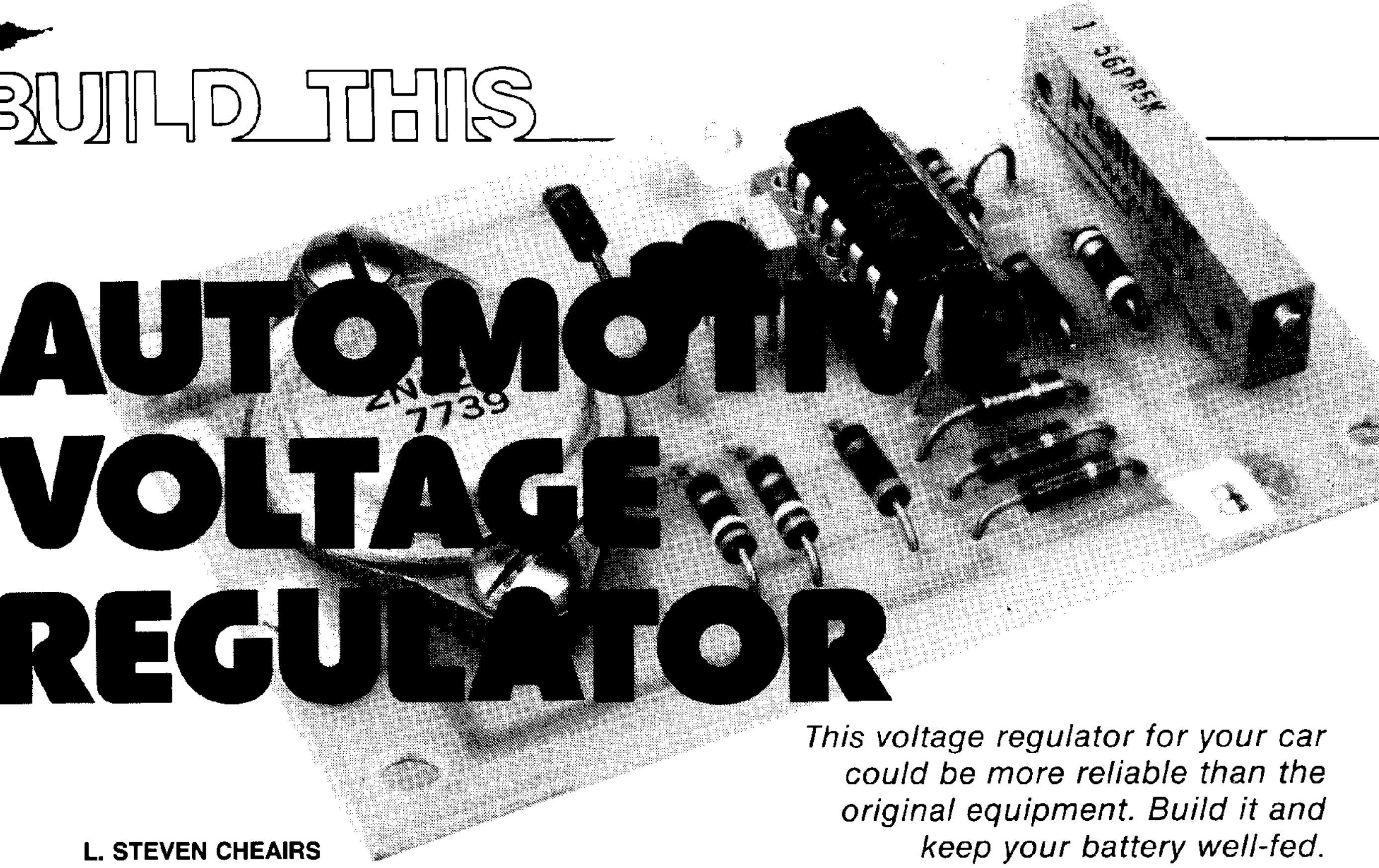
BUILD THIS

AUTOMOTIVE VOLTAGE REGULATOR



This voltage regulator for your car could be more reliable than the original equipment. Build it and keep your battery well-fed.

L. STEVEN CHEAIRS

A FEW YEARS AGO DURING A PERIOD OF excessive automobile charging-system breakdowns, I was forced to design a voltage regulator as a solution to the problem of too-frequent failures of the factory-supplied unit. My car, as are many of yours, was equipped with a solid-state module. The unit failed right after the car's warranty period expired. A replacement was purchased, for about $40.00, and installed. After a few months it also failed; again it was replaced. Again it failed after a relatively short time period.

Now, to even a thickhead like myself, it became obvious that a new approach to this problem was in order. I planned to keep the car for several years so I designed a voltage regulator that I felt would eliminate the problem in the car's electrical system. The system I designed and built is still operating without any problems. Questar later offered the unit as a kit, over one thousand units were sold, and only an occasional installation problem occurred.

Let me elaborate for a second. When the manufacturer is building an alternator and comes to the point of terminating the alternator leads for the field (rotor) and armature (stator), he is faced with three alternatives. First, ground one lead to the case and connect the other

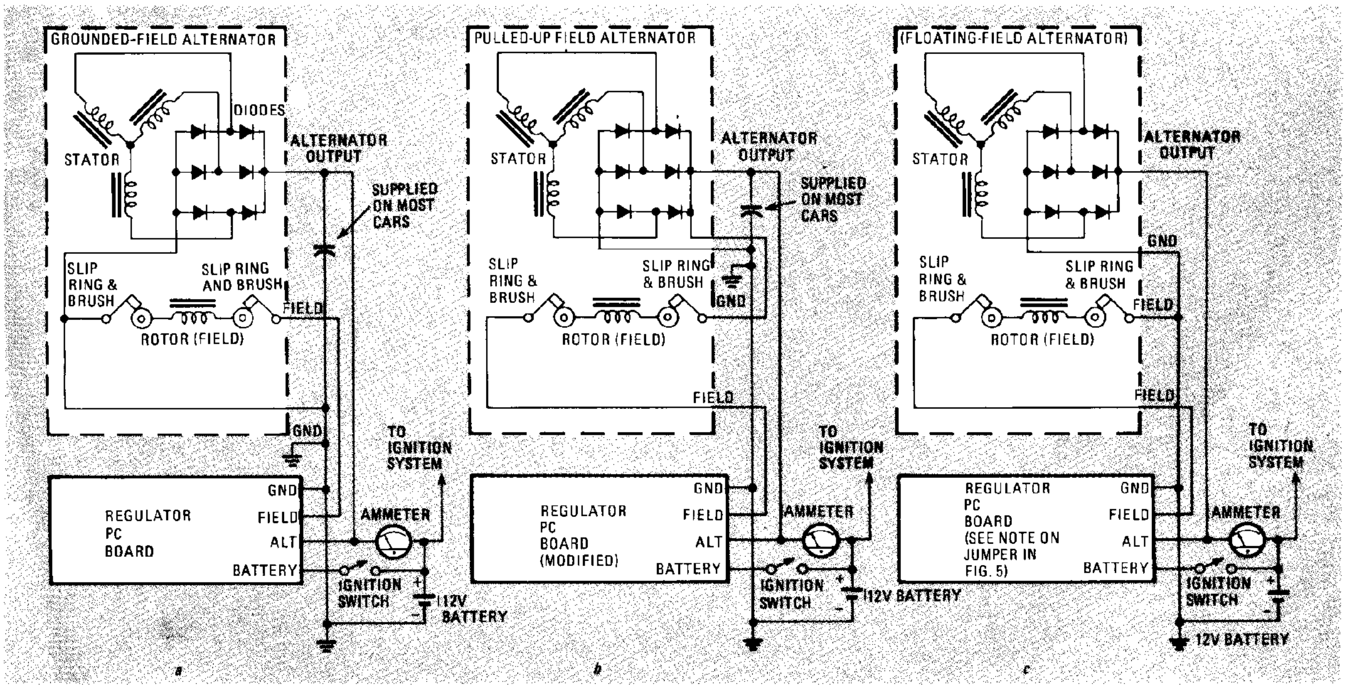


FIG. 1—THE ALTERNATOR IN AUTOMOTIVE ELECTRICAL SYSTEMS may be one of three types. The grounded-field system (*a*) is the most common and is the type this electronic voltage regulator is designed for. However, the regulator circuit and PC board wiring can be modified to work with the the pulled-up field (*b*) or the floating-field alternator at c. The floating-field alternator is wired as a grounded-field type at c. It may also be wired as a pulled-up field type.

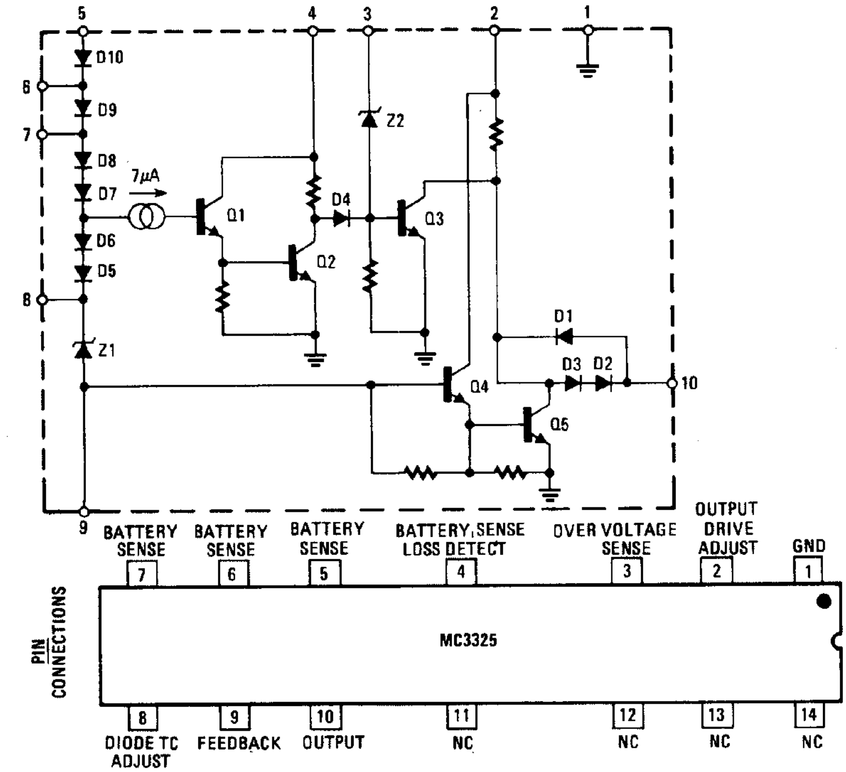


FIG. 2—CIRCUIT DIAGRAM and pin-out for the Motorola MC3352 voltage regulator IC.

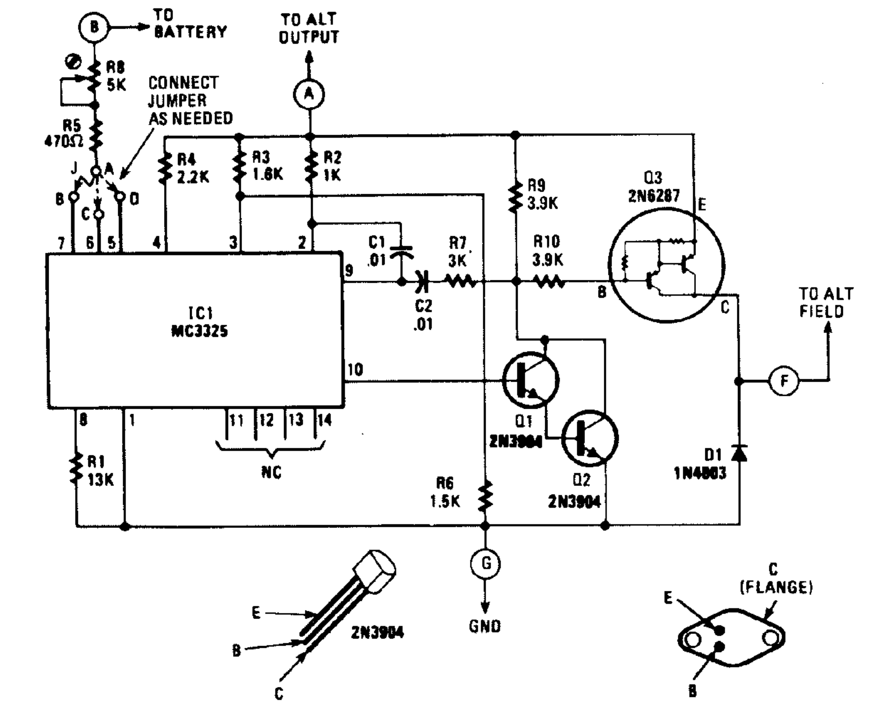


FIG. 3—SCHEMATIC DIAGRAM of the electronic voltage regulator as used with grounded-field and floating-field alternator systems.

to a terminal block, thus a grounded field system (Fig. 1-a). Second, (Fig. 1-b) connect one lead to the positive alternator output terminal and the other to a terminal block, a pulled-up field system. Third, he may simply bring both leads out (Fig. 1-c), hence floating field.

The floating-field configuration adds one terminal and for a manufacturer that could mean significant cost. The pulled-up field requires the routing of one wire to the alternator output terminal; a minor amount of extra wire is needed. The grounded-field unit is the easiest since the lead is simply attached to the case at any appropriate nearby point. *Most charging systems use the grounded-field system.*

I also chose a temperature coefficient that was optimized for my system, not necessarily the average. As the temperature varies in the engine compartment the temperature of the regulator will change. Thus, the bias levels shift. For this design, a current flow of 0.5 mA to 1.0 mA is required on the battery-sense input leg. The input resistors set a voltage level and the current level. The integrated circuit I used has three battery-sense inputs: the choice of the proper input along with external resistors set the temperature coefficient. All inputs are provided on this new design.

My auto is driven in the desert for most of the year so in my earlier design I chose a battery-voltage level best suited to this environment. Now for the fellow who lives in a cold area, a high-voltage would help his starting. Also, for the person who lives in an area that sees a fairly large-temperature fluctuation, the ability to change the battery voltage easily could be desirable.

This project is not just a modification of a three-year-old design; it is a new design which is superior to its predecessor. The new features are as described as above: 1) grounded-field operation, 2) selectable-temperature coefficient, and 3) adjustable voltage-regulation level. The previous features are also still retained: 1) high reliability from a compact solid-state design, 2) over-voltage protection, 3) automatic shutdown if the battery-sense line should be broken, and 4) a superior replacement for electromechanical and modular voltage regulators.

About the Circuit

This circuit is actually quite simple and is a good one for beginners or those who do not wish to spend the time with more complex projects. It is designed around Motorola's MC3325 voltage-regulator, IC shown in Fig. 2. However, the more advanced hobbyist will also find the completed circuit very useful. I also use the unit in a home emergency-lighting system and as a battery back-up for my home computer. The main application is still your automobile's charging system. The circuit, as shown in Fig. 3 contains one IC, three transistors, two capacitors, a trimmer resistor, and a handfull of resistors.

The IC, a Motorola MC3325 automotive voltage regulator (Fig. 2), has three battery-sense inputs (pins 5, 6, and 7) that select a tap in the diode/Zener string. The temperature-coefficient of the battery-voltage sense terminal is determined by the number of diodes used in the diode string. An approximate temperature coefficient for a diode at 1.0 mA is −2.0 mV/°C. The temperature coefficient of Zener diode Z1 is about +3.0 mV/°C. If you count from ground and sum these values a total temperature coefficient can be obtained; we have −2.0 mV for Q4 and Q5, +3.0 mV for Z1, −8 mV for D5 through D8, and an additional −2.0 mV each for diodes D9 and D10 when used. Thus the temperature coefficient will be between −9.0 mV/°C and −13 mV/°C.

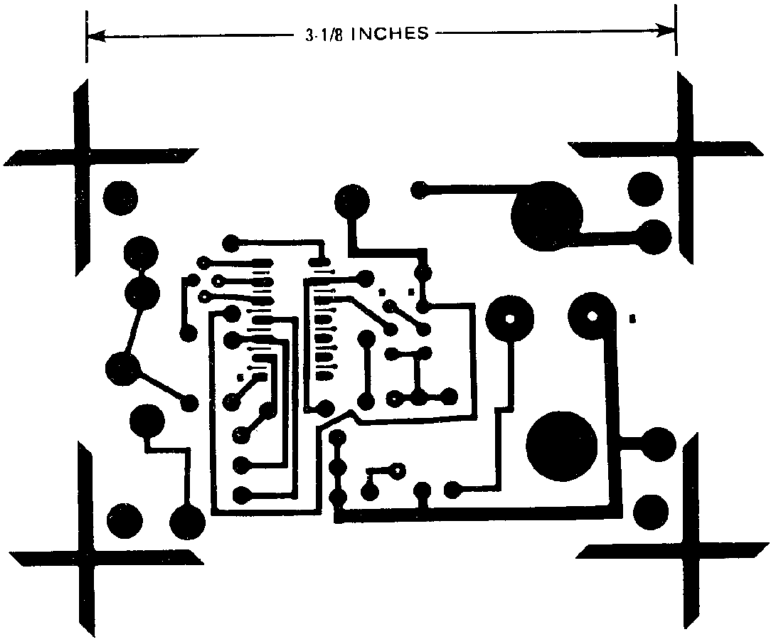


FIG. 4—FOIL PATTERN for the regulator printed circuit. The finished board measures 3-1/8 by 2-1/16 inches.

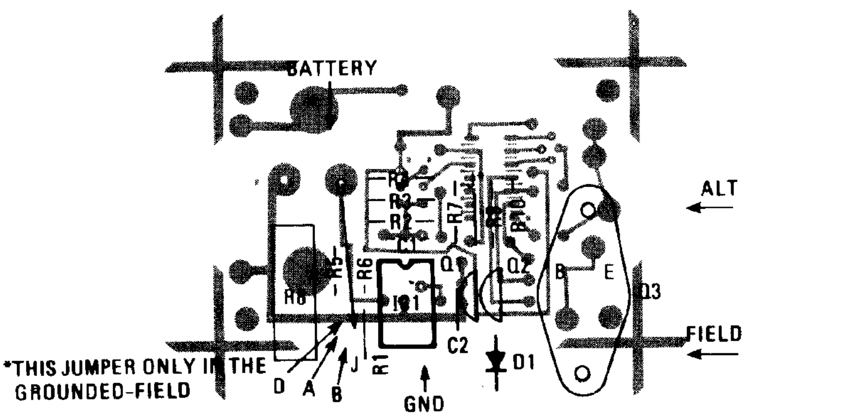


FIG. 5—PARTS PLACEMENT GUIDE for the voltage regulator. Note that the jumper between R7 and R9 is used only when the circuit is used with a grounded-field alternator. A jumper must be installed between point "A" and point "B", "C", or "D", depending on the desired temperature coefficient.

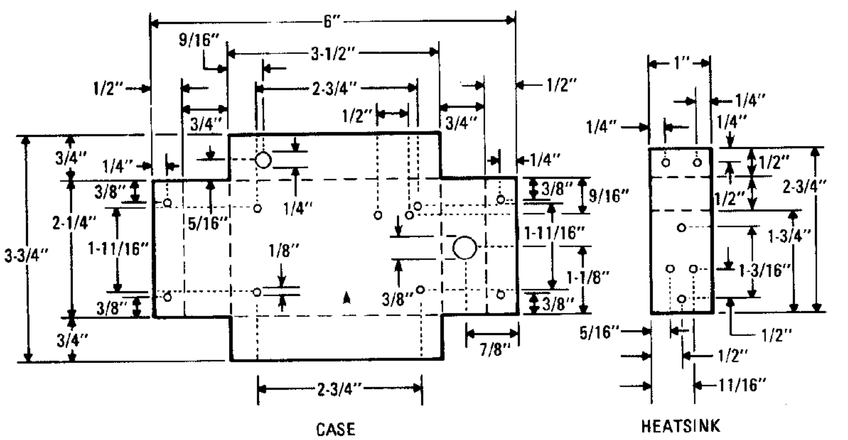


FIG. 6—THE CASE AND HEATSINK can be fabricated from easily worked tinplate or other sheetmetal. The heatsink transfers the heat generated by the power transistor to the surface of the metal case.

The complete schematic of the voltage regulator is shown in Fig. 3. Resistor R1, connected between pin 8 and ground, sets the current through the diode string between 0.5 mA and 1.0 mA. The value of R1 is directly proportional to the temperature coefficient. As the value of R1 decreases the effective temperature coefficient will decrease. The total value of the trimmer R8 and resistor R5 will determine the regulation level. Resistor R5 establishes the minimum voltage, while the maximum value of trimmer R8 plus the value of resistor R5 determines the maximum regulation voltage. The regulation voltage can be calculated from the following equation:

$$V_{reg} = \left(1 + \frac{R5+R8}{R1}\right)(8.4) + \left(n + \frac{R5+R8}{5000}\right)(0.7),$$

where n, the number of diodes in the string, is between 4 and 6 ($4 \leq n \leq 6$). Resistor R4 limits the current in case of an open battery-sense input lead. Resistor R3 is a current-limiting resistor connected between the alternator output and pin 3 of the IC. It is used along with resistor R6 to set the maximum overvoltage. The voltage at pin 3 will be about 7.5 volts, as set by an internal Zener diode. During maximum overvoltage, the current supplied to pin 3 must be between 2.0 mA and 6.0 mA; the value of R3 was chosen to insure the required current level.

Resistor R6, in conjunction with R3, sets the maximum overvoltage level. Not only does R3 set the current level for pin 3 but resistors R3 and R6 form a voltage divider used to detect an overvoltage condition. Resistor R2 determines the output-drive current of the output stage of the IC. The value chosen must provide enough current to drive the Darlington-pair (Q1—Q2) when the alternator output is at its maximum level. The Darlington-pair is formed from two NPN transistors; its function is twofold. First, it provides the required drive current to the final Darlington-type switch (Q3) and second it acts as a phase inverter. Feedback compensation is introduced via resistor R7 and

PARTS LIST

Resistors ¼ watt, 5% unless otherwise noted
R1—13,000 ohms
R2—1000 ohms
R3—1600 ohms
R4—2200 ohms
R5—470 ohms
R6—1500 ohms
R7—3000 ohms
R8—5000 ohms, 10-turn trimmer potentiometer
R9, R10*—3900 ohms
C1, C2—.01µF ceramic disc
D1—1N4003
Q1, Q2—2N3904 or equal NPN transistor
Q3*—2N6287 (Motorola or RCA) PNP power Darlington switching transistor
Q4—2N6059 or MJ1000 (Motorola) NPN power Darlington switching transistor (used only in Fig. 9 circuit)
IC1—MC3325 (Motorola) automotive voltage regulator
*R9, R10 and Q3 are not used in pulled-up field circuit

The following parts are available from Questar Engineering Co., 5412 Burntwood Way, Las Vegas, NE 89108: Kit of all parts $24.50, PC board $6.75, 2N6287 PNP Darlington $5.95 and MC3325 $2.25. Please add $1.75 for shipping and handling on all orders in the USA. Add $3.00 to all foreign orders. All COD orders incur COD charges.

capacitor C2. Capacitor C1 provides feedback from the output stage pin 2 back to the input pin 9; the total feedback is the difference of the two feedbacks' voltages. Notice that the two feedbacks are out of phase—that is, one has been inverted—thus one subtracts from the other.

The difference is applied to the base of the diode string (pin 9) and to the input of the final amplifier. This corrects for any difference between the two signals. Resistor R9 is the load for the phase inverter. The saturation current of Q1 and Q2 is 6.3 mA; 3.3 mA flows through R9. Thus 3 mA must flow from the base of the switch Q3 through R10 and into the collectors of Q1 and Q2. Of course R10 is used to set this current level. The final Darlington-configured transistor switch, Q3, is used to supply current to the alternator's field. Diode D1 is a flyback diode used as an energy return in order to prevent damage to Q3 when the inductive field load is switched on and off. In case you have not guessed, this is a switching regulator. (For more information on this type of circuit see my article "All About Switching Power Supplies" in the June and July 1979 issues of **Radio-Electronics.**)

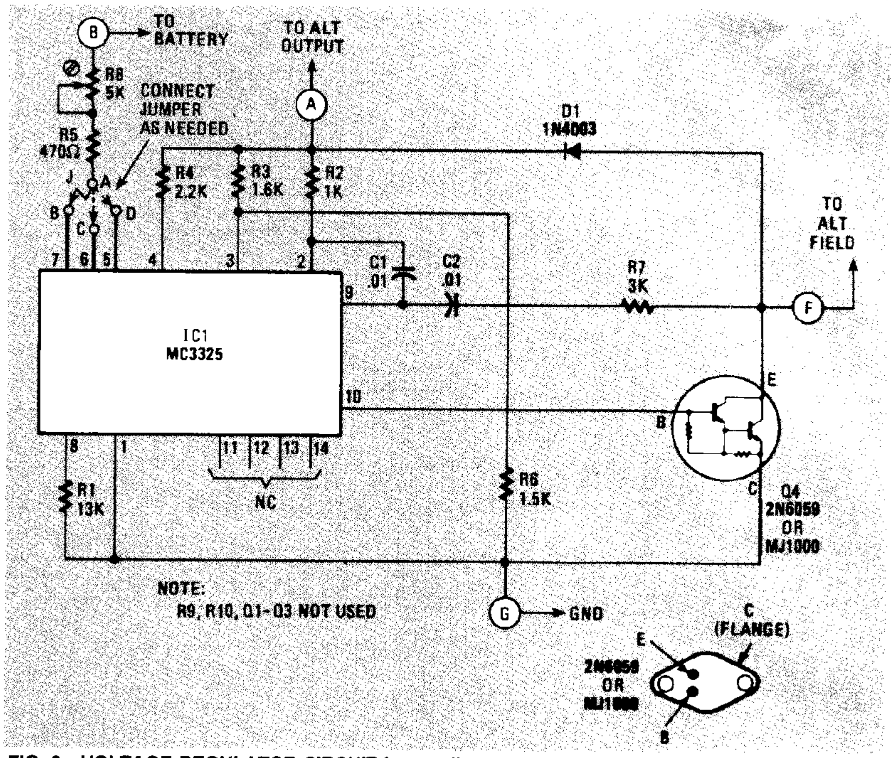
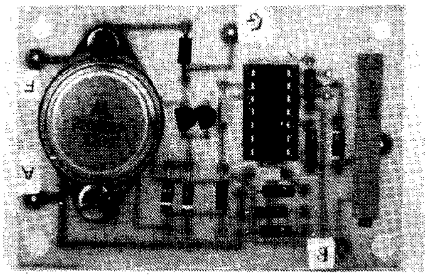


FIG. 9—VOLTAGE REGULATOR CIRCUIT for a pulled-up field alternator. The inverter formed by Q1 and Q2 has been eliminated along with R9 and R10. The driver power transistor has been replaced by a NPN type.



COMPLETED REGULATOR PC Board. Letters A, B, F and G show connecting points for alternator, field, battery and ground.

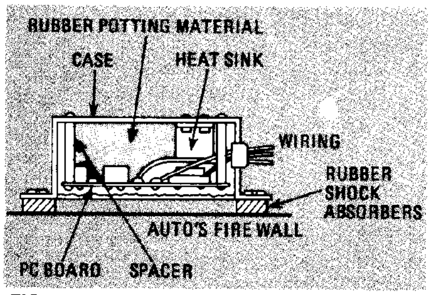


FIG. 7—A CROSS-SECTION drawing showing the shape of the case and how the PC board is suspended on four spacers.

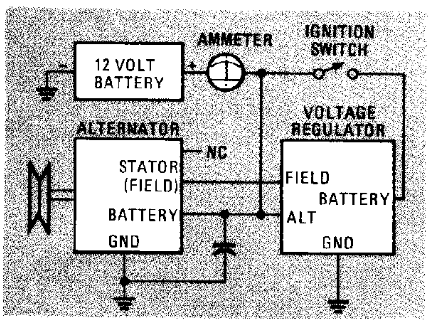


FIG. 8—TYPICAL AUTOMOTIVE BATTERY-CHARGING SYSTEM using a grounded-field alternator. Most of the wiring already exists in car's wiring. Check the connector to the old regulator; the four required interconnections probably are provided.

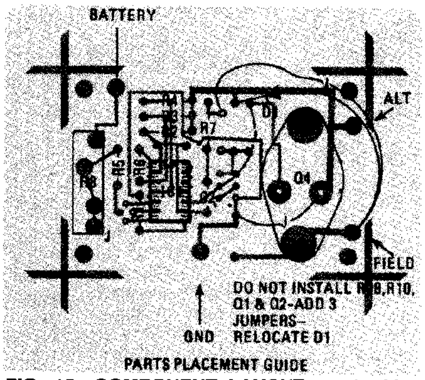


FIG. 10—COMPONENT LAYOUT used with a pulled-up field alternator. Note the three jumpers and the installation of D1.

Construction

Since the automotive environment is quite harsh—high temperature differentials, high mechanical vibrations, and corrosive chemicals—the packaging and construction are less flexible than with most other projects. It is recommended that a printed-circuit board be used. Figure 4 provides the foil pattern for a typical PC-board layout. You may use the pattern or lay out your own board. If you wish to obtain a pre-etched and drilled PC board, Questar Engineering Company is selling it. They will also supply individual major components, or a complete kit.

As to the components required: The IC and PNP transistor, to my knowledge, may be obtained by the hobbyist only from Questar; all other components are quite common. Lay all components out on your work surface and compare them, item by item, to the parts list. If any component is missing or of a radically different value than specified, *do not* proceed until that situation has been corrected.

Using the parts-placement guide in Fig. 5, install the resistors, capacitors, and the trimmer. Inspect those components for proper location and solder them into place using a 40-watt iron with rosin-core solder only.

Now install a jumper for the temperature coefficient you have chosen. The choice is based on your auto environment at the point where you install the regulator. In most cases, that will be determined by trial and error—my auto installation worked best with the mid-position jumper (between R5 and pin 6).

Next install the diode, transistors, and the IC. Orientation is important for those components! Because of the environment an integrated circuit socket is not recommended. Set the pot to mid-position—about 14 volts. Temporarily wire the circuit to your car. First, verify it is operating normally; second, convince yourself that you have chosen the correct temperature coefficient. If you haven't, you can change the jumper position appropriately. Vary the pot setting and observe that the regulation level will change. Remember, if you decrease the voltage setting it will take awhile for your battery to discharge to the new level. After you have completed that step remove the circuit and install a set of permanent wires about six or eight inches long.

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VOLTAGE REGULATOR

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Using the templates given in Fig. 6, cut a piece of sheet aluminum to form the enclosure and heatsink—use whatever gauge stock you think appropriate. Drill the holes. Bend the four sides into place and then bend the two mounting flanges outward and parallel to the surface. Install a rubber or plastic grommet in the feed through hole. Using a piece of cardboard, make a potting form to keep the area where the heatsink is to mount clear (see Fig. 7). Fill the container about a quarter full of a silicon potting compound such as RTV. Slosh it onto the walls and let it cure. At that point you have a case with a rubber-insulated cradle. Place the PC board into the cavity; feed the wires through the grommet. Using two metal screws, fasten the case to the heatsink (one should use silicon heatsink grease at the interface, see Fig. 7). Cut a piece of plastic tubing, such as a soda straw, to form a channel for external adjustment of the trimmer. Place one end of the tube over the screw end of the pot and the other to the exit hole. Seal off those two ends with some of the potting compound—make sure that none gets inside of the tube. After the tube is secure, fill the cavity with potting compound to submerge the board, and let it cure. On the wires—which should be color-coded—solder a connector that will interface to your auto's electrical system. Either obtain one from your local automotive parts store or use the connector from your old regulator if possible.

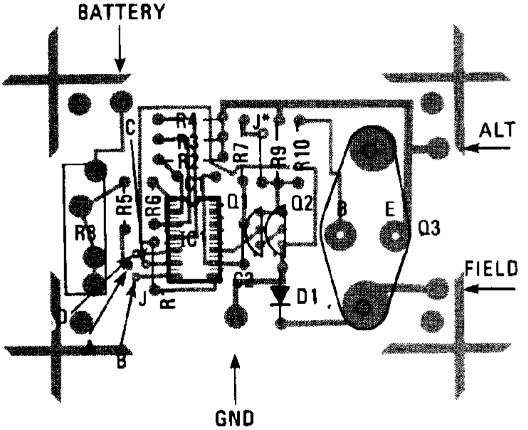
Install the unit on your car as shown in Figs. 1 and 8. Adjust the voltage to the level recommended by your auto's service manual. During the summer you can lower the level to reduce the boiling off of your battery's water; during the winter it can be increased to aid in cold-morning starting. My first regulator has operated without any problems for about three years and a prototype for this design has been in operation now for about a year.

Changes for pulled-up field

The less-often-used pulled-up field alternator (Fig. 1-b) uses a simpler voltage regulator. Its circuit is shown in Fig. 9 and components layout in Fig. 10. Note that the phase-inverter pair (Q1 and Q2) has been eliminated and the PNP Darlington-pair driver transistor, Q3, has been replaced by Q4, an NPN type. Construction and installation follow the steps just outlined. No matter which version of the voltage regulator your car requires, you can expect it to give years of reliable service and, having built one for automotive use, you'll probably find several other battery-charging applications for this versatile regulator. **R-E**

OOOOOOPS!

The diagram shown below is the corrected version of Fig. 5 that appeared on page 49 of the June 1980 issue of **Radio-Electronics.**



*THIS JUMPER ONLY IN THE GROUNDED-FIELD

FIG. 5—PARTS PLACEMENT GUIDE for the voltage regulator. Note that the jumper between R7 and R9 is used only when the circuit is used with a grounded-field alternator. A jumper must be installed between point "A" and point "B", "C", or "D", depending on the desired temperature coefficient.