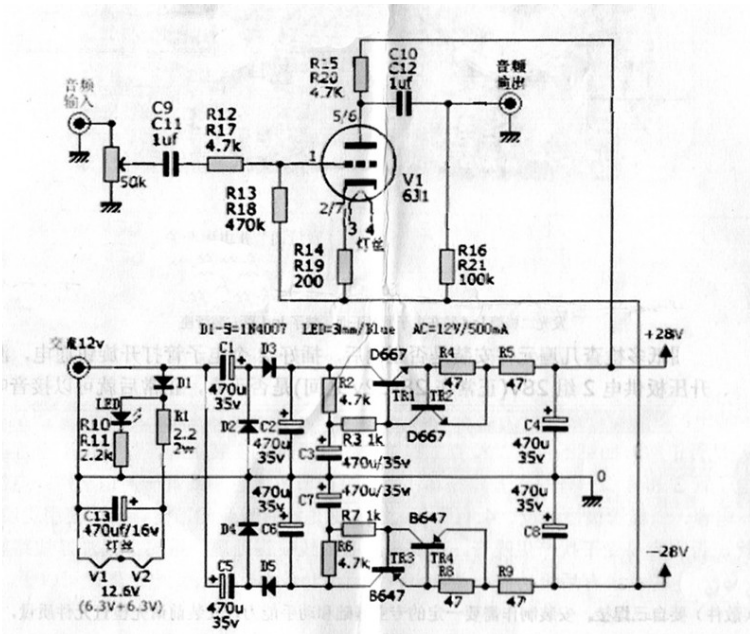
Introduction
I have been playing with the 6J1 Fever preamplifier over last x-mas and beyond.



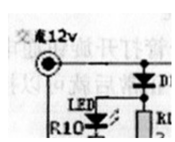
Let me give back to the community, since I took the inspiration from this forum to improve this design.

Although I do have MSEE degree, I was majoring in a different field. Audio is just one of my hobbies. Let me state that I am completely new to thermionic tubes as well as to LT Spice simulations, I have tried to learn as much as publicly available. Thus stay calm and bear with me. 

My motivation is to use as few additional components as possible to make, what is referred as toy, useful (~$1 modification as shown later), but also discuss possible approaches by forum members.

First let us dissect the circuit into parts
1. Power supply
    1A. Heater power supply as Half-way rectifier
    1B. Diode voltage quadrupler
    1C. Current limiter
    1D. Low pass filter
2. Amplifier
    2A. Input high pass filter
    2B. Thermionic valve as Common cathode amplifier
    2C. Output high pass filter

The value that has got me puzzled for a while in simulations is value specified in original schematics.



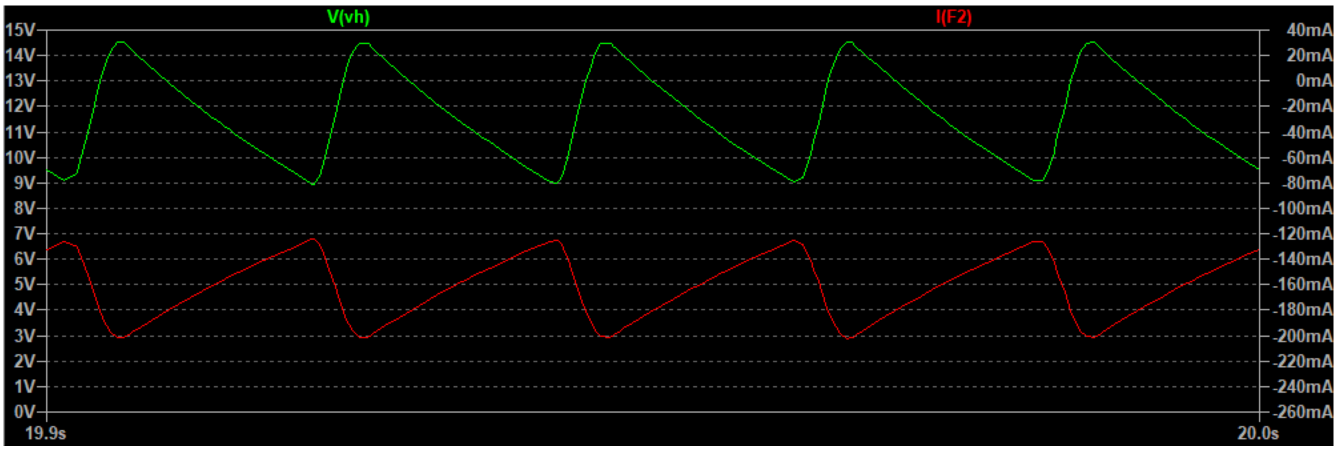
As I have learned from the mistakes in simulation, beware value 12V is not amplitude of sine wave, but rather should tell **12Vrms** (root mean square), thus peak of sine wave is ~17V for the simulation.

1A. Heater

The specification tells us that typical heater voltage should be 6.3V and current shall be 170mA. Looking at simulation picture mean values of current and voltage for heater are met.

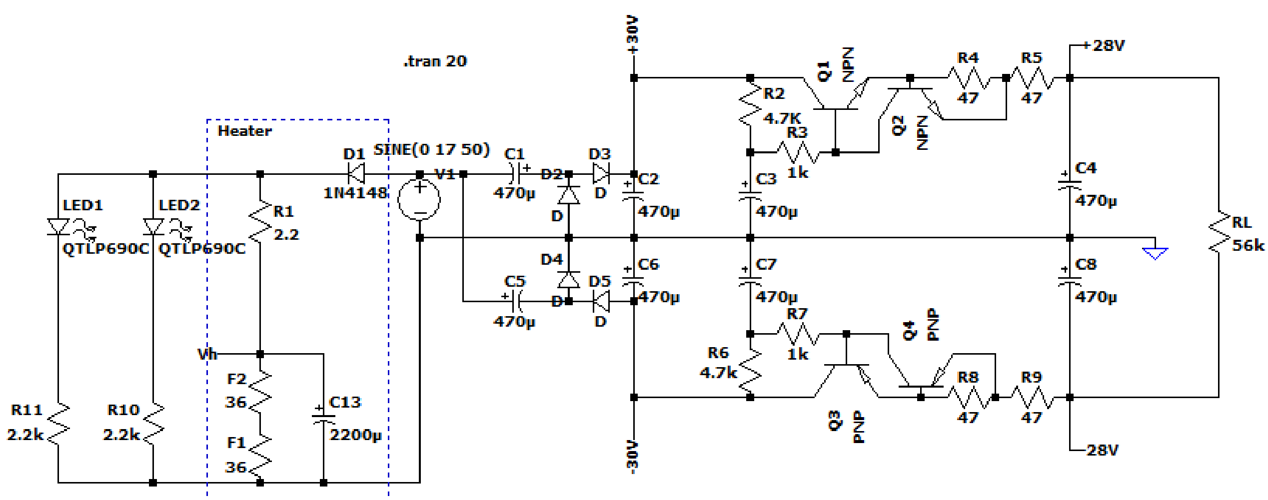
灯丝电压(～或—)	6.3 V
灯丝电流	170±20mV

The main problem of the heater circuit is the significant ripple.

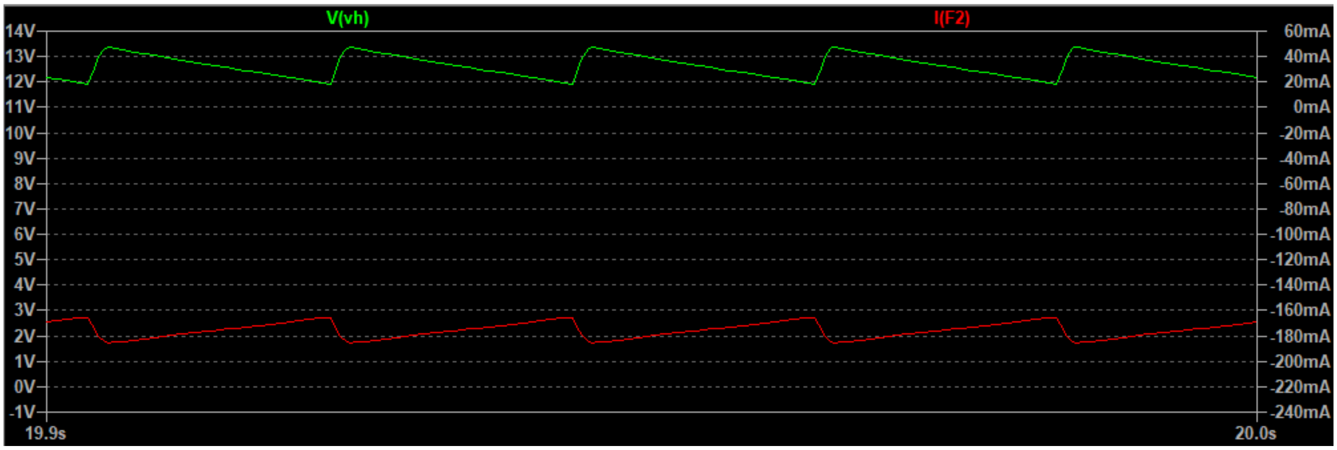


Since we are rectifying sine wave with half way rectifier it advisable to use higher capacitance as already suggested by Angiolino. Ripple at heater might influence electron flux through the thermionic tube. One can use approach with 7812 suggested by Ketje to have it fully stabilized. However full stabilization is not necessary as the heater is constructed to work with AC anyway.

My attempt is to use C13 = 2200uF/16V (used available stashed capacitor) however it is close to the capacitor voltage rating, it would be better to use 2200uF/25V.



The voltage is in the ball park of 12.6V and current 170mA with modified C13, and the ripple gets lower (see below).

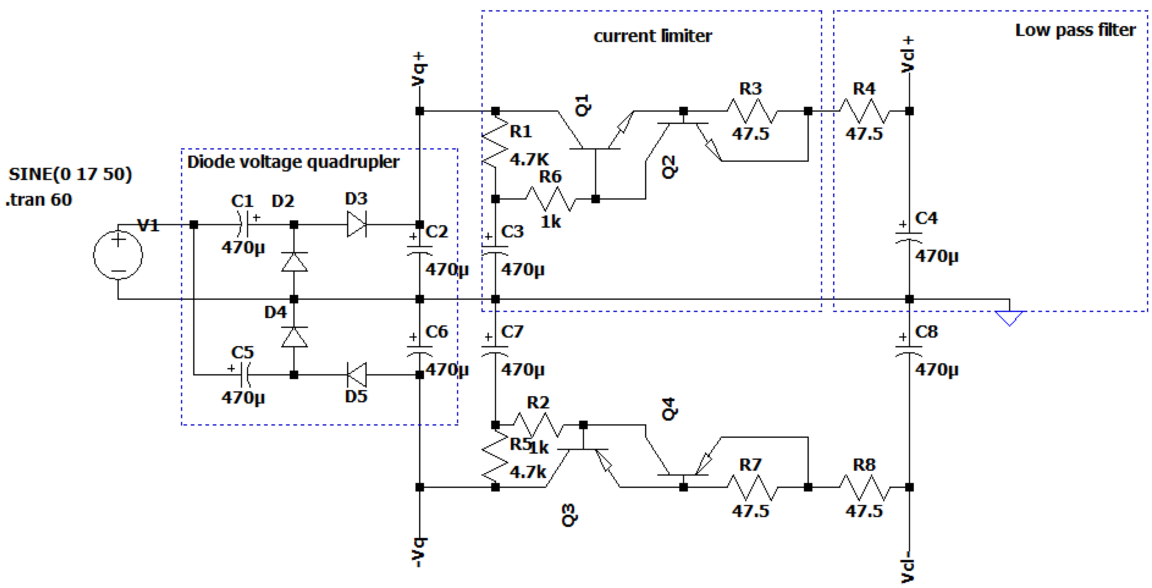


1B. Quadrupler

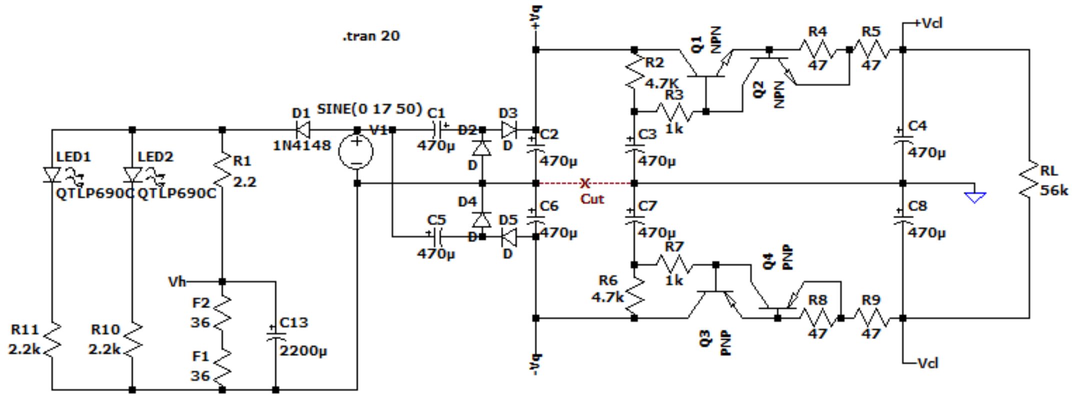
The most of us have had problems with hum. There are two reasons in this circuit.

1. Ground loop
2. Non-stabilized voltage from quadrupler.

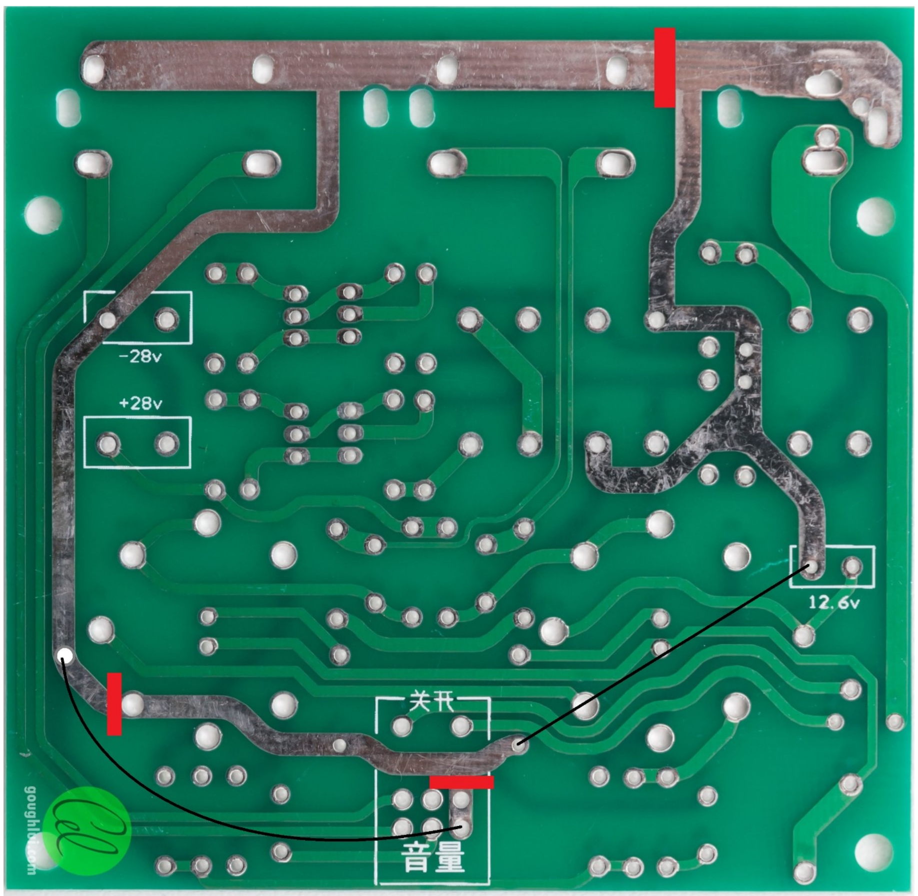
Let us have a look at power supply excluding heater now to identify discussed circuit parts.



To overcome ground loop problem we can break it at connection of C2,C6 junction to C3,C7 junction as suggested by zipob. This rectifies ground loop problem, nevertheless the hum is not removed fully.



If you use LEDs and have populated R10/R11 beware that one cut is misplaced in zipob approach. With LEDs in place correct cut/wiring:

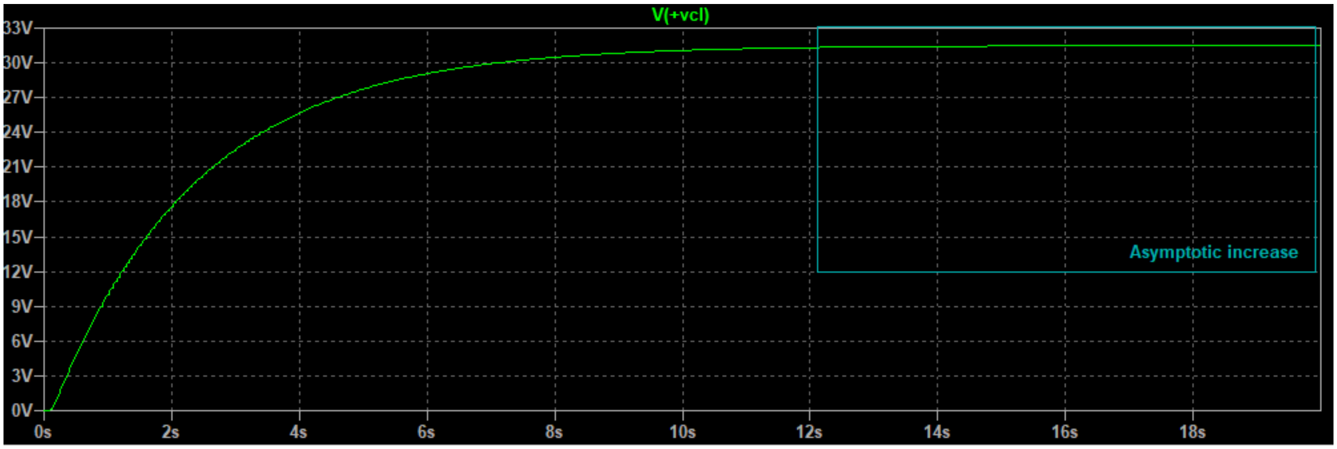


When applying sine 17V peak AC, we get the theoretical maximum that we can obtain from voltage quadrupler as +Vq =34V and -Vq =-34V. In reality we do not achieve full maximum. Here the hint from Angiolino to upgrade capacitors at 470uF/50V makes sense as we are reaching capacitors maximum voltage rating at least with C2,C6 and possibly C4,C8.

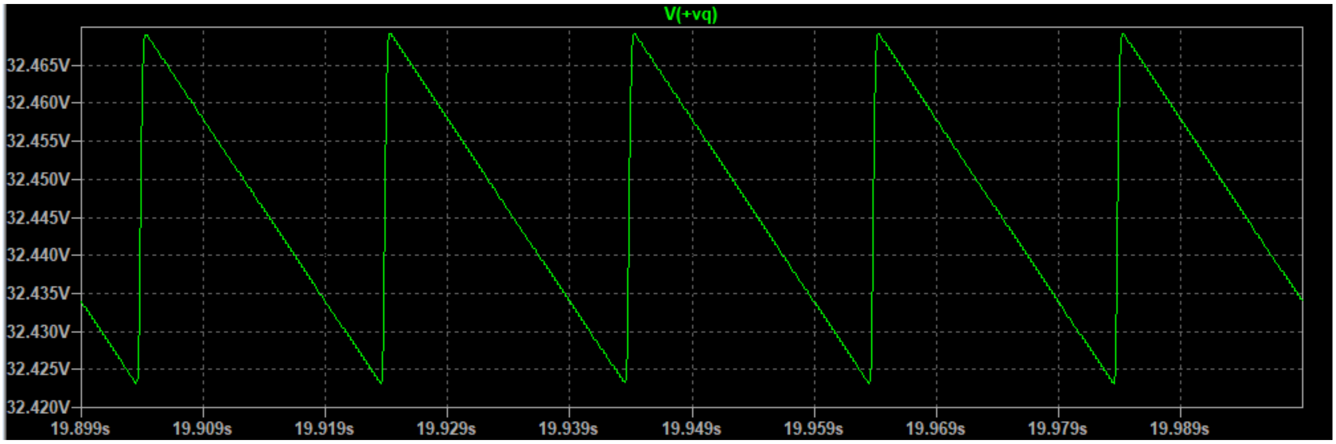
1C. Current limiter

The voltage after the current limiter Vcl+, Vcl- is lower due to drops at transistors and resistors thus theoretical maximum lies in vicinity of +-31.5V which is a bit steep for +-28V hinted in original schematics.

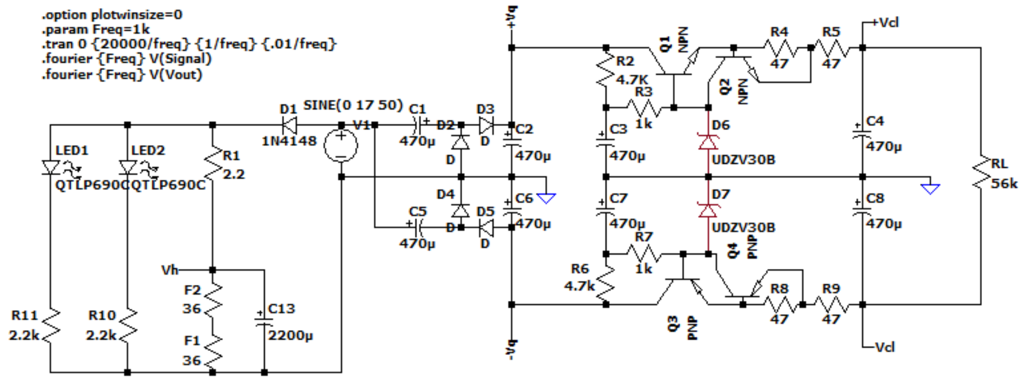
Even when we would have the design voltage at the corresponding rails, there is a lot of ripple since voltage quadrupler shows similar behavior as one way rectifier. Current limiter hides the problem in simulation because the time needed to reach maximum values at C3,C7 as well as the ones in voltage doubler is not negligible with load at the end of the rails. That reveals itself as asymptotic increase that never reaches its equilibrium.



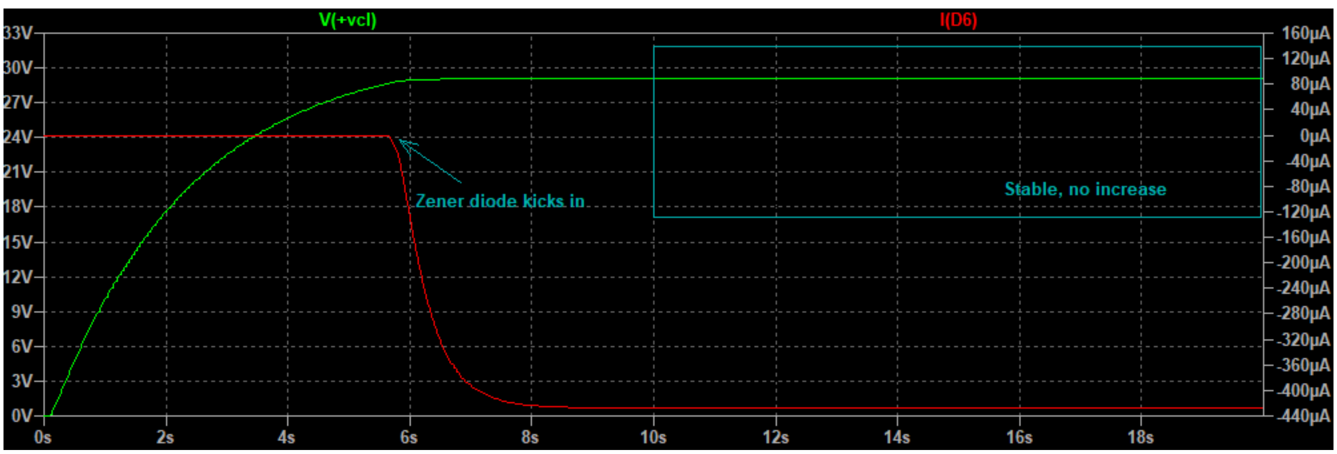
We can have a look at Vq to see the ripple, it reveals the problem, even though it is attenuated at C3,C7 and low pass filter R5,C4/R9,C8.



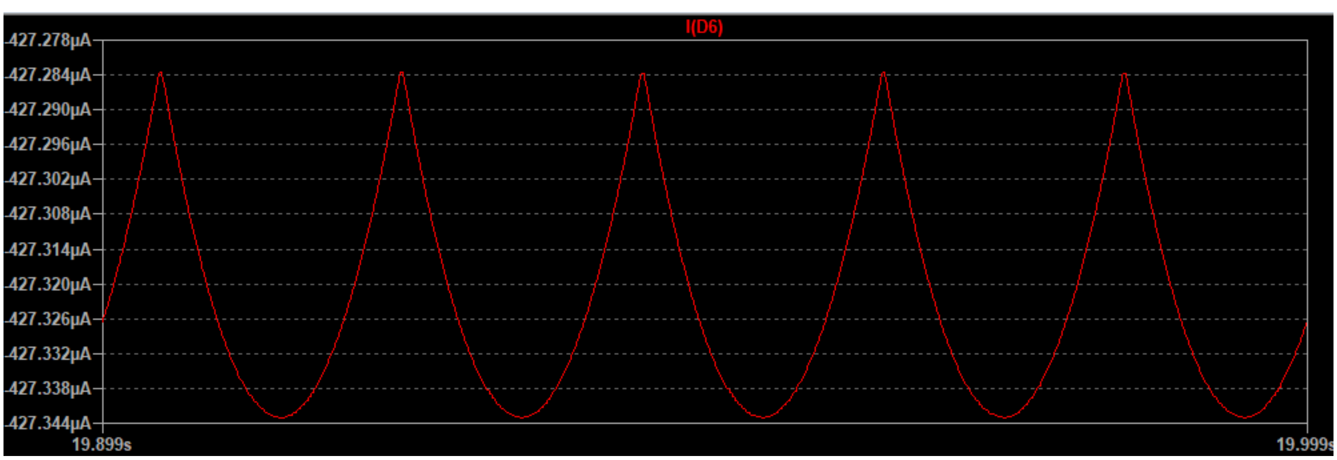
Attempt to resolve the problem is voltage stabilizer extension of current limiter.

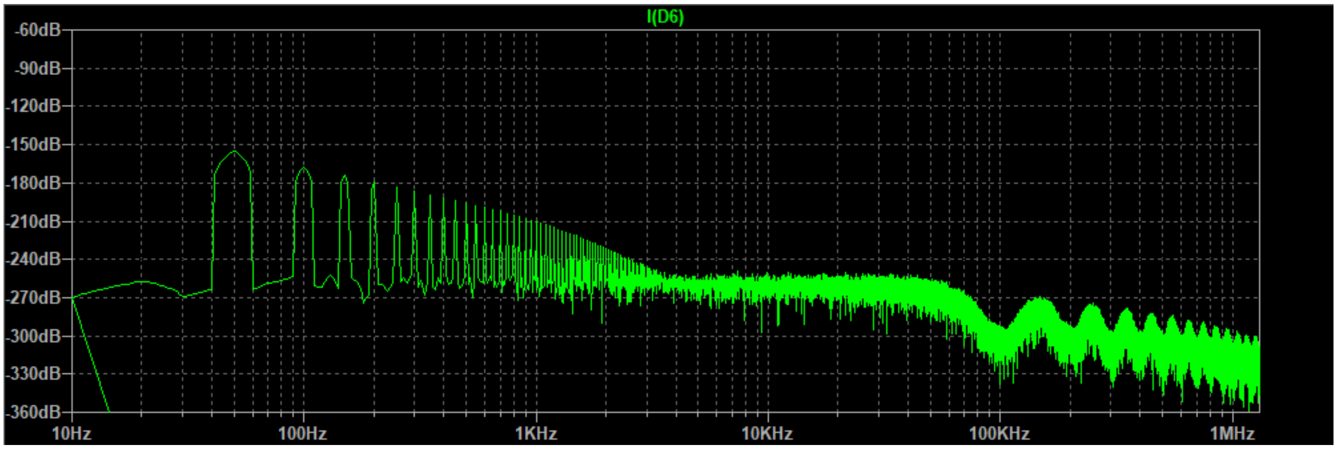


Adding Zener diode into feedback loop of limiter will cut a bit of preciously gained voltage, but will make voltage stable (thus residual hum is removed). The zener voltage has to be picked below theoretical value of +-31.5V. For 12Vrms input voltage that makes Zener diode with ~30V a good candidate. Opposed to the schematics with Zener diodes, the same can be achieved connecting Zener to junction point of R4,R5,Q2/R8,R9,Q4 as it is more convenient construction-wise (see later).



Now looking at current through Zener diode or [FFT](FFT) for Zener diode current we can see the residual hum once we have cut the ground loop.





1D. Low pass filter

Low pass filter formed with R5/C4 and R9/C8 has a cutoff at 7.2 Hz which is well below 50Hz that we want to attenuate.

2B. Valve as Common cathode amplifier

With the corrected power supply, let us now calculate operational point of thermionic tube. We can calculate current from current limiter to get anode current as it was intended by designer.

The subscript notation in subsequent text is based on German

for anode it is Ua (german ‘anode’)
for grid it is Ug (german ‘gitter’)
for plate/cathode Uk (german ‘kathode’).

We know that the base-emitter voltage (V_{be}) of transistor Q2 is 0.7 volts and the limiting resistor R4 is 47 ohms, thus allowed maximum current:

$$IL_{max} = V_{be} / R3 = 0.7\ V / 47\ ohms = 14.8\ mA$$

Allowed maximum current IL_{max} is serving two tubes thus anode current is at 7.4 mA, which corresponds to 1/3 of Ia_{max} from specification

最大阴极电流 20mA

and is stated as typical operational current.

阴极电流 $7.35^{+3.85}_{-2.75}$ mA

Since we have limited the voltage at the power supply rails with Zener diodes to +-30V, that gives the maximum voltage across rails as U_{max} = 60V. The anode voltage is placed in the middle to have a symmetric voltage swing.

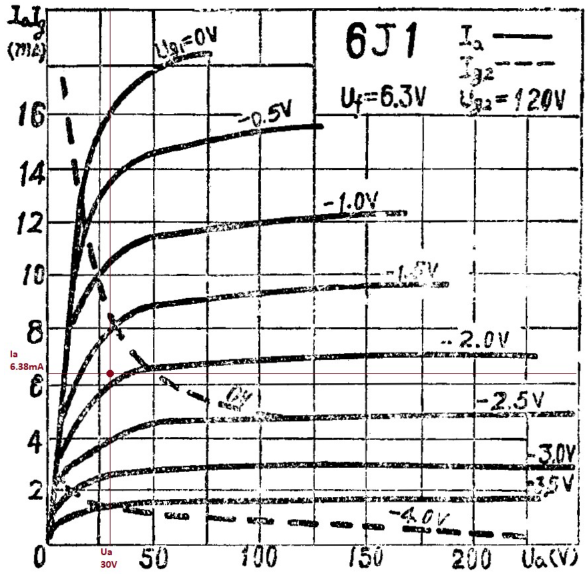
$$Ua = U_{max}/2 = 30V$$

giving effectively 0V middle point with +-30V rails.

As we have Ua,Ia we can calculate R15 as

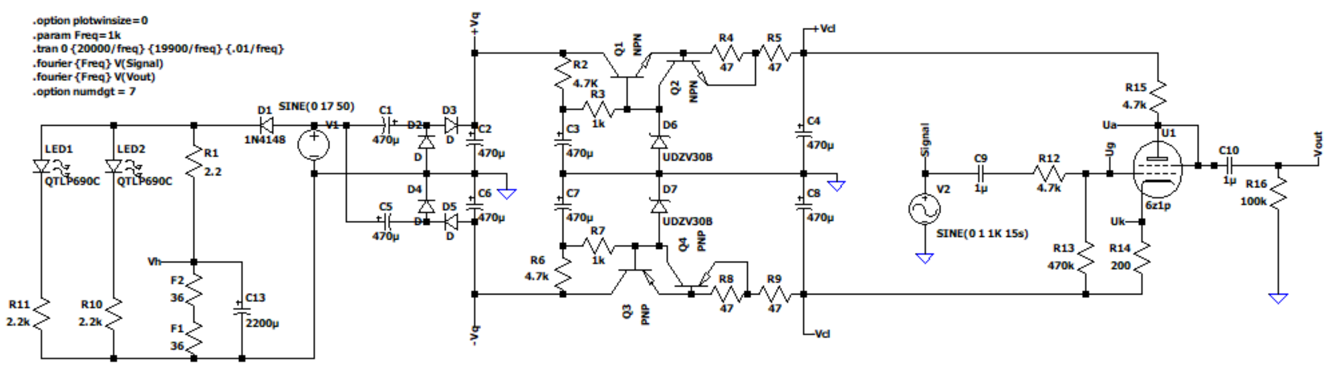
$$Ra = Ua/Ia = 30/0.0074 = 4054\ Ohm.$$

R15 = 4700 Ohm seems to be picked correctly, giving us Ia = Ua / Ra at 6.38mA which is in intended range ($7.35^{+3.85}_{-2.75}$ mA). Let us consult the specification with Ia,Ua pair to retrieve designed grid voltage Ug.



Design grid bias voltage seems to be in range -1.85V to -1.95V.

Let us now connect one channel of common cathode amplifier to corrected power supply to verify the grid bias. We could do the analysis manually, but let us save the effort and let the computers/simulators do their work. For that we will need a 6J1 model to draw schematics and do the analysis.

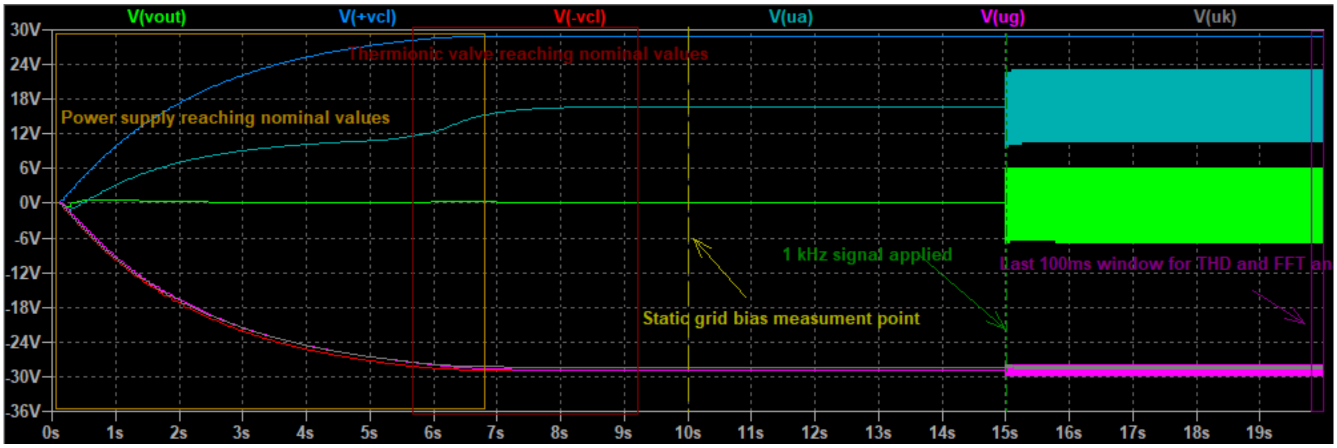


6j1 equivalents have been considered when searching for the appropriate model

- EF95 – European (Philips),
- 6Z1P – Russian (Восход,Калужский радиоламповый завод КРЛЗ),
- 6F32 – Czechoslovak (Tesla),
- 6AU6 – US (Mazda, Mullard, Brimar, Tung-Sol, RCA, GE).
- 6J1 – Chinese (Shuguang 曙光电子集团有限公司电子管厂),
- 5654 – US (Raytheon, GE, Tung-Sol, RCA, Siemens, Mazda, Philips),
- 6AK5 – US (Raytheon, Sylvania, Tung-Sol, RCA).

For the latter equivalents, the model is available here as 5654/6AK5/6J1 spice model created by Ayumi Nakabayashi (posted by jazbo8). Since there is version with more precise outcome, simulations below use 6AK5 enhanced spice model by Robert McLean.

In order to have comparable results with different setups let the simulation run for 20s, where the bias is checked after power supply nominal values are reached and the thermionic tube achieves static operation point. The time is picked as 10s. The signal is applied at the time of 15s and another 5 seconds are traced to allow input and output filter capacitors to accumulate the charge. THD and FFT analysis results are calculated from the last 100ms of the trace. The absolute values in analysis are as good as the model, but the comparison still stands. The deviation from the values is expected in reality.



Let us probe the grid bias voltage:

V(uk) = -28.362908V

V(ug) = -28.879755V

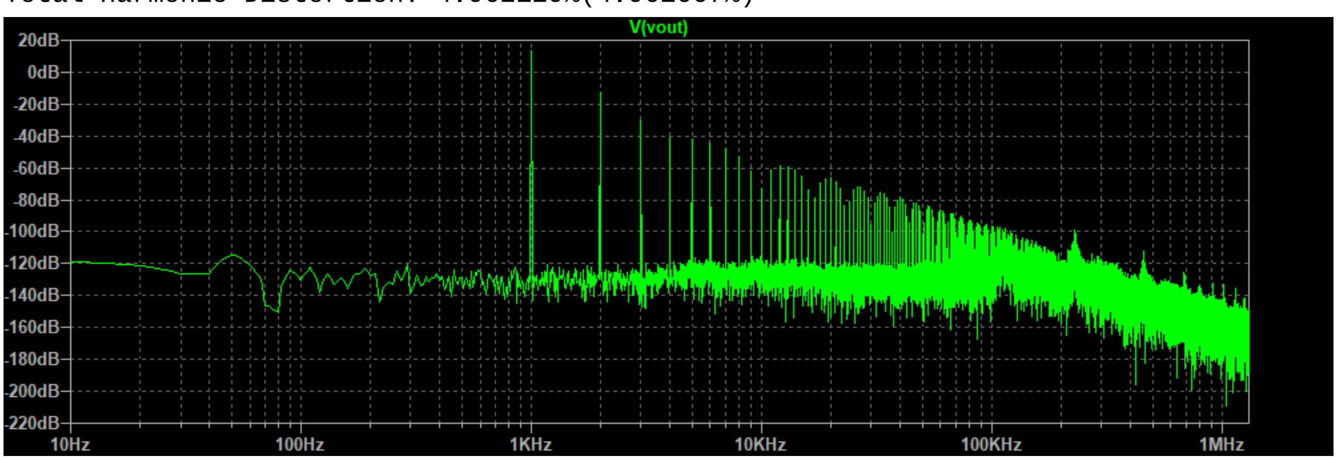
Ug = -0.51684765V

Looking at the grid bias voltage for the circuit, it does not correspond to expected grid bias coming from specification (Ug ~ -1.9V). The circuit needs re-biasing (described later).

Let us explore FFT and THD for the original circuit to have comparison measurements for modifications.

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	6.456e+00	1.000e+00	-179.88°	0.00°
2	2.000e+03	3.165e-01	4.902e-02	90.18°	270.05°
3	3.000e+03	4.529e-02	7.016e-03	179.92°	359.80°
4	4.000e+03	1.245e-02	1.929e-03	89.69°	269.57°
5	5.000e+03	1.169e-02	1.811e-03	-0.00°	179.87°
6	6.000e+03	8.383e-03	1.298e-03	-90.04°	89.84°
7	7.000e+03	5.726e-03	8.869e-04	179.84°	359.72°
8	8.000e+03	3.098e-03	4.798e-04	90.36°	270.24°
9	9.000e+03	1.122e-03	1.738e-04	-1.95°	177.93°

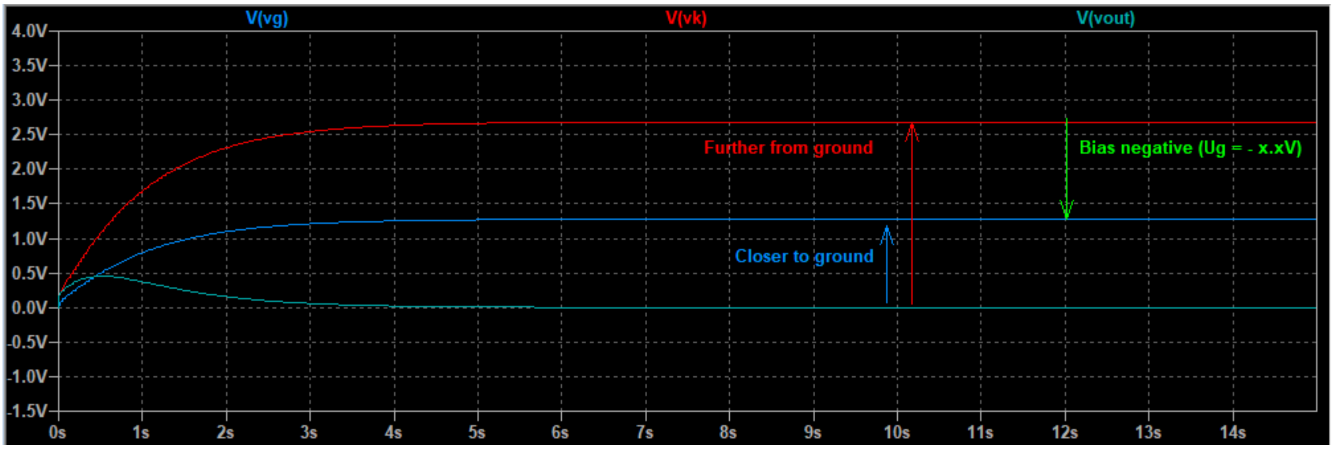
Total Harmonic Distortion: 4.962129%(4.961667%)



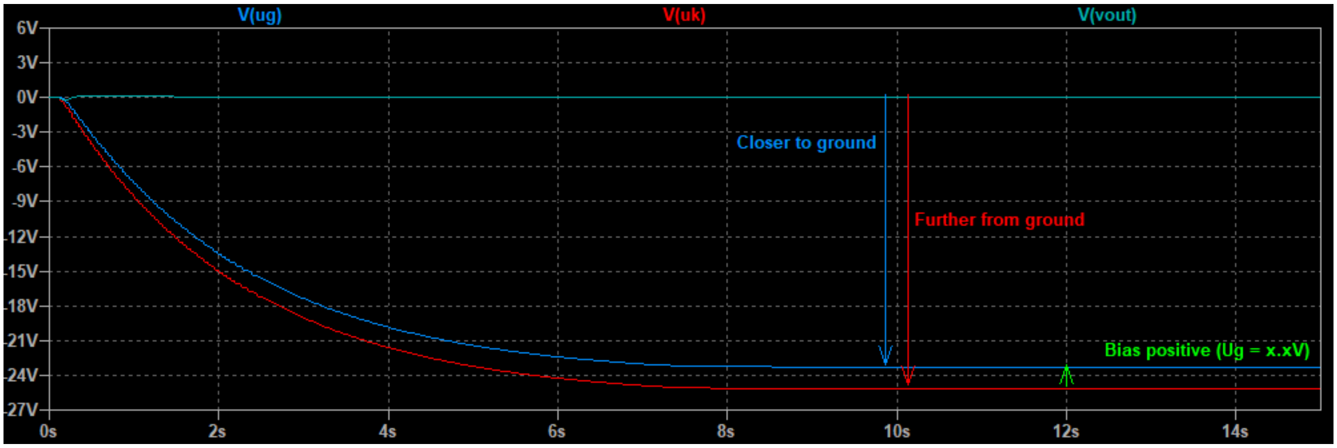
It is obvious now, what senior forum members state as a lot of distortion. THD is roughly 5%.

Valve as Common cathode amplifier re-biased.

Let us investigate how does the values change with proper biasing. I believe the crucial mistake is that typical calculations are done with traditional single rail setup with common cathode facing ground level. The biasing is **negative**.

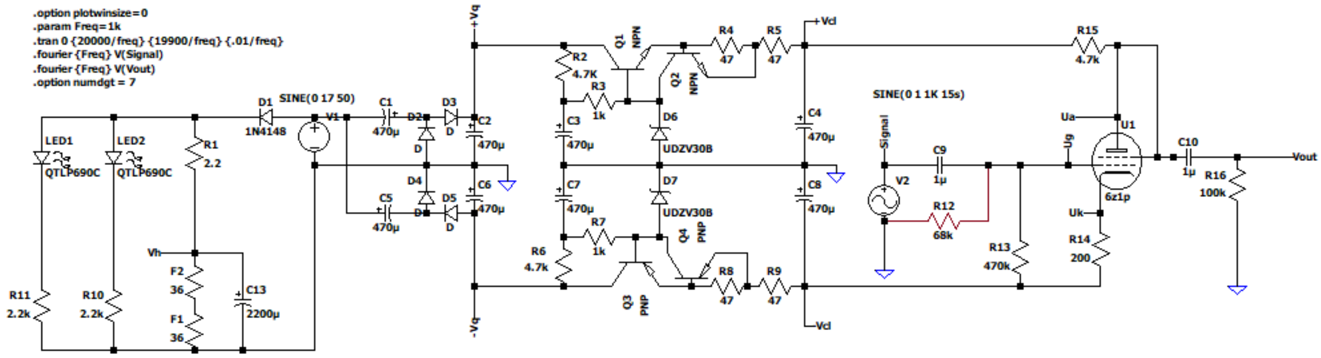


With used power supply design, we are dealing with the dual rail circuit, where cathode is facing negative rail, thus the bias logic changes and is mirrored via ground level. The biasing is **positive**.



That makes thermionic tube with original bias (Ug = -0.51684765V) actually operates in **POSITIVE** region in traditional sense of single rail setup! It is surprising that the tube is behaving so gracefully.

Since input signal is at 0V offset and positive part of voltage span is at R15, voltage divider is calculated between Vcl- = -30V and 0V with considering high pass input filter formed from divider. We want to achieve Ug = **+**1.9V, let us reposition and exchange R12 for 68kOhm value. Now we will have R12, R13 forming voltage divider for grid bias, while R13 will form resistor part of input high pass filter with cutoff at 2.4Hz.



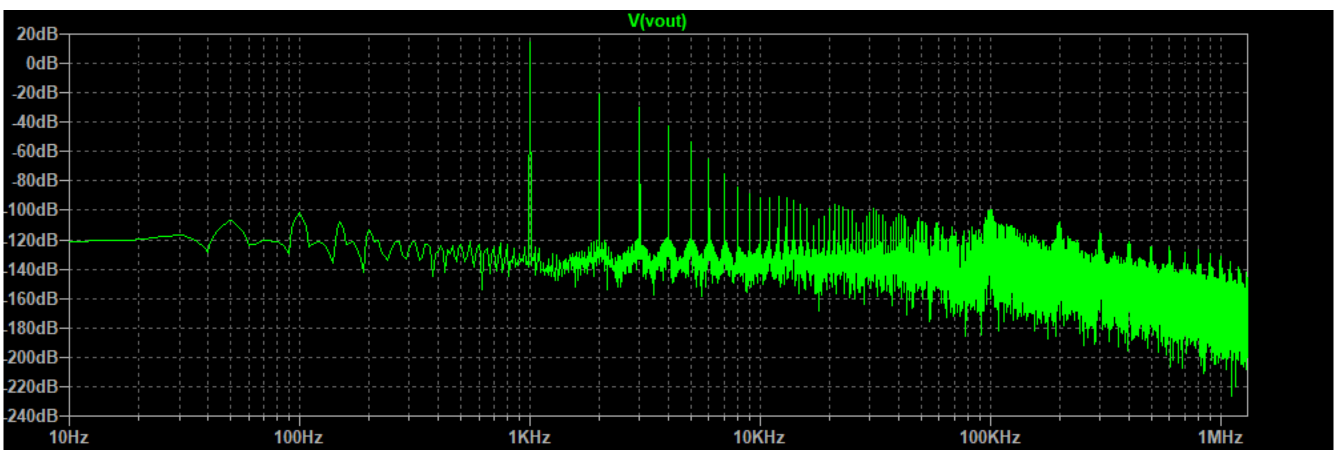
Let us probe the grid bias voltage:

V(uk) = -26.298182V
V(ug) = -24.387577V
Ug = 1.9106053V

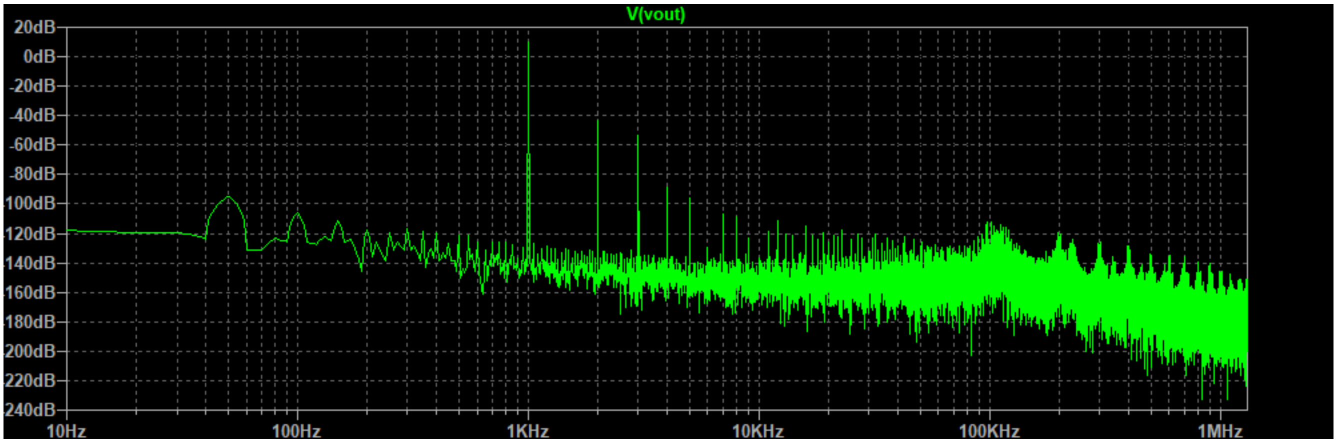
That is expected grid bias calculated from specification (Ug ~ -1.9V) with cathode facing negative rail.

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	7.959e+00	1.000e+00	-177.11°	0.00°
2	2.000e+03	1.330e-01	1.671e-02	-101.68°	75.43°
3	3.000e+03	4.594e-02	5.772e-03	-176.82°	0.29°
4	4.000e+03	1.025e-02	1.289e-03	100.73°	277.84°
5	5.000e+03	3.034e-03	3.812e-04	16.82°	193.93°
6	6.000e+03	9.330e-04	1.172e-04	-67.71°	109.40°
7	7.000e+03	1.126e-04	1.415e-05	-140.87°	36.24°
8	8.000e+03	1.848e-04	2.322e-05	114.30°	291.41°
9	9.000e+03	5.712e-05	7.177e-06	-156.11°	21.00°

Total Harmonic Distortion: 1.772670%(1.771942%)



We have reduced the distortion almost by 2/3rds. Now if we sacrifice 5dB of gain (leaving gain ~10dB), by changing R15 = 2.2kOhm we will reach better results and we will place Ua offset back at 0V (0.32598514mV), even though the current through the thermionic tube will jump out of the typical operation ($7.35^{+3.85}_{-2.75}$ mA) to 11.63767mA, which is slightly over the boundary (11.2mA), but it is still under maximum Ia_{max}= 20mA.

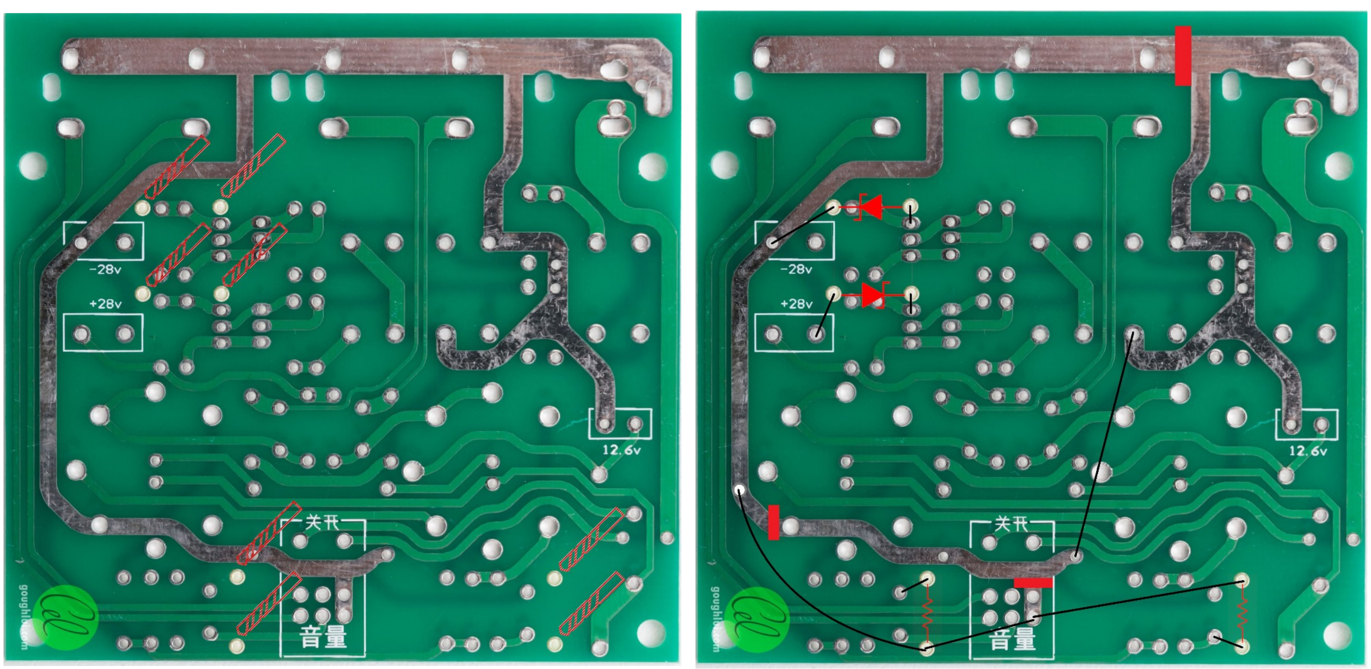


Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	5.001e+00	1.000e+00	-177.98°	0.00°
2	2.000e+03	8.869e-03	1.773e-03	159.08°	337.07°
3	3.000e+03	4.241e-03	8.479e-04	-179.15°	-1.16°
4	4.000e+03	6.170e-05	1.234e-05	-72.14°	105.85°
5	5.000e+03	5.137e-05	1.027e-05	-163.16°	14.82°
6	6.000e+03	1.765e-05	3.530e-06	91.50°	269.48°
7	7.000e+03	9.295e-05	1.859e-05	18.55°	196.54°
8	8.000e+03	1.232e-04	2.464e-05	109.27°	287.26°
9	9.000e+03	6.659e-06	1.331e-06	3.96°	181.94°

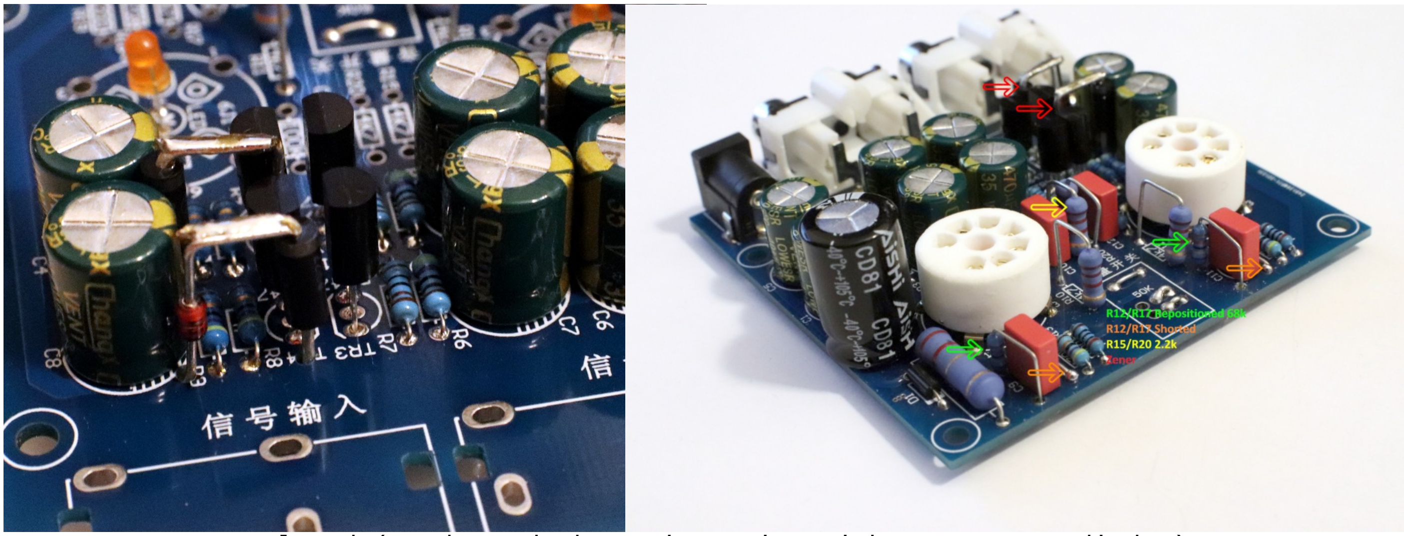
Total Harmonic Distortion: 0.196589%(0.185428%)

That seems to be better than the original Common cathode amplifier design. One can think of operational point change and recalculation, but I will not pursue that path since soft tube sound is the main reason I have invested my time here.

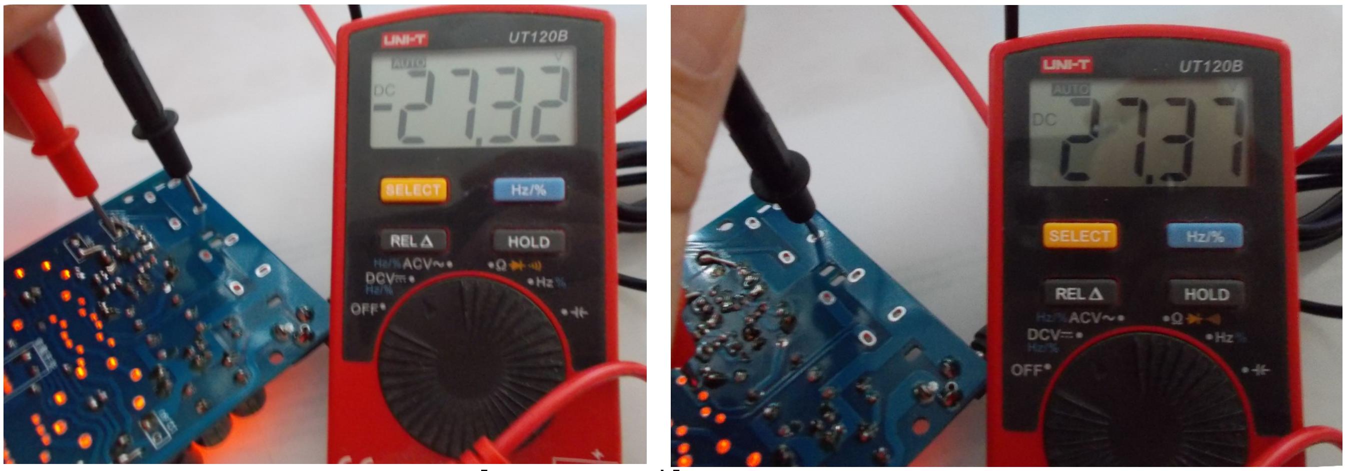
Common cathode construction



Drill positions and additional components placement.
(wire in black, cuts and components in red).



Zeners populated (used stashed 22V in series with 5.6V Zener diodes)

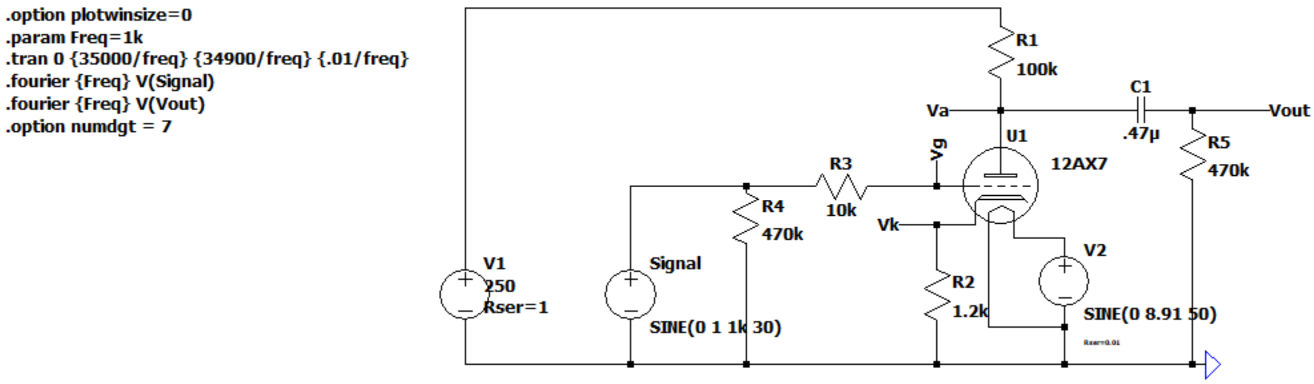


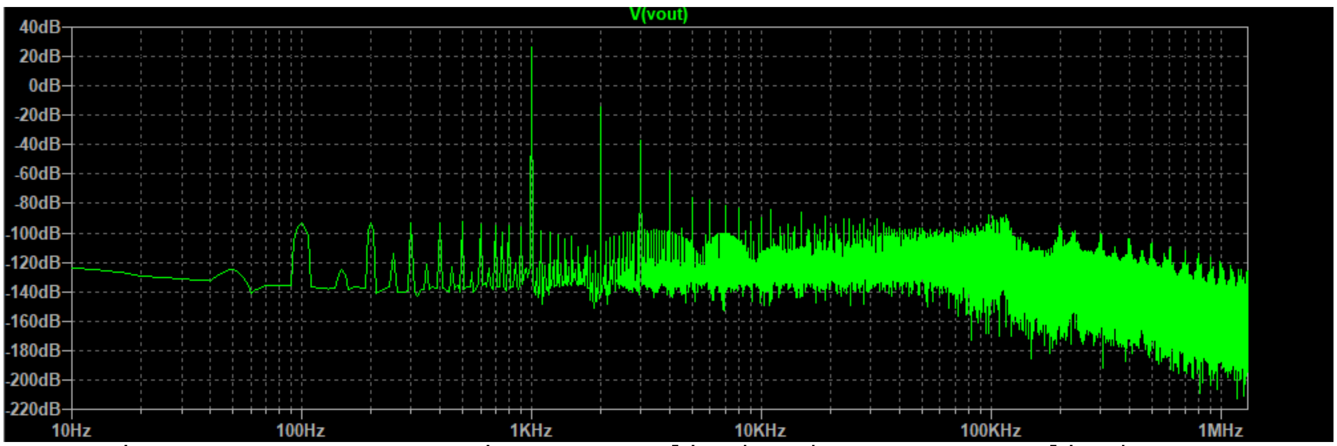
Voltage at rails V_{cl-}, V_{cl+}

Construction for testing

Alternative common cathode build with 12A*7 (for comparison)

Let us now compare to design by Matt Renaud with more frequently picked 12A*7 tube.



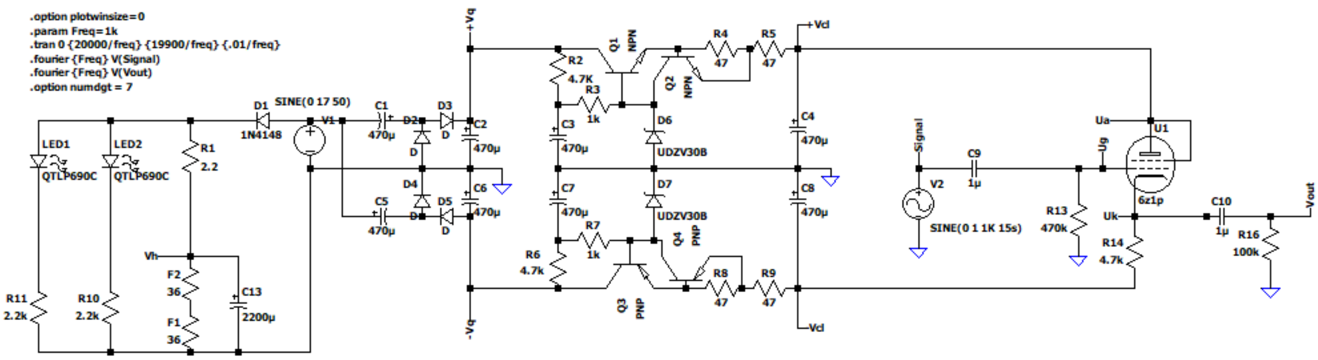


Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	2.956e+01	1.000e+00	179.51°	0.00°
2	2.000e+03	2.666e-01	9.019e-03	88.24°	-91.27°
3	3.000e+03	2.119e-02	7.169e-04	177.41°	-2.11°
4	4.000e+03	2.473e-03	8.363e-05	-93.88°	-273.40°
5	5.000e+03	7.856e-04	2.657e-05	176.04°	-3.47°
6	6.000e+03	2.375e-04	8.034e-06	-101.58°	-281.09°
7	7.000e+03	2.171e-04	7.342e-06	-19.61°	-199.12°
8	8.000e+03	5.621e-04	1.901e-05	75.38°	-104.13°
9	9.000e+03	3.247e-04	1.098e-05	-1.45°	-180.96°

Total Harmonic Distortion: 0.904796%(0.902557%)

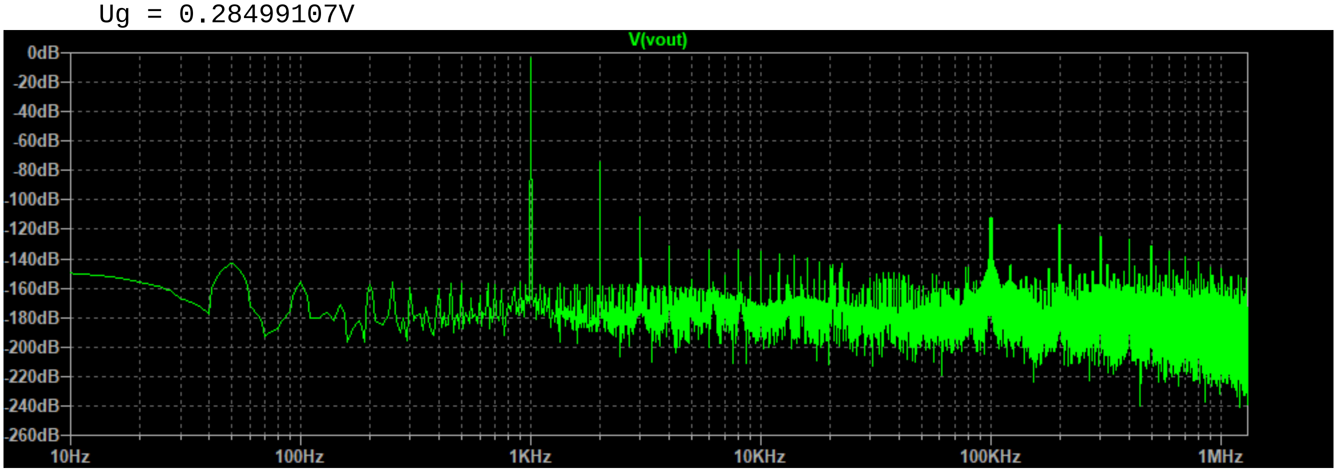
Cathode follower

Since the Common cathode amplifier is more sensitive to the power supply fluctuations and without Zener diodes we do have quite a ripple, Ketje as well as aspringv are suggesting usage of Cathode follower (buffer stage) where the amplifier becomes a slight attenuator. If we are using it in amplification chain the attenuation might not be a problem. Both modifications help with hum problem but lack proper biasing. Nevertheless if the preamplifier shall be used as headphone amplifier, the solution might be to attach operational amplifiers to have some gain as suggested by ratti3. So let us connect the cathode follower to the corrected power supply and rerun analysis. First with aspringv setup.



Let us see the bias for aspringv:

V(uk) = -7.1952797V
V(ug) = -6.9102887V
Ug = 0.28499107V



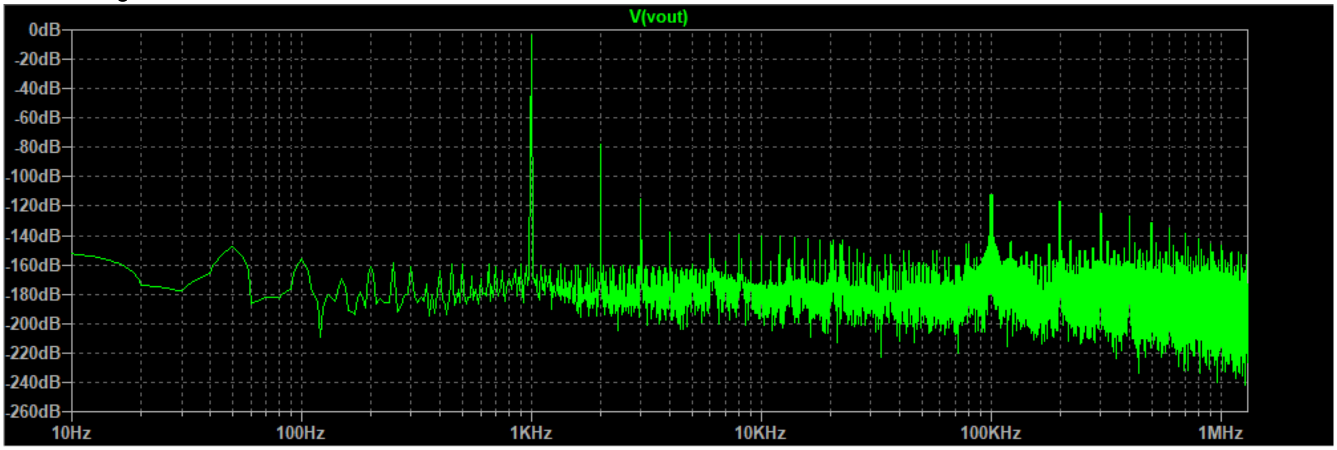
Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	9.254e-01	1.000e+00	0.15°	0.00°
2	2.000e+03	2.694e-04	2.911e-04	-88.14°	-88.30°
3	3.000e+03	3.923e-06	4.240e-06	-0.44°	-0.60°
4	4.000e+03	3.798e-07	4.104e-07	91.34°	91.19°
5	5.000e+03	2.176e-09	2.352e-09	-154.35°	-154.51°
6	6.000e+03	3.025e-07	3.269e-07	91.51°	91.36°
7	7.000e+03	2.043e-09	2.208e-09	-128.64°	-128.80°
8	8.000e+03	2.777e-07	3.001e-07	91.65°	91.50°
9	9.000e+03	2.860e-09	3.091e-09	-120.61°	-120.76°

Total Harmonic Distortion: 0.029113%(0.032529%)

We can see that cathode follower distorts much less.

And now lets exchange R14 value for 10k as [suggested by Ketje](). If we probe Ug

V(uk) = -1.4339857V
V(ug) = -1.3496811V
Ug = 0.84304566V

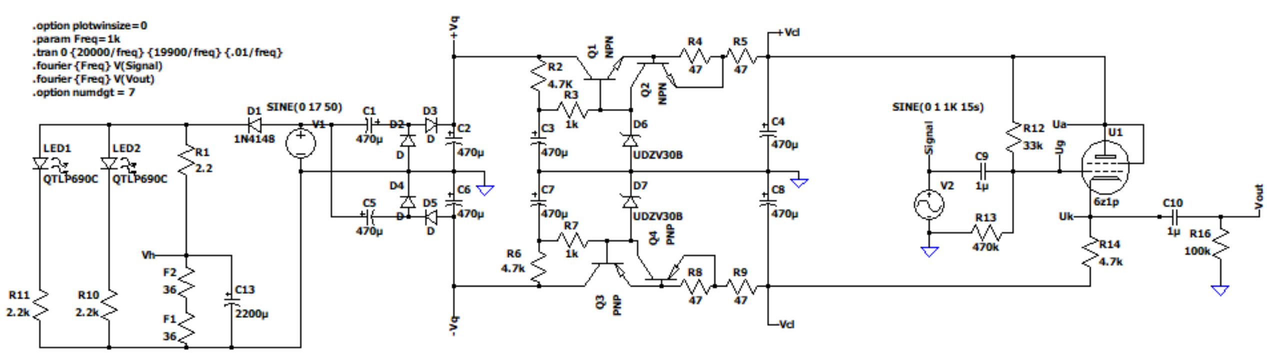


Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	9.392e-01	1.000e+00	0.13°	0.00°
2	2.000e+03	1.818e-04	1.935e-04	-88.68°	-88.81°
3	3.000e+03	2.511e-06	2.673e-06	-0.42°	-0.55°
4	4.000e+03	1.900e-07	2.023e-07	91.18°	91.05°
5	5.000e+03	2.472e-08	2.632e-08	-1.19°	-1.32°
6	6.000e+03	1.557e-07	1.658e-07	91.38°	91.25°
7	7.000e+03	3.362e-08	3.580e-08	-1.52°	-1.65°
8	8.000e+03	1.457e-07	1.551e-07	91.58°	91.45°
9	9.000e+03	4.077e-08	4.341e-08	-2.02°	-2.15°

Total Harmonic Distortion: 0.019355%(0.024191%)

[Cathode follower]() re-biased

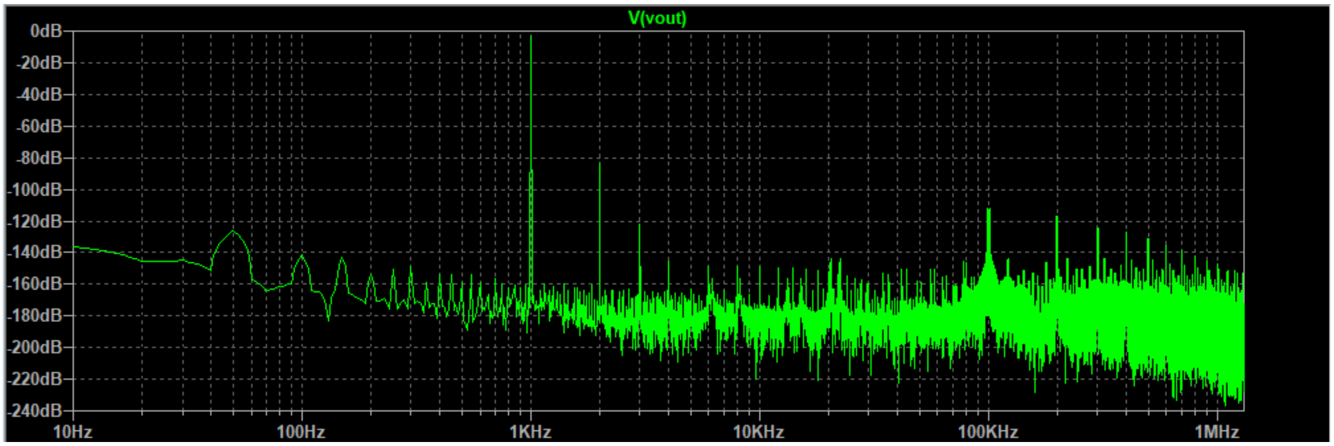
Let us now do the same magic trick as for the Common cathode design with a voltage divider. Since the cathode still faces the negative rail, the biasing is **positive.** But we have changed position of R15 to cathode, we now have the complete voltage of negative rail at R14, that changes the quadrant where the bias shall be placed to positive. So we will bias the grid from positive rail, biased positively due to cathode facing negative rail.



If we probe Ug

V(uk) = 14.845198V
V(ug) = 16.675392V
Ug = 1.8301942V

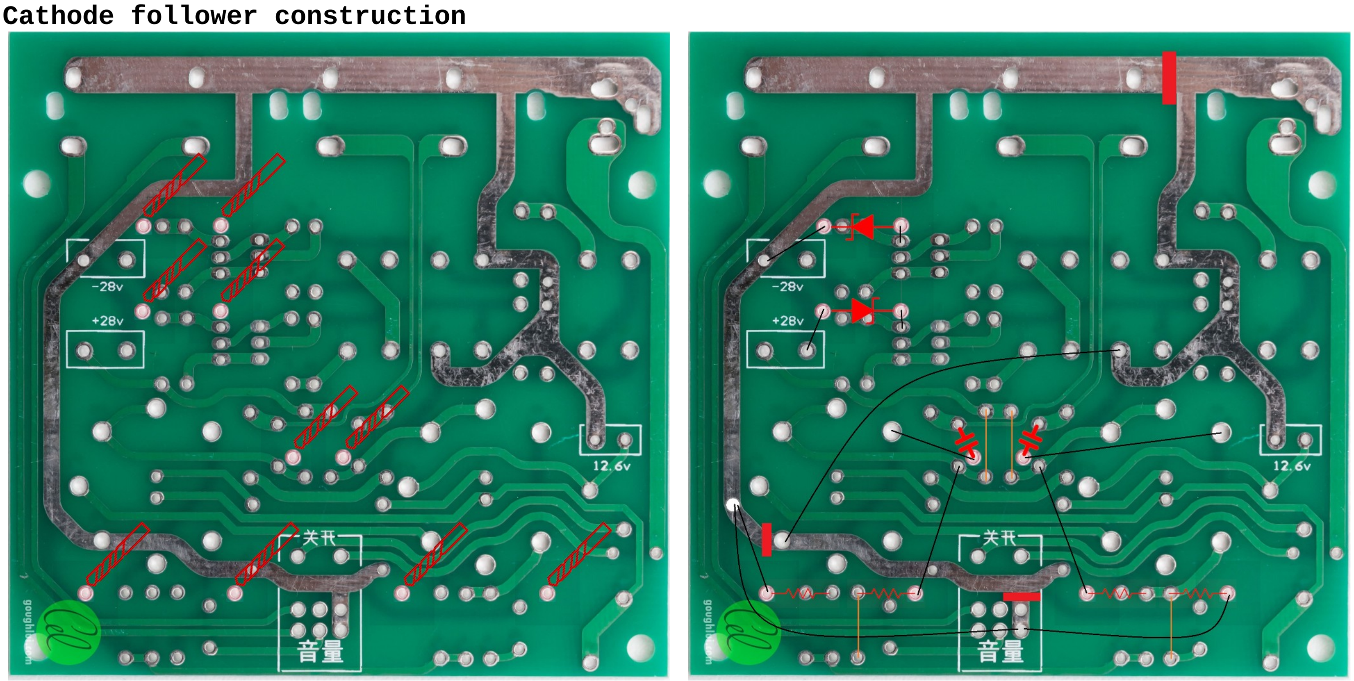
The current through the tube is 9.1596301mA well within (7.35 $^{+3.85}_{-2.75}$ mA).



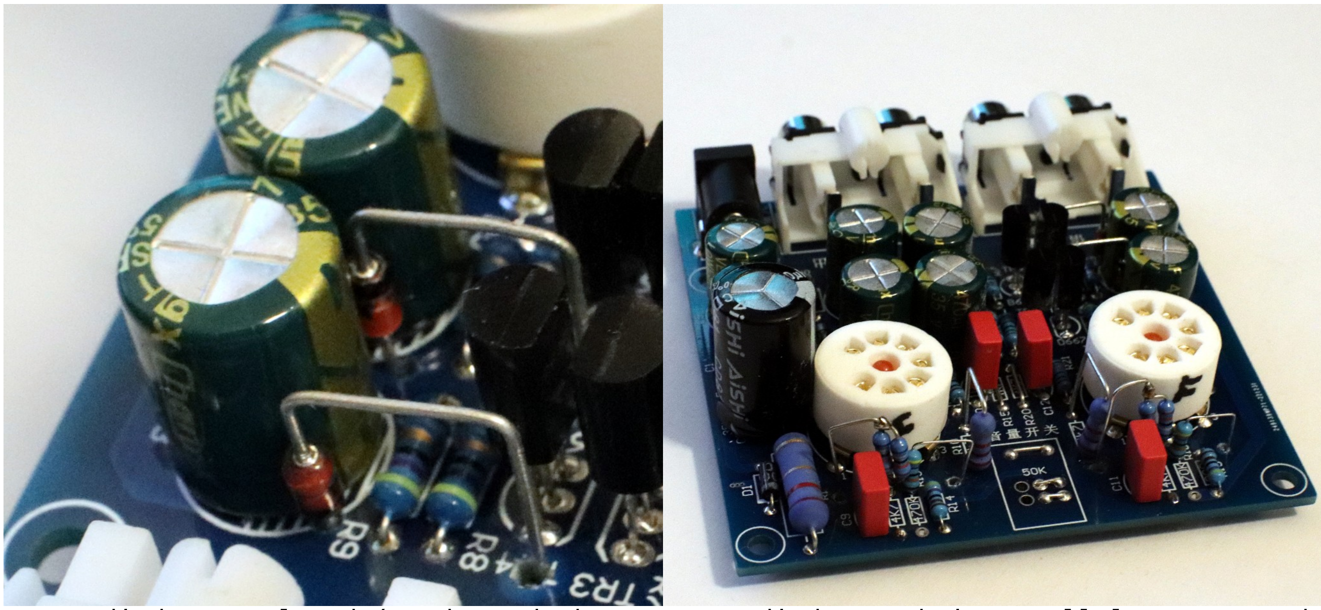
Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	9.375e-01	1.000e+00	0.64°	0.00°
2	2.000e+03	8.931e-05	9.527e-05	-56.12°	-56.76°
3	3.000e+03	8.823e-07	9.411e-07	-60.30°	-60.94°
4	4.000e+03	9.705e-08	1.035e-07	124.56°	123.92°
5	5.000e+03	1.387e-08	1.480e-08	105.12°	104.48°
6	6.000e+03	8.092e-08	8.632e-08	111.09°	110.44°
7	7.000e+03	1.348e-08	1.438e-08	91.83°	91.18°
8	8.000e+03	7.681e-08	8.194e-08	109.83°	109.18°
9	9.000e+03	1.419e-08	1.514e-08	83.99°	83.35°

Total Harmonic Distortion: 0.009528%(0.017360%)
That seems to be satisfactory for nowadays standards.

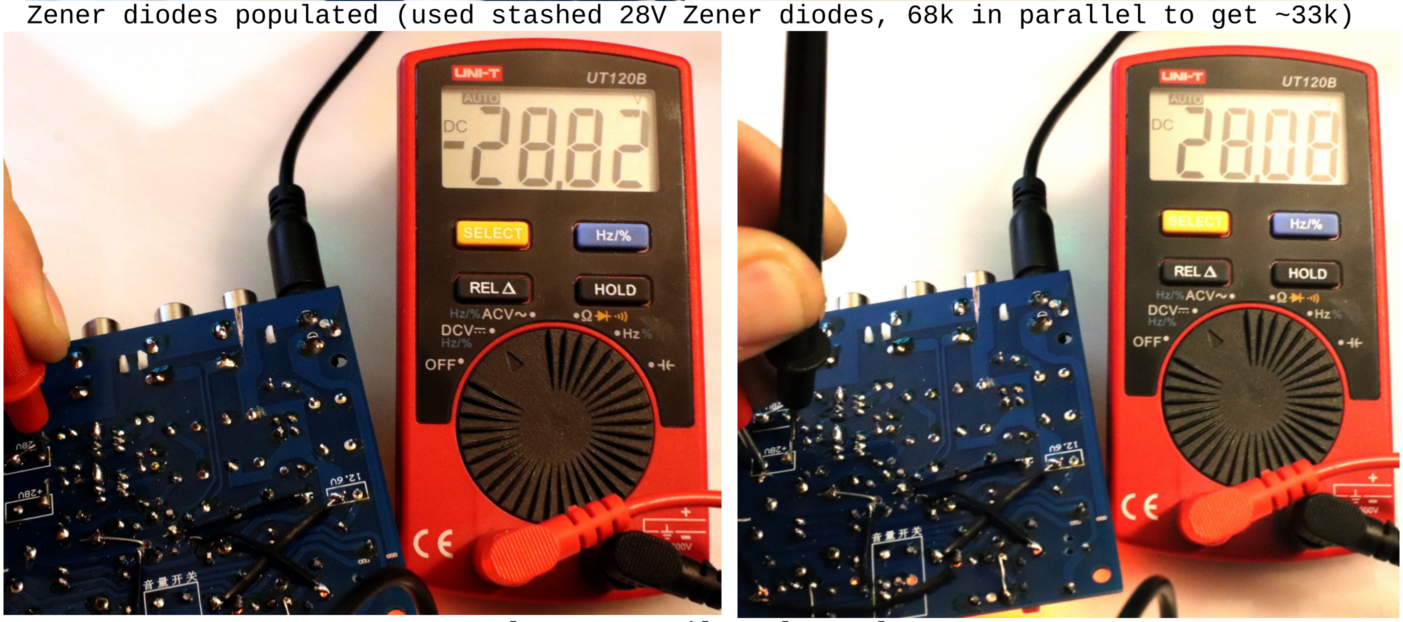
Cathode follower construction



Drill positions and components placement
(jumper links in orange, wire in black, cuts and components in red).



Zener diodes populated (used stashed 28V Zener diodes, 68k in parallel to get ~33k)

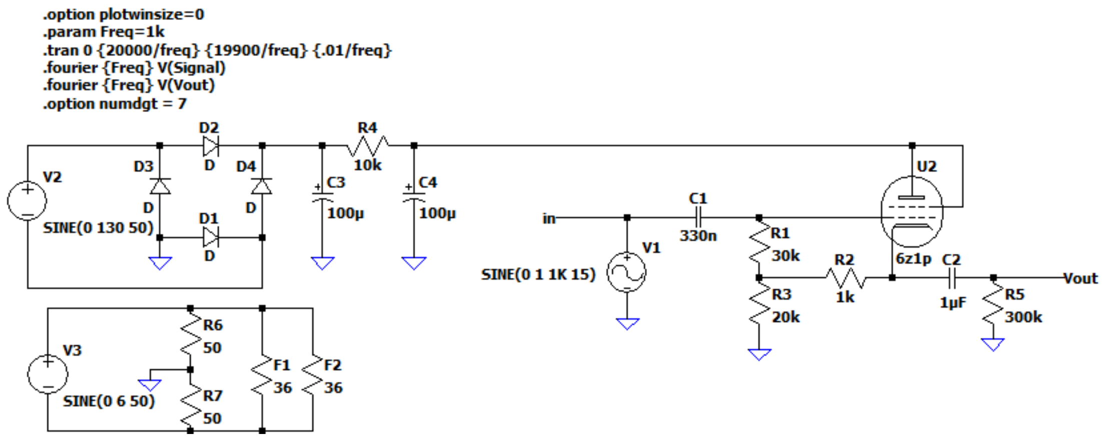


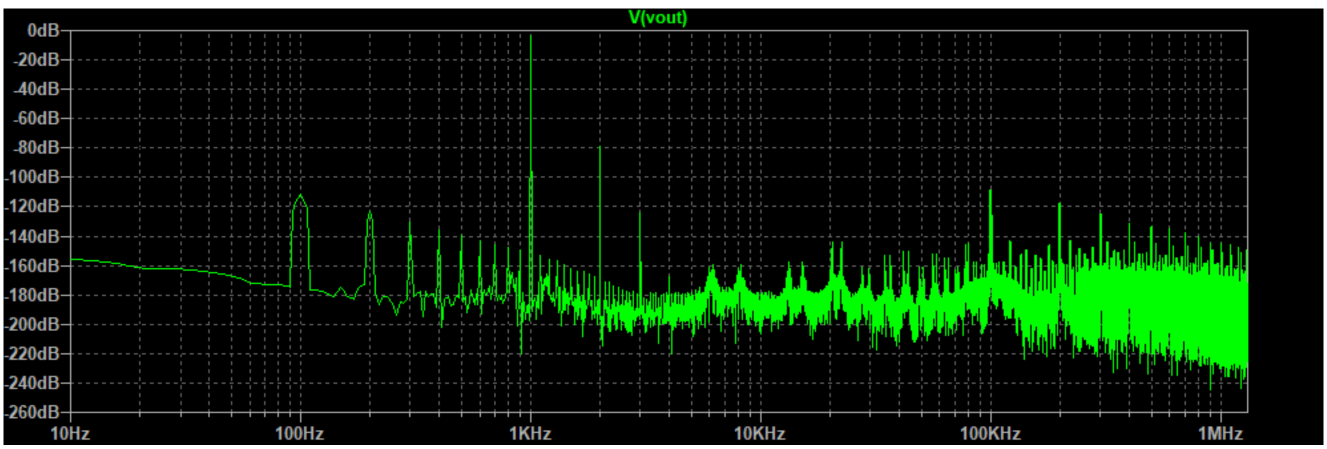
Voltage at rails Vcl-, Vcl+

Construction for testing

Alternative cathode follower

Let us now discuss the design preferred by Adason whether previously proposed changes withstand the comparison. We cannot really compare to the common cathode design as they are not comparable, let us use it for cathode follower comparison though.





Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	1.000e+03	9.398e-01	1.000e+00	0.12°	0.00°
2	2.000e+03	1.592e-04	1.694e-04	-90.22°	-90.34°
3	3.000e+03	8.427e-07	8.967e-07	-0.41°	-0.53°
4	4.000e+03	2.487e-08	2.646e-08	176.01°	175.89°
5	5.000e+03	1.226e-08	1.304e-08	-157.89°	-158.02°
6	6.000e+03	4.629e-09	4.926e-09	-99.53°	-99.65°
7	7.000e+03	9.352e-09	9.951e-09	-30.69°	-30.81°
8	8.000e+03	1.657e-08	1.763e-08	-18.12°	-18.24°
9	9.000e+03	2.339e-08	2.489e-08	-14.01°	-14.14°

Total Harmonic Distortion: 0.016937%(0.021129%)

Conclusion

There are 5 more components necessary for the modifications
1 capacitor 2200uF/25V
2 zener diodes e.g. 1N4750A
2 biasing resistors 68k (33k with cathode follower)
1 resistor 2.2k (when one decides to sacrifice 5dB of gain)

Let me calculate additional cost with DigiKey (cheapest selected)

1 capacitor	2200uF/25V	$0.29808	**$0.29808**
2 zener diodes	1N4750A	$0.14000	**$0.28000**
2 biasing resistors	68k	$0.10000	**$0.20000**
1 resistor	2.2k	$0.10000	**$0.10000**

That would make **~$1** more in total.

Thus I believe everyone can now conclude on the expectations from the 6J1 preamplifier amplification/distortion-wise and what construction/modification path to take if any. If you find my thoughts useful please consider **buying me a beer** for the dedicated free time in the span of 3 months, specially if you want to use my design for commercial purposes (**yes, I mean you Chinese people too**)