SEMICONDUCTOR BASICS

5—LIGHT SENSITIVE DEVICES

By G. J. KING

HAVING shown that current carriers multiply due to thermal activity, this month's article shows how a similar action takes place under the influence of light. Increasing light intensity releases more "free holes" or free electrons into the crystal. This makes the semiconductor less resistive allowing it to pass a greater electric current.

This could upset the normal operation of a transistor; most ordinary transistors are designed to exclude light. Those in a glass construction, for instance, are coated with an opaque paint.

If some of the paint is removed from the case, and the emitter-base junction is subjected to an increase in incidental light, the collector current will be shown (on a milliammeter) to increase quite substantially. However, some transistors are lightproofed internally, making it impossible to carry out this experiment.

A special type of transistor has been developed which is deliberately sensitive to light and will act as an amplifier at the same time. Known as a junction phototransistor, it is subjected to light rays which pass through the case and fall on the base-emitter junction. In circuit, this effectively changes the base current which is then amplified by normal transistor action.

Another light sensitive device, called the photodiode, works on a similar principle, but has no amplifying action. Another device, the light dependent resistor or cadmium sulphide cell, also presents a lower resistance when subjected to increased light rays but does not amplify.

PHOTODIODE

When a *pn* junction is formed there is an interchange of mobile carriers across the junction which builds up a potential barrier or depletion layer.

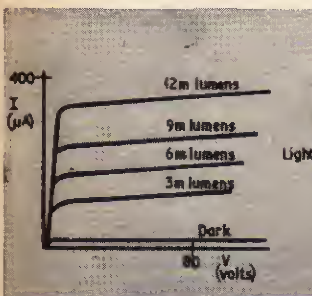


Fig. 5.1. Characteristics of a typical photodiode

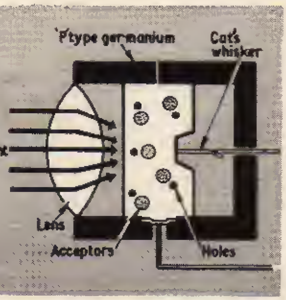


Fig. 5.2. Functional diagram of a point contact photodiode

When reverse voltage is applied across the diode, the barrier potential is increased, but some carriers under this condition generate sufficient energy to interchange across the junction. This is called leakage current or, in a photodiode, it is referred to as dark current.

When light falls on the photodiode junction, hole-electron pairs are developed on both sides. The potential at the barrier or depletion layer effectively "sweeps" the hole carriers one way and the electron carriers the other, thereby causing a flow of current through the diode, which is called light current. This is equal to the dark current (leakage) plus the photoelectric current.

The photodiode, therefore, is the semiconductor equivalent of the photoelectric cell. It consists basically of a piece of germanium or silicon with two regions, *p*- and *n*-type. The whole is encapsulated in an insulated container, designed to allow the passage of light rays on to the *pn* junction.

In action the diode is biased for reverse conduction. Fig. 5.1 shows typical characteristics of such a diode.

As we have point-contact diodes, so there are also point-contact photodiodes. Such a device in elementary form is shown in Fig. 5.2. It comprises a slice of *p*- or *n*-type germanium with a single point contact "cat's whisker", and its characteristics are similar to those of a junction type.

LIGHT DEPENDENT RESISTOR

The full title of the light dependent resistor (l.d.r.) is cadmium sulphide photoconductive cell.

Cadmium sulphide is a crystal which, when shut off from light rays, has an intrinsically high resistance (low conductivity) because the majority of its electrons are tightly bonded to its lattice atoms and very few are available for conduction. The few that are at hand, however, give the material its high dark resistance.

When radiations within the light spectrum fall upon the crystal the energy of radiation is absorbed by the lattice and a number of electrons are released to become current carriers, depending on the light intensity.

Conductivity increases and it becomes quite a good conductor when the light is bright. Hence the term light resistance refers to its minimum resistance under the influence of light.

Enhancement of action results when the basic crystal is doped with an "activating" agent, such as copper, silver or gallium. The doped crystal is powdered, then pressed into small tablets, which are sintered on to the surface of low resistance metal to form electrodes.

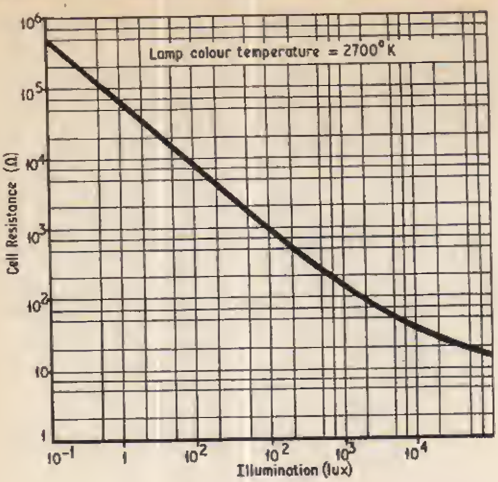


Fig. 5.3. Graph showing the typical resistance of a cadmium sulphide cell for different incidental light intensities

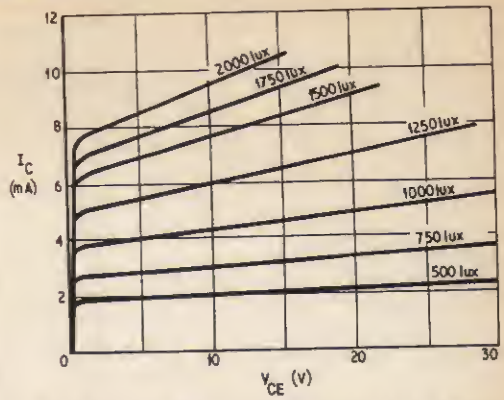


Fig. 5.4. Collector characteristic of a phototransistor over a range of light intensities

To this end the electrodes are arranged into the form of an interleaving comb-like pattern, as shown in the heading picture. Glass or plastic encapsulation is adopted with transparency for the passage of light.

The curve in Fig. 5.3 shows how a typical cadmium sulphide cell resistance falls with increase in illumination. This curve excludes the rise and fall time aspects which are of little concern to the beginner.

PHOTOTRANSISTOR

The phototransistor is equivalent to the combination of a photodiode and a transistor, with the diode being represented by the base emitter junction. The transistor action offers substantially improved sensitivity over the photodiode.

Fig. 5.4 gives the characteristics of a typical phototransistor. Notice how greatly the collector current (I_C) increases with increase in illumination (lux), and how the sensitivity is influenced over a range of collector/emitter voltage (V_{CE}), with most influence taking place at the higher lux values.

Phototransistors are encapsulated to the pattern of ordinary transistors, but an integral glass lens takes the place of the plastic or metal top.

L.D.R. APPLICATIONS

The light dependent resistor can be arranged to operate a relay in response to changes in light intensity, as shown in Fig. 5.5. In Fig. 5.5a the relay is energised only when light falls on the cell, for then its resistance is low and the relay current high.

In Fig. 5.5b the cell effectively shunts the relay when illuminated; the relay is energised only when the illumination is removed.

Light dependent resistors of sufficient power rating are available for direct relay operation, but greater sensitivity is achieved by the addition of transistors, one of which can act as a switch and replace the relay if necessary, as shown in Fig. 5.6. This is the circuit of a car parking light control.

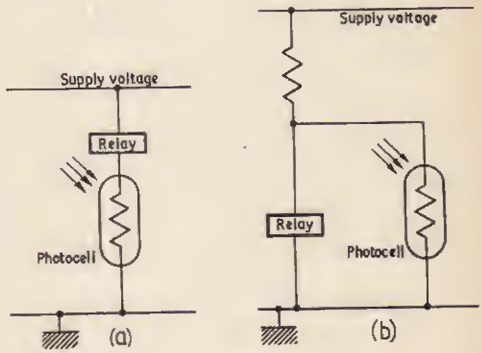


Fig. 5.5. Two simple examples of operating a relay from a cadmium sulphide cell

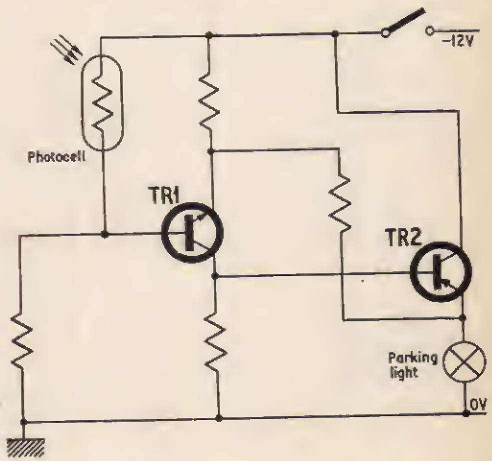


Fig. 5.6. The photocell can also be used to control the working point of a transistor, which in turn operates a switching transistor and lamp

When the cell is fully illuminated TR1 base current falls, but as the illumination falls, base current rises in TR1 due to the cell resistance rising. This makes TR1 collector, and hence TR2 base, more negative. TR2 then passes emitter collector current and the bulb comes on.

An interesting Mullard development incorporating a lamp and light cell, called a "Luxistor", is worth mentioning. This works on a similar principle and can take the place of a volume control in an audio amplifier. By adjusting the brightness of the bulb, a noise-free change in volume level can be obtained. The device is also used for the remote control of television camera equipment.

PHOTOTRANSISTOR APPLICATIONS

The phototransistor can be used to operate a relay or switching transistor; the set-up for direct relay operation is shown in Fig. 5.7. However, the base can be connected to a preset potentiometer (as shown in Fig. 5.8) to provide an adjustment of the light-to-dark current ratio. This makes the device more sensitive to changes at very low intensity light levels. The preset potentiometer is adjusted to the collector current cut-off point with the phototransistor "blacked out". Any slight increase in light would then produce collector current and activate auxiliary circuits.

Typical applications include burglar alarm systems, edge detectors, card reading machines, level indicators, batch counters, infra-red detectors and so forth. It can also be used as a linear light meter, and a suitable circuit for this is shown in Fig. 5.9.

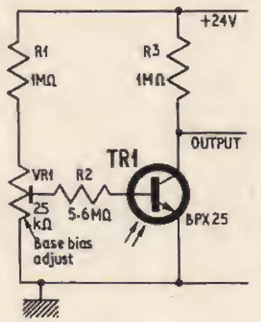


Fig. 5.7 (above). With the base wire left dis-connected the phototransistor can be made to operate a relay direct in the collector lead

Fig. 5.8 (above right). Base bias control is applied by R1 and VR1

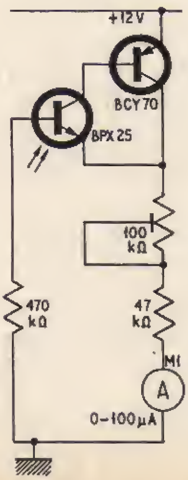


Fig. 5.9 (right). Simple linear light meter using a phototransistor

THIS month's article explores the light dependent resistor (l.d.r.) and its use in controlling a light-operated transistor switching circuit.

CIRCUIT DESCRIPTION

The circuit (shown in Fig. 1) uses a light dependent resistor (l.d.r.) X1 to control base current. The l.d.r. has a "dark" resistance of about one megohm; when light is applied to the cell this resistance will drop to 80 to 300 ohms.

From Ohm's Law it can be seen that when the photocell resistance drops, the base current, which is shared by TR1 and TR2, switches these transistors into saturation.

These transistors are in parallel so that the load current through the bulb is shared by the transistors. The maximum collector current for each transistor is 200mA. Since the bulb is rated at 0·3A or 300mA it is necessary to divide this bulb current to ensure that these transistors do not overheat. This sharing will be slightly unbalanced dependent on the individual gains of the transistors.

LIGHT FEEDBACK

The condition of saturation is also known as "bottoming" which means that the transistors are fully switched and almost all the supply volts appears across the bulb.

The action of latching or holding of the bulb on is created by the light being fed back from the bulb filament to the l.d.r. This regenerative condition maintains the switched action and can only be

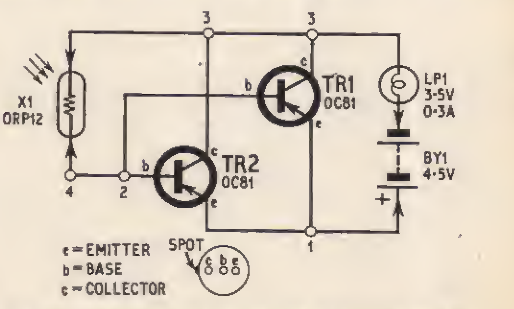


Fig. 1. Circuit diagram of the light operated switch. The numbered circles represent the terminal strip connections; arrow heads represent crocodile clips

Light Operated Switch

Mystify your friends with this "electronic candle" Light it with a match and extinguish it with the fingers!

terminated by "snuffing" or blocking the light to the l.d.r. The l.d.r. will then return to its "dark" resistance and the circuit will be switched off.

CONSTRUCTION

The construction is quite simple and follows the same general procedure as described in previous articles in this series.

Careful reading of the text and close study of the illustrations should be undertaken at each stage of construction, and all connections should be carefully rechecked before connecting the battery. Particular care should be taken to ensure that the transistor leads are wired to the correct terminals, as they can be damaged if wired incorrectly.

Commence the construction by first marking and cutting the baseboard and two hardboard panels to size. A ¾in diameter hole should be drilled 1in up from the bottom edge and 2½in from one side of the 5in × 4½in hardboard panel. This hole is to receive a rubber grommet which houses the l.d.r.

Once the baseboard and panels have been cut the next step is to wire the four-way terminal strip before mounting on the baseboard.

WIRING

The circuit diagram (Fig. 1) has numbered circles, which represent the terminal strip connections; these are also indicated on the wiring diagram in Fig. 2.

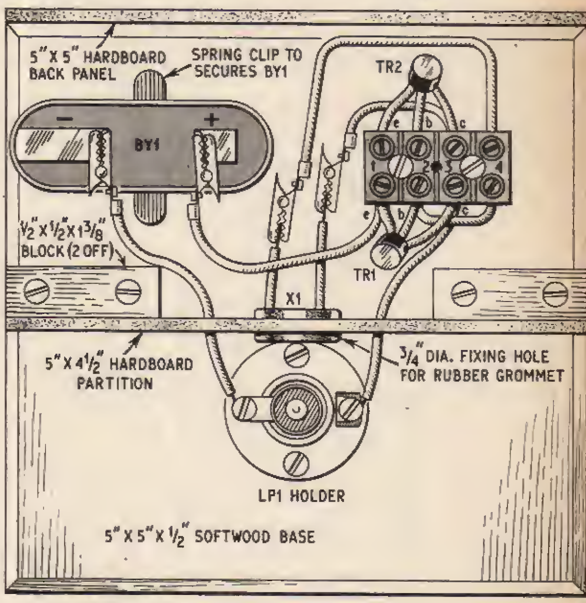


Fig. 2. Constructional and wiring details. Note the transistor connections—refer to key diagram given in Fig. 1

COMPONENTS . . .

Transistors
TR1 OC81 TR2 OC81

Photocell
X1 ORP12

Miscellaneous
BY1 4·5 volt flat pack battery
LP1 3·5 volt bulb
One m.e.s. bulb holder
One four-way plastics terminal strip
One spring clip for holding battery
Wooden baseboard 5in × 5in × ½in
Hardboard panels 5in × 5in and 5in × 4½in
Two wooden blocks ½in × ½in × 1⅜in
Four miniature crocodile clips
Woodscrews for mounting panels, terminal strip and spring clip (No. 4, 8 off) (No. 6, 6 off)
Plastic covered, single core copper wire

Total cost £1 approx.

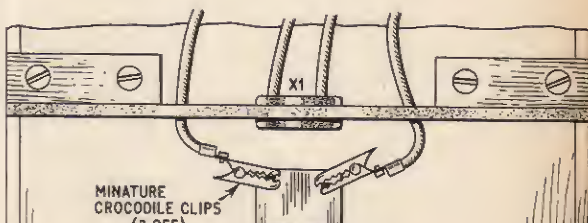
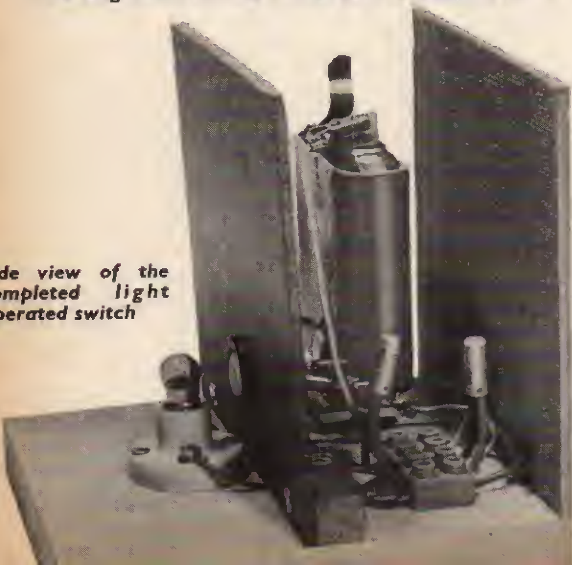


Fig. 3. Wiring details for adding a relay in place of the bulb LP1 to control an external circuit

(Left). The transistors and link wire are positioned in the terminal strip

(Below). All components and interconnecting leads are wired to the terminal strip prior to mounting on the baseboard

Mounting the m.e.s. bulb holder on the baseboard



Side view of the completed light operated switch

When the two transistors and link wire, between terminal 2 and 4, have been positioned it only remains to insert the four interconnecting leads. When these leads have been positioned the terminal screws should be tightened and each wire should be given a slight pull to ensure it has been held fast.

Check the terminal strip wiring against the wiring diagram, then screw on to the baseboard with two ¾in No. 4 countersunk wood screws in the position shown in Fig. 2. The battery clip is screwed in position with a ½in No. 6 countersunk wood screw, and the bulb holder mounted on the baseboard with two ¾in No. 4 countersunk wood screws.

One of the leads from terminal 3 is now taken to one of the connecting screws on the bulb holder.

Another lead, with a miniature crocodile clip fixed to one end, should be taken from the other bulb holder connecting screw and clipped on the negative terminal on the battery.

The partition should now be fixed to the baseboard by two ½in × ½in × 1⅜in wooden blocks. The blocks are screwed to the partition by two ½in No. 6 countersunk wood screws and fixed to the baseboard by four ¾in No. 4 countersunk wood screws. Note that two nicks are made in the bottom edge so that the leads from the bulb holder can pass under the partition.

FINISHING

Insert the light cell carefully in the rubber grommet and mount in the ¾in diameter partition hole.

The other lead from terminal 3 should now be fixed to one of the l.d.r. leads by a miniature crocodile clip. The lead from terminal 4 should be clipped to the remaining l.d.r. lead by a miniature crocodile clip. The battery positive lead from terminal 1 is clipped to the positive terminal on the battery by a miniature crocodile clip. This completes the wiring and it only remains to insert the bulb in the holder and the circuit will be ready to function.

Finally, screw the back panel to the back edge of the baseboard by three ½in No. 6 countersunk wood screws. Top and side panels can be stuck in position on the two panels with an impact adhesive to enclose the components completely. The other side piece should be screwed to the side of the baseboard to allow access to the battery for replacement.

To trigger the circuit into action shine a light into the sensitive face of the l.d.r. The small bulb will light instantly but will not go out until the light path to the l.d.r. is blocked. When not in use the bulb should be removed to prevent unnecessary drain from the battery.

ANOTHER APPLICATION

The device just described demonstrates very effectively the action of the light dependent resistor—in a novel and amusing way. This same circuit can also be applied to a more useful purpose by substituting a 6 volt relay for the lamp LP1. The relay contacts may then be used to control some external circuit. See Fig. 3. It is necessary to use an additional 4·5V battery in series with BY1 to provide an adequate supply for the relay coil. A suitable relay is the Keyswitch Relay type MH2; 6V 185 ohm coil, with two sets of changeover contacts.

Next month: Another simple "d.i.y." device

ELECTRONIC THERMOMETER (*March 1968*)

Page 198—The first two paragraphs at the top of the left hand column should be inserted *after* the first paragraph under the side heading "CALIBRATION".