

Let's build electrostatic headphones

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1 Introduction

The following document will describe the journey to construct your own electrostatic headphones starting with zero, zilch, nada, niente and nichts. In Section 2 we will list the tools required for the building process, which will be followed by a list of materials in Section 3. The actual construction process is split into five parts, the building of the driver (Section 4), enclosure (Section 4), headband (Section 6) and earpads (Section 7) with a final assembly in Section 8. Finally, the last two chapters will deal with measurements (Section 10) and things that we would do differently for the second pair (Section 11).

The whole construction is based on the Head-Fi.org thread [1], with different and more detailed sources ([2, 4, 3]) given in the respective sections.

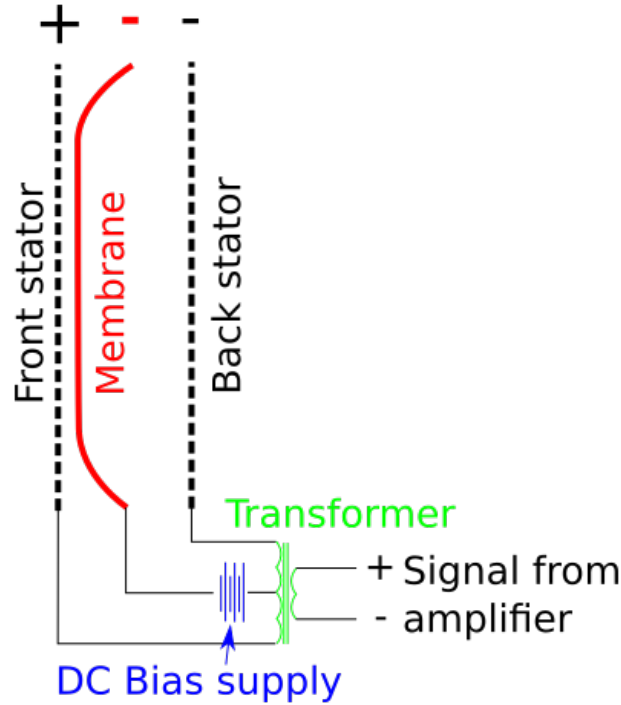


Figure 1: Electrical concept

The basic electrical concept of an electrostatic headphone can be seen in Fig. 1. An amplifier provides an input signal that is then transformed to yield the desired output voltage that drives the two stators. Additionally, there is a negative DC current that keeps the diaphragm charged.

2 Required tools

To build the drivers it is highly recommended that you have access to a good CNC machine. Since we didn't have one of those standing around, we looked for a so called fablab, i.e. a community led workshop for creative projects. We eventually ended up at the Viennese Metalab¹ which gave us access to a heavy duty level CNC machine and an introduction on how to use it by Sebastian Bachmann², which eased the learning curve significantly. The principal introduction included instructions on how to set up, start and operate the machine and the control terminal, as well as some GCode basics (the programming language that controls the machine's behaviour - more on that in section 4.1.1). Most importantly, as it can be potentially quite

¹<https://metalab.at/>

²<https://www.reox.at/>

dangerous to operate one of those things, it covered security basics, which is definitely the first starting point for anyone new to CNC. Don't skip your tutorial lessons, kids!

Since you might be interested in the budget needed for this, it of course depends on the lab's membership policy - most labs we found had a monthly fee with a minimum subscription period, but we were able to come to an arrangement with a voluntary contribution without binding membership. Most people running those kinds of open creative space are pretty chill, so don't be afraid to ask!

If you can't find a place or plan to work on more DIY-projects in the future, it might be worth it to purchase a CNC mill for yourself or with a group of like-minded people. It's amazing what's going on in the field of affordable, small-scale, DIY and hobby-use CNC in the last couple of years. Here are some links if you're more interested in a purchase:

<https://www.millrightcnc.com/product-page/millright-cnc-m3-kit-bundle>

<http://www.makerdreams.it/>

<https://www.sorotec.de/shop/>

Also, some labs require you to buy the wearout parts yourself. You can get CNC tools here:

<http://cnc-plus.de/>

<https://www.sorotec.de/shop/>

An electric drill was used for the assembly screws and headband construction. The earpads were sewn from hand and as such only thread and needle was required for that. The step up transformer that we built to drive the headphones required a basic electronics lab and in particular a soldering station.

3 Required materials

In this section we list all the materials we had to purchase for the headphones and our DIY step-up transformer. We provide you with the links where we bought the materials, but depending on where you live you might find better suppliers yourself.

1. 1 mm PCB FR-4 for stators and dust protection spacers: ³
2. 0.5 mm PCB for spacers: ⁴
3. 3 μm Mylar (for diaphragm): ⁵ (with that, you should have all your mylar needs covered for years to come!)
4. 1 μm Mylar (for dust protection): ⁶
5. Anti-static display cleaner for diaphragm coating: ⁷
6. Acrylic spray for insulating the stators: ⁸
7. Thin and stretchy artificial leather for the earpads and headband (should be available in a textile shop)
8. Wood for the enclosure and headband, several boards with 4mm and 10mm thickness; we used lime and spruce

³<https://www.conrad.com/ce/en/product/523656/PCB-material-Photo-coating-positive-single-sided-35-m?ref=list>

⁴<https://www.conrad.com/ce/en/product/523630/PCB-material-Photo-coating-positive-single-sided-35-m?ref=list>

⁵<https://www.ebay.com/itm/Electrostatic-Speaker-Membrane-Dupont-Mylar-C-3um-40M/172781729300?epid=666335680&hash=item283a97f614:g:jg0AA0SvrkLVPe61>

⁶<https://www.freeflightsupplies.co.uk/index.php/products/lightweight-covering-materials>

⁷<https://www.conrad.com/ce/en/product/995207/DataFlash-DF1620-Content-250-ml?ref=searchDetail>

⁸<https://www.conrad.com/ce/en/product/1198455/Acrylic-paint-Revell-Black-matt-08-Spray-can-100?ref=searchDetail>

9. Metal rods (3mm welding rods) for the headband
10. 3 cm acoustic foam (pads and headband)
11. Cable plus connectors
12. Screws for the assembly (2,5 x 20 mm)
13. Clear varnish or glaze for wood finish
14. Two-component glue: ⁹
15. Contact glue for gluing the membrane to the stators and the earpads: ¹⁰

Here's a more comprehensive list of material suppliers: <http://www.head-fi.org/t/826032/electrostatic-ear-speaker->

Materials needed for the amplifier:

1. 4 Audio transformers 6V - 230V (OEP N35A002F) ¹¹
2. 1 Power transformer 230V - 230V (Triad Magnetics FP230-25) ¹²
3. 2 1 Ohm wirewound resistors ¹³
4. 6 1kV diodes ¹⁴
5. 2 10 MOhm resistors ¹⁵
6. 6 10 nF capacitors ¹⁶
7. 1 3.9 kOhm resistor ¹⁷
8. Power cord plus plug
9. Cables
10. Test circuit board

4 Building the driver

4.1 Design of the stators and spacers

In the following the stators and spacers will be designed and the designs will be prepared for CNC milling. As the stators and spacers are 2-D, we decided to use Inkscape ¹⁸ for our design purposes. There are plenty of guides on how to use Inkscape around so we assume that the reader is familiar with it. But in the end we almost exclusively used the basic objects like spheres and ellipses and boolean operators (to be found under the *Path* menu).

⁹<https://www.conrad.com/ce/en/product/478703/UHU-Plus-Schnellfest-Two-component-adhesive-45700-35-g?ref=list>

¹⁰<https://www.conrad.com/ce/en/product/631802/UHU-greenit-Contact-adhesive-45401-650-g?ref=searchDetail>

¹¹<https://uk.rs-online.com/web/p/audio-transformers/2106475/>

¹²<https://eu.mouser.com/search/ProductDetail.aspx?r=553-FP230-25>

¹³<https://eu.mouser.com/search/ProductDetail.aspx?r=71-RS0101R000FE73>

¹⁴<https://eu.mouser.com/search/ProductDetail.aspx?r=625-RGP10M-E3>

¹⁵<https://eu.mouser.com/search/ProductDetail.aspx?r=594-SFR25H0001005JR5>

¹⁶<https://eu.mouser.com/search/ProductDetail.aspx?r=75-564R30GAS10>

¹⁷www.aliexpress.com

¹⁸<https://www.inkscape.org>

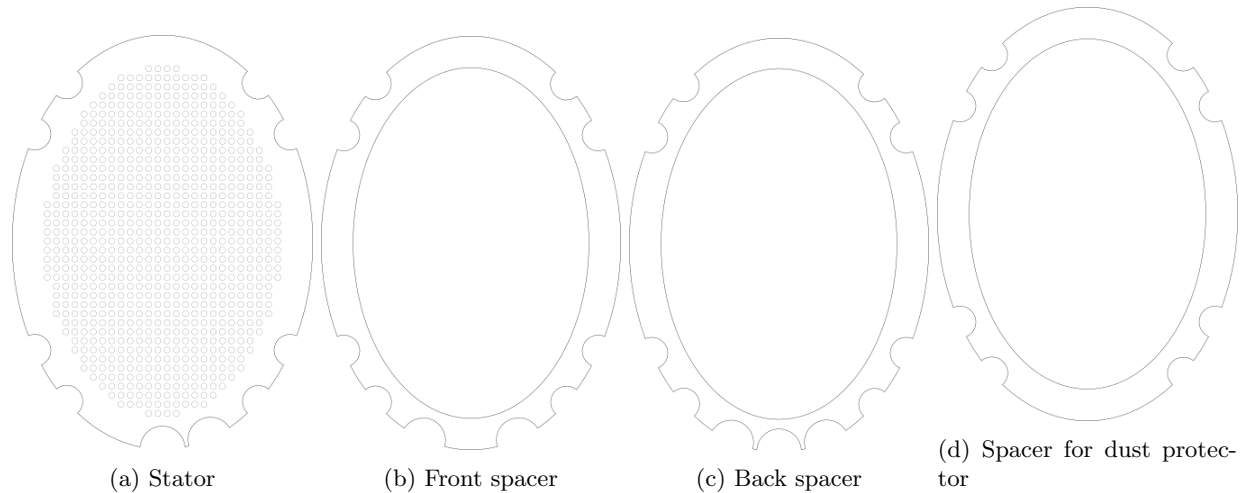


Figure 2: All PCB driver components

In general the ellipse which contains all driver components is 130 mm high and 94 mm wide. The inner ellipse that determines the active area is 110 mm high and 74 mm wide. The holes drilled into the stator only cover this active area and are laid out such that approximately 40% of the active area is open, i.e. covered by holes. The distance between the holes is 0.8421 mm in vertical and 0.88 mm in horizontal direction and each hole has a diameter of 2 mm. To generate such a tiled array of holes in Inkscape draw one hole and then use the *Create tiled clones* option that can be found under *Edit - Clone*. The holes outside the active area are where removed manually. The resulting stator can be seen in Fig. 2a. A total of four stators need to be milled from 1mm FR4 PCB. The eight cut-outs that are present in each driver component were designed to allow easier screw insertion in the enclosing. It turned out though that we only needed four screws in the end and it would have been possible to work without those cut-outs at all. At the bottom of the components there is a varying number of half-circle cut-outs. These ensure that cables can be connected at other components and provide insulation to the present one. The front and back stator seen in Fig. 2b and Fig. 2c are made from 0.5 mm FR4 PCB. The dust spacer in Fig. 2d is made from 1 mm PCB. Each spacer needs to be produced twice, one for each side.

A few general design guidelines that we found on the head-fi thread indicated the following. The diameter of the holes (2 mm in our case) should not be larger than the distance from stator to spacer. The reason for not having the holes cover the whole stator is that this increases the stability of the stator. A large diaphragm size is quite important as this improves low frequency response. Obviously, if the open area becomes too large then the diaphragm will be too flexible and touch the stators which will cause it to discharge. Because of this the ratio of spacer thickness to diaphragm width should not be larger than 1:120. If this ratio is very large a lower bias voltage can be used to avoid the membrane touching the stators.

All *.svg files that are used for the CNC milling can be found in the *resources.zip* which can be found on github.com¹⁹.

4.1.1 Gcode creation

After creating the *.svgs with the outline of all shapes the next step is to produce Gcode, i.e. the instructions for the CNC machine that can be understood by it. Note that we were using a CNC machine that was using LinuxCNC and it pretty much understood the Gcode produced by the tool presented in the following. The first important step is to create a milling strategy. For all FR4 parts (stators and spacers) we decided to use double sided tape to glue the FR4 boards to a flat piece of scrap wood. This means that all paths will

¹⁹<https://github.com/Azrael3000/headphone-guide/raw/master/resources.zip>

be cut 0.2mm deeper than the FR4 thickness. This ensures that the milling is deep enough and only leaves some scratches on the scrap wood.

Before we start with the Gcode creation we need to decide on which drills and end mills to use. Our choice for the FR4 milling consisted of a 2mm drill and a 2mm diamond coated end mill. The drill is only used for the creation of the stator holes and the end mill is used for everything else. The end mill used in our case would allow us for a vertical feed rate of 300 mm/min and a horizontal feed rate of 1000 mm/min. The spindle speed was set to 24000 rpm.

To create the Gcode from the Inkscape file we use www.makercam.org which allows a platform independent operation. It's a flash tool which allows for 2.5D designs and does everything we need for the headphone construction.

After creating the *.ngc file a few manual modifications needed to be made in our case. What is required here exactly depends on your CNC machine so either use your own personal experience or talk to someone who knows the machine you are using to avoid damaging it. In our case we needed to warm up the spindle first starting with 6000 rpm and then increasing it slowly to 24000 rpm. An exemplary Gcode file is listed below where we only took the first few lines of the file as only those need modification.

(Generated by PartKam Version 0.05)

```
G21 G90 G40
(drill 1)
G0 Z15
T0 M6
G17
M3
G0 X11.05 Y65
G1 Z-1.1 F300
G3 X11.761421319796954 Y53.845177664974614 I87.68274111675127 J0 F1000
```

Let us go through this line by line now. The first line is a comment as indicated by the brackets around it. The second line *G21 G90 G40* sets the units to mm relative to the zero position of the part and turns off cutter radius compensation. It is again followed by a comment. Line four then has the first movement command *G0 Z15*. The *G0* indicates that it is a fast move, i.e. a move in the air and not inside the material. It moves the the tip of our tool to a position which is 15mm above 0 at it's current x and y position. Note that in our case the x axis indicated left and right, y front and back and z up and down. You should ensure that you know the movement axes of your machine. The next command *T0 M6* is a tool selector. As our CNC machine did not have the capability to change its tools this irrelevant and will be deleted. The *G17* command sets the working plane to the XY axes. The *M3* command turns on the spindle. Not that it does not indicate a spindle speed so we need to change this. *G0* is a fast movement command, as X and Y positions are specified, no movement in Z direction will happen. Such a movement can be seen in the next line, i.e. the *G1* command. This is a linear movement to the specified, in this case Z position. In contrast to the *G0* command, this movement does not happen at maximum speed but at the specified one, here *F300* specifies 300 mm/min which corresponds to the plunge rate. The *G3* command specifies a circular interpolation and for us indicates the begin of the horizontal movement with a feed rate of 1000 mm/min.

We make some modifications to this file as can be seen below. The first change is that we move the tool to Z5 before starting the spindle. The spindle is then switched on and set to 6000 rpm with the *M3 S6000* command. The following *G4* command indicates a pause which is specified to last 60 seconds in our case. After that the spindle speed is increased to 12000 rpm up to 24000 rpm with 60 second dwelling periods. This allows the spindle to warm up for milling. Note that the duration of this warm up period depends on your machine. After this warm up a first movement in the X-Y plane is performed as above which is followed by a 5 second pause to check whether everything is correct. Next, the mill is lowered and the main part of the program starts.

(Generated by PartKam Version 0.05)

G21 G90 G40

(profile 1)

G0 Z5

G17

M3 S6000

G4 P60

S12000

G4 P60

S18000

G4 P60

S24000

G4 P60

G0 X11.05 Y65

G4 P5

G1 Z-1.1 F300

G3 X11.761421319796954 Y53.845177664974614 I87.68274111675127 J0 F1000

4.2 Etching the stators

Etching the PCB board ensures that electrical contacts are only where they absolutely need to be. Furthermore, having less copper surface will result in a reduced capacitance and they will be easier to drive because of that. Toner transfer can be used to define the areas that should not be etched. After etching the stators can be protected by spraying thin layers of Acrylic paint on the copper (flat not glossy paint). This insulation avoids degradation of the copper surface and potential shorts when dust is present between the diaphragm and the stators. A small area needs to be left open so that wires can be soldered onto the stators.

<http://www.instructables.com/id/Stop-using-Ferric-Chloride-etchant!--A-better-etc/>

Etching is achieved by using 2 parts Hydrogen Peroxide (3%) with 1 part Hydrochloric acid (30%). Most PCBs have a photosensitive coating that needs to be removed for this to work. The etching can be achieved by using a paintbrush to apply the solution to the desired location. The copper will be taken away rather quickly and the solution will turn greenish.

4.3 Tensioning the Mylar diaphragm

Mylar with 3 μm thickness is used to create the diaphragm. Thinner Mylar will cause a lack of bass, while thicker one will cause problem in treble and mids. The tensioning should be high enough as otherwise the diaphragm will collapse onto a stator but also low enough in order to not reduced the bass. Different ways of tensioning the Mylar:

1. With weights on the side
2. Using a bicycle tire and inflating it
3. Using tape to stretch it

http://www.head-fi.org/t/498292/my-diy-electrostatic-headphones/720#post_9217468 -i Orpheus clone tensioning; weights should be larger between 0.8 and 1.0 kg. Preferred option

http://www.head-fi.org/t/498292/my-diy-electrostatic-headphones/1095#post_9907534 -i tire tensioning jig.

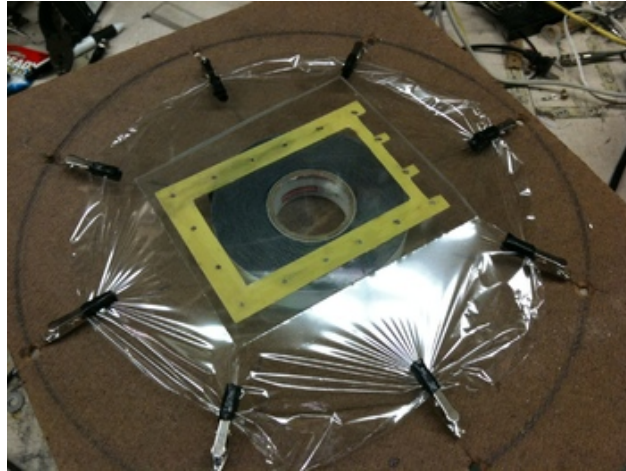


Figure 3: A Mylar tensioning rig using weights



Figure 4: A Mylar tensioning rig using an inflatable tire

Before putting it on the glass (and before coating) clean it with Acetone. To cut the Mylar after glueing use a soldering iron. Ensure there is no Mylar beyond the edges. The stators might warp slightly but this should be ok when assembling the driver.

Make sure the diaphragm is very well glued to the stator. The contact cement is applied to the spacer which is allowed to sit for 3-5 minutes. After that the spacer is put on the Mylar and a bond will be created immediately. A good contact can be achieved by running the finger along the spacers several times so that the glue is everywhere in contact with the spacer. See http://www.head-fi.org/t/498292/my-diy-electrostatic-headphones/1215#post_10400583

After glueing the Mylar onto the spacers knock them on the side of a table to check that the sound of both diaphragms is similar. If not, a hot air gun can be used to tension the one with a looser sound.

Tension is sufficient if wrinkles on the Mylar vanish during the procedure, corresponding to about 0.5% of displacement. The two diaphragms need to be glued on the same mylar film so that the tension is the same on both sides.

http://www.head-fi.org/t/498292/my-diy-electrostatic-headphones/1770#post_11440100 idea on how to identify the correct tension of the diaphragm by checking the free-air resonance frequency (should be between 100 and 200 Hz) using a white noise generator on one side and a microphone on the other.

4.4 Coating the diaphragm

As Mylar is not conductive an additional coating is required so that it can be charged. It basically should act as if it was a capacitor, so a coating that is conductive and has a high resistivity is ideal. Coating agents are:

1. Staticide 6300 (anti static cleaner for monitors)
2. Licron antistatic spray
3. Swash Floor cleaner

Coating is achieved by applying a small drop of Staticide onto the diaphragm and then spreading it with a sponge or microfibre cloth (lint free!). After it dries clean wipe the surface again with a dry lint free cloth.

Thread about coating: <http://www.diyaudio.com/forums/planars-exotics/109789-esl-diaphragm-coating.html>

Is this Staticide a gel?

4.5 Assembly

Synthetic rubber glue (contact cement, UHU Greenit, alternatives: UHU Por, 3M 4693) is used to glue the diaphragm to the spacers. The dust protection screen must also be placed on some spacers (1mm thickness PCB) and must not be in contact with the stators. 1 μm Mylar is crumpled and then stretched somewhat so that it doesn't touch the stators when on the spacer. This yields an ideal acoustically transparent material for dust protection. Normally, no dust cover is used on the outside. As no sweat protection is required on this side a very fine cloth could be used if needed. Only one spacer is glued to the diaphragm. This spacer will be the one facing the outside. The spacer on the inside will have the copper side in contact with the coated diaphragm and will be the one with the electrical contact to the DC bias voltage.



Figure 5: Arrangement and orientation of stators and spacers (missing the dust protection spacer and film)

Plastic screws are used to assemble the driver unit.

Adhesive tape (masking tape) and pressurized air can be used to clean the dust of the diaphragm and stators. A magnifying glass should be used for checking cleanliness.

The driver can be tested by hooking it up to the amp and leave it as is for 3 to 4 hours without playing any music. The diaphragm should not be sucked to one side during this.

5 Building the enclosure

Since we were already using a CNC machine to manufacture the drivers we opted for the same toolchain to create the enclosure. As wood is a common material in enclosure construction we decided to use it as well. We again designed the enclosure as a 2.5-D shape using Inkscape. The Gcode was created using www.makercam.com similarly to the driver. To machine the enclosure we used a 6mm and a 2mm 2-flute end mill.

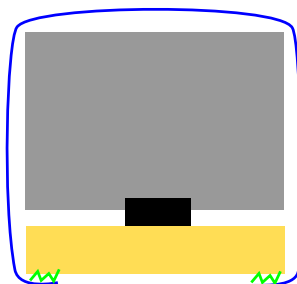


Figure 6: Earpad cut-through; materials: wood (yellow), foam (grey), screw nut (black), artificial leather (blue), contact cement (green)

6 Building the headband

http://www.head-fi.org/t/498292/my-diy-electrostatic-headphones/675#post_8943826

Headband can be made out of a metal ruler and then covered with leather http://www.head-fi.org/t/498292/my-diy-electrostatic-headphones/2385#post_13037825.

7 Building the earpads

The earpads should be thick enough so that the bass is powerful and deep enough. The earpad is based on a wooden ellipse with 4mm thickness that was also manufactured using the CNC. After we had the full enclosing together we put the front and the back of the enclosing together with this ellipse to drill four holes for the assembly. The screw nuts were glued to the inside of the ellipse using copious amounts of epoxy. A schematic of the earpad can be seen in Fig. 6. After the glue has hardened (see your glue for the time, for ours it was about 24h) we loosened the screws and disassembled everything. The next step consisted of cutting the same ellipse from acoustic foam with 3cm thickness.

The leather cover is made from a thin and stretchy synthetic leather. It's made of two parts, a rectangular one with dimension 4 x 32 cm and an elliptic one which is of the same size as the wooden ellipse of the pad plus 1 cm inside and 3 cm on the outside. The rectangular patch is sewn on the inside of the ellipse and then it's wrapped over the foam and the wooden pad connector. The leather is glued to the wood using the contact cement that was also used to glue the diaphragm to the spacers. Finally, we also glued a mesh to the wood so that the ears cannot get in touch with the dust protector.

8 Assembly

8.1 Cable

The cable that connects the headphone with the step up transformer consists of three about 3m long litz wires ($0.14mm^2$) that were braided together. One side was soldered directly onto the stators and one spacer whereas the other side was fitted with banana plugs to connect the headphones to the transformer.

While this might not be the perfect solution in terms of elegance and signal transmission it was a inexpensive and functional way to make the headphones sing.

Alternatives include replacement cables for KOSS headphones. Apparently an extension cable for the ESP-950 headphone should do the trick.²⁰

²⁰<https://www.head-fi.org/threads/my-diy-electrostatic-headphones.498292/page-51#post-9325470>



Figure 7: Final earpads

9 Amplifier

Due to the requirement of a continuously charged diaphragm and the high voltage requirements of the stators a dedicated amplifier is required for electrostatic headphones. A discussion on this amplifier design can be

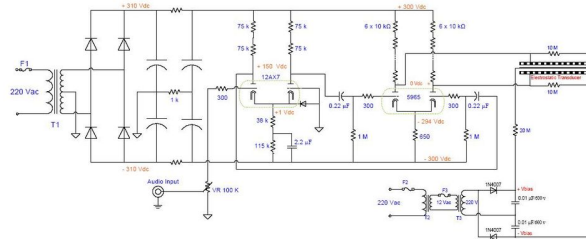


Figure 8: Amplifier design by Wachara C.

found on Head-fi.org²¹. However, to not make our lives too difficult we decided against building a full amplifier. Instead we opted to construct a step up transformer based on the designs of Charlie Mimbs²².

A note of warning before we continue with the details. We will be dealing with electronic equipment in the following which can cause serious injury or death so make sure you have a good understanding of what you are doing and follow proper safety procedures.

Since we are not building a speaker we opted for a toned down version of Charlie's step up that would only lead to 580 volts at the diaphragm. A circuit diagram can be seen in Fig. 9 that was copied from circuitjs²³.

The final step-up transformer can be seen in Fig. 10. As can be seen, we did not put it in a nice enclosing and this will also be part of next year's project. The step-up transformer is divided in three parts, the blue and yellow part are the transformers for the left and right stators, respectively. Each of these sections consists of one 1 Ohm resistor and 2 audio transformers from 6 V to 230 V. The OEP transformers that we used (see Section 3) were connected on the B-D and 1-4 pins. This yields a 4000k to 95k winding ratio. The two

²¹http://www.head-fi.org/t/498292/my-diy-electrostatic-headphones/720#post_9182523

²²<https://jazzman-esl-page.blogspot.co.at/2010/01/update-new-toroidal-step-up.html>

²³<http://lushprojects.com/circuitjs/circuitjs.html>

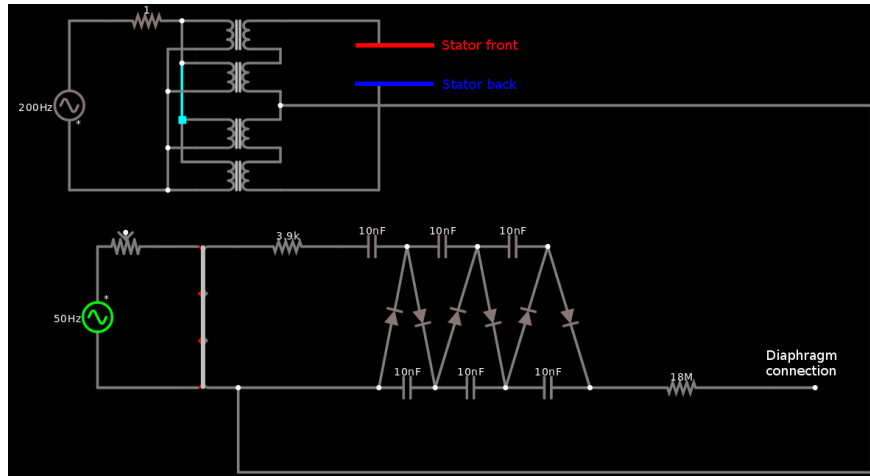


Figure 9: Step up transformer: circuit diagram

transformers are connected in series and the output side is connected to the step-up part of the transformer as can be seen in Fig. 9. Note that in the circuit diagram only one of these stator sections is depicted.

The green part in Fig. 10 corresponds to the lower part in the circuit diagram (Fig. 9) and is responsible for converting the 230 V, 50 Hz AC input to a 580 V DC current. The AC input was connected to the Triad power transformer including a 250mA fast blow fuse. On the output side a 3.9 kOhm resistor is put before the actual step-up ladder that can be seen in the circuit diagram. This ladder consists of 6 10 nF capacitors and 6 diodes to rectify the AC current. At the end of this ladder a 18 MOhm resistor is put before the connection to the diaphragm is made. Note that we made only one step-up ladder that is connected to both left and right diaphragms.

Note that when operating the headphone its component will be charged and this charge will persist even if power to the transformer has been shut down. It is necessary to discharge all components before disassembly which can be achieved by leaving the power cord connected after shutdown and using the ground connection of the power cord. We hooked up a cable to the ground connection and discharge all outgoing ports by touching them briefly with this cable.

10 Measurements

As part of the current build we did not perform any measurements and this will become a topic for the future. The head-fi thread suggests to perform measurements with and without seal. The latter should give a peak at around 200 Hz which is the free-air resonance frequency. This frequency should be lower than 150 Hz for a good bass response.

11 What to do different in the future

Allow for a little space between enclosing and driver.

Shrink wrapped cable with proper xlr connector.

Earpad made out of three pieces (2 rectangular ones and one ellipse).

11.1 Closed headphones

Materials used for damping included felt, wool or other acoustically semi-transparent materials. Some also coat the inside of the enclosure with Bitumen.

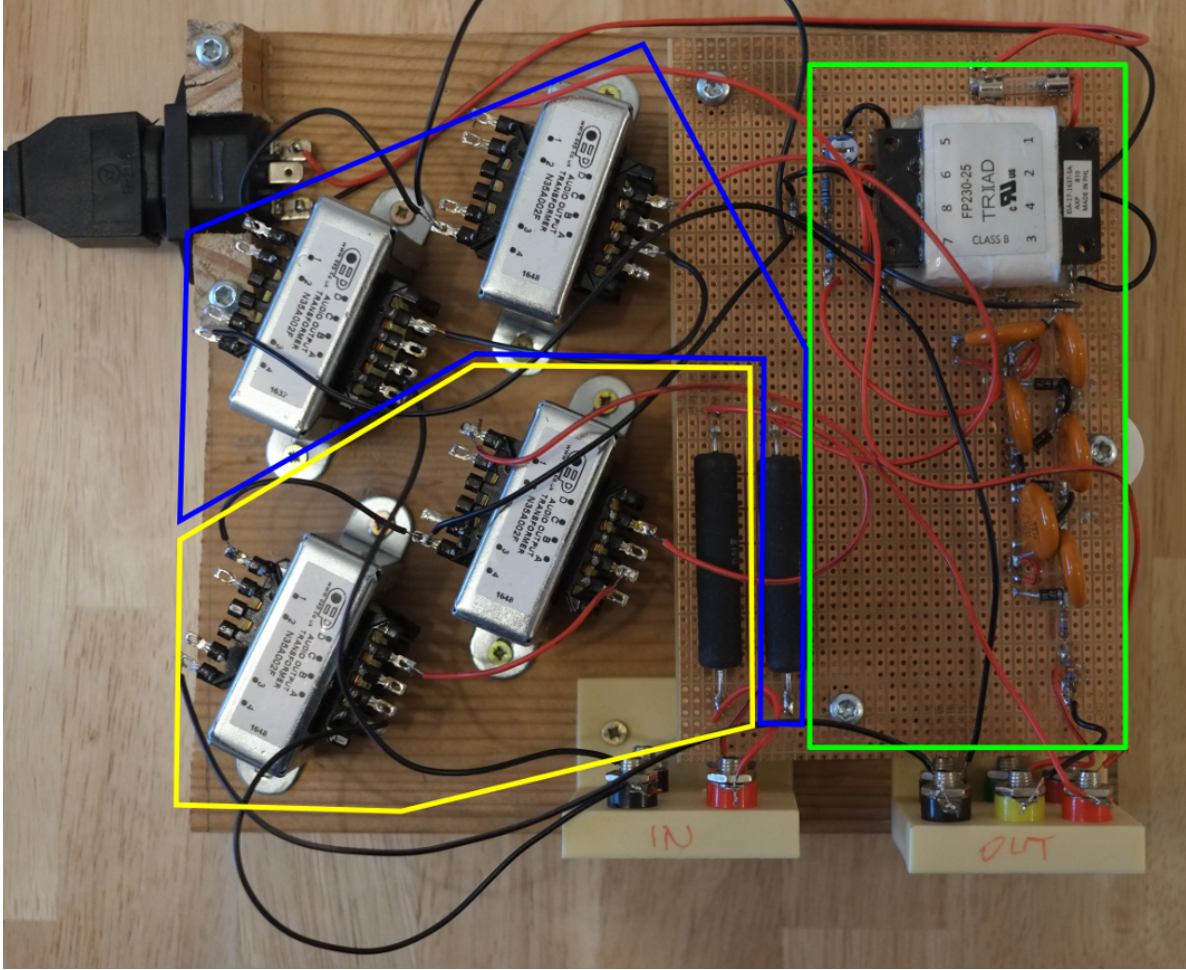


Figure 10: Step up transformer from the top

12 Collaboration & License

This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License ²⁴. The official repository for this guide can be found on github.com ²⁵. There is an issue tracker available if you do not know how to work with \LaTeX and git. We very much jumped into this venture without prior knowledge of a lot of things that we had to tackle. Because of this there might very well be mistakes in this guide or in our approach that we are happy to learn about. So do get in touch with us if you have any remarks and want to help us improve this document. We plan to build version 2 of the headphones in 2018 and with this we will also update and improve this guide.

²⁴<http://creativecommons.org/licenses/by-sa/4.0/>

²⁵<https://github.com/Azrael3000/headphone-guide>

13 Appendix

13.1 Circuit diagram for circuitjs

This file can also be found in the resources.zip file which can be found on github.com ²⁶.

```
$ 13 0.000005 146.80153516788286 47 120 28
v 448 512 448 352 0 1 50 230 0 1.5707963267948966 0.5
c 720 352 800 352 0 1e-8 -121.77903323034391
w 608 512 608 608 0
w 608 512 768 512 0
d 768 512 800 352 1 0.805904783
d 800 352 832 512 1 0.805904783
d 832 512 880 352 1 0.805904783
d 880 352 912 512 1 0.805904783
d 912 512 960 352 1 0.805904783
d 960 352 1008 512 1 0.805904783
c 800 352 880 352 0 1e-8 -188.52952984256655
c 880 352 960 352 0 1e-8 -148.45206709826482
c 768 512 832 512 0 1e-8 -188.38552969850758
c 832 512 912 512 0 1e-8 -148.28294550190276
c 912 512 1008 512 0 1e-8 -133.83898987162684
r 1008 512 1216 512 0 18000000
w 1216 512 1264 512 0
w 608 608 1328 608 0
v 416 96 416 288 0 1 200 6 0 0 0.5
T 560 96 656 112 0 4 20 -0.0002165438913044398 0.000008783616360946498 0.999
T 560 176 656 144 0 4 20 0.00021654389130444608 -0.000008783616360946477 0.999
T 560 240 656 208 0 4 20 0.00021654389130505795 -0.00000878361636097594 0.999
T 560 288 656 256 0 4 20 0.00021654389130505323 -0.000008783616360975917 0.999
w 656 128 656 144 0
w 656 240 656 256 0
r 544 96 464 96 0 1
w 544 96 560 96 0
w 544 208 560 208 0
w 544 144 560 144 0
w 544 208 544 256 0
w 544 256 560 256 0
w 544 208 544 144 0
w 544 144 544 96 0
w 560 128 528 128 0
w 528 128 528 176 0
w 528 176 560 176 0
w 528 176 528 240 0
w 528 240 560 240 0
w 560 288 528 288 0
w 528 288 528 240 0
w 416 288 528 288 0
w 464 96 416 96 0
w 1328 608 1328 192 0
w 1328 192 656 192 0
```

²⁶<https://github.com/Azrael3000/headphone-guide/raw/master/resoures.zip>

```

w 656 208 656 192 0
w 656 192 656 176 0
w 656 288 768 288 0
w 768 288 768 160 0
w 656 96 768 96 0
c 768 96 768 160 0 2e-11 -328.31758099807905
T 608 352 528 192 0 2 1 -4.752600223090209e-16 -0.18138620921599558 0.999
r 608 352 720 352 0 3900
w 448 512 528 512 0
174 448 352 512 352 0 1000 0.5 Resistance
w 512 352 528 352 0
o 16 64 0 2083 1280 0.00009765625 0 -1 0
o 49 64 0 2083 1280 0.0001953125 1 -1 0
o 51 64 0 2083 5 0.0015625 2 -1 0
o 1 64 0 2083 320 0.0015625 3 -1 0
o 3 64 0 2083 640 0.0015625 4 -1 0
o 54 64 0 2083 640 0.4 5 -1 0

```

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