FLOATSOUND

Jürg Jecklin

Projekt FLOAT 7603

Table of Content

Introduction

Roger Sanders (Innersound) provided the following information:

Please be aware that there is “Polyester” and there is “Mylar.” Cheap imported polyester film will not heat-shrink well, nor will it maintain tension over long periods like genuine Dupont “Mylar.” Also, polyester is normally annealed so that it will not heat-shrink very much, which is not what we want for ESLs.

We here at InnerSound supply the special Mylar we have custom made for us by Dupont to Barry Waldron from the ESL Information eXchange (see link below). Barry sells the Mylar to amateurs for a very reasonable price. This Mylar heat-shrinks beautifully and maintains its high tension forever.

Manufacturers

3M

3M can provide material for dustcovers.

- Name:
- E-mail:
- Homepage: 3M Innovations Network
- Address:
- Tel:
- Fax:

Dupont

- Name: DuPont International
- E-mail: info@dupont.com
- Homepage: www.dupont.com
- Address: Geneva, Switzerland
- Tel: 41-22-717-5950
- Fax: 41-22-717-5948

Mishubishi Hostaphan RE

- Name: Mitsubishi Polyester Film GmbH
- E-mail:
- Homepage:
- Address: Rheingaustrasse 190-196 65203 Wiesbaden, Germany
- Tel:
- Fax:

Suppliers

One thing Audio

- Name: One thing Audio
- E-mail: Ron Best
- Homepage: http://www.onethingaudio.com/9152MAIN.htm
- Address: Coventy, United Kingdom
- Tel:
- Fax

Model	prices (2002)
Top grade Dupont Mylar C film. Width 500mm. Gauge 6 micron. Sold only in 10 metre lengths or multiples thereof.	£ 30

Martin-Jan Dijkstra and José Nebrus

- Name: Martin-Jan Dijkstra and José Nebrus
- E-mail: mj-dijkstra@zonnet.nl, jgnaudio@planet.nl
- Homepage:
- Address: Netherlands
- Tel:
- Fax:

In our search for the perfect membrane for ESLs, we were able to get custom made, tensilized Mylar. We have two different types of Mylar®:

- Mylar® , thickness: 4 micron, width: 80 cm
- Mylar®, thickness: 6 micron, width 100 cm

This Mylar® can easily be coated with our specially developed high resistance and fully transparent coating.

Prices

Product		Price
Mylar® 4 micron		€ 3,40 /meter
Mylar® 6 micron		€ 3,06 /meter
Coating		€ 11,30 /100 ml

Package and transfer: € 7,03 within the Netherlands. Outside the Netherlands but within Europe: € 17,00

David Flinn

- Name: David Flinn
- E-mail: DavidF4797@aol.com
- Homepage:
- Address: 918 W. Winona 101 Chicago, IL 60640, USA

- Tel: +1 (773) 784-1575
- Fax: +1(773) 784-1586

I can provide the following:

- 1/2mil (.0005in) Mylar sheets for mid-tweeter panels 2ft x 10ft for $15.00 plus shipping
- 1mil (.001) Mylar 3ft x 10ft for bass panels for $20.00 plus shipping.

The ESL Information eXchange

- Name: The ESL Information eXchange c/o Dr. Barry Waldron
- E-mail: esl@information4u.com
- Home page: http://www.eslinformation4u.com
- Address: 1847 Country Club Drive, Placerville, California 95667 U.S.A.
- Tel: +1 (530) 622-1539
- Fax: +1 (603) 250-9766

Mike Roe

Coated Mylar - these products have limited availability and must be purchased through me. The company does not sell to individuals (I purchase the Mylar through my own company). They have superb heavy coated aluminum Mylar in 3 different thicknesses (50/75/100) and this stuff works best for electrostatic elements.

- Name: Mike Roe
- E-mail: mike@zanimals.com
- Homepage:
- Address:
- Tel:
- Fax:

Electret-Manufaction PDF-File about modern electret-manufaction with Dupont‘s film as main material for the process and a thyratron for “shooting” it with electrons.

Diapragm Coatings

Conductive Coating for plastic film
Conductive Lacquer (provided by Jonas Karud)
Gary Jacobson’s new original Quad Diaphragm coating
Review of Gary Jacobson’s new original Quad Diaphragm coating
Tin Dioxide

Diaphragm glueing

Nick van Beek provided the following information:

Concerning the sticking down of the diaphragm to the stator. I used after trying the glue was the double sided tape supplied with the 3M window insulation kits. I tried a no name brand but found it didn’t stick well enough. If you clean the stator surface real well with Iso Prop and then you rub the tape down to smooth it out you wind up with a nice firm bond between the tape and the stator. Then you peel off the tape backing, lay the stator on the diaphragm, and rub that down. I found this to work very well and the nice thing about it is if something goes wrong with the diaphragm afterwards it's easy to recover. With a little effort the tape can be removed and you can start over.

Will this tape stand the test of time? I don't know but what I can tell you is that I had a 10 year old roll of the stuff and it was just as fresh as a new roll I bought at the hardware store. Additionally, I rebuilt my tweeter panels last winter using this tape and to date they are still working very well.

Diaphragm material

Michael Ehrlinspiel provided the following information:

"Mylar" is Dupont's trademark. Technical this material is called PETP. In Germany this material is produced by Hoechst and is called "Hostaphan"

I use Hostaphan with 6 µm thickness for my fullrange ESL's. I produced 14 pairs for friends and others. after a certain time of playing them (more then half a year depending of listening soundpressure) the membrane becomes smooth and therefor the rumbling bass and the rough mids vanishes and booth speakers have identical frequency response in the range of membrane resonance (ca.35 Hz). In 8 years I never had problems with destroyed membranes.

Actual I'm testing Hostaphan with 2 µm thickness (but only for hybrids, because of mechanical limits). after 3 years of continuos play I have no problems. I tried to make a thermal treatment before connecting the membranes to the frame to avoid the needed playing time, but I never got reproducible results. Do you know about a successful way?

Questions and Answers

Question

Jonas Karud posted the following question:

During my years of ESL-building, there's always been one problem overshadowing the others; How to make a lasting, slightly conductive coating on the membran, so high in resistivity that no currents can flow on the membrane surface, thus eliminating arcing and the need for insulated stators.

There is also the benefit of less distorsion plus the fact that You can choose very thin films as membranes. If We DIY:ers shall take the ESL-development further, we must find the formula for this conductive compound! The compound exists. The QUAD 63 uses it in a very high resistivty coating on a 2um (!) film. The BIG QUESTION is; How is it done?

Update: Sheldon D. Stokes is not selling his indium coating, due to difficult applying techniques, graphite is to low in resistivity, even when its wiped off. I'm on the trace to a very promising compound with a resistivity at around one GigaOhm/square, that dries to a very thin durable film, must do long-time testing before presenting it to the ESL-circuit.

Answer

Barry Waldron provided the following answer:

Electrostatic loudspeakers can be designed to operate either in a "Constant Charge" mode, or non. The latter has been used in tweeter panels, and in the early days, single ended speakers. (those having a single stator. It is my understanding of CS operation that a minute amount of current must circulate, lest the device not operate.

Recent experiments with various coatings and insulations has shown that high resistance, high voltage, high dielectric stators generate a much stronger arc resulting in large holes in the diaphragm;

whereas, low(er) resistance coatings, high voltage, high dielectric stators generate an arc with considerably less destructive force. For speakers that are not expected to operate in the bass frequencies it would seem prudent to use graphite or other lower resistance media. I hope this is of help. Barry Waldron

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Question

Arthur Vered posted the following question:

Has anyone tried ½" or even 1" thick metal audio tape as "ribbons" for the membrane of an ES? What would be the resistence between two points (say a few inches apart) on such tapes? I think the tape is thin enough. It's already coated. Can it be done?

Question

MartinJan Dijkstra posted the following question:

I am worried about the durability of the soap layer on the mylar membrane. I have used "Driehoek" liquid soap with glycerine in it. It seems also to attract more dust than a graphite coated membrane. May be I have used too much soap. Who can tell me more about soap as a conductive layer?

Question

Ole Thofte posted the following question:

I just want to ask if you are aware of a Finnish product called EMFi (electromechanical film) which is a sort of electret polymerfilm with a permanent charge built in. using this film might make it possible to build an ESL-speaker without the high-voltage.....?

Does an ESL-speaker need to have a planar membrane? I'm experimenting at the moment with a dynamic driver using a large cone (250 cm tall!) as membrane. I'm going for the omnidirectioanal quality. A similar membrane might be possible as an ESL - or?

Best wishes, Ole Thofte, Copenhagen

Answer

Barry Waldron provided the following answer:

Electrostatic loudspeakers can take many forms. Modern day devices follow one of three plan forms. One is the flat (planar) cell; another is the curved cell; the last is the arced array. For the discriminating audiophile who desires the best image and transient response, the planar ESL is unbeatable. Room interaction is minimized. This and first arrival times that are not contaminated by reflections create an image that in nearly holographic in form. The curved cell, popularized by Martin Logan, widens the sweet spot to the detriment of achieving a pristine image. Moreover, the diaphragm travel is not linear. The membrane expands in the forward direction and collapses as it moves to the rear. This contributes to increased distortion. The arced array is a method that uses multiple flat panels placed about an arc. This creates multiple sweet spots. This architecture was popularized by SoundLab. The method works well but is only practical if listeners sit at the focal point of a stereo pair. Imaging also suffers due to increased room interaction.

Omnidirectional sound has its following as evidenced by the fact that Bose continues to sell speakers that bounce the sound all over the room. With the above information in mind, I do not understand how any audiophile who is serious about the ability to create an accurate illusion engine in his/her home, can want an omni directional system. Literature from manufacturers point to the fact that their products place you inside the orchestra. I guess this is alright, although I thought I purchased an admission ticket to sit in Row A center! I hope this is of help. Barry Waldron

Answer

Hans Zeeuwe posted the following answer concerning the electromechanical film:

Take a look at The Panel Loudspeaker Circuit/Commercial/Manufacturers/EMFi, I think they are using this film for their ESL's

Answer

Michael Ehrlinspiel posted the following answer concerning the electromechanical film:

Concerning finish electret polymer: Two things may be critical.

1. is the used material comparable to mylar in mechanical cases.
2. electret microphons uses in the range of 1.5V to polarize the membrane. I think it should be very difficult to make a electret membrane that keep charges comparable to 5000 V systems in ESL's.

Concerning membrane shape:

Typically you are free in dimension. martin logan uses bended esl. in praxis it is limited by production affairs. If I understood your construction of a 250cm loudspeaker, you force your membrane only in the mid, so that you have only uncontrolled movement in the outer ranges. this is comparable to "Manger"- or "Mission NXT"- technic but with the difference of not calculating this "uncontrolled movement.

Question

John Doe posted the following question concerning LIQUID SOAP:

Who has experience with liquid soap as electroconductive coating? I am specially interested in stability aspects.

Answer

Liquid dish detergent has been applied to diaphragms off and on for years. It has advantages and drawbacks. First, it is opaque, being neither translucent or transparent. Second, its appearance, depending upon how it was applied, leaves either brush marks or "finger painting" streaks. It provides a high resistance and is suitable for low frequency operation. Soap adds more mass than other substances, and, it must be used with a low resistance bus for two reasons. One, soap can corrode the diaphragm contact resulting in panel failure. A low resistance bridge keeps the contact away from the chemicals in the soap Two, in order to guarantee a rapid and equal charge recovery time over the entire surface area, the low resistance loop transmits the voltage from the diaphragm contact to all points around the perimeter equally.

Stability seems to be excellent. The material does make it difficult to remove dust from its surface, and, it can easily flake off if rubbed. I hope this is of help. Good luck.

Barry Waldron

2. One Thing Audio

Table of Content

Introduction

With over 30 years' experience in servicing/refurbishing electrostatic loudspeakers, One thing is unique in this field in providing a high standard of workmanship backed up by their own quality manufactured spares.

Currently available as a board or standalone unit, is One Thing's quality, low noise stereo decoder (reviewed Hi-Fi World, June 1999) plus servicing and alignment of Leak Trough Line and Quad FM2 valve tuners: the two finest English valve tuners ever marketed.

Prices

Miscellaneous

Model	prices (2002)
Top grade Dupont Mylar C film. Width 500mm. Gauge 6 micron. Sold only in 10 metre lengths or multiples thereof.	£ 30

ESL 57

Model	prices (2002)
Treble panel, rebuild*	£ 109
Bass panel, rebuild*	£ 130

EHT rectifier board (higher spec than original) RBT2	£ 45
Clamp board CLP2	£ 22.50
Audio transformer upgrade kit: consists of high quality (3.5kV metal film) replacement resistors, all capacitors, 303 mod kit plus loudspeaker sockets	£ 35 (pair)
303 treble panel protection board only	£ 12 (pair)
Hi-spec rebuilt audio transformer*	£ 45
Power supply rebuild (incl. new EHT board)*	£ 60

GEORGE Speaker stands, very attractive! Available in black/light oak	£ 165 (pair)
Original-design grilles (silver/black only)(coming soon)	
Standard service/refurbishment (Reviewed in Hi-Fi World, April 1999)	£ 350 (pair)
Total rebuild/refurbishment	£ 900 (pair)

ESL 63

model	prices (2002)
Panel rebuild (bass, treble)*	£ 100

Stocking (Black/Brown) Other colours available to order. Allow 28 days. Cost will be quoted	£ 38 (pair)

RUPERT Speaker stands, very attractive! Available in black/light oak	£ 165 (pair)
Full panel-replacement & servicing facility available	

*** Original defective item must be returned.**

MPX1 Stereo decoder Mk3

model	prices (2002)
ONE THING MPX1 stereo decoder Mk 3 (Reviewed Hi-Fi World, June 1999)	£ 175

Cables

Model	prices (2002)
OT high resolution speaker cables, 3 metre (per pair)	£ 65 (pair)
OT high resolution speaker cables, 5 metre (per pair)	£ 85 (pair)
OT Silver plated RF1 suppressed & voltage surge protected mains cable, 1.5 metre	£ 55

Longer lengths made up to order (Allow 10 days; quotations given)

All above prices subject to carriage & packing

Dealers and Distributors

United Kingdom

- Name: Classique Sounds, Classique House (Paul Greenfield)
- E-mail: classique_sounds@yahoo.co.uk
- Homepage:
- Address: 61 Aylestone Drive Aylestone Leicester LE2 8QE, England
- Tel: 0116 2835821, 0802 213740 (mobile)
- Fax: 0116 2835821

3. Do It Yourself Electrostatic Loudspeakers

Materials and Parts:

Membranes, Coatings, Conductive coating for plastic film

Marc Schroeyers provided the following information:

CONDUCTIVE COATING FOR PLASTIC FILM: at the following website you will find information on 'ORMECON LACQUER' 901210/17 or 900256: http://www.zipperling.de

These products enable you to apply a lasting, inert, conductive coating on plastic film; the surface resistance (depending on layer thickness) can be varied between 10exp3 to 10exp12 ohm-square. Maybe the ideal material for electrostatic loudspeakers?

I think indium-tin-oxide (this is used for example by companies like Schott, Balzers etc.. for optical coatings) is as good, but where to get it, and how can we apply it at home? (in the industry they probably use sputtering techniques). The ormecon products can be sprayed or lacquered. A drawback is the cost: I informed at Zipperling, they charge around 750USD for 0.75liter (this should be enough for around 500 square meters!) So for a home project to expensive.

Does anyone see a possibility of getting a smaller volume at much lower cost to experiment and test it to find out wether this is a good solution for the really difficult coating problem?

Jukka M. Mononen provided the following information:

I tried this tin dioxide -stuff (according what S. Stokes helped me). Well, it worked, but only in little area, near the polarizing voltage supply connection. Maybe, I put a little too small amount of tin dioxide or something... Anyway, I guess I'll stay on graphite in the future as well

Do It Yourself Electrostatic Loudspeakers
Materials and Parts: Membranes, Coatings, Conductive Lacquer

Jonas Karud provided the following information (October 2000):

After many experiments and an extensive 2 year test, I'm ready to let ESL DIY'ers test my conductive lacquer. I've got some help by Niclas Falck, researcher on the Chemical Center, University Of Lund, and have developed a nontoxic (don't drink it), water soluble polymer emulsion that dries to a tough conductive layer.

I've tested the long time durability of the lacquer, and found that the electrical properties of membranes in panels playing night and day for over 2 years have not changed to a measurable degree. You can ignore the added weight of the lacquer if diluting more than 1:7. The conductivity can be adjusted from 1E6 to 1E10 ohms/square simply by diluting with distilled water.

Diluting	Approx. Conductivity (Ohms/Square):	Charge Time (seconds)
1:1	1E5	none
1:2	1E6	none
1:3	1E7	<1
1:4	1E7	1
1:5	1E8	<2
1:6	1E8	<4
1:7	1E9	<6

1:8	1E10	<10
1:9	1E10-1E11	>30

Isolated stators for preventing arcing between stator and membrane are not necessary if you dilute more than 1:7. As always, no sharp edges or burrs are allowed to point toward membrane, as arcing then can occur from stator to stator, destroying the membrane.

If the emulsion is diluted to a higher degree than 1:10, charging the membrane will take too long time, which indicates that the high resistivity of the air surrounding the membrane acts as a element of a voltage divider....

The emulsion is expensive to produce, as always with acrylics, around 10 USDollar/centiliter, but diluting lets say one centiliter to 1:7 gives 7 centiliters which easily covers 3-4 square meters.

The best way of establishing a good electrical contact with the conductive lacquer, is to lay out self-adhering coppertape of 4-6 mm width on top of the mounted membrane, preferably where the membrane is supported by the spacers. Avoid fingerprints. Then You spread the lacquer with a soft lintfree tissue on the coppertape and membrane, allowing it to dry for 12 hours. Do not clean the membrane before applying lacquer, as the emulsion can get contaminated by the cleaning agent. Only use compressed air to blow away cat-hairs and dust.

I can send a sample of the stuff if you're interested, to let you test it before I go any further. E-mail karud@telia.com

Regards from Jonas Karud, DIY Participant of The ESL Circuit.

4. The Original Quad Diaphragm Coating
A Direct Replacement by Gary Jacobson

Personal

- Name: Gary Jacobson
- E-mail: garyjac@myall.net
- Homepage: The Quad ESL
- Address: Queensland Australia
- Tel:
- Fax:

Introduction

This article describes the broad details of a method for restoring or replacing the original Quad ESL diaphragm coating to its original specification. The description is mostly non-technical. Issues of materials obsolescence are addressed, and a number of apparent peculiarities in the original design explained. The methods described can be implemented with minimal, readily available equipment and chemicals. All surface resisitivity measurements quoted in this document were taken with a fully calibrated SR meter to ASTM D-257 standards. The accuracy is +/- 10%, and the repeatability is +/-5%.

The Background

Although almost anything, within reason, that can be spread on plastic can be used as a coating on an electrostatic speaker diaphragm, and work after a fashion; the original Quad ESL is particularly optimized in this respect, both in the chemistry and the choice of substrate material. Any old coating will not do the job quite as well.

This is not to say that other coatings (e.g. graphite) cannot be used with success in original Quads. They can, and when properly implemented they produce excellent results also. However, these substitutes, by and large place extra drainage on the EHT power supply, which is already marginal in respect of current drainage.

The original Quad speaker is a true marvel of subtle optimization within the materials / cost parameters of its day. Indeed, no polymer commonly available in production today would provide a markedly better material in their construction. I have only just begun to realise how subtle some of these optimizations are. The actual choice of which coating to employ in the original Quad ESL was/is part of this optimization.

Alas, as all of us know, the original coating is no longer available to Quad, or anyone else. The original substance is not a secret. It was called CALATON and was made by I.C.I. (U.K.). This material was a soluble form of nylon. It could be dissolved in water/alcohol solution. The resulting solution was painted (literally) on the original Quad Mylar or Saran diaphragms that made up the moving element in the Treble and Bass panels respectively. The surface resisitivity, initially, achieved is 10^{10} to 10^{14} ohms per square. Surface resisitivity is dependent on coating thickness as follows: $R(surface) = R(volume) / t$ where t is the thickness of the coating.

Did Quad just put soluble nylon on the membrane or was there an additive of some kind? A key question, obviously. Can soluble nylon still be obtained anywhere in the world? - another key question. Will it actually work? The best question of all. Let’s see about the answers to these questions then.

Soluble Nylon

Soluble nylon is still made by TORAY Inc. of Japan under the trade name of AQ-NYLON. When queried by e-mail regarding the product they are silent as the grave. Soluble Nylon was used in artifact restoration until the 1970's. It is somewhat disastrous in that application as it turns out, and its use has been discontinued. This may be why most previous manufacturers don't produce it anymore. Do not despair, there is a way around this problem, as I will describe later in this article.

Additives

Did Quad add "doping" materials to the membrane material? This question can be answered by Quad, OR, by spectroscopic and gas chromatographic analysis. OK - out the door, down the road to the chemistry department. Ask the professional chemists to "pretty please analyse this old piece of Quad diaphragm plastic and what's on it". Offer free beer and other sundry bribes, wait for a week, and see. The answer? "Yes, it's nylon and polyester, but we can't say if it has had a significant amount of additive. It might just be dirt." Great guys(!) What can you expect after 20 odd years though? So, maybe Quad did, and maybe Quad didn't "add" something. This issue was sidelined for later examination, as and if necessary.

The Theory

Firstly, unlearn, as I had to, the idea that static electricity means "stationary electricity". Think in terms of "nett charge separation", since this is actually the phenomena and also what we require. It is also nice if the charge does not move about on the membrane creating spurious capacitance variation and other bad happenings. F.V. Hunt's original mathematics shows that if capacitance variation is kept to <8% then distortions of all types are <0.5% at audio frequencies. Impressive, in a speaker.

The next basic lesson to learn (or re-learn) is about the Triboelectric Series, (see below).

- Asbestos (Acquires More Positive Charge)
- Rabbit Fur
- Acetate
- Glass
- Mica
- Human
- Hair
- Nylon
- Wool
- Fur
- Lead
- Silk
- Aluminium
- Paper
- Cotton (ZERO)
- Steel
- Wood
- Amber
- Sealing
- Wax
- Hard Rubber

- MYLAR
- Nickel
- Copper
- Silver
- UV Resist
- Brass
- Gold
- Acetate Rayon
- Celluloid
- Orlon
- Acrylic
- SARAN
- Polyurethane
- Polyethylene
- Polypropylene
- PVC
- Silicon
- Teflon
- Silicone
- Rubber (Acquires More Negative Charge)

We can see that Nylon is near the top of the series, and both Mylar and Saran are much further down. In effect, this means that electrons tend to leave the nylon and the Mylar tends to accept them. This produces a definite negativity in the Nylon. A close contact between Nylon and Mylar, as in a coating, guarantees that the electrons will stay very, very close to the Mylar "side" of the pair. Quad coated the diaphragm on BOTH sides. Perhaps now, we can see why. The Nylon surface tends to be positive and the Mylar tends to be negative. There is NO bulk current flow to speak of because of the generally insulative nature of each substance. It is a "nett separation of charge ". The migration of charge through the bulk of the membrane is slow by any normal electrical standard. If a Quad membrane was coated with Nylon on one side only, then one side of the diaphragm would tend to be in slight negative charge deficit with respect to the other side. Quad then provided a small trickle charging source at 1500 and 6000 Volts for the respective diaphragms to provide the "make up" of charge carriers in the system. I am sure that this is more obvious to us now, in an age of semi-conductors. In 1954-55, it was very clever indeed.

So, it was NOT simply a matter of placing a high resistance coating on the membrane, but a PARTICULAR kind of high resistance coating that is triboelectically positive with respect to Mylar or Saran for the most desirable effect in this system. The EHT supply is designed to work "hand-in-glove" with this specific combination of materials.

A coating such as graphite will work, but excessive current drainage on the power supply will cause the membrane to oscillate (hum) at the line frequency. This is BAD. The hum can be overcome by putting large resistances in the EHT power supply line to a panel. This limits the current drain, and the charge, as a result is more closely confined to the surface of the membrane, eliminating the hum. Sound quality is still excellent, and this is a solution proposed by both Sheldon Stokes (U.S.) and Andrew King (U.K.). It is workable and expedient, but does not exactly restore the speaker to original condition. Other benefits accrue when these resistors are added and both Andy and Sheldon have these described in detail on their web pages. I highly recommend them as essential reading, and will not elaborate further here.

The use of a large value charging resistor does not guarantee an absolute minimum of distortion at all sound levels across the normal audio spectrum, however. This is a consequence of the curvature of the membrane under dynamic conditions. As a result the capacitance will vary across the membrane - closer to the plates at the edges than in the centre. This means that a series resistance, large or otherwise, will cause variable RC time constant across the membrane. For small membrane excursions, this is negligible, so the technique is an excellent, cost-effective one for treble panels which (of course) experience low physical excursions. The ONLY way to effectively solve the problem is to place the high resistance on the diaphragm, so that a very high resistance is "in series" with every individual capacitance, so to speak. Standard calculations indicate that a minimum of 10^9 ohms per square is sufficient. The Triboelectric necessities of life raise that value somewhat (nylon is used) in the narrow confines of this particular speaker. Conveniently, this enables the designer to lower the diaphragm to stator spacing and increase the efficiency of the device overall. This is another good reason, in addition to low distortion, for a very high resistance coating.

The Practice

Maybe TORAY Inc. will reply to my e-mail about the soluble Nylon, maybe not. Please feel free to contact them, they are on the web. If available at a reasonable price, it would be a valuable resource.

DIY Soluble Nylon?

Yes! Nylon is "soluble" in Phenol/Water, Phenol/Methanol and 90% Formic Acid to name a short list of chemicals. An organosol is formed. Strictly, this is a kind of suspension, but let's not quibble about that since it won't be a problem in practice.

Recipe

Materials 25 grams Phenol

- (White, Crystalline solid, AR grade preferred)
  - 150 ml water (tap water will do, distilled or demineralised is better)
  - Nylon Fishing Line (not gel spun polyester!)

N.B. Phenol should be handled with care. Wear gloves, and mix it in a well-ventilated work area. Phenol vapours are slightly flammable at elevated temperatures.

Method

- Heat the 150 ml of water in a glass beaker to about 50 degrees Celsius. This temperature is not critical. We want pretty hot water but not boiling.
- Add the Phenol crystals to the water in 5 gram lots with constant stirring. Wait for each to dissolve.
- Chop up about 5 grams of NYLON fishing line (not critical again), into 1 cm pieces and drop into the solution about 0.5 grams at a time. Keep stirring with a glass rod over heat, but avoid boiling the solution.
- Stir for 15 to 20 minutes until all the nylon "goes into solution".
- Put the solution aside to cool to room temperature. You will see it separate into a thin dense layer, and a thick less dense one.
- Store this 'organosol' in a glass bottle with a resistant plastic stopper or glass stopper.

The "solution" made above is in fact an 'organosol' which is a kind of dual phase suspension (I'm told). It will, given a short time at rest, begin to separate into two obvious layers. The amount of nylon you have dissolved is indicated by the thickness of the lower layer. The thicker it is, the more nylon you have in ‘solution’. Hence you must SHAKE WELL before and during use. This shaking process creates a suspension of phenol/nylon in phenol/water as small droplets.

N.B. Phenol is also known as ‘Carbolic Acid’, and was used as the first hospital antiseptic/disinfectant. It is mildly corrosive. You should keep it away from skin and eyes as much as possible at these concentrations. It has a pronounced and distinctive smell, and prolonged vapour inhalation (hours and hours) can be harmful. It is very harmful if you drink it!! Don’t be put off, normal care will avoid accidents.

An alternative to aqueous phenol is Methyl Alcohol and Phenol. This vapourises from the work surface better and faster, but I prefer to avoid one more potentially flammable chemical and dry the coating with a hair dryer.

Update (June 2000)

BTW, I have found that it is possible to make Nylon (alone) dissolved in Methyl Alcohol/Phenol work as a diaphragm coating quite well without the need to ‘dope’ it at all.

The “dissolved” nylons in end-amine group solvents seem to provide a slight ‘etch’ into the polyester as well. So I think that the coating will actually stay on for longer than the original CALATON.

For folks who don’t want to mess with all these chemicals, there is a DuPont product known as ELVAMIDE which is an alcohol soluble Nylon, but I don’t know if it can be bought in small quantities.

The Application

You can apply the material produced above in a fairly direct way to the Mylar membrane as follows:

- Set out the work area with the Mylar diaphragm to be coated, using your preferred method.
- Shake the bottle of organosol you have produced above until it appears as a uniform, white, milky coloured liquid.
- Put some gloves on!
- Open the garage window!!
- Wet part of a paper towel by closing the mouth of the bottle off with the towel, and shaking until the organosol wets the folded towel.
- Wipe the wetted towel in a side-to-side motion across the width of the diaphragm, and move down the diaphragm in an overlapping zigzag fashion until you cover it. I recommend that you recharge the towel at least twice when doing a Bass panel diaphragm and once when doing a Treble panel. Your mileage may vary - as they say. The material will sit on the polyester as a streaky set of lines of droplets. It is as if you had a very bad windscreen wiper on your car. This is OK!
- Dry the membrane as you go with an ordinary hair dryer set to LOW heat. We don’t want ot heat shrink the Mylar by accident at this point.
- The Nylon coating will dry to a whitish, streaky, thin-in-parts finish.
- Re-coat if you like, but don’t expect it to ever look “even” or “uniform” - It won’t.

The Nylon will adhere to the Mylar like tar to the proverbial tomcat. Guess what? It looks exactly like the original “sloppily applied white-paint-like substance” that people talk about when re-building old Quad panels and membranes. The smell of Phenol will linger for days!

Don't worry about this, since when the panel is re-sealed inside the dust covers with a good tape all around, you won't notice an odour at all. You could also leave it in a protected out-of-doors area for the smell to dissipate for a day or so too, and then seal it up - take your pick.

DO COAT BOTH SIDES OF THE DIAPHRAGM!

Does It Work?

Yes. However, you must re-install the EHT supply bolts exactly as they were. The bolts I refer to are the two 12mm x 2mm bolts that hold the EHT wire onto the panels (Treble or Bass). As it happens, they just punch straight through the diaphragm, and this is what Quad intended - plus the fact that it is a lot faster during manufacture!

The idea is NOT to achieve a good, solid contact with the membrane. Do not use little bits of foil, et cetera., to do this. With a different membrane treatment, this may be OK, but not in this case. These fine (2mm dia.) bolts sit in the centre (approx. and automatically) of a 3 to 3.5 mm diameter rivet and panel hole. I suspect these two rivets are a mechanical device to cause simple automatic centring of the bolts. The bolts touch the diaphragm physically, but we are not trying to create a classical electrical circuit here. This is a very, very high resistance contact, at 'best'. A cylindrical radiator (bolt) is placed so that it radiates electric field to the surroundings across a very tiny air gap (in the main), and this supplies the "make up" charge on the diaphragm. The triboelectrical differences between the nylon and polyester take care of the rest. In other words, don't try to set it up in terms of a classical current flow. It doesn't work like that, and trying to make it work like that is extra effort and counter productive.

A diaphragm coated in "pure" nylon as done above will take a long, long time to charge fully - sounds just like a Quad ESL again, doesn't it? In fact, too long. We know that the original Quad membranes would charge to a useable level in one to five minutes. Although we also know that if Quads are left on, the sound continues to improve for days, especially the mids and highs. I strongly suspect that this is due, in the case of the original, factory diaphragms to partial coating loss with age, and the fact that the distribution of charge in the nylon becomes more "even" with continuous charging on a "good" membrane.

In any case, this led me down the path of additives that Quad might have used to speed up the initial charge rate. To cut a long story short - to get an acceptable charge rate - add some anions permanently to the Nylon coating. In practice, doping the membrane with anions is simple. Take about 10ml of the organosol you prepared previously. Add 4 ml of hand soap containing Sodium Laurel Sulphate. I had this done in a lab, but I have done it with a household product with the same result.

Coat a diaphragm in the same way as before with this "doped" organosol. Dry well using the hair dryer as before. Measure the surface resistance! If it is anything, anywhere below 10^10 ohms per square, polish the surface off with a dry paper towel, as hard as you like and measure again. If this fails to raise the resistance, then 'strip' the surface with the original 'undoped' (no soap in it) organosol to raise the resistance again. The surface will increase in resistance to 10^10 to 10^12 ohms per square. It will NOT be uniform across the entire membrane, and it doesn't need to be. It isn't in the factory membranes either, should you be wondering. In fact completely removing and drying the soapy nylon material seems to be sufficient. This absolutely minimal contamination seems to be locked into the nylon coating for the life of the nylon - a long time.

What you now have is an essentially insulative, by modern ESD standards, layer contaminated with anions, sitting on another insulative layer.

The effect is PERMANENT. I have completely ‘stripped’ the soap-loaded membranes with organosol until the surface measures 10^12 ohms per square. These membranes still charge rapidly and improve with time. They sound just like the originals.

Caveats

Don’t be tempted to brush large amounts of the nylon organosol onto the Mylar. For one thing, if you don’t know what fibres are in the brush, it may dissolve! Secondly, a very high phenol accumulation in a given spot for a few minutes can weaken the Mylar. I actually had to use a 95% solution to do this, and this recipe is a lot less than that. Wiping and drying immediately will fix the entire coating as permanently as the original - so expect only about 20 years service from it.

Don’t clean the EHT bolts with penetrating oil or silicone lubricants if they are a little corroded looking. I made this mistake - duh! This dramatically reduces their ability to create the small, uniform electric field where they ‘contact’ the membrane. Brush them with a small wire brush, and ‘degrease’ with isopropanol or other alcohol. In a pinch - buy a few new THIN bolts.

Typical Diaphragm Data

(as measured during trials of various diaphragm materials)

Graphite	Standard application with mechnical polishing only	10^5 to 10^7	ohms/sq
Graphite	Standard application with alcohol scrubbing	10^8 to 10^10	ohms/sq
Hand Soap	Wiped on and mechanically removed	10^7 to 10^9	ohms/sq
Nylon	Straight organosol	10^10 to 10^14	ohms/sq
Nylon (doped)	Organosol + Soap then stripped	10^11 to 10^14	ohms/sq

Remember it’s not just the high resistance, but the Triboelectric differences between materials that make this combination of materials work - and keep on working.

The Diaphragm

Just thought I’d send you a quick line regarding polyester film. I’ve been doing a few experiments with 6 micron Hostaphan (biaxially oriented film) and it seems to hold its original tension quite well. It will be ineresting to see how it fairs in the longer term, since this is the same thickness of film as in the original Quad. It is (alas) outrageously expensive, being about $AUD20 per metre !! I would like to emphasise that the Hostaphan film is just in the early testing stages, but it does have a very high tensile strength.

5. Review on the Original Quad Diaphragm Coating That Was Developed by Gary Jacobson

Personal

- Name: Ben Openshaw
- E-mail: info@electrostaticdoc.com
- Homepage: The Electrostatic Doc
- Address:
- Tel:
- Fax:

Table of content

Introduction

My original intention was to see if the conductive coating that Gary had come up with was truly the best coating to use for the Original Quad speakers. So I can offer my customers the best possible product I can. I ordered the Phenol, picked up the nylon line, studied the mechanics of mixing up the coating and began my project. As most of you know I am very close-mouthed about the techniques I use because of a promise that I made to a dear friend of mine. However, Gary's work is a public document. So here is my report on his coating for the Quads based on my findings while experimenting with it.

Discussion

Method

The first discovery I made was that Phenol in crystal form is not something that is found in a corner drug store. In fact, most chemical companies do not stock it. All the companies I found that sold Phenol in an acceptable grade were either too difficult to deal with, or required such large quantity minimum orders that it was not reasonable to order from them. The least expensive supplier I found had industrial grade Phenol at $55 a kilogram. They were rather difficult to deal with and I preferred high grade Phenol for my R&D. I finally came across a company that allowed me to order only 125 grams, that was able to ship to me in a reasonable amount of time. They were the nicest people. I ordered the Phenol from Alameda C&S, Inc. right here in Idaho (208) 463-8358. It cost $80 for the 125-gram bottle and an additional $30 handling fee for hazardous material. I believe it's possible to order the same Phenol directly from the manufacturer for $62 + shipping.

Before starting there were a couple recommendations made to me. The first was to have a fire extinguisher and a Phenol antidote kit (which consists of caster oil or any vegetable oil). When I received the Phenol I stretched my diaphragm and followed the directions that Gary had laid out exactly. I mixed 25 grams of Phenol in 150 ml of water (I used tap water the first time). I carefully weighed the nylon line, making sure there was exactly 5 grams of line. I stirred the mixture until the nylon dissolved. I then spread the mixture on the diaphragm. I reduced the heat on my hot air gun so that I did not heat shrink the diaphragm and dried the moisture off. I turned the diaphragm over and repeated the procedure on the other side. I then put the speaker together and began testing.

I tried several different ways to apply the coating on the diaphragm. The first deviation I tried began by soaking a large mouth Mason Jar lid in Acetone until all the rubber and varnish came off of the lid. I then made up another batch of Phenol/Water/nylon. This time I dissolved much more nylon in the mixture until it was so super saturated that it had a bunch of “snot” in the bottom which is a layer of phenol/nylon (please be careful because the phenol is more concentrated in this layer). I then placed a drop of the “snot” on the jar lid along with a drop of water and rubbed it into the towel. After it was worked into the towel I rubbed it onto the diaphragm in small fast circular motions. This method of application appeared to give a more consistent coating. I experimented with other changes in an attempt to make the coating more consistent.

The technique I ended up using to achieve the most consistent coating was to take a drop of the “snot” and water and work it into the towel. After working it into the towel I moved to the diaphragm and rubbed somewhere off of the speaker diaphragm until the consistency of the coating was correct. I then moved onto the diaphragm in a very slow back and forth motion, trying to avoid creating any friction. It takes so much time that by the time I have finished the second diaphragm the first is usually almost dry, without using a heat gun. You need to be very careful that you do not get the coating too thick (consequences of this is discussed later). If it is too thick, you will have to strip it off and start over again.

Findings

After the first couple of speakers I tested I noticed that the efficiency was up close to 5db from an original panel fully charged. The re-diaphragmmed panels seemed to charge instantly which was in total contrast to Gary’s findings. I left the speakers running all night. When I tested the speakers in the morning the efficiency was back down to where it should have been. I found that the discrepancy of efficiency was due to using tap water to mix the Phenol. When I used distilled water to dissolve the Phenol I had much better results. The results were so dramatically better I recommend that you do not even consider using tap water. Tap water has lead, minerals, chlorine, etc. depending on where your water comes from. I found these things do affect the outcome. In case you are considering putting a thicker coat on the diaphragm to increase efficiency this will NOT work! Discussions with Gary indicated that he seemed concerned about decreasing the resistance of the diaphragm by having the coating too thick. This has the potential to make the panel hum. Though that is a great concern, it is the least of your troubles if you get the coating too thick on the tweeter. You can load the diaphragm down and roll off your highs significantly, especially if you are using 6 micron or thinner film.

Results

I sat down in front of the speakers to conclude if the new coating was truly better. I allowed the speakers to charge a good 24 hours to make sure that both sets of panels were fully charged. I had to first turn on the pink noise and check the signature of both speakers. The first thing I noticed was that the very top frequencies were rolled off a bit more than my coating. I kind of expected this because the nylon is a much thicker coating than mine is. What I did not expect was that when I moved the mic up and down close to the diaphragm I found that the output was more consistent across the diaphragm from the nylon-coated speaker.

Ideas

The first question that I had was, "Does the slight frequency response difference really sound better? Or worse?" The speakers with the nylon coating seemed to be more alive and have better control over the diaphragm. As I was listening to the nylon-coated speakers I began to wonder about the top highs I had measured earlier that were a little more rolled off. The highs did not sound rolled off at any time during the listening test. I hear all the time that "The Original Quads do not have the highs that I remembering them having." I wonder if this is from the diaphragms and the original coating getting old causing them to not have the response they used to have. I do not know what it was like to witness a brand new pair of Original Quads off the assembly line and burned in proper. From what I was told the Quads efficiency drops by 15% over the first 5 years then stops decreasing after that. Also the tension of the diaphragm relaxes a bit, lowering the resonate frequency. Plus there is some degradation of dampening tapes used in the high frequency panels. (Another possibility is that electrostatic highs are so natural and smooth. People now days are so used to listening to over exaggerated highs to try and give a feeling of "airiness" to the common dome tweeter. Which makes the listener THINK the highs are rolled off). So if you have a 15 - 20 yr. old speaker that you blew a tweeter out on and you were able to order a new panel with all original parts, the new panel should sound better and not the same. If you were to rebuild a tweeter it shouldn't sound the same, but should sound slightly better as well. That is what I feel that this coating does. It seems to breathe new life into the panels and make them sound new again.

Conclusions

The nylon coating that Gary has come up with is the single best conductive coating for the Original Quad speakers that I have used to date; it beats soap, graphite, and everything else I have tried. It seems to work well only in the Quad type designs. If you need to match a more conductive coating it does not work that well. So it will not work in all situations. There are some drawbacks to the coating that I can think of, they would be as follows:

1. It does roll the extreme highs off a bit more than a thinner coating material with the same conductivity. **NOTE** The thinner coating has a slight rise from the original. The nylon coating makes the highs exactly the same as the original coating. The loss of highs from a thinner coating is not bad it is only a couple of dB @20KHz, and it is not something that is heard during a listening test.
2. The coating that I was using is a coating that would last as long as the diaphragm material (I was told by the distributor that it was 1000 years) and this coating lasts about 20 years.
3. The chemicals used to make the coating take a great deal of care at best to handle.

However, the advantages of the coating well outweigh the drawbacks. Anyone that is rebuilding a Quad '57 panel would benefit from the use of this coating. The first time charge on a pair of tweeters does not take long at all. The first time charge on a pair of woofers takes a very long time. The speakers are playable after 5 minuets, however they really start to sound better and really come alive as more time passes during the first 24 hours. There is not a problem with electrons falling off this diaphragm. After the first initial charge, they seem to charge much faster (The driver is a capacitor, so it may be that it is just holding a charge). The speaker will charge more quickly if you power it up immediately after rebuilding.

*** The following is speculation on my part ***

At that time all the water has not yet evaporated from the nylon causing the charge to distribute across the diaphragm more quickly.

Ben Openshaw

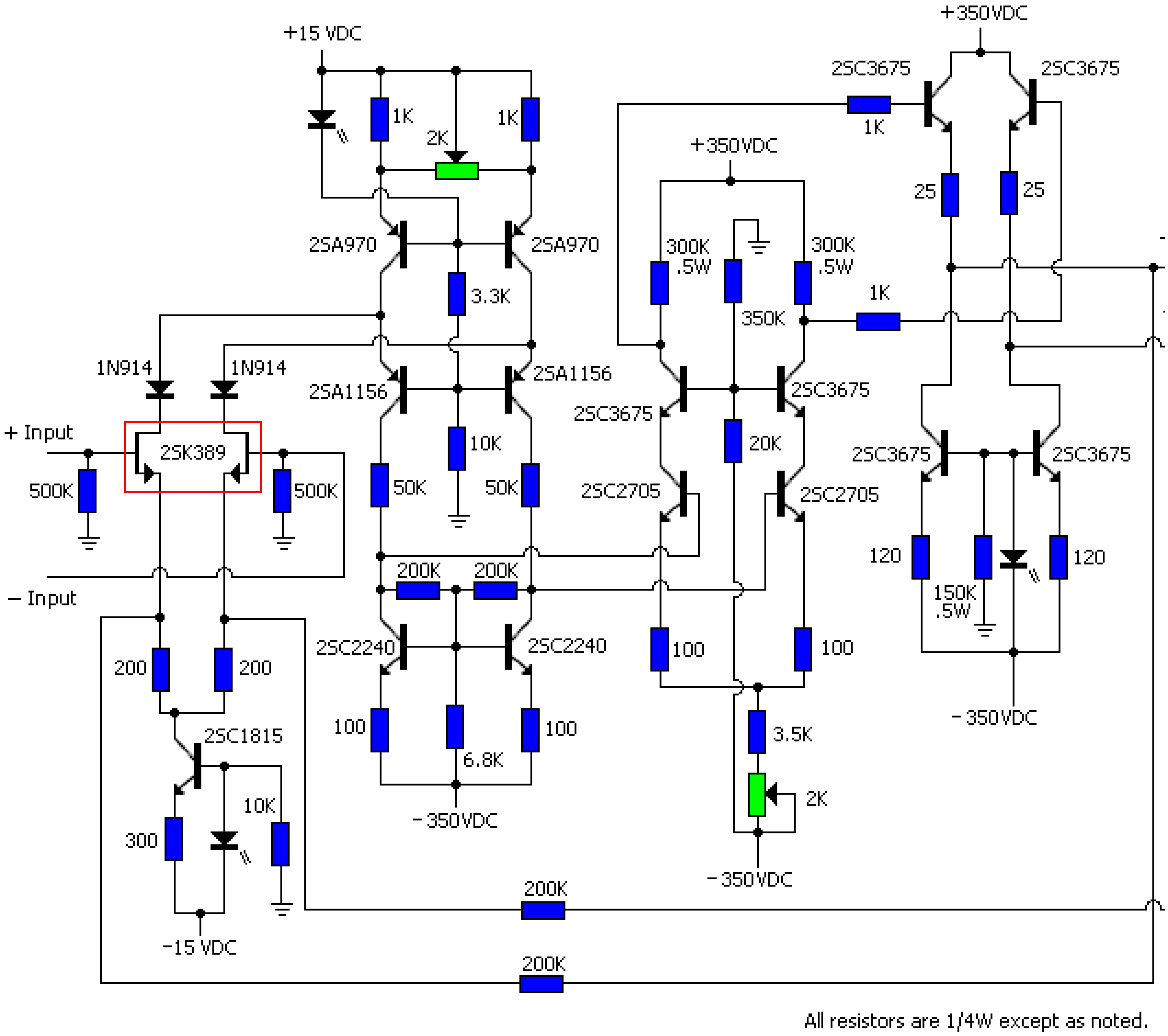
6. Patents

Patent number	Filed Granted	Description
U.S. Patent 1,550,381	Nov. 28, 1921 August 18, 1925	**Joseph Masolle**, **Hans Vogt** and **Josef Engl** assignors to Tri-Ergon Ltd., of Zurich, Switzerland “Electrostatic Telephone”
unknown	1926	**André Charlin**... receiving a patent for a push-pull electrostat...
U.S. Patent 1,622,039	May 2, 1925 March 22, 1927	**Frederick W. Lee, Owing Mills**, Maryland. “Apparatus for and Method of Reproducing Sound”.
U.S. Patent 1,631,583	February 12, 1926 June 7, 1927	**John Depew**, of New York. „Capacitatively Actuated Loudspeaker“.
U.S. Patent 1,674,683	March 24, 1926 June 26, 1928	**Walter Hahnemann, Kitzberg**, Germany, assigned rights to Lorenz Aktiengesellschaft. „Arrangement for Uniform Electrical Sound Transmission“.
U.S. Patent 1,762,981	June 6, 1928 June 10, 1930	**Ralph V.L. Hartley** of South Orange, N.J. assigned rights to Bell Telephone Labs., N.Y. “Acoustic Device”
G.B. Patent 346,646	Sept. 27, 1929 April 16, 1931	**Edward Washburn Kellogg**, Schenectady, N.Y. assigned rights to General Electric Co. N.Y. “Production of Sound”
G.B. Patent 370,248	June 1, 1931 April 07, 1932	**Albert Rauser** and **Wilhelm Steuer**, of Kottbuser-Ufer 39/40, Berlin, S.O. 26 “Improvements Relating to Electrostatic Loud-speakers”.
G.B. Patent 372,649	Sept. 8, 1930 May 12, 1932	**Hans Vogt**, Genthinerstrasse 17, Berlin, W. 35, Germany. “Improvements Relating to the Insulation of Fixed Electrodes of Electrostatic Loudspeakers”
U.S. Patent 1,881,107	Sept. 15, 1928 Oct. 4, 1932	**Hans Vogt** of Berlin-Wilmersdorf, Germany. “Sounding Condenser”
U.S. Patent 1,930,518	July 30, 1930 October 17, 1933	**Jurjen S. High** of Camden, N.J. assigned rights to Westinghouse Electric and Manufacturing Co. Pennsylvania. „Electrostatic Loudspeaker“
U.S. Patent 1,983,377	Sept. 27, 1929 December 4, 1934	**Edward Washburn Kellogg**, Schenectady, N.Y. assigned rights to General Electric Co., N.Y. “Production of Sound”
G.B. Patent 610,297	April 9, 1946 Oct. 13, 1948	**Etablissements S.M. Body Corporate** of 26 Rue de Lagny, Paris. “Improvements in Electrostatic Microphones and Loud-speakers”
U.S. Patent 2,631,196	October 5, 1949 October 5, 1953	**Arthur A. Janszen**, Cambridge, Mass. “Electrostatic Loud-Speaker” 7 claims. Description of an ESL that has on fixed electrode, and electrically divided diaphragm to control directivity, frequency response, and impedance of the speaker.
U.S. Patent 2,796,467	Dec. 12, 1951 June 18, 1957	**Winston E. Kock**, Basking Ridge, N.J., assigned rights to Bell Telephone Labs., N.Y. “Directional Transducer”
U.S. Patent 2,855,467	Dec. 11, 1953 October 7, 1958	**Paul Curry**, New Haven, Connecticut assigned rights to Curry Electronics Inc., New Haven, Conn. „Loudspeakers“
U.S. Patent 2,864,899	Nov. 29, 1954 Dec. 16, 1958	**Henry W. Parker**, Flushing, N.Y. “Transducer”
U.S. Patent	...	**Janszen**, Describes and ESL manufacturing process

2,896,025	July 1959	using wire grid fixed electrodes, one on either side of the diaphragm.
G.B. Patent 815, 978	October 19, 1955 July 8, 1959	**Peter James Walker** and **David Theodore Nelson Williamson**
U.S. Patent 3,008,013 or 3,008,014?	July 15, 1955 November 7, 1961	**David Theodore Nelson Williamson**, Edinburgh, Scotland assigned rights to Ferranti Ltd., London. **Peter James Walker** of Huntingdon, England. "Electrostatic Loudspeakers" Describes a method of makig ESLs with low distortion and a method of separatng them into different sections to reproduce different frequency ranges.
U.S. Patent 3,008,014	Sept. 12, 1957 November 7, 1961	**David Theodore Nelson Williamson**, Edinburgh, Scotland assigned rights to Ferranti Ltd., London. **Peter James Walker** of Huntingdon, England. „Electrostatic Loudspeakers"
U.S. Patent 3,014,098	... December 1961	**Malme**, Provides a good, detailed description of ESL operation, and a design that incorporates segmented stators to control directionality at high frequencies.
U.S. Patent 3,668,335	... June 1972	**Beveridge**, Describes a servo controlled ESL mounted in an enclosure, to allow low frequency reproduction, and with an acoustic lens to control high frequency dispersion. Patent includes schematics of vacuum tube servo control amplifier.
G.B. Patent 1,234,767 (PDF, 730 KB, provided by Willy Lefevbre, June 2001)	... June 1971	**Enock**, Describes electrostatic transducers in which the stators are insulated to allow the use of high operating voltages, thereby increasing the sensitivity of the transducers.
G.B. Patent 1,239,658	... July 1971	**Bowers and Greenwood**, Describes an electrostatic speaker that is built used printed circuit techniques, in which the stators are insulated to allow the use of high operating voltages, thereby increasing the sensitivity of the drivers.
U.S. Patent 3,668,336	... June 1972	**Wright**, Describes an ESL with electrical connections on one side of the speaker only.
U.S. Patent 3,778,562 (PDF, 130 KB, provided by Willy Lefevbre)	... December 1973	**Wright**, Describes an ESL mounted in a sealed enclosure filled with a gas that acts as an acoustic lens to control the directionality of the driver and allows higher operating voltages than would be possible in air, thus increasing the sensitivity of the driver..
U.S. Patent 4,289,936	... September 1981	**Civitello**, Describes an interesting inverse ESL with one perforated stator plate and two diaphragms on either side of it. The drivers are triangular, with multiple units assembled into a kind of geodesic dome structure for control of directivity of the speaker.
U.S. Patent 4,703,509	... October 1987	**Kanchev**, Describes an ESL that uses stators with resistive properties to control frequency response and directivity.

Links

The IBM patent server (provided by Mark Rehorst)



Current Domain Electrostatic Headphone Amplifier (one channel)

The first stage is a differential amplifier with feedback directly from the output stage. It works e well with both balanced and unbalanced audio input sources. The step attenuators from Goldpoi make good volume controls for this stage. The JFET device is a dual JFET all on one wafer. It is for extremely low noise and excellent matching, and is used in a number of expensive designs, the Nelson Pass amplifiers.

Because the amp is totally DC coupled from input to output, drift in the input stage is a bad ide the first two stages run in current mode, the JFET input is more linear than a pair of bipolar trai Dual transistors all on one wafer suitable for audio use are hard to find these days.

The approximate voltage gain of this stage is 5. But it really runs in current mode. The unit was designed to work equally well in both balanced and unbalanced mode. For single-ended signals, either the + or - input and apply signal to the other. The much higher impedance of the JFET wo better when one side is grounded for unbalanced inputs.

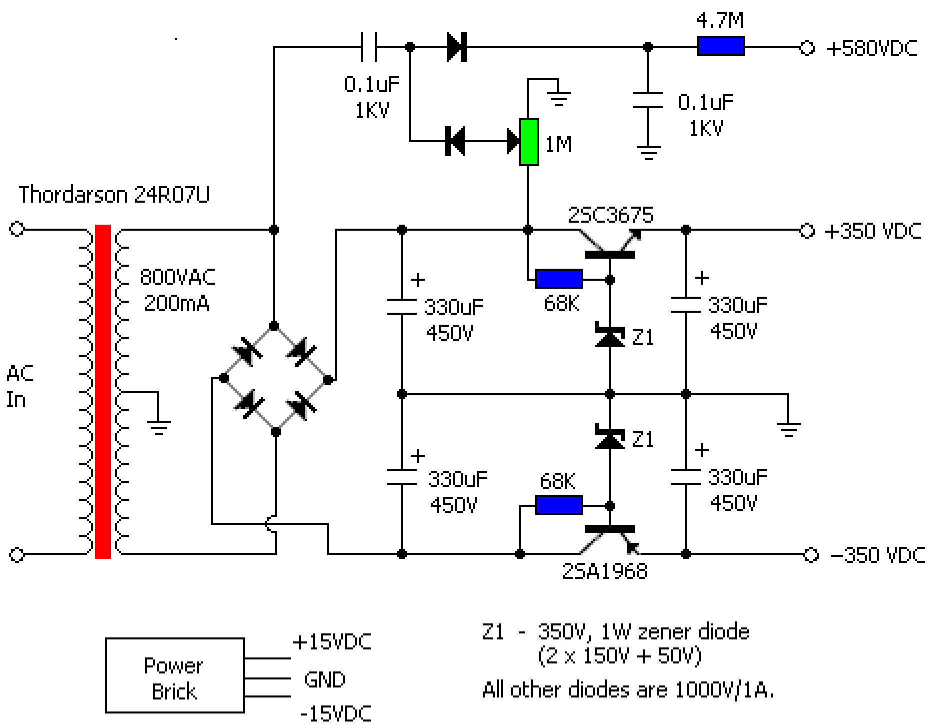
The second stage starts with a constant current source. The current source feeds a common ba amplifier. The common base amplifier feeds a modified Vbe multiplier. I believe a famous desigi now calling this circuit a current tunnel. Its the most linear way of translating the voltage down bottom rail. The voltage gain of this section is about 4. The basic idea of the first two stages is t supply the third stage with a very fast low impedance drive signal that is referenced to the bott

The current sources in the second stage supply 2 mA each. With no signal, the FETs take 1 mA, 1 mA going through the common base amplifier into the bottom transistor (which is wired as a multiplier). This generates the 13 volts (referenced to - rail) necessary to properly bias the 3rd The bottom transistor acts like a zener diode in series with a resistor, except a lot less noisy.

The third stage is another differential amplifier feeding another common base amplifier. The sin differential amplifier has a voltage gain of about 100. The common base amplifiers are used to the miller effect on the differential pair. Since the miller effect depends on both gain and output voltage swing, reducing the output voltage swing of the bottom differential transistors significar improves the speed of this circuit.

The fourth stage is an emitter follower driven by a constant current source (gain = 0.99). This stage dissipates 12 watts total (3 watts per transistor x 4 transistors). The main design goal wa output impedance. For example, my electrostatic tube amp has a 50K load resistor and thus ha output impedance. This amp has a 25 ohm output impedance (actually a little less with feedbac result is a much more extended high end. The slew rate of the solid state amp is more than 5 ti that of the tube amp.

For the output stage, each 2SC3675 sources or sinks 9 mA at a quiescent output voltage of zer referenced to ground. For the driver stage, each 2SC3675 sinks 1.1 mA, resulting in 1 VDC at tl collector (referenced to ground). The bases of the 2SC2705s sit at about 16 volts (referenced tc The overall open loop gain of the amplifier is about 2000, but feedback reduces it to 1000. Ever without any feedback of any kind the total harmonic distortion of the amp is still under .02%.

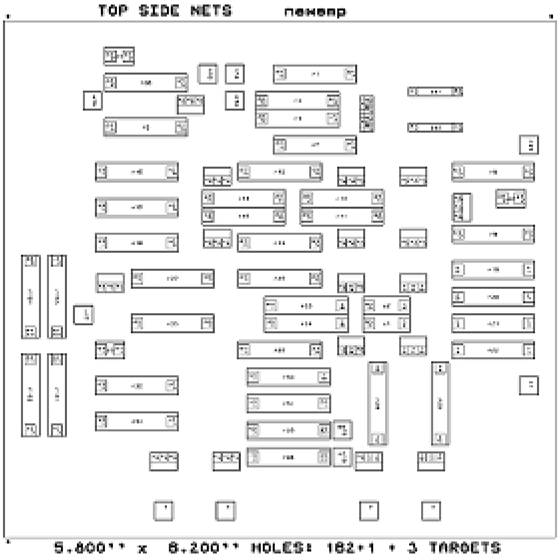


Electrostatic Amplifier Power Supply

My first prototype, the unit in the pictures, uses an unregulated power supply. Given the stiffne the capacitors, and the fact that the amplifier is pure class A, there is absolutely no fluctuation i voltage when signal is supplied. Of course, a regulated supply is always better. A regulated desi shown above. The 2SC3675 and 2SA1968 are mounted on heatsinks (the small tab ones are fin transformer is a Thordarson 24R22U (Allied # 704-0952). Adjust the pot to get 580VDC for the voltage.

The ±15 volt supply is an encapsulated fully regulated power supply brick from Sola Linear (Alli
number 921-9215), which retails for $117. I used a 60 mA version, but thats overkill, because t
total current drain is about 12 mA for both channels. Lots of companies make these. It's the bla
in the picture. It is NOT a switching supply. I do not use switchers in audio stuff if I can possibly
it.

Construction



[Download full size PC board designs and component layout]

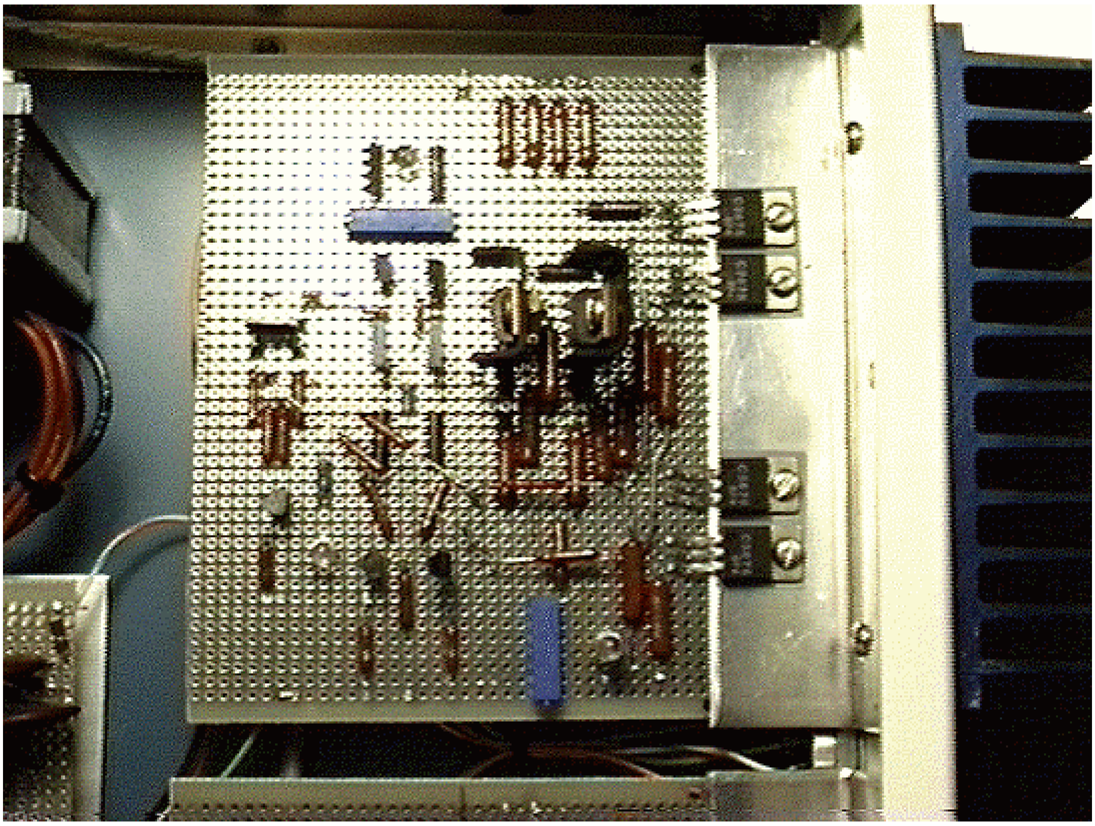
This project involves working with high voltages, so be extremely careful! Keep one ha
behind your back at all times. 600VDC across both arms might possibly stop your heart.

All resistors are 0.5W. Most do not need to be. The 300K resistors in the top of the 3rd stage ne
be 0.5W. The 150K resistor in the current drive in the last stage needs to be 0.5W. I am trying
2SA1968 transistors, which are 900 volt PNP types. If they are fast enough, then the two 300k
resistors can be replaced with current sources instead, making the amp 100% current source di

The LEDs in the amplifier circuit are voltage references (1.7 volts types in the prototype) which
changes transistor voltage with temperature (low voltage zener diodes have tracking problems)
also serve to show that the unit is running properly. If the LEDs are not lit, something is wrong.
could always replace each LED with 3 1N914 diodes in series, but the LEDs look so pretty (remi
of the glow of a vacuum tube).

I am using standard regular brightness red LEDs. The blue and green ones run at different volta
(blue = 2.6 volts, green = 2.1 volts). Using LEDs with voltage drops greater than 1.7V can affe
biasing. Higher LED voltage drops in the first and second stages will tend to cancel each other c
the numbers will be the same. That is, a higher voltage diode will increase the current sources f
2mA to maybe 3 mA (each), but at the same time, the current sink in the first stage will go fror
to 3 mA (total), so the net result is zero.

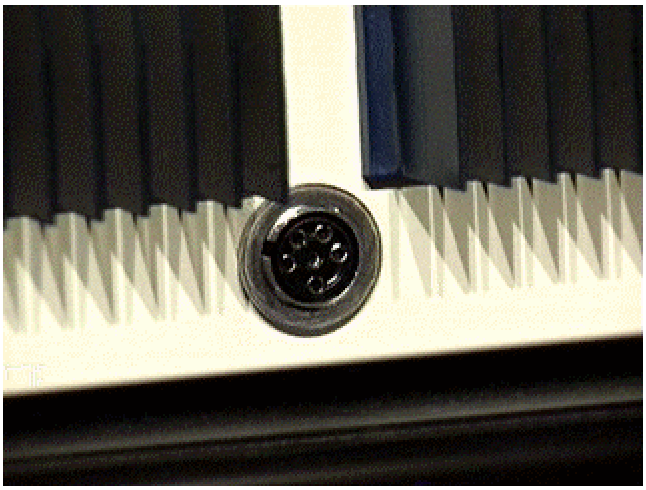
However in the final stage, a higher voltage diode will increase the standing power. As long as t
heatsinking is good, an increase from 12 watts per channel to 15 or so is just fine. The transisto
actually good for 10 watts each, so it is possible to increase the bias to 40 watts per channel.



All 4 output transistors are mounted on one aluminum angle that bolts through the front panel t
heatsink. The mounting heatsink is 4" x 5" x 1/8" aluminum plate, punched and then bent along
short axis. There are 4 holes that hold the transistors to the angle, and 5 holes that bolt the an
the heatsink. The blue-finned heatsinks I found on some old power supplies. I used them becau
were big enough and pretty at the same time. The 2 2SC3675 drivers have small standup heats

The two pots balance the output voltages to 0V referenced to ground. Begin the adjustment by
a voltmeter between + output and - output and setting the first pot for zero volts. Then put a
voltmeter between the + output and ground, and set the second pot for 0V. After the amplifier
up for 30 minutes, adjust the pots again. I adjusted my unit once, and keep checking it every s
The output voltages on my unit are less than ±200mV. Compared to the 580 volt bias, that is c
enough to 0V. And that is over a 1-month period.

Assemble the output stage with care. The full output voltage swing exists between the bases ar
collectors of the bottom output transistors. Poor soldering techniques combined with excess flux
cause an arc which may damage the transistors. It happened to me once.



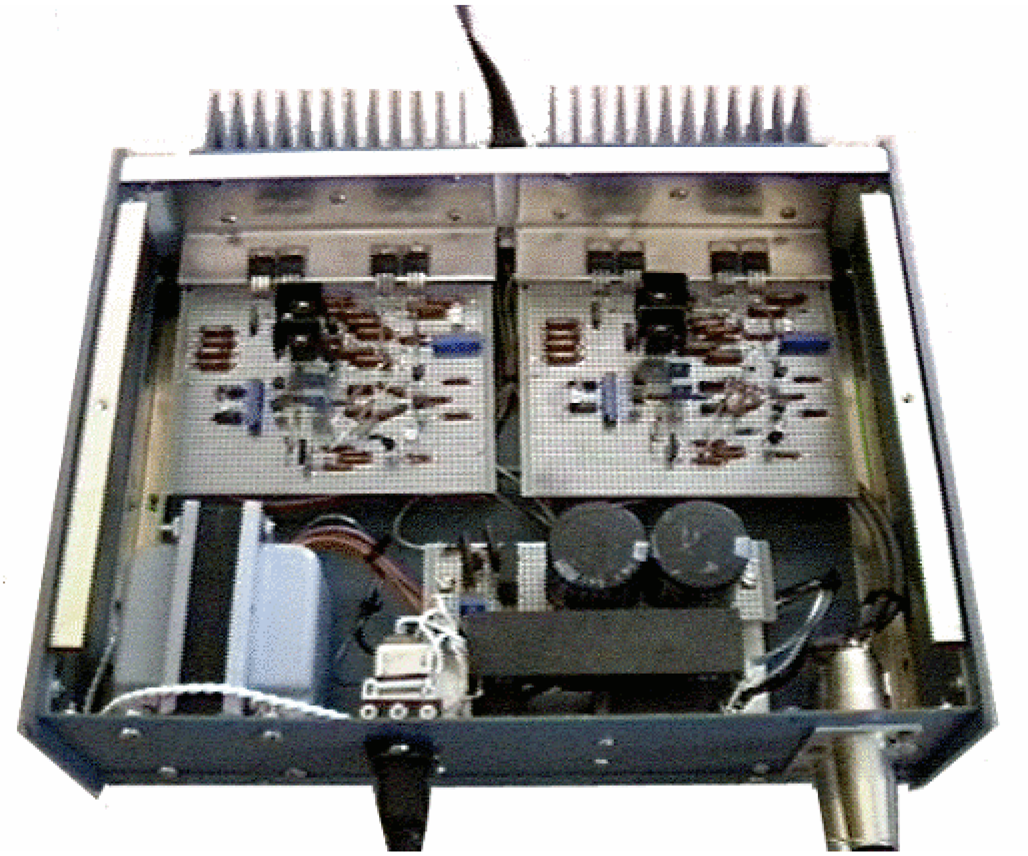
The Stax jack is Allied part number 719-4043. For all headphones except the Stax Omegas, the fits in all the way. On the Omegas, the plug is a little fatter and does not fit in all the way, beca plastic center of the jack is about 0.25" below the base of the metal rim. So I put the jack in a l and took 0.25" off the metal rim so that it is flush with the plastic insert. This modification does affect the fit of other Stax headphone plugs. For details on how to wire the jack, see All-Triode Drive Tube Amps for Electrostatic and Electret Headphones.

The 2SC3675 is made by Sanyo. The 2SA1968 and 2SA1156 are from NEC. The rest of the tran are from Toshiba. Here are the current prices:

2SK389	1.90 each
2SC1815	0.30 each
2SC380	.37 each
2SC2240	.55 each
2SA970	.79 each
2SA1156	.82 each
2SC2705	.49 each
2SC3675	1.56 each

In the USA, all of the Japanese semiconductors are available from BBW Electronics. BBW takes cards. The entire semiconductor cost not including the power supply is about $50 USD. The par also available from MCM Electronics, Farnell and Newark Electronics. Since they are all the same company, these parts can be purchased just about anywhere in the world.

There are no recommended substitutes. No American manufacturer makes 900V PNP or NPN transistors with a low Cob anymore. Neither does Phillips of the Netherlands. The only manufac of these transistors are Sanyo and Toshiba, and only because they are heavily used in dynamic applications for large CRT monitors.



The enclosure is a Mod.U.Line by Precision Fabrication Technologies Inc. (part number 03-1209
and is available from Newark Electronics, probably Allied too. It measures 3" x 12" x 9".

The Results

I do not think that the Omega II headphones can be damaged by this amp unless the bias is se
too high. If the bias is set right, the outputs are close to 0V at idle, and all the LEDs are lit, the
amp pretty much has to be working correctly. Now if one or more of the outputs is stuck at +30
300V, then something is seriously wrong and needs to be fixed. An oscilloscope really helps.

The amp can output 800Vp-p or 1200Vp-p with headroom. At 800Vp-p, THD is less than .008%
20Hz to 20kHz. The actual frequency response is 0 to 45khz (-3db at 45kHz) into an Omega II
Compared to the sound of my previous tube amplifier, the bass is no longer tubby; it's very sha
tight. The high end is no longer rolled off, so female voices sound much more real. If the bias s
reduced to 280V, the amplifier will drive all electrostatic headphones. I tried it last night on a pa
SRX's. I never ever heard them sound so good.

Last weekend, I took home a standard dummy head, and measured the SPL in Omega 2 headpl
driven by this amplifier. With a drive signal of 800 volts peak to peak per side, the resulting spl
106db. THAT'S LOUD! The amp can put out 1200 volts peak-to-peak, and thats louder! I just or
pair of Stax SR-001 MkIIs, which can reach up to 120dB. My ears distort before the
amplifer/headphones do. It is quite loud at clipping, but the clipping is a hard clip with no oscilla
ringing. To use the amplifier with electret headphones, delete the bias voltage. And probably ke
output swing under 200V. Electrets phones when driven with this amplifier can probably get ver
loud.

[*Editor:* Contact the author to discuss the possibility of obtaining pre-etched PC boards for this amplifier.]

For the latest updates, see the Project Addendum.

Addendum: A Current-Domain Electrostatic Amplifier for Stax Omega II Headphones (Kevin Gilmore)

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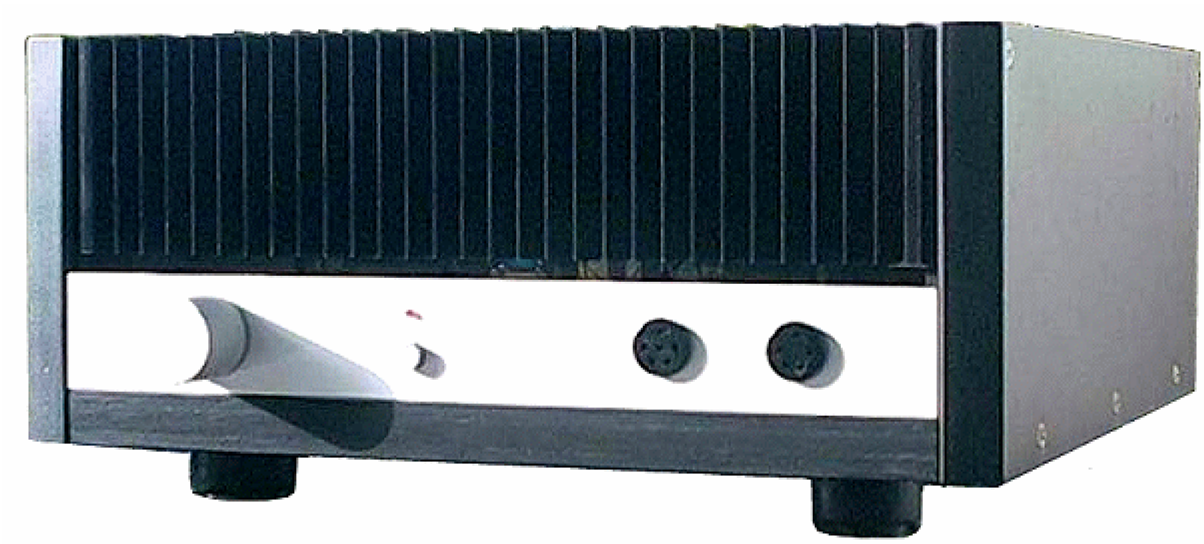
Addendum

2/21/01: Corrected mislabelled transistor part number: 2SC1815 (was 2SA1815).

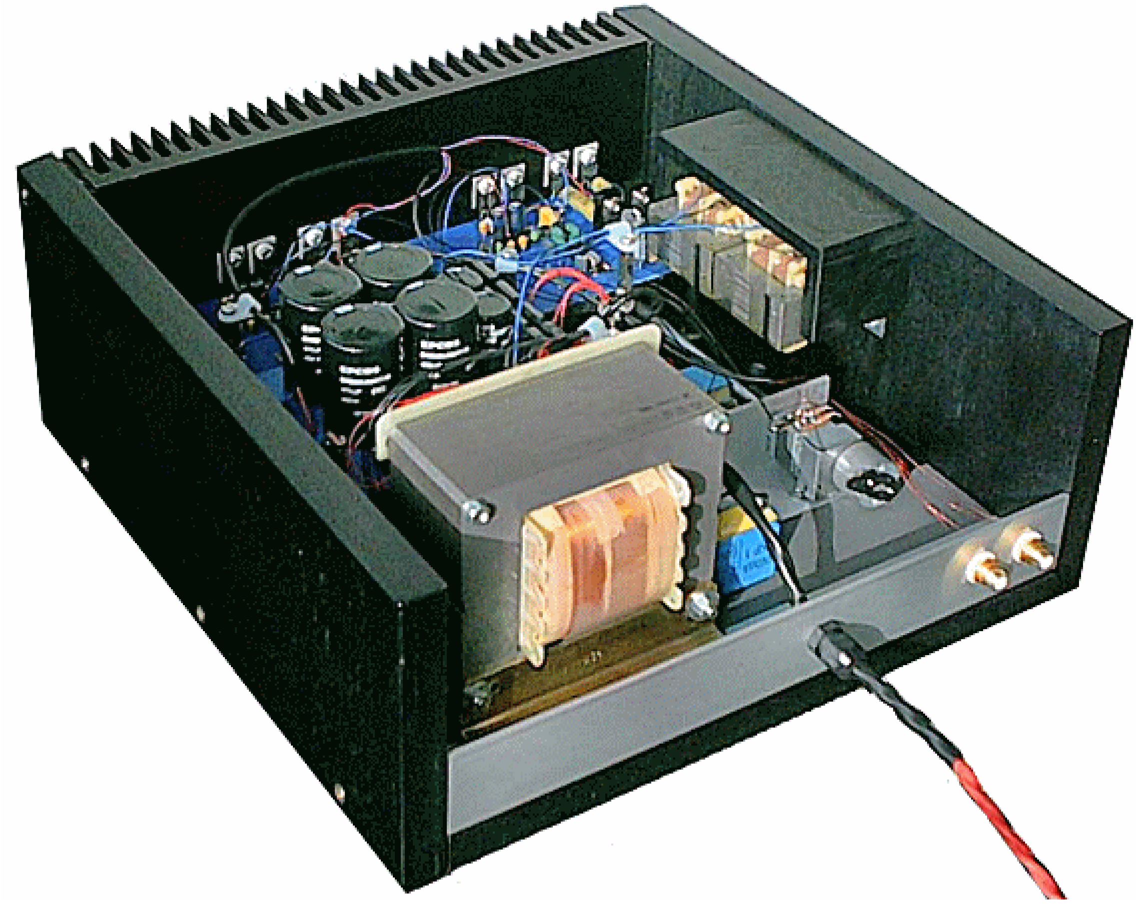
9/5/01: Corrected mislabelled transistor part number: 2SC3675 (was 2SC367).

2/12/2002: Richard Albers built the following version of the CDEA amp with some interesting modifications of the original circuit. He writes:

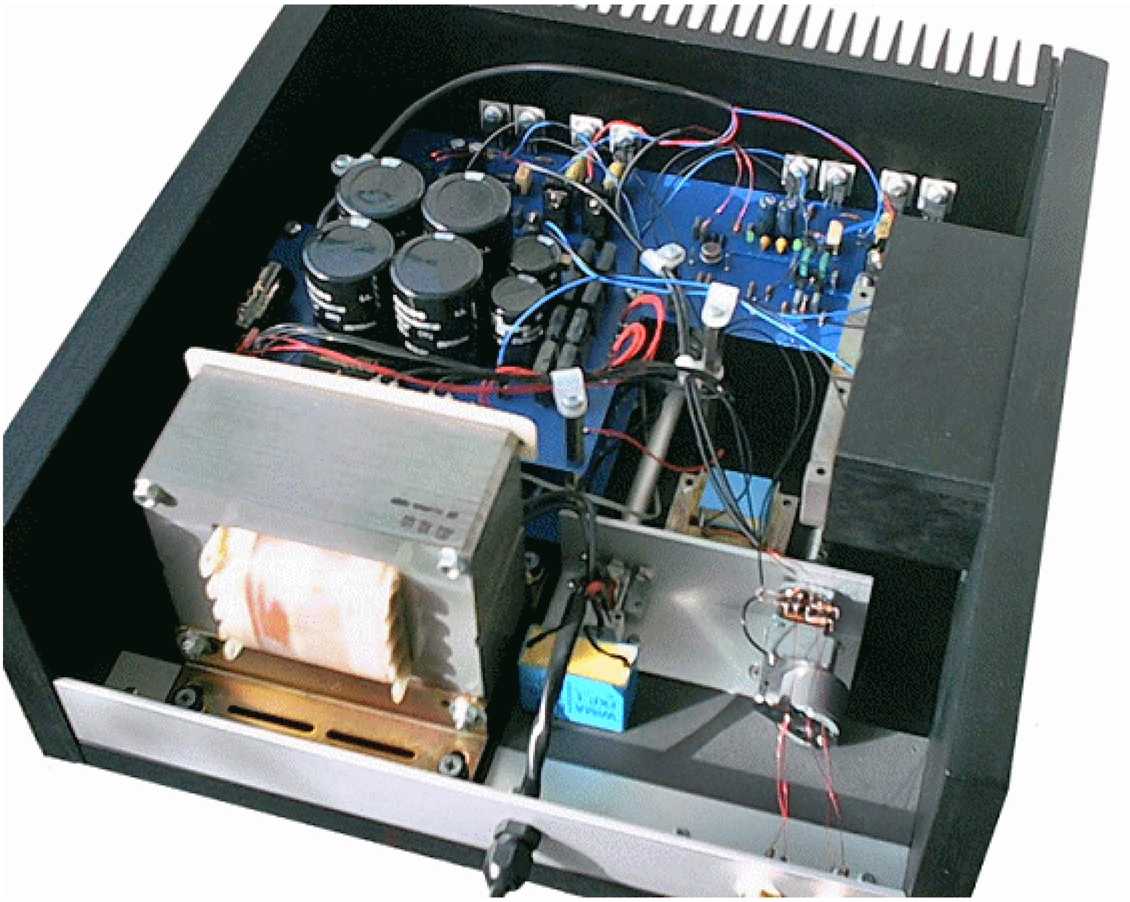
> I have changed the 2SK389 FET for a MAT02 Dual Transistor in the first Stage of the CDEH-Amp. There were no problems, and it all worked fine from the start. It sounds much cleaner then with the Dual-Fets now, and I guess they add less harmonics to the music.



> In the third Stage of the CDEH-Amp, I have changed the Voltage-Divider 350K/20K, which sets the Bases of the SC3675 at ca. 20V. For the 20K Resistor i have put in a 20V, 1.3W zener. For proper working, I set the current through the zener at 7mA. Two 25K ohm, 5W Mills non-inductive wirewounds replace the 350K, dissipating ca. 2.2W of heat. To reduce the zener noise, I have put a 4.7uF tantalum together with a 47uF electrolytic capacitor in parallel with the zener diode. Noise is no problem.



The Cabinet is a very simple construction, with the advantage of ease changing components or parts. There is only a wooden base with two side-panels. The front is the large heatsink together with an aluminium-angle. A suitable top-cover is under construction. The whole construction could be made way smaller, all parts on one pcb, with a smaller toroid-transformer, and all built in a industrial case, but for my own usage, it's ok.



The two smaller transformers under the wooden cover are the 10H-chokes for the high voltage power supply. The little transformer on the bottom generates the bias-voltage. The oversized big-one is a special-made 250W transformer, from Experience-Electronics in germany. The electrolytics are from EPCOS (Siemens).

This is a further way to tune-up this fantastic machine. Together with the MAT02 dual-bipolar input device and using only the best parts you can get, such as non-inductive Caddocks, very low ESR electrolytic caps in the high voltage section, and so on, there is no better electrostatic headphone amp in the world. It sounds just fanstastic!

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FLOAT, Systemherstellung

1. Material, Werkzeug

Glassplatte ca. 50 x 100 cm
Rollenquetscher
Scheibenputzer (Auto),10 cm breit
Skalpell
Schaumstoff, offenporig, ca 5 x 5 x 5 cm
1 Flanell-Lappen ca 5 x 5 cm
1 Flanell-Lappen ca. 20 x 20 cm
1 Flanell-Lappen gross
Ultraschallreiniger
Reagenzgläser für Leitflüssigkeit
Glasflaschen für entspanntes Wasser
1 Spritze 10 ml geeicht
1 Spritze 50 ml geeicht
Netzmittel
Aquadac
destilliertes Wasser

2. Vorbereitungen

1. Ultraschallgerät bereitsstellen
- destilliertes Wasser einfüllen
- einige Zeit laufen lassen zum entgasen

2. entspanntes Wasser herstellen
- 100 ml destilliertes Wasser im Glas mit Deckel mit 4 g Netzmittel mischen

3. Leitflüssigkeit herstellen
- 1 ml Aquadac in Reagenzglas füllen
- 20 ml entspanntes Wasser nachgiesen
- im Ultraschallgerät rund 10 min mischen

3. Herstellung der Systeme

1. Folie auf Glassplatte aufziehen

- nicht zu grosses Stück nehmen
- Glassplatte benetzen, damit sich Folie ohne Rümpfe aufbringen lässt (entspanntes Wasser benutzen)
- Folie ohne Zug auf die Glassplatte legen und mit dem Gummi des Scheibenreinigers flach ziehen.
- Ueberflüssiges Wasser unter der Folie herausquetschen.
- Scheibe und Folie vorsicht mit Flanell-Lappen trocknen

2. Leitflüssigkeit aufbringen

- Wichtig: Leitflüssigkeit zuerst im Reagenzglas für 1 min im Ultraschallgerät aufmischen
- Schaumstoff an Oeffnung des Reagenzglsses drücken und beides kurz auf den Kopf stellen
- Wichtig: der Schaumstoff darf nicht vollständig vollgesogen sein.
- Flüssigkeit mit Schaumstoff auf Folie aufreiben, zuerst mit grossen Strichen ohne Druck, dann (sobald die Folie das Graphit aufnimmt, leicht einreibend verteilen.
- Auf der Folie muss unter der Flüssigkeit ein leichter Graphitschimmer sichtbar sein.
- Ueberflüssige Flüssigkeit mit kleinem Lappen wegnehmen und gleichzeitig leicht einreiben.
- Mit grösserem Lappen die Folie mit leichtem Druck nachpolieren bis die Oberläche einen homogenen „Nebeleindruck" macht.
- Mit trockenem Lappen mit leichtem Druck nachpolieren.
- Folie umkehren und das ganze auf der andern Seite wiederholen
- Wichtig: möglichst ohne zusätzliche Flüssigkeit auf der Glasplatte, allenfalls entspanntes Wasser verwenden.
- Folie mit Föhn trocknen und auf Systemteil aufspannen

3. Folie spannen

- Folie über Heizplatte spannen: Schräg halten und über der Platte hin und her bewegen, damit das Elektrodengitter nicht zu heiss wird (Schalter Stellung 2, Abstand es Systems von der Platte 5 - 10 cm,
- Dauer des Spannvorganges: 10 - 20 Sekunden
- Wichtig: die Folie muss glatt gespannt sein (Kontrolle durch Anklopfen des Systemteils)

Der Transimpedanz-Verstärker

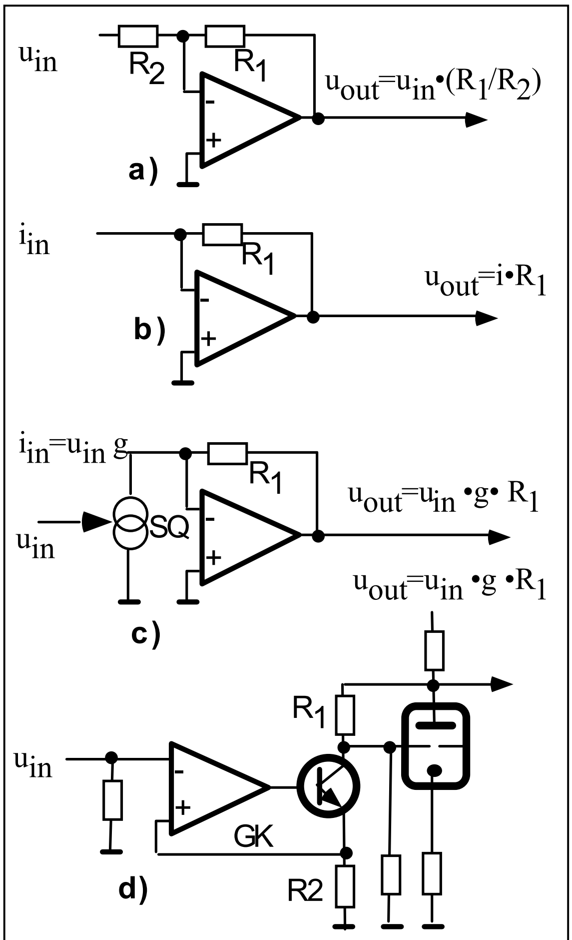


Bild 1 : Prinzip des Transimpedanz-Verstärkers

Bild 1a zeigt einen OpAmp in der üblichen invertierenden Schaltung. Am Minus-Eingang wird die Differenz von Eingangs- und Ausgangsspannung wirksam, oder, genauer gesagt, die Differenz der durch die Widerstände R1 und R2 fliessenden Ströme.
Die Schaltung gemäss Bild 1b entspricht der von Bild1a, nur dass hier der Eingangsstrom I_{in} direkt die Ausgangsspannung bestimmt.
Wenn dieser Eingangsstrom nun von einer spannungsgesteuerten Stromquelle (SQ in Bild 7 c) geliefert wird, besteht zwischen der steuernden Eingangsspannung u_{in} und der Ausgangsspannung der Schaltung folgender Zusammenhang:

$$v_{out} = v_{in} \cdot g \cdot R1$$

(g: Spannungs-Strom-Umsetzungsfaktor von SQ)

Da bei dieser sogenannten Transimpedanz-Schaltung der Gegenkopplungsgrad beim OpAmp 100% beträgt, ist der Ausgangswiderstand sehr klein.

Die Schaltung von Bild 1c lässt sich nun so modifizieren, dass sie sich für die Realisierung eines Röhren-Leistungsverstärkers eignet:

- Im Bild 1d bildet die Kombination von OpAmp, Transistor TR und R2 dank der Gegenkopplung GK eine Stromquelle für den Widerstand R1. Der durch diesen Widerstand fliessende Strom i ist der Eingangsspannung v_{in} proportional. Dank dem Gegenkopplungsgrad von 100% sind die Verzerrungen dieser Stromquelle sehr klein.
- Der durch den Widerstand R1 fliessende Strom i hat einen entsprechenden Spannungsabfall zur Folge, mit dem dann das Gitter der Röhre angesteuert wird. Da das obere Ende von R1 direkt an der Anode der Röhre (und damit am Ausgang der Schaltung) angeschlossen ist, wird auch der Gegenkopplungsgrad für die Röhre 100%. Dadurch werden auch hier die Verzerrungen sehr gering, und der Ausgangswiderstand ist klein.

Ein auf der Schaltung von 1d basierender Vorschlag für die Schaltung einer neuartigen Gegentakt-Endstufe ist im Bild 2 zu sehen.
Folgendes ist typisch für diese Schaltung:
Der Gegenkopplungsgrad der ganzen Schaltung beträgt 100%. Die Verzerrungen sind so minimal.
Ein zusätzliche Gegenkoppung mit Einbezug der Sekundärseite ist nicht zwingend notwendig
Generell gilt, dass ein an einer sehr niederohmigen Quelle betriebener Uebertrager theoretisch verzerrungsfrei arbeitet. Im Rahmen seiner linearen Möglichkeiten (damit ist gemeint, dass der Eisenkern nicht bis in den Sättigungsbereich der Magnetisierungskurve gefahren wird) macht er sich in der Schaltung nicht negativ bemerkbar, und die Primärimpedanz kann kleiner gewählt werden als bei einer konventionellen Endstufenschaltung.
Bei einer Schaltung gemäss Bild 2 ist der Ausgangswiderstand an den Anoden der Leistungsröhren tatsächlich sehr klein. Der Ausgangsübertrager ist eng angekoppelt und verhält sich wirklich so, wie wenn es sich um einen „theoretischen" Uebertrager handeln würde. Das gilt natürlich nur im Rahmen des Leistungsbereichs der Leistungsröhren.

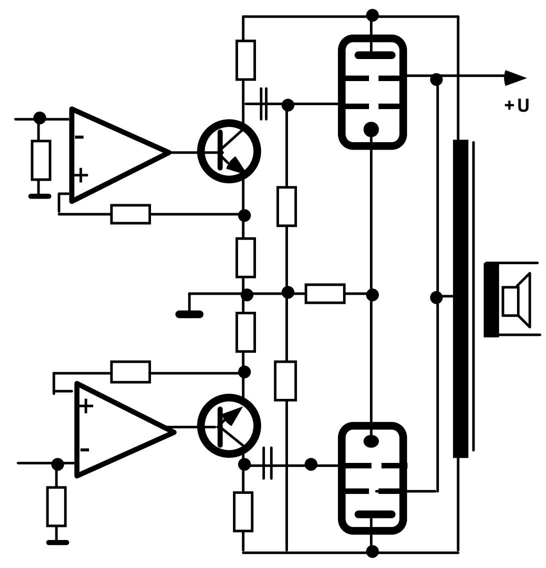
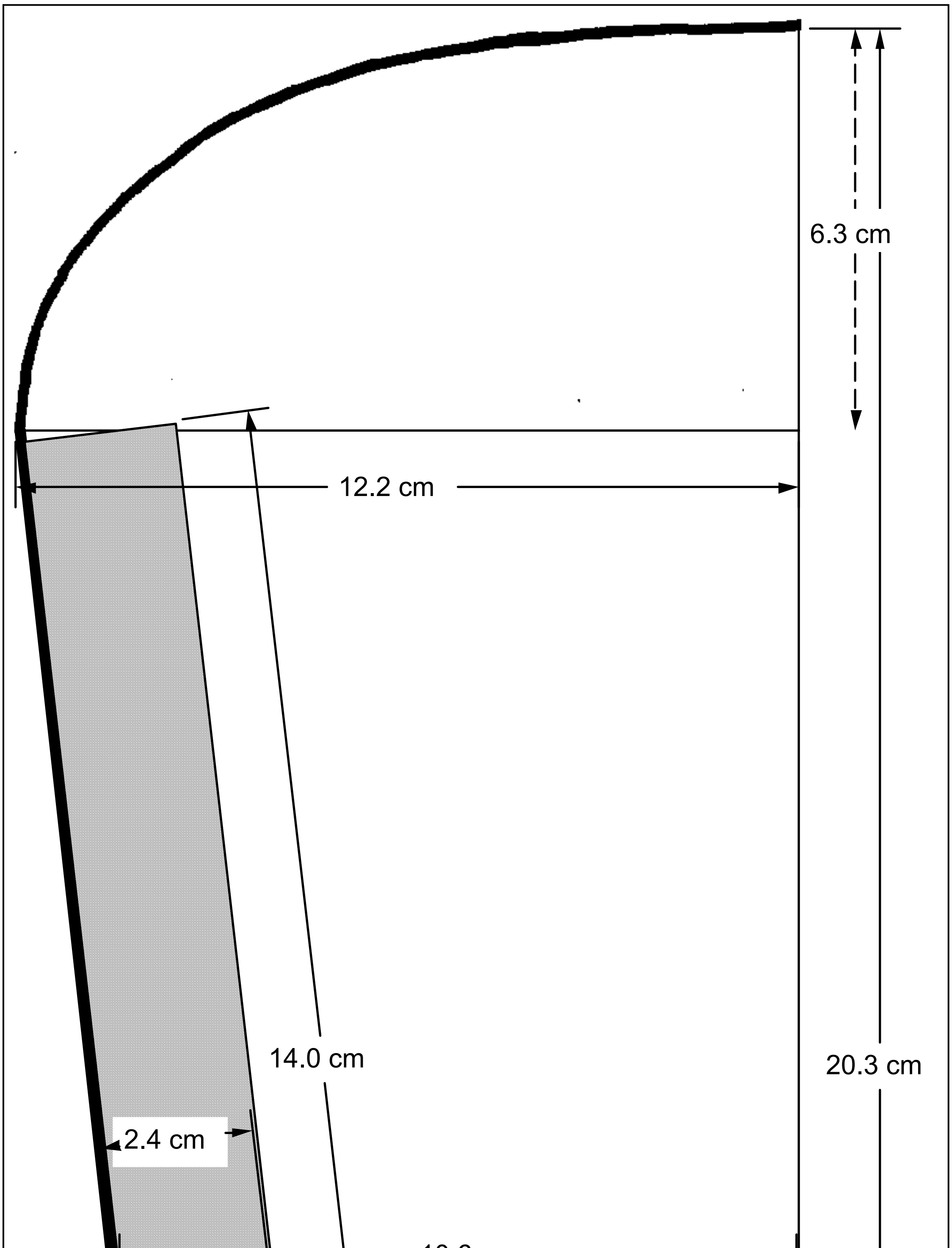


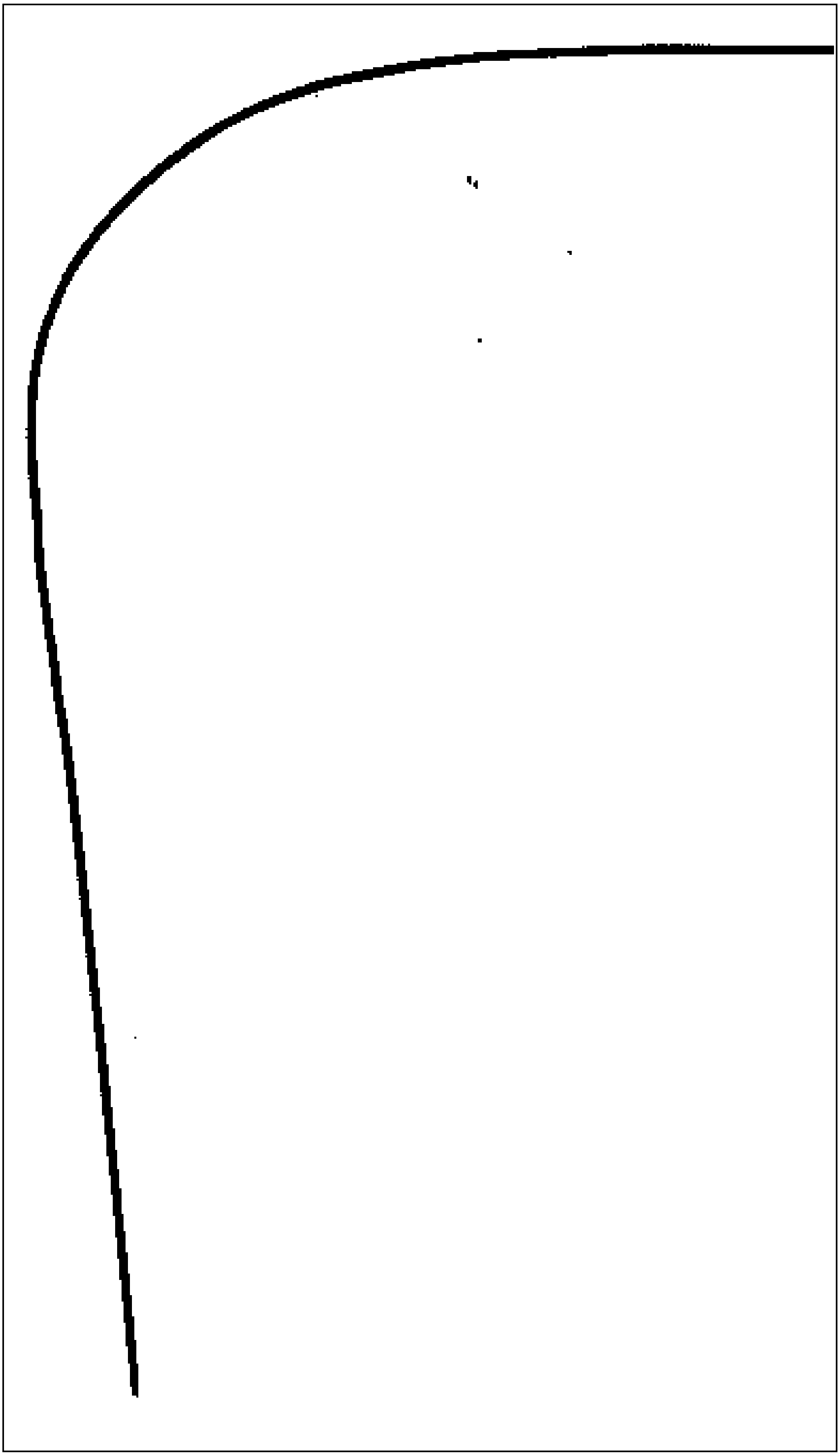
Bild 2 Transimpedanz-Endstufe

Bügel alter FLOAT

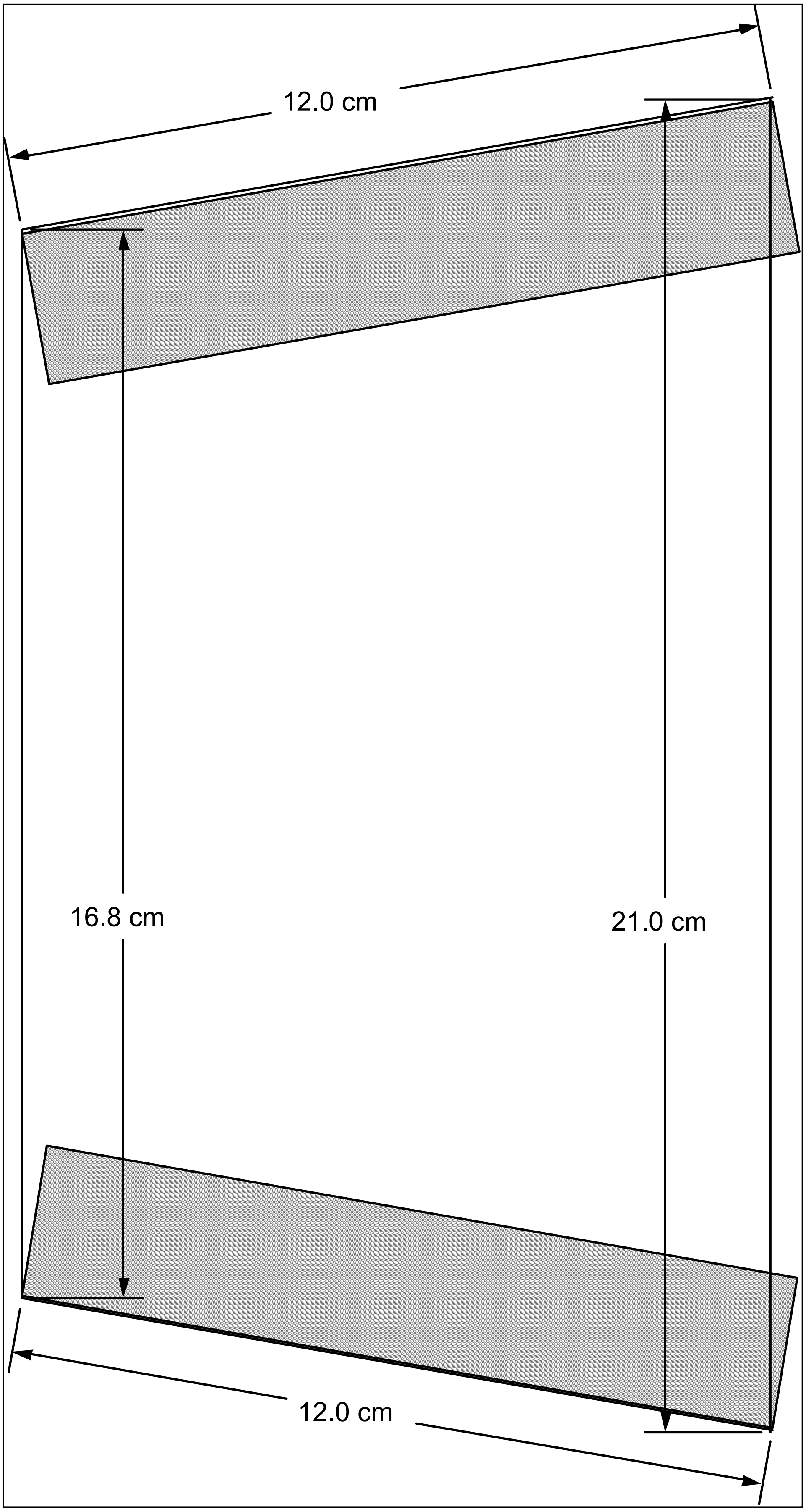
Bügel von hinten



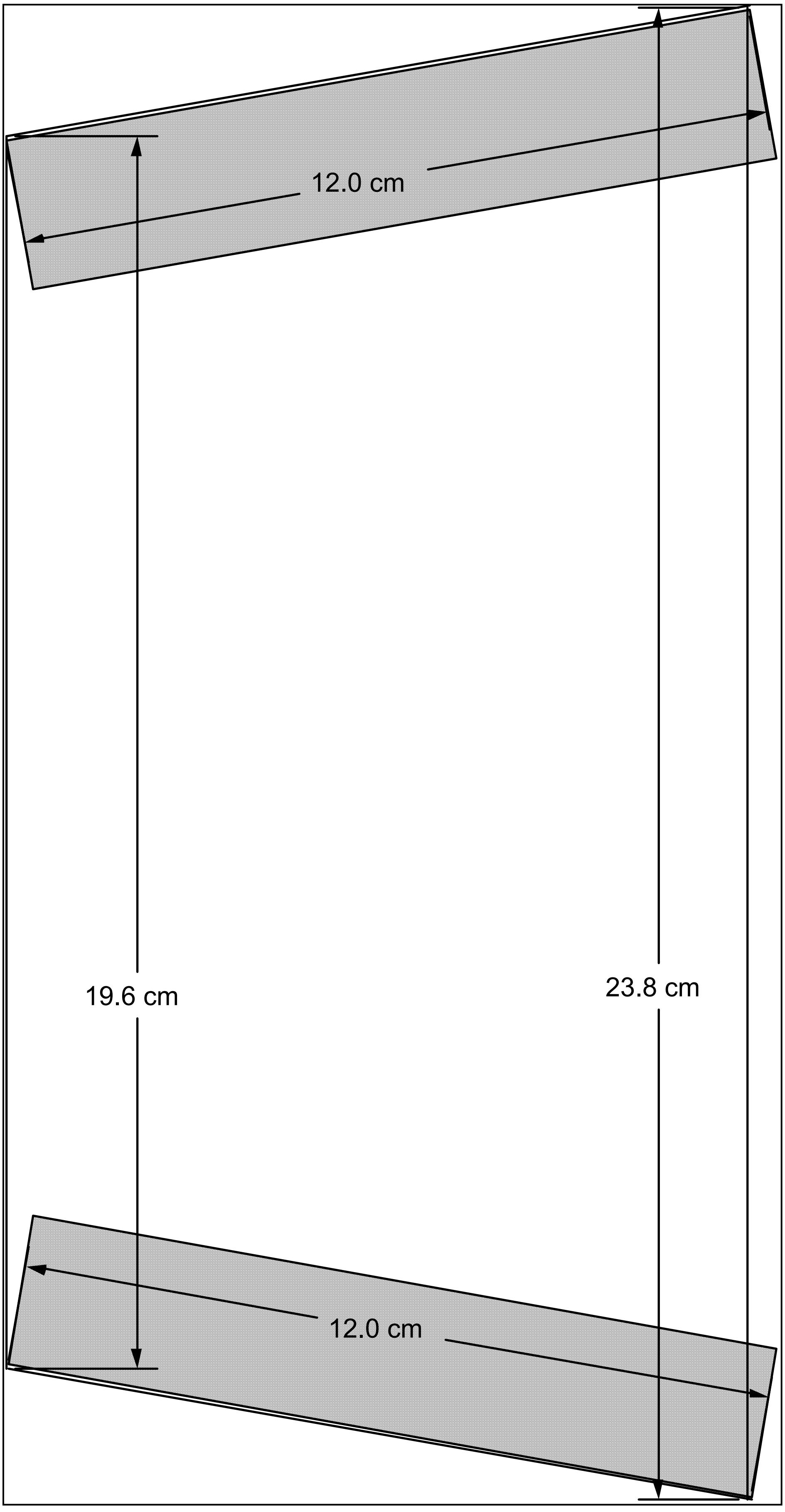
Bügel von vorn



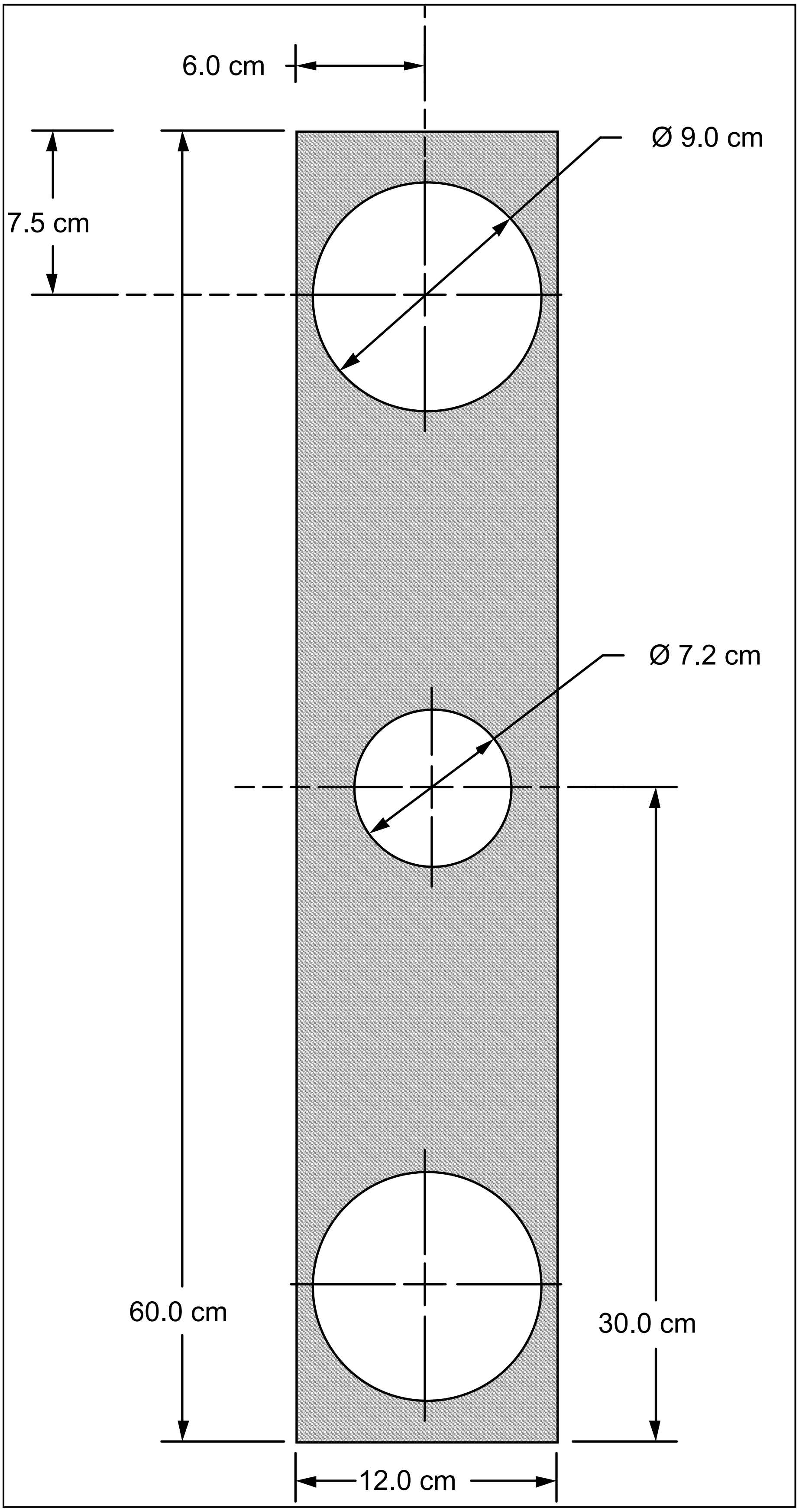
Bügel, Grundriss

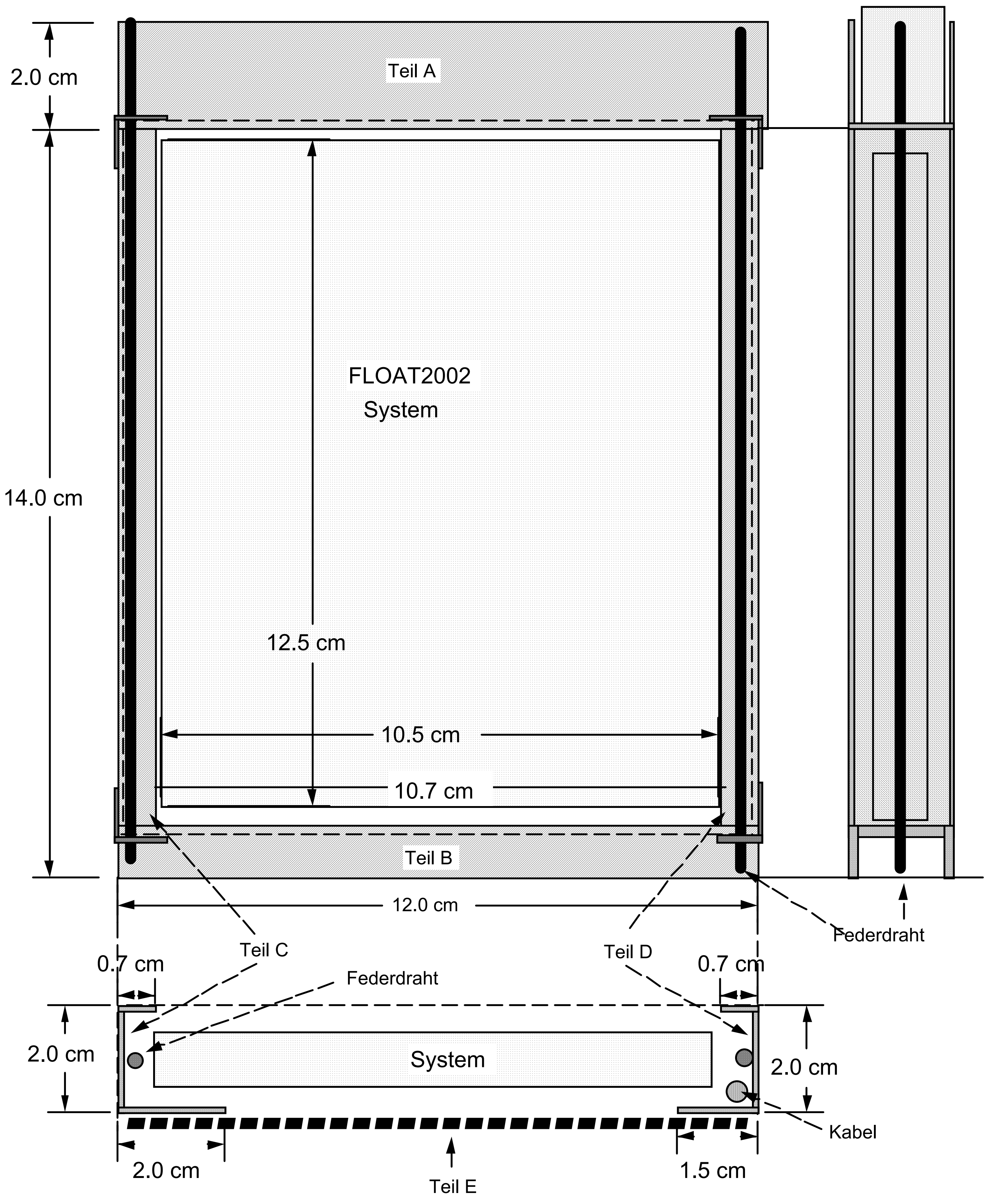


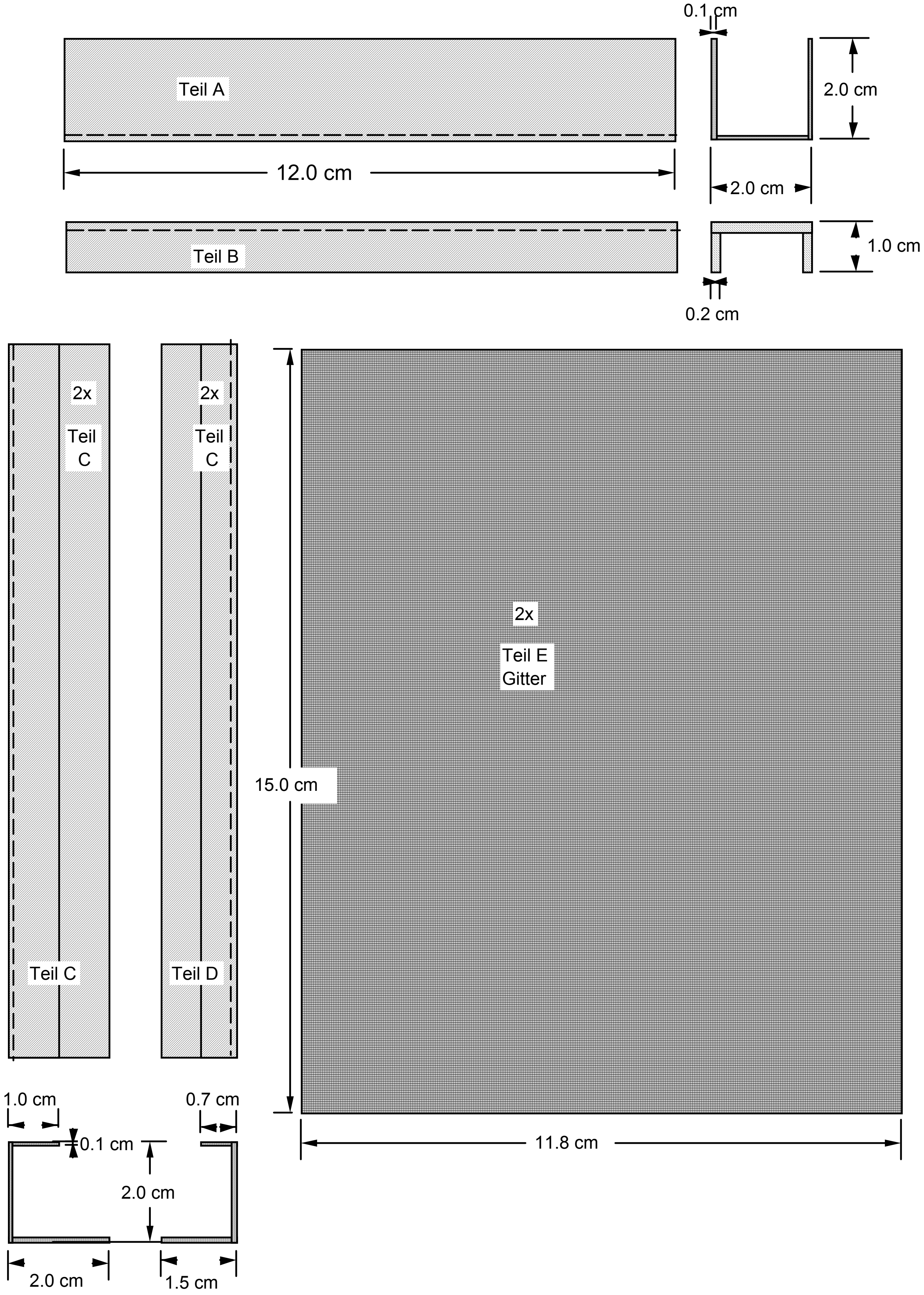
Bügel, Schnitt A-A



Bügelstreifen ungebogen




Teil A
2.0 cm
14.0 cm
FLOAT2002
System
12.5 cm
10.5 cm
10.7 cm
Teil B
12.0 cm
Teil C
Teil D
Federdraht
0.7 cm
0.7 cm
Federdraht
2.0 cm
System
2.0 cm
Kabel
2.0 cm
Teil E
1.5 cm


0.1 cm
Teil A
2.0 cm
12.0 cm
2.0 cm
Teil B
1.0 cm
0.2 cm
2x
Teil C
2x
Teil C
Teil C
Teil D
15.0 cm
2x
Teil E
Gitter
11.8 cm
1.0 cm
0.7 cm
0.1 cm
2.0 cm
2.0 cm
1.5 cm