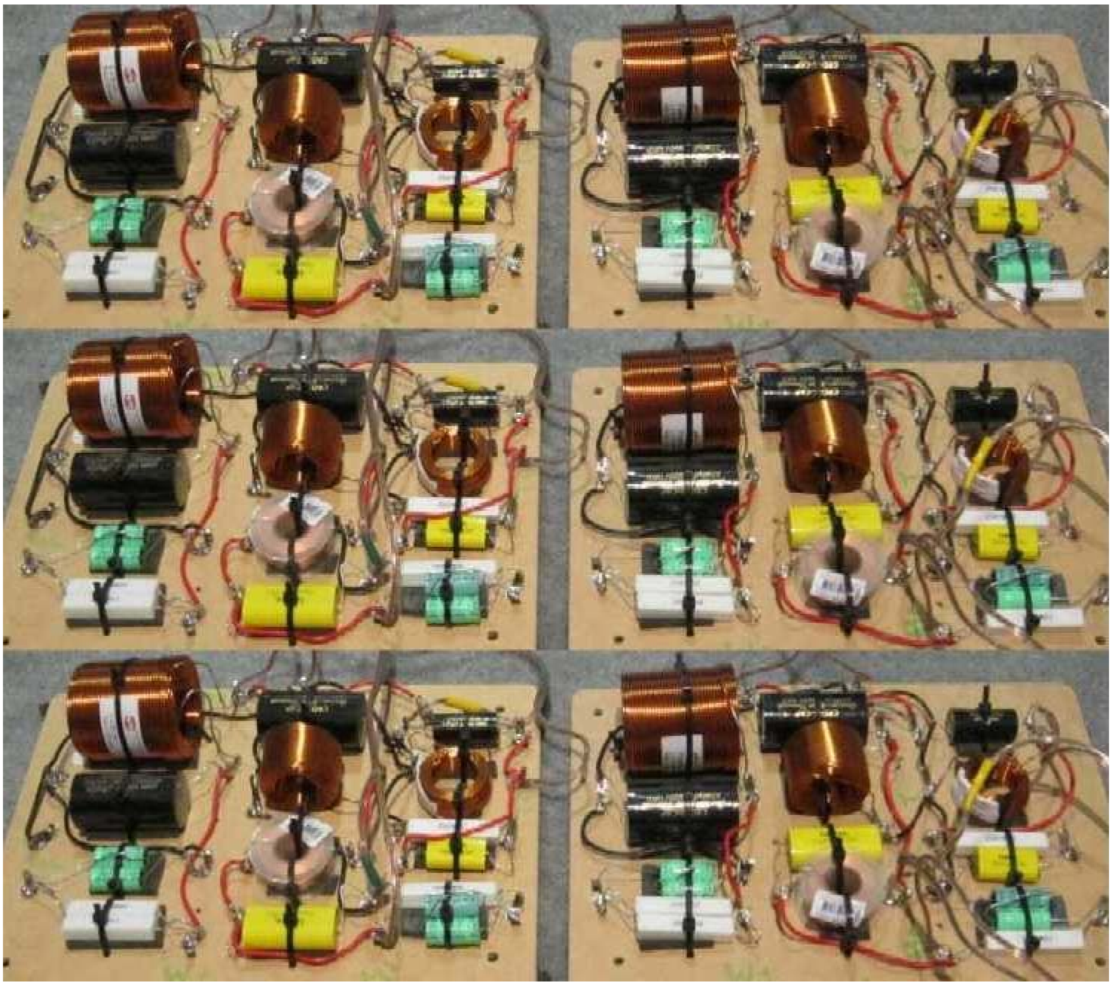
Power amplification – Concept Development

The overall purpose of this project is to replace 6in/18out device shown below……



With 6in/16out device shown below and capable of so much more…..

Part of the transformation, involves multi-channel amplification process. Here is just one option out of many.

There is obviously a number of ways one can provide adequate amplification power for a 5.2HT system. There are several types of amplifiers (class AB, PWM-type, and so on…) available on the market today, and it is well advised to conduct a thorough research before deciding on a solution, that fits the budget and meets the technical requirements.

I have settled for a very old-fashioned solution. I use several class AB modules, available from my local electronic stores. I did not want to deal with the design and making of PCBs and I preferred to perform some design modifications of the commercial amplifier modules if I need to do this. In Australia the popular suppliers are: http://www.jaycar.com.au and http://www.altronics.com.au however, Parts Express http://www.parts-express.com is possibly the best supplier world-wide. All parts are readily available and easily replaceable. The design of the modules is very straightforward, and the assembly can be executed by medium-level electronic enthusiast.

Before deciding on the technical specifics of the amplifier modules, I needed to run some rudimentary SPL analysis of what is actually required for the output power. The analysis is rudimentary, as it does not include SPL variation with listening distance and direct vs. reverberated SPL sound in the room.

Audio power required for subwoofer

THX requirements advocate 115dB SPL for subwoofer. Here is a simple SPL budget for subwoofers.

- Baseline sensitivity 90dB/1W/1m
- Amplifier power =180W, so now SPL = 112.5dB.
- There are two subwoofers, so SPL goes up by 3dB, now SPL = 115.5dB
- Corner placement will add another 9dB, so the SPL is now 124.5dB.
- I need to subtract 7dB for optimal equalization, extending F3dB to 15Hz.
- The final SPL is 124.5dB – 7dB = 117.5dB. This is excellent. We have 2.5dB margin.

Audio power required for front left/right/centre speakers

THX requirements advocate 105dB for the front speakers. Here is the SPL budget for front speakers.

- Baseline sensitivity 90dB/1W/1m
- Amplifier power = 100W, that is 50W per driver, so now SPL is 107dB.
- There are two woofers in each box, and they also combine power by mutual impedance mechanism. The gain is 6dB. Now the total SPL is 113dB.
- I have now up to 8dB spare for EQ purposes. This will come very handy, as I will be able to extend low-end frequency response using the 8dB headroom.
- This will be a 2-way system, and tweeter will be powered from a separate 50W module. It is estimated, that the tweeter will not require more than 5-10W of actual audio power.

Audio power required for rear left/right speakers

THX requirements advocate 105dB for the rear speakers. Here is the SPL budget for rear speakers.

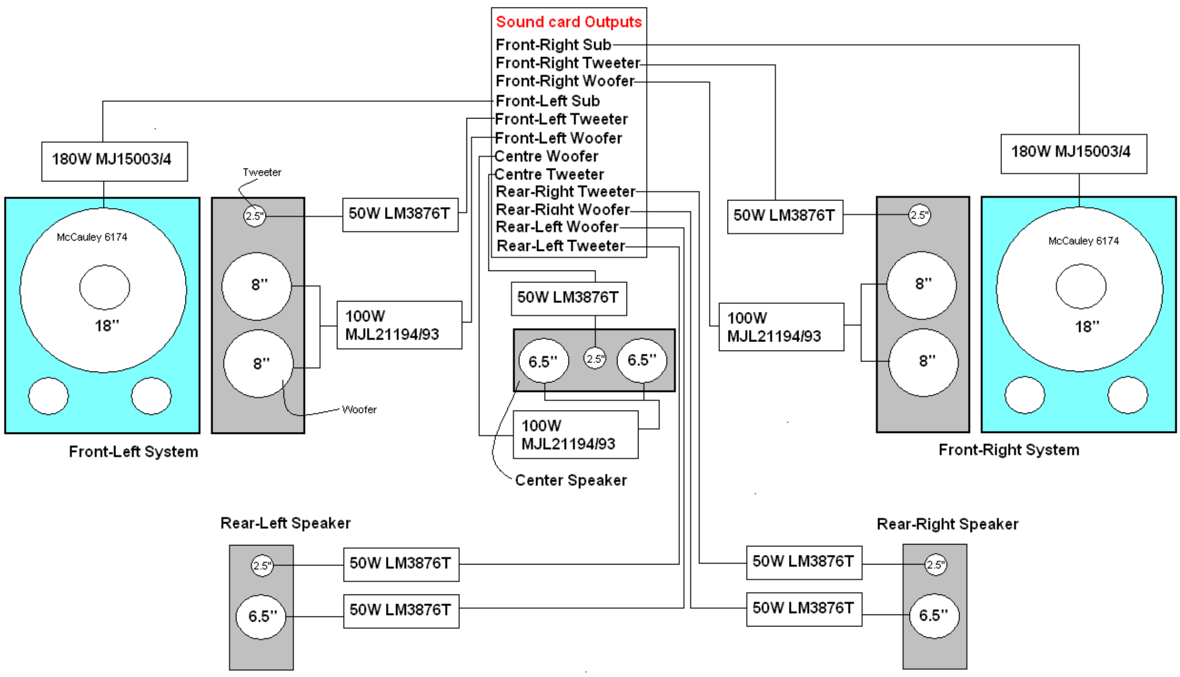
- Baseline sensitivity 90dB/1W/1m
- Amplifier power = 50W, so now SPL is 107dB.
- I have now up to 2.5dB spare for EQ purposes. This will come very handy, as I will be able to slightly extend low-end frequency response using the 2.5dB headroom.
- This will be a 2-way system, and tweeter will be powered from a separate 50W module. It is estimated, that the tweeter will not require more than 5-10W of actual audio power.

Obviously, the above are estimates only, but very useful in understanding the total power distribution requirements.

In summary:

- Two subwoofers – 180W/8ohm amplifier per subwoofer box.
- All front speakers – 100W/4ohm (woofers) and 50W/8ohm (tweeters) per box.
- All rear speakers – 50W/8ohm (woofers) and 50W/8ohm (tweeters) per box.

I will need two 180W/8ohm amplifier modules, three 100W/4ohm amplifier modules, and seven 50W/8ohm amplifier modules - see conceptual picture below.



It may be beneficial to use all woofers in front and rear speakers as 8” drivers. This may enable you to get better low-end response in the centre and rear speakers and get better quantity discounts from your supplier.

There are two enclosures, housing all amplifier modules. The two subwoofer amplifier modules are housed in their own, separate enclosure with large heat-sinks, and it’s own power supply.

All other modules 50W (7 of them) and 100W (3 of them) modules are housed in a matching-size, separate enclosure.

On the surface, it looks like there is a need for three different power supplies to secure adequate voltage and currents for all different modules. However, a possibility of using only two power supplies should be considered. If it works, the savings will be substantial, as we may only need one power transformer, smaller set of electrolytic capacitors, single bridge rectifier, etc…

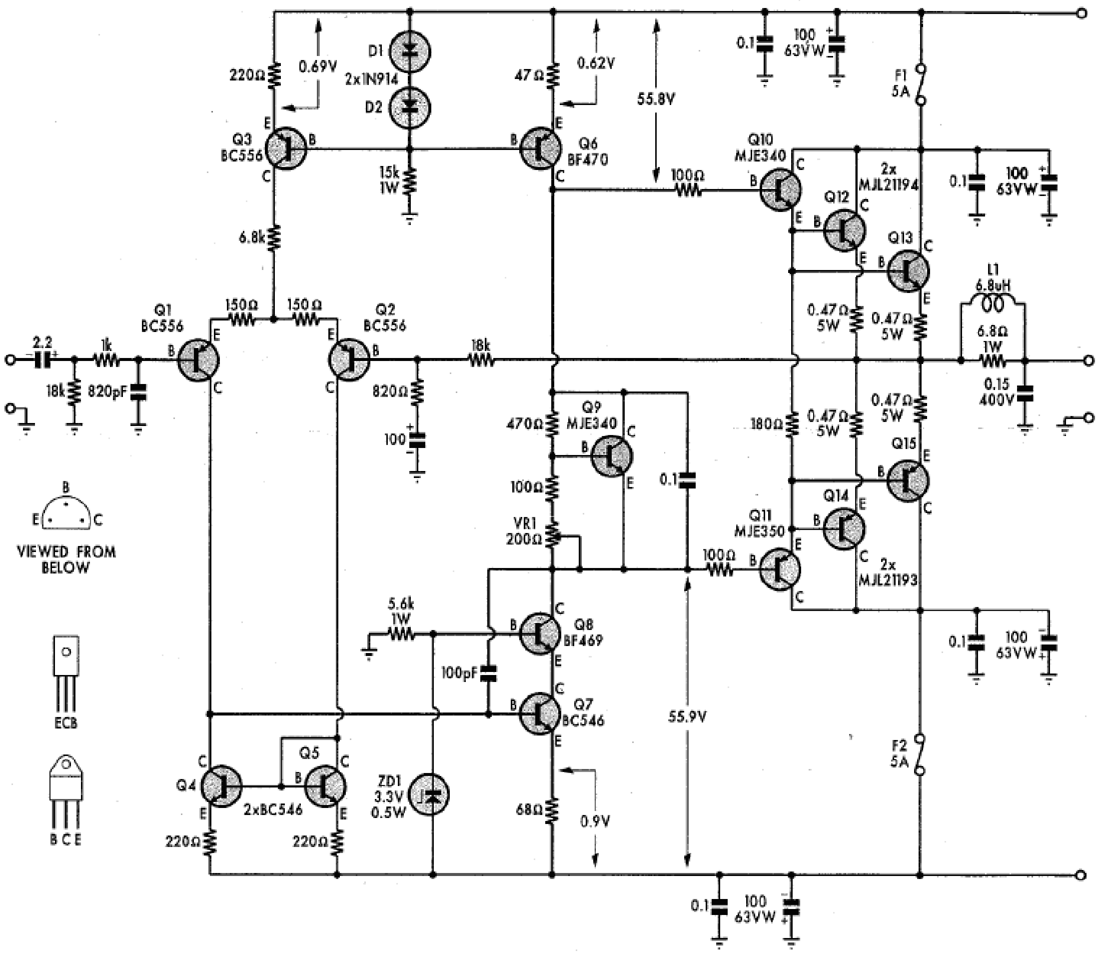
The savings come from combining power supply for 100W/4ohm and 50W/8ohm modules. A single, 500VA toroidal transformer with 2x30V secondary voltages will deliver 30*1.41 – 0.7V = + / - 41.6V DC. This voltage is on the high-side of LM3876 amplifier module capabilities, but still can be used for 50W/8ohm requirements. The same 41.6 DC voltage will power the 100W/4ohm modules.

Assuming power requirement for tweeters is 7W per tweeter (max), then all 5 tweeters will require 35W. Power requirement for two rear woofers is 100W total, and power requirement for all front woofers is 300W total. Therefore, total power requirement from the power supply is 300W + 100W + 35W = 435W. Our 500VA power transformer should be able to handle this amount of power required.

I have estimated, that by combining the two power supplies into one, it is possible to save $50-60, and a lot of real-estate inside the enclosure.

100Watt Power Amplifier Modules (3 modules)

Kit KC5201 from Jaycar Electronics, Melbourne Australia.



There are 3 x 100W modules used in this project. All 3x2 front woofer are powered via these modules. Power supply delivers about +/- 41.6 volts to all modules.

Gain adjustment is performed by setting the ratio of feedback resistors: 820ohm and 18k between.

The 3dB low-end cut-off frequency is set by input capacitor 2.2uF and resistor 18k, and also feedback resistor 820ohm and 100uF capacitor.

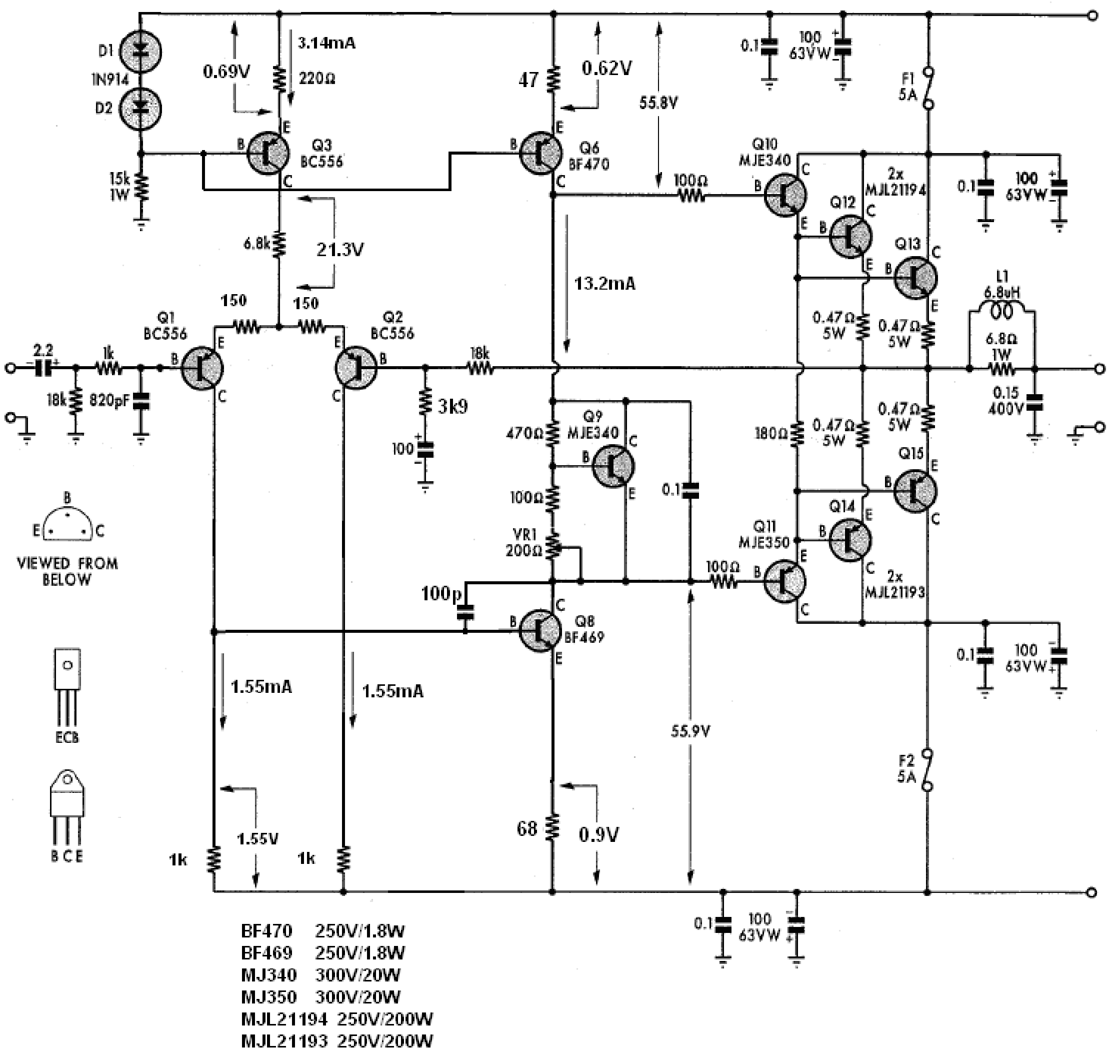
The output power is easily controlled by supply rail voltage. VR1 is used to adjust idle current of the output transistors.

Open Loop Gain a Problem in 100W module?

The original amplifier (as shown above) incorporates cascade stage consisting of Q8 and Q7, where Q8 operates in “grounded base” configuration. Such design, as claimed by the inventors, has improved linearity, gain and bandwidth. Perhaps even too much of a good thing?.

This is because, I have found, that such combination leads to high frequency instabilities. The amplifier would heat-up, and start to oscillate, after which even removal of the input signal would not extinguish the oscillations, and the amplifier would continue to oscillate and heat up.

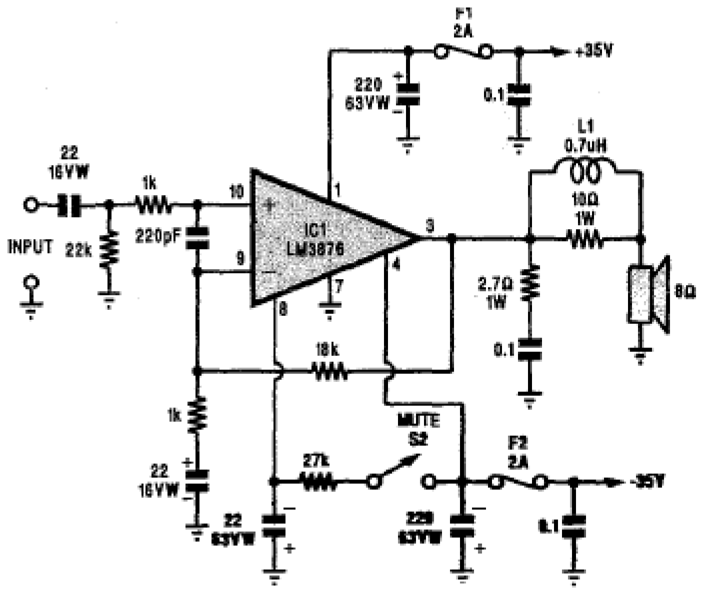
Modified circuit with the Q4 (current source) and Q5 removed and replaced by fixed resistors, and the cascade stage replaced by a standard common-emitter configuration of Q8 has reduced the OL gain and fixed this problem – see circuit below.



Modified amplifier (shown above) works very well and, when used with supply voltage of +/-41V and appropriate heat-sink, will deliver 72Vpp voltage at the onset of clipping (measured on the bench). This equals to 25.5Vrms and therefore it is 160W into 4 ohms. However, with the gain of 5.6 and maximum sound card output of 10Vpp, the power output is set to 100W into 4 ohms. The design goal has been achieved.

50Watt Power Amplifier Modules (7 modules)

Kit KC5150 from Jaycar Electronics, Melbourne Australia.



There are 7 x 50W modules used in this project. All 5 tweeters and 2 rear mid-woofer are powered via these modules. Power supply delivers about +/- 41.6 volts to all modules.

The modules are quite suitable for powering tweeters directly, as the modules do not exhibit a turn-on/turn-off “thumps”.

Gain adjustment is performed by setting the ratio of feedback resistors: 1k from pin 9 and 18k between pin 3 and 9.

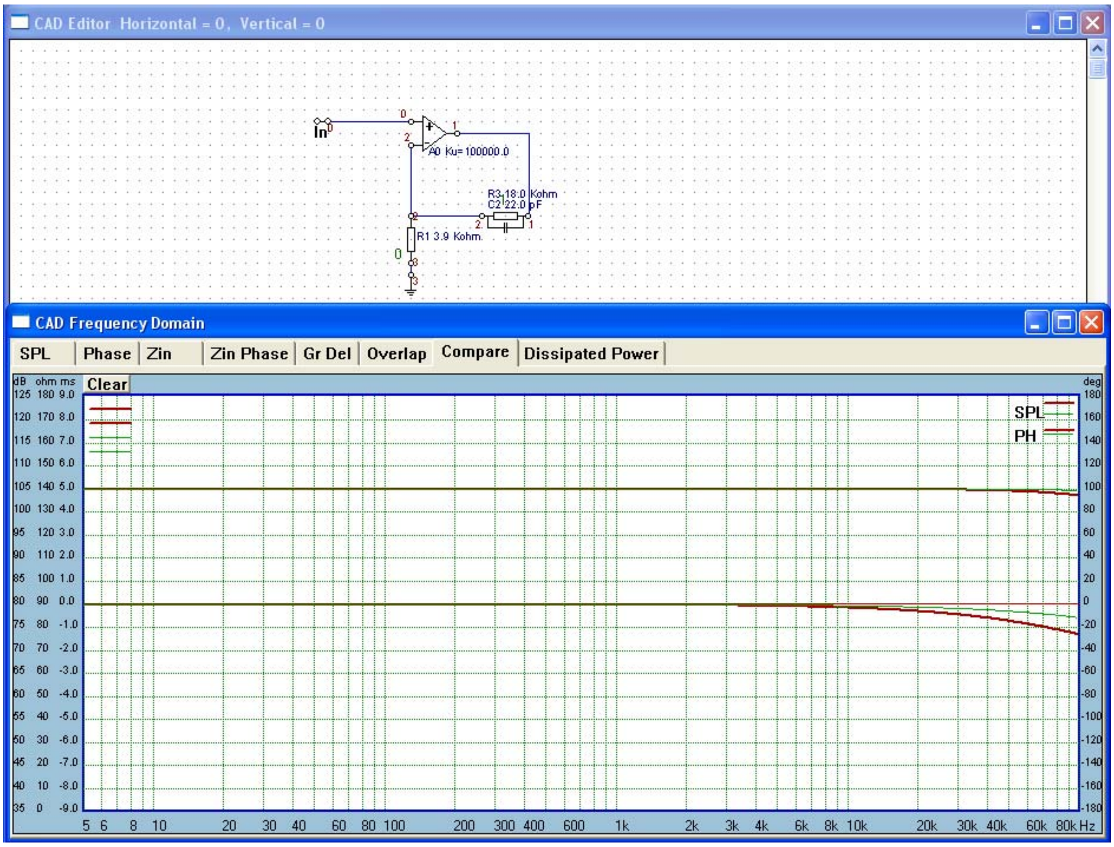
The 3dB low-end cut-off frequency is set by input capacitor 22uF and resistor 22k, and also feedback resistor 1k and 22uF capacitor.

The modules are very easy to assemble, and they work straight away, with no adjustments necessary.

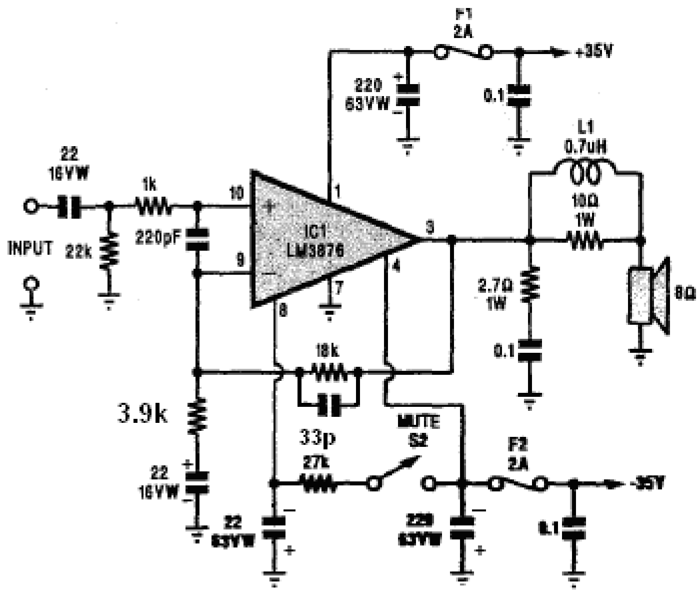
Corrections to 50W/8ohm Module

By changing 1kohm feedback resistor to 3.9kohm, amplifier’s gain has been adjusted to 5.6 or 15dB. Also a small capacitor of 33pF was added in-parallel the 18kohm feedback resistor to assist in suppressing parasitic oscillations.

Green curves – SPL and phase with C = 22pF, Brown curves – SPL and phase with C = 56pF



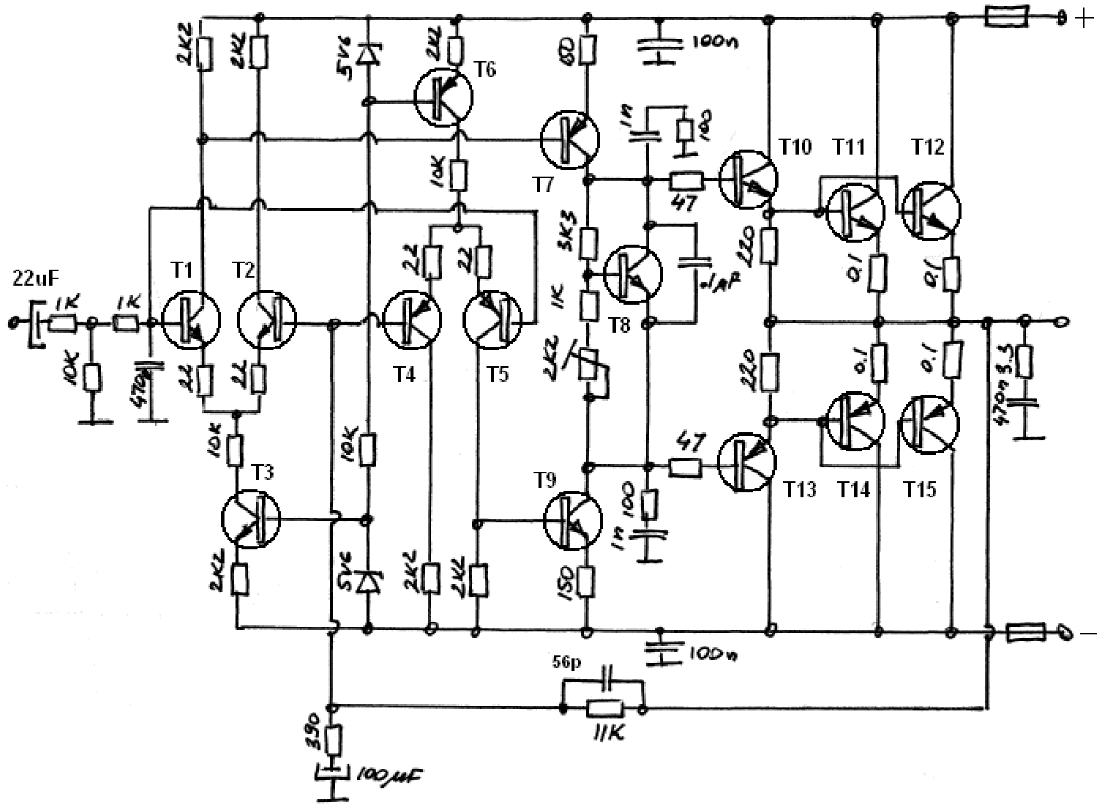
Corrected circuit is shown below. Mute switch is normally closed.



180 Watt Subwoofer Amplifier (2 modules)

This is a "symmetrical" design from input to output type of amplifier. It is my own amplifier design I built about 20 years ago and it has been working very well ever since. It has been refurbished and I also have beefed-up electrolytic capacitors and use 2 x 300VA toroidal transformers in the power supply. DC supply voltage is +/-56V. Quite reasonable amplifier for each 18" McCauley subwoofer. I would suggest using complimentary pair of Motorola MJ15003/MJ15004 transistors in the outputs stage.

T1,T2,T3 = BC546
T4,T5,T6 = BC556
T7,T13 = BD140
T8,T9,T10 = BD139
T11,T12 = MJ15003
T14,T15 = MJ15004

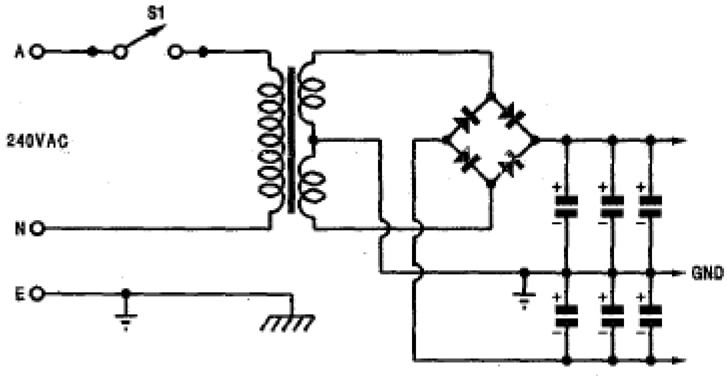


There are 2 modules of 180W amplifiers in the system. The output power is easily controlled by supply rail voltage. VR1 is used to adjust idle current of the output transistors to 25mA.

These modules are housed in a separate enclosure, that is of the same size and look as the 10-channel amplifier, so they now constitute a "matching pair".

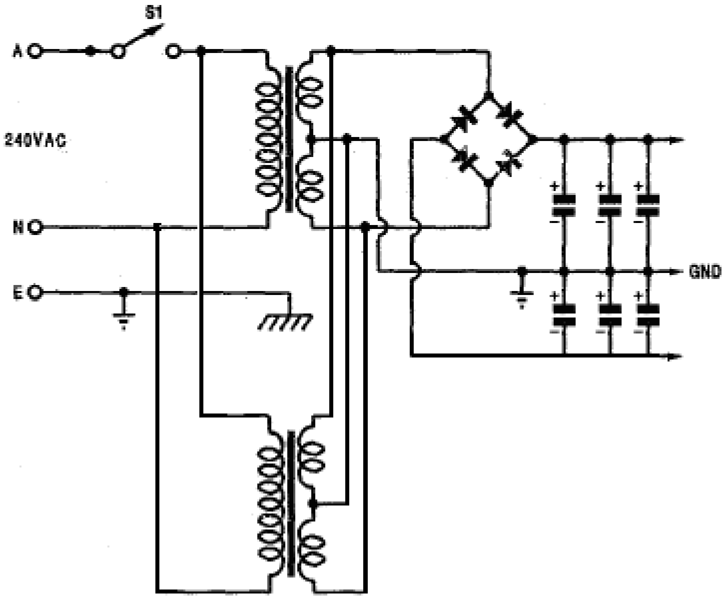
Power Supply 1 – used for 7 x 50W/8ohm modules and 3 x 100W/4ohm modules

- Transformer is 500VA toroidal transformer. Secondary 2 x 30V/8.3A
- Bridge rectifier is 400V/35A.
- Electrolytic capacitors are 10,000uF/100V x 6
- DC output is +/- 41.6V



Power Supply 2 – used for 2 x 180w/8ohm Subwoofer Amplifiers

- Transformers are two 300VA (600VA total) toroidal transformers. Primary and secondary windings are paralleled. Output is 2 x 40V/7.5A Transformers are mounted one on the top of the other, with 10mm insulating gap between them.
- Bridge rectifier is 400V/35A.
- Electrolytic capacitors are 10,000uF/100V x 6
- DC output is +/- 55.7V



Comments on Loudness vs. Volume Control

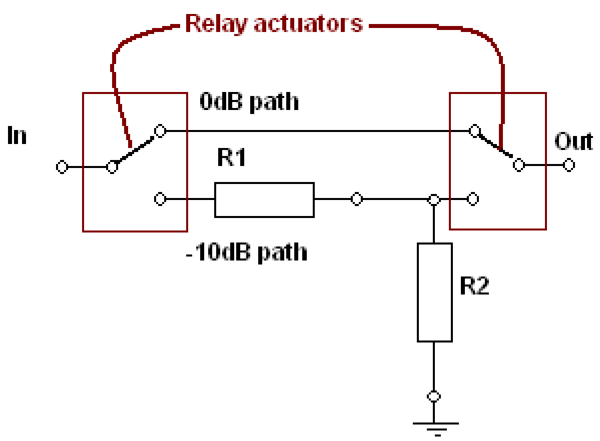
The THX specification for peak SPL of 105dB for surround speakers and 115dB for subwoofers are actually leading to quite high overall SLP levels. I found, that listening to a music DVD, peaking at these levels, is very uncomfortable – see table below.

Typically, I would crank up my old HT system to these levels for a demo purpose, and then turn it down to some more acceptable levels – typically -10dB to -15dB down from the THX 0dB level. This is also good for your hearing.

In fact, from my experience, I run the old system at -10dB level so often, that it basically become my new "reference" level.

The simplest way to reduce the output from ALL amplifiers at the same time is to use UE3 volume control slider. However, since this method does not reduce the noise floor from your PC, the action of reducing the UE3 volume by 10dB has two effects: (1) reducing the audio output by -10dB, and (2) reducing the output S/N by 10dB.

Obviously, the reduction of output S/N is not desirable. Therefore, I installed switchable, 10dB resistive attenuators for each amplifier input. The attenuators are controlled by miniature relays, and allow the signal to either by-pass the attenuator, or go through it.



Please note, that R1 may need to be split into a fixed resistor + a trimpot, to get exact attenuation value. Also, instead of R2 we may use the input impedance of the amplifier (typically within 10-20kohm), so this would simplify the design, if the input capacitance is also low.

All relays are low-current type and are activated via a pushbutton on the front panel.

Finally, the -10dB inserted attenuation may not be enough for you, and you may prefer -15dB.

Table of sound levels L (loudness) and corresponding sound pressure and sound intensity

Sound Sources (Noise) Examples with distance	Sound Pressure Level L_p dB SPL	Sound Pressure p N/m^2 = Pa sound field quantity	Sound Intensity I W/m^2 sound energy quantity
Jet aircraft, 50 m away	140	200	100
Threshold of pain	130	63.2	10
Threshold of discomfort	120	20	1
Chainsaw, 1 m distance	110	6.3	0.1
Disco, 1 m from speaker	100	2	0.01
Diesel truck, 10 m away	90	0.63	0.001
Kerbside of busy road, 5 m	80	0.2	0.0001
Vacuum cleaner, distance 1 m	70	0.063	0.00001
Conversational speech, 1 m	60	0.02	0.000001
Average home	50	0.0063	0.0000001
Quiet library	40	0.002	0.00000001
Quiet bedroom at night	30	0.00063	0.000000001
Background in TV studio	20	0.0002	0.0000000001
Rustling leaves in the distance	10	0.000063	0.00000000001
Threshold of hearing	0	0.00002	0.000000000001

From http://www.sengpielaudio.com/TableOfSoundPressureLevels.htm