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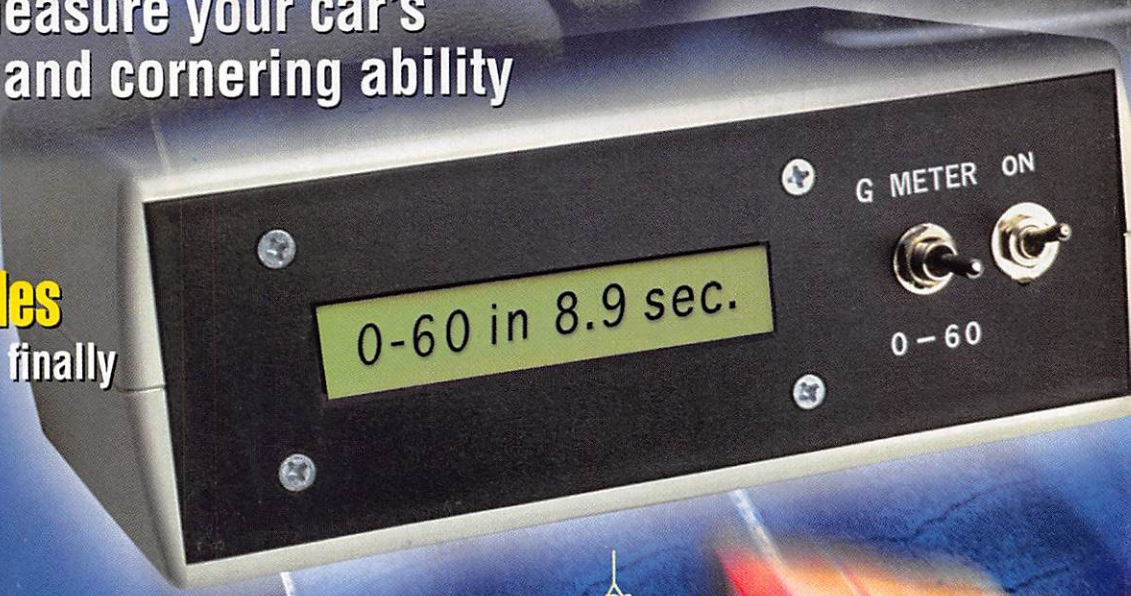

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Build the Automotive Performance Tester

BY DAN HARRISON

Measure zero-60-mph acceleration time, 'g' force, and more.

You have just spent a lot of money on a performance tune-up for your car or truck. You might have just installed a set of high-performance tires, or maybe you've just switched brands of gasoline. You *think* you're accelerating faster or cornering harder than before. How can you be sure that you're getting your money's worth of improvements?

It might not be practical to take your car to a timed drag strip. Hand-timed stopwatch measurements rely on an observer watching the speedometer. Cornering tests are even more subject to error. How can you really know whether your car or truck can pull more "g"s around a curve or can accelerate faster?

The answer to those questions is an accelerometer. With an accelerometer, you can measure cornering forces directly, and tire and brake performance by noting the maximum g force exerted during braking so you can find out at what point the tires start to lock-up. You can measure straight-line acceleration, which is a good indication of performance, but, by applying some simple physics, you also can have velocity measurements and distance-traveled measurements as well.

Measuring Zero to 60. In order to measure the time it takes to accelerate from zero to 60 mph, we need a couple of basic formulas. Measuring speed (distance × time) is simple at a constant velocity. It's when you throw acceleration in (change in speed over time) that things begin to get complicated. A typical acceleration curve for a manual-transmission automobile is shown in Fig. 1. Obviously, as the car accelerates in each gear, there is a rapid increase in the acceleration. Just before each gear shift, the amount of acceleration drops off as the accelerator pedal is released. While the clutch pedal is depressed and the transmission gear is being changed, there is a negative acceleration (slowing down) until the clutch is released and the engine can once again drive the car forward.

During a positive acceleration in a straight line, you go faster and move farther from your starting position. You can calculate both velocity and distance traveled once you know the acceleration that the vehicle is experiencing. Velocity (or speed) is found with the equation

Velocity=Acceleration × Time

Once we know the velocity, we can find out how far we've traveled with the equation

Distance=Velocity × Time

With those two formulas, it becomes much easier to calculate the classic performance standards. For the most famous one, zero-to-60-mph time, you just need to measure the vehicle's acceleration over time and calculate the velocity. When the acceleration-derived velocity equals 60 mph, count the time you've spent accelerating since you started moving, and you have your zero-to-60 mph performance measurement.

The other classic performance standard is the quarter-mile time and speed. Using the same formulas, we can both measure the quarter-mile distance and the final speed at the precise time that the quarter-mile mark has been reached.

How It Works. The Auto Performance Tester (APT) is designed around two essential components. A Motorola MC68HC705P9 microcontroller is programmed to calculate the zero-to-60 mph performance and display the results on a liquid-crystal display. An Analog Devices' ADXL05 accelerometer measures the actual acceleration forces and changes them to a variable voltage that the microcontroller can convert into a binary number using a built-in analog/digital converter circuit. The A/D converter is the main reason for choosing the P9 version of the MC68HC705. In addition, the microcontroller has a 16-bit timer that will be used as a real-time clock and sufficient digital input/output pins to control the LCD and switch inputs.

The Analog Devices' ADXL05 is a relatively new component designed primarily for automotive use. The auto industry tends to require low-cost products with a high reliability. That is the reason for choosing this particular device.

The Accelerometer. The ADXL05 is a solid-state ±5-g accelerometer that runs on a standard 5-volt supply. It has a built-in preamplifier and buffer amplifier, making the ADXL05 a complete acceleration-measure-

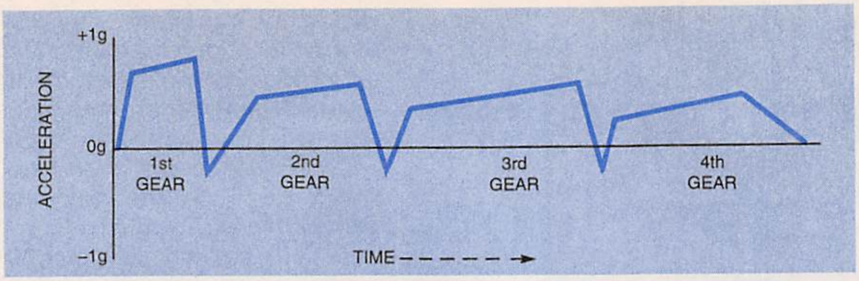


Fig. 1. When a vehicle is accelerating, there is a pattern to the amount of acceleration the vehicle experiences. As you take your foot off the gas while preparing to shift gears, the amount of acceleration drops off. While you are actually shifting gears, the vehicle starts slowing down. That causes the "negative" spikes shown here.

ment system on a chip.

When held in place in the direction of the earth's gravity, the ADXL05 will sense an acceleration of one g. That force will put 625 millivolts at the ADXL05's output pin when the circuit is properly calibrated. Because the buffer amplifier in the ADXL05 is an inverting stage, the actual voltage will be negative for a positive acceleration.

The ADXL05 is designed to be sensitive to acceleration in one axis. An ideal sensor will react to forces along or at angles to its sensitive axis but will reject signals from any force that is exactly 90° from the axis that is being measured. However, even an ideal sensor will produce an output signal if the unneeded signals are not *exactly* 90° to the sensitive axis. Any acceleration from a direction different from the sensitive axis will show up on the ADXL05's output as acceleration at a lower value. For that reason, it is important that the ADXL05 be mounted and aligned so that its axis of sensitivity is the same as the vehicle in which it is mounted.

Another common source of error in acceleration sensing is resonance of the mounting fixture. For example, the circuit board that the ADXL05 mounts to might have resonant frequencies in the same range as the signals of interest. That could cause the signals that are being measured to be larger than they really are. A common solution to that problem is to dampen the resonance by mounting the board that the ADXL05 is attached to with additional screws.

The ADXL05 is available as an evaluation-board kit. It comes complete with all parts necessary for configuring the ADXL05 accelerometer. Those parts include non-resonant surface-mount resistors and capacitors so that the circuit can be configured and customized in terms of the accelerometer's scale factor, zero-g bias level, and bandwidth with either AC or DC coupling. For those reasons, the evaluation board is an excellent choice for the APT's accelerometer sensor. The evaluation board is available through several sources including Allied Electronics; ordering information for that company is included in the Parts List.

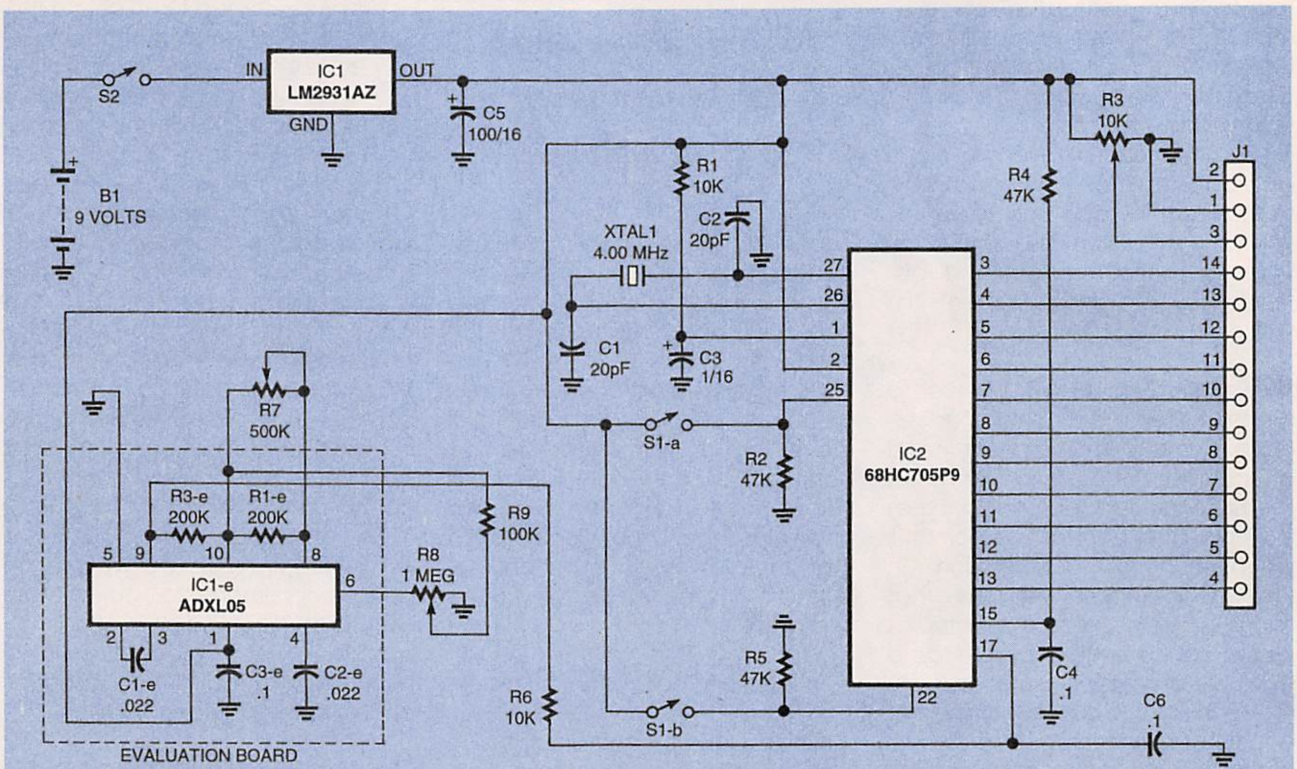


Fig. 2. The Automotive Performance Tester is built around two components—a Motorola 68HC705P9 microcontroller and an Analog Devices ADXL05 accelerometer. The ADXL05 evaluation board is used with this project. That board is sold as a kit that comes with all of the parts that are labeled "-e" within the dashed outline. Don't confuse those part designations with the part designations of the main circuit.

Circuit Description. The schematic diagram in Fig. 2 shows how simple the APT actually is. The MC68HC705 microcontroller, IC2, is the main semiconductor in the circuit. A 16-character, one-row LCD, DISP1, is connected to IC1 through J1, a 14-pin header. The LCD being used in the APT has enough on-board intelligence to accept simple commands from the microcontroller such as where to place the display cursor and what character to display at which location.

The APT is powered by B1, a 9-volt battery. The total current drain on the battery is less than 20 mA. To help keep the current consumption down, an LM2931-AZ5 voltage regulator is used for IC1. That regulator uses very little power for itself and has a very low dropout voltage. However, a standard 78L05 could be used if the LM2931 is not available. Switch S1 is a single-pole, double-throw, momentary-contact switch. That switch is a center-off type. It is used to select whether the APT will be displaying zero-to-60 time or current "g" force.

The ADXL05 evaluation board is connected to the internal A/D converter of IC2 through a simple low-pass filter made up of R6 and C6. That filter helps remove some of the random vibration noise that is present in all cars. Two panel-mount potentiometers (R7 and R8) adjust the ADXL05's gain and zero offset, respectively. Those adjustments are important for the APT to provide accurate measurements. The full-scale reading for the A/D converter is set by a reference voltage. The reference voltage in the APT is the 5-volt supply voltage filtered by R4 and C4

Software. All software for the APT was written in 6805 assembly language. The actual code is burned into IC2. If you wish to program your own IC, the code is available as apt.hex on the Gernsback FTP site (ftp://ftp.gernsback.com). While the actual programming code will not be discussed here, an overview of the action will help to explain how the APT works.

When power is applied to IC2, it automatically resets and begins running the initialization portion of the program. That includes setting the direction of the I/O pins, the internal timer, and the A/D converter.

Obviously, a zero-to-60-mph measurement cannot be accurately made without some sort of clock. The APT's clock is IC2's internal timer. During initialization, the timer is set to "tick" at 100 Hz. That rate will give a timing resolution of 0.01 second.

Once the sections of the APT are running, the main loop of the program is entered. A startup message is displayed on DISP1 and the system waits for S1 to be closed in one direction or the other. If S1-a is closed, then the g-Meter routine is run. If S1-b is closed, then the zero-to-60-mph routine is run instead.

When either routine is finished, the program loops back to the beginning of the main loop where it displays a startup message on DISP1. The system waits for S1 to be closed in one direction or the other. The entire loop runs continuously until the unit is turned off.

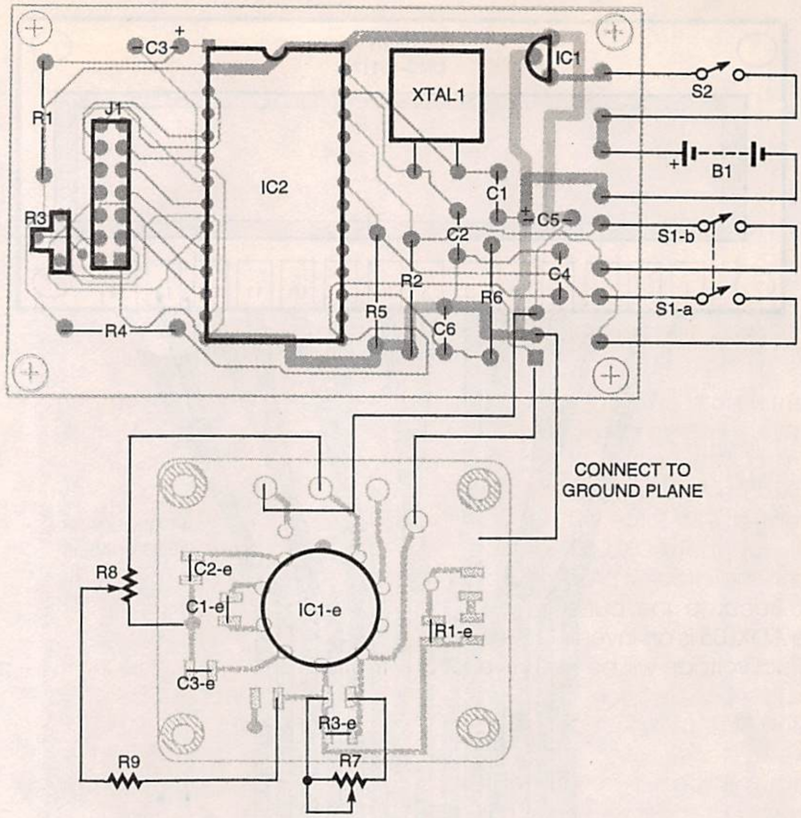


Fig. 3. If you use the foil patterns for the Automotive Performance Tester, use this parts-placement diagram when building the board. The Analog Devices ADXL05EB evaluation board is also shown. Those components that are included with the evaluation board are marked with an "-e". Not all of the parts that are included with the evaluation board will be used—only the parts shown here.

Construction. Building the APT is quite straightforward. The main PC board is double-sided. If you do not want to fabricate your own board, a pre-etched board is available from the source given in the Parts List. If you use a pre-etched board or make one from the foil patterns, the parts-placement diagram in Fig. 3 should be followed when building the APT.

Begin by assembling the accelerometer board first. The evaluation board parts-placement is shown in Fig. 3, but the part designations that end in "-e" are the components that come with the evaluation board. Any components that do not have an "-e" in their designation must come from other sources. The instructions that come with the evaluation kit, for example, will refer to R1-e as "R1." Do not confuse that R1 with the R1 that is mounted on the main printed-circuit board.

Several modifications must be followed for the evaluation board

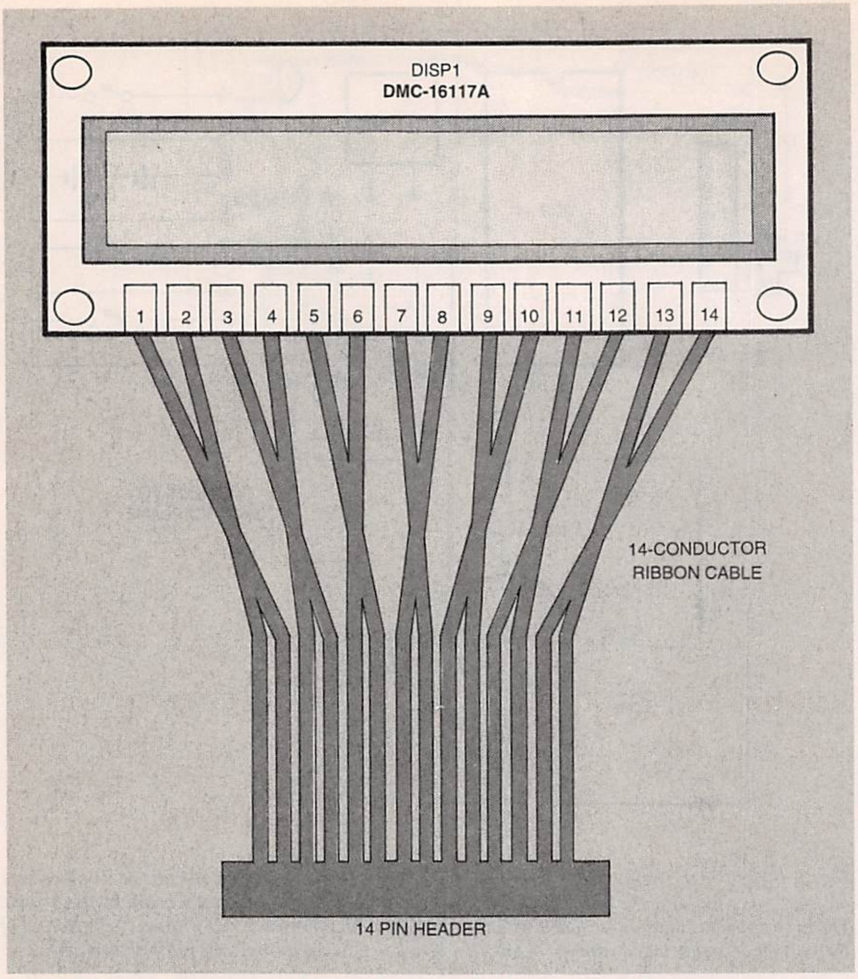


Fig. 4. The wires that connect the LCD to the 14-pin header are connected this way.

to be used in the APT. Install R1-e, R3-e, C1-e, C2-e, and C3-e only—the other surface-mount components will not be used. Calibration controls R7 and R8, along with R9, are wired to the evaluation board with suitable insulated wire, such as 30-gauge wire-wrap wire.

The ADXL05 evaluation board uses surface-mount resistors and capacitors. Those components can be difficult to install for a beginner. You should only attempt to build the evaluation board with a fine-tip 15- to 20-watt soldering iron and fine-wire solder or solder paste.

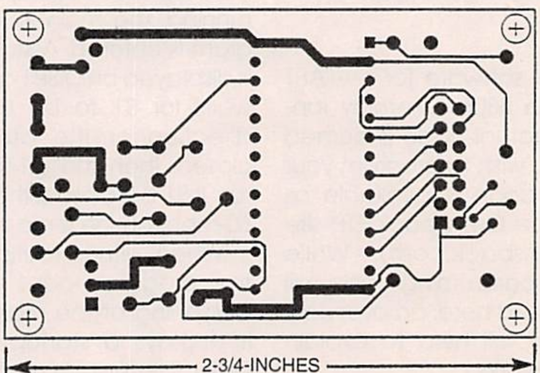
Once the evaluation board is finished, set it aside and go on to the main board itself. Assembly of that through-hole circuit will be quite easy compared to the evaluation board. If you decide to build the APT board on perfboard or some other prototyping board material, keep XTAL1 as close to IC2 as possible. Using a 28-pin socket for IC2 can be a good idea for ease of troubleshooting in case you have a problem and think that IC2 might be damaged. It will also make upgrading the APT easier in the future if you want to use a different program.

Connect two 22-gauge wires to S2 and solder it into the board as shown. When wiring S1, the "down" position should be connected as S1-a, and the "up" position will be S1-b. Solder the battery-connector leads to the board as shown. Be sure to observe the correct polarity. If you are not sure, connect a 9-volt battery and test the polarity with a voltmeter.

The LCD assembly is shown in Fig. 4. Press a 14-pin header onto a length of 14-conductor ribbon cable. Keep the marked edge of the cable and pin 1 of the header lined up. On the unconnected end of the cable, separate out the wires about 1½-inches back from the end of the cable and strip the insulation about ¼-inch from the ends. Tin all of the wires with solder, and then solder the wires to the holes in the edge-connector pads on the LCD as shown.

Connect the header on DISP1 to J1. Double-check that pin 1 on the cable and J1 are both matched properly. Don't connect the accelerometer board to the main board yet. Be sure that the power switch is in the off position and connect a fresh 9-volt battery to the battery connector. Switch the power on and DISP1 should display "Up - g's Down 0-60". If you don't get that sign-on message, turn the power off and check all of the wires and connectors carefully. Remember that the design is very simple. Most of the time the problem is a misplaced wire, bad solder joint, or other similar human error. It is very unlikely that a component is bad if you have purchased new parts and have taken the usual and proper electrostatic discharge (ESD) precautions.

When the startup message is suc-



Here is the solder side of the Automotive Performance Tester circuit board.

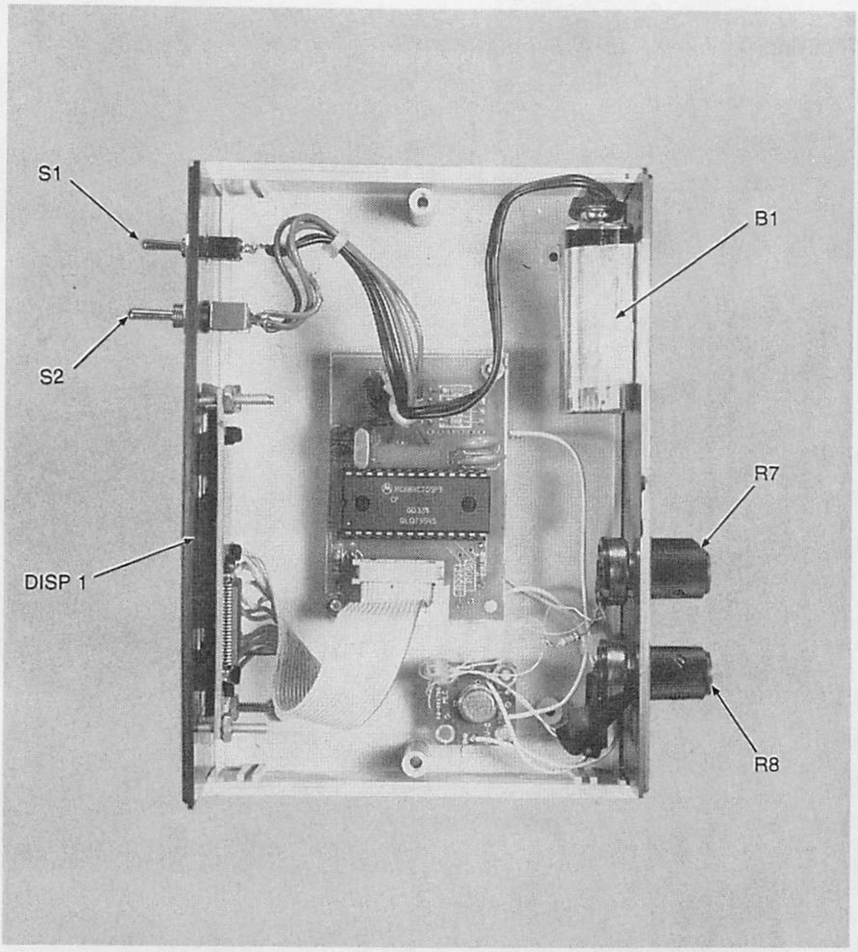


Fig. 5. Here is an inside view of the completed Automotive Performance Tester. The accelerometer board should be mounted securely so that any vibrations from the vehicle will not influence the readings taken by the APT. Mount the accelerometer so that the tab on the IC faces the front panel.

cessfully displayed, set the display contrast by turning R3. Turn off the power and disconnect the battery. The accelerometer board is then connected to the main board with three wires.

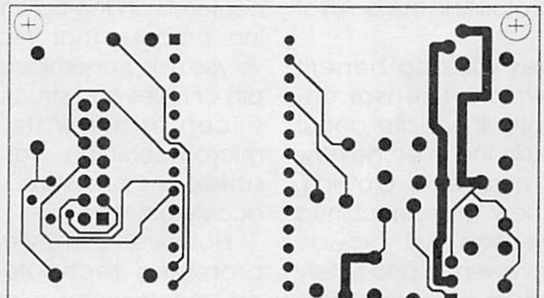
Drill and cut appropriate holes in a suitable enclosure for S1, S2, DISP1, R7, R8, and both PC boards. Mount the boards and switches in the case. A suggested mounting arrangement is shown in Fig. 5. The accelerometer board must be mounted rigidly and square with the case. The tab on the ADXL05 must point towards the front of the case. Also be sure that the accelerometer board is parallel with the mounting surface of the case. Any tilt of the accelerometer board will affect the accuracy of the APT.

Calibration. With a fresh battery installed, turn on the APT. Center both R7 (gain) and R8 (offset). Using a carpenter's level, set the case of the APT so that it is completely level. Select the g-meter function and adjust the offset until a 0.00 reading is seen on DISP1. Carefully tilt the unit exactly 90° so that the display is facing up. Do not disturb R7 or R8 while turning the unit. The reading on DISP1 should be a negative number. Adjust the gain control for a reading of –0.32. The zero offset might have changed, so recheck the level for 0.00. If it's not zero, then keep readjusting the offset and the gain until the readings are correct. You might have to repeat the procedure two or more times to get it perfect. The APT is now calibrated and ready to run.

Using the Automotive Performance Tester. It is important to mount the APT solidly in the vehicle so that it does not bounce or twist during a performance test. The errors discussed earlier will come into play if the unit moves relative to the car. The mount must be secure and should prevent the APT from shaking or swaying during driving. Suction-cup mounts sold for radar detectors will work well, but they might have to be modified slightly in order to be used with any particular enclosure housing the APT.

The APT is very good at determining the zero-to-60-mph time if certain conditions are met. First the unit must be level. That is done by using the g-meter function prior to each timed zero-60-mph run. Level the APT so that the display reads 0.00 gs. Once again, that is important because the APT will pick up some amount of gravitational acceleration in any position other than level. The gravitational acceleration component will cause erroneous zero-to-60-mph times in either the positive or the negative direction depending on whether the unit is slanted down or up. Another important fact to keep in mind is that the road or track must also be level for the same rea-

(Continued on page 72)



Here is the component side of the Automotive Performance Tester circuit board. Be sure to solder any components that have connections on both sides of the board if you etch your own board.

PERFORMANCE TESTER

(continued from page 39)

sons. The unit must also be square with the vehicle. If the unit is not lined up properly, then the measured acceleration will be in error by the sine of the angle of offset.

Once the APT is installed and calibrated, you're ready for an acceleration test. Place the car on level ground and turn on the APT. Go into the g-meter function and check the level of the APT. Go to your favorite raceway, private road, or some place where you can accelerate to 60 mph from a standing start without breaking any laws or endangering others. Put the APT in the zero-to-60-mph mode and "Waiting to go" will appear on DISP1. Begin accelerating quickly. The APT is looking for a 0.2-g "kick" to signal the start of a run. When the APT detects the start condition, the display will change to "*xx* ft/sec," displaying the real time velocity of the car in ft/sec. When 88 ft/sec is reached, the APT will stop accumulating velocity and will print "*xx.xx* sec" giving you your zero-to 60-mph time.

PARTS LIST FOR THE AUTOMOTIVE PERFORMANCE TESTER

SEMICONDUCTORS

IC1—LM2931AZ-5.0, voltage regulator, integrated circuit
IC2—MC68HC705P9, microcontroller, integrated circuit

RESISTORS

(All resistors are ¼-watt, 5% units unless otherwise noted.)
R1, R6—10,000-ohm
R2, R4, R5—47,000-ohm
R3—10,000-ohm, potentiometer, printed circuit mount
R7—500,000-ohm, potentiometer, panel-mount
R8—1-megohm, potentiometer, panel-mount
R9—100,000-ohm

CAPACITORS

C1, C2—20-pF, ceramic-disc
C3—1-µF, 16-WVDC, electrolytic
C4, C6—0.1-µF, ceramic-disc
C5—100-µF, 16-WVDC, electrolytic

ADDITIONAL PARTS AND MATERIALS

B1—9-volt battery
DISP1—16-character liquid-crystal display (Digi-Key 73-1012-ND or similar)
J1—14-pin header (Mouser 512-QSD124 or similar)
S1—single-pole, double-throw, momentary-contact switch (Digi-Key CKN1007-ND or similar)
S2—Single-pole, single-throw switch (Digi-Key CKN1023-ND or similar)
XTAL1—4-MHz crystal
Analog Devices ADXL05EB evaluation kit (available through Allied Electronics, 7410 Pebble Drive, Fort Worth, TX 76118, Tel: 817-595-3500, Fax: 817-595-6444, Web: http://www.allied.avnet.com), IC socket, enclosure, PC board, ribbon cable, wire, hardware, etc.

Note: The following is available from Harrison R&D, 9802 Sagequeen, Houston, TX 77089, Tel: 281-485-7107, e-mail: dharrison@ghgcorp.com: Pre-programmed IC2, $25.00; Main circuit board, $10.00; Pre-programmed IC2 and main PC board together, $30.00; Complete source code for IC2 on 3½-inch diskette, $49.00 (Please specify either IBM or MacIntosh format). Please add $3.50 for shipping and handling to USA and Canada. Texas residents, add 6¼% sales tax.

Other uses of the APT are braking tests. You could use the g-meter function to determine the maximum braking force. Cornering forces could be read by rotating the APT 90° so that it can sense left or right forces.

Have fun, but be safe at all times. Remember that trying to read the APT while driving is dangerous. Have a friend read the unit while you are doing cornering tests. Ω