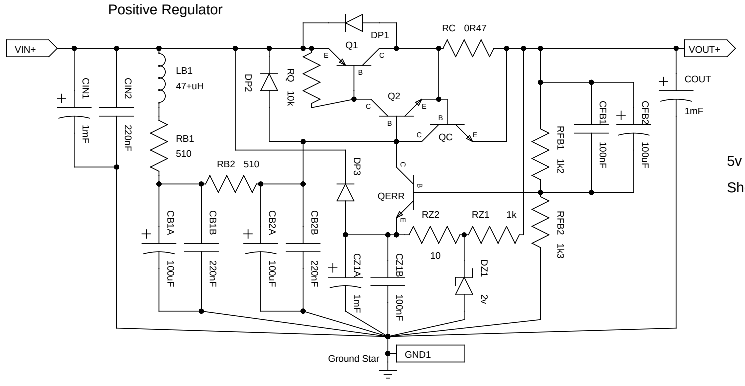
Transistor Fixed Linear Voltage Regulator

2012-07-14

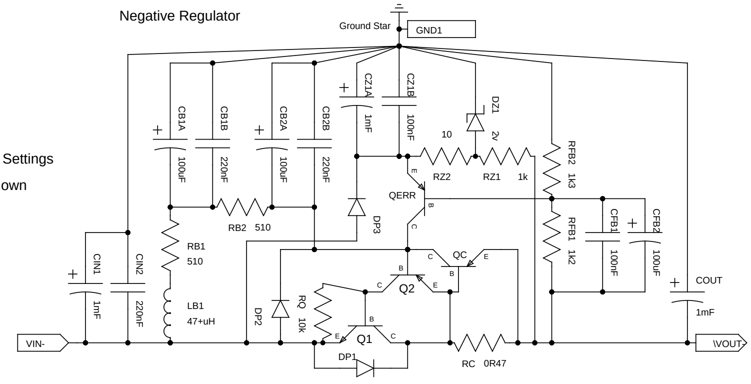
Positive Regulator



5v Settings

Shown

Negative Regulator



This design was very common in the late 1960's before chip based regulators were developed. This design also shares many features with a capacitance multiplier filter (design tricks have been shared). Discrete regulators handle high frequency noise far better than chip based regulators. By choosing appropriate voltage and current rated parts, this design can scale from very small to very large (often used in tube and Class A amps). With the design enhanced, this regulator can chase super regulators, but at much higher voltages and current levels. Both positive and negative versions are shown and can be paired using a center tap transformer for a dual rail supply. Usually the input voltage will need to be 5v higher than the output voltage for adequate regulation.

Parts will need to be chosen to handle the highest unregulated input voltage and current. The diodes and transistors will need to be selected to handle the highest pulse currents, too. The CZ*, CFB*, and COUT capacitors can be rated for the output voltage.

RB1+CB1* and RB2+CB2* form a second order low pass filter at -12db/octave. It is calculated with the usual "-3dbFreq=1/(2*PI*R*C)". For most instances, the frequency should be less than 1Hz. RB2+CB2* can be removed for a first order filter that is slightly simpler and smaller in design. Same for the inductor. (Some designs will do just fine with a simpler setup.) Note that large CB* and CZ* will cause a slow turn on.

Q1+Q2 form a Sziklai NPN compound transistor that will have a 0.7v less drop than a traditional Darlington NPN. Q1 handles all the current. Make it at least 30% higher than the highest expected voltage and current load/pulses. Higher currents will need to have a heat sink on Q1. Transistors with a higher beta will filter better. Since compound transistors multiply the beta, they will filter far better than a single transistor (10k beta preferred).

Whatever the minimum expected input voltage is, RB1+RB2 need to deliver about 1/20 to 1/5 Q2's base current rating to Q2's base. At a minimum, this should be around 10mA. Q2 should be selected to deliver the full current to Q1's base.

DP1+DP2+DP3 are protection diodes in case the output voltage rises above the input voltage. This will help keep from blowing the regulator.

QERR+RFB*+CFB* are for output feedback. RFB1 should be chosen to deliver about 1/20 to 1/5 QERR's base current rating to QERR's base (10mA minimum). QERR should be rated to fully sink all of Q2's base current. RFB2 is generally about the same size as RFB1 for the most stable performance. Smaller RFB1 will have a lower VOUT (QERR sinks more of Q2's base). Both RFB's could be replaced by a multi-turn trimmer to tune in a more exact voltage or to have a variable regulator. Without QERR+RFB*, this circuit would be regulated by DZ1, be just under DZ1's zener voltage, and would have the output floating (similar to a battery). For best load regulation, connect the load at the RFB* divider sense points.

If there's an instability problem, add a 47pF feedback capacitor to QERR between collector and base. The capacitor can be smaller if needed (or add a resistor for a zobel). A smaller capacitor will keep the regulator's high frequency response from being attenuated as much. A 33 ohm resistor can also be added to Q2's base for a little more stability control.

Generally speaking, to prevent oscillations Q2 should be faster than QERR, Q2 should be faster than Q1, and QERR should be faster than Q1. In many cases, Q2's speed can be equal to QERR's and Q1's without oscillation problems, but this depends on the load type. For optimum performance, all the transistors, RFB*, CFB*, and DZ1 should be as close together as possible.

DZ1 is a voltage reference and should be about half the output voltage. CZ1* stabilize DZ1. Zener diodes are known to have a lot of noise coming in the zener voltage transition zone. Make sure DZ1 gets at least a couple volts above this point. Other shunt devices could be used or even combined to replace DZ1 depending on the application (like an LED or diode pointing opposite the zener arrow for a smaller VOUT range). A buried zener is quieter than a regular zener and could be used (example LM329 at 6.9v). An RC filter shown helps reduce noise.

QC and RC form a simple current limiter (shown set at 1.5A). It uses Ohm's Law. As more current goes through the resistor, there is a higher voltage drop. When the voltage drop hits 0.65v (what the base-emitter voltage is for the QC transistor), QC will start sinking current away from the main pass transistor's base and lowering the output voltage. Until this voltage level is hit, QC will do nothing. RC will not affect output impedance much as the feedback voltage divider is after it and will compensate. QC and RC can be left out if the load is known to be well behaved. Equation: R = 0.65v / I where 'I' is the desired current limit.

To avoid hum and buzzing in this circuit, a star ground must be used. Since there can be very large current pulses, use a thick ground wire for least resistance.

Option Not Shown. Adding a resistor before CIN to form an RC filter is not mandatory but will help with high frequency noise and some RF problems. The same goes for adding a resistor just before VOUT. If this is not going to be a high current supply, increase the resistor to 4.7ohms for higher filtering. The resistor's typical range is 1−10ohms. Note that for each ampere being pulled through the resistor, a 1 volt drop will occur per ohm, so this may not be as appropriate before COUT. The resistor's watt rating should be calculated carefully so it doesn't burn up. Other options include splitting the RC filter into a second order filter, adding more inductors, adding ferrites, adding CRCLC filters, and so on.

Estimated Vout equations:

Vout = ((RFB1+RFB2)/RFB2)) * Vz+Vbe(qerr)

Vout = (1+(RFB1/RFB2)) * Vz+Vbe(qerr)

Note that the voltage divider RFB* will act as a multiplier for whatever is at QERR's base.

Q2's Base Current: (RB1+RB2) = (Vin-Vz)/(Iz+K*Ib) where K is a safety multiplier from 1.2-2, Ib is Q2's desired base current, and Iz is the desired zener current. (mirrors R=V/I)

Output current?: Vout / (RFB1+RFB2)

LED's vary (by design and up to 10%) and should not be definitively used unless tested. infrared: 0.95v. red=1.35-1.4v. small red=1.25v. yellow=1.45-1.5v. green=1.55-1.6v. orange=1.55v.

Transistors for 500mA positive regulator:

Q1 PNP: ksb1116y, bc327, or bc640 (slowest)

Q2 NPN: 2n3904 or 2n2222a (fastest)

QERR NPN: 2n4401 (medium)