CURRENT REGULATOR

The circuit is as shown in figure 1. Figure 2 shows the pinouts on the semiconductors. Notes in figure 2 explain how to decide how many transistors you need and how many sense resistors to use, and of what values. I hope it's clear. You could have different current ranges by switching resistors in or out, or maybe jacks with resistors mounted on the plugs so you just plug in more resistors as you want to add full-scale current. Sense resistors all go in parallel. The amount of current that a resistor adds to the full-scale value is $\mathbf{I = \frac{1}{R}}$. So a 1-ohm resistor addes 1/1 or 1 amp to full scale output, a 0.5 - ohm resistor adds $\frac{1}{0.5}$ =2 amps, and so on. If you have 5 0.5-ohm resistors plugged in , you get 5 x 2amps = 10 amps full scale. You'll want one transistor for about every 2 amps to be conservative. If you have a really good heatsink and/or if load voltages tend to be high (so the transistor doesn't have to drop so much) you can get more current from each transistor; the limitation on the transistors is operating temperature. You could also just crank back the 18-volt supply to a few volts above whatever the load is drawing. With 5 volts of overvoltage (supply > load), the circuit will control just fine, and then you could get up to 5 amps per transistor with any kind of decent heatsink. You want to stay above 7 volts, though, to keep the opamp and the 7805 happy. More about heatsinks later.

With the pot, you can then set the load current to any value from zero to whatever full-scale value is determined by the resistors plugged in.

How does it work: The circuit is basically a voltage regulator. The opamp "compares" and amplifies the difference between the setpoint voltage (set by the pot) and the value on the sense resistor. The gain of the amp is very high -- well over 10,000 -- so a very small difference between it's input terminals causes a large difference in output voltage.

Full-scale on the pot is one volt. The 7805 provides a regulated source of 5 volts, dropped to one volt by the pot and the two 2K resistors. Two resistors because 4K isn't a standard value. You could use 3.9K here just as well, if you wanted to; you'll probably set the thing with an ammeter in series with the load anyway.

Let's say the pot is set at 0.25 volts. If there's no load current the voltage on the sense resistor, and therefore the - input of the opamp, is zero. Op-amp output starts going high which drives the transistors to deliver more current. Let's say the load resistor is .01 ohm (for 10 amps full scale). The drive voltage out of the opamp rises until the voltage on the sense resistor is very near to 0.25 volts, at which point things settle out. There's about 1.4 volts of drop from the base to the emitters. (these are Darlington transistors -- current gain of about 1000) so the base needs to be somewhere around 1.4 + 0.25 = 1.65 volts. Opamp gain is say 10,000, so the <u>difference</u> in voltage between the inputs on the opamp needs to be about 1.65/10,000 or 165 microvolts. Yes, microvolts. So the circuit is happy when the sense resistor has enough current going thru it to produce .25 - .000165 or .249835 volts. -- which corresponds to a current of 2.49835 amps, or 1.65 milliamps below the setpoint.

Note that the load resistance and supply voltage don't figure into this at all. Well, they do, but only as second-order effects.

The 0.1 ohm resistors on the emitters of the transistors are just to ensure current-sharing between the various transistors. The value isn't fussy at all; just need a little something there to offset production variances between transistors. However, they should all be the same value. 10% tolerance is fine.

The resistor-capacitor network between the opamp and the transistor bank stabilizes the circuit. Without them the circuit oscillates a little. I'll spare you the gory details of why that's true and why the RC network fixes it. Suffice it to say that it does.

I simulated this circuit in SPICE (circuit modelling program). That's where I noted -- and fixed -- the oscillation. It seems to be stable now. The values of the R's and C aren't fussy; it worked over quite a

range of values. The values selected seem to be in the middle of the range.   The cap is a small electrolytic, maybe a 12 or 15-volt part. I cited 22 uF, but you can deviate from that at least 20% with no problem.

I ran it (simulation) with a variable-resistance load that runs from dead short to whatever value results in needing about 15 volts to draw the set current. Did that for 4 amps and 20 amps. The deviation in current from short-cct to max load resistance (that 15 volts would drive to the set current) was less than a milliamp at 4 amps, about 2 milliamps at 20 amps. In other words, about .01 percent of full scale.

A real circuit won't do this well of course, but I think you can easily expect a tenth percent of full scale deviation in load current from short cct to the max resistance that 16 or 17 volts will drive.   You don't get the full 18 volts because the transistors need a volt or so of "headroom" to work, and there's somewhere between 0 and 1 volts on the sense resistor -- depending on what you set the pot.

In practice, you just put an ammeter in the circuit, plug in the set of sense resistors you need to get a full-scale current that accomodates your load, and then "dial in" the current you want on the ammeter. (Use of a 10-turn pot would make precise setting a lot easer.) Then maybe dial back the power supply voltage to a few volts above whatever the load voltage is at that current to reduce heat dissipation -- or not, if everything's running cool.   If you do dial it back, you'll probably want to keep an eye on load voltage; load voltage will go up as the anodized film grows so you'll want to keep up with it at the power supply.

If you're using a transformer/rectifier rather than a car battery for a voltage source, you will need some filter capacitors. Figure on   about 2700 uF per amp.   The circuit will work without filtering, but regulation won't be as good.

HEATSINKS:

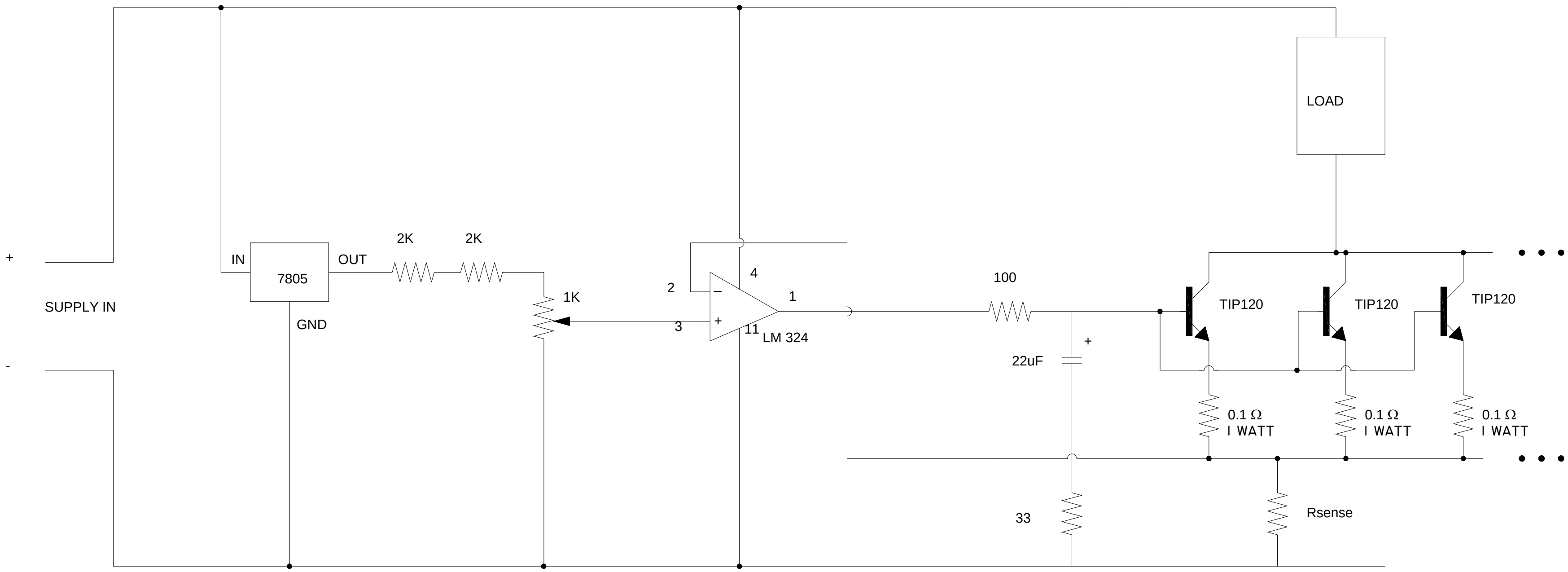
Heatsinks are   basically all about vertical surface area -- or any surface area if you have a fan. 500 fpm air seems to about double the efficiency of a heatsink as a very rough rule of thumb.   A U-shaped structure with 2 fins about 5" square and 3/16" thick, mounted on a bar maybe 1" wide and 3/8" thick   (transistor mounts on the bar) will get you easily to 2 amps per transistor. Add another 4" for each 2 amps.

A bigger structure with more fins will be more effective. If you were to make a casting maybe 4 to 6" wide with as many fins as you can cast, you can probably scale things by the fin areas and number of fins. Using a fan doubles it's effectiveness. The idea is that you want to keep the sink temperature at or below about 70C (158F). At that temperature the transistors are good for 2 amps each when driving a dead short from an 18-volt supply.

Lower supply voltage or higher load voltage increases capacity; the current capacity of the transistors is 5 amps each. Lower sink temperature also increases their capacity, up to the point where you hit the 5-amp current limit. For example, if you have a sink that runs at 50C (122F), you can safely dissipate 55 watts in each transistor, or about 3.2 amps into a dead short from the 18-volt supply.

Hmmm.   If you watch your voltages and keep the "headroom" to 5 volts, you can get the full five amps out of each transistor at sink temperatures of up to 100C -- boiling. Then you can just stick the transistors on any chunk of aluminum, and keep it wet!   Not exactly a commercially-viable design, but it would sure work.   Or you could use a cast aluminum tank filled with water, the transistors bolted to the side.

You could probably devise a little water-cooled heat-exhanger -- maybe a piece of 3/8 or 1/2 aluminum plate with tubing stuck to it, or a serpentine groove milled into it with a ball-end mill and then a plate affixed, tap water running in one end and to the drain on the other end. Very low water flow -- maybe a couple of gallons per hour -- would do the trick. Lots of possibilities.



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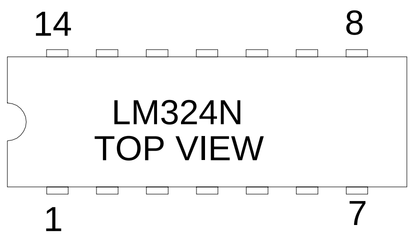

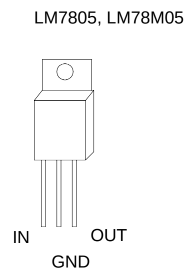

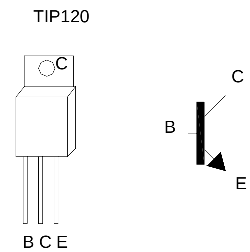

NOTES

Rsense SHOULD BE 0.5 OHM, 3 WATT FOR EACH 2 AMPERES OF FULL SCALE LOAD.
(0.47 OR 0.51 OHM IS CLOSE ENOUGH)

E.G., FOR 6 AMPS OF LOAD, USE 3 0.5-OHM 3-WATT RESISTORS IN PARALLEL.

FOR 1 AMP FULL-SCALE LOAD, Rsense WOULD BE 1 OHM 2 WATTS. THEN EACH 0.5 OHM RESISTOR ADDED IN PARALLEL WOULD ADD 2 AMPS TO THE FULL-SCALE OUTPUT.

ALSO ADD ONE TRANSISTOR AND 0.1-OHM RESISTOR FOR EACH 2 AMPS OF LOAD.

THE POT WILL VARY OUTPUT CURRENT CONTINUOUSLY FROM 0 TO FULL LOAD.

A TEN-TURN POT WILL GIVE FINER RESOLUTION OF CONTROL.

Rsense RESISTORS COULD BE SWITCHED IN AND OUT FOR VARIOUS LOAD RANGES, TO GIVE FINER RESOLUTION OF SETTING FOR LIGHTER LOADS.

TRANSISTORS, ONCE ADDED, WOULD NOT NEED TO BE SWITCHED OUT FOR LOWER LOAD RANGES.