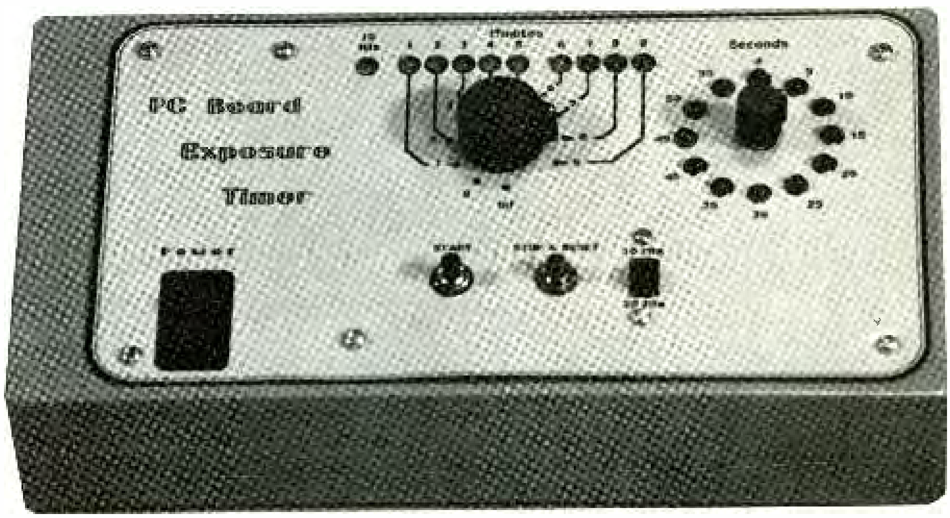
Programmable Appliance Timer

This handy device applies ac line power to any electrical appliance for a preprogrammed period of time up to 20 minutes in 5-second intervals

By Ladislav Hala & Peter Hala



A Programmable Appliance Timer like the one to be described can find application in a wide variety of work environments. Designed to apply ac-line power to an electrical device or appliance for a predetermined period, it offers a range of from 5 seconds to 20 minutes in 5-second intervals. Though the Timer was originally intended for use with exposure lights for photographic printed-circuit processing, we found it to be just as useful in a photography lab, science lab and even in the home kitchen.

Our Appliance Timer is easy to build and operate. It uses printed-circuit construction and only easy-to-get and inexpensive components. Just six switches, each of whose functions is obvious, control all timer operation from turning on power to setting the time interval to starting and stopping a countdown. The Timer can be made to handle loads up to several hundred watts, depending on the power rating of the ac line-switching device used.

About the Circuit

The schematic diagram of the Timer circuit, minus its ac-operated power supply, is shown in Fig. 1. The "heartbeat" of this circuit is 14-stage divide-by-two counter/oscillator *IC1* and frequency-determining components *C1*, *C2*, *R1*, *R2* and crystal *XTAL*. A crystal is used in this circuit for more stable operation than is usually possible with RC elements. Because the crystal is so precise, there is no need for an expensive frequency-counter/ display system.

Two functions are performed by *IC1*. One is generation of a series of pulses whose frequency is that of the crystal; the other is division of the basic oscillator frequency to provide a low-frequency output. Since the crystal specified in the Parts List oscillates at a frequency of 32,768 Hz and the 14-stage binary counter divides by 2^{14} times (or 16,384), the output from *IC1* at pin 3 is 2 Hz. Because crystals are rarely cut to an exact guaranteed frequency, trimmer capacitor *TC1* may be needed in the frequency-determining network to allow you to adjust the oscillator's frequency to exactly 32,768 Hz with the aid of a frequency counter. For less-demanding split-second timing, *C1* and *C2* can be without optional trimmer *TC1*.

Counter *IC2*, clocked at CLK input pin 14 from the output of *IC1*, delivers a pulse every 5 seconds at pin 12. (See Fig. 2 for pinouts of some 4000-series ICs used in this project.) The disadvantage of using a 4017 counter chip is that it divides by only 10 but division by 12 is required in this project. The solution is to use two 4017s, connecting them into the circuit as shown for *IC3* and *IC4* in Fig. 1. Power dissipation is equally shared by the two counters by having each drive only six of the 0 through 55 second light-emitting diodes (*LED1* through *LED12*).

The purpose of the counter is simple. Resetting both *IC3* and *IC4* so that the Q0 outputs at pin 3 are at logic high, the next clock pulse arriving at the counter arrangement changes the states of Q0 and Q1 (the latter at

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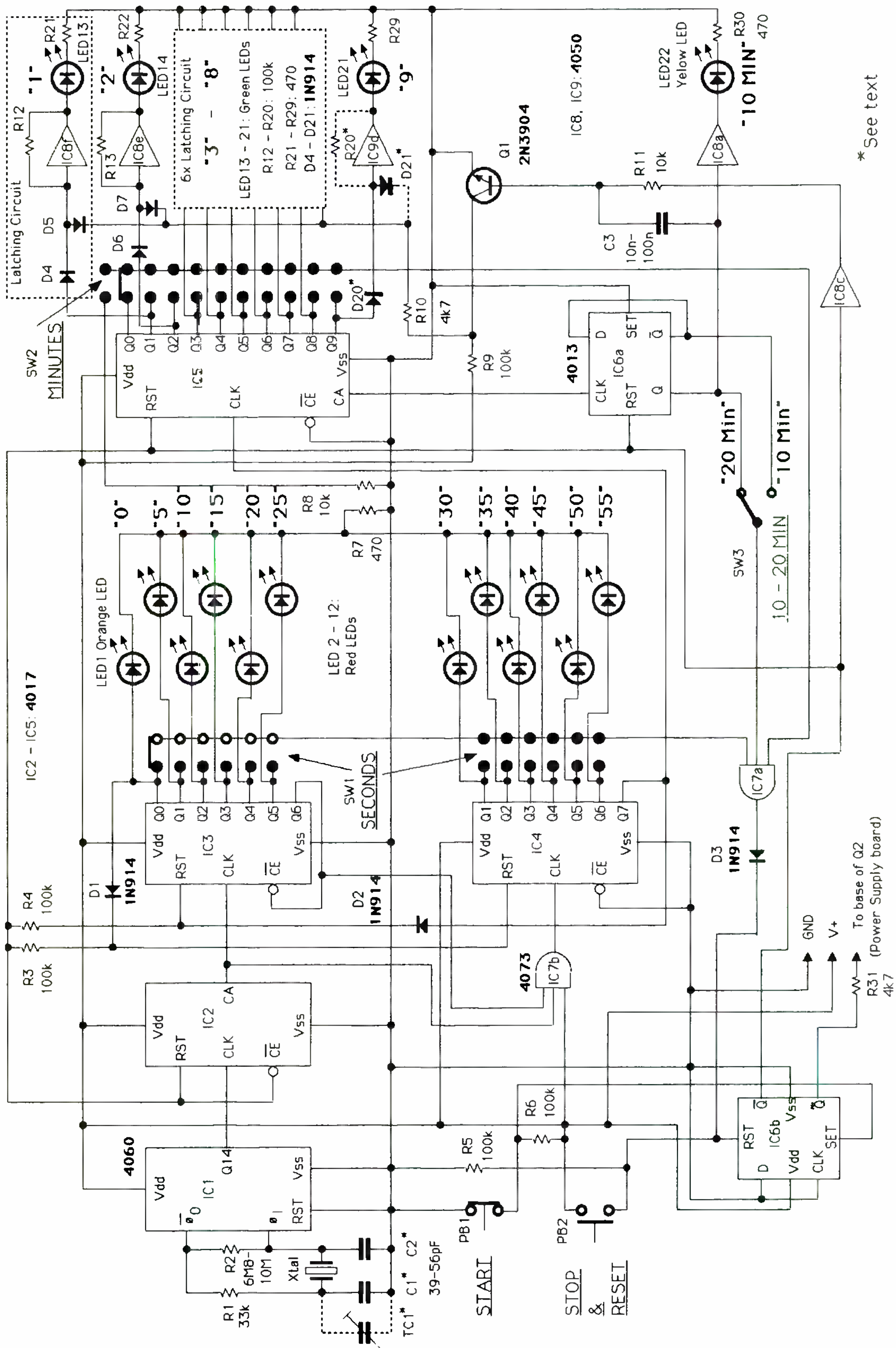

Fig. 9 - Schematic diagram of the timer

Fig. 1. Schematic diagram of basic counting circuits.

PARTS LIST

Semiconductors
D1 thru D21—1N914 or similar diode
D22 thru D26—1N4002 or similar rectifier diode
IC1—CD4060 14-stage divide-by-12 counter/oscillator
IC2 thru IC5—CD4017 Johnson counter
IC6—CD4013 dual D flip-flop
IC7—CD4073 3-input AND gate
IC8,IC9—CD4050 hex buffer
IC10—78M05 or 7805 fixed +5-volt regulator
IC11—MOC3011, MOC3021 or similar diac optical coupler
LED1—Orange light-emitting diode
LED2 thru LED12—Red light-emitting diode
LED13 thru LED21—Green light-emitting diode
LED22—Yellow light-emitting diode
LED23—Light-emitting diode (optional—see text)
Q1,Q2—2N3904 or similar npn silicon transistor
TR1—IT48 or similar 8- or 10-ampere, 2- or 4-mode triac

Capacitors
C1,C2—39- to 56-pF ceramic disc
C3—0.01- to 0.1-μF ceramic disc
C4—1,000-μF, 15-volt electrolytic
C5—1,000-μF, 16-volt electrolytic
C6—0.01- to 0.1-μF 400-volt ceramic disc, Mylar or polypropylene
C7—0.01-μF, 400-volt ceramic disc
TC1—56-pF or higher trimmer capacitor (optional—see text)

Resistors (¼-watt, 5% tolerance)
R1—33,000 ohms
R2—6.8 to 10 megohms
R3 thru R6,R9,R12 thru R20—100,000 ohms
R7,R21 thru R30—470 ohms
R8,R11—10,000 ohms
R10,R31—4,700 ohms
R32—1,000 ohms (see text)
R33—33 ohms
R34—1,000 ohms
R35—330 ohms (see text)
R36—470 ohms (see text)
R37—39 ohms (see text)
R38—See text

Miscellaneous
PB1—Normally-closed, momentary-action spst pushbutton switch with black button (Radio Shack Cat. No. 275-1548 or similar)
PB2—Normally-open, momentary-action spst pushbutton switch with red button (Radio Shack Cat. No. 275-1547 or similar)
SW1—12-position single-pole nonshorting rotary switch (Radio Shack Cat. No. 275-1385 or equivalent)
SW2—11-position single-pole nonshorting rotary switch (Armaco No. SE 5110 (S5151) or Radio Shack Cat. No. 275-1385 12-position switch)
SW3—3pdt or dpdt slide or toggle switch
SW4—Spst or spdt rocker or toggle switch
T1—12.6-volt, 300-mA power transformer (Radio Shack Cat. No. 273-1385 or similar—see text)
Printed-circuit boards or perforated board with holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware (see text); sockets for all DIP ICs; suitable enclosure (see text); chassis-mount, 3-conductor ac receptacle; three-conductor ac line cord with plug; 12-volt dc relay with suitably rated contacts (Radio Shack Cat. No. 275-247) to use in place of triac drive circuit (optional—see text); lettering kit (optional—see text); rubber grommet; plastic cable clamp or tie; machine hardware; hookup wire; solder; etc.

pin 2) to low and high, respectively. The state at Q0 of *IC4* remains unchanged because Q6 of *IC3* (pin 7) is still low, which prevents the clock signal from passing through the *IC7B* AND gate and reaching the pin 14 CLK input of *IC4*.

The "ring" counting of *IC3* continues until the Q6 output at pin 5 goes high. At this point, the clock-enable (CE) input at pin 13 of *IC3* disables the input clock signal so that *IC3* ceases counting until this chip is reset. At the same time, *IC7B* is activated so that is passes the clock signal into *IC4*. Hence, *IC4* begins to count the input pulses.

When Q7 of *IC4* at pin 6 goes high, its positive-going pulse edge causes *IC3* to reset so that Q0 of *IC3* becomes high. In turn, this causes *IC4* to reset because the reset input of this IC (pin 15) is connected to *IC3*'s Q0 output. The cycle now repeats.

There is no need to buffer the outputs of the 4017 chips that drive LEDs in this circuit because the 10 milliamperes drawn by each LED decreases the output potential from 10 volts to 8 volts nominal, which is still perceived by the ICs as a high logic state, with a safe margin of at least 3 volts above the normal logical high potential.

Clocking pulses for MINUTES counter *IC5* are taken from the Q7 output at pin 6 of *IC4*. This pulse is about 25 microseconds in duration and is long enough to clock *IC5* via its CLK input at pin 14. With MINUTES counter *IC5*, all 10 count stages are used to drive 10 separate LEDs to indicate elapsed time in minute (60-second) intervals. Since only one of the Q0 to Q9 outputs is active at any given moment, a latching system that converts a "dot" display into a bar-type display was needed.

At least eight latching circuits are required, each implemented as an IC buffer stage, resistor and two diodes. This arrangement is illustrated by *D4*, *D5*, *IC8F* and *R12* at the top-right in Fig. 1.

The IC buffer begins in the reset state and Q0 through Q9 outputs of *IC5* at logic low. (Notice that no latching circuit is used for the Q0 output from *IC5* because it is not necessary to indicate 0 minute.) The inputs to the buffers are held at logic low by positive feedback from the output to the input of the buffers through resistors *R12* through *R20*.

When the first minute has been counted down, the Q1 output at pin 2 of *IC5* becomes high and, in turn, drives its associated IC buffer high through diode *D4*, and minute 1 light-emitting diode *LED13* lights.

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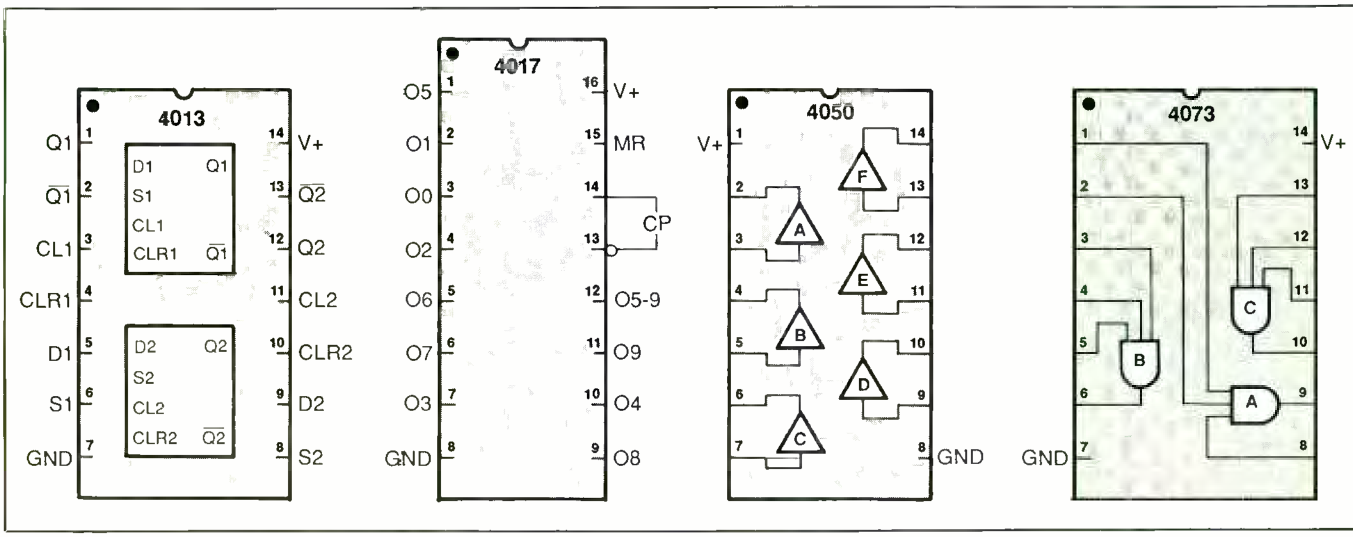

Fig. 2. Pinouts of some 4000-series CMOS ICs used in this project.

When the second minute has been counted down, the Q1 output of *IC5* goes low and the Q2 output at pin 4 goes high, this time lighting minute 2 *LED14*. Latching action keeps the minute 1 LED lit as well. As each minute counts down, the current LED remains on and the next minute LED in numerical order lights.

It is important to avoid loading down the IC buffers by too much because a decrease in the output potential from 10 to 6 volts due to a LED being turned on might not ensure proper latching. The compromise of a 10-milliampere current produces sufficient light without decreasing the output voltage too much.

Reset action of the latching circuitry is accomplished by forward-biasing *D5*, *D7*, *D9*, *D11*, *D13*, *D15*, *D17*, *D19* and *D21*. It is initiated by cutting off transistor *Q1*. Normally, when *Q1* is cut off, these diodes are reverse biased and do not conduct. When *Q1* conducts, it puts the cathodes of these diodes at essentially ground potential, allowing them to conduct and putting the inputs to the buffers at less than 1 volt. This resets all latched buffers. The buffers will remain at logic low due to the latching effect of the feedback resistors.

To provide a 20-minute timing range from the project, divide-by-2 D flip-flop *IC6* is used. This chip's CLK input at pin 11 is driven by the CA (carry) output at pin 12 of *IC5*. The Q output at pin 1 of *IC6* drives buffer stage *IC8A* to light yellow 10-minute *LED22*.

When the Timer is used to control power to an electrically operated device like a printed-circuit-board exposure light (the original purpose in designing the project), three-input AND gate *IC7A* is used. The output of this gate goes high only when all three inputs to it are also high.

Input pins 13 and 11 tie directly to the rotor (common) contact of the SECONDS and MINUTES switches, while input pin 12 goes to 10/20 MIN switch *SW3*. With this arrangement, the switches can be set to a predetermined number of minutes (*SW2* and *SW3* and seconds (*SW1*) and when the all LEDs for the times selected are on, the output of AND gate *IC7A* will go to logic high.

Once the AND gate's pin 10 output goes high, D flip-flop *IC6B* is reset. Acting like an RS flip-flop, this stage's Q output at pin 1 goes low and its Q output at pin 2 goes high. The latter state resets counters *IC2* through *IC6A* and cuts off transistor *Q1* to reset the latching circuitry.

Resetting of *IC2* is important to obtain an exact 5-second initial interval when the Timer is started again by briefly pressing and releasing START pushbutton switch *PB1*. (Any timing sequence can be interrupted and the circuit reset at any time by briefly pressing and releasing STOP/RESET pushbutton switch *PB2*.) The pin 2 Q output of *IC6* remains high until START switch *PB1* is pressed and released. This assures that the clock count is prevented from passing through *IC2*.

Power for the Fig. 1 circuit is provided by the ac-operated circuit shown in Fig. 3. Note also that this circuit contains the elements that are used to switch on and off ac line power to the electrical device being controlled. These elements are shown in the primary side of power transformer *T1* and include all but POWER switch *SW4* and the ac line cord's plug.

Closing *SW4* applies 117-volt ac line power to the primary of *T1*. At *T1*'s secondary appears about 12.6 volts ac, which then converted to pulsating dc by bridge-rectifier *D22* through *D25*and is finally converted to pure dc by filter capacitor *C4*. The + 12-volt or so potential across *C4* is now reduced and regulated down to

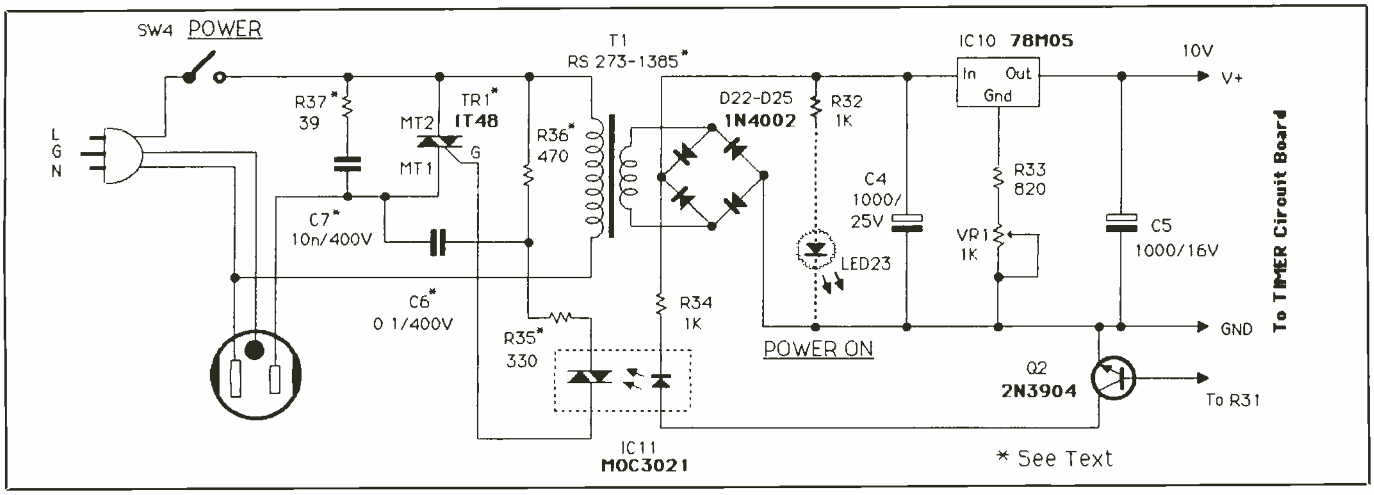

Fig. 3. Schematic diagram of power supply and load controller circuits, the latter built around a triac.

+ 10 volts by voltage regulator *IC10*.

Note that *IC10*'s ground terminal is not connected directly to ground as is usually the case with three-terminal fixed-voltage regulators. Instead, it goes through fixed resistor *R33* and trimmer potentiometer *VR1* that allow the output of the regulator to be adjusted for a fairly precise + 10 volts of regulated dc instead of being a fixed + 5 volts had the ground terminal been connected directly to ground. Once the regulated + 10 volts is obtained, it is further filtered by *C5* before being delivered to the Fig. 1 circuitry.

Notice that POWER *LED23* and current-limiting resistor *R32* are shown phantomed in Fig. 2. This is because these two components are optional. Though you may wish to install them in your project, there is really no need for a POWER indicator since at least one of the other 22 LEDs in the project will be on whenever power is turned on.

Transistor *Q2* controls triac *TR1* through optical coupler *IC11* in response to the conditions of the Fig. 1 circuit. The triac, in turn, controls power to the electrical device plugged into the ac receptacle shown at the lower-left in the schematic.

The value of resistor *R34* can be greater than that indicated in the schematic and specified in the Parts List. Just keep in mind that it must be low enough to ensure proper triggering of *TR1*. (The minimal current for the LED in the MOC3020 optocoupler of 15 milliamperes or less is typically required for adequate diac control of the triac. For the MOC-3021 or MOC3023, the current is even smaller.)

The *R36/C6* and *R37/C7* component pairs are used for "snubbing" off *IC11* and *TR1*. Generally, inductive loads require these components. If a noninductive load is being switched, these components can be omitted. If you are not sure what kinds of loads will be switched by the project, it is best to build these resistors and capacitors into the Timer. However, if you omit these components, you must raise the value of *R35* to about 1,000 ohms.

If you prefer not to use a triac as the ac-voltage switching element for the load, you can use the simpler power-supply circuit shown in Fig. 4. This circuit replaces the components on the primary side of the power transformer and the optical isolator with a simple electromechanical relay. The remainder of the circuit—that on the secondary side of the transformer—is identical in both circuits.

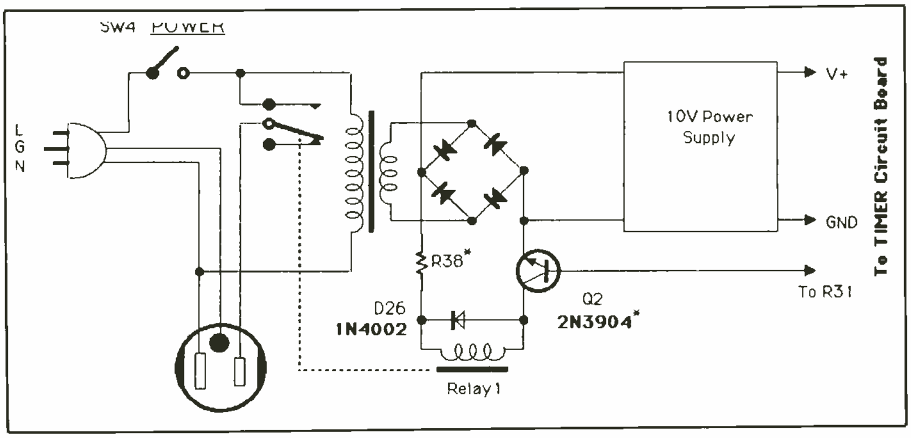

Fig. 4. An alternate controller-circuit arrangement that replaces the triac and its associated components in Fig. 2 with the simpler relay arrangement shown here. The basic power-supply circuitry remains the same.

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If you do decide to go with the Fig. 4 circuit, you must upgrade the power-handling capability of the *Q2* transistor so that is has sufficient current and power ratings to handle the additional load presented by the relay's inductive coil. Also, select a 12-volt dc relay that consumes as little power as possible and whose contacts are hefty enough to handle any reasonable load that might be plugged into the control receptacle. A good choice of relays might be the Radio Shack Cat. No. 275-247.

Since the potential across *C4* is 16 to 18 volts, it is imperative that *R38* be included in the Fig. 4 circuit. You calculate the value of resistance to use for *R38* using the formula: $R = (V+ - V_{relay})/I_{relay}$. In this formula, $V+$ is the supply potential, V_{relay} is the dc voltage rating of the relay's coil and I_{relay} is the dc current rating of the relay's coil. This formula gives only approximate results because it does not take into account the internal resistance of the power supply. For example, if you load the power supply, the voltage across its output decreases as a result of internal resistance. Even so, the figure obtained will be a good starting point from which to work.

You can also use in place of *R38* a zener diode whose zener voltage is equal to the required voltage drop. Using either *R38* or a zener diode, you must calculate the power dissipation of the device and select a device that has no less than three times the rating value of that calculated.

Diode *D26* shown connected across the relay's coil in Fig. 3 is included in the circuit to protect transistor *Q2* from damage due to the collapse of the electromagnetic field and resulting induced high-voltage spike that occurs when power is removed from the relay.

Construction

There is nothing critical about component layout. Therefore, any traditional wiring technique can be used

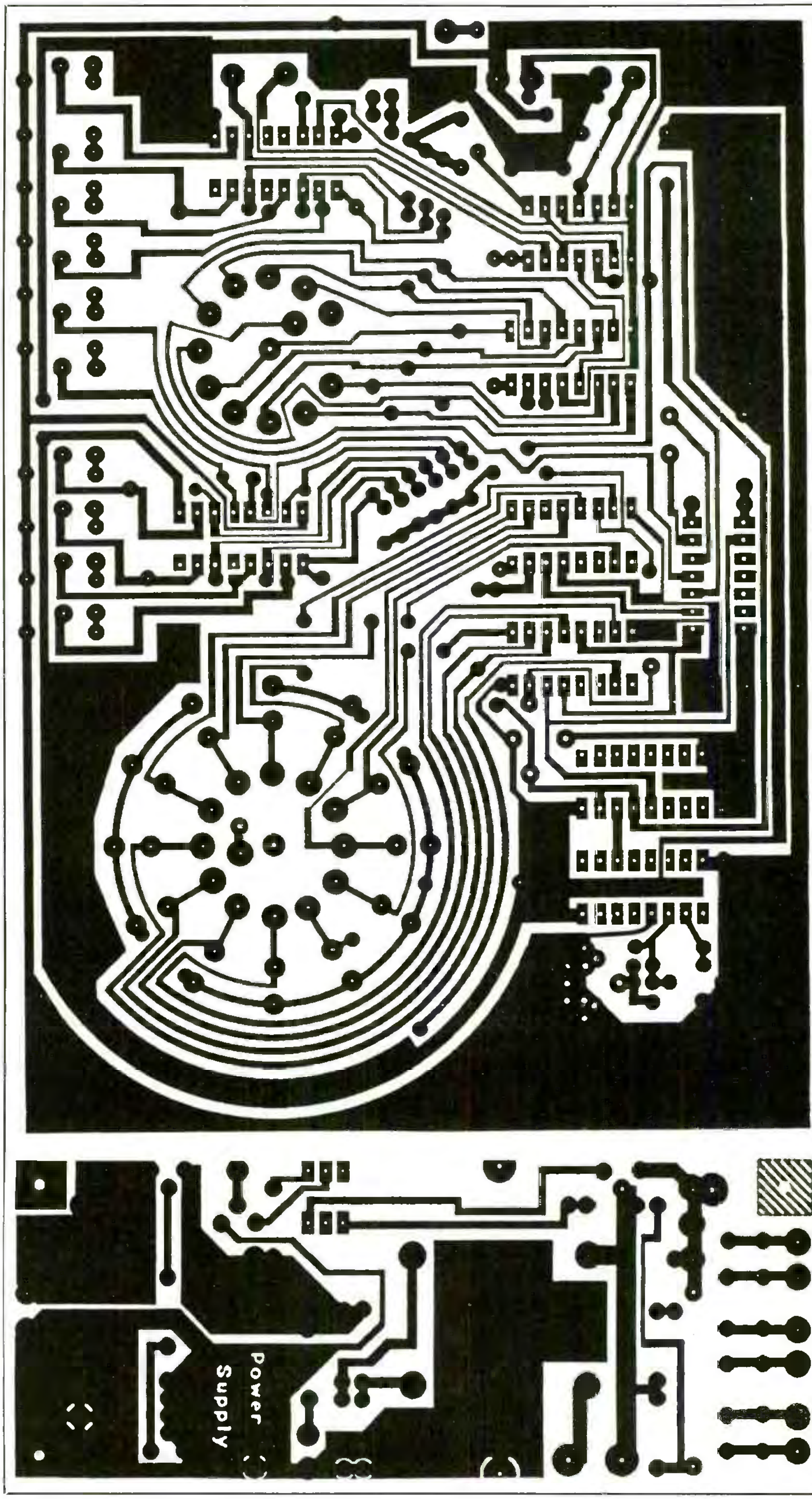

Fig. 5. Actual-size etching and drilling guides for the counter and power-supply/controller printed-circuit boards.

to assemble the Timer. If you wish to have the layout shown for the front panel in the lead photo, it is best to use printed-circuit construction. If you prefer not to make your own pc boards, perforated boards with holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware can be used in place of the pc boards. Of course, if you wish simplified construction and no mis-wired connections, use of pc boards is highly recommended. Regardless of the construction technique selected, it is a good idea to use sockets for all DIP ICs. From here on, we will assume printed-circuit construction.

Two printed-circuit boards are called for in this project. One accommodates all components shown in Fig. 1, the other most of the components shown in Fig. 3. Fabricate these boards using the actual-size etching-and-drilling guides shown in Fig. 5. When both boards are ready, temporarily set aside the smaller one and place the larger one on your work surface oriented as shown in the Fig. 6 wiring guide.

Begin populating the board by installing and soldering into place the IC sockets. Do *not* install the ICs in the sockets until after preliminary voltage checks have been made and you are sure the project has been properly wired. Once the sockets are in place, install and solder into place the jumper wires (identified with the letter "J"). You can use short lengths of bare solid hookup wire for jumpers that are shorter than 1 inch but you must use *insulated* hookup wire for any longer jumpers. When you are finished installing the jumpers, count them; there should be 21 in all.

Next, install the resistors, noting that *R13* through *R16*, *R19* and *R20*) mount upright and that *R8*, shown phantomed just below the IC9 socket, mounts on the *solder* side of the board *after* switch *SW2* has been installed. Follow up with the capacitors and then the diodes. Note that, like *R8*, *C3* mounts on the bottom of the board, its leads tack-soldered to the indicated traces as shown. Also, make absolutely certain that each diode is properly oriented before soldering its leads to the pads on the bottom of the board. Install the transistor, making sure it is properly based before soldering its leads into place. Using heat judiciously, install and solder into place the crystal in the location indicated. Trim any excess lead length after soldering.

Plug the lugs of rotary switches *SW1* and *SW2* into the specified holes in the board and solder into place. Then bend the leads of *R8* as shown and trim each as needed. Tack-solder both leads to the indicated pads on the bottom of the board.

Drill a ⅜-inch or slightly larger hole through a piece of plastic, sheet metal or stiff cardboard. Place this on the shaft of either *SW1* or *SW2* and loosely secure it in place with the switch's hardware. Measure the distance between the bottom of this and the top of the circuit-board assembly. This measurement is how far the bottoms of the light-emitting diodes must be from the top surface of the circuit-board assembly. Remove and discard the plastic, sheet metal or cardboard. If you use LEDs that have flanges around their bases, the measurement applies to the distance between the board and the *tops* of the flanges.

Measure and mark the leads of all LEDs with the measured dimension. It is best to use a permanent black or other dark-color marker for this. Then plug each LED in turn into a pair of holes up to the marks, making sure it is properly polarized, and solder its leads to the copper pads on the bottom of the board. Trim away any excess lead lengths. When all LEDs have been installed, orient them so that they are perpendicular with the board's surface.

If you build your circuitry on a perforated board, it is best to install the LEDs in the front panel of the selected enclosure and interconnect their shortened leads with the appropriate points in the circuit with lengths of hookup wire. If you do this, be sure to insulate all connections with small-diameter heat-shrinkable or insulating plastic tubing.

Strip ¼ inch of insulation from both ends of seven 8-inch lengths of insulated hookup wire. Do the same for three 4-inch lengths. If you are using stranded hookup wire, tightly twist together the fine conductors at both ends of all wires and sparingly tin with solder. Plug one end of the 8-inch wires into the holes for the switches and solder into place. Then plug one end of the shorter wires into the TO BASE OF Q2, GND and V+ holes and solder these into place as well. The other ends of these wires will be connected later. Meanwhile, set this circuit-board assembly aside.

Place the smaller printed-circuit board in front of you in the orientation shown and refer to Fig. 7 for wiring instructions. Begin wiring this board by installing and soldering into place first the resistors and then the capacitors and diodes. Make sure the electrolytic capacitors and diodes are properly oriented before soldering their leads to the copper pads on the bottom of the board.

Install and solder into place a six-pin DIP socket in the IC11 location. (If you cannot find a six-pin socket, you can substitute Molex Soldercons®.) Plug the optoisolator into the socket, making sure that no pins overhang the socket or fold under between the optoisolator and socket.

Install and solder into place trimmer control *VR1* as shown. Then plug the leads of *Q2* into the appropriate holes and adjust the height of this transistor so that the bottom of its case is about ¼ to ⅜ inch above the surface of the board and solder into place. Note that both the voltage regulator (*IC10*) and triac (*TR1*) have metal tabs protruding from the tops of their cases. These tabs must be facing *away* from the center of the

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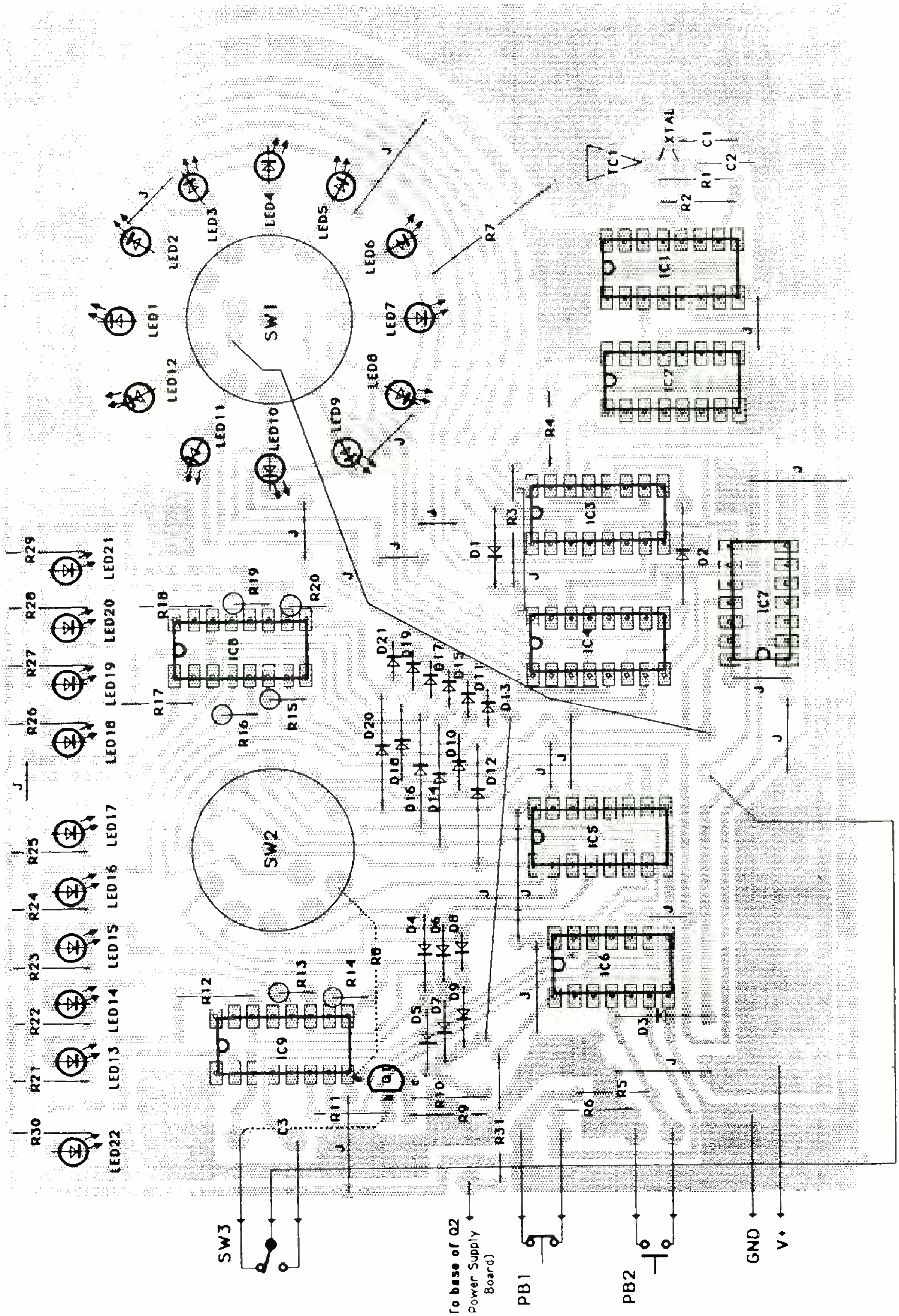

Fig. 6. Wiring guide for counter board.

board when these devices are installed on the board in their respective locations. After plugging the pins of the devices into the holes in the board, push down until the points where the pins widen are flush against the board and solder all pins into place. Trim away excessive pin lengths.

If you have decided to incorporate POWER *LED23* into your project, mount it in place so that the bottom of its case (or the top of the flange around the bottom of its case if you are using flanged LEDs) is ½ inch away from the top surface of the board. Make certain that the LED is properly oriented before soldering it into place. Also, install and solder into place resistor *R32*.

Power transformer *T1* specified in the Parts List should be the old Radio Shack type rated at 12.6 volts and 300 milliamperes with solder lugs on it. The new transformer under the same catalog number from Radio Shack has pc-mount lugs. It is not suitable for this project because it operates hot when loaded by as little as 50 milliamperes. If you cannot locate the older type of transformer, consider using one with better ratings from a different manufacturer. If the transformer is too large to fit on the circuit board, mount it off the board and run wire leads from it to the appropriate holes in the board.

Strip ¼ inch of insulation from both ends of two 6-inch stranded hookup wires. Use 16-gauge or heavier wires here. Tightly twist together the conductors at both ends and sparingly tin with solder. Plug one end of one of these wires and the other outer conductor of the line cord into the *lower* 120V IN hole and solder into place. (If necessary, enlarge the hole at this location to accommodate both wires.) Then plug one end of the other wire into the hole labeled 120V OUT and solder into place.

An enclosure with interior dimensions of 10 × 5 × 2½ to 3 inches will accommodate both boards and has sufficient panel space for the switches and LEDs. Such an enclosure is not commonly available. Unless you can find a chassis box of the required dimensions, you will have to fabricate an enclosure from ¼-inch-thick plywood or Masonite or 16-gauge or so sheet aluminum or steel.

When the enclosure is ready, use the actual-size artwork in Fig. 8 to mark the centers of the holes to be drilled in the top panel for the LEDs, switches and mounting holes for the circuit-board assemblies. After transferring the hole-center locations to the top panel of the enclosure, set aside the artwork and drill appropriate size holes in each marked location. If you are using a rocker-type POWER switch and slide-type 10/20 MIN selector switch, square up the holes as needed.

Continue machining the enclosure by cutting the opening for and

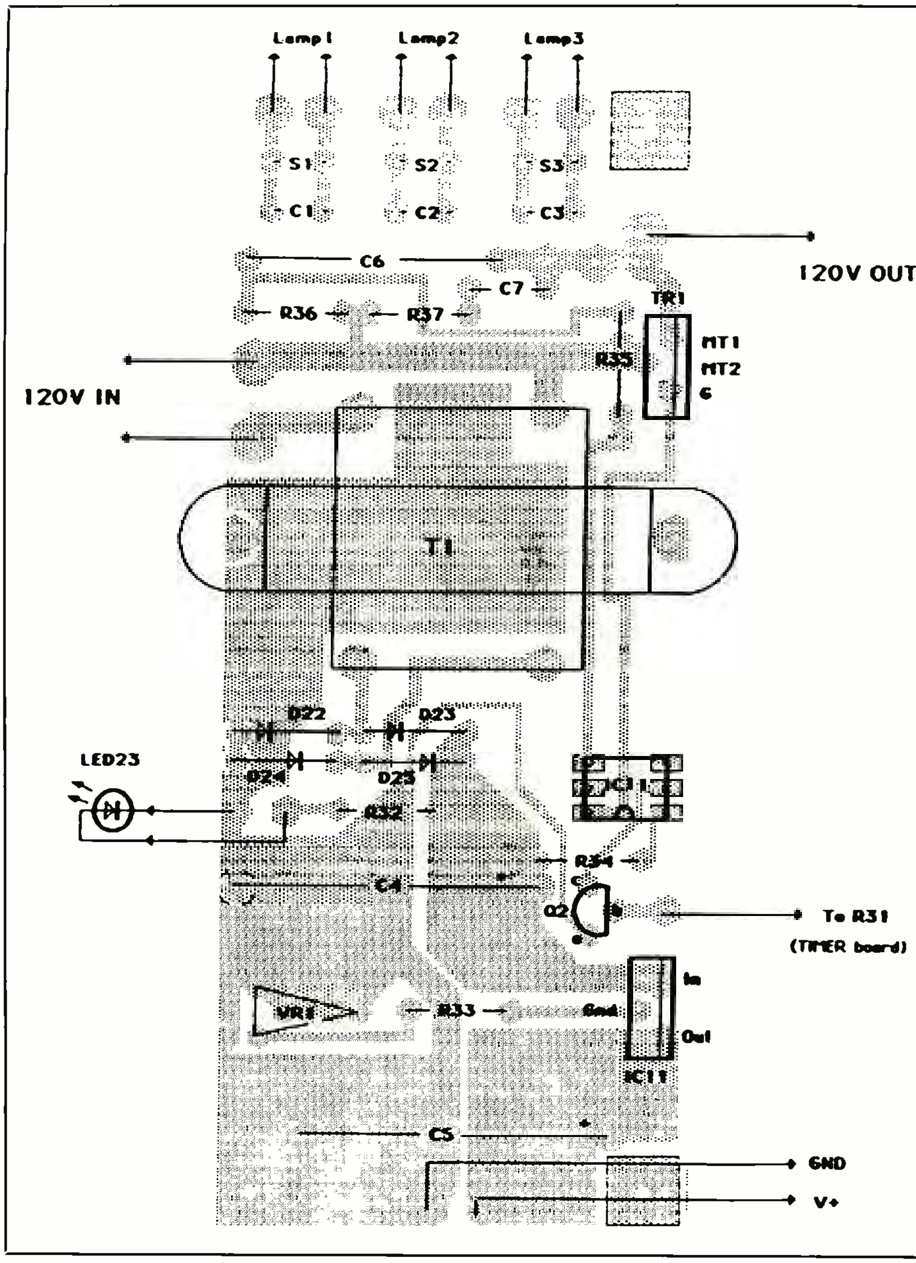

Fig. 7. Wiring guide for power-supply/controller board.

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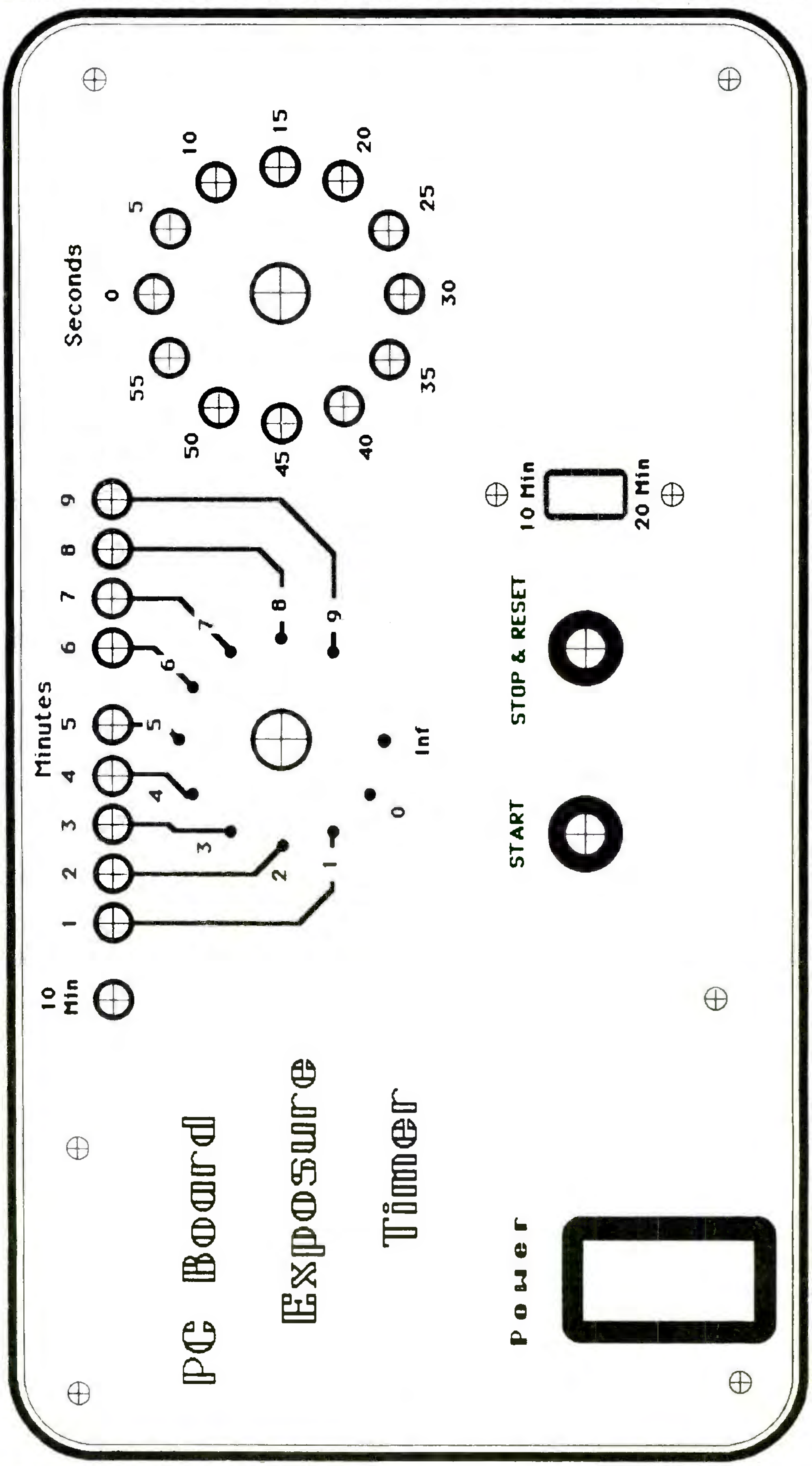
Fig. 8. Actual-size front-panel template for project. Use this as a drilling template and a same-size photocopy as the actual front panel itself.



mounting the chassis-mount ac receptacle on the end panel nearest the POWER switch. Then drill an entry hole for the ac line cord through the rear panel near the receptacle. If the panel is metal, deburr the edges of all holes and place a rubber grommet in the line-cord entry hole.

If you wish, finish and paint the enclosure. When the paint dries, use the Fig. 8 artwork to make an overpanel for the front panel of the enclosure. One way to do this is have Fig. 8 reproduced actual-size as a positive or negative film transparency. Punch all LED, switch and machine-hardware holes as needed. Then use contact cement or spray-on art adhesive to cement the transparency to the front panel of the enclosure.

If you prefer to label the front panel yourself, use Fig. 8 as a guide and apply dry-transfer letters in the appropriate locations. Then spray two or three light coats of clear acrylic over the entire panel to protect the labels.

When the enclosure is ready, route the line cord through its entry hole into the enclosure. Separate the three conductors a distance of 6 inches. Tightly twist together the fine wires in each conductor and sparingly tin with solder.

Mount the switches in their respective locations. Make sure the normally-open and normally-closed pushbutton switches mount in STOP/RESET and START holes, respectively. Then mount the ac receptacle on the end panel. This done, solder one outer conductor of the ac line cord to one lug of the POWER switch and secure the center conductor to the ac receptacle via the screw for the center contact.

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Place the circuit-board assemblies side by side near the open rear of the enclosure. Secure the free end of the wire coming from the lower 120V AC hole in the smaller circuit board assembly to one outer conductor contact of the receptacle via the appropriate screw. Crimp and solder the free end of the wire coming from the upper 120V AC hole to the other lug of the POWER switch. Route the wire coming from the 120V OUT hole to the remaining connection on the receptacle and secure it in place with the appropriate screw.

Now plug the free end of the TO BASE OF Q2 wire on the larger circuit board assembly into the TO R31 hole in the smaller board and solder into place.

Preliminary Checkout

Because dangerous ac line power is routed through portions of this circuit, it is important that all components on the primary side of the power transformer be wired correctly before attempting to power up the system to make voltage checks. Review all wiring for this circuit, marking each run off on a photocopy of Fig. 3 (or Fig. 4 if you decided to use the simpler circuit).

When you are sure of your wiring, use an ohmmeter set to its highest range to measure the resistance in *both* directions between the prongs of the power plug in every combination with the POWER switch opened. In all cases, you should obtain an infinite resistance indication ("overrange" if you are using a DMM). You should obtain the same results when the test is repeated on the project's receptacle.

If you obtain any indication other than infinite resistance during this test, do *not* plug the line cord into an ac outlet. Instead, recheck your wiring and correct the problem before proceeding.

If you do obtain the proper resistance readings with the POWER switch open, close the switch and repeat the tests on the line cord's plug, this time using a low ohmmeter range. When making checks between the blade-shaped prongs, you should obtain a fairly low resistance (the dc resistance of the power transformer's primary winding). However, you should still obtain an infinite reading between both blade prongs and the remaining round prong even on the highest resistance range. There is no need to make tests on the ac receptacle on the project. Once again, if you do not obtain the appropriate readings, correct the problem before proceeding.

Now place an insulating surface on your workbench. A thick sheet of corrugated cardboard is good. Arrange the circuit-board assemblies so that they are not touching each other or any part of the enclosure if the enclosure is made of metal. Switch to the dc-volts function of your meter and set it for a full-scale range that will accommodate readings up to 20 volts or so. Clip the meter's common probe to a convenient point in the circuit that is at ground potential.

Plug the project's line cord into a convenient ac outlet and set the POWER switch to "on." Touch the meter's "hot" probe to the OUT pin of regulator *IC10*. The meter should indicate a potential of some positive voltage. If so, adjust the setting of *VR1* on the smaller board for a meter reading of precisely +10 volts. Then probe pin 16 of the *IC1* through *IC5* and pin 14 of the *IC6* through *IC9* sockets on the larger circuit-board assembly. Once again, all readings should be +10 volts. If you do not obtain the appropriate readings at any point, pull the project's plug from the ac line and correct the problem. Do *not* proceed until the problem has been rectified.

With no power applied to the project, crimp and solder the free ends of the wires coming from the larger circuit-board assembly to the lugs of the pushbutton and slide switches. Then carefully install the ICs into their respective sockets. Make sure each is properly oriented and that no pins overhang the sockets or fold under between the ICs and sockets.

Disconnect the wire that bridges the base of *Q2* on the small circuit-board assembly and *R31* on the larger board at one end of the wire. Also disconnect one end of the V+ wire and temporarily install a 1,000-ohm, 1-watt resistor in series with the free end of this wire and the hole from which it was removed. The resistor will protect a short-circuited component, assuming there is one in the project, for a long time while the circuit is under power.

With power applied and the POWER switch set to "on," you should obtain a reading of 4.5 to 5 volts across the 1,000-ohm resistor. If either *LED1* (the 0 SECONDS LED) has not come on or the measured potential across the resistor is greater than 6 volts ac, something is wrong with the circuit. Power down and correct the problem.

Once the problem has been corrected and with the 1,000-ohm still connected into the circuit, press and release the START pushbutton switch. To decrease the 5-second clocking time, you can bridge the crystal with a wire shorting link. This will decrease each timing step to less than a second, allowing you to quickly check if the Timer is behaving as it should. Once you know the Timer is operating properly, power down the project, remove the 1,000-ohm resistor and reconnect the wire to the hole from which it was removed. Reconnect the other wire.

Test the switching circuit by plugging a table lamp into the project's ac receptacle. Make sure the lamp is turned on first. Plug the project into an ac receptacle and set the POWER switch to "on." Select a timing interval with the rotary and slide switches and press and release the STOP/RESET button to initialize the Timer. Then press and release the START button and time how long the lamp