A Multi-Channel TTL Logic Tracer

Digital test instrument incorporates six "logic-probe" channels and can be expanded as needed

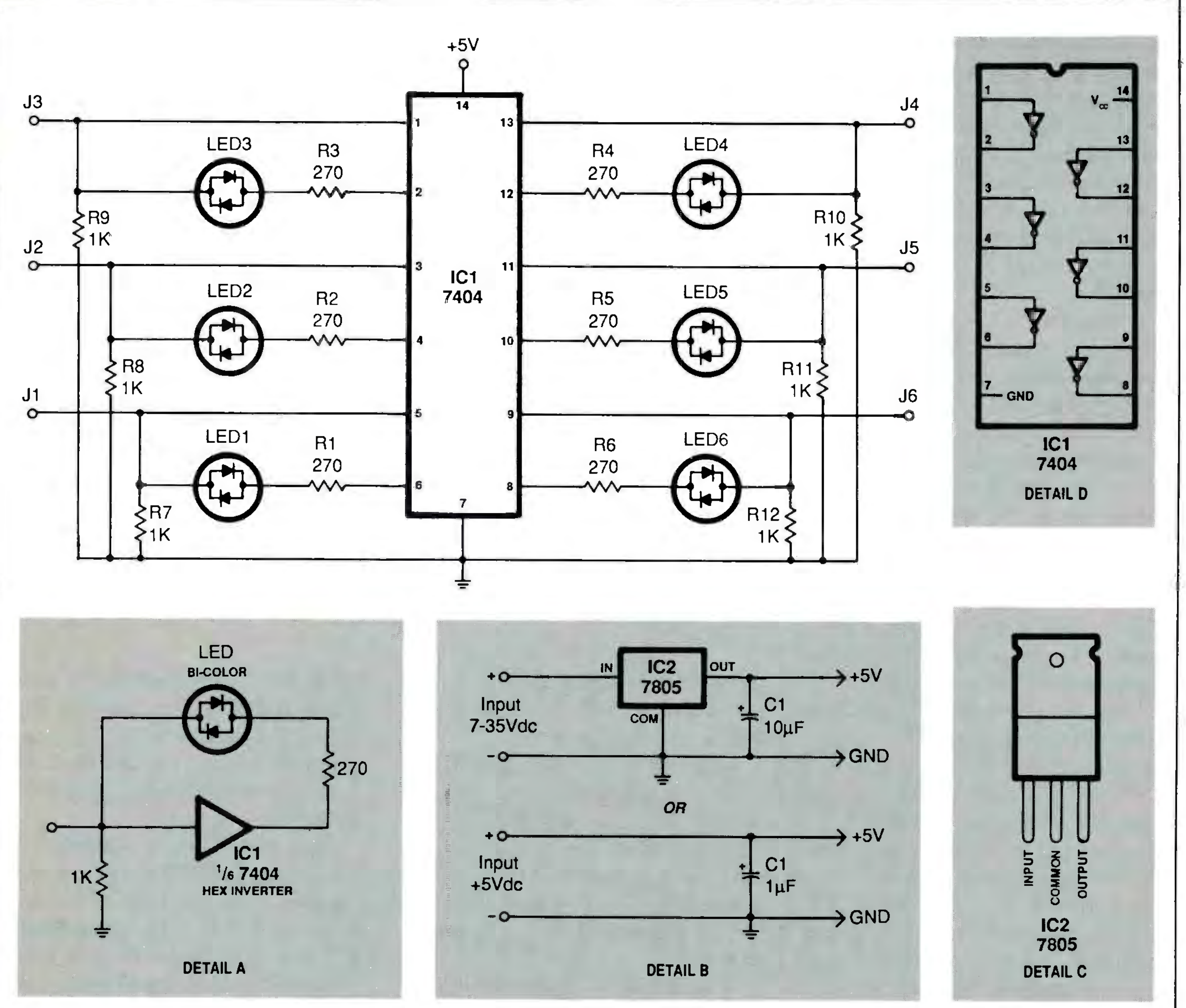
By Peter A. Lovelock

A simple logic probe that uses different-color visible indicators (usually LEDs) to tell you when a point under test in a circuit is high, low or pulsed is certainly a valuable tool in digital signal tracing. Its value, however, is limited because it is restricted to use on only one test point at a time. In many modern digital circuits, however, more than one point must be monitored simultaneously for meaningful tracing to be effected. To do this, of course, you could use multiple logic probes, but this is both cumbersome and expensive. My solution was to design a low-cost multiple logic probe that I call a "Logic Tracer." It is described in detail below.

Before designing the Multi-Channel TTL Logic Tracer discussed here, I examined a commercial logic probe. A look inside convinced me that the nine transistors and lots of other components it contained was not the way to go. What I ended up with was an elegantly simple circuit that gave me six test inputs and could be expanded as needed. The basic circuit contains only one hex-inverter IC, six bi-color LEDs and 12 resistors. It gives indications of high, low and pulsed conditions and operates reliably at frequencies up to about 1 MHz. Perhaps best of all, the entire project can be built for about the cost of just one standard commercial single-point logic probe from components purchased locally.

About the Circuit

The entire Multi-Channel TTL Logic Tracer schematic diagram is shown in Fig. 1, along with several Details that clarify circuit operation, powering options and IC pinouts and internal details. As the main schematic diagram shows, the project is built around a commonly available TTL hex inverter, *IC1*. Each channel's inverter also requires two resistors and a single bi-color (red/green) light-emitting diode. Six channels are possible with a single 7404 hex inverter.



PARTS LIST

Semiconductors
IC1—7404 TTL hex inverter
IC2—7805 + 5-volt regulator (optional —see text)
LED1 thru LED6—Bi-color (red/green) light-emitting diode (Radio Shack Cat. No. 276-035)
Capacitors
C1—10-μF, 10-volt tantalum
Resistors (¼-watt, 10% tolerance)
R1 thru R6—270 ohms
R7 thru R12—1,000 ohms
Miscellaneous
J1 thru J6 - Banana or pin jack

Double-sided printed-circuit board or perforated board and suitable soldering or Wire Wrap hardware; six banana or pin jacks; 14-pin DIP socket or Molex Soldercons® for IC1; project box (Radio Shack Cat. No. 270-231 or other 4″ × 2⅛″ × 1⅝″ box with removable aluminum panel); six micro test clips (Radio Shack Cat. No. 270-355); 2 miniature alligator clips with insulating boots; small rubber grommets (see text); plug-in wall 7- to 35-volt dc power supply and mating jack (optional—see text); dry-transfer labeling kit; clear spray acrylic; 4-40 × 1¼″ machine screws, lockwashers and nuts (2 sets); ¾″ spacers (2); red- and black-insulated test cable; hookup wire; solder; etc.

Note: The following items are available from R.&R. Associates, 3106 Glendon Ave., Los Angeles, CA 90024: Double-sided pc board with plated-through holes, $4.50; Kit of parts for six-channel Tracer, including pc board, $10.00 plus $1.50 P&H. California residents, please add state sales tax.

Fig. 1. Complete schematic diagram of Multi-Channel TTL Logic Tracer and single stage (Detail A), dc powering options (Detail B) and internal details/pin- outs for ICs.

If additional channels are needed, you can simply add as many 7404 hex inverters, resistors and LEDs as are needed. For example, if you need an 8-channel Tracer, use two 7404s, 16 resistors and eight LEDs. A 16-channel Tracer requires three 7404s, 32 resistors and 16 LEDs, while a 32-channel Tracer requires six 7404s, 64 resistors and 32 LEDs. In these three examples, not all inverters in all 7404s are used. The unused ones can be disregarded, or they can be wired as extra channels that can be called into use as needed.

Since all channels in the Logic Tracer are identical, it is easier to refer to Detail A to examine how the project works. As you can see, each inverter is accompanied by a bi-color LED and 270-ohm current-limiting resistor connected between the inverter's input and output and a 1,000-ohm pull-down resistor from the input to circuit ground.

Depending on the polarity and frequency of the input signal to any given channel, the bi-color LED will give a different color indication. If a logic 1 of near +5 volts is applied to the input of the inverter, the output of the inverter will be at a logic 0 or near ground potential. With the LED connected as shown to both the input and output of the inverter, the low at the output will cause current to flow through only the red element inside the LED. On the other hand, if the input to the inverter is a logic 0, the output will be a logic 1, reversing the flow of current through the LED and causing the green element to light. Consequently, when the red element is on, the logic level at the point under test is high and if the green element is on, it is low.

In many cases, the signal at a point under test will not be a constant logic 1 or logic 0 but a pulse train. If the pulse train is very slow (less than about 10 Hz) you will see the red and green elements alternately coming on as the pulse train goes to high and then to low. On the other hand, if the pulse train is faster than about 10 pulses per second, both LEDs will appear to be on simultaneously. Your eye's vision retentivity will then resolve the effective color to be anywhere between yellowish-green and reddish-orange, depending on the duty cycle of the pulse train. If the pulse train has a 50-percent duty cycle, the effective color will be nearly all yellow.

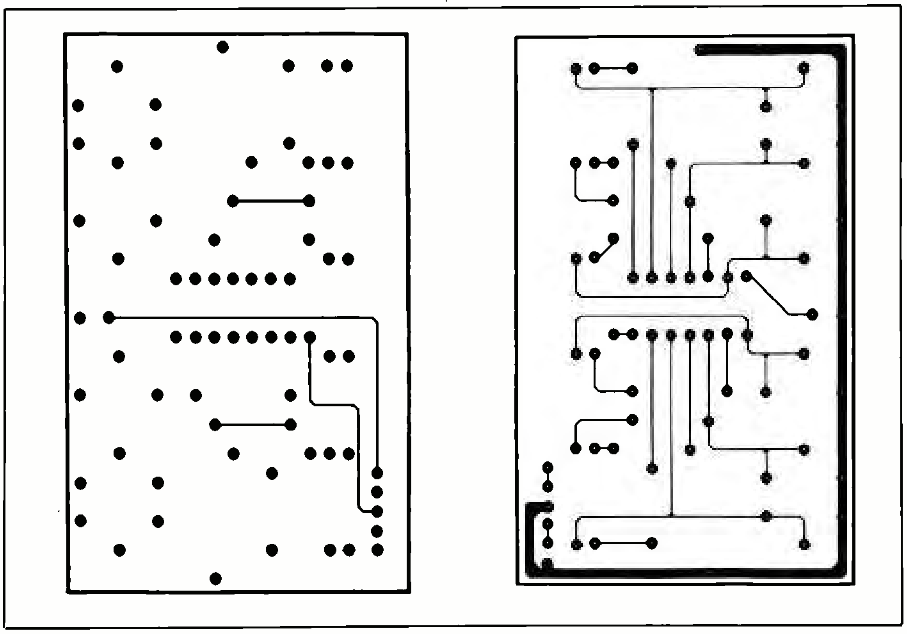


Fig. 2. Actual-size etching-and-drilling guides for top (left) and bottom (right) of double-sided printed-circuit board.

With no input applied to the inverter, no voltage difference will exist across the LED. In this case, neither element in the LED will light. A stable state is maintained by the 1,000-ohm pull-down resistor.

Since this Tracer deals with TTL levels, it requires a single +5-volt to ground power source. If only 12 or fewer inverter/LED stages are built, you can power the project directly from the power rails of the circuit under test as long as the current drain is limited to 100 milliamperes or less. If more channels are used, it is safer to power the project independently of the circuit under test. In this case, you can use a plug-in wall power supply and voltage regulator capable of delivering sufficient current to safely handle the load. These powering options are shown in Detail B. In both cases, make sure to use the 10-microfarad, 10-volt tantalum capacitor for decoupling.

Note that Detail B indicates that you should use only one of the powering options—not both. If you wish to use both, however, make certain that you connect the direct +5-volt power input into the circuit on the *output* side of the 7805 *IC2* regulator. With this arrangement, you need only one tantalum decoupling capacitor. This arrangement gives you a choice of powering options so that you can use the separate power supply if you are working on a very-low-power TTL circuit.

Detail C gives such information as the internal function information and pinouts of the 7404 hex inverter used for *IC1* and the pinouts of the 7805 +5-volt regulator used for *IC2*.

Construction

Owing to the basic simplicity of the project in terms of component count and the fact that component layout is not critical, you can wire the Multi-Channel TTL Logic Tracer by any traditional means that suits you.

You can etch and drill your own double-sided printed-circuit board using the actual-size etching-and-drilling guides shown in Fig. 2 (or purchase a ready-to-wire board with plated-through holes from the source given in the note at the end of the Parts List). Alternatively, you can assemble and wire the project on a perforated board that has holes on 0.1-inch centers using suitable solder or Wire Wrap hardware. In either case, a socket is recommended for each 7404 hex inverter used.

If you etch and drill your own pc board, you will likely not be able to plate-through the holes. Therefore, you must make sure that you solder all wiring and component leads and pins to the copper pads on *both* sides of the board to assure that all connections are properly made. There are also four jumper points on the board, indicated by the letters A through D in Fig. 3, that require short lengths of solid bare wire or cut-off resistor lead to be inserted into each hole and be soldered to the pads on both sides of the board. Of course, if you prefer to avoid having to deal with the problems of a double-sided pc board that does not have plated-through holes, you can simply etch a single-sided board with just the bottom etching guide and replace the four solid conductors shown in Fig. 3 with physical insulated wire jumpers in the usual manner.

There is only one potential wiring difficulty with regard to using a home-made pc board that does not have plated-through holes. That is that you cannot use a conventional IC socket with molded plastic housing for *IC1*. However, the problem is easily solved simply by using strips of Molex Soldercons® in place of the socket. Simply cut or flex the Soldercons into two strips of seven socket pins each and plug one strip into one

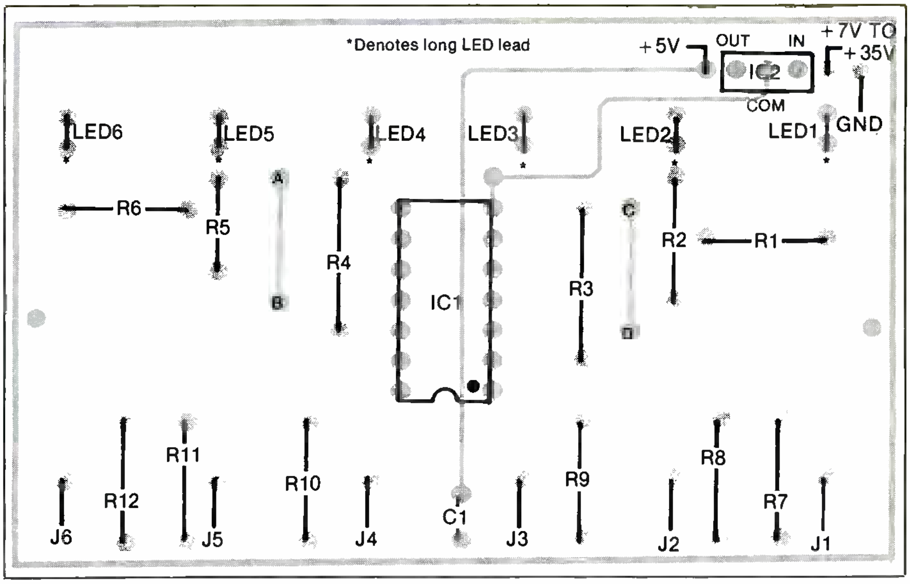


Fig. 3. Wiring guide for pc board. Use this as a rough guide to component locations and layout if project is assembled on perforated board.

set of IC1 holes in the board from the component side.

Turn over the board and solder the protruding pins to the copper pads, making sure to keep the Soldercon socket strip vertical on the component side of the board. Turn over the board and solder the sockets to the pads on the top of the board. Use solder sparingly to avoid clogging the socket pins as you solder them to the top of the board. Then flex the connecting strip free of the socket pins. Repeat for the other Soldercon strip.

From here on, we will be discussing assembly of the project on a printed-circuit board. If you opt for perforated board, lay out the circuit components as close as possible to that shown in the Fig. 3 pc wiring guide.

Start wiring the pc board by installing the IC socket (or Soldercons) and following with the resistors and the tantalum capacitor. If you are using a board with plated-through holes, simply solder each lead from the bottom of the board; capillary action will "wick" the solder into the holes and slightly mound it on the top pads and leads. If you are using a double-sided board that does not have plated-through holes, make sure you solder each lead to the pads on *both* sides of the board to complete the circuit. Do *not* install the bicolor LEDs at this time.

Decide now if you are going to power the project directly from the supply rails of the circuits that will be tested, by its own separate power source or to give you a choice of either one or the other.

If you plan on powering the project directly from the supply rails of the circuits you will be testing, strip ⅜ inch of insulation from both ends of 36-inch lengths of red- and black-insulated test-lead wires. Tightly twist together the fine conductors at both ends of both wires and sparingly tin with solder.

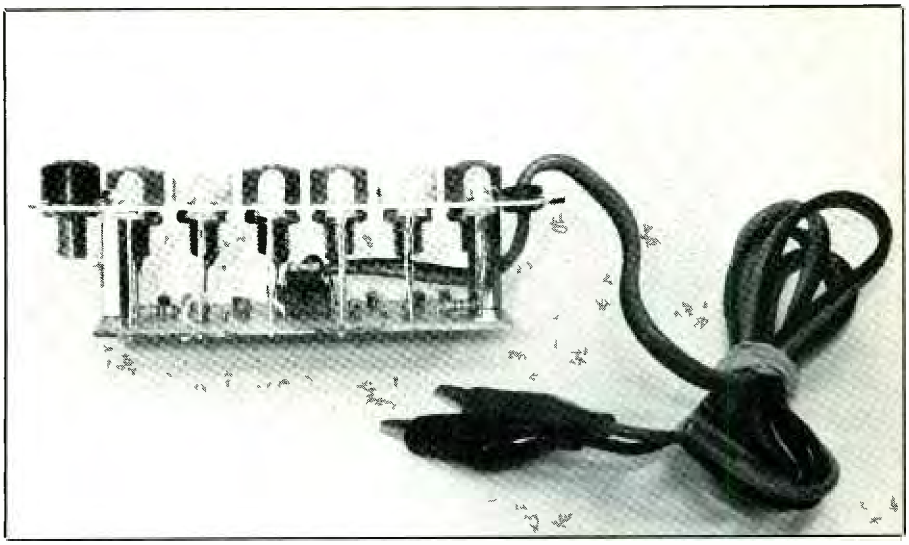
Plug the one end of the red-insulated wire into the hole labeled +5V and solder into place on both sides of the board. Repeat with the black-insulated wire and the hole labeled GND. The other ends of these wires will be terminated after the circuit-board assembly has been installed inside its enclosure. (Note: regardless of which powering option you plan on using, you must make provisions for the black-insulated test lead to serve as a ground reference for the project when making circuit tests.)

If you opt for a separate power supply or a choice of either, replace the 36-inch red-insulated wire with a 4- to 5-inch wire, and prepare a second same-length black-insulated wire in the same manner. Once again, solder just one end of each wire into the appropriate holes, leaving the other ends for connection later on.

Strip ⅜ inch of insulation from both ends of six 4-inch lengths of hookup wire. If you are using stranded hookup wire, tightly twist together the fine wires at both ends and sparingly tin with solder. Plug one end of each wire in turn into the holes labeled J1 through J6 on the circuit board and solder to the pads on both sides of the board. The other ends of these wires will be connected later. Temporarily set aside the circuit-board assembly.

A suitable enclosure in which to house the project is specified in the Parts List. This is a small plastic project box that has a removable aluminum panel. Unless you opt for a separate power supply or a choice between both powering options, all machining of the enclosure is performed by drilling holes in suitable locations through the aluminum panel of the project box.

Using the Fig. 4 template as a guide, machine the panel exactly as shown. There are separate holes for each LED and test-lead banana or pin jack, the +5-volt and ground power leads and the mounting holes for the circuit-board assembly. If you plan on using a separate power supply exclusively, do not drill the ¼-inch hole shown on the center axis at the left end of the panel. Once all the holes have been drilled, deburr them to remove sharp edges. (Note: You can save on the cost of the project by eliminating the banana or pin jacks, replacing them with small rubber grommets through which the test leads enter the enclosure and wire directly and permanently to the board.



Circuit-board assembly mounts with component side toward rear of front panel so that lenses of LEDs can drop into their respective holes.

If you do this, make sure to tie strain-relieving knots in the test-lead wires inside the enclosure.)

Feed a No. 4-40 × 1¼-inch machine screw into the small holes on the central axis and follow up with a ¾-inch spacer. Plug the leads of the bi-color LEDs into the holes in the circuit board, making sure that the long leads go into the holes near *IC1*. Plug the free ends of the screws into the board's mounting holes and follow up with a machine nut on each. Make sure the component side of the board is facing toward the inside surface of the panel and that it is oriented so that the LEDs are on the side that matches up with their holes in the panel. Make the machine hardware finger tight.

Without allowing the LED leads to fall out of their holes in the board,

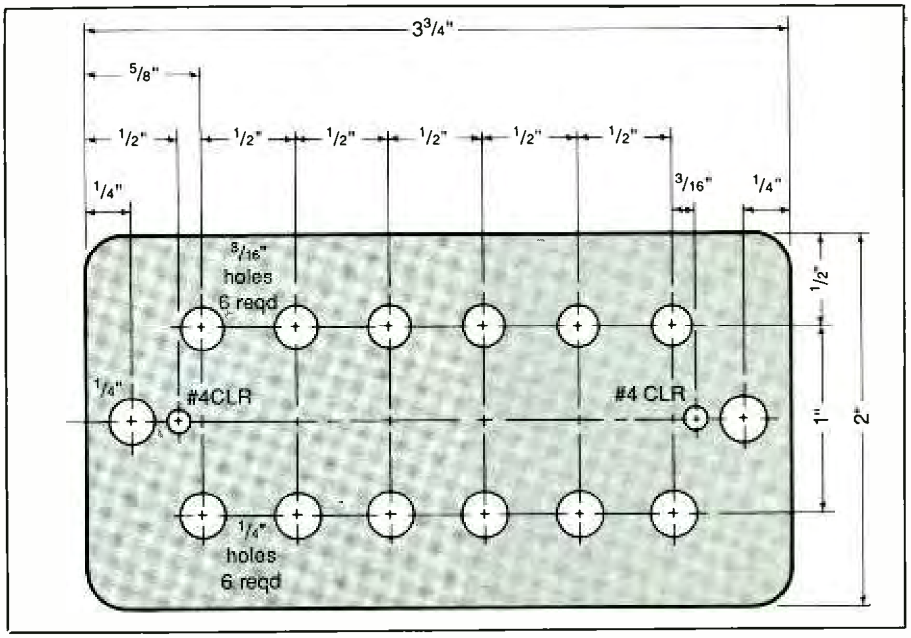


Fig. 4. Front-panel machining details.

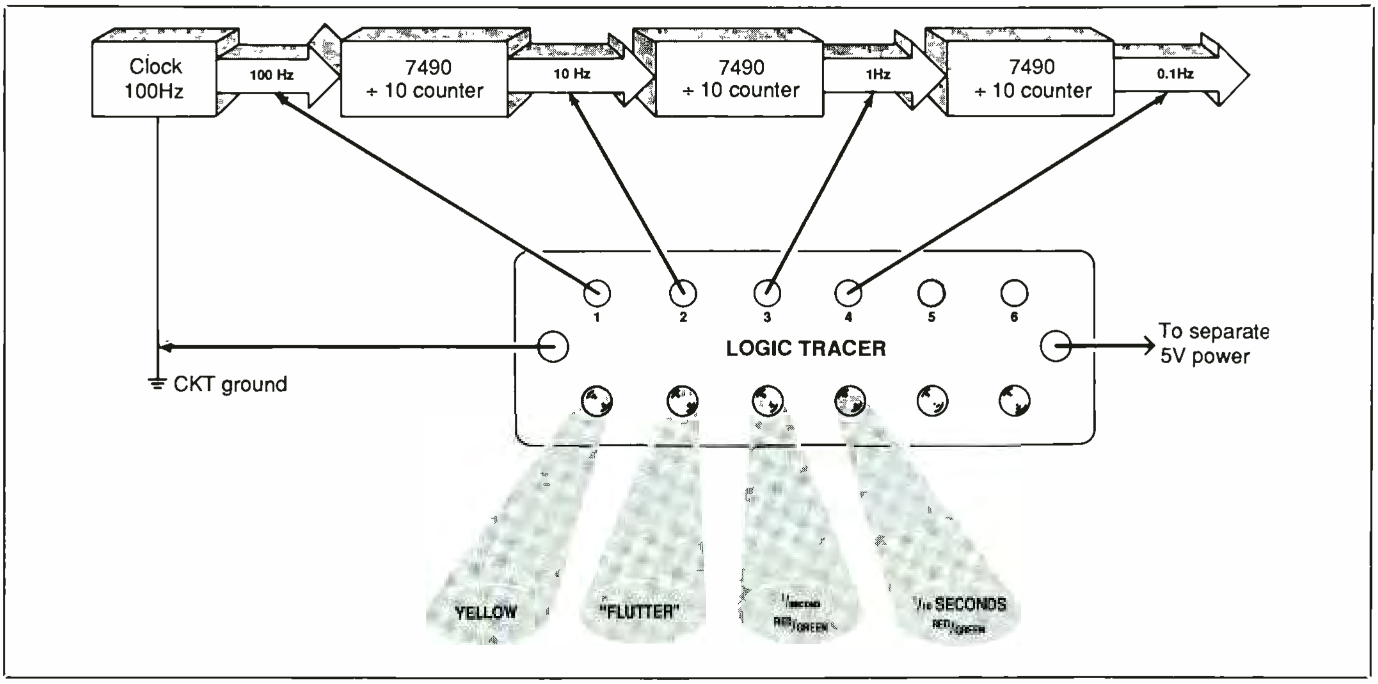


Fig. 5. Simple sequential logic application setup for using project.

invert the assembly so that the bottom side of the circuit board is facing up. Then gently push the lensed end of each LED into its respective hole in the panel. Holding the LEDs solidly against the panel, solder one lead of each to the pads on the bottom of the board. Turn over the assembly to check alignment from the front of the panel. If everything appears to be okay, solder the other lead of each LED to its bottom-of-the-board pad.

Remove the machine hardware and set it and the spacers aside. Gently remove the front panel from the circuit-board assembly, taking care to avoid displacing the LEDs from their current positions. Carefully solder the lead near *IC1* of one LED to its pad on the top of the board. Repeat for each LED in turn. Then do the same for the leads nearer the edge of the board. Make sure you do not move any of the LEDs as you do this. Lay aside the pc assembly.

Scrub the aluminum panel to remove all dirt, grease and other debris. When it is completely dry, label the panel with a dry-transfer lettering kit. For example, you might center the legend INPUTS above the line of banana or pin jacks that will be used to plug in the test leads (or the grommets for the test leads). Just below them, you can label the jacks 1 through 6. Similarly, you can label the legend CHANNELS below the LED holes and label above each hole the numbers 1 through 6 in the same sequence used for the jacks. Finally, label the left central hole +5 VOLTS and the right central hole GND. Leave enough room between hole edges and labels to clear grommets and jacks.

When all labeling is done, apply two or three *light* coats of clear acrylic spray lacquer over the entire front panel to protect the labeling from damage. Wait until each coat is fully dry before spraying on the next. After the last coat has completely dried, mount the banana or pin jacks in their respective holes and gently force small rubber grommets into the power-lead holes.

Remount the circuit-board assembly on the front panel, using the 4-40 machine hardware and spacers you used before, but place a lockwasher on each screw before screwing on the nuts. Make sure each LED aligns with and slides into its respective hole in the panel. Apply a drop of Krazy glue to each LED to secure it in its panel hole.

Locate the free ends of the short wires and connect and solder them to the lugs on their respective banana or pin jacks. Tie a double knot in the red and black test-lead wires about 5 inches from the ends connected to the circuit board and feed the free end of the red wire through the grommet in the hole labeled +5 VOLTS and the black wire through the grommet in the hole labeled GND.

If you do not plan on using the separate power supply option in the project, this completes construction but for terminating the power leads and preparing the test leads. If you are incorporating this option, install and solder into place on the circuit board the 7805 voltage regulator, making sure it is properly oriented before soldering its pins to the pads on both sides of the board.

(Continued on page 89)

TTL Logic Tracer *(from page 35)*

Drill a hole in one wall of the plastic enclosure to mount the jack for the power supply in a location where it will not interfere with the circuitry. After mounting the jack, locate the free ends of the red- and black-insulated wires and solder them to the appropriate lugs on the jack.

If your project is to have both powering options, prepare red- and black-insulated test leads as described above. Tie double knots in each about 6 inches from one end. Connect and solder these leads *and* the shorter leads coming from the board to the appropriate lugs on the power jack. Be sure to observe color coding. Then feed the free ends through the appropriate grommet-lined holes in the front panel.

Terminate the +5-volt and GND leads in miniature alligator clips with insulating plastic boots. Finally, strip ¼ inch of insulation from both ends of six 36-inch-long miniature test lead wire. Tightly twist together the fine wires at each end and sparingly tin with solder. Connect and solder to one end of each lead a banana or pin plug, depending on the type of input jacks you are using. Terminate the other ends in plunger-type micro test clips.

Checkout & Use

Once the project is completely assembled, check all soldered connections for poor soldering and solder bridges between closely spaced pads (especially around the ICs) and conductors. If you suspect any connection, reflow the solder on it. Then check all component locations and orientations.

If everything looks okay, connect the power leads to a 5-volt dc supply (or use the separate power supply if this was your option) to the project. If you are not taking power from the circuit under test, clip the GND test lead to the circuit's ground to provide a reference for the project.

Plug a test lead into INPUT jack 1 and touch its micro test clip to some point that is at ground potential in the circuit under test; the CHANNEL 1 LED should light and glow green in color. Now, touching the test clip to and +5-volt point in the circuit should cause the same LED to glow red. If the LED colors are opposite from what is expected, the device is installed backwards and must be removed from the circuit and be reinstalled in the proper polarity. Repeat this test for all channels.

If any of the LEDs glows slightly red when no input is applied to its channel, try adjusting the value of the 1,000-ohm pull-down resistor in that channel. If the LED will not completely extinguish no matter what value of pull-down resistance is used, replace it with a new one.

When everything checks out okay, disconnect and power down the project. Drop the panel/circuit-board assembly into the plastic enclosure and secure it in place with the screws provided with the project box.

Application Example

Shown in Fig. 5 is a typical example of how the Multi-Channel TTL Logic Tracer is used. A 100-Hz clock is connected to three divide-by-10 counters in series with each other. With INPUT probe 1 connected directly to the clock's 100-Hz output, the CHANNEL 1 LED will glow yellow (assuming a 50-percent duty cycle for the clock pulses). With INPUT probe 2 connected to the output of the first 7490 decade counter, where the frequency is 10 Hz, the CHANNEL 2 LED will flicker between red and green at a fairly rapid 10 times per second. With INPUT probe 3 connected to the output of the second 7490 counter, where the frequency is 1 Hz, the CHANNEL 3 LED will alternate between red and green at the much more sedate pace of once each second. Finally, with INPUT probe 4 connected to the output of the last counter, where the frequency is now 0.1 Hz, the CHANNEL 4 LED will alternate between red and green at an almost glacial rate of once every 10 seconds.

The arrangement depicted in Fig. 5 is an example of a sequential logic application. The Multi-Channel TTL Logic Tracer is also useful for keeping tabs on goings on in simultaneous logic situation, such as moment-by-moment events on a multiline logic bus as in a computer or process-control system. It can even be used in systems where you want to monitor random events that are not synchronized either sequentially or simultaneously or in two or more unrelated logic circuits. Of course, at those times when you need only single-point tests, you can use the Tracer as an ordinary logic probe as well. ME

"Smart Box" *(from page 48)*

As you use the Smart Box, remember that when *LED1* is on, the compressor is enabled if the air-conditioning system is calling for cooling. After driving a few miles with the A/C on, you will be able to select the precise adjustment of *R17* that is just right for you.

When you park your vehicle in full sunlight on a very hot day, set *S1* to BYPASS until the passenger compartment becomes cool. The BYPASS mode allows your A/C to operate at maximum cooling and is indicated by *LED2* turning on. This BYPASS LED alerts you to the fact that your A/C is running without the economy and engine-strain-relief benefits of the Smart Box. So switch back to the alternate position of *S1* when the passenger compartment is at a comfortable temperature to reap the rewards of this project. ME