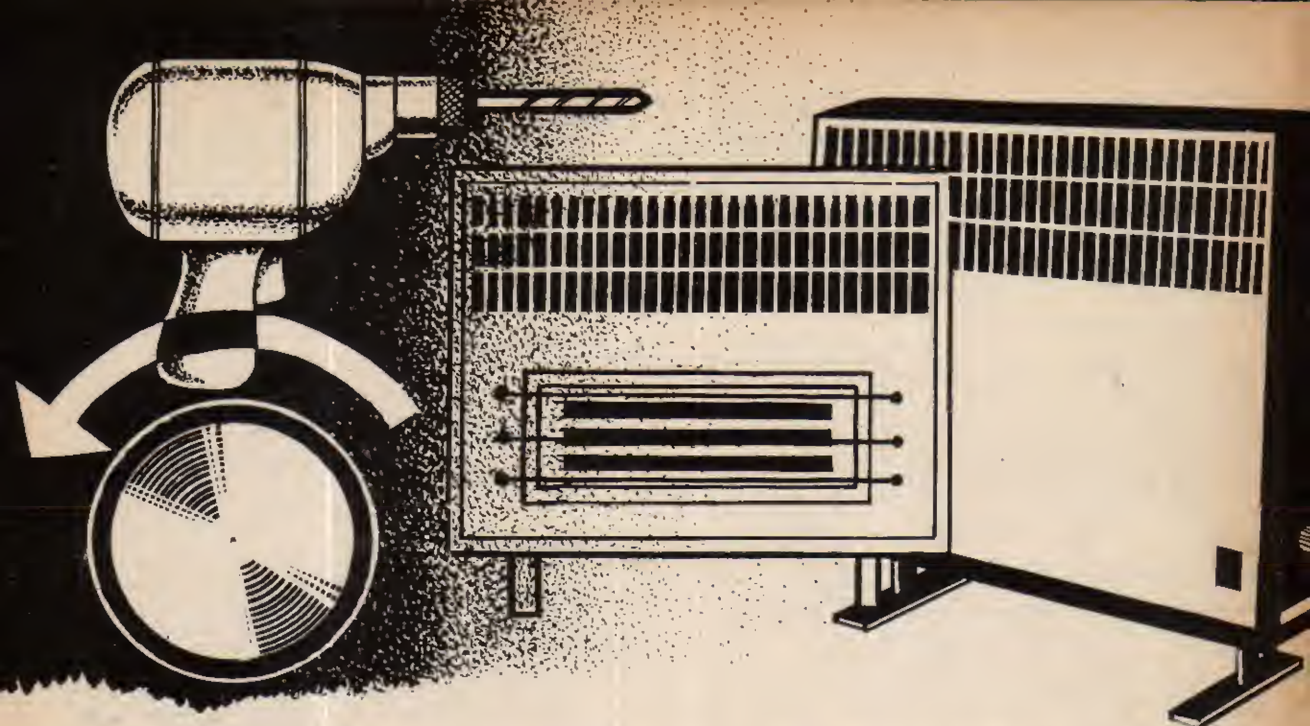


THYRISTOR POWER CONTROLLER By T. M. NAPIER

THYRISTOR power controllers described so far in PRACTICAL ELECTRONICS have been designed primarily for low power devices such as electric light bulbs. The controller described in this article is capable of working in conjunction with a wide variety of appliances, including smoothing irons, heavy duty electric drills, and fires of up to 4 kilowatts rating. Particular attention has been given to safety during use and prevention of damage to the thyristor, which could be very costly to replace.

The function of the control module is to vary the power flowing into the load in an a.c. circuit. This is done by varying the "on-time" of a thyristor connected in series between the a.c. mains and the load. The load may be a lamp, an electric fire, or an electric motor having brushes such as an electric drill; it cannot be a transformer or a brushless motor. If an output voltage lower than 240 volts is required a transformer may be used between the mains and the thyristor provided that it is connected in the correct phase sense.

The maximum permissible load current depends only on the rating of the thyristor and the size of the heat sink used. This unit is designed to drive thyristors up to the 16 amp BTY91 series and hence can control loads of the order of 4 kilowatts. This should prove adequate for most purposes.

The power level is controlled either manually or by application of an external d.c. control voltage. This permits control of large powers by simple thermistor circuits to maintain, for example, a fish tank, or a room, at a constant temperature. A possible application would be to use a photocell input to turn room lights up gradually as darkness falls outside. An input of 5 volts into the 10 kilohm input resistance of the module is sufficient to turn on the full 4 kilowatt load, a power gain of two million.

TRIGGERED CONTROL

A thyristor behaves like a rectifier but it conducts in the forward direction only after a trigger pulse has been applied between its gate electrode and its cathode. Once "on" it continues to conduct until the voltage applied to the anode is removed.

If it is connected between the a.c. mains and a load, no current will pass, even when its anode is positive, until a trigger pulse is applied. Current then starts flowing through the thyristor and the load until the end of that half-cycle when the reversal of the mains polarity turns the thyristor off again. No current flows during the half-cycle that the anode is negative.

If the trigger pulse occurs near the end of the positive half-cycle, the thyristor conducts for a very short time and the load receives a train of short 50Hz pulses corresponding to a low mean current and low power. If we trigger the thyristor near the start of each positive half cycle it conducts for almost the complete half-cycle and the load receives a train of long 50Hz pulses corresponding to a high mean current and high power.

By varying the timing of the trigger pulse relative to the start of the positive half-cycle any power between these limits can be selected. The output at maximum power consists of a train of half-cycles and hence is a form of pulsing d.c. This is why a transformer cannot be used with this device. When driving a load, such as a motor, designed to operate from the mains this train of pulses corresponds to a half of the normal power. In fact a series silicon rectifier makes a useful dimmer for a table lamp or a means of running a soldering iron at a "standby" temperature without wasting heat through a resistive dimmer.

For many purposes, this zero to half-power range is sufficient since the load resistance can be chosen to give the desired maximum power with this waveform. For example, to get from zero to one kilowatt use two 1 kW fire bars in parallel.

In order to achieve the full range of control where this choice of load is not possible (as when varying the speed of an electric drill designed for mains operation), an additional control range is added by switching a rectifier in parallel with the thyristor so as to pass the previously blocked negative half-cycle. With this switched in, the range of the control knob lies between half and full power thus covering the complete power range in two switched control ranges.

If for any reason a single range is required to cover zero to full power a second thyristor must be used, connected to pass the negative half-cycle and controlled by a second control module. The two manual controls would then become preset balance controls and a potentiometer would be used to apply an equal control voltage to both modules.

The same power supply can be used for both units. The output would now be more or less symmetrical and could be applied to a transformer. For some purposes, the additional cost and complexity might be worthwhile but the "single ended" unit described should be adequate for most requirements.

If a higher power is required a larger, more expensive thyristor must be used. The present module is not intended to drive thyristors to control above 4 kilowatts and would have to be redesigned to supply more gate current.

GATING ACTION

The control module consists of a device to detect the start of the positive half-cycle, a variable delay and a pulse generator to trigger the thyristor. The complete system is shown in block diagram form in Fig. 1.

For safety, one side of the load is connected to the neutral side of the mains via the mains switch. The thyristor is in series with the live side of the mains via the ganged mains switch. Since the cathode and gate end of the thyristor spend much of the time at mains live potential it is necessary to use a transformer to isolate them from the control unit which is connected to earth.

Since a pulse transformer is necessary it is logical to use it to generate the gate pulse by making it part of a blocking oscillator circuit. A useful property of some types of blocking oscillator is their ability to generate an output pulse only when the applied bias voltage reaches a well defined level.

If we generate a voltage ramp which starts from zero volts at the beginning of the positive half-cycle and apply this to the bias input of the blocking oscillator then the gate pulse will occur when this ramp reaches the trigger voltage of the blocking oscillator. By changing the rate of increase of the ramp voltage we can vary the delay between the start of the half-cycle and the time when the thyristor is triggered. This is the condition required to vary the load power.

If instead of applying the ramp directly to the blocking oscillator we add to it an external d.c. input then

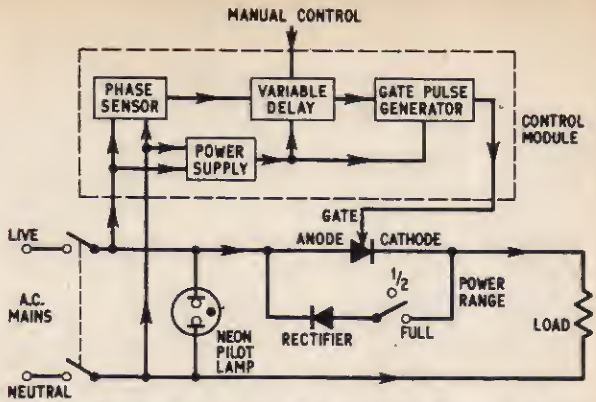


Fig. 1. Block diagram showing the basic functions in the Thyristor Power Controller

the gate pulse is generated at a time controlled by the sum of the ramp voltage and the external input. If the ramp slope is set correctly by means of the manual control the full power range can be controlled by the external d.c. voltage.

It only remains to generate a variable slope ramp commencing at the beginning of the positive half-cycle. This is done by switching a transistor on during the negative half-cycle and off during the positive half-cycle. Its collector voltage is thus clamped to zero during the negative half-cycle and returns slowly towards the supply voltage during the positive half-cycle.

The rate of return is controlled by a *CR* time constant circuit, which can be varied to change this rate of return and forms the manual power control. (The waveforms at various parts of the circuit are shown in Fig. 2.) This time constant is shown in the circuit diagram (Fig. 3) as C1 with R2 and VR1, the latter being the variable component.

PRACTICAL CIRCUIT

A small transformer T1 supplies d.c. power at −9V and also the phase reference signal via R1 for TR1, turning it on and off. D2 prevents a high

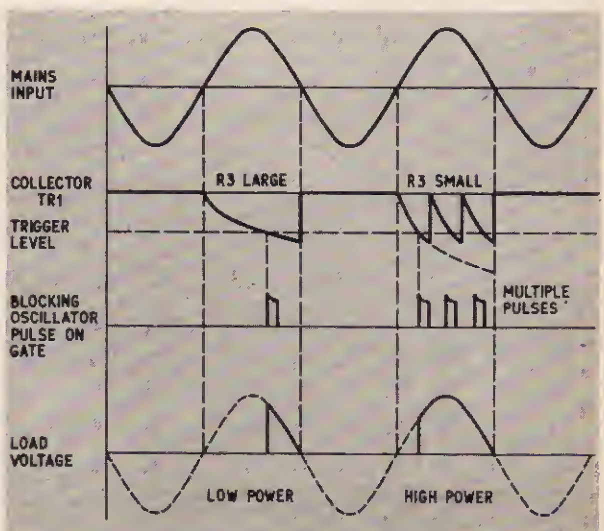


Fig. 2. Waveforms at given points in the circuit

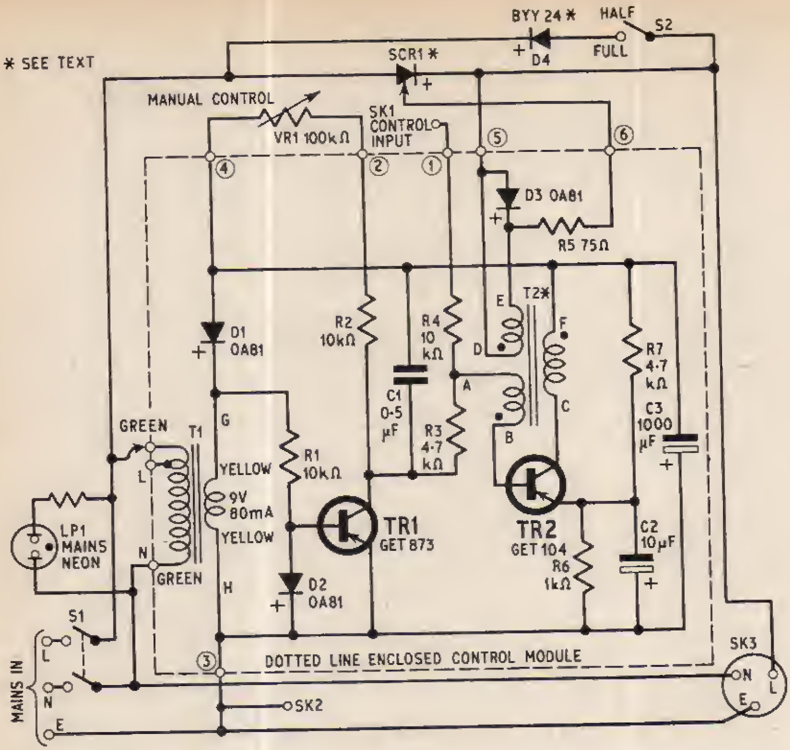


Fig. 3. Complete circuit diagram of the controller. The components inside the dotted line box are mounted on the printed circuit; pin connection numbers are shown

positive voltage being applied to the base of the transistor, a condition that would otherwise lead to breakdown of the base emitter junction in most transistors. During negative half-cycles C1 is charged via TR1 and during positive half-cycles it discharges towards −9V through R2 and VR1.

The voltage appearing at the junction of R3 and R4 is the sum of the ramp from C1 and the external voltage applied. When this reaches a value of about −2V, set by R6 and R7 TR2 conducts, generating a gate pulse by discharging C2 into the transformer T2 via TR2. The capacitance of C2 is chosen so that it has time to recharge before the next half-cycle.

In practice it may recharge in time to generate a second or third gate pulse if the first gate pulse occurs near the start of the half-cycle. These extra pulses have no effect on the operation of the thyristor and no attempt has been made to suppress them.

From the nature of the circuit it is impossible, provided it has been wired correctly, for a gate pulse to be applied to the thyristor during the negative half-cycle thus obviating a possible source of damage to the thyristor.

Turning the control knob past its "zeropower" point causes suppression of the gate pulse generator rather than triggering too late in the cycle. At the other end of the range, the delay is so short that less than 20 degrees phase difference and negligible power are lost.

CONSTRUCTION

This circuit is very tolerant of the components used. Almost any transistors can be used, except very low power types (such as microalloy transistors) and surplus types having either low beta or high leakage current. A list of possible types is given but many others can be used.

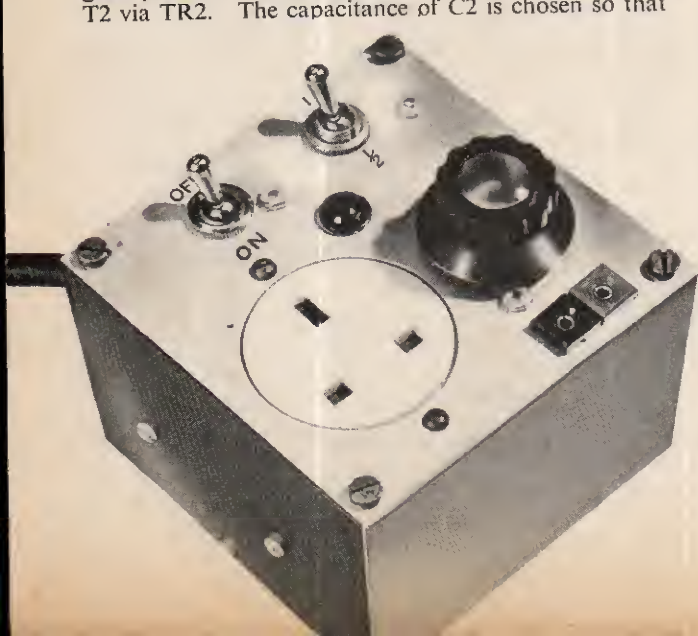
The diodes D1, 2, and 3 similarly can be whatever is available provided they can carry a mean forward current greater than 10mA and withstand 25V reverse voltage. This includes almost all diodes available to the amateur constructor. Point contact signal diodes were used in the prototype.

It is recommended that the specified mains transformer is used to avoid the risk of connecting the phase reference to TR1 incorrectly. If any other transformer is used an oscilloscope is required to make certain the trigger pulse is not being applied to the thyristor during the wrong half-cycle. This could, of course, be found by trial and error but this way the thyristor could be damaged by wrong connection.

The choice of rectifier D4 is dictated by the load to be controlled. The BYY24 is rated at 10A; for lower currents the BYZ12 for up to 6A is suitable. Advertised components can be selected according to the load current and voltage.

The blocking oscillator transformer is not a standard component and must be wound by the constructor. The ferrite core used is a Ferroxcube type LA7 supplied with a bobbin. The windings are 38 or 39 s.w.g. enamelled copper wire with thin p.v.c. covered wire used to make lead-in and lead-out connections. The output winding of 150 turns is wound on the bobbin first and covered with two layers of thin plastics insulating tape. The other two windings of 250 turns each go on top with one layer of tape between them.

The start and finish of each winding must be clearly marked as it is essential that the windings are connected the correct way round when wiring up. Correct phasing is denoted in Fig. 3 by the dots on the windings; these are the lead-out wires.



COMPONENTS . . .

Resistors
R1 10kΩ   R4 10kΩ   R6 1kΩ
R2 10kΩ   R5 75Ω   R7 4·7kΩ
R3 4·7kΩ
All 10% ¼W carbon

Potentiometer
VR1 100kΩ linear wirewound 3 watts (see text)

Capacitors
C1 0·5μF paper 150V
C2 10μF elect. 12V
C3 1,000μF elect. 15V

Transformers
T1 Mains transformer 9V 80mA (Radio Component Specialists, 337 Whitehorse Road, West Croydon, Surrey)
T2 Special transformer (see text) using Ferroxcube type LA7 and 38 s.w.g. enamelled copper wire

Transistors
TR1 OC44, OC45, or GET873
TR2 OC81 or GET104

Thyristor
SCR1 (see text and Table 1)

Diodes
D1, 2, 3 OA81 (3 off)
D4 BYY24 (10 amp) (Mullard) (see text)

Switches
S1 Double-pole on/off toggle switch (see text)
S2 Single-pole on/off toggle switch

Sockets
SK1 and SK2 Wander plug sockets for control input
SK3 Mains 13A panel mounting socket

Miscellaneous
Printed circuit kit or other assembly board
Aluminium or copper sheet for panel and heatsink (see text)
Conduit box 4¼in × 4¼in × 3½in or other suitable case
Neon mains indicator with ballast resistor

It is recommended that the control module is assembled on the printed circuit board shown in Fig. 4. Veroboard or tagboard can be used if great care is taken to connect both transformers exactly as shown for the printed circuit component layout. On the board T2 is bolted down and T1 glued in place with Araldite.

Components C1, C3, and D1 are mounted vertically on the board with the free ends of all three joined together. The positive ends of C3 and D1 are nearest the board. A short wire from pin 4 on the edge of the board, and one end of the collector winding of T2 (labelled F in Fig. 3), are both connected to the free ends of C1, C3, and D1 (see Fig. 4).

If the mains transformer is positioned as shown in Fig. 4b, with the two green mains leads next to the mains input tags, the yellow secondary leads should be conveniently placed to fit holes G and H in the board. The green lead nearest the board should be connected to the live mains lead to ensure correct phasing for firing the thyristor. The metal case of the unit must be earthed.

The thyristor cathode and gate tags (large and small respectively) are connected to the appropriate pins on the board. The anode connection to the live side of the mains is made to the stud of the thyristor or to a solder tag bolted to its heat sink.

The mains double-pole switch is specified in the components list as a toggle switch, but if desired this can be replaced by employing a carbon potentiometer VR1 with the switch ganged to it. The unit can then be switched on at low power (maximum resistance in VR1), then the control is gradually advanced to the required setting. *This switch must be capable of carrying the maximum load current.*

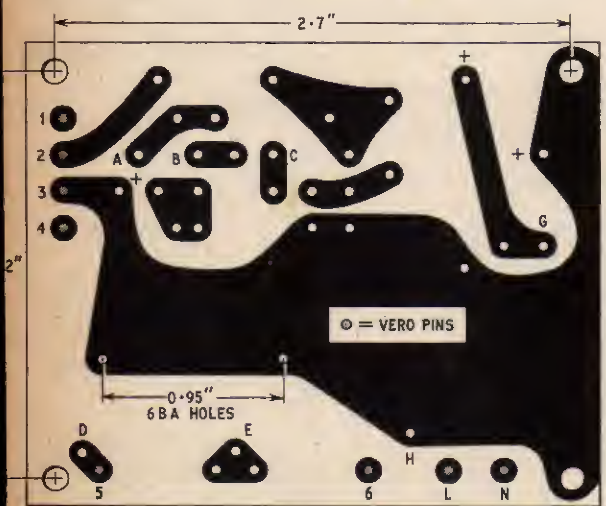


Fig. 4a. Full size pattern of the printed circuit board. Pin numbers correspond with those given in Fig. 3

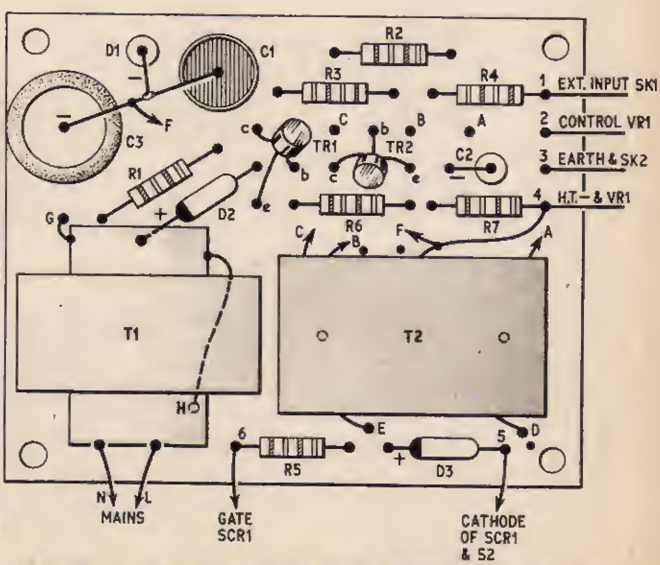


Fig. 4b. Component layout on the printed circuit board with leads to front panel components

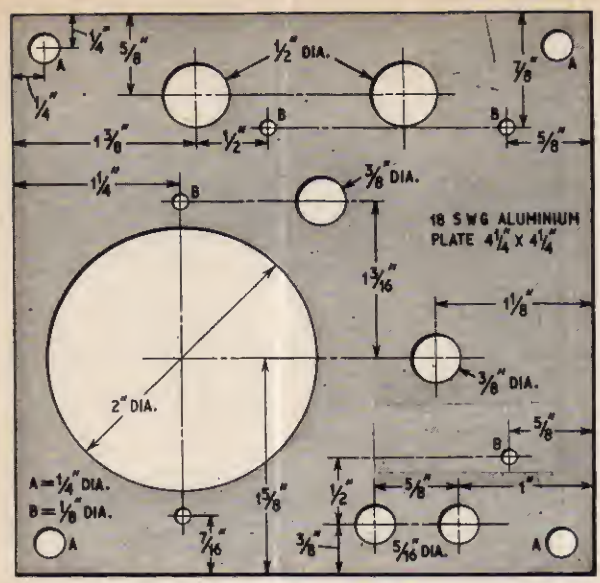
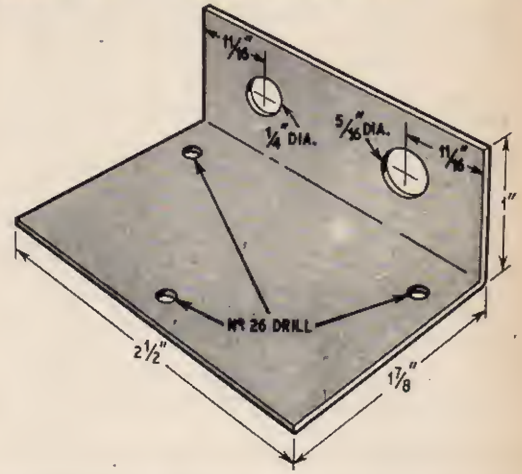


Fig. 5a (left). Drilling diagram of the front panel made to fit a conduit box 4in square. Three holes B are drilled to mount the printed circuit board on pillars

Fig. 5b (below). Heat sink for 5A load thyristor mounted on inside of box. For higher ratings see text



LARGER HEAT SINK

The final form of the unit depends on the use to which it is to be put. The prototype was built into a 4in × 4in × 3½in conduit box with the controls and a 13A socket mounted on the front panel. The thyristor and rectifier were mounted on an L-shaped bracket bolted to the side of the box by nylon nuts and bolts. These insulate the bracket, which is at mains line potential, from the earthed box.

The bracket is too small a heat sink to permit operation at the full rated power of the thyristor but the unit can handle a 5A load without complaint. A fused plug connects the unit to the mains.

Table I. THYRISTOR AND RECTIFIER RATINGS

Appliance Power Rating (Watts)	Load current at 65°C (Amperes)	Thyristor SCR1
750	3	CRS3/40AF
1,125	4·5	BTY79/400R
3,000	12	BTY87/400R
4,000	16	BTY91/400R

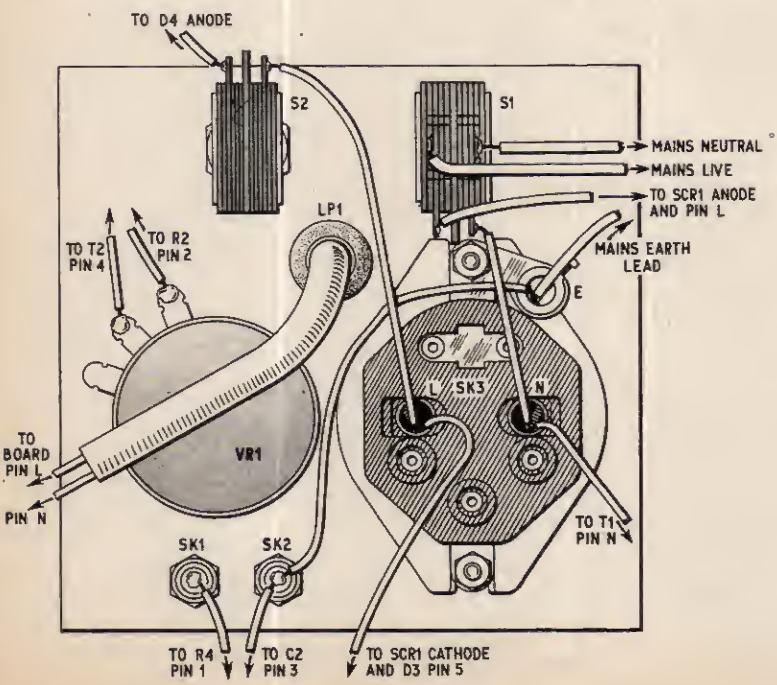
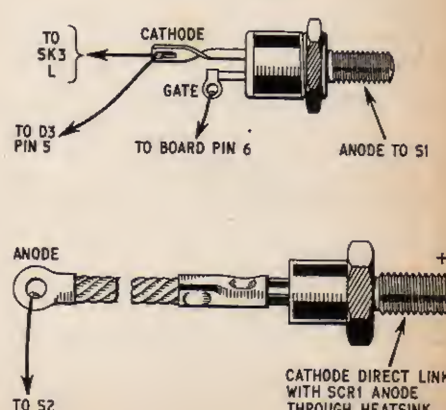


Fig. 6a (left). Component wiring on the front panel. Switch S2 is drawn inverted for clarity. The tags should be near VR1 so as not to foul on the box

Fig. 6b (below). Connections to the thyristor SCR1 and rectifier D4



For larger loads a larger heat sink is required; 100 square inches of 16 s.w.g. aluminium should be sufficient and can be bent to fit the space available bearing in mind the need for a clear air flow round it and adequately insulated supports. When switching off after a period at full power, the heat sink at the thyristor stud should not be hotter than just bearable, about 70 degrees C. If it is, a larger heat sink is required. Table 1 gives thyristor types for various loads.

One application for this control module is the temperature stabilisation of electronic equipment. In this case an existing a.c. supply between 6 and 15 volts could be used to power the module; the rectifier across the thyristor would not then be required. This would reduce the cost of the module itself by a few shillings. The manual control would then become a preset temperature control. It can be used to set the input control voltage level to any suitable value in the range; "normally off/negative signal switches on" to "normally on/positive signal switches off".

The external control signal is applied between pins 1 and 3 on the board, pin 3 being the common connection. To turn the unit on, a negative voltage should be applied to pin 1. The range of control voltage required is set by adjusting the manual control.

A 60 watt bulb makes a suitable load for testing the completed unit before attempting the control of larger loads. ★