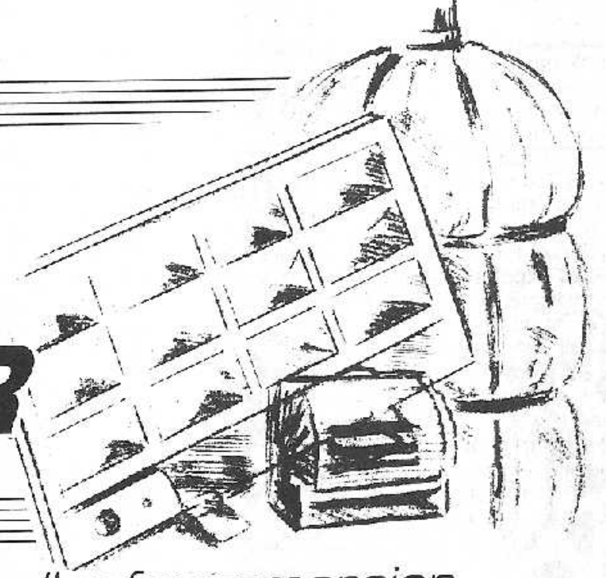
Constructional Project

POWER CONTROLLER



ALAN WINSTANLEY

Build a 13A cost-cutting controller for immersion heaters, electric fire elements and large heaters. Zero crossing ensures freedom from r.f. interference.

HAVE you got an electric fire blazing away, racking up a large fuel bill? The Chancellor of the Exchequer will be delighted! For the benefit of our many overseas readers, Her Majesty's Government has now taken a shine to our fuel bills, so much so that it has added Value Added Tax to them, much to the chagrin of your scribe. Hence any device which helps to cut those electricity bills will be welcomed, by everyone apart from the Chancellor that is!

Power control techniques can be used in certain circumstances to adjust the power consumption of particular electrical appliances. An ordinary lamp "dimmer switch" uses the *phase control* system to interrupt the mains sine wave, thereby dimming and reducing the power consumption of the lamp.

In a similar way, a basic two-speed electric drill might use a rectifier to chop one half of the sinewave, to reduce the speed of the drill. Even vacuum cleaners occasionally have an in-built power controller, to offer some marginal "boost" when the going gets tough, or to cut the speed when needed.

A typical phase control device will be described in a future constructional article. Amongst other things, such designs are suitable for electric fires with or without coal effects (**not** fan heaters) and their main advantage is that they are straightforward in operation and construction; however such circuits are notorious for generating r.f.i. (Radio Frequency Interference) on an unacceptable scale unless suitable suppression is incorporated, which can add considerably to the construction cost.

Specification ...

Type:	Burst Firing
Features:	Zero crossing: Interference free
Ideal for:	Resistive heating elements 0·5-3kW (e.g. Electric Bar Fires; Immersion Heater Elements; Oil-filled Electric Radiators; Convector Heaters, Electric Irons)
Not suitable for:	Coal-effect Electric Fires, Fan Heaters, Motors, Lighting, Low Loads (e.g. Soldering Irons).

BURST FIRING

There is, however, another method of controlling power with a technique which is inherently interference-free. The system of **burst firing** is often used to control larger heating elements such as those found in kilns, ovens or certain types of machinery. Instead of modifying or chopping the mains sine wave, the burst firing technique sends a train of sine waves to the load, at regular intervals. Fig. 1(a) shows how short bursts of sine waves are transmitted to a load which operates at a low power level. By increasing the length of the bursts, the power delivered to the load is increased.

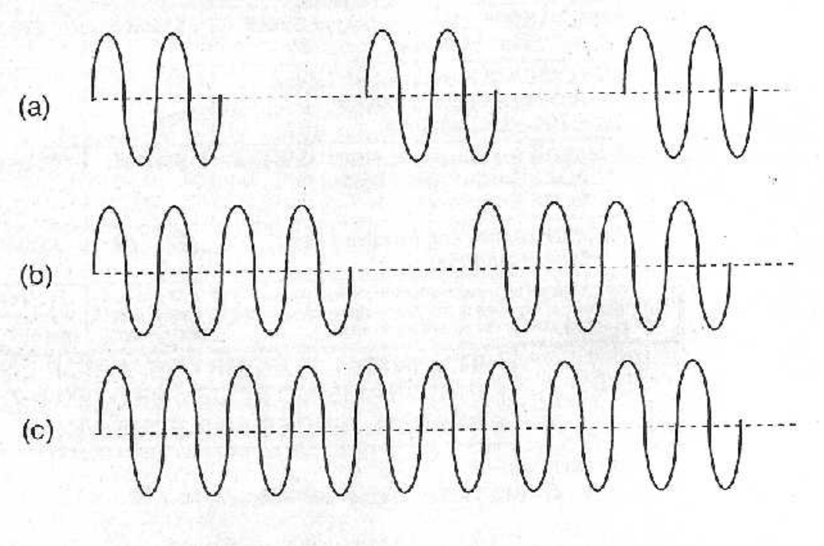


Fig. 1. Zero crossing burst firing power control (a) low (b) medium (c) full power.

In the case of a simple resistive heating element, it is feasible to deliver such bursts once every few seconds, or even just a few times every minute, since the thermal inertia of the load averages out the bursts. The user will then observe a simple rise or fall in heater power dissipation depending on the frequency of the bursts.

The device to be described here is a burst firing power controller which includes a **zero crossing** system. This synchronises the a.c. sine wave output, to ensure that only *complete* sine waves are allowed to reach the control element (a triac).

By avoiding chopping the sine wave as in the phase control system, no r.f.i. is generated and absolutely no suppression is needed. The system is completely interference free, making it ideal for use in the domestic environment. It is however *not suitable* for certain types of load, see the separate Specification panel.

APPLICATIONS

Many appliances based on resistive heating elements (e.g. an oil-filled radiator, convector, or immersion heater) incorporate a bi-metallic strip which provides simple on-off thermostatic operation. They offer an "all or nothing" approach to control which often results in temperature overshoots – wasted power – and generally imprecise temperature control.

This Power Controller will handle a 3kW load maximum, and could actually *complement* a thermostat if fitted to a domestic appliance. By burst-firing the appliance in the first place, the average power delivered to the heater is controlled more precisely which provides a more controllable temperature, as the appliance will be delivering an "average" power rather than all or nothing when controlled by a bi-metallic strip.

Apart from offering a finer degree of control, rather than using a heater continuously at full setting, this design will also help save money by enabling the user to "turn down" the heat to a lower setting – especially if the heater doesn't even have a bi-metallic thermostat.

HOW IT WORKS

The circuit diagram of the Power Controller is shown in Fig. 2. Operation is centred around IC1, an SL443 zero-crossing burst firing chip. It provides all the necessary timing signals to a control device – a suitably-rated triac in this case – to provide totally interference-free control of a suitable resistive load.

The i.c. has a built-in power supply section. 240V a.c. mains is supplied by two dropper resistors R2 and R3, to pin 2. Two power resistors are used because a total of nearly 350V *peak* is dropped across them under worst case conditions, therefore each is conservatively rated to withstand 200V at 6W.

The resultant low a.c. voltage is rectified and regulated within the i.c. to produce about 14V d.c. which is smoothed by the external capacitor C3, and is in turn passed to an internal 7V stabiliser. This is fed via pin 5 and resistor R1 to the power control potentiometer VR1 which taps the voltage at its wiper, connecting the output signal to pin 8.

The i.c. drives the gate terminal triac CSR1 directly from pin 4 which delivers a series of suitably-timed trigger pulses. A conservatively-rated 16A device was used for CSR1 which also has an *isolated tab*. This improves the insulation of the final assembly and reduces the risk of accidental short circuits. As will be described later, the triac needs to be fitted to a heatsink to aid heat dissipation when operating under peak conditions.

It is the d.c. voltage on the wiper of potentiometer VR1 which ultimately determines the time period of the "bursts". The SL443 internal logic generates a sawtooth-like ramp voltage and compares this against the d.c. voltage set up by VR1. By adjusting the voltage at pin 8, the overall length of the bursts sent to the triac is varied accordingly, see Fig. 3. The SL443 compares the d.c. signal voltage at pin 8 against the ramp

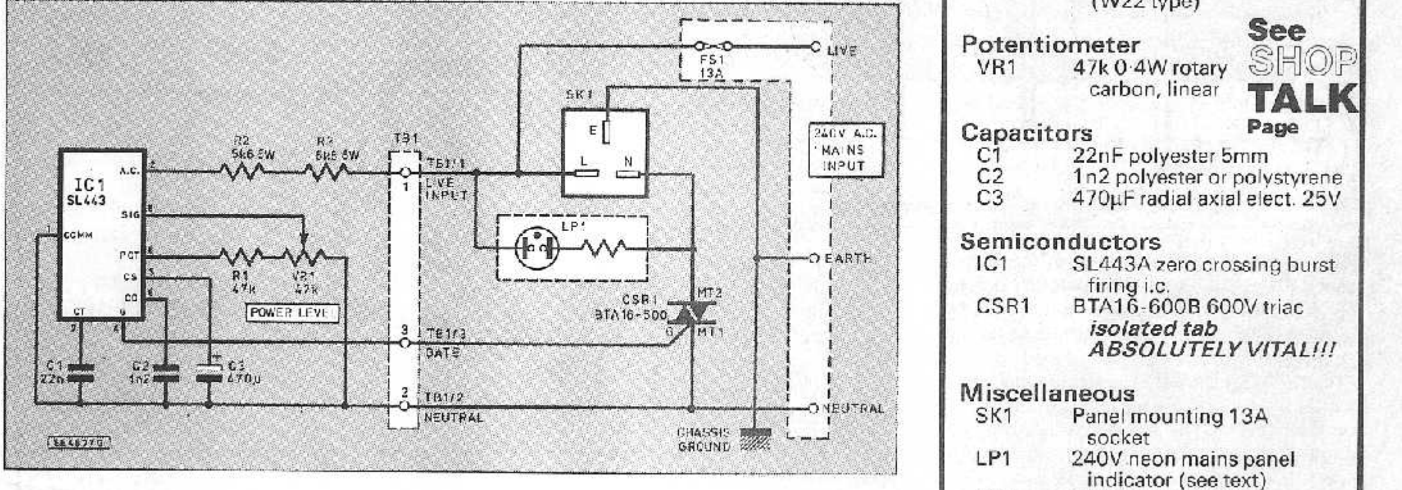


Fig. 2. Full circuit diagram for the Power Controller.

It does have one drawback in that because of its mode of operation – sending *pulses* to the load at regular intervals – it is not really suited to electric fires which have flickering coal effect lamps; it would cause the lamps to flash on and off repetitively, although the unit controls the heater elements perfectly. Nor must the unit be used with anything incorporating a synchronous motor such as a fan heater.

Additionally, trials showed that the unit does require a *minimum* load for correct operation, of roughly 500W or more. This design is not suitable for controlling a low-power soldering iron or similar small loads for example. It is designed for larger *resistive* loads such as ordinary electric bar fires or immersion heater elements rated up to 3kW, especially where r.f.i. could otherwise be a problem. The unit has a simple visual indication showing the burst firing system in actual operation, to help gauge the level of power being delivered.

BE AWARE

The circuit operates directly from the mains and has a built-in transformerless power supply, and is quite straightforward to assemble, but some skill with a soldering iron is required to make neat solder joints, some of which are at mains voltage, and care is needed when assembling to allow for certain parts which become hot in operation. Therefore, it is not really recommended for the absolute beginner due to the hazards associated with the mixture of mains and low voltages.

COMPONENTS

Resistors

R1	47k 0·25W 5% carbon film
R2	5k6 6W 200V wirewound (W22 type)
R3	6k8 6W 200V wirewound (W22 type)

See SHOP TALK Page

Potentiometer

VR1	47k 0·4W rotary carbon, linear

Capacitors

C1	22nF polyester 5mm
C2	1n2 polyester or polystyrene
C3	470µF radial axial elect. 25V

Semiconductors

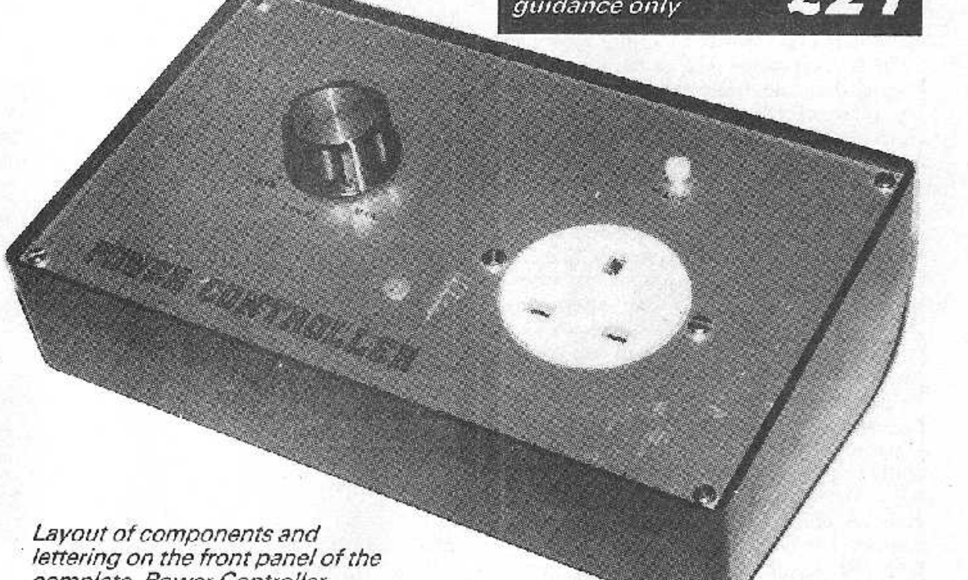
IC1	SL443A zero crossing burst firing i.c.
CSR1	BTA16-600B 600V triac *isolated tab* ***ABSOLUTELY VITAL!!!***

Miscellaneous

SK1	Panel mounting 13A socket
LP1	240V neon mains panel indicator (see text)
FS1	chassis mounting fuseholder with 13A fuse see text
TB1	3-way p.c.b. terminal block

Printed circuit board available from *EPE PCB Service*, code 905; plastic case with sloped aluminium panel, 215mm x 130mm x 78/47mm; 3-way 13A mains screw terminal block; 8-pin d.i.l. socket; control knob; P-clip; grommet; M3 x 6mm fastener; fully insulated p.c.b. mounting hardware; tie wrap with adhesive base; 13A cable; wire; solder etc.

Approx cost guidance only **£21**



Layout of components and lettering on the front panel of the complete Power Controller.

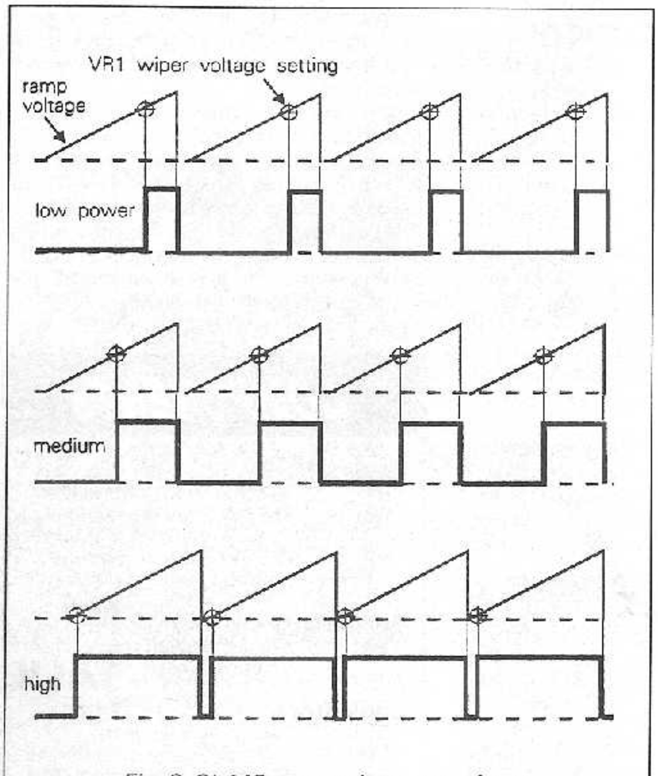


Fig. 3. SL443 ramp voltage waveforms.

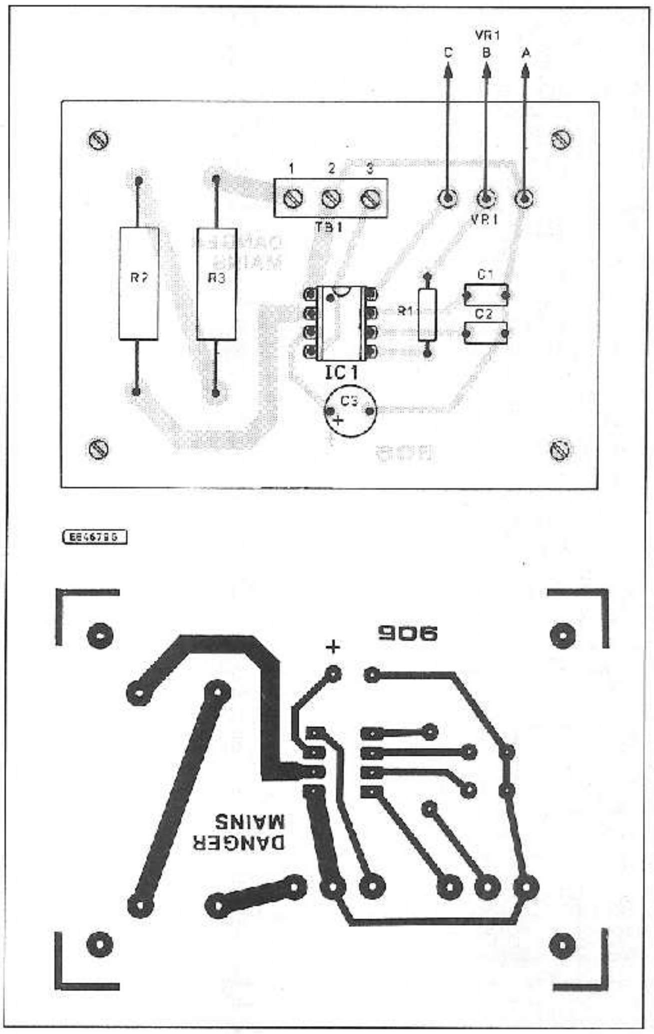


Fig. 4. (right) Printed circuit board component layout and full size copper foil master pattern.

voltage, and the power output of the unit is set by that fraction of the sawtooth during which the triac is conducting – as denoted by the square wave, which represents bursts of complete sine waves driving the load.

It was felt it would be safer to include a certain degree of "offset" by adding resistor R1. This means that there is always a minimum voltage at VR1 wiper so that the Power Controller is never turned fully off.

In the case of electric fire elements, they can still dissipate heat even though they may not be glowing brightly. Under these circumstances the user could mistakenly think that the fire was turned off altogether, although in reality it may be partially on. In order to prevent a fire hazard, the offset resistor ensures that the load is always switched on to some extent, which should then be apparent to the user.

BURST FIRING

A zero-crossing detector is also incorporated in the SL443. The triac firing pulse from pin 4 is synchronised to ensure that triac CSR1 conducts at the start of a sine wave half cycle without chopping it. The value of capacitor C2 is calculated to ensure that the triac receives a triggering pulse of an adequate length, whilst capacitor C1 determines the ramp period or *repetition rate* of the bursts.

The value of C1 was calculated for a one second period, which as a result of tests enables the project to be used with *visible* heater elements such as electric fires. A longer period (several seconds or more) would result in electric fires alternately glowing red hot and then dimming.

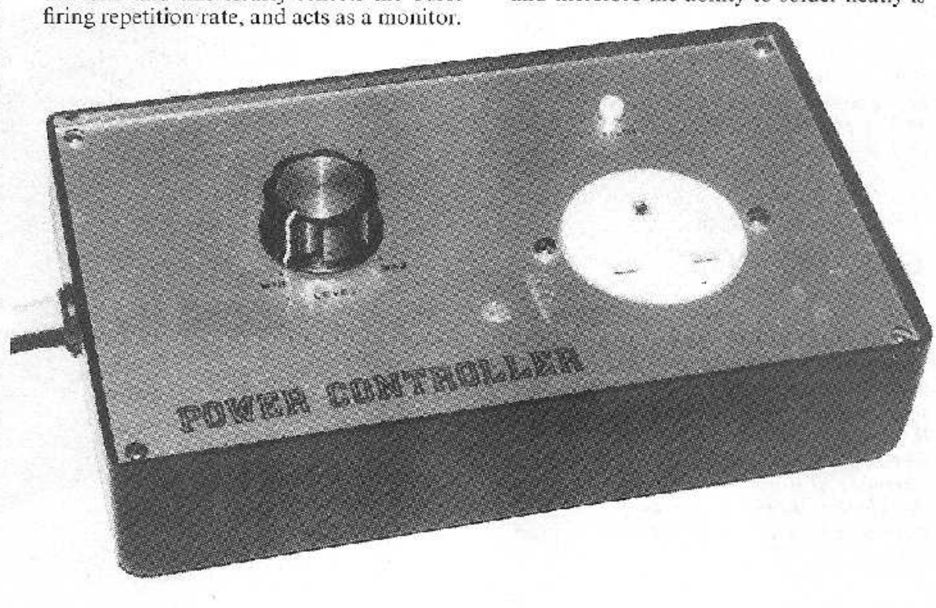
The burst rate is probably of less consequence with hidden heating elements used in kilns or immersion heaters, but is clearly relevant if the electric element is also supposed to give a comforting glow: it shouldn't be pulsating in a menacing manner! (Though the author's does anyway, courtesy of Yorkshire Electricity.) For this reason, it is not feasible to use the Power Controller with electric coal-effect fires, because the "fireglow" bulbs will indeed flash on and off. (There is probably no finer demonstration of burst firing, with the coal effect flashing disco-like whilst the heater bars average out the bursts. Impress your friends!)

The Power Controller will deliver bursts of sine waves to the load based on a fixed cycle time of one second. By adjusting potentiometer VR1, the *length* of the bursts is determined, i.e. it controls the duty cycle. At minimum power, shorter bursts of a.c. mains are delivered every second (under 50% duty cycle), whilst at maximum output the circuit delivers a continuous sine wave (100% duty cycle).

Neon indicator LP1 is in parallel with the load and this clearly reflects the burst firing repetition rate, and acts as a monitor. It will flash according to the setting of VR1, and could be omitted if necessary. If nothing else, it's useful when first testing the completed design. Finally, as mentioned earlier, the circuit requires a minimum load of, say, 500W to operate successfully, otherwise CSR1 may fail to trigger properly or hold its conduction.

CONSTRUCTION

Construction starts with printed circuit board (p.c.b.) assembly, then front panel details and finally, interwiring and finishing off. The circuit itself has a low component count and is straightforward to build. However, some parts are at mains voltage and therefore the ability to solder neatly is



essential, in order to prevent accidental short circuits or unreliable operation.

A printed circuit board simplifies assembly and is probably *essential* these days for this type of project. The p.c.b. component layout and full size copper foil master pattern for the Power Controller are shown in Fig. 4. This board is available from the *EPE PCB Service*, code 905.

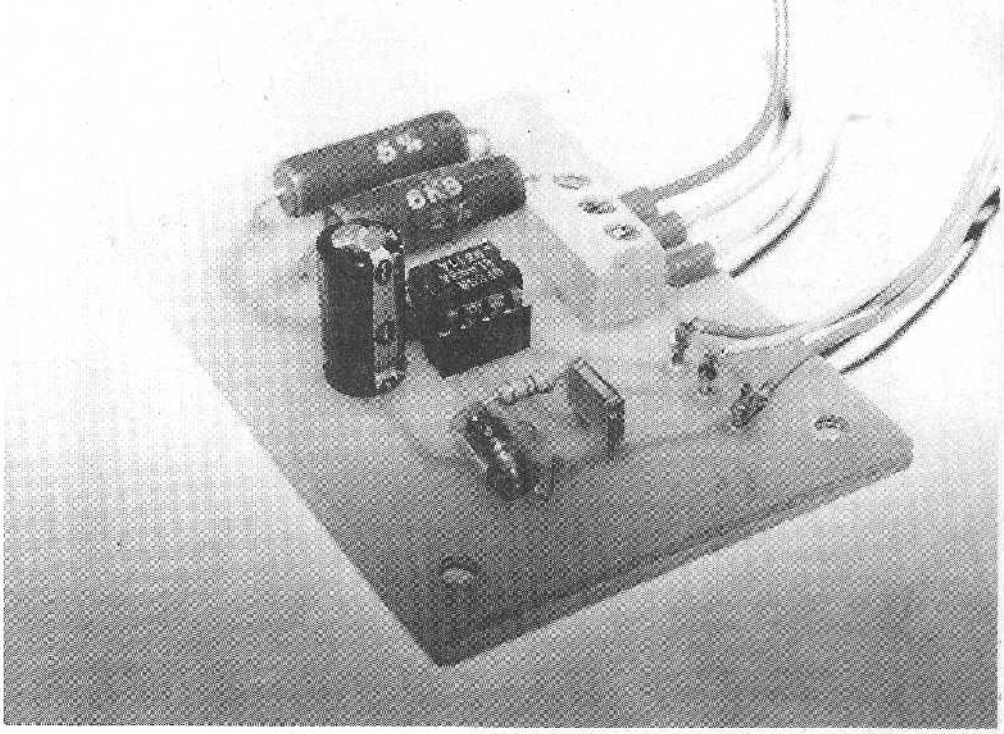
The prototype p.c.b. is housed in a plastic case which has a sloping aluminium front panel, and measures 215mm x 130mm x 78/47mm. An alternative choice might be a diecast aluminium box or other all-metal housing, since the metal front panel is used as a heatsink for triac CSR1.

The triac will become quite hot when the Power Controller is set for maximum output. Under these circumstances, the triac is passing peak continuous current and dissipates an appreciable amount of heat (which is negligible compared with the power dissipation of the load, though).

The specified case has proven acceptable in this application, however a golden rule with this project is that when selecting your own housing, allow plenty of room inside for air circulation around the components and do not be tempted to opt for too small a box. In fact ventilation slots, though not compulsory, would do no harm provided that tiny fingers cannot poke objects into the box and make contact with live terminals.

Continue construction by using the empty p.c.b. as a template on the box to mark the drilling centres for the insulated mounting hardware (see later). Then proceed with the assembly of the circuit board in accordance with Fig. 4. Power resistors R2 and R3 ***must*** be mounted proud of the board to permit air circulation around them, so stand them off by about 10mm – do not solder them flush to the p.c.b.

The i.c. should be fitted using an 8-pin d.i.l. socket and the electrolytic capacitor C3 must be correctly polarised. A three-way screw terminal block is used for TB1, this being safer and more reliable in the long term than soldering mains wires directly to the board.



Completed p.c.b. The power resistors must be mounted proud of the board.

CASE PREPARATION

Case preparation can start with the front panel which carries the panel-mounting 13A mains socket, together with neon LP1 and potentiometer VR1. It is necessary to mount the triac on the aluminium panel too, to act as a heatsink. Note that the triac ***must*** have an ***insulated*** tab. The front panel must be laid out in such a way that when the box is closed together, nothing fitted on the front panel interferes with any parts within the box.

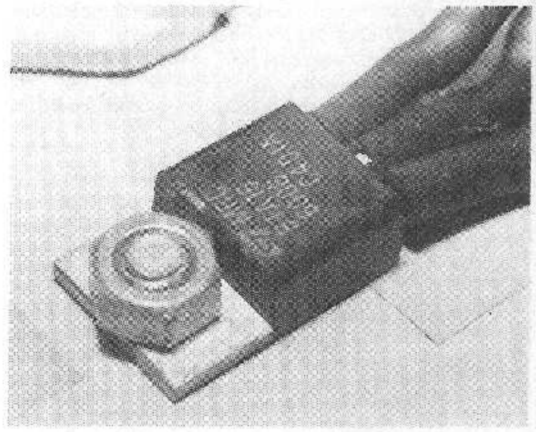
Start off with preparation for the mains socket SK1. If a socket similar to that of the prototype is used, a 50mm diameter hole is needed in the panel. Do this with a Q-Max punch if available – a two minute job. Otherwise drill a series of small holes inside the circumference of the hole, then join them together to form a rough cut-out which can then be gradually smoothed to shape, using a half-round file – hard work!

Once the large cut-out has been prepared, drill the two adjacent mounting holes for the socket such that it will align correctly when finally fitted into position. Alternatively, use a surface-mounting 13A socket which mounts on the front of the panel, although they tend to look quite cumbersome.

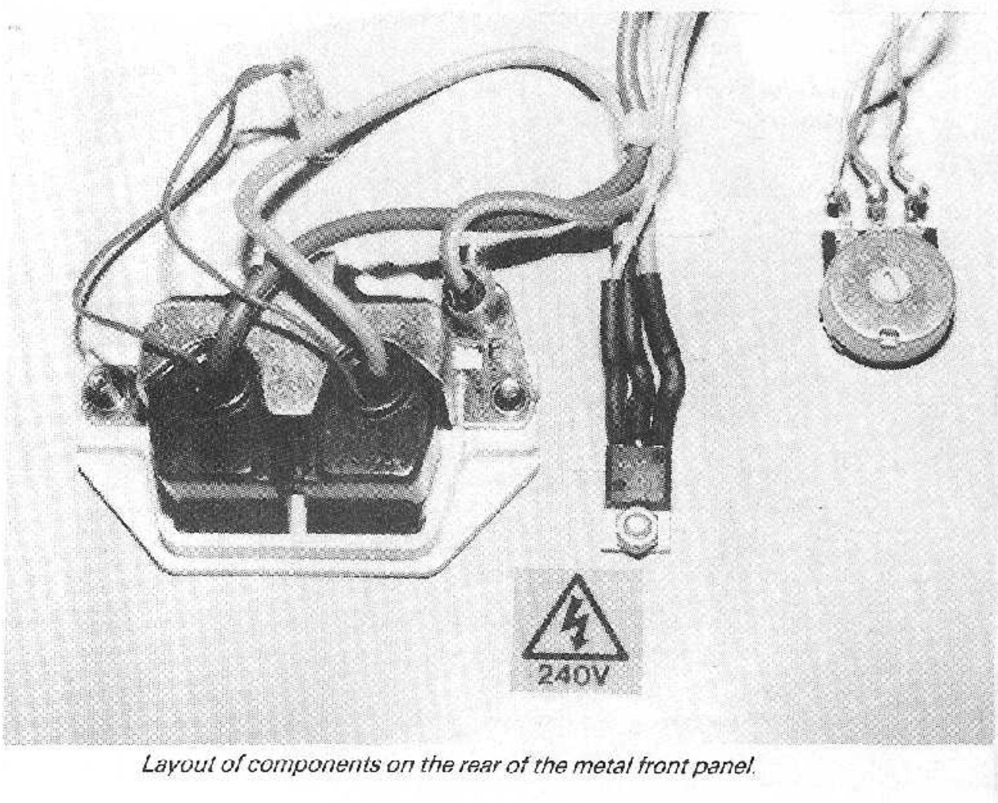
Also drill or punch the holes for potentiometer VR1 and the neon, followed by a 3mm hole centrally in the panel which will permit mounting of the triac directly using a countersunk or panel-head M3 x 6mm fastener. Although no insulation kit is needed it may be worth placing some insulation tape on the panel under the triac leads, just as a precaution to prevent against any errant strands of copper wire etc. shorting to the (earthed) panel.

Finally, once the panel has been prepared, it can be labelled with rub-down lettering as required, followed by a coat of protective spray-on lacquer to enhance the finish. Then fit all the panel-mounting parts and move onto the case.

The casing used with the prototype was made of plastic which eases any work. It needs to be prepared to accept the p.c.b., mains cable inlet and cable restraint. The



The metal front panel acts as the triac heatsink. Insulating tape under the sleeved pins provides extra protection.



Layout of components on the rear of the metal front panel.

layout of the interior is crucial, since adequate clearance must be allowed for the rear projection of the mains socket, potentiometer etc. once the front panel is secured.

The p.c.b. ***must*** be mounted with ***fully-insulated*** hardware for safety, e.g. nylon stand-offs or p.v.c. pillars using short self tapping screws at each end. Once again, organise the internal layout so that the unit will fit together without any obstructions being encountered. Also do ensure that the p.v.c. insulation of any wiring is kept away from the power resistors, whose *surface* temperature is just about adequate to melt ordinary insulation.

Still on the theme of safety, the prototype used a unique three-way 16A terminal block which incorporates a fuseholder within the Live feed. This entirely dispensed with the need to fit a separate fuseholder, also it automatically earths its own mounting bolt. If a separate fuseholder is used, it must be adequately rated (13A or more) and a 1 inch or 1·25 inch fuse type will therefore be called for.

The hole made in the box for the mains cable inlet is best fitted with a 10mm (internal diameter) grommet, to help prevent chafing or wearing of the cable insulation: it also helps to seal the hole. The three-core mains cable is rated at 13A and must of course be held in place with a cable restraint such as a nylon "P-clip" to prevent the cable from being pulled out or working loose.

INTERWIRING

Having located the main parts of the Power Controller into position, the final aspect of assembly is the interwiring. All wiring which might potentially carry a full load (up to 13A) must be adequately rated with this in mind, see Fig. 5. In actual fact, only the wiring to and from the mains inlet terminal block, the 13A socket and the triac (MT1, MT2 pins) require 13A cable.

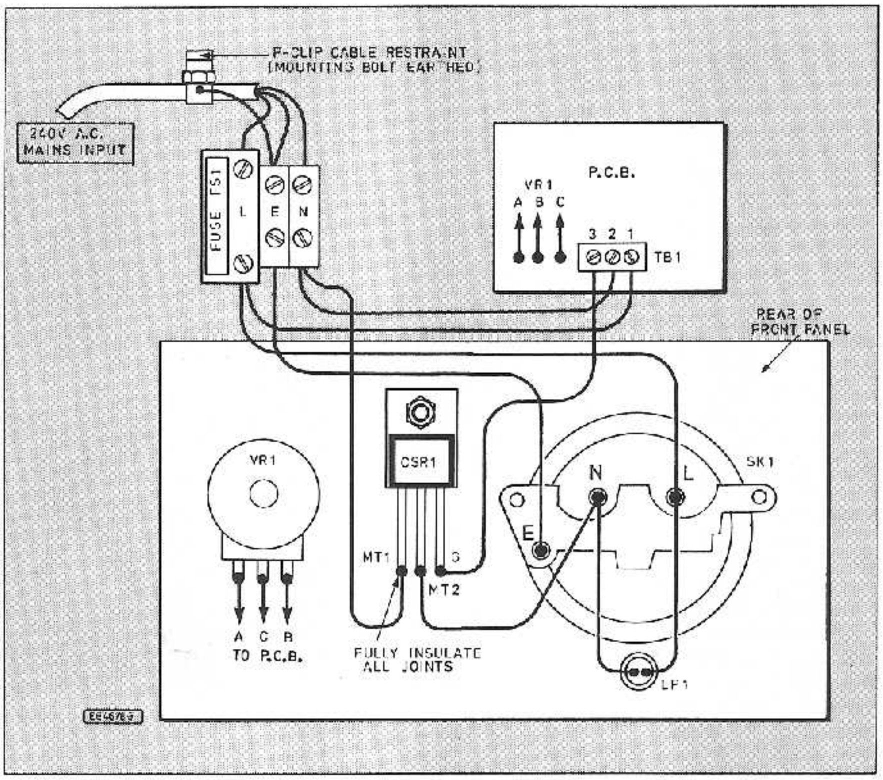


Fig. 5. Interwiring between components and p.c.b. Mains rated cable must be used between the mains terminal block, 13A socket and pins MT1, MT2 of the triac.

The potentiometer can be connected to the printed circuit board with ordinary insulated hook-up wire (7/0·2mm). All other connections can be effected with 3A wire (16/0·2mm) chosen more for its insulation strength since the mains connections to the p.c.b. itself only carry a few milliamps.

The triac wiring requires special mention: it is straightforward enough to solder the 13A wires to the appropriate leads, however because of the relative mass of the wires, precautions are needed to prevent these wires from straining the triac leads, which would undoubtedly break away if repeatedly flexed (metal fatigue). Hence, use generous lengths of p.v.c. or heatshrink sleeving on the triac wiring and leads to fully insulate them, and also provide a *strain relief* using a stick-on tie wrap base nearby. This will prevent unnecessary strain being applied to the leads.

Note also that the front panel will automatically be earthed through the Earth connection to the socket, which it will be seen is connected to the mounting screws. The P-clip mounting screw should be earthed with a separate wire, connected to a solder tag under the mounting bolt as shown.

Finally, fit a fused 13A plug and check all wiring for errors or omissions, inspecting mains joints very closely to ensure that they are adequately insulated. Having confirmed that all wiring is secured out of the way of the two power resistors, close up the case, ready for testing.

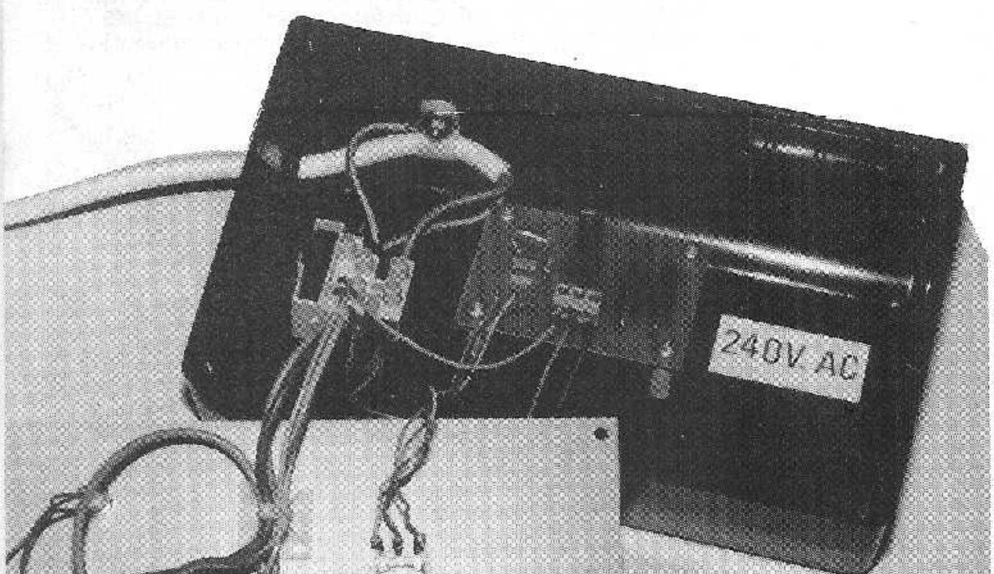
POWER UP

For maximum protection it is recommended that initial testing is performed through an ELCB/RCD Powerbreaker device, to protect against electric shock. The unit will not operate properly unless a reasonable load is connected, because the triac will not be able to conduct.

However, without a load, applying the mains will power the SL443 i.c. through the mains dropper resistors, which will become hot after a short period. Although various voltage measurements could be taken on the p.c.b. to confirm correct operation (e.g. the 7V d.c. across the potentiometer track), it is probably best to discourage any such testing because of the mixture of low voltage and full mains potential which exists on the board.

Testing is therefore restricted to ensuring the power resistors become hot after a short period, unplug the Power

The completed Power Controller with the front panel removed to show components mounted in the base of the case. The "well" to the right side of the p.c.b. accommodates the mains socket SK1.



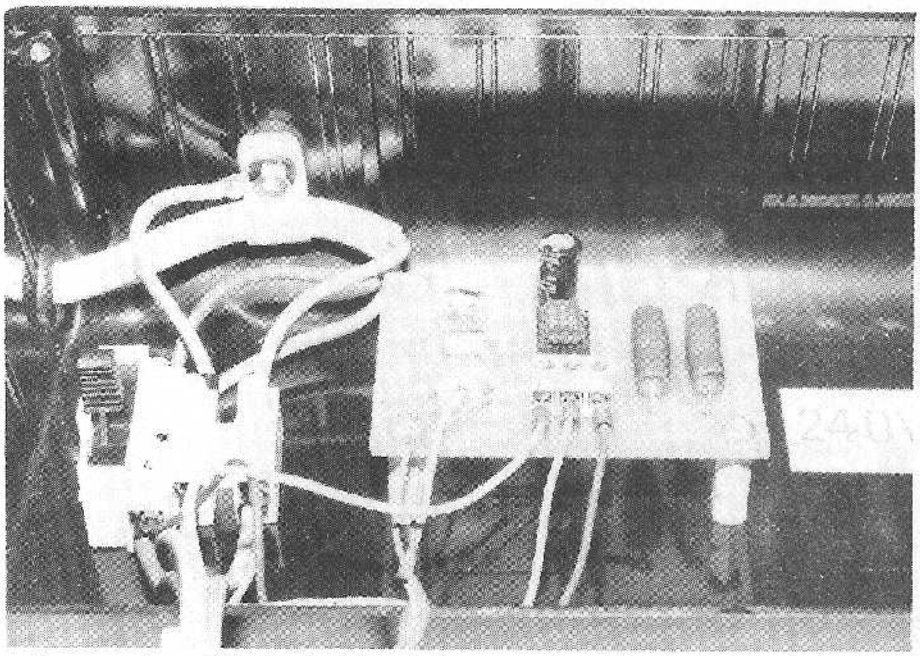
Controller completely from the mains and then check their temperature cautiously. Finally a suitable mains load can be attached, such as an electric fire (***not*** a fan heater) or even an ordinary iron.

The neon indicator LP1 should flash at a rate determined by the setting of VR1 – at "maximum" output, the neon should be continuously alight. At "minimum" setting, the neon will be blinking, indicating that short bursts of mains voltage are being applied to the load.

If everything is satisfactory so far, then apply a full load such as a two or three-bar electric fire, double checking that the burst-firing is fully variable using potentiometer VR1. As another check, the temperature of the triac mounting screw will rise when the Controller is on its maximum setting.

Monitor the prototype under full load test conditions for a good hour or more. Then unplug from the mains, inspect the interior to ensure that no insulation had caught on the power resistors and that there are no other visible problems, after which the Power Controller is ready for use.

Use the Power Controller directly on immersion heater elements or other resistive elements such as certain greenhouse heaters, oil-filled electric radiators or traditional electric bar fires. Bear in mind that a certain minimum load of say 500W is necessary for the triac to conduct properly. Below this, the burst firing may seem a little erratic.



The one-piece 16A terminal block, incorporating a fuseholder, and the p.c.b. mounted on plastic stand-off pillars

FURTHER NOTES

If readers wish to install the Power Controller as a permanently-sited unit perhaps adjacent to an immersion heater – then bear in mind the heat generated by the power resistors. The p.c.b. should be placed such that this heat will flow *away* from the i.c., not over it.

Also, in general terms, do ensure that adequate heatsinking is provided for the triac, and the size of the aluminium panel suggested by the prototype (212mm × 127mm) should be considered the *minimum* dimensions to enable the unit to handle maximum output conditions. The use of a metal box or panel as a heatsink has proven adequate for general purpose use but a ready-made heatsink would enable the design to cope more readily with extreme operating levels.

If it is likely that the Power Controller will be operated at peak output for several hours or more, the triac will dissipate maximum heat under these circumstances and it may be preferable to use a commercial heatsink rated at say 7·5°C/Watt or so, and the size of the case will need revising to accommodate this. □