Simple electronic load for testing power supplies

We describe a simple electronic load circuit that can be used for testing voltage regulators. Building and using this circuit is not a formal requirement for EE 333, but having a simple means for varying regulator current can be very handy for lab exercises and project where testing is required.

The load circuit described here is quite similar to one described by the eevblog guy: www.youtube.com/watch?v=8xX2SVcItOA, if you prefer to watch rather than read.

Testing

One important measurement for voltage regulators is load regulation — how much does the regulated voltage change as the output current changes? Obviously, measuring load regulation requires changing the output current. A second important measurement is efficiency — how much of the power going into the regulator is delivered to the load? Efficiency can range from 10% (or less!) for linear regulators to more than 95% for switched-mode types. Often efficiency is dependent on the load current, and so it is important to know the point of maximum efficiency and how the efficiency changes as the load conditions change.

Clearly, when testing a regulator, it is important to be able to change the load current in a controlled fashion. A simple-minded approach (i.e. EE201 approach) would be to attach resistors of various sizes to the regulator output to realize different currents. This can certainly be done, but it is pain switching the different resistors in and out, and it is necessary to pay attention to the resistor power ratings, since the tests may involve high currents. An added complication is that as resistors heat up, the current will change, so keeping the current constant can be difficult.

A much better approach is to make a variable current source using a transistor. With either a MOS (or bipolar) transistor, the drain (collector) current can be controlled using a voltage at the gate (base). If the transistor is operating in the saturation (forward active) mode, the current is pretty much independent of v_{DS} (v_{CE}) — as we would expect for a current source. We can sense the current with a small-value resistor. Using an op amp with feedback, we can maintained the sensed voltage at pre-set value, meaning that the current is held constant, even if other conditions (temperature, etc) are changing.

These days electronic loads have become big business. If you snoop around at Keysight, Tektronix, Rigol, or any of the other big test equipment vendors, you will see a variety of fancy (and expensive!) electronic loads. This is as testament to how important power delivery has become in the electronics systems world.

Caution

Before describing the circuit, we offer a note of caution. The purpose of a regulator is to deliver power to an electronic system. While the voltages used are probably similar to what most of us have seen in EE201 and EE230, the currents, and thus the power, may be quite a bit higher than what we are used to. It would not be unusual to up to 1 A for some projects. Depending on the regulator voltage, the power that the load must dissipate might 10 W or more. Virtually all of power will be dissipated in the transistor, and it is going to get hot. Here are some things to note when using the electronic load.

1. The transistor will require a heat sink, the bigger the better. Use thermal grease or a thermal pad between the heat sink and the transistor. Tighten the connecting bolt as much as possible to ensure good thermal conduction.
2. Even with the heat sin, the transistor will be hot, and so *do not touch it!* Once is more than enough to learn the lesson, but better to never get burned in the first place.
3. Of course, we should prototype the load on a breadboard. But remember that the breadboard is made of plastic and it will melt if any parts get too hot. When using the circuit in the breadboard, keep the power levels low (below a couple of watts). Once satisfied that the circuit is working well, it is a good idea to make a perf-board version, which will be able to handle hot transistors much better. Besides, if we are going to use this circuit in the future, we will want a more permanent version, anyway. Of course, we can even make a PCB version if we want.

Circuit

Figure 1 shows a simple electronic load that should work well for currents up to 1 A.

The output of the regulator to be tested attaches to the V_{reg} port.

The load current supplied by the regulator flows through — and is controlled by — the power NMOS. Setting the gate voltage sets the current through the NMOS, which is operating in the saturation mode. The IFR540 from the EE230 lab kit is a suitable transistor. Many other options are possible. The NMOS is going to get hot, so attach a heat sink, as discussed above.

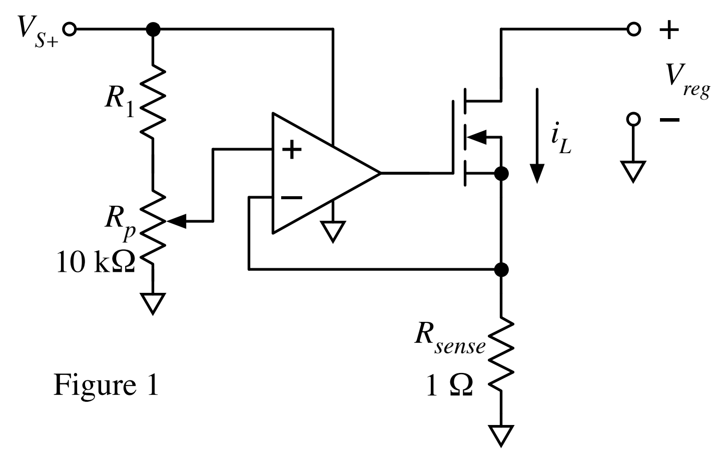

Figure 1

The load current flows through the 1-Ω sense resistor. Measuring the load current is trivial — attach a voltmeter across the resistor and the value of the voltage is equal to the value of the current. For expense and power considerations, the 1-Ω resistor is made using ten 10-Ω 1% resistors in parallel. Ten 1/4-W resistors can dissipate 2.5 W of power, corresponding to about 1.5 A. (Note: A single 1% 1-Ω high power resistor costs more that ten 1% 10-Ω resistors. Check it out.)

The voltage on the sense resistor is fed back to the inverting terminal of an op amp. The non-inverting terminal is the "set point" for the current. In this case, the set point corresponds to voltage at the center terminal of a potentiometer. As always, feedback tries to make $v_- = v_+$. For example, if v_+ is set to 0.1 V, the op-amp adjusts the gate voltage of the NMOS to make $i_L \cdot R_{sense}$ = 0.1 V, corresponding to a current of 100 mA. So, adjusting v_+ gives direct control over the load current flowing from the regulator.

There is no specific requirement on the op amp — almost any general purpose amp will do. The TL082 or LM324 from the lab kits would be OK. (You might want to stay away from the LMC660, which seems to have some issues when used in unity-gain-like configurations.)

It might be a good idea to use a 10-turn potentiometer for the v_+ adjustment — it will provide for finer control of the current. Resistor R_1 is optional, but including it allows the potentiometer to provide even better control of the current. For example, if V_{S+} = 5 V and R_1 = 0 (i.e. no R_1), then the potentiometer voltage will range from 0 to 5 V, meaning that the current could theoretically be as high as 5 A. However, this load circuit is really not intended for currents much above 1 A, so most of the range of the potentiometer is not used. On the other hand, if $R_1 \approx 40$ kΩ (22 kΩ + 18 kΩ or 33 kΩ + 6.8 kΩ), then the potentiometer voltage can swing from 0 to a maximum of about 1 V, making much better use of the potentiometer's range.

The op-amp works from a single supply. Although it is possible to use the regulator output to power the op amp (i.e. make $V_{s+} = V_{reg}$), it is probably better to have a separate supply. The 6-V supply from the triple supply in lab or a 9-V battery are good options. Note that the supply voltage may impose a limit on the maximum current. For example, if using an LM324 with V_{s+} = 5 V, then the maximum op amp output voltage will be about 4 V. For the IFR540 with the gate at 4 V, the current might not reach 1 A. If that's a problem, then the simplest fix is to increase the supply voltage so that op amp output can go higher. Other fixes are to use a rail-to-rail op amp or a transistor that provides more current at those lower voltages.

That's it. The circuit is not complicated, and it can be very handy for testing electronic power systems. Just watch out for the heat!

Enhancements

We could use replace the NMOS with a BJT (along with a current limiting resistor connected to the base.) There is no bona fide power BJT in the lab kits, but suitable transistor are readily available.

Automation-minded engineers can imagine joining this load circuit to a microcontroller to create an automated test set up for measuring load regulation and efficiency at the push of a button. (Project 2, anyone?)

Another important of aspect of regulator performance is the dynamic response. If the load current changes rapidly, there will be a transient during which the regulator voltage will deviate from the desired value. It is important to know the size of the of the transient and the recovery time. By pulsing the control voltage between two levels (using a microcontroller or a simple square-wave-oscillator circuit), dynamic response of a regulator can be observed on an oscilloscope.

Of course, the circuit could be adapted to handle higher regulator voltages and higher currents, if needed. With the increased power, "You're gonna need a bigger heat sink." (www.youtube.com/watch?v=2I91DJZKRxs). And everything else will have to be sized accordingly. Proceed with caution.