BOĞAZİÇİ ÜNİVERSİTESİ

STAJ PROGRAM DEFTERİ

TRAINING PROGRAM DIARY

ÖĞRENCİNİN
STUDENT'S

SOYADI, ADI : UZUN Aydın
SURNAME, NAME

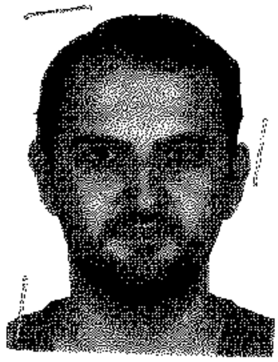
BÖLÜMÜ : Electrical and Electronics Engineering
DEPARTMENT

ÖĞRENİM YILI : 2018-2019
TRAINING YEAR

27.09.2019

Lehrstuhl für Medizinische Informationstechnik
Helmholtz-Institut, RWTH Aachen
Pauwelsstraße 20 • D-52074 Aachen
Tel.: 02 41 / 80 23 211 • Fax: 02 41 / 80 62 32 11

Staj programı
Training Program



Defter No: 1
Diary book No : 1

Soyadı, Adı : UZUN, Aydın
Surname, Name

Bölümü : Electrical and Electronics Engineering
Department

YAPILAN PRATİK [*]
ACCOMPLISHMENTS

Müessese ve iş yeri *Name and place of company*	Kısım *Department*	İşe başlama tarihi *Starting date*	Ayrıldığı tarih *Completion date*	Çalışmadığı Günler *Nonworking days*	Çalıştığı Günler *Working days*
Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University	Medical Information Technology	26.06.2019	13.09.2019	5	53

[*] Bu sayfa şirket yetkilisi tarafından imzalanıp kaşelenecektir

24.06.2019 Tarihinden 28.06.2019 tarihine kadar bir haftalık çalışma
From 24.06.2019 to 28.06.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Leave of Absence			
Salı *Tuesday*	Leave of Absence			
Çarşamba *Wednesday*	Meeting with the working staff Reading instructional documents about the department	1	9.00-17.00	8 h
Perşembe *Tuesday*	Reading instructional documents about the department Reading some scientific articles about capacitive ECG (cECG)	1	9.00-17.00	8 h
Cuma *Friday*	Introduction to capacitive ECG (cECG) and solving some exercises about cECG signal processing on MATLAB	1	9.00-17.00	8 h
Toplam (*Total*)			24h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz
İmza ve kaşe
Signature and stamp :

Lehrstuhl für Medizinische Informationstechnik
Helmholtz-Institut, RWTH Aachen
Pauwelsstraße 20 • D-52074 Aachen
Tel.: 02 41 / 80 23 211 • Fax: 02 41 / 80 82 32 11

01.07.2019 Tarihinden 05.07.2019 tarihine kadar bir haftalık çalışma
From 01.07.2019 to 05.07.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Yaprak No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Assignment to the ongoing project Detailed information about what I will do until the end of my internship	2	9.00-17.00	8 h
Salı *Tuesday*	Introduction to facilities of institution and their use (Etching room, mechanics laboratory, electronics laboratory) A demo was held in the etching room.	2	9.00-17.00	8 h
Çarşamba *Wednesday*	Introduction to EAGLE (an electronic design automation (EDA) application with schematic capture and PCB layout features) software	2	9.00-17.00	8 h
Perşembe *Tuesday*	The design of a bipolar power supply source with sockets is examined and it is produced using the tools in etching room	2	9.00-17.00	8 h
Cuma *Friday*	The soldering and testing of the produced circuit are done.	2	9.00-17.00	8 h
Toplam (*Total*)			40 h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz
İmza ve kaşe
Signature and stamp :

08.07.2019 Tarihinden 12.08.2019 tarihine kadar bir haftalık çalışma
From 08.07.2019 to 12.08.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Introduction to ballistocardiograph signals and ballistocardiographic measurement systems	3	9.00-17.00	8 h
	Meeting with my advisor and other trainees			
Salı *Tuesday*	Start of the first prototype of a ballistocardiographic measuring system prototype (sensing unit with a force resistive sensor on top of it, main board)	3	9.00-17.00	8 h
	The operation of square force resistive sensors is analyzed and understood.			
Çarşamba *Wednesday*	Some calibration measurements are made on the force resistive sensor in order to determine the values of the circuit elements on the sensing unit	3	9.00-17.00	8 h
	The design of the sensing unit with the EAGLE software			
Perşembe *Tuesday*	The design of the main board with the EAGLE software, the main board feeds the sensing unit and receives the generated signal and transfers it to the computer	3	9.00-17.00	8 h
	The designed circuits are fabricated using the etching room.			
Cuma *Friday*	The soldering and testing of the fabricated circuits are done.	3	9.00-17.00	8 h
Toplam (*Total*)			40h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior :
İmza ve kaşe
Signature and stamp :

Helmholtz-Institut RWTH Aachen
Pauwelsstraße 20 • D-52074 Aachen

15.07.2019 Tarihinden 19.07.2019 tarihine kadar bir haftalık çalışma
From 15.07.2019 to 19..07.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Yaprak No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Learned how to use the data acquisition module (NI USB 6259)	4	9.00-17.00	8 h
	Meeting with my advisor and other trainees			
Salı *Tuesday*	Write a MATLAB script to convert the measured voltage levels to appropriate pressure levels	4	9.00-17.00	8 h
Çarşamba *Wednesday*	First measurements were taken using the instruments produced.	4	9.00-17.00	8 h
Perşembe *Tuesday*	Comparisons between BCG and ECG signals were made using the manufactured instruments and the existing cECG instruments	4	9.00-17.00	8 h
Cuma *Friday*	Optimizations in the MATLAB script	4	9.00-17.00	8 h
	The results were unsatisfactory, it is decided to use a different measurement topology including FSR sensors for BCG signals			
Toplam (*Total*)			40 h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Dürmüş Umutcan Uğuz
İmza ve kaşe
Signature and stamp

22.07.2019 Tarihinden 26.07.2019 tarihine kadar bir haftalık çalışma
From 22.07.2019 to 26.07.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	The circuit of the other topology (current to voltage converter) is created with the EAGLE software	5	9.00-17.00	8 h
	Meeting with my advisor and other trainees			
Salı *Tuesday*	Introduction to PVDF films, theory and modelling of PVDF films, signal conditioning of piezoelectric sensors	5	9.00-17.00	8 h
Çarşamba *Wednesday*	It is decided to design two topologies for PVDF films, topology I (voltage mode amplifier), topology II(charge mode amplifier)	5	9.00-17.00	8 h
Perşembe *Tuesday*	The design of topology I and topology II sensing units and the design of the main board using EAGLE software	5	9.00-17.00	8 h
Cuma *Friday*	The designed circuits are fabricated using the etching room.	5	9.00-17.00	8 h
	The soldering of the fabricated circuits is done.			
Toplam (*Total*)			40h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz
İmza ve kaşe
Signature and stamp :

Lehrstuhl für Medizinische Informationstechnik
Helmholtz-Institut, RWTH Aachen
Pauwelsstraße 20 • D-52074 Aachen
Tel.: 02 41 / 80 23 211 • Fax: 02 41 / 80 22 32 11

29.07.2019 Tarihinden 02.08.2019 tarihine kadar bir haftalık çalışma
From 29.07.2019 to 02.08.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Yaprak No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	The testing of the fabricated circuits is done.	6	9.00-17.00	8 h
	The measurement setup is installed.			
	Meeting with my advisor and other trainees			
Salı *Tuesday*	Measurements were made using the sensing units for both topologies including PVDF films.	6	9.00-17.00	8 h
Çarşamba *Wednesday*	Measurements were made using the sensing units for both topologies including PVDF films, the existing cECG instruments and the instruments measuring the coupling capacitance	6	9.00-17.00	8 h
Perşembe *Tuesday*	The two topologies are compared.	6	9.00-17.00	8 h
Cuma *Friday*	The measurements using the second topology including FSR sensors were made.	6	9.00-17.00	8 h
Toplam (*Total*)			40h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz
İmza ve kaşe
Signature and stamp

05.08.2019 Tarihinden 09.08.2019 tarihine kadar bir haftalık çalışma
From 05.08.2019 to 09.08.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	All topologies are compared and discussed with the supervisor. Meeting with my advisor and other trainees It was decided to use the topology II with a PVDF film.	7	9.00-17.00	8 h
Salı *Tuesday*	Measurements were taken from different parts of the body (upper left back, lower left back, upper right back, lower right back).	7	9.00-17.00	8 h
Çarşamba *Wednesday*	Same task as yesterday	7	9.00-17.00	8 h
Perşembe *Tuesday*	After consulting with my supervisor, it is decided to increase the number of PVDF films used in the sensing unit Related improvements were made to the sensing unit.	7	9.00-17.00	8 h
Cuma *Friday*	New measurements were made after the improvements.	7	9.00-17.00	8 h
Toplam (*Total*)			40h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz
İmza ve kaşe
Signature and stamp :

Lehrstuhl für Medizinische Informationstechnik
Helmholtz-Institut, RWTH Aachen
Pauwelsstraße 20 • D-52074 Aachen
Tel.: 02 41 / 80 23 211 • Fax 02 41 / 80 62 32 11

12.08.2019 Tarihinden 16.08.2019 tarihine kadar bir haftalık çalışma
From 12.08.2019 to 16.08.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Meeting with my advisor and other trainees The measurements were processed using MATLAB.	8	9.00-17.00	8 h
Salı *Tuesday*	It has been investigated which features can be extracted from the processed data on MATLAB.	8	9.00-17.00	8 h
Çarşamba *Wednesday*	Same task as yesterday After consulting with my supervisor, necessary arrangements were made on MATLAB code.	8	9.00-17.00	8 h
Perşembe *Tuesday*	The measurements were made on a different subject (the other trainee) other than me. The instrumentation for BCG signals designed by me, the existing cECG measurement instrumentation and the impedance measurement instrumentation designed by other trainee are used for measurements.	8	9.00-17.00	8 h
Cuma *Friday*	The data is processed, and some average shapes of BCG signals are generated using MATLAB.	8	9.00-17.00	8 h
Toplam (*Total*)			40h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz
İmza ve kaşe
Signature and stamp

19.08.2019 Tarihinden 23.08.2019 tarihine kadar bir haftalık çalışma
From 19.08.2019 to 23.08.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Meeting with my advisor and other trainees The resulting shapes were examined, and conclusions drawn on the measurements. A report was created to present my conclusions to my advisor.	9	9.00-17.00	8 h
Salı *Tuesday*	Measurements were made using different clothes and the effect of different clothes on the measurements was observed.	9	9.00-17.00	8 h
Çarşamba *Wednesday*	Long-term measurements were performed and the effect of the measurement time on the average forms was observed.	9	9.00-17.00	8 h
Perşembe *Tuesday*	It is decided to use the ECG measurement device of Phillips which is used in the hospitals instead of the existing basic cECG measurement instrumentation because of the poor peak detection of basic cECG instrumentation. So new measurements were carried out with this new device.	9	9.00-17.00	8 h
Cuma *Friday*	The measurements were continued with the new setup, this time measurements were made on 3 persons.	9	9.00-17.00	8 h
Toplam (*Total*)			40h	

Öğrencinin imzası
Signature of trainee :

Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University

Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz

İmza ve kaşe
Signature and stamp

26.08.2019 Tarihinden 30.08.2019 tarihine kadar bir haftalık çalışma
From 26.08.2019 to 30.08.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Leave of Absence			
Salı *Tuesday*	Leave of Absence			
Çarşamba *Wednesday*	Leave of Absence			
Perşembe *Tuesday*	Leave of Absence			
Cuma *Friday*	Leave of Absence			
Toplam (*Total*)			0h	

Öğrencinin imzası
Signature of trainee :

Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University

Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz

İmza ve kaşe
Signature and stamp

Lehrstuhl für Medizinische Informationstechnik
Helmholtz-Institut, RWTH Aachen
Pauwelsstraße 20 · D-52074 Aachen
Tel.: 02 41 / 80 23 211 · Fax: 02 41 / 80 62 52 11

02.09.2019 Tarihinden 06.09.2019 tarihine kadar bir haftalık çalışma
From 02.09.2019 to 06.09.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Meeting with my advisor and other trainees	10	9.00-17.00	8 h
	Introduction to SignalPlant software			
	Corrected ECG peaks using this software			
Salı *Tuesday*	The final figures are generated.	10	9.00-17.00	8 h
	It was decided to combine the two sensing units for impedance measurement and BCG measurement to make the system more effective. It was also decided to put the entire instrumentation in a box and fix on the back of the measurement chair. Appropriate designs are made on EAGLE software			
Çarşamba *Wednesday*	The designed circuits are fabricated using the etching room.	10	9.00-17.00	8 h
	The soldering of the fabricated circuits is done.			
Perşembe *Tuesday*	Measurements were made using new instrumentation, but it was not successful. Debugging has begun.	10	9.00-17.00	8 h
Cuma *Friday*	Debugging continued, but the problem was not found. It was decided to make a new design and produce it.	10	9.00-17.00	8 h
	New design started.			
Toplam (*Total*)			40h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz
İmza ve kaşe
Signature and stamp : Pauwelsstr... Tel.: 02 41 / 80 23 211 • Fax: 02 41 / 80 62 32 11

09.09.2019 Tarihinden 13.09.2019 tarihine kadar bir haftalık çalışma
From 09.09.2019 to 13.09.2019 weekly service

GÜN *DAYS*	YAPILAN İŞLER *WORK ACCOMPLISHED*	Sayfa No. *Page Nr.*	ÇALIŞILAN SAAT *WORKING HOURS*	
Pazartesi *Monday*	Meeting with my advisor and other trainees	11	9.00-17.00	8 h
	The designed circuit is fabricated using the etching room.			
	The soldering and testing of the fabricated circuit are done.			
Salı *Tuesday*	Measurements were taken using the newly produced main board and sensing unit.	11	9.00-17.00	8 h
Çarşamba *Wednesday*	Documentation of the work carried out	11	9.00-17.00	8 h
Perşembe *Tuesday*	Written report	11	9.00-17.00	8 h
Cuma *Friday*	Written report	11	9.00-17.00	8 h
	Good-bye to colleagues			
Toplam (*Total*)			40h	

Öğrencinin imzası
Signature of trainee :
Çalıştığı iş yeri ve kısmı
Work place : Medical Information Technology, Helmholtz-Institute for Biomedical Engineering at RWTH Aachen University
Kontrol edenin ünvanı, soyadı, adı
Name and title of the controlling superior : M.Sc. Durmuş Umutcan Uğuz
İmza ve kaşe
Signature and stamp : Lehrstuhl für Medizinische Informationstechnik, Helmholtz-Institut, RWTH Aachen, Pauwelsstraße 20 • D-52074 Aachen, Tel.: 02 41 / 80 23 211 • Fax: 02 41 / 80 62 32 11

Kısım **Introduction** *Sectıon*	Yaprak No **1** *Page Nr.*
Yapılan İş **Reading informative documents** *Work Done*	Tarih**: 26.06.2019-28.06.2019** *Date*

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 1st WEEK –

26.06.2019, Wednesday

In the first day of my internship at Medical Information Technology, I met my internship supervisor Mr. Uguz, my co-workers and the head of electrical department Mr. Walter. Then I read some informative articles about the project I will work on.

27.06.2019, Thursday

I continued reading instructional articles about the project. Some of them were about ballistocardiogram (BCG) signals and some of them were about capacitive ECG (cECG) measurement systems.

28.06.2019, Friday

Today, I received a introduction from my supervisor Mr. Uguz about capacitive ECG signals and how to process them on MATLAB. He gave me some exercises to practice on cECG signal processing.

Kısım *Section* **Introduction to facilities**	Yaprak No **2** *Page Nr.*
Yapılan İş *Work Done* **Practice in etching room and EAGLE**	Tarih: **01.07.2019-05.07.2019** *Date*

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 2nd WEEK –

01.07.2019, Monday

A group meeting was held with other interns and my supervisor. I get the detailed information about what I will do until the end of my internship. My supervisor Mr. Uguz gave information about the subject he wanted to write an article on.

02.07.2019, Tuesday

Today we as interns get an introduction to facilities of institution and their use. The facilities were etching room, mechanics laboratory and electronics laboratory. I was told that most of my time will be spent here during the internship. In addition, my supervisor held a demo to us in etching room. He produced a power source.

03.07.2019, Wednesday

Today I learned how to use EAGLE software, which is an electronic design automation application with schematic capture and PCB layout features.

04.07.2019, Thursday

After learning how to use EAGLE software, today's task was to produce a bipolar power supply with sockets in etching room. But first the design on EAGLE should be examined.

05.07.2019, Friday

After producing PCB in etching room, today's task was to solder the components and vias on PCB. Naturally, tests were also performed.

Kısım **First prototype** *Sectıon*	Yaprak No **3** *Page Nr.*
Yapılan İş **Design and Production** *Work Done*	Tarih: **08.07.2019-12.07.2019** *Date*

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 3rd WEEK –

08.07.2019, Monday

A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week. Later on, I reviewed some articles about ballistocardiograph signals and its measurement systems.

09.07.2019, Tuesday

I started to work on the first prototype of a ballistocardiographic measuring system prototype. A sensing unit with force resistive sensor on top of it and a main board to measure the resistor values should be produced. But, first the working principles of square force resistive sensors should be understood.

10.07.2019, Wednesday

I made some calibration measurements on the force resistive sensor in order to determine the values of the circuit elements I will use on my sensing unit. After deciding on the values, I started to design the sensing unit on EAGLE software.

11.07.2019, Thursday

The design of the main board was made. The main board feeds the sensing unit and receives the generated signal from the sensor. After a conversion the signal values are transferred with digital analog converter to the computer. The designed circuits are produced using the etching room.

12.07.2019, Friday

The soldering and testing of the fabricated circuits are done.

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 4th WEEK –

15.07.2019, Monday

Today I learned how to use data acquisition module (NI USB 6259). A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week.

16.07.2019, Tuesday

I write a MATLAB script to convert the measured voltage levels to appropriate pressure levels.

17.07.2019, Wednesday

First measurements were taken using the instruments produced.

18.07.2019, Thursday

Measurements continued. I also thought about what inferences I could make from the data I obtained. To do that comparisons were made between BCG and ECG signals using the manufactured instruments and the existing cECG instruments.

19.07.2019, Friday

Some optimizations were made. I had a meeting with my supervisor Mr. Uguz. We were not satisfied with the results of the designed sensing unit. So it is decided to use a different measurement topology including FSR sensors for BCG signals.

Kısım **SENSING UNIT WITH PVDF FILMS** *Sectıon*	Yaprak No **5** *Page Nr.*
Yapılan İş **DESIGN AND PRODUCTION** *Work Done*	Tarih: **22.07.2019-26.07.2019** *Date*

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 5th WEEK –

22.07.2019, Monday

A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week. The sensing unit of the other topology (current to voltage converter) is designed using the EAGLE software.

23.07.2019, Tuesday

Today I learned some introductory information about PVDF films, like the theory behind PVDF films and how to model and use them. Some articles about signal conditioning of piezoelectric sensors were investigated.

24.07.2019, Wednesday

It is decided to use two topologies for the sensing unit with PVDF films on top of it. Topology I is called voltage mode amplifier, Topology II is called charge mode amplifier.

25.07.2019, Thursday

The corresponding designs were made using the EAGLE software.

26.07.2019, Friday

All of the designed circuits are fabricated using the etching room. After fabrication the soldering of the components on fabricated circuits is completed.

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 6th WEEK –

29.07.2019, Monday

The testing of the fabricated circuits is done. A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week. The measurement setup is installed.

30.07.2019, Tuesday

Measurements were made using the sensing units for both topologies including PVDF films.

31.07.2019, Wednesday

Measurements continued. The existing cECG instruments are introduced to me, I learned how to use them and added them to my measurement setup. From this time on, the ballistocardiograph measurements and coupling impedance measurements (designed by other trainee) were taken together at the same time.

01.08.2019, Thursday

The collected data is analyzed and the performances of two topologies are compared.

02.08.2019, Friday

Measurements using the second topology including FSR sensor were made.

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 7th WEEK –

05.08.2019, Monday

A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week. All topologies (Topology I with fsr sensor, Topology II with fsr sensor, topology I with pvdf sensor, topology II with pvdf sensor) are compared and discussed with my supervisor. It was decided to use topology II with a PVDF film (charge mode amplifier).

06.08.2019, Tuesday

Measurements were taken from different parts of the body (upper left back, lower left back, upper right back, lower right back).

07.08.2019, Wednesday

Measurements continued.

08.08.2019, Thursday

After meeting with my supervisor, it is decided to increase the number PVDF films used in the sensing unit. Related improvements were made on the sensing unit.

09.08.2019, Friday

New measurements were made after the improvements.

Kısım DATA PROCESSING *Section*	Yaprak No **8** *Page Nr.*
Yapılan İş **ANALYSIS OF MEASUREMENTS** *Work Done*	Tarih:**12.08.2019-16.08.2019** *Date*

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 8th WEEK –

12.08.2019, Monday

A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week. The measurements were processed using MATLAB.

13.08.2019, Tuesday

I have examined the data in detail and investigated which features can be extracted from the processed data on MATLAB. Some literature review is done. The similarities and differences between ECG, BCG and coupling impedance signals are researched.

14.08.2019, Wednesday

Same task as yesterday. After meeting with my supervisor, some necessary arrangements were made on MATLAB code.

15.08.2019, Thursday

The measurements were made on a different subject (the other trainee) other than me. The instrumentation for BCG signals designed by me, the existing cECG measurement instrumentation and the impedance measurement instrumentation designed by other trainee are used for measurements.

16.08.2019, Friday

The data is processed, and some average shapes of BCG signals are generated using MATLAB.

Kısım *Sectıon* **IMPROVEMENTS ON MEASUREMENTS**	Yaprak No **9** *Page Nr.*
Yapılan İş *Work Done* **DIFFERENTS PARAMETERS EXAMINED**	Tarih:**19.08.2019-23.08.2019** *Date*

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 9th WEEK –

19.08.2019, Monday

A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week. The resulting average shapes of BCG signals were examined, and conclusions drawn on the measurements. A report was created to present my conclusions to my supervisor.

20.08.2019, Tuesday

Measurements were made using different clothes and the effect of different clothes on the measurements was observed.

21.08.2019, Wednesday

Long-term measurements (5 minutes) were performed and the effect of the measurement time on the average forms was observed.

22.08.2019, Thursday

It is decided to use the ECG measurement device of Phillips (Philips Intellivue MX700 ECG monitoring device) which is used in the hospitals instead of the existing basic cECG measurement instrumentation because of the poor peak detection of basic cECG instrumentation. So new measurements were carried out with this new device.

23.08.2019, Friday

The measurements were continued with this new setup, this time measurements were made on 3 persons (me, the other trainee and my supervisor). As expected, different results were obtained from different subjects.

Kısım *Section* **NEW INSTRUMENTATION**	Yaprak No **10** *Page Nr.*
Yapılan İş *Work Done* **DESIGN AND DEBUGGING**	Tarih: **02.09.2019-06.09.2019** *Date*

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 10th WEEK –

02.09.2019, Monday

A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week. I received an introduction to SignalPlant software. Using this software, I corrected the ECG peaks, because the MATLAB algorithm sometimes fails to find the correct ECG peaks. The SignalPlant software was a manual solution.

03.09.2019, Tuesday

The final figures were generated. After meeting with my supervisor, it was decided to combine the two sensing units for impedance measurement and BCG measurement to make the system more effective. It was also decided to put the entire instrumentation in a box and fix on the back of the measurement chair. Appropriate designs are made on EAGLE software.

04.09.2019, Wednesday

The designed circuits are fabricated using the etching room. The soldering of the fabricated circuits is done.

05.09.2019, Thursday

Measurements were made using new instrumentation, but it was not successful. Debugging has begun on analog circuitry.

06.09.2019, Friday

Debugging continued, but the problem was not found. Even my supervisor had no idea about the problem we faced. It was decided to make a new design and produce it. New design started.

Kısım **LAST WEEK AND FINAL MEASUREMENTS** *Sectıon*	Yaprak No **11** *Page Nr.*
Yapılan İş **DOCUMENTATION** *Work Done*	Tarih:**09.09.2019-13.09.2019** *Date*

(Buraya sadece bu tarihte yapılan işler "günlük" olarak yazılacaktır. Yapılan işle ilgili teknik rapor ayrıca "GENEL RAPOR" kısmında verilecektir.)
(Only the daily work will be written here, as a "diary". The technical report about the complete work done, will be given separately in the "GENERAL REPORT" section.)

-- 11th WEEK –

09.09.2019, Monday

A group meeting was held with other interns and my supervisor. We told each other what we did last week and what we planned to do this week. The designed circuit is fabricated using the etching room. The soldering and testing of the fabricated circuit are done.

10.09.2019, Tuesday

Measurements were taken using the newly produced main board and sensing unit.

11.09.2019, Wednesday

Documentation of the work carried out. The MATLAB files and eagle files are commented and checked.

12.09.2019, Thursday

Written report

13.09.2019, Friday

Today was the last day of my internship so I prepared a small presentation to the my supervisor about what I did during my internship at Medical Information Technology at Helmholtz Institute for Biomedical Engineering. I had my papers signed and said goodbye to the colleagues.

Main Area of Business of MedIT

Medical Information Technology (MedIT) is a company that creates an active connection of interdisciplinary basic research, application-oriented research and development in the field of biomedical engineering. MedIT co-operates with international companies, hospitals and governmental organizations in their projects. Their project partners include Philips, German Research Foundation, RWTH Aachen University Hospital, Ford, BMBF and DAAD. The common intention of all initiated projects, activities and tasks is the invention and development of new biomedical technologies. The application of new methods should contribute to the best possible medical therapy of patients and their rehabilitation.

Some of the ongoing research projects can be listed as:
- Impedance controlled surgical instrumentation
- Aided heart assistance for optimal treatment of heart failure patients
- Capacitive ECG
- Non-contact breathing and pulse measurement
- Ballistocardiographs
- Patient customized pulmonary model for congestive heart failure

a) ECG recording by means of a car seat

b) An early prototype of a single-channel sensor that can be used for the monitoring of the heart activity

Figure 1: Demonstrations from some of MedIT's research projects

Brief History of the Company

- **2003** Foundation of the Philips Chair for Medical Information Technology (MedIT)
- **2003** Appointment of Prof. Leonhardt
- **2007** Organisation of the 4thBody Sensor Networks (BSN)Conference in Aachen (BSN 2007,March 27th - 28th, 2007, 200 participants)
- **2007** Organisation of the 41st annual conference of Deutsche Gesellschaft für Biomedizinische Technik (DGBMT in VDE) by the Helmholtz - Institute (BMT 2007, 26th - 29th September 2007, ca. 700 participants)
- **2009** Leasing of external laboratory spaces in a container building close to the Helmholtz Institute
- **2010** Prof. Leonhardt on sabbatical at Imperial College London, UK
- **2011** Visiting professor Prof. Tarun Singh from the University of Buffalo, NY, USA
- **2011** Visiting professor Prof. Dr. Kumar, IITM, Chennai, Indien
- **2012** Leasing of office space in Schurzelter Str. 570
- **2012** Organisation of the 10th AUTOMED Conference (AUTOMED2012, 29th and 30thMarch 2012) VDE
- **2014** Visiting professor Prof. Jaakko Malmivuo (Theodore von Kármán Fellow)
- **2015** Organisation of the 11th German Russian Conference (formerly Russian Bavarian Conference) on Biomedical Engineering (17th - 19th June 2015, Aachen, 70 Participants)

If I wanted to put together the topic I was working on during my internship, it would be: **Development of a dorsoventral ballistocardiographic measurement system to detect ballistocardiographic impedance distortions in capacitive ECG.**

Theory and Model

1. Capacitive ECG

Capacitive ECG (cECG) measurement which can be proceeded without contacting the skin, even through layers of different materials, is a strong alternative to classical ECG measurement. cECG electrodes cover different types and topologies which perform their coupling between the body and the rest of the instrumentation capacitively that enables noncontact patient monitoring. Noncontact patient monitoring can be used in various applications such as implementation to car seats for monitoring the driver's condition continuously. The activity of the heart causes charge movements on the surface of the human body, those movements affects the charge distribution on an electrode within a small distance from the body. Conductive electrodes need a contact gel as a conductive contact to the body surface to measure the potential between the two electrodes which is mainly resistive behaviour however the contact gel dehydrates and reduces the quality of the signals with time. On the other hand, capacitive electrodes, isolated by a very thin lacquer coating with high surface resistance, need no leading contact to the body. Each electrode forms a coupling capacitance (C) with the patient's body, which can be expressed as:

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d(t)}$$

where A is the effective surface area of the electrode, d is the thickness of the cloth, ε_r is the dielectric constant of the cloth, and ε_0 is the vacuum permittivity.

As one can see in Equation, the thickness(d) varies with time which makes the coupling capacitance(C) time-variant. The variation of the thickness with time is due to the body's own physiological vibrations.

2. Ballistocardiography (BCG)

Ballistocardiography (BCG) is the noninvasive measurement of human body's mechanical vibrations caused by the cardiac and respiratory activity, according to the conservation of the momentum. BCG can be monitored by capturing different physical quantities like displacement, acceleration or velocity. Therefore, BCG is the complex integration of different mechanical interactions related to the heart's contraction and the movement of the blood. Different sensor techniques and measurement positions led to different naming of the same phenomenon such as seismocardiogram, apexcardiogram, kinetocardiogram. Unlike electrocardiogram, BCG is not the monitoring of a single source but the measurement of the superposition of mechanical waves. Therefore, it is influenced by several cardiovascular parameters like the strength of the myocardial contraction. The location and the orientation of the BCG sensor plays a crucial role in the signal shape since the vibrations in dorsoventral direction are not identical to the ones in the longitudinal axis. Even in the same sitting position, the influence of the body orientation on the distribution of the hydrostatic pressure of the circulatory system with respect to the gravity can alter BCG amplitude and features.

Motivation

In cECG, the high impedance of the coupling between the body and the analog instrumentation converts the existence of triboelectric surface charges into a dire problem by slowing down their discharge, thus prolonging their influence. Moreover, even the smaller mismatches between the electrode impedances are reflected tremendously on the common-mode rejection of the analog instrumentation as the impedance range of the electrodes becomes closer the input impedance of the instrumentation. Aside from the electrode impedance mismatch, the variations in the coupling impedance were shown to cause motion artifacts.

In our research, it is hypothesized that the human body's physiological vibrations (BCG) can influence the coupling impedance, by distorting the thickness of the subject's clothing. The nature of ballistocardiographic pressure waveforms on cECG and their relation to time varying coupling capacitance is investigated.

My supervisor, I and another intern worked on this project. The supervisor Mr. Uguz led us always. My task was to develop the BCG measurement system. The other trainee's task was to develop an impedance measurement system. In the end, we integrated our measurement systems and observed the relation between the ECG signals and time-variant coupling impedance.

cECG Model

For a single electrode, the electric circuit model can be simplified as in Fig.2, where $R_{coupling}$ and $C_{coupling}$ stand for coupling impedance in the body-sensor interface, in this scenario the clothing of the subject. R_{in} and C_{in} are the input impedance of the active electrode, where Rin is the equivalent resistance for the input resistance of the amplifier and input bias resistor. The signal sources V_{ecg} and V_{tribo} describe the ECG signal and triboelectric surface charges accumulated due to the friction. V_{tribo} is assumed to be DC static charges.

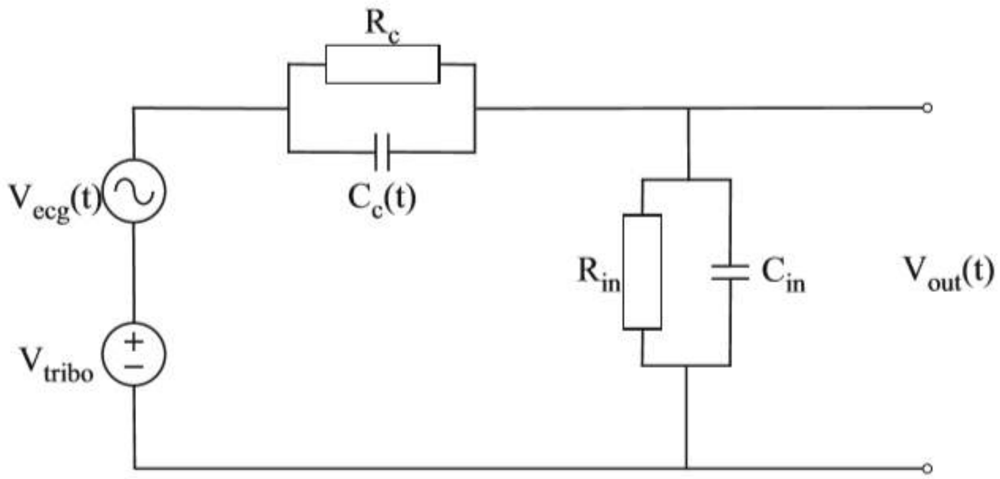


Figure 2 Simplified circuit model for the metal surface cECG electrode, assuming a time-variant coupling capacitance in the body sensor

The mathematical expression for the behaviour of the system can be given as:

$$(C_{\text{in}} + C_{\text{c}}(t))\frac{\mathrm{d}V_{\text{out}}}{\mathrm{d}t} + (\frac{1}{R_{\text{in}}} + \frac{1}{R_{\text{c}}} + \frac{\mathrm{d}C_{\text{c}}(t)}{\mathrm{d}t})V_{\text{out}} = C_{\text{c}}(t)\frac{\mathrm{d}V_{\text{ecg}}}{\mathrm{d}t} + (V_{\text{tribo}} + V_{\text{ecg}})(\frac{1}{R_{\text{c}}} + \frac{\mathrm{d}C_{\text{c}}(t)}{\mathrm{d}t})$$

There are some assumptions that can be made to simplify the equation above. First assumption is that R_c and R_{in} are much greater than their corresponding parallel branch impedances in the frequency range of the signal of interest. V_{tribo} can be investigated separately using the principle of superposition since it can be assumed independent from the signals of V_{ecg} and C_c. So, the equation above becomes:

$$(C_{in} + C_c(t))\frac{dV_{out}}{dt} + \frac{dC_c(t)}{dt}(V_{out} - V_{tribo}) = C_c(t)\frac{dV_{ecg}(t)}{dt} + V_{ecg}\frac{dC_c(t)}{dt}$$

As one can deduce from the equation above, the nonidealities are introduced by both the triboelectric potential and the time-variant coupling capacitance. However, the coupling capacitance can be correlated to the ECG signals since it can be introduced by the physical movement of the body-sensor interface which is caused by the heart's motions in other words ballistocardiographic pressure waveforms. This impact is going to be investigated and whether ballistocardiographic vibrations are the cause of the variations in the coupling capacitance can only be tested by the simultaneous measurement of those two. In other words, the developed measurement systems for ballistocardiographic vibrations (designed and developed from me) and for coupling capacitance (designed and developed from the other trainee) should be integrated into a one single system in the end of the project. Any correlation between the ballistocardiographic vibrations and coupling capacitance variations would indicate a correlation between the signal of interest and the cause of the artifact.

DESIGN OF THE BCG MEASUREMENT SYSTEM

The design of the BCG measurement system was completed unit by unit after determining the structure and the working principles of the overall circuitry. The system consists of two main parts: the sensing unit and the main board which contains two sub modules, namely the filtering module and a voltage supply unit.

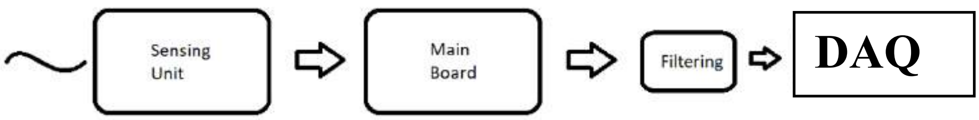


Figure 3: Overall block diagram of the BCG measurement system

Voltage Supply Unit

A simple voltage supply unit was designed to feed the main board and the sensing unit which work with 12V/-12V. The design consists of a regulator (LM7805) to maintain constant voltage level(5V) and a DC/DC converter (Murata MEJ25 series) to obtain 12V/-12V. A heat sink was utilized together with the regulator to distribute the heat in a larger space and avoid problems caused by overheating. Moreover, as one can see in Figure 5 additional ground plane were added to the circuit board in order to distribute the heat further.

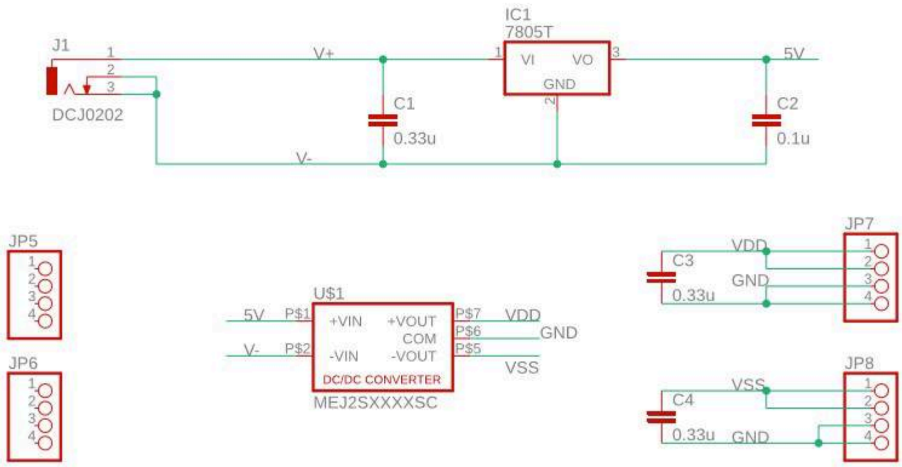


Figure 4: Demonstration of the circuit schematic of the voltage supply unit on the Eagle Design Environment

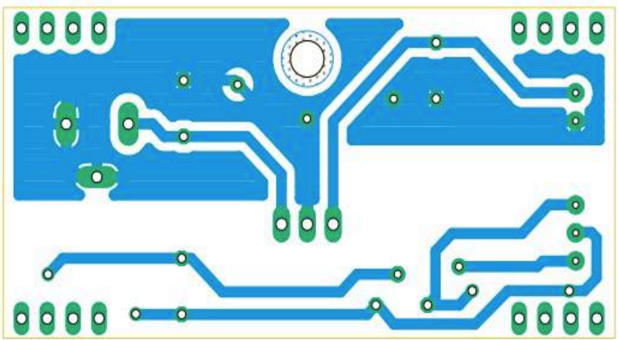


Figure 5.a: Bottom layer of the voltage supply unit

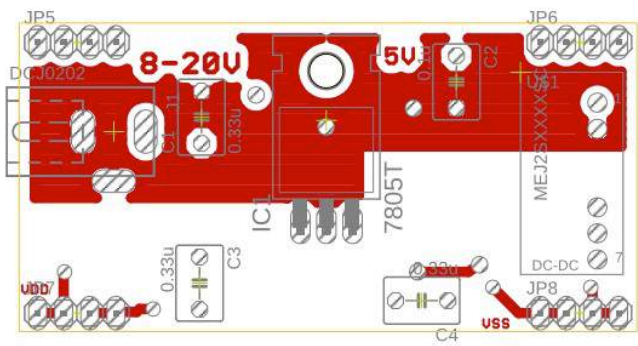


Figure 5.b: Upper layer of the voltage supply unit

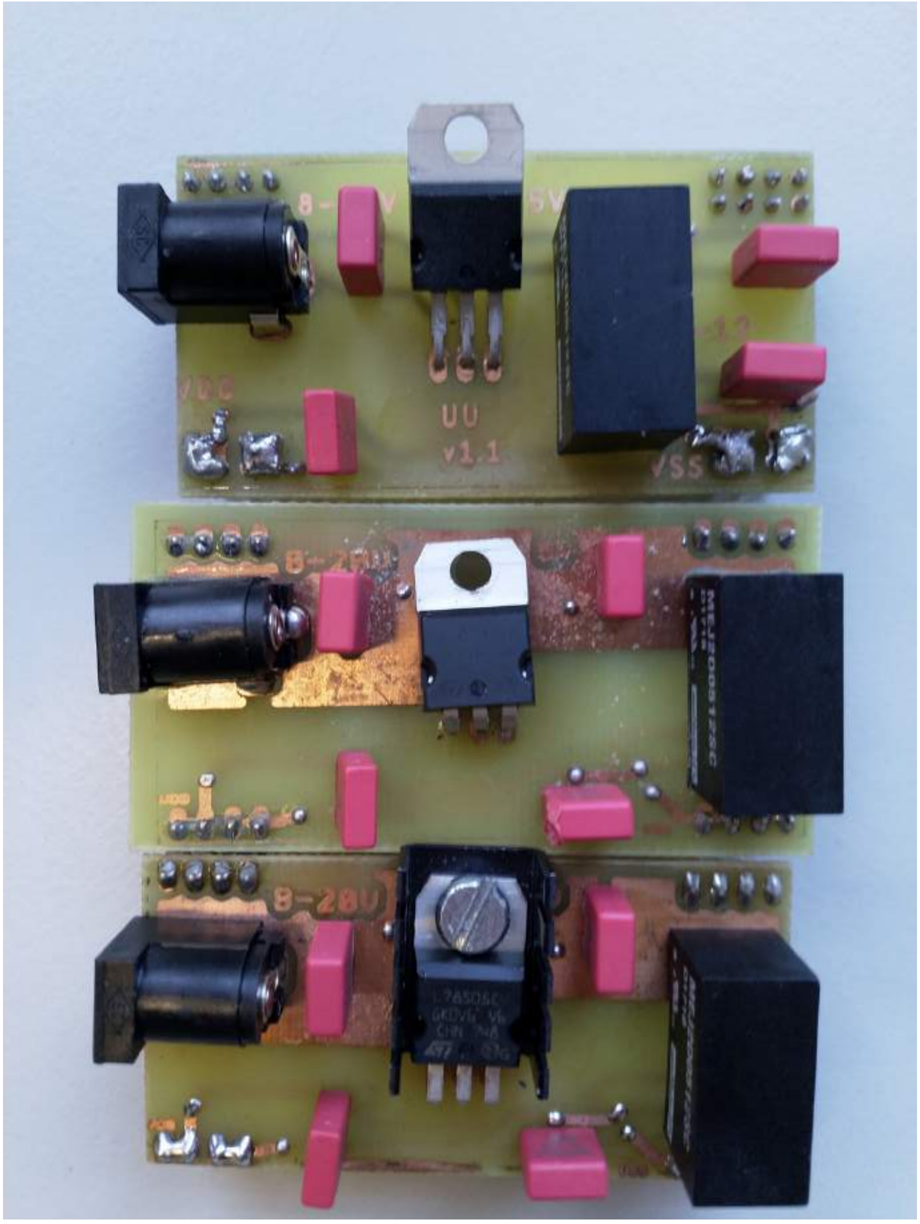


Figure 6: Produced bipolar supply power sources with sockets

TOPOLOGY I with FSR sensor

The first prototype for BCG measurement system contains a force sensitive resistor and an appropriate main board to feed the sensor. FSRs are two-wire devices with a resistance that depends on applied force. For a simple force-to-voltage conversion, the FSR device is tied to a measuring resistor in a voltage divider configuration (Figure 7). The output is described by the equation:

$$V_{OUT} = \frac{R_M V+}{(R_M + R_{FSR})}$$

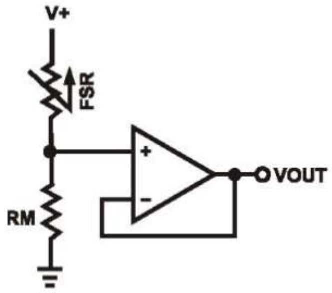


Figure 7: Voltage divider configuration

In the configuration shown in Figure 7, the output voltage increases with increasing force. If R_{fsr} and R_m are swapped, the output swing will decrease with increasing force. The measuring resistor, R_m, is chosen to maximize the desired force sensitivity range and to limit current. Depending on the impedance requirements of the measuring circuit, the voltage divider could be followed by an op-amp.

A family of force vs. V_{out} curves is shown on the figure 8 for a standard FSR in a voltage divider configuration with various R_m resistors.

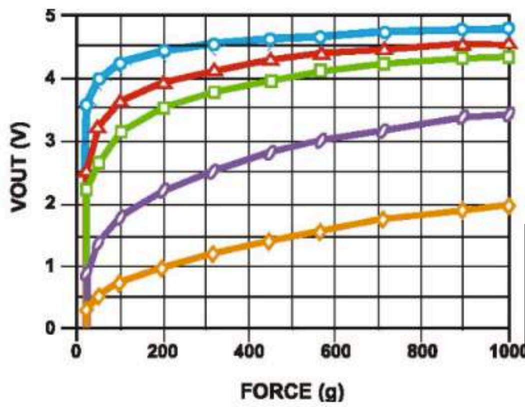
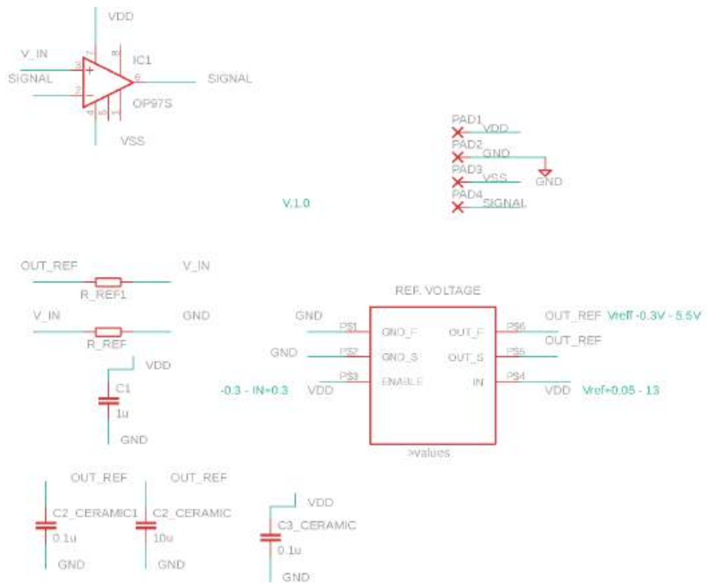


Figure 8: Force vs. V_{out} for voltage divider configuration

In my design it is decided to use 10kΩ for R_M, because the force range of the purple curve is similar to the force exerted on the sensor.



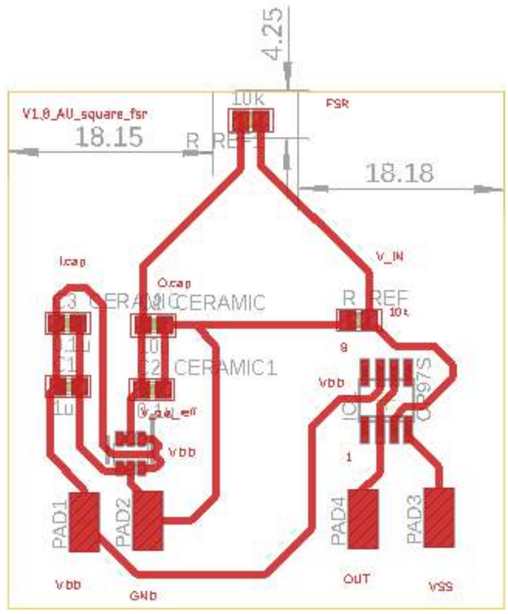
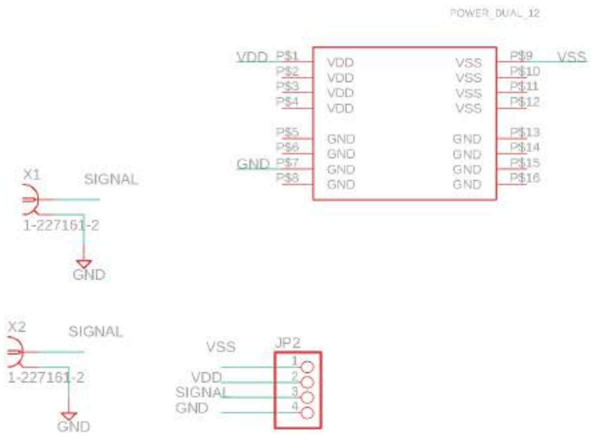


Figure 9.a: Demonstration of the circuit schematic of the Topology I fsr sensing unit on the Eagle Design Environment

Figure 9.b: Upper layer of the Topology I fsr sensing unit



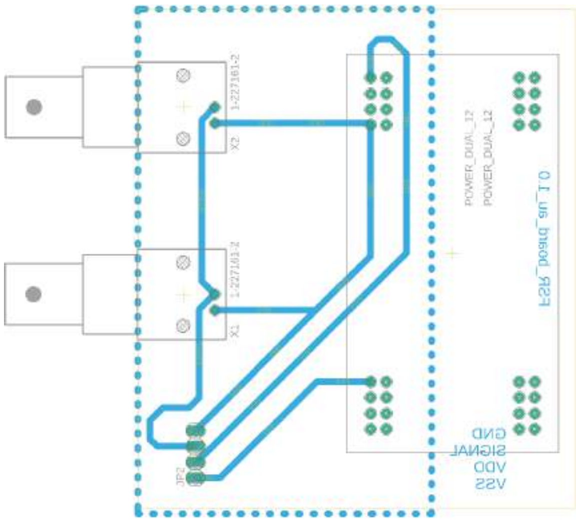


Figure 10.a: Demonstration of the circuit schematic of main board for the Topology I fsr on the Eagle Design Environment

Figure 10.b: Lower layer of the main board for the Topology I fsr sensing unit

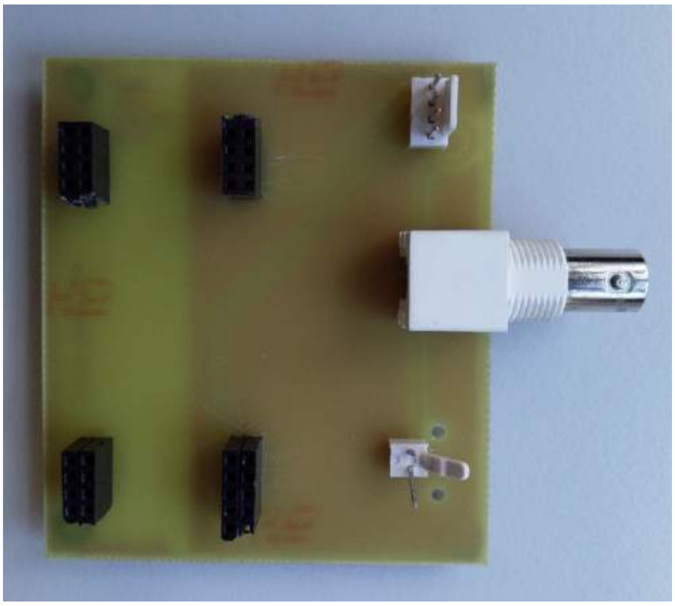


Figure 11.a: Lower layer of the Topology I main board. This main board is also used for main board of Topology II fsr sensing unit

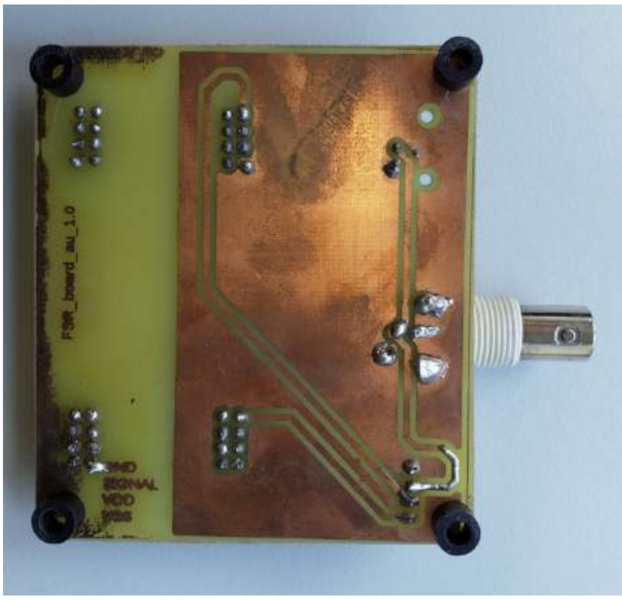


Figure 11.b: Lower layer of the Topology I main board. This main board is also used for main board of Topology II fsr sensing unit

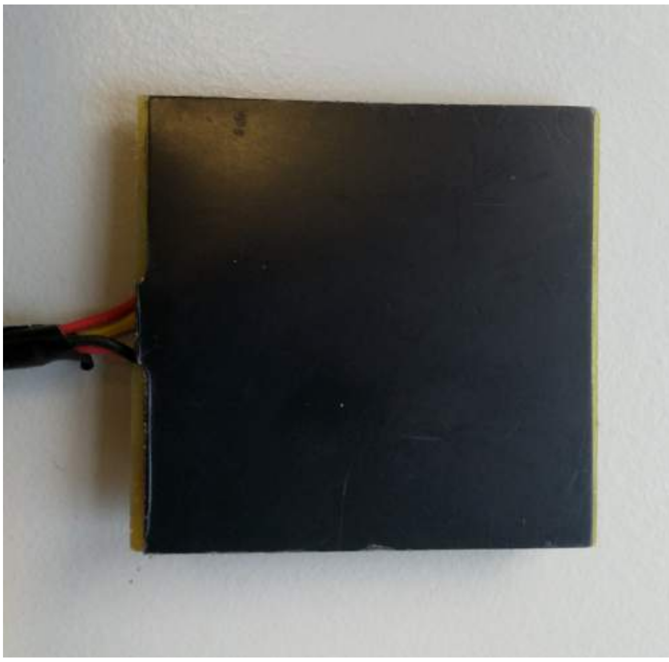


Figure 12.a: Lower layer of the Topology I fsr sensing unit. The black item is the force sensitive resistor.

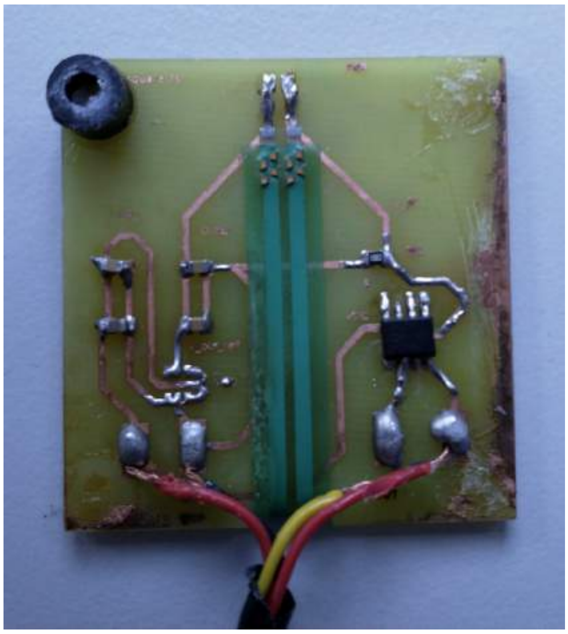


Figure 12.b: Upper layer of the Topology I fsr sensing unit.

TOPOLOGY II with FSR sensor

The second prototype for BCG measurement system contains a force sensitive resistor and an appropriate main board to feed the sensor. FSRs are two-wire devices with a resistance that depends on applied force. For a simple force-to-voltage conversion, the FSR device is tied to a measuring resistor in a current to voltage converter configuration (Figure 4).

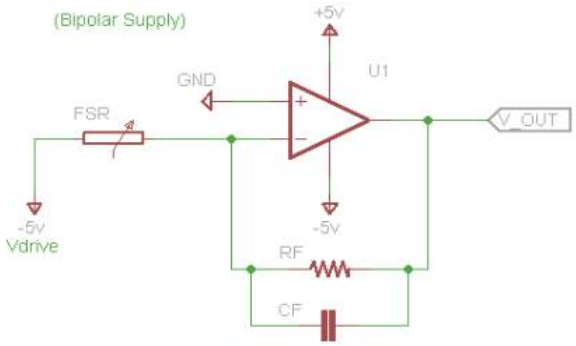


Figure 13: Current to Voltage Converter

A current-to-voltage converter, or transimpedance amplifier, exhibits a somewhat more uniform / ideal transfer function than voltage dividers. Unlike a divider, a transimpedance amp can allow a fixed voltage to be applied across a single FSR element, regardless of other parallel FSRs / resistances. Applying ideal op-amp assumptions to the example circuit above, the voltage across the input terminals is zero, so VIN- = 0v (virtual ground). Zero current flows in/out of the input terminals, so IRF = IFSR. From there, calculations are straightforward, and VOUT is given by:

$$V_{OUT} = \frac{-V_{DRIVE}}{R_{FSR}} \times R_F$$

The output swings from 0v to 12v in my design.

A feedback capacitor (C_F) is optionally used to limit bandwidth and maintain stability. For the sake of experimentation, 10pF to 33pF is often a good starting point.

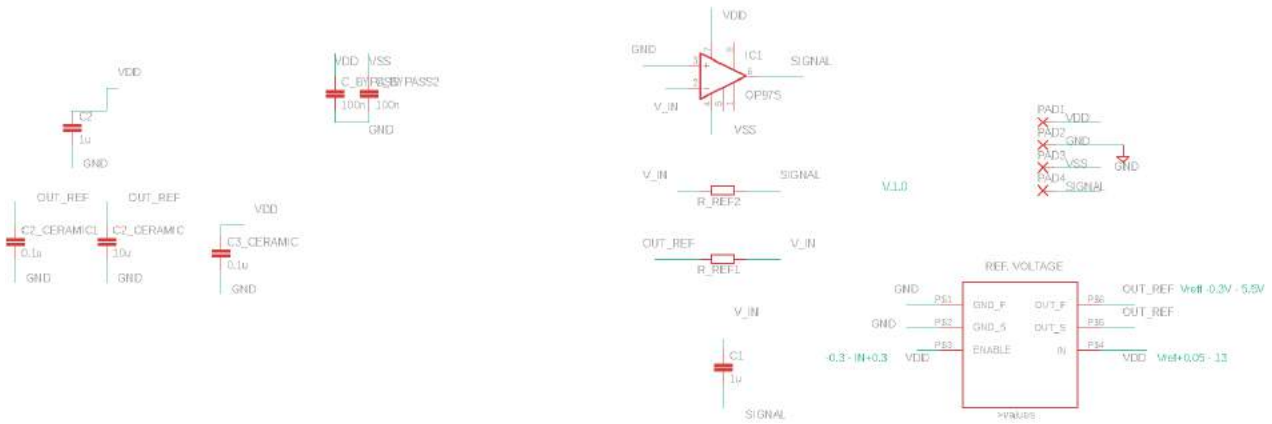


Figure 14.a: Demonstration of the circuit schematic of the Topology II fsr sensing unit on the Eagle Design Environment

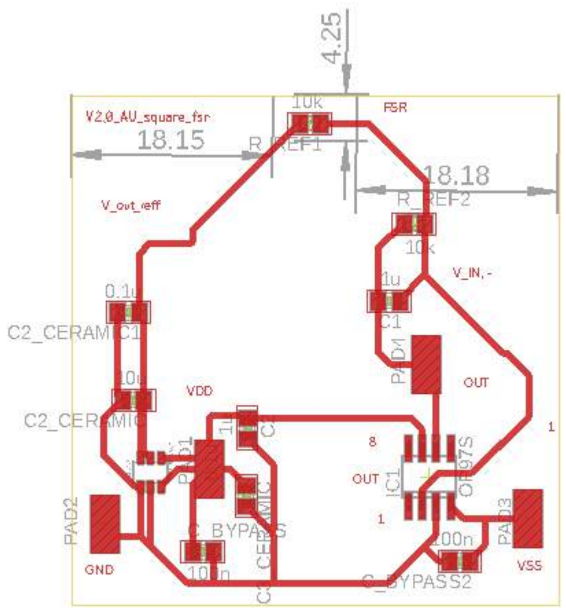


Figure 14.b: Upper layer of the Topology II fsr sensing unit

The same main board is used as the one produced for Topology I fsr sensing unit for measurements including Topology II fsr sensing unit.

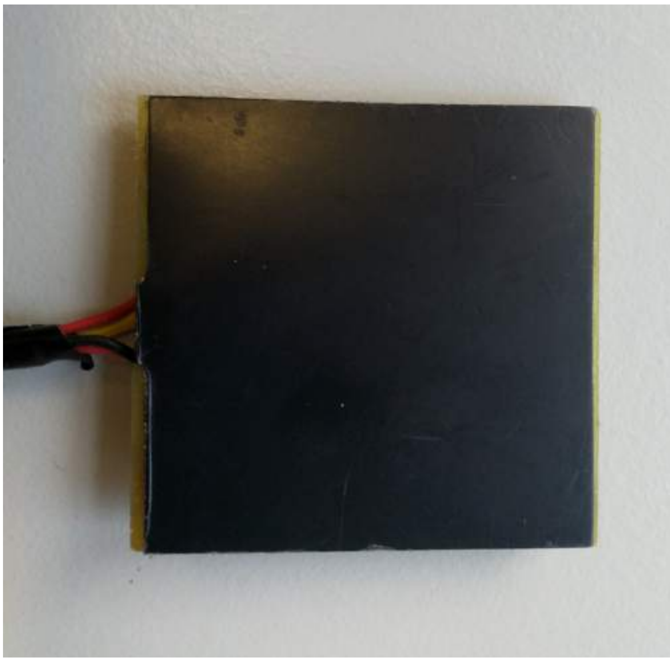


Figure 15.a: Lower layer of the Topology II fsr sensing unit. The black item on top of PCB is force sensing resistor.

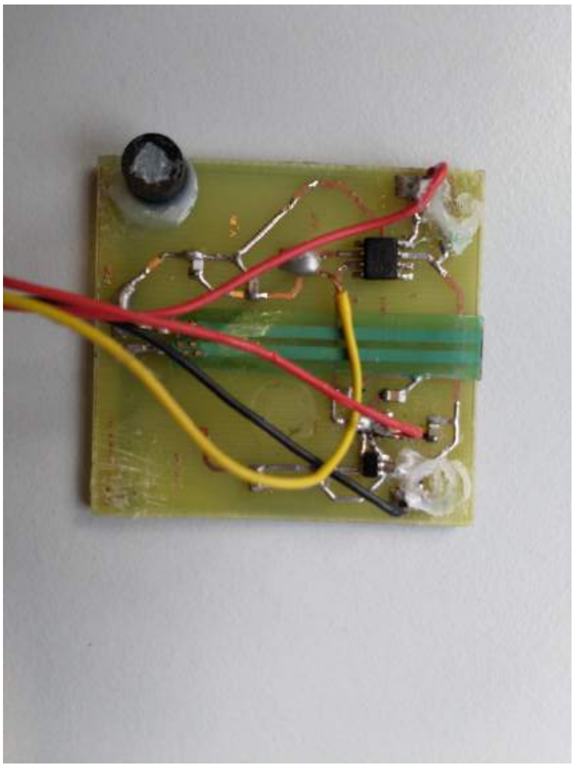


Figure 15.b: Upper layer of the Topology II fsr sensing unit. The four cables (2 red cables, 1 black cable, 1 yellow cable) stand for ground, positive feed voltage, negative feed voltage and output voltage. The green cable provides connection to force sensing resistor.

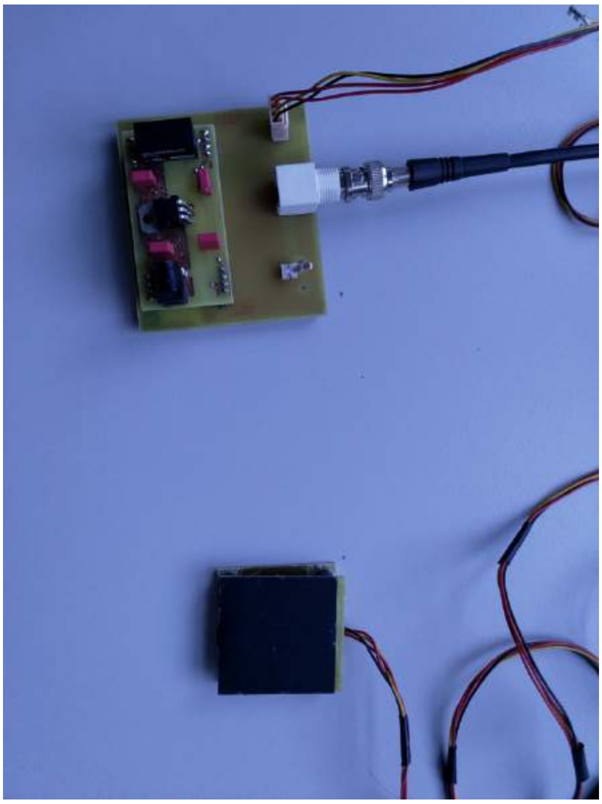


Figure 16: Measurement setup using produced main board, sensing unit and power source.

TOPOLOGIES WITH PVDF SENSORS

After realizing that the measurements made with force sensitive resistors are unsatisfactory, the measurement of BCG signals is realized using polyvinylidene fluoride (PVDF) films which are piezoelectric elements that generate electrical polarity when subjected to mechanical stress. PVDF films create an electrical potential in correlation with the pressure and the vibration exerted on them. Although they deliver a substantial SNR and are already used in several vibration detection applications, they cannot be used to measure static loads. Among the commercial options, LDT1-028K (TE Connectivity Ltd., Schaffhausen, Switzerland) is chosen for its smaller sensitive area (41mm X 12mm), laminated to be used for a longer time in direct impact sensing mode.

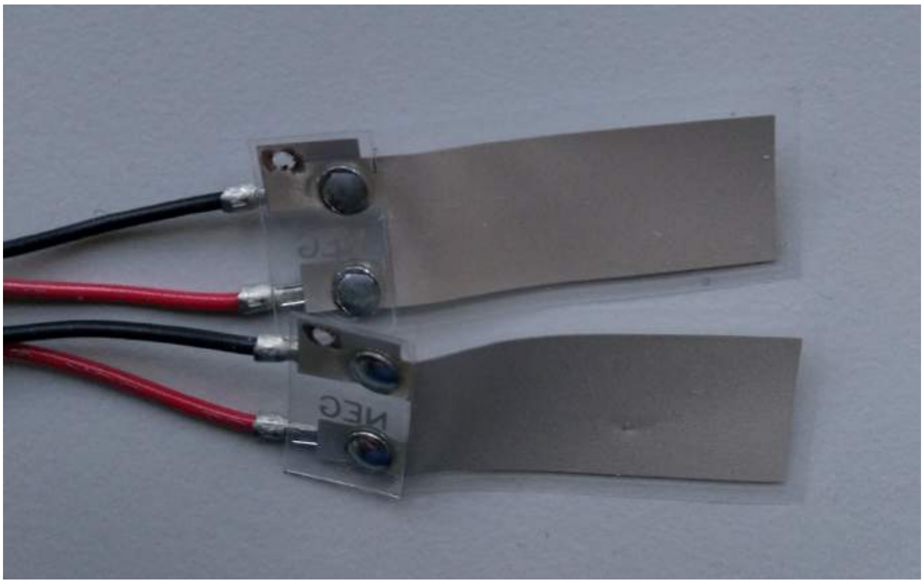


Figure 17: The PVDF films used in measurements: LDT1-028K

Two circuits are used for signal conditioning of PVDF films: voltage mode amplifier circuit and charge mode amplifier circuit. Voltage mode amplification is used when the amplifier is very close to the sensor. Charge mode amplification is used when the amplifier is remote to the sensor. The both topologies are tested, and, in the end, it is decided to use charge mode amplifier topology in the analog front-end design of the sensor.

TOPOLOGY I: Voltage Mode Amplifier Circuit

In a voltage mode amplifier, the output depends on the amount of capacitance seen by the sensor. The capacitance associated with the interface cable will affect the output voltage. If the cable is moved or replaced, variations in C_c can cause problems.

Resistor R_b provides a dc bias path for the amplifier input stage. Choice of R_f and C_f sets the upper cut-off frequency.

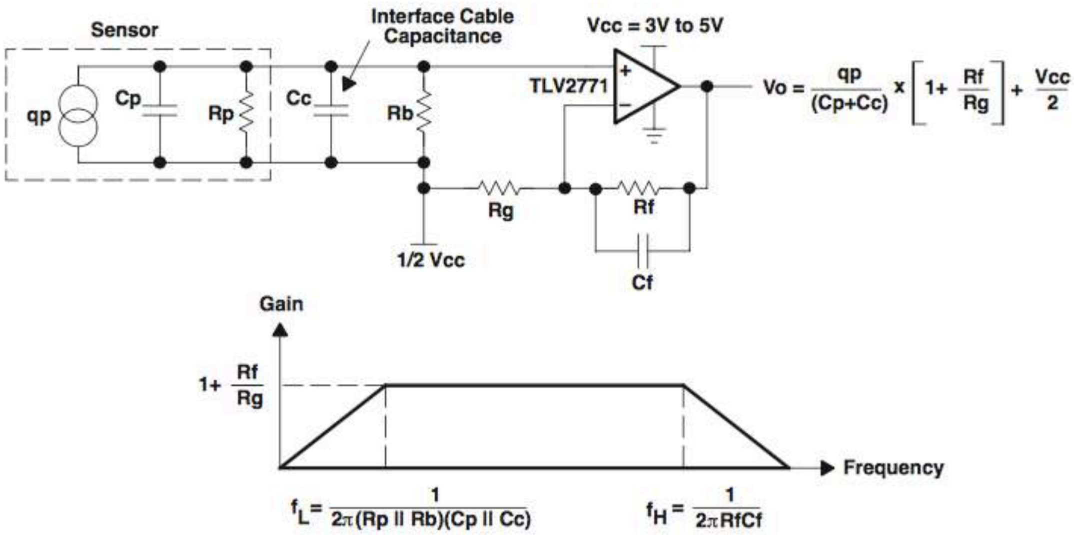
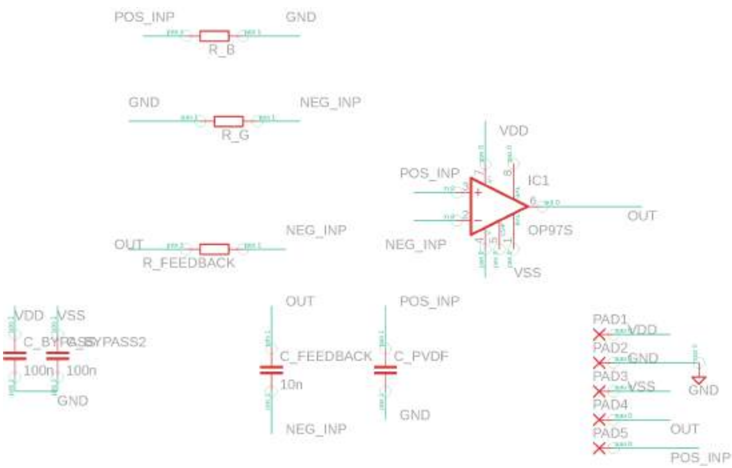


Figure 18: Voltage mode amplifier circuit



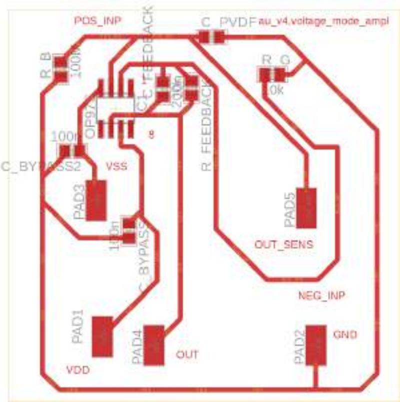
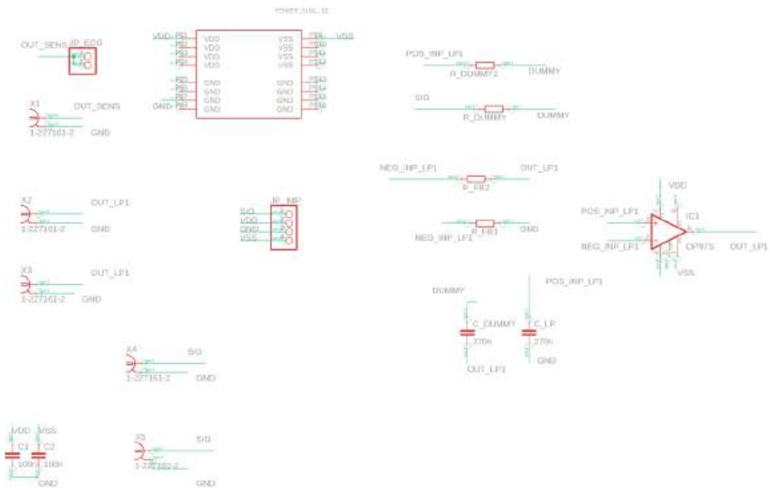


Figure 19.a: Demonstration of the circuit schematic of the Topology I: voltage mode amplifier circuit on the Eagle Design Environment

Figure 19.b: Upper layer of the Topology I: voltage mode amplifier circuit

Figure 20: Produced sensing unit which has pvdf film on top of it



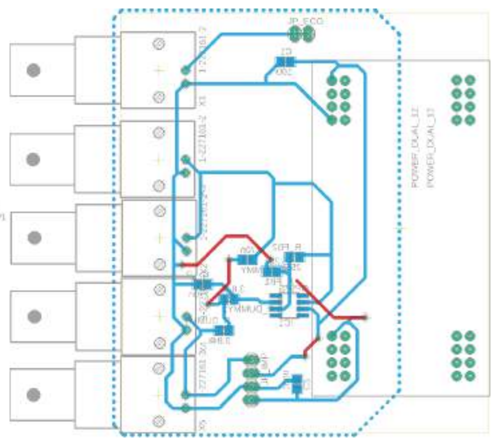


Figure 21.a: Demonstration of the circuit schematic of the main board for the sensing units on the Eagle Design Environment

Figure 21.b: Upper and lower layer of the main board for the sensing units with PVDF films

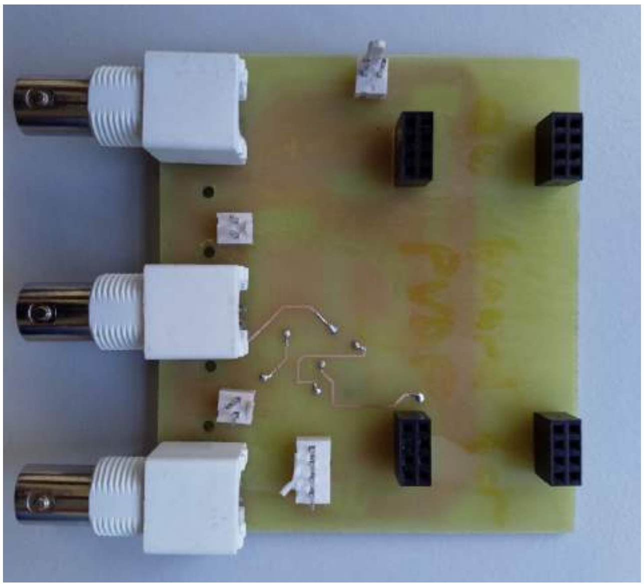


Figure 22.a: Upper layer of the produced main board

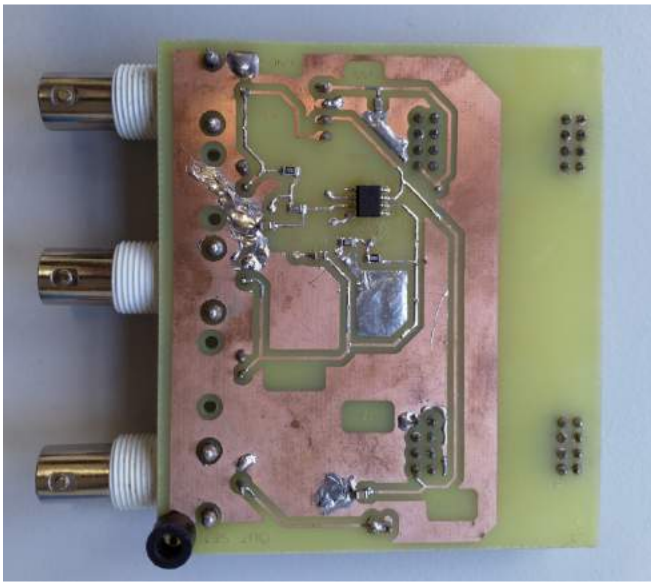


Figure 22.b: Lower layer of the produced main board

TOPOLOGY II: Charge mode amplifier

The charge mode amplifier will balance the charge injected into the negative input by charging feedback capacitor C_f. Resistor R_f bleeds the charge off capacitor C_f at a low rate to prevent the amplifier from drifting into saturation. Resistor R_f also provides a dc bias path for the negative input. The value of R_f and C_f set the low cut-off frequency of the amplifier.

The action of the amplifier maintains 0 V across its input terminals so that the stray capacitance associated with interface cabling does not present a problem. Resistor R_i provides ESD protection. Resistor R_i and capacitors C_p and C_c combine to produce roll off at higher frequency.

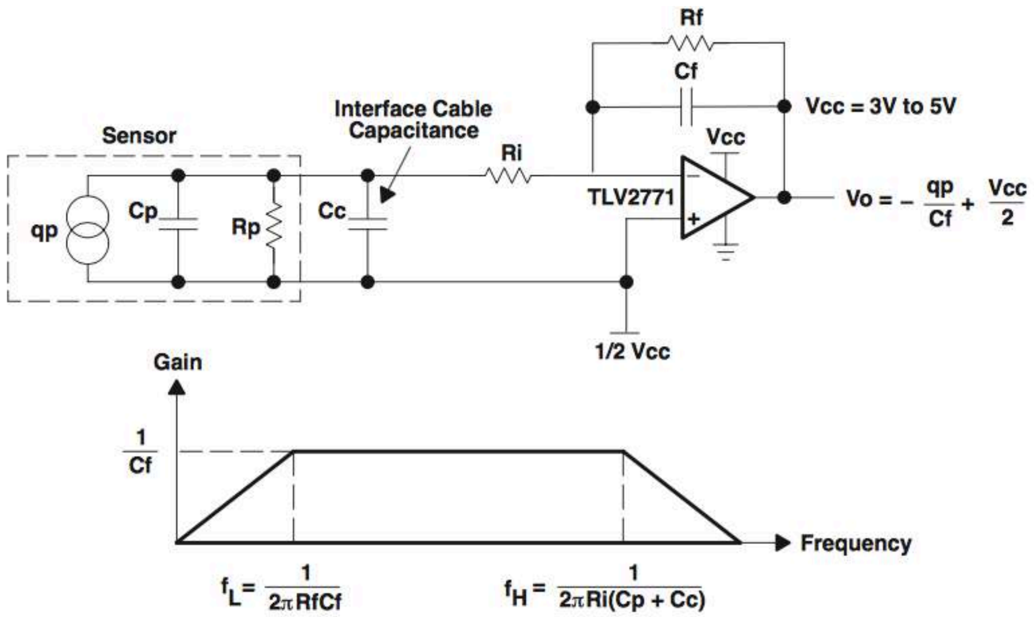
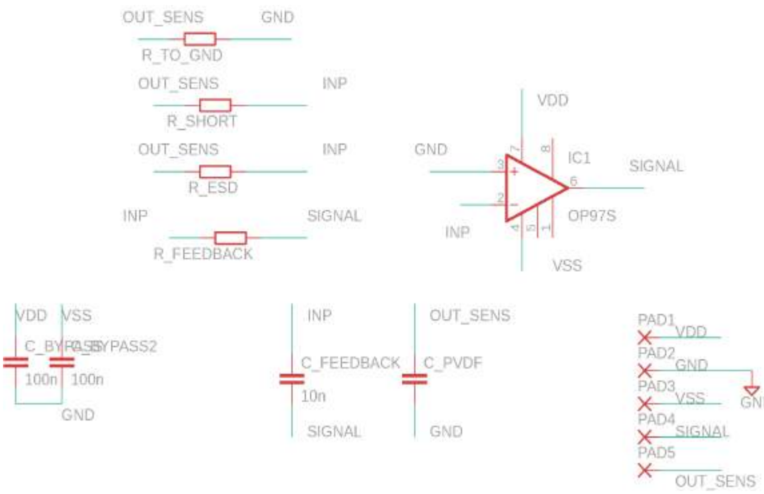


Figure 23: Charge mode amplifier circuit



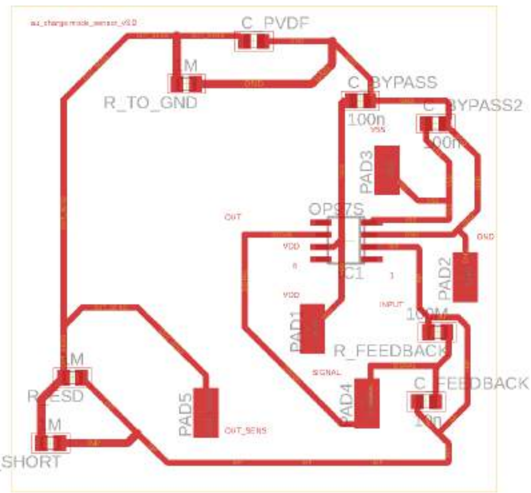


Figure 24.a: Demonstration of the circuit schematic of the Topology II charge mode amplifier sensing unit on the Eagle Design

Figure 24.b: Upper layer of the charge mode amplifier sensing unit

The values of the components R_i, R_f and C_f are chosen as 1MΩ, 100MΩ and 10 nF, respectively. These values would give a passband between 0.16 Hz to 115 Hz. The output of the sensor is further filtered and amplified before sampled with a sampling rate of 200 kHz using NI USB-6259-DAQ.

INTEGRATION OF BCG MEASUREMENT SETUP AND IMPEDANCE MEASUREMENT SETUP

Towards the end of my internship it was decided to combine the two measurement systems. I completed the designs for this, but we did not have enough time to take regular measurements with the designed system. So in this section, I will give the designs I made in order to combine the two systems, but my results will not be based on measurements made with this combined system.

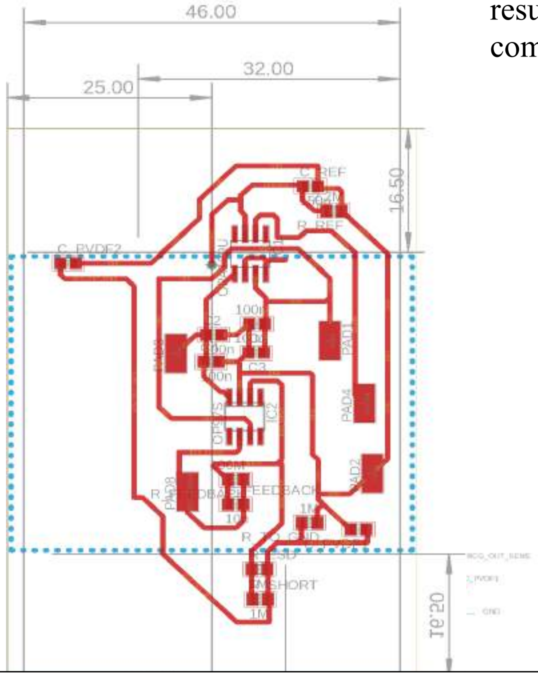


Figure 25.a: Upper layer of the integrated sensing unit

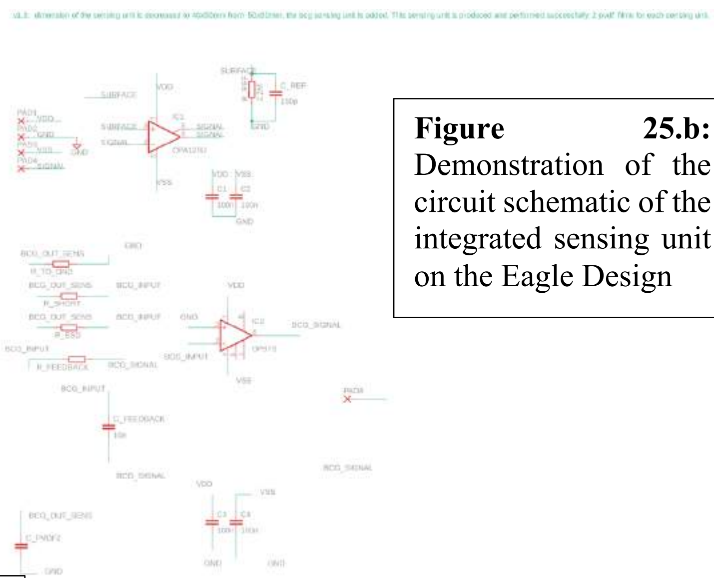
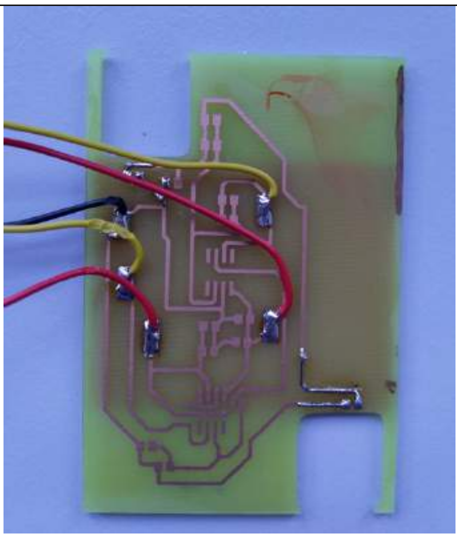


Figure 25.b: Demonstration of the circuit schematic of the integrated sensing unit on the Eagle Design



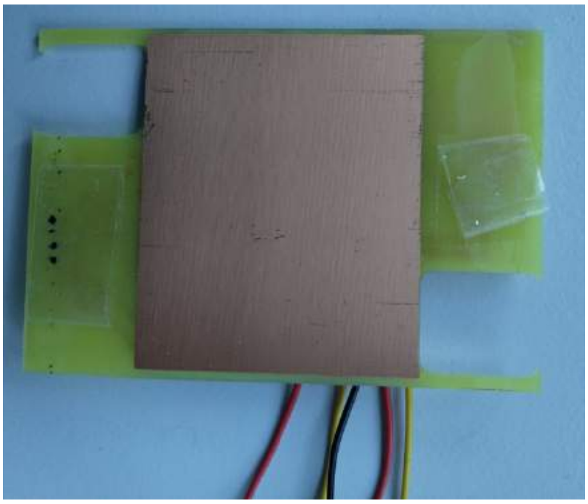


Figure 26: Produced sensing unit upper and lower layers

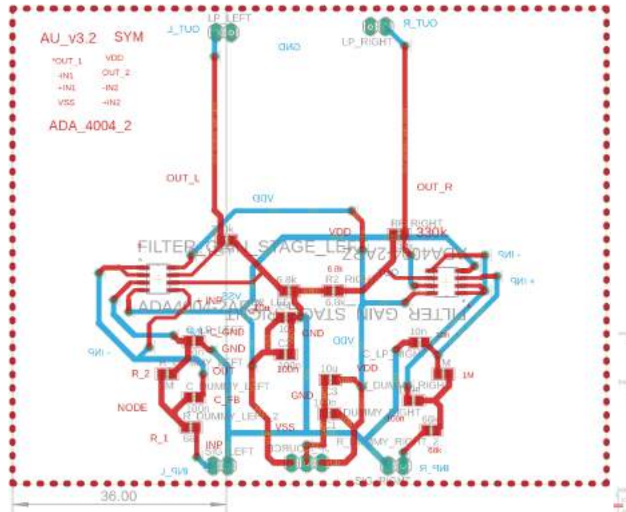


Figure 27.a: Upper and lower layer of the main board

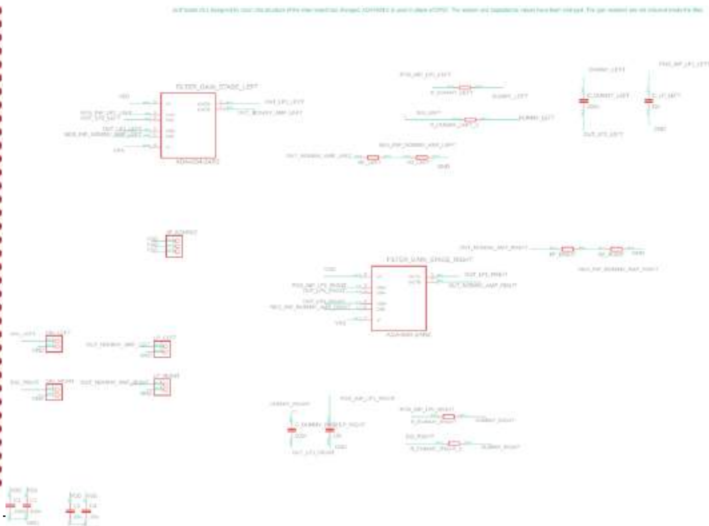
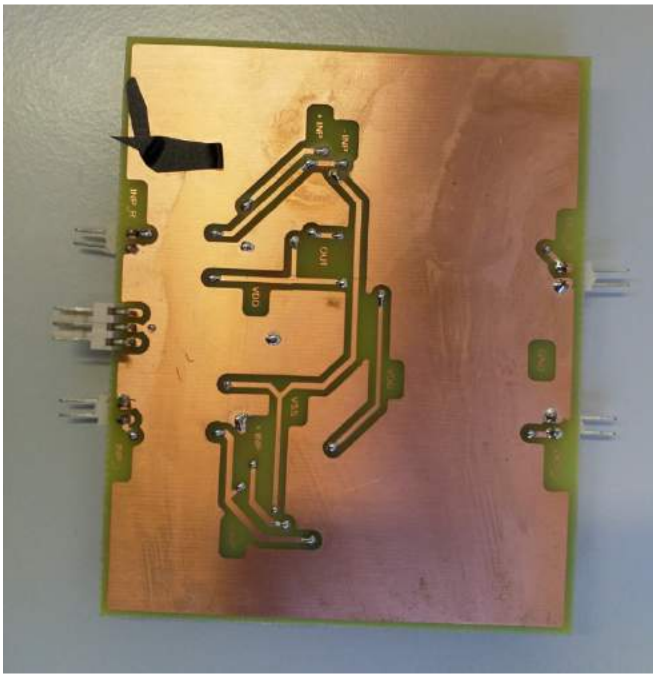


Figure 27.b: Demonstration of the circuit schematic of the main board on the Eagle Design



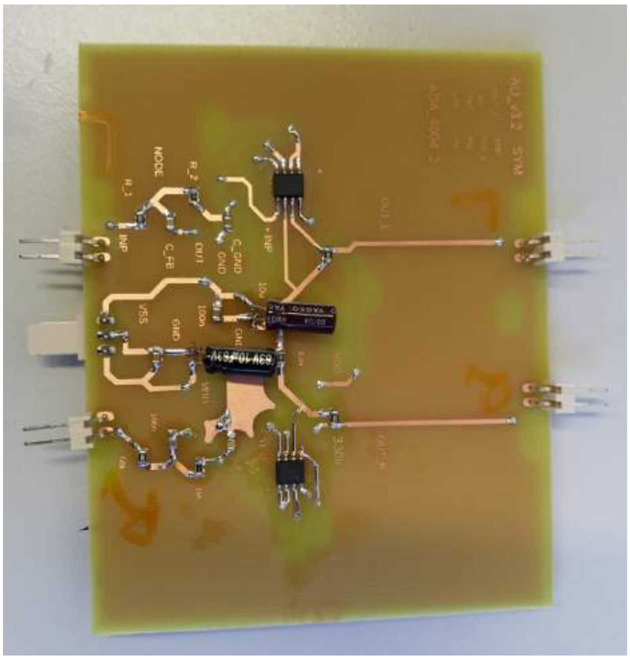


Figure 28: Produced main board upper and lower layers

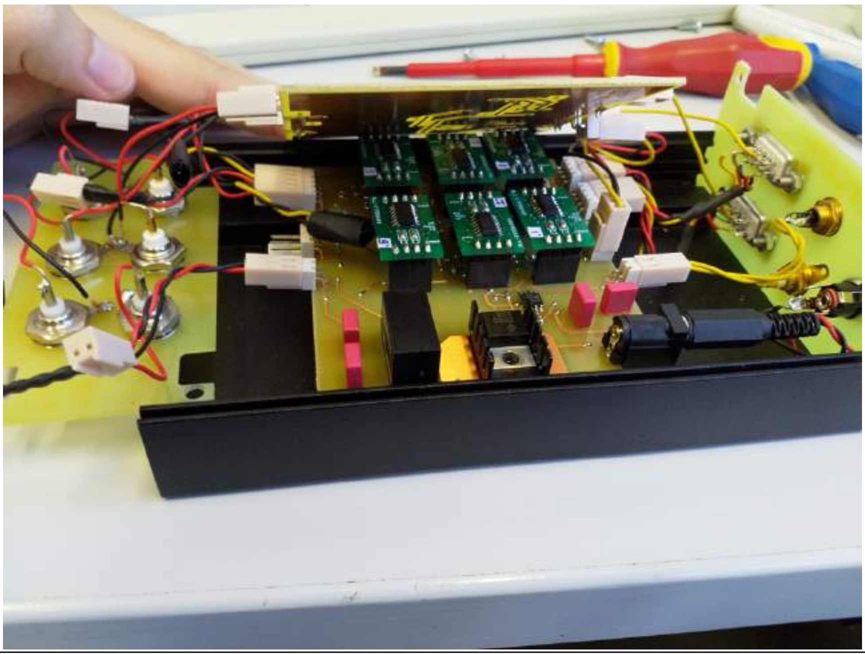


Figure 29: Main board as a medical equipment, this equipment has the main board for both the BCG and impedance sensors. It has power input, input and outputs to DAQ and sensing units.

Figure 30: Completed circuit and closed box

Experiment on a Healthy Subject

The objective of this experiment was to examine the relation between the time changing coupling impedance and the motion of the heart. For that purpose, an experimental setup was organized that provides the tools for the simultaneous measurement of ECG, BCG and coupling impedance of a healthy subject. For the measurement of ECG, Philips Intellivue MX700 ECG monitoring device was used which utilizes only one lead. Data acquisition from the ECG monitor to the NI USB-6259 was accomplished using the analog output port of the ECG monitor that can be connected to the input channel of the NI USB-6259. BCG of the subject was measured utilizing a PVDF sensor (a piezoelectric plastic material that generates equal and opposite charges on both sides of the PVDF film when it is mechanically deformed). The reason to measure the BCG together with ECG and coupling impedance was to demonstrate the change in the pressure on the clothing with the motion of the heart and how this change is related to the variation in the coupling impedance. The PVDF sensors were located just below the sensing units as seen in Figure 31.

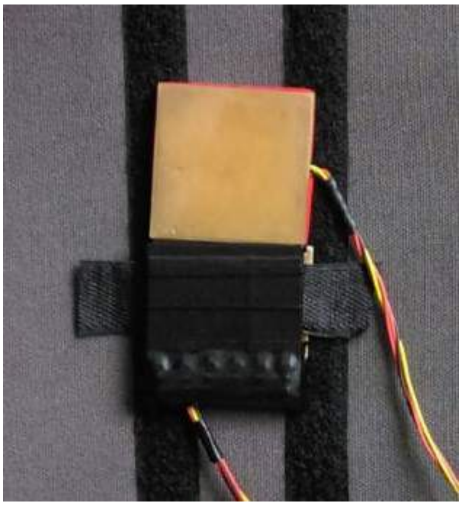


Figure 31 : Positioning of the sensing unit for BCG and coupling capacitance

Figure 32 : The conductive office chair that is used in the measurements.

Two sensing units for coupling capacitance were placed on the office chair (Figure 32) where they correspond to the upper right and upper left back of the subject when she/he is seated and below them the BCG sensors (black ones) were located. The top surfaces of the sensors were covered with a textile (100% cotton) that represents the clothing of the subject. The electrodes of the ECG were positioned to the subject’s torso according to the standard 3-electrode system. Finally, the subject was seated to the office chair and throughout the measurement procedure, which lasted 300 seconds, she/he remained seated.

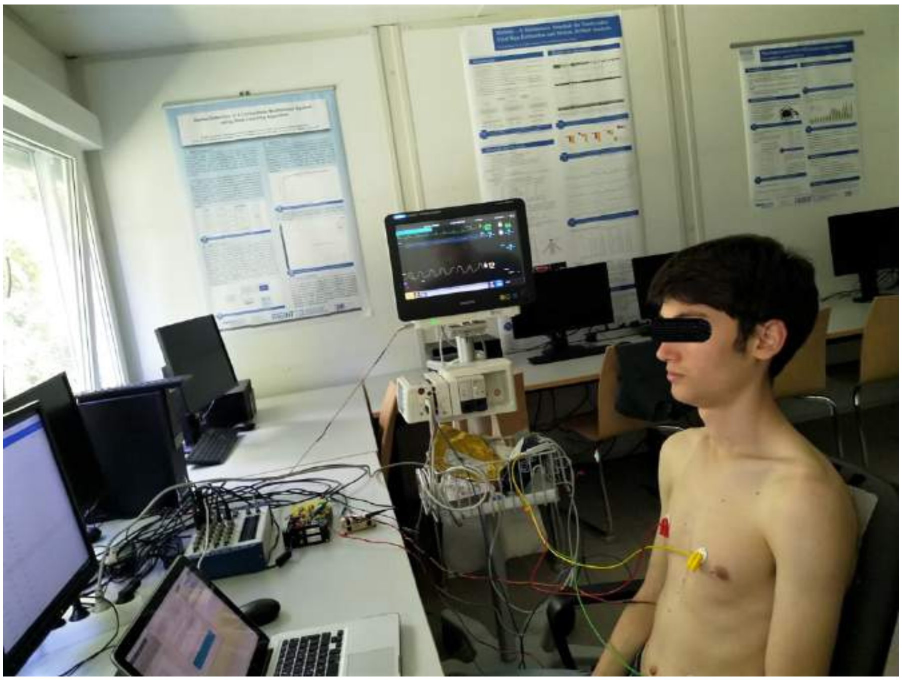


Figure 33 : Experiment on a healthy subject

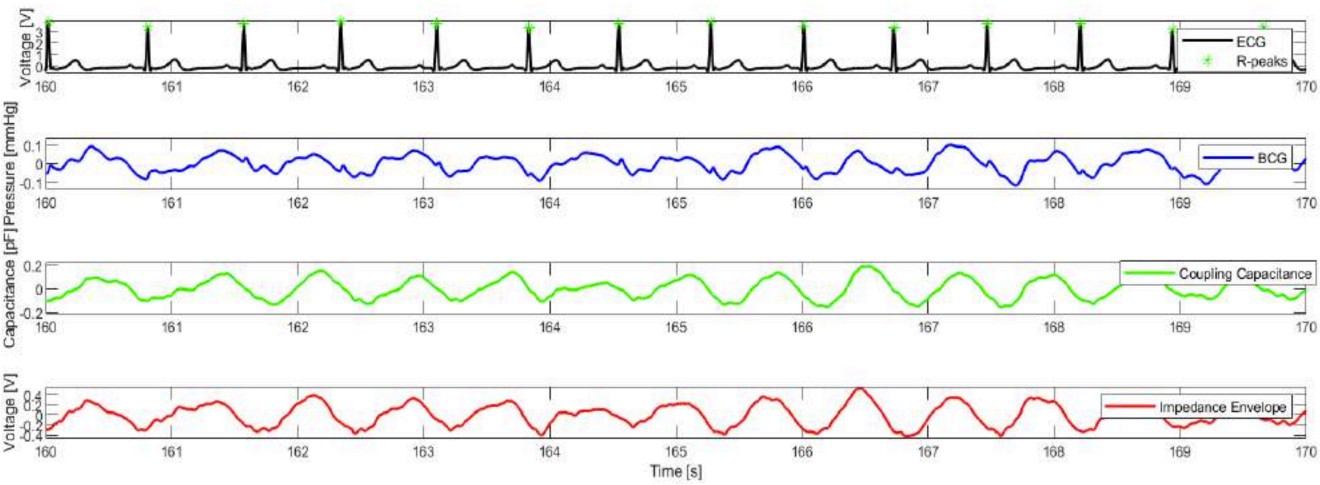


Figure 34 : Measurement results from the upper right back of the subject

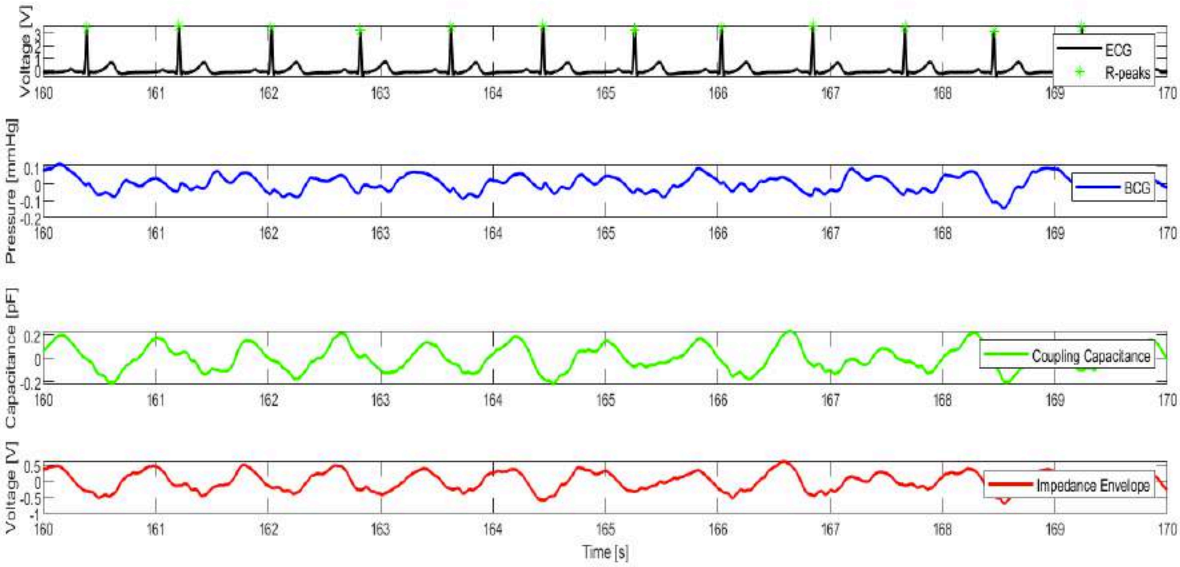


Figure 35 : Measurement results from the upper left back of the subject

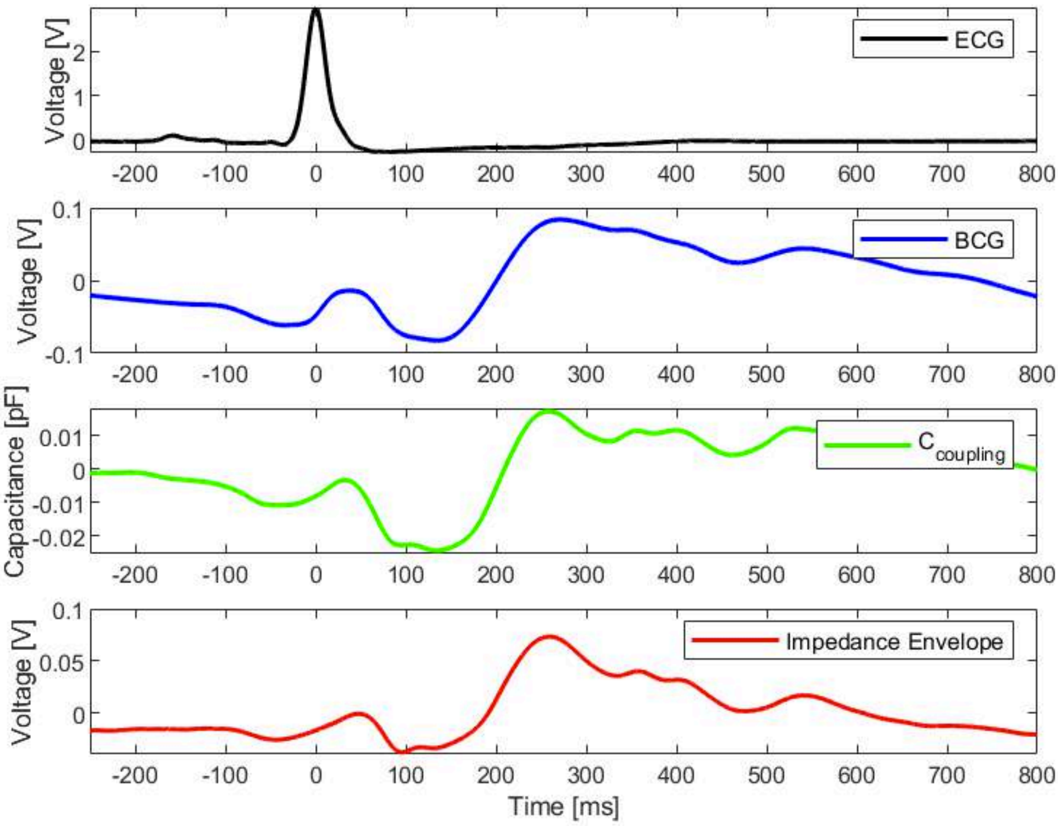


Figure 36 : Time average shapes of the measurement results from the upper right back of the subject

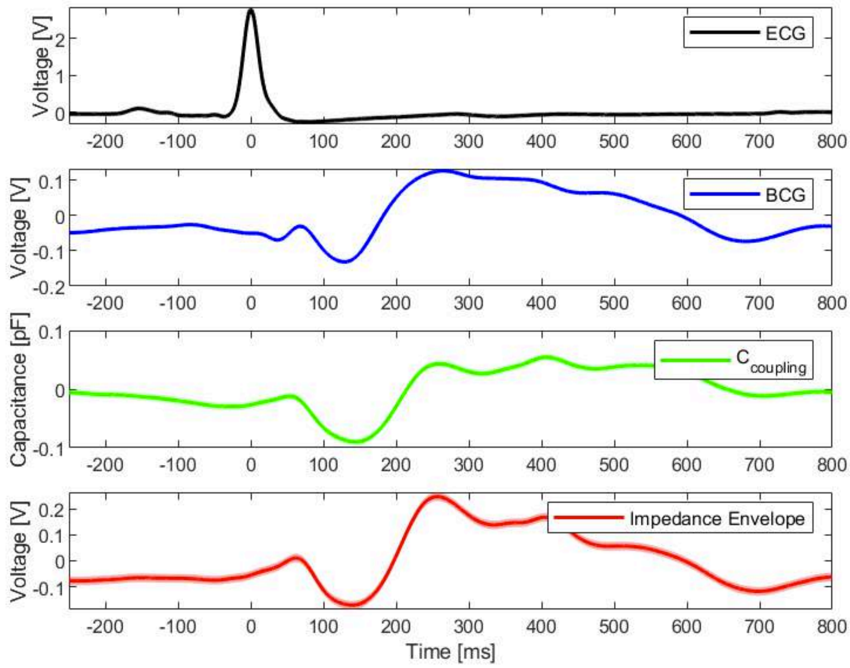
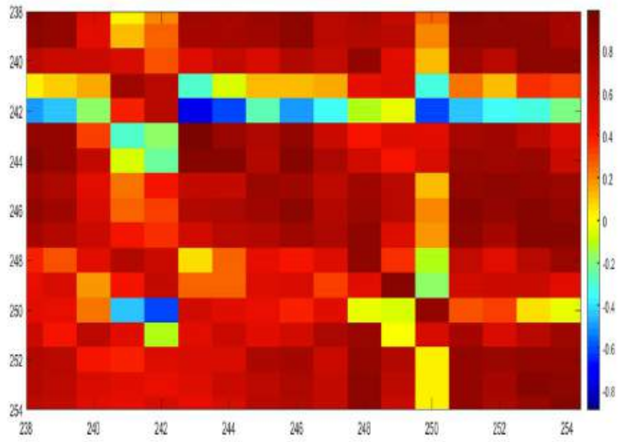
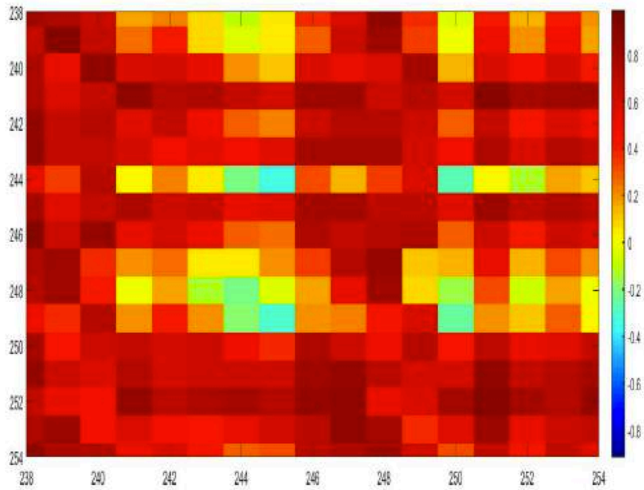


Figure 37 : Time average shapes of the measurement results from the upper left back of the subject

Figures 34-37 demonstrate that the motion of the heart corresponds to a change in the pressure on the clothing and this change in the pressure causes time-variant coupling impedance. From Figures 34 and 35, it can be observed that the R-peaks of the ECG are followed by the jumps in the pressure and the coupling impedance with some delay. This delay is caused by the distance of the sensors to the signal source (heart) and the reflections caused by the tissues on the transmission path (from the heart to the back of the torso). The average shapes shown in Figures 36 and 37 again demonstrate the same relation. Also, time average shapes in Figures 36 and 37 shows that the positioning of the sensors affects the amount of the delay. Since the sensors on the left side are closer to the heart than the sensors on the right side, the delay introduced on the left side is shorter than the one on the right side. Figure 34-37 show an obvious correlation between ECG, BCG and coupling impedance signals. To go beyond the visual examination, correlation coefficients between the signals were calculated. This code segments the signals according to a predefined window and calculates the correlation coefficients between the different signals for each segment of these signals. The results of this analysis for the segments that correspond to the time window given in Figures 34 and 35 were shown in Figure 38. Neglecting some segments which are negatively or lowly correlated with the other segments (those segments are taught to be the ones that could correspond to the time intervals where the connection between the body and the sensors are poor) the signals of examination (ECG, BCG and coupling impedance) are highly correlated which proved the hypothesis stating that the variation of coupling impedance is caused by the motion of the heart. All in all, a ballistocardiograph measurement system was developed that shows the relation between the heart's motion and the time-variant coupling impedance through the experiments that were conducted with this system and the analyses that were made on MATLAB.



a : Coefficients for the correlation between BCG and coupling impedance



b : Coefficients for the correlation between ECG and coupling impedance

Figure 38: x and y axes show the segment numbers that correspond to the time window given in Figures 34 and 35, the colour bars on the left of the figures show the scaling of the correlation coefficients

Şirket Değerlendirme Yazısı
Letter of Evaluation

Company Profile:
Medical Information Technology (MedIT)

Company Adress:
Chair for Medical Information Technology, Helmholtz Institute, RWTH Aachen University, Paulwelsstr.20, D-52074 Aachen. The Chair for Medical Information Technology (MedIT) is located in the Helmholtz Institute for Biomedical Engineering. The building of the Helmholtz Institute is located directly next to the University Hospital RWTH Aachen, which is on the west side of Aachen, approximately 2 kilometres from the Netherlands. It is within sight of the physics/electrical engineering buildings and mechanical engineering building on Hörn.

Organizational Structure of the Company and Employee Information
There are 27 employees working at Medical Information Technology. 7 of them are holding PhD degrees in the fields of Electrical Engineering, Information Technology and Computer Engineering and 16 of them are holding M.Sc. degrees and pursuing their PhD degrees in Electrical Engineering, Information Technology and Computer Engineering.

Company evaluation:
I conducted my summer practice at Helmholtz Institute for Biomedical Engineering, Chair for Medical Information Technology (MedIT). I chose MedIT as a summer practice location because of my interest in biomedical field, besides I would like to have a working experience in a foreign country. I applied for the internship position through the contact mail given in the job advertisement. After the evaluation process I was accepted for the position to fulfil my summer internship in MedIT.

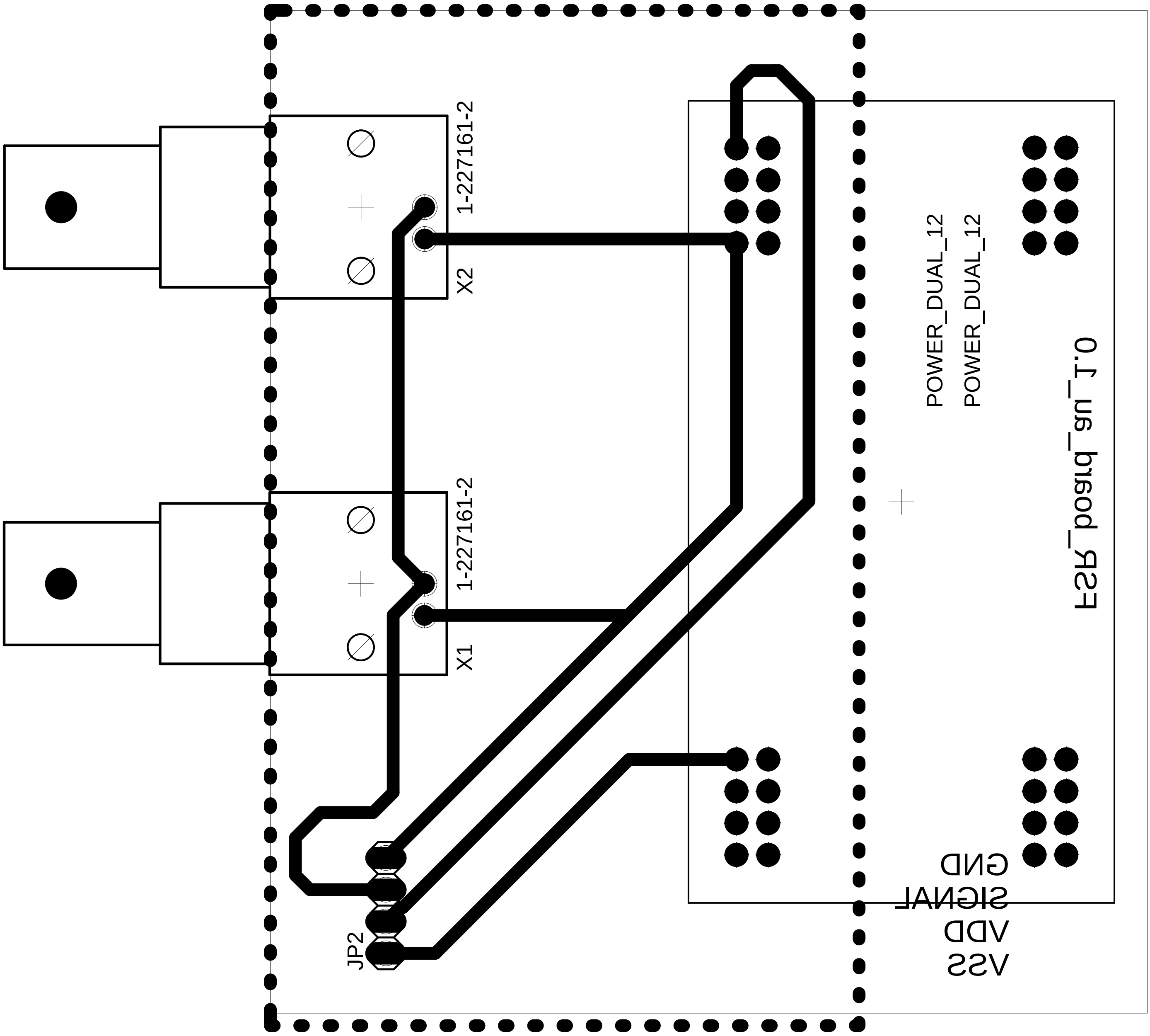
At MedIT, I involved in a project, under the lead and supervision of Mr. Uguz, which is about the development of a dorsoventral ballistocardiographic measurement system for the coupling impedance of a capacitive ECG (cECG) which is utilized to demonstrate the correlation between the heart beats and the coupling impedance of the body sensor interface (clothing). My work was mainly focused on the design of an analog circuitry that can measure the mechanical heartbeats. In addition to the design of the measurement setup, MATLAB codes were generated to acquire and analyse the data obtained from the measurements.

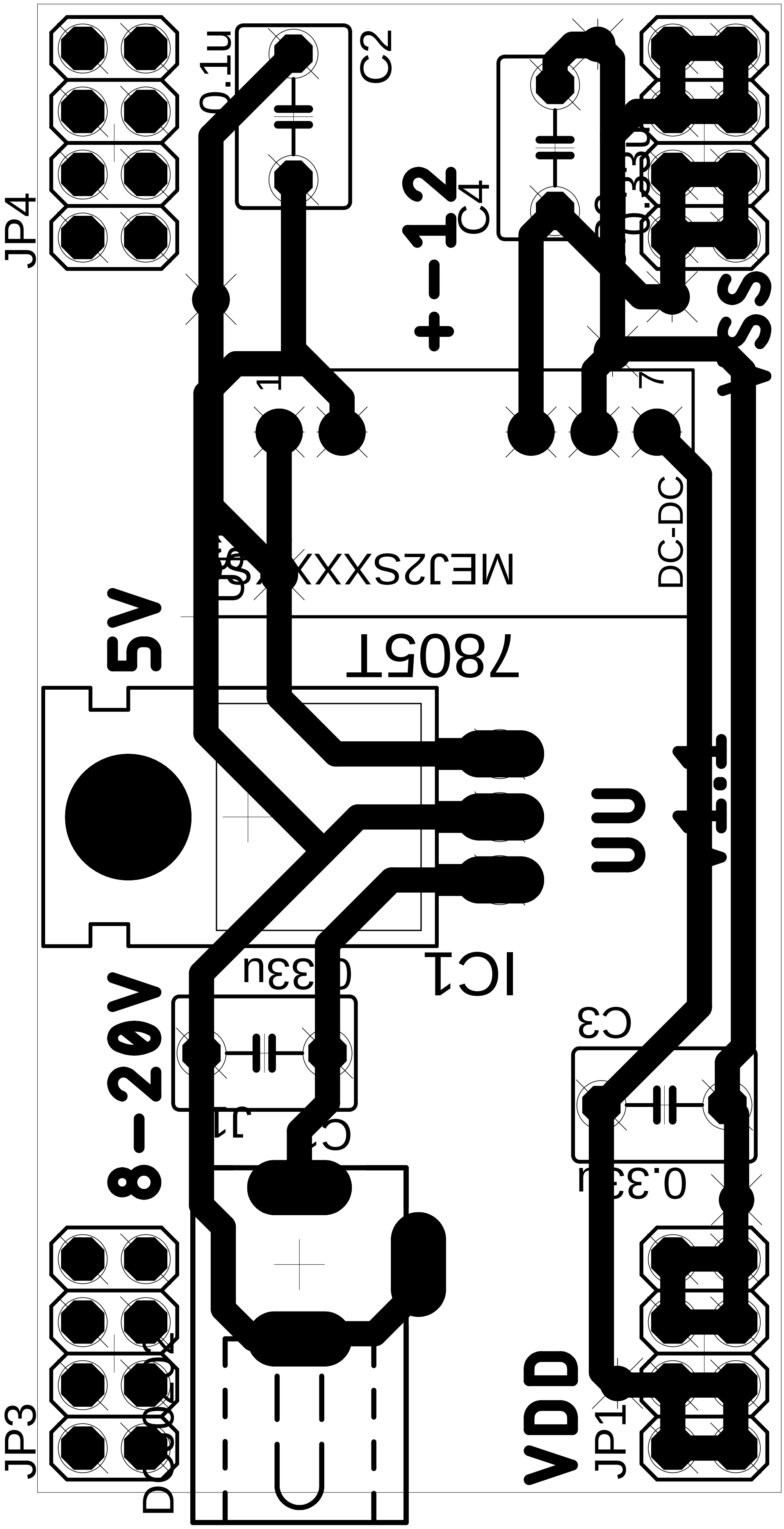
The traineeship helped me understand the working mechanism and methods of biomedical engineers in research. During this internship period, I developed my calculation skills, my social communication skills, my computer software skills and my analytical skills. I think that this experience is going to help me a lot to make my future decision after graduation.

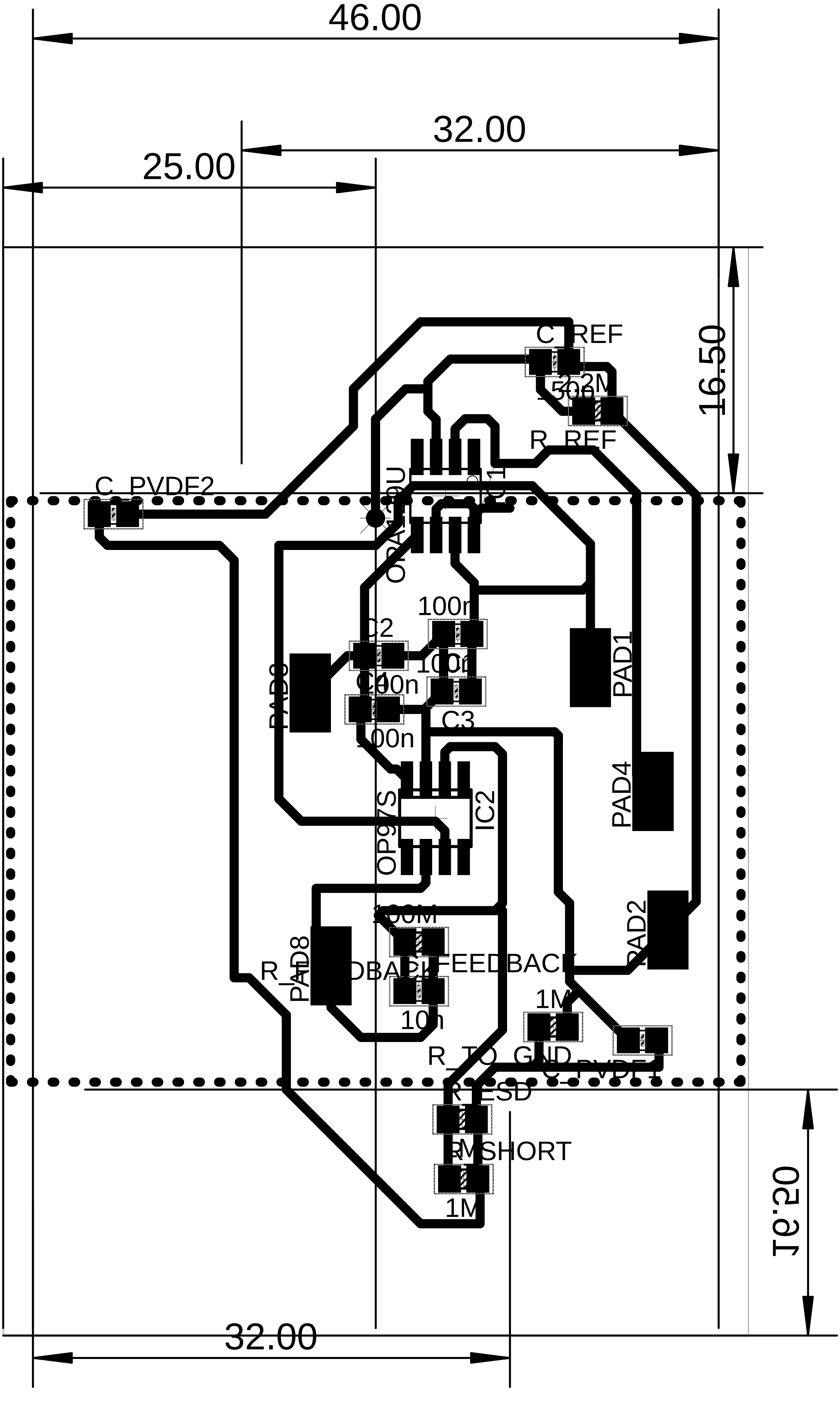
I am very pleased completing an internship in MedIT and I will suggest everyone.

DOCUMENTATION

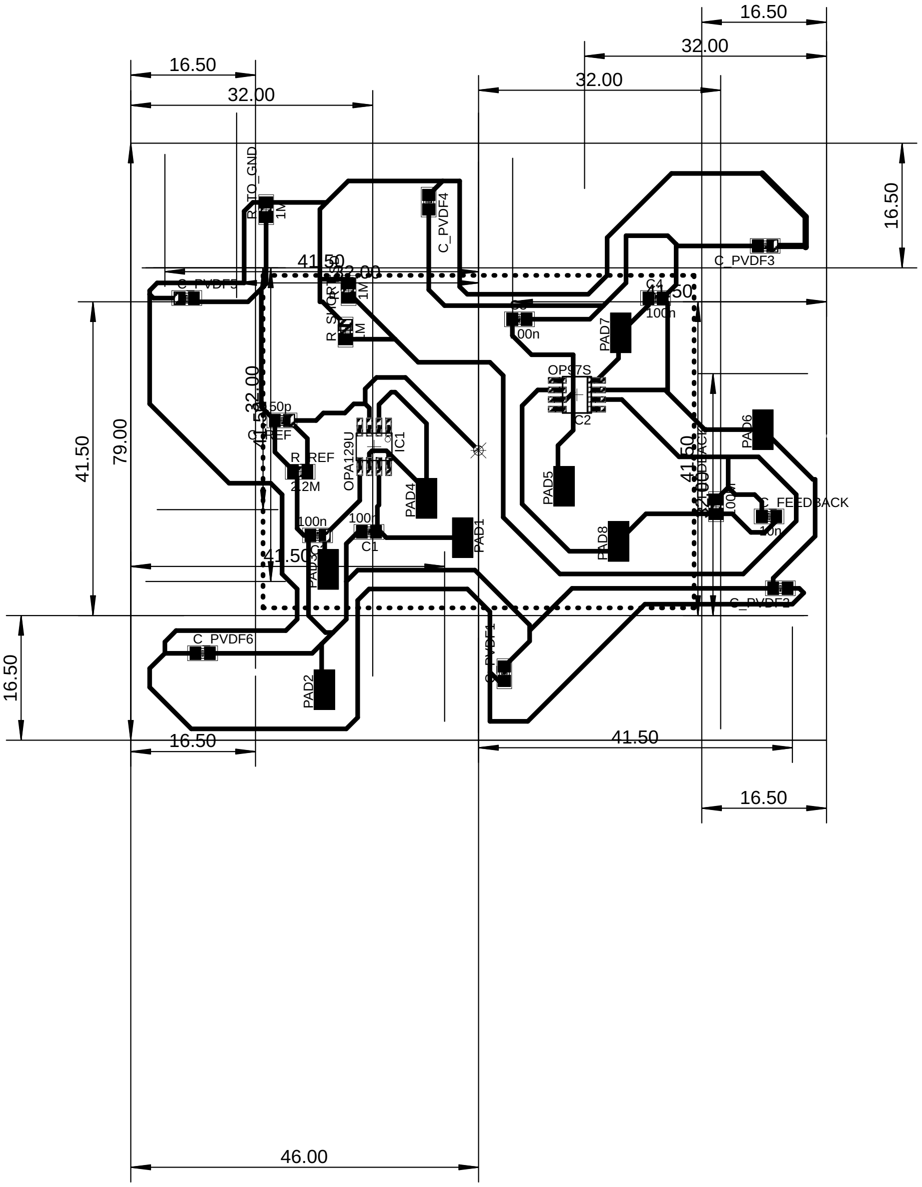
EAGLE DOCUMENTS

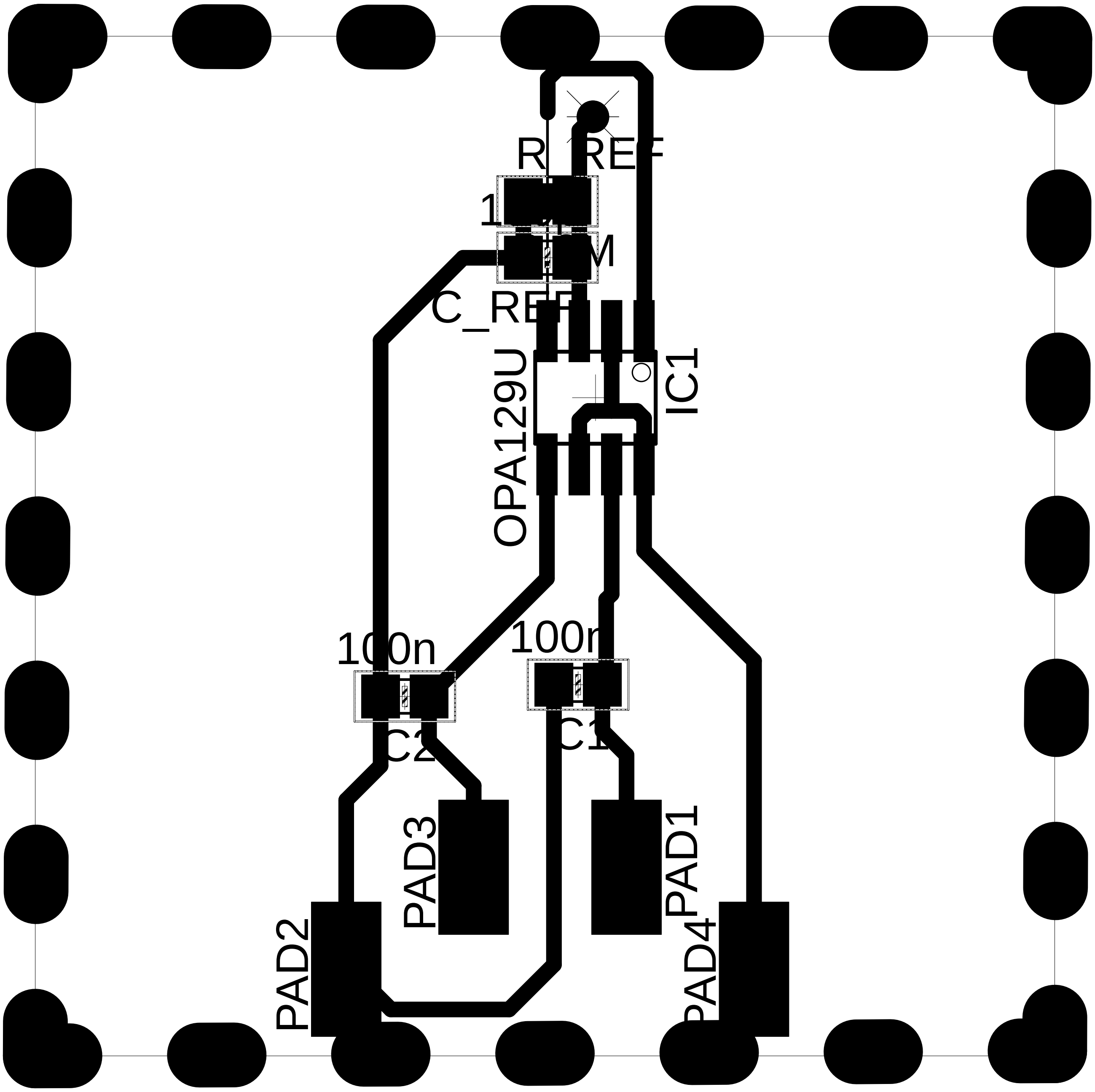

1-227161-2
X2
1-227161-2
X1
JP2
POWER_DUAL_12
POWER_DUAL_12
FSR_board_v1.0
GND
SIGNAL
VDD
VSS

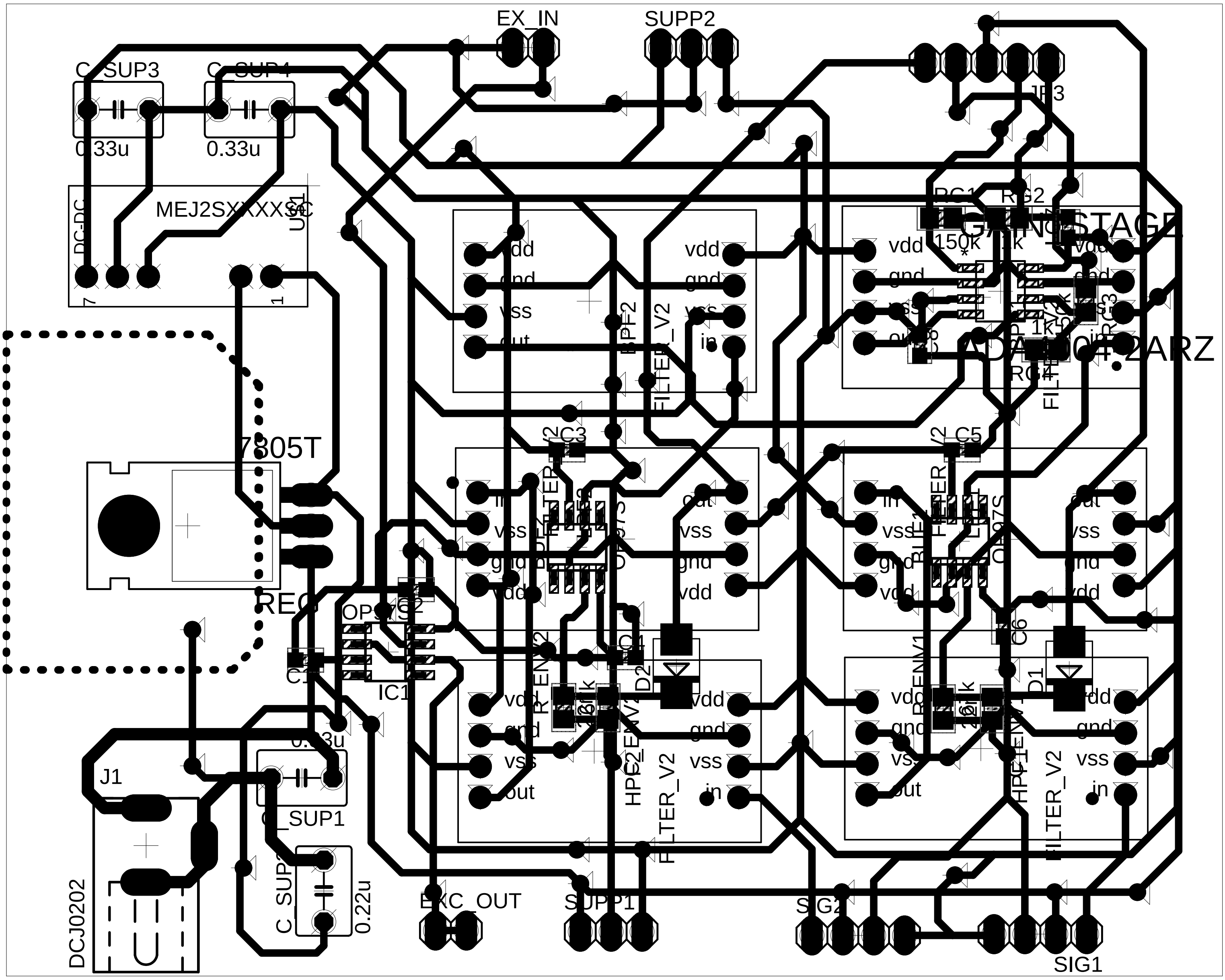

JP4
C2
0.1u
C4
0.33u
+-12
VSS
DC-DC
7805T
5V
8-20V
IC1
C3
0.33u
VDD
JP1
JP3



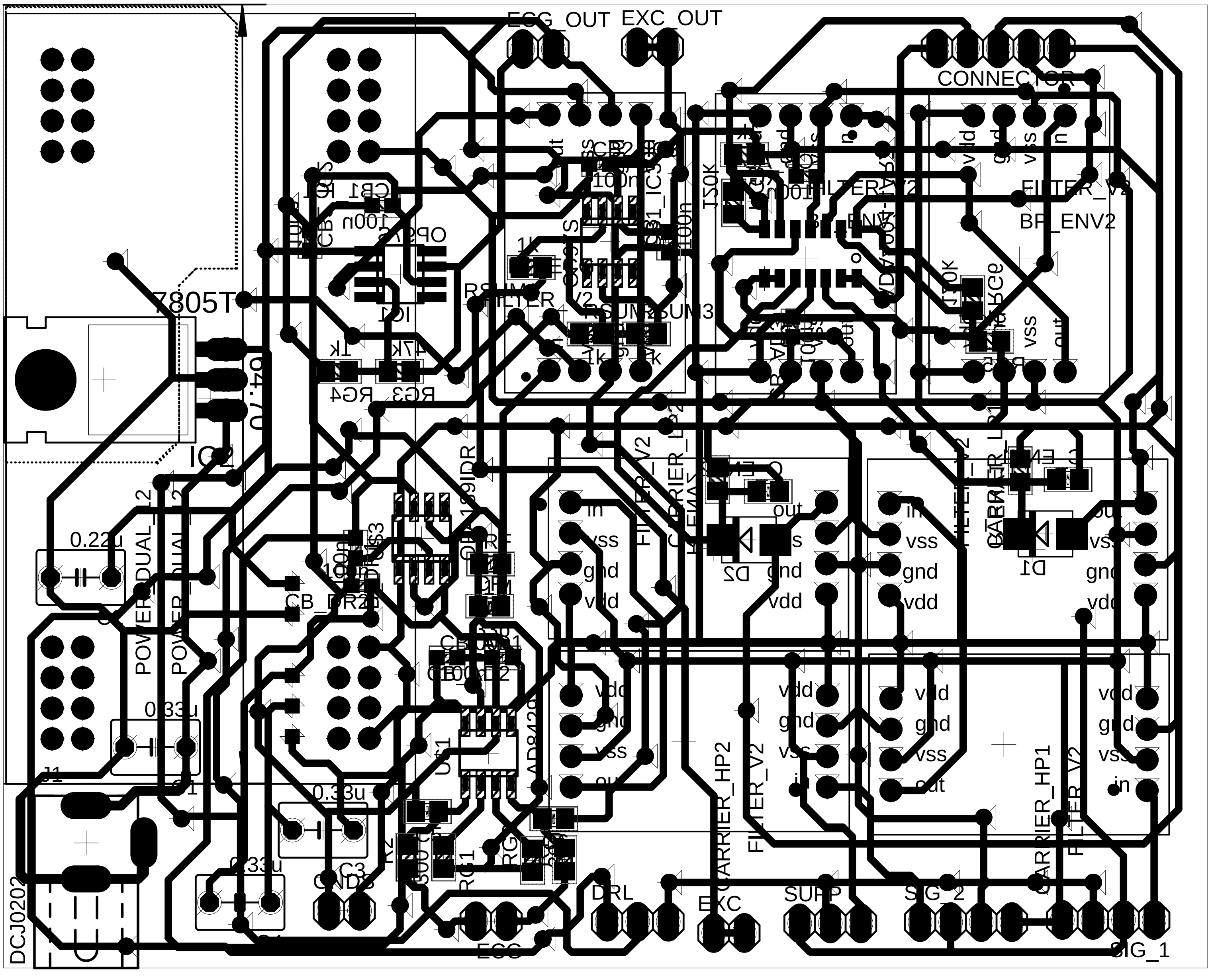
46.00
32.00
25.00
16.50
C_REF
2.2M
500
R_REF
C_PVDF2
OPA129U
IC1
100n
C2
100n
C4
100n
C3
100n
PAD1
PAD3
PAD4
OP97S
IC2
PAD2
100M
R_FEEDBACK
C_FEEDBACK
PAD8
10n
1M
R_TO_GND
C_PVDF1
R_ESD
1M
R_SHORT
1M
19.50
32.00

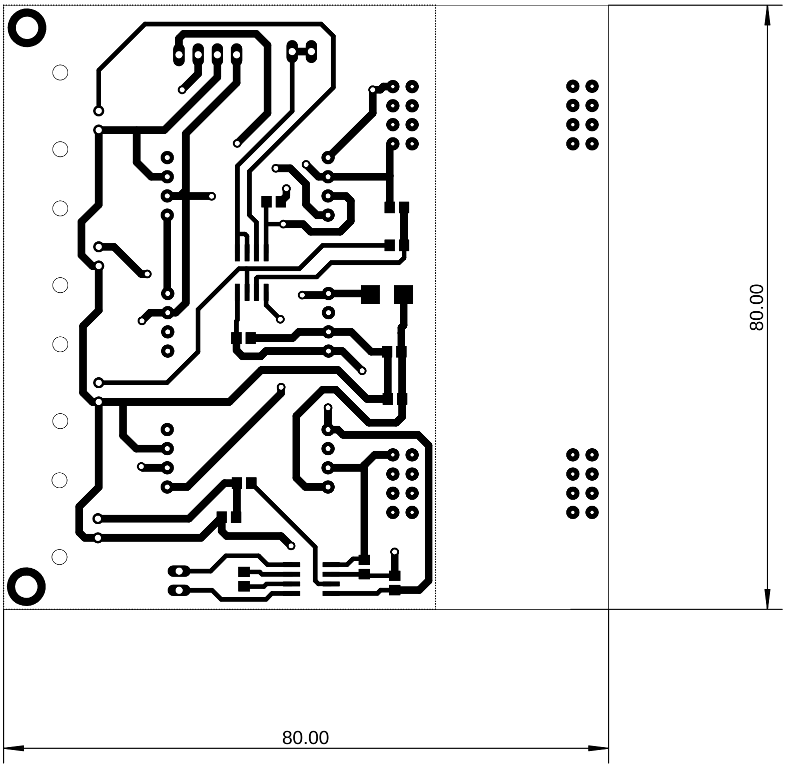

16.50
32.00
32.00
16.50
32.00
16.50
79.00
41.50
41.50
16.50
16.50
41.50
16.50
46.00
R_TO_GND
1M
C_PVDF4
C_PVDF3
C_PVDF5
C_PVDF6
C_PVDF2
C_PVDF1
R_SIG
C4
100n
PAD7
OPS7S
C2
PAD6
PAD5
PAD8
C_FEEDBACK
10n
R_REF
2.2M
OPA129U
IC1
PAD4
PAD1
C1
100n
PAD2
PAD3
150p

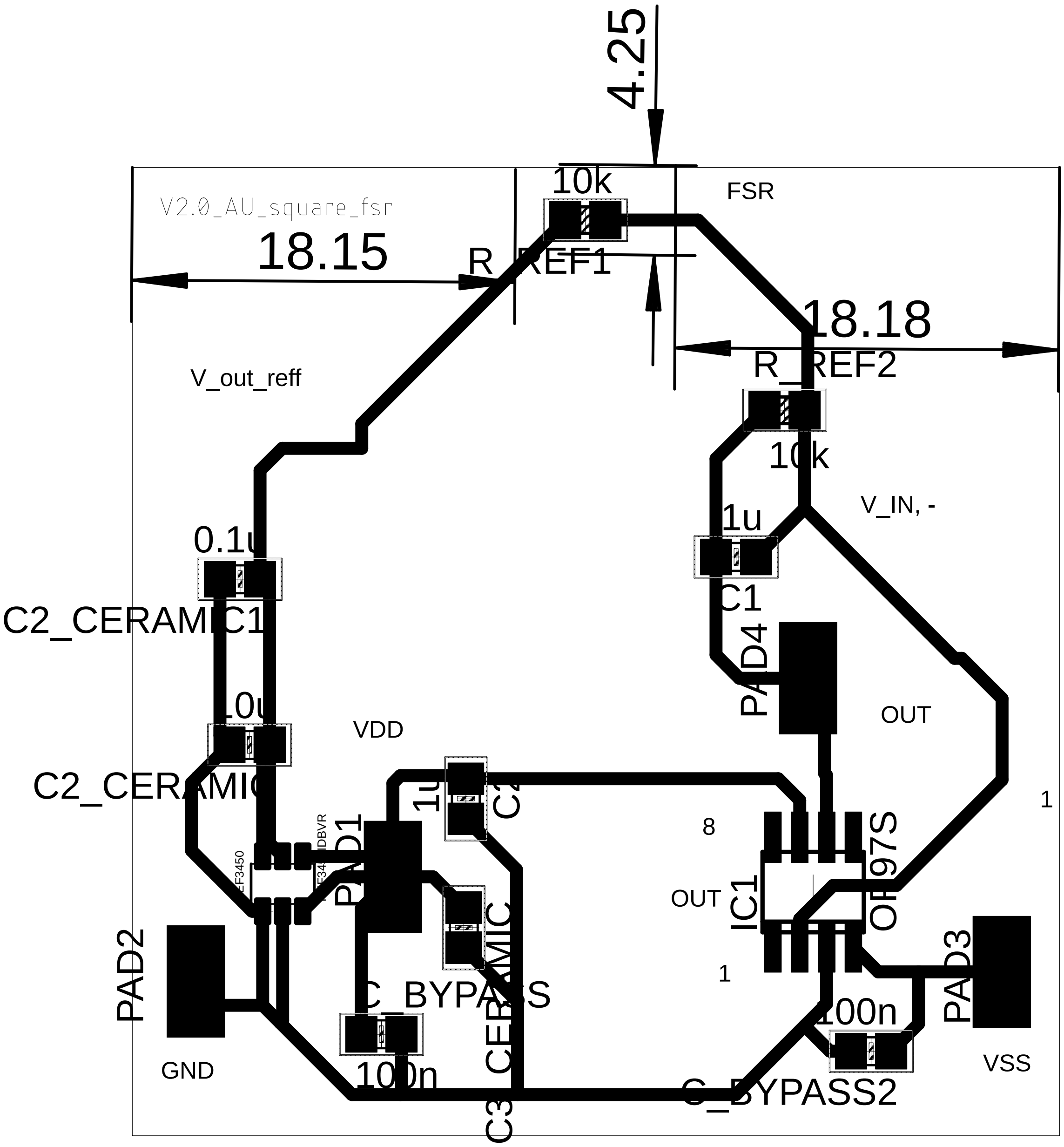

R_REF
C_REF
OPA129U
IC1
100n
100n
C2
C1
PAD3
PAD1
PAD2
PAD4

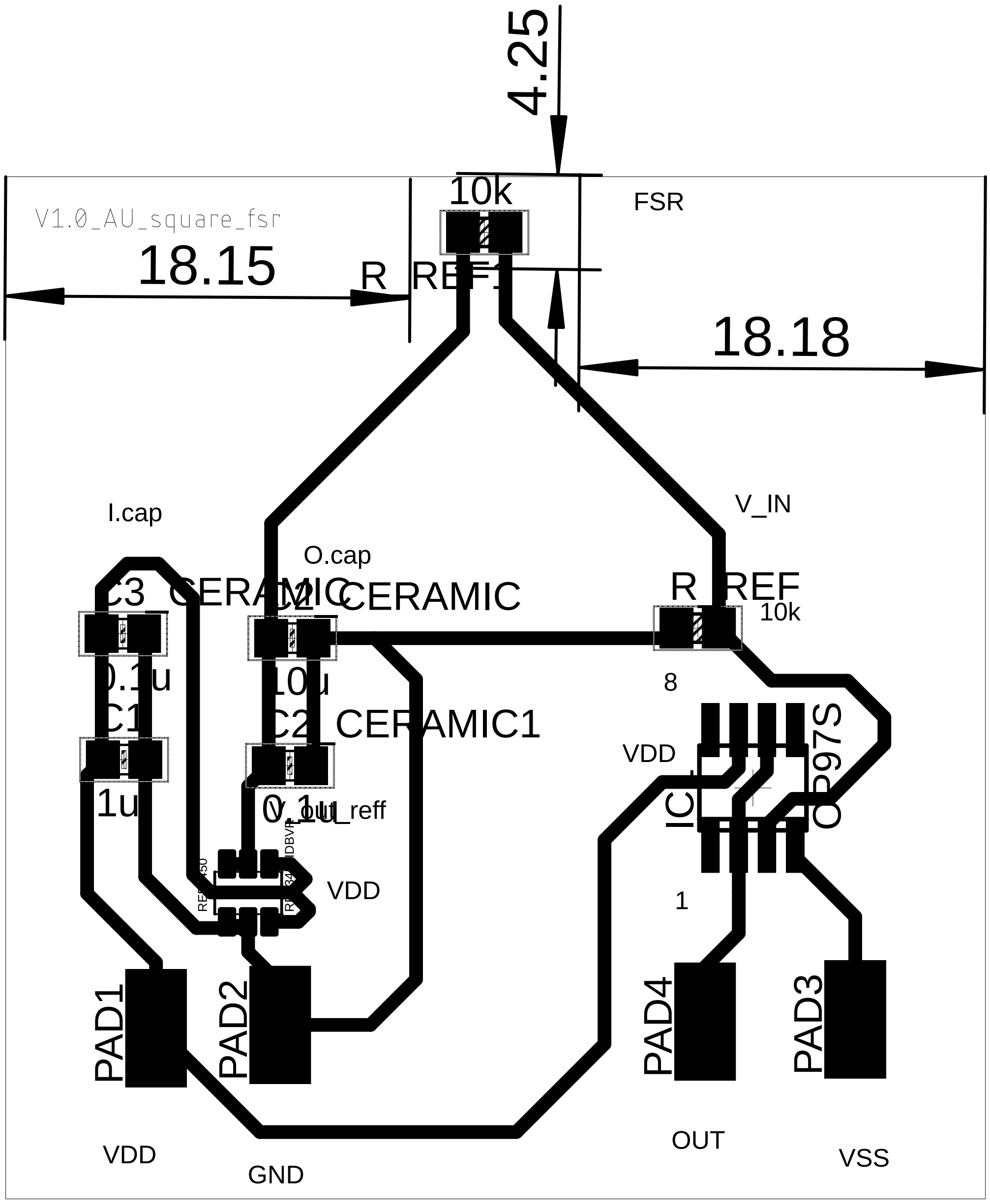


EX_IN
SUPP2
C_SUP3
C_SUP4
0.33u
0.33u
MEJ2SXXXXSC
U1
DC-DC
7805T
REG
OP97S
IC1
C1
C2
C3
C5
C6
D1
D2
BPF2
FILTER_V2
HPF2
HPF1
GAIN_STAGE
RG1
RG2
RG4
150k
JP3
vdd
gnd
vss
out
in
C_SUP1
C_SUP2
0.22u
J1
DCJ0202
EXC_OUT
SUPP1
SIG2
SIG1

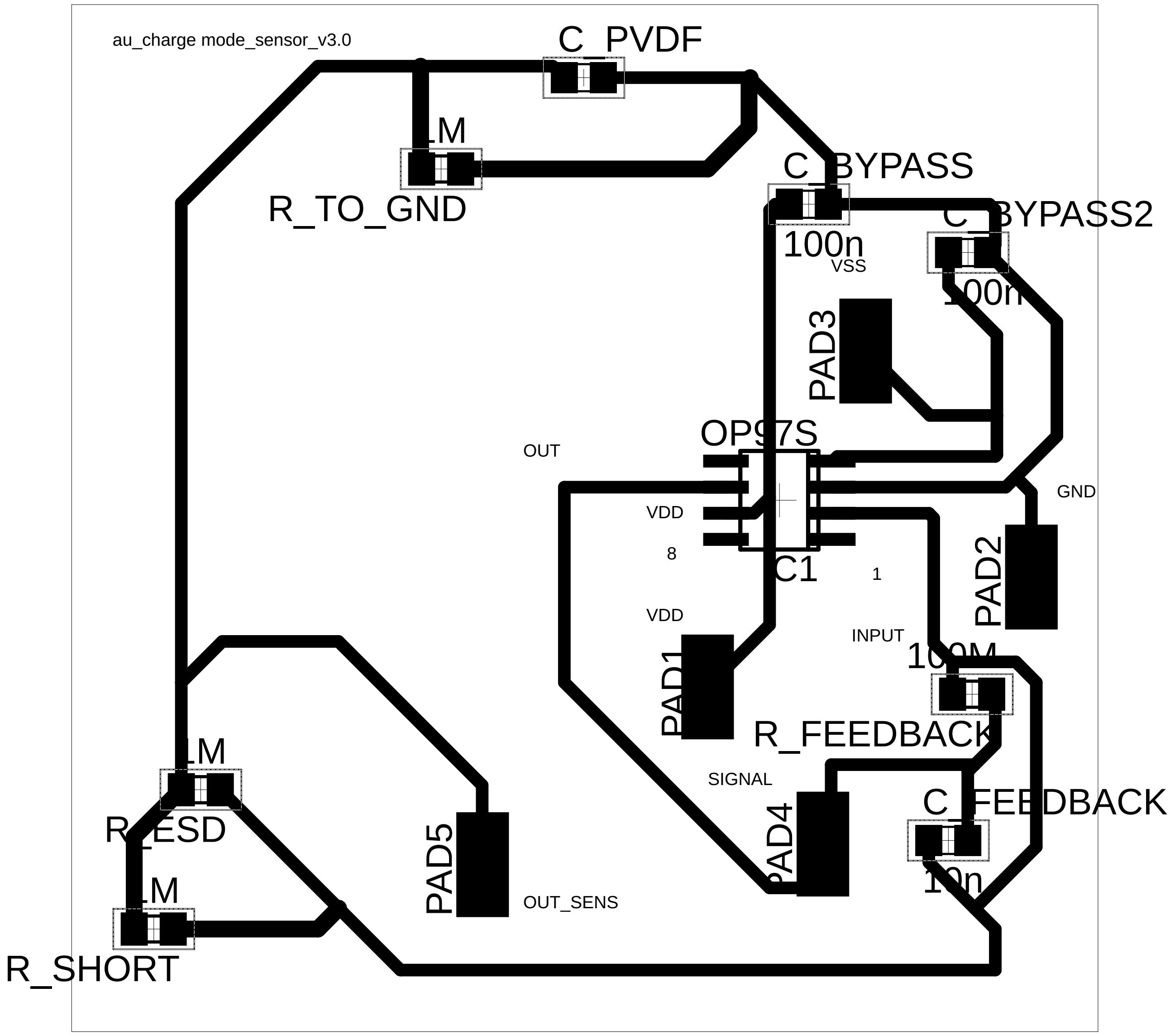


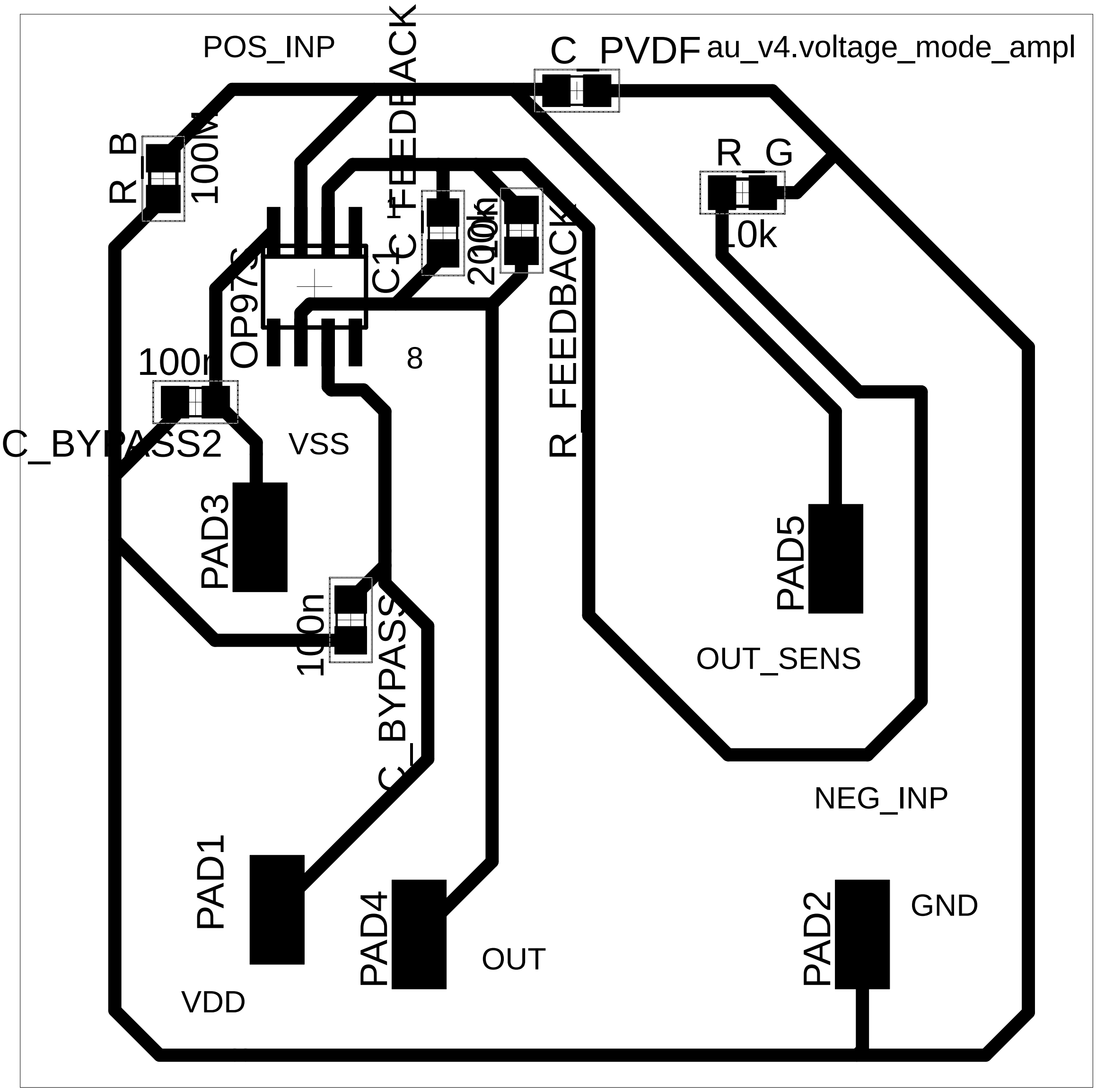

80.00
80.00


4.25
10k
FSR
V2.0_AU_square_fsr
18.15
R_REF1
18.18
R_REF2
V_out_reff
10k
V_IN, -
1u
0.1u
C1
C2_CERAMIC1
PAD4
OUT
10u
VDD
C2_CERAMIC
1u
C2
1
8
OP97S
PAD1
IC1
OUT
PAD2
C_BYPASS
1
PAD3
100n
CERAMIC
GND
100n
VSS
C_BYPASS2
C3

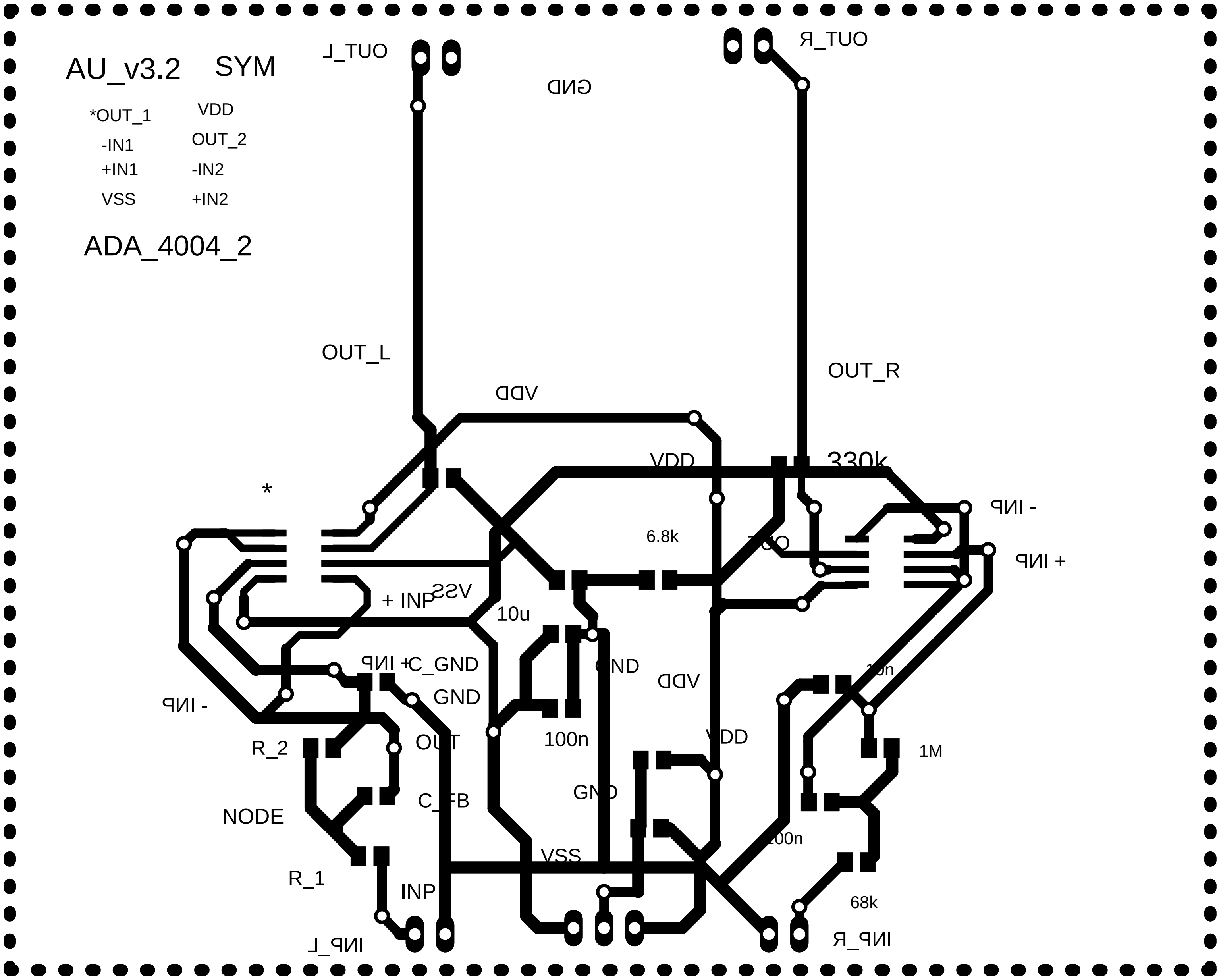


4.25
10k
FSR
V1.0_AU_square_fsr
18.15
R_REF1
18.18
I.cap
V_IN
O.cap
C3_CERAMIC
C2_CERAMIC
R_REF
10k
0.1u
10u
8
C1
C2_CERAMIC1
VDD
1u
0.1u
V_out_reff
VDD
IC1
OP97S
1
PAD1
PAD2
PAD4
PAD3
VDD
GND
OUT
VSS

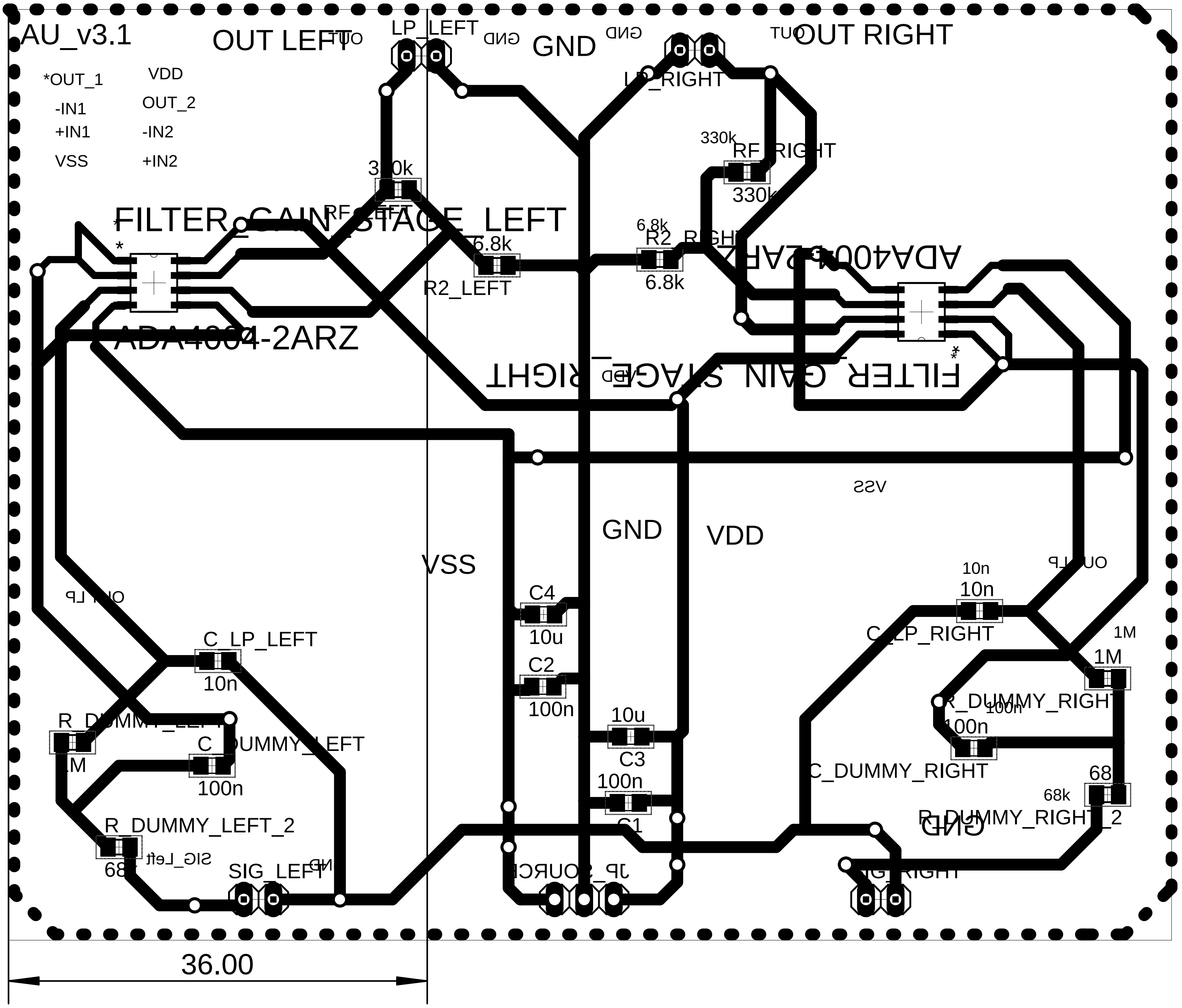

au_charge mode_sensor_v3.0
C_PVDF
1M
R_TO_GND
C_BYPASS
100n
VSS
C_BYPASS2
100n
PAD3
OP97S
OUT
VDD
8
C1
1
GND
PAD2
VDD
INPUT
PAD1
100M
R_FEEDBACK
SIGNAL
1M
R_ESD
PAD5
PAD4
C_FEEDBACK
10n
1M
OUT_SENS
R_SHORT



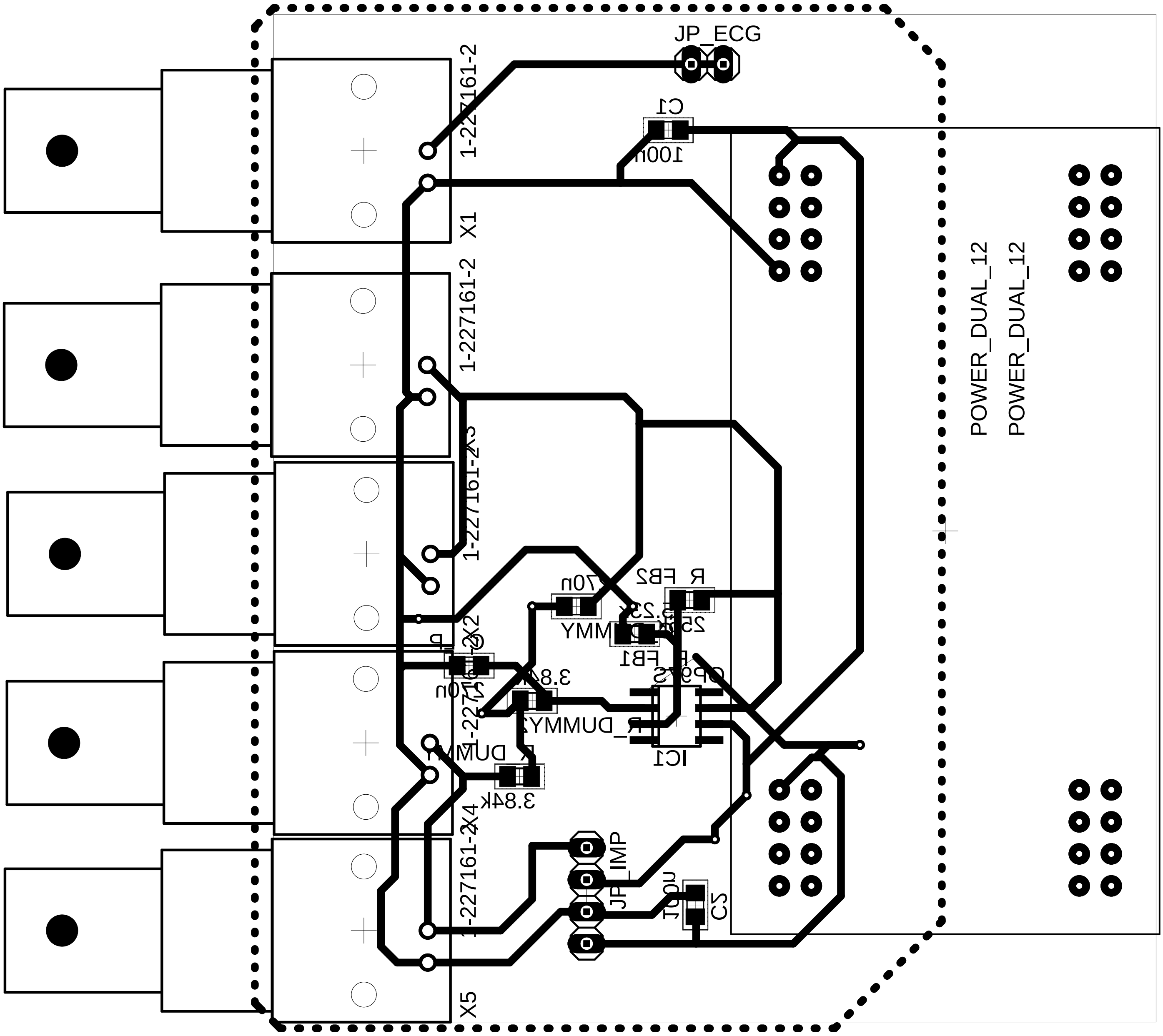
POS_INP
C_PVDF
au_v4.voltage_mode_ampl
R_B
100M
R_G
10k
OP97
C1
C_FEEDBACK
200k
R_FEEDBACK
100n
C_BYPASS2
VSS
8
PAD3
PAD5
100n
C_BYPASS
OUT_SENS
NEG_INP
PAD1
PAD4
PAD2
GND
OUT
VDD



AU_v3.2
SYM
*OUT_1
VDD
-IN1
OUT_2
+IN1
-IN2
VSS
+IN2
ADA_4004_2
OUT_L
OUT_R
VDD
330k
6.8k
10u
100n
GND
C_GND
OUT
C_FB
R_2
NODE
R_1
INP
VSS
1M
68k
INP_L
INP_R
+ INP
- INP



AU_v3.1
OUT LEFT
LP_LEFT
GND
OUT RIGHT
LP_RIGHT
*OUT_1
VDD
-IN1
OUT_2
+IN1
-IN2
VSS
+IN2
330k
RF_LEFT
RF_RIGHT
FILTER_GAIN_STAGE_LEFT
FILTER_GAIN_STAGE_RIGHT
6.8k
R2_LEFT
R2_RIGHT
ADA4004-2ARZ
VSS
GND
VDD
C4
10u
C2
100n
C3
C1
C_LP_LEFT
10n
C_LP_RIGHT
R_DUMMY_LEFT
1M
C_DUMMY_LEFT
100n
R_DUMMY_LEFT_2
68k
SIG_LEFT
JP_SOURCE
R_DUMMY_RIGHT
C_DUMMY_RIGHT
R_DUMMY_RIGHT_2
SIG_RIGHT
36.00



JP_ECG
C1
100n
1-227161-2
X1
X2
X3
X4
X5
POWER_DUAL_12
R_FB2
R_FB1
IC1
R_DUMMY
R_DUMMY2
3.84k
C3
10u
JP_IMP

MATLAB DOCUMENTS

7 Appendices

Appendix A MATLAB script for obtaining the frequency response of the designed filters

```
% Using NI-DAQ, this creates an test signal, possibly a
    chirp and measures
% the output. It needs to be used with Filter 1.1 Test
    Module

clear
close all
clc

%% Recording parameters
Fs = 1e3;
duration = 400;
amplitude = 1;

Fmin = 0.01;
Fmax = 40;

test_time = (0:1/Fs:duration)';
x_t = chirp(test_time, Fmin, duration, Fmax,'quadratic');
% pspectrum(x_t,1e4,'spectrogram','TimeResolution',1,'
    OverlapPercent',99,'Leakage',0.01, ...
%       'FrequencyLimits', [Fmin Fmax]);



%% Adjust the DAQ

daqSession = daq.createSession('ni');
addAnalogInputChannel(daqSession,'Dev1', 0, 'Voltage');
addAnalogOutputChannel(daqSession,'Dev1', 0, 'Voltage');

daqSession.Rate = Fs;
% daqSession.DurationInSeconds = duration;

%% Start Recording
disp('Recording started...');

queueOutputData(daqSession, x_t);
[y_t, time] = daqSession.startForeground;
```

```
disp('Recording finished...');
%% Calculate FFT for the processed signal
figure,
[~, x_f] = my_fft(x_t, Fs, 1);
[f, y_f] = my_fft(y_t, Fs, 1);
semilogx(f, y_f-x_f, 'k');
xlim([Fmin*1.1 Fmax*0.95]);
xlabel('Frequency [Hz]');
ylabel('Power Spectrum [dB/Hz]', 'FontSize', 12),
set(gca, 'FontSize', 12)

%% Final plots
% figure, tfestimate(x_t,y_t,[],[],[Fmin Fmax],Fs);

figure,
subplot(2,1,1), plot(time, x_t), legend('Input');
subplot(2,1,2), plot(time, y_t), legend, legend('Output')
    ;
xlabel('Time [s]');
```

Appendix B MATLAB script to record multichannel measurement

```
% Using NI-DAQ, purpose of this code is to measure and
    record the
% impedance, BCG and ECG with a data structure

clear
close all
clc

%% Recording parameters

% 1 = ECG-BCG-Imp
% 2 = ECG-BCG
% 3 = ECG-Imp
measurement_mode = 1;


Fs = 200e3; %sampling rate
```

```
duration = 120; % recording duration
date = '19.08.2019';
file_name = 'recp_1';


comments = {'Pressure Exp'...
            'P.nom = 2050 pascal',...
            'C100'};


sensors = {'Voltage Divider v2.3 no DRL', ...    % ECG
    'PVDF CM, with insulating layer raw', ...    % BCG raw
    'PVDF CM, with insulating layer', ...    % BCG
    'Sensing Unit v1.0 after BP', ...            % Impedance Raw
    'rect-BP'};                                  % Impedance Envelope

channelNames = {'ECG', ...
                'BCG Raw', ...
                'BCG', ...
                'Impedance Raw', ...
                'Impedance Envelope'};

channelUnits = {'V','V','V','V', 'V'};


%% BCG Measurement Parameters
V_ref = 5;
R_ref = 680;

%% Impedance Measurement Parameters

Fc = 5000;           % excitation frequency
V_excitation = 9;    % amplitude(V) of the excitation signal


%% Generating the Excitation Signal

time = (0:1/Fs:duration)';
```

```
signal_excitation = V_excitation*sin(2*pi*Fc*time);


%% Create Data Acquisition Session
daqSession = daq.createSession('ni');
daqSession.Rate = Fs;

% Add Channels to Session
% AI0 -- ECG
% AI1 -- BCG Raw
% AI2 -- BCG
% AI3 -- Impedance Raw
% AI4 -- Impedance Envelope
switch measurement_mode
    case 1  % ECG - BCG - Impedance
        addAnalogInputChannel(daqSession,'Dev1', 0, '
           Voltage');
        addAnalogInputChannel(daqSession,'Dev1', 1:4, '
           Voltage');
        addAnalogOutputChannel(daqSession,'Dev1', 0, '
           Voltage');
        queueOutputData(daqSession,signal_excitation);
        number_of_channels = 5;
    case 2  % ECG - BCG
        addAnalogInputChannel(daqSession,'Dev1', 0, '
           Voltage');
        addAnalogInputChannel(daqSession,'Dev1', 1:2, '
           Voltage');
        daqSession.DurationInSeconds = duration;
        number_of_channels = 3;
    case 3  % ECG - Impedance
        addAnalogInputChannel(daqSession,'Dev1', 0, '
           Voltage');
        addAnalogInputChannel(daqSession,'Dev1', 3:4, '
           Voltage');
        queueOutputData(daqSession,signal_excitation);
        number_of_channels = 3;
end



disp('in 5 seconds...');
pause(5);
```

```
disp('Recording Started...');


%% Recording and Simultaneous Plotting
data_record1 = fopen('temp1.bin','w');
lh1 = addlistener(daqSession,'DataAvailable',@plotData);
lh2 = addlistener(daqSession,'DataAvailable',@(src,event) logData(src, event, data_record1));

daqSession.NotifyWhenDataAvailableExceeds = 4*Fs;

% Start recording
daqSession.startBackground();

daqSession.wait();
delete(lh1);
daqSession.stop;
delete(lh2);
fclose(data_record1);

%% Save the session

data_record2 = fopen('temp1.bin','r');
[data_temp,count] = fread(data_record2,[(number_of_channels+1),inf],'double');
fclose(data_record2);

data(:,1) = data_temp(2,:);
switch measurement_mode
    case 1  % ECG - BCG - Impedance
        data(:,2) = data_temp(3,:);
        data(:,3) = data_temp(4,:);
        data(:,4) = data_temp(5,:);
        data(:,5) = data_temp(6,:);
    case 2  % ECG - BCG
        data(:,2) = data_temp(3,:);
        data(:,3) = data_temp(4,:);
        data(:,4) = zeros(size(data_temp,2),1);
        data(:,5) = zeros(size(data_temp,2),1);
    case 3  % ECG - Impedance
        data(:,2) = zeros(size(data_temp,2),1);
        data(:,3) = zeros(size(data_temp,2),1);
        data(:,4) = data_temp(5,:);
```

```
        data(:,5) = data_temp(6,:);
end


save(file_name, 'channelNames', 'channelUnits', 'comments',...
    'data', 'date', 'Fc', 'Fs', 'sensors', 'V_excitation', 'V_ref', 'R_ref', 'measurement_mode');

%% LogData Function

function logData(src, evt, fid)

data = [evt.TimeStamps, evt.Data]' ;
fwrite(fid,data,'double');

end

%% Plot Function

function plotData(src,event)
subplot(3,1,1);
plot(event.TimeStamps,event.Data(:,1));
subplot(3,1,2);
plot(event.TimeStamps,event.Data(:,[2 3]));
subplot(3,1,3);
plot(event.TimeStamps,event.Data(:,[4 5]));
xlabel("time(s)");
ylabel("voltage(V)");

end
```

Appendix C MATLAB script to process and plot recorded measurements

```
% This script loads and plots the already processed recordings.


clear
close all
```

```
% clc

addpath('C:\Users\Admin\OneDrive - rwth-aachen.de\Workspaces\MATLAB\functions');
addpath('C:\Users\DurmusUmutcanUguz\OneDrive - rwth-aachen.de\Workspaces\MATLAB\functions');
addpath('C:\Users\DurmusUmutcanUguz\OneDrive - rwth-aachen.de\Workspaces\MATLAB\functions\wt');

plot_lines = 1;
plot_lines = 0;
% plot_window = [65 70];
ALPHA = 0.05;

%% Choose the recording
[file,path,indx] = uigetfile('*.mat', 'Select a session');
if isequal(file,0)
   disp('User selected Cancel')
else
   disp(['User selected ', fullfile(path, file)])
   load(fullfile(path, file));
   for i = 1:length(channelNames)
%       fprintf(strcat(channelNames{i}, {' \t\t :'}, sensors{i}));
       fprintf('\t\t %s -- %s\n', channelNames{i}, sensors{i});
   end
   fprintf('\t\t\n');
   for i = 1:length(comments)
%       fprintf(strcat(channelNames{i}, {' \t\t :'}, sensors{i}));
       fprintf('\t\t %s\n', comments{i});
   end
end

%% MULTIPLOT

if ~exist('plot_window', 'var')
    plot_window = [min(time) max(time)];        % in ms
end

figure,
```

```
subplot(6,1,1),
title(file);
plot(time, ecg, 'k', 'LineWidth', 1.5), hold on,
plot(time(peaks_r), ecg(peaks_r), '*g'), legend('ECG', 'R-peaks'), hold off,
ylabel('Voltage [V]'),
xlim(plot_window),


subplot(6,1,2),
plot(time, bcg, 'b', 'LineWidth', 1.5), hold on,
if plot_lines~=0
for i =1:length(peaks_r)
    xline(time(peaks_r(i)), '--g');
end
end
ylabel('Pressure [mmHg]'),
legend('BCG', 'R-peaks'),
xlim(plot_window),

subplot(6,1,3),
plot(time, C_coupling*1e12, 'g', 'LineWidth', 1.5), hold on,
if plot_lines~=0
for i =1:length(peaks_r)
    xline(time(peaks_r(i)), '--g');
end
end
ylabel('Capacitance [pF]'),
legend('Coupling Capacitance', 'R-peaks'),
xlim(plot_window)

subplot(6,1,4),
plot(time, bcg_filtered, 'b', 'LineWidth', 1.5), hold on,
if plot_lines~=0
for i =1:length(peaks_r)
    xline(time(peaks_r(i)), '--g');
end
end
ylabel('Pressure [mmHg]'),
legend('BCG', 'R-peaks'),
xlim(plot_window),

```

```

subplot(6,1,5),
plot(time, C_filtered*1e12, 'g', 'LineWidth', 1.5), hold on,
if plot_lines~=0
for i =1:length(peaks_r)
    xline(time(peaks_r(i)), '--g');
end
end
ylabel('Capacitance [pF]'),
legend('Coupling Capacitance', 'R-peaks'),
xlim(plot_window),


subplot(6,1,6),
plot(time, imp_env, 'r', 'LineWidth', 1.5), hold on,
if plot_lines~=0
for i =1:length(peaks_r)
    xline(time(peaks_r(i)), '--g');
end
end
ylabel('Voltage [V]'),
xlabel('Time [s]'),
legend('Impedance Envelope', 'R-peaks'),
xlim(plot_window),

%% get average shape


average_window = [250 800];
[ecg_average, ecg_std] = time_average_shape(ecg, peaks_r, Fs, average_window);
[bcg_average, bcg_std] = time_average_shape(bcg_filtered, peaks_r, Fs, average_window);
[imp_env_average, imp_env_std] = time_average_shape(imp_env, peaks_r, Fs, average_window);
[C_average, C_std] = time_average_shape(C_filtered, peaks_r, Fs, average_window);

time_for_average = linspace(-1*average_window(1), average_window(2),length(ecg_average))';
% (-average_window(1):average_window(2))'/Fs*1000;

```

```
%%
figure,
subplot(4,1,1),
plot(time_for_average, ecg_average, 'k', 'LineWidth',
    1.5), hold on,
fill([time_for_average' flip(time_for_average)'],...
     [(ecg_average-std(ecg_std)) flip(ecg_average+std(
         ecg_std))],'k','LineStyle', 'none'),
alpha(0.35),
hold off,
legend('ECG'),
ylabel('Voltage [V]'),
xlim([min(time_for_average) max(time_for_average)]),


subplot(4,1,2),
plot(time_for_average, bcg_average, 'b', 'LineWidth',
    1.5), hold on,
fill([time_for_average' flip(time_for_average)'],...
     [(bcg_average-std(bcg_std)) flip(bcg_average+std(
         bcg_std))],'b','LineStyle', 'none'),
alpha(0.2),
hold off,
legend('BCG'),
ylabel('Voltage [V]'),
xlim([min(time_for_average) max(time_for_average)]),

subplot(4,1,3),
plot(time_for_average, C_average*1e12, 'g', 'LineWidth',
    1.5), hold on,
fill([time_for_average' flip(time_for_average)'],...
     [(C_average*1e12-std(C_std)*1e12) flip(C_average*1e12
         +std(C_std)*1e12)],'g','LineStyle', 'none'),
alpha(0.2),
hold off,
legend('C_{coupling}'),
ylabel('Capacitance [pF]'),
xlim([min(time_for_average) max(time_for_average)]),


subplot(4,1,4),
plot(time_for_average, imp_env_average, 'r', 'LineWidth',
     1.5), hold on,
```

```
fill([time_for_average' flip(time_for_average)'],...
    [(imp_env_average-std(imp_env_std)) flip(imp_env_average+std(imp_env_std))],'r','LineStyle','none'),
alpha(0.32),
hold off,
legend('Impedance Envelope'),
ylabel('Voltage [V]'),
xlim([min(time_for_average) max(time_for_average)]),
xlabel('Time [ms]'),


%% Scale the average shapes for plotting together
% Scale the standard deviations

% Scale option 2
% Scale the average waveforms
ecg_average_norm = (ecg_average - mean(ecg_average))./std(ecg_average);
bcg_average_norm = (bcg_average - mean(bcg_average))./std(bcg_average);
C_average_norm = (C_average - mean(C_average))./std(C_average);
imp_env_average_norm = (imp_env_average - mean(imp_env_average))./std(imp_env_average);


% Scale the standard deviations
ecg_std = ecg_std/(eps+max(ecg_average)-min(ecg_average));
bcg_std = bcg_std/(eps+max(bcg_average)-min(bcg_average));
imp_env_std = imp_env_std/(eps+max(imp_env_average)-min(imp_env_average));
C_std = C_std/(eps+max(C_average)-min(C_average));


% Scale the average waveforms
ecg_average = (ecg_average-min(ecg_average))/(eps+max(ecg_average)-min(ecg_average));
bcg_average = (bcg_average-min(bcg_average))/(eps+max(bcg_average)-min(bcg_average));
imp_env_average = (imp_env_average-min(imp_env_average))
```

```
    /(eps+max(imp_env_average)-min(imp_env_average));
C_average = (C_average-min(C_average))/(eps+max(C_average
    )-min(C_average));



%% Plot the scaled average shapes
figure,
title('Compare the average shapes after segmentation'),
plot(time_for_average, ecg_average, 'k', 'LineWidth',
    1.5), hold on,
plot(time_for_average, bcg_average, 'b', 'LineWidth',
    1.5),
plot(time_for_average, C_average, 'g', 'LineWidth', 1.5),
plot(time_for_average, imp_env_average, 'r', 'LineWidth',
     1.5),
fill([time_for_average' flip(time_for_average)'],...
     [(ecg_average-std(ecg_std)) flip(ecg_average+std(
         ecg_std))],'k','LineStyle', 'none'),
alpha(0.35),
fill([time_for_average' flip(time_for_average)'],...
     [(bcg_average-std(bcg_std)) flip(bcg_average+std(
         bcg_std))],'b','LineStyle', 'none'),
alpha(0.2),
fill([time_for_average' flip(time_for_average)'],...
     [(C_average-std(C_std)) flip(C_average+std(C_std))],'
         g','LineStyle', 'none'),
alpha(0.2),
fill([time_for_average' flip(time_for_average)'],...
     [(imp_env_average-std(imp_env_std)) flip(
         imp_env_average+std(imp_env_std))],'r','LineStyle'
         , 'none'),
alpha(0.2),
xlim([min(time_for_average) max(time_for_average)]),


hold off,
legend('ECG', 'BCG', 'C_{coupling}', 'Envelope'),
ylabel('Normalized [a.u.]'),
xlabel('Time [ms]'),


%% Plot the scaled average shapes with method 2
```

```matlab
figure,
title('Compare the average shapes after segmentation'),
plot(time_for_average, ecg_average_norm, 'k', 'LineWidth', 1.5), hold on, title(file),
plot(time_for_average, bcg_average_norm, 'b', 'LineWidth', 1.5),
plot(time_for_average, C_average_norm, 'g', 'LineWidth', 1.5),
plot(time_for_average, imp_env_average_norm, 'r', 'LineWidth', 1.5),


hold off,
legend('ECG', 'BCG', 'Impedance', 'Envelope'),
ylabel('Normalized [a.u.]'),
xlabel('Time [ms]'),
xlim([min(time_for_average) max(time_for_average)]),


%% Analysis on Correlation

% This part is added at 09.08.2019 to check different similarity metrics
% Depending on the results, this script can be separated.



    [r,p,timeDiff] = segment_correlation(bcg_average, C_average);
    if p < ALPHA
        fprintf('\nCross-Correlation between BCG AVERAGE and C AVERAGE is %f with a lag of %f ms',...
            r, timeDiff*1000/Fs);
    end


    [r,p,timeDiff] = segment_correlation(bcg_average, imp_env_average);
    if p < ALPHA
        fprintf('\nCross-Correlation between BCG AVERAGE and ENV AVERAGE is %f with a lag of %f ms',...
            r, timeDiff*1000/Fs);
    end
```

```


    [r,p,timeDiff] = segment_correlation(bcg_filtered,
       C_filtered);
    if p < ALPHA
        fprintf('\nCross-Correlation between BCG and
           COUPLING is %f with a lag of %f ms',...
            r, timeDiff*1000/Fs);
    end


    [r,p,timeDiff] = segment_correlation(bcg_filtered,
       imp_env);
    if p < ALPHA
        fprintf('\nCross-Correlation between BCG and
           ENVELOPE is %f with a lag of %f ms\n',...
            r, timeDiff*1000/Fs);
    end


    %% Optional Filter
    ecg_red = resample(ecg, 500, Fs);
        bcg_red_filtered = resample(bcg_filtered, 500, Fs
           );
            C_red_filtered = resample(C_filtered, 500, Fs
               );

    [b,a] = butter(6, 0.8/250, 'high');

%     fvtool(b,a,'FrequencyScale', 'log', 'Fs', 500);
        ecg_red = filtfilt(b,a,ecg_red);
                bcg_red_filtered = filtfilt(b,a,
                   bcg_red_filtered);
                     C_red_filtered = filtfilt(b,a,
                        C_red_filtered);
%% Multi-Spectral Analysis
cospectra_analysis(ecg_red, C_red_filtered, 500, 1);
    % bcg_red_filtered = resample(bcg_filtered, 20, Fs);
    % C_red_filtered = resample(C_filtered, 20, Fs);
    % wtc(bcg_red_filtered, C_red_filtered);
% cospectra_analysis(bcg_filtered, ecg, Fs, 1);
% cospectra_analysis(C_filtered, ecg, Fs, 1);
```

Appendix D MATLAB function to get the time average shapes of the recorded signals

```matlab
function [signal_mean, signal_std] = time_average_shape(signal, peaks, Fs, window)

% Created by Uguz, 18.07.2019

% This function takes already found annotation locatiosn of the given
% signal and do the following operations
% Segmentation
% Aligning w.r.t. given peaks
% Calculating the average shape and std

% If not given, the default values are as follows:
if ~exist('Fs', 'var')
    Fs = 1000;
end
if ~exist('window', 'var')
    window = 200;          % in ms
end
if length(window) == 1
    window_left = window;
    window_right = window;
else
    window_left = window(1);
    window_right = window(2);
end


WINDOW_LEFT_LENGTH = ceil(window_left/1000*Fs);    % in # of samples
WINDOW_RIGHT_LENGTH = ceil(window_right/1000*Fs);    % in # of samples
segments = zeros(length(peaks),WINDOW_LEFT_LENGTH+WINDOW_RIGHT_LENGTH+1);

for i = linspace(length(peaks),1,length(peaks))


    if peaks(i)-WINDOW_LEFT_LENGTH>=1 && peaks(i)+WINDOW_RIGHT_LENGTH<=length(signal)
        segments(i,:) = signal(peaks(i)-
```

```
                WINDOW_LEFT_LENGTH:peaks(i)+
                WINDOW_RIGHT_LENGTH);
    else
        segments(i,:) = [];
    end

end

signal_mean = mean(segments);
signal_std = std(segments);
```

Appendix E MATLAB function to find the peaks of an ECG signal

```
function peaks = find_pantompkins(signal, Fs, fig, T)
% This function applies the most basic form of Pan-
   Tompkins algorithm by
% applying a BP of 12-30 Hz. Later on, a finer window
   extraction and peak
% detection is realized. For plotting, one needs to give
   the third input as
% non-zero. The threshold T can also be adjusted manually
   , if the plot
% implies a manual selection of threshold


if ~exist('T', 'var')
    T = 0.1;
end
if ~exist('fig', 'var')
    fig = 0;
end
if size(signal,1) >1
    signal = signal';
end

Fs_qrs = 250;    % Some parameters are set to this Fs
signal_qrs = resample(signal, Fs_qrs, Fs);

%% Low-pass filter

```

```
signal_qrs = lowpass(signal_qrs, 30/(Fs_qrs/2));

%% High-pass filter
signal_qrs = highpass(signal_qrs, 12/(Fs_qrs/2));
signal_qrs = (signal_qrs-mean(signal_qrs))/std(signal_qrs
    );

%% Differentiator
b = [2 1 0 -1 -2]/8;
signal_qrs = filtfilt(b, 1, signal_qrs);

%% Quadrat
signal_qrs = signal_qrs.^2;

%% MA
b = ones(1,32)/32;
signal_qrs = filtfilt(b, 1, signal_qrs);

%% Find peaks

% peaks = findpeaks
peaks = [];          % Found peaks
max_val = 0;               % Maximum value
max_idx = 0;               % Index of the maximum


%Iterate through all samples
for i = 2:length(signal_qrs)

    % Sample point is larger than the current largest
        peak and above the
    % minimum threshold
    if signal_qrs(i) > max_val && signal_qrs(i) > T &&
        signal_qrs(i)>=signal_qrs(i-1)
        %New peak candidate
        max_val = signal_qrs(i);
        max_idx = i;


    % A peak candidate exists and the current sample is
        <= 50% that peaks height
    elseif signal_qrs(i) <= max_val/2 && max_idx ~= 0
        %Peak is detected (we store the location of the
```

```
              50% point)
            peaks = [peaks i];
            max_idx = 0;
            max_val = 0;

        end
    end

    if fig~=0
        figure, plot(signal_qrs), hold on, plot(peaks, signal_qrs(peaks), 'r*'), hold off;
    end

    peaks = ceil(peaks*Fs/Fs_qrs);

    signal = lowpass(signal, 40/(Fs/2));
    signal = highpass(signal, 0.8/(Fs/2));

    peaks = find_peaks_fine(signal, peaks, Fs, 100);
    end
```

Appendix F MATLAB function for demodulation

```
function C_test = my_demod(raw,Fc,Fs,V_excitation,C_ref, N_WAVE)

if ~exist('N_WAVE', 'var')
    N_WAVE = 50;
end
if ~exist('V_excitation', 'var')
    V_excitation = 1;
end
if ~exist('C_ref', 'var')
    C_ref = 152e-12;
end

% [b_hp, a_hp] = butter(8, Fc/2/(Fs/2), 'high');
% [b_lp, a_lp] = butter(8, 2*Fc/(Fs/2), 'low');
% raw = filtfilt(b_hp, a_hp, raw);
% raw = filtfilt(b_lp, a_lp, raw);
```

```
% [~,~] = my_fft(rafw, Fs, 1,1);

% raw = resample(raw, Fs*100,Fs);
% Fs = Fs*100;
% Method 6 Quadrature amplitude demodulation.
% [demod6a, demod6b] = demod(raw, Fc, Fs, 'qam');
% demod_qam = sqrt(demod6a.^2 + demod6b.^2);
% demod_qam = demod(raw, Fc, Fs, 'pm');
% clear demod6a demod6b

time = (0:1/Fs:(length(raw)-1)/Fs)';

%%
amplitude_ratio = [];
time_instances = [];
STEP = floor(Fs/1000);
WINDOW = floor(N_WAVE*Fs/Fc);

for i = 1:(floor((length(raw)-WINDOW)/STEP)-1)

    time_instances = [time_instances; time(STEP*(i-1)+(
       WINDOW)/2+1)];
    imp_sample = raw((STEP*(i-1)+1):(STEP*(i-1)+WINDOW));

%     if i == 100
%         figure, plot(imp_sample),
%         max(imp_sample)
%         min(imp_sample)
%     end

%     amplitude_ratio = [amplitude_ratio (max(imp_sample)
   -min(imp_sample))/(2*V_excitation)];
    amplitude_ratio = [amplitude_ratio ...
        sqrt(bandpower(imp_sample, Fs, [Fc-1 Fc+1])*2)/
           V_excitation];
end

%%
% figure, plot(amplitude_ratio);
C_test = C_ref*amplitude_ratio./(1-amplitude_ratio);
% size(C_test)
% size(time_instances)
% size(time)
```

```
% figure, plot(C_test), xlim([20000 40000]), title('Ctest
    '),
% figure, plot(amplitude_ratio), xlim([20000 40000]),
    title('Ratio'),
C_test = interp1(time_instances,C_test,time);
C_test(isnan(C_test)) = mean(C_test(floor(length(C_test)
    /2)-10000:floor(length(C_test)/2)+10000));
```

Appendix G MATLAB function to obtain the correlation coefficients between different signals

```
close all
clc
clear

%% Load the Data

load('collection_of_segments.mat');

%% Correlation analysis

k=0;

%Choose the type of the segments to be analyzed

for i=1:length(segments)

    if strcmp(segments(i).setup.subject, 'UU') && strcmp(
        segments(i). ...
                setup.position, 'T12')

        k=k+1;
        sub_segments(k).data.bcg = segments(i).data.bcg;
        sub_segments(k).data.C_coupling = segments(i).
            data.C_coupling;

    end
end

corr_mat1=zeros(k,k);
```

```
corr_mat2=zeros(k,k);

% Corelation between bcg and C_coupling

for i=1:k
    for l=1:k

        mat1 = corrcoef(sub_segments(i).data.bcg,
           sub_segments(l).data. ...
                C_coupling);
        corr_mat1(i,l)= mat1(2);

    end
end

% Corelation between bcg and bcg

for i=1:k
    for l=1:k

        mat2 = corrcoef(sub_segments(i).data.bcg,
           sub_segments(l).data. ...
                bcg);
        corr_mat2(i,l)= mat2(2);

    end
end


%% Plots



figure,imagesc(corr_mat1);
title("Correlation coefficients between bcg and
   C_coupling (Uguz Upper Left)");

figure,imagesc(corr_mat2);
title("Correlation coefficients between bcg and bcg (Uguz
    Upper Left)");
```