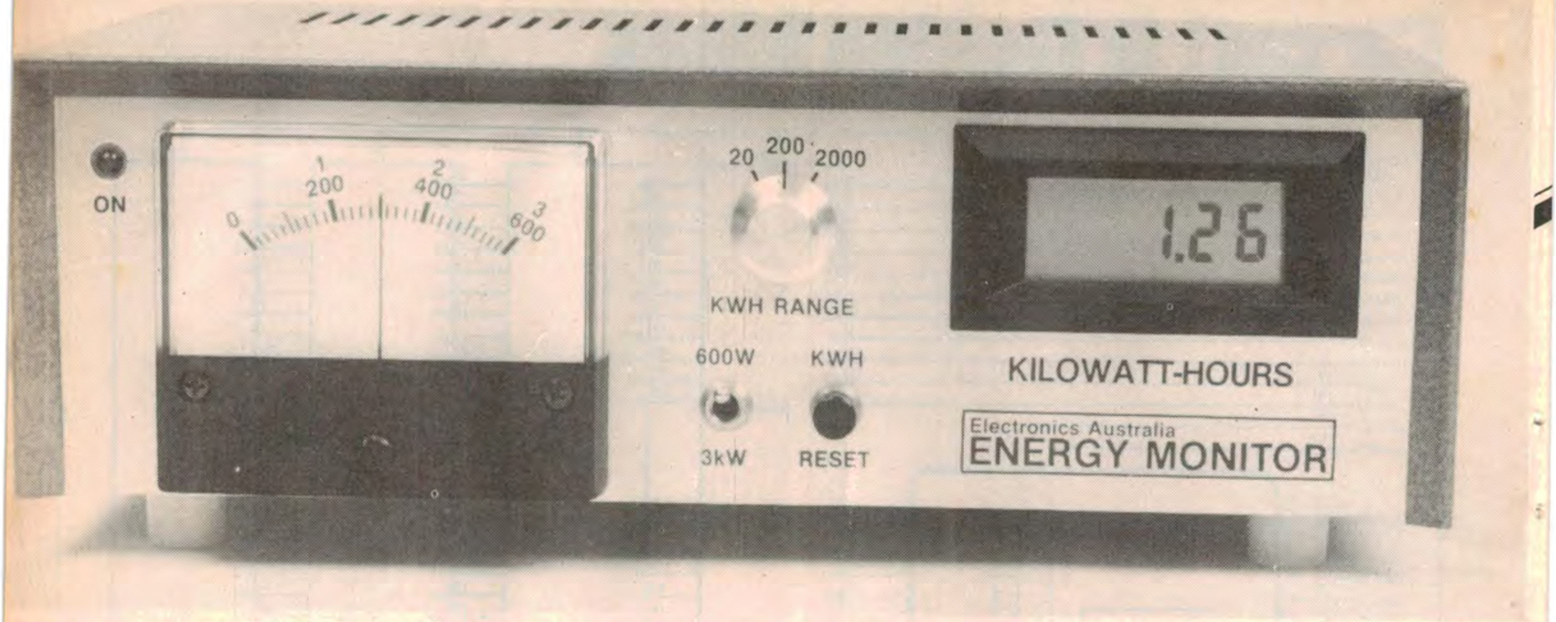


Check electricity consumption with this

Energy Monitor

by JEFF SKEEN

Still suffering from shock after that last electricity bill? With a little help from our Energy Monitor you can find out just how much that pool filter, air conditioner or freezer adds to the bills.

WARNING

This circuit will float at 240V AC if the mains active and neutral in your house wiring has been transposed.

Our Energy Monitor is really two projects in one. It couples the electronic wattmeter circuit published in September, 1983 with a kilowatt-hour meter, thus allowing both the power demand and the energy usage of an appliance to be measured.

Energy usage is of prime importance to most people because, as consumers, this is what they pay for when the electricity bill comes around. The council electricity meter fitted to your house is actually an energy meter which measures energy consumption in kilowatt-hours. One kilowatt-hour (kWh) is the energy drawn from the mains by a 1000W appliance running for one hour, or a 2400W appliance running for 25 minutes, or a 5W appliance running for 200 hours, etc.

The council meter has a series of dials which total up the kilowatt-hours used. There is no reset provided – the reading at the end of the previous quarter is simply subtracted from the reading for the last quarter, the result being the energy usage during the quarter.

Since there is only one council meter fitted to the household power circuits, it is not possible to obtain a break down of the cost of operating individual appliances.

Further, because most appliances are not run continuously, working out the cost of running them over, say a week, becomes fairly difficult. The times during which the appliance is operated must be noted, then these have to be added together and multiplied by the power rating of the appliance. Finally, the number of kilowatt-hours must be multiplied by the cost per kilowatt-hour.

If the appliance is like many these days and fitted with a thermostat, the on and off times may not even be known to the consumer.

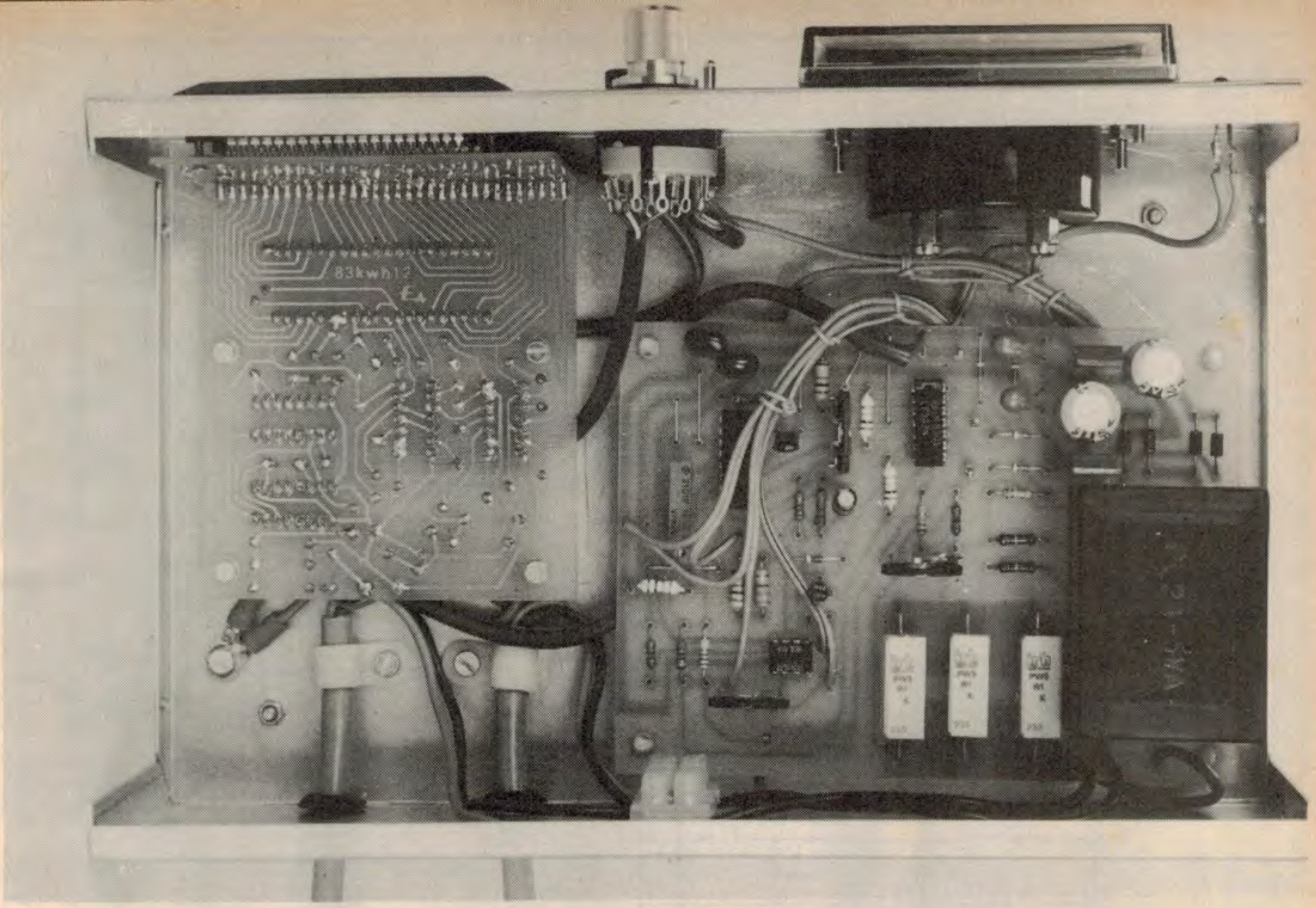
As a further complication, some appliances, such as washing machines, have different power demands at different points in their operating cycle. So, before any cost calculations can be done, the average power demand must be calculated. As far as the average consumer is concerned, this task is virtually impossible.

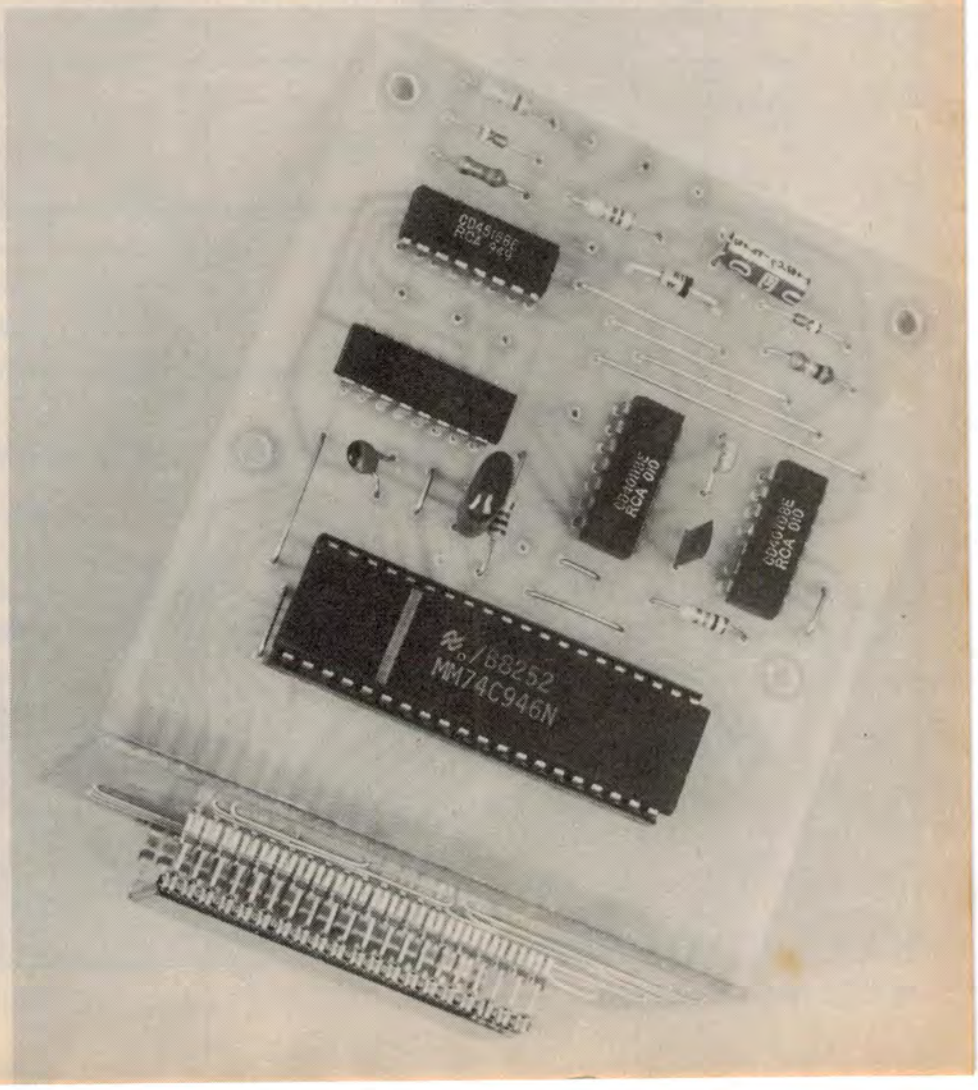
This is where our Energy Monitor comes in. By connecting the Energy Monitor between an appliance and the mains, both the instantaneous power demand of the appliance and its energy usage over a period of time is automatically measured. The cost of operating the appliance is then determined by obtaining the charge per kilowatt-hour from an electricity bill and multiplying by the number of kilowatt-hours shown on the Energy Monitor.

The appliance power demand is displayed on a large moving coil meter which has switchable full-scale readings of 600W and 3kW. The number of kilowatt-hours of energy used is read out on a 4½-digit liquid crystal display (LCD) which has switchable full-scale readings of 20, 200 and 2000 kilowatt-hours. A reset button has been provided to allow the kilowatt-hour meter to be reset to zero at the beginning of each measurement period.

How it works

For the sake of clarity, the complete





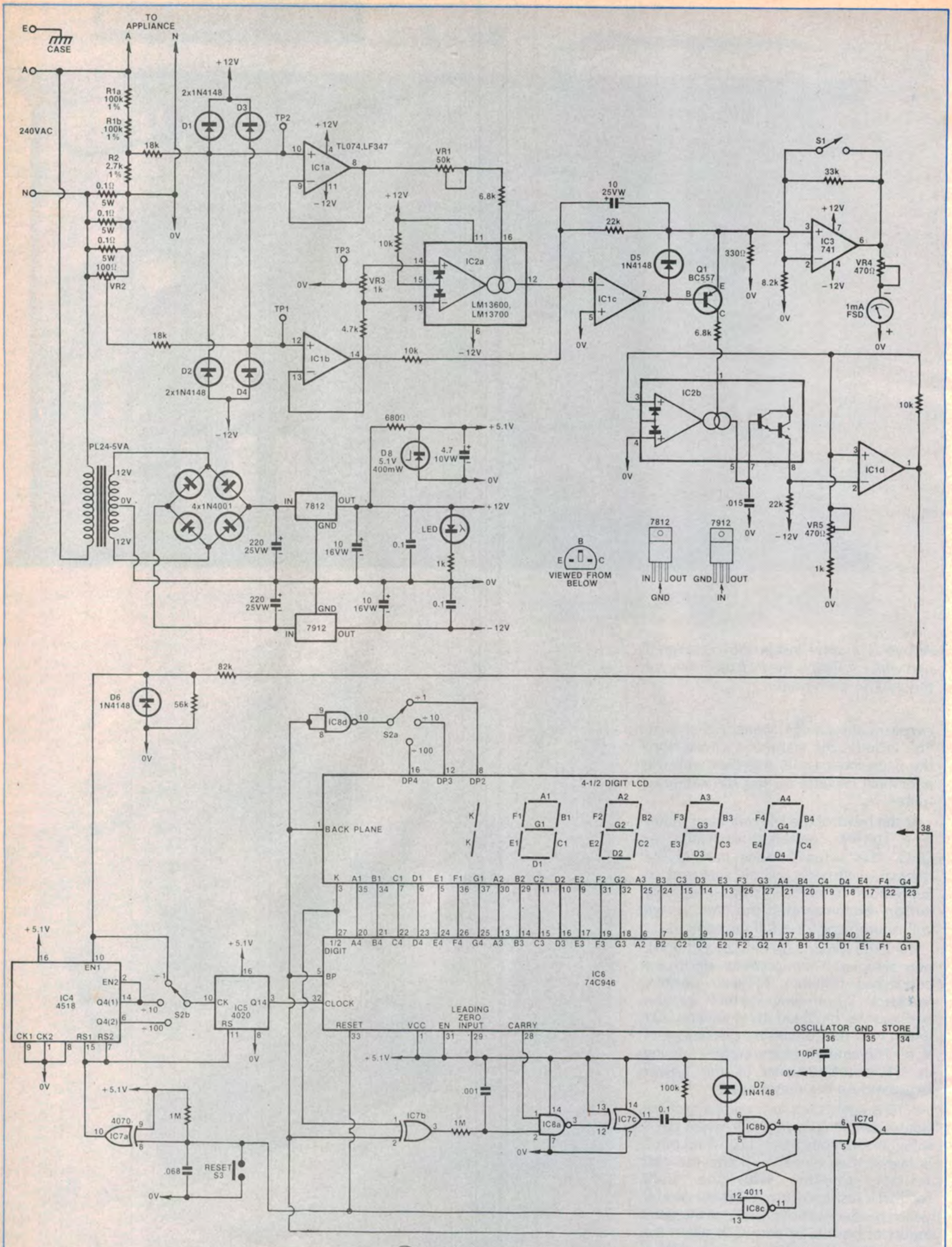
Above is a view inside the completed unit while at right is the PCB assembly for the add-on kWh meter.

circuit of the Energy Monitor is shown. This includes the wattmeter circuit from the September issue, together with the additional circuitry for the kilowatt-hour meter.

At the heart of the kilowatt-hour meter is a current controlled oscillator, or CCO. This actually forms part of the original wattmeter circuit featured in September. Its operation was given only cursory examination at the time, so we will return here for a full description.

The CCO is made up of IC2b and IC1d, plus associated components which are connected together to give positive feedback. Controlling current for the oscillator is provided by transistor Q1 which is in turn driven by the output of IC1c. The amount of the current flowing in Q1 is proportional to the power registered on the meter scale.

IC1d is connected as a comparator, its output swinging from +12V when pin 3 is higher than pin 2 to −12V when pin 2 is higher than pin 3. VR5 and the 1kΩ resistor, together with the 10kΩ feedback resistor, form a voltage divider which produces about +1.5V at the pin 3 inputs of both IC1d and IC2b when the output of IC1d is +12V (assuming VR5 is set to maximum resistance, ie 470Ω).



ENERGY MONITOR

Energy Monitor

Let's assume initially that the output of IC1d has just gone to +12V. A voltage of +1.5V will thus appear on pin 3 of IC2b and this produces a current flow from pin 5 of IC2b equal in magnitude to the control current from Q1. This charges a .015µF capacitor, thereby raising the base potential of the internal Darlington output transistor. The emitter of the Darlington transistor (pin 8) follows this rise in base voltage, although two emitter-base drops (about 1.5V) will always separate the two voltages.

Since the inverting input of IC1d is tied to the Darlington emitter, it too will rise in voltage along with the .015µF capacitor. When the voltage at the inverting input of IC1d exceeds the voltage at the non-inverting input – ie, becomes greater than about 1.5V – the comparator action of IC1d causes its output to swing from +12V to −12V.

This changes the voltage at the non-inverting inputs of IC1d and IC2b from 1.5V to −10.5V. It also reverses the direction of the current flow and so a discharge current equal to the control current through Q1 flows from the .015µF capacitor back into pin 5 of IC2b.

As current flows from the .015µF capacitor, the voltage across it drops and hence the voltage at the emitter of the Darlington output transistor also drops. The capacitor continues to discharge until the voltage at the inverting input of IC1d drops below −10.5V. At this point the output of IC1d will suddenly switch to +12V and the cycle is repeated.

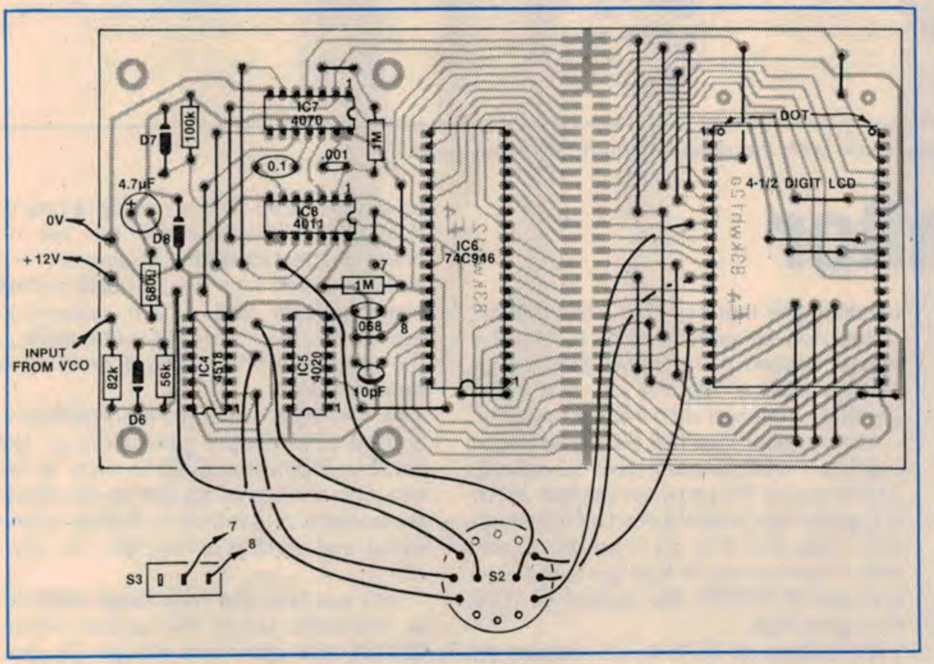
The frequency at which the CCO oscillates for a given control current may be varied by adjusting the voltage divider and hence the two reference voltages. The further apart the two voltages, the longer it will take for the capacitor to charge from one voltage to the other and hence the longer the period of the oscillator waveform. Trimpot VR5 thus allows calibration of the kilowatt-hour meter.

The output of the CCO is passed from the wattmeter circuit board to the kilowatt-hour meter circuit board. At the input of the kilowatt-hour meter is an attenuation network consisting of two resistors and a diode. These make the CCO square wave output compatible with the circuitry of the kilowatt-hour meter by reducing the positive peaks of the CCO output to about +4.9V and clipping off the negative peaks.

The input applied to pin 10 of the 4518 IC and the first position of S1a thus consists of a nominal 0V to +5V square wave at the CCO frequency.

The 4518 (IC4) contains two binary coded decimal (BCD) counters and these have been connected so that each performs a divide by 10 function.

The output of the first counter (pin 14) is applied to the second position of switch S1a and also forms the input to the second divide-by-10 stage. The output of the second stage (pin 6) is thus the CCO frequency divided by 100 and this is applied to the third S1a switch position.



Parts overlay for the kilowatt hour meter. Note that the display board must be separated from the main board and the two soldered together at right angles.

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

$55

This includes sales tax.

Switch S1a selects the divided CCO signal and feeds it directly to the clock input (pin 10) of IC5, a 4020 14-stage binary counter. This counter serves to divide the incoming clock pulses by 16,384 (ie, 2^{14}). The result of all this is that each output pulse from pin 3 of IC5 is equivalent to either .001, .01 or 0.1kWh, depending upon the setting of range switch S1.

Thus, the reading on the LCD will be an indication of the energy used in kilowatt hours.

To count and display the kilowatt-hours of energy used, we have used the event counter circuit described in the July issue of "Electronics Australia". Since we have already described this circuit thoroughly we will simply recap the basic details.

Briefly, IC3 is a 74C946 4½-digit counter/decoder/driver for use with LCDs. The internal circuitry is fairly complex but essentially the input clock pulses are applied to four cascaded decade counters and a half-digit counter (flipflop). The outputs of the counters are passed to latches which are controlled by the store pin (pin 34).

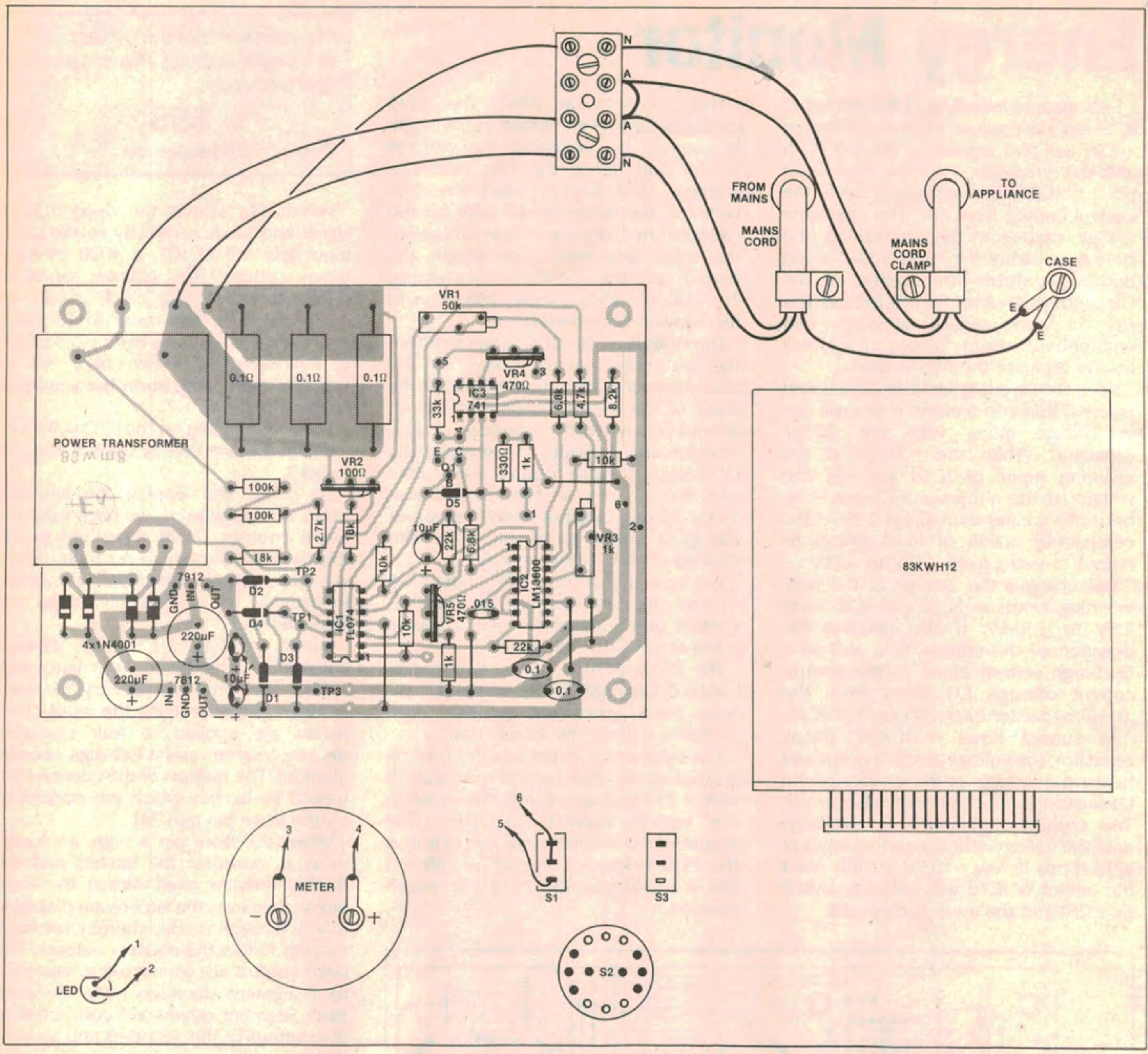
When the store pin is high, a counter value is stored in the latches and the display remains fixed. When the store pin is taken low, the latches are placed in a flow through mode whereby the latch outputs follow the counter outputs. The latch outputs are connected to four BCD to 7-segment decoders, one for each digit. Segment drivers are connected to the outputs of the decoders and provide the special drive characteristics required by the LCD.

In our circuit the store pin is connected to ground and this allows the display to update instantly whenever a pulse is received from IC5. The enable and leading zero inputs (pins 31 and 29) have been connected to the supply rail so that the counters and leading zero blanking circuitry are permanently enabled.

Over-range indication

The portion of circuit centred around IC7b, c and d, and IC8a, b and c is an over-range sensor designed to activate an arrow shaped annunciator located in the top left-hand corner of the LCD if the counter exceeds its maximum reading.

To do this, the over-range circuit must sense when both the ½-digit (pin 27) and carry out (pin 28) outputs are active and then signal the over-range annunciator



This wiring diagram should be used in conjunction with the diagram on the previous page.

Energy Monitor

to turn on at the next clock pulse.

The ½-digit output will be active (ie, out of phase with the backplane signal) whenever the four least significant digits change from 9999 to 0000. It then remains active until the counter is reset. The carry out goes high when the counter reaches 9999 then returns to the low state when the display changes to 0000.

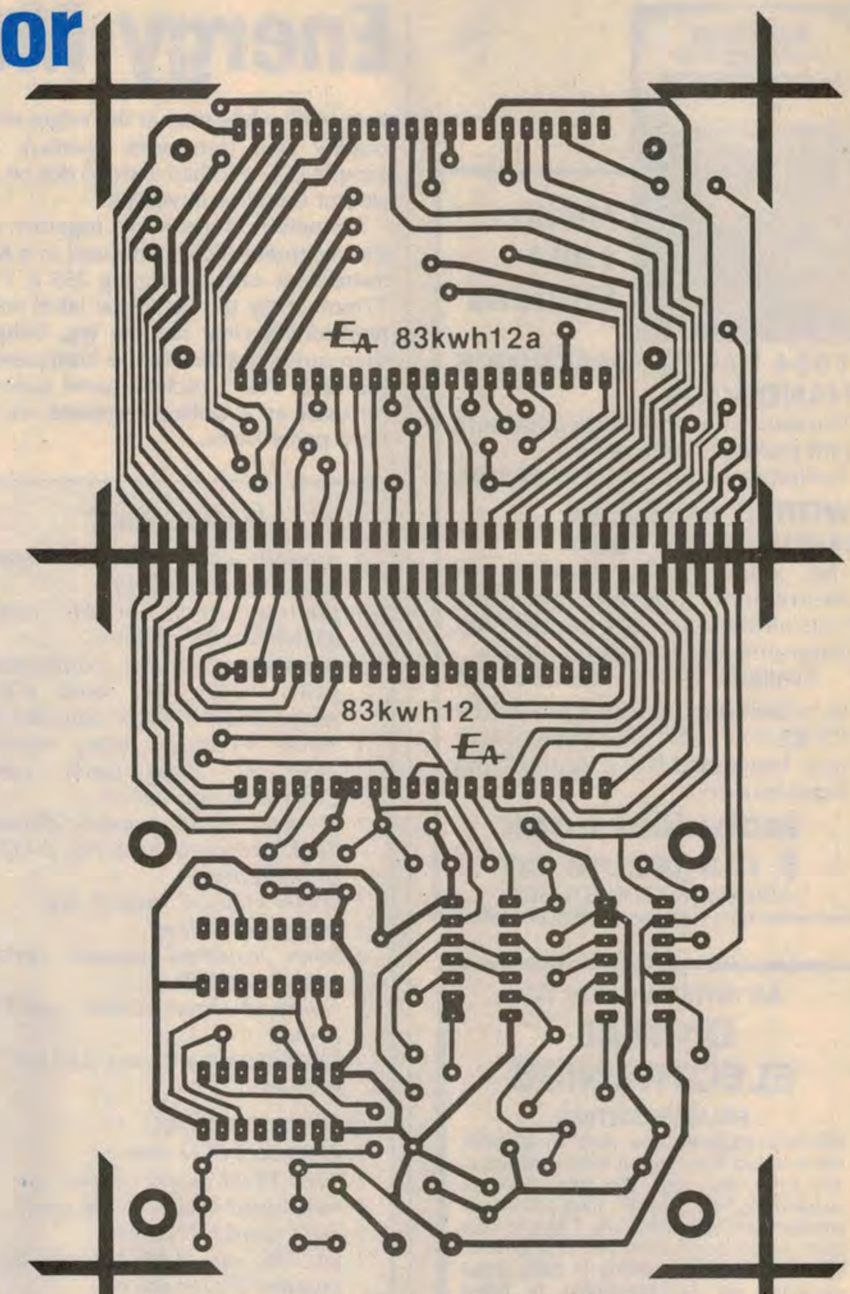
When the ½-digit output goes active, the output of IC7b goes high, sending pin 2 of IC8a high also. The 1MΩ resistor and .001μF capacitor on the output of IC7b form a low pass filter which prevents short output spikes from IC7b reaching the input of IC8a. These short spikes may be generated by IC7b if the signals applied to its inputs (the ½-digit and backplane signals) do not have perfectly matched rise and fall times.

Assume now that the displayed count reaches 19999 (ignoring decimal points). At this count, the carry out pin (pin 28) of IC6 goes high, sending pin 1 of IC8a high also. IC8a and IC7c form an AND gate. When both inputs of IC8a go high (ie, at a count of 19999), the output of IC7c also goes high.

The output of IC7c is AC-coupled to pin 6 of NAND gate IC8b via a 0.1μF capacitor. A positive pulse thus appears on pin 6 of IC8b whenever the output of IC7c goes high. However, this has no effect on the output of IC8b since pin 6 is already pulled high by a 100kΩ pull-up resistor. IC8b and c are connected together to form a reset-set (RS) flipflop, the output of which (pin 4 of IC8b) is normally low.

Pin 6 of IC7d is therefore normally low and so IC7d simply gates through the backplane pulses applied to pin 5. In this situation, the signal applied to the arrow annunciator is identical to the backplane signal and so the annunciator remains off.

Let's see how the over-range indicator is activated. When the count reaches 20,000, the carry out pin of IC6 goes low. This causes the output of IC7c to also go low, resulting in a brief negative



Here is the actual size artwork for the PCB. Separate the two sections before starting construction.

going pulse to pin 6 of IC8b. Pin 6, in fact, forms the set input of the RS flipflop.

The reset input of the flipflop (pin 13 of IC8c) is normally tied high via a 1MΩ resistor to the positive rail. When the negative pulse is applied to the set input, the combination of inputs causes the flipflop to toggle. Pin 6 of IC7d will therefore go high and so IC7d will invert the backplane signal applied to its pin 5 input.

The signal applied to the arrow annunciator is now 180° out of phase with the backplane signal and hence the arrow annunciator will turn on to indicate the over-range condition.

Note that, when the display over-ranges, the ½-digit (ie, the "1") remains on with the arrow annunciator. The four least significant digits reset from 9999 to 0000 and continue counting.

Switch S2 provides the reset function. When S2 is pressed, the reset inputs of the flipflop and IC6, together with pin 8 of IC7a, are taken low by connecting them to the 0V rail. IC7a inverts this low level reset signal to produce the high level reset signal required by IC4 and IC5.

A reset pulse is also generated automatically on switch on to ensure that all counters begin counting from zero. This is generated by connecting a .068µF capacitor in parallel with S2. Initially, the capacitor is discharged so that, when power is first applied, it appears as a short circuit. The capacitor then charges via the 1MΩ resistor to remove the reset pulse after a 50ms delay.

NAND gate IC8d forms part of the decimal point circuitry. Its job is to produce an inverted version of the backplane signal which is then used to drive the decimal point annunciators in the LCD. Switch S1b switches the output of IC8d to the required decimal point position (either DP2, DP3 or DP4).

Finally, power for the kilowatt-hour meter circuitry is derived from the +12V rail used to power the wattmeter circuit. This is regulated to +5.1V using a zener diode, with decoupling provided by a 680Ω resistor and a 4.7µF capacitor.

Construction

Construction of the additional circuitry is straightforward with most of the parts mounted on two small printed circuit boards (PCBs). These are coded 83kwh12 and 83kwh12a, and measure 86 x 93mm and 86 x 60mm respectively.

The larger of the two boards (83kwh12) holds all the ICs and various minor parts, while the smaller board accommodates the LCD. As shown in the photograph, the two boards are soldered together at right angles, an arrangement which keeps internal wiring to a minimum.

Begin construction by mounting the components on the larger board. The best procedure is to install the 10 wire links first, followed by the resistors, capacitors, diodes and ICs in that order.

Note that all ICs used in this project are CMOS and are easily damaged by static electricty. The ICs should be left in their protective foam packaging until ready for installation on the PCB and then the power supply pins should be soldered first to enable the internal static protection circuitry. The 74C946 IC is mounted using a 40-pin DIL socket.

Next, assemble the display PCB according to the parts overlay diagram, commencing with the 17 wire links. The LCD is mounted using two 20-pin Molex IC socket strips. Solder each socket strip to the PCB, then snap off the carrier strips so that each pin connector is separated from its neighbour. The two PCBs may now be butted together at right angles and the edge connectors soldered.

Now go back over your work and check that all ICs and the LCD are correctly oriented. The LCD used in the prototype is a 4½-digit type sold by Dick Smith Electronics (catalog No. Z-4175). Pins 1 and 40 of the LCD are identified by two small white dots at the edges of the display area (see parts overlay). Our sample LCD also had a green dot on one side of the glass envelope.

The new PCB assembly, together with the wattmeter PCB, is housed in a K&W instrument case measuring 255 x 157 x 77mm. Spray the Scotchcal label with a hard-setting clear lacquer (eg, Estapol), then carefully affix it to the front panel of the case. The Scotchcal panel can now be used as a drilling template for the front panel holes.

PARTS LIST

1 printed circuit board, code 83kwh12, 86 x 93mm
1 printed circuit board, code 83kwh12a, 86 x 60mm
1 momentary contact pushbutton switch, 240V AC rated (C&K model 8121, 8168 or equivalent)
1 2-pole 3-position rotary switch, 240V AC rated (Lorlin type CK1030 or equivalent)
1 4½-digit liquid crystal display (Dick Smith catalogue No. Z-4175 or equivalent)
1 40-pin Molex IC socket strip
1 40-pin DIL socket
4 8mm insulated printed circuit board standoffs
1 Scotchcal front panel, 254 x 77mm
1 K&W instrument case, 255 x 157 x77mm

SEMICONDUCTORS
1 4518 dual BCD counter
1 4020 14-bit binary counter
1 4070 quad exclusive OR gate
1 4011 quad NAND gate
1 74C946 or ICM7224 4½-digit counter/display driver
1 5.1V 400mW zener diode
2 1N4148 diodes

CAPACITORS
1 4.7μF 10VW PC mount electrolytic
1 0.1μF greencap
1 0.068μF greencap
1 0.001μF greencap
1 10pF ceramic

RESISTORS
2 x 1MΩ, 1 x 100kΩ, 1 x 82kΩ, 1 x 56kΩ 1 x 680Ω

MISCELLANEOUS
Machine screws and nuts, 240VAC hookup wire, solder etc.

PLUS: All the parts listed for the wattmeter in the September issue, except for the case and the Scotchcal front panel.

The larger cutouts for the meter and LCD are made by drilling a series of small holes around the inner perimeter of the cutout, and then filing the cutout to a smooth finish.

Although our prototype used a bezel surround for the LCD, readers are advised that these are in short supply. At least two kitset suppliers are looking into this situation, but our advice is "don't hold your breath". Fig. 1 shows the locations of the bezel mounting holes for those readers who do manage to obtain a bezel.

The PCB assemblies can now be positioned in the case according to the wiring diagram and the necessary mounting holes drilled. You will also have to drill holes for the mains cord clamps and earth solder lugs, the two cord entry grommets, and the 4-way insulated terminal block. Those readers who previously built the wattmeter project can transfer the PCB mounting hardware, mains cords and clamps, and the insulated terminal block straight into this project.

All wiring within the Energy Monitor should be run using 240V AC rated cable. If 240V AC cable is not available, then a cable with a lower rated insulation can be used and the insulation bought up to par by fitting insulating sleeving over the entire length of the cable. This includes the wiring to the switches, LED and the PCBs.

As a further precaution, a rectangular window of stiff, clear plastic should be fitted to the front panel cutout for the LCD (the plastic used for shirt box lids is ideal). This should be glued to the inside of the front panel using epoxy adhesive and will prevent the LCD pins (which could be at 240V AC) from shorting to the case. As a bonus, the plastic window will also protect the LCD from scratches.

Construction can now be completed by securing the two PCB assemblies. The wattmeter PCB is mounted using four 12mm insulated standoffs, while the kilowatt-hour meter PCB assembly is mounted using 8mm insulated standoffs.

Calibration

The kilowatt-hour meter is calibrated using a high power resistive load such as a 1000W bar radiator. Since the average 1000W radiator will not draw exactly 1000W, the power consumption of the radiator must be calculated before calibrating the kilowatt-hour meter.

This may be done in two ways. The first method involves measuring the voltage across the radiator and the current it is drawing from the mains while at operating temperature, then multiplying the two figures together to get the power consumption (P= I.V.).

For example, if the voltage is 238V AC and the current is 4.3A, the power consumption will be 1023W.

The second method involves measuring the voltage across the radiator then unplugging the radiator and quickly measuring the resistance of the hot radiator element. The power consumption of the radiator is then calculated by squaring the voltage reading and dividing this by the resistance reading ($P = V^2/R$).

Of the two methods, we prefer the latter since it is easier to measure resistance than current consumption. But whichever method you use, it is essential that all measurements be carried out with the radiator element at normal operating temperature. This is because the resistance of the element increases by about 5% as the element goes from room temperature to operating temperature. In particular, the resistance reading should be taken quickly once the radiator has been unplugged so that the element does not have time to cool.

Once the radiator power consumption has been calculated, it should be used to check the accuracy of the wattmeter circuit which may have lost calibration during the transfer to the new case. If the wattmeter has lost calibration, it should be recalibrated using the procedure outlined in the September issue.

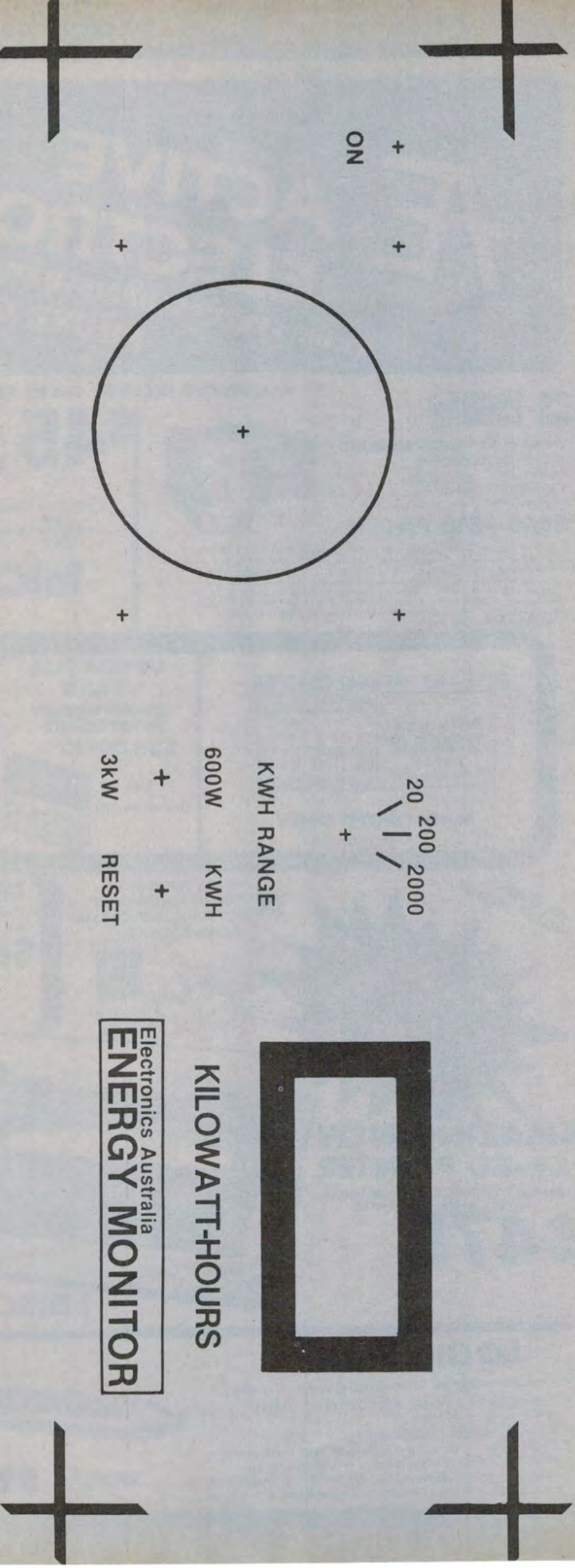
The kilowatt-hour meter is now calibrated by adjusting VR5 on the wattmeter PCB. As before, this adjustment must be made using a screwdriver with a fully insulated blade. Adjust VR5 so that the LCD reads 1/10th the calculated radiator power consumption after a period of six minutes.

An example

By way of example, if the calculated radiator power consumption is 1023W, then the display should read .102 after six minutes. Once this initial adjustment has been made, more accurate adjustments can be made over longer periods of time (eg, for the above example, the display should read 1.023 after 60 minutes. Don't forget to press the "reset" button at the start of each measurement period.

If, due to circuit tolerances, VR5 does not have enough range to allow calibration of the kilowatt-hour meter, it should be replaced with a 1kΩ trimpot.

When using the kilowatt-hour meter, it is important not to alter the setting of the range switch (S1) during the measurement period. If you do, the different counting rate will invalidate the reading. However the wattmeter range may be altered since this does not affect the output frequency of the CCO.



Actual size reproduction of the front panel artwork.