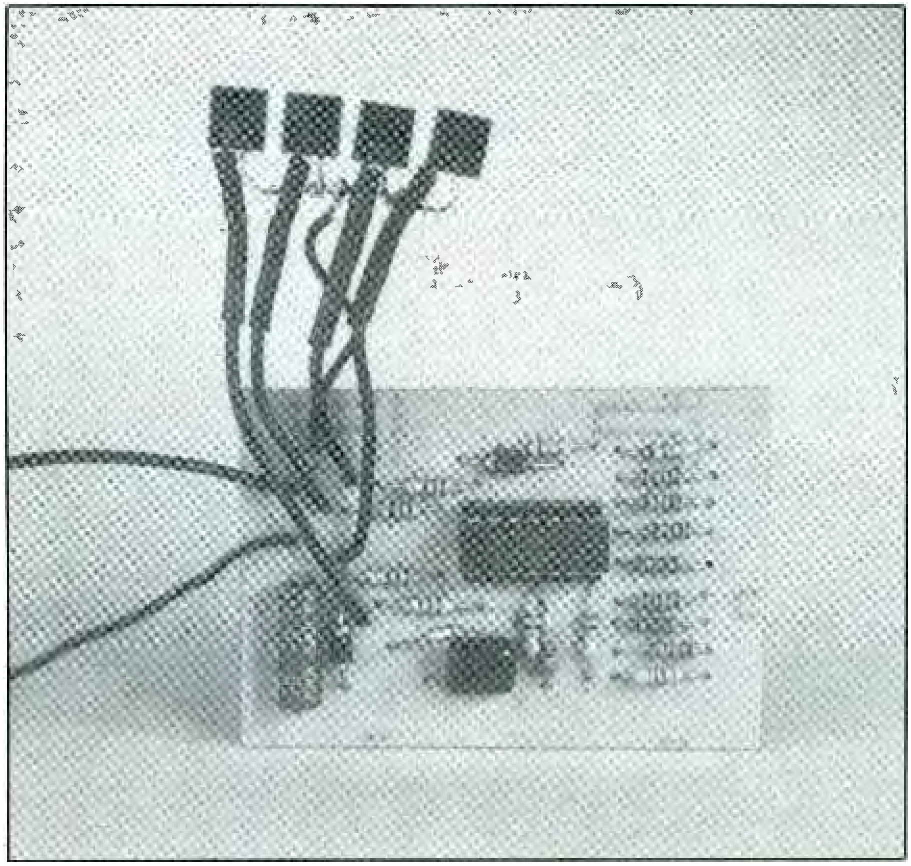
Automotive Battery/Charging System Analyzer

Simple low-cost circuit uses a series of LEDs to report on vehicle electrical system status

By Anthony J. Caristi

With labor cost so expensive today, it makes sense to diagnose and repair as many automotive problems as possible instead of having a service center do it. This was the motivation behind the development of the Automotive Battery/Charging System Analyzer described here. This instrument gives professional-quality diagnostics of a vehicle's electrical system that will help in repairing common defects. It checks the battery, alternator and voltage regulator in a vehicle while the engine is being started and is running. If it is permanently installed in a vehicle, it can provide advance warning of impending trouble so that you will be able to take corrective action before a problem disables your vehicle. A series of four light-emitting diodes, each assigned a specific unambiguous reporting task, provide all indications of electrical system status.



In addition to saving on the cost of labor, this Analyzer helps pinpoint the cause of a problem to a specific component, which minimizes your cost for parts as well. The project is easy to build, low in cost and accurate in performance. It can be used as a stand-alone instrument that can be carried from one vehicle to another, or it can be permanently installed to provide continuous monitoring of a vehicle's electrical system. The Analyzer requires no power supply to set it up for operation. Simply connect its color-coded leads in proper polarity, and whatever power is needed to drive the circuit is drawn from the vehicle's electrical system.

About the Circuit

The key to diagnosing the condition of the battery and charging system in a motor vehicle is making measurements of the battery's voltage under specific conditions. Since most motor vehicles now on the road employ a six-cell 12.6-volt lead-acid battery to supply electrical power, it is a simple matter to provide a dedicated electronic device that compares battery voltages encountered to a built-in voltage reference.

Voltage measurements on a battery must be made under two operating conditions—starting (cranking) and running. To provide meaningful results, four voltage levels are

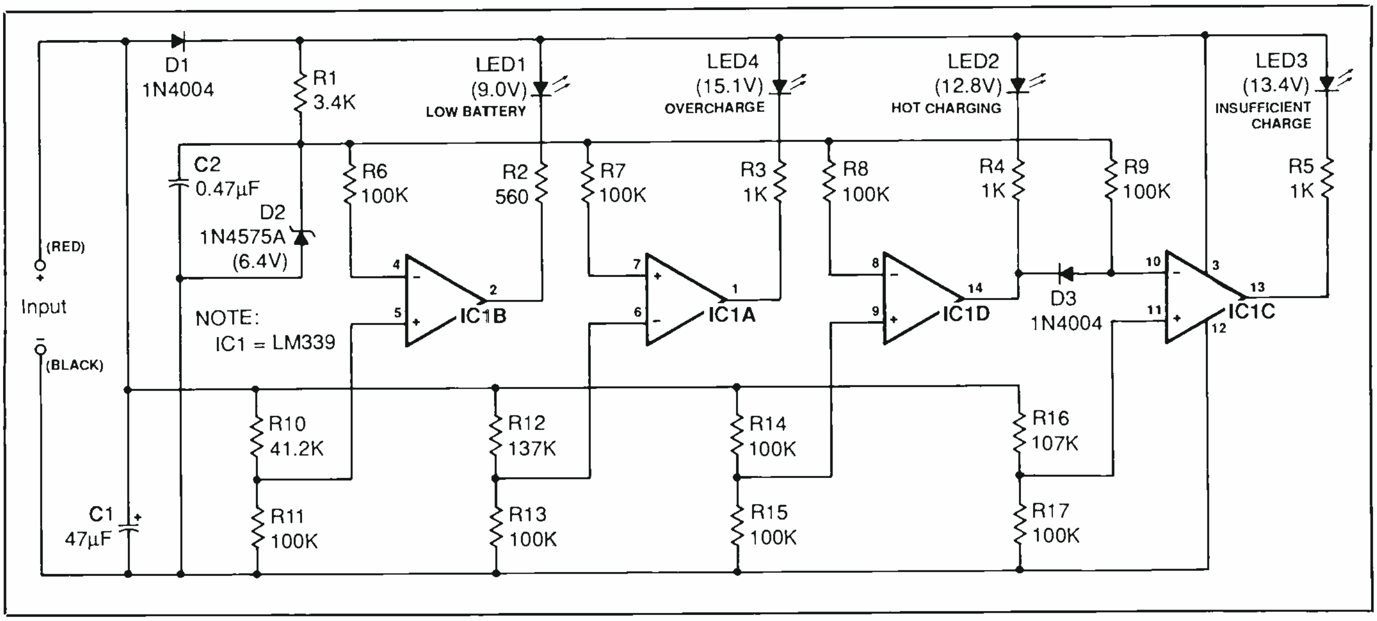


Fig. 1. Complete schematic diagram of the project's circuitry.

programmed into the Analyzer to allow you to determine if the vehicle's electrical system is operating within acceptable limits. If they are not, one of the four LED indicators will light, which one depending on the condition detected.

LED indicator voltage levels are provided for 9.0, 12.8, 13.4 and 15.1 volts. Hence, the Analyzer checks the battery and charging system for an under-charged or defective battery, no charging action, insufficient charging voltage level and overcharging. The circuit then lights the appropriate LED for the condition detected. If all is well with the vehicle's battery and charging system, none of the LEDs will be lit.

A properly operating battery and charging system will have a battery terminal potential of about 12.6 volts when the engine has been idle for some time. The potential will be between 13.5 and 15.0 volts when the battery is being charged by the vehicle's alternator. During the period the engine is being cranked, a battery that is in good condition will have terminal potential of not less than 9 volts. This Analyzer has been "programmed" to accurately detect these voltages using a temperature-compensated zener diode as a reference.

Shown in Fig. 1 is the complete schematic diagram of the Automotive Battery/Charging-System Analyzer's circuit. The heart of the circuit is four-section comparator *IC1*. As its name implies, a comparator actually "compares" one voltage to another, which causes its output stage to be at one of two logic levels. These levels are high and low or on and off, depending on how you view these conditions.

A comparator is similar to an operational amplifier that is running at full amplification with no feedback resistor network in the circuit. As a result, the output voltage will swing from ground level to V+ and vice-versa as the voltages fed to the two inputs (both referenced to circuit ground) become unequal. The LM339 comparator IC used in this project has an "open-collector" output transistor that is either held in cutoff or driven into full saturation according to the polarity of the difference potential fed to the two inputs.

Zener diode *D2*, which is designed to generate a very accurate zener breakdown potential of 6.4 volts at a current of 2 milliamperes, serves as the circuit's reference. This 6.4-volt potential is fed through isolation resistors to the reference input of each voltage comparator (*IC1A* through *IC1D*). Since the four comparator circuits in this instrument operate in the same manner, an explanation of how one works will suffice for all.

The 9.0-volt comparator is composed of *IC1B* and its associated components. The voltage reference of 6.4 volts drives the negative (−) input of the comparator at pin 4, while the voltage fed to the positive (+) input is a portion of the vehicle's battery potential as determined by the *R10/R11* voltage divider.

The values of these two resistors must be chosen so that the comparator's switch-over point occurs when the battery potential is 9.0 volts. This causes the output transistor in *IC1B* to cut off when the potential is greater than 9 volts and be saturated when it is at a lower potential. With the output transistor in cutoff, *LED1* extinguishes. On the other hand, when the transistor is switched on, current flows through and lights *LED1* to indicate a defective or under-charged battery.

PARTS LIST

Semiconductors
D1,D3—1N4004 or similar silicon rectifier diode
D2—1N4575A or similar 6.4-volt zener diode (see text)
IC1—LM339N quad comparator
LED1 thru LED4—2-volt, 20 mA light-emitting diode (see text)
Capacitors
C1—47μF, 25-volt electrolytic
C2—0.47-μF, 25-volt ceramic disc
Resistors
(¼-watt, 1% tolerance metal-film)
R1—3,400 ohms
R10—41,200 ohms
R11,R13,R14,R15,R17—100,000 ohms
R12—137,000 ohms
R16—107,000 ohms
(¼-watt, 5% tolerance carbon)
R2—560 ohms
R3,R4,R5—1,000 ohms
R6 thru R9—100,000 ohms
Miscellaneous
Printed-circuit board or perforated board with holes on 0.1" centers and suitable Wire Wrap or soldering hardware; socket for IC1; suitable enclosure (see text); large color-coded alligator clips (for portable version only); red- and black-insulated stranded hookup wire; solder; etc.

Note: The following items are available from A. Caristi, 69 White Pond Rd., Waldwick, NJ 07463: Ready-to-wire printed-circuit board, $9.95; set of nine 1% tolerance metal-film resistors, $3.50; LM339N, $2; 6.4-volt zener diode, $3.75. Add $1.50 for P&H per order. New Jersey residents, please add state sales tax.

Each remaining comparator circuit operates in the same manner, except that they successively detect and indicate potentials of 12.8, 13.4 and 15.1 volts. These potentials were selected to light LEDs that inform you when such electrical abnormalities as NOT CHARGING (*LED2*), INSUFFICIENT CHARGING (*LED3*) and OVERCHARGING (*LED4*) exist.

You will note that the positive and negative inputs of *IC1A* are connected opposite to those for the other three comparators. The reason for this is that the Analyzer must light *LED4* when battery potential exceeds 15 volts to indicate an overcharging condition. The other three comparators are used to detect potentials that fall below the specified voltage levels.

To obviate an ambiguous display when the charging system is not working at all, diode *D3* causes a "not-charging" condition to bias the negative input of *IC1C* to cause *LED3* to extinguish. This is accomplished by the output from *IC1D* pulling to ground the reference input of *IC1C*. Consequently, when the vehicle's charging system is not working at all, NOT CHARGING *LED2* will be on and INSUFFICIENT CHARGING *LED3* will be extinguished.

The function of diode *D1* in this circuit is to prevent damage to the project in the event the polarity of the input leads are accidentally reversed when connecting the Analyzer to the vehicle's electrical system.

Construction

Except for the light-emitting diodes, the entire circuit of the Analyzer can be assembled on a small circuit board that measures approximately 1.75 × 2.75 inches. Because only dc voltages are dealt with by this circuitry, there is nothing critical about component layout or conductor routing. Therefore, you can use a printed-circuit board or perforated board that has holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware to assemble the circuit.

If you wish to make your own pc board, use the actual-size etching-and-drilling guide shown in Fig. 2. If you want pc construction but do not want to go through the bother of fabricating your own board, you can purchase a ready-to-wire board from the source given in the Note at the end of the Parts List. Alternatively, use perforated board. Whichever way you go, it is a good idea to use a high-quality DIP socket for *IC1*.

From here on, we will assume you are using a printed-circuit board. With this in mind, orient the board in front of you as shown in the wiring guide shown in Fig. 3. (If you are using perforated board, use Fig. 3 as a rough guide to component layout.) Then install the socket in the indicated location and solder it into place.

Install and solder into place the resistors, capacitors and diodes. Make sure the diodes and electrolytic capacitor *C1* are properly polarized before soldering their leads to the copper pads on the bottom of the board. Bear in mind that just one of these components installed backwards will render the circuit inoperable and may even cause damage to one or more components in the Analyzer.

Now strip ¼ inch of insulation from both ends of five 3-inch lengths of *stranded* hookup wire. If possible, use four black- and one red-insulated wires. Tightly twist together the fine conductors at both ends of all five wires and sparingly tin with solder. Plug one end of the black-insulated wires into the holes labeled LED1 K through LED4 K and solder into place. Plug one end of the remaining red-insulated wire into the hole labeled TO ALL LED ANODES and solder it into place.

Carefully inspect your circuit-board assembly. Check that all components are in their correct locations and those that are polarity-sensitive are properly oriented. Then flip over the board and check all soldered connections. Reflow the solder on any suspicious connection and use desoldering braid or a vacuum-type desoldering tool to remove any solder bridges that might have been created between closely spaced pads and conductors.

Slip a 1-inch length of small-dia-

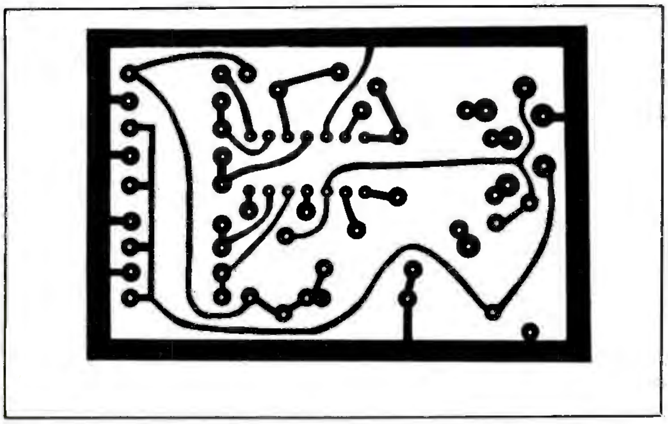


Fig. 2. Actual-size etching-and-drilling guide for fabricating a printed-circuit board for the project.

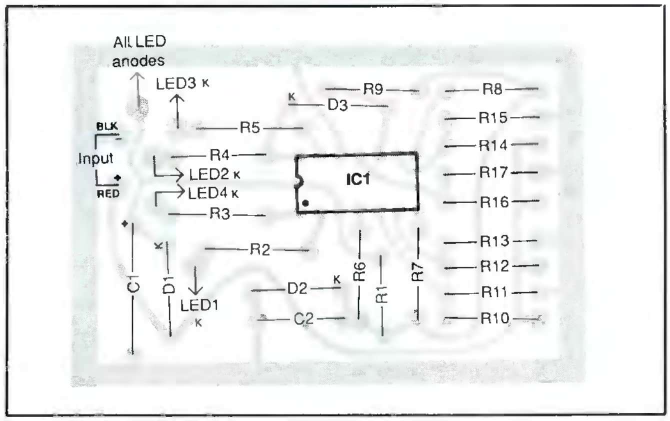


Fig. 3. Wiring diagram for pc board. Use this as a rough guide to component placement when wiring the project on perforated board.

meter heat-shrinkable or plastic tubing over the free ends of all four black-insulated wires. Identify the cathode leads of the four LEDs and clip each to a length of ½ inch. Form a small hook in the remaining lead stubs. Then crimp and solder the free ends of the four black-insulated wires to the cathode leads of the LEDs. Push the heat-shrinkable or plastic tubing up over the connections until all are flush against the bottoms of the LED cases and shrink into place.

It is important that you use the resistors specified in the Parts List for the voltage-divider networks. These are 1-percent-tolerance metal-film resistors. The accuracy of your Analyzer depends on the accuracy of the values of these resistors. Ordinary carbon-composition resistors do not have sufficient accuracy or stability for use in this part of the circuit. Additionally, zener diode *D2*, which also determines the accuracy of the instrument, *must* be a temperature-compensated reference diode. Do *not* substitute an ordinary zener diode for *D2*.

Whether you plan on using the project as a portable instrument or to permanently install it in your vehicle, house the circuit-board assembly in any enclosure that will accommodate it. If you wish to limit the amount of machining needed, you can use a small plastic project box. Otherwise, a small metal utility box will do.

Machine the box as needed. This includes drilling mounting holes for the LEDs and an entry hole for the test leads that will be used with the project. You do not have to drill mounting holes for the circuit-board assembly. It will be mounted in place inside the enclosure with a layer of thick double-sided foam tape. However, if you plan on installing the project permanently in a vehicle, drill a pair of holes to mount it in place where it will be easily seen from the driver's seat.

You will notice in the lead photo that LEDs with rectangular-shaped cases were used in the prototype of the project. Use of these requires that you cut a slot in which to mount each LED. If you do not have the proper tools for making such slots, use LEDs that are housed in round cases. Also, if you are using a metal utility box, deburr all holes and line with a small rubber grommet the one through which the project's leads will be routed.

Whether the project is to be a portable test instrument for a variety of vehicles or part of the instrument cluster in only one vehicle, it needs input leads. These must be stranded hookup wire, preferably with red insulation for positive and black insulation for negative. Light-duty wire will do, since the project draws very little current. The lengths of the leads will depend on how the project is to be used. If it is to be a portable instrument, 36- or even 24-inch leads will suffice. For permanent installations, the length of the positive lead will be dictated by where the project is mounted with respect to the battery's location, though the negative lead can be much shorter, since it need only go to a convenient nearby chassis ground point.

Prepare the input leads as you did for the LED wires above. If this is to be a portable instrument, route one end of each through the hole drilled for the input cable and tie a strain-relieving knot in the wire pair about 5 inches from the free end inside the enclosure. Plug these leads into the board holes labeled INPUT and solder into place. Then terminate the other ends in large color-coded alligator clips. For a permanent installation, simply route the leads into the enclosure, tie a knot in them, plug them into the board holes and solder into place. The other ends will be terminated later.

Once the input leads have been connected to the circuit-board assembly, mount the latter firmly inside the enclosure, using thick dou-

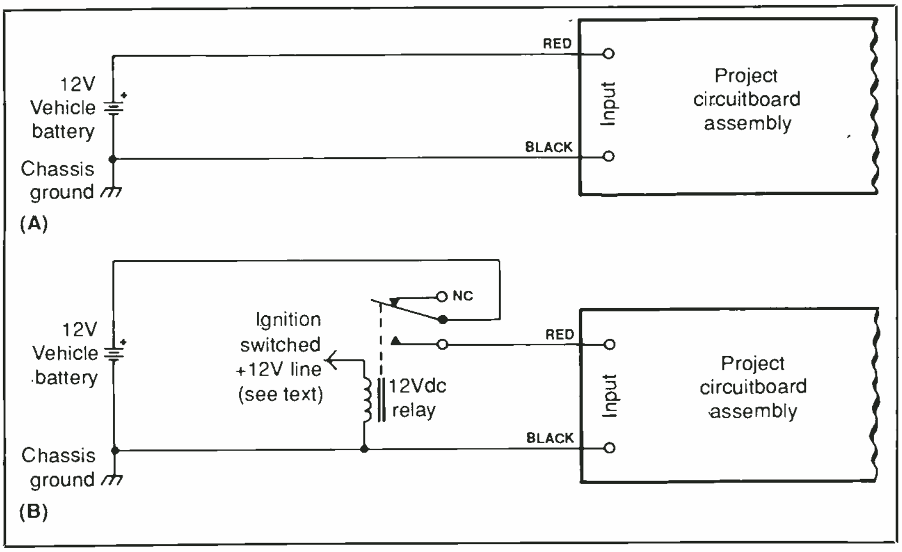


Fig. 4. Alternative means of enabling and disabling a permanently installed Analyzer. In (A), power is turned on and off manually with a slide or toggle switch. In (B), power is automatically applied and removed by the contacts of a relay that is energized when the vehicle's ignition is turned on and deenergized when it is turned off.

ble-sided foam tape. At this point, *IC1* should *not* be installed in its socket, nor should it be until after preliminary voltage checks have been made.

Connect the input leads to a dc power source, such as a variable bench supply set for an output between 9 and 15 volts or even a 9-volt battery. Make sure the polarity of the connections is correct. Then connect the common lead of a dc voltmeter or a multimeter set to measure dc volts to the negative lead of *C1*. Touch the tip of the meter's "hot" probe to pin 3 of the IC socket. The meter should register a reading of whatever the power supply is set to or the battery is rated at, and no other pin should give a reading when the "hot" probe is touched to it. If you do not obtain the proper indications, power down the circuit and rectify the problem. Do not proceed until you have ascertained that the power buses have been properly wired.

Label the LED positions on the front panel of the enclosure with legends that identify the condition each LED is to indicate (see Fig. 1). If you use a dry-transfer lettering kit, protect the legends with several light coats of clear spray acrylic. Let each coat dry before spraying on the next.

Now plug the LEDs into their respective holes in the enclosure's panel. If the LEDs do not remain in place by friction alone, secure them with plastic or fast-setting clear epoxy cement. Then tie together the anode leads of all four LEDs. Crimp the free end of the remaining wire coming from the circuit-board assembly to the four-lead bundle and solder the connection. Heat sink the anode leads of the LEDs to prevent heat damage to these devices. Then install the IC in the socket. Make sure that it is properly oriented and that no pins overhang the socket or fold under between IC and socket.

Checkout & Installation

Before actually installing the project in your vehicle or using it to conduct a test session, it is a good idea to check it out on your testbench. Use an adjustable dc power supply and an accurate dc voltmeter or multimeter set for measuring dc volts for this test. The supply must be capable of having its output vary between 8 and 16 volts. For maximum accuracy, the meter should be a digital type that has at least a 3½-decade display.

Connect the voltmeter and input leads of the project to the output terminals of the power supply. Observe polarity in both cases. With the supply's control set for minimum output voltage, turn on the power. Slowly adjust the setting of the control while observing the meter's display until a reading of 8 volts is obtained. At this point, both LOW BATTERY *LED1* and NOT CHARGING *LED2* should be on.

Slowly increase the setting of the supply's control until *LED1* extinguishes, which should occur at a meter reading of 9.0 volts. Continue adjusting the supply's control until *LED2* extinguishes and note that INSUFFICIENT CHARGING *LED3* simultaneously turns on. This should occur at a meter reading of 12.8 volts.

Continue adjusting the supply's control until the meter registers 13.4 volts. At this point, all LEDs should be off. Finally, adjust the supply's setting until OVERCHARGING *LED4* comes on, which now should occur at a meter reading of 15.1 volts. *Caution:* Do *not* permit the output voltage to exceed 16 volts while the project is connected to the power supply; if you do, irreversible damage will take place in *IC1*.

If you obtain the responses indicated above, the project is working properly and you can proceed to installation or actual use in a test situation. If not, you must troubleshoot the circuit and rectify the problem and then conduct again the operational checkout procedure. In all cases, the potentials at which the LEDs change state should be within 0.1 volt of that specified. If your project does not perform within this tolerance, it would be prudent to parallel one of the resistors in the voltage-divider network feeding the affected comparator with another resistor

(Continued on page 84)

that has a value of about 10 times the specified value for the single resistor to bring the circuit into spec.

If it is necessary to troubleshoot the project, set the power supply for an output of 14 volts and check the potential across *D2* to ascertain that it is 6.4 volts. If you obtain this indication on the meter, measure the potentials at pins 4, 7, 8 and 10 of *IC1* for the presence of this zener voltage. Assuming that you do obtain the proper indications at each IC pin, set the power supply to each of the specified voltage-detection levels (9.0, 12.8, 13.4 and 15.1 volts for *LED1* through *LED4*, respectively) and measure the corresponding comparator input terminals at pins 5, 6, 9 and 11 for a dc potential that should be 6.4 volts. Ascertain in each case that this potential rises and falls when the supply's output is raised and lowered.

Check the LEDs to make sure that they are not wired backward into the circuit. Also check the orientation of the LM339 chip in the IC socket and that all its pins are plugged firmly into their respective receptacles in the socket. If you still do not obtain the proper indications from the circuit, try another LM339.

Once you have ascertained that the project is operating as it should, you can proceed to installing it in your vehicle, if that was the reason why you built the Analyzer. Locate the project somewhere within easy view of the driver but where it will not obstruct other instrumentation or road visibility. Then route the input leads as needed.

Connect the black-insulated negative lead to any convenient nearby chassis ground point. This can be under the head of an existing screw in your vehicle's chassis or in a separate hole you drill and fill with a sheet metal screw. Whatever the case, terminate this lead in a spade or ring lug, sand or file the metal around the screw hole down to bright metal and use a toothed lockwasher on both sides of the lug.

After routing the red-insulated positive input lead behind the dashboard and through the firewall into the engine compartment of the vehicle, it is best to connect it directly to the vehicle's battery through a dashboard-mounted slide or toggle switch that allows you to manually enable and disable the project when the ignition is turned on and off. If you prefer to avoid the risk of forgetting to turn off the project when the ignition is switched off, you can route power to it through the contacts of a relay that is energized and deenergized when the ignition is turned on and off. Both options are illustrated schematically in Fig. 4.

Though it is not absolutely necessary to disable the project when the vehicle's ignition is switched off since the circuit draws only about 12 milliamperes (it will have no discernible effect on battery performance in a vehicle that is operated at least once every week or two), it is always a good idea to avoid unnecessary battery discharge in any case.

It is not recommended that you connect the positive lead of the instrument to any part of the vehicle's electrical system other than the positive battery terminal or cable. To do so will induce a voltage-drop error and may cause the Analyzer to give erroneous indications.

Using the Analyzer

The following steps should be performed in sequence when checking out an automotive battery and charging system. Before starting the vehicle's engine, connect the input leads of the Analyzer directly to the vehicle's battery terminals, making sure you observe proper polarity. Also, before switching on the ignition, check the alternator belt for proper tension.

Now do the following:

(1) Before starting the engine, the NOT CHARGING LED or INSUFFICIENT CHARGING LED will be on, which one depending upon how long the vehicle has been sitting idle. Have an assistant start the engine as you observe the Analyzer's LED display. If the LOW BATTERY LED comes on during cranking, battery terminal potential has fallen to less than 9 volts. This indicates that the battery is in a low state of charge or is near the terminal point of its life cycle. Recharge the battery and repeat the test. (Note: For sustained cranking time to observe the Analyzer's LED display, you can disable the vehicle's ignition system by removing the center lead of the ignition coil—or any other approved method of doing so—to prevent the engine from starting. Do *not* crank the engine for more than 15 seconds at a time.)

(2) With the engine idling, all LEDs should be off, indicating that everything is normal with the vehicle's electrical system. However, some vehicles will cause the INSUFFICIENT CHARGING LED to light because their battery terminal voltage does not exceed 13.3 volts during idling. This will be checked in step (3) below. If the NOT CHARGING LED lights, the vehicle's charging system is totally not operating, which can be caused by a defective regulator circuit, open alternator or bad connection somewhere in the electrical harness between alternator and battery.

(3) To check the charging capacity of the alternator, turn on the heater/air-conditioner blower at full speed, rear-window defogger/defroster, windshield wipers at full speed and headlights on high beams. Now race the vehicle's engine to 1,500 or 2,000 rpm (moderate speed). All LEDs on the Analyzer should be off. If the INSUFFICIENT CHARGING LED comes on, the alternator cannot deliver enough current to handle the accessory load, which may be caused by a shorted or open diode or a shorted winding in the alternator itself. Since the alternator is a three-phase machine that employs a six-di-

ode bridge circuit, it will be able to deliver some output even though one phase might be defective.

(4) To check the regulator, turn off all accessories and race the vehicle's engine to about 2,000 rpm. If the OVERCHARGING LED turns on, the regulator is defective. A defective regulator will cause the battery to consume excessive water, which will shorten its life. In many vehicles, the regulator is not adjustable; so the only cure for such a problem is to replace it.

Once you install the Automotive/Battery-Charging System Analyzer in your vehicle or use it as a stand-alone instrument with a variety of vehicles, you will come to appreciate how easy it is to perform diagnoses (and repairs) of electrical systems. Just one problem you diagnose and repair yourself can easily save you more than the project costs you to build. ME