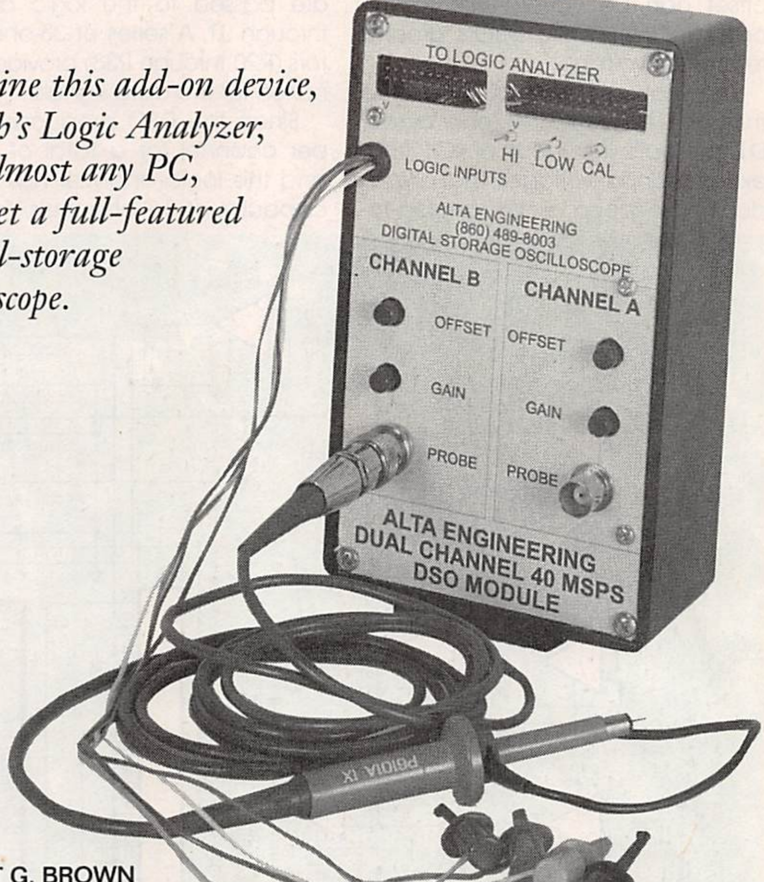
BUILD A DIGITAL-STORAGE OSCILLOSCOPE FOR YOUR HIGH-PERFORMANCE LOGIC ANALYZER

Combine this add-on device, March's Logic Analyzer, and almost any PC, and get a full-featured digital-storage oscilloscope.



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Everyone who works with electronics would like to have a decent oscilloscope as a part of their bench equipment. Unfortunately, top-end oscilloscopes command top-end prices, putting them out of reach of some hobbyists. No doubt you've studied the article "Build a High-Performance Logic Analyzer" that was featured in the March 1998 issue of **Electronics Now**. That device sported an expansion port to which you could attach additional add-on modules.

As promised, this month we are presenting such an add-on module. With this module, you can turn the High-Performance Logic Analyzer into a 40-million-samples-per-second dual-trace digital-storage oscilloscope. Like the Logic Analyzer, the digital-storage oscilloscope, or DSO, connects to any PC and only requires DOS to run the host software with a CGA or greater display. Those computer requirements mean that you can easily recycle that old PC that can't run any modern software, but is still too good to just get rid of.

The unit itself can sample two analog channels and four digital inputs simultaneously. The sampling rate can be chosen from any of 10 built-in rates ranging from 40 MHz down to 312.5 kHz. If those rates don't fit your needs, you can use either of the logic analyzer's two external clock inputs. The oscilloscope features include the ability to use standard 10X scope probes, three trigger modes including a sweep-triggered mode with settable level and slope, plus triggering of the storage cycle with the digital-logic inputs.

Like the logic analyzer that it works with, the DSO can store up to 2048 samples. Additional advantages of a computer-based DSO include the ability to capture and view a transient signal, both before and after the trigger event, and the ability to save the captured data to disk for printing and later study.

Designing a DSO. The functions of a logic analyzer and digital-storage oscilloscope are in many ways very similar. In a DSO, digitized analog signals are stored for later display, much like a logic analyzer, which stores digital signals for later display.

To take advantage of that fact, the companion logic analyzer was designed to hold all of the functions that are common to both devices. That way, the DSO module is simply an analog front-end for the logic analyzer. The main advantage to that approach is that it helps keep the cost of the project down. The result is having two very powerful test instruments, a logic analyzer and a digital-storage oscilloscope, for about the same cost as a digital-storage oscilloscope alone.

Circuit Description. The schematic diagram for the DSO is shown in Fig. 1. The two analog channels are identical, so only one channel will be described; the other channel works the same way. The input signal is buffered by IC1-a, a high-speed FET-input op-amp. There is no gain in that first stage as its only function is to prevent loading the source of the input signal—which is why the op-amp has a FET-based input. The actual input impedance is set by R1 and the scope-probe resistance (usually 9 megohms for a 10X probe).

The buffered signal is then fed into high-speed op-amp IC2-a, which is configured as an inverting amplifier. The amplifier's gain can be varied with R7. An offset voltage is also added so that the amplifier signal will be within the proper voltage range needed for digital conversion. The offset voltage source comes from IC4, the analog-to-digital converter. The reference voltage is buffered by IC3-b, and then inverted by IC3-a. The amount of offset can be varied with R13 in order to adjust the DSO's ground reference voltage.

The final output signal is then fed through R16 into IC4. A Zener diode, D1, protects the input of IC4 from excessive input voltages. That chip, a dual high-speed six-bit analog-to-digital converter, is the heart of the DSO. The rate at which the DSO takes samples is controlled by the logic analyzer through a clock signal on pin 24 of J2. Both scope channels are digitized at the same time with each clock pulse. The sample rates of the DSO are therefore the same as the rates available from the logic analyzer. The six-bit digitized signals convert the analog signal into one of 64 levels. The digital data is buffered by IC5 and IC6. The signals are passed to the logic analyzer through J1. A series of 33-ohm resistors (R20 through R33) provide termination for the data signals.

Since the DSO produces six bits per channel for a total of 12 bits and the logic analyzer has a total capacity of 16 channels, four bits are unused. Those four bits are made available as additional digital channels on the DSO as TP4–TP7. The digital channels connected to TP4 and TP5 can be used as an external trigger on a given logic condition instead of the standard triggered sweep.

There are three test points on the board that are used for probe calibration. They can also be very handy for testing the DSO and troubleshooting the unit. A steady logic low and high are available at TP2 and TP3, respectively. A 312.5-kHz squarewave signal from the logic analyzer (via pin 26 of J2) is available on TP1 as a calibration signal.

Because IC4 is a mixed-signal device—a combination of analog and digital circuits—multiple power

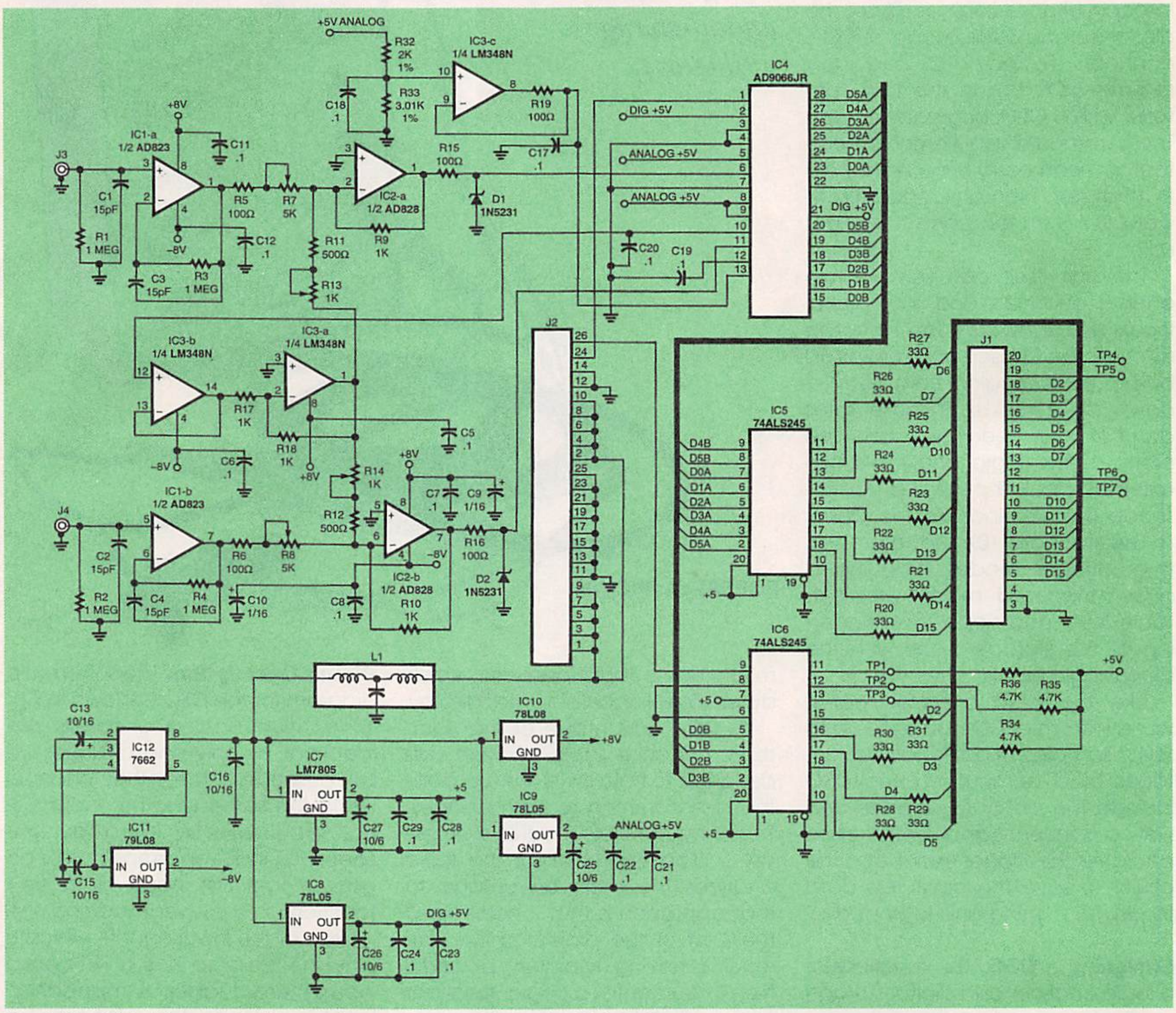


Fig. 1. The Digital-Storage Oscilloscope is an add-on module for the High-Performance Logic Analyzer. It is built around a two-channel, 6-bit analog-to-digital converter. Four additional digital-logic channels are included as a bonus.

and ground pins are used to improve performance. Separate supply-voltage regulators are used to minimize any noise that might be present.

To further improve the noise immunity and response of the DSO, external reference voltages are used for IC4 instead of the chip's internal references. The high-end reference has been raised to 5 volts available from IC9, while the low-end reference has been set to 3 volts by R32, R33, and IC3-c.

Power for the DSO module is supplied from the logic analyzer through J2 and L1, a 3-pin EMI filter that removes digital noise from the power line. The filtered 12-volt power feeds the various positive-voltage regulators in addition to IC12, a 7662 voltage inverter. That inverter creates a negative voltage, which is regulated to –8 volts by IC11.

Building the Digital-Storage-Oscilloscope Module. Construction of the DSO is very similar to, if not exactly like, the companion logic analyzer. Reviewing the construction section of that article is a good idea before beginning. You should also get a copy of the DSO software either from the Alta Engineering Web site (http://www.gutbang.com/alta) or from the Gernsback FTP site (ftp://ftp.gernsback.com/pub/EN/altadso.zip). As an alternative, you can get the software from the source given in the Parts List. Like the logic analyzer, the DSO software doubles as a demo, letting you see what the DSO can do before actually building the module. Any last-minute suggestions or details that do not make it into print will be included with the software. You will need to unzip the file using PKUNZIP or another unzip program. The DSO module connects to the High-Performance Logic Analyzer, so you will need to have built and tested that unit as well.

Like the logic analyzer, the DSO module should only be built on a double-sided PC board with plated-through holes. The layout of the components and traces are very critical to proper operation, so no other construction method is likely to work. You can make your own PC board from the foil patterns included here, or one can be purchased from the source given in the Parts List.

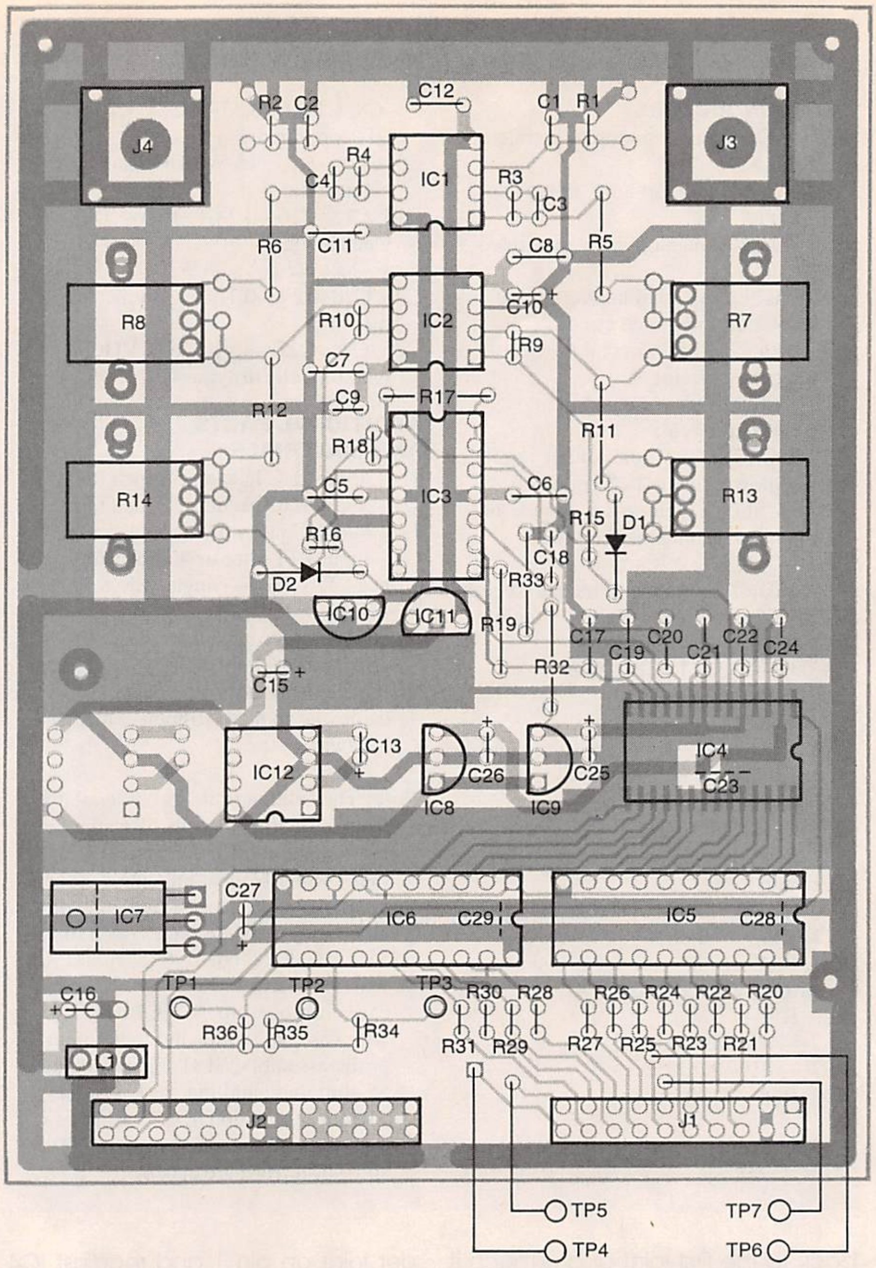


Fig. 2. Here is the parts-placement diagram for the DSO. Note that IC7 is mounted "upside down" from the normally-expected position—the metal tab will be pointing away from the board. Three surface-mount capacitors are soldered to the bottom side of the board.

Since IC4 is a fine-pitch surface-mount device, a low-wattage fine-tipped soldering iron should be used. The solder should be the smallest diameter that can be found—$^{1}/_{32}$-inch or less will work well. With a purchased board or one made from the foil patterns, we can begin construction by following the parts-placement diagram shown in Fig. 2.

Start by soldering C23, C28, and C29 to the bottom side of the board. A good technique is to first coat one of the pads with some solder. Place the capacitor on the board and hold it in place with a small screwdriver. Touch the same pad lightly with the soldering iron to re-flow the solder and tack the capacitor in place. Use a magnifying glass to carefully check the position of the capacitor to be sure that it is properly seated on the pads. Fix any alignment errors before continuing. When the part is properly aligned, solder the other end in place, being sure to create a well-coated solder joint. Once that joint is allowed to cool down, go

PARTS LIST FOR THE DIGITAL STORAGE OSCILLOSCOPE MODULE

SEMICONDUCTORS

IC1—AD823 dual op-amp, integrated circuit
IC2—AD828 dual op-amp, integrated circuit
IC3—LM348 quad op-amp, integrated circuit
IC4—AD9066JR dual analog-digital converter, integrated circuit
IC5, IC6—74ALS245 octal transceiver, integrated circuit
IC7—7805 5-volt voltage regulator, integrated circuit
IC8, IC9—78L05 5-volt voltage regulator, low-power, integrated circuit
IC10—78L08 8-volt voltage regulator, low-power, integrated circuit
IC11—79L08 8-volt negative-voltage regulator, low-power, integrated circuit
IC12—7662 voltage inverter, integrated circuit
D1, D2—1N5231 Zener diode

RESISTORS

(All resistors are ¼-watt, 5% units unless otherwise noted.)
R1–R4—1-megohm
R5, R6, R15, R16, R19—100-ohm
R7, R8—5000-ohm, potentiometer, printed-circuit mount
R9, R10, R17, R18—1000-ohm
R11, R12—500-ohm
R13, R14—1000-ohm potentiometer, printed-circuit mount
R20–R31—33-ohm
R32—2000-ohm, 1%
R33—3010-ohm, 1%
R34–R36—4700-ohm

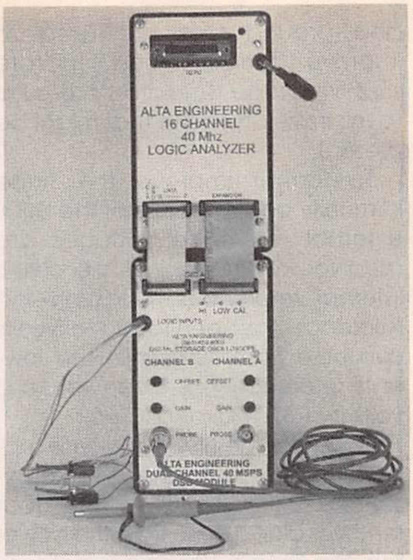
CAPACITORS

C1–C4—15-pF, ceramic disc
C5–C8, C11, C12, C17–C22, C24—0.1-µF, ceramic disc
C9, C10—1-µF, 16-WVDC, tantalum electrolytic
C13, C15, C16—10-µF, 16-WVDC, electrolytic
C14—Not used
C23, C28, C29—0.1-µF, ceramic, surface-mount
C25, C26, C27—10-µF, 6-WVDC, tantalum electrolytic

ADDITIONAL PARTS AND MATERIALS

J1—20 pin IDC header .51-inch tail
J2—26 pin IDC header .51-inch tail
J3, J4—BNC jacks, PC mount
L1—Input RFI filter or 400 mA ferrite bead TP1–TP3—Single-wire test points
TP4–TP7—Mini clips
20-conductor female connectors, 20-conductor ribbon cable, 26-conductor female connectors, 26-conductor ribbon cable, 4-conductor ribbon cable, case, hardware, etc.

Note: The following items are available from: Alta Engineering, 58 Cedar Lane, New Hartford, CT 06057-2905; Tel: (860) 489-8003; E-mail: alta@gutbang.com; Web: http://www.gutbang.com/alta: DOS software on 3½-inch disk, $10; Blank PC board, $45; Board Kit with software, $139; Board Kit with case and software, $169; Board Kit with case, software, and logic input probe assembly, $181. Please include $5 shipping/handling for US orders, $10 for international. CT residents must add appropriate sales tax. VISA and Mastercard are accepted.



When the digital-storage-oscilloscope module is hooked up to the logic analyzer, your setup will look like this. The combined instruments make an almost unbeatable pair for testing and troubleshooting both digital and analog circuits.

back to the first joint and retouch it if needed. After each capacitor is soldered in place, use an ohmmeter to check for any shorts across the capacitors that might have been caused by solder bridges.

Installing the surface-mount capacitors was good practice for soldering IC4, which we'll tackle next. Place that device in the correct location on the component side of the board and carefully align the leads so that they are centered on the pads. When you are sure of the alignment, carefully tack down pin 1 with a light touch of solder. That will hold the chip in place. Again, check the lead-to-pad alignment with a magnifying glass. If the alignment is not correct, re-melt the solder joint on pin 1 and readjust IC4 when it is free. Do not try to move the chip until the leads are free, or they will bend—a condition that is almost impossible to fix. Once the leads are lined up, solder pin 15. That will secure IC4 to the board. Carefully solder the remaining pins in place using a light touch and only enough solder to cover the joint. Do not solder pins next to each other. Instead, skip around the chip. That will prevent excessive heat from building up at any particular location. You should also not be in a rush to complete the task. When all of IC4's leads have been soldered, examine your workmanship with a magnifying glass. Look at the joints from several different angles to be sure that they are solid all the way around. Sometimes a bad joint can look good from the top, but it clearly is not properly bonded to the pad when seen from the side.

After taking a short break to relax, continue by mounting the rest of the capacitors and resistors. Keep in mind that IC4 is sensitive to static electricity—take the proper electrostatic-discharge precautions when handling the board. Note that most of the resistors are mounted vertically.

Next, mount L1 and the connectors in place. If you are going to be using a ferrite bead instead of the RFI filter for L1 (see Parts List), thread the bead onto a length of wire and solder it into the two outer holes—the center hole remains unused.

The voltage regulators should be mounted before the rest of the semiconductors. That way, you can do some simple checks of the power supply before installing the rest of the integrated circuits. If you want, you could use a socket for IC12. Once IC7–IC12 are mounted, check for any shorts between the 12-volt input on J2 and ground. If there are no shorts, or any shorts you found have been fixed, temporarily connect a 12-volt supply across pin 1 (12 volts) and pin 25 (ground) of J2. The voltage at pin 8 of IC12 should be 12 volts. Use the schematic diagram in Fig. 1 to test the volt-

SOFTWARE CONTROLS FOR THE DIGITAL-STORAGE OSCILLOSCOPE

F1—Scope mode. This selects the mode of operation from CONTINUOUS, SINGLE or NORMAL. In CONTINUOUS mode, the scope ignores any trigger conditions and continuously acquires and displays data. That mode is useful to view DC signals and to adjust the gain pot and offset pot or to determine the trigger levels. In NORMAL mode, the scope acquires and then displays only when the trigger condition is met. That mode is like the standard sweep-trigger mode in an analog oscilloscope except that you can view data from before as well as after the trigger. The SINGLE mode is the same as the NORMAL mode except that only one sample of data is acquired and displayed.

F2—Trigger level X/16 of full scale. This sets the trigger level for channel A in relation to the full scale of channel A. For example, if it is set for 8/16 then the trigger level is at mid-scale.

F3—Trigger slope ±. This sets the trigger slope to either rising ("+") or falling ("-"). If the trigger is set for 8/16 and the slope is set to rising, then the trigger will occur when the input signal rises from below mid-scale to above mid-scale.

F4—Trigger mode SCOPE/DIGITAL. This selects the type of trigger from either SCOPE for normal scope triggering using the level and slope of the channel A signal or digital logic triggering using the logic inputs 0 (TP4) and 1 (TP5). The logic trigger operates in the same manner as the logic analyzer trigger. See the discussion of logic triggering in that article for a complete explanation.

F5—Clock rate. This selects the clock rate at which the DSO acquires data. You can select any clock rate from 312.5 kHz to 40 MHz. At a rate of 40 MHz, a sample is taken every 25 nanoseconds. Using a lower rate lets you acquire and view data over longer periods.

F6—Acquire. This starts the data acquisition and display. Each scope channel has a separate grid and the four logic channels are at the bottom of the screen. Each channel is labeled on the left-hand side of the screen. The trigger location is shown by a short vertical line at the top of the grids if the trigger position is within the display. The time displayed at the top left of the grid is the number of microseconds at the start of the grid in relation to the trigger position. For example, a time of –3.2 microseconds shows that the displayed data starts at a point 3.2 microseconds before the trigger. If the time is positive, it means that the data shown is from after the trigger. You can view more of the data using the PageDown and PageUp keys to move back and forth one screen of data at a time. The END and HOME keys will jump to the start or end of the data sample. Press the escape key at any time to return to the menu.

F7—Display. This option displays the data currently stored in the program. When the program is first started before any samples have been taken, it will show some sample data that is a sawtooth waveform. You can also use this option to view data that has been recalled from a data file that has been stored on disk (see F8). The PageDown, PageUp, HOME and END keys work the same way as with F6 (Acquire).

F8—File. This option lets you save data and setup information to a file on disk for later viewing. You can also load saved data from a file with this option. The archive ALTADSO.ZIP has several data files that you can view. The CALLO, CALHI, CALCAL files are examples of correct probe compensation. The file VIDEO.DAT shows data captured from a composite video signal.

F9—Configure. This is the same as the configure option for the logic analyzer. If you have already configured the logic analyzer, you do not need to use this option.

F10—Exit. This quits the DSO program.

age at each pin location for all of the ICs. The voltages should be +5 volts, +8 volts, or –8 volts, as shown in the schematic diagram. Any problems should be tracked down and fixed before continuing.

When mounting the ICs, you may use sockets for all of the components except IC1 and IC2—those parts should be soldered directly to the board. Since the ICs are orientated in different directions on the board, double-check their orientation before soldering. It is a good idea to repeat the power-supply test with the ICs in place to catch any other assembly errors.

The three test points will need to be covered with insulating tubing to a height of a little more than a half inch if the case you will be using has a metal panel. You can use ribbon wire that has been split down and partially séparated or individual lengths of stranded wire for the digital probes connected to TP4–TP7. A good length for the wires is 12 inches, but they should not be longer than 18 inches. A set of jumper cables should also be made from 20-conductor and 28-conductor ribbon cable. Those cables will connect the DSO to the logic analyzer. The lengths of the cables should be as short as possible to reach between the connectors between the two units. A length of about 2½ inches should be about right.

Drill appropriate holes in the front panel of the enclosure that you will be using for the DSO. Mount the completed PC board to the back of the front panel with screws and threaded standoffs. The DSO is now ready for testing.

Testing the DSO Module. The logic-analyzer module should be connected to a computer and turned off. Connect the DSO to the logic analyzer with the ribbon cables and turn the logic analyzer on. You should check for +12 volts at pin 8 of IC12 on the DSO board. If that voltage is not there, you should shut off the power immediately and track down the cause of the problem.

You should have the program ALTADSO.EXE in the same directory on your PC as the logic-analyzer program ALTALOG.EXE. Both programs use the same configuration file, so once you have the logic analyzer configured, it will not be necessary to configure the DSO. Both programs are very similar, so once you are familiar with the logic-analyzer program, you will also understand the basics of the DSO program.

Start up the ALTADSO program from the DOS prompt. Press the F1 key and set the option to "SINGLE". Connect the logic probe from TP7 to TP1, then acquire a sample. The display should look like an oscilloscope screen with the four digital channels showing at the bottom of the display. The very bottom trace is from TP7; it should be showing a squarewave signal that alternates between the low and high levels. Press the escape key to return to the main menu. Repeat that test with the other probes and verify that they all produce squarewave signals.

Connect a scope probe to the BNC connector of channel A. A standard 10X probe rated at 60 MHz can be purchased from a number of mail-order sources for under $20. If the probe has a 1X–10X–REF switch, set the switch to "REF," otherwise, short the probe tip to the ground clip. Set F1 to CONTINUOUS mode and press F6 to begin acquiring samples. You should see a level trace in the top part of the grid that has an "A" on the left side. Turning R14 should move the trace up or down on the grid. There might be a short delay between adjusting the pot and seeing the results on the display, which is normal. Switch the probe to "10X" and connect it to TP1. You should see a squarewave signal on the A channel. Turning R8 will change the amplitude of the squarewave. If everything is working as described, test the B channel in the same way. If not, use a voltmeter to trace the signal path through the op-amp circuit looking for errors. When everything is working properly, mount the board in the case.

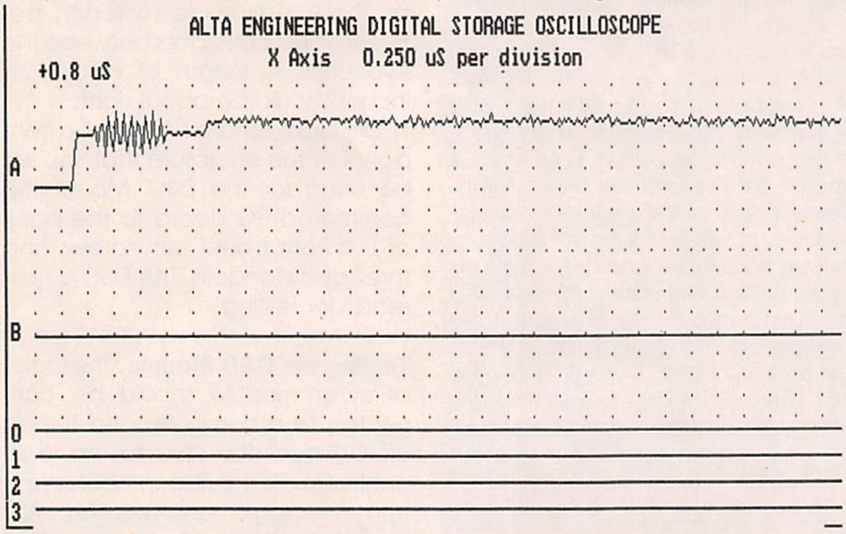
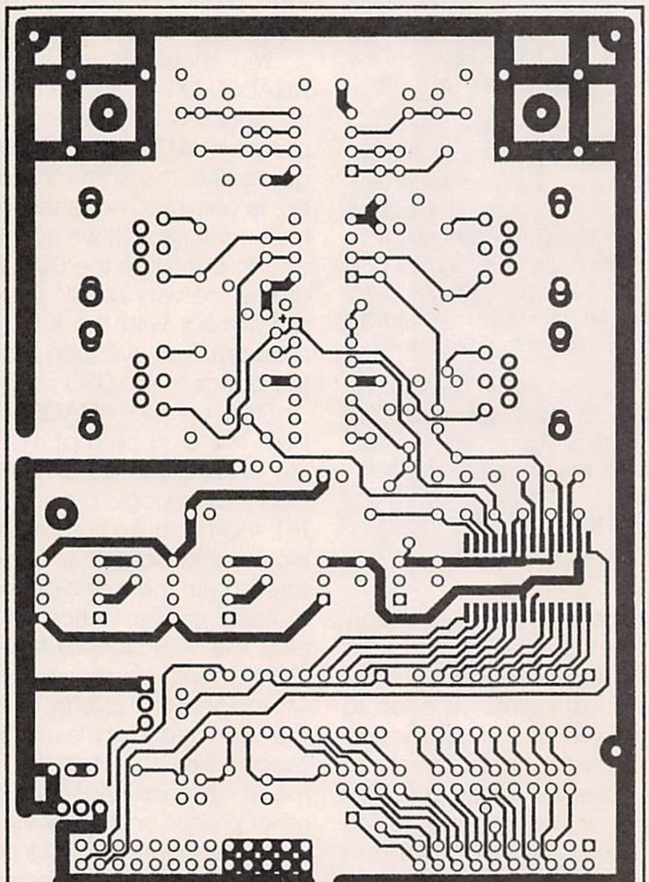


Fig. 3. The DSO software turns an IBM PC into a sophisticated piece of test equipment. As seen in this screenshot, there are two analog channels plus four digital channels. What's more, the software will work with a graphic display as low-resolution as CGA!

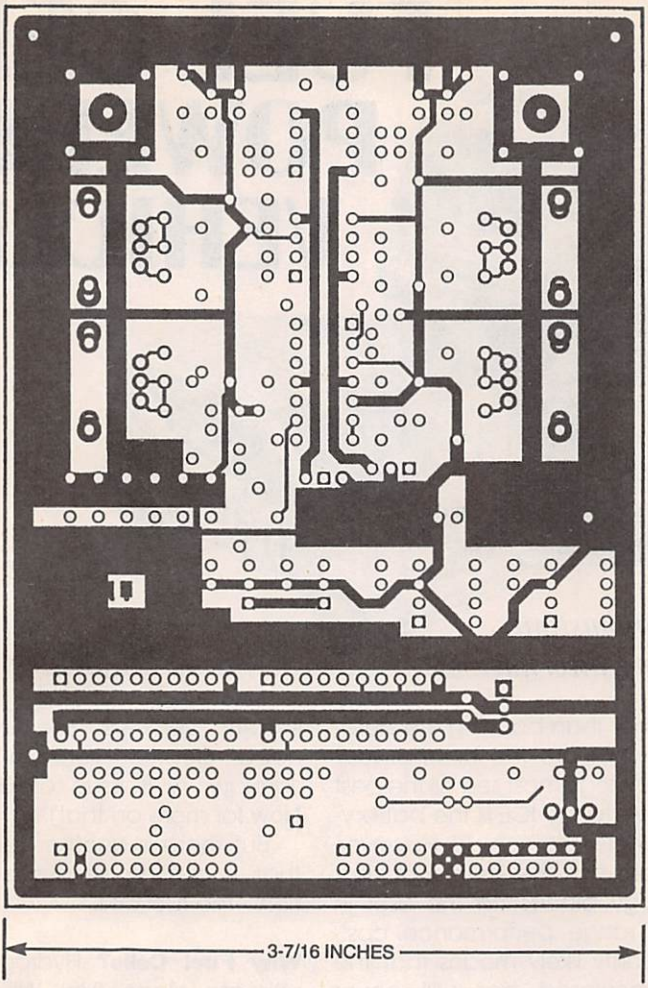


Here's the foil pattern for the component side of the DSO board.

Probe Compensation. All 10X scope probes have an adjustment that is used to match the probe to the scope input. Once a probe is adjusted to match a particular channel, that probe should always be used with that particular channel.

The adjustment procedure for the DSO module is slightly different from most scopes. Begin by setting the probe switch to "10X" and connect it to TP2. Select the CONTINUOUS mode with F1 and then start to acquire samples with F6. You should get a flat trace on the display grid. Use R14 to move the trace to the first grid line from the bottom of the grid display for that channel (remember, channel A covers the top part of the scope grid). Once the trace is on the correct grid line, connect the probe to TP3. Now use R8 to bring the trace to the second grid line from the top of the display. Once that trace is at the correct grid line, you should move the probe to TP1. The display will show a squarewave. Without touching any of the potentiometers on the DSO, adjust the probe's compensation until the top and bottom of the squarewave is at the same grid lines that were used for setting R14 and R8. Repeat the procedure for the other channel. A different probe should be used with each channel; mark each one as to which channel it was calibrated for. If you are not sure about the level settings for probe compensation, detailed information is built into the program and can be viewed by pressing F7 or F8.

Using the Digital-Storage Oscilloscope. At this point you are ready to use the Digital-Storage Oscilloscope. However, before you dive in and begin experimenting with the DSO, there are two important warn-



Here's the foil pattern for the solder side of the board. If you make your own board, the holes should be plated through.

ings that you should keep in mind. First of all, the maximum input voltage with the probes in 10X mode is ±60 volts; with the probes in 1X mode it is only ±8 volts. The second point is more important—before hooking up the DSO to a new circuit, check to be sure that there is no AC potential between the grounds of the circuit and the DSO.

A typical display of the DSO software is shown in Fig. 3. You have already become somewhat familiar with a few of the DSO's operational modes from testing and calibrating. See the sidebar for a more detailed explanation of each menu option.

To experiment with the various options, hook up the channel A probe to the TP1. Set the scope mode to NORMAL, the trigger mode to SCOPE, the trigger level to 8/16, and the slope to "+". Press F6 to acquire a sample. You should see a squarewave with the rising edge of the signal under the little trigger-position mark. Press the escape key and then set the trigger slope to "–". Press F6 to acquire another sample, and the trigger-position mark will be over the falling edge of the squarewave. When the trigger is set correctly, a repetitive signal should be steady in the display. You can experiment with the gain and offset adjustments and the other trigger settings using TP1. Remember, if the trigger condition is not met, the display will not be updated.

A Digital-Storage Oscilloscope is probably one of the handiest instruments to have on a test bench. The author welcomes questions, comments, and suggestions. He can be contacted through e-mail at alta @gutbang.com, by telephone at (860) 489-8003, or by visiting the Alta Engineering Web site at http://www.gutbang.com/alta. Ω