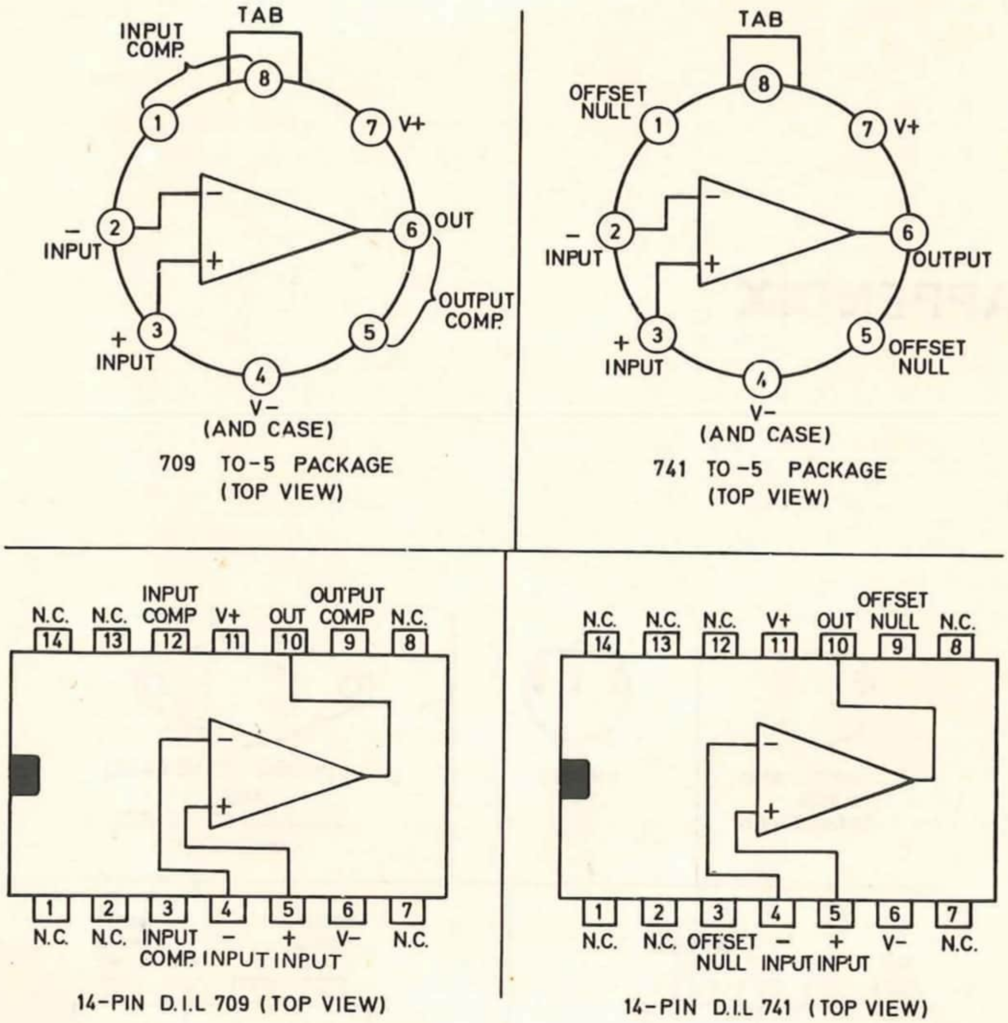



*Figure 7.2.* Pin connections of alternatively packaged 709 and 741 op-amps.