OF LIGHT-OPERATED SWITCHES

Described by G. J. KING

Our heading illustration shows the Mullard ORP cadmium sulphide photoconductive cell. The sensitive element is contained in a glass dish 14mm in diameter and 8mm deep

THERE are hosts of applications for a device capable of switching electrical contacts on or off automatically when its light-sensitive control element is subjected to changes in level of illumination. A typical application is for switching on a car parking light at dusk and switching it off again at dawn without human control.

A similar application is for switching on house, shop, office, factory or street lights when the ambient illumination drops below a predetermined level, and for switching them on again when it rises. This does away with the old-type time-switch. This application is also useful to discourage unwanted visitors when the house is left unoccupied for any lengthy period, such as during holidays and so forth.

Other applications include the automatic opening of the doors of a garage when the light-sensitive element picks up the rays of the headlights of the oncoming car, the counting of articles as they drop through and thus interrupt a ray of light which is directed onto the light-sensitive element, a smoke alarm, for use in smokeless zones, where a ray of light is interrupted by the presence of excess smoke in a chimney flue or stack, this reducing the intensity of light falling upon the light-sensitive element . . . and so on.

The basic functions of light-operated switches are the production of a potential, the change in a potential or the change in characteristics—such as resistance—of the light-sensitive control element. Such effects can be utilised to energise or de-energise a relay, thereby opening or closing a pair or more of electrical contacts, which in turn operate a light, bell or other alarm device, or an electric motor often in a form of servo arrangement.

BASIC CONTROL

In cases where the control current is very high, a secondary relay with a heavier set of contacts than those of the primary relay is controlled by the contacts of the primary relay. The basic controlling features are shown in Fig. 1.

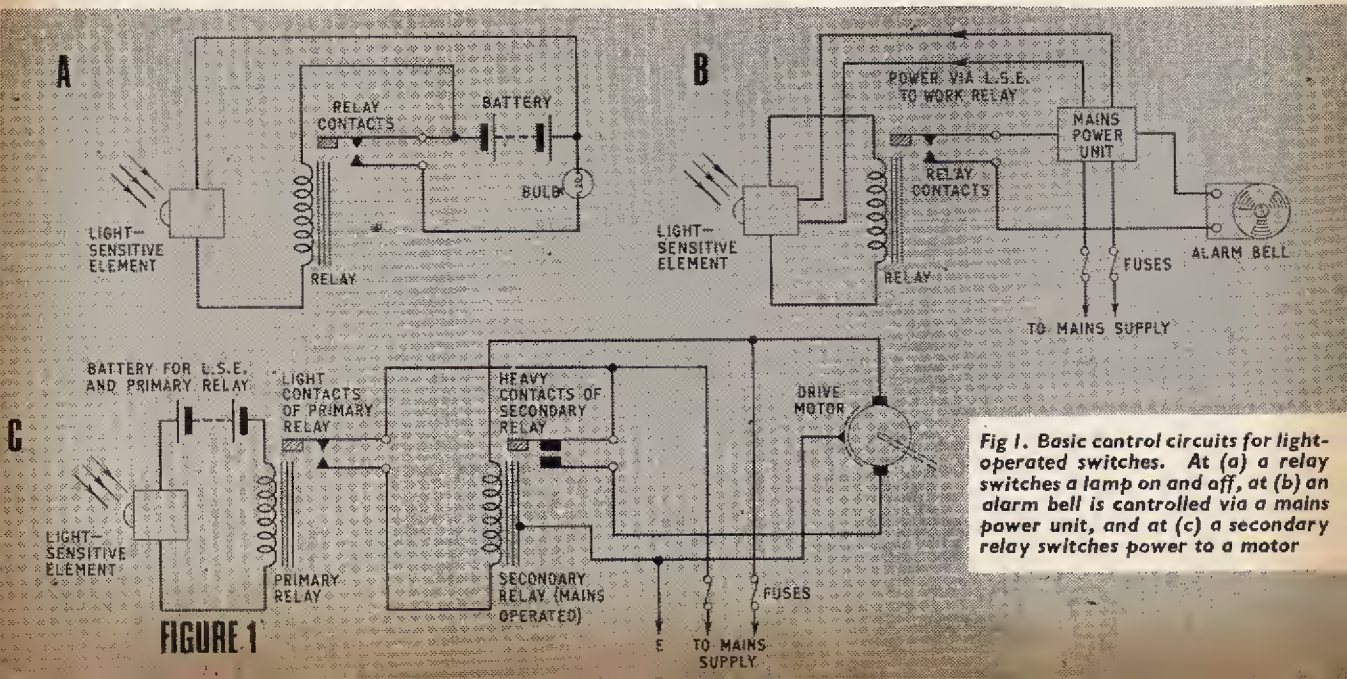

Fig 1. Basic control circuits for light-operated switches. At (a) a relay switches a lamp on and off, at (b) an alarm bell is controlled via a mains power unit, and at (c) a secondary relay switches power to a motor

At (a) we have the straightforward case, such as may be used to switch a parking light on and off. Here the battery could be the car accumulator (6 or 12V). This battery, being a d.c. supply, could both operate the relay by way of the light-sensitive element and work the bulb in the parking light.

The idea is that during the day the light-sensitive element in conjunction with its control circuit would pass insufficient current to energise the relay. The contacts thus remain open and the bulb extinguished. At lighting up time, however, the light-sensitive element and associated control produces an increase in current from the battery through the winding of the relay. This energises the relay, closes the relay contacts and thus passes battery current through the bulb which then lights.

At this juncture it should be noted that the arrangement could be reversed. That is, the relay could be energised during the daylight hours, under which condition the contacts would be *open*, and then de-energised during the night time, when the contacts would be closed to pass battery current through the bulb. It is just a matter of choosing the required light-sensitive element controlling circuit and relay.

At (b) we have a little more complicated arrangement, where a mains power unit is employed both to operate the alarm bell and the relay, the latter via the light-sensitive element and its associated circuit.

At (c) is shown an arrangement which features two relays. Here the primary relay is operated by a battery in the light-sensitive control circuit. When the contacts of this relay close, power from the mains supply is caused to pass through the winding of the secondary relay, which is a mains-operated type. The heavy contacts of this relay then close and pass mains power to the drive motor, which may work a garage door or some other mechanical device.

It is possible, of course, to make the whole control unit mains-operated to avoid the battery for the primary relay. This could be accomplished by an extension of (b), where a mains power unit supplies a d.c. voltage for the relay and light-sensitive control circuit, or by using a mains-operated primary relay.

So much, then, for the basic control and relay circuits, but what about the light sensitive element itself?

LIGHT-SENSITIVE DEVICES

An early light-sensitive element was the photo-electric cell. This was used extensively not only for controlling switching circuits by light but also for the replay of sound tracks on cine films. The photo-electric cell is, in fact, still used for the latter application, but other light-sensitive elements are better suited for control work. The photo-electric cell is a device which delivers a small amount of electricity (potential) when light is directed upon it. The greater the light intensity, the greater the potential, within limits, of course.

Recent innovations include the phototransistor and the photoconductive cell, the latter being illustrated in our heading, and it is mainly about these that this article will be concerned.

Let us first look at the phototransistor. This works in a similar way to a normal transistor into which light is allowed to enter. A transistor is, in fact, a light-sensitive device, but its usual opaque coating prevents it from responding to changes in level of illumination.

PHOTOTRANSISTOR

However, the phototransistor is a transistor designed to fully exploit the inherent photo-electric properties. It can be considered as a light-sensitive semiconductor junction diode (photodiode) in which the light current is amplified by the normal transistor action.

The forward current in any semiconductor diode is caused by a uniform interchange of current carriers across the junction. These can be electrons moving in one direction and positive holes moving in the opposite direction.

This unhindered flow across the junction, giving rise to the normal flow of electricity, results because the potential applied across the junction is in opposition to and outweighs the so-called "potential barrier" which is formed across the junction when it is manufactured, due to the initial diffusion of current carriers.

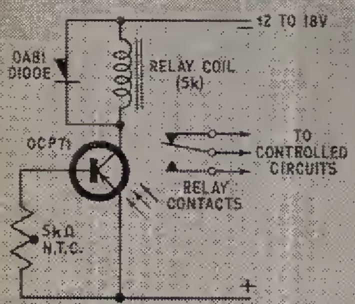

FIGURE 2

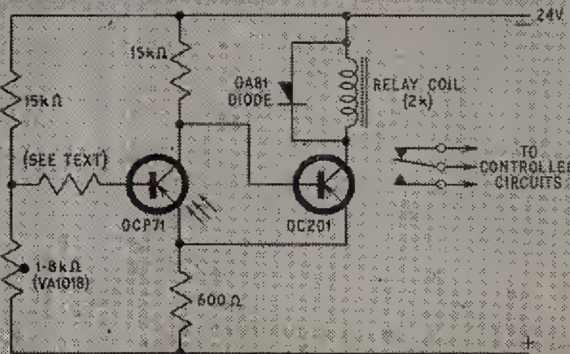

FIGURE 3

Fig 2. A basic switching circuit using the Mullard OCP71 photo-transistor

Fig 3. By the use of a transistor d.c. amplifier, the sensitivity and temperature stability are enhanced, as this circuit shows

The potential barrier is thus broken down by the applied forward potential.

Now, when the diode is biased in the reverse sense, the inherent potential barrier is effectively reinforced. This means that normal current flow is prevented because the barrier prevents the interchange of current carriers. Thus, we have the normal rectifier action where current can flow freely in one direction and is virtually prevented from flowing in the opposite direction. The same effect is exhibited by a diode valve, of course.

However, with a junction diode there is some difference. With a thermionic valve diode, if the anode is negative with respect to the cathode, no current whatsoever will be passed. But with a semiconductor diode, a "leakage current" results under this reverse-biased condition. This is because of a flow of "minority carriers" (these being positive holes in *n*-type material and electrons in *p*-type material).

In effect, the minority carriers tend to multiply when light is allowed to fall on the junction. The leakage current then rises, and as the light intensity increases, so does the leakage current increase. The normally low leakage current when no light is falling on the junction is called the "dark current", and the higher value of leakage current when the junction is illuminated is called the "light current".

The light-to-dark current ratio is enhanced considerably by amplification due to the normal transistor action of the device, and with a well designed circuit this ratio can be made as high as 480 at a temperature of 25 °C. Temperature comes into it because the minority carriers also tend to multiply as the junction temperature increases. Thus, at 45 °C the ratio may drop to around 20.

Under normal operating temperatures the sensitivity of the device is remarkable. For example, if a 2½V pea lamp is barely lit from a 1½V source, and the resulting small illumination is focused by a simple lens on to the sensitive area of the phototransistor over a distance of a few centimetres, the amplified current rises from the order of microamperes (the dark current) to in excess of 5 milliamperes! Thus, the usefulness of the phototransistor as a light-sensitive element can be appreciated.

SWITCHING CIRCUITS

Fig. 2 shows a simple switching circuit using the Mullard OCP71 phototransistor. Extra sensitivity and temperature compensation is given by the use of a transistor d.c. amplifier following the phototransistor, as shown in Fig. 3. Both of these circuits lend themselves to considerable experimentation to suit specific applications. The base resistor can give a degree of temperature compensation if of the negative temperature coefficient type. The actual value is best determined experimentally to suit both the conditions of maximum temperature and the light level. However, a component in the order of 5 kilohms is suitable for most applications.

The relay should have a coil of about 5 kilohms and it should pull-in at a power of about 5mW for reliable operation.

PHOTOCONDUCTIVE CELL

The photoconductive cell is essentially a resistive element made of cadmium sulphide which has the property of decreasing greatly in resistance when subjected to illumination. In complete darkness the resistance is in the order of 10 megohms and this can drop to as low as 75 ohms when the cell is fully illuminated. This very large dark-to-light resistance ratio means that the cell is extremely sensitive. More so, in fact, than the phototransistor.

The cell, which is often called a light-sensitive resistor (l.s.r., for short), is made by Mullard in three versions. There is the ORP12, which has maximum response in the red region and is intended for general purpose industrial applications and automatic contrast and brightness control in television receivers. This has a maximum limit of power dissipation of 200mW up to 40 °C. At higher temperatures the allowable dissipation reduces progressively to zero at 60 °C.

The RPY15 (formerly called the ORP15) has a maximum power dissipation of 400mW at 25 °C and is thus more suitable for applications where power is an important factor.

A low power unit is the RPY14. This has a maximum dissipation of 20mW at 25 °C and is designed essentially for exposure meters and automatic camera applications.

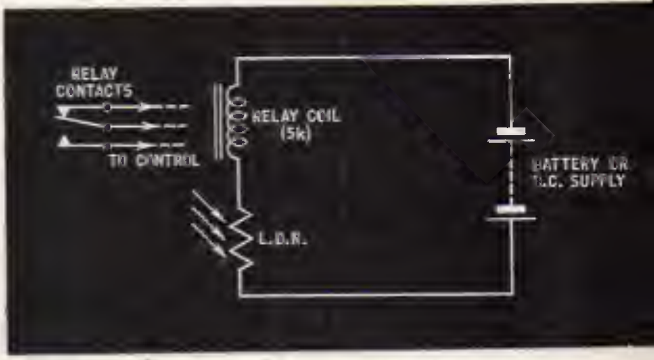

Fig. 4. A photoconductive cell (light-dependent resistor) can be arranged in this simple circuit to provide an effective light-operated switching action

The l.d.r. has several advantages over the phototransistor for certain applications. For one thing, the sensitivity that itself can convey to a control circuit is greater than that of the phototransistor. The larger versions can dissipate a greater power than the phototransistor, the collector dissipation of the OCP71, for instance, being limited to 100mW at 25 °C (50mW at 45 °C). Moreover, the l.d.r. can operate over a wider range of potentials than the phototransistor including operation at a.c., and polarity is not important. It can be arranged in a simple series circuit, as shown in Fig. 4.

SIMPLE L.D.R. CONTROL CIRCUIT

Here the l.d.r. is shown connected in series with a 5 kilohm relay coil and a 12V d.c. supply. If the relay is adjusted to pull-in at about 12mW (e.g. at a current of a little over 1·5mA), a very sensitive light-operated switching device can be evolved from the simple circuit. For reliable results, however, a sensitive relay is desirable.

A more robust Post Office type relay can be utilised by following the simple l.d.r. circuit with a transistor d.c. amplifier, as shown in Fig. 5. Here the l.d.r. is caused to change the base bias of the OC72 transistor and thus give an increase in collector current (and hence, relay current) when the resistance of the l.d.r. drops under the influence of illumination.

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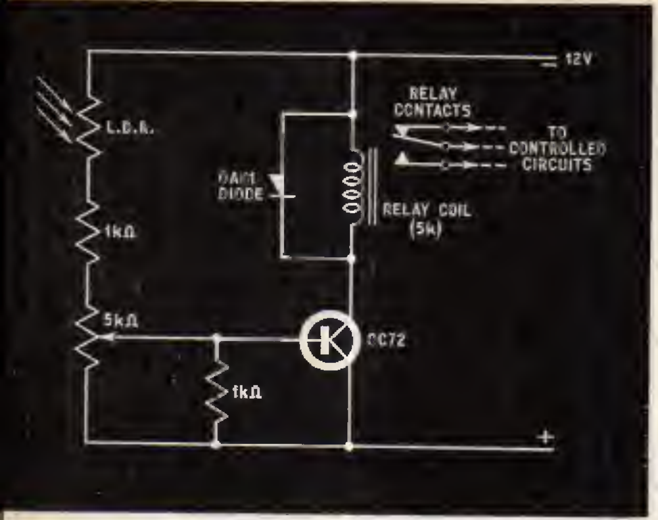

Fig. 5. A d.c. transistor amplifier following the l.d.r. allows the use of a more robust relay and provides a facility for sensitivity adjustment

The 5 kilohm potentiometer is used to adjust the base bias to give the required light/dark sensitivity conditions. Note that the diode across the relay winding in Figs. 2, 3 and 5 is to suppress the voltage surges which are otherwise likely to develop across the coil and damage the transistor during the switching cycle.

Several light-operated switches of the nature of those described in this article have been built by the author, and one application which has not yet been mentioned is for the measurement of speed.

This application is useful at race meetings of all types. At the finishing post a beam of light is arranged to cross the track and hold-on a relay of a light-operated switch. Now, when this beam is broken by the winner passing the finishing post, the relay switch changes over and operates a mechanical arrangement which stops a timing watch or other type of timer. Thus, provided the timing device is started when the race commences (this can be arranged automatically as well if needed) the winner himself stops the timing, and the actual time taken can be read off the dial in the ordinary way.

The experimenter in electronics will almost certainly find many other applications for the circuits described in this article. ★

PRECISION DECIMAL STEP PRE-AMPLIFIER

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rapidly while again applying the iron, to clear the hole of solder before inserting the new component.

It is advisable to use a miniature pencil-bit iron, e.g. of the 6 volt 10 watt variety. The copper strips on the cards take solder extremely rapidly and readily, so that it is possible to work quickly enough to prevent damage to transistors.

In the diagrams, Figs. 2, 3, 4, and 5, the rear copper strips have been numbered 1 to 16 from left to right as viewed from the front (components side) of the cards, and the 21 holes along any strip have been lettered A to U commencing from the socket end. Any hole can thus be specified by the corresponding number and letter combination. Where straps are shown between two holes these are simply short pieces of bare tinned copper wire cross-connecting different copper strips. Some of these straps are also located on the rear side, directly over the copper strips, as shown in Fig. 3 and Fig. 5.

The copper strips are to be interrupted at all the specified holes on the rear side of each card. Messrs. Vero Electronics sell a special hand awl, Cat. No. VB3011, for this purpose. This consists of a wooden tool handle carrying a small drill shaft of somewhat greater diameter than the width of the copper strips. A blunt pin extends at the front end of the drill shaft and exactly fits the holes in the circuit card. The drill is therewith held central while it scrapes the copper strip away at the desired point.

The two circuit cards, together with their associated sockets, can be accommodated quite conveniently in a box measuring approximately 8in by 5in and 2¼in deep. Fig. 7 shows the arrangement of the items inside the box and also details the interboard wiring.

Next month: the concluding part of this article will discuss some of the principles involved in the design of this pre-amplifier; factors which determine the input impedance will be explained and practical information given for adjusting this to some other value

Contributed Articles

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Intending contributors are requested to observe the style in our published articles with regard to component references on circuit diagrams and the arrangement of the components list.

The text should be written on one side of the paper only with double spacing between lines. If the manuscript is handwritten, ruled paper should be used, and care taken to ensure clarity, especially where figures and signs are concerned.

Diagrams should be drawn on separate sheets and not incorporated in the text. Photographic prints should be of a high quality suitable for reproduction; but wherever possible, negatives should be forwarded.

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