THYRISTORS AND THE EXPERIMENTER

By
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Of all the semiconductor devices which have become generally available to the home experimenter, surely the silicon controlled rectifier (s.c.r.), or thyristor, is one of the most useful, and, at the same time, least appreciated. Transistors of course have wide application, but what follows will show that thyristors are capable of a multitude of uses, often at currents and voltages—and hence power levels—well out of reach of transistor circuitry.

FIRST a mention of how one of the names for these devices, the *thyristor*, is derived. It comes from THYRatron transISTOR, and those readers who are familiar with the thyratron or gas filled valve will recognise much of the properties of the thyristor. A proper understanding of these properties is vital to a full appreciation of the circuits which follow, and it is worthwhile to set down here three basic characteristics.

BASIC CHARACTERISTICS

1. A thyristor will conduct in only one direction, and when doing so behaves very much as an ordinary silicon diode; that is, it exhibits a low resistance and hence dissipates little power.

2. However, in order to conduct it is not sufficient that the anode be made positive. For conduction to take place, a third electrode, the "gate" (corresponding to the grid of a thyratron) must be made slightly positive with respect to the cathode. The power needed to do this is only a small fraction, a *very* small fraction, of the power it is possible to control, and it is this property that can be exploited so well in thyristor circuitry.

3. Even with this positive voltage removed from the gate, the thyristor continues to pass current (as mentioned in 1 above) provided the value of this current does not fall below a certain, small, value, known as the holding current. A typical holding current for a 3A thyristor is 30mA. Should this fall in current take place, the thyristor will "block", the current will fall to zero and the re-application of a positive gate voltage will be required for conduction to start again.

PHYSICAL DETAILS

Thyristors are available with voltage ratings up to 1,200 volts and current ratings up to 250A—although it is not suggested that home experimenters should use such high power types! Devices of 400V rating will be suitable for mains use and lower voltage ratings such as 50V to 100V are satisfactory for battery driven equipment.

The physical construction of a thyristor varies of course with the voltage and current it is able to handle, and the more usual outlines and connections are as shown in Fig. 1. Also depicted is the circuit symbol for this device.

Construction (a) is used for lower current devices, say up to 2A, while higher ratings usually employ one of the other forms. Most popular is perhaps stud mounting (b), since it requires only a single hole to be made; (d) is of more recent origin, with thyristors of plastic encapsulation now being made.

TWO MAIN GROUPS OF CIRCUITS

The three important properties mentioned earlier lead to an abundance of thyristor circuits, and it will be convenient to classify these circuits into two broad groups:

1. Circuits using d.c. supplies, such as a solid state relay, flashers, and battery chargers.
2. Circuits using a.c. supplies, such as lamp dimmers, motor speed controllers (already described in PRACTICAL ELECTRONICS), temperature control, and mains lamp flashers.

In all the circuits which follow component values given are not necessarily optimum, but have been selected to show the principles involved.

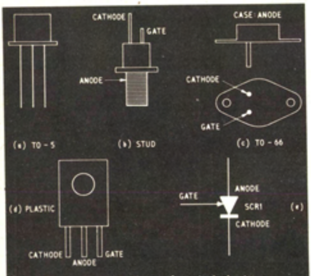


Fig. 1. (a-d) Outlines of typical thyristors; (e) symbol for thyristor and component reference used in circuit diagrams

Thyristors have large spreads in their detailed characteristics, notably gate current required for turn on, which varies with temperature, and it may be found that slight alterations in some resistor values will be required.

However, unmarked devices, advertised in PRACTICAL ELECTRONICS, as well as manufacturers' type numbered products should all work well and experimenters can proceed with confidence. Thyristors are tolerant devices (provided ratings are not exceeded of course) and will be found to be easy to use in the circuits to be given.

A SIMPLE THYRISTOR CIRCUIT

The simplest circuit which finds practical use is shown in Fig. 2. The load can be a lamp or a relay; nothing sophisticated is needed for the positive pulse shown at the gate, indeed a resistor momentarily connected to the positive supply will switch on the thyristor.

Uses for this simplest of all circuits are remote operation of a lamp where switch-on at a distance is needed and voltage drop in the lamp cable could be troublesome, for only the small gate current will be required to flow to the remote switching point, and then

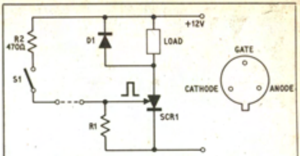


Fig. 2. Simple load switching circuit

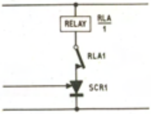
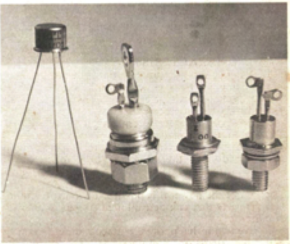


Fig. 3. Use of a relay in lieu of a buzzer

only for a few milliseconds or less. The resistor R1, which should be about 1 kilohm, is required to ensure that the thyristor does not switch on spuriously, especially at higher temperatures.

Typical connections for a 100V thyristor are as shown, and almost any device of that rating capable of carrying 1A will work well, controlling, say, a 12 watt lamp. The diode D1 across the load removes any high voltage transients present when the current changes, which could damage the thyristor.

The load in Fig. 2 could be a buzzer or bell, and the self-interrupted nature of the current through it will ensure that when the gate circuit is opened, buzzer operation ceases. Should operation of a buzzer be required from a distance, this will enable a lighter gauge cable to be used to the operating push or switch, so recouping the cost of the thyristor. If desired, a relay with a normally closed contact wired as shown in Fig. 3 can be substituted for the buzzer.



SWITCHING OFF ARRANGEMENT

To switch off the current in the load of Fig. 2 it is easiest to break the supply; however a useful alternative is given in Fig. 4. With the thyristor conducting and hence with its anode at only a volt or so positive, C1 charges to almost 12 volts. Closure of the switch earths the right-hand side of C1, and since the charge on C1 is unable to change instantaneously, the left-hand side of C1, and hence the thyristor anode, will be at about −11V; this switches off the thyristor.

A drawback of this circuit is that if the switch is left closed, C1 charges through the load with the opposite polarity, and hence an ordinary electrolytic cannot be used.

It is possible to use a second thyristor in place of the switch, and since it is called upon to pass only the current through R3 it can be a low current rating device, which will be both more sensitive and cheaper.

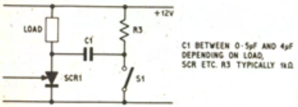


Fig. 4. A method of switching off a thyristor

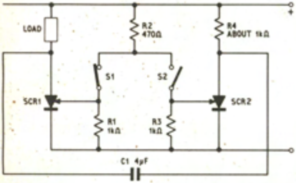


Fig. 5. A d.c. controller developed from the basic circuit of Fig. 2

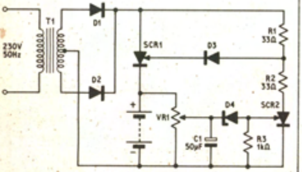


Fig. 6. Controlled battery charging

EFFICIENT MOTOR CONTROLLER

An application of this circuit which should be of interest to model control enthusiasts is given in Fig. 5.

The load is energised when S1 is closed and S2 opened, and de-energised when S1 is opened and S2 closed. If S1 and S2 are the contacts of a pair of reed relays in the collectors of a multivibrator running at, say, 200Hz, variation of the mark-space ratio will alter the mean current in the load, which could be a drive motor.

This is a very efficient controller for d.c. to run motors, lamps, etc.—there is little power wasted in dropper resistors and the use of lightly loaded reed relays ensures long life and reliability.

The control of high current d.c. supplies is thus possible where the use of a series transistor would be difficult or expensive. This circuit forms the basis of control used in fork lift trucks and in experimental electric cars.

BATTERY CHARGERS

The very name "silicon controlled rectifiers" would lead one to believe that such units as battery chargers could have their charging rate controlled, and such is the case. It is possible to arrange for the charger to be cut-off when a pre-set battery voltage is reached, so that over-charging is impossible. A typical circuit is given in Fig. 6, and is admittedly somewhat complex in appearance, although straightforward in operation.

With a discharged battery, each half-cycle of mains input delivers current to the battery via SCR1 since it is turned on at its gate via R1 and the diode. As charging proceeds, battery voltage rises until the potential at VR1 slider exceeds the Zener voltage of D4, so causing it to conduct. Its anode therefore goes positive, so switching on SCR2 (this latter thyristor is not required to carry charging current and can thus have a low current rating, which implies that its gate triggering will be more sensitive—an advantage here as it was in connection with the circuit of Fig. 4.)

Further charging, giving rising battery voltage, means that the point in the half-cycle at which SCR2 conducts will become earlier and earlier, until eventually it takes place *before* SCR1 has had a chance to turn on. With SCR2 conducting, the junction R1/R2 is only just above earth, so that SCR1 is unable to switch on; thus charging ceases. The battery voltage at which this occurs is set by VR1.

Should battery voltage fall, charging will re-start, so making the circuit suitable for those uses where a battery is called upon to provide high rate, intermittent, short discharges and is left across the charger continuously. Use of the circuit of Fig. 6 will permit a smaller battery to be employed (overcharging would be more harmful to a small battery).

CONTROL OF A.C. SUPPLIES

All the circuits mentioned up to this point have controlled d.c. supplies, but it is in the field of a.c. control that thyristors are perhaps most attractive.

There are two different methods for operating a thyristor in a.c. circuits, these are known as "phase shift" and "burst fire" operation.

In phase shift the thyristor conducts for a certain period during every positive half cycle. The point on the positive-going waveform at which conduction commences is the controllable factor, and the amount of power passed through the load is varied accordingly.

In burst-fire control the thyristor switching cycle is longer, and trains of "whole" pulses are passed. The mark-space ratio determines the length of these trains of pulses, and so the amount of power consumed in the load.

Phase shift is the easier method so far as the circuitry is concerned; it does, however, have certain disadvantages, as will be pointed out in due course. Its use is therefore best confined to low power functions, such as light control.

LAMP DIMMING

Starting with domestic lamp dimming; perhaps the only advantage of the gaslight of former decades over present electric lamps was the ease with which the intensity could be readily adjusted! Now, the availability of cheap thyristors has changed the picture dramatically.

If only slight dimming of, say, a 100 watt lamp to the equivalent of a 60 watt lamp is required, then the circuit could hardly be simpler—see Fig. 7.

HALF WAVE CONTROL

When the line is more negative than the neutral, diode D1 conducts and supplies current to the lamp. On the other half-cycle, with line more positive than neutral, the thyristor conducts, starting at a time depending on the setting of VR1. This resistor and capacitor C1 give a retarded phase shift to the gate voltage, so that as VR1 increases, the shift increases, so delaying turn on of SCR1 in alternate half-cycles. The diode D2 prevents the thyristor gate from going more negative than the cathode during the half-cycles when D1 conducts. As the waveforms in Fig. 8 show, delayed turn on of the thyristor gives reduced power in the load.

The circuit is not critical of the type of thyristors and diodes used. Unmarked devices of 400V rating as well as Mullard BTY 79-400R have worked well; D1 should be rated at 400V p.i.v. and be capable of carrying 0·5A for lamps up to 200 watts, though D2 need only be of 100V working and of lower current capacity, say 100mA.

With the circuit shown a useful reduction in light output is obtained with VR1 at maximum resistance, but of course no more than a 90 degree phase shift can be provided by a simple RC network. If D1 is switched out, control down to lower lamp brilliance is possible, but since only alternate half-cycles of the 50Hz mains are thereby being used, there is an annoying flicker from the lamp.

FULL WAVE CONTROL

With slightly more complexity and expense, full smooth control from full brilliance down to zero output is possible and two circuits for this are given. Each shows a different approach to the problem, which is not perhaps surprising since one circuit is that due to Messrs. SGS UK Ltd. while the other originated with S.T.C. Ltd.

Basically, what is required is a means of controlling both half-cycles of the 50Hz mains together, in one

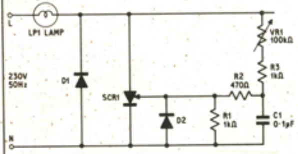


Fig. 7. Simple lamp dimmer—half wave control

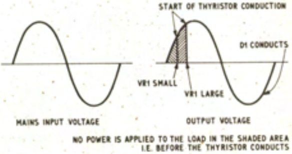
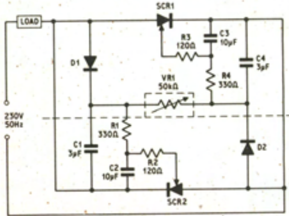
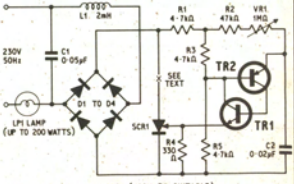


Fig. 8. These waveforms show how the thyristor controls the power in the load with the phase-shift method of operation



SCR1, SCR2 BTX60 OR SIMILAR (400V 3A SUITABLE)
D1, D2 EC402 OR SIMILAR (50V 100mA SUITABLE)

Fig. 9. Lamp dimmer—full wave control (SGS UK Ltd.)



SCR CRS30/40AF OR SIMILAR (400V 3A SUITABLE)
D1-D4 400V 1A EACH TR1, TR2 SEE TEXT

Fig. 10. Lamp dimmer—full wave control (S.T.C. Ltd.)

smooth operation. This is done in one case by using two thyristors, each exercising control on alternate half-cycles, while in the other a full wave bridge rectifier is used to enable one thyristor to control both half-cycles.

Circuits are given in Fig. 9 and Fig. 10.

TWO-THYRISTOR CIRCUIT

Dealing with the SGS circuit first, consider that part above the dotted line and including the variable resistor VR1. Positive going half-cycles at D1 anode are shifted in phase by VR1 and C4, but here extra phase shift is added by R4 and C3, so giving control of SCR1 gate firing over the whole half-cycle instead of a maximum of 90 degrees as previously described.

On the other half-cycle the remainder of the circuit behaves in a similar manner, using VR1 as phase shift control, and smooth variation of lamp brilliance is given from full brilliance to zero output.

SINGLE-THYRISTOR CIRCUIT

Turning now to the circuit from S.T.C. (Fig. 10), it will be seen that only one thyristor is used, together with a full wave bridge rectifier to supply only positive voltages to the anode.

If we imagine the thyristor already to be conducting, the output of the bridge will be short circuited, but with the lamp in series with the mains input it will drop nearly all the applied voltage and be at full brilliance. Variable delay of thyristor conduction in each half-cycle will give control of lamp brilliance; this control is achieved by charging C2 through R2 and VR1.

When the voltage across C2 and hence at TR2 emitter exceeds that at its base by more than about 0·6V, TR2 conducts, so passing current to TR1 base and this complementary pair of transistors rapidly turns to a state of conduction. Thus the positive voltage on C2 is suddenly applied to the thyristor gate, so switching it on. The point in the half-cycle at which it does so is set by the time taken for C2 to charge to the required voltage, through VR1. Once again, very smooth control of lamp brilliance is given.

DUPLICATE CIRCUITS

A variation of this particular circuit (Fig. 10) is to put the lamp at X, in the anode of the thyristor and apply the mains direct to the bridge. This will give d.c. in the lamp, but this is of no consequence. However, what is interesting is that duplicate thyristors, each with their own control circuits, can be run from the same bridge rectifier, each thyristor having a lamp (or other load) in its anode circuit.

By this means a multitude of lamps, for theatrical work, shop window displays and so on can very easily be controlled, *independently*. The bridge must of course be of adequate rating, that is, be capable of carrying the total lamp current with all lamps at maximum brilliance.

Besides the thyristors quoted in the circuits, unmarked devices have proved successful in both cases, although some slight adjustment of resistor or capacitor values may be called for to obtain full control.

The transistors used should be silicon for low leakage, and a variety of types will function well—BSY95A, 2N929, 2N3704, BSY27 for the *npn;* the OC200 series and 2N3702 for the *pnp* have all proved suitable.

RADIO INTERFERENCE

One important point which should be mentioned here is the question of radio interference. Since thyristors by their very nature switch on rapidly, many harmonics are produced and these may give rise to interference, especially if a controller is run from the same mains socket outlet as a television or radio, on which a pronounced 50 or 100Hz buzz will be heard.

Some form of suppression is required, and that depicted in Fig. 10 is typical, where L1 and C1 act as a filter, is an example of what could be used.

The construction of controllers and similar devices using circuits such as described here is best carried out in metal boxes which can be earthed, thereby reducing the radiation of interference, as well as giving greater safety.

AUTOMATIC LIGHTING CONTROL

Continuous control of lamp output has a multitude of uses—porch lights can be run dimmed, to be turned up when needed, lights can be turned down for watching television, or for parties, and photographers will be able to control studio lighting and enlarger lamps. Extra lamp life is a useful by-product of under running of course.

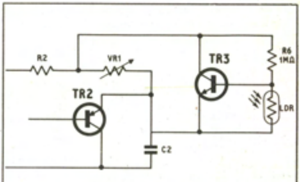


Fig. 11. Automatic Light control modification to circuit given in Fig. 10

Automatic control of lamp brilliance, depending on the level of ambient lighting, so that lights come on at dusk for example, is a desirable feature, and a modification to the circuit of Fig. 10 to carry this out is given in Fig. 11.

With VR1 set for low light output and the light dependent resistor (LDR) at minimum resistance, say 10 kilohm, the transistor TR3 will be cut off, that is it will present a high resistance between collector and emitter and hence it will hardly shunt VR1. As the LDR resistance increases up to about 300 kilohm or more with reduction in light level, the transistor conducts and shunts VR1, hence switching on the thyristor earlier in each half-cycle and turning up the lights. A suitable LDR would be cadmium sulphide (CdS) type; the transistor can be any ordinary silicon *npn* type, such as a BSY 95A.

Circuits for switching on lights as the ambient light level falls have appeared in Practical Electronics before, but that given above has the twin advantages of gradual turn on as daylight falls and of being contactless—previous circuits have usually used relays.

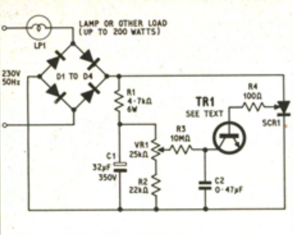


Fig. 12. Lamp flasher circuit using the burst-fire method of control

HEATING CONTROL

Similarly, the LDR could be replaced by a temperature dependent resistor, or thermistor; the temperature of aquaria, chemical solutions and so on will then be governed very efficiently. With a suitable thyristor and diodes, control of electric room heating is possible.

Remember that each kilowatt to be controlled will pass just over 4A through the thyristor and half that amount through each bridge diode; adequate surge rating is called for when switching on cold heating elements. The higher power thyristors, say 10A and upwards, may require larger gate currents than that given by the circuits here.

The circuits so far described use the "phase-shift" method of thyristor operation. The next circuit introduces a form of "burst-fire" control.

FLASHING CIRCUITS

Continuing with a.c. circuits, that of Fig. 12 will provide flashes lasting about a quarter of a second, with a repetition rate determined by the setting of the 25kΩ potentiometer VR1. With the values and thyristor shown, this can be varied from one flash every second to one every five seconds. A lower value for R3, say 4·7 megohms will quicken the rate of flashing; an increase in the value of C2, say to 1µF, will slow the rate to about one flash every nine seconds.

Flashes lasting longer than the quarter-second noted above will be obtained if C1 is increased, say to 64µF. With the potentiometer slider at the lower end a flash of about 0·6 second alternating with a space of 0·5 second gives an effective display, useful for warning lights and so on.

The use of a transistor TR1 in the gate lead of the thyristor is worthy of a mention. Connected as shown (Fig. 12), with its emitter left disconnected, very little current, certainly less than 10µA, will flow to the thyristor gate as long as the voltage across the collector-base junction is fairly small. This low level of current is insufficient to switch on the thyristor.

As C2 charges, this collector-base voltage rises until avalanche breakdown occurs, at around an applied voltage of 30 to 35 volts, when the transistor conducts suddenly and connects C2, charged to that potential, to the thyristor gate. The thyristor immediately conducts, discharging C2 for the cycle to repeat. The 100 ohm resistor R4 limits the current through the transistor.

No damage or change of important characteristic has been noted in this transistor, which may, in any case, be an inexpensive silicon *npn* such as a BSY 95A. The thyristor quoted is a BTY 79400R; an unmarked 400V 3A device worked also but various samples gave slightly varying repetition rates.

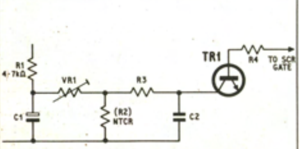


Fig. 13. Flasher circuit adapted for temperature control

TEMPERATURE CONTROL

A use for this circuit, besides the obvious one of a flashing light for display purposes and so on—without moving parts and exposed contacts of course—is the possibility of close temperature control; see Fig. 13.

Replace the 22 kilohm (R2) resistor by a suitable negative temperature coefficient resistor, placed in the environment to be controlled, say an aquarium. With the water cold, the NTC resistor will have a large resistance, and the repetition rate of the thyristor firing will be high. The thyristor load is, of course, the aquarium heater. As the water warms, the NTC resistor will decrease in value and the repetition rate will accordingly fall, so passing, averaged over some seconds, less heat to the water.

Control of water temperature is thus close and perhaps more important, rapid, since the set-up responds to NTC resistor changes immediately and continuous control is maintained. These are important improvements over an ordinary on-off thermostat, in aquaria, plating baths, photographic processing solutions and so on.

A disadvantage is that since the duty cycle of heating is no greater than say, 50 per cent, even at maximum heat output, a larger heating element is needed. In the author's opinion, it is worth while to gain the advantages mentioned; a by-pass switch could put continuous heating on if required for rapid warm up from cold.

PHASE-SHIFT v. BURST-FIRE

The phase-shift method, as described in connection with circuits for lamp dimming, can give a certain amount of r.f. interference due to the rapid turn on of the thyristor sometime during each half-cycle of mains input, that is, at a rate of 100Hz. The steps necessary

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to reduce radiation have been noted earlier and should be followed for minimum interference on radio and television.

The burst-fire control method, however, switches power to the load at a much lower rate, say every second for ½ second at a time, and hence the thyristor is required to switch on-load current that much less often. If additional circuitry is employed—rather too complex to include in the present article—then it is possible to arrange for the load to be both switched on and off at zero mains voltage, i.e. at almost zero load current, and in that case no interference can be generated.

OBJECTIONAL FLICKER

Although the potential interference level is much less using burst-fire, there is (of course!) a disadvantage. If used for lamp control there is a very pronounced, objectional flicker, although when used for the control of heaters this factor does not apply. Since heaters are generally of higher wattage, and so take more current than lamps, higher levels of interference would be generated using phase-shift control with them—hence the recommendation to use burst-fire when possible.

There is another objection to the use of the phase-shift method for high power control.

The phase-shift method introduces some distortion into the waveform of the electricity supply. If a number of high power devices were operating simultaneously in the same electricity supply area, this distortion could assume serious proportions, and affect other equipment connected to this area. For this reason, the Electricity Council recommends the use of the burst-fire method, except for low power devices such as light dimmers.

THE TRIAC

Before concluding, mention must be made of the Triac, which is equivalent to two thyristors in back-to-back parallel. Control of a.c. is possible using a single Triac and no rectifiers, but such devices are dearer than the equivalent thyristors at present. However, they will obviously make their bow in the home construction field before long, and will lead to simplification of circuitry.

SCOPE FOR EXPERIMENT

Since such a variety of circuits have been quoted in this review (most of which have either been tested, or actually evolved, by the author) it has not been possible to give here constructional details for the building of units making use of them. Rather it is hoped that experimenters will be encouraged to try some of the circuits in the applications mentioned, and to think of many more uses besides—the "Ingenuity Unlimited" pages are open to all! Thyristors are very easy to use once their principles are understood.

It would be as well to conclude by re-stating three important points:

1. Do not exceed the rating of the device in use—remember switch on surges, etc.

2. Provide adequate r.f. interference suppression such as an earthed metal case and/or a LC filter.

3. Remember that in applications involving mains, *switch off* before touching any of the exposed circuitry.

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