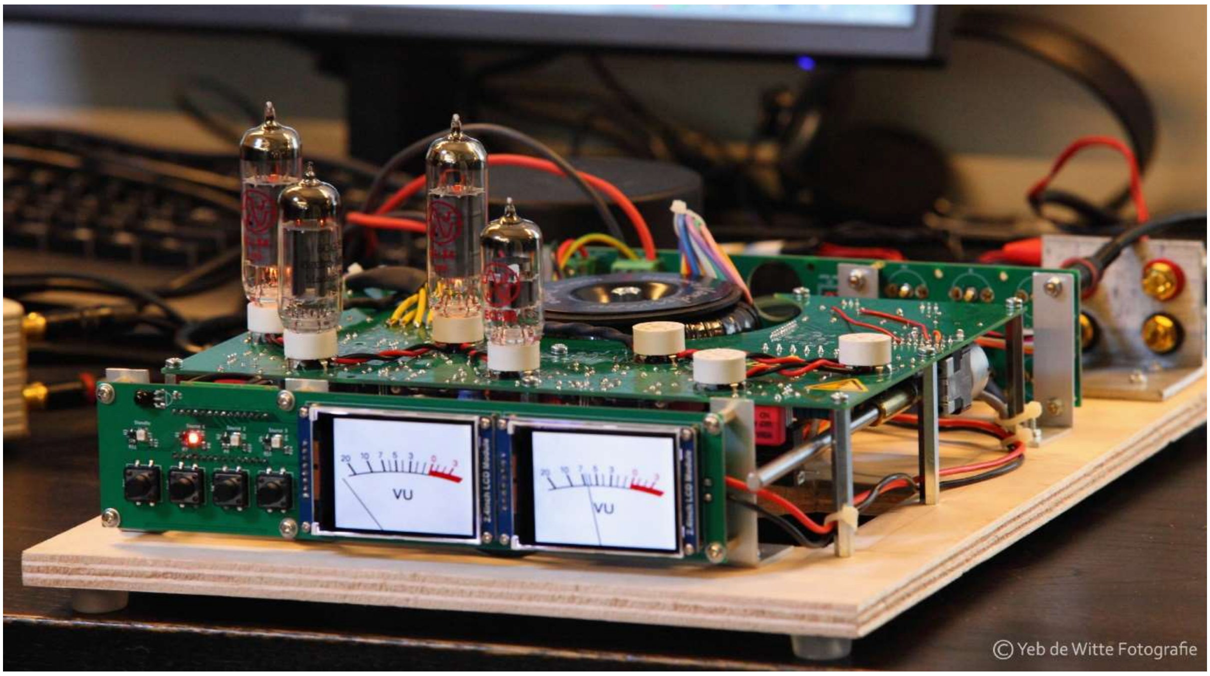
EL84 Push-Pull Amplifier

Joost Breed – TubeSociety 2021



I'm a first year student of TubeSociety and the stereo amplifier described here is my first attempt of building an (tube) audio amplifier. It was supposed to be a simple EL84 amplifier, but I had so much fun designing it that it got out of hand very quickly and a lot of features were added including a microcontroller. Not all of those features will be discussed in detail in this document. Some of them have not been tested yet. Below a list of features I've implemented.

- Low noise Active Volume Control by Texas Instruments [1]
- 600MHz microcontroller with audio board
- Remote control for selecting source and controlling the volume.
- Motorized potentiometer
- Stand-by switch
- 3 Source inputs
- Mute function
- Audio level measurements
- Cathode current measurements
- LCD VU Meters
- FFT Spectrum measurements
- Autobias control

My initial goal was to build a low distortion amplifier. I've been searching the internet for inspiration and found some interesting examples [2] on which I based the design of the preamplifier and the phase inverter.

SPICE simulation

I wanted to simulate my design as accurate as possible. So I first build a uTracer6 tube curve tracer [3] to be able to create SPICE models of the actual tubes I bought. These models were then used to simulate and finetune my design before actually building it.

Figure 1- Finished uTracer6 tube curve tracer

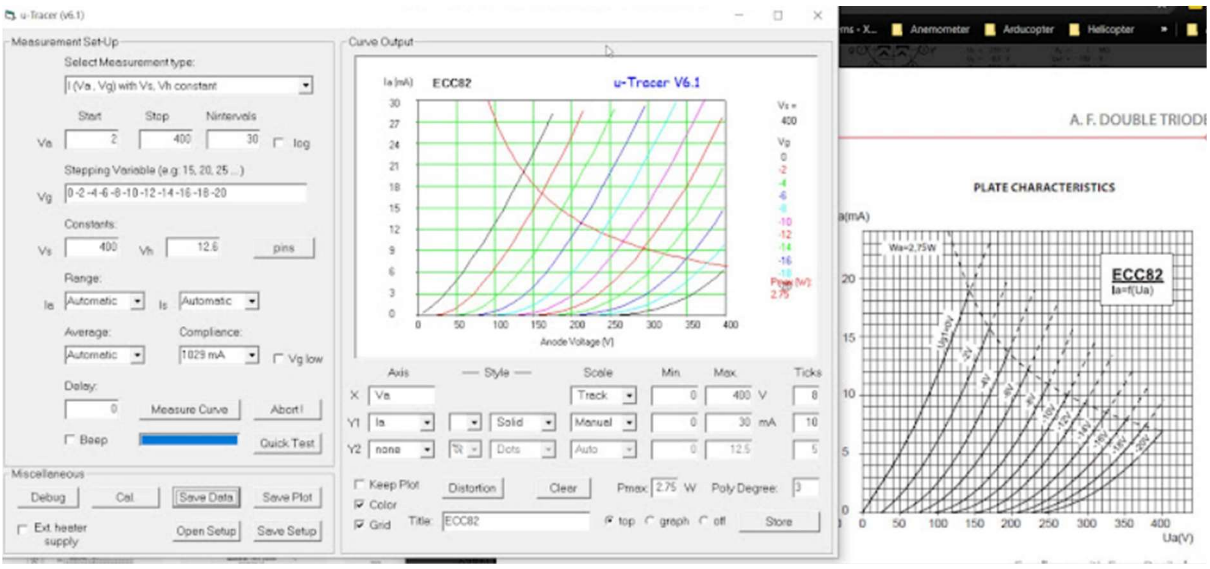


Figure 2 - Measuring an ECC82 with the uTracer6

Below the spice model of an EL84 generated with the use of the uTracer data.

```
*****************************************************
.SUBCKT EL84_1_200 1 2 3 4 ; A G2 G1 C;
*       Extract V3.000
* Model created: 17-Dec-2021
*
X1 1 2 3 4 PenthodeD  MU= 20.9 EX=1.679 kG1= 460.5 KP= 130.8 kVB =  3583.6 kG2= 8706.7
+ Ookg1mOokG2=.21E-02 Aokg1=.14E-05 alkg1palskg2=.21E-02 be=   .06 als= 13.97 RGI=2000
+ CCG1=0.0P  CCG2 = 0.0p CPG1 = 0.0p CG1G2 = 0.0p CCP=0.0P  ;
.ENDS

*****************************************************
.SUBCKT PenthodeD 1 2 3 4; A G2 G1 C
*
* NOTE: LOG(x) is base e LOG or natural logarithm.
* For some Spice versions, e.g. MicroCap, this has to be changed to LN(x).
*
RE1   7 0   1MEG    ; DUMMY SO NODE 7 HAS 2 CONNECTIONS
E1 7 0 VALUE=
+{V(2,4)/KP*LOG(1+EXP(KP*(1/MU+V(3,4)/SQRT(KVB+V(2,4)*V(2,4)))))}
E2    8 0 VALUE = {Ookg1mOokG2 + Aokg1*V(1,4) - alkg1palskg2/(1 + be*V(1,4))}
G1    1 4  VALUE = {0.5*(PWR(V(7),EX)+PWRS(V(7),EX))*V(8)}
G2    2 4 VALUE = {0.5*(PWR(V(7),EX)+PWRS(V(7),EX))/KG2 * (1+ als/(1+be*V(1,4)))}
RCP   1 4  1G       ; FOR CONVERGENCE   A  - C
C1    3 4  {CCG1}    ; CATHODE-GRID 1   C  - G1
C4    2 4  {CCG2}    ; CATHODE-GRID 2   C  - G2
C5    2 3  {CG1G2}    ; GRID 1 -GRID 2  G1  - G2
C2    1 3  {CPG1}  ; GRID 1-PLATE      G1 - A
C3    1 4  {CCP}   ; CATHODE-PLATE     A  - C
R1    3 5  {RGI}   ; FOR GRID CURRENT  G1 - 5
D3    5 4  DX      ; FOR GRID CURRENT  5  - C
.MODEL DX D(IS=1N RS=1 CJO=10PF TT=1N)
.ENDS PenthodeD
```

A schematic was built in LTSpice and several component models were included.

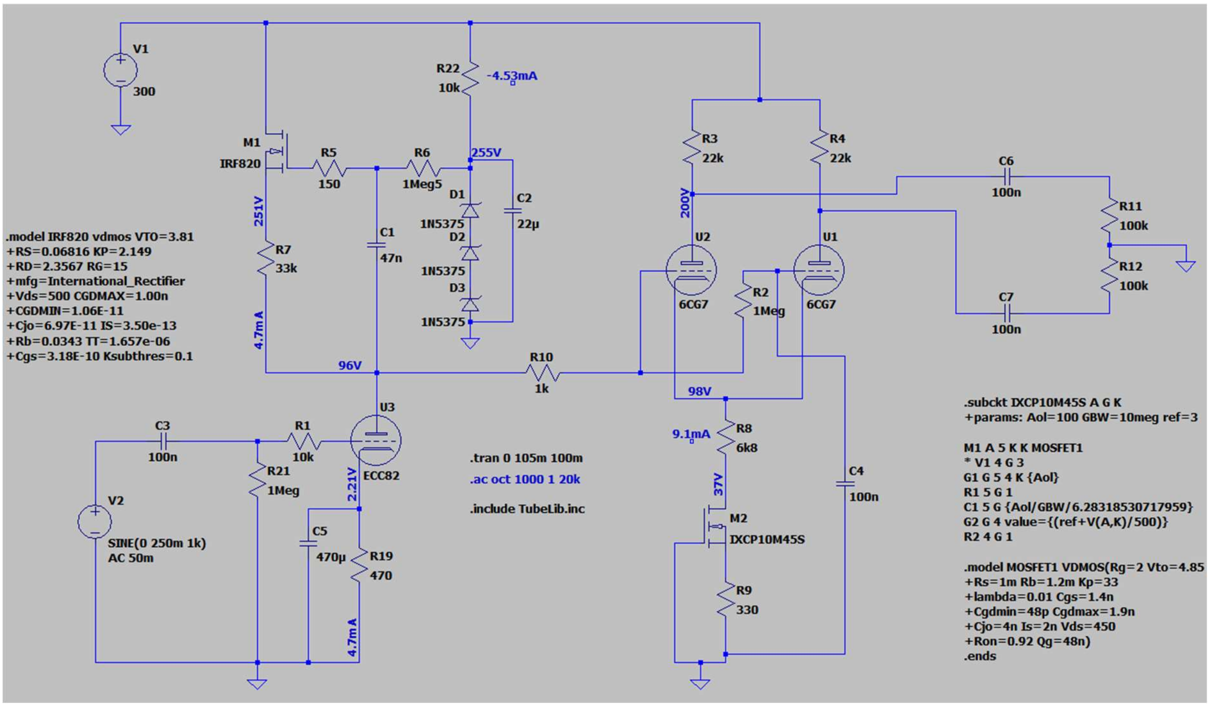


Figure 3 - Part of the amplifier in LTSpice simulator

Testing the design on a breadboard

After I finished the simulations I built the amplifier on a breadboard and compared my measurements with the simulations.

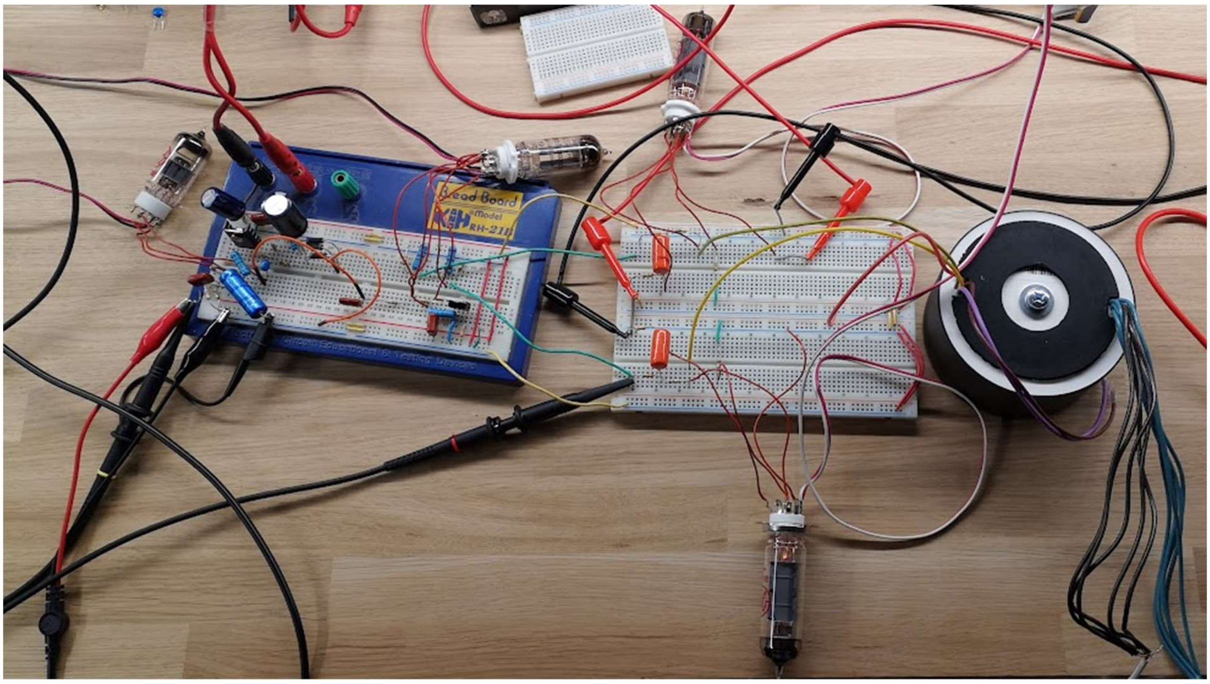


Figure 4 – The complete amplifier build on the breadboard

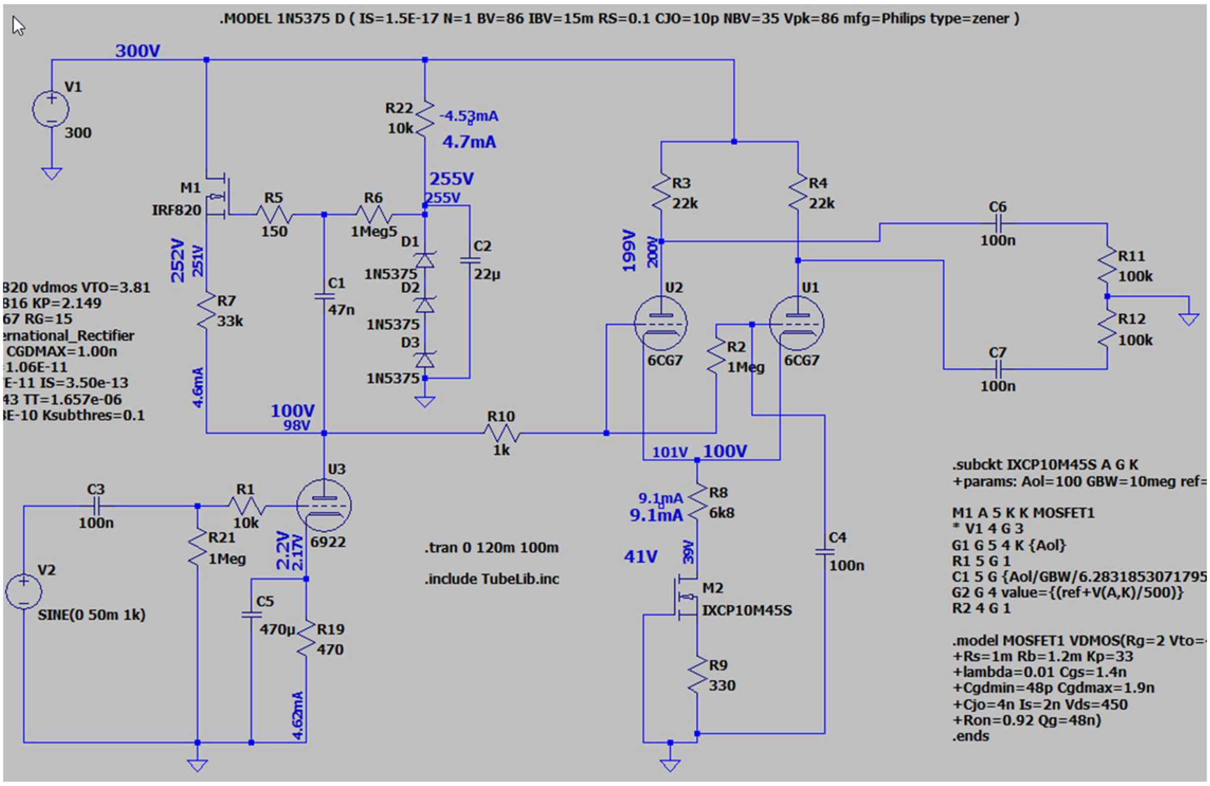


Figure 5 - Simulated DC voltages and currents (small font) next to the measured voltages and currents (large font)

As you can see in figure 5, where I added the measured DC values in a larger font next to the simulated values, that the measured values are almost spot on.

Next the AC measurements were done with an oscilloscope and compared with the simulation as well.

Figure 6 - Oscilloscope measurements. Yellow: Input signal, Pink: pre-amplified signal, Green/Blue: after phase inverter

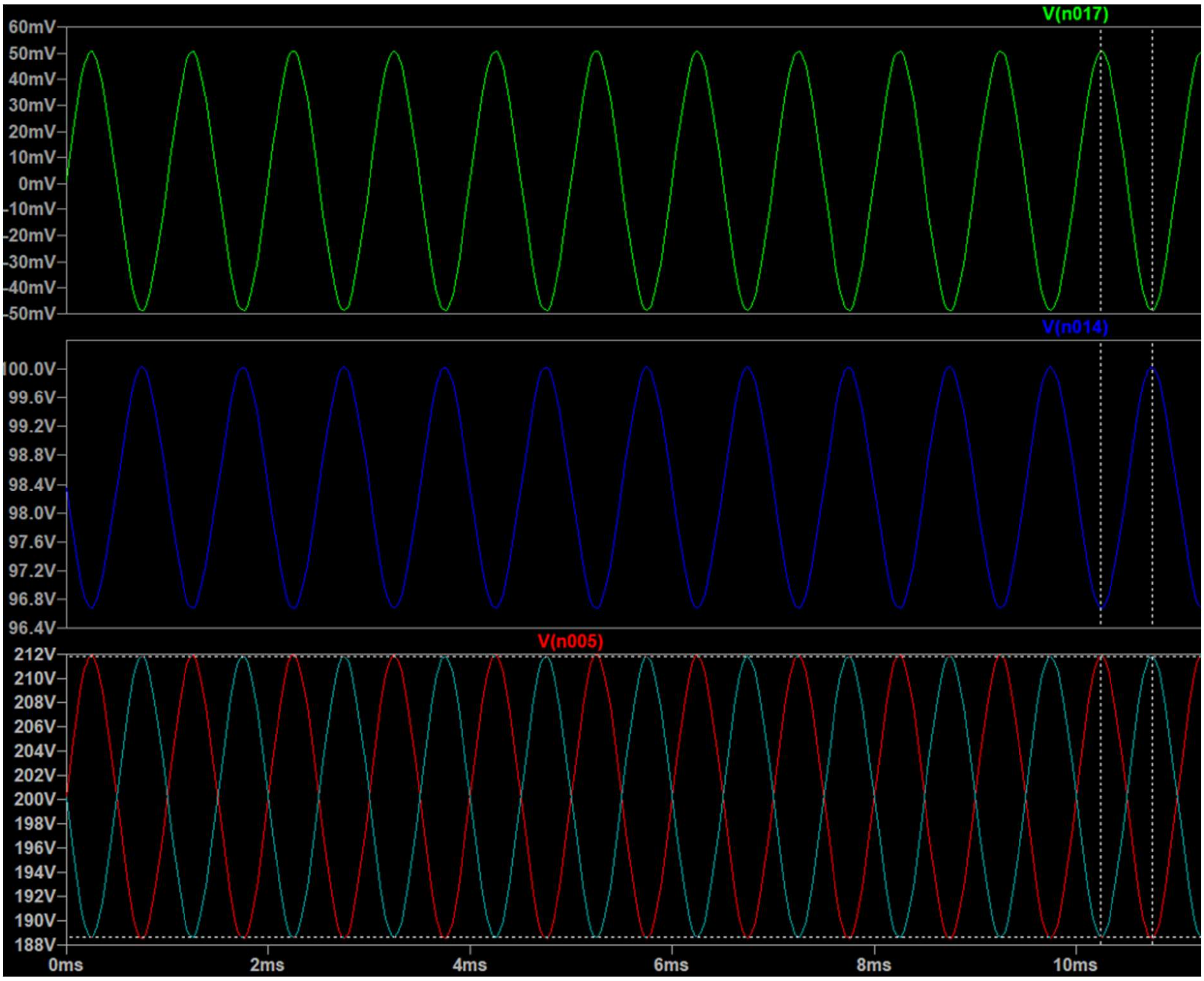


Figure 7 - LTSpice simulation output of the ac signals. ***Green****: Input signal,* ***Blue****: pre-amplified signal,* ***Red/Cyan****: signal output of the phase inverter*

The measured signals were not far off as you can see in the next table.

	Simulated	**Measured**
Input signal	100mVpp	100mVpp
Signal after preamp	3.4Vpp	3.5Vpp
Signal after phase inverter	23.2Vpp	23.3Vpp / 27.3Vpp

The preamplifier tube used during these tests was a 6922. It was replaced by an ECC82 later.

A distortion measurement was made with ARTA-2 and a Focusrite Scarlett Solo soundcard.

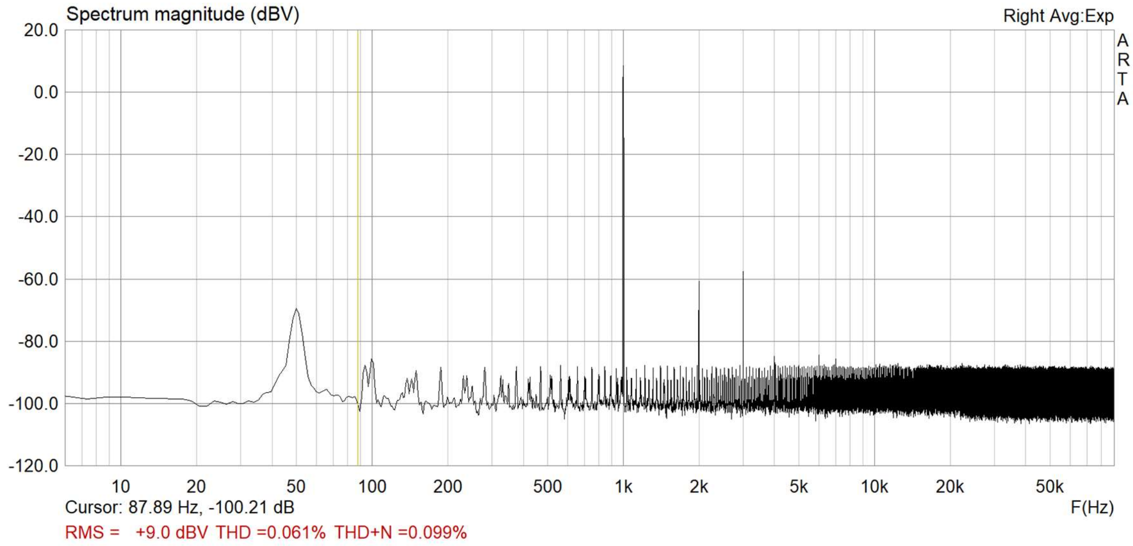


Figure 8 - Distortion measurement of the circuit on the breadboard

The distortion of the complete amplifier, including the output stage, at 9dBV output signal was measured to be THD= 0.061%, THD+N = 0.099%. The noise floor is around 90dB. The high frequency noise is coming from the power supply which is of a flyback converter type.

Amplifier design

The amplifier consists of three main components. The pre-amplifier, the phase inverter and the power amplifier. Three separate Printed Circuit Boards (pcbs) have been designed for this amplifier. One for the RCA connectors, the source selection relays and the power supply relays. Another pcb holds the front panel components. It holds the LCDs, a microcontroller, buttons, LEDs and an IR sensor for the remote control. One large pcb has been designed for the amplifier, volume control and the DC power supplies.

Figure 9 - The populated PCBs

Preamplifier

The preamplifier is based on a design I came across on the internet. I changed it to make it work with another tube, the ECC82, and a 300V supply instead of a 400V supply.

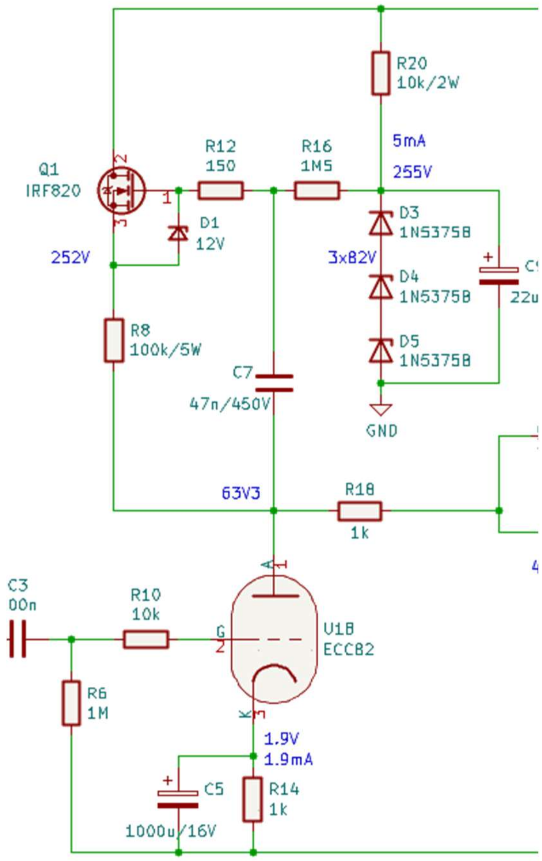


Figure 10 - The preamp circuit

The circuit contains a bootstrap circuit build around MOSFET source follower. The amplified ac signal is fed to the gate of the MOSFET through capacitor C7. The source of the MOSFET will follow the gate exactly. So the ac signal at the top of R8 is the same as at the anode of the tube. Therefore resistor R8 will only see a dc current and the ac signal will see a very high impedance. The impedance the plate sees is limited by the 1.5 Mega-Ω resistor. And because the plate sees a high impedance the amplification factor of the amplifier will be almost the same as the amplification factor of the tube (µ).

Phase inverter

The phase inverter is built as a basic differential amplifier with a 6CG7 and a constant current source build with a MOSFET. R35 sets the current to 9.3 mA. C11 shorts the grid of the right tube to ground for ac signals.

Trimpot R30 is used to balance the two output signals and minimize 2nd harmonic distortion.

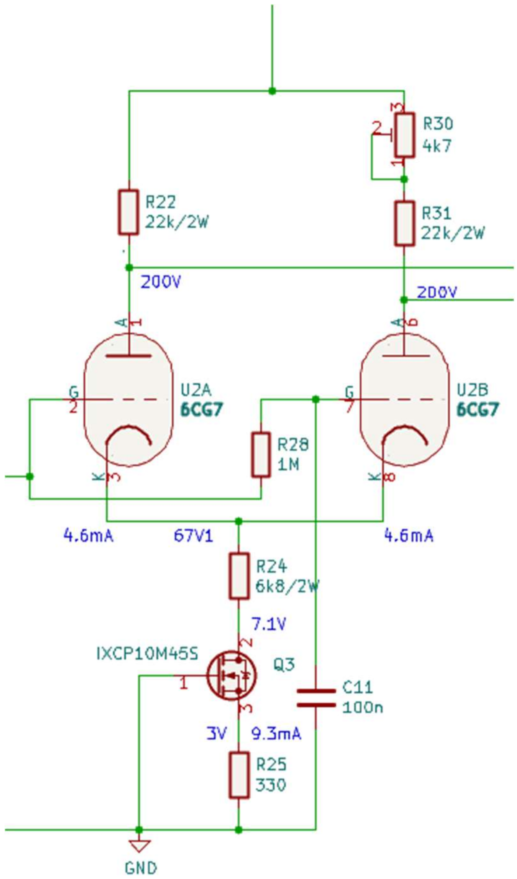


Figure 11 - The phase inverter circuit

Power amplifier

For the power amplifier EL84 tubes in a push-pull configuration are used. The transformer used is a VDV-8020-PP. It has an 8 kΩ primary impedance and a 5 Ω secondary impedance. Local feedback has been applied the same way as done with an operational amplifier with a ratio of a about 5.5. The cathode current for each EL84 has been set to 50 mA.

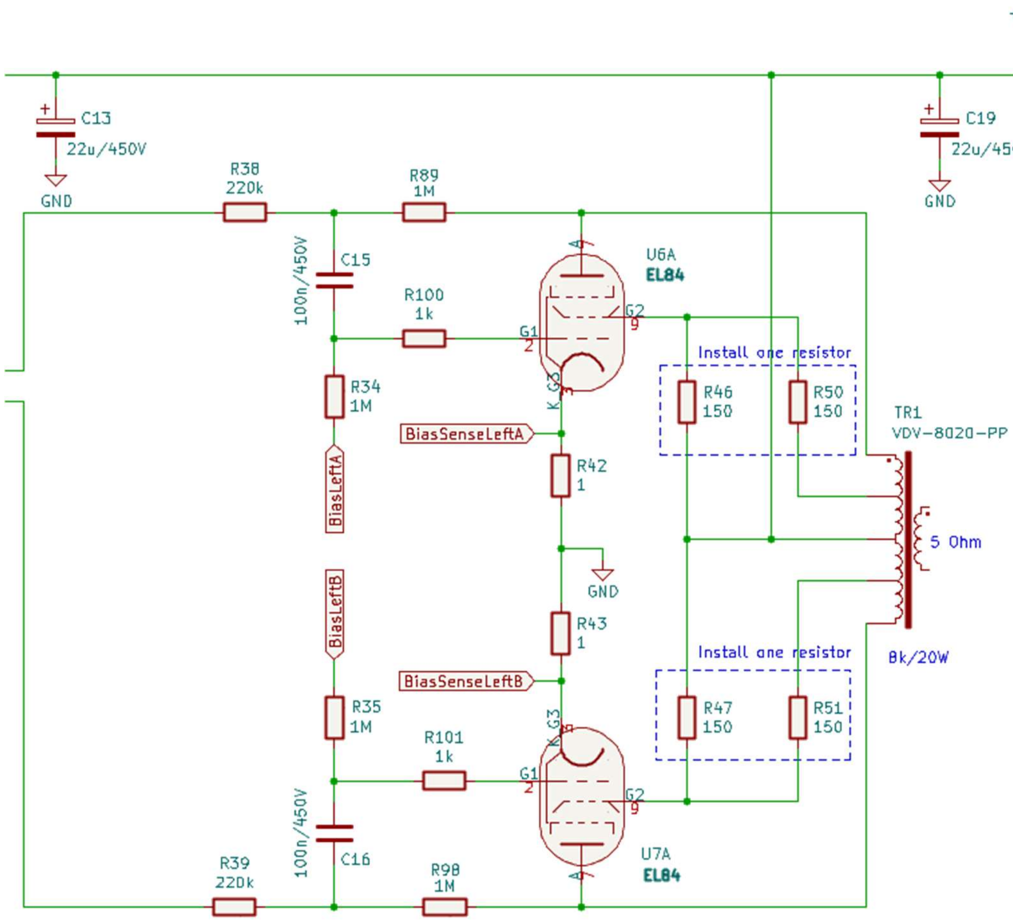


Figure 12 - The power amplifier stage

The output power was measured into a 8 Ω load with the use of an oscilloscope and a current probe. It turned out to be around 12 W. The total amplification is 26.5 x from input to the 5 Ohm secondary tap loaded with 8 Ohm.

Figure 13 - Oscilloscope power measurement

Power supply

The transformer used is a VDV-POW80. It has 230VAC / 300mA, 25VAC / 100mA and 2x 6.3V / 3A outputs. The power supply creates a 300V DC voltage for the tubes. A capacitance multiplier is used to get rid of the 100Hz ripple. The +12 and -12V voltages are made from the 25VAC voltage and two linear regulators to power the opamps. The -12V rail is also used for the negative bias voltage of the EL84 tubes.

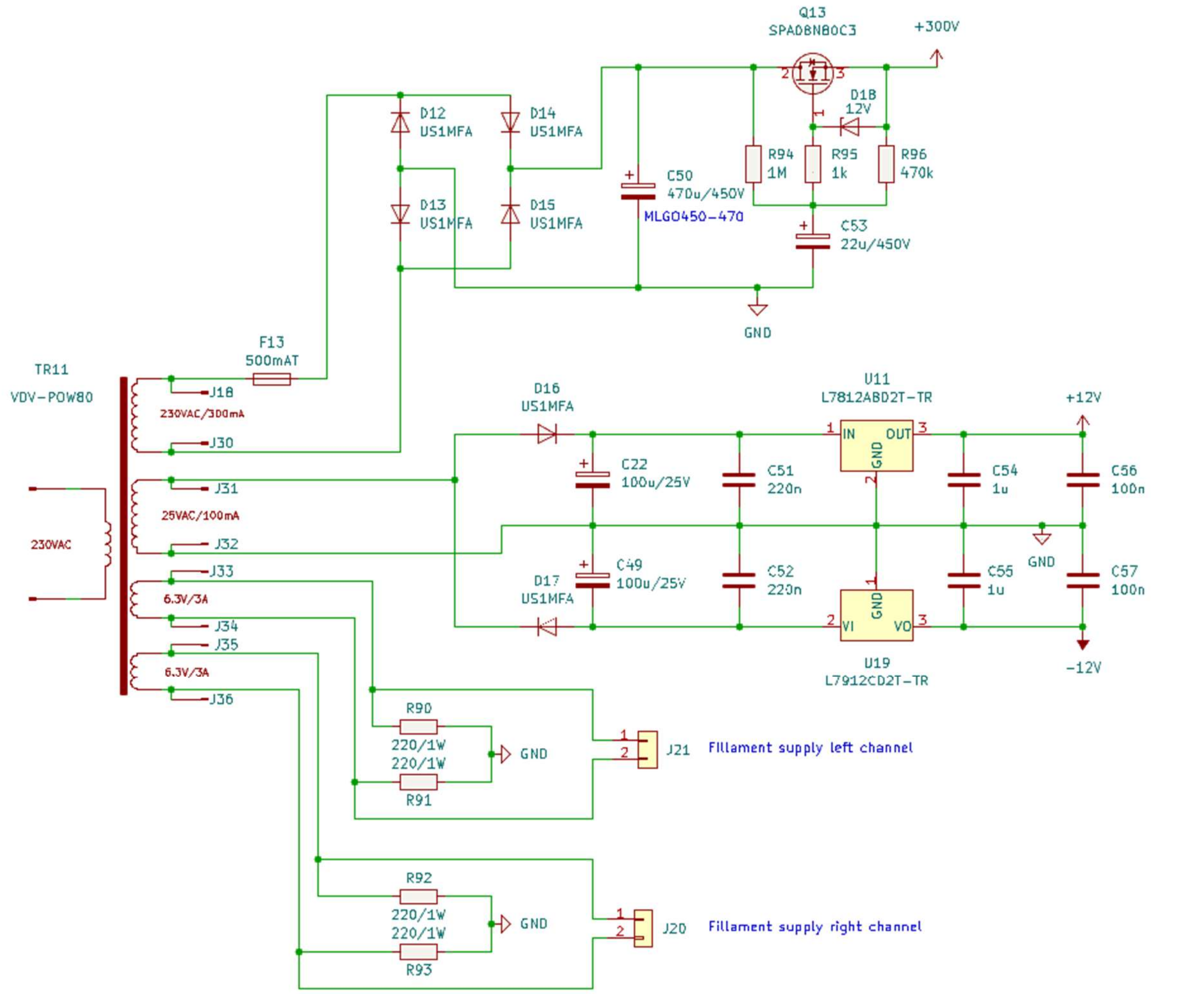


Figure 14 - The power supply circuit

Back panel

The back panel contains of some relays for the source selection and buffer opamp for the audio level measurements. It also contains the mains input circuitry with a resistor and capacitor to connect the audio ground to mains earth.

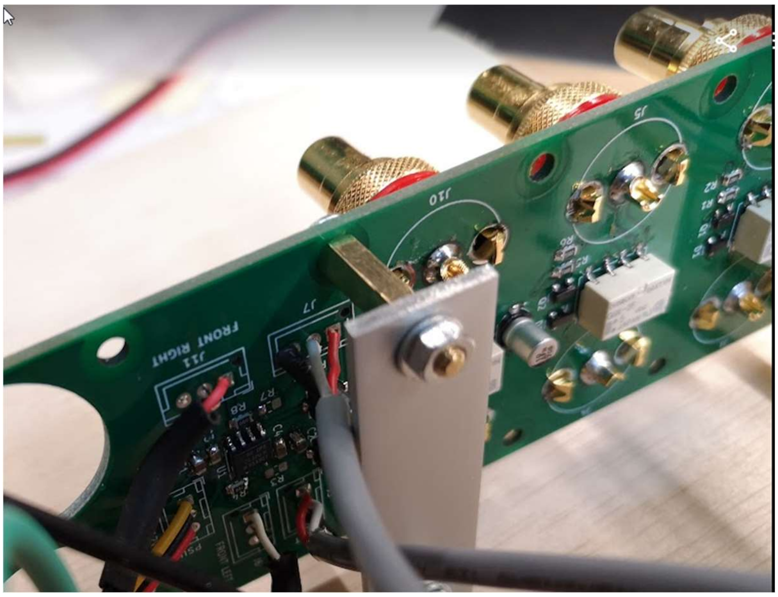


Figure 15 - Part of the back panel pcb

Front panel

The front panel contains the lcd panels, function buttons, infrared sensor for the remote control, a microcontroller and an audio module for sampling the input signal. The microcontroller also controls the relays.

Figure 15 - The front panel pcb with lcds

Measurement results

Some measurements have been made with ARTA-2.

The bandwidth of the amplifier turned out to be 8 Hz – 40 kHz.

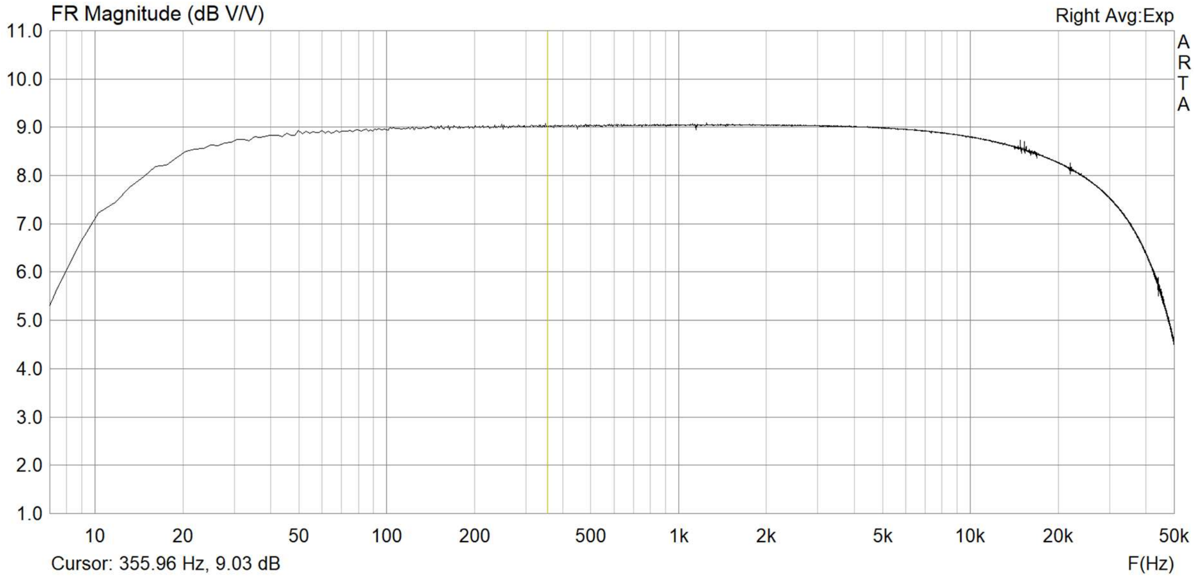


Figure 16 - Bandwidth measurement

The distortion measured at +9 dBV output signal: THD =0.061%, THD+N =0.086%

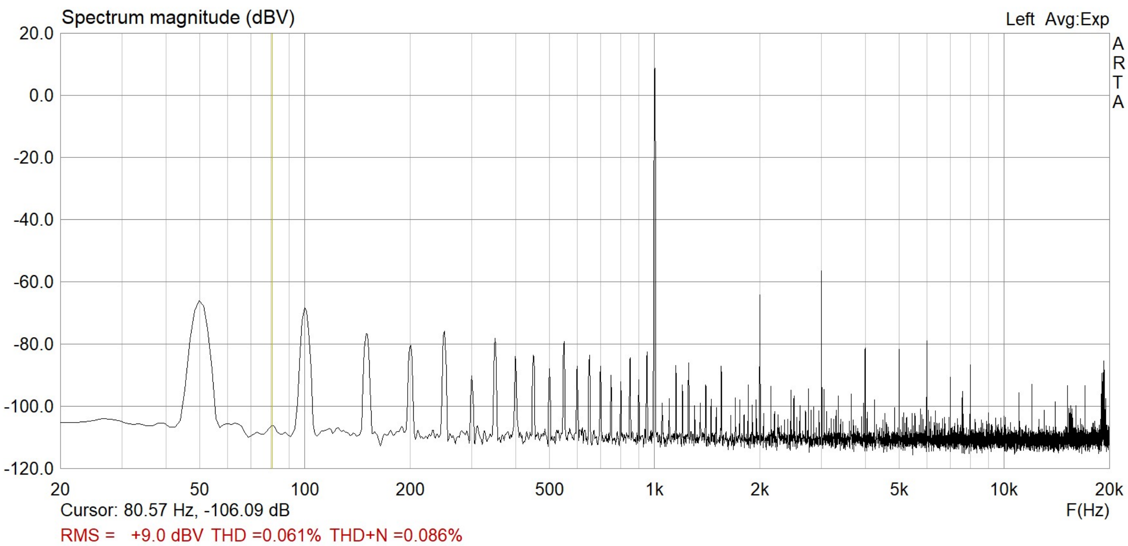


Figure 17 - Distortion measurement complete amplifier @ +9 dBV output level (105 mVrms input signal)

The spectrum contains more 50 Hz harmonics then when measured when the amplifier was built on the breadboard. This is because the breadboard circuit was powered by laboratory power supplies instead of a transformer and rectifier. Also the filament supplies where DC fed on the breadboard. Therefore I've decided to do a redesign of the power supply circuit, change the layout of the pcb and add some extra shielding in order to fix this problem and try to lower the noise floor.

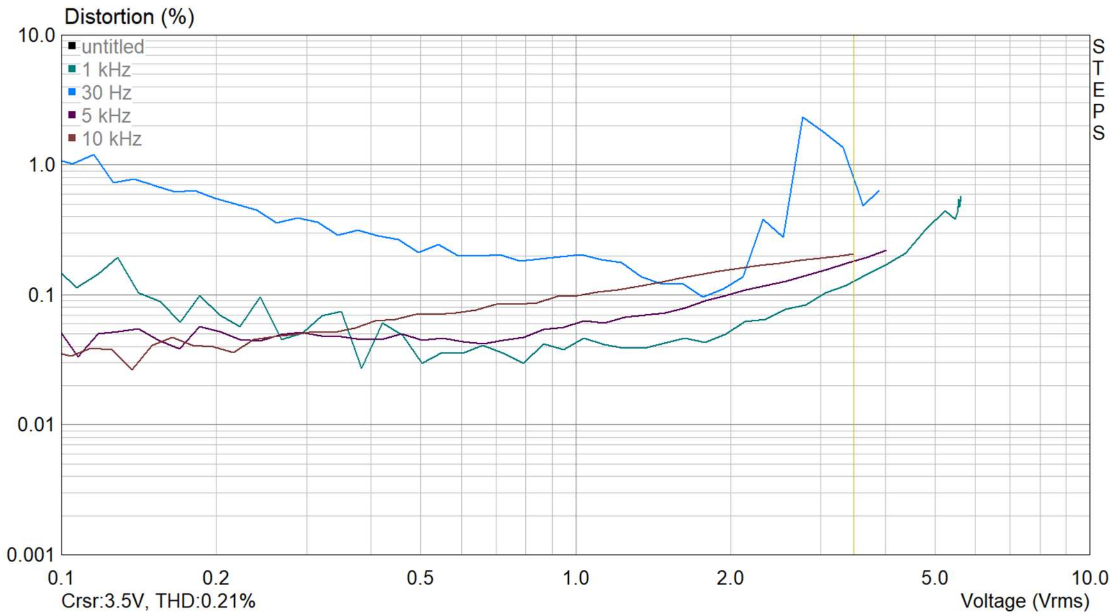


Figure 18 – Distortion against voltage at different frequencies

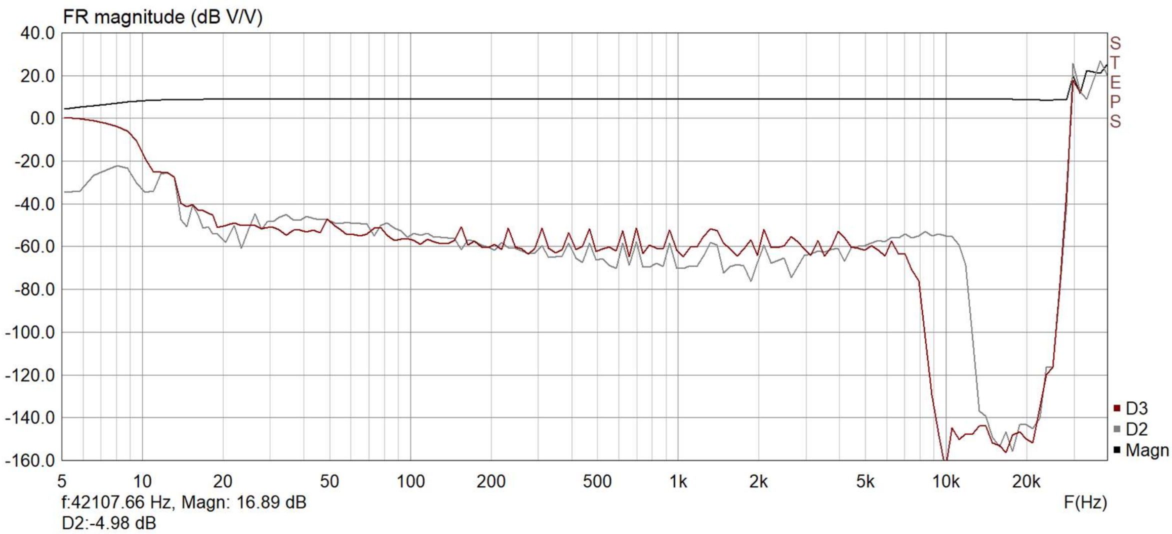


Figure 19 - 2nd and 3rd harmonic distortion measurement

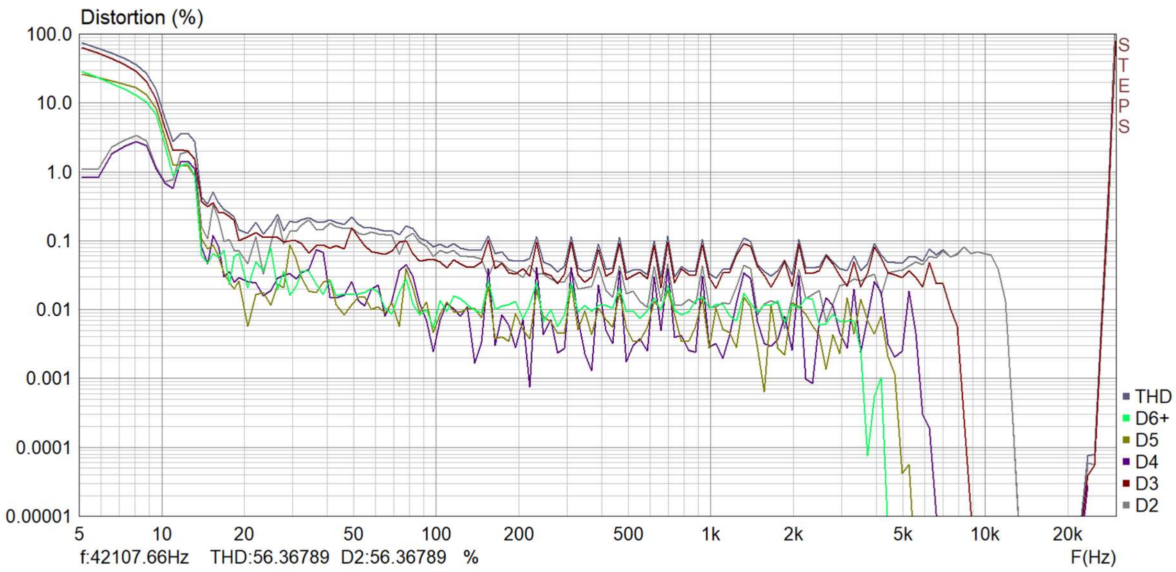


Figure 20 - 2nd to 6+ harmonic distortion measurement

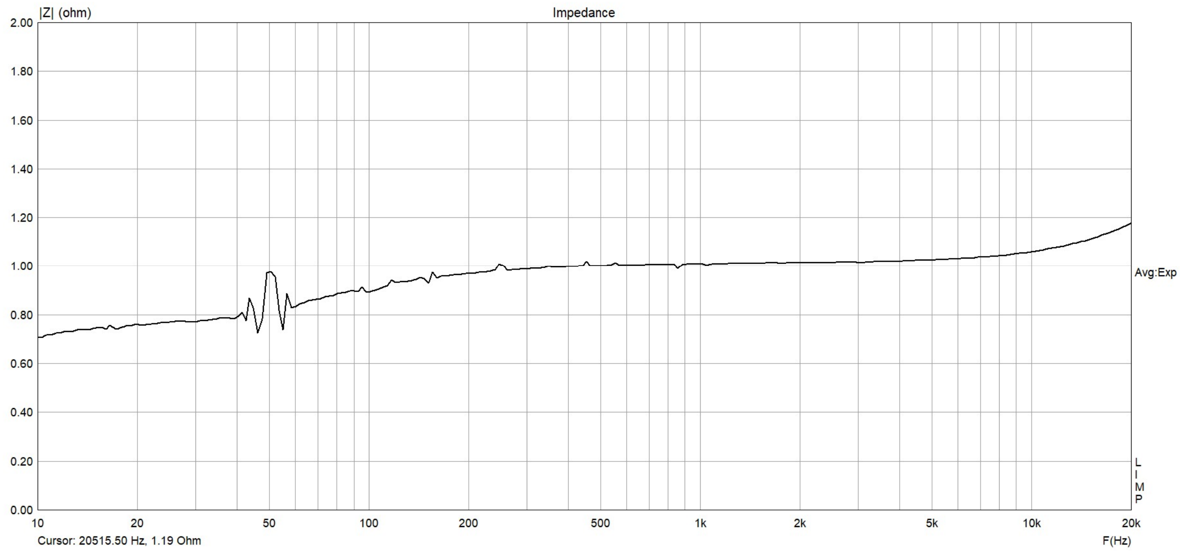


Figure 21 - Output impedance measurement

References

[1] https://www.ti.com/lit/pdf/tidu034

[2] https://www.angelfire.com/electronic/funwithtubes/more_phase_inverter.html

[3] https://www.dos4ever.com/uTracer3/uTracer3_pag0.html