Digital IC TESTER

Need to identify unmarked IC's? Check out "defective" ones? Learn how digital-logic circuits work? The Programma III, which you can build for about $100, will do all that and more.

UNTIL RECENTLY, IC TESTERS HAVE BEEN a rarity in electronics labs, and that is unfortunate because they can be so helpful—in identifying unmarked IC's, in checking for defective ones, as training devices, etc. Sad to say, they are frequently expensive, and often require other test equipment to perform their functions. But meet the Programma III digital-IC tester! It allows you to check IC's at a breakthrough low cost, and replaces several pieces of test equipment—all in one neat package.

The device was originally designed for use in identifying unknown IC's, but it seems as if every day a new use pops up for it. For example, a cable was made up using a 16-pin IC test-clip and DIP header. The header is plugged into the test socket on the IC tester, and the clip snapped over a suspect IC in another piece of equipment. The result is a low cost "logic anayzer," or a device that will display many logic states at once. That can speed up troubleshooting immeasurably in many cases. Commercial logic analyzers cost thousands of dollars, while ours costs a tiny fraction of that. More on applications later!

The Programma III has many novel features that help to make it versatile as well as low-cost. A "zero insertion force" (ZIF) test-socket is used so that components can be easily inserted and removed without bending or breaking leads. That's important—you know how easy it is to break a pin.

Connections to each pin of the test socket are made via an array of jacks. For each pin there is a jack that can be connected either to ground, a pulse signal, or +5 volts. Standard miniature phone-plugs, similar to those used on transistor radios, are plugged into the jacks, applying the desired signal or voltage, or shorting the IC-pin to ground. As a bonus, components may be wired to the plugs, allowing you to build up actual circuits for testing parts. (Good examples would be the NE555 timer, and any one-shot.) The pulse signal just mentioned can be used to increment counters or registers. It is produced by pressing the PULSE button.

Finally, the logic-level display is unique. It uses tri-color LED's to show the status of each IC pin, with red indicating a logic-high, yellow indicating a pulse condition, and green indicating a logic-low. Those features combine to make the Programma III a device that is invaluable in your work with digital IC's.

The construction of the Programma III is something special. The front panel is a PC board! That gives you a finished project that looks just like the one shown in the photographs, and there is no tedious lettering of the jacks required. In addition, the lettering on the board resists wear far better than any transfer-type lettering can. The "panel-board" concept makes project building easier, and the final result looks first rate. Inside, the panel-board greatly simplifies the wiring, as all wire connections are made directly to the jacks.

The display electronics are also something special. You'll be surprised to dis-

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cover that there are only seven IC's in the whole unit! They are all standard, low-cost parts, which makes them easy to find. In addition, this is probably one of the first projects you've seen that uses a VMOS power FET. It does a superior job in the pulse-generator section, and allows pulses to swing the full five-volt range. The display electronics mount on a separate PC board, and simply plug into the panel-board, further simplifying construction.

How it works

The Programma III owes its unique features to some clever applications of standard IC's. Let's look at the circuit before starting construction.

The device is built on two PC boards, which we'll call the panel board and the display board. The larger board, which contains the IC test-socket and the jacks, is the panel board; the smaller board, which contains the LED's and IC's, is the display board. Be sure to keep those distinctions in mind as you read the circuit theory and assemble the project.

Display board

This is the smaller board, but since it contains the active circuitry, it will be discussed first. Refer to Fig. 1, and the schematic in Fig. 2, for details as you read about it. The display board contains a power supply, pulse generator, and a set of comparators. Figure 1 shows that circuitry in its basic form, but note that the IC socket, jacks, and switches are all on the panel board. You'll be surprised to discover that the display-board isn't much more complicated than its block diagram!

The power supply is simple, but has a clever twist. The IC tester may be powered by an unregulated 12–18-volts-DC source. That voltage runs the comparators and an IC audio amplifier, IC6. Now you may be wondering what a power amplifier is doing in a power supply—especially since nothing is connected to its input! But that IC has what the manufacturer calls a "self-centering output stage." That means it will effectively divide the power supply voltage by two, providing the LED's with the proper voltage. That neat little problem-solver replaces two power transistors and an op-amp, reducing the parts count...and cost.

Power for a standard five-volt regulator, IC5, is supplied through a resistor. The IC supplies regulated power for the pulse-generator circuit and for the IC being tested. Since it is possible to short the five-volt supply with a bad IC, or by misusing the tester, overload protection is built in; that's the job of the series resistor. You can draw up to 100 mA without affecting the five-volt power, but exceed that by much and the output voltage drops quickly. That voltage drop protects the unit from damage by overloads and the OVERLOAD LED lights up to indicate that

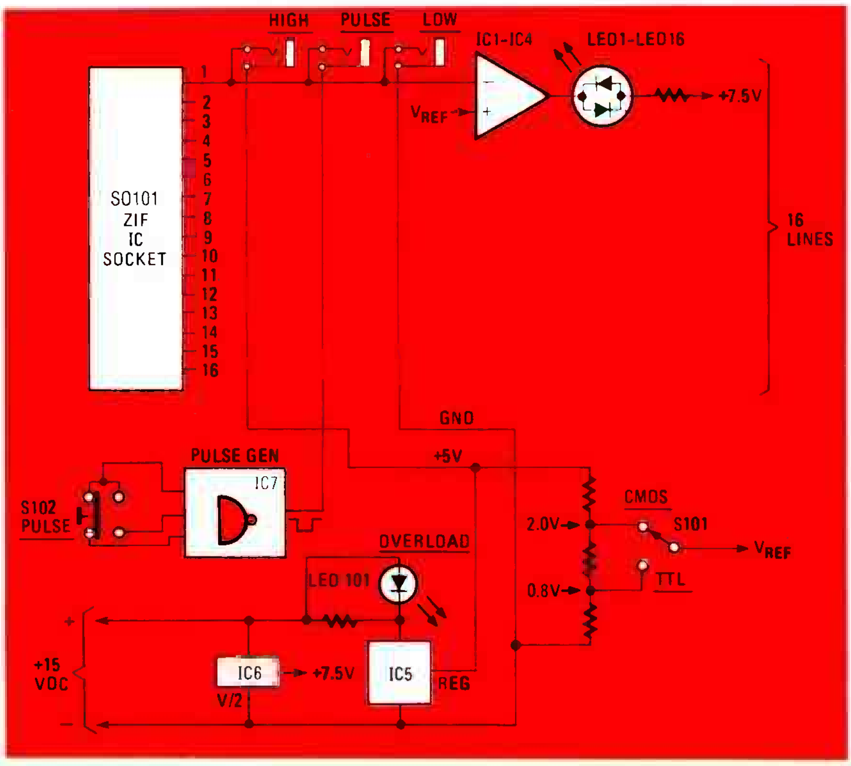


FIG. 1—SHORTING PLUGS inserted in jacks (shown at top) determine whether a logic-high, logic-low, or pulse is applied to each IC pin.

there's a problem.

Finally, the five-volt output is tapped to provide two reference voltages; those drive the comparators, which will be discussed shortly. The voltages correspond to the thresholds for TTL (0.8 volt) and CMOS (2.0 volts) devices. We want to know when the outputs from the IC being tested go above or below those values; if they don't, the part is defective.

The pulse-generator circuit is simple, and also a bit unusual. Refer to the schematic for details. It consists of NAND gates IC7-a and IC7-b, and Q1. The gates are wired as a "bounceless pushbutton"—a circuit that generates a single pulse each time the PULSE button is pressed. That's necessary because switch bounce can cause many pulses when the switch is pressed, and that makes checking flip-flops, counters, and registers impossible! The output from one of the gates switches a new device-type called a VMOS power FET, which features high input-impedance and high output-current. It is used to advantage in the circuit because it can bring the pulse line to within a few millivolts of ground. That insures more reliable switching of the IC under test, as conventional transistors may come as only close as 0.6 volt of ground.

The comparator circuit is as simple as the block diagram makes it out to be. It contains sixteen op-amp comparators, and each is driven by an IC test-socket pin. Type LM324's—with four comparators in each IC—are used, so the circuitry is contained in just four packages. The V_{REF} input goes to all comparators.

PARTS LIST—DISPLAY BOARD

All resistors ¼ watt, 5%, unless otherwise noted
R1, R2—10,000 ohms
R3—470 ohms
R4–R19—100,000 ohms
R20–R35, R40—1000 ohms
R36—68 ohms, 1 watt
R37—8200 ohms
R38—3300 ohms
R39—2200 ohms

Capacitors
C1—1000 µF, 25 volts, axial-lead electrolyic
C2–C7—0.1 µF, 25 volts, ceramic disc

Semiconductors
IC1–IC4—LM324N quad op-amp
IC5—MC7805 5-volt regulator
IC6—LM380N audio amplifier (14-pin package)
IC7—CA4011 quad CMOS NAND gate
Q1—VN10KM (Siliconix) VMOS power FET (Radio Shack 276-2070)
LED1–LED16—tri-color LED (see text)
SO1—16-pin IC socket

Miscellaneous: PC boards, 14-pin IC socket, solder, etc.

The following is available from Technico Services, PO Box 20HC, Orangehurst, Fullerton, CA 92633: set of two etched & drilled PC boards (IC-1), $30.00. Available from ABC Electronics, 2033 W. La Habra Boulevard, La Habra, CA 90631 is a set of all parts, *excluding PC boards* (IC-1P), $85.00. CA residents please add sales tax; foreign orders please add $3.00 for postage & handling.

That voltage is equal to the IC threshold-voltage, and comes from resistors connected across the five-volt power supply.

In operation, the comparators compare the voltages on the IC pins to V_{REF}. If the IC-pin voltage is greater, the output of the comparator will snap high. That connects the LED (through a current-limiting resistor) to + 15 volts, causing the red diode in the package to glow. On the other hand, if the IC-pin voltage is less than V_{REF}, the comparator output snaps to ground, causing the green diode in the package to glow. Just think of the comparator output as an SPDT switch; all it does is to switch one side of the LED to ground, or to + 15 volts. The other side of the LED stays at 7.5 volts. If the IC pin is pulsed rapidly, the two diodes in the LED package will turn on and off in turn and the colors blend to form yellow. A simple, but neat and elegant way to indicate logic levels, don't you think?

Panel board

The panel-board circuitry is restricted to just a few components. They include a switching matrix made up out of jacks, and a few switches. The arrangement for pin 1 is shown in Fig. 1. The wiring for the other pins from the IC socket are arranged in the same manner, with jacks from the HIGH, PULSE, and LOW lines connecting to it. Although it looks like quite a bit of wiring, the PC board simplifies things considerably. Furthermore, the connections to the display board are made using just two connectors. That makes construction, testing, and troubleshooting simple.

Assembly

We'll assemble the display board first. It isn't difficult, but it is important to follow instructions. The LED's, for example, must be installed *last*. They mount a fixed distance off the display board, and if you install them incorrectly, you won't be able to install the panel board! If you follow the directions, there should be no problem with assembly.

The first step is to obtain the parts. Since the display board is double sided, and tough to make, you may want to buy it from the source in the Parts List. Of course you may make your own using the artwork provided in Figs. 3 and 4. (The same goes for the panel board, which will be shown in the next part of this article.)

The IC's should be no problem, but be sure to use first-quality parts. If you scrounge the IC's from the junkbox, be sure to test them in an active circuit to make sure they are good. It's embarassing to build an IC checker and discover it won't work due to a bad IC! Actually, since the IC's this project uses are so inexpensive, I can't imagine why you wouldn't use factory-fresh IC's anyway. The extra cost of new parts is a lot less

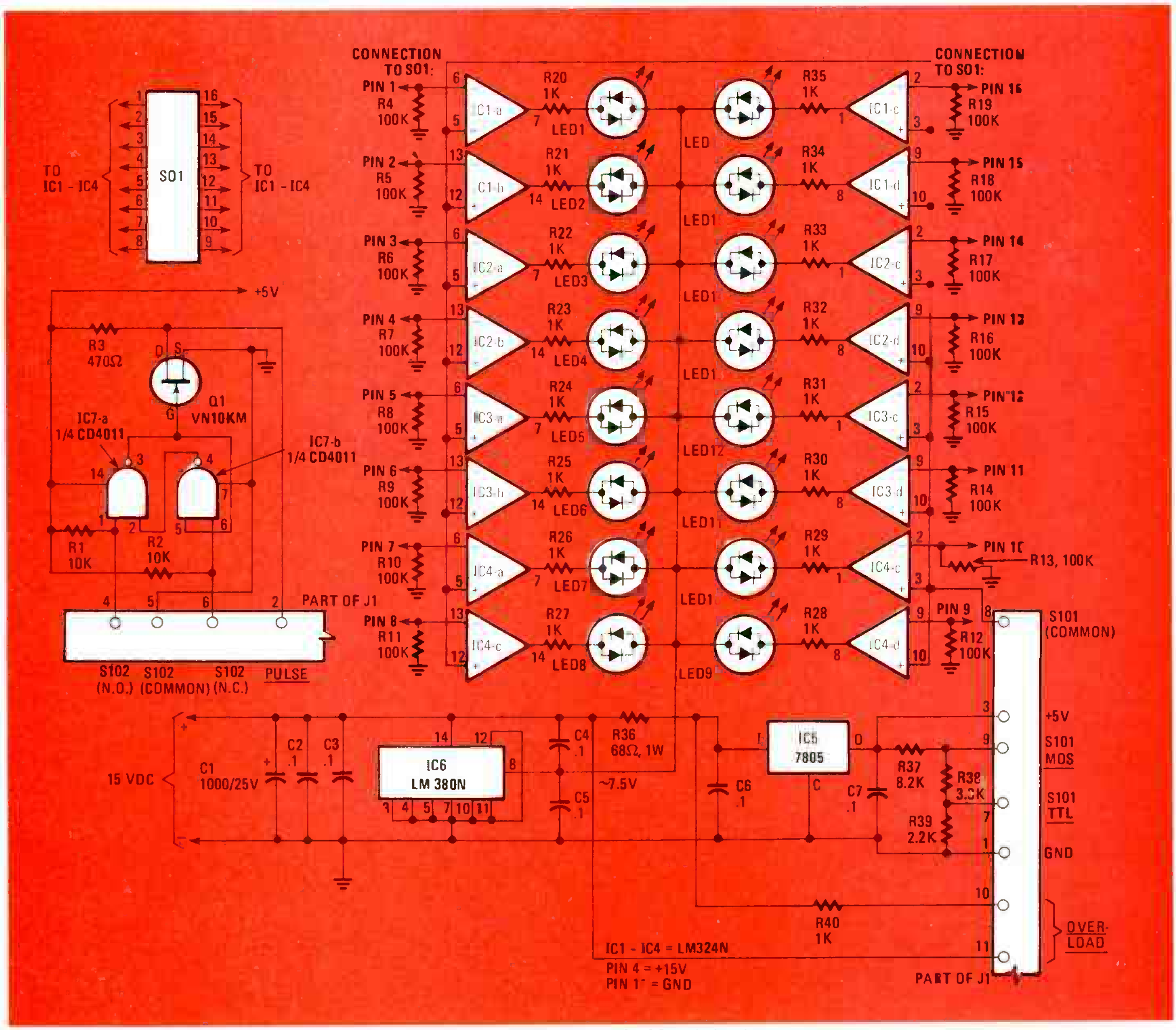


FIG. 2—VMOS POWER FET, Q1, permits test voltages to approach ideal TTL or CMOS logic levels.

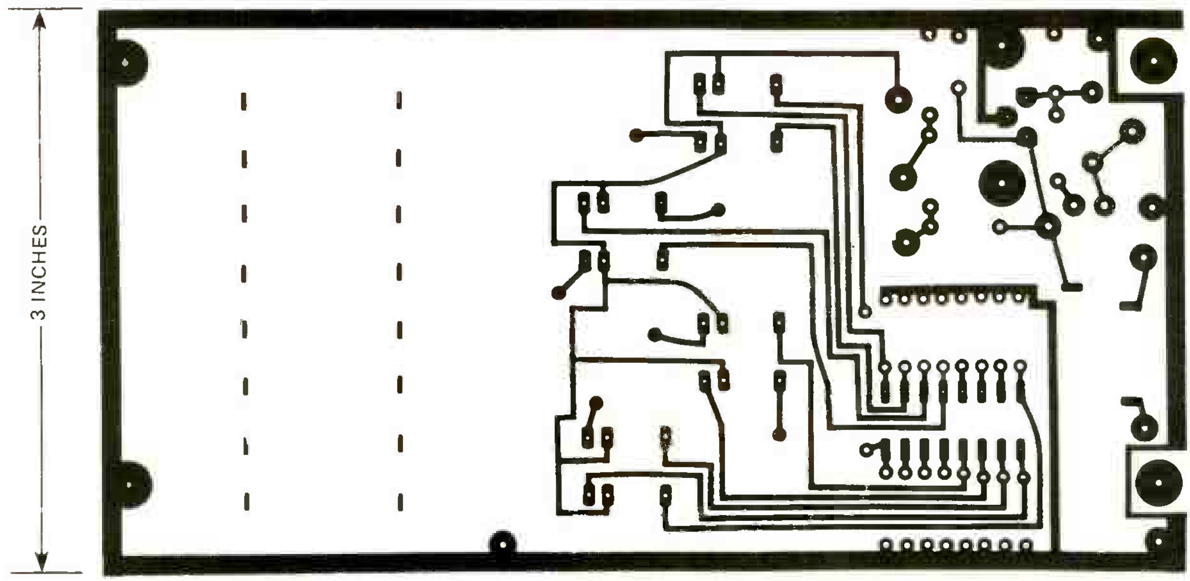


FIG. 3—THIS SIDE OF IC TESTER's display board is the one on which most components are mounted.

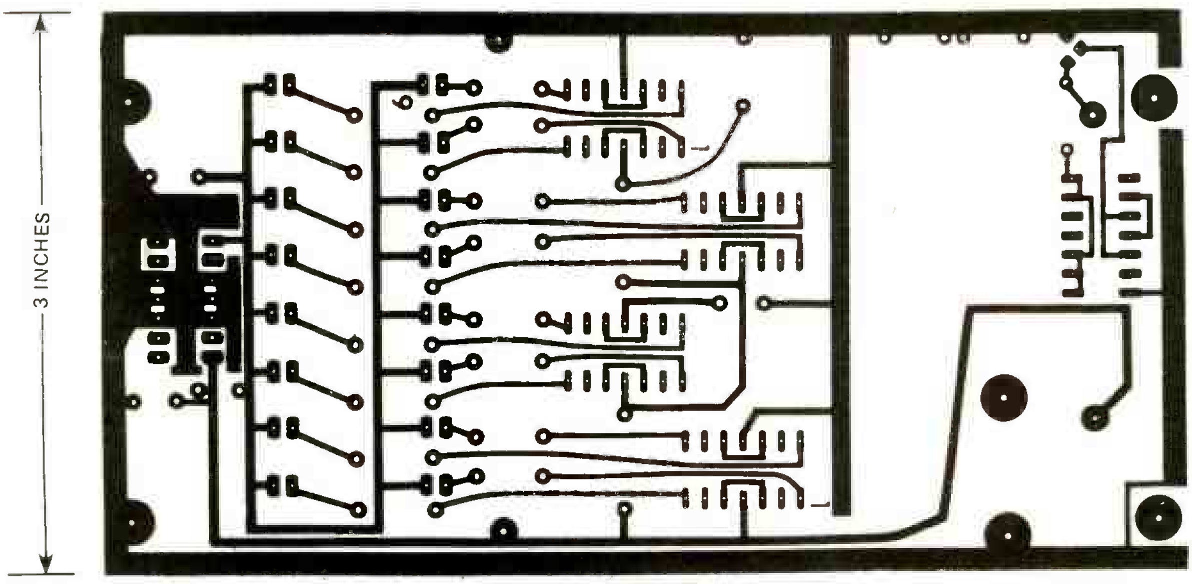


FIG. 4—"FOIL-SIDE" of display board. Note that, while board is double-sided, holes need not be plated-through.

bother than troubleshooting later on.

The LED's are important, too. There are several types of tri-color LED's on the market. The Programma III uses the kind with the two diodes in parallel, and as a result, the package has *two* leads. Another type of tri-color LED has the diodes in series, and the package has *three* leads. Stay away from that one; you want the two-leaded device. If you want to save money, you can substitute standard red LED's for the ones called for. The display won't look as elegant, because logic-low states won't be indicated, but you'll still get the information you need, and that's what counts.

Keep those tips in mind when shopping for parts. Since it is important to control costs today, keep them low by reading the ads in this magazine, comparing prices, and then buying from the best suppliers.

Once you have the boards and parts, it's time to get started. Refer to Figs. 5 and 6 for details for this phase of construction. Study Fig. 5 for a moment, and orient your board so it faces the same way. **Note that the parts-placement diagrams show the board from the side on which the components are mounted but that the foil pattern you see in the diagrams is on *the other side* of the board**. Now you are all set to install the parts, which consist of IC's, jumpers, resistors, and capacitors. The LED's—LED1–LED16—and the wires to SO1 won't be installed yet; *don't* rush and put them in first!

Begin with the IC's and insert an LM324 at IC1. Normally I would recommend using sockets for the IC's, but since the some of the IC pins have to be soldered on both sides of the board, it's better to solder the IC's directly to the board. Use gentle heat, and don't cook anything. Press the IC in place with your fingers, then flip the board over and solder all 14 leads to the foil. Then return to the *component side* of the board and carefully solder pins 2, 5, 6, 9, 19 and 13 to the foil. Use solder sparingly, and watch out for shorts. If you accidently create a solder bridge between two terminals, heat it, and push away the solder with a toothpick or X-ACTO knife.

Continue by installing another LM324 at the IC2 position. Solder it in as you did with the first IC. After that, install two more LM324's at the IC3 and IC4 positions. When you're done, check for missed connections and shorts, and correct any errors before going farther.

Moving to the left of the board, install an LM380 at IC6. (You may use a socket for this device, if you like.) Orient it as shown in Fig. 5 and solder the pins to the foil on the reverse side of the board. Move

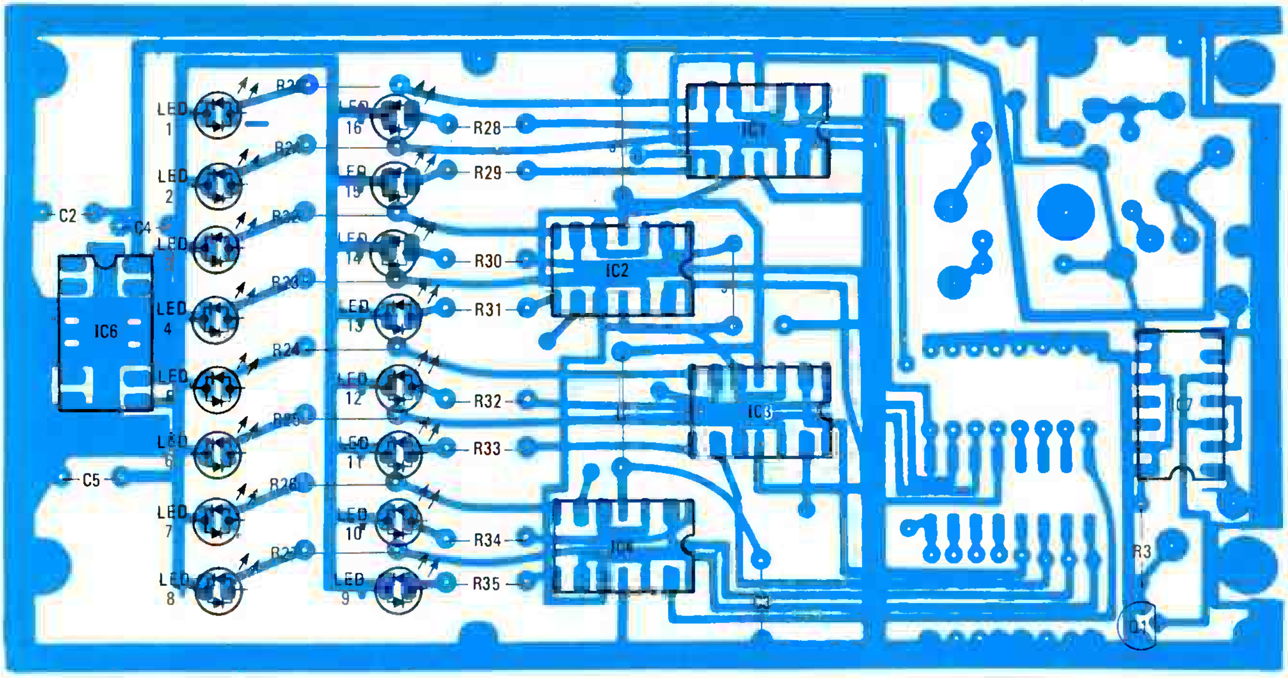


FIG. 5—PARTS PLACEMENT on "component-side" of display board. Note that foil pattern shown is on side of board *opposite* the one on which components are mounted.

to the right of the board and install a CD4011 at IC7. Press it in place with your finger, then turn the board over and solder the pins to the foil. Flip back to the component-side of the board and carefully solder pins 1, 6, and 8 to the foil on *that* side of the board. Be careful not to bridge pin 6 and pin 7; they are close together because of the foil trace nearby. That takes care of the IC's. Check your work again for shorts and errors, fix any problems, and you can continue.

There are three jumpers, and they come next. They are by IC1, IC2, and IC3, as indicated in Fig. 5. You can make the jumpers from short pieces of hookup wire, or short lengths of resistor lead. Install the first jumper to the left of IC1 and solder the leads to the foil on the other side of the board. Move across IC2, and install another jumper to the left of IC3. Position it so that it can't touch the foil that runs nearby—in fact, you should slip a piece of insulated tubing over the jumper if you used bare wire. Move to pin 1 of IC3, and install the third jumper. Note that it runs between the two IC's, and parallel to them.

The resistors come next. Note that these are all 1K units except for R3 (470 ohms), which is off in a corner by itself and which should be installed first. Solder its leads to the foil on the other side of the board. Move to the left of the LM324's and start installing the 1K resistors—note that there are 16 of them—as shown in Fig. 5. Then turn the board over and solder the leads to the foil. Be sure to clip off the excess lead lengths.

Now for the capacitors. Note that they are all of the same value—0.1 μF. Either ceramic disc or Mylar types may be used. Starting at the far left of the board, install 0.1 μF discs at C2, C5, and C4. Solder the leads on the other side of the board, and clip off the excess. Position the capacitor bodies so that they stand straight up. Then move along the bottom of the board, and install C3. Press its body flat against the board before soldering the leads; we don't want this part to stand up in the air. Clip off the excess leads, and you are finished with the capacitors.

For the time being, the last part to be installed on the component side of the board is Q1, the VMOS power FET. It goes in the bottom right corner, next to the 470-ohm resistor. Install the device as shown, with the flat in the case pointing toward the right edge of the board. Solder the leads on the other side of the board, and clip off the excess. That completes the component installation on this side of the board for now, though we still have to install the LED's and wire SO1.

Next time we'll complete the display board and wire it to the panel board. We'll also finish up construction and put the IC tester into operation. **R-E**

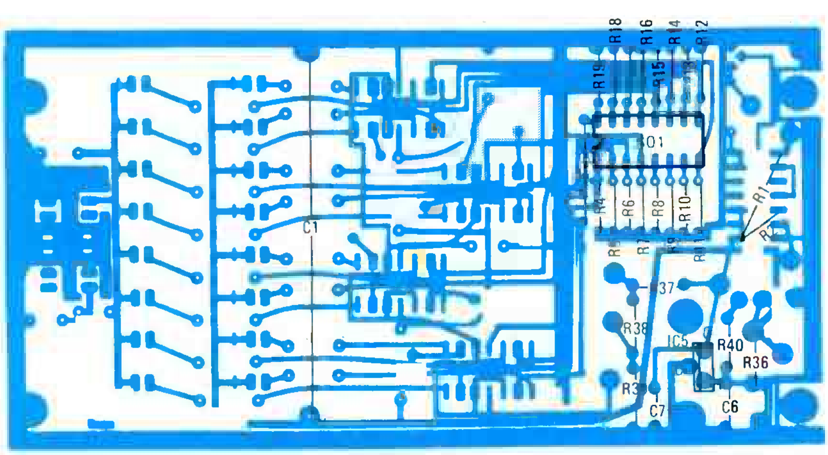
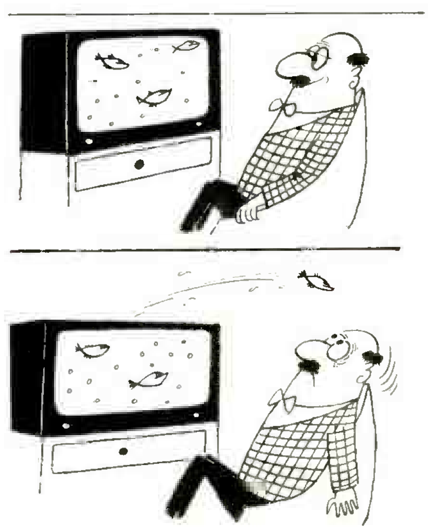


FIG. 6—PARTS PLACEMENT on "foil-side" of display board. Resistor R2 (at right) is soldered to pads on opposite sides of board.



Digital IC Tester

An IC tester like the Programma III can make work a lot easier for you. Here in Part 2 we'll continue with the construction of the device

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Part 2 IN THE FIRST PART OF this article we finished one side of the display-board portion of the IC tester. Let's now start on the other side.

Display board: other side

Turn the display board over, position it as shown in Fig. 6 and install the 7805 voltage regulator, IC5, at the bottom right corner. Note that the tab faces left. Once it is in place, turn the board over and solder the leads; then clip off any excess. Note that although there are two large pads by the voltage regulator, nothing will be mounted on them.

The next step is to install the resistors. Start with R4 through R19. They're the 100K units around SO1, and you'll need 16 of them. Install the R12–R19 units first, then solder the leads on the other side of the board and clip off the excess. Turn the board back over so the resistors are visible and solder them to the foil in four places at the edge of the board (the pads can be seen in Fig. 5, (see January 1983 issue of **Radio-Electronics**) at the bottom of the board). That step is important because it connects the ground foils on both sides of the board together, so don't forget to do it.

After that, install R4–R11 in the same way. Move to the foil side of the CD4011, and solder two 10K resistors, R1 and R2, across the IC pins. Connect R1 between pin 8 and pin 1, then connect R2 between pin 8 and pin 7. Move to the bottom, and install a 68 ohm, *1-watt* resistor at R36. Note that it mounts vertically. Solder the lead closer to the middle of the board, and to both the top and bottom sides of the board; that gets the power to the IC's. Moving on, install a 1K resistor at R40. Then move left and install an 8.2K resistor at R37. Finish up the resistors by installing a 3.3K unit at R38, and a 2.2K unit at R39. Check your work carefully. If you had any problem installing a resistor, chances are it is in the wrong place! Check to be sure. When you are sure all the resistors are installed properly, you can continue.

Next, SO1 and the jumpers can be installed. Do not omit the socket; it's the connector for the wiring from the panel board. Install SO1 as shown, and turn the board over to solder it in. Turn the board back over and install a jumper between the two points to the left of the socket and resistors. A leftover resistor lead will work fine. After the jumper is soldered in, position it away from the copper foil nearby to prevent shorts.

The capacitors finish up this phase of the wiring. Turn to the voltage regulator, and install 0.1 μF ceramic discs above and below it at C6 and C7. Clip off the excess leads and you are done. Figures 7 and 8 show how the completed component- and foil-sides of the display board should appear.

Next, position the display board so that the IC's are facing up and, referring to Fig. 9, install the six jumpers from SO2 to the IC's. Use short lengths of insulated hookup wire.

The next step is to install connector SO1. Refer to Fig. 10 for details. Note that the wires are all inserted from the "foil" side of the board. First, cut eleven pieces of hookup wire, each about four inches long. Prepare one end of each wire, and insert a wire into each of the holes indicated in the illustration. Then route the wires for pins 1, 10, and 11 of

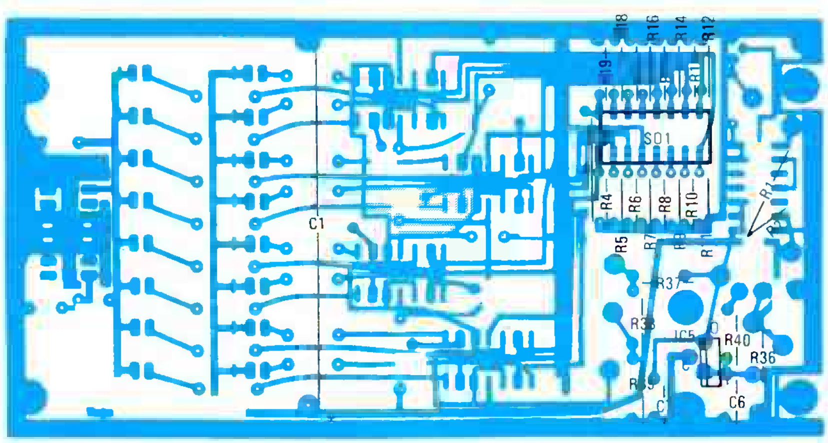


FIG. 6—PARTS PLACEMENT on "foil-side" of display board. Resistor R2 (at right) is soldered to pads on opposite sides of board.

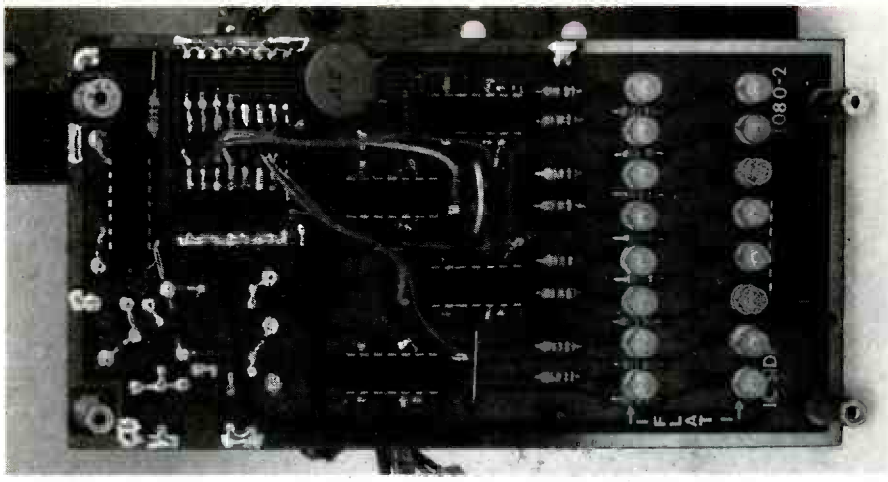


FIG. 7—"COMPONENT-SIDE" of display board. Mounting of LED's will be described in next part of article—don't install them without reading it.

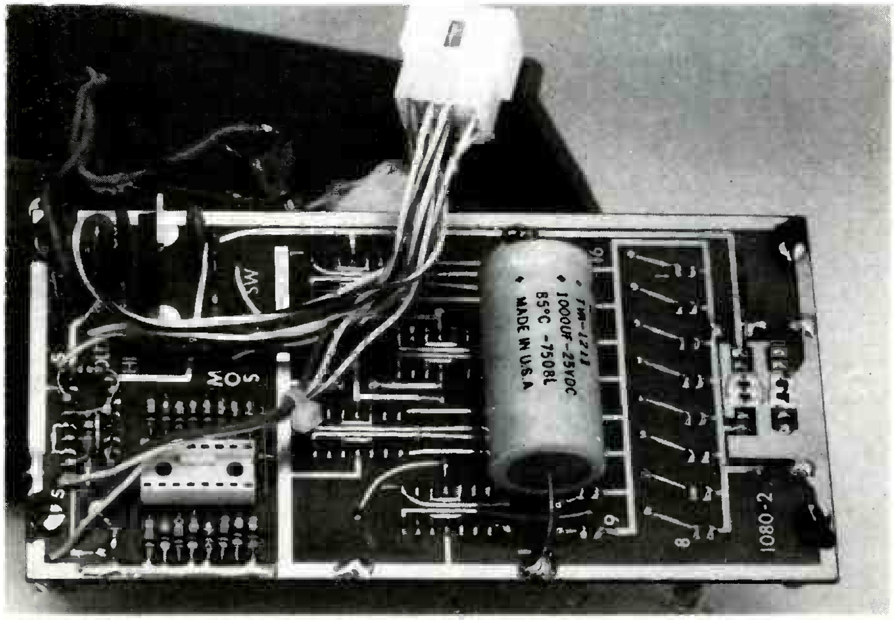


FIG. 8—"FOIL-SIDE" of display board. Multi-wire assembly connects to components on panel board.

the connector over the voltage regulator and group them with the others. That will make a neat cable.

Trim the ends of the wires so that the total cable is about three inches long. Then prepare each wire end, and install the connector. Note the pin identifications in the illustration. I used a Molex 12-pin nylon connector for P102, but almost anything with the correct number of pins will work. After the wires are connected to the pins, check your work for errors and correct any you may find. If you like, lace the wires together to give a professional appearance.

Now for the power cable. Prepare two 1-foot lengths of hookup wire. If possible, use one red, and one black, wire. Connect the wires to the board as shown in Fig. 10. The red wire should go to the hole indicated by a "+," and the black one to the one indicated by a "−." Twist the wires together.

The final step (with the exception of installing the LED's) is to install capacitor C1. Be sure that it's oriented properly. Push the leads through the foil, and solder. Be sure to solder the negative terminal on *both* sides of the board.

LED installation

If you didn't buy the double-sided panel board, you'll want to make one up using the foil patterns shown in Figs. 11 and 12. You can then install the LED's on the display board (however, you need the panel board to do that) and be done with it.

Place the panel board in front of you so that you can read the lettering on it. Notice the sixteen positions below the label "LOGIC LEVEL INDICATORS." They are for the LED's and will have to be drilled and/or filed to a diameter of 0.200 (2/10)-inch. You may want to use several increasingly larger drill-bit sizes to do that. Stop and check the hole size from time to time using one of your LED's until the fit is snug. Make another hole the same size at the position above the "OVERLOAD" label using the same procedure.

At the edges of the board there are seven large positions marked, and, slightly inboard of them, four smaller ones (those four are for mounting the display board). All eleven should be drilled to 1/8-inch for 4-40 hardware. Then, turn the panel board over and install a 3/4-inch threaded spacer at each of the four "inboard" holes. (If you can't find the spacers, you can make a substitute for them with 4-40 × 1 bolts and nuts. First, install a bolt and secure it to the panel with a nut. Then, add another nut, but screw it down only until the distance between the panel and the side of the nut away from the panel is 3/4 inch.) Now you're ready to install the LED's.

Refer back to Fig. 5 (in Part 1), and note the positioning of the LED's. The flat spot on the package (or the shorter lead) indicates the cathode, and should point to the left. Insert the top row of LED's, LED9–LED16, in the display board, but don't solder the leads. Place the panel board on the top of the spacers on the display board, and temporarily secure it in place with the 4-40 hardware. Push each LED forward so that it seats in the appropriate hole on the panel board. After all the LED's are in place, solder their leads to the foil, and clip off the excess. Separate the display board and the panel board, and install the bottom row of LED's, LED1–LED8. Again, temporarily install the display board on the panel board and push the LED's through the holes. Solder the leads in place and clip off the excess lengths. That completes the LED installation, so remove the display board.

Panel board

The rest of the work on the panel board consists mainly of installing jacks and wiring two cables. The schematic in Fig. 13 will help you understand what has to be done. It's routine work, but you'll get the best results if you take your time.

The first thing is to drill more holes. Position the board so you can read the legend "PROGRAMMA III." First, drill all the "HI," "PULSE," and "LO" holes to a diameter of 0.230-inch (a little less than 1/4 inch). A few tips on drilling PC-board material: To avoid tearing the foil, use at least three smaller drill sizes before you get to 0.230-inch. Better yet, start small and use a file or reamer to enlarge the holes. Use one of the jacks that will be installed to check hole size periodically. Carefully enlarge each hole until a jack fits snugly in it. Then deburr the holes, working from both sides of the board; use a sharp knife like an X-ACTO knife.

Next come the holes for the two switches. They, of course, are between the "TTL" and "MOS" legends, and just below the word "PULSE." Using the same technique as you did for the jack holes, enlarge the switch holes to 0.250-inch.

Now, the small parts can be mounted on the panel board. They include the IC test socket (SO101), the switches, and the OVERLOAD LED. The jacks will be installed later. Install the test socket first, from the front side of the board (the side with the lettering). After that, install a SPDT toggle switch at the TTL/MOS hole. Then install an SPDT pushbutton switch in the PULSE hole. Finish up this phase of construction by installing an LED in the OVERLOAD hole, from the rear of the board. Use quick-setting epoxy on the rear side of the board to secure the LED in place. Allow the epoxy to dry before you continue.

Now for the jacks. Refer to Fig. 14 for details, and note how the lugs on the jack bodies are oriented on the rear side of the board. For easiest installation, start at the top of the board with the "HI" row. Install the jacks, one by one, positioning the bodies as shown and then tightening the hardware. After that row is completed, continue with the "PULSE" row just below it. After that, move down to the "LO" row, and repeat the whole process. When you've finished the three rows, check for loose hardware and tighten things up as required. Then install the other three rows of jacks in the same fashion.

Panel board wiring

The jack wiring comes next. Note that only one lug of each jack will be used; the ground connections have already been made by attaching the jacks mechanically to the foil on the board. Again, refer to Fig. 14 for the wiring. Start with the pin-16 series of jacks (HI, PULSE, and LO), and tie the three terminals together with a

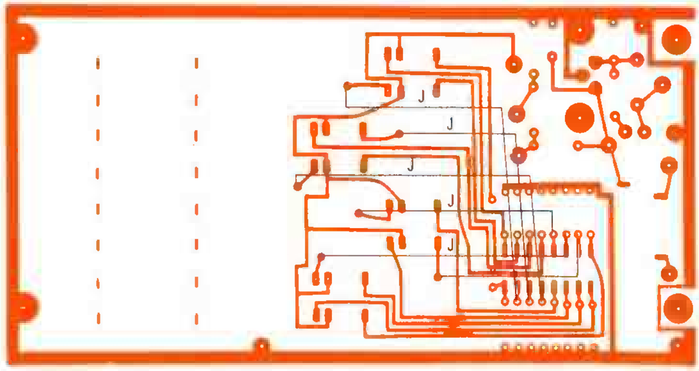


FIG. 9—RUN SIX JUMPERS between the zero-insertion-force test socket and the approriate pads on the component-side of the board.

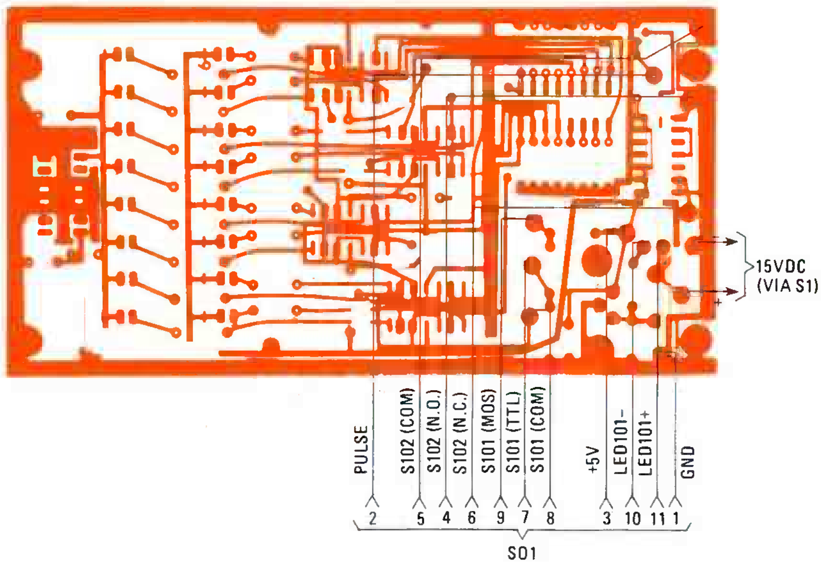


FIG. 10—MAKE UP AN 11-WIRE cable to connect SO1 to the circuit board at the points shown.

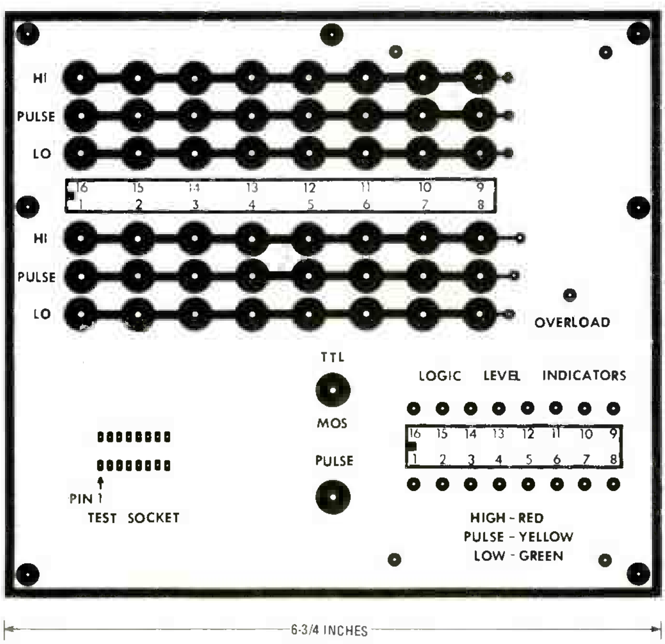


FIG. 11—TOP OF PANEL BOARD. Drill out holes at large foil pads as described in text.

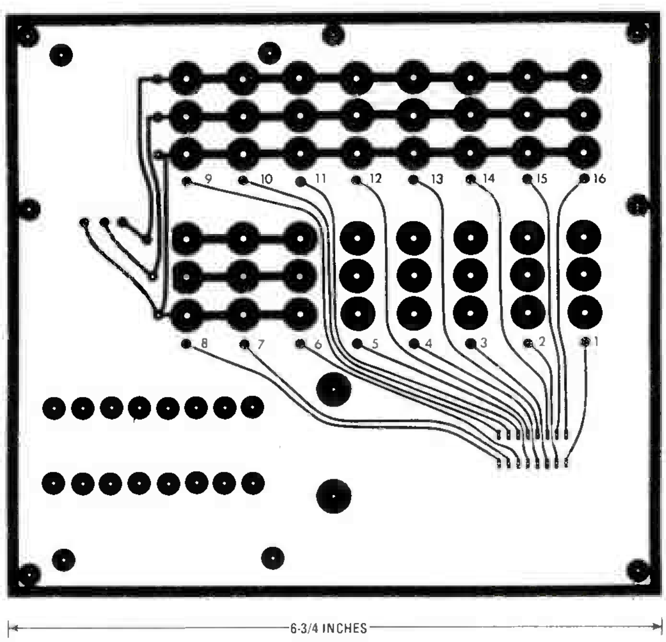


FIG. 12—FOIL SIDE OF panel board. Holes for 16 LED's are at lower left.

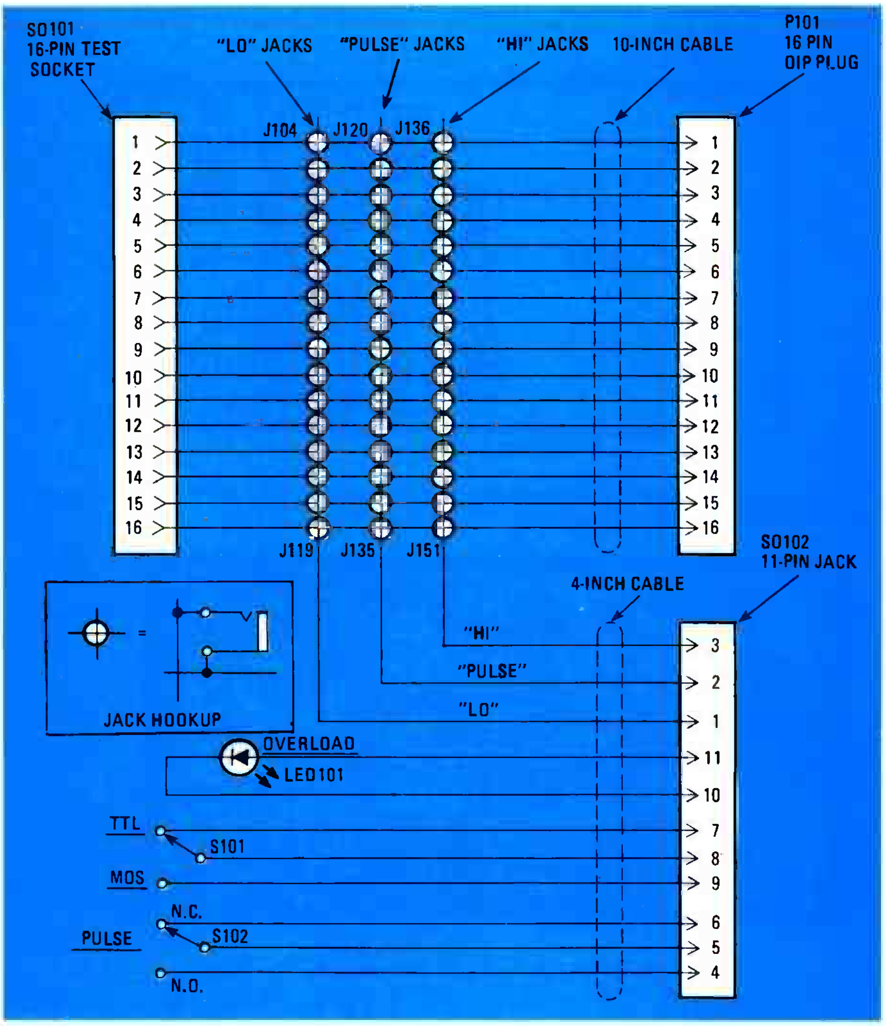


FIG. 13—PANEL BOARD SCHEMATIC shows jack array J104–J151. Inset shows how jacks are connected. Note that switch S102 is actually an SPDT pushbutton type.

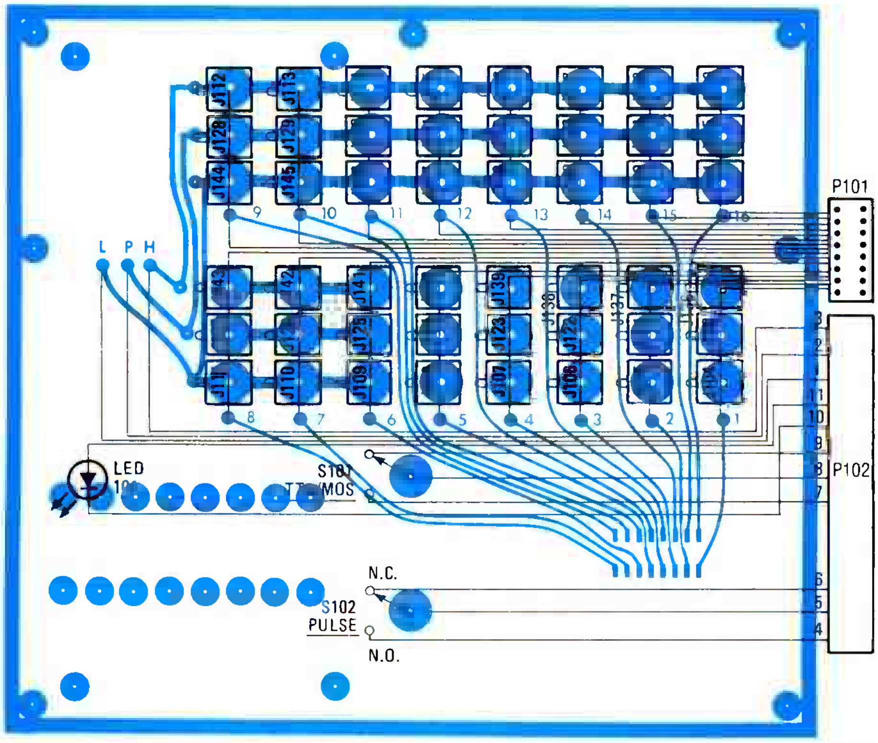
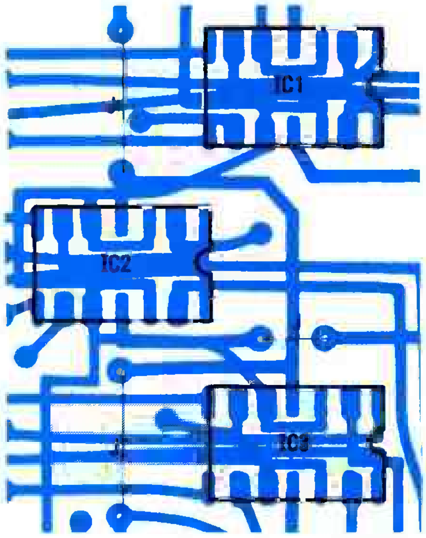


FIG. 14—CENTER PINS of the HI, LO, and PULSE jacks for each IC pin are bused together. No wires are connected to ground lugs.

OOOOOOOPS

The center jumper in Fig. 5 of Part 1 was shown incorrectly. The correct portion of that parts-placement diagram is shown below.



PARTS LIST—PANEL BOARD

Semiconductors
LED101-jumbo red LED lamp
P101—16-pin DIP header with 10-inch (minimum) cable
P102—12 pin Molex nylon connector
S0101—16 pin ZIF (*Z*ero *I*nsertion *F*orce) socket (Welcon ZIF—16 or similar)
SO102—12-pin socket to mate with P102 from display board
J104–J151—miniature phone jack
J201—two-conductor polarized jack (a phone jack is OK)
S101—SPDT mini toggle switch
S102—SPDT mini pushbutton switch (push-on/push off)
S201—SPST toggle switch
Miscellaneous: cabinet, hookup wire, 4-40 hardware, ¾-inch threaded spacers, phone plugs, etc.

The following is available from Technico Services, PO Box 20HC, Orangehurst, Fullerton, CA 92633: set of two etched & drilled PC boards (IC-1), $30.00. Available from ABC Electronics, 2033 W. La Habra Boulevard, La Habra, CA 90631 is a set of all parts, *excluding PC boards* (IC-1P), $85.00. CA residents please add sales tax; foreign orders please add $3.00 for postage & handling.

piece of uninsulated bus wire. Connect the end of the wire to the pad below the "LO" jack. Then move to the pin-15 series of jacks, and connect them in the same manner. Keep going until all the jacks are tied together and connected to the appropriate pads on the PC board. Check your work carefully. It's very easy to make a mistake here. Watch for shorts, especially, and correct any errors you find.

When we continued this article, we'll finish up the panel-board wiring and complete the assembly. Then we'll make sure the tester operates properly. R-E