Equipment for cyclic voltammetry

Atte Kauhanen

Thesis

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Ammattikorkeakoulututkinto

SAVONIA-AMMATTIKORKEAKOULU **OPINNÄYTETYÖ**
Tiivistelmä

Koulutusala
Tekniikan ja liikenteen ala

Koulutusohjelma
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Ohjaaja(t)
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Toimeksiantaja/Yhteistyökumppani(t)
Leonid Yavich (Itä-Suomen yliopisto)

Tiivistelmä

Tämän Insinöörityön aiheena oli selvittää Itä-Suomen yliopistolle aikaisemmin valmistetun prototyyppi laitteen toiminta, yksinkertaistaa sitä ja kehittää siitä kaupallista versiota. Projektin tavoitteena on lopulta tehdä prototyyppimittalaitteesta kaupallinen versio. Projektin rahoittaja toimi TEKES ja sitä tehtiin yhteistyössä Savonia IT yksikön kanssa.

Mittalaitteella tutkitaan aivojen kemiaa. Laite stimuloi aivoja jännitepulssilla ja mittaa aivojen tuottamia vastevirtoja. Työn tavoitteena oli saada valmistettua teollisesti valmistettava ja edullisempi malli laitteesta, joka sopisi niin Euroopan kuin Yhdysvaltojen markkinoille.

Työssä simuloin laitteen eri osa-alueita, suunnittelin etupaneelin ja tehonlähteen, kilpailutin yrityksiä, rakensin laitteen ja lopuksi testasin teholähteen. Työn lopputuloksena syntyi toimiva tehonlähde ja käytännön testejä vaille valmis prototyyppilaite.

Avainsanat
Equipment for cyclic voltammetry, aivojen mittaus, mittalaitteisto, aivokemia

SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS**
Abstract

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Project/Partners Leonid Yavich (University of Eastern Finland)			

Abstract

The aim of this thesis was to depict working of earlier made prototype version of this device and to simplify and develop it to more commercial version for University of Eastern-Finland. The final goal of the project was to create commercial version of this device. This project is funded by TEKES and is done in cooperation of Savonia IT unit.

With this measuring device you can study brain chemistry. The device stimulates brains with voltage and you can measure current from brains. Goal of this work was to create cheaper, industrial version that is suitable for European and American markets.

In this work I simulated different segments of this device, designed front panel and power supply, tendered companies, assembled device and did end testing for power supply. As results of this work, we got fully working power supply and the prototype device that is ready for practical testing.

Keywords
Equipment for cyclic voltammetry, measuring brains, measuring device, brainchemistry

PREFACE

This work has been done for University of Eastern-Finland. Simulations, drawings, tendering have taken a lot of time to do and time to learn. This work has had a lot of different types and interesting challenges. It has been my pleasure to work with great people. I want to thank Leonid Yavich for he have given this work to me and he has helped and guided me a lot during this work. Also big thanks goes to Kari Eskelinen for supervising this thesis. I would like also thank Timo Ollikainen, Heramb Chad-chank, Trafox oy, Shaeffer AG and Savonia for cooperation with this project.

I want also thank my fiancé for supporting and giving me strength to do this work.

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1 INTRODUCTION

This thesis is made for University of Eastern-Finland. In this project our goal was to create commercial prototype version of cyclic voltammetry. Prototype version of this device has already been made but the goal is to bring it to the commercial state, so it would available for the customers

This device is used to study animal behavior. It stimulates and measures animal brain current. This device can be divided to following parts: electrodes, head stages, main device and the computer software. There are two different types of head stages, 3-electrodesystem and 2-electrodesystem. These head stages can be used only one at a time but they are easily changed from one to another. Electrodes are surgically installed to animal brain, and it requires a professional to do it. Head stage must be near the animal because currents in the brain are really weak so wires must be as short as possible to avoid noise. You can see measuring results in graphical form on computer screen.

My part in the project was to find out how this device works, simulate circuits, test circuits with different values, design power block, design of the front panel, tendering, assembling and testing.

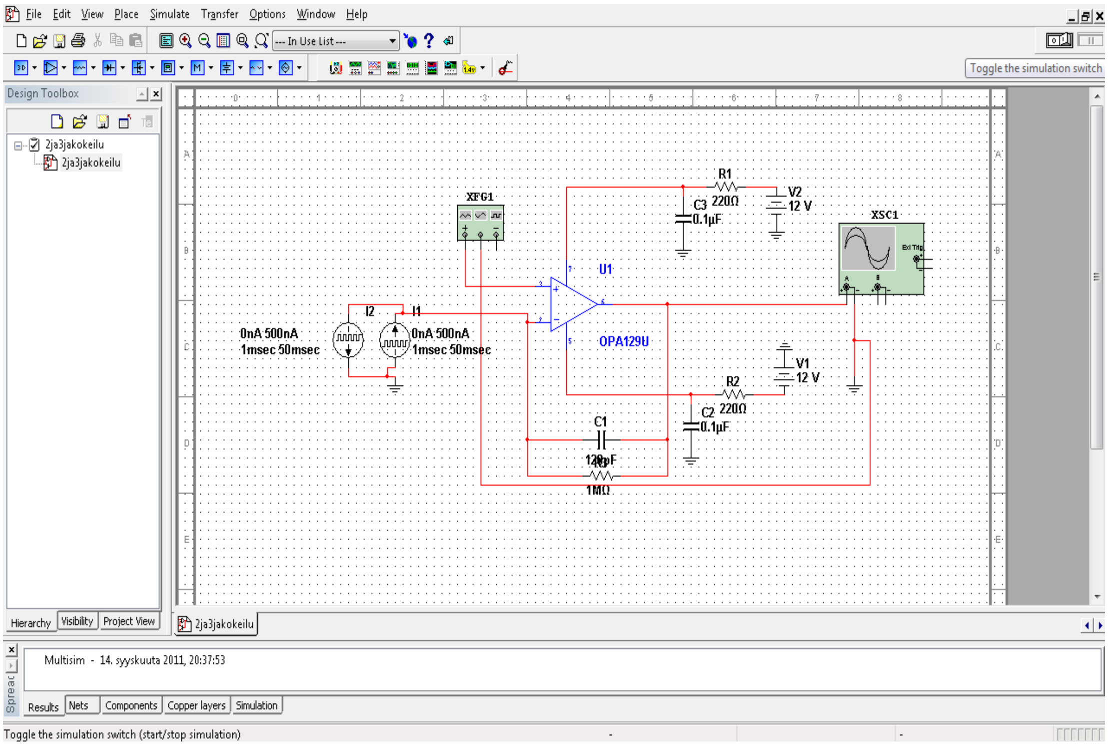
I started in February 2011 to study the theory part of the device at home. Then I worked in Savonia IT unit and I did simulations and tendering. At the end of July 2011 I started assembling in university. In simulations I dissected results with different values of resistances and capacitances. My goal was to find the most suitable values to decrease noises and to make device to be more accurate. In power block I tendered and ordered custom transformer and I did simulations. For simulations I used National Instruments: MultiSIM 11 software. When we got all components I started assembling of the device, after that I ended my part of project with testing of the circuit boards.

2 SEGMENTS OF DEVICE

This device can be divided to different segments. It helps in understanding how this device is working and makes its function clearer. Each segment has its own specific task. In this thesis segments that I have worked with are presented.

2.1 National Instruments: MultiSIM 11

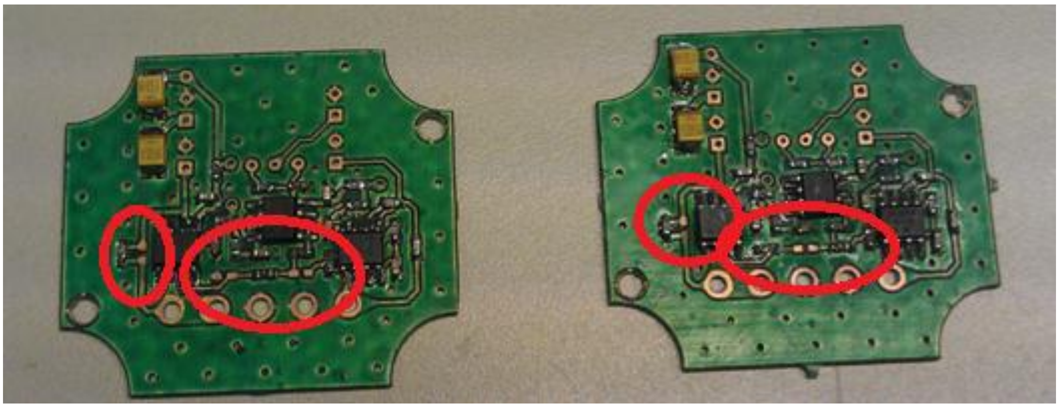
MultiSIM 11 is simulation software by National Instruments. MultiSIM is common tool for circuit design and prototyping. You can simulate circuits with custom components or power sources. It helps locating designing errors and helps adjusting components values. You can see screenshot of this program in circuit designing state in picture 2.1.A.



Picture 2.1.A Screenshot of MultiSIM 11 designing view

2.2 Head stage

The head stage is used to amplify current signal from animal brains. Head stage is external part of device and it is connected to main device with cable, because it should be as close as possible to animal. Head stage includes precision voltage to current converter and voltage follower circuit. The signal from animal brain is weak, so amplifier for it should be as close as possible to avoid interference. In picture 2.2.A you can see the 2-electrosystem circuit board and 3-electrosystem circuit board.

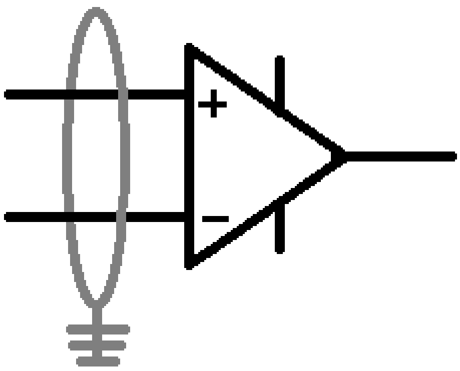


Picture 2.2.A Head stage circuit boards for 2 and 3-electrodesystems

2- and 3-electrode systems circuit boards are similar, but there are a few differences in them. Red circle is pointing different areas in them. Some components are placed to different area and some components have different values. This is done this way, because it will be more cost effective way than to do two totally unique designed circuit boards. In this device you can choose to use 3-electro measuring system or 2-electro measuring system by toggle switch from the control panel. These circuit boards are placed to their own aluminum enclosures.

2.2.1 Principles of operation

The LABview program runs user defined voltage ramps to the animal. Head stage part collects current response and converts it to voltage and amplifies it and the voltage signal goes back to the program where it is shown in graphics and can be analyzed. This part of device is using really low currents so that is why we need to use precision operational amplifiers, make wiring as short as possible and protect circuit from noises, for example guard ring is used to protect operational amplifier input pins to protect circuit. The ring is only connected to the ground, you can find the idea of guard ring in picture 2.2.1.A. To prevent noises is also the reason why the head stages have their own enclosures and they are kept as close as possible to the animal, that is being measured.



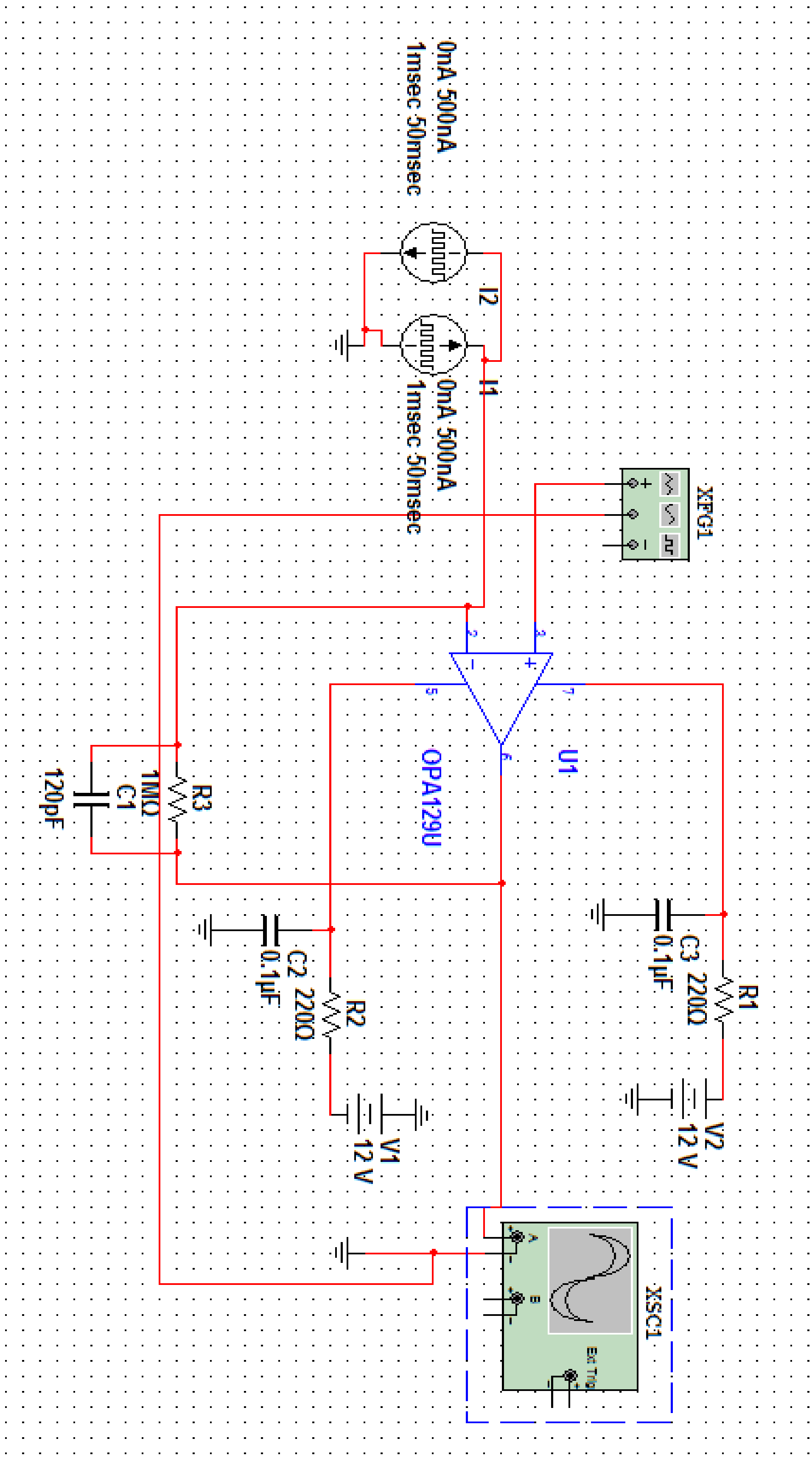
Picture 2.2.1.A the idea of the guard ring

In 3-electrode system there are working, reference and auxiliary electrodes. All of these are installed surgically to animal brain. Working electrode is used to run voltage to the brain from the computer program. Auxiliary electrode is used to read the current for current to voltage conversion. Reference is used to voltage follower circuit, to make sure everything works as they are meant to.

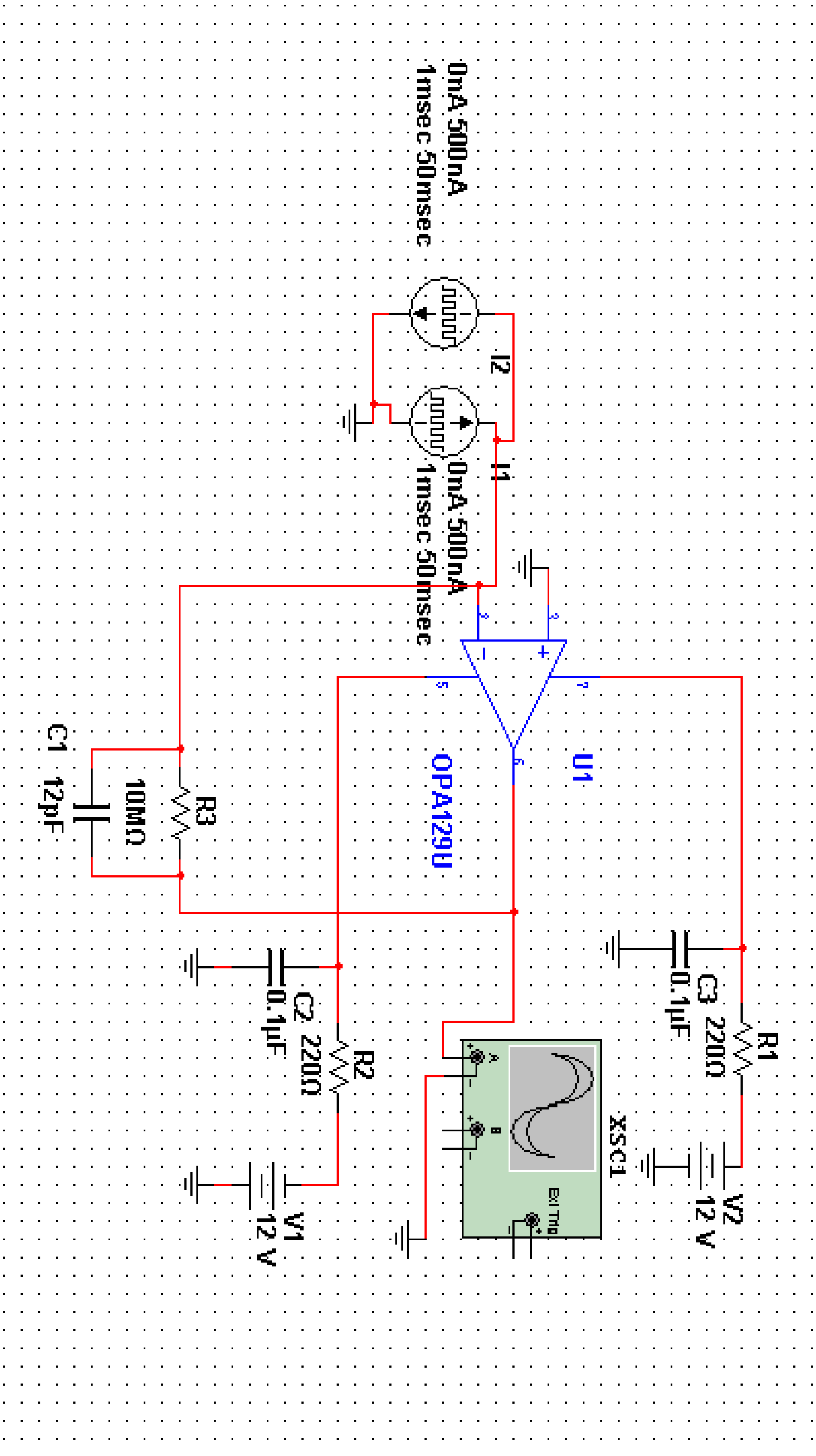
2.2.2 Simulations

In picture 2.2.2.A you can see schematics of testing 2-electrodesystem current to voltage converter. As you can see in picture 2.2.2.A I have used triangle voltage source (XFG1 in picture) and two current sources to simulate real signal as close as possible. I connected the other current supply contrary to make current source bi-polar. I also added oscilloscope (XSC1 in picture) to measure output voltage.

In picture 2.2.2.B you can find schematics of 3-electrodesystem voltage to current converter. As in previous picture I added virtual oscilloscope also to this schematic (XSC1 in picture). In this schematic there are discriminations to the picture 2.2.2.A. In this system triangle voltage is not used and R3 resistor has higher value, because it gives us output voltage in good value and shape.



Picture 2.2.2.A simulation circuit for 2-electrosystem

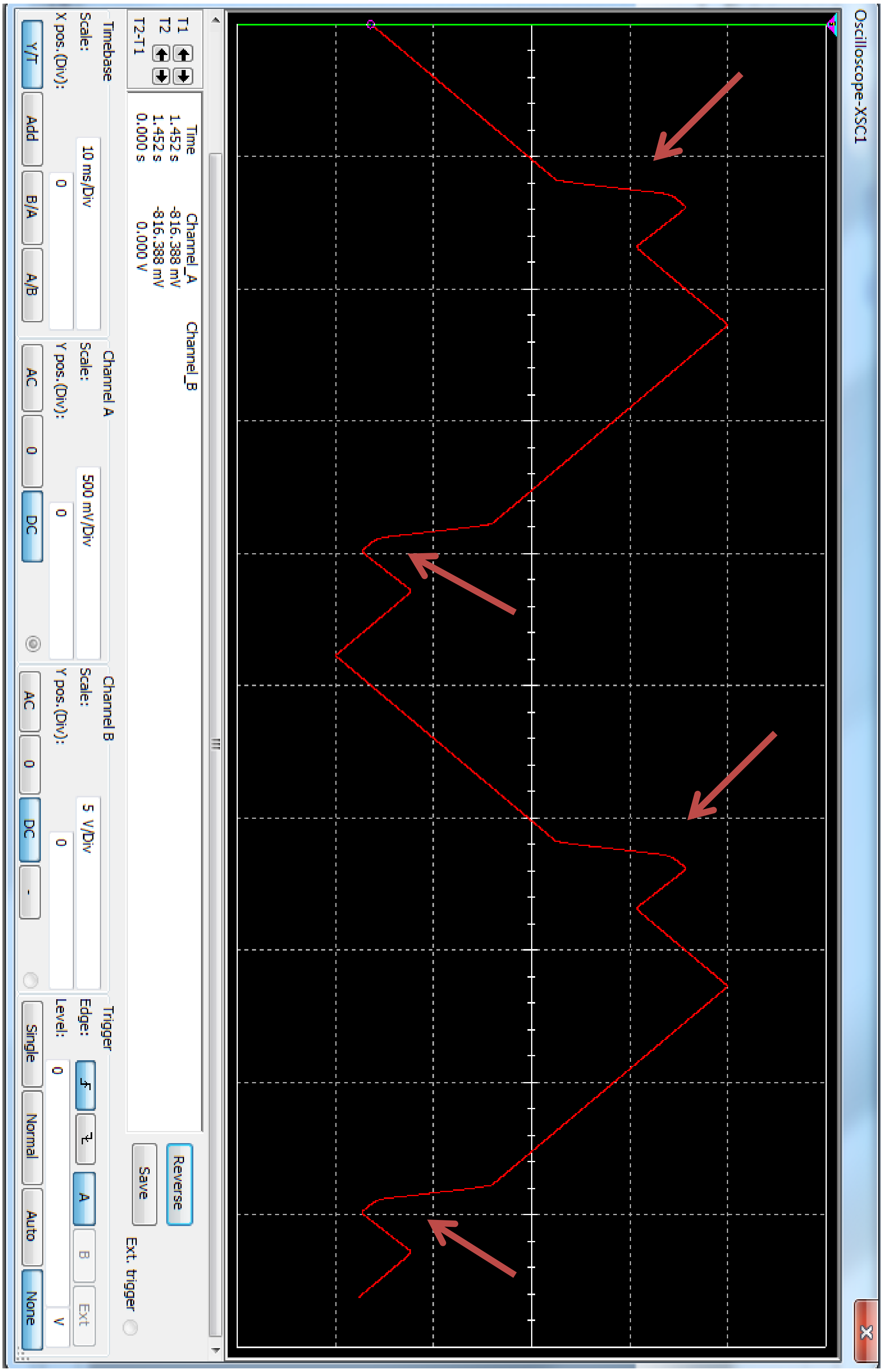


Picture 2.2.2.B simulation circuit for 3-electrosystem

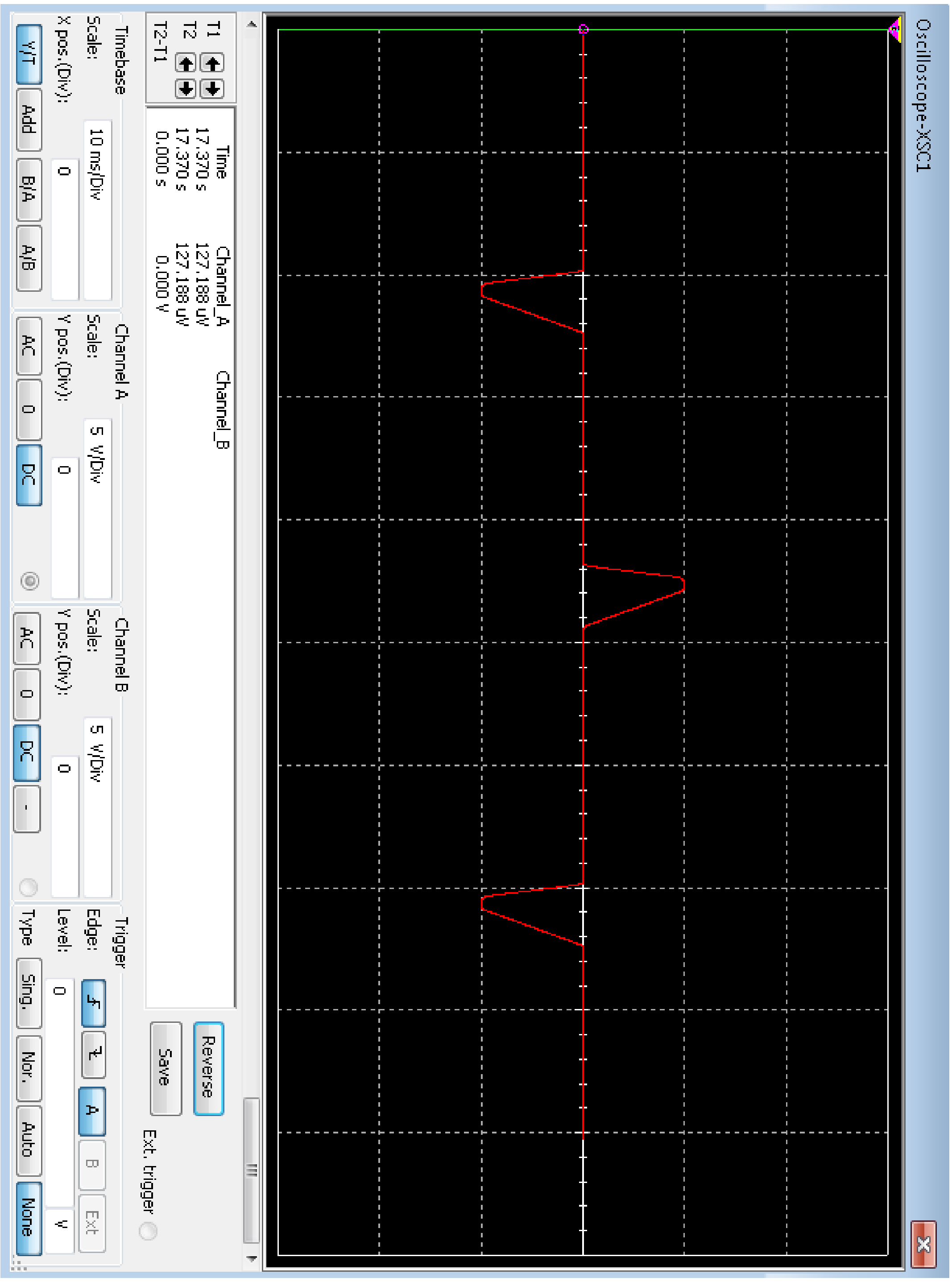
2.2.3 Testing

You can see results in picture 2.2.3.A and 2.2.3.B where the results of testing are in virtual oscilloscope view. In these pictures you can see that simulation of current to voltage conversion has been successful. In picture 2.2.3.A there are arrows on the points which break the triangle voltage. Between triangles there should be 10ms delay, but because of simulation software limits, it wasn't possible. I added arrows to the picture to mark these points. In picture 2.2.3.B there is not any input voltage so results are shown straight in oscilloscope view.

I was requested to do frequency response analyze for 2-electrode system. To this analyze you can use same simulation circuit. You just have to choose frequency response from analyses window and choose variables and values for them. You can find results of simulation at appendix 1. You can find the limit value when magnitude and phase turns to unstable, because frequency rises high enough.



Picture 2.2.3.A View in virtual oscilloscope of current to voltage converter



Picture 2.2.3.B View in virtual oscilloscope of current to voltage converter

2.3 Power supply

Power supply is required to transform electricity from electrical network to be in suitable form for device's segments. Power supply is one of the most critical segments of the device. If something goes wrong in designing this block the whole device might melt down when switching the power on. It is also important to isolate this part from other segments, because high power could easily cause interference in sensitive parts.

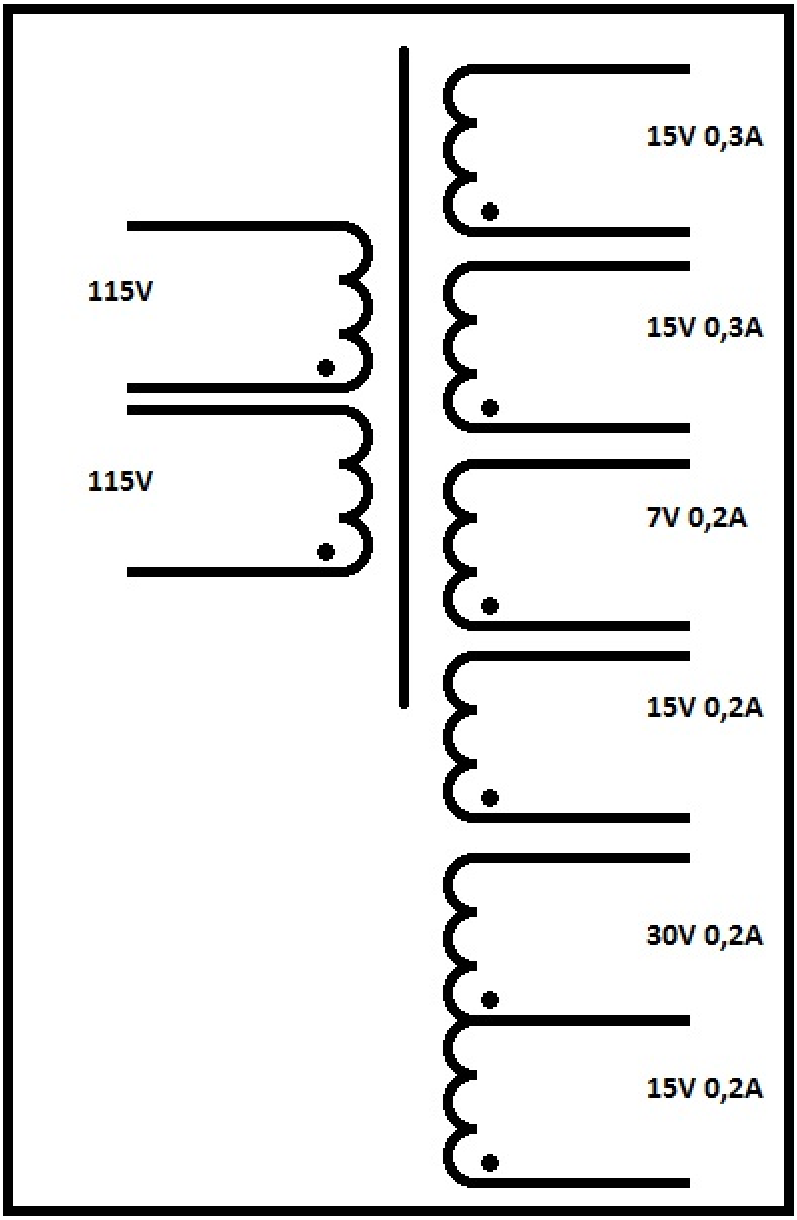
We had a couple of options in choosing transformers for power supply. We could have used six separate transformer or order custom made transformer pack. We noticed that only four of six transformers were available on markets, so we decided to tender custom transformers on couple of companies.

2.3.1 Trafox oy

Trafox is small company, that has main office in Finland and factories in Helsinki, Joensuu, Viljandi and in Suzhou. Trafox produces custom transformers, chokes, various wound components and also ground fault monitoring units.

2.3.2 Custom transformer

The best solution was to order custom made transformer pack from Trafox oy that included all six transformers. As it is shown in picture 2.2.1 below the transformer has two 115V coils on primary side because market area of device contains different type of electricity networks, for example in United States is using 115V and 60MHz electricity network. In Finland and in most European countries have 230V and 50MHz electricity network. Coils on secondary side are used to different segments of device.



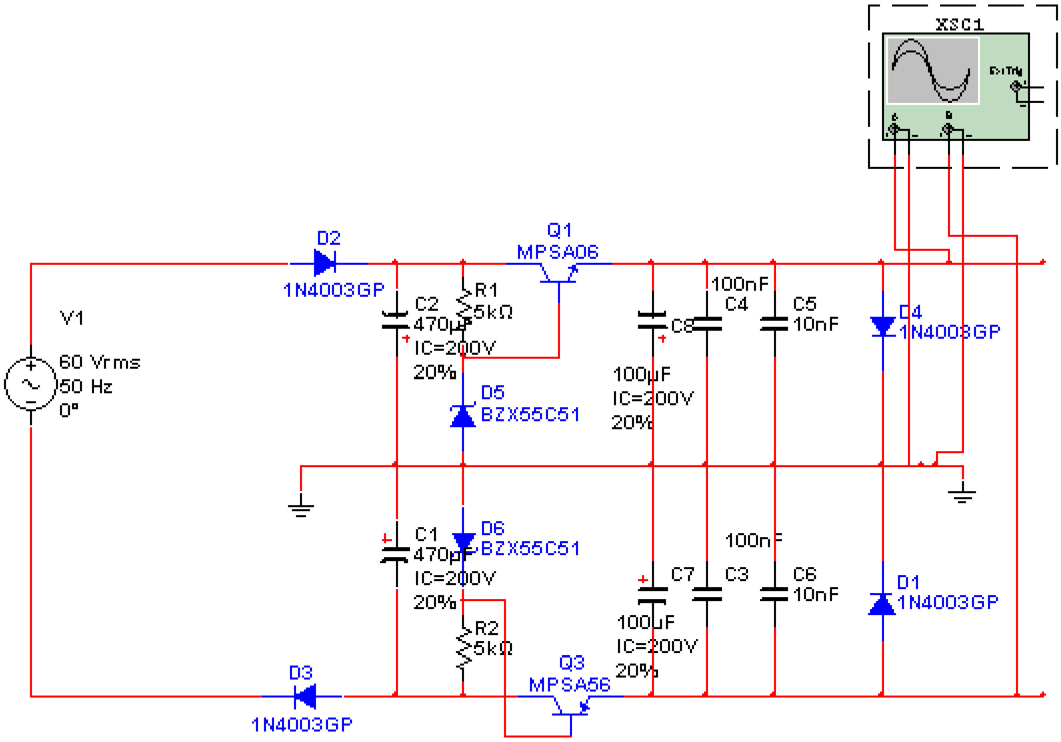
Picture 2.3.2.A Primary and secondary sides of transformer

In picture 2.3.2.B you can see complete transformer in enclosure.

Picture 2.3.2.B Transformer package installed to circuit board

2.3.3 Simulations

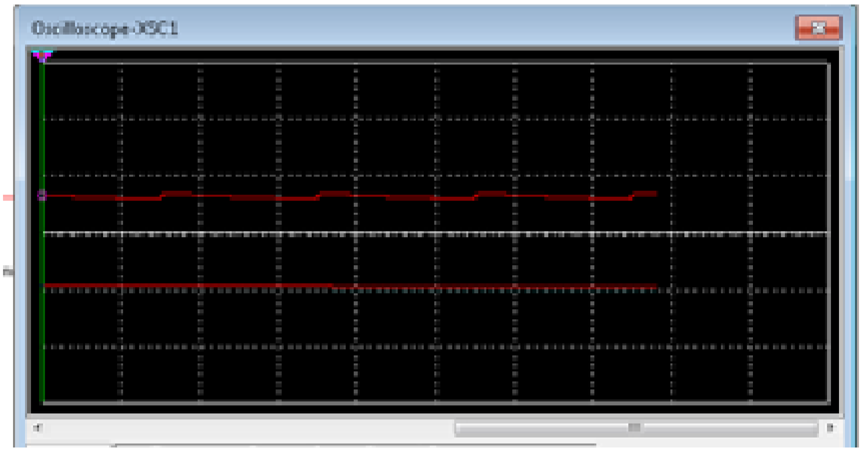
Because MultiSIM 11 doesn’t support the regulators that are used to create most output voltages, I could only simulate one segment of output voltages. In picture 2.3.3.A you can 60Vac to +50V and -50V segment schematic. XSC1 in picture is oscilloscope and it is used to measure results.



Picture 2.3.3.A schematic of +50/-50V output.

2.3.4 Testing

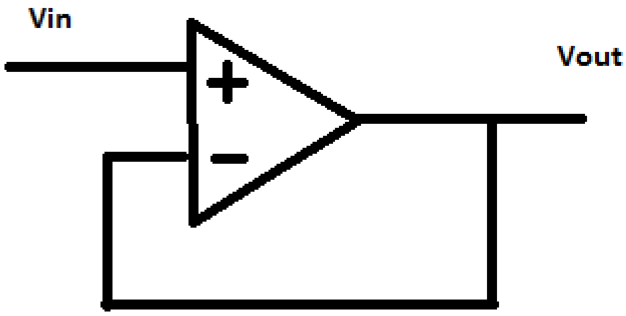
I measured circuit with virtual oscilloscope. You can see results in picture 2.3.4.A. The upper line is positive voltage, as you can see there are ripple in it. There isn't any load in this circuit and regulator is in non-load mode. Lower red line is negative output. There isn't any ripple because it has different type of regulator which doesn't cause non-load mode ripple.



Picture 2.3.4.A Screenshot of oscilloscope

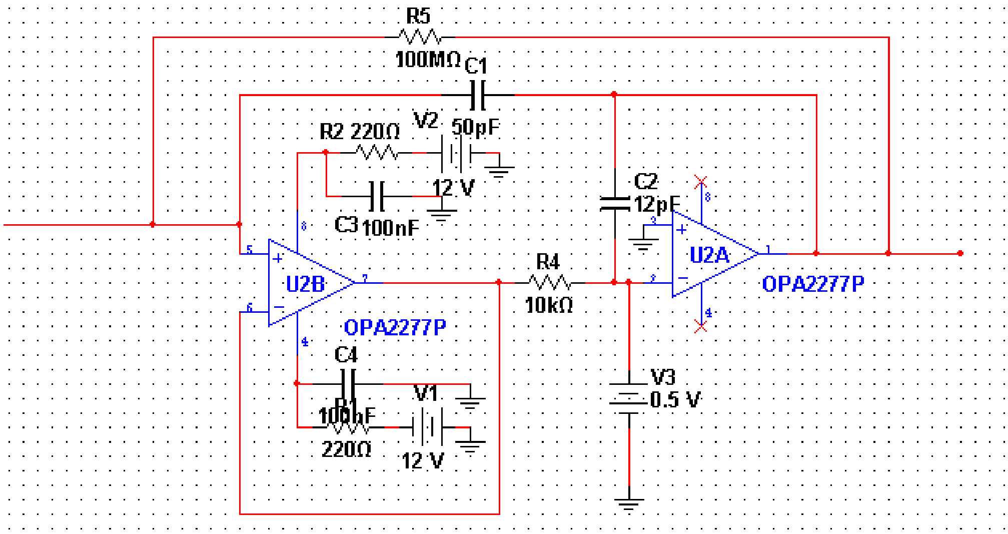
2.4 Potentiostat

Potentiostat has a pretty simple but important task. It is the voltage follower circuit. Voltage follower idea is $V_{in} = V_{out}$ but it isolates circuit and it prevents loading or buffering effects from the input voltage. In picture 2.4.A you can see the basic idea of this circuit. Output is connected to negative input of feedback amplifier.



Picture 2.4.A Voltage follower circuit

From potentiostat segment it is pretty hard to get any simulation results, because it includes measured values of electrodes. You can see the attempt schematic of po tentiostat in picture 2.4.B. In this picture R5 resistor represents animal brain and it is connected to auxiliary and reference voltage.



Picture 2.4.B Schematic of potentiostat

3 FRONT PANEL

One part of my work was to create front panel to the device. At the start I started to look for different options how it could be made. First we planned to get sticker and glue it to enclousure's front panel. This method would need also strengthening of front panel because the panel is too thin which makes it too flexible. Another option was to order a new custom made aluminum panel. After tendering we decided to choose custom made aluminum panel from Shaeffer AG, because it was cost effective, it would look better and it would require less work to assemble.

3.1 Shaeffer AG

Shaeffer AG is a small company and it is located in Marienfelde in Germany. It has 45 employees. Shaeffer AG products customised front panels and cases. Their target groups are engineering firms, development divisions in elecrtics sector, universities and electronics hobbyists. Shaeffer AG provides freeware front panel designer software.

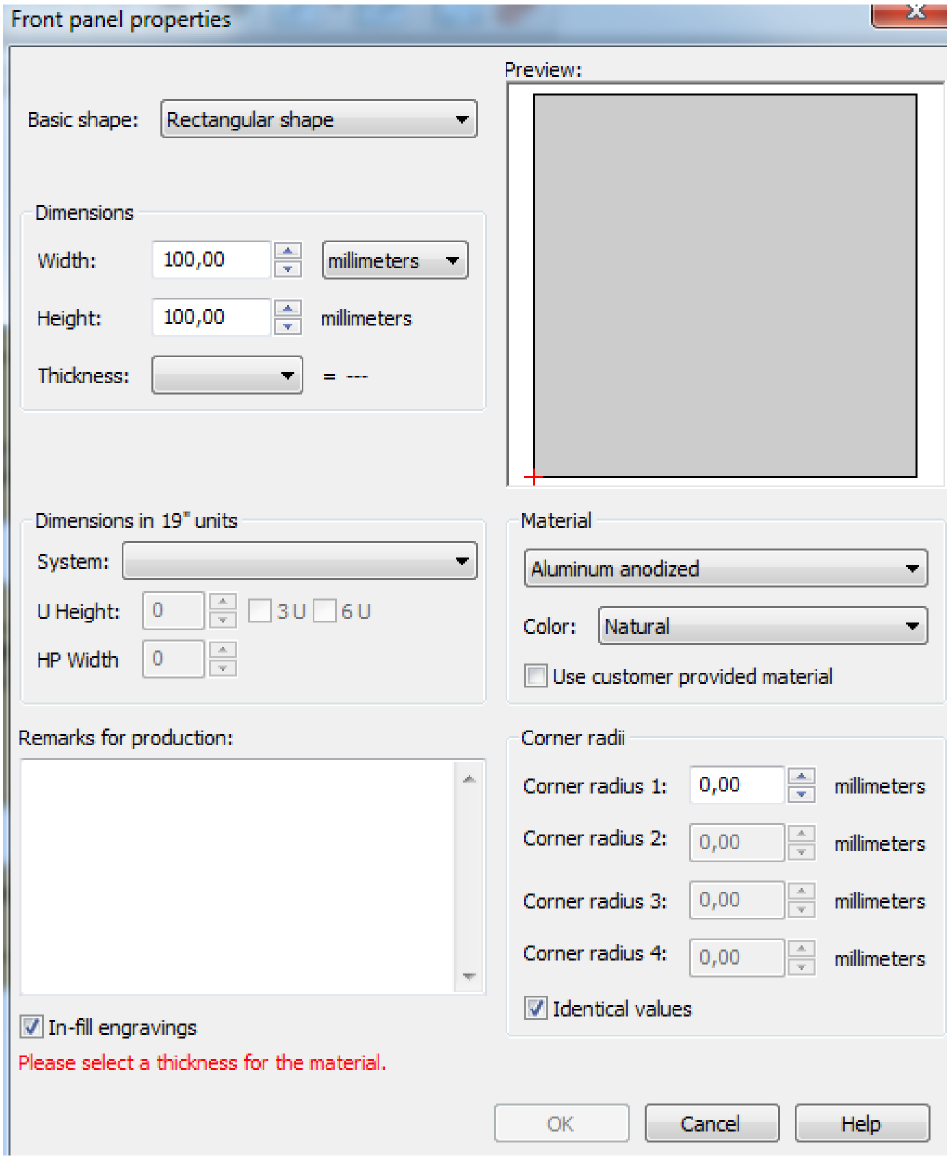
3.2 Front panel designer software

Front panel designer software is freeware software that can be downloaded for free at http://www.shaeffer-ag.de. It is CAD-based software. It is used to design custom front panels. In this software you can choose material, surface treatment, thickness, size, drilling holes, engraving and paintings. There are also a bunch of ready macro elements.

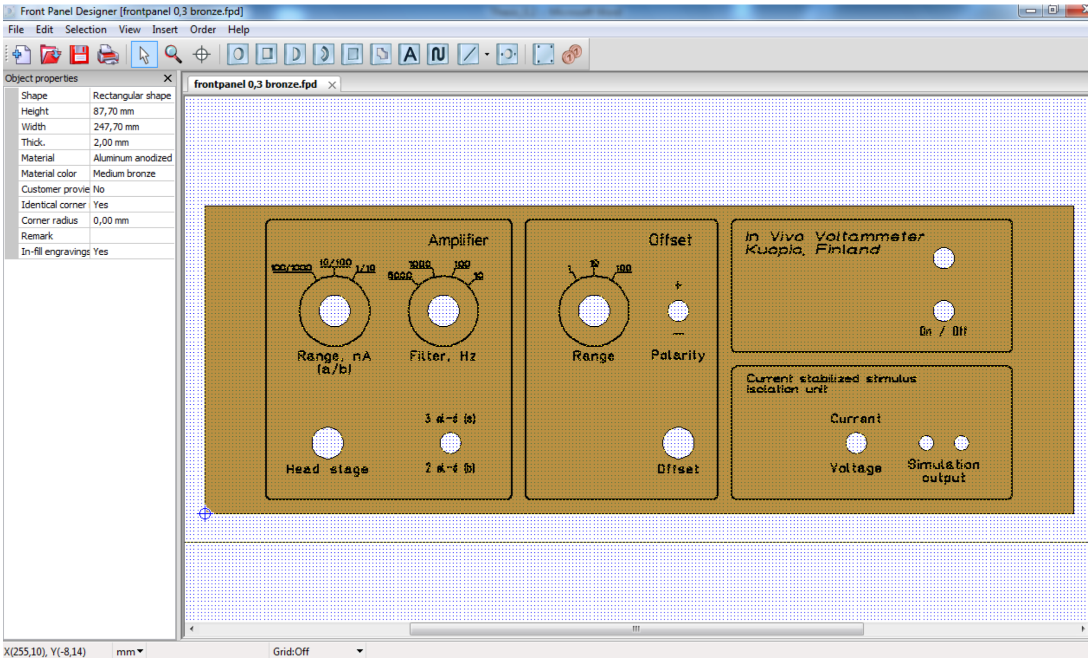
Software Front panel designer is simple and fast to learn, if you know the basics of CAD software. In this software you can use two decimals of millimeters precision on placing drill holes and engravings. When you place text or engravings you need to choose tool for making it, for example you can choose engraving tool 0,4 mm for regular text. By choosing the right tool you can make product cheaper to produce.

3.3 Designing the front panel

When opening the program and deciding to create a new panel, opens front panel properties window, see picture 3.1. You can set width, height thickness, material, color and corner shapes. In this stage you need to decide if you want to do engravings for panel. At the bottom left corner there are advice box. If there are not any option chosen it will advise the user to do so, for example in picture 3.1 case to choose thickness for panel. Also if you have chosen engraving option and your panel is too thin it won't let you continue to next phase. When everything is set you can continue to designing phase. You can change materials or thickness of panel also later in the middle of designing.



Picture 3.1 Front panel properties



Picture 3.2 Final version of front panel in front panel designer software

After designing front panel you can use “price calculation” function and a new window opens and you can see list of operations and prices to create product. It shows also discounts for product depending on amount of ordering panels, example if you order 5-9 pieces you will get 10% discount. You can order product straight through the software online. Shaeffer AG promises to deliver product in 9 days from ordering to European countries.

Price calculation for the file:[redacted].fpd

Based on price list of: Schaeffer AG
Price list date: 15.11.2010

Calculate price without VAT: [redacted] €
Price incl. 19,0% VAT: [redacted] €

Discounts:

Quantity	5-9 pieces	10-19 pieces	20-29 pieces	≥ 30 pieces
Discount	10,0%	20,0%	30,0%	
Price w/o VAT Price with VAT	[redacted] € €	[redacted] € €	[redacted] € €	upon request

The price is without tax and shipping charges. In our constant effort to improve our products and services we reserve the right to change specifications and prices without notice.

Calculation:

Type	Position [mm] X	Position [mm] Y	Description	Price
Other	-	-	Preparing/finishing	[redacted] €
Material	-	-	2,0 mm Aluminum anodized / Medium bronze	[redacted] €
Frame	0,00	0,00	Height: [redacted] mm / Width: [redacted] mm	[redacted] €
Drill hole	35,00	20,11	Diameter: 9,00 mm	[redacted] €
Drill hole	70,00	20,11	Diameter: 6,00 mm	[redacted] €

Picture 3.3 example window of calculation function

3.4 After-treatment of the panel.

After panel is manufactured and delivered to us, comes after-treatment phase. At first we need to cut corners off, to make panel suitable for enclosure. We need also to drill notches on backside of panel for knobs and switches. The notch is necessary to prevent knobs and switches spinning.

Picture 3.4 Installed front panel.

4 ASSEMBLING

In assembling the device you have to pay attention to risks of hurting yourself and avoid damaging the components. There are several things that must be done before opening the packages of components. Assembling is very precise work where you shouldn't have to hurry. Even small mistakes could destroy the whole device.

4.1 Safety

Your personal safety is the most important thing when planning and doing assembly. You must be sure that you have proper clothing and you are familiar with safety instructions of laboratory you are working in and tools you are using. Before you open packages of components you must make sure that you have grounded yourself, because static electricity could easily destroy sensitive components. You should also know how all tools that you are going to use work. You should practice using them on some easy task before using them for the device, if you haven't used them before.

4.2 Soldering of components

First thing to do is to check that the components you have ordered are the right ones, they have right voltage/current handling capacities and that they have correct package. It is also important to take a look for special components if they have special installing requirements, for example one IC-component required warm-air heater to be soldered from its bottom and after that you soldered its pins.

Next phase is the setup for tools. Because this device is classified as medical device I am allowed to non-Rohs solder, which means solder that can contain lead. Also non-Rohs solders require less heat when soldered and they are easier to solder.

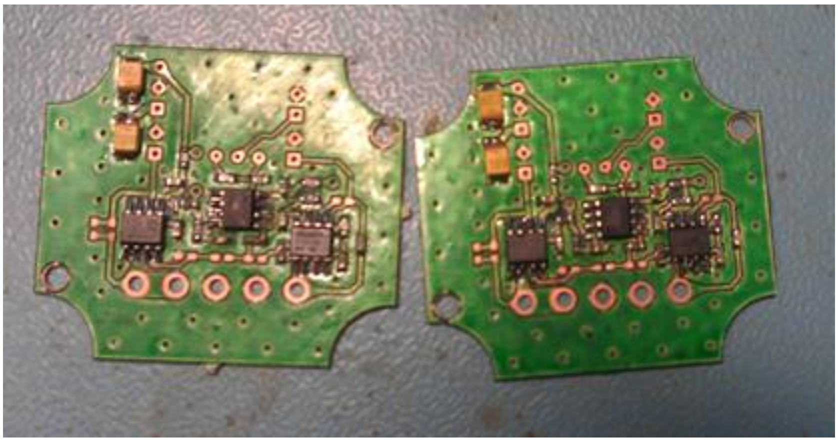
Because in circuit board components are designed to be soldered close to each other you need to plan carefully soldering order to make soldering easier. You should start with the smallest surface mounted components from the middle of circuit board and solder them in specific order, example from center clockwise to outer areas, and after that move to bigger components and solder them in same way. If you start with big components and will do soldering in random order it will be really hard to solder the last small components.

There are several important things listed below that you need to pay attention when soldering components

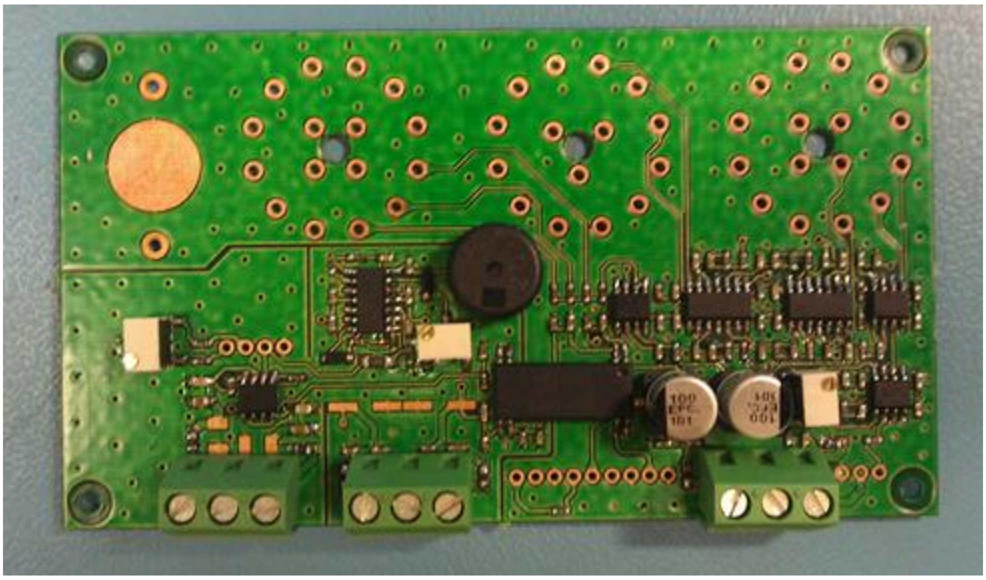
- Warm the pad and the pin before melting tin.
- Do not warm too much pads or component, because components enclosure might melt, pins can fall of or some components or pads might be destroyed.
- Be careful especially with pin headers, they melt and bend easily
- Do not warm tin too much, because tin will be hard to handle when flux burns off.
- Do not use too much or too less tin, it will less durability.
- Make sure that component is tightly on pad/board and it is placed in the middle of it.
- On through-hole components cut the long pins after soldering to prevent short circuits and in some cases they might also damage the enclosure or cut the wires.

4.2.1 Surface mounted components

Surface mounted components are placed to circuit board on pads which are meant to them. Usually surface mounted components are really small and in soldering you need microscope, tweezers for small components, soldering- and desoldering station with correct heat for solder you are using. You can see surface mounted components in pictures 4.2.1.A and 4.2.1.B.



Picture 4.2.1.A Circuit boards of headstages with surface mounted components only



Picture 4.2.1.B Main circuit board

Before placing a component, need to clean board and especially contactor pads. Then spread flux to the pads and you can start to solder some tin to the pads, it will make soldering a lot easier. When you have soldered some tin to the pad then warm the tin with soldering iron as long as it melts and then place the component and take soldering iron away and it will cool down quite fast and it locks the component. Next solder other side of component to the pad. With tweezers placing components will be a lot easier.

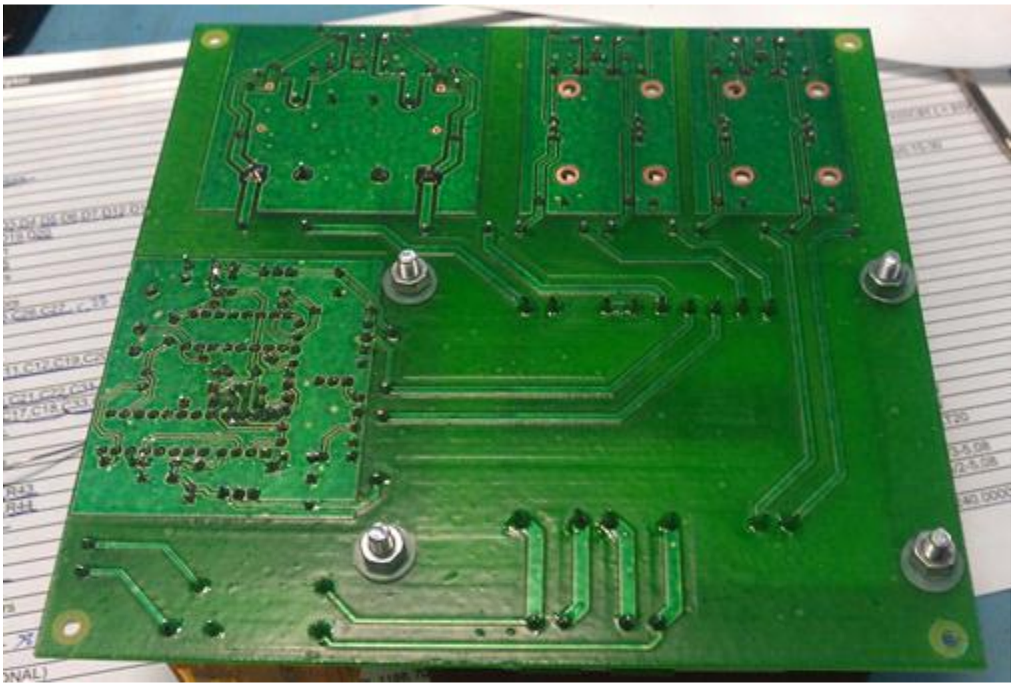
4.2.2 Through-hole components

Through-hole component’s pins are place to the hole on the board which are meant to them. Usually Through-hole components are bigger than surface mounted components so microscope and tweezers aren’t necessary to use when soldering them. These are a lot easier to solder, because pins holds them still. In powerblock circuit board all components are Through-hole components as you can see in picture 4.2.2.A below.

Picture 4.2.2.A Frontside of power block circuit board

Before soldering it you should shorten pins if they are too long and flux the contactor pads. When soldering these components you should make sure that the component is placed tightly to the board. If you are more than 3 pins on component you should solder 2 pins first and then check if component is in right position. It is much easier to move component when there are only 2 pins rather than 8 pins soldered. When the component is in right position you can solder the rest pins.

Some components requires bolts to register a mortgage. You can see in picture 4.2.2.B below that the transformer pack is strengthened with 4 bolts, because transformer is heavy component and pins might easily break off.



Picture 4.2.2.*B Backside of the power block circuit board.*

5 TESTING OF PROTOTYPE

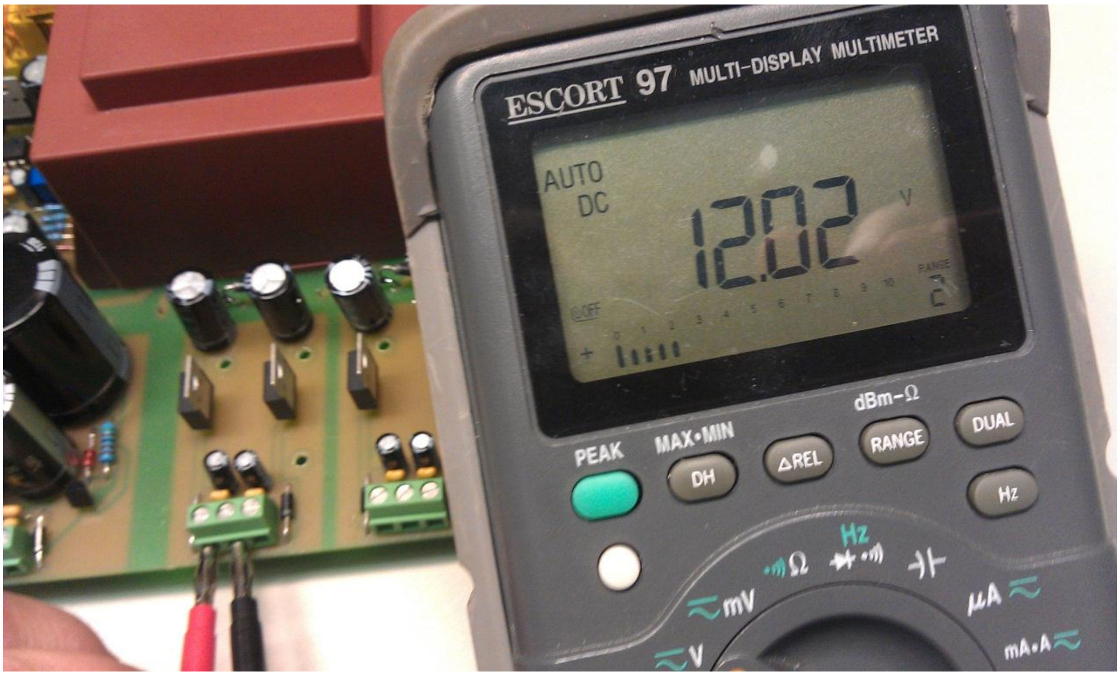
My part of end testing was to test power supply and 50Hz synchronization system. Because of high voltages I did testing in laboratory of Savonia IT unit. First I did visual check of circuit boards.

5.1 Testing of power supply

Power supply is used to modify network voltage to suitable voltages for different segments of device.

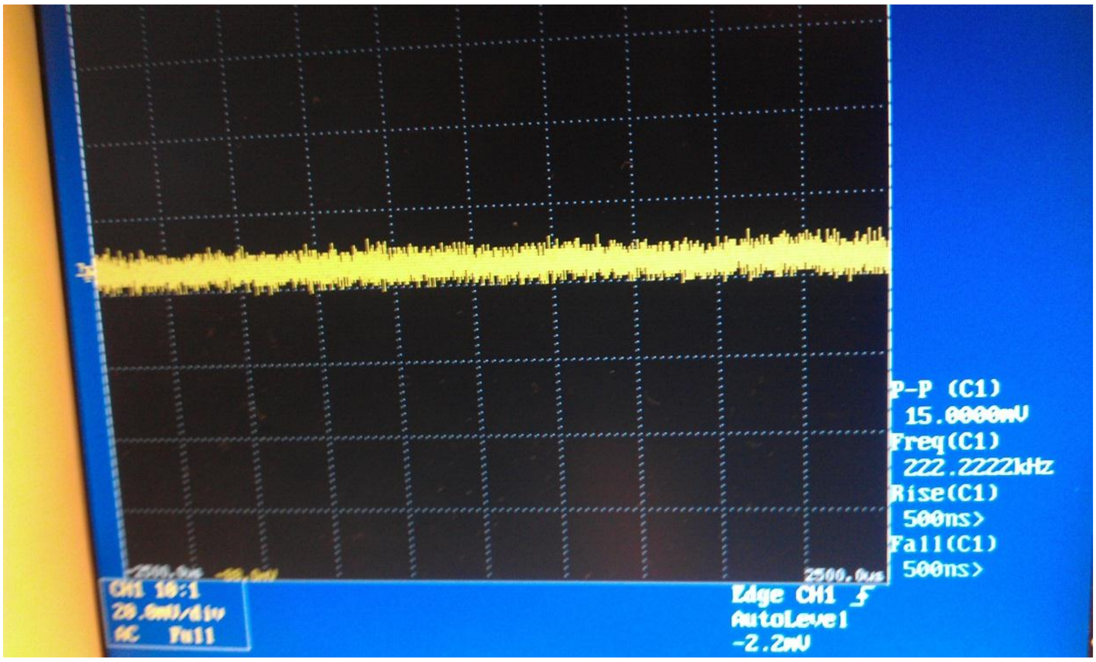
When I turned power on, first thing was to look if some components are warming up too much. I noticed soon that there weren't short circuits and components didn't warm too much, so next thing to do is start actual measuring tests.

I started with testing by measuring output voltages with multimeter. I tested all posi tive and negative outputs. You can see in picture 5.1.A voltage of positive ouput. As you can see in picture I tested voltages straight from output connectors.



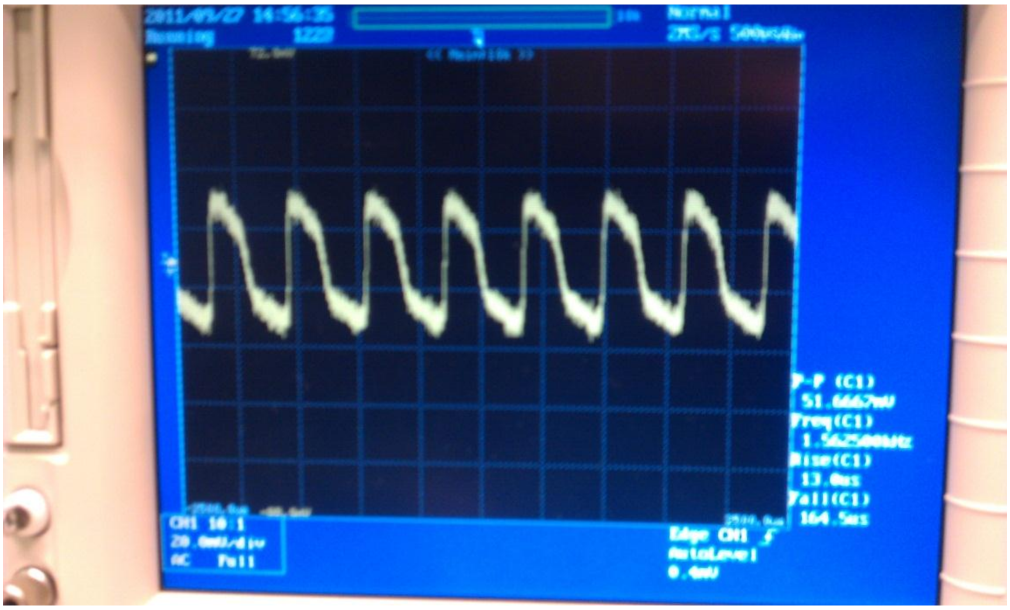
Picture 5.1.A Measuring output voltage from power supply.

When every output had been verified to produce correct voltage, I started next testing phase. In next phase I measured outputs with oscilloscope. Signals of 50V outputs and negative 12V outputs had pretty similar ripple and the signal peak to peak value is 15mV which is stable enough, but as you can see in picture 5.1.B



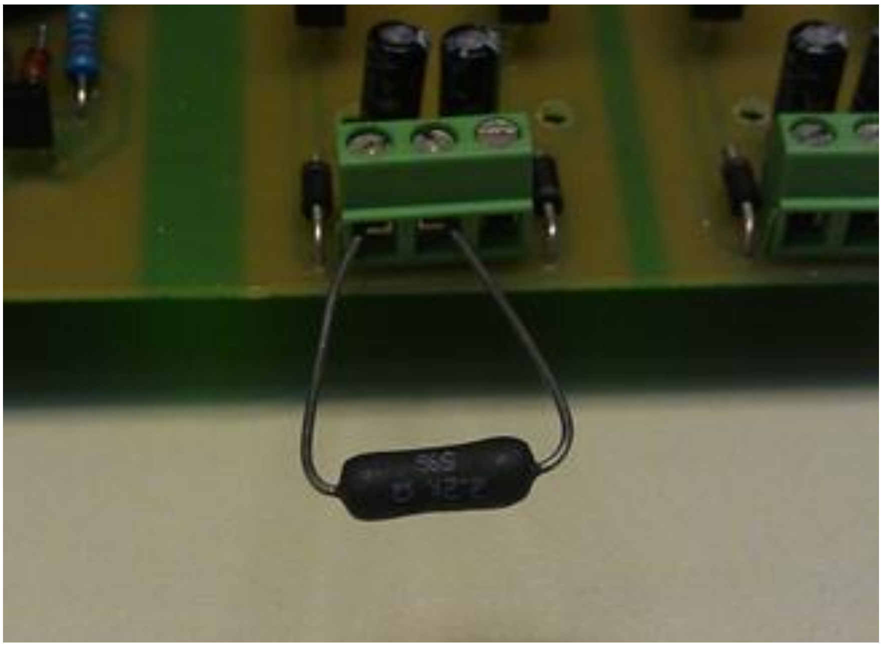
Picture 5.1.B Screenshot of oscilloscope while measuring negative side of 12V output

On the positive side of 12V outputs, peak to peak value of ripple was 51mV, which is too much for this device. You can see the ripple in screenshot of oscilloscope in pic ture 5.1.C.



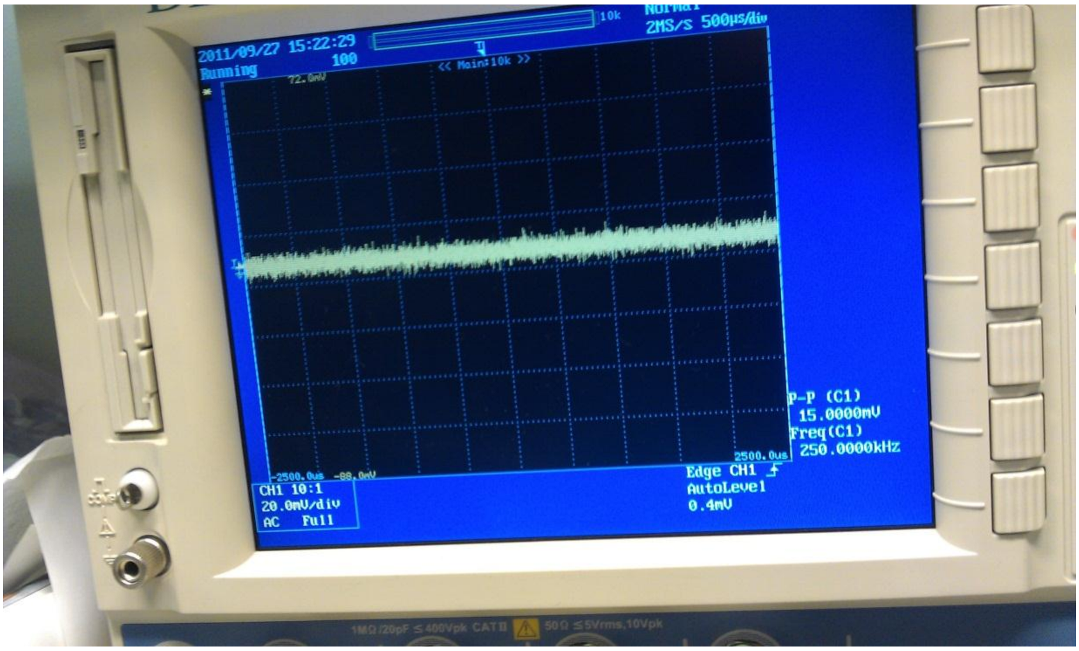
Picture 5.1.C Screenshot of oscilloscope while measuring positive side of 12V output

Because this voltage is used in measuring part of device we needed to get rid. I started studying reason for this ripple. I came up with a couple of ideas what might cause it. First I thought that regulators might be broken. Then I thought that capaci tors might have too low values so they couldn’t downsize the wave enough and regu lators would stop partly working. The last thing was that those regulators have no-load mode and when there aren’t any load there will come that ripple. I tested them with bigger capacitor, but it didn’t help at all. Then I installed 2200Ω resistor to be a load. You can see how I installed resistor in picture 5.1.D



Picture 5.1.D The load resistor is installed

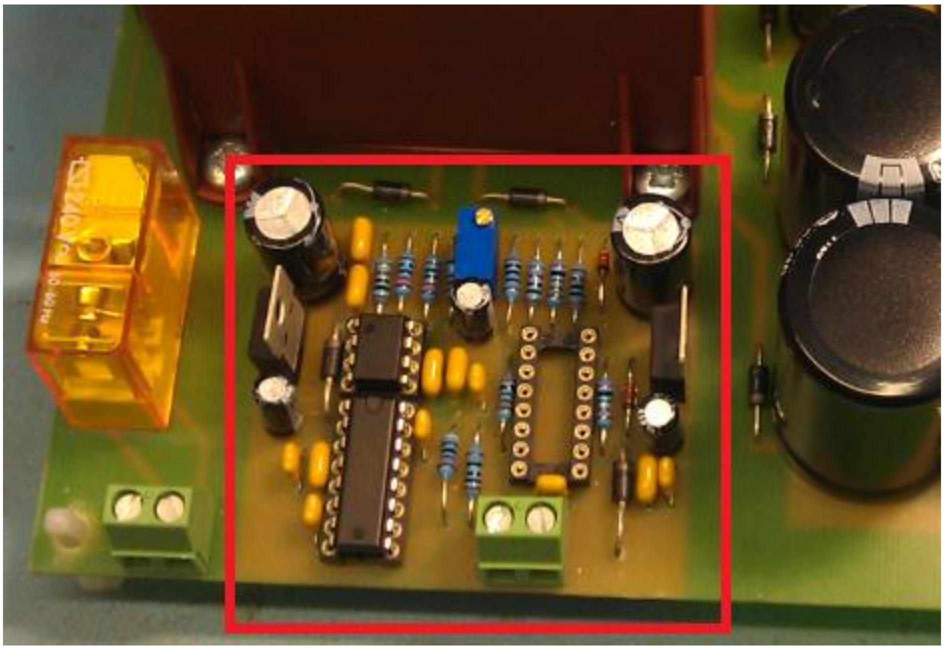
With the load on the output the ripple disappeared, so those regulators were in no-load mode, which I also checked out later from datasheet of the regulator. In picture 5.1.E. You can see the output signal with the load resistor.



Picture 5.1.D Screenshot of oscilloscope, when the load resistor is placed

5.2 Testing of 50Hz synchronization system

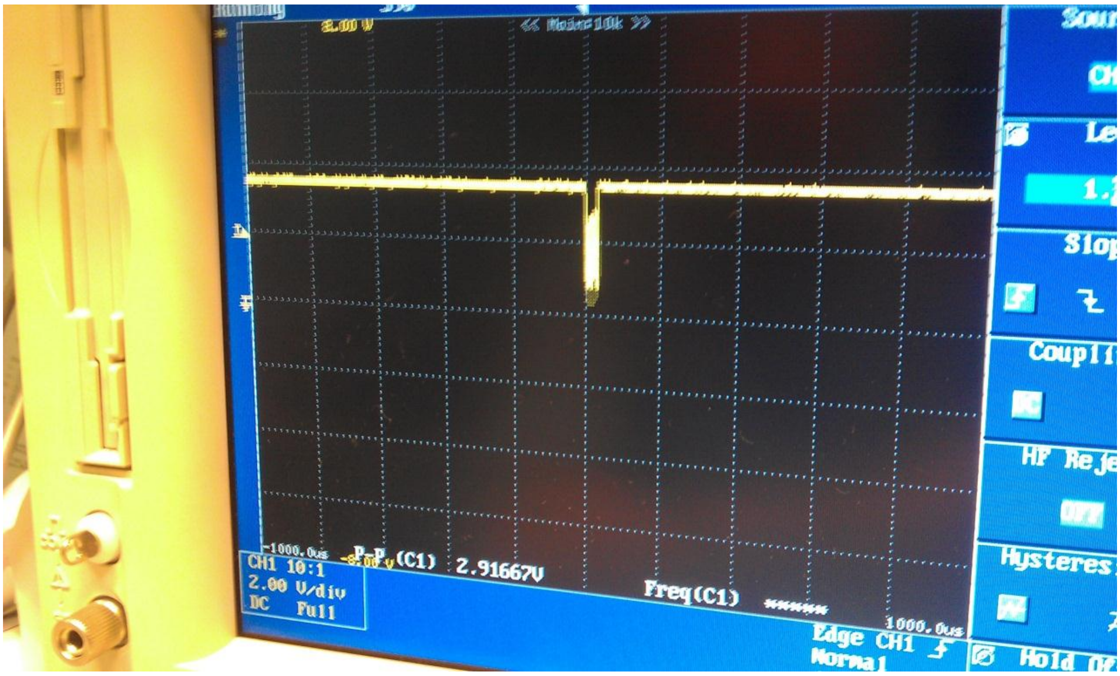
The last segment of power supply is 50Hz synchronization system. Synchronization system provides short voltage pulses at 50Hz frequency. You can find 50Hz syn chronization system in picture 5.2.A in red square.



Picture 5.2.A the 50Hz synchronization system

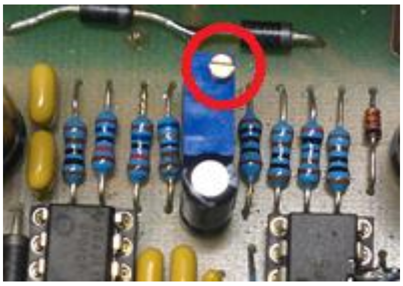
When other parts of power supply were working I installed the last IC components. Again I turned power on and looked for warming components. Once again there were no short circuits and I could continue testing.

I started testing with oscilloscope. You can see measured signal in picture 5.2.B. The Signal is at 50Hz frequency, although pulse isn’t long enough and it has ripple on it.



Picture 5.2.B Unadjusted measured signal of synchronization system.

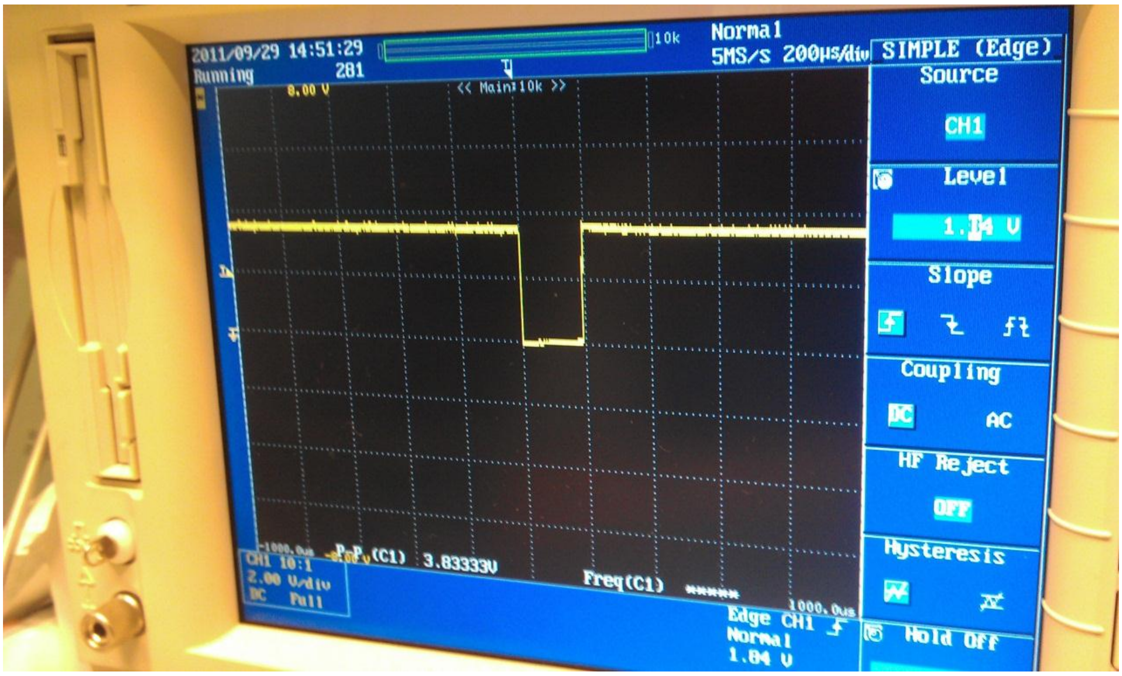
Length of this signal can be adjusted from trimmer resistor by screwdriver. You can see this adjusting screw in red circle in picture 5.2.C.



Picture 5.2.C adjusting screw.

The ripple disappeared when the pulse was long enough. I realized that the pulse was shorter than the comparator could handle and malfunction caused the ripple.

After a while signal got adjusted to correct length of 200µs. You can see the adjusted signal in picture 5.2.D.



Picture 5.2.D Adjusted signal of synchronization system on the oscilloscope.

6 SUMMARY

The goal of this project was achieved on my part. Everything went pretty smoothly although we faced some challenges during the project, but the problems were solved and the results were actually better than we expected. After the practical testing phase is over we will see how the rest of the circuit boards are working.

The work itself was pretty challenging, I faced a lot new things and I had to study a lot in order to be successful in this project. I believe this work has taught a lot of working independently, seeking information of complicated systems, how to contact and communicate with companies.

SOURCE MATERIALS

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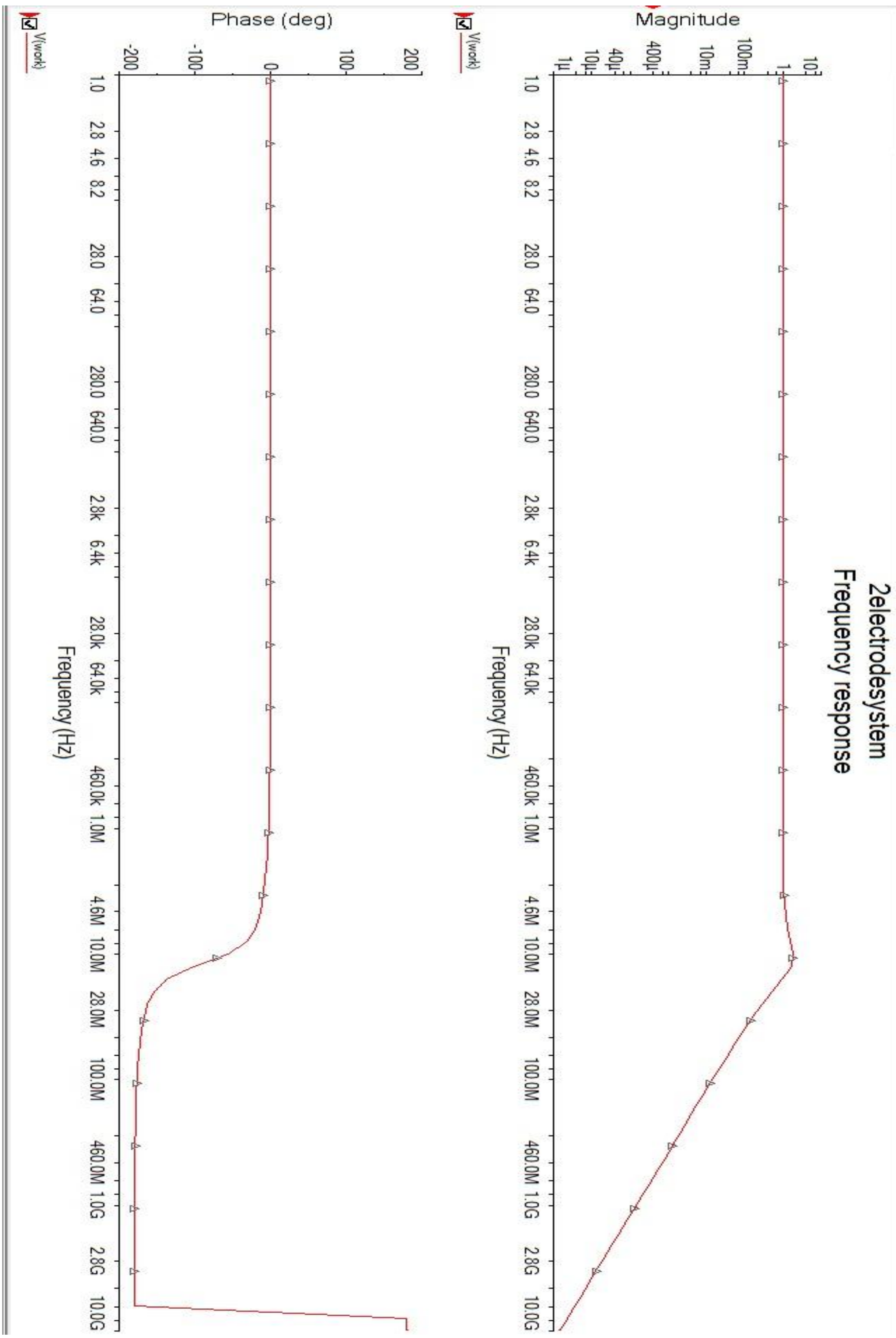
2electrodesystem
Frequency response
Magnitude
10
1
100m
10m
400µ
40µ
10µ
1µ
V(work)
Frequency (Hz)
Phase (deg)
200
100
0
-100
-200
V(work)
1.0
2.8
4.6
8.2
28.0
64.0
280.0
640.0
2.8k
6.4k
28.0k
64.0k
460.0k
1.0M
4.6M
10.0M
28.0M
100.0M
460.0M
1.0G
2.8G
10.0G
Frequency (Hz)