Switching Power Supply

by D. P. Roberts

Provides Safe, Steady 5 Volts From Vehicle's 12-Volt System

Powering a 5-volt circuit (like a single-board computer or BASIC Stamp project) off a car or truck's 12-volt electrical system is not as straightforward as you might think. A poorly designed 5-volt power supply can be the death of your automotive project.

In this article, I describe vehicular power-supply problems and present a simple solution: a modular switching regulator plus a few external components that yield a safe, efficient 5-volt supply at up to 1 ampere.

If you don't need high-current output, you can use a variation on the same circuit to armor an inexpensive linear voltage regulator against vehicular power gremlins.

Let's look at the problems that make a vehicle's 12-volt system so hostile to 5-volt regulators.

Linear Voltage Regulators Get Hot

When I need to drop some higher voltage down to 5 Vdc, I automatically reach for a three-terminal linear regulator IC like the 7805. These are cheap and easy to use, often requiring nothing more than a couple of capacitors to work (Figure 1).

In the process of reducing the input voltage, 78xx-type regulators convert excess energy to heat. When the input voltage is close to the output voltage or the current draw is low, this heating may not even be noticeable. But when the voltage and/or current is high, the regulator can get very hot.

An example: With 14 volts input and 5 volts output, there's a 9-volt drop across the 7805 regulator. If you draw 1 ampere (1A) from the circuit, the 7805 converts 9 watts (9W) of electrical energy to heat (watts = volts x amperes). This is no good; the 7805 specs say that without a heatsink, the max power (heat) dissipation for this guy is less than 2W (at an ambient temperature of 50°C/122°F, less at higher temperatures).

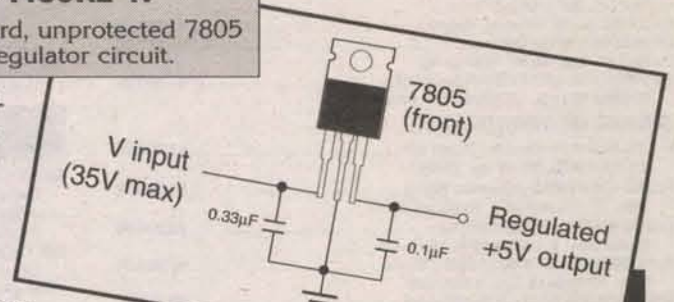
How much would a heatsink help? Finding out requires a little math, but it's not painful.

Manufacturers of power semiconductors and heatsinks publish "thermal resistance" figures for their components. To determine the temperature rise inside the component (at the semiconductor junction, where the heat originates), you add up all the thermal resistances between the junction and free air and multiply by the power. Add the temperature rise to the ambient temperature, and you've got the actual temperature inside the component.

For a 7805 in the TO-220 package, thermal resistance is 4°C/W (read "degrees Celsius per watt") from the junction to the heatsink tab. A fairly typical TO-220 heatsink has a thermal resistance of about 19°C/W to free air. There's also about a 0.5°C/W thermal resistance between the TO-220 tab and the heatsink.

Multiplying the total thermal resistance (4 + 19 + 0.5 = 23.5) by the power dissipation (9W) gives the temperature rise in °C, 23.5 x 9 = 211.5°C. Actual temperature at the junction is that figure, plus ambient temperature; 211.5 + 50°C = 261.5°C (502.7°F).

FIGURE 1.
Standard, unprotected 7805 regulator circuit.



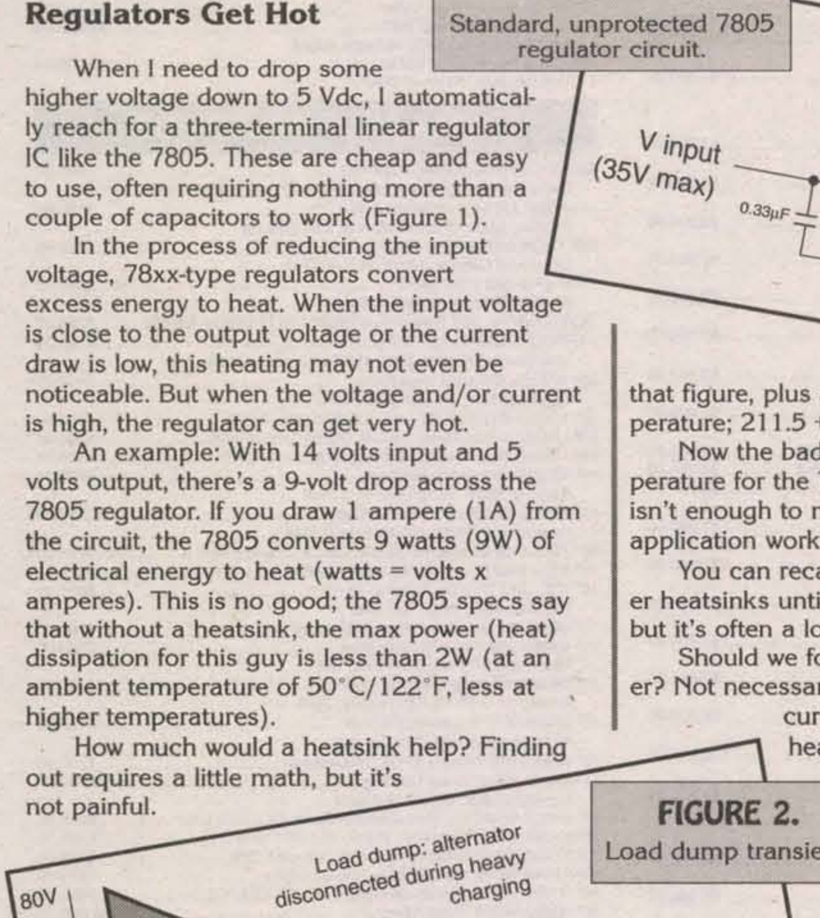
Now the bad news. The max junction temperature for the 7805 is 150°C. The heatsink isn't enough to make our automotive 7805 application work.

You can recalculate these figures with larger heatsinks until you find one that will work, but it's often a losing proposition.

Should we forget about the 7805 altogether? Not necessarily. Remember the role that current plays in the generation of heat. Less current means fewer watts means cooler components.

If the current drawn from the 7805 averages 0.4A (400 milliamperes; mA) or less, the power dissipation becomes 3.6W or less. Multiply that by the small heatsink thermal resistance of 23.5 and you get a temperature rise of 84.6°C. At an ambient temp of 50°C, the junction would be 134.6°C, just within the max of 150°C.

FIGURE 2.
Load dump transient.



Switching Voltage Regulators Stay Cool

Linear voltage regulators like the 7805 get hot because they are obliged to do something with the electrical energy that's drawn from the input but not delivered to the output. What they do is convert that energy to heat.

Switching regulators attack the problem differently. As the name implies, they switch on and off, applying the input voltage to an inductor, which stores the energy in its magnetic field. Control electronics vary the proportion of switch on and off time to regulate the output voltage to a desired level. An output capacitor smooths out the ripple caused by the switching.

The advantage of this approach is that there's very little voltage drop across the switching element. Since power (watts) = volts x amperes, low voltage drop means very little power converted to heat.

Hobbyists tend to avoid switching supplies. The math required to design them, the parts required to build them, and the careful construction required to make them work properly are all a little intimidating. As we'll see later, a neat little module solves all of these problems and allows us to use a professionally designed switcher in our vehicular application.

Before we get to the circuit, let's look at the other problem with vehicle power systems.

Vehicular Electrical Spikes and Surges

Take a look at Figures 2, 3, and 4. These graphs (based on illustrations from the excellent book *The Circuit Designer's Companion*, by Tim Williams, Newnes/Butterworth Heinenman) are a rogues' gallery of surge and spike conditions that routinely occur in a car's electrical system.

Any electronic device that draws power from the car battery must be protected against these nasties. I've shaded portions of each graph to indicate the conditions that violate the operating conditions for the 7805 (and most other voltage regulators). If the voltage regulator isn't protected, it will eventually fail, possibly subjecting the 5-volt devices downstream to 14 volts, and probably incinerating them faster than a fuse can blow.

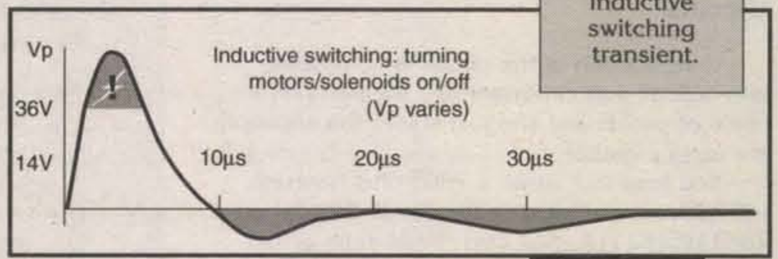
From the graphs, we can see that there are basically two problems: reversed polarity (from inductive switching and field decay), and overvoltage (load dump). Fortunately, neither of these conditions last very long; less than a tenth of a second, worst case.

Application-Note Inspired Circuit

When I set out to design my power-supply circuit, I knew I wanted to use a switching regulator to avoid having a sizzling-hot heatsink somewhere under the dashboard. I also knew that I didn't want to design a switcher. Consulting the Digi-Key catalog, I found that a company called Power Trends makes a series of switching regulator modules designed to replace linear 7805s in many applications. Perfect!

Even better, at the Power Trends web site (www.powertrends.com), I found an application note called "Vehicular Power Adapter Using ISRs (integrated switching regulators)." I took their design suggestions, made a couple of minor improvements, and built the circuit shown in Figure 5.

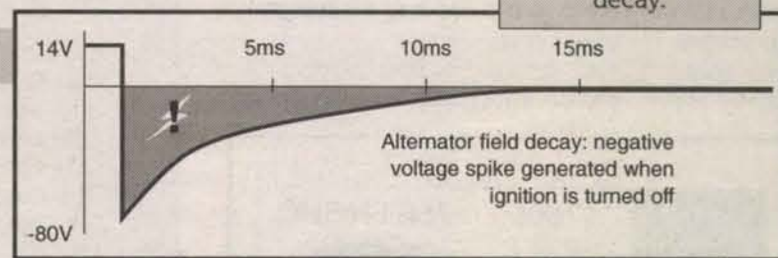
FIGURE 3.
Inductive switching transient.



The circuit is designed so that you can use either a 7805 linear regulator or the Power Trends 78ST105HC integrated switching regulator. Note that I've provided two parts lists, since slightly different component values are required depending on which way you go.

Most of the components in my circuit are simply insurance against various kinds of misbehavior of the vehicle electrical system and/or regulator components. Diode D1 blocks negative spikes, while D2 (a zener diode) clips off positive spikes exceeding 36 volts. Capacitor C2 is the only one required for proper operation of the 78ST105HC, but Power Trends recommends the input capacitor (C1) to prevent switching noise from being coupled back into the vehicle's electrical system (possibly fouling up radio reception, etc.).

FIGURE 4.
Alternator field decay.



I added the small-value cap C3 after a little poking around with an oscilloscope. I wasn't happy with the amount of ripple on the output (about 400 millivolts; mV), so I added a 0.1µF ceramic cap across the output. The ripple dropped to less than 100mV. Power Trends says that higher-value ceramic caps (1µF or more) can further reduce ripple,

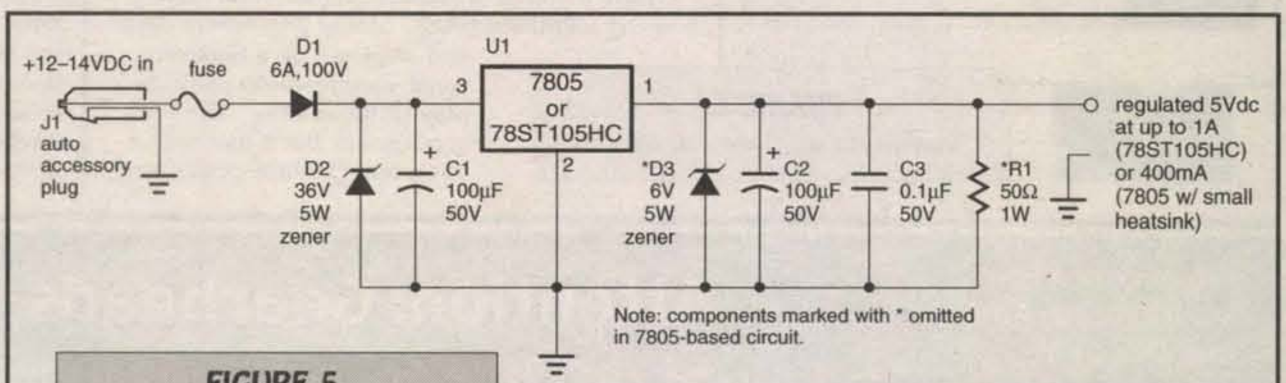


FIGURE 5.
Vehicular power supply circuit.

but such caps are not common, and 100mV ripple is acceptable for digital applications.

I added zener diode D3 to clip off any spikes that might exceed 6 volts on the output. This diode is shown in the Digi-Key application diagrams for the 78ST105HC, but not in the Power Trends documentation. Either way, if the regulator were to somehow fail with a short-circuit from input to output, the 6-volt zener diode would conduct and help to blow the fuse. A dollar well spent.

My last added component is R1. Typical of many switching regulators, the 78ST105HC requires a certain minimum current draw in order to remain in regulation. Otherwise, its output voltage could rise beyond the specified 5 volts. That minimum is 100 mA. R1 draws 100mA at 5 volts so, even with the load disconnected, the output will remain in regulation. If the load is such that it never draws less than 100mA, R1 can be omitted.

To connect my creation to the vehicle electrical system, I opted for a cigarette-lighter plug. It came with a 5A fuse, but I substituted a 2A unit. Changing the fuse is just a matter of unscrewing the knurled nose cone of the plug. A nice feature of the plug specified in the parts list is that it has a built-in power LED. If the ignition is off, the fuse is blown, or the plug isn't properly seated in the lighter jack, the LED remains dark.

Linear voltage regulators like the 7805 get hot because they are obliged to do something with the electrical energy that's drawn from the input but not delivered to the output.

Building and Using the Supply Circuit

Construction of the circuit is completely non-critical; you can assemble the parts on a piece of perf board and just solder the appropriate wires together.

You may use either a 7805 plus heatsink (400mA max output) or the Power Trends 78ST105HC (1A max out). Make sure to use the parts from the appropriate parts list. If you use the 7805, make sure to use a heatsink, and position the supply in a location where there's free air circulation.

I strongly recommend that you use a fuse in series with the +12V input to the supply. Depending on which circuit you tap for the input, the vehicle's fuses are probably rated too high (10A or more) to provide any meaningful protection for your circuit.

That's all there is to it. For me, building this power supply was an important stepping stone. I have a bunch of projects in mind that involve using a Parallax BASIC Stamp II to collect data and display it on a Seetron serial vacuum-fluorescent display (VFD) module. The VFD is gorgeous, but it draws a lot of current (500mA peak), and it's fairly expensive ($159.00; www.seetron.com). Rather than risk destroying the module with a crummy power supply, I decided to build this project. I'm happy to report that the module has been running for weeks off the switching (78ST105HC) version of this project without a hiccup. **NV**

Parts List 1: Switching Supply (1A output)

All part numbers refer to Digi-Key (1-800-digikey or www.digikey.com)

C1,C2—100µF, 50V electrolytic capacitor (part no. P1353-ND)
C3—0.1µF, 50V monolithic ceramic capacitor (part no. P4923-ND)
D1—silicon rectifier diode, 6A, 100V (part no. 6A1MSCT). Note: it's permissible to use a smaller diode, 2A or more.
D2—zener diode, 36V ±5%, 5W (part no. 1N5365BMSCT)
D3—zener diode, 6V ±5%, 5W (part no. 1N5340BMSCT)
J1—Auto accessory (cigarette lighter) plug (part no. ZA5073-ND)
R1—50-ohm, 1W resistor (part no. ALSR1F-50-ND)
U1—5V, 1.5A integrated switching regulator (part no. 78ST105HC)
fuse—2A, 250V normal-blow fuse (part no. F119-ND)

Parts List 2: Linear Supply (400mA output)

All part numbers refer to Digi-Key (1-800-digikey or www.digikey.com)

C1,C2—100µF, 50V electrolytic capacitor (part no. P1353-ND)
C3—0.1µF, 50V monolithic ceramic capacitor (part no. P4923-ND)
D1—silicon rectifier diode, 6A, 100V (part no. 6A1MSCT)
D2—zener diode, 36V ±5%, 5W (part no. 1N5365BMSCT)
D3—zener diode, 6V ±5%, 5W (part no. 1N5340BMSCT)
J1—Auto accessory (cigarette lighter) plug (part no. ZA5073-ND)
R1—not used
U1—5V, 1.0A linear voltage regulator (part no. NJM7805FA-ND)
Heatsink—aluminum heatsink, bolt to U1 (part no. HS191-ND)
fuse—1A, 250V normal-blow fuse (part no. F115-ND)

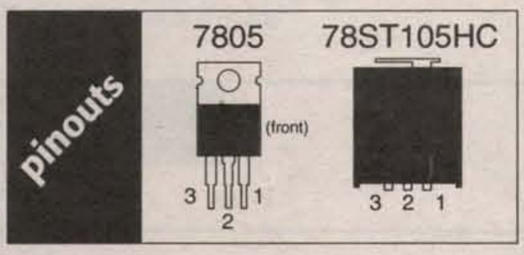


FIGURE 6.
Pinouts for U1, 5-volt regulators.