Appendix D

Volatage regulators for Audio Power Amplifier

Linear power voltage regulators for positive and negative voltage rails

Table of contents

Table of figures

Why building discrete voltage regulators for Audio power amplifier ?

When designing a power amplifier, an eye should be kept on the output power it can deliver. Power is defined as P=U*U/R or P=I*I*R.
Since current is not a big concern for domestic power ranges today, voltage is the limiting factor. If you are using integrated amplifier, they have a maximum input voltage, wich should not be exceeded, else the integrated device would be degraded or, in worst case, destroyed.

Having a look into the LM3886's datasheet [xx], the maximum voltage specified is +/-42Vpeak and +/-38V are recommended.
Using a standard power supply with mains-transformer, diode bridge and capacitors, the voltage at the capacitors should not be higher than +/-38V in idle. Now, some things should be taken into account:
- the voltage drop at the rectifier diodes. In idle mode ~ 2*0.4V, at full load ~ 2*1V
- the transformers voltage overshoot,
  wich is ~ 3%-5% with no load for transformers in the 200-500VA range
- the mains voltage with 230Vac and a specified tolerance of max. of +/-10% (Germany) giving
  207 Vac to 253 Vac
- in the loaded case, the peak voltage will only be reached if the mains
  are on the max/min voltage swing.

Designing the supply from back to front, you use the following steps:

(1) Max. voltage at the power ICs:	→	42V in idle	
(2) Diode voltage drop at idle = 0.8V	→	42V+0.8V	= 42.8V peak
(3) Transformers idle voltage overshoot: 5%	→	95.3% of 42.8V	= 40.76V peak
(4) Mains tolerance: +10%	→	90.9% of 40.76V = 37V peak	
		= 26.2Vac rms transformers output with load	

Transformers spec is: 230V/26.2Vac (ratio=8.78) to go to 42V in idle case and max. mains voltage

With the knowledge of that internal to the IC ~ 3V are lost in respect to the supplys on both voltage swings and assuming that output power is only drawn in short bursts, the following calculations can be done:

Calculate the loaded case with min. mains input:

(1) Min. mains voltage: 207V, ratio = 8.78	→	207V/8.78	= 23.58Vac rms = 33.3V peak
(2) Voltage drop at the diodes = 2V	→	33.3V peak -2V	= 31.3V peak
(3) Included 3V drop inside IC	→	28,3Vpk	= 20,0Vrms

Calculate the loaded case with nom. mains input:

(1) Mains voltage: 230V, ratio = 8.78	→ 230V/8.78	= 26.2Vac rms = 37V peak
(2) Voltage drop at the diodes = 2V	→ 37V peak -2V	= 35V peak
(3) Included 3V drop inside IC	→ 32Vpk	= 22,6Vrms

Calculate the loaded case with max. mains input:

(1) Max. mains voltage: 253V, ratio = 8.78	→ 253V/8.78	= 28.8Vac rms = 40,75V peak
(2) Voltage drop at the diodes = 2V	→ 40.75V peak -2V	= 38,75V peak
(3) Included 3V drop inside IC	→ 35,75Vpk	= 25,3Vrms

Calculating the max. output power into 4/8 ohms gives the following results:

Mains voltage min. 207V: (20Vrms)*(20Vrms)/4ohms = 100 W
(20Vrms)*(20Vrms)/8ohms = 50 W
Mains voltage nom. 230V: (22,6Vrms)*(22,6Vrms)/4ohms = 128 W
(22,6Vrms)*(22,6Vrms)/8 = 64 W
Mains voltage max. 253V: (25,3Vrms)*(25,3Vrms)/4ohms = 160 W
(25,3Vrms)*(25,3Vrms)/8 = 80 W

Now we can see, that the output power for 8ohm loads range from 50W to 80W by only changing the wall plug from one house to another.
Also using exactly 42V at the IC in the idle case seems not to be a good idea and if you wouldn't buy a special wound transformer, the next step is 25Vac for 230V input, resulting in 30Vpk at the IC in the loaded case and min. mains voltage. Output power is then 91W/4ohms and 45W/8ohms.

In the author's case, a transformer was already available, but with +/-44Vdc output peak in idle at a mains voltage of 238Vac rms.

The planned amplifier should be able of driving 3-4 ohms load with output voltages of 30Vpk and consist of paralleled power ICs.
At a load of 8-ohms, 30Vpk at the output will give (30V*30V)/(2*8R) = 56W, at a load of 4 ohms you will get 112W. That's nice range for home use.
For 30Vpk you must consider an internal voltage drop of ~ 3V with max output current, so +/-35V as rail supplys should be fine and gave a little bit of headroom.

Using diodes could be a way, but unfortunately at high currents, the voltage drop rises and rectified voltage falls, so that, if necessary, less voltage than possible is available for the amplifier circuit.

So, a voltage regulator seems to be more usefull here.

Regulator configurations

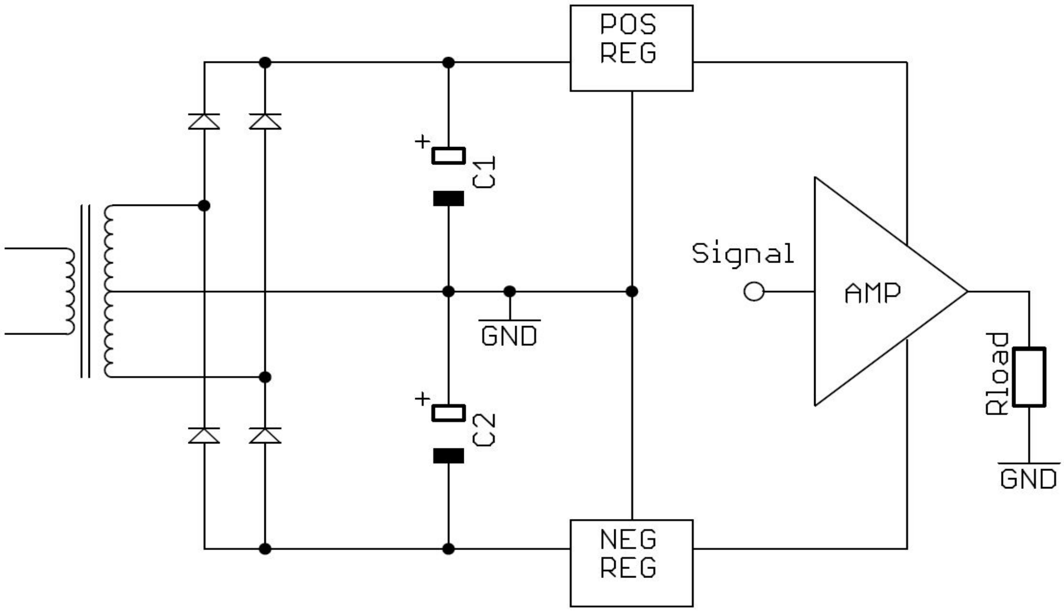

fig 1: Standard voltage regulator arrangement

Having a look on standard voltage regulators, types with more than 2A output current are not available in negative version and cannot handle up to 63V input voltage. Even the strongest positives ones are only available until ~ 7.5A but not for >40V input voltage.

Using a sub 4-Ohms load (like some speakers generates in the low bass region, e.g. 3 ohms at 30Hz) and having 30V peak output voltage, means you need ~ 10A of output current for a „long“ time, e.g.the 30 Hz sine pulse draws a current greater than 7.5A for more than 8ms.
Using big capacitors after the regulator would not help anything beside increasing costs, because while and after the burst, capacitors behind the regulators must be charged anyway but then with higher current...

This means, your supply will limit the amplifier performance.

Some people use a configuration like fig.6 With only positive regulators.

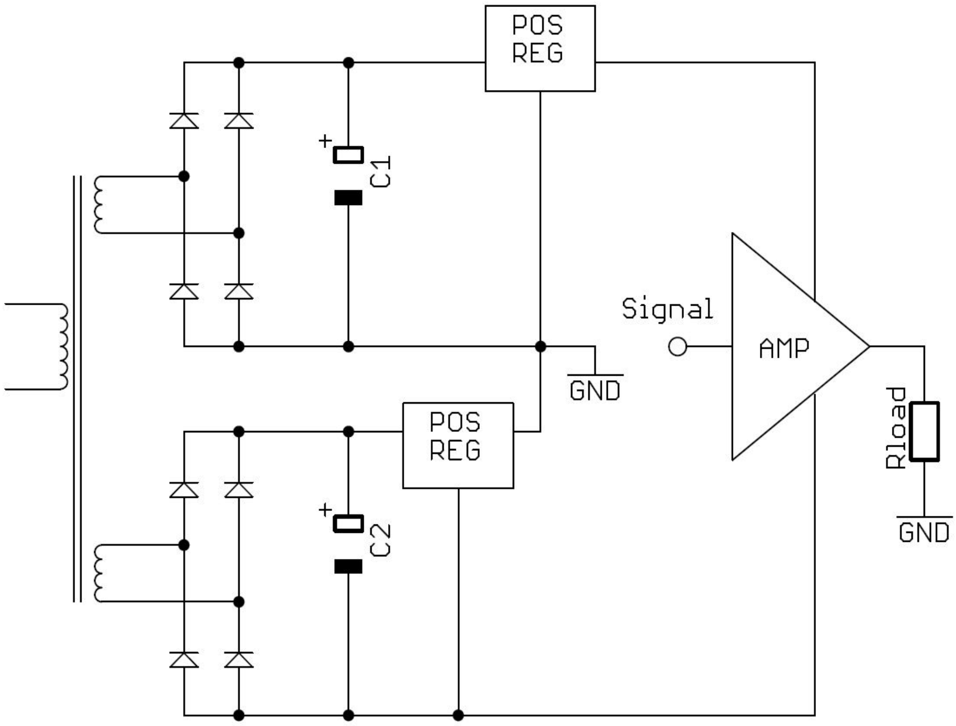

fig 2: only positive regulators used

But beside the input voltage range and current limits of the regulators, there are other drawbacks with implementing shemes like this:

- the transformer must have two seperate windings
- there is a voltage drop of 4 diodes in contrast to two diode drop using fig.1.If you are hard on the edge with the power supply, this will matter
- the amount of rectifier diodes doubles from 4 to 8
- increasing the regulators output current by additional components will end in many discrete parts and higher dropout voltage *1

*1: There are many circuits around wich enhances the output current of standard voltage regulators.

But beside the too high voltage issue, there are more arguments why to use a regulator:

PowerSupplyRejectionRatio

PSRR (PowerSupplyRejectionRatio) is not endless:
Looking at the PSRR graphs of an amplifier (e.g. datasheet of LM3886 [3]) shows that it is ~100dB for the negative and ~113dB for the positive supply at 100Hz and then falling down to be only ~ 55dB for the negative and ~105dB for the positive supply at 10kHz.

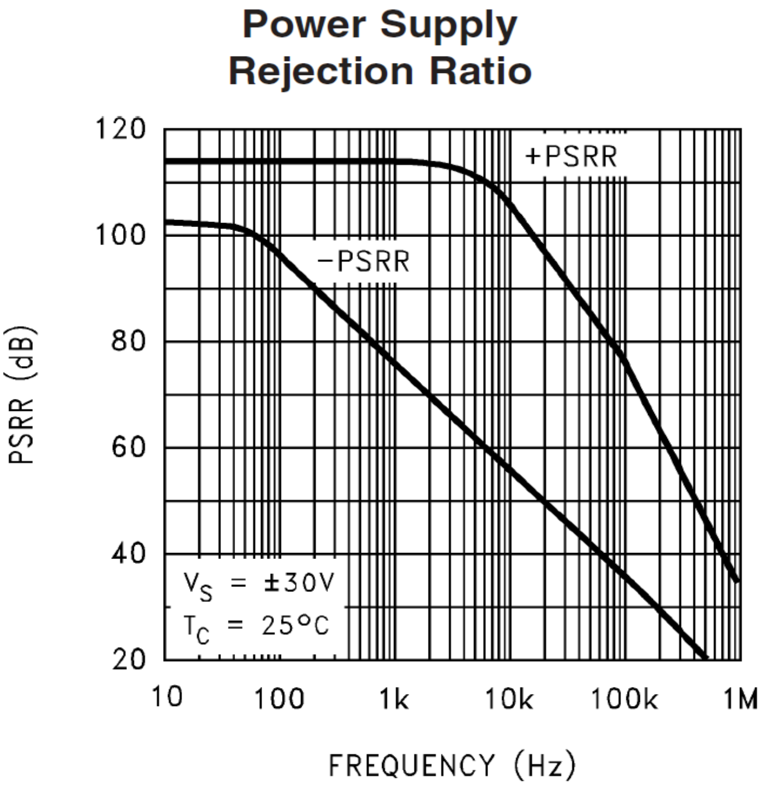

fig 3: LM3886 PSSR

These graphs are divided into positive PSRR and negative PSRR, because of many amplifier (this is valid for Opamps and Power Amplifier) reference the signal to the negative rail, (e.g. see the block diagramm in the datasheet of the LM3886 [3]). There is no signal dependent GND connection, but the VAS stage runs directly on the negative rail.
Any signal on the Supply rails with more than 10kHz are only damped by 55dB or less and can then be found in the output signal.
For archieving good THD results and very good SNR (Signal to Noise Ratio), the noise at the output must be very low.
If the nominal output voltage is 20Vrms and your design goal is to reach the 120dB range for SNR, then the noise in the output is not allowed to be higher than 20µV (120dB), with more realistic values you end up in 100dB SNR giving 200µV.
Using the numbers from above, the noise on the supply pins must be below 20V @ 100Hz (100dB PSRR) and below 112mV @ 10kHz (55dB PSRR) at fullscale output voltage

To make it even worser, the rails are not only carrying 100Hz/120Hz rectified components only but also the charge spikes of the electrolytics and output signal dependent distortions like halfwave rectified currents form the either positive or negative supply and halfwave rectified currents includes much overtones, up to the several hundred kHz range.

A more special case are integrated Power Amplifiers, because most of them doesn't have different supply pins for the input and VAS stage and the power output stage. So there's no chance make a clean supply for the input and VAS stage wich is independent of the output stage and it's currents. See [1],[2] for further informations on this topic.

For comparison, here are the simulation results regarding AC supression,
one with and one without Regulator.

For the input simulation, all incoming AC (from 0Hz to 10MHz) is supressed by the given graphs and found on the supply rail.

For the output load simulation, all AC currents (from 0Hz to 10MHz) are supressed by the given graphs and found as voltage on the supply rail.

The output load supression is referenced to 0dB=1V

AC input supression

Graphs for the input AC supression:
- constant 5A output load
- AC-source connected at the regulators input (with Regulator)
- AC-source connected in series to the transformer secondarys (no regulator)
- output electrolytics (only for the test case with regulator) would be simulated by 2.000µF in series with 20mR (2xPanasonic FC 1000µ/63V)
- input electrolytics (only for the test case without regulator) would be simulated by 24.000µF in series with 50mR including cable

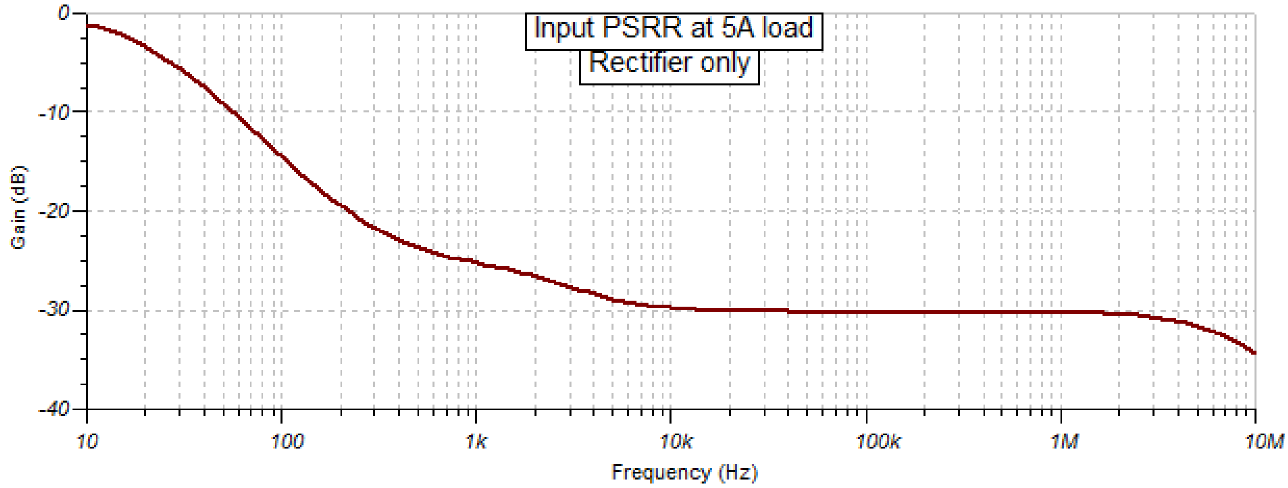

fig 4: Input PSSR, rectifier only

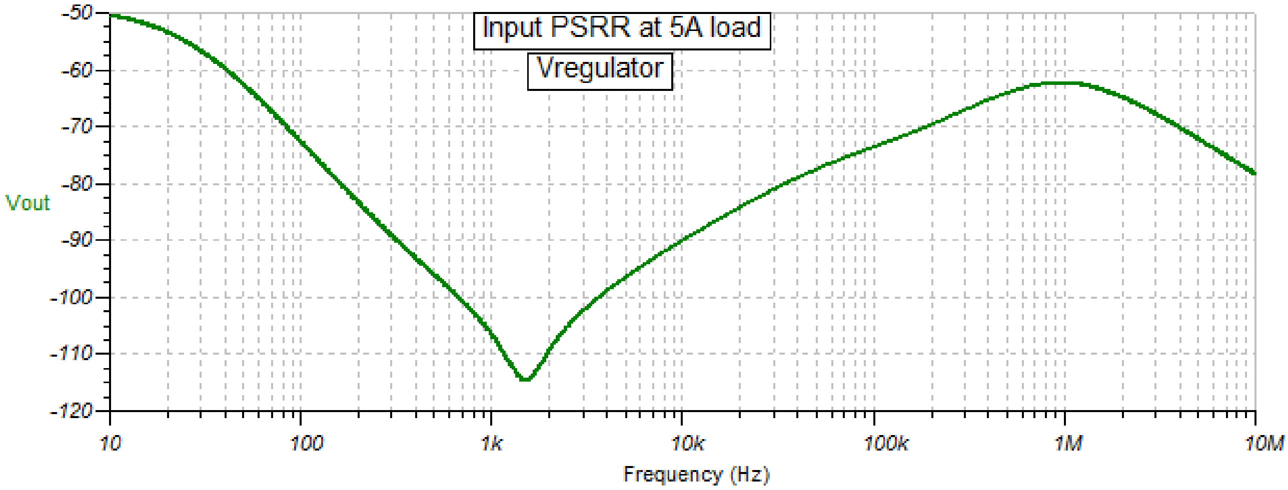

fig 5: Input PSSR, with voltage regulator

AC output supression

Graphs for the output AC supression:

- constant 0.2A output load + AC current generator with 5A AC current at the ouput
- output electrolytics (only for the test case with regulator) would be simulated by 2.000µF in series with 20mR (2xPanasonic FC 1000µ/63V)
- input electrolytics (only for the test case without regulator) would be simulated by 24.000µF in series with 50mR including cable

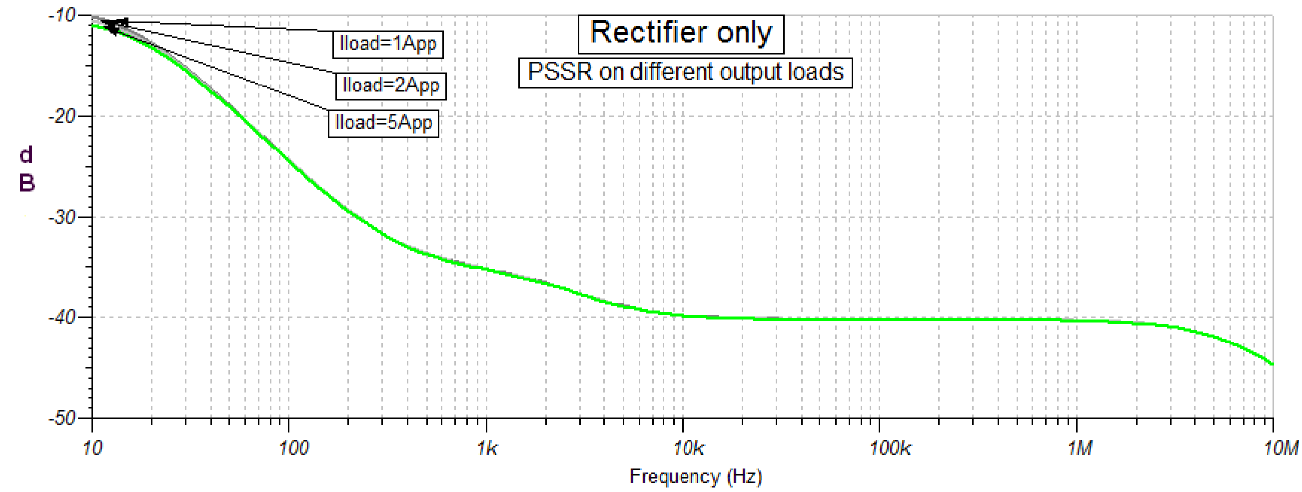

fig 6: Output PSSR, rectifier only

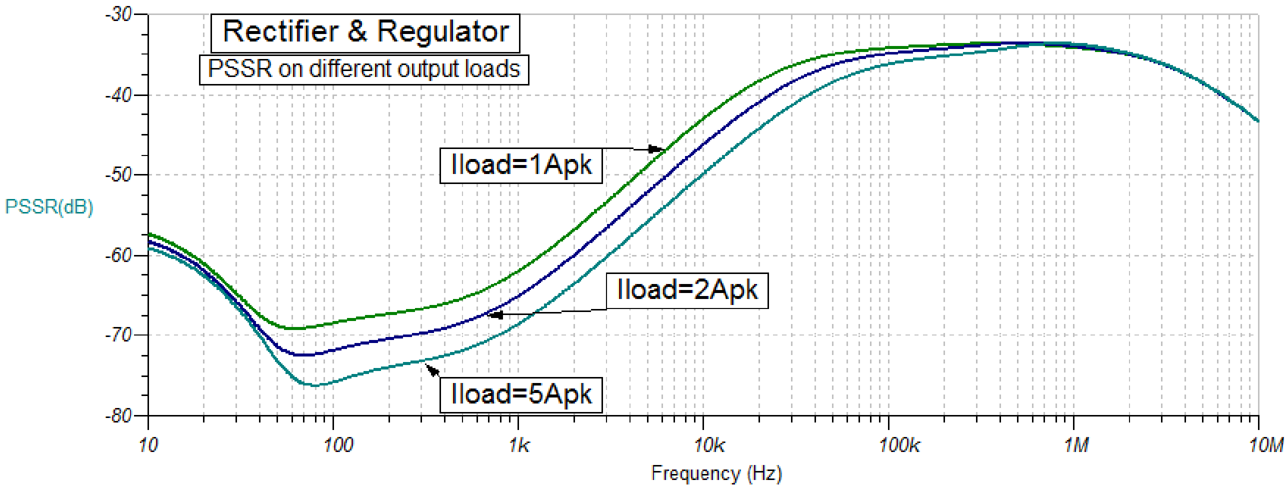

fig 7: Output PSSR, with voltage regulator

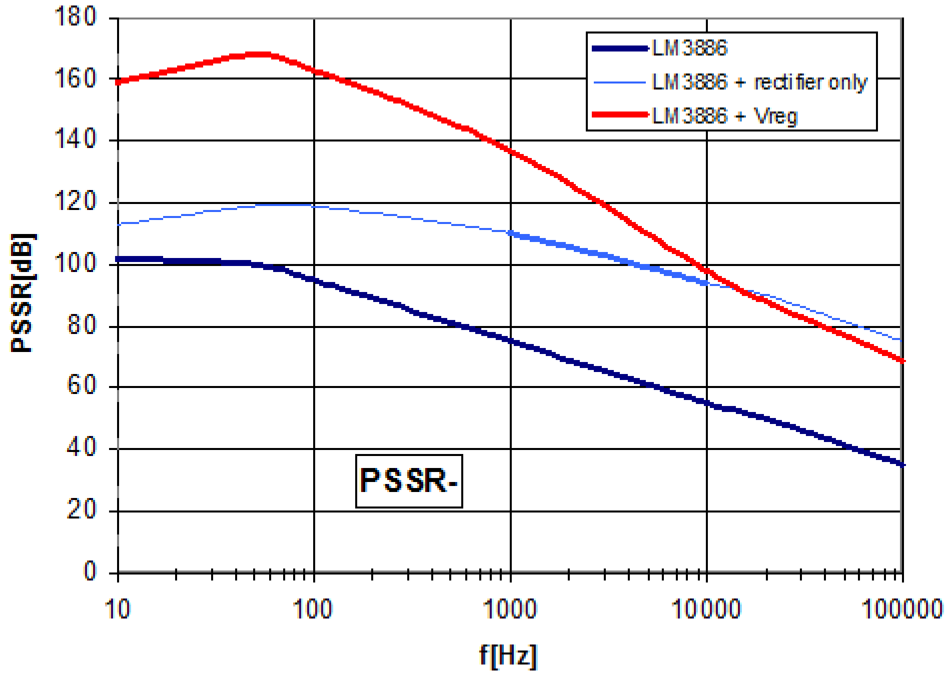

fig 8: PSRR-, LM3886;LM3886+rectifier;LM3886+regulator

In figure 8, the Powersupply PSSR and the LM3886 PSSR (-) are added up.

On the first look, it is clear that the regulator outperforms the electrolytics alone by more than a decade, especially in the interesting 50Hz..1kHz range.

Rail voltages at load

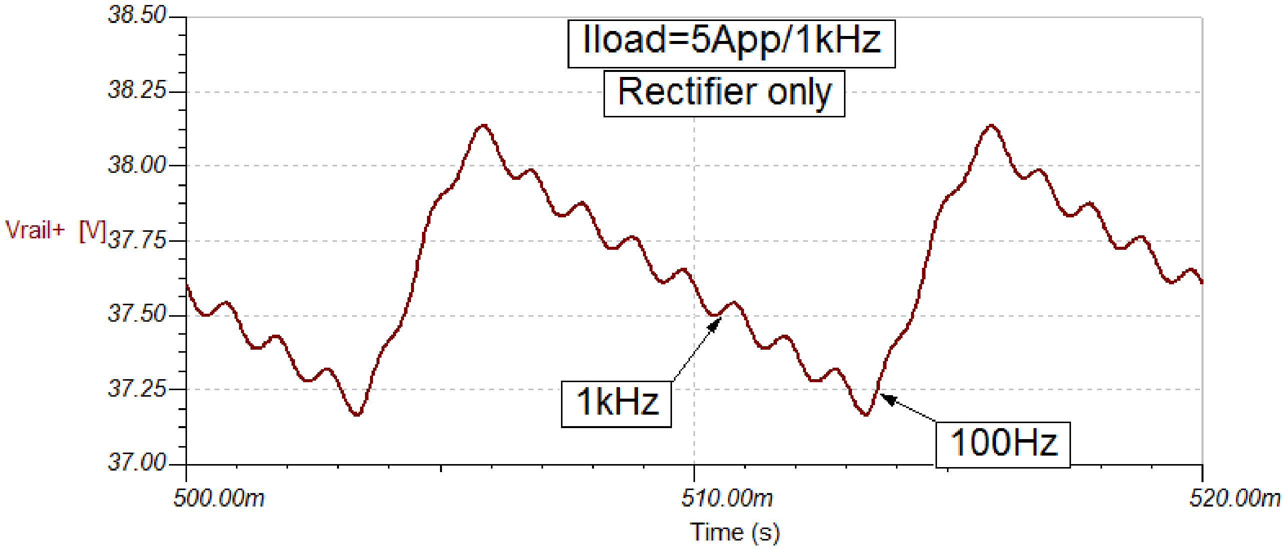

fig 9: Rail voltage with 5A load, rectifier only

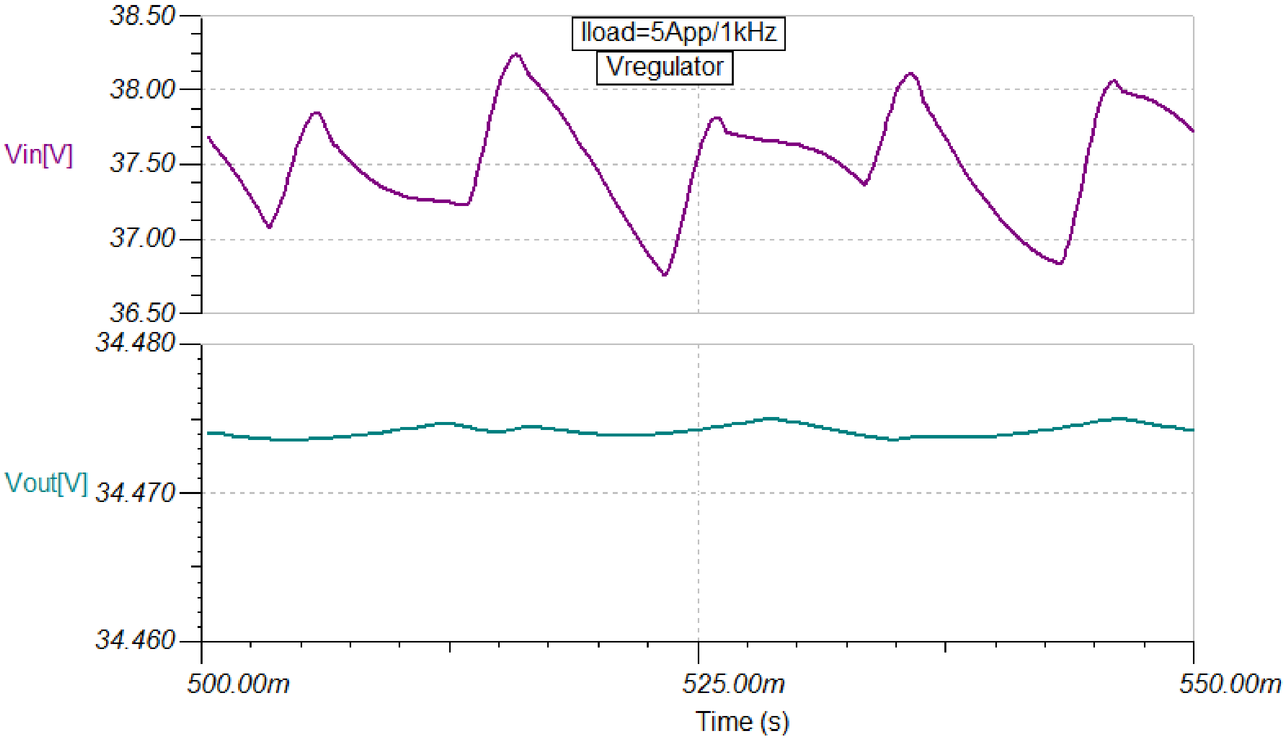

fig 10: Rail voltage with 5A load, with regulator

What this means for our integrated amplifier device ?

In the case of only a rectifier is used, the rail voltage is oscillating with 100Hz/0.9V and 1kHz/80mV and taking the PSRR into account, a distortion signal of 16µV/100Hz and 14µV/1kHz would appear at the output.

In the case of using a voltage regulator, the rail voltage is oscillation is below 5mV at 100Hz and 1kHz and taking the PSRR of 1kHz (75dB) into account, a distortion signal of below 1µV (or almost nothing) would appear at the output.

Even 16µV would not seem to be much, but take into account the rising distortions in case of higher output currents. Also, this distortions will not behave like thermal noise but it will appear as peaks, so modulated signals would appear.

As we can see, the voltage regulator will damp supply rails introduced distortions
by a factor of 10 to 20 !

The summary why to use regulators

So putting all together:

- I need a voltage of ~ 35V out of a source with 44V peak wich drops downto ~ 37V..38V under full load of 10A
- the current should not be limited below 10A
- there are no dual isolated windings on my transformer
- it would be nice to sense the rail current for limiting purposes (in software)
- using a regulated supply helps the amplifier to
  - have better PSRR , especially on the negative side [1],[2]
  - reduce rail introduced distortion and noise   [1],[2]
  - reduce rail introduced high frequency distortion and noise [1],[2]

In that dilemma, a discrete voltage regulator seems to be the only solution without having many drawbacks.
Let's see how it works and how it performs.....

Simplified Regulator function

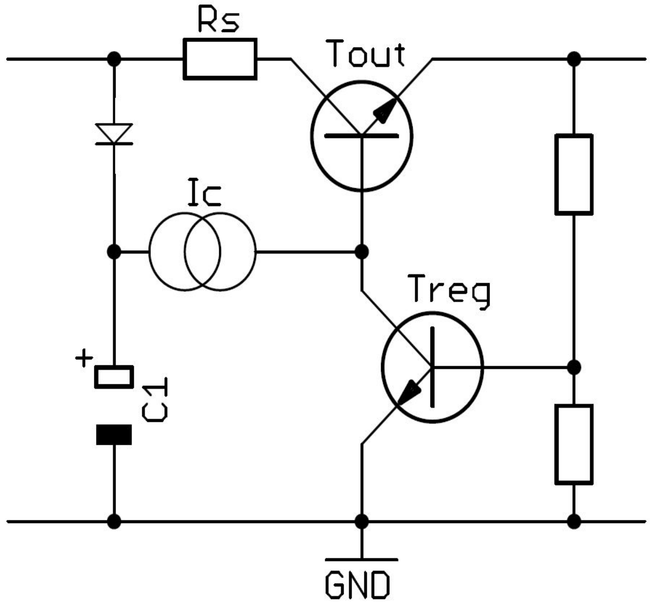

fig 11: Regulator simplified shematic

The regulator consists, in principle, of a current source (Ic), an output transistor/Tout) and a regulation element (Treg)

Treg tries to hold it's Vbe (to ~ 0.6V) by passing away more or less current of the current source, so Tout has more or less base voltage and therefore more or less voltage at its emitter.

If the output voltage is lower than Tregs Vbe, Treg will drive almost no current through it's collector, so the current source output will directly drive Tout's base and the output voltage rises.

If the output voltage is higher than Treg's Vbe, Treg´s collecor current will rise and less current from the current source will be fed to Tout's base and the output voltage decreases.

If the voltage matches Treg's Vbe, Treg's collector current will sink enough current to keep the output voltage stable.

The diode is for stopping current flowing back from C1 to the Input, in case the input voltage is lowered for a short time, e.g. between a high current output pulse and the recharge time of the main electrolytics. This helps keeping Ic's current constant and the output voltage stable.
(see PSRR discussion and rail voltages above)

Positive regulator in detail

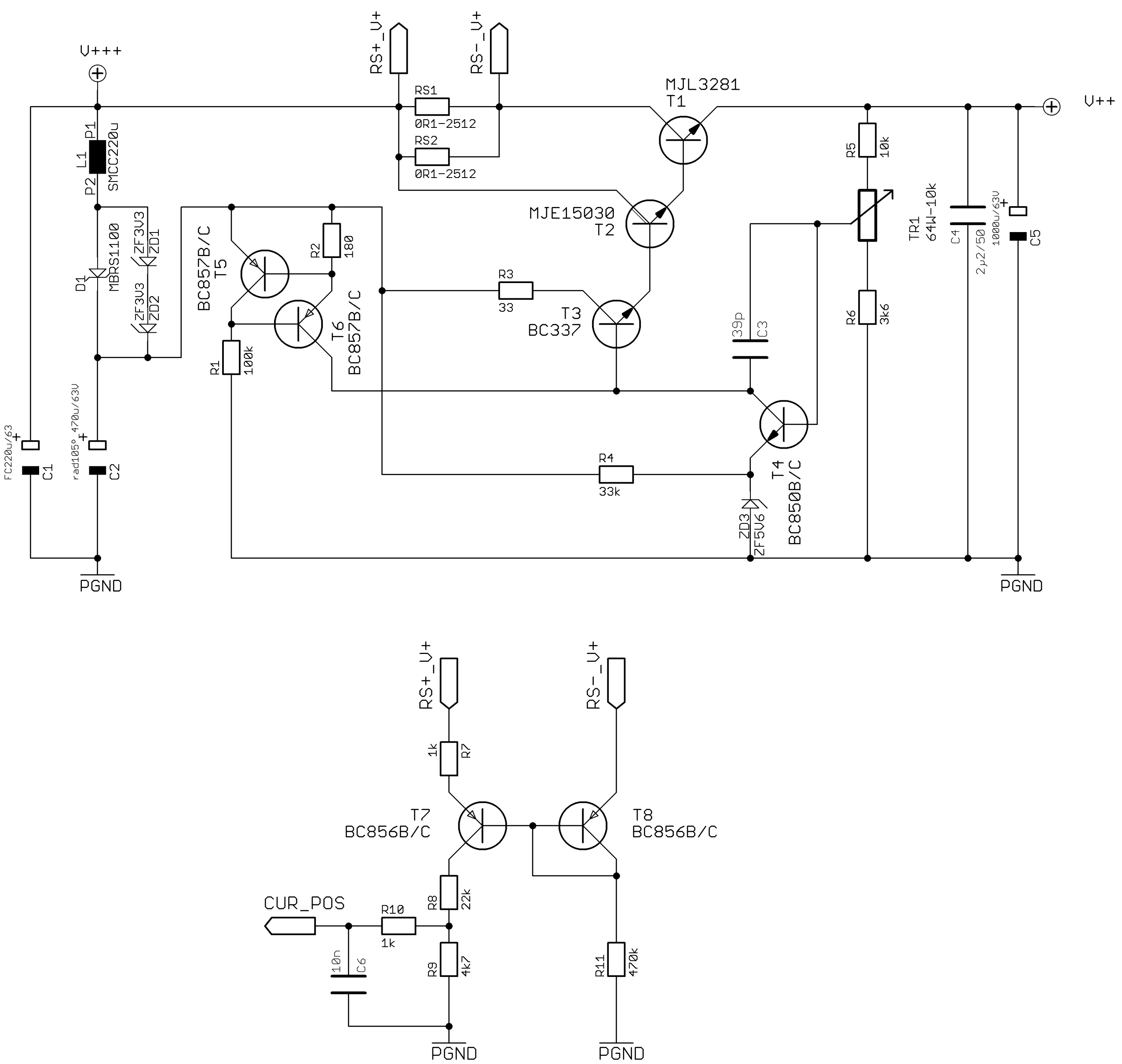

fig 12: Positive regulator schematic

Input Voltage & Current Source

C1 is the mandatory input electrolytic. It can be ommited, if the main (big) filter capacitors are not far away (< 5cm)

L1, D1 and C2 forms a buffer for the Control voltage, Drive voltage and the current source. This is the D and C2 combination of the simplified shematic.

For L1, a coil with an internal DC resistance of ~ 2-5 ohms should be used and its inductivity should be in the 100µ..470µ range.
SMCC220µ or SMCC330µ are a good choice. The inductive part of L1 damps HF input above ~ 100kHz, the internal DC resistance forms a Lowpass with C2 for frequencys above ~ 100 Hz.

Diode D1 is inserted to minimize C2 voltage drop if V+++ decreases for pulses and would be lower than V++ because of high current demand and mains zero-cross, D1 will prevent charge of C2 flowing into V+++. This keeps the drive Voltage (at the Collector) for T3 and the Current source voltage higher than V+++, at least for short intervals like the 10ms for the main transformer/rectifier.
D1 should be a shottky type for low forward voltage but with a voltage rating above V+++ maximum.

T5/T6 and R1/R2 builds the currentsource with ~ 3mA drive current Ics (Iout = VbeT5 / R2), necessary for the regulator function.

Regulator

Treg is replaced by T4 and T1,T2 and T3 forms Tout.

Also ZD3 is inserted at T4's emitter to stabilize a bit the temperature drift of a single transistor Vbe. Before ZD3's insertion, the „reference“ voltage was T4's Vbe wich would drift by 2mV/°C, wich is 0.6V / 2mV per degree = 0.3% per °C.

With ZD3, the reference voltage is Vz + Vbe and if Vz is more stable than Vbe, the total reference would also drift by 2mV/°C, but now, that's only (5.6V+0.6V) / 2mV per degree = 0.03% per °C, making temperature dependence better by a factor of 10 !

Also R4 was added to stabilize ZD3's bias current. If the output voltage would be too low, T4 would only sink a few µAs so that the Z-voltage would decrase and the regulator could go out of regulation. With R4=33k and Vin ~ 40V, approx. 1 mA is permanently drawn by ZD3 making it's Z-voltage stable over a wide input/output voltage range.

R5,R6 and TR1 forms the voltage divider for T4's base.

Power stage

T3, T2 and T1 forms an triple darlington configuration with beta > 100.000.
Rs1 & Rs2 forms a shunt to measure the output current (see later in this article).
They are not placed after T1 but in front of it, that helps in the Low Dropout case, because of it's voltage drop doesn't matter. The voltage drop of T2's C-E and T1's B-E would be in the 0.6 to 1.0V range and are therefore higher than the resistors voltage drop.

R3 is for safety only to protect T3 if the Control voltage at C2 is higher than the output voltage, else the base-emitter junction of T2,T1 would try to deliver the output current and T3 would be overloaded.

For the same reason ZD1 and ZD2 are used. They only conduct, if the voltage at C2 is ~ 6V higher than the rail voltage and discharge C2 in this event.

Building Blocks

Compensation

With low frequencys, the regulator will work without any compensation, but at high frequencys, T4 would hopelessly try to increase/decrease T3's base voltage to set the right output voltage, but T1 is so slow that it can't follow it. Oscillation would occur !

In simulation and on real hardware, the oscillations were in the 100-500kHz range.
To avoid this, C3 is inserted and makes T4 slower with rising frequency. A value of 33p-47p gives good results and there is not any spur of oscillation if C3 is inserted. The regulators gain should be fallen below 1 for freuqencies above ~ 100 kHz.
Another aspect for stable regulation is the output capacitor(s). The 2µ2 ceramic MLCC gives good results with its minimum impedance at ~ 1 Mhz, C5 is for Low Frequency stability and a reservoir for very short, high current demands.
It's value is uncritical, but should be in the 470µF...2000µF range. No special low-ESR type is necessary, in contrast a verly low ESR (<10mR) could lead to oscillation.

Current Sensing

T7 and T8 form a current mirror with R7,R8,R9,R11; R10 and C6 forms a lowpass to supress current spikes.
The voltage at C6 is almost linear to the output current. There exist a small offset, but it's neglible. See measurement results, how it performs.

Current sensing was implemented to be able for a microcontroller to measure positive and negative currents. The software can than handle short time overcurrent (e.g. shortcircuit of the output) and long time events (e.g. protect the mains transformer in overload condition for several seconds)

There is no overcurrent protection in this regulator, beacuse it will be used with integrated amplifiers, wich have their own internal current limit, e.g. the LM3886 limits to max. 7.5A current per device. This would give ~ 22A if 3 devices are paralleled. This current can be handled (for a short time) by the regulator and also by the rectifier and the transformer. Also a microcontroller will observe currents and will mute the amplifier if it detects an overcurrent or a long time high current loading. The micro cannot react that fast, but 10ms schould be in a range were no component will be destroyed.

If even higher currents should occur, a blowing fuse before the rectifiers and one after the electrolytics should prevent permanent damage.

For the neagtive regulator, see end of file.

Used parts, mechanical issues and Layout

All parts must be selected, so that their voltage and power rating are not violated, not even for a short period of time.

Part types written in the shematic are usable for up to 63V input and 10A continous / 15A peak output current

R51/R52 should be 3W types at minimum, SMD resistors are preffered (almost non-inductive). 3W types are suitable for continous output currents of 10A and 15A for a limited period of time (~ 20-50ms)

T1 should be a transistor with almost no beta drop for a given peak output current. It must also be capable to withstand the peak current, the peak voltage at input and it's wasted power of (Vin-Vout)*Iout. The given type(s) are usable for 15-20Apk and 10A continous.

T2 must be selected for voltage rating and Power and it must be capable of driving T1 even at high output currents (T1 beta can drop at high currents).

The given type(s) are usable for 15-20Apk and 10A continous.

T1 must be mounted on a big heatsink because of it's high power dissapation.

The size of the heatsink for T2 depends on the average output current, but a small heatsink (10K/W...20K/W) should be enough in normal cases.

T7 and T8 can be any small signal resistor but should be the same type and same hfe class (the A,B,C denotes the hfe class, see datasheet). Mount them physical near to each other to lower temperature differences. This makes the current mirror more linear.

The MJW1302 (PNP, TO47) can be replaced by MJL1302 (PNP, TO264) and the MJW3281 (NPN, TO47) can be replaced by MJW3281 (NPN, TO264)

Power Dissapation

The reader may think, a linear voltage regulator would dissapate much heat. He's right, it does, but....

…. all the rail voltage wich is transformed to heat by the regulator would else be dissapated by the Amplifier Power Stage.

So, total power dissapation wouldn't change and mounting the regulators Power device on the same heatsink as the Power devices wouldn't create extra heat. Also this has the advantage that less power is dissapated in the Amplifier Power devices itself and as they are integrated (as mentioned earlier), less problems with heat transfer between inside the package and the heatsink will occur.

Also, in normal cases, the voltage differential is small like 3V..6V in idle case and drops to 1V..2V by high currents, the power dissapated in the regulators Power Transistor wouldn't overload it and you can go with a single device.

Simulation showed, that even if the input is a DC source without voltage drops (and they will occur in real life), you have a 6V differential and you load the amplifier with 3 ohms speaker and continously sine wave with 30Vpk, the dissapated power will be in the 35 Watt range with 55W peak.

More realistic simulations with Vin = 42V max and 38V min, Regualtor output = 35V, Amplifier output = 30Vpk and 3 ohms load and continously driven by a sinewave showed, that the dissapated power in the regulators Power Transistor is 30Wrms and 65W peak.

But driving the Amplifier output in that way, the amplifier devices would dissapate 83W (see [3] for this topic) and going with a normal sized heatsink in the 0.5 K/W range, it would heat up to 40°C above ambient after a short time.... too much for outside a case.

But a good rule of thumb is, that music has a power factor of ~ 1/8, so the 30V and 10A only occurs 1/8 of time; if you pull the volume shortly before clippping.. even on a hot party at home, you wouldn't here music at that levels.

Normal listening levels are in the 1W..5W range (depends on speaker, your ears, your neighbours and your wife .-), so having 6Vpk and 1.5A at your speaker terminals would be the upper limit on normal use.....

Preparations

Bipolar Test Power Supply

If you want to build an amplifier or a voltage regulator with high voltage and currents, you need waht ? Right, a source to test it.

Going the standard way using a transformer, a rectifier, electrolytics and some fuses will end up in frustrated changing the fuses very often.

So what can we do, if we also want current liming, voltage preset and power limiting ? My solution was not to buy a professional one, because the prices are very high in the +/-50V/10A league... I used an old power amplifier and removed all internal stuff, beside the transformer, the rectifier and the heatsink. Then I add the voltage regulators described here and modified them a bit.

First, for low output voltages, the regulators must be capable to dissapate a huge amount of power, so I used two output transistors in parallel.

Second, a microcontroller was added wich function is to measure the current (via the current mirrors as described) and estimate the power the transformer has delivered the last 2 seconds. Looking on the transformer, it could be seen, that it is capable of roughly 100Ws, so delivering 200W for 2 seconds or even 400W for one second wouldn't kill him.

The micro measure the positive and the negative current and adds them up. If the total power mutliplied by time is greater than 400W*sec or greater than 100W for 10s, it will disable the supply. Beside this task, it also drive the fan speed dependent on measured heatsink temperature (added to keep the heatsink cool). It fits into a SO8 package and programming was done in some hours. For usability, additional Volt and amperemeters were added. The current is limited by a rotary switch with the setteings 1A, 2A, 4A and 9A.

As the supply works with low loads, the next problem arised... how to test high currents if there is only limited time to do that (because of the transformer protection) ?

Bipolar pulsed test current generator

If there is only a limited time window for test and also your test resistors can't handle the power over a long time you must use pulses instead of DC levels.So the current pulser was build. It has neither a case nor a layout, it's build up on a breadboard !

All what's necessary for it are a FET per supply (one for neg., one for pos.), the pulse generator and the FET driver.

The pulse generator was done in a micro (micros are wonderfull for this small tasks. You can change almost all things on a computer without a soldering iron!). It generates fixed frames of 20ms, where the ON-Time can be set by a potentiometer and the OFF-Time is the rest of the frame. So you can set pulses from ~ 0.5ms ON/19.5ms OFF up to 19ms ON / 1ms OFF. While testing, I found out, that using ~ 1ms ON Time is minimum to have time that all stuff can settle a bit and see usefull stuff on the scope.

The driving unit can be connected via an connector either to the positive or the negative FET. So it's possible to generate pulse for positive voltages and for negative ones. It's worth much to have the GND at the same place in both combinations, so you can use a ground/earth referenced scope. Unfortunately, you can't use both sites simultanously, but that doesn't matter in this application.

Now you can connect resistors between V+/V- an the FET drains wich are then pulld down/up to GND.

Let me add a word (or two) about the test resistors. Resistors are specified for a maximum load in the datasheet. That's the long time DC power the device can handle. But most datasheets says nothing about the short time capability, even big and well known manufactures do not. So at this point you must be a bit carefull with assumptions, because of theoreticly if the power is applied only 1/10 of time, the dissapated power should be ten time the DC power... but it isn't. Even short overloads in the µs and ms range can destroy the device by melt away wires or films. But life showed, that two or three times the rated power wouldn't hurt the resistor and you also didn't use that devices for hours over hours for testing. But it isn't a bad idea to measure the resistance from time to time.

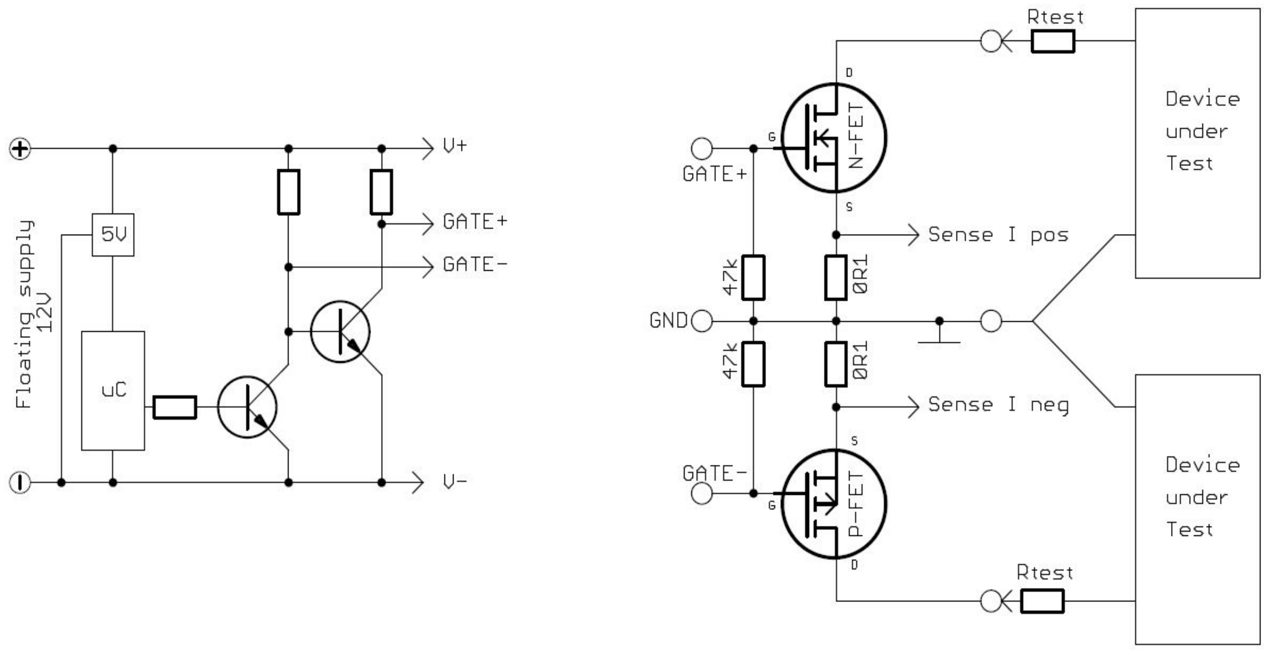

fig 13: Bipolar supply tester schematic

In case of testing positive DUT's (DeviceUnderTest), the floating supply (-) must be connected to GND and the Gate (+) signal to Gate (+).

In case of testing negative DUT's (DeviceUnderTest), the floating supply (+) must be connected to GND and the Gate (-) signal to Gate (-).

Performance

Design goals

- Output voltage: 35V
- Input voltage 38V .. 45V and 63Vpk. Short drops downto 36V and shorter than 10ms should **not** degrade regulation
- Output current > 10A

Test signals

DC:

using reistors, permanently connected to the regulators wich draws the desired current up to 4A

or

using reistors, connected to the regulators by the current pulser wich draws the desired current up to 12A/15A

AC:

a single 60Hz sine pulse with 100ms silence afterwards was created as wav file and then repeated played through a load amplifier wich draws it's current from the regulators to be tested. A single pulse was used because of the testsupply wasn't capable of delivering the necesary power for continous signals with that current demand.

Regulator

The regulator was trimmed for 35V DC at output and then measurements were taken.

There was a neglible temperature drift, wich result in less than 100mV output voltage change over a 10°C to 80°C temperature range.

Output current

Output currents up to 4A continous (DC) and 15A pulsed (5ms ON) were tested with Vin=42V and Vout=35V and the output drops less than 10mV.

Output currents up to 12A peak (AC 60Hz, single pulse) were tested and the regulators outputs were monitored with an oscilloscope.

No problems were observed regarding Output current steps or oscillations. The voltage dropped less then 10mV for up to 12A output current

with regulated 41V DC IN and 35V at the regulators output

Dropout

The dropout voltage was tested in the following way:

Test 1 (DC):

- set output to fixed 35V
- generate pulses with 60Hz (see above) so that a desired output current of the amplifier will flow (30Vpk/Rl=4R → 7.5Apk for test)
- set DC Input voltage so, that the regulator will start to drop ~ 100mV at the peak current

The input voltage was reduced down to 38.3V until Vout dropped by 100mV.

The dropout voltage in the static case will be ~ 3.4V when using a regulated DC input voltage.

Test 2 (AC):

- set output to fixed 35V
- generate pulses with 60Hz (see above) so that a desired output current of the amplifier will flow (30Vpk/Rl=4R → 7.5Apk for test)
- add 1.0 Ohms of series resistance in front of testing filter caps (10.000µF each) to simulate the transformer *1
- set Input voltage so, that the regulator will start not to be able to supply 35V (output voltage dropping by ~ 100mV) if the test filter caps start generating voltage drop. This will test the capability of short time regulation out of C2.

The input voltage was 39V when idle and dropped down to 36V at peak output current, while Vout dropped only by 100mV.

The pulsed droput voltage would be 36V-34,9V= ~ 1.1V.

Stability

With using C3=33pF, no instabilitys could be observed, even not if supplying 40Vdc + 100mV/100kHz DC and 10A output current.
The 100kHz were supressed by ~ 20dB. This was tested in simulation and with real hardware.
In real hardware, the 100kHz came from an uncompensated Powersupply wich produces ringing with changing output currents wich was in the 100kHz/100mV range.

*1: The value of 1 ohms was used so that a realistic voltage drop occurs. Normal transformer,rectifier, electrolytics combinations will have lower impedance in the 0.1 to 0.5 ohms range.

Current sense

Current sense was tested with regulated DC 40V IN and 35V OUT and resistive load, continous connected for currents up to 4A, pulsed if higher.

Offset was in the 160mV..165mV range.

Positive regulator: Output was 145mV/A at 0.25A to 180mV/A at 15A output current.

Negative regulator: Output was 150mV/A at 0.25A to 175mV/A at 15A output current.

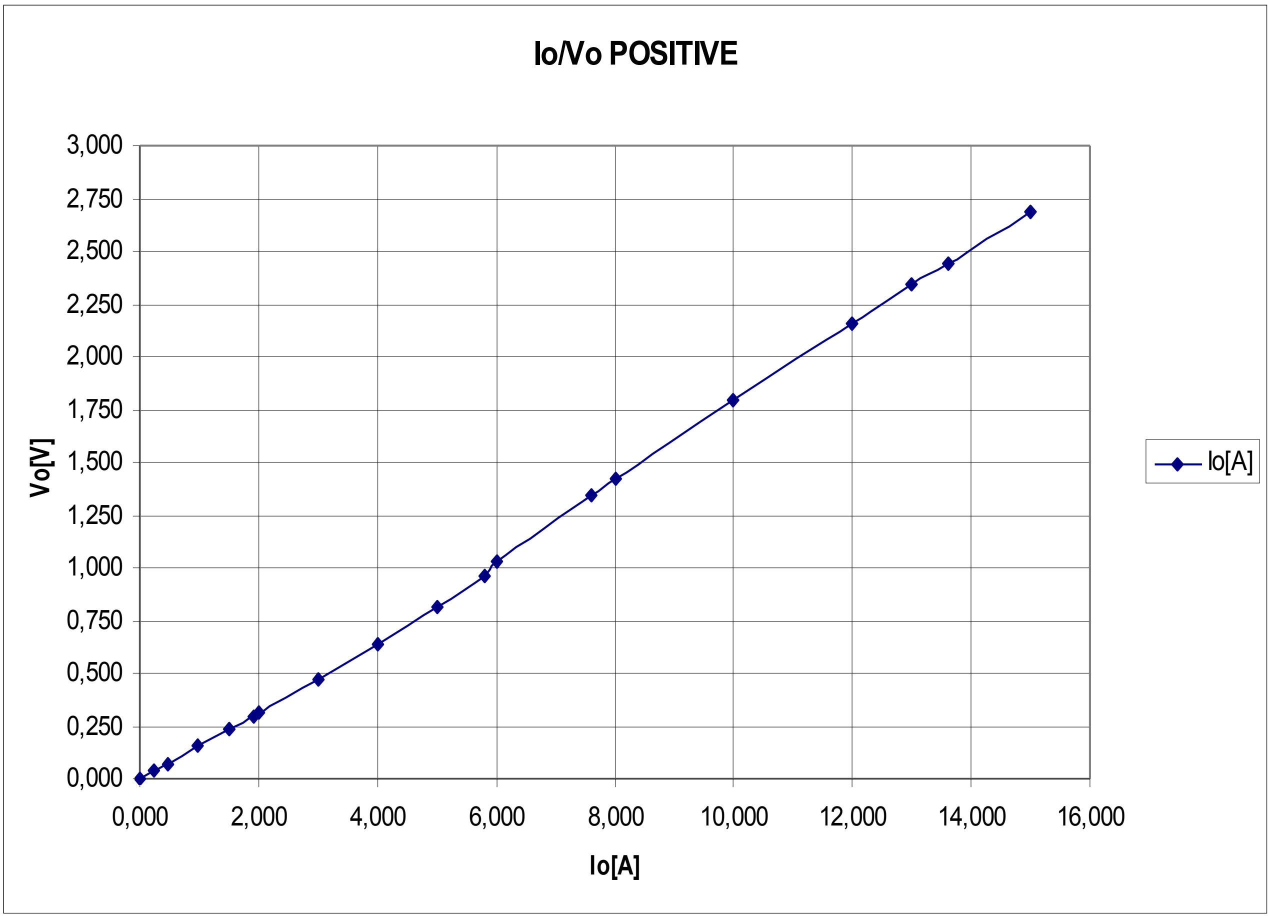

fig 14: Positive current sense

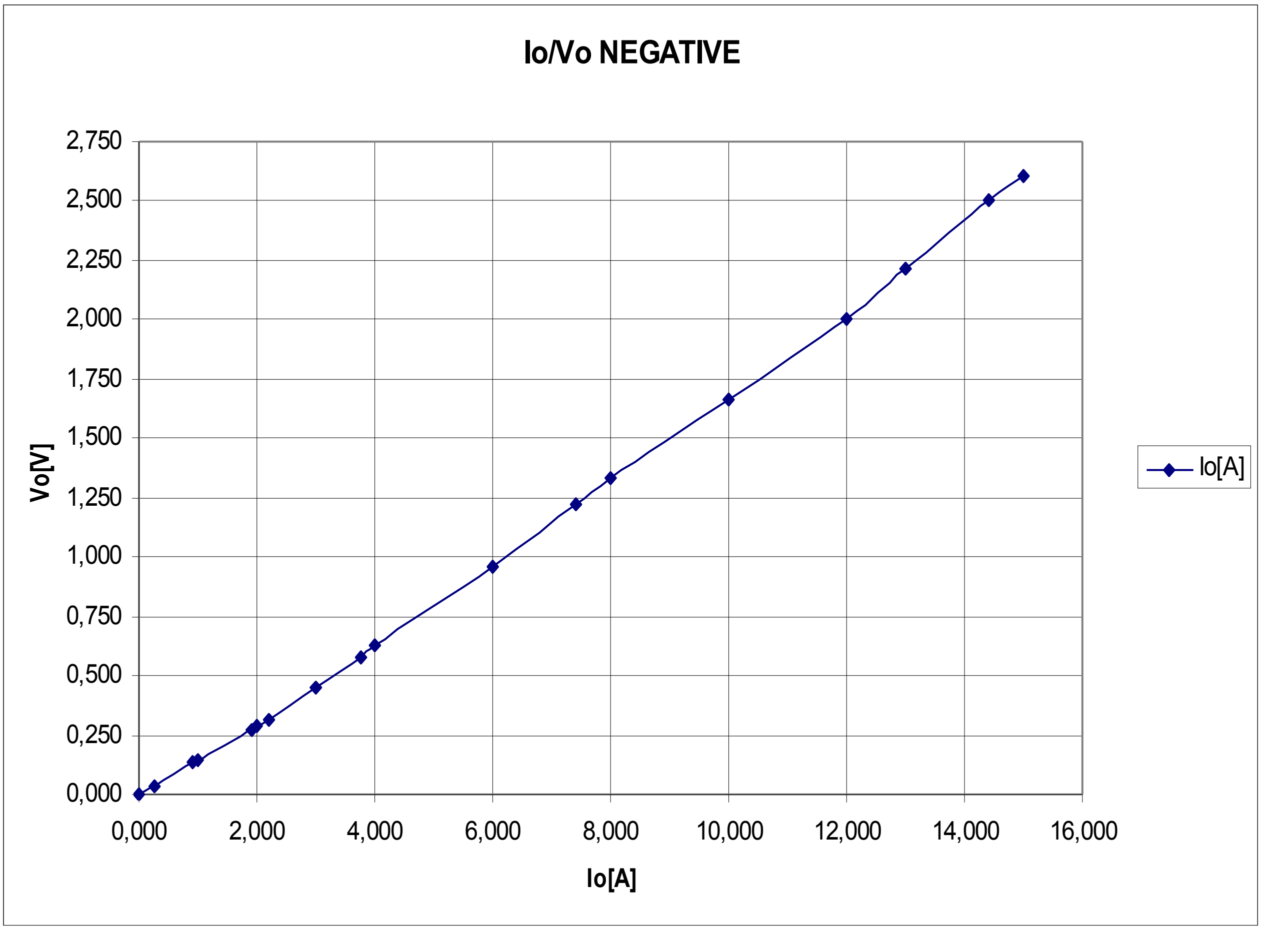

fig 15: Negative current sense

For the purpose of limiting peak currents and to limit long-time output current, this sheme is more than usefull.

Using a 10-Bit ADC and Vref=5V, this results are better than necessary.

Conclusion:

Using a voltage regulator for Audio Power Amplifier helps much with PSRR issues, rail introduced distortions and high-frequency ripple and noise.

The designed discrete voltage regulators have a medium dropout voltage of 3.4V in DC and 1.1V in AC case (see tests described earlier).

It has the advantage of beeing capable of high currents and voltages and can be introduced without opening the GND connection in existing designs.

The used parts are not that costly and in most cases they should be cheaper than a single high current voltage regulator.

As little candy, the amplifiers positive and negative input currents can be measured and used in a microcontroller to make further protections than possible in hardware only based designs.

Testing and usage

Before making a PCB and soldering the stuff together, try to run a simulation. A simulation file for TI-TINA is available for download.
Because of there is no current limit in this circuits, exess draw of current must be avoided or a current limited supply must be used.
The output transistor must be mounted on a heatsink, also at low output currents.
Input voltage or output current above the limits can destroy devices or degrade them.
Before connecting and powering sensitive circuits from this regulator, the output voltage must be checked.
Do not use a breadboard for this circuit. A single sided PCB guarantees short tracks, low inductance and small loops. A double sided PCB is recommended. Don't rely on copper traces alone with high currents. Make tracks carrieing high currents wider by using copper wire soldered on the tracks. Make vias carrieing high currents big in hole size and solder a piece of wire through it.
Copper isn't a superconductor, so connections on a PCB should be made, where they should be.
GND connection for the feedback divider and reference voltage should be seperated from the electrolytic's GND connection. Use an additional PCB track for it.
Connect the Vout end of the feedback divider to the point, where the voltage should be regulated. Avoid long traces and loops !
Don't replace parts of this circuits or change it values for cost or prestige reason without having knowlege about their function and parameters (escpecially the power transistors and the capacitors).

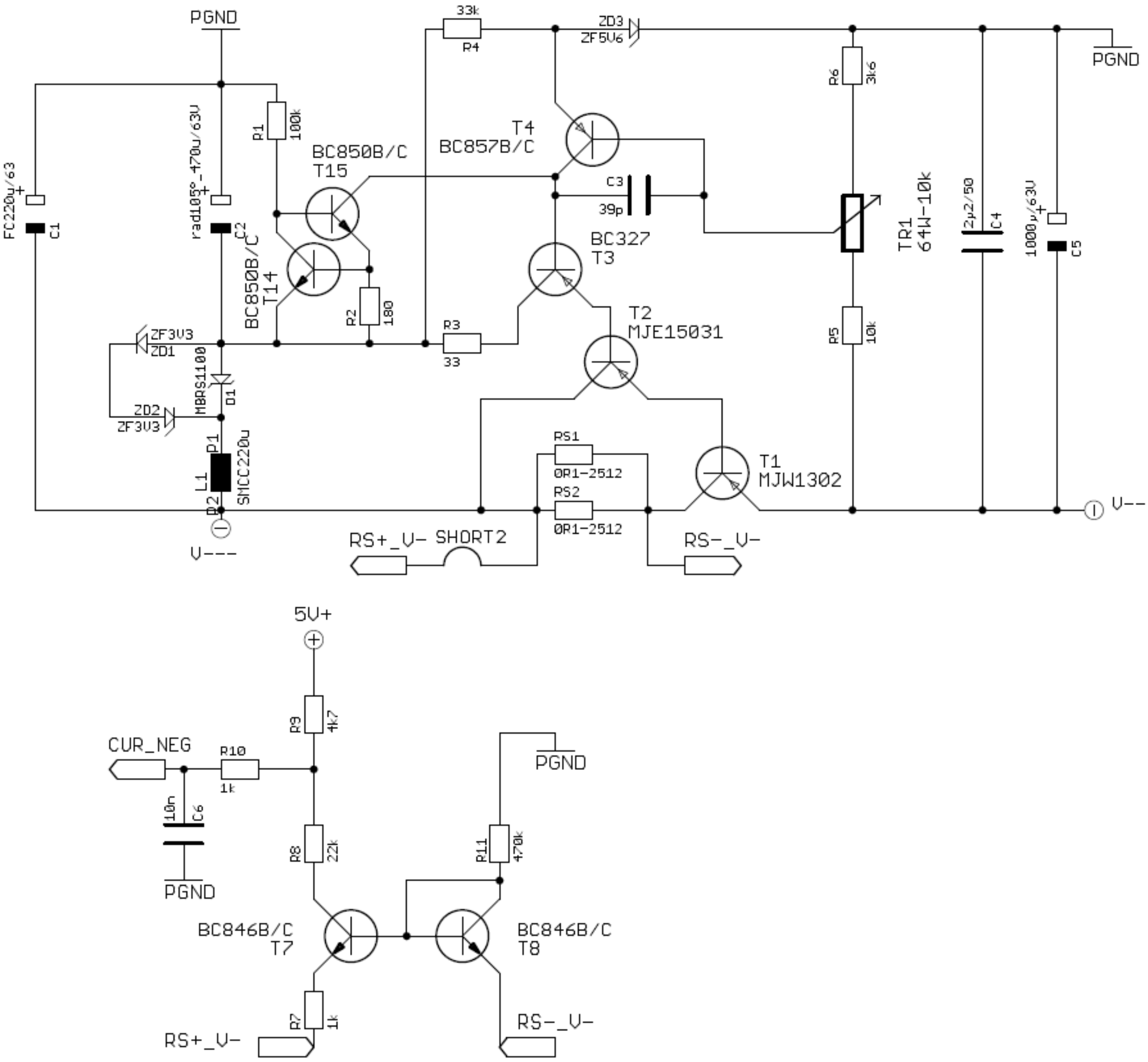

fig 16: Negative regulator

[1] *D.Self, Audio Power Amplifier Design Handbook*
[2] There exist many application notes, freely available on this topics. e.g. Analog Devices, TI/NationalSemi and others
[3] LM3886 datasheet, formerly NationalSemi, now Ti