THE DRAWING BOARD

Making fixed-output regulators adjustable

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WE ENDED OUR DISCUSSION OF VOLTAGE regulators last month looking for the answer to an intriguing problem. We were trying to figure out why diode D1 (see Fig. 1) does not conduct even though it seems that current is flowing in the right direction. I'm sure that most of you figured out why D1 doesn't shunt any current when the regulator is operating normally, but let me give you the answer anyway. In normal operation, D1 doesn't conduct because it *can't* conduct. Remember that the regulator's input voltage is always greater than its output voltage. Regulation is like anything else in life—you don't get something for nothing. With the 78*xx* series of regulators the input has to be at least 2 volts higher than the output—if you want everything to work the way it's supposed to. Therefore, the potential at D1's cathode will be at least 2 volts higher than at its anode. Since that reverse-biases the diode, there won't be any current flow.

When things *do* blow up, D1 has to be hefty enough to handle the discharge current from C4, and it has to start working quickly enough to get rid of the current before the regulator is damaged. That's why our choice for D1 has to be a fast-acting silicon diode that is capable of handling the surge current without being destroyed. Depending on the parameters of the circuit, any member of the 1N400*x* family of diodes is a good choice.

Our regulator circuit so far is fine—if all you need is a fixed standard-voltage and not much in the way of current. But suppose some circuit that you're building requires an oddball voltage, and you're sure that the current requirements are going to be rather large. Obviously we have to take our regulator a bit farther.

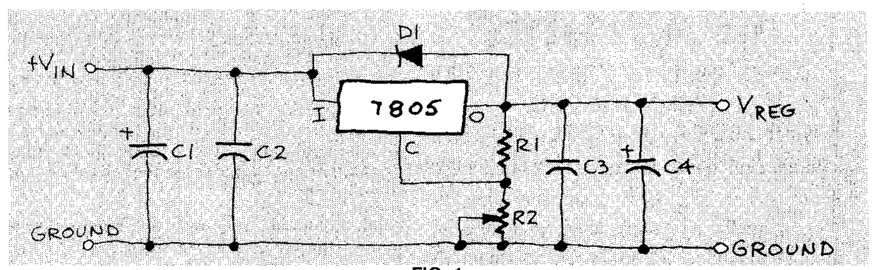

FIG. 1

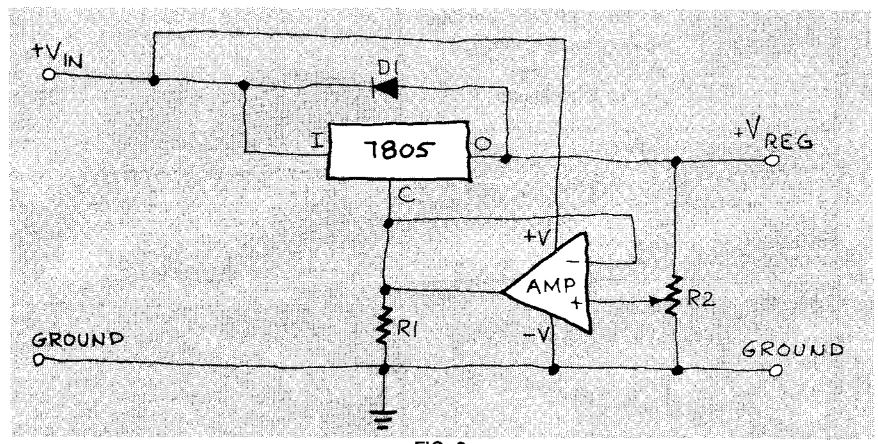

FIG. 2

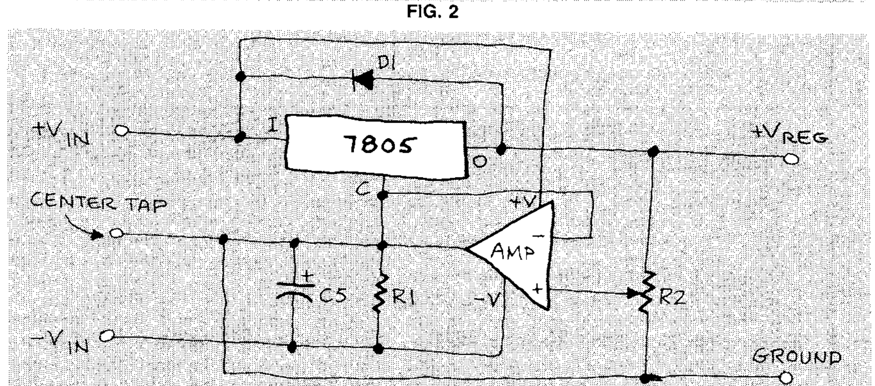

FIG. 3

Raising the output voltage

There are two ways that we can raise the output voltage—let's call them the easy way and the hard way. Figure 1 shows the easy way. Resistors R1 and R2 form a voltage divider across the regulated output-voltage. As we move the wiper of R2 toward ground, we change the ground reference of the regulator and trick it into putting out a higher regulated-voltage. I won't bother you with all the grisly details of the math, but the formula is: $V_{reg} = 5 + (5/(R-1) + I_{sb})R2$ where I_{sb} is the standby current used by the regulator. (For a 7805 with no load at its output, I_{sb} is usually about 8 mA.) Obviously that figure will change as the circuit is put under load. The formula shows us exactly what we're doing—we're adding the voltage generated across the voltage divider to the normal output of the regulator. That approach to an adjustable regulator is okay for small currents, but it leaves a lot to be desired when we're looking for substantial amounts of current and real flexibility. As you can see from the formula, the lowest voltage we can get with that arrangement is the basic voltage of the regulator. Not only that, but we're seriously interfering with the stability of the output voltage.

The reason for the instability is that the regulator can only handle a fixed amount of power. Now, since we all know that power is the product of the voltage and the current, the more voltage we get, the less current we can safely draw from the regulator. As the voltage at the IC's internal pass transistor increases, the internal protection of the IC automatically reduces the short-circuit trip-point. Not only that, but if you use that circuit and the current drawn from it comes close to the trip point, R1 and R2 will start to get warm and change value. And, changing those values will also change the output voltage. Fortunately the IC is protected and thermal runaway isn't possible, as it is with transistors. Even so, it's annoying, to say the least, to have your power supply drop out every time you put a moderate demand on it.

A better, but slightly more complicated, way to make an adjustable supply from a fixed regulator is shown in Fig. 2. I've left out the capacitors to make the drawing clearer and cleaner. If you compare this circuit with the one shown in Fig. 1, you'll see that an op-amp has replaced the potentiometer. Since some of the newer op-amps have input impedances as high as a trillion ohms, it's pretty safe to say that the output of the regulator won't be loaded down as it was in the first circuit. The op-amp is set up as a voltage follower, which means that it's nothing more than a buffer—a non-inverting amplifier that's used to isolate one part of a circuit from another.

As we move the wiper of R2 away from ground, an increasingly greater voltage is present at the ground terminal of the regulator. That raises its ground reference and tricks it into putting out a higher voltage. The drawback is that the minimum output voltage is still going to be the standard output of the regulator, in this case five volts, plus the voltage drop across R1, which is about two volts. On the other hand, we can get the regulator to put out as much as 20 volts without worrying about limiting the current-handling capability of the IC, or degrading the voltage regulation when the numbers start to get large. This adjustment range of 15 volts or so is just about the most you can hope to safely get out of a fixed regulator like those in the 78*xx* series. You can move the entire output range slightly by changing the value of R1, but trying to extend the range too far will cause you to run the risk of doing severe damage to the IC. After all, remember that it *was* designed to be a fixed regulator.

Lower output voltages

There is a way to change the range of the (fixed) adjustable regulator so that we can drop its output voltage much closer to ground. The way to do that is to allow the op-amp to swing its output below ground. Figure 3 shows how that can be done. By using a center-tapped transformer we can reference the ground terminal of the regulator and the −V input of the op-amp to a level below system ground. Then, the regulator will reference its output voltage to a point below ground. We have to be careful when we set that sort of thing up however, because the regulator's internal pass transistor was designed to source current, not to sink it. If the output level of the regulator gets below ground we're going to have the same problem we had last month and the same thing will result—one french-fried regulator.

Another alternative is to build a small circuit that generates a true negative supply from the positive system-voltage. We don't need a lot of current since the op-amp draws next to nothing and the regulator is only using the negative voltage as a reference point.

You can always use a different regulator, such as the LM317, which was designed to go as low as 1.25 volts and up to more than 35 volts. Your regulator-circuit design will be easier, but you won't learn anything. Besides, there's a certain amount of perverse pleasure that comes from making an IC do something it wasn't expected to do in the first place.

One other thing you should remember is that there's always at least a two-volt drop across the regulator. If you're planning on designing a power supply that can put out 20 volts, make sure that you have at least 22 volts available at the input to the regulator. The same goes for the amount of current you can draw—you can't get out of the regulator what the transformer and rectifier can't put in.

When we continue next month we'll increase the current-handling capability of our circuit and add additional circuitry to make it short-circuit proof. **R-E**