An Analog-Display Digital Clock

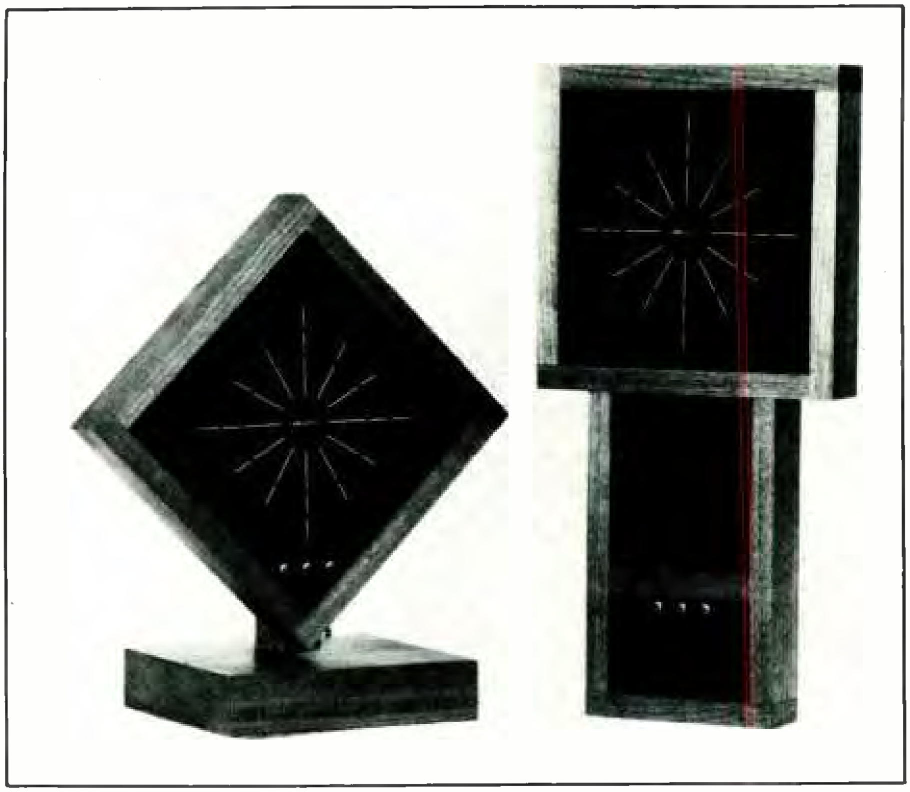
Combines appeal of the round "dial" of traditional analog movements with high-technology digital driving circuitry

By James Marshino

The clock desscribed here combines a timepiece that has the appeal of a traditional analog display with the high-tech performance of a digital "movement." This clock uses concentric circles of 60 seconds LEDs, 60 minutes LEDs and 12 hours LEDs instead of the traditional hands found on analog clocks to "point" to the time of day.

You can build either of two versions of the clock: a basic version that consists of the simple hours/minutes/seconds display and a more sophisticated version that adds to this an optional "pendulum" that consists of 10 LEDs arranged in an arc. Both versions use the same display and "movement."

You can house your clock in any of a number of different enclosures, ranging from traditional clock styles to a contemporary shallow square, depending upon your woodworking skills and taste. A shallow square enclosure that hangs on a wall is the easiest way to go, but if you are really ambitious and are a skillful woodworker, a wall-hung Regulator case or even a floor-standing long-case "grandfather" enclosure can be built to complement different decors. You can obtain either of two enclosures for your clock from the source given in the Note at the end of the Parts List if you prefer not to build your own.



About the Circuit

The complete schematic diagram of the clock's circuitry, including optional pendulum circuit, is shown in Fig. 1, which consists of four parts. At the upper-left in Fig. 1(A) is the clock's simple power supply. Incoming 117 volts ac is stepped down to 9 volts ac by power transformer *T1* and is rectified to pulsating dc by the bridge rectifier made up of diodes *D1* through *D4*. This pulsating dc is filtered to pure dc by capacitor *C1* and is subsequently delivered to the remainder of the circuitry that makes up the clock. At any given time only three LEDs will be on. Consequently, the circuit draws very little current and power demand is minimal.

A 60-Hz ac signal is picked off the secondary of *T1* and coupled through a Schmitt-trigger circuit composed of *R1*, *R2*, *IC1*, *IC2A* and

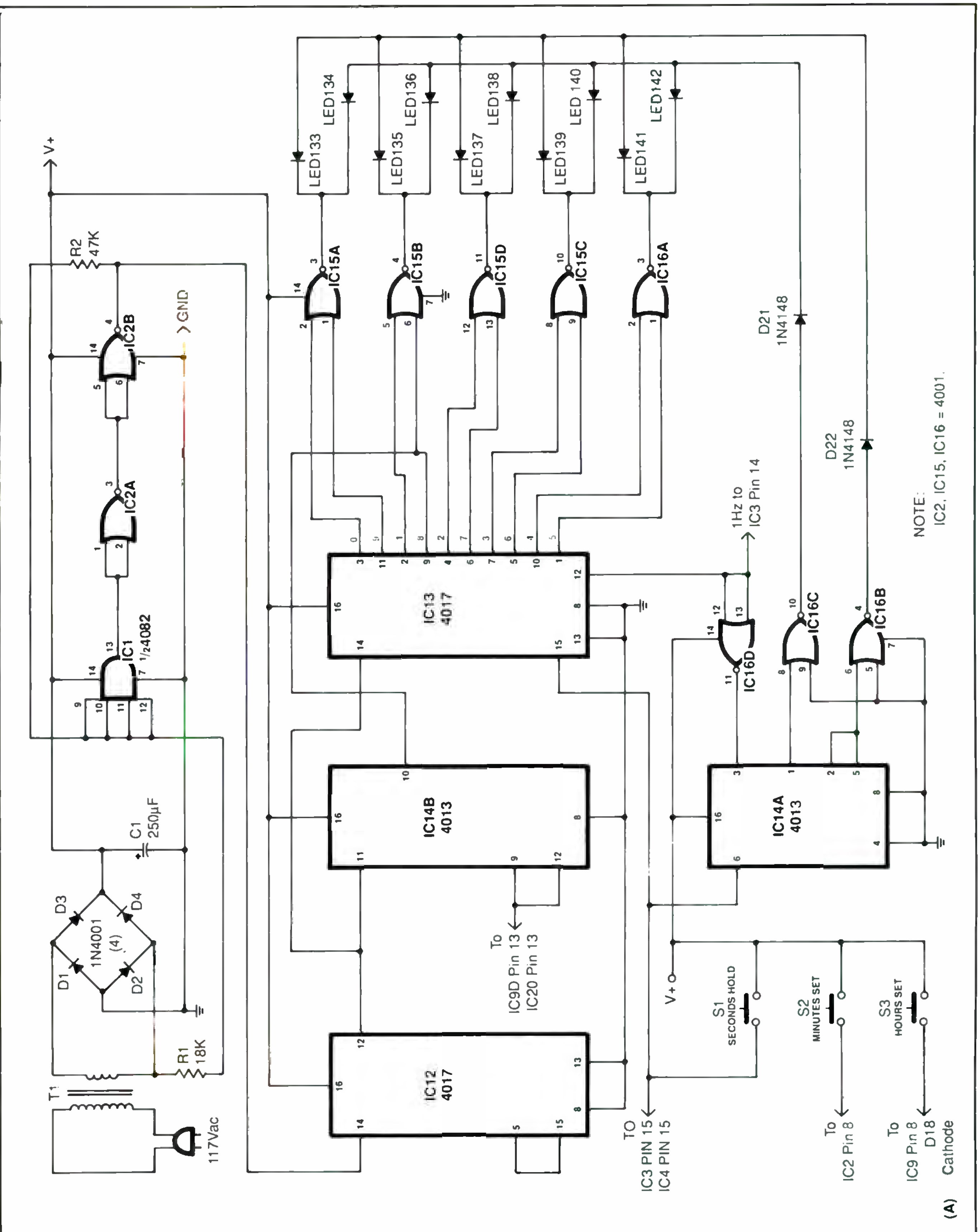
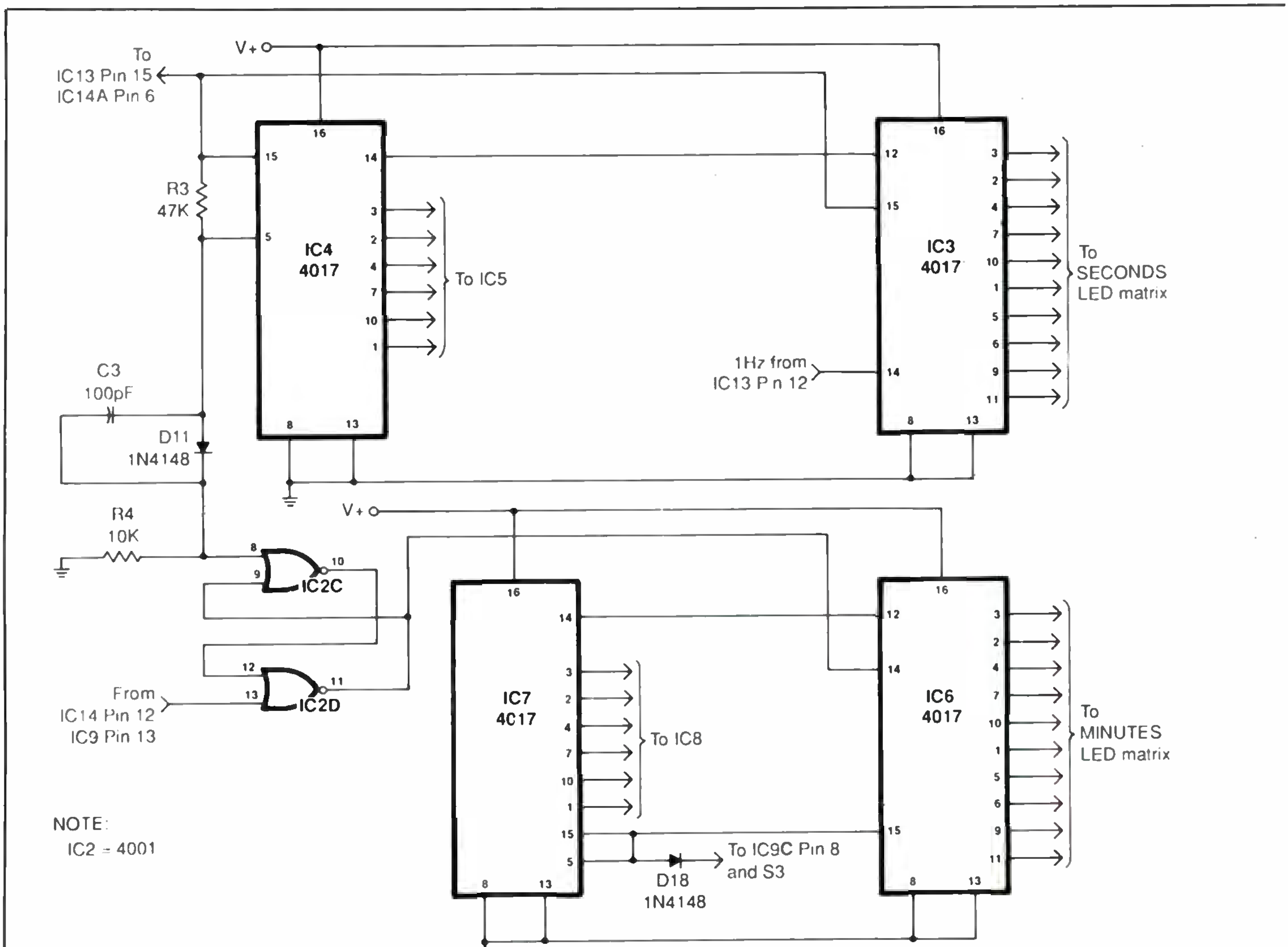
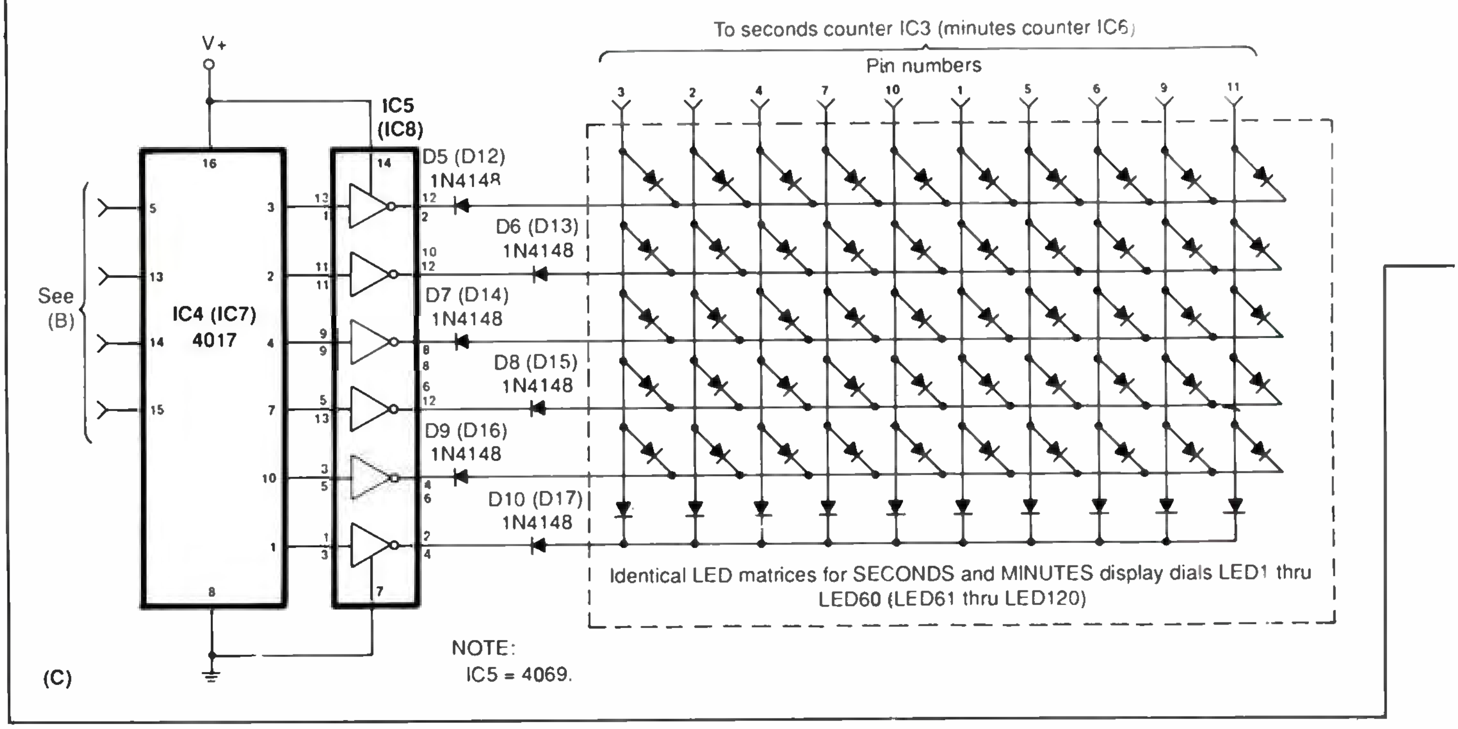


Fig. 1. Complete schematic diagram of the clock's circuit is shown here in four sections: (A) is the basic 1-Hz timing pulse generator and optional pendulum circuit; (B) is the counter/decoder circuitry for the seconds and minutes section; (C) is the circuitry for the discrete-LED displays for the seconds and minutes rings; and (D) is the counter/display circuitry for the hours ring. Parts (B), C) and (D) follow on next two pages.



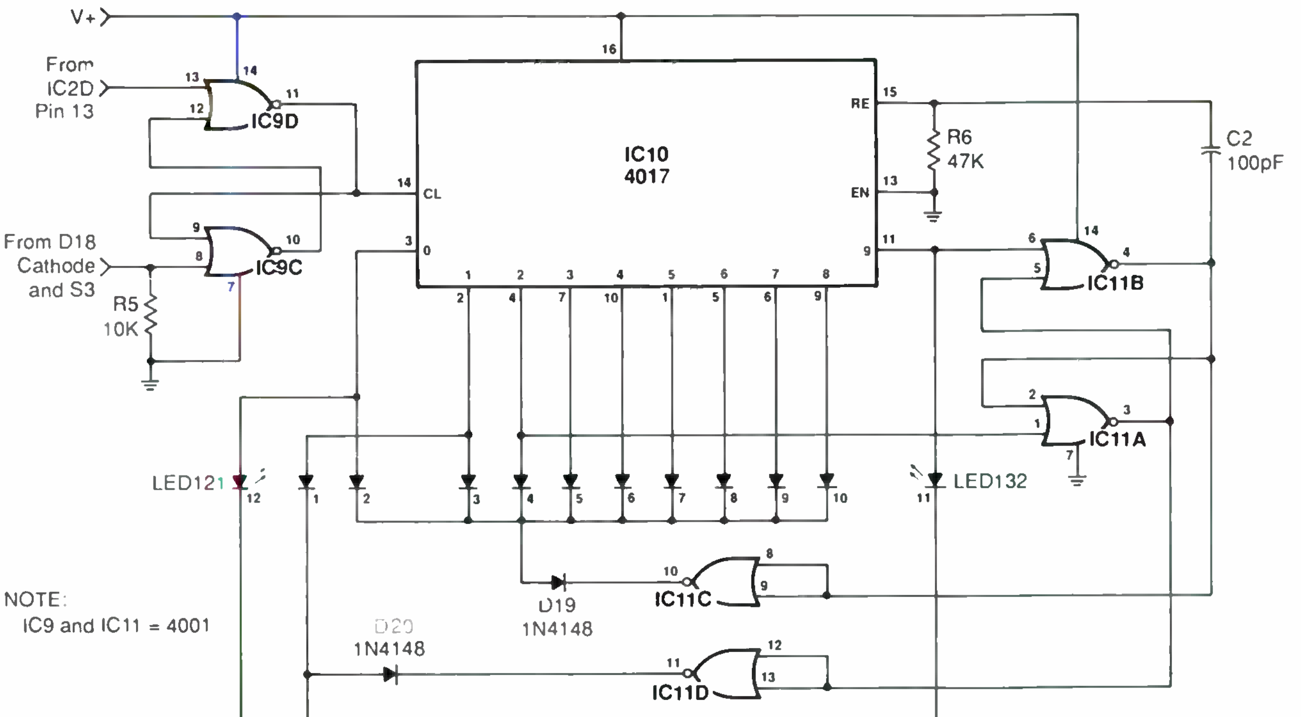
V+
To IC13 Pin 15 IC14A Pin 6
IC4 4017
IC3 4017
R3 47K
To IC5
To SECONDS LED matrix
1Hz from IC13 Pin 12
C3 100pF
D11 1N4148
R4 10K
IC2C
IC2D
From IC14 Pin 12 IC9 Pin 13
IC7 4017
IC6 4017
To IC8
To MINUTES LED matrix
To IC9C Pin 8 and S3
D18 1N4148
NOTE: IC2 = 4001

(B)



V+
To seconds counter IC3 (minutes counter IC6)
Pin numbers
3 2 4 7 10 1 5 6 9 11
IC5 (IC8)
See (B)
IC4 (IC7) 4017
D5 (D12) 1N4148
D6 (D13) 1N4148
D7 (D14) 1N4148
D8 (D15) 1N4148
D9 (D16) 1N4148
D10 (D17) 1N4148
Identical LED matrices for SECONDS and MINUTES display dials LED1 thru LED60 (LED61 thru LED120)
NOTE: IC5 = 4069.

(C)



(D)

PARTS LIST

Semiconductors

D1 thru D4—1N4001 silicon rectifier diode
D5 thru D22—1N4148 or similar switching diode
LED1 thru LED142—Jumbo red light-emitting diode
IC1—CD4082 dual 4-input CMOS AND gate
IC2—CD4001 quad 2-input NOR gate
IC3,IC4,IC6,IC7,IC10,IC12,IC13—CD4017 CMOS decade counter
IC5,IC8—CD4069 CMOS hex inverter/buffer
IC9,IC11,IC15,IC16—CD4001 quad 2-input CMOS NOR gate
IC14—CD4013 dual CMOS D flip-flop

Capacitors

C1—250-µF, 35-volt electrolytic
C2—100-pF Mylar or ceramic disc

Resistors (¼-watt, 5% tolerance)

R1—18,000 ohms
R2,R3,R6—47,000 ohms
R4,R5—10,000 ohms

Miscellaneous

S1,S2,S3—Momentary-action spst push-button switch
T1—9-volt, 30- to 40-mA power transformer (see text)
Main and pendulum printed-circuit boards; sockets (or Molex Soldercons) for ICs; ribbon cable; hardware; hookup wire; solder; etc.

Note: The following items are available from Jim Marshino, Box 262, Goodland, IN 47948: Kit containing all electronic components and both pc boards but no IC sockets or enclosure, $89.50 plus $10 P&H. Also available: double-sided main and pendulum boards with plated-through holes, $34.50; all ICs, $12.50; 9-volt power transformer, $9; packet of 143 LEDs (all needed plus a spare), $19.50; clock face kit, $9.50; plain cabinet, $45, or schoolhouse Regulator cabinet, $75. Cabinets are available in either walnut or cherry lumber (specify choice). A wired clock, not including enclosure, is also available for $124.50. Add $2.50 P&H for all orders, except $10 for electronics kit, either cabinet and wired clock. Indiana residents, please add state sales tax.

IC2B. Emerging from the output of this circuit at pin 4 of *IC2B* is a square waveform that reliably triggers the initial counter in the clock.

Shown immediately below the power-supply section in Fig. 1(A) is 1-Hz divider/pendulum circuitry. Three basic functions are served by the this circuit: it divides the line frequency down from the initial 60 Hz to 1 Hz; it provides fast-set pulses that allow you to quickly set the time in the clock's display; and it displays a LED "pendulum" that appears to swing in an arc.

Shown in Fig. 1(B) are the circuit details of the seconds and minutes counters. Figure 1(C) contains the details of the circuit for the drivers and light-emitting diode matrices that make up the seconds and minutes dial displays. Finally, Fig. 1(D) contains the circuit details for the hours counter and LED display dial.

Following the pendulum circuitry are the basic clock circuits. These are made up of two divide-by-60 and one divide-by-12 counters. Each divide-by-60 counter contains a 6 by 10 matrix of LEDs, as shown in Fig. 1(C). The LEDs are physically arranged to form two separate circles on the project's dial face, with the outer and inner circles indicating seconds and minutes, respectively.

Figure 1(C) shows the details for

just one divide-by-60 counter/display setup. Two identical such circuits are used in the clock. One consists of *IC4*, *IC5*, *D5* through *D10* and *LED1* through *LED60* and makes up the seconds counter/display system. The other consists of *IC7*, *IC8*, *D12* through *D17* and *LED61* through *LED120* and makes up the minutes counter/display system. Counters *IC3* and *IC6*, also part of the seconds and minutes counting circuitry, are shown in Fig. 1(B).

The divide-by-12 counter shown in Fig. 1(D) is simply an extended version of the standard decade counter used here to count to 12. Its outputs go to 12 hours LEDs that form the innermost display circle.

Operation of the clock circuitry is as follows. The conditioned 60-Hz square wave from the output of the Schmitt trigger goes to CLOCK input pin 14 of decade counter *IC14*. The pin 5 output from this IC coupled directly to the RESET input at pin 15 to create a divide-by-6 arrangement. Since the CLOCK OUTPUT at pin 12 of *IC14* is high for the first five counts (input pulses) and is low for the sixth count, this output is used to drive the next counter in the chain—*IC13*, which is another 4017 decade counter.

ENABLE input pin 13 of *IC12* is connected to circuit ground. The COUNT OUTPUT at pin 12 of *IC12* goes to the CLOCK inputs at pin 11 of *IC1B* and pin 14 of *IC13*. The signal that appears at the not-Q output at pin 12 of *IC14B* directly connects to the DATA input at pin 9 to form a divide-by-two counter. Hence, the FAST SET output from *IC14B* at pin 12 is a 5-Hz (60 Hz/12) square-wave pulse train that is used to quickly set the clock.

Decade counter *IC13* is permitted to run in normal-count mode, with its 10 outputs counting up and down. Its COUNT OUTPUT at pin 12 is inverted by *IC1D* to drive the CLOCK input at pin 3 of *IC14A*. The Q and not-Q outputs at pins 1 and 2 of *IC14A* are inverted and buffered by NOR gates *IC16C* and *IC16B*, respectively. These two gates, along with the diode action of pendulum light-emitting diodes *LED133* through *LED142* make up a 5-by-2 multiplexer. The LEDs are physically arranged in the display to form an arc that simulates the swinging action of a pendulum.

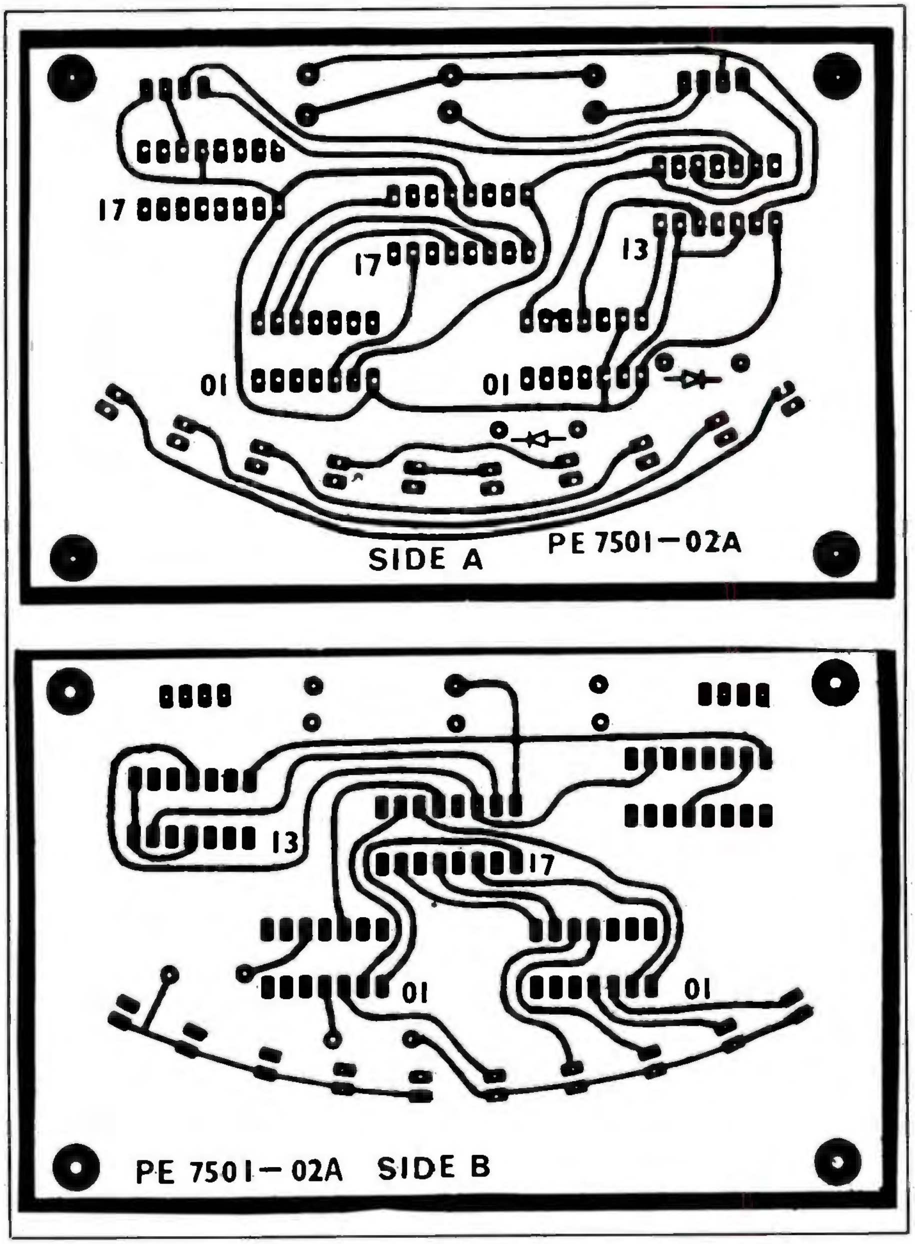


Fig. 2. Actual-size etching-and-drilling guides for the top (upper) and bottom (lower) of the pendulum printed-circuit board.

There are 10 LEDs in the pendulum circuit. These are divided into two groups of five LEDs each. Note the sequence of the numbers on the lines exiting the right side of *IC13* in Fig. 1(A). Follow these lines to the *IC15* and *IC16* NOR gates that drive the LEDs. As you can see, when the output at pin 1 of *IC13* goes high, the output at pin 3 of *IC1A* also goes high. This clocks *IC14A*, changing the states of its Q and not-Q outputs at pins 1 and 2.

The outputs of *IC16B* and *IC16C*

each drive one of the groups of five LEDs. Therefore, one pendulum LED at a time is on for about 0.1 second for each count of *IC13*. Pendulum "swing" direction changes when output pin 11 of *IC13* goes low and output pin 3 goes high because these two outputs are connected to the same *IC15A* gate. Since the counter wraps around, each pendulum LED is on for two counts, giving a more pendulum-like action.

Output pin 9 of *IC13* is used to reset *IC14B* via its pin 10 RESET input to ensure that *IC14B* is in proper phase with the rest of the clock-setting circuits. Output pin 11 of *IC16D* has a 1-second repetition-rate square wave on it and is used for timing functions in the rest of the clock.

The seconds and minutes counters shown in Fig. 1(B) are divide-by-60 units. These circuits are virtually identical to each other. The only difference between the two is in the set functions. The seconds counter is reset to 0 and minutes counter is advanced at the set frequency.

The divide-by-60 counters are each made up of two 4017 decade counters, a units counter and a tens counter with the COUNT OUTPUT at pin 12 of the units counter connected to the CLOCK input at pin 14 of the tens counter. The counter pairs for the seconds and minutes counters in Fig. 1(B) are *IC3/IC4* and *IC6/IC7*, respectively. The pin 5 outputs of *IC4* and *IC7* are connected to the RESETS at pin 15 of both counters in both cases. This forces both counters to be in proper sequence at all times.

Tens counters *IC4* and *IC7* in the seconds and minutes counting circuits, respectively, have their outputs inverted by hex inverters *IC5* and *IC8*. Circuit details are shown in Fig. 1(C). The outputs from the inverter chips are connected to the cathode side of each group of 10 LEDs by an isolation diode. For the seconds counter circuit, these diodes are *D5* through *D10*, and for the minutes counter they are numbered *D12* through *D17*.

After both counters are reset, the pin 3 outputs of both *IC3* and *IC6* are high. This turns on the first LED in the first group of 10. As the units counter is clocked, the LEDs come on in sequence thereafter.

When pin 3 of either counter chip goes high, so does COUNT OUTPUT pin 12, thus advancing the counter one increment. Now the second group of LEDs comes on. This process continues until the fifty-ninth count is reached. Then when pin 1 of the counter goes low and pin 5 of the tens counter goes high, both counters are reset. At this point, the process repeats itself for as long as ac line power is applied to the clock.

Note in Fig. 1(B) resistor *R3* connected between output pin 5 and RESET pin 15 and SECONDS HOLD switch *S1* connected between pin 15 and the V+ bus. As the name of *S1* implies, this is the "hold" circuit that allows you to adjust your clock's timekeeping to single-second accuracy.

The set circuit for the minutes counter is a set-reset (SR) flip-flop made up of NOR gates *IC2C* and *IC2D*, with *IC2C* being the set side and *IC2D* being the reset side. The output pulse at pin 5 of *IC4* is fed to the pin 8 (set) input of *IC2C*. Normally-open pushbutton MINUTES SET switch *S2* in Fig. 1(A) is also connected to pin 8 of *IC2C*, while the fast-set pulses from pin 12 of *IC14B* are fed to the reset side of the SR flip-flop at pin 12 of *IC2D*.

The pulses from the seconds counter are much narrower than are the fast-set pulses. Since the fast set is constantly occurring, the output at pin 11 of *IC2D* is kept low. When a pulse from the seconds counter occurs, the output at pin 10 of *IC2C* is forced low, which forces the pin 11 output of *IC2D* high until the arrival of the fast-set pulse resets the flip-flop. This advances the next counter with a pulse whose width is one-half the fast-set period.

To advance the counter at the fast-set rate, MINUTES SET switch *S2* must be pressed. Doing this causes *IC2D* to behave like an inverter that passes the fast-set pulses to the next counter. The hours-set circuit is operated in exactly the same manner as is the minutes-set counter, this time using the SR flip-flop made up of *IC9C* and *IC9D* and HOURS SET switch *S3*. The set and reset sides of this SR flip-flop are *IC9C* and *IC9D*, respectively.

Last but not least is the hours counter, which is depicted schematically in Fig. 1(D). The counter is made up of decade counter *IC10* and quad NOR gate *IC11*. The SR flip-flop for this circuit is made up of *IC11B* (set) and *IC11A* (reset). The other two *IC11* gates are employed as inverting buffers on the flip-flop's outputs.

Output 9 at pin 11 of *IC10* connects to the pin 6 set input of *IC11B*, and output 2 at pin 4 of *IC10* goes to the pin 1 reset input of *IC11A*. The output of the flip-flop at pin 10 of *IC11C* goes through isolation diode *D19* to hours LEDs 2 through 10 o'clock, and the output at pin 11 of *IC1D* goes through isolation diode *D20* to hours LEDs 1, 11 and 12 o'clock.

Assume that decade counter *IC10* is reset and *IC11B* is low and the hours counter is begun to be advanced. When the 2 output at pin 4 of *IC10* goes high, the output of *IC11B* at pin 4 is forced high, in turn forcing a pulse to go to RESET input pin 15 of *IC10* via the integrator made up of *C2* and *R6*. Now the 0 output at pin 3 of *IC10* goes high again, but the hours LEDs for 2 through 10 o'clock have been selected, thereby turning off the 2 o'clock LED. The decade counter now advances until its 9 output at pin 8 of *IC10* goes high. At this point, the output at pin 3 of *IC11A* is forced high, thereby selecting hours LEDs for 1, 11 and 12 o'clock.

Construction

Printed-circuit assembly is highly recommended for this project, both

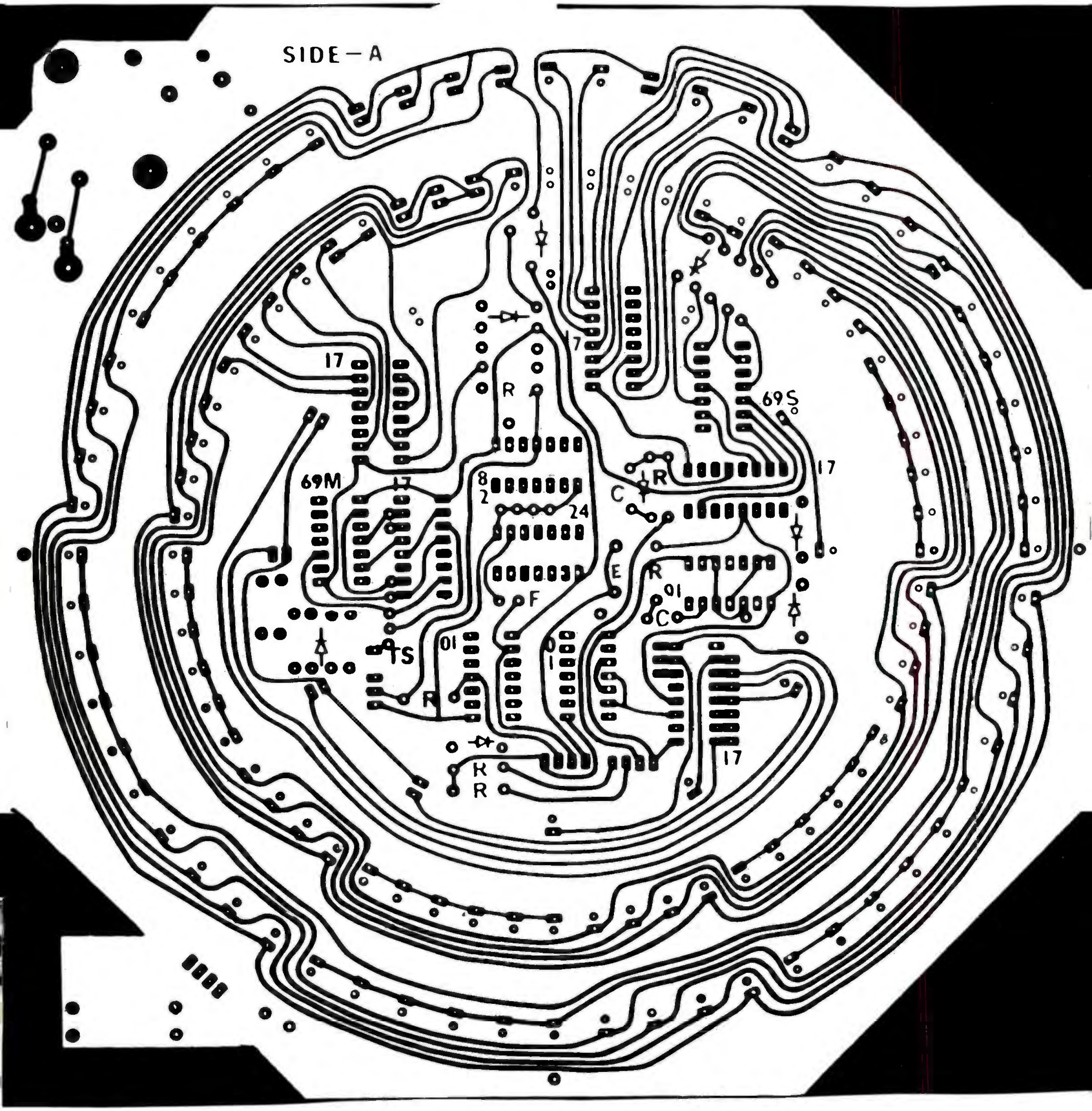
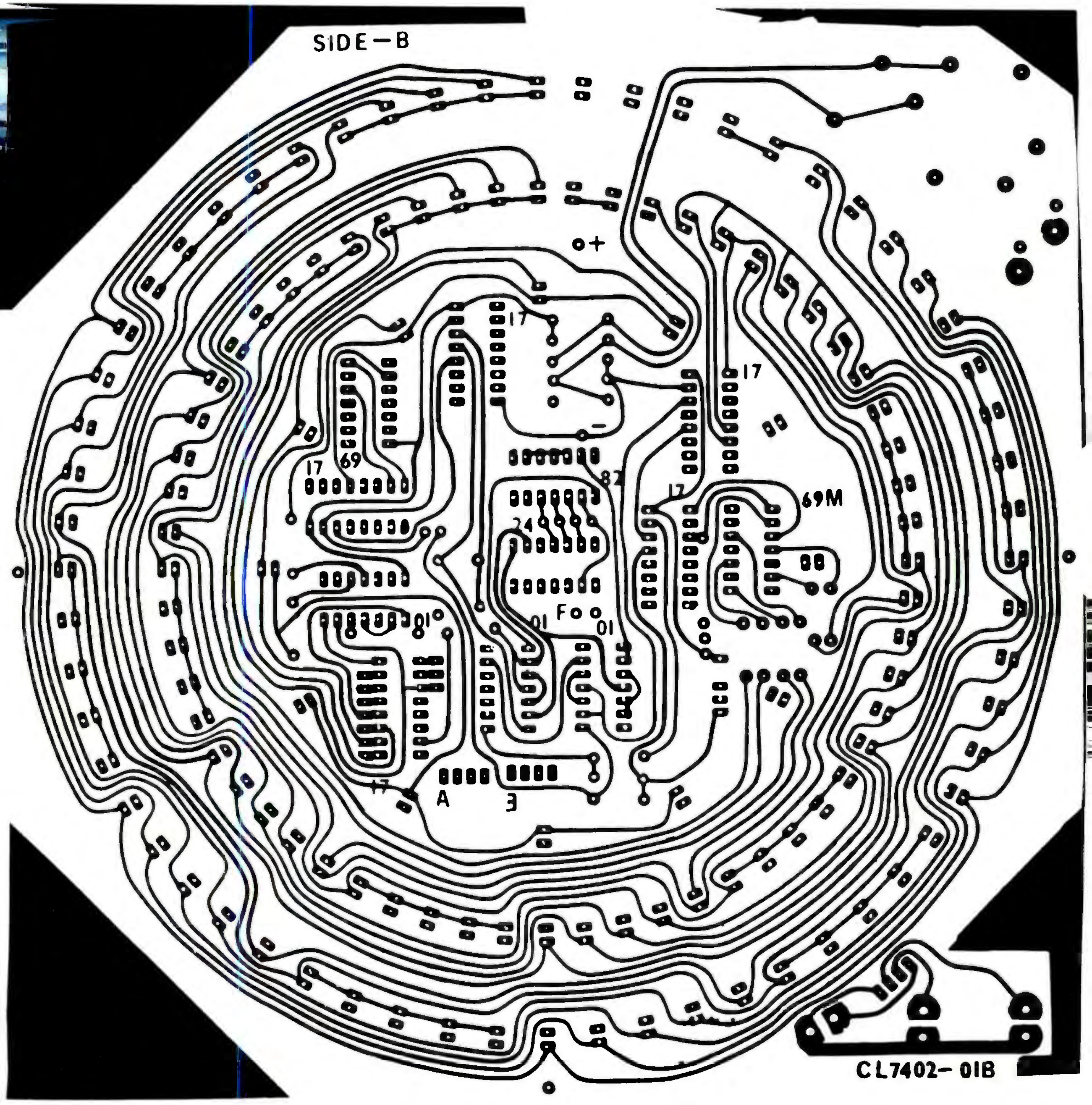


Fig. 3. Actual-size etching-and-drilling guides for the component (left) and solder (right) sides of the main board.


SIDE—B
CL7402—01B

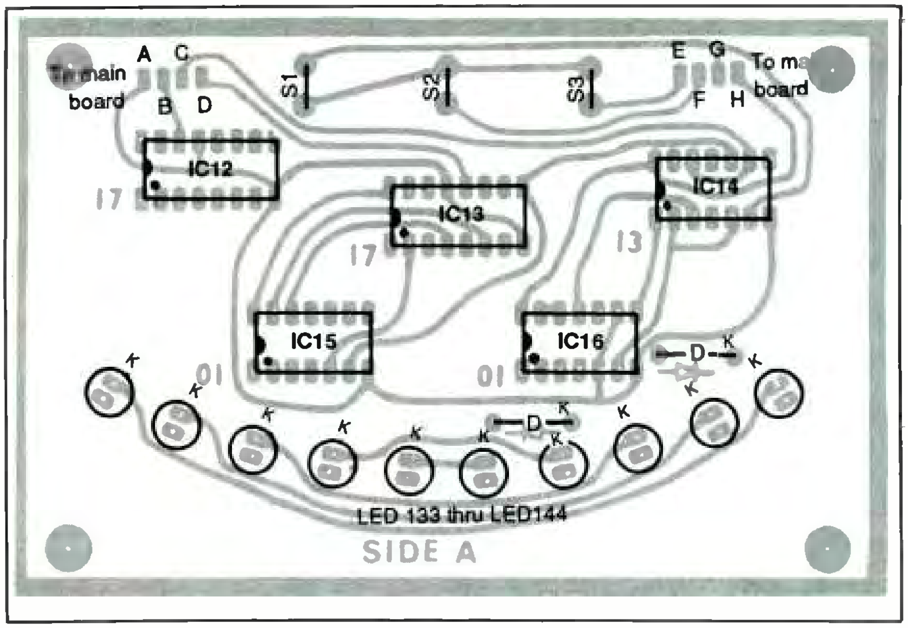


Fig. 4. Wiring guide for the pendulum board, viewed from the component side.

to simplify installing and wiring together the many components (especially LEDs) used and to reduce the possibility of creating wiring errors. Of course, if you wish, you can build the project on perforated board that has holes on 0.1-inch centers and using suitable soldering or Wire Wrap hardware. If you go this route, you might want to arrange the dial in a square or diamond pattern with 15 LEDs on each side for the seconds and minutes and 3 LEDs on each side for the hours displays.

Two printed-circuit boards are needed—one for the main circuitry and the other for the divider/pendulum circuitry. The latter is needed even if you decide not to build the pendulum into your clock because it contains the circuitry for the 1-Hz divider that drives the remainder of the clock's circuits.

Pc boards for this project are double-sided. You can make your own boards using the actual-size etching/drilling guides for the pendulum and main boards shown in Fig. 2 and Fig. 3, respectively. Keep in mind that home-made boards will not have plated-through holes and, thus, require that you solder all component pins and leads to the pads on *both* sides of the board. If you prefer not to make your own pc boards, you can obtain ready-to-wire pc boards from the source given in the Note at the end of the Parts List.

Wire the pendulum board first, referring to Fig. 4 for details. (Note: The views shown in Fig. 4 and Fig. 5 are from the top of the board.) Install the sockets (or Soldercons) first but *not* the ICs themselves in the indicated locations. This done, identify the cathode leads of the 10 light-emitting diodes that make up the pendulum. Install these LEDs on the board in the indicated locations and solder their leads into place. Note that the cathode (K) leads all face toward the top of the board. Position the LEDs so that the bottoms of their cases are a uniform ¼ inch above the surface of the board.

Plug the pins of the three switches into the holes identified by the legends S1, S2 and S3 and solder into place. Then install the two diodes near the IC16 socket, taking care to properly orient each before soldering their leads into place.

Carefully inspect your work for properly installed components and proper soldering. If you are using a home-made board, make sure that all connections are soldered to the pads on *both* sides of the board. If you locate any connections that have not been soldered or ones that have questionable soldering solder the ones missed and reflow the solder where necessary. Check also for solder bridges, particularly between the closely spaced IC pads. If you locate any bridges, remove them with desoldering braid or a vacuum-type desoldering tool.

Set aside the pendulum board and place the main board on your work surface in the orientation shown in Fig. 5. Begin populating this board by installing and soldering into place the sockets (or Soldercons) in the indicated locations. Note that no socket should be installed in the location in the center of the board. Again, do *not* install the ICs in the sockets yet. Then install and solder into place the resistors and diodes, making sure that the latter are properly oriented before soldering their leads to the copper pads.

Next, install and solder into place the capacitors. Small capacitors *C2* and *C3* mount on the top of the board with the other components. Large electrolytic capacitor *C1*, on the other hand, mounts on the *bottom* of the board; observe proper polarity when installing *C1*.

Finish up installing components on the main board with the 132 light-emitting diodes that make up the seconds, minutes and hours indicators. Before you solder any LED into place, make sure it is properly oriented. Also, position each LED so that the bottom of its case is ¼ inch above the surface of the board. When you are finished installing the LEDs, carefully position them so that they form three concentric perfect circles.

Carefully check your work as you did for the pendulum board. Follow

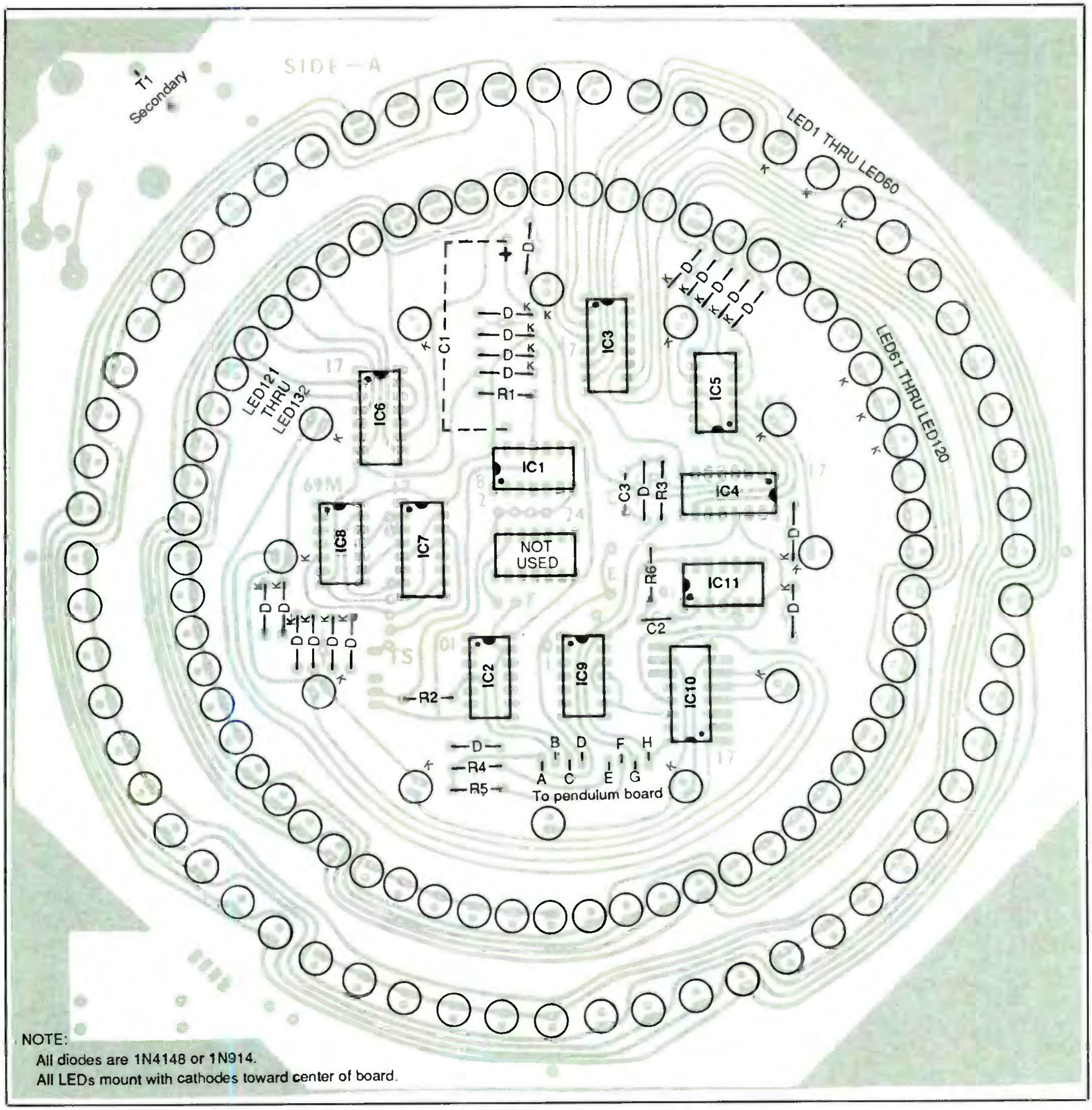


Fig. 5. Wiring guide for the main board, viewed from the component side.

the same steps detailed above for this operation.

The length of the eight-conductor ribbon cable that links the two circuit-board assemblies together depends on how far apart the two boards will be located in your clock's enclosure. If you are building a wall-hung or mantel-top version, the distance separating the two assemblies will be short. Alternatively, if you are building a long-case ("grandfather") version, the distance separating the two assemblies will be considerably greater.

It is preferable to use ribbon cable that has color-coded insulation to make it easy to keep track of which conductor goes where. Cut the cable to length. Then separate the conductors at one end into two bundles of four conductors for a distance of 6 inches. Then separate all conductors at both ends a distance of 1 inch and strip from each ¼ inch of insulation. Twist together the fine wires in each conductor and tin with solder.

Flip over the main board and plug the conductors at the end of the cable where separation is only 1 inch in all cases into the holes labeled A through H and TO PENDULUM BOARD. Solder them into place. The other end of this cable will be connected to the pendulum board after you install the main board it in its enclosure.

You can fabricate your own enclosure for the clock or purchase one ready for installation of the electronics package from the source given in the Note at the end of the Parts List. A build-it-yourself enclosure can be made from any materials you wish, including lumber, painted or veneer-finished particle board or even all acrylic plastic, depending on your tastes and shop skills. Whichever way you go, though, use a transparent red or gray smoked plastic filter in front of both the clock face and pendulum to enhance contrast and camouflage the board—unless, of course, you want the high-tech look of the circuitry showing through clear plastic.

Set the main board in place inside the enclosure, orienting it as shown in Fig. 5. Determine where to mount the power transformer. It should be located as close as possible to the TI SECONDARY holes in the upper-left corner of the board. Mount the transformer in place using two No. 5 × ½-inch wood screws.

If you are using a basic power transformer, mount a two-lug terminal strip near its primary leads and crimp but do not solder the primary leads to its lugs. Route the ac line cord through a hole you drill in the enclosure's rear panel and tie a strain-relieving knot in it about 5 inches from the free end inside the enclosure. Tightly twist together the fine wires in each conductor and tin with solder. Solder the conductors to the lugs of the terminal strip.

Plug the transformer's secondary leads into the TI SECONDARY holes in the main board and solder into place. Set the main board into place inside the enclosure but do not fasten it down.

Now plug the conductors at the free end of the ribbon cable into the holes in the pendulum board (again from the rear of the board) labeled A through H and TO MAIN BOARD and solder into place. Match letter designations between boards. Set this board in place inside the enclosure, without fastening it down.

Accurately locate and drill the holes for the pushbuttons on the three pendulum board switches through the fronting plastic sheet.

Checkout & Use

With the ICs still not installed in their respective sockets, plug the clock's line cord into an ac receptacle. Clip the common lead of a dc voltmeter or multimeter set to the dc volts function to a convenient circuit-ground point. Then use the meter's "hot" lead to probe pin 14 of the 14-pin sockets and pin 16 of the 16-pin sockets. In all cases you should obtain a reading of about +9 volts.

If you do not obtain a +9-volt reading at any of the specified pins, use the meter's "hot" probe to check the reading at the positive (+) lead of *C1* on the bottom of the main board. If you still do not obtain a +9-volt reading at this point, check the wiring of the power-supply circuitry and especially the orientations of *D1* through *D4*.

If you fail to obtain the +9-volt reading at only one or a few IC sockets, power down the project and troubleshoot it to isolate and rectify the problem. Do not proceed until you are certain that the problem has been rectified.

Once you are certain the the project has been wired properly, power it down and allow the charge to bleed off *C1*. Then carefully install the ICs in their respective sockets. Make sure you orient each IC as shown and that no pins overhang the sockets or fold under between ICs and sockets. Also, since the ICs used in this project are CMOS devices, handle them with the same precautions you would with any other MOS device to prevent damaging them from static electricity.

Plug the project's line cord back into the ac receptacle and observe its LED display. If no LEDs are on, check the power supply for proper wiring. If everything appears to be operating as it should, the pendulum should begin "moving" (its LEDs cycling back and forth) and at the end of each "swing," the seconds LEDs should increment in the clockwise direction one LED at a time.

Pressing and holding SECONDS HOLD pushbutton switch *S1* should halt the advance of the seconds LEDs and turn on the one LED at the 12 o'clock position. Doing the same with MINUTES SET pushbutton switch *S2* and HOURS SET pushbutton switch *S3* should cause the LEDs in the minutes and hours rings, respectively, to advance in the clockwise direction at a rate of once per second. If you obtain these results, the clock has been properly wired.

Once you have ascertained that the clock has been correctly wired, press and hold the MINUTES SET button and observe the display to check that all 60 LEDs light in proper sequence. Allow the LEDs to cycle completely around the dial face three or four times. Then do the same for the HOURS SET switch and the 12 LEDs that make up the hours ring.

If a "trailer" appears in either display, there is probably a leaky LED in the string. To isolate this LED, note if more than one group of 10 LEDs comes on. If so, there is more than one leaky LED. In any case, finding it or them is a relatively easy process. As the turned-on LED "moves" around the dial face, a leaky one will not turn on when it is supposed to.

If a LED is installed in the wrong polarity, the group of 10 LEDs in which it appears will will light rather brightly, but the reversed one will not light at all. If more than one second, minute or hour LED lights when the clock is first powered up, press and hold the SECONDS HOLD button and advance the minutes and hours LEDs by pressing the appropriate SET buttons. This should clear out the counters and allow them to operate in the normal manner.

Once you have your clock working as it should, power it down. Secure the two circuit-board assemblies in place with No. 6 × ½-inch wood screws. Then assemble the enclosure. Set the clock in the location where it will remain and plug its line cord into a convenient ac outlet.

Now set the time. To do this, press and hold the SECONDS HOLD button and then the HOURS SET button until the appropriate LED in the hours ring is lit. Release the HOURS SET button but not the SECONDS HOLD button and press and hold the MINUTES SET button until the appropriate minute LED is lit. Go one minute past the actual time before you release the MINUTES SET button. Continue to hold the SECONDS HOLD button until the exact second arrives to release it. Your clock will now continue to count off seconds, minutes and hours with the precision of the ac line and will continue to do so for as long as ac power is applied to it.

When the time comes to set the clock forward or back one hour in the spring and fall, simply press and hold the SECONDS HOLD button as you advance the hours indication to the proper hour. Then set the minutes display one minute ahead. Release the SECONDS HOLD button at the exact second to start the new minute. ME