The Energy Auditor

A digital electronic device to keep tabs on the amount of electricity any appliance uses

By Bill Owen

The Energy Auditor to be described here will shed light on the amount of electrical energy an applicance uses so that you can take appropriate action to cut back on its use or budget properly for anticipated utility bills.

The device is a digital electronic meter that, when connected to an air conditioner, furnace or other electrical load will display the accumulated cost of electricity in dollars and cents. Continuous monitoring of electrical consumption makes it possible to set up realistic budgets in just a few days, rather than making you wait the usual 30 days in a billing cycle. It will also enable you to quickly verify the claimed energy savings with a new appliance, allowing enough time for you to return it if it does not meet "specs."

General Comments

The Energy Auditor totalizes and displays pulses generated at a rate that is proportional to the cost in dollars in electrical power consumed while the appliance being monitored is operating. Pulses are generated within the project by a precise voltage-controlled oscillator (vco). Current to the load is sensed and enables the vco's output. (In the case of direct thermostat connection, closure of the heating or cooling contactor is sensed.)

Cost per hour to operate the load can be measured, calculated or estimated. In any case, the value used must be averaged for a given period of time. Fortunately, the unit cost per

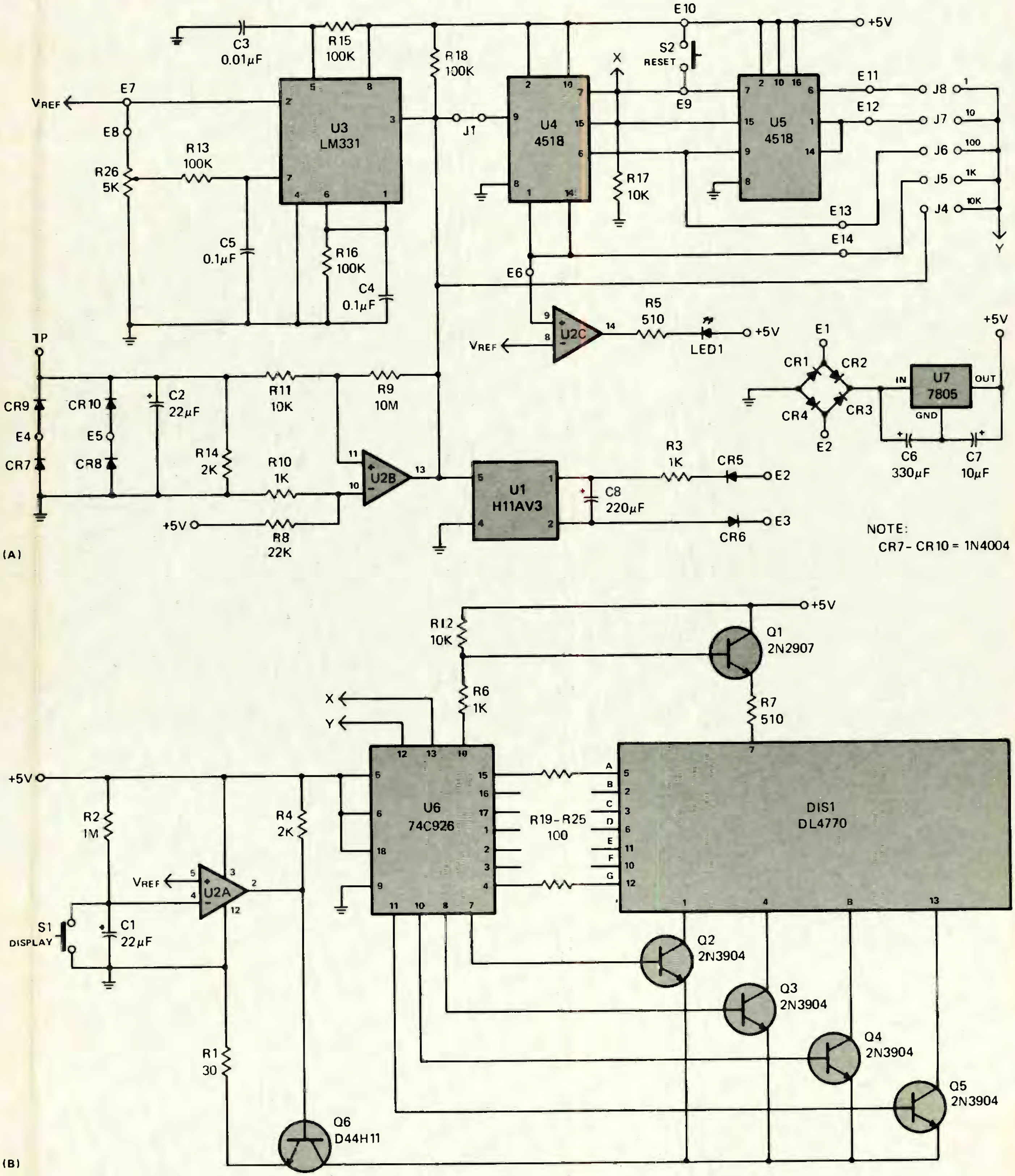

Fig. 1. Note in this overall schematic diagram of the Energy Auditor that its circuit uses a combination of analog and digital ICs to provide a direct readout in dollars of energy consumed by an electrical appliance.

PARTS LIST

Semiconductors
CR1 thru CR10—1N4004 or equivalent rectifier diode
DIS1—DL4770 4-digit common-cathode LED numeric display
LED1—Red light-emitting diode
Q1—2N2907 pnp transistor
Q2 thru Q5—2N3904 npn transistor
Q6—D44H11 npn transistor
U1—H11AV3—Optocoupler
U2—LM339 comparator
U3—LM331 voltage-controlled oscillator
U4,U5—4518 dual up-converter
U6—74C926 counter/display driver
U7—7805 5-volt regulator

Capacitors
C1,C2—22-μF, 35-volt electrolytic
C3—0.01-μF polystyrene
C4,C5—0.1-μF monolithic
C6—330-μF, 35-volt electrolytic
C7—10-μF, 35-volt electrolytic
C8—220-μF, 25-volt electrolytic

Resistors (¼-watt, 1% tolerance)
R1—30 ohms (2 watts)
R2—1 megohm
R3,R6,R10—1000 ohms
R4,R14—2000 ohms
R5,R7—510 ohms (5%)
R8—22,000 ohms
R9—10 megohms (5%)
R11,R12,R15,R17—10,000 ohms
R13,R16,R18—10,000
R19 thru R25—100 ohms (5%)
R26—5000-ohm, 22-turn Trimpot

Miscellaneous
S1,S2—Normally open momentary-action pushbutton switch
Printed-circuit board; suitable cabinet; current-sensing transformer (see text); conductive foam switch (see text); ac adapter; zip cord; hookup wire; solder; etc.

Note: The following are available from NRG Electronics, P.O. Box 24138, Ft. Lauderdale, FL 33307: complete kit of parts (not including ac adapter) for $39.95 plus $1.75 P&H; optional AC-2 adapter for $6.95; individual parts (send query). Florida residents, please add sales tax.

hour is fairly consistent for most household loads. You can calculate the cost per hour for a given appliance by multiplying the wattage of the load by the current cost per kilowatt hour (kWhr). The electric rate is the total amount for electricity on your utility bill, divided by 1000 to give you the kWhr rate. Most utility companies also indicate separately on your bill the cost per kWhr for the billing period.

Using the formula Cost per hour = Load in watts × (Cost per kWhr/1000), I calculated the hourly cost of a 42-gallon hot-water heater that uses a 4500-watt heating element as follows, using a 10-cent per kWhr electric rate. The cost per hour = 4500 × ($0.10/1000) = $0.45 (or 45 cents) per hour. This is how much it would cost every hour the heater is on.

However, hot-water heater elements switch off and on according to the temperature of the water inside the tank. The Energy Auditor totals the running time and displays total cost for actual usage. Using a meter, I discovered that the water heater actually consumes 3850 watts (16.25 amperes × 236 volts). Plugging these measured values into the equation, the cost became 39 cents per hour.

If you do not have an ac voltmeter and ammeter to make actual readings, the calculated value will be adequaate and, more importantly, will give you an accurate indication of your savings. For example, if the heater element thermostat is turned down, running time will decrease and the Energy Auditor will indicate the change.

A central air-conditioning system pulls 17.5 amperes at 236 volts, which translates to 4130 watts. Full-load compressor power is listed on the name plate as 18 amperes. Either the calculated or the actual measured value can be used in this example. When plugged into the above equation, cost becomes 42 cents per kWhr.

In the case of the hot-water heater, the Energy Auditor must be calibrated for 39 pulses per hour, the air conditioner for 42 pulses per hour. In either case, power consumption of the load can be measured or determined from the electrical data plate found on the appliance.

About the Circuit

In the schematic diagram shown in Fig. 1, precision voltage-controlled oscillator (vco) *U3* generates a series of pulses, the exact frequency of which is adjusted by trimmer control

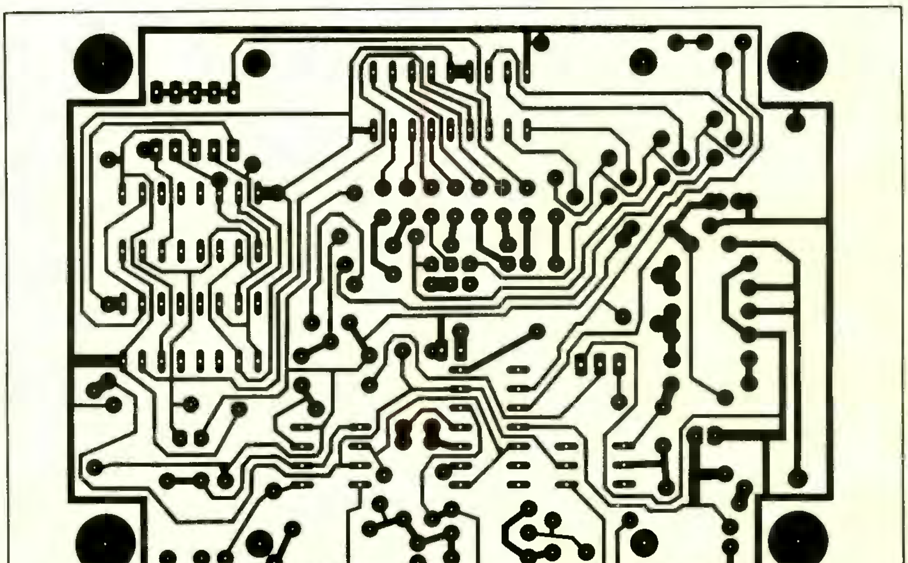

Fig. 2. Actual-size etching-and-drilling guide for the project.

R28. Dual decade counters *U4* and *U5* divide the output of the vco by 10, 100, 1000 and 10,000, respectively. The four divided outputs and the direct vco output are available for counting by 4-digit counter/LED digit driver *U6*. The appropriate count input is selected by jumpers J4 through J8. By selecting a jumper and adjusting *R28*, counts per hour from 10 to more than 1-million are obtainable, even though maximum display is limited to 9999. (Note that J4 through J8 can be either jumpers or via separate positions in a DIP switch.)

Counter/driver *U6* multiplex drives common-cathode display *DIS1* through segment limiter resistors *R19* through *R25* and digit drivers *Q2* through *Q5*. Transistor *Q1* drives the decimal point, while *Q6* enables the entire display by providing a path to ground when pin 2 of *U2* is high.

Pressing *S1* discharges *C1* to ground, unclamping pin 2 of *U2*. The display is on for 3 to 4 seconds, until *C1* recharges to a level greater than the 1.8-volt Vref. The Energy Auditor is not required to maintain a continuous display—only when you want to take a consumption reading.

A second comparator in *U2* drives activity indicator *LED1*. Jumper wire J2 connects the comparator's pin 9 input to one of the pulse outputs identified as E11 through E14. This causes *LED1* to flash when the load under test is on. Switch *S2* provides a reset function; pressing it forces *DIS1* to display all 0s.

Operation from a wall thermostat allows the Energy Auditor to be powered by the latter's 24-volt ac control voltage. The screw terminal connections on the thermostat mounting plate are color-coded red (R) for return, white (W) for heat, yellow (Y) for cool and green (G) for fan. In Fig. 1, E2 connects to R and for air conditioning E1 goes to W and E3 goes to Y. For heat, the connections from E1 and E3 are reversed.

When the cool or heat contactor is open, there is 24 volts ac across E2 and E3, which turns on the LED inside *U1*. In turn, this activates *U1*'s internal phototranistor and pulls pin 3 of *U1* low, stopping *U3* from outputting pulses. Energizing the contactor by starting the compressor or heating coil releases pin 3 of *U1* to enable output pulses from *U3* counting.

Other loads are sensed by passing one leg of the power wiring through a current-sensing transformer. This transformer is a powdered-iron toroid on which are wound 30 or so turns of insulated magnet wire. This transformer connects into the circuit at points E4 and E5 in Fig. 1. The distance between the Energy Auditor and sensing transformer is not critical; so the cable connecting the two can be as long as needed.

Current flowing to the load produces an ac voltage in the sensing transformer. This voltage is rectified by the full-wave bridge consisting of *CR7* through *CR10* and is then filtered by *C7*. The resulting dc voltage forces pin 11 of *U2* to a potential greater than that at pin 10, switching comparator output pin 13 high and enabling the output pulses at pin 3 of *U3*. Power from a 12-volt ac, 200-mA plug-in wall transformer, enters the Energy Auditor at points E1 and E2. This voltage is rectified by *CR1* through *CR4* and filtered by *C6*. The dc output from this portion of the circuit is regulated at + 5 volts by *U7* and is subsequently distributed to the rest of the circuitry in the project.

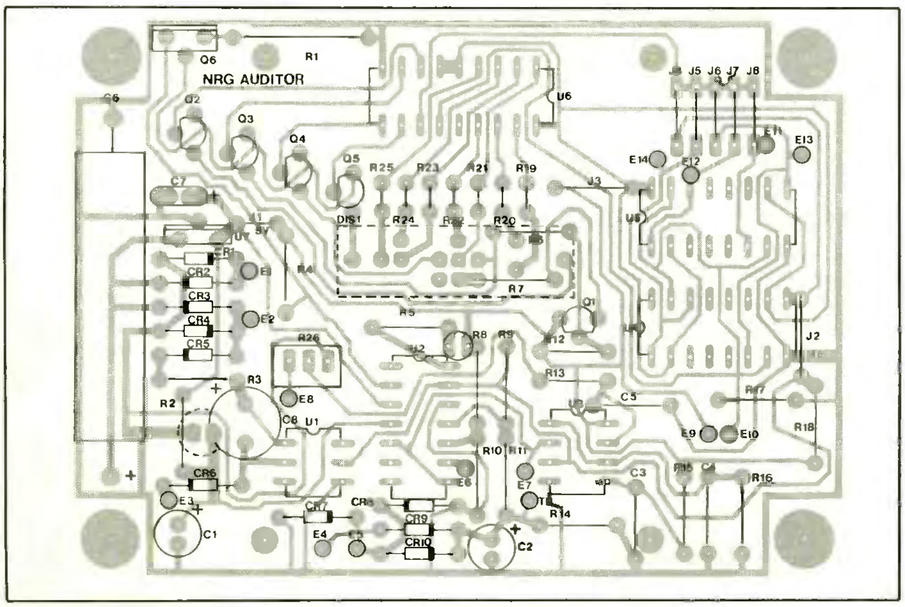

Fig. 3. The component location and orientation guide for the pc board.

Construction

To make the Energy Auditor as compact as possible and to facilitate easy assembly, printed-circuit wiring is recommended. You can fabricate your own pc board, using the actual-size etching-and-drilling guide shown in Fig. 2, or purchase one ready for component installation from the source given in the Parts List.

Wire the board exactly as shown in Fig. 3, referring back to Fig. 1 and the above text for details on interconnections between the board and off-board components. It is a good idea to use sockets for all ICs except *IC7*. Also, if you prefer, you can replace jumpers J4 through J8 with a 5-position DIP switch.

Make sure when you install the diodes and electrolytic capacitors that they are properly polarized and that the ICs and transistors are properly oriented. Note also that *DIS1* and pushbutton switch *S1* mount on the

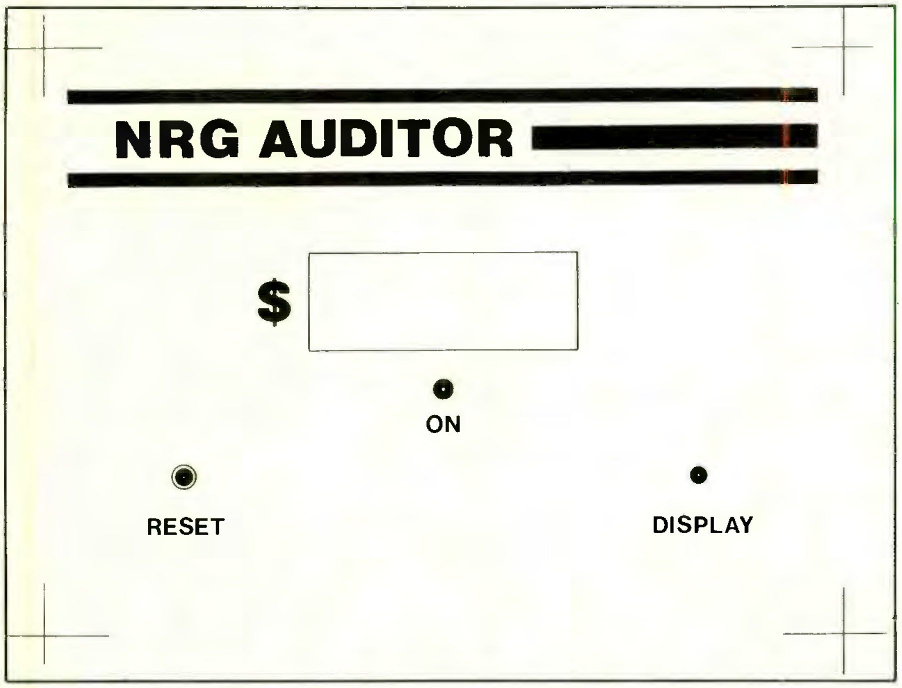

Fig. 4. A suggested panel layout for the Energy Auditor's case.

foil or solder side of the board. To accomplish this, you must mount the display panel and switch high enough above the board's surface to provide access for soldering.

Fabricate RESET switch *S2* by making a sandwich with a 0.5″ square of copper-clad pc material on the bottom (copper side facing up), double-stick foam tape in the middle and conductive antistatic foam material on top. Solder one end of a 1″ solid wire to the copper on the pc material. Cut a 0.25″ hole in the center of the double-stick foam tape and place it on the copper side of the pc material.

Form a hook in one end of a 1¼″ solid wire, hook the wire through one corner of the conductive foam, and crimp the hook. Then place the conductive foam on the exposed surface of the double-stick foam tape with the corner with the attached wire adjacent to the corner with the wire soldered to the pc material and press firmly into place. Place another layer or two of double-stick foam tape on the blank side of the pc material.

Push the wire leads into holes E9 and E10 on the pc board assembly from the *foil* side. Bend the leads to allow the *S2* assembly to lie flat on the pc board, held in place by the double-stick tape. Solder the wire leads to the pc board pads.

Actuation of *S2* occurs when the conductive foam shorts against the pc board or when a sharp metal object or paper clip pierces the foam and touches the board. Resetting the Energy Auditor is done infrequently; so fabricating *S2* in this manner is a good way to go. Besides, this approach eliminates the possibility of an accidental reset that can wipe out data. Of course, you can substitute a normally-open pushbutton switch, but make sure that you locate it where it cannot be accidentally actuated.

As mentioned above, you will have to wind your own sensing transformer if you plan to use the Energy Auditor for applications other than to sense the closure of thermostat contacts. You do this by winding 30 or so turns of No. 30 magnet wire on a 0.5″ ferrite toroid form. When you finish winding the turns, carefully scrape away ¼″ of enamel down to bare wire at both ends of the winding and connect and solder to them as long zip cord as you need. Cover the connections with electrical tape. Then connect and solder the other end of the zip cord to points E4 and E5 on the pc board assembly.

You can mount the Energy Auditor inside any enclosure that will accommodate it, although a plastic box will make the task of cutting the slot for the display easier to perform. The prototype of this product was housed inside a 4⅞″ × 3¼″ × 1½″ plastic box. If you use such a box, you can use the layout shown in Fig. 4 as a guide to dressing up the "front panel." Finally, cut a slot in the box to provide a means for the power and sensing transformer's cables to exit.

Checkout and Use

After thoroughly inspecting your wiring and soldering, you can test the circuit as follows. First temporarily connect the red (positive) and black (negative) leads of a 9-volt battery connector to points E1 and E2 (polarity is not important, since the *CR1* through *CR4* bridge circuit will apply the proper polarity to the rest of the circuit). Snap on a 9-volt battery. Then use a clip lead to connect *TP* to + 5 volts at J1 to start counting.

Adjust 22-turn trimmer potentiometer *R28* and install J5 to observe the pulses being totaled when DISPLAY switch *S1* is pressed. Check out the reset action and make any adjustments needed to switch *S2*.

Assume you are planning to use the Energy Auditor with a 42-gallon hot-water heater. You must adjust *R28* for 39 pulses per hour for a 39-cents-per-hour operating cost base.

It would be inconvenient to have to wait an hour just to find out that at its lowest setting *R28* causes the vco to output more than 30,000 pulses per hour. To obivate this, we use *U4* and *U5* to divide the vco's output by, say, 1000 by installing J5. You can then set the vco for a more convenient 39,000.

Consider that 39,000 pulses per hour works out to 650 pulses per minute, and watching a 60-second

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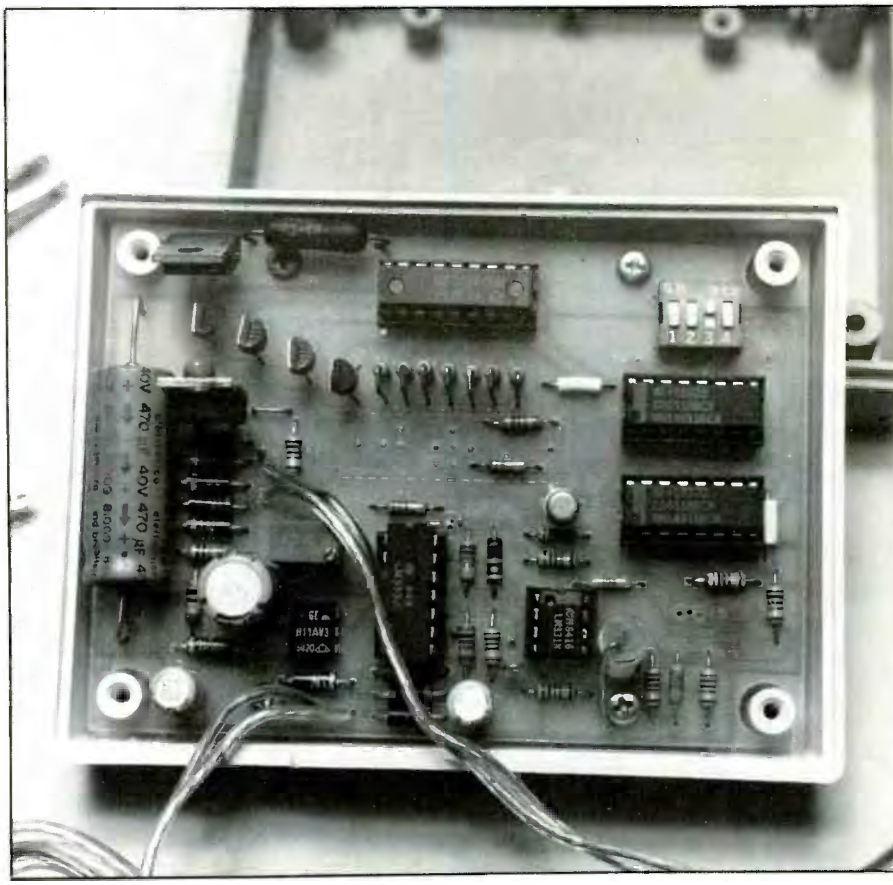
countdown is a lot more convenient than having to wait a whole hour. So you remove J5 (open position 5 if you are using the DIP switch) and solder down J4 (or close position 4) to allow the counter to count the direct vco output before it is divided down. Now adjust *R28* for a consistent 650-count-per-minute display. For more accuracy, wait 5 minutes to get a 3250-count display and then 15 minutes to obtain a 9750-count display. When calibration is as close as possible to ideal, remove J4 (open position 4 of the DIP switch) and install J5 (close position 5). The Energy Auditor is now ready for installation.

Before finalizing installation, however, check that the Energy Auditor operates reliably with the 12-volt ac wall transformer. If there is an ac outlet near the hot-water heater, mount the project directly on the heater with a couple of strips of foam mounting tape.



Interior view of completed project.

Kill power to the circuit breaker and remove the access panel to your heater's wiring. Remove the wire nut from one of the wires and separate the wires at the twisted-together joint. Slip the sensing transformer over the loose wire, reconnect the heater's wires and reinstall the wire nut. Position the sensing transformer out of the way. Restore power to the heater's breaker circuit and plug in the project.

Run the hot water until ON indicator *LED1* comes on to tell you that the heating element is energized. The LED should flash when the project senses that the load is energized, the flash rate of the LED depending on the setting of *R28*. This can be changed by moving jumper J2 from E14 to E13, E12 or E11 to achieve lower flash rates.

For alternative installation near the wall thermostat, you must first calibrate *R28* for 42,000 counts per hour (700 counts per minute) and install J5 (or close position 2 of the DIP switch). Remove the thermostat's cover and use a screwdriver to expose the base plate. Then make the three-wire connections to the R, W and Y terminals. You can then fasten the project to the wall with a couple of strips of foam mounting tape. Reassemble the thermostat and route the wires so that they will not show. This operating mode can be had with a minimum of wiring, while the previously described one offers the most flexibility for a variety of applications.

In Conclusion

From the foregoing, you can no doubt see other uses for one or more Energy Auditors. Someday, all appliances may come with direct-read cost-to-operate displays like the Energy Auditor's. Until then, this project will give you a headstart on saving money. **ME**