Project: Christoph Neuhaus

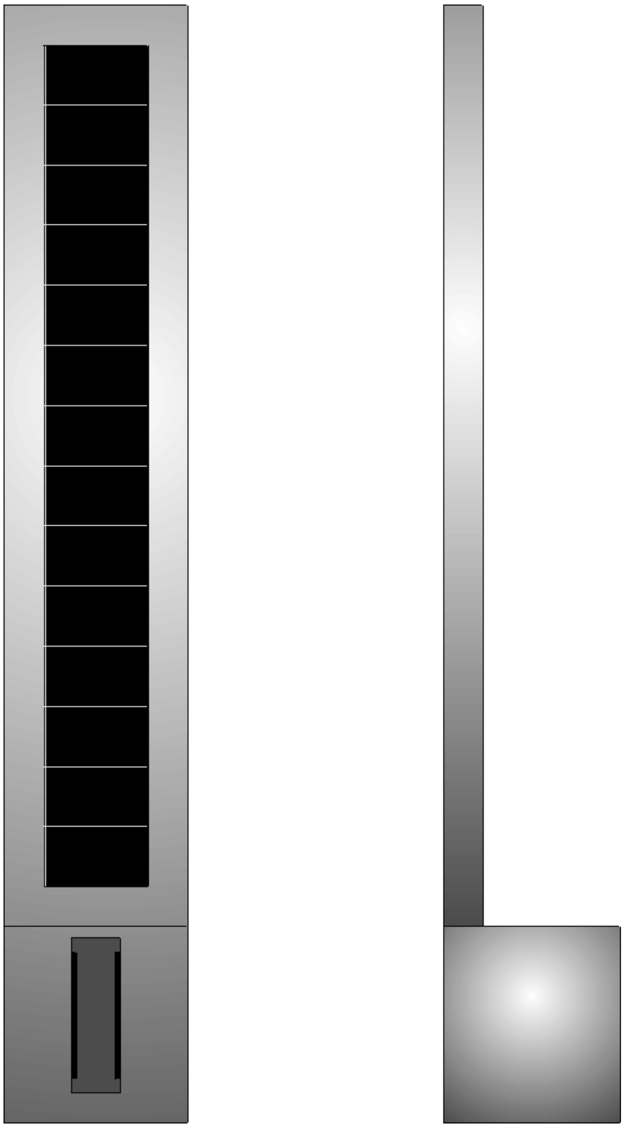


Table of content

Personal

- Name: Chris Neuhaus
- Email: Calvin_and_Hobbes@t-online.de
- Home page:
- Address: Germany
- Tel:
- Fax:

Introduction

In 1985 I had my first experience with Eletrostatic transducers. I went into a HiFi-shop and could listen to the whole chain of Audio Exclusiv. Man, That was real!! But way out of the financial capabilities of a young student. The idea to build an ESL myself came when an article appeared in a German DIY-magazine in 1989. Though it left a lot of questions open, it gave me a first impression what this was all about. In 1990 a book written by Ronald Wagner fell into my hands. IMHO that is really the stuff You need to read to get an thorough understanding of ESLs. Still there were many questions open. Than I discovered This site. Like in a puzzle the last pieces went into place and I think that now I´ve got enough knowledge to build a pair of ESLs successfully .

ESL's in general

An ESL is a relatively simple device. It consist of five major parts.

- The Stators
- The Diaphragm
- The Spacers
- The Audio Transformers
- The High Voltage Power Supply

Sounds pretty easy, eyh? The pits and falls seem to ly in the little details, e.g. choice of materials and geometry. Especially full-range-ESLs are difficult to build. So I decided to build a hybrid-system with the ESL running from app. 200Hz on upwards and a dynamic subwoofer adding the rest of the audible spectrum. Just lately I could participate with a forum demonstrating dipolar subwoofers. One could listen to one of the best bass-performances you can think of. Because of this experience and because this dipolar sub works similar to the ESL (cosine pattern, even at bass frequencies!) I decided to build this dipolar sub. The great advantage of the cosine pattern is, that it only excites room modes in one of the three room dimensions. Therefore you have much less room-colouration (reduced by a factor of 3!!). Bass is much more precise and less prone to ´booming´. It´s quite similar to using a ´velocity microphone´ instead of a ´pressure microphone´ to reduce studio colour.

Description of MyESL

Type:	Wire Stator ESL (150 x 30 x 6,4cm) + dynamic dipolar Subwoofer. Frequency division and equalizing by means of a electronic crossover
HV power supply:	app. 4-5kV, regulated from a 9V DC supply
Audio transformer:	by M. Sombetky (a quad or of small 1:100 types in serial/parallel connection to give a ratio of 1:200)

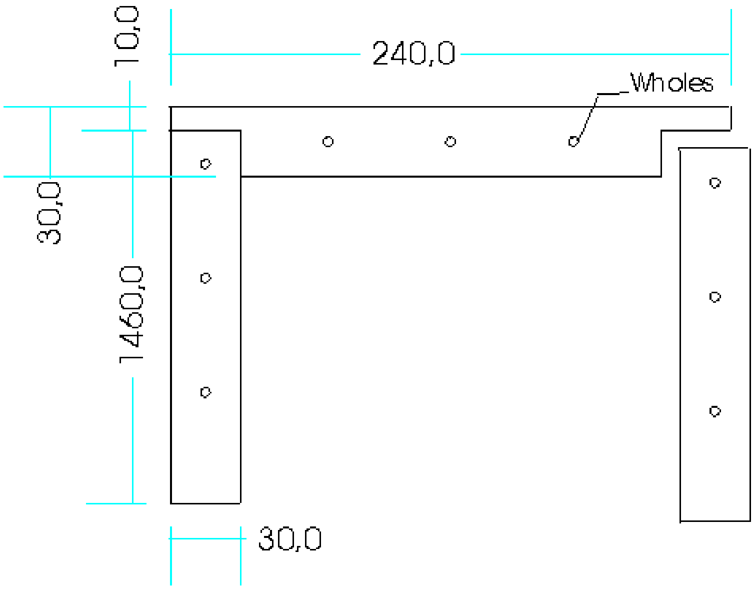
Freq. response: 200→ 20kHz for the ESL, 25 → 200Hz for the woofer

The aim is to build a hybrid-ESL that's detachable, that has an efficiency above average, that can be switched on/off when used/unused (small charging-time) and that can be paired with different subwoofers.

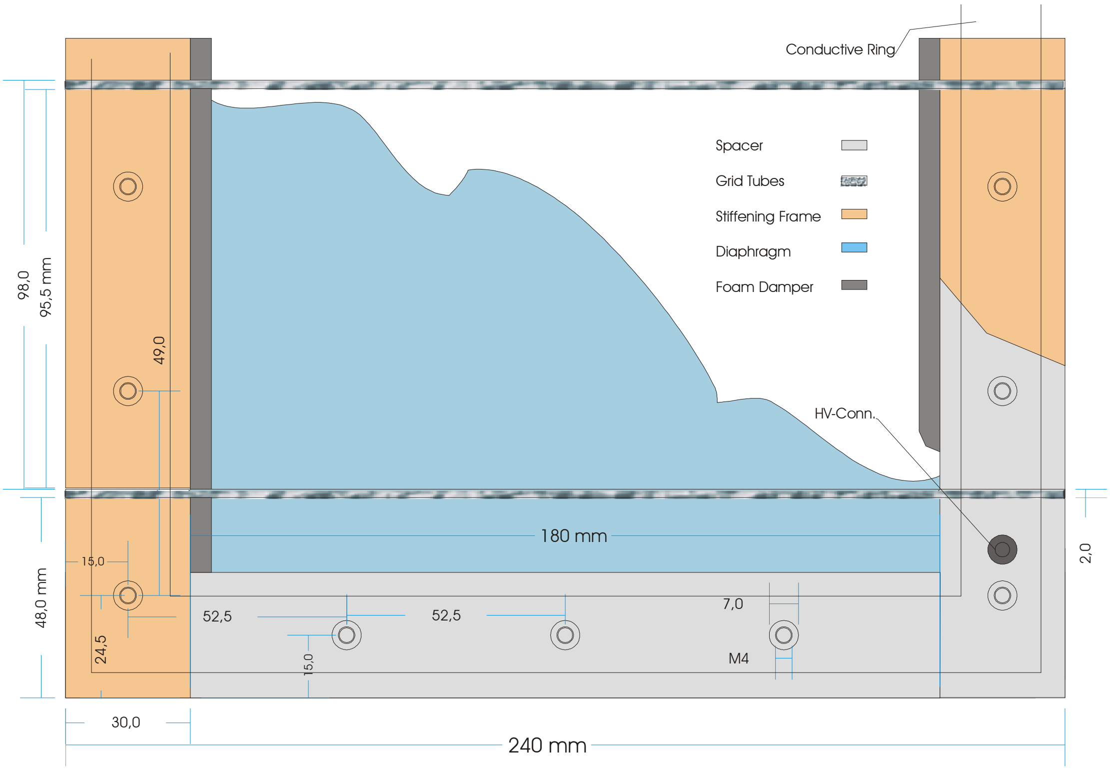
Building of the stators

The aim is to build the ESL detachable (at least the prototypes ☺). So the Stator-Diaphragm-Sandwich has to be fixed without using glue or tape. Instead of my stators will be srewed together.

The frames of the stators

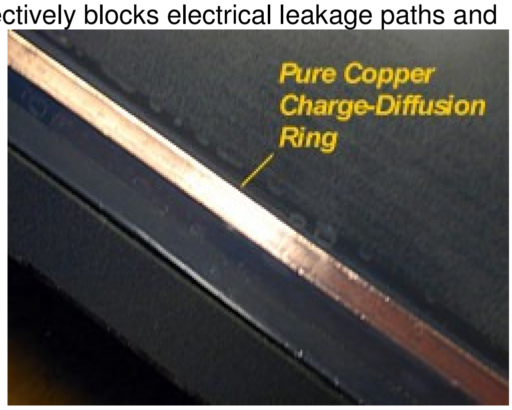


The frames for the stators are made of MDF (10 mm), PVC (5mm) and aluminium strips. The PVC (spacers) is cut into strips of 30mm width. I need 4 strips of 1450 x 30mm and 4 strips of 240 x 30mm for each ESL-element. The shorter Strips have cutouts of 20 x 30mm at their ends. This should give a stronger and more precise joint at the edges. Holes for plastic screws (M4) are drilled into the frames with a constant distance of 52.5mm (top to bottom) and 49mm (left to right). Of course one frame gets slightly bigger holes straight through (4.5-5mm), the other frame gets the windings for the screws(M4). I figured out, that the distances are close enough to hold the diaphragm safely under tension. One should sand the surface of the PVC slightly. It will give a tighter ´bond´. Metal strips (alu or steel) of the size 240 x 10 x 2mm are glued onto the vertical spacers (from left to right, horizontally) with even spacing of 96mm. Pieces of MDF (96 x 30 x 10mm, stiffening frame) are glued on the PVC and between the metal strips (these will have drilled holes to them, to give access to the plastic screws, that will join together the whole thing). I started glueing in the mid of the Stator and went to the left and right. The glue I used is made by Henkel. Pattex Kraftkleber is looking like mustard, but smelling much worse ☺. It bonds fast, but not too fast and gives a strong bond. This will give a construction that looks quite similar to the one Audiostatic uses. Obviously Audiostatic compromises on mechanical and technical issues for ease of building and lowering costs –very clever compromises indeed (just to keep things correct ☺). As a hobbyist You don´t need to do that (which is one of the few areas where DIY-products can be superior to industrial ones). So my frame will be stiffer, detachable and has a smooth outer surface for simple mounting into a mounting-frame. At one end of one stator I drilled a hole, put a screw through it and secured the srew with a nut and glue. The head of the srew should point towards the diaphragm-side of this stator and should be sunk-in to give a smooth surface. This will be the HV-connection-point! Now mask the inner and outer rim of the stator with simple tape. Spray 2or 3 layers of conductive paint or graphite paint on (Brand: Graphite33). This makes a conductive ring.



Here´s what Soundlab says to such a conductive ring:

“Ideally, the charge on the membrane should be perfectly uniform over the entire surface of the membrane. If any electrical leakage paths exist that bleed charge off of the membrane the charge density in that particular region is lessened and sound production is reduced in that area. This results in a lower overall speaker sensitivity. Leakage paths normally occur around the outer edge of the membrane where it is attached to the panel frame. These paths are usually caused by condensation of moist air in humid climates. They can also be caused by air-borne contaminants that are attracted to the membrane such as an accumulation of microscopic droplets of cooking oil, carbonaceous particles in cigarette smoke, normal room dust, etc.
The pure-copper charge-diffusion ring effectively blocks electrical leakage paths and therefore maintains a uniform charge density over the surface of the membrane. The pure- copper charge-diffusion ring consists of a copper foil strip that is placed around the periphery of the conductive membrane. The bias voltage supply is connected to this strip. Charge is diffused from this ring over the conductive surface of the membrane. If moisture or a contaminant forms a potential leakage path from the membrane to the panel frame it must cross the charge diffusion ring. The charge availability of the ring is engineered to be capable of supplying charge to any leakage paths that might occur while maintaining the proper charge density on the membrane. In this way, leakage paths may occur but they don’t affect the charge on the membrane and sound is not affected.



A simplistic model may help to understand this principle. Consider a bathtub as an analogy. In this model, the depth of water in the tub represents the charge density and the faucet represents the source of charge. If the tub has a leak, the level of the water near the leak drops as water is drained from the region (if a substance other than water was used such as molasses or sand the action would be easier to envision because of the slower flow). Now, instead of using a localized source of water to fill

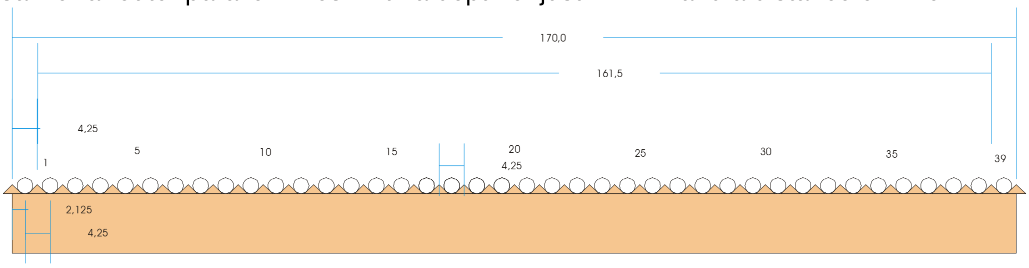
the tub, as represented by a faucet, consider using a conduit that forms a complete ring around the sides of the tub such that it feeds water into the tub at all points around its boundary. It is assumed that the amount of water that the ring can supply is adequate to feed the leak while keeping the level in the tub at the desired level. The net result is that the water in the tub is undisturbed by the leak. The action of the charge diffusion ring is directly analogous to this in a two-dimensional sense.
The pure-copper charge-diffusion ring eliminates the effects of dust and other common environmental contaminants. The "ring" is crucial in hot, salty and humid climates."   The copper ring gives a lower resistance as the graphit33, but the resistance is low enough to ensure reliable functioning.

Now I glued black foam on the inner side of the stator frame (see pic above). First it´s for optics, but secondly it's a damper for the diaphragm movement and I think it´s smoothening the transition of the diaphragm from restricted movement (where it´s clamped between the stators) and free movement. Too there will be resonances in horizontal and vertical direction that I hope to reduce in amplitude.

The stator wires

For the wires I used installation wire (H07V-U, outer diameter 2,65mm, 1,5mm^2, solid core). This comes in rolls of 25 or 100 meters. It´s quite stiff stuff. I want to use it instead of thinner wire, because of its stiffness and You can buy it cheaply in different colours in every DIY-market ☺. It comes straight off the roll and is cut into pieces of app. 150cm length. Then it is straightened out. I do this by fixing one end in a work-bench and the second end in a drilling-machine. If you let the machine turn several times in different directions while pulling at the wire (machine) You´ll end up with a nearly perfectly straight piece of wire (like a rod). This has the great advantage that You don´t have to tension the wire (I don´t like the thought of a glued connection under mechanical stress!). The bottom ends of the wires have be cut to length and de-insulated. Some cleaning of the wire´s insulation might be necessary and could be done in this step using Ethyl-alcohol. I´ll be using 40 wires for each side. So it should be app. 240m (!) of wire for 2 ESLs. The Membrane-Wire-distance will be 2.35mm.

These wires are now glued to the metal strips on the stator-frames. I´m using Pattex Kraftkleber here again, but this time in the transparent/clear version. The distance between the wires will be 1,6mm. This gives app. 40% open, 60% covered diaphragm area. Again this is similar to the Audiostatic design. I´ve read, that Quad too is working with relatively less open area. To get a parallel and even pattern I´ll use a sheet of wooden board or MDF that fits exactly into the Stator-frame cutout!! Now cut with a saw or a router parallel ´lines´ with a depth of just 1-2mm and a distance of 4.25mm.

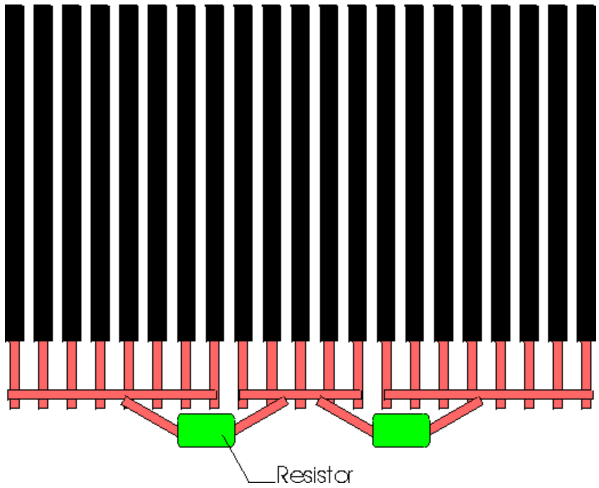


crossectional view of the ´wire-board

It is important that You work here as precise as possible, because this is the step where the looks of the final speaker is determined! Precision work will give professional looks, unprecise work will mess up the whole thing! Lay down all the wires You need for one stator onto this board. They should all be parallel with identical spacing between them. Now put the Pattex Kraftkleber (transparent) onto the inner side of the aluminium tubes of the stators (work quick here!), take the stator and lay it down onto the parallel wires. Because the bond of the glue depends from the amount of pressure you put on the joint, press down the stator onto the wires! After app. 3 minutes take the stator off the wooden board and lay it –wires up- on the workbench.

The wires already stick to the stator but the glue is still flexible, so you might correct the position of the wires a bit to give perfect looks ☺

The deinsulated ends of the wires are now connected together electrically by a simple wire, soldered to them. I read that this should be acoustically superior to just a single connection at one point. Frequency-division (equalizing) can too easily be done by soldering resistances to the appropriate Wires. ´Virtually bending´ of the diaphragm could also be accomplished by using a tapped delay line like Quad and Audio Exclusiv do (L-C-network).

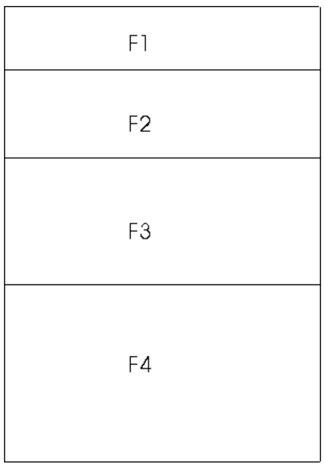


The Diaphragm

The diaphragm is made from polyester (Hostaphan RE 3.5) of 3.48um thickness (I was lucky and got a rest of a roll from a company that manufactures capacitor-films by using this kind of film and depositing a thin layer of aluminium on it☺).This film is biaxially oriented, heat set with high tensile strength and a density of 1.395g/cm$^{3.}$ I build a stretching jig (see Mr. Stokes site). It´s just a simple fixed wooden outer frame and a flexible inner frame, consisting of 6 wooden strips (2x2 vertically and 2 horizontally). I cut long rods with screw-windings on them into smaller pieces. Holes were drilled into both frames and the rods were pushed through said holes and nuts were screwed on every end. So by twisting the nuts on the outer frame, the inner flexible frame is moveable and a diaphragm attached to this inner frame by double-side sticky tape can be stretched taut easily!

The diaphragm will first be stretched just a little bit to enable one to put the coating on. I´m using Hobby-Glue made by Beiersdorf. The brand name is TESA-Vielzweck-kleber, stark+sauber (multi-purpose-glue, strong+clean). It´s clear water soluable stuff. I use 1part Hobby-glue (app. 25gr.) and mix it with 4parts of destilled (!) water (100gr.) and add 2 drops of simple black ink. You can spray or paint this stuff on the membrane. I painted it. I put quite a lot of it onto the film and painted in a criss-cross-way over the film. This coating gives a near perfect smooth surface (obviously the adhesion of the water is minimalized either by the glue or the ink). I´ve now got a clear, invisible coating that charges up rather quick (just 10-15sec after powering the HV-supply sound builds up!). This enables one to power-off the HV-Supply when it´s not needed, which should reduce problems with dust being attracted to the ESL. It should be possible to get coatings with higher resistance by applying less of this substance. Because my ESL is intended to work from app 100Hz on, I prefer to have a small charging time.

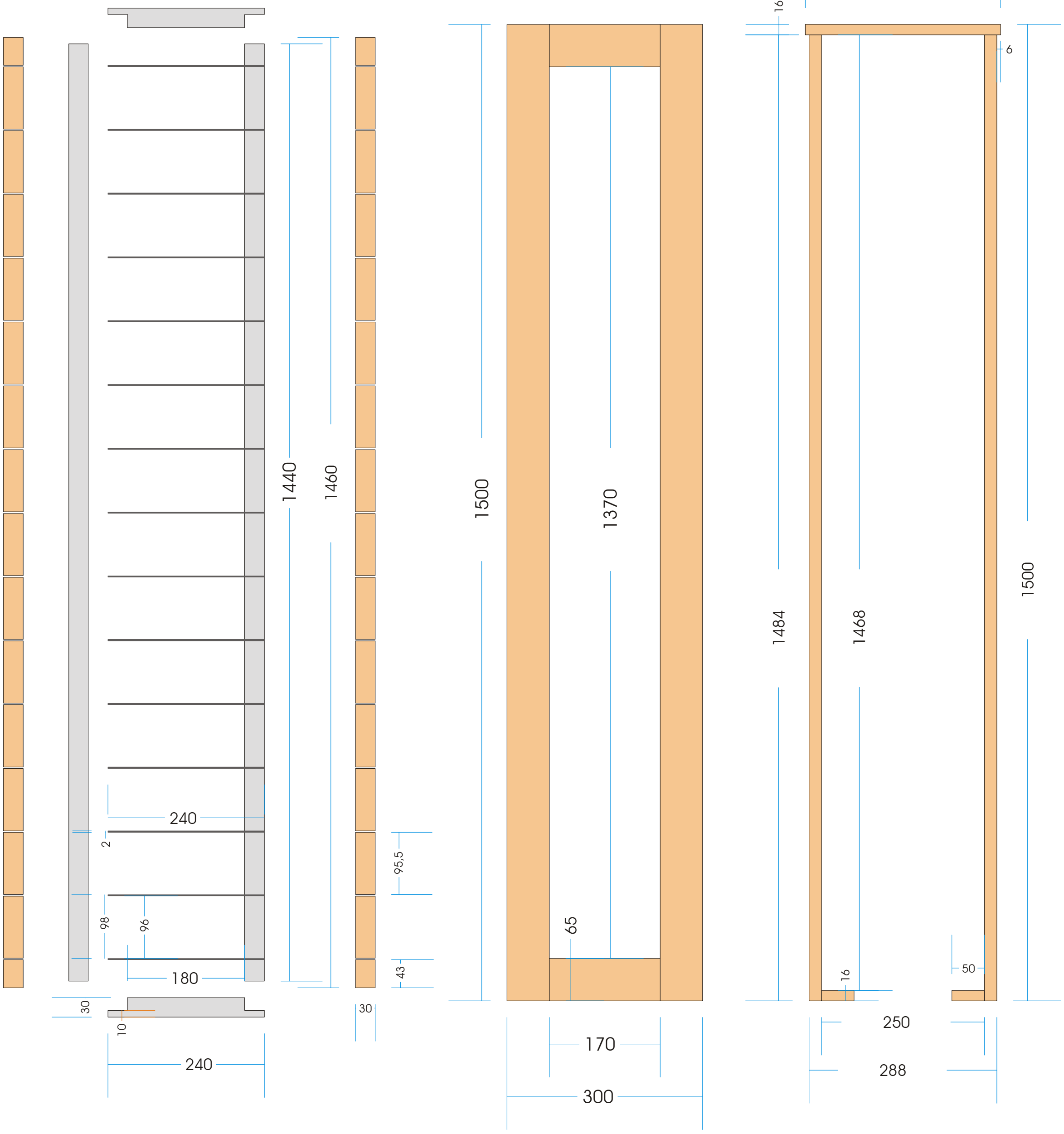
Segmenting the Diaphragm: I segment the membrane mechanically by using foam strips (3x3x180mm) that are placed between the membrane and the stator wires right under the aluminium strips that hold the wires. This way You divide the whole thing into smaller membranes. The new smaller membranes should all be of different size (area)! The aim is to get rid of the one fundamental resonance with high amplitude. Instead You get several different fundamental resonances, but with lower amplitudes, hence less influence on the sound. As a very positive sideeffect You can lower the Membrane-stator-



distance or push up the polarising voltage. Both means higher efficiency!! ☺ Again thanks to Soundlab ☺ You guys describe some nice ideas on Your site! There are 15 aluminium-strips on the stator-frame, so I put the foam strips on the 1st, 3rd, 6th, 10th and 15th alu-strip –counted from top to bottom.

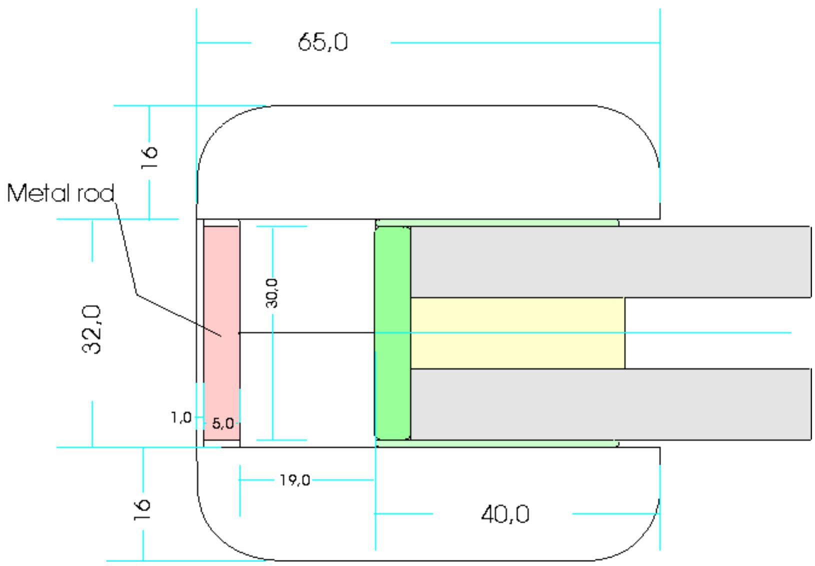
When the diaphragm coating has dried the diaphragm is stretched to its final value. I use as much tensioning force as possible. Then it is laid upon the lower stator frame (with the srew winding holes in it) and positioned carefully. Now puncture the membrane with a hot soldering iron where the screw holes are located (don´t try punching with a needleor knife because this will end up with the destroyed, torn film) Place the second stator frame exactly above the first and screw them together using the plastic screws. This may take some care and last a while, because there are 62 screws per panel! After this the membran can be cut off the stretching jig and voila here´s your ESL-panel! (hopefully working ☺)

Mounting Frame



Stator and mounting frame

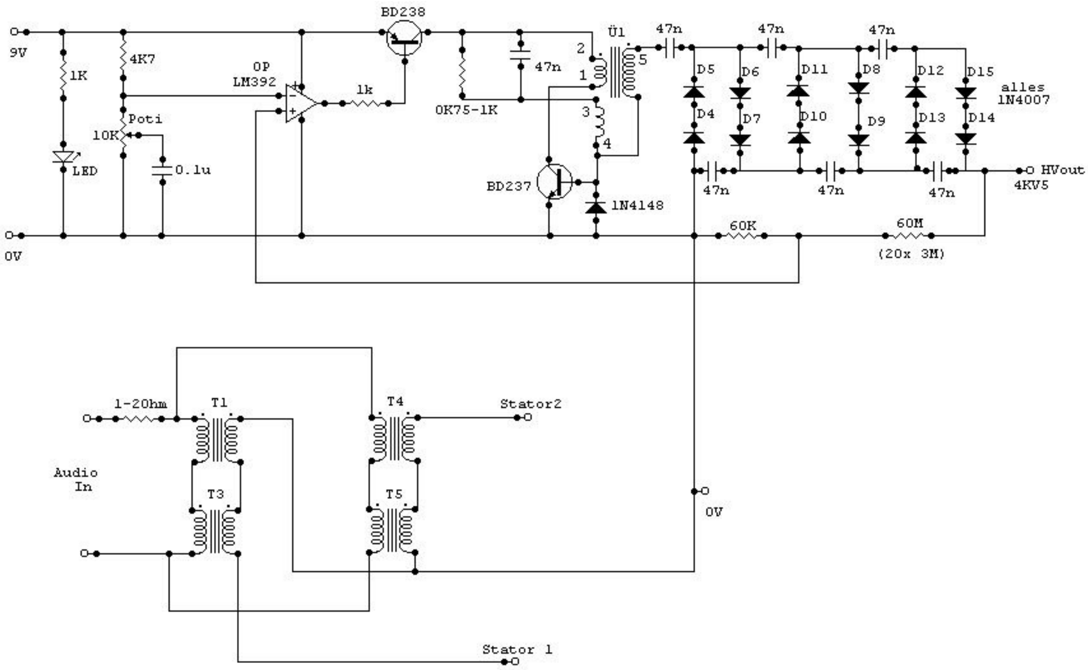
The mounting frame is made of sheets of 16mm thick MDF. The dimensions are: 4pieces of 1500 x 65mm and 4pieces of 170x65mm. Two of the long and two of the short pieces are glued together to form a frame of 1500x300mm. Now 19mm MDF is cut into 2pieces of



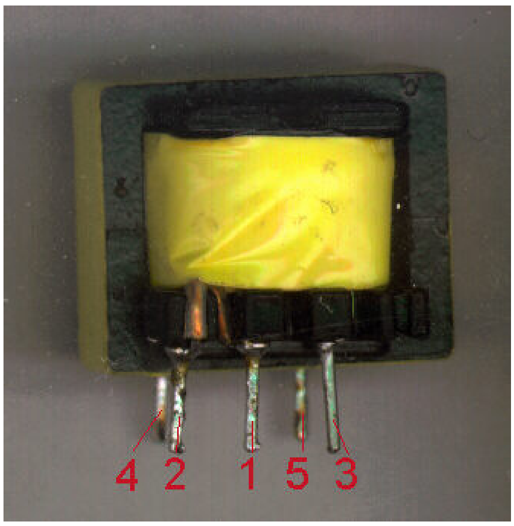
1484x32mm,and 2 pieces of 50x32x16mm MDFand 1piece of 300x32x16mm MDF. They are glued together to form a 32mm high ring, with 1500mm length and 288mm width (300mm at the top of course!), with a cutout of 150mm at one of the short sides. This frame is glued onto one of the 16mm MDF frames so it forms an open housing in which the ESL-panel fits. Foam-strips are taped everywhere where the panel could contact the frame. The ESL-panel is laid into this ´bed´ and the second outer frame is screwed to the first frame. Now 2 metal rods of 30 x 5 mm crossection are screwed onto the sides of the mounting frame. The length of these rods are 1500mm+ height of the Subwoofer. These rods connect ESL and woofer together and give additional stability. You can ´hide´ the rods optically by putting a 1mm thick, 32mm wide cover over them, or You use 6mm thick material and leave the screws to fix it visible.

The Electronics

The HV-supply is a self-build unit too. I prefered a regulated, constant HV output simply for safety reasons. First I can use a low-voltage supply (regulated, constant 9V). Second should there be less problems with arcing due to overvoltages and spikes on the supply-lines. Recently I found a nice design at the Internet and I´m using this one as a basis for my supply. Below are the schematics. Looks easy and cheap, nah? But You´re freed from the problem of winding a HV-tranny all by Yourself ☺



The transformer is a fotoflash transformer. You can buy this transformer from a mail order firm called: Conrad Electronic. You can download a Datasheet from their website It's ordering number is: 582263-11. It costs 3.04 Euro, without shipping.



None of the part values are critical. The transistors: You can use every NPN transistor for the BD237 which is capable of 2A and about 45V. For the PNP transistor you should use a fast switching type, capable of 2A and about 45V. The caps of the voltage tripler are 47nF, MKP10. The 60M resistance is made of a serial connection of 20 metal film resistors of 3Mohm each. You might use any OP-amp instead of the LM392 (which houses a comparator and an OP-Amp, but just the OP is used!). The Trim-pot is a 25-turns precision type and should be turned to its mid point before first start-up! In case the circuit doesn´t start up (the BD-Trannies will heat up very quick), you might lower the 1kOhm resistance to app. 700-800 Ohms (0K75-1K in shematics). The Problem can be twicefold. First the Cap going from Point 2 to 3 of the Transformer can be up to 100nF. Secondly I had to know that the Transformer itself is fabricated with quite big tolerances. Sometimes it helped to change the ESL-HVsupply-pairing!! I made a layout for a print that contains the complete HV-supply (the low-voltage reg supply included). It might be that the transformer is humming or hissing (its intended to swing on 15kHz), so let space around it to put a housing over it. The transistors like to be cooled (they keep cold when everything works correctly, but they heat up whilst start-up, or as long as the oscillator doesn´t work). The regulator I use is a MC7809 and this guy definitively enjoys some cooling!

Because of the short charging time of the ESL I plan to build an automatic on/off switch for it. That will help to reduce the attraction of dust. It detects a music-signal and switches the ESL on. More on this later. In the moment I´m using the switched Line-Supply connectors of my PreAmp to switch the HV on.

The Audio Transformer

The Audiotransformers are expensive, vital -and very critical too- parts for the ESL. Because this is my first project , I decided to build a hybrid system. This lowers the stress on the transformer design. You can get away with a lower turns ratio, or smaller dimensions, or higher efficiency than with a full-range-tranny. I´ll be using relatively small devices supplied by Mr. Sombetzky. They work with a 1:200 ratio and 4 or 6 are used in a serial-parallel connection (depending on the desired cut-off-frequency and power). These will be 80EUR for a quad, 120EUR for a hex.

Dipol-Subwoofer

The ESL-Panel and the Subwoofer are connected through 2 metal rods running vertically down the sides of the panel. This enables one to design the Subwoofer independently from the panel. It has only to be 288mm wide where the metal rods are coming down from the ESL. I will use a Dipol-Subwoofer for following reasons:

1: basically the same sound pattern as the ESL -- harmony

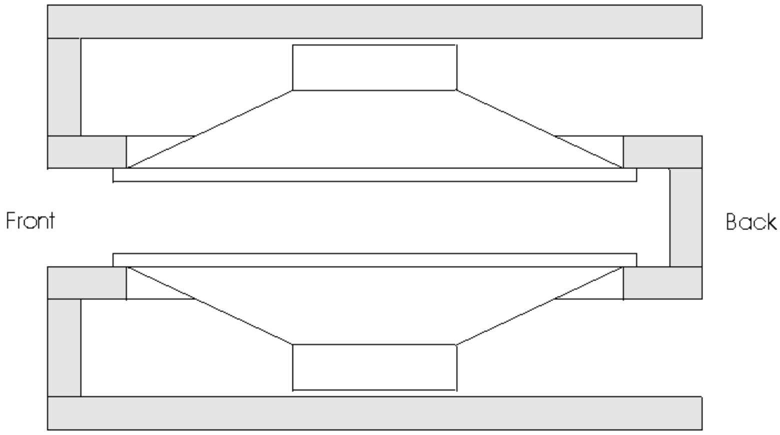
2: room-modes are far less excited – higher precision sound, less ´Boom´

3: covers less space than conventional bassboxes – greater membranes useable

4: push-push/pull-pull action of two drivers facing each other – cancellation of box´s movements, less 2nd-order distortion

5: optics – it doesn´t look like a bassbox to most uf us ☺,just a small rectangular opening at the front!

The design of dipolar Subwoofers is beautifully explained on Mr. Linkwitz Website. One major drawback of this design is that You have to have an equalizer that is making up for the loss of dipol cancellation. But since I want to use an active crossover and a dedicated amp to drive the ESL anyway, the eq for the bass is easily done within that crossover! One difference to Mr. Linkwitz design is, that the opening areas to the front and back are smaller in my design. Each opening on the backside has an area of Sd/2 and Sd/sqr2 at the front (Sd = diaphragm-area of 1 driver). In a single-driver design the front-opening is Sd/(2x sqr2). This small area leads to a velocity transformation towards the frontside that seems to be quite useful for the radiated sound pattern. Too the damping of the drivers seems to be improved and the resonance-frequency of the system is lowered than the free-air resonance of the woofer itself(!).



I´ve got a quad of cheapo 10”-drivers from the brand Ravemaster. Costing about 55€ per piece You get a massive cast basket with a beautiful machined chromed rear poleplate and a heavy magnet. Double spider suspension and a big bobbin are goodies You wouldn´t normally expect in this priceclass, eyy? A couple of these drivers just fit the width of the ESL-panels with their chrome polepieces just peeking out of the sides of zhe bassbox. Call it what You want, I call it Design ☺. (Even bigger drivers can easily be used, though you might have to rethink the connection to the ESL-panel, or use just one driver! First tests were made with a single 18”-driver in a casing of 55 x 55 x 26cm!! (H x D x W) and it´s one of the most precise things I´ve ever heard!! This design works quite good with drivers having an high Qts. You find these more often in the cheap-department. Even this cheap stuff does astonishingly well in this design (much better as in any closed or BR-design!)

The outer dimensions of the woofer are 340 x 300 x 340mm.

Current status

March 2002 The ESL´s are working and doing a wonderful job! Transparency and definition are on a absolutely astonishing level! They sound so crisp and clear and open its fantastic ☺

June 2002 The Bass drivers arrive and the housing is built. First test show that this principle is able to deliver a clean, deep bass with no booming. Actually the housing has exactly the same size as the 2 cardboxes the drivers were shipped in ☺!!!!

July 2002 The german DIY-magazine Klang&Ton organizes a meeting. My ESL is shown with provisional crossover (wrong frequencies and such stuff) and equalization done by a Behringer Ultracurve (nice thing to play with ☺). Still though it gets high recommendations (Yes Yes Yes Strike ☺) and we agreed that I should write an article about ESLs for the magazine. The measures they took showed an exceptional linearity of about +-0.25dB between 250Hz and 22kHz (on axis) with a little resonance peak that I think is due to the mechanical dimensions of the speaker (as mentioned above) Efficiency is about 80dB but with a polarising Voltage of just 800Volts. I expect to gain 2-3dB with higher Values.

Sept 2002 The electronic crossover is ready and I can listen to the Birthing-Cry of my Baby *lol* And whow!!!! THIS good for those few Bucks I paid??? Great stuff. Dynamic resolution is on a very high level. No soundcoloration. Bass is strong, dry and deep –unbelievable deep for those tiny cases!! Staging is very precise. Strings, voices and those little sounds like fingersnips are absolutely stunning! They can play quite loud, but I discovered silence new ☺ These babies even play fantastically at lowest levels when normal dynamic boxes even haven´t recognized that they are supposed to play anything at all!!

Yes, I now believe that there´s a God in Speaker-heaven and his name is ESL (Entity of Superior Loudspeaking)

Greetings,

Chris Neuhaus