I know that the shortest distance between two points is a straight line but that's not the way things work in life. Nothing ever goes according to plan—things keep coming up and getting in the way no matter how careful you are. We were supposed to talk some more about digital scopes and get into the hardware side of things. Well, that's not going to happen until next time. Something else came up.

A few months ago I answered a letter in the *Ask R-E* column from a fellow who was rebuilding an old British motorcycle (see **Radio-Electronics**, August 1991). He was looking for an alternative to Lucas electrical stuff—always a good idea, by the way—and wanted a way to build a voltage regulator. Since I've rebuilt a '65 Triumph Bonneville and a '68 Jaguar, I was naturally the person to talk to.

Since that letter appeared, we've received an unbelievable amount of mail asking for a foil pattern and ways to handle vehicles that have a slightly different charging system. Since there's no room for that in the Ask R-E column, we'll take care of it here. So bear with me... we'll get back to digital scopes next time.

At its most basic level, a car or motorcycle electrical system needs only two things: a battery to start the engine and a way to keep the battery charged. It's amazing how something so fundamentally simple can be so much of a hassle.

Once upon a time, the recharging part of the electrical system was a DC generator that was turned by the engine. The faster it turned, the more current it produced and, since overcharging a battery is what we technically refer to as a "bad thing," some way had to be found to control the amount of current produced by the generator. The voltage regulators for generators were inherently crude since the generator itself is an inherently crude device.

There's not much of a difference between a car generator and the hand-cranked generator used by Tom Edison to demonstrate his first light bulb. The faster you turn it, the more current it produces and the current limits are completely determined by the construction of the generator. This meant that the only way to regulate the amount of current being sent to the battery (and the car's electrical system) was to put something between the output of the generator and the rest of the car.

Voltage regulators designed for use with generators have to be really beefy because they often have to handle a lot of current. Remember that the amount of current produced by the generator is directly related to the engine RPM. Most of the regulators are essentially relays that constantly make and break the connection between the generator output and the rest of the electrical system. The amount of current fed from the generator to the battery is determined by how often and for how long the contacts are closed.

Since generators, and the regulators that control the current they produce, are a really stupid charging system, the car and motorcycle manufacturers jumped on alternators as an alternative (really sorry about that), as soon as they became available. Alternators are AC generators and their basic characteristics make them much more attractive for use in an automotive charging system.

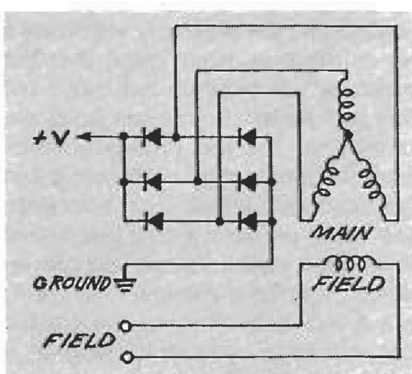

FIG. 1—YOU CAN THINK OF AN alternator as a transformer with two separate windings; the main winding and the field winding.

For starters, alternators have a much higher output at lower RPM and they're much easier to control. The best way to think of how an alternator works is to compare it to a transformer. As you can see in Fig. 1, there are two separate windings in an alternator. The main winding is the one that produces the AC current but the amount of current it can produce is controlled in two ways. The number of RPM sets the maximum possible current, but the amount actually produced (up to the maximum) is determined by the amount of current flowing in the second, or field, winding. The greater the current in the field winding, the more current you'll get out of the main winding.

The AC current produced in the main winding is rectified by a full-wave bridge made of six diodes and the resulting DC is fed to the rest of the car's electrical system. In order to regulate the current put out by the alternator, you don't (as with the generator) chop the output, but simply regulate the amount of current flowing in the field winding. A voltage regulator for an alternator has to monitor the state of the battery and send enough current to the field so the alternator will keep the system voltage somewhere around 13.5 to 14 volts.

If the battery voltage is really low, the regulator will sense that and cause the alternator to put out enough juice to charge the battery back up. Since the regulator is driven by the battery voltage, as the battery's charge increases, the regulator will lower the output of the alternator. That's certainly much better than the older generator system because the regulator is a low-current device and is therefore cheaper to manufacture and a lot more reliable.

Most modern alternators have a regulator built inside them. That may or may not be such a great idea since it means the alternators are going to be more expensive and a lot more difficult to repair. For those of us that have vehicles with alternators and external voltage regulators, there's no reason why you have to be a helpless slave to using the manufacturer's regulator. You can easily build a much more versatile one for a couple of bucks and thumb your nose at the often arrogant people behind the parts counter.

Nothing is standard and the way a part can be used is directly proportional to the number of terminals it has. Since an alternator-based electrical system is basically simple, I've got to admire the amount of creativity the vehicle manufacturers have shown in making things as complex as they are.

A basic alternator has four connections as shown in Fig. 1. The field winding has two ends and so does the outputs of the full-wave bridge. Before you can build your own voltage regulator, you first have to determine how the manufacturer has wired these four terminals since the design of the regulator is different for each one.

It's a safe bet that the two main outputs of all alternators are wired the same—the positive output goes to the hot side of the battery and the negative output goes to the system's electrical ground. However, what most likely causes the problem is what the manufacturer has done with the field winding.

There are three possibilities:

1. *A pulled-up field*—In this setup, one side of the field is connected to the positive side of the battery and the voltage regulator moves the other side closer to and further away from ground.

2. *A grounded field*—One side of the field is tied to ground and the regulator moves the other side closer to and further away from the system's positive voltage.

3. *A floating field*—Both sides of the field windings are brought out to terminals on the alternator and the manufacturer wires them into the system using one of the first two methods.

At the risk of sounding like a disclaimer at the bottom of a glitzy ad, it's extremely important to know exactly how your charging system is set up because a mismatch between the voltage and the alternator will cause a lot of damage. It's a given that the regulator will blow up but that's not too bad because you can build another one. The real problem comes from the fact that your alternator can get destroyed as well. That's not even too bad a problem if only the diodes have been trashed since you can replace them for a minimal cost too—but if you've burned out the coils in the windings, you're looking at a whole lot of bucks.

Before we get on with this, let me tell you that I've seen several alternators that had both sides of the field brought out to terminals but still had one of them tied internally to +V or ground.

Be warned.

Most British vehicles—both cars and motorcycles—use a pulled-up field and the basic charging system layout is shown in Fig. 2. One side of the field is tied to the positive side of the battery through a relay that's energized when the ignition is turned on. The relay is needed because a permanent connection would mean that the alternator's field windings were connected across the electrical system all the time and, since they usually have a resistance of about

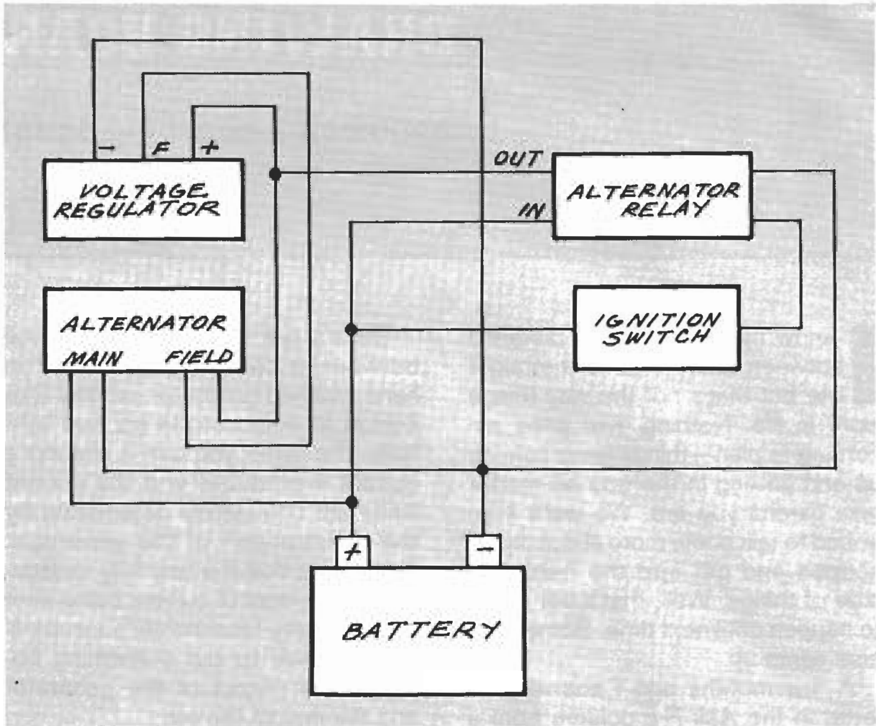

FIG. 2—HERE'S THE BASIC CHARGING-SYSTEM LAYOUT for a pulled-up field system.

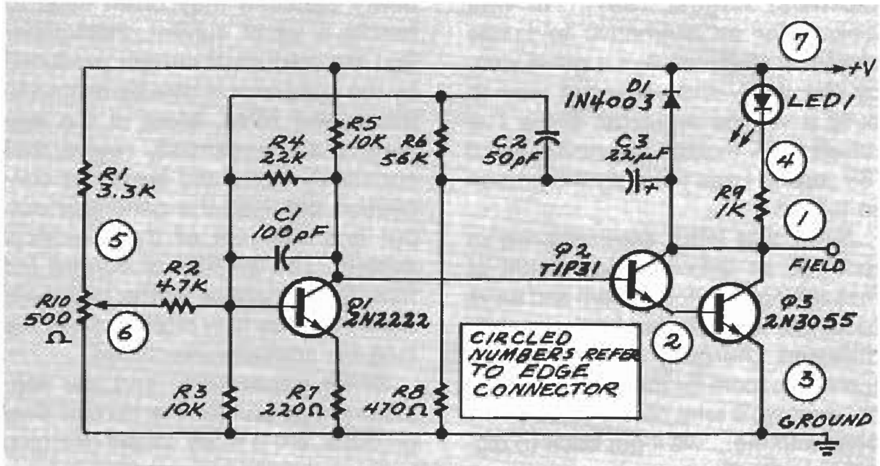

FIG. 3—THIS IS THE REGULATOR NEEDED for a pulled-up field. The circuit monitors the state of the battery through a resistive divider and causes the voltage to change at the field terminal.

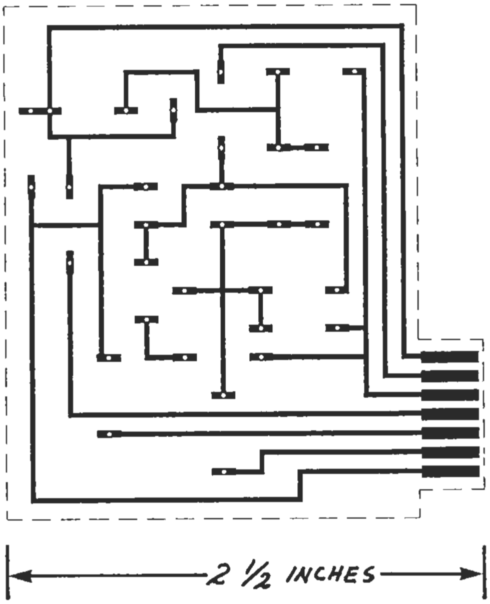

FIG. 4—THE FOIL PATTERN for our regulator circuit. It's shown here actual size.

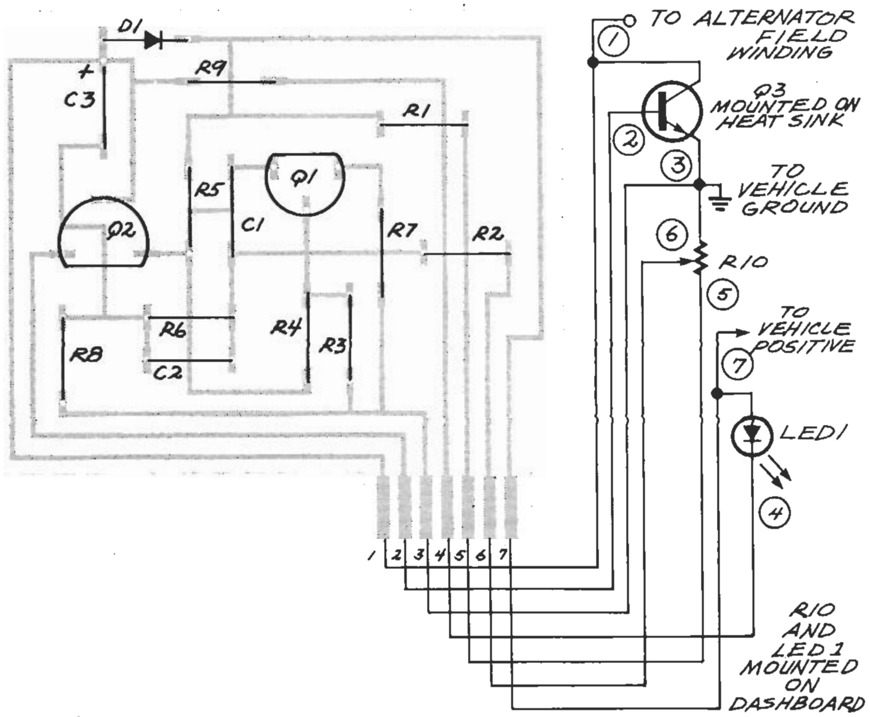

FIG. 5—PARTS-PLACEMENT DIAGRAM. Remember that Q3 should be mounted off the board on a heatsink and R10 and LED1 can be mounted on your dashboard.

four ohms, the battery would drain completely in no time at all. Not a good thing.

The circuit in Fig. 3 is the regulator needed in this case and it's designed to work with a pulled-up field. As you can see, the basic action of the circuit is to monitor the state of the battery through the resistive divider made up of R1, R2, R3, and potentiometer R10, and to cause the voltage to change at the terminal marked "FIELD."

When the ignition is turned on, current flows through R5, turns on the home-made Darlington pair consisting of Q2 and Q3, and this sends current to the field windings of the alternator. When the engine starts and the alternator begins delivering current to the system, the resulting voltage is sampled through R2 and, at a point determined by the setting of R10, Q1 begins to conduct and drops the voltage at the base of Q2. That

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causes the Darlington pair to turn off and cuts the current sent to the field windings. The alternator output will drop off which also turns off Q1.

The voltage sampled by R10 will always be a fixed proportion of the system voltage but the ratio can change due to heat and other factors. Remember that the engine area of a bike or car is a really harsh environment. If you find that to be a problem for you, replace R2 with aN 8±10 volt Zener diode.

The fundamental switching action of the regulator circuit gets help from the positive feedback supplied by C3 and R6. When the Darlington starts to turn off, the voltage at its collector increases and some current flows through C3 and R6. The current at the base of Q1 is the sum of the tapped system voltage through R10 and the feedback supplied through C3 and R6. That speeds up things to get to the point where Q1 will turn on and turn off the Darlington pair and shut down power to the field. When that point is reached, C3 dumps the rest of its charge through R7 and R8 and the current flow in the field windings drops to zero. Diode D1 protects the Darlington pair from being damaged by the induced voltage that appears when the field current collapses.

The knee of the voltage regulator is determined by the setting of R10. By adjusting the position of the potentiometer, you can change the voltage setting of the car's electrical system. The LED will provide a peace-of-mind indicator to let you know that the circuit is working, but a flashing light can be annoying so, if you put it on the dashboard, use a small LED.

The foil pattern for our regulator circuit is shown in Fig. 4. The reason for the multitude of connection points is because Q3 should be mounted outside the case on a heatsink for cooling. The board was also designed to have LED1 and potentiometer R10 mounted outside the case. If you're going to use the regulator in a car, it's nice to have them right on the dashboard near the voltage indicator.

There are fingers on the PC board so the connections to the off-board components can be made with a handy-dandy edge connector on tenth-of-an-inch centers. If you can't find one, you can always use a header and some ribbon cable, but edge connectors are a lot easier. The parts-placement diagram is shown in Fig. 5. (Remember that this setup is for a pulled-up field.)

When we get together next time, I'll talk about grounded fields and make a few suggestions about what to do if you have—gasp, gasp—a vehicle with a generator. **R-E**