THE DRAWING BOARD

Voltage regulators and power supplies

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ONE THING THAT EVERY ELECTRONICS hobbyist who builds or designs his own equipment will eventually have to contend with is a power supply—it doesn't matter whether you're working on a space shuttle or on an electric toothbrush. It's obvious that there are tremendous differences between the power requirements of a rocket ship and those of a toothbrush, but the point is that if you're designing your own equipment, you're going to have to spend some time thinking about what you want your power supply to do.

It's true that most of the things we'll be discussing in this column can be powered by nothing more complicated than a fresh battery and a pair of alligator clips. From the point of view of elegance however, that approach leaves something to be desired. The power supply you use in your designs can do a lot more for you than just supply power. Most notably, the power supply can provide *protection*.

Even the most carefully designed project in the world can blow up the first time power is applied. But a well-designed power supply can go a long way toward saving you from having to repeat the work you've done in the event of a mishap. It can guard against short circuits; it can limit the current and/or voltage; it can offer protection from transient spikes, and so on. In short, it can be an extremely valuable friend when your project is still in the development stage. Let's look at some of the many possibilities.

Series regulators

There are many different approaches to power-supply design, but this time we're going to see what we can do with the simple series regulators that we're all familiar with. Those are three-terminal devices that are set up internally to provide a fixed output-voltage of a particular polarity.

The 78xx series of positive regulators (and the 79xx series of negative regulators) are usually used by themselves to provide basic voltage regulation in small electronic systems. Like most things though, those IC's can be made to provide as many exotic features as we want, including the ability to handle much more current than their basic rated capacities would seem to indicate.

Just about everyone is familiar with the circuit shown in Fig. 1, a basic five-volt regulator. Capacitor C1 is the huge filter

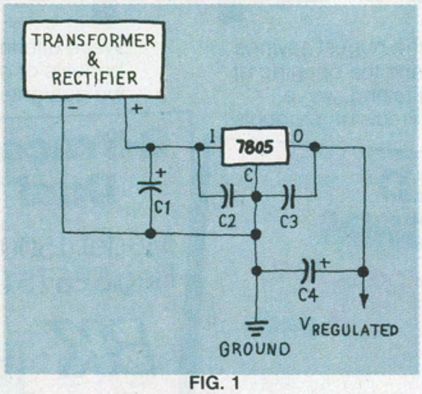

FIG. 1

capacitor that sits across the output of the rectifier. It's used to smooth out the spikes (ripple) on the line and to "brute-force" regulate the voltage going into the 7805. Even though the regulator was designed to reject noise, (referred to in the specs as "ripple rejection"), it can only cope with noise that is a certain proportion of the input voltage. Put simply, the bigger the input-voltage fluctuations, the more noise at the output.

Capacitors C2 and C3 are also filter capacitors. They are generally less than one μF and provide the regulator with local help in dealing with transients. If the regulator is physically far away from the large filter capacitor (C1), a voltage, however small, can develop on the line connecting the rectifier and the IC. The job of C2, therefore, is to make sure that those small voltage transients are eliminated before they reach the regulator. That's why C2 is always located as close to the regulator as possible—in some systems it will be soldered right to the regulator pins. Capacitor C3 does the same job at the output of the device.

Capacitor C4 can be called the "surge capacitor" because its job is to take care of the sudden surges that show up on the system +V line during power-up or power-down. The size of those surges, and consequently the size of C4, depends on the current drawn by the system. Typically though, the value of C4 is somewhere between 10 and 100 μF.

The 78xx family of regulators (and most other series regulators) is designed to be as foolproof as possible. The regulators monitor their internal temperature; and if they get too hot, they turn off. Short circuits will also cause the IC's to shut down. The trip point isn't a definite figure because it depends on the input/output voltage difference and the temperature. In general, a 78xx-series regulator that is well heat-sinked will be able to handle about an amp—but that's really the upper limit.

Now that we understand the circuit in Fig. 1, let's see what's wrong with it. As a side note here, one rule of design is *always* to design with worst-case operation in mind. Remember Murphy's Law and don't forget that one of the drawbacks to original design-work is that the responsibility for backing the warranty is yours.

Problems

Someone once said that there's no such thing as a free lunch, and that applies here. We're using capacitors to help the regulator minimize noise and transients, but capacitors cause another problem. A rapid reduction in either the input or output voltage will cause the capacitors to discharge. How much discharge current is generated depends on a lot of variables—the values of the capacitors, the rate of voltage reduction, and so on. Most regulators are built to withstand a certain amount of discharge current, but the unpredictability of the amount of that current makes for a real problem. In order to put things in perspective, consider that a 10 μF capacitor can develop 20-amp spikes when it's shorted.

If you're designing a power supply only for low-current systems, that doesn't present much of a problem. But if you're going to need a healthy amount of current, something has to be done to protect the regulator against accidental capacitor-discharge.

It will help to think of the regulator as a bunch of control circuits with a beefy pass-transistor at the output. In Fig. 2 we show only C1 and C4; since C2 and C3 are relatively small, we don't have to pay as much attention to them.

In the case of an input short, we have a big problem with C4. When the input short occurs, C1 will discharge through it and the input voltage to the collector of internal pass-transistor Q1 will rapidly fall to zero. That means the output voltage will be greater than the input voltage. Since C4 will have stored a nice, healthy charge, it will start to discharge. Some of the discharge current will go through R_{sc}—the equivalent resistance of the regulator's protection circuitry. If the current

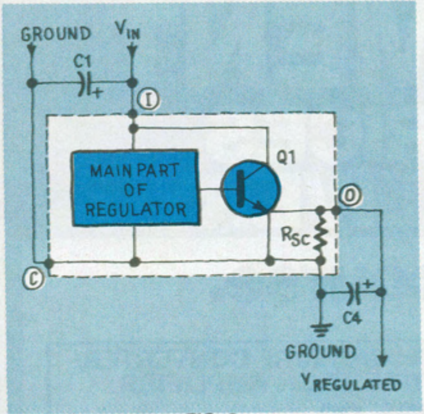

FIG. 2

is substantial enough, R_{sc} isn't going to pass it fast enough and the emitter-base junction of Q1 is going to be reverse biased. If the current is great enough, Q1 is going to break down and the regulator will be—to use a technical term—zapped.

Fortunately, an output short isn't anywhere near as serious. In that case, C4 will discharge across the output short and the input voltage will be greater than the output voltage. Luckily, the regulator was designed to deal with that. It will start to pass more and more current until its thermal-overload point is reached and it shuts down. Remember, the regulator was designed to source current, not sink

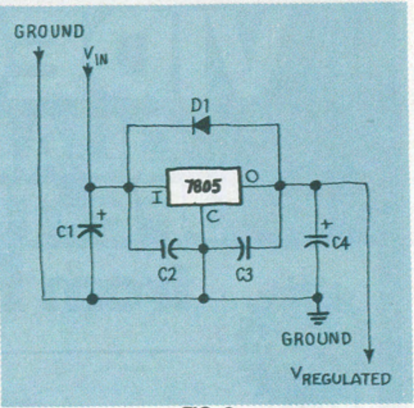

FIG. 3

it. That's why an input short is so much more potentially dangerous than an output short.

In order to protect against input shorts, we have to find a way to provide an escape path for the discharge current of C4. We'll add a diode as shown in Fig. 3.

Adding protective diode D1 gives us a really slick solution to the problem. If the input shorts out now, the discharge current from C4 will forward bias the diode and all the "bad" current will be shunted to ground through the input short. You may wonder why the diode doesn't bleed off some of the "good" current when the regulator is operating normally. But we're out of space, so you'll have to wait until next month for the answer. **R-E**