

Store Soft: A 16-bit Logic Analyzer

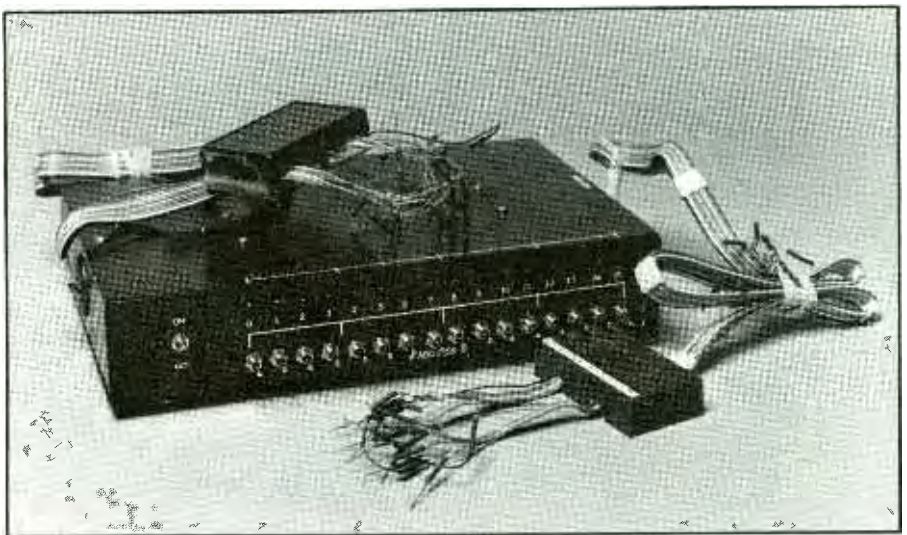
Test instrument simplifies and speeds troubleshooting of computers and other digital systems

By Desmond Stelling

Knowing immediately what the software or hardware is doing in a digital fixture—whether it is a personal computer, digital controller or another digital device—is essential to good troubleshooting. You can, of course, use a digital logic probe or an oscilloscope to aid in tracking down a problem. However, the first won't give you the whole picture and the latter can be confusing if you're dealing with more than eight channels. The solution is to use a logic analyzer, such as the Store Soft described here.

Store Soft was designed to meet the troubleshooting needs of the technician involved in repairing the 16-bit breed of personal computer, though it can be used with any other digital system up to 16-bits. It acquires data at a single address on a rising-edge command and addresses from a data word on a falling-edge command. Therefore, it can be used to verify that a program is incrementing through its proper addresses. By storing a known data word at a given address, you can use the Store Soft analyzer to verify if this address is being executed.

Store Soft can store one 16-bit word from any computer or controller. Acquisition rates can exceed 8 MHz with 100% reliability. Store Soft simply compares incoming data



or address with switch settings (the switches are in a single row on the project's front panel). When the data or address agrees and a valid strobe (trigger pulse) occurs, a latch driver stores the corresponding address or data and displays it via a row of LEDs, also on the front panel.

About the Circuit

In Fig. 2 is shown the entire schematic diagram of the basic Store Soft analyzer, including its ac power supply. Integrated circuits *IC1* through *IC4* are 54LS85 4-bit magnitude comparators. (Note: You can use either 54LS or 54S series TTL devices in this project.) When all four bits at A0 through A3 to *IC1* compare with the other four input bits at B0 through B3, the output at pin 6

goes high. The *S0* through *S3* switch arrangement on the inputs of *IC1* set up the least-significant-bit (LSB) code for the code being compared. Operation is identical for the *IC2*, *IC3* and *IC4* circuits and switches, which are identical to the *IC1* circuit.

As data is rippled through the inputs, the outputs for *IC1* through *IC4* compare as equal. When all four outputs (at pins 6) are high at the same time and a positive or negative edge is present, latches *IC6* and *IC7* store the information present at their inputs and selectively light *LED0* through *LED15* to display the unknown data. When the outputs of all four 4-bit comparators (pins 6 of *IC1* through *IC4*) go high, 4-input NAND gate *IC5A* is enabled and, in turn, applies a low on the enable in-

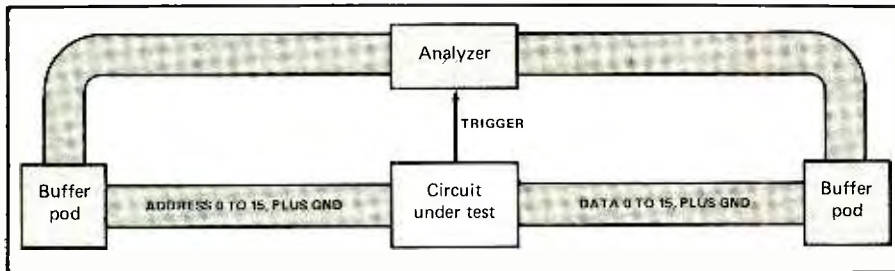


Fig. 1. Shown here is a typical setup for using a digital logic analyzer. Store Soft's buffer pods minimize undesirable effects due to long test leads.

PARTS LIST

D1 thru D4—1N4001 or similar power rectifier
 IC1 thru IC4—54LS85 4-bit magnitude comparator
 IC5—54LS20 dual 4-input NAND gate
 IC6, IC7—54LS377 octal latch
 IC8, IC9—54LS244 octal buffer line driver (four total)
 IC10—LM309 +5-volt regulator
 LED0 thru LED16—Light-emitting diode
Capacitors
 C1, C2—0.1- μ F disc (four total)
 C3—1- μ F, 10-volt tantalum (two total)
 C4—100- μ F, 50-volt electrolytic
 C5—20 μ F, 10-volt electrolytic
Resistors (1/4-watt, 10%)
 R1 thru R16—5000 ohms
 R17—1000 ohms
Miscellaneous
 F1—1/2-ampere slow-blow fuse
 J1—Panel-mount BNC jack
 S0 thru S15—Dpst, center-off toggle switch
 S16—Dpst toggle switch

S17—Spst toggle switch
 T1—12.6-volt, 500-mA transformer
 Perforated board and Wire Wrap hardware (or design-your-own printed-circuit board) for main circuit, two pc boards for buffer pods; sockets for all ICs except IC10; 12"×8"×2" aluminum chassis box, bayonet fuse holder for F1; 17 panel-mount grommets for LEDs; two 3"×2"×1" plastic boxes (see text); 6-ft. 20-conductor flat ribbon cable, preferably color-coded; ac line cord with plug and strain relief or rubber grommet; two large rubber grommets for pod cable holes; 1-lug (ungrounded) terminal strip; 34 machined push-on sockets; heat-shrinkable tubing; Wire Wrap materials; four spacers; silicone adhesive; spray paint; dry-transfer or other lettering kit; machine hardware; hookup wire; solder; etc.
Note: The following is available from DDS Systems, P.O. Box 5715, Glendale, AZ 85312: pod pc boards at \$5.95 ea.

dously. Store Soft conveniently provides the +5 volts and ground required by the pods.

Power for the project is provided by the ac-line-driven circuit shown at the bottom of Fig. 2. In this full-wave supply, filtering is provided by C4 and C5 and voltage regulation is provided by IC10. Current-limiting resistor R17 and POWER light-emitting diode LED16 are optional and can be eliminated or replaced by a panel-mount neon lamp assembly wired across T1's primary, after S17.

Construction

If you wish, you can design and fabricate a printed-circuit board on which to mount the IC1 through IC7 and power-supply circuits. It's not difficult to do. However, I found it easier and simpler to Wire Wrap these circuits on a small piece of perforated board. Besides saving time and eliminating the need to fuss with messy chemicals, the Wire Wrap approach kept the circuit assembly much more compact than it would have been if I had used a pc board.

For the two buffer pods, however, you do need pc boards to keep the depth within reasonable limits. It's much easier to connect and solder the multitude of wires that make up the ribbon cables between the main Store Soft assembly and the appropriate points in the pods if pc boards are used. An actual-size etching-and-drilling guide and components placement diagram are shown in Fig. 4.

Carefully following Fig. 2, wire the main circuit board. Use sockets for all ICs, regardless of whether you use the Wire Wrap technique or a pc board. Referring to Fig. 4, install and solder into place the three capacitors and two ICs on each of the buffer pod boards. Install the ICs, making sure you properly orient them.

Cut in half a 72" length of 20-conductor ribbon cable. This cable should preferably be color-coded to limit the possibility of wiring errors.

puts at pins 1 of IC6 and IC7. The latch stores new data only when the enable inputs of IC6 and IC7 are low and a rising edge appears on pins 11.

To be able to analyze a particular system, Store Soft's input lines should be about 36" long to permit access to various signals that may be widely separated. However, such long lengths can pose a number of problems that can interfere with proper operation of the analyzer. System noise and capacitance, for ex-

ample, can result in improper levels for triggering an input gate. Therefore, buffer pods must be used near the far ends of the address and data cables, as shown in Fig. 1.

Store Soft's buffer pods each consist of two 54LS244 octal buffer line drivers, identified as IC8 and IC9 in Fig. 3. Buffering action of these ICs effectively minimizes undesirable effects introduced by long lead lengths. Hysteresis at the inputs improves the noise margins tremen-

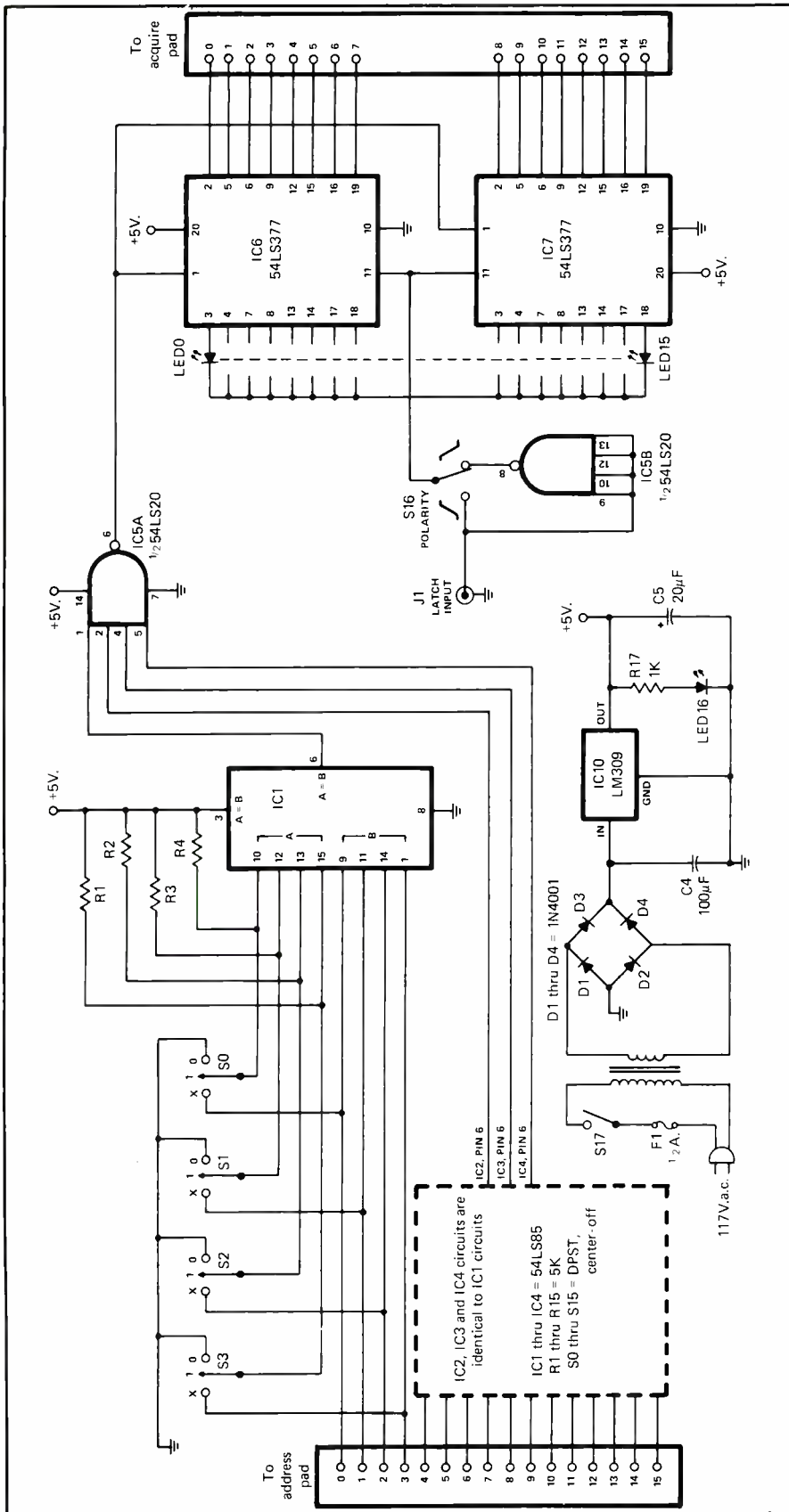


Fig. 2. This is the schematic diagram of the analyzer's main circuitry, including a 117-volt ac-line-operated power supply, shown at lower-left.

Next, divide the two cable halves into 12" and 24" lengths. Remove two conductors from each section of cable. If you're using single-color ribbon cable, remove the conductors from the *unmarked* side. Carefully separate the conductors at both ends of the 24" and one end of the 12" cables for a distance of about 2" and at the other ends of the 12" cables for a distance of about 6".

Strip 1/4" of insulation from both ends of all conductors in all four cable sections. Twist together the fine wires in each conductor and lightly tin with solder. Set one 12"/24" cable pair aside and wire the other pair to one of the pod circuit board assemblies, referring to Fig. 4 for details. Note in the drawing that the pads to which the cable conductors connect are labeled with a letter/numeral designation. The prefix letters are either an "I" for input from the circuit under test or an "O" for output to the analyzer. Keep this in mind as you wire each conductor to the board at the 2" separated ends of first the 12" (I prefix) and then the 24" (O prefix) cables.

If you're using single-color cable, start connecting at pin 20 of IC8 with the marked conductor and finish at pin 11 of IC9 with the last conductor of the 24" cable. Similarly, start with pin 2 of IC8 with the marked conductor and end at pin 10 of IC9 with the 12" cable.

At the free end of the 12" cable, install onto each conductor a machined push-on socket. Cut short lengths of small-diameter heat-shrinkable tubing and slip a length over each of the 18 sockets. The tubing should be long enough to cover the entire socket and soldered connection but not overlap

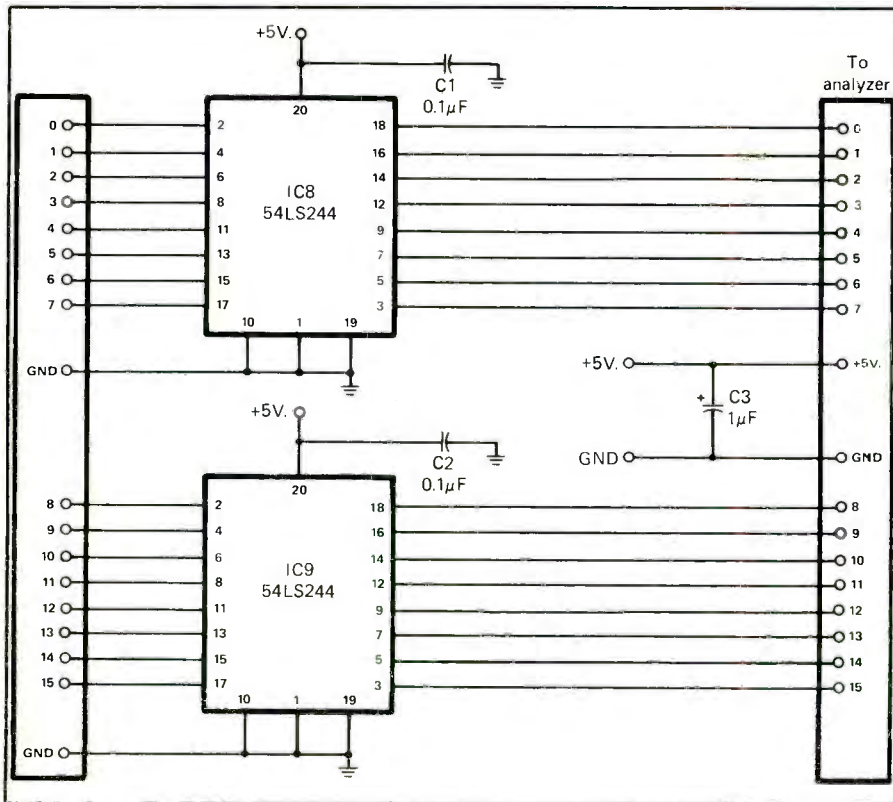
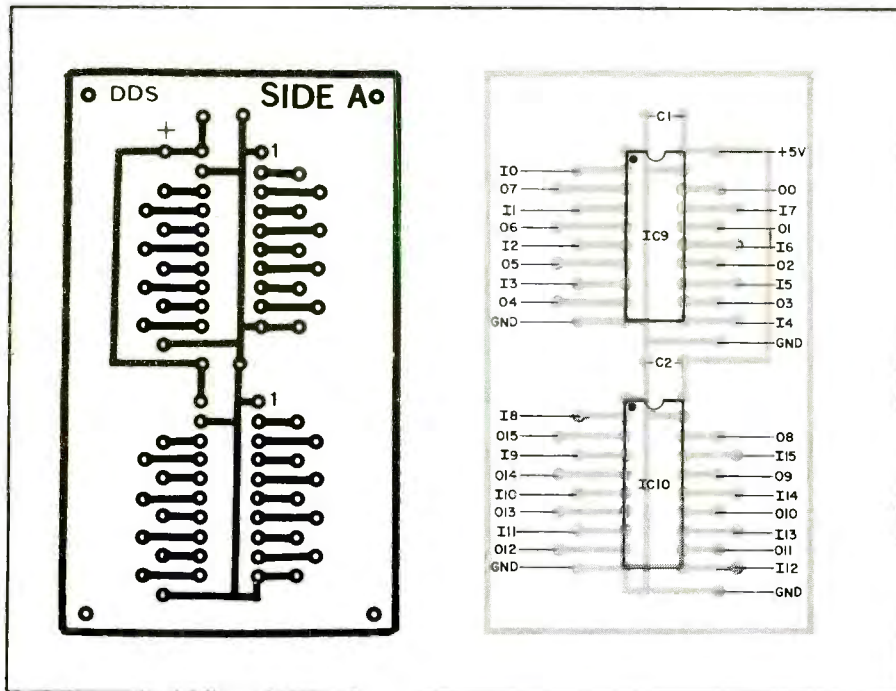


Fig. 3. Two octal buffer line drivers, located at the ends of the cables that connect the circuit being tested to the analyzer, offset noise problems.

Fig. 4. Shown here are the actual-size etching-and-drilling guide to use when fabricating the two printed-circuit boards needed for the buffer pods, plus the components placement/orientation and ribbon cable wiring diagram.



the open end of the socket when shrunk. Attach identification labels (+5V, GND, 0, 1, etc.) from a tag strip or hand made from tape to each conductor just past the tubing.

Repeat the above procedure for the second buffer pod circuit board assembly and remaining ribbon cable sections. When you've done this, separate the 12" cables in each pod assembly into two bundles, each containing nine conductors, such that all conductors for IC8 and ground are in one bundle and all those for IC9 and the second ground are in the other.

Separate the two sections of two 3" x 2" x 1" plastic boxes (the clear-top/opaque-bottom kind sold in hardware and variety stores). Set a pod circuit board assembly into the bottom (opaque) half of each box, with the 24" cables exiting the rear of the boxes between the hinge "knuckles" and the two nine-conductor bundles exiting the front. Space the nine-conductor bundles far enough apart to avoid interference with the locking mechanism. Mark the limits of the cable sections on the box halves. Remove the pod electronics and reassemble the boxes. Transfer the marked locations to the top halves. Then carefully remove just enough plastic from the top halves to provide exit room from the cable sections without causing interference with the hinges and locking mechanisms. Return the pod electronics to the boxes; reassemble the boxes and tape them shut.

A 12" x 8" x 2" aluminum chassis box is an ideal cabinet for the Store Soft's main electronics. It has sufficient room for the circuitry, a low silhouette and a high enough front panel to permit the data switches and LEDs to be arranged in two paired horizontal rows (see lead photo).

Drill the mounting holes for TRIGGER input jack J1 and the fuse holder for F1 and the entry holes for the ac line cord in the rear panel. Carefully mark the hole locations for the LEDs

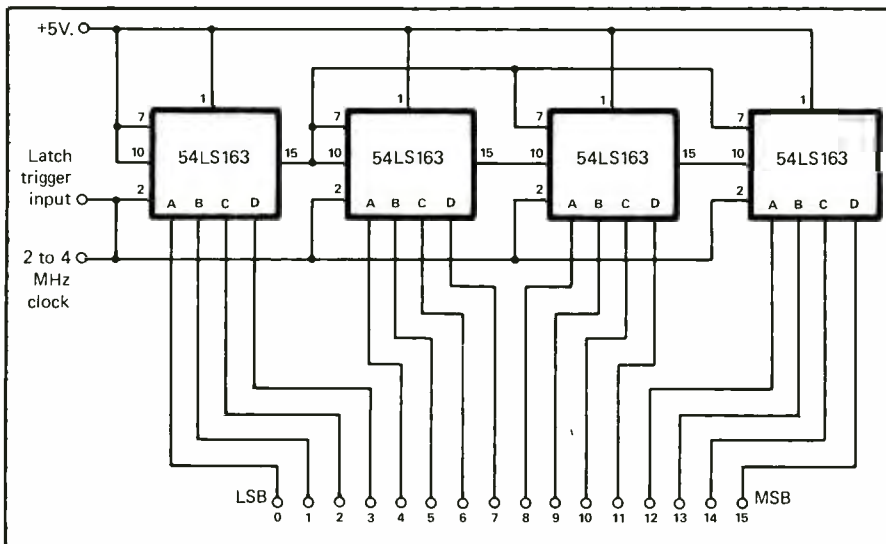


Fig. 5. Breadboard this 16-bit synchronous counter and use it to check out Store Soft's operation before putting it into service on your bench.

and all switches (except POLARITY switch *S16*) on the front panel. Dimple each marked location with a center punch to prevent the bit from slipping when you drill the holes.

Narrow rectangular slots are required for the entry holes for the buffer pod cables. A nibbling tool will speed and simplify making these slots. If you don't have a nibbler, you'll have to drill a series of interconnecting holes and use a file to obtain the desired shape.

Drill the mounting holes for the main circuit board and power transformer *T1*. Deburr all holes and thoroughly clean all exterior surfaces of the box. Allow the box to fully dry before painting it. For best results, apply two or three *light* coats of spray paint, allowing each to dry before spraying on the next. When the paint is completely dry, use a dry-transfer lettering kit or other means to label the LEDs, switches, jack and pod cables (see lead photo). If you use dry-transfer lettering, protect it with two or more very light coats of clear spray lacquer.

Line the pod cable slots with large grommets and install a small rubber

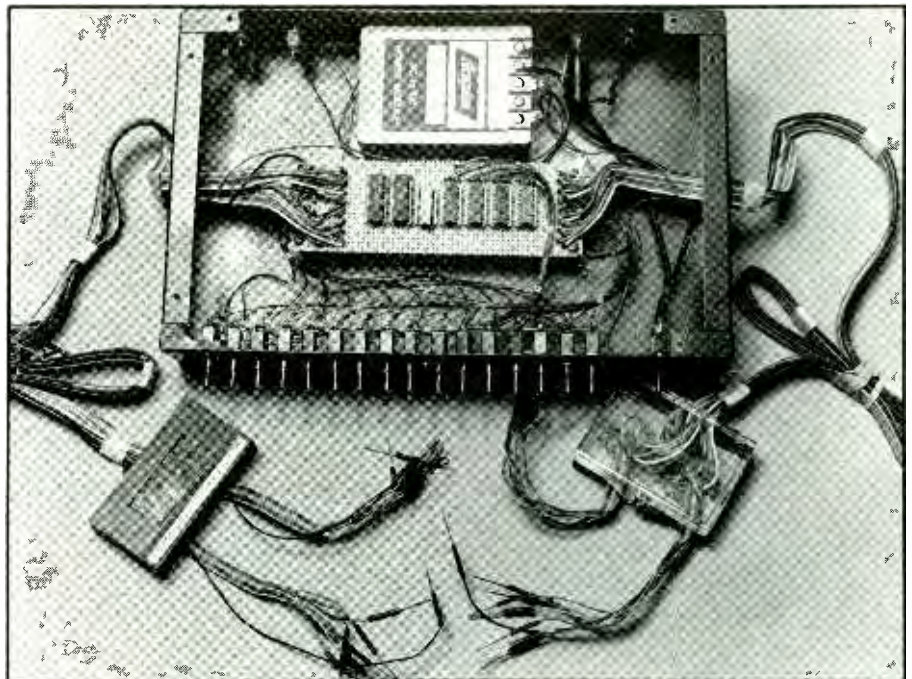
grommet in the ac line cord hole to protect the wires from fraying against bare metal. Mount *J1*, the fuse holder, LEDs (in panel-mount grommets) and switches. Feed the

unprepared ends of the pod cables into the box through the slots. Mount *T1*, placing a single-lug (ungrounded) terminal strip under the hardware of one mounting tab.

Strip $\frac{1}{4}$ " of insulation from the unprepared ends of both ac line cord conductors. Tightly twist together the fine wires in both conductors and lightly tin with solder. Pass this end through its grommet into the box. Tie a knot in the cord about 6" from the prepared end and separate the conductors for a distance of about 3". Crimp and solder one *primary* lead from the transformer and one line cord lead to the lug on the terminal strip. Then, referring back to Fig. 2, complete wiring the primary circuit of the power supply, connecting and soldering the other line cord conductor, fuse holder, POWER switch and remaining transformer primary lead in series.

(Continued on page 90) ▶

This is the interior view of the author's prototype. Main circuitry is wire wrapped on perforated board. The commercial power supply module shown was used because author had it on hand.



Store Soft *(from page 52)*

Wire the LEDs and switches to the circuit board with wrap wire or No. 22 hookup wire. To conserve space on the circuit board, it's a good idea to connect one lead of *R1* through *R16* to the "X" lug on *S0* through *S15* and then wire the other leads into the appropriate points in the circuit, using hookup or wrap wire. Then, referring to both Figs. 2 and 3, wire the pod cables to the main circuit board.

Mount the circuit board in place on appropriate-length spacers. On the inside of the box, liberally bead with silicone cement the pod cables to the grommets and the grommets to the box walls to prevent the cables from pulling loose from the circuit board.

Checkout and Use

Before putting Store Soft into service on your test- or servicebench, it's a good idea to verify that it's operating as it should. This is fairly easy to do with the help of four commonly

available ICs. What you need are four 54LS163 binary counters breadboarded to form a 16-bit synchronous counter, as shown in the circuit configuration in Fig. 5.

To use the Fig. 5 circuit, you simply parallel both pod inputs and use the counter's system clock as the TRIGGER input. Then, by incrementing the *S0* through *S15* switches one at a time, the latch display (*LED0* through *LED15*) should agree with every combination of switch settings. If all switches are in the "X" position (don't-care state), the LEDs should ripple count the same as the 16-bit test counter.

Once you've verified that Store Soft is indeed operating properly, you can out it into service. This instrument is used exactly as you would use any other digital logic analyzer. The connectors on the buffer pod cables can plug directly onto standard Wire Wrap pins or the pins on an IC test slip.