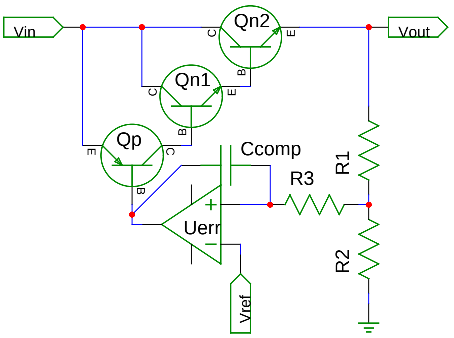
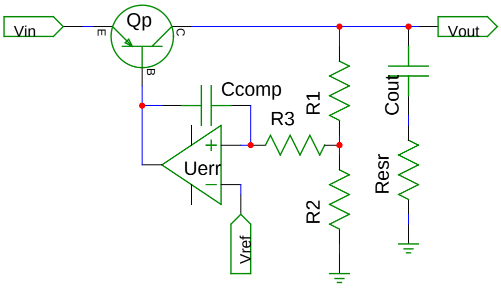
Transistor Linear Regulators

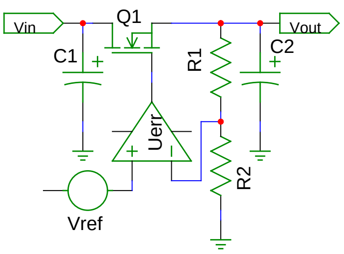
2008-07-24



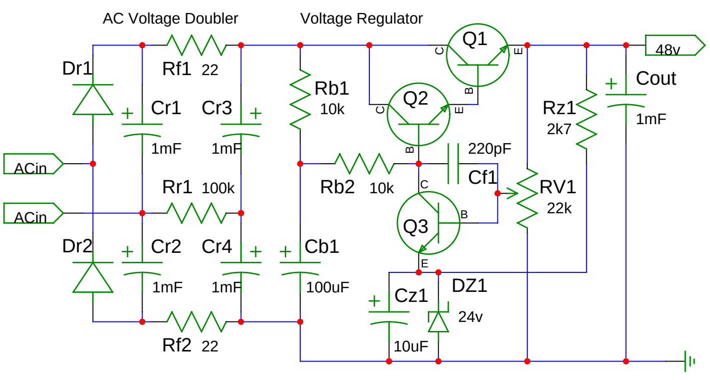
NPN Regulator and Loop Gain Example.
The PNP+NPN+NPN is generally called "unconditionally stable". This layout is similar to an LM780x type.
Dropout from the darlington configuration is typically 2-2.5v.
This darlington configuration is often called "emitter follower" because of near unity gains but high current gains.
Qn2 is the power transistor. Uerr is the error amplifier. Vref is a voltage reference.
Properly designed, this will have gain of 90db up to 10Hz and -20db/decade after. 0db crossover is usually 100kHz-1MHz.
PNP+NPN is a Sziklai Pair variation (also called compound transistor, complementary Darlington).
Sziklai have a lower turn on voltage than a Darlington pair.
Current gain is a multiplication of the transistors.



Low Dropout Regulator (PNP Regulator)
The power transistor (Qp) is a single PNP transistor.
The dropout voltage can be as low as the PNP saturation voltage.
A single PNP has lower beta compared to an NPN darlington.
Ground pin current ~= load current / PNP_beta
Good PNP beta for this would be >100.
Gain is about 90 up to 10Hz, -20db/Dec to the load pole, -40db/Dec up to the ESR zero, then -20db/Dec to unity gain.
Unity gain crossover is about 30kHz.
PNP drive the output off the collector (common-emitter configuration).
This has a high output impedance and the loop gain has a load pole in it.
freq_loadpole = 1 / (2 * PI * R_load * Cout)
Use Ohm's Law to determine R_load.
This requires a stabilization capacitor and ESR is important.
f_zero = 1 / (2 * PI * ESR * Cout)
This will add some positive phase and cancel out oscillation at unity gain frequency.
Stable ESR ranges from 0.1 to 8 ohms typically. Too much or little will also cause problems.
Ceramic caps have too low ESR, electrolytic increase too much near freezing.
Multiple caps in output will each have their own pole and zero and may cause oscillation.
To make this stable and eliminate the need for Resr, a resistor was added in series with Ccomp, adding a zero to the loop gain.



Low Dropout Linear Regulator Overview
Q1 is usually an N-MOSFET (source-gate (arrow) on right, IRF740).
Pick something with a low voltage drop.
R1+R2 adjust the output.



48v/200mA Phantom Power Voltage Regulator (Traditional Discrete Regulator Design)
48v versions of linear chip regulators don't exist, so something like this has to be used.
Capacitors should be rated for 63v or higher. Same with transistors.
The left side operates as an AC voltage doubler from a dedicated 30v/30VA transformer.
Dr1+Dr2 rectify the AC. Cr1+Cr2 initial doubler filter. Rf1+Rf2 provide RC filtering to Cr3+Cr4.
Rf1+Rf2 need to be >=1w rated. Rf1+Rf2 can be up to 100ohm if full current output isn't used.
Rr1 balances voltage for Cr1+Cr2+Cr3+Cr4 and cannot be removed.
RV1 is used to fine tune the voltage setting.
Expected Vout full load variation is 0.1v. +/-20% Vin to Vout variation is expected 0.2v.

Each phantom power channel (differential inputs) is fed through a pair of 6810 ohm resistors.
Parallel multiple metal film (or better) resistors for higher wattage and less noise.
Get the ohm meter and try to match the pair as close as possible. A 10uF capacitor or higher goes before the resistors to stabilize the power. Each signal input channel gets a 22uF DC block capacitor, 10ohm resistor, and a pair of back to back 10v/1w zeners to protect it.
Higher value film type capacitors are preferred since the average mic has a 1k ohm resistance and will form an RC filter. Paralleling and adding a ceramic would also be good.

This is a more extended version of the standard resistor+transistor+zener basic regulator. Parts: Q1 (2w medium heat sink) BD139, TIP3055; Q2=Q3 (0.5w small heat sink) BC546, BD139.
Rb1+Rb2 form the standard feedback resistor to base+zener in the basic model. ?Why is Rb1 and Rb2 split with Cb1 in the middle? RC filtering/snubber/zobel and stabilization? If transistor beta is low (non-darlington), Rb1+Rb2 will need to be lowered so more current can control the transistor base. Higher Rb's mean more low frequency smoothing (to a point) and more voltage drop on Vout.
DZ1 is the 1/2 out reference voltage and feeds the Q3 error amplifier. Higher Vin turns on Q3 more which in turn removes the base drive from Q1+Q2, reducing its output.
Cz1 provides stabilization for DZ1. ?Cb1+Cz1 also provides a soft start feature (bigger=slower)? Higher Cb1+Cz1 should mean more low frequency smoothing, but too much will cause excessive turn ons and sluggishness. Cb1 probably shouldn't exceed 470uF. Cz1 probably shouldn't exceed 47uF.
Cf1 is high frequency oscillation prevention. Rz1 feeds regulated Vout to DZ1. For different voltages, Rz1 should provide about 10-30mA to DZ1 (Rz1 = (Vout-Vz)/0.01)).
RV1 forms a voltage divider to fine tune Vout (start with it in the middle, sealed multi-turn preferred). RV1 can be split into a pair of fixed resistors summing 22k once the ratio has been determined if no moving parts are desired. Less resistance on the top of the divider will have a lower Vout (Q3 opened up more = Q1+Q2 drained more). Q3's base should have at least 1mA at its lowest voltage. If RV1 is set to full resistance (floating regulator), there will be about a 70mV drop between Vin and Vout.
Limitations. This design is weak below 10v from the darlington voltage drop (~1.2v), base resistors and capacitors drops, and zener conductance voltage. Use something like an LM317 instead.

Other Modifications. [Variable Voltage] The zener could be replaced by a regular diode (1n4001, or maybe 2+ in series for more voltage drop?) and turned around. Cz1 should be increased to 100uF or more. RV1 should have 1k protection on each side of it. [Current Overload Protection] Adding another signal level transistor (Qlimit) and small resistor (Rlimit) can limit current to about 1.5A regardless of voltage. Insert the Rlimit resistor of 0.47ohm/2watt immediately after Q1's emitter in series with Vout (a small resistor won't really effect Vout much). Qlimit's base connects between Q1's emitter and Rlimit. Qlimits's emitter connects after Rlimit. Qlimit's collector connects to Q2's base. [Capacitor Filtering Upgrades] If space isn't an issue, split the capacitors, parallel them, and add a 100nF ceramics to improve high frequency response and lower ESR (but only parallel Cf1). Cr* and Cout can safely have their capacitance increased if needed. Between the AC Voltage Doubler and the Voltage Regulator, more capacitors could be added straight from hot to ground. If a lot more capacitance is added, increase the VA rating on the transformer and current rating on the diodes so they can keep up (and maybe heat sinks and transistor current). Dr1+Dr2 could have 22nF capacitors added to each in parallel to reduce diode switching noise.