An interesting approach to energy conservation

Power Saver

Concerned about the Energy Crisis? Interested in how induction motors can be made more efficient? If so, read on and learn about the NASA-developed power-factor controller and our power saver circuit.

by JOHN CLARKE and LEO SIMPSON

Much has been said about the power factor controller developed by Frank J. Nola at NASA's Marshall Space Flight Centre. His technique for reducing the power consumed from an induction motor is reportedly very effective, especially with motors running at low loads for long periods of time.

According to an article in our magazine titled "Energy Conservation and the Electric Motor" April, 1980 the power factor controller is claimed to give 40% to 60% power savings from unloaded one-half hp to 5hp motors. Similarly in "Popular Electronics" October, 1979 p39, an article titled "Motor-Control Circuit Cuts Costs" by Myles H. Marks claimed substantial power savings in one-third hp split-phase and one-quarter to three-quarter hp capacitor start single phase induction motors.

Suitably inspired, we decided to produce our own power factor controller circuit using readily available local components.

It is well known that when an induction motor is fully loaded it is highly efficient. Typical induction motors can achieve efficiencies of 70% or more. But when lightly loaded or running with no load at all, the efficiency is very low.

This stands to reason because if a motor is spinning but doing no useful work all the input power is converted to heat in the form of resistive and friction losses. In other words, the input power is wasted.

To explain how the power saver can actually reduce power consumption, a brief description of induction motor operation is necessary. Basically, induction motors consist of a stator winding, supplying the magnetic field, and the rotor winding which is electrically isolated from the stator and rotates with the shaft.

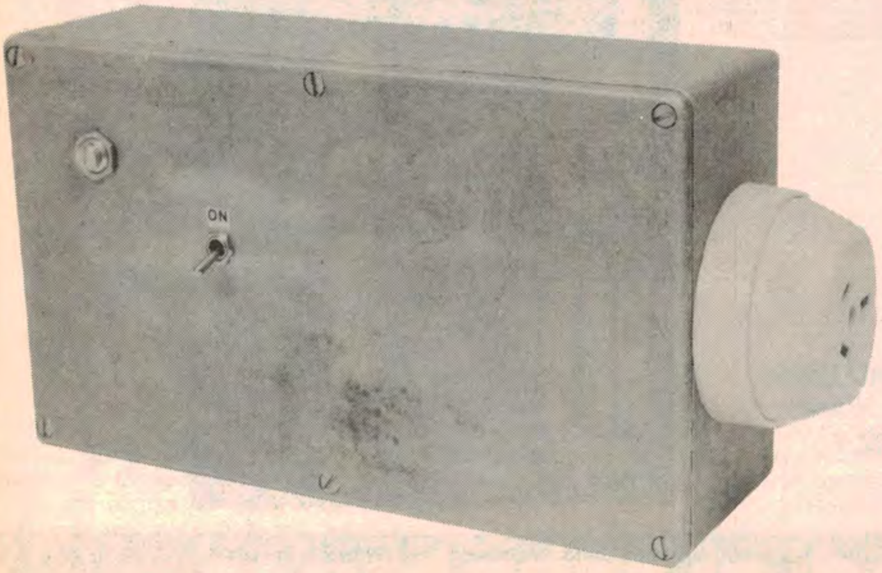
The only possible source of excitation is the stator input which induces current flow in the rotor by induction or transformer action. At no shaft load, the motor speed approaches synchronous speed (the speed of field rotation) and the angle between current and voltage waveforms approaches 90°. Consequently the cosine of this angle, the power factor, approaches zero.

The difference between the synchronous speed and the actual motor speed for an induction motor is referred to as "slip" and this is calculated as a percentage of the synchronous speed. For example, a typical 50Hz single phase motor has a synchronous speed of 1500rpm and a full load speed of 1440rpm. This means that the slip at full load is 4%. At less than full load, the motor slip will be less than 4%. At the same time, the efficiency will be markedly less than the maximum.

The power saver circuit monitors the phase difference between the motor voltage and current. If it senses a large phase difference, which is characteristic of a no-load condition, the circuit reduces the input voltage to the motor. This reduces the motor current and the available torque and so the motor slip increases. As this happens the motor efficiency rises and so the overall power consumption of the motor drops.

As far as the motor performance is concerned, the power saver circuit has negligible effect. As already explained, it does increase slip under lightly loaded conditions, so there is a very small drop in speed, but there is no change in the full-load operation of the motor. In fact, the speed regulation of the motor is slightly better with the power saver in circuit, although this is usually of no consequence.

Refer now to the circuit diagram which should be read in conjunction with the waveforms of Fig. 1. Heart of the circuit is the Triac which controls the average voltage to the load by firing late or early in the load voltage cycle.

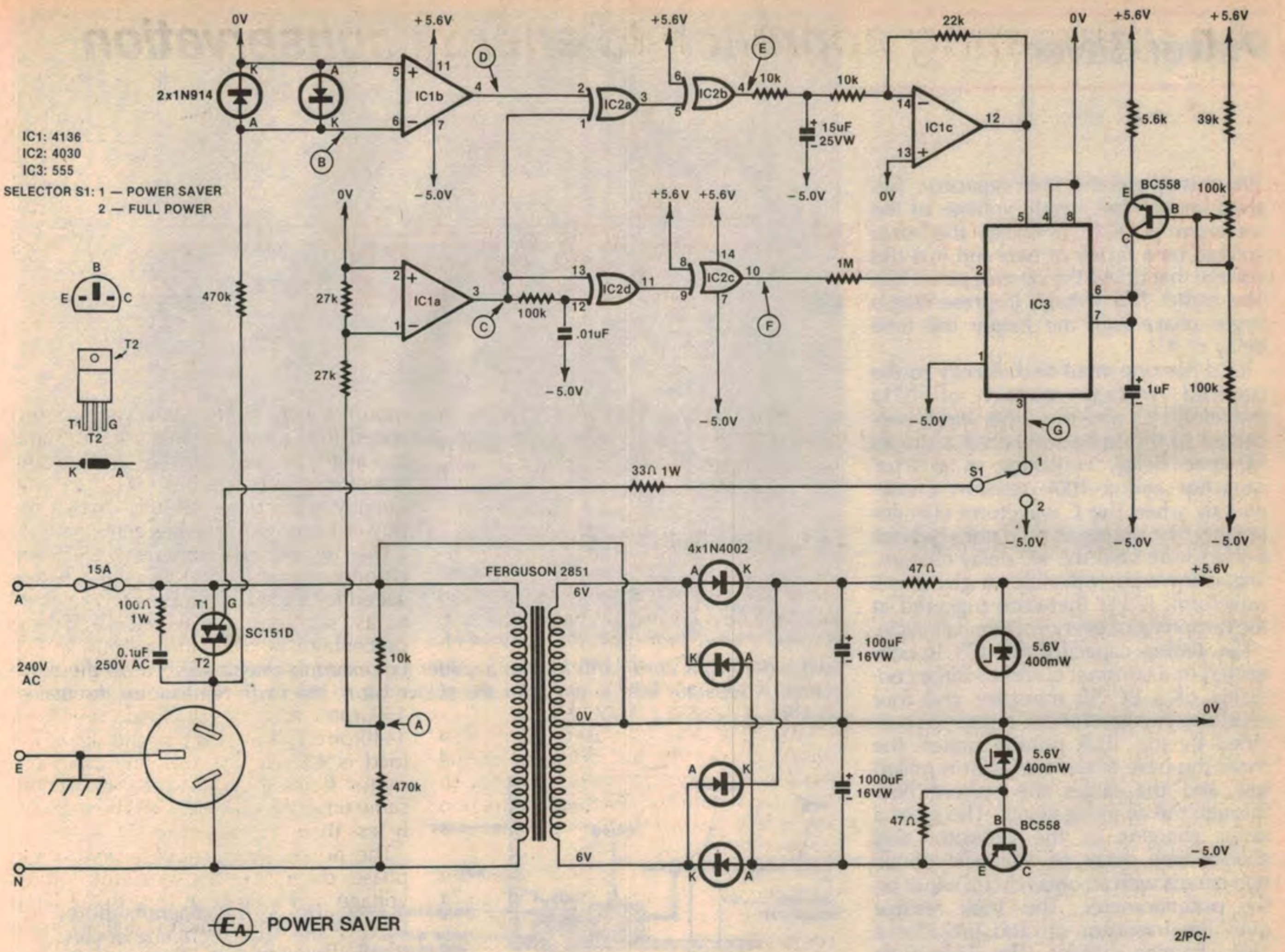


Looks are unimportant; utility is the name of the game.

We estimate that the current cost of parts for this project is approximately

$32

This includes sales tax.

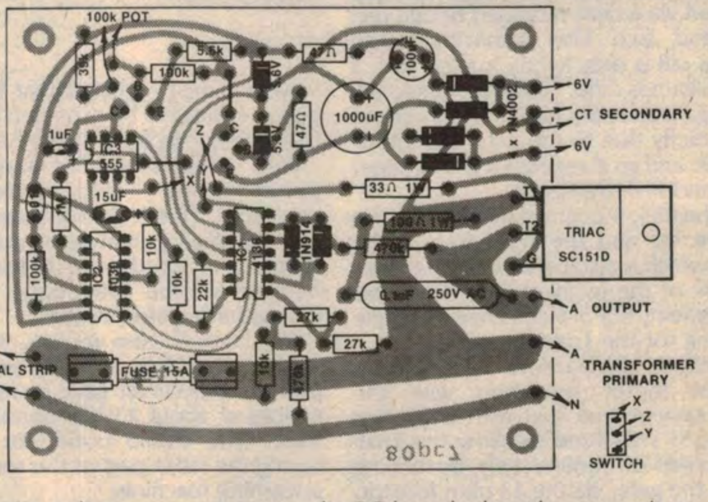


The Triac controls the average voltage to the load by firing late or early in the load voltage cycle.

The 555 timer, IC3, is connected as a monostable and is triggered at the zero voltage crossing point of the input voltage waveform, firing the Triac after a short delay period. The actual time delay between the triggering of IC3 and the firing of the Triac depends upon the error voltage at the control pin of IC3 (pin 5) and the setting of the 100k potentiometer. This error voltage is proportional to the phase difference between the current and voltage waveforms.

IC1a operates as a comparator detecting the voltage waveform (Fig. 1, waveform A) from the voltage divider formed by the 470k and 10k resistors. The output of this comparator is a square wave (waveform C) which changes polarity at the zero voltage crossing point and is in phase with the voltage waveform. This square wave therefore represents the voltage waveform.

Obtaining a square wave current waveform (D) is a little less straightforward. In this case the voltage across the Triac (waveform B) is monitored by IC1b which also acts as a comparator. This method of detecting the current waveform is valid since the Triac turns off at zero current, rather than at end of the voltage cycle.



Note that mains voltages are present on the PC board when the power is on.

The diodes across the non-inverting and inverting inputs of IC1b are to protect the op amp from an excessive input voltage when the Triac is off and a load connected.

The squared voltage and current waveforms are subtracted with IC2a, an exclusive-OR gate. The output of the gate is only high when the inputs are at opposite polarity and low otherwise. The greater the phase lag of the current to the voltage, the longer the positive pulses from IC2a. To obtain the right sense for the following circuitry the waveform is inverted by IC2b to give the waveform at E.

This waveform is integrated with the

10k resistor and the 15uF capacitor. This gives an average steady voltage of the waveform E. IC1c amplifies this error voltage by a factor of two and it is this voltage that drives the control pin of IC3. The higher this voltage (representing a larger phase lag), the longer the time delay of IC3.

IC2d has one input tied directly to the squared voltage output of IC1a (waveform C) and the other input connected to the same source via a simple RC time delay, consisting of a .01uF capacitor and a 100k resistor. Consequently when the C waveform changes polarity, the output of IC2d goes high for a short time until the RC delay charges. This is inverted with IC2c to give the F waveform. IC3 is therefore triggered at the beginning of every voltage half-cycle.

The timing capacitor for IC3 is connected to a constant current source consisting of a BC558 transistor and four resistors. The greater the resistance provided by the 100k potentiometer, the more the base of the transistor is pulled low and the larger the current flow through the charging circuit. This gives a faster charging of the capacitor and shorter time delay. (A "fail safe" condition occurs with an open circuit wiper on the potentiometer. The 100k resistor pulls the transistor on and provides a high charging current. The Triac then fires early in each half-cycle.)

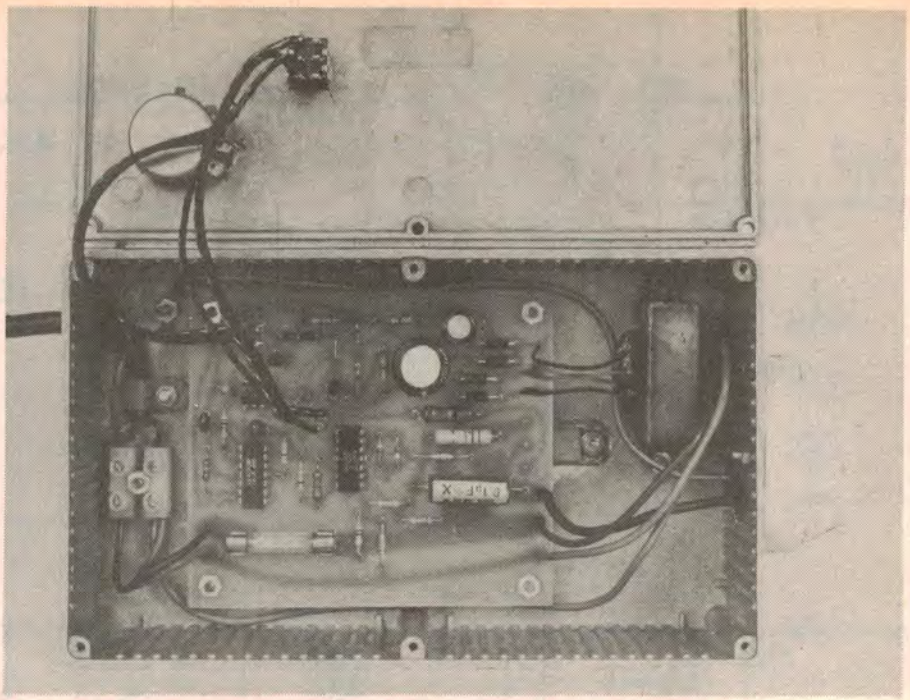
Positive and negative supply rails are provided via a centre-tapped bridge rectifier and two filter capacitors. The positive rail is only lightly loaded with a few milliamps and is zener regulated. The negative supply has a higher current load, chiefly due to the gate current for the Triac and so is regulated with a zener diode and PNP transistor.

IC3, the 555, is connected between the negative rail and the centre-tap of the supply which is also connected to the active side of the mains supply. With this arrangement, IC3 provides negative gate triggering for the Triac.

To enable comparisons to be made between motor operation with the power saver circuit and with full mains voltage, S1 was fitted to allow the Triac to be turned on continuously, by feeding −5V to the gate, via the 33 ohm resistor.

A commutating network consisting of a 100 ohm/1W resistor and 0.1uF/250VAC capacitor, is connected across the Triac to ensure reliable operation. Fuse protection is also incorporated, chiefly to guard against shorts between the circuitry and the case.

Now that we have described the circuit of the device, readers will want to know just what power savings can be expected. Well, unfortunately (or fortunately, depending on your point of view) our test revealed that the typical power savings to be expected are far less than those predicted by NASA tests.



Solder the mains cord earth lead to a solder lug bolted to chassis adjacent to the cord clamp. A separate lead is run from the solder lug to the earth terminal on the mains socket.

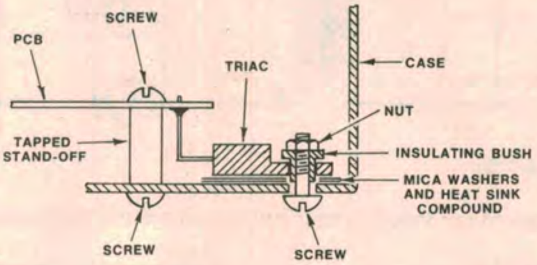


Fig. 2: This diagram shows the Triac mounting details. Note that the Triac must be fully insulated from the case.

With refrigerators, for example, any power saving would appear to be negligible. This is unfortunate, because even a small percentage saving would translate to worthwhile dollars savings, because of the long cycle times for typical refrigerator motors.

With typical ⅓hp motors as used in washing machines and drill presses, our power saver circuit gave no-load power savings of about 15% or about 50 to 60 watts. This would occur, for example, during the latter part of the spin cycle of a washing machine.

Part of the reason for these low power savings may be simply due to the fact that our domestic power mains run at 240VAC rather than 110VAC as used in the USA. Motors designed for use at 110VAC will have a much higher current drain (more than double) than an equivalent 240VAC motor. This means that resistive power losses will be more than four times as high.

Ultimately the USA could possibly save far more energy by simply converting its domestic power reticulation to 240VAC! We wonder if they have considered it. Anyone feel like writing to President Carter?

Seriously though, we have published this circuit, not because we expect it to pay for itself reasonably quickly in a domestic situation, but because it may have useful application in industrial situations anywhere where induction motors are used for long periods of time at a fraction of their rated load. Some applications which come to mind are metal presses, guillotines and lathes.

We built our power saver in a diecast box measuring 190 x 110 x 60mm. This provides a rugged and electrically safe case for the "live" circuit. All the components are mounted to the PC board coded 80pc7 and measuring 107 x 91mm.

Start construction by planning the layout within the aluminium box. It is easier to mark out the mounting holes for the PC board before the components are soldered into place. Drill the holes for the mains cord grommet, earth lug, cord clamp, terminal strip, Triac, transformer and mains socket. Wire and

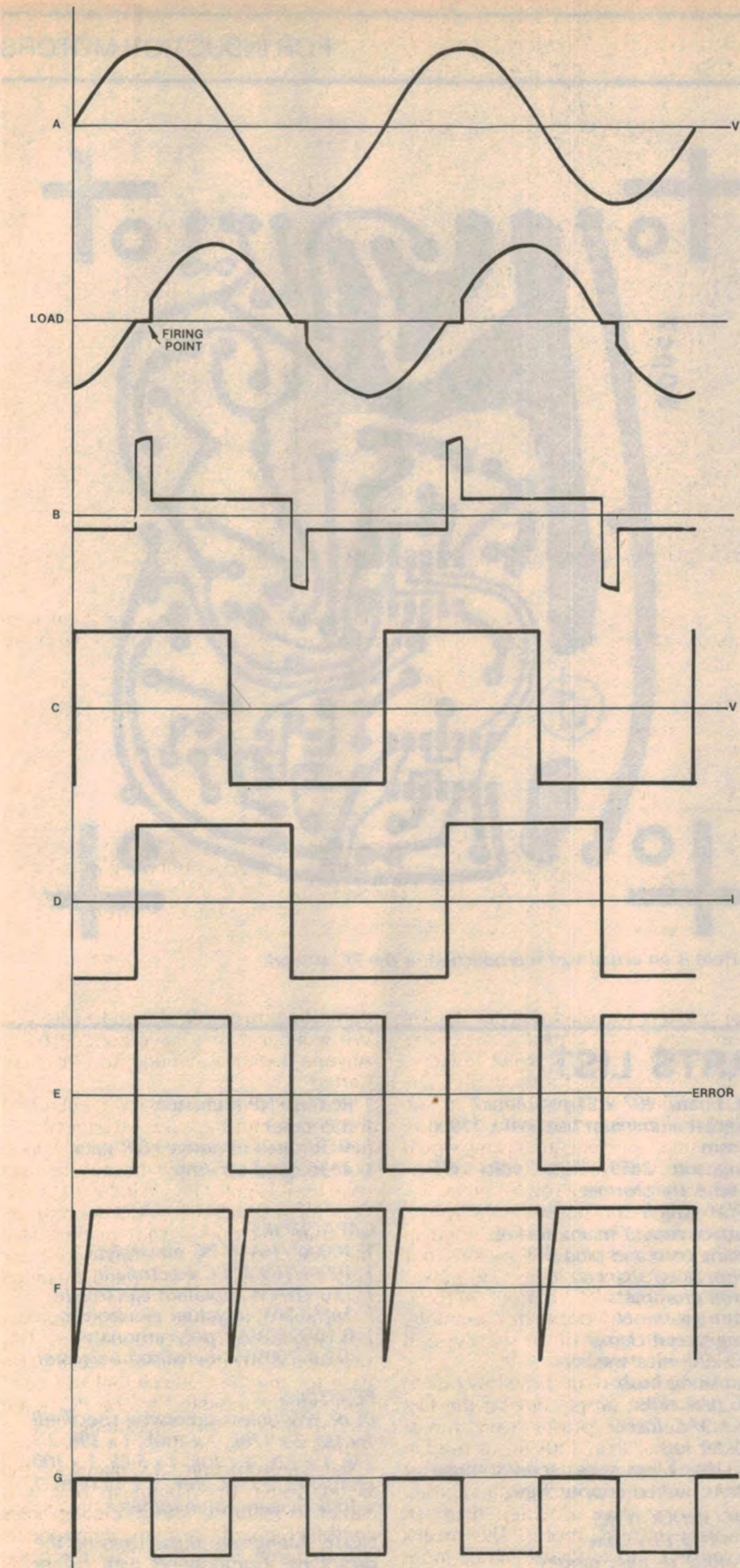


FIG. 1

Fig. 1: see text for an explanation of the various waveforms.

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bolt the socket to the case and use grommets for the leads passing through the case. The mains cord, terminal strip, earth lug and transformer can also be wired at this stage and bolted into position ready for the PCB.

Place the resistors and links into position first on the PCB and solder them into place. At this stage you should decide whether the switch is necessary for your purposes, and if not place a link between "X" and "Z" on the PCB. This will permanently connect pin 3 of IC3 to the 33 ohm resistor and the power saver will always be in operation.

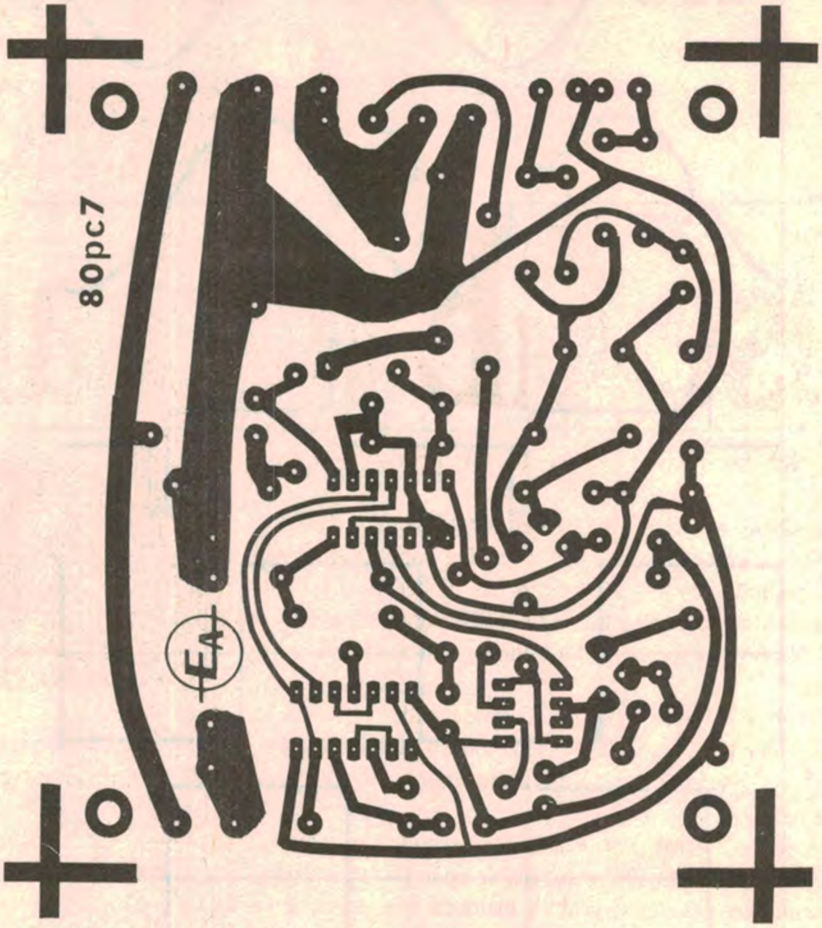
The capacitors, diodes, transistors and fuse clips can be now soldered into place, taking care with the polarity orientation. Next the ICs can be soldered. Start with IC1 and IC3, which can be soldered without special precautions other than to avoid overheating the pins while soldering. IC2 is a CMOS device and requires special precautions while soldering. Firstly the power supply pins, 7 and 14, should be soldered with the barrel of the soldering iron connected to the negative rail. Then solder the other pins.

Finally the Triac is soldered into place and the leads bent such that the metal heatsink tab is parallel to the base of the case. The PCB can now be positioned in place within the box and the mains wires connected as well as the transformer secondary leads. PC stakes are recommended for the potentiometer and switch connections. Bolt the PCB down to the box using standoff spacers on the four mounting holes.

The Triac is now ready to be bolted into place. A spacer and two mica washers are necessary to provide electrical insulation between the heatsink tab of the Triac and the case (refer to Fig. 2). Insulation is a very important factor for safety and operation of the circuit and it is necessary to check the insulation with a meter. Since the case acts as a heatsink for the Triac, it is recommended that heatsink compound be used between the surfaces of the Triac, the mica washer and case.

Connect the switch and potentiometer to the circuit and bolt them to the lid of the box, making sure that they are in a position where they will not foul the components on the PCB. Place the 15A fuse in position and screw on the lid after a final check of all the wiring.

The power saver is now ready to be tested. The power saver connects in series with the appliance power cord. With the motor running, adjust the potentiometer until the motor just audibly begins to reduce in speed. The setting, incidentally, will need to be adjusted for different motors.



Here is an actual size reproduction of the PC artwork.

PARTS LIST

1 PC board, 107 x 91mm, 80pc7
1 Diecast aluminium box 190 x 110 x 60mm
1 Ferguson 2851, 12.6 volts CT 150mA transformer
1 SPDT switch
1 surface mount mains socket
1 mains cord and plug
4 6mm brass spacers
3 3mm grommets
1 9mm grommet
1 mains cord clamp
2 TO-220 mica washers
1 insulating bush
2 PC fuse clips
1 15A 3AG fuse
1 solder lug
PLUS: hook up wire, screws, nuts, washers, tinned copper wire.

SEMICONDUCTORS
1 SC151D 15A Triac
4 1N4002 rectifier diodes
2 1N4148 switching diodes
2 5.6V 400mW zener diodes
2 BC558 PNP transistors
1 555 timer
1 4030 quad exclusive–OR gate
1 4136 quad op amp

CAPACITORS
1 1000uF/16VW PC electrolytic
1 100uF/16VW PC electrolytic
1 15uF/16VW tantalum electrolytic
1 1uF/16VW tantalum electrolytic
1 0.1uF/250VAC polycarbonate
1 .01uF/100VW metallised polyester

RESISTORS
(¼ or ½W unless otherwise specified) 1 x 1M, 2 x 470k, 2 x 100k, 1 x 39k, 2 x 27k, 1 x 22k, 4 x 10k, 1 x 5.6k, 1 x 100 ohms/1W, 2 x 47 ohm, 1 x 33 ohm, 1 x 100k (linear) potentiometer.

NOTE: Ratings are those used on the prototype. Components with higher ratings may generally be used providing they are physically compatible.